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The President Visits IUCAA

The President A.P.J. Abdul Kalam paid an informal visit to IUCAA on May 28. In the midst of several engagements in the City and its neighbourhood, he managed to spend one hour with us. He went round the Devayani block, visiting the Foucault Pendulum, the Dome, the Library and the Instrumentation Laboratory and stopping to get photographed next to Aryabhata, on the first Lagrangian point on the Roche Lobes and with school students using our science popularization labs [see the adjoining photograph]. He expressed great pleasure being amongst scientists young and old. When we offered him tea, he was delighted to accept, saying that we were the first in Pune to give him tea!

Contents...

School Students' Summer Programme

This year's School Students' Summer Programme was held from April 15 to May 24, 2003. IUCAA has been conducting this programme for the Pune students of VIII and IX standard since 1993, to give them a brief insight of doing scientific research. Each week, a new batch of 30 students was invited to work on a project at IUCAA from Monday to Friday. Groups of four to six students were attached to individual guides. The programme has no set syllabus or course guidelines. The students and the guide work out their own schedule for the week. The students were given access to the IUCAA library.

Students carried out various projects under the supervision of Amrit L. Ahuja, V. Chellathurai, N. K. Dadhich, Atul Deep, Sanjeev Dhurandhar, Ranjan Gupta, Harvinder Kaur Jassal, Vinaya Kulkarni, Jayant Narlikar, Rajesh Nayak, Shamin Padalkar, T. Padmanabhan, Arvind Paranjpye, A. N. Ramaprakash, Jatush V. Sheth and Tarun Souradeep.

On their very first day at IUCAA, the students were briefed about the programme and soon after that, they would go with their teacher to work on different projects. During the week, they also participated in various common activities. Vinaya Kulkarni conducted them guided tour of the Science Park. Arvind Paranjpye coordinated the programme and carried out a general question answer session. On the last day of the programme, that is on Friday, every student was asked to submit a report on the work carried out during the week. The programme ended with an oral presentation (by at least one student from every group) followed by Jayant Narlikar's three 'mathematical teasers'.

This year, the students of the last batch had an opportunity to interact with the Honourable President during his visit to IUCAA, which is seen in the picture above as well as on page 1.

Congratulations

... to **T. Padmanabhan** on receving the fifth prize in the Gravity Research Foundation Essay Contest 2003 [awarded by Gravity research Foundation, USA] for his essay titled "*Why gravity has no choice: Bulk spacetime dynamics is dictated by information entanglement across horizons*" .

... to **Varun Sahni** on being elected as the Fellow of the Indian Academy of Sciences, Bangalore

... to **R. G. Vishwakarma** on being elected as a Regular Associate of the Abdus Salam International Centre for Theoretical Physics from January 1, 2003 till December 31,2008.

... Farewell to

Banibrata Mukhopadhyay, who has joined the University of Oulu, Finland, as a Post-doctoral Fellow.

Professor Narlikar being felicitated by Professor P.C. Vaidya

Professor Narlikar being felicitated by Dr. Arun Nigawekar

On the occasion of the retirement of Professor J. V. Narlikar, the Founder-Director of IUCAA, we organised a meeting "The Provocative Universe" in his honour. Held at IUCAA, Pune, during June 30 - July 2, 2003, the meeting did justice to the depth and spread of Narlikar's scientific interests and there were talks on different subjects, varying from micro-organisms in interstellar space to information loss problem in Blackholes tackled by string theory. The speakers were Russell Cannon, G.C. Anupama, Roy Maartens, B.S. Sathyaprakash, Bernard Jones, Daksh Lohiya, A.D. Gangal, William Napier, Shiv Sethi, David Roscoe, Max Wallis, Van den Heuvel, Jasjeet Bagla, Kameshwar Wali, D. Lynden-Bell, Mira Dey, Richard Ellis, Judith Perry, Brandon Carter, Narayan Banerjee, Suketu Bhavsar, Sverre Aarseth, Pankaj Joshi, Samir Mathur, Moncy John and Jean-Claude Pecker. Even with a conscious decision by the Scientific Organising Committee to exclude scientists from IUCAA as speakers, we had a tight schedule for the three days.

