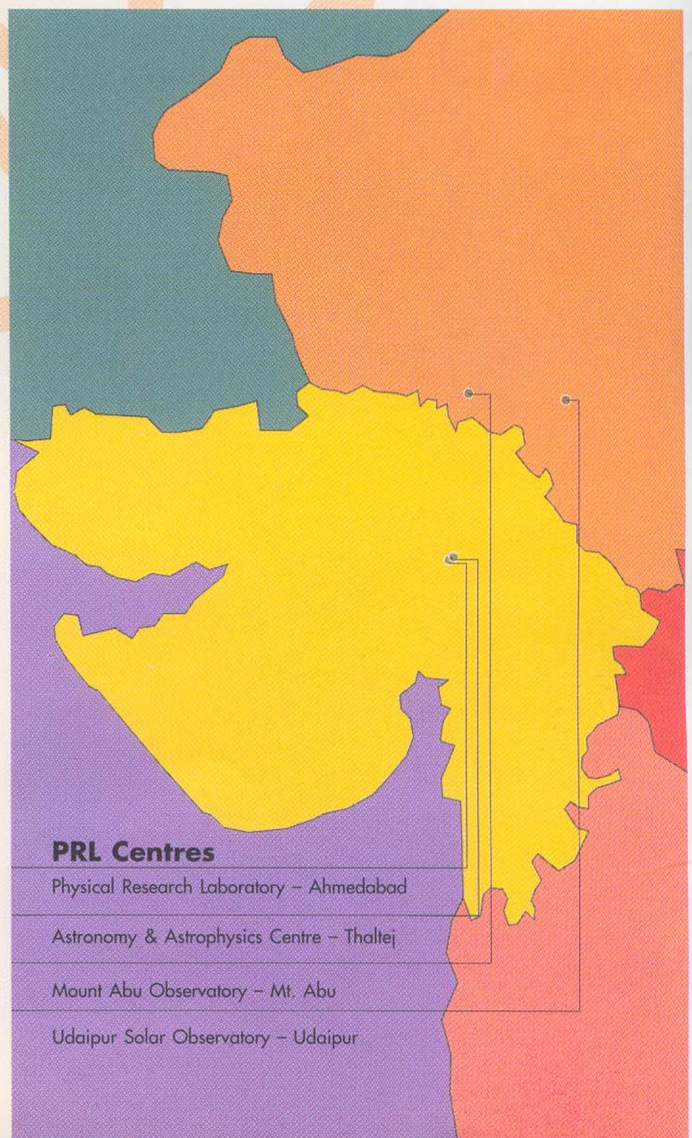
PHYSICAL RESEARCH LABORATORY

50 YEARS of PRL

AHMEDABAD

"It seems to me that a broad understanding of the physical and social environment in which man lives is the most urgent task which faces all humanity."

- Dr. Vikarm A. Sarabhai



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"RETREAT" - the first laboratory of Dr. Sarabhai

Mrs. Indira Gandhi at the Silver Jubilee Celebrations of PRL, 1973

Prof. U.R. Rao with Prof. S.P. Pandya during the National Space Science Symposium at PRL, 1987

Prof. T. W. Mossberg with Prof. G. S. Agarwal

Prof. C.V. Raman during the foundation stone laying ceremony of PRL, 1952

Dr. K. Kasturirangan receiving the Hari Om Ashram Prerit Dr. Vikram Sarabhai Research Award from Prof. M.G.K. Menon

Delegates of the National Space Science Symposium with Profs. S.P. Pandya and R.K. Varma

The open house at PRL during 1989

Dr. S.S. Bhatnagar at M.G. Science College during the Foundation Day Ceremony

Dr. S. Chandrasekhar one of the Vikram Sarabhai Professors at PRL

Shri C. Rajagopalachari visiting the laboratory while it was at the M.G. Science Institute

Pandit Jawaharlal Nehru during the inauguration of the laboratory, 1954

Prof. C.V. Raman inaugurating the 34th Annual Meeting of the Indian Academy of Sciences , 1968

FIFTY YEARS OF PRL

The Physical Research Laboratory (PRL) is celebrating its Golden Jubilee Year on November 11, 1996. The laboratory, was founded by Dr. Vikram A. Sarabhai in November 1947 following an agreement between the Ahmedabad Education Society and the Karmakshetra Educational Foundation. Fifty years ago the laboratory had its humble beginning in the M. G. Science Institute and its research activities were focussed on Cosmic Rays and Upper Atmospheric Studies. The nucleation of the laboratory served the twin objectives of Dr. Sarabhai, to establish a front ranking research institute at Ahmedabad and to learn more about cosmic rays. Within a few years of the establishment of PRL, the first Council for its Management was formed which included the eminent scientists Dr. K. S. Krishnan, FRS and Dr. S. S. Bhatnagar, FRS. The activities of the laboratory expanded considerably in the ensuing years and it actively participated in the programmes of the International Geophysical Year (1957 -58). This gave wider international coverage to its scientific contributions and enhanced its standing in the international scene.

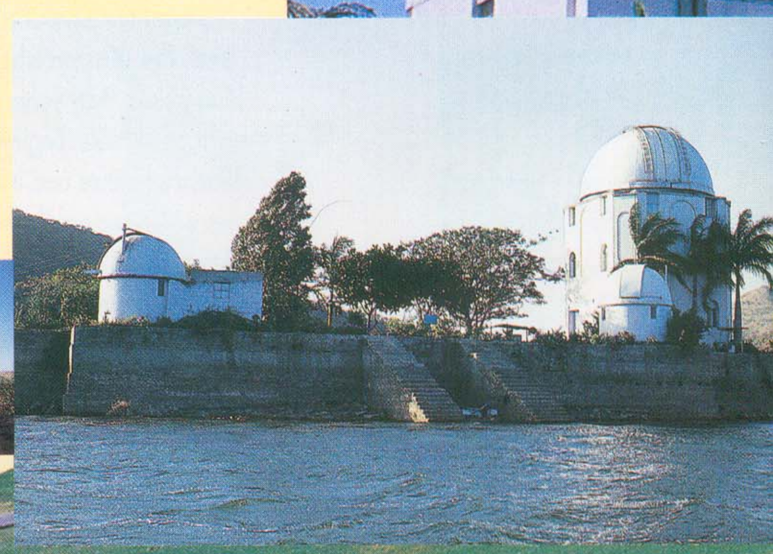
The laboratory, to support its growing research in space sciences approached the Department of Atomic Energy, which formally recognized it and provided grants for its programmes from 1963. The decade of sixties witnessed a surge of activities, on a global context, on the application of satellites to better understand the Earth and its atmosphere. Recognizing these and to provide a boost to Space Research in India, the Indian Space Research Organisation (ISRO) was formed with Dr. Vikram Sarabhai (who was then the Director of PRL) as its Chairman. Thus, PRL truly served as the cradle for the growth of the Space Programme in India. Since the early seventies the laboratory has come under the umbrella of the Department of Space (DOS).

During the early seventies, new activities were initiated in the fields of laboratory astrophysics and experimental plasma physics. The Geocosmophysics group which was nucleated at the Tata Institute of Fundamental Research, Bombay, was transplanted to PRL in 1972-73. Later in the same decade, two other major new disciplines were initiated, Infrared Astronomy and Radio Astronomy. These two programmes led to the establishment of an Infrared Observatory at Gurushikhar and an Astronomy Centre at Thaltej (near Ahmedabad). In 1981, the Udaipur Solar Observatory, engaged in the study of the Sun became a part of PRL. Research in theoretical physics were expanded with the addition of particle physics and non-linear dynamics. Recently research activities in Laser Physics and Quantum Optics have also been initiated. Some of the plasma physicists of PRL, with a view to expand their activities seperated from PRL in the mid eighties and formed a new centre, the Institute for Plasma Research.

During the past five decades the laboratory's strength and its scientific activities have grown tremendously. PRL has developed into a big campus of its own, with several buildings, laboratories and facilities in the main campus at Ahmedabad, an Astronomy and Astrophysics Centre at Thaltej, a Solar Observatory at Udaipur and an Infrared Observatory at Mt. Abu. The science at PRL has also grown significantly and currently covers a wide spectrum in the various areas of astronomy and astrophysics, planetary and space sciences, earth sciences, theoretical physics and laser physics and quantum optics.

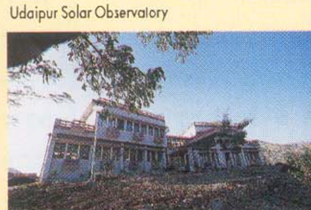
Over the years, the PRL scientists have participated in many national and international campaigns, for example, International Ozone Intercomparison Measurements, International Middle Atmospheric Programme, Lunar Science Programs, the Anuradha Spacelab Experiment, Indian Antarctic Expedition, Solar Eclipse Campaigns, Geochemical Ocean Sections Study etc. Many collaborative experiments in upper atmospheric sciences, have been conducted with international agencies under the aegis of ISRO - SCHNE (Russia), ISRO - DLR (Germany) and ISRO - CNES (France). At present scientists are actively participating in the International Geosphere Biosphere Programme (IGBP), World Ionosphere Thermosphere System (WITS), Solar Terrestrial Energy Programme (STEP), Joint Global Ocean Flux Studies (JGOFS) and Global Oscillation Network Group (GONG) etc.. Scientists from the Theoretical Physics group have active collaborations with many national and international scientists.

PRL is one of the leading centres in the country for doctoral and post doctoral research in Theoretical Physics, Atmospheric and Earth Sciences. At present, there are about forty research scholars at PRL drawn from various parts of India. The Laboratory conducts scientific courses for science students and teachers from colleges and universities. It, also imparts technical training to students from various engineering colleges and polytechnics. Over the years it has contributed in developing motivated and dynamic scientists and technologists. PRL is proud of its alumni, many of whom have made important contributions in nucleating and shaping the Indian Space Programme.



