Founders of Modern Astronomy

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From Hipparchus to Hawking

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Vigyan Prasar

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"The history of astronomy is the growth of man's concept of his world. He always instinctively felt that the heavens above were the source and essence of his life in a deeper sense than the earth beneath. Light and warmth come from heaven."

A. Pannekoek in "A History of Astronomy", 1961

"Astronomy tells us that the universe is vast and powerful, but it also tells us that we are astonishing creatures. We humans are the parts of the universe that think. The human brain is the most complex piece of matter known, so as you explore the universe, remember that it is your human brain that is capable of understanding the depth and beauty of the cosmos. To appreciate your role in the beautiful universe, you must learn more than just the facts of astronomy. You must understand what we are and how we know."

Michael A. Seeds in "Foundations of Astronomy", 2003

Preface

The roots of any of the main branches of science say astronomy, chemistry, geology, mathematics, medicine, physics and zoology can be traced to the antiquity. Undoubtedly astronomy is the oldest discipline of science. It has taken hundreds of years to shape a scientific discipline. The shaping of a scientific discipline is not the work of one or a few scientists. Thousands of scientists worked tirele ssly for hundreds of years before a particular discipline of science emerged. The early scientists contributed to these fields when the very methodology of modern science called `method of science' was yet to be even formulated. There was a time when there were no distinct scientific disciplines and a truly learned person knew all the sciences whatever there were to be known. For example, the great Greek philosopher Aristotle, who is generally credited with the demarcation of different scientific disciplines, worked in physics, chemistry, astronomy, biology, geology and so on. Gradually distinct disciplines of science emerged and the scope and content of each discipline expanded enormously.

It is also true that in every branch of science the achievements of some scientists stand apart. There are founders, those whose works led to the foundation of a particular discipline. There are scientists whose works brought new insights into a particular field and opened new vistas. Sometimes an individual's work brought about what Thomas Kuhn called paradigm shift. We find such examples in astronomy as well.

The progress of science has been uneven in the sense that there are periods when it has progressed at a very high pace and there are periods when there was hardly any progress or it progressed slowly. This is true for every discipline of science.

The different branches of science are not mutually exclusive. The research findings in one discipline may benefit another discipline. In fact the revolution in astronomy ushered in by Nicolaus Copernicus gave a stimulus to all branches of science and thus emerged the modern science. There are scientists who have made significant contributions to more than one field. Isaac Newton's contributions to physics are unrivalled but then he also made very significant contributions to mathematics and astronomy. There will be many such examples.

As stated above astronomy is one of the oldest sciences. Its origins go back to prehistoric times. It originated much earlier than the ot her branches of science. It had become a highly developed science of its own when systematic study of other branches like physics and chemistry had not yet began.

The year 2009 has been declared as the International Year of Astronomy. Vigyan Prasar has planned a number of activities around the year to utilize this unique opportunity for creating an interest in science particularly in astronomy. This book is part of the series of publication brought out by Vigyan Prasar on this occasion. There is no doubt that there cannot be a better occasion than the International Year of Astronomy to remember those who laid its foundation, whose works contributed significantly to its growth or those who pioneered its study in a particular region or country. In fact this is also one of the objectives of the International Year of Astronomy. In this book we have included 27 astronomers. The selection may not be perfect. The author would not be surprised if someone argues that some of those included here should not have been included and similarly someone may point out the omissions that is those who have not been included. But then any book takes shape based on the understanding and limitation of the resources at the disposal of the author. So is the case here.

The introduction presents some glimpses of the history of astronomy. In no way it should be treated as an account connecting all the developments that led to the emergence of modern astronomy. The history of astronomy is rather complex. This section also highlights the most prominent contributions of the astronomers included in the book. The section "Time-line of Astronomy" attempts to list the major events in astronomy. Some of the common concepts and terms in astronomy have been briefly described in the Glossary for those who have no background in astronomy. The quotations given at the beginning of each biography highlight some salient features of the life and work of the concerned scientist. Some useful information like astronomical constants, the nearest and the brightest stars, the names of the constellations and the planets and principal satellites of the solar system have been added. A list of reference has also been added for the benefit of inquisitive readers.

The length of the write-up of a particular astronomer has nothing to do with the significance and volume of his or her work. The most of the biographies are based on the biographies earlier published in "Dream-2047", Vigyan Prasar's monthly newsletter-cum-popular science magazine.

There are some repetitions and they have been kept for the reader's benefit. This is because normally it is expected that the book will not be read like a novel from beginning to end. It is quite possible somebody may be interested in some particular biographies. Keeping this fact in mind the biographies are not linked.

The book is certainly not for those who are well-versed with the development of astronomy. It is meant for general readers having interest in science and students of schools and colleges. To make them familiar some of the greatest names in the field of modern astronomy and some of whom actually laid its foundation. The aim is to highlight the circumstances in which the astronomers included in this book worked, what inspired them to pursue science, what they thought about science and human society, what are their personal traits worth emulating for the young aspiring scientists and what were their major contributions.

The ultimate aim of this book is to enthuse its readers to take an interest in astronomy and thus in science. It is not intended to teach astronomy. Here the author's may be compared with a persuasive and fairly well informed tourist guide showing historical monuments to visitors. The monuments stand as testimony to intellectual, cultural and architectural heritage of a particular period of human civilisation. The guide moves from place to place and briefs the visitors about the importance of different sites. Often visitors go only for sight seeing and are not much interested for background information. They simply admire and do not pursue further. But sometimes, a particular remark about certain aspect of a monument may ignite the mind of a visitor to marvel at it, to ponder over it and realise the true achievement. Astronomers included in this book also stand as "monuments" in the "landscape" pf the history of astronomy. The tourist guide has an advantage. He has the actual monuments before him to show and the grand monuments themselves arouse admiration and interest in the minds of the visitors . On the other hand the author tries to create the monuments based on his own imagination and understanding. The resulting image may not often match with the actual reality. The author can only hope that imagination of some enthusiastic readers will overcome this problem.

As the book has been prepared on the occasion of the International Year of Astronomy it is pertinent that we briefly describe its objectives. The year 2009 has been declared International Year of Astronomy (IYA-2009) by the 62nd General Assembly of the United Nations. The central theme of IYA-2009 is "The Universe, Your's to Discover". The International Union of Astronomy has worked out the details of the year-long celebration of astronomy. The UNESCO has also endorsed the activities.The year 2009 has been declared as the International Year of Astronomy because it coincides with the 400th anniversary of the first recorded astronomical observations with a telescope by Galileo Galilei and the publication of Johannes Kepler 's *Astronomia nova* (New Astronomy).

The IYA-2009 is intended to provide an opportunity for the people living on Earth to gain a deeper understanding on how astronomy has enriched all human cultures. "The vision of IYA2009 is to help people rediscover their place in the Universe through the sky, and thereby engage a personal sense of wonder and discovery. IYA2009 activities will take place locally, nationally, regionally and internationally. " It will also serve as a platform for informing the public about the recent important astronomical discoveries. The essential role of astronomy in science education will be emphasised. It will not only stimulate worldwide interest in astronomy, but also in science in general.

Some of the major goals of IYA-2009 are to:

- Increase scientific awareness.
- Promote widespread access to new knowledge and observing experiences.
- Empower astronomical communities in developing countries.
- Support and improve formal and informal science education.
- Facilitate new networks and strengthen existing ones.
- Facilitate the preservation and protection of the world's cultural and natural heritage of dark skies in places such as urban oases, national parks and astronomical sites.

The IYA-2009 aims to highlight the multicultural origins of modern astronomy in an attempt to broaden children's minds, awaken their curiosity in science and stimulate global citizenship and tolerance. An attempt will be made to create an international awareness of our place in the Universe.

The author of the present book wishes that some of the younger readers would become interested to know more about astronomy and astronomers.

Subodh Mahanti

Introduction

"But the 20th century, in a continuing interplay between theory and experiment and a marriage of astronomy and physics, has completely transformed our understanding of the vast realms of the universe."
Ray Spangenburg and Diane K. Moser in "The History of Science: From 1946 to the 1990s", Universities Press (India), Hyderabad, 1999

The word "astronomy" is derived from the Greek word "astronomia", and which in turn derived from two Greek words—"astron" meaning "star" and "nomos" meaning "law". Thus literal meaning of astronomy is "law of the stars". "Nomos" in Greek also means "culture", and so the word "astronomy" can also be interpreted as "culture of the stars". After knowing the actual literal meaning of the word "astronomy" let us see how astronomy is defined in the modern context.

A standard general dictionary, for example The *Webster's New Dictionary* defines astronomy as "the science of the universe in which stars, planets , etca, are studied, including their origins, evolution, composition, motions, relative positions, sizes, etca" A standard science dictionary, for example, *The McGraw-Hill Dictionary of Scientific and Technical Terms* defines astronomy as "the science concerned with celestial bodies and observation and interpretation of radiation received in the vicinity of the earth from the component parts of the universe."

Astronomy has also been defined as "The science, which investigates all the matter – energy in the universe; its distribution, composition, physical states, movements, and evolution."

For laypersons astronomy may simply be defined as the science of the universe, a branch of science that deals with celestial objects like galaxies, stars, planets, satellites, comets, meteorites etca, and phenomena that take place outside the atmosphere of the Earth. An "astronomer" is one who studies astronomy.

Now-a-days professional astronomy is often considered to be synonymous with astrophysics. However, from strictly definitional point of view there is a difference. Astronomy refers to the study of objects and matter outside the earth's atmosphere and of their physical and chemical properties. Astrophysics is a branch of astronomy, which is mostly concerned with the physical properties like luminosity, size, mass, density, temperature etc, and dynamic processes of celestial objects and phenomena. Astronomy may be regarded as the qualitative study of the subject but astrophysics may refer to the physics-oriented version of the subject. Modern astronomical researches are more and more focussing subjects related to physics and many astronomers have actually physics degrees. And so for all practical purposes modern astronomy may be treated as astrophysics.

The professional astronomy is divided into observational and theoretical branches. Theoretical astronomy is concerned with the collection and analysis of data. To analyse the data basic principles of physics are used. Theoretical astronomy is concerned with the development of computer or analytical models for describing astronomical objects and phenomena. The two branches of astronomy complement each other. The results of observational astronomy are used to confirm theoretical results and theoretical astronomy attempts to explain the observational data.

Astronomy is the only branch of science in which amateurs can play active role. Amateurs have played an important role in the development of astronomy. Amateur astronomers have contributed to many important astronomical discoveries. Amateurs are not simply hobbyists. They have their own magazines and conventions. What is more there are small industries to meet their needs. The number of amateur astronomers is also quite impressive. It is interesting to note that today it is the amateur astronomers who view the heavens directly and not the professional astronomers.

Astronomy, even the old or ancient astronomy, should not be confused with astrology, the belief system which claims that human affairs are correlated with the positions of celestial objects. It is true that two fields share a common origin and a part of their methods but they are two distinct fields.

Astronomy is one of the oldest sciences. It has played an important role in most, if not all, cultures over the ages. There are records to show that astronomers of the early civilisations made methodical observations of the night sky. Astronomical artefacts of ancient civilisations are still found.

Astronomy had its beginning in inherent curiosity of human beings. The study of astronomy began when the earliest human beings on the Earth looked up at the moon and stars in the night sky and wondered what they were. It began when human beings started wondering about the occurrence of day and night. At the beginning astronomy consisted of the observation and predictions of motions of celestial objects visible to the naked eyes. It was mostly mapping the positions of the stars and planets, a science now called astrometry. In its early days astronomy included disciplines as diverse as astrometry, celestial navigation, obeservational astronomy, and the making of calendars.

Primitive astronomy flourished almost in every parts of the world. The branch of astronomy that deals with the astronomical studies of ancient people is called archaeoastronomy. It was Gerald Hawkins who brought this subject to wider attention with the publication of his book titled *Stonehenge Decoded* in 1965. Hawkins claimed that Stonehenge, the prehistoric ring of stones found in Salisbury Plain in southern England was in fact a sophisticated astronomical observatory.

There are many other ancient sites of astronomical significance. These sites tell us how ancient people observed the sky but unfortunately there is no way of knowing of what they thought of the universe. The study of astronomy began much before humans developed written language. What is more the written records of many ancient civilisations did not survive. In many cases we do not know how they were lost. There are examples when invaders destroyed the cultural products of the lands they invaded. The Spanish missionaries burned hundreds of Mayan manuscripts because they thought they were the works of Satan. This was perhaps great loss to astronomy as the four surviving Mayan manuscripts con tain astronomical references. We do not know what people of ancient cultures thought about the universe. The situation is somewhat better in case of Greeks and this is because much of their writings have survived.

Early Greek astronomers based their work on the astronomy of Babylonia and Egypt. However, soon they developed a different approach. The ancient astronomers of Babylonia and Egypt studied the motions of heavenly bodies solely for religious and astrological purposes. But for the Greeks the study of astronomy was a means for understanding the universe. Thales of Miletus (ca624 -547 BC) proposed that it was possible to understand the way the universe works. This was a marked departure from the accepted views of the earlier cultures which believed that human mind was incapable of knowing the ultimate causes of natural phenomena and they would remain as mysteries for ever. After Thales of Miletus came Pythagoras who proposed many natural phenomena could be understood by mathematical principles as it can be seen in the case of musical notes. So Thales of Miletus and Pythagoras taught the Greeks to look at the universe in altogether new way, which was unheard of earlier. On one hand Thales of Miletus asserted that the Universe was understandable on the oth er hand Pythagoras stated that the rules governing the universe were mathematical. Based on their teachings Greeks attempted to comprehend the universe in geometrical forms.

Anaximander thought the universe was made up of wheels filled with fire and the Sun, Moon and other luminous heavenly bodies were holes in the wheels through which the flames are visible.

Philolatus (5th century BC) proposed the first theory of the motion of the Earth. He proposed that the Earth rotates around a central fire in a c ircular path. However, this central fire was not Sun and it always remained hidden behind a counter earth situated between it and the Earth.

Plato influenced the development of astronomy though he himself was not an astronomer. He argued that not only th e heavenly bodies were perfect spheres but also their motions of were combinations of circular motions. He further argued that the reality we see is a distorted version of a perfect one. Influenced by Plato later Greek astronomers tried to describe the motions of the heavenly bodies based on the principle of circular motion.

Ancient Greeks thought of a universe, which included not only Earth but also all the other visible heavenly bodies. However, they were not sure about the actual nature of the spheres. To some the spheres were not real, they simply mathematical ideas some sort of reference pointes necessary to describe the motion in the universe model. But to others they were real objects made of perfect celestial material.

Aristotle divided the universe into two parts—the Earth and the heavens. The first part that is the Earth was imperfect and changeable but the second part that is the heavens was perfect and unchangeable. The Moon marked the boundary line between these two parts. Aristotle believed that the Earth was in the centre of the Universe, a model of universe, which was later called geocentric universe. To Aristotle Earth was fixed and its shape was spherical. He thought the Earth was a sphere because the shadow cast by it during lunar eclipses was always spherical.

Aristarchus proposed that the Earth was not fixed. It not only rotated around its own axis but it also revolved around the Sun. As we know today Aristarchus was right but astronomers, who followed him were not aware of his ideas. Most of his writings were lost. Astronomers continued to believe in a fixed Earth as proposed by Aristotle.

Hipparchus put Greek astronomy on a more scientific footing by introducing arithmetic and early geometric methods. He made many accurate astronomical observations. He prepared a star catalogue containing information about 850 stars and this was possibly the first catalogue of stars. He divided the stars in six magnitude classes.

Ptolemy, Alexandrian astronomer who flourished in the 2nd century AD produced a multi-volume compendium of contemporary astronomical knowledge. He modified the concept of geocentric universe. The model proposed by him is called Ptolemaic system. It successfully accounted for the observed apparent motions of the planets. It remained unquestioned till Nicolaus Copernicus dethroned it.

Nicolaus Copernicus proposed a heliocentric model of the universe and in doing so he demonstrated the fallacy of the age-old Ptolamaic system. Galileo and Kepler not only defended Copernicus but they also modified and expanded his work.

Tycho Brahe was the greatest astronomical observer of the pre telescope ere. He was also an expert in constructing sophisticated astronomical instrument for making accurate naked-eye positional measurement. His meticulous observations were used by Kepler for deriving his laws of planetary motion. Brahe made major contribution to moons orbit. He made observation of the 1572 supernova in Cassiopeia. He published is results in *De nova stella (The New Star).*

Galileo established the Copernican system as the true model of the universe. It was Galileo who first used telescope for astronomical observations.

Modern astronomy developed after the use of the telescope for celestial observations In 1609 Galileo first turned a telescopes to the night sky and made astounding discoveries that changed mankind's conception of the universe forever: mountains and craters on the Moon, a plethora of stars invisible to the naked eye and moons around Jupiter.

In the same year, when Galileo directed his telescope towards the heavens Jaohannes Kepler published described the fundamental laws of planetary motions in his work Astronomical nova. Kepler for the first time developed a system which described correctly the motion of the planets around the Sun based on his law of planetary motions. However, Kepler could not formulate a theory as the physical basis of his laws. It was left to Newton's invention of celestial dynamics and his law of gravitation to finally explain the motions of the planets.

It was Hans Lippershey, who invented the telescope in 1608. He had given a demonstration of his new invention to the Dutch government on September 25, 1608. He was not awarded the patent. Galileo heard of this story and decided to use the "Dutch perspective glass" and point it towards the heavens.

Christiaan Huygens discovered Titan, the largest satellite of Saturn in 1655. He also observed that 'a thin flat ring' surrounds Saturn. Earlier astronomers had observed the rings but they could not figure out its nature. In 1659, he discovered dark markings on Mars, the most striking of which was Syrtis Major. Huygens along with his brother Constantijn Huygens (1628-1697) constructed aerial telescope, a tubeless telescope supported by cables. It had very long wavelength to overcome aberrations. He also designed an eyepiece, the so-called Huygens eyepiece, in 1703.

Isaac Newton's theory of gravitation and laws of motion were highly successful in describing the universe. The three laws of motion developed by Newton proved to be critical to our understanding of orbital motion. The concept of astronomy is extremely important in astronomy particularly its role in planetary motion. Newton's works enabled us to understand how the planets move around the Sun. became the basis for astronomers for than two hundred years. He refined Kepler's model of planetary motions Newton provided the basis on which Kepler's laws work.

Frederick William Herschel discovered the planet Uranus in 1781. This discovery certainly stretched the boundary of the classical universe to a great extent. Before this people since antiquity knew only about the five planets — Mercury, Venus, Mars, Jupiter and Saturn and they thought the universe was complete. He built the largest telescope in the world of his time. In 1789, he discovered the two largest telescopes of Uranus and two years later he discovered two satellites of Saturn namely Mimas and Enceladus. He observed and catalogued many double stars and over 2000 nebulae and clusters.

Albert Einstein's theory of relativity had profound implications for modern astronomy. His works provided a theory of gravity based on the geometry of curved space-time. Einstein's works showed that Galileo's inertia and Newton's mutual gravitation are fundamental properties of space and time.

Arthur Stanley Eddington made important contributions in understanding stellar structure. He explained energy generation in stars. He obtained observational proof that gravitation bends light as predicted by Einstein's theory general relativity. In 1924, he derived mass-luminosity relation.

Edwin Powell Hubble proved that nebulae were actually independent star systems like our own galaxy, Milky Way. He developed a classification system for galaxies. The system is called tuning-fork diagram of galaxies. Hubble showed that galaxies where moving away with speeds that increase with the distance. This observation was a powerful evidence to prove that universe was expending.

Meghnad Saha's thermal ionisation equation relates the fraction of ionised atoms in a stars atmosphere to the temperature of the gas and in the electron density. It provided an understanding of the relative prominence of spectra lines of different atoms and ions in the spectra of stars. This made it possible to derived the temperature of stars from there spectral type.

George Gamow alongwith Ralph Asher Alpher and Robert Herman develop the big bang theory of the origin of the universe in the late 1940s This theory proposed that the universe began with an explosion and underwent a rapid expensive from a hot, dense full of radiation. Later, Alpher and Herman suggested that the present cool down universe should be pervaded cosmic background radiation with the temperature of 5^0K.

Hans Albrecht Bethe worked out the details of the mechanism of the Nuclear Reaction by which energies produced in stars. He along with Walter Heinrich Hitler (1904-1981) developed the cascade theory of cosmic rays.

Subrahmanyan Chandrasekhar was the first identify wide dwarf as and product of stellar evolution. He showed how a star collapses when radiation pressure with in the stars fails to counter on its own gravity. He further showed that there is a upper limit of a mass of a degenerate stars above which this star would be enable support itself against the inward pools on its own gravity. This limit is 1.44 solar masses. If the mass of a degenerate stars exists this limits, it would collapse under gravity to become either a Newton stars or a black whole this limit is called Chandrasekhar limit.

Fred Hoyle along with H. Bondy and T. Gold proposed the steady state theory of the universe. Through this theory was later abandoned by most astronomers in favour of big bang theory. It never the less stimulated much important astrophysical research.

Martin Ryle developed the technique of aperture synthesis. He also undertook a series of surveys of radio sources that were published as the Cambridge catalogues.

Antony Hewish collaborated with Ryle to develop the aperture synthesis. Hewish along with his student S. J. Bell discovered pulsars.

Arno Allan Penzias (1933-) and Robert Woodrow Wilson discovered the cosmic microwave background radiation, the first real reinforcement of the Big Bang theory of the origin of the universe.

Stephen William Hawking has made significant contributions to the fields of cosmology and quatum gravity. He alongwith Roger Penrose studied singularities in the Big Bang and black in the framework of the general theory of relativity and quantum theory. Hawking theoretically showed that black holes should emit radiation now called Hawking radiations or Bekenstein -Hawking radiation.

We briefly described the main contributions of the astronomers included in this book but as stated in the preface thousands of scientists contributed to the development and growth of astronomy. The beauty of astronomy is that though it is the oldest science but even today it is the most exciting scientific discipline. The universe, which was viewed so simple and limited at the time of Hipparchus became so vastly larger and more complex by the time Hawking appeared on the scene. It seems as we are knowing more and more about the universe it is becoming more and more complex and intriguing. Today scientists tell us the visible matter is just a small fraction of the total matter in the universe, the rest is called dark matter. The scientists are yet to know the nature of this mysterious matter. There are many other questions have remained unanswered. The challenges before the astronomers of the 20th century are really daunting. Today astronomers have at their disposal far more sophisticated ways of investigating the universe than ever before. We can hope that astronomers of the 21st century will completely transform our understanding of the universe as it was done by the 20 th century astronomers. Astronomy in the 21 st century will move to a completely new and exciting territory.

Hipparchus of Rhodes
The Greatest Astronomer of the Antiquity

"…it seems highly probable that Hipparchus was the first to construct a table of chords and thus provide a general solution for trigonometrical problems. A corollary of this is that, before Hipparchus, astronomical tables based on Greek geometrical methods did not exist. If this is so, Hipparchus was not only the founder of trigonometry but also the man who transformed Greek astronomy from a purely theoretical into a practical productive science."

G. J. Toomer in Dictionary of Scientific Biography, New York, 1870 -1990

"As a theorist Hipparchus worked on the orbits of the Sun and the Moon. He established more accurate lengths of both the year and the month and was able to produce more accurate eclipse predictions. One of his lasting achievements was the construction of a table of chords, which virtually began the discipline of trigonometry."

Dictionary of Scientists, Oxford University Press, 1999

"He (Hipparchus of Rhodes) put Greek astronomy on a more scientific footing, introducing arithmetic and early trigonometric methods. His many accurate astronomical observations resulted in a catalogue of 850 stars, giving their co -ordinates and dividing them into six magnitudes."

A *Dictionary of Astronomy*, Oxford University Press, 1997

Hipparchus of Rhodes is also often referred to as Hipparchus of Nicaea or Hipparchus of Bithynia. He made phenomenal con tributions to the development of astronomy and mathematics. As an astronomer his most famous discovery was the precession of the equinoxes, a slow conical motion of the Earth's axis about the vertical to the plane of the ecliptica He discovered this while attempting to calculate the length of the year with high degree of precision. He determined the length of a year to within 6.5 minutes. After observing a new star around 134 BCA He formulated the astronomical principle that "the stars are not eternally fix ed in the heavens." It is believed that Hipparchus prepared the first star catalogue around 134 BCA

Perhaps he was the first to predict solar and lunar eclipses. He observed the annual motion of the Sun, developed a theory of its eccentric motion and me asured the unequal durations of four seasons. He made similar observations of the Moon's more complex motion. He retained the Aristotelian view that the Earth and not the Sun was the centre of the universe. However, he found that his observations did not agree with Aristotle's belief that the celestial bodies revolved around the Earth in perfect circles. To explain this he proposed that the Sun and the Moon moved in circular orbits but they did not move around the Earth's centre. Further he proposed that the planets made small loop-like movements as they moved in the bigger circle around the Earth. These circles superimposed upon the larger ones he called epicycles. His ideas were taken up by Ptolemy two centuries later to develop a system that though incorrect, lasted for centuries. Greek astronomer Aristarchus (ca 320-ca 250 BC) first proposed the heliocentric view of the universe

Hipparchus of Rhodes

Hipparchus is regarded by many as the father of plane and spherical trigonometry because it was he who first organised measurements in relation to angles in trigonometric tables. He also introduced the division of a circle into 360 degrees in Greece.

Almost nothing is known about Hipparchus' life. What is known is that he was born in Nicacea (now Iznik) in Bythynia (now in Turkey) around 190 BC, and that he made astronomical observations in Rhodes, Bythynia, and Alexandria. Most of what we know about Hipparchus comes from the writings of the Greek astronomer Ptolemy

We do not have definite details of his works because all his works except one were lost when the Library of Alexandria was burned down. Among the works that were lost include: *Catalogue of Stars*, *On Constellations, On the Arrangement of Fixed Stars*, *On the Treatise on Simultaneous Risings*, *On the Rising of the 12 Constellations of the Zodiac*, *On the Precession of the Equinoxes, On the Parallax* (2 books), *On the Size and Distance of the Sun and the Moon*, *On the Eclipses of the Sun and the Seven Climates, On the Lunar Year*, *On the Intercalary Months and Days*, *On the Length of the Year*, *Investigations of the Chords of a Circle* (12 books), *On Gravity, Against the Geography of Eratosthenes*, and *To the Noblest*.

The only surviving work, *Commentary on Aratus and Eudoxus* is not one of his major works. However, this has assumed importance because it is the only source of Hipparchus' own writings. This work, written in three books, was a commentary on three different works, viz., a treatise by Eudoxus, in wh ich he named and described constellations; a poem called Phaenomena by Aratus, based on Eudoxus' treatise; and a commentary on Aratus by Attalus of Rhodes. In this work Hipparchus also included his own account of the rising and setting of the constellations. Commenting on this only surviving work of Hipparchus, Toomer writes, "Far from being a 'work of his youth', as it is frequently described, the commentary of Aratus reveals Hipparchus as one who had already compiled a large number of observations, invent ed methods for solving problems in spherical astronomy, and developed the highly significant idea of mathematically fixing the positions of the stars."

Today the available details of Hipparchus' works come from the Alexandrian astronomer, mathematician, and geographer Ptolemy's (2nd century AD) commentaries in *Almagest*, which served as the most important book on astronomy for 1500 years. One should remember that Ptolemy's aim was not to preserve Hipparchus' work for posterity. As Toomer writes "…although Ptolemy obviously had studied Hipparchus' writings thoroughly and had a deep respect for his work, his main concern was not to transmit it to posterity but to use it and, where possible, improve upon it in constructing his own astronomical system." There are two other commentaries of Hipparchus' work namely by Theon of Alexandria and by Greek mathematician Pappus of Alexandria (4th century AD) but they do not always surpass the details given by Ptolemy in any way. Extracts of Hippachus's works are also foun d in the works of Roman scholar Pliny the Elder (AD 23-79), Greek geographer and stoic Strabo of Amaseia (ca 60BC – ca 21AD), Thyon of Smyrna and Plutarch. We do not have the original works of Hipparchus, but from the extensive extracts given by the above mentioned authors one can largely reconstruct his methods and results.

Hipparchus invented an improved version of astrolabe for accurately determining the co-ordinates of the stars. He constructed the first globe. He devised an improved version of dioptra, a devise used for estimating the apparent diameter, distance and size of the Sun and the Moon. According to Ptolemy, Hipparchus invented an improved version of theodolite for measuring angles. He improved many other instruments, which were in use in his time, like the plumb (a lead weight called plumb bob hung at the end of a line called plumb line used to determine how deep water is or whether a wall, etca, is vertical), the gnomon (a column or pin on sundial that casts a shadow indicating the time of da y), the sundial, the clepsydra (water clock), and the fixed sphere.

Hipparchus calculated the length of the year. Here it may be noted that there are two definitions of a "year" namely, sidereal year and tropical (solar) year.

He first measured the length of a tropical year, a unit of time equal to the period of one revolution of the Earth about the Sun measured between successive vernal equinoxes. The length of the year derived by Hipparchus was 365.24667 mean solar days while the true value is 365.242217 mean solar days or 365 days 5 hours 48 minutes and 46 seconds. It has been suggested that for calculating the length of the tropical year Hipparchus used old Babylonian data and checked the resulting value against his observations of equinoxes and solstices and those of the Aristarchus (made in 230 BC) and Meton (made in 432 BC). He also calculated the length of the sidereal year, the time period relative to the stars of one revolution of the Earth around the Sun and for this also he used old Babylonian data. He found that the sidereal year was 1/144 day longer than the tropical year. It was a highly accurate value. Sidereal year is about 365.2564 mean solar days. He calculated the length of the synodic (lunar) month as 29 days, 11 hours, 44 minutes and 3.33 seconds – only less than one second from the correct value. This was a highly accurate value. Synodic month is the mean period between successive occurrences of identical lunar phases for example from new Moon to new Moon, or full Moon to full Moon.

Hipparchus also determined the average distance of the Moon from the Earth based on observations of eclipses. According to him the average distance of the Moon from the Earth was 33.66 times the diameter of the Moon. The actual value is 30.20 times. He also calculated the diameter of the Moon at 0.33 that of the Earth against the actual value of 0.27. He also undertook a systematic study of the motion of the Moon and developed a theory of the Moon's motions based on epicycles.

It is said that in 134 BC Hipparchus observed a new star in the constellation of Scorpio, which led him to construct a catalogue of 850 stars. Perhaps this was the first star catalogue because there is no record of any star catalogue prepared earlier than this. He listed the stars with their celestial latitude and longitude; that is, their celestial co-ordinates. The catalogue was of high precision. It appears that Ptolemy included Hipparchus' catalogue in his own work three centuries later. Edmond Halley also used the Hipparchus' catalogue.

Hipparchus introduced the practice of dividing the stars into different classes of magnitudes based on their brightness. He was the first to assign a scale of magnitude. He developed a system of six magnitudes. He classed the brightest stars as the first magnitude and the faintest visible stars to the naked eye he classed as sixth magnitude. His scale, much refined, is still in use.

While comparing the position of the stars of his day with those given 150 years earlier he observed that the star Spica had moved 2° relative to the autumnal equinox. To explain this he proposed precession (motion) of the equinoxes. The equinoxes are the twice-yearly events when day and night are of equal length.

They denote the points where the ecliptic – the apparent path of the Sun – crosses the celestial equator. He calculated the rate of precession at about 45 seconds of arc a year, which is close to the now accepted value of 50.27 seconds. Sometimes it is claimed that Chaldeans are the true discoverer of the p recession of equinoxes. The reason for this kind of belief is that Chaldeans in their tables adopted different longitudes as zero at different times. However, it was Hipparchus who recognised it as a continuous regular progress.

Hipparchus tabulated a table of chords; that is, length of the line joining two points on a circle corresponding to the given angle at the centre. The table was based on a circle divided into 360 degrees and each degree was further divided into 60 minutes. The table of chords was a precursor of the sine table. He made weather forecasts based on his studies of weather patterns through observations. This impressed many of his contemporaries. He divided the then known inhabited world into climatic zones.

The year 127 BC is usually cited as the last year known for Hipparchus' actual work. In that year he made some observations on the star Eta Canis Majoris. He died around 120 BC in Rhodes.

A crater near the centre of the Moon has been named after Hipparchus. A crater on Mars surface has also been named after him.

Claudius Ptolemy
"The Last of the Great Classical Astronomers"

"Ptolemy was the last of the great classical astronomers, and his work dominated astronomical thought for almost 1500 years. The collapse of the Ptolemaic model and the rise of a new model of the universe make an exciting story, but it is not just the story of an astronomical idea. It includes the invention of science as a new way of knowing and understanding what we are and where we are."

Michael A Seeds in "Foundations of Astronomy" (Seventh Edition), 2003

"He (Ptolemy) produced four major works the Almagest, the Geography, the Tetrabiblos and the Optics. The first work (the Almagest) —the culmination of five hundred years of Greek astronomical and cosmological thinking —was to dominate science for 13 centuries. Ptolemy naturally relied on his predecessors, especially Hipparchus. A work of such staggering intellectual power and complexity could never be created by one person alone."

A Dictionary of Scientists, Oxford University Press, 1999

"His (Ptolemy's) work was far more than compilation of former knowledge. Ptolemy was no compiler but a scientific investigator himself; with Hipparchus he was the greatest astronomer of antiquity. He improved and extended the theories of his predecessors; he added to science through his own observations and explanations."

A. Pannekoek in A History of Astronomy, Dover Publications, Inca,1961

The ideas of Plato and Aristole, the two great Greek philosophers, on the nature of the universe dominated for more than 2000 years. Claudius Ptolemy, often referred to simply as Ptolemy (his Latin name is Claudius Ptolemaeus and Arabic scholars referred to him as Batlamyus) played a crucial role in ensuring the survival of the Aristotle's universe by fitting to it to a sophisticated mathematical model.

Aristotle proposed that the heavens were literally composed of 55 concentric, crystalline spheres to which celestial objects were attached as shown in the diagram below:

The Earth remains at the centre of the universe. The known planets, as well as the Moon and Sun, in order of increasing distance from the Earth —the Moon, Venus, Mercury, the Sun, Mars, Jupiter and Saturn —travelled around the Earth. In this model the spheres rotate at different velocities but the angular velocity of a given sphere remains constant. There are additional "buffering" spheres that lay between the spheres shown in the diagram. Aristotle thought that there was an outermost sphere, the domain of the "Prime Mover". According to Aristotle it was the "Prime Mover", who caused the outermost sphere to rotate at constant angular velocity and which was transmitted from sphere to sphere to rotate the whole thing.

By adjusting the velocities of the concentric spheres, the Aristotelian model of the universe was able to explain many features of the planetary motion. However, it also failed to explain many things for example observations of varying planetary brightness and retrograde motion.

Claudius Ptolemy

To improve the Aristotelian model, Ptolemy introduced the concept of epicycles. It was argued that the planets were not directly attached to the concentric spheres. Rather they were attached to the circles attached to the concentric spheres as shown in the diagram below:

The circles attached to the concentric spheres are called "epicycles" and the concentric spheres to which the planets were attached were called "Deferents". In this model the centres of epicycles moved in uniform motion as they moved around the deferents at constant angular velocity and at the same time the epicycles to which the planets were attached maintained their circular motion.

With this kind of model, Ptolemy was able to account for the retrograde motion and varying brightness of the planets. It is obvious that the distance of a planet from the Earth would vary and which in turn would lead to variations in brightness. Further, at times viewed from the Earth, a planet can appear to move "backward" on the celestial sphere and so it can take care of the observed retrograde motion.

The system developed by Ptolemy is known as the "Ptolemaic System" or the "Ptolemaic Universe." Ptolemy not only improved the Aristotelian model bu t also tried to preserve the concept of the geocentric universe intact.

There is virtually no information about Ptolemy's personal life. His Greek origin is derived from his name. His first name "Claudius" indicates that he was a citizen of Roman Empire. His last name "Ptolemy" indicates that he descended form a Greek family living in Egypt (some believe that ethnically he was an Egyptian, though Hellinised). There is no proof to indicate that Ptolemy was related to the royal dynasty of the Ptole mies. In fact many scholars and historians consider it very unlikely. We do not know exact dates of his birth and death. It is belived that he was born in ca A.D. 90 and died in A.D. 168. It is assumed that his teacher was Theon of Smyrna (A.D. ca 70 -ca 135), who was a well-known Greek mathematician and astronomer of his time. Ptolemy probably made astronomical observations during the years A.D. 127 to 141 in Alexandria. He wrote in ancient Greek and made use of Babylonian astronomical data. It is assumed that he wrote many scientific treatises but not all have survived.

Ptolemy presented his astronomical and mathematical ideas in his greatest work, the *Almagest.* For over 1500 years *Almagest* was not only considered as the most important treatise on astro nomy but the very subject was defined as what was described in it. It was the last word in astronomy. Undoubtedly it is one of the scientific texts to remain longest in use in human history. In this respect it can be compared with Euclid's *Elements.* The original name of the Ptolemy's work that we know as the *Almagest* was *The Mathematical Compilation* (the English version of the Greek title). Later the title was replaced by another title, which meant in English *The Greatest Compilation.* The last title was tr anslated into Arabic as "*al-majisti*" ("The Greatest") and from which the title the *Almages*t is derived. It may be noted that like many other Greek texts, Ptolemy's work on astronomy is also preserved in Arabic manuscript and hence the name "the *Almagest*" derived from the Arabic title is more familiar. The book was translated from Arabic into Latin in the 12 th century and since then it became familiar as the *Almagest*. It was translated twice in Latin, once in Sicily and again in Spain.

In the *Almagest,* Ptolemy presented the details of the mathematical theory of the motions of the Sun, the Moon and the planets. Ptolemy's most original contributions were the details fro the motions of each planet worked out by him. Commenting on the approach followed whil e writing the book Ptolemy wrote: "We shall try to note down everything which we think we have discovered up to the present time; we shall do this as concisely as possible and in a manner which can be followed by those who have already made some progress in the field. For the sake of completeness in our treatment we shall set out everything useful for the theory of the heavens in the proper order, but to avoid undue length we shall merely recount what has been adequately established by the ancients. Howeve r, those topics which have not been dealt with by our predecessors at all, or not as usefully as they might have been, will be discussed at length to the best of our ability."

Highlighting the importance of the *Almagest* Toomer wrote: "As a didactic work the "Almagest" is a masterpiece of clarity and method, superior to any ancient scientific textbook and with peers from any period. But it is much more than that. Far from being mere 'systemisation' of earlier Greek astronomy, as it is sometimes described, it is in many respects an original work."

In the *Almagest,* Ptolemy propounded the geocentric theory of the universe earlier proposed by Aristotle in a form that prevailed for 1400 years. The Almagest was finally superceeded only after the publication of the celebrated works of Copernicus and Galileo. The system described in the *Almagest* is known as Ptolemaic system, it was a geocentric model of the universe and it was based on circular uniform motion. The *Almagest* is divided into 13 books

The first two *Books* of the *Almagest* describe new geometrical proofs and theorems devised by Ptolemy. The theory of the Sun forms the subject of *Book 3*. In *Books* 4 and 5 Ptolemy presents his theory of the Moon. In *Book 6* Ptolemy describes his theory of eclipses. *Books* 7 and 8 contained Ptolemy's star catalogue containing over 1000 stars. The last five *Books* (9 to 13) discuss planetary theory.

It has been described that Ptolemy personally supported the great mathematician Euclid. When Ptolemy found it too difficult to study Euclid's seminal work Elements, he asked its author whether there was an easier way to understand it. Euclid's much quoted reply was "Sire, there is no Royal Road to Geometry."

Ptolemy published a major work on geography called *Geographia* or *Geography* (the full Latin title is *Geographia Claudii Ptolemaei)*. It was written in eight books. The first Latin translation was made by Florentine Giacomo da Scarperia in 1406 and subsequently it was translated in many other languages of the world. The first printed edition of the book was brought out probably in 1477 in Bologna. This was the first printed book with engraved illustrations. It was a compilation of what was known about the world's geography in the Roman Empire during his time. To some extent he relied on the work by an earlier geographer, Marinos of Tyre. He also depended on gazetteers of the Roman and ancient Persian empires. The orginal work included maps but because of the difficulty in copying them, these maps were left out while making subsequent copies. Ptolemy provided instructions on map-making. Though maps based on scientific principles, was made by Eratosthenes as early as 3rd century BC, Ptolemy improved projections. Ptolemy's Geographia attempts to map the known world giving coordinates of the major places in terms of latitude and longitude. He created a series of 26 maps and a general map of the world. It should be noted that in many places Ptolemy's maps were inaccurate. It was not surprising given the fact that the quality o f the available data was very poor.

The third most important work of Ptolemy was on astrology. In Greek it was called *Apotelesmatika* ("Astrological Outcomes or Effect") and in Latin the *Tetrabiblos* ("Four Books"). In Greek "tetra" means four and "biblos" book. The book became popular throughout the world. Even today it is considered as the ultimate source on astrology. It is very likely that the contents of the book were collected from earlier sources. What Ptolemy did was to arrange the material in a systematic way.

Ptolemy also wrote a book on optics in five books, where he discussed his studies on colour, reflection, refraction, and mirrors of various types. He carried out many experiments on optics and came to the conclusion that starlight was refracted in the Earth's atmosphere.

Pythagoras prepared an important treatise on music theory and the mathematics of music. It was called *Harmonics*. Like Pythagoras, Ptolemy argued for basing musical intervals on mathematical ratios. However, while Pythagoras 's approach was theoretical but Ptolemy based his arguments on empirical observations. In *Harmonics*, Ptolemy described how musical notes could be translated into mathematical equation and vice versa.

The crater Ptolemaeus on on the Moon, the crater Ptole maeus on Mars and the asteroid 4001 Ptolemaeus are named in honour of Ptolemy.

Āryabhata
The Greatest Astronomer of Ancient India

"The importance of Āryabhata lies in the fact that he probably was in the vangu ard of the new astronomical movement which resulted in the recasting of this branch of knowledge about fifth century A.D. Piecemeal efforts might have started earlier as is evident from Varamihira's account of five *sidhantas,* and before and about the time when Āryabhata flourished there were certainly astronomers of repute who were variously engaged in reforming astronomy, but little is known about their contributions as their works have not survived. As a matters stand, the *Aryabhatia* is the earliest astronomical text bearing the name of an individual of the scientific period of Indian astronomy."
S. N. Sen in "A Concise History of Science in India", Indian National Science Academy, New Delhi, 1989

"The names of several astronomers who preceded Āryabhata, or who were his contemporaries, are known, but nothing has been preserved from their writings except a brief fragments. The *Aryabhatiya*, therefore, is of the greatest importance in the history of Indian mathematics and astronomy."
Walter Eugene Clark, who brought out a definitive translation Aryabhatiya into English (quoted from Henry Scolberg's The Biographical Dictionary of Greater India).

"Like all ancient astronomy, that of India was restricted owing to ignorance of the telescope; but methods of observation were perfected which allowed very accurate measurement, and calculations were aided by decimal system of numerals. We know of no remains of observatories of the Hindu period, but those of the 17 th and 18th centuries, at Jaipur, Delhi and elsewhere, with their wonderfully accurate instruments constructed on an enormous scale to minimize error, may well have had their ancient counterparts."
A. L. Basham in "The Wonder that was India", London, 1954

Ancient Indians had shown great proficiency in astronomy since Vedic times. Āryabhata is one of the most important figures in the history of India's astronomy. He was the first Indian astronomer to propose the rotation of Earth to explain the daily eastward motion of the stars in the sky. He introduced many new concepts such as an alphabetical system of expressing numbers, rules for extraction of squares and cube roots, construction of trigonometric sine tables and eccentric - epicentric models of planetary motion. He gave the most accurate value of pi as 3.1416. He also believed that eclipses were caused by the shadows of the Moon and the Earth and not by *Rahu-Ketu* as it was believed.

There is almost nothing is known of his life. His name is sometimes spelled as "Aryabhatta". It may be noted that there is another astronomer of the name of Āryabhata who lived in the tenth century A.D. To distinguish the two, they are called Āryabhata I and Aryabhta II (ca A.D.950), who was basically a compiler and was an adherent to orthodox views. Ara bic scholars referred to Āryabhata as arjabhar or ajabhar. Al-Biruni writes “They (Alfazari and Y’kub) apparently did not understand him and imagined that Āryabhata mean a ‘thousandth part’”. Abu Raihan Muhammad ibn Ahmad Al-Biruni (973-1048), a mathematician and astronomer of some repute came to India in the eleventh century. He traveled Indiaduring A.D. 1017 and 1030 as a political hostage with Mahmud Ghazna in the course of the latter’s invasion to India. invasion to India.

Āryabhata

Earlier scholars thought that Āryabhata was either born in Kusumpura, a suburb of Pataliputra (modern Patna) and taught there. Some scholars identified Kusumpura with Pataliputra. Āryabhata himself in one of the verses of the Ganitapada stated that “he (Āryabhata) sets forth in his work the science which is held in high esteem at Kusumpura.” However recent studies on the works of Bhasakara, the greatest exponent of Āryabhata’s system of astronomy and other medieval commentators of Āryabhata reve al that earlier held belief of scholars is not correct. In these works Āryabhata is often referred to as an āś *maka* that is one who comes from Āśmaka region located in southern part of India, possibly in modern-day Kerala and his works *Āśmaka spnutatantra*. Another fact which support the view that Āryabhata came from Kerala is that most of the commentaries of *Aryabhatia* and works based on it have come largely from southern India especially from Kerala. Majority of the astronomers belonging to the Āryabhata school come from South India.

Āryabhata wrote *Aryabhatia* at the age of 23 (A.D. 499). This was lost and a revised version was written later. Bhau Daji (1822 -1874) a famous physician and Indologist of Maharashtra, India based on his serious studies publ ished a paper an Āryabhata in the Journal of Royal Asiatic Society in 1865. The revised Sanskrit version was published by J. H. CA Kern in Leiden, Holland, in 1874. A French translation was published in 1879. A definitive English translation was prepared by Walter Eugene Clark, a Sanskrit professor of the Harvard University and it was published by the Chicago University Press in 1930.

According to Clark, *Aryabhatiya* is "the earliest preserved Indian mathematical and astronomical text bearing the name of a n individual author, the earliest Indian text to deal s pecifically with mathematics, and the earliest preserved astronomical text…of Indian astronomy." There were many other works on astronomy written before Āryabhata but we do not know the names of their authors.

Aryabhatiya is written in verse couplets. It is a small works containing about 121 slokas or stanzas. It is divided into four sections called *padas* viz., *Gītik āpāda*, *Ganitapāda*, *Kālakriyāpad ā* and *Golan*āda.

The *Gitikapāda* deals exclusively mathematics. It has 33 stanzas. Among the topics covered in this section include *Varga* (squares), *ghana* (cubes), *vargamula* (square-roots), *ghanamula* (cube-roots), area of a triangle and volume of a prism, area of a circle and volume of a sphere, area of a *visamacaturasa* (quadrilateral), circumference of a circle, *bahu* (the base of a right-angled triangle), and *koti* (the upright of the right-angled triangle), *karna* (hypotenuse of the right-angled triangle), *trairasika* (rule of three), *vyasta* (reverse rule of three) and *kuttakara-ganita* (the theory of *pulveriser*).

The remaining two sections *Kālakriyāpāda* and *Golapada* deal with astronomical principles and methods of computations in very condensed form. The section *Kālakriyapada*, which means reckoning of time, has 25 stanzas. It includes topic like division of time and the circle, definitions of solar year, lunar month, civil day, sidereal day, intercalary months, omitted lunar days, planetary orders and movements, the eccentric-epicyclic models, use of these models for the calculations of the true planetary positions, calculation of the true planetary from the Earth and other related topics.

The *Golapāda* is the longest section and it is for this section Āryabhata is most famous. *Gola* means sphere. It has 50 stanzas. In this section Āryabhata explains the methods of representing planetary motions in a celestial sphere. He also defines such terms like prime vertical, meridian, horizon, hour circle, equator, parallax, and ecliptica He discusses the *pata* (ascending nodes) of the planets and the shadow of the Earth movement on the path of the Sun (*arka-apanamandala*). Āryabhata asserts that the Earth is the centre of the universe and it revolves around its axis. In fact Āryabhata was the first Indian astronomer to consider the rotation of the Earth for explaining the apparent daily motions of the fixed stars. But his idea did not find support among his contemporaries or latter astronomers. Then the current belief was that that the Earth was not only at the centre of the universe but it was fixed.

Āryabhata was severely criticized by several of his his contemporaries and astronomers who followed him. Thus Brahmagupta commenting on Āryabhata wrote: "Since Āryabhata knows nothing of mathematics, celestial sphere or time, I have not mentioned separately his demerits." Al-Birum writes "He (Brahma Gupta) is rude enough to compare Aryabata to a warm which, eating the wood, by chance describes certain characters in it, without the understanding them and without intending to draw them. In such offensive terms he attacks Āryabhata and met treats him…"Further as S. N. Sen writes "Brahmagupta attacked Āryabhata for dividing the *yuga* into four equal parts, for upholding the rotatory motion of the earth, for believing in the eclipses being caused by the shadows of the moon and the earth and not in accordance with the traditional Rahu-Ketu theory." His undue criticism of Āryabhata was noticed by al-Bīrūnī. However, al-Biruni acknowledged the merit of the ideas A.D. 796 or 800) and Ya'qub ibn Tariq (died 796) as *Sindhind* (a translation of Brahmasphuta-Sidhanta) and the *Arakand* (a translation of *Khadakhadyaka*).

Commenting on the contributions of Āryabhata, the noted Indian astrophysicist J. V. Narlikar writes: "Āryabhata gives a table of the trigonometric sine functions, calling then jya in Sanskrit. The table gives the sines of angles at intervals of $3^{0}45$. The sine tables are needed to work out the geometrical measurements of positions of stars and planets on the celestial sphere. Thus we see that Āryabhata was conversant with the notions of spherical trigonometry. Moreover, at the conceptual level, his awareness of the spherical shape of Earth and its spin around an axis reflect how advanced he was with respect to his contemporaries. For example, he argues in one verse of the *Aryabhatiya* that although the stars appear to go westwards, they are in fact fixed and we are observing them from the moving platform of the spinning Earth."

The names of Pandurangasvami, Latadeva, Prabhakara and Nihsanku are cited as direct disciples of Āryabhata. However, it was Bhāskara I (caA.D. 600), who contributed greatly in propagating Āryabhata's work. He did it by his excellent commentaries and his own independent work. He was a contemporary of Brahmagupta. Bhāskara was a native of either western India or South India (possibly Kerala). He was associated with both these regions. So it might be that he was a native of either of these two regions and he migrated to the other. His major work the Mahābhāskariya was an elaborate exposition of the three astronomical chapters of *Aryabhatiya* As S. N. Sen in *A Concise History of Science in India* has described it consisted of eight chapters dealing with follow ing topics

1. Mean longitude of planets and indeterminate analysis.
2. Longitude correction
3. Time, place and direction, spherical trigonometry, latitudes and lunar eclipses.
4. True longitudes of planets.
5. Solar and lunar eclipses
6. Rising, setting and conjunction of planets.
7. Asrronomical constants
8. Tithi and miscellaneous examples.

Bhāskara introduced many new methods of his own. While Āryabhata postulated rules for indeterminate analysis but it was Bhāskara who elaborated it and its application to astronomy. Bhāskara prepared an abridged version of his main work known as Laghubhaskariya. It may be noted that another astronomer named Bhāskara and to distinguish them they are called Bhāskara I and Bhāskara II. The latter was born around A.D.1114 and whose major work was *Siddhānta-siromoni*, which was divided into four chapters viz., *Lilavati* (on arithmetic), the *Bijaganita* (on algebra) *Ganitadhyay* and the *Goladhayaya* (the last two on astronomy).

The works and teachings of Āryabhata exerted strong influence on later generations of Astronomers in India a long line of his followers propag ated his views through their excellent commentaries.

The first Indian-built satellite launched by a rocket of erstwhile Soviet Union in April 1975 was named after Āryabhata.

