# RAMAN RESEARCH INSTITUTE
BANGALORE 560 080

# ANNUAL REPORT 1988-89

## Introduction

The Raman Research Institute founded by Prof. C.V.Raman in the late forties was reorganised, after his death in 1970, as a national Institute for research in basic science and it has been receiving generous grants from the Department of Science and Technology of the Government of India since 1972. The main fields of research are Astronomy and Astrophysics, and Liquid Crystals.

## 1. Astronomy and Astrophysics

Astronomy which is one of the oldest sciences is concerned with the study of heavenly bodies by investigating the radiation received on earth from them. Optical astronomy deals with the "visible" part (wavelength 3000 Angstroms to 6500 Angstroms, 1 Angstrom = $10^{-8}$ centimeter) of the electromagnetic spectrum. Radio Astronomy, which had its beginnings in 1932 also deals with the study of these heavenly bodies, but the radiation received by radio telescopes on earth is in the radio wavelength part (30 meters to 1 millimeter) of the same electromagnetic spectrum. The lower and upper limits in wavelength of the radio spectrum are set by the earth's atmosphere and ionosphere respectively. In spite of these limitations, the radio window is very wide (30,000 to 1 compared to the 2:1 wavelength ration in the visible part) and studies within it over the years have yielded information leading to many exciting discoveries such as the 3° k cosmic background radiation, quasars, pulsars, etc.

The Raman Research Institute has observational programmes in Radio Astronomy extending over most of the available radio spectrum. It has setup a Decameterwave Radio Telescope at Gauribidanur jointly with the Indian Institute of Astrophysics. Operating at a wavelength of 10 meters, it is among the largest telescopes in the world and is being used to study the radio emission from various types of celestial objects such as the Sun, Jupiter, radio sources of various kinds in our Galaxy, and external Galaxies. Moving to somewhat shorter wavelengths, members of the Institute use the Ooty Radio Telescope operated by the Tata Institute of Fundamental Research, Bombay. This instrument operates at a wavelength of approximately 1 meter and is used for carrying out observations of pulsars, and nebulae of various kinds in the Galaxy.

During the past two decades, millimeterwave astronomy has assumed great importance because of the discovery of numerous molecules (combinations of Hydrogen, Carbon, Nitrogen, Oxygen, Silicon, etc.) by their emitted line radiations in the shortest wavelength region of the radio spectrum. These molecules are generally found in dense molecular clouds in our own and other Galaxies where star formation is thought to be taking place. The Raman Research Institute has setup two millimeterwave telescopes of diameters 1.5 and 10.4 meters, which are used for the study of these radiations.

In addition, the Institute has theoretical research programmes in many branches of Astrophysics like Pulsars, Supernova Remnants, the interstellar medium, Galaxies and several aspects of General Relativity and Gravitation.

## 2. Liquid Crystals

Liquid Crystals are states of matter intermediate between the liquid and crystalline states. Many organic compounds whose molecules have pronounced shape anisotropy exhibit such phases. The unique combination of fluidity and anisotropic properties of liquid crystals has led to many applications of these materials. The Liquid Crystals laboratory of the Raman Research Institute has contributed significantly to the development of the field over the past decade and a half.

The laboratory has been organised to undertake studies of most of the fundamental properties of liquid crystals. Theoretical and experimental work on liquid crystals is continuing along the lines indicated in the reports of previous years.

A somewhat more technical account of the work carried out in the past year is given in the following.

## THEORETICAL PHYSICS AND ASTROPHYSICS

*Geometric phase and optics:* Further laser interferometric experiments were done to demonstrate the unbounded nature of the Pancharatnam phase, and to determine its sign. Using a new way of treating mirror reflections, a decomposition scheme to analyse propagation of light beams along arbitrary paths with arbitrary polarization changes was proposed, along with a scheme of representation of such a mixed evolution in terms of spin-1 matrices. Applied to geometric phase experiments in optics, this provided simpler interpretations.

Using a generalized form of Jordan's formulation of the geometric phase problem, it was shown that a single gadget capable of realising an arbitrary element of the unitary polarization transformation group SU (2) can be constructed using two quarter-wave plates and two half-wave plates and a variable linear retarder using a half-wave plate sandwiched between two identically oriented quarter-wave plates.

*Self Duality and Einstein's equations:* It was shown that the spinorial curvature being self dual is exactly equivalent to Einstein's equations.

