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SPACE SCIENCE IN INDIA

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Until the beginning of the 20th century, human endeavour in science and technology remained by and large in the restricted domain of individual initiative and motivation. However, the advances made over the previous few centuries, particularly in Europe, and the recognition by nations and governments that science can be used as a powerful instrument of national development and defence preparedness, have enabled countries which were, at that time, favourably positioned politically, economically and otherwise, to invest large funds in organised scientific research and development and reap their benefits. In the course of this century, these trends, together with the attainment of freedom by a large number of nations and peoples who were until then under the yoke of foreign domination, have given rise to the so-called developed and developing nations. The dominant role that space science, space technology and space applications have played in this phenomenon of development as well as defence preparedness is also well known. The new opportunities that space research has offered for the study of the earth, the solar system and the astronomical universe is a factor which has given a new dimension to man's oldest quest to know the mysteries of the celestial bodies and the origin of the universe. The accomplishments so far in space research and the multifaceted potentialities for the future are so obvious, so immense and in a sense so frightening that the present era is rightly called the space age. No nation can afford to ignore these facts if it is to continue its struggle for intellectual and material advancement, and indeed for its independent existence.

In India, ever since its independence in 1947, there has been an adequate recognition and appreciation of these considerations. In consequence, over the last 35 years a pragmatic approach has been formulated and implemented with government patronage in steps and stages, culminating in an Indian capability to develop its own satellite launch vehicle and to successfully launch its satellites in earth orbit for various peaceful applications of space. In the present paper, we first present a brief review of the progress of the Indian space science activities and then endeavour to deduce some lessons from this experience. It is good to emphasise here itself the intimate connection between space science and space technology. Modern space science cannot flourish without space technology. Hence, in our considerations here the two will be inextricably connected at many points.

INTRODUCTION

Studies in scientific astronomy in India are known to date back at least to the 5th century astronomer-mathematician Aryabhata after whom the first Indian satellite was named. Following Aryabhata, there were a host of astronomers over the succeeding centuries whose works also reveal contacts with the astronomical works of the Greeks and the Arabs. For example, the astrological work of Varahamihira (*c.* 505 AD) contains the names of Greek Zodiacal signs and planets for the first time. In the early part of the 18th century, Maharaja Sawai Jai Singh (1686-1743 AD) made considerable contribution to Indian astronomy by building a chain of five observatories at Delhi, Jaipur, Varanasi, Ujjain and Mathura with various kinds of instruments all built of masonry to great precision. He sent workers to foreign countries to study astronomy; and yet it is a mystery that he did not introduce the telescope in his obervatories. In 1792, the East India Company established an observatory at Madras for promoting the knowledge of astronomy, geography and navigation. This observatory is the precursor for the solar observatory established in 1898 at Kodaikanal (2340 m) from where a number of pioneering solar obervations were made, particularly by J. Evershed.

Of historic interest to the development of rocketry in India is the use of rocket warfare in 1792 by Tippu Sultan against the British near Mysore in South India. The British were so discomforted by this event that a detailed report had to be sent to England about Tippu's new machine. This report in turn was responsible for William Congreve to develop Tippu's ideas further.

A new development in space science took place in the 1920's when S.K. Mitra in Calcutta initiated interesting activities in radio research, which led to the sounding of the ionosphere using ground-based radio techniques. The Calcutta group also participated in the International Polar Year 1932-33. This small beginning led to the establishment over the years of a number of active programmes in universities and national laboratories in aeronomy, geomagnetism and magnetosphere.

It might also be pertinent to remark here that by the end of World War II, many Indian scientists like Raman, Bose and Saha had already made very valuable contributions in physics, thereby contributing a favourable climate for researches in physical sciences.

