P R L

IV DECADES

PHYSICAL RESEARCH LABORATORY

PRL (1952)

PRL

IV

DECADES

How strange is the lot of us mortals. Each one of us is here for a brief sojourn, for what purpose he knows not. But with deeper reflection, one knows from daily life that one exists for other people - first of all for those upon whose smiles and wellbeing our own happiness is wholly dependent, and then for the many, unknown to us, to whose destinies we are bound by the ties of sympathy. A hundred times a day I remind myself that my inner and outer life are based on the labors of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received, and am still receiving. I am strongly drawn to a frugal life and am often oppressively aware that I am unduly engrossing an undue amount of the labor of my fellow-men.

- Albert Einstein

I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

- Isaac Newton

Chairman, Indian Space Research Organisation. Chairman, PRL Council of Management.

The Physical Research Laboratory is a premier research institution of our country which is devoted to research in Space and Planetary Sciences, Astronomy and Astrophysics, and has made many pioneering contributions in its fields of activity over more than four decades of its existence.

Established in 1947 by Dr. Vikram Sarabhai, PRL played a seminal role in initiating a space science activity in the country and in producing a highly motivated cadre of space scientists and technologists of the highest international calibre. Many of these alumni have made important contributions in space sciences and cosmic rays and are holding important positions in many parts of the world. Some of them have, in fact played and continue to play prominent, pioneering role in the evolution and development of India's Space Programme. Personally, I have had the unique privilege of being associated with Dr. Vikram Sarabhai, as a student and later as a colleague for almost two decades and to have been associated with the evolution and development of the space programme since its inception. It is because of the nurturing, encouragement and inspiration provided by Dr. Vikram Sarabhai and Prof. K.R. Ramanathan, which created a band of young space scientists who shared their dreams, Indian Space programme could make rapid progress with a sense of direction and purpose. PRL can thus be rightly proud of being the cradle of India's space programme.

Looking back at PRL's overall achievements over the past four decades, there is every reason to feel a sense of pride, and I share it intimately with all those who have been associated with PRL all these years. Its scientists have always been in the forefront of their fields of activity and have attracted the highest international regard for their pioneering contributions. I have no doubt in my mind that these traditions will continue.

The present book "PRL—Four Decades", which is a somewhat popular account of the highlights of PRL's scientific activities and achievements over the past four decades, is a most appropriate and opportune venture. While it serves the purpose of a "stock-taking", evaluation and reflection on behalf of its scientists, after four decades of its existence, it is also meant to serve the purpose of informing the public in general and prospective young researchers at Universities and colleges in particular, of the excitement of scientific research being carried out at PRL.

I congratulate the Director and the scientists of PRL for bringing out this book which will serve as a very important chronicler in recording the scientific evolution and achievements of PRL. I am sure, PRL will continue in future its march towards scientific excellence and I wish the scientists of PRL all success.

(U.R. Rao)

The Physical Research Laboratory (PRL) came into existence because of the deep interest of Vikram Sarabhai in science. Vikram's background clearly defined the initial direction and base of the Laboratory. This background consisted of: a Natural Sciences Tripos from the University of Cambridge, England; work at the Indian Institute of Science, Bangalore, during the period of the Second World War under Prof. C.V. Raman; his selection of cosmic rays as his area of interest, and his close interactions during that period with that outstanding intellect, and pioneer in cosmic ray and particle physics, Homi Bhabha; and his discussions with the doyen of meteorology and ionospheric physics, Prof. K.R. Ramanathan in Pune. He initially set up, at the "RETREAT", Shahibaug, the home of his parents, a small laboratory for cosmic rays. In 1947, the PRL formally came into existence. Its initial thrust was on ground-based cosmic ray, atmospheric and ionospheric studies.
Dr. Ramanathan joined as the first Director; the first Council of Management set up in 1950 included Dr. S.S. Bhatnagar, FRS, and Dr. K.S. Krishnan, FRS.

The Laboratory got a major thrust with the planning and execution of programmes relating to the International Geophysical Year (IGY). In their fields, PRL Ahmedabad, and the National Physical Laboratory, New Delhi, were the principal focal points for the IGY. The International Geophysical Year was momentous in more ways than one. IGY (under ICSU) was the largest of the international scientific programmes till then undertaken. It saw the launch of the first satellite and the advent of the space age. PRL naturally moved into the growing field of space research. Soon thereafter, the Laboratory came under the administrative purview of the Department of Atomic Energy with substantial support from Government as needed for their new activities. I have had the privilege of being associated with the Laboratory from the end of 1955; and more particularly as a Member of the Council from 1963 to 1989, and for some years its Chairman.

PRL was the cradle of India's space programme. It nurtured the first Indian National Committee for Space Research and thereafter, the Indian Space Research Organisation.

After Vikram's passing away in December 1971, I looked after the Laboratory as Director for a short period, before Prof. D Lal, FRS, took over. During Prof. Lal's directorship, PRL moved into additional new areas of cosmo geophysics, oceanography, archaeology, hydrology; and nurtured an Institute of Plasma Physics, which is now set up as a separate entity under the Department of Science and Technology. Under later successive Directors—Prof S.P. Pandya and Prof. R.K. Varma—PRL has continued to grow, and has particularly developed considerable strength in theoretical areas.

PRL today is one of our large national laboratories, and well recognised internationally. In the broadest sense, its activity encompasses earth and space sciences, and related theoretical aspects. It has been able to move within this broad area into specific fields of great topical and current interest, demonstrating its abilities to derive strength through continuity from the past, and yet have the flexibility to change, so as to be in the forefront of the surge of science and its new moods.

PRL has throughout received support and wise guidance from Shri Kasturbhai Lalbhai, Dr. Homi Bhabha, and Prof. Satish Dhawan. A product of PRL, and the present Chairman of the Space Commission, is Chairman of its Council of Management. It is truly an institution which is a lasting tribute to Vikram and his interest in science. I wish it a glorious future as it moves beyond its four decades of existence.

(M.G.K. Menon)

President, International Council of Scientific Union. Member, Rajya Sabha (Former Chairman of PRL Council of Management)

PRL COUNCIL OF MANAGEMENT

The present Council of Management of the laboratory consists of the following members:

1. **Chairman**

   Prof. U.R. Rao
   Chairman, ISRO
   Secretary DOS
   Antariksh Bhavan
   New BEL Road
   Bangalore 560 094

2. **Member**

   Prof. V. Radhakrishnan
   Director
   Raman Research Institute
   Sadashivnagar
   Bangalore 560 080

3. **Member**

   Shri S.K. Das
   Joint Secretary
   Department of Space
   Antariksh Bhavan
   New BEL Road
   Bangalore 560 094

4. **Ex-officio Member**

   Prof. R.K. Varma
   Director
   Physical Research Laboratory
   Navrangpura
   Ahmedabad 380 009

5. **Member**

   Sheth Shri Shrenikbhai Lalbhai
   Pankore Naka
   Ahmedabad 380 001

6. **Member**

   Shri Kartikeya V. Sarabhai
   'Chidambaram'
   Usmanpura
   Ahmedabad 380 013

7. **Member**

   Secretary
   Science & Technology Cell
   Department of Education
   Gujarat State
   Gandhinagar

8. **Ex-officio Secretary**

   Dr. Dinesh Patel
   Registrar/Head, TS
   Physical Research Laboratory
   Navrangpura
   Ahmedabad 380 009

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FOREWORD

"When sixteen years ago, I urged as a thing to be sought—that for which I joined Tycho Brahe..... at last, I have brought to light and recognize its truth beyond my fondest expectations......The die is cast, the book is written to be read either now or by posterity, I care not which—it may well wait a century for a reader, as God has waited six thousand years for an observer."

So wrote Johannes Kepler in the moment of ecstasy on having discovered the laws of planetary motions based on the observations of Tycho Brahe. This solved for him the puzzle that had dogged him for many years. The statement reveals the full realization on the part of Kepler that he had indeed achieved something of eternal value and significance.

Such a moment of ecstasy is the dream of every scientist. However, it comes no more often than once in a century or even less. Yet, scientists continue to strive in the fond hope of achieving at least something of the decadal if not of centennial significance.

Scientists who have shown the way have been honoured by the fellow scientists and the societies down the centuries. Some of them, like Newton and Einstein, became legends in their own life times. Societies which produce and nurture such scientists feel justifiably proud of them. The support and promotion of science by a society is today considered more or less of an accepted fact. It has two reasons: First, it is the manifestly important role that science and technology are increasingly playing in the day-to-day lives of the human race, and there is little necessity to elaborate on this, except to say that it is purely from the point of view of its very survival in today's world. The second reason is a little abstract and is not generally much appreciated by the result and relevance oriented critics. From time immemorial, scientific inquiry about one's environment, about what one observes around oneself, has always led to the development of the human mind of the highest order. These inquirers, pioneers are the ones who have contributed to the great advancement of societies both intellectually and materially.

The role and importance of these individuals in the evolution and development of societies cannot be adequately assessed in terms of only the immediate or short term impact of their work, for there may appear to be none. However, history of scientific evolution and development has shown that every advancement in modern day technology whose benefits we almost take for granted today: lasers, solid state electronics and computers, to name only a few, has its origin not in any one particular scientific discovery, but rather in the continuum of scientific thought and inquiry at the most fundamental level. There have been, to be sure, important scientific milestones, but these are embedded in the continuum. Any attempt at an intervention in the natural flow of this continuum, which tends to disrupt the process of inquiry would be short-sighted and counter-productive, though it is often quite tempting to ask about the relevance of any particular scientific work.

This is not to suggest, however, that there should be no accountability. Indeed, the terms and norms of accountability in basic sciences are, if anything, tougher because the scientific discoveries have to be judged on a universal scale of both space and time. In fact, it has also been the fate of some scientists not to have been recognized during their life-times for their work which was ahead of their time.

We, in India, blissfully have had our share of such great thinkers, both in distant past (Aryabhata, Brahmagupta, Varahamihira, Mahavira and Bhaskara) as well as in the first quarter of the present century (Ramanujan, Raman, Saha and Bose in the mathematical and physical sciences), which is rightly regarded as the period of renaissance in science. It ought to be emphasized, however, that all these great names were completely home-grown scholars and did not even have the benefit of a free environment for their growth as would be expected in a free self governing country. Yet, the momentum of the renaissance continued to sweep the country and to generate scholarship of a high order.

In a desire to provide greater scientific opportunities to the young men of our country and to generate a larger scientific manpower, a number of scientific laboratories were started in the country after the dawn of freedom in 1947 with the encouragement and support of our first Prime Minister, Pt. Jawahar Lal Nehru.

The Physical Research Laboratory was one such laboratory which came into being in 1947, but not with government support initially, rather due to the personal initiative and vision of Dr. Vikram Sarabhai. Today of course almost the entire funding comes from the Government of India through the Department of Space. It was not to be a laboratory, as it was conceived initially, which could immediately cater to the developmental needs of the society. It was to be a pure scientific research laboratory devoted to a study of our terrestrial and extra-terrestrial environment. In common with the other institutes of a similar nature, it was meant to be a laboratory which was to continue the process of renaissance. It represented an opportunity for a large number of young and eager science graduates in the country to develop their scientific talents and to use them in the development of science (and technology) in the country. But most of all, it represented a hope that it will be one of the centres of the excellence in the country and a fountainhead of knowledge and ideas.

It is essential for an institution to undertake a periodic review to assess its scientific achievements and to present them before the society which supports them so generously. Indeed the scientists have an obligation to share with the society the excitement that they have experienced in the course of carrying out their researches. This needs to be done in simple enough terms, shorn as much as possible of the technical jargon, so that it is comprehensible at least to an educated layman eager to learn about what the scientists have achieved in the international arena.

It is with these twin objectives that this volume, "PRL—Four Decades" has been conceived. This volume, on the one hand, represents an attempt, on the part of PRL, to take stock of its achievements over four decades of its existence; on the other hand, it is also an attempt to present these achievements in as simple and non-technical terms as is possible within the constraints of space.

How much successful is this attempt going to be in terms of its desired objectives, it is not for us to say. The reader will be the ultimate judge.

Even a small effort such as this one, if it is to be done properly requires the wholehearted cooperation and dedicated contribution of a large number of members of the PRL staff. I take this opportunity to record my sincere appreciation to all of them who have helped in one way or the other in bringing out this volume. However, there are those among them who have been the central figures in the execution of this job, and without whose drive and dedication this volume would not have taken off the ground.

Thus Prof. S. Krishnaswami, has been the key figure in the entire process. The main body of the text is the dedicated effort of our band of young scientists: Drs. A. Ambastha, T. Chandrasekhar, J.N. Goswami, N. Nagesha Rao, R. Ramesh, P. Sharma, Kanchan Pande, Shyam Lal and R. Sridharan. Profs. D.P. Agarwal, S.K. Alurkar, A.C. Das, J.N. Desai, S.P. Pandya, P.R. Pisharoty, J.C. Parikh and B.H. Subbaraya have provided considerable amount of help in going through the text making valuable suggestions and appropriate changes wherever necessary, in content and style to make it more smoothly readable.

Dr. (Mrs.) P. Chakrabarty has shouldered the main responsibility for the editorial process and liaison with the printers. This is a difficult job in the best of times.

The photographs included in the book were taken by Mr. D.R. Ranpura of PRL; Vikram Dalal, adviser to photographic section; Dr. A. Bhatnagar of Udaipur Solar Observatory; Mr. K.R. Seetharaman of SHAR, and Prof. P.D. Bhavsar. Mr. and Mrs. J.M. Das of Mastermind Communications have provided ideas and suggestions for the layout and the organization of the material, while the major load of typing the manuscript was taken by Mr. K.V. Haridas and Mr. K.J. Joseph.

There is one support which is never very ostensive but which always exists everready to help. This is the administrative support from the offices of Registrar, Deputy Registrar, Purchase and Accounts Sections.

Finally I must express my personal appreciation of the help, support and encouragement I have constantly received from the members of the PRL Council of Management for the scientific activities of the laboratory and for their appreciation of the work carried out by our scientists.

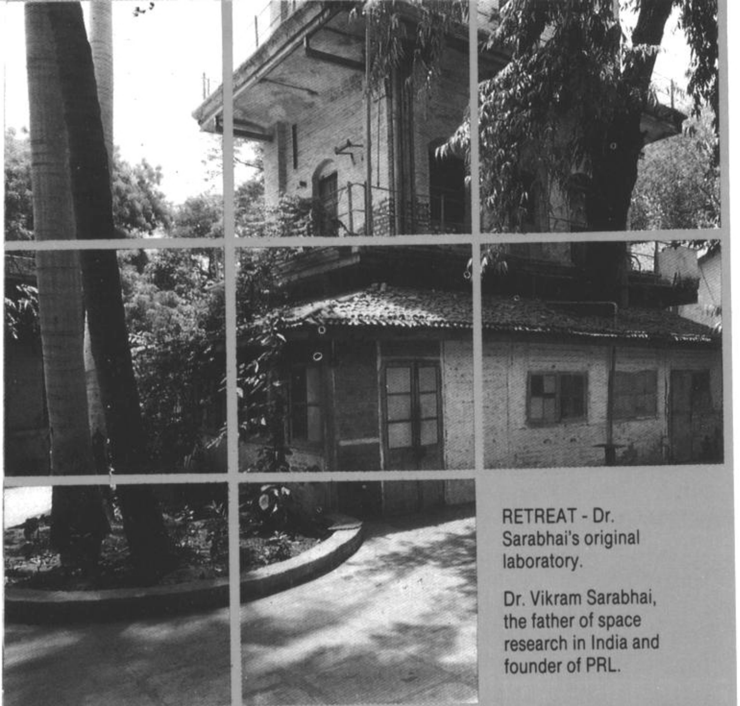
Prof. M.G.K. Menon who had been the Chairman of our Council for ten years from 1980 until very recently has been a guiding spirit and source of strength for all the members of PRL staff. Indeed being associated with PRL Council since 1956, he has guided the scientific evolution and development of PRL over more than three decades. Prof. S. Dhawan who had been an active Member of our Council for fourteen years (1970–84) has been a constant source of encouragement and has extended valuable assistance in promoting our scientific programmes. Prof. U.R. Rao, who is the present Chairman of the Council, being himself a PRL alumnus, is keen to see that PRL maintains its leadership as a centre for space research and gives his wholehearted support and attention towards this cause. Furthermore, a number of Additional and Joint Secretaries, DOS, who have been members of our Council in the past as well as those at present have contributed greatly towards the development of PRL. The other two members of the Council, Seth Shri Shrenikbhai Kasturbhai and Shri Kartikeya Sarabhai have always extended their wholehearted support and advice in the variety of issues relating to the laboratory.

I do hope that this attempt at projection of the activities of PRL in a semipopular style will go some way towards establishing communication of our scientists with the other members of the society. It is also our hope that it may generate sufficient interest in them so that they can come and visit PRL for further discussion and exchange.

R K Varma

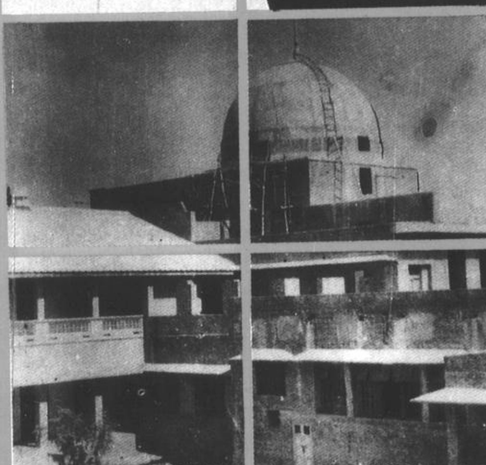
(R.K. Varma)
DIRECTOR

Go Back



RETREAT - Dr. Sarabhai's original laboratory.

Dr. Vikram Sarabhai, the father of space research in India and founder of PRL.



M.G. Science Institute - the beginning of PRL.

Dr. Vikram Sarabhai with stalwarts of Indian science. From left to right with him are Sir S. S. Bhatnagar, Dr. Homi Bhabha and Dr. C. V. Raman.

PRL BEGINNING & GROWTH

"Countries have to provide facilities for its nationals to do front rank research within the resources that are available. It is equally necessary having produced the men who can do research, to organize task-oriented projects for the nation's practical problems."

—Vikram A. Sarabhai—

The Physical Research Laboratory, which is in the fifth decade of its existence, was founded by Dr. Vikram A. Sarabhai in November 1947 following an agreement between the Ahmedabad Education Society and Karmakshetra Educational Foundation. The laboratory had its humble beginning in the M.G. Science Institute and its research programme then were oriented and pioneered by the scientific interests of its principal workers—Dr. Vikram A. Sarabhai, PRL's founder and Prof. K.R. Ramanathan, its first Director.

The laboratory grew out of a quest and a dream of Dr. Sarabhai. The quest was to know more about the then mysterious particles of very high energy, known as the 'Cosmic Radiation' that have been known to bombard the earth's surface. The dream was for establishing a front rank institute at Ahmedabad for conducting basic research in cosmic rays and few other selected areas of physics. While working for his doctoral thesis, Dr. Sarabhai had this vision and on his return to India from Cambridge, after his Ph.D., he set about the task of setting up such a laboratory in "RETREAT" where he conducted experiments on Cosmic Rays. This laboratory was funded by the Karmakshetra Educational Foundation created by his parents for carrying out advanced scientific research and educational activities of all types.

Born on August 12, 1919 Dr. Vikram Ambalal Sarabhai obtained the Tripos in 1939 from St. John's College, Cambridge. With the beginning of the Second World War he returned to India. He joined the Indian Institute of Science, Bangalore, to work with Professor C.V. Raman. Dr. Sarabhai began work on cosmic ray intensity variations which later led him directly into the studies of interplanetary space, solar terrestrial relationships and geomagnetism. In 1945, he returned to Cambridge University to continue investigation on cosmic rays and obtained a Ph.D. degree in 1947 with a thesis on "Cosmic Ray Investigation in Tropical Latitudes".

Dr. Sarabhai's laboratory at RETREAT soon attracted the attention of the Ahmedabad Education Society and in November 1947, Physical Research Laboratory (PRL) was founded following an agreement between the Karmakshetra Educational Foundation and the Ahmedabad Education Society. Prof. K.R. Ramanathan joined as the first Director of the laboratory after retiring from the India Meteorological Department. The scope of the research activities was expanded by adding a Department of Atmospheric Physics which was Prof. Ramanathan's main scientific interest.

The laboratory started with a few research students and assistants in a few rooms of the M.G. Science Institute. Soon a large devoted group of research scholars joined, many of whom have now become leaders in their respective fields of research. Dr. Sarabhai continued to guide and shape the destiny of PRL, first as a Professor of Cosmic Rays and then as its Director during 1965–71.

As the laboratory grew the overall scientific programmes evolved towards an integrated study of the different kinds of radiations which are received on the Earth, and of their geophysical consequences. In order to carry out such a programme satisfactorily, it was felt necessary to add theoretical physics, radio physics and an electronics group to the then existing cosmic ray and atmospheric physics groups. The Atomic Energy Commission of the Government of India was approached for financial assistance to create the above groups and the request was granted in 1949.

In 1950, a Council of Management for PRL was formed with representation from the Ahmedabad Education Society, the Karmakshetra Educational Foundation, the Ministry of Natural Resources and Scientific Research, the Atomic Energy Commission and the Government of Bombay.

The first Council of Management consisted of the following members:—

Chairman

Sheth Shree Kasturbhai Lalbhai
Representative of the Ahmedabad Education Society

Members

Dr. S.S. Bhatnagar, F.R.S.
Director, Council of Scientific and Industrial Research
Representative of the Govt. of India and the Atomic Energy Commission

Dr. K.S. Krishnan, F.R.S.
Director, National Physical Laboratory, Representative of the Ahmedabad Education Society

Prof. Y.G. Naik, Ph.D.
Gujarat College, Ahmedabad
Representative of the Govt. of Bombay

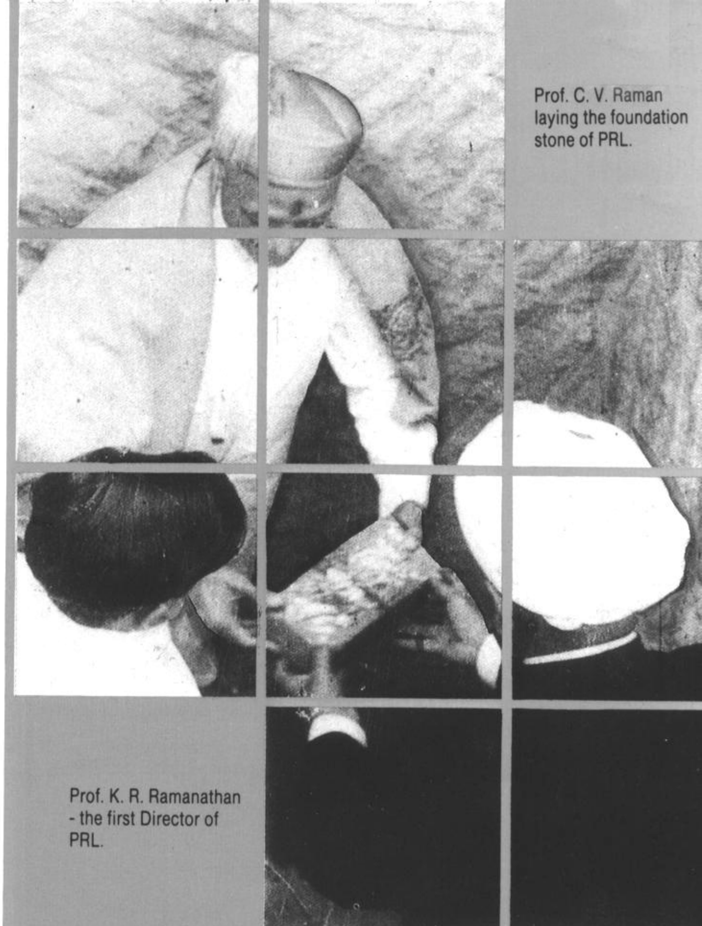
Prof. V.A. Sarabhai, Ph.D.
Physical Research Laboratory
Karmakshetra Educational Foundation

Ex-Officio Member

Prof. K.R. Ramanathan, D.Sc.
Director, Physical Research Laboratory

In 1951, Prof. Ramanathan established the ozone observing station at Mount Abu. The first observation of ozone using the Dobson Spectrophotometer was carried out on 12 October 1951. Later this station was used for twilight and air-glow observations.

With expanding activities and an increasing number of workers, the need for a separate building became urgent. Land was provided by the Ahmedabad Education Society, adjoining the Gujarat University. The cost of the building was borne by the Ahmedabad Education Society and the Karmakshetra

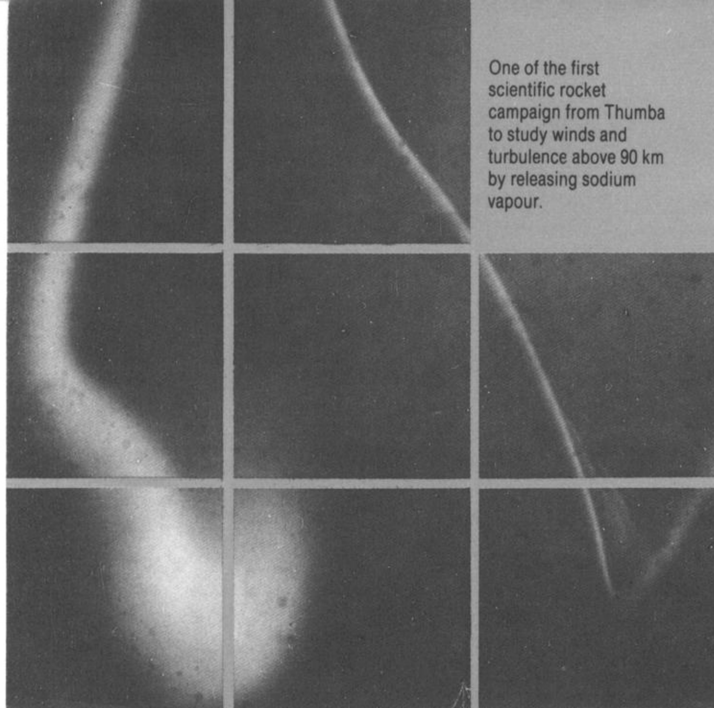


Prof. C. V. Raman laying the foundation stone of PRL.

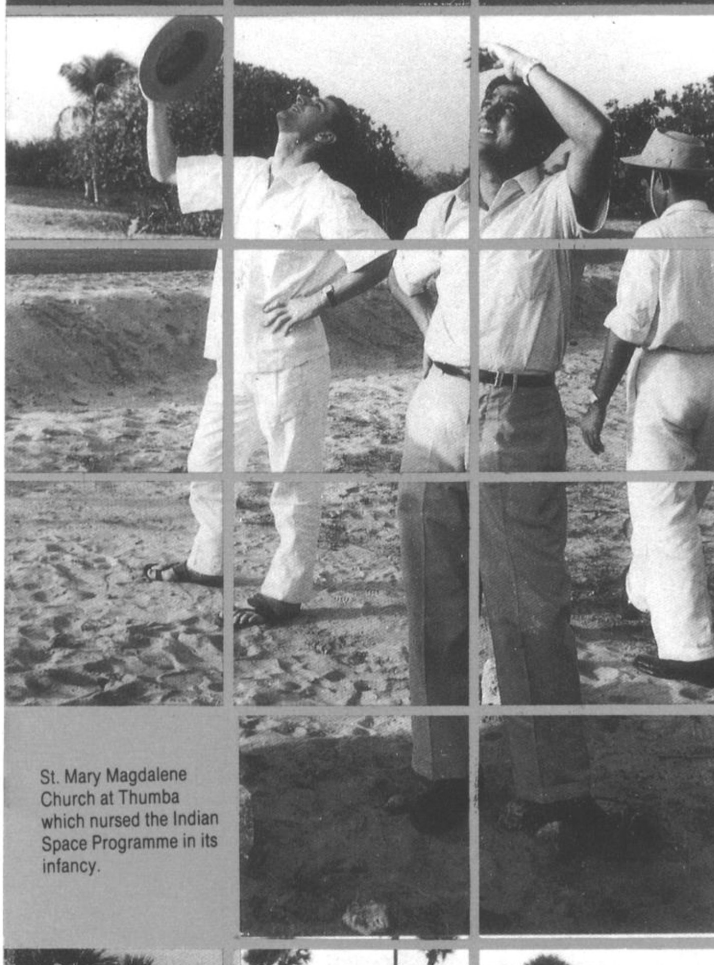
Prof. K. R. Ramanathan - the first Director of PRL.

Prof. K. R. Ramanathan with Prof. Bibha Choudhury.

"Hill View" - Ozone observing station at Mt. Abu.



One of the first scientific rocket campaign from Thumba to study winds and turbulence above 90 km by releasing sodium vapour.



St. Mary Magdalene Church at Thumba which nursed the Indian Space Programme in its infancy.

Educational Foundation. The Ministry of Natural Resources and Scientific Research had made a generous grant of rupees one and a half lakhs for equipments. The foundation stone of the laboratory was laid by the late Prof. C.V. Raman, Nobel Laureate on 15 February 1952. The first building of the campus was opened by the late Prime Minister Pandit Jawaharlal Nehru on 10 April 1954. A second floor to this building was added in 1960–61.

The year 1957–58 was the period of the International Geophysical year and the scientists of PRL under the leadership of Dr. Sarabhai and Prof. Ramanathan actively participated in various scientific programmes chalked out for Earth Sciences including Geomagnetism and Cosmic Rays. These studies required the inhouse development of electronic equipments and radiation detectors. PRL successfully developed and put into operation Geiger-Müller Counters, Meson Telescopes, Dobson Spectrophotometers, Ionosonde, Photometers etc.

The Physical Research Laboratory set up a research station at Gulmarg in Kashmir in 1955 for the measurements of cosmic ray intensities as well as atmospheric ozone and night airglow. The successful working of this station and the important results obtained there led to the establishment of a full-fledged High Altitude Research Laboratory at Gulmarg in 1963. In addition to Gulmarg, Dr. Sarabhai also had set up outstations of PRL at Kodaikanal and Trivandrum to continue the investigations of cosmic ray time variations.

After the IGY period a request was made to the Department of Atomic Energy (DAE) to support the laboratory's growing activities in the field of Space Research. The request was subsequently approved and the DAE gave substantial block grants to the laboratory. It was also decided that the laboratory would be managed through a Council of management consisting of representatives of the Government of India, Government of Gujarat, Ahmedabad Education Society, Karmakshetra Educational Foundation and the Director of the Laboratory. This was accepted by all the parties and a quadripartite agreement on behalf of the four parties was signed on February 5, 1963.

By early sixties the use of satellites for exploring the Earth's environment had become quite common. It was foreseen by Dr. Sarabhai that the satellite technology could play a seminal role in the advancement of education, agriculture, meteorology, defence and remote sensing of the Earth's resources. This led to the creation of the Indian National Committee for Space Research (INCOSPAR) in the Department of Atomic Energy in 1962 with Dr. Sarabhai as the Chairman and eleven other scientific members which included several PRL scientists. Furthermore a rocket launching station at Thumba, very close to the magnetic equator, was established. On the evening of 21 November 1963, the first scientific rocket went up from Thumba releasing sodium vapour and showing up the winds and turbulence above 90 km. With nearly all of the early rocket payloads having been fabricated here, PRL rapidly became the centre for developing and building scientific payloads for use in rockets. In February 1968, the Thumba Equatorial Rocket Launching Station (TERLS) was dedicated by the then Prime Minister Smt. Indira Gandhi to the UN as the International Equatorial Rocket Launching Station.

A satellite telemetry station was installed at PRL in 1961 with NASA's collaboration. Recordings of the Faraday rotation at 20, 40 and 41 MHz transmitted by the US satellites BE-B and BE-C were regularly recorded from 1964 onwards. In 1965 an Experimental Satellite Communication Earth Station (ESCES) was established with UNDP assistance.

In 1969 Indian Space Research Organisation (ISRO) was created, with Dr. Sarabhai as its Chairman, under the Department of Atomic Energy to carry on national programmes of Space Research and its applications to the social and economic development of the country. With this in view, Dr. Sarabhai initiated the Remote Sensing Programme with Prof. P.R. Pisharoty as its head. This later became a major activity of the Space Applications Centre.

While he was in the midst of a very bold and vigorous formulation of the space programme of the country including that of PRL, Dr. Sarabhai passed away rather suddenly on December 30, 1971. He had combined in him the Directorship of PRL, the Directorship of the then Space Science and Technology Centre (SSTC) besides the Chairmanship of the Indian Space Research Organisation (ISRO) and the Atomic Energy Commission (AEC). However, for him PRL was his base, while PRL and its scientists played a crucial role in the evolution of the country's space programme.

After the sad demise of Dr. Sarabhai, Prof. M.G.K. Menon, Director, Tata Institute of Fundamental Research and Chairman, Electronic Commission, served as the Director of the laboratory for ten months. He continued to be associated with the laboratory, first as a member and then as the Chairman of its Council of Management till January 1990.

The year 1972 was a landmark in the national space programme. In June 1972, the Space Commission and the Department of Space was created to develop the national space effort with Prof. M.G.K. Menon taking over the Chairmanship of the Space Commission. To develop and implement the ten year profile for space research as envisioned by Dr. Vikram Sarabhai, a National Seminar on the Indian Programme for Space Research and Applications was held in Ahmedabad from 7–12 August, 1972. PRL served as the cradle of this programme.

Prof. Devendra Lal joined as the Director, PRL in November 1972. Two new areas of research, which were his fields of interest, were added to the laboratory's scientific activities; (i) the studies of moon rocks and meteorites and (ii) the Earth Sciences. The moon and meteorite research was aimed at understanding the formation of solar system objects. The studies in Earth Sciences were focussed on the application of environmental isotopes to study surface processes such as the evolution of the Indian sub-continent, ocean circulation, groundwater movement and the palaeoclimate.

Prof. Lal was the Director of PRL during November 1972-March 1983. During this period Professor Lal contributed immensely to the growth of PRL. Several new programmes in the fields of plasma physics, astronomy, atmospheric physics and earth sciences were initiated and nurtured during his tenure.

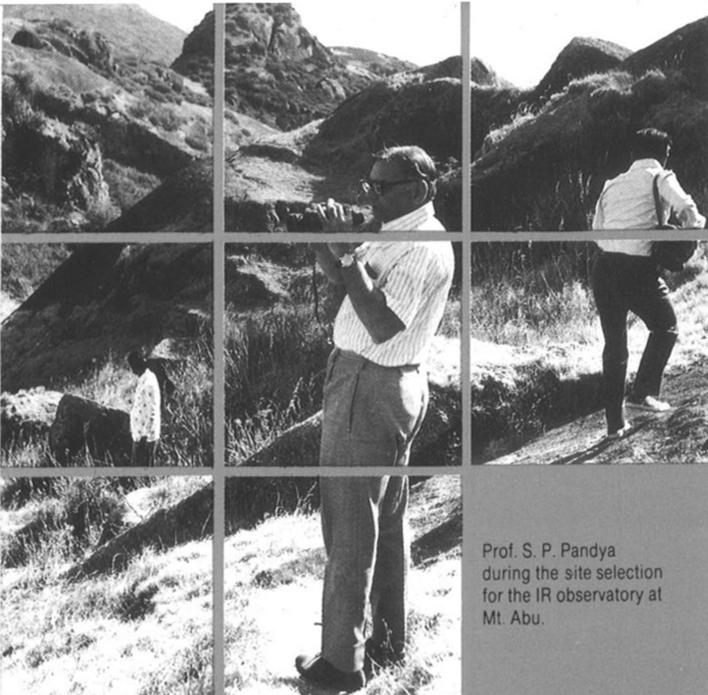
A new activity, namely the plasma physics activity which was initiated in 1968 developed rather vigorously during the seventies. This had twin objective: (i) to provide a theoretical and laboratory support to the existing ionospheric and space research activities at PRL and (ii) to initiate a high

Smt. Indira Gandhi dedicating the Thu Equatorial Rocket Launching Station (TERLS) to the Uni Nations.

Prof. P. R. Pisharot initiated the Remot Sensing Programm which later became major activity of the Space Applications Centre.

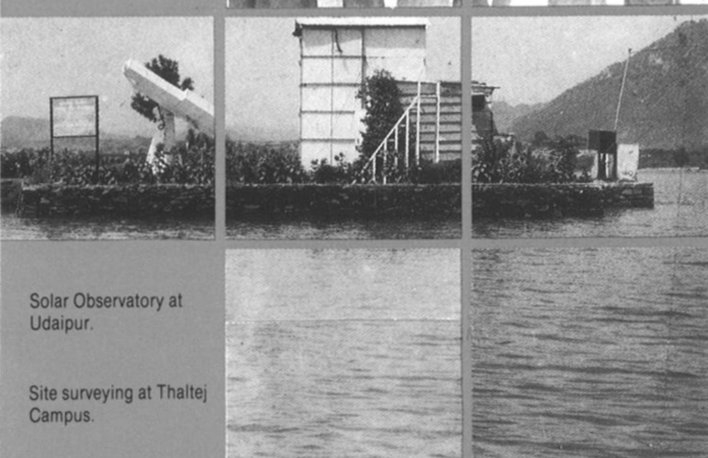
Prof. M. G. K. Menon, handing over charge to Prof. D. Lal.

Prof. D. Lal with eminent scientists at PRL (from l to r) Profs. Yash Pal, D. Lal, B. Peters and B. V. Srikantan.



Prof. S. P. Pandya during the site selection for the IR observatory at Mt. Abu.

Astronomical Observations with 14" celestron telescope were initially started from our Thaltej Campus. The photograph shows the metal pier for the fork mounting of celestron being installed at Thaltej.



Solar Observatory at Udaipur.

Site surveying at Thaltej Campus.

temperature plasma research activity which may form the basis in the future of fusion-oriented research and development programme. The second part of the activity, having been nucleated at PRL has since been seperated from PRL as the Institute for Plasma Research at Bhat, Gandhinagar.

Furthermore, having realized the important role that atomic and molecular reactions play in atmospheric chemistry and astrophysics, another activity on the studies of atomic and molecular reactions was initiated in the early seventies. This also has evolved considerably over the years.

Two major disciplines were initiated at PRL around 1975. They were (i) the infra-red astronomy and (ii) the interplanetary scintillation (IPS) studies. The major aim of the infra-red astronomy group is to study the stars, the galaxies and molecular clouds and to understand the star formation processes as well as energy production and emission processes from active galaxies. Towards this a variety of sophisticated back-end instruments to be used with telescopes were fabricated. An infra-red observatory was also planned to be set up at Gurushikhar with a 1.2 metre mirror-telescope with both Cassegrain and Coude foci.

Past studies of the radio emissions from the Sun as well as from solar flares and bursts have yielded important information regarding the plasma processes in the Sun's atmosphere. These studies later culminated into the development of the exciting programme of setting up three radio telescopes at Thaltej (near Ahmedabad), Rajkot and Surat. The main objective of this 3-station telescope was to estimate the solar wind velocity by simultaneous measurements of scintillations of the radio sources with the three radio telescopes. The scintillations are produced by the interplanetary medium through which flows the solar wind.

On August 12, 1974, the fiftyfifth birthday of Dr. Vikram A. Sarabhai, the Hari Om Ashram instituted at PRL a set of four awards named as "Shri Hari Om Ashram Prerit Dr. Vikram Sarabhai Research Award" to outstanding Indian scientists. The awards are given biennially to outstanding Indian scientists for their contribution in the fields of Space Sciences; Space Applications; Electronics, Informatics, Telematics and Automation; and System Analysis or Management. The awards are given to the distinguished recipients on August 12, the birthday of Dr. Sarabhai.

The Vikram Sarabhai Professorship was instituted at PRL in 1977 to provide a continuing stimulus to the young researchers at PRL and to expose them to the latest developments in the various areas of research through interaction with distinguished researchers around the world. The institution of this professorship was made possible mainly through the funds provided by the Sarabhai Foundation, Karmakshetra Charity Trust (No. 2) and the Kasturbhai Lalbhai Charity Trust. This scheme provides for inviting distinguished scientists to spend some time at PRL in delivering lectures, on topics of high current interest and participating in research programmes of the laboratory if possible. Under this scheme fourteen Vikram Professors have so far visited PRL.

In December 1981, the Department of Space took over the Udaipur Solar Observatory and entrusted its administration to PRL. The observatory was established in 1975 by the Vedshala Trust, Ahmedabad, in an island in Fatehsagar Lake, Udaipur. This site was chosen for its extremely good solar 'seeing' over long uninterrupted periods. Since its inception the solar observatory has been engaged in exciting and 'front line' researches pertaining to the Sun.

On March 30, 1983 Prof. Devendra Lal stepped down from the Directorship and continued to be at PRL as a Senior Professor till his retirement. At present he is Honorary Fellow of PRL. On April 1, 1983 Prof. S.P. Pandya took over the Directorship of PRL. Some of the exciting programmes like the Plasma Physics Programme, the Infra-red and the Interplanetary Scintillations matured during this period.

The mid-eighties has been an important period in the history of PRL. The building of the Gurushikhar Observatory was completed around this period. The year 1985–86 was also the period of Comet Halley and the observations on Halley by our scientists marked the beginning of the astronomical observations from Gurushikhar Observatory using the 14" Celestron Telescope. Final assembling and testing of the 1.2m IR telescope is in progress and is expected to be completed soon.

During the year 1986–87, the three radio telescopes at Thaltej, Rajkot and Surat, which constituted the interplanetary scintillation network, became operational.

The K.R. Ramanathan Memorial Lecture was instituted at PRL in 1987 in honour of Professor K.R. Ramanathan. This lectureship provides for inviting distinguished meteorologists to deliver lectures related to meteorology and climate. The lectureship was instituted with funds provided by his son Dr. K. Ramanathan and supplemented by PRL.

Prof. S.P. Pandya laid down the office of the Directorship of PRL on May 31, 1987 and Prof. R.K. Varma took over. Prof. Pandya continues to be at PRL as an INSA (Indian National Science Academy) Senior Scientist.

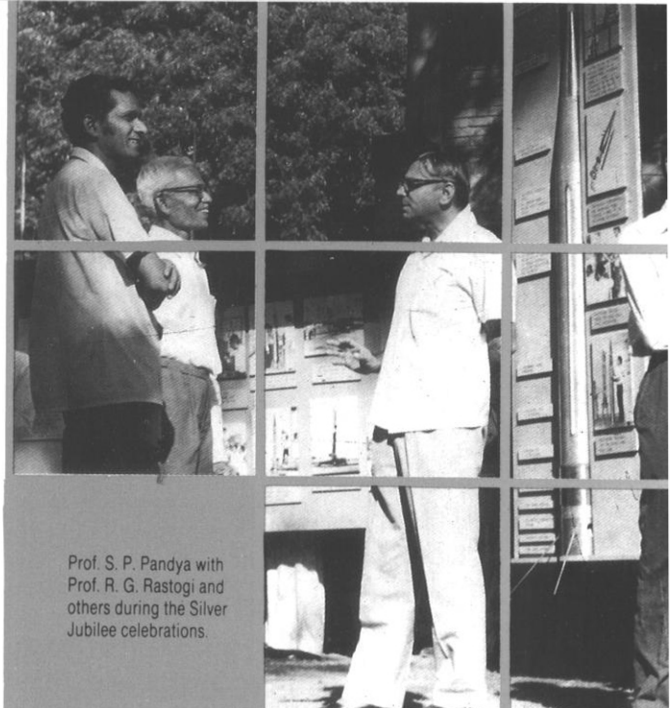
As it stands today, PRL has a number of disciplines under investigation. Recently, programmes which have common goals have been grouped together and the activities of the laboratory have been reorganised into four divisions (i) astronomy and astrophysics, (ii) theoretical physics (iii) planetary atmospheres and aeronomy and (iv) earth sciences and solar system studies. These areas onto which the future PRL activities are projected, are in fact the frontline areas of future scientific activity all over the world and each one of these areas has the potential of growing in future into centres devoted to these studies.

PRL is planning to go vigorously into the astronomical studies of active galactic nuclei (AGN), star formation etc. using the IR (infra-red) telescope, solar system processes using ground based optical techniques and ion microprobe, earth's middle and upper atmosphere using rockets and satellites and also earth-system processes using various dating techniques.

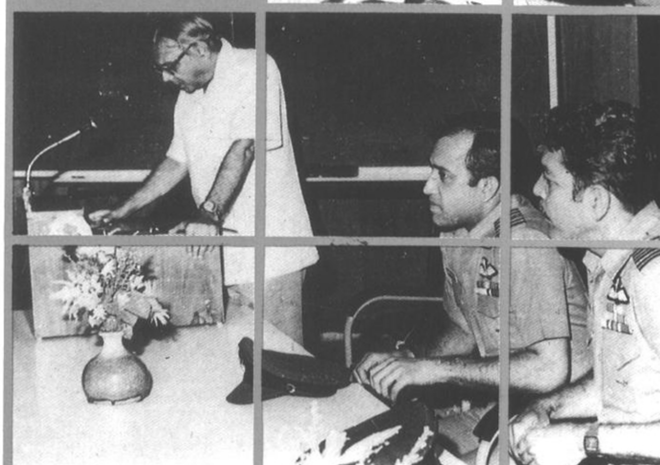
In the fifth decade of its existence, while PRL moves on to take up new scientific challenges of the advancing science frontiers, it must also face the challenge of searching young and bright scientists for being inducted into PRL as more and more first generation scientists retire.

During the last three years, a good number of young scientists have been inducted into various scientific disciplines at PRL. Equally importantly, a new scientific work culture has been initiated which emphasizes synergetic cooperation and complementation among scientists. This will help further raise the standards of research and in PRL's march towards excellence.

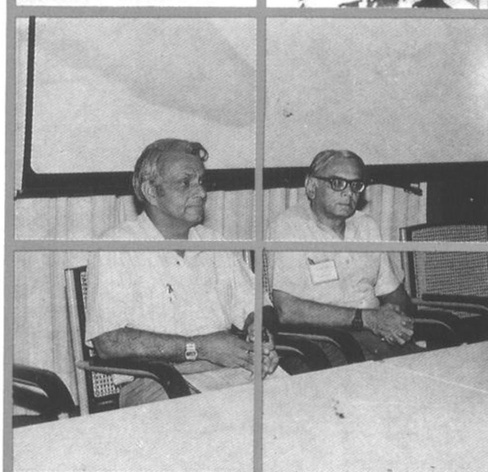
During this period, the



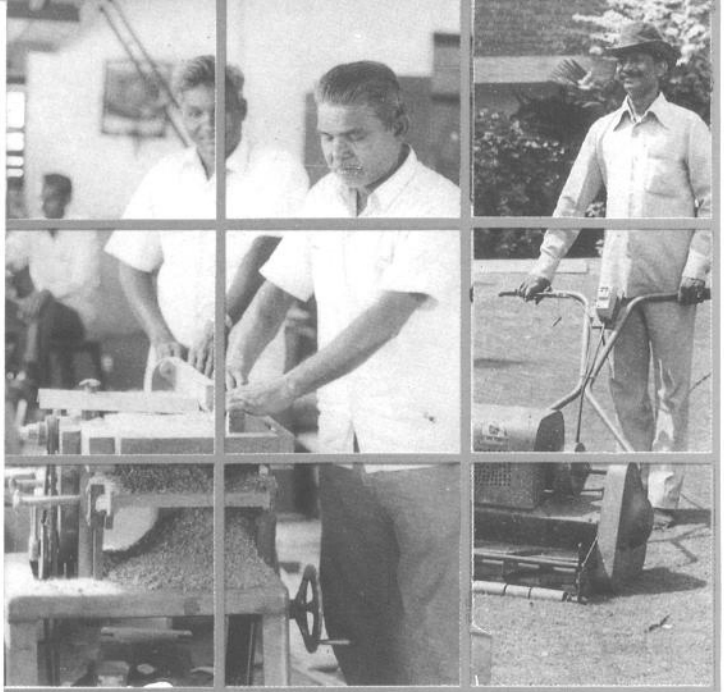
Prof. S. P. Pandya with Prof. R. G. Rastogi and others during the Silver Jubilee celebrations.

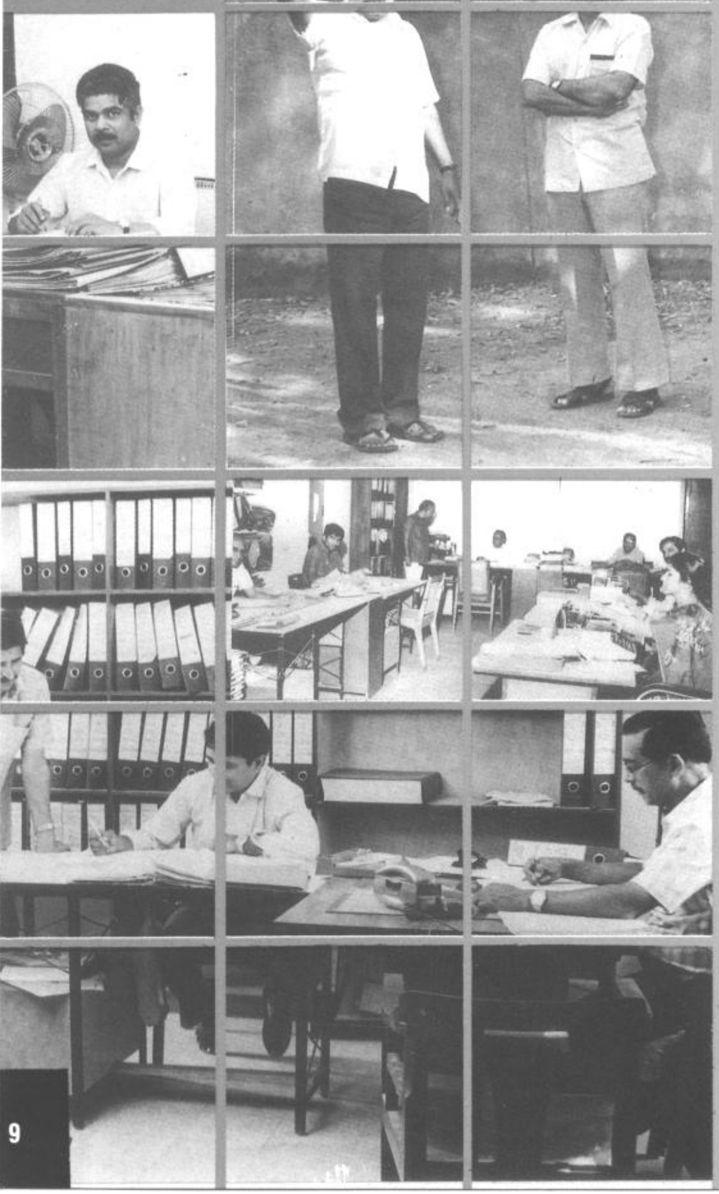


Prof. S. P. Pandya wit two Indian Astronauts Squadran Leader Rakesh Sharma and Wing Commander Ravish Malhotra.



Prof. S. P. Pandya wit Prof. R. K. Varma.





The administrative and services section of PRL which provides an excellent management support to the laboratory's scientific activities.

Thaltej Campus of PRL has also developed considerably and is to house the "Astrophysics and Astronomy" activity of the Laboratory, including, of course, one of the IPS stations which is already located there.

In the foregoing we have tried to give a glimpse of the evolution of PRL since its inception. Starting from a few rooms at M.G. Science College the laboratory has during this period expanded into a big campus of its own at Ahmedabad, with an Astronomy and Astrophysics campus at Thaltej (near Ahmedabad), a Solar Observatory at Udaipur and an Infrared Observatory at Mount Abu. The science at PRL has also grown considerably and covers a much wider spectrum in the various areas of astronomy and astrophysics, planetary atmospheres, earth sciences and theoretical physics.

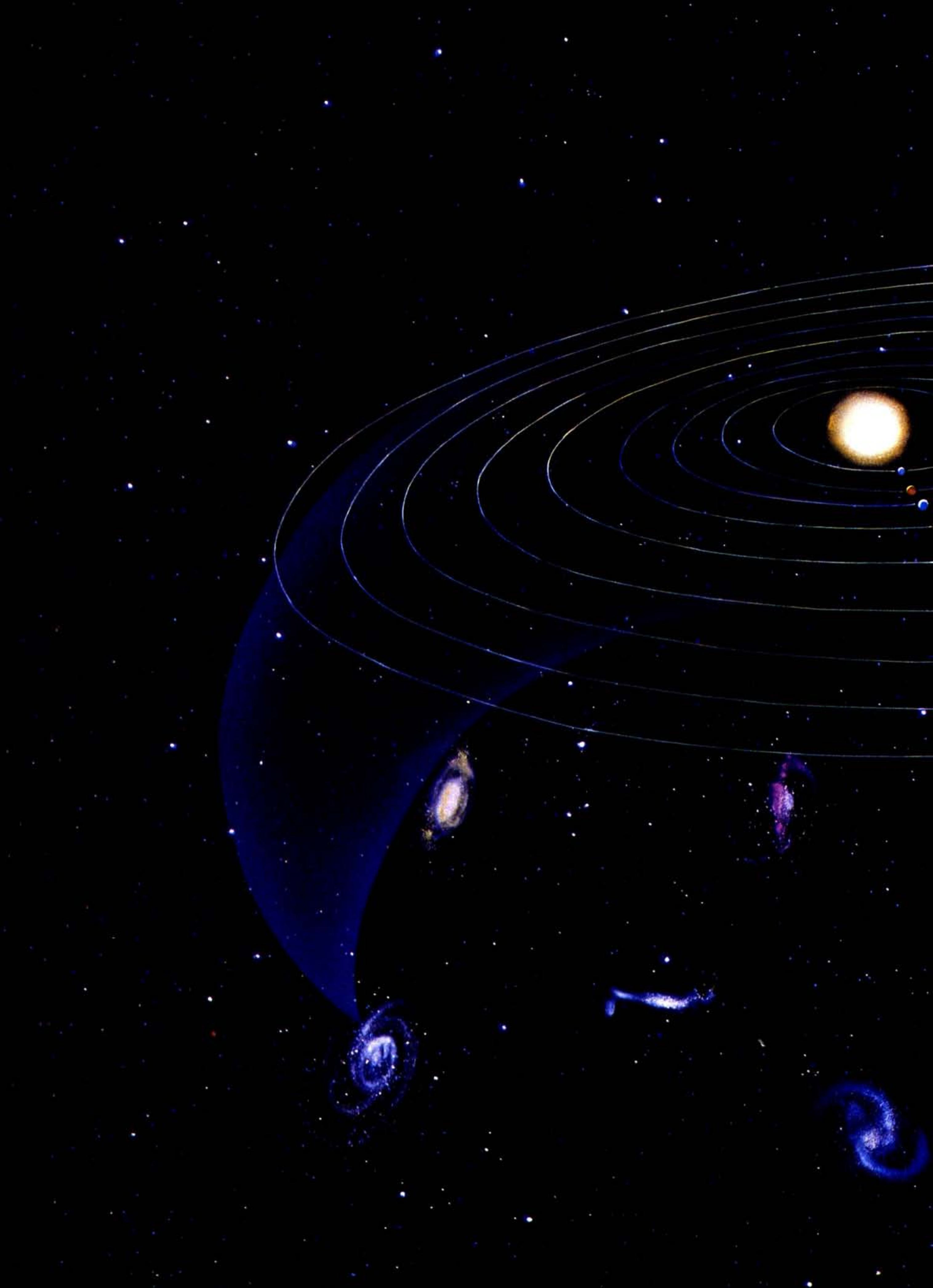
Behind the achievements of PRL scientists is the able and efficient support given by the administrative and the technical staff. The administrative section of our laboratory continues to play a pivotal role in providing an excellent management support to carry out our scientific activities. The administrative structure at PRL is large and varied, and includes public relations, establishment, catering, transport and security, finance, legal matters etc. In addition, it also provides management support to the Solar Observatory at Udaipur and the Infrared Observatory at Mount Abu. The technical support consists of highly specialized and centralized facilities like library, computer centre, electronics laboratory, glass blowing, liquid nitrogen and workshop. These facilities have played important role in the fulfillment of our scientific objectives.

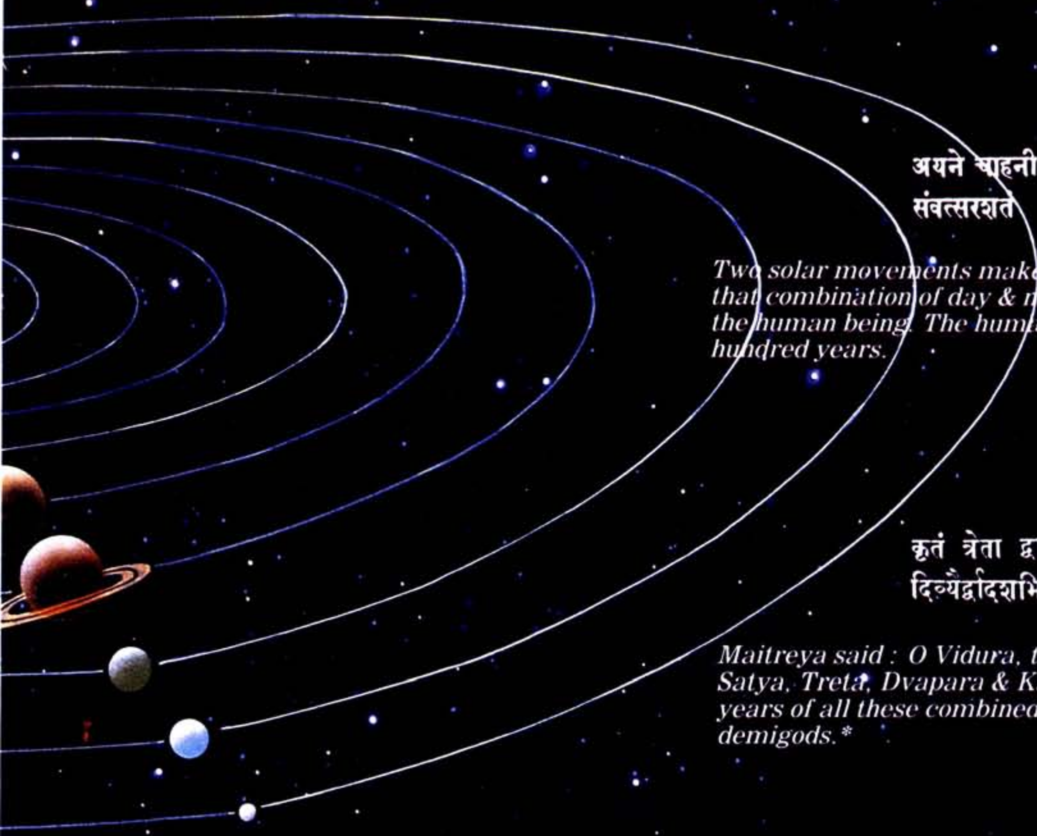
One of the important aims of the laboratory is to serve as a post graduate and post-doctoral study centre for physics and Earth Sciences and to train research students in experimental and theoretical physics. To this end, the laboratory has received encouragement and support, from different Universities and government agencies. There are at present forty research scholars drawn from various parts of India. The laboratory also imparts technical training to students from various engineering colleges and polytechniques.

The laboratory has, from time to time, organized science exhibitions and open houses for the general public. The purpose of these activities was to share with the people of Ahmedabad and Gujarat the excitement of our scientific activities and also to enthuse a spirit of scientific curiosity in the young school and college going students. In addition, the laboratory also arranges popular scientific talks by distinguished scientists. PRL also publishes PRL News and Science Focus which contain popular and informative science articles and these are distributed to about two hundred Universities, scientific institutes and public enterprises.

The intellectually rich past of the laboratory owes its being on the one hand to the vision and scientific contribution of Dr. Vikram Sarabhai and Prof. K.R. Ramanathan, and on the other, to a number of PRL scientists who grew with the laboratory, and worked in it with great devotion and untiring spirits. As we, reminisce over the past forty years, we pay our homage to our founder, to our founder director and to all those dedicated scientists who shaped the destiny of PRL.

As a part of its obligation to the society and to create scientific awareness amongst the general public PRL opens its gate to the public periodically. Glimpses of the open house exhibitions arranged on the occasion of Silver Jubilee celebrations in 1973; in 1982 and during the celebrations of Four Decades of PRL in 1989.





स कालः परमाणुर्वै यो भुङ्क्ते परमाणुताम् ।
सतोऽविशेषभुग्यस्तु स कालः परमो महान् ॥ ४ ॥

Atomic time is measured according to its covering a particular atomic space. That time which covers the unmanifest aggregate of atoms is called the great time.

Srimad Bhagwatam : 3: 11: 4

अयने चाहनी प्राहुर्वत्सरो द्वादश स्मृतः ।
संवत्सरशतं नृणां परमायुर्निरूपितम् ॥१२॥

Two solar movements make one day & night of the demigods, & that combination of day & night is one complete calender year for the human being. The human being has a duration of life of one hundred years.

Srimad Bhagwatam : 3: 11: 12

कृतं त्रेता द्वापरं च कलिश्चेति चतुर्युगम् ।
दिव्यैर्द्वादशभिर्वर्षैः सावधानं निरूपितम् ॥१८॥

*Maitreya said : O Vidura, the four millenniums are called the Satya, Treta, Dvapara & Kali yugas. The aggregate number of years of all these combined is equal to twelve thousand years of the demigods.**

Srimad Bhagwatam : 3: 11: 18

त्रिलोक्या युगसाहस्रं बहिराब्रह्मणो दिनम् ।
तावत्येव निशा तात यन्निमीलति विश्वसृक् ॥२२॥

निशावसान आरब्धो लोककल्पोऽनुवर्तते ।
यावद्दिनं भगवतो मनून् भुञ्जंश्चतुर्दश ॥२३॥

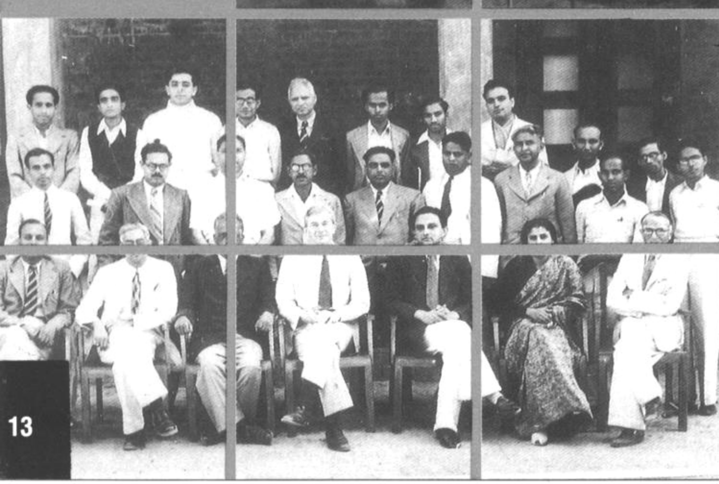
Outside of the three planetary systems, the four yugas multiplied by one thousand comprise one day on the planet of Brahma. A similar period comprises a night of Brahma, in which the creator of the universe goes to sleep. After the end of Brahma's night, the creation of the three worlds begins again in the daytime of Brahma.

Srimad Bhagwatam : 3: 11: 22-23

* Translation by His Divine Grace A.C. Bhaktivedanta Swami Prabhupada

* Duration of 4 yugas = 12,000 demigod years or 12,000 x 360 = 4,320,000 human years
1 Day of Brahma = 4320000 x 1000 = 4320,000,000 or 4.32 x 10^9 years.
Strangely enough, this figure seems to be close to the current estimate of the age of the Earth.

Sir S. S. Bhatnagar speaking at the Foundation Stone laying ceremony of PRL.



PRL scientists and delegates at the Prof. Sydney Chapman Lecture series.

EVOLUTION OF THE SCIENTIFIC ACTIVITIES OF PRL

Ever since his advent on this planet, man has been aware and conscious of his environment—both terrestrial and extra-terrestrial. He has looked around on the Earth and identified "elements" of the environment crucial for his existence: the air and the water. He discovered fire and realized the all pervading existence of "akash" (space). In course of time, he realized that the weather and climate played a very crucial role in his day-to-day activities and requirements. He also soon realized that an extra-terrestrial object—the Sun—played a very dominant role in the very sustenance of life and gave it the status of God—the Sun God. It was also quickly realized that the Sun also played a central role in determining the weather and climate on Earth through the generation of wind, evaporation of water from the ocean etc.

When the Sun is set and the night falls, man is exposed to the spectacle and the splendour of the night sky—his extra-terrestrial environment. His curiosity and the power of observation led him to discern the heavenly bodies—planets—which were found to move at different time scales against the background of "fixed" stars—the other innumerable luminous point like objects which appeared fixed over the time scale of observation. The heavenly sphere itself was found to rotate around the Earth which is attributable, as proposed by Aryabhata, to the rotation of Earth around its axis.

The early observations of the motions of the planets were made painstakingly by astronomers with the unaided eye through the medium of the visible light of the Sun reflected by the planets. With the development of the telescope, more detailed observations of the planets began to be made; in particular, Galileo was led to discover the four moons of Jupiter. Subsequent improvements and breakthroughs in the observational techniques led to the unravelling of deeper layers of space and to the discoveries of "nebulae" which are recognized to be huge clusters of billions of stars, of a variety of shapes and sizes now, known as "galaxies". It was also recognized that our Sun itself is one of the billions of stars that also constitute a galaxy—our own galaxy—known now as the Milky Way.

Man's curiosity knows no bound. He is now looking beyond the galaxy, at "clusters of galaxies" and at the structure of the Universe at the largest scales.

Beyond the discoveries of the mere existence of the various objects, the Earth, the Sun, the solar system, the galaxies and the clusters of galaxies, man is now asking about the hows and whys of the various objects and structures observed through a variety of astronomical windows—from radio through infrared, optical to X-rays and gamma rays.

The Sun, our own star, being so close to us offers us a unique opportunity to study its structure and dynamics, the structure of its surface features, magnetic field and a variety of explosive and spectacular processes that have been observed over the last few centuries since Galileo first discovered the "Sun Spots".

Our Sun is also, perhaps, one of the very few stars, if not the only one, in the galaxy which has a rich system of planets around it with most of the planets in turn having a rich system of satellites around them.

LOOKING homeward, the earth-system itself presents a very complex and fascinating object to study. One of the most challenging problems is understanding its weather and climate which is of direct interest and relevance to mankind. Perhaps, the first of the phenomena that man began to investigate about his environment were the winds and the rainfall—winds, because they played a dominant role in the sea navigation which was intimately tied to trade and economic activity of man; and monsoon and rainfall because they affected the water resources and the agriculture—the two life lines of man.

A variety of phenomena relating to our environment as enumerated above thus present very fascinating and challenging area of study. The Physical Research Laboratory was established by Dr. Vikram Sarabhai with this broad objective in view. When the laboratory was started in 1947, the cosmic radiation was one of the most exciting areas of study and research and was being vigorously pursued around the globe. Cosmic radiation may be regarded as nature's messenger which can tell us about the electromagnetic state of the medium through which they travel before reaching us. The study of the primary cosmic radiation was one of the major disciplines of choice which was started at PRL. A number of pioneering discoveries were made by Dr. Vikram Sarabhai and his students over more than two-and-a-half decades.

The other important area which constituted the thrust of research activity at PRL was the area of atmospheric sciences. A number of important and pioneering investigations were carried out under the stewardship of Prof. K.R. Ramanathan the first Director of PRL. These include,

- the measurement of total ozone content of the atmosphere and its variability on various time scales in response to changes in the solar radiation input as well as changes in atmospheric circulation and

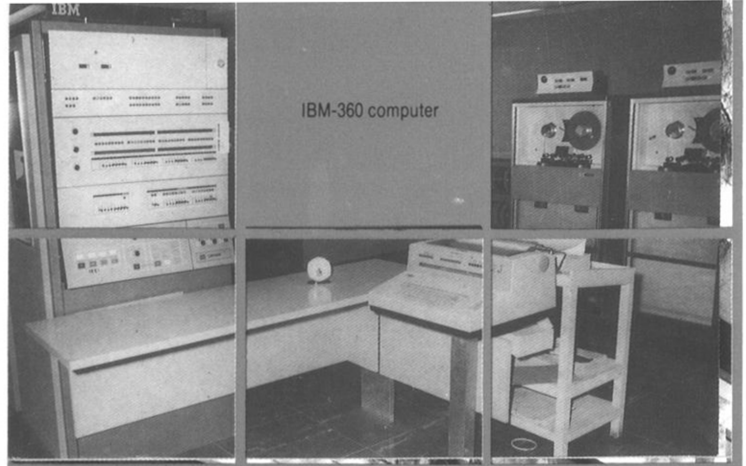
- a study of night airglow—the faint radiations that emanate from different regions of the atmosphere whose measurements can be used to study the structure, energetics and dynamics of these regions.

Scientific investigations in other directions, namely the propagation of radio waves through the Earth's atmosphere, led to the outstanding discovery by Appleton, of what is known as the 'Ionosphere'. It opened up entirely new vistas to the knowledge of our atmospheric envelope. The role of the ultra-violet (UV) radiation in producing the ionized layer was soon appreciated and this led to an entirely new field of study, the "ionospheric physics" in which vigorous researches were carried out all over the world and also at PRL. Our scientists made full use of our special geographical locations—the equatorial latitudes—to make pioneering contributions in the field.