One afternoon was devoted to felicitation of Professor Narlikar and this session was marked by the affection, love and respect, the people in different walks of life had for him.

Participants of The Provocative Universe

The IUCAA Associates felicitated Professor Narlikar on the evening of June 30, 2003.

Participants of The Provocative Universe

A Search for Microorgnism at High Altitudes

The recent ISRO stratospheric cryosampler experiment and the analysis of its data provide evidence of the presence of microorganisms in the stratosphere from where they must rain down on Earth. Findings of this kind may provide credibility to the panspermia hypothesis as one of the major contenders amongst theories of the origins of life on Earth.

1. The Hoyle-Wickramasinghe hypothesis

During the period 1974-1978, Fred Hoyle and Chandra Wickramasinghe developed the theory that grains in space had a complex organic composition, and furthermore that their inclusion in hundreds of billions of comets led to transition from prebiotic matter into primitive bacterial cells (Wickramasinghe, 1974; Hoyle and Wickramasinghe 1976, 1977a,b, Wickramasinghe et al., 1977). The realisation that comets were not the beginning, but merely a stepping stone for cosmic microbial life soon followed. It was argued that pre-existing viable bacterial cells derived from interstellar space may have become included in comets in the primitive solar system when it was found that the extinction properties of interstellar dust matched with uncanny precision the expected behaviour of freeze-dried bacteria (Hoyle and Wickramasinghe, 1979).

Not long afterwards, using the above technique, it was found that observations of the infrared absorption by dust in the 2.9-3.9 mm waveband for the galactic centre source GC-IRS7 had a distinctly bacterial signature (Hoyle et al, 1982). Hoyle and Wickramasinghe (H-W henceforth) recognised that the 2175Å ultraviolet extinction band may be better explained by an ensemble of biological aromatics than by spherical graphite grains as was hitherto thought (Hoyle and Wickramasinghe, 1991). Thus, at least two striking spectroscopic features of dust seemed to suggest strongly that living material is present everywhere in the galaxy and the stage was set for a revival of the concept of panspermia.

The theory of panspermia has very ancient roots dating back to Greek times and even earlier. It was, however, first scientifically discussed by Lord Kelvin and then, at the beginning of the 20th century by Svante Arrhenius (1903). Arrhenius's argument that bacterial spores could be transported across the galaxy came to be bitterly contested in the 1920's. Becquerel (1924) argued, on the basis of laboratory experiments, that bacteria could not survive space conditions, particularly exposure to ultraviolet radiation . But this and many similar early criticisms of panspermia were later shown to be flawed. For example, a thin coating of carbonaceous matter around a bacterial grain, that would inevitably form in space, would act as a screen against ultraviolet light. Protection from ionising radiation (cosmic rays) might be more difficult, but still achievable. During an average residence time of 10 million years in a typical location in interstellar space, the cumulative radiation dose received by a bacterium is estimated as ~ 10^5 rad. Although, many terrestrially adapted bacterial species may not survive such a large dose, some almost certainly would. For instance, *Micrococcus radiodurans* can withstand a million rad under laboratory conditions, and there are others that are known to thrive within working nuclear reactors. The H-W panspermia theory requires life to have been introduced to Earth for the first time by comets some 4 billion years ago, with an ongoing incidence of microorganisms continuing to the present day.

Panspermia models would require that all the higher members of the tree of life came in the form of genetic components to be assembled in response to the changing physical conditions on the Earth. The perceived evolution in the phylogenetic tree of terrestrial life (within its branches, Archaea, Bacteria and Eukaya) then becomes an artefact of the re-assembly process of the cosmically derived genes.