Nicolaus Copernicus
Founder of the Heliocentric Model of the Solar System

"The 'Scientific Revolution' is often dated from Copernicus's work, reaching its climax with Newton about 150 years later. In the same year (1543) that Copernicus's *De revolutionibus* appeared Vesalius's book, *On The Structure of the Human Body* was published. Men's views of nature were changing fast."

The Cambridge Dictionary of Scientists

"Copernicus stands at the crossroads to modern science because his radically new plan for the cosmos, a heliocentric system to replace the time-honoured earth-centred cosmology, required a radically new physics."

Owen Gingerich in The Oxford Companion to the Modern History of Science

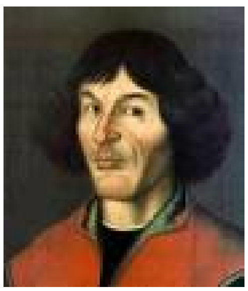
"Of all discoveries and opinions, none may have exerted a greater effect on the human spirit than the doctrine of Copernicus. The world had scarcely become known as round and complete in itself when it was asked to waive the tremendous privilege of being the centre of the universe. Never, perhaps, was a greater demand made on mankind - for by this admission so many things vanished in mist and smoke! What became of our Eden, our world of innocence, piety and poetry; the testimony of the senses; the conviction of a poetic-religious faith? No wonder his contemporaries did not wish to let all this go and offered every possible resistance to a doctrine which in its converts authorised and demanded a freedom of view and greatness of thought so far unknown, indeed not even dreamed of".

Johann Wolfgang Goethe (1749-1832)

The celebrated German poet and dramatist Goethe's beautiful description of Copernicus' work quoted above has aptly underlined its significance. Copernicus, like many other great scientists, did science for the sheer love of it. Science was not his 'profession'. Copernicus put an end to the long-standing belief, that the Earth was the centre of the universe. He said, "That which to us appears as a movement of the Sun is not due to any motion of the latter, but to a motion of the Earth.... during which we rotate about the Sun like any other planet"

Copernicus asserted that his theory was true in the sense that it gave a correct picture of the physical structure. Copernicus' assertion forever changed the place of man in the universe. This claim of Copernicus triggered off the entire sequence of ideas that make up modern science. Thus Copernicus set into motion not only the Earth, but the entire spirit of inquiry. Copernicus' contribution and further advancement made by Galileo Galilei (1564-1642) and Johannes Kepler (1571-1630) triggered off the scientific revolution, which culminated into the writings of Isaac Newton (1642-1727). Copernicus' contribution to the scientific revolution concerns astronomy and he is regarded as the first harbinger of modern astronomy. However, he was not just an astronomer in the technical sense. He restored the supremacy of reason over the senses and 'opened the path to the affirmation of the infinite and the freedom of thought of modern man'.

The emergence of the Copernican theory did not come about in isolation. Copernicus lived at the zenith of the Renaissance. One of the key themes of Renaissance was the rebellion against traditional thinking and particularly against Aristotelian philosophy. The simple repetition of ideas from the ancient texts was no longer considered a valid means of understanding nature. There was a general desire for innovation, and a burning passion for knowledge about the "mysteries of the sky and the secrets of nature'. There was a tremendous thirst for information about all branches of knowledge.



Nicolaus Copernicus

Copernicus was a contemporary of Erasmus of Rotterdam or Desiderius Erasmus (ca1466-1536), the Dutch scholar and one of the most influential figures of the Renaissance; Martin Luther (1483-1546), leader of the Protestant Reformation in Germany; Michelangelo (1475-1564). The Italian sculptor, painter, architect and poet; Leonardo da Vinci (1452-1519), the Italian painter, sculptor, architect, scientist and engineer; Christopher Columbus (1451-1506), the great Spanish explorer and discoverer of the New World; Paracelcus (1493-1541), the German alchemist and physician; and Niccolo Machiavelli (1469-1527), the Italian statesman, writer and social philosopher. The purpose of citing these names is to higlight the fact that multi-talented giants lived and worked in the time in which Copernicus lived and worked.

Copernicus was born on February 19, 1473, in Torun, a commercial town in north central Poland. His original name was Niklas Koppernigk. During his student days he Latinised his name, a common practice among scholars of those days. There is a plausible story about the origin of his family name. There was a place called Koppernigks in Upper Silesia, on the eastern side of Germany and this place acquired its name probably because most of its inhabitants worked in the local copper mining industry. By the fourteenth century Koppernigk had become a family name and many Koppernigks migrated from Sileslia into Poland. Some of these Koppernigks may have been among the ancestors of Nicolaus Copernicus. But we do not know much about Copernicus' ancestors except his parents. His father, also named Niklas Koppernigk was a wholesale copper dealer. Niklas Koppernigk the elder became a burger of Torun in 1458. His mother Barbara Waczenrode belonged to a respected local German family. Both his parents died when Copernicus was 10. Lucas Waczenrode took charge of the children of his sister. Waczenrode studied at Cracow, Leipzig, Prague and Bologna. In 1489 Waczenrode became the Bishop of Ermland (or Varmia), a small principality on the Baltic Sea. Being a learned man himself, Waczenrode encouraged Copernicus and his brother Andreas to enter the Cracow's Jagiellonian University.

In those days Cracow, a flourishing town with prosperous trade and industries, was the capital of Poland. At Cracow Copernicus studied canon law and medicine. It was at Cracow where the young Copernicus acquired his first notions of astronomy. It is said that he studied astronomy under the famous astronomer and mathematician Wojcieaj Brudziwski. At Cracow he acquired a thorough knowledge of Aristotelian and Ptolemaic astronomy and Euclidian geometry. He read all the books on astronomy and mathematics that he could lay hands on. He did not miss any opportunity to learn about astronomical observations of his time. In 1496, Copernicus went to Italy and he first joined the University of Bologna. Later he studied at Padua and Ferrara. In Italy while he studied canon law, he also pursued with deepest interest his first loves, astronomy and mathematics. He also studied Greek literature, medicine, philosophy and Roman law. In Bologna he had an opportunity to study under Domenico Maria da Novara (1454-1504), one of the greatest astronomers of the day. It is at Bologna University, under the guidance of Novara, that Copernicus made his first recorded astronomical observation. Copernicus advanced his theory that the Moon was a satellite.

In 1503, Copernicus got his doctorate in canon law from the University of Ferrara and returned to Frauenburg to take up his duties as canon. It may be noted that his uncle Waczenrode nominated him a canon of the chapter of Vermia at the Cathedral of Frombork (Frauenburg) in 1497, a post he held till his death. While there were administrative duties including the organisaton of armed resistance against provocations by neighbouring Teutonic Knights, that needed to be attended to the post did not demand his continued presence or preoccupation. In fact he could afford to spend most of his time in pursuing his interest in astronomy. He also practised medicine. He made his astronomical observations using very simple instruments. At the time of Copernicus there were no telescopes/lenses. The lens was invented 100 years later.

It was at Frauenburg, where Copernicus spent the latter part of his life, he made his celestial observations from a turret situated on the protective wall around the cathedral. His investigations were carried on quietly and alone. He was not assisted by anyone and there was nobody to consult.

At the time, the Ptolemaic system of the universe or geocentrism was the gospel truth. Religious conceptions and the writings of Plato (ca427 -ca347 B.CA) and Aristotle (384-322 B.CA) were expounded by Ptolemy or Claudius Ptolemaeus (A.D. ca90-168), the Egyptian-Greek astronomer and geographer. The Ptolemaic system handed on by Byzantines and Arabs assumed that the Earth was the centre of the universe, and that the heavenly bodies revolved around it.

Three incorrect Ideas viz.: i) the Earth at the centre of the universe; ii) uniform circular motion of heavenly bodies; and iii) the objects in the heavens are made from a perfect, unchanging substance not found on the Earth prevented the development of astronomy from the time of Aristotle until the 16th & 17th centuries.

Copernicus was not the first to propose a Sun-centred universe. As early as 260 BC (or thereabouts) Aristarchus of Samos (ca320 -230 BC) proposed such a system. However, because of Aristotle's influence it was not taken seriously. The following arguments were raised against Sun-centred universe:

1. In the heliocentric system, the Earth needs to rotate around its axis, to explain the diurnal motion of the sky. If this is the case then why did objects not fly off the spinning Earth?

2. If the Earth is really moving then why the birds flying in the sky are not left behind?

3. If the Earth was really on an orbit around the Sun then why did not we see a parallax effect with regard to the stars. A moving Earth ought to imply apparent movement in the fixed stars, but none could be observed.

Today we can explain all these easily. However, till the seventeenth century there was no correct understanding of the physics of motion. So till then the first two objections appeared quite valid. The parallax effect is there. As the stars are so far away, their parallax cannot be seen without the help of precise instruments. The first conclusive measurement of parallax was made in 1838.

The concept of the heliocentric universe proposed by Aristarchus was totally forgotten till it was revived by Copernicus in the 16th century. It has been reported that Copernicus himself originally gave credit to Aristarchus of Samos. He devoted a long passage to Aristarchus in the manuscript of *De revolutionibus.* However, this passage was crossed out just before the manuscript was sent for publication. We do not know why Copernicus deleted this passage. But as Olof Pederson points out that "...perhaps Copernicus was afraid that the memory of how the heliocentric system was rejected in Antiquity might prejudice the acceptance of his own theory"

As Copernicus continued his astronomical observations he discovered many inconsistencies in the Ptolemaic system. Keeping the Sun at the centre of the universe and to fit the complicated movements of the planets in an otherwise very simple system all kinds of compromises had to be made: concepts like epicycles, eccentric and equants had to be invoked. All this brought in lot of complications in an otherwise simple system.

The Ptolemaic system also miserably failed to predict accurately the movement of the planets. In fact there was no semblance of accuracy. For example a conjunction of the major planets in 1503 predicted by the almanacs of the day was found to be as much as ten days off.

Copernicus started examining another simpler idea about the structure of the universe, that is the heliocentric system in which the Sun was placed at the centre and the Earth alongwith the other planets revolved around the Sun. Earlier a number of ancient Greek philosophers including Aristarchus of Samos as mentioned earlier put forth similar ideas. However, unlike the ancient Greeks, Copernicus did not stop at putting forth the idea. He followed it through by making calculations to see if his theory worked. It was Copernicus who, for the first time, not only considered the idea, but also went on to calculate the results of a planetary system with interrelated circular orbits around the Sun, instead of the Earth. By 1514 Copernicus had sketched out a rough synopsis of his new system. This synopsis called *Commentariolus* ("Little Commentary") was privately circulated among his friends. It was a six-page hand-written text describing his ideas about the heliocentric hypothesis. This work formed the basis of his masterpiece, *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*). Initially the idea of the Earth moving around the Sun appeared absurd even to Copernicus. As he would later write in *De revolutionibus orbium coelestium* "... I began to meditate upon the mobility of the Earth although the opinion seemed absurd".

Copernicus was not in a hurry. He took a long time to be convinced about the validity of his new system. And finally he became convinced that it was the Sun and not the Earth, which was the centre of the planetary orbits. However, even after being fully convinced, he hesitated to make his idea public. There were good reasons for it. The Ptolamaic system enjoyed the endorsement of not only scholars, but also of the church. Copernicus did not live to see how the church would react to his theory. Giordano Bruno was burnt at the stake for his ideas contrary to the existing ones and Galileo was forced to live under house arrest even after disavowing his belief in the Copernican system.

Perhaps the delay was not entirely due to Copernicus' concern with what the church might say. Copernicus was a perfectionist. So even after working for thirty years he was not sure whether his complete work was ready for publication. For Copernicus observations were to be checked and rechecked. Copernicus' original manuscript, which was located in Prague in the middle of the 19th century (that is it remained out of sight for nearly 300 years), showed that Copernicus made revision after revision.

In any case whatever might have been the reasons Copernicus hesitated to make the whole thing publica Copernicus wrote: "I hesitated for a long time a s to whether I should publish that which I have written to demonstrate the Earth's motion or whether it would not be better to follow the example of the Pythagoreans, who used to hand down the secrets of philosophy to their relatives and friends in oral form....I was almost impelled to put the finished work wholly aside, through the scorn I had reason to anticipate on account of the newness and apparent contrariness to reason of my theory". However, when completed, Copernicus had no doubt about the greatnes s of his work.

Thus in the dedication of *De revolutionibus orbium coelestium.* Copernicus wrote: "If, however, there be guileful men who, although they know nothing of mathematics, nonetheless allow themselves to pass judgment upon such matters, and who, on the basis of a cunningly distorted interpretation of a passage of the scriptures, dare to attack and condemn my work, I dismiss them so entirely as to despise their judgment as blindly presumptuous."

The great work of Copernicus might not have ever reach ed the printing press if it were not for George Rheticus and Tiedemann Giese Bishop of Chelmno (Kulm), humanist and a faithful friend of Copernicus. In 1539 George Rheticus (born Georg Joachim Von Lauchen), a 25 year old German Lutheran professor of mathematics, came to Frauenburg intending to spend a few weeks with Copernicus, who was at that time 66 years old. However, Rheticus became so fascinated with Copernicus and his theories that he ended up staying as a houseguest for two years. Rheticus wrote a bo ok, *Narratio prima* (“First Account”), outlining the essence of Copernicus’ theory. He also published a treatise on trigonometry by Copernicus in 1542.

It was Rheticus and Tiedmann Giese who persuaded him to publish his work. In fact Rheticus himself publi shed a volume titled *De Libris Revolutionum D. Doctoris Nicolai Copernici Narratio Prima* in 1540. Two years later Rheticus also published a lengthy extract from the Copernicus treatise. It mainly dealt with spherical trigonometry.

De revolutionibus orbium coelstium ranks with such great works as the *Almages*t by Ptolemy, *Principia* by Newton and *Origin of Species* by Charles Robert

Darwin (1809-82). Besides the unauthorised preface *De revolutionibus orbium coelstium* is divided into six sections or "Books" which in turn were divided into chapters. In *Book I* Copernicus describes his general picture of the universe and his arguments in favour of the Sun being at the centre instead of the Earth. The *Book I* also deals with trigonometry. The *Book II* describes Copernicus' rules of trigonometry to all sorts of problems related with the apparent motions of the heavenly bodies on the sphere of the sky. The remaining four books deal in detail with supposed motions of the Earth (*Book III*), the Moon (*Book IV*) and the planets (*Books V and VI*).

Copernicus even did not give the title of his work, which made him immortal. In fact the original manuscript handed over to Giese for publication had neither a title nor the name of its author. The title given to the work by its editors was *Six Books Concerning the Revolutions of the Heavenly Spheres* (*De Revolutionibus Orbium Coelestium Libri vi*).

The first printed copy of great work of Copernicus was brought to him on May 24, 1543, the day he died. Tiedemann Giese, described the sad scene to Rheticus in the following words: "He had lost his memory and mental vigour many days before; and he saw his completed work at his last breath upon the day that he died"

The final stages of the printing of the book were supervised by Andreas Osiande, a leading Lutheran theologian in Nurenberg. Osiander added an unsigned preface, without the knowledge of Copernicus, stating that the Copernican system was purely a hypothetical one. Further it stated that the theory was just an imaginative way to help astronomers predict the positions of the planets and it does not claim to represent reality. There are no specified reasons, why Osiander chose to write this unauthorised preface. One probable reason might be that he, by doing so, thought to please Martin Luther, founder of the Lutheran church, who had ridiculed Copernicus' ideas, declaring that, "this fool wishes to reverse the entire science of astronomy; but sacred scripture tells us that Joshua commanded the Sun to stand still, and not the Earth". Besides Osiander's preface there were alterations made by other hands and the first printed version differed considerably from the original manuscript handed over by the author for publication.

While the heliocentric theory of Copernicus explained the movements of the moon and planets in a much more elegant and accurate way than the old system, Copernicus' insistence on perfect circular orbits brought in no less complexity than found in the older system. The Copernicus' system was further refined by Galileo, Kepler and others.

We would like to close this brief account of the life and work of Copernicus by quoting from an article written by Jerzy Bukowski on the occasion of the quincentenary of Copernicus' birth: "Copernicus had the courage to expound his innovative ideas in a scientific work of profound maturity and to contradict the traditional authority of the Ancients. This is why today the world is celebrating the quincentenary of his birth. The object of our admiration is not only the creator of the heliocentric system: to an even greater extent, Copernicus should be remembered as the scholar who opened the way for the long procession of the creators of modern science."

Tycho Brahe

The Greatest Observational Astronomer of Pre-Telescopic Era

"Brahe was without doubt the greatest astronomical observer of the pre -telescopic era. In 1572 he observed a nova (exploding star) in Cassiopeia, the first to be visible to the naked eye since 134 BC, and demonstrated that it was 'fi xed' star and outside the solar system…this was cosmologically very important as it had been believed since Aristotle's time that the stars were eternal and immovable."

The Cambridge Dictionary of Scientists, 2003

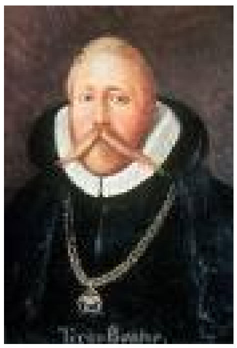
"Brahe's accomplishments played a highly significant role in the development of modern astronomy and the way humans view the world and the universe. He created a remarkably accurate star catalogue of approximately 1 000 stars, proved that comets were not objects in the atmosphere but instead existed beyond the Moon, and made overall improvements on the known methods of observation."

Scott McCutcheon & Bobbi McCutcheon in Space & Astronomy: The People Behind the Scienc e, New Delhi, 2007.

Johannes Kepler tells us that, Tycho Brahe, during the last few days of his life, would keep repeating the words, "Let me not seemed to have lived in vain", whenever he was in delirium. Kepler writes: "No doubt he (Brahe) wished that t hese words should be added to the title page of his works, thus dedicating them to the memory and uses of posterity." That Tycho's fear of being `lived in vain' was unfounded is evident from the fact that in the title page of Kepler's great work, *Astronomia nova*, the following words were written: "Founded on observations of the noble Tycho Brahe." As acknowledged by Kepler, the laws of planetary motion could not have been formulated without Brahe's enormous and meticulous data. Tycho produced more accurate data than anyone before him including Ptolemy (2nd century AD) and Nicolaus Copernicus (1473 -1543).

Tycho rejected the Copernican model by assuming that the Earth had to be stationary. But then he also rejected the Ptolemaic model because of its inaccur ate predictions. After rejecting the two opposing models Tycho proposed a more complex model in which the Earth was stationary at the centre of the universe around which the Sun and the Moon moved. The other planets moved around the Sun and not around the Earth. Though Tycho's model was more popular than the Copernican model at the beginning but it was discarded in favour of the latter within a century.

He prepared a star catalogue of 777 stars with such accuracy that it provided a vital source of information for later astronomers. He became an international celebrity for making meticulous observations on the new star that appeared in 1572 now known as 'Tycho's Star'. He proved that comets are not objects in the Earth's atmosphere and that their orbits are far beyond the Moon. Earlier Aristotle had explained comets and meteors as atmospheric events that took place in the space between the Earth and the Moon. Tycho showed irregularities in the Moon's orbit. His many instruments became widely copied and led to improved stellar instruments.



Tycho Brahe

Tycho was the greatest observational astronomer of the pre-telescopic age. He was a very colourful personality in the history of astronomy. He was haughty and proud. He always asserted his own elevated position. He made all his astronomical observations wearing the dress of a nobleman. He liked to lead a luxurious and comfortable life. He kept a dwarf to amuse him. He was the first to establish a fully equipped observatory. Tycho himself was an object of admiration and emulation. He occupies a special position in the history of astronomy. He was held in enormous respect by generations of astronomers. While Copernicus left room for traditional solid spheres, Tycho clearly pronounced: "Now it is quite clear to me that there are no solid spheres in the heavens."

Tycho was born into a noble family in Knudstrup in southern Sweden (then under Danish rule). His father, Otto Brahe, was the Governor of Helsinborg Castle and his uncle, who brought him up, was an admiral in the navy. The adoption of Tycho by his uncle was a highly dramatic affair. Tycho's father promised his childless brother that if he had a son he would allow Joergen to adopt him and bring him up as his own. But then Tycho's father went back on his words when one of the twin sons that his wife bore him in 1546 was a stillborn. Joergen waited until another son was born to his brother and then kidnapped Tycho, the firstborn child. The Governor threatened to kill Joergen but afterwards cooled down, perhaps realising that Tycho would be well-looked after and inherit some of Joergen's fortune. Joergen died while saving the life of his king, Frederik II (1534 -1588), who while crossing the bridge joining Copenhagen and the royal castle had fallen into the river. Joergen valiantly jumped into the cold water to save the king. He could save his king but he himself died of pneumonia. This happened when Tycho was a student. This incident made Frederik II more sympathetic to Tycho, the adopted son of Joergen.

At the age of 18 Tycho fought a duel with another noble Danish youth over a trivial point: of the two Danish nobles who was the better mathematician? In the course of the duel Tycho got a part of his nose sliced off. The lost piece of the nose was replaced by a patch made of a gold and silver alloy. This fact has recently been confirmed when his grave was opened and the remains were inspected.

Following the family tradition, young Tycho was to take up the career of a statesman. For this purpose he was sent at thirteen to study rhetoric and philosophy at the University of Copenhagen. However, a partial solar eclipse, that he happened to witness on 21st August 1560 changed the whole future course of his life. The event itself was not at all spectacular but its impact on Brahe was because of its predictability. This solar eclipse, which had been predicted before hand stuck young Tycho as "something divine that men could know the motions of the stars so accurately that they were able long time beforehand to predict their places and relative positions." From the very beginning Tycho had developed a passion for exact observation. Tycho chose to pursue astronomy, as Arthur Koestler wrote, "not as an escape or metaphysical life belt, but rather as a full-time hobby of an aristocrat in revolt against his milieu."

After three years at the Copenhagen University Tycho was sent to the University of Leipzig accompanied by a tutor, Andreas Soersen Vedel. For Tycho's uncle astronomy was a profession unworthy of pursuit by a nobleman. So he instructed Vedel, who was just four years older than his pupil, to cure Tycho of this undignified preoccupation and persuade him to take up a profession befitting a nobleman. But Vedel was not successful in his mission. He found Tycho beyond remedy. Tycho was completely engrossed in his study of astronomy. However, Tycho had to hide his celestial globe, which he had bought for learning the names of the constellations, from Vedel. He could use this only when Vedel was asleep. But finally Vedel accepted his defeat and they remained life-long friends. It may be noted here that Vedel later became famous as the first great Danish historian. From Leipzig Tycho moved to different universities of northern Europe namely Wittenberg, Rostock, Basle and Augsberg.

While moving from one university to another, Tycho went on collecting bigger and better instruments. As we now know Tycho later designed his instruments himself. Among his early collections was a huge quadrant of brass and oak. The quadrant, which happened to be first among Tycho's fabulous instruments, was thirty-eight feet in diameter and turned by four handles. A quadrant, which is now obsolete, was a device for measuring angles. It consisted of an engraved arc of a quarter of a circle, with a plumb line suspended from the centre of the circle. Stars were sighted along one arm and their elevation was read off the scale against the plumb line.

After completing his study, he spent the next five years first on the family estate at Knudstrup and then with his uncle Steen Bille, the only one in Tycho's family who approved of Tycho's unseemly hobby.

On the evening of November 11, 1572, Tycho noticed a star brighter than Venus at her brightest, at a place where no star could be seen before. The star was visible in the Cassiopeia constellation. Initially Tycho did not believe his own eyes. So he called some of his servants and peasants who all confirmed the observation of the star at a place where no star was there before. The star remained in the same spot for eighteen months.

The star was so bright that people with sharp eyes could see it even in the middle of the day. This was an extraordinary event. No new star had been seen in Europe since the days of Hipparchus (second century BC). Pliny in his second book of *Natural History,* had noted that Hipparchus had seen a new star in the sky. It may be noted that new stars were seen in AD 1006 and 1054 by Japanese and Chinese astronomers. But these observations were not known to the European scientific community

Naturally Tycho was not the only one to witness this extraordinary event. Many other astronomers of the day also observed the star. But Tycho surpassed others in his meticulous observations. With his newly constructed sextant, with arms five and a half feet long, the result of Tycho's observations was unequivocal. Sextant is a navigation device for measuring the altitude of celestial objects above the horizon. It consists of a graduated 600 arc (one sixth of a circle) with a movable arm and sighting devices.

Tycho demonstrated that the new star showed no large parallax or 'proper motion' and which meant that the new star truly belonged to the sphere of the fixed starts. (Parallax is defined as angular difference between an object's direction as seen from two points of observation). Tycho did not comment on the nature of the star or how it was created. Today we know that it was a supernova. In 1573 Tycho published his first book *De nove et nullius memoria prius visa stella* (*On the new as never previously seen star*), commonly referred to as *De stella Nova* (*The New Star*).

In those days the observation of a new star had a special significance. It contradicted the basic Aristotelian worldview. Aristotle (384 -322BC), the Greek philosopher, based his geocentric model of the universe on the system of concentric spheres originally proposed by Eudoxus of Cnindus (ca480 -ca350 BC), the Greek mathematician and astronomer. Eudoxus had developed a model of planetary motion in which the Sun, Moon and planets were carried around the Earth on a series of 27 Earth-centred spheres, with axes at different angles and rotating at different speeds.

Callippus (ca370-ca300 BC), also a Greek mathematician and astronomer, modified the Eudoxus scheme by adding extra spheres for the Sun, Moon and some other planets. Callippus brought the total number of spheres to 34. This system was further modified by Aristotle who increased the number of spheres to 49 to account for the movement of all celestial bodies. The outermost spheres, in which the fixed stars were located, controlled the motion of the other spheres. The outermost sphere itself was thought to be controlled by a supernatural agency. And this sphere was thought to be immutable (that is no change takes place there) from the day of creation to eternity. Changes can take place only in the immediate vicinity of the Earth, the sublunary sphere. Ptolemy modified Aristotle's world-view by introducing epicycles but otherwise kept its basic tenets intact. The church accepted the Ptolemaic system, which was essentially the Aristotelian system. The stars were called 'fixed stars' as they did not show any detectable 'proper motion'. It only participated in the daily rotation of the firmament as a whole. So the sight of new star and if it was really a star with no 'proper motion', would force one to think the world afresh

The whole Europe was excited to know the cosmological and astrological significance of the new star. Most of the people considered it a sinister omen. However, the serious astronomers of the day with few exceptions tried to explain the unprecedented phenomenon by calling the new star a tailless comet with slow motion.

Thus proving the existence of a new star Tycho demonstrated a basic flaw in the Aristotelian worldview of the unchangeability of the heavens. His observation of the comet of 1577 and five subsequent comets also convinced him that their orbits were far beyond the moon. There is no doubt that Tycho's discovery and his meticulous observations of planetary motions, laid a firm basis for the breakthrough of the Copernican worldview in the 17th century.

In 1575 Tycho, whose reputation was already established, made a tour of Europe visiting his astronomer friends. After completing his tour when Tycho returned to Denmark, the king Frederik II offered him various castles to choose from. But Tycho had no intention settling in Denmark and so he declined the offer made by the king. He was planning to settle in Basle, a city in Switzerland where the French, German and Swiss borders meet. The city became a major literary centre during the Reformation. Desiderius Erasmus (1466-1536) taught at the

University of Basel. Among other great thinkers and scholars settled in Basle was Phillippus Aureolus Paracelsus (1493-1541). Frederik II was determined to induce Tycho to stay in Denmark. So he offered Tycho an Island, the Island of Hveen. The island was three miles in length and extending over 200 acres of flat tableland. He was promised enough money to build an observatory on the island and an annual grant plus various positions that would provide regular income with little or no work. After a week's hesitation Tycho accepted the offer.

A royal instrument, signed on May 23, 1576 decreed that: "We, Frederik the Second, & ca make known to all men, that we of our special favour and grace have conferred and granted in fee, to our beloved Tyge Brahe, Otto's son, of Knudstrup, our man and servant, our land of Hveen, with all our and the crown's tenants and servants, who thereon live, with all rent and duty which comes from that, and is given to us and to the crown, to have use and hold quit and free, without any rent all the days of his life and as long as he lives and likes to continue and follow his *studia mathematicus* ...."

In 1577 Tycho moved to the Island of Hveen and built his observatory. The observatory was built by a German architect under Tycho's supervision. Tycho combined his meticulous precision with fantastic extravagance. It had an onion-shaped dome, flanked by cylindrical towers. Each tower had a removable top housing Tycho's instruments. In the basement Tycho had his own printing press, an alchemist's furnace and a private prison for punishing his servants and the peasants living on his lands when they broke one of his strict rules. Tycho had his own paper mill, pharmacy, game preserves and artificial fishponds. He gathered or built some of the most fabulous astronomical instruments of his day. Tycho created a remarkable range of instruments from armillary spheres after the manner of Ptolemy to large quadrants of bold and original design. Most of his instruments were built in his own workshop. His largest celestial globe was five feel in diameter. It was made of brass. Tycho engraved the fixed stars one by one on this celestial globe, which was placed in his library, after their correct positions were determined by him and his assistant. Tycho's largest quadrant was fourteen feet in diameter. It was fastened to the wall and the space inside the arc was filled with a life-sized fresco of Tycho himself in the midst of his instruments.

Tycho published a detailed account of his observatory and instruments in a book titled, *Astronomiae instauratae mechanica (The New Astronomy's Instrumentology)*. This became a model for others.

Tycho highlighted the importance of precise and continuous observational data. For him meticulous and precise observation was a form of worship. Tycho never believed in the Copernican system. At the same time he discarded the Ptolemaic system, because it was incompatible with his observations of planetary motions. Tycho sought a compromise between the two systems. Thus he proposed a new model for planetary motions. According to the Tychonic system, the Earth is the centre of the solar system, the Sun and the Moon revolve around the Earth, and the other planets revolve around the Sun. One reason for his quest for precise and continuous observation was to substantiate his own system. Tycho was attracted to astronomy by the predictability of a partial solar eclipse. But then on August 17, 1563 he noticed that Saturn and Jupiter were so close together as to be almost indistinguishable from each other. Tycho found that the Alphonsine tables were almost one month in error regarding this event and the Copernican table by several days. This discovery was so shocking to Tycho that he took unto himself to correct the existing inconsistencies.

Frederik II died in 1588 and he was succeeded by his son Christian IV (1577 - 1648). Tycho who had already acquired the image of a despo tic ruler of his island, quarrelled with the young king. Christian IV, though well disposed towards Tycho, did not ignore Tycho's despotism in the Island of Hveen. This was added to Tycho's arrogance. Tycho did not bother to answer the king's letters. He d isobeyed provincial as well as high court's decision by holding a tenant and all his family in chains. Still Christian IV did not initiate any direct action against Tycho but he did reduce Tycho's fantastic income assured by Frederik II to a reasonable lev el. This measure prompted Tycho, who was becoming restless and bored on his Island, to resume his wanderings. In 1597 Tycho left the Island of Hveen. The last recorded observation made at Hveen was on March 15, 1596.

His luggage consisted of the printing press, library, furniture and all his instruments except the four largest ones, which followed later. From the very beginning Tycho had ensured that all his instruments were made in such a way that they could be dismantled and taken from one place to anoth er. Tycho was of the opinion that, "An astronomer must be cosmopolitan, because ignorant statesmen cannot be expected to value his services." Before leaving the Danish territory Tycho wrote to Christian IV. He bitterly complained about the way his ungrateful country treated him. He intended "to look for help and assistance from other princes and potentates". But Tycho also wrote that he would be willing to return to his country "if it could be done on fair condition and without injury to myself." Christian IV in his letter to Tycho refuted every complaint made by Tycho and made it clear that condition of Tycho's return to Denmark was "to be respected by you (Tycho) in a different manner if you are to find a gracious lord and king".

As there was no chance of reaching a compromise with the king of Denmark, Tycho continued his wanderings for two years before reaching Prague in June 1599. In Prague Tycho found a new patron. Ruldolph II (1552 -1612), king of Hungary and Bohemia and Holy Roman Emperor, appointed Ty cho as Imperial Mathematicus of the Holy Roman Empire at his court in Prague. Tycho was again given a castle of his choice (the castle at Benatake outside Prague) and an annual salary of three thousand florins. The magnitude of Tycho's salary could be gues sed if we compare it with Kepler's salary of two hundred florins a year in Gratz. Tycho took possession of the Castle in August 1599. It was in Prague that Kepler met Tycho and their association heralded a new era in astronomy.

Throughout his life Tycho also practised alchemy. He had prepared a wonderful potent medicine to cure all disorders. This was widely circulated in Europe in its time as Holloway's pills. Among many ingredients it contained a little of antimony, a well-known sudorific (causing or increasing sweating).

Tycho died on October 24, 1601. He was buried with great pomp in Prague. Tycho's coffin was carried by twelve imperial gentlemen-at-arms, preceded by his coat of arms, his golden spur and favourite horse. After Tycho's death Kepler was appointed as Tycho's successor and inherited Tycho's large collection of astronomical observations from which Kepler deduced his famous laws of planetary motion.

Tycho wrote in his *Astronomiae instauratae Mechanica* (*The New Astronomy's Instrumentology*): "The person who cultivates divine Astronomy ought not to be influenced by ignorant judgements, but rather look upon them from his elevated position considering the cultivation of his studies the most precious of all things, and remaining indifferent to the coarseness of others. And when statesmen or others bother him too much, then he should leave with his possessions."

Giordano Bruno
The Defiant “Scientist”

“In general, Giordano Bruno paved the way for the cosmology of our time. To his lasting credit, the most recent empirical discoveries in astronomy and rational speculations in cosmology (including the emerging science of exobiology) support many of his brilliant insights and fascinating intuitions. This is an appropriate legacy from a daring and profound thinker, who presented an inspiring vision which still remains relevant and significant for our modern scientific and philosophical framework.”

*H.James Birx (**www.theharbinger.org/xvi/971111/birx.html**)*

“Giordano Bruno…was an Italian philosopher best-known as a proponent of heliocentrism and the infinity of the universe. In addition to his cosmological writings, he also wrote extensive works on the art of memory, a loosely-organised group of mnemonic techniques and principles. He is often considered an early martyr for modern scientific ideas, in part because he was burned at the stake as a heretic by the Roman Inquisition. However, some argue that his actual heresy was his pantheist beliefs about God, not an idea that would be characterised today as scientifica”

Wikipedia, the free encyclopedia

Giordano Bruno was burnt at the stake by the Inquisition in 1600. Many will tend to argue that Bruno deserves to be called a forerunner, if not a founder of modern science. He was one of the first philosophers to discuss scientific and philosophical issues in the vernacular (Italian). During his time Latin was the language of intellectual discourse. Thus Bruno may be called one of the earliest science popularisers. Bruno’s name is invoked as a prime example of the enormous struggle suffered by the early scientists in the 16th and 17th centuries at the hands of religious authorities.

Bruno lived in a period when modern science was just beginning to emerge. He was a fiery public speaker, a radical thinker and a devout mystica He believed in and strongly advocated the reason and logic as the basis for determining truth. Thus he wrote in *De triplici minimo et mensura* (1591): “He who desires to philosophise must first of all doubt all things. He must not assume a position in a debate before he has listened to the various opinions, and considered and compared the reasons for and against. He must never judge or take up a position on the evidence of what he has heard, on the opinion of the majority, the age, merit, or prestige of the speaker concerned, but he must proceed according to the persuation of an organic doctrine which adheres to real things, and to truth that can be understood by the light of reason."

Giordano Bruno

It is often maintained that Bruno was burnt at the stake by the Inquisition because of his advocacy of the Copernican view of a heliocentric universe and his belief in the infinity of inhabited worlds. Today we know that before Nicolaus Copernicus it was assumed that the stationary (unmoving) Earth was at the centre of the universe around which not only the Moon but also the Sun and the known planets revolved with perfect uniform circular motion. The system was known as geocentric universe. The idea of a geocentric universe goes back to the Greek philosopher Plato and received its fullest development in the Almagest of Ptolemy (Claudius Ptolemaeus in Latin), the Alexandrian astronomer, mathematician and geographer, in the second century AD. It was Copernicus who came up with the revolutionary hypothesis that, "All the spheres revolve about the Sun as their midpoint and therefore the Sun is the centre of the Universe." This new system, which came to be known as the Heliocentric (Sun-centred) Universe, the truth of which was fully affirmed by Galileo's discoveries, which that the Earth is merely one of the planets going around the Sun and rotating on its axis. Initially Copernicus hesitated to make his work publica However, he was persuaded by his disciple Rhectius (1514-1574), the German astronomer and mathematician, to publish his work. Thus his great work *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*) was published in the month of his death in 1543. Copernicus dedicated it to Pope Paul III. The book carried (without the knowledge of its author) a 'Preface to the Reader' written by Andreas Osiander (1498-1552), a Lutheran pastor of Nuremberg, who supervised the last stages of the printing. The unauthorised preface presented the work as a hypothesis rather than a true physical reality.

Unlike in the case of Galileo where we have extensive documentation, the exact grounds on which the Church declared Bruno a heretic (a person or especially a church member who holds beliefs opposed to church dogma) are not known. It has been reported that the relevant records have been lost. It is quite likely that the Inquisition's complain with Bruno was theological and constituted a determined direct attack on the philosophical basis of the Church's spiritual tenets. Moreover, the Church formally condemned Copernicanism only after 15 years of Bruno's death. In fact, it is said that the Pope and a cardinal of the Church were among those who encouraged Copernicus to publish his full manuscript. In 1600, few astronomers really supported Copernicus' system. The situation changed only when Galileo started his telescopic observations in 1610 and his discoveries, which followed one after another, demonstrated that Copernicus' ideas, once considered 'outlandish', could be more realistic than the conventional ones. Further, Paolo Antonio Foscarini (1565-1616) in a publication defended Copernicus' views against charges made by itinerant preaching monks that they were in conflict with scripture. The Church felt compelled to react.

Though, among his writings we find an espousal of Copernican theory, Bruno was not an astronomer. But he certainly played a definite role in furthering the cause of science. He compelled natural philosophers and scientists to open their minds to the far-reaching implications of Copernicus theory. It helped open the door of modern science. Bruno challenged all dogmatism. Though he spent the greater part of his life wandering from one place to another in hostile and foreign countries, he wrote nearly 20 books. He was interested in the nature of ideas and he might be called an epistemologist or a pioneer semanticist (a specialist in semantics – a branch of linguistics concerned with the nature, the structue, and the development and changes of the meaning of speech forms or with contextual meaning). His pantheistic philosophy viewing all creation as one life animated by God as "World-soul", influenced Benedict (Baruch) Spinoza (1632-77), Rene Descartes (1596-165) and Gottfried Wilhelm Leibniz (1646-1716) among others.

Bruno's views on cosmology are described in his three works. *La Cena de le Ceneri* ("The Ash Wednesday Supper", 1584); *De la causa, Principio et Uno* ("On Cause, Principle and Unity", 1584) and *De l'Infinito Universo et Mondi* ("On the Infinite Universe and Worlds", 1584). These works are in the form of dialogues, where Bruno's characters argue various philosophical positions from different points of view. One of these characters was represented by Bruno himself.

In the *Ash Wednesday Supper* Bruno defended the Copernican view of the heliocentric universe. It is a story of a private dinner, where Bruno spreads the Copernican view fo the universe in the midst of English guests. The guests laugh heartily at the new astronomy, which is at variance with the teaching of Aristotle.

In his book on *Cause, Principle and Unity*, he wrote: "This entire globe, this star, not being subject to death and dissolution and annihilation being impossible anywhere in Nature, from time to time renews itself by changing and altering all its parts. There is no absolute up or down, as Aristotle taught; no absolute position in space; but the position of a body is relative to that of other bodies. Everywhere there is incessant relative change in position throughout the universe, and the observer is always at the centre of things".

In his *On the Infinite Universe and Worlds*, Bruno argued that the universe was infinite, it contained an infinite number of worlds and all these infinite worlds are inhabited by intelligent beings.

Giordano Burno's real name was Filippo Bruno. He was born near Naples, in a place called Nola (Compania) in Italy, not far from Vesuvius, He was the son of Giovanni Bruno, a soldier, and Fraulissa Savolino, He attended school at the Monastery of Saint Dominico, in Naples. It was the great Dominician monastery where St. Thomas Aquinas (1225-74), the Italian scholastic philosopher and theologian once had lived and taught. He entered the Order of St. Dominic and took the name of Giordano. In 1572 he was ordained priest.

It may be noted that Dominician ordfer, or *Ordo Praedictatorum* in Latin, was founded by St. Dominic de Guzmon; ca1170-122) and formally organised at Bologna, Italy, in 1220-21. The main objective of the order was preaching and teaching. They were prominent defenders of orthodoxy in the Inquisition and also led missionaries to the `New World' Inquisition was formally instituted by Pope Gregory IX in 1231. The purpose was to combat the growing threat of heresy. Inquisitors were appointed by the Pope, especially from the Dominicians and Franciscans orders and they wielded considerable powers. The use of torture was authorised in 1252. Trials used to be held in secrecy. Inquisitors imposed penances on those who confessed and those who did not were imprisoned or executed by burning.

Even as a student, Bruno was quite well known for originality of his views and his outspoken criticism of accepted theological doctrines. In 1576, he was formally accused of heresy by the Inquisition. He left Naples to escape prosecution and reached Rome but there was no change in his views. So accusations were renewed against him. At this stage he severed his relations with the Dominicians and left the city of Rome.

Bruno travelled throughout Italy, France, England and Germany. In France he was patronised by Kind Henry III (1551-89), Who found a position for him at the College de France. Bruno rached London in 1583 and stayed there for three years. His stay in England was one of the most fruitful periods of his life. In England he published six books in Italian, fully elaborating his philosophical ideas for the first time. Outstanding scientists like William Gilbert (1544-1603) and Thomas Harriot (1560-1621) became leading proponents of Bruno's cosmological views. Gilbert, who in 1600 published the first great scientific work *De Magnete, Magnetisque Corporibus, et de Magno Magnet Tellure* (*On the Magnet, Magnetic Bodies, and the Great Magnet Earth*) was interested in developing his magnetic theories in relation to

Bruno's cosmological views. It may be noted that Gilbert's book, which remained a chief source book on magnets for 300 years, was very influential in the creation of the new mechanical vie of science. In fact it is one of the first classics of experimental science. Harriot, a noted mathematician and astronomer exchanged letters with Johannes Kepler (1572-1630) in 1608, discussing Bruno's idea of infinite universe. It may be noted that Harriot made notable contributions in practical astronomy. He discovered, independent of Galileo, the moons of Jupiter.

In 1591, Bruno came back to Italy at the invitation of a Venetian nobleman named Zuane Mocenigo. However, Mocenigo denounced him to the Inquisition in Venice and Bruno was arrested on May 23, 1592. Subsequently he was handed over to the Inquisition in Rome and was thrown into prison. After seven years of trial, the Inquisition delivered its verdict on January 20, 1600.

Bruno's stubborn refusal to bow down to the authority even after the alleged torture and knowing the fact that he might be burnt to death will no doubt be an inspiration for scientists for centuries to come. Even after the delivery of the sentence he was given eight days to see whether he would repent. But he did not.

On February 16, 1600 Bruno was burnt at the stake on the Campo del fiori in Rome. Bruno was defiant to the last moment. On hearing the sentence delivered by the Inquisition he exclaimed: "perchance you who pronounce sentence are in greater fear than who receive it."

In 1992, the Church admitted that Galileo had been right in supporting the theories of Copernicus. However, no such admission has been made in case of Bruno. His works are still on the Vatican's list of forbidden texts.

Galileo Galilei
Founder of Modern Astronomy

"Pure logical thinking cannot yield us any knowledge of the empirical world; all knowledge of reality starts from experience and ends in it. Because Galileo saw this and particularly because he drummed it into the scientific world, he is the father of modern physics — indeed, of modern science altogether."

Albert Einstein (1879-1955)

"Although Galileo is widely remembered for his astronomical discoveries, it is in the field of mechanics that he made substantial contributions to our under standing of nature, for he laid the foundations for the science of motion, presented in his masterpiece, *Discourses and Mathematical Demonstrations Concerning Two New Sciences*, more frequently called *Two New sciences*."

Mauro Dardo in Nobel Laureates and Twentieth-Century Physics, 2004

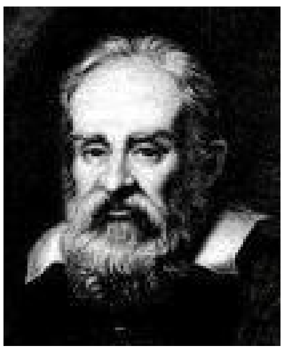
"Most people know two facts about Galileo, and both facts are wrong. We should begin our discussion by getting those facts right: Galileo did not invent the telescope, and he was not condemned by the Inquisition for believing that Earth moved around the sun."

Michael A Seeds in "Foundations of Astronomy", 2003.

Galileo's career was a major turning point in science. Galileo revolutionised the way scientists approached their work. In this respect he departed from his contemporary scientists or 'natural philosophers'. He did not confine himself to simply reasoning his ideas through logically as was the practice of his day. He searched for and devised suitable experiments for demonstrating his theories. He measured time and distance. In fact he was the first to conduct time experiments and to use measurements in a more systematic way. He introduced mathematics into physics, reduced things to quantity to examine whether a particular phenomenon could be described with simplicity and generality. The invaluable contribution of Galileo to modern science was aptly capitulated by none other than Albert Einstein as quoted above.

Galileo was the first to observe the sky systematically with the help of a telescope and to make use of his observations to solve the most discussed theoretical problem of the day—the place of the Earth in the universe. He found that the Moon was not a perfect body as the Ptolemaic model had supposed it to be. He found that the Moon's surface had mountains, valleys and craters. He discovered that the Milky Way consisted of innumerable stars not visible to the unaided eye, as they were too faint. He also found satellites orbiting Jupiter. The discovery of the satellites of Jupiter helped to establish the Copernican model. Critics of Copernican model argued that the Earth could not move otherwise it would loose its Moon, as it would be left behind. This belief was proved wrong by Galileo by showing that though Jupiter moved but kept the satellites with it. Galileo's observations also showed unlike the earlier belief that all motion centred around Earth that there could be other centres of motion. Galileo published his amazing observations in a small book called *Sidereus Nuncius* (*The Sidereal Messenger*). Soon after the publication of *The Sidereal Messenger*, Galileo made two other important discoveries — the phases of the Moon and the sunspots.

As the moons of Jupiter were key evidence in favour of Copernican model they caused the most debate. But it should be mentioned t hat the craters of the moon and the phases of the Venus were critical evidence against the Ptolemaic system.



Galileo Galilei

Before Galileo experiment was not popular among scientists or natural philosophers. The Greeks, who dominated the intellectual scene of the West, disliked experiments. They considered experiment not only irrelevant but also a hindrance to the process of beautiful pure deduction. They were content with accepting the 'obvious' natural facts as starting points for their reasoning. Moreover in case of a disagreement between an experiment and deduction aiming to arrive at a conclusion, they felt no reason to discard deduction in favour of experiment. In fact the very idea of testing a perfect theory of nat ure with 'imperfect' instruments did not appeal to the Greeks. This became the dominant tradition among the scholars.

It is true that philosophers and scholars like Roger Bacon (a.1220 -ca1292) and Francis Bacon (1561-1626) made experimentation philosophic ally respectable and some others, including Achimedes, did use experimentation as a means to arriving at truth. The English physician and physicist William Gilbert (1544 -1603). Gilbert made a detailed study of magnetism in a long series of carefully detai led experiments and observations. It is interesting to note what Galileo thought of Gilbert, because it is relevant even in the present context: "I think him worthy of the greatest praise for the many new and true observations which he has made, to the disgrace of so many vein and fabling authors, who write not from their own knowledge only, but repeat everything they hear from the foolish and vulgar, without attempting to satisfy themselves of the same by experiment." It was Galileo who overthrew the Greek view and ushered in a scientific revolution. He made experimentation attractive. By virtue of his literary ability he could describe his experiments and theories very clearly and beautifully. He made quantitative method famous and fashionable.

Galileo Galilei is always known by his first name. He owed both his first and his last name to an illustrious ancestor, Galileo Bonaiuti, an eminent physician and magistrate. The family name was changed to Galilei in honour of this illustrious ancestor in the middle of the fifteenth century.

Galileo was born on February 15, 1564 in Pisa, in the Tuscany region, of northwest Italy. It happened to be a centre of the Renaissance. His parents were Vincenzio Galilei (1520-91) and Pisan Giulia Ammannati (1538-1620). His father was an accomplished professional musician. Vincenzio was also interested in mathematics and musical theory. He published a book titled Dialogue of ancient and modern musica Galileo's family moved to Florence in 1572, the heart of Renaissance culture, but Galileo stayed there for another two years. He joined the family in Florence in 1574 when he was 10.

Until he was 11, Galileo was educated privately at home. In 1574 he was sent to the monastery at Vallombroso for more formal education. The monastery was situated in the mountains 30 kilometres east of Florence. Galileo liked the place and the atmosphere in the monastery so much that he joined the order as a novice. However, his father brought him back. Galileo must have been influenced by his father, who did not accept anything unquestioned. To quote his father: "It appears to me those who rely simply on the weight of authority to prove any assertion without searching out the arguments to support it, act absurdly. I wish to question freely and to answer freely without any sort of adulation..."

In 1581, Galileo was enrolled as a medical student at the University of Pisa. While he was in his second year of medical studies, Galileo met Ostilio Ricci (1540 - 1603), a well-known mathematician of his time. Ricci was the court mathematician of the Grand Duke of Tuscany. Galileo's encounter with Ricci had a profound effect on his career. He left his medical studies and started studying mathematics. However, Galileo failed to obtain a scholarship he very much needed for his study in Pisa. Finally he left the university in 1586 without a degree and came back to Florence. Though, he left the university, he did not stop studying mathematics. The same year Galileo invented a hydrostatic balance, a device that measured the pressure in fluids. Galileo published a pamphlet about this invention. This first brought him the attention of the scholarly world. However, in those days without a powerful patron it was impossible to secure any academic position. Fortunately

Galileo found one in the form of Marquis Guidobaldo del Monte (1545 -1607), an influential nobleman. It may be noted that del Monte was very much interested in science. He had written an important book on mechanics. Galileo managed to secure his first academic position, a junior post in mathematics, at the University of Pisa, in the same university he had left without a degree four years earlier. But in those days mathematics was not regarded as an important discipline. The salary associated with the post was low and Galileo had to augment his salary by giving private tuition.

Galileo took lodgers, the sons of the noblemen, who lived in his home and thus the students had the benefit of constant interaction with the teacher at all hours. This arrangement, a standard practice of his time, not only helped Galielo to increase his income but also spread his reputation as a teacher.

In October 1592 Galileo joined the University of Padua, in the Republic of Venice, where he was offered the chair in Mathematics. Here he taught for 18 years. His salary was trebled. He taught in the Auditorium Maximum (the "Large Auditorium") to packed audiences. People from all over Europe came to listen to his lectures and his audience included Gustavus Adolphus, the crown prince of Sweden, besides representatives of many noble houses. He taught how mathematical principles could be used for practical applications viz., building bridges, planning harbours, fortifying cities and buildings and constructing artillery. He proved to be a very successful teacher. He gave practical demonstrations in his classes. He used to bring bones to his class to prove that strong construction could be made by hollow materials. This resulted in hollow pipe construction and which brought down the construction cost drastically. He urged his students to seek truth in nature by using their own eyes and minds and not to depend solely on ancient revered texts. He showed them how mathematics and experiments could be used to study nature.

In public life Galileo's fame was enhanced by the publication of his treatise in military fortification. He also published a book on mechanics based on the lectures he was giving in Padua. Though his salary was trebled money was a constant problem for Galielo during his stay at Padua. To solve this problem, Galileo during his stay in Padua was trying hard to make suitable inventions. In this effort he developed an early kind of thermometer. Though the device was quite ingenious, it was not practical enough to commercialise it. Another of his inventions was a system for lifting water for irrigation and Galileo also obtained a patent for the same in 1594. It was technically successful but not commercially.