"Hill view" - The first ozone observing station at Mt. Abu

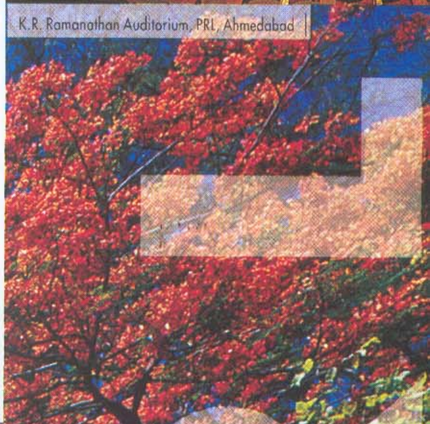
Udaipur Solar Observatory

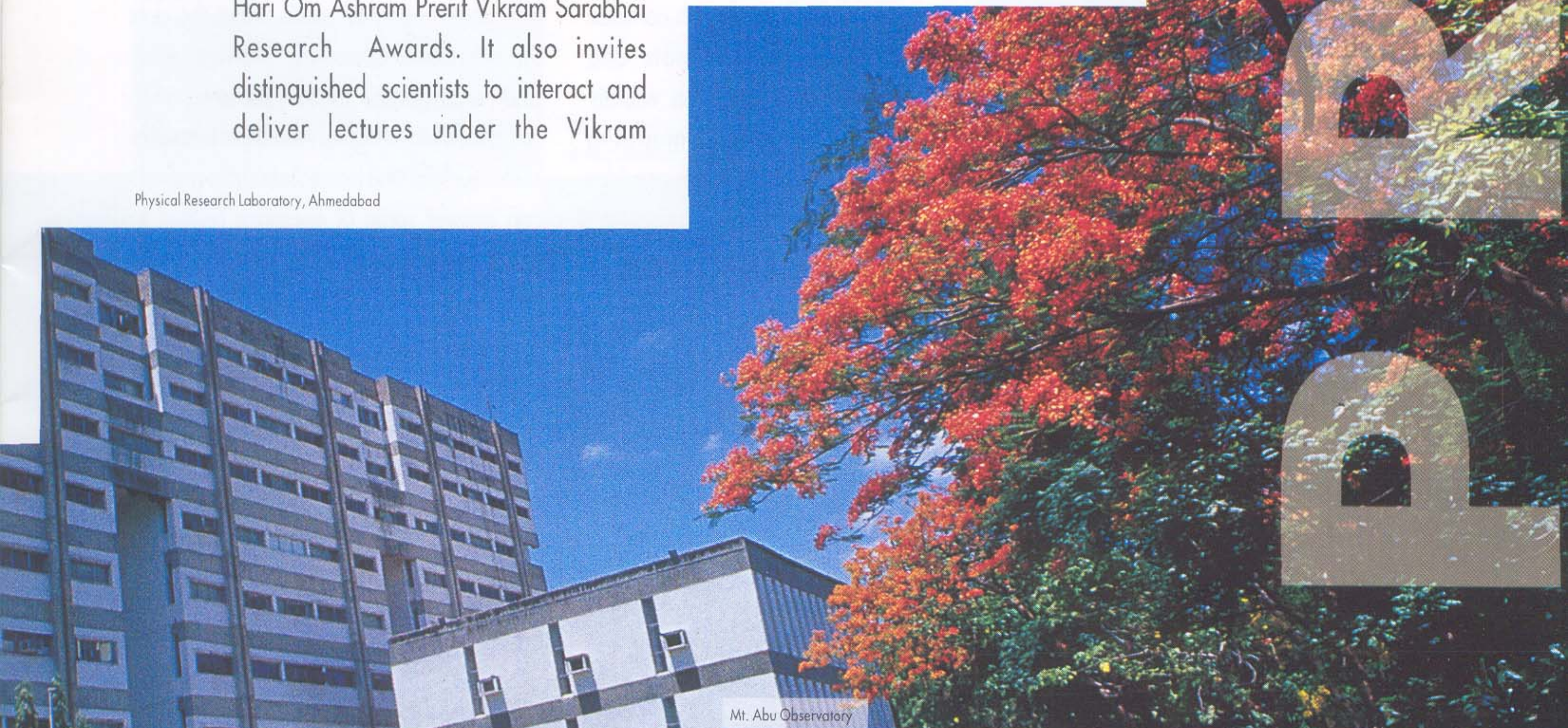


The laboratory's contribution to basic research in various fields has been recognized, both nationally and internationally. Many of PRL scientists have been honoured by a number of prestigious national and international honours and awards and fellowships to various scientific academies. The laboratory itself was awarded the Vikram Sarabhai Award, instituted by the Government of Gujarat for excellence and achievements in Science. As a part of its continuing efforts to promote science and encourage outstanding scientists, the laboratory has instituted the Hari Om Ashram Prerit Vikram Sarabhai Research Awards. It also invites distinguished scientists to interact and deliver lectures under the Vikram Professorship Programme and the Ramanathan Memorial Lectures.

With the successful launching of the Polar Satellite Launch Vehicles (PSLV) and the procurement of sophisticated instruments such as lidars, lasers, variety of telescopes and mass spectrometers and introduction of research programmes in particle physics, nonlinear dynamics, laser physics and quantum optics, PRL looks forward to ushering the twenty first century with exciting and vibrant research activities.

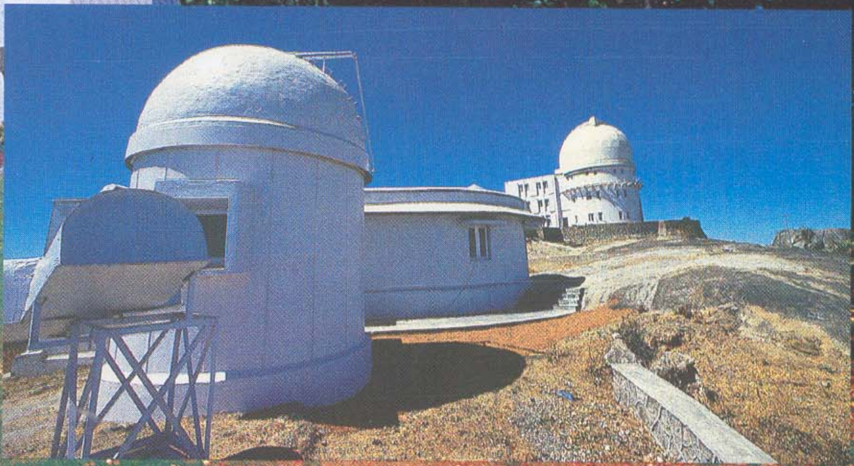
K.R. Ramanathan Auditorium, PRL, Ahmedabad





Physical Research Laboratory, Ahmedabad

Mt. Abu Observatory

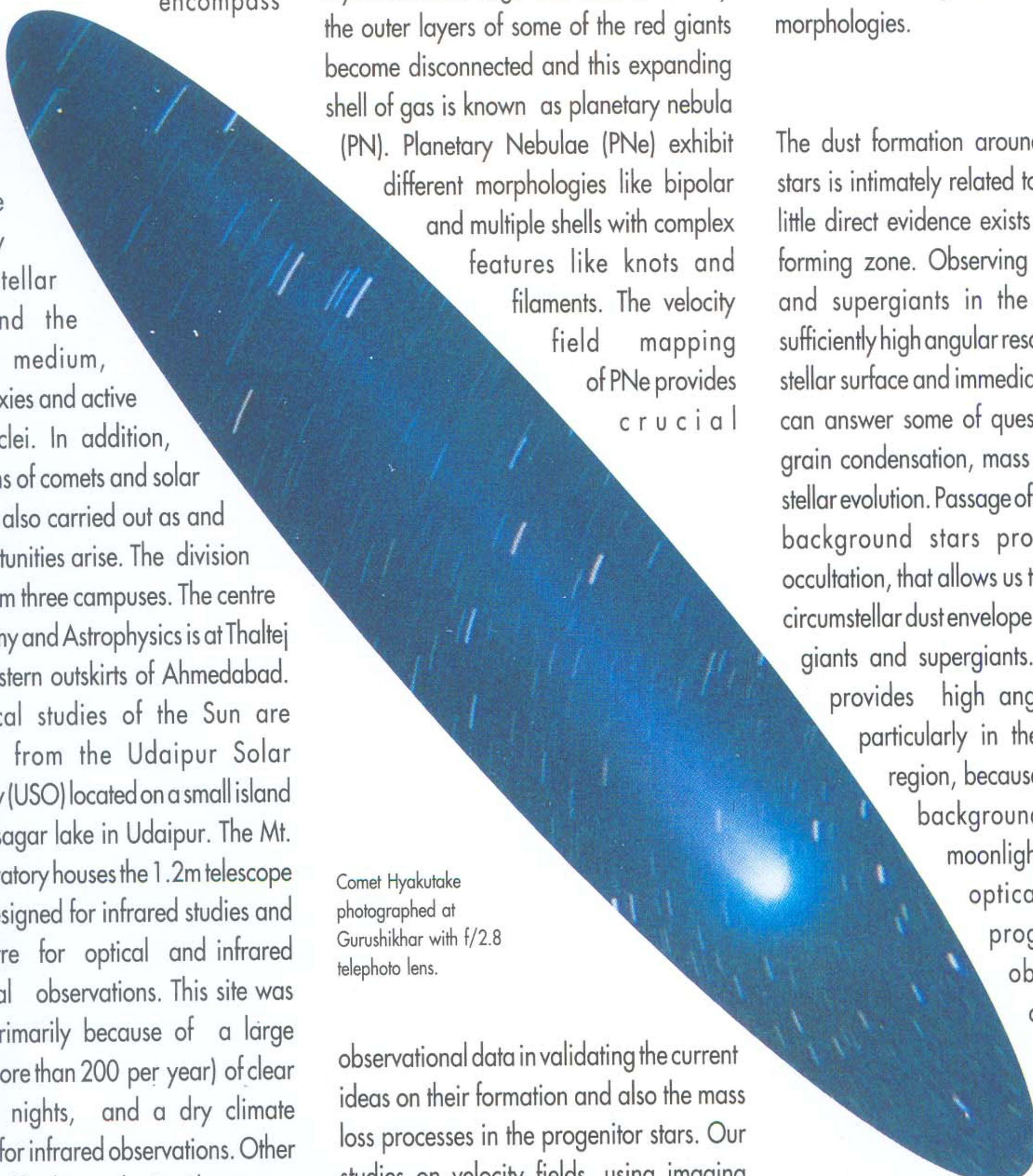


Centre for Astronomy & Astrophysics, Thaltej

ASTRONOMY AND ASTROPHYSICS

During the last few decades studies in astronomy have revealed fascinating new information concerning the Sun, stars, nebulae and the galaxies. The research activities of the Astronomy and Astrophysics division encompass the study of physical processes on the Sun and the interplanetary medium, stellar systems and the interstellar medium, normal galaxies and active galactic nuclei. In addition, investigations of comets and solar eclipses are also carried out as and when opportunities arise. The division operates from three campuses. The centre for Astronomy and Astrophysics is at Thaltej on the western outskirts of Ahmedabad. Astronomical studies of the Sun are conducted from the Udaipur Solar Observatory (USO) located on a small island in the Fatehsagar lake in Udaipur. The Mt. Abu Observatory houses the 1.2m telescope specially designed for infrared studies and is the centre for optical and infrared astronomical observations. This site was selected, primarily because of a large number (more than 200 per year) of clear observable nights, and a dry climate favourable for infrared observations. Other observational facilities at the Mt. Abu campus include a 35 cm Schmidt-Cassegrain telescope and a 20 cm aperture prime focus Schmidt camera. Various sophisticated instruments such as polarimeters, a CCD camera, infrared photometers and Fabry-Perot Spectrometers have been developed in-house and used for the observational programmes.

Stars with masses comparable to that of the Sun, after using most of the hydrogen in their core become red giants as their outer layers become large and cool. Eventually the outer layers of some of the red giants become disconnected and this expanding shell of gas is known as planetary nebula (PN). Planetary Nebulae (PNe) exhibit different morphologies like bipolar and multiple shells with complex features like knots and filaments. The velocity field mapping of PNe provides crucial observational data in validating the current ideas on their formation and also the mass loss processes in the progenitor stars. Our studies on velocity fields, using imaging Fabry-Perot spectrometer in about a dozen bipolar and multiple shell PNe show that they attest to the current idea on their formation based on the mechanism of interacting winds. However, the results for the nebula IC4593 deviate from the general trend which require reexamination of the model. Other new findings were the detection of a bipolar flow in NGC 6153 and first results of the expansion velocities in a few PNe. Further it is shown that a small rotation of the progenitor star influences PN evolution leading to different observed morphologies.

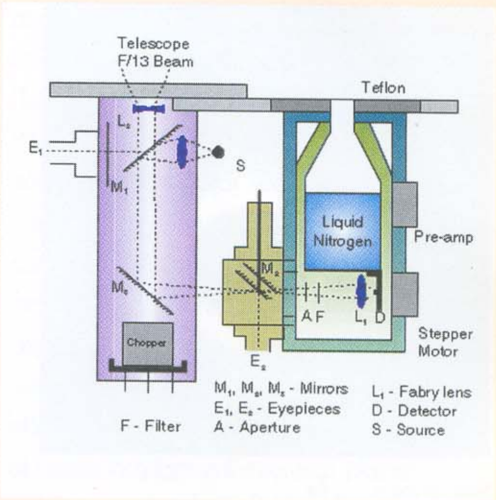


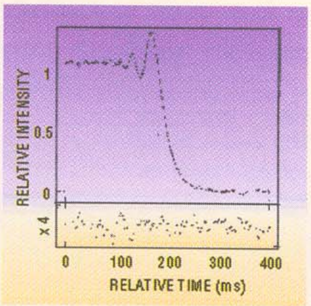
Comet Hyakutake photographed at Gurushikhar with f/2.8 telephoto lens.

The dust formation around cool evolved stars is intimately related to mass loss, but little direct evidence exists about the dust forming zone. Observing evolved giants and supergiants in the infrared with sufficiently high angular resolution to resolve stellar surface and immediate surroundings can answer some of questions related to grain condensation, mass loss and hence stellar evolution. Passage of the moon across background stars produces lunar occultation, that allows us to investigate the circumstellar dust envelope around late type giants and supergiants. This technique provides high angular resolution particularly in the near infrared region, because of the reduced background of scattered moonlight compared to optical region. A programme of observing lunar occultation in the near-infrared is in progress at PRL. Several occultations have been successfully observed. In case of the supergiant star TV Gem a circumstellar dust envelope has been directly detected and sporadic dust condensation is suggested.

Novae, newly visible stars in the sky, are double star systems that brighten several hundred thousand times as expanding gas from a large companion star falls on the white dwarf and briefly the nuclear reactions take place at an enhanced rate leading to ejection of surface layers on the white dwarf.