According to H-W, cosmic life having its fullest range of evolution-potential, is a fact that needs to be in some way reconciled with cosmology. If we assume an ultimate origin, then all the resources of all the stars in all the galaxies in the observable universe would be needed to accomplish this near miraculous feat. But once life originates, then its continued existence and dispersal is assured by the well-attested survival properties of bacterial cells.

Besides the radiation resistance of bacteria that we have alluded to, the limits of microbial life on our planet have expanded to encompass an extraordinarily wide range of habitats. Microbes are found in geothermal vents, the ocean floor, in radioactive dumps and in Antarctic soil. Microorganisms have been recovered from depths of 8 km beneath the Earth's crust, and laboratory studies have shown that bacteria can survive pressures at ocean depths of thousands of kilometres or more. The long-term survivability of bacteria has also been extended from the range of 25 to 40 million years (Cano and Borucki, 1995) to a quarter of a billion years in the case of a bacterium entrapped in a salt crystal (Vreeland et al., 2001). Direct proof of the survival of bacteria exposed to radiation in the near Earth environment has also been demonstrated using NASA's Long Exposure Facility.

What is now required is a direct demonstration that viable microbes exist within cometary material and that they are being transferred to the Earth. Studies of cometary dust in the stratosphere have been initiated and may soon provide such evidence. While such in situ space experiments are a long-term objective of space science, definitive results from this quarter may be at least a decade away. In the mean time, there is need to collect evidence that comes close to demonstrating the reality of panspermia.

2. The ISRO experiment

An experiment of this kind was recently sponsored by the Indian Space Research Organization (ISRO). It consisted of collection of samples of air from varying heights in the stratosphere followed by their microbiological analysis under aseptic conditions. This was a multidisciplinary effort in which several scientists from different institutions in India and the UK have participated at various stages. The Indian side included J.V. Narlikar from IUCAA as the leader of the group with P. Rajaratnam from ISRO, S. Ramadurai from the Tata Institute of Fundamental Research, Mumbai, S. Shivaji and G.S.N. Reddy from the Centre for Cellular and Molecular Biology, Hyderabad and P.M. Bhargava from Anveshna, Hyderabad. The UK side was led by N.C.Wickramasinghe, and included David Lloyd and Melony Harris from the School of Pure and Applied Biology, Cardiff University and Martin Wainwright from the Department of Molecular Biology and Biotechnology, University of Sheffield. The late Sir Fred Hoyle was an advisor for the experiment in the early stages: he expired just when the first positive results were coming out. This experiment is described in the rest of this article.

Air samples were collected over Hyderabad, India on January 21, 2001 in four height ranges: 19-20 km, 24-28 km, 29-39 km and 39-41 km. The collection involved the deployment of balloon-borne cryosamplers of the type described by Lal *et al.* (1996). The cryosampler comprised of a 16-probe manifold, each probe made of stainless steel capable of withstanding pressures in the range 10^{-6} mb (ultravacuum) to 200 b.

At every stage in the design and construction of the cryosampler instrument the most stringent precautions were taken to avoid any risk of contamination. Prior to assembly and launch the probes and all their components were again thoroughly sterilized. The payload trailed at a shallow angle of elevation behind the balloon gondola, being tethered by a sterilised 100 m - long rope. As a further precaution against the possibility of collecting any traces of outgassed material from the balloon surface, a sterilised intake tube 2 m long formed an integral part of the cryosampler ensemble. The payload manifold is shown in Figure 1.

Throughout the flight, the probes remained immersed in liquid Ne so as to create a cryopump effect, allowing ambient air to be admitted when the valves were open. Air was collected into a sequence of probes during ascent, the highest altitude reached being 41km. The cryosampler manifold, once the probes were filled was parachuted back to ground.