In 1595-96 Galileo invented a geometrical and military 'compass' - a forerunner of the slide rule. It was a kind of all-purpose calculating instrument. Initially it found use as a device for gunners who used it for calculating elevations when ranging their guns. It was a great success after Galileo adapted it to include scales showing the relative densities of various metals, lines for calculating cube roots and square roots and other data useful in geometrical applications. While Galileo sold the instruments cheap, he charged for giving training on how to use it.

Between 1619 and 1624 Galileo started to produce microscopes or "Occhlialini" as he called them. The Galilean microscope was made up of the tube of telescope of reduced size furnished with two lenses.

Towards the end of the 16th century Galileo dedicated himself to research on heat and during this period he invented (1593) the Galilean thermometer, a device, which was used to carry out experiments on the relationship between changes of temperature and variations of the level of the liquid. It was a crude device and it took about hundred years or until the time of the French physicist and scientific instrument inventor, Guillaume Amontons (1663-1705), to make a reasonable beginning in thermometry. The development of Florentine thermometer had its origins in Galileo's early research on heat.

Galileo also studied magnetism, inspired by William Gilbert's *De Magnete.* He tried to enhance the strength of loadstones by means of special armature.

Galileo produced major insights about motion and mechanics. In 1590 Galileo published his book *De motu gravium* ("On the motion of heavy bodies") in which he updated Aristotle's basic thoughts about motion using some ideas of the French philosopher Jean Buridan (ca1295-1358).

Galileo is most talked about for three incidents, though their description may be a little far from the truth. They have become legends. These are :

i) Dropping cannon balls of different weights from the leaning tower of Pisa to demonstrate that they reached the ground together.

(ii) Inventing the telescope

iii) Being martyred for his beliefs about the Copernicus system.

According to legend Galileo dropped a cannon ball and a wooden ball from the top of the Leaning Tower of Pisa to demonstrate that two balls of different weights fall at the same rate. Following Aristotle almost all scholars believed that the rate of fall of any falling body is proportional to its weight. Galileo did not actually conduct the experiment. In fact, his predecessors conducted similar experiments. Benedetti Giambattista (1530-1590), an Italian mathematician published a similar experiment demonstration in 1553 and the Flemish engineer and a mathematician Simon Stevin (1548/49-1620) conducted an experiment in 1586. Whether Galileo conducted the experiment or not but he definitely disproved Aristotle's theory about falling objects. It has been reported that Galileo thought about this, during a hailstorm when he noticed that hailstones of different sizes fell simultaneously with the same speed. However, there is a connection between Galileo, falling bodies and the Leaning Tower. In 1612 one of the Peripatic professors at Pisa dropped objects of different weights from the tower. His purpose was to prove Galileo wrong and he was very happy to note that they did not hit the ground simultaneously. To this Galileo react ed: "Aristotle says that a hundred-pound ball falling from a height of a hundred cubits hits the ground before a one-pound ball has fallen one cubit. I say they arrive at the same time. You find, on making the test, that the large ball beats the smaller o ne by two inches. Now, behind those two inches you want to hide Aristotle's ninety-nine cubits and, speaking only of my tiny error, remain silent about his enormous mistake." One of the Galileo's students did perform the demonstration and he found a slight difference in the time the two balls struck the ground. However, this was no surprise to Galileo as he had already explained the effect of the air resistance. The air resistance slows the fall of light objects like leaves, feathers, snowflakes etca that offer comparatively large areas to the air. On the other hand, the heavier objects reduce this effect to a quantity small enough to be insignificant value and fall at the same rate.

Galileo's name is often associated with the inventing of the telescope. However, he was not the original inventor. The telescope was first invented in 1608 by Hans Lippershey (1570-1619), a German-Dutch lens-maker, in Holland. Recently it has also been shown that Leonard Digges (1520-1559), a well-known English mathematician and a surveyor of England built a telescope before 1550. However, Galielo reintroduced the instrument on his own and used it for the first time for astronomy. He was the best lens maker in Europe at the time and built a number of telescopes. He used his 30 po wer telescope to discover craters on the moon (which he called maria or 'seas'), sun spots which rotated with the sun, four largest satellites of Jupiter (Io, Europa, Ganymede and Callisto, today known as Jupiter's "Galilean moons", named in his honour) an d phases of Venus, that is he saw that like the Moon, this planet also had phases - from crescent to disc to crescent. The last two observations demonstrated that the Copernican theory was correct. The discovery of sunspots and craters and mountains on the moon showed that Aristotle was not right in his thesis that the heavenly bodies were perfect and that only on Earth was there irregularity and disorder. Galileo was not alone in discovering sunspots, there were other astronomers who discovered sunspots simultaneously with Galileo. So, there was dispute over priority. But whether Galileo was the first to discover or not, he did something more than mere discovery of sunspots. He used them to demonstrate that the Sun rotated about its axis in twenty-seven days. This he did by following individual spots around the sun.

While Galileo observed that even with the telescope the brightest stars could not be seen bigger than mere dots, the planets became as big as little globes. He also observed that with the aid of telescope many more stars were visible than those could be seen by naked eye. From these observations, Galileo reached the conclusion that the stars were much further away than the planets and the universe might be infinitely large.

In February 1616, the Holy Office of the Church at Rome formally condemned the heliocentric view of the universe propounded by Copernicus. The church declared that the Earth's motion was physically false and contrary to scripture. The church banned Copernicus' book *De revolutionibus orbium coelstium* (1543) until revised. In 1620 a revised edition was issued in which suggestions that the Earth's motion is physically true were removed. The revised edition gave the impression that Copernicus treated Earth's motion as a hypothetica l means for astronomical calculations. The pope asked Cardinal Robert Bellarmine to convey the ruling to Galileo. Galileo was given a private warning forbidding him to hold, or defend Earth's motion.

Galileo decided to keep quite. However, when in 1623 o ne of his old admirers became Pope Urban VIII he felt encouraged to put his views in writing. In 1632, Galileo published his *Dialogue on the Two Chief Systems of the World* . It went on sale in Florence in March 1632. As the title suggested the presentation took the form of a conversation between two people, one supporting each of the two opposing world views. This form of presentation goes back to the ancient Greeks. Galileo, however, added a third character, who listened to the conversation between the two and raised points for debate. The name of the three characters were Filippo Salviati (who argued the Copernican case or in other words presented Galileo''s views) Giovanfrancesco Sagredo (the independent observer), and Simplicio (the supporter of Aristotle or the Earth-centred cosmology of Ptolemy). The first two characters were named after Galileo's friends and the third character after an ancient Greek who had written a commentary of Aristotle's work. Though Galileo claimed that he meant to show a fair an d even battle but by naming the character supporting Aristotle's view Simplicio he undoubtedly intended to imply that anyone who supported Aristotle was a 'simpleton.' Moreover the arguments for Copernicus' ideas were articulated in a much better way.

Conservatives, those who were after Galileo for quite sometime, persuaded Pope Urban VIII to believe that the character in Galileo's book supporting Aristotle's views was nothing but a deliberate and insulting caricature of the pope himself. Further someone dug out of the files the unsigned minute from 1616, forbidding Galileo to 'hold, defend or teach' the Copernican view of the universe. Galileo was brought before the Inquisition on charges of heresy. He was summoned to Rome. The infamous trial formally beg an on 13 April 1633 when Galileo was in his 70th year. Galileo's opponents refused even to look through Galileo's telescope or listen to his reasoning. They believed that they knew the truth and if Galileo's telescope showed something else than there must be something wrong with the telescope itself. So why waste time! He was sentenced to indefinite prison. The sentence was commuted by the pope at the request of Duke of Tuscany. Fearing torture (and he had also the example of Bruno) Galileo renounced his views in his famous public apology: "I do not hold and have not held this opinion of Copernicus since the command was intimated to me that I must abandon it." And he was allowed to live under house arrest in his own house at Arcetri near Florence. According to legend when Galileo rose from his knees having completed his renunciation, Galileo remarked under his breath: "Eppur si muove" [But it (Earth) does move]. There is no evidence whatsoever to prove that Galileo uttered this sentence. However, because of the unparalleled contribution to the growth of science and his unique personality the legend has been kept alive.

During the period Galileo was kept under house arrest he did not stop working. In fact during this period he completed his greatest book, *Two New Sciences.* The manuscript was smuggled out of Italy and published in Leyden in 1638 by Lonis Elzerir. This book, which exerted enormous influence in the following decades summed up all of Galileo's work, on mechanics, inertia, pendulum, the strength of bodies and the scientific method.

In his later years (1638 onwards) Vicenzio Viviani joined him as his scribe and assistant. It was Viviani who wrote Galileo's first biography. Galileo died in his sleep on the night of 6/7 January 1642, in the same year Isaac Newton was born. The Catholic Church finally agreed with Galileo. In 1992, a commission under the Vatican Cardinal Paul Poupard observed that Galileo had been 'more perceptive' in his interpretation of the Bible than his prosecutors. Galileo was formally pardoned on 31 October 1992 that is about 350 years after his death.

Galileo was a true Renaissance man. He liked music and art. He studied literature and poetry. He played the flute for pleasure and he had enough familiarity with painting so that he could illustrate his own astronomical findings. He was an excellent writer.

Galileo was aware of the implications of his work. He said that he had "Opened up to this vast and most excellent science, of which my work is mere the beginning, ways and means by which other minds more acute than mine will explore in remotest corners."

We would like to end this article by quoting Stephen Hawking: "Galileo, perhaps more than any other single person, was responsible for the birth of modern science ... [he] was one of the first to argue that man could hope to understand how the world works, and, moreover, that we could do this by observing the real world".

Johannes Kepler

Founder of Celestial Mechanics

"My aim is to show that the heavenly machine is not a kind of divine, live being, but a kind of clockwork (and he who believes that a clock has a soul, attributes the maker's glory to the work), insofar as nearly all the manifold motions are caused by a most simple, magnetic and material force, just as all motions of the clock are caused by a simple weight. And I also show how these physical causes are to be given numerical and geometrical expression."

Johannes Kepler

"Kepler was a productive polymath. In addition to his astronomical work, he made important contributions to optics and mathematics."

James R. Voekel in "The Oxford Companion to the Modern History of Science" (2003)

Johannes Kepler is regarded as the founder of celestial mechanics. He formulated the three laws of planetary motion. He demonstrated that the planets moved in elliptical orbits and not in circular orbits as it was earlier believed. To answer the question, why the distance and velocities of the planets were as they were, Kepler expounded that "there must be a force emanating from the Sun which drives the planets round their orbits". Further he thought that this driving force diminishes as the distance from the Sun increases. This explains why the outer planets move more slowly. Thus Kepler not only attempted to describe the motions of heavenly bodies but also ascribed them a physical cause. Kepler's laws of planetary motion, as Arthur Koestler wrote: "were the first 'natural laws' in the modern sense: precise, verifiable statements about universal relations governing particular phenomena, expressed in mathematical terms. They divorced astronomy from theology, and married astronomy to physics". It was Kepler's Third law of planetary motion that led Isaac Newton to his law of gravitation.

Kepler is also regarded as the founder of modern optics. He was the first to investigate the process of picture formation in a pinhole camera. He explained the process of vision by refraction within the eye. *Astronomia pars optica* (1604), one of his major works, included a good approximation of Snell's law, improved refraction tables and discussion of the pinhole camera. His *Dioptrice* (1611) has been called the first work of geometrical optics. In this work Kepler was the first to explain how a telescope works. It also contained an improved telescope design. He was also the first who explained that the tides were caused by the Moon. Kepler also contributed significantly to mathematics. His *Nova sterometria doliorum vinariorum* (1615) was a pioneering work of pre-calculus. He also published an important work on logarithms called *Chilias logarithmorum* (1624).

Johannes Kepler

Johannes Kepler was born on December 27, 1571 in the township of Weil-der-Stadt in Swabia in southwest Germany between the Black Forest, the Neckar, and the Rhine. His father Henrich Kepler was a soldier for hire, who once 'ran the risk of hanging' vanished forever from the sight of his family in 1588. His mother Katherine Kepler nee Guldenmann was an innkeeper's daughter. Katherine was brought up by an aunt who was burnt alive as a witch. Kepler's mother was also tried for witchcraft but narrowly escaped being burnt alive. Kepler defended her mother. She was released after fourteen months of imprisonment.

Kepler's parents neither had the inclination nor the means for his education. However, fortunately for Kepler, his native land had exceptional educational facilities. There was also a system of scholarships and grants for "the children of the poor and faithful who are of a diligent, Christian and God-Fearing disposition". Thus because of his brilliance Kepler had no problem for his progress from school to seminary and from there to university.

In his elementary Latin school in Leonberg he was taught in Latin. The German vernacular was yet to be considered a worthy medium of expression for scholars. After passing the Elementary Latin School Kepler attended the Theological Seminary at Adelberg (earlier Hundsholz) in Germany. In the seminary he was taught Latin, Greek, theology, Pagan classics, rhetoric and dialectics, mathematics and musica

In the seminary he was quite unpopular among his fellow students. They beat him at every opportunity. He had described his childhood in his memoirs, *Johannis Kepleri Astronomi Opera Omnid*, a remarkable document of self-analysis, perhaps the most introspective piece of writing of the Renaissance. This was written when Kepler was 26 and he refers himself in the third person and often mixes present tense with past tense. Kepler wrote: "He was constantly on the move, ferreting among the sciences, politics, and private affair s, including the lowest kind; always following someone else, and imitating his thoughts and actions. He is bored with conversation...He tenaciously persecuted wrong -doers...He is malicious and bites people with his sarcasm. He hates people exceedingly, and they avoid him but his masters are fond of him...His recklessness knows no limits ...yet he takes good care of his life...His teachers praised him for his good disposition though morally he was the worst among his contemporaries...He was religious to the point of superstition. As a boy of ten years when he first read Holy scripture...he grieved on account of the impunity of his life, the honour to be a prophet was denied him. When he committed a wrong, he performed an expiatory rite hoping it would save him from punishment: this consisted in reciting his faults in publica..In this man there are two opposite tendencies; always to regret any wasted time, and always to waste it willingly...Since his caution with money kept him away from play, he often played by himself. It must be noted that miserliness did not aim at acquiring riches but at removing his fear of poverty -although, perhaps avarice results from an excess of this fear."

In the same document Kepler wrote about himself: "In philosophy he read the text of Aristotle in the original...In theology he started at once on the predestination and fell in with the Lutheran view of the absence of free will...But later on he opposed it ...Inspired by his view of divine mercy, he did not believe that any notion was destined to damnation... He explored various fields of mathematics as if he were the first man to do so (and made a number of discoveries), which later on he found to have already been discovered. He argued with men of every profession for the profit of his mind... He jealously preserved all his writings and kept any book he could lay hands on with the idea that they might be useful at some time in the future. He was the equal of Crusius (his teacher) in his attention to detail, far inferior to Crusius in industry, but his superior in judgement. Crusius collected facts, he analysed them; Crusius was a hoe, he a wedge..."

At the age of twenty he graduated from the Faculty of Arts at the University of Tuebingen. Then he continued his studies at the Theolog ical Faculty. At this stage it seemed that he was destined to be a priest. However, before he could pass his final examination, he was offered the post of a teacher of mathematics and astronomy in Gratz, the capital of the Austrian province of Styria, a co untry ruled by a Catholic Hapsburg prince and its predominantly Protestant Estates. Kepler had no real knowledge of either mathematics or astronomy, and he had no plan to become an astronomer. If he had earlier shown interest in Copernicus it was not because of his interest in astronomy but because of mystical implications of the Sun-centred universe. Kepler's first reaction to the offer was not very enthusiastica Kepler later observed that he was hesitant 'not because I was afraid of the great distance of the place (a fear which I condemn in others), but because of the unexpected and lowly nature of the position, and my scant knowledge in this branch of philosophy'. Though Kepler initially hesitated he finally took up the appointment.

Kepler reached Gratz in April 1594. Besides being the teacher of astronomy he was also the "Mathematicus of the Province". In addition to his teaching activity he was also responsible for publication of an annual calendar of astrological forecasts. As a teacher he proved to be totally unsuccessful. In his second year no student came to attend his class. Kepler himself wrote that his lectures were "tiring or at any rate perplexing and not very intelligible". In his self -analysis Kepler attributed his failure as a teacher to his peculiar kind of memory while he forgot everything that did not interest him he was very good at relating one idea to another. Fortunately for Kepler the director of the school was not alarmed by the absence of students in Kepler's class. They thought if s tudents were not there it was "because the study of mathematics is not every man's affair."

They certified Kepler as "a learned and a fitting magister and professor". They asked Kepler to give some additional lectures on Virgil and rhetoric, "so that he should not be paid for nothing - until the public is prepared to profit from his mathematics too".

Kepler's first book, *Mysterium Cosmographicum* or *The Cosmic Mystery* (the full title was a long one) was published in 1596. In this book Kepler describes hi s attempts to make centuries old idea that the universe is built around certain symmetrical figures-triangle, square, pentagon etca, fit with the Copernican system. Kepler heard about Copernicus, when he was a student in Tuebingen, from his astronomy teacher Michael Maestlin (1550-1631), a German astronomer and mathematician, who was one of the earliest scholars fully to comprehend and accept the work of Copernicus. Kepler was convinced that the Sun must be at the centre of the universe "for physical or, if you prefer, for metaphysical reasons". From Kepler's writings the following four reasons may be attributed to his belief in the Copernican system.

i. Sun is the symbol of God, the Father.

ii. Sun is the source of light and heat

iii. Sun is the generator of the force, which drives the planets in their orbits.

iv. A Sun-centred universe is geometrically simpler to deal with.

However, it appears that his basic desire was to synthesise mysticism and science. In any case it was more mystical than scientifica It was based on false premises. However, it contained the seeds of his future discoveries. This book clearly brought out Kepler's belief in a mathematical harmony underlying the universe. Kepler spent rest of his life in search of this mathematical harmon y. After 25 years of publication of his first book Kepler wrote: "The direction of my whole life, of my studies and works, has been determined by this one little book". Further he wrote: "For nearly all the books on astronomy which I have published since t hen were related to one or the other of the main chapters in this little book and are more thorough expositions or completions of it".

In 1597 Kepler, through a friend, sent his first publication, *Cosmic Mystery* to Galileo "to a mathematician named Galil eus Galileus, as he signs himself". Galileo promptly acknowledged the gift. He wrote: "Your book, my learned doctor, which you sent me through Paulus Amberger, I received not a few days but merely a few hours ago; since the same Paulus informed me of his i mpending return to Germany, I would be ungrateful indeed not to thank you at once: I accept your book gratefully as I regard it as proof having been found worthy of your friendship. So far I have only perused the preface of your work, but from this I gained some notion of its intent and I indeed congratulate myself on having an associate in the study of Truth who is a friend of Truth..."

Further in the same letter while promising to read the book Galileo wrote: "... this I shall do more gladly as I adopted the teaching of Copernicus many years ago, and his point of view enables me to explain many phenomena of nature which certainly remain inexplicable according to the more current hypotheses. I have written (conscripsi) many arguments in support of him and in refutation of the opposite view, which, however, so far I have not dared to bring into public light, frightened by the fate of Copernicus himself, our teacher, who, though he acquired immortal fame with some, is yet to an infinite multitude of others (f or such is the number of fools) an object of ridicule and derision. I would certainly dare to publish my reflection at once if more people like you existed; as they don't, I shall refrain from doing so."

Kepler was overjoyed with Galileo's prompt response and he did not miss the earliest opportunity to respond to Galileo. In those days you could send letters only through travellers. Kepler wrote: "Your letter, my most excellent humanist....caused me to rejoice twice: first because it meant the beginning of a friendship with an Italian; secondly because of our agreement on the Copernicus cosmography... I assume that if your time has permitted it, you have by now become better acquainted with my little book, and I ardently desire to know your critical opinion of it; for it is my nature to press all to whom I write for their unvarnished opinion; and believe me, I much prefer even the most acrimonious criticism of a single enlightened man to the unreasoned applause of the common crowd.

I would have wished, however, that you, possessed of such an excellent mind, took up a different position. With your clever secretive manner underline, by your example, the warning that one should retreat before the ignorance of the world, and should not lightly provoke the fury of the ignorant professors; in this respect you follow Plato and Pythagoras, our true teachers. But considering that, in our era, at first Copernicus himself and after him a multitude of learned mathematicians have set this immense enterprise going so that motion of the earth is no longer a novelty, it would be preferable that we help to push home by our common efforts this already moving carriage to its destination... You could help your comrades who labour under such iniquitous criticism, by giving them the comfort of your agreement and the protection of your authority. For not only your Italians refuse to believe that they are in motion because they do not feel it; here in Germany too, one does not make oneself popular by holding such opinions. But there exists argument, which protect us in the face of these difficulties...Have faith, Galilii, and come forward!"

Galileo did not reply to Kepler's exhortations. In fact after this letter Kepler did not hear from Galileo for the next 12 years. Kepler had endorsed Galileo's views and discoveries. He even persuaded some of Galileo's opponents to consider Galileo's claims more seriously. For many years Galileo's response to Kepler's services to him was complete silence. Galileo finally wrote to Kepler on August 10, 1610: "I have received both your letters, my most learned Kepler. The first, which you have already published, I shall answer in the second edition of my observations. In the meantime, I wish to thank you for being the first, and almost the only, person who completely accepted my assertions, though you had no proof, thanks to your frank and noble mind". Kepler had requested Galileo to send an improved telescope constructed by him. Kepler wrote: "You have aroused in me a great desire to send me your instrument so that at last I too can enjoy, like yourself, the spectacle of the skies". But Galileo never sent one to Kepler.

In 1600, Kepler met Tycho Brahe at Prague. Kepler had realised that without the immense data of Tycho, the greatest astronomical observer before the invention of the telescope he would not be able to 'erect a wonderful edifice'. Once Kepler wrote: "Let all keep silence and hark to Tycho, who has devoted thirty-five years to his observations... For Tycho alone do I wait; he shall explain to me the order and arrangement of the orbits...Then I hope I shall one day, if God keeps me alive, erect a wonderful edifice". But there was no way of laying hands on Tycho's data as he refused to publish his observations until he had worked out his own theory. One year before he met Tycho, Kepler wrote: "Any single instrument of his cost more than my and my whole family's fortune put together...My opinion of Tycho is this: he is superlatively rich, but he knows not how to make proper use of it, as is the case with most rich people. Therefore, one must try to wrest his riches from him".

Tycho also needed Kepler, of course for different reasons. Tycho thought Kepler with his knowledge in mathematics would prove to be an able assistant. His former assistants of Hveen were not in a hurry to join him in his new observatory at Benatek castle. Tycho wrote to Kepler in December 1599: "You have no doubt already been told that I have been most graciously called here by his Imperial Majesty and that I have been recei ved in the most friendly and benevolent manner. I wish that you would come here, not forced by the adversity of fate, but rather on your own will and desire for common study. But whatever your reason, you will find in me your friend who will not deny you h is advice and help in adversity, and will be ready with his help. But if you come soon we shall perhaps find ways and means so that you and your family shall be better looked after in future."

We may say with certainty that each of them was looking for th e other. And each was determined to make use of the other for his own purpose. Finally Tycho and Kepler met face to face on February 4, 1600. Kepler, an amateur astronomer, as he was at the time, was overwhelmed by the wealth and precision of Tycho's observations. He expressed his initial reaction in the following words: "Tycho possesses the best observations, and thus so to speak the material for the building of the new edifice; he also has collaborators and everything he could wish for. He only lacks the architect who would put all this to use according to his own design. For although he has a happy disposition and real architectural skills, he is nevertheless obstructed in his progress by the multitude of the phenomena and by the fact that the truth is de eply hidden in them. Now old age is creeping upon him, enfeebling his spirit and his forces."

Kepler was given the assignment to study the orbit of Mars, 'the most difficult planet. Earlier this was handled by Tycho's senior assistant Longomontanus. Later this proved to be very important decision in the history of astronomy. Though Kepler boasted to solve the problem in eight days he took nearly eight years. What Kepler did not know was that the movements of the Mars had been thoroughly and accurately docu mented but which did not remotely correspond to anyone's expectation. What we should remember is that Kepler did not have any computing assistance as we take it now for granted. What is more Kepler was working before the invention of logarithm. But Kepler did succeed and the result was his *New Astronomy (Astronomia Nova*), which was published in 1609.

In this earth-shattering publication Kepler described two of the three immortal Kepler's laws of planetary motion. The first law summarised the following proposition. The planets travelled not in the perfect circles as proposed by Plato, Aristotle and Ptolemy and which formed the basis of Christian theological conception of the universe but in elliptical path with the Sun at one focus. As we know unlike circle, which has one centre an ellipse has two foci. Kepler proposed that the Sun was located at one of the two foci. In summary Kepler's first law states: planets move in eclipses with the Sun at one focus.

Kepler's Second Law described the variations of the planet's speed along its orbit. It asserted that the line joining the Sun to a planet (radius vector) sweeps out equal areas in equal times. The Kepler's Third Law which was published in his *Harmonice Mundi* (1619) states that the squares of the periodic times are to each other an the cubes of the mean distances.

The association between Kepler and Tycho lasted for eighteen months, that is from February 1600 to Tycho's death in October 1601. Out of this Kepler spent eight months in Gratz to settle his personal affairs. The relations between Tycho and Kepler were far from cordial. However, what is important is Kepler could make use of Tycho's data.

To make his unorthodox astronomy acceptable, Kepler published a detailed exposition of his astronomy in a textbook form in three volumes. It was called *Epitome astronomiae Copernicanae* (1618-1621). Kepler also undertook the task of completing the "Rudolphine Tables" (*Tabulae Rudolphine*), the tabulation of Brahe's results for his sponsor Emperor Rudolph, a job he did not complete until 1627. These were the first tables to be prepared using logarithms.

After Tycho's death Kepler was appointed as Tycho's successor to the post of Imperial Mathematicus. Kepler lived in Prague as Imperial Mathematicus from 1601 to 1612 to the death of Rudolph II. This period was the most fruitful period of his life.

Kepler died in Regensburg on November 15, 1630.

We should remember, as Kepler had said, "The roads by which men arrive at their insights into celestial matters seem to be almost as worthy of wonder as those matters in themselves."

Christiaan Huygens
Founder of the Wave Theory of Light

"Less famous than Galileo, Descartes, Isaac Newton, or Leibniz, Huygens nevertheless belongs among them for his exceptional mathematical and experimental skills, more importantly, his deep intuitions about motion and light. He developed the best ideas of Cartesian mechanism with the help of Galilean principles and classical geometry."

The Oxford Compan ion to the Modern History of Science

Christiaan Huygens was one of those who laid the foundations of modern science. Historians of science usually associate Huygens with the scientific revolution, the period of advances in science that was at its height i n the 17th century and produced widespread change in traditional beliefs held since the Middle Ages. Huygens is regarded after Newton, as the most influential physical scientist of the late 17th century. As one of his biographers A. E. Bell wrote: "Huygens had not the religious feeling of a Spinoza or the sensitivity of a Pascal, nor was he a philosopher of the rank of Leibniz. In an age when human mind was making great marches into the territory of natural philosophy, Huygens's energies were thrown into the study of applied mathematics, into optical researches or astronomy and he managed somehow to pursue the most strikingly original researches in several subjects quite simultaneously. In that interesting period in Europe, between the death of Galileo in 1642 and the rise to fame of Newton, Huygens, in fact, stood unchallenged as the greatest man of science of that age."

Huygens' reputation as a modern physicist rests on his wave theory of light. He discovered the phenomenon of polarization. He made origi nal contributions to the science of dynamics; that is, the study of the action of forces on bodies. He discovered the laws of collision of elastic bodies at the same time as John Wallis and Christopher Wren.

Huygens' contributions as an astronomer were quite significant. He designed improved telescopes and discovered Titan, the largest moon of Saturn. Huygens was the first to describe correctly the nature and true shape of Saturn's ring system in 1656. He found that Saturn's rings consisted of rocks an d could explain the phases and changes in the shape of the ring. His findings on the nature of Saturn's rings were based on prolonged observations with a home -made telescope. Some scientists attacked not only Huygens's ring theory but also his observations. However, eventually they had to agree with his observations because improved telescopes proved Huygens to be right. A division near the outer edge of Saturn's B ring, discovered in 1981, was named after Huygens. In 1656, Huygens observed the Orion Nebula and he also prepared the first known drawing of this nebula. The brighter interior of the Orion Nebula is named Huygens Region in

Huygens' honour. Huygens also discovered several interstellar nebulae and some double stars.

Christiaan Huygens

Huygens was born on April 14, 1629 at The Hague, The Netherlands. His father Constantin Huygens (1596-1687) was an important Dutch diplomat. It is through his father's influential connections that Huygens could establish cont acts with a number of important scientists in Europe. Huygens himself wrote his name as "Hugens". It is also sometimes written as "Huyghens". Huygens was taught at home by private tutors until he was 16 years old. He was greatly influenced by René Descartes, who was a friend of his father and used to be a frequent guest at their home. Descartes took keen interest in the mathematical progress of his friend's young son. In 1645, Huygens attended the University of Leiden and stayed there until 1647. At Leiden he studied law and mathematics. In 1647, he shifted to the College of Orange at Breda. Here also he continued to study law and mathematics.

Huygens started his research in science in 1651. In that year he showed the fallacy in a system of quadratures prop osed by Gregoire de Saint-Vincent and it was followed by his work on the quadrature of the conics. Thereafter, Huygens engaged his attention to the improvement of the telescope. Assisted by his brother, he developed a new and better method of grinding and polishing lenses. In 1657 he wrote a book on probability theory – the first book on the subject – after being encouraged by the French mathematician, physicist and philosopher Blaise Pascal (1623-62).

Huygens' first major achievement was the invention of the pendulum clock. Though in 1581, Galileo had observed that a pendulum would keep the same time whatever its amplitude, but it was Huygens who could use this insight successfully to construct a more reliable clock. Huygens demonstrated that when a pendu lum moves in an arc of a circle it does not move with an equal swing. He further demonstrated that a pendulum would produce an equal-timed or isochronous swing if it moves in a curve called cycloid – a curve traced by a point on the circumference of a circle rolls along a straight line. He also demonstrated how the pendulum could be made to move in a cycloidal path to run the escapement. The first clock based on Huygens' design was built by a local clock - maker named Salomon Coster in 1657. It was patented in 1658. The clock is kept at Museum Boerthaave in Leiden. This clock is described in Huygens' book *Horologium* (The Clock) published in 1658. The importance of Huygens' invention of the pendulum clock lies in the fact that it raised the measurement of time both in science and daily life to a new level which in those days nobody imagined to be possible. In 1656, Huygens discovered the law of conservation of momentum and also proved that the quantity $\frac{1}{2}mv^2$ is conserved in a collision. He studied the centrifuga l force, and in 1659 he brought out the similarity between the centrifugal force and gravitational force. During his visit to England in 1663, the Royal Society of London elected him a Fellow. In his best -known work *Horologium oscillatorim* (The Clock Pendulum), published in 1673, Huygens presented a brilliant mathematical analysis of dynamics, including discussions of the relationship between the length of a pendulum and its period of oscillation, and the laws of centrifugal force.

Huygens described his wave theory of light in his second most important book *Traite de la lumiere* (Treatise on Light) published in 1690. This work established him as a great modern physicist. He was the first to describe the propagation of light as a wave of motion. Huygens ass umed that the whole space is pervaded by extremely rare medium called aether and light is produced by a series of waves or vibrations in this medium. These vibrations or waves, which spread outwards from the source, are set in motion by the pulsations of t he luminous body. So, according to him light moves in aether in the same way as sound moves in air. According to Huygens, an expanding sphere of light behaves as if each point on the wave front were a new source of radiation of the same frequency and phase. This is known as "Huygens' principle". He worked on his wave theory of light almost at the same time Isaac Newton (1642 -1727) was developing his emission or corpuscular theory of light. Because of the Newton's tremendous influence in the scientific world, Huygens' theory was not given due importance. English physicist Thomas Young (1773 -1829) gave experimental support to the wave theory of light. Today we know that both concepts are appropriate depending on the experimental situation.

Gottfried Wilhelm von Leibniz (1646-1716), one of the greatest mathematicians of all time, was taught by Huygens. E. T. Bell wrote: "Up till 1672 Leibniz knew but little of what in his time was modern mathematics. He was then twenty-six when his real mathematical education began at the hands of Huygens, whom he met in Paris in the intervals between one diplomatic plot and another. Christiaan Huygens (1629-1695), while primarily a physicist, some of whose best work went into horology and the undulatory theory of light, was an accomplished mathematician. Huygens presented Leibniz with a copy of his mathematical work on the pendulum. Fascinated by the power of the mathematical method in competent hands, Leibniz begged Huygens to give him lessons, which Huygens, seeing that Leibniz had a first-class mind, gladly did…Under Huygens' expert guidance Leibniz quickly found himself. He was a born mathematician."

Huygens invented numerous devices and patented a pocket watch (1675). He carried out experiments with internal combustion and designed a basic form of internal combustion engine, fuelled by gunpowder. However, he never built a successful combustion engine.

It is interesting to note that Huygens believed that planets were populated. In his book, *Celestial Worlds Discover'd: or, Conjectures Concerning the Inhabitants, Plants and Productions of the Worlds in the Planets*, he speculated that the universe was brimming with life. In fact he wrote in detail about shipbuilding and other engineering on Jupiter and Saturn. Giordano Bruno also believed in many inhabited worlds but he was burnt at the stake for harbouring such liberal views including the Copernican theory. But in Huygens' Netherlands there was a liberal climate, which encouraged such speculations.

Huygens was a loner. He worked alone; he did not gather disciples around him. After the death of his father he almost became a recluse and lived in his country home. He died on 8 July 1695 at The Hague, Netherlands. A mountain on Moon is named after Huygens. It is called *Mons Huygens*. Among other things named after Huygens include: The *Huygens probe*, which landed on Saturn's moon, Titan; Asteroid 2801 Huygens; a crater on Mars; Huygens eyepiece – an achromatic two-element processing eyepiece; Huygens wavelet – a secondary wave as used in Huygens' principle; and Huygens Software – a microscopic image package.

The important works on life and work of Christiaan Huygens include the following: *Huygens and Barrow and Newton and Hook: Pioneers in mathematical analysis and catastrophe theory from evolvents to quasicrystals* by V. I. Arnol'd (Basel, 1990); *Christiaan Huygens and the Development of Science in the Seventeenth Century* by A. E. Bell (London, 1947); *Christiaan Huygens* by E. J. Dijksterhuis (Haarlem, 1951); *The Land of Stevin and Huygens* by D. J. Struik (Dordrecht-Boston, Massachusetts, 1981) and *Unrolling Time: Christiaan Huygens and Mathematisation of Nature* by J. G. Yoder (Cambridge, 1988).

Isaac Newton
Founder of the Theory of Gravity

"Newton's laws changed astronomy and our view of nature. They made it possible for astronomers to predict the motions of the heavenly bodies using the analytic power of mathematics. Newton's laws also show that the apparent complexity of the universe is based on a few simple principles, or natural laws."

Michael A. Seeds in Foundations of Astronomy, 2003

"Nature was to him an open book, whose letters he could read without effort. The conceptions which he used to reduce the material of experience to order seemed to flow spontaneously from experience itself, from the beautiful experiments which he ranged in order like playthings and describes with an affectionate wealth of detail. In one person, he combined the experimenter, the theorist, the mechanic and, not least, the artist in exposition. He stands before us strong, certain, and alone; his joy in creation and his minute precision are evident in every word and every figure."

Albert Einstein in his foreword to a twentieth century edition of Newton's Opticks.

Isaac Newton, one of the foremost scientific intellects of all time, single-handedly contributed more to the development of modern science than any other individual in history. He surpassed the achievements made together by all the great scientific minds of antiquity by producing a scheme of the universe, which was consistent, elegant, and intuitive.

Newton stated explicit principles of scientific methods, which applied universally to all branches of science. His methodologies produced a neat balance between theoretical and experimental inquiry and between the mathematical and mechanical approaches. Newton mathematised the entire gamut of physical sciences. He reduced the study of the physical sciences to a rigorous, universal and rational procedure, which marked the ushering in of the Age of Reason. The basic principles of scientific investigation stipulated by Newton have survived without any alteration until modern times.

Newton's methodology was strictly logical. He presented his methodology as a set of four rules for scientific reasoning: 1) We are to admit no more causes of natural things such as are both true and sufficient to explain their appearances; 2) The same natural effects must be assigned to the same causes; 3) Qualities of bodies are to be extended as universal; and 4) Propositions deduced from observations of phenomena should be viewed as accurate until other phenomena contradict them. These four concise and universal rules for investigation were truly revolutionary.

By their application Newton was able to unravel virtually all the unsolved problems of his day. Commenting on his approach to science once Newton wrote: "The best and safest way of philosophising seems to be, first to enquire diligently into the properties of things and to establish those properties by experiments and then to proceed slowly to hypotheses for the explanation of them. For hypotheses should be employed only in explaining the properties of things, but not assumed in determining them; unless so far as they may furnish experiments."

Isaac Newton

Newton's methodologies led the natural philosophers to appreciate the "scientific method" – observation, generalisation and experimentation – above all other methods of inquiry. Francois Marie Arouet de Voltair (1694 -1778) the French writer and philosopher, said: "Newton taught men to examine, weigh, calculate and measure but never to conjecture … He saw, and made people see; but he did not put his fancies in place of truth." The scientific revolution that Galileo Galilei (1564-1642) had initiated at the beginning of the seventeenth century was triumphantly completed by Newton at the century's end. Newton's scientific work brought him great fame. He was idolised, almost deified, in his own lifetime. Newton was not right about everything. For example he thought that 'absolute motion' could exist, which Albert Einstein (1879 - 1955) later disproved with his theory of relativity. Newton was never on very cordial terms with any of his contemporaries. Since his childhood he remained a loner all his life. He did not marry. He was always slightly paranoid and unquestionably contentious. Newton quarrelled often and pettily. His quarrels with Robert Hooke (1635 -1703), Christiaan Huygens (1629-95), Gottfried Wilhelm Leibniz (1646-1716) and John Flamsteed are much discussed episodes in the history of science. Newton encouraged and prompted his friends and followers to join the fray.

Newton was born on December 25, 1642 at a village Woolsthorpe in Lincolnshire in Eastern England. Here it is important to note that when Newton was born, the British Calendar was ten days ahead than the Gregorian calendar. This is because though the Gregorian calendar was introduced in Catholic countries in 1582 but it was not applied in Britain until 1752.

His father, also Isaac Newton, who was a farmer, died a few months before Newton's birth. Newton was born prematurely and christened Isaac in memory of his father. Newton's mother Hannah remarried in 1645 and left him under the care of his maternal grandmother at Woolsthorpe. After gaining the rudiments of education at the local school Newton joined the Grammar School at Grantham, where he lived with the family of an apothecary, called Mr. Clark. The Clarks were no ordinary apothecary's family. Mrs. Clark's brother Humphrey Babington was a Fellow of Trinity College who spent most of his time at Boothby Pagnell, near Grantham, where he was Rector. The School provided Newton a grounding in the classics mainly Latin with some Greek and a little mathematics. The knowledge of Latin proved to be very useful in Newton's scientific career. In those days academics across Europe used to communicate in Latin. Many important scientific books were available only in Latin. At the school Newton was a lonely boy. He was not a very good student. Nobody paid much attention to him. One incident at the school that had influence on his life was his fight with a larger lad. This lad was the school bully, who also happened to be first in studies as well. The fight ensued after Newton was punched by the bully. Newton fought back, he pushed the bully onto the ground and rubbed his face in the mud. The other students, who were watching the fight, cheered for Newton as they all hated the bully. Newton found that he could fight better than the bully and this made him think that he could do anything better than the bully. As a result he decided to pay attention to studies to compete. He stood first in his class. At school his greatest delights were solitary study and manufacturing mechanical devices. He made windmills, water-clocks, and sundials. It is said that he invented a four-wheel carriage, which was to be moved by a rider. He also caused one of the earliest recorded UFO (Unidentified Flying Object) scares by flying a kite at night with a paper-lantern attached to it.

After the death of her second husband in 1656, Newton's mother came back to Woolsthorpe. Towards the end of 1659 Newton's mother removed him from the school so that he might prepare himself for managing the farm he would one day inherit from his mother. However, Newton proved to be no good in farming. He neglected his work in order to read books. On several occasions he was fined for allowing animals in his care to wander and damage other farmers' crops. There is an interesting story linked to Newton during the period when he was supposed to practise farming. A steep hill is situated between Grantham and Woolsthorpe. It was a usual practice to dismount and lead one's horse to the top of the hill before remounting. It is said that one day Newton arrived home with a book in one hand and the bridle in the other, his horse trotting behind him, as he had forgotten to remount.

Throughout his life he had this habit of forgetfulness. There are many stories about his forgetfulness. In one story he had invited some of his friends to his house for dinner. They had the dinner and then went to the lounge. After an hour Newton jumped up and announced, "we have talked long enough – let's have dinner". It was only after finding lot of bones and other leftovers, he did realise to his great embarrassment that they had already taken dinner. His maternal uncle William Ayscough, Rector of Burton Coggles, wanted Newton to go to Trinity College, Cambridge. Ayscough was a Cambridge graduate. Newton needed to prepare for getting admission in Trinity College. So he needed to go back to his school. Henry Stockes, the schoolmaster of the Grammar School offered to take Newton into his own home, without being paid for lodging. In the autumn of 1660 Newton went back to school mainly to prepare for entrance to Cambridge. He was admitted to Trinity College of the Cambridge University on July 1661. Newton was certainly benefited by the advice and influence of Babington. In those days young gentlemen used to be admitted to the Cambridge University at the tender age of 14 accompanied by a servant to look after them. But Newton entered Trinity College at the lowest level, as a so-called subsizar, who paid for his keep by acting as a servant himself for the Fellows of the College and even for wealthy students. To be a subsizar was not at all a pleasant experience. Rather at its worst it could be extremely unpleasant. For Newton it was not so unpleasant. He was the servant to Humphrey Babington, who was seldom in residence in Cambridge and so Newton had few menial duties to perform. But at the same time Newton's status as subsizar was not at all enjoyable.

Newton graduated in 1665. He had displayed no special brilliance. Nobody had an inkling that Newton would become the great unifier of the scientific revolution, drawing from the ideas of Nicolaus Copernicus (1473-1543),Johannes Kepler 1571-1630) and Galileo and others or that he would make great contribution to the fields of optics and mathematics. In 1665 the Great Plague hit London, virtually shutting that city down. Cambridge soon followed. The Cambridge University was temporarily closed. Some students alongwith their tutors moved to the nearby villages. Newton went to live at his mother's farm in Lincolnshire. The farm was purchased by his grandfather Robert Newton. Newton stayed 18 months at Lincolnshire before he permanently returned to Cambridge in April 1667. It was a forced vacation. This period was Newton's *annus mirabilis* (a year regarded as pivotal or crucial). Commenting on this period Newton said: "In those days (1665-67) I was in the prime of my age for invention and minded, Mathematics and Philosophy more than at any time since." Here Newton began putting together some of his ideas. The results marked the beginning of a long and a fruitful career in science. It is during this forced vacation Newton laid the foundations for the calculus, a mathematical method of calculation that revolutionised scientists' ability to handle complicated equations. It was also during this period that Newton noticed an apple falling to the ground. There is no evidence to indicate that the apple did hit him on the head as legend claims. Seeing the falling apple Newton started wondering whether the force that pulled the apple towards the Earth is the same force that kept the Moon in its orbit. It marked a major departure from earlier belief held by scientists followed by Aristotle, who insisted that the Earth and the heavens operated on two entirely different sets of laws. But Newton started thinking that there is only one set of universal laws and not two. At Lincolnshire, Newton also carried out a fascinating series of experiments with light.

The Cambridge University was among the best universities when it was founded in the thirteenth century. However, at Newton's time Cambridge was not a very good place for learning particularly for learning science. It's learning was church-oriented. The only scientific professorship, the Lucasian Chair of Mathematics, was established in 1663. Its first incumbent was Isaac Barrow, who was a Professor of Greek. Its only relevant courses were in theology and medicine. So Newton had to depend on his own study. Newton became so absorbed in his studies that often he would forget to eat and would stay up all night at his book. He did not care about his dress and hardly took a bath. He studied the writings of Galileo, Kepler, Rene Descartes (1596-1650) and Euclid (fl. 300 BC) among others. It is said that he turned to Euclid because he was bothered by his inability to comprehend certain diagrams in a book on astrology, which he had bought at a fair. However, he thought its propositions as self-evident and thus he put it aside as "trifling book". He took it up again after being persuaded by his teacher, Isaac Barrow. He received a scholarship in April 1664, which ensured his stay at Cambridge till 1668. Newton received his BA in January 1665 and got his MA degree in 1668.

In 1667, Newton was elected a Fellow of the Trinity College and two years later he was appointed Lucasian Professor of Mathematics succeeding his teacher Isaac Barrow. The post of Lucasian Professor was one of the most desirable appointments in Cambridge. The professorship brought with it an income of 200 pounds a year with no tutorial responsibilities. It was a secure tenure for life. Its incumbent was to give only one course of lectures a year.

In 1672, Newton was elected a Fellow of the Royal Society of London and later that year he published his first scientific paper in the *Philosophical Transactions* of the Society describing his new theory of light and colour. The paper was titled "New Theory about Light and Colours." In this paper Newton demonstrated that the ordinary white light was a mixture of the various colours of the spectrum. Though the paper was well received but two leading natural philosophers, Robert Hooke and Christiaan Huygens rejected Newton's claim by stating that his theory was derived with certainty from experiments alone. Particularly they objected to what they took to be Newton's attempt to prove by experiment alone that light consists in the motion of small particles or corpuscles rather than in the transmission of waves of pulses. By publishing this paper Newton started a lifelong feud with Hooke. Newton was a mathematician of incomparable power. In 1696 the Swiss mathematician Johann Bernouli (1667-1748) posed a problem to the mathematicians of Europe, allowing them six months to solve. Newton solved the problem in single night and published it in the *Transactions of the Royal Society*. Though the paper did not bear Newton's name but Bernouli was not fooled. He claimed to recognize the author as ‘the lion by his claw’. In 1716 the German mathematician Leibniz issued a difficult problem. It is said that Leibniz had devised the complicated problem for the express purpose of stumping Newton. However, Newton solved the problem before going to bed after a day’s work at the Mint.

Newton discovered the generalised form of the binomial theorem. He wrote about his discovery to Henry Oldenburg in 1676. He did not publish this discovery. It was later published by John Wallis (1616-1793) with due credit to Newton. Newton laid the foundation for elementary differential and integral calculus. Calculus was also independently discovered by the German philosopher and mathematician Leibniz. However, Newton did not immediately publish it. His work on calculus, *Methodis fluxionum* (*Method of Fluxions*) composed between 1670 and 1671, was only published posthumously in 1736. Of course, Newton showed his unpublished works to his friends and colleagues. In fact in 1676 Newton deposited with Oldenburg his *epistola prior* (first letter) claiming discovery of his method of fluxions in an anagram. The terminology arose from his considering the path of a continuously moving body as a curve made by a continuously moving point. The moving point Newton called a fluent and its velocity he called a fluxion. He denoted fluxion by $\dot{X}$ and its acceleration as $\ddot{X}$ However, presently the notation used are that of Leibniz. On the other hand Leibniz published his own work on the differential and integral calculus in 1684 and he did not acknowledge any unpublished work of Newton though he had seen some Newtonian manuscripts on a visit to London in 1673. This started a bitter dispute of priority between Newton and Leibniz. The dispute began in 1700 when Leibniz objected the practice of the followers of Newton referring to him (Leibniz) as the ‘second inventor’ of the calculus. Leibniz applied to the Royal Society in 1712 to conduct an inquiry into the matter. At that time Newton was the President of the Royal Society. He appointed the committee, decided what evidence it should examine and actually drafted the report himself. What is more he used to refer this report the *Commercium epistolicum* (1713, On the Exchange of Letters) as an independent justification of his position. Newton’s behaviour was rather shameless. Leibniz and Newton bickered unbecomingly for some years as to who had the idea first. However, in this context it is worthwhile to note what Einstein had to say on this controversy. Einstein wrote: “The differential law is the only form which completely satisfies the modern physicist’s demand for causality. The clear conception of the differential law is one of Newton’s greatest intellectual achievements. It was not merely this conception that was needed but also a mathematical formalism, which existed in a rudimentary way but needed to acquire a systematic form. Newton found this also in the differential and the integral calculus. We need not consider the question whether Leibniz hit upon the some mathematical methods independently of Newton or not. In any case it was absolutely necessary for Newton to perfect them, since they alone could provide him with the means of expressing his ideas.”

Newton's masterpiece *Philosophiae Principia Mathematica* (*Mathematical Principles of Natural Philosophy*), is considered to be the greatest scientific work ever written. The book originally written in Latin was published in 1687. It did not appear in English until 1729, forty-two years after its original publication and two years after Newton's death. The book is often referred to as *Principia Mathematica* or simply the *Principia.* Newton was very reticent in publishing and he was extremely sensitive to criticism. It was Edmond Halley who persuaded Newton to publish the *Principia*. Halley played an important role in its publication. When the Royal Society could not afford to finance its publication it decided that "Mr. Halley undertake the business of looking after it and printing it at his own charges". Halley provided the necessary funds from his own pocket. He edited the text, corrected the proofs and saw it through the press.

The publication of *Principia* represented the culmination of the scientific revolution that had begun with Copernicus a century and a half earlier. In this book Newton presented an overall scheme of the universe, one far more elegant and enlightening than any of his predecessors had devised.

The book was divided into three parts. In Book I of *Principia*, Newton opened with definition of the three laws of motion, now known as Newton's laws – laws of inertia, acceleration proportional to force and action and reaction. Newton's first law of motion, which is also known as law of inertia, states that an object at rest tends to stay at rest and an object in motion tends to continue in motion at constant speed in a straight line. Newton's second law states that the more force is placed on an object, the more it accelerates but the more heavier it is, the more it resists acceleration. For example it is easier to throw a lighter object than a heavier one. Newton's third law states that for every action there is an equal and opposite reaction. For example a rocket exerts a downward push on the exhaust gases which push it upward. And when the upward push of the exhaust gases exceeds the weight of the vehicle, the rocket rises off the launch pad in the air. It was Newton who first differentiated between the mass and the weight of an object. Often these two terms are used interchangeably in everyday language. The mass of a body is its resistance to acceleration or in other words a body's mass is equivalent to its quantity of inertia. On the other hand the weight of a body is the gravitational force between it and another body. In Book II of Principia Newton presented new scientific philosophy which came to replace Cartesianism. The last part, Book III consisted of applications of the laws and conclusions derived in the first two sections. The Book III included an explanation for tides and a theory of lunar motion. Newton made some interesting projections. Newton had shown that the gravitational forces of the Earth's various parts combined to form a sphere. But as the Earth spins around its axis, the additional force resulting from the spinning should prevent it to take up a perfect spherical shape there should be bulge at the equator. He even predicted the size of the bulge. In his life time efforts were made to verify the prediction but because of errors in calculation by mapmakers Newton appeared to be wrong. Today we know that Newton was right. In fact his predicted size of the bulge was accurate within one percent.

Newton's work in physics and celestial mechanics culminated in the theory of universal gravitation. Newton's great insight of 1666 was to imagine that the Earth's gravity extended to the Moon, counterbalancing in centrifugal force. From his law of centrifugal force and Kepler's third law of planetary motion, Newton deduced that the centrifugal force of the moon or any planet must decrease as the inverse square of its distance from the centre of its motion. Newton's law of universal gravitation states that every piece of matter attracts every other piece with a force proportional to the product of their masses and inversely proportional to the square of the distance between them. Given the law of gravitation and the laws of motion Newton could explain a wide range of hitherto disparate phenomena such as eccentric orbits of comets, the courses of the tides and their major variation, the precession of the Earth's axis and the perturbation of the moon by the gravity of the Sun. Newton's one general law of nature and one system of mechanics reduced to order most of the known problems of astronomy and terrestrial physics.

