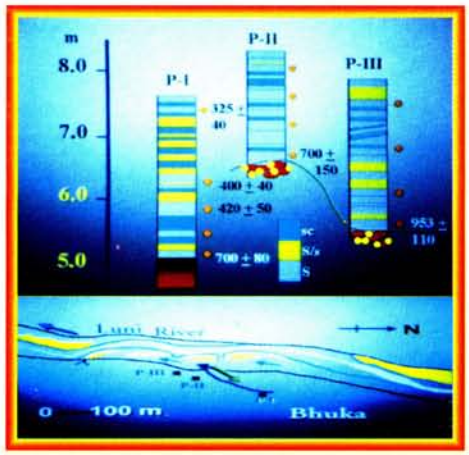

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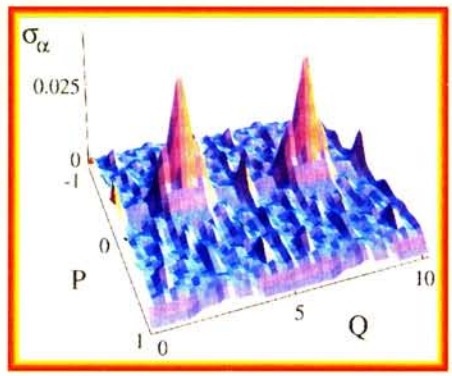
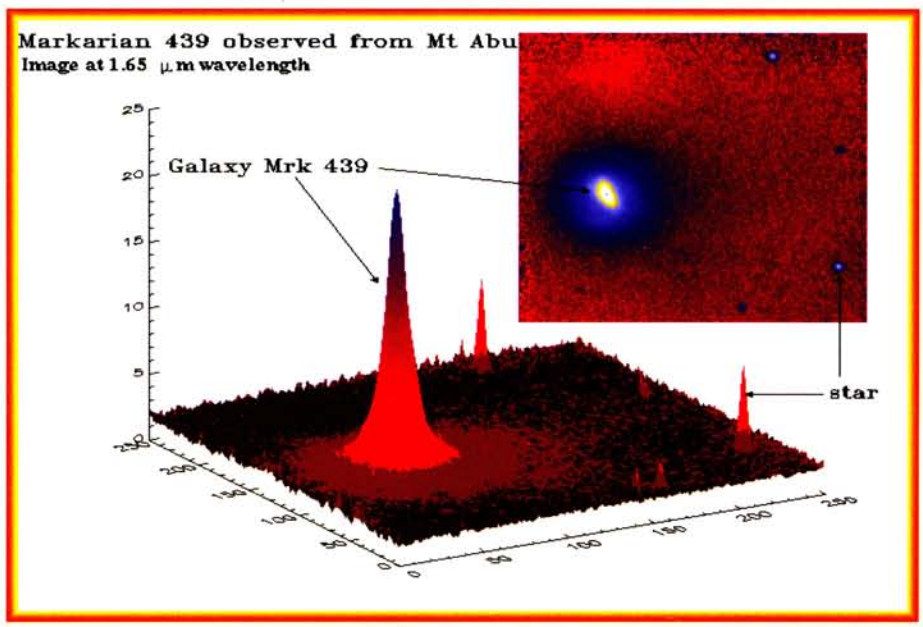
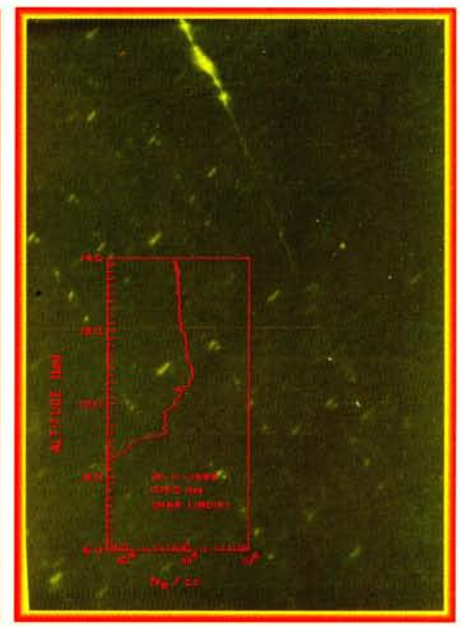
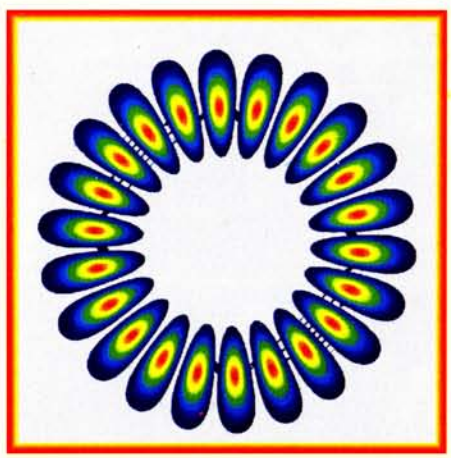
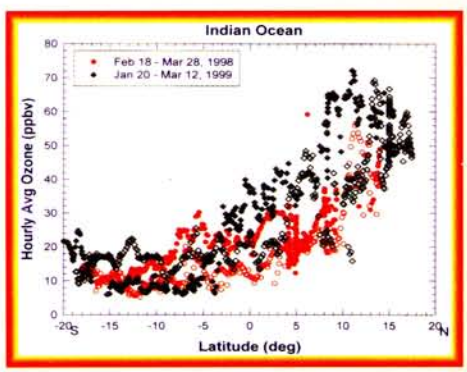


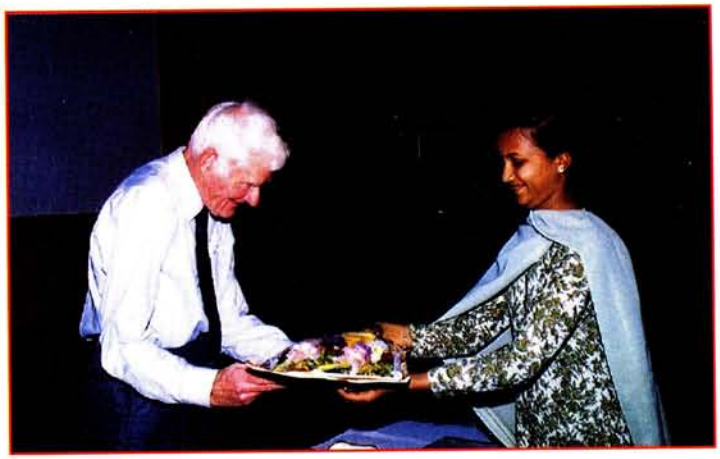


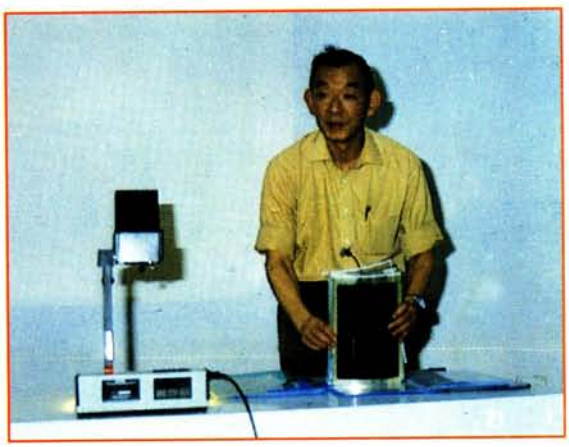






वार्षिक रिपोर्ट
Annual Report
1999-2000





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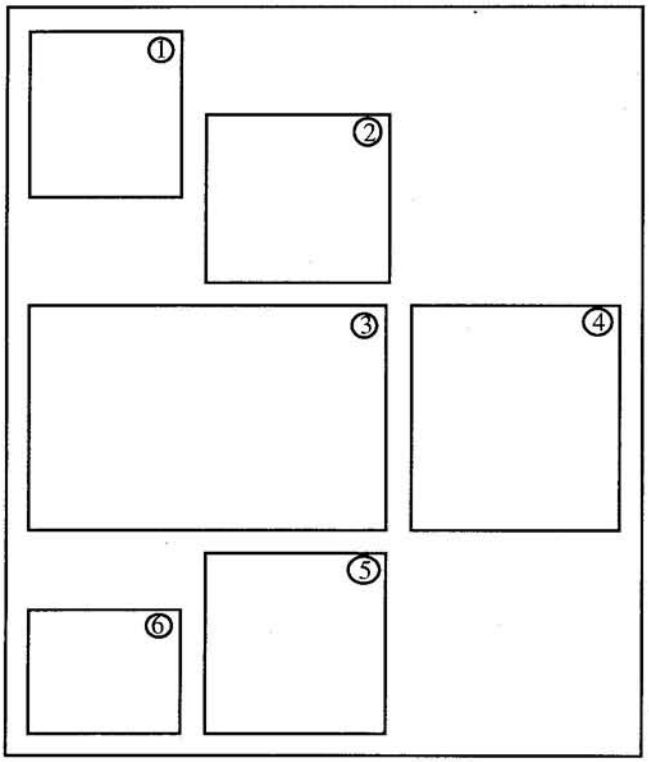
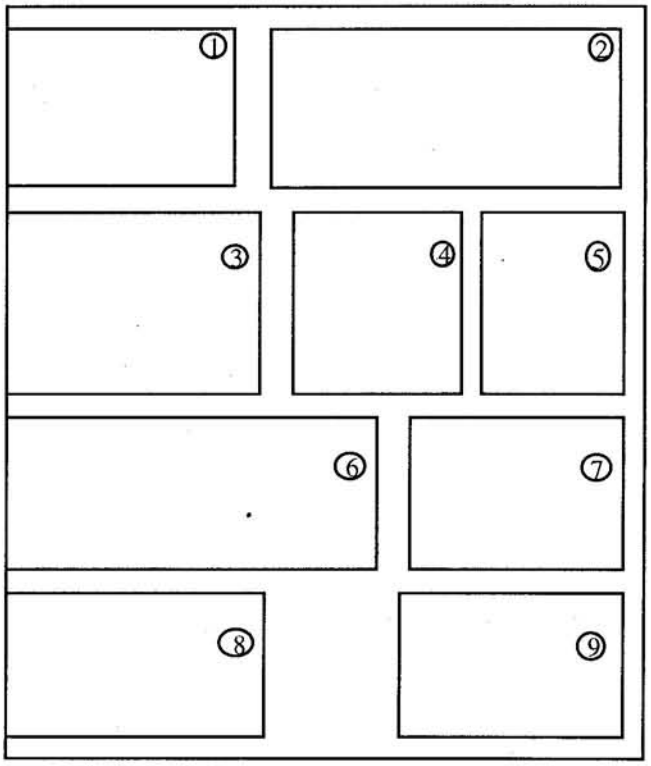
Annual Report 1999-2000



Title Cover :

1. *Stratigraphy and luminescence ages of slack water deposits of R. Luni. In conjunction with channel geometry these enabled reconstruction of major flood events in this river during the past 1000 years.*
2. *Quantum correlation showing strong localisation due to classical orbits in a chaotic billiard.*
3. *Surface brightness distribution of the galaxy MrK439 in H band from Mt. Abu.*
4. *Electron density measurements during the Leonid meteor shower from rocket-borne Langmuir Probe. Also shown are the trails of Leonid meteor shower from Mt. Abu.*
5. *Quadrature distribution of a SU(2) coherent state.*
6. *Latitudinal distribution of hourly average Ozone over the Indian Ocean during INDOEX field experiments*



Inner Title Cover :

1. *Dr. A. P. J. Abdul Kalam and Dr. R. Chidambaram - recipients of the Senior Scientist Award.*
2. *Prof. Henry Rishbeth being welcomed before his Public Lecture.*
3. *H. E. Mr. Claude Blanchemaison, the Ambassador of France visiting the Ion Probe Laboratory.*
4. *Dr. R. Cowsik delivering the K. R. Ramanathan Memorial Lecture.*
5. *Dr. S. Chandrasekhar delivering the K. R. Ramanathan Memorial Lecture.*
6. *Prof. Jean - Patrick Connerade with Prof. G. S. Agarwal.*
7. *Prof. Kosugi delivering a lecture at the Udaipur Solar Observatory.*
8. *Prof. J. N. Goswami with Prof. G. Mehta, President, Indian National Science Academy.*
9. *Dr. Tarun Kumar receiving the Best Thesis Prize from Prof. G. S. Agarwal.*

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Contents

Introduction

During the year 1999-2000, the laboratory continued to make important scientific contributions in different sub-disciplines of basic and space sciences. A summary of scientific achievements is given on page 5.

Studies on issues of a fundamental nature are being conducted on problems such as, the propagation of gravitational waves in a dispersive medium, effects of curvature and torsion on electromagnetic signals from the cosmos, neutrino oscillations, black hole evaporation induced baryogenesis, schemes for slowing down decoherence due to environmental perturbation, tunnelling of ultra cold atoms, and quantum measurements with single atoms. The emergence of complex behaviour from simple deterministic physical laws forms the study of chaos and quantum effects of classical chaos, as well as, on a more practical side, the encoding of signals on chaotic carriers are being investigated.

The laboratory continued with the various collaborations in national and international programmes involving many institutions. As a part of a multi-institutional endeavour to identify the effects on the equatorial ionosphere due to enhanced Leonid Meteor Shower activity, rocket - borne and ground based experiments were conducted from SHAR during November, 1999.

A new Indo-French Project on Infrared Astronomy has been initiated from October, 1999. This project, governed by Indo-French Centre for Promotion of Advanced Research, New Delhi, is a collaborative project among Institute of Astrophysics and PRL, Tata Institute of Fundamental Research and Indian Institute of Astrophysics. The project aims at the study of the stellar population in the central regions of our Galaxy. High resolution observations obtained from ISO (7 and 15 microns) and Denis survey data in near IR-JHK bands are to be used to gain deeper understanding of the Milky way. Our participation in the Indian Ocean Experiment (INDOEX) has continued. A comparison of four year ship cruise data from 1996-99, show a biennial type oscillation in the observed aerosol concentration over the Arabian Sea with low values in 1996 and 1998 and high values in 1997 and 1999, the highest being observed during the 1999 spring. Our collaboration with the Global Oscillations Network Group (GONG) is continuing. Our own scientists used the GONG data to detect a spin-up of the Sun by about 0.6% over the period 1995 to 1999.

The developmental activities of the Accelerator Mass-spectrometry in Bhubaneshwar in cooperation with the Institute of Physics, Bhubaneshwar are in progress. A multi institutional, DST funded programme on the origin and evolution of Thar was co-ordinated by the PRL scientists and successfully concluded in 1999. This programme provided a detailed chronological and chemical characterization of Thar desert, its response to various climatic epoch and connection to the reconstruction of past monsoon epochs including, human impact on dune mobility rates, records of major floods in Luni during the past 1000 years. PRL scientists are currently involved in coordinating a major international initiative on understanding the climatic records from the drylands and deserts and presently are working on samples from the Arabian, Chinese and the Sahara Desert. The laboratory's involvement in the national programme on Land Ocean Interaction in the Coastal Zone (LOICZ) is being continued in order to document the fluxes of inorganic and organic carbon into the coastal ocean through the Godavari river system. In another multi-institutional programme, the Indian Solar Terrestrial Energy Programme, a coordinated equatorial Spread-F campaign conducted under I-step programme revealed significant dispersive nature of irregularities in the scale sizes 3-8m indicating different physical processes are operational in those wavelength regime. Our scientists have also initiated a research project with the Gujarat State Government to tackle the problem of the declining water table. The project aims at estimation of natural and artificial groundwater recharge using environmental, chemical and isotopic tracers and development of mathematical models of regional aquifer systems in North Gujarat. PRL also has collaboration with the Geological Survey of India for the study of meteorites. Three fresh meteorites which fell in India have been studied under this programme.

The scientific findings were presented in a large number of first rate publications. The laboratory is also involved in the creation of new facilities and the development of new programs such as sub-mm wave astronomy. A total of **one hundred and fifty eight** papers have been published. Our scientists convened a number of symposia/workshops, one of which was held during the International Congress of the International Quaternary Union, Durban, South Africa. Also our scientists continued to participate actively in national and international conferences with large number of invited and contributed presentations. During the reporting year **seventy four** papers were invited review talks. At present PRL has thirty five research scholars and fifteen post-doctoral fellows working in various disciplines. Four Ph.D. theses were submitted. Three of the theses were astronomy related covering topics on lunar occultation studies in the near infrared, spectroscopic investigations of planetary nebulae and near infrared investigations on regions of star formation. The fourth thesis focussed on palaeoclimate simulation studies of the Indian Monsoon.

Our contribution to basic research in various fields has been recognised both nationally and internationally. Some of our scientists have received prestigious awards and honours such as the *(INSA) Medal for Young Scientists* of Indian National Science Academy; *Fellow of the Indian National Science Academy* and *the Indian Academy of Sciences and Jawaharlal Nehru Birth Centenary Lecture* for the year 2000.

Physical Research Laboratory honoured two distinguished scientists, **Dr. A. P. J. Abdul Kalam** and **Dr. R. Chidambaram**, for their pioneering contributions in Science and Technology, at a glittering function on the occasion of the presentation of the **Hari Om Ashram Prerit Senior Scientist Award** for the year 1998. The Senior Scientist Award has been instituted in 1998 by the Hari Om Ashram Trust, Nadiad to commemorate the birth centenary of Pujya Shri Mota, Founder of the Hari Om Ashram, Nadiad. The award of Rs.1 lakh is made to an Indian scientist for outstanding contributions in Science and Technology. An endowment fund, administered by PRL was created for this purpose by the Hari Om Ashram Trust and the award will be made every alternate year.

Prof. Henry Rishbeth, Emeritus Professor, University of Southampton in UK visited PRL as the second **K. R. Ramanathan Professor**. During his visit he gave five lectures and a popular lecture on *The Sun and Earth : A View of Solar Terrestrial Physics*. **Prof. S. Chandrasekhar**, FRS, Director, Centre for Liquid Crystal Research, Bangalore; Hony. Prof. at the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, delivered the fourteenth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Recent Advances in Liquid Crystals*. **Prof. R. Cowsik**, Director, Indian Institute of Astrophysics, Bangalore and a Distinguished Professor of Physics at the Tata Institute of Fundamental Research, Bombay, delivered the fifteenth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Rubies and Diamonds from Outer Space*.

A symposium on **Vision for Space Science and Technology** was organised to commemorate the *80th Birth Anniversary of Dr. Vikram A. Sarabhai*. The symposium was jointly planned by PRL Alumni and Gujarat Science Academy at PRL on August 12-13,1999. More than 300 delegates attended. Invited talks by leading scientists from the country covered different areas in Space Science, Technology and Applications. A book entitled *Space Research in India: Accomplishments and Prospects* published by PRL Alumni was also released on this occasion.

Physical Research Laboratory (PRL), Ahmedabad and Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, jointly organised a workshop on **Current Trends in Infrared Astronomy** during August 17-20, 1999 at PRL, Ahmedabad. The workshop covered a wide range of topics in IR astronomy, both from instrumentation and theory/ observation view points. Dr. Ian S.Glass of South African Astronomical Observatory, main resource person, gave a series of talks covering basics of near IR photometry, study of the Milkyway through the imaging of the inner bulge and variability of AGNs in near IR. In addition, there were talks by the experts from various institutes

within the country on various topics. One of the main attractions of the workshop was presentation of the new results obtained using NICMOS-3 and other IR instruments relating to galactic and extra-galactic studies.

The symposium **Deccan Trap Basalts and the K/T Boundary** was held during November 25-26, 1999. Twelve review talks by leading experts in the field in four topical sessions, in addition to presentations of contributed papers in two sessions formed the scientific programme of the conference. The deliberations of the conference are being published in a special issue of the Proceedings of the Indian Academy of Sciences (Earth Planet. Sci.).

The **65th Anniversary General Meeting** of the Indian National Science Academy was hosted by PRL during December 18-20,1999. About eighty five, including Council Members, Fellow, INSA Young Scientists and special invitees attended the meeting. The highlights of the meeting were the *Symposium on Isotope Applications in Earth and Planetary Sciences* and a *Seminar on Advances in Sciences of Sustainable Environment and Development in the Next Decade (Energy and Food Security).* Visits to Institute of Plasma Research and the Space Applications Centre were also a part of the programme.

A two day symposium on **Indian Space Programme in the New Millennium** was organised by the Indian Physics Association (Ahmedabad Chapter) during 22-23 January 2000. The aim of the symposium was to bring awareness to the physics community from colleges and universities in Gujarat. About 150 delegates, mainly from colleges and universities, as well as from SAC, IPR and PRL attended the symposium. The scientific programme of the symposium consisted of invited talks by leading experts in four sessions, as well as panel discussions.

PRL organised a discussion meeting on the **Methodological Aspects and Possible New Applications of Luminescence Dating in India**. The meeting was attended by dating experts from five countries and over thirty Indian scientists from Universities, Geological Surveys of India, Archaeological Survey of India and the Deccan College. Besides discussing the new developmental methods, the meeting also focussed on problems and prospects of dating a variety of landforms for climate reconstruction, dating of past seismic events and marine geological and archaeological sequences in the Indian context.

A **Summer Training Programme** was organised at PRL during May 17 - June 30, 1999. Seventeen students from various universities and institutions of the country, who appeared for M.Sc. (Pre.) examination this summer, attended the training programme. Each trainee worked on a specific project, either experimental or theoretical, under the supervision of a faculty member. A three-day visit was organised for the trainees to see Infra-red Observatory at Mt. Abu and the Udaipur Solar Observatory. The trainees gave a short presentation of their work and also submitted their project report.

A **Training Course for the College Teachers** of Gujarat State was organised at PRL during May 10 - 28, 1999. Eighteen college teachers affiliated to the various universities of the State attended the course. The theme of the course was on *Basic Physics & Instrumentation.* Forty five lectures were delivered, 20 in Basic Physics and 25 in Instrumentation. Three popular lectures were arranged under this programme, on "College Education" by Prof. J.N.Desai, on "Global Warming/Cooling" by Prof. Shyam Lal and on "Satellite Communication" by Mr. O.P.Kaushik of Space Applications Center, Ahmedabad. In addition to the lectures, each participant interacted with a faculty member on a specific problem, either experimental or theoretical, for about two weeks and at the end of the course presented a brief account of the work done on the project.

As a part of implementation and progressive use of Hindi in PRL, the **Hindi Week** was celebrated at PRL from September 14 - 19, 1999. The highlights of the celebrations included word quiz, essay, elocution, poetry and recitation competitions, including self written poetry and Antakshari. All staff members alongwith their families were invited in some of the programmes to make this celebration attractive. The special attraction of this year's celebration was lectures of two eminent

personalities - one by Prof. Govindbhai Raval, Vice Chancellor of Gujarat Vidyapeeth, who gave the inaugural lecture, the other was by Shri T.P. Singh of Remote Sensing and Communication Centre, Gandhinagar who gave very interesting talk on *Sudursanvedan ka prakratik sansadhan ke prabandhan mein upyog.*

The **National Science Day** was organised on February 26, 2000 at the Physical Research Laboratory in association with the Indian Physics Association (IPA), Ahmedabad Chapter. Science Quiz, both written and oral, popular science lectures and video shows formed part of the programme. The science quiz was open to students of stds. IX and X from schools all over Gujarat. One hundred and seventy three students participated in the written science quiz. Prizes in various forms were distributed. On this occasion, the **PRL Scholarships** from the Aruna Lal Endowment Fund were also awarded.

I take this opportunity to thank all my colleagues including administrative, technical and supporting staff and also convey my appreciation to the PRL Council of Management for their guidance and advice in enabling the laboratory to pursue its goal of attaining scientific excellence.

G S Agarwal

Director

PRL in a Nutshell

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

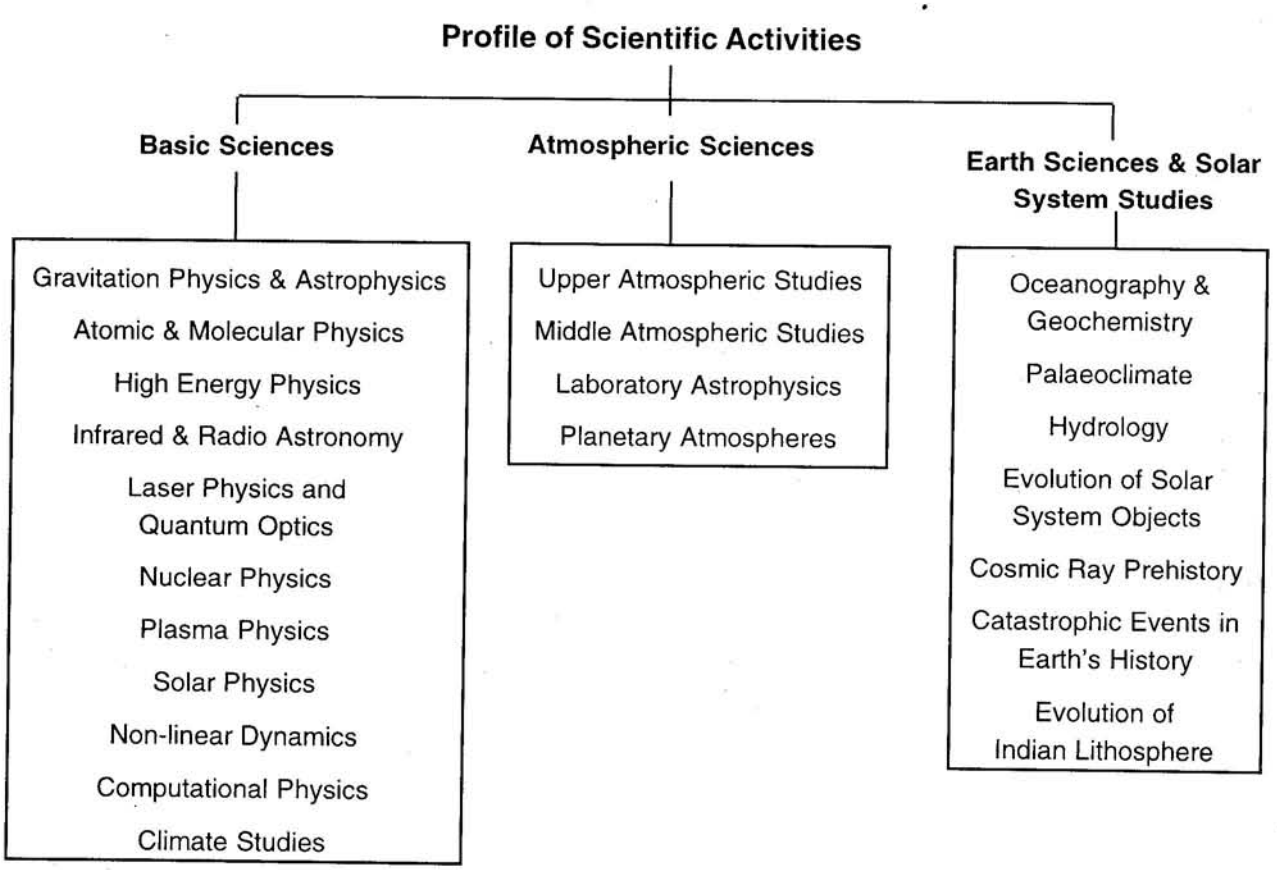
i. Astronomy and Astrophysics;
ii. Theoretical Physics;
iii. Nonlinear Dynamics and Computational Physics;
iv. Laser Physics and Quantum Optics;
v. Planetary Atmospheres and Aeronomy;
vi. Earth Sciences and Solar System Studies.

The chart below profiles the scientific activities.

Some of the important research contributions are summarised.

Astronomy and Astrophysics

The division's research programme covers a wide spectrum of topics in astronomy starting from solar physics, interplanetary medium, cometary physics to stellar physics (star formation and late stages of stellar evolution) to extragalactic objects; star burst galaxies and active galactic nuclei (AGNs). The Astronomy and Astrophysics Division operates an Infrared Observatory at Mt. Abu (MIRO) housing a 1.2m infrared telescope equipped with world class state-of-the-art back-end instruments such as IR camera (NICMOS-3), thinned back illuminated CCD camera, high resolution Fabry-Perot Spectrometer, Optical and IR polarimeters, high speed dual channel IR photometer, a grating spectrograph etc. Majority of the back-end instruments were developed in-house. For simultaneous imaging in optical and near IR, a two-channel hybrid camera combining a CCD camera and the NICMOS-3 has been developed. Udaipur Solar Observatory (USO), equipped with modern instruments is a premier facility in the country in the area of solar physics. The USO is also participating in the GONG project which aims to study the solar interior using helioseismology. A solar X-ray spectrometer



(SOXS) payload for inclusion on a satellite in near future is under development in PRL.

The key research areas continue to be the study of AGNs and star forming regions in our galaxy and starburst galaxies and late stages of stellar evolution. One of the hottest issue in astronomy these days is the Gamma Ray Burst (GRB) phenomenon. One single GRB produces perhaps as much energy in a very short interval as the whole of the remaining universe put together. The nature of GRBs is still not clear. A program was started last year to follow the optical afterglow of GRBs and one such case was detected, though very faintly. Some more events were tried this year using the NICMOS-3 array, but the sources were either too faint to be detected, or perhaps were missed due to the not so accurate and delayed localization of GRBs.

Work continued on a multi-band study of a sample of starburst galaxies. Their optical morphologies and structural properties have been studied. Signatures of dust were found in the central regions of some of the galaxies. In the case of the peculiar starburst galaxy MK 439, massive star formation was detected along a misaligned bar.

At near IR wavelengths, as compared to at optical wavelengths, the extinction towards the Galactic Centre is much reduced. Under the Indo-French collaboration, using DENIS Survey observations in the near IR, it has been possible, for the first time, to make a complete and homogeneous map of the extinction over a large area (> 20 sq. degree) which is being used to study the inner milky way in detail. Mid IR observations of the ISOGAL survey were used to make a mosaic of the view of the inner galactic bulge at 7 microns. As extinction is almost negligible at these wavelengths, one hopes to have a more complete view of the inner galaxy as compared to that at optical or near IR wavelengths.

Using the PRL Imaging Fabry-Perot Spectrometer at the Mt. Abu telescope, spatio-kinematic observations were made on NGC 246 in the [OIII] 5007 A line. First time evidence was found for the deceleration effect in the leading edge of the nebular shell, due to its interaction with the interstellar medium. Several selected low-mass YSOs have been studied using the R=1000 grating spectrometer attached with NICMOS IR array camera to understand their precise stages of evolution. Almost all the sources showed strong outflows through the Bracket γ-emission line at 2.16 μm. Three new Herbig-Haro flows in the star forming region L1340 have been found, which seem to be unique and interesting in several ways.

In continuation of the nova programme, multi-epoch IR spectra of two outbursting novae were obtained. While in one case the shell ejected in the outburst appears uniform to a large extent, in the second case the indications are that the ejected shell is clumpy. A program of spectroscopy of Be stars has been initiated at Mt. Abu Observatory to investigate the characteristics of Be stars in the near IR.

Lunar occultations carried out at 2.2μm at Mt. Abu telescope during the past few years have resulted in a sample of 15 M giants, yielding information on their angular diameters and effective temperatures. Using lunar occultations fine structure in the dust shell of IRC 10216 was seen.

Using differential image motion monitor consisting of 35 cm Celestron telescope, an SBIG ST4 CCD camera and a PC, seeing measurements have been started at the Mt. Abu site. Results from 20 nights during December 1999-March 2000 have shown several spells of sub arcsec seeing lasting for 3-4 hours on many of these nights, indicating good seeing conditions at the observatory site.

A study of the pulsars PSR 0950+08 at three different observatories at different frequency bands (Rajkot Radio Telescope, at 103 MHz, Ooty Radio Telescope, at 327 MHz and Westerbork Synthesis Radio Telescope (WSRT), Netherlands at 297 MHz) has shown the presence of giant pulses in all three places. More over variations in the strength and frequency of occurrence of giant pulse emission were also observed in all cases, though individual giant pulse correlation did not seem to be there between the three data sets. The very high temporal resolution observations with the WSRT showed that many pulses remained unresolved even at milli-

second time scales, indicating that giant pulse may perhaps be an intrinsic phenomenon in the pulsar.

At the Udaipur Solar Observatory main activity continued to be helioseismology using the GONG data. The development of the Solar X-ray spectrometer (SOXs), a soft X-rays payload has been initiated in PRL jointly by the Astronomy and Astrophysics Dvision and USO. GONG data sets were utilized to obtain empirical relations between the p-mode frequency shift and the change in solar activity indices. GONG data was also used to infer solar rotation rate with varying depth and latitude, and variations in the acoustic spectrum were mapped on the solar disk in terms of the peak frequency of the spectra envelope. From the MSFC photospheric magnetograms, maps of local shear and vertical current density were produced which showed that sites of large currents have a close relationship with flares than with strong shear. To resolve the controversy about the role and contribution of micro/nano flares in coronal heating, a study of the distribution of flares as a function of their size and decay time, the peak flux, total energy etc. is being carried out. Total solar eclipse observations during August 11, 1999, were carried from Isfahan in Iran, for the photometry and polarimetry of solar corona to a distance of upto 1.5 R-sun from the limb. Digital images were acquired in the visible and near IR region.

Theoretical Physics

In atomic and molecular physics, analytical formulas of the quantum form factor and dipole moment for Rydberg Stark states have been derived and all earlier expressions are shown to be special cases of these two formulas. These earlier expressions, because of the complications caused by a large number n^3, n being the principal quantum number of oscillations in the Rydberg wave functions, were derived using quasi-classical approximations and the correspondence principle.

As all the information we get from the cosmic sources are in the form of electromagnetic waves, it is essential to understand the nature of these waves when they propagate over cosmic distances. We have found that the coupling of the electromagnetic field with curvature of spacetime arising from perturbation induces optical rotation of the photons of the microwave background. Further it has been seen that the photon propagating around a rotating black hole would suffer a phase difference and could possibly produce interference at the observer's location. A very important result obtained concerns the possible breakdown of the self similar solution very close to accreting black holes, which would require a fresh look at the possible new solution for the analysis of emission from the inner region of accretion disks.

In high energy physics, major themes of studies are neutrino masses and mixings, baryogenesis and quark-gluon plasma. In neutrino physics two largely seperated scales corresponding to the solar and atmospheric neutrinos have emerged from experimental studies. A possibility that these scales are related to 1-loop and 2-loop corrections in quantum theory was suggested and discussed. In addition, structure of neutrino masses as well as generation of electric dipole moments is studied in the supersymmetric Standard model with specific attention paid to R-parity violation. In baryogenesis, a systematic study was made of different approaches to generate baryon asymmetry through the decay of a heavy Majorana neutrino. This provides a detailed formalism to investigate the issue of generation of baryon asymmetry in a large class of models. In the topic of quark-gluon plasma, the possibility of di-quark forming a Cooper like pairs and leading to colour superconductivity was investigated in Nambu-Jona-Lasino type of model. It was shown that both the chiral symmetry breaking and di-quark condensation can co-exist at finite density.

In nuclear physics, shell model studies of occupation numbers and Gamow-Teller strength sums are carried out using hamiltonians that generate order-chaos transitions. With these studies there is a newly emerging understanding that in the chaotic domain of isolated and finite interacting many particle systems smoothed densities define the statistical description of these systems and these densities follow from embedded random matrix ensembles.

In plasma physics, work on the physics of dusty plasmas has been continued and three new results have been obtained. First, the concept of dust fugacity has been introduced, and dusty plasmas have been classified into tenuous, dilute or dense types. Second, a new kind of dust wave mode driven by Coulomb pressure has been found in the dense regime. This mode can be considered as the electrostatic analogue of the hydromagnetic (Alfvén) waves in ordinary plasmas. Third, dusty plasmas are shown to be governed by a new kind of length-scale, which plays a fundamental role in the dense regime, like the Debye length of the tenuous regime.

Nonlinear Dynamics and 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. Quantum chaos, control and synchronization of chaos, numerical relativity and cosmology, and image proccessing form some of the topics on which work is being carried out. We focus attention this year on certain quantum mechanical implications of chaos, on encoding messages using chaotic systems, and on the small world phenomenon.

Classical chaotic dynamics when quantized leads to a variety of important and interesting effects. One of the foremost is the phenomenon of quantum suppression of chaos through interference of "probability waves". We have studied a novel measure of this suppression by analysing the response of the chaotic systems to external perturbations. The allowed energy levels move under such conditions in ways that are sensitive to the chaos in the dynamics while reflecting the quantum localization. Classical correlations have been studied that reveal, semiclassically, the quantum localization of chaotic states. We have also studied the quantum dynamics of a particle trapped in a well and exposed to an external field. Various phenomena including exponential localization of states have been studied. Chaotic systems are also used for encoding messages. A method proposed recently that uses the unstable periodic orbits for phase modulation of a binary message has been shown to be unsafe. Without an apriori knowledge of the chaotic systems actually used in the encoding process, the message was shown to be decodable. The small-world phenomenon is important for networking. We have studied random walks on random small-world networks and this has revealed a crossover from regular to random average access times as a function of the distance from the starting point. An analytical model of this complex behaviour has been shown to be remarkably successful.

Laser Physics and Quantum Optics

The research of this division has been mainly theoretical although collaborative work with experimental groups elsewhere continues and preparatory work at PRL has been completed.

Interaction of atoms with a cavity brings out new results when the atoms are cold enough for their motion to be quantized. In such cases the cavity acts like a combination of potential barrier and well for the external motion of atoms. Tunneling of cold atoms through two cavities in succession show resonances similar to a double barrier system. The cavities get coupled by the quantized motion of the atom, and for a single bimodal cavity, the reflection and transmission of cold atoms give rise to a strong anti-correlation between the cavity modes.

When different pathways exist for a given process to take place, it gives rise to interference. New channels can be opened up by the application of a control field. This is the basis of optical manipulation of matter by quantum interference. To this end, it is shown how the application of a strong electromagnetic field can make wave propagation possible in the forbidden region of a resonant optical medium and how the magneto-optical rotation of a probe field can be enhanced and even controlled leading to the possibility of realizing a magneto-optical switch. In non-degenerate pump-probe spectroscopy of V systems, we demonstrate that quantum interference between different paths of spontaneous emission can produce gain under conditions when one would have otherwise observed absorption peaks.

Furthermore, we relate the gain to the existence of a new vacuum-induced quasi-trapping state.

