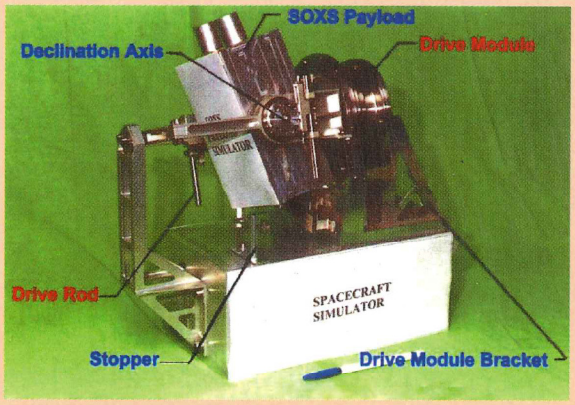
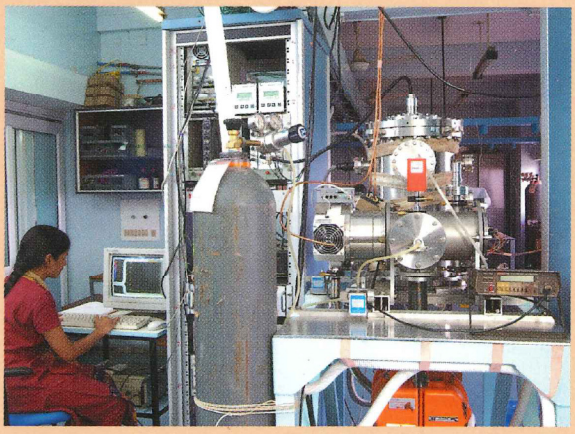
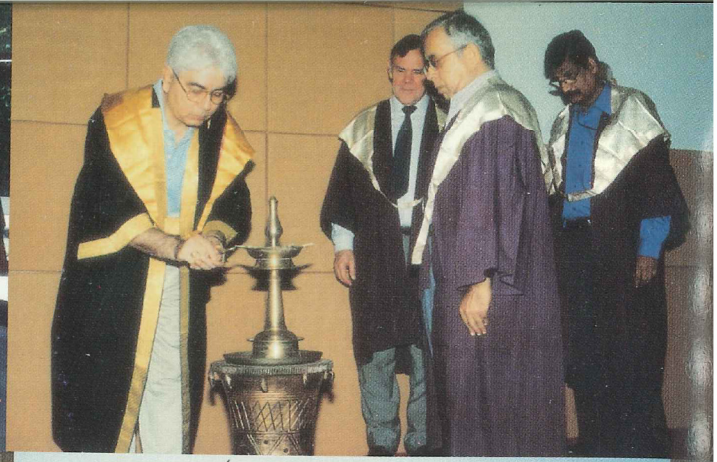
# वार्षिक रिपोर्ट
# Annual Report
# 2002-2003



## भौतिक अनुसंधान प्रयोगशाला, अहमदाबाद
## Physical Research Laboratory, Ahmedabad




CENTRE FOR SPACE SCIENCE AND TECHNOLOGY
EDUCATION IN ASIA AND THE PACIFIC (CSSTEAP)
(AFFILIATED TO THE UNITED NATIONS)
VALEDICTORY FUNCTION
POST GRADUATE COURSE ON SPACE AND ATMOSPHERIC SCIENCES
APRIL 30, 2003
PHYSICAL RESEARCH LABORATORY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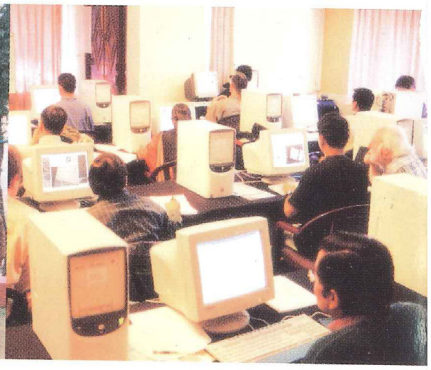

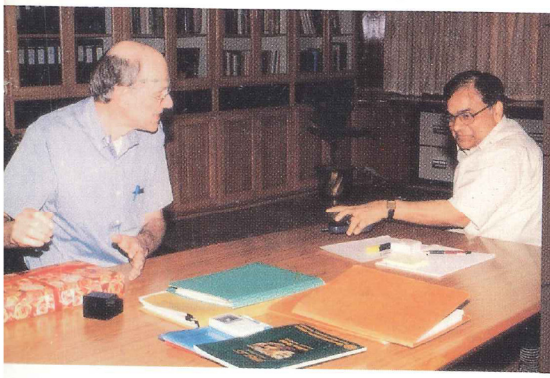

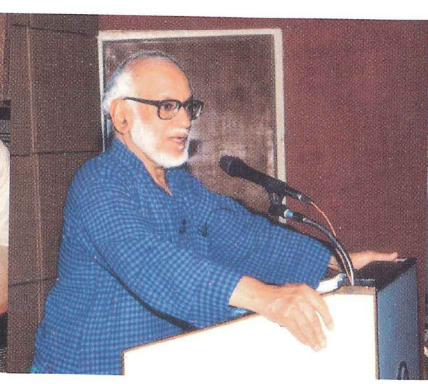

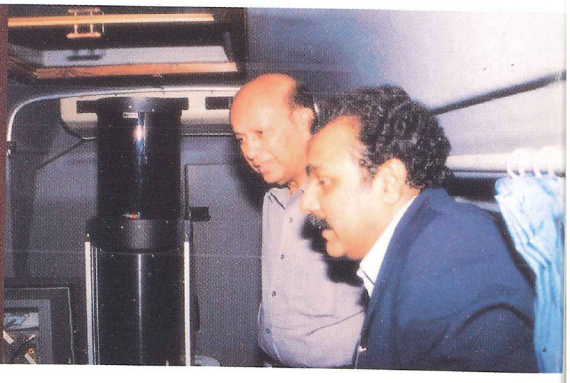

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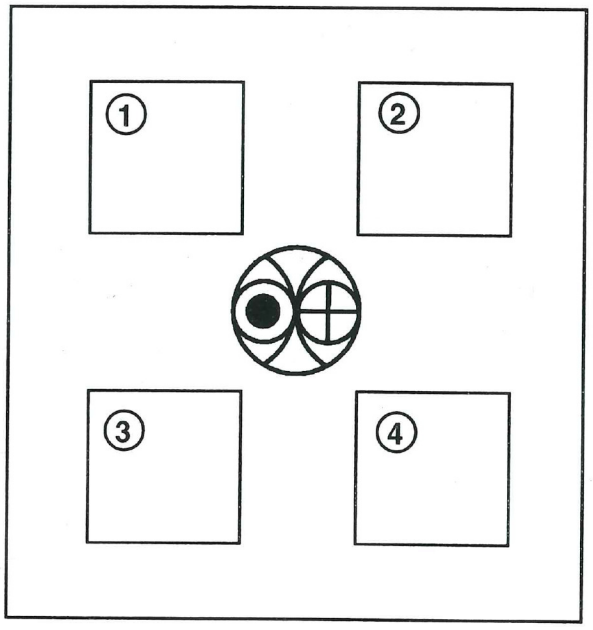


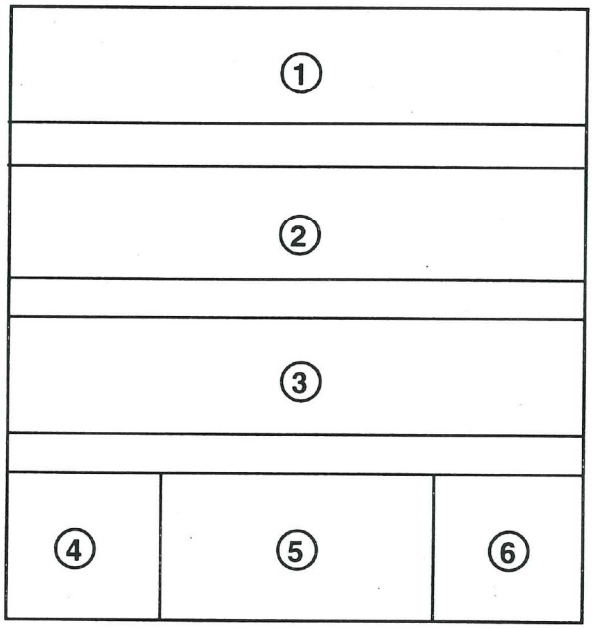


***Title Cover :***

1. *Laboratory for preparation of extraterrestrial samples like meteorites and lunar rocks for mineralogical and petrographic examination and study of thin reflectance spectra.*
2. *The Solar X-ray Spectrometer (SOXS) Low Energy Detector payload on the GSAT-2 Indian Mission, launched by GSLV D2 rocket.*
3. *Momentum Spectrometer for measuring photoionisation cross section of atomic oxygen.*
4. *Mobile micro pulse lidar to measure aerosol distribution over different geographical environments.*

***Inner Title Cover :***

1. *Valedictory function of 3rd Space Science Course of the Center for Space Science and Technology Education in Asia and the Pacific (CSSTEAP).*
2. *Workshop on Data Processing from the Chandra and XMM - Newton Space Mission.*
3. *Prof. J. Eberly, Prof. M.G.K. Menon and Prof. U.R. Rao at PRL.*
4. *Inaugration of Satish Dhawan Memorial Lecture; Hindi Book Exhibition and Workshop on 30 years of Radio Sounding*

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# Contents

# Introduction

Physical Research Laboratory (PRL) completed 55 years in November, 2002. The year 2002-2003 was a milestone in many ways. Quite a few new programmes, which were initiated some years back and pursued vigorously, matured fully. One of the exciting activities was the SOXS payload on the GSAT - 2 Indian mission, launched by GSLV - D2 rocket. Very good quality data are being received on solar flares which, we hope, will further assist in understanding the explosive phenomena on the Sun, in particular the solar flares.

A new dimension has been added to the programme on stratospheric aerosol, one of the key research programmes in atmospheric sciences. Observations of the vertical distribution of aerosols and cloud structures to study aerosol - cloud interaction over different regions using the newly acquired mobile micro pulse lidar are being pursued vigorously. This system can be used to study the height profile of aerosol optical depth from ground to about 15 km, both during day and night and over diverse geographical regions. Further, in order to understand the changes in ozone in the troposphere, which are caused by natural as well as man made activities, PRL has initiated a new programme at Ahmedabad to measure the vertical distributions of ozone and humidity simultaneously using balloon-borne sensors.

Coordinated radar and airglow measurements were planned and carried out during September, 2002 and March, 2003. The new Mesospheric Scanning Photometer, which has been recently developed in PRL, was operated in conjunction with the Indian MST Radar during those periods. Nocturnal emission intensities of 630.0 nm and 777.4 nm reveal large (macro) and small time scale (micro) temporal variations. The macro variations are usually associated either with F region layer movements or with the movement of equatorial plasma fountain. The micro variations are identified to be due to plasma bubble or enhancement structures.

The Indian Space Research Organisation (ISRO) is considering sending a scientific mission to Moon to study its early evolution based on chemical, mineralogic and photogeologic mapping. Scientists from PRL took an active part in formulating scientific objectives for the mission and preparing the feasibility report as a part of the Moon Mission Task Force. A presentation was made on scientific challenges of Moon Mission which defined the goals for the Indian Moon mission. PRL has already initiated a Planetary Sciences and Exploration Programme and it is expected that science aspects, such as building payloads, their laboratory calibration and analysis of the data which will be sent back by the Indian Moon Mission - CHANDRA, will be carried out as part of this programme.

Scientists from our solar systems studies group have found unique evidence of short-lived $^{10}Be$ in hibonite grains from the Murchison meteorite. In a paper published in Science, they speculate that the most plausible source of $^{10}Be$ is energetic particle irradiation of gas and dust in the solar nebula.

A new laboratory for photoelectron and photo-absorption studies has been established. Our scientists have built a recoil ion momentum spectrometer, in which photo-ionisation of atomic oxygen and dissociation of molecules will be studied. Atomic oxygen is generated from the molecular counterpart by microwave discharge and the mixture is subjected to photo-ionisation. The idea is to momentum resolve the ions from the photo-ionisation reaction and separate the contaminant contribution to the atomic ion yield from dissociative ionisation of the molecule.

Observations have been made by our astronomers at South African Astronomical Observatory on the inner regions of the Galactic bulge. These revealed, for the first time, a very detailed view of the region. The 1.4 m survey facility telescope utilizes three 1k x 1k infrared detector arrays for the three near-infrared bands.

The collaborative project on the Infrared Survey of the Inner Milky Way, between PRL and the Institut d'Astrophysique, was successfully completed in March 2003. With the usage of data from ISO and DENIS surveys and Mt. Abu, many important contributions were made, such as finding the (near and mid-) infrared extinction map of the Galactic central region and making of a near and mid-infrared catalog of nearly 100,000 sources.

In collaboration with scientists at Radioastronomisches Institut, Bonn, Germany, the PRL

radio astronomy group has made studies on fine structure of solar wind turbulence using coronal radio sounding experiments with the Ulysses spacecraft. This study has revealed continual deformation of solar wind density irregularities.

The data from KamLand was used to show that such measurements (1) could provide an independent determination of the age of the universe; (2) could be used to determine neutrino properties more precisely and (3) could ultimately test models for the origin of geothermal neutrinos. PRL has initiated new work in quantum information science as well as in Bose condensates. Various quantum protocols are being developed. The entanglement between two Bose condensates has been produced. Further the role of entanglement in quantum chaos has been demonstrated. Studies of the newly discovered left handed materials have also been initiated.

**A summary of scientific achievements is given on page 5.** A total of *one hundred and forty two* papers have been published in high impact journals, of which *one hundred and eighteen* 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 *seventy-one* were invited talks. At present, PRL has *forty* research scholars and seven post-doctoral fellows besides other visitors working in various disciplines. *Four* Ph.D. theses were submitted. The topics covered were study of trace gases in the tropical troposphere; anomalous fractionation of oxygen isotopes in photochemical reactions; some studies in violation of symmetry principles in particle physics and dynamics of cold atoms in high quality cavities.

Some of our scientists have received prestigious awards and honours such as the *Young Scientist Awards* from different national and international bodies; *Fellowships of the National Academy of Sciences; Geochemical Society-European Association of Geochemistry; the Third World Academy of Sciences and the American Geophysical Union.*

PRL organised an International Workshop, under the Chairmanship of Dr. Peter Wilmore, on *Data Processing from the Chandra and XMM-Newton Space Missions* at Udaipur during January 13-24, 2003. The main objectives of this workshop were to provide young astronomers in the Asia-Pacific region all necessary information on (a) basic astronomy and a glimpse of the most challenging scientific problems in X-ray astronomy; (b) how to access state-of-the-art scientific data of the Chandra and XMM-Newton Space Mission and the required software; (c) some standard mathematical and statistical techniques essential for data analysis and (d) practical demonstration of downloading the data and the software and its analysis. Scientific topics, which were covered in this workshop, include galaxy clusters and groups, galaxies, active galactic nuclei, galactic sources, X-ray emission from hot plasmas and X-ray from solar system objects. Twenty-five participants from Asia-Pacific countries attended the workshop.

*50 years of radio soundings* over Ahmedabad were completed this February. Ahmedabad is the only station in the anomaly crest region in India which has provided long series of good quality ionospheric data. In view of the very significant contributions that have come out of the radio soundings and other ground-based radio and optical experiments and its role in future programmes, like CRABEX, space weather and ionospheric tomography, a 3-day Workshop was organized at PRL during 6-8 February, 2003. Prof. U. R. Rao spoke about the early history of PRL and the role it played in the shaping of aeronomy and space research in India. About fifty reputed scientists from major research institutes and universities in India attended.

The *3rd Space Science Course of the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP)* was conducted at PRL. Eleven participants from three countries namely India, Mongolia and Uzbekistan attended the nine months' course. The Space Science Course of the CSSTEAP is a two-stage program leading to a M. Tech. degree in Space Science from the Andhra University, Visakhapatnam, India. The first stage of the course was of nine months' duration and was conducted at PRL, Ahmedabad during 1st August 2002 to 30th April 2003. The first phase had four modules consisting of lectures, experiments, seminars and a pilot project. The course curriculum covered broad disciplines of Space Science. The second stage of this course is of one-year duration and would be conducted in the home country of the participant during 2003-2004.

The pilot project of two months' duration was conducted towards the end of the first stage in an attempt to lay the foundation of one year project at home and was undertaken in consultation with the supervisors in India as well as in the home country. During the two- month period, each of the participants worked under the guidance of one Indian supervisor and got (a) the guidance on the line of action to be pursued at home and (b) all sources and access procedures for the experimental data and necessary software tools, etc.

The *Joint Entrance Screening Test - 2003* (JEST-2003) for admission to Ph.D. programme was coordinated this year by PRL. JEST is a multi-institutional collaborative arrangement in which there are 14 participating institutions at present. In Physics, from the 3328 applications received, 2731 candidates took the written test this year.

PRL organised to review the progress of the *RESPOND* Programme in Space Sciences.

Under the joint venture between the Embassy of France, Alliance Francaise of Ahmedabad and Physical Research Laboratory, a public lecture entitled *Are we alone in the Universe?* by Mr. Alfred Vidal-Madjar, Director of Research, Institute of Astrophysics, Paris was arranged at PRL. A movie on Sunstroke was also screened.

As a part of our continuing efforts to promote and encourage college students in pursuing science, a *Summer Training Programme* for Graduate and Post Graduate students in Science was held during May 15 - July 14, 2002. The training programme aimed to acquaint and expose the students with research activities of PRL. Each student was placed under the guidance of a faculty member to carry out a scientific project. The trainees were also taken to Mt. Abu and Udaipur Solar Observatory campuses. Thirty-six first year M.Sc. students and five B.Sc. students participated in the programme.

As a part of the implementation and progressive use of Hindi in PRL, the *Hindi Week* was celebrated at PRL during September 16 - 20, 2002. The highlights of the celebrations included quiz, essay, elocution, Hamara Karya, self-written poetry competitions etc. The special attraction of this year's celebration was the inaugural lecture delivered by Shri R. N. Tripathi, who was representing Rajya Bhasa chief, Ahmedabad. Another unique activity of the Hindi Day celebrations was a *Seminar on Paperless Office*. The seminar was inaugurated by Shri R. P. Soni, Director, GLS Institute of Information Technology. Other invited speakers included Shri G. F. Vora from Space Applications Centre and Dr. Dilip Ahalpara from Institute for Plasma Research. About forty- eight staff members participated and thirteen papers were presented. On this occasion, an Exhibition of Hindi Books in PRL was arranged which was inaugurated by Shri R.P. Soni. The Hindi Book Exhibition was attended by a large number of visitors.

With the possibility of an Indian Mission to Moon in the near future, in which PRL is an active participant, a one-day *Technical Seminar in Hindi on Moon Mission - Somayana* was held to discuss the technical details of the mission.

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. More than three hundred and fifty teachers and students attended the celebrations. About two hundred students participated in the Science Quiz which formed the main part of the programme. 50 Years of DNA - 25 years of IVF - The Blueprint of Life was the theme for the National Science Day for this year. Further, lectures on Indian Space Programme and the Indian Moon Mission; Physics Olympiads; Physics for Fun and Learning Science were arranged. On this occasion PRL Scholarships from the Aruna Lal Endowment Fund, established by Prof. D. Lal, Honorary Fellow and former Director, were awarded to five 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 its guidance and advice.

Director

# PRL in a Nutshell

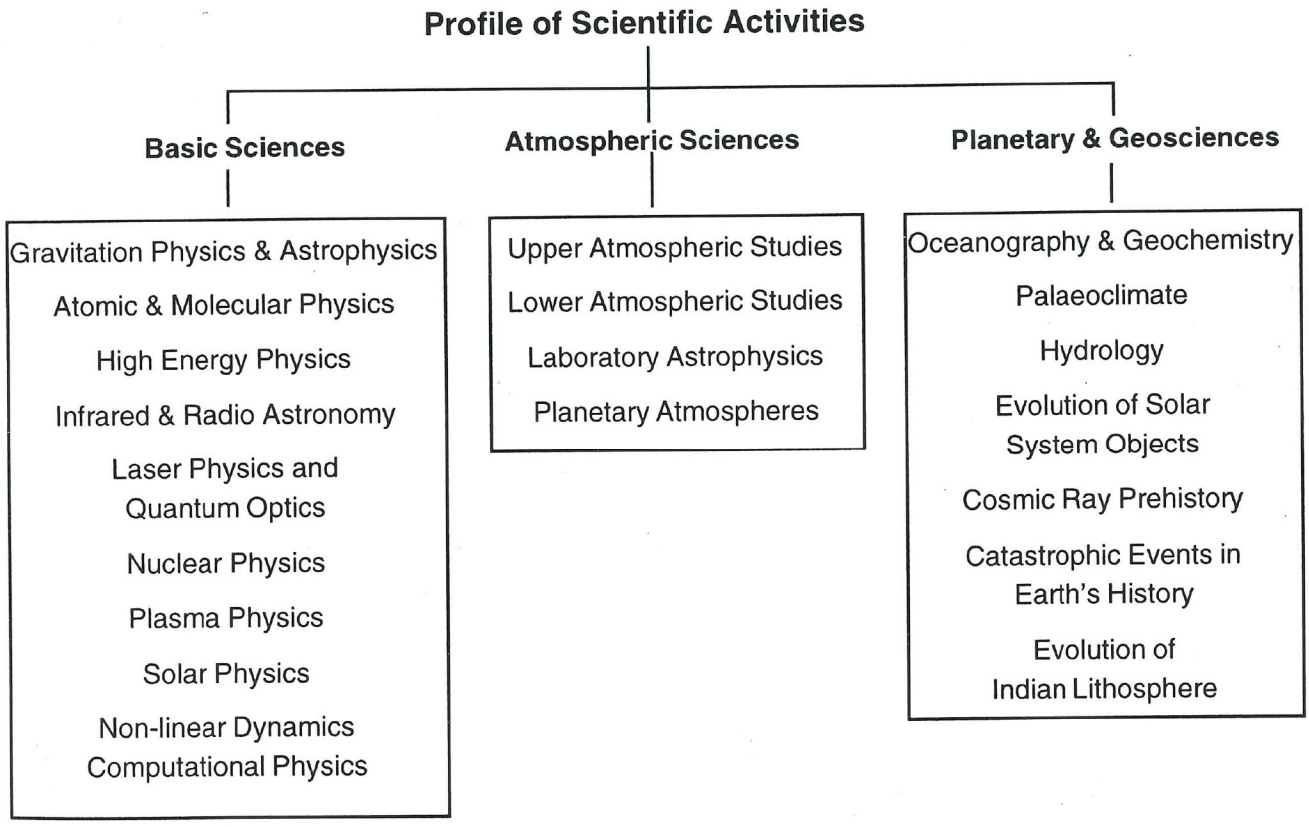
# Scientific Achievements

The research programmes of the laboratory can be broadly grouped as shown in the profile below. Some of the important research contributions are summarised.

## Astronomy and Astrophysics

The group has made decisive strides in reconfirming its pioneering role in Near-Infrared Astronomy in our country. A number of important and significant observations have been made not only using our facility at Mt. Abu Infrared Observatory but also facilities elsewhere in the world. The group has meticulously monitored the infrared spectra of the outburst source V838 Mon - an object that is classified as a new type of eruptive variable. The Mt. Abu IR observations put constraints on the nature of V838 Mon. Lunar Occultation technique which had been yielding a number of interesting results, had used a single detector so far. Efforts to use NICMOS 3 array for this purpose have yielded very good results, whereby increasing the detection sensitivity of the technique. The near-infrared broad and narrow band imaging of a massive star forming region in Gemini OB1 revealed remarkable molecular hydrogen emission knots and jets emanating from a young stellar object. These are the infrared counterparts of the optically classified Herbig-Haro objects. Observations made by the group at the South African Astronomical Observatory on the inner regions of the Galactic bulge revealed for the first time a very detailed view of the region. The 1.4 m survey facility telescope utilizes three 1k x 1k infrared detector arrays for the three near-infrared bands. This survey made simultaneously in JHK bands, is expected to give new insight into the Galactic bulge region.

The collaborative project on the Infrared Survey of the Inner Milky Way, between PRL and the Institut d'Astrophysique was successfully completed on 31 March 2003. With the usage of data from ISO and DENIS surveys and to some extent Mt. Abu facility, many important contributions were made through this collaboration, such as finding the (near and mid-) infrared extinction map of the Galactic central region, and making of a near and mid-infrared catalog of nearly 100,000 sources.



In addition to the infrared astronomy, a number of studies are being carried out in radio astronomy using the GMRT/ORT facilities of TIFR and also facilities in Brazil. Using the Brazilian radio telescope, observations at several frequencies have been made to study the implications of coronal electron density model on the gradient of coronal rotation with altitude. In collaboration with scientists at Radioastronomisches Institut, Bonn, Germany, the PRL radio astronomy group has made studies on fine structure of solar wind turbulence using coronal radio sounding experiments with the Ulysses spacecraft. This study has revealed continual deformation of solar wind density irregularities. Although, the Sun has been studied extensively in the metric and microwave regions, which has led to a fairly good understanding of prevailing plasma phenomena, there is hardly any study made at decimetric wavelengths (500-1000 MHz). Using the GMRT facility of TIFR, our group has made the first set of snapshot images with 16 sec cadence at 1060 MHz of a complex flare region on November 17, 2001. This flare is associated with an M 2.8 solar flare and a partial halo CME. Using GMRT facility, a unique quasar was discovered which seems to be the only one beyond a redshift of 1 with a giant size in radio wavelength (~ 1.8 Mpc). This result has important implications on the unified models for radio galaxies and quasars.

## Solar Physics

Velocity oscillations in low degree global solar p-modes were found to have more power on the low frequency side while intensity oscillations have more power on the higher frequency side. The observed frequency shift of local modes is a function of location on the solar disk. Variation in intermediate degree global p-mode frequencies over the solar cycle 23 reveals that the mean frequency shifts are equally correlated with both magnetic and radiative indices even at the shorter time scales. The intermediate degree modes adjust to changes in the activity measured on time scales of 18 to 27 days. Rapid variations of solar magnetic fields which appear to be enhanced significantly above the background variability have been observed within solar active regions. Variations in amplitude, frequency and width of acoustic modes have been found to be associated with observed flares in solar active regions, and the peak in flare index has been found to coincide with that in the amplitude. A study of activation phase of filament indicates that the process of detachment of barbs or the footpoints, results in eventual eruption of the filament, the process being slow for quiescent and fast for active filaments. Analysis of images taken in He II line show that the transition region network elements have a lifetime of 27 hours and size of 25000 km respectively, while correlation with extrapolated magnetic field implies a formation height of about 3000 km. A good correlation between the He II network brightening and the photospheric magnetic field has been found. A study of geoeffective CMEs observed during 1996-2002 shows the travel time of the CMEs is strongly dependent on their initial speeds; geo-effectiveness of such a CME is mainly determined by the strong coupling between the solar wind plasma and orientation and magnitude of the interplanetary magnetic field. Simulations of the maximum possible compensation performed by an adaptive optics system have been used to arrive at the optimum size of a solar telescope for high angular resolution studies of solar features.

## Submillimeter Science and Solar X-ray Astronomy

The activities of the submillimeter group are mainly focussed on developing state-of-the art instrumentation using techniques to study the inter stellar dust, star formation and planetary atmosphere. Work on the development of highly sensitive heterodyne receiver system, detectors and a narrow band IF state-of-the-art Chirp Transform Spectrometer for IF signal processing is underway.

In the high sensitive heterodyne receiver system, sub-millimeter group is using Optically Pumped Molecular Laser (OPML) as a local oscillator, which is designed on the basis of two independent and linear cavities configuration. As a result, whole system becomes very bulky and undesirable for space based applications. Therefore to make the system most suitable for space applications, we are trying to upgrade the existing OPML. In the same regard, the group is trying to replace the conventional OPML configuration by **folded and intra-linked cavities structure.** Simulation of some of the

folded cavity structures like Z and W to increase the system compactness has been done. We are developing a highly directive united construction of oversized slotted rectangular waveguide and horn antenna which will substitute the conventional coupling scheme. Optimization is done for almost all the dominating factors for such configuration. Thus after absolute execution of whole concept, design and fabrication of a most suitable system for space based applications is in progress.

The year 2002-2003 was mainly spent on the completion of the **Solar X-ray Spectrometer (SOXS). The efforts were rewarded with the successful launch of the GSAT - 2 Indian mission, launched by GSLV - D2 rocket on 08 May 2003 on board of which the SOXS experiment was housed.** Good quality data are being received. The SOXS aims to study the explosive phenomena on the Sun, in particular solar flares with high resolution in 4-20MeV regions. The SOXS consist of two independent payloads viz. SOXS Low Energy Detector (SLD) payload and SOXS High Energy Detector (SHD) payload. The SLD payload has been designed and developed at Physical Research Laboratory (PRL) in collaboration with ISRO Satellite Centre, Bangalore and Space Application Centre Ahmedabad.

## Theoretical Physics

The main activities of the theoretical physics division are concentrated in the areas related to (1) high energy and astroparticle physics (2) nuclear and atomic physics (3) cosmology and gravitational physics and (4) plasma physics.

Interesting experimental results were reported this year in the field of neutrino physics and cosmology which are among the focal themes being studied at PRL. The results from the KamLand experiments in Japan helped in identifying definite solution to solar neutrino problem. Results from WMAP satellite determined cosmological parameters very precisely and put a strong constraint on the neutrino contribution to the dark matter density. Theoretical implications of both these results were studied at PRL. It was pointed out that KamLand results allow determination of the (anti) neutrino flux originating from radioactivity inside the earth. It was shown that these results can be used to determine the age of the earth. This determination is sensitive to neutrino masses and mixing and further study can be used to fix these parameters from the existing knowledge on the age of the earth.

Theoretical models were studied to understand neutrino masses and mixing implied by the recent data. It was shown that physics in more than five dimension can be responsible for generating the required neutrino spectrum. Detailed study of the radiative generation of the solar scale were made and it was shown that the results from WMAP have very profound implications for this scenario and nonsupersymmetric version of this scenario gets ruled out by these results.

The detailed study of neutrino properties needs very intense neutrino beams. It was pointed out that nuclear devices (e.g. submarine) can provide very intense neutrino beam. This in association with new generation of neutrino detector can be used as a probe of neutrino properties.

The other topic of interest to the group is search of CP violation at possible future colliders. In this context, the usefulness of photon-photon collisions to study CP properties of Higgs bosons was examined in detail. In particular, the angular distribution of leptons arising from top decay in $\gamma\gamma \rightarrow t\bar{t}$ was calculated and shown to be a sensitive tool to study the CP-violation in the Higgs sector. Angular asymmetries of leptons were found to be capable of discriminating models with loop-induced CP-violation from the standard-model scenario. These being experimentally directly observable would prove extremely useful in testing alternative models, like supersymmetry.

In the area of gravitational physics, study of the influence of spacetime curvature on propagating electromagnetic waves was undertaken. It was found that curvature produces gravitational birefringence which could result in the rotation of the plane of polarisation. Calculating the influence of gravitational waves on electromagnetic waves, estimates have been obtained of the induced rotation for different astrophysical sources.

Further using a similar methodology, constraints have been obtained on the possible non-minimal couplings, which could, in principle, lead to violation of the equivalence principle.

In the area of atomic physics a new mathematical technique to study transition of Rydberg states in the first Born approximation was evolved. This involves transforming a general terminating hypergeometric function into a Jacobi polynomial. This method is found to give better results than other currently available methods.

Nuclear Physics group carried out a number of studies towards establishing the 'universality' of embedded random matrix ensembles, which include one plus two-body matrix ensembles and their various extensions with group symmetries, for finite interacting quantum systems such as nuclei, atoms, quantum dots, small metallic grains, etc. These studies include: localization in 2p-1f nuclear shell model wave functions vs one plus two-body random matrix ensembles, establishing that these ensembles have three chaos markers, carrying-out applications of these markers to give a theory for occupation numbers and strength sums, finding a good first atomic physics example in Sm I atom and examining interacting boson systems with random two-body interactions.

A system of charged particles in a magnetic field in the parameter domain appropriate for the applicability of classical dynamics has been shown to exhibit matter wave behaviour including the observation of the magnetic vector potential in macro-dimensions. This may appear to contravene the classical Lorentz equation of motion but is found surprisingly to be a quantum manifestation in the correspondence limit of large Landau quantum numbers, being governed by the elements of the S-matrix involving transitions across one or more Landau levels. Similar considerations have been applied to atoms and molecules in the correspondence limit.

## Nonlinear Dynamics & Computational Physics

In this division we study 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, quantum information theory, and large scale computations of the properties of large atoms are some of the topics on which work is being carried out. This year we provide a highlight of our research on entanglement in spin chains, quantum chaos assisted entanglement, coupled networks, new identities of Jacobi elliptic functions, coupled 3-D anharmonic oscillators and complexities in the lanthanide spectra.

Solid-state systems are important contenders for realization of quantum computers. In this respect new insights have emerged from our studies on entanglement sharing within spin-chains of solids. We have found that metal-insulator transition impact show that the entanglement is shared. We have also carried out a first of its kind study of entanglement sharing between two strongly chaotic systems. Appropriate schemes have been developed to quantify the entanglement from the phase-space pictures.

In a study of interest to mathematicians as well as physicists we have discovered several identities of Jacobi elliptic functions. This has led to identification of nonlinear difference equations which has Jacobi elliptic functions as solutions.

We have observed from our study on the dynamics of coupled maps on networks that there are two mechanisms of synchronized cluster formation, self-organized with dominant intra-cluster couplings and driven with dominant inter-cluster coupling. Research on secure communications using chaos has matured to application stage. We have tested it successfully in real life situations and is currently under evaluation for final implementation.

We have initiated studies on the coupled 3-D anharmonic oscillators and complexities in the lanthanide spectra. The former topic is expected to provide insights to phenomena such as Arnold diffusion and later can perhaps explain how complexities arise in atomic spectra from the well understood electron-electron Coulomb interactions.

## Laser Physics and Quantum Optics

Major activities of our group in the recent past have been in the areas of quantum entanglement, quantum teleportation, quantum thermodynamics, storage and retrieval of light, pulse propagation in nonlinear media and also in media with negative refractive index, phased array resonators, experimental realization of charge inversion in optical vortices and application of wavelet transforms.

Two or more quantum systems are entangled when it is impossible to describe their physical properties by means of a direct product of their respective density operators. Entanglement can be produced in a variety of systems and in a number of ways. In cavity QED, we show that multipartite entanglement can be produced by vacuum Rabi coupling when a system of N-two level atoms in a cavity of high quality factor is driven by a strong classical field. It is even possible to produce entangled states involving different cavity modes. In Ramsey interferometry in which each Ramsey zone is represented by a quantized field in a cavity, we show that the passage of an atom can entangle the fields. We demonstrate that two spatially separated Bose condensates can also be entangled by stimulated Bragg scattering of light and atom pairs in optical lattices can be entangled via laser-induced dipole-dipole interactions. We have also developed a generic theory of entanglement in a bipartite bosonic system.

Use of entangled photon pairs may be preferable over coherent sources in many spectroscopic applications, such as the generation of squeezed light. We suggest a way in which entangled photons produced by a type II down converter can be used for magneto-optical spectroscopy with distinct advantages.

We find minimum-correlation states associated with the quadratures of single-mode and two-mode electromagnetic fields in a cavity and show that in general, the states with the least amount of correlations are mixed and they exhibit squeezing.

We present a protocol for teleporting an unknown atomic state from one cavity to a distant cavity. This protocol is based on sequential interaction of a detuned two-mode optical cavity, with three-level atoms in $\Lambda$-configuration in their ground states. We also propose a scheme for quantum networking between the distant cavities based on an atomic channel and discuss the possibility of an efficient quantum memory for the entangled states of the field in the cavity. The entanglement can be stored in the ground states of the atom and can be retrieved as well in another cavity.

Quantum thermodynamics of systems slightly out of equilibrium is an area of active interest. We propose a quantum Carnot engine in which coherence allows certain features of engine operation that are beyond the classical limit.

In quantum optics, investigation of various aspects of pulse propagation in different types of media is an area of active research. We have shown that light pulses at moderate powers can be stored and retrieved without significant absorption and broadening-a result having potential application in the storage of information. In suitable nonlinear resonant media, we have also obtained superposed pulse train solutions with widely different amplitudes. Exact solutions have recently been found for nonlinear Schrödinger equation with a source term that appears in Josephson-junction arrays, optical fibers and many other physical systems.