3. Biological analysis

In order to test the feasibility of collection of air samples asepectically and to test the rDNA sequencing as well as other procedures for identification of the microorganisms, a preliminary analysis of one of the probes having air sample collected from the altitude range of 10-36 km had earlier been conducted by Shivaji and Reddy along with Bhargava,. This sample had been collected in a balloon flight launched from Hyderabad on April 29, 1999 and showed on examination the presence of culturable bacteria. Based on the morphological, physiological and biochemical characteristics and additionally on the basis of the 16 S rDNA sequencing these isolates were identified as *Pseudomonas stutzeri*. As these samples were collected from a range of heights including altitudes as low as 10 km where contamination from Earth occurs, such experiments gave us a wealth of practical experience for future balloon flights, but could not be considered as providing convincing evidence for the existence of microorganisms in the stratosphere. These studies did, however, emphasise the need for samples to be collected at heights well above where terrestrial contamination is even remotely possible.

Returning to the samples from the 2001 flight, we discuss here laboratory analysis that was conducted in the UK relating to only two probes:

Probe A: Collection between 30 and 39 km altitude, a total quantity amounting to 38.4 litres of air at NTP
Probe B: Collection between 40 and 41 km altitude, a total quantity amounting to 18.5 litre of air at NTP.

The microbiological aspects of the analysis that are summarised in this section are described in more detail by Harris *et al.* (2002) and Wainwright *et al.* (2003). Harris *et al.* (2001) reported the discovery of clumps of cocci shaped sub-micron sized particles of overall average radius 3.0μm from isolates of filters. The clumps were identified first using a scanning electron microscope and subsequently by epiflourescence microscopy. The latter technique involved the use of a membrane-potential-sensitive dye (a cationic carbocyanine) with fluorescence interpreted as revealing the presence of viable cells. Such fluorescent spots are seen, for example, in Fig. 2. Initial attempts to culture the coccoid cells were unsuccessful and they were deemed to be viable, but non-cultureable bacteria.

This was indeed the situation until early February 2002, when Wainwright succeeded serendipitously in obtaining cultures from isolates of air filters. Using a soft potato dextrose agar medium (PDA) and taking every conceivable precaution against contamination the following cultures of microorganisms were grown:

(a) The coccus (spherical bacterium, often growing in clumps) 99.8% similar (as determined by 16S rRNA analysis) to *Staphylococcus pasteuri*
(b) The bacillus (rods), 100% similar (as determined by 16S rRNA analysis) to *Bacillus simplex*
(c) A fungus identified as *Engyodontium album* (Limber) de Hoog

Figure 3 shows images of (a) and (b) with a light microscope.

None of the above, (a), (b) or (c), are common contaminants, nor had they been used in the laboratories in which this work was done. Furthermore, the lack of any growth on the control membranes, not exposed to stratospheric air that were placed in the same media under the same conditions, gives us confidence to assert that the organisms were collected from the stratosphere.

To most microbiologists, the fact that these isolates have essentially the same characteristics as terrestrial microorganisms is a problem, since one would assume that non-terrestrial microbes would have evolved at different rates elsewhere. This finding is however, fully consistent with panspermia theories in which Earth organisms are derived from cometary organisms that transit through the stratosphere. The main features of bacterial genotypes are derived, according to this theory, through a process of cosmic evolution and they are being constantly replenished from space.

With instrumental and laboratory contamination excluded at all stages of the experiment, two options remain. Firstly, one might think that the organisms obtained from the stratosphere were carried from the ground in a volcanic eruption or in an exceptional meteorological event. The other possibility is that they arrived from space. A volcanic origin is ruled out for the simple reason that there was no volcanic eruption recorded in a two-year run-up to the balloon launch date on January 20, 2001, and calculations along the lines carried out by Colbeck (1998) suggest that steady infall would drain out particles of 3 μm radius in a matter of weeks. A similar objection applies to rare meteorological events. Assuming our collections on January 20, 2001 gave us representative stratospheric samples at 39-41km, no process that is purely terrestrial can account for these findings of bacterial clusters.