Coherent states are at the heart of quantum optics. We have carried out a comparative study of the non-linear wave packet dynamics of coherent states of various symmetry groups. Although important differences exist in the evolution of coherent states belonging to different symmetry groups, in each case, we find certain generic signatures of non-linear evolution such as quick onset of decoherence followed by Schrödinger cat formation and revival. Schrödinger cats are superpositions of coherent states. Such superpositons are rather fragile and they decohere (that is, lose their structure) in interactions with the environment (bath). Stability of a coherent superposition state is desirable and sometimes even essential as in the context of quantum computation. We demonstrate in a general way that the process of decoherence and relaxation can be slowed down considerably by fast modulation of the coupling to the environment.

A new method was proposed for determining structures of semi-transparent media from measurements of the extinguished power in scattering experiments without having to measure the phase of the scattered field. A simple scheme was suggested for the reconstruction of two-mode SU(1,1) states using parametric amplifiers.

The underlying SU(2) structure of the Poincare sphere that represents the recently discovered light beams with orbital angular momentum, was revealed for both classical and quantum fields.

In the case of pulse propagation through a near-resonant four-level medium, we have found shape-preserving solutions for an odd number of co-propagating correlated pulses, apparently the first such example in three decades. The use of a probe pulse in our theory will facilitate experimental tests of correlated pulse theory as it lifts a rigid restriction on experimental realization.

In the experimental front, preparatory important tests have been concluded. These include production and characterization of photorefractive polymer films, generation of optical vortices with elliptic Gaussian beams and Doppler-free saturated absorption spectroscopy of Rubidium.

Planetary Atmospheres and Aeronomy

Planetary Atmospheres and Aeronomy Division continued with its major thrust to investigate a variety of physical and chemical processes that occur in the atmospheres of the earth, planets and comets. These investigations are carried out using ocean cruises, balloon and rocket-borne payloads. The research work also includes the remote sensing of atmospheres by ground-based radio and optical techniques, laboratory experiments, atmospheric modelling and numerical simulation studies.

The PRL lidar facility at Gurushikhar has been operated to study atmospheric temperature. Based on nearly one hundred nights of observations in Rayleigh scatter mode of operation during the period of November 1997 to March 2000, monthly mean temperature profiles have been obtained for the altitude region of 30-70 km. The altitude coverage of temperature measurements has been extended to cover 10-70 km since March 1998 by operating the lidar in the Raman mode of operation (10-40 km) at 607 nm (nitrogen). Measurements of water vapour at altitudes up to 10 km have also been initiated.

During the INDOEX ship cruises, high ozone has been observed over the Arabian Sea off the Indian coast. This is surprisingly higher than the average day time ozone at Ahmedabad or at Trivandrum. These continental stations also show strong diurnal variations with high ozone during the day. Such variation is not observed in the marine region. These results together with 3D model calculations indicate that the ozone levels in the marine boundary layer are affected by the downward transport from the continental free troposphere. These measurements of ozone and other gases during the INDOEX cruises present many new results. Also, surface ozone measurements at Gadanki show that the ozone production per molecule of NO_x is much lower at Gadanki than at many other global sites.

Comparison of the four year ship cruise data from 1996 to 1999, collected as part of the INDOEX field campaign shows a biennial type oscillation in the observed aerosol concentration over the Arabian Sea with low values in 1996 and 1998 and high values in 1997 and 1999, the highest being observed during the 1999 spring. The 1999 increase is believed to be caused by the increase in the number density of anthropogenically produced sub-micron size particles brought from the continents as a result of a strong inversion layer and larger number of anti-cyclones observed over this region. One of the important consequences of increased aerosol loading in the atmosphere is the aerosol radiative forcing of the climate. The startling discovery is that these aerosols contain a relatively larger portion of soot particles which absorb the solar radiation and lead to a warm atmosphere. The highlight of the INDOEX is the finding that there is a reduction of about 27 Wm^{-2} in the surface reaching solar radiation near the coastal India of which about 20.1 Wm^{-2} radiation energy is absorbed in the atmosphere while only 6.9 Wm^{-2} energy is scattered back to space. The amount of aerosol absorption however decreases with increasing distance from the coast. The high absorption detected near the coastal Indian region adds to the well known Greenhouse effect and contributes to warming than counteracting the Greenhouse effect.

The contribution of water vapor to greenhouse heating is about double of that of CO_2. But its density and variability are not accurately known. Using a ground-based visible absorption spectroscopy technique, the slant column density of water vapor has been measured. We find that its value in winter varies from 10^{21} to 10^{24} cm^{-2}.

Global warming has affected the tropopause height. Analysis of 30 years of radiosonde data at four stations of India shows that tropopause height has been increasing over the years. The magnitude of increase varies from 0.57 to 3.25% per decade. This increase is explained by the decreasing trend of ozone in the ozone maximum layer of the stratosphere.

Latest satellite measurement of nitric oxide density (NO) and ground-based measurements of temperature have been used to explain the diurnal asymmetry of the D-region ionization. We conclude that life time of NO in the mesosphere has to be less than a day. Also the concentration of NO in the mesosphere is not solely dependent on its transport from the lower thermosphere.

Detailed analysis of 630 nm and 777.4 nm images obtained earlier from SHAR showed that on highly disturbed magnetic epochs, the inter-depletion distance increased by a factor of about 2 and became as high as 1600 km. This is the first experimental evidence that the gravity waves of auroral origin are responsible for modulation of the bottom side of the F region as suggested earlier by Kelley et al. 1981 and by Hysell et al. 1990. During magnetically quiet periods, gravity waves having their origin in the lower atmosphere were responsible for perturbing the F region.

The all sky optical imaging system of PRL was upgraded by incorporating a 12-bit CCD camera and by developing the electronic control for automatic and programmed movement of the filter wheel. This system was successfully used from Kavalur to detect gravity waves.

The effects of molecular ions in the night time equatorial F-region irregularities have been investigated by means of linear and nonlinear analysis which brought out the role of molecular to atomic ion concentrations in the growth of plasma irregularities. This result is in contrast to the previous analysis based on single ionic constituent. Further, the investigation revealed that the molecular ion density variations are found to be enhanced in plasma depleted region similar to that of the satellite observations over the equatorial region.

A new magnetic field parameter was derived using measured magnetic field and hourly ring current index Dst to isolate the contribution of the ionospheric current. The temperature variations of this parameter was found to have good correlation with thermospheric dayglow intensity variations during magnetically disturbed period.

Significant heating (>500 K) of the low latitude thermosphere was observed with a time delay after the onset of magnetic disturbance indicating the intricacies in the coupling of high latitude thermosphere with low latitude thermosphere.

The rapid radio soundings made over Ahmedabad during the Leonid meteor shower event of November 1998 and supplemented by similar observations at equatorial stations have shown clear evidence of the association of sporadic-E layers with meteor shower activity. The sporadic-E layers associated with enhanced meteor shower activity were often characterised by multiple stratification between 100 and 140 km.

VHF scintillation observations at 244 MHz, at a chain of 20 stations in India during one of the AICPITS campaigns (February-March 1993), were used to estimate the vertical velocity of large-scale plasma depletions associated with equatorial spread-F from the mean time delays between the onset times of scintillations. The velocities ranging between 40 and 420 m/s with maximum at altitudes of 400 to 800 km are consistent with the in-situ electric field measurements from satellites.

Rocket experiments were conducted on 18th and 20th November 1999 at 0725 hrs and 0705 hrs during the high activity period of Leonid meteor shower and electron density, ion composition and electron density irregularities were measured. The results show that on 18th November, the dominant ions present in lower ionosphere were iron, nickel and probably cobalt. MST Radar measurements from Gadanki during that time showed that meteor shower activity was maximum on 18 November at 0725 hrs i.e. at the time of rocket flight. Other ionospheric effects associated with meteor shower are also being investigated.

The first results on the studies of the upper ionosphere of Mars due to solar wind interaction show that the induced magnetic field originated from solar wind plays a very important role in the upper ionosphere of Mars. The chemistry of the ions corresponding to masses < 40 amu inside the ionopause of comet Halley has also been studied. The ionization processes due to impact of photons, photoelectrons and auroral electrons are included in this model. The results thus obtained have been compared with the measurements made by Martian and cometary spacecrafts.

Pressure dependence of fluorescence excitation spectrum of sulphur dioxide has been studied in the laboratory at incident photon wavelengths ranging from 202 to 232 nm and at a large number of pressures in the region 100-5000 m Torr. At low pressures, the band intensities in the predissociating region (202-220 nm) show an increase and sometimes are comparable to a few bands in the normal excitation region (220-232 nm). At high pressures, the effect of collisional quenching has been observed for a few bands in the normal excitation spectral region.

A new sophisticated experiment has been designed and fabricated to study the dispersed fluorescence spectra of different molecules at incident photon wavelengths 220-400 nm using excimer laser pumped dye-laser. The redeeming feature of the experiment is the replacement of conventional system (monochromator, photomultiplier etc.) by a polychromator/spectrograph and a liquid nitrogen cooled CCD. The experiment has become operational and the research work on different molecular systems would start in the near future.

Earth Sciences and Solar System Studies

The programmes of Earth Sciences and Solar System Division focus on the spatial and temporal evolution of the Earth and other planetary bodies through studies of the isotopic and chemical signatures contained in samples derived from them. Such studies are critically dependent on the availability of necessary analytical expertise and sophisticated instrumentation to make highly precise measurements in small samples which this group has developed over the years.

The evolution of the Earth is intimately coupled to climate which has undergone drastic changes over various time scales. A major effort of this group is to reconstruct the palaeoclimatic history of the Earth by

investigating a variety of continental and marine records and modelling . Chemical and isotopic studies of carbonate nodules from sediments of Permo-Carboniferous basins, Talchir were carried out to infer their depositional environment and the nature of hydrological cycle at that time. The results suggest that the nodules were deposited from a fresh water system and that the global hydrological cycle at that time was functioning similar to that of today. Sr isotope composition of these nodules indicate that granites from Chotanagpur and granulites from the Eastern Ghats have contributed to their trace element abundances.

Weathering and transportation is a major component of the exogenic cycles of elements. As a part of our continuing efforts to understand and quantify these processes in the Himalaya extensive studies of the Yamuna basin were carried out. The dissolved Re concentration in these rivers centre around 1-2 ng l^{-1}. The source of such high Re concentration is inferred to be weathering of black shales, though their abundance in the drainage basins is small. More importantly, black shale weathering can also influence the budget of other elements enriched in them, e.g. U, P and V and that of CO_2 in the atmosphere.

Modelling is an important component of hydrological studies. Analysis of pump test data using a groundwater flow modelling package was carried out to assess the cause of low yield of RC wells constructed in the Mahi and Sabarmati basins. The results show that the shape of the aquifer and anisotropy of permeability seem to be the dominant factors responsible for the low yield.

To improve the precision of quartz based optically stimulated luminescence dating two aspects were examined, viz. (i) the role of feldspar micro-inclusions and (ii) inter-aliquot normalisation procedure. Based on simulation experiments it was shown that the interference of feldspar micro-inclusion could be quenched using a pre-stimulation of the sample with 880 nm infra-red light at an elevated temperature. The normalisation procedure to reconcile the inter aliquot variability in luminescence output was examined. This study suggests that the use of component specific normalisation provides substantially improved results whereby the errors in ages in some cases could be reduced from 50% to 5% or less.

Oceanic basalts have always been found to have air-like noble gases along with noble gases of mantle origin and the source of this air like component has remained a puzzle so far. By an innovative use of nitrogen and argon systematics from these basalts, we have demonstrated that the air-like noble gases are due to recycled component introduced into them during their ascent through the enriched mantle (EM) and not due to 'air contamination' as hitherto believed. The EM forms a thin layer below the asthenosphere and concentrates the volatiles escaping out of subducting slabs.

We have investigated the thermal evolution of the plutonic rocks associated with the subduction of Tethys oceanic crust by Ar-Ar thermochronology. Taking the muscovite closure temperature for Ar as ~350°C, a cooling rate of ~20°C/m.y. is obtained for the Ladakh batholith. These results indicate that plutonic rocks took a long time in exhumation and cooling and hence the tectonic uplift did not start before 18 m.y..

We have initiated a program of studying fullerenes (C_{60},C_{70} and higher fullerenes and fulleranes) in the iridium-rich Cretaceous-Tertiary boundary (KTB) layers.As a first case the intertrappean beds of Anjar within the Deccan volcanic province were studied. Fullerenes (C_{60}) have been identified in the two iridium rich horizons from this section by high-resolution electron-impact ionization mass spectrometry and ^{13}C-NMR studies. Fullerenes are absent in four other iridium-poor horizons of the same section and confirm their impact origin.

We have started a study of K/T boundary clays by Mössbauer spectroscopy. Four sites, Gubbio, Turkmenia, Anjar and Meghalaya have been studied. Our results show the presence of nanometer size superparamagnetic particles in all the four boundary clays and their absence in adjacent horizons.

Research Facilities

Major Equipments

Infrared Telescope at Mt. Abu with back-end instruments like Infrared Camera (NICMOS.3);1Kx1K Pixel Thinned Back Illuminated CCD Camera; Polarimeter both optical and IR; Imaging Fabry-Perot Spectrometer and Infrared Fast Photometer

Solar Telescopes, Video Magnetograph and Dopplergraph Telescope at USO

Radio Telescope at Rajkot

Lidar

Gas Chromatographs

Dobson Spectrophotometer

Digital Ionosonde

Day-Glow Photometer

Multiwavelength Daytime Photometer

Scanning Fabry-Perot Interferometer

Doppler Imaging Spectrometer

All Sky Imaging Camera

UV Photoelectron Spectrometer

Excimer Laser

Ion Probe

Radiation Detectors

Luminescence Dating Systems

Atomic Absorption Spectrophotometer

Ion Chromatograph

CN Analyser

Spinner Magnetometer

Leitz Microscope with accessories

Inductively Coupled Plasma Emission Spectrophotometer (ICP-AES)

Stable Isotope Mass Spectrometer

Solid Source Mass Spectrometer (Rb-Sr & NTIMS)

Noble Gas Mass Spectrometer

Ar-Ar Mass Spectrometer

Nuclear Track Laboratory and X-ray Diffractometer

Radiocarbon Laboratory

Technical Developments

Installation of GEO 20-20 System

The Stable Isotope Laboratory facilities were augmented with the acquisition of a new mass spectrometer GEO 20-20 and four associated extraction and inlet systems from Europa company of UK. Since its inception a large number of accurate measurements of carbon and oxygen isotope ratios has been done in carbonate rocks and water samples. The acquisition of the new mass spectrometer gave us opportunity to update our two old VG 602 mass spectrometers. These two machines are now converted appropriately such that one can measure nitrogen isotopic ratio in nitrogen gas and the other can measure oxygen isotope ratios in oxygen gas. This added facility has allowed us to extend our sediment programs to include nitrogen isotope variation and also to start work on the new field of mass-independent isotopic fractionation in photochemical reactions.

Computer

The Computer Centre at PRL began with the first generation IBM1620 machine in the early sixties. It has today a work-station cluster consisting of five IBM RS6000/580 machines and HP9000/735 machine connected on a high speed fibre optic network. In addition, there are several PC's and workstations in all the scientific and administrative areas of the laboratory. Almost all the machines in PRL are connected to the main workstation cluster through a campus wide ethernet LAN. This enables PRL scientists to have ac-

cess to the workstations from their desks and laboratories. PRL scientists can access the global Internet and have facilities like *telnet* and *ftp* on their desks. Many software packages like AVS, IDL, IMSL, NAG, Mathematica etc. and public domain packages are also available.

Infra-structural Facilities Available

Scanning Electron Microscope,

Liquid Nitrogen Plant, Glass Blowing Facility,

C-14 Dating Laboratory

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

PRL also offers training and apprentice programmes in computers, electronics, 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. Some of our scientists have also edited books.

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. They are also invited to convene and chair sessions during symposia and meetings. The research output during the reporting year are shown in **Fig. 4**.

Books / Journals Published / Edited

A.S. Joshipura (ed), A special issue on *Neutrino Physics, Pramana* ***54****, January, 2000.*

S. P. Gupta (ed), *Advances in Space Research, 26, No.8, 2000*, Pergamon Press, UK.

D. K. Chakrabarty (ed), *Advances in Space Research, 24, No.12, 1999*, Pergamon Press, UK.

M.S. Narayanan, **Hari Om Vats**, B. Manikiam, **Harish Chandra and S.P. Gupta (eds)**, *Space Research in India: Accomplishments and Prospects* (1999), published by PRL Alumni Association, Ahmedabad.

A.K.Singhvi and E. Derbyshire (eds), *Palaeoenvironmental Reconstruction in Arid Zone*, A.A. Balkema Publications, The Netherlands, 1999, (330 pp).

J. N. Goswami and S. Krishnaswami (eds), *Isotopes in the Solar System*, Indian Acad. Sci., Bangalore, 1999, (234 pp).

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 "Future dryland changes from past dynamics", during the International Congress of the International Quaternary Union, Durban, South Africa, August 1-9, 1999, **A.K. Singhvi, Co-Convener**.

2. Workshop on "Current Trends in IR Astronomy", PRL, Ahmedabad, August 17-20, 1999, **U. C. Joshi and** Ranjan Gupta (IUCAA).

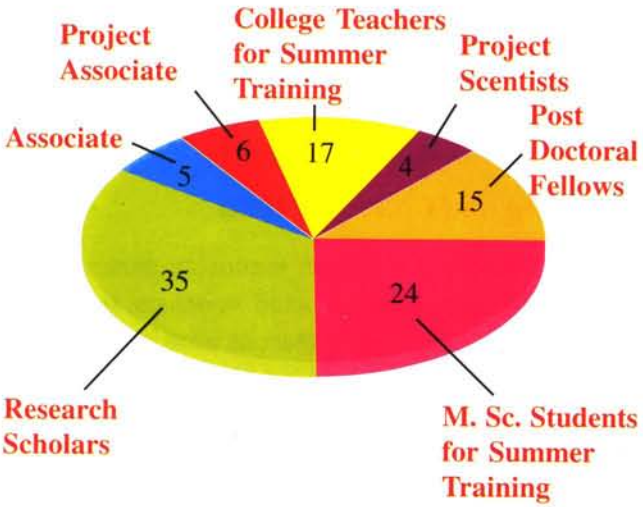


Fig. 1 Doctoral, Post Doctoral and other Research Programmes

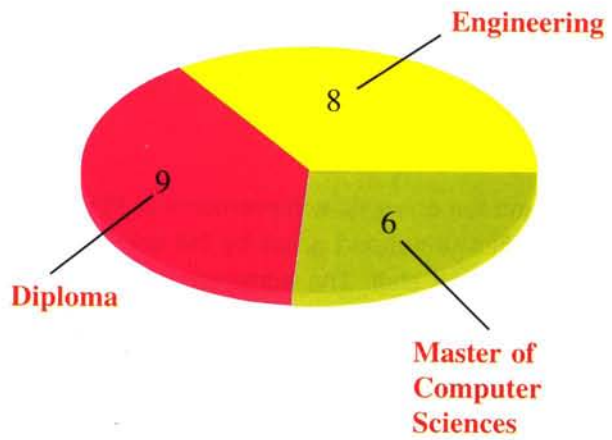


Fig. 2 Technical Projects for Engineering and Diploma Students

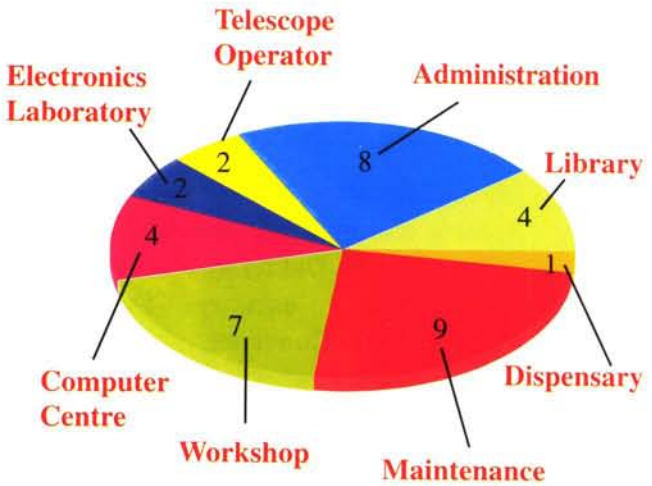


Fig. 3 Apprentice Programme at PRL

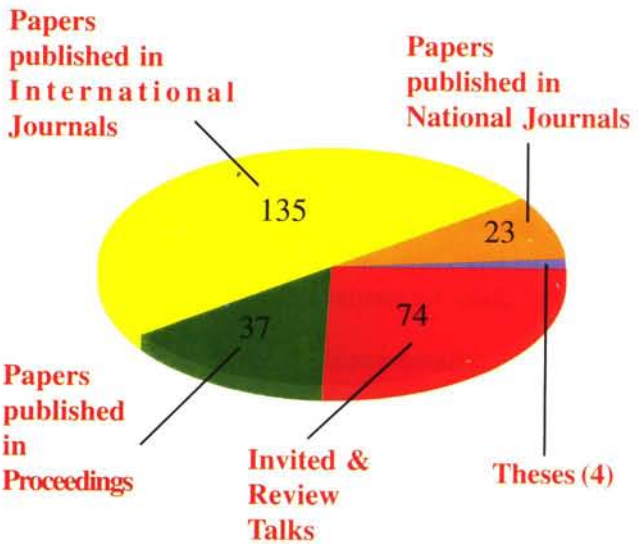


Fig. 4 Scientific Output of PRL

3. Symposium on "Vision for Space Sciences and Technology", PRL, Ahmedabad, August 12-13, 1999, **Dr. Shyam Lal - Convener.**

4. Symposium on "Deccan Trap Basalts and the K/T Boundary", PRL, Ahmedabad, November 25-26, 1999, **S.V.S.Murty and Pande K. – Conveners.**

5. "65th Anniversary General Meeting of the INSA - December 18 - 20, 1999", at PRL, Ahmedabad, December 18-19, 2000, **J. N. Goswami - Convener.**

6. "Isotope Applications in Earth and Planetary Sciences", during the 65th Anniversary General Meeting of INSA, PRL, Ahmedabad, December 18, 1999, **J.N. Goswami and S. Krishnaswami – Conveners.**

7. Symposium on "Indian Space Programme for the New Millenium", organised by IPA(AC),

at PRL, Ahmedabad, January 22-23, 2000, **S.V.S. Murty – Convener.**

8. Symposium on "Hindi and Internet in the New Millenium", at PRL, Ahmedabad, February 10-11, 2000, **M. R. G. Murthy – Convener.**

9. Discussion Meeting on "Methodological Aspects and Possible New Applications of Luminescence Dating in India", at PRL, Ahmedabad, February 14, 2000, **A. K. Singhvi - Convener**.

Distinguished Visitors at PRL

Dr. A. P. J. Abdul Kalam, Principle Scientific Advisor to the Government of India **and Dr. R. Chidambaram,** Chairman Atomic Energy Commission and Secretary, Department of Atomic Energy were awarded the **Hari Om Ashram Prerit Senior Scientist Award** for the year 1998.

Prof. Henry Rishbeth, Emeritus Professor, University of Southampton in UK visited PRL as the second **K. R. Ramanathan Professor**. During his visit he gave five lectures and a popular lecture on *The Sun and Earth : A View of Solar Terrestrial Physics.*

Prof. S. Chandrasekhar, FRS, Director, Centre for Liquid Crystal Research, Bangalore; Hon. Prof. at the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, delivered the XIVth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Recent Advances in Liquid Crystals.*

Prof. R. Cowsik, Director, Indian Institute of Astrophysics, Bangalore and a Distinguished Professor of Physics at the Tata Institute of Fundamental Research, Bombay, delivered the XVth **Prof. K.R. Ramanathan Memorial Lecture** entitled *Rubies and Diamonds from Outer Space.*

A number of distinguished visitors visited PRL. They are H.E. Mr. Claude Blanchemaison, Ambassador of France to India, Profs. Jean-Patrik Connerade, FRS, UK; S.Y. Zhu, Hongkong; Anil Kumar, India; Ian Glass, South Africa; Tom Gehrels, USA; Richard Strom, Netherlands; Alain Omont, France; Nigel Linge, UK; S. W. S. McKeever, USA; A. S. Murray, UK; D. W. Sanderson, Glasgow, UK; R. C. Canfield; Alex A. Pevtsov and Takeo Kosugi. The visitors had extensive interactions with PRL scientists. Some of them also delivered seminars and public lectures.

Seminars and Colloquia Held

The laboratory has an extensive seminar and colloquium programme. Reputed scientists, both from national and international institutions were invited to give seminars and colloquia. 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	133
Colloquia including public lectures held	37

About 60% of seminars and colloquia were delivered by visitors from within and outside the country.

Administrative Support

Behind the scientific achievements of PRL is the able and efficient support given by the administrative and the technical staff. The administrative section of our laboratory continues to play a pivotal role in providing an excellent management support to carry out our scientific activities. In addition, it also provides management support to the Solar Observatory at Udaipur and the Infrared Observatory at Mt. Abu. The budget and staff structure of PRL are shown in **Fig. 5 and 6**.

Miscellaneous

The **National Science Day** was organised on February 26, 2000 at the Physical Research Laboratory in association with the Indian Physics Association (IPA), Ahmedabad Chapter. Science Quiz, both written and oral, popular science lectures and video shows formed part of the programme. The science quiz was open to students of stds. IX and X from schools all over Gujarat. One hundred and seventy three students participated in the written science quiz. Prizes in various forms were

distributed. On this occasion, the PRL Scholarships from the Aruna Lal Endowment Fund were also awarded.

As a part of implementation and progressive use of Hindi in PRL, the Hindi Week was celebrated at PRL from September 14 - 19, 1999. The highlights of the celebrations included word quiz, essay, elocution, poetry and recitation competitions, including self written poetry and Antakshari. All staff members alongwith their families were invited in some of the programmes to make this celebration attractive. The special attraction of this year's celebration was lectures of two eminent personalities - one by Prof. Govindbhai Raval, Vice Chancellor of Gujarat Vidyapeeth, who gave the inaugural lecture, the other was by Shri T.P. Singh of Remote Sensing and Communication Centre, Gandhinagar who gave very interesting talk on *Sudursanvedan ka prakratik sansadhan ke prabandhan mein upyog.*

Fig. 5 Budget of PRL

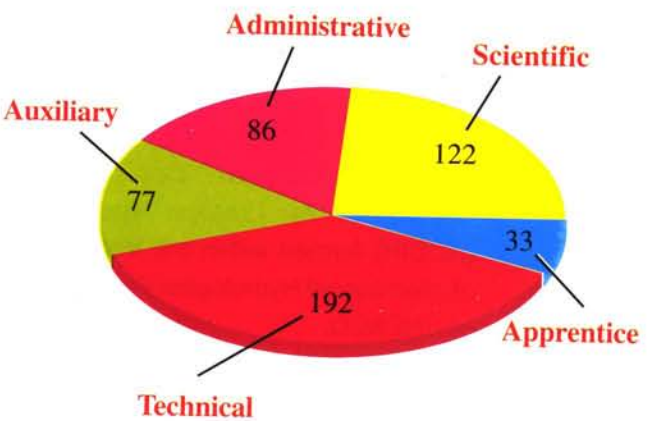


Fig. 6 Staff Structure of PRL

As a part of Golden Jubilee Year of adoption of Hindi as the Official Language of the Union of India, a two day conference on *Hindi and Internet in the New Millenium* was organised at PRL during February 10-11, 2000. The two-day conference focussed on four aspects, namely, the role of Space/Satellite Technologies in Internet, Applications of Internet, Hindi and Internet and Future Prospects of Hindi and Internet. Most of the speakers were drawn from leading institutes in the country. About twenty one papers were presented in the above topics. Live demonstrations on the internet was also shown. The participants around 135, were from different units of Department of Space, other government institutes and universities.

PRL has also participated in DOS Inter Centre Technical Seminar on *Future Trends in Space Technology*, held at VSSC, Thiruvananthapuram during December, 1999. Six of our staff members presented papers on various topics.

The Hindi Section also participated in various symposium, seminar and workshops conducted by the Space Applications Centre, Door Darshan, Oriental Insurance Company in Ahmedabad and Trivandrum and gave talks on different topics including *Antarix Marg se Hindi.*

Awards and Honours

1. **Prof. U.R. Rao** has been awarded the *Gujar Mal Modi Science Foundation Award* for the year 1999.

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

   i. *Padma Vibhushan* from the Govt. of India

   ii. *Shri Murli M. Chugani Memorial Award for Excellence in Applied Physics* by the Indian Physics Association, Bombay.

   iii. *H. K. Firodia Award for Excellence in Science & Technology* conferred by H.K.Firodia Memorial Foundation, Pune.

   iv. *The Degree of Doctor of Sciences* (Honoris Causa) by University of Roorkee at the 50th Convocation.

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

   i. selected for the *Jawaharlal Nehru Birth Centenary Lecture* for the year 2000; Indian National Science Academy.

   ii. appointed *Advisor on the Editorial Board of Optics Communications* for another term of three years.

   iii. appointed *Honorary Editor of JOPB: Quantum and Semiclassical Optics* for a period of two years.

   vi. appointed *Third World Academy of Science Lecturer* to China.

4. **Prof. J.N. Goswami** has been elected *Fellow, Indian National Science Academy*, New Delhi.

5. **Prof. A.K. Singhvi** has been elected -

   i. *Fellow, Indian National Science Academy*, New Delhi.

   ii. *Fellow, Indian Academy of Sciences*, Bangalore.

   iii. *Member, International Scientific Steering Committee of PAGES*, a Core Project of IGBP.

   iv. *Co-leader, UNESCO-IGCP-413* on Future Dryland Changes from Past Dynamics.

6. **Prof. M.M. Sarin** has been elected *Fellow, Indian Academy of Sciences*, Bangalore.

7. **Prof. Harish Chandra** elected as *Fellow of the Indian Geophysical Union*, Hyderabad.

8. **Prof. S. Krishnaswami** has been elected -

   i. *Vice-President, International Association for the Physical Sciences of the Ocean* (IAPSO).

   ii. *Member of the Scientific Committee of the International Geosphere-Biosphere Programme.*

9. **Dr. T.R. Venkatesan** has been awarded the *Best Mass Spectrometrist Prize* by Indian Society for Mass Spectrometry in December 1999.

10. **Dr. Kanchan Pande** has been elected *Member, National Working Group of IGCP - 411.*

11. **Prof. S. K. Bhattacharya** has been elected

    i. *Member, National Working Group of IGCP-380* on Correlation of Biosedimentology of Microbial Build-ups.

    ii. *Member, National Coordination Committee for Isotope Hydrology* (NCCIH) formed within the framework of International Hydrological Programme of UNESCO.

12. **Prof. S.P. Gupta** elected *Member of the Working Group on International Reference Ionosphere* in 1999 for four years.

13. **Dr. J. S. Ray** has been awarded the *Young Scientist Medal* of the Indian National Science Academy in the field of Earth Sciences.

14. **Dr. Tarun K. Pant** received the *PRL Gold Medal for the Best Thesis for the year 1998* for his thesis entitled 'Study of the low latitude thermosphere ionosphere coupling under varying geophysical conditions'.

15. The paper 'Laser microprobe for the analysis of noble gases and nitrogen in a single grain' by **Mahajan R.R., Prasad M.K. and Murty S.V.S.** has been awarded the *Best Paper* prize in the Instrumentation section, at the 8th ISMAS Symposium on Mass Spectrometry, held at Hyderabad, during 7-9, December 1999.

16. The paper 'Mg and K isotopic compositions and refractory, trace element abundances in early solar system solids' by **K.K. Marhas, A.M. Davis and J.N. Goswami** has been awarded the *Second* prize in the Earth and Planetary Sciences section at the 8th ISMAS Symposium on Mass-spectrometry, held at Hyderabad, during 7-9, December 1999.

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4. Hari Om Vats,"Radio Astronomy in India: Achievements and Future,", in "Space Research in India: Accomplishments and Prospects", Eds. Narayanan M.S. et al., Publ. P.R.L. Alumni Association, Ahmedabad, pp 245-271.

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   Near Infrared Investigations on regions of Star Formation
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1. **M.M. Kimothi, J.K. Garg, V. Joshi, R.L. Semwal, R. Pahari and N. Juyal**

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   3. Electronics Schematics, Telemetry, and Telecommands for SOXS Low Energy Detector (SLD) Payload

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   Ionization and Airglow in the Martian Atmosphere

Papers Presented in Symposia/Schools in 1999-2000

Astronomy and Astrophysics

1. "PRL Near Infrared Camera NICMOS-3", at the *East Asian Meeting on Astronomy*, January 3-6, 1999, **Kumring, China**, by **U. C. Joshi**.

2. "Current Trends in Imaging Spectroscopy in the Infrared Region", at the *Prof. V.A. Sarabhai 80th Anniversary Symposium on Vision for Space Science and Technology* , PRL, **Ahmedabad**, August 12-13, 1999, by **B.G. Anandarao.**

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10. "Infrared Studies of Early Type Stars and Infrared Studies of Close Binary Systems", at the *Workshop on Observational Programme with 2 m Class Optical Telescope* organised by UPSO/IUCAA at UPSO, **Nainital**, October 25-29, 1999, by **N.M. Ashok**.

11. a) "Fabry-Perot Interferometry", b) "Molecular Hydrogen Emission Lines as Probes of Star Forming Regions", at the *Workshop on Interstellar Molecules*, **Anantpur**, October 29-31, 1999, by **B.G. Anandarao.**

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14. "Solar Physics from High Altitude", at the *National Workshop on Science From High Altitude*, I.I.A., **Bangalore**, April 15-16, 1999 by **A. Ambastha**.

15. "Relationship of Non-potentiality and Flaring", at the *IAU Colloquium No. 179 on Cyclical Evolution of Solar Magnetic Fields*, IIA., **Kodaikanal**, December 13-16, 1999 by **A. Ambastha**.

16. "Flares and Eruptive, Energetic Activities in Solar Atmosphere", at the *Special Session on Recent Developments in Solar Physics, National Space Sciences Symposium*, **Puri,** March 1-4, 2000 by **A. Ambastha.**

17. "Helioseismic Solar Cycle Changes in Frequencies and Splitting Coefficients", at the *IAU Colloquium No. 179, Cyclical Evolution of Solar Magnetic Fields*, IIA, **Kodaikanal**, India, December 13-16, 1999, by **Tripathy S.C.**

18. "Accoustic Frequency Map of the Solar Disk", at the *National Space Science Symposium*, March 1-4, 2000, **Puri**, India, by **P. Venkatakrishnan**

Theoretical Physics

High energy Physics

19. "Neutrino Physics" (**a series of 9 lectures**), at the *15th SERC Main School on High Energy Physics*, Saha Institute of Nuclear Physics, **Calcutta**, 14 Febuary - 4 March, 2000, by **A.S. Joshipura**.

20. "Baryogenesis in the Early Universe" , at the *Annual Meeting of the Indian Academy of Sciences*, Central

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Nuclear Physics

21. "Transition Strength Sums and Quantum Chaos in Shell Model States", at the *National Seminars on Nuclear Physics*, at Institute of Physics, **Bhubaneswar**, July 26-29, 1999 by **V.K.B. Kota**.

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25. "VLF Emissions in Planetary Magnetosphere", at the *International Workshop on Co-ordinated Study of very low Frequency (VLF) Phenomena : Global Approach*, Barkatullah University, **Bhopal** during November 25-27, 1999, by **A. C. Das**.

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27. " Non-Ideal Effects in Dusty Plasmas", at the *Second International Conference on the Physics of Dusty Plasmas* (ICPDP-99), Hakone, **Japan**, during May 24-28, 1999, by **N.N. Rao**.

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31. "State Reconstruction for Systems with Two Degrees of Freedom" at the *Sixth International Conference on Squeezed States and Uncertainty Relations (ICSSUR VI),* **Napoli**, Italy, May 24-29, 1999, by **G.S. Agarwal**.

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38. "Decoherence and its Coherent Control", at the *Winter Institute on Foundations of Quantum Mechanics and Quantum Optics,* **Calcutta**, India, January 01-13, 2000, by **G.S. Agarwal.**

39. "Vacuum Induced Coherence", at the *School on Foundations of Quantum Mechanics and Quantum Optics,* **Calcutta**, India, January 01-13, 2000, by **G.S. Agarwal.**

40. "Non-linear Wave Packet Dynamics of Coherent States of Various Symmetry Groups", at the *School on Foundations of Quantum Mechanics and Quantum Optics,* **Calcutta**, India, January 01-13, 2000, by **J. Banerji**.

Planetary Atmospheres and Aeronomy

41. "Mapping of Red Sprites, Blue Jets and Elves at the Top of the Thunder Clouds using CCD Camera", *Workshop on Potential Indian Participation on Board International Space Station (ISS) for Conducting Scientific Experiments,* Indian Space Research Organization (ISRO) Headquarters, **Bangalore**, 9-10 July, 1999 by **S.P. Gupta**.

42. "Solar Wind Interaction with Mars", *XI National Space Science Symposium* at **Puri**, March 1-4, 2000 by **S.A. Haider.**

43. "Minor Atmospheric Constituents and their Chemistry", **Two** talks at *the UN Affiliated CSSTE AP, Third Post-Graduate Course on Remote Sensing and GIS, IIRS,* at **Dehradun**, March 31, 1999 by **Shyam Lal**.

44. "Global Warming - Protocol to the UN Framework Convention in Climate Change", *INSA Seminar on Advances in Science for Sustainable Environment and Development in the Next Decade (Energy and Food Security)* at PRL, **Ahmedabad**, December 19, 1999 by **Shyam Lal**.

45. "Tropical Atmospheric Chemistry and Global Change", *XI National Space Science Symposium,* **Puri**, March 1-4, 2000 by **Shyam Lal.**

46. "Plasma Instabilities and Their Simulations in the Nighttime Equatorial F-region", *XI National Space Science Symposium,* held at **Puri** during March 1-43, 2000 by **R. Sekar**.

47. "Behaviour of Tropical Tropopause", at the *National Workshop on Atmospheric Chemistry* at IITM, **Pune** October 12-14, 1999 by **D.K. Chakrabarty**.

48. "Atmospheric Effects of Solar Eclipse", at the *National Seminar on Total Solar Eclipse'99-Astronomical & Meoteorological Aspects,* at the Centre for Atmospheric Sciences, University College of Technology, Calcutta University, **Calcutta**, December 8, 1999 by **D.K. Chakrabarty**.

49. "Electrodynamics of the Equatorial Ionosphere", *XI National Space Science Symposium,* **Puri**, March 1-4, 2000 by **H. Chandra.**

Earth Sciences and Solar System Studies

50. "Moon as an Evolutionary Link in the Formation of Solar System", *Indian Acad. Sciences Meeting,* **Lucknow**, October 28-30, 1999 by **N. Bhandari**.