Newton's another famous prediction concerned comets. He stated that comets were not as mysterious as they appeared to be and like planets they also followed elliptical path around the Sun. However, comet's path was far more flattened and elongated than followed by the planets and which probably take them far beyond the edges of the solar system. Based on the Newton's calculation, Halley predicted that the comet sighted by him in 1682 (Halley's comet) would return in 76 years in 1758 and it did return.

Newton's second great book *Opticks* was published in 1704, though it was completed in the mid-1690s. It is said that Newton had quietly waited to publish it until his arch rival Hooke had died. In *Opticks* Newton observed that white light could be separated by a prism into a spectrum of different colours, each characterised by a unique refractivity and proposed the corpuscular theory of light. While the Principia was a "hard book" in Newton's own words, the Opticks was written in easily intelligible language and dealt with ideas, such as light and colour, that everyone could relate to.

In 1669, the first earl of Halifax Charles Montague, Chancellor of the Exchequer, offered Newton the post of Warden of the Royal Mint. Newton, who wanted to leave Cambridge, readily accepted the offer. Newton's appointment was confirmed on 19 March 1696 and he moved to London by the end of April. Montague while informing Newton of his appointment wrote that the post was 'worth five or six hundred pounds (a year), and has not too much business, to require more attendance than you may spare'. But Newton took his work very seriously. As Warden he was the number two at the Mint. It was the Master of the

Mint who was in charge. However, Thomas Neale, the Master of the Mint, was quite happy to leave all the work to Newton. It was Newton's duty to pursue the counterfeiters and clippers of his day. Between June 1698 and Christmas of 1699 Newton interviewed 200 witnesses on 123 separate occasions and 27 counterfeiters were executed. At the end of 1699 Thomas Neale died and Newton succeeded him as the Master of the Mint. He held the post until he died. Newton supervised the introduction of a union coinage in 1707 following the union of kingdoms of England and Scotland, the issue of new copper coins in 1718, the evaluation of the guinea to 21 shillings in 1717, and a general improvement in the assaying of the currency.

Newton had studied theology quite seriously. Newton strongly believed in the necessity of a God. His theological views are characterised by his belief that the beauty and regularity of the natural world could only "proceed from the counsel and dominion of an intelligent and powerful Being". He thought that "the supreme God exists necessarily and by the same necessity he exists always and everywhere". He believed that God periodically intervened to keep the universe going on track. He believed that the foundation of established religion in England was based on corrupted form of the original biblical texts. Further he thought that the concept of the Holy Trinity, placing Jesus Christ on equal footing with God was a false concept. This idea was known as Arianism, after Arius who established the doctrine. This kind of religious belief came in the way of Newton's taking holy orders - a requisite condition for all Cambridge Fellows. And for Newton also a time came when without ordination he would not be able to continue the Fellowship. Losing Fellowship meant he would also require to relinquish the Lucasian Chair. But in any case Newton would not take the holy orders because to him worshipping Christ as God would mean idolatry, a moral sin that would put his soul in peril. By the beginning of 1675 Newton was almost sure that he would have to part with Cambridge University. In fact he wrote to Henry Oldenburg, the then Secretary of the Royal Society, requesting him to be excused from paying his subscription to the Royal Society. He wrote, "I am to part with my Fellowship, and as my income contract, I find it will be convenient that I contract my expenses".

Newton had only one chance that is to petition the king for dispensation from the requirement of ordination. So after obtaining permission of the then Master of Trinity Isaac Barrow Newton petitioned the King Charles II. Newton sought such dispensation not for himself alone as a special case but for all the Lucasian Professors. He argued that the requirement of ordination goes against the spirit of the bequest under which Henry Lucas had established the chair. It had a specific requirement that a holder of the post should not be active in the church. King Charles II, a patron of the Royal Society and lover of science, granted the dispensation in perpetuity, "to give all just encouragement to learned men who are and shall be elected to the said professorship".

Throughout his life Newton displayed a deep interest in reli gion and alchemy. Newton spent much of his time in later part of his life in theological speculation, astrology and alchemical research. Newton wrote extensively on religious matters. Among his religious writings discovered after his death were 1000 manuscript pages to nearly 1.5 million words and two completed books. For obvious reasons he kept his writings secret. Much of his life was spent on deep studies of church history, the Bible and the chronology. He wanted to show that the text of the Bible had been corrupted by later Trinitarian editors and a similar corruption was introduced by Athanasius in the fourth century.

In Newton's library were 138 books on alchemy and his own manuscripts on the subject contained more than 600,000 words. It cannot be said with certainty whether Newton was a genuine alchemist committed to dreams of the philosopher's stone or his chemical interests led him to practise alchemy. He had established a chemical laboratory in Trinity College. Though he was very much interested in chemistry but he published very little on his chemical works. He published one brief work on chemistry, *De nature acidorum* (1710, *On the Nature of Acids*). There were also several passages devoted to chemistry scattered among the Queries that Newton added to his *Optiks*.

On being asked by Halley that how he managed to make so many discoveries Newton said that he never relied on inspiration or serendipity to give him insight. Once he undertook a problem to solve, Newton did not rest until he found out the answers — he would think relentlessly and explore every angle during every available moment. Newton became a Member of Parliament in 1689. In 1703, Newton was elected President of the Royal Society, a position he retained until his death. Newton was Knighted by Queen Anne in 1705. Newton was the first scientist to be honoured this way. However, it is interesting to note that Newton was not Knighted for his scientific achievements.

Newton died on 20 March 1727 and he was buried in Westminster Abbey, on 28 March 1727. Voltair, who witnessed the burial ceremony, said that it was like "the funeral of a king who had done well by his subjects." The Latin inscription of Newton's tom reads " Mortals! rejoice at so great an ornament to the human race !" Perhaps no one will disagree that the inscription is fully justified. Newton was also a human like us and this fact alone should challenge the rest of us to reach for height like his.

We would like to end this article by quoting what Einstein wrote on the occasion of the two hundredth anniversary of Newton's death: "It is just two hundred years ago that Newton closed his eyes. We feel impelled at such a moment to remember this brilliant genius, who determined the course of western thought, research and practice like no one else before or since. Not only was he brilliant as an inventor of certain key methods, but he also had a unique command of the empirical material available in his day, and he was marvellously inventive as regards detailed mathematical and physical methods of proof. For all these reasons he deserves our deepest reverence. The figure of Newton has, however, an even greater importance than his genius warrants because destiny placed him at a turning point in the history of the human intellect. To see this vivid ly, we have to realise that before Newton there existed no self -contained system of physical causality which was somehow capable of representing any of the deeper features of the empirical world."

Commenting on his achievement Newton himself said: " If I have seen further it is by standing on the shoulders of giants."

Edmond Halley (1656-1742)
Founder of Modern Cometary Science

The period during which he (Halley) held the post of Astronomer Royal, compared with those of his predecessor Flamsteed, and his successor Bradley, is hardly entitled, if we look at its effect upon the progress of science, to be called more than strong twilight night between two bright summer days.

Augustus De Morgan (1806-71), the first President of the London Mathematical Society.

Under this marble, together with his beloved wife, rest Edmund Halley, LL.D. unquestionably the greatest astronomer of his age.

The inscription on the Halley's tomstone at the churchyard of St. Margaret, Lee near London.

The above two assessments about Edmond Halley's contributions to science are two extremes. (Though Halley's first name is often given as Edmund, he always wrote it as Edmond.) A large number of people perhaps know Halley because of the Halley's comet (the best-known periodic comet, returning to perihelion at average intervals of 76 years - the time between returns ranges from 74 to 79 years) and for his role in the publication of Newton's *Philosophiae Naturalis Principia Mathematica* (popularly known as *Principia*).

Halley was fortunate to live through a period of scientific revolution that strengthened the foundation of modern science. When the England's monarchy was restored under Charles II (1630-85) in 1660 Halley was four year old. Two years later Charles II granted a charter to the informal organisation of natural philosophers under the aegis of 'invisible college' which later became the Royal Society of London with the motto, *Nullis in verba* - take nobody's word; see for yourself - set the stage for the centuries to come. Halley's scientific work and his life covered a vast range. He made enormous contribution in almost every branches of physics and astronomy. Halley published his first scientific paper when he was 20. It was on the theory of planetary orbits and was published in *Philosophical Transactions* of the Royal Society. In 1679 Halley published his *Catalogue of the Southern Stars* (*Catalogus stellarum australium*). It was the first catalogue of telescopically determined star positions in the southern hemisphere. It not only established Halley's reputation as astronomer but it was also partly responsible for his being awarded a Master of Arts degree by the Oxford University without going through the usual examinations. Halley's catalogue of stars was useful for navigation at sea.

Halley's masterpiece on comets, *A Synopsis of the astronomy of comets* (*Astronomiae cometicae*) published in 1705 laid the foundation of modern cometary study. Halley predicted with considerable accuracy the path of totality of the solar eclipse visible over England in 1715. After a long and careful study he was the first to realise in 1693 that the Moon's mean motion had a secular acceleration. An apparent gradual acceleration of the Moon's motion in its orbit, as measured relative to mean solar time. He was the first to predict extraterrestrial nature of the precursors of meteors. He was the first to suggest that observations of transits of Venus could be used to measure the distance of the Sun. However, this was first done long after his death. He offered the first proof of motions of stars by showing that they had moved since Ptolemy's time. In 1721, he raised the problem of what has come to be called Olbers' paradox —the apparent contradiction between the simple observation that the night sky is dark and the theoretical expectation that an infinite, static Universe, consisting of stars and galaxies more or less uniformly distributed, should be as bright as a star.

Edmond Halley (1656-1742)

It was Halley who published the first meteorological chart in 1686. He extensively studied the distribution of the prevailing winds, magnetic variations and tides over the oceans. In map-making Halley was the first to use an isometrically representation. (Isometric projection is a method of drawing figures and maps so that these dimensions are shown not in perspective but foreshortened equally). The sea voyages undertaken by Halley are considered as the first sea voyages undertaken for purely scientific purposes. It can be said that Halley practically founded the sciences of geomagnetism and physical oceanography. He is considered the founder of geophysics, especially for his paper on trade winds and his work on tides. In 1686 he formulated the mathematical law concerning barometric heights and pressure above the sea levels. He also made many advances in barometric designs. By studying extensively the evaporation and salinity of lakes during the period 1687-94 he drew conclusions about the age of the Earth. He was constantly concerned with the magnetism of the Earth and developed a general theory about this. He was also concerned with weather and published on the relation of barometric pressure to the weather. He improved the design of the diving bells. In 1693, he published the mortality tables for the city of Breslau. This was the first attempt to relate the mortality and age in a population. It influenced the future development of actuarial tables in life insurance.

Halley published innumerable articles on natural history and classical studies. Halley published important editions of Apollonius of Myndus (fl. 4th century BC) and of other ancient astronomers. He also published papers in pure mathematics. Many would like to cell Halley an 'idea man'. His intellect was so lively for him to concentrate on a single problem for long. However, by any standard he made remarkable contributions.

One may be really bewildered to know the type of appointments Halley held. During 1696-98 Halley was deputy controller of the mint at Chester. Between 1698-1700 Halley was commissioned as a naval captain and he actually commanded a Royal Navy man-of-war, the Paramour, making prolonged and eventful ocean voyages. At the instance of the Queen Anne he made two diplomatic missions (1702 & 1703) to Vienna (Austria). As he completed his first Austrian mission, the Holy Roman Emperor presented him with a valuable diamond ring. His first mission to Vienna was to advise on the fortification of a port on the Adriatic and on his second mission he oversaw the actual building of the fortifications. In 1703 Halley was elected to the Savillian Chair of Geometry at Oxford. In 1720 he succeeded Flamsteed as astronomer royal at Greenwich. (Following the realisation that knowledge of the stars and their position was the key to navigation the British government created the post of astronomer royal. Flamsteed was the first incumbent). Halley served as the first corresponding secretary to the Royal Society of London and published the scientific works of its members.

Halley was born on November 8, 1656. His father, also Edmond Halley, was a wealthy London merchant, a soapmaker and salter. After studying at St. Paul's School at London he entered the Queen's College, Oxford, which he left in 1676 without a degree. While still a student Halley published a little book on Kepler's laws. John Flamsteed (1646-1719) who became Britain's first Astronomer Royal took note of this book and he was impressed by Halley's work. Flamsteed encouraged Halley to take up the study of astronomy seriously. On the lines of Flamsteed, who compiled an accurate catalogue of northern stars, Halley wanted to prepare a catalogue of the stars of the southern hemisphere. With this view he sailed in a ship of the East India Company in November 1676 for the Island of St. Helena, the southernmost territory under British rule in the South Atlantica This was possible for the financial assistance from his father and a letter of introduction from the king. Halley spent one and a half year (1676-78) at this bleak island. The weather of the Island was harsh and inhospitable and particularly it was extremely hostile for astronomical observation. Without being frustrated by this adverse condition. Halley spent hour after hour gazing at the sky with his telescope. He was successful in listing the positions of no fewer than 341 previously uncharted stars. He became an immediate celebrity among scientific elite. Flamsteed heralded him as the "The Southern Tycho", thereby he linked Halley's name to the great Danish astronomer, Tycho Brahe (1546-1601). Halley was made a fellow of the

Royal Society. Suddenly he found himself in the company of great intellects like Newton, Flamsteed Robert Hooke (1635-1702), the inventor and microscopist, and Christopher Wren (1632-1723), the famous architect.

During his long voyage to St. Helena Halley had noticed that unlike the commonly held belief the ship's compass did not point exactly to the North Pole. Though the difference was not very significant but it showed that the magnetic pole and the North Pole were not the same. In any case this observation was of commercial significance as the worldwide explosion of commercial trade in the second half of the 17th century had opened up may new ocean routs. There was a fierce competition to take advantage of the situation. So along with the maps of the skies there was demand for better marine charts for efficient navigation. In 1698 Halley undertook a voyage, which lasted for two years. 'Under his command was the world's first ship ever commissioned solely for the scientific purpose. Halley thus measured magnetic declinations around the world. He prepared new navigation charts. He also tried to determine the correct attitudes and longitudes for the major ports.

What is the distance of the Sun from the Earth? Astronomers asked this question from almost the beginning of time. Today every high school student knows the answer. But at the beginning this question was one of the most difficult questions to answer. There was no direct method for measurement. In any case Aristarchus and Hipparchus of Samos (fl.3rd century BC) the two ancient Greek astronomers, attempted to answer it. Aristarchus placed the distance between 18 and 20 times more distant than the Moon. This was exceedingly far from the reality as the actual distance is more like 340 times as far. Though Hipparchus fared little better than Aristarchus but he was also still very far off. Better method was developed only after Johannes Kepler (1571-1630) made some key discoveries about planetary orbits Kepler found that the planets orbit the Sun in ellipses. Further according to Kepler the average distance of a planet from the sun and the time it takes to complete an orbit are mathematically related. This implies that from the distance of a planet from the Earth and how long it takes to orbit the sun the distance between the Sun and the Earth can be determined. So finally there was a method for accurately determining the distance between the Sun and the Earth as following the trigonometrical method known as triangulation it was theoretically possible to measure the distance between the Earth and a nearby planet. Such an attempt was made by Giovanni Domenico Cassini (1625-1712) in 1672. He used Mars for the calculation. It may be noted here that Cassini was brought to France by Louis XIV (1638-1715), whose reign encompassed a flourishing French culture. Though he came up with a much closer figure than ever before -86 million miles against the actual distance of 93 million miles but the problem remained far from being solved. It was Halley who pointed out that instead of Mars one should try to use Venus as the latter approaches closer to Earth than the former. But then it is rarely possible to see Venus during its closest approach to the Earth. This is because Venus appears to be too close to the Sun. The Venus in its closest approach to the Earth can be observed only on those rare occasions when its crosses to the Sun's disk. Such a period of crossing is called transit in in astronomy.

In 1691 Halley suggested that such a transit of Venus would be ideal situation to make measurements from all locations of the Earth. Halley in his life time did not witness a transit of Venus because they only occur in pairs separated by eight years at intervals of more than 100 years. After the suggestion made by Halley the nearest transit was to occur in 1761. Though Halley did not live to see the transit but in 1716 he had presented a paper to the Royal Society of London calling for coordinated worldwide preparation to utilise the forthcoming rare opportunity. He also devised a method for observing transits of Venus across the disk of the sun for correctly determining the distance of the sun from the Earth by solar parallax.

Halley's appeal to the scientific community did not go unheeded. Perhaps the transit of Venus in 1761 was the first great international scientific event. Scientists from all over the world joined together to make use of the opportunity. The planet was sighted by 122 observers from 62 different locations, including Newfoundland, Siberia, Bejing (then Peking), Calcutta, Rome, the Indian ocean and St. Helena. The popular press recorded the enthusiasm generated. However, the results were not conclusive. So a greater effort was mounted again in 1969. This time the planet was sighted by 151 observers from 77 sites. Captain James Cook (1728-79) sailed to then newly found island of Tahiti in the South pacific to observe the planet. After analysing the measurements (which took nearly 60 years to complete) made in 1769 the average value achieved turned out to be 96 million miles. This measurement expanded the solar system nearly 100 times the size that Ptolemy estimated the entire universe to be. It may be noted that no transit of Venus took place in 20th century. The only transits of 21st century will occur in 2004 and 2012.

Halley played a very important role in the publication of *Principia*, one of the greatest masterpieces of science. He persuaded Newton to work for it. When the Royal Society could not afford to finance its publication it decided that "Mr. Halley undertake the business of looking after it, and printing it at his own charges." Halley provided the necessary funds from his own pocket. He edited the text, corrected the proofs, and saw it through the press in 1687. He even contributed some laudatory Latin verses in honour of the author.

The Synopsis of the Astronomy of Comets, Halley's celebrated treatise, which laid the foundation of modern cometary science was rather brief. It was first published in Latin in 1705 as a six-page folio pamphlet. An English version was also brought out in the same year. A longer and slightly modified Latin version also appeared in the Philosophical Transaction of the Royal Society. In this treatise Halley presented the orbital features of 24 comets seen from 1337 through 1698. This information was presented in tabular form. Though Halley noted in this treatise that all the 24 comets had parabolic paths he himself believed that the true paths of comets were very eccentric ellipses. The most important observation put forward in this treatise was that the comets observed in 1531, 1607 and 1682 were the same object. Halley noted that their orbital features were identical except that the historic periods between their perihelion (the point nearest the Sun in the orbit of a planet, comet or man-made satellite) passages were different over 76 years between 1531 and 1607 and just under 75 years between 1607 and 1682.

Halley's interest was not confined to pure science alone. He was equally interested in technological pursuits. In 1731 he published a method to measure longitude via lunar position. He drew up a map of magnetic declination as a possible means for longitude measurement. He produced a world map with trade winds shown. Besides mapping magnetic declination, his expedition in the Atlantic was also concerned with determining the exact location of islands and ports. He was deeply involved in instrumentation. He developed a thermometer, a device for measuring the speed of ship through the water, and an improved version of the back staff for measuring the height of the Sun and his much talked about diving bell. He also helped Harrison to build his clock.

Halley died at Greenwich on January 14, 1742

Frederick William Herschel
Founder of Stellar Astronomy

"The rise of Herschel is one conspicuous anomaly in the otherwise somewhat quiet and prosy eighteenth century. It proved decisive of the course of ev ents in the nineteenth. It was unexplained by anything that had gone before, yet all that came after hinged upon it. It gave a new direction to effort; it lent fresh impulse to thought. It opened a channel for the widespread public interest which was gathe ring towards astronomical subjects to flow in."

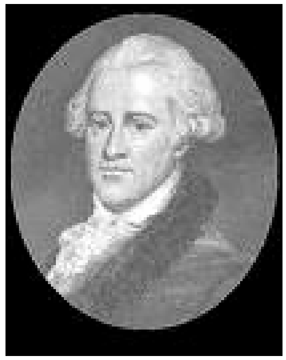
Agnes M. Clerke in The Herschels and Modern Astronomy, London, 1895

"During *his time,* Herschel was a leader in his field. The achievements of other astronomers paled in comparison, since by no other means in the history of the Earth had a human being served as witness to the secrets harboured in such far reaches of the heavens. Not only had he discovered the first new planet since ancient history, Herschel could proudly claim that he had looked further into th e universe than any before him."

Scott McCutchean and Bobbi McCutcheon in Space and astronomy: The People Behind the Science, New Delhi, 2007.

The rise of William Frederick Herschel on the horizon of the 18th century astronomy was really spectacular. The w hole tendency of eighteenth century astronomy was to complete and round off the earlier works. After Isaac Newton (1642-1727) and Marquis Pierre Simon de Laplace (1749 -1827) astronomy appeared to be devoid of any challenge. It was thought that whatever was to be explained had already been explained and whatever there was to know had also ready been discovered. All practical astronomers were busy calculating and cataloguing. Nobody seemed to bother about pursuing new and original lines. There was only one exception towards the end of the century. That was Herschel, a man who had no formal training in science and who was brought up as a musician. He suddenly made astronomy exciting again. With his sheer enthusiasm and love of nature William Herschel could infu se into astronomy a healthy spirit of fresh life and activity.

Herschel showed that none of the stars was really fixed as was assumed to be earlier. They were moving in all manner and ways. Thus Herschel changed the perception of heavens for man forever. He reviewed, described and gauged the entire portion of the sky from his location not once but four times. He had devised a careful method of "sweeping" the skies. Each night Herschel would work only a small portion of the sky, usually a strip of only abou t two degrees. Herschel would explore such a strip twice every night before he retired to sleep. The next night he would explore an adjacent portion. In this way he would explore the entire sky visible from his location. Each survey occupied him several ye ars. He discovered nebulae, double stars, variable stars, comets and satellites. He discovered and catalogued 2,5000 nebulae and 806 double stars.



Frederick William Hersc hel

Herschel's most startling discovery was the planet Uranus in 1781, which he originally thought to be a comet. The importance of this discovery could be gauged when we realise that since antiquity the existence of only five planets viz., Mercury, Venus, Mars, Jupiter and Saturn was known. There was no increase in the number of planets till Herschel discovered Uranus. Galileo and others did discover satellites but no primary planets. So the discovery of a new primary planet was an utterly unexpected nove lty. Herschel discovered two satellites (Mimas and Enceladus) of Saturn and two (Oberon and Titan) of Uranus.

Herschel's contributions to astronomy were really astounding. He defined the discipline of Stellar Astronomy and led astronomers to focus their e yes far beyond the Solar System. Of course, he was fortunate to be alive at a time when prolonged viewing with a large reflector could not but be amply rewarded. Herschel utilised this opportunity to the fullest extent. His work is characterised by unbelievable comprehensiveness with which he extended the observations of other astronomers. For example following the publication of Charles Joseph Messier’s (1730-1817) catalogue known as Messier Catalogue of 103 nebulae, star clusters and galaxies in 1781, Herschel began a systematic search for the non -stellar objects. His systematic effort revealed 2,500 such objects, which he listed in three catalogues (published in 1786, 1789 and 1802). He not only began the study of double stars but he catalogued over 800 of them. It was Herschel's work on double stars that provided the first demonstration of the assertion that Newton's laws of gravitation are also applicable outside the solar system.

Herschel's contribution to astronomy was not confined to the observationa l aspect alone. He made theoretical contributions on the structure of the Universe. He was the first to establish the motion of the Sun along with its planets and their satellites and other objects in the Solar System. He found that the Sun is moving in space relative to its stellar neighbours towards a point in the Hercules Constellation not far from the bright star Vega. He began to study the structure of the galaxy. His famous paper *On the Construction of the Heavens*, published in 1784, produced a model of the Milky Way Galaxy (the Galaxy which contains our Sun) as a non-uniform aggregation of stars. Herschel concluded from his star counts (he had counted over 90,000 stars) that the Milky Way had the shape of a disk, like a grindstone. Herschel placed the Sun near the centre of the Milky Way. Later studies confirmed Herschel's deduction that our Galaxy is disk -shaped but the Sun was found far from the centre and the Galaxy was found to be much larger than Herschel originally supposed. The Sun is 30,000 lig ht years away from the centre of the Milky Way Galaxy . In 1800, using a thermometer and prism, he discovered infrared radiation. In 1802 Herschel coined the term 'Asteroids' for the new celestial objects discovered by Giuseppe Piazzi (1746 -1826) and Heinrich Wilhelm Matthans Olbers (1758-1840). In 1821, Herschel was elected president of the Royal Astronomical Society. Herschel was responsible for launching the field of solar influence on Earth's atmosphere.

Herschel was born on November 15, 1738 at Hanove r, Germany, His father, Isaac Herschel, a military musician and a cultured man, was an oboe player in a military regiment. His mother Anna Ilse Moritzen had no education. Isaac and his wife had ten children. However, four of them died very young. William H erschel and the five other surviving children were brought up as musicians. Isaac also instilled an interest in astronomy among his children by his fireside talks and visual observations. At the age of seventeen Herschel became an oboist to the Hanoverian guards the same military musical orchestra on which his father played. In 1756 the regiment was sent to England for some months. Herschel learnt the English language quickly. He served the regiment only for two years. In 1757 Herschel and his brother Anton Jakob left for England on a ship from Hamburg. They planned to earn a living as musicians. After Jacob's return to Hanover, Herschel joined the Orchestra of the Earl of Darlington at Richmond. In 1762, Herschel moved to Leeds. After staying four years at Leeds Herschel moved to Halifax where he stayed for some months. On December 9, 1766 Hershcel went to Bath, where he stayed for 15 years. On October 4, 1767, he became the organist at the Octagon Chapel in Bath. Situated in South -west England, on the bank of the river Avon. Bath was an early Roman centre known as Aquae Sulis because of its hot natural springs, at a temperature of around 49O CA The elaborate Roman baths have survived and are considered the best Roman remains in England. Bath became fashionable as an elegant town in the 18th century. In Bath he lived a hard and successful life. He taught many pupils and wrote many musical pieces.

After the death of his father in 1765, his brother Alexander joined him in Bath. His sister Caroline Lucretia Hers chel (1750-1848), who herself devoted her entire life to astronomy, joined him in 1772 when she was twenty -two. Initially Caroline did not share her brother's passion for astronomy. However, at the age of

32 she became on apprentice to her brother. Carol ine discovered eight comets and the companion of the Andromeda Nebula. She was the first woman to play a key role in astronomy. In 1787, she was granted an annual salary of 50 pounds by the king as her brother's assistant at Slough. This was the first inst ance when a woman was recognised for her scientific position. Her Index to Flamsteed's Observations of the Fixed Stars alongwith a list of errata was published by the Royal Society in 1798. After William's death Caroline went back to Hanover where she work ed on the reorganisation of his catalogue of nebulae.

While leading the musical life of Bath, Herschel became deeply involved in optics and astronomy. At night Herschel studied mathematics, optics, Italian or Greek. His position as organist gave him enoug h money to help finance his growing interest in astronomy. Herschel had become so fascinated with astronomy that he read hundreds of books on astronomy, calculus and optics. He also bought a small telescope and spent most of his nights by gazing at the sky . And as time passed Herschel's enthusiasm for watching the night sky increased. To Herschel the night sky was a vast, dark ocean mostly uncharted and filled with the perpetual promise of new discoveries. As Caroline would later recall: "If it had not been for the intervention of a cloudy or moonlit night, I knew not when he or I either would have got any sleep."

The first obstacle that Herschel encountered in exploring the poorly uncharted sky was the lack of good telescope. However, he was not daunted. H e decided to build a telescope himself. In 1774, he was successful in making a 5.5 ft telescope. He was never tired of making better and better instruments. Herschel and his sister Caroline were considered to be the world's best telescope -makers of their time. They built a large number of telescopes culminating in the enormous 48 -feet (12 m) reflector.

Leisure was unknown to Herschel. He grinded mirrors in the day, performed in concerts in the evening and spent the night gazing at the sky. How his health permitted all this was a wonder. The way they worked could be guessed from the observations made by Caroline in her diary: "My time was taken up with copying music and practising, besides attendance on my brother when polishing, since by way of keeping him alive I was constantly obliged to feed him by putting the victuals by bits into his mouth. This was once the case when, in order to finish a 7-foot mirror, he had not taken his hands from it for sixteen hours together. In general he was never unemployed at meals, but was always at those times contriving or making drawings of whatever came in his mind. Generally I was obliged to read to him whilst he was at the turning -lathe, or polishing mirrors, Don Quixote, Arabian Nights' Entertainments, the novels of St erne, Fielding, &ca; serving tea and supper without interrupting the work with which he was engaged ,.. and sometimes lending a hand. I became, in time, as useful a member of the workshop as a boy might be to his master in the first year of his apprentices hip...

But as I was to take part the next year in the oratorios, I had, for a whole twelvemonth, two lessons per week from Miss Fleming, the celebrated dancing-mistress, to drill me for a gentlewoman. So we lived on without interruption. My brother Alex, was absent from Bath for some months every summer, but when at home he took much pleasure in executing some turning or clockmaker's work for his brother."

On March 13, 1781 Herschel in one of his careful 'sweeps' discovered the planet Uranus. Before Herschel many astronomers had noticed it but they invariably took it as a star and so they did not further ponder over it. But Herschel had memorised the positions of thousands of stars and so when he found Uranus, he was sure that no star could be expected in that position. Describing his finding Herschel wrote to the Royal Society: "On this night in examining the small stars near Geminorum, I perceived one visibly larger than the rest. Struck with its uncommon appearance, I compared it to Geminorium and another star, and finding it so much larger than either I suspected it to be a comet."

Professional astronomers computed the orbit of Herschel's 'comet' and it was found to move in nearly a circle and not in elongated ellipse that a comet would be expected to move. So it was a new planet, more than 100 times bigger than the Earth and nearly twice as far way as Saturn. Herschel wished to name it after his patron as *Georgium Sidus* (George's Star) but finally the name 'Uranus' was universally adopted. There were only five planets known since the prehistoric times and there was no increase in their number till Herschel made his discovery. This unique and utterly unexpected discovery made Herschel famous overnight. The Royal Society made him a Fellow the same year, the Oxford University awarded him a doctoral degree and what is more the king of United kingdom and Ireland, George III (1738-1820) appointed him his court astronomer. Thus the discovery of Uranus made Herschel a practical astronomer. So from Bath, Herschel moved to a small house at Datchet, near Windsor. Herschel was awarded an annual stipend by the king. This enabled Herschel to devote all his time to astronomy without resorting to earning a living as a professional musician. However, his stipend was not enough to take care of his experimental work and his frequent trips to London. So Herschel and his sister had to supplement their income by making and selling telescopes. Among Herschel's customers were the King of Spain, the Prince of Canino, the Russian court and the Austrian Emperor. One of his instruments was sold to China. Herschel also made telescopes for well-known astronomers like Johann Elert Bode (1742-1826) Johann Hieronymus Schroter (1745-1816), Giuseppe Piazzi (1746-1826) and John Pond (1767-1836).

With the king's patronage Herschel was able to build a telescope with a 48-inch (1.22m) mirror and a focal length of 40 ft (12.2m) the largest in the world then. The telescope cost the king 400 pounds plus 200 pounds a year for its maintenance. The eyepiece of the telescope was attached to the open end. This arrangement eliminated the loss of light caused by the secondary mirror used in Newtonian and Gregorian reflectors. However, there was a serious disadvantage arising out of this arrangement. One was required to climb up to the open end in the dark. While doing this maneuvering Giuseppe Piazzi fell and broke his arm. With this telescope Herschel in 1787 discovered the two satellites of Uranus and two more of Saturn. (It may be noted that after Herschel's discovery the two satellites of Uranus were not seen till some forty years later, when his son Sir John Frederick William Herschel (1792-1871) observed them again). The telescope was dismantled in 1839 while John conducted his family in a special requiem specially composed for the occasion.

On May 8, 1788, Herschel at the age of 50, married Mrs. Mary Pitt, a wealthy widow and his financial worries came to an end. They moved to a more spacious house at Slough, where he remained for the rest of his life. However, after the marriage Caroline lived in lodgings and went over at night time to help Herschel observe. Herschel and his sister for all practical purpose turned night into day. They slept only during daytime as they often watched the sky till daylight. At the time they moved from Datchet to Slough, Caroline wrote: "The last night at Datchet was spent in sweeping till daylight, and by the next evening the telescope stood ready for observation at Slough."

Before Herschel the stars had been mainly observed for nautical and other practical purposes. Astronomers noted their times of rising and setting but nobody bothered to observe them in detail. They were just considered as fixed points of reference. People treated them as clock or piece of dead mechanism. In the meantime all the attention of astronomers was concentrated on the Solar System, studying the planets and satellites. Tycho Brahe (1546-1601) patiently and meticulously observed the positions and movements of the planets over two decades. Based on Tycho's observations Johannes Kepler formulated his celebrated laws of planetary motions. Galileo Galilie discovered their peculiarities and satellites. Newton and Laplace elaborated every detail of their laws. But as far as the stars were concerned they remained the same as Ptolemaic system assumed them to be, some fixed points in the sky. Herschel found that the stars were not of the same kind. He found a variety in them. Every star was not at the same distance from the Earth. The stars were not at rest, Herschel found them moving and full of activity. It is worthwhile to note that in 1718 Sir Edmond Halley (1656-1742) pointed out that stars had proper motion. His conclusion was based on the fact the brightest stars had changed position since the time of Ptolemy's Almagest. The stars were moving in all directions and in all manners. He found stars revolving around stars at mind-boggling distances but at the same time obeying the law of gravitation. It may be noted that the stars are at such great distances that by moving even at very high speeds their positions may appear to us unchanged for thousands of years. For Herschel every star was a Solar System.

Herschel was fascinated with the nebulae, the mysterious objects as initially they appeared to be. He freely speculated on the nature of these objects. Herschel considered them in various forms—as cluster of stars, other universes at almost infinite distances or nascent stars. He visualised the universe as conglomeration of innumerable worlds—some dead, some old, some at the prime stage of their life and some in their infancy or in the process of being born. He likened the universe to a garden with all manner of plants growing at different stages.

Herschel died on August 25, 1822.

Nebula

In Herschel's time any fixed, extended and somewhat fuzzy white haze observed in the sky with a telescope was termed nebula. Many of these objects can now be resolved into clouds of individual faint stars and have been identified as galaxies. As early as in 1864 William Huggins (1824-1910) demonstrated that true 'nebulae' could be distinguished from those composed of stars on the basis of their spectra. Now-a-days the term nebula refers to a gaseous nebula, which cannot be resolved into individual stars and consists, for most part, of interstellar dust and gas. The gaseous nebulae have been classified into three broad groups viz., emission nebulae, reflection nebulae and dark nebulae.

An emission nebula is a luminous cloud of gas and dust in space which shines with its own light. For example the Orion Nebula, H II regions, and planetary nebulae. Emission nebulae glow brightly because the gas in these nebulae is energised by stars that have formed within them. There are other ways by which the light can be generated. A gas cloud or nebula can glow because it has become ionised in a violent collision with another gas cloud. Herbig-Haro objects (small nebulae found in the regions of star formation) are examples of emission nebulae. In Crab Nebula, a supernova remanent, the light is produced by a process known as synchrotron radiation (electromagnetic radiation emitted by a charged particle moving in a magnetic field at a velocity very close to that of light).

Reflection nebulae appear bright because they reflect or scatter starlight. A reflection nebula surrounds the stars of the Pleiades cluster, a star cluster about 400 light years away in the Constellation Taurus, representing the seven Sisters of Greek mythology.

A dark nebula is a dense cloud, composed of interstellar gas and dust which partially or completely absorbs light behind it. Examples include the Coalsack Nebula in Crux, the smallest Constellation better known as the Southern Cross and the Horsehead Nebula in Orion, a magnificent Constellation on the celestial equator.

Tarantula Nebula, an emission nebula, is the largest and the brightest nebula. Its name comes from its spider-like shape (tarantula is the name of a tropical or subtropical American spider). The nebula is located in the Large Magellanic cloud. It has a diameter of over 800 light years with faint extensions to 6000 light years and contains half-a-million solar masses of ionised gases. The ionisation is caused by several clusters of O and B stars. O star is the brightest, hottest and most massive of all normal, hydrogen-burning stars. B-type stars are hot and appear blue in colour, emitting strongly in the ultraviolet. Normally they have masses upto 25 solar masses and luminosities as high as 260,000 times the Sun's.

Samanta Chandra Sekhar
India's Last Noted Siddhantic Astronomer

"Samanta Chandra Sekhar was …an inspired figure who came up on his own after a long gap in our history of astronomer mathematicians. Bhaskara II was his role model. Samanta Chandra Sekhar was essentially a naked eyed astronomer who produced his tables with astonishing accuracy. There was nothing that was recorded in the Siddhant Darpan which had not been verified through observation. He was striving for knowledge for its own sake, and learnt everything that he knew in astronomy and mathematics on his own. "

M.G.K Menon in "Scientific Contributions of Samanta Chandra Sekhar To Astronomy, 2006".

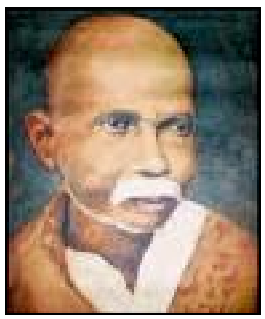
"India has a rich heritage of astronomy having produced great astronomers like Aryabhata, Varamihira, Brahmagupta and Bhaskara. The genius of these luminaries bloomed at various places spread all over the country, scaling a time span of nearly 1500 years beginning with 5th century AD. Mahamahopadhyaya Chandra Sekhar Simha Harichandan Mahapatra Samanta…seems to be the last link of this long order of great Hindu astronomers."

P. CA Naik and L. Satpathy in Current Science, 25 October 1995

One hundred years ago, *Siddhanta-Darpana*, a treatise on astronomy was published. Though it was written by a man, who lived throughout his life in a place amidst hills and jungles of Orissa and far away from the contemporary seats of learning or for that matter far from any educational activity, proved to be the most important work published in India after *Siddhanta-Shiromani* (written in A.D. 1150) by Bhaskara II. The author of the book, Mahamahopadhyaya Pandit Samanta Chandra Sekhara Harichandan Mohapatra (locally and lovingly known as Pathani Samanta) observed, verified and corrected wherever necessary all that was known to astronomers of ancient India. Often he surpassed them. He discovered new phenomena and gave new formulations. He was the first Indian astronomer to notice all the three irregularities of the moon viz., evection, variation and annual equation. His achievement is amazing. In fact it would appear incredible when we take into account the fact that he had no formal education. He knew no other language except Sanskrit and his mother tongue Oriya. The open blue, starry sky was his observatory and he made all the astronomical observations without any optical assistance. He did not see a telescope till late in his life, and did not even possess a timepiece.

The work was written in the style of our *siddhantas*. It may be noted here that by about A.D. 400 or may be even earlier a new class of astronomical works, known as *siddhantas*, emerged which attempted to present the correct solution of astronomical problems. In fact, the Sanskrit word "siddhanta", means "final conclusion" or "solution". It is said that there were 18 original *siddhantas*. However, we know of only about five *siddhantas*, which were summarised by Varahamihira (born CA A.D. 505) of Avanti (modern Ujjain) in his *Panchasiddhantika*. These are: the *Paitamaha-siddhanta*,, the *Vasistha-siddhanta*, the *Paulisa-siddhanta*, the *Romaka-siddhanta* and the *Surya-siddhanta* (also known as *Saura-siddhanta*). The *siddhantas* have come down to us through revisions made by several authors. The *siddhantas* laid special emphasis on computations and thus opened the way to new methods of analysis.

Leading astronomers of this period were Aryabhata I (born A.D. 476), Varahamihira (6th century A.D.), Bhaskara I (born ca A.D. 600), Brahmagupta (born ca A.D. 598), and Bhaskara II (born A.D. 1114). Besides the compilation work of Varahamihira, the immortal works of this period were *Aryabhatia* (by Aryabhata I), *Brahmasphuta-siddhanta* (by Brahmagupta) and *Siddhanta-Shiromani* (by Bhaskara II).



Samanta Chandra Sekhar

Pathani Samanta was born on January 11, 1836 in Khandapara, a village in western Orissa. From an early age Pathani Samanta was taught Sanskrit Grammar, Smritis, Puranas, Logic, Medicine and all the important *Kavyas* in original. At the age of ten his father taught him a little of astrology. As we know the determination of *lagnas* (the rising point of ecliptic) is a very frequent necessity in horoscopy and, traditionally without the knowledge of the positions of the stars — which changed night after night — astrological predictions could not be made. This led him to watch the position of the stars night after night. The idle curiosity exhibited in star-gazing developed into the habit of really fruitful study of astronomy. He had no one to guide him in his observations except the *Siddhantas* available in his family library. He undertook the systematic study of these works with the help of commentaries. By the age of 15 he mastered the rules for calculating the ephemerides (tables showing the positions of heavenly bodies at regular intervals in time) of the planets. While calculating the positions of the planets he found that neither the stars appeared on the horizon at the right moment nor could the planets be seen in the right places. He began to observe and calculate the movement of heavenly bodies night after night. At the age of 23 he began to note down systematically the results of his observations.

His grandfather was a local king (Raja of Khandapara) and the king of his time Raja Mardaraj Bhramaravara Ray w as the son of his eldest cousin. However, he was ignored by the king as he did not appreciate that his uncle should do the work of star gazing which, according to him, was derogatory to his position. Thus throughout his life he remained Samanta (member of king's family) by name and did not enjoy any privilege. He had very small income — Rs. 500 a year from a few villages, and a quantity of food grain from his tenants. With this small income he had to support a number of attendants maintained hereditarily.

Siddhanta-Darpana was originally written on palm leaves in Sanskrit (in Oriya characters). The book was first published in *Devnagari* script in 1899 from a Calcutta press with the financial support of the king of Athmallick and the king of Mayurbhanj. J. CA Ray, Professor of Physical Science, Cuttack College (today's Ravenshaw College), wrote a very illuminating introduction and also supervised its printing. The treatise contains 2,500 slokas of various poetical metres. Out of the total 2,500 slokas 2,284 sl okas were composed by Pathanai Samanta and the remaining 216 were quoted from the old siddhantas mainly from the *Surya Siddhanta* and the *Siddhanta-Shiromani*. In fact in writing *Siddhanta-Darpana* Pathani Samanta followed in the footstep of Bhaskara -II. But he was not a blind follower of his guru. Pathani Samanta did not accept the elements of planets given by Bhaskara-II as they were not correct in his time.

The treatise was of highest literary merit. As Prof. Ray wrote: "It appears to me that the metrical composition alone, apart from its value as a contribution to Hindu astronomy is such as to entitle him to a high place among the writers of Sanskrit verse of the present day." The treatise is broadly divided into two parts — *Purvardha* (first half) and *Uttarardha* (latter half). In its 24 chapters called *Prakasa* or illumination reflects the whole gamut of *Siddhanta* calculations for exactly composing an almanaca The first part contains 15 chapters and the second part 9. Further the chapters are grouped under five sections viz., *Madhyamadhikara*, *Sphutadhikara*, *Triprasnadhikara, Goladhikara* and *Kaladhikara*. The contents of different chapters are shown in Table 1.

Table 1 : Titles of the chapters of *Siddhanta-Darpana*

Serial No.	Name of the Chapter
1.	Different measures of time
2.	Revolution numbers of planets
3.	Determination of mean planets
4.	Corrections to be applied
5.	True position of the planets
6.	Computation of accurate calendar, declination etca,
7.	Gnomon and its shadow

8. Lunar eclipse
9. Solar eclipse
10. Graphical representation
11. Conjunction of planets
12. Conjunction of stars and planets
13. Rising and setting of planets
14. Peak of the cusps of the moon
15. Moments defined by the equality of declination of the sun and the moon
16. List of questions
17. The situation of the Earth
18. Description of the Earth
19. Description different spheres
20. Description of Instruments
21. Rationale for the questions
22. Units of time like year etca
23. Praise of the Lord Jagannatha
24. Conclusion

The journal *Knowledge*, which reviewed the book in 1899, wrote: "Of all the numerous works on astronomy that have been published within the last few years, this is by far the most extraordinary and in some respects the most instructive. It is written in Sanskrit by a Hindu of a good family of Khandapara in Orissa, and is a complete system of astronomy founded upon naked eye observations only, and these made for the most part with instruments devised and constructed by the writer himself.... To Hindus, for whom their religious observances are regulated by astronomical configurations, this work by one of themselves, a strict follower of the severest laws of their religion, and conducted throughout solely by traditional Hindu methods, is of the highest importance, as it removes the confusion which had crept into their system, without in the least drawing upon the sources of western science. But the work is of importance and interest to us westerners also. It demonstrates the degree of accuracy-which was possible in astronomical observation before the invention of the telescope, and it enables us to watch, as it were, one of the astronomers of hoary, forgotten antiquity actually at his work before us to-day."

Pathani Samanta made contributions to the following four important aspects of astronomy:

(1) Observations
(2) Calculation
(3) Method of measurement and instrumentation
(4) Theory and models

Commenting on Pathani Samanta's achievement, the international science journal Nature (Vol. 59, 9 March 1899) which reviewed *Siddhanta-Darpana* wrote: "We get some notion of the success that attended the work, and of how much it is in one man's power to accomplish, if we examine the difference between the values he assigned to some of the constants of astronomy and those in use with ourselves. The error in the sidereal period of the sun is 206 seconds: of the m oon, 1 second: Mercury, 79 seconds: Venus, about 2 minutes: Mars, 9 minutes: Jupiter, an hour: and Saturn, rather more than half a day. The accuracy with which he determined the inclination of the planets to the ecliptic is still more remarkable. Mercury o ffers the largest error, and that is only about two minutes. In the case of the Solar orbit the greatest equation to the centre is only 14 seconds in error. In the lunar theory, the revolution of the node has been concluded with an error of about 5.5 days, less than the thousandth part of the whole period: while he has independently detected and assigned very approximate values to the evection, the variation, and the annual equation."

The instruments used for his practical observation of the night sky were made by him indigenously. His instruments, which were mostly made up of wood and bamboo pieces, can be broadly classified into three categories:

i. Instruments for measuring time included sun -dials, like *Chakra yantra* consisting of a calibrated wheel with an axis at the centre measured time for an entire day; *Chapa Yantra*, a calibrated wheel with an axis at the centre measured time for half of a day and *Golardha Yantra*, a hemispherical dial. He had also *Swayambaha Yantra,* a water clock.

ii The versatile instruments which mainly included a *Shanku* or Gnomon as it is popularly known and *Mana Yantra*. The *shanku* consisted of a stick of measured height fixed vertically on a levelled ground. By measuring the shadow length of the stick cast by the sun one could me asure the local time, the altitude, zenith distance and declination of the sun, its position in the Zodiac, latitude and direction of a place and many other things.

Mana-Yantra (measuring instrument) essentially a tangent staff, was invented by himself. It consisted of a thin rod of wood at one end of which is fixed another rod at right angles in the form of a T with unequal horizontal arms. Careful use of the device can give both height and distance of the mountains and other distant objects. The instrument is described in detail in *Siddhanta Darpana*. Holes are drilled in to the vertical side at the measured distances. All the three arms are calibrated.

iii. Amillary Sphere or *Gola Yantra* which used to be widely used by ancient astronomers of India for determining the position and motion of planets and as a demonstration kit for showing to the students various great circles used in astronomy was improved by Pathani Samanta. With this improved version he could measure the longitude and declination of planet s.

In his introduction to *Siddhanta Darpana* Prof. J.CA Ray has drawn a number of parallels between Tycho Brahe (A.D. 1546 -1601) and Pathani Samanta. Tycho Brahe made accurate astronomical instruments and used them to make observations enabling him to revi se the existing, often inaccurate, astronomical tables. Tycho Brahe rejected the Copernican doctrine and constructed a system of his own, combining the elements of the Ptolemaic and Copernican theories.

All our ancient astronomers subscribed to the geocen tric hypothesis. Pathani Samanta based on his own observations, proposed a different model in *Siddhanta Darpana*. The model is geocentric with Sun, Moon and stars revolving around the Earth. However, five planets Mercury, Venus, Mars, Jupiter and Saturn rev olve round the Sun and the Sun with the planets around it revolve round the Earth (Fig.2). This model independently developed by Pathani Samanta is similar to the model developed by Tycho Brahe. To quote from the review of *Siddhanta-Darpana* in *Nature*:

"Prof. Ray compares the author very properly to Tycho. But we should imagine him to be greater than Tycho, for without the same assistance, without the encouragement of kings and the applause of his fellows, he has advanced his favourite science quite as effec tually as did the Danish astronomer. It is specially curious to notice that the system at which Samanta Chandrasekhara ultimately arrived, and the explanation he offers of it, bears a very considerable resemblance to that which Tycho taught. The author has never been able to convince himself that the Earth turns on its axis or that it goes round the sun; but to the planets he assigned heliocentric motion, much as Tycho did."

The study of astronomy became a passion with him. Prof. J.CA Ray has informed us that Pathani Samanta could not be persuaded to stay in Cuttack even one day more after receiving the title of honour conferred on him by the British Government as eclipse of the sun was to occur a few days later. He did not want such a momentous event to pa ss by unnoticed. He was honoured with the title of Mahamahopadhyaya on June 3, 1893 at a special conference for his significant contribution to the field of astronomy. He strived after knowledge for its own sake and that too, as Prof. J. CA Ray wrote, 'und er difficulties whose magnitude is no less startling than the boldness of his attempt.' Finally we will end this article by quoting Prof. J. CA Ray:

"What has he (Chandra Sekhar Samanta) done after all?" - asks the impatient - critica To him, I would say, is it not enough to find in this man a true lover of science who regardless of other people's unfavourable opinions of his work, their taunts and dissuasions, has devoted his whole life to the one pursuit of knowledge; who has shown the way to original research amidst difficulties serious enough to dishearten men in better circumstances: who has employed his time usefully, instead of frittering it away like the usual run of men of his rank, on a work which guides the daily routine of millions of his countrymen?”

Pathani Samanta died on June 11, 1904.

Albert Einstein
Founder of Theory of Relativity

"In the first two decades of the twentieth century Einstein advanced two remarkable theories -- *the special theory of relativity* (1905) and the *general theory of relativity* (1915-16) -- in which he revolutionized our way of thinking about space, time, motion and gravitation. These theories played a central role in the development of twentieth-century physics. He also made important contributions to quantum theory, in particular his light quanta hypothesis (1905), the concept of stimulated emission in atom (1916-17), and the development of the Bose-Einstein statistics (1924-5)".

Mauro Dardo in Nobel Laureates and twentieth century physics (2004).

"For the most part, I do the thing which my own nature drives me to do. It is embarrassing to earn so much respect and love for it".

Albert Einstein

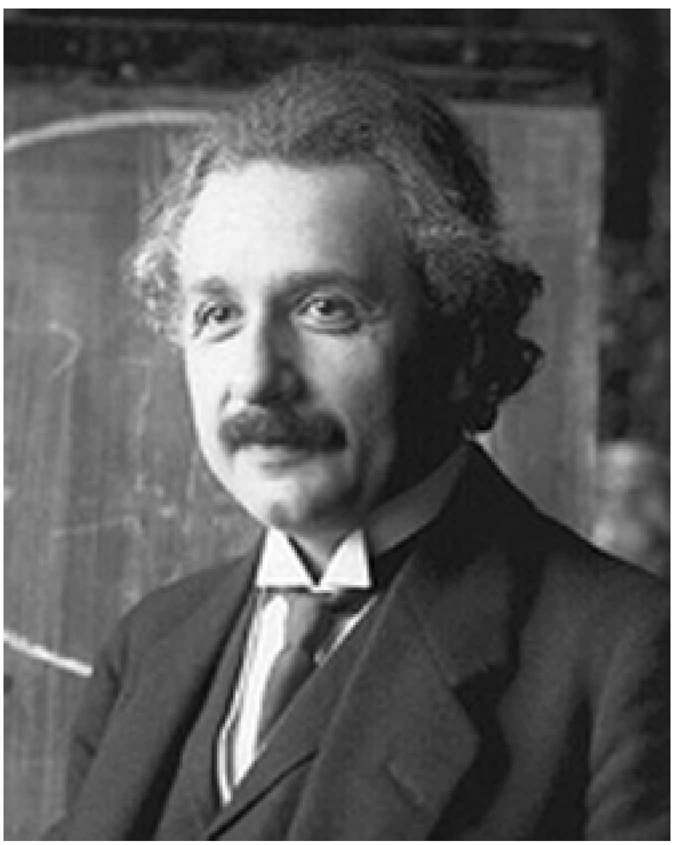
"One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike—and yet it is the most precious thing we have."