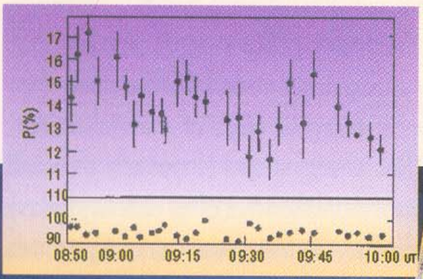
Infrared studies of novae is a direct means of detecting formation of dust in nova ejecta and for studying its subsequent evolution. The existing infrared studies of novae have shown a wide variety in their dust forming





Schematic diagram of the near infrared photometer and occultation light curve of TV Gem

Polarization light curve depicting 25 min period variability in OJ 287



The 1.2 metre telescope at Gurushikhar, Mt. Abu

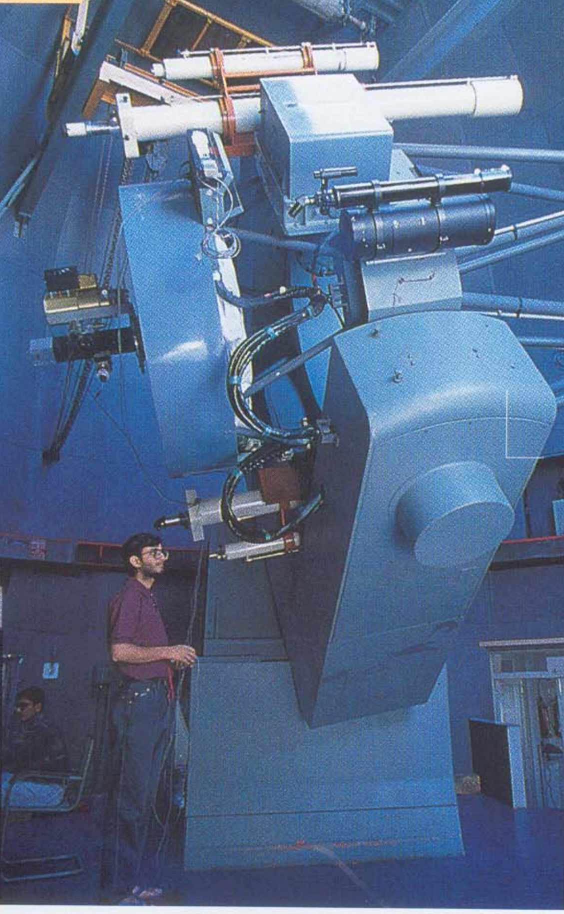
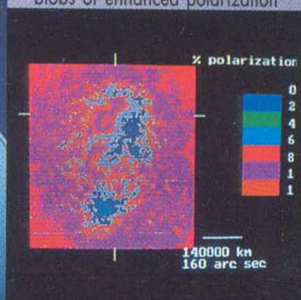
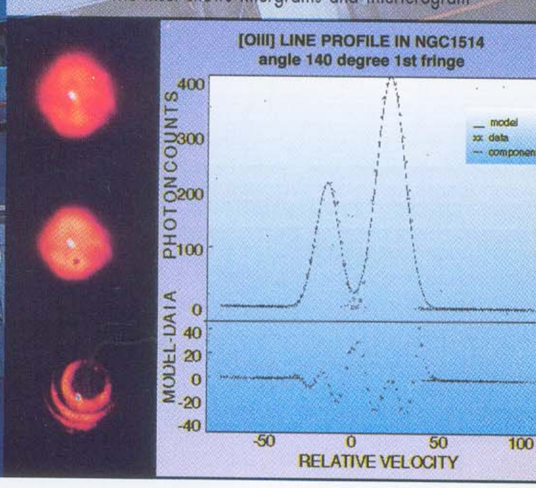


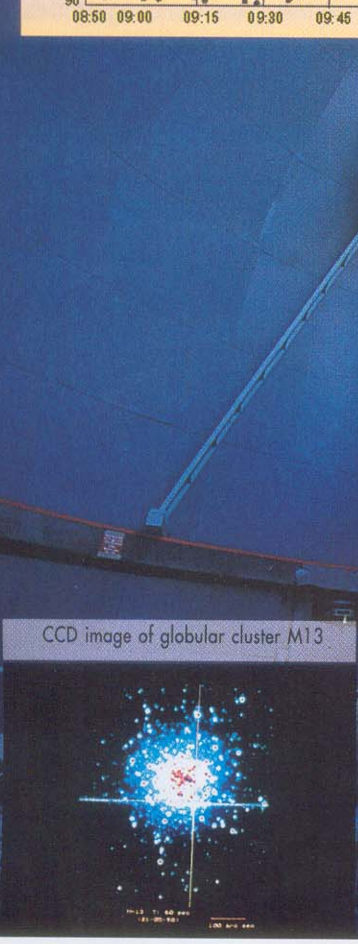
Image of Comet Halley showing two blobs of enhanced polarization

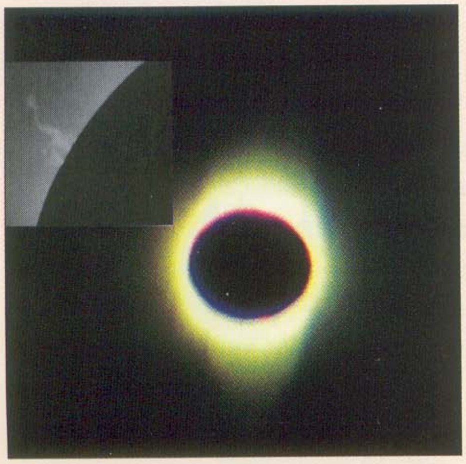


Doubly ionized oxygen line profile of planetary nebula NGC 1514. The inset shows filtergrams and interferogram



CCD image of globular cluster M13

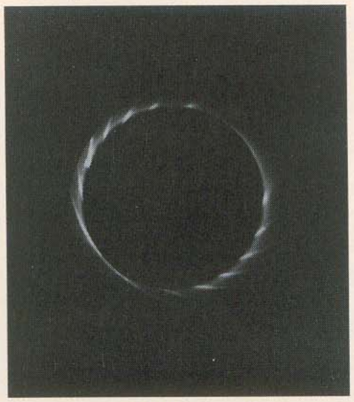




Solar corona during the eclipse of October 24, 1995, photographed at Neem Ka Thana (Rajasthan). An erupting prominence is clearly seen (inset)

behaviour making it important to monitor the temporal behaviour of every nova in the infrared. Whether fast novae can form substantial dust shells remains to be established. In an attempt to answer some of these questions infrared studies of novae are carried out. Our observations of Nova Herculis 1991 showed that the dust formed within a week after the eruption which is unusually rapid development in a fast nova.

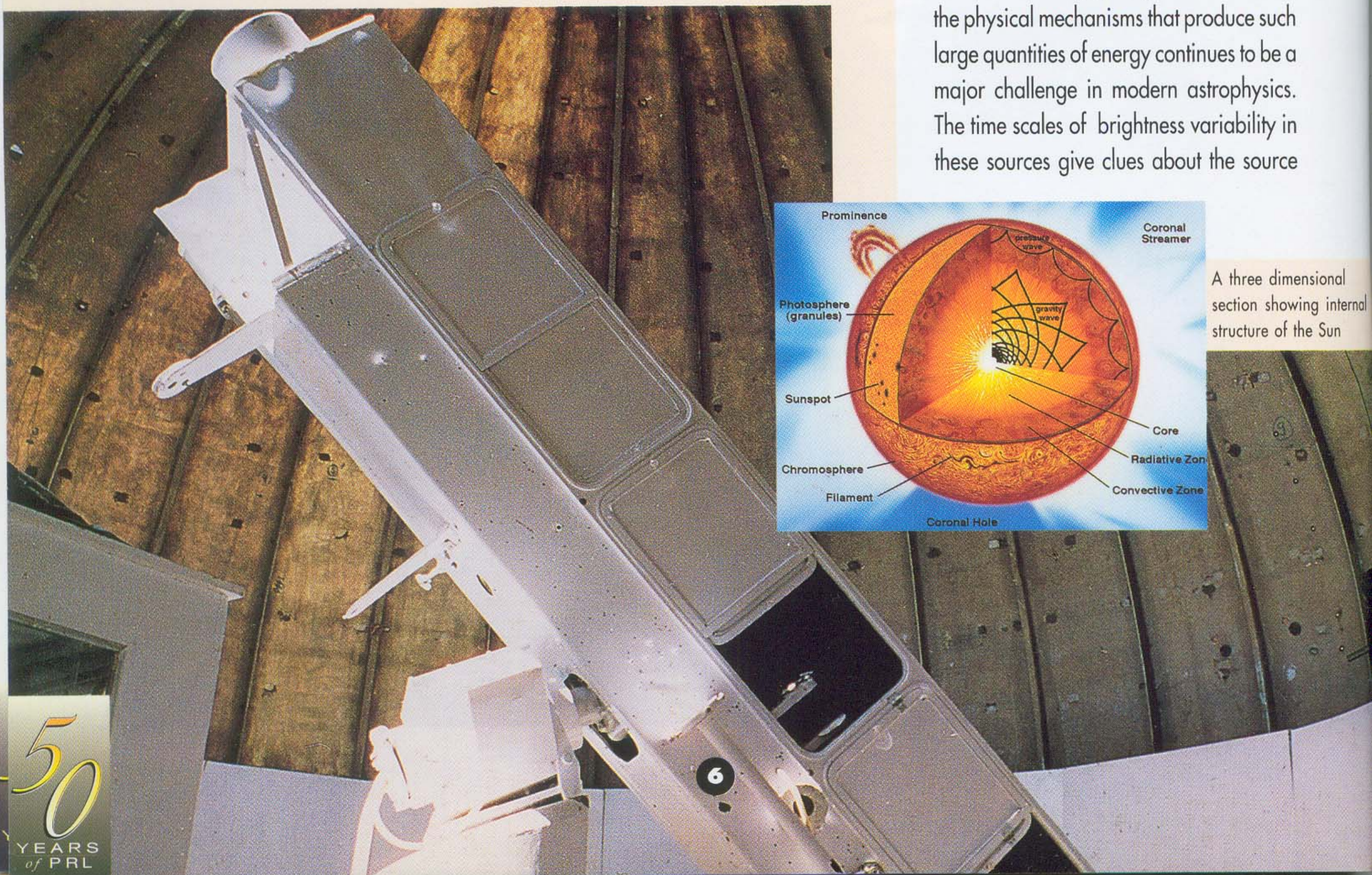
Coronal interferogram (1995) taken in the red line of highly ionized iron



Symbiotic stars display spectra that indicate co-existence of hot and cool components, leading to the binary model for these objects. Our polarization measurements of one such system R Aquarii show strong wavelength dependence and time variations suggesting a hot dwarf star accreting material from a cool evolved star and a precessing jet emanating from the accretion disk surrounding the white dwarf.

Active galactic nuclei (AGN) are one of the most energetic class of celestial objects. Their energy output is typically thousand times more than that of an ordinary galaxy like the Milky Way, whereas the light comes from a nuclear region a million times smaller than an ordinary galaxy. Understanding the physical mechanisms that produce such large quantities of energy continues to be a major challenge in modern astrophysics. The time scales of brightness variability in these sources give clues about the source

The solar telescope at Udaipur Solar observatory



A three dimensional section showing internal structure of the Sun size. Several AGN have been monitored for rapid variability in optical polarization. In case of AGN called OJ 287 a 25 minute variation is detected which implies a source size of nearly half a billion kilometres. This deduced nuclear size is consistent with a model involving a black hole and a disk of accreting matter.

The Udaipur Solar Observatory has a 12 feet Solar spar with a 25 cm aperture lens, a 6 feet Razdow solar spar with 12.5 cm aperture telescope, and a 15 cm Zeiss Coude telescope, used in conjunction with multislit Littrow spectrograph for spectroscopic study of solar prominences, flares and active regions.

Solar observational programmes at USO have focussed mainly on understanding the solar flare mechanisms and the associated phenomena, including solar mass ejection and propagation of inter planetary disturbances. USO scientists have developed a methodology for computing the magnetic energy build up from measurements of sunspot proper motions observed in white light full disc pictures. Several flares of class M and X have been studied to look for changes in magnetic field parameters. The studies show that the general belief that solar flares prefer to occur in locations of strong magnetic fields and high shears is not always correct.

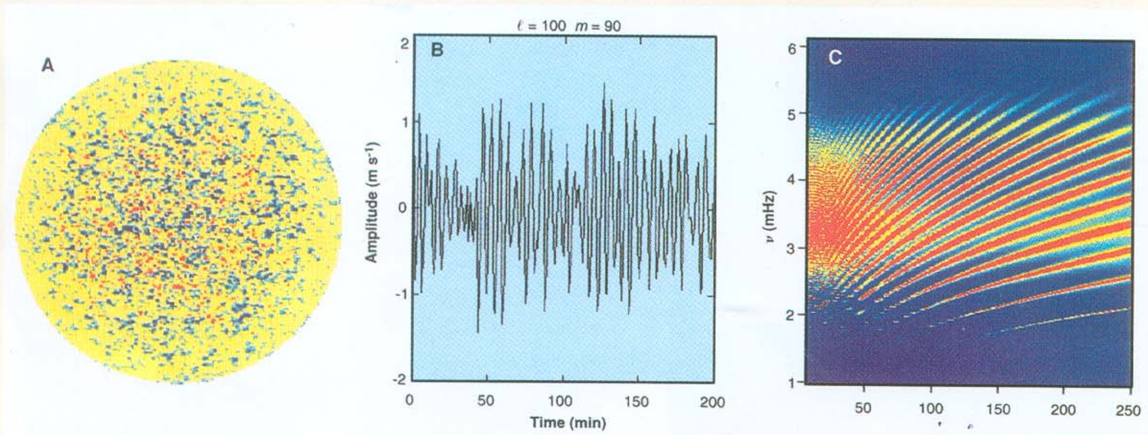
Studies of solar mass ejections have been carried out to understand the stability and dynamics of prominences, surges and erupting filaments. From these studies, some general conditions for the onset of micro and macro instabilities, destablizing otherwise stable prominences have been derived.