Media possessing negative refractive index have attracted considerable attention in recent times. We have analyzed pulse propagation in such media and shown that, unlike the normal case, there can be very large group delays in the propagation of narrow band pulses. This may be useful in the development of delay lines.

We show that the transmission of unpolarized light through an otherwise isotropic medium can be made sensitive to the direction of the magnetic field by the application of a suitable control field.

In the quest for realizing high output powers from semiconductor laser arrays, our original design of a phased array resonator was shown to have significant advantages over the widely used Talbot array resonator. However, the intracavity power density can be very

high in some cases leading to catastrophic mirror damage. We present a new design that overcomes these problems whilst maintaining the advantages of the original design.

We have produced a canonical vortex using a computer-generated hologram, which was converted to a non-canonical vortex using a cylindrical lens. We have observed vortex charge inversion experimentally. The theoretical treatment of our observations was also given.

We have made use of wavelet transform to extract statistically significant parameters from the fluorescence data of cancerous, benign and normal tissue samples. These are then used for the purpose of a better differentiation of various tissue types.

## Space and Atmospheric Sciences

The research programmes of the Space and Atmospheric Sciences Division are multidimensional covering the earth's lower and upper atmosphere to the planetary atmospheres. Two ship cruises have been conducted to study aerosol characteristics and distributions of ozone and related trace gases over the Bay of Bengal. High levels of aerosols and trace gases are found over this region. The newly acquired mobile Micro Pulse Lidar has been used in the western Gujarat to study aerosol loading in the atmosphere. Radiative impacts of the aerosol loading on atmospheric temperature and other parameters have been estimated. A box model is developed to study the chemical and physical processes in the lower atmosphere. The air glow measurements have given many new results. Microstructures associated with equatorial spread F irregularities and gravity waves in the mesosphere have been observed in the air glow emissions. Solar wind electron flux is found to be responsible for the nighttime emissions in the Martian atmosphere.

Ozone is a potential greenhouse gas in the troposphere and is increasing due to increasing levels of pollutants at many sites over the globe. A new programme has been initiated to measure vertical distributions of ozone and humidity simultaneously using balloon-borne sensors. The first balloon flight of this series was inaugurated on May 30, 2003. The radio beacon experiment, launched successfully onboard the GSAT-2 in May 2003, will be used to study ionospheric parameters related to space weather.

Many new developments have taken place. The radio beacon experiment has been launched successfully onboard the Indian geostationary satellite (GSAT-2). The recoil ion momentum spectrometer (RIMS), to measure absolute photoionization cross section of atomic oxygen, is operational now.

## Planetary and Geosciences

Records of now-extinct short-lived nuclides in meteorites provide information about the formation and evolution of the solar system. We have found excess $^{10}B$ that we attribute to the decay of short-lived $^{10}Be$ (half-life 1.5 million years) in hibonite grains from the Murchison meteorite. The grains show no evidence of decay of two other short-lived nuclides - $^{26}Al$ (half-life 700,000 years) and $^{41}Ca$ (half-life 100,000 years) - that may be present in early solar system solids. The most plausible source of $^{10}Be$ is energetic particle irradiation of gas and dust in the solar nebula or in the protosolar cloud. The presence of $^{10}Be$ coupled with the absence of $^{41}Ca$ and $^{26}Al$, rule out energetic particle irradiation as the primary source of $^{41}Ca$ and $^{26}Al$ present in some early solar system solids. Our result strengthens the case of a stellar source for the short-lived nuclides $^{41}Ca$ and $^{26}Al$ in the early solar system that constrains the time scale of protosolar cloud collapse to less than a million years and bolsters the proposition of a triggered origin of the solar system.

The building blocks of planet Mars are shown to be enstatite and ordinary chondrites in the proportion of 74:26, based on the N and O isotopic systematics of martian meteorites. Geochemical modeling, starting from these precursors demands that the core of Mars should accommodate up to 6.7 wt. percent of Si. Laboratory studies on the partitioning of Si in Fe melt at pressures corresponding to the depth of core of Mars as well as the recent finding that up to 12.5% Si is found in the dark metal rich grains from E- chondrites are consistent with this suggestion.

A comprehensive study of ureilites and their acid resistant C-rich residues for N and noble gases has shown that diamonds in ureilites are of nebular origin. Diamonds have acquired their gases by ion implantation from nebular plasma at ~$10^4$K. Phase Q, the noble gas carrying carbonaceous phase in primitive chondrites, has also acquired the noble gases by ion implantation, but from a plasma at ~ 8000K.

## PLANEX

The Planetary Sciences has taken a leading role in defining the scientific objectives and payloads for the Indian Mission to Moon which ISRO proposes to launch during this decade. A simultaneous chemical mineralogic and photogeologic mapping of the whole lunar surface with special emphasis on the South Pole Aitken region on the far side of the Moon has been defined as the primary goal of this mission. It will be accomplished by using two X-ray detectors and a hyperfine imaging spectrometer. A National Facility has been built at the Thaltej campus where work on development and laboratory calibration of various sensors for planetary exploration has been initiated.

## Technical Developments

### *Chirp Transform Spectrometer*

As a part of the back-end electronics in the super heterodyne receiver system operating in the Sub-millimeter (SMM) range of frequencies, the spectrometer plays an important role. The design of the high-resolution Chirp Transform Spectrometer is under consideration. The prototypes of the Filter Bank Spectrometer and Chirp Transform Spectrometer have been designed and developed during the year 2002-2003. Also, the operating curves of the Sub-millimeter Mixers were checked and verified. The mounting arrangement of the mixer was designed and it is under development.

### *Leaching of Meteorite with Ultra Gas-free Water in Vacuum*

Halites of ~ 4.6 Ga age have crystallized from brines on primitive meteorite parent bodies have been recently discovered accidentally in two meteorites Zag and Monahans. Occurrence of halites could be a more common feature than hitherto imagined. We began a search for halites in primitive chondrites as they offer clues about the earliest parent body processes. A simple way to look for halites is to look for noble gas isotopes produced either by short lived nuclides $^{36}$Cl (decays to $^{36}$Ar) and $^{129}$I (decays to $^{129}$Xe) or by the reaction products through (n,$\gamma$) reactions on $^{35}$Cl, $^{79}$Br, $^{81}$Br, $^{127}$I giving respectively $^{36}$Ar, $^{80}$Kr, $^{82}$Kr and $^{128}$Xe. This is best done by leaching the meteorite with ultra gas-free water in vacuum, wherein halite dissolves and the gases are liberated, which can be separated, purified and measured. This is easier said than done. We have fabricated a gas extraction line that gives low blanks without any trace of water background and have started the hunt for halite bearing chondrites. This method is also useful to analyse any water soluble phases for their noble gases and will have applications for dating or monitoring certain nuclear particle fluences.

## New Computational Facility

Computer Centre is equipped with IBM RS-6000 SP computer having 16 processors and 32GB RAM to cater for high computing needs of scientists. Centre also has high-end graphics station, IBM RS-6000 Model 270 with 4 processors. These machines are in addition to existing five IBM RS-6000/580 machines and all are connected to our high speed local area network (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 Abu are connected to the PRL LAN on a 64 Kbps BSNL leased line. To cater for the needs of scientists, online electronic journals etc., internet bandwidth has been appropriately upgraded this year. The centre provides centralized virus free E-mails by automatically scanning all E-mails. Internet authorisations, monitoring and reporting functions have been added to have optimal usage of internet bandwidth.

## Infrastructural Facilities Available

Computer Centre, Scanning Electron Microscope, Liquid Nitrogen Plant, Glass Blowing Facility, Radio Carbon Dating Laboratory and Aluminising facility at Mt. Abu.

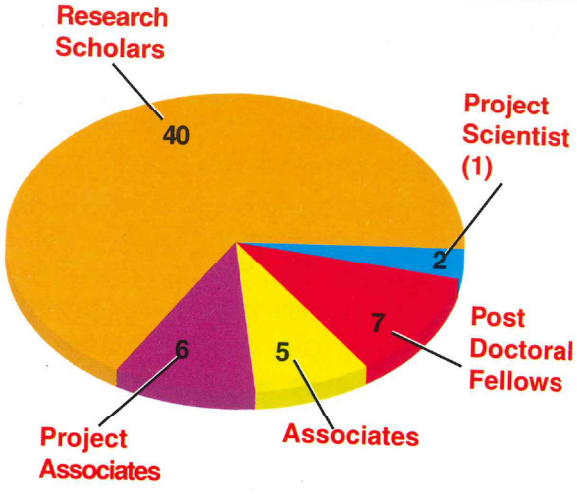



*Fig.1 Doctoral, Post Doctoral and other Programmes*

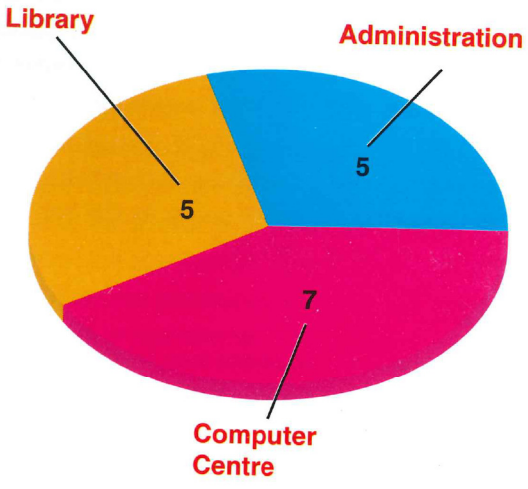



*Fig.3 Training Programme at PRL*

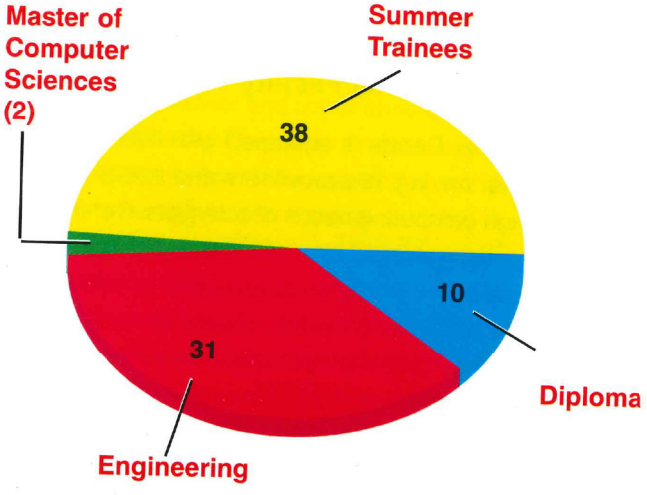



*Fig.2 Graduate & Post Graduate Programme*

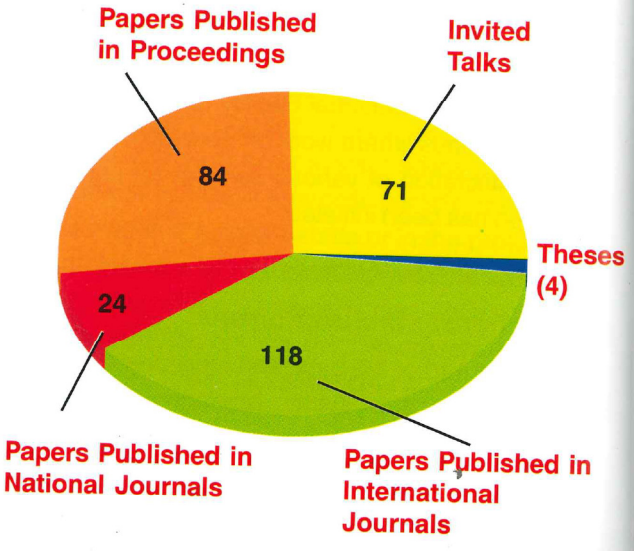



*Fig.4 Scientific Output of PRL*

## 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**)

## Training Opportunities

PRL organises extensive summer programmes for students as well as college teachers every year. The purpose is to initiate them to current research activities being pursued at PRL which they can continue even after returning back to their colleges and also motivate them to take up research in basic sciences. Students studying in first year masters degree and fi-

nal year bachelors degree are considered for participating in this programme. Selected students visit PRL for two months in summer. The students are given a project under the supervision of a faculty member. At the end of the programme they submit a report on the work carried out by them. PRL also provides project training in computer sciences and application to post-graduate students. It also offers training in electronics and computer engineering to engineering and diploma 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**.

## 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. 3rd Space and Atmospheric Science Course of CSSTEAP, PRL, August 2002 - April 2003, **Dr. H. S. S. Sinha**, Director of the Course.

2. Regional Workshop for Asia-Pacific Astronomers on Data Processing from the Chandra and XMM-Newton Space Missions, Udaipur, January 13-24, 2003, Dr. A. P. Wilmore and **Dr. H. S. S. Sinha**, Co-organisers.

3. COSPAR 2002: Long-Term trends in the Thermosphere-Mesosphere-Stratosphere Coupling, Houston, USA, October 2002, **Dr. Harish Chandra**, Member Organizing Committee.

4. Workshop on Radio and Optical Probing of Upper Atmosphere, PRL, 6-8 February, 2003, **Dr. Harish Chandra,** Convener.

5. National Conference on Radio and Atmospheric Science, NPL, New Delhi, February 17-18, 2003, **Dr. Harish Chandra,** Member, National Organizing Committee.

## Distinguished Visitors at PRL

**Prof. M. G. K. Menon,** FRS, Dr. Vikram Sarabhai Distinguished Professor, ISRO, Bangalore delivered the nineteenth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Windows to the Universe : Opportunities for Indian Science.*

## Seminars and Colloquia Held

The laboratory has an extensive seminar and colloquium programme. Regular seminars are held by different groups both in PRL and Thaltej campus. Reputed scientists, both from national and international institutions were invited to give seminars and colloquia. Prof. K. I. Oyama of Institute of Space and Astronautical Science, Japan; Dr. Ernest Hilsenrath, of Goddard Space Flight Center, NASA, USA; Prof. Takeo Kosugi, Director, Space Solar Astronomy Division and project manager Solar- B mission, Institute of Space and Astronautical Sciences (ISAS), Japan; Prof. Eberly, University of Rochester, USA gave interesting seminars. 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 | 115 |
| Colloquia including public lectures held | 20 |

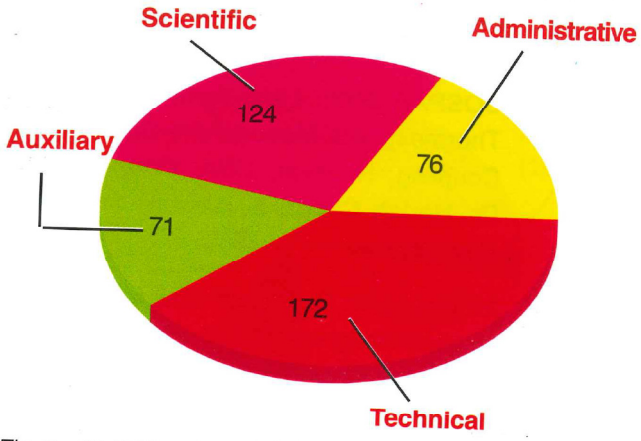



*Fig. 5 Staff Structure of PRL*

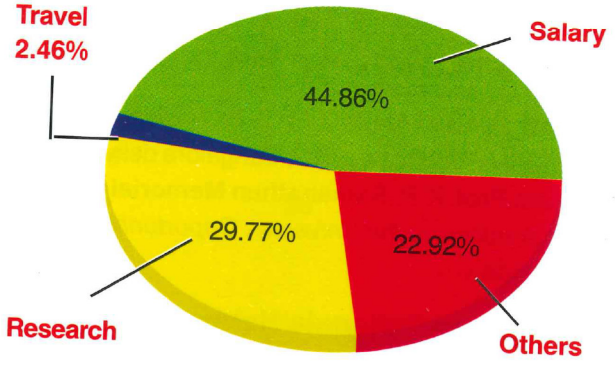



*Fig. 6 Budget of PRL*

## 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 provide an excellent management support to carry out our scientific activities. The budget and staff structure of PRL are shown in **Figs. 5 and 6**.

## Miscellaneous

As a part of implementation and progressive use of Hindi in PRL, the **Hindi Week** was celebrated at PRL from September 16 - 20, 2002. The highlights of the celebrations included word quiz, essay, elocution, Hamara Karya, self written poetry competitions. The special attraction of this year's celebration was a lecture by Shri R. N. Tripathi, Income-Tax Commissioner, Ahmedabad who delivered the inaugural lecture. Another unique activity of the Hindi Day celebrations was a *Seminar on Paperless Office*. The seminar was inaugurated by Shri R. P. Soni, Director, GLS Institute of Information Technology . Other invited speakers included Shri G. F. Vora from Space Applications Centre and Dr. Dilip Ahalpara from Institute of Plasma Research. About forty eight staff members participated and thirteen papers were presented. On this occasion, an Exhibition of Hindi Books in PRL was arranged which was inaugurated by Shri R.P. Soni. The Hindi Book Exhibition was attended by a large number of visitors.

With the possibility of an Indian Mission to Moon in the near future in which PRL is an active participant, a one day *Technical Seminar on Moon Mission - Somayana* was held to discuss the technical details of the mission. The inaugural address was delivered by Dr. George Joseph, Chairman, Moon Mission Task Force and Dr. Narendra Bhandari, Member Moon Mission Task Force. Eight papers covering all aspect of the experiments planned to be put on board a GSAT satellite were presented and discussed.

Two 2-day Computer Training Programs in Hindi were held at PRL during 22-25 October, 2002 under the aeges of Town Official Language Implementation Committee, Ahmedabad for the staff members of Central Govt. Deptt./Undertakings. Two All India Essay Writing and Noting & Drafting Competitions were held in PRL during November, 2002 organised by Deptt. of Space, Bangalore and Kendriya Sachivalaya Parishad, New Delhi one each.

Two *Hindi Workshops* were conducted to acquaint & train the administrative staff with the usage of Hindi in their daily work.

The Hindi staff participated in the *Technical Seminar on Antarix Taknik Evam Upyog ke Naye Aayam*, held at Space Applications Centre, Ahmedabad.

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. More than three hundred and fifty teachers and students attended the celebrations. About two hundred students participated in the Science Quiz which formed the main part of the programme. *50 Years of DNA - 25 years of IVF - The Blueprint of Life* was the theme for the National Science Day for this year. Dr. Harish Padh, Director, B. V. Patel PERD Centre, Gujarat gave an invited talk on *Advances in Cell and Genetic Engineering*. Keeping in view of new directions in the research conducted in PRL, two interesting talks on *Indian Space Programme* and *Indian Moon Mission* were planned. To make the programme more exciting and interesting programmes on *Physics Olympiads; Physics for Fun; Learning Science; Space Shuttle 2002 and DNA and its Music* were arranged.

**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. *The Degree of Doctor of Science (Honoris Causa)* from the Ch. Charan Singh University, Meerut.

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

   i. *G M Modi Science Award, 2002* conferred by Centre by the Gujar Mal Modi Science Foundation.

   ii. *Office of the Legion d'honneur* conferred by the President of the French Republic.

   iii. The *Degree of Doctor of Science (Honoris Causa)* conferred by Indira Gandhi National Open University (IGNOU), New Delhi.

3. **Prof. G. S. Agarwal**

   i. has been invited to serve on the *editorial board of optics communications* for another period of three years.

   ii. has been invited to be one of the *few speakers in the 125th Anniversary series of lectures of the Indian Association for the Cultivation of Science*, Kolkata.

   iii. was *one of the three plenary speakers at the 19th Congress of the International Commission of Optics*, August 2002, Florence, Italy.

   iv. listed in the new edition of the American Men and Women of Science.

4. **Prof. S. Krishnaswami** has been

   i. invited to be a member of *Interim Council of the Asia-Oceania Geosciences Society* and

   ii. elected *Fellow of Geochemical Society-European Association of Geochemistry.*

5. **Prof. B. L. K. Somayajulu** has been elected

   i. *Fellow of the Third World Academy*, Trieste, Italy.

   ii. *Fellow of the American Geophysical Union, USA.*

6. **Prof N. Bhandari** was elected as the *Vice President of the International Lunar Exploration Working Group (ILEWG).*

7. **Prof. R. Ramesh** has been elected *Fellow of the National Academy of Sciences*, Allahabad.

8. **Dr. Kanchan Pande** elected *Fellow of the Indian Geophysical Union.*

9. **Prof. M. M. Sarin** has been invited to be a member of the

   i. *International Commission on Atmospheric Chemistry and Global Pollution (ICACGP)*

   ii. *International Scientific Committee on Estuarine Biogeochemistry.*

10. **Dr. Bhas Bapat** has been awarded the *Prof. S.N. Ghosh Young Scientist Award* at XIVth National Conference on Atomic and Molecular Physics held at Visva Bharati, Shantiniketan during January 28 to February 1, 2003.

11. **Dr. S. Ramachandran** has been awarded the *Young Scientist Award* by the IGBP-Global Change System for Analysis, Research and Training (START).

12. **Som Kumar Sharma,** has been awarded the *Young Scientist Award* by the International Union of Radio Science (URSI).

13. **S. Chakraborty** has been awarded the *Best Thesis Presentation Award* at ISMAS Silver Jubilee Symposium on Mass Spectrometry, Goa, India, January, 2003.

14. **Prof. B.G. Anandarao** has been invited to continue to be a *Member of the Editorial Board of Journal of Astrophysics and Astronomy* published by Indian Academy of Sciences, Bangalore.

15. The paper entitled *Late Quaternary Productivity Variations in the Equatorial Indian Ocean Close to Eastern Arabian Sea* by **M. Tiwari, B. L. K. Somayajulu, R. Ramesh, A. J. T. Jull, G. S. Burr and R. Bhushan**, won the *Second Prize in the Earth Science Category* in the ISMAS Silver Jubilee Symposium on Mass Spectrometry, Goa, January 27-31, 2003.

16. **Y. B. Acharya and A. Jayaraman**, received the *Third Prize in Scientific / Technical Essay Writing*, Kendriya Sachivalaya, Hindi Parishad, New Delhi, 2002

# Books/Monographs/Reviews Published in 2002-03

## Books/Monographs

1. S.P. Gupta (ed), *Advances in Space Research*, **30**,(2002).
2. V.K.B. Kota (ed.), *Nuclear Models*, Allied Publishers Pvt. Limited (2002).
3. S. C. Tripathy and P. Venkatakrishnan (eds.), *Probing the Sun with High Resolution*, Narosa Publishing House, New Delhi, (2003).
4. A. K. Kapoor, P. K. Panigrahi and Bindu A. Bambah (eds), *Proceedings of XIV Symposium on High Energy Physics, Hyderabad University Press,*(2003).

## Review Papers

### Solar Physics

5. A. Ambastha, "The Active and Explosive Sun", *Lecture Notes in Physics*, **619**, Eds.: H.M. Antia, A. Bhatnagar, and P. Ulmschneider, Springer-Verlag, Germany, 128-172 (2003).
6. A. Bhatnagar, "Solar Instrumentation", *Lecture Notes in Physics*, **619**, Eds.: H.M. Antia, A. Bhatnagar, and P. Ulmschneider, Springer-Verlag, Germany, 27-79 (2003).
7. P.Venkatakrishnan, "Solar Magnetic Fields", *Lecture Notes in Physics,* **619**, Eds., H. M. Antia, A.Bhatnagar and P.Ulmschneider, Springer-Verlag Germany, 204-231 (2003).

### Planetary and Geosciences

8. S. Chakraborty, and S.K. Bhattacharya, "Mass Independent Isotopic Fractionation: Recent Development", *Curr. Science*, **84**, 766-774 (2003).

### Theoretical Physics

#### *Plasma Physics*

9. R.K. Varma, "Classical and Macroquantum Dynamics of Charged Particles in a Magnetic Field", *Phys. Reports,* **378 (5-6)** , 301-434 (2003).

# Papers Published in Journals in 2002-03

## Astronomy and Astrophysics


1. A.Tej, K.C. Sahu, T. Chandrasekhar and N.M. Ashok, "Substellar Mass Functions of Young Open Clusters as Determined Through a Statistical Approach Using Two Micron all Sky Survey and Guide Star Catalog Data", *Ap. J*, **578**, 523-535 (2002).

2. M.S. Nandakumar, B.G. Anandarao and K.C.Yu, "Ongoing Star-formation Activity in the L1340 Dark Cloud", *Astron. J.*, **123**, 2583-2589 (2002).

3. D.P.K. Banerjee and N.M. Ashok, "Near Infrared Spectroscopy of V838 Monocerotis", *A&A*, **395**, 161-167 (2002).

4. C. Alard, J. A. D. L. Blommaert, C. Cesarsky, N. Epchtein, M. Felli, P. Fouque, S. Ganesh, and 34 Co-authors, "Mass-losing Semiregular Variable Stars in Baade's Windows", *Ap. J*, **552**, 289-308 (2001).

5. V. Balasubramanian, P. Janardhan, S. Srinivasan, and S. Ananthakrishnan, "IPS Observations of the Solar Wind Disappearance Event of May 1999", *J. Geophys. Res.*,**108**, A3, 1121-1131 (2003).

6. N.M. Ashok and D.P.K. Banerjee, "Limited Seeing Observations at Mt. Abu Infrared Observatory", *Bull. Astro. Soc. of India*, **30**, 851-858 (2002).

7. A.C. Gupta, U.C. Joshi and J.H. Fan, "Optical Variability of Gamma-ray Loud Blazars", *Astrophysics and Space Science*, **4**, 665-668 (2002).

8. P. Hennebelle, M. Pe'rault, D. Teyssier and S. Ganesh, "Infrared Dark Clouds from the ISOGAL Survey", *A&A*, **365**, 598-611 (2001).

9. B.W. Jiang, A. Omont, S. Ganesh, G. Simon and F. Schuller, "The ISOGAL Field FC-01863+00035: Mid-IR Interstellar Extinction and Stellar Populations", *A&A*, **400**, 903-915 (2003).

10. U.C. Joshi, K.S. Baliyan and S. Ganesh, "Polarimetric Study of Comets C/1995 O1 (Hale-Bopp) and C/2000 WM1 (LINEAR)", *EM&P*, **90**, 413-421 (2003).

11. S. Mondal and T. Chandrasekhar, "Dust Structure around Wolf-Rayet Star WR 104 from Lunar Occultation Observation at 2.2 Microns", *Mon. Not.R. Astron. Soc.* **334**, 143-148 (2002).

12. R. Ortiz, J.A.D.L. Blommaert, E. Copet, S. Ganesh, H.J. Habing, M. Messineo, A. Omont, M. Schultheis and F. Schuller, "OH/IR Stars in the Inner Bulge Detected by ISOGAL", *A&A* , **388**, 279-292 ( 2002).

13. R.R. Rosa, Vats Hari Om, F.M. Ramos, A. Zanadrea, C. Rodrigues Neto, F.C.R. Fernandes, M.J.A. Bolzan, E.L. Rempel, R.C. Brito, N.L.Vijaykumar, and H.S. Sawant, "Characterization of Local Self-Similarity and Criticality in the Solar Active Regions", *Advances in Space Research*, **29**, 463-468 (2002).

14. H.S. Sawant, F. C. R. Fernandes, J. R. Cecatto, Hari Om Vats, J. A. C. F. Neri, V. A. Portezani, A. R. F. Martinon, M. Karlický and H. Mészárosová, "Decimetric Dot-like Structures", *Advances in Space Research*, **29**, 349-354 (2002).

15. M. Schultheis, M. Parthasarathy, A. Omont, M. Cohen, S. Ganesh, F. Sevre, G. Simon, "Low Resolution Spectroscopy of ISOGAL Sources", *A&A*, **386**, 899-909 (2002).


## Solar Physics


16. A. Bhatnagar, Kiran Jain and S.C. Tripathy, ."Variation of Solar Irradiance and Mode Frequencies during Maunder Minimum", *Astrophysics and Space Science*, **281**, 761-764 (2002).

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# Theses Submitted during 2002-03

1. **S. Chakraborty**

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2. **Rishikesh D. Vaidya**

   "Some Studies in Violation of Symmetry Principles in Particle Physics", (2002).

3. **R. Arun**

   "Dynamics of Cold Atoms in High Quality Cavities", (2002).

4. **Duli Chand**

   Study of trace gases in the tropical troposphere (2002)

# Scientific/Technical Reports Submitted

1. **S.A. Haider, S.P. Seth, S.W. Bougher and K.I. Oyama**

   "Longitudinal distributions of photoelectron spectra, production rates and densities at low latitude of Mars : Comparison with Accelerometer and Radio measurements", ISAS Research Note : Technical Report published by Institute of Space and Astronautical Science (ISAS), Japan, ISAS RN, 755, 1-33 (2003).

2. **Rajmal Jain, Hemant Dave, A. B. Shah, Vishal M. Shah, N. M. Vadher, K. J. Shah, G. P. Ubale. V. D. Patel, S. L. Kayastha, K. S. B. Manian and M. R. Deshpande**

   "Characterization and Response of Si PIN and CZT Detectors", May 2002, ISAC-GSAT-2-PR-0180.

3. **D. V. Subhedar, T. Chandrasekhar & N. M. Ashok**

   "Automating a networked telescope on an e-mail trigger for rapid observations of Gamma Ray Bursts",PRL TN-80-2002

# Invited Talks Presented in Symposia/Schools in 2002-03

## Astronomy and Astrophysics

1. "Remote Sensing Interplanetary Disturbances", *Workshop on Radio and Optical Probing of the Upper Atmosphere*, PRL, **Ahmedabad**, India, February 6-8, 2003, by **P. Janardhan.**

2. "Spectral Energy Distributions in Gaseous Nebulae and Supernova Remnants: Filter Definitions in UV", *Workshop on UVIT Science-Filter Definition*, 27-28 March 2003, IIA-ISRO, **Bangalore**, 27-28 March 2003, by **B.G. Ananadarao.**

3. "IR Spectroscopy of Nova-like Sources", 22nd *Meeting of Astronomical Society of India*, February 13-15, 2003, **Thiruvananthapuram**, by **D.P.K. Banerjee.**

4. "Galaxies", *Summer School on Astronomy at State Observatory*, **Nainital**, June 3-8, 2002, by **U.C. Joshi.**

5. "The Inner Bulge from Near and Mid-infrared Surveys", at the *Symposium on Sun, Stars and the Extragalactic Universe* on M.K.V. Bappu's 75th Birth Anniversary, IIA, **Bangalore**, August 8-10, 2002, by **S. Ganesh**.

6. "The Strange World of Interacting Binary Stars I-Introduction" and "The Strange World of Interacting Binary Stars II - Role of Small Telescopes" **(2 talks)** at the *Workshop on Astronomy with Small Telescopes*, IUCAA, **Pune**, January 6-10, 2003, by **N.M. Ashok.**

## Solar Physics

7. "The Structure and Dynamics of Solar Interior and Exterior", *UGC Refresher Course in Physics*, ML Sukhadia University, **Udaipur,** July 29, 2002 by **A. Ambastha**

8. "Detachment of Filament Barbs Prior to Filament Eruption, Prominence Observations and Models", in *PROM 2002 Workshop*, Catholic University of America, **USA**, by **Nandita Srivastava**

9. "Space Weather Prediction: Recent Progress and New Challenges", *Workshop on Radio and Optical Probing of Upper Atmosphere*, Physical Research Laboratory, **Ahmedabad**, India February 6-8, 2003 by **Nandita Srivastava.**

## Submillimeter Science and Solar X-ray Astronomy

10. "Remote Sensing with Submillimeter Wave", presented at the *National Conference on Sensor Technology*, CEES/DRDO, Metcalfe House, **Delhi,** 26-27 September 2002, by **Hemant Dave** and Ravindra Pratap Singh.

11. "Gratings and Detectors in X-rays", COSPAR, *Regional Workshop for Asia Pacific Astronomers*, Udaipur, India, 13-24 January 2003, by **Hemant Dave.**

12. "High Resolution Spectroscopy with Submillimeter Wave", Presented at the *XXII ASI Meeting*, **Thiruvanthapuram**, 13-15 February 2003, by Vinay Kumar, **H. Dave,** R. P. Singh, P. Pathak, A. Dubey, R. S. Thampi and J. Pabari.

13. "Scientific Expectations from Solar X-ray Spectrometer (SOXS)", at the *XXIInd Meeting of the Astronomical Society of India* held at **Thiruvananthapuram** from 13-15 February 2003 by **Rajmal Jain**.

## Theoretical Physics

### *High Energy Physics*

14. "Chiral Symmetry Breaking, Color Superconductivity and Color Neutral Quark Matter", at the *Workshop on Mesons and Quarks*, Bhabha Atomic Research Centre, **Mumbai**, January 28-February 1,2003, by **H. Mishra.**

15. "CPT Violation in Microphysical Processes in External Gravitational Fields", at the *First International Conference on String Phenomenology*, **Oxford**, U.K., July 6-11, 2002, by **S. Mohanty.**

16. "Constraints on Neutrino Properties from Solar Neutrino Experiments", at the *8th Summer Insti-*

*tute in New Dimensions in Astroparticle Physics*, **Gran Sasso Laboratories**, July 11-19, 2002, by **S. Mohanty.**

17. "Neutrino Physics", at the SERC School in T*heoretical High Energy Physics*, I.I.T. Madras, **Chennai**, February 10-19, 2003, by **S.D. Rindani.**

***Nuclear Physics***

18. "Two-body Random Matrix Ensembles for Finite Quantum Systems", at the *National Conference on Recent Developments and Challenges in Physics*, University of Hyderabad, **Hyderabad**, December 19-22 2002, by **V.K.B. Kota.**

19. "Group Theoretical Models for Heavy N=Z Nuclei", at the *International Workshop on Nuclei at Extremes of Isospin and Mass*, **Puri**, March 10-22 2003, by **V.K.B. Kota.**

## Nonlinear Dynamics & Computational Physics

20. "Adiabaticity and Chaos Assisted Quantum Tunelling ",at the *Fano Memorial Symposium , Institute of Theoretical Atomic, Molecular and Optical Physics*, Harvard University,**Cambridge**,USA,July 24-26 2002,M.Santhanam,**V.B.Sheorey**and A.Lakshminarayan.

21. "Quantum Transport using Non - KAM chaos", at the *XVIII International Conference on Atomic Physics,* **Cambridge**, Massachusetts, USA, July 28 - August 2, 2002 by Sankaranarayanan, **V.B.Sheorey** and A.Lakshminarayan.

22. "Quantum Chaos and Entanglement ", at the *XVIII International Conference on Atomic Physics,* **Cambridge**, Massachusetts, USA, July 28 - August 2, 2002. by **V. B. Sheorey,** J. N. Bandopadhyay and A.Lakshminarayan.