THE early work in cosmic rays and atmospheric and ionospheric research was carried out using ground-based instruments: for instance, Geiger-Müller counters, meson telescopes, neutron monitors were used to measure the cosmic ray intensity, its time

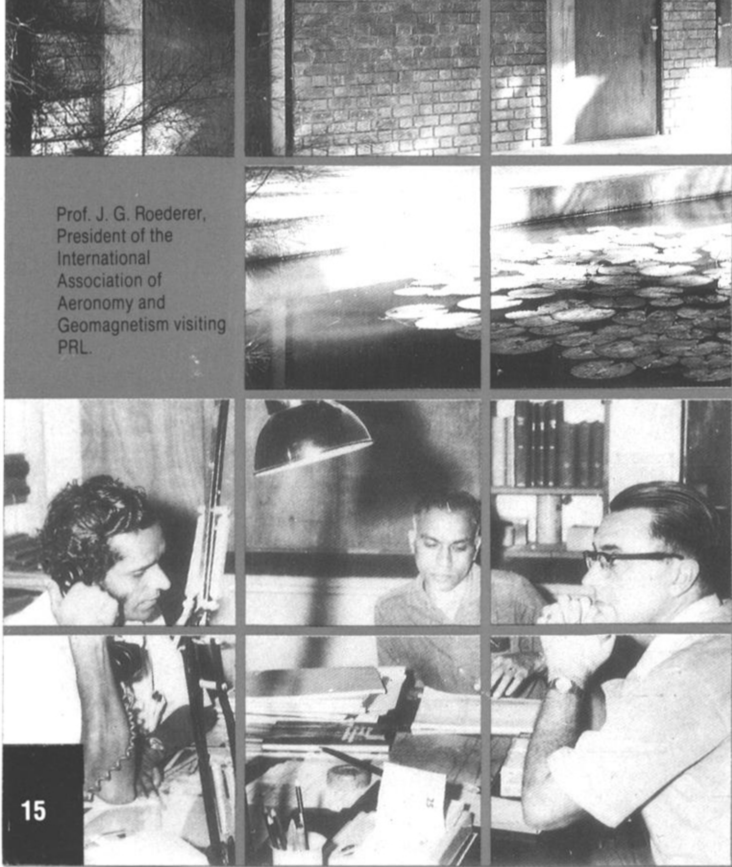
Telemetry antenna on PRL terrace to receive balloon flight signals.

Balloon flights were initially conducted from the Gujarat University ground to measure the background gamma rays.



IBM-360 computer

Prof. J. G. Roederer, President of the International Association of Aeronomy and Geomagnetism visiting PRL.



variation and anisotropies. Likewise, the measurements of the atmospheric and ionospheric constituents, parameters and the electromagnetic states were carried out using the ozonesondes, the ionosondes, the magnetometers, photo-electric photometers (for night air glow) and the riometer.

THE International Geophysical Year (IGY) was launched on July, 01, 1957, and PRL became an active participant in the programmes associated with the IGY, thanks primarily to the initiative and drive of Dr. Vikram Sarabhai and Prof. K.R. Ramanathan. This led to a great spurt of activity at PRL in a large variety of areas: the cosmic rays, the geomagnetism, solar physics, atmospheric physics and meteorology. This, in turn, contributed a great deal to the evolution of PRL into a space science laboratory that it became known for. With rare foresight, Prof. Ramanathan took the opportunity of the IGY to establish the Indian Dobson network—a chain of stations to study the behaviour of ozone in the tropics. Looked at in a broader perspective, the studies at PRL could be considered at that time to constitute an exploration of the solar-terrestrial relationship through the agency of particles, fields and electromagnetic radiation in its widest possible scope.

The setting up of Thumba Equatorial Rocket Launching Station (TERLS) was watershed in the history of the development of the Indian space programme in general, and space sciences in particular. It was from here that the rockets that carried the scientific payloads relating to the various scientific experiments also launched India's space programme. History should record the crucial part played by PRL in the initial stages of space sciences which led to the subsequent development of the space programme. Indeed many of the scientists who were at PRL played a leading role in the formulation of the space programme, with Dr. Vikram Sarabhai being its chief architect. PRL is thus rightly regarded as the cradle of the Indian space programme.

THUS, the era of the rocket-based space programme in India of began on the evening of November 21, 1963, when the first scientific rocket went up from Thumba releasing sodium vapour which showed up the state of winds and turbulence above 90 kilometres. Over subsequent year, PRL became a centre for developing and building scientific payloads for use in rockets, in high flying balloons and later satellites. Between 1963 and 1975, a total of twenty-five scientific payloads were fabricated and flown to measure a variety of atmospheric and ionospheric parameters. Thus, in the sixties and seventies, rockets played an important part in space research whereby electron density profiles at day and night were measured. Magnetometers were flown to measure the magnetic field and study the height structure of the electrojet currents over Thumba. Special Langmuir probes were flown to measure electron density irregularities in the E-and F-regions, while vapour releases were used to measure the neutral winds. In addition, the ground-based instruments, such as the ionosonde, the magnetometer etc., continued to play important complementary role.

The rocket–based space programme also provided an opportunity to carry out astronomical investigations besides the aeronomy studies. Thus payloads were fabricated and flown to study the energy spectra of the X-ray sources such as SCO-XI, CYG-XI and CEN-XI.

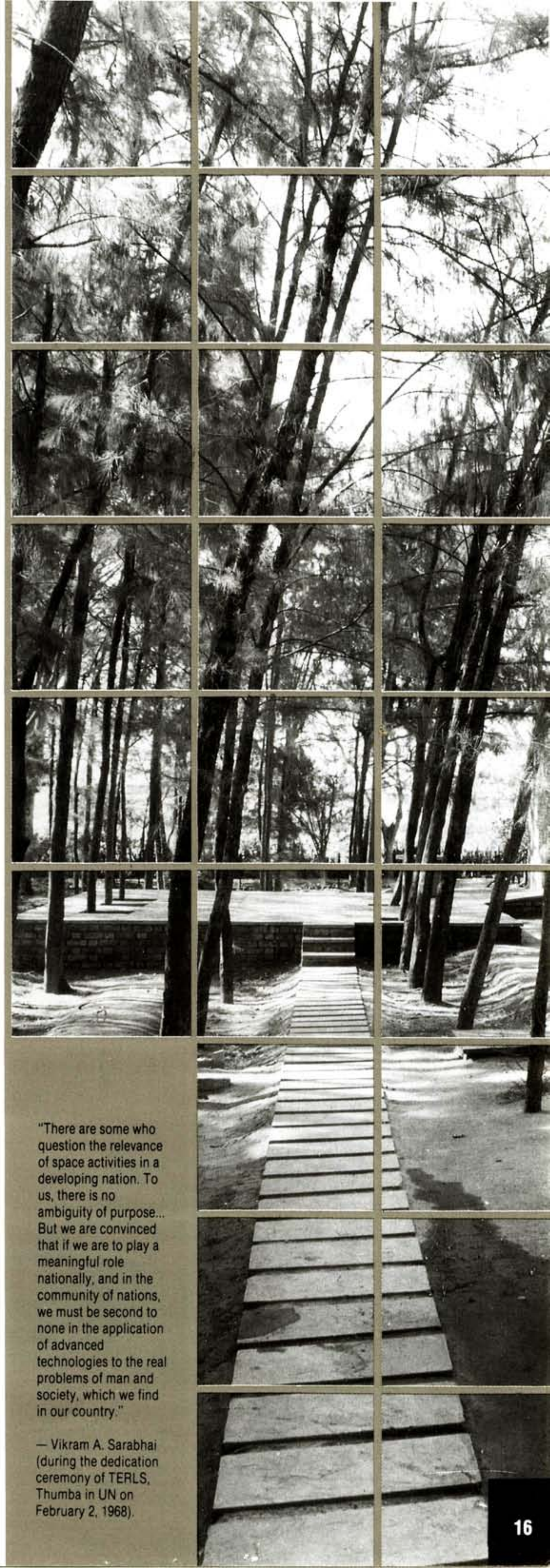
Studies aimed at understanding the extra-terrestrial environment in its totality cannot remain confined to one or two windows as represented by cosmic radiation and X-rays. To understand the various dynamical and electromagnetic aspects of the gamut of phenomena occurring within the solar system and beyond, one has eventually to view the phenomena through all the available windows of the electromagnetic spectrum. Radioastronomical studies of the Sun and its corona have been carried out since 1967, even though some instruments, such as the cosmic radio noise monitor and riometer have been operated since 1956. Subsequently, a three-station IPS (interplanetary scintillation) telescope (at Thaltej (Ahmedabad), Surat and Rajkot) has been installed by PRL which is, inter alia, capable of measuring the solar wind velocities at higher helio-latitudes.

Infra-red is another important window in the electromagnetic spectrum which yields information about phenomena and processes in the Universe, which have hitherto been hidden from our vision. Thus, infra-red astronomy gives information about objects which are not yet hot enough to glow and thus gives clues about possible sites where stars may be forming. An infra-red telescope (1.2 metre diameter) is being installed by PRL at Gurushikhar (1500 metre above the mean sea level) in Rajasthan, to carry out such studies.

FOLLOWING the sad demise in December 1971, of Dr. Vikram Sarabhai, who was the then Director of PRL (as also the Chairman, Atomic Energy Commission and Indian Space Research Organisation), Dr. Devendra Lal came to PRL as its new Director. He brought with him his group on Earth Sciences and Solar System studies. A new dimension was thus added to PRL's scientific activities. Studies of the solid Earth and oceans complemented the studies of the Earth's atmosphere, so that at least some aspects of the total earth–system came under the purview of the studies at PRL. Likewise, the studies of meteorites and the moon which are directed towards understanding the early history of the evolution of the solar system extended the scope of the earlier studies of solar-terrestrial system.

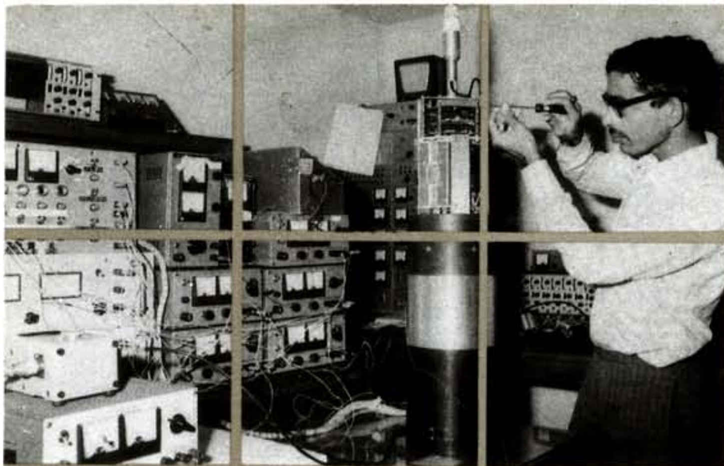
WHILE experimental programmes are the very backbone of scientific investigations, an understanding of the variety of natural phenomena require a conceptual and a theoretical framework. Such a framework enables the various phenomena to be understood in terms of a small number of basic laws. It is the continuous quest of scientists to reduce all the observed phenomena to a smaller and smaller set of basic laws. It is, therefore, essential to have a theoretical physics group in a scientific institution which provides a broad theoretical environment. While it is desirable to have a theoretical and modelling activity associated with every major experimental programme, it may not always be possible. Nevertheless theoretical physics is a highly desirable activity in its own right and provides a core around which a meaningful and sustainable modelling activity can develop.

Perhaps it was with this view that a small theoretical physics activity was initiated at PRL from the very beginning. For historical reasons the activity started with nuclear physics as the main discipline. It was, however, soon realized that the discipline which was most relevant from the point of view of the experimental programmes of the laboratory at that time, was plasma physics. Thus plasma physics activity started with a one member group in 1968, which rapidly grew to a sizable group by 1972. Both plasma physics and nuclear physics activities have

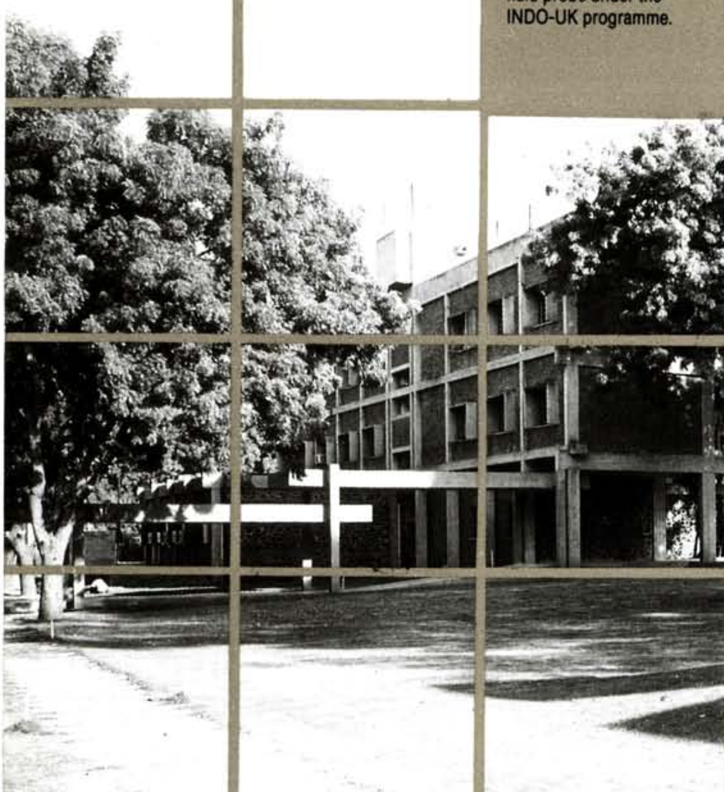


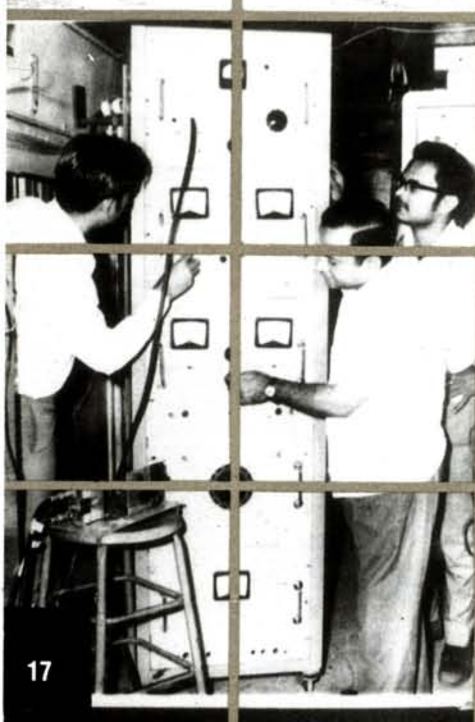
"There are some who question the relevance of space activities in a developing nation. To us, there is no ambiguity of purpose... But we are convinced that if we are to play a meaningful role nationally, and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society, which we find in our country."

— Vikram A. Sarabhai (during the dedication ceremony of TERLS, Thumba in UN on February 2, 1968).



Integration of the Langmuir and electric field probe under the INDO-UK programme.





A 50 Kilowatt transmitter being tuned to probe the D-region of the ionosphere using the partial reflection technique.

continued vigorously, with plasma group addressing problems of space and astrophysical interest besides those pertaining to basic plasma physics.

With time, the nuclear physics activity which earlier concentrated on low energy regime and nuclear spectroscopy has gone on to address problems of high energy regime involving the quark degrees of freedom and the studies of the state of high energy nuclear matter known as the "quark-gluon-plasma". Very recently a small high energy particle physics group has also been added to address the problems of cosmology.

The other areas of theoretical physics which have relevance from the point of view of the atmospheric sciences programme of the laboratory are atomic and molecular physics and atmospheric dynamics including the monsoon studies. Small theoretical groups devoted to these studies have thus been developed. Together, their expertize can be used to model both dynamical and the chemical aspects of not only the Earth's atmosphere but also atmospheres of other planets.

THE decade of the eighties have given us the first ever glimpses of the outer planets (Jupiter, Saturn, Uranus and Neptune) and brought forth spectacular revelations about their physical structure through the agency of the deep space probes, the Pioneer I and II. The decade has also seen an increasing emphasis on the study of the middle atmosphere—its chemistry and dynamics. This study has been prompted by the increasing concern of man about his environment—particularly the environment as it is being affected by anthropogenic causes, the alarmingly increasing levels of the so-called "green house" gases in the atmosphere—the CO_2, H_2O and methane. He is now feeling that his abode on earth is getting threatened as he has begun to fear that the green-house effect may lead to warming of the atmosphere and consequent melting of the polar ice caps. This may lead to the submergence of large coastal areas of land under the oceans.

Man's attention is now drawn towards these important survival issues and so there has been increasing scientific activity to understand, what has so far been a rather neglected area, namely the middle atmosphere. It has now been realized that so little is known about the middle atmosphere—its chemistry, its dynamics, its minor constituents and the radiation transport and budget. All these aspects of the middle atmosphere, it is now appreciated, play an important role in determining our weather and climate. Perhaps, the minor constituent of the middle atmosphere which has drawn the greatest attention is Ozone. Man is now worried that he has, by his own actions, been depleting the protective ozone layer that nature has so generously provided to protect him against the hazards of the solar ultraviolet radiation. The discovery of the Antarctica Ozone Hole in 1985 has sent alarm bells up his spine. The importance of monitoring the Chloro-fluoro carbons (CFCs) and NO_x compounds in the stratosphere injected by freons and use of spray cans and by supersonic aircrafts was realized. Likewise, the importance of monitoring the aerosols for the radiation budget of the atmosphere has also been appreciated.

OCEANS are extremely important in determining our climate through the gaseous (CO_2) exchange processes and other chemical reactions involving nitrogen exchange, and most importantly, in supplying water vapour to the atmosphere which eventually appears as rain. Water vapour in the atmosphere is also responsible for greenhouse warming of the planet. Our understanding of the variety of processes involved in the ocean-atmosphere interaction is still very rudimentary. It is both a highly interesting and extremely important area of investigation for the understanding of the monsoon dynamics. It is crucial to study the wind induced ocean currents and evaporation in order to be able to understand the moisture budget in the atmosphere particularly during active monsoon periods.

The importance of studying our immediate environment, the troposphere and the middle atmosphere, oceans and ocean-atmosphere interaction, has now been acutely realized. The earth-system is a complex nonlinear one with a large number of feedback loops involving strong couplings among its various components, the geosphere, the hydrosphere, the cryosphere, the atmosphere and the biosphere. Realizing this a comprehensive programme named as the International Geosphere Biosphere Programme (IGBP) has been launched by the International Council of Scientific Union which has been taken up by countries around the globe.

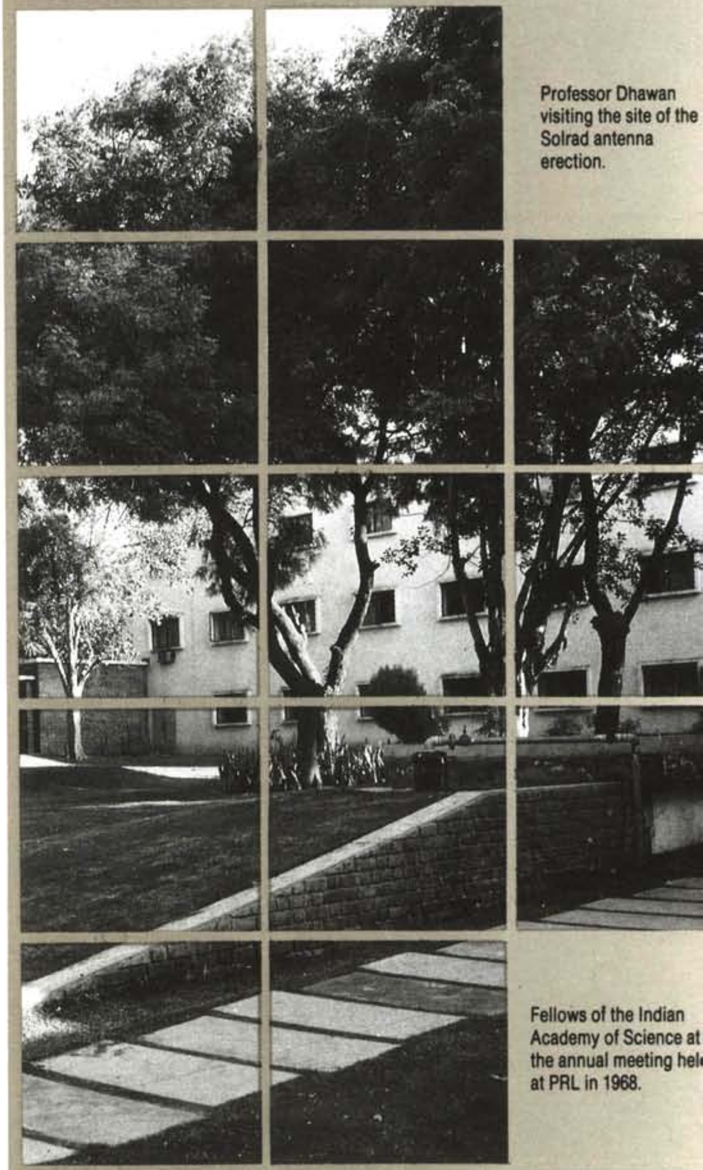
PRL is a unique laboratory, probably one of its kind in the world which has a good number (certainly not all) of the components of IGBP under its roof. We have an atmospheric sciences programme which aims to study the chemistry and dynamics of the lower and middle atmosphere: We have a theoretical group studying the dynamics of the troposphere as it relates to atmospheric circulation and the monsoons. We have a palaeoclimate programme which aims to understand the climatic processes on various time scales, from millions of years to a few tens of years through the studies of oceans and lake sediments, tree rings, sand dunes, loess and palaeosols. We are also involved in hydrological programmes, the ocean circulations—both surface and deep water—groundwater movements and recharge, the glacier dynamics, river water chemistry and fluxes of materials to the oceans. We also plan to add another small group on the studies of the ocean-atmosphere interaction which is very important for the understanding of both the dynamics of oceans and atmosphere and of the evaporation process so crucial for the monsoons.

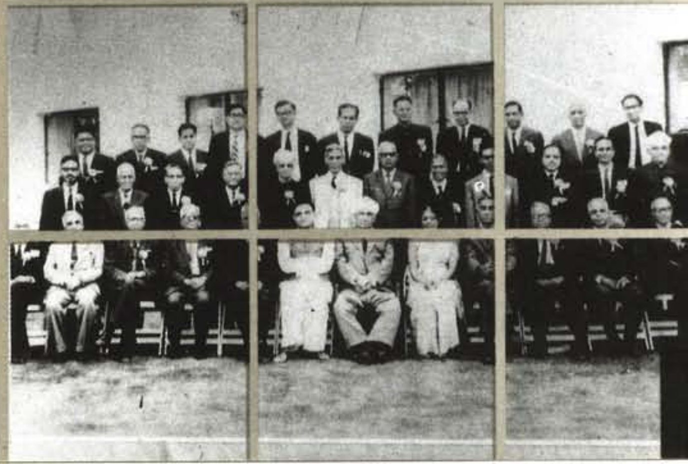
With all these components, we plan to embark on a coordinated study of the various earth-system processes to try to understand our climatic changes on various time scales from tens of thousands of years to the decadal. We shall try to understand how modern man has been tampering with the climate and the biosphere through the chemical releases—the bye-products of his "progress", and what the short and long term effects of these anthropogenic factors are going to be on our climate and biosphere. In the Indian context, it is very important for us to study the wind induced ocean circulations and evaporation as these constitute a very crucial input for the monsoon processes.

LOOKING into the future complexion of PRL scientific activities, we would like to focus our research efforts into three to four directions which are consistent with our existing and evolving facilities and expertize and with the evolving international scenarios and emphases. We shall, however, also continue to look for areas and problems which may be entirely new and unchartered territories and hope that we would succeed in bringing major "firsts" to PRL's credit.

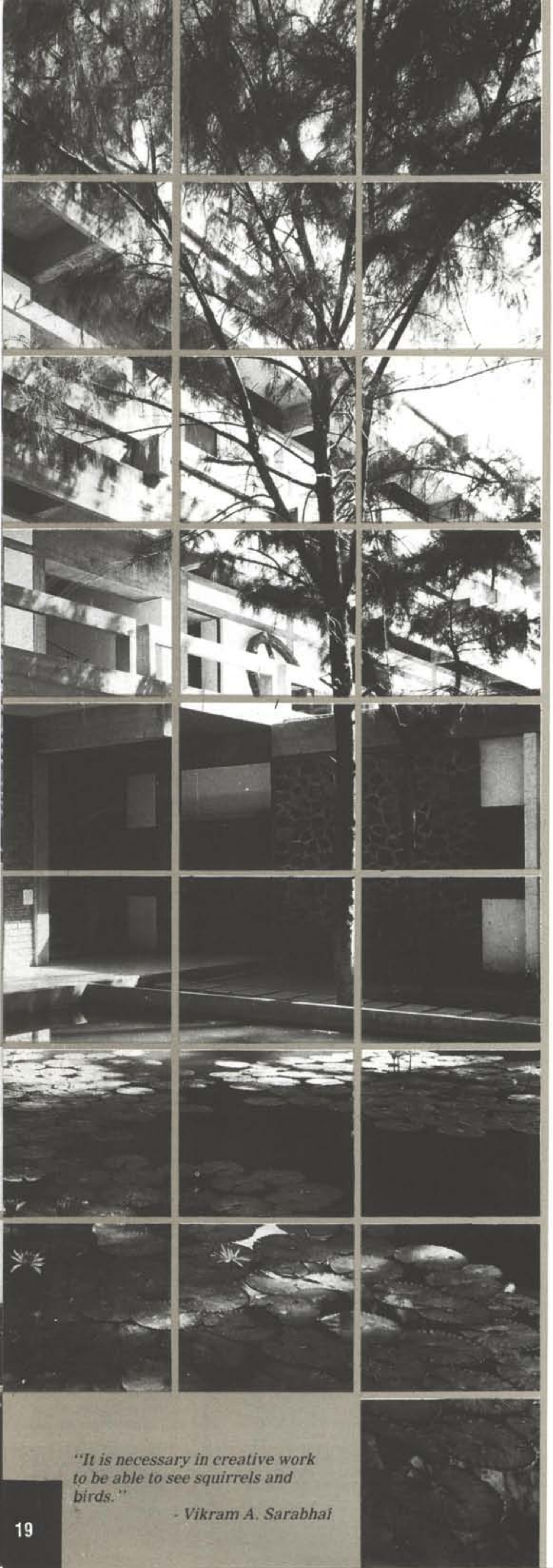
Thus, apart from the study of our climate and monsoon and

Professor Dhawan visiting the site of the Solrad antenna erection.





Fellows of the Indian Academy of Science at the annual meeting held at PRL in 1968.



"It is necessary in creative work to be able to see squirrels and birds."
- Vikram A. Sarabhai

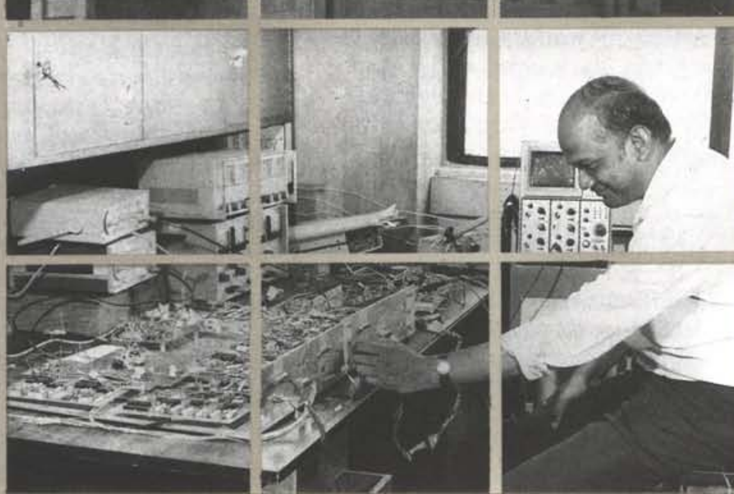
IGBP related activities described above, we would also like to extend the studies of the earth's ionosphere and atmosphere to other planets using ground-based optical methods such as the Fabry-Perot Interferometry in which PRL is known for its high degree of expertize. Understanding the structure and dynamics of the planets and satellites and other solar system bodies—the comets and the meteorites—should constitute a natural programme of study for PRL which has made pioneering contributions to the studies of the Earth's ionosphere and atmosphere. On the other hand, the evolution of the solar system itself, the mechanism of the formation of planets and their satellites from the primordial circumsolar nebulae is another complementary rich area of study. PRL already has a small group which has been studying the chemical composition of meteorites to peep into the early stages of the formation of the solar system bodies. However, these studies must be accompanied and supplemented by appropriate modelling and perhaps, also laboratory studies to understand the process of aggregation which is one of the most crucial phenomena in the formation of the solar system bodies.

ASTRONOMICAL studies of the Sun and other galactic and extragalactic objects in the optical and infra-red windows will constitute another major area of activity for PRL. With the commissioning of the Infra-red Observatory at Gurushikhar, we will be embarking on an extensive programme of the study of Active Galactic Nuclei (AGN) and star forming regions. The work on these has already been carried out using other telescopes in the country.

Likewise, the Solar Observatory at Udaipur has been studying the eruptive processes on the solar surface, the solar flares and prominences and proposes to map the associated magnetic field using a solar magnetograph. The eruptive processes on the Sun and coronal streams lead to the propagation of associated disturbances into the interplanetary plasma. The plasma turbulence associated with these disturbances will be mapped using a 20,000 square metre antenna array operating at 103 Mega Hertz at Thaltej. This is one of a three-station IPS telescopes which is being used to measure the three dimensional solar wind velocity field. The other two are at Surat and Rajkot with 5000 square metre antenna area each.

Scanning electron microscope for studing Ion microprobe for studying solar system objects.

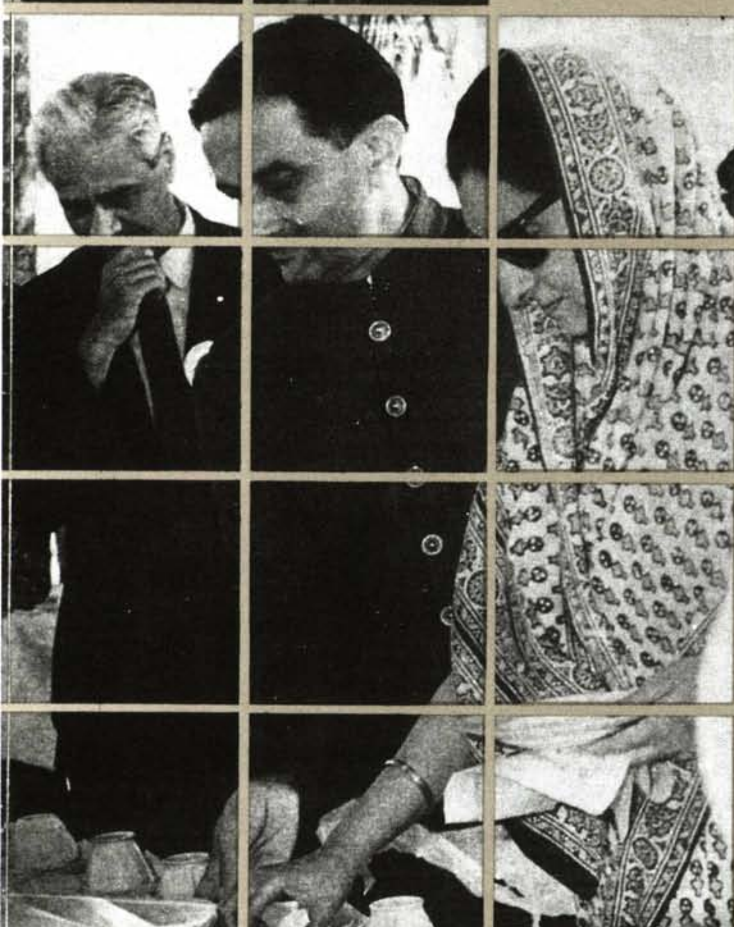
Benzene synthesis system fabricated in PRL for Carbon-14 dating.



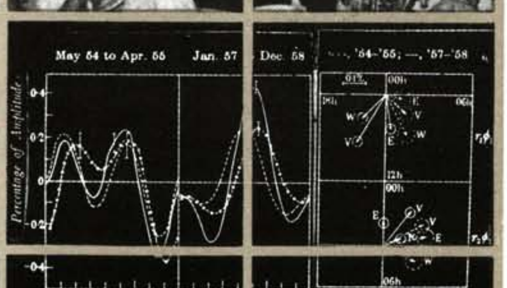
Testing of the laboratory model of the Langmuir probe to be flown in SROSS-3

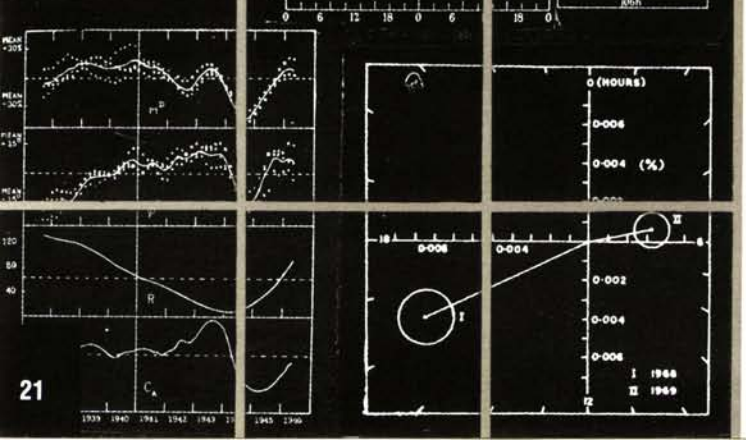
Go Back

Dr. Vikram Sarabhai — pioneer of time variation studies of cosmic rays in India.



Dr. Vikram Sarabhai with the Prime Minister, Srimati Indira Gandhi.





Some significant results from inclined cosmic ray telescopes at Ahmedabad by Vikram Sarabhai and students.

THE FIRST TWENTY FIVE YEARS

THE main areas of research during the first twenty five years were Cosmic Radiation, Atmospheric Sciences, Aeronomy and Theoretical Nuclear Physics. These topics were chosen following the interests of Dr. Sarabhai and Prof. Ramanathan. Dr. Sarabhai's specialization was in the field of cosmic rays, their origin and temporal variations. Prof. Ramanathan was interested in studies relating to solar-terrestrial relations, geomagnetism and upper atmospheric properties. With time it was realized that to obtain a better understanding of the Universe it was necessary to have an integrated study of different kinds of radiations which were received on the Earth and their geophysical consequences. To achieve this goal, programmes in X-rays and radioastronomy were initiated. In addition, theoretical physics was also initiated. Researches in theoretical nuclear physics were carried out under the leadership of Profs. Vachaspati and S.P. Pandya. The main architects of the X-ray and radio astronomy groups were Profs. U.R. Rao and R.V. Bhonsle.

COSMIC RADIATION

THE research in cosmic rays during this period evolved through three distinguishable phases. The first and the exploratory phase was prior to the decade of 1947–57, the International Geophysical Year (IGY). The second, consolidating phase was the decade containing the IGY and the International Quiet-Sun Year, 1965 (IQSY). The last phase, a stock-taking and improvement phase was the years after 1965. The classification is made only to facilitate the highlighting of the developments which were more or less continuous.

Dr. Vikram Sarabhai's research at Bangalore and Apharwat in Kashmir, well before the formation of PRL, had established small diurnal and semi-diurnal variations in cosmic-ray intensity at ground level. Understanding the details of these variations and their causes was a major programme of cosmic-ray research at PRL. This involved the development of sophisticated instrumentation, data gathering and modelling. As the nature of cosmic-ray anisotropy was not known during the exploratory phase, innovation was made in the form of cosmic-ray telescopes various opening angles in the east-west plane, the narrowest semi-opening angle being 2.5°. Atmospheric effects due to air mass and its distribution were corrected for by measuring the meteorological parameters. Another substantial improvisation was the pair of cosmic-ray telescopes symmetrically inclined with respect to the vertical. In this set-up the atmospheric processes are equal but the primary anisotropy is different for the two telescopes.

These studies at PRL and the analysis of data from ionization chamber network of Carnegie Institution resulted in the following significant contributions during this period:

- Establishment of cosmic-ray anisotropy as something originating beyond the atmosphere and geomagnetic field.

• Solar control of the anisotropy, particularly due to the long term twenty-two year variation of the solar polar magnetic field was discovered for the first time.
• The existence of a semi-diurnal anisotropy as seen by meson data was established.
• Twenty-seven day modulation of cosmic ray intensity on Earth due to solar rotation was discovered.
• Sharp anisotropies which should better manifest in narrow angle telescope data than in wide angle telescopes were ruled out.

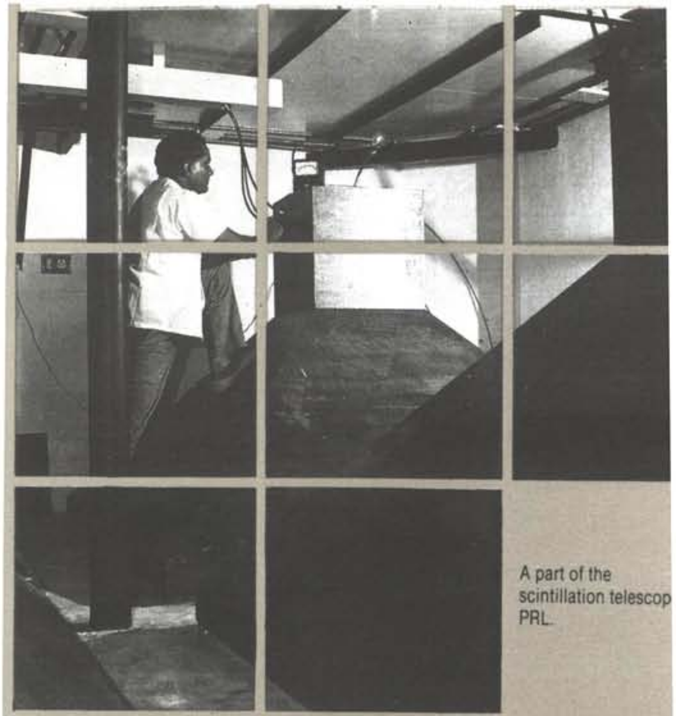
DURING the second phase of development the instruments were standardized: the cubic meson monitor, and the IGY type neutron monitor. The international cooperation and the data exchange under the aegis of IGY, the space age, particularly the Mariner II and Imp I satellites to measure insitu, the solar wind and the interplanetary magnetic field brought a new perspective to the analysis of data. On the theoretical side, the interaction with scientists such as E.N. Parker and A.J. Dessler contributed to a better understanding of the processes involved. On the instrumentation side during this period, large area plastic scintillators used as detectors led to a new branch of study, the cosmic ray intensity scintillations.

During this period of intensive study:

• The concept of the asymptotic cone of acceptance of cosmic ray detector on the Earth was made clear. This is the solid angle which contributes significantly to the counting rate of the detector.

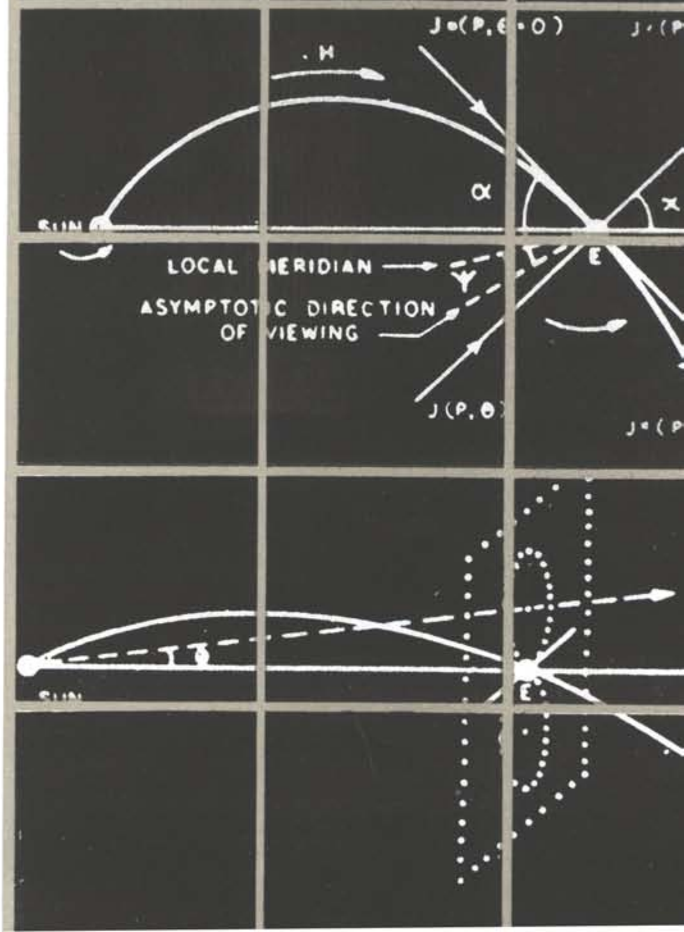
• The concept of variational coefficients were outlined. These coefficients relate the observed variation at the instrument to the primary variation beyond the atmosphere and the magnetosphere. Precise calculations were made for the variational coefficients for several cosmic-ray detectors on Earth.
• For the first time the amplitude, direction and energy spectrum of diurnal anisotropy was established.
• The existence of the more enigmatic semidiurnal anisotropy as seen by neutron monitors was established, and its amplitude, direction and energy spectrum was determined.

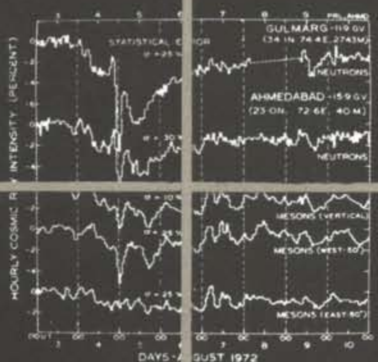
On the theoretical side,
• A first preliminary theory of diurnal anisotropy was proposed.
• The consequences of the non-uniformity of the solar wind velocity were pointed out and the configurations of the magnetic field and solar wind were outlined with measurable cosmic ray effects.
• The consequences of cosmic ray density distribution was examined and a model was proposed to explain for the first time the observed properties of the second harmonic.
• The termination of solar wind, where the solar wind pressure balances the pressure due to interstellar medium was proposed leading to the concept of a heliosphere.
• The relationship between anisotropy and intensity gradients was pointed out and used for the first time to estimate the gradients from anisotropy measurements where such gradients cannot be easily measured by spacecrafts such as in a plane perpendicular to the ecliptic or at high energies 10 GeV < E < 400 GeV (where the space-borne instruments have low counting rates).
• The high variability of anisotropy on a day to day basis was emphasised.
• The intensity of the green coronal emission at wavelength 5303A over a narrow band of solar latitudes was shown to be a better indicator of cosmic-ray modulation at the ecliptic near the Earth.



A part of the scintillation telescop PRL.

Models of interplaneta medium to explain cosmic ray anisotropy

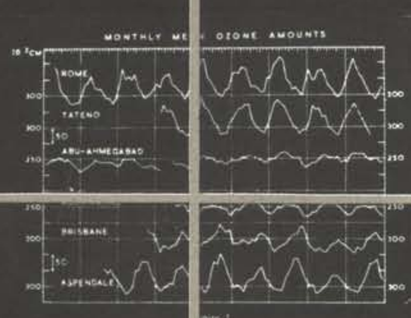




Cosmic ray intensity changes during the great magnetic storm of August 1972.

Prof. K. R. Ramanathan - initiator of atmospheric ozone research in India, with the Prime Minister, Pandit Jawaharlal Nehru.

Dobson Spectrophotometer and some significant results obtained on the ozone distribution and its variation by Prof. K. R. Ramanathan and his students.



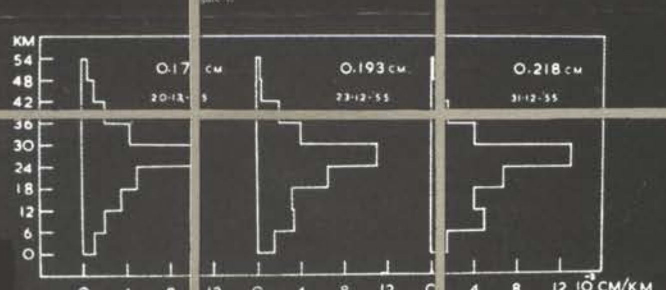


Figure 1. Srinagar – vertical distribution of ozone, using Nye and Chong's values of absorption coefficients of O_3.

In the third phase it was realized that the outstanding problems were:

- Short term variations of anisotropy to be studied in correlation with measured interplanetary parameters.
- cosmic ray intensity scintillations and
- study of higher harmonics n>3.

Detectors responding to much higher energy were desirable. For all these problems a thrust towards larger counting rate was necessary. Several cosmic ray telescopes vertical and inclined were constructed with large area plastic scintillators at Ahmedabad. Other high counting rate monitors that operated during this time were the Super Neutron monitor at Ahmedabad and the IGY type at Gulmarg. Research activity was tapered off after 1972 and the collection of data discontinued after 1974.

In addition to the much awaited effect of the reversal of solar polar field on the diurnal anisotropy, the totally unexpected reversal of cosmic ray gradients perpendicular to the ecliptic was first seen in our data. The usefulness of the high counting rate data was also clear for the fine structure study of transient phenomena such as during—August 1972, for Forbush decrease.

The observations made with Pioneer and Explorer space crafts by the PRL group at the University of Texas at Dallas provided proof for the acceleration of cosmic-ray particles in shock fronts and turbulent sector boundaries. The dominant role played by convection mechanism and field–aligned diffusion in producing anisotropies was discovered.

This report covering almost three decades of cosmic-ray research at various stages of development cannot do full justice to all the results and much less to the excitement that was characteristic of the early exploratory phase. Though the research has been discontinued at PRL it is being pursued at other centres of activity. Higher harmonic components of the anisotropy upto the fourth has been established, cones of acceptance have been calculated for cosmic rays in the heliospheric magnetic field for correcting the observed sidereal anisotropy and obtaining the anisotropy beyond the heliosphere. Cosmic ray scintillation studies have been continued with higher counting rate monitors. The world-wide network of super-neutron monitors with larger counting rate is still operating. Cosmic rays continue to serve as probes to study the electromagnetic conditions of the heliosphere.

ATMOSPHERIC SCIENCES AND AERONOMY

THE early work in atmospheric sciences and aeronomy was of necessity limited to remote sensing of the atmosphere by ground-based optical and radiowave techniques (in-situ measurements with rockets and balloons came much later). However, even in the beginning the research programmes of PRL had a wide perspective and covered various aspects of the neutral and ionized components of the Earth's atmosphere. In addition to surface meteorological and upper air observations which are helpful in analysis and interpretation of the cosmic ray data, the programme included not only the study of ozone and night airglow but also the study of ionospheric D–, E–, and F–regions by several radiowave techniques. The systematic ozone programme at Mount Abu and Gulmarg was the forerunner to the establishment during the IGY (1958–59) of the Indian Dobson Spectrophotometer network which has over the years provided a very valuable data set on ozone in the tropics. Most notable contributions of PRL in ozone studies during the earlier years are:

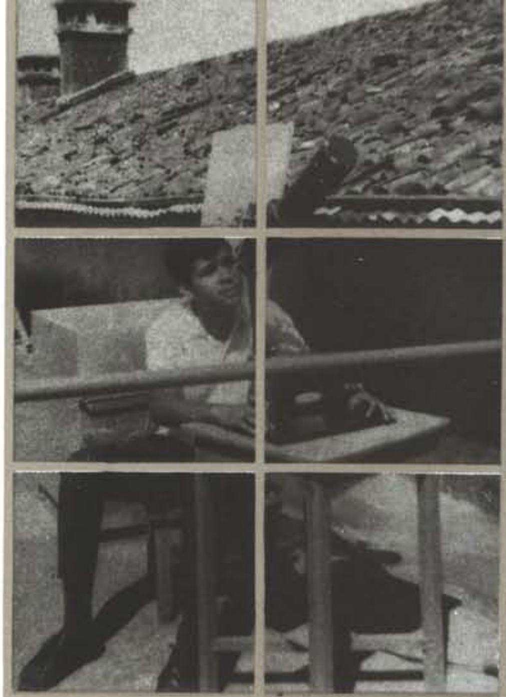
• The development of a method to estimate the vertical distribution of ozone from the Umkher observations. Later with the availability of fast computers, this method evolved into a methodology for ozone measurements from satellite remote sensed data.
• The discovery of the biannual oscillation in atmospheric ozone. In recent years the importance of quasibiannual oscillation (QBO) in a variety of atmospheric phenomena including those that involve interaction between atmospheric chemistry and dynamics has become highly topical.

WHILE ozones studies were largely concentrated on the lower regions of the atmosphere—the troposphere and the stratosphere, the night airglow observations at Mt. Abu and Gulmarg, especially the OH and the sodium emissions, enabled a systematic study of the structure and dynamics of the mesosphere. Apart from the seasonal variation of the airglow intensities, the night to night variability and variations during night were used to study the dynamical characteristics of this crucial region of the atmosphere which separates the lower neutral component dominated region, where weather related processes dominate, from the upper region, where ionization phenomena and electromagnetic effects play a dominant role. These observations yielded some very early evidences based on optical observations for the existence of internal gravity waves in the mesosphere.

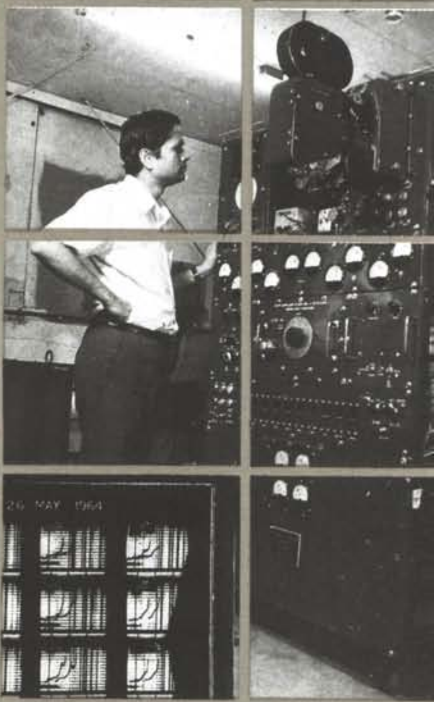
A variety of ground-based radiowave techniques such as low and high frequency radio absorption, cosmic radio noise measurements, ionospheric studies with the ionosonde and measurement of ionization drifts using spaced receiver technique were utilized to study the entire ionosphere, the morphology, variations, and special phenomena such as the response to solar flares, solar eclipses, magnetic storms etc. PRL participated in a major way in the international programme IGY (1958–59) which provided a big boost to ionospheric and geomagnetic studies all over the world, especially in the tropical region.

Radiowaves in the low (LF) to very low frequency (VLF) region (<200 KHz) are reflected by the D–region (60–90 km region) of the ionosphere. Hence monitoring the strength of LF and VLF transmissions from known stations, e.g. 164 KHz signals from Tashkent is very useful to monitor the changes in the characteristics of the D–region of the ionosphere. This region is specially sensitive to direct inputs from the Sun by way of EUV and X-rays. Several interesting results on the effect of solar flares and solar eclipses on the ionosphere have been obtained at PRL during the sixties from such observations. This programme later evolved into the large scale programme of Partial Reflection measurements of the seventies. However the most significant and pioneering result that came from this programme is the discovery of the effect of cosmic X-rays on the ionosphere. X-ray emission's from strong cosmic X-ray sources such as SCO-XI, CEN-XI can influence (specially during night time) the ionization characteristics of the D-region and the PRL work showed that a simple ground-based radiowave measurement can monitor the passage of X-ray stars in the sky.

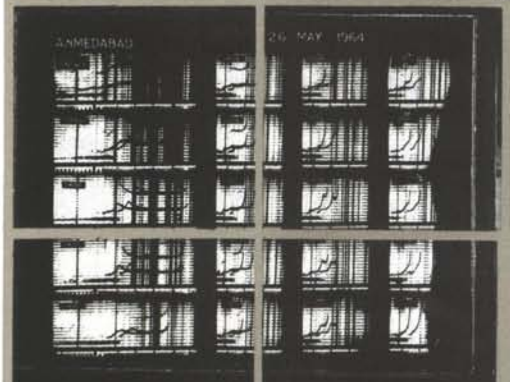
The low latitude ionosphere (E–and F–regions) is dominated by phenomena associated with the equatorial electroject currents. In the E–region there is a systematic electron-current flow in the east-west direction and also

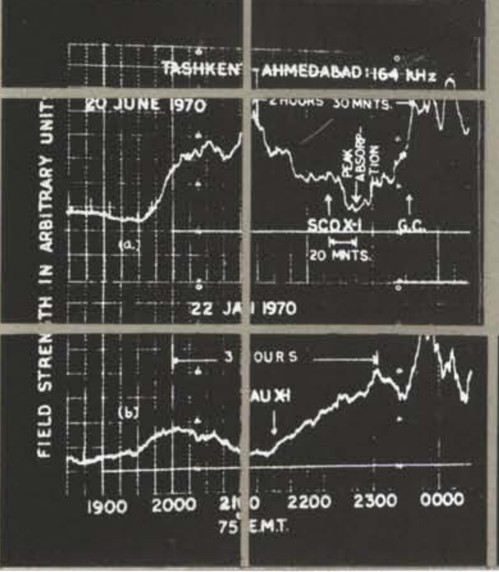


Extinction Photometer used at Mt. Abu to measure the extinction caused by molecular and aerosol constituents of the earth's atmosphere.

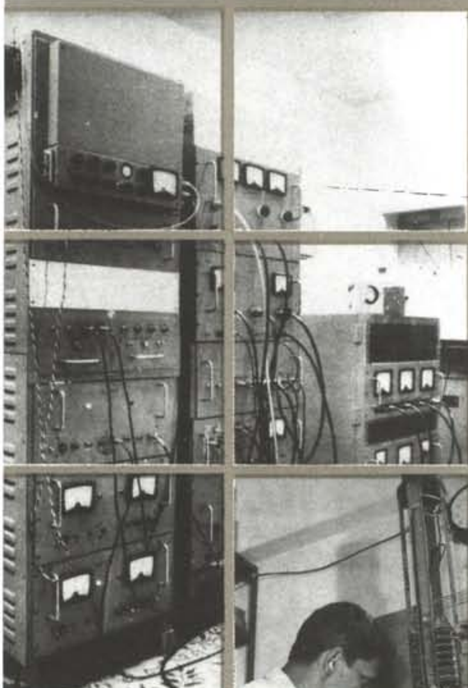


A vertical ionospheric Sounding Radar, type C-4 Ionosonde to record upper regions (E and F) of the ionosphere along with its antenna and typical ionograms.





Cellestial X-ray sources increase absorption in the D-region of the ionosphere. The records show the absorption caused to 164 KHz radio waves by two X-ray sources ScoX-1 and TAU X-1.



The antenna and the transmitter of the earlier model of the VHF back scatter radar at Thumba was developed and established by PRL scientists.

Design and fabrication of rocket-borne payloads were important contributions of PRL scientists towards space research in India.

Integration of rocket payload for the Langmuir Probe and the proton precision magnetometer experiments.

An integrated payload of Langmuir Probe, Resonance Probe and UV detectors along with sensors mounted on the nose cone.

there is the production of electron density irregularities in a wide variety of scale sizes some of which manifest themselves as the Equatorial Sporadic E in the ionospheric records—the ionogram. In the F–region there is the so-called fountain effect due to the vertical uplifting of ionization over the equator. The peculiar configuration of the electric and magnetic fields cause the uplifting of the ionization and later downward diffusion along the field lines to higher latitudes. Investigations conducted by PRL scientists demonstrated unambiguously that the so-called Equatorial (Appleton) Anomaly is controlled by the Earth's magnetic field. Ahmedabad is ideally situated at the crest of the equatorial anomaly and hence ionization over Ahmedabad responds sharply to changes in the parameters of the equatorial electrojet. These early pioneering discoveries at PRL were substantiated by later more extensive work based on satellite data and also led to the development of several programmes based on satellite topside sounders.

WITH the establishment of the Thumba Equatorial Rocket Launching Station (TERLS), PRL scientists not only undertook an extensive rocket programme involving fabrication of rocket payloads at PRL, taking them to Thumba and launching them on different types of rockets (American, French and later Indian made rockets) but also a systematic ground–based ionospheric observational programme. PRL scientists were responsible for setting up of a C4 ionosonde at Thumba and a Space-Receiver Drift Experiment. Also the construction and the initial operation of the more sophisticated VHF backscatter radar that is currently operational at Thumba was due to the efforts of PRL scientists. The early rocket experiments conducted at TERLS were mainly to study the dynamics of the low latitude lower ionosphere, the winds and the shears, height structure of the equatorial electrojet current and the electron density irregularities associated with it. These rocket measurements yielded scientific results of a very pioneering nature.

RADIO ASTRONOMY

RESEARCHES in Radio Astronomy were initiated at the Physical Research Laboratory in 1955 with the application of the techniques of radio science to study physics of the Earth's upper atmosphere. Regular monitoring of the galactic radio noise commenced in 1956 following the developmen of a Cosmic (galactic) Radio Noise monitor in the form of a simple radio telescope. The sudden cosmic noise absorption event associated with the great solar flare of 23 February 1956 was recorded with this equipment. The next important step was taken in 1964 when a Relative Ionospheric Opacity Meter (Riometer) was constructed and installed for measuring ionospheric attenuation at 21.3 MHz.

Solar radio astronomy programmes began in PRL during the early sixties, primarily to study solar flares and associated radiobursts. This led to the development of a very sophisticated instrument, the solar radio spectroscope. Three swept frequency receivers and cathode ray display units were procured from Germany. Three wide-band rhombic antennae, which were equatorially mounted and driven electrically to track the Sun, were indigenously developed. The solar radio spectroscope (40–240 MHz) became fully operational in June 1967. This equipment filled the gap between the far eastern and European stations for a twenty four hour patrol of solar bursts.

New features called "complementary bursts" and other detailed phenomena were discovered which were attributed to short duration bursts of mono-energetic electrons shooting through the solar corona.

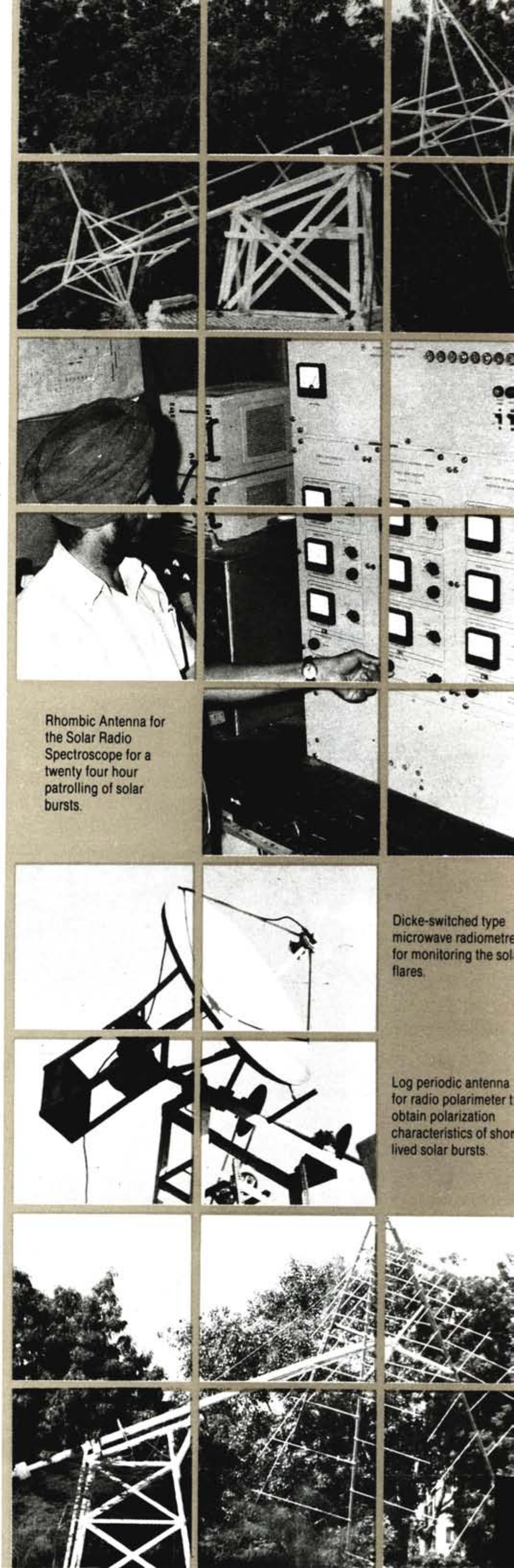
Since September 1970, PRL put in operation a "Dicke-switched type" microwave solar radiometer operating at 2800 MHz for patrolling solar flares. This radiometer was used to measure with good accuracy the quiet Sun component of radiation, the slowly varying component associated with centres of activity on the Sun and the burst component associated with solar flares.

In order to obtain information on polarization characteristics of short-lived solar bursts, a time sharing radio polarimeter operating at 35 MHz was put into operation in 1969. The polarimeter continuously recorded quantities proportional to the Stokes parameters, which define the state of polarization of incoming solar radiation. The aim of this experiment was to measure the depolarization caused by the Faraday dispersion resulting from finite receiver bandwidth. This allowed the measurement of total Faraday rotation suffered by the burst radiation during its passage through the solar corona, interplanetary medium and ionosphere. It was shown that out of a total Faraday rotation of about 1000 radians, only about 100 radians occur in the Earth's ionosphere.

When a very high frequency radio wave from a radio star passes through the ionosphere, it undergoes an irregular refraction owing to the presence of irregularities in the electron density distribution in the Earth's ionosphere. The radio star scintillations thus produced are best studied using two antennae Ryle-type phase-switched radio interferometers. PRL set up two phase-switched interferometers, one at Ahmedabad operating at 60 MHz, and the other at Gulmarg, operating at 74 MHz. Unlike at high and equatorial latitudes, the scintillation activity at Ahmedabad and Gulmarg was found to be relatively moderate. Further at these latitudes both the scintillation index and scintillation rates were more or less independent of the fluctuation of the Earth's magnetic field on a day-to-day basis.

X-RAY ASTRONOMY

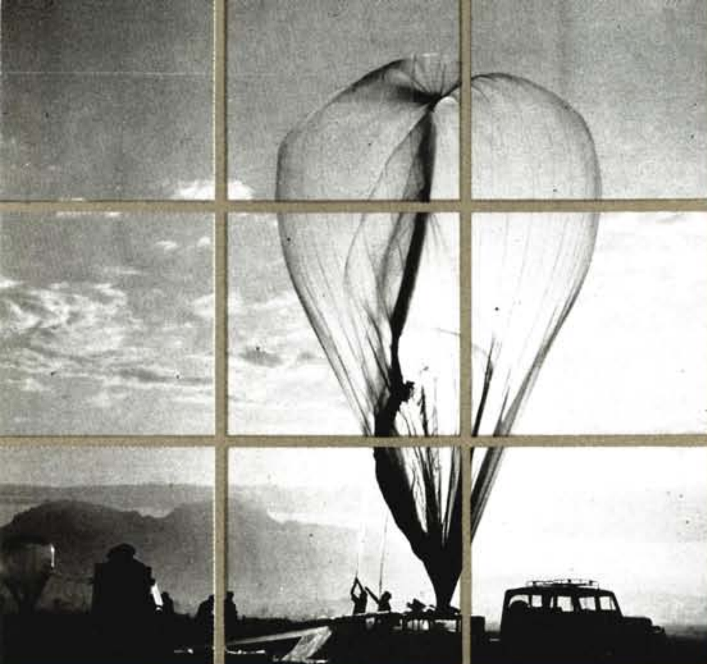
TAKING advantage of the minimal charged particle fluxes at equatorial latitudes due to the high geomagnetic cut-off, balloon experiments from the TIFR balloon launching station at Hyderabad and rocket experiments from Thumba, were started in 1968 for studies of X-ray sources and their emissions. The balloon-borne X-ray astronomy payload has an oriented platform from which the telescope can be made to look in pre-programmed directions. Other technological development includes the fabrication of thin-window proportional counter for the detection of X-rays of low energies (below 1 KeV) and electrons in the energy regime 10 KeV. Stars like CEN-XI and CYG-X1 having spectacular time variations have been studied. The CYG-X1 was observed from two balloon flights over a period of about an year. The data showed softening of the spectrum during flare time. Similarly, detailed analysis of the observations on SCO-X1 showed large temporal variations in its flux and energy. The diffuse background of X-rays, which is apparently isotropic has also been studied and the nature of its spectrum in the region 1-1000 KeV has been established. The results showed that a simple power law could represent the X-ray background in the region 2 KeV–1 MeV.



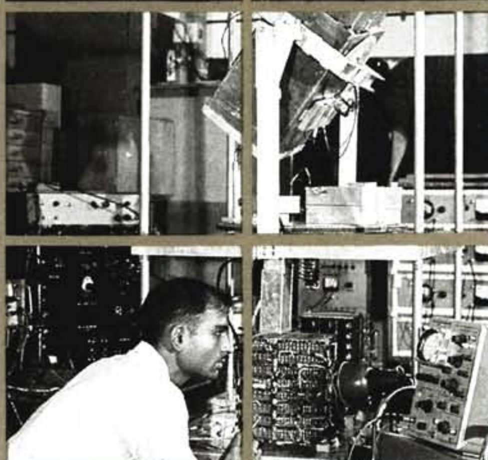
Rhombic Antenna for the Solar Radio Spectroscope for a twenty four hour patrolling of solar bursts.

Dicke-switched type microwave radiometre for monitoring the sol flares.

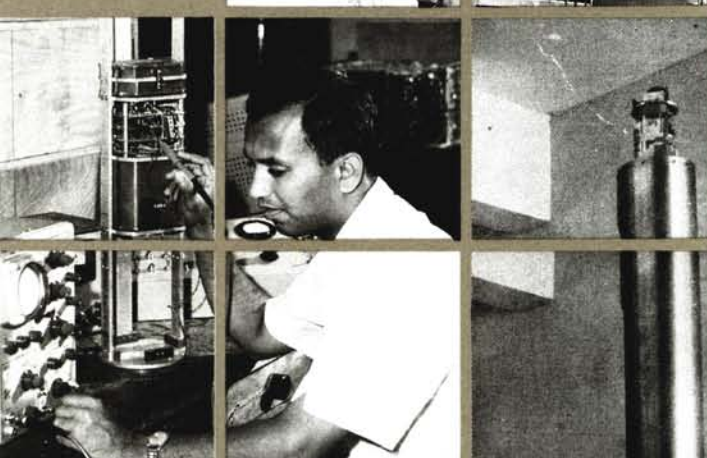
Log periodic antenna for radio polarimeter t obtain polarization characteristics of shor lived solar bursts.

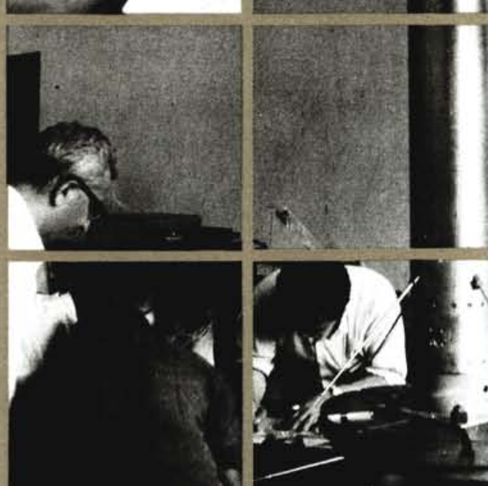


Balloon ready for launch from Balloon Facility, Hyderabad carrying the X-ray telescope.



Integrated testing of the X-ray telescope flown on balloon.





Testing the rocket payload for X-ray astronomy.

X-ray payload (with Japanese collaboration) being mounted on the USSR vibration table.

The X-ray Astronomy Group had designed and fabricated a celestial X-ray experiment package to be flown in the first Indian Satellite Aryabhata. The emphasis of this experiment, was to detect X-rays from various celestial sources and the diffuse X-ray background in energy region 2-100 KeV. Unfortunately the experiment was not successful because of damage to one of the power supplies and malfunction in the telecommand relay.

e. NUCLEAR THEORY

THE nuclear theory group carried out extensive applications of the shell model to:

- Explain and predict many observed features of nuclear states,
- Use it as a tool for exploring and elucidating the nature of the effective nucleon-nucleon forces inside nuclei.

A shell model analysis of the observed spectra of nuclei in d–s and f–p shells showed that the interaction in relative s-states of two nucleons is the dominant component of the total interaction. This information coupled with the use of Hartree-Fock techniques provided a better understanding of the major features, such as deformations and shapes, in d–s shell nuclei.

Simple physical considerations were used to analyse the nuclear interactions and the coupling schemes in nuclei. The famous Kuo-Brown interaction was shown to preserve SU_4 symmetry but to break the SU_3 symmetry for two particles in d–s shell, and the dominance of the SU_3 symmetry in the first half d–s shell and lack of it in f–p shell are shown to arise from the nature of the single-particle orbits and spin-orbit interaction. The powerful techniques of spectral distribution methods were utilized to examine systematically various group symmetries of nuclear wave-functions.

Detailed analysis of the collective modes of excitations in nuclei and their origin in microscopic theories of nuclei has been another fruitful activity of this group. One of the first applications of the unified model (which combines single-particle dynamics and collective vibrations) to light nuclei in d–s shell was carried out to explain the spectra and electromagnetic transitions in silicon and phosphorus isotopes. The range of self-consistent-field methods (HF and HFB), was extended to study the collective properties of nuclei. As an example, the first collective model calculation for Ne^{24} was done, including, besides the lowest HF configuration, several particle-hole excited configurations and shape-mixing. The calculations agreed well with the observed spectra. Several additional states and electromagnetic properties were predicted.