The Formative Years 1945-60

The men behind the beginning

The beginning of an organised approach to researches in space science in India goes back to the late forties. This beginning was nucleated and stimulated by two individual scientists – Homi Bhabha and Vikram Sarabhai. Between them they shared many qualities and achievements. Both had acquired distinction through researches on cosmic rays at an early age; both were visionaries with immense foresight; each one founded an institution for basic research – The Tata Institute of Fundamental Research in Bombay by Bhabha in 1945, and the Physical Research Laboratory in Ahmedabad by Sarabhai in 1947; both developed and enjoyed during their lifetimes the right rapport with and support from the government as well as private enterprise; both were good managers with the right appreciation of the existing milieu in the country; both were successful institution builders; and both died in harness at the peak of their productive careers.

The nuclei for basic space science

At the Tata Institute of Fundamental Research (TIFR), studies on cosmic radiation were initiated in 1947. The main approaches were two-fold: (1) to send instruments such as nuclear emulsions and electronic particle detectors to great altitudes in balloons to study the nature of the primary radiation; and (2) to set up installations at mountain altitudes and deep underground in the Kolar Goldfields to study the nature of the very high energy nuclear interactions produced by primary cosmic rays in the atmosphere and the secondary particles that result from them. One important motivation to undertake balloon studies for primary cosmic rays was the favourable geographic location of South India where one can study the high energy cosmic radiation (>15 GeV) in the absence of the intense low energy radiation which is prevented by the geomagnetic field to reach equatorial latitudes. For this we had to develop suitable balloon technologies to carry payloads to great altitudes. This was first carried out with clusters of rubber balloons and later upgraded to large volume polyethylene balloons which can carry heavy payloads to altitudes of 35-40 km; over the years, considerable improvements and indigenisation have also been carried out at the Balloon Facility at Hyderabad. In the case of the study of secondary cosmic rays, we fully exploited the existence at Kolar of one of the deepest mines in the world (3000 m) where at depths available to us even the cosmic ray muon flux drops to near zero enabling thereby the study of high energy neutrinos in an otherwise radiation-free (nearly) environment. These experiments started in 1950's have in a natural sequence made it possible to conduct in succeeding years pioneering investigations. Stimulated by work on cosmic rays, a very rewarding programme of activity on the application of cosmic ray produced stable and radionucleides to geophysical investigations was initiated. Also, pioneering work on the development of new techniques of track revelation in meteoritic crystals was initiated which led to a series of major contributions in fossil cosmic rays in lunar samples and meteorites. These activities which were the products of considerable foresight for the 1950's paid tremendous dividends in later years.

At the Physical Research Laboratory (PRL), one of the two primary concerns in the beginning was long-term monitoring of secondary cosmic rays – the muons and neutrons – at sea level as a function of latitude and longitude. Such studies were used in a powerful way to extract information on the modulation of cosmic rays in the heliosphere, and the nature of the interplanetary medium. The second field of research initiated early at PRL was upper atmospheric studies over low latitudes, including meteorology, ionosphere investigations, geomagnetism and solar-terrestrial relations. In cosmic ray studies it became necessary to design and fabricate Geiger-Muller and neutron counters with high reliability and long life in large numbers. This was achieved by training an adequate number of supporting technical personnel in the concerned instrumentation. Also, the extent of the Indian subcontinent extending from Trivandrum almost at the magnetic equator (geog. lat, 8°29′ N) to Kashmir in the north (geog. lat. 34°03′ N) was used in a powerful way to obtain latitude dependent effects.

During this period, interesting beginnings on atmospheric studies were made at a number of other institutions, including university centres where significant contributions were made in the study of the ionosphere, particularly on ionospheric drifts and relative ionosphere capacity measurements. Pioneering activity was also initiated on optical emissions from D, E and F regions of the atmosphere. The study of radio propagation and monitoring of Radio Tashkent gave interesting results. Particular mention may be made of the discovery of reflections from meteor trails by the Research Department of All India Radio for the first time in the world. Furthermore, through studies of long wave propagation, a new method of detecting solar flares from the sudden change in field intensity was discovered. For all such investigations, electronic equipment, radio transmitters and receivers were fabricated locally.

Studies of the geomagnetic field which in India date back to 1823 when the Colaba Observatory in Bombay was established, were begun at a number of other stations all over India. Continuous observations from these stations provided a powerful data bank for long-term correlation studies on ionosphere and solar-terrestrial relations. The data obtained from Trivandrum on the geomagnetic equator proved to be a very useful input in a variety of investigations.