*Canonical (2+1) gravity:* Work by Witten has shown that gravity in (2+1) dimensions (formulated after Ashtekar) can be quantised by noticing that the action can be reduced to the Chern-Simons form, a class of theories that have already been solved. We show that a straight forward application of canonical methods within the Ashtekar formalism is equally successful. This provides a test of the canonical programme of Quantum gravity and a simple solvable "toy model" for the related problem of 3+1 Canonical Quantum Gravity.

*Higher dimensional gravitation theories:* The Kaluza-Klein approach to the unification of forces has led to interest in higher dimensional gravitation theories and their exact solutions. The Vaidya metric representing the gravitational field of a radiating star has been generalized to dimensions greater than four.

*Scalar Waves in the Boulware Deser Black Hole background:* Superstring theory has motivated a study of higher derivative corrections to Einstein gravity. Spherically symmetric black hole solutions of such theories have been obtained by Boulware and Deser. Scalar perturbations of these black holes have been studied. The Klein-Gordon equation is separated into radial and angular parts. The angular functions are written in terms of Gegenbauer polynomials. The radial equation is cast into a Schrodinger-form and used to study the effect of the string parameter on scattering of Scalar waves by Quasi-normal modes.

*Quasi - normal Modes of Rotating (Kerr) Black holes :* The fundamental and low-overtone quasi-normal modes of Kerr black holes for scalar and gravitational perturbations were determined using a semi-analytic technique based on a higher order WKB approximation. For gravitational modes, these results were compared with numerical results. In the case of some of these modes, the agreement is within 1% over a wide range of values for the rotation parameter 'a'; for other modes good agreement is limited to lower values of 'a'.

*Speckle Interferometry :* Signal-to-noise ratio calculations and limiting magnitudes implied by them for the detection of parity of a binary system using triple correlation speckle interferometry were investigated.

It was found that at low light levels the photonic nature of light introduces dominant bias terms. Unbiased estimators and the noise on them for general $N^{th}$ order correlations of focal plane image were derived. The signal-to-noise ratio calculated for parity detection using the Knox-Thompson (double correlation) method were found to be at variance with those published in the literature.

*Studies in Stellar Dynamics :* The investigations of the nature of approach to a steady state in collisionless stellar systems were continued. Recent efforts were concentrated on the construction of self-consistent models which showed **undamped** oscillations.

*Supernova Remnants :* A numerical code for the evolution of supernova remnants with pulsars was developed and used for a study of the evolution of surface brightness and morphology of supernova remnants.

*Pulsars :* The implications of the recently discovered sub-millisecond optical pulsar at the site of the recent Supernova 1987A were explored.

The investigations relating to the origin and evolution of millisecond pulsars were continued, with particular emphasis on the recently discovered pulsars in globular clusters.

There is mounting evidence that the galactic population of millisecond pulsars may be as large as a hundred thousand. It is pointed out that such a large population may make a significant contribution to the diffuse gamma ray

background of the Galaxy. Estimates were made based on the various existing models for high energy radiation from pulsars.

The circular polarization associated with pulsar emission was examined phenomenologically. Virtually all circular polarization is observed in core components and two extreme types of circular signature are identified in the observations, an antisymmetric, and a symmetric type. Circular polarization of the antisymmetric variety is almost certainly an intrinsic property of the radio process, whereas symmetric circular polarization appears to be an effect of propagation in the pulsar magnetosphere.

*Positronium recombination lines :* A search was made for possible radio recombination lines of positronium at wavelengths of $\lambda$ 6 and $\lambda$20cms, using the Very Large Array (VLA) of the National Radio Astronomy Observatory, USA, and at $\lambda$3mm using the IRAM 30 m telescope in Spain. The searches yielded upper limits to the line optical depths in the range $1.3 - 2.0 \times 10^{-3}$, which imply an upper limit to the positron production rate of $<3.1 \times 10^{43} S^{-1}$, within ~2" of the galactic center.

*Radio wave scattering in the Solar wind :* A series of experiments have been conducted, using the VLA, to study the characteristics of scattering in the solar wind. Using the VLA in a novel, timegated mode, the scattering disk of 3C279 was imaged with a time resolution of 10-40 milliseconds when the source was within 1° from the sun. This "freezes" the scattering screen and produces fine structure in the radio image which is similar to optical speckles. It was shown that under these conditions, the scattered radiation is spatially coherent. Presence of refractive scintillation, which occurs due to focussing and de-focussing of the radiation by large scale structures in the solar wind have been demonstrated. The strength and direction of the scattering disk was studied for a number of positions around the Sun by observations of several sources over a period of one week.