## Laser Physics and Quantum Optics

23. "Entanglement of Independent Systems by Detection and Quantum Interferometry", at the *Workshop on Quantum Correlation and Nonlinear Photon Physics*, **Rochester**, May 2002, by **G.S. Agarwal.**

24. "Control of Light by Light", **(Plenary Talk)**, at the *19th Congress of the International Comission of Optics*, **Florence**, Italy, August 25-30, 2002, by **G.S. Agarwal.**

25. "Cavity QED for Multiparticle Entanglement", at the *International Conference Photonics-2002*, **Mumbai**, December 16-18, 2002, by **G.S. Agarwal.**

26. **Inaugural Lecture** "Entanglement of Microscopic and Macroscopic Systems", at the *Recent Developments and Challenges in Physics*, **Hyderabad**, December 19-22. 2002, by **G.S. Agarwal.**

27. "Quantum Entanglement in Bose Condensates", at the *Indian Science Congress*, **Bangalore**, January 3-7, 2003, by **G.S. Agarwal.**

28. A series of **four** lectures on "Coherent Control", at the *SERC School on Precision Spectroscopy of Atoms, Molecules and Bose Condensates*, **Bangalore**,xFebruary 20 - March 12, 2003, by **G.S. Agarwal.**

29. "A New Perspective on Single and Multivariate Differential Equations", at the *International Conference on Special Functions and their Applications*, Institute of Mathematical Sciences, **Chennai**, September, 23-27, 2002, by **P.K. Panigrahi.**

30. "The 'Missing' Levels of the Quasi-Exactly Solvable Systems: A Novel Approximation Scheme", at the *Recent Development and Challenges in Physics*, University of Hyderabad, **Hyderabad**, December, 19-22, 2002, by **P.K. Panigrahi.**

31. "Coherent States: A General Approach", at the *Fourth International Symposium on Frontiers of Fundamental Physics*, January 09-11 2003, B.M. Birla Science Centre, **Hyderabad**, by **P.K. Panigrahi.**

## Space and Atmospheric Sciences

32. "50 years of Radio Sounding from Ahmedabad", at the *Workshop on "Radio and Optical Probing of Upper Atmosphere"* held at Physical Research Laboratory, **Ahmedabad** during February 2003 by **H. Chandra**

33. "Solar Activity and Ionospheric Tide Effect on Polar Conductivity and Vertical Electric Field of Stratosphere over Low Latitude", *34th COSPAR Scientific Assembly* 10-19 October 2002, **Houston**, USA by **S.P. Gupta.**

34. "Aerosol Forcings Inferred from Indoex", at the *Workshop on Air pollution as climate forcing*, April 29-May 3, 2002, Honolulu, **Hawaii**, USA by **A. Jayaraman.**

35. "Aerosol Studies and Observatories in India", *Workshop on Project Asian Brown Cloud*, 4-5 November 2002, SIO, UCSD, **La Jolla**, USA by **A. Jayaraman.**

36. "Aerosol Studies in India: Issues and Priorities", at the *International Workshop on Asian Brown Cloud*, 20 December 2002, TERI, **New Delhi** by **A. Jayaraman.**

37. "Aerosols, Radiative Forcing and Climate", **6 lectures** *at the SERC School on Mathematical Modeling of Air Pollution*, 28-31 May 2002, Bangalore Univ., **Bangalore** by **A. Jayaraman.**

38. "Dynamical Coupling in Equatorial Spread-F Modeling", at the *I-STEP Sponsored Workshop on Dynamical Coupling in Equatorial Atmosphere Ionosphere System* held at **Thirunelveli** during 2-3 May 2002 by **R. Sekar.**

39. "Plasma Instabilities and their Simulation in the Equatorial F-region", at the *World Space Environment Forum*, held during 22-25 July 2002 in **Adelaide**, Australia by **R. Sekar.**

40. "Nonlinear Numerical Simulation Model of Equatorial Spread-F", at the WISER *Workshop on High Performance Computing in Space Environment Research* (HPC 2002) held on August 2, 2002 in **Adelaide**, Australia by **R. Sekar.**

41. "Equatorial electrodynamics", at the *Workshop on Radio and Optical Probing of upper Atmosphere* held at Physical Research Laboratory, **Ahmedabad** during February 2003 by **R. Sekar.**

42. "All Sky Optical Imaging of Plasma Depletions", at the *Workshop on Radio and Optical Probing of Upper Atmosphere* held at Physical Research Laboratory, **Ahmedabad**, February 2003, **Ahmedabad**, by **H. S. S. Sinha.**

43. "Global Change Studies- Climate and Environment", at *Space Applications Center*, **Ahmedabad**, CSSTE-AP, May 17, 2002, by **Shyam Lal**

44. "Air Pollution and Modelling", *Second DST SERC School on Mathematical Modelling and Atmospheric Pollution*, Bangalore University, **Bangalore**, June 7-8, 2002 by **Shyam Lal**

45. "Water Vapour Observations in upper Troposphere and Possibility of Simultaneous Ozone Observations along with Megha-Tropiques SAPHIRE", at *Space Applications Center*, **Ahmedabad**, July 23, 2002, by **Shyam Lal**

46. "Ozone and Trace Gases : Greenhouse Effect and Climate Change", **5 lectures** *at Space Applications Center*, **Ahmedabad**, CSSTE-AP, January 6-11, 2003, by **Shyam Lal**

47. "Greenhouse Gases and their Role in Atmospheric Chemistry and Climate Change", **2 lectures** at CSSTEAP Course at *Indian Institute of Remote Sensing*, **Dehradun**, March 17-18, 2003 by **Shyam Lal**

## Planetary and Geosciences

48. "Optically Stimulated Luminescence:Terrestrial and Planetary Applications", at the *National Semiar on Progress in Luminescence and its Applications*, **Junagadh**, December 15, 2002 by **D. Banerjee.**

49. "Application of Natural U-Th series Daughter Products as Tracers and Chronometers of Environmental Studies", at the *Eleventh National Symposium on Environment*, **Udaipur**, June 10, 2002 by **S. Krishnaswami.**

50. "Contemporary Silicate Weathering Rates in the Himalaya : Impact on $CO_2$ Consumption", *in Mantle to Monsoon Symposium*, Indian Academy of Sciences Annual Meeting,**Chandigarh**, November 9, 2002,by **S. Krishnaswami**.

51. "Mars and Earth: A Comparative Planetology", at the *13th Mid-year Meeting of the Indian Academy of Sciences*, I. I. Sc., **Bangalore**, July 5-6, 2002 by **S. V. S. Murty**.

52. "Formation of Inner and Outer Planets", and "Evolution of Planetary Atmospheres", at the *Workshop on Planetary Atmospheres and Magnetospheres*, at V. S. S. C., **Trivandrum**, February 17-12, 2003, by **S. V. S. Murty**.

53. "Geochronology and Isotope Geology", at *the UGC Refresher Course*, M.L. Sukhadia University **Udaipur**, January 21-22, 2003, by **K. Pande**.

54. "Paleomonsoon Reconstruction from Cave Calcites", at the *School on Physics of Atmosphere and the Ocean*, Indian Institute of Science, **Bangalore**, 5th July, 2002 by **R. Ramesh.**

55. "Paleoclimate: Data Model Comparison for the Indian Region", at the *Late Quaternary Environmental Change- Emerging Issues, An International PAGES Workshop cum Training Programme on Global Change* (EQUILEC & POLTRAIN), **Pondicherry**, 10th February 2003 by **R. Ramesh.**

56. "New Production in the Bay of Bengal", at the *Bay of Bengal Process Study Meeting, NIO*, **Goa**, 18th March 2003, by **R. Ramesh.**

57. "Role of Upland Tributaries in Carbon Transport to a large Tropical Estuary, Godavari (India)", at the *7th Intl. Estuarine Biogeochemistry Symposium*, **Norway**, 28-30 May 2002, by **M.M. Sarin.**

## PLANEX

58. Moon Mission Study Group, "Indian Mission to Moon: Science Goals, Payloads and Launch Scenario", *34th COSPAR Scientific Assembly*, at **Houston**, from October 1-10, 2002 by V. Adimurty, P.C. Agrawal, T.K. Alex, **N. Bhandari**, G. Joseph, E. Janardhana, M. Jayraman, A.S. Kirankumar, K.N. Malik, K.N. Sankara, S.K. Shivkumar, V. Sundararamaiah and K. Thyagarajan.

## 3rd Space and Atmospheric Science Course

Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP)
1st August 2002 to 30th April 2003, PRL, Ahmedabad

| Name | No. of Lectures | Topic |
|---|---|---|
| Prof. Shyam Lal | 9 | Basic Concepts of Earth's Atmosphere |
| Prof. H.S.S. Sinha | 7 | Ionospheric Propagations and Measurement Techniques |
| Prof. B.G. Anandarao | 8 | Introduction to Astronomy and Astrophysics |
| Prof. H. Chandra | 7 | Ionospheric Propagations and Measurement Techniques |
| Prof. A.C. Das | 10 | Magnetospheres of Earth and Other Planets |
| Prof. J. N. Desai | 10 | Airglow Emissions |
| Prof. P. Venkatakrishnan | 5 | Elements of Solar Physics |
| Prof. N.M. Ashok | 10 | Optical and Near IR Studies of Stars and Galaxies |
| Prof. A. K. Singal | 3 | Radio Astronomy Studies |
| Prof. U. C. Joshi | 7 | Introduction to Astronomy and Astrophysics |
| Prof. A. Jayaraman | 12 | Solar Radiation and its Effect on Atmosphere |
| Prof. T. Chandrasekhar | 9 | Astronomical Instruments and Observation Techniques |
| Dr. Y.B. Acharya | 5 | Dynamics of Earth's Atmosphere |
| Dr. S.A. Haider | 7 | Ionospheres of Other Planets and Satellites |
| Prof. Ashok Ambastha | 8 | Measurement Techniques for and Solar Geomagneti Parameters |

Lectures given in PLANEX Workshop on

**Planetary Atmospheres, Ionospheres and Magnetospheres**

at SPL, VSSC, Thiruvananthapuram, February 17-22, 2003
organised by Indian Space Research Organisation

| Name | No. of Lectures | Topic |
|---|---|---|
| N. Bhandari | 3 | Origin of Solar System Origin of Moon and its future exploration Indian Planex Programme |
| J.N. Goswami | 2 | Laboratory studies of planetary materials Outer solar systems |
| S.V.S. Murty | 2 | Formation of inner and outer planets Evolution of planetary atmospheres |
| Hemant Dave | 2 | Sub-millimeter astronomy Remote sensing of planetary atmospheres |
| T. Chandrasekhar | 2 | Minor bodies (comets, asteroids, meteors) IR Spectroscopy of minor bodies |
| P. Venkatakrishnan | 2 | Solar radiation spectrum Sources of particle radiation and ionizing radiation from the Sun |
| S.A. Haider | 2 | Planetary Atmospheres Planetary Ionospheres |

# Science at PRL

In what follows are given the summaries of some significant results obtained in the fields of Optical/IR Astronomy and Radio Astronomy.

## The Outburst of V838 Monocerotis

V838 Mon is presenting one of the most mysterious outbursts in recent times. This enigmatic variable erupted in January 2002 in what looked originally like a nova outburst. However many unusual features were seen in the object - the most striking being a light echo surrounding it. The interest in the object has led to several papers on it ( by researchers in the field) in the last few months. It's enigma however, has still not been understood and astronomers have provisionally categorized it as a new class of astronomical object. From our IR observations of V838 Mon we find the following salient features: i) the unusual presence of Ti I lines in emission in the spectra. This helps to estimate the mass of the ejected shell; ii) Deep CO bands with a complex structure in the K band; and iii) a rapid, temporal evolution of V838 Mon towards a very cool M type supergiant. The IR observations put constraints on the nature of V838 Mon and support the contention that it belongs to a rare class of objects.

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

## Near IR Studies of R Coronae Borealis

RCB stars are a category of variables which show episodic dimming due to ejection of dusty carbon shells. The prototype of this category is R Corona Borealis itself (RCrB). This object underwent a recent episode of fading in February 2003. Near IR spectra and photometry of RCrB was done at several epochs during it's fading and subsequent recovery. The spectra during the faintest phase show a steeply rising continuum towards the red indicative of dust at a temperature of ~ 1100-1200K. Further analysis of the data is on. This work is done in collaboration with IIA, Bangalore who have obtained optical spectra for RCrB during the present episode.

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

## Lunar Occultations with NICMOS IR Array

Infrared arrays like NICMOS due to their higher sensitivity and smaller detector size, in comparison with single element IR detectors, can yield higher S/N and reach fainter objects in principle for high angular resolution studies by Lunar occultations. However, while a single element detector can be made to sample a fast event (like lunar occultation of a star ) readily at 1 millisec per sample, the same is not true for an array, due to the readout required of a large number of pixels in the array. The problem of rapid sampling has been addressed by choosing only a small sub-array and positioning the star within this sub-array during an occultation event. A software using C++ for fast readout of a preselected area of interest (AoI) has been developed. So far two lunar occultation events (IRC + 20120) (**Fig. 1.1**) and (IRC + 10241), have been successfully observed in the K band in the sub-array mode with a field of view of 10" x 10" (20 pix x 20 pix). The smallest time between two samples in the sub-array mode is 16 millisec. For binary detections and for resolving extended sources (> 10 milliarcsec) the present arrangement would be suitable. Efforts are on to reduce the sub-array sampling time to about 3

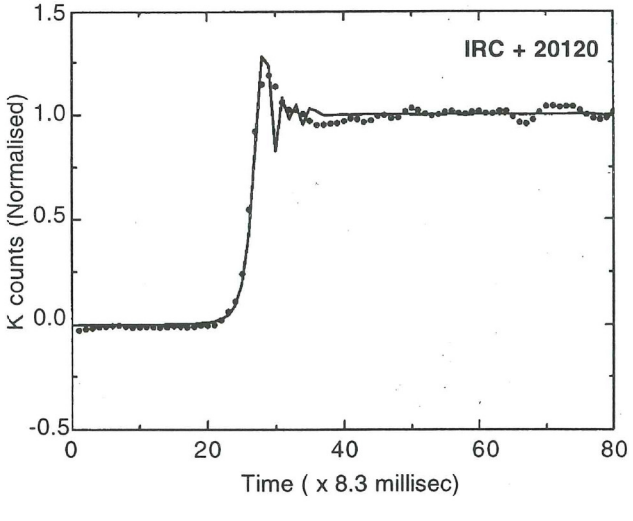



*Fig. 1.1 : Lunar occultation of carbon star IRC+20120 recorded in the NICMOS subarray fast acquisition mode. A model light curve with a source size of 4 mas fitted to the data is also superposed.*

millisec so that conventional Lunar occultation observations can be taken up and other rapidly varying sources can be studied.

(T. Chandrasekhar, Rajesh Shah and Soumen Mondal)

## Asteroid Occultation using NICMOS IR Array

A spin off of the work on rapid readout of a NICMOS sub-array for lunar occultations has been to observe occultations of stars by asteroids. Till recently, asteroidal occultations could not be undertaken in a regular manner as the predictions of the event at a site were not precise enough (due to the small size of asteroids) and success rate was low. With accurate ephemeris of asteroids becoming available, refined predictions for a particular site are now possible. Unlike lunar occultations, asteroidal occultations involve sampling the star signal at a rate of 200 millisec or more. A typical event could last 5 seconds or more. Knowing the relative movement of the asteroid with respect to the star field and its distance, the duration time of the occultation dip can be translated to a chord length on the asteroid. Such direct measurements of asteroidal sizes are few and greatly valued.

Using a NICMOS sub-array size of 20" x 20" (40 pixel x 40 pixel) we have successfully observed the occultation of a star TYC 6256 - 00276 - 1 (J = 9.22, V = 10.2) by asteroid 259 Aletheia on February 28, 2003 in the J band **(Fig. 1.2)**. 427 frames were recorded in 3 minutes centred on the event. The asteroidal occultation was noted to last 17 frames or 7.17 sec. A chord length across the asteroid of 204 $\pm$ 3 km is derived.

(T. Chandrasekhar, N.M. Ashok and Rajesh Shah)

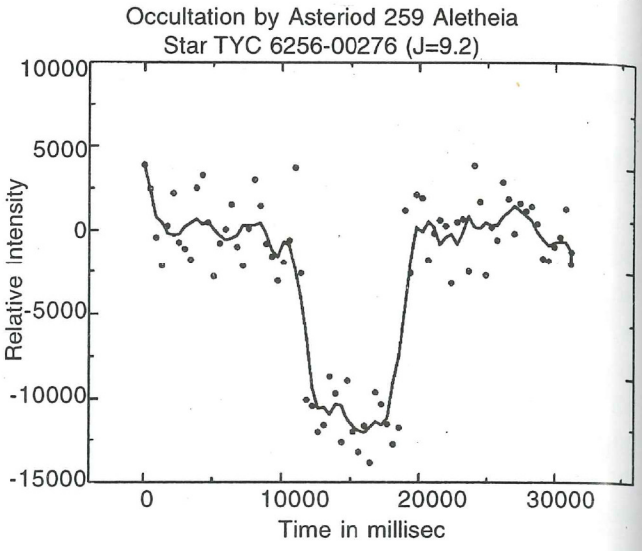



*Fig. 1.2: Occultation of Star TYC 6256-00276 (J=9.2) by asteroid 259 Aletheia observed in the infrared J band at 1.2 $\mu$ m with the NICMOS Subarray Data points and a five point running average line are shown.*

## Study of Milky Way

### *Catalog of Mid Infrared Point Sources with Near Infrared Counterparts*

A catalog of mid-infrared point sources was prepared from the ISOCAM images of the Galactic Plane obtained under the ISOGAL project in collaboration with French team. Nearly 1 lakh sources are catalogued. The catalog contains measurements for these sources at 5 wavelengths viz. 7 and 15 microns from the Infrared Space Observatory and 1.25, 1.65 and 2.2 microns from the DENIS ground based survey. This catalog has been made available to the general astronomical community. PRL members were involved in developing the pipeline for the basic reduction of the ISOCAM images and later in the validation of the cross-identification of the ISO and DENIS sources.

### *Morphological Study*

Using the mosaic of the mid-infrared images of the Nuclear Bulge of the Galaxy as a basis for study, we have made a multi-wavelength morphological comparison of a large part of the Nuclear Bulge. Among the interesting correspondences are that of the Sgr B1 at mid-infrared wavelengths with archival radio (VLA 3.6, 20cm) imagery. A large number of dark molecular clouds are seen in strong emission at sub-mm wavelengths (data from SCUBA obtained by Pierce-Price et al in collaboration with some members of the ISOGAL collaboration) and also in archival $^{12}CO$ data.

### *Extinction Towards the Galactic Plane*

Using the near infrared data from the DENIS Survey we have constructed a large scale map of the ex-

tinction towards the Inner Bulge all along the Galactic Plane. Comparison has been made with CO, IRAS and COBE data for a large section of the Galactic Plane. Results indicate that the near-infrared window can probe up to an extinction of about 40 magnitudes in the visual band but beyond that we need to look to other wavelengths.

The above work was carried out under an Indo-French collaboration program.

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

### *Near Infrared Survey of the Inner Bulge of Milky Way from SAAO*

We have surveyed the inner 300 pc of the nuclear bulge region of our Galaxy from Sutherland, South Africa using 1.4 m IRSF telescope. We used Simultaneous Infra Red Imager for Unbiased Survey (SIRIUS) camera fitted with three 1k x 1k detectors capable of deep imaging in J, H and Ks bands simultaneously. The observations were made during June 25-July 1 and June 9-15, 2002 of a 1.5 sq degree field centered around Galactic Center (**Fig. 1.3**). These observations have resulted in deepest (about 2 magnitudes deeper than 2MASS/DENIS) view of this region in the near infrared and coupled with the information available from surveys at other wavebands, should lead to much better understanding of these highly obscured central regions of the Milky Way. The color magnitude diagram of the central field **(Fig. 1.3)**, obtained after difficult data reduction and photometric procedures, shows various populations distinctly.

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

### Discovery of Knots and Jets in a Massive Star Forming Region in Gemini OB 1

IRAS 06061+2151 is one of the most luminous objects discovered by IRAS in the galactic massive star forming region called Gemini OB 1 at a distance of 2kpc. Radio and near-infrared surveys suggest that luminous IRAS sources are usually associated with massive cores. A near-infrared survey was conducted on this object involving JHK photometric observations and narrow band filter-grams using NICMOS 3 at Mt. Abu Observatory, narrow band imaging and K band spectroscopy using the 3.5 m Telescopio Nazionale Galileo (TNG) at La Palma as well as the 2 MASS archival data. The results revealed a cluster of at least five sources surrounded by a

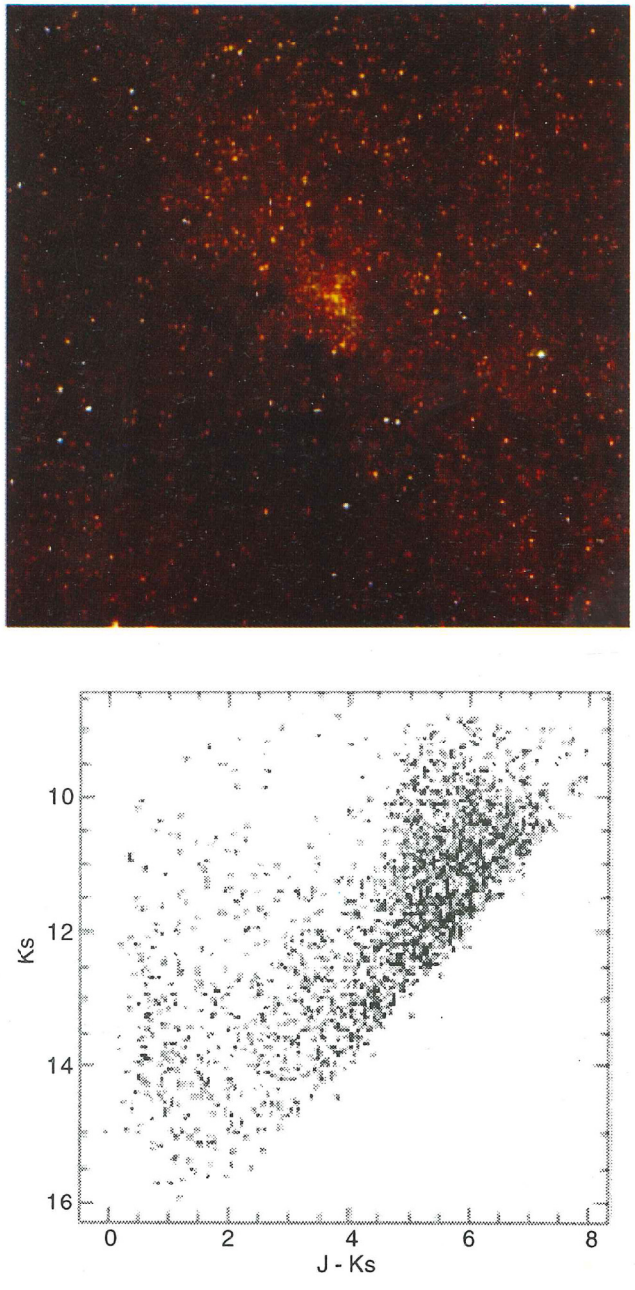



***Fig. 1.3** : J, H, Ks colour composite image of the 20 x 20 parsec region around the Galactic Center (upper panel) and colour magnitude diagram of the same region (lower panel).*

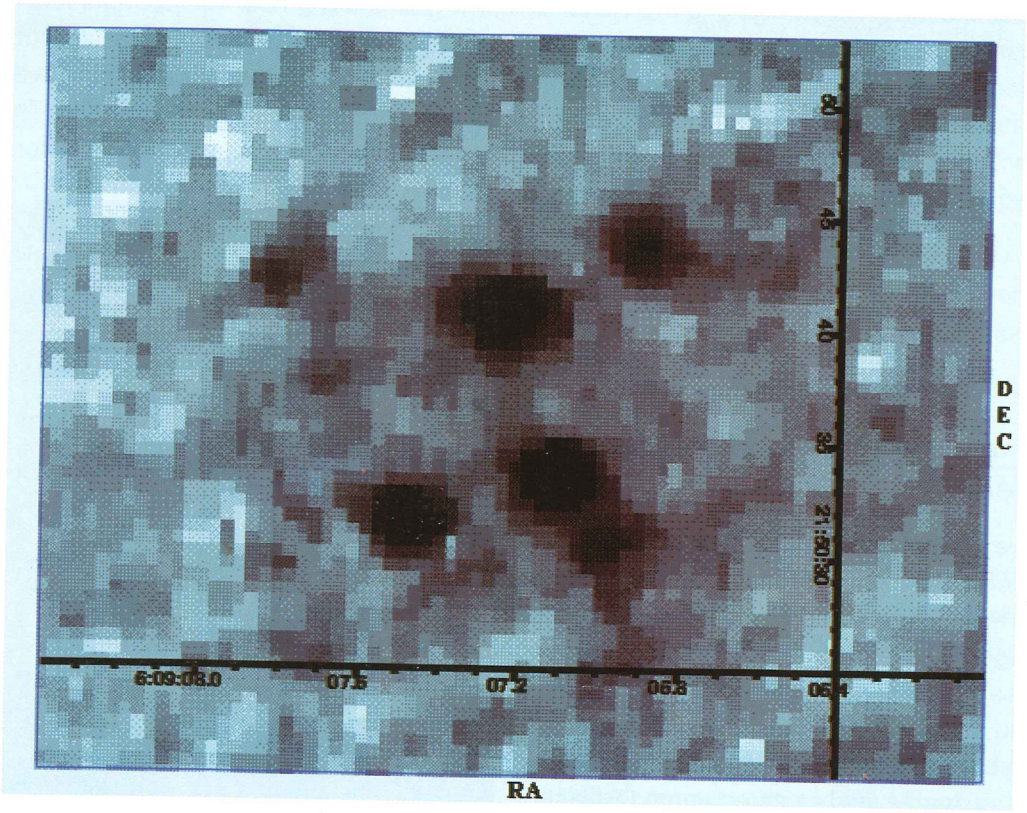



*Fig. 1.4 : K image of the central region of the massive YSO IRAS 06061+2151, taken at Mt. Abu using NICMOS 3 camera. The stars shown are a cluster of intermediate mass stars - the most massive being a B5-B0 type star.*

nebulosity, the most massive being an early-mid B type protostar. The narrow band images from TNG revealed molecular Hydrogen (2.121 micron line) knots arising out of interstellar matter shocked by jets from a class I type young stellar object. The K-band spectra support shock excitation of molecular hydrogen. The ultra-compact HII region is powered by a cluster of intermediate mass stars (**Fig. 1.4**).

(**B.G. Anandarao**, A. Chakraborty, D. K. Ojha and L. Testi)

## A Model for Infrared Spectral Energy Distribution in Accretion Disks of Young Stellar Objects

During their pre-main sequence phases, Young Stellar Objects (YSO's) emit a large amount of excess infrared radiation primarily due to the presence of an accretion disk. By modelling infrared colors it is possible to determine the evolutionary status of these objects before they enter the Zero-Age Main-Sequence phase. Essentially there are two dominating heating processes : viscous heating and reprocessing of radiation by dust. A model that takes these two processes into account has been developed to determine the spectral energy distributions (SEDs) of YSOs as a function of several free parameters such as mass and temperature of the central star, mass accretion rate and the geometry of the disk as well as the evolution of the YSO. The results are compared with two sets of YSOs namely Herbig Ae-Be stars of intermediate mass range and T-Tauri stars of low mass range for a flared disk assumption (**Fig. 1.5**).

(**B.G. Anandarao** and S. Mishra)

## A Multiwavelength Observation Campaign on the Blackhole Candidate SS433

SS433 is a well-observed, bright emission compact system that ejects matter at relativistic speeds in two

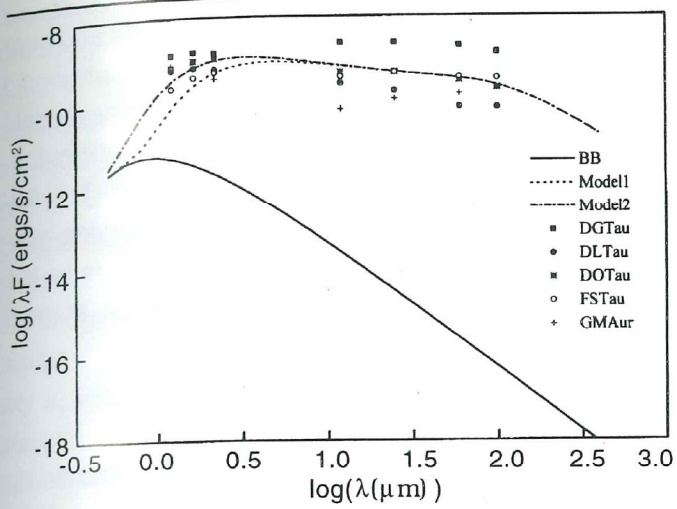



*Fig. 1.5 : Spectral energy distributions for a flared disk for a low mass star. The points are observed data for a few T Tauri stars.*

oppositely - directed jets. In order to look for short-time variability (of the order of seconds), a multiwavelength campaign was conducted by SN Bose National Centre, Kolkata. The campaign involved near - simultaneous observations in radio (using GMRT), optical (Nainital and Kavalur), near-infrared (Mt. Abu) and X-rays (RXTE). The observations at Mt. Abu were made during 25-30 September 2002 using the NICMOS 3 in JHK bands. The near-infrared results showed a clear day-to-day variability in all the three bands to a level of ≥ 0.06 Jy, the cause of which may be traced back to the varying accretion disc structures. No sub-hour variability was observed. On one night's observation, a sudden drop of flux of about 10 mJy in J and H bands was observed in a duration of a few minutes.

(B.G. Anandarao and Soumen Mondal)

## Coronal Electron Density Model and its Implication for the Gradient of Coronal Rotation with Altitude

There are two major efforts for the determination of coronal rotation, namely, optical method and radio emission as the diagnostic tool. These recent results show a dissimilarity. There are two main differences; (1) Radio measurements give a lower rotation period than optical ones and (2) Radio measurements show a systematic variation of rotation period with height (a gradient of coronal rotation) which does not appear to be the case with optical measurements. The radio measurements use electron density model for estimating the height of radio emission in the solar corona. We performed the calculations of the gradient of coronal rotation using electron density model over an extended range of parameters (s =1, 8, where s is the harmonic number of plasma frequency in solar corona) and the rotation measurements. A typical variation is shown in **Fig. 1.6** for s = 1 - 8, giving variation of plasma frequency with height. However, radio emission at the plasma frequency is not usually possible. The emission and propagation takes place at the harmonics of plasma frequency. This shows that height of coronal emission at 405 MHz will vary from 4.5 x $10^4$ to 18 x $10^4$ kms above the photosphere and under similar conditions that at 2800 MHz will vary from 1.12 x $10^4$ to 3.55 x $10^4$ kms. This will give the gradient of coronal rotation period around 760 msec/km for second harmonic which will reduce with increasing harmonic number. For 8 th harmonic it would be around 240 msec/km. This shows that if the emission from solar corona is at higher harmonics that will explain one of the differences between radio and optical measurements. However, if

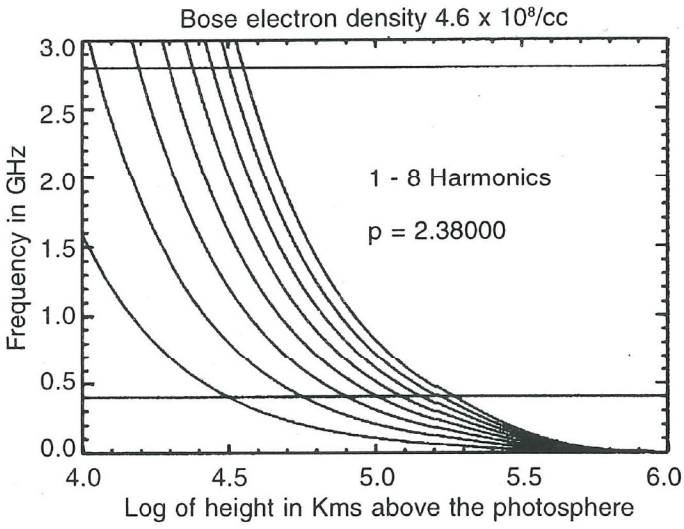



*Fig. 1.6 : Variation of emission frequency as a function of height above the photosphere. The lowest curve is for fundamental frequency and above seven are for 2 – 8 harmonics of the coronal plasma frequency. The two straight lines are for 405 and 2800 MHz.*

the emission takes place at the fundamental frequency the gradient of coronal rotation with height will be even higher ~ 1 sec/km. More detailed calculations are necessary to understand the difference. This work is being done in collaboration with INPE, Brazil and SU, Rajkot.

(Hari Om Vats)

## Study of Solar Irradiance

One of the most important solar parameters that controls the Sun-Earth relationship is the total power received as irradiance from the Sun at Earth. Until about 20 years ago this was believed to be constant, as the term "solar constant" indicates. Now it is possible to make high-precision measurements of the total solar irradiance outside the Earth's atmosphere. It has been confirmed that there are indeed small but systematic variations in phase with the solar activity with an increase in irradiance from sunspot minimum to sunspot maximum of about 0.1 % corresponding to a global average of 0.3 W $m^{-2}$. The solar irradiance is essentially the contribution from the small scale solar surface structures integrated over the solar disk. The data set for level 1.8 and 2 is available from the SOHO/VIRGO team site. Here an attempt is made to investigate the short and long term variation of total solar irradiance during 1996- 2001. The correlograms of 1996 and 1998 show that there is clear and strong evidence of solar rotational modulation. The rotational modulation is more in 1998 than that in 1996. However, the data of 1998 shows a splitting of the modulation peak. The synodic rotation period is estimated to be about 27 days. The variation of rotational modulation is independent of solar activity and it is found to be drastically different from other solar emissions, e.g. solar Lyman-Alpha, radio emission etc. There exists a large yearly variation in the correlograms having periodic and aperiodic peaks.

(Hari Om Vats)

## Giant Radio Galaxies and Quasars

A study of giant radio sources could be of interest not only for understanding the physics of their emission processes and of their interaction with the intergalactic medium. But may be equally important as a check on the unified scheme models for radio galaxies and quasars. For example finding too many giant quasars would contradict the orientation-based unified scheme models for these AGNs. With this in mind, five giant radio galaxies and quasars were observed with the GMRT in August 2002. Among these we have discovered one quasar which among the known quasars appears to be the only one beyond a redshift of 1 with a giant size at radio wavelengths (~1.8 Mpc).

(Ashok K. Singal)

## Seyfert Galaxies and Radio-quiet Quasars

### *Seyfert Galaxies*

In recent years there has been a report in the literature where Sy2's were reported to have statistically more unresolved compact components as compared to Sy1's. This finding, if true, goes very much against the orientation-based unified scheme for Seyferts. We want to independently check these findings, considering their importance for the unified scheme models. Towards this end, a sample of about 20 Seyferts containing a mixture of Sy1 and Sy2's, was observed with the GMRT. The idea is to compare their unresolved radio emission.

(Ashok K. Singal)

### *Radio-quiet Quasars*

A sample of a couple of radio-quiet quasars was observed with the GMRT to detect them at faint levels and to see if we can find extended low-brightness regions of FR I-type that extend way beyond the host galaxies. Recently a radio-quiet quasar with such radio morphology has been reported in the literature, the only such known case. We want to examine whether there are more such cases or whether it is only an exception.

(Ashok K. Singal)

## Fine Structure of Solar Wind Turbulence from Radio Occultation Observations

Coronal radio sounding experiments with the Ulysses spacecraft at superior conjunction provided numerous opportunities for simultaneous observations of

the downlink signals at two widely spaced ground stations. In some instances the duration of these observations extended for up to four hours, thereby allowing one to track solar wind turbulence dynamics at spatial scales comparable with the coronal projected distance between ground stations (a few thousand km). The frequency and phase fluctuations produced by electron density inhomogenities are normally well correlated on these scales. Whereas the mean frequency fluctuation intensity $\sigma_f$ was found to change only slightly over the duration of the observations, the spectral index of the temporal frequency fluctuation spectra varied over a wide range. The cross correlation coefficient reached maximum values (~ 0.5) when the spectral index was high (~ 1), but no correlation could be detected when the spectral index became small (< 0.4). Similar behavior in many of the data sets implies that this is common, if not a permanent feature of the solar wind. Possible reasons for the fluctuation decorrelation were analyzed. The decorrelation at heliocentric distances ~ 10 $R_\odot$ most likely results from continual deformation of the solar wind density irregularities during their motion across the radio ray paths.

(**P. Janardhan** and M.K. Bird)

Monitoring of solar activity, participation in the international GONG project for helioseismology and conducting research on magnetic field induced solar activity, helioseismology and space weather are the major tasks of USO. Currently, a detailed study on the feasibility of installing a modern solar telescope with adaptive optics capability is underway.

## On the P-mode Asymmetry between Velocity and Intensity as Seen in GONG+ Data

The ring diagram technique was applied to the GONG+ velocity and intensity data over small regions on the solar surface. We find that at low degrees, the velocity oscillations have more power on the low frequency side and intensity oscillations have more power on the higher frequency side. The frequency shift between velocity and intensity is found to be a function of the location on the disk and is higher near the disk center than those near the limb. This strongly suggests that the mechanism for the frequency shift is due to the correlated noise from the granulation rather than radiative transfer effect.

(**S. C. Tripathy**, Kiran Jain, Frank Hill and Cliff Toner)

## Validity of Prediction of P-mode Frequency Shifts from Empirical Models

The observed frequency shift from minimum to maximum of solar cycle 23 as calculated from MDI frequency data sets is 251 ± 7 nHz and from GONG data is 238 ± 11 nHz. This is in close agreement with the value of 271 ± 22 nHz that is predicted empirically from the activity indices. However, the discrepancy near the maximum phase of the cycle indicates the complex nature of the relationship that may exist between the activity index and the frequency shift.

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

## Changes in Intermediate Degree P-mode Frequencies over the Solar Cycle 23

The solar cycle variation of the intermediate degree mode frequencies is examined with the new data sets available from GONG and MDI projects. In addition to the 108 days time series that are produced by the GONG project, we have calculated frequencies from shorter time series of 18 and 27 days respectively. We find that the mean frequency shifts are equally correlated with both magnetic and radiative indices even at the shorter time scales (**Fig. 2.1**). Our analysis indicates that the intermediate degree modes adjust to changes in the activity measures on time scales of 18 to 27 days.