The generator coordinate method was successfully used to obtain states in Ne^{20} upto an excitation energy of about 18 MeV. This was the first realistic practical demonstration of the method.

The alpha-cluster model for light even-even $N = Z$ nuclei was studied and the role of the effective interaction (density-dependence, repulsion in odd states) in producing clustering was clearly demonstrated.

In the next few chapters the research activities of the laboratory carried out during the subsequent couple of decades are described.

NEXT

XV

YEARS

1.1 Stellar systems like our own solar system are born out of collapse and fragmentation of a dark molecular cloud - perhaps triggered by a shock from a supernova. Towards the end of its life a star may evolve as a red giant, eject a planetary nebula and end up as a white dwarf, or terminate its life in a spectacular explosion - the supernova. The evolutionary history of star critically depends on its initial mass

Go Back

ASTRONOMY AND ASTROPHYSICS

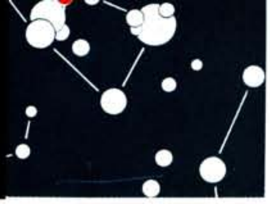
ग्रहर्क्षताराचक्रस्थः परमाण्वादिना जगत् ।
संवत्सरावसानेन पर्येत्यनिमिषो विभुः ॥१३॥

Influential stars, planets, luminaries and atoms all over the universe are rotating in their respective orbits under the direction of the Supreme, represented by eternal time.
—Srimad Bhagwatam 3:11:13

The planet Earth, the only life supporting planet we know of, is just a small member of the solar system that has the Sun as the central body with nine planets, their satellites and many other smaller objects like asteroids and comets revolving around the Sun. The Sun is an ordinary star among the billions of stars in our galaxy (Milky Way) which in turn is one of the billions of galaxies in the cosmos. The quest for a philosophical as well as scientific understanding of the origin and the evolution of the Sun and the planets, and what lies beyond—stars and galaxies—has been continuing ever since the dawn of human civilization. Modern scientific developments, both technological and conceptual, have accelerated the pace and the quest continues.

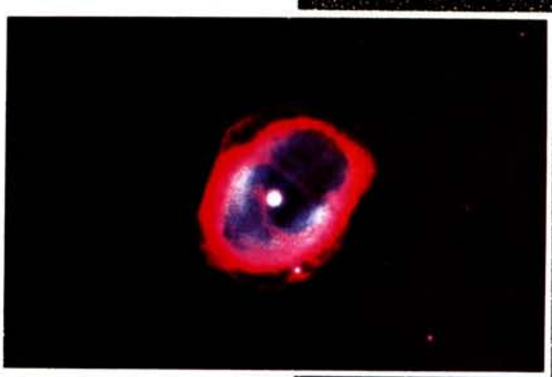
There is now a firm scientific basis for accepting that the Sun and the solar system objects formed from a molecular gas and dust cloud about four and a half billion years ago. Processes involving evaporation and condensation of solids, formation of grains and their aggregation to form small objects followed by accretion of these small objects led to the formation of a large number of planetesimals (kilometre to hundred kilometre-sized objects) during the first few million years of the evolution of the solar system (Fig. 1.1). These planetesimals have finally evolved into the present day objects—the planets, satellites, asteroids and comets. The theory of formation and evolution of Sun-like stars also tells us that the early Sun should have been very different from what it is now. It must have been more active, ejecting more intense energetic radiations and charged particles than it does now. It is natural to look for clues which provide information on the young Sun and the conditions in the solar system that must have been prevailing during that time. It is also equally important to understand the processes operating in the near surface regions of the contemporary Sun that results in the outpouring of energetic radiations and particles that fill the entire interplanetary space.

Within the solar system our Earth is unique; it has the right type of atmosphere and other conditions to evolve and sustain advanced forms of life. However, the Earth's atmosphere was not always as we know it to be now. The primitive atmosphere of the Earth must have been quite different—devoid of oxygen but rich in hydrogen, methane, ammonia, and carbonmonoxide, the type of gases that constitute the gaseous clouds whose collapse led to the formation of the solar system. One may wonder what processes led to the present atmosphere on the Earth and why there are different types of atmospheres on other planets.



Scientists at PRL are engaged in the fascinating game of unfolding the mysteries of the Universe.

What exactly are the pathways that lead to formation, evolution and eventual death of stars ? Even today there are no complete answers to these fundamental questions though there are numerous theoretical conjectures.



Energetic particles emitted from the Sun and from other stellar sources cause nuclear reactions that leave fossil records in the solar system solids. Such records, le in the form of stable and radioactive nuclei (and their decay products), are scattered over the entire solar system—i planetary, lunar and meteorite samples. These records together with the large amount of information collected by modern scientific techniques, enable us to solve the mystery of creation and evolution of the solar system.

Similar to the creation of our Sun 4.6 billion years ago, some stars are being created even today in large molecular clouds that exist in the space between the stars. With time, the stars evolve and die when their nuclear fuel (mainly hydrogen) gets exhausted. But even the old stars are fascinating. They become cooler, redder, but bloat up some thousand times in size, a stage during which they are called super giants. Some of them then eject their outer envelopes to form tenuous objects called planetary nebulae. Some others even end their lives with a stupendous explosion, brilliantly shining as supernova for a brief period of a few months. Some massive stars have an even more interesting end to their lives, they turn into strange entities called "black holes" and vanish from sight!

Astronomers with sophisticated observing equipments, new space probes, and with the help of basic laws of physics endeavour to understand these processes of creation and destruction going on in the cosmos. Scientists at the Physical Research Laboratory are engaged in this fascinating game of unfolding the mysteries of the Universe—a glimpse of which follows.

THE STARS AND BEYOND

INFRA - RED ASTRONOMY

Far, far away in the vastness and void of interstellar space begins the fascinating story of the birth, evolution and eventual demise of stars. Drawn inexorably by the weak but persistent force of gravitation, perhaps triggered by a propagating shock wave, the thinly spread out gas and dust particles begin to collapse. The accumulating mass composed mainly of molecules of hydrogen, grows denser by self-contraction due to gravity, and, hotter by converting the gravitational energy of infalling matter into heat. A time comes when the density and temperature at the centre of this mass become sufficiently high to squeeze together hydrogen nuclei and liberate the energy of fusion as heat and light. The nuclear furnace is lit—a star is born.

Is this scenario correct? Have all the stars we see in the night sky gone through such birth pangs? What happens in regions where stars form in groups? What happens to the material surrounding the stars? There are many unanswered questions regarding the birth of stars. Equally many are the queries about a star's subsequent evolution when the hydrogen and other fuels in its core are exhausted and it enters a zone of instability. How do stars die and return the material to the interstellar medium from which they have emerged? What exactly are the pathways that lead to formation, evolution and eventual death of stars? Even today there are no complete answers to these fundamental questions though there are numerous theoretical conjectures.

One of the ways of choosing among the many theoretical possibilities on the birth and death of stars is to observe stellar emission in the infra-red part of the electromagnetic spectrum, which bridges the gap between the visible radiation and the radio waves. The infra-red radiation has a longer wavelength compared to visible light and hence is able to penetrate more easily through regions of interstellar gas and dust, which are the breeding grounds of stars. Following developments in solid state technology in the mid 1960's sensitive detectors of infra-red radiation became available and the new field of Infra-red Astronomy came into being. At PRL, scientists are actively engaged in seeking answers to several of the questions posed on the birth, life and death of stars.

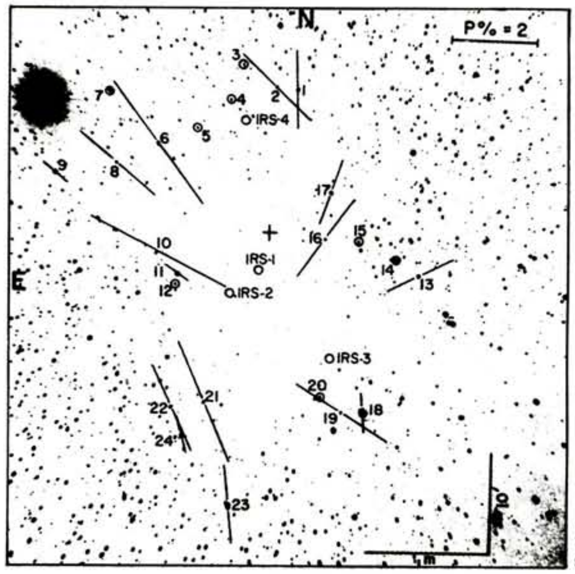
Observations made by telescopes play a key role in deciding between different lines of theoretical inquiry. They also provide at times new insights which can lead to a better understanding of the problem; sometimes such observations uncover entirely new phenomena. Progress in astronomy today generally involves the use of very sophisticated instruments attached to large telescopes. In the first decade of its existence, the astronomy area at PRL has been in the forefront of developing such instrumentation in the country—both in the optical and infra-red spectral regions. These include, among others, Infra-red Spectrophotometer, Fabry-Perot Spectrometer and Optical Polarimeter.

The infra-red spectrophotometer detects energy coming from stars in certain wavelength bands between 1 and 5 microns. The distribution of energy in these bands alongwith some additional information about the star's spectrum in visible light can tell us if the star is embedded within a dusty environment which is at a somewhat cooler temperature, in comparison with stellar surface.

Spectral lines are among the most important tools in an astrophysicist's kit for remote sensing an astrophysical environment. They provide information about the temperature of the source, the state of the different elements residing there, their abundances and also on how rapidly the source is approaching or receding from us. In a sense spectral lines are

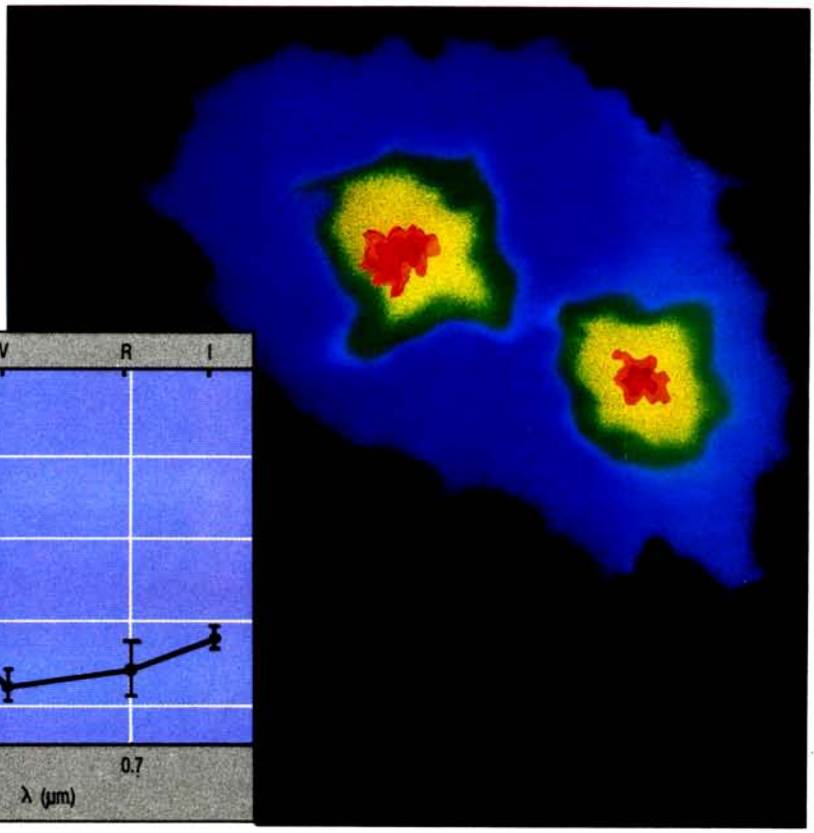
▼ **1.2** The PRL High-Resolution Fabry-Perot Spectrometer (FPS) coupled to the 1 metre reflecting telescope at Kavalur. The FPS utilizes piezo-scanned servo-controlled etalons and can resolve spectral features separated by 12 hundreths of an angstrom unit. The FPS is being used to obtain kinematic information on extended objects like Planetary Nebulae and some stars surrounded by emission nebulosities like R Aquarii. The operation of the FPS, the acquisition, the storage and the on-line display of the data on spectral line profile are all managed by a personal computer.

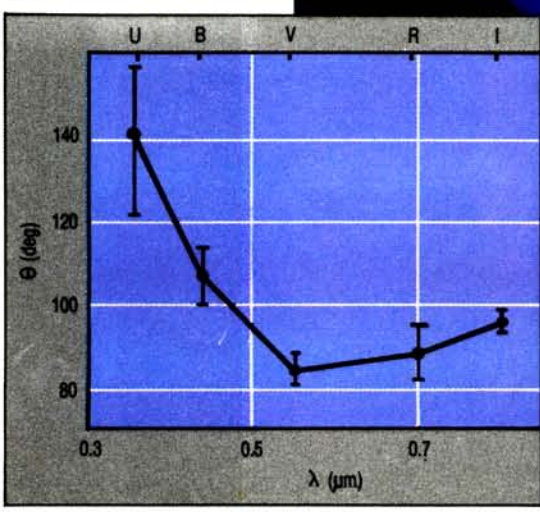
▶ **1.3** The polarimeter with 1 metre telescope at Nainital. The polarimeter is controlled by a computer which also has a data acquisition system and gives on-line processed results with error analysis. The measurements can be done upto an accuracy of 0.03%.



◀ **1.4** Polarization vectors of stars in the region of the globule B-5 are shown. Four infrared sources as detected by the IRAS satellite are also shown. It has been found that the bulk of the cloud is supported against gravity by stellar wind from the IR sources. The polarization vectors are indicative of the magnetic field geometry, which is estimated to be around 100 micro Gauss. The results also indicate that the dustgrains in B-5 are larger than the interstellar grain size.

▼ **1.5** The polarization angle (Θ), for a highly polarized quasar 4C 2945, shows a bimodal distribution with the wavelength. Usually such a large change in Θ and also a bimodal distribution are not observed. The most plausible model seems to be a two-component synchrotron model, for this object. The figure shows artistic view of this object with the observed bimodal distribution in polarization angle.





In the first decade of its existence, the astronomy area at PRL has been in the forefront of developing instrumentation in the country — both in the optical and infra-red spectral regions.

tracers of the conditions prevailing in a region. The Fabry-Perot Interferometer (Fig. 1.2) can be used for a detailed study of isolated spectral lines emitted in the visible region. From such studies, the conditions of the line emitting region, namely its temperature and the prevailing gas motions are determined.

Like other electromagnetic waves, optical radiation also consists of waves transverse to the direction of propagation, and hence can be polarized (when oscillations of the electric field vector are in a preferred direction in the transverse plane, the wave is said to be polarized). Although thermal emission (e.g. from a normal star) is unpolarized, interaction of this light with interstellar grains, aligned under the influence of interstellar magnetic fields, can render it partially polarized. Similarly, special mechanisms like synchrotron emission from fast moving electrons in a magnetic field can also produce polarized light.

Observing polarization of radiation from astronomical objects can be a valuable source of information on the nature of interstellar grains, prevailing magnetic fields, synchrotron radiation and/or physical conditions of emitting regions. PRL scientists have built a very sensitive polarimeter (Fig. 1.3) to measure the degree of polarization of star light in optical region and are engaged at present in building another polarimeter for extending this study to the infra-red region. Observations made at Kavalur and Nainital observatories, with the optical polarimeter of PRL, provided interesting new results (Fig. 1.4) on objects like Bok globules (dense molecular cloud that could be a site of star formation), active galactic nuclei (galaxies with extremely energetic central region or nuclei) and supernova, SN-1987. From polarization studies it is concluded that some active galactic nuclei have multicomponent energy source (Fig. 1.5).

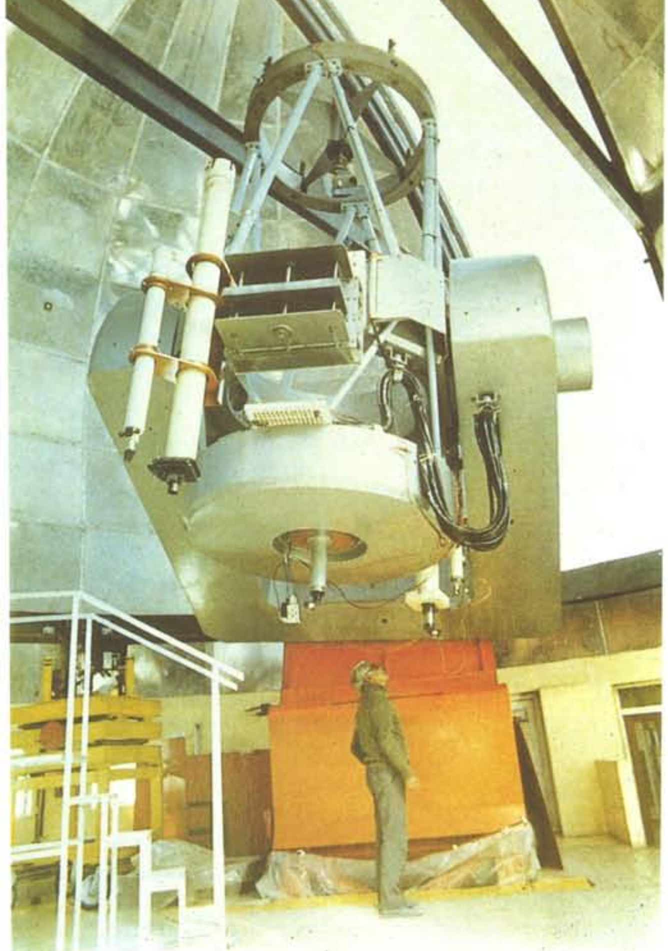
Around 1974, PRL decided to build a special telescope for astronomical observations. Many years of sustained efforts went into the complex tasks of site selection, construction of the observatory building, design, fabrication and installation of the telescope and its various subsystems. The telescope mirror has a diameter of 1.2 metre which makes it more than 20,000 times as powerful as the human eye. This telescope is different from other telescopes in the country: it has a special device called the vibrating secondary mirror which permits the efficient detection of infra-red radiation from celestial sources, by subtracting out the large background noise.

The telescope is located at an altitude of about 1.7 km above mean sea level on the mountain top of Gurushikhar (Mt. Abu) about 240 kms from Ahmedabad (Fig. 1.6). Located on a mountain peak in the semi-arid-region of South Rajasthan, the telescope site is expected to provide a large number of clear nights with good transmission in the infra-red region for astronomical observations.

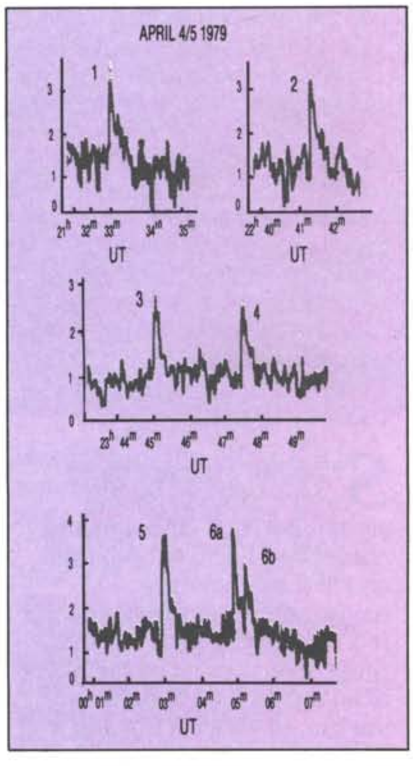
While PRL's own infra-red telescope was being built at Mt. Abu, the astronomical instruments developed at PRL were used with the existing one metre telescopes of the Uttar Pradesh Observatory, Nainital and the Vainu Bappu Observatory, Kavalur. Notwithstanding the limited observing time available at these busy telescopes, several important scientific results have emerged from these observations. Some of these observations have been made in collaboration with scientists from these observatories.

An early observation made by the Infra-red Astronomy group of PRL, that created a world wide interest, was that of infra-red bursts from a peculiar galactic X-ray source known as Rapid Burster MXB [1730–335]. This was the first observation of its kind. Amongst galactic X-ray sources, X-ray burst sources form an interesting class. It is generally believed that in low mass binary star systems in which one of the stars has evolved to become a compact neutron star, mass accretion on it from the companion star causes thermonuclear flashes on its surface giving rise to X-ray bursts. Rapid Burster is unique amongst X-ray burst sources in that, in addition to the X-ray bursts of the usual type it produces episodically a succession of rapid bursts—several thousands in a day separated by a few seconds during its burst active phase. These are believed to be powered by the gravitational energy released from the accreted matter. During April 1979 scientists from PRL and the Tata Institute of Fundamental Research, Bombay, jointly reported several infra-red bursts from this source (Fig. 1.7). Subsequently, in September 1979, observers from Imperial College, London, also reported similar bursts. Theoretical implications of these observations were so important that during 1979–80 a world wide effort was organized to simultaneously observe this source in X-rays, infra-red and radio waves. Infra-red bursts were not observed during the X-ray active phase of the Rapid Burster probably due to the peculiar nature of the source. These results make the nature of the infra-red bursts from the Rapid Burster a mystery.

During late stages of evolution, after the core hydrogen and helium fuel is exhausted, an intermediate mass star (2–9 solar mass) evolves into a giant star,



▲1.6 1.2 metre aperture telescope for infra-red astronomy established at Gurushikhar peak, Mount Abu (Rajasthan).



◀ 1.7 PRL scientists discovered bursts in the infra-red emission at 1.65 microns from an X-ray burster called Rapid Burster 1730-335.

An early observation made by PRL, that created a world wide interest, was that of infra-red bursts from a peculiar galactic X-ray source known as Rapid Burster.

Planetary nebulae exhibit a variety of shapes. What causes the bipolar flows ? What forces control the dynamics of these nebulae ? These are some of the questions to which PRL scientists are seeking answers.

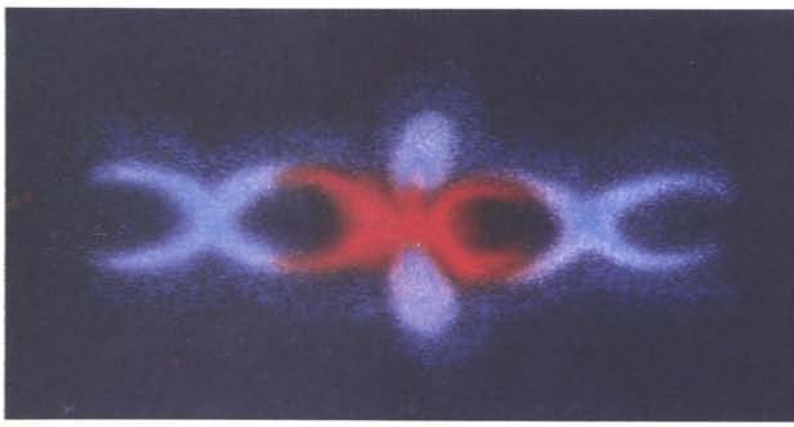
increasing in size a few hundred times. At a certain epoch during this stage, instabilities start, and the giant star loses its outer hydrogen rich envelope, which gets detached from the central core. The central core contracts and eventually evolves into a very highly dense star, called white dwarf while the surrounding shell expands. This shell of gas is excited by the energetic radiations of the hot core and shines as a spectacular nebula from which a large number of spectral lines are emitted. These objects are called the planetary nebulae (Fig. 1.8). These planetary nebulae exhibit a variety of shapes like butterfly (bipolar), ellipsoidal, multiple shells and toroids. How are these shells detached from the star and what causes the bipolar flows? What forces control the dynamics of these nebulae? Is the shell ejection phenomenon a singular event or episodic? These are some of the questions to which PRL scientists are seeking answers. These studies are being carried out using a high resolution Fabry-Perot spectrometer which measures the line profiles and the velocities of gases in the expanding shells of the planetary nebulae by observing Doppler shifts of emission lines. The study has resulted in a number of important new results like the observation of bipolar flows with a separation velocity of 110 km/sec in the compact nebula NGC 6153 (Fig. 1.9), and the double shell structure in the nebula IC 4593 implying that shell ejection could be episodic.

Some galaxies have very energetic central parts. They emit a thousand times more energy than the Milky Way. In one of these objects, called OJ287, PRL scientists have recorded rapid polarization bursts.

Symbiotic stars are those which exhibit spectral signatures (rich emission and absorption lines) of both high and low temperature environments at the same time. It is now firmly believed that, these objects must be members of an unresolved close binary system, in which a hot and a cool star go round each other.

◀ **1.8** The spectacular carcass of an intermediate-mass star or a Planetary Nebula (PN): The Helix nebula (NGC 7293) in the constellation Aquarius (Exploring the southern sky — an Atlas of European Southern Observatory). The progenitor star from which the expanding nebulosity was ejected may be seen at the centre as a tiny bright spot. The somewhat complex structure of the nebula suggests that the ejection of PN may not after all be a simple isotropic process.

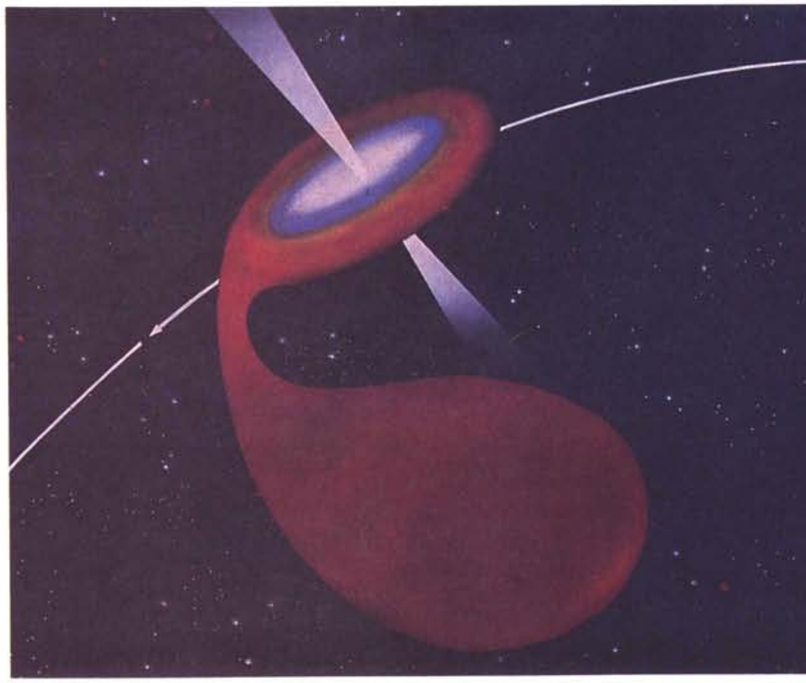
▲ **1.9** The Planetary Nebula NGC 6153 showing two prominent bright ansae-like features flanking the spot like central star (Pottasch et al., Astro.Astrophys., 155, 397, 1986). PRL's spectroscopic observations of this object have revealed that these features in fact represent a bipolar flow at a velocity of about 110 km/s with respect to each other.



▼ **1.10** R Aquarii is one of the most peculiar variable stars known to us. This drawing by Rob Hess portrays prominent features of R Aquarii (James B. Kaler, Sky & Telescope, Aug. 1982 p. 141-143). Most of the nebular emission comes from a dense inner core with a diameter of less than one arc second. The nebula is generally red and the blue shading shows the increasing strength of the low-excitation line of ionized oxygen in the near ultraviolet with increasing distance from the star.

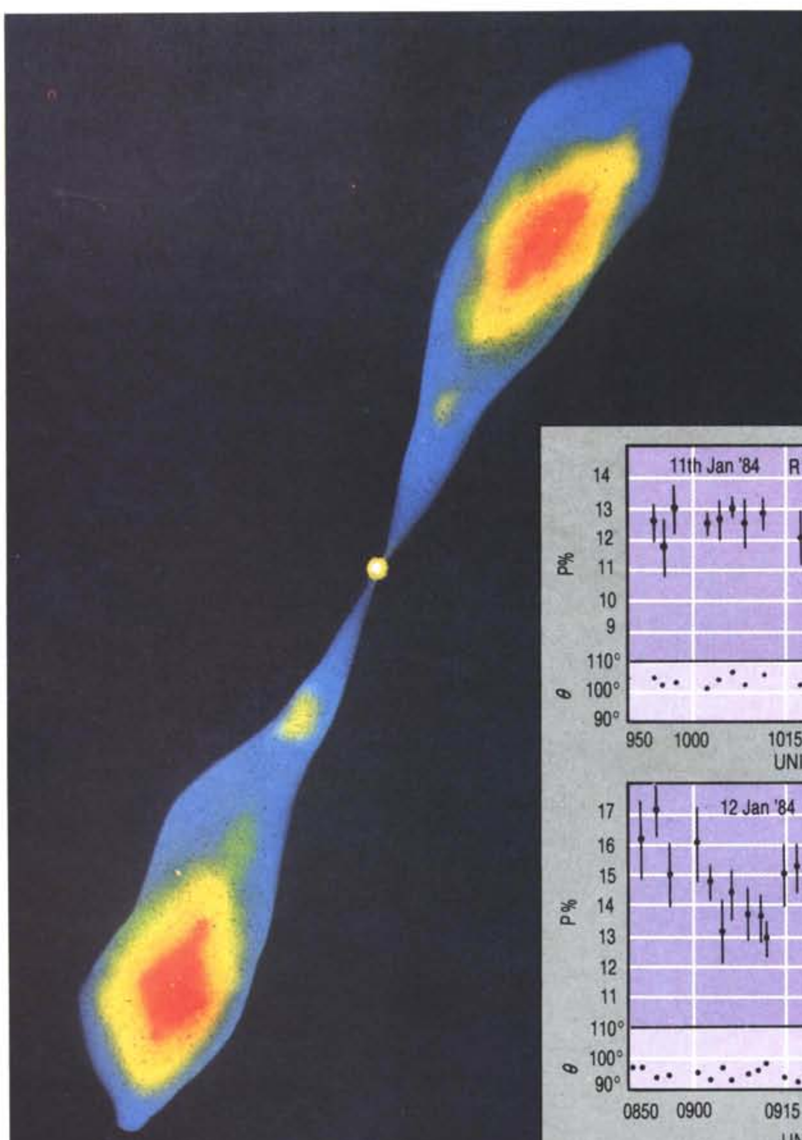
Interesting episodes of mass transfer from one star to another can occur under such a situation, entirely changing the course of evolution that an isolated star of similar mass would experience otherwise.

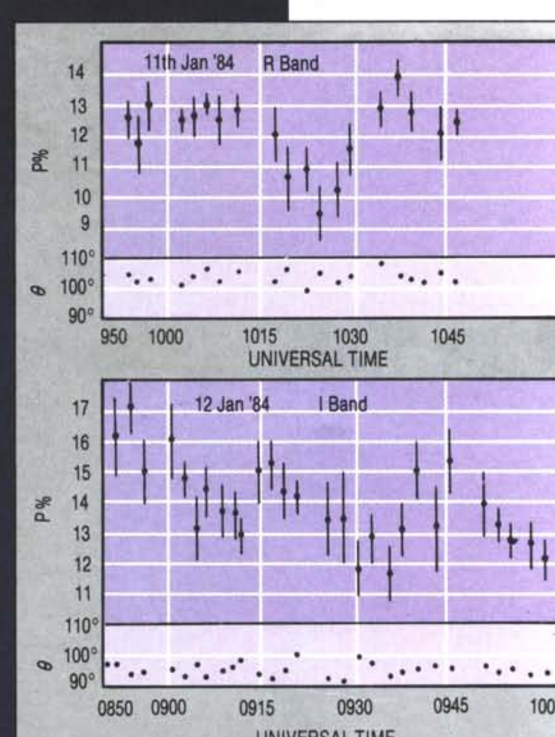
One such system that has received special attention from PRL scientists is the R Aquarii. This system is unique among the symbiotic stars in that it has variabilities in its light emission which are difficult to comprehend (Fig. 1.10). High resolution observations of this system have revealed shells of matter expanding with a velocity of about 15 km/sec (Fig. 1.11) from the central source (a cooler star). Measurements of linear polarization support the idea that a precessing jet of matter exists between the two components.



◀ **1.11** A model of R Aquarii with a white dwarf (W) going around a Mira variable (MV). The white dwarf, probably, has a jet system which may be precessing. Most of the peculiar properties of R Aquarii can be explained by the above model. Polarization observations are being made to determine the period of the jet precession.

Apart from studying problems connected with stellar evolution and peculiar stellar systems in our galaxy PRL scientists have also ventured into the larger realm of extra-galactic research. Our own galaxy, the Milky Way is only a small speck among the multitudes of other galaxies in our Universe. There are some galaxies which have very energetic central parts or nuclei and can be seen at very large distances. In fact, these galaxies are the celestial beacons which define the limits of our Universe. The galaxies with active galactic nuclei (AGN) comprise of several types—Quasars, BL Lac objects, Seyferts. They emit typically a thousand times more energy than what is emitted by an ordinary galaxy like the Milky Way. However the cause of this immense energy output is still only vaguely understood. Some of them, namely BL Lac objects, show a high degree of polarization and their light output is found to vary with time. In one of these objects, called OJ 287, PRL scientists have recorded rapid polarization bursts (variability of the degree of polarization on a time scale of minutes (Fig. 1.12)). This behaviour could be due to the source behaving like a celestial light house beacon which channelizes the optical energy output in specific directions. Another possible explanation is that the source may have a very compact central region which can rapidly accrete matter from the surrounding.





▼ **1.12** Discovery of polarization bursts (25 min. duration) in a BL Lac object OJ 287 was made by PRL. The burst period of 25 min is the shortest reported so far. Subsequent to this,two independent groups, one in optical and the other in radio, have confirmed the period of 25 min. With this we conclude that if the radiation observed is due to synchrotron mechanism, then there must be a high degree of relativistic beaming in OJ 287. On the other hand if inverse Crompton effects are invoked, OJ 287 must have a very compact central source, probably a blackhole accretion-disk system. The figure shows artistic view of OJ 287 with its bursts in polarization.

The proximity of the Sun gives us an excellent "close-up" view of a star. Using a moderate telescope it is possible to see various layers of the solar atmosphere where hot gases (or plasmas) interact with magnetic fields.

THE SUN

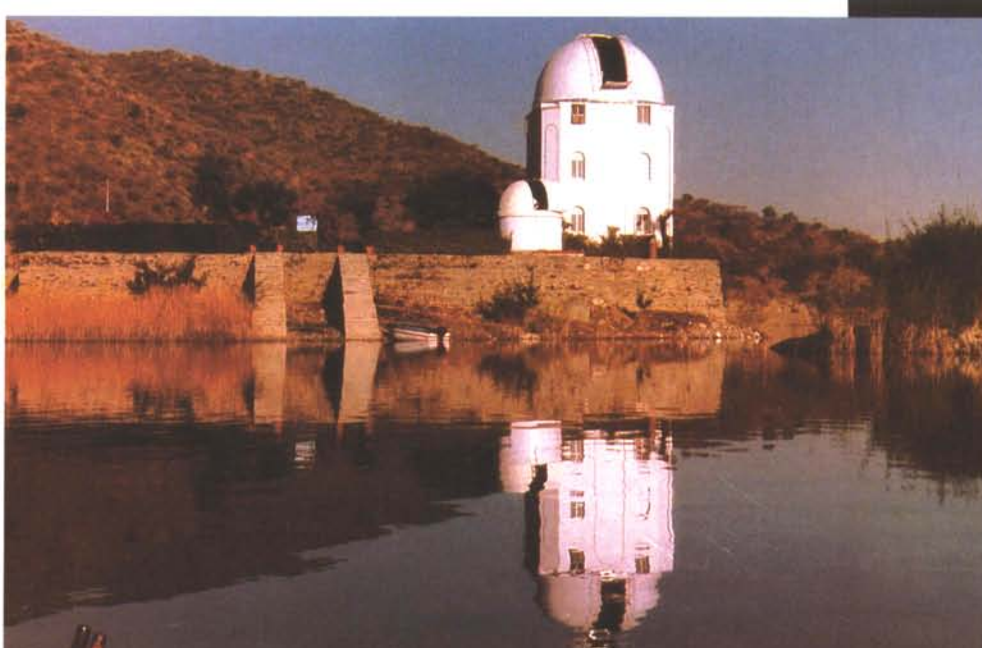
OPTICAL AND RADIO ASTRONOMY

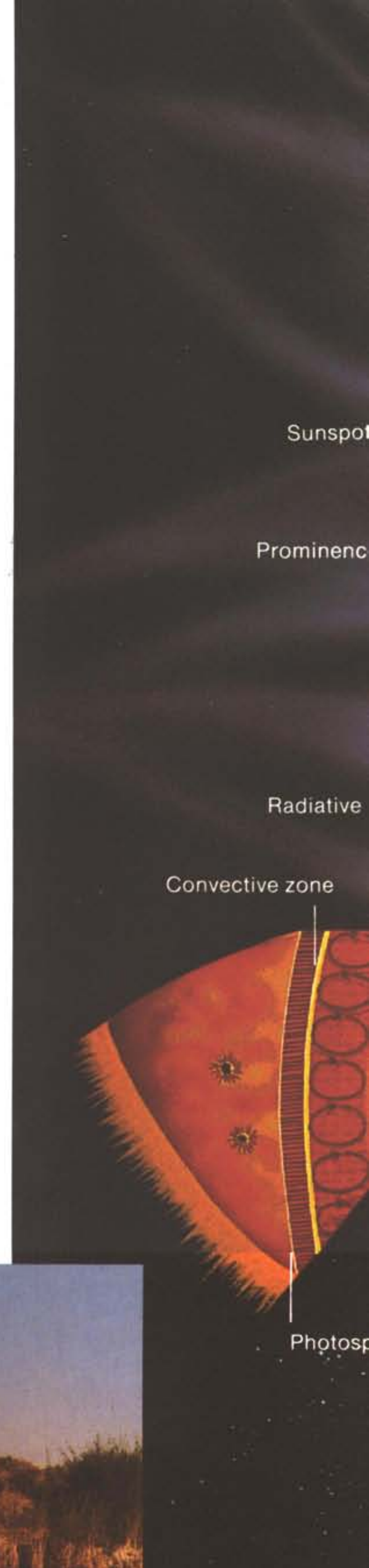
The Sun is an object of great beauty and fascination that has been studied with interest for thousands of years. Our Sun is just 8.5 light-minutes away (one light minute is the distance travelled by light in one minute i.e. 18,000,000 kilometres). The next nearest star, Proxima Centauri is about four light-years away. The proximity of the Sun gives us an excellent "close-up" view of a star.

The Sun is a hot, gaseous globe, about 108 times the diameter and 330,000 times the mass of the Earth. The visible disk of the Sun is known as photosphere, which is at a temperature of about 5500°C. Above the photosphere comes the chromosphere. The temperature of the Sun rises to 15 million degrees at the centre, nearly 700,000 km below the surface. The energy generated at the central core is transferred by radiation and then by convection to the outer layers (Fig. 1.13). The convection currents give rise to the observed rippling structure to the solar surface, generate magnetic field and cause many spectacular solar activities, including the well known sunspots, solar flares and mass ejections. Using a moderate telescope it is possible to see various layers of the solar atmosphere where hot gases (or plasmas) interact with magnetic fields. New observational techniques in optical, X-ray, ultra-violet and radio regimes of the spectrum are extending our knowledge about solar structure and dynamics.

For making high resolution solar observations a modern solar observatory was established on a small island in Fatehsagar Lake at Udaipur (Fig. 1.14) with funds received from the Vedhshala Trust, Ahmedabad, the Department of Science and Technology and the

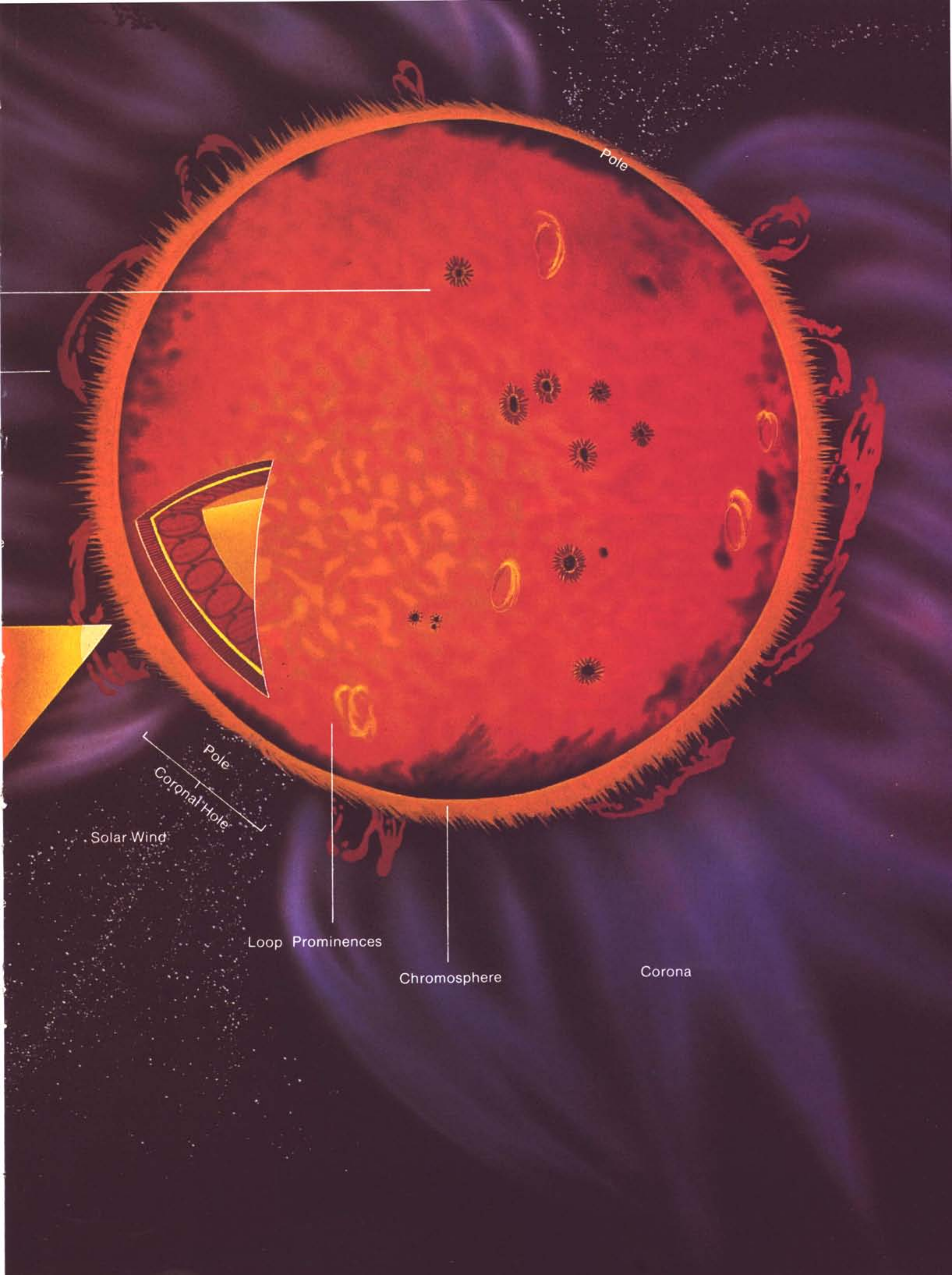
For making solar observations a modern solar observatory was established on a small island in Fatehsagar Lake at Udaipur.





▶ **1.13** A three-dimensional section showing internal structure of the Sun. Also shown are the outer layers, i.e., photosphere, chromosphere and the corona alongwith various features associated with them.

◀ **1.14** The island solar observatory at Udaipur.

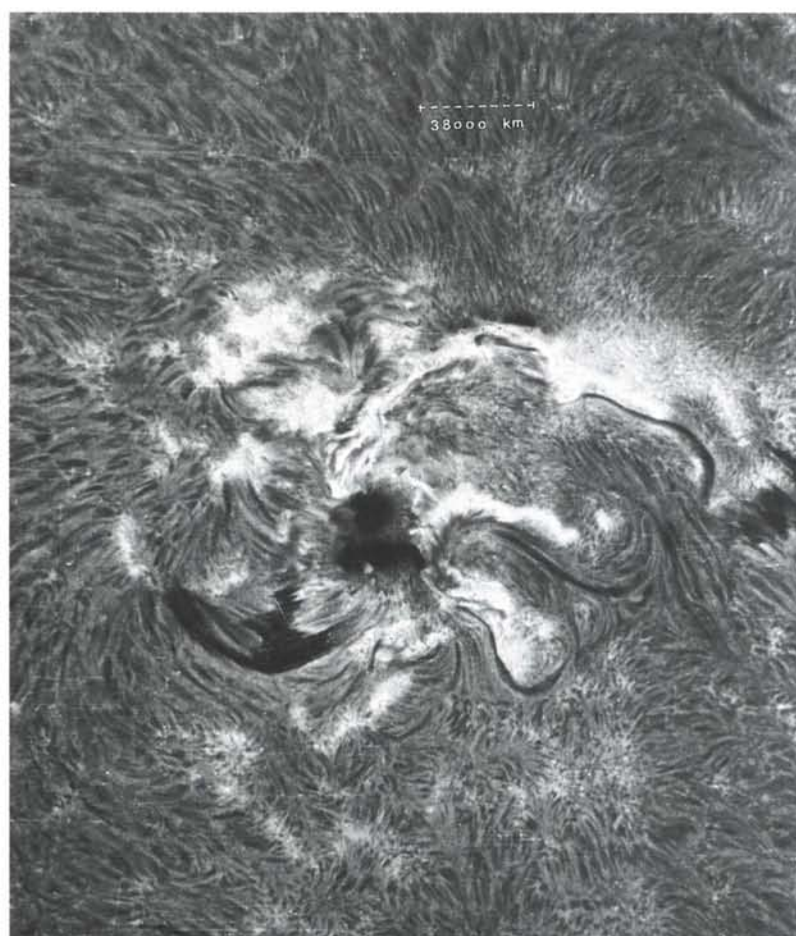

Pole
Pole
Coronal Hole
Solar Wind
Loop Prominences
Chromosphere
Corona

Department of Space.

The ultimate capability of large telescopes to see details of astronomical objects—such as on the solar surface—is limited by turbulence in the Earth's atmosphere. Placing the observatory in the middle of a lake reduces convection currents around the telescope, produced by heating of the ground and the telescope itself. Added advantages of the site are the low rainfall and cloud coverage. This makes the Sun accessible for long uninterrupted periods of time making it possible to monitor long term solar phenomena.

◀ **1.15 (a)** The 12 feet spar telescope used at USO for high resolution observations of solar chromosphere.

▼ **1.15 (b)** Fine features around a typical solar active region.



Since its formation, USO has been engaged in research pertaining to solar photospheric and chromospheric activities. The main instrument at the Udaipur Solar Observatory is a 12-foot spar telescope with a 25 centimetre aperture lens for high resolution, small field studies of the solar chromosphere (Fig. 1.15). Facilities are also available to divert the light beam to several instruments for the simultaneous study of different aspects of a given solar event. For white light (or photospheric) solar observations and to obtain Sun images on real time basis additional telescopes are available at USO (Fig. 1.16). Scientists here study various activities occurring on the solar chromosphere on spatial scale sizes of around 700 km (close to the theoretical limit of seeing from a ground-based observatory) (Fig. 1.17).

Several energetic phenomena occur on the Sun. The most spectacular are the explosive release of large amount of energy from small regions. Scientists at USO have made large number of observations to understand the phenomenon of flares.

Several energetic phenomena occur on the Sun. The most spectacular among them are the explosive releases of large amount of energy from small localized regions on the Sun—the solar flares. The energy output from typical flares may be equivalent to a billion hydrogen bombs exploding simultaneously. They produce intense radiation over the entire electromagnetic spectrum from gamma-rays to radio waves and also high speed atomic particles which fill the interplanetary space. Sometimes, large gaseous filaments—huge cool clouds of hydrogen suspended over the solar chromosphere start rising up in fountain-like jets with velocities exceeding the escape velocity on the Sun, i.e. 700 km/sec (Figs. 1.18, 1.19). These energetic events create interplanetary disturbances, cause radio interferences, magnetic storms and aurorae.

Solar flares occur in various sizes, shapes and energy contents. It is observed from high resolution pictures of flares that they consist of several bright patches, called 'kernels' or 'knots'. Scientists at USO have made large number of observations to understand the phenomenon of flares. These are usually divided into two broad classes—two-ribbon and normal flares. It is revealed from a statistical study of these two types of flares that the two-ribbon flares are 2–4 times more energetic and better associated with microwave, X-ray and radio bursts. It is also found that compact kernels are closely associated with these emissions, thereby implying that they are more energetic parts of the main flare. From our studies, we have developed a methodology for predicting when an H-alpha flare will be a proton or a cosmic ray flare. This methodology is useful for particle detection experiments and to predict geomagnetic storms.

To understand the energy build-up in solar active regions, before its release as flares, a study was made on the relative motion of sunspots of an intensely flaring solar active region. As the sunspots are foot-points of the magnetic structures, their relative motions stretch or shear the magnetic structures, which lead to energy storage in the active region. It is found that huge amount of magnetic energy, 10^{32} ergs/day can be stored in the active region due to the observed sunspot motions of a few hundred metres/sec. A part of the stored energy can be released subsequently in the form of flares when triggered by changes in magnetic field (magnetohydrodynamic instabilities). It is also found that more extensive and energetic flares occurred during the period of large sunspot motions, while flares of lesser magnitude ensued when the motions ceased.

Mass ejections from the solar surface are other interesting events. These contain relatively smaller energies (compared to major flares) and are usually associated with flares. These events occur as surges, sprays, and filament eruptions, named according to their visual characteristics. These eruptive phenomena are in fact the source of interplanetary disturbances and cause radio 'scintillations' of compact astronomical objects like quasars and pulsars. It is found that magnetic fields associated with surges range from 35 to 70 Gauss, while in sprays or eruptive filaments, they are larger. It is also possible to estimate magnetic fields in the corona using chromospheric observations of eruptive filaments and simultaneous radio emissions.

▲ **1.16** Razdow telescope for full disk solar observations and solar flare patrol.

▲ **1.17** A full disk chromospheric image of the Sun showing sunspots, dark ribbon-like features called filaments and the bright plages.

▲ **1.18** An artist's impression of various chromospheric features and energetic activities.

▼ **1.19** An erupting solar prominence - hot gaseous material is shot up in fountain-like jets with velocities around 700 km per second.

Coronal magnetic field of about 3 Gauss at two solar radii from the disk centre has been found by scientists at USO. To show the variety of phenomena that occur on the Sun, USO has published a pictorial atlas of the solar chromosphere. Important flares and mass ejection events observed from USO during 1978–84 are included in the atlas to illustrate their spatial and temporal development.

It is not possible to probe the solar interior beyond photosphere by direct observational means due to high optical opacity and our knowledge of the interior is based on theoretical solar models. A frontline emerging tool to probe depths of the Sun is 'helioseismology' which is promising to yield direct information on the internal density, pressure, rotation and composition of the Sun. This method is based on observations of global modes of oscillations of the Sun and is based on techniques similar to those used to probe Earth's internal structure. This is likely to revolutionize our understanding of the Sun and models of solar structure. Helioseismology requires uninterrupted, long observing sequences, which is not possible to obtain from a single ground-based site due to the sunrise-sunset cycle. Alternatives for a continuous 24-hour coverage are observations from space, from geographic south pole or by a network of observatories around the world. USO is part of an international network of observatories participating in helioseismology.

USO is presently striving to develop high resolution observational facilities for obtaining solar magnetic and velocity fields. Simultaneous observations of these are essential to understand the physics of solar flares, filament eruptions, emergence of active regions and related aspects. These observational capabilities are expected to unravel various facets of solar structure and dynamics and hold a good deal of excitement for scientists at USO in the coming years.

SOLAR RADIO ASTRONOMY

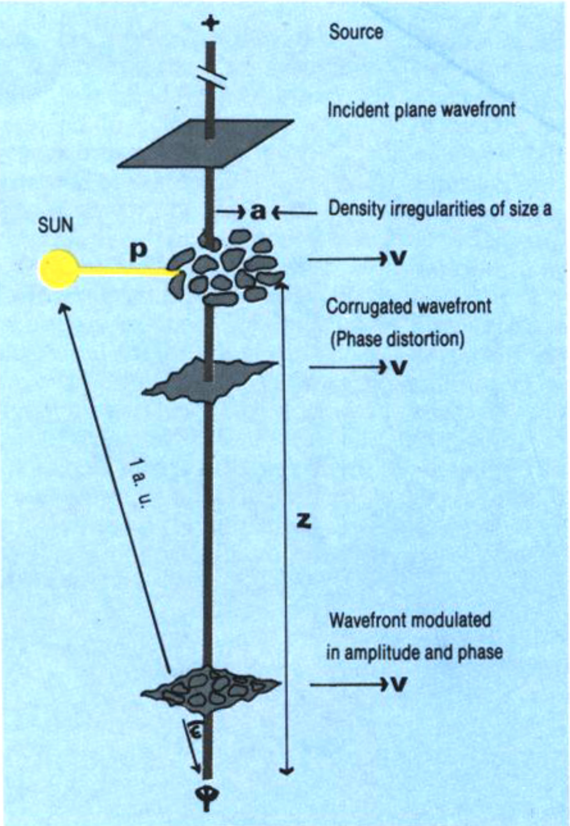
The extended, tenuous outer envelope of the Sun—the corona, is invisible except during brief periods of total solar eclipse. The temperature of the solar corona is about two million degrees. It is believed that the corona is heated by the action of magnetic fields emerging from the photosphere. The corona is also highly variable and is a seat of many energetic phenomena like bursts of energetic particles, which stream across the interplanetary space—at times striking our Earth.

These eruptive phenomena also give rise to bursts of energy in the radio wavelength region that could be studied by radio astronomy methods. Solar radio astronomy programme was initiated in PRL during early sixties to study solar flares and associated radio bursts. Our extensive observations of bursts of radio emissions allowed determination of the velocity of ejection of particle streams in the solar corona and their mechanism of emission. In addition, polarization properties of these radio emissions enabled us to estimate electron density in the interplanetary space between the Sun and the Earth.

A very sophisticated instrument called radio spectroscope was designed at PRL to study the fine structures in the radio bursts from the Sun. This led to the discovery of several new features called "Complementary Bursts", and various other detailed phenomena. These were explained in terms of very short duration bursts of mono-energetic electrons, shooting through the solar corona causing bursts of radio energy.

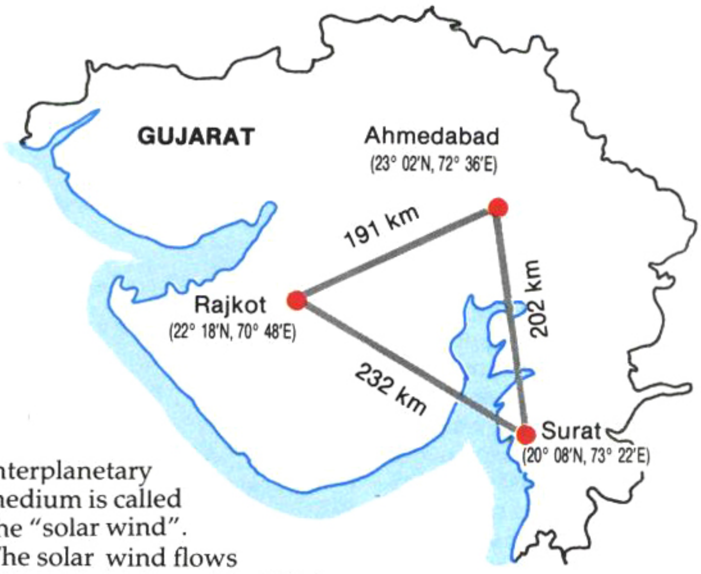
The high temperature corona of the Sun gives rise to an expanding outer envelope. This solar plasma (electrons and protons) that streams into the interplanetary medium is called the "solar wind". The solar wind flows at least upto the orbit of Pluto. The interaction of solar wind and interplanetary medium leads to the formation of the heliosphere. Study of the physics of the heliosphere is fundamental to the understanding of various solar-terrestrial phenomena. Properties of the solar wind (number density and velocity) are studied by spacecrafts in the plane of the ecliptic. But the regions outside the ecliptic are not easily accessible to the spacecrafts.

Since its discovery more than two decades ago the radio astronomy technique of Interplanetary Scintillation (IPS)



◀ **1.20** Phenomenon of Interplanetary Scintillation.

▼ **1.21** Geometry of the three IPS radio telescopes, showing their separations and actual direction.



Solar radio astronomy programme was initiated at PRL during early sixties to study solar flares and associated radio bursts. The radio astronomy technique of Interplanetary Scintillation (IPS) has proved to be a powerful and relatively inexpensive tool for the study of different aspects of the interplanetary medium (IPM). Recently this method has been successfully used for mapping the variations of plasma density or turbulence in the IPM.

▲ **1.22 (a)** Antenna of the IPS radio telescope.

Radioastronomers of PRL initiated a research programme in the eighties for studies of interplanetary medium utilizing the IPS technique.

has proved to be a powerful and relatively inexpensive tool for the study of different aspects of the interplanetary medium (IPM). These include electron density distribution, movement of solar plasma and solar disturbances propagating through the IPM. Recently this method has been successfully used for mapping the variations of plasma density or turbulence in the IPM. These "interplanetary weather" maps are then used to detect travelling interplanetary disturbances which were shown to be associated with 'coronal holes'. This is at variance with the traditional belief that these disturbances originate in solar flares. Using such interplanetary weather maps, it is possible to forecast the occurrence of geomagnetic storms, interruption of radio communication links and also caution cosmonauts against hazardous cosmic radiations.

Distant, small-sized radio galaxies show fast flickering of intensity when observed through the solar wind—a radio analogy of the twinkling of stars. This radio scintillation (IPS) is a result of scattering of radio waves from these objects by the "clouds" of charged density in the solar plasma (Fig. 1.20). The resulting flickering intensity pattern moves along the ground as the solar wind rushes across the line of sight to the source. By comparing the moving patterns recorded by three separate ground-based radio telescopes, the velocity of the solar wind is determined.

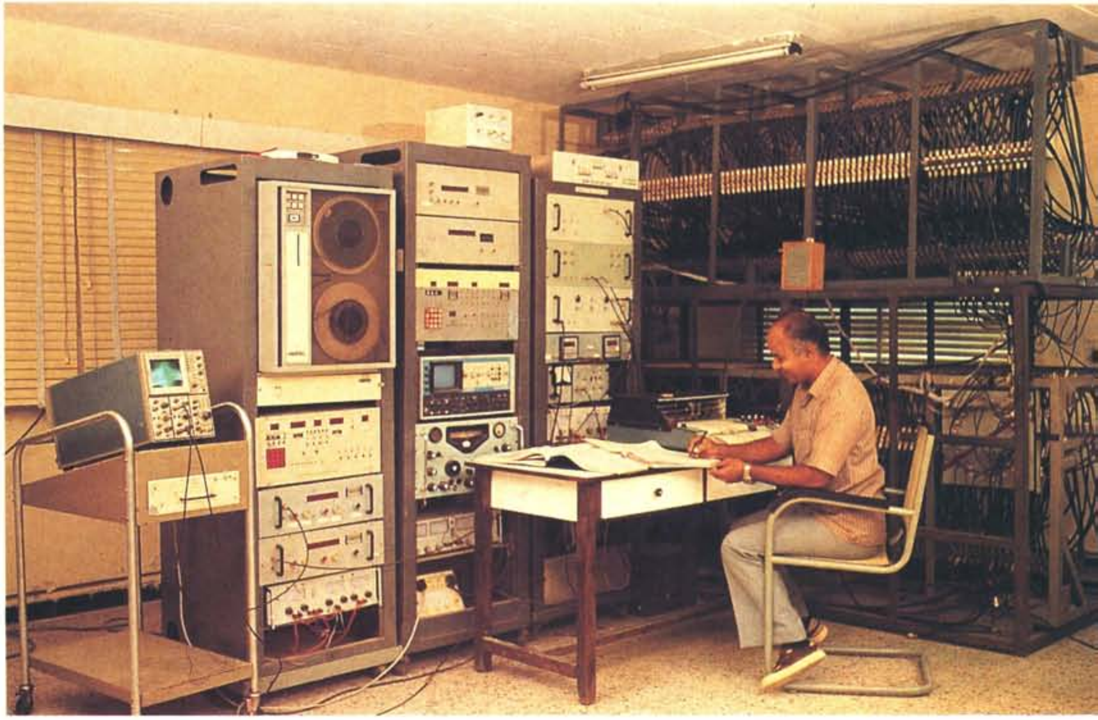
Radioastronomers of PRL initiated a research programme in the eighties for studies of interplanetary medium utilizing the IPS technique. These observations will be used to mark different velocity regions on the Sun. Three large radio telescopes have been commissioned at Thaltej (near Ahmedabad), Rajkot and Surat and the solar wind velocity is being measured regularly from March 1987 onwards.

Each of the three radio

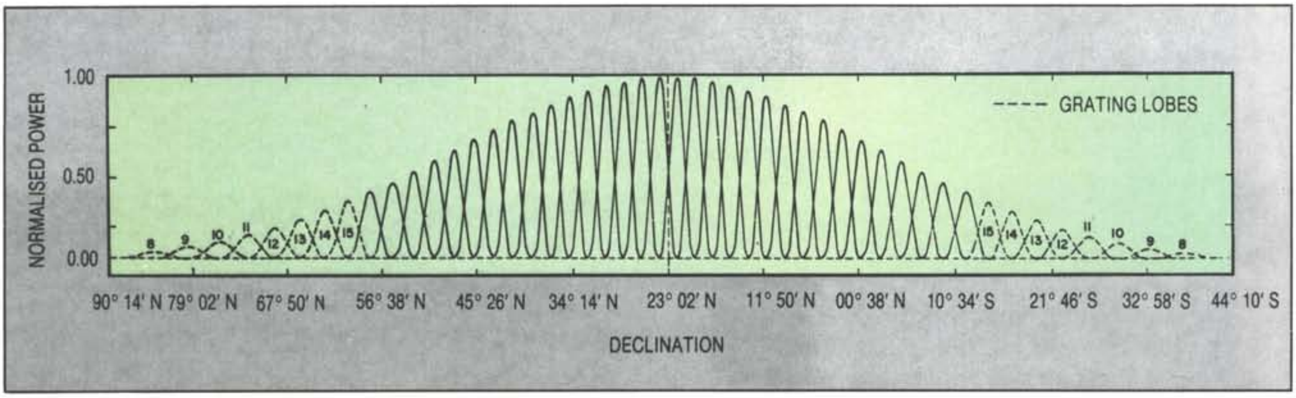
telescopes, together form the antenna array of 1024 full wave dipoles operating at 103 MHz forming an aperture of 5000 m^2. The aperture of the Thaltej telescope was later doubled with a view to observe more scintillating sources around the Sun for the study of density distribution in the interplanetary medium. The triangular arrangement of the telescopes at Thaltej, Rajkot and Surat is shown in Fig. 1.21.

The layout of the antenna array, good quality boosters, devices called Butler Matrices (BM), receiving and recording systems are shown in Fig. 1.22. The Thaltej antenna observes the sky through 32 different 'windows' as shown in Fig. 1.23. Specimen IPS recording made on paper chart of flickering of intensity of the radio galaxy 3C 48 using the Thaltej telescope is presented in Fig. 1.24. These data are also recorded on special magnetic tapes using an indigenously developed digital data acquisition system. The IPS project is now part of an Indo-US collaborative project on Interplanetary Scintillation.

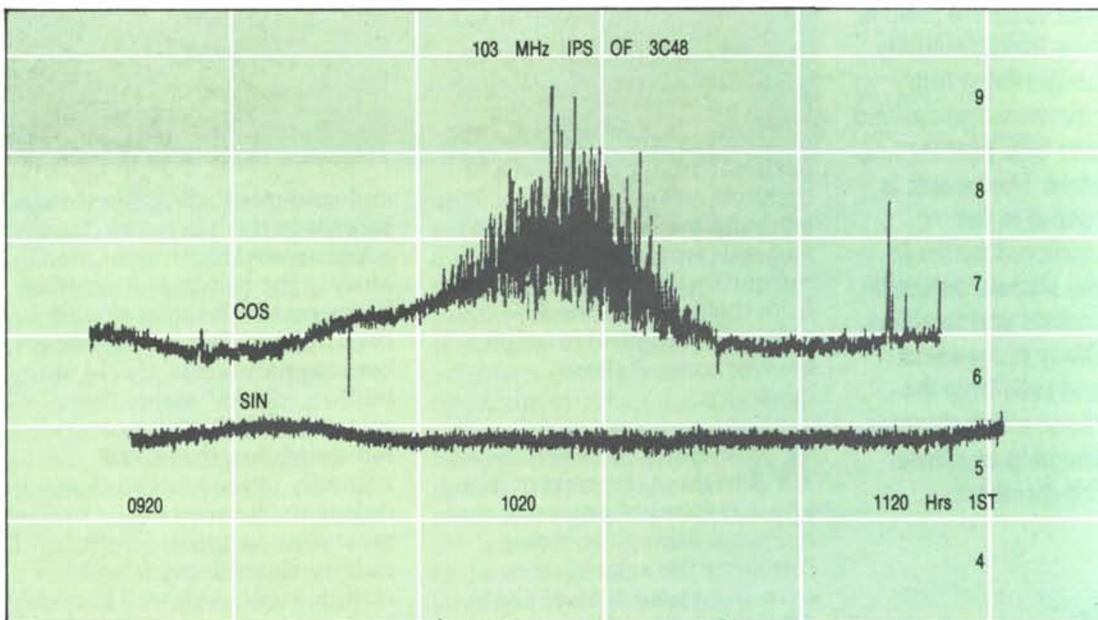
Thus, we shall soon be in a position to forecast "space weather" which would allow earth-based control centres to caution astronauts to protect themselves from hazardous particle radiation and communication engineers on the ground to adjust their radio links to avoid paths over the poles.



▲ **1.22 (b)** Butler Matrix, correlation receiver and the recording system at Thaltej Field Station.



◀ **1.23** Computer plot of 32-beam power response in declination of the IPS antenna array. Solid lines indicate main lobes, while numbered dashed lines show corresponding grating lobes.



▼ **1.24** Typical IPS observations of a radio source.

ANCIENT SUN AND THE SOLAR SYSTEM

THE MOON AND METEORITES

The solar system consists of the Sun, the planets, their satellites and also two types of smaller objects, Comets and Asteroids.

The solar system consists of the Sun, the planets, their satellites and also two types of smaller objects, Comets and Asteroids (Fig. 1.25). Comets occupy the coldest part of the solar system, the so-called "Oort cloud" region; far, far out from the Sun (~20,000 astronomical units (A.U.) away; 1 A.U. = Sun-earth distance). Asteroids, on the other hand are within the planetary system and populate the region called the 'asteroidal belt', between the planets Mars and Jupiter. A natural question that comes to mind is how these bodies came into existence and evolved into their present state. The answer is locked in the unaltered solar system matter in the planets, asteroids, comets and satellites. Fortunately, we have some of these objects available for laboratory studies (e.g. rocks and soils from the Moon, the meteorites which are fragments from the asteroids, and terrestrial samples) to help us answer some of these questions.

A natural question that comes to mind is how these planetary bodies came into existence and evolved into their present state. The answer is locked in the unaltered matter in the planets, asteroids, comets and satellites. Study of the rocks and soils from the Moon and meteorites can help us answer this question.

Meteorites have preserved in them imprints of many physicochemical processes that operated during the entire history of the solar system covering a time span of about 4.6 billion years. Our endeavour is to decipher these records in the laboratory, using sophisticated techniques, and analyse the results to infer what happened in the solar system back in time. This is possible because nature has provided built-in "clocks" inside the meteorites in the form of radionuclides, that occur naturally or are produced during the journey of meteorites in space. These radionuclides decay to stable nuclides following well known laws of physics and hence the concentrations of either the radionuclides or their stable end products are a measure of elapsed time for a given system. Meteorites can thus be considered as 'time-capsules' in our effort to unravel the mystery of the birth of the solar system and its subsequent evolution. Unlike the meteorites, which remain relatively unaltered as parts of small-sized (1–100 km) asteroids, the lunar samples (rock and soils) are modified due to processes operating in

Meteorites can be considered as time-capsules, preserving the imprints of many physico-chemical processes that operated during the entire history of the solar system covering a time span of 4.6 billion years.

◀ **1.25** A view of the solar system (size and distances are not according to scale) (Copy right (c) (1990) Hansen Planetarium, Salt Lake City, Utah; Reproduced with permission).

the early stages of formation of large-sized planets/satellites (e.g. impact cratering and volcanism). Study of the lunar samples can thus help us to understand the formation and evolution of planets and satellites under the influence of these processes. It is in fact a challenge to the scientists to read the hidden records in the meteorites and Moon samples and decipher the origin and evolution of the solar system.

