PRL-55

2001-2002

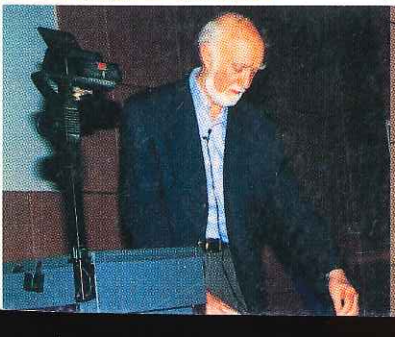
वार्षिक रिपोर्ट

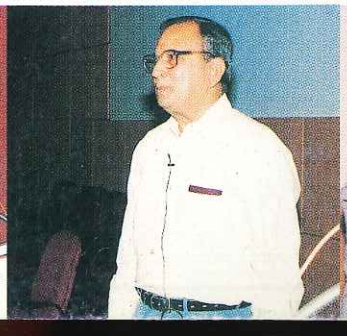
ANNUAL REPORT

भौतिक अनुसंधान प्रयोगशाला, अहमदाब


H. S. S. SINHA
CENTRE FOR SPACE SCIENCE AND TECHNOLOGY EDUCATION
VALEDICTORY FUNCTION OF THE SECOND POST
SPACE AND ATMOSPHERIC
PHYSICAL RESEARCH LABORATORY
APRIL 20, 2001


CENTRE FOR SPACE SCIENCE AND TECHNOLOGY EDUCATION IN ASIA AND THE PACIFIC (CSSTE-AP)
VALEDICTORY FUNCTION OF THE SECOND POST GRADUATE COURSE
SPACE AND ATMOSPHERIC SCIENCE
PHYSICAL RESEARCH LABORATORY, AHMEDABAD





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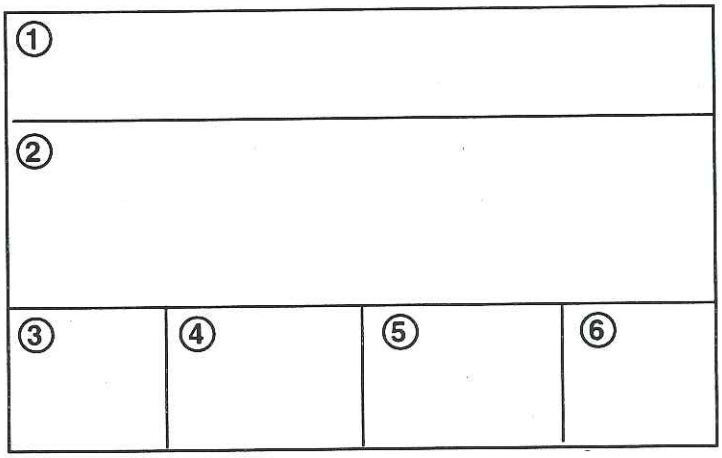

Title Cover :

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1. *Members of the Second Subcommittee of the Committee of Parliament on Official Language visiting PRL.*
2. *Valedictory function of the Second Post Graduate Course on Space Sciences of the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTE-AP).*
3. *Prof. A. Dalgarno, delivering the Vikram Sarabhai Professorship Lecture.*
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Dr. (Mrs.) P. Chakrabarty

Pictures by :
D.R. Ranpura

Published by :
Physical Research Laboratory,
Ahmedabd - 380 009

Layout by :
Mukesh Enterprise,
Odhav, Ahmedabad - 380 054

Printed by :
Creative Printers, Pvt. Ltd.
Ahmedabad - 380 021

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Introduction

The year 2001-2002 was the fifty fifth year of PRL's existence. During the year, the laboratory made important scientific contributions in different sub-disciplines of physics, space sciences, earth and planetary sciences. The laboratory also initiated a number of new research programmes. The Udaipur Solar Observatory completed 25 years. Some highlights of the activities of the laboratory are described below :

Stratospheric aerosol studies has been one of the key research programs in atmospheric sciences at PRL for more than a decade. Such studies are continuing using high power lidar at Mt. Abu. As the aerosol characteristics could be significantly different over different ecosystems, it was felt that a *mobile lidar system*, which is first of this type in the country, would give further thrust to the study of the cloud aerosol interaction at different locations in the Indian sub-continent. For this purpose *a Micro Pulse Lidar* has been procured and put into field tests.

Atomic oxygen is one of the major constituent of earth's upper atmosphere. Thus, photoionization cross section measurement of atomic oxygen is of great relevance for the modelling of the earth's ionosphere. Experimentally, it is very difficult to perform such experiments due to the contamination of the O^+ signal from other channels. However, these processes can be clearly differentiated by doing the momentum analysis of the residual ion. *Recoil Ion Momentum Spectroscopy (RIMS)*, a state-of-the-art experimental scheme, has been initiated at PRL to measure photoionization cross sections of atomic species.

The laboratory has added a new dimension to *Luminescence Geochronology of young sediments* by the addition of a *single grain OSL reader* with capabilities of laser stimulation of single 200 micron size grains.

Planetary Sciences have evolved into a very exciting field of research over the past few decades, leading to many discoveries which have changed our concepts of the way our solar system was formed. The space programme in India has also developed tremendously and launching capabilities have been proven so that planetary missions can be thought of. Realising this a new programme on *Planetary Sciences and Exploration* has been initiated at PRL this year. The programme aims to focus on planetary astronomy; modelling of planetary interiors, atmospheres, ionospheres, etc; laboratory studies of planetary materials, e.g. meteorites, lunar samples etc. and planning and preparation for planetary missions. The programme also plans to develop and train manpower for its activities through workshops. Two workshops have already been held for post graduate students and teachers of differnt universities and institutes. The programme would also support institutional proposals in the country. Studies related to an orbiter mission to Moon and sensor development have been taken up.

The submillimeter (SMM) wavelengths region of the electro magnetic spectrum is extremely important in observational astronomy. Most of the luminosity emitted in the critical initial phases of structure formation is emitted at far infrared (FIR) and submillimeter (SMM) wavelengths. The star forming region, is shrouded by the interstellar dust (ISD) and dense molecular clouds. Precise observations with sufficient spatial and spectral resolution is required to characterize the total luminosities, physical conditions, and morphological characteristics of these developing systems. We continue to *develop required technologies in the submillimeter wave region.* The development of state-of-the-art high-resolution receiver system is underway.

Work on the satellite payload *Solar X-ray Spectrometer (SOXS)* is in full swing. The experiment comprises of two independent payloads, namely SOXS Low Energy Detector (SLD) and the High Energy Detector (SHD). The SoXS Low Energy Detector (SLD) payload employs state-of-the-art semiconductor devices viz. Si-PIN and CZT detectors. The laboratory model of the SLD payload is designed, developed and tested successfully at the Physical Research Laboratory. The energy resolution of about 500 eV at 5.9 keV and 800 eV at 22.2 keV has been achieved to meet the scientific goals. Recently, the Qualification Model (QM) of SLD payload has also been tested successfully for all critical environmental tests, while the Flight Model (FM) is currently under fabrication. The support of the scientists & engineers from ISRO units, SAC and ISAC is gratefully acknowledged.

Indian Radio Beacon Experiment CRABEX is to be flown on GSAT-2, due for launch early next year. A chain of twelve receivers is to be set up over Indian region to record the differential phase, modulation phase, Faraday rotation and amplitude/phase scintillations using the 150 MHz and 400 MHz coherent radio beacons along with modulations with 1 MHz (149 MHz and 399 MHz) from GSAT-2. The receivers are provided with option to record the coherent beacons from orbiting satellites also. Testing of the prototype of the receiver being fabricated at Bangalore is nearly complete and transmissions from the orbiting satellites are being recorded for performance evaluation. High gain antennae for 150 MHz (2x2 Yagi array) and 400 MHz (2x2 helical array) for recording transmissions from GSAT-2 are also being developed independently at PRL.

Scientists at our Udaipur Solar Observatory, besides carrying out their research in different areas of solar physics, such as the effect of flares on solar oscillation characteristics; magnetic flux imbalance in solar active regions; solar eclipse studies, also did detailed scientific studies on its plans to set up a *state-of-the-art one meter aperture solar telescope (MAST).*

The *upgradation of the GONG instrument* being operated at USO as part of a six-site international network of ground-based observatories was completed by Dr. John Leibacher, Project Director GONG program, National Solar Observatory, USA and the USO scientists. The initial 256x256 pixel detector was replaced with a 1024x1024 pixel detector, along with a new data acquisition system. It is now possible to detect shorter wavelength p-modes which will help in probing closer to the solar surface. The new GONG+ will also provide full disk magnetograms with a cadence as short as 16 seconds. The upgraded GONG+ network of observatories will continue observing for a full solar cycle with an overall duty cycle of ~ 90%.

Our scientists have participated in a number of collaborative programmes. In particular our astronomers have collaborated with (i) Space Telescope Science Institute, Baltimore, USA, on a project on *substellar mass function in young open clusters* using a novel statistical approach involving ground-based observations and archival data in the near-infrared; and with (ii) Institute of Astronomy, Edinburgh, UK and Joint Astronomy Centre, University of Hawaii, USA, on a programme to study *episodic dust formation in some Wolf-Rayet stars* using near-infrared spectroscopic monitoring observations. In addition, the *Indo-French collaboration on investigations of the Galactic Centre region* using ground-based near-infrared and satellite based mid-infrared data is being continued.

During the past year PRL acquired *new computational facilities* and a new high-speed local area network (LAN). The LAN was designed by PRL engineers keeping in mind the requirements of various scientific programmes. The new computer facility consists of a IBM-SP RS/6000 system which has sixteen Power3-II processors with 32Gbytes of physical memory. Each processor is capable of 1.5 GFLOPS at peak performance and the sixteen processors can give a combined peak performance of 24 GFLOPS. In addition, for visualization and image processing a four processor graphics IBM RS270 workstation was acquired. Thus the IBM-SP and IBM RS270 together provide a complete solution to the laboratory's requirement for high performance computing and open avenues to new computationally challenging problems. The new computers are complemented with appropriate high quality scientific software and libraries like Mathematica and the IMSL, while software for visualization is provided by IDL and the Data Explorer package.

After the successful installation of the Aluminising Plant at the Gurushikhar Observatory, the primary and secondary mirrors of the Infrared Telescope have been aluminised. They have since been optically aligned.

A *summary of scientific achievements* is given on *page 5*. A total of **one hundred and fourteen** papers have been published in high impact journals, of which **ninety seven** were in international journals. During the year our scientists participated actively in national and international conferences with large number of significant presentations, out of which **sixty three** were invited talks. At present PRL has *thirty nine* research scholars and *eleven* post-doctoral fellows besides other visitors working in various disciplines. **Nine Ph.D. the-**

ses were submitted. The topics covered were widely varying, covering investigations of equatorial F-region plasma instabilities under different background conditions; chemical and isotopic studies of sediments from the Arabian sea and the Bay of Bengal; ^{40}Ar-^{39}Ar thermochronological study of the trans-Himalaya in Ladakh sector, India; study of marine processes in the northern Indian Ocean using radiocarbon; isotopic studies of refractory phases in primitive meteorites by an ion-microprobe; nitrogen isotopic systematics in ureilites; major ions, stable isotopes, $^{87}Sr/^{86}Sr$ and Re in the headwaters of the Yamuna: implications to chemical weathering in the Himalaya; stable isotope systematics in cave calcites: implications to past climatic changes in tropical India and studies on time dependent and stationary classically chaotic quantum systems.

Some of our scientists have received prestigious awards and honours such as the *M.N. Saha Birth Centenary Award; Fellowships* of the *Indian National Science Academy*, New Delhi; *Indian Academy of Sciences*, Bangalore and the *INSA Albert Einstein Centenary Research Professorship*.

The Second Subcommittee of the Committee of Parliament on Official Language comprising of nine MPs from both Rajya Sabha and Lok Sabha and three officers visited PRL on October 4 -5, 2001 to inspect the implementation of the Official Language. The activities of the Laboratory for proper implementation and progressive use of Hindi in day-to-day official activities were briefed to the committee through audiovisual presentations.

Prof. A. Dalgarno, FRS, Harvard Smithsonian Centre for Astrophysics, Cambridge, USA visited PRL as twenty second **Vikram Sarabhai Professor**. During his visit he gave a number of lectures, a colloquium and a popular lecture on *Molecular Synthesis in the Universe*.

Prof. N. Mukunda, Honorary Professor at the Indian Institute of Sciences and the Jawaharlal Nehru Centre, Bangalore delivered the seventeenth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Phases in Physics*.

Prof. B. L. K. Somayajulu, CSIR Emeritus Scientist, Physical Research Laboratory, Ahmedabad delivered the eighteenth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Past holds Clues to Future*.

The laboratory honoured **Prof. C. N. R. Rao**, Linus Pauling Research Professor at the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore and former Director of the Indian Institute of Science, Bangalore with the award of the **Hari Om Ashram Prerit Senior Scientist Award** for the year 2000 for his outstanding contributions in science and technology. The award was presented by Dr. K. Kasturirangan, Chairman, ISRO & Secretary, DOS. The function was presided over by Prof. U. R. Rao, Chairman, PRL Council of Management.

The laboratory conducted the **Second Post Graduate Course on Space Sciences of the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTE-AP)** affiliated to UN. The Space Science Course was conducted at PRL during August 1, 2000 to April 30, 2001. A Valedictory function was organized at PRL on April 29, 2001. Dr. A. E. Muthunayagam, Former Secretary, Department of Ocean Development, Govt. of India was the Chief Guest. Diploma certificates were presented to the participants.

The **RESPOND Programme in Space Sciences**, sponsored by the Indian Space Research Organization (ISRO), provides unique opportunity to scientists in Universities and other academic institutions to pursue research in Astronomy and Astrophysics, Middle Atmosphere of the Earth, Ionospheric Physics, Solar Physics, Planetary Atmospheric Science and other related subjects. The Respond Programme is being administered by PRL. All sponsored proposals are annually reviewed at PRL. One such review was held during 10-11 April, 2001, reviewed about 20 on-going and new projects.

A meeting on **Probing the Sun with High Resolution** was held in Udaipur from 16-19 October, 2001 to commemorate the Silver Jubilee of Udaipur Solar Observatory. The meeting was inaugurated by Prof U.R. Rao, Chairman, Council of Management, Physical Research Laboratory. The meeting brought out the intimate con-

nection between the physics of the solar interior with the dynamics of the outer layers of the solar atmosphere. More than 65 solar physicists from India and abroad participated in this workshop. Some of the distinguished participants included Dr. John Leibacher, Project Director GONG program, USA; Dr. Robert Rutten, Utrecht University, the Netherlands; Dr. Satoshi Masuda, Nagoya University, Japan; Dr. Pavan Kumar, Princeton, USA; Dr. N. Gopalaswamy, NASA-Goddard Space Flight Center, USA; Dr. Luc Dame, Service d'Aeronomie du CNRS, France and Prof. S. M. Chitre among others. They delivered lectures and participated in the deliberations on the setting up of the high-resolution solar telescope.

Under the joint venture between the Embassy of France, Alliance Francaise of Ahmedabad and Physical Research Laboratory, a public lecture entitled *Can Earthquake be Predicted ?* by **Mr. Jean-Philippe Avouac**, Head of Teledetection and Seismic Risks, Paris was arranged at PRL.

A residential **Workshop on Meteorites, Asteroids and Planets** was organized under the PLANEX programme at Mt. Abu during 15-20 December 2001. Twenty five M.Sc. students and a few Post Doctoral fellows and few young teachers were selected from various institutions and universities of the country. The six day workshop was oriented towards ground based Planetary Astronomy. One night was devoted to training in use of IR telescope and making observations relevant to some astronomical problems.

A **summer training programme** was organised at PRL during May 15 - July 14, 2001. A total of 47 graduate and postgraduate students participated in this programme. Thirteen of the students were from the IITs and the remaining were from the various universities.

As a part of implementation and progressive use of Hindi in PRL, the **Hindi Week** was celebrated at PRL from September 10 - 14, 2001. The special attraction of this year's celebration was a lecture by eminent educationist - *Dr. Chandrakant Mehta,* Ex-Vice Chancellor of Gujarat University, Ahmedabad who delivered the inaugural lecture. PRL also participated in *DOS Inter Centre Technical Seminar* on *Towards Self Reliance* organised by the Department of Space at ISRO Satellite Centre, Bangalore on 13 September, 2001 in which five of our staff members participated and presented their papers on various topics. In addition, DOS also organised another *Inter Centre Technical Seminar* on *Rashtriya Vikas ke liye Antarix Prodyogiki* at Space Applications Centre, Ahmedabad on 22 February, 2002, in which four PRL participants presented papers. Library facilities were augmented by the addition of books of various disciplines including Hindi Literature. Also the Hindi section and others extensively participated in a number of workshops and seminars on Hindi.

PRL celebrated the **National Science Day**, in association with the Indian Physics Association (IPA), Ahmedabad Chapter. The Science Day was dedicated to teachers and students of Stds. IX and X from schools all over Gujarat. Science Quiz, both written and oral, formed the main part of the programme. Two hundred and thirty three students participated in the written science quiz. PRL presented science kits to top eighteen students from the written science quiz and popular science books to the three best teams in oral quiz. *Wealth from Waste* was the theme for the National Science Day for this year. Accordingly, **Dr. Jagdish Barot** from World Health Organisation, Gandhinagar was invited to deliver a talk on the above subject. The talk was highly informative and evoked a lot of interest in students and teachers. Keeping in view of new directions in the researches conducted in PRL, two interesting talks on *Excitements in Planetary Sciences* and *New Facts on Mars* were presented by our scientists. **PRL scholarships** from the Aruna Lal Endowment Fund were awarded to five best students.

I take this opportunity to thank all my colleagues including administrative, technical and supporting staff for their cooperation. I also thank the PRL Council of Management for their guidance and advice.

Director

PRL in a Nutshell

Scientific Achievements

The research programmes of the laboratory can be broadly grouped under six major disciplines. These are,

i. Theoretical Physics;

ii. Nonlinear Dynamics and Computational Physics;

iii. Laser Physics and Quantum Optics;

iv. Astronomy and Astrophysics;

v. Planetary Atmospheres and Aeronomy;

vi. Earth Sciences and Solar System Studies.

The chart below profiles the scientific activities.

Some of the important research contributions are summarised.

Astronomy and Astrophysics

The group has been innovatively using the medium-sized 1.2 m IR telescope at Gurushikhar. Transient events, bright sources that vary with time, large scale mapping and techniques that do not primarily depend upon the size of the telescope are some of the ideas we are using to obtain maximum output out of the modest facility. However, some specific observations demand the use of larger/better facilities available elsewhere. The group is thus continuing its efforts to propose and obtain precious observing time on outside telescopes – Isaac Newton 2.2 m telescope at La Palma had been used earlier; UKIRT, KPNO are also being used by us for optical/IR observations. Radio astronomy is being pursued at outside facilities such as Ooty Radio Telescope and GMRT. Apart from these regular programmes, we do take advantage of opportunities offered by cosmic events such as the apparition of comets and the total solar eclipse. We did have two such occasions during the past one year. Udaipur Solar Observatory (USO), equipped with modern instruments is a premier facility in the country to conduct research in Solar Physics. A solar X-ray spectrometer (SOXS) payload for inclusion on a satellite in near future is under development in PRL.

Profile of Scientific Activities

Basic Sciences	Atmospheric Sciences	Earth Sciences & Solar System Studies
Gravitation Physics & Astrophysics	Upper Atmospheric Studies	Oceanography & Geochemistry
Atomic & Molecular Physics	Middle Atmospheric Studies	Palaeoclimate
High Energy Physics	Laboratory Astrophysics	Hydrology
Infrared & Radio Astronomy	Planetary Atmospheres	Evolution of Solar System Objects
Laser Physics and Quantum Optics		Cosmic Ray Prehistory
Nuclear Physics		Catastrophic Events in Earth's History
Plasma Physics		Evolution of Indian Lithosphere
Solar Physics		
Non-linear Dynamics		
Computational Physics		
Climate Studies		

In addition, a state-of-the-art laboratory facility to develop required technologies in the submillimeter wave region has also been initiated.

Total solar eclipse (TSE) provides an opportunity to unravel the mysteries of the corona of the sun. Although a tremendous amount of information is being obtained from the spacecrafts such as SOHO, YOHKOH, Ulysses and so on, the ground-based observations are still important to study the inner coronal regions at a faster sampling rate. One such chance came our way on 21 June but the totality could be seen in Southern Africa.The PRL Astronomy & Astrophysics group in collaboration with the Udaipur Solar Observatory group made an expedition to Lusaka, Zambia to make the observations. The teams conducted two major experiments : the first to measure the coronal temperature and kinematic features from the line profiles in [FeXIV] line using the technique of Fabry-Perot Interferometry and the second to measure the polarization in the coronal continuum and across the [FeXIV] line. These two experiments were intended for obtaining clues for the coronal heating mechanism. These experiments were successfully carried out. The analysis is in progress.

Comets provide opportunity to study the pristine matter in the solar system. Observations related to the cometary plasma and dust throw light on the comet – solar wind interaction mechanisms as well as on the growth and destruction of dust particles. The apparition of Comet Linear triggered off a series of important observations at Mt. Abu using an optical polarimeter and NICMOS 3 for imaging in the infrared bands. Critical observations were made on the phase angles where the turn over takes place from positive to negative polarization which is sensitive to the nature of dust grains.

In continuing our on-going programmes on the spatio-kinematic studies on Planetary Nebulae, we found a highly complex structure in the nebula NGC 1514. Our spatially resolved line profile study using the imaging Fabry-Perot Spectrometer provided evidence for a morphology of a double-lobed structure embedded in an elliptical shell. This structure suggests a common envelope ejection from a binary central star with a progenitor mass of 3.5 $M_{\odot}$ and a binary period of 14-20 days.

Be phenomenon is believed to be caused by mass ejection from rapidly rotating B type stars evolving in the main sequence phase. Non-radial pulsations could also contribute to the mass loss. A third and often ignored mechanism is that of mass loss due to tidal interaction in a binary system at the periastron encounter of the components. One such rare example was caught in its act at Mt. Abu using both visible (FLAGS) and infrared (NICMOS 3) spectroscopy which revealed rich Hydrogen emission spectrum, a feature that indicates Be phenomenon.

Observations of interplanetary scintillations (IPS) at Ooty radio telescope at 327 MHz (on a collaborative basis with TIFR) revealed probably the first evidence for extremely low densities of plasma over a very wide spread region around the Sun. This was accompanied by unusually low solar wind velocities too. This event, occurred around 11 May 1999, resulted in the widening of the earth's magnetosphere and receding of the bow shock away from the earth. One possible cause could be the magnetic field reversals leading to regions of reconnection in which the depletion of plasma can in principle occur.

On the development of new facilities/techniques, the group has successfully commissioned the country's first e-mail-triggered robotic telescope for observations of transient phenomena such as γ- ray bursts. A software developed in-house checks incoming e-mail alerts at one-minute intervals and triggers an 8-inch telescope equipped with a CCD camera. It can also alert observers through telephonic message. The facility awaits occurrence of a suitable event.

PRL has initiated building a state-of-the-art laboratory facility to develop required technologies in the submillimeter wave region. The development of state-of-the-art high-resolution receiver systems is underway. A step tunable optically pumped laser local oscillator (LO) has been installed successfully. Typical output of the pump laser in the mid-IR (λ= 9-11 μm) is between 10-50 watts. We have achieved more than 30milliwatts of power at 96.5μm, 118.8 μm, and 163.0 μm wavelengths. Currently, laser is being optimized for longer

wavelengths. This LO is used to optimize mixer performance in the laboratory. A room temperature Schottky diode has been optimized for the heterodyne operation. Traditionally, two kinds of spectrometers have been used for IF signal analysis in receiver system, Acousto-Optic Spectrometer and Filter bank Spectrometer. However, for eventual space payload we have chosen a state-of-the-art Chirp Transform Spectrometer (CTS) capable of giving 45 KHz resolution and 180 MHz processing bandwidth with 4096 channels. Preliminary design review is underway.

The Solar X-ray Spectrometer (SOXS) payload, scheduled to fly onboard GSAT-2 Indian Mission, will achieve sub-keV energy resolution and 100ms temporal resolution for uninterrupted ten hours period everyday. This will enable us to study the break-energy point among thermal, superhot and non-thermal components of the solar flare. The high-resolution observations of SOXS payload will also enable to study, for the first time, short and long term solar coronal variability, and its effects on the Earth's environment. The SOXS Low Energy Detector (SLD) payload employs state-of-the-art semiconductor devices viz. Si-PIN and CZT detectors. The laboratory model of the SLD payload has been designed, developed and tested successfully at the Physical Research Laboratory. The energy resolution of about 500 eV at 5.9 keV and 800 eV at 22.2 keV has been achieved to meet the scientific goals. Recently, the Qualification Model (QM) of SLD payload has also been tested successfully for all critical environmental tests, while the Flight Model (FM) is currently under fabrication.

The effect of flares on solar oscillation characteristics is rather elusive, but recent work was able to detect several flare events leading to distinctive changes in solar oscillation characteristics. Magnetic flux imbalance in solar active regions was shown to vary in step with the solar cycle, implying large scale connectivities that changed with the solar cycle. A study of approximately 54 large geomagnetic storms (Dst <-100 nT) in the present solar cycle during 1996-2001, showed that near solar minimum, the geoeffective CMEs were more associated with eruptive prominences, while near the maximum of the solar cycle they had association with strong flares.

Theoretical Physics

Theoretical Physics division is mainly concerned with the fundamental interactions of nature, electro-magnetic, weak, strong and gravitational, and as a part of this in addressing some basic questions in Astrophysics, High Energy Physics, Atomic Physics, Nuclear Physics and Plasma Physics. In Astrophysics, the focus is on some aspects of relativistic astrophysics, cosmology and astro-particle physics; in high energy physics, on neutrino physics, weak interactions, hadronic physics and quark-gluon plasma; in nuclear physics, on drip line nuclei, symmetries and chaos in nuclei; in atomic physics, on atoms in fields and Rydberg atoms and in plasma physics, on the phenomena in dusty plasmas and space plasmas.

Considering the effects of curvature coupling to fermions in the realm of general relativity two important effects have been realised, through the CPT violating terms, arising from a vector and a pseudo-vector potential. While on one hand numerical estimates are made that could be measured through satellite based torsion balance experiments, on the other, it has been shown that the left-right asymmetry could lead to lepton asymmetry, which when used along with primordial tensor perturbations would result in a baryon asymmetry of the correct magnitude as required in the early universe scenario for baryogenesis. Few other significant results obtained concern the effects of introducing Coriolis force in the context of accretion flows around rotating compact objects and the effect of centrifugal force reversal, which is realised to exist only for particles on circular geodesics, implying a condition that the angular velocity has to be larger than the radial velocity. This result has implications of the well known Mach's principle concerning inertial forces in general relativity.

Some aspects of neutrino physics, strong interactions, cosmology and collider physics have been studied. An important experimental result was obtained in neutrino physics this year by the solar neutrino detector at Sudbury Neutrino Observatory (SNO). This experiment provided for the first time a complete determination of all flavours of neutrino fluxes coming from the

Sun. These results were exploited by the group to derive important constraints on the neutrino magnetic moment and lifetime of neutrino. The solar neutrino results also constrained neutrino masses and mixing very strongly. Radiative mechanisms for neutrino masses were proposed which could explain the observed neutrino parameters correctly. In collider physics, following the observation of CP violation in K and recently in B mesons, it has become important to look for signatures of such violations in other systems. A systematic study was made to see CP violation in the production of tau meson using polarized beams at future collider TESLA. Also studied were quantum corrections to CP violating angular asymmetry in $e^+e^- \rightarrow t\bar{t}$. In cosmology, understanding the dynamics of inflation which is supposed to have taken place during very early evolution of our universe is a challenging task. A systematic study was made of the inflationary phase transition including a specific cases which considered effects of couplings between two scalar fields. In hadron physics, it is known that the properties of the known hadrons can change considerably at very high temperature and/or at very high nuclear density. A study of how quantum corrections change the vector meson masses in the presence of hot and dense hadronic matter was made. It was shown within a specific non-perturbative framework that the quantum corrections tend to increase the masses of vector mesons.

In order to understand the structure of N=Z odd-odd nuclei above ^{56}Ni, which is a topic of high current interest in nuclear physics, binding energy data were analyzed and predicted that remnants of Wigner's spin-isospin SU(4) symmetry should be present in these nuclei. Secondly, for spectroscopic studies of these nuclei, isospin projected deformed shell model is being developed and first successful analysis of the isospin T=0 and T=1 levels in ^{62}Ga and ^{66}As are carried out.

For the study of transitions between neighboring states of Rydberg atoms, a *new* approximate expression of the Jacobi polynomial $P^{(\alpha,\beta)}_k(\cos\phi)$ valid for small ϕ and arbitrary α, β and k is obtained which for large k, reduces to a known *asymptotic* expression of the mathematical literature.

Collective phenomena in dusty plasmas have been investigated in weakly as well as strongly interacting regimes. In addition, in partially ionized plasmas, it is found that the neutral dynamics in partially ionized plasma is responsible for suppression of macro-instabilities. It is the collision between ions and neutrals that is important for the suppression and it is not necessary to invoke viscosity as was done by some workers on this topic.

Nonlinear Dynamics & Computational Physics

We have studied the emergence of complex behaviour from often deterministic and simple physical laws with the aid of both theoretical and computational physics. Control and synchronization of chaos, networks, cryptography, quantum chaos and large scale computations of the properties of large atoms are some of the topics on which work is being carried out. We focus attention this year on implementing chaos based secure communication, dynamical networks, and universal bounds on quantum entanglement.

We have developed methods for estimation of initial conditions of both periodic and chaotic dynamical systems. This has enabled us to propose a method of secure communication that is practically very difficult to crack. We are also exploring ways to implement these algorithms. Study of networks such as the small world network and growing networks are very important in understanding the emergence of complexity. We have studied the effects of dyanmical chaos at the nodes of networks and the resultant complex behaviour, especially synchronization and cluster formation.

We had recently found that quantum chaos can substantially increase entanglement. Subsequently, employing random matrix theory modelling we have derived an universal statistical upper bound on entanglement that we may expect generic interactions to lead to.

Laser Physics and Quantum Optics

Major activities of our recent work have been in the areas of coherent control of the propagation of light pulses, cavity QED, entanglement of quantum systems and optical vortices.

We show that a suitably applied control field can facilitate the stoppage of light pulses in a coherently driven atomic medium via electro-magnetically induced transparency. We demonstrate that a control field can also be used to separate temporally the two polarization components of a linearly polarized pulse propagating through a coherent medium.

The decoherence of coherently prepared superposition of states is a major issue in several fields such as quantum information processing. We show how the interaction of a system with a sequence of 2π pulses can slow down its decay into continuum and help realize an analog of quantum anti-Zeno effect.

In cavity QED, we have studied the feasibility of enhancing the fundamental radiative interactions between distant atoms. In particular, we showed how giant dipole-dipole interaction can be produced by placing dipoles close to micron sized silica spheres and resonantly coupling them via the whispering gallery modes. We have also examined how one- and two-photon processes compete when an ultra cold three-level atom undergoes cascade transitions in a bimodal cavity.

We show the existence of dramatic non-classical spatial correlations in the resonance fluorescence produced by identical coherently driven two level atoms, and point out that the non-classical features are produced by state reduction as a consequence of detection. The detection of the first photon produces entanglement between two atoms and the detection of the second photon becomes a probe for such entanglement. Such ideas have also been applied to Bose condensates to entangle three different many-particle states by Bragg spectroscopy with nonclassical light. We demonstrate that high-gain parametric amplifiers can be used as intense sources of entangled photons for potential applications in quantum information and quantum imaging.

We have studied the one-dimensional projection of a vortex field and calculated the extent of spatial coherence and entropy of such projections. Finally, we have produced a symmetrical optical vortex using a computer generated hologram. This is made into a non-canonical vortex after passing it through a cylindrical lens. We have studied the propagation of such a vortex in free space experimentally and the results were explained theoretically.

Planetary Atmospheres and Aeronomy

Planetary Atmospheres and Aeronomy Division aims to understand various scientific phenomena taking place in the upper part of the earth's atmosphere, which is accessible by balloons, rockets and satellites and the near earth environment. These studies are conducted by developing suitable experiments and taking them up on balloons, rockets and satellites and analyzing the scientific data by modelling and numerical simulation techniques. In addition to space-borne measurements, the division also undertakes laboratory studies of some of the most intriguing reactions occurring in the upper atmosphere.

A Nd-YAG laser based lidar is operational at Gurushikhar in Mt. Abu since November 1997 to study the temperature structure and dynamics in the middle atmosphere at tropical latitudes. Climatology of the temperature in the region 30-75 km is obtained using the Rayleigh scattered signals and compared with existing models. While the measurements compare well with model values below 50 km, there exists considerable difference above 50 km. Day to day and year variability is also evaluated. For the past 2 years lidar is also used to obtain temperature in the region 5-30 km from Raman scattered signals. Density perturbations are also being used to study features of atmospheric gravity waves at tropical latitudes.

A unique set of rocket measurements was carried out from Sriharikota during Leonid meteor storm which occurs once in 33 years with enhanced meteoric activity. Experimental evidences are obtained for the first time, for the presence of sub-meter (50 cm) scale sizes plasma irregularities having peak amplitude at 105 km. The properties of these sub-meter irregularities are different from the conventional irregularities observed in the equatorial E-region during non-meteor storm days. Preliminary theoretical analysis suggests that the streaming of plasma cloud associated with meteoric trails

are likely to be responsible for the generation of such irregularities.

In the area of planetary atmosphere, theoretical studies on the ionosphere/magnetosphere of Mars and comets are carried out to understand solar wind interaction processes on them. This study suggests that protons can precipitate down in the dayside and nightside ionosphere of Mars and comets. The energy of solar wind electron is not found to be sufficient to penetrate deep in to the dayside Martian atmosphere. It contributes significantly in the nightside ionosphere. The photon impact ionization is the dominant process in the dayside ionosphere of Mars and comets.