*Recombination lines from the starbust galaxy NGC 253* : The VLA was used to study recombination line emission at wavelengths of $\lambda$20, $\lambda$6 and $\lambda$3.6 cm from the galaxy NGC 253. The lines are detected only near the nucleus of the galaxy, and the intensities clearly indicate the presence of stimulated emission. The velocity field near the nucleus indicates non-circular motion of the ionized gas near the nucleus.

*Hydrogen recombination lines near the Galactic Centre* : A systematic survey of H78 $\alpha$ and H98 $\alpha$ emission from the inner 40 arcminutes of the galactic centre was carried out using the 140 ft telescope at Green-Bank, USA. Lines were detected in more than half of the 130 positions that were observed, which include the Sgr A complex and the radio Continuum arc.

*The Galactic Centre at 327MHz* : Continuum emission at 327 MHz from a 2° region around the Galactic Centre has been studied by combining observations with four VLA configurations. The "mini-spiral" structure of the thermal source Sgr A west is seen in absorption against the non-thermal source Sgr A East, showing conclusively that Sgr A West is in front of Sgr A East. The 7 arcminute halo surrounding both these sources shows a low frequency spectral turnover and it is suggested that the halo contains a mixture of thermal and non-thermal gas. The

spectral index of the Continuum Arc and the enigmatic "thread-like" features near the galactic centre are being investigated.

*At the Radio Astronomy Centre, Ooty* : It is proposed to make pulsar observations using the Ooty radio telescope at 327 MHz in collaboration with the TIFR Group. For this purpose an existing auto/cross correlation receiver (512 channels) which was used for spectral line observations has been suitably modified to suit the fast sampling requirement for pulsar observations.

An extensive software code has been developed on the PDP 11/24 (at RAC Ooty) to acquire and process the receiver outputs. Initial tests of both the hardware and software were successfully completed. Preliminary test observations on some strong pulsars have yielded encouraging results. Fine tuning of the algorithms used is in progress.

## DECAMETER WAVE ASTRONOMY

An all-sky map at 34.5 MHz was produced using the observations made in 1987 with the Gauribidanur Telescope. Calibration of the flux scale, and its repeatability, was checked using about 100 strong point sources detected in the survey. The 34.5 MHz maps were produced in a suitable representation to enable a comparison with the already available 408 MHz all-sky survey. Such a comparison yielded spectral index information of the galactic background radiation. In addition, several regions in the galactic plane which contain thermal gas were identified. A colour representation of the all-sky map at 34.5 MHz was made for visual display and quick identification of various features.

*Sun*: The data obtained with the broadband antenna in the frequency range 35 to 65 MHz during the quiet period, May - September 1985, was used to determine the spectral index and its variations. It is found that the spectral index varied from 1.6 to 3.6 during this period. The large positive spectral indices suggest the existence of temperature gradients in the outer corona.

We have used the compound grating interferometer to obtain high resolution (3') one dimensional scans of the continuum emission from the Sun. These scans revealed large scale short term structural changes in the outer corona. Analysis of the data is in progress.

*Extragalactic Sources* : We used the decameter wave radio telescope to measure the flux densities of 12 radio sources identified with clusters of galaxies. The measured flux densities at 34.5 MHz are combined with other low frequency measurements to derive their radio spectra. It is found that the average spectral index in the frequency range 34.5 MHz to 408 MHz is –1.32, much steeper than the average for all extragalactic sources.

### Instrumentation

The construction of the south array of the broad-band 'T' has been completed. This array consists of 64 log periodic dipoles usable in the frequency range 30-150 MHz. They are spaced 7.0 metres apart and the total length of the array is 0.45 Km.

An Acousto Optic spectrograph with a band width of 30 MHz has been installed. It has 1760 channels giving a frequency resolution of about 30 KHz, and is interfaced via an A/D converter and a memory bank to a VAX 11/730 computer. All its 1760 channels are scanned every 250 ms and the data are recorded either on disk or magnetic tape.

A VLBI receiving system using Rb oscillators with a band width of 50 KHz and a recording rate of 250 KHz has been constructed and is being tested.