The India Meteorological Department has made extensive data collection of meteorological parameters from a large network of stations using ground-based and balloon-borne instruments over a long period of time. This again is proving to be of tremendous use, particularly in the study of the Indian monsoon, and has enabled an early capability to undertake space meteorology work.

In astronomy, two new observatories came to be set up during this time. In 1954, the Uttar Pradesh State Observatory (UPSO) was commissioned at Nainital in the Himalayan slopes by the Government of Uttar Pradesh, primarily for stellar and solar observations. The observatory has been participating in the photographic tracking of earth satellites with the Smithsonian Astrophysical Observatory of USA since the IGY in 1957. The second is the Rangpur Observatory of Osmania University at Hyderabad where sanction was given in 1957 for a 1.20 m telescope with funds from the US Wheat Loan Exchange Programme. However, because of undue delay, the telescope was commissioned only in 1968.

The early organisation

It is good to examine at this stage the organisational structure and the governmental support that was lent to the space programme and space sciences during this formative period. Tata Institute of Fundamental Research was founded in 1945 with Bhabha as the Director. Then in 1948, the Government of India set up the Atomic Energy Commission with Bhabha as the Chairman. Until 1950, there was no organised governmental support for space science. However, at the initiative of Homi Bhabha and Vikram Sarabhai, the Department of Atomic Energy (DAE), of which Bhabha was the Secretary, assumed responsibility for space research in the country by the early 1950's. In 1953, DAE constituted a Board of Research in Nuclear Sciences to provide funding for research projects from university scientists in nuclear sciences, mathematics and space science. As a result, the first national symposium on cosmic rays and related astrophysics was organised in Delhi in 1955. Subsequently, these national symposia came to be held regularly, though with the passage of time the scope of the symposium was enlarged to include other space sciences too. These symposia provided an important forum to bring together space scientists, particularly the young researchers, regularly for exchange of ideas, arrange cooperative efforts and plan future programmes.

By the close of the 1950's, the atomic energy programme had been given concrete shape, and long-term plans were well defined under the leadership of Bhabha. This was possible because of the support and encouragement extended to Bhabha and the DAE programme by the Government of India under the enlightened leadership of Jawaharlal Nehru who shared with Bhabha his vision and foresight. Then in 1957, the year of the International Geophysical Year Programme, Soviet Russia launched the first Sputnik. The potentialities of rockets and satellites for the future burst into clear sight. India too shared in this excitement and the stage was set for enlarging and enhancing the scope of space research.

It is interesting to note that even the early intentions and commitments of the Indian Government were made manifest in the Scientific Policy Resolution of 1958 in which it is stated:

> "It is an inherent obligation of a great country like India with its traditions of scholarship and original thinking, and its great cultural heritage, to participate fully in the march of science which is probably mankind's greatest enterprise today".

THE CONSOLIDATION DURING THE 1960'S

The organisation

Activities in space research in India continued to be looked after by the Department of Atomic Energy of the Government of India during this period also. But there was an increasing realisation that it needed greater attention, organisation and funds. In recognition of this, the Indian National Committee for Space Research (INCOSPAR) was constituted in 1962 by DAE under the Chairmanship of Vikram Sarabhai with the charge of looking after the interest of space research in India. Following this, in 1963, the Thumba Equatorial Rocket Launching Station (TERLS) was commissioned near Trivandrum under the sponsorship of UNESCO. TERLS, located at the geomagnetic equator, was primarily meant for scientific experiments with rocket payloads and was made freely available to scientists from all over the world. On 2 February 1968, it was dedicated as a United Nations sponsored range by the Prime Minister of India.

It is clear that in the beginning, the main motivation and objective of the space programme in India was space science. However, during this decade it became evident that for a large developing country like India, space offered great opportunities for applications such as in communication and remote sensing. A realisation of this and an intention to take advantage of it influenced the plans of Bhabha and Sarabhai. At this juncture, on 24 January 1966, Bhabha died in a tragic air crash on Mont Blanc and the partnership between the two was abruptly broken. Vikram Sarabhai then took Bhabha's place as the Chairman of the Atomic Energy Commission and Secretary, Department of Atomic Energy.