51. "Scientific Importance of Lunar Research", *Astronautical Society of India Meeting,* Space Applications Centre, **Ahmedabad**, February 4, 2000 by **N. Bhandari**.

52. "Life Beyond Earth", *Popular Lecture* given during the *IPA Symposium on Indian Space Programme for the New Millennium,* PRL, **Ahmedabad,** January 22-23, 2000 by **N. Bhandari**.

53. "Extinct Nuclides and the Formation of the Solar System", at the *Gordon Conference on the Origins of the Solar Systems,* **New Hampshire**, USA, June 13-18, 1999 by **J. N. Goswami**

54. "Chronology of the Early Solar System: Dating with Short-lived Nuclides", at the *ACS Symposium on Origin of Elements in the Solar System,* **New Orleans**, USA, August 22-26, 1999 by **J. N. Goswami**

55. "Origin and Early Evolution of the Solar System: Isotopic Constraints", at the *INSA Symp. Isotope Application in Earth and Planetary Sciences* , PRL, **Ahmedabad**, India, December 18-20, 1999 by **J.N. Goswami**.

56. "Challenges in Planetary Exploration", at the *IPS Symposium on Indian Space Programme for the New Mil-*

lennium, PRL, **Ahmedabad**, January 22-23, 2000 by **J.N. Goswami**.

57. "Cretaceous-Tertiary (K/T) Extinction and Deccan Volcanism", at the *Deccan Trap Basalts and the K/T Boundary Symposium*, PRL, **Ahmedabad**, November 25-26, 1999 by **P.N. Shukla**.

58. "Age and Duration of the Deccan Volcanism : A Review", at the *Deccan Trap Basalts and the K/T Boundary,* **Ahmedabad**, November 25-26, 1999 by **Kanchan Pande**.

59. "From Deccan to ReUnion : No Role for a Mantle Plume", at the *Deccan Trap Basalts and the K/T Boundary,* **Ahmedabad**, November 25-26, 1999 by **Hetu C. Seth**.

60. "Palaeoenvironmental Record from the Deserts of the Middle East", at the *XIXth Congress of the International Quarternary Union,* **Durban**, South Africa, August 1-9, 1999 by **K.W. Glennie** and A.K. Singhvi.

61. "Chemical Weathering of the Himalaya CO_2 Consumption and Marine Isotopic Budgets", at the *INSA Symp. Isotope Application in Earth and Planetary Sciences*, PRL, **Ahmedabad**, December 18-20, 1999 by **S. Krishnaswami**.

62. "Stable Isotope Studies on Sediment Cores from the Arabian Sea", at the *SEAMONS Working Group Meeting*, **Amsterdam**, May 17-22, 1999 by **R. Ramesh**.

63. "Sub-Milankovitch Climatic Cycles", at the *INSA-SCOR Meeting*, **Goa**, October 25-28, 1999, by **R. Ramesh**.

64. "Dipole Mode Oscillations in the Indian Ocean Recorded in Corals from the Red Sea", at the *PAGES Workshop*, **Pune**, February 4-5, 2000 by **R. Ramesh**.

65. "Uranium in Sea Water and its Removal in Sediments", at the *VIIIth National Symposium on Environment*, IGCAR, **Kalpakkam**, June 22-25, 1999 by **M.M. Sarin**.

66. "Changing Scenario with Respect to Water Quality in the Gangetic Plains", at the *NELDA Expert Meeting on Land Use Land Cover Changes in the Indo-Gangetic Plains - Data Related Issues*, **Faridabad**, October 28-30, 1999 by **M.M. Sarin**.

67. "High Resolution Holocene Palaeomonsoon Record from the Arabian Sea", at the *SCOR-IMAGES Workshop*, Trins, **Austria**, February 16-19, 2000 by A. Sarkar, **R. Ramesh**, B.L.K. Somayajulu, A. Agnihotri, A.J.T. Jull and G.S. Burr.

68. "Techniques in Thermoluminescence and Optically Stimulated Luminescence Dating and Dosimetry", at the *National Seminar on Luminescence Dosimetry - Recent Developments, Techniques and Applications*, **Mumbai**, July 31-August 1, 1999 by **A.K. Singhvi,** A.J. Kailath and M. Jain.

69. "The Thar Desert in Rajasathan during the Last Interglacial - Evidence from Dunes and Lakes : A Review", at the *XIXth Congress of the International Quaternary Union*, **Durban**, South Africa, August 1-9, 1999 by **A.K. Singhvi** and A. Kar.

70. "Thermoluminescence and Optically Stimulated Luminescence Dating of Loess-Palaeosol Sequences - Methodological Aspects and Palaeoclimatic Implications", *Loessfest 99*, **Bonn**, March 28 - April 1, 1999 by **A.K. Singhvi,** A. Bluszcz and M.D. Bateman.

71. "Climatic Record from Aeolian Sands and Silts", at the *British Association for Science*, **Sheffield**, September 14, 1999 by **A.K. Singhvi**.

72. "Palaeoclimatic Inferences from Eastern Arabian Sea Sediments", at the *Past Global Charges (PAGES) Workshop on South Asia Palaeoenvironments*, **Pune**, February 4-5, 2000 by **B.L.K. Somayajulu**.

73. "Past Monsoon Rainfall Variations Observed in Tropical Indian Speleothems", at the *PAGES Workshop*, **Pune**, February 4-5, 2000 by M. G. Yadava and **R. Ramesh**.

74. "Geochemical Applications of Stable and Radio Isotope in PRL", at the Workshop on Isotope Techniques for Hydrological Studies, **Calcutta,** January 8, 2000, by **S. K. Bhattacharya**.

Science at PRL

The Astronomy and Astrophysics Division is located at Thaltej (7 kms from main campus of PRL), and operates an observatory at Mt. Abu equipped with a 1.2m IR telescope and a host of world-class state-of-the-art back-end instruments - IR camera (NICMOS-3), large format CCD camera, Imaging Fabry-Perot spectrometer grating spectrographs, optical and IR polarimeters, high speed dual channel IR photometer etc., to cater to the needs of astronomers. The Udaipur Solar Observatory (USO) is equipped with three solar telescopes to make observations on Sun. A GONG experiment operates to probe the interior of Sun using helioseismology. PRL also plans to put an X-ray experiment (SOXS) on satellite platform to study the activity on Sun in soft X-rays.

Near IR Variability of Blazars

Four blazars AO 0235+164, PKS 0521-36, OJ 287 and PKS 2155-304 have been monitored for flux variability. These blazars have redshift range 0.06 to 0.60 and visual magnitude range 12.5 to 16.5. Since blazars display variability on diverse timescales, it was decided to study them over both short and long timescales, ranging from minutes to years. These blazars were observed in J passband on 9 nights at 1.2 meter telescope at Mt. Abu Observatory using NICMOS camera. Data analysis is in progress.

(Alok C. Gupta and U.C. Joshi)

Rapid Optical Variability in Radio-quiet QSOs

Eight radio-quiet quasi stellar objects (RQQSOs) have been observed at the Vainu Bappu Observatory and the Uttar Pradesh State Observatory during 1996-99. This is a part of an ongoing programme to search for intranight optical variability in RQQSOs. Additional evidence for very rapid variability was found in three of the five optically bright and very luminous RQQSOs which were observed earlier. Of these, two show strong hints of microvariability.

(Alok C. Gupta)

Multiband Photometry of Starburst Galaxies

A multiband (UBVRIH$_\alpha$) study of starburst galaxies was carried out based on CCD imaging from the 1.2 m Gurushikhar telescope. Twenty starburst galaxies from the Markarian lists were studied under this program. Some of the interesting results obtained are :

Optical Morphology

The morphology of the galaxies was studied through various broad bands, narrow-band H_α and colour maps. This study revealed that starbursts occur in a variety of morphological environments. The galaxies in which the starburst phenomenon is seen can be broadly grouped into S0's/E's, spirals and irregulars. Starburst activity as indicated by blue colours and H_α emission is seen predominantly in the central region of the galaxies. However, activity is not only confined to the central kpc, but is also found in the form of circumnuclear rings, at the ends of bars or even globally. Except in the case of Mrk 439, the line emission and the blue regions are coincident indicating that the same episode of star formation is responsible for both these observed results.

Structural Properties

The structural properties of the underlying galaxies were studied using ellipse fitting techniques. Isophotal twists were detected in all the S0's/E's galaxies in the sample. Signatures of dust were found in the central regions of Mrk 1379, Mrk 439 and Mrk 1134. A strong dust lane was detected in Mrk 449. Besides these, all the other objects appear to be relatively dust free along the line of sight. Ellipse fitting analysis reveals variety of fine structures indicative of mergers, hidden distortions like bars, rings of star formation, etc. Spiral arms extending right into the nuclear region were found in Mrk 363. We detect secondary bars in Mrk 213 and Mrk 1194.

(Aparna Chitre and U.C. Joshi)

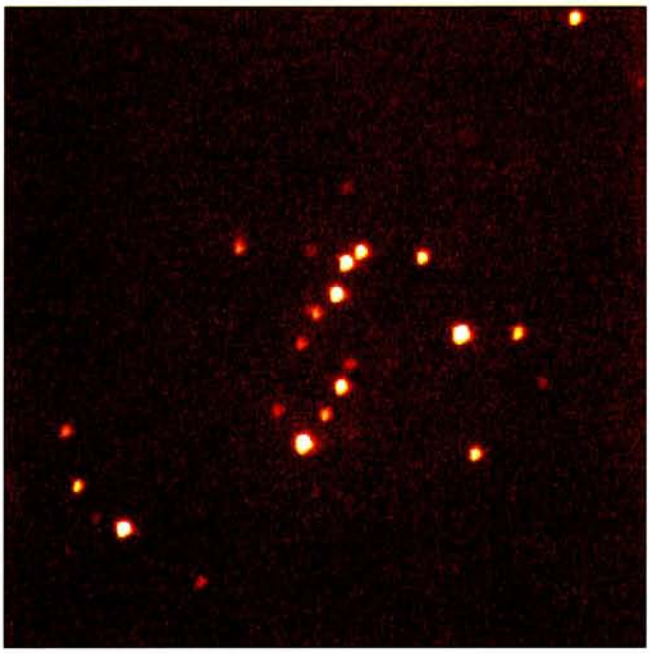

Fig. 1.1 RN07 in Lynds dark cloud L1340 observed with PRL-NICMOS Camra in J band at Mt. Abu on November 3, 1999.

Star Formation along a Misaligned Bar in the Peculiar Starburst Galaxy Mrk 439

Mrk 439 is a nearby early type starburst galaxy having a peculiar morphology. The galaxy image appears circular and featureless. The outer isophotes are smooth and nearly circular in B and R bands (**Fig.1.1**). However, in the inner parts isophotal contours show highly complex features. The presence of molecular bar in the central region, based on CO mapping, has been reported. Based on the images taken in visual bands B,R, H_α and near IR H-band, we find that the signature of the bar becomes progressively weaker at longer wavelengths. Massive star formation is detected along the bar. The comparison of H_α image with R and H-band images shows the bar to be misaligned with the main body of the galaxy. H_α image is also found to be aligned with CO image. The peak H_α emission does not coincide with the bluest region seen in the colour maps. We infer that the starburst is young since the stars in the burst have not started influencing the light in the near-infrared. This indicates that the galaxy has undergone some perturbation which triggered the bar formation and the starburst along the bar in recent times. There are indications of dust in the inner region of the galaxy. The stars in the bar are young and have not yet started influencing the light in the near infrared region.

(A. Chitre and U.C. Joshi)

GRB Counterpart : Follow up Observation

We continued follow up observations for the optical and IR counterparts of the Gamma Ray Bursts. Though optical counterparts for about half a dozen GRBs are detected, a large number are still required to attempt on the physical mechanism of their generation. Due to not-so-accurate and delayed localization of the GRBs we could not detect several GRBs tried this year - GRB 990506, GRB 991216 and GRB 000210 using NICMOS-3 as their counterpart fade quickly. We also did deep imaging to detect host galaxy of the GRB 00301C. This data is being analyzed. This year when HETE-2 is launched in space, it would be possible to obtain accurate position of the GRB within few minutes, making it easier to detect their counterparts in optical and IR. This program is followed in collaboration with Caltech group.

(K.S. Baliyan, U.C. Joshi, B.G. Anandarao, S. Ganesh, N.M. Ashok and C. Muthu)

Study of the Inner Milky Way

Our view of the Galactic Center region at optical wavelengths is impeded by the large amount of dust and gas towards this region of the Galaxy. At near IR wavelengths the extinction is much reduced. Using DENIS Survey observations in the near IR it was for the first time that a complete and homogeneous map of the extinction over a large area (> 20sq. degrees) around the Galactic Center was made by us. This extinction map is essential to study the inner Milky Way in more detail. With the understanding of the extinction in this area it will be possible to study the stellar populations in this highly complex part of our Galaxy. It will also be of some interest to trace out the structure of the inner Galaxy. Work is currently in progress along these lines using complementary data from other sources such as molecular surveys.

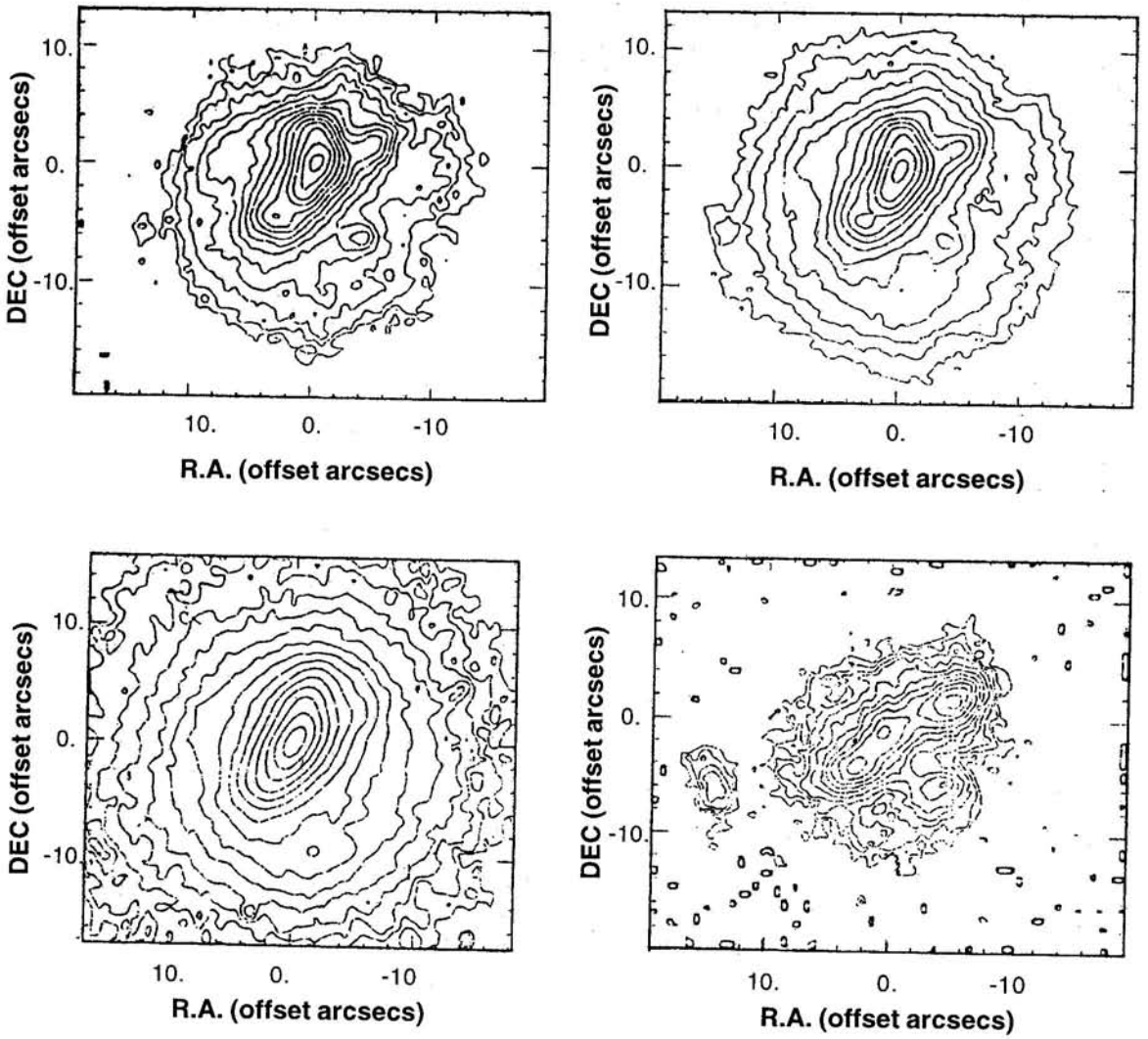

Fig. 1.2 Top panel : B (left) R (right) band contours. Bottom panel : H (left) and continuum subtracted H_α+ [NII] (right) isophotal contours of Mkn 439. North is at the top and East is to the left. The isophotal contours are plotted on a logarithmic scale at intervals of $0^m.3$ with the peak contours being at $17^m.5$, $17^m.0$ and $14^m.7$ for B, R and H respectively. The H_α+ [NII] contours are plotted such that the lowest contour corresponds to 2σ of the background.

Mid IR observations of the ISOGAL survey (a large European program with the Infrared Space Observatory) were used to make a mosaic of the view of the Inner Galactic Bulge at 7microns. At mid IR wavelengths the extinction is negligible and one hopes to have a more complete view of the inner Galaxy as compared to that at optical or near infrared wavelengths. Results of the analysis have been partly published. Further work is in progress to use this information in conjunction with the DENIS, 2MASS and MSX survey data. Some interesting regions identified in the course of the analysis of the survey data are being reimaged using the Mt Abu Infrared Telescope at relatively higher resolution. This work is part of Indo-French collaboration.

(S. Ganesh)

Study of Open Young Clusters

IR array has opened up new and exciting avenues for the study of heavily reddened open clusters in the

central part of galactic disk. These clusters are embedded inside the molecular gas and dust and contain extremely young stars. These stars contain varying amount of circumstellar gas and dust. For this reason they radiate substantially in IR. These young stellar objects can be classified in different categories based upon their infrared excess and spectroscopic character. This classification may be taken to represent phases of early stellar evolution - from protostar to young main sequence star. In order to understand the early stellar evolution and star formation, we have taken up the study of such young clusters using NICMOS-3 IR array at the Mt. Abu Observatory. Several such clusters NGC 6611, NGC 2453, NGC 2384 and NGC 1960 were observed - some of them in collaboration with Astronomy Group of Osmania University, Hyderabad. A new young cluster is detected in L1340 (**Fig. 1.2**).

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

Kinematics and CMDs of the Globular Cluster NGC 4147

Astrometry and BVRI CCD photometry of 115 stars down to B = 17.6 mag in the region of 11' x 11' in the globular cluster NGC 4147 was made. In the astrometric reduction, three earlier epoch plates taken at Sheshan, Shanghai, China, in 1958 and four recent epoch B-passband CCD frames taken at Kavalur, India, were used. The data were reduced to a catalogue based on measurements of stars on seven plates with an epoch period from 1917 to 1979 taken in Bonn, Germany, and ultimately to the Hipparcos catalogue. The reduction was done with central overlapping method. Based on the new proper motion data, the membership probabilities of 115 stars were determined. Furthermore, three colour magnitude diagrams (CMD) of V versus B-V, V-R and V-I respectively, for HB and GB stars were constructed from the CCD photometry obtained with the Vainu Bappu Telescope. An absolute proper motion of the cluster of -2.08 ± 0.48 mas/yr in right ascension and - 3.07 ± 0.46 mas/yr in declination has been obtained. The space velocity and apogalactic distance of the cluster with respect to the Galactic standard of rest were calculated. In contrast to the first results given in the literature we obtain a significantly lower velocity and a smaller apogalactic distance for NGC 4147.

(Alok C. Gupta)

A Complete Photometric Study of the Open Cluster NGC 7790 Containing Cepheid Variables

A new CCD photometry of the northern open star cluster NGC 7790 has been carried out in BVI photometric passbands down to V ~ 21 mag. 1150 stars were measured. Out of which for ~ 700 stars the data have been obtained for the first time. These along with all available photometric, spectroscopic and proper motion data have been used to derive the most reliable parameters for this cluster. The interstellar extinction over the cluster face is uniform and normal with E(B-V) = 0.51 ± 0.03 mag. A distance of 3.2 ± 0.23 Kpc has been determined to the cluster. The theoretical isochrone fitting to the Cepheid variables as well as evolving part of the main sequence near turn-off point indicate an age of 120 ± 20 Myr to the cluster. The cluster radius has been estimated to be 3'.7 using radial stellar density profile. Both distance and age determined using period luminosity/age relations for the Cepheid variables are consistent with their membership of the cluster. This unique opportunity has therefore been used to refine the zero-point of the period-luminosity relation for the Galactic Cepheids.

(Alok C. Gupta)

Kinematic Evidence for the Interaction of the Planetary Nebula NGC 246 with the Inter Stellar Matter

Spatio-kinematic observations were made on NGC 246 in the [OIII] 5007 A line using the PRL Imaging Fabry-Perot Spectrometer at Mt. Abu 1.2m telescope. First ever evidence for the deceleration effect was found in the leading edge of the nebular shell, due to its interaction with the interstellar medium (ISM). Indications were shown for the onset of the Rayleigh-Taylor Instability. Further, the [OIII] electron temperature derived from the slit-spectrographic data was shown to be longer in the leading half of the nebula than in the trailing half. This is attributed to the compressional heating of

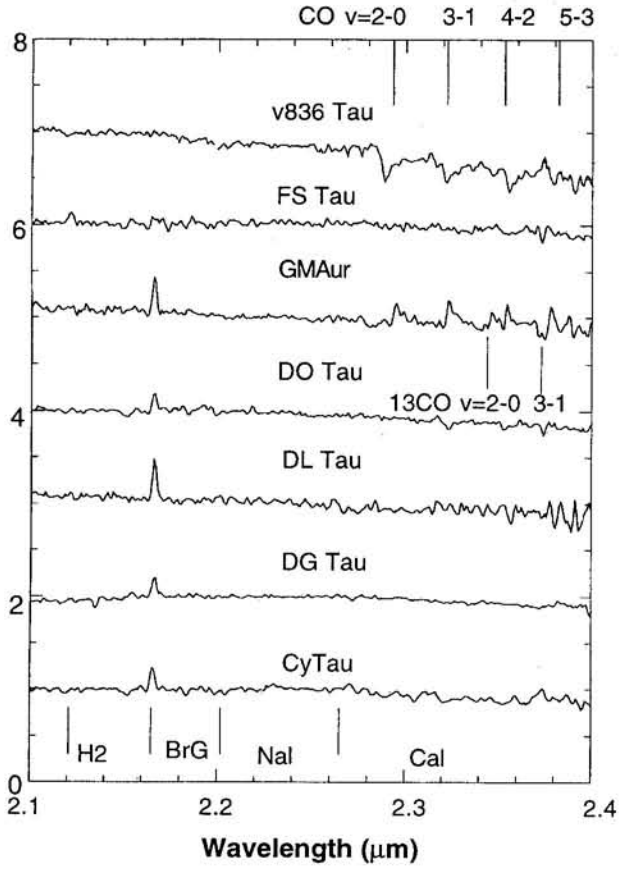

Fig.1.3 K band spectra of young stellar objects

the leading edge by the ISM. This work was done in collaboration with S.R. Pottasch of University of Groningen, Groningen, The Netherlands.

(B.G. Anandarao and C. Muthu)

Near-Infrared Spectroscopic Study of the Envelopes of YSOs

Several selected low-mass YSOs have been studied using the R = 1000 grating spectrometer attached with NICMOS IR array camera to understand their precise stage of evolution. The hot inner disks and the warm outer disks appear to coexist and to be in Kaplerian motion. Almost all the sources showed strong outflows through the Bracket γ emission line at 2.16 μm (**Fig.1.3**). One source namely FS Tau showed a modest emission in the molecular hydrogen vibrational line at 2.12 μm (v = 1-0 S(1)). This may be attributed to the presence of an infrared companion (so far undetected and unresolved) in the FS Tau multiple system.

(B.G. Anandarao and M.S. Nandakumar)

Detection of New Herbig-Haro Flows in the Star Forming Region L1340

L1340 is one of the most interesting molecular clouds in Cassiopeia. The visible part of the cloud is associated with three extended objects called RNO 7, 8 and 9 which are believed to be star forming cores. With an aim to identify new out-flows (called Herbig-Haro objects) from young stellar objects in these clouds we have proposed imaging observations in the [SII], H_α and Gunn Z filters on the 0.9m telescope of the Kitt Peak National Observatory in collaboration with the scientists there. These flows can best be identified in shock-excited [SII] lines at 6716/6735 A. The imaging detector is called MOSAIC which is a 8K x 8K mosaic of 8 2K x 2K CCDs providing a field of view of ~ 1 degree of arc with 0."423/pixel. Follow-up observations were made in the near infrared at Mt. Abu using the NICMOS camera. We have detected three new HH outflows in these objects which seem to be unique and interesting in several ways. These objects identified by us are given names of HH 487, HH 488 and HH 489 by an International Committee.

(B.G. Anandarao and M.S. Nandakumar)

Near IR Spectroscopic Observations of Classical Novae

In continuation of our nova programme, we obtained multi-epoch infrared spectra of two outbursting novae - Nova Sagittarii 1999 and Nova Aquilae 1999 No 2 with PRLNIC during this observing season. Nova Sagittarii 1999 was observed when its ejecta had become optically thin. The Paschen and Brackett emission lines are well-rounded and do not show much splitting, implying that the shell ejected in this outburst is uniform to a large extent. The ionization level of the ejecta is low because of the relatively larger ejected mass and low luminosity of the nova. The early spectra of Nova Aquilae 1999 No 2 show broad P Cygni absorptions in all lines. This is indicative of mass loss in an optically

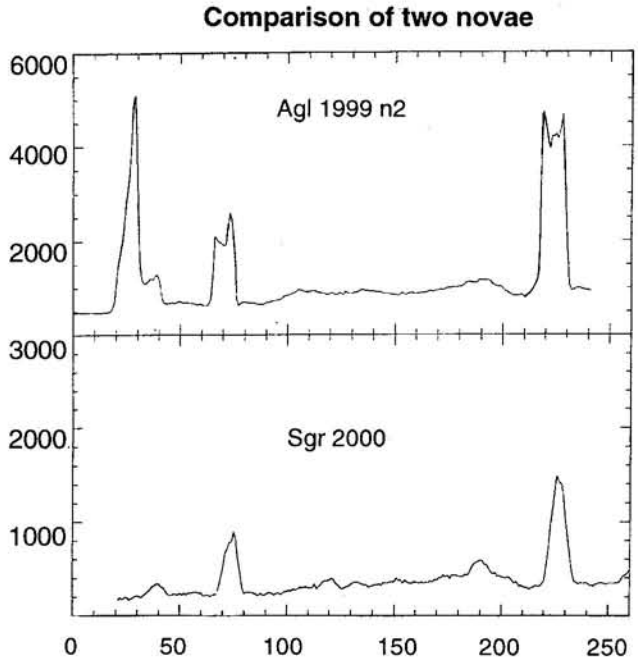

Fig. 1.4 J band spectra of young stellar objects

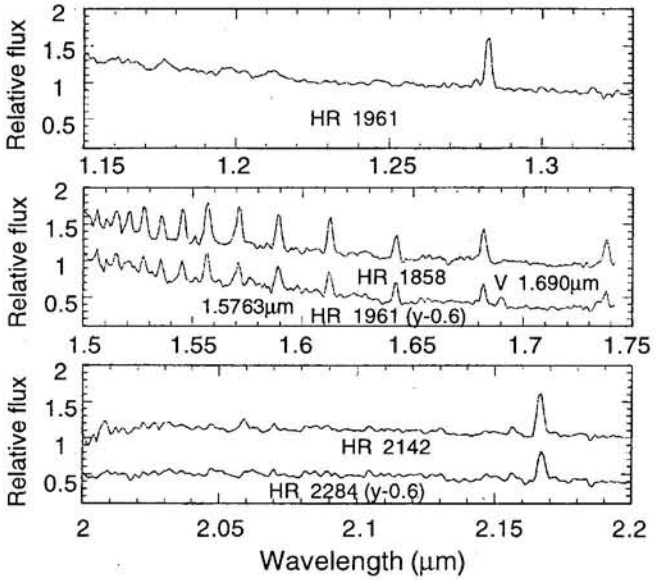

Fig. 1.5 J band spectrum of HR1961, H band spectra of HR 1868 and HR 1961, K band spectra of HR 2142 and HR 2284

thick wind. The emission lines also show a lot of structure, indicating that the ejected shell is clumpy. Also, the structure of the O I lines is quite different from that of Paschen and Brackett lines; this could be because of the inhomogeneities in the ejecta (**Fig.1.4**). The P Cygni absorptions have weakened with time and the ionization level of the ejecta has increased. This signals that the ejecta have become optically thin to the ionizing radiation of the central source.

(U.S. Kamath and N.M. Ashok)

Near Infrared Spectroscopic Studies of Be Stars

The Be stars are characterised by the Balmer line emission and IR excess. The limited observations taken by different groups in 1980s showed that the higher quantum level transitions of the Brackett Series are present in H band spectra in addition to Brγ emission line in K band. The observed line ratios deviated from the Case B values indicating optical depth effect. There is no systematic near infrared spectroscopic study covering the Brackett series emision lines of large number of Be stars in the spectral range 1.5 to 2.5μm. (**Fig.1.5**).

A programme of spectroscopy of Be stars has been initiated at Mt. Abu Observatory to investigate the characteristics of Be stars in the near infrared. The medium resolution (R=1000) JHK band spectra of 35 Be stars have been obtained using the Near Infrared Imager/ Spectrometer (PRLNIC) with NICMOS array. The Paschen α and Brackett γ emission lines are clearly seen in emission in majority of these stars. The higher order Brackett series lines from m=10 to 20 are detected in emission with significant strength compared to the Brackett γ emission line flux. The correlation studies of Brackett series and Paschen α lines with Balmer series H_α line will be done to study the optical depth effects in the regions where these lines originate.

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

Angular Diameter and Effective Temperatures of M Giants

Lunar occultation observations carried out at 2.2 μm (K band) at Gurushikhar Observatory during the past few years have resulted in a sample of 15 M giants. We have derived uniform disk (δ_{UD}) and limb darkened angular diameter (δ_{LD}) for 11 of these sources. Five of

these are first ever determinations of angular diameter (IRC - 10305, IRC - 20999, IRC 20090, IRC 10038, IRC - 10580). Effective temperatures were derived for these. For four other sources it has been possible to put stringent upper limits on angular size.

(Anandamayee Tej and T. Chandrasekhar)

Fine Structures in the Dust Shell of IRC 10216 from Lunar Occultation Observations at 2.2 Microns

IRC 10216 (CW Leo) is a carbon rich Mira variable with an unusually dense dust shell embedded in a larger molecular envelope. Though optically very faint its flux increases sharply in the infrared making it one of the brightest sources at mid infrared wavelengths. IRC 10216 has been the focus of attention for many years as it is an extreme carbon star evolving rapidly into a planetary nebula. Due to its large mass loss rate ($\sim 2 \times 10^{-5}$ M/yr), periodicity of ~ 630 days and proximity (distance ~ 120 pc) significant changes in the inner dust shell that take place on a time scale of a few years can be studied by high angular resolution observation in IR.

The lunar occultation observation of IRC 10216 in December 1998 in the IR K band at Gurushikhar has yielded a good quality occultation light curve with a lot of source structure at the level of a few milli arc seconds. Apart from the dominant source (A) at least three other secondary sources (B, C, D) can be resolved within the dust shell. The separation between these sources within the envelope in comparison with speckle observations of a few years earlier has altered signifying real changes in inner dust forming zone of this rapidly evolving star. A detailed study is in progress.

(T. Chandrasekhar and Soumen Mondal)

Search for Brown Dwarfs through Near Infrared Imaging of Open Clusters M45 and M48

The stellar mass function below hydrogen burning limit of 0.08 solar masses has remained extremely uncertain. Determination of the stellar mass function in the brown dwarf (BD) regime however is important since these objects could contribute significantly to the 'dark matter' in the galaxy. Until recently there were no convincing observations of brown dwarfs but the situation is changing rapidly especially with the advent of near IR imaging detector arrays. Another important open question is the minimum mass required for fragmentation of molecular clouds. It is important to characterize the properties of faintest BD candidates in order to guide the search of even lower mass objects.

Open clusters are ideal places to look for brown dwarfs. Brown dwarfs are bright when young and since open clusters are relatively young objects, brown dwarfs should be more easily detectable in them. Further it is possible to get a census of all stars in the cluster which facilitates the derivation of mass function even with the detection of a small number of objects. It is expected that M45 (Pleiades) alone could harbour several hundred brown dwarfs.

Observations of several 4' x 4' fields in M45 and M48 open clusters were carried out in J H and K filter bands using the PRL NICMOS IR array at Gurushikhar. The data is under analysis. This work is being carried out in collaboration with Dr. Kailash Sahu of the Space Telescope Science Institute, Baltimore, USA.

(N.M. Ashok and T. Chandrasekhar)

Pulsar Observations

Two pulsars, PSR 0950+08 (P=253ms) and PSR 1133+16 (P=1.18s) have been monitored for giant pulses with the Rajkot Radio Telescope (at 103 MHz) and with the Ooty Radio Telescope at 327 MHz. PSR 0950+08 has also been observed with the Westerbork Synthesis Radio Telescope, Netherlands at 297 MHz. Giant pulses have been seen from all three stations. Moreover all these observations have shown that giant pulses, both in their strength and frequency of occurrence, fluctuate wildly. There are stretches of observations where the pulses almost disappear, followed by stretches where giant pulses are seen which may be as much as two orders of magnitude above the average pulse strength. The time scales of these variations appear to be too short for either the refractive or diffractive scintillation, and we see a similar pattern at

frequencies which differ by a factor of three. Moreover many individual giant pulses observed in 0950+08 with the WSRT remain unresolved at milisecond time scales. This points to an origin of the giant pulse activity in an intrinsic phenomenon.

(Ashok K. Singal, Hari Om Vats and M. R. Deshpande)

Astronomical Seeing Measurements at Mt. Abu IR Observatory

PRL has been operating 1.2m telescope at Mt. Abu since the year 1995. The telescope site was selected on the basis of low water vapour content and good record of cloud free nights. An additional requirement of the site for astronomical observations is good seeing. Beginning December 1999 seeing measurements have been started using differential image motion mointor (DIMM) consisting of 35 cm Celestron telescope, an SBIG ST4 CCD camera and a PC. A mask in which two circular holes, of diameter 5 cm and separation of 20 cm, is put at the entrance of the telescope. A small wedge angle prism placed in one of the 5 cm holes deviates the incoming light by ~ 30 arcsec giving two images of the same star. Bright stars are imaged for 10 ms and 100 such frames are used to measure the centroids of the star images. The standard deviations of the differential image motion are used to estimate the seeing measurements done on 20 nights during December 1999 to March 2000. These measurements have shown several spells of subarcsecond seeing lasting for three to four hours on many nights indicating good seeing conditions at Mt. Abu Observatory site.

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

Empirical Model for *p*-mode Frequency Shifts

Empirical relations between the *p*-mode frequency shift and the change in solar activity indices are obtained, based on BBSO and GONG data for solar cycle 22. These relations are applied to estimate the change in mean frequency for the cycle 21 and 23. A remarkable agreement between the calculated and observed frequency shifts for the ascending phase of cycle 23 (**Fig.1.6**), indicates that the derived relations are independent of epochs and do not change significantly from cycle to cycle. These relations could be used to estimate the shift in *p*-mode frequencies for past, present and future solar activity cycles, if the solar activity index is known.

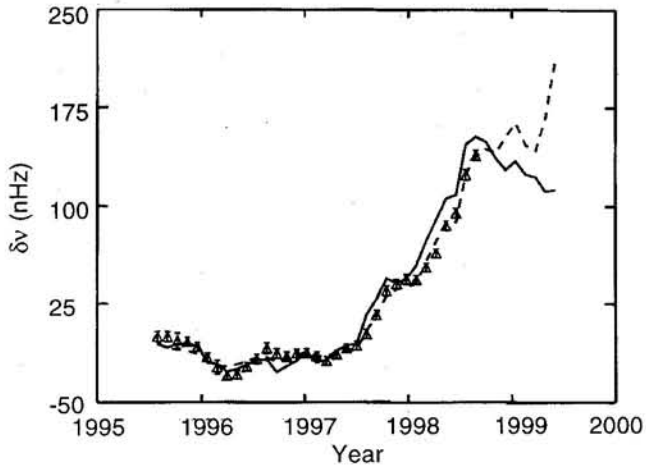

Fig. 1.6 The estimated and observed frequency shifts for 1995-1998. The solid line shows the shift as estimated from the sunspot numbers and the dashed line for the 10.7 cm radio flux. The triangles represent the observed frequency shifts from the GONG data.

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

p-mode Frequency Shifts and Total Solar Irradiance during Maunder Minimum

Using the empirical relation between mean annual sunspot numbers and shift in *p*-mode frequencies, the acoustic mode frequencies during Maunder minimum from 1645 to 1715 AD have been estimated. The maximum change in frequency during this period is found to be 11% of the maximum change during solar cycle 22. It is also found that the total solar irradiance and 10.7 cm radio flux decreased by 0.19% and 52% respectively, as compared to the average values for solar cycle 22.

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

Helioseismic Solar Cycle Variation and Splitting Coefficients

We have analysed the recently available GONG *p*-mode frequencies and splitting coefficients for a period

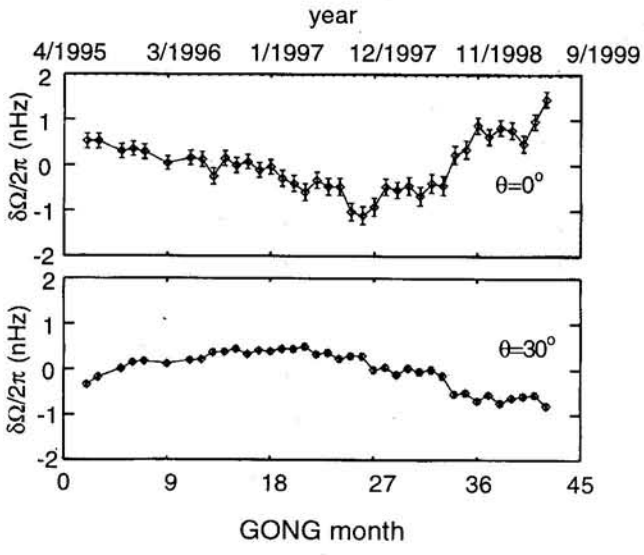

Fig. 1.7 The temporal variation of zonal flows (residual rotation rate) near the solar surface at two different latitudes.