Currently USO is actively participating in the Global Oscillation Network Group (GONG) and is one of its six global sites. The scientific goal of the GONG programme is to deduce the internal structure of the Sun by obtaining full disk solar velocity images over a minimum period of three years.

Comets Halley, Austin and Hyakutake have been extensively studied to characterize their dust parameters from polarization and its variation with wavelength and phase angle. Molecular band polarization in Comet Halley was detected. It is inferred that Comet Halley dust characteristics were significantly different from that of Comet Austin but similar to that of Comet Hyakutake.

Three expeditions were undertaken to observe solar corona during total solar eclipses of 1980 (Gadag, India), 1983 (Tanjung Kodok, Indonesia) and 1995 (Neem ka Thana, India). On all these occasions, the major experiment was interferometric study of few selected coronal line emissions to understand the temperature structure and energetics of the coronal plasma. The important findings from these experiments are the existence of large scale motions and macro turbulence at certain locations in the coronal plasma, possibly associated with field reconnection sites. During the 1995 eclipse USO conducted investigations of intensity and polarizations of large scale coronal streamers using photographs acquired from aircrafts flown at 24 and 12 km altitudes.

Many of the above programmes will be continued. The Mount Abu observatory will soon be equipped with an Infrared array detector for imaging, spectroscopic, polarimetric and occultation studies in the 1- 2.5μm regions. This equipment will provide a boost to many of the programmes of the division. In addition active participation in the Indian astronomy satellite programme with multi wavelength payloads is also envisaged.

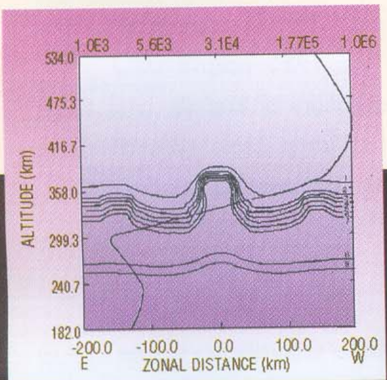


Helioseismology : GONG data to obtain information on the internal solar conditions (a) Doppler velocity image (b) Decomposition into spherical harmonics (c) A fourier transform of the time series

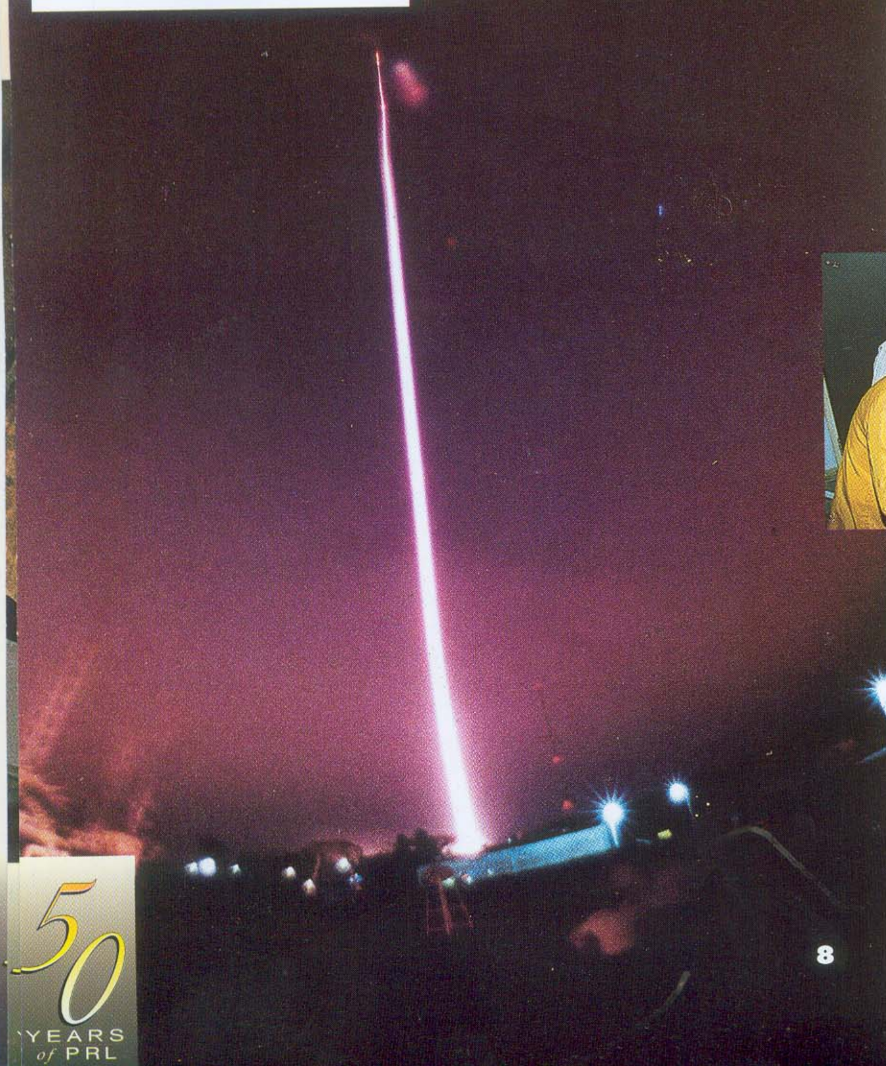
PLANETARY ATMOSPHERES AND AERONOMY

Aeronomy, devoted to the study of the composition, dynamics and thermal balance of the planetary atmospheres has been a major area of scientific research at PRL since its inception. Early topics of research were the measurements of atmospheric ozone using the Dobson Spectrophotometer and that of the cosmic rays. Over the decades the activities of the group expanded tremendously and it currently includes studies on global changes in earth's near environment from natural and anthropogenic effects, investigations of the various equatorial phenomena like the equatorial electrojet and the spread - F and optical studies of the upper atmosphere and ionosphere employing sophisticated ground-based, rocket and balloon-borne instruments developed and fabricated indigenously in the laboratory.

The establishment of the first ozone measuring station at Mt. Abu in the early fifties led to the discovery of the biennial oscillation of ozone density and the development of a method to estimate the vertical distribution of ozone from ground-based measurements. The ozone measurements are still continuing and provide a nearly continuous long term (~ 50 years) record of atmospheric ozone in the tropics. With the establishment of the Thumba Equatorial Rocket Launching Station (TERLS) a variety of ground-based and rocket-borne radio probing experiments were designed and developed in the ensuing decades and pioneering contributions made to understand various equatorial phenomena such as the equatorial electrojet, equatorial ionization anomaly and the equatorial

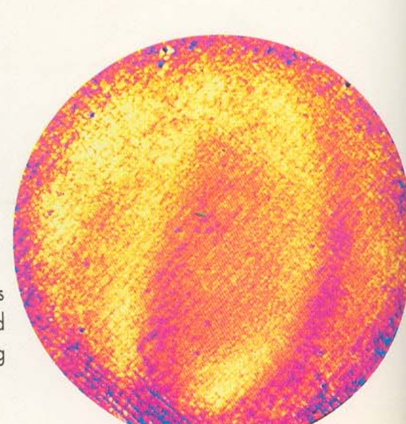


Numerical simulation model results revealing the development of irregularities in the negative gradient region



The rocket flight trajectory and the released vapour clouds

Preflight test being carried out on the instrumented payload

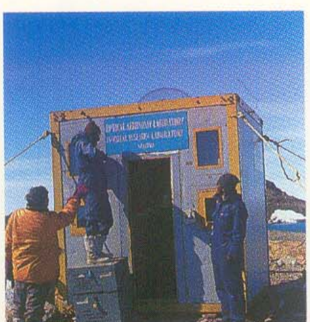


"Plasma bubble" event as recorded by ground based all sky imaging camera spread-F. In addition, studies were also conducted on the low latitude atmosphere and ionosphere. The effect of the cosmic X-rays in the D-region ionization, the features of the E-region drifts during normal and counter electrojet conditions by spaced receiver technique are some of the significant contributions.

During the eighties, the Division embarked on a variety of *state of the art* optical instruments for the investigation of the neutral upper atmosphere, as a comprehensive understanding of the ion-neutral interactive processes could not be attained without this vital input. Coordinated measurements using high resolution Fabry-Perot spectrometer and ionospheric sounders provided evidence for the direct coupling between the ionosphere and the thermosphere even during geomagnetically disturbed periods. All Sky Imaging Cameras and spectrometers have enabled investigations of large scale wave motions, plasma depletions and of the Equatorial Ionization Anomaly. Late eighties saw a technological breakthrough in PRL, in the form of a dayglow photometer capable of retrieving faint optical emissions that form as low as 0.05% of the background intensities. These measurements were used in providing evidence for the close link between the daytime equatorial ionization anomaly and the night-time equatorial spread-F and also in obtaining a precursor for the same in the dayglow. Further, the role of neutral dynamics, especially the vertical winds have been conclusively shown to have a significant control on triggering the equatorial spread-F.

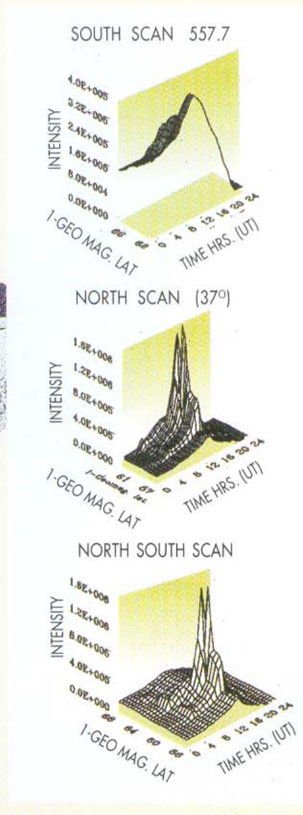
The development of a multiwavelength daytime photometer during nineties provided the first continuous measurements of auroral emissions during daylit conditions from *Maitri*, the Indian station in Antarctica. Using this technique inferences have been made on the acceleration processes that occur at and around the plasmapause region (~ 5 earth radii above the equator).

The experimental programmes have been supported by modelling studies. Some of the important contributions have been on the role of vertical winds to explain the equatorial counter electrojet, formation of sharp layers of ionization in the equatorial E-region incorporating three dimensional gravity waves and the role of gravity waves in producing fluctuations in electric field which can seed ESF irregularities. Complex nonlinear numerical simulation model to explain the features of equatorial spread-F were developed. Some of the recent investigations in the low latitude ionosphere-



Optical aeronomy experiments conducted from Maitri, the Indian station in Antarctica during XIII and XIV Indian scientific expeditions.