Meteorites are aptly called the 'poor man's space probes', as nature provides these precious extra-terrestrial messengers free of cost. The meteorites fall on the Earth when they come within the influence of the Earth's gravitational field during their interplanetary voyage. A meteorite fall is a spectacular and rare event to watch. It is accompanied by flashes of light and detonating sound, due to the burning and breaking up of the meteoroid as a result of frictional heat and pressure generated during its entry and travel in the atmosphere at speeds exceeding 10 km/sec. Watching a meteorite fall, and collecting the same through a search is an exciting and scientifically rewarding experience. PRL scientists got such an opportunity when the 'Dhajala' meteorite fell near the village Dhajala (the meteorites are generally named after the nearest village/town of fall) in the Surendranagar district of Gujarat on January 28, 1976. A large number of fragments survived the atmospheric burn-

Meteorites are aptly called the 'poor man's space probes', as nature provides these precious extra-terrestrial messengers free of cost. Several tens of kilograms of material of the Dhajala Meteorite in the form of a few hundred fragments have been collected. PRL scientists have carried out extensive studies on this meteorite.

out and showered over an area of about 15 km × 3km around the village Dhajala (Fig. 1.26). Search parties that included local school children and villagers, guided by PRL scientists, made a thorough and systematic search for meteorite fragments over the entire area of fall. Several tens of kilograms of material of the Dhajala meteorite in the form of a few hundred fragments, ranging in mass from 1 g to 12 kg have been collected. PRL scientists have carried out extensive studies on this meteorite. Samples of this meteorite, which belonged to a rare and unique type, have been utilizec by scientists world over for carrying out important researcl work.

Meteorites were the only extra-terrestrial material available for laboratory investigations until 1969, when the U.S. "Apollo" missions returned Moon samples to Earth (Fig. 1.27). Later the USSR "LUNA" missions have also succeeded in bringing

▶ **1.26 (a)** Recovered fragments of the Dhajala meteorite.

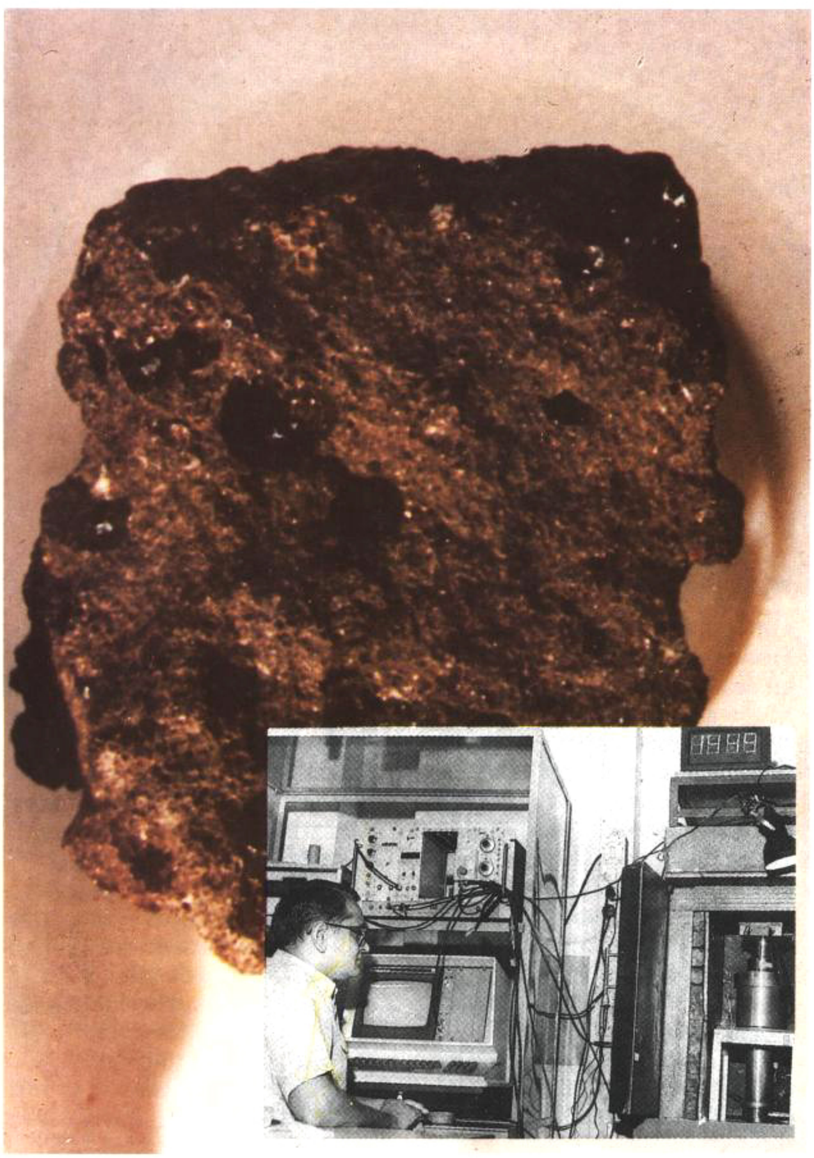
▶ **1.27** A lunar rock brought back by the Apollo astronauts (Courtesy : NASA).

▶ **1.28** Radio nuclide counting system for analysis of lunar samples and meteorites.

▶ **1.26 (b)** Looking for a meteorite! School children searching for fragments of the Dhajala meteorite.

lunar soil to Earth. Through collaborative programmes with NASA and Soviet Academy of Sciences, PRL scientists have obtained lunar samples for laboratory investigations to study various aspects of lunar and planetary sciences. A variety of sophisticated experimental techniques developed indigenously, like the noble gas mass spectrometry, high sensitive radiation detectors and nuclear track techniques, have been utilized by PRL scientists to analyse the meteorites and lunar samples (Fig. 1.28). Some significant results of these studies are briefly described.

As mentioned earlier, the Sun and the solar system objects formed from an initial gas and dust cloud, representing average interstellar material. Investigations of some very primitive meteorites carried out at PRL have shown that the time required for the formation of large (km-sized) objects from the initial gas and dust cloud was extremely short (10,000–100,000 years) compared to the age of the solar system. This short time scale also agrees with the theoretical estimates based on dynamical considerations. Our studies have also revealed that the gas and dust cloud, from which the Sun and planets have formed, contained tiny amounts of material processed at specific stellar sources, in addition to the average interstellar material. This conclusion is based on difficult and delicate measurements of isotopic abundances of certain elements (oxygen, titanium) in several extremely rare and tiny meteorite grains. In fact, some of these isotopic signatures must have been produced during the explosive death phase of a star (e.g. supernova explosion) that preceded the formation of the solar system by a few tens of million years. Thus, studies of very special solar system material can in fact tell us about stellar processes operating far back in time within our own galaxy. This is almost akin to 'seeing the Universe in a few grains of sand'.



The surfaces of planets and satellites have been intensely bombarded by asteroid-sized (1–100 km) bodies during the initial stages of planetary evolution, and are being continuously bombarded even today by objects ranging in size from microns (0.0001 cm) to kilometres. This is clearly evident in the case of the Moon, whose surface is covered with giant craters, visible even to naked eye as dark spots (Fig. 1.29). Several other processes, like intense volcanism, chemical differentiation, and formation of atmosphere that occurred somewhat later in the history of a planet can also be deciphered from studies of the lunar, meteorite and terrestrial samples (Fig. 1.30). Studies of lunar samples by PRL scientists have established that the time scale for impact induced turnover of the lunar surface in centimetre to metre scale is of the order of one million to one billion years. Further, the results obtained from analysis of such samples coupled with spacecraft data on atmospheres of terrestrial planets Venus and Mars led us to suggest that

Through collaborative programmes with NASA and Soviet Academy of Sciences, PRL scientists have obtained lunar samples for laboratory investigations to study various aspects of lunar and planetary sciences.

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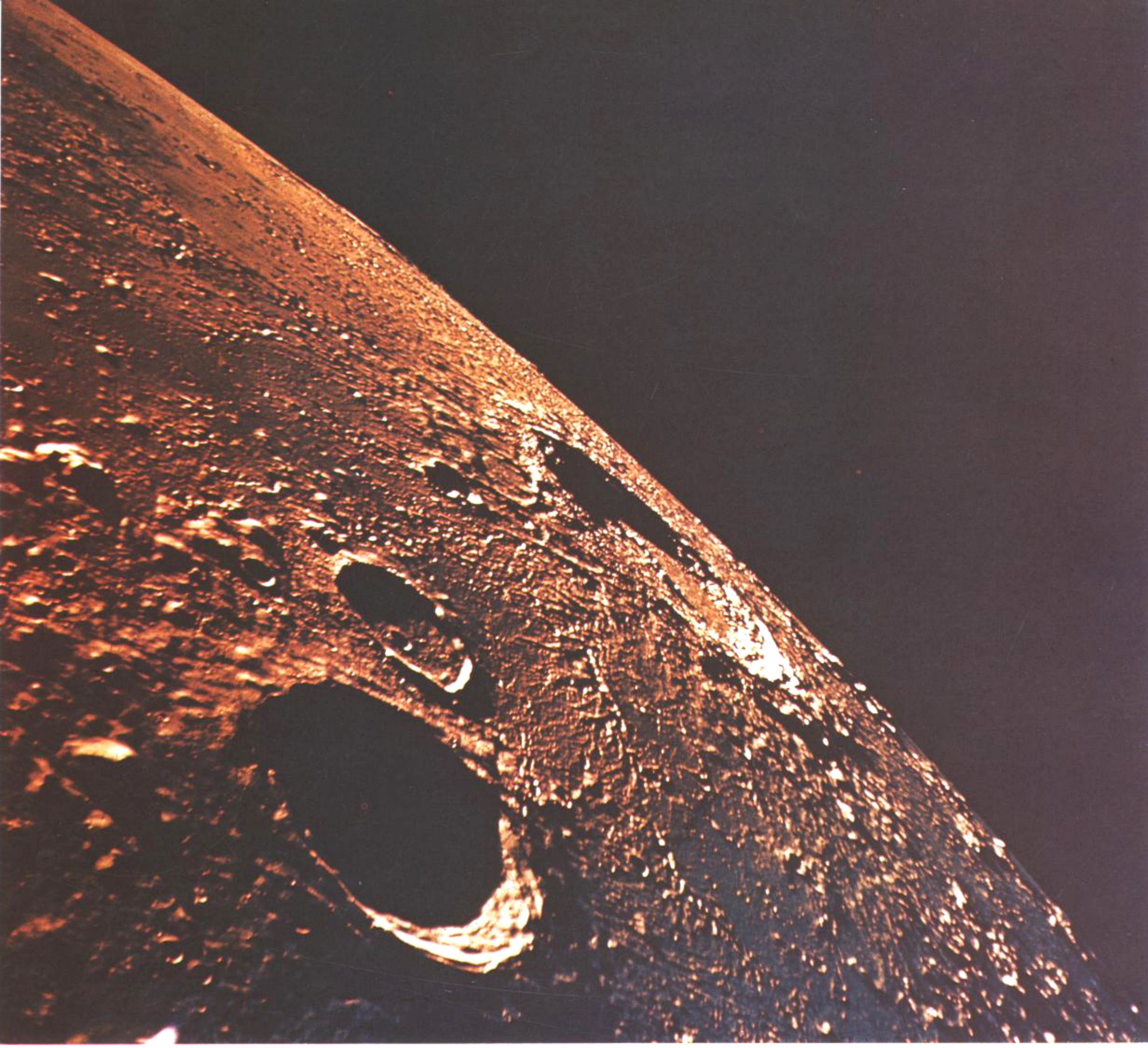
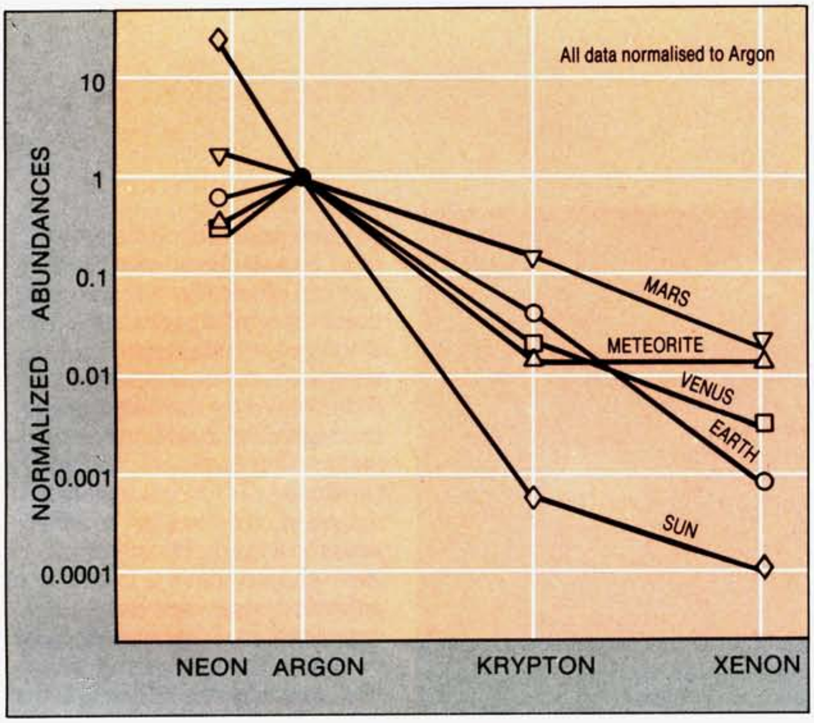


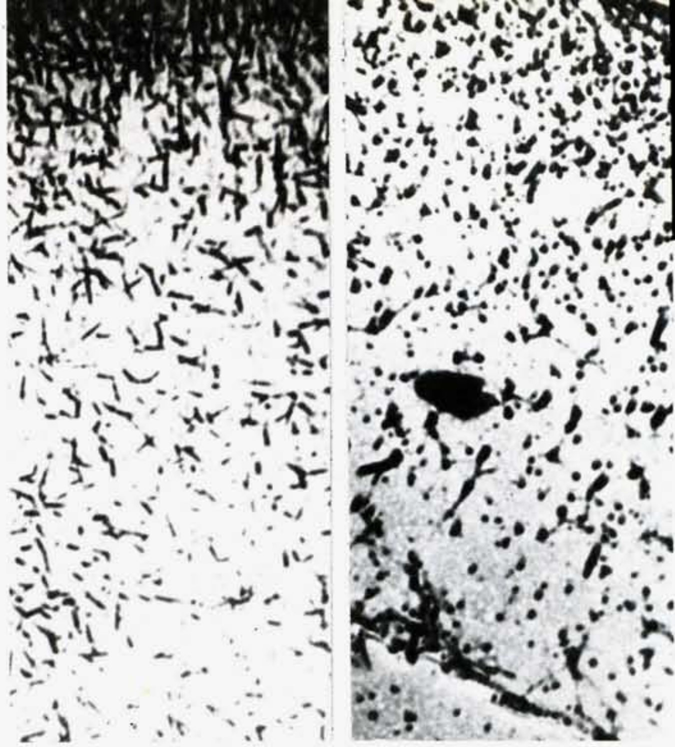
▲ **1.29** A close-up view of the heavily cratered surface of the Moon (Courtesy : NASA).

The surfaces of planets and satellites have been intensely bombarded by asteroid-size bodies. This is clearly evident in case of the moon, whose surface is covered with giant craters.

impact events on planetary surfaces, early in their evolutionary history, may have played an important role in degassing of the planetary interiors that aided the formation of planetary atmospheres.

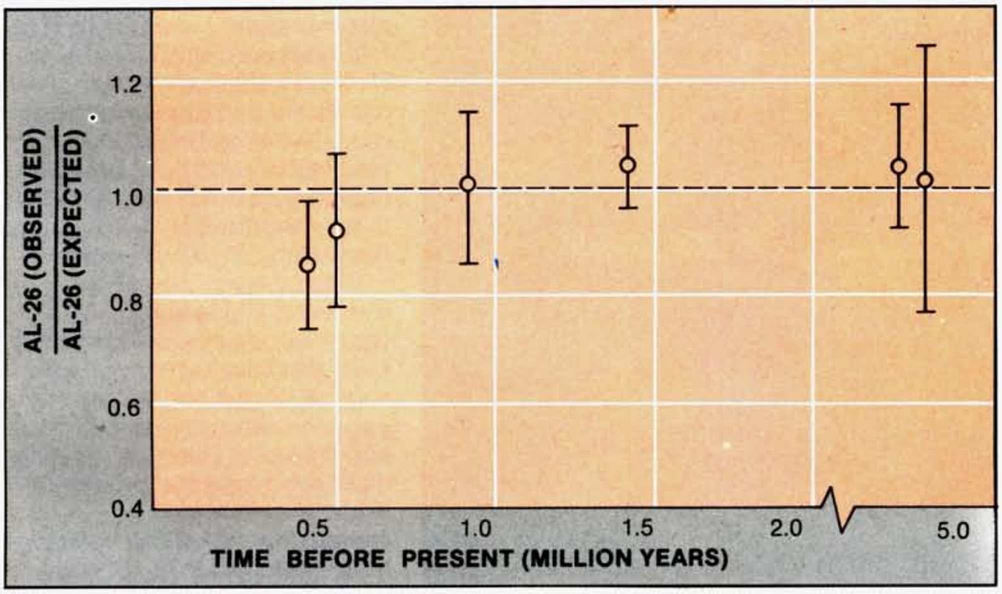
In addition to serving as probes of the solar system history, meteorites and lunar samples also serve as unique probes to understand the radiation and energetic particle environment in the interplanetary space. Terrestrial rocks are shielded from this radiation and particle environment by Earth's atmosphere and magnetic field. However the Moon is devoid of an atmosphere and both the Moon and the meteorites are constantly interacting with the radiations and energetic particles during their journey through interplanetary space. These energetic particles are primarily nuclei of all known elements, with protons, being the most dominant, accounting for ~ 90 percent. These particles originate either in the Sun or in stellar sources within our galaxy. A component of the low energy particles emitted continuously by the Sun is termed the 'solar wind' and they move at a relatively slow speed of ~ 400 km/sec. There are more energetic particles that are emitted from the Sun sporadically during solar flares. These are called solar cosmic rays (SCR). There are even higher energy particles that are constantly streaming into the solar system, from stellar sources in our galaxy, at speeds close to that of light. These are called galactic cosmic rays (GCR). Studies of solar wind, SCR and GCR particles thus tell us about processes operating in the Sun, in the interplanetary medium and in stellar sites and interstellar space in our galaxy. While rockets, balloons and space crafts are used for studies





▼ **1.30** Noble gas abundances in meteorites and solar and planetary atmospheres.

▲ **1.31** Nuclear tracks (the dark linear trails) produced by energetic solar particles in lunar samples and meteorites.



◀ **1.32** Comparison of expected and measured radioactivity due to Al-26 produced in lunar samples by solar energetic particles.

of the contemporary energetic particles, the lunar rocks and meteorites offer the opportunity to study the energetic particle environment in the inner solar system, going back in time, almost to the very beginning of the solar system history. These energetic particles interact with meteorites and lunar samples and induce nuclear reactions leading to the production of both stable and radioactive isotopes and also cause radiation damage in constituent silicate grains. By studying these effects one can understand the long-term trends in solar and stellar activity. PRL scientists have pursued such studies using a multidisciplinary approach and have made several important contributions.

An important discovery made by PRL scientists, about a decade ago was that some meteorites contain records of solar activity from the very early stages of the evolution of the Sun. The importance of such studies stems from the fact that stars similar to the Sun, genearlly go through a phase called 'T-Tauri' phase in their infancy. During this phase, these stars are much more vigorous and active, in terms of their energy output, compared to the present day Sun. Studies of fossil records of Sun's activity, as found in certain meteorite samples (Fig. 1.31) have led PRL scientists to infer that the Sun in its infancy was about 100 to 1000 times more active than at present. The implications of this observation towards early solar system processes are currently being investigated.

We have mentioned earlier that radionuclides present in meteorites and Moon samples act as natural clocks. As the radionuclides are produced in the meteorites by energetic particle interactions

Studies of fossil records of Sun's activity led PRL scientists to infer that the Sun in its infancy was about 100 to 1000 times more active than at present.

▶ **1.33** The 'Anuradha' cosmic ray experiment on Spacelab-3 was a major project of this laboratory during the eighties. In this photomosaic are shown : (a) The 'Anuradha' experiment payload, (b) The sub-components of the payload, (c) Electronic check-test conducted at PRL, (d) Schematic view of Anuradha on Space Shuttle, and (e) Close up of 'Anuradha' in space (atop the inclined stand) onboard the Spacelab

(e.g. by reactions induced by solar or galactic cosmic rays) one can study the intensity of these energetic particles, averaged over certain characteristic time period, determined by the half-lives of the radionuclides. Studies of solar and galactic cosmic ray produced radionuclides of different half-lives (from a few years to a few million years) have shown that the intensity o galactic cosmic rays has remained constant over the last tens of million years and has not varied by more than a factor of two, over the last billion years. Solar cosmic ray intensity averaged over a million year time scale has also remained almost constant over the last ter million years (Fig. 1.32). However, there are some significant variations when one considers averages over shorter time scales during the last million years. The exact cause o these short-term ($10^4 - 10^5$ years) fluctuations is still unknown.

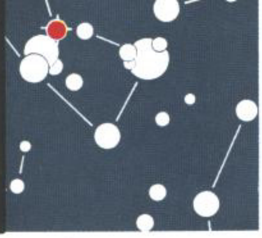
Extensive studies of both elemental and isotopic compositions of specific interest have also been carried out for solar wind and solar and galactic cosmic rays using lunar and meteorite samples, utilizing mass spectrometric techniques. While the elemental composition in galactic cosmic rays was found to be constant over time, the same is not true for solar winds and the solar cosmic rays. There are variations in solar elemental and isotopic compositions as a function of time. All these results have important bearing in our understanding of the processes affecting the generation, energization and transport of particles to interplanetary space both from the Sun and from stellar sources in our galaxy.

Apart from the studies on meteorites and lunar samples, PRL scientists have carried out two significant experiments using the Skylab and Spacelab platforms in 1973 and 1985. In 1973–74, a new component of energetic particles was discovered in interplanetary space. This component was significantly different from the galactic and solar cosmic rays in composition and intensity and was named anomalous cosmic rays (ACR) due to its unknown source and anomalous character. PRL scientists in collaboration with scientists from the Tata Institute of Fundamental Research (TIFR) carried out an experiment in Skylab in 1973, and discovered the presence of anomalous cosmic rays in near-earth-space. To further probe the source and origin of this component the 'ANURADHA' cosmic ray experiment, designed and developed by PRL and TIFR scientists, was conducted in 1985 on board Spacelab-3 of the US Space Shuttle Challenger (Fig. 1.33). The experimental package consisted of two stacks of specially arranged plastic foils, to record the trails of the anomalous particles as they go through the detector. The instrument-electronics and ground-support equipments were designed and fabricated at PRL. The results obtained so far unequivocally show that the source of the ACR ions are interstellar neutral particles. These particles can enter the solar system unhindered and get singly ionized by interacting with solar radiation and solar wind. Once ionized they move outward and are energized at the boundary of the heliosphere, the merging zone between the "solar" and "interstellar" space, before streaming back into the solar system again as energetic particles that are detected as anomalous cosmic rays.

The possibility of getting samples from the planet Mars and even from some comets and asteroids for laboratory investigations in the coming decade holds some exciting prospects and challenging times ahead. The recent acquisition by PRL of an extremely sensitive high resolution secondary ion mass-spectrometer, commonly known as Ion-Probe (Fig. 1.34), has tremendously enhanced the analytical capability of measuring the isotopic composition in extremely small samples. This instrument will be extensively used over the next decade to obtain data fròm meteorite and terrestrial samples that will improve our understanding of the early evolutionary history of the solar system and the evolution of our planet Earth over geological time scales. In addition to these exciting opportunities, the growing capability of the Indian Space Research Organisation to send large scientific payloads into space also opens up new possibilities for studying energetic particles and radiation in space. We, at PRL are looking forward to participate in these efforts to further our knowledge of the origin and evolution of the solar system and the nature of the energetic radiation and particle environment in the near-earth-space.

The recent acquisition by PRL of an Ion-Probe has tremendously enhanced the analytical capability of measuring the isotopic composition in extremely small samples.

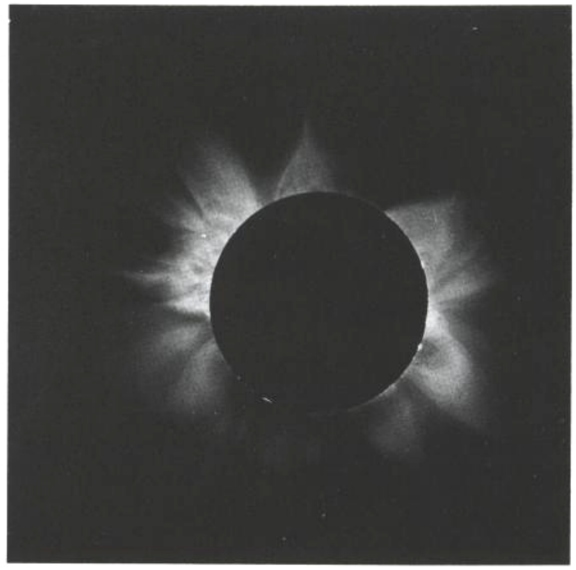
▼ **1.34** Ion Probe: A high resolution secondary ion Mass Spectrometer which is routinely used for high precision measurement of isotopic ratios of Mg, Al, Ca, Ti, Re and Os in meteoritic and terrestrial samples. These studies provide us with information regarding the source of pristine matter contained in meteorites and the early evolutionary history of the solar system.



PRL scientists carried out two expeditions to observe total solar eclipse on 16 February 1980 and on 11 June 1983.

SPECIAL EVENTS

THE TOTAL SOLAR ECLIPSE AND HALLEY'S COMET



◀ **1.35** The solar corona during the total solar eclipse of 1980. The Solar corona is a high temperature, low density plasma in which magnetic fields play a major role in controlling and directing mass flows. The myriad structures seen in the picture are manifestations of the complexity of the underlying magnetic field geometry. The overall shape of the corona changes with the cycle of solar activity from nearly symmetric during solar maximum period, as in this picture, to distinctly asymmetric shape during the minimum of activity. (Photograph : HAO Boulder)

The observation of the corona in 1980 and 1983 represented two distinct phases of the Sun; very high (1980) and low activity (1983). These observations showed that the dominant scale size of regions of intensity of the radio Sun are comparable with giant granular cells on the solar surface.

◀ **1.36** On June 11, 1983 there was a spectacular total solar eclipse lasting over five minutes visible from Indonesia. PRL scientists, as part of the Indian eclipse expedition set up an interferometric experiment to study the red and green lines of the corona. The experiment was successfully carried out from Tanjung Kodak, a coastal village adjoining the Java sea near Surabaya, Indonesia.

One of the fascinating aspects of astronomy is observing special events—some of which can be predicted and looked forward to—like a total solar eclipse or the appearance of a bright periodic comet such as the Halley's Comet. Some events are totally unpredictable but could be very spectacular like the occurrence of a supernova—when a massive star explodes. Such events offer rare opportunities to study certain details which are otherwise difficult. For example, the total solar eclipse provides the best opportunity to study solar corona in great detail. Bright comets serve as probes to study the interaction of interplanetary magnetic field of solar origin with their ion tails. Similarly during the supernova explosion one is witnessing the final stages of evolution of a massive star when the outer envelopes are thrown out and the core collapses to form a neutron star.

PRL scientists carried out two expeditions to observe total solar eclipse. On 16 February 1980, total solar eclipse occurred over parts of Southern India. During this event the optical corona was studied (Fig. 1.35) from Gadag in Karnataka and the radio corona from Rangapur near Hyderabad. On 11 June 1983, another total solar eclipse occurred over portions of Indonesia; an expedition was undertaken to observe the solar optical corona from Tanjung Kodak near Surabaya in Eastern Java (Figs. 1.36, 1.37).

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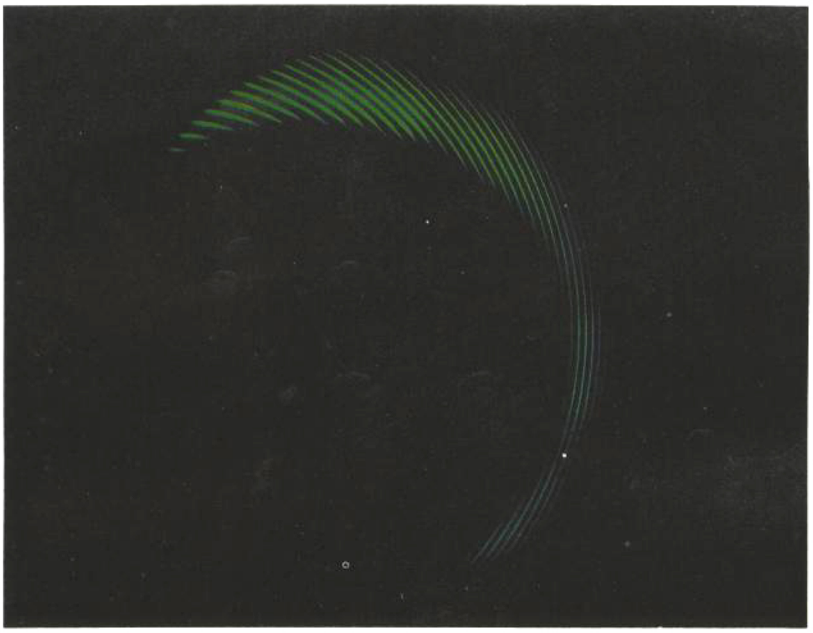


◀ **1.37** The coronal interferogram taken in the green line of a highly ionised iron atom from which thirteen electrons have been removed. The interferogram was recorded during the Indian eclipse of 16 February 1980 under very good sky conditions at Gadag, Karnataka close to the centre of the path of totality. A detailed analysis of the interferogram has yielded temperature and velocities of the iron ions at many positions in the corona.

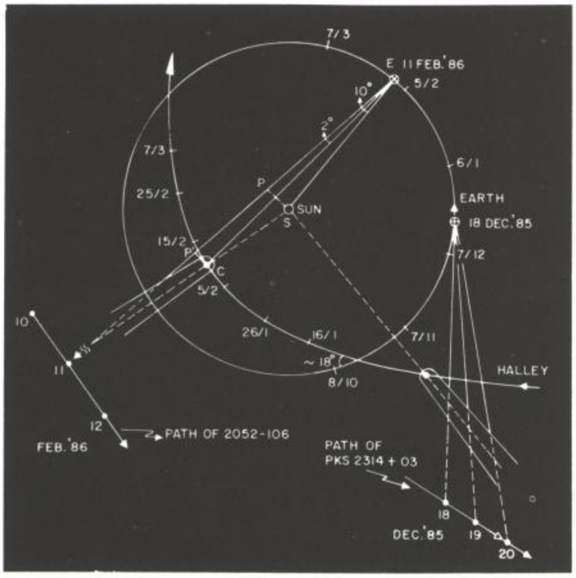
▼ **1.38** Colour picture of Comet Halley recorded on March 1, 1986. (Exploring the southern sky - an Atlas of European Southern Observatory.) Comet Halley had passed perihelion (the nearest point to the Sun) on Feb. 9, 1986 and this picture is one of the earliest post-perihelion records of the comet. It captures the comet in a very active period of its passage.

very high (1980) and low activity (1983). The optical study mapped the temperatures and gas motions in corona. The observations in 1980 showed many localized high temperature regions (over three million degrees) which were absent in 1983. Large scale motions in corona were also predominant in 1980. These results demonstrate that energetics of the corona is essentially governed by the solar magnetic fields.

During the 1980 eclipse, the Sun was observed in many frequencies using radio telescopes from Rangapur, in collaboration with the Space Applications Centre, Ahmedabad and Department of Astronomy, Osmania University. These observations showed that the dominant scale sizes of regions of intensity of the radio Sun are comparable with giant granular cells on the solar surface.

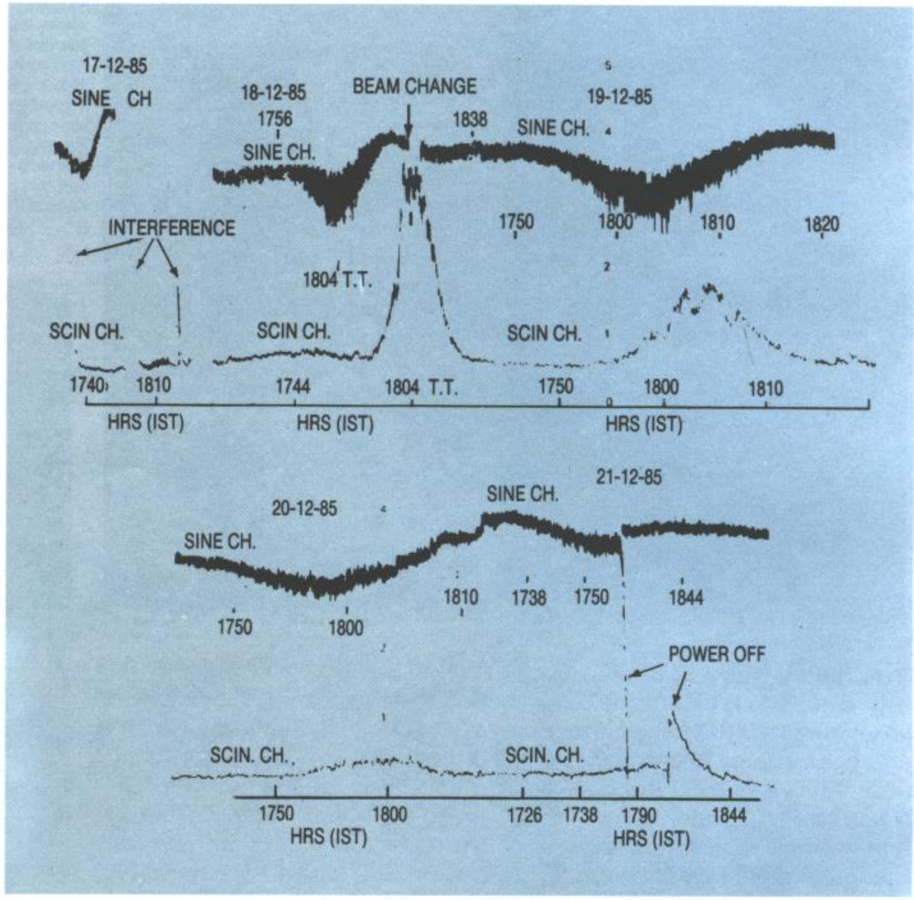
The winter of 1985–86 witnessed one more of the historically recorded passage (30th) of Halley's comet (Fig. 1.38) close to the Sun. Comet Halley's visit is a rare event as it transits the inner solar system only once in every seventy six years. Though a comet appears to be a huge body with a fearsome head and a long tail, it has actually very little matter in it—less than a millionth of Earth's mass, made mostly of volatile material like water-ice and ices of ammonia, carbon dioxide and methane. Its peculiar appearance is due to the evaporation of its volatile matter, mainly water-ice when it comes nearer to the Sun. The evaporated matter is pushed away by the pressure of Sun's radiation into a long tail. Comets are remnants of the original matter which went into the making of the solar system, and hence their study has a special significance.

Halley's comet was studied by PRL scientists in two ways—in its optical radiation and through the influence on the radio waves from a distant source propagating through its ion tail. During the period 17–21 December, 1985 the ion tail of the comet came between the Earth and a strong radio source—radio galaxy PKS 2314 + 03. During this time the radio waves from the galaxy as received by the Thaltej radio telescope showed strong scintillations—especially on 18th December, the enhancement was almost six



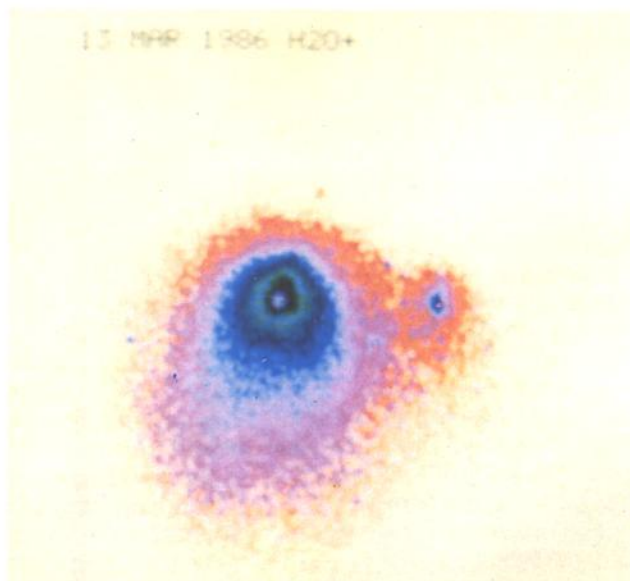
Halley's comet was studied by PRL scientists in two ways — in its optical radiation and through the influence on the radio waves propagating through its ion tail.

▲ **1.39 (a)** Geometry of occultations of PKS 2314+03 and 2052-106 by the ion-tail of Comet Halley during 18-20 December 1985 and on 11 February 1986.



▶ **1.39 (b)** Enhanced scintillations of 3C 459 by the ion-tail of Comet Halley.

▲ **1.40** The Celestron 35 cm telescope and its Fabry-Perot instrument with some observers at Gurushikhar, Mount Abu. The telescope along with its sliding roof housing was specially set up to observe the comet during the winter of 1985-86. One of the earliest sightings of Comet Halley from India was made with this telescope in October 1985.

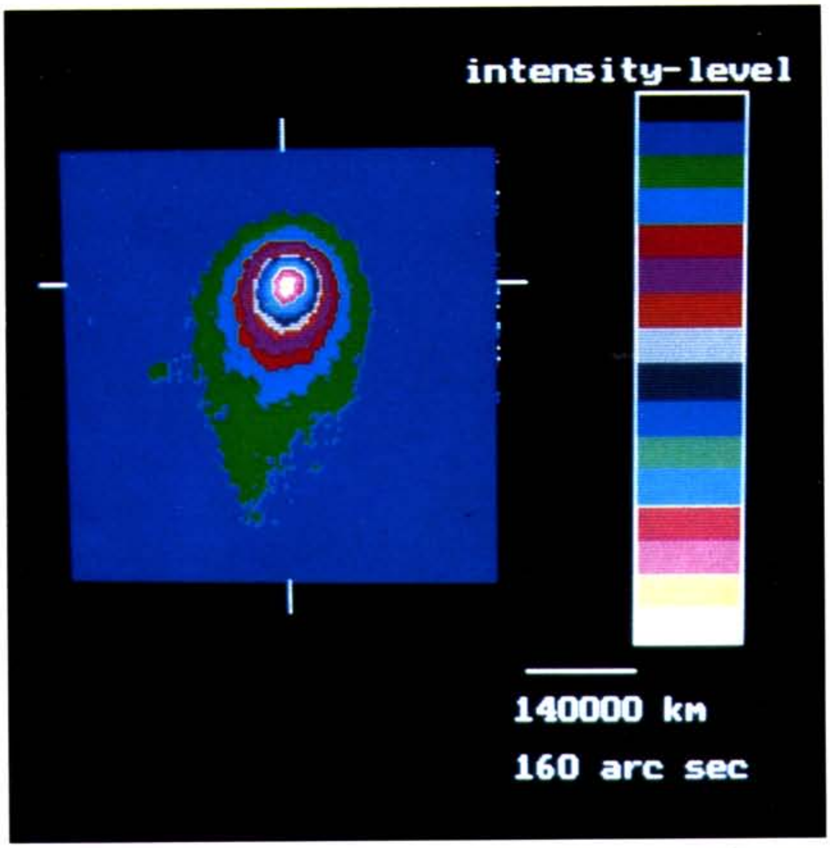


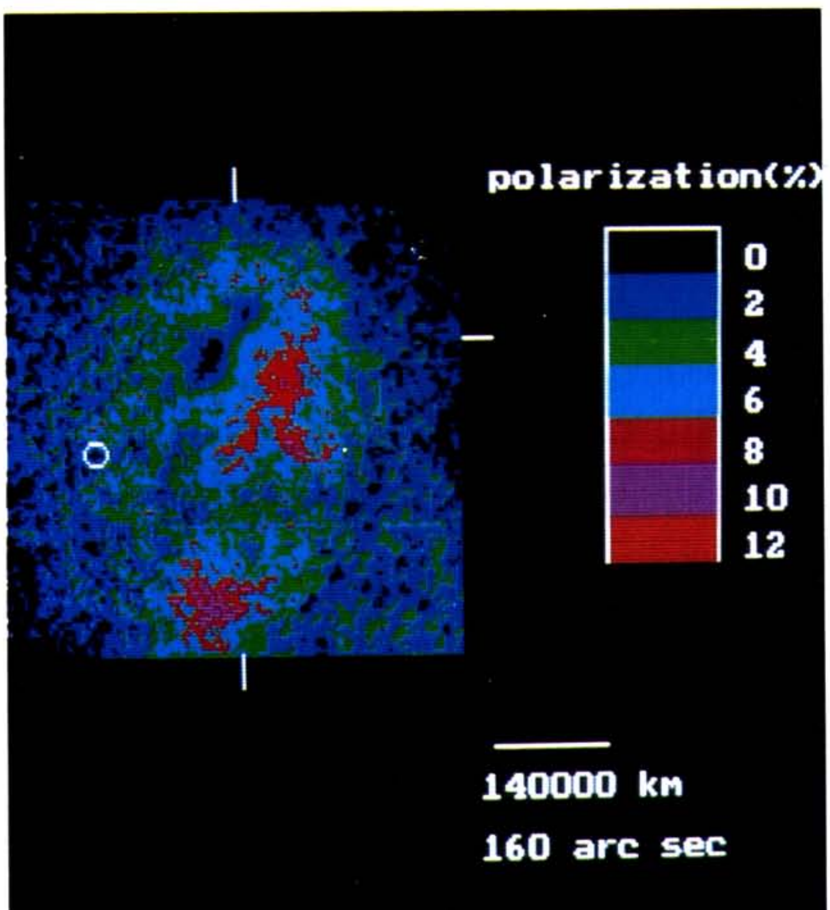
▲ **1.41** On 13 March 1986 an interesting event was recorded on Halley's Comet from Gurushikhar, with a 14" telescope. In this picture which was taken in 700OA band filter which transmits H_2O^+ emission distinct isolated blob is seen. The event is inferred to be associated with tangential immersion of Halley's Comet in an interplanetary magnetic field sector boundary.

times the normal interplanetary value. This observation (Fig. 1.39) permitted the determination of the mean plasma density in the ion tail to be about 200 ions/cc. This value agrees with the value observed by the American space craft "ICE" which crossed Giacobini Zinner's ion tail in September 1985.

Interplanetary magnetic fields of solar origin interact with the cometary plasma and produce interesting events in the ion tail. One such unusual event was recorded on 13th March 1986 from Gurushikhar Observatory (Fig. 1.40) when Halley's comet was under close scrutiny. A detached blob (Fig. 1.41) of ionized matter from the main coma of the comet revealed itself both in the photographs taken in the red light of ionized water molecule and also in an interferogram in the emission line of hydrogen atom recombination (H-alpha). Unlike the more usual tail disconnection event, the blob separated sideways. The event was also associated with passage of the comet through a region of reversal of the interplanetary magnetic field.

In addition, polarimetric studies of Comet Halley have resulted in many new and exciting findings. For example, theoretical and laboratory studies available in literature show that resonance fluorescence emissions are polarized. To test this phenomenon, polarization observations were made for Comet Halley in the neutral (C_2, C_3 and CN) and ionized (H_2O^+ and CO^+) molecular bands. High degree polarization was detected for all these molecules. Our findings on neutral band emissions are confirmed by French astronomers. Similarly, imaging polarization studies (Figs. 1.42, 1.43) of the Comet





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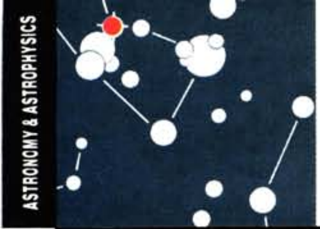
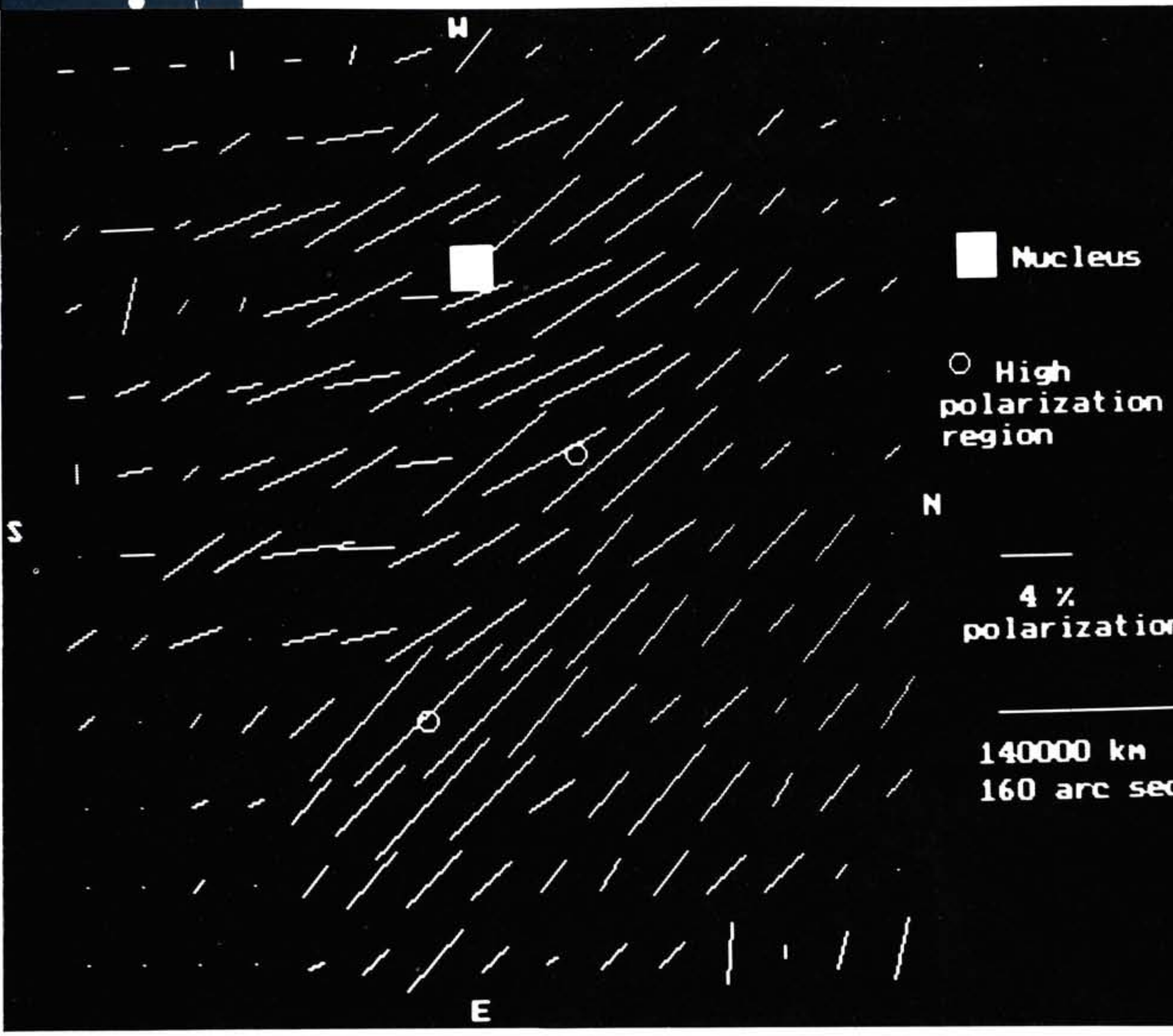
◀ **1.42** Intensity image of Comet P/Halley on 5 January, 1986 is shown. Colour coded intensity levels are expressed in some arbitrary linear scale. A set of four small white lines indicate the nucleus of the comet.

◀ **1.43 (a)** The polarization image of a comet (P/Halley) encompassing nuclear and coma regions. This image recorded on 5 January 1986 shows two blobs of high polarization (10-20%) and a region very close to the nucleus void of polarization (less than 2%). These blobs may be caused by the jet activity in the nucleus of the comet.





1.43 (b) The alignment of polarization vectors over different parts of the comet is shown. The degree of polarization is expressed in a suitable scale as shown along with. Position angle of each vector is measured from north towards east. In order to avoid the merging of two vectors which are almost parallel to the north south direction, we have added an angle of 45 degrees to each of the actual position angle values of the polarization vectors.

Exciting times appear to be ahead for the PRL scientists. With the commissioning of the infra-red telescope the technical capabilities developed over the years in PRL are expected to achieve their highest utilization and significant scientific results should follow.

Halley indicate that dust blobs ejected from the nucleus travel to its tail region. Studies of such phenomena provide clues to bulk motions in cometary atmosphere. These results pave way for new areas of research in cometary physics.

What of the future? Exciting times appear to be ahead for the PRL scientists. The telescope is expected to be fully operational soon. New instruments are nearing completion. One of them is the Charge Coupled Device (CCD) camera (Fig. 1.44). It is an imaging device like a photographic film but differs in being much more sensitive and provides a convenient digital output which can be readily used for image processing. The CCD will be used to image faint structures in objects like Quasars and Seyfert galaxies to better understand their energetic behaviour. A powerful faint light camera—single photon counting camera—has been acquired to map the detailed kinematics of planetary nebulae. The fabrication of a high resolution Fourier Transform spectrometer is also nearing completion; it will be utilized to study the processes in the envelopes of cool giant stars.

With the commissioning of the infra-red telescope the technical capabilities developed over the years in PRL are expected to achieve their highest utilization and significant scientific results should follow. Future research programmes of the area are likely to include the use of special high spatial resolution techniques like Speckle Interferometry and Lunar occultation of stars for overcoming the limiting effects of the Earth's atmosphere in probing regions of star formation. Exciting programmes are also likely to be taken up in the difficult but rewarding mid-infra-red regime of wavelength, 8 to 14 microns, developing the technique of infra-red polarization and use of optical and infra-red array detectors.

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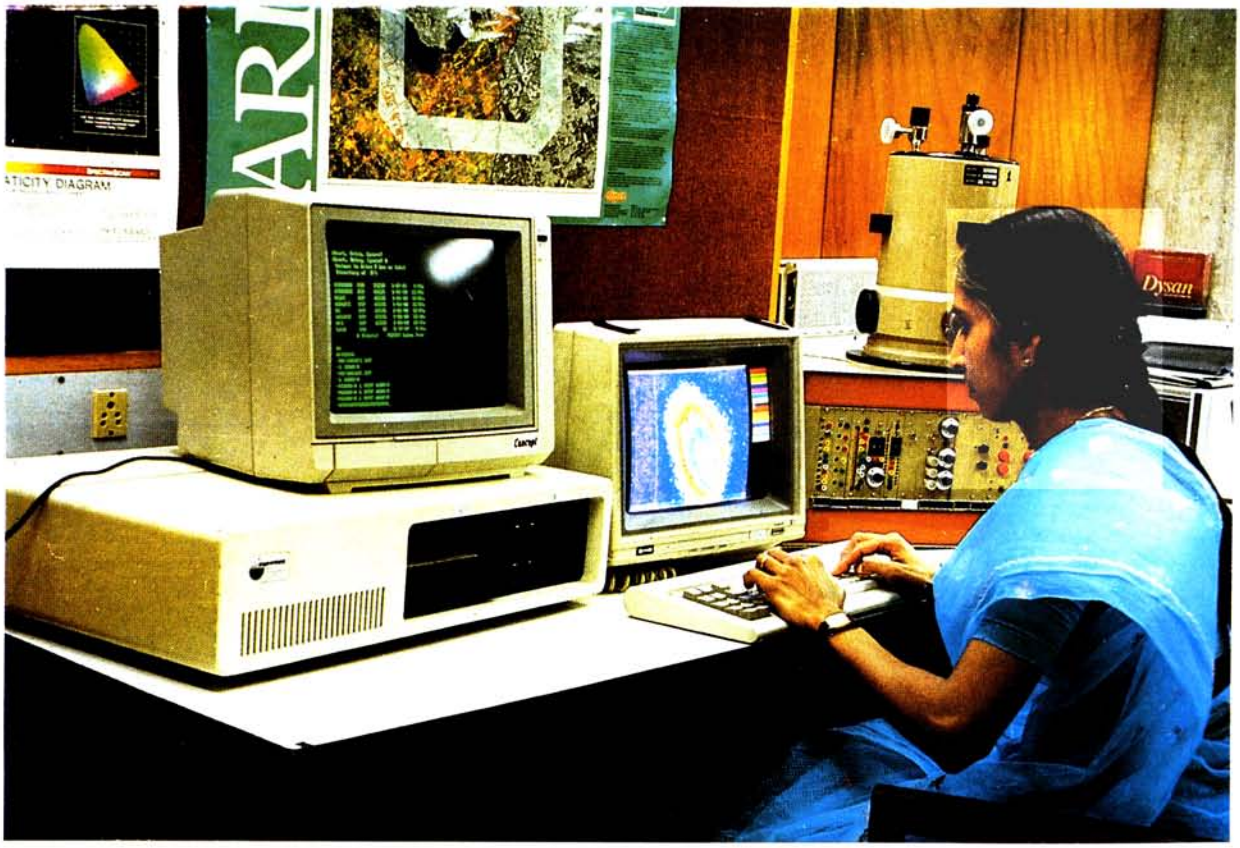
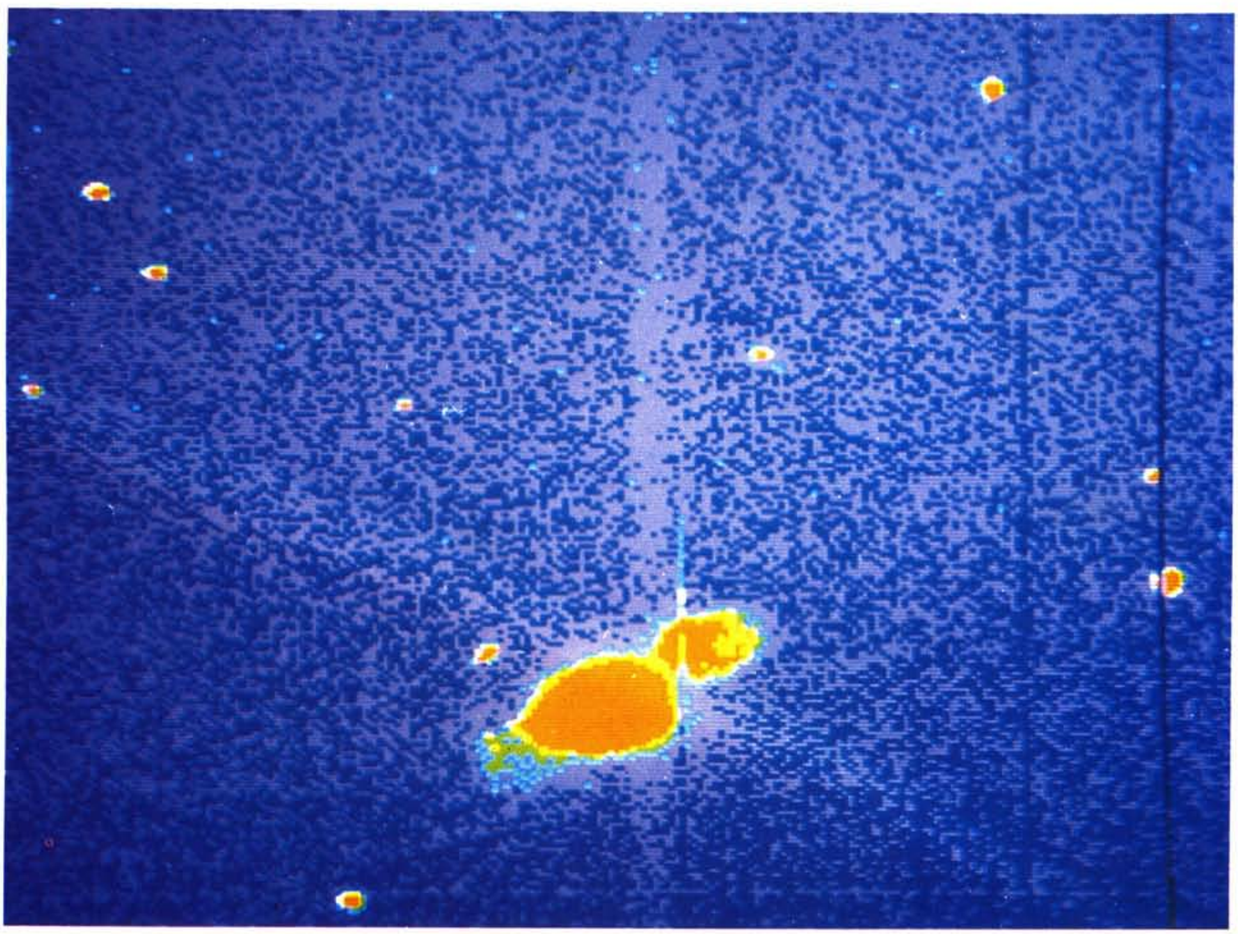
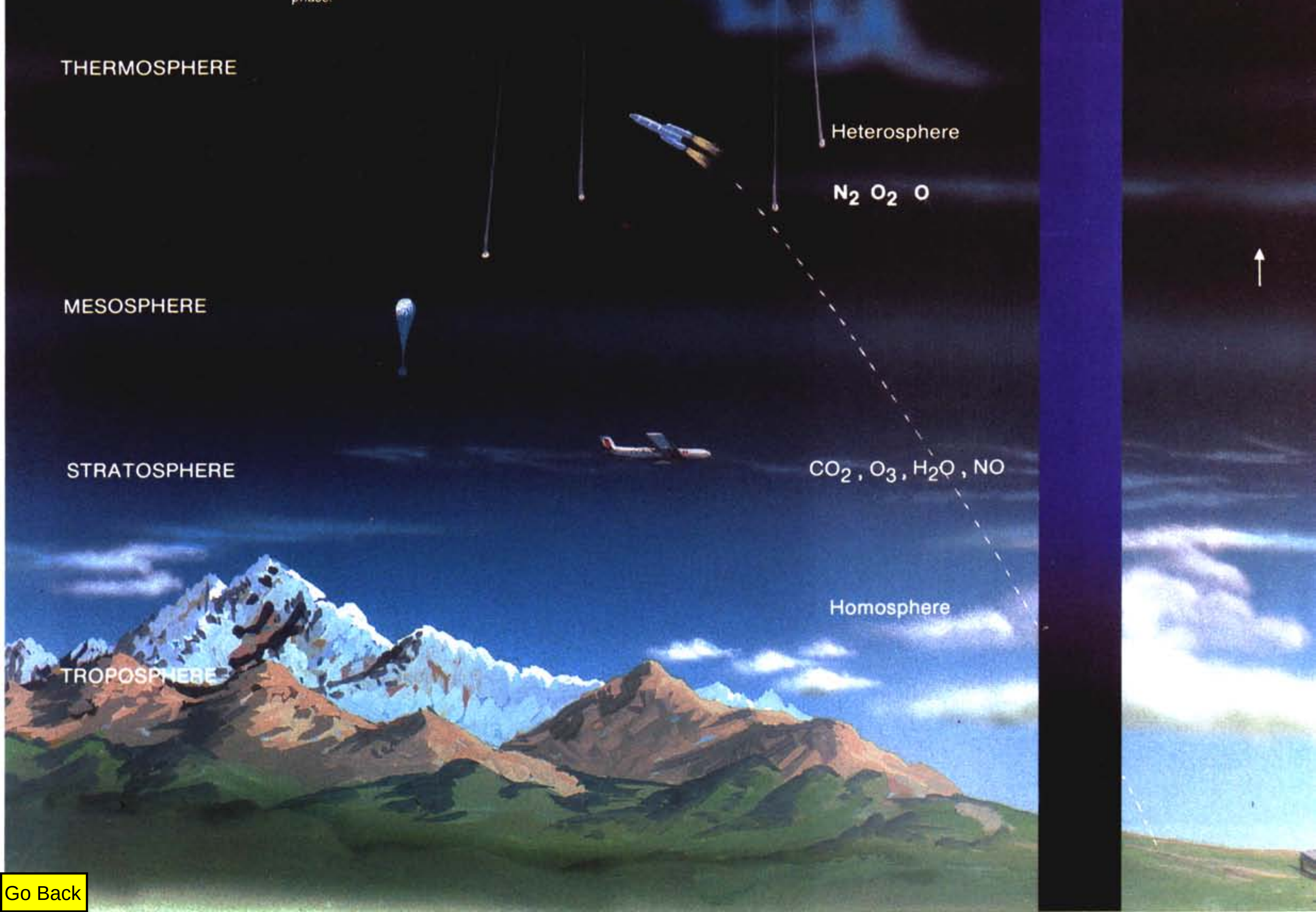


◀ **1.44 (a)** A view of the CCD camera developed at PRL. With the camera faint objects can be studied. The camera is fully computer controlled and gives digital image, which is very convenient for further analysis like image processing etc.



◀ **1.44 (b)** A star field photographed from CCD camera with 6" telescope. The fainter stars in this field is about 10 magnitude. To record such a star one would need about 30" telescope without CCD camera.



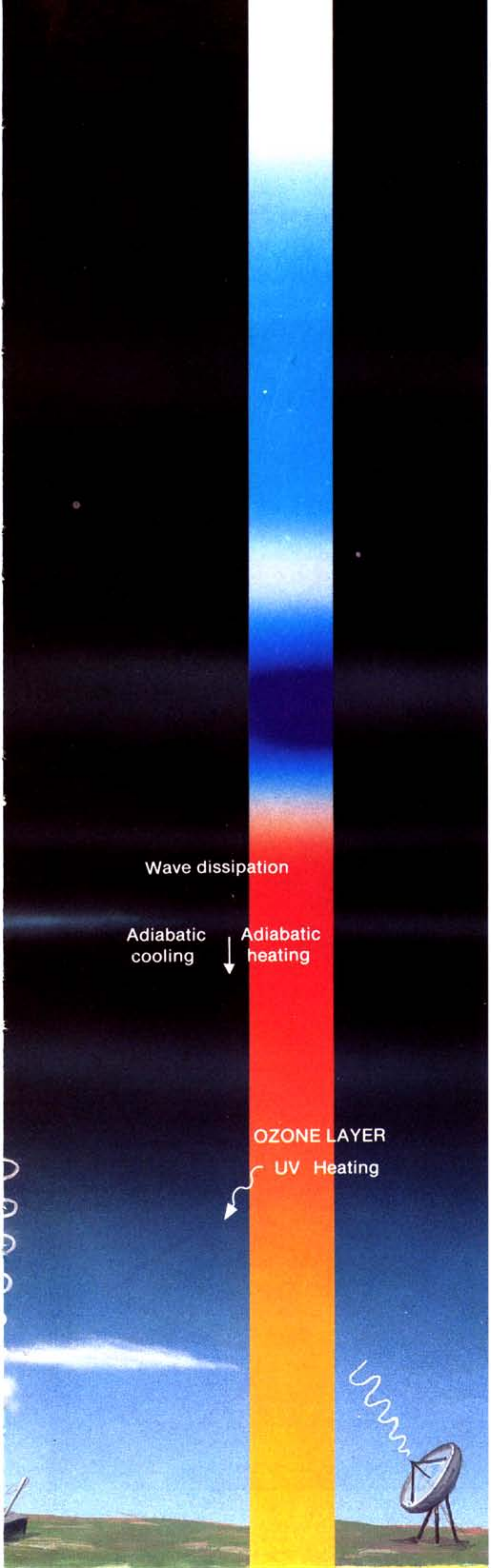
▶ **2.1** The temperature and compositional structure of the atmosphere with altitude. The various regions (spheres) are classified depending on the dominance of different physical processes.

◀ **2.2 (a)** A high altitude balloon capable of reaching upto 35 km (stratosphere) and carrying upto 1000 kilogramme of scientific instrumentation, is being prepared for a launch.

◀ **2.2 (b)** A Rohini-200 meteorological rocket capable of reaching upto 80 kilometre, just before take off.

▲ **2.2 (c)** One of India's scientific satellites (SROSS-series) in its integration phase.

Go Back



PLANETARY ATMOSPHERES

प्राणादभूद् यस्य चराचराणां
प्राणः सहो बलमोजश्च वायुः ।
अन्वास्म सम्राजमिवानुगा वयं
प्रसीदतां नः स महाविभूतिः ॥३७॥

All living entities, moving and non-moving, receive their vital force, their bodily strength and their very lives from the air. All of us follow the air for our vital force, exactly as servants follow an emperor. The vital force of air is generated from the original vital force of the Supreme Personality of Godhead. May that Supreme Lord be pleased with us.

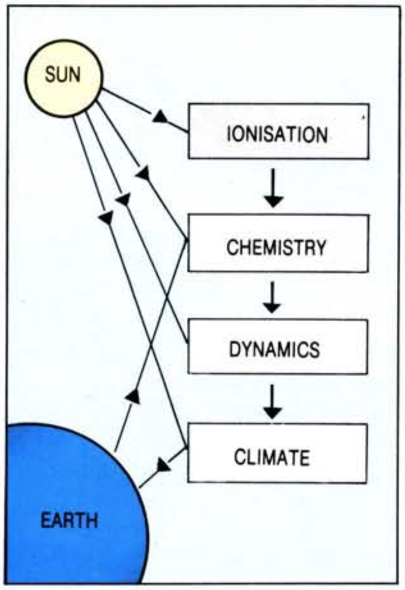
—*Srimad Bhagwatam 8:5:37*

The Earth's atmosphere is unique among those of the inner planets of our solar system. Most importantly it has a composition which supports life and maintains Earth's surface temperature. The temperature of the atmosphere at different heights depends on the absorption of incoming solar radiation and/or reflected radiations from the Earth's surface by different atmospheric constituents. The atmosphere is divided into various layers depending on the temperature. In contrast to the temperature, the pressure and the density of the atmosphere decrease monotonically with height (Fig. 2.1). The atmosphere becomes tenuous above a few hundred kilometres. For example, the atmospheric pressure at 100 km is only about a few millionths of that at the ground level. This tenuous atmosphere extends to several thousand kilometres until it finally merges with the interplanetary medium and the space beyond. It is important to understand the physical, chemical and dynamical processes that operate in the various regions of the atmosphere and which help to maintain its composition.

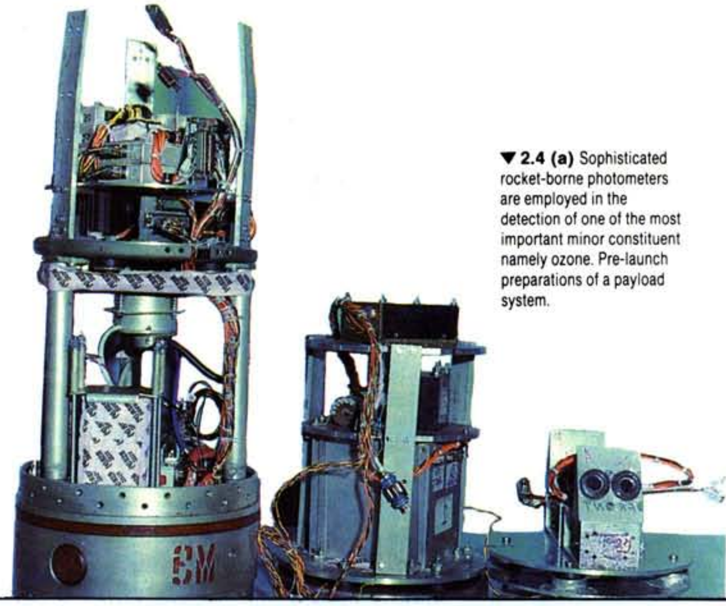
Indeed, atmospheric research (or in a broader sense space research), has been one of the major scientific activities of PRL since its inception in 1947. During the last four decades these studies at PRL have progressed by leaps and bounds, mainly due to major technological advancements. The advent of rockets, satellites and more sophisticated remote sounding techniques has contributed significantly to PRL's space research programme, in the middle and the upper atmosphere (Fig. 2.2). Over the years PRL scientists have developed indigenously a number of different types of payloads and flown them successfully on rockets and balloons to measure simultaneously several atmospheric constituents and parameters. PRL scientists are one of the major users of the rocket launching facilities at Thumba, (near Trivandrum) and SHAR (near Madras) and the balloon facility at Hyderabad. We present below some of the atmospheric research programmes of PRL.

MIDDLE ATMOSPHERE

One of the major programmes of PRL has been the study of atmospheric ozone, a photochemically active molecule having three oxygen atoms.



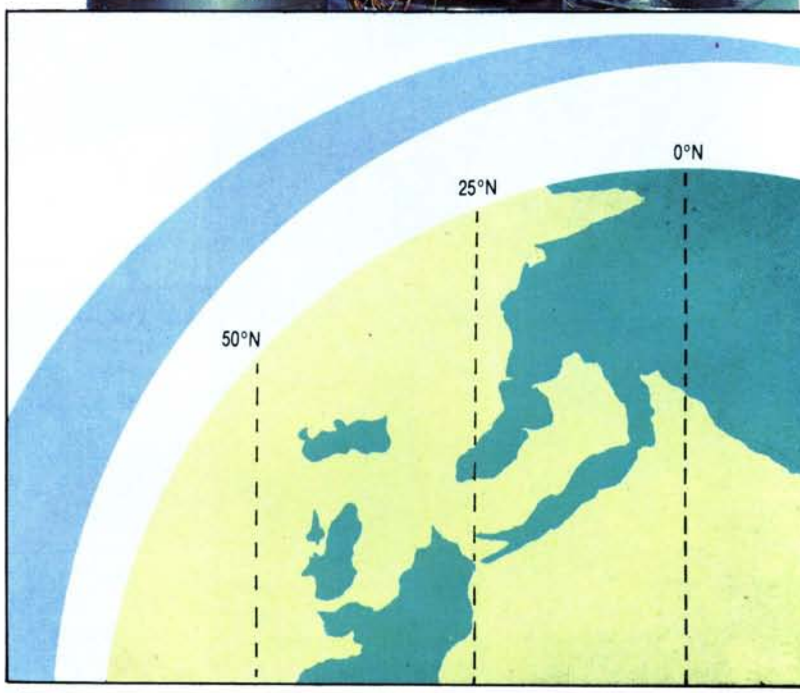
▶ **2.3** Schematic representation of the dominant middle/lower atmospheric processes. The Sun is the main source of energy which causes ionization, initiates several chemical reactions and is responsible for the large scale motions and the overall climate.