Albert Einstein

Einstein contributed more than any other scientist to the 20th-century vision of physical reality. In 1905 Einstein proposed his theory of relativity. While proposing this theory, Einstein discarded the concept of time and space as absolute entities, as they were regarded till then. In the same year he explained the phenomenon of photoelectric effect by postulating light quanta or photons comparable to energy quanta. In 1916 Einstein published his theory of general relativity considered by many physicists as the most elegant intellectual achievement of all time. It had vast implication especially on the cosmological scale. Einstein forever changed the way we contemplate the universe.

Einstein was more than a scientist, more than a philosopher, and more than a world statesman. Einstein lived by a deep faith but then his was not a life of prayer and worship. His life-long pursuit was to discover the laws of Nature, to cultivate the fruit of pure learning.

Einstein's life and his work have been well chronicled. In fact there is hardly any other scientist on whom so much has been written or who has received such public attention. The first scientific subjects that the newly emerging mass media of the 1930s tried for popularization were Einstein's theories of relativity. But the media found it extremely difficult to make people understand what Einstein had to say. This is because even the simplest explanations of the theories were counterintuitive and were hard to follow. But the media did not leave at that. Instead of Einstein's work, the media concentrated on Einstein, the person. The media hype on Einstein created something of a creature, which became the popular image of a modern scientist. Einstein became a peerless myth. Many people think that they understand Einstein's work but in reality they are familiar with the image of Einstein created by the media. In 1931, Einstein and Charlie Chaplin travelled together to Los Angeles to view the opening of the film "City Lights". They were recognised by the crowd and enthusiastically greeted. On this occasion, Chaplin noted: "The people applauded you (Einstein) because no one understands you, and me, because everyone understands me." What Chaplin said is largely true even today. Not many people really understand what actually Einstein did. In fact many physicists themselves may not be in a position to fully grasp Einstein's work and what to talk about laypersons. The statement, "In the last analysis, fame is only the epitome of all the misunderstandings which gather about a new name" by Rainer Maria Rilke is very true for Einstein. Even Einstein did not understand why he was so well liked but at the same time so little understood. By writing this it is not intended to mean that Einstein's work cannot be understood but it is to highlight the fact that one needs a thorough background in physics and mathematics to understand Einstein's work.



Albert Einstein

Einstein was born in a small town named Ulm in Germany on March 14, 1879 to Hermann and Pauline Einstein. The family moved to Munich when Einstein was an infant. At Munich, Hermann Einstein and his brother Jakob Einstein established a small electrical plant and engineering works. The family later moved to Milan. The business activities of Einstein's father were never very successful. Like in many other cases, there were no early indications of Einstein's genius. He did not begin to talk until the age of three and he was not fluent till the age of nine. Einstein received his first instructio n at home from a woman teacher, when he was five year old. At the same time he started taking lesson on the violin. He entered the public primary school (called Volksschule in Germany) at the age of seven. There is a popular myth that Einstein was a poor s tudent in his early years. It is not true. His grades were excellent and he was consistently placed at the top of the class. He did not always get along with his teachers at primary school. He did not like the rigid discipline and the rote -learning techniques.

Einstein was a quite child. He had a natural antipathy for sports or outdoor activities. He made few friends at school and felt isolated and alone. He did not enjoy in playing with his classmates. He did not even join other children for playing at home. Instead he preferred solitary games that required patience and persistence. His sister Maja wrote: "The children of family and relatives often got together in his parents' garden in Munich. Albert refrained from joining their boisterous games, however, and occupied himself with quieter things. When he occasionally did take part, he was regarded as the obvious arbiter in all disputes. Since children usually retain a very keen and unspoiled instinct for the exercise of justice, the general recogniti on of his authority indicates that his ability to think objectively had developed early." Among his favourite games was building a house of cards. However, his major recreational interest was musica Since his early childhood Einstein was taught to become s elf-reliant. His sister wrote : "The boy was trained early in self-reliance, in contrast to the customary European child-rearing method which consists of over-anxious tutelage. The 3- or 4-year old was sent through the busiest streets of Munich; the first time he was shown the way, the second, unobtrusively observed. At intersections he conscientiously looked right, then left, and then crossed the road without any apprehension. Self -reliance was already ingrained in his character and manifested itself prom inently on various occasions in his later life", It may be noted here that the biographical sketch of Einstein written by his sister Maja Winteler-Einstein is the major source of information on their family and Einstein's early life.

Einstein entered the Luitpold Gymnasium (high school) in 1888 and he studied here until he was fifteen. The school placed more emphasis on classical languages like Latin and Greek than to natural sciences. Einstein did well in Latin and mathematics, but he disliked the harsh and pedantic regimentation. To quote his sister Maja: "Actually, he was very uncomfortable in school. The style of teaching in most subjects was repugnant to him…. The military tone of the school, the systematic training in the worship of authority that wa s supposed to accustom pupils at an early age to military discipline, was also particularly unpleasant for the boy. He contemplated with dread that not-too-distant moment when he would have to don a soldier's uniform in order to fulfill his military obliga tions. Depressed and nervous, he searched for a way out. Hence, when the professor in charge of his class (the same one who had predicted that nothing good would ever come of him) scolded him on some occasion, he obtained a certificate from the family doctor, presented it to the school principal and abruptly left to join his parents in Milan. They were alarmed by his high-handed behaviour, but he most adamantly declared that he would not return to Munich, and reassured them about his future by promising them most definitely that he would independently prepare himself for the entrance examination to the Zurich Polytechnical School in autumn. This was a bold decision for a 16-year-old, and he actually carried it out. His parents resigned themselves to the new situation with grave misgivings, but were persuaded to do all they could to further the plan."

In October 1895, Einstein took the Entrance examination to the prestigious Eidgenossische Technische Hochschule (the Federal Institute of Technology or ETH as it is usually referred to), in Zurich. Einstein failed the examination. He did quite well in science and mathematics but not well enough in languages, history, literature and art to qualify. This was a serious setback for Einstein. Bu t considering his youth the school authorities took a lenient view. They told Einstein's parents that they would admit him after he attends the final year of a Swiss secondary school. Thus Einstein got enrolled in the Cantonal school in Aarau, a small Swiss town. The school had a high reputation. It attracted students even from overseas.

While in school, Einstein had decided to embark on a life-long study of the "huge world". He would later say: "There was this huge world out there, independent of us human beings and standing before us like a great, eternal riddle, at least partly accessible to our inspection and thought. The contemplation of that world beckoned like a liberation." He also said: "I have never imputed to Nature a purpose or a goal, or anything that could be understood as anthromorphica What I see in Nature is a magnificent structure that we can comprehend only very imperfectly and that must fill a thinking person with a feeling of humility. This is a genuinely religious feeling that has nothing to do with mysticism."

Einstein often talked about one story about his childhood—it was of a wonder he saw when he was four or five years old, a magnetic compass. Einstein was profoundly impressed by the needle's invariable n orthward swing, guided by an invisible force. By seeing it he was convinced that there must be "something behind things, something deeply hidden."

Einstein learned geometry by himself before it was taught in class. He was impressed by geometry for its precision and definiteness. Einstein said: "At the age of 12, I experienced a wonder in a booklet dealing with Euclidean plane geometry, which came into my hands at the beginning of a school year. Here were assertions, as for example the intersection of the three altitudes of a triangle in one point, which—though by no means evident—could nevertheless be proved with such certainty that any doubt appeared to be out of question. This lucidity and certainty made an indescribable impression on me." He also studied differential and integral calculus on his own.

Einstein's interest in mathematics was aroused and sustained by his uncle, Jacob Einstein. His sister Maja wrote: "In Gymnasium, the boy was supposed to begin the study of algebra and geometry at the age of 13. But by that time he already had a predilection for solving complicated problem in applied arithmetic, although the computational errors he made kept him from appearing particularly talented in the eyes of his teachers. Now he wanted to see what he could learn about these subjects in advance, during his vacation, and asked his parents to obtain the textbooks for him. Play and playmates were forgotten. He set to work on the theories, not by taking their proofs from books, but rather by attempting to prove them for himself. For days on end he sat alone, immersed in the search for solution, not giving up before he found it. He often found proofs by ways that were different from those found in the books. Thus, during this one vacation of a few months, he independently worked his way through the entire prospective Gymnasium Syllabus. Uncle Jacob, who was an engineer had a comprehensive mathematical education, reinforced Albert's zeal by posing difficult problems, not without good- natured expressions of doubt about his ability to solve them. Albert invariably found a correct proof; he even found an entirely original one for the Pythagorean theorem. When he got such results, the boy was overcome with great happiness, and was already then aware of the direction in which his talents were leading him."

Besides his uncle, Max Talmud, a medical student with little money, also influenced Einstein in his school days. Talmud used to take one evening meal each week with the Einsteins. Talmud used to give book on science and philosophy to young Einstein. The two used to discuss for hours together.

Einstein's power of mental concentration was proverbial. He could easily engross in deep thought in a corner of a noisy room. He could work without being disturbed by the conversations of others. Once Einstein said to one of his students: "I am always available to speak to you. If you have a question come to me without worrying. You will never disturb me because I can always break off my work at any moment and return to it immediately after the interruption." One of his students actually witnessed how Einstein could concentrate without being disturbed by the surroundings. He described it in the following way: "He was sitting in his study in front of a heap of papers covered with mathematics formulae. Writing with his right hand and holding his younger son in his left, he kept replying to questions from his elder son Albert who was playing with his bricks. With the worlds, "Wait a minute, I am nearly finished," he gave me the children to look after for a few moments and went on working. It gave one glimpse of his immense powers of concentration."

Einstein graduated from the Swiss Polytechnic in the spring of 1900 as a secondary school teacher of mat hematics and physics. After graduation his primary objective was to secure a job. He expected to get a position as teaching assistant but to his disappointment he did not get one. His disregard for authority in school and in college was responsible for hi s inability to secure a position. His mathematics teacher at the Polytechnic, Hermann Minowski, considered Einstein a "lazy dog" who seldom came to class. His other teachers did not hold good opinion of him. Heinrich Weber, his physics teacher a t the polytechnic is supposed to have told him: "You are a smart boy. But you have one great fault, you do not let yourself be told anything." It is said that one of his teachers even suggested Einstein leave school, since his very presence destr oyed the other students' respect for the teacher. So naturally his teachers refused to recommend him for a teaching position. Perhaps they thought that if he could not show enough enthusiasm for class work, he might not show it for professional work.

After two years of struggling to eke out living as a tutor and substitute teacher, Einstein finally got a job. In June 1902 Einstein got an appointment, on a temporary basis, as a technical expert, third class, in the patent office in Berne, Switzerland. Einstein got this job through the efforts of his friend Marcel Grossman, whose father was a friend of the Director of the Swiss patent office. Einstein enjoyed his work at the patent office, where he worked from 1902 to 1909. Einstein wrote: "The work on satisfactory formulation of technical patents was a true blessing for me. It compelled me to be many -sided in thought, and also offered important stimulation for thought about physics. Following a practical profession is a blessing for people of my type. Because the academic career puts a young person in a sort of compulsory situation to produce scientific papers in impressive quantity, a temptation to superficially arises that only strong characters are able to resist."

Einstein's son-in-law Rudolf Kayser wrote: "Albert's work, though it was not too trying, was still a strain. He was not used to sitting eight hours over official duties, which he could discharge with the some degree of faithfulness in three or four. He was much too young and too high -strung to perform his duties as slowly as the others. He soon discovered that he could find time to devote to his own scientific studies if he did his work in less time. But discretion was necessary, for though authorities may find slow work satisfactory, the s aving of time for personal profit is officially forbidden. Worried, Einstein saw to it that the small sheets of paper on which he wrote and figured vanished into his desk -drawer as soon as he heard footsteps approaching behind his door."

While working at the Patent Office he completed an astonishing range of publication in theoretical physics. He had to do a lot of outside reading and analysis to keep up with modern physics. He worked in his spare time even during office hours as described by his son -in-low above. Einstein did not have the benefit of close contact with either the scientific literature or fellow scientists. In 1905 Einstein published four papers that changed the face of physics. These papers were to direct the progress of physics during the 20th century. Einstein achieved all this working alone in the backroom of his small apartment in Bern. Perhaps the only period in the entire history of physics comparable to this one is Isaac Newton's stay at Woolsthrope during 1665-66. The four papers published by Einstein in 1905 were:

1. "On the Motion of Small Particles Suspended in a Stationary Liquid According to the Molecular Kinetic Theory of Heat."

2. "On a Heuristic Point of View about the Creation and Conversion of Light."

3. "On the Electrodynamics of Moving Bodies."

4. "Does the Inertia of a Body Depend on its Energy Content?"

By seeing the titles of the papers a layperson would have no clue about their contents. Einstein's first paper, which he sent for publication in March 1905, w as on Brownian motion, a phenomenon first described by Robert Brown in 1828. Einstein derived a formula for the average displacement of particles in suspension, based on the idea that a tiny particle in a fluid being constantly bombarded by surrounding molecules dart around in an erratic movement. Jean Perrin confirmed Einstein's formula in 1908. It represented the first direct evidence for the existence of atoms and molecules of definite sizes and thus he put an end to a millennia -old debate on the fundamental nature of chemical elements.

The second paper was on photoelectric effect. In this paper he gave a new understanding of light. Einstein proposed that light could act as though it consisted of discrete, independent particles of energy, in some ways like particles of a gas. It may be noted that Max Planck had earlier suggested discreteness in energy. Einstein showed that light quanta or the particles of energy could explain many phenomena studied by experimental physics, for example ejection of elec trons from metals by light. Einstein's theory of light formed the basis for much of quantum mechanics.

In the third paper Einstein first time introduced the concept of theory of relativity. It was called 'special' theory of relativity because the theory is restricted to certain special circumstances like bodies at rest or moving with uniform relative velocities. It should be noted that the special theory of relativity does not state that everything in the universe is relative. It stated that time and space (which were thought to be absolute) are relative and the speed of light is absolute. The special theory of relativity had a number of seemingly unusual consequences:

i. The length of a body along its direction of motion decreases with increasing velocity.
ii. The mass increases as the velocity increases. And at the speed of light the mass of a body becomes infinite.
iii. Time slows down for a moving body.

In his fourth paper Einstein reported a remarkable consequences of his special theory of relativity—if a given body emits a certain amount of energy, then the mass of that body must decrease by a proportionate amount. Einstein concluded that if a body gives off energy (E) in the form of radiation, its mass (m) diminishes by E/c^2, where c is the velocity of light. He thus derived the equation $E=mc^2$, which unifies the concepts of matter and energy. It is certainly the best-known equation of all time. This equation accounts for the thermonuclear processes that empower the stars and it also accounts for the explosive power of the atomic bomb.

Even after publishing such papers having far reaching implications, Einstein did not get an academic appointment easily. In 1907, Einstein applied for a position of a Privatdozent, an untrained lecturer, at Berne University. A Privatdozen, however, was an official member of university who could give lectures on a subject of his choice, charging students a fee to attend. Einstein's application was turned down. It is said that one of the reasons for turning down his application was that the head of the department of physics of the Berne University termed Einstein's papers on special theory of relativity as 'incomprehensible'. The next year he finally got a position of a privatedozent. But Einstein could not afford to resign from the patent office, as his position at the University did not carry any regular salary. His first lectures as a member of the university delivered in the winter of 1908/9 were not well-attended. However, within a short time Einstein's work on relativity was widely recognized to be original and profound. And then there was no dearth of important academic appointments.

After two years of publication of his special theory of relativity, Einstein started thinking of extending this theory to frames of reference, which are being accelerated with respect to one another. By doing this restrictions imposed on the special theory of relativity would be removed. Einstein realized that on certain assumptions, accelerated motion could be incorporated into his new, general theory of relativity. The main consequences of the general theory of relativity are:

i. Gravity and inertia are two different words of the same thing.
ii. While thinking about space, four dimensions must be considered —length, width, height, and time. Every event that takes place in the universe is an event occurring in four-dimensional world of space and time.
iii. Space-time is curved or warped by the presence of large masses like the sun.
iv. Light would bend as it passes a large body like the Sun. Einstein had predicted in 1911 that starlight just grazing the Sun should be deflected by 1.7 minute of arca During a total solar eclipse of the Sun, Eddington measured this and the deflection measured by him was 1.61 minute of arca

In 1919, when a student asked Einstein what would happen if the general theory of relativity was not validated by experimental measurement, Einstein replied: "I would have felt sorry of the dear Lord, because the theory is correct." Early in the twenties, Einstein started working on the unified field theory, which engaged his attention till the very end.

Einstein was awarded Nobel Prize in 1922. Interestingly he was given Nobel Prize for his contribution to mathematical physics and particularly for his discovery of the photoelectric effect. Einstein did not attend the award giving ceremony as he was on voyage to Japan. He did not mention it in his dairy or in his letters to friends. It is said that he even forgot to include it on a form listing honors he had received. However, it is interesting to note that when he divorced his first wife, Mileva, he had promised her the Nobel Prize money as alimony.

Einstein was not a mere pure abstract thinker. He tried to visualize the physical universe in concrete images. To quote Einstein: "The words or the language, as they are written or spoken, do not seem to play role in my mechanism of thought. The physical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined. The above-mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously only in a secondary stage, when the mentioned associative play is sufficiently established and can be reproduced at will."

One common myth about Einstein is that he played a prominent role in making the atom bomb. In fact many consider Einstein as the father of the atom bomb. There are two apparent reasons for this kind of belief. First people think that his famous equation $E=mc^2$ has something to do with the atom bomb. Second Einstein wrote a letter to the US President Roosevelt. But the truth is that Einstein had no direct role in the atom bomb project. Explaining his role Einstein wrote:

"My part in producing the atomic bomb consisted in a single act: I signed a letter to President Roosevelt pressing the need for experiments on a lar ge scale in order to explore the possibilities for the production of an atomic bomb. I was fully aware of the terrible danger to mankind in case this attempt succeeded. But the likelihood that the German were working on the same problem with the chance of succeeding forced me to this step. I could do nothing else, although I have always been a convinced pacifist. To my mind, to kill in war is not a whit better than to commit ordinary murder. As long, however, are nations are not resolved to abolish war through common action and to solve their conflicts and protect their interests by peaceful decision on a legal basis, they feel compelled to prepare for war. They feel obliged to prepare all possible means, even the most detestable ones, so as not to be left behind in the general armament race."

Einstein worked for the world peace. He took up many social issues. But at the same time he did not feel strongly for direct contact with other human beings or communities. He built his inner equilibrium not upon the foundation of personal relationships but upon the foundation of his quest for understanding the laws of Nature. He once said: "My passionate sense of social justice and social responsibility has always contrasted oddly with my pronounced lack of need for direct contact with other human beings and human communities. I am truly a "lone traveller" and have never belonged to my country, my home, my friends or even my immediate family with my whole heart; in the face of all these ties, I have never lost a sense of distance and a need for solitude – feelings which increase with the years. One becomes sharply aware, but without regret, of the limits of mutual understanding and consonance with other people. No doubt, such a person loses some of his innocence and unconcern; on the other hand, he is largely independent of the opinions, habits, and judgement of his fellows and avoids the temptation to build his inner equilibrium upon such insecure foundations".

Einstein studied philosophy in great detail. He was fully convinced that science, mathematics and technology not only needed to be balanced with philosophy, ethics, spirituality, and the arts, but they were merely "different branches of the same tree." Einstein said: " All religions, arts and sciences are directed toward ennobling man's life, ennobling it from the sphere of mere physical existence and leading the individual toward freedom." Further according Einstein: "Both churches and universities—insofar as they live up to their true function –serve the ennoblement of the individual. They seek to fulfill this great task by spreading moral and cultural understanding, renouncing the use of brute force." Einstein was deeply concerned with the way education is imparted in schools. He was of the opinion that a sch ool's main goal always be to produce individuals who are "harmonious personalities", not specialists. He said: "… I want to oppose the idea that the school has to teach directly that special knowledge and those accomplishments, which one has to use later directly in life. The demands of life are much to manifold to let such a specialized training in school appear possible. Apart from that, it seems to me, moreover, objectionable to treat the individual like a dead tool. The school should always have as it s aim that the young person leave it as a harmoniums personality, not as a specialist. This in my opinion is true in a certain sense even for technical schools, whose students will devote themselves to a quite definite profession. The development of genera l ability for independent thinking and judgment should always be placed foremost, not the acquisition of special knowledge. If a person masters the fundamentals of his subject and has learned to think and work independently, he will surely find his way and besides will be better able to adapt himself to progress and changes than the person whose training principally consists in acquiring of detailed knowledge."

In 1940 Einstein become a citizen of the United States but he retained his Swiss citizenship. In 1994 he prepared a hand-written various of his 1905 paper an special theory of relativity and put it an action for contributing to the war effort. It could raise six million US dollar. The manuscript subsequently found its place in the US Laboratory of congress. In 1952 Einstein was offered the Post of the President of Israel. He was to become the second president of Israel but he declined the offer.

Einstein died on 18 April 1955. He was cremated at Trenton, New Jersey. In his last letter, which he wrote to Bertrand Russel, one week before his death, Einstein agreed that his name should go an a manifesto urging all nations to give up nuclear weapons. He worked till the very end. Abraham Pais, who has written a scientific biography of Einstein, records that the day before Einstein died, he was studying the most recent pages of his calculations on the unified field theory.

We would like to end this article by quoting what Einstein had to say to school students: "Bear in mind that the wonderful things you learn in your schools are the work of many generations, produced by enthusiastic effort and infinite labour in every country of the world. All this is put into your hands as your inheritance in order that you may receive it, honour it, add to it, and one day faithfully hand it on to your children…If you always keep that in mind you will find a meaning in life and work and acquire the right attitude toward other nations and ages."

Arthur Stanley Eddington
Who Pioneered the Study of Internal Structure of Stars

I believe there are 15 747 724 136 275 002 577 605 653 961 181 555 468 044 717 914 527 116 709 566 231 425 076 185 631 031 296 (136×2256) protons in the universe and the same number of electrons.

Eddington in Tarner lecture (1938)

"Eddington's work has opened up the interior of the stars to science. The science of astrophysics, i.e., the study of the inner as well as the outer nature of the stars, t akes increasing precedence of astronomical investigation. Its latest development is so intimately connected with modern astrophysical problems that it can hardly be treated in adequate manner as a piece of history."

A. Pannekoek in A History of Astronomy (1989)

"Eddington wrote a number of books for both scientists and laymen. His more popular books, including *The Expanding Universe* (1933), were widely read, went through many editions, and opened new worlds to many enquiring minds of the inter-war years. It was through Eddington that Einstein's general theory of relativity reached the English speaking world."

A Dictionary of Scientists, Oxford University Press (1999)

Arthur Stanley Eddington was the most distinguished astrophysicist of his time. He pioneered the study of internal structure of stars. He discovered the fundamental role of radiation pressure in the maintenance of stellar equilibrium. He realised that there was a limit to the size of a star. He also explained the mechanism by which energy of a star moves from its inner parts to outer parts. He discovered the mass-luminosity relationship for a star. This relationship shows that the more massive a star the greater its luminosity. The significance of this relationship is that it allows the mass of a star to be determined if its intrinsic brightness is known. This discovery forced a complete revision of contemporary ideas of stellar evolution. He was a foremost supporter of Albert Einstein's theory of relativity. Einstein himself considered Eddington's treatise on relativity published in 1923 to be the best written in any language.

Eddington was a great science populariser. In fact his popular science writings made him a household name in England between the two World Wars. He gave numerous lectures, interviews and radio talks on difficult and abstract subjects like relativity and quantum mechanics and made them understandable to laypersons. Later his lectures were compiled into book forms.

Eddington did not believe that science would be able to provide proof for religious propositions. Though, he argued for a deeply-rooted philosophical harmony between scientific investigations and religious mysticism.

Arthur Stanley Eddington

Eddington is also known for his famous dispute with Subrahmanyan Chandrasekhar, who was then a student of Cambridge University. This incident portrayed Eddington as cruel and dogmatic, a personal trait that was unknown to many of his contemporaries. Perhaps Eddington could not believe that a mathematical theory derived from quantum mechanics was enough to explain the inherent extreme physical situations of degenerate stars.

Summarising the achievements of Eddington, the obituary in *The Times* noted: "He (Eddington) was a gifted astronomer whose original theories and powers of mathematical analysis took his science a long way forward; he was a brilliant expositor of physics and astronomy, able to communicate the most difficult conceptions in the simplest and most fascinating language; and he was an able interpreter to philosophers of the significance of the latest scientific discoveries."

Eddington was born on 28 December 1882 in Kendal, England. His parents Arthur Henry Eddington and Sara n Ann Eddington, were Quakers (members of the Society of Friends, a Christian denomination founded in England around 1650 by Georges Fox). His father taught at a Quaker training college in Lanchashire before he moved Stramongate School at Kendal as its Hea dmaster. It may be noted that English chemist and physicist John Dalton (1766 -1844) taught at Stramongate School. After Eddington's father's death in 1884 the family moved to Weston - super-Mare.

After spending three years in a preparatory school, Eddingt on entered the Brynmelyn School. In his school he proved to be an exceptionally brilliant student, particularly in mathematics and English literature. Based on his outstanding performance he was given a scholarship for studying at Owens College of Manchester University, where after studying the general course for a year he turned to physics. During his college days he was greatly influenced by Horace Lamb (1849-1934), who is most known for his work on fluid mechanics, Arthur Schuster (1854-1934), and John William Graham, a Quaker mathematician.

In 1902, Eddington graduated with a BSc in physics with a First Class Honours. Based on his performance he was given a scholarship, which enabled him to study at Trinity College, University of Cambridge. After obta ining a BA degree in 1905 he started doing research on thermionic emission at the Cavendish Laboratory. His progress in research was not satisfactory. He started teaching mathematics to first-year engineering students but he did not enjoy it. Fortunately he did not continue long at the Cavendish Laboratory. He left Cambridge in 1906 to join the Royal Greenwich Observatory as Chief Assistant to the Astronomer Royal. Here he got involved with a project that had started in 1900 and called for the analysis of photographic plates of Eros taken over the period of a year. Eddington's task was to determine an accurate solar parallax from these photographic plates. To do that, he developed a new statistical method of analysis of two star-drifts. His essay on the pro per motions of stars won him the Smith's Prize in 1907. The same year he became a Fellow of the Trinity College.

In early 1913, Eddington became the Plumian Professor of Astronomy and Experimental Philosophy at Cambridge University. He succeeded George D arwin, son of Charles Darwin (1809-1882), the originator of the theory of evolution by natural selection. George Darwin had died in December 1912. In 1914 Eddington became the Director of the Cambridge University Observatory.

As mentioned earlier, Edd ington pioneered work on the internal structure of stars. His works in this field were compiled in his classic work, *The Internal*

Constitution of Stars. Radiative equilibrium formed the central theme of Eddington's work. In 1905, German astronomer Karl Schwarzschild (1873-1916) proposed a theory of the Sun's atmosphere. It was based on the principle of radiative equilibrium, which assumed that temperature at any point is the result of the radiation it received from all directions as the chief mechanism of heat transfer at such high temperatures. Schwarzschild's theory made the cloud theory of the photosphere irrelevant, as temperature and density increased towards the centre. Before Eddington, attempts were made to account for the internal structure of stars. For example, Swiss-born German physicist A. Ritter carried out theoretical investigations during 1878-83 for obtaining results about the internal structure of the Sun. However, when Ritter was working, the concept of radiation was unknown to physicists and so Ritter's approach lacked the right basis. In 1907, Swiss astrophysicist Robert Emden (1862-1940) developed a general numerical theory of gaseous sphere in space, applicable to Sun and stars. But Emden also had no idea on any other mechanism of heat transfer other than convection and conduction. So he also failed to make any breakthrough. Eddington in his attempt to understand the internal structure of stars not only extended Schwarzschild's earlier work on radiative equilibrium but also made use numerical computations of Emden. In doing so Eddington made a real breakthrough. Now it was possible to calculate the physical conditions (temperature, density, pressure, ionisation and coefficient of absorption) at any given point of the interior of a star as a function of its distance from the centre.

In Eddington's interpretation three new points of view were introduced. First, the radiative pressure can carry a significant part of the weight of the matter in the stars. Second, the high degree of ionisation is caused by highly intense radiations. Entire electron shells of atoms are torn apart and a situation is reached where electrons are either torn away or caught up in recombination. The energy of the interior of the star is transported to the outside through an endless process of alternate absorption and emission of radiation. The third point in Eddington's interpretation was the production of energy in the interior of the star, which maintains the outward flow of energy from the centre.

Eddington's theoretical investigations demonstrated that energy radiated outward by a spherical layer of a star must equate the energy produced in the interior of the star. But then one must know where this energy is produced, by what matter and under what conditions. In Eddington's time nothing was known about these things. Eddington went ahead by assuming two extreme suppositions—energy is produced uniformly throughout the entire mass, or it is produced in the centre only. Eddington found that results obtained by the two extreme suppositions did not differ significantly. Einstein's principle of relativity indicated a possible source of newly generated energy. Einstein showed by his famous equation $E = mc^2$, that mass and energy were equivalent. This meant that 1 g of mass was equivalent to 9×10^{20} ergs of energy. So one could assume that new energy production in a radiating star would be possible by annihilating mass and in this process the mass of the star would gradually decrease.

Eddington in his classic work *Internal Constitution of Stars* put forward two possible mechanisms for production of energy. One, could be direct annihilation of matter by the coalescence and mutual destruction of two oppositely charged particles namely proton and electron where charges woul d disappear and mass would be transformed into high-frequency radiation. The other could be transformation of hydrogen into helium. When four hydrogen nuclei and two electrons combine to form an atom of helium some amount of mass is lost and which is converted into energy. Now the question was which one of these two processes actually took place. This question was later answered by German -born American physicist Hans Albrecht Bethe (1906 -2005), who observed that stellar energy production resulted from the fusion of four hydrogen atoms. It is not a direct fusion but it happens through the so -called carbon-nitrogen cycle, a cycle of six consecutive nuclear reactions that lead to the formation of a helium nucleus from four protons.

From Eddington's work on the internal constitution of stars emerged the mass-luminosity relationship, according to which the luminosity of a star is entirely determined by its mass. Earlier, while enumerating masses of binary stars, astronomers had observed that stars of simila r mass but of different spectral class had almost the same luminosity. It was thought to be causal coincidence. But Eddington showed the relationship is of general applicability.

Eddington was an enthusiastic supporter of the idea of an expanding universe. But he did not believe that an expanding universe would require a beginning, which is now part of the accepted theory of the origin of universe known as Big Bang theory. For Eddington such idea was "too unaesthetically abrupt."

During the last 20 years of his life Eddington mostly worked on a problem what he called "fundamental theory" for unifying the quantum theory, relativity and gravitation. He proposed that the fundamental constants of science, such as the mass of the proton and charge of the electr on were a natural and complete specification for constructing a universe. Eddington did not succeed in his attempt. His book entitled *Fundamental Theory* was published posthumously in 1948. His ideas were later abandoned by scientists.

Eddington wrote a number of books which included: *Stellar Movements and the Structure of the Universe* (1914), *Space, Time and Gravitation: An Outline of the General Theory of Relativity* (1918), *The Mathematical Theory of Relativity* (1923), *Stars and Atoms* (1926), *The Internal Constitution of Stars* (1926), *Science and the Unseen World* (1929), *The Expanding Universe : Astronomy's Great Debate, 1900 -1931* (1930), *Why I Believe in God: Science and Religion as Scientist Sees It* (1930), *New Pathways in Science* (1935), *Relativity Theory of Protons and Electrons* (1936), *Philosophy of Physical Science* (1939), *The Domain of Physical Science* (1925), and *Fundamental Theory* (1948).

Eddington received a number of awards including the Smith's Prize (1907), Bruce Medal of Astronomical Society of the Pacific (1924), Henry Draper Medal (1924), the Gold Medal of the Royal Astronomical Society (1924), and Royal Medal of the Royal Society (1928). He was knighted in 1930. He received the Order of Merit in 1938. He was the President of the Royal Astronomical Society from 1921 to 1923). He was Fellow of the Royal Society of London, the Royal Society of Edinburgh, the Royal Irish Academy, the National Academy of Sciences, the Russian Academy of Sciences, the Prussian Academy of Sciences and many others. A crater on the Moon and an asteroid (asteroid 2761) are named after him. In the film 'Einstein and Eddington', jointly produced by BBC and HBO, Eddington was portrayed by actor David Tennant.

Eddington died on 22 November 1944 in Cambridge, England. At the time of his death he was the President of the International Astronomical Union.

In 1947, the Royal Astronomical Society of London instituted the Eddington Medal to be awarded for outstanding work on theoretical astronomy. Its first recipient was Belgian astronomer and cosmologist Georges Edouard Abbe Lemaitre (1894-1966), the originator of the idea of 'Big Bang' theory for the origin of the universe. Lemaitre was awarded the Medal in 1953.

Some of the books written on Eddington are: *Eddington: The Most Distiguished Astrophysicist of His Time* by S. Chandrasekhar (Cambridge, 1983); *The Source of Eddington's Philosophy* by H. Dingle (Cambridge, 1954); *The Life of Sir Arthur Stanley Eddington* by A. V. Douglas (Edinburgh-New York, 1956); *Sir Arthur Eddington: Man of Science and Mystic* by L. P. Jacks (Cambridge, 1948); *Eddington's Search for a Fundamental Theory: A Key to the Universe* by CA W. Kilmister (Cambridge, 1994); *Sir Arthur Eddington* by CA W. Kilmister (Oxford, 1966); *Reflections on Philosophy of Sir Arthur Eddington* by A. D. Ritchie (Cambridge, 1948); *From Euclid to Eddington: A Study of Conceptions of the External World* by E. T. Whittaker (1949) and *Philosophy of Science of A. S. Eddington* by J. W. Yolton (The Hague, 1960).

Edwin Powell Hubble
Founder of the Science of Cosmology

"The history of astronomy is a history of receding horizons."

Edwin P. Hubble (Quoted in *To Infinity and Beyond* by E. Maor, 1991)

"He (Hubble) found that spiral nebulae are independent stellar systems and that Andromeda nebula in particular is very similar to our own Milky Way galaxy. In 1929 he announced his discovery that galaxies recede from us with speeds which increase with their distance. This was the phenomenon of the expansion of the universe, the observational basis of modern cosmology. The linear relation between speed of recession and distance is known as Hubble's law."

Chambers Biographical Dictionary (Centenary Edition), 1997

"It is interesting to note that Hubble was always cautious in interpreting Hubble's Law of 1929, which is based on the spectroscopic red shift and Doppler's principle, as meaning that the universe is expanding. Hubble's rather ambiguous writings on this imply that possibly the observed increase in red shift with distance had other causes; and bearing in mind the novel views advanced in cosmology since 1929, he was probably right to be prudent."

The Cambridge Dictionary of Scientists, 2003

Edwin Powell Hubble was one of the leading astronomers of the 20th century. *The Times* obituary rightly noted: "Dr. Hubble's work was outstanding for the power and originality of its method, his observational skill, the objective character of his deductions, and the general brilliance of his results."

Hubble dramatically changed astronomers' understanding of the universe. In Hubble's days most astronomers believed that the universe was synonymous with the Milky Way galaxy, which meant that the entire universe – that is, the planets, the stars and other objects including the fuzzy objects called nebulae seen with the naked eye and the powerful telescopes – was contained within the Milky Way galaxy. However, contrary to the then prevailing belief, Hubble proved that the so-called spiral nebulae were in fact spiral galaxies. Hubble's discovery was as profound as the discovery of the heliocentric solar system, which placed the Sun at the centre of the Solar System. So it is no wonder that Hubble's contribution to science has been compared to the works of epoch-making scientists like Isaac Newton and Galileo Galilei. Today we know that the idea of an expanding universe is fundamental to our understanding of the cosmos. Hubble's work provided the first direct evidence supporting the idea of an expanding universe. It is true that some cosmologists had earlier theoretically predicted the idea of an expanding universe – Willem de Sitter (1872-1934) in 1917, Aleksandr Alexandrovich Friedmann (1888-1925) in 1922, and Georges Edouard Lemaitre (1894-1966) in 1927. However, it was Hubble's work, which persuaded the astronomers to take the idea of expanding universe seriously. Hubble's observations demonstrated for the first time that two fundamental quantities of the universe could be measured – the knowable size and age of the universe. Knowable size of the universe means the distance at which the recession velocity reaches the speed of light and this has been estimated to be about 18 light years. The age of the universe is somewhere between 12 and 15 billion years. Hubble himself estimated the age of the universe as 2 billion years. It is interesting to note that Hubble's original value for the age of the universe was less than the age of the oldest rocks on the Earth measured by radiometric dating. This was certainly a curious anomaly. Hubble also made a major contribution to the study of galactic evolution by producing the first significant classification of galaxies. Hubble's classification of galaxies is widely used today.

Edwin Powell Hubble

Hubble was born on 20 November 1889 in Marshfield, Missouri, USA. His parents were John P. Hubble and Virginia Lee James Hubble. Hubble's father was an agent in a fire insurance firm. His mother was a descendant of the American colonist Myles Standish (ca1584-1656). Edwin was the third of seven children of his parents. He spent his childhood in Missouri, and entered school in 1895. In 1898, Hubble's father was transferred to the Chicago office of his firm and the family followed him. They first stayed at Evaston and then moved to Wheaton, both Chicago suburbs. In 1906, Hubble passed from Wheaton High School and received a scholarship for studying in Chicago University. At the University, Hubble studied mathematics, physics, chemistry and astronomy. To meet his college expenses he tutored and worked in the summer. While studying at Chicago University he worked as assistant to the physicist Robert Andrews Millikan (1868 - 1953). Hubble graduated from Chicago University in 1910 with a BS in mathematics and astronomy. While Hubble did well in his studies in school and college, he did much better in sports. In 1906, he won seven first places and a third place in a single high school track meet. In the same year he also set a state record in high jump. He was also an amateur boxer. Apparently sports promoters tried to persuade Hubble to become a professional boxer. However, Hubble declined such offer. Based on his combined achievements in sports and studies Hubble was awarded the Rhodes scholarship for studying at Oxford University in 1910. Hubble joined the Queen's College at Oxford University. He first studied law and then shifted to Spanish. At Oxford he continued to pursue his athletic interests. He excelled in high jump, broad jump, shot put, and running.

Hubble returned to USA in 1913 and started his career as a high school Spanish teacher and a basketball coach in New Albany High School in Indiana. He also became a member of the Kentucky bar, but never actually practised law. He did not stay long as a schoolteacher. He went back to Chicago University to work at the Yerkes Observatory for doing a PhD in astronomy. He worked under the supervision of Edwin B. Frost, then the Director of the Observatory. He was awarded his PhD degree in 1917. The title of his PhD thesis was "Photographic investigations of faint nebulae". After getting his PhD he was offered a position at the Mount Wilson Observatory by its Director George Ellery Hale. It was Hale who had established the Yerkes Observatory. Hubble could not take the offer to join the Observatory immediately as he had to serve in the First World War. He served in France and rose to the rank of a Major. During the Second World War Hubble worked as chief of exterior ballistics and director of the supersonic wind tunnel at the Ballistic Research Laboratory at Aberdeen Proving Ground in Maryland.

After being discharged from his war duties in 1919, Hubble joined the staff of the Mount Wilson Observatory, near Pasadena, California and worked there till his death, except during the period of the Second World War. At Mount Wilson Observatory, Hubble got the opportunity to use the newly built Hooker Telescope, a 100-inch (254-cm) telescope. It was then the world's largest telescope. For his PhD work Hubble had studied the faint nebulae, the objects that appeared as fuzzy extended images. Hubble believed that while some of these objects were indeed members of the Milky Way galaxy and were clouds of luminous gas and dust, some others – particularly the objects known as spiral nebulae – could be objects that lay beyond the Milky Way galaxy. With the help of the powerful telescope at Mount Wilson Observatory, Hubble produced some of the significant findings of 20th century astronomy.

In 1923, he was able to resolve the outer region of the Andromeda nebula (now called Andromeda galaxy) into "dense swarms of images which in no way differ from those of ordinary stars." Hubble also identified a special type of stars called Cepheids in one of the photographs of the Andromeda nebula. This finding was very important because Henrietta Leavit and Harlow Shapely had earlier shown that Cepheids could be used to measure distance. Making use of their work

Hubble calculated that the distance to the Andromeda nebula was 900,000 light years. The distance found was unexpectedly large. Hubble's results were in direct conflict with the results earlier obtained by the Dutch astronomer Adrian van Maanen. However, Hubble continued with his observations. Based on his observations he published three major papers during the period 1925 - 1929. These papers clearly demonstrated that the spiral nebulae were at enormous distances, well beyond the Milky Way galaxy, and that they were independent systems of stars. Van Maanen, on reexamining his data, found them unsatisfactory and he discarded them in favour of Hubble's results.

Based on his own determination of the distances of 18 galaxies and measurements of radial velocities from the galactic red shifts carried out by Vesto Sliper and Milton Humason, Hubble found that the recessional velocity of the galaxies increased proportionately with their distance. This relation between recessional velocity of a galaxy and its distance came to be known as 'Hubble's law'. Mathematically this observation is put as $v = H_0D$, where v is the velocity, D is the distance, and H_0 is a constant called the 'Hubble constant', the figure that relates the speed of an object's recession to its distance. Hubble constant is measured in units of kilometres per second per mega parsec (1 mega parsec = 1 million parsecs, or 3.08×10^{22} metres). This work of Hubble finally convinced astronomers that the idea of an expanding universe proposed earlier was indeed correct. It should be noted here that Albert Einstein could have proposed the idea of an expanding universe as a natural consequence of his theory of general relativity. Instead he introduced an arbitrary constant in his mathematical equations so that his theory did not predict an expanding universe. Today the constant introduced by Einstein is known as cosmological constant. When Hubble's measurements confirmed that the universe was indeed expanding, Einstein declared that the introduction of the cosmological constant in his equation was the greatest blunder of his life. It was soon realised that the Hubble constant, which could be measured from the mean value of the ratio of the velocity and distance: that is v/D, contained the key to the size, age and future of the universe.

In 1931 Hubble proposed value of Hubble's constant to be 558. Soon it became apparent that there was something wrong in Hubble's measurements. In 1952, Walter Baade announced that the Hubble constant was about 250 and this meant that the Andromeda galaxy was twice as far away as Hubble had originally estimated. In 1956 Allan Sandage, in a paper jointly written with Milton L. Humason and Nick Mayall, calculated the value of Hubble constant as 180. Sandage further revised this value and by the early 1960s his best estimate of Hubble constant was 75. Sandage was proved right when in the 1990s data sent by the Hubble Space Telescope confirmed that the value of Hubble constant is between 65 and 77. According to the Big Bang Theory, the Hubble constant varies with time and in that sense it is not truly a constant. It is more appropriately called the Hubble parameter.

Hubble developed a classification system for galaxies based on their visual appearance. Today the Hubble classification is widely used. The classification starts with round elliptical galaxies having no disks. Increasing flattening of a galaxy denoted by a number derived from $10(a-b)/a$, where a and b are the major and minor axes as measured in the sky. The galaxy with a number 7 (E7 galaxy) is the flattest galaxy. After E7 an apparent clear disk is seen in the lenticular or S 0 galaxies. The classification then branches into two parallel sequences of disk galaxies showing spiral galaxies – ordinary spirals and barred spirals. The diagram developed to show different types of galaxy in Hubble's classification is called 'tuning-fork' diagram. It is so named because it resembled a tuning fork. The 'handle' of the fork consists of elliptical galaxies arranged in order of increasing flattening. One of the parallel prongs consists of ordinary spiral galaxies from type *a* (near the handle) to type *d* (tip of the prong). The other prong consists of the barred spiral galaxies in the same order.

Hubble took interest in collecting antique books on history of science. He was a Trustee of the Hutington Library in San Marino, California (1938-1953). His personal interest also included fishing. He fished in Scotland and the Colorado Rockies. He frequently interacted with famous movie stars and literary figures of his time including English film actor and director Charlie Myles Standish Chaplin (1889-1977), Swedish-born US film actress Greta Garbo (1905-90), English novelist and essayist Aldous Leonard Huxley (1894-1963), US novelist Christopher William Bradshaw Isherwood (1904-86) and US writer Anita Loos (1893-1981).

The awards received by Hubble include the Catherine Wolfe Bruce Medal (1938), the highest honour of the Astronomical Society of the Pacific, and the Gold Medal of the Royal Astronomical Society (1940). He was a Fellow of the US National Academy of Sciences; the Royal Astronomical Society of London; the American Astronomical Society, and the American Philosophical Society. Hubble delivered many lectures, the most notable being the course of lectures delivered in Oxford under the Rhodes Trust. The lectures delivered at Oxford were later brought out in book form under the title *The Observational Approach to Cosmology*. The 2.4-m aperture Space Telescope, launched in April 1990 by the space shuttle *Discovery*, was named Hubble Space Telescope in Hubble's honour. It orbits at an altitude of about 600 km. The Hubble Space Telescope has shown that the universe is not only expanding, as Hubble had discovered, but the expansion is accelerating. It is believed that a mysterious force called dark energy is behind this acceleration.

A crater and an asteroid on the Moon have been named after Hubble. An award called the Edwin P. Hubble Medal of Initiative has been instituted by the city of Marshfield, Hubble's birthplace. Hubble died on 28 September 1953 at San Marino, California.

Meghnad Saha

Pioneer of Astrophysics

"The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it a nd much of the subsequent work has the character of refinements of Saha's ideas."

S. Rosseland in Theoretical Astrophysics (Oxford University Press, 1939)

"Scientists are often accused of living in the "Ivory Tower" and not troubling their mind with realities and apart from my association with political movements in my juvenile years, I had lived in ivory tower up to 1930. But science and technology are as important for administration nowadays as law and order. I have gradually glided into politics because I wanted to be of some use to the country in my own humble way."

Meghnad Saha

"He (Saha) was extremely simple, almost austere, in his habits and personal needs. Outwardly, he sometimes gave an impression of being remote, matter of fact, and even harsh, but once the outer shell was broken, one invariably found in him a person of extreme warmth, deep humanity, sympathy and understanding; and though almost altogether unmindful of his own personal comforts, he was extremely solicitous in the case of others. It was not in his nature to placate others. He was a man of undaunted spirit, resolute determination, untiring energy and dedication."

D. S. Kothari in Biographical Memoirs of Fellows of the National Institute of Sciences of India, Vol .2, New Delhi, 1970

'Meghnad Saha's place in the history of astrophysics and in the history of modern science in India is unique', wrote Subrahmanyan Chandrasekhar. Saha's theory of thermal ionisation, which explained the origin of stellar spectra, was one of India's most important contributions to world science during the 20th century. It was an epoch-making discovery. Arthur Stanley Eddington (1882 -1944), while writing on stars in the *Encyclopaedia Britannica*, described Saha's theory of thermal ionisaiton as the twelfth most important landmark in the history of astronomy since the first variable star (Mira Ceti) discovered by David Fabricius (1564 -1617) in 1596. Besides his epoch-making discovery Saha made important contributions in different branches of physics. Saha (jointly with B.N. Srivastava) wrote the renowned textbook, entitled, *Treatise on Heat*, which was originally published in 1931 under the title, *A Text Book on Heat*. It was Saha who first started the teaching and training in nuclear physics in the country. The first cyclotron in the country was built with Saha's initiatives. Saha was a great institution builder. Among the institutions that he built were: National Academy of Sciences, India, at Allahabad; Indian Physical Society, Kolkata; National Institution of Sciences of India (which was later renamed Indian National Science Academy), New Delhi; Indian Science

News Association, Kolkata; and Saha Institute of Nuclear Physics, Kolkata. Saha was an active member of the National Planning Committee constituted by the Indian National Congress in 1938 with Jawaharlal Nehru as its Chairman. He was the Chairman of the Indian Calendar Reform Committee constituted by the Council of Scientific and Industrial Research in 1952. He was an elected Independent Member of the Indian Parliament. He advocated large-scale industrialisation for social development.

Meghnad Saha

Meghnad Saha was born on October 06, 1893 in the village of Seoratali in the Dhaka (then Dacca) district (now in Bangladesh) of undivided India. He was the fifth child of his parents, Jagannath Saha and Bhubaneswari Devi His father, Jagannath, was a petty shopkeeper. Given their social and economic background his parents had neither the means nor the inclination for educating their children beyond the primary education. Saha's elder brother Jainath, after failing to pass the matriculation examination, started working in a jute company on a monthly salary of Rs.20. His second brother had to discontinue his school education in order to help his father in running the shop. At the age of seven Saha joined the village primary school and from the very beginning he demonstrated an unusual aptitude for learning.

After the completion of his primary education there was no certainty that his education would continue further. Their parents would have preferred to have him work in the family's grocery shop. In any case they did not see any use of further education in running the shop. Moreover there was no middle school nearer to his village. The nearest middle school was at Simulia, which was 10 km away from his village. Saha's parents did not have the means to take care of the expenses of his boarding and lodging. At this stage his elder brother Jainath came in his rescue by locating a sponsor in Ananta Kumar Das, a local doctor. The kind-hearted doctor agreed to provide Saha free boarding and lodging in his house provided Saha washed his own plates (a condition that reflected the prevailing rigid caste system) and attend minor household works including the taking care of the cow. Saha readily accepted all the conditions as he had a strong urge to continue his studies further. Every weekend he used to visit his village. When the village became flooded he would row all the way, otherwise he would simply walk down. Saha completed his middle school by topping the list of successful candidates in the entire district of Dhaka. As a result he secured a scholarship of Rs.4 per month. In 1905 Saha came to Dhaka, where he joined the Collegiate School, a government school. His elder brother sent him a monthly allowance of Rs.5, it was indeed a great sacrifice on his part, as his total monthly salary was Rs.20. The Purba Banga Baisya Samiti gave another Rs.2 per month. So Saha had Rs.11 to manage his food, lodging and other expenses.

There were widespread political disturbances in Bengal in 1905. In this year Lord Curzon, the then Viceroy of British India, had decided to partition Bengal. Saha, like many others, was affected by this political upheaval. He, along with some other students, were rusticated from the Collegiate School, because of their participation in the demonstration against the visit of the Bengal Governor, Sir Bamfylde Fuller, to the school. It is not certain whether Saha actually participated in the demonstration or not, because there is another version of the story. According to this version, Saha did not take part in the demonstration. On that fateful day as usual he had gone to school barefooted. For Saha it was a usual practice, as he had not enough money to buy shoes. But on that day the authorities took it as a deliberate insult directed against the Governor. Besides being rusticated Saha was deprived of his scholarship. Fortunately a private school, named Kishori Lal Jubilee School, accepted Saha with a free studentship and a stipend. In 1909 Saha passed the Entrance Examination from Kishori Lal Jubilee School standing first amongst all the candidates from erstwhile East Bengal.

In school Saha's favourite subject was mathematics and he also liked history. He was particularly fond of reading Todd's *Rajasthan*. He used to be fascinated by the heroic tales of Rajput and Maratha warriors. Among his favourite books were Rabindranath Tagore's *Katha O Kahini*, which glorifies the values of the Rajput and Maratha warriors and Madhusudan Dutt's epic poem *Meghnad Badh*. During his school days Saha also attended the free Bible classes conducted by the Dhaka Baptist Mission. He stood first in one of the competitive examinations of Bible conducted by the Mission and received a cash prize of Rs.100.