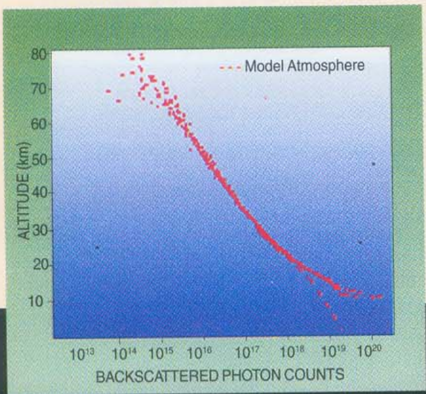
The multi wavelength day time photometer for the measurements of day time auroral emissions

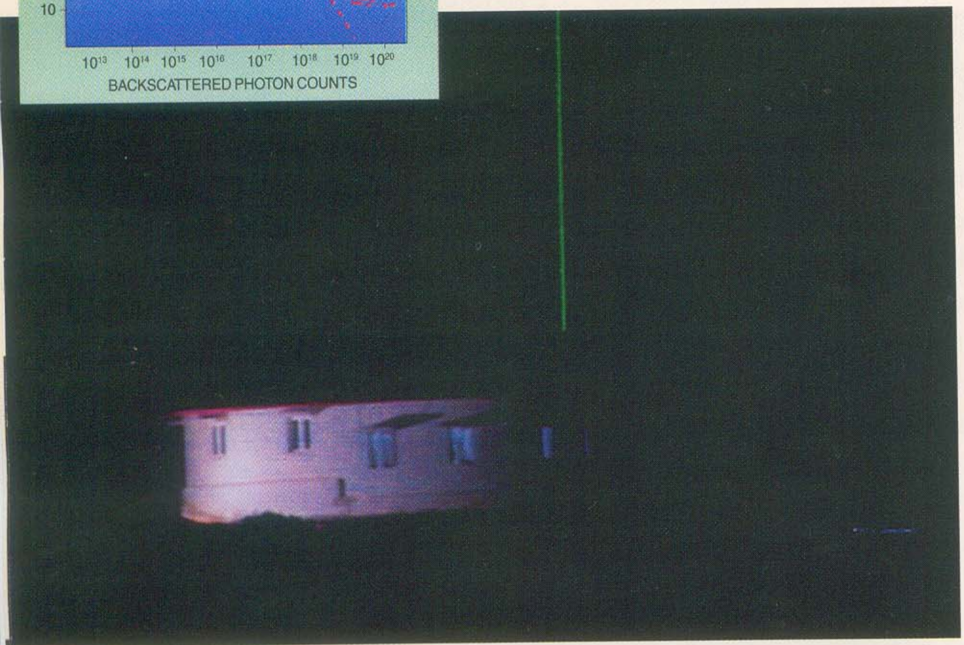


Surface plots of OI557.7 nm emission intensities. The peak intensity indicates the narrow region of particle precipitation associated with plasma pause boundary

thermosphere system, using coordinated measurements have enabled improvements in the existing atmospheric models, increasing their finesse and making them to predict the atmospheric temperature and density reasonably well. Recently a programme to model the neighbouring planetary (Mars and Venus) atmospheres has been initiated.

During the decade of eighties the Indian Middle Atmospheric Programme was launched to assess the anthropogenic effects on global change in the earth's near atmosphere. These include co-ordinated study of minor constituents, radiations, ionizations, turbulence and electro-dynamics of the lower and middle atmosphere using indigenously developed rocket and balloon-borne instruments. Measurements of trace gases and minor constituents have been conducted from the ground, over the oceans,

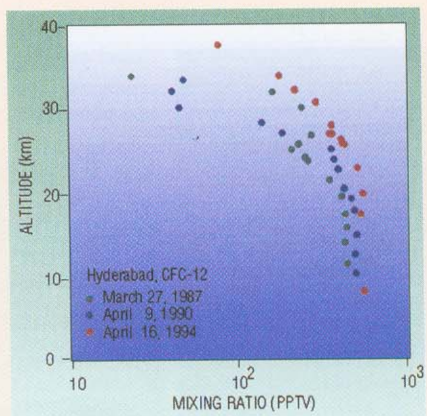




Nd : YAG backscatter lidar in operation at Mt. Abu

The system is used to study the vertical profiles of aerosols and atmospheric structure up to about 80 km

Hydrogen inflated balloon ready for launch at the National Balloon Facility in Hyderabad to study middle atmospheric parameters



An example of the trace gas concentration profiles measured using the balloon-borne cryogenic air sampler

Balloon-borne cryogenic air sampler

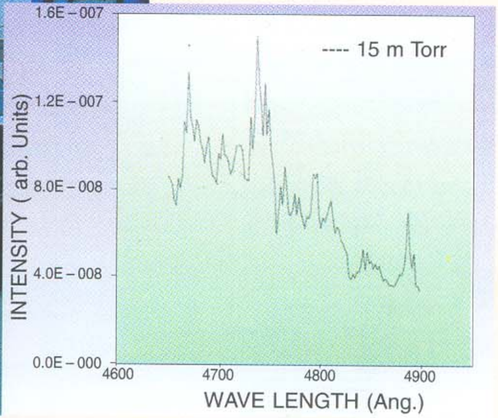
and by balloon-borne indigenous cryosampler. A modern gas-chromatography laboratory has been set up to carry out these measurements. A significant contribution being the first measurements of $CBrClF_2$ whose atmospheric abundance is increasing at an alarming rate of 20% per year. This compound being the primary source of bromine in the stratosphere, contributes to more efficient destruction of ozone. The relative importance of chlorofluorocarbons in the depletion of ozone layers are being evaluated. Further, detailed chemical schemes have been invoked taking into account relevant chemical reactions to study some unique features of the mesospheric electron density.

Realizing the role of aerosols in the overall control of the earth's radiation budget and its relevance to ozone related processes densities and size distribution of aerosols have been measured using ground based, balloon- and rocket-borne multiwavelength photometers and insitu samplers. To address the issues on the role of atmospheric aerosols in cooling or heating the earth's surface, a detailed study on their physical evolution and optical properties has been made. Apart from an indigenously developed sun-scanning photometer system capable of measuring the aerosol concentration and size distribution being used onboard balloons, to obtain stratospheric aerosol characteristics, a *state of the art* Nd:YAG laser lidar system is in operation since 1992 for regular monitoring of aerosol distribution and dynamics of the earth's atmosphere.

To understand the complex atmospheric and ionospheric processes which involve a variety of reactions between photons, electrons, and atoms an experimental facility to simulate some of these reactions has been set up. This facility, which includes high power lasers, focusses on the determination of the rates of various reactions, photo-absorption and fluorescence cross-sections in the vacuum EUV range. Identification of intermediate steps in a chain of reactions, its by-products, temperature dependence of the respective cross-sections, electron scattering cross-sections of atoms and molecules at low electron energies and radiative life time measurements of species of aeronomic interests, are some of the important contributions.

Future plans envisage global mapping of various atmospheric parameters using orbitting satellites. A number of experiments have been proposed for equatorial aeronomy satellite and the climate satellite missions which will enable the study of the coupling processes between different regions.

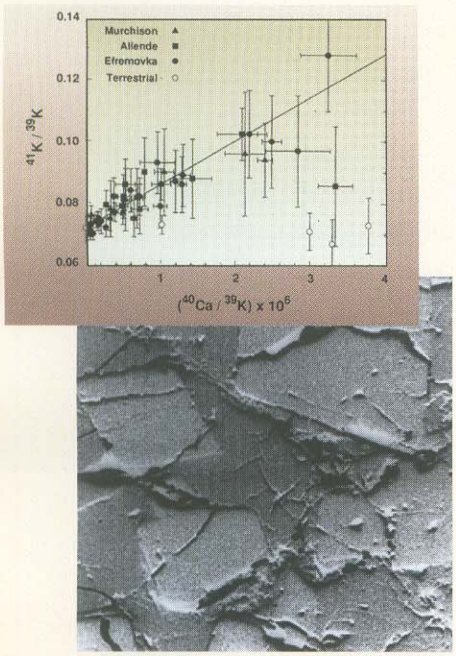
Laser Spectroscopy Laboratory



Fluorescence excitation spectrum of NO_2 by photon impact using excimer laser pumped tunable dye laser

EARTH SCIENCES AND SOLAR SYSTEM STUDIES

The research programmes of the Earth Sciences and Solar System Division focus on the characterization and temporal evolution of the Solar System objects, the Sun, Earth, Moon and the meteorites through the measurements of chemical and isotopic signatures contained in the constituent phases of these objects. A key component of these studies is the development of novel experimental techniques and the use of custom made and indigenously developed high precision instruments. The activities of the Division fall under two areas: (i) Solar System and Geochronology (ii) Oceanography and Climate Studies.



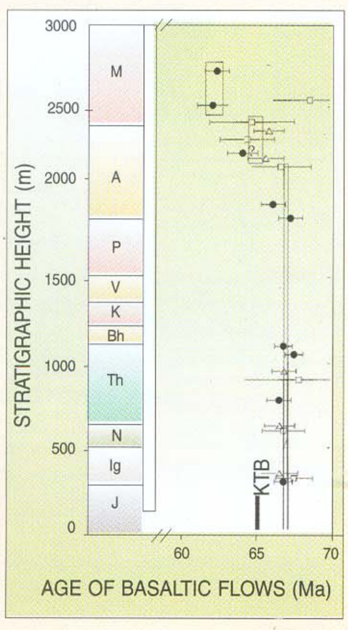
Early solar system grains and evidence for ^{41}Ca in meteorites

Solar System and Geochronology

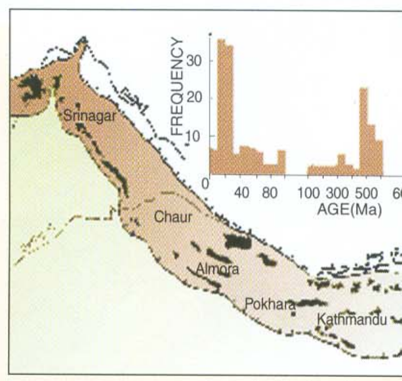
It is known that the solar system objects formed from a molecular cloud of gas and dust which collapsed and evolved to form the Sun and the planetary bodies . This evolution is believed to have occurred in a series of steps, the records of which are preserved in some primitive meteorites. Studies of the constituent phases of such meteorites have allowed construction of scenarios for the formation and evolution of the solar system.

The contributions of the solar system group have helped in understanding the time scales of early solar system processes by identifying primitive grains in meteorites formed during the initial stages of its evolution and by delineating the environment in the solar nebula where they could have formed. These inferences, made on the basis of isotopic records in these grains, led to the identification of fossil records of the short-lived isotope ^{41}Ca (half life ~ 10^5 a) produced in stellar nucleosynthesis. These measurements established that the formation of grains from nebular gas took place rapidly, at most within a million year.

An important contribution of the group has been the documentation of intense solar activity during the early stages of the evolution of the Sun. Records of heavy particle tracks and isotopic composition of rare gases in selected grains from specific meteorites that were exposed to the Sun during its infancy (first ~10^7 years) have provided evidence that the flare and wind intensity of the Sun was 10^2-10^3 times more at that time, when the Sun passed through a highly active T- Tauri phase, than at present.



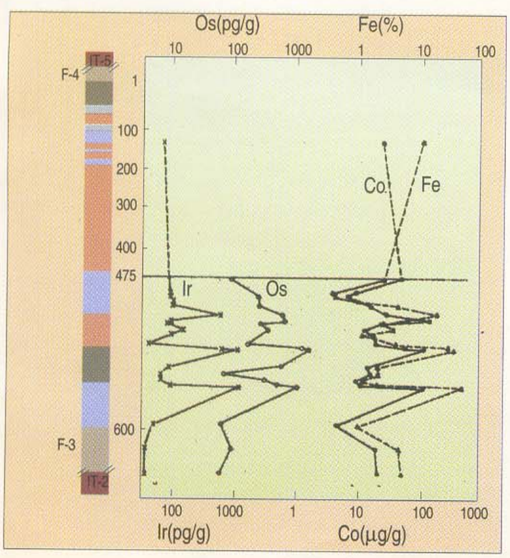
Ar-Ar ages of Deccan Traps. The bulk of the eruptions occurred at ~67 Ma, ~ 2Ma prior to K/T extinctions



Age distribution of granites from the Himalaya determined by the Rb-Sr method

Meteorites and lunar samples are ideal for studying the flux and composition of cosmic rays and their temporal variations. The group was one of the few in the world which carried out extensive studies of lunar samples brought by the American and Russian missions. Investigations of long term (millions of years) averaged solar activity have been carried out through measurements of radioactivity in lunar rocks combined with calculations of their production rates. The results show that the flux of solar energetic particles has remained nearly the same for the past 2-3 million years. Several radioisotopes (e.g. ^{24}Na, ^{48}Cr, ^{57}Ni, ^{47}Ca) produced by the interaction of energetic particles in space were detected in meteorites for the first time by the group. The solar and galactic cosmic ray records in dust and rocks of the Moon provided an understanding of the evolutionary process of the lunar regolith.

The group also participated in an experiment to determine the source and the ionization state of anomalous cosmic rays (ACR). This experiment, ANURADHA, was conducted on board Spacelab - 3 in which plastic detectors were exposed in space for nearly a week to capture energetic particles in space including the ACR. The results show that the ACR are singly ionized and their source is interstellar neutral particles.



Abundance of noble metals, Iridium (Ir) and Osmium (Os) across the KTB layer from Anjar

Studies of the Indian lithosphere focus on the evolution of the Himalaya and the Deccan traps, two of the geologically "young" events which have drawn the attention of earth scientists from all over the globe. Formation of the Himalaya is a unique event in the history of the Earth. To understand the time scales of the evolution of the Himalaya and its relation to global tectonics, the geochronology group has carried out extensive Rb-Sr dating of rocks, which show that the ages cluster in three groups; 20, 500 and 1900 million years, the youngest event being associated with the Himalayan orogeny. More recently, the emphasis has been to determine the ages of collision /uplift events and associated thermal history based on Ar-Ar chronology.