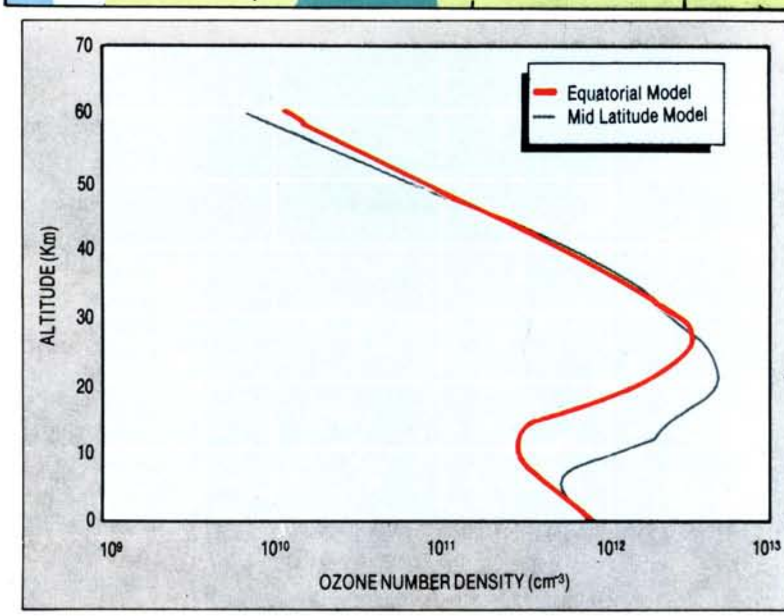


▼ **2.4 (a)** Sophisticated rocket-borne photometers are employed in the detection of one of the most important minor constituent namely ozone. Pre-launch preparations of a payload system.

During the last fifty years we have contaminated our planet's environment. These contaminants interact with ozone in the atmosphere and cause its destruction.

Realising the importance of basic research in atmospheric sciences, PRL initiated a programme for the study of the various atmospheric components and physical, chemical and dynamical (Fig. 2.3) processes using ground-based, radio wave and optical techniques. One of the major programmes of PRL since those days has been the study of atmospheric ozone, a photochemically active molecule having three oxygen atoms. The ozone concentrations are maximum around an altitude of 27 km and taper off to lower values at higher and lower altitudes. Though the concentration of ozone is quite small (only about ten parts per million at 25 km) it plays two important roles. It protects us from the biologically harmful solar ultraviolet radiation (2000–3000 A) by absorbing it in



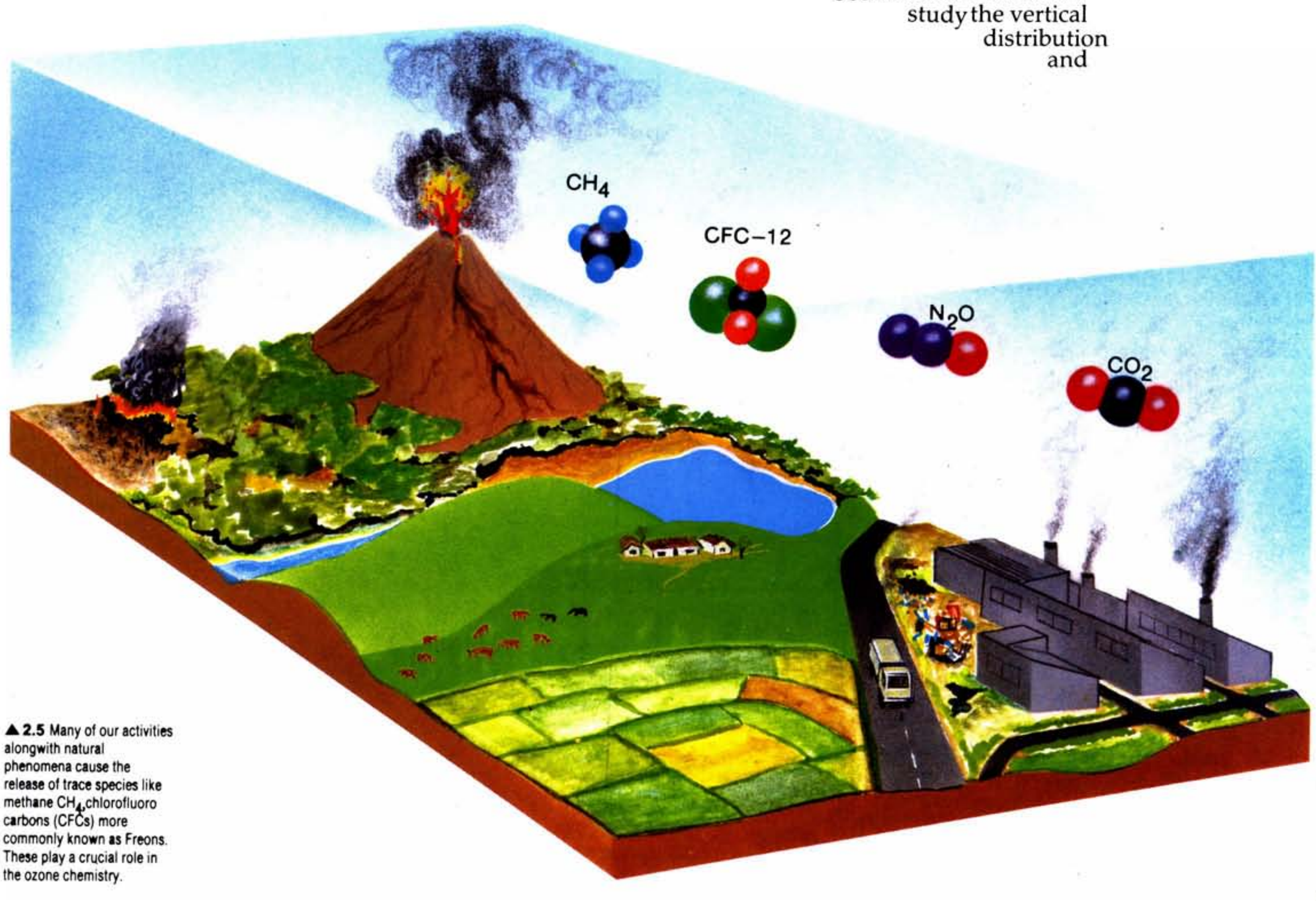


▶ **2.4 (b)** Artist's representation of the significant differences that exist in the ozone concentrations between equatorial and mid latitudes. (inset) Ozone maximum over the equator is at approximately 27 kilometres, 3 kilometres higher than the mid latitudes, while the concentration is less by a factor of about 1.5.

the atmosphere. Secondly, ozone plays a crucial role in the thermal budget of the atmosphere. Its strong emission/absorption band at 9.6 microns is responsible for the warming of the stratosphere; the atmospheric region between 15 and 50 km altitudes. Major contributions have been made at PRL in the measurement of atmospheric ozone using the standard Dobson Spectrophotometer and the recently developed rocket-borne photometers. The ozone distribution below a height of 35 km is found to be quite different over southern India compared to that over the mid and high latitude regions (Fig. 2.4). Large, short term ozone increases have been observed above 40 km altitude during events such as a solar eclipse.

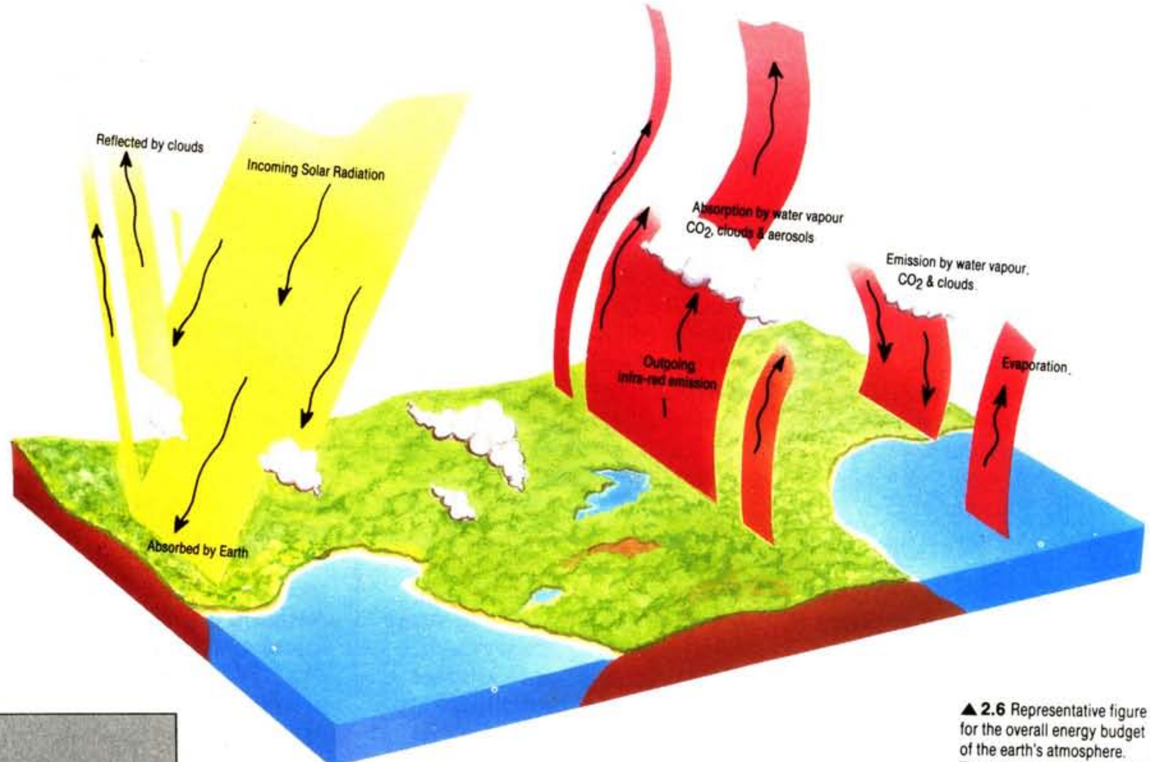
The natural cycle of ozone in the atmosphere is slowly and systematically getting tampered by man's activities. During the last fifty years we have contaminated our planet's environment (Fig. 2.5). The contaminants introduced into the Earth's atmosphere include, oxides of nitrogen (from the ground, through the use of fertilisers and chemicals and by high flying aircrafts), various types of freons (used in refrigeration and aerosol spray cans) and other trace gases. These contaminants interact with ozone in the atmosphere and cause its destruction. In addition to the above trace gases, we are also adding carbon dioxide and carbon monoxide (through burning of fossil fuels and destruction of forests) and methane (from cattle breeding and increased paddy cultivation) to the atmosphere. These gases trap the outgoing Earth's infra-red radiation thus impeding the return of solar energy to space (Fig. 2.6). This results in the warming of the Earth's surface. This property, also possessed by ordinary glass, of allowing the visible radiations to pass through while trapping the outgoing infra-red radiations, is known as the Greenhouse effect. With the ever increasing man's activities, more and more of Greenhouse gases are being released into the atmosphere resulting in its slow but steady alteration. A programme has been initiated at PRL to study the vertical distribution and

Man's activities are releasing increasing amounts of green-house gases into the atmosphere. Scientists at PRL study the vertical distribution and growth rate of these gases and their effect on ozone depletion and climate.

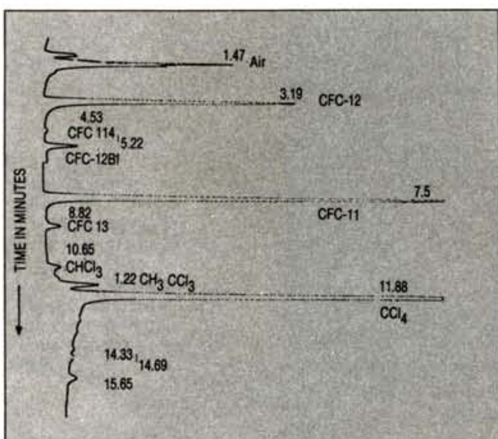


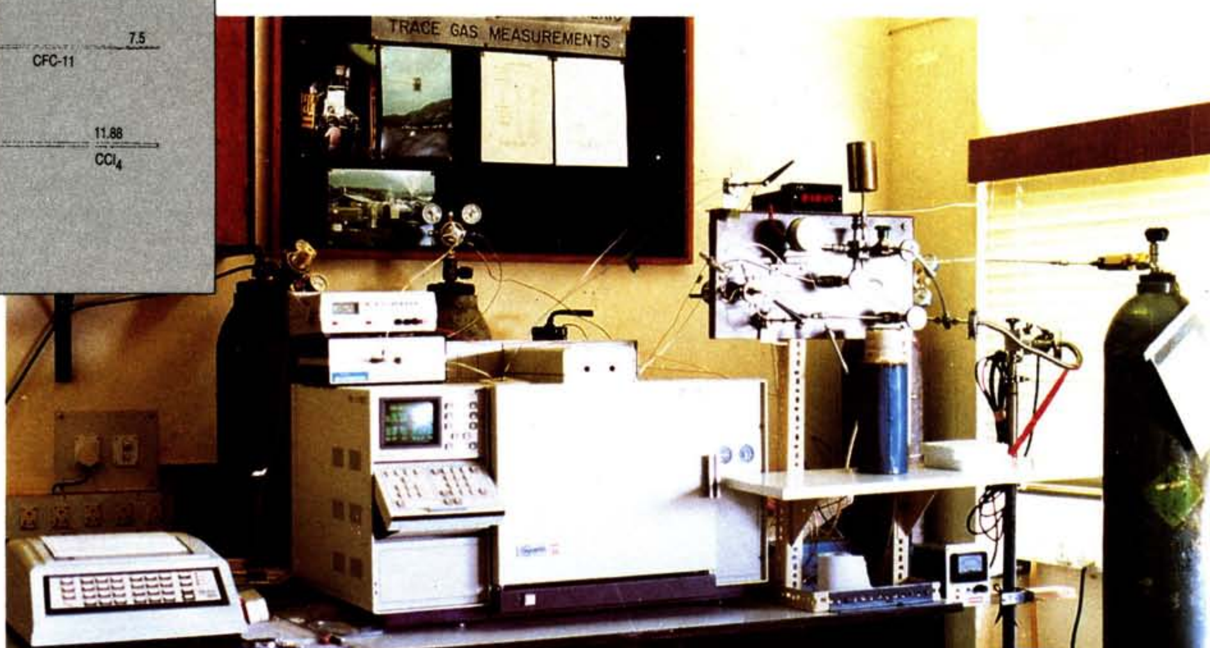
▲ **2.5** Many of our activities alongwith natural phenomena cause the release of trace species like methane CH_4, chlorofluoro carbons (CFCs) more commonly known as Freons. These play a crucial role in the ozone chemistry.

Realizing the importance of aerosols in climate, atmospheric composition and electrical properties, studies on its abundance and size distribution are being made by PRL scientists using indigenously developed rocket — and balloon-borne photometers.



▲ **2.6** Representative figure for the overall energy budget of the earth's atmosphere. The relative magnitude of the incoming and outgoing radiations are shown.



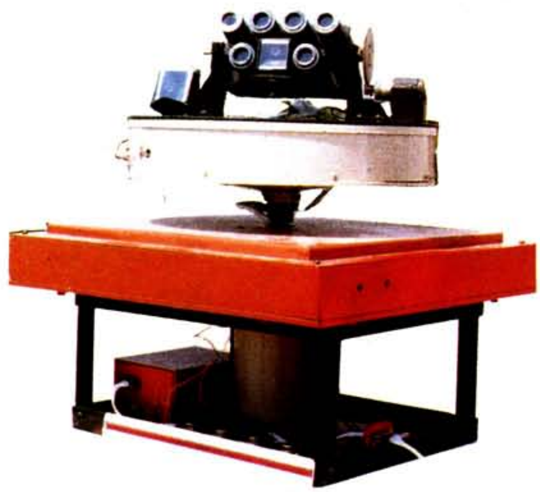


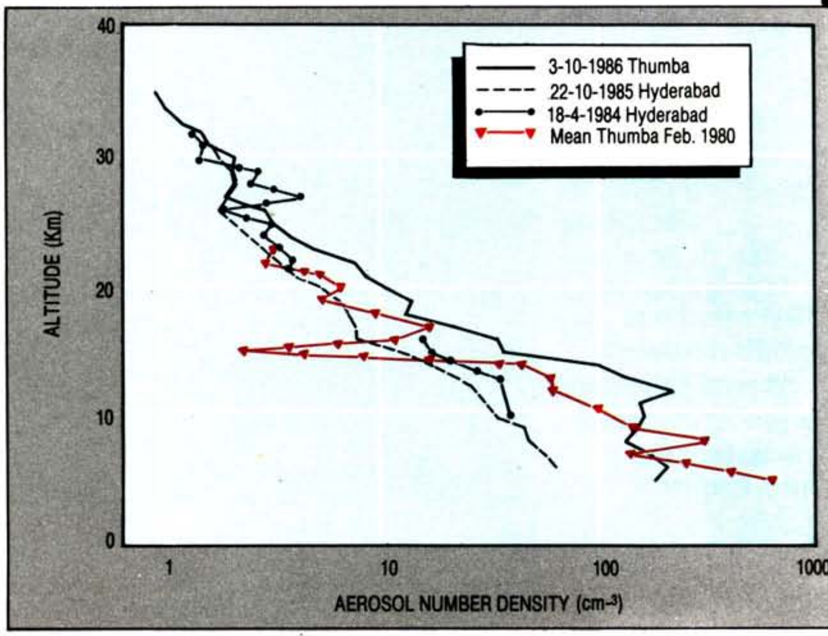
▶ **2.7 (a)** Gas chromatograph — a very sophisticated and sensitive instrument for the measurement of minute concentration of trace gases (1 part in 10^{12}).

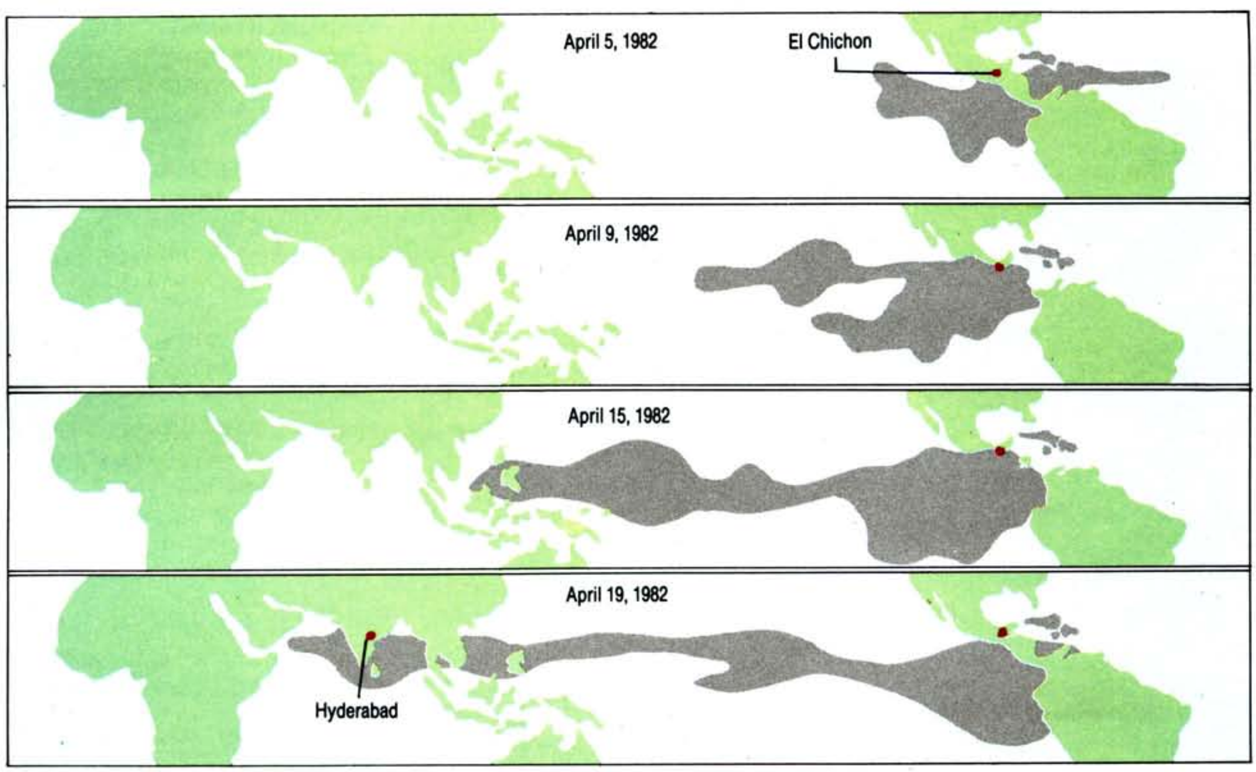
▲ **2.7 (b)** Typical gas chromatogram showing the separation of various halogenated hydrocarbons in air sample.

growth rates of these gases and to study their effect on ozone depletion and climate. These trace gases which are in extremely low abundances are being accurately determined at PRL by gas chromatographic techniques (Fig. 2.7).

In addition to the Greenhouse gases, tiny dust particles (size 0.01 to 10 microns) are present in the atmosphere. These particles known as aerosols also affect the radiation balance, weather and climate. They serve as nuclei for condensation of other smaller particles, gaseous molecules and ions. This changes the neutral composition, ion chemistry and electrical properties of the atmosphere, particularly below 40 km altitude. The sources of aerosols include volcanic eruptions, deserts and industries. Realizing the importance of aerosols in climate, atmospheric composition and electrical properties, studies on their abundance and size distribution are being made by PRL







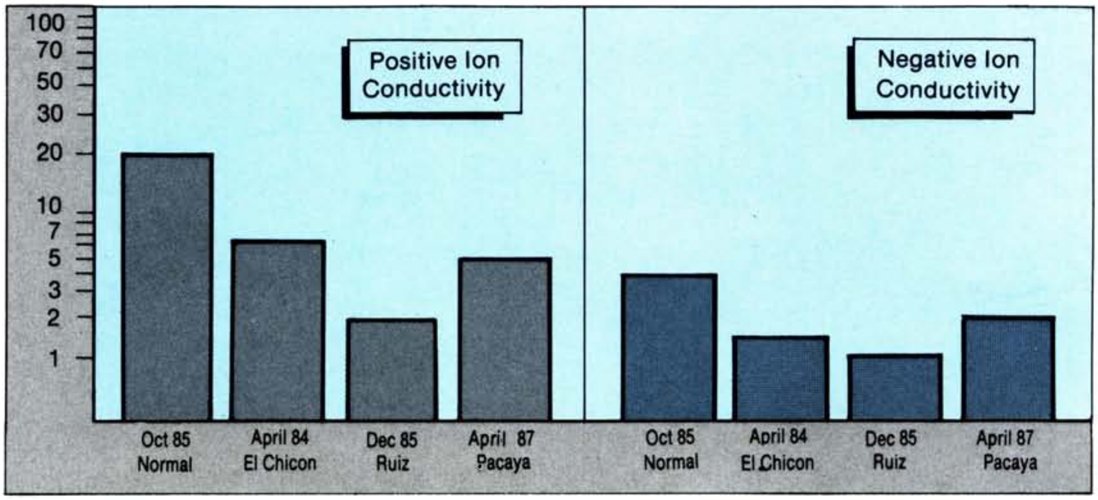
2.8 (a) An automatic suntracking multichannel photometer used for the measurements of aerosol number density and size distribution on balloons.

2.8 (b) Aerosol number densities obtained from an equatorial station Thumba and Hyderabad, a low latitude station, on different occasions.

2.8 (c) Volcanoes are potential sources of aerosols. The Elchicon volcano is one of the most intense of its kind. The volcanic dust coverage in its different phases of spreading is depicted.

scientists using indigenously developed rocket-and balloon-borne photometers (Fig. 2.8). Our results indicate that volcanic eruptions play a major role on the abundance of aerosols, which in turn effect the electrical conductivities in the atmosphere (Fig. 2.9.). Significant differences obtained in the positive and negative ion conductivities have been explained on the basis of mass differences in the positively and negatively charged (ions) aerosols. These positive ions are mostly hydrated ions with mass in the range of 55 to 70 atomic mass units (amu) while the negative ions are heavier ions of nitrate and sulphate composition having mass in the range of 270 to 300 amu. This mass difference causes the difference in the ion mobility and hence in the conductivity.

Middle atmospheric dynamics is one of the important topics wherein significant contributions have been made. The altitude profile of one of the least known

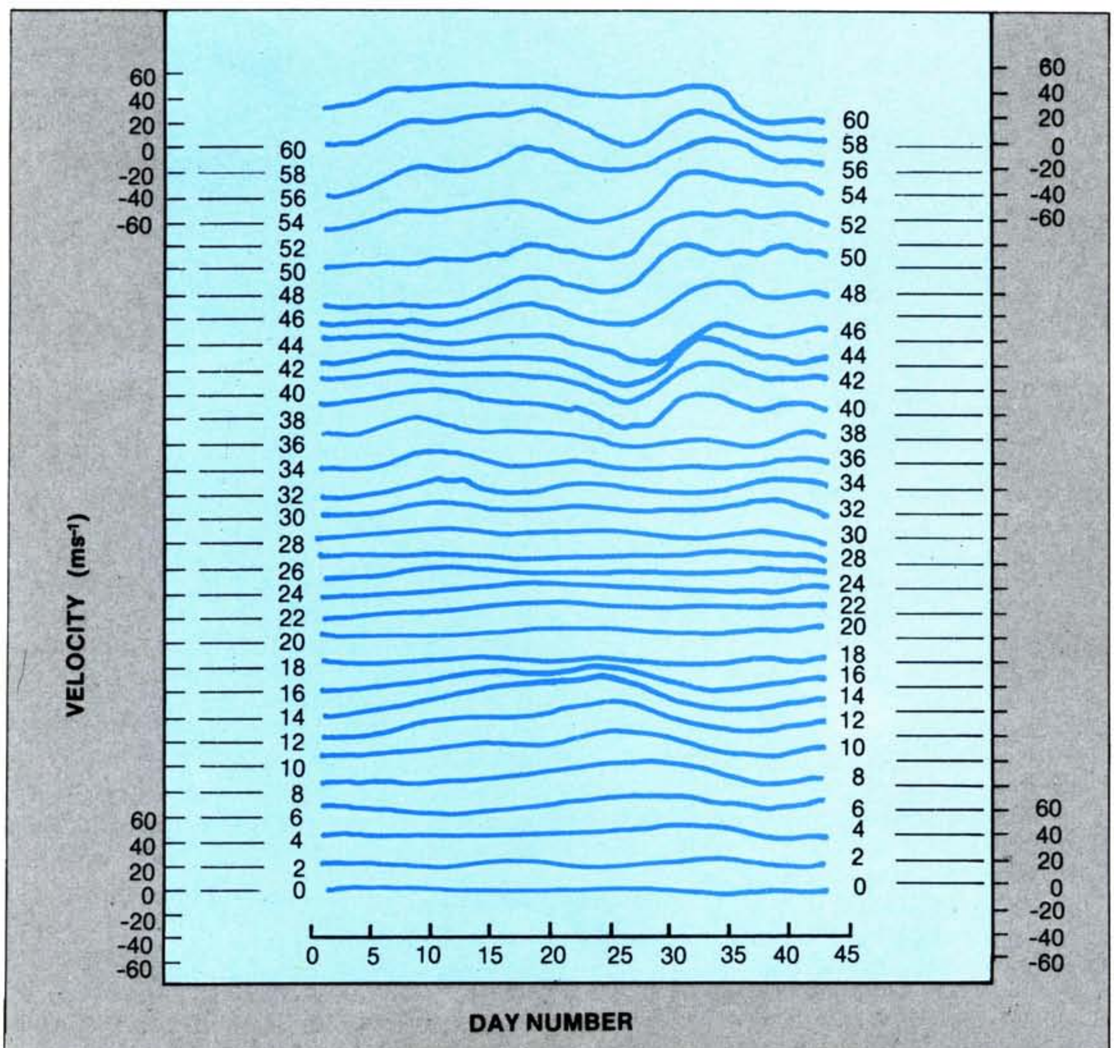


Determination of middle atmospheric dynamical paremeters is vital for theoretical calculations and modelling.

▲ **2.9** The effects of volcanic dust is to alter the electrical properties namely the conductivity of the middle atmosphere as shown above.

▼ **2.10** The middle atmosphere is full of wave activity as seen from a multi-rocket experiment conducted from SHAR (Sriharikota) during 1986.

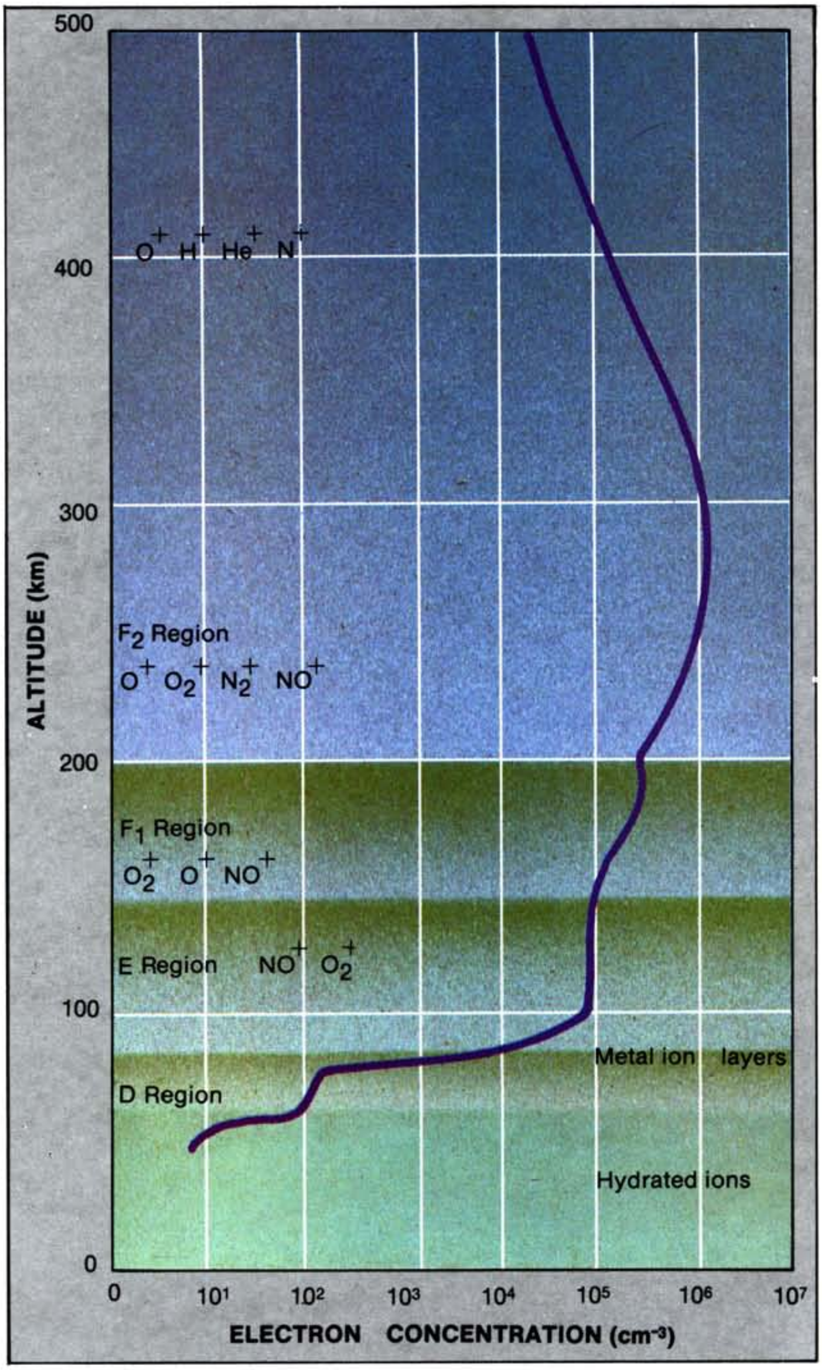
parameters namely, the eddy diffusion coefficient, has been successfully determined by releasing chemicals at different altitudes and measuring the dispersion rates of these clouds. The unambiguous determination of this parameter is vital for theoretical calculations and also in the formulation of models. A major campaign in three phases was conducted using multiple rockets and balloons to study the wave activity in the equatorial latitudes (Fig. 2.10). The dominant periods, the potential source regions, their propagation characteristics and the nature and the regions of wave/mean-wind interaction, have successfully been delineated for the first time from the three campaigns. It has been identified that long period (>22 days) waves dominate the wave activity. A potential source region around the stratopause has also been identified and ascribed to the absorption of solar ultra-violet by ozone.



UPPER ATMOSPHERE

Above 80 km, many atoms and molecules get ionized by photoionization. This results in the formation of electron-ion pairs (this state of gas is known as the 'plasma' state). Due to high abundance of charged particles, the electrical conductivity of this region is quite high. This region of the atmosphere, where the charged particles significantly control the physical processes, is known as the 'Ionosphere' (Fig. 2.11). The ionosphere is broadly divided into three regions namely the D-, E- and the F-regions. The D-region extends upto an altitude of about 95 km. The E-region extends from 95 km to about 150 km and the higher altitudes can be considered to be the F-region. In the D-region the neutral species far out number the charged particles and the motions are dominated by the neutral atmosphere. The ionization is characterized by a deep minimum around 80 km altitude and at lower altitudes the electron density is much less than the positive ion density. The Earth is like a permanent magnet. The magnetic field of the Earth has a significant influence on the motion of the charged particles in the ionosphere. Further, due to solar heating and the gravitational effects of the Moon, tidal forces are produced in the atmosphere which result in air motion (winds). The motion of ionized air across the geomagnetic field induces electromotive forces which in turn drive currents at levels where the electrical conductivity is large (principally in the E-region). The electrical conductivity of the ionosphere is not uniform in all directions because the Earth's magnetic field allows particles to move freely only along the magnetic field lines. Therefore, current flow is limited only to certain directions. The atmospheric dynamo is global in scales and it manifests itself as an east-west electric field at the geomagnetic equator. Over the geomagnetic equator, the magnetic field lines are horizontal in the north-south direction. This is a special configuration wherein the electric and the magnetic fields are mutually perpendicular and it gives rise to a variety of ionospheric phenomena. One of them is the generation of an

Above 80 km, many atoms and molecules get ionized by photoionization. This region of the atmosphere, where the charged particles significantly control the physical process, is the 'Ionosphere'.



◀ **2.11** Various classification of the ionized part of the upper atmosphere (ionosphere). The classification is on the basis of the different physical properties of the atmosphere.

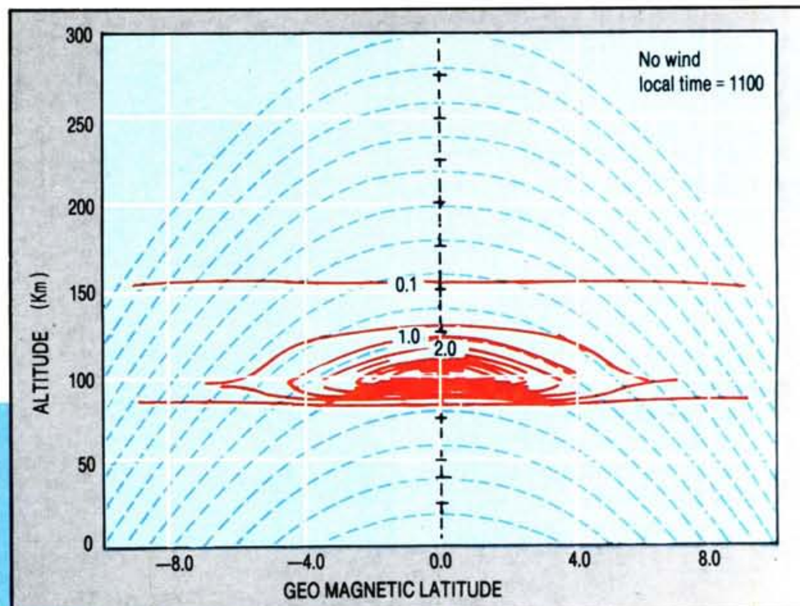
Ionospheric parameters such as plasma densities, irregularities and their movements are continuously monitored by ionosondes, spaced-receivers, phase meters and scintillation receivers.

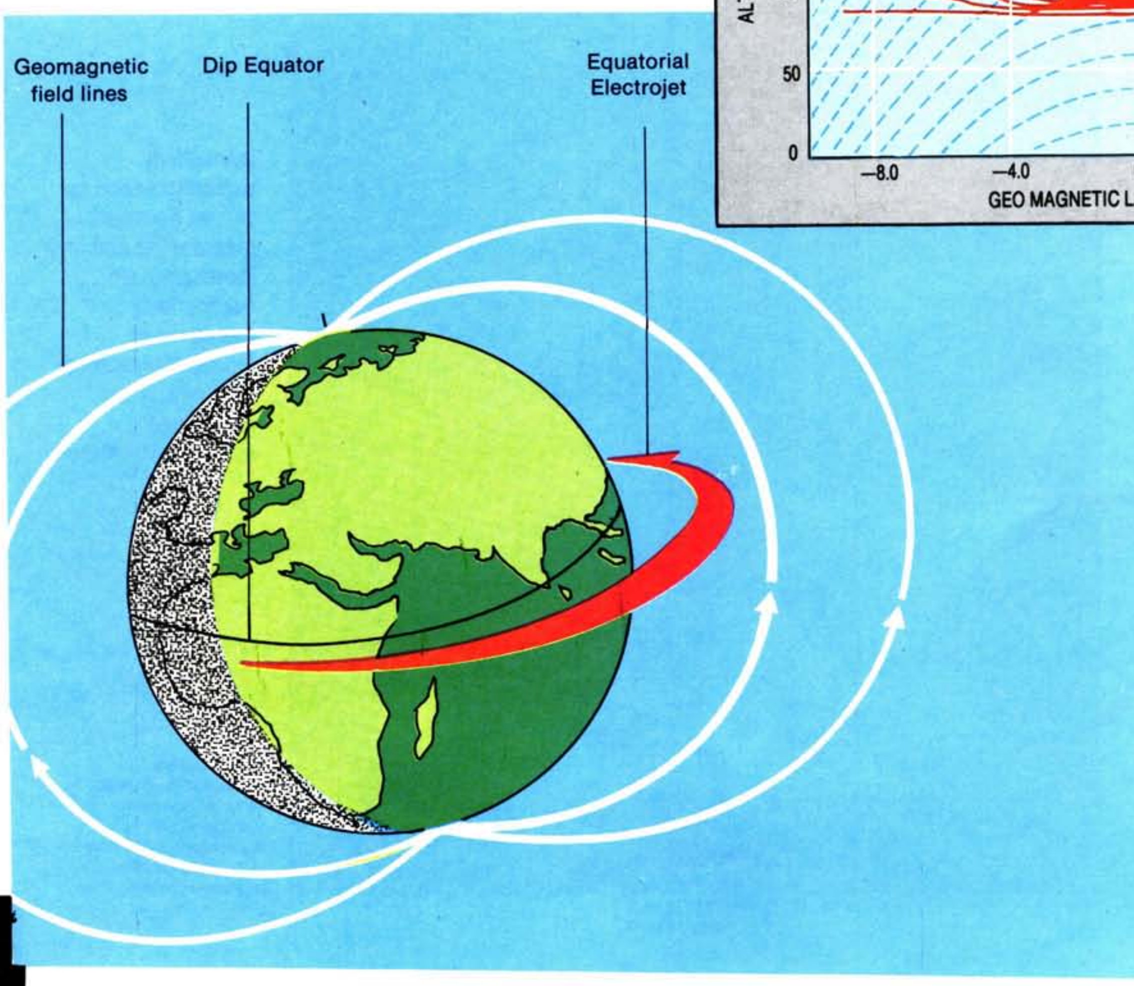
The 'Equatorial Electrojet' is a special geophysical phenomenon which has been receiving considerable attention from PRL scientists.

intense band of current in the east-west direction around 100 km in a narrow latitudinal zone of 3° on either side of the geomagnetic equator (Fig. 2.12). This current flow, with a density of several amperes/ square kilometre is called the 'equatorial electrojet'. This is a special geophysical phenomenon which has been receiving considerable attention from PRL scientists.

In the F-region, however the charged particles dominate the physical processes. In some cases even the properties of the neutral medium, the structure and the dynamics in the F-region are influenced by ionization related processes.

A major programme for study of the D- and E-regions was undertaken at PRL during the seventies. A high power partial reflection radar system with a large antenna array was built to monitor the electron densities in the altitude region of 70 kms to about 100 kms (Fig. 2.13). The system was used to delineate the basic features of the low latitude lower ionosphere and to study the behaviour of the electron density profiles under quiet and disturbed conditions (magnetic storms and solar flares). Another ground-based radiowave experiment that was conducted by PRL scientists during the period was the study of ionization drifts by the Spaced Receiver Technique. Extensive measurements were made at Ahmedabad, Udaipur, Trichirapalli and Thumba to study the drifts both outside and within the electrojet belt. This technique measures the actual electron

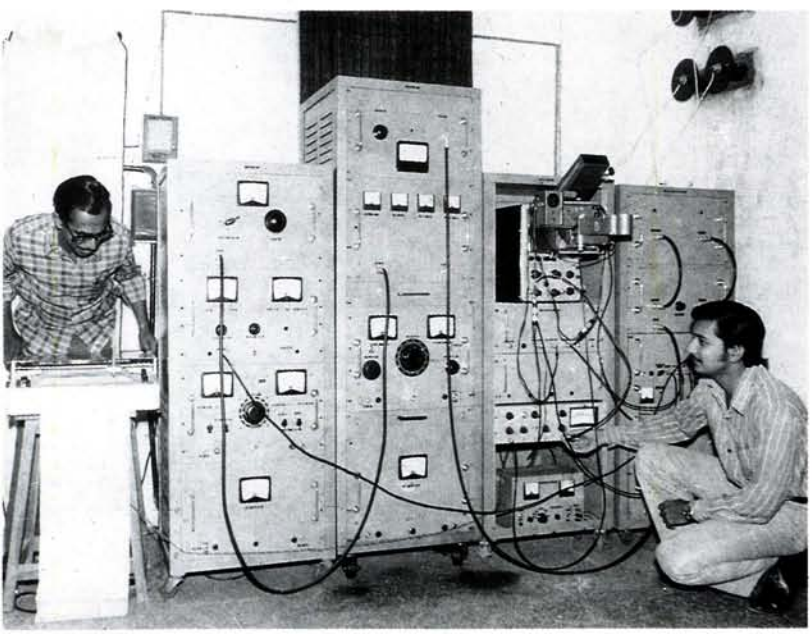


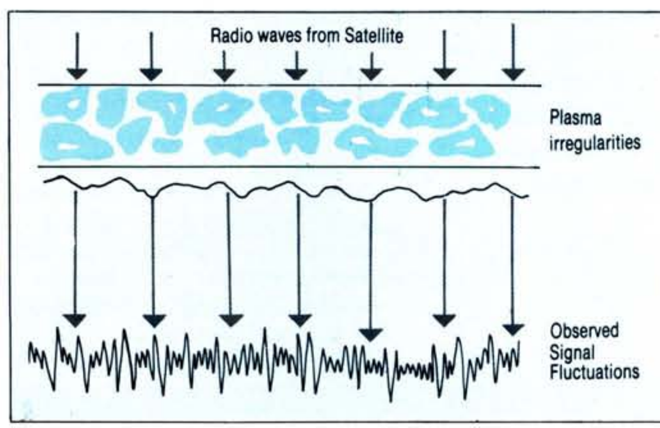


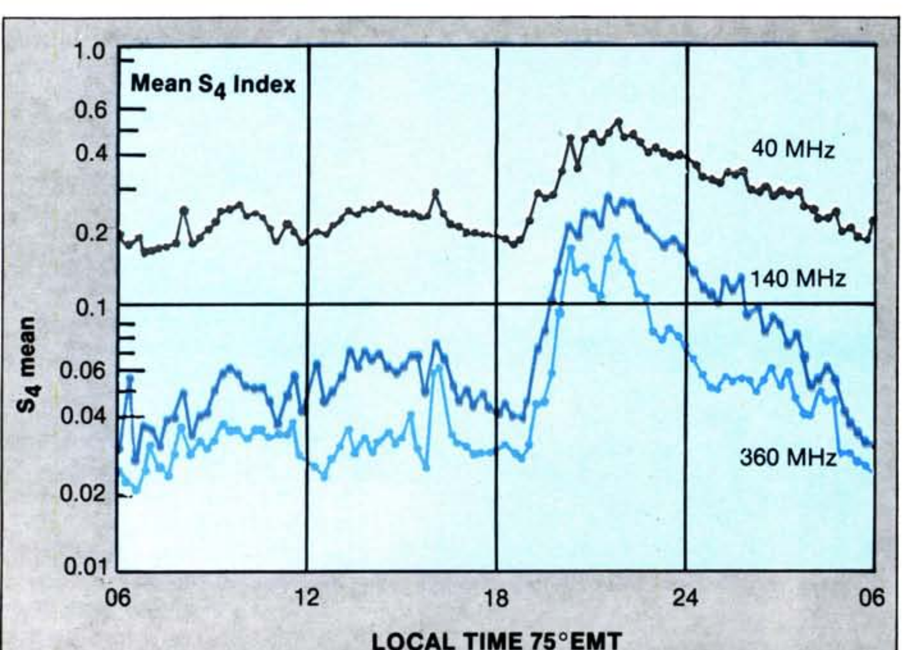
◀ **2.12** An artist's view of the 'equatorial electrojet' over the dip equator. The east-west cross-sectional projection of equatorial electrojet computed for a local time of 1100 hrs extending to 10° on either side of the dip equator. The dotted lines represent the geomagnetic lines of force. (inset) velocities in the medium and hence can monitor the day to day behaviour of the electrojet as such. Extensive measurements were made to study the morphology of drift in low latitudes, its dependence on local time, season, solar and geomagnetic activity, relation with the electrojet current strength and equatorial spread F, (another equatorial F-region phenomenon) and the effects of external influences such as the interplanetary magnetic field on it.

Information on the E- and F-region parameters could be obtained by means of ground-based satellite beacon studies. Receiving signals from VHF and UHF beacons onboard geostationary satellites helps in studying not only the total (integrated) ionization content but also the ionization irregularities. Multistation Radio Beacon studies in 1975–76 using ATS-6 satellite that was stationed over India enabled an exhaustive study of the ionization irregularities and also mapping of the total electron content (TEC) over the Indian sub-continent. From the scintillation measurements it has been shown that the ionospheric irregularities have a wide spectrum of scale sizes and also their occurrence maximizes around 2100 hrs during low solar activity periods (Fig. 2.14). The total electron content measurements revealed lunar oscillations around the anomaly crest region ($\pm 20°$ dip latitude) (Fig. 2.15). Further a very close coupling has been shown to exist between the equatorial electrojet strength and the total

Receiving signals from VHF and UHF beacons onboard geostationary satellites helps in studying not only the total (integrated) ionization content but also the ionization irregularities.







▼ **2.13** A powerful partial reflection radar built in PRL for lower ionospheric (D-region) studies in the seventies. The radar operated in 2.523 MHz, 50 KW peak power and had an antenna array covering 25 acres of land.

▲ **2.14 (a)** Presence of plasma density irregularities in the path of radio waves causes the phenomenon of scintillation. These scintillations are seen as fluctuations in the amplitude of the received signal from a beacon satellite.

◀ **2.14 (b)** Time variations in the scintillation parameter (S_4 at different frequencies).

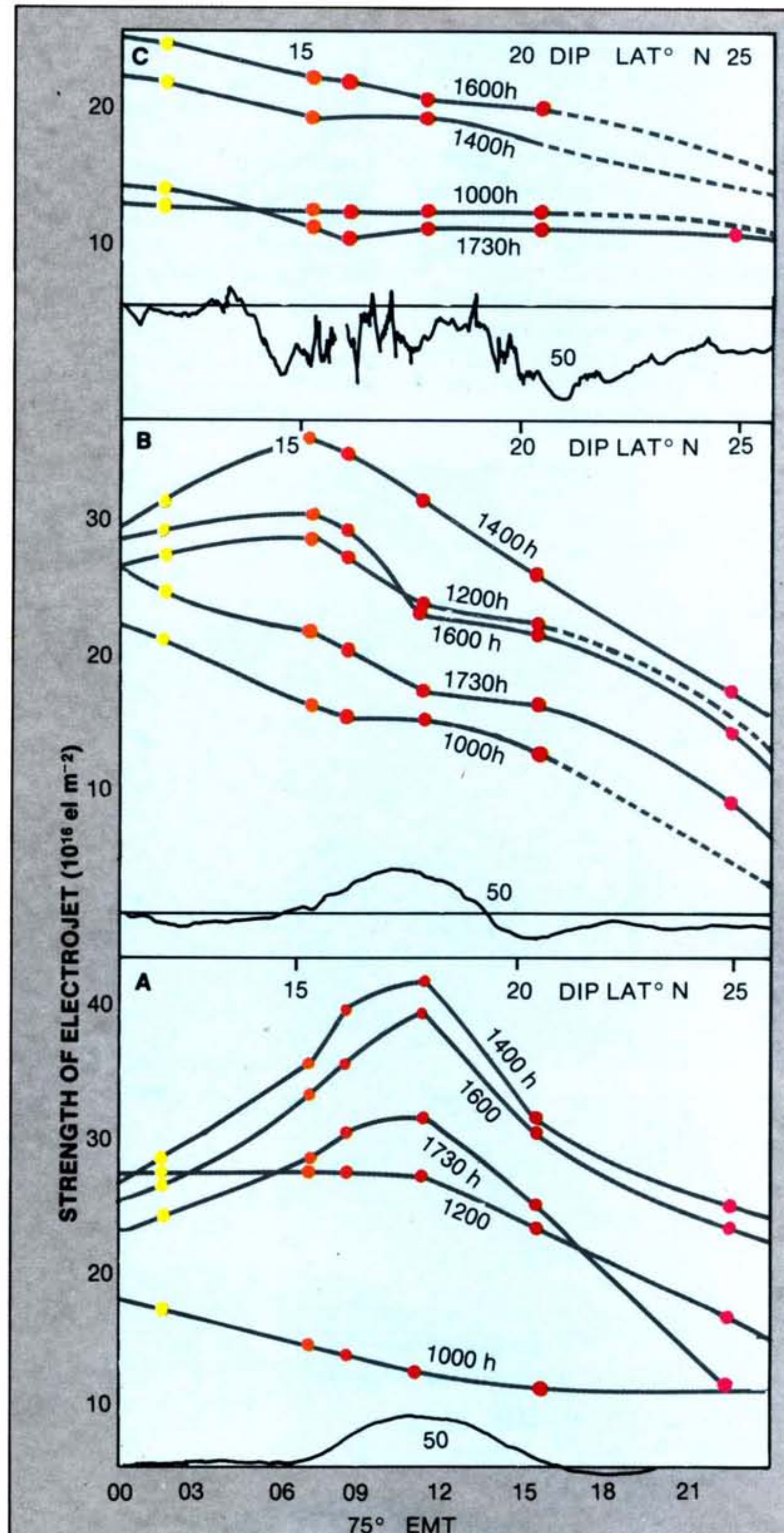
A very close coupling has been shown to exist between the equatorial electrojet strength and the total electron content. The TEC increased with the intensity of the electrojet though with a small time delay.

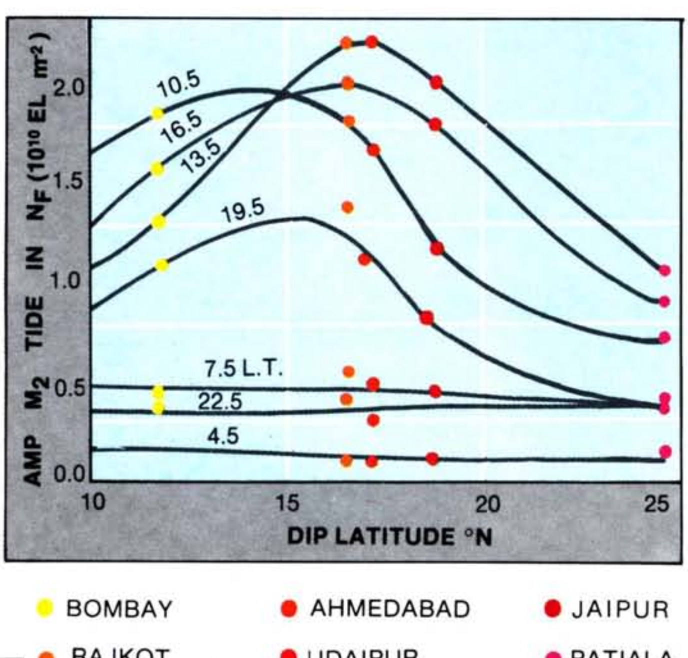
In India, we have the geographical advantage of the magnetic equator passing through the southern tip of the country.

PRL scientists have fully utilized this advantage and have made pioneering contributions to the understanding of the equatorial electrojet and associated phenomena.

electron content. The TEC increased with the intensity of the electrojet though with a small time delay. During reversed electrojet as well as during disturbed conditions TEC registered changes accordingly (Fig. 2.16).

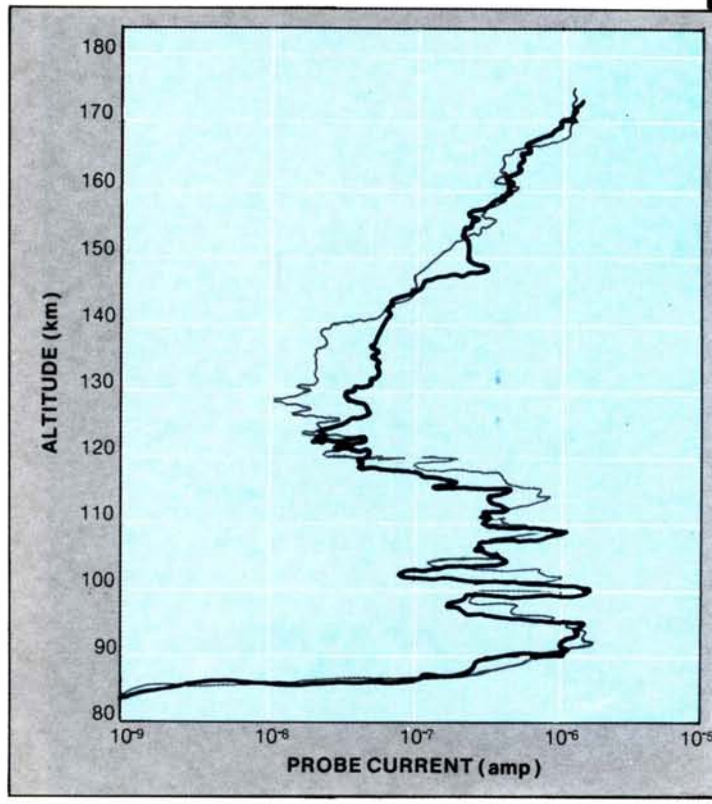
In India we have the geographical advantage of the magnetic equator passing through the southern tip of the country. The Thumba Equatorial Rocket Launching Station (TERLS) was established mainly for the investigation of the equatorial ionosphere, especially the equatorial electrojet and associated phenomena. PRL scientists have fully utilized this advantage and have made pioneering contributions to the understanding of the equatorial electrojet and associated phenomena. For nearly two decades now, PRL scientists have been making extensive, continuous and detailed studies in the equatorial ionosphere using sophisticated techniques developed inhouse. These studies constitute a major part of presently available observations on equatorial ionosphere.





One of the most significant developments is a special probe, the Langmuir probe which can measure, with a high resolution, very weak and rapid fluctuations in the electron densities in the ionosphere (Fig. 2.17). Fluctuations in the electron densities (irregularities) arise out of intricate plasma processes in the equatorial ionosphere and they have a profound influence on radio wave communications. From the shapes and sizes of the irregularities PRL scientists have identified plasma processes responsible for their generation. Further the altitude of the electrojet current flow, the vertical structure (variation of current intensity with altitude) and the overall variability like, within a day, seasonal and with solar activity have been investigated using indigenously developed magnetometers. These measurements formed the first set of comprehensive in-situ measurements of the electrojet from the Indian zone (Fig. 2.18).

The charged particles in the ionosphere are essentially embedded in a large concentration of neutral particles, the ratio being less than (1/1000). Therefore, any changes in the neutral atmosphere promptly affect the ionosphere. By conducting a systematic programme of rocket measurements from Thumba for more than a decade it was demonstrated that the turbulent mixing in the lower atmosphere has a significant control over the distribution of the neutral constituents higher above. Further, it was shown that metallic atoms/ions are responsible for the formation of layers of ionization having an altitude extent of a few kilometres. Sophisticated electric field probes developed in PRL have provided the complete spectrum of electric field structure in the E- and F-regions of the ionosphere.

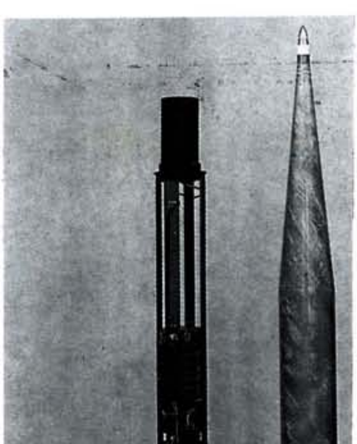


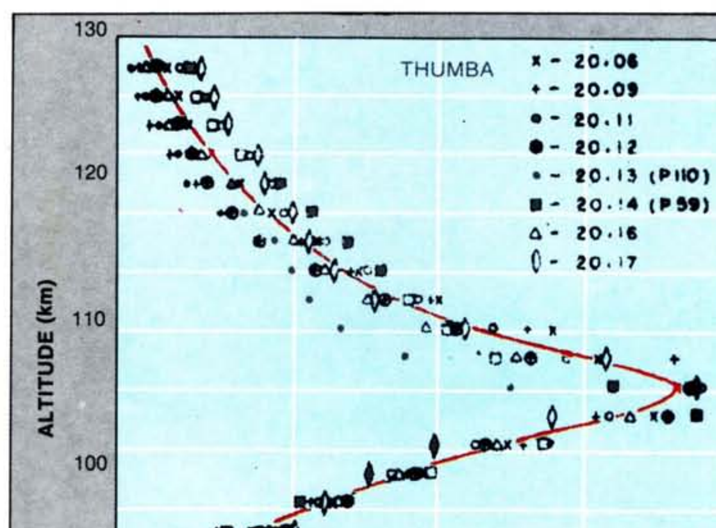
▲2.17 (a) Plasma probes for making insitu measurements of plasma parameters like electron density, electron temperature, and ac electric fields have been developed in PRL. A combination of such probes in the payload section of a rocket is shown.

▼2.18 (a) The intricate rocketborne magnetometer built in PRL for measuring the altitude variation of the electrojet current intensity.

▲2.17 (b) Large scale structures in the plasma densities over the equator as seen by a high frequency Langmuir probe.

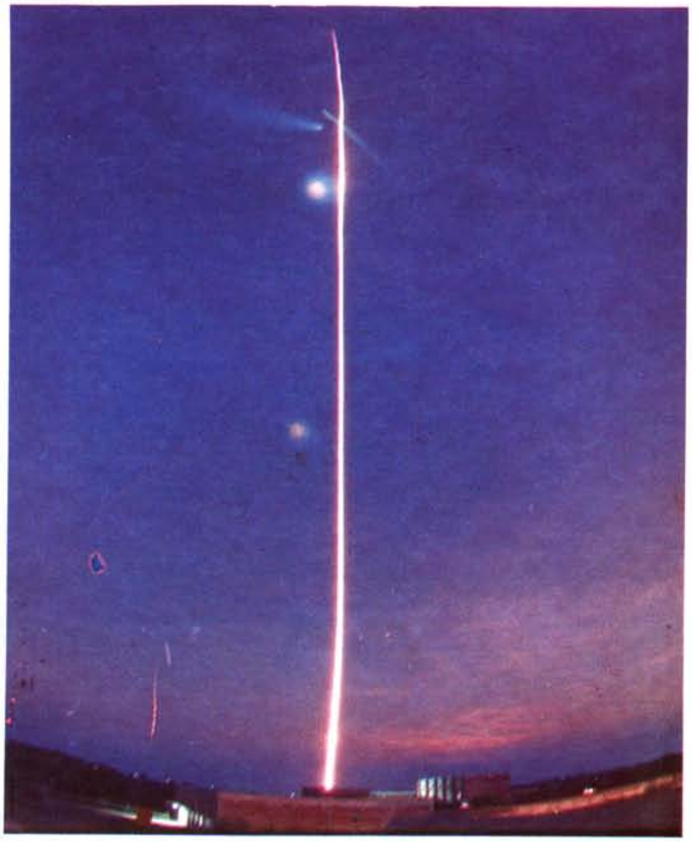
▼2.18 (b) The vertical distribution of normalized current density measured during noon time flights over Thumba.





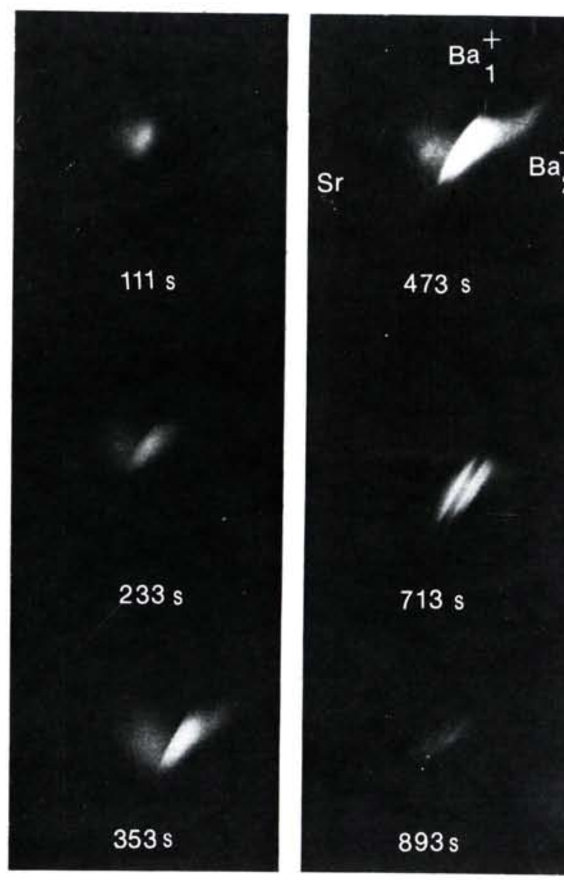
Apart from these, PRL scientists have been conducting active experiments in space by releasing colourful clouds of metals like barium, strontium, lithium and sodium both in the form of continuous trails and 'puffs' or 'blobs'. These clouds are used as tracers for the measurement of the dynamical parameters of the atmosphere namely, winds, temperature and electric fields and their altitude variations. Photographs of the clouds taken from ground (Fig. 2.19) at definite time intervals provide these basic informations. Winds and their variabilities have been obtained both in the E- and F-regions. One of the important discoveries in this area is the presence of large scale gradients in the atmospheric electric fields at the onset of equatorial spread-F (Fig. 2.20), a turbulent phenomenon in the F-region of the ionosphere. Another important result is the presence of vertical winds of significant magnitudes (25–40m/s). The presence of such large winds have been shown to have far reaching consequences in the F-region phenomenon like the equatorial spread-F.

Rocket measurements of the upper atmosphere have the advantage of providing an excellent height resolution. However it is an one shot affair. Systematic and continuous measurements are needed to meaningfully understand the complex atmospheric processes. Ground-based experiments have this specific advantage. Ionospheric parameters such as plasma densities, irregularities and their movements are continuously monitored by ground-based ionospheric sounders (ionosondes), spaced-receivers, phase meters and scintillation receivers (Fig. 2.21). A discontinuous feature in the ionization was discovered in the equatorial



▼ **2.19 (a)** Winds and electric fields (DC) in the upper atmosphere are measured by releasing chemicals in the form of artificial clouds and tracking their movements using ground based photography. Wide angle long exposure photograph of a rocket flight and the artificial clouds are shown in the figure.

◀ **2.19 (b)** The high altitude (above 200 km) blob releases depicting the ion (purple) and the neutral (blue) clouds in their different stages of development.

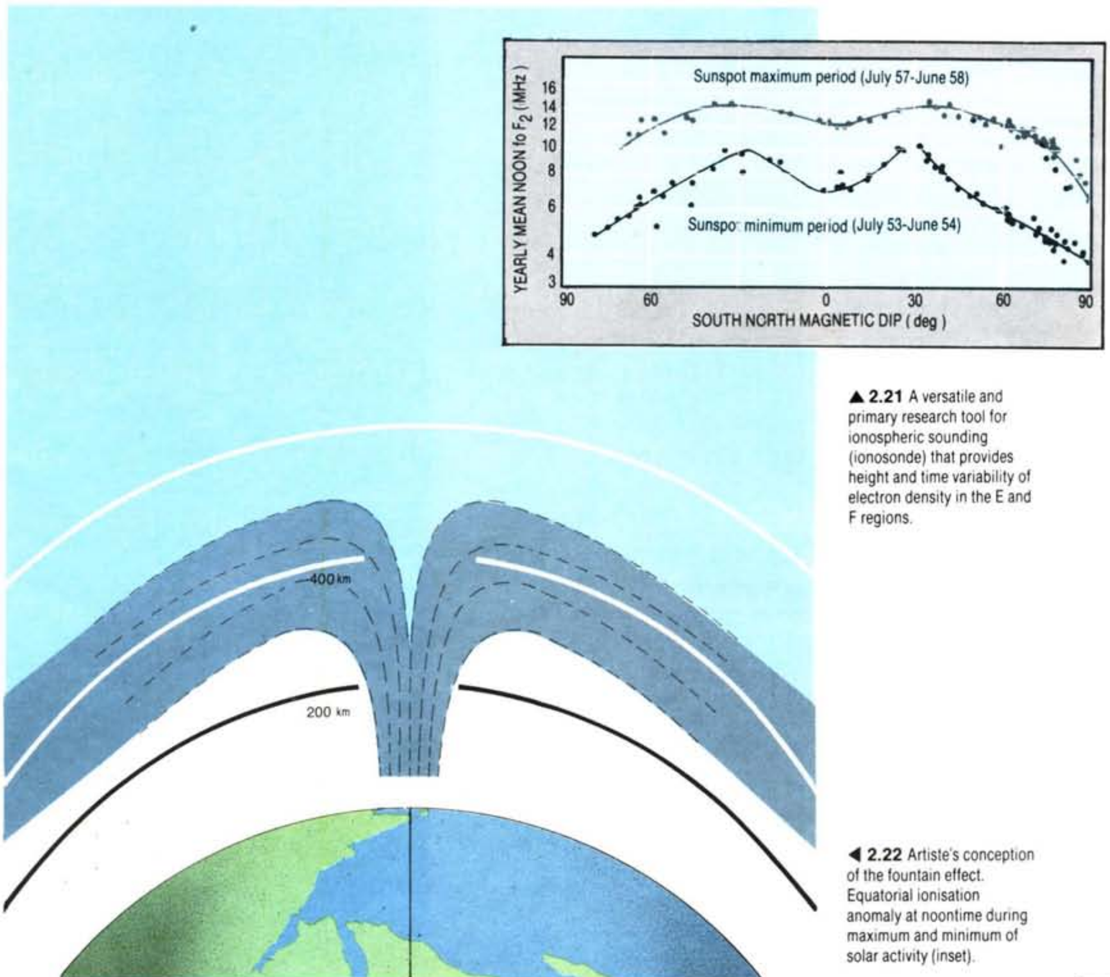


◀ **2.20** An event showing the splitting of a single ion cloud into two ion clouds due to spatial gradient in the ambient electric field.

ionosphere using ionospheric sounders. These are referred to as 'kinks', and have been successfully used as tracers for inferring the vertical motion of the ionization. As this motion is directly controlled by the east-west electric field, an estimate of the electric field has thus become possible, which otherwise is an extremely difficult parameter to measure.

One of the special features of the equatorial ionosphere is the equatorial ionization anomaly. The electron densities in the F-region of the ionosphere over the magnetic equator show with the time of the day, a double humped structure with a minimum during noon. This is unexpected because, with the Sun overhead the electron density should be maximum during noon. The latitudinal variations also show the double humped structure with a minimum over the equator and maximum on either sides, around $\pm 20°$ latitude. This anomalous feature has been explained on the basis of plasma transport from the equatorial region, initially upward over the dip equator and later diffusing to low latitudes along the geomagnetic field lines. This is known as the 'fountain effect'. The plasma is lifted up from the equator to latitudes around $\pm 20°$ from the magnetic equator, referred to as the 'crest region'. Ground-based ionospheric sounding measurements have revealed the development of this anomaly. Ahmedabad is located right under the crest of the equatorial ionization anomaly (Fig. 2.22). This natural advantage of a strategic location and accessibility to the geomagnetic equator, have enabled PRL scientists to make pioneering contributions to the understanding of ionospheric phenomena in the equatorial region. Ground-based optical and radio sounding

▲ **2.21** A versatile and primary research tool for ionospheric sounding (ionosonde) that provides height and time variability of electron density in the E and F regions.



◀ **2.22** Artiste's conception of the fountain effect. Equatorial ionisation anomaly at noontime during maximum and minimum of solar activity (inset).