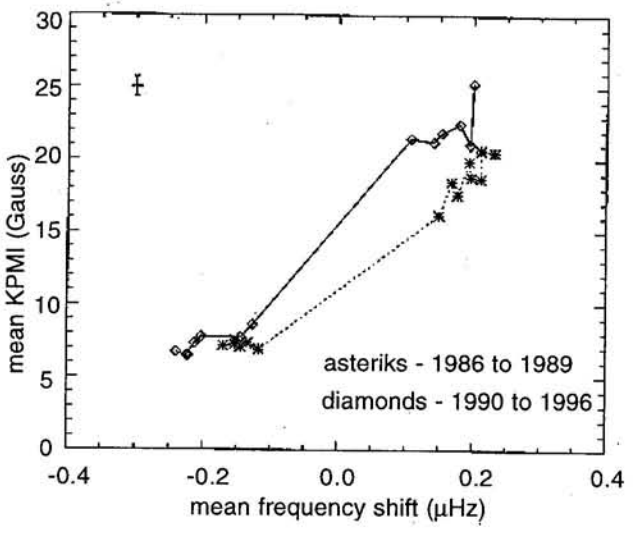

Fig. 1.8 Variation of Kitt Peak Magnetic Index (KPMI) with frequency shift for cycle 22. It is observed that the descending phase follows a higher track than the ascending one showing "hysteresis" phenomenon. The error bars at the top left corner indicate 1-sigma values.

of three and half years, including the rapidly rising phase of solar cycle 23. We find that the mean frequency shifts are equally correlated with both magnetic and radiative indices. During the onset of the new cycle 23, we notice that splitting coefficient, a_2, is linearly correlated with activity indices while higher order even coefficients are anti-correlated. However, odd order splitting coefficients do not show any significant change with time.

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

Solar Rotation Rate Inferred from GONG Data

Using the helioseismic techniques and GONG data, we have estimated the solar rotation rate with varying depth and latitude for a period of four years from May 1995 to August 1999. In the equatorial region, the rotation first increases with depth and then decreases while an opposite behaviour is seen in the polar region. We further notice that the change in rotation rate near the pole and equator is slower than the change in mid latitudes. We also find a significant temporal variation in the rotation rate (**Fig. 1.7**)

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

Observation of Hysteresis between Solar Activity Indicators and *p*-mode Frequency Shifts for Solar Cycle 22

Using intermediate degree *p*-mode frequency data sets for solar cycle 22, we find that the frequency shifts and magnetic activity indicators show a "hysteresis" phenomenon. It is observed that the magnetic indices follow different paths for the ascending and descending phases of the solar cycle; the descending path always seems to follow a higher track than the ascending one. For radiative indices, although both the phases follow different paths, separation between the paths is well within the error limits. We believe that this phenomenon may explain the reason for the better correlation of radiative indices with the frequency shift than the magnetic indices (**Fig.1.8**)

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

Acoustic Frequency Map of the Solar Disk

The variations in the acoustic spectrum are mapped on the solar disk in terms of the peak frequency of the

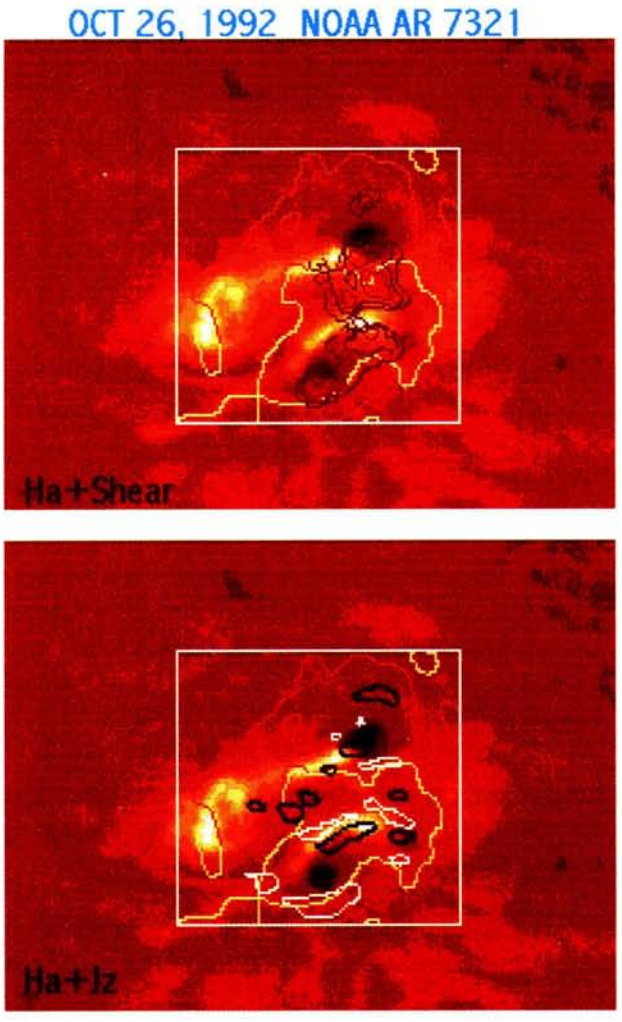

Fig. 1.9 H_α filtergram (halftone) of NOAA AR 7321 observed on October 26, 1992 along with the overlays of cotemporal maps of - (top) magnetic shear (dark brown contours) , and (bottom) vertical current Jz (black and white contours). These maps are derived from MSFC vector magnetograms. The contours of longitudinal magnetic fields at ± 10G level (light brown and yellow), and are also overlaid to show the magnetic neutral line. These overlays show the spatial association of magnetic shear and current with the M4/2B flare (bright patches) observed during 17:45-18:34 UT.

spectrum envelope using GONG Dopplergrams. It is seen that significant excursions of these frequencies occur on a spatial scale of 320 arc seconds. These excursions show neither any obvious signature near a sunspot, nor any rotation with the solar plasma.

(P. Venkatakrishnan, Brajesh Kumar and S.C. Tripathy)

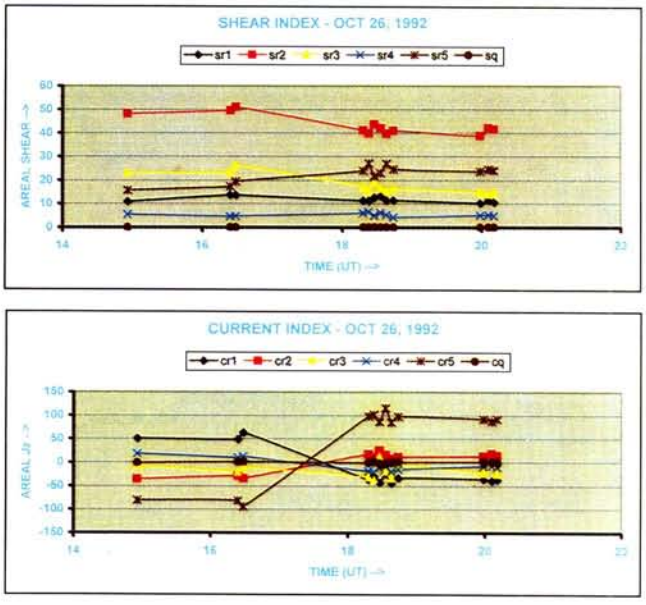

Fig . 1.10 Temporal evolution of the area-averaged magnetic shear and vertical current Jz computed over selected 30x30 arc-sec areas in NOAA AR 7321 covering time period of before, during, and after the M4/2B flare. The flare onset, maximum, and decay times are marked along the time axis. Locations near the flare patches showed remarkable changes both in shear- as well as in J_z - indices.

Changes in Magnetic Shear and Vertical Currents in Large Flares

Maps of local shear and vertical current density J_z have been deduced from the MSFC photospheric magnetograms. It is found that sites of large currents have a closer relationship with flares, than with strong shear. In some events, flare ribbons are seen in locations of low shear, but there are indications that they may be connected to remote sites of stronger shear through loop-like structures as seen in high-resolution H_α filtergrams (**Fig. 1.9**). The time series of area-averaged quantities of shear and vertical current density do not show significant changes during the period of flare, when evaluated at the large scale of the entire active region. In fact, the positive and negative currents nearly cancel out at this scale. On the other hand, at the smaller spatial scale of a pixel, it is difficult to follow the variations due to a variety of observational errors.

Therefore, we selected areas-of-interest (a-o-i) of intermediate spatial scale of around 30x30 arc-sec around flares and quiet locations for reference. Significant changes in area-averaged indices of shear, and in particular, J_z, are found in the flaring a-o-i's. Interestingly, we found that there is an increase in the J_z index at one flare ribbon, along with a corresponding decrease in another (**Fig. 1.10**). This may indicate exchange of shear between these locations due to twisting/detwisting of the field configuration. Although the search for flare-related changes in non-potential parameters is affected by a number of solar and non-solar effects, the method of averaging the physical parameters show promise in the understanding of flare evolution and mechanism.

(Ashok Ambastha and Shibu K. Mathew)

Complex H_α Loop Activity in a Long Duration Flare

A long duration flare (LDF) was observed in the active region NOAA 6555 on March 23, 1991 at a location of low magnetic shear. This flare displayed complex H_α loop activity during the decay phase. Initially, there were a few long loops oriented at an angle of 45 degree with the east-west axis. This was followed by their alignment parallel to the east-west axis. This configuration consisted of shorter loops than those seen in the initial phase of the flare. By using different magnetic field models, we have extrapolated the photospheric magnetograms to the chromospheric heights. The magnetic field lines computed by using the potential field model correspond to most of the H_α loops. This shows that no strong currents were present in the upper magnetic field configuration. The LDF involved a vast area of the active region, where magnetic shear was low. It is suggested that during the decay phase of the LDF, the flare energetic particles heated the chromosphere. As a result of the injection of the hot chromospheric material through the foot-points of the magnetic field lines, H_α loops were generated.

(Debi Prasad C., Ashok Ambastha and G.A. Gary)

Evolution of Large Scale Photospheric Magnetic Field during the Ascending Phase of Cycle 23

The uninterrupted observations of full-disk photospheric magnetograms obtained by GONG network was used to study the evolution of large scale photospheric magnetic field during the ascending phase of cycle 23. Before the polarity reversal for the present cycle the large scale bipolar magnetic regions (BMRs) are observed to last for 4 to 7 Carrington rotations (CR). The westward drift of the BMRs will be studied for their drift velocities and its correlation with net and total flux as well as with their spatial extent.

(Sanjay Gosai, B. Ravindra, P. Venkatakrishnan and Debi Prasad C.)

Polarization of Near Corona Observed during the Total Solar Eclipse of August 1999

Total solar eclipse observations during August 11, 1999, were successfully carried out from Isfahan (32° 40'N, 51° 38'E, 1597 mtr altitude), Iran, for the photometry and polarimetry of solar corona to a distance of up to 1.5 R-sun from the limb. Digital images were acquired through filters centered at 6993 A and 9500 A in the visible and near IR region. A f/12, 642 mm aperture lens system, and a cooled 1kx1k CCD detector were used for the observations. For polarization measurement at these wavelengths, we obtained images through a rotating polaroid, at four positions of angles 0°, 45°, 90°, and 135° during 1 minute 15 second period of the totality. Coronal polarization map of the inner corona has been obtained using these observations. Electron density distribution is being derived from the polarization map. The Institute of Advanced Studies in Basic Sciences, Zanjan (Iran) provided the support in making local arrangements for the USO-PRL team in Isfahan and Tehran.

(Ashok Ambastha, Shibu K. Mathew and Sudhir K. Gupta)

Mechanism of Solar Coronal Heating and Contribution of Different Class of Flares

There is a controversy about the role and contribu-

tion of micro/nano flares in coronal heating. In order to resolve the problem, we are carrying out a study of the distribution of flares as a function of their rise & decay time, and the peak fluxes, total energy. In addition, we expect to understand whether these flares have a common origin. The rise, decay and total flare times are expected to be intimately connected to the mechanism of solar coronal heating. For example, shorter rise/decay times may indicate impulsive heating; while longer decay times indicate that heating continues for longer times, and the heating mechanism is slow. We have initiated an analysis of GOES-7 soft X-ray (1-8 A) data to deduce the most common rise (t_R), decay (t_D) and total times (t_T) from a large sample of C-, M- and X-class flares observed during the solar maximum years 1990-92. We found $t_R = 6.25$, $t_D = 11.8$ and $t_T = 22.8$ minutes from the analysis of 758 M- and X-class flares in 1991. The data base is required to be increased to provide a better statistics. Therefore, it is planned to supplement this work with Ha observations using USO and Solar-Geophysical Data base.

(Ashok Ambastha and Udit Narayan)

Granulation and 5-min Oscillations in Photosphere

The high spatial resolution observations of solar photosphere obtained with G-band (4305A) filter from Sacramento Peak observatory (USA) on 08 October, 1998 have been analyzed using a special software developed by us. All the images were re-registered using cross-correlation technique, and appropriate corrections for flat field and dark current were applied. Using Sac Peak code all time lapse images were then destreched. A time series of these destreched images has been formed that revealed a k-ω diagram which enabled us to separate granules and predominant 5-min oscillations. Our analysis shows that power of 5-min oscillations increase at the boundaries of the bright granules and dark inter-granules. To confirm this significant result, we are extending our study to various regions on the photosphere and large data sample obtained by us.

(Lokesh Bharti and Rajmal Jain)

Evaluation of Seeing at the Island Site

The 15 cm coude telescope at the Udaipur island observatory was used to obtain high resolution images with the motivation of applying the technique of triple correlation in speckle imaging. We obtained information on the amount of image motion as a by-product. We converted the rms value of the image motion into the Fried's parameter r_0 that characterizes the seeing. We obtained a typical value of 13 to 15 cm. This translates into a seeing of about 0.8 arcsec at optical wavelength. This is an upper limit for the seeing, since the telescope's mechanical motions have not been eliminated. We have devised a method to obtain the atmospheric seeing, that is independent of the telescope's motion, which will be tried out in the near future.

(R. Sridharan and P. Venkatakrishnan)

Solar X-ray Spectrometer

PRL plans to put an experiment, the Solar X-ray spectrometer - SOXS on board an Indian Satellite to study X-ray spectrum of the Sun during the present solar cycle. The solar flares exhibit thermal and nonthermal spectrum in X-ray energy band and the available models do not explain them satisfactorily as they have hybrid spectral shapes. Many flares unambiguously show break in the energy during their spectral evolution and it has been found that this break varies as a function of time during the flare evolution. Such studies will be taken up with the planned SOXS experiment. The spectral shape of class C-type flares is extremely complex and vary throughout their evolutionary phase. The sub- KeV spectral resolution in the energy range <100 KeV may enable to better understand the mechanism of such flares.

The experiment comprises of two independent payloads, namely SOXS Low Energy Detector (SLD) payload, and SOXS High Energy Detector (SHD) payload. The responsibility for design, development, fabrication and delivery of SLD payload is of PRL. The lab model is now ready.

The SLD is based on solid state Si PIN and CZT detectors, which have been procured and successfully

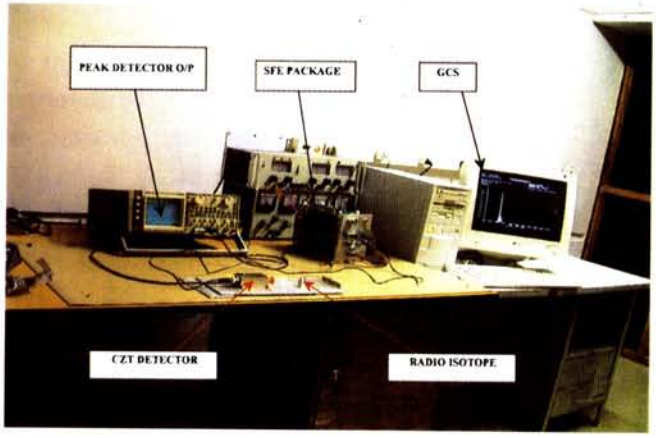

Fig.1.11 An integral line of the laboratory model testing of SLD/SOXS payload. The Cadmium-Zinc-Telluride (CZT) detector receives radiation from Fe55 radioisotope and the pulse-height signal is processed through front-end electronics to form the spectra through Ground-check-out-system (GCS).

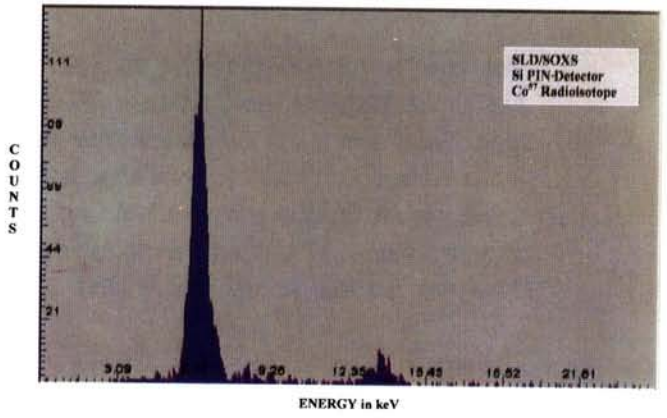

Fig. 1.12 The spectra from Si PIN detector, a candidate detector for SLD/SOXS payload, through Co57 radioisotope clearly indicating the peak at 6.27 keV line with a resolution < 500 eV. Note the small peak around 14 keV.

tested. The space qualified electronic hybrids viz. charge sensitive amplifier, pulse amplifier, DC/DC converters and BLR etc, have also been procured and tested.

The Lab model of the detector package was integrated with the front-end electronics and has been tested successfully. We have developed a Ground Checkout System (GCS) comprising of all features that are necessary for processing electronics. Using this GCS, recently, we have carried out an integral line testing of the detector and front-end electronics packages as shown in **Figure 1.11**. The detectors reveal sub-keV energy resolution, < 500eV at 5.9 keV as shown in **Figure 1.12**, required to achieving the scientific goals of the experiment. Work on the flight model is in progress.

(Rajmal Jain, M.R. Deshpande, H.H. Dave, K.S.B. Manian, N.M. Vadher, A.B. Shah, G.P. Ubale, G.A. Mecwan, J.M. Trivedi, C.M. Solanki, V.M. Shah, V.D. Patel and S.L. Kayastha)

Genesis of X-ray Flares

An analysis of a large sample of the solar X-ray flare observations made by SMM, YOHKOH, and GOES satellites during solar cycle 21 and 22 was carried out to compare flare classification based on hard X-ray (>10 keV) and soft X-ray (< 10 keV) data. The main findings are as follows :

1. More than 90% solar flares are of class C type, 5-10% of M class and only 0.10-1% are of X type.

2. Though it is well known that the occurrence frequency of solar flares is dependent upon the number of sunspots during the solar cycle, the class C type flares occur along the whole solar cycle. The expected number of M and X types of flares will be extremely small, < 5 flares per year, averaged over the whole descending phase of the current solar cycle ending in year 2006.

3. The class C type flares are low energy flares and visible up to < 100 keV, while the M and X type flares are more energetic and produce hard X-rays up to 300 keV or much above it. However, it was also observed that a few C type flares produce HXR emission to > 300keV and as well as GR emission. The production of such high-energy emission is purely dependent upon the magnetic field conditions in

the active region and the flare generating mechanism at that time.

The analysis of HXRBS/SMM data shows that almost 30% of class C type and 3% of M type flares are impulsive flares (rise time < 10s in hard X-ray band), while almost all X type flares are gradual and slow flares. Among all type of flares, 30% flares are impulsive and 70% are gradual flares, and in this 30% impulsive class, C type are 29% and rest, M and X type, are only 1%.

4. The flare recurrence in the same active region or in other region is generally observed at time interval > 20 minutes, however, on some occasions but very rarely flares with less than 20 min interval are also observed.

(Rajmal Jain, Pradhyuman Pathak, and M.R. Deshpande)

Astrophysics

Cosmic Microwave Background

Considering the earlier obtained wave equation in curved space, we solve it for the electromagnetic field tensors associated with CMBR photons in Friedman Universe with scalar perturbations. We have shown that the coupling of the electromagnetic fields with the curvature associated with the perturbations gives rise to an optical rotation of the microwave background photons. We have calculated the magnitude of the gravitationally generated V-Stokes parameter anisotropy. However, from the point of view of the present observational limits, the rotation of the plane of polarisation so obtained is rather small in comparison with the linear polarisation caused by Thomson scattering.

(S. Mohanty and A.R. Prasanna)

Photon Propagation in the Gravitational Field of Rotating Compact Objects

The wave equation in curved space time is considered on the background geometry of rotating objects (Kerr black holes, Hartle-Thorne metric) in the eikonal approximation and the dispersion relation is studied for the eigen values. Using these, one obtains the phase and group velocities of the photons for both longitudinal and transverse modes. Further, the actual trajectories of photons (modified due to the explicit presence of curvature terms) are being analysed to calculate various physical parameters like time delay, rotation of plane of polarisation, etc., to look for applications to observations related to millisecond pulsars in the background of black holes, or gravitational lensing and other related phenomena. This work was done in collaboration with M. Sofonova of Delhi University.

(A.R. Prasanna)

Charged Particle Trajectories in Electromagnetic Fields of Compact Objects

In continuation of our studies of charged particle trajectories in electromagnetic fields on curved space time, we are analysing the forces acting on a particle in the field of rotating compact objects. This study is needed to consider parameters like Alfvén radius of the compact object and other magnetospheric attributes. A rigorous analysis using Hartle-Thorne type of metric would provide the necessary background for considering plasma processes near ultra compact objects that lead to a better understanding of pulsar emission mechanisms, as well as the magnetic field structure of such objects. The particularly interesting feature one is looking for deals with the change in the magnetospheric structure that could arise due to centrifugal force reversal very close to ultra compact objects. This work was done in collaboration with A. Thampan of IUCAA.

(A.R. Prasanna)

Ellipticity of Ultra Compact Objects

The formalism developed to study inertial forces in general relativity, is being invoked to study the ellipticity of ultra compact objects through a sequence of quasi-stationary configuration keeping the mass and angular momentum conserved. Using the recently obtained scheme of Glendenning and Weber, we are analysing the change in the Kepler frequency at the equator of the compact object that would lead to change in the centrifugal acceleration. The exact nature of dependence of ellipticity on centrifugal and Coriolis forces (inertial drag of the frames) is being considered to see the change in ellipticity that would bring in change in shape of the compact object. One of the main ideas is to see the effective change in shape that could have an observable signature on the dynamics of the compact object.

(A.R. Prasanna)

Analysis of Self-similar Solution of Advection Dominated Accretion Flows around a Black Hole

It is well-known that accreting gas flow around a black hole possibly carry most of its internal energy into the black hole. In the regions very much far from the black hole, such flow could be described by self-similar solutions. However, in spectroscopic calculation self-similar solutions are used in the close proximity of the black hole. Also there are exact numerical solutions which could describe behaviour of the gas in the vicinity of a black hole. We have developed an analytical

perturbative method to incorporate effect of strong gravity of the black hole. We find that our analytical solutions matches well with the exact solution of the numerical code. We also find that for a certain parameter regime, there is a complete break down of the perturbation theory. Interestingly, in the same parameter regime numerical code face the difficulty of convergence. This might be indicative of a new branch of solutions, other than the self-similar, for the accretion flows.

(J.R. Bhatt and A.R. Prasanna)

Atomic and Molecular Physics

Inelastic Form Factor Born For Rydberg Stark States

The study of Rydberg atoms is an ongoing work. We have already reported that we have obtained a formula of the quantum inelastic form factor for transition between arbitrary excited states of parabolic coordinate system (Stark states) in terms of the Jacobi polynomials and, from which, have also derived a formula for Rydberg states (large parabolic quantum numbers) in terms of the Bessel functions. We have demonstrated that the earlier formula of the form factor, available in the literature, in terms of the Airy functions is a special case of the present formula. We have shown by numerical computation that the present formula gives accurate numbers over a wide range of the Stark states, ranging from low lying states to very high Rydberg states.

(D.P. Dewangan)

Quantum Dipole Moments For Transition Between Arbitrary Rydberg Stark States

Previously in the literature, basically three formulas of the dipole matrix element for Rydberg Stark states (i.e. parabolic states) were available. Two of these formulas were obtained using quasi-classical approaches in terms of the Airy functions. But there was a problem with these two formulas in that they differed from each other and it was not clear which of the two, if any, was the correct one. The third formula was derived using the the correspondence principle in conjunction with classical mechanics. It expressed the dipole matrix element in terms of the Bessel functions. As is known, the treatments based on the correspondence principle for large quantum numbers are of general interest. Indeed, there have been discussions in the literature on the region of applicability of formulas based on the correspondence principle in various context and also on how to extend the applicability region to lower quantum numbers but no satisfactory answer was found. In addition, it was not clear how the correspondence principle formula is related to the other two formulas. We have addressed these problems by deriving an *exact* quantal formula, without resorting to any quasi classical approximation, for the dipole transition between arbitrary Stark (parabolic) states in terms of the Jacobi polynomials. We have then obtained an asymptotic expression of the dipole moment in terms of the Bessel functions for large parabolic quantum numbers. We have shown that the present expression in terms of the Jacobi polynomials together with its asymptotic expression gives accurate values of the dipole matrix element, over an extended region of the parabolic quantum numbers, covering from the ground state to very high Rydberg states. We have derived the correspondence principle formula as a special case of the present formula and discussed the underlying approximations. Our analysis clarifies some long-standing points about the limitations of the two formulas expressed in terms of the Airy functions as well as about the region of applicability of the formula based on the correspondence principle. The wide region of applicability of the present approach implies that the previously obtained formulas are of mainly of academic interest.

(D.P. Dewangan)

The Tricomi Exapnsion and the First Born Approximation for Rydberg Atoms

In the literature on collisions of electrons with Rydberg atoms, the first Born cross sections are usually computed by introducing further approximation based on the Tricomi expansion to avoid the catastrophic cancellation errors caused by rapid oscillations of the Rydberg wave functions. To study the accuracy of this approach, we have devised a model for the first Born amplitude and calculated it exactly and also by using the

Tricomi expansion. A large deviation is observed indicating the need for further work.

(D.P. Dewangan)

High Energy Physics

Trilinear R Violating Interactions and Gauge Mediated SUSY Breaking

The neutrino mass spectrum was analyzed under the assumption that (1) soft symmetry breaking terms in the minimal supersymmetric standard model are generated by means of the gauge mediated interactions and (2) R symmetry is violated by trilinear terms and (3) all the trilinear terms are similar in magnitudes. Unlike the bilinear case, studied earlier, the trilinear interactions have richer phenomenology. The trilinear interactions between quarks and leptons can lead to solution of neutrino anomalies. In contrast, the trilinear interactions involving leptons alone cannot explain neutrino anomalies if all of these are assumed similar in magnitude.

(A.S. Joshipura, R. Vaidya and S. Vempati)

$U(1)_x$ Symmetry and R Violation

We systematically analyzed the consequence of assuming a spontaneously violated $U(1)_X$ symmetry at a high scale. The quantum numbers of supersymmetric multiplets under the $U(1)_X$ are assumed integer and are chosen so as to explain quark masses and mixing as well as charged lepton masses. This allows several possibilities for the $U(1)_X$ charges. Structure of R violating interactions in all these cases is investigated and it is shown that in all these cases one gets either phenomenologically inconsistent or extremely suppressed trilinear couplings. Thus $U(1)_X$ symmetry seems to lead to almost purely bilinear interactions.

(A.S. Joshipura, R. Vaidya and S. Vempati)

Chiral Symmetry Breaking, Color Superconductivity and Quark Matter Phase Diagram : A Variational Approach

We discuss in this note simultaneous existence of chiral symmetry breaking and color superconductivity at finite temperature and density in a Nambu-Jona-Lasinio type model. The methodology involves an explicit construction of a variational ground state and minimisation of the thermodynamic potential. There appears to be a phase at finite densities with both quark antiquark as well as diquark condensates for the "ground" state. Chiral symmetry breaking phase appears to catalyse the threshold for the diquark condensates to appear. We also compute the equation of state, and obtain the structure of the phase diagram in the model.

(Hiranmaya Mishra and Jitendra C. Parikh)

Pair Production of Light Pseudoscalar Particles in Strong Inhomogeneous Fields by the Schwinger Mechanism

We generalize the Schwinger mechanism and calculate the probability of the decay of intense electromagnetic fields to pseudoscalar particles. In the SLAC E144 experiment electron-positron pairs are produced from the interaction of intense laser fields with a high energy electron beam (by a multiphoton Breit-Wheeler process). We show that from the experimental result that the laser field does not decay into pseudoscalars by the Schwinger process, one can constrain the allowed region of pseudoscalar mass and the pseudoscalar-photon coupling. A better constraint on pseudoscalar properties is obtained from the observation that over the lifetime of the universe the atomic electric field has not decayed into pseudoscalars by any significant probability. In particular we show that the stability of the hydrogen atom over the lifetime of the universe rules out the Peccei-Quinn symmetry breaking scale f_a in the range 1.6×10^7 GeV $< f_a < 1.6 \times 10^{11}$ GeV. This work was done in collaboration with J.A. Grifols and Eduard Masso (Autonoma University, Barcelona).

(K.V. Shajesh and S. Mohanty)

Neutrino Oscillations and the Effect of Finite Lifetime of the Neutrino Source

We consider a neutrino source at rest and discuss a condition for the existence of neutrino oscillations which derives from the finite lifetime of the neutrino

source particle. This condition is present if the neutrino source is a free particle such that its wave function is non-stationary. For a Gaussian wave function and with some simplifying assumptions, we study the modification of the usual oscillation probability stemming from finite source lifetime. We discuss some experimental situations where the source lifetime becomes relevant in the oscillation formula. This work was done in collaboration with W. Grimus (Vienna University).

(S. Mohanty and P. Stockinger)

Leptogenesis with Heavy Majorana Neutrinos Reexamined

The mass term for Majorana neutrinos explicitly violates lepton number. Several authors have used this fact to create a lepton asymmetry in the universe by considering CP violating effects in the one loop self-energy correction for the decaying heavy Majorana neutrino. We compare and comment on the different approaches used to calculate the lepton asymmetry including those using an effective Hamiltonian and resummed propagators. We also recalculate the asymmetry in the small mass difference limit.

(R. Rangarajan and H. Mishra)

A Critique of Spontaneous Baryogenesis

We criticise a basic assumption in the original spontaneous baryogenesis models, namely that a time varying scalar field coupled to the baryonic current in the Lagrangian provides an effective potential for baryon number. We show that if the scalar field ϕ is a dynamic field then the term ϕj^0_B in the Lagrangian does not enter the Hamiltonian, where j^μ_B is the baryonic current, just as the energy of a charged particle moving in a magnetic field is not affected by the velocity dependent interaction with the magnetic field. Therefore, the simple argument that the baryon and antibaryon energies are shifted by ϕ is not valid, if ϕ is a dynamic field. This work was done in collaboration with A. Dolgov at INFN, Ferrera, Italy and K. Freese at the University of Michigan, Ann Arbor, USA.

(R. Rangarajan)

Fermion Dipole Moments in Supersymmetric Models with R-Parity Violaion

A simple analysis was proposed that allows the extraction of the leading mass dependence of the dipole moment of matter fermions that might be induced by new physics. Explicit results were obtained for the supersymmetric standard model with broken *R*-parity as an illustration. It was shown that the extra contributions to the electric dipole moment of fermions from *R*-parity violating interactions can occur only at two loop level, contrary to claims in the literature. Further, unlike the generic lepto-quark models, the extra contributions to the dipole moments of the leptons can only be enhanced by m_b / m_l and not by m_t / m_l relative to the expectations in the standard model. Using experimental constraints on the electric dipole moments of e^- and n bounds are obtained on (the imaginary part of) products of *R*-parity violating couplings. This work was done in collaboration with R.M. Godbole, S. Pakvasa and X. Tata.

(S.D. Rindani)

Neutrino Anomalies in an Extended Zee Model

An extended SU(2) x U(1) model is proposed which naturally leads to mass scales and mixing angles relevant for understanding both the solar and atmospheric neutrino anomalies. No right-handed neutrinos are introduced in the model. The model uses a softly broken $L_e - L_\mu - L_\tau$ symmetry, where L_e, L_μ and L_τ are respectively e, μ and τ lepton numbers. Neutrino masses arise only at the loop level. The one-loop neutrino masses which arise as in the Zee model solve the atmospheric neutrino anomaly while breaking of $L_e - L_\mu - L_\tau$ generates at two-loop order a mass splitting needed for the vacuum solution of the solar neutrino problem. A somewhat different model is possible which accommodates the large-angle MSW resolution of the solar neutrino problem.

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

Naturally Light Sterile Neutrinos

The explanation of the atmospheric neutrino anomaly implies a positive evidence of neutrino oscillation

whereby a muon neutrino oscillates into a tau neutrino. There are also indications of neutrino oscillations in the neutrinos coming from the sun. There is also an evidence of neutrino oscillation reported by the LSND experiment. All these results can be explained simultaneously by extending the standard model to incorporate a sterile (non-interacting) neutrino. Incorporating such light sterile neutrino with large mixing with the other light neutrinos is non-trivial. We proposed a new scenario with an SU(2) symmetry, which can provide a naturally light sterile neutrino with large mixing with the other left-handed neutrinos. The lepton number violation associated with the neutrino mass can generate a baryon asymmetry of the universe in this model.

(U. Sarkar)

Neutrino Masses and Baryon Asymmetry of the Universe

We pointed out that the lepton number violation implied by the Majorana masses of the neutrinos would wash out any baryon asymmetry of the universe (BAU) in the presence of the sphalerons. This gives a model independent bound on the Majorana masses of the neutrinos. From the same consideration two classes of interesting models of neutrino masses, namely, the Zee type radiative models and the R-parity breaking generic supersymmetric models are ruled out, except when these models are suitably extended. We also used the gravitino bounds from cosmology to discriminate models of neutrino masses in some supersymmetric inflationary models. These works were done with Ernest Ma of the University of California at Riverside, USA, David Delepine of DESY, Germany and Thomas Hambye of Frascatti, Italy.

(U. Sarkar)

Constraining New Gravitational Interactions from Neutrino Experiments

If there are new gravitational interactions which modify the general theory of relativity, they will contribute to the neutrino experiments. We pointed out that the contribution of these new interactions to the neutrinoless double beta decay is significant. Thus the non-observation of the neutrinoless double beta decay gives strong bound on the amount of these new interactions. These works were done with Hans-Volker Klapdor-Kleingrothaus and Heinrich Paes of Max-Planck-Institut fur Kernphysik at Heidelberg, Germany.

(U. Sarkar)

Nuclear Physics

Transition Strength Sums and Quantum Chaos

For the embedded Gaussian orthogonal ensemble of random matrices (EGOE), the transition strength sums vary with energy as the ratio of two Gaussians. This general result, derived by PRL scientists earlier, is compared to exact shell-model calculations of occupancies and Gamow-Teller strength sums using two different hamiltonians generating order-chaos transitions in ^{24}Mg nucleus. Good agreement is obtained in the chaotic domain of the spectrum, and strong deviations are observed as nuclear motion approaches a regular regime. Thus transition strength sums (they follow Dyson's Δ_3 statistic) seem to be a new statistic sensitive to the chaoticity of the system. For further confirming the generality of this result, occupation numbers and strength sums generated by some simple one-body transition operators are calculated for a one plus two-body embedded ensemble EGOE(1+2) generated by a mean-field producing one-body Hamiltonian h(1) plus chaos generating two-body ensemble {V(2)}, with six particles in 12 single particle states. **Fig. 2.1** shows the results for occupancies. These studies shed new light on the newly emerging understanding that in the chaotic domain of isolated finite interacting many particle systems smoothed densities, generated by embedded random matrix ensembles, define the statistical description of these systems. This work is done with R. Sahu (Berhampur), K. Kar (Calcutta), and J.M.G. Gómez and J. Retamosa (Madrid, Spain).