Earth Sciences and Solar System Studies

The programmes on Earth Sciences and Solar System Studies focus on the spatial and temporal evolution of the Earth and other planetary bodies through studies of the isotopic and chemical signatures contained in samples derived from them. Such studies are carried out using sohisticated instrumentation and a subtle combination of analytical methods and theoretical models.

Chemical composition of aerosols near sea surface is expected to have Na:Cl ratio very similar to that in sea water. Contrary to this, aerosols over the Bay of Bengal show unusually large chloride deficit, 55%-98%, highest values observed in aerosols. This results from volatilization of chloride by interaction with sulphuric acid produced from SO_2 in the atmosphere. The strong positive correlation between chloride deficit and non-sea-salt SO_4 in these aerosols supports this hypothesis. The impact of this process is to sequester sulphuric acid as SO_4.

One of the unique characteristics of rivers draining the southern slopes of the Himalaya, such as the headwaters of the Ganga and the Yamuna is their high dissolved uranium concentration. Identifying sources for such high uranium has been a topic of study of the Earth Sciences group. It is shown that black shales on an average have ~37μg U per gram, Weathering of ~50 mg of the black shales can contribute ~1.7μg U, its average concentration per liter of the Ganga and Yamuna headwaters. This further, brings to light the importance of minor lithologies in influencing budget of trace elements in the Himalayan rivers.

The group added a new dimension to Luminescence Geochronology of young sediments by the addition of a single grain OSL reader with capabilities of laser stimulation of single 200 micron size grains. This system is equipped with three optical excitation sources including a precision Nd:YV04 laser, an IR laser and Blue laser diodes giving a flexibility of excitation wavelength. A precision XY stage allows laser beam of ~ 100 micron diameter to focus onto a single grain of ~ 200 micron size with a position precision of ~ 2 micron. This system has been installed and has been used to date young sediments from the Anantpur district, Thar and Kalahari Desert sequences.

Ion microprobe studies of Al-Mg, Ca-K and Be-B isotopic systematic in a set of first generation solar system solids isolated from the primitive meteorite Murchison allowed to place a limit on the energetic particle irradiation of the solar nebula. An effective fluence of solar energetic protons of $10^{18}cm^{-2}$ with $E > 10$ MeV and characterized by a hard spectra than the contemporary solar flare particles, is consistent with the observed data.

Refractory Ca-Al-Inclusions (CAIs) from the CR carbonaceous chondrites, with different mineralogical characteristics show uniform abundance of ^{26}Al at the time of their formation suggesting a very short time interval within which these early solar system objects formed in the solar nebula. However, there are sharp contrasts in isotopic records between CAIs from CR chondrites and that from CH chondrites indicating possible temporal or spatial differences in their formation epochs or locations.

New data on Al-Mg systematics in differentiated meteorites strengthened earlier observations and confirms the role of ^{26}Al as an important heat source leading to early melting and differentiation of planetesimals.

Petrologic, minerological, isotopic and spectroscopic (Mössbaur) studies of the ferruginous Permian-

Triassic boundary sections revealed presence of quartz vein with strained quartz, nanometer-sized particles of iron minerals that are absent in samples above and below the boundary layers. These observations resemble findings in the K/T boundary sections and suggest the possibility of a large impactor as the cause of P/T extinction during the phanerozoic.

A detailed geochronological study of well-constrained chemical- and magneto-stratigraphic lava flow sequence in the Narmada region of the Deccan Volcanic Province clearly demonstrate that the onset of Deccan volcanism predate the Cretacious-Tertiary boundary event. The study also resolved a long standing inconsistency between the radiometric and palaeomagnetic age constraints.

Unambiguous identification of carrier phases of anomalous isotopic components is a pre-requisite for understanding the early solar system processes. An isotopically heavy nitrogen component has been identified in the solar wind bearing dark lithology of the L3-5, brecciated Itawa Bhopji chondrite, which fell on May 30, 2000, in Rajasthan. Its low temperature release and association with radiogenic ^{129}Xe are highly suggestive that a halogen rich labile phase is the host of this heavy nitrogen.

A new programme on Planetary Sciences and Exploration has been initiated at PRL this year. It has four components related to : (1) Planetary Astronomy; (2) Modelling of Planetary interiors, atmospheres and ionospheres; (3) Laboratory studies of Planetary materials, e.g. meteorites, lunar samples and (4) Planning and preparation for planetary missions. The programme also plans to develop and train manpower for its activities and would support institutional proposals in the country. Two workshops, one at Ahmedabad and the other at Mt. Abu were conducted for orienting young students and scientists for working in problems related to Planetary Sciences. Facilities for preparation and study of thin sections has been set up. Studies related to an orbiter mission to Moon and sensor development have been taken up. This programme is supported by the Department of Space.

Technical Developments

Vacuum Crusher

Noble gases in a given sample (both terrestrial or extraterrestrial) are a mixture of trapped and *in situ* produced (radiogenic, cosmogenic and nucleogenic) components. It is a challenge to decouple these various components by clever experiments. The normal step heating pyrolysis technique is not very fruitful at times. Crushing the sample in ultra high vacuum wherein trapped gases are selectively released has been shown to be very effective in achieving this component separation. We have fabricated a vacuum crushing device, wherein about one gram samples can be processed. A magnetic hammer (inside vacuum) is operated by an external electro-magnet, and weighing about 500 g pounds the sample at a rate of 30 strokes per minute and liberates the gases trapped in the sample, which can be processed and measured. Presently we are studying gases trapped in carbonatites, which cannot be analysed by any other method and are planning to analyse some martian meteorites in near future.

Development of Mesospheric Scanning Photometer

In view of obtaining intrinsic parameters of gravity waves and their influences in mesospheric region using simultaneous measurements of mesospheric region with MST radar, lidar and airglow photometric techniques, a mesospheric scanning photometer (MSP) is developed. This instrument which has 4^0 field of view can monitor the OH emission intensities from OH (8,3) band and O_2 (0,1) band emissions from mesospheric region. By monitoring two rotational lines from a same vibrational band, it is possible to derive rotational temperature of the mesospheric region. This MSP is fitted with mirror arrangement to provide multidirectional scanning by moving the mirror assembly with computer controlled stepper motors. Faster scanning or the mirror assembly attached to the photometer provides sampling of airglow emission from different azimuthal regions which enables to derive wave parameters. Field trials are being planned.

New Computational Facility

Modern scientific research requires modern computational facilities and during the past year PRL acquired new computational facilities as well as a new high-speed local area network (LAN). The new LAN has a gigabit backbone and has star topology with structured cabling standard (SCS). The LAN was designed by PRL engineers keeping in mind the requirements of various divisions. The best of the passive and active components were procured from various manufacturers and integrated into a system. This design provides for sufficient redundancy, high-speed connectivity and future expandability. Thus, it was the most cost effective method of building a state of the art network. In addition, other PRL centres at Udaipur and Mt. Abu were connected to the PRL LAN on a 64 Kbps BSNL leased line.

The new computer facility consists of a IBM-SP RS/6000 system which has sixteen Power3-II processors with 32Gbytes of physical memory. Each processor is capable of 1.5 GFLOPS at peak performance and the sixteen processors can give a combined peak performance of 24 GFLOPS. In addition, for visualization and image processing a four processor graphics IBM RS270 workstation was acquired. The enormous computing power of IBM-SP offers the possibility of taking up numerically intensive problems which were impossible with the earlier system. It also opens avenues to new problems which are computationally challenging. The large amount of data generated using IBM-SP can be visualized for interpretation and analysis using the graphics workstation. Thus the IBM-SP and IBM RS270 together provide a complete solution to the laboratory's requirement for high performance computing. The new computers are complemented with high quality scientific software and libraries like Mathematica and the IMSL while visualization is provided by IDL and the DataExplorer package.

Infrastructural Facilities Available

Computer Centre, Electronics Laboratory,

Scanning Electron Microscope,

Liquid Nitrogen Plant, Glass Blowing Facility,

Radio Carbon Dating Laboratory,

Aluminising Facility at Mt. Abu

Research Opportunities

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. With this in view, PRL offers graduate programme leading to Ph. D. degree. It also provides opportunities for carrying out post-doctoral research (**Fig.1**). The laboratory's visitor's programme includes an Associateship Programme for university teachers to interact with its scientists.

Training Opportunities

PRL provides summer training programme to students doing their Master's degree in Physics to acquaint them with the research programmes and opportunities available at PRL. PRL provides project training in computer science and application to post-graduate students. It also offers training in electronics and computer engineering to engineering students (**Fig.2**)

PRL also offers training and apprentice programmes in computers, library science, engineering and administrative services (**Fig.3**).

Research and other Scientific Details

The research work carried out by PRL scientists are published in reputed national and international journals. Few of our scientists are also invited to write review articles in the field of their specialisation.

Many of our scientists attend conferences and symposia at home and abroad where they present the results of their research investigations. Some of them are invited to present review papers. Few of them serve as chairmen and members of scientific committees for organising national conferences and symposia. Sometimes they are also invited to convene and chair sessions during symposia and meetings. The scientific output during the reporting year is shown in **Fig.4**.

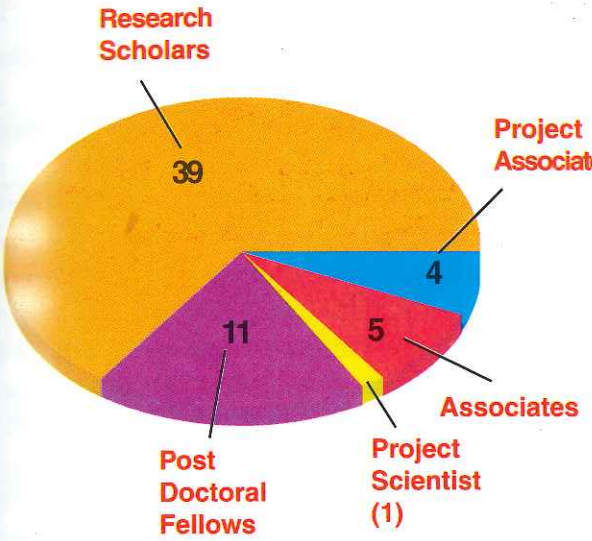

Fig.1 Doctoral, Post Doctoral and other Programmes

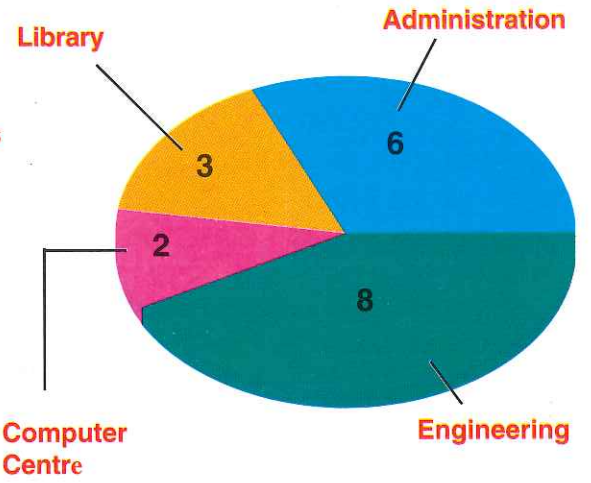

Fig.3 Apprentice Programme

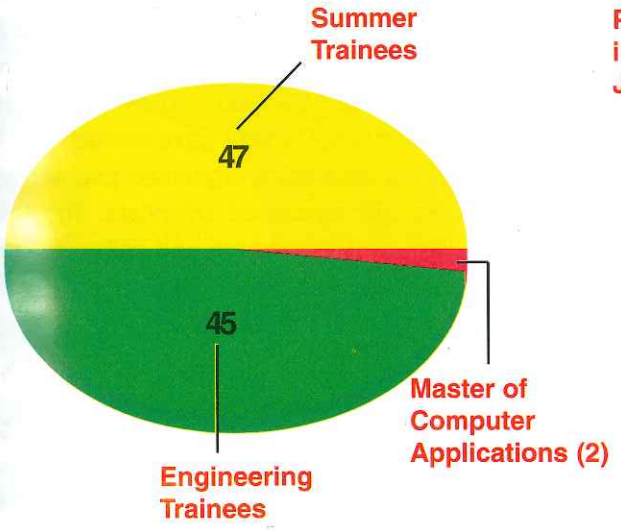

Fig.2 Graduate & Post Graduate Programme

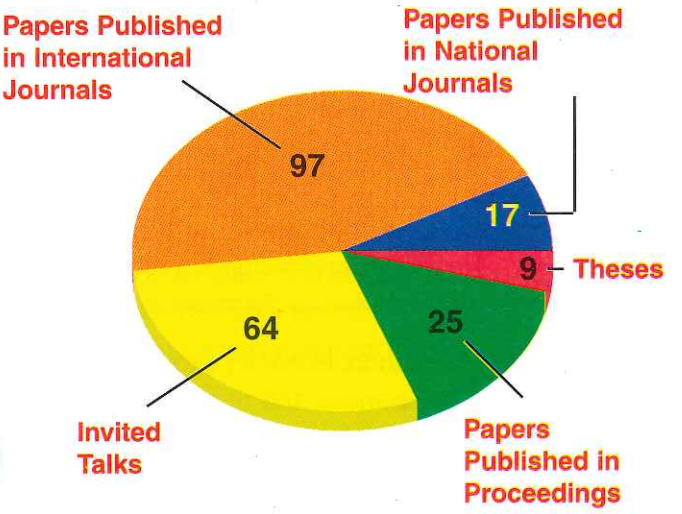

Fig.4 Scientific Output

Books/Journals Edited/Published

D.S.G.Thomas and **A.K.Singhvi** (eds.), Special issue of *Quaternary Science Reviews on Interaction between Arid and Humid Records of Climatic change in Drylands (IGCP-413).*

Conferences / Symposia Convened

The laboratory from time to time convenes symposia, conferences and workshops in different disciplines. Scientists and research students from other institutions and universities are invited to participate. During the reporting year PRL convened the following :

1. Workshop-cum-Training Course on Meteorite, Asteroids and Planets, December 15 -20, 2002, **Drs.J. R. Trivedi and N. M. Ashok - Conveners**

2. Meeting on Probing the Sun with High Resolution was held in Udaipur from 16-19 October, 2001, **Dr. P. Venkatakrishnan**

Distinguished Visitors at PRL

The Second Sub-committee of the Commitee of Parliament on Official Language comprising of nine MPs from both Rajya Sabha and Lok Sabha and three officers visited PRL on October 4 -5, 2001 to inspect the implementation of the Official Language in six central government offices, PRL, BSNL, Railways (Western Zone), BIS, FCI and Air India. The activities of the laboratory for proper implementation and progressive use of Hindi in day-to-day official activities were briefed to the committee through audio-visual presentations.

The Committee under the Chairmanship of Prof. B. V. Sreekantan, Former Director, TIFR and Fellow of NIAS, Bangalore visited PRL during October 28-29, 2001 to conduct a peer review of the laboratory. The activities of the laboratory was presented and the committee members had extensive interaction with the scientists. The committee was highly appreciative of the activities and the ongoing programs of the laboratory.

Prof. A. Dalgarno, FRS, Harvard Smithsonian Centre for Astrophysics, Cambridge, USA visited PRL as twenty second **Vikram Sarabhai Professor**. During his visit he gave a number of lectures, a colloquium and a popular lecture on *Molecular Synthesis in the Universe*.

Prof. N. Mukunda, Honorary Professor at the Indian Institute of Sciences and the Jawaharlal Nehru Centre, Bangalore delivered the seventeenth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Phases in Physics*.

Prof. B. L. K. Somayajulu, CSIR Emeritus Scientist, Physical Research Laboratory, Ahmedabad delivered the eighteenth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Past holds Clues to Future*.

During the Silver Jubilee celebrations of the Udaipur Solar Observatory few distinguished visitors participated in the meeting on Probing the Sun with high resolution. **Dr. Robert Rutten**, Utrecht University, the Netherlands gave a talk on *High-resolution Solar Physics* using image restoration through speckle and phase-diverse reconstruction technique, and image improvement through adaptive optics. **Prof. SM Chitre** delivered a talk on recent results of helioseismology and solar neutrinos. **Dr. Luc Dame**, Service d'Aeronomie du CNRS, France presented details of the *French Solarnet Experiment* - a novel technique for high resolution observations using multi-telescope solar interferometer. **Dr. Satoshi Masuda**, Nagoya University, Japan gave a detailed review of high energy processes in solar flares based on the results obtained from Yohkoh observations. **Dr. John Leibacher,** Project Director, GONG program, National Solar Observatory, USA and the USO scientists completed the *upgradation of the GONG instrument* being operated at USO as part of a six-site international network of ground-based observatories.

Seminars and Colloquia

The laboratory has an extensive seminar and colloquium programme. Reputed scientists, both from national and international institutions were invited to give seminars and colloquia. Prof. Paul Hickson of University of British Columbia, Canada and Prof. R. U. Haq of Laurentian University, Canada gave interesting colloqua. In addition, the laboratory organised popular lectures by internationally renowned scientists. The following gives an idea of the seminars and colloquia including popular lectures held at PRL :

Seminars held	112
Colloquia including public lectures held	33

Administrative Support

Behind the scientific achievements of PRL 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. In addition, it also provides management support to the Solar Observatory at Udaipur and the Infrared Observatory at Mt. Abu. The budget and staff structure of PRL are shown in **Figs. 5 and 6**.

Miscellaneous

The laboratory honoured **Prof. C. N. R. Rao,** Linus Pauling Research Professor at the Jawaharlal Nehru

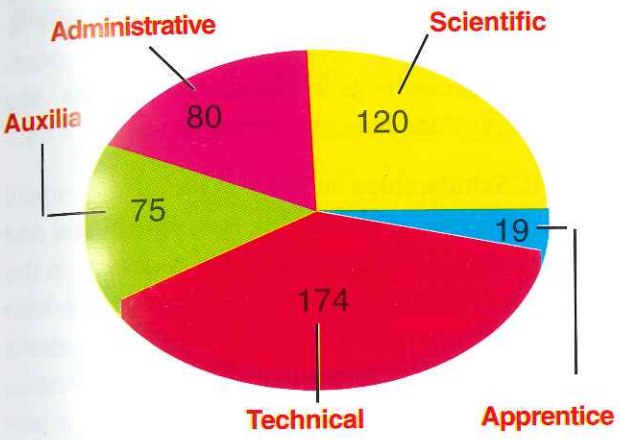

Fig.5 Staff Structure of PRL

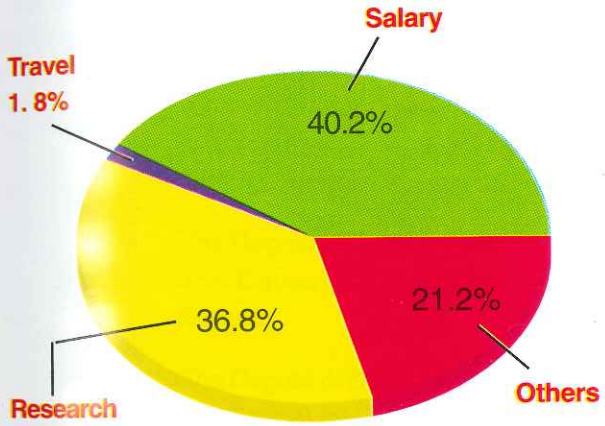

Fig.6 Budget of PRL

Centre for Advanced Scientific Research, Bangalore and former Director of the Indian Institute of Science, Bangalore with the award of the **Hari Om Ashram Prerit Senior Scientist Award** for the year 2000 for his outstanding contributions in science and technology. The award was presented by Dr. K. Kasturirangan, Chairman, ISRO and Secretary, DOS. The function was presided over by Prof. U. R. Rao, Chairman, PRL Council of Management. The Senior Scientist Award has been instituted in 1998 by the Physical Research Laboratory, with the funds donated by the Hari Om Ashram Trust, Nadiad, to commemorate the birth centenary of Pujya Shri Mota, Founder of the Hari Om Ashram. The award, being given biennially, carried an amount of Rs. 1 lakh and a citation.

As a part of implementation and progressive use of Hindi in PRL, the **Hindi Week** was celebrated at PRL from September 10 - 14, 2001. The highlights of the celebrations included word quiz, essay, elocution, Hamara Karya, self written poetry competitions and Antakshari. The special attraction of this year's celebration was a lecture by eminent educationist - *Dr. Chandrakant Metha*, Ex-Vice Chancellor of Gujarat University, Ahmedabad who delivered the inaugural lecture.

PRL also participated in *DOS Inter Centre Technical Seminar on Towards Self Reliance* organised by the Department of Space at ISRO Satellite Centre, Bangalore on 13 September, 2001 in which five of our staff members participated and presented their papers on various topics. In addition, DOS also organised another Inter Centre Technical Seminar on Rashtriya Vikas ke liye Antarix Prodyogiki at the Space Applications Centre, Ahmedabad on 22 February, 2002, in which four PRL participants presented papers.

Shri Som Sharma participated in the DOS Inter Centre Technical Seminar on Rashtriya Vikas ke liye Antarix Prodyogiki, held at SAC, Ahmedabad on 22 February, 2002 and presented his paper *Green House Gaison ka aayanmandal par prabhav*. He also received the IInd prize for best presentation. To encourage the participants the organisers presented all the participants Rs.2000/-.

The Hindi Officer also participated in the 12th International Hindi Sangosthi organised by Gujarat Vidyapith, Ahmedabad during 8-9 December, 2001 and delivered a talk on *Prodyogiki ki Sahayata se Hindi ka Prasar*.

The Hindi section attended the *Rajbhasha Sammelan* at Mumbai, on 29 March, 2002, organised by Deptt. of Official Languages and Hindi workshops held by various Deptts. like United Insurance, SAC, SISI, NTC, Door Darshan and Aakashvani and delivered lectures on different topics.

PRL celebrated the **National Science Day**, in association with the Indian Physics Association (IPA), Ahmedabad Chapter. The Science Day was dedicated to teachers and students from high schools. Science

Quiz, both written and oral, formed the main part of the programme. The science quiz was open to students of Stds. IX and X from schools all over Gujarat. Two hundred and thirty three students participated in the written science quiz. PRL presented science kits to top eighteen students from the written science quiz and popular science books to the three best teams in oral quiz.

Wealth from Waste was the theme for the National Science Day for this year. Accordingly, **Dr. Jagdish Barot** from World Health Organisation, Gandhinagar was invited to deliver a talk on the above subject. The talk was highly informative and evoked a lot of interest in students and teachers. Keeping in view of the new directions in the research conducted in PRL, two interesting talks on Excitements in Planetary Sciences and New Facts on Mars were presented by our scientists.

PRL Scholarships from the Aruna Lal Endowment Fund, established by Prof. D.Lal, Honorary Fellow and former Director, were awarded to five students on the basis of their performance in Science Quiz, both written and oral, and personal interview. All the five students are to receive Rs.5000/- per year for three consecutive years provided the students continue to study in science stream with high academic record.

Awards and Honours

1. **Prof. U. R. Rao** has been awarded the

   i. *Life Time Contribution Award in Engineering* for the year 2001 from *Indian National Academy of Engineering*, New Delhi.

2. **Dr. K. Kasturirangan** has been awarded the

   i. *International Collaboration Accomplishment Award 2001* by the International Society for Air Breathing Engines (ISOABE), Bangalore.

   ii. *Rathindra Puraskar for the year 1999* by Visvabharati, Santiniketan.

   iii. *4th Sri Chandrasekarendra Saraswati National Eminence Award* by the South Indian Education Society, Mumbai

   iv. *The Degree of Doctor of Sciences* (Honoris Causa) by Calcutta University, Kolkata.

   v. *The Degree of Doctor of Sciences* (Honoris Causa) by Gurunanak Dev University, Amritsar.

3. **Prof. G. S. Agarwal** has been :

   i. awarded the *INSA Albert Einstein Centenary Research Professorship.*

   ii. awarded the *M.N. Saha Birth Centenary Award* by Indian Science Congress.

   iii. invited to be a *Member of Editorial Board* for Journal of Optics B: Quantum and Semiclassical Optics, 2003.

   iv. invited to be a *Fellow of the Institute of Physics, London* for a year.

4. **Prof. N. Bhandari** has been elected *Fellow of the Indian National Science Academy*, New Delhi.

5. **Dr. S.V.S. Murty** has been elected *Fellow of the Indian Academy of Sciences*, Bangalore.

6. **Prof. A.K. Singhvi** has been elected *Fellow of the National Academy of Sciences*, Allahabad.

7. **Dr. S. K. Gupta** has been elected a *Fellow of the National Academy of Sciences*, Allahabad.

8. **Prof. S. Krishnaswami** has been invited to be :

   i. a *Member of the Editorial Board* of Proc. Ind. Acad. Sci. (Earth and Planetary Sciences).

   ii. a *Member of the Editorial Board* of Indian Jour. Marine Sciences.

   iii. an officer (Treasurer) of the International Geosphere and Biosphere Programme.

9. **Prof. J.N. Goswami** has been invited to be a *Member of the Advisory Editorial Board* of *Earth and Planetary Science Letters* (Elsevier)

10. *Three* of the eight *optics postcards of the Institute of Physics, Bristol, U. K. for the year 2002* were designed from coloured images off a paper by **J. Banerji** co-authored with R. M. Jenkins and A. R. Davies.

11. **Dr. Vinai K. Rai** has been invited to chair the scientific session *Let there be Ureilites* at the 64th Meteoritical Society Meeting in Rome, September 10 -14, 2001

12. The paper ^{187}*Re* - ^{187}*Os systematics of Black Shales from the Vindhyans: Implications to their Chronology* by **Sunil K. Singh, Santosh K. Rai and J.R. Trivedi,** presented at the 10th ISMS workshop on Mass Spectrometry, held at Puri during February 25 to March 1, 2002, received the *First Prize in the Research Scholar section.*

Papers Published in Journals in 2001 -02

Review Papers

Theoretical Physics

1. V.K.B. Kota,"Embedded Random Matrix Ensembles for Complexity and Chaos in Finite Interacting Particle Systems", *Physics Reports*, **347**, 223-288 (2001)

Planetary Atmospheres and Aeronomy

2. J.E. Penner, M. Andreae, H. Annegran, L. Barrie, J. Feichter, D. Hegg, A. Jayaraman, R. Leaitch, D. Murphy, J. Nganga and G. Pitari, "Aerosols : Their Direct and Indirect Effects", *Climate Change 2001*, 289-348, *IPCC*, Cambridge Univ. Press., (2001).

Earth Sciences and Solar System Studies

3. S. Krishnaswami, "U-Th Series Isotopes in Ocean Profiles", in *Encyclopedia of Ocean Sciences*, Eds. H.H. Steele, K.K. Turekian and S.A. Thorpe, Academic Press, pp.3145-3156 (2001).

4. R. Korisettar and R. Ramesh, "The Indian Monsoon: Roots, Relations and Relevance" in *Archaeology and Interactive Disciplines (Indian Archaeology in Retrospect)* Eds., S. Settar and R. Korisettar, Indian Council for Historical Research Publication, New Delhi, **III**, pp.23-59 (2002).

5. K. W. Glennie and A. K. Singhvi, "Event Stratigraphy, Paleo-environments and Chronology of Southeast Arabian Deserts", *Quaternary Sci. Revs.*, **7**, 853-869 (2002).

6. A. K. Singhvi, A. Bluszcz, M. D. Bateman and M. Someshwar Rao, "Thermo-luminescence and Optically Stimulated Luminescence Dating of Loess-Paleosol Sequences - Methodological Aspects and Paleoclimatic Implications", *Earth Sci. Revs.*, **54**, 193-221 (2001).

Papers Published

Astronomy and Astrophysics AND

7. D.P.K. Banerjee, P. Janardhan and N.M. Ashok, "Near Infra-red and Optical Spectroscopy of Delta Scorpii", *A&A*, **380**, L13-16 (2001).

8. A.Chitre and U.C. Joshi, "H-alpha Emission Line Morphologies in Markarian Starburst Galaxies", *Journal of Astron. Astrophys.*, **22**, 155-172 (2001).

9. R.P. Kane, Hari Om Vats and H.S. Sawant, "Short-term Periodicities in the Time Series of Solar Radio Emissions at Different Solar Altitude", *Solar Physics*, **201**, 181-190, 2001.

10. N.A. Lotova, V.N. Obridko, K.V. Vladimirskii, M.K. Bird and P. Janardhan, "Flow Sources and Formation Laws of Solar Wind Streams", *Solar Physics*, **205**, 149-163, 2002.

11. C. Muthu and B.G. Anandarao, "A Spatio-kinematic Study of the Planetary Nebula NGC 4361 : Evidence for Quadrupolar Flows", *Astron. J.*, **121**, 2106-2114 (2001).

12. H.S. Sawant, K.R. Subramanian, J.H.A. Sobral, C. Faria, F.C.R. Fernandes, J.R. Cecatto, R.R. Rosa, Hari Om Vats, J.A.C.F. Neri, E.M.B. Alonso, F.P.V. Mesquito, V.A. Portezani and A.R.F. Martinon, "Brazilian Solar Spectroscope", *Solar Phys.* **200**, 167-176 (2001.).

13. Ashok K. Singal,"Giant Radio Pulses from Pulsars", *Astrophys. Sp. Sc.* **278**, 61-64 (2001).

14. Hari Om Vats, H. S. Sawant, Rupal Oza, K. N. Iyer and Ravi Jadhav, "Interplanetary Scintillation Observations for the Solar Wind Disappearance Event of May 1999", *J. Geophys. Res.*, **106**, 25121 - 25124 (2001).

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17. D. A. Hooper, H. Chandra and S. Sharma, "Signal processing of Mesospheric echoes from Indian MST Radar" *Proceedings of Fifth User Scientist's*

Workshop, NMRF, ed. By A R Jain, D Narayan Rao and Vijaya Bhaskar Rao, , p 178-181, (2001).

18. A. Jayaraman., "Aerosols and radiation", *Proc. of the First DST-SERC School on Mathematical Modelling of Atmospheric Pollution*, N. Rudraiah et al., eds., SBS Pub., Bangalore, p. 173-201 (2001)

19. S. Sharma and H. Chandra, "Leonid meteor shower and the ionospheric effects over Ahmedabad", *Proceedings of Workshop on Recent developments in atmospheric and space sciences*, Dept. of Physics, University of Roorkee, Roorkee, in CD (2001).

20. S. Sharma, H. Chandra, Y. B. Acharya, A. Jayaraman. and G. Das, "Lidar studies of atmosphere", *Proceeding of Symposium in Hindi on Earth to Space*, ed. By N. Khare and P.C. Pande, Goa, 113-128, (2001).

21. S. Sharma and H. Chandra, "Greenhouse gases and ionosphere" *Proceeding of Inter-center conference in Hindi*, SAC, Ahmedabad, in CD (2002).

Earth Sciences and Solar System Studies

22. N. Bhandari, H.C.Verma, C.Upadhyay, Amita Tripathi and R.P. Tripathi, "Global occurrence of magnetic and superparamagnetic iron phases in cretaceous-Tertiary boundary clays", *Proceedings of Catastrophic Events and Mass Extinction: Impacts and Beyond, Geol. Soc. Am. Special paper,* **356**, 201-211 (2002).

23. S. K. Gupta, "Modelling advection-dispersion process for dual radiotracer dating of groundwater with an example of application to a ^{14}C and ^{36}Cl data set from Central Australia". *In Modelling in Hydrology* (Eds. L. Elango & R. Jayakumar) pp.169-190. Allied Publishers. Workshop in Modelling in Hydrology, Centre for Geoscience and Engineering, Anna University, Chennai, December, 2001.

24. G. Parthasarathy, N. Bhandari, M. Vairamani, A.C. Kunwar and B. Narasaiah, "Natural fullerenes from the K-T boundary layer at Anjar, Kutch, India", *Geological Society of America Special Paper Proceedings of Catastrophic Events and Mass Extinction:Impacts and Beyond, Geol. Soc. Am Special paper,* **356**, 345-350 (2002).

25. A. D. Shukla, N. Bhandari and P. N. Shukla, "The chemical signatures of the Permian-Triassic transitional Environment in Spiti Valley, India", *Proceedings of Catastrophic Events and Mass Extinction:Impacts and Beyond, Geol. Soc. Am Special paper,* **356**, 445-454 (2002).

Theses Submitted during 2001-02

1. **E.A. Kherani**

   "Investigations of Equatorial F-region plasma in stabilities under different background conditions" (2001).

2. **Rajesh Agnihotri**

   Chemical and isotopic studies of sediments from the Arabian sea and the Bay of Bengal (2001).

3. **Rajneesh Bhutani**

   ^{40}Ar-^{39}Ar thermochronological study of the trans-Himalaya in Ladakh sector, India (2001)

4. **Koushik Dutta**

   Study of marine processes in the northern Indian Ocean using radiocarbon (2001).

5. **Kuljeet K. Marhas**

   Isotopic studies of refractory phases in primitive meteorites by an ion-microprobe (2001)

6. **V.K. Rai**

   Nitrogen isotopic systematics in ureilites (2001)

7. **Tarun K. Dalai**

   Major ions, stable isotopes, $^{87}Sr/^{86}Sr$ and Re in the headwaters of the Yamuna: Implications to chemical weathering in the Himalaya (2002)

8. **M.G. Yadava**

   Stable isotope systematics in cave calcites: Implications to past climatic changes in tropical India (2002).

9. **R. Sankaranarayana**

   Studies on time dependent and stationary classically chaotic quantum systems (2002).

Scientific/Technical Reports Submitted

1. **Vishal N. Shah, Vinod Namboodiri, K. P. Subramanian and A. P. Gohil**

   "Remote Controlling of Tektronix DSO by IBM-PC using GPIB Interface", PRL-TN-79-2001.

2. **R. E. Amritkar and D. R. Kulkarni**

   "Application of Chaotic Dynamics to Communications through Synchronization", PRL TN-80-2001.

