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R R Daniel

1 Space–The Exciting Scientific Frontier

R R Daniel and B V Sreekantan

> There will certainly be no lack of human pioneers when we have mastered the art of soaring. Let us create vessels and sails adjusted to the heavenly ether and men will present themselves who are unafraid of the boundless voids. In the meantime, we shall prepare for the brave sky travellers, maps of the celestial bodies – I shall do it for the Moon and you, Galileo, for Jupiter.
>
> Johannes Kepler (1571–1630)

Preamble

From time immemorial, men have been fascinated by the birds gliding and soaring in the air, the glorious rising and setting of the Sun, the waxing and waning Moon and the countless stars twinkling tantalizingly in the night. However, the earliest recorded reference to space technology goes back only to 1232 AD when the Chinese are known to have used "black powder" to strike "fire arrows" on the Mongolian enemy. During the European Renaissance, Leonardo da Vinci (1452–1519), who is usually known for his creative genius in painting and art, also designed numerous war machines and aviation techniques. His sketches and doodles include scientific studies of the flight of birds and designs of a parachute and a helicopter. The writings of Kepler in 1610 AD (quoted above) demonstrate the beginning of the serious thoughts of scientists on space travel. Then came Isaac Newton (1642–1727), the originator of the Law of Gravitation and the three Laws of Motion, who wrote with scientific authority in his work ***Principia*** that a projectile can be fired horizontally from the top of a mountain with such a velocity that it can go into the Earth's orbit.

An interesting development in rocketry was the crude but effective use of rocket warfare by Tippu Sultan, the Maharaja of Mysore State, in 1792, against the British colonizers at Sriranga-patnam in South India. The British were so discomfited that a detailed report had to be sent to England on the new war machine. This report, in turn, led William Congreve, in England, to take up Tippu's ideas further. Since then rockets have been used in many battlefronts in Europe but their lack of reliability and feeble destructive power inhibited their use in the 19th century.

Jules Verne, the prodigy in science fiction, wrote his book ***Earth to Moon*** in 1865, and followed it with the story ***Around the Moon*** in 1872. His writings had such a sound scientific basis and were so enchanting to read that they amused and inspired innumerable people over the years. These included the space pioneers Konstantin Tsiolkowsky (1857–1935) of the erstwhile USSR, Robert Goddard (1862–1945) of USA and Hermann Oberth (1894–1989) of Germany, followed by Werner Von Braun (1912–1977). The V–2 rockets fuelled with a mixture of liquid oxygen and alcohol, and used by Germany against England across the English channel in 1944 during World War II, under the direction of Von Braun carried a warhead of about 2000 pounds.

When Germany surrendered in 1945, there was a scramble between the USA and USSR for the spoils of the German rocket centres. In this, the USA beat Soviet Russia by a matter of days and carried away all the unused V–2 rockets, documents and drawings, a large number of engineers and technicians, and Von Braun himself. The Soviets had to be satisfied with whatever the Americans had left behind. It was the beginning of a mad race between the two countries to develop rocket technology to deliver nuclear and fusion warheads over long distances as part of the Cold War.

In 1954, the International Council of Scientific Unions (ICSU), which had decided to observe 1957–58 as the International Geophysical Year (IGY), recommended to the two super powers that they launch Earth satellites for the study of the upper atmosphere and near space, during the IGY. On July 29, 1955, the US government declared its intention to launch a satellite during IGY. A day later, USSR made a similar declaration. In the subsequent two years, the repeated announcements of the Soviets to implement their declaration were taken lightly by USA and the world at large. No one thought that they had the necessary technological capability. Therefore, the world and in particular USA, was rudely shocked on October 4, 1957, when the 83 kg *Sputnik–1* was launched into orbit by USSR. It was soon followed by the 500 kg *Sputnik–2* carrying Laika, the dog, on November 3, 1957. After hectic preparations and a failure in December, USA launched the 15 kg *Explorer–1* on January 31, 1958. The incredible and unprecedented advances during the succeeding four decades in space technology, science and applications have been truly awe-inspiring.