What about debris from man-made spacecrafts that litters the atmosphere? Since the amount of such material is very small (estimates are available from space agencies), the chance of these organisms being derived from such debris is extremely low.

4. Concluding remarks

The alternative hypothesis of extraterrestrial origin (Hoyle and Wickramasinghe, 1981, 1999), although controversial, is more attractive as an explanation of our findings. The bacterial material, cultured in the Sheffield experiment, and detected earlier through fluorescence microscopy, can be regarded as forming part of the 100 tonnes/day input of cometary material known to reach the Earth. Critics of panspermia may argue that 3 μm radius particles get burnt through frictional heating and end up as meteors. Some fraction may do, but others would not. Survival depends on many factors such as angle of entry and mode of deposition in the very high stratosphere. Several modes of entry can be considered that permit intact injection into the stratosphere, possibly starting off as larger aggregates released from comets that disintegrate into a cascade of slow-moving smaller clumps at heights above 270 km, where frictional heating would be negligible. Evidence for such disintegrations have been available for many years and more recent studies of Brownlee particles collected using U2 aircraft have also shown the survivability of extremely fragile organic structures (Clemett, *et al*, 1993).

A further check on the infall hypothesis may be made by estimating the bacterial abundance at different heights, since as per this hypothesis, the number density should fall exponentially with height under a steady infall conditions (Kasten 1968).

Future studies will concentrate on the use of isotopic analysis of the stratosphere-derived samples to determine if the abundances of various isotopes differ from those of microorganisms found on Earth. In addition, attempts will be made to undertake a similar balloon experiment within a few weeks to months of a major cometary passage or a meteor shower, in the hope of detecting a significant rise in the numbers of microorganisms in the collected air samples; such a finding would point to a cometary origin for these organisms.

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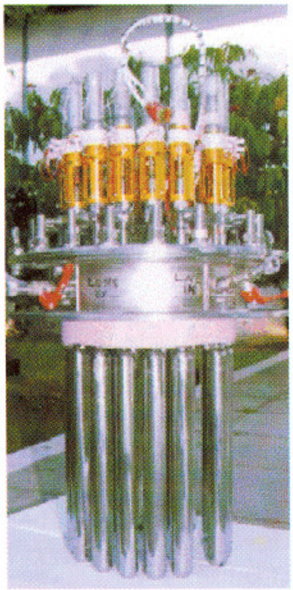

Figure 1: Evacuated and sterilised cryoprobes assembled in a manifold ready for immersion in liquid Ne for launch.

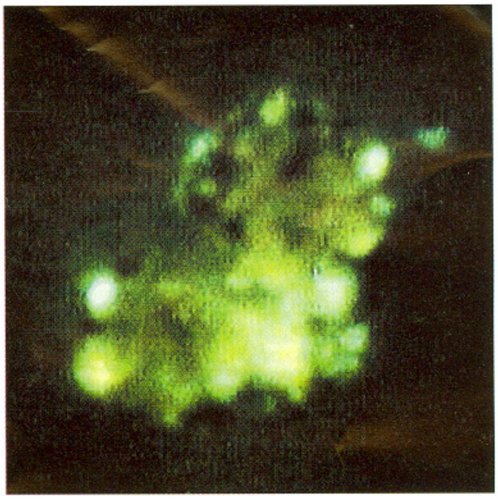

Figure 2. Clump of cells from a stratospheric isolate fluorescing after staining with carbocyanine dye, detecting membrane potential and viability of cells.