## Millimeter Wave Astronomy

*10.4 meter millimetrewave telescope*

a) Receiver Development : Several modifications in the receiver system was carried out during the year. The receiver system ground was isolated from the computer ground by using optoisolators. Inclinometers were installed and elevation offset errors due to the tilt in the Azimuth axis can now be directly corrected by reading the appropriate inclinometer. Computer control of the beam-switch and chopper calibration system was incorporated. Quasi-optical beam waveguide systems were designed and fabricated to enable observations in the band from 86 GHz to 115 GHz with minimum change in components. The efficiency of the telescope at 86 GHz, 96 GHz and 115 GHz were determined to be 46%, 35% and 25% respectively. Studies are being carried out to determine if the reduction in efficiency at higher frequency is due to surface errors of the telescope or improper illumination.

A new Data Acquisition System was developed based on a micro computer to work as a slave computer in acquiring the data from the spectral line back ends and to transfer the data at the end of observation to the host computer. Final testing of this system is in progress.

b) Observations : A sample of about 150 Mira variables has been observed in the $V = 1$, $J = 2 \rightarrow 1$ masing transition in Si0 to investigate the dependence of the masing phenomenon on the stellar spectral type and the pulsational phase of the star.

$^{12}CO$ ($J = 1 \rightarrow 0$) line emission at 115 GHz was observed in cometary globules in the Gum-Nebula region. Selected globules were mapped to study their distribution around the Vela Pulsar.

A search was carried out for $^{12}CO$ line emission from selected Pre-Main sequence objects in the Lupus-Norma region at 115 GHz. The molecular cloud complex in this region contains more than a hundred T Tauri Stars associated with it indicating current star formation.

*1.5 Meter Millimetrewave Telescope*

A dual polarization receiver was designed and fabrication is in progress. This incorporates a novel design with a single Diplexer and Local Oscillator. The front ends will be cooled in a closed cycle Helium refrigeration system.

## Mauritius Telescope Project

The design optimization of the Helical antennas for the Mauritius Radio Telescope has been completed. An interferometer using 32 of the helices has been set up at Gauribidanur to try out several new techniques before incorporating them in the main Radio telescope. It will also provide a preliminary assessment of phase and amplitude stability of the sub-assemblies.

## Liquid Crystals

Work is continuing on various aspects of the physics, chemistry and technology of liquid crystals. It has been a fruitful year, during which a number of fundamentally important observations have been made. A very brief summary of the more significant results is given below .

Probably the most notable achievement has been the prediction and discovery of a biaxial nematic ($N_b$) liquid crystal in a simple thermotropic system. The molecule, a copper complex, was specifically designed to combine the features of a rod and a disc, as suggested some years ago, and was found to exhibit the nematic phase. The optical texture of the mesophase was closely similar to that of the uniaxial nematic ($N_u$), except that often the schlieren pattern consisted entirely of $|s| = 1/2$ (two brush) disclinations and no $|s| = 1$ (four brush) disclinations. Zig-zag disclinations were seen occasionally,but they made their appearance quite unpredictably. While these features are indicative of biaxiality, they were not regarded as conclusive evidence and therefore conoscopic observations on thick, aligned samples were carried out. It has been possible to demonstrate (i) the occurrence of the $N_b$ phase in the pure complex, (ii) a reversible $N_u$-$N_b$ transition in a binary mixture, and (iii) the temperature variation of the biaxility near this transition. The I - $N_u$ -$N_b$ phase diagram was also obtained for the binary system. Recent Xray studies have confirmed the biaxial arrangement of the molecules in this phase.

A new type of flexoelectric instability has been predicted in a homogeneously aligned nematic liquid crystal under a DC electric field. The instability sets in at a critical value of the field applied normal to the undistorted director and in the plane parallel to the bounding plates. It is characterized by a uniform non-planar distortion of the director field involving both polar angles $\theta$ and $\phi$ and has a threshold lower than that of the twist Freedericksz transition. The theory is being extended to AC fields and experimental studies of the effect are under way.

The effect of a magnetic field on ferronematics (i.e., nematic liquid crystals with minute rod-shaped or disc-shaped ferromagnetic particles suspended in the medium). It is shown that first order Freedericksz transitions are possible in such systems as a consequence of elastic and diamagnetic anisotropies. Interestingly, the possibility exists for a first order transition from a splay-bend distortion to a pure twist distortion or vice versa at a second threshold. A super-imposed electric field can also result in a first order Freedericksz transition.