Notwithstanding the current use of high technology rockets, Earth satellites and deep-space probes, we must not forget the role played by the lowly, manned hot-air balloons, clusters of gas-filled rubber balloons, large volume hydrogen- or helium-filled polyethylene balloons rising to over 35 km with payloads of about 1000 kg, and aircrafts used as platforms for carrying out science experiments. They continue to be used for specialized needs even today. In fact, Victor Hess discovered cosmic rays from a series of gas-filled balloon ascents, at great personal risk, from 1911–1913. Hess personally carried instruments sensitive to the passage of charged atomic particles, and recorded the data by hand from the swaying gondola. He was awarded the Nobel Prize in 1936 for his pioneering work.

The incredible progress in space science has been facilitated not only by the increasing capability of rocket technology but also by the pioneering advances in the reliability and durability of mechanical and electronic components and systems under extreme space environment. In addition to miniaturization, control and guidance systems, radio and telemetry capacity, safety of manned flights, robotics and innovative techniques and methods in scientific payloads. The myriad achievements in both science and technology, in this brief period of 50 years, are a truly astounding and exhilarating tribute to the human spirit. Examples of this are many. A few discussed below may give us a glimpse into this. The very first photograph of planet Earth from space dramatically revealed the terrestrial globe suspended alone in the black void, and struck home to the discerning mind, the common heritage and destiny of humanity.

Equally striking was the philosophic impact world over, of the first "small step" taken by the US astronauts on the surface of the Moon. Yet another fascinating example is the tireless sojourn of the spacecraft *Voyager–1,* which, launched from Cape Canaveral, USA on September 5, 1977, is now more than 10.5 billion km away from the Earth and is at the very edge of the solar system far beyond all planets and all other man-made spacecrafts. It sends back data and signals which, at the receiving antenna on Earth, is just 20 million times weaker than the power of a digital watch battery. *Voyager–1,* which is transmitting data on the state of the outer regions of the solar system – the heliosphere – is expected to leave the solar system and enter into interstellar space in about another 10 years in its endless journey into the cosmos. What a marvel of human ingenuity and intelligence! No less astonishing is the stunning evidence captured by space experiments for the existence of black holes, which are bizarre celestial objects with a singular physical state of "infinite" density, not describable by any physical law. All particulate matter and radiation entering their immediate vicinity is sucked in by their overpowering gravity and devoured; nothing whatsoever can escape from their depths. Space science is indeed the best example of the soaring of the human spirit. We are confident that the future holds many more surprises in store for us. Despite all this, we must caution against the misuse of space for spying, reconnaissance and warfare, all of which could endanger the very existence of human life on this benign planet, made hospitable for humans by the relentless evolutionary processes of nature over the last 4.5 billion years of the Earth's existence.

The Space Environment

What makes space science possible and so powerful in gathering new scientific knowledge not accessible from ground-based laboratories? Clearly, it is the physical state of the environment surrounding the Earth and the position of the spacecraft above the blanket of the Earth's atmosphere. Therefore, it is essential to be first introduced to the most important aspects of the nature of the space environment. They are: the microgravity effect on the object under study; the density of matter or, in other words, the 'vacuumness' of space; the low temperature of the near void; the frequency distribution or spectrum and intensity of the electromagnetic radiation field; the energy distribution or spectrum and intensity of the particle radiation; and the magnetic field pervading near and distant space. Let us briefly describe these.