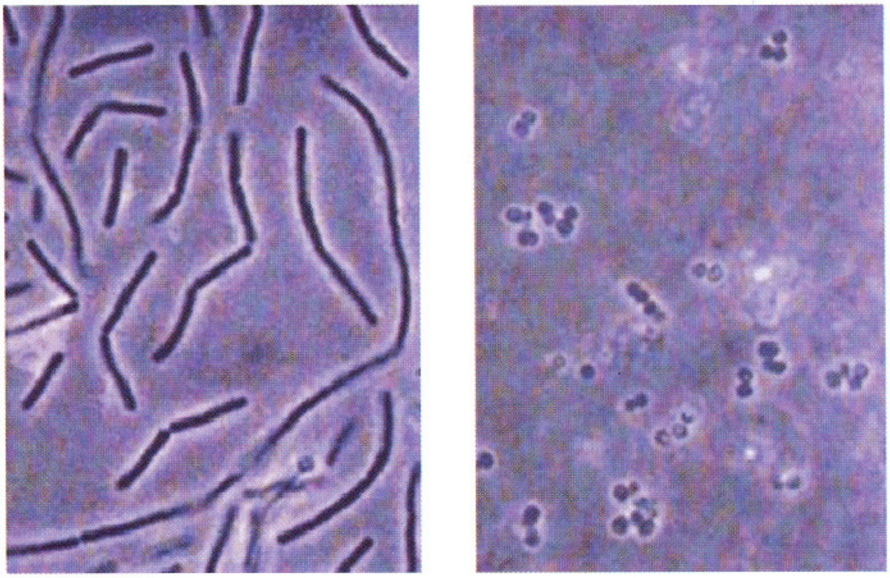

Figure. 3 Cultures of *B. Simplex* (Left) and *S. pasteuri* (Right) grown on LB medium after isolation using soft PDA from stratospheric samples at 41km. (x1000 using phase contrast microscope)

Refresher Course in Astronomy and Astrophysics

Participants and a few lecturers of the Refresher Course in Astronomy and Astrophysics

Nineteen highly motivated university and college teachers from all over India attended the Refresher Course in Astronomy and Astrophysics at IUCAA during May 19 - June 20 2003. Varun Sahni and Prasad Subramanian co-ordinated the course, and were ably assisted by students, post-docoral fellows, faculty members and members of the scientific and administrative staff at IUCAA.The course included core modules that covered the basics of modern astronomy and astrophysics. It also included shorter lecture modules addressing advanced topics. Invited speakers from the Indian Institute of Astrophysics, Bangalore, the ISRO Satellite Centre, Bangalore, and the Tata Institute of Fundamental Research, Mumbai, delivered special lectures on selected frontier research areas and emphasized the role of upcoming Indian observatories in each of these areas. Basic laboratory experiments and sky observing sessions comprised an important part of the course, providing valuable hands-on experience. Popular movies on topics in astronomy were occasionally screened, and the participants were given copies of CDs containing astronomy software and teaching aids. The participants of the refresher course, together with those of the Vacation Students' Programme visited the Giant Metrewave Radio Telescope at Narayangaon and the IUCAA telescope site at Giravali on June 16, 2003. Judging by the feedback received, the participants benefited from the course, and went back considerably enthused about research and teaching in astronomy and astrophysics.

Vacation Students' Programme

The thirteenth Vacation Students' Programme (VSP) was held in IUCAA during May 19-June 27, 2001. Eight students in the penultimate year of their M.Sc. (Physics) and Engineering degree course were selected from over 200 applicants from various Indian universities, IITs and engineering institutes. Depending on their aptitude and interest, each student chose the research project to work during the programme from a selection offered by the IUCAA faculty members. The students displayed a lot of enthusiasm and made good use of the IUCAA facilities and resources and interacted with the IUCAA graduate students, post-docs, visitors and faculty members during their stay. The students also attended over 40 expository lectures given by members of NCRA and IUCAA on a broad range of topics in Astronomy and Astrophysics. The lectures were jointly organised with the Vacation Students' Research Programme (VSRP) of NCRA. During their stay, day trips were organised to the IUCAA's 2-meter telescope site and the Giant Meterwave Radio Telescope (GMRT) near Pune. S. V. Dhurandhar and R. Srianand were the faculty coordinators for this programme.