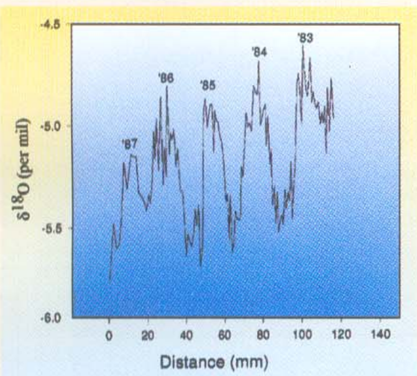
The oldest rocks on the earth date to 3800 million years. A search for the oldest rocks in India based on ^{87}Rb-^{87}Sr has identified a 3400 million years old granitic gneiss near Anamod Ghat, representing north - west extremity of the southern Indian pre-Cambrian craton. Individual zircon grains that are remnant of an even older granitoid rock of 3600 million years, have been found in the Singhbhum - Orissa craton in eastern India. These grains were dated by the Pb-Pb method using the ion probe.

The Deccan, covering a large part of the western and central India, is one of the largest flood basalt provinces on the Earth. These were formed at nearly the same time when dinosaurs and other species, which thickly populated central India, suddenly disappeared while the Earth experienced a severe climatic stress from the Cretaceous to Tertiary (K/T) epochs. High precision Ar-Ar dating of rocks sampled from more than a km thick Deccan traps showed that the major phase of the Deccan volcanism was at ~ 67 million years (Ma) which preceded the dinosaur extinction by at least 2 Ma. The Deccan volcanism, therefore, could not have been primarily responsible for the extinction of dinosaurs and other land and marine life forms that occurred at ~ 65 Ma ago.

An alternative hypothesis for the catastrophic mass extinction during the K/T transition is the impact of a large extra-terrestrial object on the Earth. This suggestion is based on the significantly higher concentrations of noble metals, Ir and Os, relative to earth's crust in sediments deposited during the K/T transition . The group has been carrying out extensive geochemical studies of sediment layers deposited during the K/T transition from several regions in India. They have identified two new sites, (Meghalaya and Anjar), where Ir and Os rich sediment layers that deposited during the K/T transition are well preserved. The occurrence of three iridium rich layers in Anjar, superimposed on a high base level, and a sharp iridium peak in the Meghalaya sediments, superimposed on a broad band suggests multiple impacts, probably of cometary nuclei, which is responsible for the mass mortality of a large number of species, including the dinosaurs, during the K/T transition.

Oceanography and Climate Studies

Earth is a unique planet in our solar system that sustains life. The climate of the Earth, though generally habitable has undergone changes on various time scales. Today there is an increasing urge for a comprehensive scientific understanding of the earth's climate system. During the past decade a major topic of research of the group has been on palaeoclimate and palaeoenvironment of India and its adjoining regions.

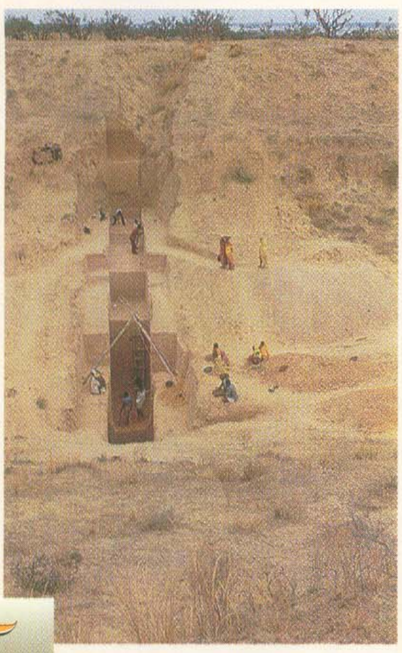


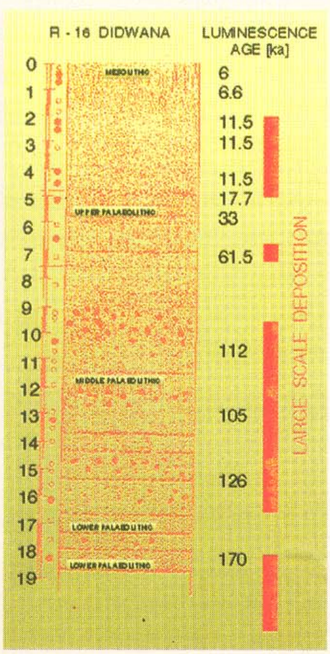
High resolution oxygen isotope record from annual bands of corals from Lakshadweep

In this context, the current interest is to quantify the spatial and temporal variability of the Indian monsoon during the past ~ 200 ka and its relation to global climate. To achieve this goal, multiproxy mapping of a number of continental and marine archives which provide information on a variety of climatic parameters is being made. These include (i) short term high resolution recorders which provide a means to calibrate the proxies contained in them with instrumental records and help assess the impact of man on global change and (ii) long term recorders which hold clues to major climatic changes, such as the glacial-interglacial transitions. Our analyses of chemical and isotopic tracers in tree rings, corals and glaciers in and around India have established their potential for yielding high resolution palaeoclimatic data for the region. The goal now is to extend some of these studies to longer time scales, ~ 10^3a.

Efforts to retrieve long term climatic and environmental information of the region rely on archives such as the sediments of lakes and seas (Arabian Sea and the Bay of Bengal), sand dunes of Thar desert and peat bogs from south India. Integration of information derived from these different archives help in the construction of composite scenario of palaeoclimate of the region. The Karewa from Kashmir are a unique lake deposit which provided a near continuous record of palaeoclimate of the region for the past ~ 4 Ma. Through faunal, floral, geochemical, sedimentological and isotopic studies of these deposits we could obtain a detailed chronicle of the timing and amplitude of climate changes in the region. Studies of oxygen isotopes in planktonic foraminifera from the Arabian Sea sediments and carbon isotopes in peat bogs from Nilgiris have provided valuable information on the relative strengths of southwest and northeast monsoons during the past~20 ka.

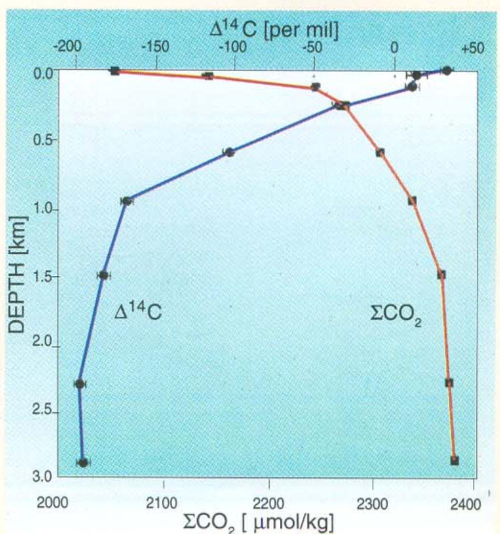
An independent approach to assess the palaeomonsoon conditions is through the study of sand profiles in deserts. Our success with the development of a method for dating desert sand grains based on luminescence principles opened new





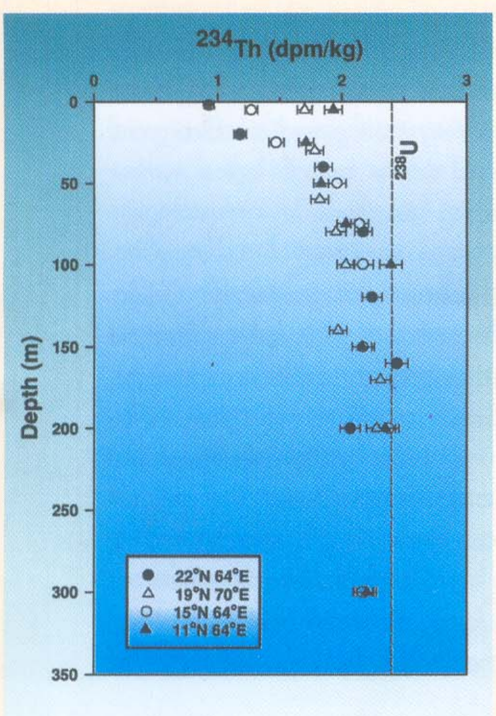
Sampling sand dunes from Thar and their chronology based on thermoluminescence

Profiles of radiocarbon and total inorganic carbon from the Arabian Sea



avenues for research on desert based palaeoclimatology. Analysis of sand profiles from the Thar using this dating method show that it is ~ 200 ka old and that the dune building activity is episodic, coinciding with the re-establishment of southwest monsoon. This observation offers promise for the reconstruction of palaeomonsoonal conditions during the past 200 ka.

The coupling between climate, weathering and tectonics, addresses to the issues of global change on million year time scales. One of our activities has been to understand weathering in the Himalaya and the impact of Himalayan Orogeny on the evolution of Sr isotopes in the oceans through the study of the Ganges, Brahmaputra and the Indus river systems. Our results coupled with model calculations reveal that the weathering of the Himalaya has contributed significantly to the Sr isotope evolution of sea-water since the Cenozoic (last 65 million years). These studies also provide information on the silicate and carbonate weathering in the Himalaya and their role in global climate change on long time scales.



^{234}Th-^{238}U disequilibrium data from the Arabian Sea

In oceanography, our interests are to study surface and deep water circulation and particle dynamics in the water column all of which influence climate and the sediment deposition on the sea floor. As a part of the Geochemical Ocean Sections Study (GEOSECS) synoptic measurements of cosmic ray produced ^{32}Si in the water column of the Atlantic, Pacific and the Indian oceans were made, leading to the determination of lateral and vertical advection velocities and eddy diffusivities in the three oceans. The present focus is to study water circulation in the Arabian Sea using radiocarbon and radium isotopes. The radiocarbon measurements also provide estimates of CO_2 air-sea exchange fluxes in this region which will address to the role of the Arabian sea in the global CO_2 air - sea exchange balance.

Study of particle dynamics in the oceans is important for understanding the transport and distribution of carbon and other elements in the water column. We pioneered in the determination of the nature and time scales of particle settling and solute-particle interactions using naturally occurring daughter-parent nuclide pairs (e.g. ^{234}Th-^{238}U) in the water column. Over the past few years our measurements of these nuclides in the Arabian sea and the Bay of Bengal have led to a wealth of data on the removal time scales of chemically reactive contaminants from the surface and deep waters of these regions. Our efforts are now to understand the relation between the removal rates and various components of biological productivity and thereby explore the possibility of using these results as proxy indicators of carbon flux from the euphotic zone.

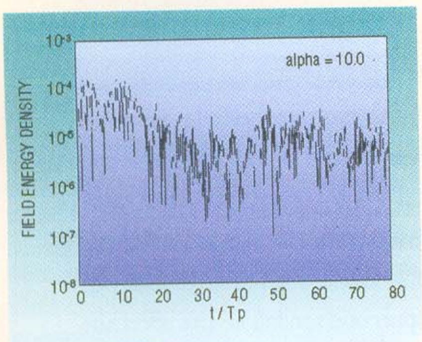
Another important topic of research of the group has been on basic hydrological processes such as ground water recharge and movement, and river-groundwater interactions, using environmental tracers. These studies have yielded significant insights into the water problems being faced in arid and semiarid parts of India, Gujarat and Rajasthan. As a natural spin off of these studies, we are currently engaged in evolving sustainable solutions to the twin problems of water supply and sanitation. This effort has resulted in the development of the *Akshaydhara* concept, which relies on soil-aquifer system to renovate storm and waste water and use it to recharge ground water.

National radiocarbon facility

THEORETICAL PHYSICS

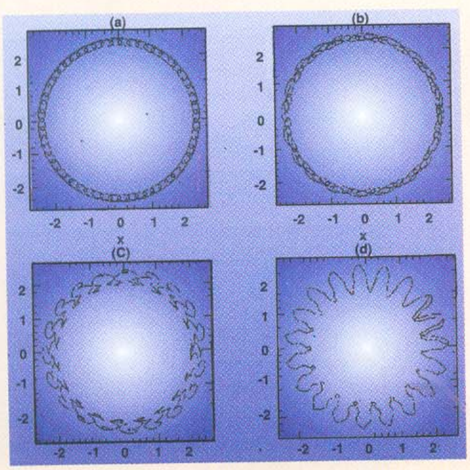
The Theoretical Physics group was initiated at PRL soon after its establishment. Starting with activities in Nuclear Physics, it diversified itself into many new areas which supported other activities of the Laboratory and also carried out independent research in problems of fundamental importance.