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

## On the Rapid Variations of Solar Magnetic Fields

We report on the rapid variations of solar magnetic fields that appear to be enhanced significantly above the background variability, at a few locations within the solar active regions, as observed with the Michelson Doppler Imager (MDI) on board the SOHO spacecaft (**Fig. 2.2**). The pressure fluctuations estimated to arise from this variability far exceed the general level of acoustic pressure fluctuations. The equivalent mechanical flux that could be generated from these rapid magnetic variations is more than adequate for the heating of the active region chromosphere and corona.

(P. Venkatakrishnan, Brajesh Kumar and B. Ravindra)

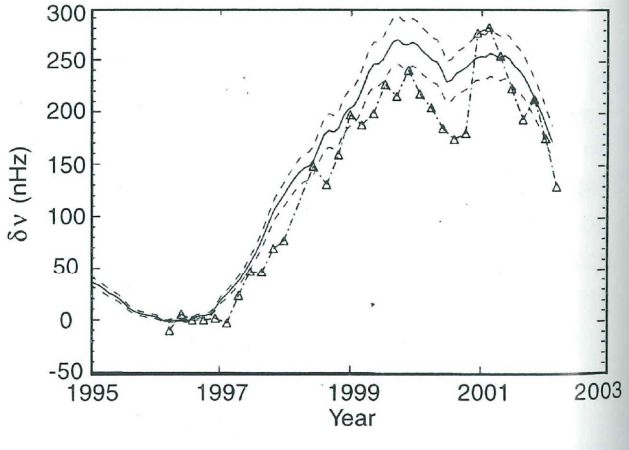



*Fig. 2.1 : The calculated (solid line) and observed (triangles) frequency shifts as calculated from the MDI data for the year 1995-2002. The dashed lines show the 1-s errors in calculated frequencies.*

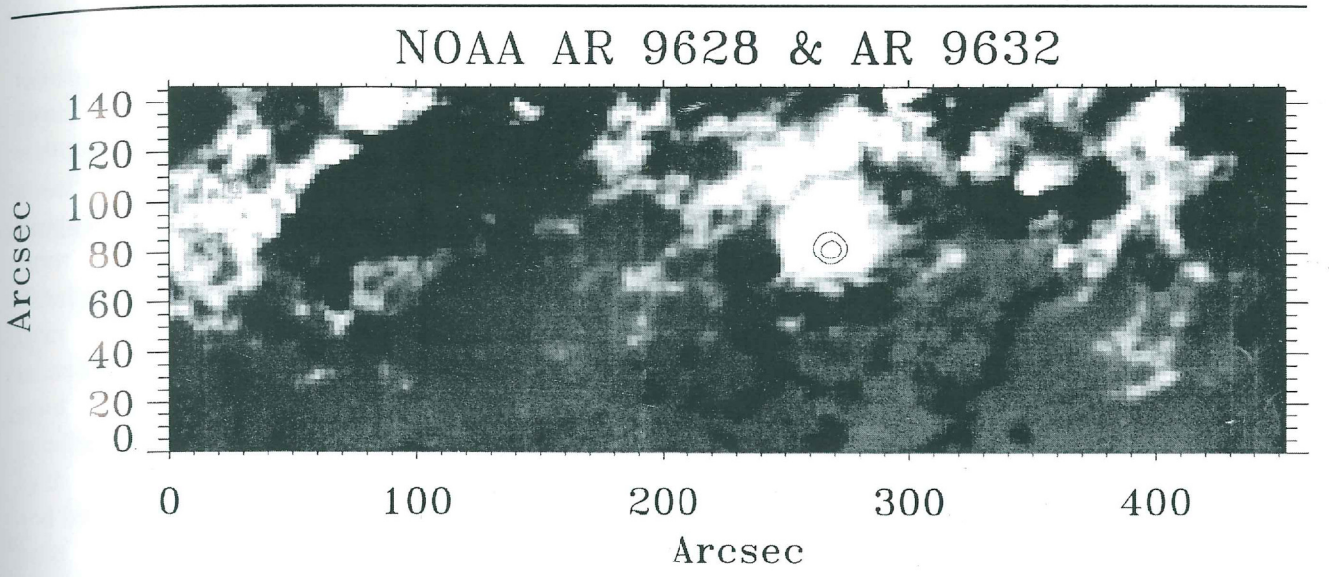



*Fig. 2.2: Contours of the rms of magnetic field variations are shown overlaid on the mean magnetogram of the active region. The lowest and highest contour levels are 30G and 70G, respectively.*

## Variations in Mode Amplitude with Flares in Solar Active Regions

We studied 11 active regions using the ring diagram analysis technique to obtain 3-D power spectra in order to infer the effect of flares on the amplitude, frequency and width of the acoustic modes. A composite diagram was made for these active regions to illustrate the variations in mode amplitude with flare-index, FI. It can be seen that in most cases the peak in FI coincides with that in the amplitude. After compensation for the suppression of amplitudes by magnetic fields, the maximum amplitude is seen for NOAA9393 which was one of the most active region in terms of flare production. Out of the 11 active regions studied by us 8 showed enhancement in power after accounting for variation in magnetic index, MAI. We find that the extent by which the p-mode power is enhanced by flares does not have any obvious correlation with the flare index (**Fig. 2.3**).

(**Ashok Ambastha**, Sarbani Basu, and H.M. Antia)

## Detachment of Filament Barbs from the Chromosphere Prior to Filament Eruption

The footpoints or the barbs of a filament display conspicuous variation during its evolution. Prior to the eruption of filaments, the barbs become activated, and finally either erupt or disappear. We have examined the role of barb detachment in four cases of eruptive filaments observed at USO. The study clearly shows that more number of barbs or footpoints provide stability to

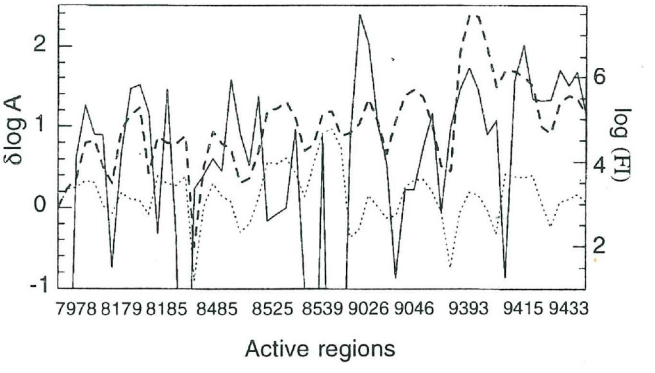



***Fig. 2.3:*** *Variation in average amplitude A of p-mode oscillations (for n=0,1,2,3) for all 11 active regions. The differences plotted are averages over all f-modes (n=0) in frequency range 2.5-3 mHz and p-modes (n=1,2,3) in the frequency range 3-3.5 mHz. To check the correlation with flares the logarithm of flare index, FI, for each of these active regions is also shown. The solid curve shows log(FI) on a scale marked on the right axis, while the dotted curve represents $\delta log(A)$. The heavy dashed curve shows $\delta log(A)$ after correcting for magnetic index, MAI.*

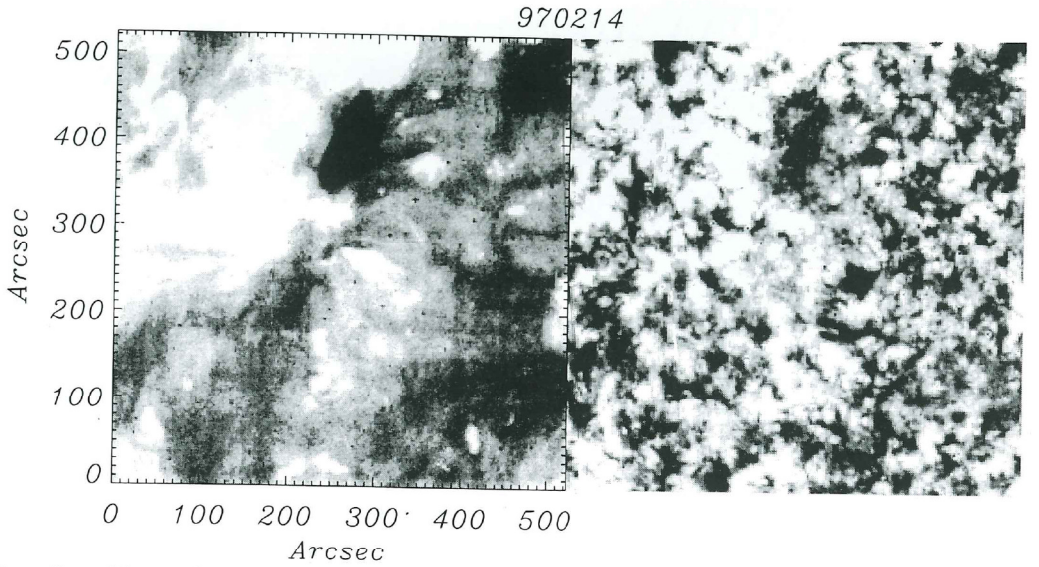



***Fig. 2.4:*** *A portion of the sun's image obtained from the central part of the full disk image of Fe XII 195A (left) and He II 304A (right).*

the filament. The number tends to decrease prior to eruption on a time-scale of several hours to days. It was found that above a critical value of the aspect ratio of the separation of the footpoints to their height, the filament erupted. The height-time plots for the events studied show that the rise of the filament is slow (~ few km/s) in case of quiescent filaments in agreement with the slow process of detachment of the barbs. However, in case of active prominences a rapid change of the order of minutes is seen in pre-eruptive phase and therefore a faster rise of the filament is observed.

(**Nandita Srivastava** and Sara Martin)

## Structure and Evolution of the Transition Region Network Observed in He II 304 A.

The temporal structure function for the evolution of the He II network was calculated from a time-series of the spatially aligned He II images. The estimated life time of the network cell was about 27 hours. The spatial structure function calculated from the He II filtergrams shows saturation at ≈ 25000 km. The transition region network elements are bigger in size than the photospheric magnetic network element. The magnetic network element for a field extrapolated to 3000 km above the source surface takes the size of the He II network element. The derived value of the diffusion speed of the network elements was 0.098 km $sec^{-1}$.

(B. Ravindra and P. Venkatakrishnan)

## On the Correlation Between the He II 304 A Network Brightening and the Photospheric Magnetic Field

Near simultaneous coronal EUV images were used to show that the He II ( λ304A) network brightening is independent of coronal EUV radiation (**Fig. 2.4**). An almost linear relationship was found between the He II network brightening and the magnetic field for a field strength higher than 10 G with exceptions at neutral lines and in the intra-network.

(B. Ravindra and P. Venkatakrishnan)

## Space Weather Prediction

A study of geo-effective CMEs observed during 1996-2002 shows the travel time of the CMEs is strongly dependent on their initial speeds: (a) the CMEs with very high initial speeds (greater than 1500 km $s^{-1}$) arrive in about 30 ± 5 hours, (b) the CMEs with moderate speeds (ranging between 1000-1500 km $s^{-1}$) arrive in about 50±15 hours and (c) the CMEs with low initial speeds arrive in about 80 hours.

The study also suggests that the speeds of the resultant IP shocks are not strongly-correlated with the strength of the geomagnetic storm. On the other hand, a strong correlation coefficient (0.63) between the initial speed of a CME (as measured in LASCO-C2 and C3 images) and the strength of the related geomagnetic storm indicates that it is the initial speed of a CME that dictates the strength of the related geomagnetic storm. Once launched from the solar surface, a high speed CME tends to increase the ram pressure exerted by the solar wind on the earth's magnetosphere. Further, the geoeffectiveness of such a CME is mainly determined by the strong coupling between the solar wind plasma and orientation and magnitude (IVBzI) of the IP magnetic field (**Fig. 2.5**). These findings can prove useful in space weather prediction, particularly for major geomagnetic storms.

(Nandita Srivastava and P.Venkatakrishnan)

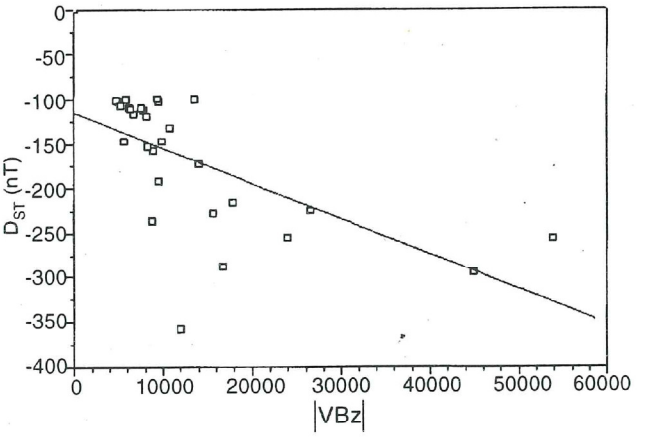



*Fig. 2.5: The dependence of the magnitude of the geomagnetic storm on the solar wind speed and the southward component of the interplanetary field given by IVBzI*

## Simulations on the Optimum Size of a Solar Telescope for High Angular Resolution Studies of Solar Features

Meter Aperture Solar Telescope (MAST) is a proposed modern solar telescope to be equipped with low order adaptive optics, operating at visual and infrared wavelengths. It is planned to make use of low order adaptive optics system coupled with post detection techniques to achieve the performance that would meet the science requirements. Simulations were performed in order to assess the capability of such an hybrid imaging system for the typical seeing conditions at Udaipur Solar Observatory. **Fig. 2.6** shows the result of the simulations for a 91 cm telescope operating at 430.5 nm for 3 cm $r_0$.

(R. Sridharan, A. Raja Bayanna and P. Venkatakrishnan)

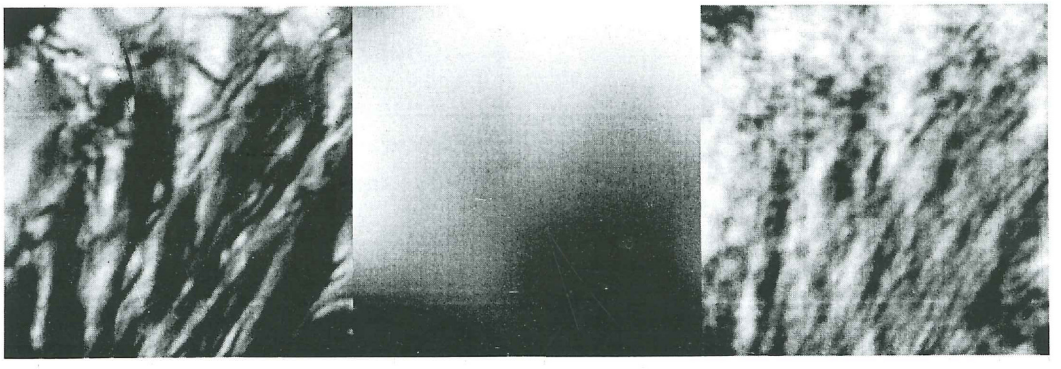


*Fig. 2.6: A portion of the G-band (430.5 nm) image obtained from New Swedish Solar Telescope, used as object in the simulation (left). The middle image is obtained after correcting for 28 Zernike modes (proven capability of NSST). Image obtained after AO and Speckle Interferometry (right).*

# Submillimeter and Solar X-ray Astronomy

The high resolution, spectral and spatial, observations in the submillimeter wave region provides information on the chemistry, energy balance, structure, and internal motions of molecular gas clouds in our own Milky Way galaxy. The SMM group is developing state-of-the-art instrumentation using quasi-optical techniques to explore Inter Stellar Dust (ISD), Cool Molecular clouds, and Planetary Atmosphere. In particular, following activities are being pursued rigorously.

## Star Formation

Simple hydride molecules are of great importance in astrophysics and astro-chemistry. Physically they dominate (beside CO and $H_2O$) the cooling of dense, warm phases of the interstellar medium, such as the cores and disks of young stellar objects. Chemically they are stable end points of chemical reactions, which can be used to test the validity of the process. Due to the low moment of inertia, hydrides have fundamental spectral lines in the sub-millimeter region. Detailed survey of hydrides such as LiH, HF, HCl, SiH, FeH etc. is needed to study the abundance and dynamic process of molecular clouds. The process of star formation is vital in understanding of the cosmos. Unfortunately, a complete model has not yet been established. We are developing spectral modelling, which includes hydrides and other molecular species. Analysis of resulting theoretical spectral line profiles with observed ones will help us to interpret the basic cooling mechanism in the star forming regions.

## Planetary Atmosphere

We have designed a sophisticated gas cell, which gives pre-defined SMM spectral signal using a black body source. We want to study this generated signal of different intensity profiles in a broad SMM band. The high resolution systematic study in the laboratory will be used to develop planetary atmospheric models.

## Local Oscillator Development

Sub-millimeter wave group is developing a highly sensitive heterodyne receiver system. In the laboratory system, we are using step tunable Optically Pumped Molecular Laser (OPML) as a local oscillator, which is designed on the basis of independent and linear cavities configuration. Routine operation of LO is established at 70, 96, 118, 163, 394, and 495 μ lines. Power and Frequency Stabilization scheme is routinely achieved. Propagation of SMM radiation through over-sized wave-guide is studied for an optimized installation of various quasi-optical components for efficient mixing. The I-V characteristic of the Schottky diode mixer device has been established. Beam quality tested using LO beam profiles for efficient coupling into the antenna lobe.

For space and defense related applications we are developing folded and intra-cavity pumped structures. Simulations for folded cavity structures like Z and W to increase the system compactness have been developed. We have incorporated innovative slotted wave-guide and horn antenna in the wave-guide structure to improve the efficiency of the resonator. All major dominating parameters have already been optimized for eventual space based laser local oscillator. Computer simulation programs to optimize the laser cavity are under development.

## Detector Development

The room temperature Schottky diode detector performance is optimized. Cryogenically cooled SIS mixer development has been initiated. A receiver mixer block has been designed for SIS element mounting.

## IF Signal Processing

A narrow band IF state-of-the-art Chirp Transform Spectrometer (CTS) has been fabricated. Final performance characterization is under way.

(Hemant Dave, Ashish Dubey, Satheesh Thampi, S. D. Rawat, Jayesh Pabari, Ravindra Singh, and Vinay Chaudhari)

## Spectral Response of the SOXS Low Energy Detector Payload

The Solar X-ray Spectrometer (SOXS) Low Energy Detector (SLD) payload comprises of Si PIN and CZT solid-state detectors. We carried out the character-

ization and spectral response study of these detectors at the Lab Model. In order to simulate the conditions close to solar flare we have to shine the detectors with the strong radioactive source. With this in view, the payload was taken to Tata Institute of Fundamental Research (TIFR), Mumbai. We used strong $Am^{241}$, $Cd^{109}$ and $Fe^{55}$

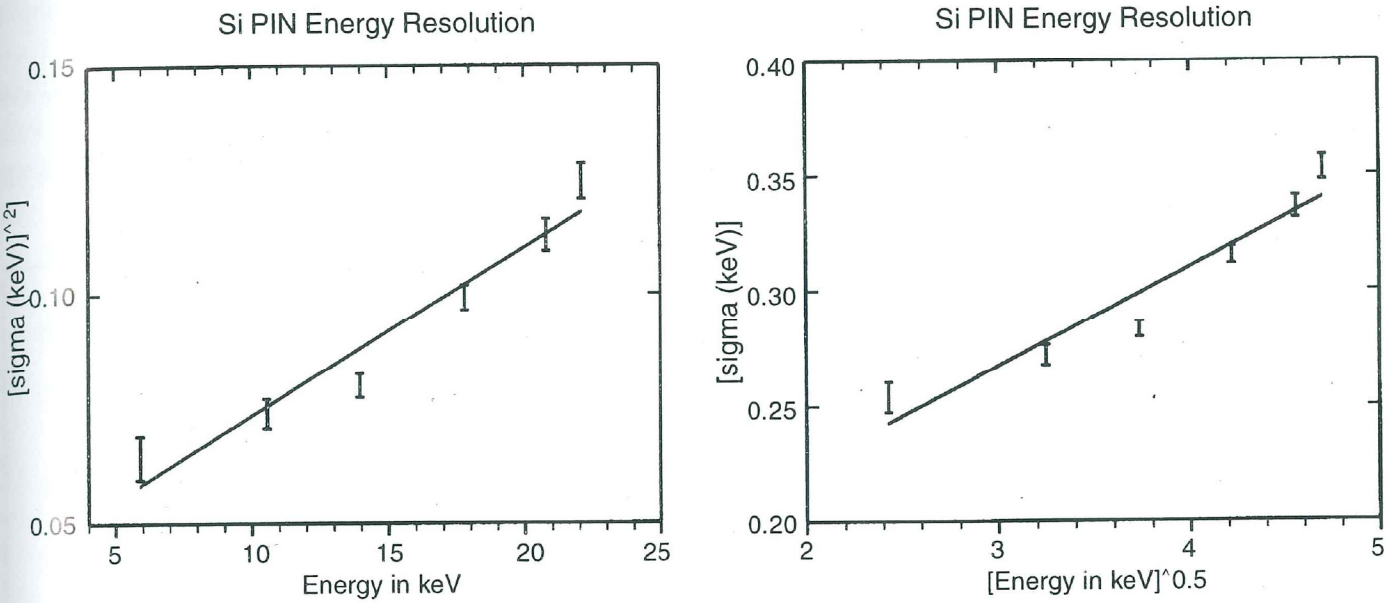



*Fig. 3.1 Left panel: plot for Energy Vs $[\sigma_e (keV)]^2$, Right panel: plot for $[Energy (keV)]^{0.5}$ Vs $[\sigma_e (keV)]$. The plot shows the resolution function of the Si PIN detector of SLD/SoXS payload. The FWHM (keV) shows a linear response with the increase in energy. The response of the detector in the energy range 4-25 keV is satisfactory. Linear fit for Energy Vs $[\sigma_e (keV)]^2$ gives the parameters as follows: Constant parameter, a=0.0401, and linear parameter, b=0.0037. Where a = noise factor that is contributing in the FWHM, and b = product of Fano factor and average energy of the detector material (Fw).*

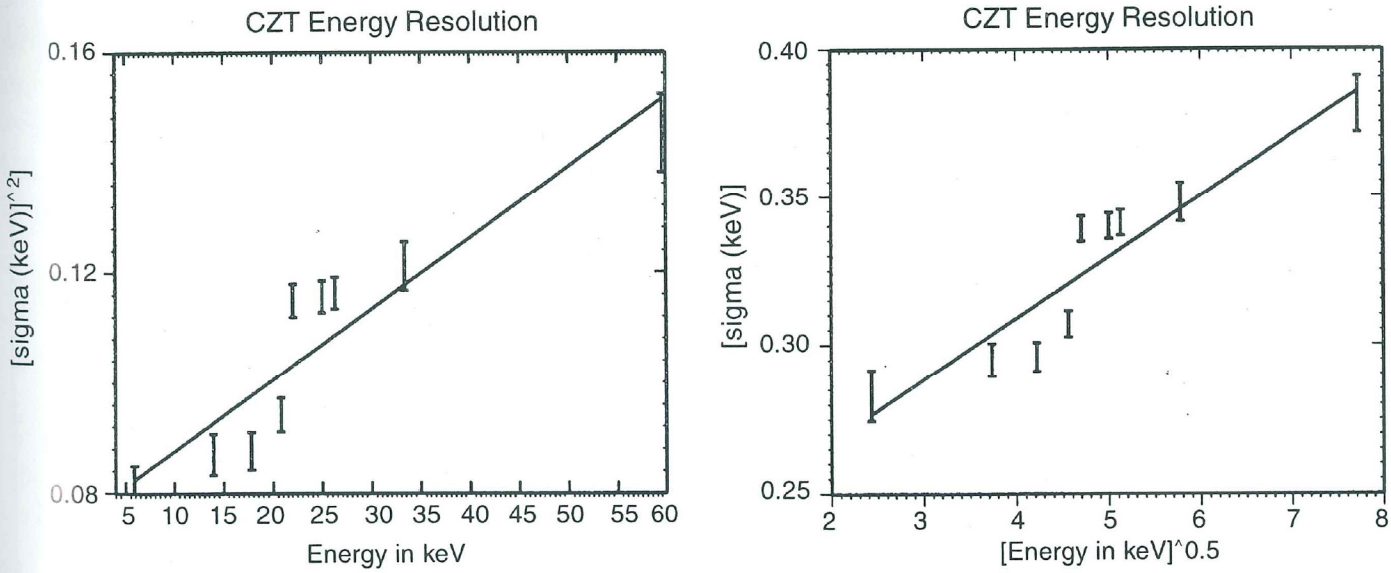



*Fig. 3.2 Left panel: plot for Energy Vs $[\sigma_e (keV)]^2$, Right panel: plot for $[Energy (keV)]^{0.5}$ Vs $[\sigma_e (keV)]$. The plot shows the resolution function of the CZT detector of SLD/SoXS payload. The FWHM (keV) shows a linear response with the increase in energy. The response of the detector in the energy range 4-60 keV is satisfactory. Linear fit for Energy Vs $[\sigma_e (keV)]^2$ gives the parameters as follows: Constant parameter, a=0.080, and linear parameter, b=0.0010. Where a = noise factor that is contributing in the FWHM, and b = product of Fano factor and average energy of the detector material (Fw).*

radioactive sources to characterize the X-ray line emission covering the energy range from 4-25 keV and 4-60 keV for Si PIN and CZT respectively. The observed line emission peaks in the pulse height spectrum were simulated with the Gaussian plus quadratic assumption to derive peak counts, peak energy, FWHM and excess counts. These data sets enabled us to derive the spectral response of Si PIN and CZT detectors. Shown in **Figs. 3.1 and 3.2** are the response function of the Si Pin and CZT detectors respectively. The FWHM (keV) shows a linear response with the increase in energy for both the detectors of SLD/SOXS payload. This linear fit reveals the noise level (a = constant in the fit), and b i. e product of Fano factor (F) and average energy of the detector material (w). We found the Fano factor for Si PIN and CZT of the order of 0.97 and 0.22 respectively.

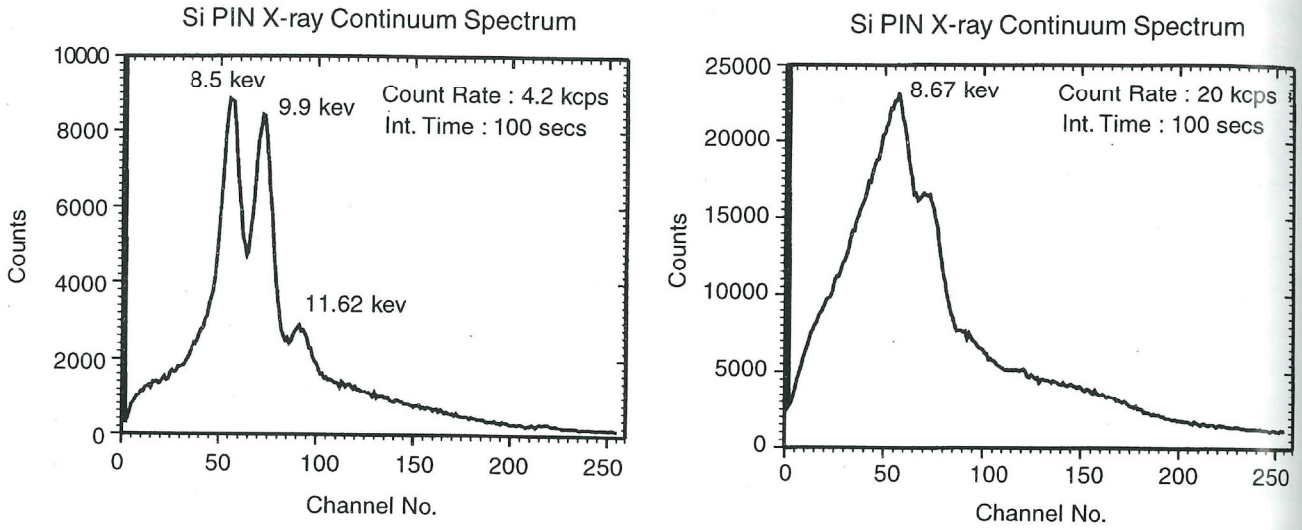



*Fig. 3.3 The X-ray continuum spectra represented by Si detector when exposed to X-ray gun for 100-sec integration time. The count rate for left panel spectra is 4.6kcps while for right panel spectra it was increased to 20kcps. Energy resolution significantly reduced with increase in count rate.*

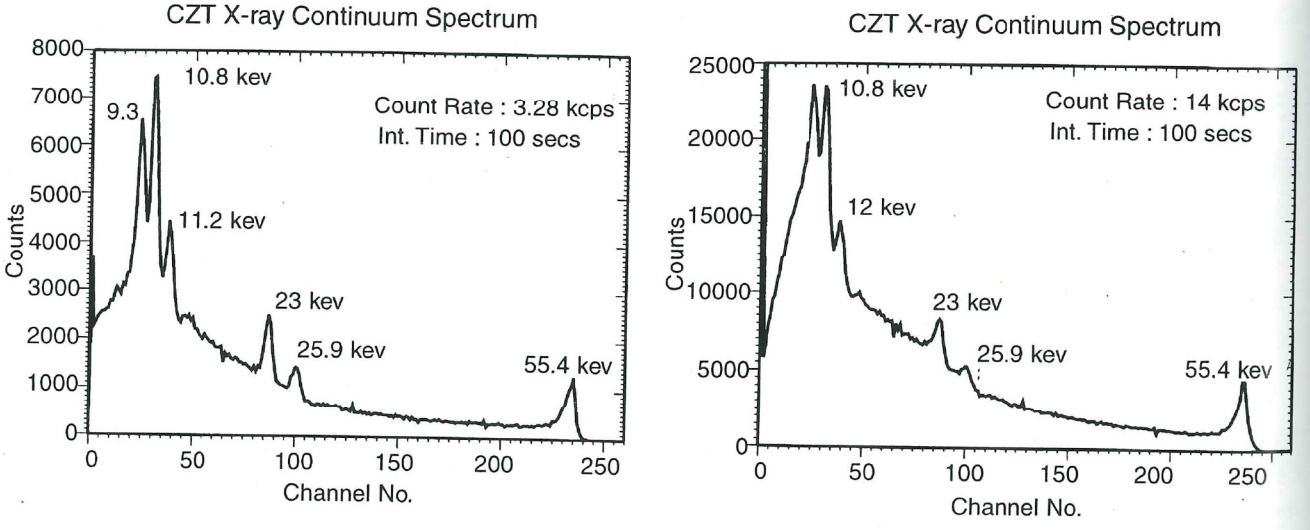



*Fig. 3.4 The X-ray continuum spectra represented by CZT detector when exposed to X-ray gun for 100-sec integration time. The count rate for left panel spectra is 3.28kcps while for right panel spectra it was increased to 13.9kcps.*

We also carried out the experiment to simulate the continuum spectra. For this purpose, we used the X-ray gun at TIFR. X-ray photons of various energies were allowed to fall on the detectors, however through a copper filter to know the 8 keV and satellite lines. In **Figs. 3.3 and 3.4** we have shown the continuum spectrum observed through Si PIN and CZT detectors respectively. Both the detectors showed their performance satisfactorily in line and continuum spectra.

(Rajmal Jain and Hemant Dave)

## Simulation of X-ray Emission from a Solar Flare

We have simulated a model for X-ray emission from the Sun and Solar Flares that enables to measure the line emission and continuum in the energy range 0.1 keV to 1 MeV. This model is of great significance in view of its high application in solar astronomy research as well as it helps to quantify the photons as a function of energy, which is a scientific requirement to design a space-borne experiment related to solar astronomy. Our model considers pre-flare background, in the energy range of 0.1-10 keV as well as the thermal, superhot and non-thermal emission from solar flares. We use the data from various missions in general and YOHKOH in particular, and generate the plasma codes to simulate the model in the energy range 0.1-1000 keV. Our model shows extremely well the X-ray line emission from the quiet Sun at appropriate energies below 6 keV. The model also exhibits the X-ray lines that emit during the solar flares at 6.7 and 7.4 keV. Our simulation for a M5 solar flare reveals unambiguously all three components of X-ray flare emission viz. thermal, superhot and non-thermal. It may be noted from **Fig. 3.5** that in the energy range of 10-60 keV there are break energy points between thermal and superhot, and superhot and non-thermal components of a solar flare. These break energy points have not been measured so far with high spectral resolution, which however, may improve our current understanding of energy release and particle acceleration mechanism in solar flares.

(**Rajmal Jain** and S. Masuda)

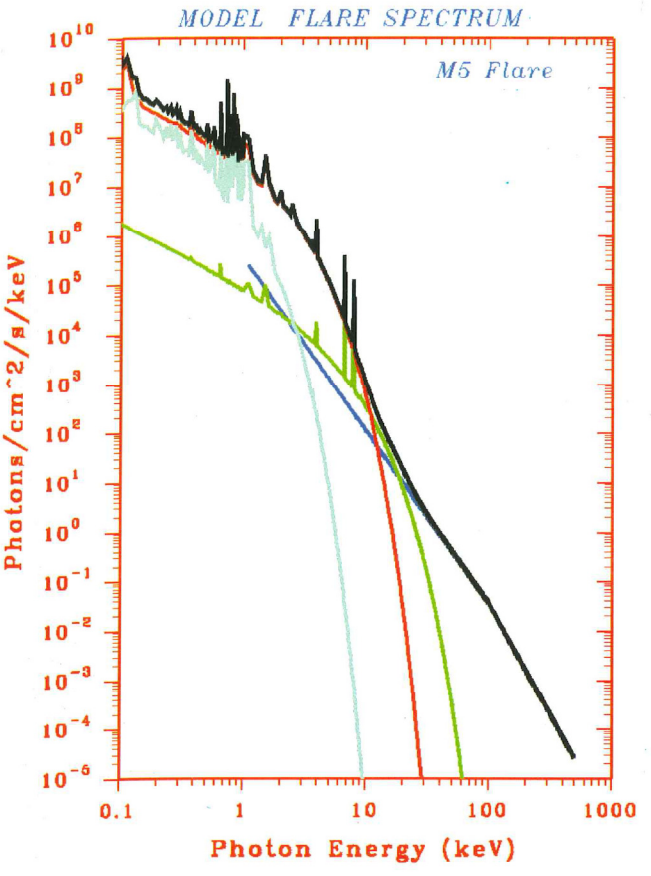



*Fig. 3.5 Model solar flare spectrum simulated in IDL solarsoft package using the YOHKOH X-ray mission data. The model explicitly exhibits the line emission below 5 keV from the Quiet Sun. The line and continuum emission from M5 importance flare are also shown. The break energy points may be noted between thermal and superhot components, and superhot and non-thermal components in the energy range 10-60 keV as predicted by the model.*

## Astrophysics

### *Strange Stars - Have They Been Discovered?*

There have been controversial claims about the nature of the isolated compacts star RXJ1856.5-3754, with one group claiming it to be a strange star while the other asserting it to be a normal neutron star. The controversy arises mainly due to the distance estimate, which in turn is used to resolve the measured angular diameter and thus the radiation radius $R_\infty$. We discuss the theoretical constraints that appear from analysing the usual mass-radius relation along with the redshift factors arising from the strong gravity effects and possible lensing. Unless the distance estimate is confirmed independently, without any uncertainty, it is premature to come to any conclusion regarding the nature of this star.

(A.R. Prasanna and S. Ray)

### *Sonic Point Analyses of Fluid Flow in Accretion Disks around Rotating Compact Objects*

Extending the concept of Paczynski-Wiita potential to the case of rotating central object, we consider the kinematics of the fluid flow in an accretion disk around the compact object. It is shown that for very slow rotation (rotation parameter $b \leq 0.3$), the potential can mimic the features of general relativistic treatment approximately. The introduction of the Coriolis term in the fluid equation renders a change in the effective angular momentum of the fluid and affects the known parameter space of the non-rotating system. Further, the possibility of shock formation is reduced with several parameter regions which were thought to be stable are shown not to be so even for low values of *b*.

(**A.R. Prasanna** and B. Mukhopadhyay)

### *Constraints of Non-Minimally Coupled Curved Space Electrodynamics from Astrophysical Observations*

We study interactions of electromagnetic fields with the spacetime curvature of the form $\lambda R_{\mu\nu\alpha\beta\phi} F^{\mu\nu} F^{\alpha\beta}$. Such coupling terms though are invariant under general coordinate transformation and CPT, however, violate the Einstein's equivalence principle. These couplings do not cause any energy dependent dispersion of photons but they exhibit birefringence. We put constraints on the coupling constant $\lambda$ using results from solar system radar ranging experiments and millisecond-pulsar observations. We find that the most stringent constraint comes from pulsar observations and is given by $\lambda < 10^{11} cm^2$ obtained from the timing of binary pulsar PSR B1534+12.