During the second half of this decade, a number of important new decisions were taken and new activities generated. These include:

- The setting up of the Space Science and Technology Centre (SSTC) next to TERLS. It is the main research and development centre for space technology.

- The Experimental Satellite Communication Earth Station (ESCES) became operational in 1967 in Ahmedabad. This station was primarily set up to train scientists and engineers from India and other developing countries in the use of satellite communication.

- The first phase of work started on the Sriharikota (SHAR) Centre on the east coast just north of Madras to set up the national range for launching multi-stage sounding rockets as well as satellite launch vehicles developed indigenously.

- The Indian Satellite System Project (ISSP) was initiated as a wing of SSTC in Trivandrum.

- The INCOSPAR was reconstituted under the Indian National Science Academy which is the national body affiliated to ICSU.

- In 1969, the Indian Committee for Space Research (ISRO) was constituted by the Department of Atomic Energy under the Chairmanship of Vikram Sarabhai. ISRO has the charge of executing all space activities.

Science activities

The establishment of the Equatorial Rocket Launching Station at Thumba stimulated considerable work on equatorial aeronomy and X-ray astronomy. It also acted as a starting point for a variety of international collaborations with scientists from many countries, including USA, UK, France, West Germany, USSR and Japan. In these experiments, Arcas, Judi Dart, Nike Apache and Nike Tomahawk rockets supplied by NASA, Dragon and Centaure rockets supplied by CNES, and Petrel and Skua rockets supplied by UK were launched from TERLS. Under an agreement with France, India started fabricating Centaure rockets at the Bhabha Atomic Research Centre, Bombay towards the end of the sixties. Further, the first in the series of Indian rockets, Menaka, meant for meteorological studies to reach 45 km were made at SSTC and launched from TERLS.

These rockets were used for studies relating to the neutral atmospheric winds and temperatures using sodium vapour cloud and chaff payloads. Langmuir probes were used for electron density and electron temperature profiles. Magnetic fields were measured by proton precession magnetometers, and electric fields by barium release technique. In addition, riometers, high frequency capacity probes and plasma noise probes were also used in these experiments. They gave a series of very interesting results on the equatorial electrojet and ionosphere, ionisation irregularities, the neutral atmosphere and a number of other parameters which not only gave a better understanding of the equatorial upper atmosphere but also highlighted its peculiarities.

Upper atmosphere studies were also carried out using ground-based experiments and satellite data. A back-scatter experiment to study the dynamics of the electrojet developed by PRL was set up at Thumba. Satellite radio beacons were employed extensively for ionospheric studies; transmissions from Explorer 22 and 27 satellites were used in these investigations. Equatorial topside ionosphere was studied by receiving the transmissions from Alouette I and II satellites at a number of stations; interesting results were obtained during times of magnetic storms.

Major improvements were incorporated in the scientific ballooning techniques. Polyethylene balloons of $10^5 m^3$ were successfully made and flown for X-ray and gamma-ray astronomy and primary cosmic rays wherein a variety of rewarding results were obtained. During this decade, two major Indo-USA balloon expeditions were organised in Hyderabad, the first one in 1961, and the second in 1965 as part of IQSY; in this a number of universities from not only USA but also from UK, Ireland and Australia participated.

Rocket experiments at Thumba were also carried out for a number of investigations in X-ray astronomy, some of which were in collaboration with scientists from USA and Japan.

At the invitation of the cosmic ray scientists of the country, the 8th International Cosmic Ray Conference was held in Jaipur in 1963.

By the end of the decade, there was visible progress in India in both space technology and science. New facilities were installed, new technologies developed, and future plans reviewed and defined. Elsewhere in the world, countries other than USSR and USA were developing the capability to build and launch their own satellites. Numerous satellites for science were being launched by USA and USSR. Manned missions into space were repeated many times culminating in the landing of man on the moon in July 1969. Following all this, the Indian Space Research Programme was also assuming a definite shape and direction by the close of this decade.