3. **A. Bhatnagar**

   "Study of Solar Oscillations Phase I, II, III from 1990 to 2001", Report on the INDO-US Collaborative Project.

4. **P. Venkatakrishnan, D. P. Choudhary, A. Ambastha, S. C. Tripathy and N. Srivastava**

   "Metre Aperture Solar Telescope : Proposal for a Modern Ground-based Solar Facility".

5. **S. K. Bhattacharya, R. J. Francey, D. V. Borole, C. E. Allison, P. Steele and Ken Masarie**

   "Isotope aided studies of atmospheric carbon dioxide and other greenhouse gases, Phase II", *Technical Document of International Atomic Energy Agency*, IAEA-TECDOC-1269, 81-89 (2001).

Invited Papers Presented in Symposia/Schools in 2001-02

Astronomy and Astrophysics

1. "Near - Infrared Investigations of Star Forming Regions", *21st Meeting of Astronomical Society of India*, IUCAA, **Pune**, February 5-8, 2002, by **B.G. Anandarao**.

2. "Understanding the Sun-Earth Connection", *XII National Space Science Symposium, Barkatulla University*, **Bhopal**, 25-28 February 2002, by **P. Janardhan**

3. "The Active and Explosive Sun", *UGC Refresher Course in Physics*, ML Sukhadia University, **Udaipur**, October 25, 2001, by **Ashok Ambastha**.

4. "Can Geoeffectiveness of CMEs be Predicted?", at the *21st Annual ASI* meeting held in **Pune** during Feb 5-8, 2002 by **Nandita Srivastava.**

5. "New Insights into Solar Magnetic Activity", at *National Space Science Symposium*, **Bhopal**, February 25-28, 2002 by **P. Venkatakrishnan**.

Theoretical Physics

Astrophysics

6. "Advection Dominated Flows around Rotating Compact Objects", at the *International Conference on General Relativity and Gravitation* (GR16), **Durban**, South Africa, July 2001, by **A.R. Prasanna**.

7. "Electromagnetic Fields on Curved Spacetimes", at the *International Workshop in General Relativity*, **Durban**, South Africa, July 2001, by **A.R. Prasanna**.

8. "Inertial Forces in General Relativity", at the *International Workshop on Mach's Principle and Origin of Inertia*, Indian Institute of Technology, **Kharagpur**, February 6-8, 2002, by **A.R. Prasanna**.

Atomic and Molecular Physics

9. "Analytical Evaluation of Quantum Mechanical Matrix Elements for High Rydberg States", at the *Two-day Symposium on Recent Advances in Mathematical Physics*, Calcutta University, **Kolkata**, March 12-13, 2002, by **D.P. Dewangan**.

10. "Jacobi Polynomial Method for Transition between Rydberg States", at the *International Conference on Current Developments in Atomic, Molecular and Chemical Physics With Applications (CDAMCP)*, Department of Physics and Astrophysics, University of Delhi, **Delhi**, March 20-22, 2002, by **D.P. Dewangan**.

High Energy Physics

11. "CP Violation in Open tt Production at a Linear Collider", at the *4th ACFA Workshop on Physics & Detector at the Linear Collider*, **Beijing**, October 31-November 2, 2001, **S.D. Rindani**.

12. "U(1) Symmetry and R Violation", at the *7th Workshop on High Energy Particle Phenomenology (WHEPP-VII)*, Harish-Chandra Research Institute, **Allahabad**, January 4-15, 2002, by **Rishikesh Vaidya**.

Nonlinear Dynamics & Computational Physics

13. "Neural Networks and Their Applications", four talks at the *Instructional Workshop On Soft Computing with MATLAB* at M. S. University, **Baroda**, January 7-12, 2001, by **D. R. Kulkarni**.

14. "Synchronization of coupled map networks", at the *Conference on Dynamics of Networks and Spatially Extended systems*, held at Saha Institute of Nuclear Physics, **Kolkata**, January 21-23, 2002 by **R. E. Amritkar**.

15. "Chaos and Quantum Entanglement", at *Second Winter School on Quantum Computation and Information*, held at S. N. Bose National Centre for Basic Sciences, **Kolkata**, January 2-11, 2002 by **A. Lakshminarayan.**

Laser Physics and Quantum Optics

16. "Multiparticle Entanglement using Cavities" at the *School on Quantum Physics and Information Pro-*

cessing (QPIP-02), TIFR, **Mumbai,** February 18, 2002, by **G. S. Agarwal.**

17. "Controlling Light by Light - Stoppage, Storage and Superluminal Propagation of Light" at *Golden Jubilee Year* of the Indian Institute of Technology, **Kharagpur,** January 9, 2002, by **G. S. Agarwal.**

18. "Entanglement Non-locality and Non-classical Interference Effects in Radiation from Trapped Atoms" at *2nd International Conference on Foundation of Quantum Theory and Quantum Optics*, S. N. Bose National Centre for Basic Sciences, **Calcutta,** January 3-11, 2002, by **G. S. Agarwal.**

19. **Inaugural address** on "Quantum Entanglement" at *National Laser Symposium*, **Indore** , December 19, 2001, by **G. S. Agarwal.**

20. "Controlling Light by Light - Stoppage, Storage and Superluminal Propagation of Light", at the *67th Annual Meeting of the Indian Academy of Sciences*, **Tirupati,** November 9-11, 2001, by **G. S. Agarwal.**

21. "Heisenberg's Uncertainty Relations and Quantum Optics" at conference *on 100 years of Werner Heisenberg - Works and Impacts,* Bamberg, **Germany,** September 26-30, 2001, by **G. S. Agarwal.**

22. "Traversal of Ultra-Cold Atoms through Vacuum Induced Potentials" at the *7th International Conference on Squeezed States and Uncertainty Relations* (ICSSUR-2001), **Boston, USA,** June 4-8, 2001, by **G. S. Agarwal.**

23. "Freezing and Unfreezing Dynamical Evolution by Co-herent Fields" at the *International Workshop and Seminar on Coherent Evolution in Noisy Environments*, Dresden, **Germany**, , May 21-25, 2001, by **G. S. Agarwal.**

Planetary Atmospheres and Aeronomy

24. "In-situ Measurements of Electron Density and Electric Field Fluctuations over Low Latitudes", at the *National Space Science Symposium,* 25-28 February, 2002, **Bhopal** by **H. S. S. Sinha**

25. "Space Science", at the *International Course on Application of Space Science and Technology for Social Scientists* organized by CSSTEAP and Dept. of Space at Space Applications Centre, December 6, 2001, **Ahmedabad**, by **H. S. S. Sinha.**

26. "Overview of Space Science and Applications", at *6th RS & GIS Course of CSSTEAP*, October 5, 2001, **Dehradun** by **H. S. S. Sinha**

27. "CRABEX", *National Workshop on Recent Developments in Atmospheric and Space Sciences*, University of Roorkee, **Roorkee**, March 19-21, 2001, by **Harish Chandra.**

28. "Space Weather Studies at PRL", *Space Weather Workshop*, Boston College, **Boston**, June 7-8, 2001, by **Harish Chandra.**

29. "Long Term Changes in Ionosphere at Low Latitudes", *10th Quadrenial STP meeting* at Longmont, **Colorado, USA**, June 17-22, 2001, by **Harish Chandra.**

30. "Spread-F at Tropical Latitudes in the Indian and American Longitudes", *SIRI Workshop*, San Jose Dos Campos, SP, **Brazil,** June 25-29, 2001-07-17, by **Harish Chandra.**

31. "Aerosol Radiative Forcing and Climate Feedback" at the *Workshop on Aerosols, Cloud and Climate*, 9-13 July 2001, IISc., **Bangalore by A. Jayaraman.**

32. "Knowledge Gaps in Aerosols and Radiation", *Brainstorming Workshop on INDOEX*, 17-21 September 2001, IIP, **Dehradun**, by **A. Jayaraman.**

33. "Cruise Observations of Aerosol Properties over Indian Ocean" at the *International Symposium on Global Aerosol Climatology Database,* 13-14 October 2001, **Portland, USA**, by **A. Jayaraman.**

34. "What Have We Learnt during INDOEX and the Gap Areas" at *the INDOEX Brainstorming Session*, 12-13 December 2001, Calcutta Univ., **Kolkatta** by **A. Jayaraman.**

35. "Aerosol Radiative Forcing over the INDOEX Region" at the XII *National Space Science symposium*, 25-28 February 2002, Barkatullah Univ., **Bhopal**, by **A. Jayaraman**.

36. "Aerosols and Radiation" (**three** lectures) at the SERC School on *Mathematical Modeling of Air Pollution*, 28-29 May 2001, Bangalore Univ., **Bangalore** by **A. Jayaraman**.

37. "Aerosol Cloud Interaction and Climate Feedback of Aerosols", (**three** lectures) at the *2nd SERC School on Cloud Physics and Atmospheric Electricity*, 7 June - 5 July, 2001, IITM, **Pune** by A. Jayaraman.

38. "Vertical Distributions of Trace Gases in the Upper Troposphere and Lower Stratosphere and their Applications", *8th Scientific Assembly of IAMAS*, Innsbruck, **Austria**, July 2001 by **S. Lal**.

39. "Atmospheric Chemistry- Knowledge Gaps", *INDOEX Workshop*, **Dehradun**, 18-21 September. 2001 by **S. Lal**.

40. "Composition, Structure and Dynamics of the Atmosphere" (**3 lectures**), *First SERC School on Mathematical Modelling of Atmospheric Pollution*, held at Bangalore university, **Bangalore**, May 15-16, 2001 by **S. Lal**.

41. "Trace Gases and Gas to Particles Conversion Processes" (**2 lectures**), *Second SERC School on Cloude Physics and Atmospheric Electricity-Frontiers*, Indian, Institute of Tropical Meteorology, **Pune**, 11-12 June, 2001 by **S. Lal**.

42. "General Structure and Properties of the Atmosphere and Stratospheric Ozone" (**2 lectures**), *Refresher Course in Environmental Science and Engineering* at Guru Jambheshwar University, **Hisar**, 2-3 November, 2001 by **S. Lal**.

43. "Structure of the Earth's Atmosphere and Trace Gases" (**2 lectures**), *Refresher Course in Physics at Mohan Lal Sukhadia University*, **Udaipur**, 1-2 Nov., 2001 by **S. Lal**.

44. "Trace Gases, Ozone Depletion and Global Warming" (**3 lectures**), *Centre for Space Science and Technology Education in Asia and the Pacific region (CSSTE-AP)* affiliated to the United Nations, IIRS, **Dehradun**, April 2-3, 2002 by **S. Lal**.

45. "Solar Wind Absorption into Martian Atmosphere", in *XII National Space Science Symposium*, **Bhopal**, February 25-28, 2002 by S.**A. Haider**.

46. "Upper Atmosphere Electrodynamics", in *Third winter school on MST radar* at **Tirupati** 2001 by **R.Sekar**.

47. "Plasma Instability Models in the Equatorial F Region of the Ionosphere" in *16th National Symposium on Plasma Science & Technology* at **Guwahati** , December 2001 by **R.Sekar**.

Earth Sciences and Solar System Studies

48. "Mystery of the Origin of the Moon" at Astronomical Society of India meeting, **Pune**, February 5, 2002, by **N. Bhandari**.

49. "Heavy Nitrogen and Nucleogenic Kr and Xe in Itawa Bhopji Chondrite" at 64th Meteoritical Society Meeting, Rome, Italy, Sept . 10-14, 2001, by **S.V.S. Murty**.

50. "Noble Gases in Individual Chondrules of Dhajala: A Laser Microprobe Study" at 64th Meteoritical Society Meeting, **Rome**, Italy, Sept. 10-14, 2001, by **S.V.S. Murty**.

51. "Solar System Research at PRL" at Refresher Course to College Teachers of Gujarat, S.P. University, **Vallabh Vidyanagar**, Jan. 1-15, 2002, by **S.V.S. Murty**.

52. "Current Trends in Solar System Research" at National Space Science Symposium-2002, Bhopal, Feb.25-28, 2002, by **S.V.S. Murty**.

53. "Past Monsoon Variations over Peninsular India Deciphered using Margin Sediments from the Eastern Arabian Sea: Role of AMS ^{14}C dating",

10th ISMAS Workshop, Thoshali Sands, **Puri**, Feb 25-Mar 1, 2002, by **B. L. K. Somayajulu.**

54. "Quantitative Reconstruction of Paleomonsoon from Cave Calcites", "12th *Mid-year Meeting of the Indian Academy of Sciences*, **Bangalore**, July 7, 2001 by **R.Ramesh**.

55. "Application of stable carbon and nitrogen isotopes in climate studies" at the Agricultural University, **Bangalore**, March 9, 2002 by **R.Ramesh**.

56. "Stable isotopes as tools in paleoclimatic research," *PAGES Workshop*, IITM, **Pune**, May 2001 by **R. Ramesh**

57. "Nuclear and Chemical Dating Techniques: Interpreting the Environmental Records", *PAGES Training Workshop on Paleoclimatic Methods*, IITM, **Pune**, May 14 - 19, 2001, by **M.M. Sarin**.

58. "Sediment Trap and ^{234}Th methods for Carbon Export Flux Determination" *SCOR Working Group (No. 116) Meeting*, July 8 - 10, 2001, **Amsterdam, The Netherlands**, by **M.M. Sarin**.

59. "Chemical & Isotopic Characterization of Aerosols", *Aerosol, Clouds & Climate Workshop*, July 10 - 13, 2001, IISc., **Bangalore**, by **M.M. Sarin**.

60. "Carbon and Nutrient Fluxes in Marginal Seas and Tropical Coastal Zones", *Continental Margin Task Team (CMTT) Workshop*, September 27 - 29, 2001, **Taipei, Taiwan**, by **M.M. Sarin**.

61. "Past 150000 years of Thar Desert", **Review talk** at the 150th year celebration of GSI during the *Symposium on the Role of Earth Sciences in Integrated Development and Related Societal Issues*, November 1-3, 2001, **Lucknow**, by **A.K. Singhvi**.

62. **Invited** training course lecture on "Luminescence Dating: Principles, Applications and Prognostics", *International Conference on Global Correlation of Late Cenozoic Fluvial Sequences*, December 2001, IIT, **Kanpur**, by **A.K. Singhvi**.

63. "Terrestrial and Marine Records of Climatic change in India", *International Seminar on Austral-Asian Pole-Equator-Pole transect,*. November 2001, **Singapore**, by **A.K. Singhvi**.

64. "Ca-K and Al-Mg studies of CAIs from CH and CR chondrite" at 64th Meteoritical Society Meeting, **Rome**, Italy, September 10-14, 2001, by **G. Srinivasan**.

Lectures given at Workshop on

Meteorites, Asteroids and Planets

Dec. 15-21, 2001, at Mt. Abu, PRL,

organised by Indian Space Research Organisation.

Name	No. of Lectures	Topics
J.N. Goswami	4	Extinct nuclides records in solar system objects, Planets of other/extra solar system, Nucleo synthesis processes, Laboratory studies of Planetary material.
N. Bhandari	3	Origin of the Solar System, Remote sensing of planets, Planetary Science Exploration - Indian perspective
S.V.S. Murty	3	Cosmic Ray effects on solar system objects, Study of Inner Planets, Atmospheres of terrestrial planets
G. Srinivasan	3	Kuipers belt objects, Heat sources for planets and Asteroids, Meteorites and Early Solar System
P.N. Shukla	2	Evolution of Moon, Trace elemental studies
J.R. Trivedi	2	Evolution of life in the universe, Radiogenic Isotopes used to understand Planetary Processes
A. Ambastha	2	Structure of the Sun and Structure and Dynamics of the solar corona
T. Chandrasekar	2	Observational Aspects of Asteroids, Observations of Outer Planets and their Satellites
N.M. Ashok	2	Minor Objects in the Solar System, Origin and Evolution of Comets
Kanchan Pande	1	Dynamic planets
H. Dave	1	High Resolution Spectroscopy for Planetary wind & Composition Measurements
H. Chandra	1	Lidar Probing of Upper Atmosphere
S. A. Haider	1	Role of Solar Wind on Mars.

Science at PRL

Complex Kinematic Features in the Planetary Nebula NGC 1514 with a Binary Central Star

The Planetary Nebula NGC 1514 presents a complex morphology with a suspected close binary central star. Our spatio - kinematic observations of this nebula in the [OIII] 5007 Å line using the Imaging Fabry-Perot Spectrometer at Mt. Abu, revealed complex kinematic features. Our results indicate that the nebula has two bright blobs along the polar axis embedded within an elliptical outer shell. The initial mass of the progenitor that had a common envelope phase is estimated to be ~ $3.5M_{\odot}$. The binary period is derived to be 14-20 days.

(C. Muthu and B.G. Anandarao)

Near Infrared Spectroscopy of AGB and Post-AGB Stars

Asymptotic Giant Branch (AGB) stars are intermediate mass stars evolving towards the planetary nebula stage having exhausted their core helium. Using the NICMOS-3 spectrograph on the 1.2 m telescope at Mt. Abu, a number of AGB/Post-AGB stars were observed in the J, H, K bands. A majority of the stars showed CO first overtone bands $\Delta v = 2$ in the K band and second overtone bands $\Delta v = 3$ in the H band. A study is being made of these spectral features to relate them to the evolution of the AGB stars.

(A. Trivedi and B.G. Anandarao)

Near Infrared Study of Star Forming Regions

As a part of the on-going study of Star Forming Regions in the near-infrared, photometric observations were carried out on a few selected massive protostellar candidates identified by IRAS. Color-color and color-magnitude maps are being made using the NICMOS-3 observations at Mt. Abu as well as the archival 2MASS data. In addition, narrow band imaging of the sources is being made in spectral emission lines such as HI Br γ and H_2 (v=1-0 S(1)) lines. In the massive protostar IRAS 02230+6202 our narrow band imaging clearly brings out the morphology of the compact HII region created by the central massive star (**Fig. 1.1**). The spectral type of this Zero Age Main Sequence star is O7-O8. The age of the HII region is determined to be ~ 2×10^5 years which matches with this. A part of this program is being carried out in collaboration with TIFR.

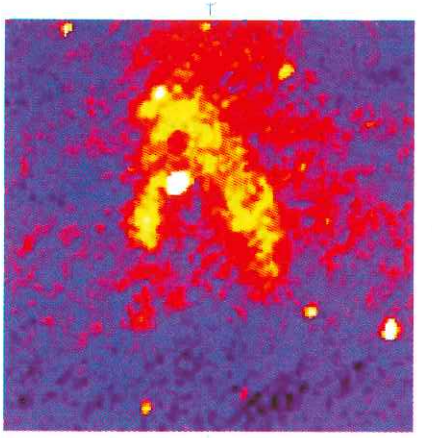


Fig. 1.1 Br γ filtergram image of the YSO IRAS 02230+6202 in the W3 star forming region. The HII region can be seen clearly around the central O7 type Zero-Age Mainsequence star.

(S. Mishra and B.G. Anandarao)

Optical Polarimetry and Near-IR Imaging of Comet C/Linear (2000WM1)

Study of comets is becoming increasingly important with new findings that comets contain grains typical of those found in interstellar space. We performed optical polarimetry and near IR imaging on the recent apparition of Comet C/Linear (2000WM1) from Mt Abu. Optical polarimetry was done in several broad and narrow bands at several phase angle from 14° – 22° during November. 23-26, 2001 and March 16-18, 2002 (phase angle ~ 47°). The polarimetric data on comets is very meager for the low phase angles (0 - 22°), where the polarization becomes negative. The change over to positive polarization takes place at a phase value around 20° - 25° which is sensitive to the nature of grains. Near-IR imaging observations were done during November, 2001 and March 2002 using the NICMOS-3 array (J, H & K bands). The imaging observations of Comet Linear 2001 provide important information on the various structures in the coma of the comet, e.g. jets, filaments.

(U.C. Joshi, K.S. Baliyan and S. Ganesh)

Study of Galactic Young Star Clusters Associated with Molecular Clouds

Young open clusters provide interesting clues to the knowledge of the early stages of stellar evolution. Most of these clusters are still embedded in dust and molecular gas in which the process of star formation is going on. We have been observing a number of such young clusters using NICMOS-3 camera mounted on the 1.2 m Mt. Abu telescope. (i) The central region of Milky Way contains a large number of massive molecular clouds and has been surveyed by ISO (7 and 15 μ m) and DENIS (I, J, K μ bands). However, not only is the DENIS survey poorer in resolution, it does not have information in the wavelength region intermediate to J and K. Therefore, to complement the DENIS observations we surveyed with higher resolution, a region of 27' x 40' in the molecular cloud M16, including the young cluster NGC 6611 in J and H bands. The color-magnitude diagram of the field **(Fig. 1.2)** indicates two populations of stars in this region - those in front of the cloud of dust and gas and those behind or embedded in the cloud. The second population can provide information on the intra-cluster extinction. (ii) Near IR photometry of the young cluster, NGC 1960, reveals populations of highly reddened stars and stars with normal reddening indicating that some of the cluster members are in the foreground to the partially embedded cluster. A distance of 1584 pc is estimated for the cluster. This work is done in collaboration with Osmania University.

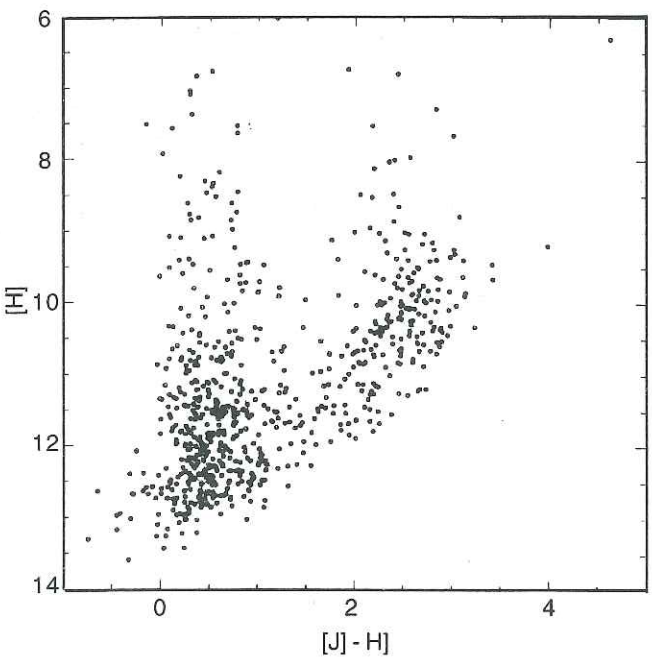


Fig. 1.2 : Colour-magnitude diagram for NGC 6611 in the M16 field observed from Mt Abu using NICMOS-3 IR Array. Two populations of the stars in field are clearly seen- foreground stars and those with higher extinction.

(U.C. Joshi, K.S. Baliyan and S. Ganesh)

Variability in Blazars

As a long term program, we continue to monitor a sample of blazars using near infrared camera, NICMOS-3. Knowledge of the variability at various time scales and different wavelengths helps in understanding the physical mechanisms responsible for the energy generation. The observations in near IR show that OJ287, which was in quiescent phase, is showing increased activity presently. Other blazars monitored are Mrk 421, Mrk 501, BL Lac, 3C273, 3C279, 3C66a etc. Some of these objects are also monitored for the variation in optical linear polarization using a a photo-polarimeter. Study of Mrk 421 revealed unusually high polarization of more than 10% in B band – a finding which is confirmed by other observations elsewhere.

(K.S. Baliyan, U.C. Joshi and S. Ganesh)

Near Infrared Spectroscopy of Nova Sagittarii 2001 (V4643 Sgr)

Near-infrared spectra of the very fast He/N type nova, Nova Sagittarii 2001 (V4643 Sgr) were obtained in the early decline phase and the period 110 to 170 days after the discovery date. The spectrum in the early decline phase is dominated by emission lines of hydrogen and accompanied by fluorescence excited OI line at 1.129 μ m. These emission lines have broad symmetric emission wings with full width at zero intensity (FWZI) corresponding to velocity of ~ 10,000 kms^{-1}. About 120 days after discovery, the K band spectrum obtained using the UKIRT, is dominated by emission lines due to Si VI and Si VII at 1.963 μm and 2.476 μm indicating

that the nova had entered the coronal phase. The line ratios of Brackett series deviate substantially from Case B values indicating optical depth effects. This work is done in collaboration with Joint Astronomy Centre, Hawaii, U.S.A.

(N.M. Ashok and D.P.K. Banerjee)

Substellar Mass Functions of Young Open Clusters : A Statistical Approach

The Initial Mass Function (IMF) of stars is one of the most fundamental and crucial ingredients in models of galaxy formation and stellar evolution. While the IMF is well determined by the Saltpeter function for stars in the mass range 1-10 $M_\odot$, it is poorly known for objects with masses below 0.5 $M_\odot$. In this investigation we have derived mass functions in three young open clusters IC 348, α Orionis and Pleiades, using the 2MASS data (with a limiting magnitude of K_s ~ 15) and the Guide Star Catalog (with limiting magnitude R ~ 21). Based on recent evolutionary models for low mass stars, selection criteria for masses below 0.5 $M_\odot$ have been formulated. Using a statistical approach to determine cluster membership, mass functions have been derived from 0.5 $M_\odot$ to 0.025 $M_\odot$. The resultant slopes of the mass functions are 0.8, 1.2 and 0.5 for IC 348, σ Orionis and Pleiades respectively – significantly different from the Saltpeter canonical value of 2.35. The results show that low mass objects are at least as numerous as their higher mass counterparts in clusters. The contribution of objects below 0.5 $M_\odot$ to the total mass of the cluster is ~ 40% and the contribution of objects below 0.08 $M_\odot$ is only ~ 4%. This work was carried out in collaboration with Space Telescope Science Institute, Baltimore, USA.

(A. Tej, T. Chandrasekhar and N.M. Ashok)

Total Solar Eclipse 2001 from Lusaka, Zambia– Fabry-Perot Interferometric Observations of the Green Coronal Line at λ 5303 Å

A scientific expedition to Southern Africa was successfully undertaken to study the Solar Corona during the total solar eclipse of 21 June 2001 from Lusaka, Zambia. During totality lasting 194 seconds, a Fabry-Perot Interferometric experiment in the green coronal line at λ 5303 Å [FeXIV] was successfully carried out. As many as 17 interferograms with exposures ranging from 2 to 30 seconds were recorded on a 1024 x 1024 pixel, thermoelectrically cooled CCD camera. Fabry-Perot fringes of the green line extend well beyond 1.5 $R_\odot$. Line profiles at various positions in the corona are being derived. Inter-comparison between the interferograms is also being made for temporal variations. A line profile derived from the interferogram at a specific position (1.062 $R_\odot$ and azimuth 129°.2 (NESW)) is also shown (**Fig. 1.3**). The data fits well with a coronal temperature of 2.5 x 10^6 K. A large number of such profiles can be derived from the interferograms thereby providing a detailed picture of temperature and velocity structure of the emission corona with implications for various coronal heating mechanisms under conditions of peak solar activity.

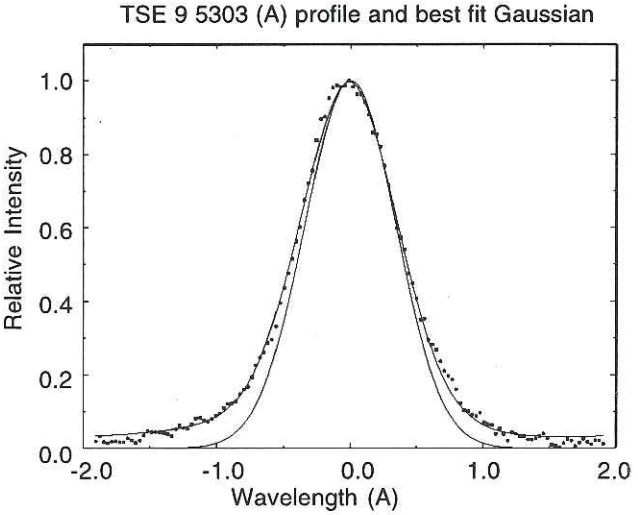


Fig. 1.3 : Profile of [Fe XIV] line in the solar corona at a specific position at 1.062 $R_\odot$ and Position Angle 129°.2. The line width indicates a coronal temperature of 2.5 x 10^6 K.

(T. Chandrasekhar, N.M. Ashok, B. G. Anandarao and F. M. Pathan)

Dust Shells around Wolf-Rayet Star R104: Lunar Occultation Observations at 2.2 μm

A rare opportunity of observing the lunar occultation of a Wolf-Rayet Star (WR104) from Gurushikhar Observatory presented itself in May 2001. The thick circumstellar dust shell around the star was studied at a

wavelength of 2.2μ m and at a high angular resolution of ~ 2 milliarcseconds. Analysis of the occultation light curve shows clear structures in the dust shell departing from the uniform disk profile. We have compared our observations with recent aperture masking interferometry on WR104 carried out at the 10m Keck I telescope and find our results are in good agreement. Due to the superior but one dimensional resolution of the lunar occultation technique compared to the Keck resolution of 50 mas, we are able to recover additional fine structures in the dust shell. Further, in comparison with earlier Keck images it appears that no large scale changes in the pinwheel shaped dust structure are taking place over time scales of a few years.

(S. Mondal and T. Chandrasekhar)

Near IR and Optical Spectroscopy of δ Scorpii

The star Delta Scorpii has been considered to be a typical B0.3IV star for many years. It has not shown emission lines in its spectrum in the past except for weak Hα emission once in 1993. During June 2000, a sudden brightening was reported in the object accompanied by strong Hα emission. These sudden changes coincided with the periastron passage of δ Sco around its known binary companion indicating that mass loss has taken place and led to the formation of a Be star envelope around δ Sco. Formation of a Be star due to binarity effects is rare and therefore δ Sco provides a good opportunity to see how such systems behave and evolve. Thus spectroscopic observations in the near IR and optical wavelengths were made at a few epochs after periastron passage. The spectra were found to be dominated by the HI Paschen and Brackett series emission lines. These line intensities deviate significantly from Case B predictions indicating optical depth effects. The IR excess in the star was modeled and found to be attributable to free-free emission from a circumstellar shell (**Fig. 1.4**).

(D.P.K. Banerjee, P. Janardhan and N.M. Ashok)

Giant Pulses from Pulsars

Giant pulses from a normal-period pulsar (PSR B0950+080) for the first time were found with the Rajkot Radio Telescope at 103 MHz. The only other two pulsars

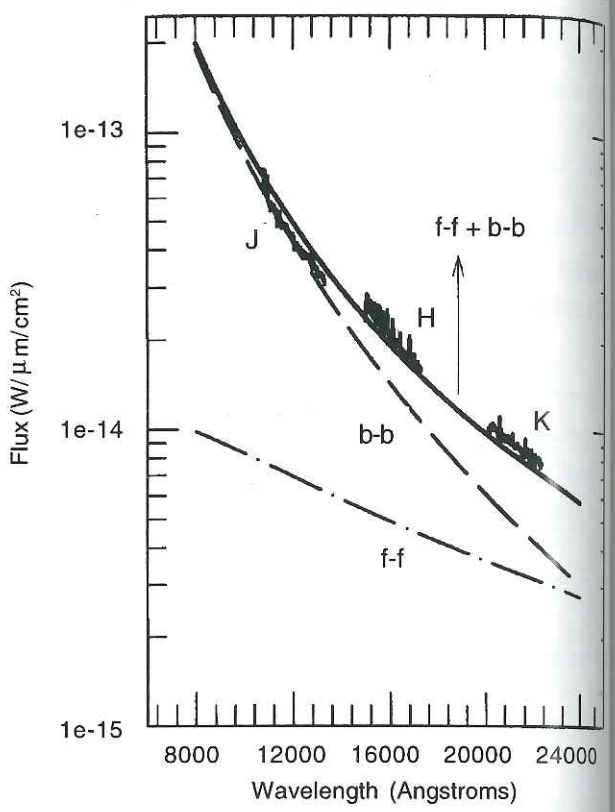


Fig. 1.4: Infrared spectra (in J, H, K bands) from the newly detected binary Be star δ Scorpii. The continuum radiation is shown to fit a combined spectrum of a blackbody and free-free emission.

known to emit giant pulses, namely Crab pulsar and PSR B1937+21, are both relatively fast-period pulsars. In both these pulsars, the cumulative distributions of the giant pulse intensity, S, have been shown to follow a power law $N(>S) \mu S^{\alpha}$. The cumulative distribution of giant pulses from PSR B0950+08 has also been now examined. The power-law fits to the observed distributions, yield the best-fit values for the index α to be in a tight range around -2.2. This is quite similar to those found in the case of Crab pulsar (α = -2.3) and PSR B1937+21 (α = -1.8). In the literature it has been suggested that the giant-pulse emission phenomenon may have something to do with the strength of the magnetic field at the light cylinder radius B_{lc}. But, for PSR B0950+08, we find B_{lc} to be only ~ 150 Gauss while the Crab pulsar and PSR B1937+21 yield rather high values of $B_{lc} \sim 10^6$ G. This almost rules out the hypothesis that the giant pulse

emission physics is in particular dependent on B_{lc}. It also shows that giant pulses are not associated with fast pulsars alone.

(A. K. Singal and Hari Om Vats)

Study of Solar Rotation

Using radio emission probes we have made the discovery of differential rotation as a function of height in the solar corona. Recently we extended this method to chromospheric Lyman α emission whose measurements are available over several years from 1947 – 1999. Auto and cross-correlation analysis is used for this. We found that the rotational modulation is highly variable. In several years it is very high up to 60% and in some others the evidence of rotational modulation is negligible. The rotational modulation shows evidence of longer period (> 100 years) in Lyman α which is not so evident from sunspot numbers. The cross-correlation coefficient of the sunspot number and solar Lyman α irradiance has a peak positive value of 0.12 at a lag of 5 years and a peak negative value of -0.18 at a lag of -1 year. Thus rotational modulation is highly variable and seems to be almost independent of the phase solar activity cycle. The synodic rotation period is also found to be variable with maximum as much as ~ 32 days. This work is done in collaboration with Saurashtra University, Rajkot and INPE, Brazil.