(V.K.B. Kota)

Strength Functions and Breit-Wigner to Gaussian Transition

Strength functions (also called local spectral density of states) are basic ingredients of a many particle

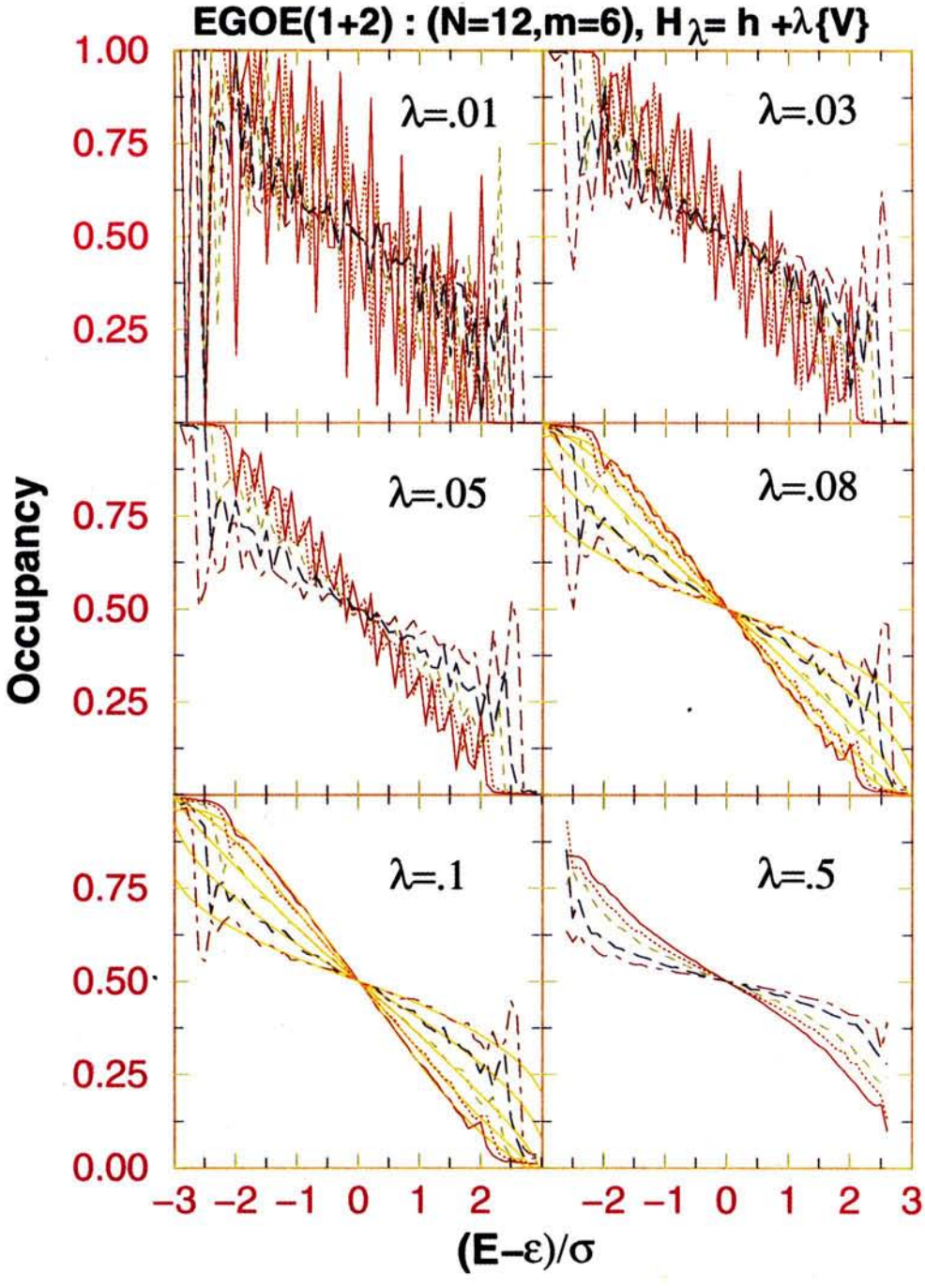

Fig. 2.1 Occupation numbers vs energy (E) for a 25 member (1+2)-body embedded ensemble defined by the Hamiltonian h (1)+ λ{V(2)}. In the calculations, the energy of the i^{th} single particle state is i + (1 / i). Results are shown for the lowest 5 single particle states and for six values of λ. Note that the energies are zero centered (ε is centroid) and scaled to unit width (σ is width). λ_c ~ 0.05 marks the order-chaos border in the sense that here level fluctuations make transition from Poisson to Wigner form. It is clearly seen that once chaos sets in, the occupation numbers take stable smoothed forms. For λ= 0.08 and 0.1 the EGOE smoothed forms are also shown.

system; given a compound state | k >, the probability of its decay into stationary states | E > defines the strength function $F_k(E)$. Starting with EGOE(1+2) Hamiltonian $h(1)+ \lambda\{V(2)\}$, it is expected that for sufficiently large values of λ, EGOE description should be valid and therefore the shape of the strength function should be Gaussian. However, the standard form, normally employed in many applications, for strength functions is the Breit-Wigner form. We have investigated numerically the nature of $F_k(E)$ as a many particle system makes order-chaos transition and found that order-chaos transition implies transition from Briet-Wigner to Gaussian form for strength function. However, the value of λ for which this transition occurs is found to be much larger, just as in some ^{24}Mg shell model calculations, compared to the value of λ that marks order-chaos transition in level statistics and strength sums. Thus there are at least two layers of chaos in interacting particle systems such as atomic nuclei. This work is done with R. Sahu (Berhampur).

(V.K.B. Kota)

Matrix Elements of One-Body Transition Operators in the Quantum Chaotic Domain of Interacting Particle Systems

Demonstrating the equivalence between the recent theory of Flambaum and collaborators which is based on smoothed strength functions, with the much earlier formulation (developed in the context of time reversal non-invariance in slow neutron resonances) due to French and collaborators which is based on embedded random matrix ensembles and smoothed transition strength densities, derived is a theory for matrix elements of one-body transition operators in the quantum chaotic domain of isolated finite interacting particle systems with a mean-field and a chaos generating two-body interaction (V). The role of the bivariate correlation coefficient (ζ) arising out of the non-commutability of V and the transition operator (in Flambaum et al. theory $\zeta = 0$) is tested in numerical embedded ensemble calculations with a one plus two-body Hamiltonian generating order-chaos transitions. This work is done with R. Sahu (Berhampur).

(V.K.B. Kota)

Plasma Physics

Instabilities in Partially Ionized Plasma

In continuation of our study on the role of neutral dynamics in a partially ionized plasma, we have investigated the instability triggered by the equilibrium pressure gradient of neutrals. It is found that this instability gets damped as a result of neutral dynamics. Following the same concept and approach demonstrated earlier in partially ionized plasma, we have been currently investigating the role of neutral dynamics in a partially ionized dusty plasma where it is assumed that a substantial quantity of dust remains uncharged. In particular, a study of an instability in such a plasma is being carried out in which the perturbations in neutral dust grains are considered to be important. This work is done in collaboration with A.A. Shaikh, C.U. Shah Science College, Ahmedabad.

(A.C. Das)

Electrostatic Modes and Instabilities in Non-Ideal Dusty Plasmas with Sheared Flows and Grain Charge Fluctuations

The combined effects of non-ideal contributions and grain charge fluctuations on the propagation of low-frequency electrostatic modes such as the dust-acoustic waves and drift waves as well as on the excitation of (parallel) Kelvin-Helmholtz instabilities in a dusty inhomogeneous magnetoplasma are investigated. In the low-frequency regime, dust-acoustic waves and drift waves are recovered with modifications due to the non-ideal as well as charge fluctuation contributions. Magnetized dusty plasmas support dust temperature gradient driven drift wave which exists even in the absence of density inhomogeneities. In the dust gyro-frequency regime, the electrostatic dust cyclotron mode is modified by the transverse shear in the field aligned flow. The other branch of the cyclotron mode becomes unstable when the shear flow exceeds a threshold value which is determined by the ratio of the parallel to perpendicular component of the wavenumber. In general, the charge fluctuation leads to an overall decrease in the growth rate of the excited instability. For the Kelvin-Helmholtz

configuration, we show the existence of a temperature gradient driven instability which occurs when the relative flow speed between adjacent layers exceeds a critical value. The latter is found to be much smaller than the dust-acoustic phase speed which is applicable for the density gradient driven Kelvin-Helmholtz instability. On the other hand, the effects of the non-ideal contributions in the two cases show quantitative behavior which are complementary to each other. For frequencies larger than the charging frequency, there is a net reduction in the growth rate of the instabilities due to the grain charge fluctuations.

(N.N. Rao)

Effect of Dust Charge Inhomogeneity on Linear and Nonlinear Dust-Acoustic Wave Propagation

Propagation of linear as well as nonlinear dust-acoustic waves (DAWs) in an inhomogeneous dusty plasma consisting of electrons, ions and dust particles is investigated by taking into account equilibrium dust charge inhomogeneity along with the density inhomogeneity of the plasma and dust particles. For the linear case with harmonic perturbations, coupled equations for self-consistently determining the wave amplitude and the wavenumber have been derived. On the other hand, nonlinear DAWs are shown to be governed by a Korteweg-de Vries (KdV) type of evolution equation having variable coefficients arising due to charge and density inhomogeneities. Qualitatively, the amplitudes of the linear and nonlinear DAWs are found to decrease (increase) as the waves propagate into regions of increasing (decreasing) dust charge, which is similar to the behavior found in the case with density inhomogeneity alone. Quantitatively, the amplitude of the dust number density perturbation in the linear wave is proportional to $q_{d0}^{-3/2}$, $n_{d0}^{-1/2}$, for a cold dusty plasma, while in the nonlinear regime it scales as q_{d0}^{-1}, $n_{d0}^{-1/4}$. Approximate analytical solutions of the KdV equation have been obtained by making use of a suitable set of coordinate transformations.

(S.V. Singh and N.N. Rao)

Triple-Hump Upper-Hybrid Solitons

Nonlinear propagation of coupled upper-hybrid and magnetoacoustic modes in a magnetized plasma is investigated within the framework of generalized SchrÖdinger-Boussinesq (or,-KDV) system of equations. The latter includes nonlinearities in the low-frequency response of the plasma up to cubic order in the magnetoacoustic wave amplitude. For stationary propagation, a new type of upper-hybrid soliton consisting of triple-hump structured field intensity accompanied by density trough having single-dip profile is obtained. This solution may be considered as the higher—order nonlinear stationary eigenstate of the upper-hybrid field trapped in the self-created density cavity. The existence of single-hump and double-hump solitons as well as parameter regimes for the integrable coupled mode propagation are also discussed. This work was carried out in collaboration with P.K. Shukla.

(N.N. Rao)

Dust-Coulomb Waves in Dense Dusty Plasmas

Dusty plasmas can be considered as tenuous, dilute or dense when the dust fugacity parameter $f \equiv 4\pi n_{do}\lambda_D^{\,2} R \sim N_D R/\lambda_D$ satisfies $f \ll 1, \sim 1$, or $\gg 1$, where n_{do}, λ_D and R denote respectively the dust number density, the plasma Debye length and the dust grain size (radius), and $N_D = n_{do}\lambda_D^{\,3}$ is the dust plasma parameter. Dense dusty plasmas are shown to support a new kind of ultra low-frequency electrostatic dust mode which may be called the *Dust-Coulomb Wave* (DCW). In contrast to the dust-acoustic wave (DAW) and the dust-lattice wave (DLW) which exist even for constant grain charge, DCWs are accompanied by dust charge as well as number density perturbations which are proportional to each other. For frequencies much smaller than the grain charging frequency, DCWs propagate as normal modes with the phase speed $C_{DC} \equiv q_{do}/\sqrt{m_d R}$ where $q_{do}(m_d)$ is the charge (mass) of the dust grains. In the long wavelength limit, the DCW phase speed is much smaller than that of DAW (C_{DA}), and scales as $\sim C_D/\sqrt{f}$ Thus, for a given wavenumber, the frequency

regime for the existence of DCW is much lower than the DAW regime. A comparison between the three types of dust-modes (DCWs, DAWs and DLWs) has been carried out.

(N.N. Rao)

Dust-Coulomb and Dust Acoustic Wave Propagation in Dense Dusty Plasmas with High Fugacity

A detailed investigation of electrostatic dust wave modes in unmagnetized dusty plasmas consisting of electrons, ions and dust grains has been carried out over a wide range of dust fugacity and wave frequency by using fluid as well as kinetic (Vlasov) theories. In particular, attention is focused on the *Dust-Acoustic Waves* (DAWs) and the *Dust-Coulomb Waves* (DCWs) which exist in the tenuous (low fugacity) and the dense (high fugacity) regimes, respectively, when the wave frequency is much smaller than the grain charging frequency. Unlike the DAWs which exist even with constant grain charge, the DCWs are the normal modes associated with grain charge fluctuations, and exist in dense dusty plasmas. In the long wavelength limit, the DCW phase speed scales as ~ $C_{DA}/\sqrt{f}$ where C_{DA} is the DAW phase speed and f is the dust fugacity. In the dilute (medium fugacity) regime, the two modes merge into a single mode, which may be called the *Dust Charge-Density Wave* (DCDW) since the latter involves contributions arising from both the DAW and the DCW. On the other hand, for frequencies much larger than the charging frequency, DAWs are shown to exist also in the dilute regime. The real frequency as well as the damping rate in each case are explicitly calculated from both the fluid as well the kinetic theories, and a comparison between the two has been carried out. In the allowed fugacity regimes (tenuous, dilute or dense), all the three waves are weakly damped and, hence, can propagate as normal modes. The present analysis of wave propagation in dusty plasmas over different fugacity regimes suggests the introduction of a new length scale defined by $\lambda_R \equiv d_{ws}\sqrt{d_{ws}/3R\delta}$ where d_{WS} is the Wigner-Seitz radius, R is the grain size (radius), and δ is a parameter related to the charging frequencies. This length scale which governs the dispersive properties of the DCW modes is most useful in the dense regime, and plays a role which is very similar to that of the Debye length in the tenuous regime. The very recent experimental observation on a self-excited instability associated with grain charge fluctuations may be an indication of DCWs in the strong coupling regime. The possibility of the existence of a dust thermal wave (DTW) in the super dense regime has been pointed out. An heuristic, but simple, derivation of DCWs based on grain dynamics but supplemented by physical inputs from the plasma response has also been presented.

(N.N. Rao)

Electrostatic Dust Modes in Self-Gravitating Dense Dusty Plasmas with High Fugacity

Self-Gravitational Instabilities in Dusty Plasmas have been investigated over different regimes of dust fugacity. The Jeans instability associated with dust-acoustic waves is shown to exist in the low fugacity regime. On the other hand, in dense dusty plasmas characterized by high fugacity, the instability is found to occur at much smaller scale sizes, and is associated with dust-Coulomb waves. The general case of arbitrary fugacity corresponding to dust charge-density waves and the associated Jeans instability has also been discussed. A comparison between the critical Jeans lengths for the different cases has been carried out. This work was carried out with F. Verheest.

(N.N. Rao)

A Kinetic Description for the Low Frequency Longitudinal Waves in a Dust Plasma including Charge Fluctuations

A kinetic description is presented for the study of low frequency electrostatic waves in a dusty plasma, using the charge on the grains as a dynamical variable as a generalization of the usual kinetic model to describe the charge fluctuation effects. The treatment leads to the appearance of a new term in the dispersion relation which strongly modifies the known plasma dust modes, such as the dust-acoustic mode, the dust-Coulomb

mode etc., besides leading to new modes of oscillation in the zero wave number limit, both in the tenuous and dust plasma regimes. The latter are termed as "grain capacitance oscillation".

Because of the presence of such a frequency of oscillation, the possibility is also pointed out of the reflection of dust-acoustic wave from the region of increasing plasma density, very much analogous to the reflection of a plasma wave in a region of increasing plasma density. There is also found the existence, in the tenuous plasma regime, a new purely oscillatory and purely damped *dust hybrid* mode with a frequency as a geometric mean of the new term-modified dust acoustic mode frequency and discharging frequency.

(R. K. Varma)

Fluid Equations for a Dusty Plasma with Dust Charge and Mass Distribution Interacting with Neutral Dust through Dust Grain Charging and Secondary Emission

A set of fluid equations is obtained for a dusty plasma, with dust charge and mass distributions, interacting with ambient neutral dust through inelastic collision processes involving dust grain charging and discharging and secondary electron emission from the dust grains. These are obtained as appropriate moments of the Boltzmann-Vlasov equations for the positively and negatively charged dust components, neutral dust component, electrons and ions. Also odtained are the charge and mass moments of these equations which bring out a new term involving the charge dispersion in the equation for the phase space charge density. The inelastic collision process involving dust grain charging and discharging and secondary electron emission provide a coupling between the positive and negatively charged dust components and the neutral dust component. The source/sink terms in the equations of continuity, momentum balance and heat equations then are the proper terms obtained systematically from the Boltzmann-Vlasov equations as against some *ad hoc* formulations that have used earlier. The set of equations so obtained should prove useful in analysing the various dusty plasma phenomena: waves, instabilities and nonlinear processes in space and astrophysical scenarios.

(R. K. Varma)

Grain Charging Instability

The stability of the steady grain charge state corresponding to the net zero current flow to the grains is investigated. Besides, the usual equations of continuity and momentum balance, for the electron and ion fluids, the energy balance equations for the two species are also included in the analysis which properly accounts for the exchange of energy between the plasma particles and the electrostatic energy of charged dust grains. Such an energy equation has been derived, as it does not exist in the literature. It is found that the steady grain charge state is unstable in the dense plasma regime $f \ll (4\pi n_d \lambda_d^2 a) \gg 1$, (where n_d is the dust grain number density, λ_d, the plasma Debye wave length, and a, the grain radius). In the tenuous plasma regime, $f \ll 1$, the state is found to be stable. The consequences of the instability is to make the dust charge grow at the expense of the electrons, which may lead to sweeping up of all the electrons by the dust particles, resulting in a plasma which would be essentially an ion and dust plasma.

(R. K. Varma)

Small-world Network

We have carried out analytical and numerical work on a random walk on the family of small-world graphs. The average access time shows a crossover from the regular to random behavior with increasing distance from the starting point of the random walk. We introduce an *independent step approximation*, which enables us to obtain analytic results for the average access time. We observe a scaling relation for the average access time. The behavior of average access time as a function of the small-world parameter (p), shows striking similarity with that of the characteristic length of the graph. This observation may have important applications in routing and switching in networks with large number of nodes.

(S.A. Pandit and R.E. Amritkar)

Cluster-cluster Aggregation

A stochastic hierarchical model of cluster-cluster aggregation which is obtained by introducing a sticking probability into the recently proposed hierarchical model by Sornsen and Oh, is introduced. The fractal dimension and aspect ratio calculated using the model give good agreement with those obtained in standard simulations of cluster-cluster aggregates. An interesting result is that the fractal dimension shows a peak as a function of the sticking probability.

(R.E. Amritkar)

Quantum Level Velocities, Classical Diffusion and Random Matrix Theory

We studied the response of the quasi-energy levels in the context of quantized chaotic systems through the level velocity variance and related them to classical diffusion coefficients using detailed semiclassical analysis. The systematic deviations from random matrix theory, assuming independence of eigenvectors from eigenvalues, was shown to be connected to classical higher order time correlations of the chaotic system. We studied the standard map as a specific example, and thus the well known oscillatory behavior of the diffusion coefficient with respect to the parameter was found to be reflected exactly in the oscillations of the variance of the level velocities. We studied the case of mixed phase-space dynamics as well and noted a transition in the scaling properties of the variance that occurs along with the classical transition to chaos. This work has been done in collaboration with N. Cerruti and S. Tomsovic of the Washington State University, Pullman, USA.

(A. Lakshminarayan)

Quantum Chaos of a Particle in a Well

We had previously studied the classical dynamics of a particle in a one dimensional well that is kicked by an external field periodically in time. We had found non-KAM behaviour for most ratios of well width and field wavelengths. This resulted in increased chaotic regions and global diffusion. This generalized the well studied and important model of the standard map in significant ways. Recently we have studied the quantum mechanics of such a system. Recent experiments in quantum optics with kicked sodium atoms and other experiments with semiconductor nanostructures provide motivation for such a quantum analysis. We found Anderson like dynamical localization in this system as well and are investigating a possible delocalization of the wavefunctions. Large matrices are being numerically diagonalized to study this. Time evolution of Gaussian wavepackets has been treated with special emphasis on Accelerator Modes (AM). The existence of these structures has dramatic classical effects and can lead to anomalous diffusion as opposed to normal random walks in phase space. We are studying the quantum manifestations of these AM.

(R. Sankaranarayanan, V.B. Sheorey, and A. Lakshminarayan)

Barnett-Pegg Formalism of Angle Operators, Quantum Revivals and Magnetic Flux Lines

We have used the Barnett-Pegg formalism of angle operators to study a rotating particle with and without a flux line. Requiring a finite dimensional version of the Wigner function to be well defined we found a natural time quantization that leads to classical maps from which the arithmatical basis of quantum revivals

was revealed. The flux line, that fundamentally alters the quantum statistics, forces this time quantum to be increased by a factor of a winding number and determines the homotopy class of the path. The value of the flux is restricted to the rational numbers, a feature that persists in the infinite dimensional limit.

(A. Lakshminarayan)

Semiclassical Analysis of a new Measure of Localization of Chaotic Eigenstates

Recently a new correlation measure was introduced that sensitively probes phase space localization properties of eigenstates. It is based on a system's response to varying an external parameter. The measure correlates level velocities with overlap intensities between the eigenstates and some localized state of interest. Random matrix theory predicts the absence of such correlations in chaotic systems whereas in the stadium billiard, a paradigm of chaos, strong correlations were observed. We developed further the theoretical basis of that work, extended the stadium results to the full phase space, studied the $\hbar$ dependence, and demonstrated the agreement between this measure and a semiclassical theory based on homoclinic orbits. In a separate study we worked out the details for almost exactly solvable chaotic systems such as the bakers map and showed that the semiclassical study could reproduce very detailed phase space structures.

(A. Lakshminarayan)

Diagonalization of Large Matrices

In the study of time independent bounded chaotic quantum systems it is necessary to work with very large matrices. The Hamiltonian matrix is large because, for such systems, quantum eigenvalues and eigenfunctions in the semiclassical domain are required for the study of quantum chaos. For systems with more than two degrees of freedom the matrix size becomes larger. It thus becomes imperative to devise methods to diagonalize large matrices, typically of dimensionality of several tens of thousands. Most diagonalization procedures are very computer intensive both in terms of CPU time and memory. In order to overcome this problem we have implemented a block Householder algorithm with secondary storage. The algorithm converts given real symmetric matrix into a real banded matrix of desired band width. This reduces the requirement of primary memory by a quadratic factor. The algorithm is modified and implemented to work efficiently on vector parallel machines. The code is currently undergoing tests.

(S.A. Pandit and V.B. Sheorey)

Decoding of Signal from Phase Modulated Unstable Periodic Orbit

In the method of secure communication suggested by Abarbanel and Linsay, a binary message is encoded by phase modulation of an unstable periodic orbit (UPO) of a chaotic system. It is demonstrated that the encoded message can be decoded from the transmitted signal alone without the knowledge of chaotic system, its orbit and encoding scheme. This decoding method is based on the fact that errors in single step prediction for models which reconstruct the state space using the local linear approximation are relatively large for the points on UPO in the transmitted signal. This enables us to extract the UPO from the transmitted signal. The identification of UPO is then used to recover the original message.

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

Improved Initial Data for Neutron Star Evolution

Padé approximants to truncated post-Newtonian neutron star models have been constructed. The Padé models converge faster to the general relativistic (GR) solution than the truncated post-Newtonian ones. The evolution of initial data using the Padé models approximates better the evolution of full GR initial data than the truncated Taylor models. In the absence of full GR initial data (e.g., for neutron star binaries or black hole binary systems), Padé initial data could be a better option than the straightforward truncated post-Newtonian (Taylor) initial data. We have generalized the standard Padé expansion to the case with 3 parameters. This work was done in collaboration with A. Gupta, B.R. Iyer and A. Gopakumar.

(Sai Iyer)

Numerical Simulation of Axisymmetric Systems

A new technique for the numerical simulation of axisymmetric systems, developed at the Albert Einstein Institute (AEI), Germany, is being used to study axially symmetric configurations. Many realistic systems like rotating neutron stars fall in this category. We are in the process of developing a module to study such systems under the computational environment known as Cactus. This work is done in collaboration with the Numerical Relativity group at AEI.

(Sai Iyer)

The Astrophysics Simulation Collaboratory

The Knowledge and Distributed Intelligence (KDI) program of the US-NSF includes an ambitious project to build a computational collaboratory to bring the numerical treatment of Einstein's theory of general relativity to astrophysics. The aim is to integrate advances in distributed computing, real-time visualization, numerical techniques, relativity and astrophysics to create an Astrophysics Simulation Collaboratory (ASC) to solve fundamental problems in astrophysics. The ASC will serve as a model for scientific projects involving large scale collaborative code development and execution. The driving application for the development of the ASC will be the simulation of an accreting, rapidly rotating neutron star undergoing collapse to a black hole, triggered by a nuclear phase transition. The observational consequences, including the gravitational waves emitted in such processes that would be detected by gravitational wave detectors such as LIGO and VIRGO, will be determined. The study of accretion induced collapse of neutron stars in X-ray binaries is not only significant for astrophysics and X and gamma ray astronomy, but is also a problem that involves all components (general relativity, relativistic hydrodynamics and nuclear astrophysics) of the central code in the ASC. This collaboration includes groups at Washington University, NCSA, University of Chicago, Rutgers University and Albert Einstein Institute.

(Sai Iyer)

Computer Science and Neural Network

Distributed Image Processing

The presence of large number of high-end workstations present on a network offer the opportunity to do distributed processing with a platform independent language such as Java. A Distributed Image Processing system has been developed for homogeneous Java Virtual Machine environment taking advantage of Java object model. The application developed consists of various servers developed for class of image processing functions. The servers are deployed on various platforms and appropriate functions invoked from a client applications concurrently. The application is scalable in number of servers and processing tasks.

(S.N. Pradhan)

Use of Large Databases

In collaboration with Planetary Atmospheric Division, mining of INDOEX (Indian Ocean Experiment) archive databases has been taken up. Databases of interest have been identified, down loaded and converted into suitable format for modelling work. The work on visualisation of data using IDL is in progress.

(Jayshree Trivedi)

The research interests of this division cover a broad range of both theoretical and experimental topics in quantum and non-linear optics. The activities of the past year are summarized as follows.

Control of Decoherence and Relaxation by Frequency Modulation of a Heat Bath

In recent times, the decoherence of a coherent superposition state has acquired a new dimension because of the requirement of the stability of such a superposition in the context of quantum computation. Clearly the stability of coherent superpositions require methods for slowing down the decoherence. We demonstrate, in a very general fashion, the considerable slowing down of decoherence and relaxation by fast frequency modulation of the system-heat-bath coupling. The slowing occurs as the decoherence rates are now determined by the spectral components of bath correlations which are shifted due to fast modulation. We present several examples including the slowing down of the heating of a trapped ion, where the system-bath interaction is not necessarily Markovian.

(G.S. Agarwal)

SU(2) Structure of the Poincare Sphere for Light Beams with Orbital Angular Momentum

Currently light beams with orbital angular momentum are attracting considerable attraction. In a recent paper a geometrical representation of such beams was developed in analogy to the Poincare representation of polarized light. We find the underlying SU(2) structure of the Poincare sphere that represents the states of light beams with orbital angular momentum, treating both classical and quantum fields. The treatment thus includes even the nonclassical states of the field.

(G.S. Agarwal)

Diffraction Tomography using Power Extinction Measurements

In the short-wavelength limit, tomographic reconstruction of two-and three-dimensional media has long been carried out from intensity measurements. More accurate methods of reconstruction that take into account diffraction require knowledge of both the field amplitude and the phase of the scattered field. For rapidly varying fields such as optical fields the phase may be prohibitively difficult to measure and presents, at best, a technical challenge at lower frequencies.

We use a generalization of the optical cross section theorem for determining structures of semi-transparent media from measurements of the extinguished power in scattering experiments. Our method avoids the problem of measuring the phase as well as the directional dependence of the scattered field. We illustrate how this method may be used to reconstruct both deterministic and random scatterers. This work was carried out in collaboration with P. S. Carney and E. Wolf, University of Rochester, Rochester, U. S. A.

(G.S. Agarwal)

Possibility of Wave Propagation in the Forbidden Region of a Resonant Optical Medium

It is well known that electromagnetic waves cannot propagate in the frequency region where the dielectric function of the medium is negative . This region corresponds to a band gap in which only evanescent waves are possible. Using the ideas of quantum interference, we demonstrate that this band gap can be removed and thus wave propagation *can* be allowed in this region by the application of a strong electromagnetic field which is resonant with some additional transition of the material system. The frequencies at which these effects can occur are found to be strongly influenced by local-field effects. This work was carried out in collaboration with R. W. Boyd, University of Rochester, Rochester, U. S. A.

(G.S. Agarwal)

Propagation of a Pulse Trio in Four Level Systems

Propagation of a shape-preserving (self-similar) pulse pair in a three-level system has been studied extensively in the past. The existence of self-similar pulses has been established only under the condition that the oscillator strengths of all transitions are equal.

Such an equality would require special arrangements to be realized experimentally. We have discovered what appears to be the first exception to this rule by the use of a co-propagating probe pulse along with the pulse pair propagating in a medium with four-level atoms. The inclusion of the probe pulse lifts the rigid restriction on the oscillator strengths of the transitions potentially opening the way for experimental testing of predicted long-range multi-pulse correlation effects. This work was carried out with J. H. Eberly, University of Rochester, Rochester, USA.

(G.S. Agarwal)

Correlated Photon Statistics Produced by Cold Atoms in a Bimodal Cavity

We consider the passage of cold, Λ type three-level atoms in excited state through a bimodal cavity. We find that the quantized cavity field with fixed number of photons in the two modes, acts like a combination of potential barrier and well for the external motion of the atoms. These potentials induced by the cavity field are entirely different from those produced by laser fields in the optical lattice. Since the two modes are populated by the emission from the same excited atom, a study of correlation between the cavity modes was carried out. It was found that the reflection and transmission of cold atoms through the cavity-induced potentials give a strong anti-correlation between the cavity modes in steady state.

(R. Arun and G.S. Agarwal)

Tunneling of Cold Atoms through Vacuum Induced Potentials

We consider the transmission of an excited, cold two-level atom successively through a system of two cavities in vacuum state. Each cavity acts like a combination of potential barrier and well for the external motion of atoms. The transmission probability exhibits resonances as a function of the energy of the incident atom. We show the close relation of these resonances to the tunneling resonances of the double barrier system.

(R. Arun and G.S. Agarwal)

Laser Field Induced Birefringence and Enhancement of Magneto-optical Rotation

An initally isotropic medium having magnetic sublevels, when subjected to a magnetic field, exhibits birefringence due to the Zeeman splitting. An asymmetry is thus created between the susceptibilities corresponding to the two circularly polarized components of a linearly polarized probe field, causing magneto-optical rotation (MOR) of the plane of polarization of the probe field. Detailed calculation on ^{40}Ca system shows that the application of a strong control field coupling the magnetic sublevels to another excited singlet state can also produce large birefringence. Thus the rotation of the plane of polarization due to the magnetic field alone, can be controlled efficiently by the control field. We show that the *new frequency regions* emerge at the Autler-Townes components where large MOR could be obtained. The above work is further generalized by taking the inhomogeneous broadening of the medium into account. Complete analytical solutions are obtained for a configuration where the probe and the control fields are counter propagating.

(A.K. Patnaik and G.S. Agarwal)

Gain in Autler-Townes Doublet due to Quantum Interference

When a medium is driven by strong, resonant, coherent fields, its properties are significantly altered and one can even produce gain. We demonstrate that quantum interference between different paths of spontaneous emission (which can arise when spontaneous emission from one level strongly affects a neighboring transition) in a V system can produce gain under conditions when one would have otherwise observed absorption peaks. We relate this gain to the existence of a new vacuum-induced quasi-trapped state. We further show how this also results in a large refractive index with low absorption. As a consequence of quasi-trapping, the observed gain features arise with sub-natural line-with, which is important for coherent sources at small wavelengths with very small band-width.

(S. Menon and G.S. Agarwal)

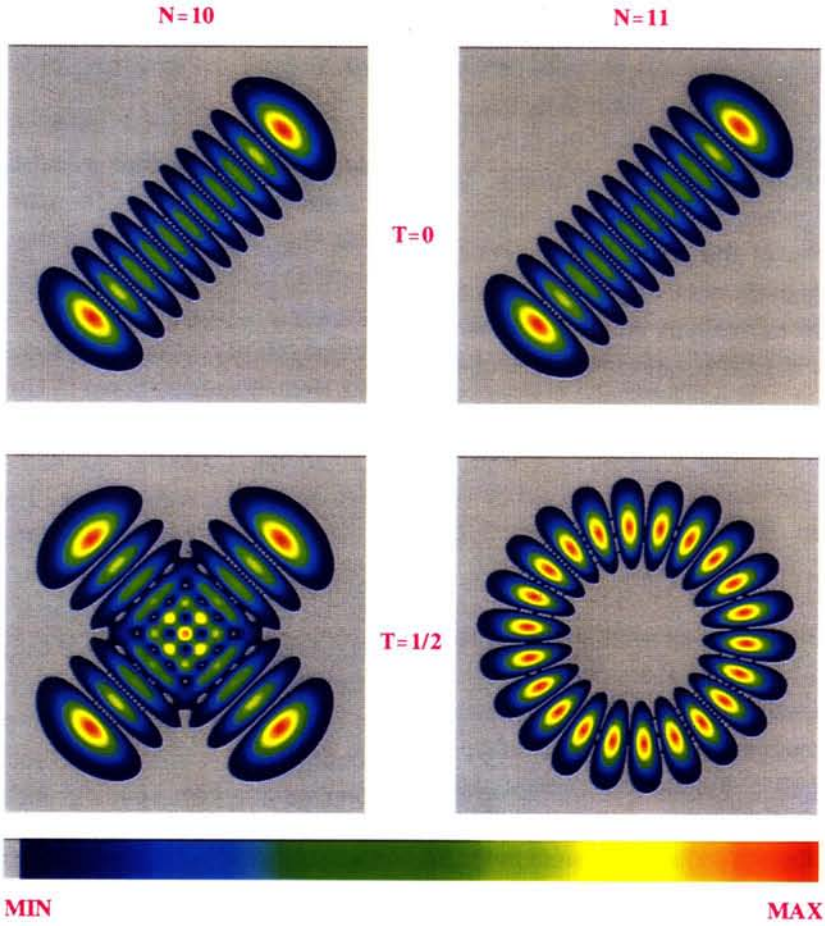

Fig. 4.1 Time evolution of a two-mode SU(2) coherent state with N bosons under the action of a nonlinear Hamiltonian. Shown here are the contour plots of the quadrature distributions for N=10 (left column) and N=11 (right column). Initially (T=0), the distributions are very similar (top row) but at a later time (T=1/2), they are drastically different (bottom row); the state with 10 bosons forms a Schrödinger cat (two identical replicas superimposed) whereas the state with 11 bosons breaks up into 22 petals.

Non-linear Wave Packet Dynamics of Coherent States of Various Symmetry Groups

It is well known that coherent states, originally defined for harmonic oscillators (H. O.) or the radiation field, can experience the quantum phenomenon of revival and form Schrödinger cat states under certain conditions. From a group theoretic point of view, the H. O. coherent states arise in systems whose dynamical symmetry group is the Heisenberg-Weyl group. Coherent states of other symmetry groups also exist. A question arises whether revival and cat formation occur for coherent states of these groups as well. In a bid to answer this question, we made a comparative study of how coherent states of various symmetry groups (Heisenberg-Weyl, SU(1,1) and SU(2)) evolve under the action of the *same* generic Hamiltonian which was two-mode, phase-insensitive and quadratic in the photon number operators. Although the Hamiltonian was the same in each case, it was found that the states evolve quite differently which can be traced to their belonging to different symmetry groups. However, certain similarities in their evolution also emerged. Through a series of pictures and movies, we show how the initial coherent structure is lost due to quantum dephasing and then regained later on to form spectacular and varied quasi-coherent structures (**Fig. 4.1**) leading up to the formation of Schrödinger cats in some cases and to full revival in all cases.

(J. Banerji and G.S. Agarwal)

Quantum Reconstruction of SU(1,1) States

Since a quantum system is completely described by its density matrix, the task of reconstructing a quantum state is essentially the extraction of its density matrix from information obtained by a set of measurements performed on an ensemble of identically prepared systems.

We propose a feasible procedure for the reconstruction of two-mode SU(1,1) states. In our scheme, one allows the input state to pass through a non-degenerate parametric amplifier and measures the probability of finding the output state with a certain number (usually zero) of photons in each mode. The density matrix in the Fock basis is retrieved from the measured data by the least squares method after singular value decomposition of the design matrix. Several illustrative examples involving the reconstruction of a pair coherent state (**Fig. 4.2**), a Perelomov coherent state, and a cat state of pair coherent states are considered.

(J. Banerji and G.S. Agarwal)

Doppler-free Saturated Absorption Spectroscopy

As a first step in our work on high resolution spectroscopy, we have studied the hyperfine structure of Rb ($5S_{1/2} \rightarrow 5P_{3/2}$) using saturated absorption spectroscopy. Two counter-propagating beams, a weak probe and a strong pump, were made to overlap across the Rb vapour cell. The probe absorption was observed in the presence of the saturating pump beam by scanning the laser frequency across the Doppler-broadened width of Rb transition (5S1/2 → 5P3/2). In the experiment, the pump and probe beams are derived from the same diode laser (EOSI-2001, λ = 780 nm). A ramp voltage of amplitude 600 mV and frequency 500 Hz is applied to the piezo-modulator of the laser to scan the laser frequency for a range of 0.8 GHz. A photodiode is used to measure the transmission of the probe. Both the ramp voltage and the photodiode signal are traced on the oscilloscope. The widths of Lamb dips observed in the probe absorption were found to be 25 -30 MHz limited by the spectral width of the laser used. The

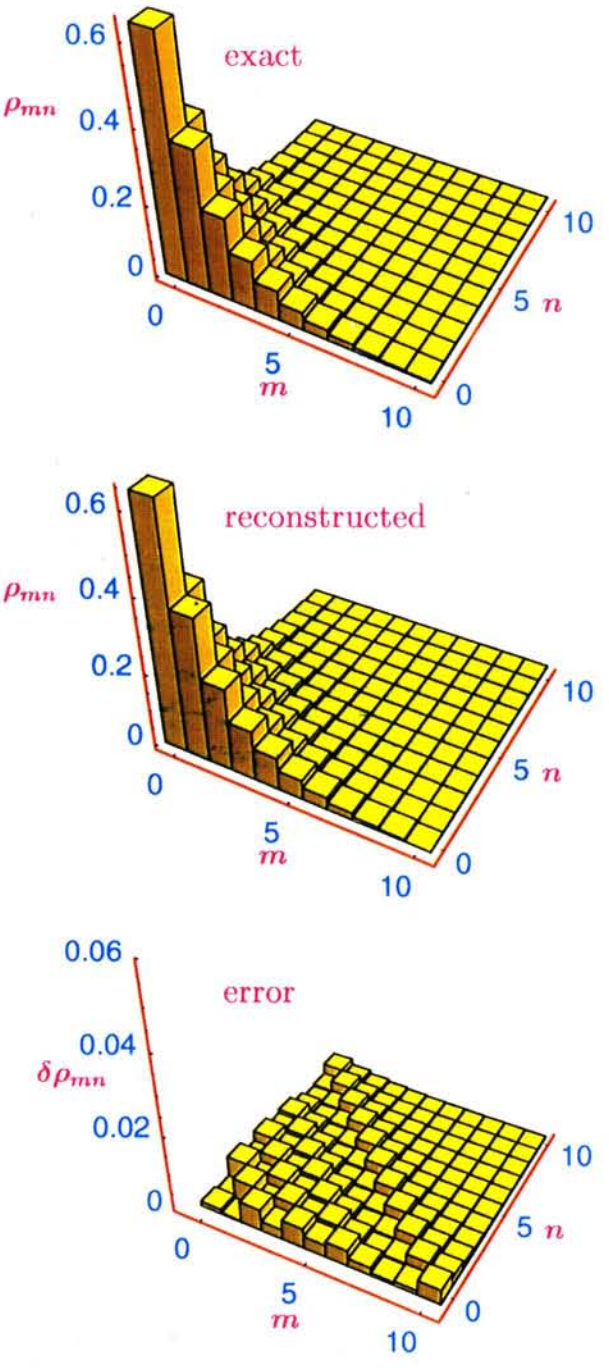

Fig. 4.2 Reconstruction of the density matrix elements r_{mn} of a Perelomov coherent state by least squares method after singular value decomposition of the design matrix. From top to bottom: exact values, reconstructed values and the absolute error in the reconstruction.