Progress in the Period since 1970

Organisation

In 1969, the Department of Atomic Energy, which was still in charge of the Space Programme in India, formulated a ten-year profile for consideration of the government. This document made it clear that the long-term objectives should be aimed primarily towards national development; accordingly, telecommunication, remote sensing for resource survey, and meteorology were identified. These objectives were to be realised by ultimately building a capability to design, fabricate and launch Indian satellites, including geosynchronous ones, with Indian launchers.

In December 1971, Sarabhai died suddenly. During an interim period, when Prof. M.G.K. Menon was in charge of the Indian Space Programme, he convened a large national seminar of scientists, engineers, technocrats and administrators to discuss and define the ten-year profile prepared by Sarabhai.

Recognising the growing demands and importance of the space activities, the government constituted in June 1972 an independent Space Commission and a Department of Space and requested Prof. S. Dhawan to head both; he also took over as Chairman, ISRO, which functions under the Department of Space. With his appointment, serious plans were under way to implement the profile for the seventies. Of special importance to space science is the introduction of a system of ISRO support for sponsored research (RESPOND) in universities and national laboratories in space science and technology in 1976. In the first four years, 1976-80, of its functioning, RESPOND had funded 34 research projects in space science.

Recognising the great need to coordinate the isolated activities and programmes of space scientists all over the country, to mobilise new support and opportunities in space science, and to utilise the emerging opportunities and facilities in space technology, ISRO constituted in 1980 the Advisory Committee for Space Sciences (ADCOS). The Committee has been very active during the last two years in consolidating existing strengths and planning for the years to come.

Of interest here is the identification by the Department of Science and Technology, which has the general charge of science and technology in the country, of astronomy and atmospheric studies as major thrust areas for intensive funding.

Major achievements in space research

A major landmark in the space programme of India was the launching of the first Indian Scientific Satellite Aryabhata in 1975 by USSR. This 360 kg satellite designed and built at the ISRO Satellite Centre (ISAC) at Bangalore carried out three scientific experiments: (i) X-ray astronomy, (ii) ionosphere, and (iii) emission of energetic gamma rays and neutrons from the sun. Useful results were obtained from two of the experiments. Aryabhata was followed by the launching by USSR of two Indian satellites for remote sensing, Bhaskara I in 1979 and Bhaskara II in 1981. The 670 kg India's first experimental three axes stabilised geostationary telecommunications satellite APPLE (Ariane Passenger Payload Experiment) built at ISAC was successfully launched by Europe's launch vehicle Ariane in June 1981.

Among the other major achievements we should include: (i) the Satellite Instructional Television Experiment (SITE) during 1975-76, when the NASA geosynchronous satellite ATS-6 was moved to a suitable location to permit special instructional and educational TV programme to be directly broadcast to about 2500 community centres in rural India; and (ii) the Satellite Telecommunications Experiments Project (STEP) in which the Franco-German satellite Symphonie was used during 1977-79 for telecommunication experiments.

Of special pride to the Indian space programme is the first successful launch of the 35 kg Rohini satellite RS-1 by India's own launcher SLV-3 in July 1980. India thus became the seventh nation in the world to achieve the capability to launch a satellite. This was followed by a second SLV-3 launch of a 38 kg satellite RS-D1 carrying a land marker camera in May 1981.

Scientific activities

The bustling activities in space technology were accompanied by an accelerated pace in space science. In order to be brief, we list below only the major research activities in space science during the last decade or so.

- Space meteorology: Under an arrangement with USSR, weekly firings of Soviet rockets M-100 are conducted since 1971 from TERLS to measure winds and temperature up to 80 km. Satellite cloud pictures are regularly received at many stations. An international one year (1979) Monsoon Experiment (Monex) with instruments on ground, balloons, ships, rockets, planes and satellite was carried out. Microwave radiometers on Bhaskara satellites were used to derive meteorological parameters. Data from satellites like TIROS-N and NOAA-6 were received at the National Remote Sensing Agency (NRSA).