(Hari Om Vats)

Space Weather Studies

Using IPS observations at 103 MHz made at Rajkot, we have investigated a few earth-directed CME's (coronal mass ejection) events with a view to understand the solar-terrestrial relationship. We also used the satellite data (ACE) of solar plasma parameters. As seen in SOHO/LASCO images a halo CME with a bright front began on April 04, 2000 at about 1632 UT. This appeared to be associated with a C9 flare in AR 8933. With IPS observations, we detected the effect of this CME in the line of sight of 3C459 two days later and in the line of sight of 3C2, 3C119 and 3C122 three days later. In the line of sight of 3C48 there appeared a very feeble or no effect of the passage of this CME. This could be due to the projection effect of the CME or along that direction the interplanetary disturbance associated with the CME is absent. The CME produced a shock which was detected by ACE solar wind velocity measurement (the radial velocity increased from 375 km s^{-1} to 575 km s^{-1} at 16 UT on April 6, 2000). This shock led to a very large drop (~ 300 nT) in equatorial Dst and produced one of the largest geomagnetic storms of this century. This work is done in collaboration with Saurashtra University, Rajkot.

(Hari Om Vats)

Flow Sources and Formation Laws of Solar Wind Streams

The large-scale stream structure of the solar wind flow was studied in the main acceleration zone from 10-40 $R_{\odot}$. Three independent sets of experimental data were used (a) radio observations of scattering using the large telescopes of the Lebedev Physical Institute, (b) Dual frequency Doppler solar wind speed measurements from the Ulysses Solar Corona Experiment and (c) Solar magnetic field strengths and configuration computed from the Wilcox Solar Observatory data. The position of the transonic region of the solar wind flow and solar wind speed estimates were used as parameters reflecting the solar wind acceleration process. Correlation studies of these data with the magnetic field strength in the solar corona revealed several types of solar wind flow differing in their velocities and location of their primary acceleration region. This work was carried out with collaborators at the Radioastronomisches Institut, Universitat Bonn, Germany and the Lebedev Physical Institute, Moscow, Russia.

(P. Janardhan)

Subsidence of Solar Wind over a Large Part of the Inner Heliosphere Monitored by IPS during 3 - 16 May 1999

Extensive Interplanetary scintillation (IPS) observations of the solar wind were carried out during the period centred around May 11, 1999 when the earth was engulfed by a region of solar wind with unusually low densities (< 1 cm^{-3}) and velocities (< 350 km s^{-1}). One consequence of this extremely tenuous solar wind was

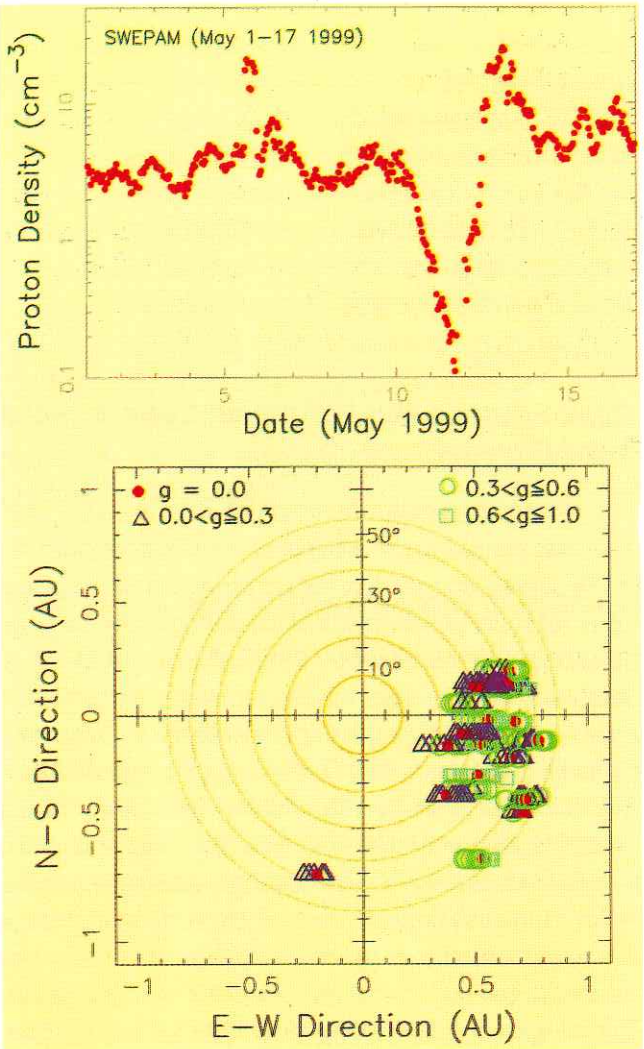


Fig. 1.5 The subsidence of solar wind parameters : satellite-measured proton density (top figure) and Ooty-IPS observations of scintillation index (g) (bottom-figure).

a spectacular expansion of the earth's magnetosphere and bow shock. The expanding bow shock, extended beyond the lunar orbit and was observed by several space craft as it reached record upstream distances beyond 60 earth radii. Using IPS observations with the Ooty Radio Telescope (ORT), operating at 327 MHz, the southern half of the inner heliosphere was monitored everyday between 3 and 16 May 1999. The data show that the solar wind densities and velocities were globally subdued, since May 3, 1999 itself at different parts of the heliosphere. The IPS data also reveal a small subset of closely spaced sources lying to the west of the sun that show a steep drop in g-values to immeasurably low amounts on and around the 11th May. The actual morphology of the subsidence event, as inferred by IPS observations, is shown to be that of a "void-within-a-void" (**Fig. 1.5**). To the best of our knowledge this is the first time that sustained levels of low densities and velocities have been recorded for such a long period over a large part of the inner heliosphere. This work was carried out in collaboration with TIFR Radio Astronomy Centre, Ooty and NCRA, Pune, India.

(P. Janardhan)

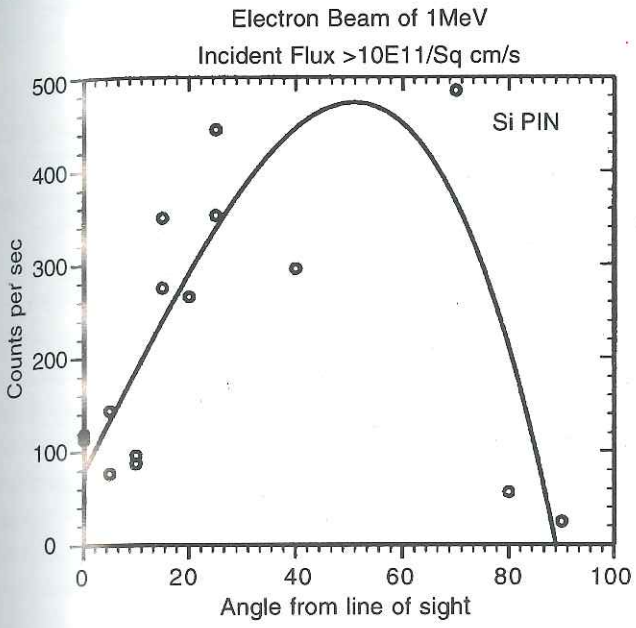
Submillimeter Science And Technology Program

The construction of the Submillimeter wave laboratory facility at PRL is completed. We have begun the design and construction of a heterodyne receiver system. Typical heterodyne receiver system for a high-resolution astronomical observation consists of a stable local oscillator, a mixer device and IF signal processor. A step tunable optically pumped laser local oscillator has been installed successfully. Typical output of the pump laser in the mid-IR (λ = 9-11 μ m) is between 10-50 watts. We have achieved more than 30 milliwatts of power at 96.5 μ m, 118.8 μ m, and 163.0 μ m wavelengths. Currently, laser is being optimized for longer wavelengths.

A room temperature Schottky Barrier diode mixer has been optimized for the heterodyne operation. For high sensitivity SIS mixer and Hot Electron Bolometer (HEB) devices are being considered.

Traditionally, two kinds of Spectrometers have been used for IF signal analysis in receiver system, Acousto-Optic Spectrometer and Filter bank Spectrometer. However, for eventual space payload we have chosen a state-of-the-art Chirp Transform Spectrometer (CTS) capable of giving 45 KHz resolution and 180 MHz processing bandwidth with 4096 channels. Preliminary design review is underway.

(Hemant Dave, Jayesh Pabari, Ravindra Singh, and Vinay Chaudhari)



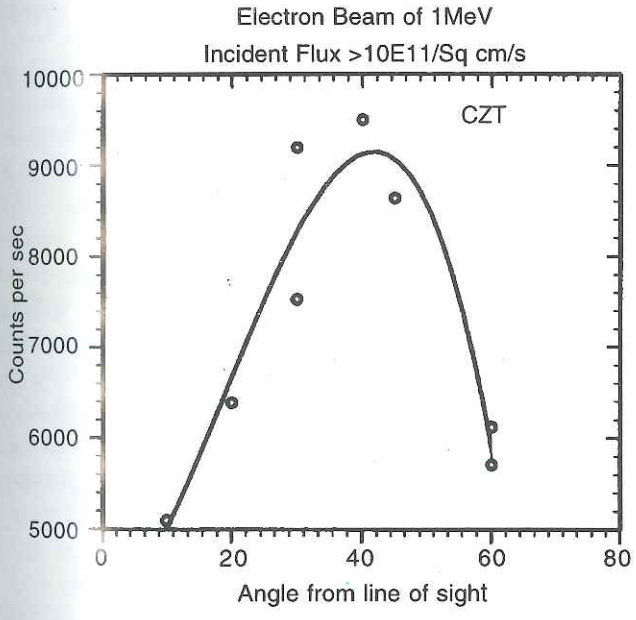


Fig. 1.6 Observed X-ray photon counts produced by collision of 1 MeV electrons while passing through the collimator of the Si PIN (a) and CZT (b) detectors of SLD/Solar X-ray Spectrometer payload. The x-axis is angle from the line-of-sight of the incidence of electron beam of Microtron, while y-axis is counts/s indicating the number of electrons that produced bremsstrahlung out of incident flux of 10^{11} electrons/cm²/s

Solar X-ray Spectrometer–Bremsstrahlung Study

As the SLD payloads, which comprises of Si PIN and CZT detectors, will be mounted on the Anti-Earth view deck of the geosynchronous satellite GSAT-2, it will be bombarded by a very high flux of charged particles. This may cause not only high background noise through bremsstrahlung process but also permanent damage to the detectors. To circumvent this problem , we restrict the field-of-view of our detectors to 3.4° with the aid of specially designed collimators. However, to study the total noise in the detectors generated by direct entry of electrons / protons in the line-of-sight through FOV, and due to bremsstrahlung produced by collision of electrons with collimators, we conducted experiment at Microtron facility at Pune University. The experiment was conducted for 1 MeV electrons with a flux of ~10^{11} electrons/cm²/s on each detector – Si PIN and CZT. The observations were made as a function of angle from the line-of-sight of incident beam of electrons to simulate total bremsstrahlung in 4π space. Shown in **Fig. 1.6 (a, b)** is observed total counts/s in all 256 channels of the spectrum as a function of angle of incidence of electron beam on the detector. It may be noted that bremsstrahlung is extremely high from the electrons impinging on the detector at an angle between 30 and 50°. It may also be observed that CZT detector shows higher bremsstrahlung than Si PIN detector. This is because CZT detector's wafer has area of 0.25 sq. cm and thickness 2 mm in contrast to Si PIN wafer's dimensions of 0.13 sq. cm and 0.3 mm respectively. However, the observed integrated flux of electrons of ≥1 MeV in the geosynchronous orbit is ~ 4.7 X10^5 electrons/cm²/s, almost 6 order less than the flux with which the experiment conducted by us. Thus the expected bremsstrahlung should be insignificant.

We have estimated the background noise expected from bremsstrahlung caused by electrons and protons in the geosynchronous orbit of energy 250 keV. The integrated flux at 250 keV in the geosynchronous orbit is estimated of the order of 7.6 x10^5/cm²/s/steradian. The noise generated by the charged particles entering directly in the line-of-sight in FOV of 3.4° is estimated to be of

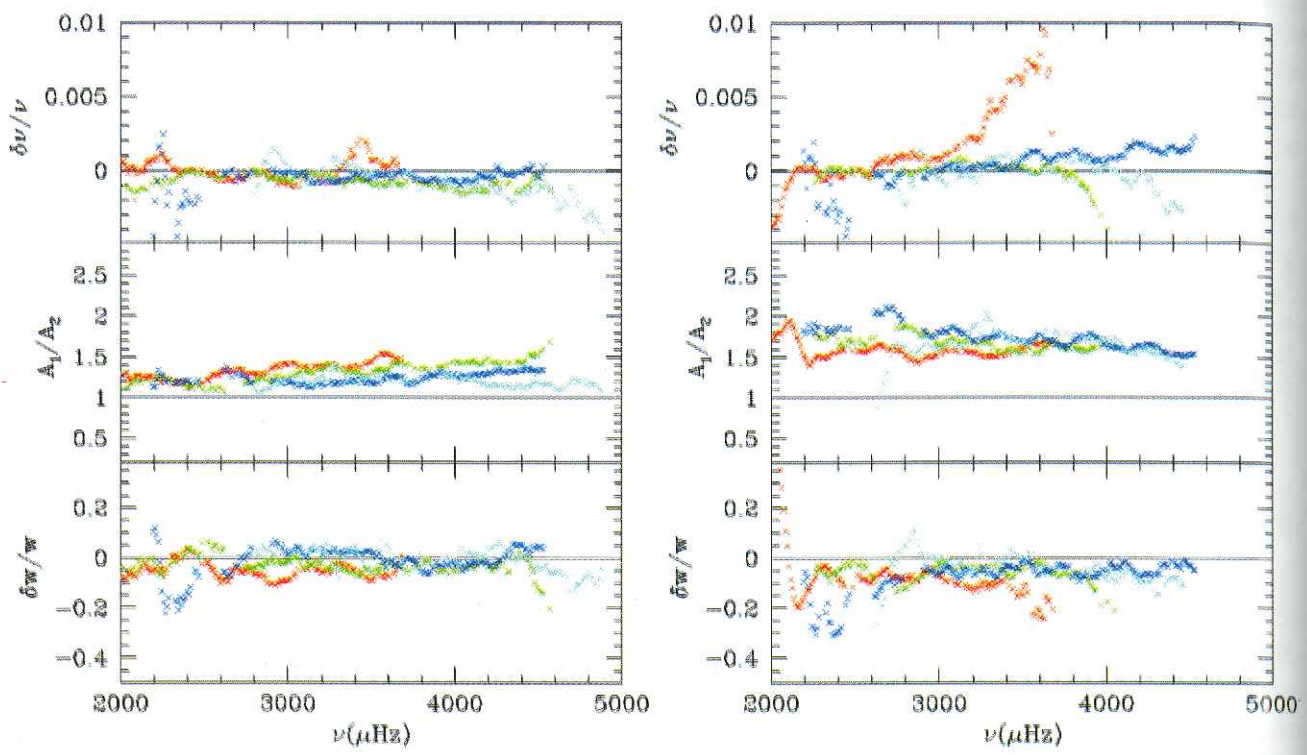


Fig. 1.7 The relative difference in mode characteristics, viz., frequencies, and widths as well as ratio of peak power for the active region NOAA9393 when it is away from the central meridian. The left and right panels respectively show the difference between corresponding preflare and postflare regions. The red, green, blue and cyan points show the modes with n=0,1,2,3 respectively.

the order of 250 and 600 counts/s in Si and CZT detectors respectively. However, noise generated through collimators would be about 50 and 400 counts/s, which gives total noise in Si and CZT detectors of about 300 and 1000 counts/s respectively, while both the detectors are designed to handle ~ 45000 counts/s, hence the background noise would be insignificant.

(Rajmal Jain and Hemant Dave)

Solar Physics at Udaipur Solar Observatory

Effect of Flares on Solar Oscillation Characteristics

There have been some observations elsewhere, suggesting that some large flares may excite waves on the solar surface. In order to study the effect of flares on solar oscillation modes we use the well known ring diagram technique applied to 3D spectra from GONG+ and MDI instruments. To study the effect of flares, we have chosen 3 active regions (NOAA9026, NOAA9393 and NOAA9415) which caused flares when they were close to the central meridian. We use ring diagram spectra obtained before, during and after the flares to study if there is any variation in mode characteristics such as frequency, width, power and asymmetry (**Fig. 1.7**). The data taken around the flares of June 6-7, 2000; March 29, 2001 and April 10--11, 2001 are studied. We find that during some flares, the power in acoustic modes increases beyond the normal values expected from the influence of magnetic field. This work was done in collaboration with Sarbani Basu (Yale University, U. S. A.), and H. M. Antia (TIFR, Mumbai).

(Ashok Ambastha)

Solar Cycle Changes in Mode Frequencies from 1995-2001

The time evolution of centroid frequencies of solar oscillations is analysed for a period of 6 years using data sets from GONG and MDI projects. The shift in f-mode frequencies is found to be smaller than that observed for p-modes and less correlated with solar activity. It is found that frequency shift can be decomposed into two components: an oscillatory part which have a one year periodicity and a smooth or non-oscillatory part which increases sharply with rising activity. The validity of previously derived empirical relations for p-modes is tested for the period 1995-2001 and the calculated frequency shifts were found to agree well with the observed shifts except around the maximum phase of the solar cycle. On the other hand, the width and amplitude of individual modes were found not to have significant correlation with the solar activity.

(Kiran Jain, S..C. Tripathy and A. Bhatnagar)

Variation of Solar p-mode Frequencies on Short Time Scales of 18 and 27 Days

The temporal changes associated with intermediate degree mode frequencies and splitting coefficients derived from time series spanning less than a month are investigated. We find that the p modes adjust to changes in the activity measures on time scales as short as 18 days and are well correlated with the activity indices. The surface rotation rate derived from the odd order coefficients agrees reasonably well with other helio-seismic and Doppler measurements. This work was done in collaboration with Frank Hill.

(S.C. Tripathy, Kiran Jain and A. Bhatnagar)

Determination of Fried's Parameter

A few methods of estimating Fried's parameter (r_0) from specklegrams of solar features were attempted. The speckle data obtained from Kodaikanal Observatory (KO), Uttar Pradesh State Observatory (UPSO) and Udaipur Solar Observatory (USO) were used. The average value of r_0 was found to be approximately 3 cm at USO and UPSO during our observations. At KO, the values of r_0 ranging from 6 to 10 cm were estimated. This work was done in collaboration with R. Sridharan and V.K. Verma.

(P. Venkatakrishnan)

On Magnetic Flux Imbalance in Solar Active Regions

The magnetic flux imbalance of active regions has been studied using the longitudinal magnetograms obtained from National Solar Observatory, Kitt Peak. The maximum and the median value of the flux imbalance in 137 active regions situated near the disk centre are found to be about 62% and 9.5% respectively. The detailed analysis of a few selected active regions shows that the local flux asymmetry is compensated on global scales. For example, the active region NOAA 7978, which appeared during the solar activity minimum period and evolved during five solar rotations (July - October, 1996), shows a flux imbalance of about 9.5% with an excess of following negative flux. However, on a global scale, the positive and negative flux in the entire solar disk was found to be nearly balanced during the same period. The global flux imbalance of the sun, during a full magnetic cycle, is estimated from the Carrington maps. These maps are made by merging the solar images obtained during a complete solar rotation (about 27 days), hence represents the entire surface of the sun. The 10° - ~40° active latitudinal zone in the individual hemispheres during the solar maximum shows flux imbalance of more than 20%. This is reduced to below 10% when the entire sun is considered. The present study indicates that a fraction of the magnetic field from the localized active regions connects with far away locations.

(Debi Prasad Choudhary, P. Venkatakrishnan and Sanjay Gosain)

Total Solar Eclipse 2001 from Lusaka, Zambia: USO Experiments and Results

An imaging polarimter was developed at USO to obtain digital images at 4 positions of polaroid axes, i.e., 0°, 45°, 90°, 135°, as required for the polarization analysis. During the recent total solar eclipse (TSE) of June 21, 2001, we conducted our experiment from the USO-PRL camp location 28° 17.5'E 15° 24.5'S, Alt. 1300 m at

Lusaka, Zambia. The main objective was to obtain the structure, and polarization of inner corona using observations in broad band Hα 6563 Å (FWHM 80 Å), as well as, around the coronal emission lines 5303 Å (FWHM 12 Å), and 6374 Å (FWHM 12 Å). We have found linear polarization degree up to 25-30% in both the emission lines FeXIV 5303 Å and Fe X 6374 Å. Intensity and polarization images in both these emission lines show a good correlation. The location of maximum intensity and polarization show a lag, similar to the anti-correlation effect earlier reported in the literature. The Hα data showed negligible polarization at the sites of the cooler chromospheric prominence structures. In the Hα, the polarization vectors were tangential, as expected, however, at larger distances, there was a significant departure from the tangential orientation, which may be of non-solar origin, i.e., Rayleigh scattering in the Earth's atmosphere. It was found that the bright inner coronal emission, identified as the close loop structures of an active region located at the NE-limb did not correlate with the outer large scale streamers.

(Ashok Ambastha, Sanjay Gosain and P. Venkatakrishnan)

On the Occurrence of Large Geomagnetic Storms in the Present Solar Cycle

Our study of approximately 54 large geomagnetic storms (Dst <-100 nT) in the present solar cycle during 1996-2001, shows variation with solar activity cycle. While the frequency of occurrence of the geoeffective CMEs increased 2 to 3 times from solar minimum to solar maximum on an average, they also had different solar sources or origins. Near minimum geoeffective CMEs were more associated with eruptive prominences. However, near the peak of the solar cycle they had association with strong flares. Another interesting result, is a double peak in the number of geoeffective events in the ascending phase. Although the geomagnetic activity peaks ahead of the solar cycle, more intense events occur after the solar maximum suggesting different causes of storm occurrence.

(Nandita Srivastava)

Astrophysics

Inertial Forces as Viewed from the ADM Slicing and their Behaviour for Particles in Non-Circular Geodesics

Considering the definition of inertial forces acting on a test particle, following non-circular geodesics, in static and stationary space times we show that the centrifugal force reversal occurs only in the case of particles following prograde orbits around black holes. We first rewrite the covariant expressions for the acceleration components in terms of the lapse function, shift vector and the 3-metric γ_{ij}, using the ADM 3+1 splitting and use these, for different cases as given by pure radial motion, pure azimuthal motion and the general non-circular motion. It is found that the reversal occurs only when the azimuthal angular velocity of the particle supersedes the radial velocity, which indeed depends upon the physical parameters *E*, *l* and the Kerr parameter *a*.

(A.R. Prasanna)

Fluid Flow and Inertial Forces in Black Hole Space Time

We discuss the nature of the radial and azimuthal components of centrifugal force associated with fluid flows in the equatorial plane of black hole space times. The equations of motion are solved for the radial and azimuthal components of the 3-velocity V^i which are then used in evaluating the nature of the various components of inertial accelerations. It is shown that the reversal of centrifugal force is governed mainly by the dominance of the azimuthal velocity and the reversal occurs for *r*, mostly at $2m \leq r \leq 3m$, depending upon the boundary condition.

(A.R. Prasanna and B. Mukhopadhyay)

Experimental Tests of Curvature Couplings of Fermions in General Relativity

Spin 1/2 particles in geodesic trajectories experience no gravitational potential but they still have non-zero couplings to the curvature tensor. The effect of space time curvature on fermions can be parameterized by a vector and a pseudo-vector potential. These apparent CPT violating terms can be measured with satellite based spin-polarized torsion balance and clock comparison experiments. The Earth's curvature effect is of the order of 10^{-37} GeV which is not far from the present bounds of ~ 10^{-29} GeV on such CPT violating couplings.

(A.R. Prasanna, S. Mohanty and B. Mukhopadhyay)

Gravitational Wave Induced Rotation of the Plane of Polarization of Pulsar Signals

We derive in this an expression for the rotation of plane of polarization, of an electromagnetic wave, induced by the field of a gravitational wave propagating along the same direction $\approx \frac{G\mu d^2\Omega^4}{3\omega}$, ω and Ω being their respective frequencies using the geometrical optics limit of the wave equation for fields. Estimating the effect for the case of pulses from binary pulsars, one finds it too small to be observable, there could be other sources like inspiralling binary or an asymmetric neutron star where the effect could be in the observable region.

(A.R. Prasanna and S. Mohanty)

Baryogenesis from Primordial Tensor Perturbations

During inflation primordial quantum fluctuations of the spacetime metric become classical and there is a spontaneous CPT violation by the spin connection coupling terms of the metric with fermions. The energy levels of the left and the right chirality neutrinos is split which gives rise to a net lepton asymmetry at equilibrium. A net baryon asymmetry of the same magnitude can be generated from this lepton asymmetry either by a GUT, *B* - *L* symmetry or by electroweak sphaleron processes which preserve *B* + *L* symmetry. If the amplitude of the primordial tensor perturbations is of the order of 10^{-6} (as is expected from inflation models) and the lepton/baryon number violating processes freeze out at the GUT era T_d ~ 10^{16} GeV, then a baryon number asymmetry of the correct magnitude 10^{-10} can be generated.

(A.R. Prasanna, S. Mohanty and B. Mukhopadhyay)

Atomic and Molecular Physics

A New Approximate Expression of the Jacobi Polynomial

We have obtained a *new* approximation for the Jacobi polynomial

$$P_k^{(\alpha,\beta)}(\cos\phi)=\frac{2^\alpha(k+\alpha)!}{k!A^\alpha}\sqrt{\frac{\phi}{\sin\phi}}\;\frac{J_\alpha(A\phi)}{(\sin\frac{1}{2}\phi)^\alpha\,(\cos\frac{1}{2}\phi)^\beta}$$

$$A^2=N^2-\frac{\beta^2}{4}-\frac{\alpha^2}{12}+\frac{1}{12}$$

where $N=k+\frac{1}{2}(\alpha+\beta+1)$. This expression is valid for small ϕ and arbitrary α, β and *k*. Moreover, for large *k*, it reduces to an *asymptotic* expression available in the mathematical literature. This expression is useful in the study of high Rydberg transitions between states in the neighbourhood of the principal quantum number n.

(D.P. Dewangan)

Radiative Transitions between the Stark Levels and the Correspondence Principle

In the days of the old quantum mechanics, Born used Heisenberg's correspondence principle and the classical Kepler orbit to derive a formula in terms of the Bessel functions J_n for the intensity of radiative dipole transition between the Stark (or parabolic) $|nn_1n_2m\rangle\rightarrow|n'n_1'n_2'm-1\rangle$ levels in which the magnetic quantum number m changes by unity. Subsequently, Gordon in 1929 obtained the corresponding quantum formula containing the terminating hypergeometric functions. It has not yet been clarified in the literature how these two formulas which contain two different special functions are related. We have established the relationship and also investigated the region of applicability of the correspondence principle method.

(D.P. Dewangan and Neerja)

First Born Amplitudes for Transitions Involving an Arbitrary Circular Rydberg State

As has been previously reported, we have developed a special technique to study the first Born cross section for transitions between states of large (l , m). We have extended the method to the study of $|n_i,(l_i=n_i-1),(m_i=n_i-1)\rangle\rightarrow|n_f,(l_f=n_f-2),(m_f=n_f-2)\rangle$ transition, i.e. from an arbitrary initial circular state to a *near* circular final state of the orbital and magnetic quantum numbers, each of magnitude one unit less than that of the circular state. We have obtained a closed form expression of the first Born amplitude in terms of the Jacobi polynomials $P_n^{(\alpha,\beta)}(x)$. The expression, unlike the conventional one, is not an algebraic series containing the Clebsch-Gordan coefficients and spherical harmonics and therefore suited for numerical computation for high principal quantum numbers. It is worth recalling that the properties of $P_n^{(\alpha,\beta)}(x)$ permit the deduction of the asymptotic form of the first Born amplitude for high Rydberg transitions.

(D.P. Dewangan)

High Energy Physics

Radiative Origin of the Solar Scale

Neutrino masses and mixing are characterized by very small solar scale and a small mixing element U_{e3}. We discussed the possibility that these small numbers may be result of radiative corrections. We considered CP conserving theory and discussed all possible neutrino mass matrices which lead to vanishing solar scale and U_{e3} at a high scale. These quantities are induced through radiative corrections in the standard model and are predicted in terms of other observables. The solar scale is shown to be strongly correlated with the effective mass measured in neutrinoless double beta decay. It is shown that the large mixing angle solution can arise if this effective mass is near its present experimental limit.

(A.S. Joshipura)

Bounds on Neutrino Magnetic Moment Tensor from Solar Neutrinos

We use the solar neutrino experiments to put bounds on the elements of the neutrino magnetic moment matrix. Neutrino magnetic moment will give rise to extra scattering events in the Super-Kamiokande $\nu e^- \rightarrow \nu e^-$ elastic scattering experiment. Neutrino magnetic moments will shift the allowed parameter space of neutrino masses and mixng angles to the extent that they will no longer be compatible with other experiments. This allows us to put upper bounds on nutrino magnetic moments at the level of $10^{(-10)}\mu_B$.

(A.S. Joshipura and S. Mohanty)

Constraints on Decay Plus Oscillation Solutions of the Solar Neutrino Problem

We study the possibility that the observed solar neutrino deficit is due to possible neutrino decay in addition to oscillations. We put bounds on neutrino lifetime based on the fact that neutrino decay has a energy dependence due to the Lorentz factor which can be checked with observations of low energy (0.1 Mev) neutrinos in Gallium detector experiments with high energy neutrinos (10 Mev) at Super-K and SNO and this work was done in collaboration with Dr. Eduard Masso of Barcelona Autonoma University.

(A.S. Joshipura and S. Mohanty)

A Predictive Scheme for Neutrino Masses

The solar and atmospheric data and possibly large value for the effective neutrino mass in neutrinoless double beta decay experiment together indicate that all the three neutrinos are nearly degenerate. A verifiable texture for the neutrino mass matrix is proposed to accommodate these results. This texture allows almost degenerate neutrino masses two of which are exactly degenerate at tree level. The standard model radiative corrections lift this degeneracy and account for the solar deficit. The solar scale is correlated with the effective neutrino mass m_{ee} probed in neutrinoless double beta decay experiments. The model can accommodate a value of O(eV) for m_{ee}. Six observables corresponding to three neutrino masses and three mixing angles are determined in terms of only three unknown parameters within the proposed texture.

(A.S. Joshipura and S.D. Rindani)

Production of Light Pseudoscalars in External Electromagnetic Fields by the Schwinger Mechanism

We have shown that intense electromagnetic fields will decay into axions by the non-perturbative Schwinger mechanism. This allows us to put contraints on axion properties from intense laser-elctron beam scattering experiments. This work was done in collaboration with Drs. J.A. Grifols and Eduard Masso of Barcelona Autonoma University.

(S. Mohanty)

Vector Meson Masses in Hot Nuclear Matter : The Effect of Quantum Corrections

The medium modification of vector meson masses is studied taking into account the quantum correction effects for the hot and dense hadronic matter. In the framework of quantum hadrodynamics (QHD), the quantum corrections from the baryon and scalar meson sectors were earlier computed using a non-perturbative variational approach through a realignment of the ground state with baryon-antibaryon and sigma meson condensates. The effect of such corrections was seen to lead to a softer equation of state and an increase in the in-medium baryonic masses as compared to when such quantum effects are not taken into account. The ω and ρ-meson masses in hot nuclear matter, as well as the masses for ω and ϕ vector mesons in hyperon-rich matter are studied in the present work, taking into account such quantum effects. It is seen that the strange vector meson (ϕ) mass has a smaller medium modification than the ω meson in the strange hadronic matter. The quantum corrections arising from the scalar meson sector result in an increase in the masses of the vector mesons in the hot and dense matter, as compared to the

situation when only the vacuum polarization effects from the baryonic sector are taken into account. This work was done in collaboration with Drs. Amruta Mishra and Walter Greiner of Institut für Theoretische Physik, JW Goethe Universität, Germany.

(J.C. Parikh)

The Dynamics of the Inflationary Phase Transition

In a series of papers Boyanovsky et al. have studied the evolution of the inflaton during inflation using the Closed Time Path formalism relevant for out-of-equilibrium dynamics. Including a negative mass squared and only a quartic self-coupling for the inflation, they verified that the inflationary phase transition can last long enough to solve the horizon and flatness problems. Because of the existence of certain errors in the literature we rederive the earlier calculations and point out where we differ from earlier works.

(J.R. Bhatt and R. Rangarajan)

CP-Violating Angular Asymmetries in $e^+e^- \to t\bar{t}$ Including $O(\alpha_s)$ QCD Corrections in the Soft-Gluon Approximation

While the top quark has been discovered a few years ago, study of the detailed properties of the top quark will have to await the construction of a linear e^+e^- collider. Polarization of top quarks can give useful information about its couplings. It is important to predict angular distributions of top decay products at such a collider, in order to get a handle on the polarization. Until now, such predictions included effects of anomalous top couplings, but not QCD corrections. Order- α_s QCD corrections in the soft-gluon approximation to angular distributions of decay charged leptons in the process $e^+e^- \to t\bar{t}$, followed by semi-leptonic decay of t or $\bar{t}$, which were obtained recently, have now been incorporated in the study of CP-violating angular asymmetries of the decay leptons in the centre-of-mass frame. The sensitivity of proposed linear collider experiments with polarized beams to CP-violating dipole moments of the top quark has been studied.

(S.D. Rindani)

CP-Violation in the Production of Tau Leptons at TESLA with Beam Polarization

The prospects of discovering CP-violation in the production of tau leptons in the reaction $e^+e^- \to \tau^+\tau^-$ at TESLA, an e^+e^- linear collider with centre-of-mass energies of 500 and 800 GeV are studied. Non-vanishing expectation values of certain correlations between the momenta of the decay products of the two tau leptons would signal the presence of CP-violation beyond the standard model. It is shown how longitudinal beam polarization of the electron and positron beams can enhance these correlations. T-odd and T-even vector correlations are well suited for the measurements of the real and imaginary parts of the electric dipole form factors. It is expected that measurements of the real part with a precision of roughly 10^{-20} e cm and of the imaginary part of 10^{-17} e cm would be possible. This compares well with the size of the expected effects in many extensions of the standard model. This work was done in collaboration with B. Ananthanarayan of CTS, IISc Bangalore, and Achim Stahl of TESLA, DESY Zeuthen, Germany.