(A.R. Prasanna and S. Mohanty)

### *Reissner Nordström Solution : Dynamical Coordinates, Semiclassical Analysis and Behaviour of Radiation*

We cast the Reissner Nordström solution in dynamical coordinates and demonstrate the occurrence of covered and naked singularity depending upon choice of initial data. We also work out the quantum stress tensor in the Reissner Nordström background employing this coordinate system. We recover the divergence on the Cauchy horizon obtained earlier. We show semiclassically that the naked Reissner Nordström solution is stable over a considerable time. Unlike the covered solution, it emits radiation only within Planck scales of the Cauchy horizon.

(S. Barve and A.R. Prasanna)

### *Spin Precession as Referred to the Tetrad Frame and a Possible Test for General Relativity*

Referring the equation for spin of a particle on a geodesic to the locally non-rotating frame, in the spacetime of a slowly rotating object we calculate the ratio of precession frequency to orbital frequency in equatorial and polar orbits. Subtracting out the geodetic part one can get an estimate for the difference which comes only from the Lense-Thirring effect of inertial frame dragging, proportional to $\frac{R^2 \omega \Omega}{2c^2}$

(A.R. Prasanna)

## Atomic and Molecular Physics

### *Asymptotic Methods in Rydberg Collisions*

Analytic expressions of some physical quantities for Rydberg transitions, like the first Born cross section for $n \rightarrow n'$ transition, are found to contain terminating hypergeometric functions of large arguments which pose certain analytical and numerical problems that are well documented. We describe a simple method based on the use of the Jacobi polynomial to understand analytic properties and deduce an asymptotic expression of a general terminating hypergeometric function. To illustrate the utility, we apply the method to the $n \rightarrow n'$ Born cross section for which case the Tricomi asymptotic method has been used earlier in the literature. It is found that the Jacobi polynomial method gives strikingly good results for $n \rightarrow n'$ transitions over the entire range of the physical momentum transfer in contrast to the Tricomi asymptotic method which gives unrealistically large results for large momentum transfers.

(D.P. Dewangan)

### *A New Approximation for Radial Dipole Matrix Element*

As we have already reported last year, we have obtained a new approximation for the Jacobi polynomial $P_k^{(\alpha,\beta)}(\cos\phi)$ in terms of the Bessel function $J_\alpha(A\phi)$, where A depends on $(\alpha, \beta, k)$. This expresson is valid for small values of $\phi$ but for arbitrary values of $k$. This helps us to obtain an approximate expression for the radial dipole matrix elements for transition between Rydberg states. Our initial numerical study shows that it gives accurate values for high Rydberg states. Further numerical work is in progress.

(D.P. Dewangan)

### *Compact Expressions of the First Born Amplitudes for Rydberg Transitions*

We have obtained a compact expression for the first Born amplitude of the transition $n,s \rightarrow n+1,s$ induced by electron impact on hydrogenic atom of nuclear charge z. This expression involves familiar Legendra polynomials and allows easy study of these transitions both analytically as well as numerically.

(D.P. Dewangan)

## High Energy Physics

### *Baryogenesis at the Electroweak Phase Transition*

In thick wall electroweak baryogenesis models, the interaction of quarks with the Higgs bubble wall during the electro weak phase transition can be treated as a classical force which acts differently on left handed and right handed quark. Earlier models have assumed that the distribution function is quasi-thermal. We have studied the possibility of quarks being accelerated by the classical force field leading to a phenomenon in plasma physics known as "runaway", which will give a non-thermal distribution of high energy quarks. Such phenomenon may occur in electroweak plasmas which can modify the estimate of the baryon asymmetry obtained in these models.

(J.R. Bhatt and R. Rangarajan)

### *Implications of the Radiatively broken $L_e - L_\mu - L_\tau$ Symmetry*

$L_e - L_\mu - L_\tau$ symmetry provides a very good framework to understand masses and mixing among neutrinos. This symmetry needs to be broken to get the realistic neutrino spectrum. We discussed a specific breaking mechanism based on the ordinary electroweak interactions and investigated its consequences. This mechanism implies signatures which can be checked. Two specific predictions correspond to large ( $\geq .05$ ) $U_{e3}$ and the solar angle satisfying $\tan^2\theta_S > 0.4$.

(**A.S. Joshipura** and K.S. Babu)

### *Radiatively Generated $\nu_e$ Oscillations : General Analysis, Textures and Models*

The consequences of assuming that the mass scale $\Delta$ corresponding to the solar neutrino oscillations and mixing angle $U_{e3}$ corresponding to the electron neutrino oscillation at CHOOZ are radiatively generated through the standard electroweak gauge interactions are studied. All the leptonic mass matrices having zero $\Delta_\odot$

and $U_{e3}$ at a high scale lead to a unique low energy value for the $\Delta_{\odot}$ which is determined by the (known) size of the radiative corrections, solar and the atmospheric mixing angle and the Majorana mass of the neutrino observed in neutrinoless double beta decay. This prediction leads to the following consequences: (i) The MSSM radiative corrections generate only the dark side of the solar neutrino solutions. (ii) The inverted mass hierarchy (m,-m,0) at the high scale fails in generating the LMA solution but it can lead to the LOW or vacuum solutions. (iii) The $\Delta_{\odot}$ generated in models with maximal solar mixing at a high scale is zero to the lowest order in the radiative parameter. It tends to get suppressed as a result of this and lies in the vacuum region. Specific textures which can lead to the LMA solution in the present framework and provide a gauge theoretical realization of this in the context of the seesaw model are discussed.

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

### *Predictive Framework with a Pair of Degenerate Neutrinos at a High Scale*

Radiative generation of the solar scale $\Delta_{\odot}$ is discussed in the presence of leptonic CP violation. It is assumed that both the solar scale and $U_{e3}$ are zero at a high scale and the weak radiative corrections generate them. It is shown that all leptonic mass matrices satisfying these requirements lead to a unique prediction $\Delta_{\odot} \cos 2\theta_{\odot} \approx 4\delta_{\tau} \sin^2\theta_A |m_{ee}|^2$ for the solar scale in terms of the radiative correction parameter $\delta_{\tau}$, the physical solar (atmospheric) mixing angles $\theta_{\odot}(\theta_A)$ and the Majorana neutrino mass $m_{ee}$ probed in neutrinoless double beta decay. This relation is independent of the mixing matrix and CP-violating phases at the high scale. The presence of CP-violating phases lead to dilution in the solar mixing angle defined at the high scale. This allows bi-maximal mixing pattern at the high scale which leads to large but non-maximal solar mixing in the low-energy theory. An illustrative model with this feature is discussed.

(**A.S. Joshipura**, **S.D. Rindani** and N. Nimai Singh)

### *Chiral Symmetry Breaking, Color Superconductivity and Color Neutral Quark Matter : A Variational Approach*

We consider quark matter at high density with non-trivial structure for the ground state having both quark antiquark related to chiral symmetry breaking as well as diquark and diantiquark condensates related to color superconductivity. We also impose conditions of charge neutrality and color neutrality conditions as would be appropriate for description of neutron star interior. These neutrality conditions are imposed through introduction of appropriate chemical potentials. It appears that in a small window of baryon chemical potential it is possible to have condensation of massive quarks when neutrality conditions are not imposed. When charge neutrality conditions are imposed there appears to be gapless modes for densities above the chiral restoration density and the number densities of the quarks that condense are no longer the same when the superconducting gap is less than half the difference in the chemical potentials of the condensing quarks. In this region, there are four quasiparticle modes which are gapless with color Meissner effect but no minimum excitation energy.

(**H. Mishra** and Amruta Mishra)

### *Hybrid Compact Stars with Color Super - conducting Core*

We consider here gross structural properties of compact hybrid stars with a color superconducting core. We take Nambu Jonalasinio model for the equation of state for the superconducting quark matter. Color and electric charge neutrality conditions are imposed through introduction of appropriate chemical potentials. For matter on the crust of the compact star we use the hadronic equation of state obtained from Walecka model. The quark core is surrounded by a mixed phase made of hadronic and quark matter core. Gross structural properties of such a star are calculated.

(**H. Mishra**, Amruta Mishra and D. Bandypadhyaya)

### *QCD Sum Rules at Finite Densities and Properties of Nucleon at Finite Temperature and Densities*

Relativistic phenomenological models of nuclear physics - the quantum hadrodynamics describes successfully many of nuclear physics problems in particular the saturation properties of nuclear matter and spectroscopy of nuclei. The scalar and vector meson exchange here give rise to attraction and repulsion respectively which leads to saturation of nuclear matter. These contributions are large (several hundred MeV) and cancelling in nature and give rise to the binding energy/ nucleon as 15 MeV at the saturation density. However, despite the appeal of phenomenology it has not been clear how this physics might be motivated from the fundamental theory of strong interactions - namely QCD. QCD sum rule techniques is being used to relate the nucleon self energies to quark and gluon condensates at finite densities. We calculate the phenomenological side of the sum rule taking into account the nucleon pole as well as absorptive part by considering definite intermediate states with $N_\pi$, $N_\rho$, $N_\omega$ and $N_\phi$ states. The reason for considering heavy states as above lies on the fact that they contribute singularities not only for $q_0^2>(m_N+M_\rho)^2$ but also for $q_0^2<(m_N-M_\rho)^2$ - a peculiarity of in-medium processes. The spectral side of the sum rules has already been evaluated and the QCD side of the sum rule is being calculated.

(**H. Mishra** and Samir Mallik)

### *Determination of the Age of the Earth from Kamland Measurement of Geo-Neutrinos*

The low energy component of the anti-neutrino spectrum observed in the recent Kamland experiment has significant contribution from the radioactive decay of $^{238}U$ and $^{232}Th$ in the earth. By taking the ratio of the anti-neutrino events observed in two different energy ranges we can determine the present value of the Thorium by Uranium abundance ratio, independent of the U, Th distribution in the earth. Comparing the present abundance ratio with the r-process predicted initial value

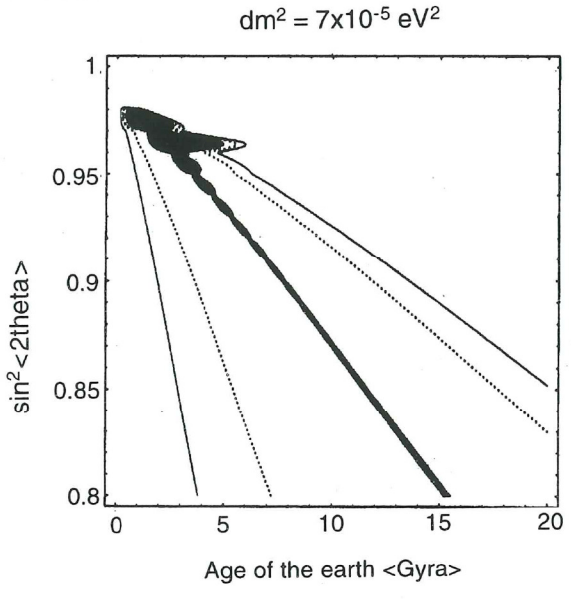



*Fig. 4.1 Age of the earth as a function of neutrino mass difference and mixing angle.*

we determine the age of the earth as a function of $\Delta m^2$ and $\sin^2 2\theta$ **(Fig. 4.1)**. We find that the age of the earth determined from Kamland data matches the age of solar system (4.5 Gyrs determined from meteorites) for the neutrino parameters which also solve the solar neutrino problem.

(Subhendra Mohanty)

### *Relativistic Particle Simulation of Color Diffusion in a SU(2) Yang-Mills Plasma*

We report on a relativistic particle-in-cell simulation study of color transport in a SU(2) Yang-Mills plasma. Simulation results reveal that the color distribution starting from a spiky form spreads to a flat one, through a diffusive process in color space. By numerically performing a "Perrin" like experiment, we explicitly show that the ensemble averaged color fluctuation square ($<\Delta I)^2>$) grows linearly with time indicating that the color vector of a parton executes brownian motion in color space. Depending on the choice of input parameters, color diffusion time scale can either be shorter or longer than the momentum diffusion time scale. Simulation results

for a case where color diffuses faster than momentum are presented.

(**Jitendra C. Parikh**, S. Sen Gupta and P. K. Kaw)

### *Study of CP Property of the Higgs at a Photon Collider using* $\gamma\gamma \to t\bar{t} \to \ell X$

Possible effects of CP violation in the Higgs sector on $t\bar{t}$ production at a $\gamma\gamma$ collider are studied. These studies are performed in a model-independent way in terms of six form-factors which parametrize the CP mixing in the Higgs sector, and a strategy for their determination is developed. The angular distribution of the decay lepton from $t/\bar{t}$ produced in this process is independent of any CP violation in the $tbW$ vertex and hence best suited for studying CP mixing in the Higgs sector. Analytical expressions are obtained for the angular distribution of leptons in the c.m. frame of the two colliding photons for a general polarization state of the incoming photons. Combined asymmetries in the initial state lepton (photon) polarization and the final state lepton charge are constructed. They involve CP even ($x$'s) and odd ($y$'s) combinations of the mixing parameters. Limits up to which the values of $x$ and $y$, with only two of them allowed to vary at a time, can be probed by measurements of these asymmetries, using circularly polarized photons, are obtained. This method can be sensitive to the loop-induced CP violation in the Higgs sector in the MSSM.

(**S.D. Rindani**, R.M. Godbole and R.K. Singh)

### *Neutrinos in Extra Dimensions*

During the past few years an interesting theory has emerged, in which there are some extra dimensions in which only gravity propagates. All other interactions and ordinary particles are confined to our four dimensional world. Since gravity propagates mostly in other dimensions, it appears to be very weak in our world although it could be very strong in the other dimensions. The effective Planck scale could then be as low as a few TeV. This theory gives us prospect of detecting effects of quantum gravity and many new physics in the next generation accelerators. However, since there are no large scales in the theory, it becomes difficult to explain the smallness of the neutrino masses. We proposed a new mechanism of generating neutrino masses in this theory. The smallness of the neutrino mass is attributed to the exponential suppression due to small wave function overlap of the neutrinos of different chirality.

(**U. Sarkar** and H.V. Klapdor-Kleingrothaus)

### *Applications of Neutrino Physics*

In recent times our knowledge of neutrino physics has improved dramatically. The progress in experimental techniques to understand the properties of neutrinos now make us think of some applications of neutrino physics. We proposed the possibility of some defense applications of neutrino physics. An appropriately placed array of new generation neutrino detectors, in conjunction with the use of nuclear devices as a source of intense flux of neutrinos, can serve as a powerful precision probe of neutrino oscillation parameters. One may even use these neutrino detectors to locate nuclear powered vehicles like submarines, aircraft carriers and any other strong neutrino sources. Since neutrinos cannot be shielded, it may not be possible to escape detection.

(P. Panigrahi and U. Sarkar)

### *Baryon and Lepton Number Violation*

In all fundamental interactions we experience in nature, we find baryon and lepton number is conserved. On the other hand, to explain why there are more matter compared to anti-matter in the universe, we require baryon and lepton number violation. Lepton number violation is also required for a technically natural explanation of the smallness of neutrino masses. We studied the various baryon and lepton number violating couplings allowed by all possible scalar bilinears, which couple to two fermions of the standard model. We calculated the constraints on these couplings from limits on proton lifetime, neutron-antineutron oscillations, neutrinoless double beta decay and baryon asymmetry of the universe.

(**U. Sarkar**, H.V. Klapdor-Kleingrothaus and E. Ma)

## Nuclear Physics

### *Deformed Shell Model for Collective T = 0 and T = 1 Bands in $^{46}V$ and $^{50}Mn$*

Deformed configuration mixing shell model with isospin projection (DSM-T), developed last year by PRL scientists, is applied to study the structure of collective T=0 and T=1 bands in the odd-odd N=Z pf-shell nuclei $^{46}V$ and $^{50}Mn$. The pf-shell KB3 interaction is employed in the calculations. Low-spin states of the T=0 and T=1 bands in both the nuclei compare well with all the recent experimental data including the E2 and M1 transition strengths. The DSM-T predicted structures of the bands in these nuclei are similar to those in the so-called rotor plus quasi-deuteron model (R-QD model). Clearly, DSM-T with T projection via the last unpaired proton and neutron is a microscopic equivalent of the R-QD model as the DSM-T starts with a given effective nucleon-nucleon interaction and deformed single particle states that are generated via Hartree-Fock.

(**V.K.B. Kota** and R. Sahu )

### *Entropy and Duality in (1+2)-body Random Matrix Ensembles*

Random matrix ensembles defined by a mean-field one-body plus a chaos generating random two-body interaction (called embedded Gaussian orthogonal ensembles of (1+2)-body interactions[EGOE(1+2)]) predict for the entropy defined by the occupation numbers of single particle states, in the chaotic Gaussian domain, an essentially one parameter Gaussian form for their energy dependence, just as the thermodynamic entropy defined by the state density and information entropy defined by wavefunctions in the mean-field basis. These EGOE(1+2) results are observed in nuclear shell model calculations. More importantly, it is shown that there is a critical strength ( $\lambda_t$ ) of the two-body interaction for which, as seen in nuclear shell model examples, all the three entropies coincide for EGOE(1+2) and also the critical strength $\lambda_t$ defines the duality point where entropies become basis independent. This result is numerically verified using the mean-field basis and the basis defined by the two-body interaction. The $\lambda_t$ marker, which appear to define the thermodynamic region, is above the two known markers $\lambda_c$ defining Poisson to GOE transition in level fluctuations and $\lambda_F$ marker defining Breit-Wigner to Gaussian transition in strength functions for EGOE(1+2). Significance of the new chaos marker $\lambda_t$ is being studied further.

(**V.K.B. Kota**, **S. Ghosh** and R. Sahu)

### *Convergence of Moment Expansions for Expectation Values with Embedded Random Matrix Ensembles and Quantum Chaos*

Smoothed forms for expectation values $\langle \mathbf{K} \rangle^E$ of positive definite operators **K** follow from the **K** - density moments either directly or in many other ways each giving a series expansion (involving polynomials in $E$ ). In large spectroscopic spaces one has to partition the many particle spaces into subspaces. Partitioning leads to new expansions for expectation values. All the moment expansions and their truncated versions developed in the last thirty years in various branches of physics are re-examined and it is shown that all the expansions converge to compact forms depending on the nature of the operator **K** and the operation of embedded random matrix ensembles (for example, EGOE(1+2)) and quantum chaos in many particle spaces. Explicit results are derived for occupancies, spin-cutoff factors and strength sums. It is seen that the spin-cutoff theory is not complete and this requires detailed study of EGOE(1+2) - $J$ mentioned in the last year report.

(V.K.B. Kota)

### *Statistical Properties of Dense Interacting Boson Systems with One Plus Two-Body Random Matrix Ensembles*

Interest in the study of statistical properties of interacting boson systems is enhanced due to recent experimental studies of atomic Bose-Einstein condensates. Statistical properties like nearest neighbor spacing distribution (NNSD), number of principal components

(NPC), information entropy and number entropy are studied for interacting boson systems using one-body ( $H_1$ ) and embedded GOE of two body ( $H_2$ ) interactions. The NNSD for the bosonic ensembles move steadily from Poisson to Wigner form as the 2-body interaction strength $\lambda$ in $H = H_1 + \lambda H_2$ is varied. The numerically deduced critical strength $\lambda_c$ for the transition agrees with Jacquod and Shepelyansky criterion derived for interacting fermions. For NPC, $S^{info}$ and $S^{occu}$ there is another transition point $\lambda_F$ as in fermionic ensembles. Bosonic ensembles in the dense limit tend to be ergodic with increasing number of single particle states. Further studies of statistical properties of interacting boson systems using interacting boson models of atomic nuclei are in progress.

(**V.K.B. Kota** and V. Potbhare)

### *Localization in 2plf Nuclear Shell-Model Wavefunctions*

For the study of complexity and chaos in many-particle nuclear wavefunctions in large shell-model basis spaces, the localization length related to the number of principal components is calculated for several Ca, Sc and Ti isotopes, and compared to the predictions of the Embedded Gaussian Orthogonal Ensemble. The large dimensionalities involved, up to many thousands, ensure good statistics, and the agreement is very good in the chaotic region of the spectra. The localization length of shell-model wavefunctions in Ca isotopes is much smaller than in Sc, showing a strong isospin dependence of nuclear chaos, in good agreement with previous results based on energy level fluctuation properties.

(**V.K.B. Kota**, J. M. G. Gomez, J. Retamosa and K. Kar)

## Plasma Physics

### *The Neo Electromagnetic Modes Attributed to Neutral Dynamics in Partially Ionized Plasma*

The neoelectromagnetic instabilities/modes in partially ionized plasma (PIP) with neutral dynamics are studied. We present the almost general dispersion relation and have shown how significant the neutral dynamics in PIP is. It is shown that the neutrals, being a "reservoir of momenta", are playing an instrumental role either to, onset new instabilities or modify existing instabilities in PIP. For example, Alfvèn time scales are seen to be modified. We discuss specific results for limiting cases that may be appropriate for applications to space and laboratory plasma phenomena.

(**A.C. Das** and A.A. Shaikh)

### *Couette Flows in Strongly Coupled Plasma*

The presence of highly charged massive grains in plasmas could lead to a variety of new phenomena. Such plasma can said to be strongly coupled if the inter-grain Coulomb energy is much larger than their thermal energy. In this situation the plasma could under go a phase transition from a gaseous to a liquid or a solid phase. We have analyzed Coquette flow of such a plasma using generalized hydrodynamic equations. We find that the flow can become unstable due to the elasticity arising due to "strongly coupled" nature of the plasma. The flow may become unstable even when the Rayleigh stability criterion is satisfied!

(J.R. Bhatt)

### *Evidence of Levy Stable Process in Tokamak Edge Turbulence*

The time series of floating potential and poloidal electric field fluctuations in the edge plasma of ohmically heated ADITYA tokamak are analysed for self-similarity. It is observed that the distribution function of a sum of n data points converges to a self-similar distribution of Levy scale index, $\alpha$ = 1.1-1.3 for $\eta \leq 40$ and $\alpha$ = 1.8-2.0 for larger $\eta$. This shows that the scaling properties of small scale fluctuations are non-Gaussian and those of large scale fluctuations are Gaussian. Implication of this observation to our understanding of plasma transport is discussed.

(**Jitendra C. Parikh**, R. Jha and P.K. Kaw)

### *Observability of the Magnetic Vector Potential in One-Dimensional Interference in Quantum and Classical Macrodomain*

We have discussed here the observability of the magnetic vector potential in one-dimensional interference for both the quantum domain, where it is contrary to the canonical concept of the Aharonov-Bohm effect, and for the classical macrodomain where it is not expected to occur, but where its observability has been recently demonstrated experimentally. The latter case in fact contravenes our present understanding of charged particle dynamics in the classical macrodomain, but is predicted in the framework of a macroscopic matter wave formalism for the system. We discuss here some important features of the observations already made and others which could be looked for.

(R.K.Varma)

### *A Topological Action Principle for Classical Mechanics*

A new variational principle for classical mechanics is formulated which seeks to furnish equations for the canonical momentum as a vector field. The principle which yields the required field equations- the Hamilton-Jacobi equation, is that the circuit integral around a reducible circuit of the differential form (pdq - Hdt) over the space (q, t) vanishes. On the other hand the stationarity of the circuit integral, in general, over an irreducible circuit, is shown to yield conditions which constrain the admissible initial values to a discrete set. This prescription thus constitutes a topological action principle.

(R.K. Varma)

## Entanglement Sharing in Spin Chains

Entanglement is a peculiar quantum mechanical property that leads to quantum information being qualitatively different from classical. This has lead to it being intensively studied over the last few years. The possibility of scalable solid-state quantum computing and the dominance of the bit in classical computing leads to quantum spin chains of spin-1/2 particles, or qubits, having a preferred position. We have begun a systematic study of entanglement sharing among the various spins of standard spin chain hamiltonians, as well as modifications that include non-trivial, non-integrable spin chains. We have found and explained universal entanglement distributions in one-magnon states, using the measure of concurrence and random matrix theory. We have also found that a metal-insulator transitions impacts on the way entanglement is shared. We are currently working on the many-magnon cases of interest.

(**A. Lakshminarayan** and V. Subrahmanyam)

## Entanglement and Quantum Chaos

In this work we continue our exploration of the connections between quantum entanglement and quantum chaos. We have studied thoroughly a four-dimensional phase space map involving two tops, that shows a wide range of dynamical behaviours from integrable to completely chaotic. We have shown that there are many subtle issues that lead to entanglement in such a system. Chaos can sometimes enhance or suppress entanglement production. We have developed methods and intuition concerning the relationship betwen phase-space pictures and entanglement, that explains what happens. We have also developed approximation schemes that work for coupled strongly chaotic systems. These also form first of its kind studies for higher-dimensional quantum chaotic systems.

(J. N. Bandyopadhyay and A. Lakshminarayan)

## Cyclic and Local Identities for Jacobi Elliptic Functions

Hundreds of identities involving the important Jacobi elliptic functions were recently found by some of us in this collaboration. We extended, rigorously proved, and evaluated these identities by classifying them into four master identities. We have also found local identities from which the cyclic identities found earlier can be proved. These identities lead to exact discretizations of several ordinary nonlinear differential equations that have the Jacobi elliptic functions for solutions. In turn these then imply that we have found several new nonlinear integrable discrete time systems. These techniques have also led to the evaluation of several hitherto unevaluated integrals involving the Jacobi elliptic functions. These results are now being recognized in the mathematics community and form part of online mathematical tables.

(**A. Lakshminarayan**, A. Khare and U. Sukhatme)

## Coupled Maps on Networks

We investigate the synchronization behaviour of coupled maps on different kinds of networks. The dynamics is governed by a local nonlinear map and interactions between the nodes of the network. We find that synchronized clusters are observed for coupling constant larger than some critical value. We find two mechanisms of cluster formation. (a) Self-organized synchronization:- here most of the couplings are of the intra-cluster type. (b) Ordered synchronization:- here most of the couplings are of the inter-cluster type. We observe both types of clusters and clusters of the mixed type where both mechanisms contribute. We use simple two and three node networks to study the mechanism of synchronizations. We find that for the self-organized behaviour the coupling term gives a decay term in the difference variable while for the driven behaviour the coupling terms cancel out.

( R. E. Amrithkar and S. Jalan)

## Secure Communication using Chaotic Systems

We use chaotic systems to code signals by adding the signal to dynamical variables other than the one which is used as cipher text. The decoding is done using initial condition estimation. We demonstrate the use of the method and show that the method has some advantages over other methods using chaotic systems. We

have also studied the effect of parameter variation and channel noise on this coding and decoding procedure.

(R. E. Amritkar and D. R. Kulkarni)

## Coupled Three Dimensional Anharmonic Oscillators

In our ongoing work on chaotic quantum systems we are investigating the quantum spectrum and quantum wave functions of a coupled three dimensional anharmonic oscillator. Detailed study of such 3-D systems is challenging computationally and theoretically, and forms an important class of less-explored problems with the possibility of novel phenomena like Arnold diffusion that are absent in the better studied case of 2-D systems. The nonlinear coupling terms are of two-body nature and the dynamics of the system is crucially dependent on the coupling constants. Such systems describe, for example, Rydberg atoms in crossed static electric and magnetic fields. In these type of problems, upon choosing a suitable set of basis states, it is required to diagonalize very large sparse matrices to obtain the spectrum and wave function. These computationally intensive problems are now tractable on machines available in PRL. We are studying the effect of the change in the coupling constants on the underlying periodic orbit stability, their bifurcation and hence on the localization of the quantum wave function.

(**Dilip Angom, V. B. Sheorey, A. Lakshminarayan** and M. S. Santhanam)

## Complexity in Sm I

Atomic Sm which has eight valence electrons is an ideal system to study complexities arising from two-body interations. We calculate and study properties of several thousand eigenvalues and eigenfunctions. The nearest neighbour spacing distribution follows GOE, whereas the strength function, number of principle components and localization length are Gaussian and agree with the predictions of two-body random matrix ensembles (TBRE). This is first example in literature to demonstrate operation of TBRE in an atomic system. We are currently studying the other atoms in the lanthanide group to investigate the transition to TBRE along the period.

(**Dilip Angom** and V. K. B. Kota )

# Laser Physics and Quantum Optics

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

## Extracting Work from a Single Heat Bath via Vanishing Quantum Coherence

We present here a quantum Carnot engine in which the atoms in the heat bath are given a small bit of quantum coherence. The induced quantum coherence becomes vanishingly small in the high temperature limit at which we operate and the heat bath is essentially thermal. However, the phase associated with the atomic coherence, provides a new control parameter that can be varied to increase the temperature of the radiation field and to extract work from a single heat bath. The deep physics behind the second law of thermodynamics is not violated; nevertheless, the quantum Carnot engine has certain features that are not possible in the classical engine.

(M.O. Scully, M.S. Zubairy, **G.S. Agarwal** and H. Walther)

## Strong-Driving-Assisted Multiparticle Entanglement in Cavity QED

Entanglement is a natural consequence of linearity of Hilbert space and its controlled generation and measurement have been intensively pursued. We propose a method of generating multipartite entanglement by considering the interaction of a system of N-two level atoms in a cavity of high quality factor with a strong classical driving field. It is shown that with a judicious choice of the cavity detuning and the applied coherent field detuning, vacuum Rabi coupling produces a large number of important multipartite entangled states. It is even possible to produce entangled states involving different cavity modes. Tuning of parameters also permits us to switch from Jaynes-Cummings to anti- Jaynes-Cummings-like interactions.

(**G.S. Agarwal**, E. Solano and H. Walther)

## Reciprocity Relation for Reflected Amplitudes

In a recent experiment, an interesting non-reciprocity in the reflection of light from the semiconductors and micro-cavities was discovered. It was found that the reflected amplitude exhibits an asymmetry, depending on whether the quantum well is in the first or the second cavity. The data was explained in terms of the interference between the exciton and the cavity modes. The experiment raises an interesting question: Can one derive a reciprocity theorem starting from Maxwell's equations such that one obtains a general result ? We investigate this question and show that, how it is indeed possible to derive general relations for reflection amplitudes. We also present examples of structures for which non-reciprocal effects can be significant.

(**G.S. Agarwal** and S. Dutta Gupta)

## Entangling Two Bose-Einstein Condensates by Stimulated Bragg Scattering

Apparently puzzling, yet most profound, first formulated as a paradox, quantum entanglement lies at the very heart of quantum information processing and in many issues in the foundations of quantum mechanics. Generation and manipulation of entanglement is, therefore, of prime interest. Bose-Einstein condensates (BEC) of weakly interacting atomic gases seem to be suitable macroscopic objects for producing many-particle entanglement. We propose an experiment for entangling two spatially separated BEC by Bragg scattering of light. When Bragg scattering in two condensates is stimulated by a common probe, the resulting quasi-particles or particles in the two condensates get entangled due to quantum communication between the condensates via the probe beam. The entanglement is shown to be significant and occurs in both number and quadrature phase variable and depends strongly on relative atom-field coupling strength of the two condensates. We present two methods of detecting the generated entanglement.

(B. Deb and G.S. Agarwal)

## Magneto-optical Spectroscopy with Entangled Photons

The entangled photon pairs, produced, say in the process of down conversion, are increasingly being utilized for very basic experiments to test the foundation of quantum mechanics and to do quantum information pro-

cessing. For example, it has been argued that the resolution in quantum lithography can be improved by a factor of 2 by use of entangled photon pairs. It is clear that the use of entangled photon pairs may be preferable over coherent sources in many spectroscopic applications such as the generation of squeezed light.

We suggest a way in which entangled photons produced by a type II down-converter can be used for magneto-optical spectroscopy with distinct advantages. Both collinear and non-collinear geometries can be used. We present quantum mechanical results for the coincidence detection of different polarizations at the output.

(**G.S. Agarwal** and M.O. Scully)

## Minimum-correlation Mixed Quantum States

The Heisenberg uncertainty principle has played an important role in the development of modern quantum theory of measurement and more recently, in research on quantum computation and quantum information. Here we consider states leading to equality sign in the uncertainty inequalities associated with correlations in open quantum systems which have been recently derived by Ponomarenko and Wolf. The new inequalities involve fluctuations defined in terms of the square of density operator that characterizes mixed states. We find minimum-correlation states associated with the quadratures of single-mode and two-mode electromagnetic fields in a cavity and for the angular momentum operators which can describe atomic degrees of freedom. We show that while in case of single-mode quadratures the functional form of the minimum-correlation state is uniquely specified, this is not so for the other pairs of noncommuting operators. In general, the states with the least amount of correlations are mixed and they exhibit squeezing.

(**G.S. Agarwal** and S.A. Ponomarenko)

## Topological Charge Inversion of a Vortex

Vortices, manifestation of phase singularities, are characterized by topological charges and recognized as important features common to all waves. The field associated with the vortices possesses a helical wavefront and the direction of rotational flow around the phase singularity defines the sign of topological charge associated with the vortex. In optical field these are called optical vortices and find variety of applications in optical tweezers, optical spanners, optical trapping of atoms and also in quantum information and computation. As reported earlier we produced a canonical vortex using a computer generated hologram, which was converted to a non-canonical vortex using a cylindrical lens. We used the same ABCD law for vortex propagation that was used to find out the trajectory of the canonical and non-canonical vortex to show that for a non-canonical vortex topological charge gets inverted as it propagates. An optical vortex of charge +1 is converted to the optical vortex of charge -1 and vice versa. We verified our theoretical results with experiments. The point of inversion was found to be same experimentally as well as theoretically, validating our theoretical treatment of the process of charge inversion.

(**R. P. Singh**, S. Roychowdhury and V. K. Jaiswal)

## Storage and Retrieval of Light Pulses at Moderate Powers

We investigate whether it is possible to store and retrieve an intense probe pulse using a medium which can be modeled as a set of atoms with the relevant energy levels in $\Lambda$-configuration. We demonstrate that it is indeed possible to store and retrieve the probe pulses which are not necessarily weak. We find that the retrieved pulse remains a replica of the original pulse, although there is overall broadening and loss of the intensity. The loss of intensity can be understood in terms of the dependence of absorption on the intensity of the probe. Our calculations include the dynamics of the control field, which becomes especially important as the intensity of the probe pulse increases. We use the theory of adiabatons to understand our numerical results on the storage and retrieval of light pulses at moderate powers.

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

## Existence of Superposition Solutions for Pulse Propagation in Nonlinear Resonant Media

Studies of pulse propagation in nonlinear atomic resonant media have been pursued in quantum optics since the late 60's. We show the existence of self-similar, superposed pulse-train solutions of the nonlinear, coupled Maxwell-Schrödinger equations, with the frequencies controlled by the oscillator strengths of the transitions. Some of these excitations are specific to the resonant media, with energy levels in the configurations of *L* and *N* and arise because of the interference effects of cnoidal waves, as evidenced from some recently discovered identities involving the Jacobian elliptic functions. Interestingly, these excitations can have widely different amplitudes, which can lead to substantially different field intensities and population densities in different atomic levels.

(P.K. Panigrahi and G.S. Agarwal)

## Laser-induced Breakdown of the Magnetic-field-reversal Symmetry in the Propagation of Unpolarized Light

We show a medium, under the influence of a coherence control field that is resonant or close to resonance to an appropriate atomic transition, can lead to very strong asymmetries in the propagation of unpolarized light when the direction of the magnetic field is reversed. We show how electromagnetically induced transparency (EIT) can be used in atomic vapor to mimic this magnetochiral effect that occurs in natural systems.

(G.S. Agarwal and S. Dasgupta)

## Scheme to Measure Quantum Stokes Parameters and their Fluctuations and Correlations

Polarization of light is a well studied subject. Text book descriptions of light polarization are based on the Stokes parameters. Methods for measuring the Stokes parameters are also well known. The Stokes parameters have been generalized in several ways. Recently, there has been considerable interest in the so called quantum Stokes parameters to describe the polarization characteristics of a non classical field possessing very strong quantum fluctuations.

We propose a scheme to measure quantum Stokes parameters, their fluctuations and correlations. The proposal involves measurements of intensities and intensity-intensity correlations for suitably defined modes, which can be produced by a combination of half wave and quarter wave plates.