The Nuclear Theory group, over the years, obtained systematic, precise and detailed results in the spectroscopy (structure, transition etc.) of light and medium energy nuclei using microscopic self consistent field methods. These studies threw new light on effective nuclear interactions in these regions of the periodic table. In a complimentary approach, new group theoretical and statistical methods were employed to study average properties of nuclei and to examine the general questions about nuclear symmetries and models. PRL scientists have developed a successful model which simultaneously describes low lying energy levels of normal and exotic nuclei. A significant understanding of properties of nuclear energy levels is obtained by treating the nuclei as collection of Bosons and analyzing them in terms of some underlying symmetries.



Varation of field energy density with time

With the advent of the higher energy accelerators, there has been a shift to research in high energy physics and PRL was no exception. Some of the activities in Nuclear Physics focussed on the study of the basic strong interactions at the level of the fundamental constituents - quarks and gluons. In particular, an extensive study of the properties of the quark gluon plasma at classical but non perturbative level was carried out. For instance, it was shown that non-abelian features of quantum chromodynamics gives rise to chaotic behaviour in the system which contributes to the thermalization of the plasma. Also models that provide unified description of the hadron spectroscopy and the strong forces between protons and neutrons starting from the basic interactions between quarks and gluons were developed.



Projection of the trajectories of a particle in X-Y plane with increase in meridional velocity

In the last few years, there has been intense research activities on the properties of weak and electromagnetic interactions and there are signatures which hint at the deviation from the already established laws of these interactions. Neutrino masses provide one such strong hint. Masses for the known neutrinos have a variety of implications in astrophysics, cosmology and particle physics. Understanding these inter-relationships in a coherent framework has been one of the major activities of the group. Another hint of interactions beyond standard laws is provided by the phenomena of CP violation. Various models of CP violation were developed at PRL. Also a systematic strategy to uncover CP violation at the linear accelerator using polarized beams was developed. The group also contributed to the study of the unified forces and their implications. Particular attention was paid to the question of baryon asymmetry and its generation without grand unified theory through lepton number violating interactions.

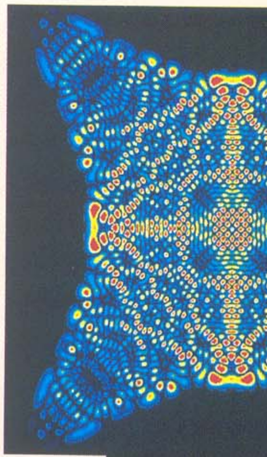
PRL also has an active group studying physics at the atomic level, particularly to understand the atomic process of electron capture. This process has significant implications in some of the astrophysical processes and laboratory experiments. A significant contribution of PRL group was, to point out the importance of the long range nature of Coulomb interactions in a detailed treatment of the problem. This improvement over the conventional formulation of Oppenheimer, Brinkman and Kramer resulted in better agreement with experimental results.

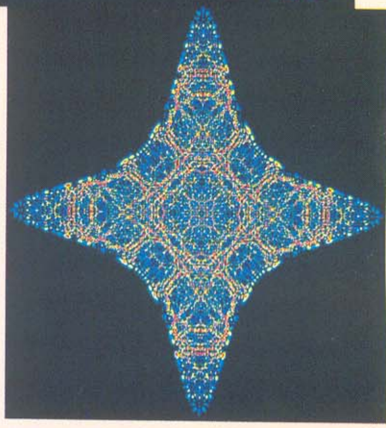
In addition to the above microscopic physics, the group is also carrying out front line research in macroscopic domain. These include gravitational physics, plasma physics and dynamics of a variety of non-linear phenomena. These are interlinked and some of the activities involved study combined implications for the description of physical phenomena.

The main interests of the Gravitational Physics group have been general theory of relativity (GTR), relativistic astrophysics and cosmology. Introducing the language of forces in general relativity, the effect of centrifugal reversal (purely GTR effect), dragging of inertial frames and the possible change of shape of collapsing fluid configurations have been studied in detail. Considering the role of general relativity in astrophysics, the structure and stability of plasma disks with self-consistent electromagnetic fields around compact objects has been studied in the context of models for pulsars, quasars and X-ray binaries. One of the significant results in this context is the effect of rotation on the magnetosphere of a compact body as evidenced from the trajectories of a charged particle. This feature may indeed have a physical bearing on the radiation pattern when the emission from such compact objects is due to cyclotron processes. As a fore runner to the gravitational wave astronomy, the generation in binary systems and propagation of gravitational waves through material media have been investigated with utmost rigour, without using any approximations.

In Plasma Physics, which had been a major area till early nineties, the group had several interests. During the last few decades, the plasma physics group has made important contributions towards the understanding of the propagation of different plasma modes and the generation of instabilities which are supported by free energies that can exist in the system in various forms like, strongly accelerated ablated plasma with steep density gradient, non-Maxwellian velocity distribution, magnetic field topology, plasma streaming and powerful radio waves. All these studies have been able to successfully describe many interesting plasma processes including solitons, cavitons, magnetic field-line reconnection, vortices, wave-couplings, turbulence and chaos. They also explain many outstanding phenomena observed in space as well as laboratory plasma like substorm, VLF emissions, striations or fine structure, stimulated electromagnetic emissions, solar flares, major disruption in fusion devices, etc. It may be noted that the Institute for Plasma Research, now a premier institute for plasma physics research in India, was nucleated at PRL, supported by the Department of Science and Technology during late seventies and early eighties.

Theoretical physics group has active interest in the study of various non-linear phenomena which are known to have crucial influence in complex classical systems such as, planetary dynamics, climate physics, fluid mechanics and pattern formation etc. The modelling of such complex systems involves, among other techniques, time series analysis of data. The effects of nonlinearity in systems that require quantum or semi classical description are less understood and more challenging. We have been investigating both time dependent and autonomous



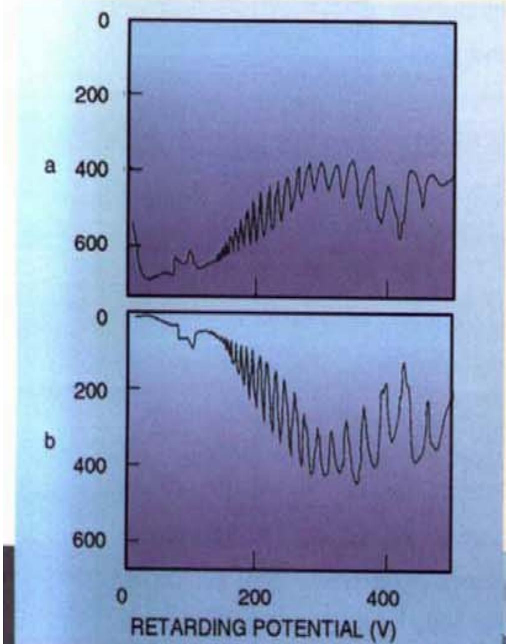


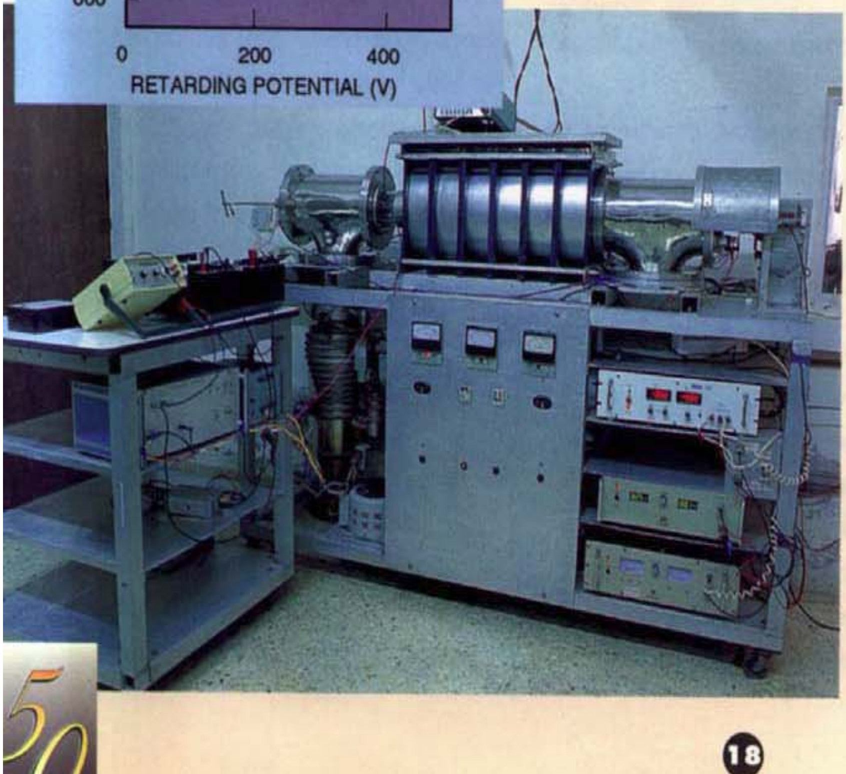
Charge density plots of chaotic quantum states in nonlinearly coupled quadratic oscillator system

Hamiltonian systems which model the physics of some of the systems mentioned above. We have focussed on two dimensional classically chaotic systems, studying the statistical properties of the spectra, quantum wave functions, time evolution of arbitrary states and semi classical approximations. The extension to three dimensional systems which classically reveals new physics is currently underway.

During last two decades the meteorology and climate studies group has carried out a number of theoretical and modelling studies of the dynamics of Indian monsoon and monsoon variability on different time scales and also the relationship between monsoon and global atmospheric circulations, global climate and its variability. Some major achievements of the group include insights into the mechanism of formation of monsoon depressions, their movements, energetics, instability of the summer monsoon flow, understanding the origin of intra-seasonal oscillations, and analysis of inter annual monsoon rainfall variability. The group developed a 3-dimensional climate model (General Circulation Model GCM) using which, winter and summer climates are simulated, as well as the variability of global climate by bottom boundary conditions like sea surface temperature and surface albedo, are studied.

An unusual novel behaviour of charged particle dynamics has been discovered in the parameter domain of classical mechanics through experiments carried out in the Basic Physics Laboratory. The motion of charged particles in the classical mechanical domain is known to be well described by the Lorentz equations of motion supplemented by the initial conditions. The experiments, though belonging to the classical mechanical parameter domain, have been found to be at variance with what is expected from classical mechanics. Specifically, there is evidence for the existence of discrete (as against continuous) allowed (and forbidden) states very much as in quantum mechanics, but which are non-Planckian, (not being characterized by the Planck quantum of action $\hbar$). The novel enigmatic behaviour, was predicted by a quantum-like theory, developed at PRL and represent an entirely new physics in the classical mechanical domain of parameters.

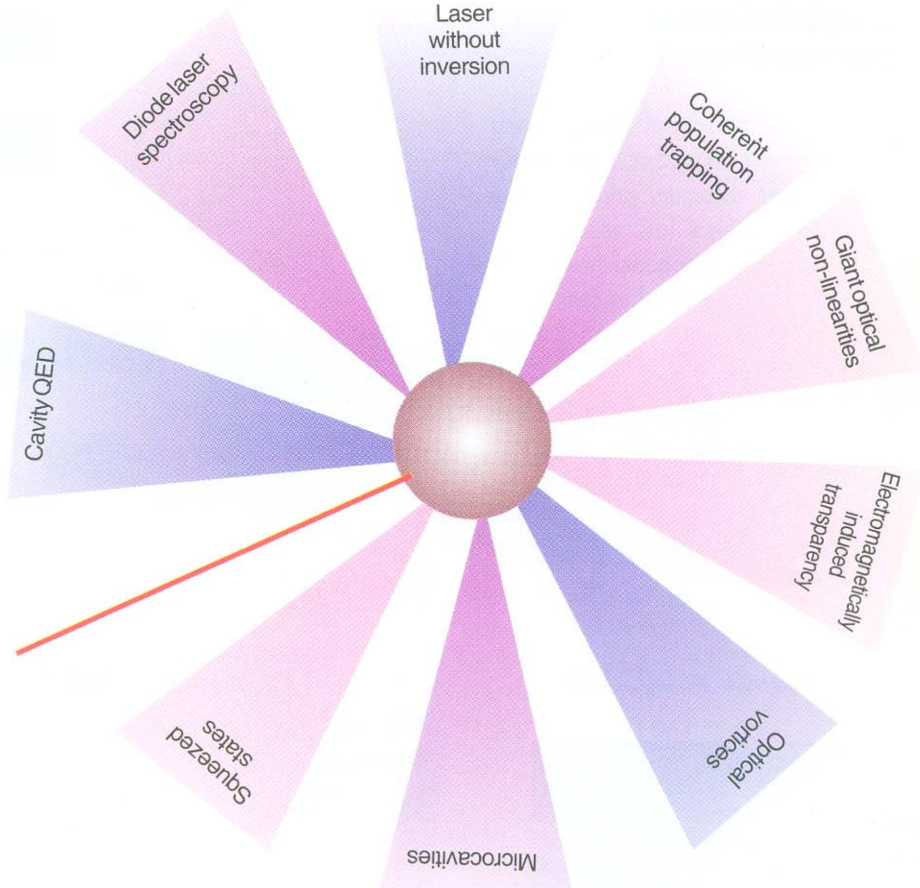




Experimental observations of discreet energy states in classical mechanical domains

The future directions in Gravitational Physics, will be on application of general relativity in the study of astrophysical and cosmological scenario on the macrolevel, and attempts would be made to initiate programmes in the study of quantum gravity. On the Particle Physics front, while investigations in physics and astrophysics of neutrinos will be continued, studies beyond the standard model will be taken up with future experiments in view. Also, experimental data both at high energy accelerators and astronomical observations would be analyzed in the context of astroparticle physics to assess possible bounds for particle physics models. Studies of complex systems involving methods from nonlinear dynamics, equilibrium and non-equilibrium statistical mechanics would be initiated.