Gravitational Force

We know that any two bodies attract each other according to Newton's famous Law of Gravitation. It states that

$$F = \frac{G.M.m}{r^2}$$

where M and m are the masses of the two bodies, r is the distance between them and G is a constant called the gravitational constant. The equation means that the gravitational attractive force F is directly proportional to the masses of the two bodies (i.e., it increases or decreases as their masses increase or decrease, respectively). Further, F decreases rapidly as the square of the distance between them; for instance, when the distance r between them increases by a factor of 3, the gravitational force decreases by a factor of 9. Combining Newton's Law of Gravitation with Newton's Laws of Motion, two important consequences follow, which are of interest to us here. First, in the case of an object under free fall from rest due to gravity, the acceleration (or rate of increase of velocity) due to free fall being the same as acceleration due to gravity ($G.M/r^2$), the object experiences weightlessness. Such a condition exists in the free fall phase of a rocket fired from the ground. Secondly, such a state of weightlessness will exist in the case of stable orbit of an Earth-orbiting satellite. Of course, near weightlessness or zero-gravity condition can also exist in deep-space probes travelling with constant velocity.

The Density and Temperature in Space

The density of air near the ground is 0.0013 gm/cc. This corresponds to roughly 2.7×10^{19} particles (gas molecules) per cc. As one goes higher in altitude, the gravity decreases and the atmosphere which consists of gas molecules in random motion becomes thinner. For example, at 500 km above mean sea level, the particle density decreases to about 10^7 per cc, whereas at 1000 km it is only about 1000 per cc. The uncertainties in these numbers can be as much as a factor of 5–10, but it does not alter the nature of the argument. These numbers may be compared to 1–10 particles per cc in interstellar space. Thus, it is seen that at Earth-orbiting altitudes and higher, near-vacuum conditions exist. Note that the gas number density in the lower atmosphere is larger than that at satellite altitudes by more than a factor of a trillion (10^{12}). The temperature of the medium is taken as equivalent to the molecular kinetic energy. In near space, the solar radiation imparts kinetic energy to the individual atoms and molecules. However, since the gas density is incredibly low, their capacity for heat transfer to a body in this mechanism is exceedingly small, i.e., its temperature is very low.

The Electromagnetic Radiation

The electromagnetic radiation emitted by the Sun, peaked at the visible band, approximates the spectrum radiated by a black body at a temperature of about 6000 K (degrees Kelvin). The intensity of the solar radiation decreases as the square of the distance from the Sun. At 70 times the distance of the Earth from the Sun, called the Astronomical Unit–AU – which is the present position of *Voyager–1* – the solar radiation intensity will be feebler than near the Earth by 4900 times (70 × 70). We must also remember that in Earth-orbiting satellites, direct sunlight can heat up the Sun-facing side to very high temperatures, thus necessitating heat insulating and dissipating shields. On the other hand, the shadow side can become frigid.

Particle Radiation

In addition to the electromagnetic radiation, there is also a continuous outpouring of solar plasma (hot ionized gas) from the intensely hot outer regions of the Sun. This is called the solar wind. The intensity or flux of the solar wind depends on the sporadic activity on the Sun, like solar flares, as well as the 11-year cycle of the Sun-spot activity. Flowing out from the Sun with velocities of about 1/100 velocity of light of 3×10^{10} cm/sec, it propagates outwards growing continuously weaker. This sub-relativistic plasma engulfs all planets, including the Earth. At this point, it must be mentioned that the motion of this ionized gas will be influenced by magnetic fields, as we shall soon see.

The interplanetary space is also pervaded by relativistic (moving with a velocity near that of light) charged particles. There are two main sources for this particle radiation. The first is cosmic rays, which fill all galactic space including the solar system. An important source of cosmic rays are supernova explosions which release, among other things, unimaginable amounts of energy in electromagnetic and particle radiation. Cosmic rays consist of relativistic protons, helium and heavier nuclei, and some electrons. The second source is the Sun itself which, at times of very intense solar flares, accelerates charged particles to relativistic energies, though these are relatively less energetic than cosmic rays. When such fast particles traverse any material medium, solid or gas, they lose energy by ionizing the target material; the slower the particle, the greater is its rate of energy loss and the ionization damage of the target.