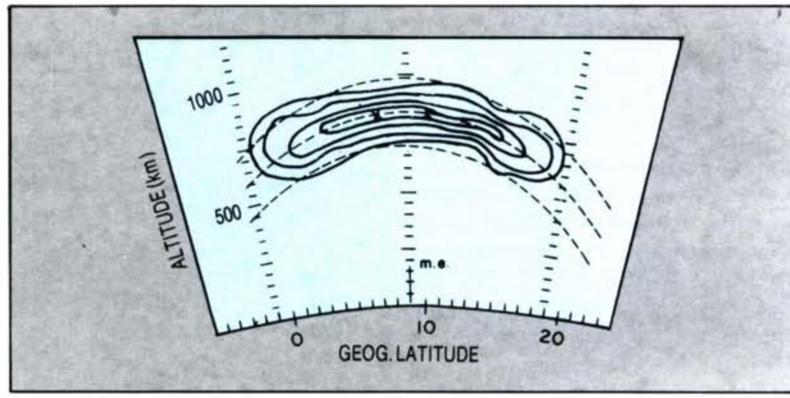
Ahmedabad is located right under the crest of the equatorial ionization anomaly. This natural advantage of a strategic location and accessibility to the geomagnetic equator, have enabled PRL scientists to make pioneering contributions to the understanding of ionospheric phenomena in the equatorial region.

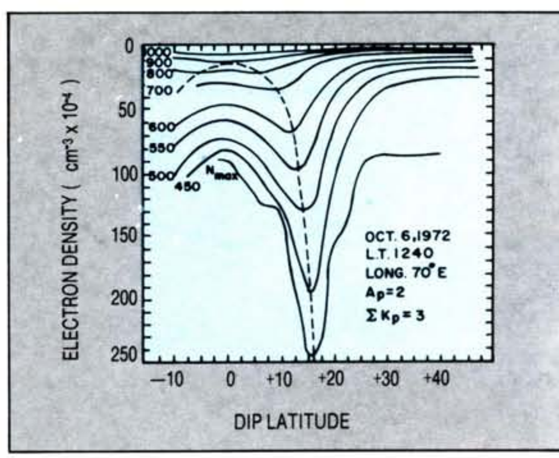
measurements, as well as satellite-borne radio sounders, have been employed in these investigations. New features like the occasional formation of enhanced ionization in the topside ionosphere referred to as 'ledges' have been discovered (Fig. 2.23) and their characteristics have been studied in detail. It had been shown that these ledges of excess ionizations are well correlated with the occurrence of counter electrojet over the equator. The accretion of ionization in the form of a ledge occurs due to the interaction of the ionization crest and the associated dynamical effects with the neutral atmosphere and its dynamics.

One of the most interesting ionospheric phenomena is the emission of faint optical radiations from different regions (85–300 km) of the atmosphere. These emissions known as 'airglow' occur in the atmosphere all the time. For example, molecular oxygen ions (0_2^+) produced in the upper atmosphere (by chemical reactions and by solar ultraviolet induced photoionization) when recombine with ambient electrons dissociate into atomic oxygen. These oxygen atoms are in an excited state. Their transition to ground state gives out a photon.

$$0_2^+ + e \rightarrow 0^* + 0^*$$
$$0^* \rightarrow 0 + h\upsilon$$

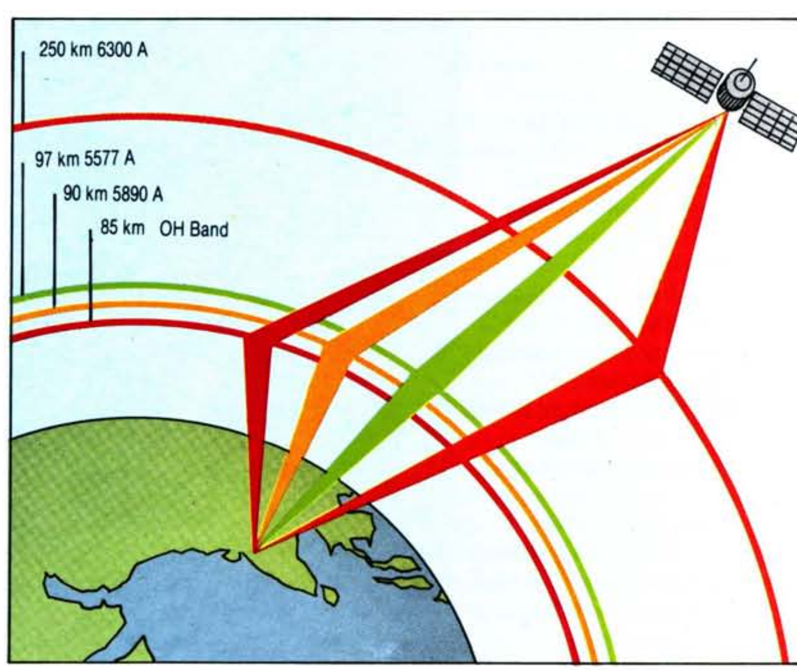
Depending on the excitation level of the oxygen atom, photons of either 6300 A or 5577 A wavelength are emitted. Similar reactions are known to occur at different height regions and airglow emissions of 5577 A, 7774 A, 7320 A, all of atomic oxygen and 5893 A of sodium take place (Fig. 2.24). Measurements of airglow emissions are being carried out at PRL using an array of indigenously developed instruments. Photometers for 6300 A, 5577 A and OH emissions have been developed for the measurement of total intensity. The variations in the intensity with time directly corresponds to changes in the emitting region. This makes the intensity measurements a unique tool to study large scale wave motions such as gravity waves and the development of phenomenon like the equatorial ionization anomaly. New results on the mesospheric temperature on the basis of the





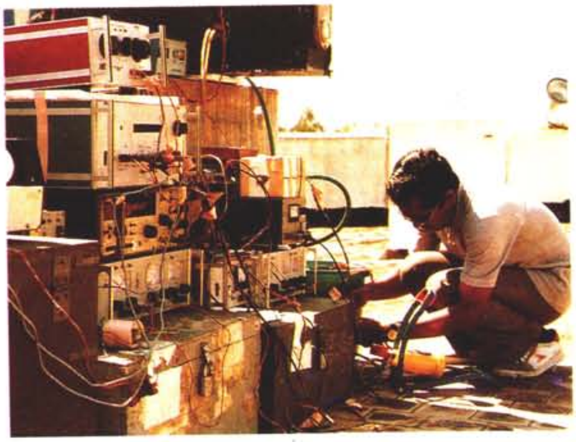
◀ **2.23** A ledge of enhanced ionization in the top side of the ionosphere showing one-to-one correlation with the occurrence of counter electrojet over the equator.

▼ **2.24** An artist's view of the various airglow emitting regions in the upper atmosphere.



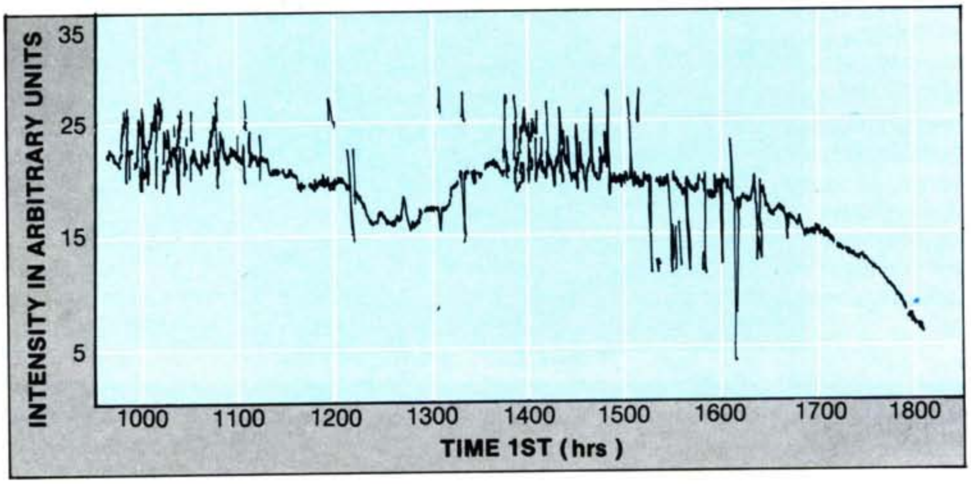
measured ratios of the intensities in the 'OH' emission band have been obtained for the first time. A recent technical breakthrough has been made in PRL, in the detection of faint airglow emission in the presence of bright background continuum similar to daytime conditions. First continuous daytime measurements of airglow have thus become possible (Fig. 2.25). Measurements using high resolution spectrometers (Fig. 2.26) in turn yield the emission line profiles, which contain information about the temperature of the neutral atmosphere and the line-of-sight neutral motions. These experiments have yielded a number of interesting results. For example neutral temperatures around 250 km (6300 A emission region) show occasionally a sudden spurt in their magnitudes by 200–300 °K. These increases have been shown to be closely associated with the occurrence of the equatorial spread-F. Further, the neutral temperatures reveal short period fluctuations of the duration of 30–40 minutes periodicities with a close correlation of the movement of the ionospheric F-layer, revealing the coupling between the neutral and ionized parts of the atmosphere.

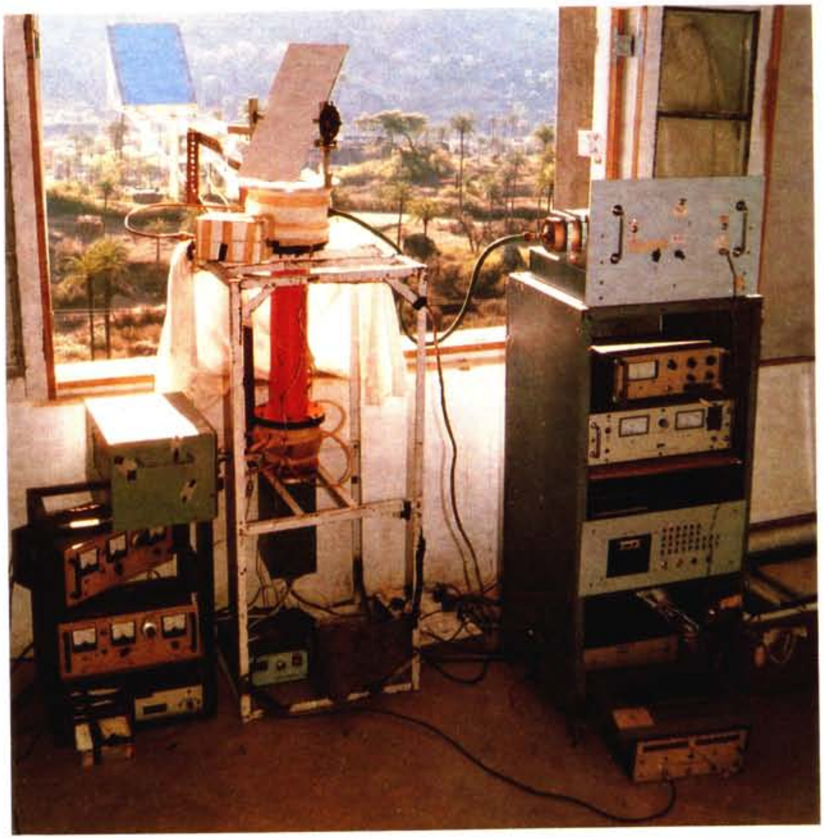
As had been briefly outlined, the upper atmosphere/ionosphere system is a complex space laboratory wherein a variety of chemical processes like photon-atom/molecule interaction, atom-atom, atom-charged particle and atom-molecule reactions occur constantly (Fig. 2.27). To fully understand the various reactions and to bring out the possible missing links, laboratory simulation studies become important. Determination of the rates of various reactions, identification of intermediate steps in a chain reaction and the by-products



◀ **2.25 (a)** Newly developed dayglow photometer for the measurement of faint daytime airglow (dayglow) in the presence of bright daylight.

▼ **2.25 (b)** Typical variabilities of dayglow intensity over SHAR during the course of the day.





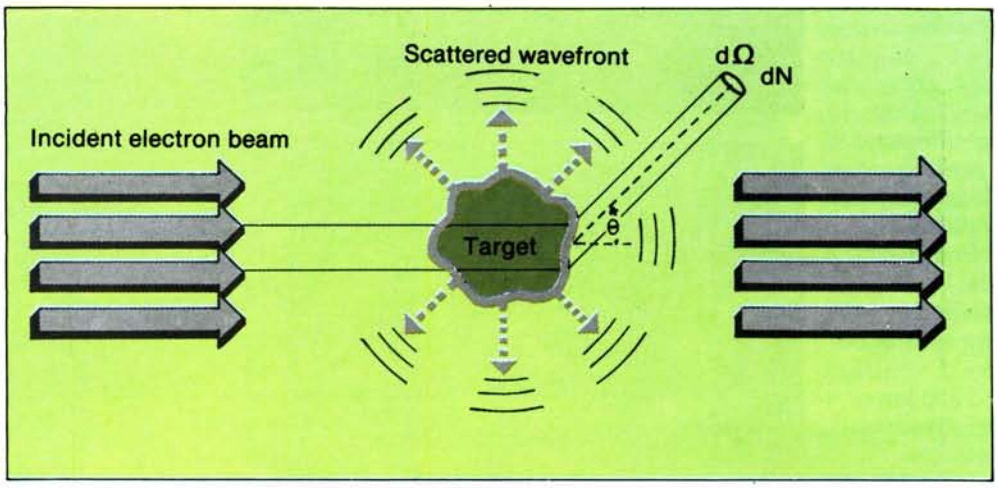
◀ **2.26** A high resolution Fabry-Perot spectrometer for measuring winds and temperatures in the airglow emitting regions.

The ionosphere is a complex space laboratory wherein a variety of chemical processes and atom-molecule reactions, occur constantly. To fully understand the various reactions and to bring out the possible missing links, laboratory simulation studies become important.

are the primary aims of the simulation studies. Reaction cross sections of a variety of species that have relevance to the Earth's atmosphere as well as to other planets have been determined in the laboratory. One of the most significant developments at PRL is the technique of determination of electron scattering cross-sections of atoms and molecules using photoelectron source at low electron energies (Fig. 2.27).

With the development of indigenous satellite technology, space research in India has acquired a new dimension. PRL scientists have been actively participating in these studies from the beginning. Large spatial coverage and in-situ measurements of atmospheric and ionospheric parameters over extended periods under varying geophysical conditions became feasible with the help o orbiting satellites.

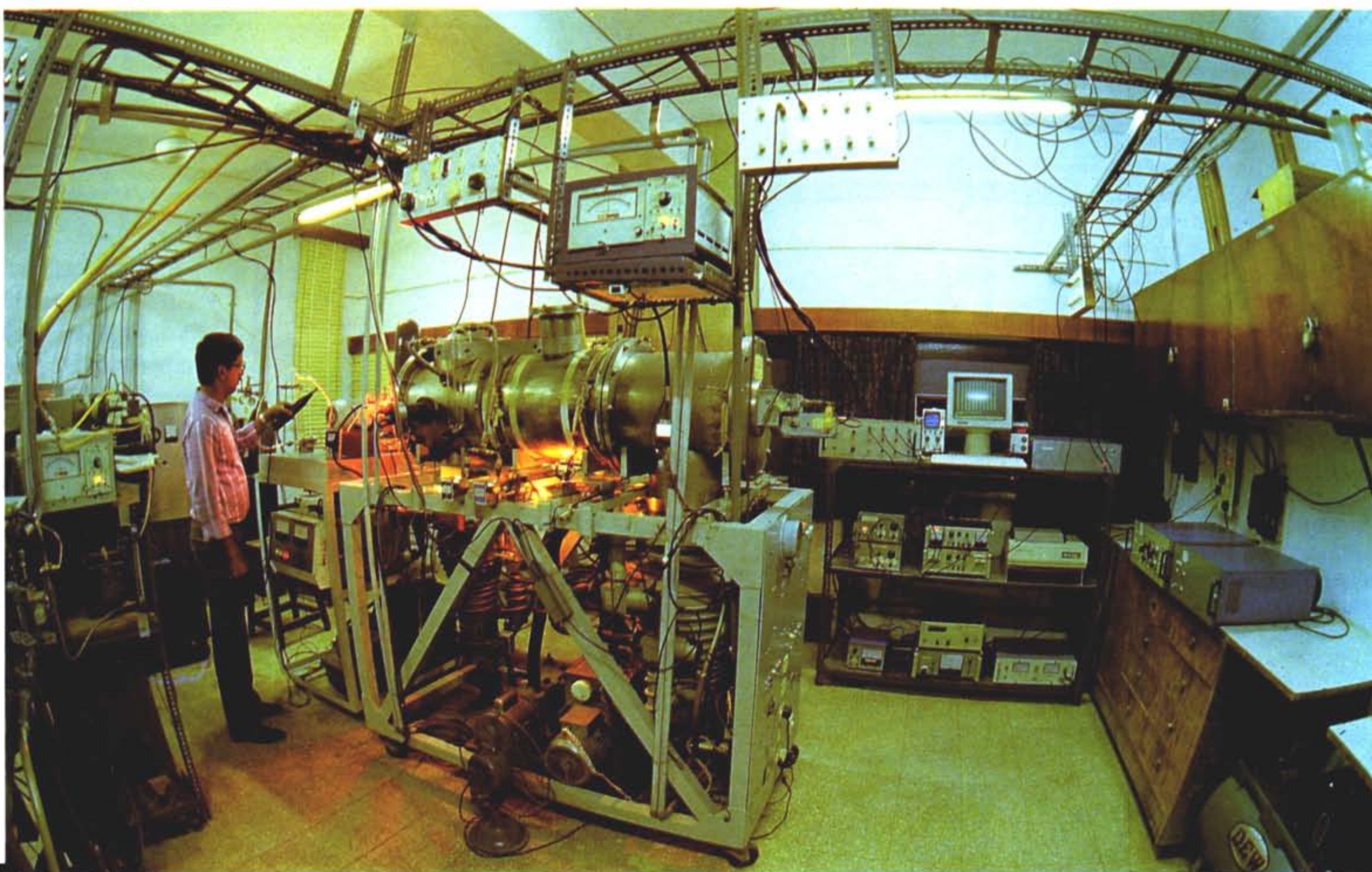
One of the most significant developments at PRL is the technique of determination of electron scattering cross-sections of atoms and molecules using photoelectron source at low electron energies.

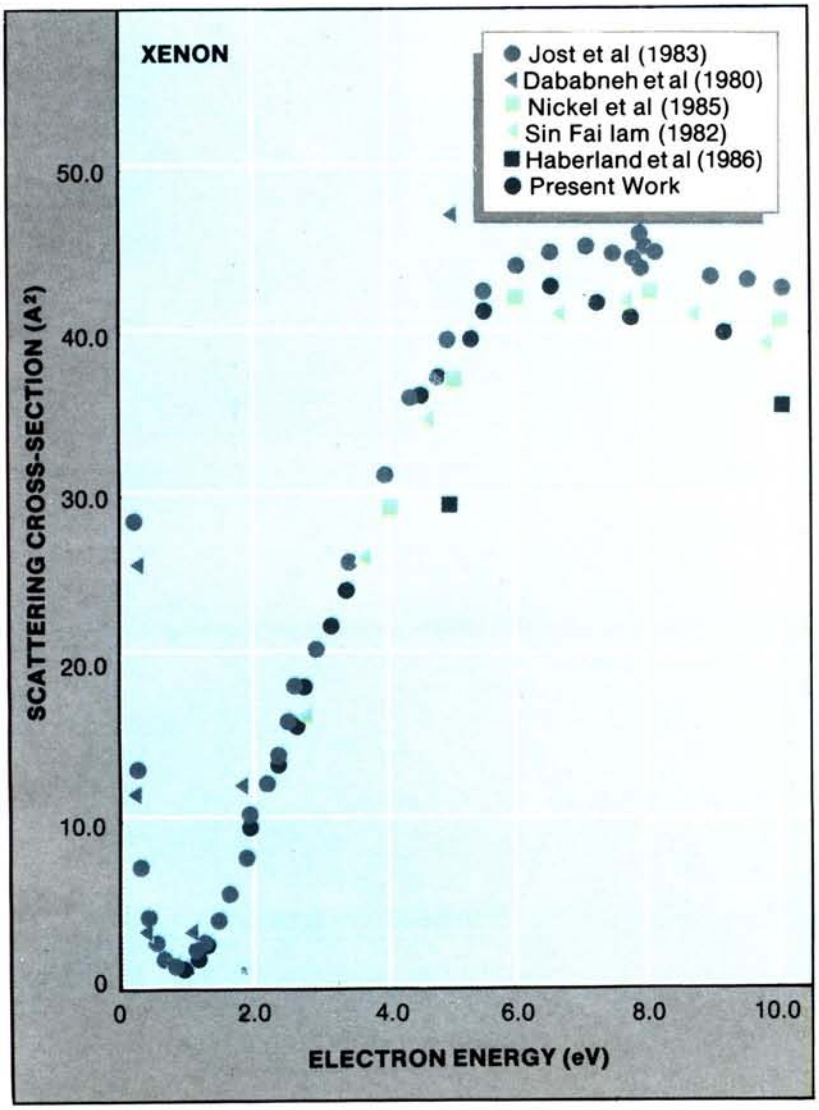


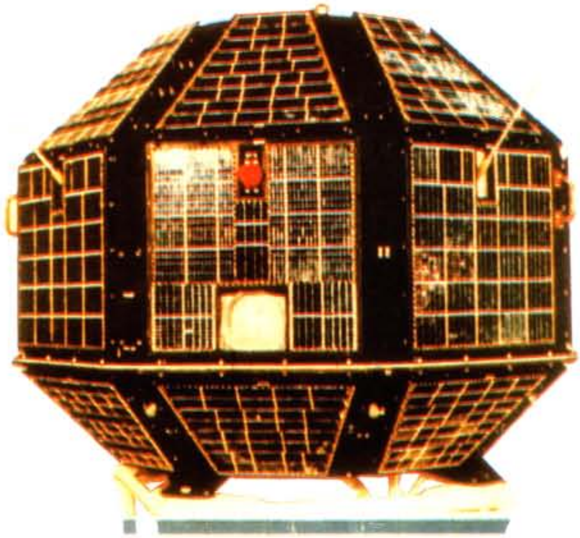
◀ **2.27 (a)** An artistic representation of electron scattering process.

▼ **2.27 (b)** A sophisticated laboratory setup for studying various scattering, ionization and fluorescence processes, which are relevant to planetary atmospheric sciences.

▶ **2.27 (c)** Electron scattering cross-section of Xe at very low electron energies obtained using a photo-electron source.







▲ **2.28 (a)** Aryabhata, India's first scientific satellite launched from a Soviet cosmodrome in 1975.

▼ **2.28 (b)** SROSS (Stretched Rohini Satellite) India's ongoing scientific satellite series being launched using indigenously developed satellite launch vehicle.

The country's first indigenous satellite 'Aryabhata' (Fig. 2.28) launched from a Soviet Cosmodrome had an aeronomy experiment from PRL to make in-situ measurements of the ionospheric parameters. With the development of more powerful indigenous satellite launch vehicles, PRL's satellite programme got a major boost. The third satellite in the Rohini series, SROSS-3 (Stretched Rohini Scientific Satellites) would have a sophisticated experiment from PRL (Fig. 2.28). The very high spatial resolution Langmuir probe and electric field probes of unique geometry constitute the experimental package. Such a high resolution Langmuir probe will be flown for the first time in a satellite. The satellite experiment, likely to be carried out by 1991, would be complemented by a number of ground-based experiments. In the satellite experiment, in-situ measurement of ambient electric fields, plasma temperatures, densities and structures would be made in the equatorial ionosphere. One of the main objectives of this experiment would be to investigate equatorial spread-F.

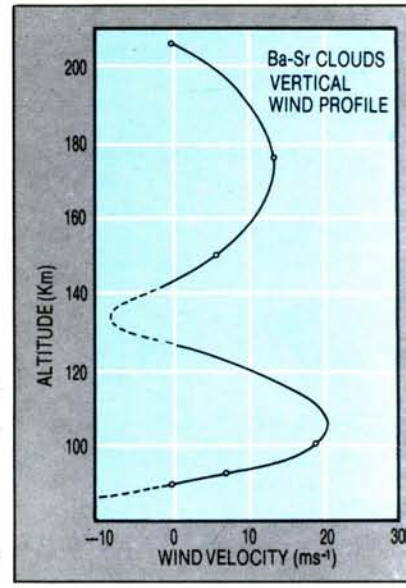
In addition to the wide spectrum of experimental activities, PRL space scientists have also been engaged in theoretical studies of atmospheric processes.

Significant contributions have been made in the modelling of the equatorial electrojet. The electrojet model has very successfully been used in explaining the various observed features of the equatorial E-region. The effect of the neutral wind components, zonal (east-west) and meridional (north-south) in altering the altitudinal and latitudinal electrojet parameters, has been quantitatively estimated (Fig. 2.29). Further, using this model vertical winds have been shown to be capable of reversing the direction of the electrojet, and producing the counter electrojet phenomenon (Fig. 2.29).

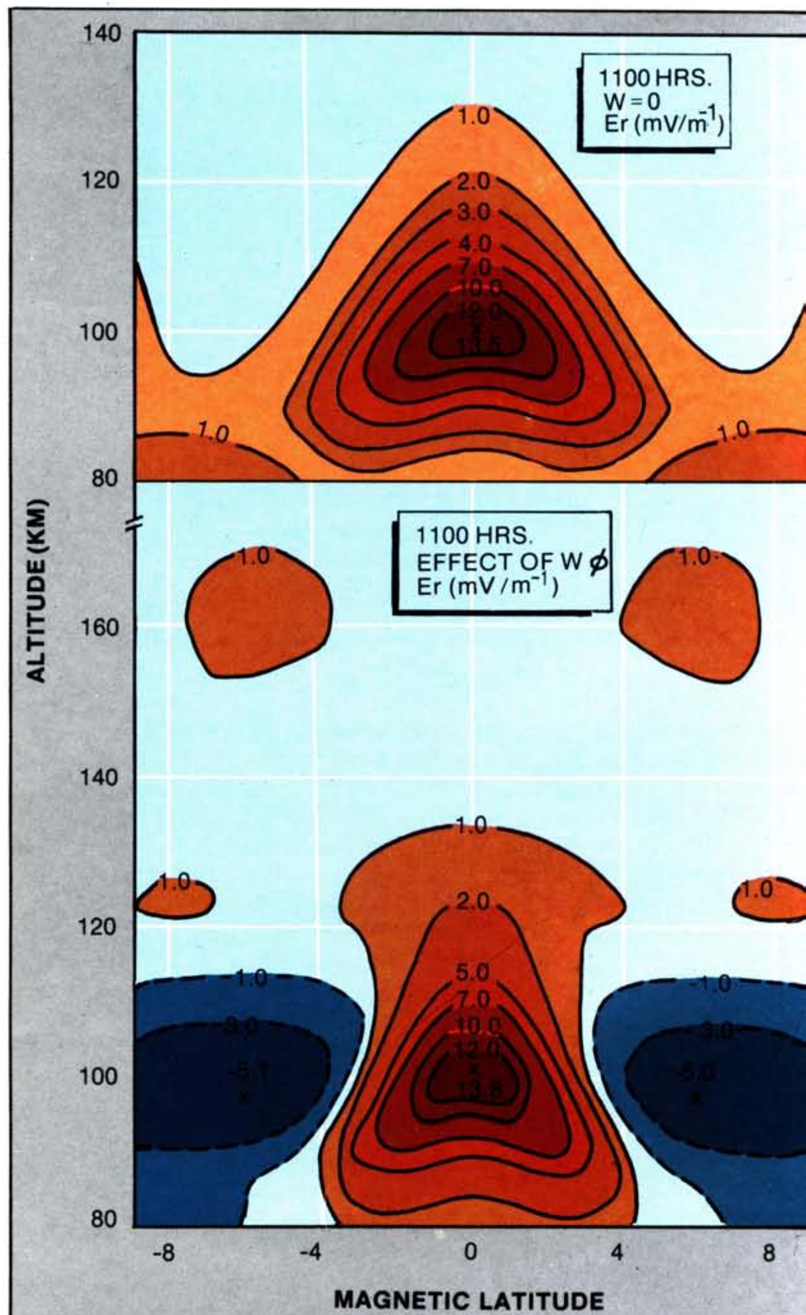
The equatorial spread-F is a complex geophysical phenomenon. Theoretical studies using numerical simulation techniques, are the only means of getting a better insight into this problem. Complex numerical simulation of the equatorial spread-F phenomenon has been accomplished in PRL. The role of neutral dynamics in triggering the plasma instability processes that culminate into spread-F is evaluated for realistic conditions. The significant role of vertical winds and electric fields has been demonstrated for the first time (Fig. 2.30).

Significant contributions have been made in the modelling of the equatorial electrojet. Complex numerical simulation of the equatorial spread-F phenomenon has been accomplished in PRL.

On the whole 'space research' has been a thrust area in PRL and it continues to be so. PRL has played a pivotal role in the establishment of the Thumba Equatorial Rocket Launching Station that has now grown into the giant Indian Space Research Organisation. Two more rocket launching stations, one at Sriharikota and another at Balasore under the Department of Space alongwith a high altitude balloon launching facility at Hyderabad have come into being since then. The pioneering effort by late Professors K.R. Ramanathan and Vikram A. Sarabhai have put India in the space map of the world.



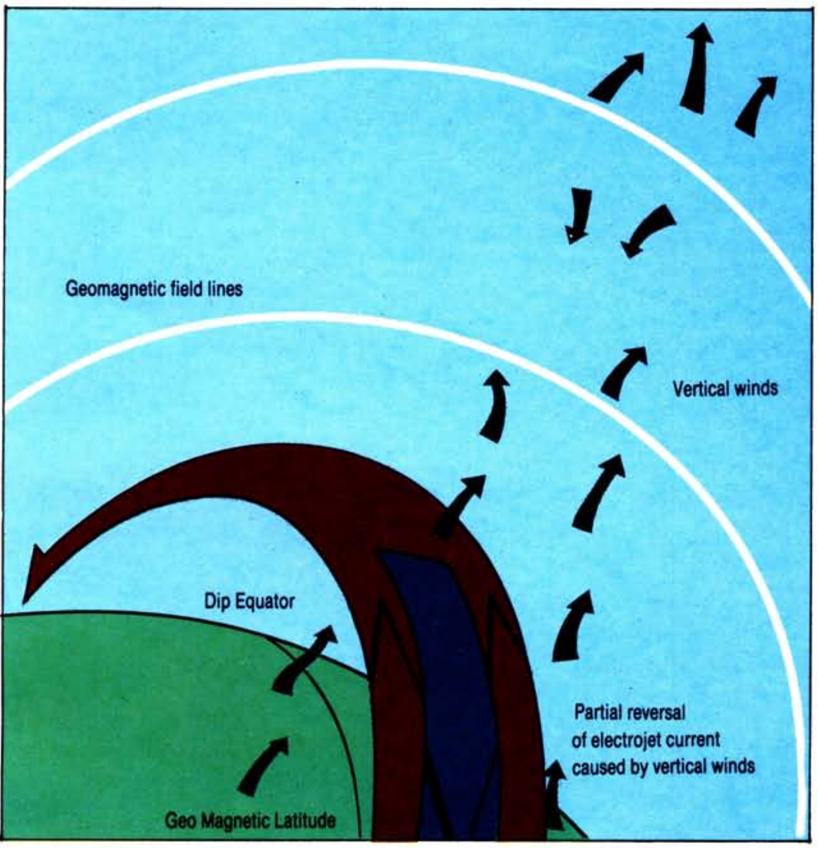
▼ **2.29 (a)** Numerical simulation/modelling is one of the most powerful method to understand geophysical phenomenon completely. An equatorial electrojet model formulated in PRL has successfully been used to study the effect of neutral winds. Effect of zonal wind on the vertical electric field is demonstrated.

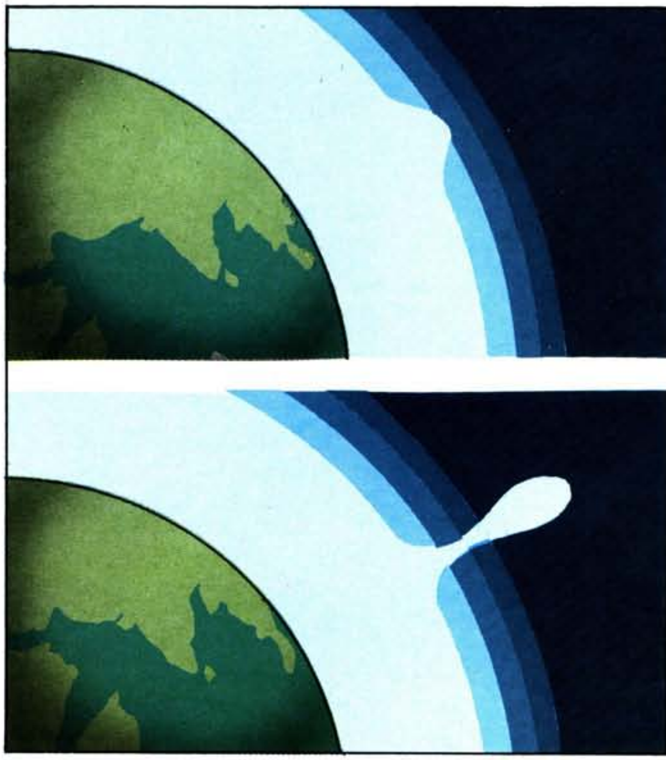


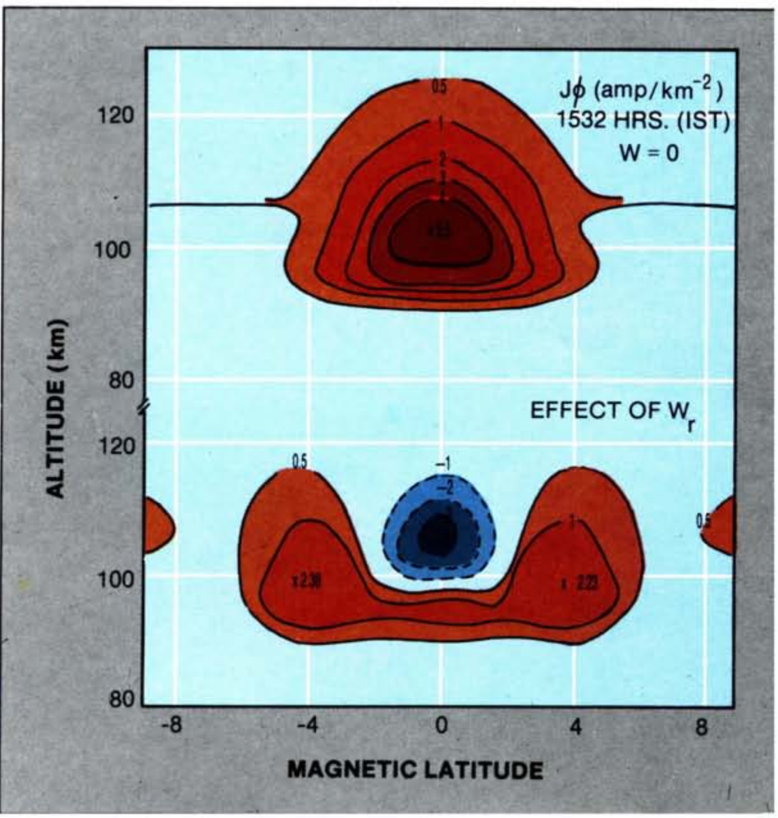
▼ **2.29 (b)** Artist's representation of the effect of vertical winds in reversing the electrojet (counter electrojet);
simulation of a counter electrojet.

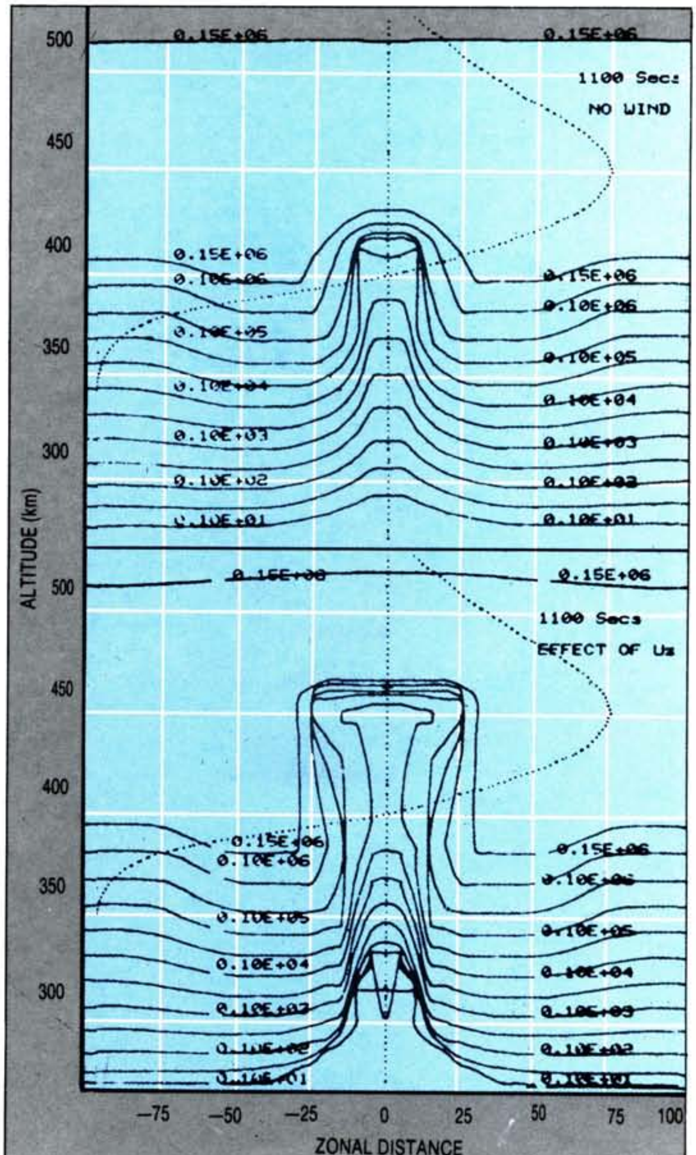
◀ altitude profile of measured vertical winds;

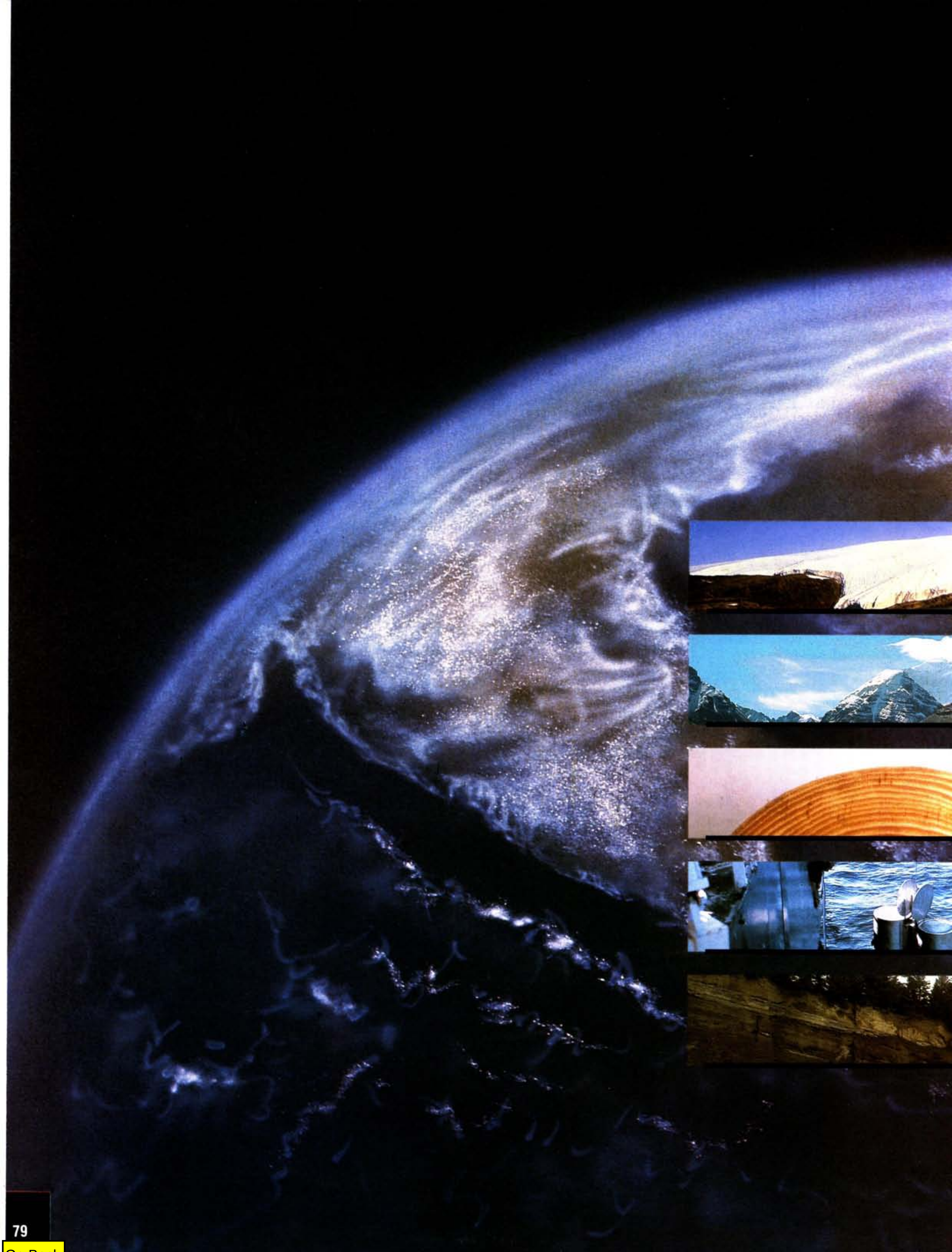
▶ **2.30** Pictorial representation of the evolution of large scale plasma depletions (bubbles) and the effect of vertical winds (downward) in enhancing the evolutionary process which eventually culminates into the night time turbulent F-region known as 'equatorial spread-F'.











Go Back

EARTH SCIENCES

नद्योऽस्य नाड्योऽथ तनूरुहाणि
महीरुहा विश्वतनोर्नृपेन्द्र ।
अनन्तवीर्यः श्वसितं मातरिश्वा
गतिर्वयः कर्म गुणप्रवाहः ॥३३॥

O King!, the rivers are the veins of the gigantic body, the trees are the hairs of His body, and the omnipotent air is His breath. The passing ages are His movements, and His activities are the reactions of the three modes of material nature.

—Srimad Bhagwatam 2:1:33

The fascination of man about the elements of nature, namely, air, fire (energy), water, Earth and space has led him a long way in understanding the origin and evolution of the Earth, its components and the interactions among them. This natural curiosity has over the years blossomed into a field of science, the Earth Sciences. The study of the Earth—its rocks, its oceans and atmosphere and its life forms, though all began long long ago, the knowledge we gained during the past few decades has revealed that all these are intimately coupled components of a complex dynamic system. These studies have served to underscore the need to understand in detail the interactions among the various Earth-system components. PRL is one of the few institutions in the world where such research programmes are being actively pursued. These programmes are aimed at attaining a fuller knowledge of the contemporary processes occurring on the Earth's surface, their history and evolution through time.

The Earth we inhabit has witnessed a fascinating and eventful history ever since its formation about four and a half billion years ago. Records of its history that lie around, an outcrop of a rock, soil layers in a forest, periglacial boulders, fossils in sediments of oceans and lakes all provide us with clues to the processes that have shaped the surface of the Earth. The study of the Earth has been motivated by two considerations, to understand it's development as a planet and to reap benefits for mankind from it. A third consideration added in recent times is man's role in altering the face of the Earth. We, through our quest for better living, are continuously influencing our environment thus eventually contributing to major global changes.

To understand the Earth as a planet we have to start from the very beginning. Soon after its formation the Earth got restructured into three layers, the core, the mantle and the crust. The Earth's surface (crust) is being continuously modified in several ways—by the continued addition of new rocks from the mantle and by its interactions with the atmosphere, the hydrosphere and the biosphere. These interactions result in a slow but steady alteration of the face of the Earth and its life forms. These interactions fall into two groups, the creative and the destructive. The creative interactions cause the building of mountain chains and result from crustal instability and readjustments (tectonic activity). They are driven by the heat contained within the Earth. The creative activities are counteracted upon by the destructive forces of weathering and erosion which try to level the surface of the Earth. Water and wind are the chief agents of weathering and erosion and they derive their energy from the Sun. The eroded materials from the land are deposited as layers of sediment in lakes and oceans. These sediments are a library that contain long term continuous records of the Earth's geological and environmental history. A look at the Earth's history shows that it is a slow succession of events caused by the patient and ceaseless interactions among its components, punctuated occasionally by catastrophes such as those resulting from impact of planetary bodies on the Earth.

The Earth Science research at PRL is aimed to understand many of the creative and destructive processes that shape the Earth's surface and their evolution through space and time. Such a programme naturally encompasses the study of rocks, the water bodies on Earth (glaciers, rivers, ground water, lakes and oceans), environmental recorders (sedimentary deposits, tree rings, sand dunes), the atmospheric constituents and the interactions among them. Many of these observational data would ultimately serve as inputs to quantitative models that attempt to simulate the different earth-system processes and their inter-relationships over various spatial and temporal scales. PRL too has an active programme in this direction, focussing primarily on the atmospheric circulation models and monsoon dynamics. In the following paragraphs we provide a closer look at some of our programmes in solid Earth and hydrosphere.

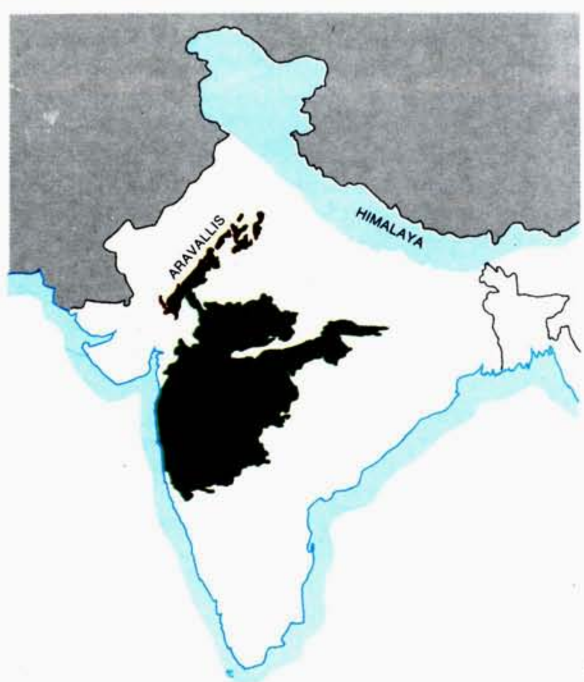
Several questions arise while looking at these intimidating land forms : how old are they ? Where did they come from ? Are they related to each other.......

THE LITHOSPHERE

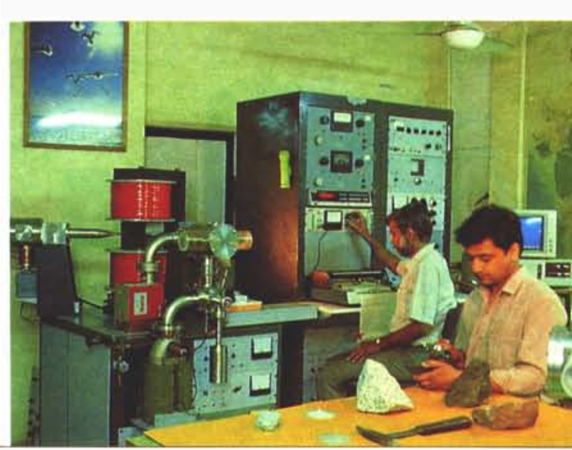
The Earth Science researches at PRL are aimed to understand many of the creative and destructive processes that shape the Earth's surface and their evolution through space and time.

All of us have learnt about India and its geological features, the mountain ranges, plateaus and rivers. The list of mountain ranges would begin with the mighty Himalaya followed by the Vindhyans, Aravallis and the Western Ghats (Fig. 3.1). Several questions arise while looking at these intimidating land forms: how old are they? Where did they come from? Are they related to each other and to other surface features of the Earth? One of PRL's major contributions over the years has been to answer some of these questions, particularly those regarding their age and their source. Determination of the ages of geological samples rely on radioactivity and are based on the study of radioactive elements present in them. The atoms of radioactive isotopes are intrinsically unstable and they decay to more stable "daughter" isotopes, according to a definite rule and a characteristic time constant: the half-life of the radioactive isotope. Several elements possess natural radioactive isotopes, e.g., potassium (^{40}K), rubidium (^{87}Rb) and uranium (^{238}U, ^{235}U). All these elements are contained in rock-forming minerals, some of them such as Rb, U and Th in minute quantities, typically a few grams of the element in a ton (thousand kilograms) of the rock. Precise measurement of both the parent and daughter isotopes is necessary to determine the age of the rock. PRL's research relies on the $^{87}Rb-^{87}Sr$ and $^{40}K-^{40}Ar$ systems and is focussed on the three prominent geologic features—the Himalaya, the Aravalli mountains of Rajasthan and the extensive lava flows (Deccan Traps) that cover parts of the vast Deccan plateau (Fig. 3.2). The Rb–Sr isotopic measurements at PRL are made using an indigenously fabricated mass spectrometer (Fig. 3.3). Detailed investigations based on these isotopes have led to the identification of three major mountain building episodes in Rajasthan, about 3000, 1500 and 750 million years ago and the presence of rocks older than 3000 million years near Udaipur. It is a point of interest

▼ **3.1** The Himalaya : The youngest and highest mountain chain in the world. The Himalaya began forming about 40 million years ago as a result of collision of the Indian and Asian plates and is still rising. PRL through its geochronological studies has contributed significantly to the understanding of the evolution of the Himalaya .



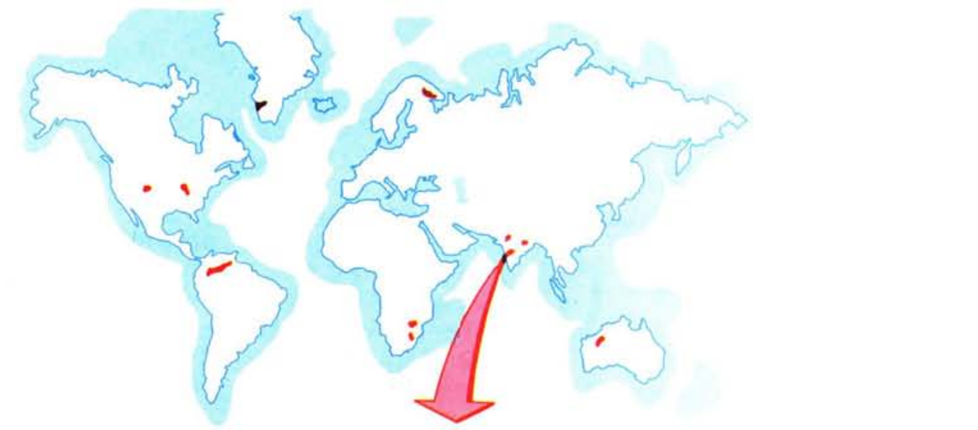
◀ **3.2** The Himalaya , the Aravallis and the Deccan plateau are some of the prominent geologic/ geomorphic features of the Indian sub-continent. The geochronological and geochemical studies conducted by PRL scientists on these mountain chains have provided valuable insight into their evolutionary history.

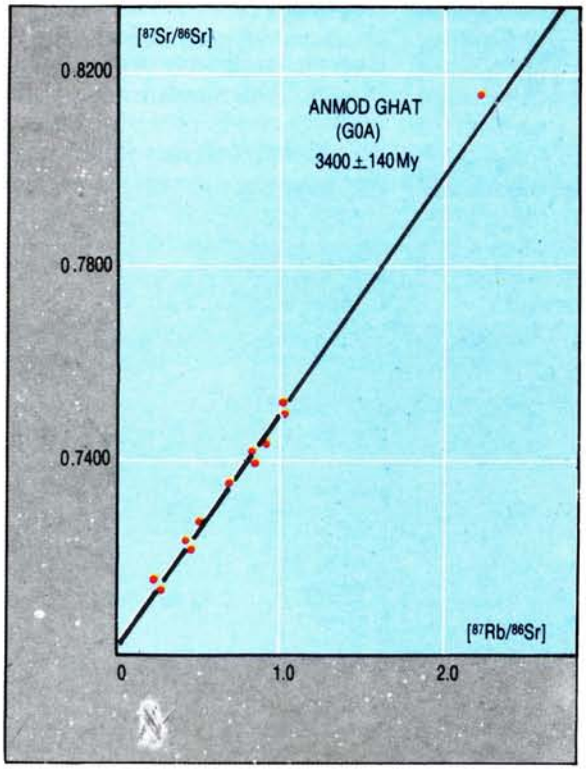


◀ **3.3** A sensitive solid source mass-spectrometer used for Rb-Sr geochronology. This instrument was fabricated at PRL and is routinely used to "date" rocks from selected geological formations in India. This mass-spectrometer is capable of measuring small differences in the Sr isotopic ratios, a few parts in 10,000.

to note that rocks near Goa (Fig. 3.4) and Udaipur are some of the very few places on the surface of the Earth where such old rocks are still preserved (weathering and erosion have by and large destroyed the rocks formed during the early periods of the Earth's history). Similarly, geochronological studies of the Himalaya have revealed that these geologically young mountain chains, contain very old rocks dating back to about 1800 to 2100 million years.

On the other hand, radioactive dating of Deccan Trap samples (by Ar-Ar method, a variation of the K-Ar method) shows that most of these rocks were the result of widespread volcanic eruptions around 66 million years ago. Nearly 1200 m thick layers of basalt rocks were deposited during this period in Mahabaleshwar. These basalt rocks are derived from the Earth's mantle and their study adds to our present understanding of these regions of the Earth's interior. For example, geochemical studies show that the Deccan basalts have erupted from a source similar to the one that is feeding the lava to the ridge in the Indian Ocean.

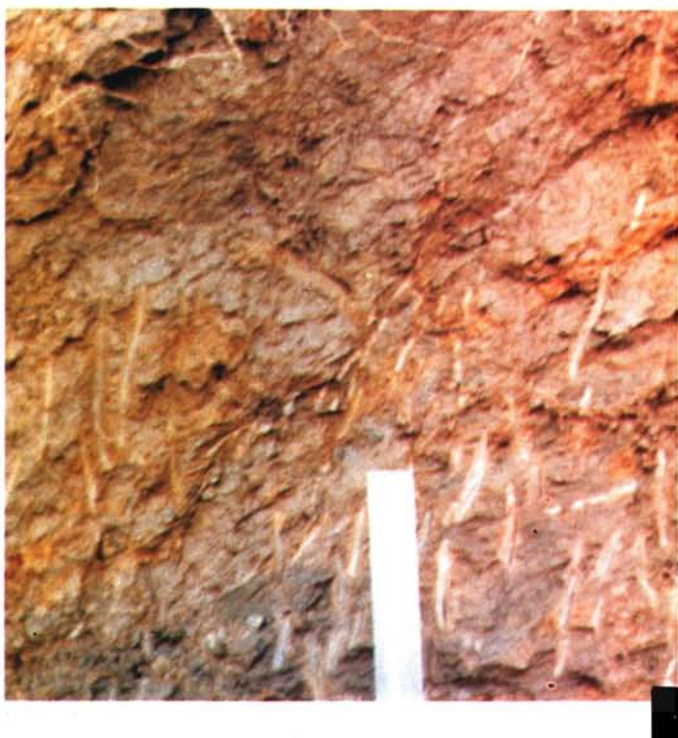




▲ **3.4** This map shows the worldwide distribution of rocks older than about 3500 million years. The occurrence of such old rocks is rare primarily because most of the Earth's surface has been reworked by geological processes. These rocks hold vital clues to Earth's early history. A search for such old crustal remanants is therefore a continuing activity. At PRL we have been able to identify some old rocks like the Anmod Ghat gneisses near Goa. Graph shows the isochron formed by a suite of whole rock samples from Anmod Ghat. All the samples lying in the isochron have the same age and at their formation had the same $^{87}Sr/^{86}Sr$ ratio. The age of these rocks deduced from the slope of the line is about 3400 Ma.

▼ **3.5** The Um Sohryngkew river section in Meghalaya, is one of the sedimentary sequences in India which contains the Cretaceous/Tertiary (K/T) boundary. The brown layer in the above figure marks the K/T boundary. This layer shows an enrichment of iridium and other siderophile elements such as osmium, nickel, iron and cobalt. The enrichment in iridium is attributed to the deposition of extra-terrestrial material, resulting from the impact of meteorites (comets) with the earth.

The period of Deccan eruptions coincides with one of the most dramatic global extinctions of life forms (including the dinosaurs) from the surface of the Earth. This marks the boundary between the Cretaceous and Tertiary periods of the geological time scale (K/T boundary ~ 66 million years ago). This coincidence has led to the suggestion that the Deccan volcanic activity could have been the cause of the extinctions. The K/T boundary is also characterized by geochemical anomalies, notably the enrichment of the noble metal, iridium (Ir). The iridium enrichment has been attributed to the deposition of extra-terrestrial matter resulting from the impact of extra-terrestrial objects, comets or asteroids, on the Earth. It has further been suggested that this impact could have caused the K/T extinctions. Eastern India has sedimentary sequences deposited during this period. Scientists from our laboratory working on Um Sohryngkew river section in Meghalaya have also observed such Ir anomalies, attesting to the global nature of Ir excess at the K/T boundary (Fig. 3.5). However, the large spread of ages obtained for the Deccan Traps and the associated geochemical data do not favour these eruptions as a cause of the global extinctions.



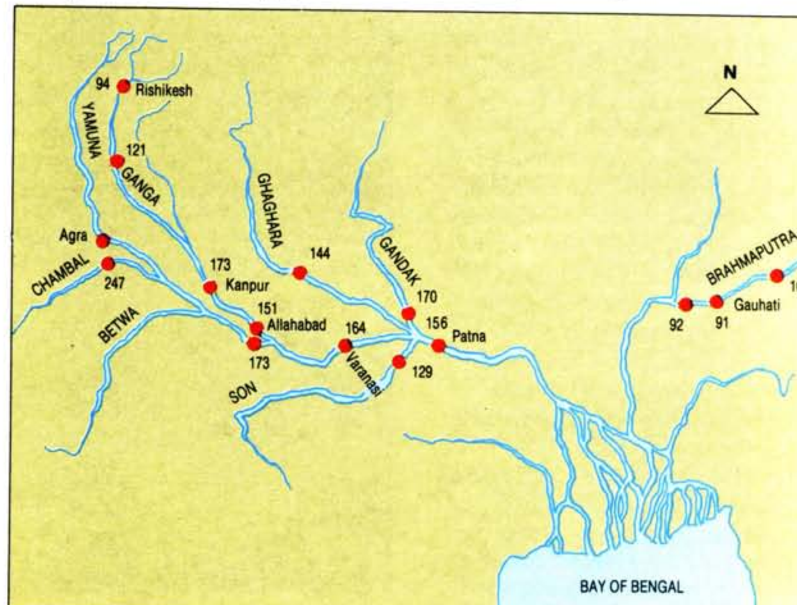
Scientists from our laboratory working on Um Sohryngkew river section in Meghalaya have observed Ir anomalies, attesting to the global nature of Ir excess at the K/T boundary.

GLACIERS RIVERS AND OCEANS

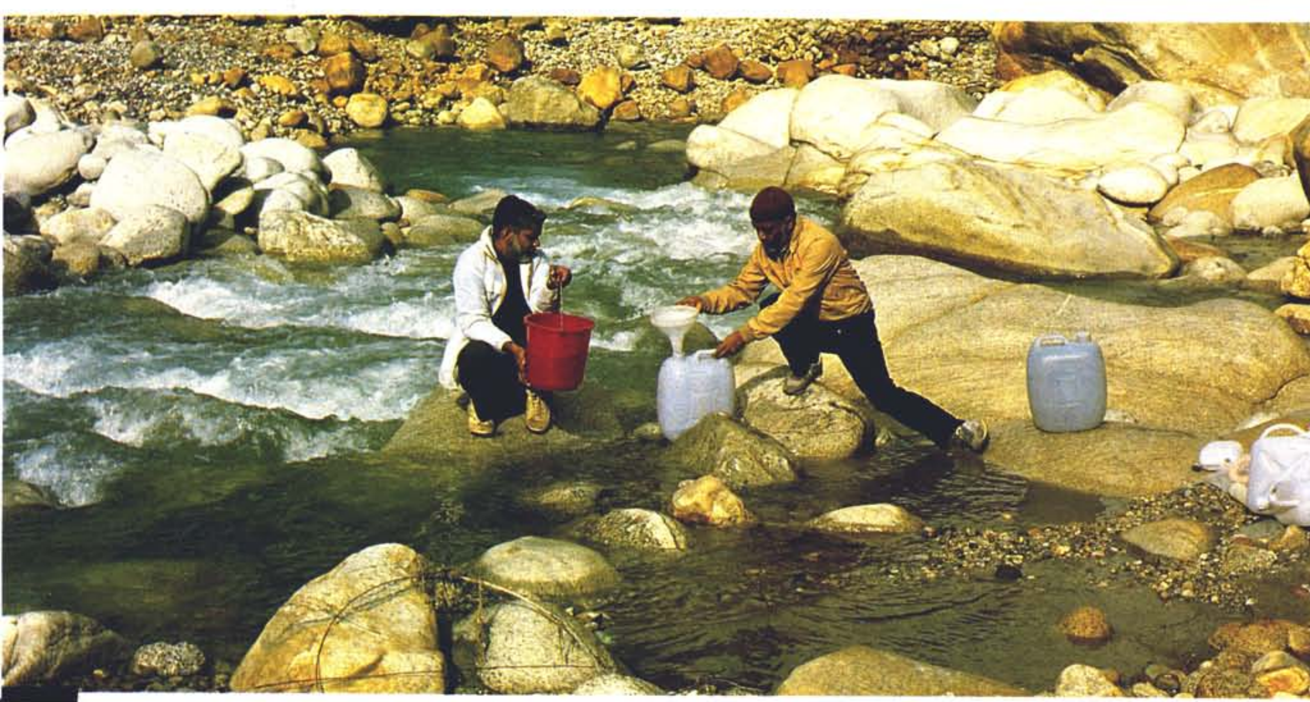
Glaciers are important water resources. Our scientists are involved in a programme to understand the dynamics of a few selected Himalayan glaciers.

Looking at the hills and mountains and knowing that they are millions and billions of years old, one wonders if they are everlasting. However, our knowledge that streams and rivers carry dissolved and suspended materials derived from rocks they drain, tells that these mountains cannot be eternal, but are being destroyed slowly and steadily. Rivers and streams are the major geological agents involved in the chemical cycle of elements and in shaping the continental surface.

India is gifted with many rivers, foremost among them are the Ganga and the Brahmaputra followed by about a dozen other major rivers. On a global scale the Ganga and the Brahmaputra rank first in terms of their suspended matter transport and fourth in terms of their water discharge to the oceans. Scientists from our laboratory have been studying the major ion chemistry of these rivers to determine (i) the fluxes of various elements transported by them and their significance on a global scale and (ii) the relation between elemental abundances, regional geology and mineral weathering. On an average the Ganga is about twice as saline as the Brahmaputra, together these rivers transport about 130 million tons of dissolved salts annually to the Bay of Bengal (Fig. 3.6). This accounts for ~ 3% of the global supply of dissolved salts to the ocean. More important is that about 1000 tons of dissolved uranium is transported by these rivers



▲ **3.6 (a)** The Ganga and Brahmaputra are the major rivers of India. They weather the Himalaya and drain through the alluvial plains before entering the Bay of Bengal. The chemistry and salt content of rivers provide insight to the weathering processes. The map shows the total dissolved salt content of the rivers and their tributaries (given in square brackets in units of milligrams per litre). The Ganga and Brahmaputra together transport about 130 million tons of dissolved salts to the Bay of Bengal annually.



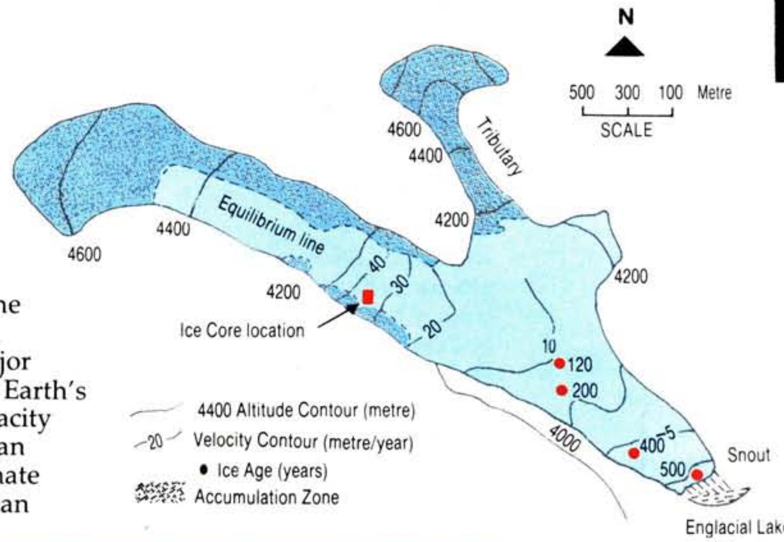
◀ **3.6 (b)** PRL scientists collecting Ganga source water samples at high altitude.

annually, ~ 10% of the global supply of uranium to the ocean, far exceeding the supply by any other major river.

The Ganga has its source at the Gangotri glacier in the Kumaun Himalaya and the Brahmaputra rises in the Chumyungdung glacier in the Tibetan Himalaya. Realizing the importance of glaciers as water resources of our country, our scientists are involved in a programme to understand the dynamics of a few selected Himalayan glaciers. This study includes the determination of accumulation rates of snow in the glaciers, ages of glacier ice and their mass balances based on radioactive dating techniques. Radioactive isotopes (e.g. ^{210}Pb, half-life ~ 22 years and ^{32}Si, half-life ~ 150 years) occurring naturally and incorporated in snow during precipitation serve as useful tracers for this purpose. The ages of the ice at the glacier termini range between 100–500 years for the Nehnar in Kashmir, Gara in Himachal Pradesh and Changme Khangpu glacier in Sikkim. The results confirm model predictions, that basal flow rates at the glacier bottom are much slower than at surface

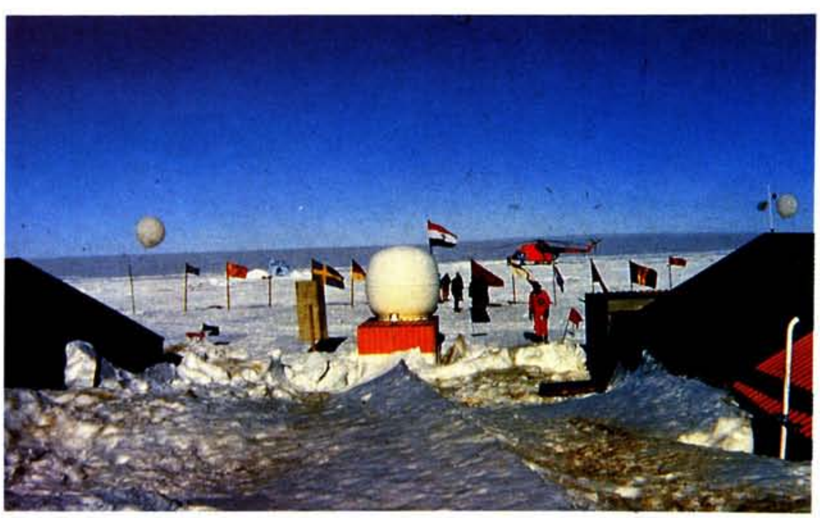
(Fig. 3.7a). Similar studies have been carried out by us in Antarctica as well (Fig. 3.7b).

The materials transported by rivers and glaciers finally end up in the oceans. The oceans exert a significant control over major processes occurring on the Earth's surface. The high heat capacity of the oceans makes them an important regulator of climate and hence the study of ocean circulation is an essential requirement for global climate modelling. The oceans circulate in response to two forces. The turbulence generated by wind contributes to the surface water circulation. The flow of the cold and dense deep waters of the ocean is induced by differences in density. In many places in the oceans, water from the two layers, the surface and the



▲ **3.7 (a)** Map of Nehnar glacier, Kashmir; one of the glaciers in which PRL scientists have carried out detailed elemental and isotopic studies. The altitude and velocity contours and ages of the ice determined using naturally occurring radioactive isotope, ^{32}Si are shown. A number of Himalayan glaciers have been studied using this technique.

◀ **3.7 (b)** A view of an Antarctic ice sheet near Dakshin Gangotri.



◀ **3.7 (c)** Photograph of the Indian Station in Antarctica, Dakshin Gangotri. One of the PRL scientists has participated in the Antarctic expedition and has conducted elemental and isotopic studies in samples collected from Antarctica.

Studies on ocean circulation and particle dynamics have direct relevance to programmes related to climate and chemical cycles of elements through the hydrosphere.