Colloquium

01.04.2003 Anatoly Klypin on *Probing Galaxy Masses with SDSS.*

Seminars

08.04.2003 Sujan Sengupta on *Polarization from Brown Dwarfs: Theoretical Prediction and Observational Confirmation*; 24.04.2003 Sanjeev Dhurandhar on *Algebraic Structures Underlying LISA Data Analysis*; 08.05.2003 Axel Brandenburg on *Structured Outflow from a Dynamo Active Accretion Disc*; 15.05.2003 Shivaji Sondhi on *Quantum Liquids and Topological Order*; 29.05.2003 Vinod Krishan on *Structure Formation Through Turbulence*; 19.6.2003 Sushan Konar on Magnetic Fields in Compact Objects; 23.06.2003 Chandrima Mitra on *Evidences of Blackholes*; Tulsi Dass on *Non-Commutative Geometry and Quantum Mechanics*; 26.06.2003 T.K. Ramkumar on *The Earth's Ionospheric Dynamo under the Influences of Atmospheric Periodic Oscillations* and 27.06.2003 Mohemmad Sami on *Brane-World.*

IUCAA Preprints

S.G. Ghosh and D.W. Deshkar, *Gravitational collapse of perfect fluid in self-similar higher dimensional space-times*, IUCAA-21/2003; Mat Visser, Sayan Kar and Naresh Dadhich, *Traversable wormholes with arbitrarily small energy condition violations*, IUCAA-22/2003; Kandaswamy Subramanian, *Hyperdiffision in non-linear, large and small-scale turbulent dynamos*, IUCAA-23/2003; Neeraj Gupta, R. Srianand, Patrick Petitjean, Cedric Ledouz, *Outflowing material in the* $Z_{EM} = 4.92$ *BAL QSO SDSS J160501.21 - 011220.0*, IUCAA-24/2003; Ujjaini Alam, Varun Sahni and A.A. Starobinsky, *Can dark energy be decaying*?, IUCAA-25/2003; Parampreet Singh, M. Sami andNaresh Dadhich, *Cosmological dynamics of Phantom field*, IUCAA-26/2003; A. Pai, K. Rajesh Nayak, S.V. Dhurandhar and J.-Y. Vinet, *Time delay interferometry and LISA optimal sensitivity*, IUCAA-27/2003; and R. G. Vishwakarma, *Is the present expansion of the universe really accelerating*?, IUCAA- 29/2003.

Visitors during April - June 2003

M. Sami, Tulsi Dass, S. Kar, S. Sengupta, F. Rahaman, S. Chandra, G.P. Singh, C.D. Ravikumar, S. Deshingkar, A. Srivastava, D. Rosario, P.C. Agrawal, K. Alkendra Pratap Sing, R.C. Verma, S.G. Ghosh, D.W. Deshkar, A. Varghese, J. George, G. Binukumar, A. Lahiri, A. Paranjape, K. Shanthi, G. Ambika, M.K. Patil, K.P. Harikrishnan, P.K. Suresh, S.C. Kaushik, A. Brandenberg, S.P. Bhatnagar, S. Ramadurai, A.C. Kumbharkhane, D. Lohiya, S. Konar, T.R. Seshadri, S. Chakraborty, U. Debnath, K.D. Patil, Sanjay Pandey, U. Dodia, D.B. Vaidya, S. Ramani, G.V. Babu, S.N. Hasan, A. Pradhan, K. Jotania, R.S. Kaushal, T.P. Prabhu, S. Sahijpal, H.S. Das, A. Usmani, U. Malik, R. Tikekar, P. Sreekumar, R. Chhetri, S.K. Pandey, A. Jadhav, M. John, T. Chatterjee, K.K. Nandi, J. Dey, M. Dey, D. Chandra, S. Mukherjee, K.P. Singh, V.C. Kuriakose, B.C. Paul, A. Nigavekar, Sajith Philip, R. Shelke, K.K. Mondal, Lalan Prasad Verma, P.K. Srivastava, K. Wali, J.C. Pecker, L.K. Patel, S. Banerjee, S. Sahayanathan, S. Shivaji, Lalji Singh, P. Rajaratnam, J. Perry, M. Sohnius, N. Banerjee, S.K. Banerjee, Bhim Prasad Sarmah and D.K. Chakraborty. Apart from the above, 8 students attended the Vacation Students' Programme, 19 attended the Refresher Course and about 100 attended the meeting, The Provocative Universe.