The Magnetic Field in Space

All space is pervaded by magnetic fields of varying strengths. The field strength in interstellar space is roughly 5×10^{-6} Gauss. This may be compared with a fraction of Gauss due to the Earth's magnetic field (geomagnetic field) on its surface. The geomagnetic field may be well approximated by an imaginary dipole magnet near its centre, with its axis tilted with respect to the Earth's rotational axis by 11.4°. The magnetic field-lines connecting the two poles extend into space in layers enveloping one another like an onion (the magnetosphere) over a distance of up to about 10 times the radius of the Earth, which is 6378 km near the equator. However, the magnetosphere is not symmetric in shape. The solar wind leaving the surface of the Sun drags with it, the embedded magnetic field lines. The ionized (electrically charged) particles in the solar wind spiral along the magnetic field-lines and the two move together, propagating outwards. We say the magnetic field is frozen in the ionized gas. When this plasma hits the sunward side of the Earth, the magnetosphere is slightly compressed without much penetration. It then flows around the field lines and stretches them to great distances on the dark side (magneto-tail). The complex structure of the solar wind and the associated magnetic fields greatly affect the trajectories of cosmic rays in interplanetary space.

Looking Down and Looking Up

The space environment typically associated with Earth-orbiting satellites has the unique advantage of looking down on the Earth through windows (sensors) in the optical, infrared and microwave regimes with sensors of great sensitivity and spatial and spectral resolution. Such observations can be made frequently and over long periods of time. On the other hand, one could also look up at the star-studded heavens through any of the electro-magnetic windows, from the most energetic gamma rays through x-rays, ultraviolet, optical, infrared, microwave to the radio regime. The Earth's atmosphere will not hinder the observation of the sky, as is the case with ground-based telescopes.

Amazing Opportunities in Varied Sciences

When we talk about weightlessness, several types of questions come to mind. All terrestrial life has evolved and adapted to the environment of Earth's gravity and the small dosage of cosmic rays. The typical questions that can, therefore, be asked immediately are: What will be the effect of weightlessness and the increased cosmic ray dosage on plants, insects and other animals and birds? What will be their impact on human beings and their physiology during long space missions? When scientists are seriously considering manned missions of long durations to explore the Moon and Mars and even exploit their resources, such scientific knowledge becomes an indispensable pre-requisite. Second, we can think of the preparation of materials, composites, alloys, crystals, etc. in weightless condition. Can better or newer materials be made in such exotic environments?

Innovative technologies will make it possible for scientists to exploit the extreme vacuum conditions and ultra-low temperatures of the space environment, in order to carry out experiments which may be extremely difficult in terrestrial laboratories.

The abundant solar radiation can be used to power solar cells and solar sails. The solar spectrum can be accurately monitored to understand their effect on the Earth system. Perhaps in some future time man will learn to extract large quantities of solar energy and transport it to the ground using appropriate technologies. The fundamental properties of plasma and its behaviour in space is a subject of great importance. Space missions can be used to make *in situ* measurements and study-associated problems.

Imagine the incredible opportunity of being located in an Earth-orbiting satellite and looking down on the Earth with a battery of state-of-the-art on-board sensors and instruments to conduct research in various areas of Earth sciences. With a suitable combination of sensors, cameras, radars, image-processing techniques, etc. in selected wavelengths, numerous parameters, phenomena and events could be studied over a long period of time. Examples of such observations are: dynamics and composition of the atmosphere, cloud cover, precipitation, storms and cyclones, sea surface colour and temperature, ice cover, plant cover and many more. Further, there are diverse applications of remote sensing data in such areas as land use and land cover, forest monitoring, wasteland mapping, ground water prospecting, ocean and coastal resources survey, cyclone tracking, urban planning, and pollution studies. Finally, it lends us a powerful capability to establish long-term trends in global changes, including global climate change and global warming due to human actions.