After passing the Intermediate Examination of the Calcutta University in 1911 from the Dhaka College, Dhaka, Saha joined the Presidency College at Kolkata (then Calcutta). Among his classmates was Satyendranath Bose, of the Bose-Einstein Statistics fame. Prasanta Chandra Mohalanobis, the founder of the Indian Statistical Institute, was his senior by a year. His teachers included Prafulla Chandra Ray in chemistry and Jagadis Chandra Bose in physics. Saha passed his BSc Examination with Honours in Mathematics in 1913 and MSc (Applied

Mathematics) Examination in 1915. Saha stood second in order of merit in both the examinations. The first position in both cases w ent to S.N. Bose.

Saha was appointed lecturer in the Department of Applied Mathematics in 1916 in the University College of Science. The foundation stone of the University College of Science was laid down on 27 March 1914 just four days before Asutosh Mookerjee laid down his office as Vice Chancellor of the University. It may be noted here that Mookerjee who was the Vice Chancellor of the Calcutta University during 1906-14 and then again during 1921-23. Both Saha and S.N. Bose, who also joined the Department as a lecturer, got themselves transferred to the Physics Department, where a year later CAV. Raman joined as Palit Professor of Physics. After joining the physics department Saha started giving lectures to the post-graduate classes on topics like hydrostatics, the figure of the Earth, spectroscopy and thermodynamics. For teaching physics to the postgraduate classes, Saha had to learn it himself first, as he studied physics only in the undergraduate classes. It was a great challenge indeed. Besides teaching Saha also started doing research. It was not an easy task. In those days there was no experimental laboratory in the Department of Physics of the University College of Science. He had only one 'research facility' that is the well-equipped Library of the Presidency College. Saha had no guide for supervising his research work. He totally depended on his knowledge acquired from private studies. During this period Saha did not have enough money to pay for publication of his research paper in foreign journal. To quote Saha :

"By the end of 1917, I had written a long essay on `Selective Radiation Pressure' elaborating on theory of the role of radiation pressure' acting on the atom selectively and compensating the action of gravity on solar atoms. This paper was sent to the Astrophysical Journal for publication, but the editors replied that as the paper was rather long, it could be published only if I were willing to bear a part of the printing costs, which ran to three figures in dollars. Much as I would have lik ed to do so, it was not possible me to find out so much money as my salary was small and I had to maintain my old parents and a younger brother who was studying within this salary. So I wrote to the editors of the Astrophysical Journal expressing my inability to pay the costs of printing, but never heard anything more about the publication of this paper nor was it returned to me. Years afterwards, in 1936, when I visited Yerkes Observatory, Dr. Morgan showed me the manuscript which was still being kept there. I got a short note published in the Astrophysical Journal, Vol. 50,220 (1919) and submitted a duplicate of the original article on `selective radiation pressure and problem of solar atmosphere' (*Journal of the Department of Science*, Calcutta University, 1919) sometime afterwards for publication in our own university journal which had no circulation worth mentioning. I am mentioning these facts because I might claim to be the originator of the Theory of Selective Radiation Pressure, though an account of above discouraging circumstances, I did not pursue the idea to develop it. E.A. Milne apparently read a note of mine in

Nature 107, 489 (1921) because in his first paper on the subject `Astrophysical Determination of Average of an Excited Calcium Atom', in *Month. Not. R. Ast. Soca*, Vol.84, he mentioned my contribution in a footnote, though nobody appears to have noticed. His exact words are: `These Paragraphs develop ideas originally put forward by Saha'."

Initially Saha worked on diverse topics as reflected from the titles of his published research papers as indicated below:

- "On Maxwell's Stresses" (*Philosophical Magazine*, 1917), this paper was based on his studies of the electromagnetic theory of radiation;
- "On the Limit of Interference in the Fabry-Perot Interferometer" (*Physical Review*, 1917),
- "On A New Theorem in Elasticity" (Journal of the Asiatic Society, Bengal, 1918),
- "On the Dynamics of the Electron" (*Phil. Mag*. 1918)
- "On the Pressure of Light" (*Journal of the Asiatic Society*, Bengal, 1928)
- 6. "On the Influence of Finite Volume of Molecules on the Equation of State" (*Phil. Mag* , 1918). This paper was jointly written with S.N. Bose.
- 7. "On the Mechanical and Electro-dynamical Properties of the Electron" (*Physical Review,* 1919);
- 8. "On the Radiation Pressure and the Quantum Theory" (*Astrophysical Journal*, 1919);
- 9. "On the Fundamental Law of Electrical Action" (*Phil. Mag.* 1919).

Based on his above work Saha submitted his thesis for the degree of Doctor of Science of the Calcutta University in 1918. He was awarded the degree in 1919. The same year he was awarded the *Premchand Roychand Scholarship* for his dissertation on the 'Harvard Classification of Stellar Spectra'.

While working on diverse topics he was also preparing for his main work in astrophysics. For this work he profited from reading Agnes Clarke's two popular books on astronomy and astrophysics. He had also read Planck's Thermodynamics and Nernst's Das Neue Warmestaz and research papers of Niels Bohr and Arnold Sommerfeld on the quantum theory of atom. He published four papers on his astrophysical research in the first six months of 1920 in the Philosophical Magazine viz. "Ionisation of the Solar Chromosphere" (March 04, 1920), "On the Harvard Classification of Stars" (May 1920), "On Elements in the Sun" (22 May 1920) and "On the Problems of Temperature-Radiation of Gases" (25 May 1920). In these papers Saha formulated his Theory of Thermal Ionisation. His thesis on the 'Origin of Lines in Stellar Spectra' won him the Griffith Prize of the Calcutta University in 1920.

It is interesting to note here that Saha, jointly with S.N. Bose prepared an English translation of Einstein's papers on theory of relativity and got it published in a book form. Incidentally their translation of Einstein's wo rk on the theory of relativity happens to be the first on record. Chandrasekhar wrote : "…In 1919, only three years, after the founding of the general theory of relativity, Saha and S.N. Bose should have taken the time and the effort to translate and publi sh Einstein's papers which have since become epochal. At a celebration of the Einstein centennial at Princeton University, three years ago, reference was made to a Japanese translation of Einstein's papers as the first on record and I was glad that I was able to correct the impression. A Xerox copy of the Saha -Bose translation is now in the Einstein Achieves at Princeton".

The Premchand Roychand Scholarship of the Calcutta University awarded in 1919 enabled Saha to spend about two years in Europe. He first went to London where he spent about five months in the laboratory of Alfred Fowler (1868 -1940). From London he moved to Berlin where he worked in Walther Nernst's Laboratory.

For a long time after Saha published his work on thermal ionization theory, the European scientific community used to believe that Saha did this work under the supervision of Albert Fowler. For example in 1972 while commenting on Saha's paper on the ionization in the solar chromosphere, A.J. Meadows in his biography of Sir Norman Lockyer wrote: "Shortly after Lockyer's death, an Indian physicist M.N. Saha, came to work under Fowler at Imperial College. The paper he wrote during this visit … showed how the spectra of stars could be understood in terms of the new quantum theory of the atom together with the dissociation hypothesis. After some initial opposition, his results were rapidly accepted. The theory showed that both temperature and pressure affected the dissociation of atoms in stellar atmospheres. So both Lockyer and his oppone nts had been partly right. It is only fair to Lockyer to add that the influence of temperature on stellar spectra is much more marked than of pressure."

Medows' observation was far from truth. To quote D. S. Kothari: "It is pertinent to remark that the io nization theory was formulated by Saha working by himself in Calcutta, and the paper quoted above was communicated by him from Calcutta to the Philosophical Magazine - incorrect statements to the contrary have sometimes been made. (Saha's first visit to Eu rope was made a couple of months later.) Further papers soon followed. It is not too much to say that the theory of thermal ionization introduced a new epoch in astrophysics by providing for the first time, on the basis of simple thermodynamic consideratio n and elementary concepts of the quantum theory, a straight forward interpretation of the different classes of stellar spectra in terms of the physical condition (temperature and to a lesser extent pressure) prevailing in the stellar atmospheres."

To describe how Saha got the idea of working on this topic and when he completed his work we quote Saha rather extensively: “It was while pondering over the problems of astrophysics, and teaching thermodynamics and spectroscopy to the MSc classes that the theory of thermal ionization took a definite shape in my mind in 1919. I was a regular reader of German Journals, which had just started coming after four years of first world war, and in course of these studies, I came across a paper by J. Eggert in the Physikal ische zeitschrifts (p.573) Deca 1919, “ Uber den Dissociationzustand der Fixterngase” in which he applied Nernst’s Heat Theorem to explain the high ionization in stars due to high temperatures, postulated by Eddington in course of his studies on stellar st ructure.

Eggert, who was a pupil of Nernst and was at the time his assistant, had given a formula for thermal ionization, but it is rather strange that he missed the significance of ionization potential of atoms. Importance of which was apparent from the theoretical work of Bohr, and practical work of Franck and Hertz which was attracting a good deal of attention in those days…Eggert used Sackur’s formula of the chemical constant for calculating that of the electron, but in trying to account for multiple ionization of iron atoms in the interior of stars on this basis, he used very artificial values of ionization potential.

While reading Eggert’s paper I saw at once the importance of introducing the value of ionization potential in the formula of Eggert, for calculating accurately the ionization, single or multiple, of any particular element under any combination of temperature and pressure.

I thus arrived at the formula, which now goes by my name. Owing to my previous acquaintance with chromospheric and stellar problems, I could at once see its application. I prepared in the course of six months of 1919 (February to September) four papers and communicated them for publication in the Philosophical Magazine from India within August to September.” “I had no personal acquaintance with Prof. A. Fowler except that I had read his paper on the spectrum of ionized helium. “On my arrival in England, I saw Prof. Albert Fowler who at first thought that I had come to work for the DSc degree of the London University like other Indian students working under him. But when I explained to him that I wanted to work there only for a short period to obtain verification of my theory, he did not show himself very enthusiastic, but allowed me to read and work in his laboratory. P robably he had not much time to listen to me at the first meeting. This was in November of 1920. If you look at the records of Imperial College, you will find that I never got my name registered for my degree work. In the meantime, my first paper “Ionizati on in the Solar Chromosphere” communicated from India had appeared in *Phil. Mag*, thanks to a personal call, which I made on Mr. Francis, the publisher of the journal. After its publication, Prof. Fowler began to take a more lively interest in my work and i n my views.”

In November 1921 Saha returned to India and joined the University of Calcutta as Khaira Professor of Physics, a new Chair created from the endowment of Kumar Guruprasad Singh of Khaira. But Saha did not stay long in Kolkata. He moved to Allahabad in 1923 as Head of the Department of Physics. Saha's decision to move out of Kolkata was mainly because there were no financial grants for carrying out research. Though Asutosh Mookerjee could create additional chairs out of donations but the Government did not approve his plan for expansion. The then Governor Lord Ronaldshay, while praising the work done in the post-graduate departments of the Calcutta University, said: "In a poor country there are obvious limits to the extent to which such studies can be financed by public funds. The legislature will, I hope, be prepared to make some additional contribution towards the university in the present difficulties. But the legislature itself with extremely exiguous resources is faced with many urgent demands . And under the circumstances it appears to me that the university may have to consider whether it is bound to provide post-graduate teaching on every subject in which it is prepared to examine and confer awards…" Irrespective of Governor's assurance there was no increase in the funds allocated to the Calcutta University.

In 1922, the Government was willing to give an additional grant of two-and-a-half lakh. But the grant was subjected to certain conditions and which were not acceptable to Asutosh Mookerjee. While declining the offer Mookerjee said: "We will not take the money. We shall retrench and we shall live within our means. We shall go from door to door and make the people of Bengal realise their responsibility. Our Post-graduate teachers will starve themselves rather than give up their freedom." Under these circumstances Saha's decision to leave Calcutta evoked adverse feelings. The Calcutta Review made scathing attack on Saha's decision to leave Kolkata. However, it may be noted that Saha before leaving the Calcutta University wrote to its Syndicate: "I am however, willing to continue to serve my alma mater, provided the university is willing to grant me a graded scale of pay namely Rs. 650-50-1000 plus Rs. 15,000 to be placed immediately at my disposal as my personal research grant." The Syndicate rejected his request stating that "….in view of the present financial position of the university and in view of the claims of other university teachers, his request cannot be complied with." And so finally Saha went to the Allahabad University. At Allahabad before he could start research work he had to improve the workshop, the laboratory and the library. Moreover, he found hardly any time for research after discharging heavy teaching responsibilities. But Saha was not to be detracted by adverse conditions. And very soon research papers started appearing from Saha and his students. Among his collaborators at Allahabad were N.K. Sur, P.K. Kichlu, D.S. Kothari, R.CA Majumdar, Atmaram, K.B. Mathur and B.D. Nag Choudhary.

After his becoming Fellow of the Royal Society in 1927, the Governor of the United Province, Sir William Morris provided a research grant of Rs. 5,000 per year to Saha's Department. At Allahabad, besides continuing his research work on astrophysical problems, he initiated and organized research in several other branches of physics viz. statistical mechanics, atomic and molecular spectroscopy, electron affinity of electro-negative elements, active modification of nitrogen, high temperature dissociation of molecules propagation of radio waves in ionosphere and physics of the upper atmosphere. It is here that Saha wrote his famous textbook, *A Treatise on Heat*, which was first published in 1931 under the title of A *Textbook of Heat*. The book was written jointly with B.N. Srivastava. CAV. Raman in his foreword to the book wrote: "By undertaking the necessarily laborious task of producing a systematic and up-to-date treatise on the theory of heat, Prof. Saha has earned a claim to the gratitude of the wide circle of readers both in and outside of India, who it is confidently hoped, will study this book and appreciate its merits." A concise version of this book was published for science graduates. It was tilted Junior Text Book of Heat. He wrote another book (jointly with N.K. Saha) titled *Treatise on Modern Physics*.

At Allahabad Saha established the United Province Academy of Sciences in 1930. Interestingly the suggestion for establishing such an Academy had come from the Governor of the United Province, Sir Malcolm Hailey. While addressing the scientists of the United Province gathered at Allahabad on the occasion of the Indian Science Congress Association Malcolm said: "Now I am well aware that there are definite limits to the extent to which the efforts of our research workers or students can be directed to these problem (of economic and utilitarian value), and I am also well aware that coordination of their labours cannot be directed from outside. It must be voluntary effort, or at the most, it must be advice given by some Academy of Science, which will contain authoritative representatives of all the specialized branches of scientific activity now at work in the province. But if some form of visible co-ordination could be attempted, and if it could be proved to the public that science workers were contributing at least some of their energies in the direction I have suggested, then I believe we should have a far more effective case in calling for that public support and private liberality on which the further progress of scientific work must depend."

Saha returned to the Calcutta University in July 1938. He became the Palit Professor and Head of the Department of Physics. At that time Shyama Prasad Mookerjee was the Vice Chancellor of the University and who was soon to be succeeded by Sir Mahammed Azizul Haque. After joining Saha immediately got involved in organizing research in the Palit Laboratory. He also took the task of remodeling the MSc syllabus in physics. Saha introduced a general and a special paper in nuclear physics in 1940. One may note that, the phenomenon of the fission, was discovered in 1939 by Otto Hahn (1879-1968) and Fritz Strassmann (1902-80). Saha also added a general paper in quantum mechanics. Commenting on Saha's research work at the Calcutta University D.S. Kothari wrote: "His researches in Calcutta were concerned largely with the systematics of atomic nuclei, particularly beta-activity, the propagation of electromagnetic waves in the ionosphere, and the problem of the solar corona."

Saha was a great institution builder. He made the Physics Department of the Allahabad University, which he joined in 1923, as one of the most active centres of research in the country, particularly in the field of spectroscopy. The Department attracted students from all over the country. In 1911 Saha founded the UP Academy of Sciences at Allahabad, which was later renamed as National Academy of Sciences, India. The Academy, which was inaugurated on March 1, 1932, was modelled on the lines of the Asiatic Society of Bengal. Saha was its first President. In 1933 Saha founded the Indian Physical Society at Calcutta. The Society published the Indian Journal Physics. Eminent scientists like Raman, Saha and Krishnan regularly contributed their important papers to the Indian Journal of Physics.

With Saha's initiative National Institute of Sciences of India was established in Calcutta. Its formation was formally announced on January 7, 1935 in the Senate Hall of the Calcutta University under the Chairmanship of the J.H. Hutton. L.L. Fermor was elected the first president of the Institute. The formation of such an All India Academy of Sciences was first proposed by Saha in his Presidential Address of the Indian Science Congress Association in Mumbai (Bombay) in 1934. The National Institute of Sciences was later renamed as the Indian National Academy of Sciences and its headquarters were transferred to New Delhi.

Saha was closely associated with the planning and establishment of the Central Glass and Ceramic Research Institute, a constituent laboratory of the Council of Scientific and Industrial Research, at Kolkata. In 1944 Saha was elected the Honorary Secretary of the Indian Association for the Cultivation of Science and he was its President during 1946- 50. Saha became the full-time Director of the Laboratories of the Association in 1952, a post he held till his death. Under the leadership of Saha, there was a large-scale expansion of the activities of the Association. As President of the Indian Association for the Cultivation of Science he built its modern laboratories.

Saha played a significant role in the establishment of departments of Radio Physics and Electronics and Applied physics of the Calcutta University.

In 1950 Saha founded the Institute of Nuclear Physics. The Foundation Stone of the Institute was laid by Dr. Shyama Prasad Mukherjee the then Civil Supply Minister of the Government of India. The institute, which was formally inaugurated by Irene Joliot-Curie on January 11, 1950, was originally situated in the campus of the Calcutta University. Among those who attended the inauguration ceremony were Robert Robinson and J.D. Bernal.

It was Saha, who first introduced nuclear physics in the MSc physics syllabus of the Calcutta University in 1940. He also started a post-MSc course in nuclear science for the country. He initiated steps for building a cyclotron, the first of its kind in the country.

The Conference of Scientific workers in Britain held in July 1946 led to the formation of the World Federation of Scientific Workers. Saha had participated in this Conference and after coming back to India he wrote editorials in the Science and Culture urging Indian scientific workers to form a similar kind of organisation. Explaining the objectives of such an Association Saha wrote: "the aim and objects of the Association are for fuller use of science for national life – for education through meetings and for action in public field." On some other occasion he wrote: "It is high time for the scientific workers in India that they exert their inherent right to live like decent citizen and shoulder responsibilities for the betterment of their motherland." The Association for Scientific Workers (India) was eventually formed on 7th July 1947.

Saha founded the Indian Science News Association at Calcutta in 1935. Its main objective was to disseminate science amongst the publica The Association started publishing its journal called Science and Culture. On receiving, a copy of the first issue of the Journal, Netaji Subhash Chandra Bose wrote: "The appearance of Science and Culture is to be warmly welcomed not only by those, who are interested in abstract science but also by those who are concerned with nationbuilding in practice. Whatever might have been the views of our older "Nation builders" we younger folk approach the task of nation building in a thoroughly scientific spirit and we desire to be armed with all the knowledge which modern science and culture can afford us. It is not possible however, for political workers with their unending preoccupations to glean that knowledge themselves, it is therefore, for scientists and scientific investigators to come in their rescue." Saha himself wrote more than 200 articles in Science and Culture on a wide range of topics which included: organization of scientific and industrial research, atomic energy and its industrial use, river valley development projects, planning the national economy, educational reforms and modification of Indian calendar. The journal is presently running in its 68th volume.

Saha wrote extensively on his vision of scientific economic planning for India. It was Saha who persuaded Netaji Subhash Chandra Bose, then President of the Indian National Congress, to set up a National Planning Committee. At the beginning M. Visvesvaraya, the most celebrated Indian engineer, was the Chairman of the Committee. However, Saha thought that to have its impact the Committee should be headed by a powerful Congress leader and he persuaded Rabindranath Tagore to convince Jawaharlal Nehru to accept the Chairmanship of the Committee.

Saha was an advocate of the peaceful use of nuclear energy. He had initiated the first Parliament debate on this subject on 10th May 1954. Saha was against the establishment of the Atomic Energy Commission. He was of the view that the researches on nuclear energy could be undertaken in the university sector. In fact he wanted the 'Indian Atomic Energy Act' to be scrapped altogether. Saha wanted that the Government should first build up necessary infrastructure and trained manpower before it undertook such a programme. However, in spite of Saha's opposition the Atomic Energy Commission was created in 1948 under the chairmanship of Homi J. Bhabha. Many people may agree with what D. M. Bose had to say in 1967. "The decision of the Prime Minister (Jawaharlal Nehru) to locate the Department of Atomic Energy and Atomic Energy Commission with Bhabha as Secretary of the former and Chairman of the latter must have caused some disappointment to Saha. Since 1935 Nehru and Saha cooperated in many fields of common interest, including the formation of the planning committee in 1938 by Subhash Chandra Bose with Nehru as Chairman and Saha as an important member. A growing estrangement with the Prime Minister with some of the later decisions may have been one of the factors, which decided Saha to enter politics in 1952. There can be no doubt, however, as the events shaped subsequently that the Prime Minister Nehru was undoubtedly right in entrusting Bhabha with the development of India's plan for utilization of atomic energy. Bhabha identified himself completely with the development of atomic energy in India. Saha's interest was many and varied."

Saha was deeply concerned with the recurring disastrous floods in many Indian rivers. The extensive damage caused by floods in North Bengal in 1923 prompted Acharya Prafulla Chandra Ray to organize relief operation under the aegis of North Bengal Relief Committee. Ray was able to collect a large fund from the general public for the relief work and he was assisted by Subhash Chandra Bose, Meghnad Saha and Satish Chandra Dasgupta. And it was while carrying out the relief work Saha got a first hand experience of the devastating power of floods. Saha wrote about his experience in newspapers and magazines. In his Presidential address to the Indian Science Congress in Mumbai in 1934 he drew specific attention to serious problems caused by floods. He also emphasized the need for a River Research Laboratory. Again in 1938, in his presidential address to the National Institute of Sciences of India he highlighted the danger posed by recurrent floods in Indian rivers particularly in the deltaic ones. In 1943 the flood in Bengal isolated Kolkata from rest of India and Saha wrote extensively on the issue. Saha's writings and speeches made the government realize the gravity of the situation. As a result the Damodar Valley Enquiry Committee came into being in 1943. The Committee was chaired by the Maharaja of Burdwan. Saha was also a member of the Committee. Saha presented a plan for handling the Damodar river system before the Committee. He also wrote extensively on river control based on modern science and technology. He argued that the model of Tennessee rivers system under the Tennessee Valley Authority (TVA) in USA could be adapted to the

Damodar Valley. At the instance of Dr. B. R. Ambedkar, the then member -in-charge of power and works in the Viceroy's cabinet, the Government adopted a resolution to set up a Damodar Valley Corporation (DVC) after the model of TVA. The DVC was set up in March 1948. Saha's interest was not confined to the rivers of Bengal alone.

Saha's work relating to reform of Indian calendar was very significant. Saha was the Chairman of the Calendar Reform Committee appo inted by the Government of India in 1952 under the aegis of the Council of Scientific and Industrial Research. Other members of the Committee were: A. CA Banerjee, K. K. Daftari, J. S. Karandikar, Gorakh Prasad, R. V. Vaidya and N. CA Lahiri. It was Saha's effort, which led to the formation of the Committee. The task before the Committee was to prepare an accurate calendar based on scientific study, which could be adopted uniformly throughout India. It was a mammoth task. The Committee had to undertake a de tailed study of different calendars prevalent in different parts of the country. There were thirty different calendars. The task was further complicated by the fact that with calendar religion and local sentiments were involved. Nehru, in his preface to th e Report of the Committee, which was published in 1955, wrote: "They (different calendars) represent past political divisions in the country…now that we have attained Independence, it is obviously desirable that there should be a certain uniformity in the calendar for our civic, social and other purposes and this should be done on a scientific approach to this problem." Some of the important recommendations of the Committee were:

i. The Saka era should be used in the unified national calendar. (The year 2002 corresponds to the Saka era of 1923 -24.)
ii. The year should start from the day following the vernal equinox (occurs about March 21) day.
iii. A normal year would consist of 365 days while a leap year would have 366 days.
iv. After adding seventy -eight to the Saka era, if the sum is divisible by four, then it is a leap year. But when the same becomes a multiple of 100 it would be a leap year when it is divisible by 400, otherwise it would be a common year.
v. Chaitra should be the first month of the year. From Chaitra to B hadra each month would have thirty -one days and the rest to have thirty days.

According to Saha, large-scale industrialization was the only answer for improving the quality of life. He thought that India had no hope if she failed to develop science and technology. Saha wrote: "The philosophy of kindliness and service to our fellow-men was preached by all founders of great religions, and no doubt some great kings and ministers of religions in every country and at all ages tried to give effect to this (altr uistic) philosophy. But the efforts were not successful, for the simple reason that the methods of production of commodities were too indifferent to yield plenty for all, which is an indispensable condition for practical altruism. We can, therefore, hold that so far as individual life is concerned, science has achieved a target aimed at by the great founders of religions in advanced countries of the world. The effects of maldistribution of wealth, due to historical causes, are being rapidly cured by introduction of social laws."

In 1952 Saha was elected Member of the Parliament as an independent candidate from the North-West Calcutta constituency. Welcoming Saha's election JBS Haldane said: "May I also be allowed to congratulate him on his recent successful reentry recently into politics. India (and Britain too) needs men who will bring some understanding of science to the government of the country. Even those who do not share his political views may rejoice that he can make his voice heard in the council of the people." Many wonder why Saha, an internationally known scientists decided to fight election.

Saha died suddenly due to a massive heart attack on his way to the office of the Planning Commission on 16 February 1956. As D. S. Kothari one of Saha's illustrious students, wrote: "The life of Saha was in a sense an integral part of the growth of scientific research and progress in India and the effect of his views and personality would be felt for a long time to come in almost every aspect of scientific activity in the country. His dedication to science, his forthrightness and utter disregard of personal comforts in the pursuit of his chosen vocation will long remain an inspiration and an example."

Books written by Meghnad Saha

1. *The Principles of Relativity* (with S.N. Bose) Calcutta University, Calcutta, 1920. (It was a translation of Einstein's papers on theory of relativity).

2. *Treatise on Heat* (with B.N. Srivastava), Indian Press, Allahabad, 1931.

3. *Junior Textbook on Heat* (with B.N. Srivastava), Indian Press, Allahabad, 1932.

4. Treatise on Modern Physics, Vol-1 (with N.K. Saha) Indian Press, Allahabad, 1934.

5. *My Experience in Soviet Russia,* Bookman Inc, Calcutta, 1947.

George Gamow
Scientist and Science Populariser

"Gamow made many contributions to nuclear and atomic physics, but he is mainly noted for his work on interesting problems in cosmology and molecular biology."

A Dictionary of Scientists, Oxford University Press,1999.

"Gamow was fantastic in his ideas. He was right, he was wrong. More often wrong than right. Always interesting; and when his idea was not wrong it was not only right, it was new."

Edward Teller

"He (Gamow) raised popular science writing to a fine art. Interestingly, some of his serious colleagues felt that he was wasting his time with these trivial pursuits! I only wish we had more Gamows in our own country who would come forward and write for the uninitiated. This can make learning science an inspired process and help take out some of the drabness of science curriculum in schools and colleges."

S. Mahadevan in his Editorial, Resonance, July 2004

The year 2004 is the birth centenary of George Gamow, a highly creative scientist and who by his superb popular writings made abstract concepts of science accessible to millions of laypersons or the uninitiated ones. Gamow was a first class physicist. However, Gamow's attitude to physics was larger than life. He was particularly known for finding the right scientific problems for research and introducing conceptual simplicity to them. Gamow was pioneer in theoretical investigations of atomic nuclei. He proposed a so-called nuclear fluid model of the nucleus. Gamow's model of alpha decay (a form of radioactive decay) represented the first application of quantum mechanics to the study of nuclear structure. He also described beta decay (another form of radioactive decay). Gamow's interests were not confined within the bounds of physics. His ideas influenced research in a variety of topics. Gamow made important advances in both cosmology and molecular biology. He studied the structure and evolution of stars and creation of elements. He showed how the collision of nuclei in the interior of the Sun could produce the nuclear reactions that produce the energy. Gamow was a major expounder of the 'Big Bang' theory of the origin of the universe. He suggested how DNA might provide the code for protein synthesis. Gamow is regarded as one of the greatest science popularisers of all time.

George Gamow (his original name in Russian was Georgi Antonovich Gamow) was born on March 04, 1904 in Odessa, Russia (now in Ukrain). His father was a schoolteacher. Astronomy fascinated Gamow since his early school years. He used to patiently examine the starry sky through a little telescope presented by his father. During 1923-29 he studied optics and cosmology at the University of Leningrad (St Petersburg). Before joining the University of Leningrad, Gamow had spent a year (1922-23) at the Novorossia University in his hometown, Odessa. In 1926 Gamow attended summer-school in Gottingen in Germany. During his PhD work Gamow explained the then mysterious phenomenon of natural radioactivity as well as Rutherford's experiments on the Induced transformation of light elements by applying the newly developed quantum theory.

In 1928 he received his PhD degree from the University of Leningrad. After receiving his PhD Gamow went to work at the Institute of Theoretical Physics in Copenhagen, where Niels Bohr (1885-1962) became very interested in his work. Bohr offered Gamow a one-year scholarship (1929-30) from the Royal Danish Academy. While working there Gamow proposed a hypothesis that the atomic nuclei can be treated as little droplets of so called nuclear fluid. In this model, called the liquid drop model of the nucleus, neutrons and protons behave like the molecules in a drop of liquid. John Archibald Wheeler (1911-) and Niels Bohr adopted this model for explaining the process of nuclear fission. Wheeler and Bohr proposed that the spherical nucleus may get distorted into dumb-bell shape and when sufficient energy is acquired by the nucleus, say, by absorption of a neutron, the nucleus splits into two fragments. And in this process energy is released. These discoveries led to today's theory of fusion and fission. During 1929-30 Gamow worked in Cambridge University with Ernst Rutherford (1871-1937) as Rockefeller Fellow.

In 1931, Gamow was asked to return to the ers twhile Soviet Union to join as Master of Research at the Academy of Sciences in Leningrad. In those days Joseph Stalin (1879-1953) was in power. Gamow and his wife wanted to leave USSR. In their first attempt to escape from Russia, they planned to go to Turkey by crossing the Black Sea. They undertook this journey of 270 km on a small boat (kayak). After continuing their journey for 36 hours they had to abandon it because of bad weather. They came back. Gamow somehow could convince that they were carrying out some experiments on the boat. After making a few more unsuccessful attempts they finally got a chance to realize their goal. In 1933 Gamow was permitted by the authorities to attend the Solvay Congress in Brussels. Gamow's wife Luybov Vokhminzeva was also allowed to go as his Secretary. They did not return to the Soviet Union. After getting an invitation for lecturing at the University of Michigan, Gamow and his wife left for USA in 1934. While in USA, he was offered a professorship at the George Washington University. For accepting the offer he put forward three conditions; His first condition was that the university also appoint a colleague of his choice to work with him in the physics department. His choice was Edward Teller (1908-), who was then working at Birbeck College in London. His second condition was the support of Cloyd Heck Marvin, the president of the university, and Merle Antony Tuve (1901-82), Director of the accelerator laboratory at the Carnegie Institution of Washington, in organizing a conference on theoretical physics to be held annually in Washington under the joint auspices of the university and the Carnegie Institution. Third condition was that is initially appointment in the George Washington University be described as Visiting Professor. The conditions were accepted by the University authorities. In his early years at the George Washington University, Gamow's collaboration with Edward Teller on the theory of beta decay (that is emission of electrons from the nucleus) led to the formulation of the so-called "Gamow-Teller Selection Rule for Beta Emission". Among his other research works carried out while working at the George Washington University were: the theory of the internal structure of red giant stars, the theory of so-called Urca process jointly with Mario Schoenberg) and the theory of the origin of chemical elements by the process of successive neutron capture, jpintly with Ralph Asher Alpher (1921-). The beta decay or the emission of an electron from the nucleus is accompanied by the emission of a neutrino. When a nucleus captures an electron an antineutrino is emitted. Gamow proposed that when these processes take place in the interior of stars the resulting neutrinos and antinutrinos escape, and matter in the stellar interior can rapidly loose energy. Gamow called this process `Urca process' after a casino in Rio de Jeneiro where the customers lose money easily.

During the Second World War, Gamow worked in the Manhattan Project, developing an atomic bomb. Gamow also took part in the research at Los Alamos, which finally led to the production of the Hydrogen bomb.

In 1948 Gamow and his colleague Rlaph Alpher wrote a paper about the Big Bang theory and how matter originated. Gamow proposed that the matter of the universe originally existed in a primordial state (primordial elementary leptonic particles) called the "Ylem". Helium and perhaps other elements formed from the Ylem shortly after the Big Bang had started the Univers's exapansion. The Big Bang theory was originally proposed by Abbe Georges Edouard Lemaitre (1894-1966).

In his last years Gamow started working in biology. He made a major contribution to the problem of how the order of the four different kinds of bases (adenine, cytosine, thymine and guanine) in DNA chains could control the synthesis of proteins from amino acids. He proposed that short sequences of the bases could form a 'code' capable of carrying necessary information for the synthesis of proteins. As there are only twenty amino acids that make up all the proteins, the code must consist of blocks of three bases because then only it ill have a vocabulary of sufficient instructions. It cannot be one base for one amino acid because then there will be only four amino acids. If two bases code for one amino acid then they could produce only 4x4 = 16 amino acids. So it would therefore need a sequence of three bases to code for one amino acid, with a capacity of 4x4x4 =64 words, which was more than adequate for the construction of all proteins. Gamow's coding scheme generated a great deal of interest among scientists working in the concerned fields. His great innovation was the introduction of mathematical reasoning to the coding problem without going into much biochemical details. For regular exchange of ideas on the coding problem Gamow formed the so-called *RNA Tie Club* consisting of 20 handpicked scientists corresponding to the 20 amino acids. Each member of the Tie club was given the nickname of an amino acid, and all were presented with a diagrammed tie and tiepin made to Gamow's specifications. Though the members were located in different parts of the world, the Tie Club brought physical scientists and biologists together to work on one of the most challenging problems in modern science. The concept code for transferring genetic information was casually mentioned by Watson and Crick in a 1953 article. However, this was first publicly articulated in an article published in late 1954 by Gamow Martynas Ycas and Alexander Rich. By 1960 it was shown that Gamow's central idea was correct.

In 1956 Gamow joined the University of Colorado as Professor and stayed there till his death.

Besides his excellent research contributions in physics, cosmology and biology, Gamow wrote a number of important textbooks:

1. T*he Constitution of Atomic Nuclei and Radioactivity* (1931)
2. *Structure of Atomic Nuclei and Nuclear Transformations* (1937)
3. *Atomic Energy in Cosmic and Human Life* (1947)
4. *Theory of Atomic Nucleus and Nuclear Energy Sources* with CA L. Critchfield (1949)
5. *The Creation of the Universe* (1952)
6. *Matter, Earth and Sky* (1958)
7. *Physics: Foundations & Frontiers* with John M. Cleveland (1960)
8. *The Atom and its Nucleus* (1961)

Perhaps to many Gamow is known as a popular science writer. His popular science writings have influenced millions in all parts of the world. His keen sense of humour is very much evident in his popular science writings. His books will remain as classics in the history of science popularization. Gamow is regarded as one of the most successful writers of all time. He wrote many books and most of these are still in print. Through these beautiful written books Gamow succfully conveyed much of the excitement of the revolution in physics that he lived through and other scientific topics of interest. Gamow himself prepared the illustrations for his books. Thus the illustrations added a new dimension. They complemented what he intended to convey in text. Wherever it was essential he used mathematics. His books have been translated into many languages. In 1956, Gamow was awarded the UNESCO's Kalinga Prize, the only international award given for science popularization.

1. *Mr. Tompkins in Wonderland* (1939, it was on relativity)
2. *The Birth and Death of the Sun* (1940)

3. *The Biography of the Earth* (1941)
4. *Mr. Tompkins Explores the Atom* (1944, it was on quantum physics)
5. *One, Two, Three…Infinity: Facts and Speculations of Science* (1947, according to Gamow, the book is "…of atoms, stars, and nebulae, of entropy and genes; and whether we can bend space, and why the rockets shrinks").
6. *The Moon* (1953)
7. *Mr. Tompkins Learns the Facts of Life* (1953, it was on biology)
8. *Puzzle-Math* (1958)
9. *Biography of Physics* (1961)
10. *Gravity* (1962)
11. *A Planet Called Earth* (1963)
12. A Star called the Sun (1964)
13. *Thirty Years that Shook Physics: The Story of Quantum Theory* (1966)
14. *Mr. Tompkins Inside Himself* (1967 This book rewritten version of the Mr. Tompkins learns the facts of life to give broader view of biology, including recent developments in molecular biology. It was rewritten with M Yeas)

Commenting on Gamow's writings CAS.Yoganand wrote "There have been many great scientist – I don't need to give examples! – and many popular science writers – Isaac Asimov's is perhaps one of the names that come to mind immediately. But Gamow belong to that rare species of first class scientist who are also first class science communicators. It is hard to name another form the same species—A distinguishing feature of Gamow's writings, indeed of his life itself, is universality. There represent science as a whole. Importantly, he does not avoid mathematics is and when necessary unlike most of the 'popular science writer'.

Gamow died on August 19, 1968. After his death, his second wife Barber Gamow and the physics Department of the University of Colorado started the George Gamow Lecture series.

Hans Albrecht Bethe

Who Proposed Mechanism for the production of Stellar Energy

"Professor Bethe. You may have been astonished that among your many contributions to physics, several of which have been proposed for the Nobel Prize, we have chosen one which contains less fundamental physics than many of the others and which has taken only a short part of your long time in science. This however,…do es not imply that we are not highly impressed by the role you have played in so many parts of the development of physics ever since you started doing research some forty years ago. On the other hand your solution of the energy source of stars is one of the most important applications of fundamental physics in our days, having led to a deep -going evolution of our knowledge of the universe around us."

Quoted from the Presentation Speech at the Nobel ceremony (1967) delivered by Oskar Klein, a theoretical physicist and a member of the Swedish Academy of Sciences

Hans Albrecht Bethe was one of the most noted and versatile theoretical physicists of the 20th century. Freeman Dyson regarded Bethe as the "supreme problem solver of the 20th century." He was one of the chief architects of quantum mechanics. He made significant contribution towards enhancing the understanding of the atomic processes responsible for properties of matter and of the forces governing the structures of atomic nuclei. He is best known for his theory of production of stellarenergy. His scientific career spanned nearly sixty years. He published at least one major paper (in real sense) in his field every decade of his career. Not many scientists can claim this kind of unique achievement. In 1939, Bethe developed a detailed theory for production of energy inside a star through a series of nuclear reactions.

In 1947, with the American physicist Robert Eugene Marshak Bethe anticipated the discovery of the pi-meson by putting forward the two-meson hypothesis. The same year he explained the Lamb shift in the hydrogen spectrum, which laid the foundation for the development of quantum electrodynamics. Lamb shift is a small shift in the energy levels of a hydrogen atom, and of hydrogenlike ions, from those predicted by the Dirac electron theory. He worked on the theory of metals, the most noted contribution of Bethe in this field was his theory of order and disorder in alloys.

It is often mentioned that Bethe alongwith Ralph Alpher and George Gamow developed the alpha-beta-gamma theory of the origin of the chemical elements. However, Bethe had no role in this. Bethe simply added his name albeit against the wishes of Alpher.

Jointly with Robert Bacher and Milton Stanley Livingston Bethe wrote three review articles summarising then existing literature on nuclear physics. These articles were published in *Reviews of Modern Physics*. This account became informally known "Bethe's Bible" and served as a textbook for nuclear physics for many years.

He was a man of profound integrity and simplicity. He actively advocated the peaceful exploitation of nuclear energy.

Hans Albrecht Bethe

He was greatly influenced by Arnold Sommerfield, his PhD supervisor at the University of Munich and Enrico Fermi, with who he worked as a post-doctoral student in Rome. Sommerfeld taught him the necessity of a rigour in approaching problem in becoming a successful researcher. From Fermi he learned to value quantitative reasoning. He was also greatly in fluenced by Frmi's simplicity.

Bethe was born in Strasbourg (then Strassburg) on July 02, 1906. Today Strasbourg is in the French province of Alsace-Lorraine. At the time when Bethe was born, Strasbourg was part of the German empire of Kaiser Wilhelm II Bethe's father Albrecht Bethe was a well-known physiologist. His mother, the daughter of a professor of medicine was an accomplished musician.

Bethe attended the Goethe Gymnasium at Frankfurt. It was a traditional Humanistisches Gymnasium where the major emp hasis was on the humanities particularly Latin and Greek. In his childhood he displayed unusual mathematical abilities He was able to compute square roots when he was just four years old. This was just a beginning. He developed a full understanding of fractions at the age of five and he could find prime numbers at seven. By the age of fourteen he developed a mastery over calculus by his own initiative. It looks rather surprising that he did not pursue mathematics as a career. This is because to him "…mathematics seemed to prove things that are obvious." His childhood talent was not just simply confined to mathematics alone. He learned to write at a very early age and filled many notebooks with stories. He developed an unusual technique in writing. One line he wrote from left to right and then he wrote the second line that followed from right to left. In his later life Bethe learnt that this unusual technique was followed by the ancient Greeks in some of their tablets.

In 1928, Bethe obtained his PhD in theor etical physics working under Arnold Sommerfeld. His thesis was on the diffraction of electrons in crystals. His thesis proved to be one of his most important works. This work remained of fundamental valu in understanding observational data. After his PhD h e worked as a physics instructor for a year first at Frankfurt and then at Stuttgart. In 1930, he became a Prvadozent at the University of Munich and where he worked till 1933. While working at Munich he was awarded a Rockefeller Foundation Fellowship that enabled him to work with Ralph Fowler in Cambridge and Enrico Fermi in Rome. He was appointed as Acting Assistant Professor at the University of Tubingen in the winter semester of 1932 -1933. He lost the job because of the rise of the Nazis in Germany. Be the's mother was born to Jewish parents. He migrated to England, where he first worked at the Manchester University (1933-34) and then at the Bristol University (1934 -35).

In 1934, Bethe jointly with german physicist Walter Heitler developed the quantum mechanical theory for bremsstrahlung of relativistic electrons. Bremsstrehlung is the radiation that is emitted by an electron accelerated in its collision with the nucleus of an atom. Bethe and Heitler also initiated the theory of electron and proton showe rs in cosmic rays.

In 1935 Bethe moved to the Cornell University in the United States. His initial appointment was as Assistant Professor and then in 1937 he was promoted to Professor. Bethe became a US citizen in 1941.

He remained in the Cornell Univer sity till the end of his life except for sabbatical leaves and his absence for war duties during the Second World War. He formally retired in 1975. After his retirement he was made a professor of emeritus. It was at Cornell Bethe became interested in inves tigating the source of energy in stars. It was during his stay at the Cornell University he established himself as one of the leading theoretical physicists of his time. He alongwith Stanley Livingston, Robert Wilson and Robert Backer put Cornell Universit y on the map of world physics.

During the Second World War, Bethe worked on microwave radar at the Radiation Laboratory of the Massachusetts Institute of Technology. He served as Director of the Theoretical Physics Division of the secret atom bomb project (known as Manhattan project) at the Los Alamos Laboratory.

The net result of these reactions is the conversation of four hydrogen atoms into a helium atom and the release of radiation energy equivalent to the loss of mass in the process. The relation betwe en mass and energy is shown in Einstein's famous equation $E = mC^2$. Bethe's process for energy production inside stars is sometimes referred to as the "carbon Cycle" as C -12 plays a key part in these reactions. The process developed by Bethe gave good agree ment with observations of some stars. The carbon cycle (also referred to as CNO cycle) begins with a hydrogen nucleus or proton (^1H) and a carbon-12 atom. This cycle has the following six stages:

$^{12}_{6}C + ^{1}_{1}H \rightarrow ^{13}_{7}N + \gamma$

$^{13}_{7}N \rightarrow ^{13}_{6}C + e^{+} + \nu$

$^{13}_{6}C + ^{1}_{1}H \rightarrow ^{14}_{7}N + \gamma$

$^{14}_{7}N + ^{1}_{1}H \rightarrow ^{15}_{8}O + \gamma$

$^{15}_{8}O \rightarrow ^{15}_{7}N + e^{+} + \nu$

$^{15}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + ^{4}_{2}He$

Here γ denotes gamma ray, e^+ positron, and ν a nutrino.The net result is the production of He-4 atom plus release of energy. After the end of step-6 C-12 remains available for further reation. In the process 27 MeV (million electron volts) are released. The amount of enegy produced per cycle appears to be modest but the large amount of stellar matter involved leads to producti on of enormous amount of energy. The carbon cycle depends on the presence of carbon in stars. Bethe gave no indication with regard to the origin of C -12 that starts the cycle. The presence of carbon in stars had been confirmed by their spectral lines in stellar atmosphere. However, at that time physicists were not aware of any mechanism that could explain the abundance of carbon in stara. Fred Hoyle and his colleagues resolved this issue in the 1950s.

The other process by which energy is produced inside sta rs is the proton-proton chain reaction. This process involves direct convertion of hydrogen atoms into a hillium atom. In the first step to protons collide to form a nucleus of deuterium this reaction releases a positron and a nutrino. In the second step t he deuterium nucleus reacts with another proton to form helium three. In the third step 2He-3 combined to produced a nucleus of ordinary helium (called alpha particle) and two protons.

$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + e^{+} + \nu$

$^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{2}He + \nu$

$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2\, ^{1}_{1}H$

The net result of both the processes is the fusion of four hydrogen nuclei into one helium nucleus plus a release of energy. The proton -proton reaction is more important in stars like Sun. However, in massive and hotter stars carbob cycle becomes more important.

In 1958 he served as a delegate to the Geneva Conference, which negotiated the first test-ban treaty. He played an instrumental role in persuading the US administration to sign the ban of atmospheric nuclear tests in 1963 and the 1972 Anti-Ballistic missile Treaty.

Some of the important works of Bethe are: *Theory of High Frequency Rectification by Silicon Crystals* (1942); *Elementary Nuclear Theory* (1948), *Theoretical Estimate of Maximum Possible Nuclear Explosion* (1950); *Three-body Problem in Nuclear Matter* (1967, with R. Rajaraman), *Note on Inverse Bremsstrahlung in a Strong Electromagnetic Field* (1972), *Pauli Principle and Pion Scattering* (1972); *Intermediate Quantum Mechanics* (2^{nd} Edition, 1968), *Fusion Hybrid Reactor* (1981) and *The Road from Los Alamos* (1991).

In 1957, Bethe became a foreign member of the Royal Society, London as well as a member of the National Academy of Sciences, USA. In 1967, Bethe was awarded the Nobel Prize in Physics "for his contributions to the t heory of nuclear reactions, especially his discoveries concerning the energy production in stars." Among other awards received by Bethe included Henry Draper Medal (1947); Max Planck Medal (1955); Eddington Medal of the Royal Astronomical Societry (1961); Enrico Fermi Award (1961); Rumford Prize (1961); Lomonosov Gold Medal (1993) and Bruce Medal (2001). Bethe served as the US President's Science Advisory Committee.

Bethe died on March 06, 2005 in Ithaca, New York. Asteroid 30828 was named after Bethe. The American Physical Society has introduced a prize called Hans Bethe Prize.

Subrahmanyan Chandrasekhar

One of the Greatest Astrophysicists of the 20th Century

"Chandrasekhar showed that stars upto a particular mass limit evolve into white dwarfs, implying that more massive stars collapse to form black holes. He wrote through mathematical monographs inspired by a variety of astrophysical problems, including relativity and black holes, and evolved the Astrophysical Journal to world-class status during his nineteen-year editorship."

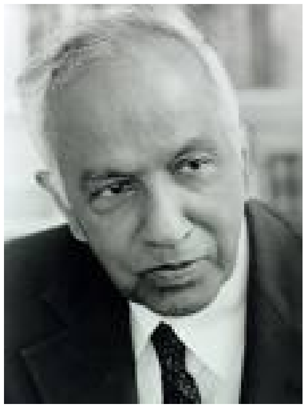
Norriss S. Hetherington in The Oxford Companion to the Modern History of Science

"…Chandrasekhar, during the period that he was a research student at Cambridge University, England, pioneered theoretical studies precisely on white dwarfs. He used Fermi and Dirac's quantum statistics, and the special theory of relativity, to calculate what should be the maximum mass of a white dwarf. This is called Chandrasekhar limit, and it proved to be about 1.4 times the mass of our sun….As well as his first work on white dwarfs, Chandrasekhar contributed greatly to the study of stellar evolution. Beginning in the 1970s he also developed a theory on black holes using general relativity."

Mauro Darado in Nobel Laureates and Twentieth-century Physics, 2004.

Subrahmanyan Chandrasekhar, one of the greatest scientists of the 20th century, became a legend in his lifetime. Chandrasekhar's life, as Kameshwar CA Wali wrote, "stands out for its singular dedication to the pursuit of science, and for practising the precepts of science and living up to its values to the closest possible limit in one's life." His prolific contributions spanned astrophysics, physics and applied mathematics. His life is the best example of the height one can achieve provided one has the will power, skill and patience. His journey was not smooth. He had to struggle against all odds. He was a product shaped by complexities of three widely different cultures--that of India (where he was born), England and USA. He believed in common heritage of human beings. He said: "The point is the human mind works in the same way. It's reassuring that things we find pleasurable are pleasurable to other people in every part of the world. And the fact that there is a common interest emphasises that there is a common heritage." He was a great scientist, an accomplished teacher and a formidable scholar.

Subrahmanyan Chandrasekhar was born in Lahore on October 19, 1910. His father CA Subrahmanyan Iyer was in Government Service. CAV. Raman, the first Indian to get Nobel Prize in science was the younger brother of Chandrasekhar's father. Chandrasekhar grew up in Madras (now Chennai). He went to a regular school when he was eleven. He joined the Madras Presidency College in 1925 where in the first two years he studied Physics, Chemistry, English and Sanskrit. On July 31, 1930 Chardrasekhar left for England for higher studies and thus began a long and outstanding scientific career, which spanned 65 years. Except for the first six years he worked at the University of Chicago.



Subrahmanyan Chandrasekhar

He is best known for his celebrated discovery of Chandrasekhar Limit. He showed that there is a maximum mass, which can be supported against gravity by pressure made up of electrons and atomic nuclei. The value of this limit is about 1.44 times a solar mass. This was derived by Chandrasekhar in 1930, when he was a student. The Chandrasekhar Limit plays a crucial role in understanding the stellar evolution. If the mass of a star exceeded this limit, the star would not become a white dwarf. It would continue to collapse under the extreme pressure of gravitational forces. The formulation of the Chandrasekhar Limit led to the discovery of neutron stars and black holes. It may be noted that stars are stable, that is they do not collapse because internal pressures caused by the thermal motion of the atomic nuclei and electrons and also the pressure of the radiation generated by nuclear reactions balance gravity. However, for every star a time will come when nuclear reactions will cease and that means there will be no internal pressure to match the gravitational pull. Depending on the mass there are three possible final stages of a star - white dwarf, neutron star and black hole. Chandrasekhar was awarded (jointly with the nuclear astrophysicist W.A. Fowler) the Nobel Prize in Physics in 1983 While Chandrasekhar is best known for Chandrasekhar Limit, for him there was no limit. As mentioned earlier his work spanned physics, astrophysics and applied mathematics. Chandrasekhar's research activity can be divided into several distinct periods:

1) The structure of stars and the theory of white dwarfs (1929-39).

2) The dynamics of stars (1938-43).

3) The theory of of the atmospheres of stars and planets (1943-50).

4) Relativistic astrophysics (1962-71).

5) The theory of black holes (1974-83).

His research output is phenomenal and every monograph or book published by Chandrasekhar has become a classica No serious students of the concerned fields can ignore Chandrasekhar's work. He was not motivated by a single problem but by a desire to acquire a perspective on an entire area. He was never concerned with the relative importance or unimportance ofa pasrticular subject. He simply chose a subject and worked on. He was least concerned whether his work was going to bring him laurels and recognition. He said: "After the early preparatory years, my scientific wor k has followed a certain pattern motivated, principally, by quest after perspectives. In practice this quest has consisted in my choosing (after some trials and tribulations) a certain area which appears amenable to cultivation and compatible with my taste, abilities, and temperament. And when after some years of study, I feel that I have accumulated a sufficient body of knowledge and achieved a view of my own, I have the urge to present my point of view *ab initio*, in coherent account with order, form, and structure."