Welcome to the IUCAA Family

IUCAA is happy to announce the selection of the fourteenth batch of Visiting Associates. The Visiting Associateship is for a tenure of three years beginning July 1, 2003.

New Visiting Associates :

- Badruddin, Aligarh Muslim University.
- Siddhartha Bhowmick, Barasat Government College, Kolkata.
- Umesh Dodia, Sir P.P. Institute of Science, Bhavnagar.
- Dhananjay V. Gadre, Netaji Subas Institute of Technology, New Delhi.
- Abhinav Gupta, St. Stephen's College, Delhi.
- Deepak Jain, Deen Dayal Upadhyaya College, New Delhi.

Extension to the Eleventh Batch of Visiting Associates :

- Shyamal K. Banerjee, Mody College of Engineering and Technology, Lakshmangarh.
- Ngangbam Ibohal, Manipur University, Imphal.
- Moncy V. John, St. Thomas College, Kozhencherri.
- Manoranjan Khan, Jadavpur University, Kolkata.
- Ashok K. Mittal, University of Allahabad.
- Udit Narain, Meerut College.
- Bikash Chandra Paul, University of North Bengal, Siliguri.
- Sandeep Sahijpal, Panjab University, Chandigrah.
- Asoke K. Sen, Assam University, Silchar.
- K. Shanthi, University of Mumbai.
- G.P. Singh, Visvesvaraya National Institute of Technology, Nagpur.
- Santokh Singh, Deshbandu College, New Delhi.
- P.K. Suresh, University of Hyderabad.

For the Younger Minds - 5 **T. Padmanabhan**

Estimate the angular width of the rainbow which we see in the sky.

Answers to the questions
which appeared in Khagol - April 2003

This question turns out to be fairly subtle and I would refer the reader to an article by N. Kumar in *Resonance*, July 2000, page 56, for a more detailed discussion. The broad features which are relevant to this issue are the following:

It is important to take into account the wave nature of light in discussing this issue. The angular resolution $\delta\theta$ of the eye is given by $\delta\theta = 1.22\ (d/\lambda)$, where λ is the operating light wavelength and 'd' the aperture. For the human eye, we have $d \cong 0.2\ cm$ (the pupil diameter), and taking $\lambda = 550$ nm, we get $\delta\theta \simeq 1$ arc minute. The angular diameter of the Sun, however, is about 30 times this diffraction limit, and so the latter is not quite relevant in the case of our Sun. But, if there is a hypothetical observer on Pluto, say, the angular diameter of the Sun would be just under 1 arc minute and the Sun can burn a hole in the retina. Its apparent faintness adds to the danger.

There is, however, another subtle mechanism which protects the retina against starlight. This has to do with the fact that there are irregular, rapid, movements of the eye taking place at the rate of about 30 to 70 times a second making angular excursions of about 20 arc seconds. Since 20 arc seconds is much larger than the angular diameter of even closest star, the resulting rapid averaging introduces a smearing of the image. It is generally believed that this effect is what protects the eye. [For an observer on Earth, atmospheric refraction (twinkling) will also help but astronauts in spacecrafts do not have this protection and they have not been blinded by starlight either.]

Visitors Expected

July: P.N. Pandita, North Eastern Hill University; L. Sriramkumar, Mehta Research Institute; Ali Shojai Baghini, Tehran University; Fatima Shojai Baghini, Tehran University

September: Zafar Turakulov, Uzbekistan

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