(S.D. Rindani)

Nuclear Physics

SU(4) Symmetry and Wigner Energy in Heavy N=Z Nuclei

Study of the structure of N=Z odd-odd nuclei above ^{56}Ni is a topic of high current interest in nuclear physics. In view of this, the measures for Wigner's spin-isospin SU(4) symmetry and the Wigner energy, in terms of double binding energy differences, for even-even and odd-odd nuclei in the A=56-100 mass region are studied using the infinite nuclear matter (INM) mass model of atomic nuclei. Using the INM model, predicted is that the SU(4) symmetry is broken in even-even nuclei but remnants of this symmetry should be present in N=Z odd-odd nuclei in this region. Similarly the estimates of the Wigner energy indicate that the isospin T=0 states in odd-odd N=Z nuclei should start appearing around 0.5 MeV above the ground states that are T=1 in nature. These results present the first clear evidence for a pos-

sible SU(4) symmetry in heavy odd-odd N=Z nuclei (they lie close to the proton drip line). This work is done with R.C. Nayak (Sambalpur).

(V.K.B. Kota)

Deformed Shell Model for T=0 and T=1 Bands in ^{62}Ga and ^{66}As

In order to make spectroscopic studies of heavy N=Z nuclei, deformed configuration mixing shell model developed by PRL scientists many years back was modified to include isospin (T) projection from the beginning. The model is applied to study the structure of low-lying levels in the odd-odd N=Z nuclei ^{62}Ga and ^{66}As. A new realistic effective interaction for the ($f_{5/2}$ p $g_{9/2}$) space derived by the Madrid-Strasbourg group is employed in the calculations. The calculated T=0 and T=1 spectra for ^{62}Ga compare well with experiment and shell model. The predicted spectrum for ^{66}As is close to the recent interacting boson model results. These results suggest that DSM, with isospin projection, can be used for understanding the structure of N=Z odd-odd nuclei in the A=60-100 region. The DSM model is now being used in analyzing excited states in many other N=Z odd-odd nuclei in the A=60-100 region, for example ^{70}Br, ^{74}Rb etc. In addition, this may also allow one to study the structure of high-spin states in even-even N=Z nuclei. This work is done with R. Sahu (Berhampur).

(V.K.B. Kota)

O(12) Limit and Complete Classification of Symmetry Schemes in Proton-Neutron Interacting Boson Model

It is shown that the proton-neutron interacting boson model (pnIBM) admits new symmetry limits with O(12) algebra which break F-spin but preserves the F_z quantum number M_F. The generators of O(12) are derived and the quantum number v of O(12) for a given boson number N is determined by identifying the corresponding quasi-spin algebra. The O(12) algebra generates two symmetry schemes $O(12) \supset O(6) \otimes O(2)$ and $O(12) \supset O(2) \oplus O(10)$ and for both of them, complete classification of the basis states and typical spectra are derived. Search for empirical examples for these symmetry limits, in γ-soft nuclei, is under progress. In addition to the O(12) limit schemes, a new $U(2) \oplus [U(10) \supset O(10)]$ limit of pnIBM, which may be relevant for vibrational type nuclei, is also identified. With these, the longstanding problem of complete classification of pnIBM symmetry schemes with good M_F is solved. It should be pointed out that a major application of the complete classification is in the studies of quantum chaos and phase transitions in finite quantum systems where one can use pnIBM as a model.

(V.K.B. Kota)

Group Symmetries in Two-body Random Matrix Ensembles

The two-body random matrix ensembles with spin (TBRE-s) and in a single j-shell (TBRE-j), introduced recently in the context of ground state structures in complex interacting particle systems, are shown to possess $U(N) \supset U(N/2) \otimes SU(2)$ and $U(N) \supset O(3)$ group symmetries respectively with N the number of single particle states. For TBRE-s the group symmetry alone gives simple structure for the centroids and variances (also for the excess parameter) of the level densities with a given spin S. Using these one sees the dominance of S=0 ground states for TBRE-s. In the case of TBRE-j in addition to the group symmetry one needs the random matrix nature of the ensemble as well as the dilute limit conditions for deriving expressions for centroids and variances for fixed-J densities. It is shown that the derived centroid formula coincides with the result given recently by a Michigan group where the cranking approximation and Fermi occupancies are used in the derivation. It is also seen that the conclusions regarding the dominance of J=0 ground states in TBRE-j based on centroids alone may not remain valid once variances are also included. This work for the fist time used the notion of group symmetries in TBRE. This work is done with K. Kar (SINP, Kolkata).

(V.K.B. Kota)

Plasma Physics

Dust Acoustic Gravity Vortices in Barometric Equilibrium

It is well known that Acoustic Gravity modes can play very vital role in dynamics and evolution of barometric equilibria found in various branches of science e.g. planetary science, solar and astrophysics. Acoustic gravity waves has been analyzed in dusty environment by Shukla and Shaikh. In dusty plasmas collisions could play a very important role in determining low frequency response of the system. In the present work we study dust acoustic gravity modes in a partially ionized dusty plasma where the effect of frictional forces between dust grains and neutral and dust grain with ions are important. We have derived appropriate a coupled set of partial differential equations with non-Boussinesq approximation. The problem has been studied in both linear as well as non- linear regimes. We find that the presence of frictional force strongly affects the growth of instability leading to vortex formation. It is also noticed that for charged dependent decay length, with cold dust, the condition for existence of chain of vortices is modified. Possible application of the results in context of lower planetary dusty atmosphere and astrophysical dusty fluid is discussed. This work was done with Dr. A.A. Shaikh of C.U. Shah Science College, Ahmedabad.

(J.R. Bhatt)

Barometric Equilibria in Dusty Plasma

We study unmagnetized dusty plasma under the influence of external gravity. The equilibrium of the plasma defined by balance between pressure gradient and the force due to gravity. We find that the dust grains can have a vertical equilibrium arrangement in which its charge either can increase or decrease with the height. We find that this situation can lead to a novel kind of instability which would make the vertical equilibrium unstable. This is in contrast with what is found in literature of neutral gas or simple electron and ion plasma where barometric equilibrium is stable and support stable acoustic and gravity modes.

(J.R. Bhatt)

Neutral Dynamics and Instabilities in Weakly Ionized Plasma

The investigation on the role of neutral dynamics on the generation of plasma instabilities is being continued. It is found that the neutral dynamics in partially ionized plasma is responsible for suppression of macro-instabilities. It is the collision between ions and neutrals that is important for the suppression and it is not necessary to invoke viscosity as was done by some workers on this topic.

In continuation to our endeavour to understand the role of nonlinear dynamics in partially ionized plasma, we are presently working on (i) the generation of electromagnetic waves by incorporating magnetic fluctuations, (ii) the development of tearing mode instability in presence of neutral dynamics, and also we plan to (iii) initiate numerical studies on the above problems. These investigations are done in collaboration with Dr. A.A. Shaikh of C.U. Shah Science College, Ahmedabad.

(A.C. Das)

Classical and Macro-quantum Dynamics of Charged Particles in a Magnetic Field

The investigations relating to the dynamics of charged particles in a magnetic field carried out over the last four decades have been reviewed with special reference to the problem of nonadiabaticity due to field inhomogeneity and other perturbations. A detailed review is presented of the standard approach to the problem of determining residence times of charged particles in an adiabatic magnetic trap. The emergence and evolution of a new paradigm described as 'macroquantum dynamics' is next presented. This consists of a probability amplitude Schrödinger-like formalism in the macrodomain. The problem of the nonadiabatic leakage of charged particles from the adiabatic trap takes the appearance here of quantum-like tunnelling of the adiabatic potential. The multiplicity of residence times predicted by the set of Schrödinger-like equations have been well confirmed by experiments. It is demonstrated that this formalism represents a persistence of matter wave behaviour well into the classical macrodomain

through its probability amplitude description. Experimental results confirming some of the spectacular predictions of this formalism are presented. These refer to the existence of macroscopic matter wave interference phenomena and the observations of the curl-free vector potential a'la Aharonov-Bohm in the macrodomain. Some of the outstanding questions relating to this system are also discussed.

(R.K. Varma)

Probability Amplitude Schrödinger-like Description in the Macrodomain for the Charged Particle Dynamics in a Magnetic Field in Three Dimensions

Starting from the Schrödinger wave equation in its path integral representation, a set of probability amplitude Schrödinger-like equations have been derived here for the complete three dimensional motion of charged particles in a magnetic field. These are a generalization to three dimensions of the one-dimensional equations obtained earlier and are derived here for the neighbourhood of the guiding centre motion. As before, these equations refer to the macrodomain and therefore describe all phenomena characteristic of the amplitude description, including the matter wave interference phenomena. Such interference matter wave phenomena with macroscopic matter waves have already been observed by the author with his collaborators. The three dimensional Schrödinger-like equations derived here are shown to yield the guiding centre equations of motion in the WKB approximation in the same manner as the classical equations of motion follow from the Schrödinger wave equation. The adiabatic invariance of the "longitudinal action" in this formalism follows rather interestingly from the adiabatic invariance of the corresponding quantum number as in quantum mechanics. Furthermore this wave formalism also enables, as in quantum mechanics, to calculate transition probabilities for transition across flux surfaces induced by the azimuthal inhomogeneity of the magnetic field.

(R.K. Varma)

Diffraction of Diatomic Molecules from a Lattice with Coupling to the Internal Excited Vibrational State

Matter wave diffraction of diatomic molecules from a lattice of grids is considered with the energy exchange with the internal excited vibrational states of the molecules. The energy exchange leads, in general, to a shift in the matter wave fringes, reminiscent of the Aharonov-Bohm shift, with the important difference that it is independent of $\hbar$ while the A-B shift involves $\hbar$. When the interference is considered strictly to be one dimensional, then the phase difference describing the shift is the sole nonzero phase difference and describes a macroscopic interference with a mesoscopic wave length which is independent of $\hbar$.

(R.K. Varma)

Observation of Magnetic Vector Potential a la Aharonov-Bohm in the Classical Macrodomain

An experiment has been performed to detect the presence of a curl-free vector potential in the classical macrodomain in the manner of Aharonov-Bohm effect of quantum mechanics. The observability of such an effect has been predicted by the theory. The experiment was carried out by passing an electron stream of a very low current (few nA) from an electron gun along an external axial magnetic field in a vacuum glass chamber. The curl-free vector potential was produced by a solenoidal ring with a very high magnetic permeability core (~ 1000) wound over by two layers of compensating windings. A current in the windings produces a magnetic field in the solenoidal ring, which in turn produces a large magnetic flux trapped inside the solenoidal ring. This acts as a source of the curl-free magnetic vector potential outside the ring. The solenoidal ring is placed around the glass chamber outside, so that the electron beam passes through the ring centre on its passage from the electron gun to the detector. The experiment is performed for a set of electron energies E = 500, 600, 800, 900, 1000, 1100, and 1200eV. For a given electron energy there exists a particular value of the magnetic field for

which the effect sought for is most prominent. The current in the solenoidal ring was then swept which changes the flux in the ring monotonically, and consequently the vector potential outside. Plots of the detector plate current as a function of the solenoidal current, clearly show the presence of rather large amplitude variation of the detector current as a function of magnetic flux, and hence the curl-free vector potential in the space outside **Fig. 2.1**. These results clearly establish the observability of the curl-free vector potential because of the strong modulation of the detector current observed as a function of the solenoidal current, although according to the well known Lorentz equation, a curl-free vector potential should have no effect on the detector current. These observations thus exhibit effects, which are in apparent contravention of the Lorentz equation of motion and thereby raise issues of a fundamental nature.

(R. K. Varma, A. M.Punithavelu and S. B Banerjee of PLT-ÁR)

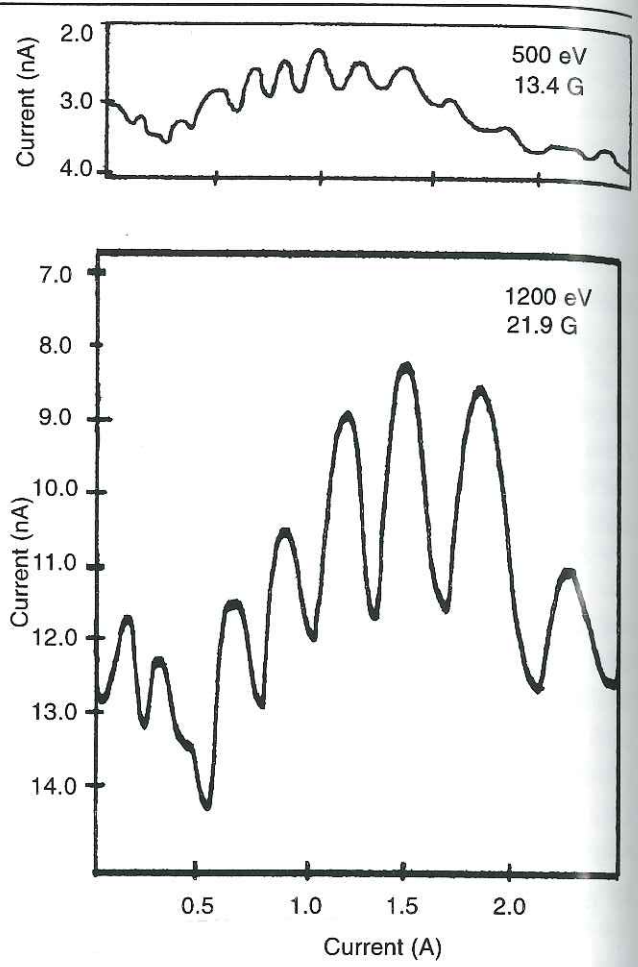


Fig. 2.1 The detector plate current as a function of the solenoidal current for electron energies E = 500 and 1200eV

Nonlinear Dynamics and Computational Physics

The research activities carried out during the past year are summarized below :

Synchronization of Coupled Map Networks

We have studied dynamics of coupled map networks and investigated synchronization of such maps. We find that phase synchronized clusters are formed in two different ways. (a) A cluster may be synchronized due to interactions of intra-cluster type which we call as self-organized synchronization. (b) A cluster may be synchronized due to interactions of inter-cluster type which we call as driven synchronization. The driven synchronization is observed in tree type networks with average degree more than two.

(R. E. Amritkar and S. Jalan)

Estimation Of Initial Conditions and Secure Communication

We estimate the initial conditions of a multivariable dynamical system from a scalar signal using a modified Newton-Raphson method incorporating the time evolution. We can estimate initial conditions of periodic and chaotic systems and the required length of scalar signal is very small. An important application of the method is in secure communications. The communication procedure has several advantages as compared to others using dynamical systems. Firstly the transmitted signal is not directly modulated by the information signal which is added to more than one variable. As a result, local approximation for the flow of the dynamical system in the embedded phase space cannot be used to attack the coding procedure. Secondly, the transmitted signal is of the same size as that of the information signal, and there is no initial transient as required in other synchronization based methods. Thirdly, as in other methods using chaotic encoding the same signal will give different outputs for reruns of the coding procedure thereby making any attempt to crack the coding very difficult.

(A. Maybhate, R. E. Amritkar and D. R. Kulkarni)

Parity Non-Conservation in Atomic Yb

Studying parity non-conservation (PNC) in atoms and ions provide important information complementary to the high energy physics results. In these systems E1 transition amplitude E_{PNC} between states of same parity arising from the PNC induced mixing of states is the signature. We have calculated $E1_{PNC}$ of the $6s6p^3P_0$ - $6s6p^1P_1$ transition in atomic Yb. The transition is suitable for an experiment using the optical rotation method. Our calculations were carried out using the multi-configuration Dirac-Fock method and configuration interaction which are suitable for heavy atoms like Yb. The hyperfine structure constants of the low lying levels were also calculated and are in good agreement with the experimental data. This indicates that the wave-functions are accurate near the origin. The results shows that $E1_{PNC}$ of the said transition is two orders of magnitude larger than the $E1_{PNC}$ of 6s-7s transition in Cs. It, therefore, offers the possibility of improving the accuracy further. This work was done in collaboration with Prof. Bhanu Das of Indian Institute of Astrophysics.

(Angom Dilip Kumar Singh)

Adiabaticity and Chaos Assisted Quantum Tunneling

It has recently been recognized that an unique quantum phenomenon like tunneling can be strongly influenced by classical chaos. Large level splittings of states condensed on symmetry related tori are due to the presence of a chaotic sea that separates the tori in phase space. Such chaos-assisted tunneling leads to tunneling times that are orders of magnitude smaller than direct tunneling. Recent experiments with cold atoms and microwave cavities have probed chaos-assisted tunneling.

Chaos-assisted tunneling has by and large been studied between states that are well localized on regular islands. The localization on the tori provides a classical phase space dynamical barrier that is surmounted

quantum mechanically. However quantum states are known to be strongly scarred by short periodic orbits even in quantum chaotic Hamiltonians. Thus these orbits may also provide some amount of classical isolation that may lead to quantum tunneling. One class of strongly scarred states have already been identified fruitfully as "Feshbach resonance scarring". These class of states occur in a wide spectrum of Hamiltonian systems, and have been studied by many authors. They provide a novel example of chaos-assisted tunneling as the relevant region of the phase space undergoes repeated stability changes with respect to a coupling parameter.

Such strongly scarred "channel states" show tunneling splittings that vary over several orders of magnitude as a classical control parameter is changed. We demonstrate the strong correlation between tunneling times and classical orbit stability. When the classical scarring orbit is most unstable, a small tunneling time is obtained. Thus after a short time, motion along one channel tunnels to motion along the orthogonal channel. Work done in collaboration with Dr. M. S. Santhanam of IBM Research, New Delhi.

(A. Lakshminarayan and V. B. Sheorey)

Quantum Chaos and Entanglement

The classical limit of generic quantum systems have a mixed phase space with both chaotic and regular motions coexisting in an intricate manner. The effects of classical chaos on quantum spectra, tunneling, wavefunction localization etc. are well studied, both experimentally and theoretically. Recently entanglement has been discussed extensively due to its crucial role in quantum computation and quantum information theory. More recently, studies have explored connections between quantum entanglement and classical chaos, two phenomena that are prima facie uniquely quantum and classical respectively. We report here some of our work in this direction.

We have shown that the eigenvalue distribution of reduced density matrices, corresponding to stationary states and arbitrary time evolving pure states, of composite bipartite quantum chaotic systems have a universal distribution that can be derived from Random Matrix Theory. This implies a statistical bound on quantum entanglement, for stationary states, as well as for arbitrary time evolving pure or mixed states, given by $\log(\gamma N)$, where γ is a known function of the ratio of the dimensions of the Hilbert spaces involved, which are N and M and $N \leq M$. This is less than the maximal possible entanglement namely log(N). We have verified this result with detailed calculations in a variety of bipartite systems, such as coupled kicked tops and coupled quartic oscillators.

Short unstable periodic orbits are known to scar quantum wavefunctions and affect their localization. We have shown the direct imprint of the stability oscillations of such short classical periodic orbits on quantum entanglement. Thus the purely quantum measure of entanglement is susceptible to some key classical properties such as chaos and periodic orbit stabilities. Our results also have bearing on the general questions of decoherence and, in particular, relating to entropy production in systems coupled to the environment, and in treating the environment as a quantum chaotic system.

(J. N. Bandyopadhyay, A. Lakshminarayan and V. B. Sheorey)

The research activities of this division over the past year are summarized as follows.

Stoppage of Light Made Flexible by an Additional Control Field

It is well known that light pulse can be stopped in a Doppler broadened atomic medium through *Electromagnetically induced transparency* by using the property of spatial dispersion of the refractive index of the medium.

We consider a closed three level Λ system wherein one of the transitions is coupled to a strong pump field and the other transition is coupled to a probe field. We show that the application of an additional control field connecting the two lower level metastable states in the Λ system allows one to change the group velocity of the pulse inside the medium from negative to a positive value. This change helps in *stopping light* provided that the two-photon resonance condition is satisfied by the probe field and the control field is suitably detuned.

(G. S. Agarwal and T. N. Dey)

Coherent Medium as Polarization Splitter of Pulses

We investigate how a coherent control field can be used to temporally separate out two orthogonal polarization components of a linearly polarized pulse propagating through a coherent medium. One of the components propagates through the medium with an ultraslow group velocity as if the medium is transparent. The other component being off-resonant from the corresponding transition, suffers very little absorption and propagates with a velocity not too different from that in the vacuum. Thus the two components come out of the medium at different times and thereby get separated. We have demonstrated the above concept, both analytically and numerically, for two different atomic vapor media and found two proper frequency zones where this can happen.

(G. S. Agarwal and S. Dasgupta)

Suppression of Spontaneous Emission

One of the fundamental causes of noise at the optical frequencies is the intrinsic spontaneous emission. It is well known that the performance of many systems is limited by spontaneous emission. One of the challenges therefore is to find ways in which spontaneous emission noise can be reduced if not totally inhibited.

We propose a scheme for slowing down spontaneous emission from an excited atom. We make use of a sequence of ultra short 2π pulses applied on an auxiliary transition of the system so that there is a destructive interference between the two transition amplitudes--one before the application of the pulse and the other after the application of the pulse. We give explicit results for a structured continuum and show that the scheme can also inhibit unwanted transitions.

This work was done in collaboration with M. O. Scully and H. Walther, Max Planck Institute for Quantum Optics, Germany.

(G. S. Agarwal)

Giant Radiative Interactions Among Distant Atoms

It is well known from the early days of quantum electrodynamics that the exchange of a photon between two atoms leads to the radiative coupling between the atoms. It is also known that the strength of such a radiative coupling is significant only if the distance between the two atoms is much smaller than the wavelength of the transition involved in the coupling.

We examine the feasibility of enhancing the fundamental radiative interactions between distant atoms. We present general arguments for producing enhancement. In particular, we show how giant dipole-dipole interaction can be produced by considering dipoles placed close to micron sized silica spheres. The giant interaction arises as the whispering gallery modes can resonantly couple the dipoles.

This work was done in collaboration with S. Dutta Gupta, University of Hyderabad.

(G. S. Agarwal)

One and Two Photon Processes in Ultracold Atoms in a Cavity

The dynamics of atom-field interaction in cavities lead to a direct verification of quantum electrodynamic (QED) predictions on radiation-matter interaction. Cavities are especially attractive for studying the regime of strong interaction between the atoms and the quantized fields.

In our work, we consider an ultra-cold, three-level atom in the ladder-type configuration interacting with a bimodal cavity. We discuss the competition among the one- and two-photon emissions from the excited atom as a result of its interaction with the bimodal field. It is found that the field always induces two-photon transition in an excited atom when the corresponding one-photon transition is forbidden. Next, we considered the interaction of a beam of excited atoms with the cavity. The stimulated photon emissions from the atoms and cavity losses balance each other to give a steady field in the cavity. The dominant two-photon emissions from the atoms give rise to a Poissonian-like statistics of photons in the steady field of the cavity. The steady state field also exhibits sub-Poissonian photon distribution in one mode which is a non-classical behavior of quantized fields.

(R. Arun and G. S. Agarwal)

Nonclassical Interference Effects in the Radiation from Coherently Driven Uncorrelated Atoms

Resonance fluorescence from a single atom driven by a coherent field was the first example allowing observation of nonclassical effects such as antibunching and sub-Poissonian statistics.

We have studied two-atom fluorescence where two identical two-level atoms are driven coherently by a continuous laser source. The photon-photon correlations of the fluorescence light show a spatial interference pattern not present in a classical treatment. A feature of this phenomenon is that bunched and antibunched light are emitted in different spatial directions. We point out that correlations are induced by state reduction due to the measurement process when the detection of the photons does not distinguish between the atoms. We also note that the phenomenon shows up even without any interatomic interaction.

This work was done in collaboration with C. Skornia, J. von Zanthier, H. Walther (Max Planck Institute for Quantum Optics, Germany) and E. Werner, Institute for Theoretical Physics, University of Regensburg, Germany.

(G. S. Agarwal)

Tripartite Entanglement in a Bose-Einstein Condensate by Stimulated Bragg Scattering

Entanglement is a profound feature of quantum mechanics. It serves as a resource for quantum information processing and quantum communication. In recent times, many schemes for entanglement production have been proposed and demonstrated. Entanglement between two particles is quite common, for example, Einstein-Podolosky-Rosen states, polarization states of twin-photons, down converted two-photon states in optical parametric oscillator and so on. In contrast, three-particle entanglement is not so common, though recently three-photon Greenberger-Horne-Zeilinger entangled states have been experimentally realized. Bose-Einstein condensates of weakly interacting trapped atomic gases are macroscopic quantum objects, which, because of reduced quantum fluctuations, offer a good testing ground for studying many-particle quantum entanglements.

We show that it is possible to entangle three different many-particle states by Bragg spectroscopy with nonclassical light in a Bose condensate of weakly interacting atomic gases. Among these three states, two are of atoms corresponding to two opposite momentum side modes of the condensate and the other is of single mode photons of the output probe beam. We demonstrate strong dependence of the multi-particle entanglement on the quantum statistics of the probe light and present detailed results on entanglement keeping in view the possible experimental situation.

(B. Deb and G. S. Agarwal)

Nonclassical Two-Photon Interferometry and Lithography with High-Gain Parametric Amplifiers

Optical parametric amplification is a process that leads to the generation of quantum states of light. In the limit of low single-pass gain, this process is often referred to as parametric down conversion, and produces entangled two-photon states. However, the generated light field is typically quite weak. Certain applications, however, require the use of more intense light fields with quantum features.

We present an analysis of the quantum statistical properties of the output of a parametric amplifier for arbitrary values of the single-pass gain. We find that although certain signatures of quantum light disappear in the high-gain limit, others (such as the existence of two-photon interference fringes) remain. As a result, we demonstrate that high-gain parametric amplifiers can be used as intense sources of entangled photons for various applications such as quantum information and quantum imaging

This work was done in collaboration with E. M. Nagasako, S. J. Bentley and R. W. Boyd, University of Rochester, U. S. A.

(G. S. Agarwal)

Spatial Coherence and Information Entropy in Optical Vortex Fields

Optical vortices are potential candidates for transmitting information at high speed over long distances. Therefore, certain aspects of an optical vortex, such as its spatial coherence and information entropy, are of vital importance. A physically realizable field distribution that contains optical vortices is a higher-order Laguerre-Gaussian (LG) mode. The distribution is spatially coherent in two-dimensional space. A useful way to study fields in higher dimensions is by means of their projections. Clearly the projections of a two-dimensional LG mode onto one dimension will not be fully coherent, as we lose information in the process.

We show how a vortex structure manifests itself in its one-dimensional projection. We calculate the extent of spatial coherence (**Fig. 4.1**) and entropy of such projections. We quantify the spatial coherence and discuss the properties of the Wigner function for the projected field.

(G. S. Agarwal and J. Banerji)

Non-canonical Optical Vortices

We produce a symmetrical optical vortex using a computer generated hologram and a He-Ne laser

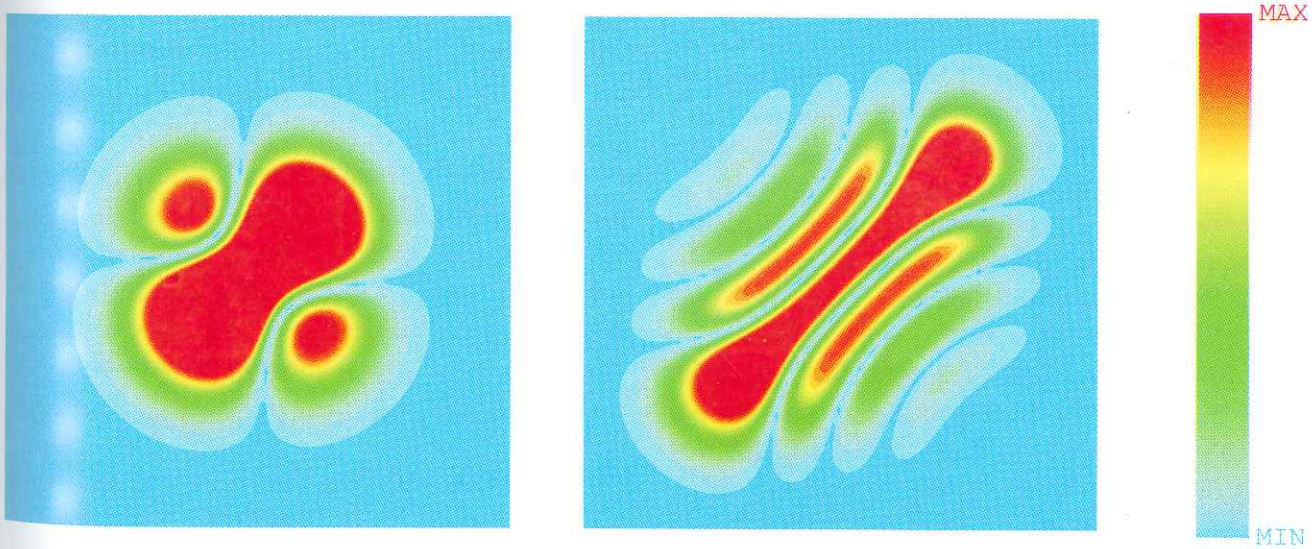


Fig . 4.1 Spatial distribution of coherence in the one dimensional projection of a vortex field of helicity one (left) and five (right).

(λ=632.8 nm, power less than 1 mW). This is made into a noncanonical vortex after passing through a two-dimensional optical system (a cylindrical lens). Noncanonical vortices are characterized by the general angles other than right angle reserved for canonical ones, between the real and imaginary parts of the field, which cross at zero defining the phase dislocation point or the vortex. The propagation of such a vortex in free space has been studied experimentally as well as theoretically revealing some interesting behavior different from canonical vortices. An analytical expression for the generation and propagation of such a vortex was obtained by applying the ABCD law of Gaussian beam propagation to the two-dimensional optical system. Theoretical results were found to be in good agreement with our experimental results.

(R.P. Singh)

Planetary Atmospheres and Aeronomy

Research programmes of the Planetary Atmospheres and Aeronomy Division have evolved in three disciplines viz., (a) study of earth's near environment including the middle atmosphere, (b) study of the upper atmosphere and ionosphere and (c) laboratory studies for studying important reactions taking place in space. A recently acquired mobile micro-pulse lidar would be used extensively from different geographical locations to study the role of aerosols in modulating the earth's radiation budget. Development of Quadrupole Mass Spectrometer is the major new activity initiated for the study of upper atmosphere. A new programme of momentum spectroscopy has been started this year for studying the momentum spectra of recoils in ionization of atoms and molecules by photons or electrons.

Middle Atmosphere

Aerosol Characteristics Studied over Ahmedabad and Indore

Measurement of the aerosol optical depth (AOD) at four wavelengths over Indore was carried out from May 2001 to March 2002 and compared with the data obtained over Ahmedabad. Indore is a rapidly growing industrialized city and has typical urban atmosphere like Ahmedabad. Both the cities are situated at almost the same latitude, but Indore is more interior from the coastline. Preliminary analysis of data shows that AOD values at both the locations are comparable within one sigma variability. Difference in the shape of the AOD spectra indicate the variations in the aerosol size distribution. The wavelength exponent α, in Angstrom's power law ($\tau=\beta\lambda^{-\alpha}$) which describes the size distribution, was found to be 1.09 over Ahmedabad and 1.62 over Indore indicating that sub-micron size particles are more dominant over Indore. This work was done in collaboration with Mr. Pawan Gupta of Devi Ahilya Vishwavidyalaya of Indore.

(Harish Gadhavi, Y.B. Acharya and A. Jayaraman)

Balloon-borne Study of the Background Stratospheric Aerosols

A high altitude balloon carrying Sun-scanning/tracking multichannel photometer systems was launched from Hyderabad (17.5° N, 78.6° E) on 10th April 2001 to study the background aerosol characteristics in the upper troposphere and stratosphere. The hydrogen gas filled balloon, which was launched at 0626 hrs, reached the expected ceiling altitude of about 33.5 km around 0900 hrs. By estimating the attenuation of the incoming solar radiation at each altitude and after correcting for molecular scattering and gaseous absorption, aerosol extinctions were obtained. The 500nm aerosol extinction coefficient was about 10^{-2} km^{-1} in the upper troposphere and in the range of 10^{-3}-10^{-4} km^{-1} in the stratosphere. The 532 nm aerosol extinctions derived from independent lidar measurements conducted on 3 and 4 April 2001 over Mt. Abu were in good agreement with balloon results in the stratosphere. The mean mode radius of the aerosols in the stratosphere was found to be 0.10 μm, which represents the background (nonvolcanic) aerosols in the stratosphere.