Once he finished a particular area he would be ready to start on a fresh one. The essence of Chandrasekhar's scientific life was `attaining a complete understanding of an area, grasping and internalising it'. Whatever he did he did not only with a seemingly unmatched meticulousness but also with elegance. Lymnan Spitzer said: "It's a rewarding aesthetic experience to listen to Chandra's lecture and study the development of theoretical structures at his hands. The pleasure sentences and divide them into paragraphs. Do they make them short or long? For example, the idea of just using one sentence for a paragraph, or of a concluding sentence without subject or object. Just a few words ... `so it is' ... or some small phrase like that. I delibera tely follow such devices..."

Being so deeply involved in science, he had other interests as well. From the beginning he had developed interest in literature. He said: "My interest in literature began in a serious way in Cambridge around 1932. I used to de vote most of the two to three weeks between terms to the study of literature. The real discovery for me at that time was the Russian authors. I read systematically, in Constance Garnett's translation, all the novels of Turgenev, Dostoevski's *Crime and Punishment*, *Brothers Karamazov* and *Possessed*. Chekov, I read of course all his stories and plays. Not all the Tolstoy's, but *Anna Karenina* certainly. Among the English writers I started reading Virgina Woolf, T.S. Eliot, Thomas Hardy, John Galsworthy, and Bernard Shaw. Henric Ibsen was also one of my favourite authors...."

Chandrasekhar had the rare ability to inspire enthusiasm for hard work in others. More than 50 students did PhD work under his guidance. His relation with his students reminds us of *guru-sishya* tradition of earlier times. While he evoked respect from his students, he also encouraged them to put their viewpoints without any fear. He said: "My students, students with whom I have worked closely, are respectful in a way, that is reminiscent of earlier times that we read of in books. At the same time they are not at all intimidated by what I say. They will react either positively or negatively, discuss and argue. If a person agrees with everything you say, then there is no point in the discus sion."

Throughout his professional life he continued interacting with young people. Once he said: "I can easily imagine not having lost anything if I hadn't worked with Fermi or Von Neumann; but I cannot say the same thing with respect to my students".

He was the managing editor of the *Astrophysical Journal* from 1952 to 1971. He converted essentially a private journal of the University of Chicago into a national journal of the American Astronomical Society. For the first twelve years, the Journal was managed by Chandrasekhar and a part-time secretary. "Between us we took care of all the routine work. We took care of scientific correspondence. We prepared the budget, advertisements, and page charges. We made at the reprint orders and sent out the bills." When Chandrasekhar became the Editor, the Journal had six issues in a year totalling 950 pages but towards the end of Chandrasekhar's editorship, the journal became twenty-four issues totalling over 12,000 pages a year. Under his leadership the journal became financially independent of the University of Chicago. He left behind a reserve fund of US $ 500,000 for the journal.

Chandrasekhar mostly lived and worked abroad. In 1953, he became a US citizen. However, he was deeply concerned with India's well-being. He had strong association with many scientific institutions and young scientists in India. In his childhood, he was inspired by Ramanujan's example - an example of total dedication to science. His interest in Ramanujan was life long. He played an instrumental role in establishing the Ramanujan Institute of Mathematics in Madras in the late 1940s and when the Institute was facing financial crisis he took up the matter with Nehru. He also managed to get increased pension for Ramanujan's widow who was living in abject poverty. He was also responsible for the busts of Ramanujan cast by Richard Askey.

What was the motivation for Chandrasekhar in pursuing science? As one of his students Yavuz Nutku said: "Forever learning, Chandra couldn't care one bit about the establishment. Everything he did was out of being curious in a productive way. He did it for one reason and one reason only -- it would give him serenity and inner peace."

For those who are pursuing science or are planning to do we would like to end by quoting Chandrasekhar. "The pursuit of science has often been compared to the scaling of mountains, high and not so high. But who amongst us can hope, even in imagination, to scale the Everest and reach its summit when the sky is blue and the air is still: and in the stillness of the air survey the entire Himalaya range in the dazzling white of snow stretching to infinity. None of us can hope for a comparable vision of nature and of the universe around us. But there is nothing mean or lowly in standing in the valley below and awaiting the sun to rise over the Kunchenjunga."

Chandrasekhar died on August 21, 1995.

Fred Hoyle

The Most Versatile Astrophysicist of the 20th Century

"There is a coherent plan in the universe, though I don't know what it's a plan for."

"Hoyle's enduring insights into stars, nucleosynthesis, and the large-scale universe rank among the greatest achievements of 20th century astrophysics. Moreover, his theories were unfailingly stimulating, even when they proved transient."

Martin Rees, in Hoyle's obituary in Physics Today (November 2001)

"…..even his (Hoyle's) critics admit his unique creativity, originality and extraordinary perception. It would not be an exaggeration to call this extraordinary personality, the Galileo of modern times."

J. V. Narlikar in Hoyle's obituary in Current Science (October 2001)

Fred Hoyle is regarded 'as the most original and versatile astrophysicist' of the 20th century. Hoyle together with the British cosmologist and mathematician Hermann Bondi (1919-2004) and the Austrian-American astronomer Thomas Gold (1920-2004) proposed the Steady State theory of the universe, which was later discarded by most cosmologists in favour of the Big Bang theory. Irrespective of its present fate the Steady State theory will always be regarded as one of the highest points of intellectual development in human history. To many, Hoyle's fame as scientist primarily rests on his work on nucleosynthesis in stars; that is, the idea that the chemical elements were synthesised from primordial hydrogen and helium in stars. His work on stellar evolution is also highly significant.

To give a glimpse of Hoyle's diverse research works here we quote the well-known India astrophysicist J.V. Narlikar, who worked with Hoyle: "Hoyle's researches have given new directions to many branches of astrophysics. The origin of solar system, the evolution of stars, the origin of cosmic rays, the mystery of dust in the interstellar space, the phenomenon of accretion on stars, the formation of the Milky Way, radio sources, pulsars, quasars and, of course, his favourite branch cosmology…. In today's era of narrow specialization, it is extremely rare to find a scientist with such a variety of research interests and with such a seminal record of contributions with high impact factor".

Hoyle rejected many well-established theories, like chemical theories explaining the origin of life and Darwin's theory of evolution. He also propounded many unorthodox ideas. He was a great populariser of science, particularly of astronomy. He wrote many popular science books and was also a highly accomplished science fiction writer. Hoyle established the Institute of Theoretical Astronomy in Cambridge in 1967 and he was its first Director.

Fred Hoyle

Hoyle was born on 24 June 1915 at Bingley in West Yorkshire, England. Hoyle's father George Hoyle worked in the wool trade. His mother Mabel Hoyle (*nee* Pickard) was an expert in musica She had studied music at the Royal College of Music at London and excelled in playing the piano. Hoyle displayed unusual analytical ability at a very early age. He also developed an interest in the piano. At the age of three he was able to work out the way to read the clock and tell the time all by himself. At four he could write out the multiplication tables up to 12×12 =144. In his childhood Hoyle was much influenced by books such as Arthur Eddington's *Stars to Atoms* and T. E. Lawrence's *Seven Pillars of Wisdom*. Hoyle's interest in astronomy developed at a very young age.

Hoyle's primary education began at the Morning Road School in Bingley and he later studied at the Bingley Grammar School. Hoyle was anti-establishment since his childhood. Throughout his life he was "at war with the system." Hoyle himself wrote: "Between the ages of five and nine, I was perpetually at war with the educational system. My father always deferred to my mother's judgement in several crises of my early educational career, because she had been a school teacher herself…events would suggest that my mother was unreasonably tolerant of my obduracy. But, precisely because she had been a teacher herself, my mother could see that I made the best steps when I was left alone."

Hoyle did not take anything for granted until he was satisfied with it. In this context an interesting episode of Hoyle's childhood, described by Narlikar, may be worth quoting. "In his first primary school, a teacher once taught in the cla ss that a certain type of flower has five petals. The next day, Fred produced a flower of the same kind with six petals and asked the teacher to justify her statement.

The teacher, embarrassed and angered by this counter example, smote the boy's ear. Shocked by this unjustified response, Fred left school at once and came back home. He told his mother that he would never go to the school where such injustice prevailed. His mother supported his stand and argued his case with the school authorities, who finally gave her permission to change the boy's school. Later in his life, Hoyle had to face many such incidents, whenever he challenged the set attitudes of the establishments."

Hoyle joined the Emmanuel College in Cambridge where he was taught by some of the most outstanding scientists like Max Born (1882-1972), Arthur Stanley Eddington (1882-1944) and Paul Adrien Maurice Dirac (1902-1984). In 1936, he passed the Mathematical Tripos. He was among the top ten students of that year and was awarded the Mayhew Prize for being the best student in applied mathematics. He continued to do research in applied mathematics at Cambridge. For his outstanding work he was awarded the top Smith's Prize in 1938. In 1939, Hoyle published a major research paper on quantum electrodynamics in the *Proceedings of the Cambridge Philosophical Society*. After this his interest shifted towards mathematical problems in astronomy. In May 1939 Hoyle was elected to a Fellowship at St John's. He also received a highly prestigious award from the Commission for the Exhibition of 1851. With all these developments he was to embark upon a successful research career, but the outbreak of the Second World War disturbed everything. Hoyle had to join the war efforts. He worked for the Admiralty Signals Establishment where he worked on the development of radar with Hermann Bondi and Thomas Gold. The three together discussed astronomy in their spare time.

In 1944 Hoyle visited the US. Though he went there in connection with his work on radar, it gave him an opportunity to get familiar with the work on the atom bomb project. Here he became interested in nucleosynthesis, the process by which elements were produced in stars. After the War was over Hoyle came back to Cambridge and started working in astronomy.

The theory of the origin of most of the elements was worked out by Hoyle jointly with William Alfred Fowler and the husband-wife team of Geoffrey and Margaret Burbidge. This theory is referred to after its four authors as the 'B^2FH theory'. Their work was published in 1957 in the *Reviews of Modern Physics.* The conclusion reached in this classic paper has stood the test of time. This work earned William Alfred Fowler the Nobel Prize in Physics, jointly with the Indian-born astrophysicist Subrahmanyan Chandrasekhar in 1983. Many thought that Hoyle was denied the rightful claim to the Prize. In fact, Fowler himself in an autobiographical sketch prepared for the Nobel Foundation wrote: "The concept of nucleosynthesis in stars was first established by Hoyle in 1946. This provided a way to explain the existence of elements heavier than helium in the universe, basically by showing that critical elements such as carbon could be generated in stars and then incorporated in other stars and planets when that star "died ". The new stars formed now start off with these heavier elements and even heavier elements are formed from them. Hoyle theorised that other rare elements could be explained by supernovas, the giant explosions which occasionally occur throughout the universe, whose temperatures and pressures would be required to create such elements."

Nucleosynthesis is the process of creating elements by nuclear reactions. First, hydrogen is converted to helium by the proton-proton reaction or the carbon-nitrogen cycle. In proton-proton reaction, four hydrogen nuclei (that is, protons) fuse to form one nucleus of helium. The reaction also produces a number of intermediate nuclei such as deuterium and isotopes of lithium, beryllium, and boron. The carbon-nitrogen cycle converts hydrogen into helium and in the process releases nuclear energy. Carbon, nitrogen, and oxygen act as catalyst to speed up a six-stage reaction. It is also known as carbon-nitrogen-oxygen cycle. At temperatures below 18 million Kelvin the proton-proton reactions becomes more important than the carbon-nitrogen cycle. However, as temperatures go above 18 million Kelvin then the carbon-nitrogen cycle takes over the proton-nitrogen reaction.

Hoyle jointly with Bondi and Gold proposed a theory of the origi n of the Universe. This theory is known as the 'Steady State Theory'. According to this theory, the universe has no beginning and no end. It has remained unchanged with time. The theory assumes that the universe is homogeneous and isotropica To take care of the known expansion of the universe the theory stipulates that matter is spontaneously created and that is how the mean mass density of the universe remains at a constant value. To explain the appearance of new matter Hoyle postulated the existence of so-called the "creation field" or just the "C-field". This hypothetical field was thought to have negative pressure in order to be consistent with the conservation of energy. The C-field anticipated the later development of cosmic inflation.

It is interesting to note that that a ghost film provoked Hoyle and his co-workers Bondi and Gold to finally propose the Steady State Theory. The film was in four parts but linked the sections together to create a circular plot in which the end of the film became its beginning. From this film Hoyle got the idea, as he later admitted, that it was not necessary that unchanging situations had to be always statica Thus the universe could perhaps be both unchanging and dynamica

The steady-state model is based on four assumptions collectively known as the perfect cosmological principle:

1. Physical laws are universal. This means that any science experiment, if performed under identical conditions, will have the same result anywhere in the universe.
2. On a sufficiently large scale the universe is homogeneous.
3. The universe is isotropic; that is, there is no preferred direction in the universe.
4. Over sufficiently long time the universe looks essentially the same at all times.

The Steady State Theory was the only serious alternative to the Big Bang theory, which was in agreement with the Hubble's red-shift observations. According to the Big Bang theory, the universe originated from the initial state of unimaginably high temperature and density and it has been expanding ever since its origin. The theory of general relativity predicts the existence of a singularity at the very beginning, where the temperature and density of matter were infinite. The Big Bang theory also accounted for the expansion of the universe, the cosmic background radiation, and the abundance of light nuclei such as helium, helium-3, deuterium, and lithium-7.

Hoyle disagreed with the assumptions of the Big Bang Theory. To Hoyle the very idea of a universe with a beginning seemed to be philosophically troubling. A beginning implies a cause and there should be someone (a creator!) to begin it. The Steady State Theory attempted to demonstrate how the universe could be eternal and essentially unchanging while still expanding where the galaxies we observe move away from each other.

Incidentally, the term "Big Bang" was coined by Hoyle, and it was reported that the term was meant to make fun of the theory, which competed with Hoyle's own theory on the creation of the universe. However, Hoyle had no such thing in mind. The expression was intended to help his listeners to grasp the ideas behind the theory. In fact Hoyle himself explicitly stated that he had no intention to be insulting. He coined the term just to emphasise the difference between the two theories for radio listeners.

In 1993, a newer version of the Steady State Theory known as 'Quasi-Steady State cosmology' (QSS) was proposed by Hoyle, Geoffrey Burbidge, and Jayant V. Narlikar. It was an attempt to explain additional features unaccounted for in the initial proposal. The theory suggests pockets of creation occurring over time within the universe, sometimes referred to as 'mini-bangs', 'mini-creation events', or little bangs. According to the theory the creation events are linked with strong gravitational fields and can occur on various scales, with our part of the universe being in created about 15 billion years ago. After the observation of an accelerating universe, further modifications of the model were done.

Hoyle was highly critical of theories of chemical evolution used to explain the origin of life. He strongly believed in extra-terrestrial origin of life. He suggested that biological molecules such as amino acids are synthesised in space on dust particles. Hoyle also believed that infective agents such is viruses arrived from space. With Chandra Wickramasinghe, Hoyle promoted the theory that life evolved in space, spreading through the universe via panspermia, and that evolution on Earth is driven by a steady influx of viruses arriving via comets.

In his book *Evolution from Space* (co-authored with Chandra Wickramasinghe), Hoyle calculated that the chance of obtaining the required set of enzymes for even the simplest living cell was extremely remote. He argued that even a whole universe full of primordial soup would grant little chance to evolutionary processes. He claimed: "The notion that not only the biopolymer but the operating program of a living cell also could be arrived at by chance in a primordial organic soup here on the Earth is evidently nonsense of a high order." He further stated: "The chance that higher life forms might have emerged in this way is comparable with the chance that a tornado sweeping through a junk-yard might assemble a Boeing 747 from the materials therein…I am at a loss to understand biologists' widespread compulsion to deny what seems to me to be obvious."

Hoyle believed that the universe is governed by a greater intelligence. Hoyle presented 'Evolution from Space' for the Royal Institution's Omni Lecture. After considering the very remote probability of evolution he concluded: "If one proceeds directly and straightforwardly in this matter, without being deflected by a fear of incurring the wrath of scientific opinion, one arrives at the conclusion that biomaterials with their amazing measure or order must be the outcome of intelligent design. No other possibility I have been able to think of..." In his book *Evolution from Space* (1982), he distanced himself completely from Darwinism. He was of the opinion that "natural selection" could not explain evolution. In his book *The Intelligent Universe* (1983) he wrote: "Life as we know it is among other things dependent on at least 2,000 different enzymes. How could the blind forces of the primal sea manage to put together the correct chemical elements to build enzymes?"

In one of his early papers Hoyle made an interesting use of the anthropic principle. While trying to figure out the routes of stellar nucleosynthesis, he observed that one particular nuclear reaction generating carbon called the triplealpha process would require the carbon nucleus to have a very specific energy for it to work. The presence of large amount of carbon in the universe demonstrated that this nuclear reaction must work. Based on this assumption Hoyle made a prediction of the energy levels in the carbon nucleus. This was later proved to be correct experimentally. However, those energy levels, while needed in order to produce carbon in large quantities, were statistically very unlikely. Hoyle later wrote: "Would you not say to yourself, 'Some super-calculating intellect must have designed the properties of the carbon atom, otherwise the chance of my finding such an atom through the blind forces of nature would be utterly minuscule.' Of course you would . . . A common-sense interpretation of the facts suggests that a super-intellect has monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature. The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question."

Hoyle wrote a large number of popular science books. Some of the titles are: *Frontiers of Astronomy* (1955); *Astronomy: A history of man's investigation of the universe* (1962); *Nicolaus Copernicus* (1973); *The Intelligent Universe* (1983); *Evolution from Space: A Theory of Cosmic Creationism* (1984); *Home Is Where the Wind Blows: Chapters from a Cosmologist's Life (Autobiography)* (1994); and *Mathematics of Evolution* (1987).

Hoyle played a great role in popularising science, particularly astronomical sciences, through his radio talks, popular science writings and science fictions. Commenting on his science popularisation efforts the citation of the Royal Medal of the Royal Society stated: "…his popularisation of astronomical science can be warmly commended for the descriptive style used and the feeling of enthusiasm about his subject which they succeeded in conveying."

Hoyle wrote about 40 books on science fiction, many of which he co-authored with his son Geoffrey Hoyle. Some of his science fiction works are: *The Black Cloud* (1957); *Ossian's Ride* (1959); *A for Andromeda: A Novel for Tomorrow* (Co-authored with John Elliot, 1962); *Fifth Planet* (co-authored with Geoffrey Hoyle, 1963); *Andromeda Breakthrough* (co-authored with Geoffrey Hoyle, 1965); *October the First Is Too Late* (1966); *Element 79* (1967); *Rockets in Ursa Major* (co-authored with Geoffrey Hoyle, 1969); *Seven Steps to the Sun* (co-authored with Geoffrey Hoyle, 1970); *The Inferno* (co-authored with Geoffrey Hoyle, 1973); *The Molecule Men and the Monster of Loch Ness* (co-authored with Geoffrey Hoyle, 1973) ; *Into Deepest Space* (co-authored with Geoffrey Hoyle, 1974), *The Incadescent ones* (co-authored with Geoffrey Hoyle, 1977); *The Westminster Disaster* (co-authored with Geoffrey Hoyle, 1978); and *Comet Halley* (1985).

He was elected to many academies and learned societies including the Royal Society of London (1957), the National Academy of Sciences of the United States of America (1969), the Royal Irish Academy (1977), and the American Philosophical Society (1980). He was the Vice President of the Council of the Royal Society. He was the President of the Royal Astronomical Society. Among the awards received by Hoyle included: *Gold Medal* of the Royal Astronomical Society (1968); *Bruce Medal* (1970): *Henry Norris Russell Lectureship* (1971); Royal Medal (1974); *Klumpke-Roberts Award* of the Astronomical Society of the Pacific (1977) and *Crafoord Prize* from the Royal Swedish Academy of Sciences, with Edwin Salpeter (1997). It may be noted here that the Crafoord Prize is a highly prestigious award given by the Swedish Academy in recognition of outstanding basic research in fields not covered by the Nobel Prize. Asteroid '8077 Hoyle' is named in his honour. He was awarded the United Nations' Kalinga Prize in 1968 for his contributions in the field of science popularisation.

Besides his autobiography, other important biographical works include: *Conflict in the Cosmos: Fred Hoyle's Life in Science* by Simon Mitton (2005); *The Scientific Legacy of Fred Hoyle* by Douglas Gough (ed) (2005); *A Journey with Fred Hoyle: The Search for Cosmic Life* by Chandra Wickramasinghe (2005); and *Fred Hoyle's Universe* by N. CA Wickramasinghe, Geoffrey Burbidge a nd J. V. Narlikar (Editors) (2003).

J. V. Narlikar wrote: "Hoyle believed that a scientist should be sensitive to the issues affecting society and he himself did not hesitate to express his opinions publicly. In the 1970s, he wrote a book arguing that nuc lear power alone can solve the energy crisis of the world. He had published a scholarly book which seeks to relate the old relics at Stonehenge in England to practices related to astronomy in the ancient civilization. He gave well -argued lectures on the dangers of the future growth of population."

Hoyle died on 25 August 2001 in Bournemouth, England.

In the last page of his autobiography Hoyle wrote: "After a lifetime of crabwise thinking, I have gradually become aware of the towering intellectual structure of the world. One article of faith I have about it is that, whatever the end may be for each of us, it cannot be a bad one."

Martin Ryle

A Pioneer of Radio Astronomy

"Radio astronomy didn't really begin to catch on until after World War II, but when it did, astronomers became excited about this new way of searching the skies. Radio waves could penetrate the dust clouds in space that absorb sunlight and make optical astronomy difficult. Radio waves are especially helpful, therefore, in studying the Centre of our galaxy, which we cannot see at all by ordinary means."

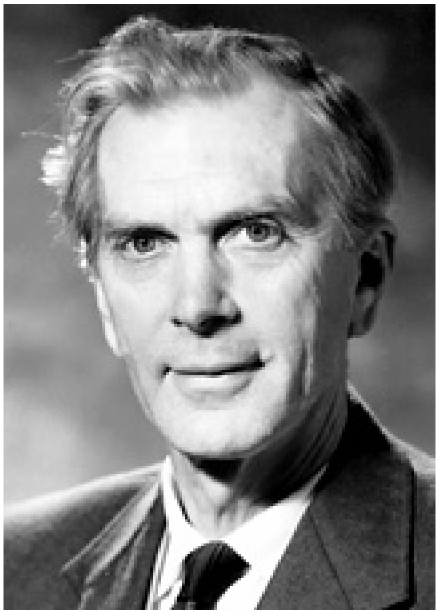
Ray Spangenburg and Diane K. Moser in "The History of Science: From 1946 to the 1990s", Universities Press (India), Hyderabad, 1999

"Ryle quickly appreciated that the distribution of radio sources throughout the universe had cosmological implications and that the number of sources found tended to support the evolutionary big bang theory rather than the steady-state theory." *A Dictionary of Scientists*, Oxford University Press, 1999 "Ryle was a key figure in the development of radio astronomy after the Second World War, following the pioneering discoveries of Jansky and Reber."

The Cambridge Dictionary of Scientists, 2002

Martin Ryle is considered as one of the great astronomers of the 20 th century. He developed revolutionary radio telescope system for locating weak radio sources. Ryle observed the most distant known galaxies of the universe of his time. He received the Nobel Prize for Physics in 1974, jointly with Antony Hewish. They were given the Prize "for their pioneering research in astrophysics: Ryle for his observations and inventions, in particular of the aperture synthesis technique, and Hewish for his decisive role in the discovery of pulsars." This was first Nobel Prize given in recognition of astronomical research.

Under Ryle's guidance the radio astronomy group of the Cavendish Laboratory developed the radio source catalogues, known as the *Cambridge Catalogues*. The *Third Cambridge Catalogue*, which was produced in 1959, led to the discovery of the first quasi-stellar object or quasar. Ryle's results, which showed that the distant parts of the universe appeared different from the nearer parts, supported the Big Bang theory of the origin of the universe rather than a steady state theory. In 1948 Ryle was appointed to a Lectureship in Physics and in 1949 he was elected to a Fellowship at Trinity College of Cambridge University. In 1959 Cambridge University created its first Chair of Radio Astronomy and Ryle became its first incumbent. Ryle founded the Mullard Radio Astronomy Observatory in 1957 and he was its first Director. In 1959 Ryle became the first professor of Radio Astronomy at the University of Cambridge. He succeeded Richard Woolley as Astronomer Royal (1972 -82).



Martin Ryle

Ryle was born on 27 September 1918 at Brighton, England. His father John A. Ryle was a doctor who was appointed to the first Chair of Social Medicine at Oxford University. Ryle was the nephew of the wellknown British philosopher Gilbert Ryle (1900-1976). In 1939, Ryle graduated from the University of Oxford in physics and then he worked with the Telecommunications Research Establishment on the design of radar equipment during the Second World War. After the War he got a Fellowship for working at the Cavendish Laboratory of Cambridge University. In getting the fellowship at Cambridge he was helped by the influential British Radio physicist John Ashworth Ratcliffe (1902-1987). Ryle had earlier worked with Ratcliffe during the War. At Cambridge, Ryle became an early investigator of extraterrestrial radio sources. He developed an advanced radio telescope.

During his early period at the Cavendish Laboratory, Ryle was encouraged by Ratcliffe and William Lawrence Bragg. Ryle wrote: "During these early months, and for many years afterwards both Ratcliffe and Sir Lawrence Bragg, then Cavendish Professor, gave enormous support and encouragement to me. Bragg's own work on X-ray crystallography involved techniques very similar to those we were developing for 'aperture synthesis', and he always showed a delighted interest in the way our work progressed." Ryle's early work at the Cavendish Laboratory centred on studies of radio waves emitted by the Sun, sunspots, and a few nearby stars. Ryle realised the need of developing better observing techniques for better observation of the radio sources. Under his leadership the Cambridge group took up this challenge and created and improved the astronomical interferometry and aperture synthesis technique. Radio astronomy is a branch of astronomy that studies celestial objects at radio frequencies. Before the emergence of radio astronomy, astronomers knew only about objects in the universe that shone in visible light. Radio astronomy opened up many parts of the universe that were invisible to astronomers till then. There is a wide radio window covering wavelengths from about 1 mm to 30 m, almost all of it accessible from ground-based observatories, both day and night. Radio window is the region of the electromagnetic spectrum in the radio frequency band within which radio waves can pass through the Earth's atmosphere without significant amount of reflection or attenuation by the constituents of the atmosphere. Radio signals from space are detected and measured by instruments called radio telescopes.

The advances in radio astronomy led to many important discoveries including radio galaxies, quasar, pulsars, maser sources, and the cosmic microwave background radiation. A radio galaxy is a radio source outside the Milky Way that has been previously identified with an optical visible galaxy. A radio galaxy is an unusually powerful emitter of radio waves with output of the order of up to 1038 watts – a million times greater than a normal galaxy such as the Milky Way. It is believed that the radio source of a radio galaxy is powered by super-massive black hole located in the nucleus of the galaxy. A quasar is an object with a high red shift, which looks like a star, but is probably the very luminous active nucleus of a distant galaxy. The name is a contraction of 'quasi star', from their star-like appearance. Quasars were discovered by Allan Sandage and Maarten Schmidt.

Pulsars are rapidly spinning neutron stars having a diameter of 20-30 km. A pulsar is a radio source from which highly regular train of pulses are received on Earth. Pulsars were discovered by Anthony Hewish and Jocelyn Bell. A maser source in space is a radio source in which the spectral lines of an atom, ion, or molecule are greatly amplified by maser action to produce an intense source of radio emission. It may be noted that in maser, radiation at a certain frequency causes excited atoms, ions or molecules of a gas to emit further radiation in the same direction and the same wavelength, resulting in amplification.

The idea that dark matter is an important component of the universe has been substantiated by the findings of radio astronomy. Radio measurements of the rotation of galaxies have indicated there should be much more mass in galaxies than what has been actually observed.

The fact that celestial objects may be emitting radio waves was anticipated before its actual discovery. James Clerk Maxwell's equations developed in the 1860s had indicated that electromagnetic radiation from stellar sources could exist with any wavelength and not just in optical wavelengths. Noted scientists and experimentalists like Nikola Tesla, Oliver Lodge and Max Planck had predicted that the Sun should be emitting radio waves. In fact, Lodge had attempted to observe radio signals emitted by the Sun but he failed to detect them due to technical limitations of his apparatus.

It was American Radio engineer Karl Guthe Jansky (1905-1950), who discovered the first astronomical radio source. It was an example of chance discovery. Jansky, an engineer with Bell Telephone Laboratories, was investigating static that interfered with short-wave transatlantic voice transmission by using a large directional antenna. During his investigation Jansky found that his analog pen-and-paper recording system was continuing recording a repeating signal, the origin of which was not known. Jansky's original assumption was that the Sun might be the source of the interference. His assumption was based on the fact that the signal peaked once a day. However, detailed continuous analysis revealed that the source of the signal was not following the 24-hour cycle for the rising and setting the Sun. Instead it was repeating on a cycle of 23 hours and 56 minutes, a cycle typical of an astronomical source 'fixed' on the celestial sphere rotating in synchronous with sidereal time. After comparing his observations with astronomical maps Jansky reached the conclusion that the source of the radiation was located in the Milky Way. He also observed that the radiation was the strongest in the direction of the centre of the Galaxy or the Sagittarius constellation. Jansky's discovery was announced in 1933. Jansky wanted to investigate further but he had to abandon his plan as he was asked by the Bell Laboratories to work on another project. In 1937, American amateur astronomer Grote Reber (1911-) built a large paraboloidal "dish" radio telescope with a diameter of 9.4 metres. The telescope was movable in declination like a transit instrument; that is, a telescope constrained to rotate in the plane of the meridian about a horizontal axis mounted east-west. Reber conducted the first sky survey in the radio frequencies. He detected many radio sources or radio stars including Cassiopeia A and Cygnus A that did not correspond to visible stars. He also found that the Sun and the Andromeda Galaxy emit radiatio at radio wavelengths. From the time he built his radio telescope till the end of the Second World War, Reber was the only radio astronomer in the world. Like Jansky, he was a pioneer in radio astronomy. Another early radio astronomer was J. S. Hey, a British Army research officer, who made a discovery that the Sun emitted radio waves.

It was Martin Ryle who brought a revolution in radio astronomy. After the end of the Second World War, Ryle began to establish a centre for radio astronomy at the Cavendish Laboratory, Cambridge. He opted for radio interferometers rather than parabolic receivers employed earlier. It was the difficulty in achieving high resolutions with single radio telescopes that led Ryle and Australian-born engineer, radio physicist, and radio astronomer Lade Pawsey to develop radio interferometry. A radio interferometer consists of widely spaced radio telescopes that are connected together for observing the same object at the same time.

Using radio interferometry Ryle developed the technique of aperture synthesis, a technique used in radio astronomy to achieve vast increase in William Lawrence Bragg Grote Reber angular resolution. The technique uses an array of telescopes to simulate a single telescope of large aperture. To achieve a high-quality image a large number different separations between different telescopes called baselines are required. Aperture synthesis requires complex data-reduction techniques and powerful computers. Examples of aperture telescopes are MERLIN, the Ryle Telescope, the Very Large Array, and the Westerbork Synthesis Radio Telescope. Ryle used 12 t elescopes to develop the first radio interferometer. The Very Large Array has 27 telescopes giving 351 independent baselines at once.

Ryle and his group conducted surveys of radio -emitting sources in the universe. These surveys called cosmological survey s mapped the radio sources. The results of the surveys were published in the form of catalogues known as *Cambridge Calalogues*. The first cosmological survey was completed in 1950 and it identified 50 radio sources. The second survey completed in 1955identi fied about 200 radio sources.

The third survey was the most crucial. The results of the third survey were published in 1959 in the *Third Cambridge Catalogue* (3C). It listed the positions and strengths of 500 radio sources. It has become the definitive ca talogue used by all astronomers. The third survey led to the discovery of the first quasi -stellar object. Ryle and his group identified a radio source 500 million light years away from the Solar System. This object was located in the Cygnus constellation. This discovery underlined the importance of radio telescopes. The identification of an object at such great distance mean that one can see very far back into the history of the universe, and which in turn can help reveal information on the origin of the universe. The fourth survey, which was completed in 1965, detected radio sources five times fainter than those in the third survey. This was made possible by use of more sensitive receivers.

The fourth survey covered whole of the northern sky and it catalo gued 5,000 sources. Further in-depth surveys of the sky were undertaken with the opening of two highly sensitive radio telescopes in 1965 and 1971.

Ryle was not an easy person to work with. He had a hot temper. Most of the time he used to work in an offi ce at the Mullard Radio Astronomy Observatory so that he did not get entangled in heated arguments with other members of the Cavendish Laboratory. He had a famous heated argument with

Fred Hoyle on the latter's Steady State Theory. This debate is believed to have reduced collaboration between Hoyle's Institute of Astronomy and Ryle's Radio Astronomy Group at the Cavendish Laboratory.

Ryle believed that the only way to save our planet from complete nuclear annihilation was to put indefinite ban on use of a ny kind of nuclear device. He wrote on the politic of nuclear disarmament or the so -called nuclear proliferation. In his book, *Towards the Nuclear Holocaust* (1981), Ryle expressed his concerns about nuclear arms race and the misuse of science. He was great advocate of renewable sources of energy. He championed the cause of wind power in England.

In recognition of his work Ryle received numerous awards and honours. He was elected a Fellow of the Royal Society of London in 1952. He was the President of Commission 40 of the International Astronomical Union (1964 -1967). Among his other awards included Hughes Medal of the Royal Society of London (1954); Gold Medal of the Royal Astronomical Society of London (1964); Henry Draper Medal of the US National Academy of Sciences (1965); Royal Medal of the Royal Society of London (1973); Bruce Medal of the Astronomical Society of the Pacific (1974). In 1966, the British Government Knighted Ryle for his achievements in radio astronomy. Ryle died on 14 October 1984 in Cam bridge after fighting a long battle with lung cancer.

Antony Hewish
Who Played a Decisive Role in Discovery of Pulsars

"I believe scientists have a duty to share the excitement and pleasure of their work with the general public, and I enjoy the challenge of presenting difficult ideas in an understandable way."

Antony Hewish

Antony Hewish is known for his work on the development of radio aperture synthesis and its role in the discovery of pulsars. The discovery of pulsars revolutionised astrophysics. A pulsar is a shortened term for `pulsating radio star'. Pulsars are extremely dense. Pulsars are actually rapidly spinning neutron stars. The spinning periods of neutron stars vary from few seconds to thousandths of a second. Neutron stars are formed by the explosions of certain stars at the end of their lives. Such explosions are called supernovae. The masses of neutron stars are more than 1.4 times the mass of the Sun, the upper limit being two and three solar masses. Exotic astronomical objects like pulsars and quasars (quasi stellar objects) were first detected in the 1960s by their radio emissions. Since the first discovery of pulsar in 1967 astronomers have identified more than 100 pulsars and it is estimated that there are more than one million active pulsars in our galaxy Milky Way.

Hewish was born on May 11, 1924 in Fowey, Cornwall. His father was a banker. Hewish grew up in Newquay, on the Atlantic coast. He was educated at King's College, Taunton before he joined the Gonville and Caius College of the Cambridge University as an undergraduate student. However, his studies at Cambridge were interrupted because of the Second World War. He had to join the war service. He first worked at the Royal Aircraft Establishment and then at the Telecommunications Research Establishment. During this period he came in contact with Martin Ryle. He returned to Cambridg e in 1946. Immediately after completing his undergraduate studies at the Gonville and Caius he joined Ryle's research team at the Cavendish Laboratory. Commenting on how he developed an interest in radio astronomy Hewish said: "My decision to begin reasear ch in radio astronomy was influenced both my wartime experience with electronics and antennas and by one of teachers, Jack Racliffe, who had given an excellent course on electromagnetic theory during my final undergraduate year and whom I had also encountered at Malvern. He was head of radiophysics at the Cavendish Laboratory at that time."

Hewish obtained his PhD in 1952. In 1971, Hewish was appointed Professor of Radio Astronomy at the Cambridge University. He also served as

Director of the Mullard Radio Astronomy Observatory from 1982 to 1988. Commenting on his professional career Hewish writes: “Returning to Cambridge in 1946 I graduated in 1948 and immediately joined Ryle’s research team at the Cavendish Laboratory. I obtained my PhD in 1952, became a Research Fellow at Gonville and Caius College where I had been an undergraduate, and in 1961 transferred to Churchil College as Director of Studies in Physics. I was University Lecturer during 1961-69, Reader during 1969-71 and Professor of Radio Astronomy from 1971 until my retirement in 1989. Following Ryle’s illness in 1977 I assumed leadership of the Cambridge radio astronomy group and was head of the Mullard Radio Astronomy Observatory from 1982 -88.”

Antony Hewish

In the early phase of his research career, Hewish exploited the apparent scintillations or ‘twinkling’ of radio sources to probe conditions in the ionosphere. Radio scintillation is a phenomenon similar to the twinkling of visible stars, that arises from random reflections of radio waves by ionised gas. The three types of scintillations are caused by ionised gas in the interstellar medium, in the interplanetary medium, and in the Earth’s atmosphere. Hewish was involved in the investigations of the three radio scintillations. He pioneered measurements of the height and physical scale of plasma clouds in the ionosphere and estimated wind speeds in this region. Following his successes in exploiting interstellar scintillations he conceived the idea of a giant phased-array antenna so that he can exploit his technique on a large sample of radio galaxies. He constructed a large array radio telescope at the Mullard Radio Astronomy Observatory, Cambridge University. Hewish got funds for constructing the antenna in 1965 and it was completed by mid-1967. The survey started in July 1967.

Hewish played decisive role in the discovery of pulsars. It was Jocelyn Bell who first discovered the radio source in July 1967, which later proved to be pulsar. The discovery was published in a paper published in Nature. The paper had five authors. Hewish was the first author and Bell was the second. The other three authors were J D. H. Pilkington, P. F. Scot and R. A. Collins. This discovery attracted lot of attention from the generally public as well as astronomers. It dramatically extended the existing knowledge of the universe. There was a particular reason for widespread interest in this subject. The period of the pulsar identified by Bell and Hewish was so regular that its discoverers initially thought that it might be an interstellar beacon or radio lighthouse of an alien civilisation. They named the source Little Green Men-1 (LGM1). The idea was dropped after the rapid discovery of three more pulsars.

Though Bell made the first actual observation, she was not considered for the Nobel Prize alongwith Hewish. Many fellow astronomers including Fred Hoyle expressed their discontentment on this issiue. But then one can argue that Ryle and Hewish were given the Prize for their total work on radio astronomy with special mention of Ryle's work on aperture-synthesis, and Hewish's on pulsars.

In his Nobel Prize lecture Hewish gave a fascinating account of this sensational discovery. "The trail which ultimately led to the first pulsar began in 1948 when I joined Ryle's small research team and became interested in the general problem of the propagation of radiation through irregular transperant media…In 1965 I drew up plans for radio telescope with which I intended to carry out a large-scale survey of more than 1000 radio galaxies…The final design was an array containing 2048 dipole antennas. Later that year I was joined by a new graduate student, Jocelyn Bell…The radio telescope was complete, and tested, by July 1967 and we immediately commended a survey of the sky…One day around the middle of August 1967 Jocelyn showed me a record indicating fluctuating signals…we first thought that the signals might be electrical interference…It was not until November 28th that we obtained the first evidence of our mysterious source was emittining regular pulses of radiation at intervals of just greater than one second. I could not believe that any natural source would radiate in this fashion and I immediately consulted astronomical colleagu es at other observatories to enquire whether that had any equipment in operation which might possibly generate electrical interference…Still sceptical, I arranged a device to display accurate time marks at one second intervals…To my astonishment the readings fell in a regular pattern, to within the observational uncertainty of 0.1s (second), showing that the pulsed source kept time to better than 1 part in 10^6. Meanwhile my clleagues Pilkington, and Scot and Collins, found by quite independent methods that the signal exhibited a rapidly sweeping frequency of about –5MHz/s the duration of each pulse…was approximately 16 milli seconds. Having found no satisfactory terrestrial explanation for the pulses we now began to believe that they could only be generated by some source far beyond the solar system, and the short duration of each pulse suggested that the radiator could not be larger than a smaller planet…The months that followed the announcement of our discovery were busy ones for observers and theoreticians alike, as radio telescopes all over the world turned towards the first pulsars and information flooded in at a phenomenal rate."

Hewish believes that there should be a relationship between science and religion. When he was asked why there what this relationship should be he replied: "I think both science and religion are necessary to understand our relation to the Universe. In principle, Science tells us how everything works, although there are many unsolved problems and I guess there always will be. But science raises questions that it can never answer. Why did the big bang eventually lead to conscios beings who question the purpose of life and the existence of the universe? This is where religion is necessary."

Hewish was elected a Fellow of the Royal Society of London in 1968. He was awarded the Nobel Prize for Physics in 1974. He shared the prize with Martin Ryle. They were awarded the Prize for their pioneering research in radio astrophysics: Ryle for his observations and inventions, in particular of the aperture synthesis technique, and Hewish for his decisive role in the discovery of pulsars." Hamilton Prize, Cambridge (1952); Eddington Medal, Royal Astronomical Society (1969); Charles Vernon Boys Prize, Institute of Physics (1970); Dellinger Medal, International Union of Radio Science (1972); Michelson Medal, Franklin Institute (1973); Hopkins Prize, Cambridge Phiolosophical Society (1973); Holwech Medal and Prize, Societe Francaise de Physique (1974).

Manali Kallat Vainu Bappu
Doyen of Modern Indian Astronomy

"His (Vainu Bappu's) spirit was generous, kind, non -cynical—even hero-worshipping in the best sense of the word. He deeply admired if not even venerated his teachers and those, living or dead, who had really accomplished something. He well knew and understood human frailities, but to Vainu the important things were those qualities and works of great men and women which should be admired and emulated as far as possible in his own life."

Harlan J Smith, the first Director of the McDo nald Observatory of the University of Texas at Asutin and a close friend of Vainu Bappu (quoted from Resonance, 2002)

"Bappu had formulated ambitious plans for the growth of astronomy in India. He had identified new thrust areas and convinced other physic al laboratories to take up work in related projects. He played major roles in the formation and growth of academic societies, nurtured a new international journal in astrophysics, and took great interest in the popularisation of astronomy among the young."

J CA Bhattacharya in Resonance, August 2002.

Vainu Bappu is rightly regarded as the `main architect of revival of astronomical studies in India.' He played an instrumental role in establishing a nu mber of astronomical institutions in India. He played a significant role in establishing the Indian Insitute of Astrophysics in Bangalore.

Bappu, alongwith two of his colleauges discovered the Bappu -Bok-Newkirk comet. Bappu alongwith Olin Chaddock Wilson described Wilson-Bappu effect in a paper published in 1957. This paper opened up the stellar chromospheres for research. The Wilson -Bappu effect not only became a new luminosity indicator but it also gave an impetus to the study of stellar chromosphere.

He had wide ranging interest including painting, music, literature, gardening and architecture. He was an eloquent speaker and he could hold an audience spellbound with his lecture. While giving lectures he used to often quote from classics. So there was no wonder that one would find woks of Shakespeare, Scott, Kippling among others.

Bappu was born in Chennai (then Madras) on August 10, 1927. His father Sunanna Bappu was an astronomer at the Nizamiah Observatory, Hyderabad. His mother was Manali kukuzhi. He was the only child of his parents. Influenced by his father Bappu developed a keen interest in astronomy since his childhood.

Once he said: "I learnt my astronomy on the lap of my father." Since his school days he was an accomplished amateur astronomy. In 1946, he published two papers on astronomy in Current Science, a journal of the Indian Academy of Sciences, Bangalore. The papers were titled "The effect of colour on the visual observations of long-period variable stars" and "On the visual light curve of LT Eridani."

For preparing his MSc degree he joined the Nizam College (1946 -48) as its Fellow. While a student of the Nizam College he built a spectrograph of dispersion 120 A^0 /mm. He used it to obtain spectrograms of the air glow. In 1949, he obtained his MSc degree in physics from the Madras University, for which he submitted a thesis on spectroscopic and photoconducting properties of amethyst quartz.

Manali Kallat Vainu Bappu

After completing his Master's degree in physics from the Madras University, he joined Harvard Graduate School of astronomy as a "hyderabad state scholar for postgraduate studies in astronomy (1949 -51)." Spencer Jones and Harlow Shapley, who visited India, persuaded the Hyderabad government to grant Bappu a scholarship. At the time Bappu joined the Harvard astronomy school, it faculty included such accomplished astronomers as Harlow Shapley, Donald Menzel, Bart J. Bok, Cecilia Payne-Gaposchkin and Fred Whipple. Commenting on Bappu's days as a research student at Harvard, his friend and colleague Harlan J. Smith wrote: "…Vainu was anything but solemn. He laughed, and joined in most of the games and jokes. He found the necessary paraphernalia, and organised at the observatory what must have been the only cricket team within a few hundred miles, teaching us the mysteries of the sticky wickets and googlie-balls. On one occasion he gaily commented on some virtues of yoga, to the amused condescension of some of the graduate students."

After a few months of his arrival at Harvard, Bappu with Bart J. Bok and Gordon A. Newkirk, Jr., discovered a comet. This purely accidentaly discovery was made on July 02, 1949. Perhaps Bappu is the only Indian who has discovered a comet. The comet was named Comet Bappu-Bok-Newkirk (C/1949 N1). Sometimes it is also referred to as Comet Bappu-Bok-Whipple. The discovery has been beautifully described in an obituary on M. K. Vainu Bappu written by R. K. Kochhar and M. G. K. Menon in the Bulletin of the Astronomical Society of India. They wrote: "The discovery (of the comet) has an interesting history. On the early morning of 2 July 1949, Vainu Bappu took a 60 min exposure plate in Cygnus, for a special program, with the 24-33 inch Jewett Schmidt telescope at the Oak Ridge station of the Harvard college observatory. The plate was developed the following afternoon, and just as Bok and Bappu started to examine it for image quality and focus, Newkirk, and undergraduate student, who chanced to pass by—it had been a hot day and he was looking for his shirt—was invited to note the excellent quality of the plate. On inspecting it, he noticed the trail of `an asteroid or something'. Upon which Bok took a look and commented: `This is no asteroid—this is a hairy comet.' Apart from the discovery of the comet on the plate that he took, Bappu's achievement was in computing its orbit immediately, ahead of the more experienced workers."

When the news of the discovery reached to India, the Hyderabad state government sent a communication to the Indian Embassy in Washington DC to advise the student (Bappu) to undertake research as per the terms and conditions and not indulge in discovering comets. "See that your government's wishes are carried out in every respect", the communication noted. Fred Whipple took up the matter with the officials of the Hyderabad state government. He wrote: "This is the first occasion in my experience in which a foreign government has taken on itself the criticism of our educational methods in the Astronomy Department of Harvard University." He further requested them to communicate the reasons for their criticism to the Harvard authorities instead of "reprimanding the student in such a way that he finds it difficult to follow our guidance in his advance education."

He obtained his PhD in 1952. The title of his thesis was "The problems of Wolf-Rayet atmospheres". His PhD superviser was Donal Menzel. After his PhD he worked for a brief period as Carnegie post-doctoral fellow at the Mt Wilson and Palmar observatories where jointly with Olin CA Wilson he discovered an important phenomenon now called the Wilson-Bappu effect. It is the correlation between the measured width of the emission feature at the centre of the Ca II K line and the absolute visual magnitude of the star. This correlation is independent of spectral type and applicable to stars of type G. K, and M.

Bappu returned to India in December 1952. While returning to India he also visited observatories in England, France, and Italy. He returned with the determination to put India on the astronomical world map. However, to start with he did not even a job. In those day India did not have institutional infrastructure to carry out research in modern astronomy. Bappu was fully aware of the prevailing situation in India with respect to astronomical research in India. He himself once said: "I was returning to a country with facilities which were primitive compared compare to those in the United States; the largest telescope I could expect to use was a 15-inch refractor. For this reason, I took…with me…a photomultiplier tube, some optics for a spectrograph, and some Coude and Cassegrain spectra taken at Mt Wilson and Palomar. My principal encouragement was some advice from Plaskett on how it was possible to do good work even with limited resources if the topics were chosen carefully. Such words were crucial and have on occasions had great significance; I have had occasion to recall them many times in the next quarter-century."

One of the conditions of the scholarship, which enabled him to go to the Harvard University was that on return to India he would serve the Hyderabad state. The government could not offer him a job in astronomy and so by July 1953 he was told that he could try elsewhere. In January 1954, he got a senior research fellowship of the National Institute of Sciences (later renamed as the Indian National Science Academy).

In November 1954, Bappu joined the Uttar Pradesh State Observatory (UPSO), Varanasi, as the Chief Astronomer. This Observatory had been established in April 1954 with the initiative taken by A. N. Singh, the Principal of the newly established DSB Government College, Nainital. Singh became its honorary director. After his death in July 1954, Bappu headed the observatory. He could convince the then Chief Minister of Uttar Pradesh to promote astronomy in the state in a big way and shift the observatory to a location better suited for observation. Thus the observatory was moved to Nainital in November 1955.

In 1960 he took over as Director of the Kodaikanal Observatory in Tamil Nadu. The observatory was originally established by the East India Company in the late eighteenth century "to promote the knowledge of astronomy, geography and navigation in India." It had a glorious past and accomplished astronomers like Norman Pogson and John Evershed worked here. But when Bappu took over its charge was in a very bad shape. But Bappu transformed this old and outdated institution into an active centre of astronomical research. In early 1970s he established a new observing station at Kavalur and it produced results that could be compared to those of the world's leading observatories. He conceived and steered a project building a 93-inch telescope. It was completely designed and fabricated indigenously. However, because of his untimely death Bappu could not see it functioning. Both the observatory and the telescope have been named after Bappu.

He was not simply concerned with institution building. He also pursued his research career. He worked on diverse topics including structure of the solar atmosphere, planetary rings, Wolf-Rayet stars, clusters, stellar associations and galaxies. Bappu had a special interest in solar eclipses.

Bappu served as a visiting professor at the University of Arizona and Kitt Peak National Observatory (1963), a Fellow of the Japan Society for the Promotion of Science (May-June 1981), Vikram Sarabhai Professor at the Physical Research Laboratory, Ahmedabad (November-December 1981). He also served as Editor of the Journal of Astrophysics and Astronomy, a journal of the Indian Academy of Sciences, Bangalore. He was the first President of the Astronomical Society of India (1973-74).

He was awarded the Donhoe Comet-Medal (1949) instituted by the Astronomical Society of the Pacifica He served as Vice President (1967-73) and President (1979) of the International Astronomical Union. He was elected as Honorary Fellow of the Belgium Academy of Sciences, an honorary foreign associate of of the royal Astronomical Society, London and Honorary Member of the American Astronomical Society. Bappu was awarded the Shanti Swarup Bhatnagar Prize of the Council of Scientific and Industrial Research (1970), the Hari Om Trust's Meghnad Saha Award of the University Grants Commission for research in theoretical sciences (1977), the Satyendranath Bose Medal of the Indian National Science Academy (1983). The Government of India awarded him Padma Bhushan in 1981.

Bappu died on August 19, 1982 in Munich. At the time of death he was just 55 years old.

Arno Allan Penzias and Robert Woodrow Wilson
Discoverers of the Cosmic Background Radiation

"Cosmology is a science which has only a few observable facts to work with. The discovery of the cosmic microwave background radiation added one—the present radiation temperature of the universe. This, however, was a significant increase in our knowledge since it requires a cosmology with a source for the radiation at an early epoch and is a now probe of that epoch. More sensitive measurements of the background radiation in the future will allow us to discover additional facts about the universe."

Robert W. Wilson in his Nobel Lecture delivered on December 08, 1978.