The crystal and molecular structure of a discotic mesogen has been analyzed in detail for the first time by Xray methods. The transition metal containing discogenic bis[1,3-di(p-n-octyloxyphenyl1)-propane-1, 3-dionato]copper (II)

crystallizes in the triclinic space group p1 with two molecules in a unit cell of dimensions a = 11.300(9), b = 16.101(1), c = 17.089(2)A°, $\alpha$ = 82.23(1),$\upsilon$ = 74.88(4), ~ = 77.43(3). The crystal structure was solved by direct methods and refined to R = 0.097 by the structure factor least squares procedure. The copper atom is surrounded by four oxygen atoms in a square planar arrangement. The octyloxy chains are fully extended. The crystal structure has both layer-like and columnar characteristics. The repeating unit along the column is a molecular pair. The copper atoms are distributed about the column axis in a zig-zag fashion.

Some thirty ferroelectric liquid crystals have been synthesized and systematic measurements have been made of the spontaneous polarization and other physical parameters. The discovery of ferroelectricity in chiral smectic C liquid crystals ($S_C^*$) and the potential for high speed switching electrooptic devices have stimulated the search for new compounds exhibiting low temperature $S_C^*$ phase. It is well known that compounds with ester linkages are reasonably stable. Some ester derivatives have been prepared using trans-p-n-alkoxy-$\alpha$-methyl-cinnamic acids which exhibit the $S_C^*$ phase. It has been established that a halogen substituent on the chiral carbon of a ferroelectric material yields high spontaneous polarization. An attempt has been made to incorporate a chloro substituent on the chiral carbon.

Extensive high precision studies have been carried out on the nature of the smectic A -smectic C, smectic A - smectic A and smectic A - nematic transitions and on critical and multicritical points associated with these transitions. Precise Xray measurements of the tilt angle near the smectic A - smectic C* tricritical point show clear evidence of mean-field to tricritical crossover behaviour, the mean-field region shrinking to zero at the tricritical point.

Studies have been carried out on the effect of pressure on phase transitions in the series of nematic main chain polyesters. Detailed calculations have also been made on deformations and instabilities in polymer nematics under the action of an external field.

Work has started recently in collaboration with BEL on the design of LCD panels for the cockpit of the Light Combat Aircraft.

Advanced training in research is being offered to the following teachers from other Organizations.

| Name | Topic of Study | |
|---|---|---|
| H.P. Padmini<br>The National College<br>Bangalore | Some Physical studies on Liquid Crystals | |
| P.R. Maheshwara Murthy<br>Govt. Science College<br>Bangalore | Electric and Magnetic Field effect in Liquid Crystals | UGC Faculty Improvement Programme |
| Sharanabasava M. Khened<br>Laxmi Venkatesh Desai College, Raichur | Experimental Studies of phase Transitions in Ferroelectric Liquid Crystals | |

**Ph.D**

| | | |
|---|---|---|
| T.N. Ruckmongathan | Some New Addressing Techniques for RMS Responding Matrix LCDs | Awarded |
| C. Nagabhushan | Experimental Studies of Phase Dielectric Properties of Liquid Crystals | Reports awaited |
| S. Somasekhara | Experimental Studies of Phase Diagrams of Liquid Crystals | Reports awaited |
| V.N. Raja | High Pressure and Xray Studies of Liquid Crystals | Reports awaited |
| R.Prathiba | Investigations on Liquid Crystalline Mixtures | Reports awaited |
| V.A. Raghunathan | Investigations on Some Field Induced Instabilities in Nematic Liquid Crystals | Reports awaited |

**Publications:**

The research work done by the staff of the Institute has been published in a number of journals. A list of publications that have already appeared and those submitted and in press is given at Annexure - I (Page 16).

## Conference/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, 56 lectures were given by them elsewhere.

## Raman Centenary Meeting:

To commemorate the Birth Centenary of the founder of the Institute, a symposium on 'Waves and Symmetry' was held at the Institute between 12 and 17, December 1988. This symposium was attended by scientists from within and outside the country.

## Matrix Addressed Liquid Crystal Displays

A one day meeting on 'Matrix Addressed Liquid Crystal Displays' was held at the Institute on the 23rd of September 1988 in cooperation with the Indian Institute of Science and the Bharat Electronics Ltd., under the support of the Department of Electronics. This meeting was attended by scientists from within and outside the Institute.

## Gandhi Memorial Lecture

The Gandhi Memorial Lecture for 1988 was given by Dr. P.K. Sethi of Jaipur on 'Medicine, Science and Humanism', on 2nd October, 1988.