Doppler width of the transition was found to be 516 MHz which was close to the theoretical value of 502 MHz at 297 K.

(R.P. Singh and P.K. Datta)

Optical Vortices

In continuation of our previous work on the generation of optical vortices using computer generated holograms and the circular Gaussian beam of a He-Ne laser, we have used *elliptical* Gaussian beam of a diode laser to produce optical vortices. Elliptical beams have some peculiar properties like change of aspect ratio while propagating in free space. This property shows up in the vortex structure generated and gives some new patterns yet to be explained. The images captured by the CCD camera and a frame grabber are being processed to analyze these structures. Numerical simulations along with experiments to study the generation of such patterns and their propagation in free space as well as nonlinear media are under progress.

(R.P. Singh and P.K. Dutta)

Preparation and Nonlinear Optical Characterization of Some Novel Dye-doped Polymer Films

Recently, photorefractive (PR) polymers have emerged as a new type of promising PR materials because of their high efficiency and ease of processing into large, thick films at low cost and the advantage of tailoring the properties using molecular engineering techniques.. Also the PR sensitivity is inversely proportional to the static dielectric constant and PR polymers have low dielectric constants.

We have prepared some azo and DMASPB dye-doped Poly(methyl methacrylate co-methacrylic acid) (PMMA-PA) and Poly-vinyl-carbozole polymer thick and thin films using hot press moulded technique. Nonlinear absorption and optical limiting behavior of these films based on two-photon induced fluorescence are studied using a single beam z-scan technique. The values of the excited state absorption coefficients and the two-photon absorption coefficients are calculated in both types of films at different wavelengths and intensities using theoretical simulations. It is found that both dye-doped films show strong nonlinear absorption and high damage threshold in the near infra-red region for optical limiting applications.

(P. Sreeramana Aithal and R.P. Singh.)

The results in brief, of the various research activities carried out during the last year in the fields of middle and upper atmosphere, planetary and cometary atmospheres and laboratory astrophysics are described in the following sections :

Middle Atmosphere

Anomalously High Ozone in the Marine Boundary Layer (MBL) over the Arabian Sea

Measurements of surface ozone together with other precursor gases have been made during the Intensive Field Phase (IFP) of the INDOEX during January 20 to March 13, 1999. Ozone levels in the range of 40-60 ppbv have been observed off the Indian coast in the marine boundary layer (MBL) of the Arabian Sea. Also, there is no appreciable decrease during the night as is observed at land sites like Ahmedabad and Trivandrum. The continental surface ozone levels are in the range of 20-35 ppbv during the day and 5-15 ppbv during nighttime. Based on wind trajectory and observations at higher heights, it appears that higher ozone in the MBL is being transported from the continental free tropospheric region. A 3D-model simulation at the Max Planck Institute for Chemistry, Mainz, Germany, also shows similar features.

Ozone levels in the north of the ITCZ region are observed to be higher during the INDOEX-1999 campaign than during INDOEX-1998 (**Fig. 5.1**). This is attributed to anti-cyclonic conditions prevailing over the Indian region during January 1999.

(Shyam Lal, Manish Naja, Duli Chand and K.S. Modh)

Surface Ozone at Gadanki, a Rural Site

Under the ISRO-Geosphere Biosphere Programme, we have made measurements of surface ozone and NO_x using in situ analyzers. Despite being a rural site, Gadanki shows daytime production of ozone like at Ahmedabad. The peak noontime annual average ozone is found to be about 34 ± 13 ppbv. However, the afternoon decrease in ozone is slower due to slower titration with NO. The morning increase rate is found to be about 4.8 ppbv/hr, while the afternoon decrease rate is about 2.6 ppbv/hr. This data set also reveals that the photochemical ozone production at Gadanki is only 2.9 ppbv per ppbv of NO_x. Other studies show ozone production per ppbv of NO_x in the range of 7-17 ppbv.

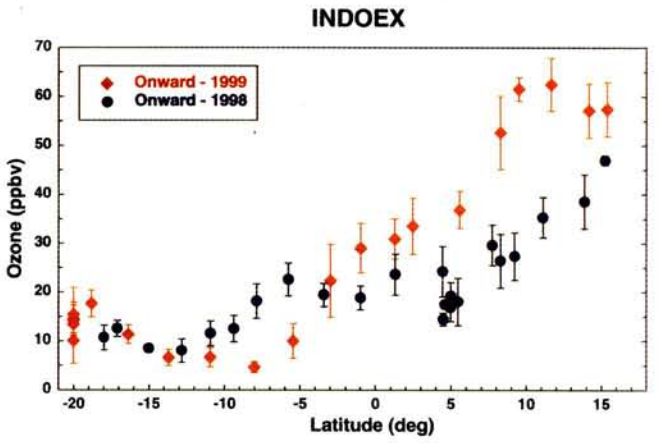

Fig. 5.1 Daily average surface ozone measured during ship cruises in February 18-March 30, 1998 and January 20-March 12, 1999. Higher ozone values north of equator during 1999 cruise reflect the effect of anticyclonic condition in January 1999 over the Indian region.

(Manish Naja, S. Venkatramani, K.S. Modh and Shyam Lal)

A Model Study of N_2O Atmospheric Loss using Observed Vertical Distributions

The budget of atmospheric N_2O has been under discussion, particularly to explain the observed isotopic anomaly in N_2O. We have used vertical distributions of N_2O alongwith other long-lived trace gases, like CH_4, CFC-12, CFC-11 observed from Hyderabad, to compare with the 2D model derived profiles. The model incorporates the standard photochemistry of N_2O and other species known todate. This comparison does not indicate a possibility of a new sink within the spread of the measurements. The model is currently being used to estimate N_2O production from the recently proposed new photochemical sources.

(Varun Sheel and Shyam Lal)

Higher Aerosol Concentration over the Arabian Sea during the 1999 Spring

As part of the Indian Ocean Experiment (INDOEX), regular observations of aerosol concentration and optical properties were measured over the Arabian Sea and the tropical Indian Ocean during the months January to March from a series of ship cruises conducted over the region. A large latitude gradient, in terms of higher aerosol concentration along the west coast of India to a very low concentration (reduction by about an order of magnitude) in the pristine open ocean region south of the equator is a regular feature observed over this region. This is understood in terms of the low level surface wind flow from the Indian subcontinent to the open ocean region during this period and dilution of the particle amount due to gravitational settling and dispersion. However, comparison of the four year data, from 1996 to 1999 show that the 1999 value is the highest. Lower wavelength optical depth show still larger variation than the higher wavelength data implying that the 1999 increase is caused by the increase in the number of anthropogenically produced sub-micron size particles brought from the continents. A strong inversion layer and larger number of anti-cyclones observed over the Indian sub-continent in 1999 resulted in the trapping of the pollutants whereas during the low aerosol concentration periods, the inversion was weaker. This resulted in aerosols raising to higher altitudes with a sizable portion getting caught in the westerlies and moved east.

(A. Jayaraman)

Clear Sky Aerosol Radiative Forcing over the Tropical Indian Ocean

One of the important consequences of increased aerosol loading in the atmosphere is the aerosol radiative forcing of the climate. The ship cruise studies made over the Arabian Sea and the tropical Indian Ocean show a significant amount of continental aerosols getting entrained with the surface air flow down to thousands of kilometers over the ocean surface. The startling discovery is that these aerosols are highly absorbing (due to the presence of soot) and contribute to absorption (leading to a warm atmosphere) more than

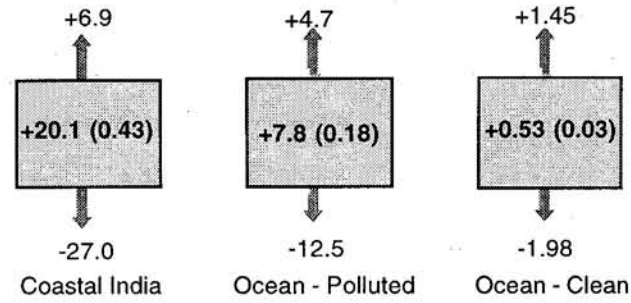

Fig. 5.2 Results of clear sky aerosol radiative forcing obtained from the Indian Ocean experiment. The top values are the radiation energy W/m² lost to the space due to aerosol scattering, the values within the boxes are the radiation loss within the atmosphere due to aerosol absorption, the values within the brackets are the average aerosol optical depth values for the region and the bottom values are the net loss in the surface reaching solar radiation.

scattering (resulting in a cooling of the earth's surface) particularly near the coastal region and the polluted open ocean region. Simultaneous measurements of the columnar aerosol optical depth, surface reaching direct as well as scattered sky radiation flux values are used to obtain the aerosol radiative forcing (reduction in the radiation energy due to the presence of aerosols compared to an aerosol free clear atmosphere). **Fig. 5.2** summarizes the results. Over the coastal region, where the average aerosol optical depth is about 0.43, there is a reduction of 27 Wm^{-2} in the surface reaching solar radiation. About 20.1 Wm^{-2} radiation energy is absorbed in the atmosphere while only 6.9 Wm^{-2} energy is scattered back to space. The amount of aerosol absorption however decreases with increasing distance from the coast. The high absorption detected near the coastal Indian region adds to the well known Greenhouse effect and contributes to warming than counteracting the Greenhouse effect and inducing a cooling effect as the conventional aerosols are expected to behave.

The radiation data used in the above study are provided by the Center for Cloud, Chemistry and Climate (c4), Scripps Institute of Oceanography, San Diego, USA.

(A. Jayaraman)

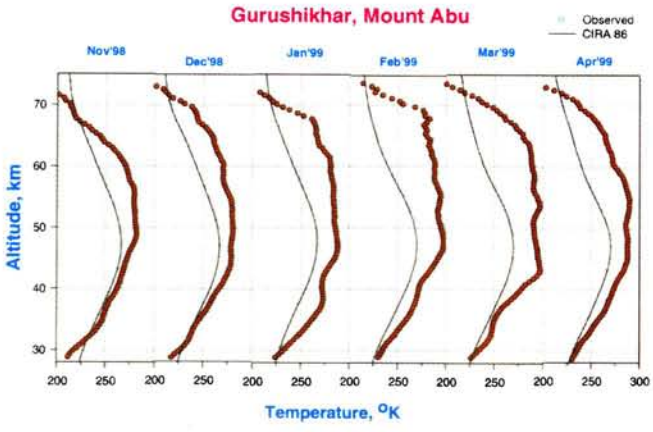

Fig. 5.3 Monthly mean temperature profiles over Mt. Abu during November, 1998 to April, 1999 for 30-75 km altitude region derived form the atmospheric density measurements using Rayleigh Lidar. Also shown in the figure are the CIRA-86 model values of temperature.

Lidar Operation at Mt. Abu

Rayleigh Lidar facility at Gurushikhar, Mt. Abu is being operated regularly for few nights every month to measure atmospheric density profiles in the range of 30 to 80 km. Reliable temperature profiles in the altitude range of 30 to 70 km are being derived from the variations in the measured density profiles. The measurements are being made with photon counts integrated for an hour in time and 480 m in range. The accuracy of temperature determined with these measurements are better than 2 K at 50 km and about 10 K at 70 km. Based on nearly one hundred nights of operation during the period November 1997 to March 2000, monthly mean temperature profiles have been obtained (**Fig. 5.3**). Aerosols below 30 km are also being monitored on a regular basis.

The Lidar is also being operated in the Raman mode to obtain density of nitrogen below 30 km. The composite density profiles obtained by Raman and Rayleigh modes of operation have been used to get temperature profiles from 10 to 70 km on a regular basis since March 1998. Detailed analyses are being carried out.

As part of the INDOEX, regular measurements of density, temperature and aerosols were made on every night from the Rayleigh and Raman modes of operation of Lidar during the period 17 January to 12 March 2000.

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

Measurement of Iodine Oxide (IO)

Studies relating to stratospheric ozone have predominantly centered around chlorine and bromine chemistry. However, models still cannot account for the large losses of ozone (0.68% per year) observed in the lower stratosphere. Recently Wennberg and his colleagues have shown by model study that if significant amount of iodine oxide exists in the stratosphere then reaction of IO with ClO, BrO and HO_2 would play an important catalytic pathway for the destruction of ozone in the lower stratosphere. But nothing was known about the column distribution of this species.

We, therefore, initiated its measurement last year. The twilight slant column density of this species was found to be 10^{15} cm^{-2}. This value of column density shows that IO chemistry is comparable to the chlorine and bromine chemistry for the destruction of ozone in the stratosphere. **Fig. 5.4** shows slant column density of IO during morning and evening twilight conditions from 20 March to 13 May 1999. Evening values appear to be slightly higher than the morning values. This is the first measurement of column density of IO reported so far.

(S.B. Banerjee and, D.K. Chakrabarty)

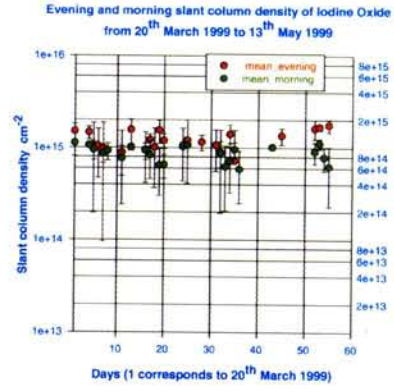

Fig. 5.4 Slant column density of IO during twilight morning and evening conditions.

Slant Column Density of Water Vapour

Water vapour is a major greenhouse gas. Its contribution towards atmospheric heating is 2 times more than that of CO_2. But its variabilty, specially at low latitude, is not properly known. Water vapour has absorption signature at 442 nm and this property has been used to measure the column density of H_2O. Experimental setup consists of a scanning monochromator and a photomultiplier as a detector. The whole setup was programmed to make the required observations. Large day to day variation has been observed. The value of twilight slant column density is found to be in the range of 10^{21} to 10^{24} cm^{-2} for the winter months. This work was done in collaboration with S. Patel and P. Wala of St. Xavier's College, Ahmedabad

(D.K. Chakrabarty and N.C. Shah)

Long-term Trend of Tropopause Height

Changes in the concentration of Greenhouse gases are known to warm the troposphere and cool the stratosphere. Since tropopause is linked with the thermal structure of the Earth's atmosphere, this may have caused changes in the altitude of the tropopuase. We have examined if any such change has occurred. We have analysed 30 years of balloonsonde data taken by the India Meteorological Department at four stations of India. The stations are New Delhi in the north, Thiruvananthapuram in the south, Patna in the east and Ahmedabad in the west. A time series plot shows a large scatter in the data. This was due to the influence of diurnal cycle, annual cycle, semi-annual cycle, quasi-biennial oscillation (QBO) in zonal winds, El-Nino-Southern Oscillation, solar activity and volcanic eruptions. We have filtered out these effects from the raw data. We find an increasing trend of tropopuse height at all the stations of India. The magnitude of increase varies from 0.57% to 3.25%/decade. This increase is explained by the decreasing trend of ozone in the ozone maximum layer of the stratosphere. This is the first work on long-term changes of tropopause height. This work was done in collaboration with S.K. Peshin of Indian Meteorological Dept., New Delhi.

(D.K. Chakrabarty and K.V. Pandya)

Effect of Recent Satellite Measurements of Nitric Oxide and Ground-based Measurements of Temperature on the D-region Ionization

It is expected that electron density in the middle mesosphere will peak around noon time when solar zenith angle is minimum. But observations by rocket and ground-based techniques show that this peak is before noon during summer and after noon during winter. This feature could not be explained so far due to the absence of adequate knowledge of variabilty of NO and temperature in the mesosphere. In recent years, several measurements of NO by satellite have been reported. Also some measurements of temperature by ground-based technique have been made. Using this information, the diurnal asymmetry of electron density in the mesosphere has been theoretically reproduced. An important outcome of this study is that the life time of NO in the mesosphere has to be less than a day. Also the production of NO is not solely dependent on the transport of NO from the lower thermosphere to the mesosphere as believed so far.

(D.K. Chakrabarty)

Upper Atmosphere

The Effects of Molecular Ions in the Nighttime Equatorial F-region Irregularities

A few ion composition measurements over equatorial regions, including the ionization hole campaign conducted over Sriharikota, India revealed the presence of molecular ions (NO^+, O_2^+) as dominant species till the base of F-region where the plasma instability processes originate. The linear stability analysis developed in PRL earlier, revealed that the growth rate of the instability reduces with the introduction of molecular ions and depends on the number densities of both molecular and atomic ions, which is in contrast to the results obtained by previous analyses based on single ionic constituent. In order to understand the evolution, an investigation is carried out using nonlinear numerical simulation model developed in PRL. This investigation revealed that the molecular ions (NO^+) are transported along with atomic ions (O^+) to higher altitude region where plasma density depletions are formed. Further,

the molecular ion density variations inside the plasma depletions are found to be anticorrelated with the density variations of atomic ions similar to that of the earlier satellite observations over the equatorial region.

(E.A. Kherani and R. Sekar)

An Investigation of the Daytime Low Latitude Thermosphere-ionosphere System Response during a Geomagnetic Storm

In order to investigate the relative importance of neutral and electrodynamical processes in low latitude thermosphere-ionosphere system, observations were carried out from Mt. Abu, India during the 'space weather event' of March 7-19, 1999, using a day-night photometer and a simultaneously operating Proton Precession Magnetometer (PPM). To isolate the ionospheric currents and their contributions, a new magnetic field parameter (B_i) has been identified. This B_i is obtained using an empirical relation consisting of PPM recorded total magnetic field (B) and hourly ring current index Dst after proper normalization. The investigation made using simultaneous measurements of the temporal variation of B_i for individual days alongwith ionosonde and dayglow measurements exhibits unambiguously a good correlation of B_i with the observed dayglow variations and also the ionospheric heights (h'F). This correspondence suggests a possible way to parameterize the dayglow intensity changes in terms of the new parameter B_i. Another important result is that most of the dayglow variations including the day to day changes in overall dayglow intensity levels are the consequence of the electrodynamical effects over other processes during geomagnetic storm. This study was done in collaboration with Prof. R. Sridharan of Space Physics Laboratory, Trivandrum.

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

A Case Study of the Nighttime Low Latitude Thermosphere-ionosphere System during a Geomagnetic Storm

During a prolonged geomagnetic storm event (March 7-19, 1999), the Optical spectrometric measurements were carried out simultaneously with the day-night photometer and a Proton Precession Magnetometer (PPM) for the first time to investigate the low latitude nighttime upper atmosphere. The results indicate that the temperatures and winds do not exhibit fast (less than 30 min) variations in general. Nonetheless, significant heating (>500K) is observed on individual nights responding to the varying levels of storm energy input over high latitudes. Interestingly, the rise in thermospheric temperature is observed to be always faster than the recovery on individual nights which is attributed to the effects of the thermal inertia of the system. Apart from that, the temporal variations seen in temperature show a delayed response to geomagnetic forcing as recorded in terms of total magnetic field intensity by the PPM (**Fig. 5.5**). The former was seen to have a strong correlation with the time rate of latter. The rapid (<10-15 min) changes in nightglow, as seen on 17, 18 March are envisaged to be due to the enhanced electrodynamical forcings. This investigation brings out an important understanding of the night time low latitude F-region and its strong dynamical dependence on changes occurring in temperature, winds and plasma drifts. This work was carried out in collaboration with Prof. R. Sridharan of

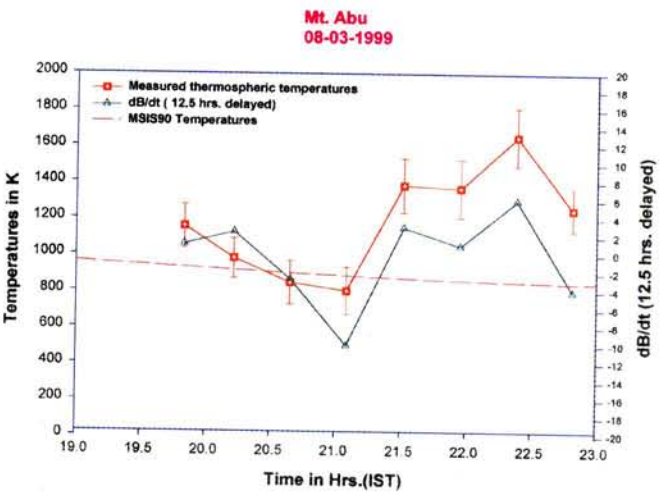

Fig. 5.5 The nocturnal variations of thermospheric temperatures and their correlation with the rate of change of total magnetic variations with an estimated time delay. The dashed line represents the model (MSIS) predicted nocturnal variation of thermospheric temperatures.

Space Physics Laboratory, Trivandrum.

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

Round the Clock Measurements of OI 630.0 nm Airglow Intensities over Waltair

The unique dayglow photometer has been modified into day - night photometer, by diverting the ray path after the interference filter to the photomultiplier manually, after sunset, and thus making it capable of giving representative airglow intensities round the clock. In order to understand wave propagation in thermosphere over the crest region of equatorial ionization anomaly and to identify the dominant periodicities in the thermospheric $O(^1D)$ 630.0 nm intensity variabilities, this day - night photometer was operated from Waltair (17.7°N, 83.3°E). Fractional intensity $[(I-I_0)/I_0$, where I is actual intensity and I_0 is long period smoothed intensity] analysis was carried out both for the day and night time. These fractional intensity variabilities are further subjected to Fourier analysis to obtain the dominant periodicities. Fourier analysis reveals 0.3, 0.5, and 1 hour periodicities to be dominant during daytime, while 0.3 and 0.5 hour periodicities are found to be dominant during night time conditions, on most of the days. This work was carried out in collaboration with Prof. R. Sridharan of Space Physics Laboratory, Trivandrum.

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

Coordinated VHF Scintillation Observations in India

VHF scintillation observations made at a chain of 20 stations in India during the third campaign of February-March 1993 under the All India Coordinated Programme of Ionosphere-Thermosphere Studies (AICPITS) using the 244 MHz radio beacon on-board FLEETSAT were analysed jointly at a workshop held at Saurashtra University, Rajkot. The occurrence features of scintillations were similar to those observed during the first campaign of March-April 1991 with the maximum occurrence slightly reduced due to the decrease of the solar activity. The latitudinal variations showed an increased occurrence of scintillations around 17-18° latitude. The campaign period covered the extensive 'Ionization hole campaign' conducted during the night of 19-20 February 1993 involving rocket-borne and ground-based optical and radio experiments to study the onset conditions of equatorial spread-F. Scintillations during this night were marked by earlier onset and longer duration at stations Waltair and Nuzvid than at stations closer to the magnetic equator. Based on the mean onset time of scintillations at different latitudes, vertical rise velocity of large-scale plasma depletions was estimated for different altitude regions. The velocities range from 40 m/s to 420 m/s with maximum velocity in the altitude region of 365 to 850 km. The results are consistent with the velocities obtained elsewhere from radar and satellite measurements. This work was done jointly with the participants of the AICPITS satellite scintillation network.

(H. Chandra)

Sporadic-E Associated with Leonid Meteor Shower Event of November 1998

Rapid radio soundings were made over Ahmedabad during the period 16-20 November 1998 to study the sporadic-E layers associated with the enhanced meteor shower activity during the Leonid meteor showers. Examination of the quarter hourly ionograms for 17-19 November during the years 1996, 1997 and 1998 showed a distinct increase in the occurrence of sporadic-E from 1996 to 1998. The daily variations of f_oE_s and f_bE_s also showed significantly enhanced values in the morning hours of 18 and 19 November 1998. The ionograms clearly show, at times of peak shower activity, strong sporadic-E reflections with multiple traces in the altitude region of 100-140 km. Sporadic-E layers with multiple structures were also noted from ionograms at Thumba, situated near the magnetic equator. Few of the ionograms recorded at Kodaikanal, also located near the magnetic equator, show sporadic-E reflections in spite of the transmitter power lower during the period of observations. The results do provide evidence of the formation of sporadic-E layers during strong shower activity. This work was done in collaboration with Dr. C.V. Devasia, Dr. K.S.V. Subbarao and Prof. R. Sridharan of Space

Physics Laboratory, VSSC, Trivandrum and Prof. J.H. Sastri and Shri J.V.S.V. Rao of Indian Institute of Astrophysics, Banglore.

(H. Chandra and Som Sharma)

Total Solar Eclipse of 11 August 1999

Special radio soundings were made over Ahmedabad to study the ionospheric effects of the total solar eclipse of 11 August 1999. The obscuration was almost 100 % over Ahmedabad and peaked at 1800 hr. Since the echoes from E and F_1 layers were not observed after 18h variations in fmin and f_oF_2 were studied on eclipse day and control day. A decrease of about 20% in f_{min} was observed associated with the eclipse. The event was also marked by strong spread-F observed during the night of 11 August.

(Som Sharma, H. Chandra and Bharati Bhatt)

Spread-F at Tropical Latitudes in the Indian and American Longitudes

Numerous studies have been made on the occurrence features of spread-F at stations close to the magnetic equator and strong longitudinal differences are noted between Indian and American sectors. The features of spread-F at tropical latitudes are not studied as extensively. A comparative study is made on spread-F occurrence at Ahmedabad (23° N) in India based on the examination of quarter hourly ionograms during the period 1975-95 and at Cachoeira Paulista (23° S) in Brazil covering the years 1978-89. The occurrence of spread-F is strongly seasonal and solar cycle dependent. Frequency type spread-F is most frequent during J-solstice of low sunspot years. The range type spread-F is frequent during equinoxes and D-solstice (with lower occurrence) of high sunspot years. The occurrence over Cachoeira Paulista in Brazil shows a distinct maximum during local summer for both low and high solar activity.

This work was done in collaboration with Dr. M.A. Abdu and Dr. I.S. Batista of INPE, Brazil.

(Som Sharma and H. Chandra)

Equatorial Electrojet Study Using Rocket and Ground Measurements

Combining the data of *in-situ* measurements of eastward electrojet current density, obtained by rocket-borne magnetometers and the horizontal component of the earth's magnetic field, obtained at stations close to the magnetic equator, by ground based magnetometers, a linear relationship was found between the peak current density, J_m and the daily range of H, (R_H). This relationship was used to convert long series of R_H data into the peak current density J_m. Combining the peak current density, J_m and the E-region peak electron density, N_m, the electron drift velocity in the ionosphere, V_E, was calculated. After making all the necessary corrections for the solar zenith angle variations, it was shown that the ionospheric current as well as electron drift velocity in American and Indian sectors, show strong equinoctial maxima. The mean values of both the parameters were found to be larger in American than in the Indian sector. The solar cycle variation of the electrojet current was found to be primarily due to the variations of N_mE, and not due to the variations of electric field. The diurnal variation of the electric field, which peaks between 0900 and 1000 hrs LT, in conjunction with the noon peak of N_mE, results in a peak in ΔH around 1100 hrs LT. This study brought out the importance of the electric field in diurnal, seasonal and longitudinal variations of the equatorial electrojet current. This work was done in collaboration with Prof. R.G. Rastogi.

(H. Chandra and H.S.S. Sinha)

Some New Features of Electron Density Irregularities over SHAR during Strong Spread F

Detailed analysis of the electron density data obtained on an RH-560 rocket flight, conducted earlier from Sriharikota rocket range (SHAR) (14°N, 80°E, dip lat. 5.5°N), during a strong spread F epoch was made. A new and the most important finding of this study is the detection of two very sharp layers of ionization at 105 km and 130 km (**Fig. 5.6**). The electron density in these layers increased by a factor of 50 in a vertical extent of just 10 km. The mechanism of generation of these sharp

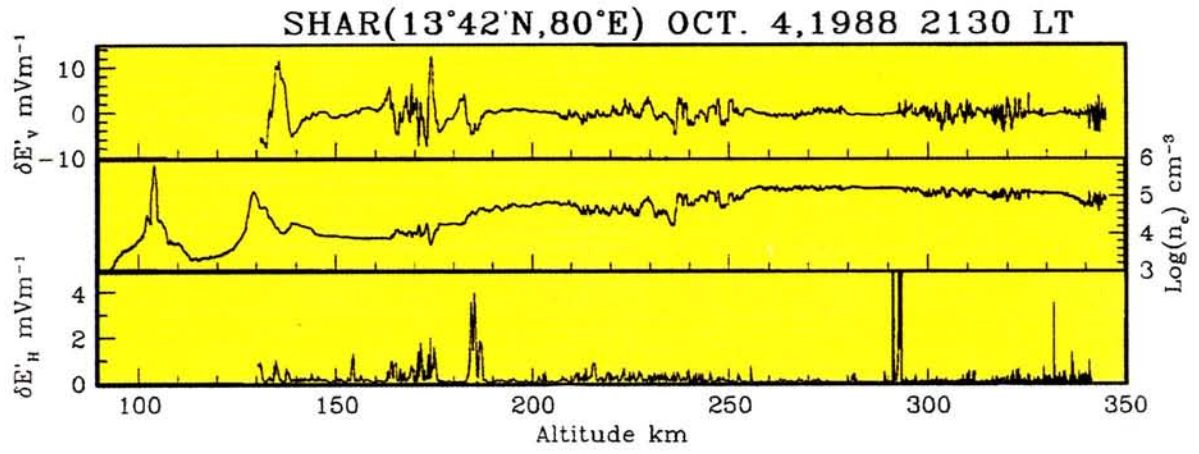

Fig. 5.6 Horizontal electric field, electron density and vertical electric field fluctuations at 2130 LT on October 4, 1988 over SHAR during ascent of a RH-560 rocket.

layers is not known. Some possibility of the role of gravity waves has been conjectured based on the scale sizes involved but this has to be examined more rigorously. In addition to these sharp layers, two very prominent electron density depletions were also observed at 175 km and 238 km during the ascent of the rocket. Both the sharp layers and the depletions, were observed during the descent of the rocket also but their location was about 5 km higher as compared to the ascent. These features unambiguously show the existence of very significant horizontal electron density gradients at the time of fully developed spread F. Very weak large scale horizontal gradients in electron density during non-spread F period have been observed earlier using satellite as well as the rocket data. Horizontal gradients, observed during non-spread F periods, were, however, much weaker than the ones reported here, and these were attributed to large-scale disturbances propagating as internal gravity waves. The present study shows that the horizontal gradients become much more pronounced during the spread F. Another important finding of the present analysis is that the electron density irregularities observed at 176 km do not exhibit any peak at kilometer scale sizes and hence can not be explained in terms of the image striation theory or any other known theory. These irregularities also appear to be of a new type.

(H.S.S. Sinha and Shikha Raizada)

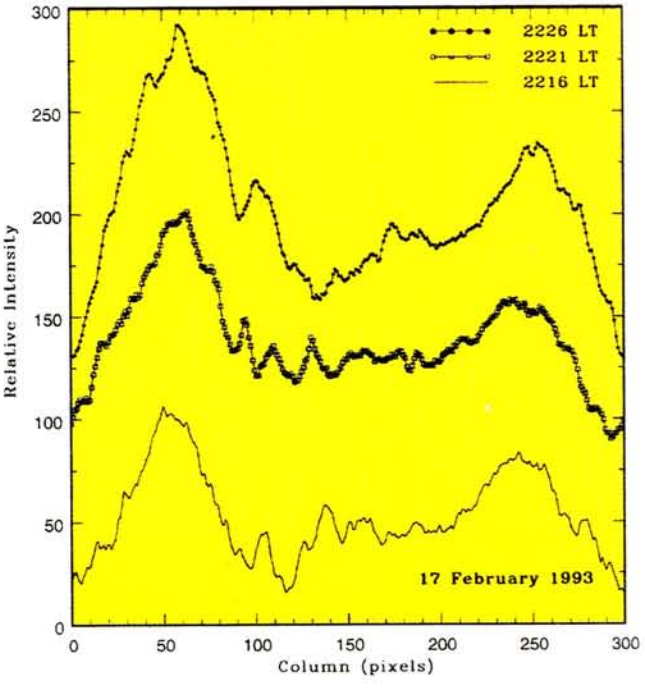

Fig. 5.7 East-west scans of the 630 nm airglow images, through zenith over SHAR, showing enhancements in airglow intensity on the night of February 17, 1993, which was a magnetically disturbed period. Intensity values at 2221 and 2226 LT, have been shifted up on the ordinate axis by 50 and 100 for viewing convenience. Total east-west extent covered by 300 pixels is about 2400 km.

First in situ Measurement of Electric Field Fluctuations during Strong Spread F in the Indian Zone

Vertical and horizontal electric field fluctuations in the F region were measured for the first time over SHAR using two pairs of double probes on a RH-560 rocket. Strong ESF irregularities were observed in three regions, viz., 160-190 km, 210-257 km and 290-330 km. The vertical electric field exhibits the first major peak at 135 km and highest electric field fluctuations were observed in the 160-190 km region. These irregularities do not seem to be generated locally. These have been explained in terms of the image striation theory. The irregularities at 176 km do not exhibit any peak at kilometer scales and appear to be of new type. The intermediate range irregularities (100 m - 2 km) observed in 210 km-257 km and 290 km - 330 km regions have been shown to be generated by the gradient drift instability. Scale sizes of vertical electric field fluctuations showed a decrease with increasing altitude. Most prominent vertical scales were of the order of a few kilometers around 170 km and a few hundred meters around 310 km. Spectra of intermediate scale vertical electric field fluctuations below the base of the F region (210- 257 km) showed a tendency to become slightly flatter (spectral index $n = -2.1 \pm 0.7$) as compared to the valley region ($n = -3.6 \pm 0.8$) and the region below the F peak ($n = -2.8 \pm 0.5$).

(H.S.S. Sinha and Shikha Raizada)

Ionospheric Plasma Depletions over SHAR Using All Sky Optical Imaging

Some new features of the ionospheric plasma depletions observed using the PRL's all sky optical imaging system are reported here. The imaging system, which made use of 630 nm and 777.4 nm nightglow lines to observe ionospheric plasma depletions, was operated from SHAR (14°N, 80°E, 5.5°N dip latitude) during January-March, 1993. Some of the important results are: (a) Strong plasma enhancements or brightness patterns were observed on two nights. The degree of enhancement was by a factor, which ranged between 1.4 and 3.8. These enhancements lasted for more than 15 minutes. Although, these observations look similar to the transient brightness wave reported earlier, the high degree of enhancement and an extended duration of more than 15 minutes, observed in the present case, is a new feature and needs to be understood, (b) The average inter-depletion distance (IDD) was 1500±100 km during the magnetically disturbed period (**Fig. 5.7**) and 740±60 km during quiet periods. This is the first experimental evidence of gravity wave modulation of the bottom side of the F region. While the large scale gravity waves (1500±100 km) of auroral origin are shown to be responsible during magnetically disturbed period, smaller scale gravity waves (740±60 km) having their origin in the lower atmosphere produce initial perturbation in the bottom side of the F region, during magnetically quiet periods, (c) It was found that the east-west extent of plasma depletions varied with the degree of depletion; for the 630 nm images the degree of depletion ranged between 6-9% per 100 km east-west extent and for 777.4 nm images it was 3% per 100 km east-west extent, (d) Plasma depletions were observed to have an eastward tilt in the range of 10-15° with respect to the geomagnetic field. It has been suggested here that these tilts are associated with the variation of plasma drift with altitude, (e) plasma depletions are observed to be moving eastwards with drift velocities in the range of 40-190 ms^{-1}.

(H.S.S. Sinha and Shikha Raizada)

Gravity Wave Imaging Using CCD Camera

The optical imaging system of PRL was upgraded by incorporating a CCD camera and by making the automatic electronic control of the movement of the filter wheel. The oxygen green line was added for the detection of the gravity waves. In addition to the gravity wave parameters, the observations of plasma depletions were also made using 630 nm and 777.4 nm airglow lines. This system was operated from Kavalur during January - March, 2000. Preliminary analysis of images showed a) the presence of wave like features on a few nights, b) the growth and decay of these wave like features did not have any fixed pattern or onset time and c) the brightness wave observed earlier in 630 nm was seen

again on a few nights and it lasted for more than 15 minutes. The detailed analysis is in progress.

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

Solar Cycle Effect on Equatorial-E region Electric Field

In the equatorial-E region, the vertical electric field can be derived from the measurements of drift velocity of type-I irregularities. If type-I irregularities are present in 105-110 km region, then the east-west electron drift velocity should be more than ion thermal velocity. Rocket experiments conducted on 28 January, 1971 (high solar activity) and on 19 February, 1975 (low solar activity) at nearly same time 1110 hrs IST and 1105 hrs respectively have measured type-I irregularities in 105-110 km region. These measurements clearly indicate that electric field in equatorial E-region does not depend on solar cycle. The ion thermal velocity at 105 km has been found to be 360 m/s. This leads to a value of 432 m/s for electron drift velocity.

Ground-based measurements by VHF radar operating at 55 MHz over Thumba have been used to study the type-I irregularities in scale size 3 meter. Type-I irregularities have been observed over Thumba during low as well as high solar activity period. These measurements show that Hall polarization field at E region heights over magnetic equator does not depend on solar activity.

(S.P. Gupta)

Preliminary Results on the Rocket Flights Conducted during Enhanced Leonid Meteor Shower

Two RH-300 Mk.II rocket flights were launched on 18th and 20th November, 1999 from Sriharikota (SHAR 14°N, 80°E), India at 0725 and 0705 hrs IST respectively with the objective to investigate the effects over equatorial ionosphere due to the enhanced Leonid shower activity which occurs once in 33 years. Both the rockets carried identical scientific payloads, namely, radio frequency mass spectrometer for neutral and ion species, Langmuir probe for electron, ion densities and the irregularities in them, alongwith electric field probe. Simultaneous groundbased experiments consisting of ionosonde, VHF and HF radars were also operated from nearby stations as a part of the campaign to obtain background ionospheric and thermospheric conditions alongwith meteoric activity. The Leonid shower activity was found to be maximum when the first rocket was launched which attained the apogee of 140 km while the activity was considerably less when the second rocket was launched which reached an apogee of 136 km.

Preliminary analysis of the rocket flight data revealed that the metallic ions presumably originated from the meteoric activity, are found to be dominant in contrast to the conventionally dominant NO^+ ions in the E-region of the ionosphere on 18th November. Further, the electron density profiles did not show any sharp layers in the E region during both the flights. Detailed data analysis is in progress.