(S. Ramachandran, A. Jayaraman and Y.B. Acharya)

Aerosol Mass Loadings and Size Distributions over the Tropical Indian Ocean

From the cruise expeditions conducted onboard the Oceanographic Research Vessel *Sagar Kanya* during 1996-2000 over the Arabian Sea and the Tropical Indian Ocean aerosol mass concentrations and size distributions were measured *in situ* using a Quartz Crystal Microbalance Impactor in the radius range of 0.025-12.5μm and analysed. The mass concentrations measured individually in 10 different size ranges are grouped into three categories *viz.*, coarse (aerosols in the radius range (1-10μm)), accumulation (0.1-1μm) and nucleation (0.01-0.1μm) modes. The mass concentrations measured at the ambient relative humidities are scaled to 50% RH. Mass concentrations were obtained during 1996-2000 over coastal India, Arabian Sea and the tropical Indian Ocean (**Fig. 5.1**). Mass concentrations (in all the size ranges) for Coastal India were found to be higher than Arabain Sea and Tropical Indian Ocean concentrations. A latitude gradient is visible as the ship moves away from the coast to the interior ocean and the gradient is relatively steeper for the nucleation mode than compared to accumulation and coarse modes. The aero-

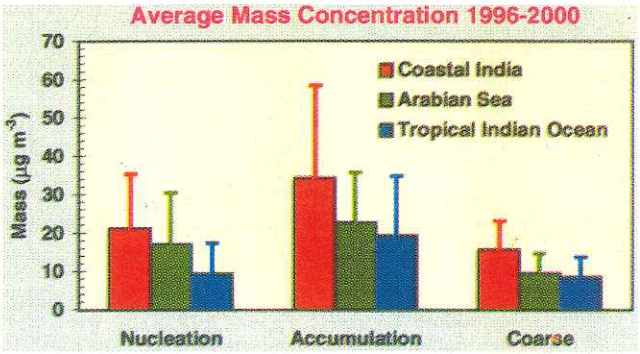


Fig. 5.1 Average aerosol mass concentrations during 1996-2000 over coastal India, Arabian Sea and tropical Indian Ocean.

sol mass distributions obtained are converted into aerosol number densities. The aerosol size distribution obtained over Coastal India for the 1996-2000 was used to determine mode radius (r_m), width of the distribution (σ) and the total aerosol concentration by fitting for each mode lognormal functions. The aerosol size distribution could be fitted with 3 modes, with mode radius in the range of 0.025-0.035μ m for the nucleation size range, mode radius in the range of 0.11-0.15μ m for the accumulation size range and with a mode radius around 1.2μ m for the coarse size range.

(S. Ramachandran and A. Jayaraman)

Aerosol Optical Characteristics over Bay of Bengal

A cruise experiment to study the aerosol optical characteristics was conducted in February-March 2001 over Bay of Bengal, a data void region, onboard *Sagar Kanya*. Aerosol optical depths were measured at 5 wavelengths centered at 0.4, 0.5, 0.66, 0.85 and 1.05μ m using hand held Sun photometer. Aerosol optical depths obtained in the wavelength region of 0.4-0.85μ m over Bay of Bengal were compared with the aerosol optical depth spectra obtained earlier over Arabian Sea and Tropical Indian Ocean. The differences in the aerosol optical depths are more in the smaller wavelength region of 0.4μ m when compared to the longer wavelength region of 0.85μ m. This indicates the dominance of submicron aerosols over Bay of Bengal when compared to the larger size particles. The measured aerosol optical depths are then reconstructed using a model fit, taking into account different aerosol types and relative humidities. The Bay of Bengal aerosol optical depths could be explained by prescribing water soluble and soot particles in the model aerosol size distribution, both of which are in the submicron size range. The estimated and the measured aerosol optical depth spectra compare well.

(S. Ramachandran and A. Jayaraman)

Transport of Surface Ozone over the Bay of Bengal

Measurements of surface ozone, and related trace gases were made for the first time over the Bay of Bengal, Indian Ocean and the Arabian Sea during a cruise from February 18 to March 23, 2001 (**Fig. 5.2**). An important feature of these measurements was that the highest levels of ozone (60-64 ppbv) were observed over the central Bay of Bengal (10-15N, 84-86E) and not near

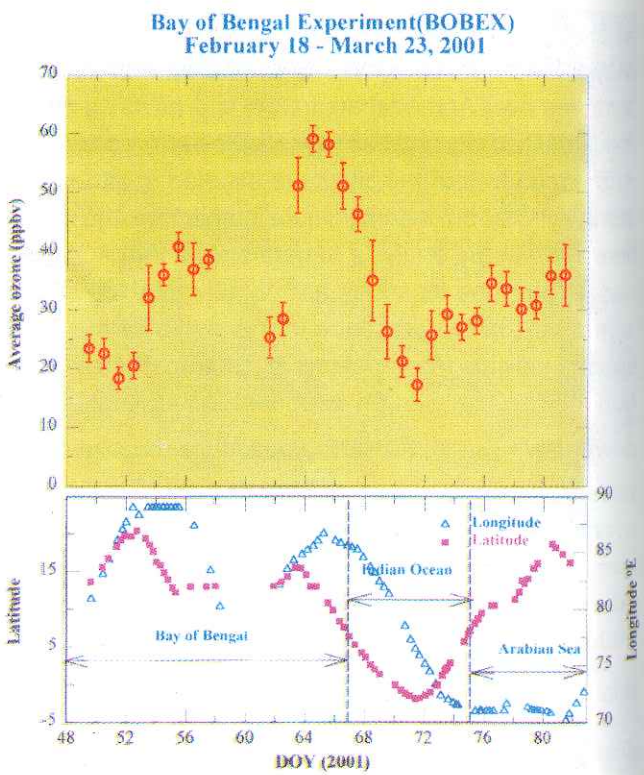


Fig. 5.2 Spatial distribution of surface ozone (daily average) measured during the Bay of Bengal experiment (BOBEX) conducted in February - March,2001

the coastal regions due to abnormal wind patterns. These ozone levels are higher than the average ozone levels measured during all the INDOEX cruises conducted each winter from 1996 to 1999 over the Arabian Sea, except north of 12°N. Elevated levels of CO, CH_4, SF_6 have also been observed over the Bay of Bengal. These observations and seven days back trajectory analyses suggest that higher levels of ozone over the Bay of Bengal are the results of transport from the continent and photochemical production on the way.

(Duli Chand, S. Venkataramani, T. K. Sunil, K. S. Modh and Shyam Lal)

High Surface Ozone in the Downwind of Industrial Region of Gujarat

Surface measurements of ozone were made in the downwind side of major industrial region of Gujarat (India) adjoining the Arabian Sea during the Mobile Lab Experiment (MOLEX) in January of 2001 and 2002. The first set of measurements were made from two vans to cover the complete downwind side. But in 2002, the instruments were kept stationary at Khambhat, a rural site along the Gulf of Khambhat, which is in the downwind side of the industrial region of Gujarat. Elevated ozone levels in the range of 70 to 110 ppbv were recorded around noon hours at different sites in the downwind of urban Gujarat. Observations of elevated ozone levels during January 2001 and 2002 indicate that this is a regular process in this region. Ozone in the downwind side was higher by about 60% than the major urban center and its surroundings. In contrast to the downwind observations, the ozone observed at the continental stations in rural, urban and free tropospheric sites in India rarely exceeded 60 ppbv during the month of January. These observations along with the back trajectory analysis suggest that the elevated ozone is neither transported from the free troposphere nor from the urban center but produced in-situ on the way in downwind side of the urban region.

(Duli Chand, T. K. Sunil, K. S. Modh, S. Venkataramani and Shyam Lal)

Upper Atmosphere

Dynamics of Plasma Depletions over Mt. Abu

A study of plasma depletions observed from Mt. Abu (24.5 °N, 72.7 °E) during April 1999 revealed some interesting results. The depletions obtained on 14th April 1999 were much stronger and almost covered the entire image FOV. Depletions obtained on 15th April 1999 were weaker and were limited to the southern half of the image FOV. But the bubble rise velocity calculated from the movement of the northern end of the depletions for both the nights was almost equal (~65 ms^{-1}). The northern end of the depletions obtained for both the nights appeared to be bifurcated. The southern end of some of the depletions obtained on 14th April 1999 showed a westward tilt while the northern end appeared almost vertical, indicating strong shear in the zonal plasma drift. This shear in plasma drift caused the southern and northern halves of a depletion, observed on 14th April 1999, to move with different velocities and finally ended up in breaking of the depletion into two. The southern part

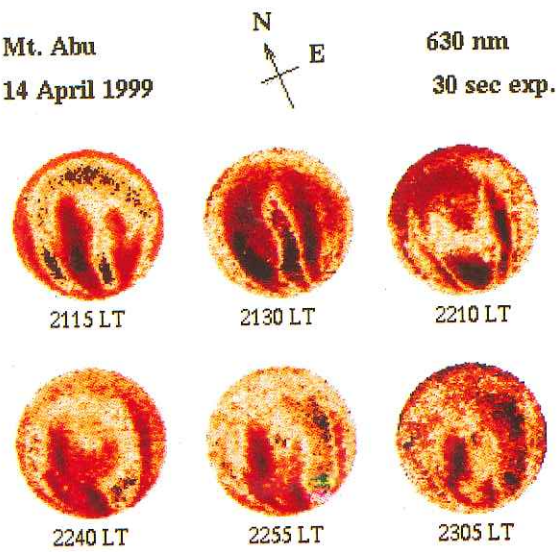


Fig. 5.3 Ionospheric plasma depletions as seen in 630nm images taken from Mt. Abu. The arrow points towards geomagnetic north. The dark regions indicate depleted airglow intensity. Breaking and joining of plasma depletion can be seen in images taken at 2240, 2255 and 2305 LT.

drifted eastward as an independent depletion, while its northern half, which was drifting eastwards with lower velocity joined together with a depletion band that was following it and drifted eastwards as a single depletion band. This breaking and joining of depletions is observed for the first time **(Fig. 5.3).**

(H.S.S.Sinha, P.K. Rajesh, R.N. Misra, N. Dutt, M.B. Dadhania, V.K. Parmar and R.I. Patel)

Some New Features of Plasma Depletions Observed over Kavalur

An all sky imaging campaign was conducted from Kavalur (12.5°N, 78.8°E) from February to March 2002. A modified version of PRL's all sky imaging system was used for this campaign. The main modifications were a) the incorporation of a new high gain image intensifier, and b) a new CCD camera with a better sensitivity. The images were recorded at 557.7 nm, 630.0 nm and 777.4 nm wavelengths. A preliminary analysis of the images showed the presence of very strong plasma depletions in all the three wavelengths. There were two new features observed during this campaign. The first one being the appearance of depletions from about 2200 LT till about 0500 LT on one of the nights in February, 2000. The other important feature, which has been observed for the first time, is the continuous occurrence of depletions for about 10 nights in the month of March, 2002. Depletions were observed on almost all the nights from 4th to 17th March. On some nights it was observed that after disappearing around midnight, the depletions reappeared towards the early morning hours.

(H.S.S.Sinha, P.K. Rajesh, R.N. Misra, N. Dutt, S. B. Banerjee, M.B. Dadhania, V.K. Parmar and R.I. Patel)

Radar Observations of 2.8 m Irregularities during a Spread F Event

Multiple plumes were observed in the Height Time Intensity Plot (HTIP) obtained using the Indian MST Radar at Gadanki (13.47° N, 79.18° E) on the night of 17/18 May 1994. The plumes appeared in the radar field of view in the post midnight period from 0130 LT to 0330 LT. The ionograms taken at a nearby station SHAR (14° N, 80° E), showed the onset of spread F around midnight (2353 LT) with a weak frequency type spread F. The normal pre-reversal enhancement was absent on that night. The F layer movement inferred from h'F variation showed a wavy pattern with periodicity of few hours, indicating corresponding reversals in the zonal electric field. The irregularities, recorded in the radar map were confined to the bottom side only until the appearance of plumes. The tilt of one of the plumes indicated a shear in the zonal plasma flow. The Height Time Velocity Plot (HTVP) showed that the shear existed in the vertical velocity of irregularities also. Very intense layers of irregularities were also observed in 100-130 km altitude region by the radar during 0130–0330 LT, which appeared to be responsible for strong sporadic E layers, seen on SHAR ionograms at same time. A very intense layer seen at the 0138 LT in radar echoes appeared as two well separated Es layers in ionograms taken at SHAR. The production of such intermediate layers by gravity wave activity has already been suggested in the literature.

(H.S.S. Sinha, P.K. Rajesh and N. Dutt)

Temperature Structure over Mt. Abu from Rayleigh Lidar

Forty five nights of observations in Rayleigh, Raman and aerosol modes of operation were conducted during the year. Based on more than 120 nights of Rayleigh mode of observations from November 1997 to December 2001, climatology of the temperature structure over Mt. Abu has been obtained and compared with CIRA 86 and equatorial models. Photon counts integrated over 2 hour in time and 480m in altitude give temperature values with errors (one sigma level) of about 1K, 3K, and 10K at 50, 60 and 70km, respectively. Observed temperature profiles are in good agreement with CIRA 86 below 50km but are higher by up to 10K above 50 km **(Fig. 5.4)**. The agreement is better during winter months. The day to day variability is less than $\pm$5K for altitudes below 50 km and up to $\pm$10K around 70km. The variability seems to be lowest around 40-42km. The mean values of the stratopause level and temperature are found to be 48 km and 271 K respectively over the measurement site. Seasonal variation of the temperature below 60km shows equinoctial and summer maxima

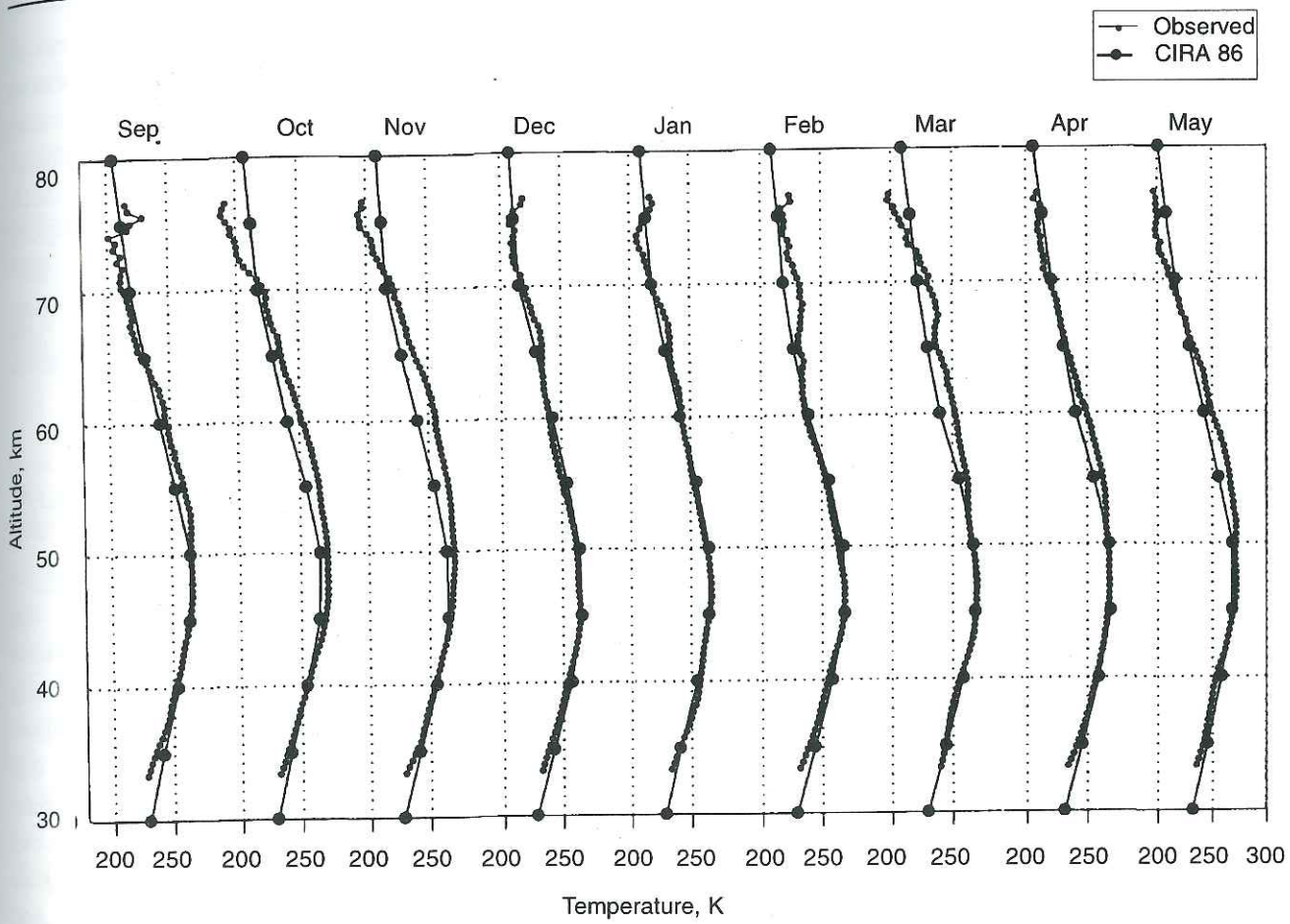


Fig. 5.4 Comparison of measured temperatures at Mt. Abu from Rayleigh Lidars with CIRA 86.

whereas above 70km winter maximum with equinoctial minima are seen.

(H. Chandra, Som Sharma, Y.B. Acharya, A. Jayaraman and J.T. Vinchhi)

Radio Signatures of Leonid Meteor Shower on Transionospheric VHF Satellite Signal

VHF scintillations of the 244 MHz satellite beacon from the geo-stationary satellite FLEETSAT (73° E) recorded at Haringhata field station (23° N, 88.5° E) of the Calcutta University during the night of 16-17 November 1998 are shown to be associated with the sporadic-E layer generated by meteoric ionization. Two examples of scintillations corresponding to the peak period of Leonid meteor shower are transient and quasi-periodic in nature with much shorter duration (30-100 s) than normally observed during the nighttime. Critical frequency of the sporadic-E layer (f_0E_s) obtained from the radio soundings over Ahmedabad (23° N, 72.4° E) for the same night also shows two isolated spikes. The occurrence of the oscillating diffraction patterns due to the meteoric ionization is validated from the model plots obtained using the diffraction theory from a series of one-dimensional irregularities. This work was done in collaboration with Prof. A Dasgupta, Calcutta University.

(H. Chandra)

Tropical Spread-F

Based on quarter hourly ionograms during the period 1983-95, occurrence features of range and frequency types of spread-F over Ahmedabad are studied. The frequency type spread-F is most frequent during

equinoxes and December solstices of low sunspot years. The range type of spread F is frequent during equinoxes and December solstices (with lower occurrence than equinoxes) of high sunspot years. Comparison is made with the occurrence features at Cachoeira Paulista, tropical latitude station in Brazilian sector. The occurrence of range spread F over Cachoeira Paulista shows strong seasonal dependence with a distinct maximum during local summer for both low and high sunspot years. The occurrence frequency at Cachoeira Paulista is much higher than over Ahmedabad. This work was done in collaboration with Dr. Abdu and Dr Batista, INPE, Brazil.

(H. Chandra and Som Sharma)

Scintillations

Nocturnal, seasonal and solar cycle variations of VHF scintillations at equatorial and anomaly crest locations in India are compared with similar variations of spread-F occurrence. At equator scintillations and range spread-F occur predominantly during premidnight period of equinoxes and increase with solar activity. At anomaly crest scintillation occurrence is always less than at equator with similar pattern during equinoxes. Post midnight scintillations are associated with frequency spread-F, predominantly in summer and decrease with solar activity. Comparison of spread-F in Indian and Brazilian sectors brings out magnetic declination control. This work was done in collaboration with Prof K N Iyer, Saurashtra University, Dr B M Pathan, IIG and Dr Abdu, INPE, Brazil.

(Som Sharma and H. Chandra)

Total Solar Eclipse of 11 August 1999

A number of experiments were conducted from Ahmedabad to study the ionospheric effects of the total solar eclipse of 11 August 1999. Rapid radio soundings were made from the ionosonde operated by PRL. A Riometer at 30 MHz was installed by IIG, Colaba at the Thaltej campus of PRL and field strengths measurements were made along three oblique incidence paths by Gujarat University using transmissions from Colombo (11905 kHz), Bombay (538 kHz) and Rajkot (810 kHz). The path of totality was about 100km south of Ahmedabad with maximum obscuration of 99.4% at 1801h. Reduction of 20% was noticed both in f_{min} and in the F_1 layer critical frequency. The signal strengths of the oblique incidence paths also point to eclipse associated decrease in ionization in the D and lower E region. The Riometer recordings also show higher signal during eclipse day. This work was done in collaboration with Dr Girija Rajaram, Dr. A. Hanchinal of IIG and Dr. P.D. Lele of Gujarat University.

(H. Chandra and Som Sharma)

On the Relationship between the Width of the Diurnal Shapes of OI 630.0 nm Dayglow Intensity Variations and the Electrojet Strength

An investigation was carried out to understand the causative mechanisms responsible for the changes in the day-to-day shapes of OI 630.0 nm dayglow intensity variations measured by means of the Dayglow Photometer (DGP) at Mt. Abu (24.6° N, 73.7° E, dip lat 19.09° N), a station under the crest of Equatorial Ionization Anomaly (EIA). This investigation revealed that the width (the time span corresponding to 0.8 times the maximum dayglow intensity) of the diurnal profile (**Fig. 5.5**) has a linear relationship with the integrated electrojet strength obtained using the magnetometer data from equatorial and low latitude stations. The deviation from this linear rela-

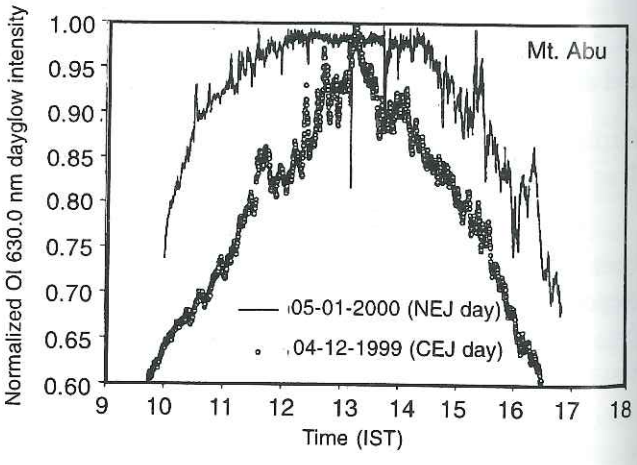


Fig. 5.5 Variation of 630nm dayglow intensity over Mt. Abu on a normal electrojet and a counter electrojet day

tionship, on occasions, is attributed to the presence of mean meridional wind. This work is carried out in collaboration with Dr. B.M. Pathan of IIG, Mumbai and Dr. K.S.V. Subbarao of SPL, Thiruvananthapuram.

(D.Chakrabarty, R. Sekar, H. Chandra and R. Narayanan)

OI 630.0 nm Dayglow Responses from Mt. Abu during Different Phases of Geomagnetic Storm

OI 630.0 nm dayglow intensity data are being obtained from Mt. Abu, a region under the crest of equatorial ionization anomaly (EIA) on a regular basis. Based on the dataset available during different phases of geomagnetic storms, which occurred during the recent ascending phase of solar activity, a detailed investigation is being carried out. Preliminary harmonic analysis shows that during "disturbed period", the dominant periodicities in the dayglow intensity variations differ from those during "quiet time". Data obtained from the EIA crest region and from the regions supposedly free from the influence of EIA with the help of mirror scanning arrangement show differences in the responses of OI 630.0 nm dayglow.

(D.Chakrabarty, R.Sekar, R.Narayanan and N.K.Modi)

On the Sudden Midnight Enhancements in the Sodium Airglow over Mt. Abu – a Case Study

As a part of an exploratory campaign using the multi-wavelength day-night photometer, nocturnal variations of airglow intensities at OI 557.7 nm, OI 630.0 nm and Na D 589.0 nm were recorded simultaneously during January 12 – 16, 2002. Sudden enhancements in the sodium airglow intensity was noticed at around midnight while the other two airglow line emissions did not exhibit any appreciable changes in the intensities during that time. Investigations over the association of these enhancements with the sporadic E layers are being carried out.

(Alok Taori, R. Sekar, D. Chakrabarty, R. Narayanan and N. K. Modi)

Investigations on the Coupling of E and F Region Irregular Structures during Nighttime

An investigation was carried out to understand the observed coupling between E and F region irregular structures by extending equatorial spread F numerical simulation model to E region altitudes in the equatorial region. Solutions were obtained for the development of the large scale irregularities by gradient drift (GD) instability in the E- region and also by generalized Rayleigh-Taylor (GRT) instability in the F region. This investigation revealed that the development of large-scale irregularities by GD instability is essential, in addition to the fringe fields associated with GRT instability, to explain the upward movement of E region structure to the F region of the ionosphere.

(E.A. Kherani and R.Sekar)

Sub-meter Plasma Waves over Low Latitude Ionosphere during Leonid-99 Meteor Storm

Detailed analysis of the data obtained from two rocket flights conducted earlier from Sriharikota, during enhanced Leonid shower activity showed the presence of sub-meter scale plasma irregularities. The amplitude of these irregularities was about 4% of the ambient electron density at 105km on both occasions. This is the first experimental evidence of the such short scale irregularities during the Leonid shower activity. All the available data indicates that these irregularities are not produced by gradient drift or two stream instabilities. The mechanism of generation of these irregularities is being looked in to.

(S.P. Gupta, R. Sekar and Y.B. Acharya)

Laboratory Astrophysics

Measurement of Velocity of Plumes in Laser Produced Plasmas

Laser produced plasma plumes (LPP) were created by the incidence of high power UV laser on metal targets placed in vacuum. The spectra of spatially resolved LPP were recorded using a CCD spectrograph.

Simultaneously, the time evolution of the plasma was also studied by recording the variation of the photon flux from LPP as a function of the distance from the target. Two such simultaneous measurement enables systematic study of emission in LPP and the propagation of the ablated material from the metal surfaces. LPP of copper and aluminium were studied in detail at distances ranging from 0 to 8 mm from the origin of plasma. The spectroscopic measurements were carried out in the visible to near infrared region of the spectrum, which shows emission from excited neutral, and various ionic states of the metal. The time resolved measurements indicate inverse square root mass dependence of the species. The time shift of the local maximum measured at different distances in the plasma provided the local velocity of expansion of the plume whereas the width of the profile shows the average plume size at various distances.

(I.A. Prajapati, K.P. Subramanian and A.P. Gohil)

Supersonic Atomic Oxygen Beam Source for RIMS

RIMS, Recoil Ion Momemtum Spectroscopy, has been recently started at PRL to measure photoionozation cross-sections of atomic species. In the first experiment, atomic oxygen produced in the form of supersonic jet will be ionized in a multiphoton ionization using a frequency doubled tunable UV laser. Ions will be detected in coincidence with the electrons and are differentiated in terms of their momenta. A facility for the generation of supersonic atomic oxygen beam is being developed. Atomic oxygen is produced in a microwave discharge and is led to the stagnation region terminated on a supersonic jet. Efficient differential pumping design enables extraction of discharge products very close to the production region as well as establishment of reasonable pressure ratio for supersonic expansion in the first stage of the differential pumping. The second stage of differential pumping houses a chopper wheel mounted on a synchronous motor for pulsing the atomic beam. The beam path lengths are minimized for efficient transport of the atomic species into the interaction region in the spectrometer. This apparatus is fully designed and now is under fabrication.

(Bhas Bapat, K.P. Subramanian and I. A. Prajapati)

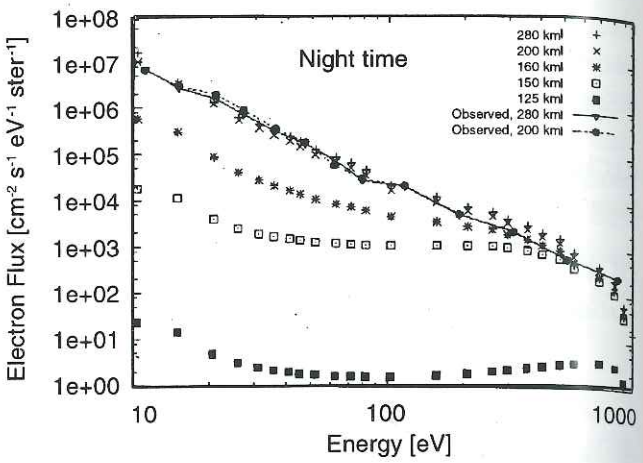


Fig. 5.6 Secondary electron flux at different altitudes in the nightside atmosphere of Mars. The measured spectra at 280km and 200km are shown.

Planetary/Cometary Atmospheres

Electron Spectra in the Nightside Martian Ionosphere

An earlier calculation, which involved two dimensional yield spectrum, was extended in three dimensions to calculate secondary electron spectra due to precipitation of solar wind electrons in the nightside atmosphere of Mars. This model calculates the energy and positions of secondary electrons after primary electrons ionize the atmospheric gases. Secondary electron spectra were determined at 125, 150, 160, 200 and 280 km altitudes. The secondary electron spectra fall gradually at about 700-800 eV because high-energy electrons disappear very fast as the electrons penetrate deeper in the medium. Above 200 km, the secondary electron spectra are nearly independent of altitudes. The calculated electron fluxes were compared at 200 km and 280 km with those measurements made by Mars Global Surveyor spacecraft (**Fig. 5.6**).

(S.A. Haider)

Earth Sciences and Solar System Studies

The research programmes in the Earth Sciences and Solar System Division are carried out by two seperate areas: (i) Oceanography and Climate Studies, and (ii) Solar System and Geochronology. The primary focus of research of these areas is to understand the physical and chemical processes and the time scales governing the evolution of the major reservoirs on Earth and the origin and early evolution of the Sun and solar system objects such as the Moon, Mars and asteroids. Isotopic studies of terrestrial and extraterrestrial samples using a variety of techniques are carried out to achieve these objectives. Some of the important research activities of the division during the last year are described below :

Oceanography and Climate Studies

^{14}C Reservoir Ages in the Arabian Sea and the Bay of Bengal

^{14}C reservoir ages of the north Indian ocean have been determined through ^{14}C analysis of archived marine shells from pre-nuclear era. These ages range from 229 ± 56 yr to 385 ± 37 yr for the Bay of Bengal and 390 ± 38 yr to 500 ± 46 yr in the northern Arabian sea. The enclosed basin of the Gulf of Kutch has an age of 264 ± 34 yr. The distribution of these ^{14}C reservoir ages reflect the upper ocean circulation patterns. Thus the oldest reservoir ages are in the Arabian sea where mixing with deeper ^{14}C depleted waters is favoured through wind-induced upwelling. The ^{14}C reservoir ages are younger in the Bay of Bengal where vertical mixing is hampered due to sharp isopycnal gradients, maintained by large freshwater inputs.

Radiocarbon measurements in the water column as well as in over head air of the Arabian sea and the Bay of Bengal show that the mean penetration depth of bomb ^{14}C increased in the Arabian sea from 270 m in 1978 (based on GEOSECS data) to ~330 m in 1994/95, whereas, in the Bay of Bengal penetration was deeper from ~168 m in 1978 to ~300 m in 1997. At one station near the equator it increased from 194 to 533 m while bomb inventory almost doubled from 5×10^9 to 9.5×10^9 atoms. m^{-2}. These values indicate lateral advection of southeastern Pacific waters.

(R. Bhushan, K. Dutta and B. L. K. Somayajulu)

Paleoclimatic Studies using the Arabian Sea Sediments

Paleoclimatic and paleoproductivity variations during the past ≤ 45 ka was ascertained using two AMS ^{14}C dated gravity cores from the south-eastern Arabian Sea. In addition to usual isotopic stages, both cores show freshening of surface waters in the region, at 8-9 ka before present. Sedimentary C_{org} and N abundances are decoupled from surface productivity trend with higher concentrations during the last glacial maximum (LGM). This is interpreted in terms of increase in sedimentation rates (by factor of 3-4) during the LGM associated with better preservation of C_{org}. The provenance effect and intensity of aeolian transport have not changed significantly as revealed by the constancy of Ti/Al ratios. The Mg/Al ratios appear to follow the surface productivity trend in contrast to NW Arabian sea, where it is used as an indicator for arid conditions.

(R.Agnihotri, M.M. Sarin and B.L.K.Somayajulu)

Satellite Oceanography

ERS-1 and GEOSAT satellite altimeter data have been used to map and interpret the mechanical behaviour of the Bay of Bengal (BOB) lithosphere. The preliminary interpretation of ship-borne gravity and seismic data along a few profiles across the BOB indicates submerged aseismic ridge at 85°E and its overcompensated topography due to increased sediment load. The first phase of the work, namely, processing and assimilating the satellite data to retrieve the marine gravity and geoid into its multiple wavelength components has been completed in collaboration with Space Application Centre, Ahmedabad.

In another study relating to ocean productivity using ^{15}N isotope, a new equation for fractionation of nitrogen isotopes, when phytoplanktons fix them, has been developed. The isotopic composition of the source nitrate varies as $\delta = [\varepsilon / (1 + f\beta)][\ln f - \varepsilon(1 - f)]$, unlike in

Rayleigh fractionation, where $\delta = \varepsilon \ln f$. Here f is the fraction of the source (nitrate) left in surface water, ε the fractionation factor between plankton and nitrate and the factor β is the Michaelis-Menton constant.

(S. Kumar, S. Rajesh and R. Ramesh)

Chemical Weathering Rates in Basalts

Chemical constituents of rivers draining Deccan traps was measured to understand chemical weathering processes in basaltic terrains and calculate CO_2 consumption in the region. Samples were collected in August 2001 from several streams and rivers at 27 locations with field measurements of pH (7.0-8.2), EC (32-750 $\mu S.cm^{-1}$) and temperature (22-28°C). HCO_3^- constitutes 40–88 % of total anions followed by Cl^-, SO_4^{2-} and NO_3^-. Ca^{2+} dominates with 30–53% of total cations followed by Mg^{2+}, Na^+ and K^+. The total dissolved solids (TDS) are higher (24-500 $mg.lit^{-1}$) compared to other world river systems such as the Congo (28-49$mg.lit^{-1}$), the Amazon (6-55 $mg.lit^{-1}$) and are comparable to the G-B system (91-461$mg.lit^{-1}$). The silica content ranges from 91–629 $\mu mol.lit^{-1}$.

The average specific chemical weathering flux is 24 $t.km^{-2}.yr^{-1}$. Considering large surface area of the Deccan traps, the total annual chemical erosional flux amounts to 1.2×10^7 tons, two orders higher than many of the other basaltic provinces in the world. The specific CO_2 consumption rates vary with an average of 0.52×10^6 $mol.km^{-2}.yr^{-1}$. This corresponds to annual average consumption of 0.26×10^{12} $mol.yr^{-1}$, 2.1% of the world average.