Having seen the numerous scientific returns of looking down on planet Earth, we may look up at the black sky above through any of the electromagnetic windows. Unlike ground-based telescopes, whose seeing power is either hampered or eliminated because of the absorption and distortion of the cosmic signals by the atmosphere, from space we have full seeing power. This advantage gave birth to high-energy astronomy in gamma ray, x-ray and ultra-violet windows. Technological capabilities in orbiting large telescope facilities, incredible accuracies and control in telescope pointing, the development of ingenious detector systems for gamma ray and x-ray astronomies, versatile and ultra-sensitive back-end instrumentation for large mirrors in UV, optical and infrared windows, have all contributed to a deluge of discoveries in astronomy and astrophysics which are continuously revising our ideas about the solar system, our galaxy, the Milky Way and the universe. Of the many innovative and sometimes revolutionary astronomical observatories orbited so far, the Hubble Space Telescope launched by USA on April 24, 1990, is by far the most advanced facility, a product of the best of international cooperation with unparalleled sensitivity and high accuracy, the very embodiment of human ingenuity. No wonder it is spewing out discovery after discovery!

A word may be added about the presence of astronauts in scientific missions. This gives, in addition to all that we have said above, the intelligent intervention of humans without which the experiment would have been poorer in many ways. Special reference may be made to a major repair work carried out in orbit to the Hubble Space Telescope by astronauts, which not only saved the mission but improved it in a major way.

Finally, the prodigious technological advances in robotics and the capability to carry out complex experimental operations by remote control have empowered scientists to survey and study conditions on Mars to investigate the existence of extraterrestrial life. All such space missions and the exciting scientific knowledge obtained from them appear like science fiction to most of us.

Innovations in Scientific Payload

When a scientific experiment is to be selected for carrying out observations in space, it has to comply with many requirements and objectives. During the rocket blast-off, the instruments are subjected to high levels of acceleration many times the value of *g*, the acceleration due to gravity. The volume and weight of the experiments must be minimized to be accommodated within the space capsule. This calls for miniaturization of the electronics, optimization of volume, and the use of special materials. Since in-flight repair and service are not normally possible, the instruments must have a high degree of reliability in operation and manoeuvres in space. Not only that, the long duration of the space missions calls for durability of the instrument functioning, without degradation in efficiency. Furthermore, the experimental payload must have sufficient tolerance to the space environment. It must be designed to function normally under temperature variations, depending on its orientation with respect to the Sun and its orbital path. It is also essential that the scientific experiments operate for long periods of time consuming just minimal power. All sub-systems of the payload must incorporate ingenious methods of low power consumption and conservation, as well as power generation. While solar power is normally used, in cases where the spacecraft has to reach the most distant regions of solar system where the intensity of solar radiation is feeble, as in the case of the *Voyager* missions, radio isotope thermoelectric generators provide the necessary power. Each experiment, depending on its scientific objectives, requires a dedicated data-collecting system sensitive to the electromagnetic, or sometimes to the atomic particle, signal relevant to the experiment. It may be in the optical or infrared or even microwave windows for astronomy and remote sensing. It may be in the x-ray or gamma ray windows for high-energy astronomy. Or, it may be an instrumented astronaut for studying human physiology in space. In space biology, scientists may use living organisms to study their cell function, reproduction, etc. in the weightless space environment. In many of these experiments, it becomes necessary to design and fabricate novel sensors, as in the case of x-ray and gamma-ray detectors. It is indeed exciting to see the ingenuity and novelty of these sensors tailored to respond optimally to exceedingly feeble signals among the sea of noises.

We also need to refer here to the design and fabrication of the Hubble Space Telescope of which we have already made mention as the ultimate, at least currently, in space experiment incorporating human ingenuity at its very best.

Many of the space experiments collect data at such an amazingly rapid pace, often along with unwanted information. In such cases, on-board data processing is needed to reduce the unwanted data or to select wanted signals. Programmed on-board computers do this job. There are other, wherein ground-based intervention is sometimes needed to control the orientation and pointing direction of the telescope system, or to shut off the payload for special reason like conserving power or avoiding environmental hazards. Finally, the data collected has to be telemetred to the ground faithfully. The fact that *Voyager–1*, more than 20 years after its launch in 1977, at a distance of 10.5 billion km from Earth and at the very fringes of the frigid solar system, is sending back data to the Earth sounds unbelievable but is true. This speaks volumes about the sensitivity of the transmitting and receiving systems.