The work was done in collaboration with the scientists from Space Physics Laboratory, Trivandrum and National MST Radar Facility, Tirupati.

(S.P. Gupta, R. Sridharan, R. Sekar, Y.B. Acharya, S.R. Das, C.L. Piplapure, D.D. Damle, J.T. Vinchhi and K.S. Patel)

Planetary / Cometary Atmospheres

Dayside Ionosphere of Mars

The continuity and momentum equations are solved self consistently to calculate the pressure, ion and electron densities in the dayside ionosphere of Mars between subsolar region and terminator at low solar activity. The calculations are made for several ionic species. The ionosphere of Mars is assumed to be permeated by a large scale horizontal magnetic field generated by currents induced by the solar wind interaction. The observed induced magnetic field has been used in this calculation. The calculated results are compared with Viking 1 and 2 radio occultation measurements at solar zenith angle 45 degree. The calculation suggests that the induced magnetic field plays an important role in explaining the features of electron density profiles near ionopause .

(S.A. Haider)

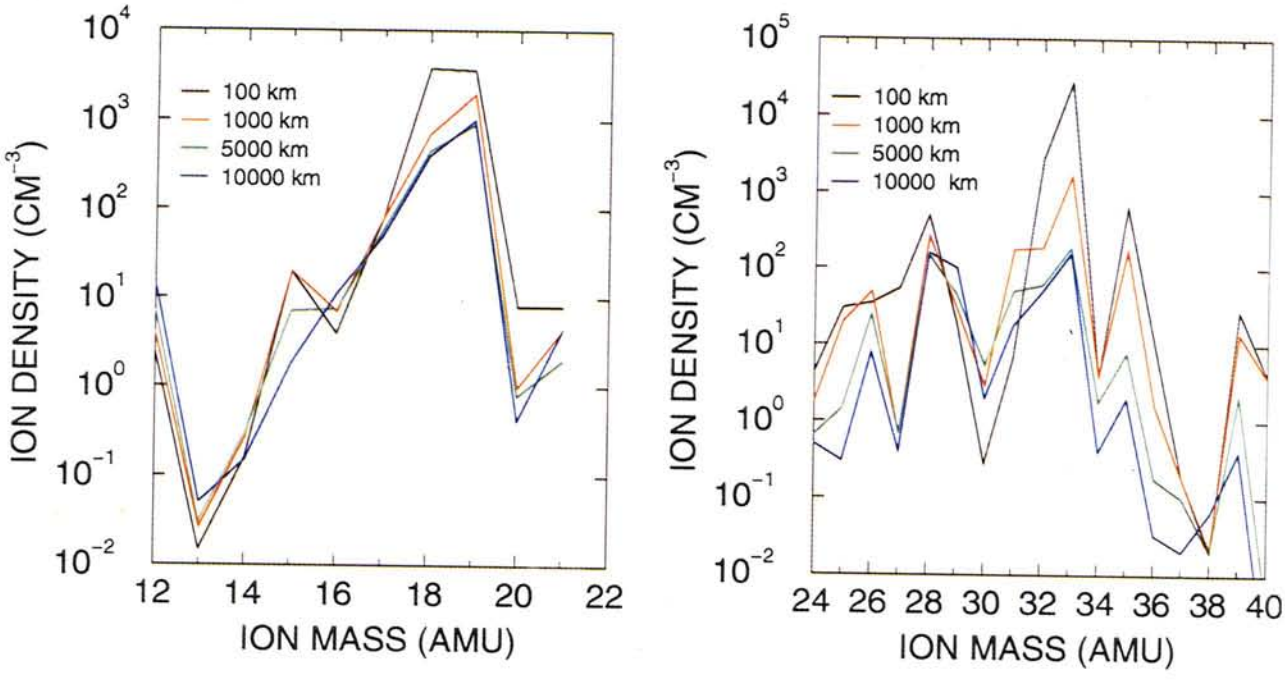

Fig. 5.8 Calculated ion densities for ion masses 12-21 amu (left) and 24-40 amu (right) at different distances from the comet nucleus.

Nightside Ionosphere of Mars

The first in situ measurement of the magnetic field in the upper atmosphere of Mars (above 100 km) is made by magnetometer on-board Mars Global Surveyor (MGS) spacecraft. The preliminary analysis of this experimental data suggests that Mars has no significant planetary magnetic field. Thus the nightside ionosphere of Mars could be produced by plasma transport from the dayside of Mars through terminator as it was observed on Venus in the absence of the magnetic field of the planet. For this study we have imposed on a model of the nightside thermosphere downward fluxes of O^+, O_2^+, NO^+, N^+ and CO^+ which are the maximum escape fluxes that can be sustained by the dayside ionosphere of Mars. The escape fluxes of these ions are calculated earlier using the kinetic model. The calculation of the nightside ionosphere of Mars is being carried out using these models in collaboration with Mr. S.P. Seth of Bhavan's R.A. College of Science, Ahmedabad.

(S.A. Haider)

Cometary Coma

The ions corresponding to 40 amu inside the ionopause of comet Halley is studied using the analytical yield spectrum approach and coupled continuity equations for the steady state condition. The chemical reactions including the chemistry of carbon, hydrogen, nitrogen, oxygen and sulphur compounds are taken in this calculation. The ionization of these compounds due to impact of solar extreme ultraviolet radiation, photoelectrons and auroral electrons of solar wind origin have been studied in detail. The results are compared with the measurements made by ion mass spectrometer onboard Giotto spacecraft at 100 km, 1000 km, 5000 km and 10000 km (**Fig. 5.8**). The peak at 19 amu corresponds to H_3O^+ while mass 18 amu corresponds to H_2O^+ and NH_4^+. The density of H_2O^+ is smaller than that of NH_4^+ because it quickly combines with H_2O and NH_3 forming H_3O^+ and NH_4^+ respectively. The peak at ion mass 15 is mainly due to CH_3^+ ion since this ion does not react with H_2O. The peaks at 26 and 28 amu are due to $C_2H_2^+$ and

H_2CN^+ respectively. The ions CH_3O^+, $CH_3OH_2^+$, H_3S^+ and $C_3H_3^+$ are responsible for other peaks in the cometary coma. This work was done in collaboration with Dr. Anil Bhardwaj, Space Physics Laboratory, VSSC, Trivandrum.

(S.A. Haider)

Laboratory Astrophysics

Pressure Dependence of Fluorescence Excitation Spectrum of Sulphur Dioxide

Fluorescence excitation spectrum for sulphur dioxide has been studied as a function of the target gas pressure at incident photon wavelengths ranging from 202 to 232 nm. The pressure dependence of the excitation spectra was studied at a large number of pressures in the region 100-5000 m Torr. The experimental set up used includes an argon mini-arc light source, an one-meter asymmetrical near normal incidence concave grating monochromator, a beam splitter to monitor the change in intensity of the light source during the experiment, an evacuable stainless steel chamber with fluorescence port at right angle to the photon beam axis, appropriate detection optics, thermoelectrically cooled photomultiplier, data acquisition and handling system.

The fluorescence emission corresponding to the C^1B_2 X^1A_1 bands has been observed in the excitation spectrum which basically consists of two regions; one, the normal excitation spectrum region at incident photon wavelengths 220-232 nm having large band intensities and the other less intense region between 202 to 220 nm which indicates the occurrence of predissociation. Two new characteristics of the excitation spectrum have been noted. At low pressures less than/equal to 30 m Torr, the band intensities in the predissociating region increase and sometimes are comparable to a few bands in the normal excitation region. At high pressures in the normal excitation spectral region, the effect of collisional quenching for some bands has clearly been observed. Qualitatively, the rates of such a quenching process appear to be different for different bands. A quantitative method is now being developed to calculate quenching rate constants for different bands.

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

A New Experiment for Studying the Dispersed Fluorescence of Molecules

A new sophisticated experiment has been designed and fabricated in the laboratory to study the dispersed fluorescence spectra of different molecules at various incident photon wavelengths using either a conventional argon mini-arc light source or an excimer laser pumped dye laser. The experiment consists of a combination of argon mini-arc and 1m concave grating monochromator or a combination of excimer and dye-laser, a compact multi-port collision cell, a 300 mm polychromator/spectrograph positioned perpendicular to the photon beam-axix, a very low noise liquid nitrogen cooled CCD with appropriate software to acquire the required data. The different components of the experiment have now been integrated and the experiment would become operational in the near future.

The compact multi-port cell designed and fabricated in the laboratory has been provided with removable metal-to-metal joints for the crossed arms. This cell offers possibility of carrying out various types of experiments such as laser-induced dispersed fluorescence, fluorescence life time studies, multiphoton ionization studies etc. For the study of photon-gas interaction, the multi-port cell could be used with effusive or supersonic beams of the neutral molecules.

A very low noise liquid nitrogen-cooled CCD has been integrated to a 300 mm polychromator/spectrograph to study the dispersed fluorescence spectra for different molecules. Also, work has been initiated to interface all the laboratory instruments under the IEEE protocol of laboratory automation and efficient handling. The interfacing is achieved by the GIPB standard. With this, all the laboratory instruments such as lasers, CCD, polychromator/spectrograph, digital storage oscilloscope and CAMAC data acquisition system are connected to the PC. Various protocols have been developed for setting the talk-and-listen data link between the PC and the instruments. As of now, the automation has been achieved for the digital storage oscilloscope only and

similar automation will be achieved for other instruments in near future.

(K.P. Subramanian, V. Sivakumaran, A.P. Gohil, P. Rawat and V. Kumar)

Upgradation of the Dye-Laser

The Lambda-Physik dye laser LPD-3000 has now been upgraded to LPD-3002 by adding one more amplifier (dye cell) and angle-tuned BBO-I and BBO-II crystals. The original version of the dye laser had the tunability from 390 nm to near infra-red. The tunability has now been extended upto 220 nm in the upgraded version of the dye laser. Counter rotating compensator optics and prism beam selectors have also been added to present beam walk-off and to remove fundamental frequency from the output beam. By adding one more stage of optical amplifier in the dye laser, the efficiency has been improved from 12 to 17% where as the second harmonic generation conversion efficiency has been observed to be 7 to 8%.

Using the above facility, the fluorescence life time studies and laser induced dispersed fluorescence work can now be carried out in the laboratory at all incident photon wavelengths from 220 nm to near infra-red.

(K.P. Subramanian and V. Sivakumaran)

The research programs on Earth Sciences and Solar Systems are carried out by two seperate areas: (i) Oceanography and Climate Studies and (ii) Solar System and Geochronology. Scientists of the first area are engaged in research in oceanography, low temperature geochemistry, palaeoclimate and palaeoenvironment while the scientists from the second area focus on the studies of meteorites and other solar system objects and geochronology of the continents. The research programs of the division mainly aim to understand the processes of evolution of the Earth and other solar system bodies through studies of their characteristic isotopic and chemical signatures using a subtle combination of analytical methods and theoretical models.

Oceanography and Climate Studies

Palaeoclimate and Palaeoenvironmental Studies

Desert Records

Study of dune sequences in Gujarat indicated that the aeolian accretion continued till about 5ka. Coupled with records from Thar desert this implies a spatial shift in the dune forming climate (monsoonal winds) at around the end of mid-Holocene. Dune accretion shows a 1500 year cyclicity indicating lack of stable climatic regime. A contour map of the spatial extent of the desert during the past 20ka has been prepared.

A study of sequences from Loess-desert margin at Taipingcuan, China also indicated several phases of desert expansion and contraction during the Holocene.

Fluvial Records

Luminescence dating along with granulometric and sedimentary facies data from Khudala in the Luni Basin of the Thar desert show that during the Last Glacial Maximum, both the aeolian and fluvial processes in the region were dormant. A peak in the aeolian sedimentation is noted during 17-12ka, coinciding with periods of re-establishment of the SW monsoon wind system.

Our studies on the western Indian dry land river systems (Luni, Sabarmati and Mahi) suggests that fluvial regimes were stronger and persistent in their flow with cohesive banks during the marine isotopic stage 3 with periodic flooding giving rise to thick over bank sequences.

Wet Lands

The Central Ganga plain was investigated to establish the chronology and hierarchy of different geomorphic surfaces. Infra-Red Stimulated Luminescence (IRSL) dating of Bhur sand ridge suggests that fluvial activity on these surfaces occurred around 8-7ka (a phase of enhanced precipitation) following which the rivers were abandoned during 7-5ka. The aeolian sediments that blanket these surfaces have been dated to 5- 4ka. Thus, while there was a continued fluvial aggradation in the wet land river systems (8-5ka), the dry land river systems were already experiencing arid climate suggesting a shift in monsoon precipitation and geomorphic thresholds. The comparison also shows a gradational geomorphic response to climatic perturbation. The above programmes were done jointly with Drs. A. Kar, R.P. Dhir, S.N. Rajaguru, V.S.Kale, S. Mishra, S.K. Tandon, M. Jain, D. Banerjee, Z.P. Lai and groups at SAC, Sheffield and Oxford.

(N. Juyal, A.J. Kailath, P.K. Mishra, A.K. Singhvi and P. Srivastava).

Speleothems

The coupling between band widths of speleothem and climate (rainfall) needs to be assessed if it has to serve as a climate proxy. The first step in this task is to determine if the bands are deposited annually. To check this, band widths were measured in a speleothem sample collected from Karnataka. There were 292 measurable distinct layers consistent with the radiocarbon date of 210 ± 100y.BP. with bomb carbon activity at its growing tip. Thus it appears that the bands may be annual in nature. The speleothem band-widths, however, do not show a significant correlation with monsoon rainfall over Karnataka unlike the case of tree rings.

Cave seepage waters, rain and ground waters were collected from Orissa and Madhya Pradesh to quantify the amount effect needed to reconstruct mon-

soonal precipitation from the oxygen isotope ratios of speleothems. It was found that there is indeed an amount effect in the local monsoon rainfall (-1‰ per 10 mm) and the cave seepage water isotopic composition is very similar to that of the rainfall and the local ground waters.

(R. Ramesh and M.G. Yadava)

Marine Record

A 150 cm long gravity core 3104G from the eastern Arabian Sea (~ 12°N,~ 75°E, 1700 m depth) was analyzed for a number of climate proxies $\delta^{18}O$ and $\delta^{13}C$ in *G. sacculifer* (surface dwelling) and *G.menardii* (mixed layer dwelling) and major and trace metal abundances in sediments. The core was dated by radiocarbon to be ~ 35 ka using the NSF-AMS facility, Arizona, USA (G.S. Bur and A.J.T.Jull). The results show that between ~ 35ka to ~ 17 ka, $\delta^{18}O$ of *G. sacculifer* increases marginally. $\delta^{13}C$ also shows a similar trend with positive swings (**Fig. 6.1**). These are indicative of strong monsoonal winds contributing to upwelling and enhanced productivity. Between ~ 17 ka and ~ 5 ka there is a decreasing $\delta^{18}O$ trend (~ - 2-4 ‰) in *G. sacculifer* and - 1.6 ‰ in *G. menardii*, the difference is due to excess precipitation over evaporation (negative E-P). In an earlier PRL study, it was shown that such an E-P trend was stronger in regions closer to the coast indicating discharge of fresh water from the monsoon dominated adjacent coastal region.

(R. Agnihotri, R. Bhushan, K. Dutta, R. Ramesh, A. Sarkar and B.L.K. Somayajulu).

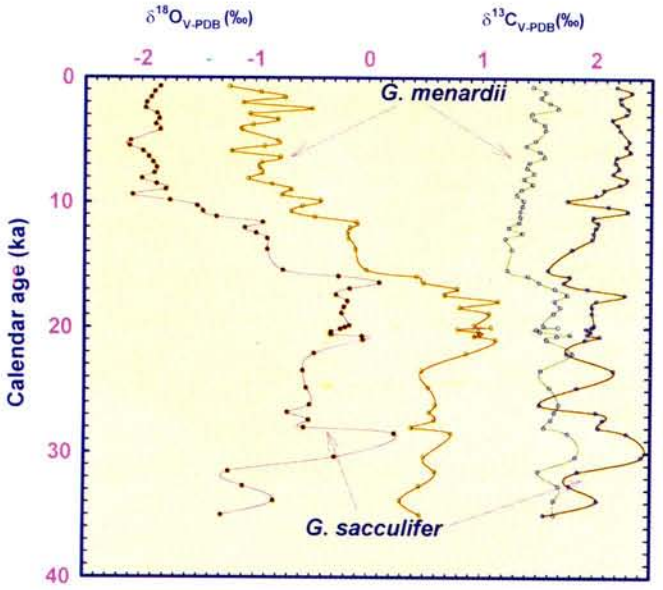

Fig. 6.1 $\delta^{18}O$ and $\delta^{13}C$ values of two species of foraminifera G. sacculifer and G. Menardii plotted against the age of the samples from sediment core 3104G taken from the Arabian Sea

Palaeoclimate Modelling

Atmospheric General Circulation Models (AGCMs) are tools to understand the processes influencing climatic changes. With increase in spatio-temporal extent of palaeomonsoon proxies, and developments in climate models, the impact of factors such as vegetation feedbacks in contributing to past monsoonal variations are better understood. Previous AGCMs show notably higher sensitivity to insolation compared to present AGCMs attributable to changes either in numerical aspects (e.g. horizontal resolution) or to physical parameterisations (e.g. convection). In order to infer the impact of these factors, we did simulations using National Centre for Atmospheric Research (NCAR) Community Climate Model Version 2 (CCM2), with two horizontal resolutions (T42 and T21) and convection parameterisations i.e. a simple mass flux (MFX) scheme and moist convective adjustment (MCA) scheme in annual cycle mode by prescribing the insolation for the present day, 6 and 115 ka. Major inferences are : (i) the model sensitivity changes drastically to changes in convection parameterisation, (ii) the model sensitivity on a large scale is relatively higher at T42 (high) resolution than T21 (low) resolution, (iii) the sensitivities inferred from annual cycle simulations indicate an important limitation of the perpetual mode simulations in addressing past monsoonal changes, namely hydrological processes. This work was done in collaboration with

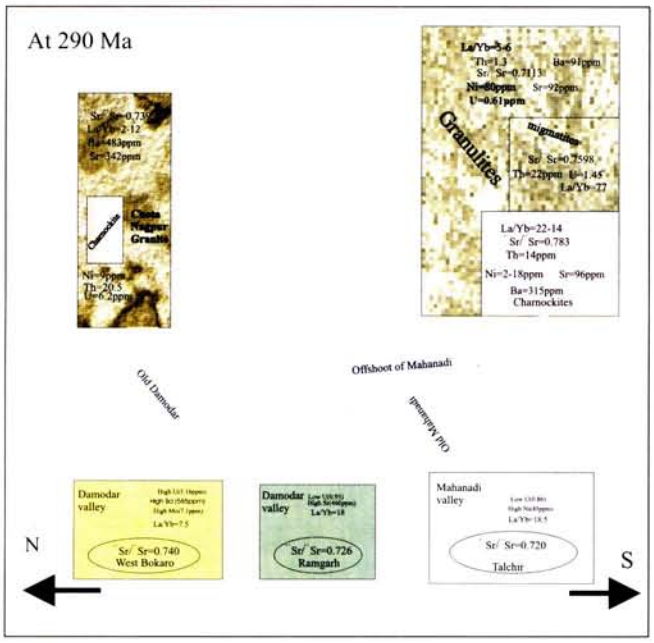

Fig. 6.2 Isotopic and elemental correspondence between three Talchir (Gondwana) basins : West Bokaro, Ramgarh and Talchir and their proposed drainage sources : Chotanagpur Granite and Eastern Ghat Granulite mediated through predecessors of Damodar and Mahanadi rivers.

the Centre for Atmospheric and Oceanic Studies, Indian Institute of Science, Bangalore.

(D. Jagadheesha and R. Ramesh)

Environment of Early Gondwana Sedimentation in India: Inference from Isotopic and Geochemical Study of Talchir Deposits

Carbonate nodules in sediments of Permo-Carboniferous basins in peninsular India offers promise for delineating the climate and environment of deposition at that time. Isotopic composition of carbon and oxygen have been determined in nodules collected from the basal formation (Talchir) of three Gondwana basins of east-central India along with a few samples from contemporaneous Dwyka tillite of South Africa. Petrographic, cathodoluminescence and sedimentary evidences suggest that many of these nodules contain primary carbonate precipitates and therefore their geochemical signatures can be used for palaeoclimatic inference. The mean $\delta^{18}O$, $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ values of the calcites in the nodules are 10.8‰ w.r.t. SMOW, - 9.7‰ w.r.t. PDB and 0.730 respectively suggesting a freshwater environment (probably lacustrine) for formation of these concretions. The oxygen isotopic composition of meteoric water at that time (Early Permian) and location (70°S palaeolatitude) estimated from mean $\delta^{18}O$ of calcite is - 22.9‰ and is close to the expected isotopic composition of precipitation (-20‰) at this latitude. This similarity suggests that (i) assignment of palaeolatitude of this location is reasonably correct and (ii) the global hydrological cycle in Early Permian was operating in a similar way as that of today. There is a slight depletion in oxygen isotope ratio which can be interpreted either in terms of an amount effect due to enhanced rainfall or an altitude effect if the precipitation occurred at high altitude as expected for development of the Talchir glacier. The Sr isotopic composition indicates that samples from Damodar valley region (with Sr ratio ~0.730), received water draining from adjoining granitic terrain of Chotanagpur region as suggested by isotopic ratio of 0.730 for its most weatherable component i.e. plagioclase mineral (**Fig. 6.2**). Nodules from Mahanadi valley have $^{87}Sr/^{86}Sr$ ratio of 0.720 similar to the ratio observed in mafic granulite of Eastern Ghat suggesting this region to be the water source for Talchir basin in Mahanadi valley. These inferences are supported by REE pattern and trace element concentration of carbonate phase of bulk nodule samples. This work was done in collaboration with Prof. A. Chakarvarty of IIT Kharagpur and Dr. A. M.Dayal of NGRI, Hyderabad.

(S.K. Bhattacharya, P.Ghosh, M.M. Sarin and J.R. Trivedi)

Weathering and Transport : River Water Studies

Organic Carbon and Nitrogen Transport in Godavari River

Under the national LOICZ (Land Ocean Interaction in the Coastal Zone) programme, efforts were continued to assess the fluxes and processes controlling riverine transport of organic carbon and nitrogen in the Godavari basin. Water samples from Godavari river were collected from headwaters at Nasik to its mouth at Bhairavapalam and from its major tributaries, Wardha,

Penganga, Wainganga, Pranhita, Indravati and Sabari during moderate (November, 1998), lean (March, 1999) and high (September, 1999) discharge conditions. The major distributary, Gautami was also sampled to represent the estuarine region.

The concentrations of POC and PON in the tributaries show significant seasonal variations with high values during monsoon, 20 and 2.7 mg l^{-1}. Likewise, concentrations in the main stream are also higher (POC:9.8 and PON: 0.7 mg l^{-1}) during the peak flow; while the lowest concentrations occur during the lean flow. The higher C:N ratios, in the range of 9 to 14, observed in samples from highly turbid rivers probably result from land (soil) derived organic matter. The lower C:N ratio during lean stages is attributed to organic matter composed of riverine algal material. The discharge-weighted concentrations for POC, PON and DIC, near the river mouth,are 7.2,0.6 and 24 mg l^{-1}, respectively. The total load of DIC by the river into the estuarine zone is 2.2 x 10^{12}g y^{-1}, nearly four times that of POC (0.6 X 10^{12}g y^{-1}), which is an order of magnitude more than the PON flux (0.06 x 10^{12} g y^{-1}). Analyses are underway to assess the DOC transport through the Godavari river system.

(K. Balakrishna and M.M. Sarin)

Re and Stable Isotopes in Headwaters of the Yamuna

The river Yamuna, a major tributary to the Ganga, originates in the Higher Himalaya from the Yamunotri Glacier. The headwaters of the Yamuna predominantly drain Higher Himalayan crystallines and sedimentaries in the Lesser Himalaya. As a part of our continuing efforts to understand and quantify weathering processes in this basin, water and sediment samples of the Yamuna and its tributaries were collected along its entire stretch, from Hanuman Chatti to near Saharanpur during three seasons, October, 1998, June, 1999 and September 1999.

The range in Re concentrations during peak discharge is ~ 0.35 to 4.7 ng l^{-1} (mean 1.8 ng l^{-1}), marginally lower than that measured during October 1998 ~1 to 6.2 ng l^{-1} (mean 2.1 ng l^{-1}) mimicking the TDS variations. The dissolved Re concentration of 1- 2 ng l^{-1}, typical of these rivers, is difficult to be accounted for by weathering of the crystallines and common sedimentary rocks from the Himalaya, as they generally have low Re, 0.02 to 2 ng g^{-1}. Weathering of blackshales is likely to be the dominant source of dissolved Re in the waters. The dissolved Re flux at the foothills of the Himalaya from the Yamuna and the Ganga are 120 and 200 moles y^{-1} respectively.

Analogous to Re, weathering/alteration of blackshales can also influence the budget of PGEs, uranium, phosphorous and vanadium which are enriched in them. Similarly, if oxidation of organic matter is the dominant process during the weathering/alteration of the blackshales, it could also contribute to CO_2 budget. Rough estimates indicate that dissolved Re flux of 120 moles y^{-1} can yield a CO_2 flux of ~ 5 x 10^4 moles km^{-2} y^{-1}. This compares with ~ 3-4 x 10^5 moles $km^{-2}y^{-1}$ of CO_2 consumption rate for silicate weathering in the Bhagirathi and Alaknanda basins.

Stable isotopes ($\delta^{18}O$ and δD) studies in the headwaters of the Yamuna were carried out to characterise the various sources contributing to its waters. $\delta^{18}O$ and δD for monsoon samples yielded a regression (best fit) line:

$$\delta D = (7.66 \pm 0.35)\ \delta^{18}O - (7.16 \pm 2.93).$$

This compares well with the world meteoric water line and with the data for the Ganga headwaters. The slope of the line indicates that there is no significant evaporation of the precipitation (rainfall and snow) which contributes to the river waters during this period. In contrast, the best fit lines for samples collected during June and October , $\delta D = (5.93 \pm 0.31)\ \delta^{18}O - (6.79 \pm 2.59)$ and $\delta D = (6.21 \pm 0.26)\ \delta^{18}O - (2.91 \pm 2.27)$ respectively, are similar within errors and show that these waters carry signatures of evaporation of the precipitation. The more depleted $\delta^{18}O$ signatures during monsoon in samples from the same locations compared to those during non-monsoon can result from "amount effect". The $\delta^{18}O$ signatures during the monsoon also show a strong correlation with TDS.

(S.K. Bhattacharya, T.K. Dalai, R.A. Jani, S. Krishnaswami and J.R. Trivedi).

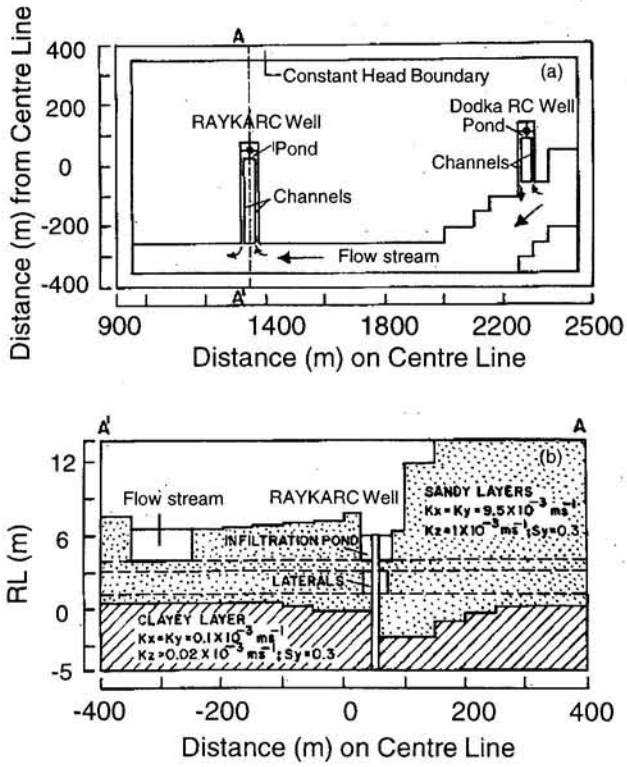

Fig. 6.3 (a) Plan and (b) cross section along AA' across the riverbed of the Finite Difference model used to simulate infiltration pond around the Rayka and Dodka RC wells in the River Mahi near Vadodra. The analysis indicates that the saucer shape of the sandy aquifer bottom and the aquifer permeability anisotropy strongly govern the flow to the laterals of the RC wells and restrict the yields at Rayka and Dodka

Hydrological Studies

Fluoride in Groundwater : Distribution in Cambay Basin

Fluoride concentration in groundwater is increasing beyond permissible levels in several parts of Gujarat, the causes for which are only vaguely understood. We have measured fluoride concentration in groundwater in the Cambay basin and contoured its distribution.

Although deeper waters in general have higher conductivity and salinity, the fluoride concentration does not necessarily increase with depth. Our data suggests that high fluoride concentration is primarily controlled by geological factors and only certain aquifer zones are enriched.

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

Radial Collector Wells in Streambeds: Effect of Aquifer Permeability Anisotropy on Yield and Capture Zone

The RC wells constructed in the Mahi and Sabarmati rivers are designed to provide water to the cities of Baroda and Ahmedabad but their yield is not always satisfactory. Causes for low yields in the Mahi River wells were investigated by the analysis of pump test data using a groundwater flow-modelling package VMODFLOW. The saucer shape of the aquifer (**Fig. 6.3**) and anisotropy of the permeability seem responsible for the low yield.

We also re-examined the pump-test data of Sabarmati RC well at Ahmedabad to study the influence of aquifer permeability anisotropy along stream flow, transverse to stream flow and in the vertical direction. Conventional pump-tests assume isotropic aquifers and result in high permeability value. The yield from the RC well, with surface water flow around it, on the other hand is largely governed by the vertical permeability. Permeability anisotropy also results in the capture zone being elongated in the flow direction.

(R.D. Deshpande, S.K. Gupta and V. Somayajulu)

Oceanography

Upwelling Rates in the Arabian Sea and Equatorial Indian Ocean using Bomb Radiocarbon

Upwelling influences marine biological productivity which in turn regulates the air-sea exchange of CO_2 and its budget in the atmosphere. Knowledge of long term (2 to 4 decades) average upwelling rates in the upper 1000 m column of the ocean are needed to model these processes. As a part of our continuing studies on mixing of water masses in the Arabian Sea and the Equatorial Indian Ocean we have measured radiocarbon profiles at eleven locations (including re-occupation of five GEOSECS stations). Some of these results provide information on CO_2 air-sea exchange and upwelling rates. Using available models upwelling rates are calculated (2 to 5.5 my^{-1}) which compare favourably with five GEOSECS (1977-1978) station data that yield 3-7my^{-1}. The spatial and temporal variations of upwelling rates are within about a factor of two.

Concentrations and Burial Fluxes of Organic and Inorganic Carbon on the Eastern Margins of the Arabian Sea

The eastern continental margin of the Arabian Sea (22°N to ~10°N), is well known for its high biological productivity and perennial denitrification layer (~200 to 1000m). Eleven sediment cores were collected and analyzed for organic carbon (C_{org}), N and $CaCO_3$ contents; three of these cores are dated by radiocarbon using AMS. Both depth and spatial trends in the concentrations of C_{org}, N and $CaCO_3$ are similar, ~1 - 6%, 0.13 - 0.82% and ~16 - 80% respectively. C/N ratios range from 6 to 15 (average 9.3) and indicate that C_{org} is mostly of marine origin. The C_{org} and $CaCO_3$ burial fluxes range from 1 to 22 g m^{-2} y^{-1}. The export flux accounts for ~10 to 25% of primary productivity. C_{org} and $CaCO_3$ are anti-correlated, implying effective scavenging of particulate organic carbon by the finer fractions (clay and fine silt) of sediments. This study indicates that high detrital content and faster sedimentation rates enhances the preservation of C_{org}. An overall productivity increase of about a factor of two is inferred during the past ~10 ky with significant periodicities of ~500 and ~2700 y.

(R. Agnihotri, R. Bhushan, K. Dutta, R. Ramesh, A. Sarkar and B.L.K. Somayajulu)

Other Studies/Programmes

Participation in Inter-calibration Exercise of IAEA Water Standards

International Atomic Energy Agency, Vienna invited stable isotope laboratory scientists to participate in the second inter-laboratory calibration test to determine the oxygen and hydrogen isotopic composition of four water standards spanning the natural range of variations. This inter-comparison exercise was carried out in the framework of Analytical Quality Control Service of the IAEA. Scientists from about 40 countries engaged in stable isotope research were involved in this exercise through analysis of four reference water samples (OH-1, OH-2, OH-3 and OH-4). PRL scientists determined the oxygen and hydrogen isotopic ratios of these water samples using the newly acquired GEO 20-20 mass spectrometer and its associated extraction systems. Each sample was analyzed several times and the mean and standard deviation were determined. Subsequently, IAEA has sent us the summary of determinations by about 80 laboratories.

The PRL determinations agree excellently with the grand means calculated from the acceptable measurements of these 80 laboratories suggesting that our systems and procedures give results in agreement with the majority of the laboratories in the world. This exercise has reconfirmed the credibility of the measurements at the stable isotope laboratory of PRL among the world community.

(S.K. Bhattacharya, P. Ghosh and R.A. Jani)

Radiocarbon Dating Laboratory

Bengal Fan sediments, consisting mainly of ooids, shells and clay were dated by ^{14}C. Four radiocarbon ages ranging from 12 to 19 ky BP indicate that the cores cover the LGM period. The rate of sedimentation in this area is found to vary between 2 to 14 cm ka^{-1}.

The radiocarbon chronology of peat and loess material collected near Pindari glacier, were determined. Peats, clustered around ~ 0.92 m depth below surface, dates to ~1 ka BP. Loess layers from the same area gives ages as 3,520 ± 140 and 7160 ± 110y BP. In the loess section the estimated deposition rate is 0.2 mm y^{-1}.

Marine sediment samples from Karara, off S-W coast of Karnataka, were analyzed for ^{14}C. Sedimentation rates based on six radiocarbon dates on two cores are, 28 cm ka^{-1} (14°24'N, 74°0'E) and 80 cm ka^{-1} (14°51'N, 73°60'E). Ages range from 4190 ± 110 to 10,760 ± 130y BP.

(S. Kusumgar and M.G. Yadava).

Discovery of Anomalous Oxygen Isotopic Fractionation in Photo-dissociation of Carbon Dioxide and Study of Ozone Isotopomers

An interesting case of isotopic fractionation was discovered last year. Several earlier studies related to carbon containing gases in the atmosphere of Earth and Mars suggested unusual fractionation associated with photochemistry of CO_2. This motivated us to investigate

the isotopic composition of the photolysis products of CO_2 i.e., oxygen and carbon monoxide. The photodissociation was carried out using Hg and Kr lamps. Hg lamp gives out UV emissions at two wavelengths- 185 and 254 nm of which only 185 nm photon has sufficient energy to dissociate CO_2. The continuum Kr lamp emits photons in the range of 120 to 160 nm. Isotopic composition of the product oxygen is characterized by a large enrichment of ^{17}O isotopic species relative to ^{16}O. The range of enrichment varies from 67 to 132 parts per thousand. In contrast, the ^{18}O species appear normal.

In conventional dissociation (thermal or chemical) the products are depleted in both the heavy isotopes. A preliminary assessment of the process of photon absorption and CO_2 dissociation on potential energy surfaces suggests involvement of a spin forbidden transition between singlet and triplet states causing the dissociation. It seems that substantial differences may exist among isotopomers in pre-dissociation through curve crossing due to sensitivity of coupling matrix element (responsible for singlet-triplet transition) to small shifts in the vibrational energy levels. Further studies are in progress to gain more insight in this process. This work was done in collaboration with Prof. M.H. Thiemens and Dr. J. Savarino of the University of California, San Diego.

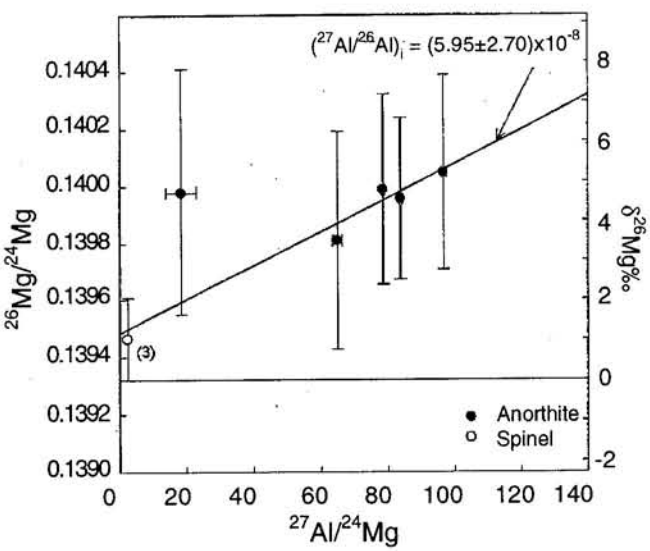

Fig. 6.4 Al-Mg isochron for the chondrules from CR carbonaceous chondrite EET92174

As a sequel to this study we have initiated research in PRL in the area of mass-independent oxygen isotopic fractionation in photochemical processes. We have set up the experimental procedure to study the isotopic composition of ozone formed by UV dissociation and high frequency discharge of O_2. The ozone formed shows large enrichment in both the heavy isotopes. The factors defining the extent of enrichment are being determined. The newly acquired GEO 20-20 mass-spectrometer is playing an important role in this study.

(S.K. Bhattacharya and S. Chakraborty)

Solar System and Geochronology

Early Solar System Processes

^{26}Al in Chondrules from Carbonaceous Chondrites

Chondrules are spheroidal objects present in chondritic meteorites and are formed by fast cooling of silicate melt droplets produced by some transient high temperature events in the solar nebula. Pinpointing the formation time of these objects, in relation to the Ca-Al-rich inclusions (CAIs), some of the first objects to form in the solar nebula, is very important in establishing the time scales of nebular processes. We have looked for fossil records of the short-lived nuclide ^{26}Al (half-life~7×10^5 years) in a set of chondrules from carbonaceous chondrites (CR group) to address this question. Chondrules from six CR meteorites have been analyzed by the ion probe. Only a few of them have fossil records of ^{26}Al, and the initial $^{26}Al/^{27}Al$ ratios at the time of their formation are close to ~ 5×10^{-6} (**Fig. 6.4**). The other chondrules do not have detectable signal of ^{26}Al, indicating that the initial $^{26}Al/^{27}Al$ values < 10^{-6}. Our results imply that chondrule formation started much after the CAIs, and chondrule forming process must have been operating for a few million years. Dynamical considerations, however, suggest that gas drag effect will push these mm-sized objects into the Sun in such a time scale. We propose that the chondrules got incorporated into meter-sized objects soon after their formation, and aggregation of these objects finally lead to the formation of the meteorite parent bodies within a few million years.