## Colloquia

The scientists of the Institute and visiting scientists both from within and outside the country gave 31 colloquia at the Institute on different topics during the year.

## Journal Club Meetings

Nineteen meetings were held on various topics of interest to the scientific activities at the Institute.

## In-house Discussion Meeting

An in-house discussion meeting was held on 25th March 1988 on the current research activities of all the groups in the Institute.

## Visiting Scientists

A number of scientists from institutions within the country and outside visited the Institute during the year. Their names are listed following those of the scientific and technical staff of the Institute given towards the end of the report.

## Library

Five hundred and twenty two books were added to the book collection during the year. The total number of books now is 16471. The library subscribes to one hundred and fifty seven journals and has 20348 bound volumes of journals.

## General

The following grants were received from the Department of Science and Technology during the year :

| | (Rs. in lakhs) |
|---|---|
| PLAN-RECURRING | 60.00 |
| PLAN-NON RECURRING | 185.00 |
| NON PLAN - RECURRING | 50.00 |
| Total | 295.00 |

## STAFF

The scientific and technical staff of the Institute is given below. Additions during the year are marked with an asterisk.

V. Radhakrishnan
S. Chandrasekhar
S. Krishnan+
G. Srinivasan
S. Krishna
G.S. Ranganath
R. Bhandari
K.A. Suresh@
D.K. Ravindra
T.N. Ruckmongathan
K. Smiles Mascarenhas
T. Ramachandran
C. Ramachandra Rao
B.R. Iyer
J. Samuel$
M. Vivekanand##
K.S. Dwarkanath
Jayanthi Ramachandran
B.V. Nataraja
R. Nandakumar
N. Jayaprakash
P.N. Ramachandra
K. Sukumaran
S. Chanthrasekharan
H. Subromonyam
G. Rengarajan
P.S. Sasi Kumar
P.S. Ram Kumar
R. Vijayalakshmi
Chitra M. Gokhale
V. Rajeshwari
S. Krishnaprasad
V.K. Anuradha*
T.K. Babu*

### Joint Astronomy Programme

S. Karbelkar
S.Sridhar
Nimesh Patel
B. Ramesh
T.K. Sridharan
S. Ramaseshan
N.V.G. Sarma
C.V. Vishveshwara++
N.V. Madhusudhana
R. Nityananda
B.K. Sadashiva
C.S. Shukre
U.D. Kini
M. Selvamani
N. Udaya Shankar
M.O. Modgekar
Mohd. Ateequlla
V. Lakshminarayanan
B.R. Ratna%
K.R. Anantharamaiah#
A.A. Deshpande
D. Bhattacharya
P.A. Johnson
R. Ganesan
T.S. Ravishankar
M.R. Subramanyam
K. Subramanya
P.G. Ananthasubramaniam
P.S. Somasundaram
Antony Joseph
G. Sarabagopalan
K. Chandrasekhara
G. Jayakumar
V. Suresh Rao
K. Ramesh Kumar
S. Shivkumar Nair*
Lakshmy P. Usha*
Shaji P.*

### Resignations:

R. Shashidhar
D. Baranidharan
R.S. Arora
H.P. Subramanya
V. Surendranath
L. Saira
B.S. Srikanta

### Consultant Physicians

A.R.Pai
M.R. Baliga

**Research Fellows:**

Rani P. Rao
V.N. Raja
K. Usha
G.B. Sivakumar
Archana Ghode
P.B. Sunil Kumar
Sai K. Iyer*
R. Pratibha
V.A. Raghunathan
Getha G. Nair
Veena Prasad
D.S. Shankar Rao
L. Uma Devi*

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+ On deputation with National Aeronautical Laboratory, Bangalore.

++ On deputation as Director, Bangalore Planetarium, Bangalore.

@ On leave with Carnegie-Mellon University, Pittsburgh,U.S.A.

% On leave with Georgetown University, Washington DC, U.S.A.