LASER PHYSICS AND QUANTUM OPTICS



Lasers have found a large number of applications in almost every field of science and technology. PRL already has programmes in earth and atmospheric sciences where lasers are used as diagnostic and measurement tools. In addition to these applications, there is a growing need to start a programme to carry out research in fundamentals of laser physics and quantum optics to keep pace with the world and explore the possibilities of technology of the future. Realizing these, a strong group on theoretical aspects of laser physics and quantum optics has been started at PRL and an experimental group in these disciplines is being set up.

One of the major topics of study of this group is Optical Manipulation of Atoms. In the recent past it has been shown, by our group as well as by others, that by exposing atoms to appropriate electromagnetic fields it is possible to change, in a controlled fashion, their optical characteristics. Several schemes involving various laser fields and atoms have been proposed to produce atoms with tailor made optical properties and would be tested in the laboratory soon. This laser field induced control has tremendous potential in applications involving, for example :(i) distortionless pulse propagation - a basic requirement and still a distant reality for optical communication and fast optical computers; (ii) beam cleanup; (iii) enhancement of the efficiency of nonlinear processes; (iv) quenching of spontaneous emission noise leading to the possibility of spectroscopy beyond the natural linewidth; (v) quenching of motional noise leading to spectroscopic methods where lines within the Doppler width can be resolved; (vi) development of a new class of lasers, which do not even require population inversion; (vii) control of optical pattern formation and even optical turbulence; (viii) quenching of quantum tunnelling and (ix) controlled excitation by appropriately phased array of pulses.

These possibilities will be extensively studied. Work on optical manipulation of atoms will be extended to solid state systems.

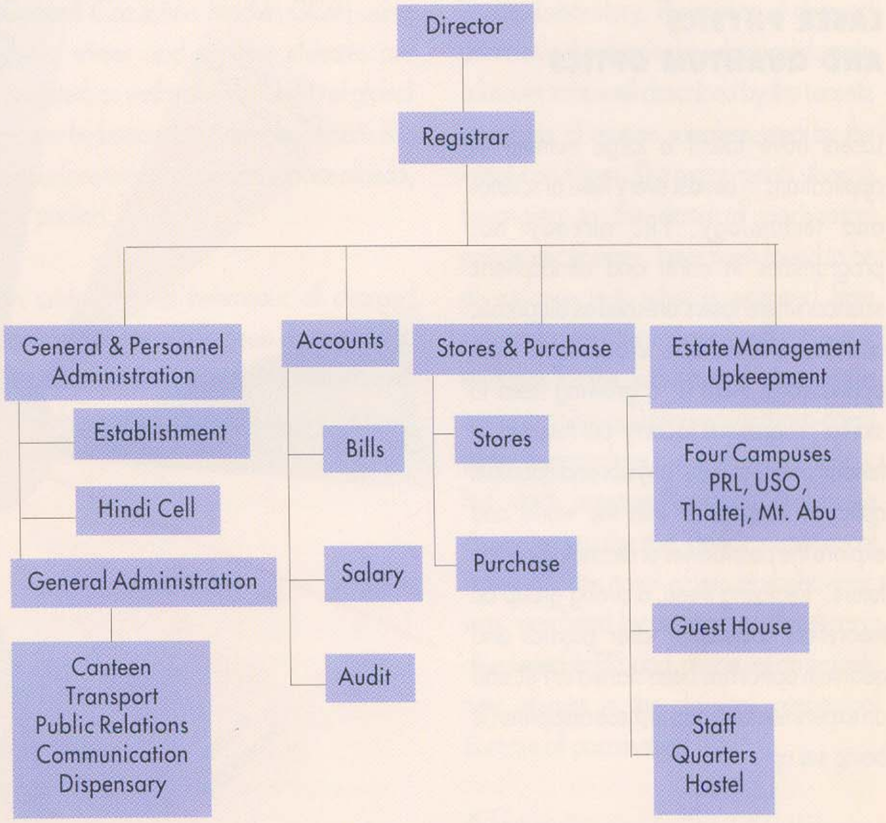
Another major area of interest is quantum electrodynamic (QED) and nonlinear optical effects in confined geometries. The excitation of whispering gallery modes, their role in enhancing nonlinear optical interactions as well as QED effects are being studied in detail. For example it has been shown that micron size silica spheres have some modes with very high quality factor, of the order of 10^9 and, therefore, are ideal candidates for laser action.

Novel low-loss laser resonators (both single and phased array) based on the self-imaging properties of multimode waveguides are also being investigated.

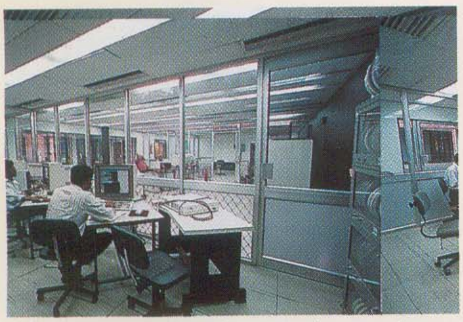
Finally optical systems are being studied for strictly quantum characteristics which have important bearing on many of the fundamental issues in quantum physics. New quantum regimes of parametric interactions have been discovered. In such systems, it is possible to study quantum interference between different parts of the wave packet.

ADMINISTRATION AND FACILITIES

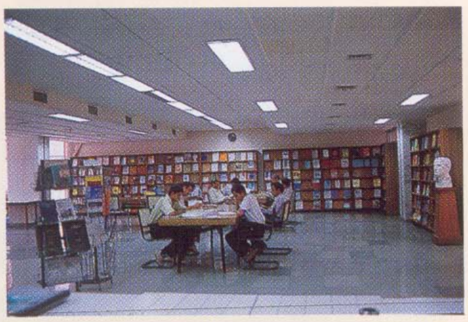
The success of the scientific programmes of PRL critically depends on the timely availability of necessary administrative support and technical facilities. PRL from its very inception recognized these needs and promoted their development which over the years have contributed in many ways to the scientific achievements of the laboratory.



The Administration Section plays a pivotal role in providing necessary management support to carry out the scientific activities in various campuses

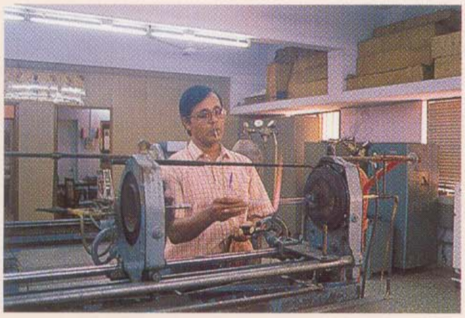


The Computer Centre has a workstation cluster consisting of five IBM RS6000/580 machines and one HP9000/753 machine connected by a high speed fibre optics network. The PC's and workstations in the various scientific and administrative areas are connected to the main workstation through a campus wide Ethernet LAN. The PRL system is connected through a VSAT link via the INSAT-II B satellite to the Department of Electronics (ERNET) hub at Bangalore to provide scientists access to the global Internet and facilities like *telnet* and *ftp*. The PRL computer centre is also equipped with computer graphics facilities.

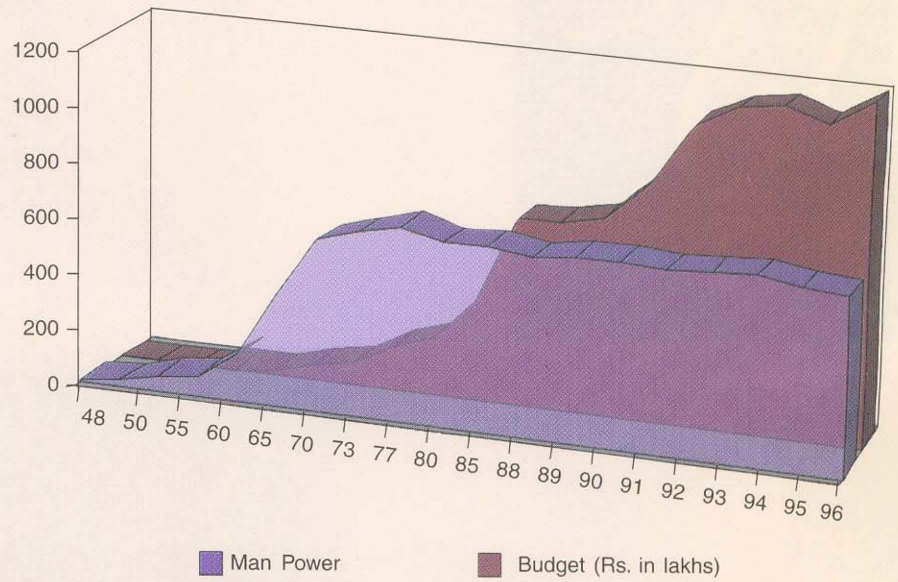


The Library is one of the leading scientific libraries of the country, with a rich collection of over 44,000 documents. It subscribes to over 200 international and national scientific journals. PRL library is probably the only library in India to have introduced automation in the early sixties, resulting in the development of the Mechanized Indexing using the first IBM - 1620 computer. Besides the computerised service such as circulation control, it also provides OPAC (Online Public Access Catalog). Another service the library provides is the Research Alert, a current awareness service given on the LAN.

The Electronics and Techniques Laboratories cater to the specific needs of scientists working in the areas of space sciences, particularly for development of payloads for balloon, rocket and satellite borne experiments. Electronics Laboratory is also working on hardware and software aspects of neural and fuzzy logic based systems focussing on pattern recognition, handwritten character recognition and neural VLSI (Very Large Scale Integrated Circuit) design. The development of thin films in the Techniques Lab paved way for acquiring technical skills in producing various types of optical coatings, for example, making metallic and multilayer dielectric beam splitters, filters and anti-reflection coating which are used on a routine basis in our research programmes.

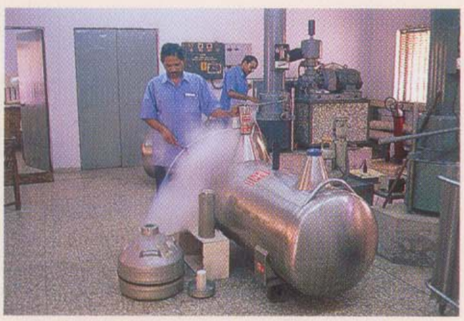


The Glass Blowing facility provides support for the design and fabrication of vacuum and gas extraction systems and sophisticated glass assemblies for various experiments.



The Engineering and Maintenance Section of the laboratory looks after the basic amenities of the laboratory. It is responsible for civil and electrical engineering work and the general upkeepment of the various campuses.

The various publications of PRL (reports, lecture notes, annual reports, in-house news magazines) are looked after by the Photo Documentation Group. The group extends photography, draughting and xeroxing facilities to our scientists. The group also helps with logistics for arranging lectures and symposia and maintenance and upkeepment of the lecture rooms and the K. R. Ramanathan Auditorium.



The Liquid Nitrogen Plant, established at PRL in the early seventies is responsible for round the clock supply of liquid nitrogen to the experimental programmes of the laboratory. Both the glass blowing and liquid nitrogen facilities in addition to catering to the needs of the PRL scientists, have also been providing support to other research and educational institutions at Ahmedabad.

The Workshop is the back bone of all experimental programmes of the laboratory. The workshop contributed significantly to the design and development of sophisticated payloads for space science research and the fabrication and installation of mechanical systems of the Infrared Observatory at Mt. Abu. More recently it has fabricated the mechanical systems for the dayglow spectrometers, lake sediment corers and experimental systems for studies in dusty plasma .

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