Work carried out in collaboration with scientists from Univ. of Hawaii and Lawrence Livermore Laboratory, USA.

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

Solar Particle Production of Short-lived Nuclides

Production of the short-lived nuclides ^{41}Ca, ^{36}Cl, ^{26}Al, ^{60}Fe, ^{10}Be and ^{53}Mn by solar energetic particles (SEP) interacting with dust grains of chondritic composition is estimated considering a broad range of spectral parameters for the SEP and appropriate nuclear reaction cross sections. The dust grains (10 micron to 1 cm) were assumed to follow power-law size distribution. The irradiation is considered to have taken place in the meteorite forming zone and we have ignored possible effect of nebular shielding of the SEP. The possibility that an enhanced flux of SEP from an active early (T-Tauri) Sun could have been responsible for the production of these short-lived nuclides in the early solar system has been investigated. While production of ^{60}Fe is ruled out from target abundance considerations, it is also not possible to co-produce ^{26}Al with any of the other nuclide, to match their initial abundances in the early solar system, for any combination of irradiation time and SEP flux enhancement factor. The lowest observed value for ^{53}Mn and the recently reported value for initial abundance of ^{10}Be can be matched by a much lower SEP flux enhancement factor and irradiation time of the order of a million years; this will not lead to significant production of the other nuclides.

(J. N. Goswami, K. K. Marhas and S. Sahijpal)

Isotopic and Trace Element Abundances in Early Solar System Solids

Thermodynamical considerations suggest that the refractory hibonites (Ca-Al-oxide with minor amount of Mg and Ti) are some of the first solids to form in the solar nebula. Potassium and magnesium isotopic compositions in hibonites from two primitive carbonaceous chondrites, Murchison and Allende, are determined by an ion probe to look for the possible presence of the short-lived nuclides ^{41}Ca (half-life~10^5 years) and ^{26}Al (half-life~7×10^5 years) at the time of their formation. Abundance anomalies in the neutron-rich isotopes, ^{50}Ti and ^{48}Ca, as well as rare-earth-element (REE) and additional refractory element abundances have also been determined to infer plausible formation environments of the hibonites in the solar nebula. Hibonites with highly enriched REE abundances and showing ultrarefractory pattern are nearly devoid of both the short-lived nuclides, ^{41}Ca and ^{26}Al, but have high magnitude anomalies of the neutron-rich isotopes ^{48}Ca and ^{50}Ti. On the other hand, hibonites with lower REE enrichments, often incorporate these nuclides and also have lower magnitude anomalies in ^{48}Ca and ^{50}Ti. We suggest that the first group of hibonites formed early in the nebula before the short-lived nuclides injected from an external source into the collapsing nebula could reach the region of hibonite formation, while the second group formed at a later time and incorporated the short-lived nuclides. The lower abundances of stable isotopic anomalies in the later group is due to removal of this preexisting anomalous component by the earlier forming solids and also its dilution by the freshly introduced stellar material containing the radioactivities. Work carried out in collaboration with scientists from Enrico Fermi Institute, Chicago.

(K. K. Marhas, N. Sinha, S. Sahijpal and J. N. Goswami)

Study of Differentiated Meteorites

Vissannapeta: A New Cumulate Eucrite

A wholly crusted single stone which fell in Vissannapeta, Andhra Pradesh, India has been identified as a cumulate eucrite based on its primary texture and mineral composition. The stone is pyramidal in shape and the crust shows rib-like flow features indicating that it had an oriented passage through the atmosphere towards the terminal stage of its flight. Conditions of its fall, mineralogical characteristics and results of measurements of cosmogenic radioactivity (^{26}Al, ^{22}Na and ^{54}Mn) and track density are described. Compared to Piplia Kalan eucrite, which fell about 18 months before Vissannapeta, the observed activity levels of these nuclides are approximately 75% whereas higher activity of ^{22}Na and ^{54}Mn would be expected from solar cycle modulation of galactic cosmic rays. These results, as well as the track density gradient indicate that

Vissannapeta was a small meteoroid (50kg) wherein the nuclear cascade due to galactic cosmic rays did not develop fully. Tracks, surface morphology and crustal features indicate at least two fragmentation events in the atmosphere. Cosmic ray exposure age of 37Ma and a K-Ar age of 3.9 Ga have also been determined for this meteorite. Some of this work was done in collaboration with Geological Survey of India, Calcutta

(N. Bhandari, P.N. Shukla, A.D. Shukla S.V.S. Murty, R.R. Mahajan, K.M. Suthar, and P. Adhyaru)

^{26}Al in Piplia Kalan Eucrite: Further Confirmation by TIMS

Mg isotopic studies are carried out by TIMS in Piplia Kalan (PK) eucrite. Two analyses of Mg from pyroxene are consistent with the analyses for the Mg standards, indicating the absence of an excess of ^{26}Mg in this high-Mg, low-Al/Mg PK phase. Both plagioclase samples show a small but distinct excesses δ^{26}Mg = 2.3±0.3‰ and δ^{26}Mg = 2.9±0.3‰. These data demonstrate that PK plagioclase shows a definite excess in ^{26}Mg while PK pyroxene has normal ^{26}Mg/^{24}Mg composition.

The best-fit line through the PK plagioclase and pyroxene data (**Fig. 6.5**) yields an initial $(^{26}Al/^{27}Al)_0$ = (2.6± 0.5) x 10^{-6}. The initial $(^{26}Mg/^{24}Mg)_0$ in PK, as established by the pyroxene, is normal. The evidence for ^{26}Al in Piplia Kalan by TIMS, is consistent with the data from the ion microprobe. The excesses, which do not appear to be well correlated with Al/Mg in the plagioclase, are indicative of the remobilization of Mg isotopes in the plagioclase. This process within the plagioclase may be aided by the fact that this phase does not readily accommodate Mg. The difference in the inferred initial ^{26}Al abundance between Allende CAIs and PK suggests a time interval of ~3 Ma. We consider PK as a planetary differentiate, produced in the presence or due to the presence of ^{26}Al and cooled sufficiently fast to preserve evidence of further ^{26}Al decay, in a high Al/Mg phase. We consider that the excess ^{26}Mg was remobilized within the plagioclase subsequent to the decay of ^{26}Al. The low Rb-Sr age and the possible absence of effects for the ^{53}Mn-^{53}Cr system could reflect this partial remobilization. This work was done in collaboration with California Institute of Technology, USA.

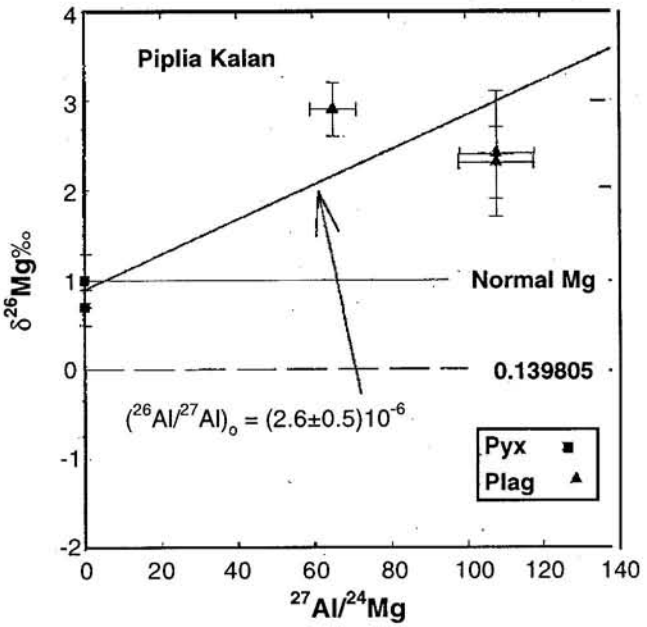

Fig. 6.5 Correlation of δ^{26}Mg with ^{27}Al /^{26}Mg in Piplia Kalan eucrite. Excess δ^{26}Mg clearly establishes the presence of live ^{26}Al in this meteorite

(G. Srinivasan)

Martian Meteorite Studies

To understand the distribution and evolution of nitrogen and noble gases in the atmosphere and the interior of Mars, we have analysed two martian meteorites Nakhla (to understand the elemental fractionation of noble gases in the Mars atmosphere) and the newly discovered meteorite Dar al Gani 476 (to look for trapped gases).

DaG 476 is from Libyan Sahara and has been identified as martian in May 1998. It has suffered heavy weathering in the desert. By a clever stepped temperature extraction, we could peel off the weathered component and could successfully show the martian atmospheric Ar and Xe signatures in this meteorite. We could also establish its cosmic ray exposure age to be 1.1 Ma, which requires separate impact on Mars for the ejection of this meteorite.

It has been shown by earlier workers, that the martian atmospheric noble gases found in the Nakhla meteorite show an elemental fractionation, favouring the heavy gases (i.e. Xe in preference to Ar). Our nitrogen and noble gas studies in Nakhla clearly confirm this noble gas elemental fractionation. More importantly we also showed that there is no fractionation between Xe and N, a fact hitherto unknown. Our earlier work on meteorite ALH 84001, wherein similar fractionation is observed, also confirms this trend.

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

Parent Material for the Accretion of Mars

It is generally assumed that terrestrial planets are made up of two types of primitive meteoritic matter, one oxidising in character and volatile rich (similar to carbonaceous chondrites) and the other reducing in character and volatile poor (somewhat similar to enstatile chondrites). It has been well established that each meteorite class has a distinctly well defined oxygen (a major element) and nitrogen (a volatile trace element) isotopic composition. Using the isotopic composition of martian meteorites to be representative of Mars, it has been predicted that Mars is made of meteorites belonging to the classes H, CV and CI in the proportion of 85:11:4. Our work on martian meteorites has yielded a clear value of $\delta^{15}N = -30 \pm 5‰$ for the mantle of Mars. We made use of both N and O isotopic data of martian meteorites to derive the parent material of planet Mars. In **Fig. 6.6**, the oxygen and N isotopic data of martian meteorites is shown along with other primitive meteorites. The Mars data is only consistant with Mars being made of enstatite and ordinary chondrites in the ratio of 60:40.

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

Silicides: A Previously Unknown Class of Meteorites?

Silicides are strange mineral assemblages, with often aerodynamic shapes, found in some sedimentary horizons in parts of Russia. Their mineralogy suggests them to be of unnatural occurrances on Earth and their very old age (millions of years) rules out their synthetic

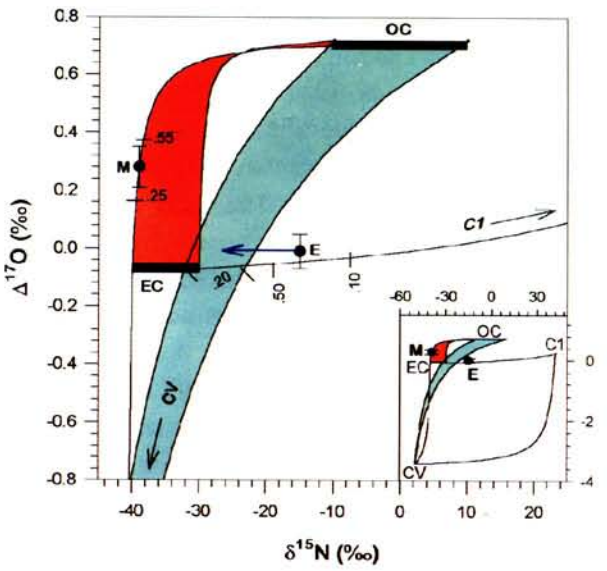

Fig. 6.6 Oxygen and nitrogen isotopic systamatics of ordinary (OC), enstatite (EC) and carbonaceous (C1) chondrites. M and E represent Mars and Earth. Shaded regions are mixing curves between the two end members. Mars can only be explained as an admixture of EC and OC in 60:40 proportion

origin. These considerations together with some chemical and isotopic systamatics have led to the suggestion that 'Silicides' are extraterrestrial and represent a hitherto unknown class of meteorites. Since meteorites of known classes belonging to reduced formation conditions have distinctly lighter nitrogen, we analysed two silicides for their nitrogen isotopic composition, in an effort to settle their origin. Our results indicate that $\delta^{15}N$ is ~ 10‰ and is accompanied by Ar, Kr and Xe with air like composition. These observations are clearly suggestive of terrestrial origin for Silicides. This work is carried out in collaboration with Dr. Sergi Batovrin, New Jersey.

(Sudeshna Basu and S.V.S. Murty)

Physico-chemical Studies of Geological Boundaries

Global Appearance of Magnetic and Super-Paramagnetic Iron Phases in K/T Boundary Clays

Iron mineralogy of the Cretaceous-Tertiary boundary (KTB) clays from four different sites Gubbio,

Turkmenia, Anjar and Meghalaya has been analyzed using Mössbauer spectroscopy. At all the four sites, the KTB samples show presence of oxide and/or oxyhydroxide phases of iron, often in the form of particles of a few nanometers in size, exhibiting superparamagnetic behavior. The abundance of these iron phases across the boundary correlates fairly well with the iridium content, which is considered as the geochemical signature of impact of an extraterrestrial body. These results are consistent with the formation of the superparamagnetic particles in the impact vapour plume. We propose that global appearance of magnetic/ superparamagnetic oxides as the dominant iron phase at a geological boundary, irrespective of the lithology of local sediments, signifies a large impact on the Earth and can be used as a geological impact marker. This work was done in collaboration with the Indian Institute of Technology, Kanpur and the J.N.V. University, Jodhpur.

(N. Bhandari and A.D. Shukla)

Study of Natural Fullerenes in Cretaceous-Tertiary Boundary Clays

Fullerenes have been found in rocks which had witnessed singular geological events like lightning strikes, wild fires at the Cretaceous-Tertiary boundary and shock-produced impact generated breccias from Sudbury Meteorite crater.

We have studied the properties of the carbonaceous matter in a sediment bed from Anjar, a K/T boundary site found by us in Deccan. We find that fullerenes are present at two horizons in this section. The highest concentration of fullerenes was found in sample L having the highest average concentration of iridium (1287 pg/g). We also carried out ^{13}C NMR spectroscopic studies on the powdered carbonaceous material to confirm the presence of fullerenes, and find a single NMR line at 143.28 ppm for sample L corresponding to the sp_2 carbons of the fullerene C_{60}. The other peaks expected for C_{70} are not observed in any of the samples. The concentration of fullerene C_{60} given in **Fig. 6.7** is approximate but appears to be comparable to the values found in Woodside Creek and Flaxbourne River sections. The absence of C_{70} is also noticed in K/T boundary clay from some sections, e.g. at Woodside Creek and Shungites of Karelia.

The origin of C_{60} in Anjar may be related to forest fires as at the other K/T sites. Whether the forest fires were impact related or due to volcanism still remains to be established. However, their association with iridium-rich horizons favors their impact origin. This work was done in collaboration with the Indian Institute of Chemical Technology and National Geophysical Research Institute, Hyderabad.

(N. Bhandari and A.D. Shukla)

Permian-Triassic Mass Extinction

The Permian-Triassic (P/T) mass extinction took place around 250 Ma ago. Siberian volcanism has been suggested as the major cause for this extinction. Recently shock quartz has been reported from Antarctic and Australian P/T sections supporting the possibility of an impact as a cause for this mass extinction. To further find support for an impact hypothesis we have sampled

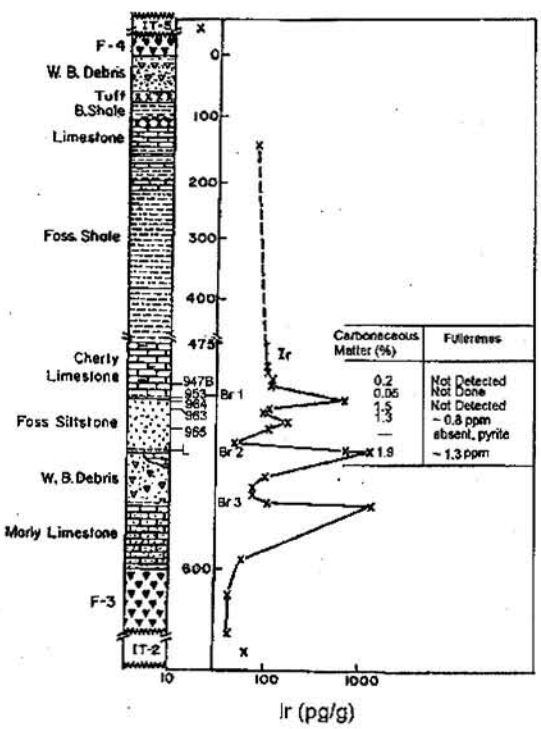

Fig. 6.7 Natural fullerenes (C_{60}) were found to be associated with two Ir rich layers in Anjar K/T boundary section.

two more sections from Spiti Valley (Attargoo and Ganmachidam) during an IGCP field trip. Multielemental analysis using neutron activation and γ-ray spectroscopy have been carried out on some of these samples and U, Th, REE and various other elements have been studied. One of the interesting observation is an increase in U concentration at the PTB which would suggest a reducing environment at PTB.

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

Isotope Geology and Geochronology

Origin of Air-like Noble Gases in Oceanic Basalts

One of the uncertainities in exploiting the noble gas data from oceanic basalts, lies in the poor understanding of a ubiquitous air-like noble gas component in them. Although air like noble gases in oceanic basalts are attributed to atmospheric contamination by interaction with air saturated water (ASW), atmospheric gases recycled into the mantle at subduction zones provide an equally plausible source. But the recycled noble gases are isotopically indistinguishable from those due to ASW. However, the nitrogen isotopic composition of ASW and recycled gases differ significantly, making a simultaneous study of N and noble gases a useful approach to investigate this component. We identified a gas component in oceanic basalts having $\delta^{15}N \sim +18‰$ and accompanied by $^{40}Ar/^{36}Ar$ values much lower than the mantle value. This component can be attributed to recycled materials from subduction zones, which are incorporated into these basaltic magmas during their ascent through a shallow enriched region in the mantle. This suggests that a part of the air-like noble gases in oceanic basalts is due to recycled atmospheric gases. Thus, the air like noble gases in the oceanic basalts, hitherto considered a hinderance, provide useful clues for understanding the geochemical evolution of these samples.

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

^{40}Ar-^{39}Ar Thermochronology of the Suture Zone, Ladakh, India

Ladakh region of North-West Himalaya presents the best preserved history of pre-syn-, and post-collision signatures. It has rocks ranging from Precambrian passive margin sediments to the post collision molasses. The suture zone in Ladakh, referred to as the Indus Suture Zone (ISZ), is characterized by the several occurrences of ophiolitic melange. Apart from these, various linear belts of the volcanic rocks have been found in the Indus Suture Zone, . The Trans Himalya Batholith represents the plutonic magmatism associated with the subduction of the Tethys oceanic crust beneath the Asian continent, and is known as the Ladakh batholith.

The Ar-Ar age spectrum of a sample that has remained thermally undisturbed subsequent to its formation yields a plateau whearas the age spectrum for a sample thermally disturbed subsequent to its crystallization maps the Ar loss due to the thermal events at different times. This gives the clue for the different tectono-thermal events experienced by the sample.

The two whole rock samples from the Ladakh Batholith yielded cooling patterns and a few steps yielding plateau like ages. The mineral separates from these samples yielded excellent plateau ages (**Fig. 6.8**). The biotite separated from a granodiorite, LK24, gives a plateau age as 40.6 ± 0.7 Ma. The whole rock spectrum of the same rock has yielded a plateaulike age as 46.25 ± 0.6 Ma. A muscovite separated from a granite LK198, gives a plateau age as 29.82 ±0.2 Ma, and the whole rock spectrum shows a cooling pattern with maximum age ~50 Ma and a minimum age as 18 Ma. Taking the muscovite closure temperature for Ar as ~350°C, a cooling rate of ~20°C/Ma is obtained. These results indicate that plutonic rocks have taken a long time in exhumation and cooling and hence the tectonic uplift had not started, may be till 18 Ma. ago.

(Rajneesh Bhutani and Kanchan Pande)

^{40}Ar-^{39}Ar Geochronology of the Ophiolite of Indus Suture Zone, Ladakh, India: Implication for the Timing of Initiation of the Collision

The collision between the Indian and Asian plates has given rise to some of the highest mountains of the world. Various indirect approaches have been em-

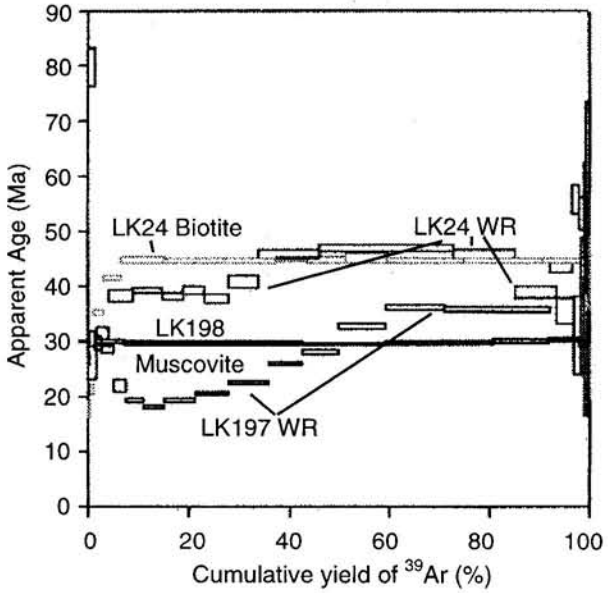

Fig. 6.8 Age spectra of whole rocks and their minerals of the Ladakh Batholith.

ployed to constrain the age of initiation of this collision, which is still being quoted anywhere between ~60 to 40Ma. We present the Ar-Ar ages of the ophiolites from the Indus Suture, Ladakh and discuss the scope of this approach in constraining the age of the collision more tightly.

Several ophiolitic melange occurrences have been reported belonging to the Indus Suture in the Ladakh sector. These are characterized by the typical oceanic floor assemblages like chert, limestone mixed with the peridotites, serpentinites, dolerites, basalts, and pillow lavas. We report the ^{40}Ar-^{39}Ar age spectra of two volcanics from the Sumdo Nala section of central Ladakh and one pillow lava from Chiktan, which is about 100 Kms west of the Sumdo Nala.

Two ophiolitic melange samples yield complex age spectra. One of the sample yielded a cooling pattern with last 23% of ^{39}Ar released giving a maximum age as 38.3 ± 0.6 Ma and a minimum age at the lowest temperature as ~14Ma. This age spectrum indicates a strong thermo-tectonic event at 38Ma which has reset this sample completely with respect to Ar and then it slowly cooled through its closure temperature until 14Ma. Another sample from the same section yielded a plateaue age of 46. 8± 0.7 Ma at intermediate temperature, consisting of 64% of the totatl ^{39}Ar released. The higher temperature gas release of this sample yields a complex pattern of apparent ages, which may be due to some secondary alteration. We interpret this age of 46Ma as the age of the last major thermo-tectonic event experienced by this sample.

The major thermo-tectonic event that could reset their original radiogenic signature, could more probably be the continental collision between Indian and Asian plate. These two samples indicate that the syn- collisional ophiolite obduction may have started in this region around ~46 Ma and continued up to 38 Ma. A pillow lava, from western Ladakh yielded a plateau age of 128.2 ± 2.6 Ma for the initial steps comprising 62% of ^{39}Ar released. The higher temperature steps yield complex age pattern due to the redistribution of the radiogenic argon into some phases.

These results show that the ophiolites which have been formed much earlier than collision got trapped during the initiation of the collision and the lower members of the ophiolite suite got affected by the collision more severely than the upper most member like pillow lava.

(Rajneesh Bhutani and Kanchan Pande)

The Record of Cosmogenic in-situ Produced ^{14}C in Vostok and Taylor Dome Ice Samples: Implications to Strong Role of Wind Ventilation Processes

We measured the concentrations of in-situ cosmogenic ^{14}C in several ice samples from the Vostok and Taylor Dome cores, spanning the time intervals of 20 ky BP and 11 ky BP, respectively. The results are very intriguing when examined in context to the earlier data obtained for the GISP 2 ice core samples covering the past 17 ky time span. The total in-situ concentrations are smaller by factors of an order of magnitude or more than expected on the basis of the estimated accumulation rates. This result is in divergence with our findings for the GISP 2 samples where near quantitative ^{14}C retention was observed. The partitioning of ^{14}C in the CO and CO_2

phases is however quite similar in the GISP and the two Antarctic ice samples.

Noting that most of the in-situ ^{14}C is produced in the ice during its accumulation to thickness of up to about 10m, we interpret the observed ^{14}C deficiencies in Antarctic ice samples as being due to grain metamorphism due to recrystallization and sublimation/evaporation caused by wind ventilation. The firnification processes are expected to become more significant in low accumulation rate situations. In the case of the Vostok and Taylor Dome samples we are dealing with accumulation rates in the range of (1-2) and (1-5) cm/y, respectively, in contrast to an order of magnitude higher accumulation rates of (10-30) cm/y in the case of the GISP 2 samples studied.

We have constructed simplified models for wind ventilation caused losses of in-situ ^{14}C during the process of ice accumulation. These models should allow us to postulate a likely scenario as to what processes may be operative when ice accumulates in situations of low accumulation rates. An interesting feature of the firnification processes, which are seen to be important in the Antarctic low-accumulation rate ice samples, is that they differently affect the concentrations of the cosmogenic nuclides scavenged from the atmosphere in the accumulating firn. By studying the concentrations of in-situ cosmogenic ^{14}C, and the atmospheric cosmogenic ^{10}Be and ^{36}Cl in the same ice samples, one can hope to obtain fairly realistic models of firnification processes; specifically relationships between precipitation and accumulation, and the main processes contributing to modifications in the nuclide concentrations.

(Devendra Lal, A.J. Timothy Jull, D.J. Donahue, G.S. Burr, B. Deck, J. Jouzel and E. Steig)

Facilities

Computer Centre

The Computer Centre is equipped with five IBM RS-6000/580 servers. These servers are interconnected with FDDI Network forming a powerful cluster for computing. This cluster is further connected to six X-stations and more than 200 PCs and few work-stations distributed throughout the Laboratory. It is also connected to the INTERNET via a fast leased line. Thus full connectivity has been provided to users all the time from anywhere in the main premises and the Thaltej Campus. Application Software Libraries have been provided to cater to the need of scientific community in performing the mathematical and numerical calcaulations and visualization of data. The provision of making colour slides, prints and video tapes is available. The centre provides the consultations and other facilities including archival of file systems, system security, authorisation, updating the system softwares, third party softwares and public domain softwares. It also maintains internet connectivity and the local area network.

Library

PRL library consists of rich collection of Books, Journals, Reports, Data and articles in various forms. The total collection exceeds 50000 items with more than 16000 books and 30,000 bound volumes of journals. Other collection includes reports, Ph.D. Thesis, videos, CDs, PRL publications like reprints and Technical Notes. Besides circulation of books, journals and other documents library provides to the readers services like photocopying, Reference services, Internet search, SDI services and Retrospective literature search, Inter library loan, Translation and procure books for individual bookgrants etc.

For the year 2000 library has subscribed to 172 journals and periodicals. About 150 books were added to the collection apart from large number of other documents like reports, data and maps for scientific use. PRL library also subscribes to Searchable databases namely STN and Uncover to get full articles from 18000 other journals on request to satisfy specific queries of the users. The articles are received by FAX for quick delivery to the users. Under Inter Library Loan (ILL) more than 300 requests were served for which PRL library works closely with other libraries in Ahmedabad as well as other science and technology libraries.

During the year more than 3000 books and journals were issued and more than 4,50,000 photocopies were supplied using in-house facility and external resources. The library extensively uses computerization to serve the readers.

For easy access, electronic resources are linked through library home page which acts as front end to the users.

Workshop

The workshop and its extension at Thaltej Center provide major design & technical support to all the experimental programs at PRL. The workshop also provide support to field observatory at Mt. Abu and Udaipur. The facilities in the workshop range from lathe, milling, shaping, and drilling machines, profile projector system, argon gas welding system, plasma cutting machine and a CNC machine.

In order to maximize the utilization of available space the entire workshop layout was modified during the year. This resulted in better use of shop floor, sitting, store and workspace. This also improved the man, machine and material movement around the workshop with a greater safety.

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

1. Design and fabrication of sub-assembly of selectable filter assembly unit for 'All Sky Imaging System' of Planetary Atmospheres and Aeronomy Division. The sub assembly consists of 4-filters in precision housing with mechanism for accurate positioning using linear motion.
2. Design, fabrication and installation of various components (idler rollers, shock absorbers etc) and sub-assembly for Dome of Spar telescope at Udaipur Solar Observatory (USO). A precision X-Y movement for the

other telescope was also designed fabricated and installed. Complete maintenance of the Dome with modifications was done. A 6-member team visited USO several times for the above-mentioned jobs. All the jobs have been completed in a record time of about 3 months. All the systems are now working satisfactorily. Some of the components were manufactured using the CNS machine.

3. A Solar X-ray Spectrometer (SOXS) satellite payload is being developed at PRL. For this a conceptual, space qualified model was designed and fabricated. Based on the evaluation report a new model is being designed now.

4. Special instrument adapter for declination adjustment and RA drive mechanism, to observe Solar Eclipse was designed, fabricated and installed.

5. Electronic Instrument boxes were designed and fabricated for Rocket payload for 'mass-spectrometer' for Planetary Atmospheres and Aeronomy Division.

6. Very precision holders were fabricated for mounting optical components for Laser Physics Division.

In addition to above job a large number of jobs from different groups were completed including some major modifications in old instruments.

A one-day workshop on 'Use of CNC machines for scientific application' was held at PRL on April 1999. In all there were 80 participants from PRL, SAC, LDCE and Industries. There were slide slows from HMT and SANDVIC company highlighting the products used in CNC machines.

As a part of training for workshop personnel, 5 of the workshop staff were deputed for, training for operation, programming and maintenance of CNC machine at HMT training center, Cochin.

A new high speed PC was recently installed in the design section of the workshop. Training to student and apprentice were also provided during the period in various trades. About 100 students and 25 teachers visited the workshop on 28th February 2000 under 'National Science Day celebration' by PRL. Some live demonstrations were arranged for the benefit of the students and teachers.

Engineering Services

The Engineering Services section renders all the technical services pertaining to civil engineering works and related building and laboratory services such as electrical, air-conditioning, internal telephone system, elevators, etc. Right from the land acquisition to maintenance of all the residential and non-residential buildings and its related services for various campuses of the laboratory are handled. These include architectural planning, designing, estimating and execution of various civil works and related services, landscaping, horticultural development, interiors & furnishings of buildings & structures of all the six campuses - PRL main campus, Staff Quarter Campus, Thaltej Campus, Mt. Abu Campus, Udaipur Campus and Vikramnagar Staff Quarter Campus.

Site preparation works were executed for installation of sophisticated research equipments by meeting with all special requirements.

Alteration & modification work in the Director's Bungalow has been carried out.

Honorary Fellows & Professors at PRL

Honorary Fellows at PRL

Professor Hannes Alfvén

Professor J.E. Blamont

Professor S. Chandrasekhar

Acad. V.L. Ginzburg

Professor B. Rossi

Professor J.B. French

Professor A.M.J. Tom Gehrels

Professor D. Lal

Professor P.R. Pisharoty

Professor M.G.K. Menon

Professor S. Dhawan

Professor U. R. Rao

Prof. P. Crutzen

Prof. K. Kasturirangan

Prof. A. Hewish

Honorary Professors at PRL

Professor Yash Pal

Professor S. P. Pandya

Professor R. K. Varma

Professor J. C. Parikh

Professor B. L. K. Somayajulu

Academic Faculty of PRL

Academic Faculty of PRL

Name	Specialisation	Academic Qualification
Prof G S Agarwal FNA, FASc, FNASc	Quantum Optics, Nonlinear Optics and Laser	Ph D Rochester Univ. (1969)
Prof N Bhandari FASc, FNASc	Planetary Physics	Ph D TIFR Bombay Univ. (1967)
Prof S Krishnaswami FNA, FASc, FNASc	Aqueous Geochemistry and Nuclear Oceanography	Ph D TIFR, Bombay Univ.(1974)
Prof A R Prasanna	General Relativity and Astrophysics	Ph D Poona Univ.(1970)
Prof Vijay Kumar	Experimental Atomic and Molecular Physics	Ph D Univ. of Adelaide, Australia (1970)
Prof D P Dewangan	Atomic and Molecular Physics	Ph D Calcutta Univ. (1973)
Prof J N Goswami FASc, FNASc	Solar System Studies (Pre - Solar Processes)	Ph D PRL, Gujarat Univ. (1978)
Prof V K B Kota	Nuclear Physics	Ph D Andhra Univ.(1977)
Prof A S Joshipura FASc	Particle Physics	Ph D Bombay Univ. (1979)
Prof A K Singhvi FASc, FNASc	Palaeoclimatology and Geochronology	Ph D IIT, Kanpur (1975)
Prof S K Bhattacharya FASc	Isotope Geochemistry	Ph D PRL, Gujarat Univ. (1980)
Prof. V B Sheorey	Theoretical Atomic Physics and Non linear Dynamics	Ph D Univ. College, London Univ.(1968)
Prof. S D Rindani	Particle Physics	Ph D IIT, Bombay (1976)
Prof. Harish Chandra	Ionospheric Studies and Dynamics of Middle Atmosphere	Ph D PRL, Gujarat Univ. (1970)
Dr B G A Rao	Spectroscopic Diagnostic in Astrophysical Plasmas	Ph D PRL, Gujarat Univ. (1978)
Dr. Hemant H. Dave	Laser Spectroscopy and Astrophysical Plasmas	Ph D, Uni. of Lowell, (1980) Mass., USA
Dr S P Gupta	Electrodynamics of Middle Atmosphere	Ph D PRL, Gujarat Univ. (1971)
Dr. D.K. Chakrabarty	Ion and Neutral Chemistry of Earth's Atmosphere	Ph D NPL, Delhi Uni. (1973)
Dr. R. E. Amritkar	Nonlinear Dynamics & Chaos	Ph D IISc, Bangalore (1978)
Dr U C Joshi	Star Formation, AGNS and Comets	Ph D Kumaun Univ. (1981)

Name	Specialisation	Academic Qualification
Dr H S S Sinha	Upper Atmospheric and Ionospheric Studies	Ph D PRL, Gujarat Univ. (1977)
Dr Utpal G Sarkar	Particle Physics	Ph.D Calcutta Univ. (1984)
Dr S. K. Gupta	Geophysics, Hydrology	Ph D IIT, Bombay (1974)
Dr P N Shukla	Geochemistry	Ph D IIT, Kanpur (1977)
Dr. D R Kulkarni	Computational Physics	Ph D M S Univ (1972)
Dr P Sharma	Geophysics and Hydrology	Ph D PRL, Gujarat Univ. (1977)
Dr N M Ashok	Infrared Observations	Ph D PRL, Gujarat Univ. (1983)
Dr.T.Chandrasekhar	Optical & Infrared Astronomy	Ph D PRL, Gujarat Univ. (1982)
Dr N Nagesha Rao	Theoretical Plasma Physics	Ph D PRL, Gujarat Univ. (1982)
Dr Shyam Lal	Atmospheric Chemistry of Trace Gases	Ph D PRL, Gujarat Univ. (1982)
Dr R Ramesh	Isotope Geochemistry	Ph D PRL, Gujarat Univ. (1984)
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 M M Sarin FASc	Geochemistry and Oceanography	Ph D PRL, Gujarat Univ. (1985)
Dr S V S Murty	Isotope Cosmochemistry	Ph D IIT, Kanpur (1981)
Dr A K Ambastha	Solar Plasma Physics	Ph D PRL, Gujarat Univ. (1981)
Dr. J Banerji	Laser Physics	Ph D City Univ.(New York)(1982)
Dr. K S Baliyan	Atomic Physics & Atomic Astrophysics	Ph D Roorkee Univ.(1986)
Dr Sai K Iyer	Large Scale Structure, General Relativity	Ph D Washington Univ. USA (1987)
Dr Kanchan Pande	Geology, Geochronology	Ph D PRL, Gujarat Univ. (1990)
Dr Ashok K Singal	Radio Astronomy	Ph D TIFR, Bombay Univ.(1986)
Dr A M Punithavelu	Experimental Plasma Physics	Ph D Patrice Lumumba Univ., Moscow (1975)
Dr D P K Banerjee	Astronomy & Astrophysics, High Resolution Spectroscopy	Ph D PRL, Gujarat Univ. (1991)

Name	Specialisation	Academic Qualification
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 J R Trivedi	Geochronology	Ph D PRL, Gujarat Univ. (1991)
Dr Subhendra Mohanty	Astroparticle Physics	Ph D Wisconsin Univ. (1989)
Dr Debi Prasad	Solar Cometary Physics	Ph D PRL, Gujarat Univ. (1990)
Dr S C Tripathy	Solar Physics	Ph D PRL, Gujarat Univ. (1993)
Dr Rajmal Jain	Solar Physics	Ph D PRL, Gujarat Univ. (1983)
Dr. J R Bhatt	Astrophysics	Ph D Gujarat Univ. (1992)
Dr A Lakshminarayan	Nonlinear Dynamics &	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 Datta	Laser Physics and Nonlinear Optics	Ph D, Burdwan Uni. (1994)
Dr S Ramchandran	Atmospheric Aerosols and Radiative Studies	Ph D, MS Uni. (1996)

Back Cover :

Each class of primitive meteorites (the building blocks of terrestrial planets) is distinguished by a specific isotopic composition for its nitrogen and oxygen. In a plot of $\Delta^{17}O$ vs $\delta^{15}N$ they define separate fields. By plotting the composition of a planet in this diagram, we can derive the proportion of different meteorites that formed the particular planet (top). In the mass spectrometry laboratory at PRL, (centre) Nitrogen isotopic measurements of Martian meteorites and Oceanic basalts, have led to the identification of the mantle signatures of Mars and Earth. Combined use of nitrogen and oxygen isotopic data has helped in constraining the contribution of the different types of Chondritic meteoritic material that accreted to form planets Mars and Earth (bottom).

Inner Back Cover :

Glimpses of few events at PRL