Innovative ideas open new opportunities in science

Concepts in science and technology have also provided singular opportunities for enriching the scope of space experiments. We shall try to illustrate this by means of a few examples.

Earth satellites and spacecrafts are launched close to the ecliptic plane, which is the surface in which the Earth and most other planets revolve round the Sun. This is because while launching rockets, they take advantage of the Earth's rotation and thereby reduce the demands on the rocket system and the fuel needed. Minor orbit corrections and other manoeuvres in space are carried out with on-board thrusters which are special bottles of gas under pressure with many orifices which, when opened, give a thrust to the satellite in the direction opposite to that of the gas jet. However, this method has its limitations, because of the prohibitive problems involved in carrying large gas bottles on board. A technique which has been successfully used in many scientific missions is to take the satellite in the right orbit around another planet, which also is moving along the ecliptic plane. With the right velocity, direction and distance from the planet, the gravitational pull of the planet will swing the satellite in the right direction in space. A good example of this is the *Ulysses* spacecraft designed to study particles, plasma and radiations emitted by the Sun, particularly from its polar regions. The *Ulysses* was launched towards Jupiter in October 1990, by the US space shuttle *Discovery*. Arriving at Jupiter in February 1992, the giant planet provided the gravity swing to propel the *Ulysses* back towards the Sun in an elongated sun orbit perpendicular to the ecliptic, i.e., over the poles of the Sun with a period of 6 years. It has yielded a rich harvest of data over the solar poles, which are inaccessible to the usual spacecrafts. Similar gravity-assisted science missions have been resorted to in many other instances.

SOHO, the Solar and Heliospheric Observatory, is yet another mission to monitor the Sun and the heliosphere continuously. Launched on December 2, 1995, the spacecraft is placed at a point between the Sun and the Earth where the gravity of the two bodies is exactly balanced—called the Lagrangian Point. It is 1.5 million km sun-ward from the Earth, providing an uninterrupted view of the Sun for *SOHO*. The data obtained from a battery of on-board instruments have already revealed many a secret about the interior of the Sun and the processes taking place in the solar atmosphere.

Another innovative idea relates to the study of planets and their moons using orbiters, landers and rovers. Since manned missions to study the surface of these solar system bodies are risky to the astronauts, and their demands on technology and money are prohibitive, space scientists and engineers have resorted to novel ideas by building robots to do what even humans cannot do in the environment that prevails there. The first robot to land on the Moon was the Soviet "Lunakhod" or Moon buggy, which even brought back samples of lunar soil. On the other hand, Mars, the red planet, has received maximum attention because of its similarity to the Earth and the possibility of finding life on its surface. Of the many Mars missions, the Mars *Pathfinder* has many novel features. Launched on 4th December 1996, it is a combination of an inexpensive robotic lander and a 10.5 kg roving prospector. Assisted by a 36 foot-diameter parachute, the spacecraft descended to the surface of Mars and landed with a speed of about 40 miles/hr on air-bags and gently bounced 16 times over a distance of almost 1 km before coming to rest. Both vehicles are solar powered. With the battery of highly- sophisticated instruments in the lander and rover, and the rover's periodic treks around the lander, the data collected have been nothing short of extraordinary. This mission has demonstrated the ingenuity of space specialists to design low-cost robust robots that operate in hostile environments and collect and transmit data that lead to discoveries on planetary bodies.

These are only a few examples of the vast array of ingenious and innovative techniques, methods and sub-systems that have been designed and used most successfully to make spectacular discoveries. (For further information, see Chapter 2).