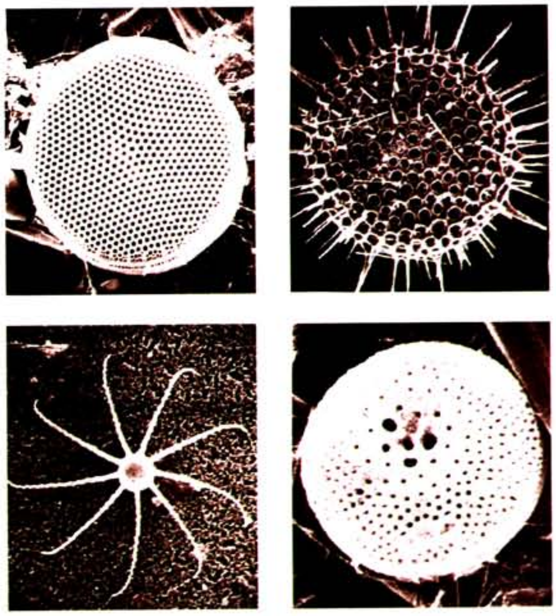
deep, mix through a process known as upwelling. Biological productivity in the oceans is higher in regions of upwelling. The oceans through their circulation and biological productivity exert considerable control on the global carbon budget. The biogenic particles also play a key role in the biogeochemical cycles of several elements in the ocean. They continuously exchange trace elements and radioactive isotopes with those dissolved in sea water, a process which is important in determining the fate of contaminants introduced into the oceans. Thus studies on ocean circulation and particle dynamics have direct relevance to programmes related to climate and chemical cycles of elements through the hydrosphere.

An area of research in Earth Sciences at PRL addresses to questions regarding the time scales of (i) coastal and deep water circulation and (ii) particle associated processes in the water column. The deep water circulation studies are based on the radioactive isotope ^{32}Si. The concentration of ^{32}Si in sea water is quite low, about 10^{-5} decays per minute per litre (corresponding to the decay of one atom of ^{32}Si in one litre of water per month). Therefore its measurement requires special collection techniques from hundreds of tons of water and efficient assay using high sensitivity counters (Fig. 3.8). The necessary techniques for all these have been developed in-house and have been used successfully during international oceanographic expeditions. The results of these measurements are being modelled to obtain upwelling velocities. Typical values obtained are in the range of

3.8 Si-32 is a radioactive isotope used for determining the rates of large scale ocean circulation. Its measurement requires its extraction from tons of sea water and assay using high sensitive counters. Techniques towards some of these have been developed by PRL scientists. (a) Scientists filling the bag sampler with fibres on the ship's deck. (b) Bag sampler containing chemically coated synthetic fibres for extraction of silica from seawater. (c) Si^{32} counting laboratory — the radiation detectors are developed at PRL.

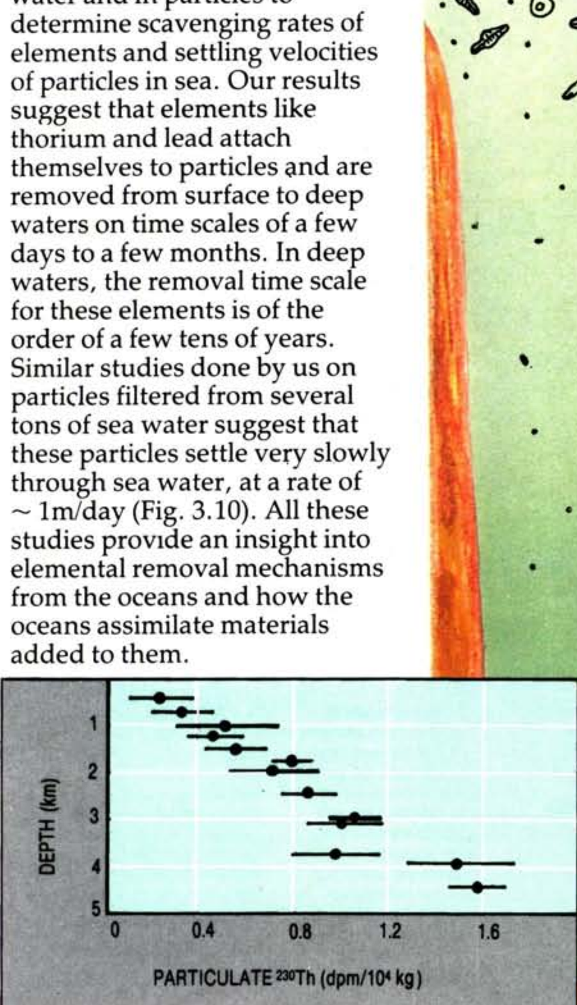
1–10 m/year, suggesting a very slow vertical mixing in the deep ocean.

Modelling of ^{32}Si data to derive upwelling velocities required that we consider all processes which can regulate its distribution in the water column. In this connection, an important process is the addition of silicon (including ^{32}Si) to deep waters by dissolution of biogenic particles (Fig. 3.9). This led us to a major study of particle associated processes in the oceans, particularly those involving the removal of elements from the water column, a process commonly known as scavenging. We have pioneered in the uses of natural radioactive isotopes (^{234}Th, half-life ~ 24 days and ^{210}Pb, half-life ~ 22 years) present in sea water and in particles to determine scavenging rates of elements and settling velocities of particles in sea. Our results suggest that elements like thorium and lead attach themselves to particles and are removed from surface to deep waters on time scales of a few days to a few months. In deep waters, the removal time scale for these elements is of the order of a few tens of years. Similar studies done by us on particles filtered from several tons of sea water suggest that these particles settle very slowly through sea water, at a rate of ~ 1m/day (Fig. 3.10). All these studies provide an insight into elemental removal mechanisms from the oceans and how the oceans assimilate materials added to them.



◀ **3.9** The upper few tens of metres of the ocean water is a layer of high biological productivity. This productivity depends on availability of sunlight and nutrients. Various types of micro-organisms, (plants and animals) live in this zone. Photograph shows some types of biogenic particles found in surface seawater. These particles exert considerable influence on the distribution and transport of elements from surface to deep waters.

Oceanographic research at PRL addresses to questions such as the time-scales of (i) coastal and deep water circulation and (ii) particle associated processes in the water column.

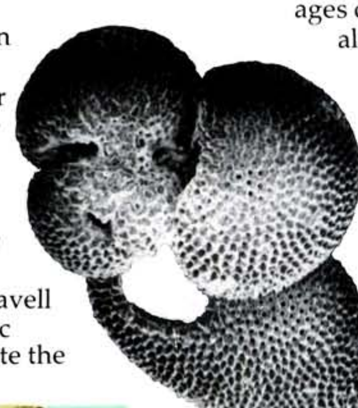


◀ **3.10** Particles in the oceans play an important role in regulating the distribution of elements in the water and their transport to sediments. Particle concentration in the ocean is generally high near the surface because of biological productivity. In the ocean interior the particle concentrations are quite low and are generally uniform. Typical concentration of particles in the ocean interior is about a gram per 100 tons of water. The particles in the ocean are continuously cycled by biological and chemical processes, resulting in their aggregation and break up. The settling velocity of particles in the oceans is determined by measuring the ^{230}Th activity in them. The graph shows the particulate ^{230}Th concentration measured in the Indian ocean. The vertical settling velocity of particles in seawater is derived from these data to be about 1 metre per day.

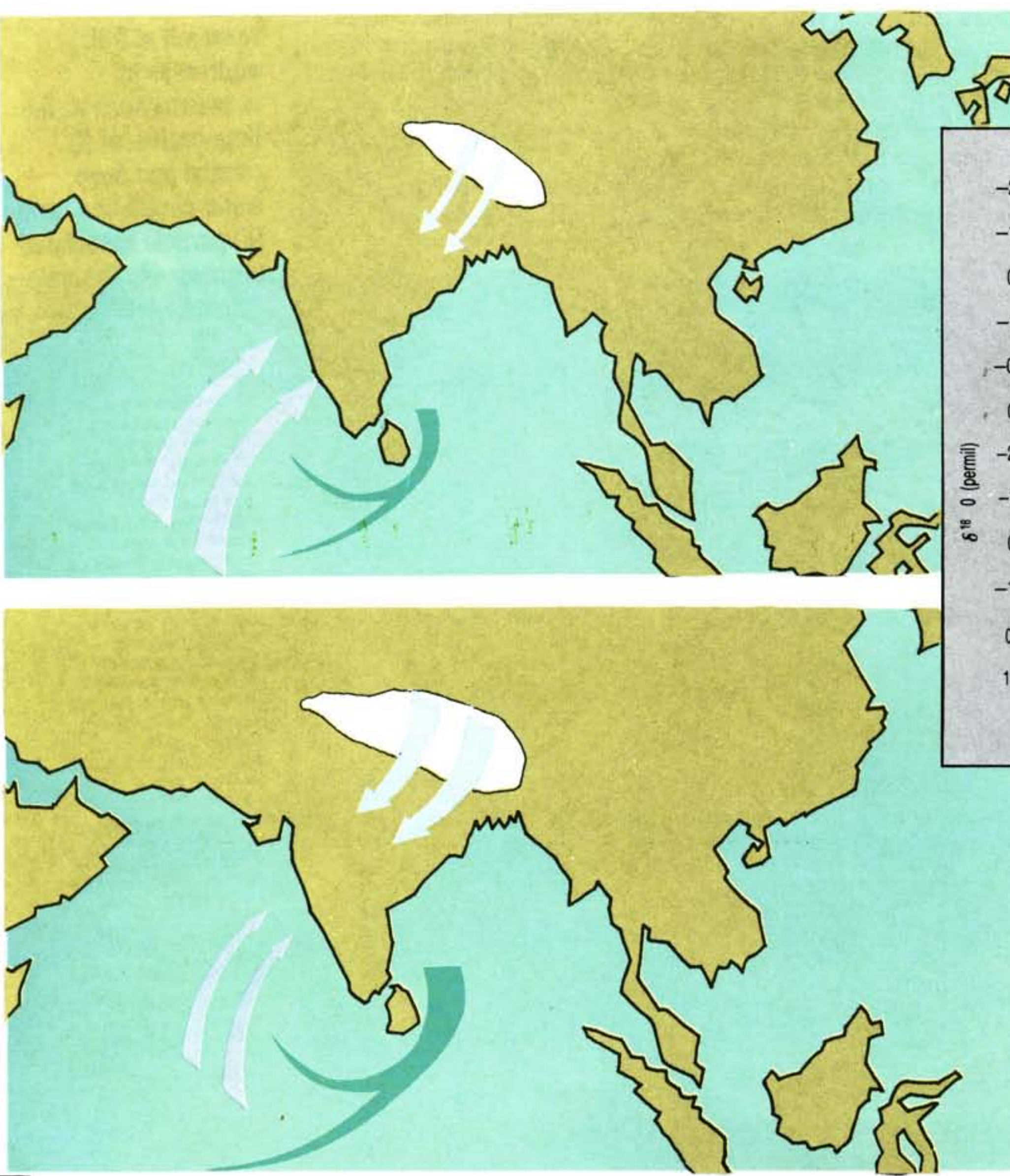
PRL scientists are carrying out a study to chronologically decipher the climatic records stored in the sediments of the Arabian sea, the Bay of Bengal and the Indian Ocean.

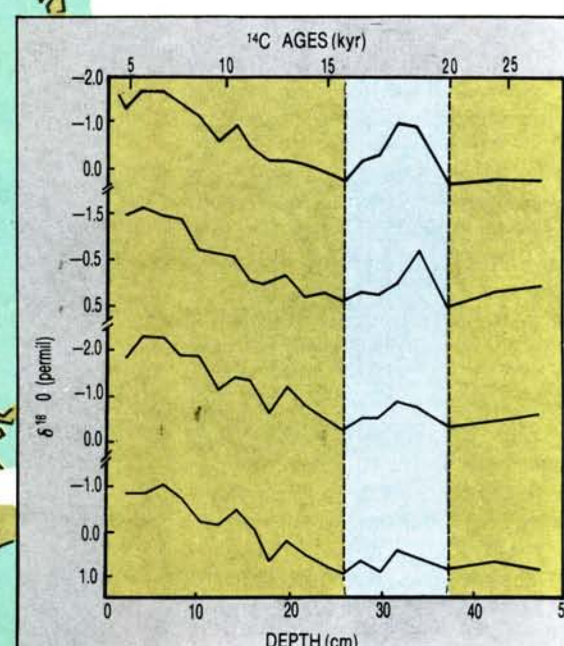
PALAEO CLIMATES

Particles accumulating on the ocean floor as sediments record the history of major environmental changes that have occurred on the Earth. These records go back in time to about 100 million years and in places these records are quite complete and well preserved. Of all types of information contained in sediments perhaps the most important is that pertaining to past climate. An important question in climatology is whether we can predict future climate. Understanding of the past climatic patterns may aid us to develop predictive capability. The key to unravelling the climatic records is to date the sediment layers and also obtain information on climatic indicators in the same layers. There are several methods that use environmental radionuclides to determine the ages of sediments. Nature also has provided us



◀ **3.11** Minute organisms called foraminifera live in the sea surface and secrete calcium carbonate shells. The picture of one such foraminifera (called Globigerinoides sacculifer) taken with a scanning electron microscope is shown here. The oxygen isotopic composition of such shells can be used to infer changes of the sea surface temperature and salinity in the past, which give clues to changes in climate, especially the Indian monsoons.





◀ **3.12** The two maps show the winds during the summer and winter monsoons at present (top) and during the ice age 18,000 years ago (bottom). Today the south-west (summer) monsoon is strong and the north-east (winter) monsoon is weak. 18,000 years ago the summer monsoon was weaker and the winter monsoon was strongest. This inference is based on the measurement of the oxygen isotopic composition ($\delta^{18}O$) of four different foraminiferal species (see inset) Between 16 to 20 thousand years ago there was a peak in the isotopic composition (shown between two vertical dotted lines) which, we believe, is due to increased transport of low-salinity water from the Bay of Bengal to the core location because of the intensification of the winter monsoon and the associated circumpeninsular oceanic surface currents (thick arrow in the lower map).

with an elegant tool, the stable oxygen isotopes, ^{16}O and ^{18}O, to obtain past temperature and salinity data of the oceans.

Many organisms in sea water have calcareous ($CaCO_3$) shells (Fig. 3.11). While constructing their shells, the organisms incorporate oxygen isotopes in a ratio that depends on (i) ambient temperature and (ii) the oxygen isotope ratio of the water. Typically marine shells have $^{18}O/^{16}O$ ratio about 3 percent higher than that in sea water. At any given temperature, the difference in the oxygen isotope ratio between the shell and the water is fixed. Thus by measuring $^{18}O/^{16}O$ ratios in fossil shells of organisms that lived in surface and deeper waters we can determine with a fair precision the temperature and salinity conditions of the water where they once lived. PRL scientists are carrying out a study to chronologically decipher the climatic records stored in the sediments of the Arabian sea, the Bay of Bengal and the Indian Ocean.

Results available show that about 18,000 years ago the waters of the eastern Arabian sea were colder by about 2°C and about 125,000 years ago the temperature of the Arabian sea surface waters were as warm as the present. These results follow the global trend. The cold temperature ~ 18,000 years ago corresponds to the last glacial maximum, a period when giant glaciers covered large parts of northern continents and high mountain ranges of the world, making the entire Earth's surface extremely cold. Since then the Earth's surface has been warming up. We at present are in the midst of an interglacial period. Our oxygen isotope data from the Arabian sea core indicate that the interglacial began in this region ~ 13,000 years ago and that surface water temperature has been progressively increasing since then. Many theories have been proposed to explain the alternation of glacials and interglacials. A widely accepted theory attributes this to changes in the orbit of the Earth around the Sun.

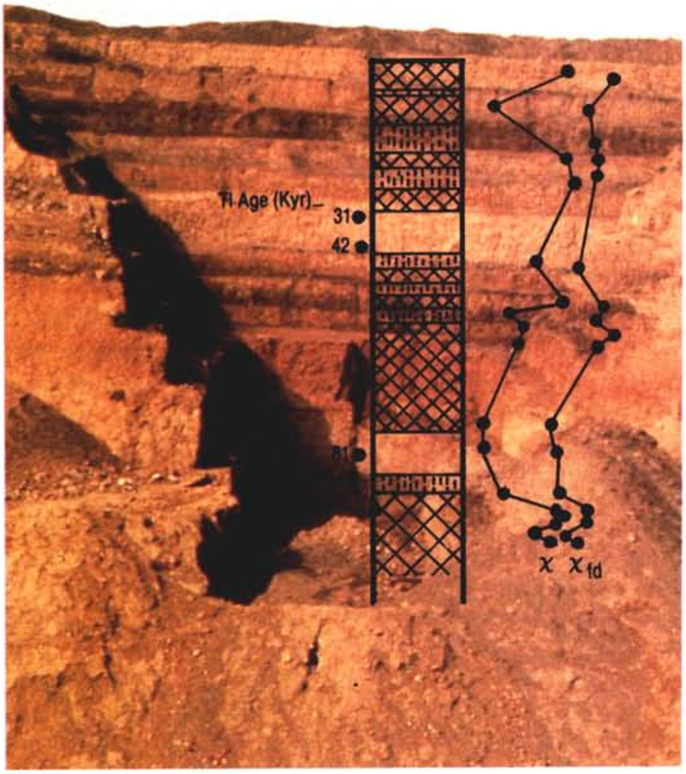
In addition, results (Fig. 3.12) suggest that during the glacial period (~ 18,000 years ago), the south-west monsoon became weak. We have found evidence from the oxygen isotope data that during this period the north-east monsoon became stronger. This resulted in increased input of low salinity water from the western Bay of Bengal to the eastern Arabian sea.

Similar to deep sea sediments, lake muds are also a rich store of information about the past climate. Most of these records refer to recent past, last tens of thousands of years. An exception to this is the relict lake sediments from Kashmir. Around 4 million years ago, the rise of the Pir Panjal range impounded the Himalayan rivers, forming a boat-shaped lake. Subsequent upheavals shifted the lake and eventually drained it out. The erosion and down cutting of the deposits of this primeval lake (called Karewas by the local people) provides an easily accessible 1.2 km thick geological record (Figs. 3.13, 14). The lake sediments were uplifted and exposed due to tectonic activities about 200,000 years ago. Following the exposure, the sediments were covered by wind-blown material known as loess. The loess and the underlying sediments are easily accessible and offer an opportunity to study the climatic changes of the region for the past four million years. Such long and continuous deposits from the land are rare and hence their value; otherwise most of the long term environmental records come from sea sediments or polar ice-cores.

We undertook a major multi-disciplinary programme to unravel the records stored in

We undertook a major multi-disciplinary programme to unravel the records stored in the Karewas by studying floral, faunal, geochemical and geological signatures contained in them. The most important finding in the Karewa sediment is the association of climatic change with palaeomagnetic reversals.

▲**3.13** The Karewas of Kashmir : Lake sediments with the record of past climate for 4 million years. These sediments have been studied at PRL using a multi-disciplinary approach to decipher the climatic records.



▲ **3.14** An exposed section 20m thick of loess-palaeosol sequences at Khanchikhol in Kashmir valley showing alternation of loess (light coloured) and palaeosol (dark coloured) horizons. Superposed on the section are the TL ages of a few horizons and variations of magnetic susceptibility (χ) and its frequency dependent component (χ_{fd}). Note the enhancement of both χ and χ_{fd} corresponding to palaeosol horizons.

the Karewas by studying floral, faunal, geochemical and geological signatures contained in them. The first hurdle we faced was to date these deposits. For young sediments (<40,000 years) we used the well established radiocarbon dating method (Fig. 3.15).

Living organisms while forming from lake water incorporate into them radiocarbon (^{14}C) along with ordinary carbon (^{12}C) to build their tissues and shells. After the death of the organisms, there is no replenishment of ^{14}C in them, only its radioactive decay. By comparing the radiocarbon specific activity ($^{14}C/^{12}C$) of the sample from sediments with that in the reservoir (lake water) it is possible to determine the time elapsed since the death of the organism. To determine the chronology of the loess we used the thermoluminescence dating technique (Fig. 3.16). The crystal structure of minerals undergoes a small electronic rearrangement on exposure to radiation. On heating, the crystal regains its original electronic configuration with a simultaneous emission of light (i.e. thermoluminescence). The intensity of the emitted light from a mineral is proportional to the total radiation exposure and is a measure of the time that elapsed since the most recent thermoluminescence zeroing event. In nature these events correspond to either heating of a crystal (thermal zeroing) or Sun exposure (optical zeroing). Application of this method to date Kashmir loess provided chronology for climatic changes recorded in them, and their relation to global climatic changes. The development of soil layers in the loess and changes in their magnetic properties seem to coincide with glacial/interglaci periods. More recently, we have successfully applied the thermoluminescence techniqu to determine chronology of desert sands. These studies provide us valuable informatic about the evolution of Thar desert.

Underlying the loess, there are about a kilometre thick lake sediments. We determined the chronology of these lake beds based on the magnetic reversa technique. The north and sout poles of the Earth's magnetic field have undergone fairly frequent reversals in the past; the last one being about 700,00 years ago. Such magnetic reversals are well preserved in fine grained lake sediments. By identifying the strata at which the reversals have occurred, it becomes possible to assign age for them. In the Karewa, we identified two boundaries, the Brunhes-Matuyama (700,000 years B.P.) and the Matuyama Gauss (2.5 million years B P.).

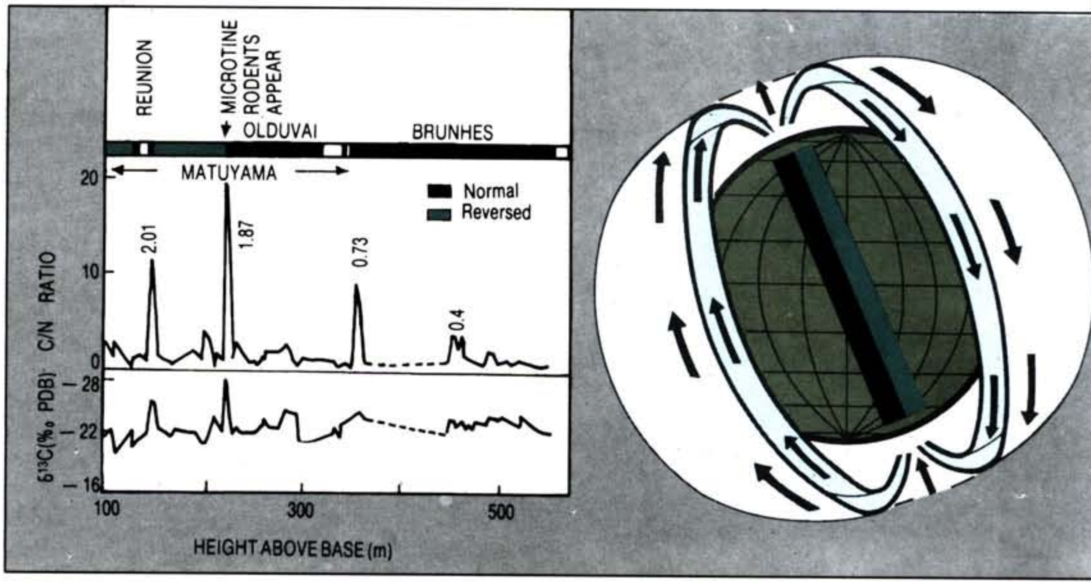
From the Karewas we could understand the climatic changes of the past four millio years. We could trace the gradual transition of a sub-tropical climate into a tempera one, with several markedly co (glacial) oscillations during the last 700,000 years. The most

▶ **3.15** A view of the Radiocarbon Laboratory. The glass vacuum assembly used for purification of carbon dioxide and methane gas was fabricated at PRL.

▶▶ **3.16** Thermoluminescence laboratory at PRL, where geochronological studies on loess from Kashmir and sand grains from Thar desert are being conducted.

important finding in the Karewa sediment is the association of climatic changes with palaeomagnetic reversals (Fig. 3.17). Short periods of extreme cold climate coincide with the reversals. Thus in Kashmir we have unravelled a unique four million year old lake deposit record to reconstruct the climatic changes, by employing multidisciplinary techniques. This is the first such record from Asia. For higher resolution and quantitative information on environments of the recent past we are now studying sediment cores raised from the Manasbal lake of Kashmir (Fig. 3.18).

The deep sea sediments and the Karewas provide long term climatic records, with resolution of a few thousands of years. To obtain information on the past few hundreds to thousands of years with resolution of a year to a decade, we have to look for other recorders. Tree rings, glaciers and corals meet this requirement. The tree rings can be sampled on an yearly basis and provide high resolution climate data (Fig. 3.19). It was demonstrated by us that stable hydrogen, oxygen and carbon isotopes in the cellulose of fir trees from Kashmir preserve in them a high resolution record of changes in temperature, humidity and rainfall. Similarly our isotope studies show that teak trees from Maharashtra preserve a record of monsoon rainfall. Such high resolution information of the last few centuries is useful in climate modelling. For example, one can in principle reconstruct the rainfall history over India for the past few centuries based on stable isotope studies on tree rings. These records could serve to test climate models help predict future trends in Indian monsoon.



▲ **3.17** Schematic diagram showing reversal of earth's magnetic field as indicated by the direction of flux lines. Picture on left shows correlation between magnetic reversals and climatic changes as revealed by elemental and isotopic ratios. Peaks correspond to colder periods.

◀ **3.18** Sediment sampling from a Naukuchia Tal lake bottom by means of a 6 m Mackereth corer made at PRL. Recent sediments from lakes are being studied at PRL to infer the characteristics of the depositional environment.

▼ **3.19** A cross section of deodar tree showing the annual growth rings. There are about 30 rings corresponding to 30 years of growth. The sample is from Dehra Dun. The ring width and the isotopic composition of hydrogen in cellulose extracted from rings yield data on climate parameters.

The increasing demand for water by the ever increasing population has resulted in a negative ground water budget, i.e. more consumption than recharge.

These studies show that in the Sabarmati basin of Gujarat about 8-15% of rainfall percolates through soil to form groundwater.

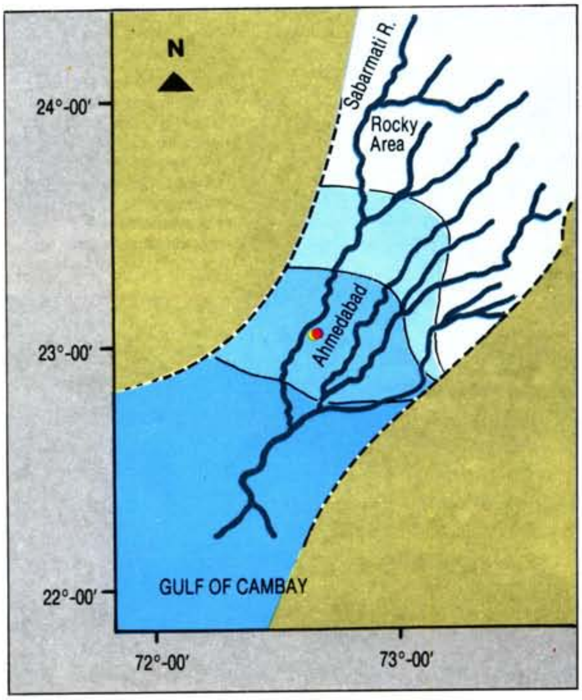
WATER AND MINERAL RESOURCES

An important aspect of Earth Science studies has been the exploration and management of natural water resources. In regions of arid and semi-arid climate like Gujarat or Rajasthan, groundwater is the main and sometimes the only source of water. The increasing demand for water by the ever increasing population has resulted in a negative groundwater budget, i.e. more consumption than recharge. For example in Ahmedabad, the groundwater level is being lowered at an alarming rate of 2–3 m/year for the past 1–2 decades. Proper management of our meagre groundwater resources requires a detailed understanding of

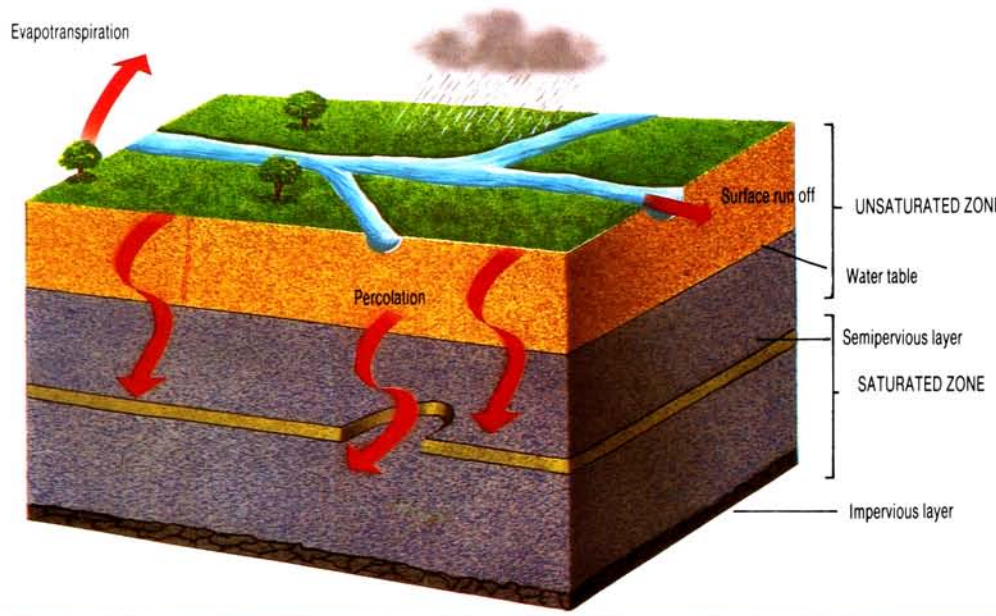
- size of the groundwater body and time scales of its renewal through rainwater infiltration
- velocity of groundwater flow
- nature and extent of link between the various groundwater reservoirs and surface waters.

PRL has made significant contributions in these directions.

We have determined the infiltration rates of groundwater in the arid regions of Gujarat and Rajasthan using the tritium injection method. Tritium is a radioactive isotope of hydrogen, both having identical geochemical properties. Water containing tritium is injected at a given depth in soil and its movement with time is monitored periodically by sampling the soil moisture. These studies show that in the Sabarmati basin of Gujarat about 8–15% of rainfall percolates through soil to form groundwater (Fig. 3.20).



◀ **3.20** Schematic diagram showing the various components, namely run off, evapotranspiration and deep percolation of hydrological cycle in a vertical section of a soil profile. Gujarat State critically depends on its groundwater resources. Determining the rate of recharge of these groundwaters is important in their management. PRL scientists have measured these recharge rates in the Sabarmati basin using the tritium technique. The above figure shows zones of various fractional groundwater recharge in the Sabarmati basin.



Groundwater recharge occurs predominantly during the monsoon season. However, during this season, most of the rainwater from the catchment channels into rivers and flows into the sea. Therefore any water management programme should attempt to store this excess water for use during non-monsoon periods. A novel experiment was conducted near Ahmedabad to recharge deep groundwater reservoirs with the Sabarmati river water during the monsoon season. The experiment was based on siphon principle in which groundwater from shallow depths at the bank of the river was siphoned into deeper reservoirs; the shallow groundwater reservoir was in turn getting continuously recharged by percolation from Sabarmati river. This method, which does not use any external energy source, should find application in the artificial recharge of deep groundwater reservoirs.

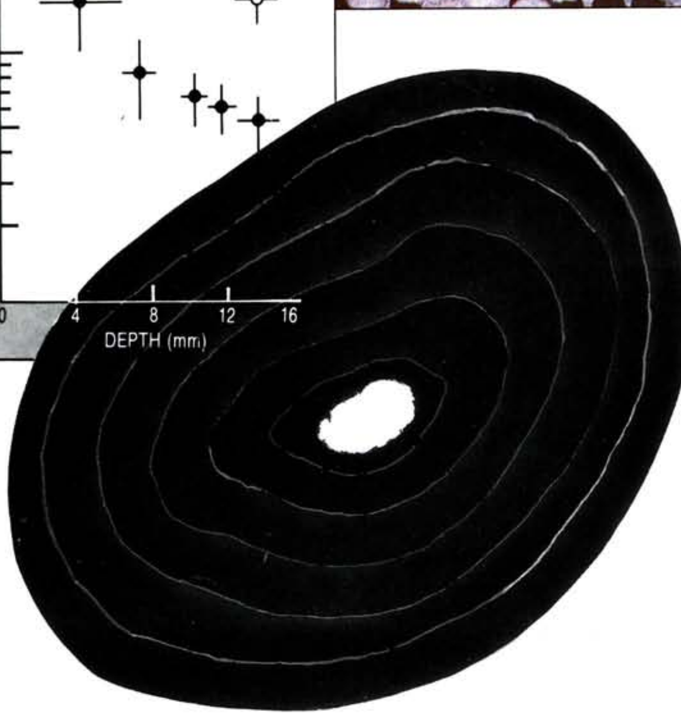
In addition to water, the development of a nation also depends on mineral resources. India is reasonably well endowed with minerals, but like many other nations it is also trying to explore and exploit the ferromanganese minerals (manganese nodules) from the ocean floor for metals like copper, nickel and cobalt (Fig. 3.21).

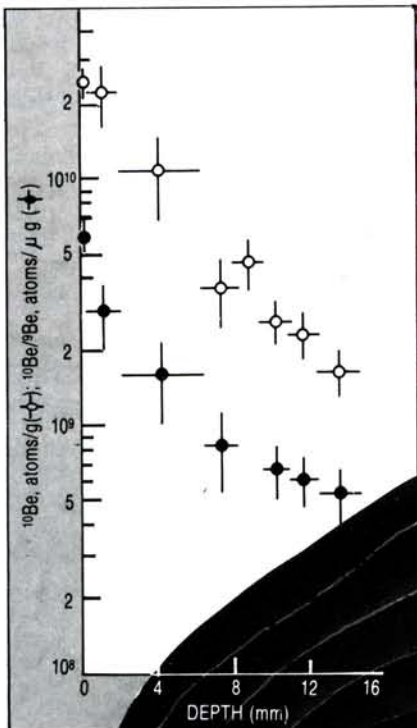
An important aspect relating to the study of manganese nodules is their growth rate. Knowledge of their growth rates provides us data to test chemical models of their formation and also to plan their exploitation better. PRL scientists have determined the chronology of manganese nodules and their role in the geochemical cycles of elements. Using radioactive ^{10}Be and ^{230}Th we have been able to show that these deposits grow very slowly, at a rate of a few millimetre in a million year or a few atomic layers per month (Fig. 3.22). These are some of the slowest chemical reactions known to man. Such slow growth rates of nodules presented a major puzzle. How do they occur on the surface of sediments, which accumulate thousand times faster? This query has not been adequately answered yet. It is hypothesized that organisms living on ocean floor turn the nodules around and keep them afloat on sediment or that water currents slowly winnow away the fine sediments and keep the nodules exposed. Our studies of ^{230}Th and ^{226}Ra at the top and bottom surfaces of nodules indeed show that they turn around on the ocean floor, once every few tens of thousands of years. Whatever may be the mechanism which maintains them on the surface of the sediments, these potato-sized objects are quite antique and store in them, several million years of ocean history and billions of tons of important metals.

The twenty first century is only a decade away from us. During this decade, one of the major multidisciplinary Earth Science programmes, the "International Geosphere Biosphere Programme" (IGBP) would be underway. The primary goal of this international programme is to understand the earth-system as a whole and how it is changing with time. This requires the study of the interactions among the physical, chemical and biological components of the Earth. As mentioned earlier, PRL is one of the few institutions in the world where active research in various earth-system components are being pursued. One of PRL's efforts in future would be to integrate many of its Earth Science programmes and promote interdisciplinary studies of the earth-system. Towards this, in addition to some of the programmes discussed earlier, studies and observation on air-sea interaction, high resolution records of palaeoenvironmental changes stored in corals, glaciers, tree rings and lake sediments would be taken up. These studies and observations would be used to develop models which would address to the functioning of the earth-system as a whole.

An important aspect relating to the study of manganese nodules is their growth rate. Using radioactive ^{10}Be and ^{230}Th we have been able to show that these deposits grow very slowly, at a rate of a few millimetre in a million year. These are some of the slowest chemical reactions known to man.

▲ **3.21** Manganese nodules lying on the ocean floor. These potato sized objects contain in them economically valuable elements such as cobalt, nickel and copper.





◀ **3.22** Sketch of the cross section of a manganese nodule. The nodules generally have a layered structure (like an onion) with a nucleus at the centre. The growth rate of nodules are determined by measuring the concentration of the radionuclide ^{10}Be as a function of depth from the surface. The inset shows the ^{10}Be depth profile in a nodule. The average growth rate of the nodule is about 2 millimetre per million years.

The action of classical gravity

$$S = \int R \sqrt{-g}\, d^4x + A$$

Variation of S with respect to g_{ik} gives

Einstein's equation

$$R_{ik} - \frac{1}{2} g_{ik} R = -k\, T_{ik}$$

(the energy-momen…

from variation…

Supersymmetric…

string action:

$$S = -\frac{1}{4\pi\alpha'} \int d\ldots$$

gives us consist…

gravity.

1) <u>Quarks</u>

potent…

$\frac{1}{2} c_g^4 r\ldots$

Dirac equation

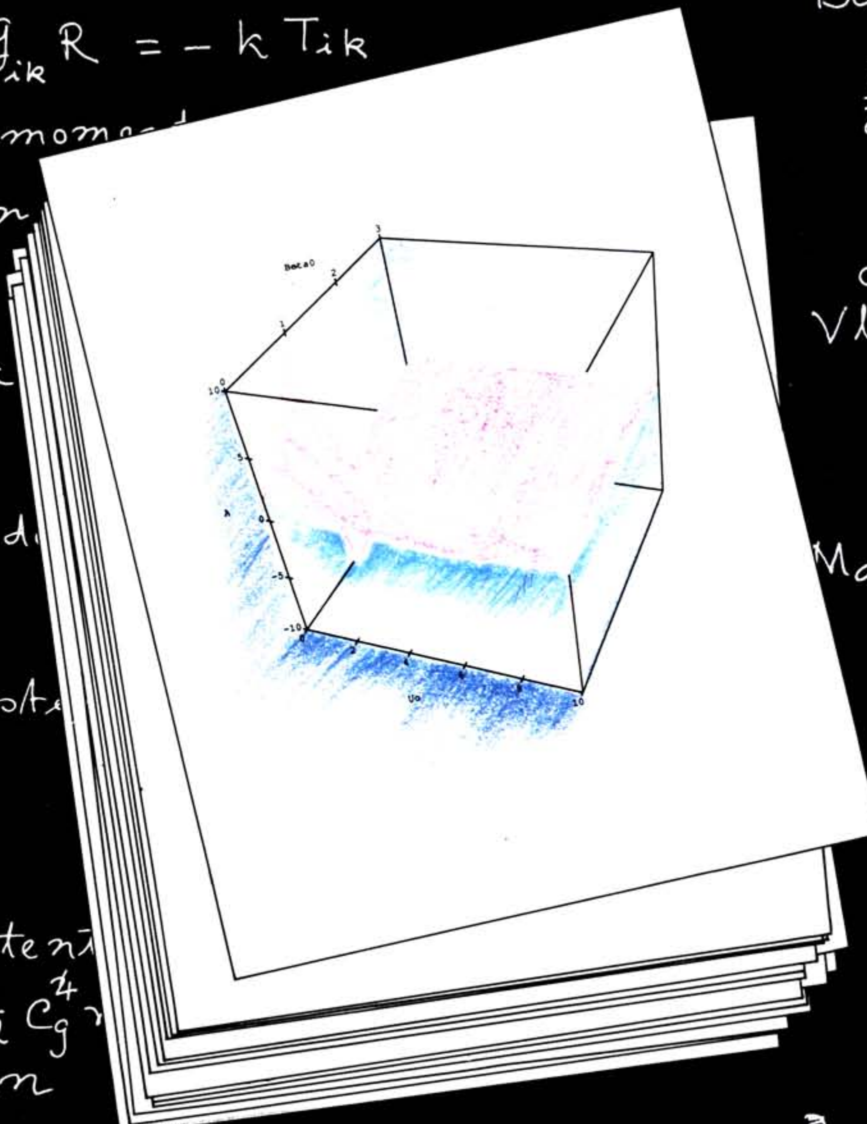
$$\left(\underset{\sim}{\alpha} \cdot \underset{\sim}{p} + \frac{1}{2}(1+\beta) c_g^4 r^2 + \beta M\right) \psi = E \psi$$

C M correction + One gluon exchange potential

2) Gluons current $j_\mu = \theta_\mu^2 A_\nu$ (CCM)

$$\theta_\mu^\nu = \delta_\mu^\nu \left[c_g^4 r^2 - \delta_{\mu,0}\, 2 c_g^2 \right]$$

Maxwell's equation with induced current



$$\partial^\mu f_{\mu,\nu} + j_\nu = 0$$

Kinetic descri…

Form…

Boltzmann Eq…

$$\frac{\partial f}{\partial t} + (\underset{\sim}{v} \cdot \underset{\sim}{\nabla}) f \ldots$$

If $\underset{\sim}{F} = \ldots$

and collisi…

Vlasov Equ…

$$\frac{\partial f}{\partial t} + (\underset{\sim}{v} \cdot \underset{\sim}{\nabla} \ldots$$

Maxwell's Equ…

$\underset{\sim}{\nabla} \cdot \underset{\sim}{B} \ldots$

$\underset{\sim}{\nabla} \cdot \underset{\sim}{E} \ldots$

Curl $\underset{\sim}{B} \ldots$

& ~~Curl~~ Curl E…

Dynamics of…

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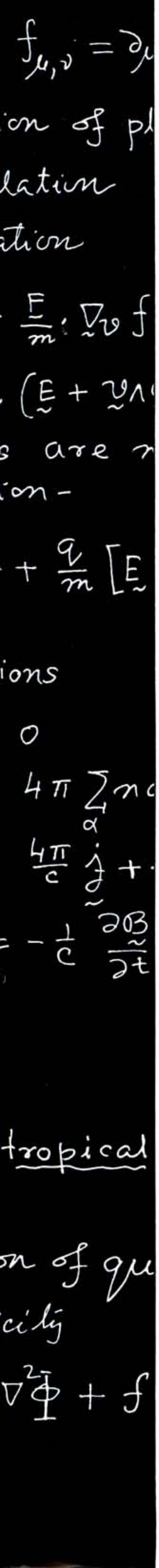
$$\left(\frac{\partial}{\partial t} + \underset{\sim}{v_g} \cdot \underset{\sim}{\nabla}\right)(\ldots$$

Go Back



THEORETICAL
AND
FUNDAMENTAL PHYSICS

मैत्रेय उवाच
चरमः सद्विशेषाणामनेकोऽसंयुतः सदा ।
परमाणुः स विज्ञेयो नृणामैक्यभ्रमो यतः

The material manifestation's ultimate particle, which is indivisible and not formed into a body, is called the atom. It exists always as an invisible identity, even after the dissolution of all forms. The material body is but a combination of such atoms, but it is misunderstood by the common man.

—Srimad Bhagwatam 3:11:1

When Copernicus expressed the view that it is the planets which went around the Sun, the common centre for all of them, it was a point of view of great significance in the methods of science. This was referred to as the heliocentric theory (Helios-Sun), a theory which regards Sun as the centre of the solar system. While viewed from the frame of the Earth, the planets were observed to execute complicated motions, in the heliocentric frame the motions became confocal, elliptical trajectories. This point of view later enabled Kepler to postulate his laws of motion, which were based mainly on the painstaking observations of Tycho Brahe. Kepler's laws of planetary motions were an expression of the systematics of the observations, and exemplifies a most crucial step in scientific methodology.

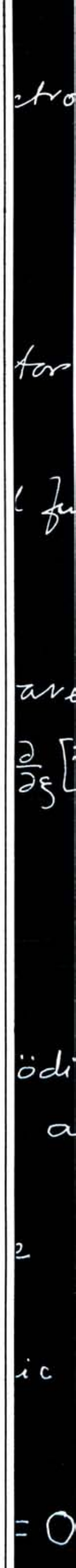
However, when Newton, by a stroke of genius stated that the planets, and indeed all material bodies were attracted towards each other, and towards the Sun by a law of force which varied inversely as the square of the distance, and wrote down the *equation of motion* which contained in it all the planetary motions as its solutions with different *initial conditions*, the concept of a theory as we know it today was born. Newton was thus the first theoretical physicist and his theory, the first theory ever. This theory thus provided a condensation of all the information about the planetary motions in a compact one-line equation of motion, and typifies in some sense the methods of theoretical physics.

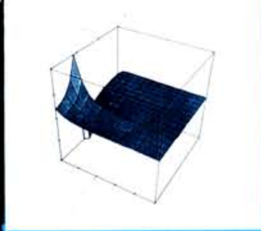
But a theory does more than describe or explain known facts. It has the power of prediction, which it constantly does until it reaches the limits of its domain. A new theory must then be found to explain new experimental facts not explicable in terms of the old theory. Thus in the first quarter of twentieth century, the Newton's theory was superseded by the theory of Relativity and the Quantum theory. Both brought in conceptually radical changes in our perception of the physical world around us.

At PRL we have been engaged in formulating theories in the domains of both micro and macrophysics. In microphysics our interests are in the structure of the nuclei, atoms and molecules. We also study the structure of the quantum theory itself which has intrigued the physicists ever since it came into being in 1925.

On the larger scale, we have been trying to understand through theoretical modelling, the dynamics of the Indian summer monsoon. The interaction of the Sun with the atmosphere and the wind system it generates in the lower region of the atmosphere is mainly responsible for the weather system. The upper atmosphere where the gaseous density is lower and the solar radiation stronger, the ionization of the gases due to energetic solar radiation occurs quite freely. This ionized gas known as plasma exhibits very interesting and complex electromagnetic and dynamical behaviour. It is responsible for many of the interesting phenomena that occur in the upper atmosphere. These can be explained in terms of the properties of the plasma and its interactions with the electromagnetic field as well as ambient neutral gas, a topic of considerable interest to the theoretical physicists of PRL.

The following paragraphs provide an overview of PRL's contribution in the various areas of theoretical physics.

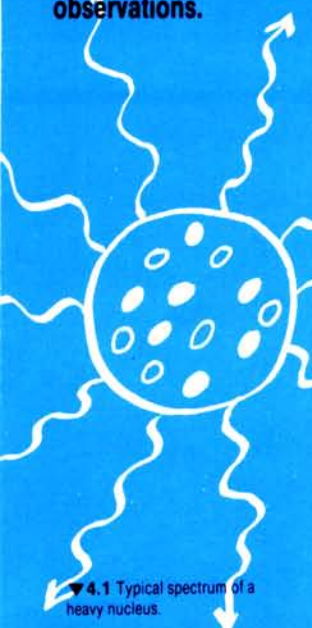




PRL scientists have been able to reslove the anomaly in the theory of electron capture and formulate a theory which was consistent with experimental observations.

THE MICROCOSM

PHYSICS OF ATOMIC AND SUB-ATOMIC DOMAIN

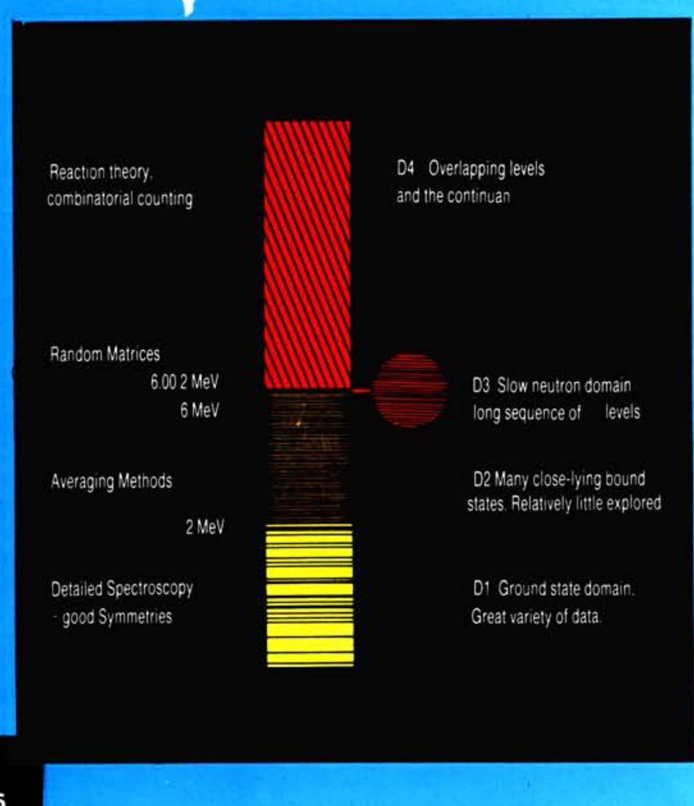


ATOMIC AND MOLECULAR PHYSICS

Some time ago, the cosmic ray experiment Anuradha focussed our attention on the origin of the low energy cosmic rays. A space-borne experiment like Anuradha can measure the cosmic ray particles in the vicinity of the Earth only. However, to understand the origin of these rays, information about their composition in the interstellar space will also be required. This information can be obtained by using a fundamental atomic reaction called electron capture.

As the cosmic ray particles, which are composed of almost fully stripped atomic nuclei, such as neon ions, gush through the interstellar medium, they will occasionally collide with a neutral hydrogen atom and capture the bound electron in an excited state. The newly formed cosmic ray atoms will return to the ground state by emitting X-rays. By measuring these X-rays information about the intensity and composition of the cosmic rays can be deduced if the electron capture cross sections are known. But this is just one example of the importance of electron capture. There are numerous other situations in astrophysics and laboratory physics in which electron capture plays a fundamental role. Therefore, since the early days of quantum mechanics, electron capture has received a great deal of theoretical attention. Since its birth in late 1920's, the theoretical formulation of Oppenheimer, Brinkman and Kramers was considered to be the fundamental approach but this theory failed to explain some of the experimental data. One of the major contributions of PRL scientists has been to resolve this anomaly and formulate a theory which was consistent with experimental observations. PRL scientists showed that the earlier theory failed because it treats the long range nature of the Coulomb potential incorrectly. We have formulated a new theory by correctly treating the Coulomb force; our theory explains the experimental results quite satisfactorily.

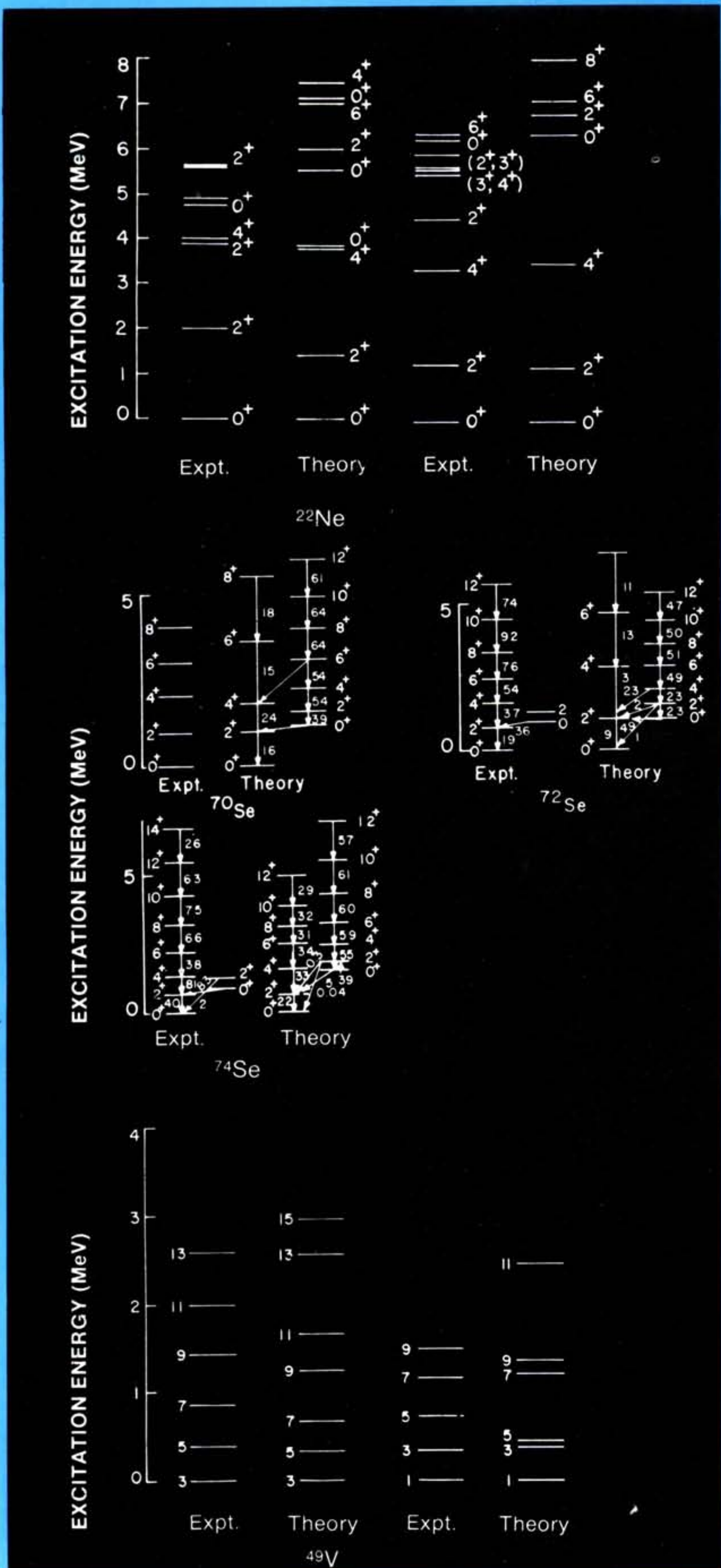
▼**4.1** Typical spectrum of a heavy nucleus.



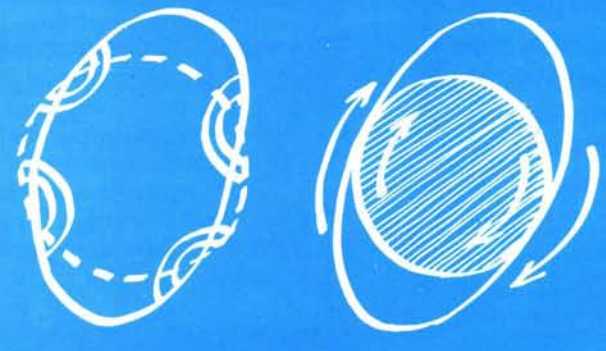
NUCLEAR AND SUBNUCLEAR PHYSICS

The atomic nucleus, a cluster of protons and neutrons at the centre of the atom, is the crucial object that appears in astrophysical phenomena such as nucleosynthesis in stars and collapse of stellar cores in supernova explosions, radioactive dating, nuclear reactors, etc. The nucleus exists in various states (levels) usually characterized by energy (measured in million electron volts, MeV) and angular momentum (spin). Moreover, the nucleus makes transitions from one state to another of the same nucleus or another one by emitting energy and/or particles.

The task of the nuclear spectroscopist is to predict and understand the properties of the various states of the nucleus. In (Fig. 4.1) we show the typical spectrum of a heavy nucleus: it has well separated levels when the excitation energy is small (< 2 MeV) and they become denser with an increase in energy. Thus, one attempts to study, in detail, the properties of each level in the low energy domain, while one focusses on the average (statistical) properties of levels in the high energy domain. For such studies, both the detailed as well as the average properties are required. From the properties of the low-lying levels of a nucleus (Fig. 4.2) one can establish the shape, which can be for a normal nucleus, spherical, prolate (like a cigar or American football) or oblate (like a discus). Recently, exotic nuclei (like ^{72}Se, selenium with 34 protons and 38 neutrons) in which number of protons and neutrons are markedly different from naturally occurring nuclei, are found to possess the property of *multiple personalities* or shape co-existence. PRL scientists working over the decades have developed a model which mixes different shapes, and have perfected the accompanying machinery, for reproducing and predicting the properties of the low-lying levels of both normal and exotic nuclei. As illustrations, a few results among a very large array of them, which are the first of their kind, are shown in Fig. 4.2.



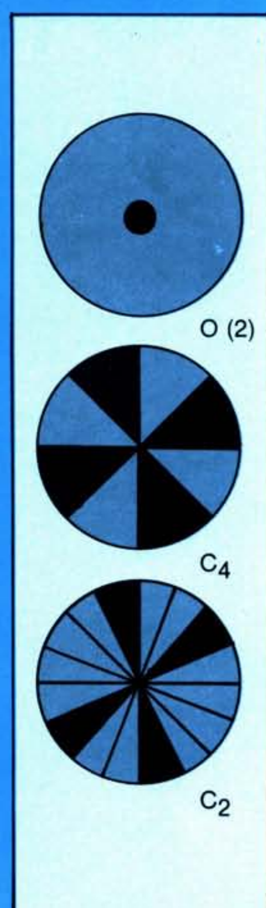
◀ **4.2** Spectra for various nuclei. The figures show the spin of the levels (in the case of ^{49}V it is 2 x spin). For Se isotopes which exhibit shape coexistence decay probabilities are also shown.

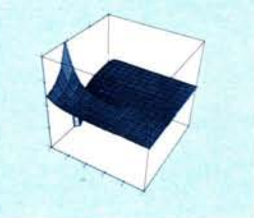


For a simple description of the collective motion associated with the shapes, the atomic nucleus can be imagined as a system of interacting Bose type particles. These objects (bosons) may be thought of as correlated pairs of neutrons or protons. Furthermore, using the notion of symmetries (Fig. 4.3) coupled with the boson picture, elaborate and diversified energy level patterns and decay properties are predicted by PRL scientists; these are observed in a variety of nuclei. An example of this work is shown in Fig. 4.4. A unique contribution from PRL scientists is in developing theories and applying them for studying the extent to which various (hypothesized) symmetries of the nuclear force are violated ((Fig. 4.3) for the concept of symmetry breaking) in real nuclei.

As the energy of the nucleus increases, the level density (number of energy levels per unit energy interval) becomes very large. For instance, in a heavy nucleus, at an excitation energy of about 6 MeV, there are about a million levels per MeV. As a result, for most purposes, only the average properties of these levels become relevant. Though the higher energy domain is complex, there is a narrow region (typically 6 MeV from the lowest energy) where the levels are that of a nucleus with

▼**4.3** Illustration of dynamic symmetries by regular breaking of rotational invariance.



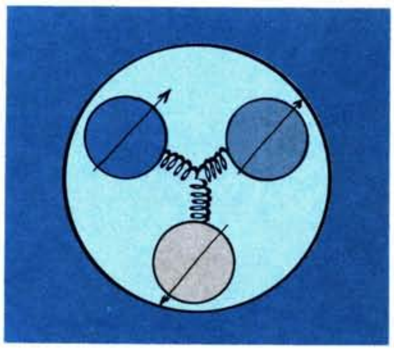


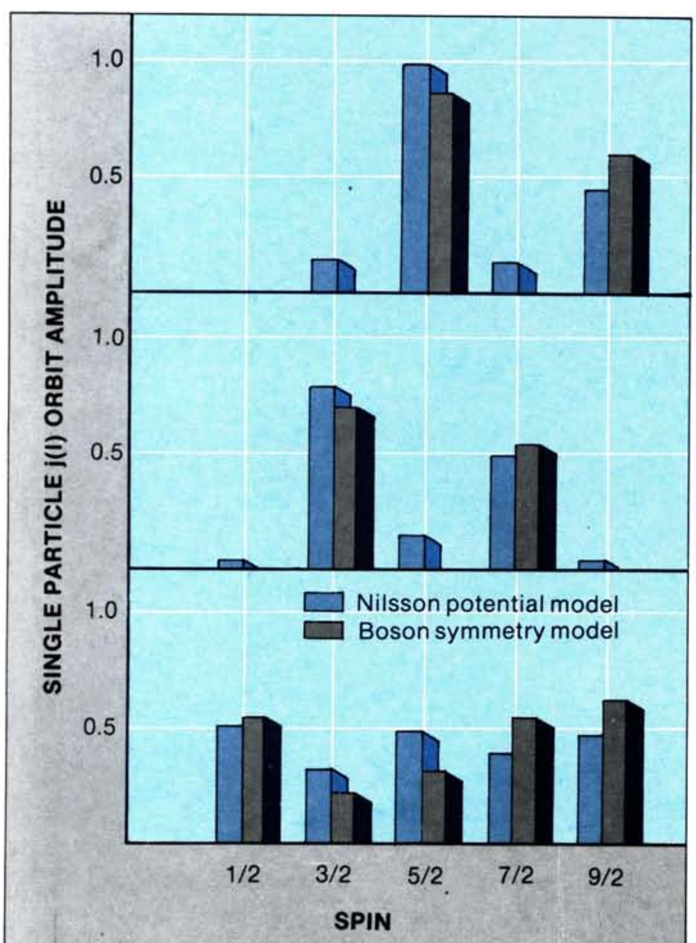
A model for reproducing and predicting the properties of the low-lying levels of both normal and exotic nuclei have been developed.

▼ **4.4** Single particle j(1) amplitudes in the geometric Nilsson model and a boson symmetry model. The "finger print" patterns seen in the complicated Nilsson model calculations (results for three Nilsson orbits, which are energetically lowest, are shown in the figure) come out naturally in the boson symmetry model and demonstrate that the observed patterns are consequence of a (dynamical) symmetry of the nuclear Hamiltonian.

▶ **4.5** Quark substructure of the nucleon.

a neutron attached to it. These levels (~100 in a given nucleus) are accessible to measurement. This extraordinary window allows us to ask the following questions: (1) are there viable models for reproducing observed average properties? (2) can one derive any useful information from these levels? PRL scientists working over the past ten years have answered these questions in the





affirmative. More specifically, an ab-initio approach for producing density of states at higher energies was developed. It was also shown using the statistical methods, that one can derive a bound on the extent to which nuclear force breaks the symmetry of time inversion. This is found to be about 3 parts in 1000.

One of the basic aims of physical sciences is to go deeper and deeper into the structure of matter. The structure of the atom is understood in terms of the electrons moving around the nucleus which itself, as mentioned earlier, consists of neutrons and protons. Further, the neutrons/protons have more elementary constituents called quarks. These come in three types, designated in terms of *colours* in addition to having other quantum numbers, such as spin (1/2). The colour of the quarks in these particles add up to make them colourless. This is known as confinement of colour. As a result, free quarks are not observed in nature. The neutron or proton consists of three quarks bound to each other. The mesons such as the π-mesons are colourless bound states of a quark and an antiquark. The dynamics of this colour called *quantum chromodynamics* is accepted to be the underlying theory of strong interaction. Thus, the residual molecular type forces from this colour interactions are expected to describe *strong* nuclear forces which result, for example, in the binding of neutrons and protons in nuclei.

The confinement mechanism is unknown. However, (Fig. 4.5) assuming certain spring like forces, PRL scientists have been able to obtain for light hadrons precise values of magnetic moments, sizes and masses with only a few parameters. These quark models are further employed to study the cross-sections in scattering processes involving hadrons, and decay probabilities of mesons. The gluons, unlike photons, interact among themselves and can form novel colourless objects called glue-balls. Considerable progress has been made by PRL scientists to understand and predict their properties.

CLASSICAL AND QUANTUM MECHANICS

Classical and quantum mechanics are two fundamental formalisms of physics which are so intimately related to each other and yet the nature of this relationship is not yet completely understood. Born four hundred years ago and reformulated through the centuries in the hands of Euler and Lagrange, Hamilton and Jacobi, and Gauss and Hertz, classical mechanics is basically a deterministic theory. The trajectory of a system is completely determinable once the initial conditions are known, and which are propagated forward in time by the equations of motion. Classical mechanics which withstood the test of time in describing the dynamics of macroscopic objects, failed miserably in the atomic domain.

Quantum mechanics was born sixty five years ago and has been an extremely successful theory in describing a vast variety of atomic and subatomic phenomena. But it is a probabilistic theory. Most physicists regard it as an intrinsically and irreducibly a probabilistic theory. Yet it is supposed to reduce in a certain approximation to the deterministic classical mechanics. Quantum mechanics itself, as a theory is enigmatic and is replete with conceptual difficulties which are being currently analysed and hotly debated.

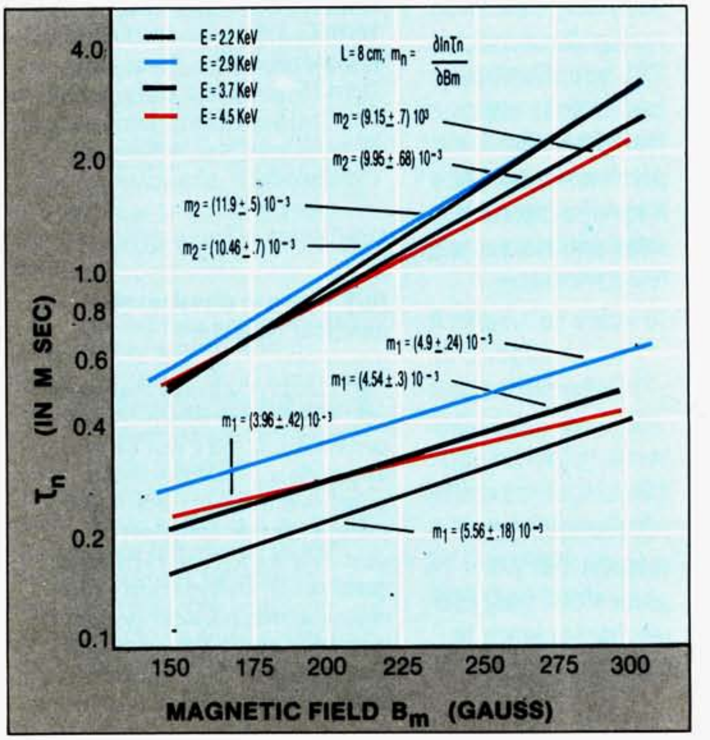
(i) A 'theory' for quantum mechanics:

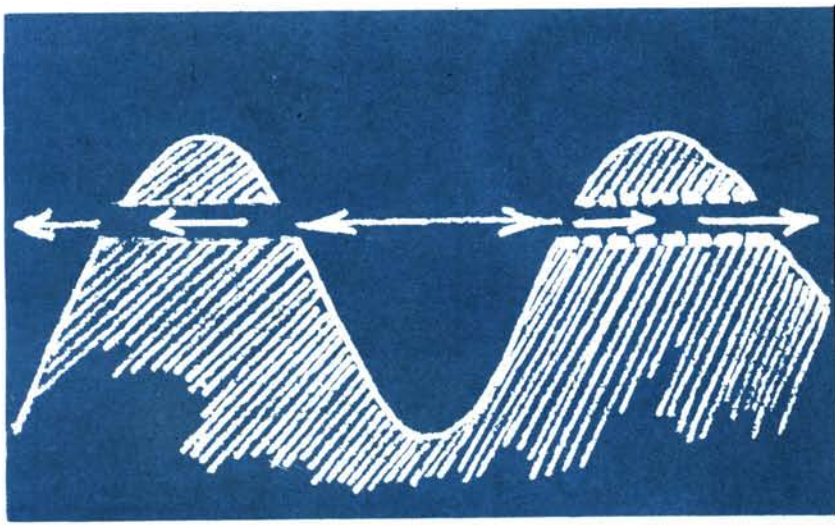
In an attempt to understand quantum mechanics and in particular, the nature of its probabilistic description better, a theoretical framework has been advanced at PRL whereby quantum mechanics is regarded as the Hamiltonian dynamics of a certain appropriately prepared ensemble of systems in a higher dimensional space. Indeed, a systematic derivation starting from the Liouville equation for the ensemble furnishes a generalized Schrödinger formalism complete with the standard Born prescription for the probability, but now in a generalized form, the generalized Schrödinger formalism describes the projections of the higher dimensional trajectories on to the lower dimensional physical configuration space.

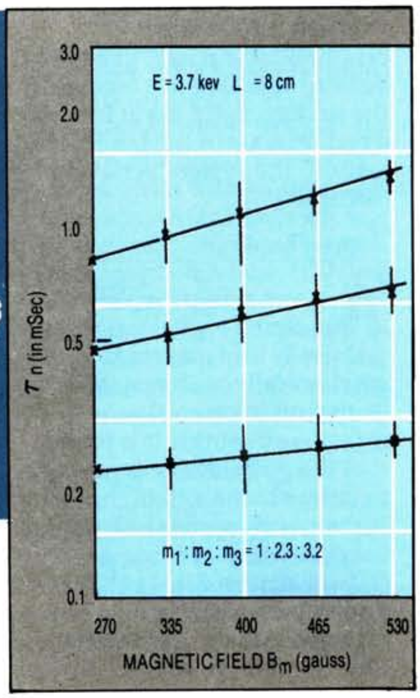
(ii) Quantum-like behaviour of a classical mechanical system:

It may appear heretical to suggest that a classical mechanical system could exhibit quantum-like behaviour. A certain classical mechanical system has indeed been identified, namely charged particle motion in an inhomogeneous magnetic field, a particular ensemble of which is shown to be describable in terms of a set of Schrödinger-like equations. The Schrödinger description is for the one dimensional projected motion along the magnetic field lines. The formalism is, in fact, completely analogous to the one described earlier for a theory of quantum mechanics, and in fact appears to be quite generic. It, therefore, naturally predicts the existence of quantum- or wave-like phenomena in the one-dimensional projected motion, such as interference and diffraction and quantum-like tunnelling. The quantum-like tunnelling refers to the loss of charged particles from "adiabatic mirror traps" as a consequence of the departure of the exact motion from the idealized one—the adiabatic motion which results in consequence of the existence of the adiabatic invariant, the gyroaction. The theory makes surprising predictions of the existence of a multiplicity of life times in the nonadiabatic loss. Such predictions are not available in the standard treatment of the problem. Upto three such life times have in fact been experimentally observed (Fig. 4.6).