- Stratospheric and mesospheric studies: Rockets launched from TERLS (8°33'N), SHAR (13°47'N) and Balasore (21°30'N) are used for structure and dynamics studies. The use of satellite data for such studies has been initiated. Ozone concentration and profile are studied with rockets and balloons. Work on other minor constituents, including aerosol, is being initiated with lasers, UV photometers, aerosol scatterometer, Gerdian condensers, UV spectrometers, etc. A model atmosphere over Thumba has been formulated.

- Ionosphere: The D-region has been extensively studied using ground-based experiments such as multifrequency HF absorption technique, riometers, VLF propagation, partial reflection, and cross-modulation technique at several universities and other institutions. Electric and magnetic fields have been measured with rocket payloads. E and F region ionosphere has also been studied with ground-based ionosonde, rocket probes, mass spectrometers and topside sounder satellites. The equatorial electrojet, counter-electrojet, and the equatorial spread F have received intense attention. Nevertheless, there is still very much we do not understand about these phenomena.

- The Indian Middle Atmosphere Programme (IMAP): As part of the International MAP, a well coordinated, cooperative programme was initiated for the period 1982-85. It will receive multiagency financial support and will be implemented by ISRO through an appropriate organisational structure. It is hoped that over 200 scientists from about 20 institutions will participate in a scientific programme jointly evolved. In this, ground-based instruments, rubber balloons and large polyethylene balloons, rockets and satellite data will be used. A number of joint campaigns, consolidation studies and modelling programmes will form the core of IMAP. The design and construction of a mesosphere-stratosphere-troposphere radar is also part of IMAP.

- Plans are under way for a dedicated satellite of the 150 kg class for aeronomy experiments in another 3-4 years.

- Theoretical plasma studies have been carried out by a number of groups to investigate problems in the ionosphere and magnetosphere. Solar-terrestrial physics has also received attention.

- Solar system studies: Extensive work has been carried out on the sun using optical and radio techniques. Energetic ancient solar particle radiation has been studied with great success by new track revelation techniques developed for lunar and meteoritic samples. Energetic solar flare particles have been studied with photographic emulsions and plastics sent up in rockets. Pioneering work has been done on moon samples and meteorites. Some work has been done on planets and comets in the optical and IR.

- Optical astronomy: There are now three optical telescopes of the 1 m class and a number of smaller ones located at the three observatories at Kavalur (IIA), Rangapur (Osmania University) and Nainital (UP State Observatory). A 2 m class telescope is expected to be commissioned in a year's time at Kavalur. These telescopes are used for solar, galactic and extragalactic work.

- IR astronomy: Far infrared astronomy is being studied using a 1000 kg balloon payload with a 1 m mirror and a pointing accuracy of better than a minute of arc achieved with star tracker and gyros. Near IR observations are made using the various optical telescopes. A 1.2 m IR telescope for ground observations is under construction at Mt. Abu. Site survey for an astronomical observatory at about 4000 m in the Himalayas is under consideration.

- Radio astronomy: A novel 530 m long parabolic cylindrical telescope mounted in the N-S direction at Ooty in South India on a mountain slope exactly same as the geographic latitude of 11°23′ has been conceived, constructed and extensively used for lunar occultation studies of extragalactic radio objects, interplanetary scintillation, pulsar discovery, etc. in a very powerful way; completed in 1970 it operates at 326 MHz. Work is nearing completion to set up a 9 km synthesis radio telescope with 7 smaller antennas in conjunction with the large Ooty telescope. A decameter wave radio telescope in the form of a T of 1.5 km in the E-W and 0.5 km in the N-S direction has been commissioned in 1979 near Bangalore. A three station interplanetary scintillation array operating at 103 kHz will be ready in a year's time. A mm radio telescope with a 10 m reflector will also be ready in a year or two.