International Cooperation

The challenge of space has fostered international cooperation on a large scale. The most spectacular event, demonstrating the cooperation of erstwhile Soviet Union (now Russia), and the United States. It was the one witnessed on the world television channels on July 15, 1975, of the handshakes between the *Apollo* astronauts and the *Soyuz* cosmonauts in the interlinking module orbiting at an altitude of 225 km above the Earth. After exchanging their respective country's flags, the spacemen signed the following certificate: "Here, today in Space, on board *Soyuz 19*, we, the representatives of the two countries, the Soviet Union and the United States, have affixed our signatures to a document symbolizing the beginning of joint international exploration by manned spacecraft. This flight is an important stage in the exploration and development of space by the joint effort of all mankind".

The first Earth satellite, *Sputnik–1* was launched by the USSR on October 4, 1957, and the first US *Explorer* satellite in 1958. At that time, space research was an activity mainly confined to these two countries. But the Cold War between the two super powers was intense and there was no internationa fora where space scientists could meet and discuss their research findings. It was at a juncture like this that the International Council of Scientific Unions (ICSU) deliberated on the matter and decided to set up a Committee on Space Research (COSPAR), in November 1958. Ever since, COSPAR has been a powerful facilitator of international cooperation in space research. During the early years, it provided, through it International Assemblies, the only forum where scientists from USSR and USA could meet and discuss problems of common interest. These assemblies have grown with time and now cover all disciplines of space science.

International cooperation is now common to almost all scientific missions. The main reasons are: they are expensive; they thrive on the best of scientific ideas; the technological and technical demands are stringent and different countries have the best expertise in different technologies; the piles of data flooding over many years of operation of the experiment require a large number of scientists to analyze and interpret; and they provide opportunities for scientists from different countries to work together and foster peer criticism and views.

The Space Station is a venture for the future, and many countries are actively participating in this gigantic human endeavour. It will be the ultimate space laboratory providing diverse opportunities for new science and technology, and may be the springboard for the exploitation and perhaps colonization of space.

Contents of the Book

From the foregoing introduction to space science, it must be evident that space offers scientists daring challenges, awe-inspiring opportunities and a unique potential for research in a diversity of scientific disciplines. It is the prime objective of this book to convey to the reader the excitement of these challenges, the manner in which scientists have exploited the opportunities with innovative and smart strategies and techniques and a sample of the remarkable, and sometimes startling, results that have been obtained. This is supplemented by the existing basic knowledge in the respective disciplines to enable the reader to recognize the role of space opportunities and appreciate the new knowledge thus obtained. Experts from all over the world have made contributions in their respective fields of space research in this book.

Although, space scientists currently depend heavily for their research on Earth satellites and deep-space probes, early endeavours in the 19th century began with hot-air balloons as space platforms. In these, the inventive and daring scientists ascended themselves in the balloon gondola and recorded, by hand, the data from the instruments. The discovery of cosmic

rays was made this way. Such attempts were followed by observations collected from mountain stations, aircraft, free-flying clusters of rubber balloons and large-volume stratospheric balloons made of plastic, as well as with sounding rockets, both big and small. Then came the Earth-orbiting satellites and deep-space missions. The spectacular advances in space platforms for scientific research are discussed in Chapter 2. (The reader is strongly recommended to read this chapter before embarking on the remaining chapters).

While the Earth's atmosphere has often been a kind of hindrance in space research, a proper understanding of its composition, structure and dynamics is essential for numerous scientific and application purposes, including the proper interpretation of space data as exemplified in remote sensing. Though a great deal of basic knowledge on the atmosphere has been collected over the last century by meteorologists, from ground-based measurements and meteorological sounding balloons, space platforms have provided valuable inputs to our knowledge during the second half of the 20th century. All these are described in Chapter 3.

Remote sensing of the Earth and its environment has yielded spectacular results in Earth Science and myriad applications, including those for surveillance and monitoring for civil as wel as military purposes. All this required a whole host o innovative ideas, detectors, methods and techniques; these are summarized in Chapter 4. Another area of prime interest t scientific advancement and human welfare is a reliabl understanding of regional and global weather and climate an the ability to predict them in advance. Space studies hav contributed significantly to our knowledge on these comple processes and phenomena involving the atmosphere–ocean-land interactions. Chapter 5 deals with this important subject.