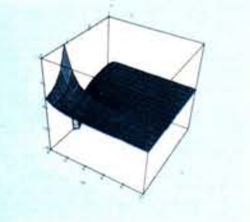
Even more astonishing is the prediction and the subsequent observations at PRL of wave-like phenomena—interference and diffraction (Fig. 4.7) for this classical mechanical system. The observation of these wave-like phenomena implies an interaction between the ensemble and the magnetic field in the momentum space, and a consequent nonlocality







◀ **4.6** Dependence of $\ln \tau_n$ on B_m at the mirror throat: for different energies of the particles, and for different magnetic field scale lengths. The straight lines in these figures represent the residence life times of an ensemble of particles in an adiabatic mirror trap plotted on a semi-log plot as a function of the magnetic field. The theory has given a rather surprising prediction of the existence of a multiplicity of life times for the ensemble for the same energy and pitch angle of injection. Fig. (a) depicts two such life times observed experimentally. The slopes of the straight line plots are found to be in the ratio m_1/m_2 of 1:2, in good agreement with the theory Different sets of straight lines correspond to different energies E and magnetic field scale length L as indicated. Fig. (b) gives the case of an observation of three distinct life times with the slopes in the ratios $m_1 : m_2 : m_3$ = 1:2.3:3.2, in reasonable agreement with the theoretical prediction of 1:2:3.



Assuming certain spring like forces, PRL scientists have been able to obtain for light hadrons precise values of magnetic moments, sizes and masses with few parameters.

which cannot be understood in terms of the standard classical mechanical paradigm. The results point to a new paradigm for dealing with at least a class of problems in classical mechanics.

(iii) Chaos in classical and quantum systems:

Though classical mechanics has been known for four centuries, it may not be widely appreciated that the exact solutions are not obtainable except for the simplest of systems which are termed as integrable. Integrability of a classical mechanical system is determined by the symmetry properties of the Hamiltonian or of the potential. Conditions can be found on a potential such that it is integrable.

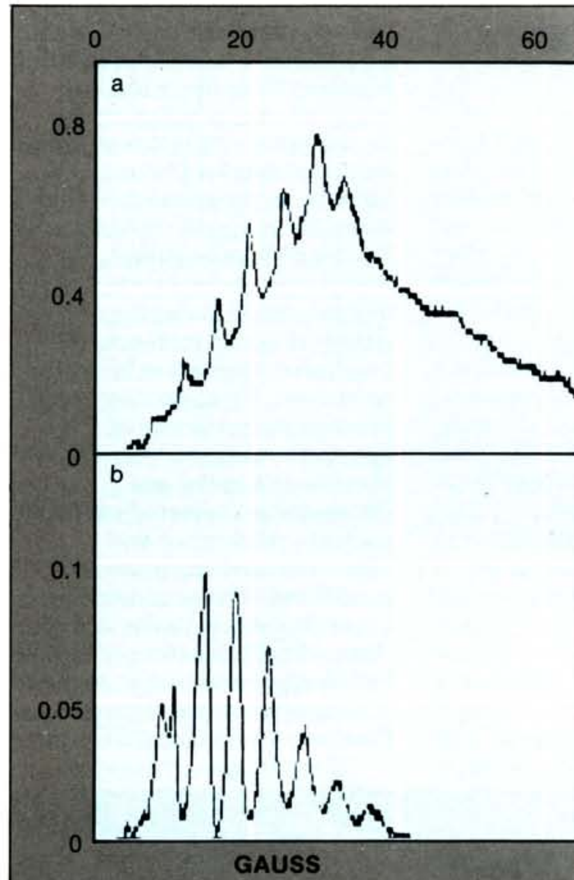
When a system is nonintegrable it can, in general, be very sensitive to a change in the initial conditions at least for a certain class of the latter. This leads to the system behaving *chaotically*.

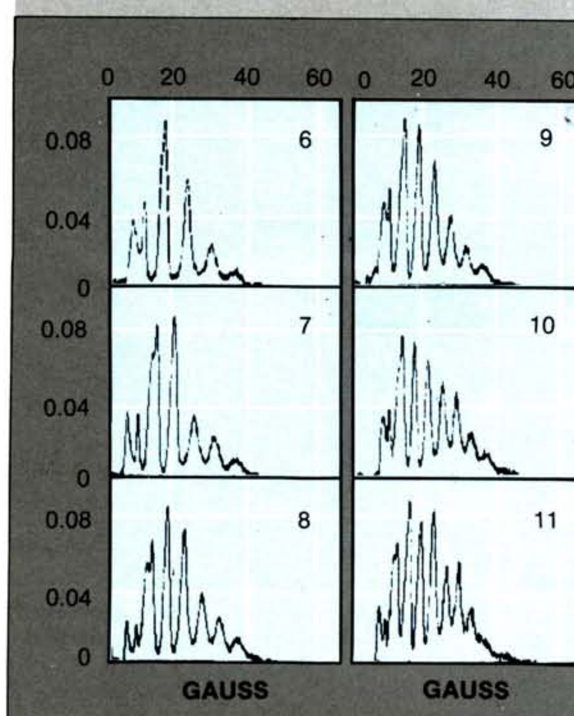
For some strange reasons, not yet understood quantum mechanics tends to suppress chaos.

A given nonintegrable system can be studied both classically and quantum mechanically with respect to transition to *chaos*. Again rather surprisingly it is found that the quantum system tends to be less chaotic than the corresponding classical system. In other words, for some strange reasons, not yet understood quantum mechanics tends to suppress chaos.

It is also of great interest to examine the manner in which chaos manifests itself in a quantum system. Basically, this implies searching for those characteristic properties of the eigenvalues and eigenfunctions of a Hamiltonian which would distinguish between an integrable and a non-integrable system. It has been shown that

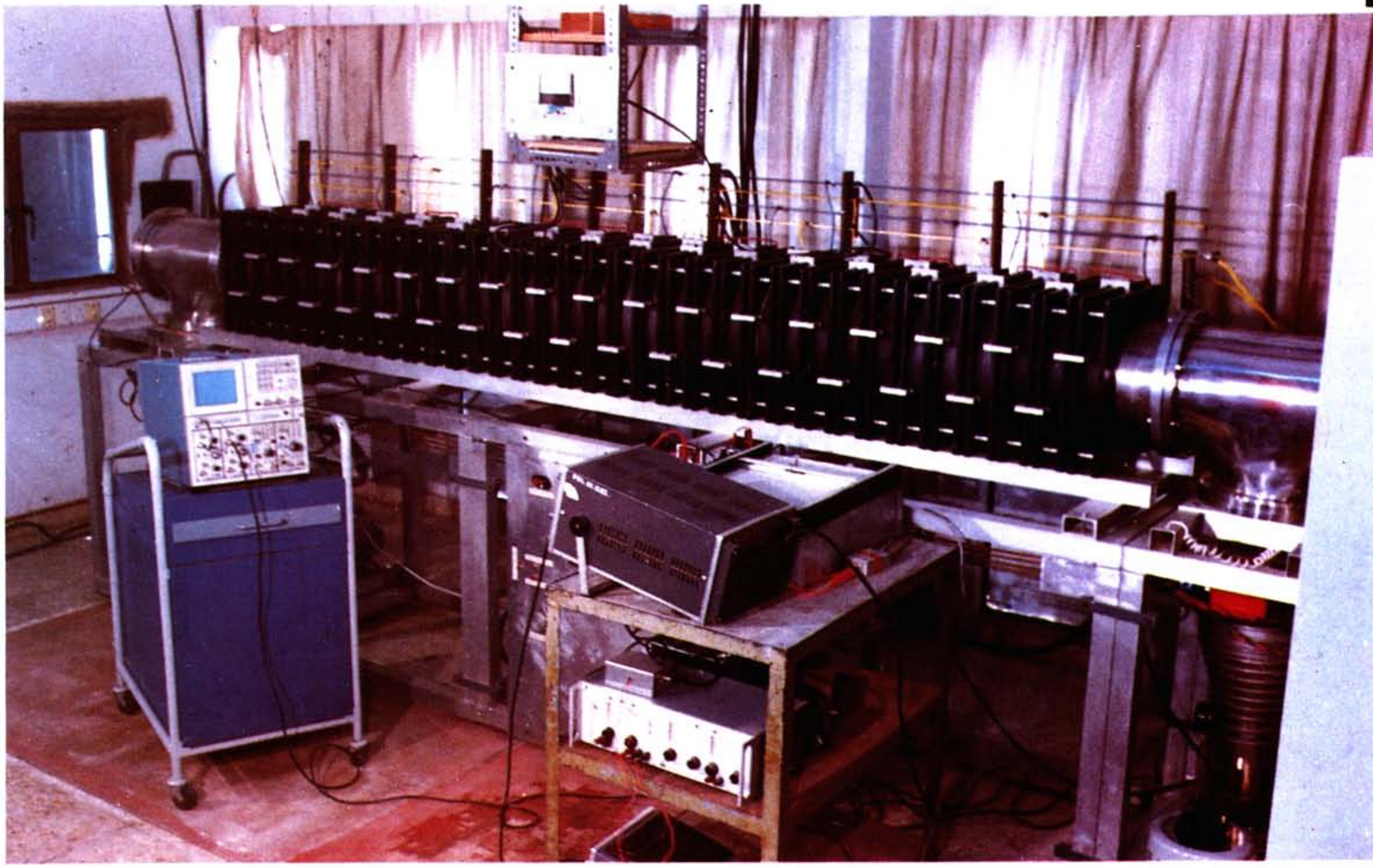
Even more astonishing is the prediction and the subsequent observations at PRL of wave like phenomena - interference and diffraction for this classical mechanical system.

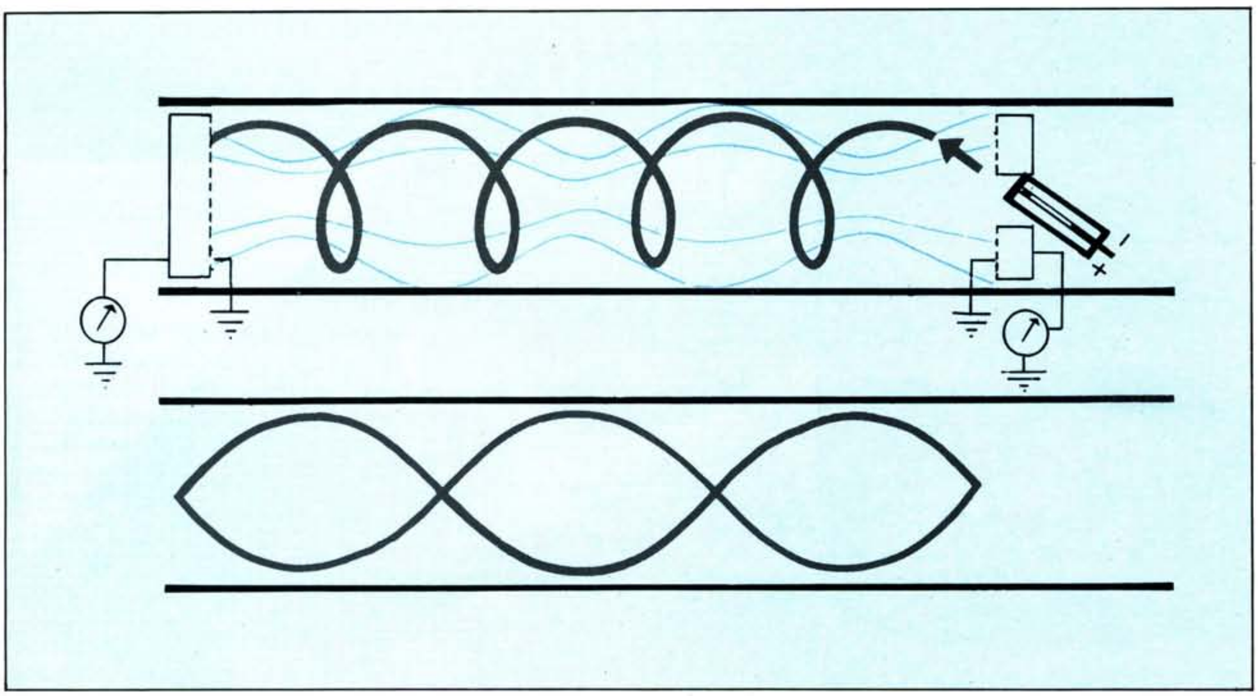




◀ **4.7 (a,b)** Represent the "interference phenomenon" observed in the dynamics of an ensemble of charges in inhomogeneous magnetic fields in a classical mechanical domain. Fig. (a) gives transmitted (A) and reflected (B) currents as a function of the magnetic field strength, for a given length, 9D (D = periodic length of the magnetic field) of the system and for a given energy of the electron beam and pitch angle of injection. The length of the system is defined by the position of the detector with respect to the gun, which records the transmitted current across its plane. The detector - a Faraday Cup - covers the entire cross section of the cylindrical system. A similar detector positioned close to the electron gun records the reflected current.
Note that the peaks in the reflected current (B) coincide, as expected, with the dips in the transmitted current (A). It may also be emphasized that with the angle of injection for the electron beam being well within the loss cone, such reflections at these discrete positions are not expected to occur according to the standard paradigm.

Fig. (b) represents the reflected current as a function of the magnetic field (for a given energy and pitch angle) for various lengths of the system L = 6D, 7D, 8D, 9D, 10D and 11D. What is interesting to note is that the *reflected current profile* is determined in a rather surprising manner by the length of the system L. This is a manifestation of nonlocality, which is astonishing in view of the system belonging to the classical mechanical domain. It is worth noting that the interpeak distance in the curves of Fig. (b) decreasing inversely with the length L. All the observed characteristics are, however, found to be in accordance with the predictions of the Schrodinger-like theory





▲ **4.7 (c)** An experimental set-up for observing wave-like phenomenon in a classical mechanical system.
◀ Schematic diagram representing electrons moving in an inhomogeneous magnetic field. (Top)
Electron standing waves in macroscopic dimensions. (Bottom).

the statistical properties of the eigenvalues, in particular their fluctuations, provide one such signature for differentiating between a regular integrable system and a chaotic non-integrable one. PRL scientists have made important contributions to these studies.

THE MACROCOSM

PHYSICS OF TERRESTRIAL AND EXTRA-TERRESTRIAL PROCESSES

How do the large-scale rain producing systems develop during the monsoon? What are their sources of energy? What are the physical mechanisms for the variations in the monsoon within a season as well as from year to year?

METEOROLOGY AND CLIMATE STUDIES

The dynamics of the Indian summer monsoon and of its variations on different time scales—within a season, from year to year and during different climatic regimes is fascinating and its study challenging. How do the large-scale rain producing systems develop during the monsoon? What are their sources of energy? What are the physical mechanisms for the variations in the monsoon within a season as well as from year to year? Whether such variations arise largely from interactions within the system, or through external factors. These are some of the questions being addressed by the theoretical climatologists of PRL.

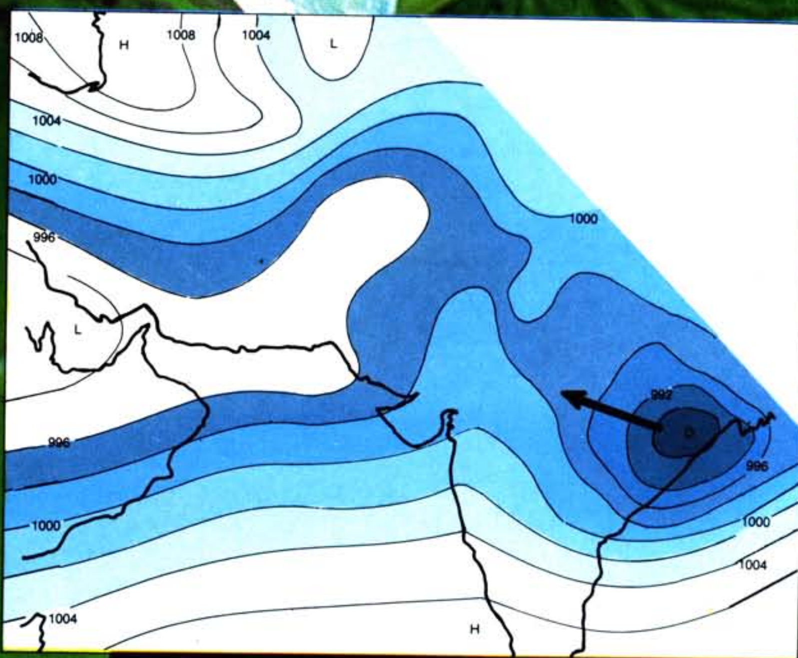
Using the monsoon rainfall record of the past 116 years PRL scientists have found that a large part of monsoon variability from year to year arises from internal variability.

Two synoptic systems which contribute significantly in giving rain to the country are

(i) the areas of low pressure in the atmosphere (lows and depressions) which form over north Bay of Bengal and move across central and adjoining north India (Fig. 4.8) and

(ii) the anticlockwise movements of air in the upper atmosphere (3 to 6 km) developing over Gujarat.

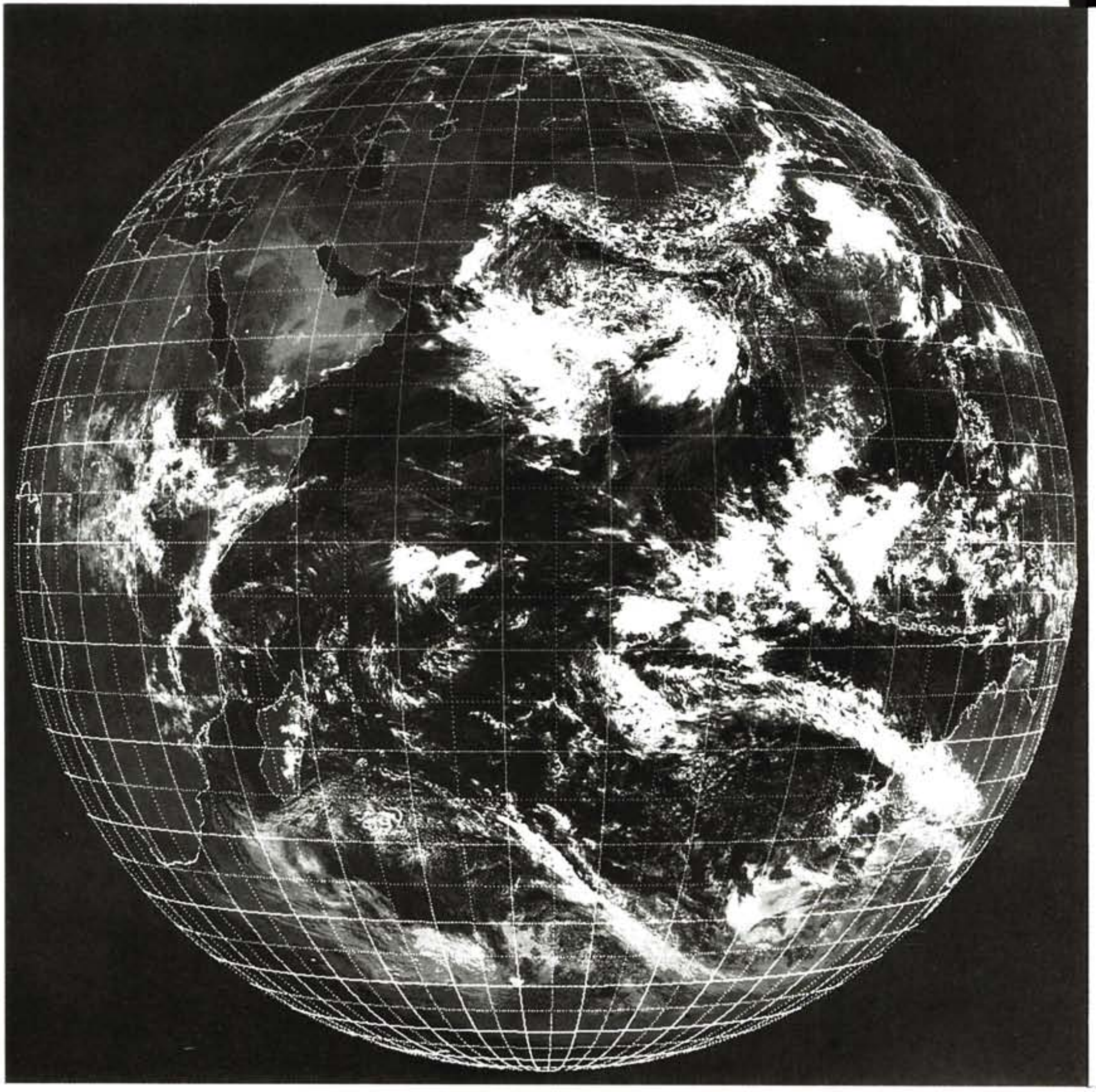
▼ 4.8 Sea level pressure map of a typical monsoon depression. The centre is marked 'D'. The arrow indicates typical direction of movement.



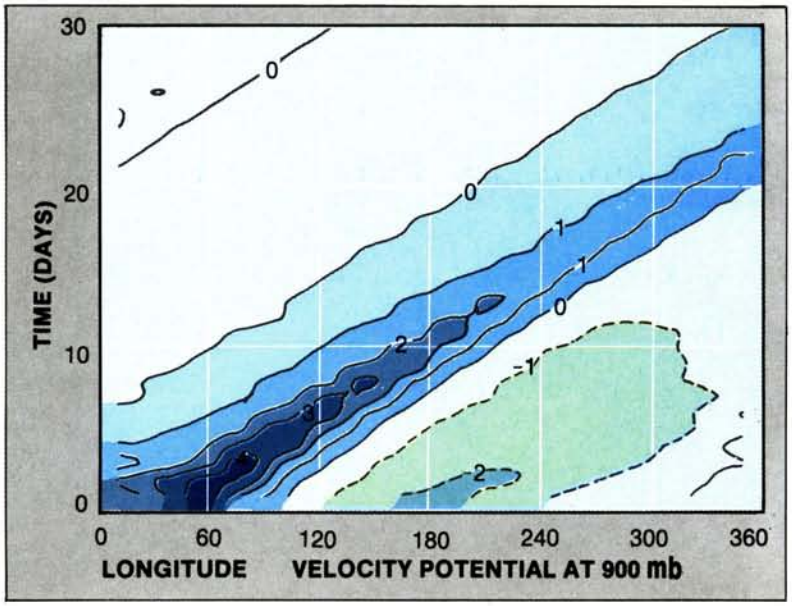
PRL scientists have conducted extensive theoretical studies to understand the physical mechanisms for the growth of these low pressure areas and upper air circulations during the monsoon. It was found that such circulations grow in regions where there are large variations of wind with latitude and altitude and where latent heat is released through formation of clouds and rain. The theory predicted that waves in the atmosphere about 2500 km long developed fastest and their amplitudes would double in about three days. These predictions were found to agree with what have been observed in nature.

Features related to monsoon flow, cloudiness and rainfall show a tendency to repeat after 30–50 days and these areas of clouds and rain shift slowly northwards. The PRL group has given a new theory to explain these observed features. Fig. 4.9 shows the INSAT cloud picture of an active monsoon phase. In the equatorial region variations of 30–50 days move slowly eastwards. Fig. 4.10 shows the eastward propagation of such an oscillation with a period of 25 days, derived through theoretical calculations.

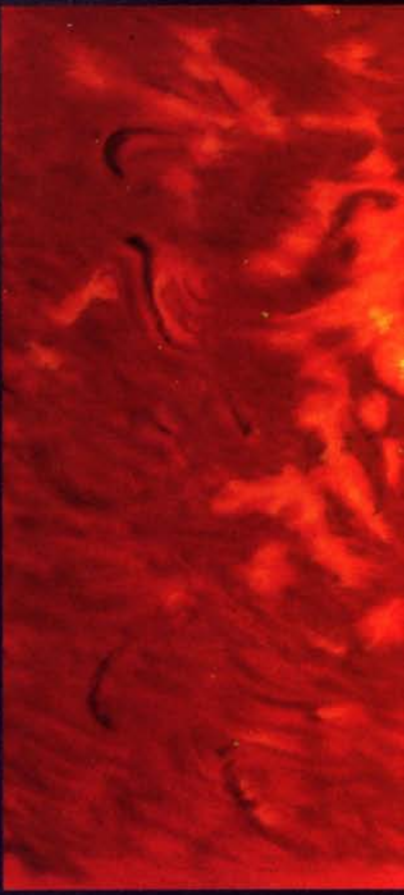
The fluctuation of monsoon rainfall may be due either to variations in the external forcing like effective solar radiation or to internal variability within the monsoon wind system. The latter occurs when there are interactions between factors within the different components of the monsoon. Using the monsoon rainfall record of the past 116 years PRL scientists have found that a large part of monsoon variability from year to year arises from such intrinsic or internal variability.



▲ **4.9** INSAT cloud picture of a typical active monsoon day. Note the east-west cloud band extending from north Arabian sea to Burma.



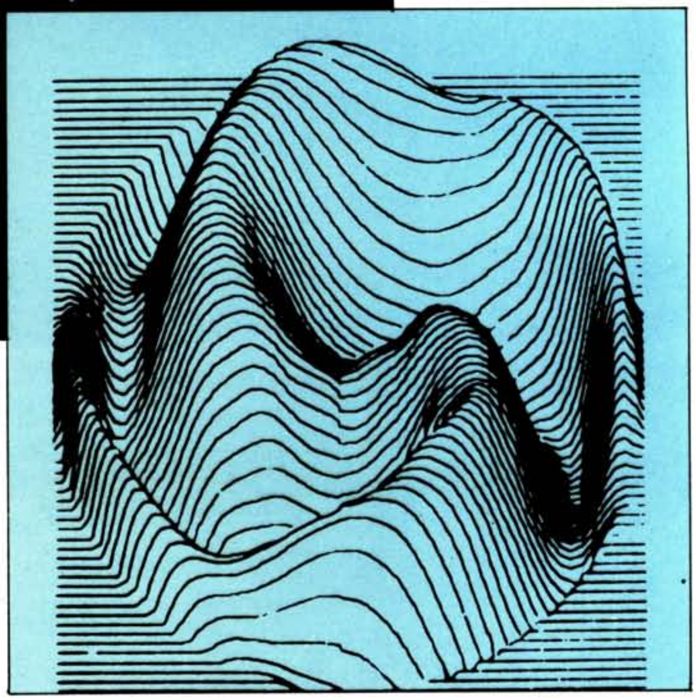
◀ **4.10** Longitude - time section showing an eastward moving wave of period twenty five days predicted in a global model.



▶ **4.11** Sun spots and Solar flares: The most powerful and explosive form of solar activity. They appear in the Chromosphere suddenly with unexpected brightness lasting from a few minutes to half an hour. These produce many kinds of radiation disturbing Earth's magnetic field, disrupting the ionosphere and radio communications, aurorae and other effects. Flares are high temperature phenomena and the secret of the generation and development lies in the full understanding of the plasma processes.

◀ **4.12** Aurora Borealis - These belong to a class of the most spectacular and lovely natural phenomena. They produce very bright illuminations in the sky. At times, this light is visible upto a very great height such as 1000 kms. The light may be white, green, blue, yellow, violet or red. These are seen to be associated with the solar-activity. The generation mechanism is not yet fully understood. However, it is now believed to be generated by the charged particles coming directly from the Sun and the particles from the tail, energized by some plasma processes, during their journey to atmosphere.

Among different types of galaxies, those with spiral structures are one of the most interesting objects.



▲ **4.18** Development of a spiral structure in a differentially rotating thin gravitating disk of interstellar matter.

of charged particles in electromagnetic fields in the formalism of General Relativity, the significance of the magnetic fields in trapping the particles and consequent formation of disk-like structure was investigated. Further the studies also established the necessity to use General Relativity vis-a-vis the Newtonian theory of Gravitation in the dynamics of accretion disks.

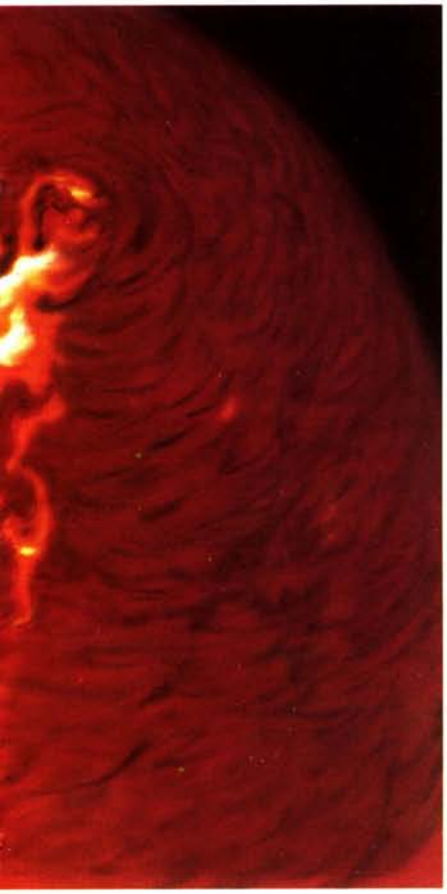
Whereas General Relativity becomes significant in the context of high energy sources, one could describe the structure of galaxies purely in terms of Newtonian physics. Among different types of galaxies, those with spiral structures are one of the most interesting objects. Starting with a differentially rotating thin gravitating disk of matter, it has been shown that if the azimuthally symmetric disk is perturbed by a small density perturbation in the form of a spiral, then the perturbation grows at the expense of gravitational energy in the disk, thus leading to the development of a spiral structure (Fig. 4.18). A very interesting finding is made that the sense of the spiral found observationally in most galaxies (trailing as against leading) is reproduced through the present analysis for galaxies with at least 15% of their energy in the random (thermal) motion of the matter. The effect that the different masses of the galactic bulge have on the nature of the spiral structure is also determined. The analysis appears to reproduce the spiral characteristics of Sa, Sb and Sc type of galaxies.

The activities of PRL scientists in theoretical physics, over the next decade, are expected to continue in the areas of astrophysics and space physics, climate studies and microscopic physics involving atomic and molecular physics, nuclear physics and particle physics.

Major emphasis will be to evolve an integrated astrophysics programme where inputs from plasma physics as well as different aspects of microscopic physics will be considered. The meteorology and climate programme would also have a broader perspective whereby the effects of ocean and of middle and upper atmosphere on the weather would be examined. Another aspect of many of these programmes would be to explore at the basic level the implications of non-linearities and chaotic behaviour in the physical system.

We also foresee a vigorous programme in the physics of the microscopic systems at the atomic, nuclear and sub-nuclear levels. The group hopes to contribute significantly to:

- microscopic understanding of atomic and molecular scattering processes,
- ab initio studies of nuclei,
- a deeper and fundamental understanding of strong interactions and
- going beyond the standard model to understand the unity of elementary particles and their interactions.



PLASMA PROCESSES IN TERRESTRIAL, SPACE AND ASTROPHYSICAL SYSTEMS

The plasma is referred to as the fourth state of matter. It is produced when a gas is heated to such a high temperature that one or more electrons in the atoms of the gas are knocked out of them due to their highly energetic random thermal motions. This process of ionization is referred as the "thermal ionization" and the overall charge neutral ionized gas that results therefrom is known as a 'plasma'. The process of thermal ionization was proposed by the Indian astrophysicst, M.N. Saha, and has been vital for the understanding of the constitution of stars which consist of matter in the plasma state due to their high temperature. Indeed, more than 99% of the matter in the Universe including the stars, the galaxies, the interstellar and intergalactic space etc. is in the plasma state.

If we look at our own star—the Sun, we see a variety of very fascinating phenomena—the solar flares, the solar prominences, the sun spots and many eruptive phenomena which are but the manifestations of the complex plasma processes (Fig. 4.11). Close to our own terrestrial environment, the *Aurora Borealis* provides a spectacular and fascinating display (Fig. 4.12) of the beauty of natural phenomena involving plasma processes and related in a rather complex manner, to the disturbances which have their origin on the Sun and in the interplanetary space.

Because it consists of positively and negatively charged particles (in equal numbers, so that the whole assembly is charge neutral), a plasma responds to the action of electromagnetic fields. It is, thus, a hydromagnetic fluid which displays a dynamical behaviour that is much more complex than simply a fluid dynamical behaviour.

To understand the plasma processes relating to natural phenomena in various terrestrial and astrophysical settings, plasma physicists have to begin by first drastically simplifying the situations by invoking certain limiting conditions under which it may be easier to understand the plasma behaviour. Almost all plasma phenomena involve disturbances of one kind or another: Usually, they are large amplitude disturbances. But the behaviour of large amplitude disturbances is difficult to understand. Thus, one begins by assuming the limiting condition that the disturbances are of an infinitesimally small amplitude over a certain undisturbed equilibrium state. A plasma by virtue of its complex electromagnetic nature can support a large variety of waves, which propagate with a speed determined by the nature of disturbance. When the amplitude of disturbance is infinitesimally small compared to its wave length, it is known as a linear wave. Otherwise, one has, in general, a non-linear wave.

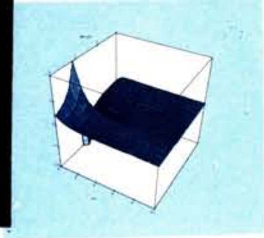
A plasma has a variety of energy storages in it: thermal energy, fluid kinetic energy, electromagnetic energy and energies which reside in the departures from thermodynamic equilibrium state. Some of these may be in the form of *free energy* which the plasma may be able to release (if suitable trigger is provided) to its fluid motion, electromagnetic field or both. Thus, if, in a certain equilibrium state, a plasma is given an infinitesimal perturbation in its field quantities, these may grow at the expense of the plasma free energy. The plasma is then said to be unstable to these perturbations. Such an analysis is known as a linear instability analysis. Even though these studies are yet far removed from the real fullfledged large disturbance behaviour, they are nevertheless of great importance in understanding in an analytical fashion,the nature of the plasma behaviour and its characteristics.

A plasma which departs from thermodynamical equilibrium state may have inhomogeneities in its density distribution and anisotropy in its temperature distribution or may possess non-Maxwellian velocity distribution for its particles (electrons and ions). These are all sources of free energy. Such plasmas exist in the natural settings as well as in the laboratory. PRL plasma physicists, over the last two decades, have studied a number of instabilities arising from these free energy sources. Some of the instabilities studied have been related to the

Solar flares, solar prominences, sun spots and many eruptive phenomena are manifestations of complex plasma processes.

A plasma by virtue of its complex electromagnetic nature can support a large variety of waves, which propagate with a speed determined by the nature of disturbances.

Because it consists of positively and negatively charged particles, a plasma responds to the action of electromagnetic fields. It is, thus, a hydromagnetic fluid which displays a dynamical behaviour that is much more complex than simply a fluid dynamical behaviour.

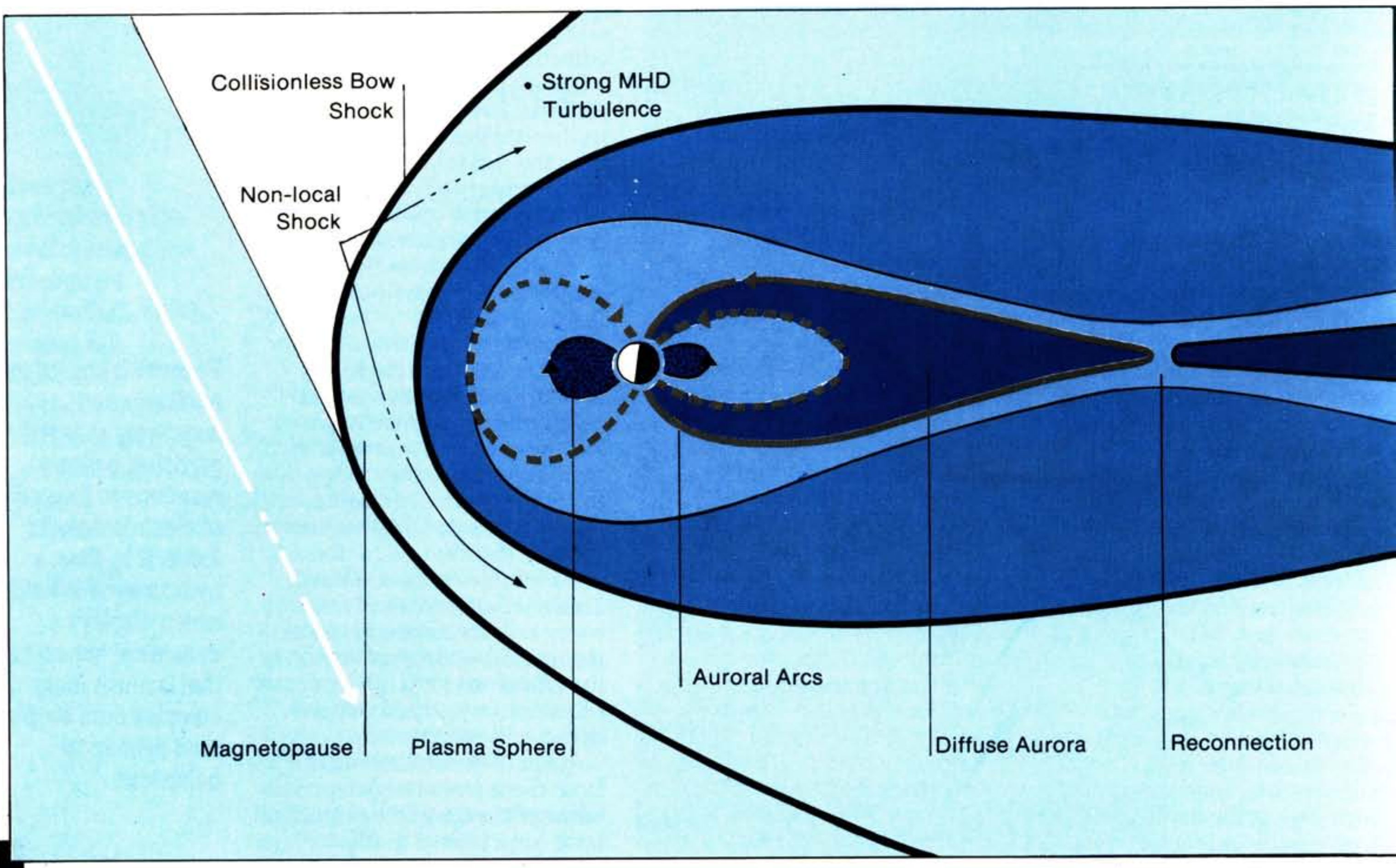


observations of the ionospheric plasma irregularities using rocket-borne probes as well as ground-based ionosondes.

A class of instabilities which are frequently encountered in natural plasmas are generically related to the Rayleigh-Taylor instability, that of a fluid with an inverted density distribution in a gravitational field. A similar instability arises if the gravitational field is replaced by an electric field and the plasma be partially ionized; or if, in the spirit of the equivalence principle, a gravitational field is simulated in the frame of an accelerated plasma. The latter provides a mechanism for the spontaneous generation of magnetic fields in laser produced strongly accelerated ablated plasmas with steep density gradients. All these instabilities have been studied by the PRL plasma physics group in relation to ionospheric, space and laboratory plasmas.

Another class of instabilities which are very important for understanding some of the space plasma phenomena, particularly in the magnetosphere and in the interplanetary space as well as in big plasma machines (fusion devices) are the velocity space instabilities. For these, the free energy resides in the departure of the velocity distribution from the Maxwellian distribution. A large number of such instabilities have been studied.

Yet another interesting and important class of instabilities may be called topological instabilities, in which case the free energy resides in the topology of a magnetic field configuration. A plasma will exhibit such an instability if another magnetic field configuration with a different topology is accessible to it. Such changes in topology are possible only through dissipative processes. These topology changes are referred as magnetic field reconnections. The associated instabilities are commonly known as tearing instabilities and have wide ranging applications in the explanation of disruptive processes occurring in the geomagnetic tail; which, in turn, lead to the precipitation of electrons in the polar latitudes and the production of Aurora Borealis, the solar flares on Sun's surface and the so-called disruptive instability observed in the fusion device known as the tokamak. Important work has been carried out at PRL relating to this instability in connection with the substorm phenomenon.



▼**4.13** Schematic illustration of the noon-midnight section of the magnetosphere. The interaction of solar-wind from the left with the magnetic field of the Earth creates a region where the solar-wind particle cannot enter directly. This region is called the magnetosphere. Different plasma instabilities can occur at different regions of the magnetosphere and produce many puzzling and interesting magnetospheric phenomena. These are also shown schematically in the diagram.

Solar wind in the form of a plasma stream emanating from the Sun interacts with Earth's magnetic field and produces a cavity called the magnetosphere (Fig. 4.13). Inside the magnetosphere, highly energetic electrons and ions are trapped in a region called radiation belt. Many interesting plasma phenomena are seen to occur in this region. Whistlers, which were first observed during World War I, are nothing but radio signals in audio-frequency that whistle. These are natural magnetospheric plasma events although initially they were popularly described as *voices from outer space*. There are many puzzling phenomena associated with these whistlers, known as VLF emissions. PRL scientists have explained the origin as well as the different features of these emissions on the basis of a series of studies on wave-particle interactions in the radiation belt of the magnetosphere. Another important phenomenon where our scientists have made contribution is the auroral kilometric radiations which are associated with the radiation-belt particles.

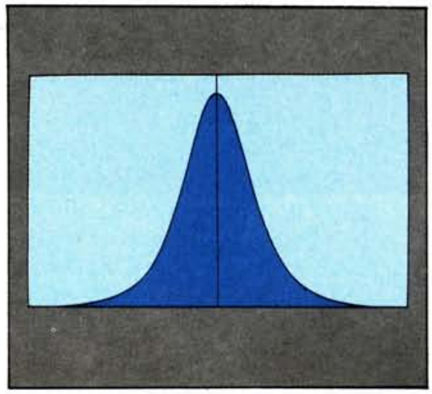
Powerful high frequency radio-waves from the ground were used in recent years to modify the density and temperature of the ionosphere in the height range between 100 and 350 kms. Fortunately, for plasma physicists, these experiments produced a host of interesting and unexpected plasma phenomena. The most unexpected phenomenon of striations or fine structures in densities was explained by the scientists of our laboratory on the basis of a plasma instability called parametric instability

However, as mentioned earlier, the natural phenomena involved distrubances of arbitrarily large amplitude and, therefore, are, in general, non-linear. This means that the differential equations governing the evolution of field quantities have in them terms of higher degrees in the field quantities besides those with degree one. The presence of these non-linear terms undoubtedly makes the solution of the differential equation much more difficult. But, on the other hand, it is these non-linearities which are responsible for the spectacular nature of many of the natural phenomena. Thus, the overturning and breaking of the ocean surface waves, the von Karman vortex structure behind an obstacle in a fluid flow are well known examples of the effects of non-linearities.

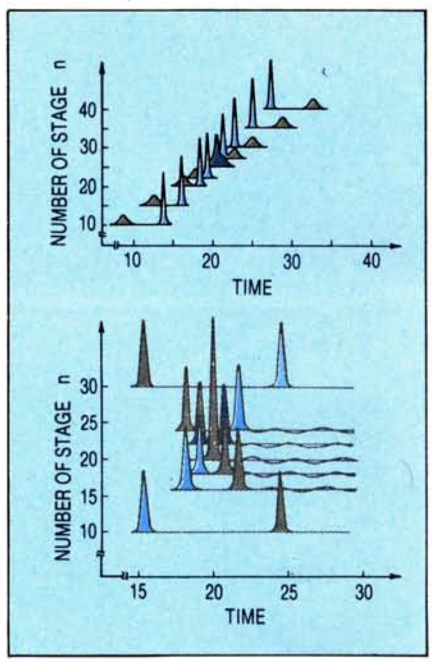
A non-linear structure which has received considerable attention since the sixties is known as a soliton. It is however, reported to have been first observed in 1834 by J. Scott Russell in a water stream. Solitons in plasmas have, however, been extensively investigated since the sixties. A considerable amount of work has been done on solitons in plasmas by PRL plasma physicists. A soliton is a stationary structure which propagates like a wave, but without changing its shape. It may be a hump or a depression, or a discontinuity (Fig. 4.14). The stationarity of the strcuture arises from a balance between the effects of non-linearity which steepen a disturbance and the dispersive effects which tend to flatten it. It is, therefore, necessary to have both these effects to have the stationary structure.

Solitons possess another remarkable property, namely that two solitons of different shapes can collide with each other, but are found to preserve their identity after the collisions (Fig. 4.15). In this sense, they behave like particles.

One can construct a soliton for any linear mode of plasma oscillations. Thus, PRL plasma

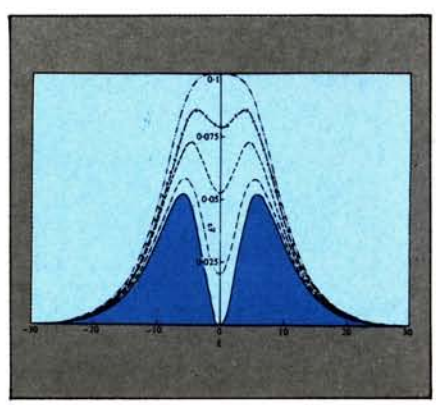


◀ **4.14** Solitons are nonlinear waves in the form of humps or depressions. They retain their form for a long time. They behave like particles and even after interactions do not change their shapes and sizes.

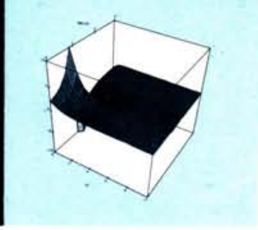


◀ **4.15** Numerical observations of the collisions of two solitons. (a) A case of "overtaking" collisions in which a large amplitude soliton was propagating from the same end as the small amplitude soliton but slightly delayed in time. The collision has taken place almost in the middle.
(b) A case of 'head-on' collision in which two solitons of same amplitude are launched from two ends. Collisions took place in the middle approximately. However, there is some noise generated in the medium.

In both cases, solitons emerge out of the interacting regions without any change in shape and size (Daikoku et.al., Jap. J. App. Phys., 14, 367, 1975)



◀ **4.16** Transition of a single hump soliton to a camel-back type double hump formed when the Mach number (M) increases from 0 to 1. The ordinate denotes high-frequency Langmuir wave intensity for
-·-·- M = 0.83
— x — M = 0.85
— — — M = 0.87
— · — M = 0.89
——— M = 0.90



All these instabilities (Rayleigh-Taylor, velocity space, topological and parametric) have been studied by the PRL Plasma Physics Group in relation to ionospheric, space and laboratory plasmas.

physics group has studied ion and electron acoustic solitons and the effect of plasma density gradient and of finite ion temperature, effect of multiple species and two temperature populations of particles.

In certain cases, a large amplitude wave is found to be unstable to the modulation of its amplitude in space. As this instability grows to its non-linear stage, the envelope of the wave acquires a soliton like form: such solitons are referred to as envelope solitons and have properties similar to those of other non-linear wave solitons. A substantial amount of work has been done at PRL to study the propagation characteristics of a variety of such solitons. For example, it has been shown that in a magnetized plasma, there exist two types of solitary waves (corresponding to the so-called lower hybrid mode): one with a constant phase pulse and the other with an envelope solitary wave. Similarly, the electron acoustic waves with the inclusion of appropriate non-linearity have been shown to give plane solitary waves in a magnetized plasma. In a study of large amplitude Langmuir (envelope) solitons with arbitrary ion non-linearity, the solitons have been found to undergo transition from a single hump to a camel-back-type double hump (Fig. 4.16) form as the Mach number, M (ratio of soliton speed u to ion acoustic speed v; $M = u/v$) increases from zero to one; the transition occurring around $M = 0.6$.

Solitons have been observed not only in the laboratory plasma experiments, but also exist in plasmas in outer space. For example, the ever persisting Great Red-Spot of Jupiter is supposed to be a solitary vortex structure. Solitons have also been observed in the auroral region which have been successfully explained by PRL scientists. A suggestion has also been made that the radio wave emissions from the pulsar can be explained as radiation emitted by the Langmuir envelope solitons in pulsars.

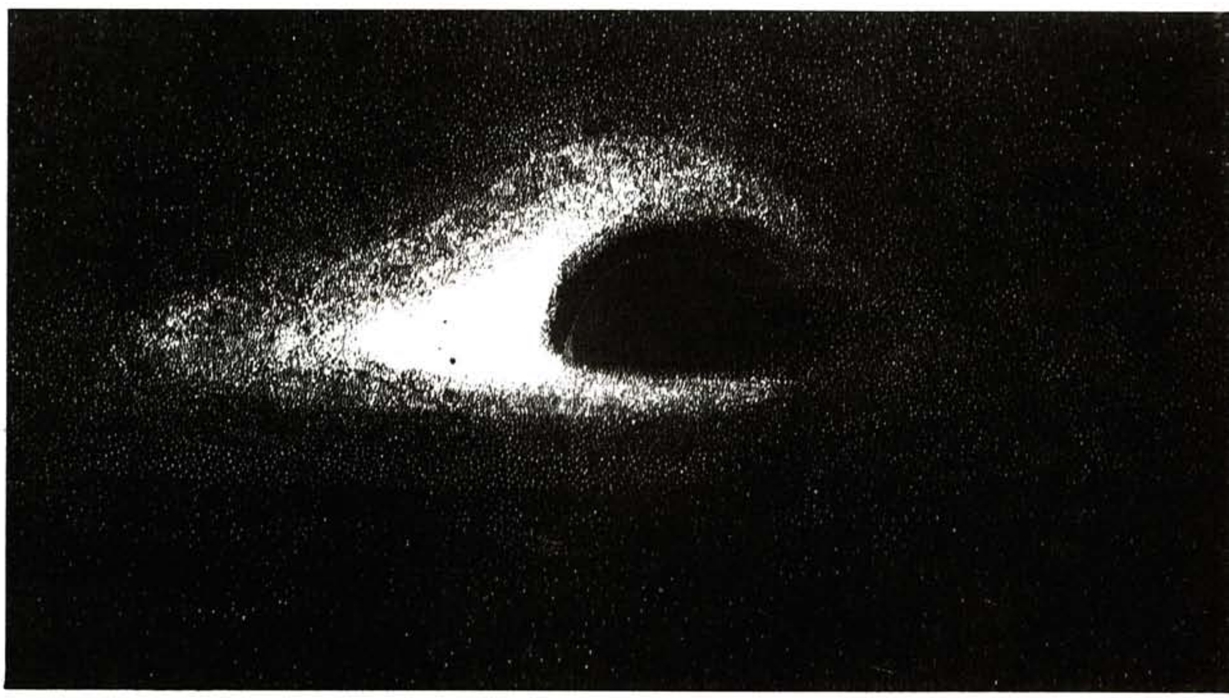
When do disks form and when does the matter accrete giving rise to the emission of radiation? To answer these questions one needs to understand the dynamics of plasma in strong gravitational fields.

A plasma, in general, supports both low frequency long wave length and high frequency short wave length distrubances driven respectively by macroscopic density/velocity/temperature gradients and velocity space free energy sources. A novel concept of coupling these two types of disturbances has been developed at PRL whereby a macroscopic mode causes a faster breaking of current filaments by its interaction with high frequency wave fluctuations. This theory has potential applications in understanding the phenomena, such as solar flares and major disruption in fusion devices.

GRAVITATIONAL PROCESSES IN ASTROPHYSICAL SYSTEMS

During the past two decades the foremost idea that has occupied the attention of astrophysicists in connection with modelling of high energy sources like Quasars, Pulsars and X-ray binaries is the phenomenon of accretion of matter by compact objects through disks around them (Fig. 4.17). When do disks form and when does the matter accrete giving rise to the emission of radiation? To answer these questions one needs to understand the dynamics of charged matter (plasma) in strong gravitational fields. Starting with a systematic analysis of the orbits

The most unexpected phenomenon of striations or fine structures in densities was explained by the scientists of our laboratory on the basis of a plasma instability called parametric instability.



▶ **4.17** Luminet's computer picture of a black hole with accretion disk. (Astro. Astrophys. 75, 228, 1979).

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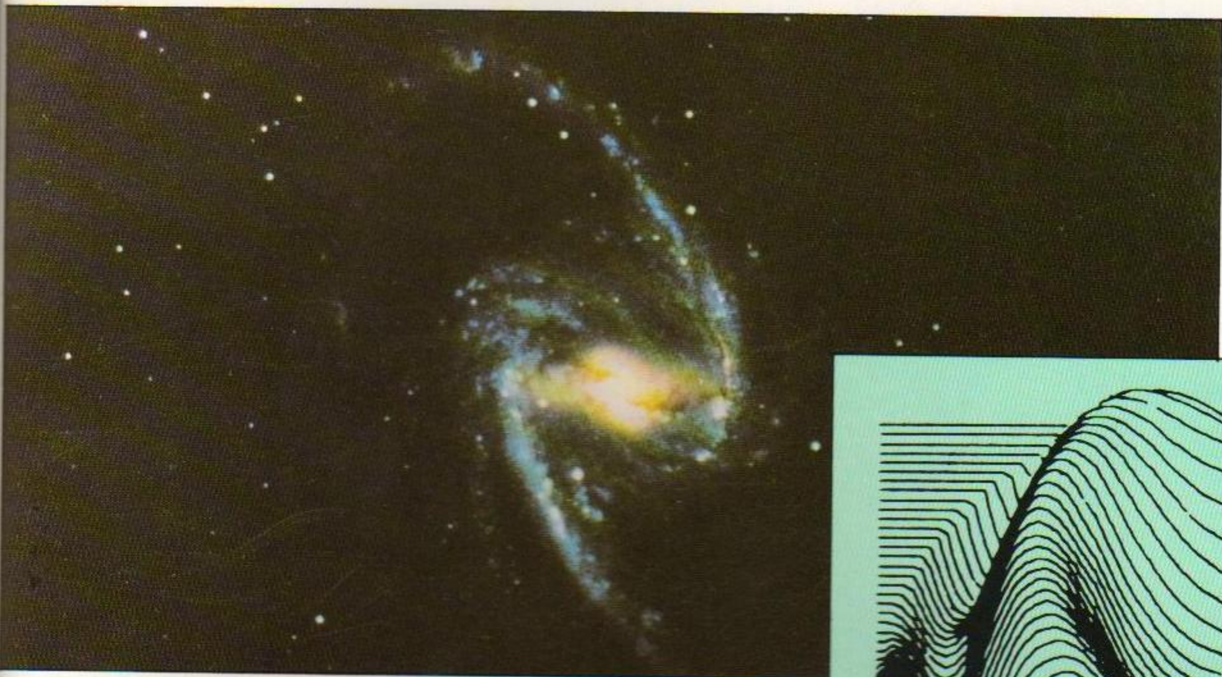
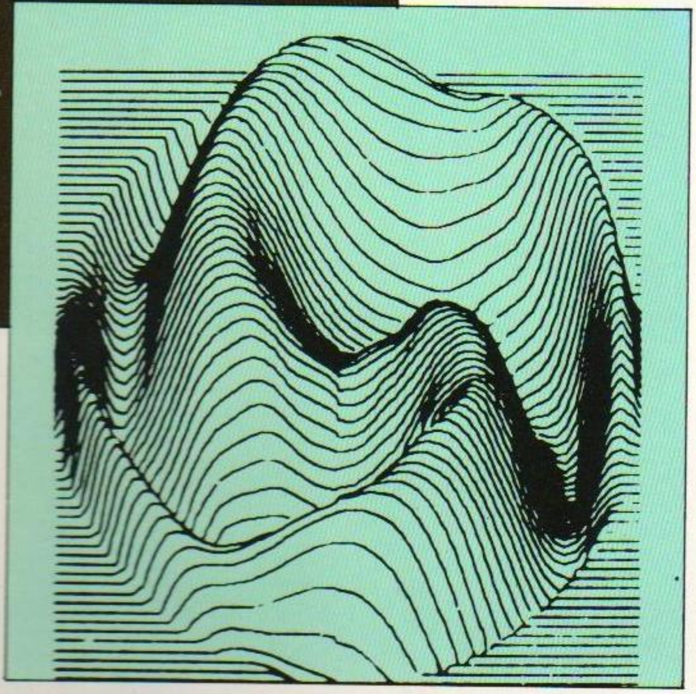


Among different types of galaxies, those with spiral structures are one of the most interesting objects.



▲ **4.18** Development of a spiral structure in a differentially rotating thin gravitating disk of inter-stellar matter.

of charged particles in electromagnetic fields in the formalism of General Relativity, the significance of the magnetic fields in trapping the particles and consequent formation of disk-like structure was investigated. Further the studies also established the necessity to use General Relativity vis-a-vis the Newtonian theory of Gravitation in the dynamics of accretion disks.

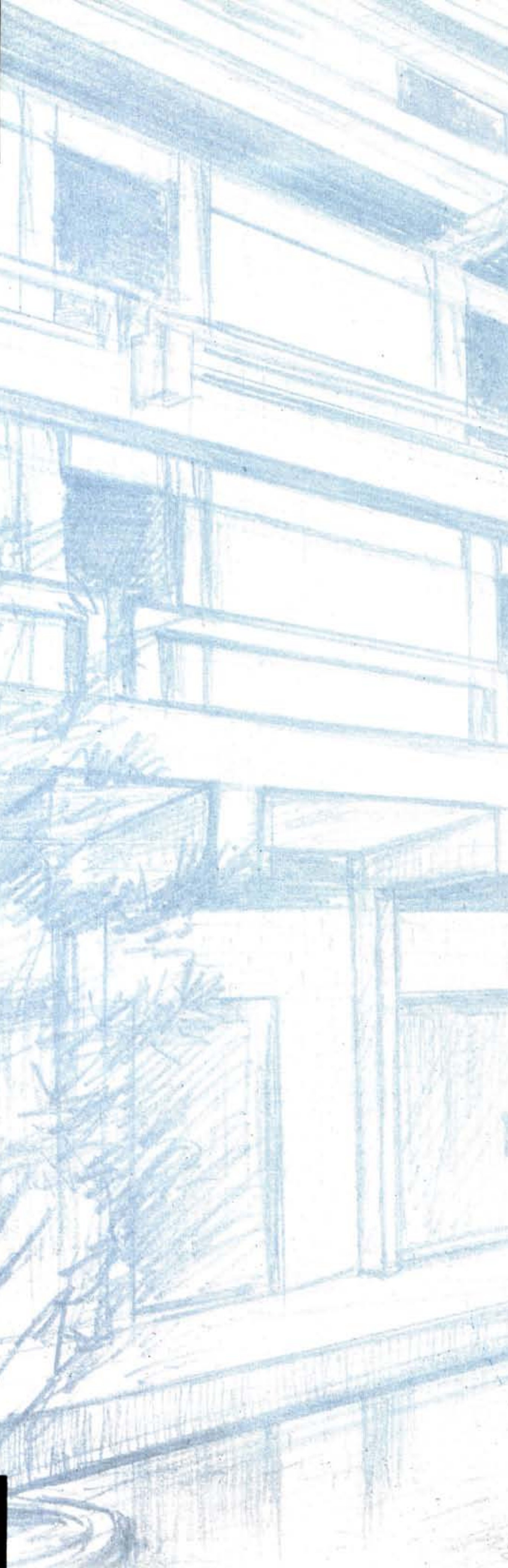
Whereas General Relativity becomes significant in the context of high energy sources, one could describe the structure of galaxies purely in terms of Newtonian physics. Among different types of galaxies, those with spiral structures are one of the most interesting objects. Starting with a differentially rotating thin gravitating disk of matter, it has been shown that if the azimuthally symmetric disk is perturbed by a small density perturbation in the form of a spiral, then the perturbation grows at the expense of gravitational energy in the disk, thus leading to the development of a spiral structure (Fig. 4.18). A very interesting finding is made that the sense of the spiral found observationally in most galaxies (trailing as against leading) is reproduced through the present analysis for galaxies with at least 15% of their energy in the random (thermal) motion of the matter. The effect that the different masses of the galactic bulge have on the nature of the spiral structure is also determined. The analysis appears to reproduce the spiral characteristics of Sa, Sb and Sc type of galaxies.

The activities of PRL scientists in theoretical physics, over the next decade, are expected to continue in the areas of astrophysics and space physics, climate studies and microscopic physics involving atomic and molecular physics, nuclear physics and particle physics.

Major emphasis will be to evolve an integrated astrophysics programme where inputs from plasma physics as well as different aspects of microscopic physics will be considered. The meteorology and climate programme would also have a broader perspective whereby the effects of ocean and of middle and upper atmosphere on the weather would be examined. Another aspect of many of these programmes would be to explore at the basic level the implications of non-linearities and chaotic behaviour in the physical system.

We also foresee a vigorous programme in the physics of the microscopic systems at the atomic, nuclear and sub-nuclear levels. The group hopes to contribute significantly to:

- microscopic understanding of atomic and molecular scattering processes,
- ab initio studies of nuclei,
- a deeper and fundamental understanding of strong interactions and
- going beyond the standard model to understand the unity of elementary particles and their interactions.



FACILITIES

In the forty years of its existence, PRL science has grown considerably; from the initial days of cosmic ray detection by Geiger Müller counters to the present day sophisticated experiments flown on balloons, rockets and satellites; infrared and radio telescopes to probe the earth's atmosphere and far into the outer space. The success of our research programmes, depended, not only on the novel scientific ideas behind them, but also on the in-house development of the appropriate technologies to execute the programme. The importance of the facilities was recognized at PRL from its very beginning and their growth was nourished and encouraged side-by-side along with the science. Today, PRL can boast of highly specialized and excellent centralized facilities like the electronics laboratory, library, computer centre and workshop. These facilities form the backbone of our research programmes.

Electronics Laboratory

The electronics laboratory started almost at the same time when microprocessors came into the world market. Today it is equipped with 8, 16 and 32 bit CPU and numerous VLSI circuits and components for hardware and software development. With the notable progress in the last decade the electronics laboratory is now recognized as a leading national computer application research centre.

One of the outstanding achievements of the electronics laboratory was its design and fabrication of the electronics and electrical systems for Anuradha—the cosmic ray payload on the NASA's Spacelab-3; which was flown successfully on the space shuttle Challenger in April-May 1985. This was the only Asian experiment on the Spacelab-3.

More recently the electronics laboratory has developed very sophisticated Data Acquisition Systems for PRL's Infrared Telescope at Mount Abu and Radio Telescopes at Thaltej (Ahmedabad), Rajkot and Surat. In addition a real time decoder, integrator and a Fast Fourier Transform (FFT) array processor was recently developed for the proposed national Mesospheric-Stratospheric-Tropospheric radar at Tirupati and can be used as a hub for many similar applications in real time data processing.

The electronics laboratory has been chosen as the Western Zone Centre for the Appropriate Automation Promotion Programme (AAPP) launched by the Department of Electronics with financial assistance from the Government of India and United Nations Development Programme. The role of the AAPP centre is to identify areas for microprocessor-based control technology and to impart manpower training. Under this programme many products were developed at PRL for textile applications. Recently this Western Zone Centre has been made an independent centre by the

◀ Electronics Laboratory started in early sixties is now recognized as a leading national computer application research centre.

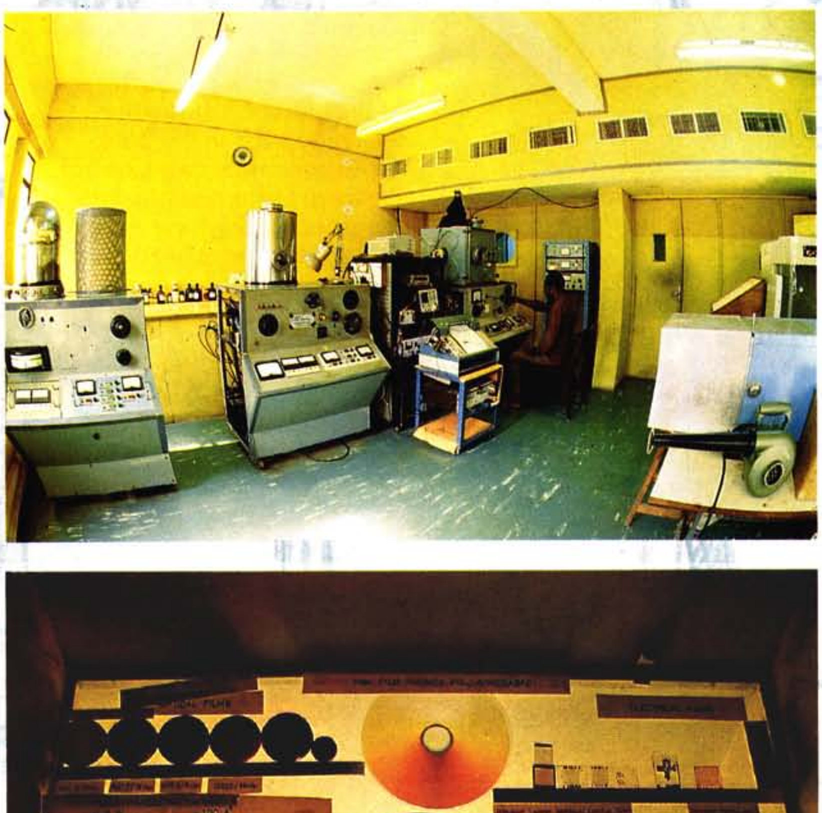
Department of Electronics.

The electronics laboratory also provides training to graduate and undergraduate engineering students from all over the country. The students trained here have received recognition from educational and industrial institutions.

Techniques Laboratory

Techniques laboratory was established in mid-sixties with a view to develop sophisticated techniques at a centralized facility for various research projects of PRL.

Significant developments have taken place in two specific fields; vacuum technology and optical coatings. In vacuum technology a number of vacuum systems in the ranges of medium, high and ultra-high vacuum have been designed and fabricated. As regards the optical coatings, capabilities have also been developed to make multilayer all-dielectric interference filters, multilayer dielectric and single layer metal-film high reflectance mirrors, antireflection coatings and neutral density filters.



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Library

Libraries are the "store house of knowledge" where research ideas are conceived and developed. It is the heart of any research institution. PRL has always been holding the above views and has maintained an up-to-date library. This is not an easy task considering the widely varying fields of its research activities.

The PRL library has an extensive and valuable collection of publications in the fields of Astronomy and Astrophysics; Space and Earth Sciences; Theoretical Nuclear and Plasma Physics; Computers and Electronics. It receives about 280 periodicals per year and has a total collection of over 35000 documents. The library also has a large collection of maps which provide data on ionospheric, geomagnetic and cosmic rays from over hundred stations.

Currently the PRL library is undergoing extensive automation. The PRL library automation programme was started in the mid-sixties, ever since PRL acquired the first IBM 1620 computer. The very first work to have been done in India on Mechanized Indexing was done in PRL using this computer. Over the years many mechanized systems like the Periodical Management System, Book Procurement System, the READFAST, and Personal Documentation have been developed. All these systems are user friendly. Some of the Library Automation Systems, such as the Book Procurement, Serials Control, Personal Documentation etc. designed at PRL have been the first work to have been done in India.

Computer Centre

One of the major areas of research at PRL from the very beginning has been in the field of theoretical nuclear physics, meteorology and climate modelling, quantum and classical mechanics, atomic and molecular physics. Many of these programmes require a lot of numerical analysis and simulations. Calculations for these studies depend critically on the availability of high speed computers with large memory. PRL's computing requirement have been steadily increasing over the years and this requirement has resulted in the rapid growth of our computer centre. Over the decades, PRL computing facility has grown from that of IBM-1620 to IBM-360/44 and finally to the present DEC-1091. The DEC-1091 computer system was installed in 1983 with 2M Bytes of memory with a number of sophisticated peripherals.

Being a service-oriented centre, it caters to the

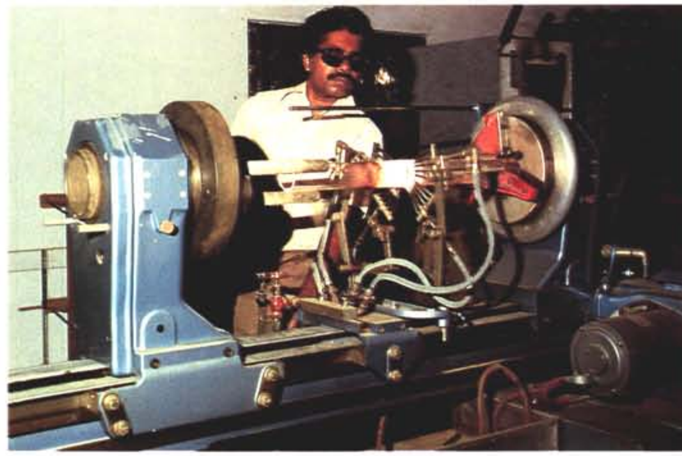
computing needs of the different scientific projects of PRL as well as of other academic institutions. A few government organizations are also making use of this facility. Various courses, both long-term and short-term, are being conducted at the centre every year. The centre also imparts training on computer applications to students from various colleges of Gujarat.

Workshop

The workshop is one of the oldest and largest service centres of the laboratory. Today it continues its tradition of extending valuable services to the research and development activities of the laboratory. Over the years it has played a crucial role in the design and fabrication of many of our experiments, quite a few of which were very difficult and complicated. Starting from the fabrication of nose tips for rocket and huge antennae for receiving signals during the early days of the laboratory, the workshop is at present fabricating sophisticated payloads for rockets, balloons and satellites.

The workshop has also been an active participant in the establishment and the evolution of the Three Station Radio Telescope at Thaltej, Surat and Rajkot and the Infrared Observatory at Mount Abu. It has also made many intricate equipments for the Earth Science research. Recently the workshop has designed and fabricated a novel double-walled insulated house for DST sponsored project at Ladakh. The project was a multi-institutional endeavour for site survey at Mount Abu (Leh) for the National High Altitude Observatory.

Besides the above centralized facilities PRL also has other supporting facilities like the Liquid Nitrogen Plant, Glass Blowing section and the Scanning Electron Microscope.



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Udaipur Solar Observatory, Udaipur

Gurushikhar Infrared Observatory, Mount Abu

Astronomy & Astrophysics Campus, Thaltej

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