(**G.S. Agarwal** and S. Chaturvedi)

## Single-atom and Two-atom Ramsey Interferometry with Quantized Field

The method of using spatially separated fields as proposed by Ramsey has been proved to be very useful for high-resolution work. It was originally proposed as a technique in microwave domain, which was then extended to studies in optical domain. Since interference effects at single-photon or few-photon levels are becoming quite common, it is natural to inquire how the results of Ramsey interferometry would be modified if the field in each Ramsey zone were quantized. We discuss the implication of field quantization on Ramsey interferometry and obtain general conditions for the occurrence of interference. We find that interferences do not occur if the fields in two Ramsey zones have a precise number of photons. However, in this case we show how an analogue of Hanbury-Brown Twiss photon-photon correlation interferometry can be used to discern a variety of interference effects as two independent Ramsey zones get entangled by the passage of the first atom. Interferences are restored by working with fields at single photon level. Finally we demonstrate the entanglement of the fields in two Ramsey zones from the passage of an atom.

(**P.K. Pathak**, **G.S. Agarwal** and M.O. Scully)

## Translational Entanglement of Dipole-Dipole Interacting Atoms in Optical Lattices

We propose and investigate a realization of the position- and momentum-correlated Einstein-Podolsky-Rosen (EPR) states that have hitherto eluded detec-

tion. The realization involves atom pairs that are confined to adjacent sites of two mutually shifted optical lattices and are entangled via laser-induced dipole-dipole interactions. The EPR "paradox" with translational variables is then modified by lattice-diffraction effects, and can be verified to a high degree of accuracy in this scheme.

(B. Deb, T. Opatrny and G. Kurizki)

## Quantum Teleportation, Quantum Networks and Memory using Cavity QED

We present a protocol for the transfer of an unknown atomic state from one cavity to a distant cavity. This protocol is based on sequential interaction of a detuned two-mode optical cavity with three-level atoms in Lambda configuration in its ground states. We also propose a scheme for quantum networking between the distant cavities based on an atomic channel. This is unlike the other networking protocols, which use a photon as a carrier between the cavities and thus are prone to decoherence due to photon absorption. We also discuss the possibility of an efficient quantum memory for the entangled states of the field in the cavity. The entanglement can be stored in the ground states of the atom and can be retrieved as well in another cavity.

(Asoka Biswas and G. S. Agarwal)

## Entanglement by Mode Mixing can Generate Vortices

We consider the evolution of a two-mode bosonic system under the action of a Hamiltonian that preserves the total number of bosons. The Hamiltonian is generic in that it represents a host of entanglement mechanisms, which can thus be treated in a unified way. We start by solving the quantum dynamics analytically when the system is initially in a Fock state. We show how the two modes get entangled by evolution to produce a coherent superposition of vortex states in general, and a single vortex state under certain conditions. The degree of entanglement between the modes is measured by finding the explicit analytical dependence of the Von Neumann entropy on the system parameters. The reduced state of each mode is analyzed by means of its correlation function and spatial coherence function. Remarkably, our analysis is shown to be equally as valid for a variety of initial states that can be prepared from a two-mode Fock state via a unitary transformation and for which the results can be obtained by mere inspection of the corresponding results for an initial Fock state. As an example, we consider a quantized vortex as the initial state and also find conditions for its revival and charge conjugation. While studying the evolution of the initial vortex state, we have encountered and explained an interesting situation in which the entropy of the system does not evolve whereas its wave function does. Although the modal concept has been used throughout the paper, it is important to note that the theory is equally applicable for a two-particle system in which each particle is represented by its bosonic creation and annihilation operators.

(G. S. Agarwal and J. Banerji)

## Group Index for Pulse Propagation in a Negative Medium

Refraction of light is one of the basic electro-magnetic phenomena in optics, whereby a light wave changes its direction during propagation from one medium to another. The dielectric constant $\varepsilon(\omega)$, the magnetic permeability $\mu(\omega)$ and their frequency $\omega$ dependence are the fundamental quantities which determine the propagation of electro-magnetic waves in matter.

All naturally occurring materials are known to exhibit positive values for the material constants $\varepsilon(\omega)$ and $\mu(\omega)$. However, recently, there have been reports of new, artificial materials which can have negative values for the material parameters. These materials, known as Negative or Left-Handed material, exhibit negative index for refraction of light. During passage through this medium, a light ray bends on the same side of the incident ray, thereby accounting for a negative angle of refraction in the usual Snell's law. We have studied the propagation of an electro-magnetic pulse through this medium. We consider a narrow-band pulse with center frequency at the region of negative index. We report that the group delays of pulse propagation can be very large

for a negative medium in comparison to the usual case of positive refraction. We also demonstrate superluminal passage and saturation of phase time in the same material albeit in a different spectral region.

(**R. Arun**, **G.S. Agarwal** and S. Dutta Gupta)

## Development of an Approximation Scheme for Quasi-exactly Solvable Systems

Quasi-exactly solvable quantal systems have manifested in physical systems ranging from anharmonic oscillators to double-well potentials appearing in the description of ring lasers. A recently developed method is employed to not only find the analytically obtainable part of the eigenspectra, but also to develop a perturbation theory to determine the low-lying states to the desired accuracy.

(Rajneesh Atre and P.K. Panigrahi)

## An Improved Design for Phased Array Resonator

Semiconductor lasers enjoy growing popularity because of their rugged, compact, low cost nature. However, the power output from a single laser diode is limited and there are many applications where the ability to increase the output power would be valuable. One possible way of achieving this goal is to phase (and frequency) lock a lateral array of laser diodes by means of the so-called Talbot effect. Sometime ago, we proposed an alternative design based on the splitting and regeneration of a symmetric input beam inside suitably designed multimode waveguides. Our design was shown to have significant advantages over the widely used Talbot resonator in terms of improved modal stability, unique photon mixing characteristics and, near and far field outputs of quasi-Gaussian form. However, depending on the number of array elements, the intracavity power density on the output facet can be very high resulting in catastrophic optical mirror damage. We present a variant of our original design which overcomes these power density problems while maintaining all the desirable features of the original design (**Fig. 6.1**).

(**J. Banerji**, R. M. Jenkins and A. R. Davies)

## Exact Solution of Nonlinear Schrödinger Equation in the Presence of Source and Damping

Nonlinear Schrödinger equation with a source term has manifested in Josephson-junction arrays, optical fibers and many other physical systems. Exact solutions are obtained for this equation, which can be both oscillatory and hyperbolic type. Exact solutions are also obtained in the presence of specific type of damping and space dependent nonlinearity.

(T. Soloman Raju and P.K. Panigrahi)

## Differentiating Normal and Cancer Tissues through the Wavelet Transform of Fluorescence Data

Fluorescence spectroscopy is being increasingly used for characterization of biological tissues because of its sensitivity. However, extraction of statistically significant parameters to differentiate various tissue types, e.g. cancerous, benign and normal has been a challenge. In this context, we have employed Wavelet Transform for the first time to extract subtle information from the fluorescence data for a clear tissue differentiation.

(P.K. Panigrahi and A. Pradhan)

## A Simple Algorithm of Image Binarization and Compression

Image binarization has been an area of active research in light of the fact that it can allow considerable compression of images without losing significant details. This is particularly useful in satellite and medical imaging which generates enormous number of images, which may need online processing and compression. A simple method for binarization is developed which achieves the same and brings out a number of detail features of the image.

(S. Hemachander and P.K. Panigrahi)

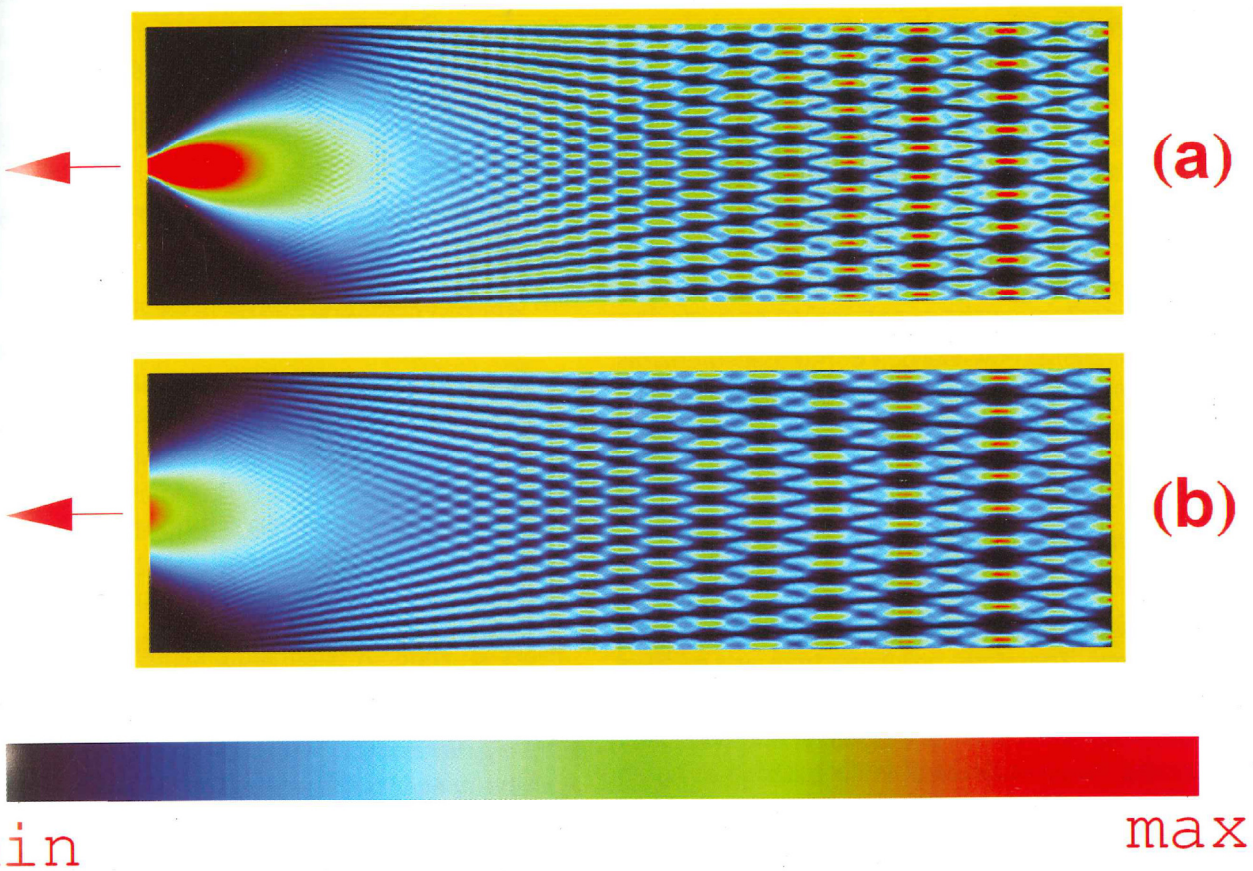



*Fig. 6.1 Intra cavity power density of the lowest loss resonator mode for (a) the original design, (b) the new design.*

## Fractal Dimension as a Tool to Characterize Scattering Samples

Light scattering provides a noninvasive technique to study an object in many different ways. We have used light scattering to find out fractal dimension of two objects with a degree of similarity, to differentiate one from another. We have taken two ground glass samples of same thickness but different grindings. A He-Ne laser is passed through these samples. The transmitted light generates speckle patterns, random sequence of dark and bright spots, on a screen. These speckle patterns are imaged with a CCD camera. The images are used to find out the fractal dimension of these scatterers using box counting method. We find different fractal dimensions for the two samples. We propose to use this method to distinguish between two biological tissues for diagnostic purposes or any two rough surfaces in general. The fractal dimensions of the samples obtained using box counting method is being verified by another method as well, based on wavelets.

(R. P. Singh, P. K. Panigrahi and Ashif A. Khoja)

The research programmes of the division are focussed to study the radiative, chemical and dynamical processes in the earth's atmosphere using observations from different platforms, laboratory measurements and modeling. Modeling of Martian atmosphere has been extended to study the effects of solar radiation. Many new research programmes are being initiated. The recoil ion momentum spectrometer (RIMS), to measure absolute photoionization cross section of atomic oxygen, is operational now. Balloon borne measurements of vertical distributions of ozone and humidity have been just started from PRL.

## Lower Atmosphere

### *Ozone and Related Trace Gases over the Bay of Bengal*

The Bay of Bengal is surrounded from three sides by land mass. Therefore, pollutants from any or all of these sides can get transported over this marine region. In order to study transport of pollutants over the region, continuous measurements of surface ozone using an onboard analyser were made during a cruise from September 15 to October 12, 2002. A large number (~80) of air samples were also collected in special glass bottles during the cruise period. These samples have been analysed at PRL for various trace gases like CO, $CH_4$ and many other hydrocarbons which are mostly anthropogenic in origin and can be used to study the transport of pollutants over the marine region. The measurements were made over the central Bay of Bengal as well as along the Indian east coast. Lower values of these trace gases at the south most point (7°N, 88°E) and higher values near the northern region of the Indian coast were observed. Ozone values are generally in the range of 20 to 40 ppbv over the marine region. A comparison of these measurement is made with the earlier measurements made in February-March 2001 over the Bay of Bengal as well as over the Arabian Sea. Ozone levels in the 10° to 20° N region are almost similar during both the periods and over both the marine regions. However, ozone values over the Bay of Bengal south of 12°N were very high during February-March 2001 compared to the present measurements. A short duration cruise was made over the Bay of Bengal during February 19-28, 2003 to study the transport of pollutants during winter period. These results are being analysed.

(L. K. Sahu, S. Venkataramani, K. S. Modh, T. K. Sunil Kumar and Shyam Lal)

### *Carbon Monoxide over the Bay of Bengal from a 3-D Model*

Carbon monoxide can be used as a tracer of pollution. The results of ECHAM 5 model of the Max Planck Institute for Meteorology, Hamburg, Germany for the period of the Bay of Bengal Experiment (BOBEX) during February-March 2001 are used for such a study. This model, which incorporates a simple chemistry of CO, was run to support the TRACE-P field campaign conducted in March-April 2001. The model has a high resolution of ~1.8° x 1.8° with 31 vertical levels from surface to about 10hPa. Operational analyses from ECMWF were interpolated on the model grid and served as input for the model. The CO emissions are based on the EDGAR2 inventory. The results of the model run are available at each 6 hours. Very high level of ozone, CO, methane, $SF_6$ etc. were found over the central Bay of Bengal during this period. The model results for CO and the average wind pattern show very clearly that these high levels of CO are getting transported from the Dhaka-Burma region. The model results also confirm low value of CO near the Indian east coast and also over the Arabian Sea as observed during the BOBEX cruise. Simulation results of the MOZART (model for ozone and related chemical traces) of Max Planck Institute of Meteorology, Hamburg, Germany are also being used to study observed distributions of ozone and related trace gases during INDOEX cruises over the Arabian Sea and the Indian Ocean. This study is a joint work of PRL and Max Planck Institute of Meteorology, Hamburg, Germanay.

(Shyam Lal)

### *Measurements of NMHCs and their Implications in the Troposphere*

Non-methane hydrocarbons (NMHCs) are important precursors as they contribute in photochemical production of ozone with higher efficiencies as compared to the main precursor like CO and $CH_4$ in the troposphere.

The lower order hydrocarbons (C2 - C5) are mostly emitted by anthropogenic activities related to industrialization and urbanization and are relatively long-lived. Ratios of some of these hydrocarbons with each other and with other species like CO, NO can be used in source identification and age determination of the air parcels.

Measurements of some of the NMHCS along with other important trace gases like CO, $CH_4$ and ozone at Mt. Abu and Ahmedabad representing free tropospheric and urban sites respectively are being made from September, 2001. Air samples collected over the Bay of Bengal were analyzed for these gases. Typical diurnal variations of one of the non-methane hydrocarbons (ethene) along with ozone and CO observed at Ahmedabad in January 2002 are shown in **(Fig. 7.1)**

(L.K. Sahu, S. Venkataramani, T. K. Sunil, S. Desai, K. S. Modh and Shyam Lal)

## Diurnal Variation of Trace Gases using a Box Model

Recently study of tropospheric trace gases has become important due to their direct impact on pollution and global warming. A photochemical zero-dimensional model (box model) has been developed at PRL to simulate such trace gases. It can be used to explain observations of surface ozone and related gases over various regions in India.

The model solves a set of stiff differential equations for 22 species using a variant of the Gear code. The model is used in Lagrangian mode, not taking into account the dynamics. The concentrations of the species are simulated for Ahmedabad for the month of March with input parameters (initial emissions, concentrations, dry deposition) typical of an urban region. The diurnal variations of $O_3$, OH and $HO_2$ are shown in **Fig. 7.2** with inclusion of $C_2H_6$ (a typical non-methane hydrocarbon-NMHC). Without this NMHC, the peak value of ozone is lower by about 17 ppbv. Ozone concentration peaks in daytime due to photolysis of $NO_2$. In turn, the photolysis of ozone is the source of OH radicals, which similarly show a peak in daytime.

(Varun Sheel)

## *Cruise Study of Aerosol Characteristics over the Bay of Bengal*

Aerosols found over oceans are expected to be particles mostly produced by natural oceanic processes. However this scenario can change, particularly downwind of polluted source regions where the anthropogenic aerosols can dominate over the natural oceanic aerosols. In order to study the transport of aerosols over the Bay of Bengal (BOB) and their characteristics, a ship cruise study by ORV Sagar Kanya was conducted between 19 to 28 February, 2003, when the prevailing surface level wind flow was predominantly from the conti-

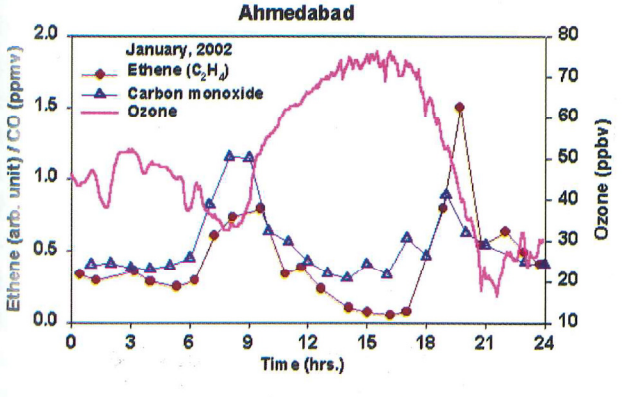



*Fig. 7.1 Typical diurnal variations of Ozone, CO and ethene measured at Ahmedabad.*

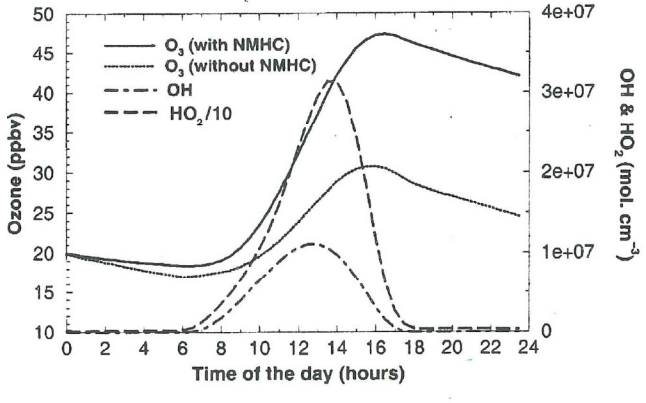



*Fig. 7.2 Diurnal variation of $O_3$, OH, $HO_2$ simulated by box model.*

nent towards the ocean. The columnar Aerosol Optical Depth (AOD) measured using sun-photometer varied from 0.35 to 0.70 at 380nm and from 0.10 to 0.25 at 1020nm. These high values indicate that the BOB region is one of the highly polluted oceanic regions in the entire globe. The water soluble particles and soot were the main constituent of the aerosols over this region. For the first time surface level aerosol size distribution was measured over BOB using a Quartz Crystal Microbalance cascade impactor. An increase in the accumulation and the nucleation mode aerosols was observed over the northern and coastal areas of BOB showing the influx of particles from the Indian sub-continent.

(D. Ganguly and A. Jayaraman)

### *Mobile Lidar Study of the Aerosol Extinction Profiles over Western Gujarat*

To study the cross boundary transport of aerosols and to build a three dimensional model profiles of aerosol over Gujarat a field campaign was undertaken from December 26, 2002 to January 11, 2003 using the newly built Micro Pulse Mobile Lidar. The expedition started from Ahmedabad, taking observations at approximately every 50 km interval and ended at Narayan Sarovar, close to the Indian border. **Figure. 7.3** shows the aerosol extinction profiles obtained for four selected locations, viz., Bhuj, Somnath, Ahmedabad and Rajkot. Ahmedabad and Rajkot are urban locations whereas Bhuj and Somnath are semi-urban. Integration of extinction profile over altitude gives the aerosol optical depth (AOD). The highest AOD is observed at Ahmedabad and the lowest at Bhuj. Bhuj is less industrialized and does not fall in the downwind of any major pollution sources. Though Ahmedabad, Rajkot and Somnath have comparable values of AOD the vertical profiles of extinction differs significantly. Over Ahmedabad more than 55 % of AOD is contributed from 0 to 0.5 km indicating the dominance of local pollution, whereas for Somnath and Rajkot it is only 36 % and 39 %. Difference in boundary layer height plays a major role in the vertical distribution of aerosols. Detailed study on the geographical variation along with vertical wind structure is in progress.

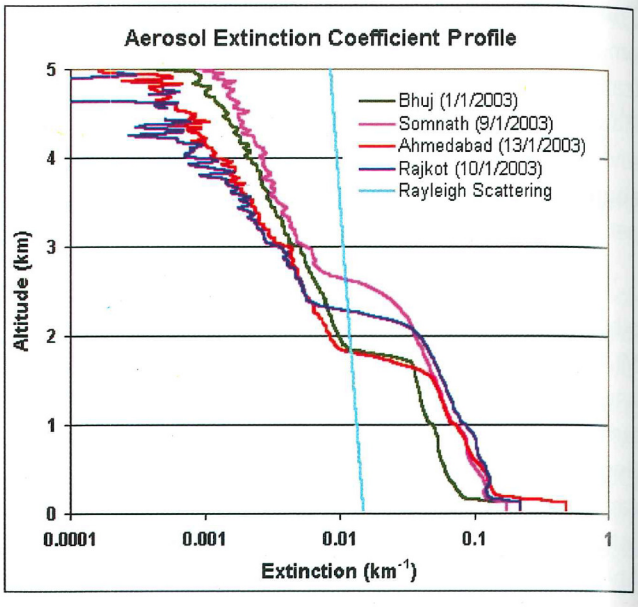



*Fig. 7.3 Typical profiles of aerosol extinction measured using the Micro Pulse Mobile Lidar at locations and dates shown above.*

(H. Gadhavi, A. Jayaraman and T. A. Rajesh)

### *Balloon-borne Study of the Upper Tropospheric and Stratospheric Aerosols over India*

A high altitude balloon carrying Sun-scanning/tracking multichannel photometer systems was launched from Hyderabad (17.5N, 78.6E) on 10 April 2001 and the aerosol characteristics in the upper troposphere and stratosphere are studied. In the upper troposphere the integrated aerosol extinction coefficients at 500 nm are found to show an average increase of about 11±1% per year during the 1985-2001 period. The increase is found consistent with the observed increase in the long term columnar aerosol optical depth data over selected locations in India. We estimate that the sulfur dioxide and aerosol emissions from coal over India have increased by 10% per year during the past 2-decades. The increase in emissions from high speed diesel oil and petrol are higher and are in the range of 13-14% per year over India. These increases could possibly be responsible for

the observed increase in the upper tropospheric aerosol optical depths over India.

(S. Ramachandran and A. Jayaraman)

### *Modeling the Radiative Impacts due to Stratospheric Aerosols*

Mount Pinatubo erupted in June 1991 injecting about 30 Mt of $SO_2$ into the stratosphere which produced an almost equal amount of sulfate particles. Using the GFDL SKYHI General Circulation Model an ensemble of experiments have been performed to study the radiative and dynamic impacts of Pinatubo aerosols on the Earth-atmosphere system. There have been larger eruptions in the 19th century such as Krakatoa, Tambora which resulted in much larger quantities (of the order of ~ 100-200 Mt) of sulfate aerosols into the stratosphere. Using the global aerosol data set of Pinatubo aerosols and by jacking up the aerosol amounts to 3, 5 and 10 times an ensemble of experiments are performed **(Fig. 7.4)**. The aim of this experiment was twofold: (i) to determine whether the thermal responses are linear in the stratosphere and in the troposphere, and (ii) to isolate the mechanisms by which large natural forcings affect climate.

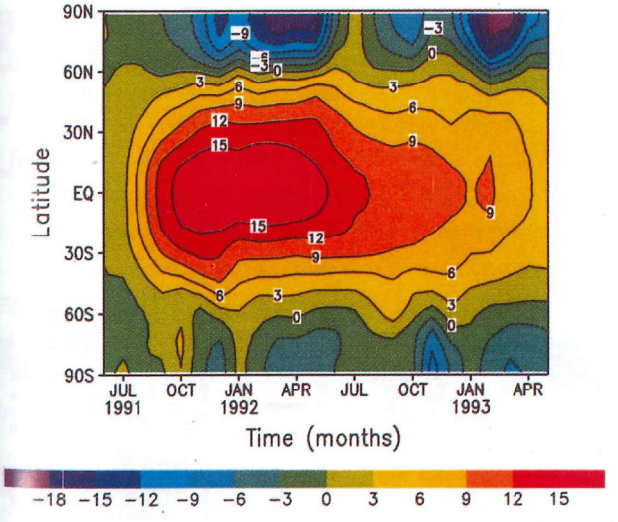



*Fig. 7.4 Latitude-time diagram of zonally averaged temperature anomalies (K) of lower stratosphere temperature at 50 hPa caused by an eruption of magnitude 10 times that of Pinatubo. Note that the maximum warming due to Pinatubo aerosols is 3K in the tropical lower stratosphere.*

(**S. Ramachandran** and V. Ramaswamy)

### *Arctic Oscillation Response to the Mount Pinatubo Aerosols*

One phenomenon that has generally been observed in the two boreal winters following major explosive volcanic eruptions is an anomalously positive phase of the Arctic Oscillation (AO). This phenomenon was studied by focusing on the atmospheric response to aerosol and ozone forcings, which involves large-scale stratosphere-troposphere dynamic interaction. In addition to the control and perturbation experiments with Pinatubo aerosols, a second set of experiments were performed by including only the effects of aerosols in reducing the solar flux in the troposphere, and the aerosol heating effects in the stratosphere were suppressed. A third set of perturbation experiments imposed the stratospheric ozone losses in the post-Pinatubo period. Forced with Pinatubo aerosols, SKYHI GCM produces a statistically significant phase of the AO in winter, as observed. Ozone depletion causes a positive phase of the AO in late winter and early spring by cooling the lower stratosphere in high latitudes, strengthening the polar night jet, and delaying the final warming. A positive phase of the AO was also produced in the experiment with only the tropospheric effect of aerosols showing that aerosol heating in the lower tropical stratosphere is not necessary to force positive AO response, as was previously assumed.

(**S.Ramachandran**, A.Robock, G.L.Stenchikov and V. Ramaswamy)

## UPPER ATMOSPHERE

### *Rayleigh/Raman Lidar*

The Rayleigh lidar at Gurushikhar in Mt. Abu is being operated for few nights each month for studies of atmospheric aerosols, density and temperature studies. For the past 2 years it is also operated in the Raman mode to obtain density profiles in the altitude region of 5-25 km. Density profiles obtained from the Rayleigh

and Raman modes of operation have been combined to get temperature profiles in the altitude region of 5-70 km.

Comparative study of the temperature structure in the region 30-75 km at Gurushikhar is also being attempted with the measurements made using the Rayleigh lidar at NMRF in Gadanki.

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

### *Association between Equatorial and Tropical Spread-F*

Comparative study of spread-F is made from the quarter-hourly ionograms at Huancayo, near the magnetic equator and Bogota, close to the anomaly crest region in the same longitude sector. The occurrence of equatorial spread-F is seen only during nights, preceded by very rapid rise of the F-layer close to the magnetic equator. Based on quarter- hourly ionospheric data at a chain of 8 stations in the American sector, the occurrence of spread-F at low latitudes is shown to be associated with the post-sunset intensification of the ionization anomaly. The ratio of foF2 at Bogota (anomaly crest) to that at Huancayo (dip equator) shows sudden intensification on spread-F days around 1900hrs LT, peaking between 2000 and 2100hrs LT and can be used as a precursor to predict spread-F near the magnetic equator. The onset of spread-F at Bogota, however, requires additional condition of strong spread-F at Huancayo covering a wide range of altitudes and stronger uplift of the F-layer. There are indications that the vertical uplift velocity of F-layer between 1800 and 1900hrs LT could be used to predict the onset of equatorial spread-F (ESF) even at crest.

(**H Chandra**, S Alex and R G Rastogi )

### *Spectral Analysis of OI 630.0 nm Dayglow Intensities Observed over Low and Equatorial Latitudes*

A large data set obtained by systematic observations during 1995-2002 on OI 630.0 nm dayglow emission intensity variations over Mount Abu, a station under the crest region of equatorial ionization anomaly have been subjected to harmonic analysis to understand the propagation of atmospheric waves in thermosphere under varying geophysical conditions. The analysis reveals that the waves with the periodicities of 0.5 to 1.0 hr are dominant in the thermospheric region over low latitude. In order to identify the source of wave activities, similar analysis was carried out using the similar data set obtained from Waltair and Thumba. The dominant periodicities are found out to be 2.0-2.5 hrs over Waltair and 1.0 to 1.5 over Thumba which are different from Mt. Abu revealing the local origin of this wave activities **(Fig. 7.5).**

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

### *Co-ordinated Optical and Radar Observation of F-region Plasma Structures*

Numerical simulation studies by us on the F-region plasma structures with more than one wavelength mode as seed perturbations revealed the presence of down drafting enhancements in addition to upward moving plasma depletions. In order to identify such structures, measurement with VHF radar alone is inadequate.

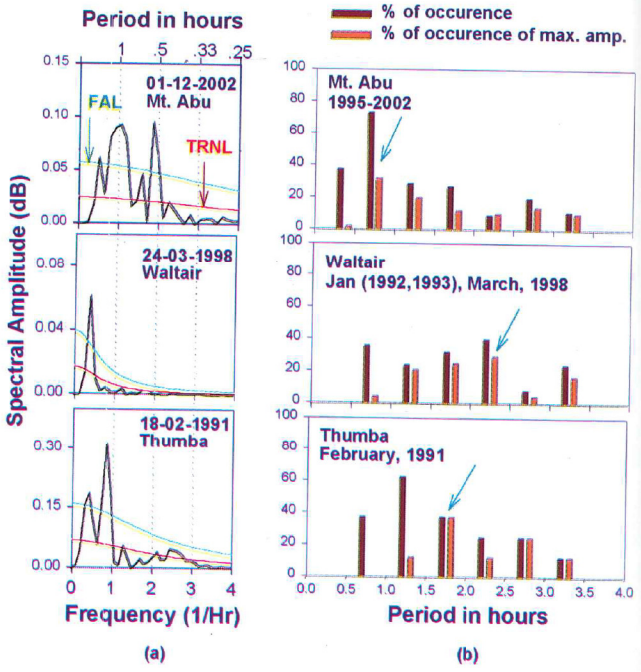



*Fig. 7.5 : (a) Spectra of normalized OI 630 .0 nm dayglow intensity variations where TRNL and FAL indicate the theoretical red-noise level and false alarm level and (b) histograms of periodicities obtained.*

The optical observation of thermospheric OI 630.0 nm airglow emission which is proportional to electron density variation is needed. A computer-controlled scanning photometer whose field of view is close to the field of view of VHF radar was built in PRL. Temperature turned narrow band (~ 3 Å) interference filters were used to obtain microstructures. Co-ordinated optical and radar measurements were planned and conducted during September 2002 and in March 2003. Results obtained from these campaigns, reveal microstructures in airglow intensities which corroborate with structures obtained by the VHF radar. Evidences for a down drafting enhancements were also obtained.This work was done in collaboration with NMRF, Gadanki

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

### *Investigation of Energetics and Dynamics of Mesosphere using Optical and Radar Observation*

In order to obtain temperature and gravity wave parameters from mesospheric region a fast, computer controlled scanning multi wavelength photometer was built in PRL. By monitoring two appropriate rotational lines (731.6 nm and 740.2 nm) from the same vibrational band (8,3) emission of OH, mesospheric temperatures are deduced. Intensity variabilities obtained by multidirectional scanning, the gravity wave parameters are deduced. A co-ordinated campaign involving optical and radar measurements was planned and conducted from Gadanki during March 2003. The Indian MST radar was operated in meteor and Doppler modes to obtain mesospheric temperature and winds. The temperature and gravity wave parameters obtained by optical measurements are being looked in conjunction with the corresponding radar measurements. This work was done in collaboration with NMRF, Gadanki.

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

### *Evidence of an Ionization Layer in E-region over SHAR During Counter Electrojet Event*

Two rocket flights were conducted from SHAR during November 1999 of which one on 20th November 1999 happened to be during counter electrojet condition as revealed by ground based magnetometer. The absence of 3 m irregularities by the Langmuir probe and VHF radar over Gadanki reveals that the direction of the electric field was downward during the time of flight. An ionization layer with a full width of about 3 km was observed in the electron density profile at 105 km. An excess ionization of about 40% of the background was observed. Such layer formation during counter electrojet events have been observed over Thumba. However, an evidence for the first time for the formation of such layers over SHAR is obtained. The importance of downward electric field in their formation is being investigated.

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

### *Detection of Mesospheric Gravity Waves in the 557.7 nm Airglow Images*

The design of PRL's all sky optical imaging system was modified to make it more suitable for the detection of gravity waves. An observational campaign was conducted from Kavalur (12.5 $^0$N, 78.8 $^0$E) in January 2003 with the modified system to detect the gravity waves. The atomic oxygen airglow emissions were imaged using a narrow band filter at 557.7 nm and the OH emissions using a high pass filter with a cutoff at 650 nm. Clear cut signatures of gravity waves were observed in the 557.7 nm images taken on 30 January 2003 **(Fig. 7. 6)**. Very prominent band like structures were seen in the image, which is the manifestation of modulations

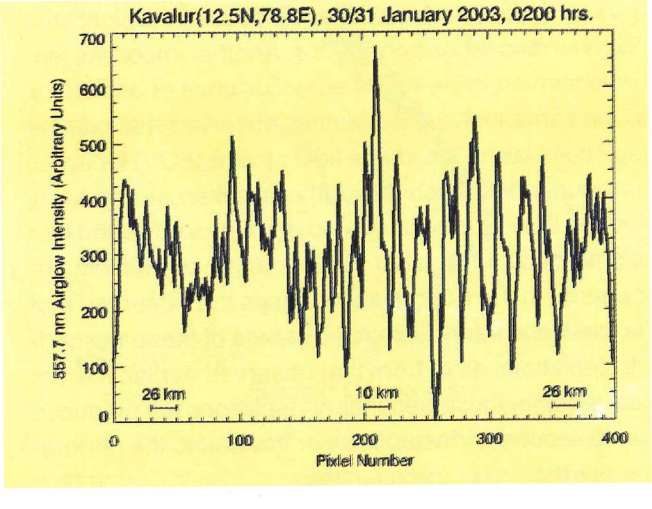



*Fig. 7.6 Gravity wave structures seen in 557.7 nm images taken over Kavalur (12.5 $^0$N,78.8$^0$E) on January 30,2003*

created by the gravity waves. These bands did not show any alignment like plasma depletions, which are normally aligned in the N-S direction. These band type structures were present in the field of view for about 20 minutes after which they weakened and ultimately disappeared. This period of 20 minutes matches with the typical period of mesospheric gravity waves. This is the first detection of gravity waves using PRL's all sky imaging system.

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

### *Post-midnight Plasma Depletions over Kavalur*

The plasma depletions observed over Kavalur (12.5 $^0$N, 78.8 $^0$E) during February to April 2002 showed some interesting features, which can be used to understand more about their generation mechanism . The speciality of this period was that a large number of post midnight plasma depletions were observed. The steep density gradients necessary for the instability mechanisms to operate are generally present after sunset. The post midnight occurrence of plasma depletions will help in clearly establishing the seed for the generation of irregularities as well as the influence of other background ionospheric conditions in the development of plasma depletions. Also, the difference in the appearance of pre- and post-midnight plasma depletions and their relationship with various ionospheric parameters can be used to predict whether depletions will occur on a night with the given ionospheric conditions. Another important feature observed is the repeated occurrence of depletions on the same night. It is normally observed that plasma depletions last in the image field of view (FOV) for about 3-4 hours after which they either weaken or drift away from the FOV. During this campaign it was observed that plasma depletions, after disappearing completely, reappeared in the FOV. In some cases it is observed that the width and inter-depletion distance of these 'secondary' depletions differ from that observed earlier. It is not clear whether these 'secondary' depletions are produced due to secondary instabilities or it is due to the generation of fresh set of irregularities.