"Throughout most of recorded history, matter was thought to be composed of vari ous combinations of four basic elements; earth, air, fire and water. Modern science has replaced this list with a considerably longer one; the known chemical elements now number well over one hundred. Most of these, the oxygen we breathe, the iron in our blood, the uranium in our reactors, were formed during the fiery lifetimes and explosive deaths of stars in the heavens around us. A few of the elements were formed before the stars even existed during the birth of the universe itself."

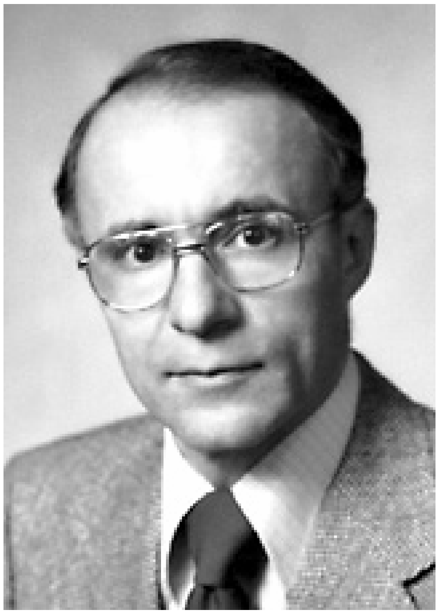
Arno A. Penzias in his Nobel Lecture on December 08, 1978.

Penzias was born on April 26, 1933 in Munich, Germany. With the rise of Hitler Jews were forced to leave the country or face persecution. The situation was such that his parents had to send their two small children o n their own to England. At the time Penzias was barely six year old. Penzias in his autobiographical note prepared for the Nobel Foundation wrote: "In the late spring of 1939, shortly after my sixth birthday, my parents put their two boys on a train for En gland; we each had a suitcase with our initials painted on it, as well as a bag of candy. They told me to be sure and take care of younger brother." Penzias and his brother somehow reached England. His parents also followed them but at different points of time. They had to wait to meet their father.

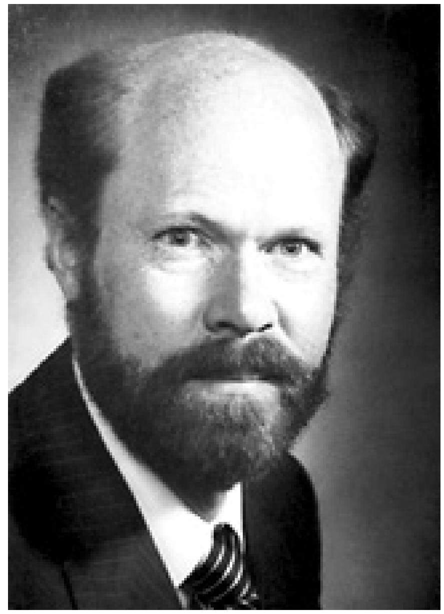
Describing the situation Penzias wrote: "My mother received her exit permit about a month later (just a few weeks before the war broke out) and was able to join us in England. My father had arrived in England almost as soon as the two of us, but we hadn't seen him because he was interned in a camp for alien men. The only other noteworthy event in the six or so months we spent in England, awaiting passage to America, occurred one morning in a makeshift schoolroom. At that moment, I suddenly realised that I could read the open page of the (English) school book I had been staring at."

They did not stay in England for long. They went to America. To quote Penzias: "We sailed for America toward the end of December 19 39 on the Gunard liner Georgic—using tickets that my father had foresightedly brought in

Germany a year and half earlier. This ship provided party hats and balloons for the Christmas and New Year's parties, as well as lots of lifeboat drills. The grey three-inch gun on the aft deck was a great attraction for us boys."



Arno Allan Penzias



Robert Woodrow Wilson

The Penzias family settled in the Garment district of New York in January 1940. Penzius and his brother joined Brooklyn Technical High School. Penzias' parents initially worked as superintendents of an apartment building, where they were given free accommodation in the basement of the building. Subsequently his mother took up a swing job in a coat factory and his father became a carpenter in the carpentry shop of the Metropolitan Museum of Art.

He graduated from the High School in 1951 and then he joined City College of New York from where he received a bachelor's degree in 1954. In the college he first joined the chemical engineering course but soon he discovered his interest in physics. So he switched his "major" from chemical engineering to physics. He spent two years in the US Army Signal Corps befor e he got a research assistantship in the Radiation Laboratory of the Columbia University. He did his PhD under the supervision of CA H. Towens. His PhD work involved building a maser amplifier in a radio -astronomy experiment

After completing his PhD work, Penzias went to Bell Laboratories, Holmdel, New Jersey in search of a temporary assignment because he thought it would be an ideal place to complete his observations that he had began during his PhD work. However, being persuaded by Rudi Kompfner, th en Director of Radio Research Laboratory of Bell Laboratories he took up a permanent assignment and remained there for 37 years. At the Bell Laboratories he met Wilson and their collaboration led to the discovery of the cosmic microwave background radiatio n. But before we describe the discovery and significance we shall know little about Wilson's biography.

Robert Woodrow Wilson was born on January 10, 1936 in Houston, Texas, USA. His father worked in oil well service company in Houston. Wilson attended a public school in Houston. While in school he took piano lessons for several years. Influenced by his father Wilson developed a keen interest in electronics. He wrote: "During my pre-college years I went on many trips with my father into the oil fields to visit their operations. On Saturday mornings I often went with him to visit the company shop. I puttered around the machine, electronics and automobile shops while he carried on his business. Both of my parents are invertebrate do-it-yourselfers, almost no task being beneath their dignity or beyond their ingenuity. Having picked up a keen interest in electronics from my father, I used to fix radios and later television sets for fun and spending money. I built my own hi-fi set and enjoyed helping friends wit h their ameteur radio transmitters, but lost interest as soon as they worked."

Like Penzias Wilson also went to Bell Laboratories. He wrote: "I joined Bell Laboratories at Crawford Hill in 1963 as part of A. B. Crawford's Radio research department in R. Kompfner's laboratory. I started working with the only other radio astronomer, Arno Penzias, who had been there about two years."

Engineers working at the Bell Laboratories had built a radio antenna and which was used in the early 1960s to transmit and re ceive radio signals to and from Telstar satellites. When the antenna was made available for research purpose Penzias and Wilson planned to use it to examine whether the gaseous halo surrounding the Milky Way was made up of glowing radio waves. Their initial task was to calibrate the instrument particularly to eliminate its noise. They took device apart. They checked the dish and all other connections. While cheking the device they found peagons nesting on the dish, which they carefully removed and took them to miles away so that they do not return. But the peagons returned and they were removed again. They set up the instrument for a wavelength of 7.35 centimetres. This is because they thought at this wavelength the Milky Way's gaseous halo would be practica lly invisible. A highly sensitive solid-state maser detected the waves received by the antenna. The device detected a microwave noise for which Penzias and Wilson had no explanation. They found that it was far less energetic than the radiation given off by the Milky Way and it was isotropica Assuming that their device was subject to interference by terrestrial sources, they initially assumed that the radio noise emanated from New York City. However, soon they rejected their assumption. They continued to look for any possible source of the faint background radiation for almost a year. They did not find any. Penzias was advised by one of his colleagues to discuss the matter Robert Dicke, a professor of Physics at the Princeton University.

Dicke and one of his postdoctoral students, James Peeble made detailed calculations to find out the radiation that should have permeated the universe soon after the Big Bang. They argued that because of the expansion of the universe, the originally produced short-wavelength photons should become long-wavelength photons, in the microwave region of the electromagnetic spectra. Further they argued that such photons should now form a radiation field encompassing the entire universe. The situation is such that it can be assumed that the radiation is emitted by a blackbody and its temperature can be estimated from the Plank's radiation law. After discussing with Dicke, Penzias realized that the mysterious radiation discovered by them was actually left -over cooleddown radion of the Big Bang. The theory of the Big Bang was originally proposed by George Gamow and Ralph Alpher. The term "Big Bang" was coined by Fred Hoyle. Later Alpher and Robert Herman argued that if there was really a Big Bang then the accompanying radiation shou ld still be present today, though it would lose energy as the universe expanded. As stated above the idea of a left - over radiation was further elaborated by Dicke and his group.

Penzias and Wilson finally published their findings in the Astrophysical Journal (1965). In the same issue of the journal, Dicke and his colleagues in which they argued that the radiation studied by Penzias and Wilson was actually the remnant of the Big Bang. After the pioneering observations made by Penzias and Wilson, physicists in different parts of the world carried out similar measurements and all of them came to the same conclusion that is a radiation as 'frozen remnant' of the Big Bang really exists. The discovery of the cosmic microwave background radiation was a clinchin g evidence in favour of the Big Bang theory.

Stephen Hawking
Who Predicted Black Holes Should Emit Radiation

"The progress of science has shown us that we are a very small part of the vast univers e, which is governed by rational laws. It is to be hoped that we can also govern our affairs by rational laws, but the same scientific progress threatens to destroy us as well…Let us do all we can do to promote peace and so insure that we will survive till the next century and beyond."

Stephen Hawking in his acceptance speech while accepting the Wolf Prize in Physics of the Wolf Foundation, Israel

"In the early 1970s, Hawking, unable physically to manipulate mathematical equations on paper, combined relativity theory and quantum physics to produce a new understanding of black holes…Implications drawn from Einstein's general theory of relativity won fame and respect for Hawking after the discovery of quasars and pulsars demanded explanations that his work p rovided."

Norriss S. Hetherington in The Oxford Companion to the History of Modern Science, Oxford University Press, 2003

"Hawking is generally regarded as one of the foremost theoretical physicists of this century despite a severe physical handicap."

A Dictionary of Scientists, Oxford University Press, 1999

Stephen Hawking is regarded as one of the foremost theoretical physicists. His achievements appear more glaring when one considers his severe handicap. In the early 1960s he developed motor neuron disease (amyotrophic lateral sclerosis), also known as Lou Gehring's disease and since then he has been confined to a wheelchair. He communicates through a computer speech synthesiser. Commenting on his physical state vis -à-vis his professional career Hawking once said that he "was fortunate in that I chose theoretical physics, because that is all in the mind."

Hawking's main work is in the area of cosmology. He is best known for his theory on black holes. Following the o bservation made by Roger Penrose in 1965 that star collapsing to form a black hole would ultimately form a singularity

Stephen Hawking was born on January 08, 1942 in Oxford, England. Hawking was born exactly 300 years after the death of Galileo. His fat her Dr. Frank Hawking was a research biologist and he headed the division of parasitology at the National Institute for Medical Research in London. His mother Isobel Hawking was a political activist. Hawking was the first child of his parents. In 1942, the year in which Haking was born, London was under attack by the German forces.

Stephen Hawking

One of his physics teachers at the University College, Oxford wrote: "It was only necessary for him to know that somet hing could be done, and he could do it without looking to see how other people did it…He didn't have very many books, and he didn't take notes. Of course, his mind was completely different from all of his contemporaries."

Hawking decided to study cosmolog y. In those days cosmology was not considered a very respectable discipline. Many considered it a merely speculative and controversial subject. There was no significant body of observational data to support it. It also lacked well -argued theories. Thus Dennis Sciama in the preface to her popular book The Unity of the Universe described cosmology as "highly controversial subject, which contains little or no agreed body of doctrine." Hawking was aware of the situation but then Hawking considered cosmology fro m different angle. He felt cosmology and Einstein's theory of general relativity to be "neglected fields that were ripe for development at that time. Unlike elementary particles, there was a well -defined theory…thought to be impossibly difficult. People we re so pleased to find any solution to the field equations; they didn't ask what physical significance, if any it had."

Hawking was profiled on a 1983 BBC television programme. This programme made him immensely popular. *A Brief History of Time* was released in

April 1987. The book has been printed in more than 20 languages. A film version of the book appeared three years later. A six -part television series titled Stephen Hawking's Universe was produced in 1997.

Hawking's other books include: *The Large Structure of Space-Time* (with George Lilly, 1973); *Three Hundred Years of Gravitation* (edited with W. Israel, Cambridge University Press, 1987); *Black Holes and Baby Universes and Other Essays* (Bentham Books, New York, 1993); *Hawking on the Big Bang and Black Holes* (World Scientific, Singapore, 1993); The Nature of Space and Time (with Roger Penrose, Princeton University, Princeton, 1996), *The Universe in a Nutshell* (Bentahm Books, New York, 2001); *The Theory of Everything:The Origin and Fate of the Universe*, New Millennium Press, Bevery Hills, 2002);Stephen *Hawking's A Brief History of Time: A Reader's Companion,* Bentham Books, New York, 1992), On the Shoulders of Giants.

Hawking was one of the signatories to the Charter for the Third Millennium on Disability in 1999**.**

Hawking has been awarded anumber of awards in recognition of his outstanding contributions including: *Hughes Medal*, Royal Society of London (1976), *Dannie Heinman Prize for Mathematical Physics*, American Physical Society (1976), *Albert Einstein Award* from the Lewis and Rose Strauss Memorial Fund (1978), *Commander of the British Empire* (1982), *Gold Medal* of the Royal Astronomical Society (1985), *Paul Dirac Medal* of the Institute of Physics (1987), *Wolf Prize* in Physics (1988); *Naylor Prize*, London Mathematical Society, London Mathematical Society (1999), *Julius Edgar Lilienfeld Prize*, The American Physical Society (2005), *James Smithson Bicentennial Medal*, Smithsonian Institute (2005),

Kristine Larsen, biographer of Stephen Hawking says: "Hawking continues to remind us why such esoteric studies as singularity theorems and M - theory are worthy realms of human inquiry. He says they may not "help feed anyone or get their wash whither. But men and women do not live by bread alone. We all need to understand where we come from and these observations show us a glimpse of our origin." Hawking embodies the very spirit of scientific exploration and the self-correcting nature of science, where admitting error is a normal sign of progress rather than shame.

A number of books and innumerable articles have been written on the life and work of Stephen Hawking. Three books are listed here: Stephen Hawking: Quest for a theory of every thing by kitty Ferguson (Frankling works, New York 1991); Music to move the Stars: A life with Stephen Hawking by Jane Hawking (Pan books, London 2000); and Stephen Hawking: A Biography by Kristine Larsen (Jaico Publishing House, Mumbai, 2008).

Time-line of Astronomy

ca530 BC Pythagoras (ca572-ca479) proposes that Earth is a sphere and other heavenly bodies move around it.

ca475 B.CA Parmenides (ca515-ca4280 Explains the phases of the Moon in terms of its illumination being reflected sunlight.

ca460 B.CA Anaxagoras (ca500-ca432) proposes that eclipses of the Sun and Moon in terms of Earth or the Moon casting a shadow.

ca 450 B.CA Empe les (ca492-ca432) proposes that eclipses of the Sun are caused by the Moon coming between Earth and the Sun.

ca360 B. CA Eudoxus of Cnidus (408-355) introduces the idea that the Sun, Moon, planets, and stars are on 27ating crystal spheres, each centred on Earth.

ca 270 B.CA Aristarchus (ca310-ca230) makes first calculation of the distance and size of the Moon and proposes that Earth and the planets move around the Sun.

ca150 B.CA Hipparchus (ca190-ca210) makes the first star map and determines the correct distance of Moon from Earth.

ca130 B.CA Hipparchus of Rhodes calculates the inclination of the ecliptic and the precession of the equinoxes, makes the first star catalog.

46 B.CA The Roman Emperor Julius Caesar introduces the Jullian calendar

A.D. ca150 Clausius Ptolemy (ca100-ca170) catalogues constellations, stars, and nebulas visible to naked eyes.

1424 (Ulugh Beg (1394-1449), ruler of Samarkhand builds a large naked-eye observatory and uses it to compute the most accurate star positions to this date. He prepares a star catalog based on his own observations.

1540 Peter Apian (1495-1552) observes that a comet's tail points away from the Sun, the same observations were earlier made by Chinese observers in A.D. 635.

1543 Nicolaus Copernicus (1473-1543) proposes that Earth revolves about the Sun and not vice versa in *De revolutionibus orbium colestium* ("On the Revolution of the Heavenly Spheres")

1572 Tycho Brahe (1546-1601) observes a supernova and determines that it is a star.

1577 Tycho Brahe shows that a comet is farther from Earth than the Moon.

1582 Pope Gregory XIII introduces the Gregorian calendar, the form of calendar is now in almost worldwide civil use.

1603 Johann Bayer (1572-1625) publishes his star atlas, *Uranometria*, which introduces the method of naming the brightest stars in each constellation with Greek letters for brightness and with the name of the constellation in which they are located. *Uranometria* is the first star atlas covering the entire sky.

1608 Hans Lippershey, a Dutch spectacles maker, invents the telescope.

1609 Galileo Galilei (1564-1642) makes first use of telescope for astronomical observations, observes that the Moon is covered with mountains and p lains, and the gour largest moon of Jupiter.

1609 Johannes Kepler (1571-1630) publishes his *Astronomia Nova* (New astronomy) in which he describes his first two laws of planetary motions and demonstrates that the planets move in elliptical orbits.

1619 Kepler in *De Harmonices Mundi* ("Harmony of the World"), develops the mathematical relation between a planet's distance from the Sun and its speed. This is known Kepler's Third Law of Planetary Motion.

1632 Galileo publishes The Dialogue in which he pre sent a powerful argument for Copernicus ideas of heliocentric model of the solar system.

1632 The world's first official observatory is established in Leiden in the Netherlands.

1647: Johannes Hevelius (1611-1687), German astronomer, publishes Selenographia containing the first fairly detailed map of the Moon.

1655 Christiaan Huygens (1629-1695) discovers Titan, the largest moon of Saturn.

1656 Huygens describes the rings of Saturn.

1659: Huygens discovers dark markings on Mars, notably the wedged -shaped Syrius Major.

1656 Giovanni Cassini discovers Great Red Spot of Jupiter.

1668 Isaac Newton (1643-1727) builds the first telescope based on a mirror (reflector) instead of a lens (refractor).

1675 Cassini observes a gap in the ring about Saturn, now called the Cassini gap.
1675 The Royal Greenwich Observatory is established in England.

1675 Danish astronomer Ole Romer measures the speed of light.

1676 Edmond Halley (1656-1742) underlines the significance of transit of Mercury and Venus across the Sun in understanding the size of the solar system.

1687 Isaac Newton's Principia was published, including his law of universal gravitation.

1705 Halley claims that comets are periodic with long orbits and that the comet of 1682 (now called comet Halley) has been seen and will return in 76 years.

1718: Halley discovers proper motion of stars, the movement of stars with respect to each other. He observes that the positions of stars change with time and he explains the changes in position as due to individual motions of stars through space.

1728: James Bradley (1693-1762) demonstrates that stars shift their apparent positions depending on whether Earth is moving toward or away from them (a phenomenon known as aberration of light), an indication the Earth indeed revolves around the Sun.

1729: The achromatic lens is invented by the English optician Chester Moor Hall (1703-1771)

1738: Jacques Cassini (1677-1756), French astronomer makes one of the first definite determination of a star's proper motion, that of Arcuturus.

1753: John Dollond (1706-1761), English astronomer invents heliometer, an instrument formerly used for measuring the diameter of the Sun or angular separation between close stars.

1755: Immanuel Kant (1724-1804) formulates ideas on the evolution of the Sun and planets from a cloud of gas.

1758: Johann Palitzsch observes Halley's comet as predicted by Halley in 1705.

1760 Charles Messier (1730-1817) prepares a list of 100 fuzzy-looking bright patches in the sky that could be mistaken for comets.

1761 First observation of transit of Venus was organized.

1762 James Bradley compiles new star catalog of 60000 stars.

1766 James Cook observes a solar eclipse during his survey of the coast of Newfoundland

1769 James Cook (1728-1779) and Joseph Banks (1743-1820) time the transit of Venus across the Sun from Tahiti to help astronomers to establish the size of the solar system.

1772 Joseph-Louis Lagrange (1736-1813) calculates that each orbit contains five Giuseppe Piazzi (17stable points, now called Lagrangian points, in which a body of smaller mass than the orbiting body can travel.

1781 William Herschel (1738-1822) discovers the planet Uranus. Charles Messier compiles a catalogue of more than 10 nebulas

1783 John Goodricke announces his observation of a variable star, Algol

1783 Herschel discovers the speed and direction of Sun's motion.

1787 Herschel discovers Titania and Oberon, moons of Uranus.

1794: Ernst Florens Friedrich Chladni (1756-1827), Hungarian-born German physicist, proposes correctly that fireballs—glowing objects that pass rapidly across the sky—are caused by stones falling from sky.

1796 Pierre-Simon Laplace (1749-1827) in Eposition du systeme du monde ("Explanation of the World System") advocates his "Nebular hyp othesis" as the most plausible explanation for the formation of the solar system.

1800 Herschel builds 40-feet long reflecting telescope.

1801 Giuseppe Piazzi (1749-1826) discovers first known asteroid, Ceres

1802 Herschel establishes the existence of b inary star system that is two stars revolving about a mutual centre of gravity and catalogues 848 examples.

1802: William Wolleston sees dark lines in solar spectrum

1803: Jean-Baptiste Biot (1774-1862) investigates the meteorite fall at l'Aigel in France, the first properly study of meteorite and the first conclusive evidence that stones of cosmic origin could fall from the study.

1820 The Royal Astronomical Society is founded in London'

1821 Joseph Fraunhofer (1787-1826) identifies 574 dark lines in the solar spectrum.

1823 John Herschel suggests the so-called Fraunhoffer lines might indicate the presence of metals.

1829: Clladni suggests that there could be a connection between meteors and comets.

1835 Casper de Coriolis discovers Coriolis effect .

1838 Wilhelm Bessel (1784-1846) is the first to make first measurement of the distance to a star by using parallax.

1840 John William Draper takes the first photograph of the Moon.

1842 Christian Johann Doppler describes Doppler effect.

1843 Samuel Heinrich Schwabe announces his discovery of the cyclic action of sunspots.

1845: The German amateur astronomer Karl Ludwig Henke (1793-1866) discovers Astraea, the fifth largest asteroid to be discovered.

1846 Johann Galle (1812-1910) discovers the planet Neptune in a location predicted by Urbain Jean Joseph Le Verrier (1811-1877) and independently by John Adams.

1846: William Lassel (1799-1880) observes Triton, largest moon of Neptune

1851: Lassell discovers Ariel, the fourth largest satellite of Uranu s.

1859 Gustav Robert Kirchhoff (1824-1887) explained the dark lines in solar spectrum.

1860 James Clerk Maxwell (1831-1879) concludes that Saturn's rings are composed of many small bodies orbiting the planet.

1862 Alvan Clark (1832-1897) observes the companion star of Sirius, the first white dwarf to be observed.

1863 William Huggins (1824-1910) based on spectroscopic studies propose that stars are made of same elements as the Sun and Earth.

1868 Huggins records the first Doppler shift in light from a star, Sirius.

1868: Anders Jonas Angstrom (1814-1874), Swedish physicist publishes an atlas of solar spectrum and measurements of the wavelengths of over a thousand spectral lines.

1877 Asaph Hall (1829-1907) discovers Phobos and Deimos, the moons of Mars.

1879 Benjamin Apthorp Gould (1824-1896), establishes the existence of Gould's Belt, a band of hot, bright stars forming a circle around the sky.

1883: Andrew Ainslie Cammon (1841-1903), English telescope-maker photographs the Orion Nebula.

1887 American physicist Albert Abraham Michelson (1852-1931) and Edward Williams Moreley (1838-1923) conducts the famous Michelson-Moreley experiment.

1889 George Ellery Hale (1868-1938) invents a device to study the Sun's prominences.

1892 Edward Emerson Barnard (1857-1923) discovers Amalthea, the fifth satellite of Jupiter.

1895 Edward Emerson Barnard photographs the Milky Way.

1905 Ejnar Herzsprung (1873-1967)introduces absolute magnitude, a measure of the actual brightness of stars.

1905: Jacobus Kapteyn uses star counts to map Milky Way.

1906 Jacobus Kapteyn Cornelius (1851-1922), Dutch astronomer, uses star counts to map Milky Way.

1907 Hertzsprung plots the brightness against the colour of stars and recognizes that some stars are red giants and red d warfs.

1908 Henrietta Leavitt (1868-1921) observes that Cepheid variable stars can be used to measure the distance to galaxies.

1912 Victor Hess (1883-1921) identifies cosmic rays and proves that they originate in space.

1915: Robert Thorburn Ayton Innes (1861-1933), Scottish astronomer discovers Proxima Centauri.

1916: Edward Emerson Barnard (1857-1923), American astronomer discovers Barnard's star, the second closest star to the Sun.

1916 Albert Einstein proposes his general theory of relativity.

1917: William de Sitter (1872-1934) proposes the first theoretical model of an expanding universe, now called de Sitter Universe.

1919 Arthur Stanley Eddington (1882-1944), English astronomer obtains observational proof that gravity bends light as predicted by the general theory of gravity.

1920 Albert Michelson (1852-1921) measures the diameter of the star Betelgeuse using an interferometer, the first measurement of any star other than Sun.

1920: Meghnad Saha shows that the temperature of a star determines the appearance of its spectrum.

1922 William Wallace Campbell (1862-1938), American astronomer and mathematician detects the deflection of starlight by the Sun, as predicted by the Einstein's theory of general theory of gravity.

1924 Edwin Hubble (1899-1953) demonstrates that galaxies are large collections of stars outside the Milky Way.

1925 Arthur Stanley Eddington (1882-1944) observes that the light and heat produced by stars results from nuclear fusion.

1925: Hubble develops a system for classification of stars based on their shape.

1927 Georges Edouard Lemaitre (1894-1966), Belgian priest and cosmologist, proposes his model of an expanding universe.

1928 Harold Delos Babcock (1882-1968) publishes wavelengths of 20000 solar spectral lines.

1929 Hubble demonstrates the expansion of the universe by showing that distant galaxies are all moving away from each other.

1930 Clyde Tombaugh (1906-1997) discovers Pluto, once considered a planet.

1930 S. Chandrasekhar shows white dwarf stars are made of d egenerate electrons.

1930 Robert Trumpler discovers diffuse interstellar dust.

1932 Karl Jansky (1905-1950) discovers that radio waves from centre of the Milky Way galaxy.

1935 Subrahmanyan Chandrasekhar (1910-1995)

1936-37: Benjamin Boss (1880-1970), American astronomer, publishes five-volume *General Catalogue of 33,342 Stars*.

1937: Robert Grant Aitken (1864-1951), American astronomer, publishes his *New General Catalogue of Double Stars*, containing measurements of 17180 double stars.

1938: Seth Barnes Nicholson (1891-1963), American astronomer, discovers Carme, a satellite of Jupiter farthest from the planet.

1939 Robert Oppenheimer and George Volkoff calculate properties of neutron stars.

1944 Grote Reber (1911-2002) completes the first radio map of the sky.

1946 Horace Welcome Babcock (1912-) discovers the first magnetic star, 78 Virginis.

1948 Gerard Peter Kuiper (1905-), Dutch astronomer discovers Miranda, the fifth largest satellite of Uranus.

1948 George Gamow (1904-1968) and Ralph Alpher(1921-) develop the Big Bang theory of the origin of the universe.

1948: Fred Hoyle (1915-2001), Thomas Gold (1920-) and Hermann Bondi (1919-) propose their steady state theory.

1949Fred Lawrence Whipple (1906-), American astronomer describes comets as "dirty snowballs" of frozen gases and dust.

1949 Kuiper discovers Neraid, the outermost satellite of Neptune.
1949Jan Hendrik Oort (1900-1992), Dutch astronomer discovers the Oort Cloud, the vast number of bodies that orbit the Sun just beyond the farthe st planet.

1949Gerard Kuiper (1905-1973) discovers the Kuiper belt that orbits the sun just beyond the orbit of Neptune.

1957 The first artificial satellite Sputnik is launched.

1958James Van Allen discovers Van Allen radiation belt.

1958: George Ogden Abell (1927-1983), American astronomer, publishes a catalogue of 2712 rich clusters of galaxies. It is known as Abell catalogue.

1959 Erstwhile Soviet Union send probes to the Moon.

1960 Allan Sandage (1926-) in collaboration with Thomas Matthew succeed s in making the first optical identification of a quasar or quasi -stellar object.

1960 Robert Leighton discovers solar oscillations that is the Sun vibrates at variety of frequencies.

1961: Horace Babock proposes model for sun spot cycle

1961: Robert Henry Dicke (1916-1997), American physicist and astronomer, suggests that gravitation constant varies with time.

1962 OSO 1 (Orbiting Solar Observatory), the first space telescope, is launched.

1962Hermann Bondi ( ), Briti sh cosmologist and mathematician shows the existence of gravitational waves.

1963 Reymond Davis builds the first Solar Neutrino Telescope.
Maarten Scmidd shows quasars have large red -shift.

1964 Arno Penzis and Robert Wilson discover cosmic bac kground radiation.

1964 C-C Lin and Frank Shu explain spiral arms of Milky Way

1964: Gerard Henri de Vancouleures (1918-1995) and his wife Antoinette de Vancouleures nee Pietra (1921-1987) publish the *Reference Catalogue of Bright Galaxies*, a revised version of the Shapelay-Ames catalogue.

1966 Luna 9 is the first spacecraft to soft-land on the Moon.

1967 Jocelyn Bell Burnell (1943-) discovers pulsars.

1969 US astronauts Neil Armstrong and Buzz Aldrin land on Moon, the first humans to step foot on the Moon.

1971 Mariner 9 becomes the first satellite orbiting another planet as it enters Mars' orbit.

1976 Vikings land on Mars.

1977 Uranus is discovered to have rings.

1978 Pioneer 12 is the first satellite to orbit Venus

1978 International Ultraviolet Explorer is launched.

1979 Pioneer 11 is the first spacecraft to visit Saturn.
Mariner 10 is the first spacecraft to visit Mercury.

1980 Infrared Astronomical Satellite (IRAS) is the first infrared telescope in space.

1980Voyager I discovers Atlas, the second closest satellite of Saturn.

1986 Fleet of space probes encounters Comet Halley.

1987 Supernova SN1987A flares up, becoming the first supernova to be visible to the naked eye since 1604.

1988 A supernova located in the AC118 cluster of galaxies 5 billion light years away is recorded.

1989 Voyager 2, the first spacecraft visits Neptune and discovers six previously unknown moons and three rings.

1990 Hubble Space telescope is launched

1990 First Keck 10-m telescope is launched. Keck telescope, unlike most earlier large optical telescopes, has a mirror made of many hexagonal segments.

1991 The Galileo spacecraft takes a photo of Gaspra, the first photo ever taken of an asteroid in space.

1994 Fragments of Comet Shoemaker-Levy 9 strike Jupiter.

1995 Galileo becomes the first spacecraft to orbit Jupiter

1997 Pathfinder lands on mars and Mars Global Surveyor begins mapping of Mars.

2000 NEAR-Shoemaker becomes the first spacecraft to orbit an asteroid.

Glossary

Absolute magnitude: The brightness that a celestial object (star) would have if it were at a distance of 10 parsecs in perfectly clear space without any interstellar absorption. Its symbol is M.

Acceleration: The rate of change in the velocity of a moving body is called acceleration.

Antimatter: Matter composed of antiparticles. Every particle has an antiparticle. For example antiproton is antiparticle of proton and positron is antiparticle of electron. When an antiparticle and a particle come together both are annihilated and mass of both the particles are converted into energy.

Aphelion: The farthest point from the Sun in the orbit of a planet or comet, or of a man-made satellite around the Sun.

Apogee: The farthest point from the Earth in the orbit of the Moon or of a man-made satellite around the Earth.

Apparent Magnitude: The brightness of a celestial object as measured by the observer.

Archaeoastronomy: The study of traditional and ancient astronomies in their cultural context.

Asteroid: One of those small celestial bodies, larger than meteoroid but smaller than planet, revolving around the Sun. They range in size from almost 1000 km to less than 10m.

Asteroid belt: It is where most asteroids are found and it lies between the orbits of Mars and Jupiter. It extends from 2.15 to 3.3 AU.

Astrobiology: A branch of astronomy that deals with the study of the advent and evolution of biological systems including the possibility of non-terrestrial life.

Astrochemistry: The branch of astronomy that is concerned with the study of chemicals found in space including their formation, interaction and destruction.

Astrogeology: The branch of science that deals with the application of geology, geochemistry and geophysics to the Moon and planets other than Earth.

Astrograph: A telescope exclusively used for astronomical photographs.

Astrolabe: An ancient instrument used for observing the position and measuring the altitudes of celestial bodies. It was replaced by the sextant.

Astrometric position: The position of heavenly body or space craft on the celestial sphere corrected for aberration but not for planetary aberration.

Astrometry: The branch of astronomy concerned with the geometrical relation of the celestial bodies and their real and apparent motions.

Astronavigation: The technique of position-finding by reference to celestial bodies.

Astronomical Unit (AU): A measure of distance equal to mean distance between the Earth and the Sun. It is equivalent to 149,598,000 kilometres. It is used within the solar system.

Astrophotography: The application of photography in astronomy.

Big Bang Theory: A theory of the origin of the universe, which states that the universe originated from an explosion (Big Bang) of a small agglomeration of matter of extremely high temperature and density. The explosion sent matter and energy in all directions giving rise to the expanding universe.

Binary star: A pair of stars, which are bound together by their mutual gravitation and orbit their common Centre of mass.

Blackbody radiation: The emission of radiant energy that takes place from a blackbody at a fixed temperature. A blackbody is an ideal surface or body that can absorb completely all the radiation striking it.

Black dwarf: The last phase of a white dwarf that has cooled to low temperature.

Black Hole: Classical physics defines black hole as the region of space-time from which nothing including light escape. However, quantum mechanics indicates a black hole radiates particles with temperature inversely proportional to the mass and directly proportional top Planck's constant.

Blazar: A type of quasar whose light exhibits strong optical polarization and large variability.

Brown Dwarf: A black dwarf star that radiates its internal heat. It is a low luminosity star whose mass is not sufficient to ignite nuclear fusion.

Carbon-nitrogen cycle: A series of thermonuclear reactions that produce energy inside a star. The net result is the synthesis of four hydrogen atoms into a helium atom, the emission of two positrons and large a mount of energy. Carbon-12 with which the cycle begins is released back at the end of the cycle.

Carbon-nitrogen-oxygen cycle:

Comet: A small body consisting of ice and dust in orbit around the Sun.

Constellation: Any one of the star groups interpreted as forming configurations in the sky or a particular area of the sky assigned to a such a group. Currently the sky is considered to have 88 constellations.

Corona: By corona we usually mean solar corona. The layer of ionised gas surrounding the Sun is called corona. The corona becomes visible around the darkened Sun during a total solar eclipse. It is characterised by an extremely low density and a constantly changing shape extending great distance from the Sun.

Cosmic Background radiation: A nearly uniform flux of microwave radiation, which is believed to permeate the entire space. The background radiation is believed to have original in the Big Bang, an explosion which created the universe.

Cosmic rays: Sub-atomic particles mostly electrons and protons that reaches the Earth's atmosphere from all directions of space with nearly the speed of light.

Cosmochemistry: A branch of chemistry dealing with the study of the chemicals found within the solar system, including the origins of elements and variations in the isotope ratios.

Cosmogony: The study of the origin of the universe.

Cosmography: The science dealing with the structure of the universe as a whole and of its related parts.

Cosmology: It generally refers to the study of universe as a whole

Doppler Shift: The amount of change in the observed frequency of a wave due to Doppler effect that is resulting due to relative motion of source and observer.

Escape velocity: The initial velocity an object requires to escape from the surface gravity of a celestial body.

Extragalactic astronomy: The study of objects outside of our galaxy.

Focal length: The distance from the optical centre (focal point) of a lens or curved mirror to the point (principal point) where light rays from a distant object converge.

Frequency: The number of cycles completed by periodic quantity in a unit time. The frequency of a wave is the number of cycles that pass the observer in one second.

Galaxy: A large, independent system of stars, typically containing billions of stars. Besides star, a galaxy contains dust and gas and it orbits a common centre of mass. The galaxy in which our Sun is located is called Milky Way Galaxy.

Galilean satellites: The four largest satellites of Jupiter discovered by Galileo are called Galilean satellites. These satellites are: Io, Europa, Ganymede and Callisto.

Gamma-ray astronomy: A branch of astronomy that studies astronomical objects at the shortest wavelengths of the electromagnetic spectrum.

Hubble constant: The rate at which the velocity of recession of the galaxies increases with distance.

Hypernova: The explosion caused by the collapse of a massive star resulting into a black hole.

Kuiper belt: The region from just beyond Neptune out to 100 AU or more where a collection oficy planetesimals orbit around the Sun.

Light year: A unit of distance equal to the distance that light travels in a vacuum in one year and it is equivalent to 9460,000,000,000 km.

Lunar eclipse: An eclipse of the Moon. A lunar eclipse takes place when the full Moon passes through the shadow of the Earth.

Meteorite: Any meteoroid that has fallen to Earth's surface.

Meteoroid: Any rock or solid object moving in interplanetary space that is smaller than a planet or asteroid but larger than a molecule.

Meteor: A phenomenon accompanied by a rock from space in its passage through the Earth's atmosphere.

Milky Way Galaxy: The galaxy of which Sun is a member. It is a large aggregation of stars and interstellar gas and dust.

Nebula: A cloud of gas and dust in space.

Nova: A star that suddenly becomes explosively bright making it appear as a "new" star. "Nova" is a Latin word and it means "new". In a sense the term is misnomer because it does not denote a new star but the brightening of an existing star.

Oort cloud: A cloud of comets at distances from 75000 to 150000 astronomical units from the Sun. This is named after its discoverer Jan Hendrik Oort. Comets that are seen near the Sun are supposed to have originated in this region.

Parsec: A unit of astronomical distance equivalent to the distance at which an object has an annual parallax of one second arca One parsec is equal to 206,265 astronomical units or 3.26 light years or 3.09×10^{13} km.

Perigee: The nearest point to the Earth in the orbit of the Moon or or a man-made satellite around the Earth.

Perihelion: The nearest point to the Sun in the orbit of a planet, comet, or man-made satellite around the Sun.

Planet: A large, opaque, non-luminous mass, usually with its own moon, that revolve around a star, especially one of the Sun's eight major planets viz., Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

Pulsar: A celestial radio source, emitting intense short burst of radio emission. Actually a pulsar is rapidly spinning neutron star, 20 -30 km in diameter. Such a star is highly magnetized, with the magnetic axis inclined to the spin. A pulsar is a radio source, which send a highly regular train of pulses.

Quasar: The abbreviated form of quasi-stellar astronomical objects. They are often radio source and they have large radio shift.

Radio galaxy: A galaxy that exits most of its energy in radio frequencies often from regions without any visible matter.

Radio telescope: An astronomical device that measures the amount of radio energy in the sky. It consists of highly directional antenna and associated electronic equipment.

Red giant: A star whose envelope has expanded to perhaps 100 times its initial size. A star reaches such a stage when its hydrogen core burning is completed and the helium core becomes hotter and denser than originally.

Red dwarf: A dwarf star of low luminosity. Red dwarfs are the faintest and coolest of the dwarfs.

Red shift: A systematic displacement toward longer wavelengths in the spectrum of light observed when the source and observer are receding from each other.

Reflecting telescope: It is a kind of telescope in which a concave parabolic mirror gathers light and forms a real image of an object. It is also called reflector telescope.

Refracting telescope: A telescope in which a lens gathers light and forms a real image of an object. It is called refractor telescope.

Saros cycle: A time cycle after which the Centres of the Sun and the Moon, and the nodes of the Moon's orbit return to the same relative position. It equals to 18 years 11.33 days or 18 years 10.33 days if 5 rather than 4 leap years are included.

Satellite: A solid body moving in an orbit around a planet. A planet may have one or more satellites or no satellite at all. The Moon is the satellite of the Earth.

Schwarzschild radius: The radius of the event horizon around a black hole.

Singularity: In mathematics singularity is a point where a function of real or complex variables is not differentiable or analytica In astronomy it is the object of zero radius into which the matter in a black hole is supposed to fall.

Solar eclipse: An eclipse of the Sun. It takes place when new Moon passes between the Earth and the Sun and the shadow of the Moon thus formed reaches the Earth. A so0lar eclipse may be total, partial or annular.

Star: A celestial body consisting of a large, self-luminous mass of hot gas held together by its own gravity and it is supported by nuclear fusion occurring in its interior.

Steady State Theory: A theory of the origin of the universe, which states that the average density of matter in the universe does not vary with space or time inspite of the expansion of the universe. The theory implies that there is continuous creation of matter.

Sunspot: Any of the temporarily cooler regions appearing cyclically as dark spots on the surface of the Sun. Sunspots contain intense magnetic fields and they are usually accompanied by increased geomagnetic disturbances.

Super-cluster: A large number of galaxy clusters make a super-cluster.

Supernova: A rare, extremely bright nova that suddenly increases upto a billion times. A supernova is caused by the violent explosion of a star. There are two types of supernovae—Type I and Type II. A Type I supernova is caused by the transfer of matter to a white dwarf. A Type II supernova is caused by a collapse of a massive star.

Telescope: A device consisting of lenses or mirrors or both that enhances the ability of the eye either to see objects with greater resolution or to see fainter objects.

Terrestrial planets: Earth like planets are called terrestrial planets. They are small, dense and rocky. In the solar system, Earth, Mercury, Venus and Mars are called terrestrial planets.

Transit: Passage of a smaller celestial body across a larger one.

Ultraviolet astronomy: A branch of astronomy that generally refers to observations at ultraviolet wavelengths between approximately 100 and 3200 Angstrom.

Van Allen Belts: Two radiation belts encircling the Earth, containing charged particles. These were discovered by the American space scientists James Alfred van Allen (1914-) in 1958 from measurements obtained by the Explorer 1 satellite. The inner belt, which contain protons and electrons of both solar and ionospheric origin and lies around 9400 km above the equa tor. The other belt lies at an equal distance of 28000 km and it contains mostly electrons from the solar wind.

Van Allen belts: The belts of intense ionising radiation in space around the Earth formed by high energy charged particles that are trapped b y the geomagnetic field.

Variable star: A star whose brightness varies periodically. The changes in brightness may be few thousandths of a magnitude to 20 magnitudes or even more.

Velocity: A rate of travel that specifies both speed and direction.

Wavelength: The distance between two points having the same phase in two consecutive cycles of a periodic wave.

White Dwarf: An intrinsically faint star of very small radius and great density. The average diameter of such star is 16000 km and mass is about 0.6 that of the Sun.

X-ray astronomy: It is the study of astronomical objects at X -ray wavelengths.

Zodiac: A band of the sky extending 8^0 on each side of the ecliptic, within which the Moon and principal planets move.

Useful Astronomical Facts

1. Astronomical Constants

Astronomical unit (AU)	1.495979 x 10^{11}m
Parsec (pc)	206,265AU
Velocity of light (c)	2.997925 x 10^{8}m/s
Light-year (ly)	9.46053 x 10^{15}m
Gravitational constant (G)	6.67 x 10^{-11}m^3/s^2 kg
Mass of Earth (M)	5.976x10^{24} kg
Earth Equatorial Radius	6378.164km
Mass of Sun (M)	1.989x10^{30} kg
Radius of sun (R)	6.9599X10^{8} m
Solar Luminosity (L)	3.826x10^{26} J/s
Mass of Moon	7,350x10^{22} kg
Radius of Moon	1738 km
Mass of hydrogen atom	1.67352x10^{-27} kg

2. The Brightest Stars

Name	Apparent Visual Magnitude	Absolute Visual Magnitude	Distance (Light Year)
Sirius	-1.47	1.4	8.7
Canopus	-0.72	-3.11	98
Rigil Kentauurus	-0.01	4.4	4.3
Arcturus	-0.06	-0.3	36
Vega	0.04	0.5	26.5
Capalla	0.05	-0.6	45
Rigal	0.14	-7.1	900
Procyon	0.37	2.7	11.3
Betelgeuse	0.41	-5.6	520
Achernar	0.51	-2.3	118
Hadar	0.63	-5.2	490
Altair	0.77	2.2	16.5
Aldebaran	0.86	-0.7	68
Acrux	0.90	-3.5	260
Spica	0.91	-3.3	220
Antares	0.92	-5.1	520
Fomalhaut	1.15	2.0	22.6
Pollux	1.16	1.0	35
Deneb	1.27	-7.1	1600

Beta Crucis	1.28	-4.6	490

3. The Nearest Stars

Name	Distance (ly)
Sun	
Proxima Cen	4.28
□Cen A	4.3
B	4.3
Barnard's Star	5.9
Wolf 359	7.6
Lalande 21185	8.1
Sirius A	8.6
B	8.6
Luyten 726-8A	8.9
B (UV Cet)	8.9
Ross-154	9.4
Ross 248	10.3
□□Eri	10.7
Luyten 789-6	10.8
Ross 128	10.8
61 CYG A	11.2
B	11.2
□□Eri	11.2
Procyon A	11.4

4. Planets of the Solar System

Mercury

Average distance from the Sun	5.79×10^{7} km
Maximum distance from the Sun	6.97×10^{7} km
Minimum distance from the Sun	4.59×10^{7} km
Eccentricity of orbit	0.2056
Orbital period	87.969 days
Average orbital velocity	47.9 km / s
Equatorial diameter	4878 k m
Mass	3.31×10^{23} kg
Average density	5.44 g / cm ^{3}
Surface gravity	0.38 Earth's gravity
Escape velocity	4.3 km / s

Surface temperature	-173^0 to 330^0 C

Venus

Average distance from the Sun	1.082×10^8 km
Maximum distance from the Sun	1.089×10^8 km
Minimum distance from the Sun	1.075×10^8 km
Eccentricity of orbit	0.0068
Orbital period	224.68 days
Average orbital velocity	35.03 km / s
Equatorial diameter	12104 km
Mass	4.870×10^{24} kg
Average density	5.24 g / cm ^{3}
Surface gravity	0.38 Earth's gravity
Escape velocity	10.3 km / s
Surface temperature	472^0 C

Earth

Average distance from the Sun	1.495979×10^8 km
Maximum distance from the Sun	1.5210×10^8 km
Minimum distance from the Sun	1.4710×10^8 km
Ecentricity of orbit	0.0167
Orbital period	365.26 days
Average orbital velocity	29.79 km / s
Equatorial diameter	12756 km
Mass	5.976×10^{24} kg
Average density	5.497 g / cm ^{3}
Surface gravity	1.0 Earth's gravity
Escape velocity	11.2 km / s
Surface temperature	-50^0 to 50^0 C

Mars

Average distance from the Sun	2.279×10^8 km
Maximum distance from the Sun	2.492×10^8 km
Minimum distance from the Sun	2.066×10^8 km
Eccentricity of orbit	0.0934
Orbital period	686.95 days
Average orbital velocity	24.13 km / s
Equatorial diameter	6796 km
Mass	0.6424×10^{24} kg
Average density	3.94 g / cm ^{3}

Surface gravity	0.38 Earth's gravity
Escape velocity	5.0 km / s
Surface temperature	-140^0 to 20^0C

Jupiter

Average distance from the Sun	7 .783 x10^8 km
Maximum distance from the Sun	8.160 x 10^8 km
Minimum distance from the Sun	7.406 x 10^8 km
Eccentricity of orbit	0.0484
Orbital period	4334. 3 days
Average orbital velocity	13.06 km / s
Equatorial diameter	142,900 km
Mass	1.899 x 10^{27} kg
Average density	1.34 g / cm^3
Gravity at base of clouds	2.54 Earth's gravity
Escape velocity	61 km / s
Surface temperature	-120^0 C

Saturn

Average distance from the Sun	14.27 x10^8 km
Maximum distance from the Sun	15.07 x 10^8 km
Minimum distance from the Sun	13.47 x 10^8 km
Eccentricity of orbit	0.0560
Orbital period	10760 days
Average orbital velocity	9.64 km / s
Equatorial diameter	120660 km
Mass	5.69 x 10^{26} kg
Average density	0.69 g / cm^3
Surface gravity (at base of cloud)	1.16 Earth's gravity
Escape velocity	35.6 km / s
Temperature at cloud tops	-180^0 C

Uranus

Average distance from the Sun	28.69 x10^8 km
Maximum distance from the Sun	30.0 x 10^8 km
Minimum distance from the Sun	27.40 x 10^8 km
Eccentricity of orbit	0.0461
Orbital period	30685 days
Average orbital velocity	6.81 km / s
Equatorial diameter	51118 km

Mass	8.69×10^{25} kg
Average density	1.29 g / cm ^{3}
Surface gravity	0.919 Earth's gravity
Escape velocity	22 km / s
Surface temperature	-220^{0} C

Neptune

Average distance from the Sun	44.971×10^{8} km
Maximum distance from the Sun	45.40×10^{8} km
Minimum distance from the Sun	44.52×10^{8} km
Eccentricity of orbit	0.0100
Orbital period	60189 days
Average orbital velocity	5.43 km / s
Equatorial diameter	49500 km
Mass	1.030×10^{26} kg
Average density	1.66 g / cm ^{3}
Surface gravity	1.19 Earth's gravity
Escape velocity	25 km / s
Surface temperature	-216^{0} C

5. Principal satellites of the solar system

Planet	**Satellite**	**Radius** (km)	**Distance from Planet (10^3km)**	**Orbital period (days)**
Earth	Moon	**1738**	**384.4**	**27.322**
Mars	Phobos	14x12x10	9.38	0. 3189
	Deimos	8x 6 x 5	23.5	1.262
Jupiter	Metis	20	126	0.29
	Adrastea	12 x 8 x 10	128	0.294
	Amalthea	135 x 100 x 78	182	0.4982
	Thebe	50	223	0.674
	Io	1820	422	1.769
	Europa	1565	671	3.551
	Ganymede	2640	1071	7.155
	Callisto	2420	1884	16.689
	Leda	~8	111 10	240
	Himalia	~85	11470	250.6
	Lysithia	~20	11710	260

	Elara	~30	11740	260.1
	Ananke	15	21200	631
	Carme	22	22350	692
	Pasiphae	35	23300	735
	Sinope	20	23700	758
Saturn	Pan	10	133.570	0.574
	Atlas	20 x 15 x 15	137.7	0.601
	Peromethers	70 x 40 x 50	139.4	0.613
	Pandora	55 x 40 x 50	141.7	0.629
	Epimethus	70 x 50 x 50	151.42	0.694
	Janus	110 x 80 x 100	151.47	0.694
	Mimas	196	185.54	0.942
	Enceladus	250	238.04	1.370
	Tethys	530	294.67	1.888
	Calypso	17 x 11 x 12	294.67	1.888
	Telesto	12	294.67	1.888
	Dione	560	377	2.737
	Helene	20 x 15 x 15	377	2.74
	Rhea	765	527	4.518
	Titan	2575	1222	15.94
	Hyperion	205 x 130 x 110	1484	21.28
	Iapetus	720	3562	79.33
	Phoebe	110	12930	550.4
Uranus	Cordelia	20	49.5	0.3333
	Ophelia	15	53.8	0.375
	Bianaca	25	59.1	0.433
	Cressida	30	61.8	0.462
	Desdemona	30	62.7	0.475
	Juliet	40	6 4.4	0.492
	Portia	55	66.1	0.512
	Rosalind	30	69.9	0.558
	Belinda	30	75.2	0.621
	S/1986 U10	20	76.2	0.638
	Puck	85	85.9	0.762
	Miranda	242	129.9	1.414
	Ariel	580	190.9	2.520
	Umbriel	595	266.0	4.144
	Titania	805	436.3	8.706
	Oberon	775	583.4	13.463
	Caliban	40	7164	579
	Stephano	~20	7900	676

	Sycorax	80	12174	12.84
	Prospero	~20	16100	1950
	Setebos	~20	17600	2240
Neptune	Naiad	30	48.2	0.296
	Thalassa	40	50.0	0.312
	Despina	90	52.5	0.333
	Galatea	75	62.0	0.396
	Larissa	95	73.6	0.554
	Proteus	205	117.6	1.21
	Triton	1352	354 .59	5.875
	Nereid	170	5588.6	360.125

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