(Anirban Das, Kanchan Pande, M. M. Sarin and S. Krishnaswami)

The Distribution of Rare Earth Elements (REE) in River Water and Sediments

Bed sediments in the Yamuna and the Chambal river basins are characterized by REE concentrations in the range of 78 to 291 $\mu g\ g^{-1}$ and 96 to 157 $\mu g\ g^{-1}$ respectively. The shale normalized REE compositions of these bed sediments, show negative Ce and Eu anomalies, Ce/Ce* = 0.95 and 0.91, Eu/Eu* = 0.55 and 0.76.

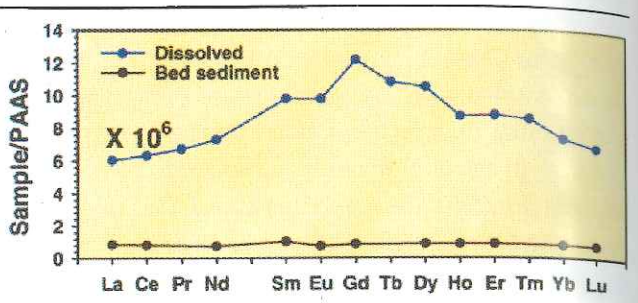


Fig. 6.1 Distribution of rare earth elements in river waters and sediments.

HREE are enriched relative to LREE in downstream bed sediments of the Yamuna river, $(La/Lu)_{upstream}/(La/Lu)_{downstream} = 1.3$. In the Chambal river, HREE are depleted downstream, $(La/Lu)_{upstream}/(La/Lu)_{downstream} = 0.6$. A comparison of river water composition and bed sediments (**Fig. 6.1**) suggests that dissolved REE is enriched in MREE with respect to sediments, presumably due to preferential dissolution of phosphate minerals during weathering processes while the sediment pattern of REE is nearly flat.

(R. Rengarajan and M.M. Sarin)

U-Th Series Isotopes in Carbonates and Black Shales from the Lesser Himalaya

^{238}U and ^{232}Th concentrations and the extent of ^{238}U-^{234}U-^{230}Th radioactive equilibrium have been measured in a suite of Precambrian carbonates and black shales from the Lesser Himalaya to determine their contributions to dissolved uranium budget of the headwaters of the Ganga and the Indus and to assess the impact of weathering on ^{238}U-^{234}U-^{230}Th radioactive equilibrium in them. ^{238}U concentrations in Precambrian carbonates range from 0.06 to 2.07 $\mu g\ g^{-1}$ with a 'mean' U/Ca, 1.2×10^{-4} $\mu gU/\mu MCa$. These low U concentrations and low U/Ca suggest that the carbonates make only minor contributions to the uranium budget of the Ganga-Indus headwaters on a basin wide scale. Similar estimates for silicate contribution to uranium budget of these rivers show that silicates can contribute significantly (~40% on average) to their U balance.

Uranium concentration in black shales averages about 37 $\mu g\ g^{-1}$. Based on this value, supply of U from at

least ~50mg of black shales per liter of river water is needed to balance the average river water U concentration, 1.7 $\mu g\ l^{-1}$ in the Ganga-Indus headwaters. This requirement would be significantly less if silicate uranium becomes an important component of the uranium budget. $^{234}U/^{238}U$ activity ratios in both carbonates and black shales are at or near equilibrium, thus preferential mobilization of ^{234}U from these deposits, if any, is within analytical uncertainties. ^{230}Th is at or in excess of ^{238}U in many of the carbonates, indicating that during weathering uranium is lost preferentially over Th from them. ^{232}Th concentrations in carbonates are generally quite low, $<0.5 \mu g\ g^{-1}$. The variation in its concentrations seem to be regulated by alumino-silicate content of the carbonates as evidenced from the strong positive correlation between ^{232}Th and Al.

(Tarun K. Dalai, S. Krishnaswami and Sunil K. Singh)

Chemical Characteristics of Aerosols in the Marine Boundary Layer of the Bay of Bengal

Aerosol samples collected from the near surface MBL, during mid-February to March 2001 along a transect (20°N 89°E to 2°N 82°E) in the Bay of Bengal, were analysed to investigate the relationships among atmospheric sea salts (Na^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}), mineral aerosols (Ca, Mg, Fe, Al), biogenic emissions and anthropogenic constituents (SO_4^{2-}, NO_3^- and various trace metals). The pronounced non-sea-salt (nss) components of K^+ (60-99%), Ca^{2+} (36-99%), Mg (5-80%) and SO_4^{2-} (73-99%) indicate that during February-March mineral aerosols and anthropogenic constituents dominate the aerosol composition in the boundary layer over the Bay of Bengal. The nss- SO_4^{2-} and nss-Ca^{2+} are strongly correlated, suggesting that continental pollution and dust sources overwhelm marine biogenic source of SO_4^{2-}. The impact of enhanced levels of aerosol SO_4^{2-} (range: 2.3 to 7.4 g m^{-3}) is conspicuously reflected in the high-chloride deficits (55-98%, **Fig. 6.2**), presumably caused by displacement of chlorine from deliquescent sea-salt aerosols to the gas-phase by sulphuric acid. These results suggest that aqueous-phase reactions in sea-salt aerosols may be a sink for anthropogenic SO_2 from the marine atmosphere. The concentrations of Fe and Al are strongly correlated (r^2=0.98, n=24) indicating similarities in their source (from crustal-dust) and transport processes.

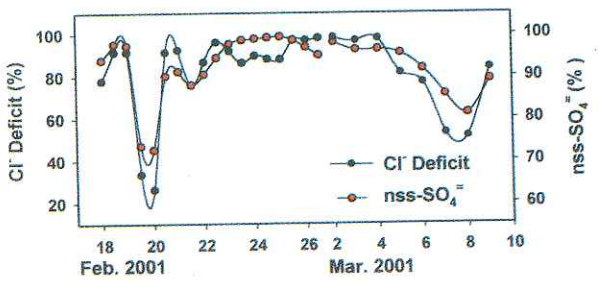


Fig. 6.2 Chloride loss from sea-salts as a function of nss-SO_4^{2-}

(M.M. Sarin, A.K. Sudheer and N. Rastogi)

Temporal Variation of ^7Be and ^{210}Pb in Ambient Aerosols

Cosmogenic ^7Be ($t_{½}$ = 53d) and ^{210}Pb ($t_{½}$ = 22.3 yr) have been measured continuously from June 2000 to May 2002 in ambient aerosols, representing semi-urban atmosphere. Aerosol sampling is done at ~ 40 m above ground, on the terrace of an eight-storey building in PRL campus. Each sampling period was about 30 hrs, taken at an interval of ~15 days. The ^7Be and ^{210}Pb concentrations vary between 0.8 to 6.0 mBq m^{-3} and 0.2 to 1.9 mBq m^{-3}, respectively. The temporal variations show (**Fig. 6.3**) a strong increase of ^7Be (av. 4.0 mBq m^{-3}) and ^{210}Pb (av. 1.1 mBq m^{-3}) in winter succeeding the monsoon period (^7Be : 2.7 mBq m^{-3}; ^{210}Pb : 0.4 mBq m^{-3}). The higher concentrations of ^7Be and ^{210}Pb in the former period are due to the newly formed aerosols. During monsoon season wet deposition is responsible for their short residence time and hence lower concentrations.

(N. Rastogi and M.M. Sarin)

Linear Dunes in Western Sahara

The western Sahara in Mauritania is dominated by extensive sand seas that consist largely of linear dunes. Previous workers reported crossing dune trends and superimposition of dunes, suggesting shift in wind regimes in the region. We sampled one area in the west-

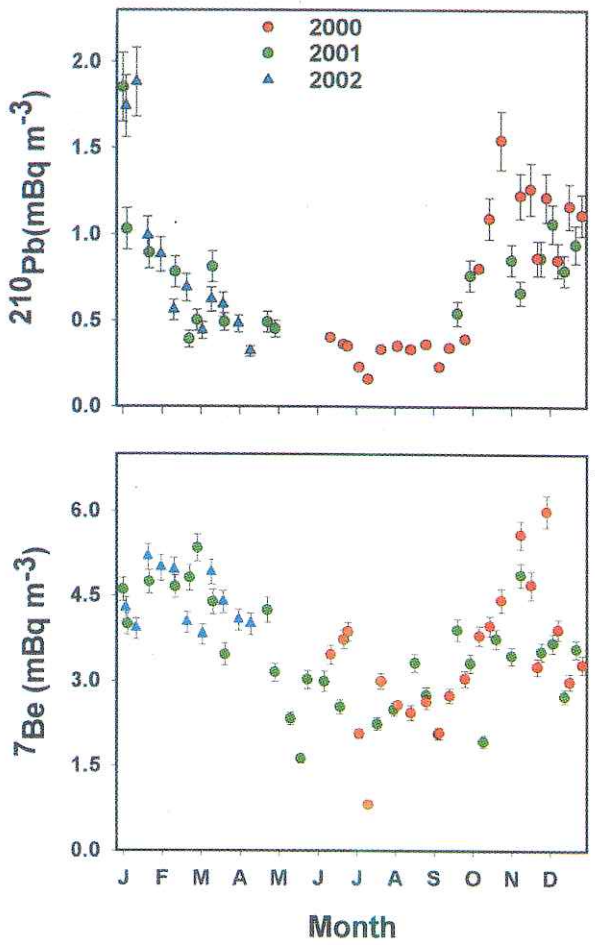


Fig. 6.3 Temporal variation of ^{7}Be and ^{210}Pb in aerosols over Ahmedabad

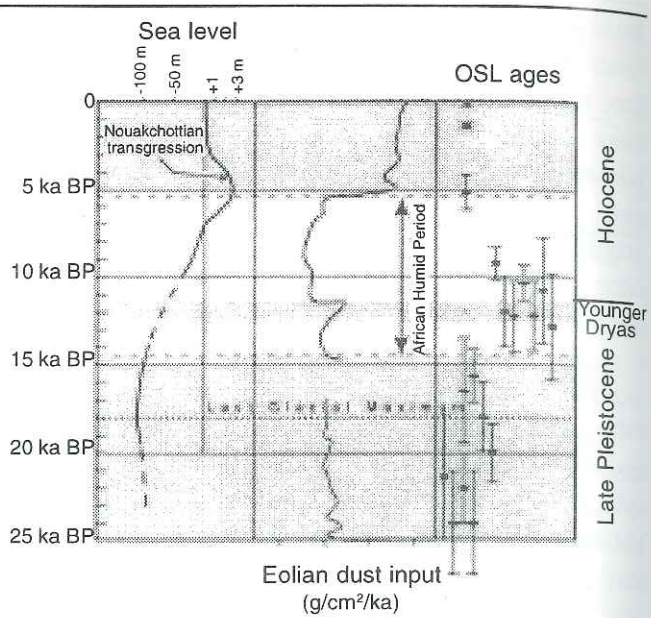


Fig. 6.4 Periods of OSL-dated aeolian dune construction, compared to eolian dust input to marine sediments off northwestern Africa, and sea level curve

ern part of Mauritania between 18°30′ and 20°30′ N, in which several dune trends are visible on satellite images, and where three of the sand seas (Azefal, Agneitir, Akchar) are in close proximity.

Mapping of the sand seas using Landsat TM images, identified (1) a NE-SW-trending large, degraded linear ridge, (2) a NNE-SSW-trending moderate-sized linear dune with active crestal areas, and (3) N-S-trending small linear dunes.

Luminescence ages on samples cluster into three groups (**Fig. 6.4**): (1) 24-15 ka, (2) 13-10 ka, and (3) after 5 ka and each of these periods of eolian activity is associated with a distinct linear dune trend, the oldest ages (24-15 ka) with the NE-SW and 13-10 ka for NNE-SSW dune trend. Simulations of the dune-forming winds indicate that wind regimes in this area during the Last Glacial Maximum were characterized by enhanced E and N trade winds, and reduced thermal monsoon effects.

(A.K.Singhvi)

Semi-arid Records from South Indian Rivers

Flood histories and associated fluvial dynamics in tropical rivers are intimately related to climatic changes that control both the water budget and sediment fluxes. In this context, chronological controls on fluvial records from south India are virtually non-existent. To fill this gap, Luminescence dating of quartz extracts from fluvial and slack water deposits and from an artificial pond of a south Indian River Pennar was attempted. Some key results are :

Both single aliquot (BGSL) and single grain (GLSL) ages on quartz extracts were concordant with each other as also with two age controls of historical events. The OSL ages along with sedimentological studies on paleoflood and flood plain sequence revealed that

R. Penner aggraded between 2.4 ka -1.9 ka. Two major flood events, at 1.7 ka and 150a were recorded, of which the later event has historical evidence. A period of long break in fluvial aggradation between 1.8ka and 0.7ka was inferred from incipient soil formation on the over bank deposits .

Further, the sedimentation sequence shows that the intensity of the SW monsoon increased during the last 200 years compared to the previous 300 years. The pond sequence also indicates that individual intense rainfall events increased over the past 200 years as a result of warming since the end of Little Ice Age. Overall results accord well with climate reconstruction in Central and North Western India.

(N.Juyal, A.K.Singhvi and P.J.Thomas)

Glacial and Lake Deposits in the Himalaya

A new application of luminescence method to date glacial deposits was initiated with studies on the Gangotri glacier. These gave ages in the range 220a to 2200a stratigraphically consistent with radiocarbon ages.

Comparative radiocarbon and infrared stimulated luminescence dating studies on paleo-lake sediments from Goting and Garbyang indicated that in general radiocarbon gave stratigraphically inconsistent, overestimated ages. IRSL ages were < 50% of radiocarbon ages (e.g. 17ka IRSL age and 40ka radiocarbon ages) and were stratigraphically consistent. As an additional check, blue green stimulated luminescence ages on quartz extracted from sand horizons were measured and these also confirmed the IRSL ages. This study, therefore suggests that radiocarbon ages from the lakes in this region are likely to be over estimated and therefore necessitates a revisit of the chronology of all the lakes in the Himalya.

The luminescence studies described above were done in collaboration with Prof. K.W. Glennie, V.P. Pandey, Prof. N. Lancaster, Prof. G. Kocurek, Prof. M. Deynoux, Prof. V.S. Kale, Dr. D.D. Awasthi, Dr R. Bali and Dr. R.K. Pant.

(N. Juyal, A.K. Singhvi and M.G. Yadava).

Origin of Artesian Groundwater and Escaping Gas at Narveri after the Bhuj Earthquake

At Narveri, in the Great Rann of Kutch post earthquake outflow of groundwater continued for more than four months after the Bhuj earthquake of 26 January 2001. Gas bubbling through the freshly oozing water was also observed. A large number of samples from different parts of Gujarat reporting post-earthquake groundwater outpourings were analysed for dissolved helium. Narveri, however, was the only site where the samples showed dissolved helium concentrations significantly above the air equilibration value. At this location three groundwater outpourings were observed in a small area of about 100 m^2. Based on measurements of helium, chloride, sulphate and sodium concentrations and groundwater temperature, it was inferred that water and escaping gases at the three Narveri vents had a common deep confined source. Dating by $^4He/^{222}Rn$ method indicated that the age of groundwater in this common deep reservoir was in excess of ~10^4 years.

(S.K. Gupta, N. Bhandari and R. Rengarajan)

Oxygen and Hydrogen Isotopes in Shallow Groundwaters from South India

Oxygen and hydrogen isotopic investigation of ground and river water samples from the southern Indian peninsula showed that : (i) regions dominated by NE monsoon have distinctly depleted isotopic composition compared to those dominated by SW monsoon. (ii) $\delta^{18}O$-δD regression line slope of ~ 6 in the east coast region is lower than that expected for local precipitation suggesting secondary evaporation, (iii) the orography of the Western Ghats hill ranges plays a significant role in controlling the isotopic distribution along the west coast region. (iv) the low 'd-excess' values (< 6) in most part of study area indicate secondary evaporation, (v) the high 'd-excess' values (> 10) over the Deccan Plateau region in the NW part of the study area suggest admixture of recycled moisture with the inflowing oceanic vapour.

(R.D. Deshpande, S.K. Bhattacharya, R.A. Jani and S.K. Gupta)

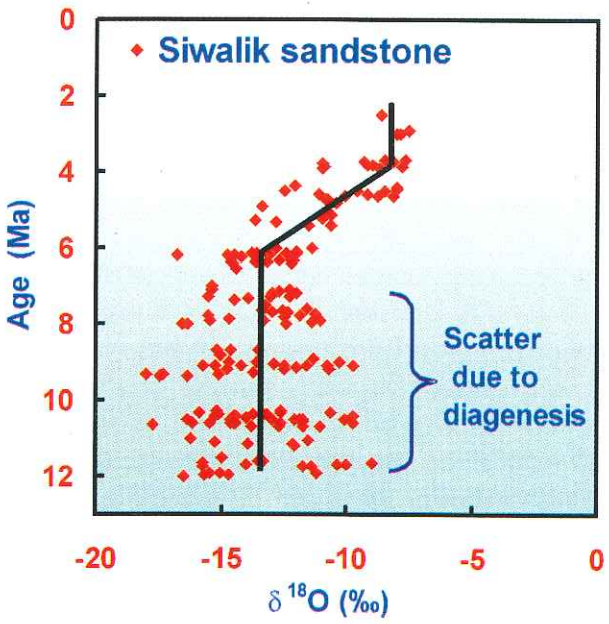


Fig. 6.5 Oxygen isotope ratio ($\delta^{18}O$ in ‰ wrt smow) in carbonate cement from Siwalik sandstones of ages from 12 to 2 million years. Note shift to lower $\delta^{18}O$ values after 6 million years indicating change in monsoon precipitation.

Evolution of Monsoon System from Oxygen Isotope Composition of Siwalik Sediments

The Siwalik sediments were deposited from mid Miocene to early Pleistocene. The lower and middle Siwalik is characterized by alternation of sandstone and mudstone beds while the upper Siwalik is made of conglomerate and mudstone bed. The cementing material in the sandstone facies is mainly calcite, which are of ground water origin. We have studied the oxygen isotopic composition of the calcite cement to understand the evolution of ground water. The chronology is based on available palaeomagnetic ages.

The $\delta^{18}O$ (PDB) value of sandstone cement ranges from -17 to -7 ‰. Upto about 8Ma the oxygen isotope ratio shows depleted values with large scatter (-17 to -12‰). The time variation shows that after 8Ma $\delta^{18}O$ increases continuously till 5Ma and subsequently it has a constant value of about -7‰ (**Fig. 6.5**).

Depleted and scattered oxygen isotope values in the lower level may be partly due to high temperature diagenesis as attested by transformation of smectite to illite. After 8Ma $\delta^{18}O$ shows continuous enrichment trend with less scatter. This change in $\delta^{18}O$ value probably indicates a change in isotopic composition of ground water caused by strengthening of Asian monsoon. This inference about precipitation is corroborated by lithological changes which suggest dominance of flood after 8Ma.

(S.K. Bhattacharya and P. Sanyal)

Flux and Carbon Isotopic Ratios of Methane from Paddy Fields

Air samples were collected from paddy fields from the east Godavari district of Andhra Pradesh during the growing season (July- November) in 2000 for measurement of methane concentration and its isotopic composition. The concentrations, measured at NRSA, Hyderabad are used to calculate the methane flux which varies from 0.77 to 22.6 mg / m^2 /hr with an average of 5.4 mg / m^2 /hr. Using this average value, the integrated seasonal flux is estimated to be 15.3g/m^2. The $\delta^{13}C$ of emitted methane varies from -56.2 to -46.1‰ (w.r.t PDB).

The flux weighted $\delta^{13}C$ of methane from the present work is calculated to be -54.1‰ which is enriched compared to the values in Japanese paddy fields (-63.7 & -65.3‰) and in Chinese paddy fields (-63.8‰). This enrichment is probably due to different production pathways and its subsequent oxidation.

(D.K. Rao, S.K. Bhattacharya and R.A. Jani)

Oxygen Isotope Fractionation in Surface Dissociation of Ozone: a New NOMAD Effect

Photolysis of molecular oxygen produces isotopically heavy ozone but the cause for this enrichment is not clear. Here we report an experiment outlining the isotopic fractionation of ozone during its dissociation on surface of glass and quartz. Ozone was produced by UV photolysis of oxygen and passed through spirals of glass and quartz.

The left over ozone is enriched and the product oxygen is depleted with respect to the initial ozone composition. A covariation plot (**Fig. 6.6**) of ($\delta^{18}O$ and ($\delta^{17}O$ shows that for small fractionation (< 8 ‰), the slope is

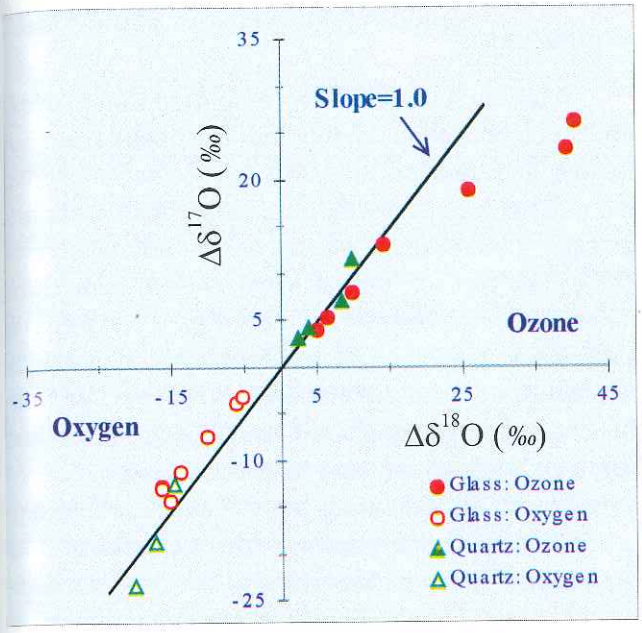


Fig. 6.6 Co-variation plot of $\Delta\delta^{18}O$ and $\Delta\delta^{17}O$ for surface dissociation process

about one and as the fractionation increases, the slope decreases (up to 0.7 for fractionation of ~30 ‰). It is clear that dissociation of ozone, occurring on a surface (heterogeneous reaction) does not follow the conventional mass fractionation pattern (slope ~ 0.5). To explain our data, we propose a reaction model in which ozone and a reactive surface molecule combine and form a weakly bonded energetic complex (O^3W^*). It is possible that during dissociation of $(O_3W)^*$ the total available energy is not fully randomized. If the dissociation takes place by tunneling across a small barrier or transition from a weakly bound state to a repulsive state the quantum selection rules would prefer symmetric molecules and molecules containing ^{17}O and ^{18}O would have lower and equal dissociation rate.

(S.K. Bhattacharya and S. Chakraborty)

Solar System and Geochronology

A Limit on Energetic Particle Irradiation of the Solar Nebula

Short-lived nuclides present in the early solar system are generally considered to be of stellar origin. However, the possibility that some of them are products of interaction of solar energetic particle (SEP) with material in the solar nebula is strengthened by recent detection of the short-lived nuclide ^{10}Be in early solar system objects as this nuclide cannot be produced during stellar nucleosynthesis. We have studied fossil records of ^{10}Be, ^{41}Ca and ^{26}Al in a set of refractory objects from the primitive meteorite Murchison using ion microprobe to characterize the nature of SEP irradiation of the solar nebula.

The refractory hibonite grains selected for this study have platy morphology, extremely high abundance of refractory trace elements and host large magnitude stable isotopic anomalies, all characteristics of some of the first generation solar system solids. All of them have resolved excess of ^{10}B, indicating presence of the short-lived nuclide ^{10}Be at the time of their formation; the initial $^{10}Be/^{9}Be$ ratio being ~10^{-3}. However, the abundance of ^{41}Ca and ^{26}Al in the hibonite grains are below our detection limit with upper-limit initial $^{26}Al/^{27}Al$ and $^{41}Ca/^{40}Ca$ values of 1.6×10^{-6} and 3×10^{-9}, respectively. If we attribute the presence of ^{10}Be in the hibonites to irradiation of precursor nebular material by SEP, it is possible to infer the "effective" fluence and characterize the SEP spectrum that will be consistent with the observed data. A hard spectra with $\gamma \sim 2$ in the power-low representation of SEP ($dN \propto E^{-\gamma} dE$) and an fluence of protons (E >10 MeV) of ~10^{18} cm^{-2} are consistent with the initial abundances of ^{10}Be and also the near absence of ^{41}Ca and ^{26}Al in these objects.

(K. K. Marhas and J. N. Goswami)

Short-lived Radionuclides in Early Solar System

Stellar nucleosynthesis as well as energetic particle irradiation could be the possible sources for the short-lived radionuclides ^{26}Al and ^{41}Ca found in early solar system. Presence of ^{10}Be (half-life ~ 1.5 million years) in the early solar system objects raises the possibility of ^{26}Al and ^{41}Ca being produced locally by particle irradiation. A study of Ca - Al - Inclusions (CAIs) from CH and CV chondrites has been initiated to address the following: (i) feasibility of determining the Be-B systematics using the small ion microprobe, (ii) distri-

bution of ^{10}Be in early solar system by studying several different classes of primitive meteorites, and (iii) presence or absence of correlation between ^{41}Ca, ^{26}Al and ^{10}Be.

Efremovka CAI E65 has both ^{26}Mg and ^{41}K excess due to the decay of short-lived radionuclides ^{26}Al and ^{41}Ca respectively. Our preliminary result suggests the presence of ^{10}Be in E65 with an initial $^{10}Be/^{9}Be$ value of ~ 2×10^{-3}, which is similar to the values reported earlier on other primitive meteorites, suggesting that either the source of these three were same, or if they were different then CAI sampled the source(s) of these three isotopes because of efficient mixing in the early solar nebula. Since the half-life of ^{41}Ca is extremely small, ~ 0.1 million years, the production and mixing time scales of ^{10}Be has to be of this order.

Most of the CAIs from CH chondrites are characterized by lack of ^{26}Al, pristine O-isotope composition and nearly normal Ca and Ti composition. On the other hand, a few grossite containing inclusions from CR chondrites Acfer 059 and El Djouf 001 show evidence for ^{26}Al with canonical abundance. The largest hibonite bearing CAI from CH chodnrite was studied for Ca-K isotopic system. The hibonite from the core yields an initial $^{41}Ca/^{40}Ca$ of nearly 2×10^{-8} similar to the values observed in Efremovka CAIs. However this CAI has no initial ^{26}Al. Three CAIs from CR chondrites were analyzed for Al-Mg system and the initial ^{26}Al values are close to the canonical value of ~ 5×10^{-5}. The CAI 022/1 for the first time showed evidence for lack of correlation between the abundance of ^{26}Al and ^{41}Ca, implying that the source for ^{26}Al and ^{41}Ca need not be the same as suggested earlier. The CAIs from CR chondrites both with grossite and those with melilite and hibonite (this work) have uniform ^{26}Al abundance suggesting that they formed within a narrow interval of time from the same reservoir. The work on CH and CR chondrite CAIs were carried out in collaboration with Dr. A. Bischoff of University of Münster, Germany

(G. Srinivasan)

Isotopic Systematics in CR Carbonaceous Chondrites

A detailed study of ^{26}Al records in ten CAIs in primitive CR carbonaceous chondrites have been carried out to infer their relation with CAIs from other chondritic group. The major mineral phases in these CAIs are grossite, melilite, spinel with occasional anorthite. Most of the CAIs contain ^{26}Al with initial $^{26}Al/^{27}Al$ value close to the canonical value of 5×10^{-5} (**Fig. 6.7**). Only one CAIs is devoid of ^{26}Al. The results obtained in this study further substantiate the presence of ^{26}Al in CAIs from CR chondrite with canonical initial $^{26}Al/^{27}Al$. In contrast very few CAIs from another prisitine carbonaceous chondrite group (CH) show presence of ^{26}Al. This would suggest either a temporal sequence in the formation of CAIs of CH and CR chondrites similar to the case of refractory objects in CM and CV chondrites or a spatial inhomogeneity in the distribution of ^{26}Al in the solar nebula. Work carried out in collaboration with Hawaii University.

(K.Marhas and J.N. Goswami)

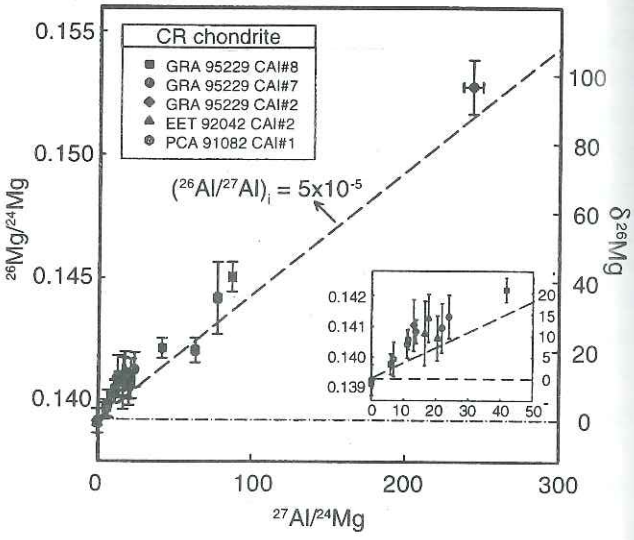


Fig. 6.7 Al-Mg isotopic systematics in refractory Ca-Al-rich Inclusions (CAIs) from several CR chondrites. The solid line represents the evolution for an initial $^{26}Al/^{27}Al$ value of 5×10^{-5}. The data for CR chondrites are consistent with this value. The inset is an enlarged view of data points near the origin.

Heat Source for Asteroidal Heating

The presence of ^{26}Al (half-life of ~ 0.7 million years) in the early solar system, was postulated as a possible heat source very soon after its discovery. The presence of ^{26}Mg excess due to decay of ^{26}Al was first demonstrated in CAIs from the Allende meteorite with an initial $^{26}Al/^{27}Al \sim 5 \times 10^{-5}$. Studies of CAIs from other primitive meteorites suggest that the initial distribution of ^{26}Al in the solar nebula was widespread and nearly uniform. After the recent discovery of ^{26}Al in eucrite Piplia Kalan, it was recognized that ^{26}Al may have played an important role as a heat source. To asertain the global role of ^{26}Al as a heat source during the early planet forming epoch several eucrites are studied for their Al-Mg systematics. For the eucrite A881394, the pyroxene shows normal Mg isotopic composition, while plagioclase with $^{27}Al/^{24}Mg$ values of ~ 400, show ^{26}Mg excess that correlate with $^{27}Al/^{24}Mg$ giving initial $^{26}Al/^{27}Al = (2.1 \pm 0.4) \times 10^{-6}$. Presence of ^{26}Al in these two eucrites confirm its role in early melting and differentiation of planetesimals.

The observed difference in ^{26}Al abundance between pristine CAIs and the eucrite A881394 translates into a time difference of ~ 3 million years between their formation and suggests that eucrite parent body (EPB) had accreted very early, and was sufficiently heated to experience melting and differentiation to produce some of the first basalts within three million years of the formation of the solar system

(G. Srinivasan).

Transport of Meteoroid from Asteroidal Belt

It has been proposed that asteroidal fragments were launched into earth-crossing orbit from one of the main orbital resonances within the asteroidal belt. Long-term (tens of million years) drift of asteroidal fragment due to diffusion induced by thermal forces may be responsible for placing these objects in the resonances. Such a drift should leave an imprint on the cosmic ray records preserved in some meteorites. We have carried out detailed study of cosmogenic records in the carbonaceous chondrite Kobe that appeared to have undergone a two-stage cosmic ray exposure history making it suitable for testing the drift hypothesis.

Based on data for cosmic ray produced tracks, noble gas isotopes and radio-nuclides (^{26}Al, ^{36}Cl, ^{41}Ca and ^{60}Co) we could reconstruct the formation and exposure history of this meteorite. The Kobe meteorite was initially ejected from a deep-seated layer from its parent asteroid as a meter-sized object and was exposed to cosmic rays in space for ~ 40-60 million years and the analyzed Kobe samples were shielded by $\geq$ 30 cm for most of this duration. A recent collisional event led to fragmentation of the original meter-sized meteoroid and Kobe underwent a second stage of exposure to cosmic rays as a small object (~ 20 cm in size) for about a million years prior to its fall on Earth. The first stage of exposure may be related to the proposed drift periods of tens of millions years towards resonance and the fragmentation event may have placed the recovered Kobe fragment in the resonance orbit. The short recent exposure is consistent with the predicted short transfer time to Earth for objects placed in the main resonance in the asteroid belt. Work carried out as a consortium effort with two groups from Japan and USA.

(N. Sinha and J.N. Goswami)

Studies of Recently Fallen Indian Meteorites

In recent years (e.g. 1991 to 2001) unusually large number of meteorites (~10) have fallen in India. Five falls have been recorded from Rajasthan alone, even though record of meteorite falls in last 200 years would predict one fall per decade for Rajasthan. These falls belong to different classes of meteorites with distinct chemical composition and varying cosmic ray exposure ages. Here we report our findings on three most recently fallen meteorites. These are Itawa Bhopji, L3/5 (May 30, 2000, Rajasthan), Devgaon, H4 (February 12, 2001, Bastar, M.P.) and Dergaon, H5 (March 2, 2001, Assam). Itawa Bhopji shows light and dark lithologies suggesting it to be a L type regolith breccia which are very rare (< 1%). Further, it shows neutron-induced effects and presence of solar gases suggesting a multistage exposure on the parent body. Other cosmogenic signatures such as

tracks, noble gases and radionuclides suggest it to be a small size (~11 kg) body with an exposure age of 19.6 Ma. The Devgaon (H4) meteorite was found to have exposure age of 101 Ma which is unusually high for a chondrite. The Dergaon (H5) meteorite has an unusually low K content in the range of 327 to 362 ppm, which is much below the average range of 725-860 ppm observed for H chondrites

(N. Bhandari, P.N. Shukla, A.D. Shukla, K.M. Suthar, S.V.S. Murty, V.K. Rai, R.R. Mahajan, G. Srinivasan and J.N. Goswami).