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

## LABORATORY ASTROPHYSICS

### Multiple Ionization Cross Section Measurements Using INDUS-1 Synchrotron

A collaborative program has started between PRL and the Center for Advanced Technology (CAT), Indore. The INDUS-1 synchrotron at CAT, a national facility, supplies tunable extreme ultraviolet photons with critical wavelength 4.2 nm. An experiment has been designed and developed to use this facility to measure the multiple ionization cross sections of gases at different incident photon wavelengths. It is also proposed to measure the thresholds of multiple ionizations with the same experimental setup. A Wiley-McLaren type time-of-flight mass spectrometer (TOFMS) has been fabricated in PRL for this purpose . It is designed to fit onto one of the ports of the experimental chamber available on the material characterization beamline of INDUS- 1

A uniform extraction field extracts electrons and ions resulting from the photoionization event and ions are detected at the far end of a drift tube in coincidence with the photoelectron. Different *m/q* events are time-dispersed and histogrammed. Relative flow method is used to convert the relative cross sections to absolute. The thresholds for multiple ionizations are measured by observing the onsets when the monochromator is in scanning mode.

It is proposed to measure the multiple ionization cross-sections of argon first, followed by similar studies in other atomic and molecular gases.

The TOFMS is assembled, tested and has been mounted on the CAT vacuum chamber and experiments are ready to start once the time on beamline is allotted.

(Bhas Bapat, K.P. Subramanian and A.P. Gohil)

### *Measurement of Photoionization Cross Section of Atomic Oxygen*

A recoil ion momentum spectrometer (RIMS) has been designed and fabricated in the laboratory to measure absolute photoionization cross sections of atomic

oxygen. Inability of discrimination of atomic oxygen ion formed due to various other processes is a serious limitation in such measurements. RIMS offer possibly the best solution for this problem, where ions of same kind produced in different processes are recorded as separable events by virtue of their momentum analysis. With various conditions applied to the acquired data, it is also possible to derive other useful information.

A recoil ion momentum spectrometer has been fabricated at PRL to study various photoionization processes. It is a multiport evacuated chamber and uses a position sensitive detector in conjunction with time-of-flight technique for momentum measurement of the ions. The various components of the spectrometer such as ion extractor, detector etc. are being integrated onto the system. Photoionization is achieved by multiphoton ionization using a tunable dye laser.

An innovative method has been developed to generate atomic oxygen in the form of a supersonic beam by means of microwave discharge on flowing molecular gas. Various differential pumping stages are employed for efficient handling of different pressure stages in this machine. This unit has been tested and has been integrated to the RIMS.

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

### *Characterization of Laser Produced Plasma*

A new apparatus has been designed and fabricated for the measurement of spectra and evolution features of the laser produced plasma (LPP). This apparatus is much more versatile than the similar experimental system already existing in the laboratory and the scope and range of measurements has been considerably increased. This system uses a XYZ translation stage in vacuum for accurate and reproducible manipulation of the target. It also has got 6 observation ports in a single plane for simultaneous observation of different parameters of the LPP.

The main processes that are being studied are the ablation, breakdown and evolution of plasma into the ambient. The main focus of this study is to understand the different energy coupling mechanisms in the formation and evolution of LPP. The spectral emission features of the space resolved LPP is being studied by a CCD spectrograph. Attempts are being made for the estimation of electron temperature by measurement of ratio of line intensities. It is proposed to study the evolution of non-luminous debris of the plasma by way of extinction studies.

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

## PLANETARY/COMETARY ATMOSPHERES

### *Impact of Solar EUV, X-ray and Proton on Martian Atmosphere*

The ion production rates, ion densities and electron densities are calculated in the dayside ionosphere due to impact of solar EUV, X-ray and $H^+$-H atom on Mars at solar zenith angle 75°. The ion production rates are calculated using two different methods namely (1) Analytical Yield Spectrum Approach and (2) Hybrid Simulation based on Monte Carlo method. Later, these production rates were used in continuity-momentum equation to calculate densities of seven ions $CO_2^+$, $O_2^+$, $NO^+$, $O^+$, $CO^+$, $N_2^+$, and $N^+$ in the dayside ionosphere. The electron density produced by solar EUV, X-ray and $H^+$-H are represented in **(Fig. 7.7)**. This calculation is

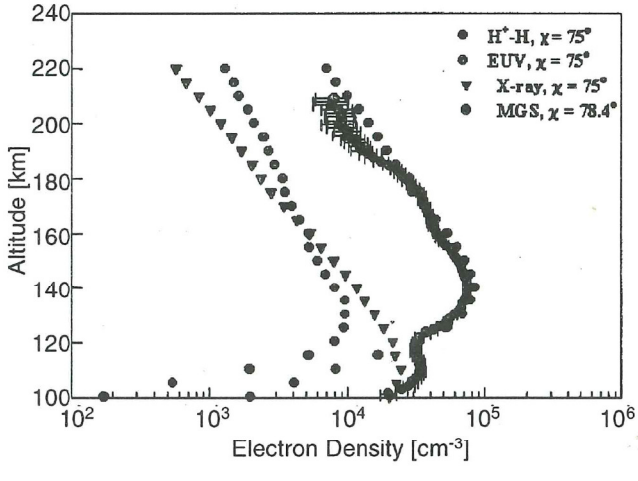



*Fig. 7.7 The calculated electron density profiles at solar zenith angle 75° due to impact of $H^+$-H, solar EUV, and X-rays with the atmosphere of Mars. The electron density measured by MGS at solar zenith angle 78.4° is also plotted.*

compared with radio occultation measurements made by Mars Global Surveyor (MGS). This measurement has obtained two ionization peaks at about 134 km and 110-112 km in the dayside ionosphere. The values and position of these peaks are in good agreement with the calculated results. The $H^+$- H impact process is not responsible significantly for reproducing these measurements. The primary and secondary peaks of the measurements are produced by solar EUV and X-ray photons respectively.

(S.A. Haider)

### *Night Time Limb Emissions at Mars*

The excitation rates, emission rates and limb intensities of 5577 Å and 6300 Å lines are calculated due to precipitation of solar wind electron at energy range 10-1000 eV which were measured by MGS in 1998 in the nighttime ionosphere of Mars at solar zenith angle ~ 106 degree. In the vicinity of the peak altitudes, it is found that excitation/emission of atomic oxygen after the electron impact dissociation of $CO_2$ is the main source of 5577 Å emission while dissociative recombination of molecular oxygen ion is the major source of 6300 Å emission after the electron impact excitation of atomic oxygen. The total limb intensities of both these emissions are found to be 100 Rayleigh which is larger by a factor of ~ 2 from the upper limit of ~ 50 Rayleigh set by Mars 5 spectroscopic observations in the dark limb of the planet. The difference between these two results is due to use of solar winds electron flux which was measured by MGS in 1998 when density and velocity of solar wind were larger by a factor of ~ 2 from Mars 5 observation during 1974-75.

(S.A. Haider)

The research activities of the division encompass studies of a wide variety of natural processes pertaining to the solar system, earth, ocean and atmosphere. Selected activities are described below under the following headings: Planetary evolution, Meteorites and Solar System Studies, Geochronology and Geochemistry, Oceanography, Aqueous Geochemistry, and Atmospheric Studies.

## Planetary Evolution

### *Si in Mars Core*

Based on N and O isotopic systematics of martian meteorites, we have deciphered that the planet Mars is made of enstatite and ordinary chondrites in the proportion of 74:26 as against the earlier belief that carbonaceous chondrites have significantly contributed to the make up of Mars. Our model is consistent with the $^{53}Cr$ isotopic anomaly as well as Fe/Si ratio and the moment of inertia for Mars. Using the oxygen fugacity for the above precursors and constraining the FeO content of Mars mantle to be 17 wt%, we partition the remaining O to make the other major oxides of mantle. Balancing the total Si content of 17.8% will only be feasible if part of Si is accommodated into the core, amounting to 6.7 wt% of core. The recent observation that Fe metal in E-chondrites has up to 12.5% Si in it and the recent experimental result that significant amounts of Si is soluble in Fe metal at < 25 G Pa, corresponding to the pressure at the core of Mars are very much consistent with our finding.

(**S.V.S. Murty** and R. Mohapatra)

### *Planetesimal Formation and Destruction : A Time Constraint*

The Rumuruti chondrites (R-chondrites) constitute a new chondrite group. Most R chondrites contain the typical components of primitive chondrites including chondrules, chondrule and mineral fragments, sulfides, and rare Ca, Al- rich inclusions (CAIs). In Hughes 030 (a rumarutite) an interesting Ca, Al-rich inclusion was found consisting of abundant hibonite and spinel. The hibonite grains show resolved $^{26}Mg$ excess, yielding an initial $^{26}Al/^{27}Al = (1.2\pm0.3)10^{-6}$, which is ~50 times lower than the initial value measured in CAIs from primitive meteorites, and a time difference of ~4 million years between the formation of CAIs from primitive chondrites and the Hughes 030 CAI. Based on mineralogy and the petrographic setting of the hibonite-rich CAI it is suggested that 4 million years reflect the time interval between the formation of the CAI and the end of its secondary alteration, in the nebula. As the CAI could not have survived in the nebula as a free floating object for a long period of time, the possibility of storage in a precursor planetesimal for a few million years, resetting the magnesium-aluminum isotopic system, prior to impact brecciation, excavation, and accretion of the final R chondrite parent body cannot be ruled out.

(G. Srinivasan)

## Meteorite and Early Solar System Studies

### *Model for Interstellar Origin for $^{10}Be$*

The presence of short-lived radionuclide $^{10}Be$ (half-life ~1.5 Ma) was established recently. The canonical $^{10}Be/^{9}Be$ value at the beginning of solar system formation is $\sim 1x10^{-3}$. Although production in stellar explosions has been suggested, abundant Be production requires spallation reaction between C, N or O and H or He nuclei. If production outside the solar system could be ruled out then spallation would have to occur within the solar nebula implicating the X-wind model. The significance of $^{10}Be$ hinges on whether it can be produced outside the solar nebula. Preliminary analyses did not seriously consider Galactic cosmic ray as a mechanism for production of $^{10}Be$. Recently improved calculations were carried out using GCR in a molecular cloud when it collapses to form a protostar and protoplanetary disk. The flux of protons and $^{10}Be$ GCRs in the Sun's molecular cloud core at 4.5 Ga is constrained. Numerical magnetohydrodynamic simulation of star formation to model the time evolution of magnetic field strength and column density of gas in collapsing cloud core is modelled. After accounting for magnetic focusing and mirroring we constrain the rates of production of $^{10}Be$ by spallation and its decay, it is estimated that at the time of formation of protostar the $^{10}Be/^{9}Be$ ratio is $1x10^{-3}$. Galactic Cosmic rays can account for most of the $^{10}Be$ observed in

CAIs. This model naturally explains the decoupling of production of $^{26}Al$ and $^{10}Be$ and its observation in CAIs in early solar system.

(G. Srinivasan)

### *Sources of Short-lived Nuclides in the Early Solar System*

Pristine early solar system solids recovered from meteorites contain fossil records of several now-extinct short-lived nuclides. Some of these nuclides are considered to be products of stellar nucleosynthesis while others like $^{10}Be$ must have been produced by energetic particle interactions because it is not a product of stellar nucleosynthesis. Whether energetic particle interactions also produced some of the other short-lived nuclides considered to be stellar products remained a contentious issue. We have carried out an ion microprobe study of fossil records of three short-lived nuclides, $^{41}Ca$, $^{26}Al$ and $^{10}Be$, in a set of refractory oxide grains (hibonite) obtained from the primitive carbonaceous chondrites, Murchison and Allende, to address this question.

$^{41}Ca$ and $^{26}Al$ are below detection level in these grains except in the Allende sample (HAL), where a very small signal of $^{26}Al$ was detected in an earlier study. However, all the samples show presence of the short-lived nuclide $^{10}Be$ at the time of their formation that may be inferred from the excess abundance of its daughter nuclide $^{10}B$ **(Fig. 8.1)**. Since $^{10}Be$ is a product of energetic interactions, it is clear that this process did not lead to significant production of either $^{41}Ca$ or $^{26}Al$ in the early solar system. One plausible source of the observed $^{10}Be$ is solar energetic particle irradiation of material in the solar nebula. An effective irradiation dose of ~$2x10^{18}$ protons $cm^{-2}$ with kinetic energy >10MeV/amu can explain our measurement. The absence of $^{41}Ca$ and $^{26}Al$ at detectable level may be explained by postulating a hard (flatter) energy spectrum for the solar energetic particles. Our result strengthens the case of a stellar source of $^{41}Ca$ and $^{26}Al$ present in some early solar system solids and bolster the proposal of a triggered origin of the solar system. This work was carried out in collaboration with of University of Chicago.

(**J. N. Goswami**, **K. K. Marhas** and A. M. Davis)

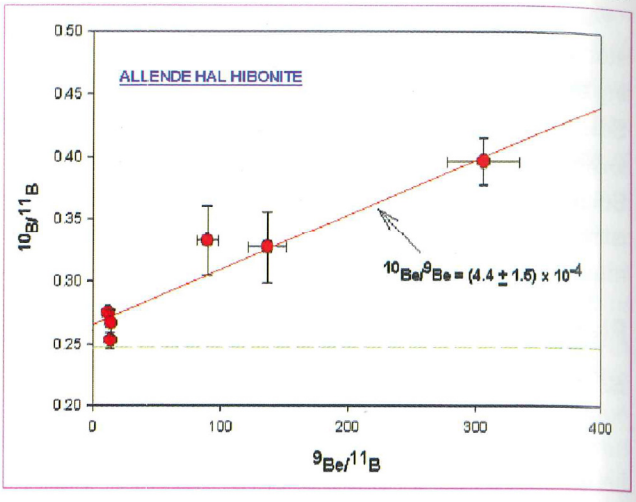



*Fig. 8.1 Be-B isotopic systematics in the hibonite (HAL) from the Allende meteorite. The dotted line represents normal $^{10}B/^{11}B$ ratio. The experimental data show a clear excess in $^{10}B/^{11}B$ ratio over the normal value that also increases with increasing $^{9}Be/^{11}B$ suggesting that the excess is due to in-situ decay of $^{10}Be$ present in HAL hibonite at the time of its formation and suggest an initial $^{10}Be/^{9}Be$ value of ~$5 \times 10^{-4}$. Error bars are 2$\sigma$.*

### *Mechanism of Noble Gas Trapping in Ureilites and In Phase Q*

Phase Q, an ill defined carbonaceous phase in chondrites, comprising < 0.5% of the bulk meteorite carries > 90% of the trapped noble gases. Diamond and amorphous C in ureilites are also similarly enriched in noble gases. Noble gases in both phase Q and ureilites have almost identical isotopic compositions and it has been suggested that both these phases have acquired the noble gases by the same mechanism, most likely from an ionized medium. Our work on ureilites has clearly brought out the following subtle but significant differences between phase Q and ureilites that can be only accounted for by ion implantation from plasma. 1) The elemental ratios $^{132}Xe/^{36}Ar$ and $^{84}Kr/^{36}Ar$ show a decreasing trend with depth in the ureilite diamonds. This can be best explained if Ar, Kr, Xe are ion implanted into diamonds, as has been demonstrated by computer simulation of ions into diamond grains. 2) The $^{36}Ar/^{132}Xe$ ratio in ureilites is about an order of magnitude higher than in phase Q requiring a higher plasma temperature for the case of ureilites. 3) The isotopic ratio $^{129}Xe/^{132}Xe$ in

ureilites is 1.035 and is independent of $^{132}Xe$ content and thus defines a pure trapped component (**Fig. 8.2**). The same ratio for phase Q on the other hand is 1.042, a significant excess due to insitu decay of $^{129}I$, an observation that can be reconciled if I/Xe ratio in phase Q is higher as compared to ureilites, which in turn requires a plasma temperature of about 2000 K lower in the region of the nebula where phase Q got its noble gases.

(**S. V. S. Murty**, **V.K. Rai** and U. Ott)

### *Cosmic Ray Effects in Meteorites*

Study of meteorites for cosmic ray effects like induced radioactivity and tracks was continued this year. One important finding is that measurement of $^{44}$ Ti in fresh meteorite falls showed that the galactic cosmic ray intensity has decreased by a factor of 1.5 to 2 over the past 200 years. It was shown that the $^{44}Ti$ in stony meteorites, $^{10}Be$ in Greenland ice core and the heliospheric magnetic field as estimated by Solanki et al. are all mutually consistent with this result. This work was done in collaboration with Instituto di Cosmogeophysica, Torino, Italy.

(N. Bhandari)

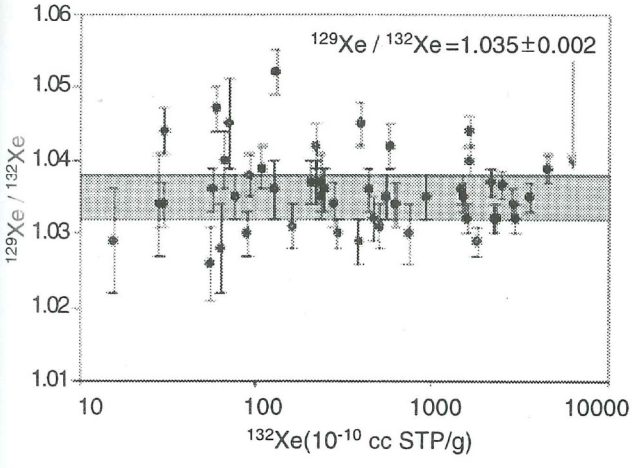



*Fig. 8.2 $^{129}Xe/^{132}Xe$ ratios for temperature steps of 9 acid resistant residues from 6 ureilites have been plotted against their respective $^{132}Xe$ contents. $^{129}Xe/^{132}Xe$ is clearly independent of $^{132}Xe$ amount and demonstrate its trapped origin. The weighted mean of the ratio (1.035 ± 0.002) is significantly different from the value for Phase Q (1.042 ± 0.002).*

## Geochronology and Geochemistry

### *Study of Permian -Triassic Boundary (PTB) Transition*

Continuing our study of a Permian Triassic horizon (~250 Ma) in the Spiti valley, which was identified by us a few years ago, we have found some evidence of planar deformation features in quartz, supporting impact of an Ir poor and probably Eu rich bolide on the Earth at that time. This observation is consistent with a short duration climatic and oceanic environmental changes at that time indicated by available chemical and isotopic data. Absence of metamorphic features in the PTB section due to tectonic processes (e.g. Himalayan orogeny) rule it out as a possible cause for the origin of shock features in quartz.

(N. Bhandari, A. D Shukla and P. N. Shukla)

### *Evolution of Amba Dongar Carbonatite Complex: Evidence from $^{40}Ar$-$^{39}Ar$ Chronologies of the Inner Basalt and an Alkaline Pslug*

Amba Dongar carbonatite-alkaline complex is one of several alkaline complexes present within the Chhota Udaipur sub-province of the Deccan Flood Basalt Province, Western India. Results of the $^{40}Ar$-$^{39}Ar$ dating of the basalt exposed inside the ring dyke at Amba Dongar and phonolite from an alkaline plug located at Tawa at the northernmost edge of the sub-province give plateau ages of 68.5 ± 0.9 Ma and 65.2 ± 0.7 Ma, respectively. These results not only suggest that the basalts present inside the Amba Dongar complex predate the complex itself but also confirm the earlier view that all the alkaline activities in the Chhota Udaipur sub-province are contemporaneous. With these new geochronological inputs it is becoming perceptible that the alkaline activities in the entire sub-province (~1200 $km^2$) belonged to a single magmatic episode that postdated the main tholeiitic pulse of the Deccan CFB. In such a scenario this activity becomes very important in the debate on K/T extinctions because of their capacity to pump catastrophic amounts of $CO_2$ and $SO_2$ into the atmosphere. Also, any model for the generation of Deccan CFB (plume or non-plume) must now explain such a large

alkaline magmatism along the Narmada Fracture Zone, which has very different chemical and isotopic attributes compared to those for the tholeiites.

(K. Pande, S. Pattanayak and J. S. Ray)

### *Zircon Geochronology of Gneisses and Metasediments from the Dharwar Craton*

The Dharwar craton forms a major part of the southern Indian shield and comprises of two blocks, the western and the eastern, with the eastern margin of Chitradurga schist belt acting as a notional boundary between them. A variety of mafic and ultramafic rocks, many having affinities with komatiites, high-magnesian basalts and tholeiites, that are regarded as some of the early recognized greenstone rocks, are exposed in the Dharwar craton. Nuggihalli schist belt in the southern part of the craton is one such unit. We have determined $^{207}Pb/^{206}Pb$ ages of individual zircon grains from metasediments and tonalite-trondhjamitic and granitic gneisses from this schist belt. Zircons identified in a metasedimentary rock have ages up to ~ 3.2 Ga suggesting an upper limit age of 3.3 Ga for the onset of sedimentation in this region. The ages of the gneissic protoliths cluster around 3.1 Ga and they appear to be nearly contemporaneous with the metasedimentary protoliths. Overprint of a secondary event at ~ 2.8-2.9 Ga can also be inferred from the zircon data for both the gneissic samples and the metasediment. Our data and those reported previously are indicative of a span of crystallization ages for the gneissic protoliths spreading from 3.0 to 3.3 Ga suggesting multiple emplacement of the gneissic precursors and an episodic evolution of the Dharwar craton over an extended period during the early Achaean.

(M. P. Deomurari, J. N. Goswami and B. Maibam)

### *Re-Os age of Vindhyan Black Shale: Time of the Origin of Multicellular Organisms*

The time of the first appearance of multicellular organisms is a fundamental question relating to biological evolution on Earth. The oldest reliable date tracing multicellular organisms was 555 Ma until a few years ago. Based on molecular clocks, earlier studies had suggested a much longer period that extended to 1000 Ma or more. The latter was supported by the report of trace fossils in sedimentary rocks from the southern margin of Vindhyan Basin, Central India datable to 1100 Ma. In spite of its regional and global significance, precise ages for Vindhyan Super Group are but a few, mainly due to want of a suitable isotope system. We dated samples of Kaimur group from Vindhyan sediments by the $^{187}Re$-$^{187}Os$ method and our preliminary result yields an age of 1670 ± 60 Ma.

(S. K. Singh and J. R. Trivedi)

### *Relict Lake Deposits from Higher Central Himalaya*

The relict lake deposit at Garbyang in the Trans-Himalaya of Uttranchal, has preserved a rare combination of records of climate and seismicity. Magnetic susceptibility, geochemistry, luminescence and radiocarbon dating techniques along with conventional sedimentological parameters were used to deduce past climatic and seismic events. Our studies suggest that the Trans Himadri Fault (THF) controlled the extent of past glaciers and impounded rivers giving rise to lakes that have preserved near continuous record of regional events since past 60 ka. Present study involved the investigation of the upper lacustrine succession (29 m below the surface) that provides a sedimentary record dating from 20 ka to 10 ka.

In Central Himalaya north south extension that define the lithological and tectonic boundary between Higher Himalayan crystalline and the Tethyan sedimentaries is well defined. Termed, as the Trans-Himadri Fault (THF), it is equivalent of the South Tibetan Detachment System (STDS). It was believed that THF was dormant since its inception around 21 Ma and the seismicity progressively shifted southward towards the Main Boundary Thrust (MBT). Based on seismically deformed lacustrine sediments and the geomorphological features such as incised terraces, perched glacial valleys and lateral shifting of the snout position, it has been suggested that the THF was active during the Late Quaternary. Luminescence chronology provide broad time frame for the palaeoseismic events in the vicinity of THF

that occur during > 60 ka, 24 ka to 17 ka, 14 ka to 13 ka and < 11 ka. The study allows us to draw the following inferences :

1. A near continuous record of climate change since LGM to the beginning of Holocene is well preserved in the higher Central Himalaya. LGM is dated to 20±3 ka during which the deposition was dominated by varve sedimentation.
2. Between 20±3 ka to 13±2 ka geochemical and mineral magnetic data suggest prevalence of low magnitude, high frequency oscillations in the climate.
3. A significant lowering of temperature is seen during 12 ka to 11 ka, and has been attributed to the postglacial cooling corresponding to the Younger Dryas cooling. This is the first direct evidence from the higher Central Himalaya.
4. IRSL chronology demonstrated that the radiocarbon ages on organic carbon from predominantly limestone terrain suffers from hard water effect and is therefore overestimated the real age.
5. The study further shows that the Trans Himadri Fault (THF) was active episodically during the past 60 ka.

(**N. Juyal , A .K .Singhvi, M.G. Yadava**, R. K. Pant and N. Basavaiah )

## Oceanography

### *Satellite Oceanography and New Production*

As a part of the ongoing collaborative work between PRL and SAC aimed at studying tectonics and related offshore processes in The Bay of Bengal and the Arabian Sea, ERM and ERS-1 altimeter data were used to produce prospecting geoid and gravity anomaly maps and their spectral components. Satellite- derived gravity contour patterns match well with ship-borne observations. The continental margin, 85$^0$E and 90$^0$E ridges could be demarcated well along a latitudinal profile (**Fig. 8.3**). This work has been done in collaboration with T. J. Majumdar of SAC, Ahmedabad.

We have measured for the first time the $^{15}$N based 'New Production' in the Bay of Bengal in 9 stations (both coastal and open ocean) during Sepember-October 2002. Three types of $^{15}$N enriched (99 atom %) tracers were used: nitrate, ammonia and urea. The total production varied from 3 to 12 mmolN/m$^2$/day. Euphotic zone integrated nitrate-induced productivity ranged from 0.09 to 2.8 mmolN/m$^2$/day, while ammonium regeneration rates lie in the range 0.8 to 2.3 mmolN/m$^2$/day. Urea regeneration rates were the highest, from 1.4 to 8.7 mmolN/m$^2$/day. The ratio of new to total production is well correlated with the total production, implying that Bay of Bengal has a more significant role in the draw-down of anthropogenic $CO_2$ than was believed so far.

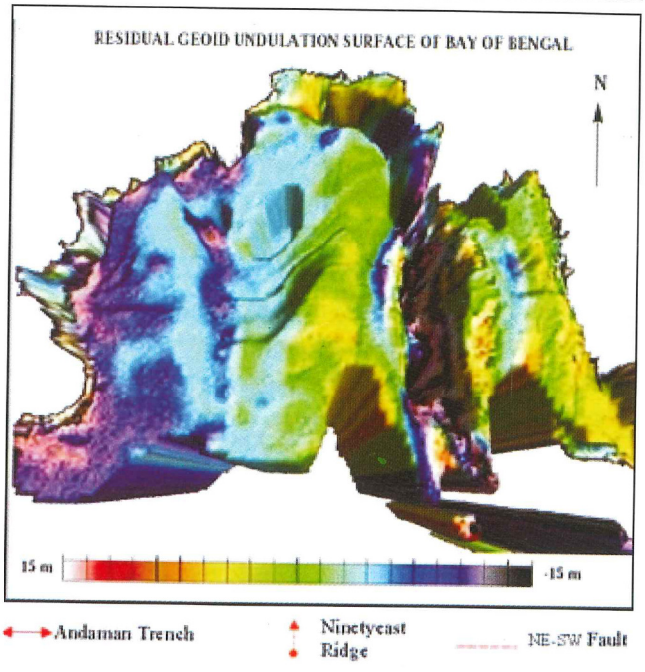



*Fig. 8.3 Residual geoid undulation surface of Bay of Bengal*

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

### *Quaternary Productivity Variations in the Equatorial Indian Ocean and Arabian Sea*

To study variations in past climate and environment, such as precipitation, surface productivity and subsurface denitrification, samples from two sediment cores, SS3827G (03$^0$42'N, 75$^0$54.5'E) and SK-145-9 (12.5$^0$N, 74.2$^0$E) from the equatorial Indian Ocean and southern Arabian Sea were analysed. $^{14}$C dates yield sedimentation rates of ~ 2-4 cm/ ka and 8-30 cm/ka re-

spectively for these cores. The cores were sampled at one cm interval corresponding to a few hundred years. Overall the $C_{org}$ and N contents vary from 0.1% to 1.25% and 0.05% to 0.09% respectively. C/N ratios range between 6.0 to 16, typical of marine organic matter. Productivity, based on $CaCO_3$, shows decrease from ~35ka BP to LGM (21 ka), however, between LGM and present it increases reaching maximum during ~2-5 ka BP. The data show common spikes, in productivity in these cores and also in others studied earlier. Select species of foraminifera *(G. ruber* and *G. sacculifer)* are separated for $\delta^{18}O$ and $\delta^{13}C$ measurements.

(R. Bhushan, R. Ramesh, B.L.K. Somayajulu and M. Tiwari)

### *Provenance and Depositional Characteristics of Sediments of the Bay of Bengal*

Two gravity cores, one from central Bay of Bengal (~13.36°N; 88.9°E) and other from the 90°E ridge (6.03°N; 89.94°E) were analyzed to determine the spatial and temporal variations in sediment supply from rivers and in biological productivity through time. These cores provide history for the past ~ 50 ka as determined by $^{14}C$. Several other gravity cores were also collected from the Bay of Bengal (including the Andaman Sea) to provide a good spatial coverage of this basin. Surface sections were analyzed for $CaCO_3$, organic carbon, major and trace elements and Sr and Nd isotopes. Major and trace elemental abundances, proxies of lithogenic component, decrease away from coast. Sr and Nd isotopic composition of surface sediments indicate that major source of sediments in Bay of Bengal is the Higher Himalaya with minor contributions from less radiogenic sources. The provenance of these are under investigation.

(R. Bhushan, S.K. Singh, B.L.K. Somayajulu and M. Tiwari)

### *Phosphorus Deposition in Arabian Sea Sediments through Time*

Phosphorus deposition through time was studied in the core 3268G5 from the oxygen minimum zone (OMZ) of the Arabian Sea (12.5° N; 74.2°E; water depth 600 m) for which organic carbon and nitrogen data are available. Towards this, phosphorus was measured spectrophotometrically in 72 sub-samples (resolution ~ 125 years). Age vs. phosphorus plot shows that the concentration of phosphorus steadily increased during the past ~10,000 years with concomitant increase in organic carbon, implying steady increase in primary productivity in the region. The data also show a steep hike in the concentration of organic carbon and phosphorus from around 6,000 to 4,000 yr BP. Spectral analysis of the data (SPECTRUM software) shows significant periodicity at ~ 500 years. The cause for the high deposition ~ 5000 yr BP and periodicity ~ 500 yr is under investigation.

(S. Eswaramoorthi, S. Krishnaswami and M.M. Sarin)

## Aqueous Geochemistry

### *Tectono-Hydrothermal Model of Cambay Basin Explaining Groundwater Helium and Temperature Anomalies*

Geographical distribution of natural helium and temperature of groundwater from Cambay region of Gujarat, India was investigated. Areas of anomalous helium concentration (> 5.3ppm AEU) are in general associated with higher than average (~ 30°C) groundwater temprature. Origin of groundwater helium and temprature anomalies was explained by a conceptual Tectono-hydrothermal Model of Cambay basin **(Fig.8.4)**.

In this model, helium is released at the micro-scale from the rocks and grains by diffusion, $\alpha$ - recoil and weathering processes that include etching, dissolution and fracturing. The released helium migrates upwards due to concentration gradient (with lowest concentration in the atmosphere) by diffusion and temperature variations facilitated by micro and macro-cracks, pores, fractures and fissures that act as collectors and conduits of helium from the underlying formations. The upward migration of helium can be further facilitated by mass flow of crustal fluids (e.g. groundwater and petroleum), which may also be present in the conduits.

On a regional scale, therefore, higher concentration of helium in soil-gas and groundwater are expected over regions where such preferred pathways lie close to the

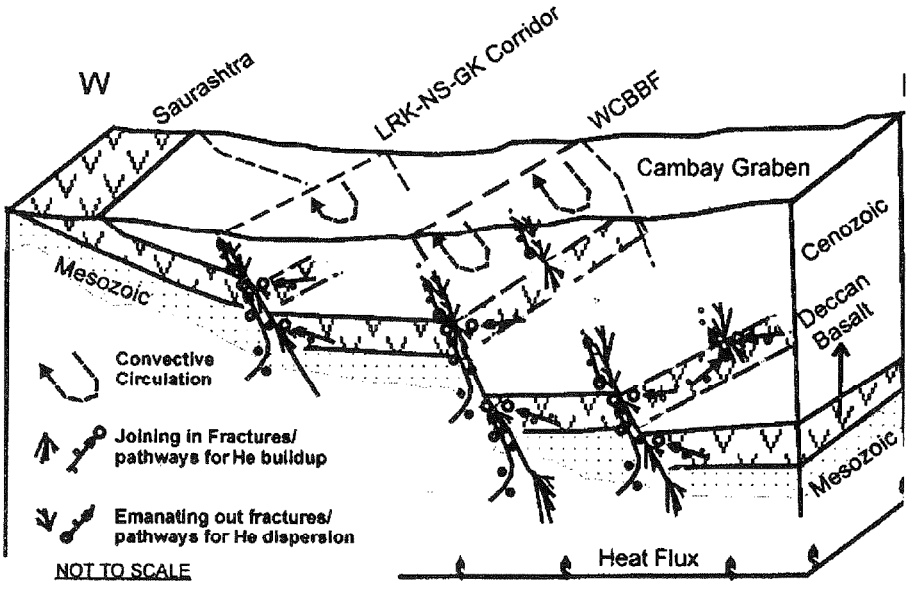



*Fig. 8.4 A conceptual tectono-hydrothermal model for the origin of groundwater helium and temperature anomalies in the Cambay basin, Gujarat, India is depicted schematically in an E-W block diagram across the Cambay Graben. The size of open circles schematically depicts the changing helium concentration during upward migration. The continuous arrows depict the preferred migration pathway of radiogenic helium derived from a large area. The broken arrows depict the shallow depth (~1-2 km) hydrothermal circulation facilitated by high heat flux.*

surface. Inherent differences in the migratory pathways between the crystalline and sedimentary formations however, modulate the near surface helium distribution.

The deep seated faults and fractures also facilitate percolation of groundwater to deeper layers which, in a high heat flow regime such as the Cambay basin, establishes a convective circulation with thermal waters of meteoric origin, which may emerge as thermal springs or vents into shallower aquifers. This explains the association of helium anomalies with temperature anomalies.

(R.D. Deshpande and S.K. Gupta)

### *Origin of High Fluoride in Groundwater of North Gujarat-Cambay Region, India*

North Gujarat - Cambay (NGC) region is one of the worst endemic fluorosis affected areas of India. With a view to understand the factors controlling origin of high fluoride concentration in groundwater of this region, 225 groundwater samples from different depth zones tapping shallow dug wells, geothermal springs, hand-pumps and tubewells including free flowing artesian wells were analysed for their fluoride content and other water quality parameters. Radiocarbon age determination of groundwater samples from selected location was also done. Spatial distribution of fluoride concentration in groundwater is shown in **Fig. 8.5** The groundwater with high fluoride concentration is seen distributed in four linear belts. These four belts of high ionic concentration can also be identified in the distribution of electrical conductivity (EC) of groundwater.