- X-ray and gamma ray astronomies: Observations in X-ray and gamma ray astronomies were continued with high altitude balloons launched from Hyderabad. Rocket experiments for soft X-rays and source studies have been carried out. Many guest observer programmes in X-ray astronomy have been conducted with the NASA Einstein satellite. Joint balloon X-ray experiments have been carried out with scientists from Itlay and Canada. Joint balloon gamma ray experiments have been carried out with Soviet scientists.

- Following the X-ray experiments included in the two Indian satellites, Aryabhata and Bhaskara I, plans are under way for a dedicated X-ray mission in a 150 kg class of satellite to be launched in 3-4 years. Optical studies of X-ray sources are being conducted.

- Guest observations in UV have been made in the IUE satellite on a number of interesting stars.

- Cosmic ray studies have been continued with balloon payloads and installations in mountain altitudes, sea level and deep in Kolar Goldfields. The deep underground experiments on cosmic ray muons and neutrinos have given us a lead to initiate the first on-going experiment in the world on proton decay. A cosmic ray experiment in NASA's space shuttle is scheduled for 1984 for studying the very low energy heavy nuclei of the cosmic rays. This is a follow-up of an earlier experiment in Skylab satellite.

- A large number of groups in the country are involved in theoretical studies in astrophysics and cosmology.

- Cosmic evolution: A programme to coordinate and stimulate work in chemical and biological evolution is under way. Steps are taken to encourage work on the evolution of planetary atmospheres, paleobiology and related fields.

- International cooperation: International cooperation whether it be in space technology or space science has been an important factor in all our plans and activities. These have helped us in a large measure to catch up with the rapidly advancing frontiers of science and technology. Some active collaboration has also been generated with other developing countries. Notable among this is an advanced proposal to set up a Giant Equatorial Radio Telescope based on the principle of the Ooty radio telescope exactly at the equator, so that the cylindrical N-S antenna 1000 m long can be mounted horizontally and celestial objects followed for as many as 9 hours a day.

- The 22nd COSPAR Plenary meeting was held in Bangalore, India in 1979.

- New opportunities: The space programme for 1980-90 envisages the development of launchers for 150 kg class of satellites and 1000 kg class of sunsynchronous satellites. These and other new or improved facilities and installations, such as rockets to reach higher altitude, balloon facility, a new generation of optical, IR and radio telescopes, the MST radar and new opportunities for international collaboration are bound to lead to a greater tempo in the eighties.

The Indian Experience

Right men at the right time

The successful nucleation and promotion of space science, and indeed all space activities in India, can be traced back to a choice combination of right men at the right time. Bhabha and Sarabhai were in their thirties when this happened and had already achieved eminence in their chosen field of research – Bhabha in theoretical high energy physics and cosmic rays, and Sarabhai in experimental and interpretative cosmic rays. Independently, both wanted to build schools of excellence. They succeeded in doing this by founding institutes of science to which they could attract men and women with the right bent of mind and intelligence. The success of this enterprise was ensured because of the confidence and patronage they received from private enterprise and leaders in government. Thus, the two institutes of basic science they founded became the springboards of space science and space research in India. Following this, they pressed on the promotion of space science, space technology and space application in the country and formulated the strategies and long-term plans. This enabled the space programme to take off the ground.

Favourable national climate

The general climate and mood in the country was also just right. The country had achieved independence; there was a surge in the mood of the people to dare the unknown; eminent contributions in physics had just been made by men like Raman, Bose and Saha; isolated islands of pioneering activity such as in ionospheric studies, astronomy and geomagnetism were existing; the destruction wrought by the war machines of the second World War had brought home to all people the power of science; the post-independence political leadership of India symbolised in the person of Jawaharlal Nehru shared with the scientific leadership in the intrinsic value of basic science, in the role of science and technology for national development and in the necessity of a scientific method and temper for the people at large to overcome superstitions and blind faith and tackle their everyday problems with objectivity and reason; there already existed public men and private enterprise to perceive and appreciate the vision of men of science; and there was a favourable climate for international cooperation and collaboration, particularly under the aegis of the United Nations Organisations – the concept of IGY and the establishment of ICSU are examples of this.