$ On leave with University of Syracuse, N.Y., USA

# On leave with National Radio Astronomy Observation, Tucson, Arizona, U.S.A.

## On leave with Institute de Radio Astronomie Millimetrique, Grenoble, France (until Feb., 1989)

On leave with U. S. Naval Observatory, Mt. Wilson, California, U.S.A (from March, 1989 0nwards)

## LIST OF VISITORS

| | |
|---|---|
| J.Ya.Istomin<br>P.N.Lebedev Physical Institute<br>The USSR Academy of Sciences<br>Moscow, USSR | April 5-16, 1988 |
| S.Veeraraghavan<br>University of California<br>Berkeley, California, USA | April 9-10, 1988 |
| G.A.Fuller<br>University of California<br>Berkeley, California, USA | April 9-10, 1988 |
| M.D.Pollock<br>Tata Institute of Fundamental<br>Research, Bombay | June1-7, 1988 |
| James R.Lyons<br>JPL, California Inst. of<br>Technology,<br>Pasadena, California, USA | July 2-16, 1988 |
| H.S.Mani<br>Indian Inst. of Technology<br>Kanpur | June 23 - July 13, 1988 |
| R.Kulkarni<br>University of Poona<br>Pune | July 18 - August 2, 1988 |
| T.Dray<br>Oregon University<br>Corvallis, USA | July 18 - August 4, 1988 |
| R.Shankar<br>Yale University<br>New Haven, USA | August 22-24, 1988 |
| W.J.Welch<br>University of California<br>Berkeley, Calif., USA | October 7-13, 1988 |
| P.Dierich<br>Observatorie de Paris<br>Paris, France | October 18-25, 1988 |
| T.R.Seshadri<br>Tata Institute of Fundamental<br>Research, Bombay | November 2-13, 1988 |

| | |
|---|---|
| D.N.Cooper<br>Chief of the CSIRO Division of<br>Radiophysics<br>Epping, NSW, Australia | November 7-12, 1988 |
| R.Hanbury-Brown<br>School of Physics<br>Australian National Uni.<br>Sydney, Australia | December 9-18, 1988 |
| M.V.Berry<br>Bristol University<br>Bristol, UK | December 9-16, 1988 |
| D.Lynden-Bell<br>Institute of Astronomy<br>Cambridge, UK | December 11-23, 1988 |
| L.Matveyenko<br>V.Pokrovski<br>Space Research Institute<br>Moscow, USSR | January 17-25, 1989 |
| Tishin<br>USSR Academy of Science<br>Moscow, USSR | January 17-25, 1989 |
| P.Morrison<br>Mass.Institute of Technology<br>Cambridge, MA, USA | January 25-28, 1989 |
| E.E.Salpeter<br>Cornell University<br>Ithaca, N.Y., USA | Jan 21-Feb 7, 1989 |
| P.A.G.Scheuer<br>Cavendish Laboratory<br>Cambridge, UK | March 3-April 7, 1989 |
| M.Cohen<br>California Institute of<br>Technology, Pasadena,<br>California, USA | March 12-18, 1989 |

**ANNEXURE - I**

## PUBLICATIONS

1. A general setting for Berry's Phase. (Joseph Samuel and Rajendra Bhandari) - Phys. Rev. Lett., **60**, 2399 (1988).

2. Observation of non-integrable geometric phase on the Poincare Sphere. (Rajendra Bhandari) - Phys. Lett. A, **133,** 1 (1988).

3. Geometric phase in an arbitrary evolution of a light beam (Rajendra Bhandari) - Phys. Lett. A.**135**, 240 (1989).

4. Gravitational Instantons from the Ashtekar variables. (J.Samuel) - Classical and Quantum Gravity, **5,** L. 123, (1988).

5. Speckle interferometry and the Mystery Spot. (R.Nityananda) - Kodaikanal Obs. Bull, **10,** 55 (1988).

6. Atmospheric noise on the Bispectrum: Limiting faintness for binary stars. (S.N.Karbelkar) - in Proc. of NOAO-ESO conference on "High Resolution imaging by interferometry" ed. F.Merkle Part I, p217, July 1988.

7. Stellar dynamics around black holes in galactic nucleii : Collisional evolution of a stellar disk. (Rajaram Nityananda) - in Proc. International Conference on Gravitation and Cosmology, eds. B.R. Iyer, A.Kembhavi, J.V.Narlikar and C.V.Vishveshwara, Cambridge Uni. Press, Cambridge (1988).

8. On the semi-classical approximation to the wave function of the Universe and its stochastic interpretation. (M.D.Pollock) - Nuclear Phy. **B306,** 931 (1988).

9. Black Holes: A slanted overview. (C.V. Vishveshwara) - in "Highlights in Gravitation and Cosmology", eds. B.R. Iyer, A. Kembhavi, J.V. Narlikar and C.V. Vishveshwara. Cambridge University Press (1989).

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