(M. Agarwal, R.D. Deshpande, S.K. Gupta, V. Somayajulu and M. G. Yadava)

### *Potamic Studies*

Chemical and isotopic studies in rivers were continued to determine the factors contributing to their composition, such as drainage lithology, climate, relief etc. Towards this, three river systems were investigated, the Brahmaputra in the Himalaya, the Chambal in the Vindhyan and the rivers of the Deccan Traps. Among these, the Chambal derives major part of its cations from

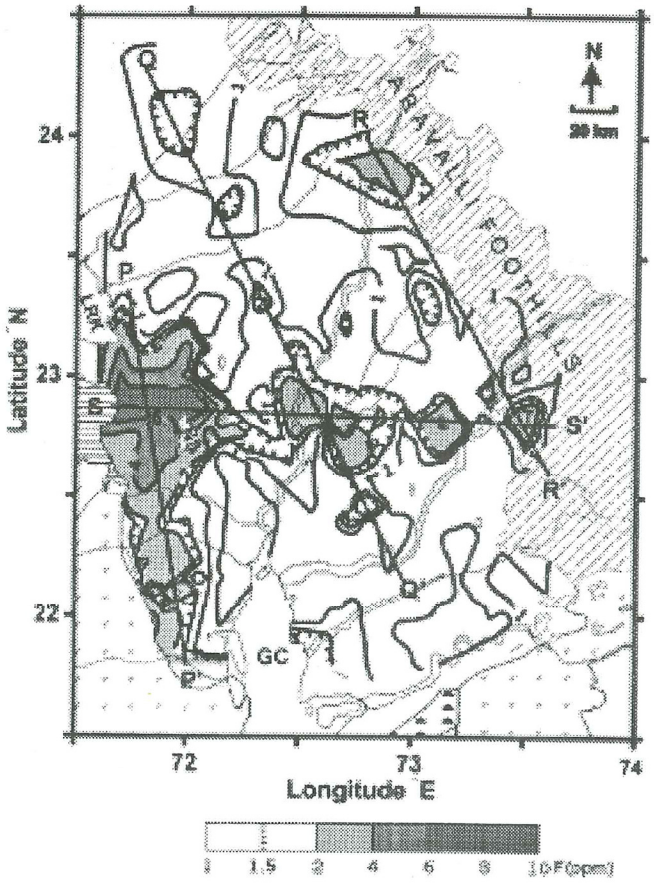



***Fig. 8.5*** *Contour plot of fluoride concentration in groundwater from NGC region. Patches of high fluoride concentration (>1.5ppm) appear aligned along four linear belts (PP', QQ', RR', SS') separated by low fluoride areas.*

carbonate weathering and evaporite/saline salts. In contrast, the rivers from the Deccan Traps and the Brahmaputra, silicate weathering is the dominant component of major ions. The chemical weathering rate in the Deccan, after correcting for marine and evaporite components, average about 30 t $km^{-2}$ $y^{-1}$, whereas in the Brahmaputra at Dhubri it is 120 t $km^{-2}$ $y^{-1}$.

Sr abundances in the Brahmaputra waters range from 250-1034 nM. $^{87}Sr/^{86}Sr$ of the Brahmaputra main channel varies from 0.7151 to 0.7300. The Northern tributaries which drain different Himalayan formations have quite variable $^{87}Sr/^{86}Sr$ (0.7157 - 0.7597) resulting from exposures of Lesser and Higher Himalaya having very radiogenic Sr. Eastern tributaries are less radiogenic Sr (0.7149-0.7160) due to weathering of mafic-ultramafic rocks of the Mishmi Hills.

Sr concentrations in the Deccan rivers vary from 130-1390 nM. Unlike the Himalayan rivers, $^{87}Sr/^{86}Sr$ ratios show a very narrow range, 0.70614-0.70986. The variations are consistent with the range of $^{87}Sr/^{86}Sr$ in Deccan basalts (0.704-0.713). Sr shows a positive correlation with Ca, the Sr/Ca (nM/μM) in the water being 1.2. This is lower than in basalts, indicating a preferential release of Ca and/or additional sources for it, such as carbonates. Coulometric analyses of these basalts show presence of carbonates in many of them (0-1.6%). The $^{87}Sr/^{86}Sr$ and the Sr/Ca ratio in these rivers can result from mixing of three end members, rain, basalt and carbonate with basalts dominating the composition.

(**A. Das, S. Krishnaswami, R. Rengarajan, M. M. Sarin, S. K. Singh** and Anil Kumar)

## Atmospheric Studies

### *Mass-independent Oxygen Isotopic Fractionation during UV Photo-dissociation of Ozone*

Stratospheric ozone is essentially in a steady state due to simultaneous formation and dissociation and found to be enriched (mass-independently) in heavy oxygen isotopes. Though there have been a number of experimental and theoretical studies on the mechanism(s) associated with the formation of isotopically heavy ozone, the decomposition processes were not studied in necessary detail. Here we report a novel feature in the isotopic fractionation of ozone during photo-dissociation in the UV and visible wavelengths. Photo-dissociation of ozone produces isotopically light oxygen, enriching the left-over ozone pool. Interestingly, dissociation at visible wavelengths displays a mass-dependent slope ($\Delta\delta^{17}O/\Delta\delta^{18}O = 0.54$) whereas UV dissociation shows a mass independent character ($\Delta\delta^{17}O/\Delta\delta^{18}O = 0.63$) as shown in **Fig. 8.6**. $O_3$ photo-dissociation in UV wavelengths is normally associated with another effective channel of dissociation, i.e., $O_2 + O(^1D)$. It is experimentally demonstrated for the first time that pure UV photo-dissociation of ozone (i.e. without the

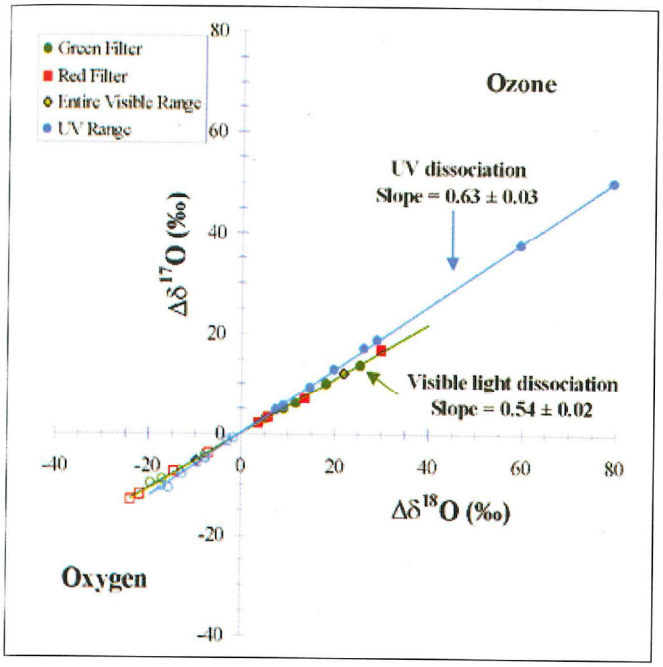



*Fig. 8.6 : Covariation plot between $\Delta\delta^{17}O$ and $\Delta\delta^{18}O$ for the Photodissociation of ozone with UV and visible light.*

$O(^1D)$ channel) gives a slope of unity intriguingly similar to that obtained in the ozone formation process. A combination of the two processes i.e. mass dependent $O(^1D) + O_3$ reaction and pure UV photo-dissociation is responsible for the observed slope of 0.63

(S.K. Bhattacharya and S. Chakraborty)

### *Carbon Isotopic Composition ($\delta^{13}C$) of Methane from Atmospheric Air in Ahmedabad*

Air samples for determination of methane concentration and isotopic composition ($\delta^{13}C$) were collected once in a week at 2 p.m. during the period September and October in previously evacuated 10L Stainless Steel cylinders up to 2 bar level. Samples were taken on roof of the PRL main building. The range of methane concentration is 1611 to 1814 ppbv whereas the $\delta^{13}C$ values vary between - 46.62 to - 47.65 ‰. From the correlation of $\delta^{13}C$ and inverse concentration of methane, we estimated the isotopic composition of mean methane source at Ahmedabad to be - 52.5 ‰. Air samples were also collected during night-time on 4-5th December 2002 to find the diurnal variations of methane concentration and its isotopic composition. The methane concentration varies from 2176 to 2360 ppbv during the night time between 11 p.m. to 7 a.m. where as its $\delta^{13}C$ value vary in a narrow range of - 47.96 to - 48.45 ‰. Using this data and background value of methane concentration (1768 ppbv) and $\delta^{13}C$ value (- 47.24‰), the mean isotopic composition of the local methane source is calculated to be - 51.67 ‰. These values may be close to the isotopic composition of methane from gas leaks from natural oil wells existing around Ahmedabad.

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

### *Mineral Dust and Anthropogenic Trace Element Inputs to the Tropical Bay of Bengal*

A detailed study was conducted in the marine boundary layer (MBL) of the Bay of Bengal to assess the concentrations of trace elements in aerosols transported from south and south east Asia to the Bay of Bengal during late NE monsoon.

The Fe and Al concentrations exhibit large spatial variations (between 20°N 88°E to 2°N 80°E) during the 20 day sampling period (February-March); Fe: 40-807 and Al: 40-605 ng $m^{-3}$ respectively with Fe/Al mass ratio of 1.0±0.1 **(Fig. 8.7)**. In the northern Bay, dust concentrations were a factor of ~ 2 higher than those at other

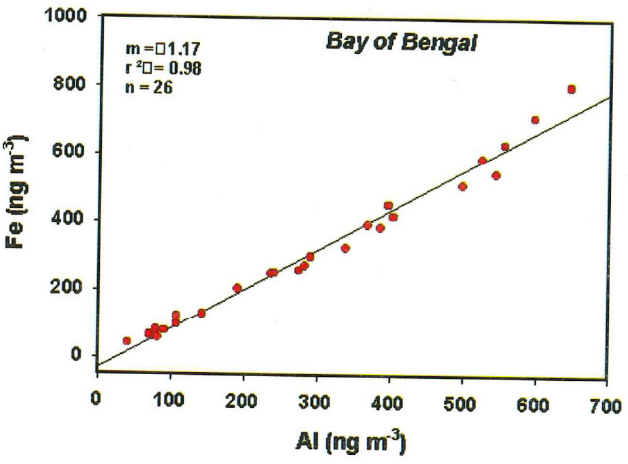



***Fig. 8.7 :*** *Correlation between Fe and Al in aerosols over Bay of Bengal*

sites. The impact of anthropogenic sources on trace element abundances was evident from the high concentrations of Pb, Zn, Mn and Cu varying as 3.7 - 17, 2.1 - 21, 0.8 - 7.2 and 0.06 - 2.5 ng $m^{-3}$, respectively. The analyses of trace element ratios, with the exception of Mn, reveal large spatial variations; attributable to differences in the transport and biogeochemical changes occurring within the boundary layer. The aerosol $^{7}Be/^{210}Pb$ ratios over the Bay of Bengal ranged from 2.4 to 5.0; with consistently higher ratio (4.2 to 5.0) in the southern bay, suggesting the intrusion of upper tropospheric air mass.

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

## Accretion Rates of $^{3}He$ and iridium on the Earth: New Insights on their Delivery on the Earth

The isotope, $^{3}He$ and noble elements belonging to the platinum group have been extensively studied in diverse samples on the Earth, since although the mass flux of extra-terrestrial matter on the Earth is small, ~ 3-5 x $10^{-16}$ g/($cm^2$.y), their terrestrial abundances are very low. Consequently their presence in a terrestrial sample can be used to obtain estimates of the rates of influx of extra-terrestrial matter.

In the past decade, scientists of the Cal-Tech and Woods Hole Oceanographic Institution have made extensive measurements on the concentrations of $^{3}He$ in marine sediments. It had so far been assumed that the $^{3}He$ in sediments derived primarily from small interplanetary dust particles (IDPs) of size < 50 microns size, which are not heated much during their entry through the atmosphere, and that therefore their $^{3}He$ is not lost due to diffusion from the grains. Basing on this model, there will be no difficulty in explaining the observed $^{3}He$ concentrations of sediments. However, this model has certain serious problems. The IDPs are known to be fluffy and amorphous (as a result of radiation damage due to implantation of solar wind and solar flare ions). Consequently, the $^{3}He$ carried by the IDPs may in fact be quickly lost in sediments by chemical action of seawater.

An alternate model seems to satisfactorily explain the observed $^{3}He$ concentration of sediments. In their passage through the atmosphere, meteoritic bodies undergo appreciable mass-wastage due to ablation and fragmentation. Recently, Lal and Jull (2002) considered in some detail the effect of this process in altering the population of small size particles, which are produced from fragmentation of meteoroids impacting the Earth. They showed that this leads to an appreciably larger flux of: (i) a new population of secondary fragments in the size range, $10^{-4}$ to 10 cm, produced in the fragmentation of meteoroids of size ~ few hundred cm, and (ii) vaporized mass flux, both of which exceed the near Earth mass influx due to meteoroids of mass, m, $10^{-11} < m < 10^{7}$ g (corresponding radius, r, $10^{-4} < r < 10^{2}$ cm). Production of small size fragments in the ablation process is of great importance because of two reasons: (i) these (small) fragments are efficiently sampled in marine sediments, and (ii) it provides a mechanism for "safe" landing of inner parts of the meteoroid (Lal and Jull, 2002), which are subsequently not subjected to much heating after the break-up of the meteoroid. Noble gases and organic matter would be expected to be well preserved in these fragments.

As a natural extension of the model of Lal and Jull (2002), these authors have now estimated the fluxes of several isotopes and platinum group elements on the Earth. They show that meteoritic ablation produces a significant "realizable" flux of $^{3}He$, platinum group metals, and cosmogenic $^{26}Al$. Realizable flux is defined as the surviving mass fraction of size << 1cm, which gets mixed with terrestrial samples, and is included in normal terrestrial assays of sediments. Larger surviving meteoroid fragments, of the order of cm to m or larger, obviously belong to the non-realizable flux category, since they are not considered in the chemical analysis of sediments. In fact their measurements in ocean sediments should allow a reasonable estimate of temporal variations in the flux of meteoroids of 50 cm to 5 m radii, which produce most of the secondary fragments in the size range < 1cm.

(D. Lal)

## Lunar Science and Exploration

Some scientific problems related to origin and early chemical evolution of the Moon have been identified and feasibility of studying them by remote sensing techniques using suitable sensors on board a lunar orbiter have been investigated. This study shows that a chemical, mineralogical and topographic mapping of the lunar surface offers an ideal choice for future lunar missions. This study forms a part of the proposal of a mission to Moon prepared by ISRO. Some stages of an animation showing the journey of a lunar craft from Earth to Moon using PSLV and various proposed payloads have been prepared.

A laboratory has been set up at the Thaltej campus for determining response functions of various detectors proposed for the Moon mission. This facility also includes preparation of thin and polished section of rocks and microscopic and petrographic studies. Thin sections of some meteorites e.g. Piplia Kalan (Eucrite), Dhajala (H3.8), Itawa Bhopji (LL) etc. have been prepared. Some polished samples of lunar analogues were also prepared followed by measurement of their reflectance spectra by a spectrometer available at Space Application Centre. The purpose is to make a Spectral Library of minerals which would help in developing suitable algorithms for analyzing lunar spectra.

Fluxes of X-rays and low energy gamma rays due to some natural radionuclides in the energy range 10-200 keV, expected from the lunar surface were calculated using laboratory spectra of U and Th standards. Lead-210 which deposits on the lunar surface in form of a thin paint, following decay of radon emanating from the lunar interior due to thermal diffusion, provides a natural tracer for understanding the transport of volatiles on the Moon. Some Rare Earth Elements having high neutron capture cross sections also emit measurable flux in this energy region. Possibility of measuring these radiations with pixelated detectors on lunar orbiters have been studied and appears encouraging. Some work has been initiated for development of X-ray detectors and associated electronics for signal processing. A microcontroller based random pulse generator has been developed for testing and calibrating X-ray imaging detectors like cadmium zinc telluride (CZT).It generates pseudo-random height pulses from 0-5 volts having programmable energy and time profile through PC serial interface.

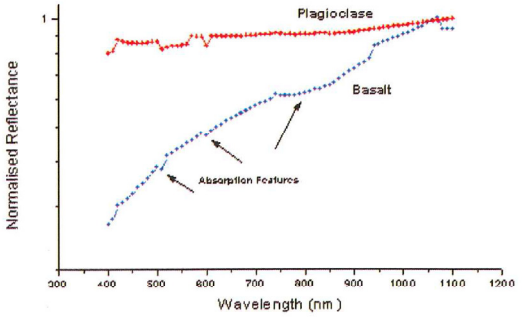



*Fig. : The two major rocks types on Moon are Anorthosite (dominantly Plagioclase) and Basalt. Reflectance Spectra of these Lunar Analogues with prominent absorption features taken with Reflectance Spectrometer at Space Application Centre are shown.*

## Study of Asteroids

Study of reflectance spectra of two asteroids namely Vesta and Fortuna were made using the Gurushikhar infra-red observatory in J, H and K bands with the aim of comparing them with the spectra of some known class of meteorites. There is a distinct difference in the spectra of these asteroids, indicating their different composition.

This work was done in collaboration with Dr T.Chandrashekhar and N.M.Ashok as a part of UN students project.

(D. Banerjee, N.Bhandari, D. Dhingra, H.S. Mazumdar, A. Singh, M.Shanmugham, N. Srivastava and M.Tomar)

## Image Processing with Neural Network

A simulation with 2D graphics of accelerating body under the influence of Earth and Moon has been developed to demonstrate different strategies to go to moon's orbit.

A feedback type partially connected neural network configuration and associated training algorithm has been developed to store and recall associative gray images since the currently used Hopfield's model works only with binary images. Number of connections required in this configuration is K*N instead of $N^2$ as required in Hopfield's model.

(H.S.Mazumdar)

# 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. Centre also has high-end graphics station, IBM RS-6000 Model 270 with 4 processors. These machines are in addition to existing five IBM RS-6000/580 machines and all are connected to our high speed local area network (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 Abu are connected to the PRL LAN on a 64 Kbps BSNL leased line. To cater for the needs of scientists, online electronic journals etc., Internet bandwidth has been appropriately upgraded this year. Thus full connectivity has been provided to users all the time from anywhere in the Main campus, Thaltej, USO and Abu. The Centre provides centralized virus free E-mails by automatically scanning all E-mails. Internet authorisations, monitoring and reporting functions have been added to have optimal usage of Internet bandwidth.

Mathematical, numerical and visualization application software like IMSL, IDL, Mathematica, Data Explorer etc. have also been installed on the new computers to provide smooth transition and cater to the needs of the scientific community. 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 LAN.

## Library and Information Services

Libraries are the Store House of Knowledge and serves as a centre of Knowledge Management and Information. It is an essential and vital part of any research instittution. PRL has always maintained an up to date Library to cater to the changes in the research activities of the Laboratory.

PRL library has an extensive and valuable collection of Publications in the fields of Astronomy and Astrophyscis ; Space and Geosciences ; Theoretical Physics including Nuclear, Plasma, High Energy, Atomic and Molecular Physics. It has added 230 books (English) and 220 books (Hindi) to its collection. It has fulfilled 268 ILL requests from other libraries and received 165 documents on ILL from other libraries. The library procured 15 articles from STN, which is a paid Document Delivery Service. In December 2002, the library software - Libsys was upgraded to release 4.1and shifted to LINUX platform. One of the salient features of this version is the availability of web OPAC.

One more digital resource has been added to the library resources. PRL library has become a part of Indian Astrophysics Consortium and as a part of this we can access 23 Kluwer Journals even though we subscribe to only four of them. ScienceDirect has been subscribed this year too. This allows access to 1100 Elsevier Journals. Out of 165 journal subscription, 76 are available online.

Another important activity in which the PRL Library is actively associated is training of students of Library Sciences in Graduate and Post Graduate Studies. Last year PRL trained 3 Post Graduate Students in all aspects of Library Management including circulation, inter-library loan, books and journal acquisition and accession etc.

## Engineering Services

Engineering Services renders all the technical services pertaining to the Civil, Electrical and Air-conditioning works. It also looks after the upkeep and the efficient functioning of the internal telephone system, elevators, and maintenance of all the official buildings, offices, and residential buildings in the various campuses. These jobs include architectural planning, designing, estimating and execution of the various civil works landscaping, horticultural development, interiors & furnishings of the buildings & structures of all the six campuses situated at Ahmedabad, Mt. Abu & Udaipur.

The site preparation works during the year under report were executed for the installation of sophisticated research equipment, duly complying with all the special

requirements. The major works undertaken during the year have been :

1. Renovation of Room No.570 for the SPA-AM Laboratory.
2. Designing & execution of the work for Planex Laboratory including the air-conditioning plant at Thaltej Campus.
3. Erection of a new cooling tower for the Central Plant for the main building.
4. Construction of Guesthouse Annexe & Eight C Type quarters at Mt. Abu.
5. Renovation of 6 units of PDF blocks - C.
6. Designing & Construction of a New Car Shed at Vikramnagar Staff Quarters campus
7. Replacement of old Air-conditioners, about 80, by new ones equipped with power saver compressors.
8. The DG Set room at Udaipur nearing completion.

## Workshop

With the existing modern facilities like CNC lathe, General purpose machine shop, Design & drawing section, sheet metal and welding shop, the PRL workshop gives valuable support to the experimental groups of various divisions by providing designs and fabricating sophisticated systems. Some of the major works carried out during the year are listed below.

### *Fabrication of 400 MHz Quad Helix Antenna*

A prototype Quad Helix Antenna was designed and fabricated. This involves the pivot mounted rigid structure of 5 feet height with azimuthal and rotational movements of Antenna. Four helix were fitted on a PVC pipe with insulators and mounted on a base plate. This Antenna is used in the receiver system of the Coherent Radio Beacon Experiment (CRABEX). This satellite (GSAT-2) experiment will be used for Tomographic studies in low latitude Ionosphere.

### *SOXS Payload for GSAT-2*

Designed and developed the mechanical packages (GXLD-10 and GXFE-10) of the SOXS payload. Conceptual model and proto-model were fabricated at PRL. Various mounts, fixtures, adapters were also fabricated for testing and calibration of the payload. Workshop personals assisted in the assembly and testing of the flight model at SAC, Ahmedabad. These two packages were integrated with the spacecraft of GSLV-D2 satellite and flown successfully on 8th May 2003.

### *LIDAR Facility at Mt. Abu*

Designed and fabricated structural assembly of 0.4m Telescope for the simultaneous study of Aerosol. Precision mount for the Beam Expander and Various precision housing for the optical components and detectors were also made.

### *Mesospheric Scanning Photometer*

Designed and fabricated the photometer consisting of mirror scanning arrangement with DC stepper motor drive, temperature controlled filter wheel assembly, PMT mounting and other optical components assembly.

### *Time of Flight Spectrometer Assembly*

Manufactured several precision components from SS-304 Material. All components were highly precise and polished. Different components like S. S.Flanges, Mesh-Holders, Polished Rods, Tubes and Channeltron End-Caps were fabricated for high vacuum systems. The components were assembled as per the design and mounted in the S.S. Chamber.

### *Construction and Installation of Lead Shield for Gamma Ray Spectrometer*

The Lead-Shield structure with door has been designed and fabricated. The size of the structure was 700mm (L), ( 675mm (W), ( 920mm (H). Structure has been made from M.S. square pipe (80mm) and M. S. sheet. The Lead-Shield Assembly consists of a set of Lead Bricks and a mechanism for the adjustment of the Detector (Germanium).

### *Precision Job's Done on C.N.C Machine*

Various jobs like pair of Mesh-Holder Flanges, Channeltron End Caps for Ions & Electron Time of Flight Spectrometer and also Beam Ioniser Parts have been manufactured from S.S-304 material for Space and Atmospheric Science division. Screws from EN-8 material for Infrared Astronomy Group (Mount Abu), large number of sample holders for collecting rock samples have been manufactured.

In addition to above, miscellaneous jobs of various kinds have been attended to cater the need of PRL administration.

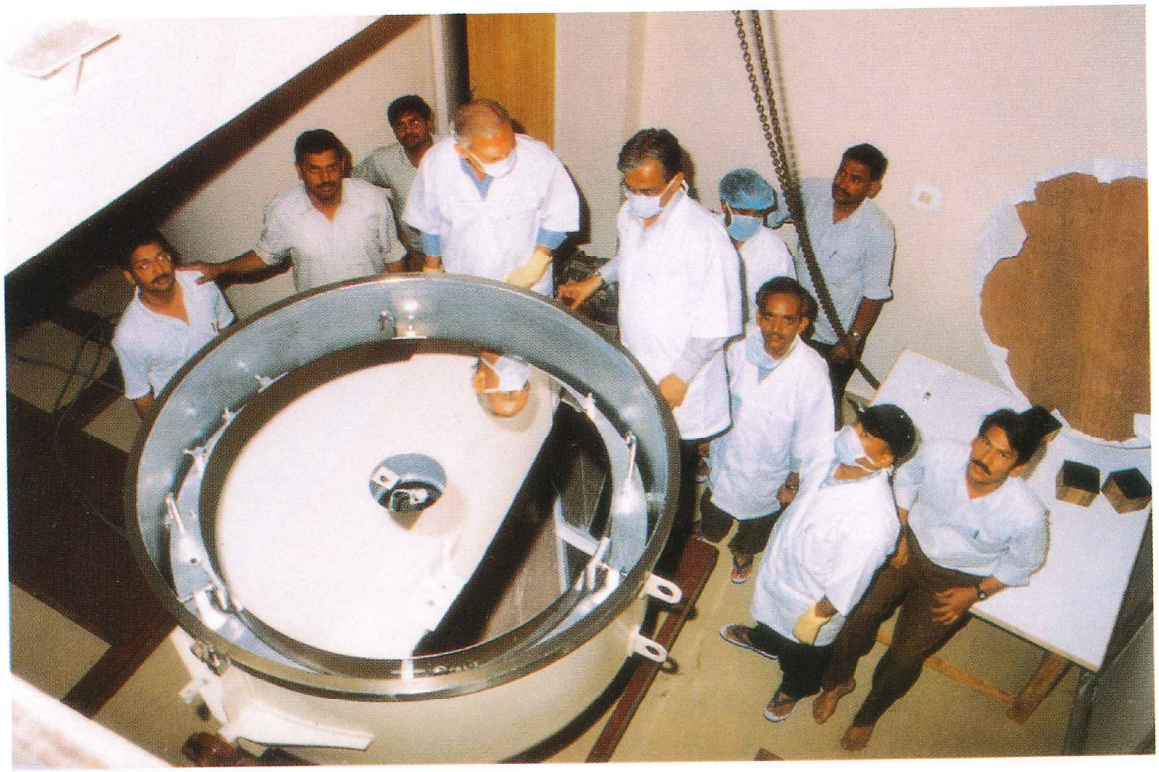
## Aluminizing and Indium Tin Oxide Coating Facility of Mt. Abu IR Observatory

After the installation of the facility during April 2002, a few initial problems like those related to uniform heating of all the aluminium (Al) vapour sources, calibration of the quartz crystal thickness monitor, and mechanical adjustment for fixing the primary mirror on the substrate holder were detected and solved. During October 2002, the 1.2 m primary mirror and the 0.3 m secondary mirror of the telescope were recoated with about 80 nm thick Al film. The fresh coatings looked blemish-free and apparently perfect.

The realuminization of the mirrors has greatly enhanced the "light gathering" efficiency of the telescope as evidenced by the astronomical observations in the last observing season. An increased overall sensitivity of about four times was recorded.

The facility has also been extensively and successfully used by PES/PEPF Group, VSSC, Thiruvananthapuram, for deposition of indium-tin-oxide (ITO) coatings on polyamide sheets for satellite applications.

Recently, the BARC's Mt. Abu based observatory has also started using this facility for aluminizing their 0.6 m telescope mirrors.



*The 1.2m primary mirror after the fresh Al coating at the Aluminising Facility, Gurushikhar Observatory, Mt Abu*

# Honorary Fellows

# Honorary Fellows

Professor J.E. Blamont

Acad. V.L. Ginzburg

Professor A.M.J. Tom Gehrels

Professor D. Lal

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<br>FNA, FASc, FNASc,FTWAS | Quantum Optics, Nonlinear Optics and Laser | Ph D Rochester Univ. (1969) |
| Prof. N. Bhandari<br>FNA, FASc, FNASc | Planetary Physics | Ph D TIFR Bombay Univ. (1967) |
| Prof. S. Krishnaswami<br>FNA, FASc, FNASc, FTWAS | 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<br>FNA, FASc, FNASc | Solar System Studies<br>(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<br>FASc | Particle Physics | Ph D Bombay Univ. (1979) |
| Prof. A. K. Singhvi<br>FNA, FASc, FNASc | Palaeoclimatology and Geochronology | Ph D IIT, Kanpur (1975) |
| Prof. S. K. Bhattacharya<br>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<br>FASc | Atmospheric Chemistry of Trace Gases | Ph D PRL, Gujarat Univ. (1982) |
| Prof. R. Ramesh<br>FNA, FASc, FNASc | Isotope Geochemistry | Ph D PRL, Gujarat Univ. (1984) |
| Prof. M. M. Sarin<br>FASc | Geochemistry and Oceanography | Ph D PRL, Gujarat Univ. (1985) |
| Prof. U. C. Joshi | Star Formation, AGNS and Comets | Ph D Kumaun Univ. (1981) |
| Prof. P. Venkatakrishnan | Solar Physics | Ph D, Bangalore Univ. (1984) |

| Name | Specialisation | Academic Qualification |
|---|---|---|
| Prof. R. E. Amritkar FASc | Nonlinear Dynamics & Chaos | Ph D IISc, Bangalore (1978) |
| Prof. Utpal G. Sarkar | Particle Physics | Ph.D Calcutta Univ. (1984) |
| Dr. Hemant H. Dave | Laser Spectroscopy and Space Instrumentation | Ph D, Univ. of Lowell, Mass., USA (1980) |
| Dr. S. K. Gupta FNASc | Geophysics, Hydrology | Ph D IIT, Bombay (1974) |
| Dr. H. S. S. Sinha | Upper Atmospheric and Ionospheric Studies | 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. K. S. Baliyan | Atomic Physics & Atomic Astrophysics | Ph D Roorkee Univ.(1986) |
| Dr. Kanchan Pande | Geology, Geochronology | Ph D PRL, Gujarat Univ. (1990) |
| Dr. P. N. Shukla | Geochemistry | Ph D IIT, Kanpur (1977) |
| Dr. P. Sharma | Geophysics and Hydrology | Ph D PRL, Gujarat Univ. (1977) |
| Dr. J. R. Trivedi | Geochronology | Ph D PRL, Gujarat Univ. (1991) |
| Dr. J. Banerji | Laser Physics | Ph D City Univ.(New York)(1982) |
| 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) |
| 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. Subhendra Mohanty | Astroparticle Physics | Ph D Wisconsin Univ. (1989) |

| Name | Specialisation | Academic Qualification |
|---|---|---|
| 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. P.K. Panigrahi | Field Theory | Ph D, Rochester Univ. (1988) |
| 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) |
| Dr. D. Banerjee | Thermoluminscence | Gujarat University (1996) |
| Dr. J. S. Ray | Isotope Geochemistry | MS University of Baroda (1997) |
| Dr. S. K. Singh | Isotope Geochemistry | MS University of Baroda (1999) |

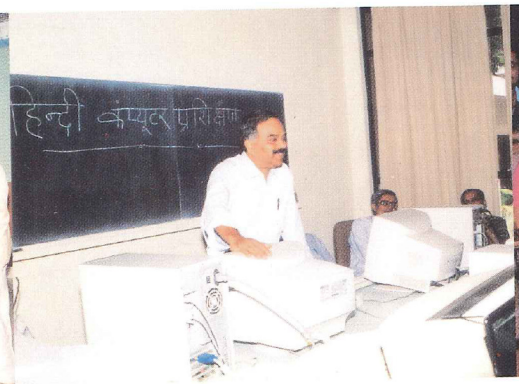
***Back Cover :***

*Neutrino physics is one of the core activities of PRL.*

***Inner Back Cover :***

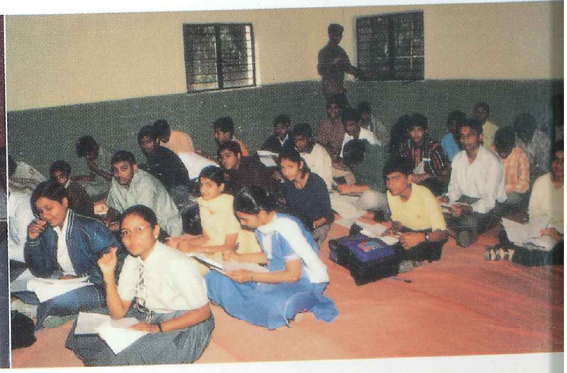
*Glimpses of a few events at PRL.*

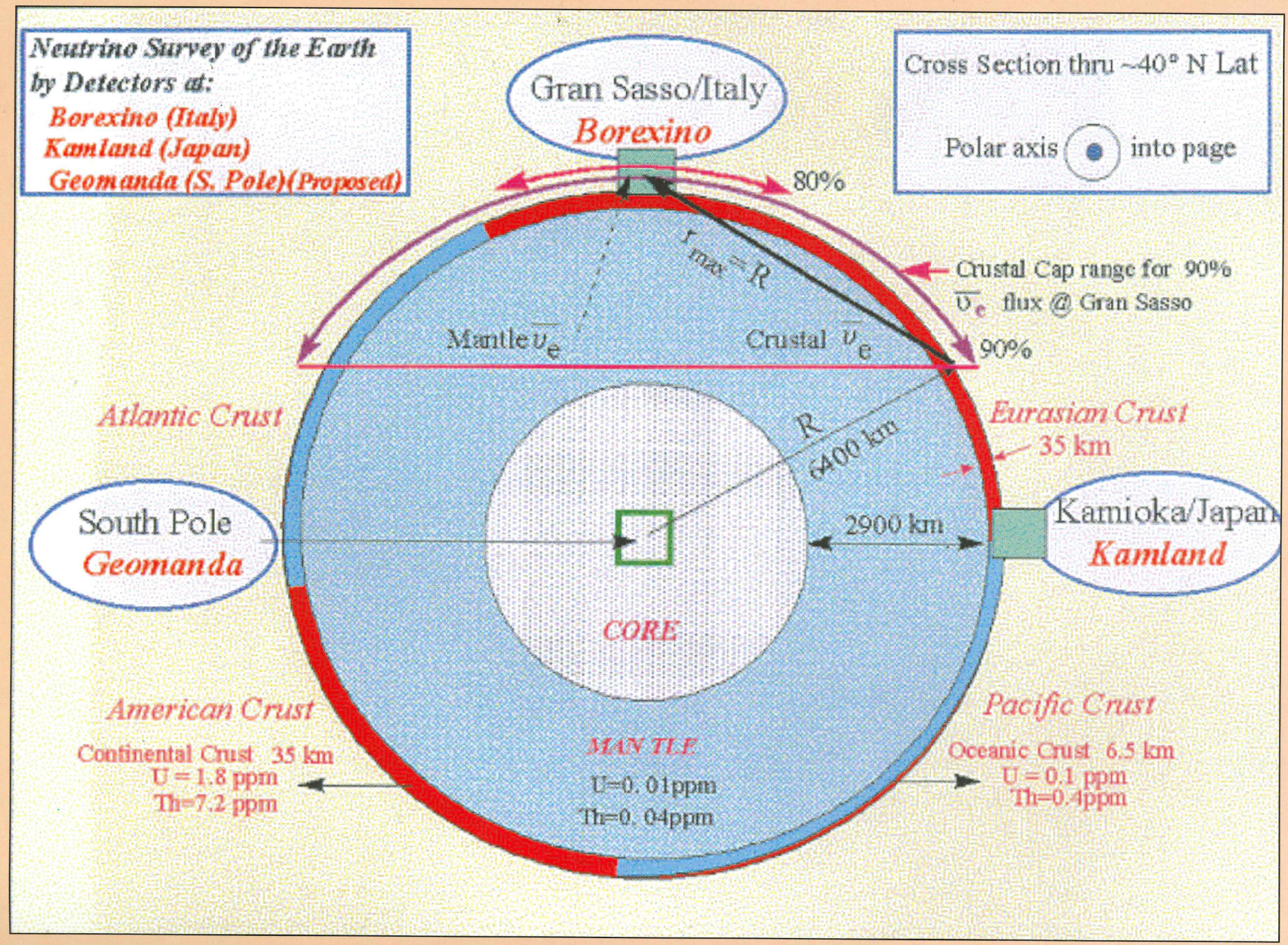

कागज विहीन कार्यालय
18 सितम्बर, 2002


हिन्दी कम्प्यूटर


चन्द्र मिशन-सोम यान
सेमिनार 13 मार्च, 2003
भौतिक अनुसंधान प्रयोगशाला, अहमदाबाद


हिन्दी




Neutrino Survey of the Earth by Detectors at:
Borexino (Italy)
Kamland (Japan)
Geomanda (S. Pole)(Proposed)
Gran Sasso/Italy
Borexino
Cross Section thru ~40° N Lat
Polar axis
into page
80%
$r_{max} = R$
Crustal Cap range for 90%
$\bar{\upsilon}_e$ flux @ Gran Sasso
90%
Mantle $\bar{\upsilon}_e$
Crustal $\bar{\upsilon}_e$
Atlantic Crust
Eurasian Crust
35 km
R
6400 km
South Pole
Geomanda
2900 km
Kamioka/Japan
Kamland
CORE
American Crust
Continental Crust 35 km
U = 1.8 ppm
Th=7.2 ppm
MANTLE
U=0. 01ppm
Th=0. 04ppm
Pacific Crust
Oceanic Crust 6.5 km
U = 0.1 ppm
Th=0.4ppm