Global changes to the Earth system, caused by natura processes and human actions, is a subject of internationa concern these days. For example, scientists now suspect tha global warning, due to copious emission of greenhouse gases lik carbon-dioxide, is setting in gradually with all its attendant effect like climate changes, sea-level rise and polar ice melting. Reliabl knowledge of such large-scale but small changes is necessary i order to take precautionary action. For this, monitoring suc changes on land and sea from space, over an extended period time, is a powerful method. These are highlighted in Chapter 6.

The planet Earth along with its Moon is a part of the solar system which comprises the Sun, the planets with their moons and rings, the asteroids and comets—all enveloped within the heliosphere extending more than 50 times Sun–Earth distance. Human ingenuity and curiosity, backed by high technology, have facilitated the exploration of the entire solar system with unmanned survey missions, robotic landers and rovers to study planetary surfaces, rendezvous with comets and manoeuvring in space using on-board thrusters and planetary gravitational swings. Such pioneering experiments have given us a wealth of data. Chapter 7 gives an overview of all this.

Space platforms have also been adroitly utilized for making astronomical observations in the entire electromagnetic (em) spectrum, ranging from radio wavelengths to high energy gamma rays. Telescopes for each em window have been designed with ingenious ideas for photon collection and collimation and using state-of-the-art detecting devices at the back-end of the telescope and high precision pointing technology to view the chosen celestial object. These space telescopes covering radio, infrared, optical, ultraviolet, x-rays and gamma rays have collected an unimaginable wealth of data for every kind of astronomical object. In the ultraviolet, optical and infrared regimes, surprising findings have been made on objects in our own galaxy–the Milky Way—and also in external galaxies. These are covered in Chapter 8.1. On the other hand, observations from x-ray and gamma-ray telescopes and sometimes simultaneous observations in a number of em windows have surprised the astronomers with incredible information on exotic condensed objects like neutron stars and black holes. These are described in Chapter 8.2

The near absence of gravity during the freefall stage of a rocket and in Earth-orbiting satellites, provides an unique opportunity to carry out imaginative experiments in Materials Science, including alloys and crystals. These are summarized in Chapter 9.

One of the long-held dreams of humans to conquer space has been realized, as demonstrated by the manned, long duration flights of the Russian *Mir* missions and the landing of US astronauts on the Moon. It is evident that man in space will be subject to a variety of physiological changes. These have been studied in great detail on Russian cosmonauts and US astronauts and very interesting results obtained. Also, it is instructive for the reader to know about the criteria for selection of these people, the on-board requirements for living in a spacecraft and the results obtained on the effects of space environment on body functions. These are summed up in Chapter 10.

Further, the microgravity conditions in satellites and the particle radiation environment in space have offered challenging opportunities for biologists to investigate the response of biological systems to this environment. Important discoveries have been made in topics such as cellular function. This has encouraged elaborate plans to conduct ingenious experiments with high-tech biological space laboratories like "Biorack" for basic and applied biological research in a variety of Russian and US missions. They are reviewed in Chapter 11.

The enquiring minds of humans have always wondered about the possibility of the existence of life-forms and intelligent beings in celestial bodies beyond the Earth. Recent advances in space technology and planetary missions on the one hand, and biological sciences on the other, have stimulated daring explorations to detect primitive forms of life in other planets and other solar system bodies. Radio astronomers are setting up giant radio receivers to eavesdrop on coded messages that may be broadcast by advanced civilizations elsewhere in the universe. Such fertile ideas, speculations and novel experiments are highlighted in Chapter 12.

The Space Age is just about 40 years old, and we have already witnessed incredible achievements in space technology and Space Science. So, what lies in store for us in the 21st century? What are the plans? What are the prospects? These are surveyed in the last chapter.

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