Heavy Nitrogen in Itawa Bhopji Chondrite

Itawa Bhopji L(3-5) chondrite is a regolith breccia having light and dark lithologies typical of gas rich meteorites. The light lithology sample has purely cosmogenic light noble gases and nitrogen (0.64 ppm N, $\delta^{15}N$=14‰) typical of L-chondrites. The dark lithology sample on the other hand, has solar Ne, large amount of radiogenic $^{129}Xe^*$ and most importantly a heavy nitrogen (5.9 ppm N, $\delta^{15}N$ = 446‰). The peak N release with $\delta^{15}N$ = 629‰ occurred at 800°C and is accompanied by large radiogenic $^{129}Xe^*$ release, while peak release of solar ^{20}Ne and trapped ^{36}Ar occurred respectively at 1000°C and 1600°C. In **Fig. 6.8**, release patterns of $^{15}N_{exc}$. (a measure of the amount of heavy N), ^{36}Ar and radiogenic $^{129}Xe^*$ are shown. Low temperature release of heavy N and its association with $^{129}Xe^*$, but not with solar ^{20}Ne or trapped ^{36}Ar clearly indicates the possibility that the heavy N is hosted in a halogen rich labile phase.

(S.V.S. Murty and R.R. Mahajan).

Trapped Gases in a Carbon Free Ureilite Meteorite

Ureilites are carbon rich achondrites. The carbon in ureilites is all pervasive and is extremely enriched in nitrogen and noble gases. Separation of pure silicate phases (free of carbon) is very difficult and the trapped gas contents in silicates are mostly inferred from mass balance between a bulk sample and the acid residue, which is mostly carbon, resulting in large uncertainties. The ureilite FRO90054 which is extremely low in carbon, provides an unique opportunity to investigate trapped gases in the silicate phases. A bulk sample analysis yielded ^{36}Ar which is about 100 times lower than in normal ureilites though the elemental ratios $^{36}Ar/^{132}Xe$=205 and $^{84}Kr/^{132}Xe$=1.9 are normal, clearly demonstrating that silicates in ureilites are extremely poor in trapped noble gases. Nitrogen on the other hand is not so. We find 11.8 ppm N with $\delta^{15}N$=21.8‰. Light nitrogen, typically found in ureilites (due to presence of diamond), is not present in FRO90054. Compared to other differentiated meteorites (HEDs and Angrites), N in silicates of ureilites is about an order of magnitude

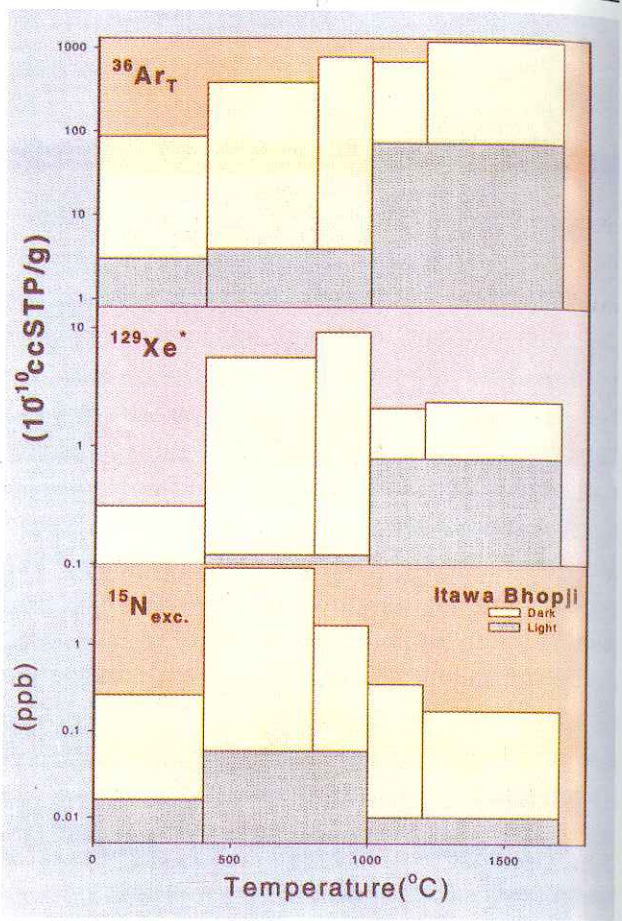


Fig. 6.8 Release pattern of $^{15}N_{exc.}$ is compared with those of radiogenic $^{129}Xe^*$ and trapped ^{36}ArT for the light and dark lithologies of Itawa Bhopji chondrite. Correlation of $^{15}N_{exc.}$ with $^{129}Xe^*$, clearly indicates that heavy nitrogen is hosted in a halogen rich labile phase.

higher, as well as isotopically heavier, hinting at some genetic differences. This work has been carried out in collaboration with Prof. U. Ott, Max-Planck- Institut für Chemie, Mainz, Germany.

(S.V.S. Murty and V.K. Rai)

Nitrogen in Individual Chondrules of Dhajala Meteorite

The origin of chondrules, a major component of chondritic meteorites is still enigmatic. Oxygen isotopic studies suggest that the precursors of chondrules are different from their host meteorite. Studies of size separated chondrules of Dhajala have revealed oxygen isotopic exchange of ^{16}O poor precursors with ^{16}O rich nebular reservoir. We have analyzed individual Dhajala chondrules for nitrogen and noble gases with the recently established laser microprobe, to understand the types of precursors and the environment of formation of chondrules. Data on four chondrules ranging in mass from 0.8 to 0.98mg showed N contents of 1.3 to 3.9ppm with $\delta^{15}N$ (corrected for cosmogenic contribution) of 33 to 163‰. Chondrules seem to have a heavy nitrogen component, which is much different than the bulk Dhajala value of 2‰, suggesting that the chondrule precursors have different N composition than the host, similar to the case of oxygen.

(S.V.S. Murty and R.R. Mahajan)

Studies on Permian/Triassic Boundary (PTB)

The Permian-Triassic transition during the Phanerozoic represents the most severe extinction event causing ~90% demise of the marine species. We have studied three sections from the Spiti valley of North West Himalaya. These sections comprise of a ferruginous band representing the PTB in contact with overlying Triassic limestones and underlying Permian shales. Among all these sections the one exposed at Attargoo was found to be most prominent in its thickness and its mineralogical variations. We have carried out a detailed sampling of this section. Preliminary field and laboratory studies show that the ferruginous band is 12 cm thick and consists of three parts, a nodular black pebbly part with gypsum crystals and iron in contact with the Permian shale, a chocolate color friable iron band (~ 2 cm) in the middle and yellow limonitic top portion (~ 3-4 cm) in contact with Triassic limestone. An important finding is the presence of quartz viens with strained quartz. ^{57}Fe Mössbauer spectroscopy studies are done to understand the nature of iron mineralogy at the boundary and compare it with those observed at Cretaceous/Tertiary boundary (KTB). The spectra were recorded at 295K and 12K. At 295K the spectra from all the three localities show a strong doublet superimposed on a weak magnetically split component. At 12K, the doublet intensity is reduced and magnetic splitting with a distribution of hyperfine magnetic field (HMF) appeared. The spectra suggest that each sample contains nanometer size particles of iron minerals (goethite and hematite). Further, the spectra for samples few centimeters above and below PTB do not show such a pattern indicating that magnetically ordered fine particle component at PTB is not a normal deposit sequence and is peculiar to PTB. The results show that at PTB the iron occurs mainly as nano particles of hematite and goethite with a broad size distribution and is similar to those observed at KTB indicating possibility of an impact at PTB as well. This work was done in collaboration with I.I.T., Kanpur and J.N.V. University, Jodhpur.

(P.N. Shukla, A.D. Shukla, B.K. Sharma and N. Bhandari).

Isotopic Signatures across the PTB

$\delta^{13}C$ excursions across the PTB were studied from three P/T sections (Lalung, Guling and Attargoo) located in Spiti Valley of North West Himalaya. The measurements were carried out in organic matter, kerogen fraction and inorganic carbonates. For all the sections the PTB is marked by a ferruginous band with underlying Permian shales and overlying Triassic limestones. The shale samples are poor in carbonates and have total organic carbon contents varying between 0.8 to 2.2%. The important observation is that a similar decrease of $\delta^{13}C$ of ~ 3‰ was observed for both organic and inorganic carbon across the PTB which marks the peak of

anoxicity as inferred from trace element studies. Similar observations have been reported from a P/T section in Japan where a 2‰ and 2.6‰ shift was observed for $\delta^{13}C$ for organic and inorganic carbon respectively. These studies suggest that there was a decrease of $^{13}C/^{12}C$ ratio of the two carbon reservoirs (organic and inorganic). Such large magnitude changes cannot be solely ascribed due to changes in ocean biology alone. Highly depleted ^{13}C sources such as methane hydrates could bring about such changes.

(P. Ghosh, S.K. Bhattacharya, A.D. Shukla, P.N. Shukla and N. Bhandari).

$^{40}Ar/^{39}Ar$ Chronology of the Deccan Province, Western India

We continued our efforts towards addressing the ongoing debate regarding the hypothesised link of the Deccan flood basalt (DFB) to the Cretaceous-Tertiary Boundary (KTB) events and the Reunion mantle plume by determining the $^{40}Ar/^{39}Ar$ ages of whole rock samples from the Narmada and Central regions of the Deccan Province. The $^{40}Ar/^{39}Ar$ ages for whole rock samples of basaltic flows and dykes from the well-constrained chemical and magneto-stratigraphic lava flow sequence in the Narmada region of the Deccan Volcanic Province **(Fig. 6.9)** clearly demonstrate that (i) the onset of Deccan volcanism was prior to 67 Ma predating the Cretaceous-Tertiary boundary (KTB, 65.2 ± 0.2 Ma), and (ii) the volcanism episodically continued for a long duration of at least 6 m.y.(up to 61 Ma) covering six magnetic chrons (30N-27N), thus resolving the longstanding inconsistency between the radiometric and paleomagnetic age constraints.

The ^{40}Ar-^{39}Ar age (66.0 ± 0.9 Ma) of a tholeiitic flow of Bhimashankar Formation from Giravali ghat is concordant with the evidence that the 1.8-2 km thick bottom segment of the exposed basalt flow sequence in the Western Ghats was extruded very close to 67 Ma. The ^{40}Ar-^{39}Ar age of Mahabaleshwar Formation flow from Buldana is 68.4 ± 0.8 Ma indicating that the onset of Deccan volcanism was prior to 68 Ma. These results suggest that it is likely that flows of similar chemistry

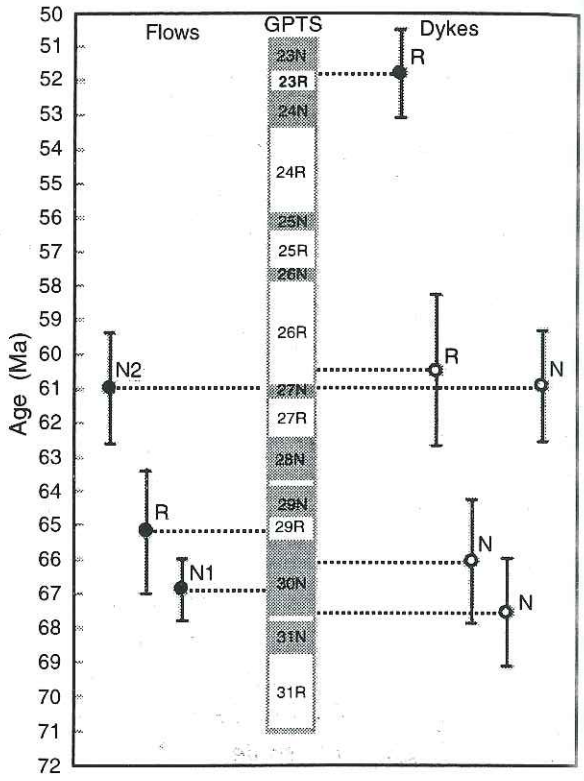


Fig. 6.9 $^{40}Ar/^{39}Ar$ inverse isochron ages (±2σ) for lava flows (●) and dykes (o) from the Narmada region plotted against the geomagnetic polarity time scale (GPTS) at 71-51Ma. N1 and N2 correspond to the lower and the upper normal flows, respectively. N - normal polarity, R - reverse polarity.

were erupted at different times and in different regions during a prolonged Deccan volcanic episode and warrant a more detailed investigation.

A far reaching implication of these result is that the existing hypotheses proposing a link amongst the mantle plume, Deccan flood basalt volcanism and Cretaceous-Tertiary (KT) mass extinction events need to be reexamined. Further, they also demonstrate that magnetostratigraphic record in a given area is not necessarily complete. This work was carried out in collaboration with Prof. K. V. Subba Rao, IIT, Mumbai

(Kanchan Pande, Sanjay Pattanayak and T R Venkatesan).

$^{40}Ar/^{39}Ar$ Ages of Sylhet Traps, Rajmahal-Bengal-Sylhet Igneous Province, Eastern India

Sylhet Traps of eastern India form part of a Large Igneous Province (LIP) that includes, besides Rajmahal and Bengal Traps (eastern India), the Bunbury Basalts (southwestern Australia) and basalts forming the central and southern Kerguelen Plateau. This LIP is believed to have come into existence during the Cretaceous Normal (K-N) superchron (118-84 Ma) as a result of a mid-Cretaceous (124-83 Ma) superplume activity. The ^{40}Ar-^{39}Ar dating of two Sylhet lava samples yield a weighted mean plateau age of 115.2 ± 3.3 Ma (n =2), which corresponds to the magnetic reversal interval ISEA*(M-1r)* in Aptian. This finding suggests that the Rajmahal-Bengal-Sylhet lavas could possibly have recorded such rare brief reversal events (*M0* and *M-1r*) within the K-N superchron.

(Kanchan Pande, S. K. Pattanayak and Jyotiranjan S. Ray)

Facilities

Computer Centre

Computer Centre is equipped with IBM RS-6000 SP computer having 16 processors and 32GB RAM to cater for high computing needs of scientists. The centre also has high-end graphics station, IBM RS-6000 Model 270 with 4 processors and 8GB RAM for visualization and other graphical applications. These servers are in addition to existing five IBM RS-6000/580 machines. These servers are connected to our high speed LAN to provide easy, fast and reliable access to more than 200 PC's and few workstations distributed throughout the laboratory. Also, other centres at Udaipur and Mt. Abu are connected to the high computing servers and PRL LAN on 64 Kbps BSNL leased line. Centre also provides Internet connection through a leased line. Thus full connectivity has been provided to users all the time from anywhere in the main campus, Thaltej, USO and Mt. Abu. Application softwares like IMSL, IDL, Mathematica, Data Explorer etc. have also been installed on the new computer to provide smooth transition and cater to the needs of scientific community in performing the mathematical and numerical calculations and in visualization of data. The provision of making colour slides and prints is available. The centre provides the consultations and other facilities including archival of file systems, system security, authorisation, updating the system softwares, third party softwares and public domain softwares. It also maintains internet connectivity and the local area network.

(P. S. Shah, G. Dholakia, M. Patel, J. Trivedi and R. Shukla)

Library

The aim of PRL library is to keep track of the latest developments in science and technology and to make relevant information available to the scientific community. The methods of information acquisition and dissemination are changing rapidly due to innovations in information technology. PRL library tries to keep pace with contemporary technology for the benefit of information seekers. PRL library consists of rich collection of books, journals, reports, scientific data, maps and articles in various forms. The total collection exceeds 50,000 items with more than 16,000 books and 30,000 bound volumes of journals. Other collection includes reports, Ph.D.

New Computational Facility at PRL

thesis, videos, CDs, PRL publications like reprints and technical notes. Besides circulation of books, journals and other documents, library provides to the readers services like photocopying, reference services, Internet search, SDI services and retrospective literature search, inter library loan, translation and procure books for individual book-grants etc.

For the year 2002 library has subscribed to 162 journals and periodicals, half of them are available online. About 262 books were added to the collection apart from large number of other documents like reports, data and maps for scientific use. A large number of Hindi books have been added to the PRL library collection to promote official language. More than 60 audio-visual documents were added to the collection. PRL library also subscribes to searchable databases namely STN and Uncover to get full-text articles from 18000 other journals on request to satisfy specific queries of the users. The articles are received by FAX for quick delivery to the users. Under Inter Library Loan (ILL) many requests were served for which PRL library worked closely with other libraries in and outside Ahmedabad.

All the library users very well received the Science Direct Service started last year and many important scientific research papers were downloaded. This provided immediate availability of research papers from the journals, which laboratory could not subscribe. The service has, therefore, been continued for the year 2002.

Library upgraded photocopying facility by replacing old photocopier machine with a state of art digital photocopier machine cum printer. During the year more than 4200 books and journals were issued and more than 4,30,000 photocopies were supplied using in-house facility and external resources. The library extensively uses computerization to serve the readers. For easy access, electronic resources are linked through library home page.

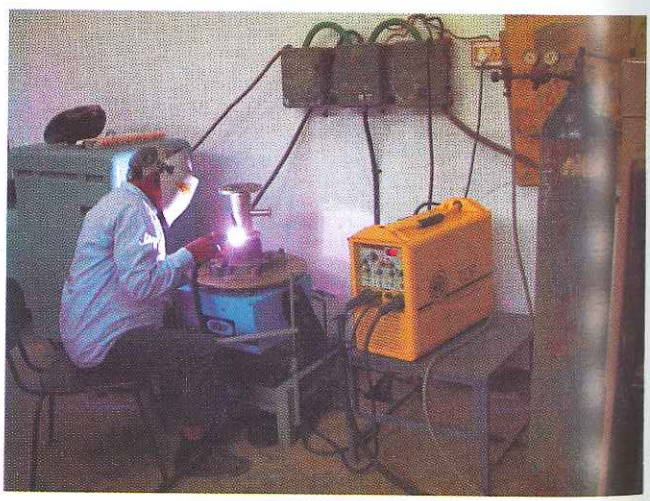
(S. M. Pradhan, U. Ghiya and N. Anilkumar)

Workshop

The workshop services provide support to scientists and engineers, in designing and fabrication of various mechanical components and systems for various scientific experiments. Workshop has most of the manufacturing and measuring equipments to carry out the precision work required by the user. The range of equipments varies from simple lathe machine to CNC lathe machine, milling and drilling machines. Workshop also has one of the best welding machines. Recently a TIG (Tungsten Inert Gas) welding machine has been procured. This machine is best suited for thin section welding of ferrous and non-ferrous metals.

Some of the major works carried out during the year are listed below:

1. Work of qualification model for two SOXS payload has been completed during the year. The requirements were stringent dimensional tolerance and surface finish as per space standards. These models were assembled, and mechanical integration of detector and control cards was done. These models are now being tested under test plan document of SOXS payload for GSAT-2. Engineering support required for flight model preparation is being provided to SOXS group.



Welding work, using the newly acquired TIG welding machine.

2. Optical Photometer for mesospheric studies was fabricated. The photometer consists of filter wheel of 450 mm diameter and can hold four filter using filter housing. This filter wheel can be rotated with high accuracy using stepper motor. Other system components such as Photo Multiplier Tube (PMT), Scanning mirror, etc are mounted properly on a sturdy structure. The final assembly is in progress.

Some other important work includes, 'cathode press' used in preparing 1mg of graphite cake for 'accelerator mass spectrometer', precise 'housing for grating' used with Vacuum UV monochromator, and a system for 'wind born salt collection'. All these were developed, fabricated and assembled with close interaction with the user group scientists/ engineers. Our CNC machine was utilized during the year to manufacture various precision components required for various projects in PRL.

During the year a large number of jobs from different groups/divisions were completed. Support to astronomy division was provided from our Thaltej workshop, where we have some of the machines installed specifically to carry out the work for the division. Workshop also provides support to Mt. Abu Infrared Observatory and Udaipur Solar Observatory from time to time.

(A. D. Bobra, G. P. Ubale, H. R. Vaghela and their team)

Engineering Services

The Engineering services render all technical services pertaining to civil engineering works and related building and laboratory services such as electrical, air-conditioning, internal telephone system, elevators and maintenance of all the laboratory, office, residential buildings in various campuses. These include architectural planning, designing, estimating and execution of various civil works, landscaping, horticultural development, interiors and furnishings of buildings and structures of all the six campuses – PRL main campus, Navrangpura Staff Quarter Campus, Thaltej Campus, Mt. Abu Campus, Udaipur Campus and Vikramnagar Staff Quarter Campus. Site preparation works were executed for installation of sophisticated research equipments by meeting with all special requirements. The major work undertaken during the year has been:

1. The old passenger lifts have been replaced with new pair of lifts of modern design which are energy efficient and thus expected to give saving in electricity.
2. The work on modification of lab space in room No.251 had been taken up.
3. Spacenet installation work also had been taken up.
4. Erection of new cooling tower for central A/c Plant is under progress.
5 Construction of Guest House Annexe & Eight 'C' type quarters at Mt. Abu is under progress.
6. Land at Udaipur has been acquired to develop Guest House and Staff Quarters.

(R. N. Mishra, D. H. Jokhakar, K. V. K. Reddy, S. K. Bhavsar and their team)

Aluminizing-cum-ITO Coating Facility at Mt. Abu IR Observatory

A high vacuum coating facility has been established at Mt. Abu IR Observatory for aluminizing the 1.2 m telescope mirrors, and for depositing transparent conducting caotings of indium-tin-oxide (ITO) on polyamide sheets for satellite applications of VSSC Trivandrum.

Alluminizing facility developed at Mt. Abu Infrared Observatory

The coating plant has been manufactured by M/S Vacuum Instruments Company, Delhi; and, has been commissioned recently. The coating chamber is a SS vessel of 1.5m diameter and 1.5m length. It is fitted with all the evaporation gadgetry like a substrate holder, a number of Al (and ITO) vapour sources, a vapour shutter, a quartz crystal thickness monitor, an ion-bombardment cleaning arrangement, a rotary jig for ITO coatings, and view-ports. It can attain a vacuum of ~10^{-5} mbar employing a combination of a rotary pump, a booster pump and a diffusion pump connected through a refrigerator-cooled Chevron baffle. The attainable uniformity of film thickness on a f/3 substrate of 1.2 m diameter is ~ 8 %.

(S. D. Rawat, N. M. Ashok and B. G. Anandrao)

Honorary Fellows

Honorary Fellows

Professor J.E. Blamont

Acad. V.L. Ginzburg

Professor A.M.J. Tom Gehrels

Professor D. Lal

Professor P.R. Pisharoty

Professor M.G.K. Menon

Professor U. R. Rao

Prof. P. Crutzen

Prof. K. Kasturirangan

Prof. A. Hewish

Academic Faculty

Academic Faculty

Name	Specialisation	Academic Qualification
Prof. G. S. Agarwal FNA, FASc, FNASc	Quantum Optics, Nonlinear Optics and Laser	Ph D Rochester Univ. (1969)
Prof. N. Bhandari FASc, FNASc	Planetary Physics	Ph D TIFR Bombay Univ. (1967)
Prof. S. Krishnaswami FNA, FASc, FNASc	Aqueous Geochemistry and Nuclear Oceanography	Ph D TIFR, Bombay Univ. (1974)
Prof. A. R. Prasanna	General Relativity and Astrophysics	Ph D Poona Univ.(1970)
Prof. D. P. Dewangan	Atomic and Molecular Physics	Ph D Calcutta Univ. (1973)
Prof. J. N. Goswami FNA, FASc, FNASc	Solar System Studies (Pre - Solar Processes)	Ph D PRL, Gujarat Univ. (1978)
Prof. V. K. B. Kota	Nuclear Physics	Ph D Andhra Univ.(1977)
Prof. A. S. Joshipura FASc	Particle Physics	Ph D Bombay Univ. (1979)
Prof. A. K. Singhvi FNA, FASc, FNASc	Palaeoclimatology and Geochronology	Ph D IIT, Kanpur (1975)
Prof. S. K. Bhattacharya FASc	Isotope Geochemistry	Ph D PRL, Gujarat Univ. (1980)
Prof. V. B. Sheorey	Theoretical Atomic Physics and Non linear Dynamics	Ph D Univ. College, London Univ.(1968)
Prof. S. D. Rindani	Particle Physics	Ph D IIT, Bombay (1976)
Prof. Harish Chandra	Ionospheric Studies and Dynamics of Middle Atmosphere	Ph D PRL, Gujarat Univ. (1970)
Prof. B. G. A. Rao	Spectroscopic Diagnostic in Astrophysical Plasmas	Ph D PRL, Gujarat Univ. (1978)
Prof. Shyam Lal FASc	Atmospheric Chemistry of Trace Gases	Ph D PRL, Gujarat Univ. (1982)
Prof. R. Ramesh FASc	Isotope Geochemistry	Ph D PRL, Gujarat Univ. (1984)
Prof. M. M. Sarin FASc	Geochemistry and Oceanography	Ph D PRL, Gujarat Univ. (1985)
Prof. P. Venkatakrishnan	Solar Physics	Ph D, Bangalore Univ. (1984)
Dr. Hemant H. Dave	Laser Spectroscopy and Space Instrumentation	Ph D, Univ. of Lowell, Mass., USA (1980)

Name	Specialisation	Academic Qualification
Dr. S. P. Gupta	Electrodynamics of Middle Atmospher	Ph D PRL, Gujarat Univ. (1971)
Dr. R. E. Amritkar FASc	Nonlinear Dynamics & Chaos	Ph D IISc, Bangalore (1978)
Dr. U. C. Joshi	Star Formation, AGNS and Comets	Ph D Kumaun Univ. (1981)
Dr. H. S. S. Sinha	Upper Atmospheric and Ionospheric Studies	Ph D PRL, Gujarat Univ. (1977)
Dr. Utpal G. Sarkar	Particle Physics	Ph.D Calcutta Univ. (1984)
Dr. S. K. Gupta FASc	Geophysics, Hydrology	Ph D IIT, Bombay (1974)
Dr. P. N. Shukla	Geochemistry	Ph D IIT, Kanpur (1977)
Dr. D. R. Kulkarni	Computational Physics	Ph D M S Univ (1972)
Dr. P. Sharma	Geophysics and Hydrology	Ph D PRL, Gujarat Univ. (1977)
Dr. N. M. Ashok	Infrared Observations	Ph D PRL, Gujarat Univ. (1983)
Dr. T. Chandrasekhar	Optical & Infrared Astronomy	Ph D PRL, Gujarat Univ. (1982)
Dr. A. Jayaraman	Atmospheric Aerosols and Radiative Studies	Ph D PRL, Gujarat Univ. (1985)
Dr. Hari Om Vats	Ionospheric Physics and Radio Astrophysics	Ph D PRL, Gujarat Univ. (1979)
Dr. S. V. S. Murty FaSc	Isotope Cosmochemistry	Ph D IIT, Kanpur (1981)
Dr. A. K. Ambastha	Solar Plasma Physics	Ph D PRL, Gujarat Univ. (1981)
Dr. J. Banerji	Laser Physics	Ph D City Univ.(New York)(1982)
Dr. K. S. Baliyan	Atomic Physics & Atomic Astrophysics	Ph D Roorkee Univ.(1986)
Dr. Kanchan Pande	Geology, Geochronology	Ph D PRL, Gujarat Univ. (1990)
Dr. Ashok K Singal	Radio Astronomy	Ph D TIFR, Bombay Univ.(1986)
Dr. D. P. K. Banerjee	Astronomy & Astrophysics, High Resolution Spectroscopy	Ph D PRL, Gujarat Univ. (1991)
Dr. K. P. Subramanian	Experimental Atomic and Molecular Physics	Ph D PRL, Gujarat Univ. (1987)
Dr. Syed Aftab Haider	Planetary and Cometary Atmospheres	Ph D Banaras Univ. (1984)

Name	Specialisation	Academic Qualification
Dr. P. Janardhan	Radio Astrophysics	Ph D PRL, Gujarat Univ. (1992)
Dr. R. Sekar	Upper Atmospheric and Ionospheric Physics	Ph D PRL, Gujarat Univ. (1991)
Dr. J. R. Trivedi	Geochronology	Ph D PRL, Gujarat Univ. (1991)
Dr. Subhendra Mohanty	Astroparticle Physics	Ph D Wisconsin Univ. (1989)
Dr. Debi Prasad	Solar Cometary Physics	Ph D PRL, Gujarat Univ. (1990)
Dr. S.C. Tripathy	Solar Physics	Ph D PRL, Gujarat Univ. (1993)
Dr. Rajmal Jain	Solar Physics	Ph D PRL, Gujarat Univ. (1983)
Dr. J. R. Bhatt	Astrophysics	Ph D Gujarat Univ. (1992)
Dr. A. Lakshminarayan	Nonlinear Dynamics & Quantum Chaos	Ph D State Univ.,New York (1993)
Dr. H. Mishra	Strong Interaction Physics & Nuclear Astrophysics	Ph D, Utkal Univ. (1994)
Dr. G. Srinivasan	Cosmochemistry	Ph D, PRL, MS Univ. (1995)
Dr. R. Rangarajan	Particle Physics & Cosmology	Ph D, Univ. of California, Santa Barbara (1994)
Dr. S. Ramachandran	Atmospheric Physics	Ph D, PRL, MS Univ. (1996)
Dr. Varun Sheel	Modelling of Lower Atmosphere	Ph D, PRL, Guj. Univ. (1996)
Dr.(Ms.) N. Srivastava	Solar Physics	Ph D, PRL, Ravi Shankar Shukla Univ. (1994)
Dr. Bhas Bapat	Atomic Collisions	Ph D, TIFR, Mumbai Univ. (1997)
Dr. Bimalendu Deb	Quantum Optics	Ph D, Jadavpur Univ. (1997)
Dr. Angom D. Singh	Atomic Physics	Ph D, IIA, Bangalore Univ. (1998)

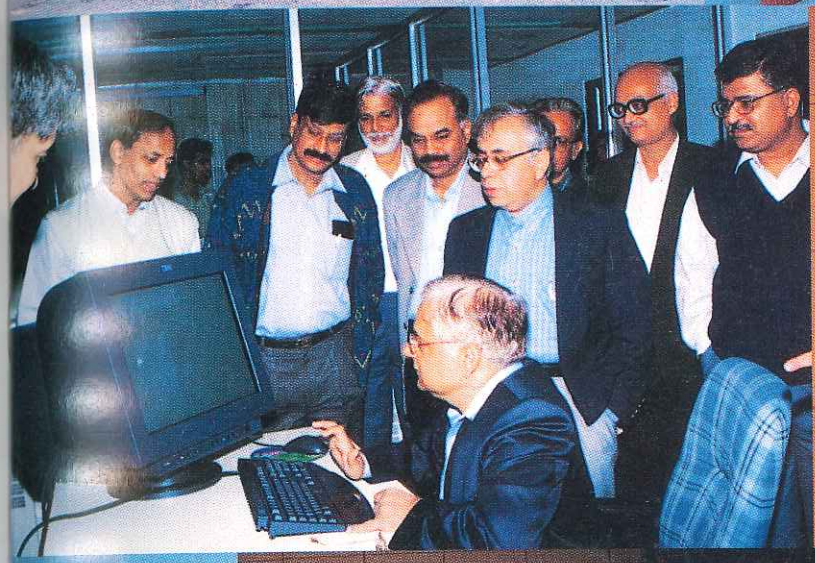
Inner Back Cover :

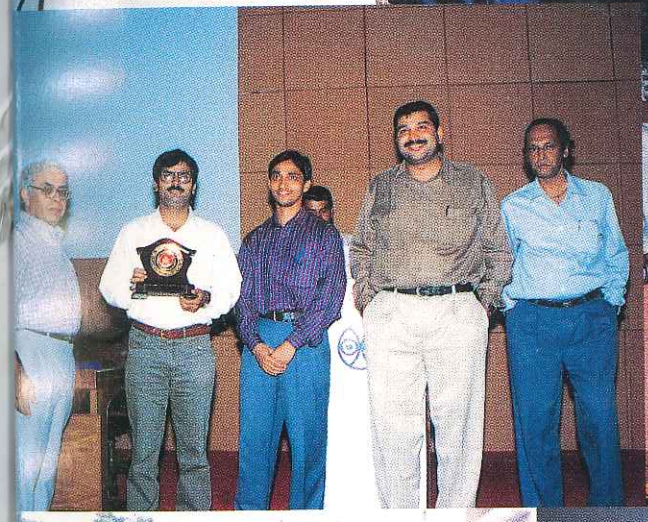
Glimpses of a few events at PRL

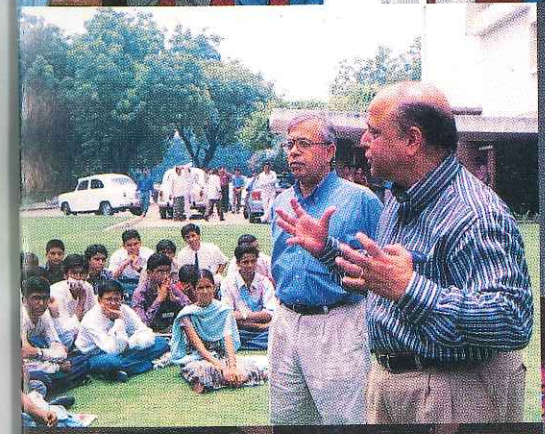
Back Cover :

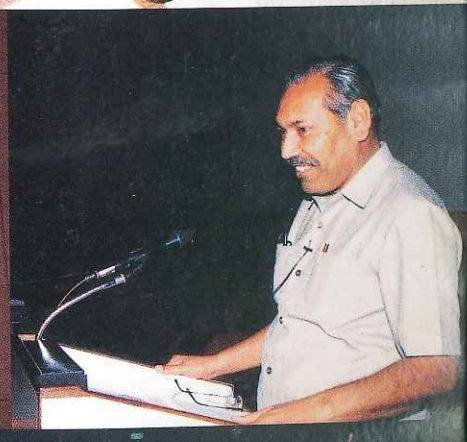
Glimpses of the Silver Jubilee Celebrations of the Udaipur Solar Observatory


WORKSHOP ON 'METEORITES, ASTEROIDS & PLANETS'









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रजत जयंती समारोह

Silver Jubilee Celebration