Unexpected benefits of basic science in nurturing leadership

Space activities in India started with space science and space scientists. This had its impact in the philosophy and methodology of our space programme in the formative years. Science and the wonder of space played an important role in the early period. The scientists had an adequate appreciation and recognition of the potentialities of the field, the importance of innovation and problem solving and the importance of encouraging individual initiative. It is a fact that cosmic ray scientists have played a decisive role in initiating and carrying on the Indian Space Programme. The unexpected benefits of basic science cannot be better exemplified than this even in a developing country in nurturing leadership.

Importance of management structure

A highly sophisticated, complex and large enterprise like space research demanding a cooperative and coordinated approach with high technology, miniaturisation, high reliability, etc. needs the right kind of organisation and management structure. This was fully recognised in India and suitable steps taken in spite of the fact that this was a new culture and it was not easy either to build it or maintain it at the required level of excellence.

Manpower requirement

In any large scale human enterprise of this kind, the right kind of manpower is a critical factor. In this we were fortunate to have in the country a number of reputed universities, and colleges of engineering and technology and more were coming all the time. Young and aspiring people from these institutions joined the space programmes with immense motivation and worked with dedication, freely giving themselves to the exacting demands of their work – indeed for these young people work was worship.

Political stability and support for basic science

The consolidation of space programmes over the years and the enduring support for basic science was also due to the political stability and the continuity of political leadership and a good level of funding. In spite of this, there were periods of uncertainty when even an optimist like Sarabhai complained of the government blowing hot and cold. But in the long run we have been fortunate in having a stability and continuity of the political system and leadership which is somewhat unusual for a developing country. The value of organised support of science and technology we have received in India could be better appreciated if one remembers the extremely difficult social and economic condition of the people and the recurrence of natural calamities, which together continuously demand the priorities and immediacy of the government towards the immense basic needs and necessities of the poor and less privileged people of the country. At present, we have half a dozen government departments all headed by scientists and engineers under the charge of the Prime Minister. This is a good measure of the importance that the government has assigned to science and technology in India.

Choice of subjects for study

While we seem to have done exceedingly well for a developing country in space technology and application, there is much to be done in space science, and our achievements so far are quite modest, except in certain fields. In the author's view, in topics in which we started with some initial advantage of one kind or other, we have done better. Some examples of this kind will be of interest here. (i) We have made important contributions in the area of equatorial upper atmosphere (electrojet, counter electrojet, spread F, etc.) mainly because we could utilise with advantage the rocket range at TERLS situated close to the equator. (ii) A similar reasoning applies to the development of polyethylene balloon launching capability at Hyderabad from where interesting observations have been made on the composition and spectrum of high energy cosmic radiation. (iii) Painstaking work on developing new techniques of track revelation in meteoritic grains led to a wealth of rewarding information on the history of solar system through the study of meteorites and moon samples. (iv) A conceptually new design of the large cylindrical radio telescope at Ooty, the mechanical system for which became feasible because of the small slope needed at low latitude, led to significant results in studying the very distant radio galaxies. (v) The very deep underground experiments at the Kolar Goldfields enabled the first observations on cosmic ray neutrinos, and now proton decay experiments. All this clearly demonstrates that choice of problem for study with care and foresight pays for scientific returns in terms of quality.

Importance of national scientific meetings

The regular national space science symposia and many smaller meetings, seminars and workshops have played an important role in promoting space science in India.

International cooperation

In all our space science programmes, we have been benefited immensely by international cooperation. This was either through scientist to scientist interaction, bilateral government arrangements or through international bodies. Our rocket ranges and the balloon facility have been the focus of many joint experiments with foreign scientists. Many interesting experiments in X-ray and UV astronomy have been carried out through Guest Observer Programmes in the scientific satellites Einstein and IUE. Satellite data from many satellites of other countries have been received and analysed in studies of meteorology, upper atmosphere and remote sensing. These are only a few examples of the very fruitful and extensive international cooperation that we have received.

In conclusion, it can be said that in many ways much ground work has been done and new facilities are being set up and new opportunities are emerging for the future. All this augurs well for a bright future for basic space science in India.