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Editor : T. Padmanabhan (e-mail :nabhan@iucaa.ernet.in) *Design, Artwork and Layout* : Manjiri Mahabal (e-mail :mam@iucaa.ernet.in)

To Jayant : With Love

Professor Jayant Narlikar assumed charge of the Director, IUCAA, on his 50th birthday, 19 July 1988. It was the birthday resolve for him to build up a world class facility focused on growth of teaching and research in astronomy in the Indian universities. On 18 July 2003, he has retired to celebrate his 65th birthday free from the hassels of the office.

In the intervening 15 years, we have seen the earth as well as the trees being moved, concrete being poured and casted, and a new structure taking shape both in physical as well as intellectual space - a dream called IUCAA coming to life - Jayant's creation.

There are some people who do things effortlessly while the others have to work hard. Jayant belongs to the former category. He leaves behind a very healthy and democratic way of functioning, a well geared up infrastructural machinery, a committed and dedicated team of colleagues, and a clear direction to follow. As a successor to him, I simply need to float. That is, however, not the case. Since, I belong to the latter category, I have to run faster and faster to keep pace. A challenging task sometimes gets the best out of ordinary people.

With much affection and reverence, I salute both Jayant and Mangala and wish them both good health and good time together. Jayant would, however, remain bound to IUCAA for life as an Emiretus Professor. It is my pleasure and privilege to welcome him back in this new avatar.

I count on my colleagues as well as all the University Associates and I am sure we could all put our heads and hands together to take IUCAA to greater heights and do Jayant proud.

- Naresh Dadhich

Welcome to . . .

Ramakant Singh Yadav, who has joined as a Post-doctoral Fellow. His research interests are Star Clusters, Observational Astronomy, and Astronomical Instrumentation.

Susmita Chakravorty, **Ramu Katta**, **Gaurang Yashwant Mahajan**, **Tapan Naskar**, and **Saumyadip Samui**, who have joined as Research Scholars.

... Farewell to

Abhijit Bhattacharyya, who has joined the Centre for Space Physics, Kolkata, as Young Scientist.

Sanjay Kumar Sahay, who has joined the Raman Research Institute, Bangalore, as a Post-doctoral Fellow.

R.G. Vishwakarma, who has joined the University of Zacatecas, Mexico, as a Faculty Member.

Contents...

Introductory School on Astronomy and Astrophysics

Participants and Lecturers of the Introductory School on Astronomy and Astrophysics

An Introductory School on Astronomy and Astrophysics was held at the American College, Madurai, during September 22 - 26, 2003. The participants of the school were primarily from postgraduate level students (about 80) and College/University teachers (about 20) in and around Madurai (mostly southern Tamilnadu).

Seven topics were covered during the school: Time and Co-ordinate System (B.A. Kagali, Bangalore University); Observational Astronomy (Ranjan Gupta, IUCAA, Pune); Radio Astronomy (Yashwant Gupta, NCRA, Pune): Solar Astronomy (S.S. Gupta, IIA, Kodaikanal Observatory); Introductory Cosmology (M. Sami, IUCAA, Pune); Extra Galactic Astronomy and Quasars (R. Srianand, IUCAA, Pune); Gravitation and Pulsars (A. Israel Stalin, The American College, Madurai). There were two evening popular talks on Radio Astronomy and Cosmology by Y. Gupta and M. Sami respectively.

The response from the participants was very good as this was the first time such a school was organized in this region and it was expected that this would help in introducing this subject at various teaching levels in the concerned universities and colleges.

Ranjan Gupta and A. Israel Stalin were the coordinators for the school.

IUCAA Preprints

M. Sami and N. Dadhich, *Steep inflation followed by Born-Infeld reheating*, IUCAA-32/2003; A.A.Usmani and S. Murtaza, *Variational Monte Carlo calculations of* ${}^{5}_{\Lambda}$*He hypernucleus*, IUCAA-33/2003; Deepak Chandra and Ashok Goyal, *Effects of curvature and interactions on the dynamics of the deconfinement phase transition*, IUCAA-34/2003; Subharthi Ray, Jishnu Dey, Mira Dey and Siddhartha Bhowmick, *Possible evidence of surface vibration of realistic strange stars from stellar observations*, IUCAA-35/2003; Kandaswamy Subramanian, T.R. Seshadri and John D. Barrow, *Small-scale CMB polarization anisotropies due to tangled primordial magnetic fields*, IUCAA-36/2003; Amir Hajian and Tarun Souradeep, *Measuring statistical isotropy of the CMB anisotropy*, IUCAA-37/2003; Tarun Souradeep and Amir Hajian, *Statistical isotropy of the cosmic microwave background*, IUCAA-38/2003; S.V. Dhurandhar and Jean-Yves Vinet, *Gravitational wave data analysis for laser interferometric space antenna*, IUCAA-39/2003.

Workshop on Brane and Quantum Cosmology

A workshop on Brane and Quantum Cosmology will be conducted at IUCAA during January 13 - 15, 2004, during which current problems on braneworld and loop quantum cosmology would be discussed in a compact group of active workers. The discussion would be led by Roy Maartens and Martin Bojowald. Since this is a highly specialized workshop, participation would be restricted to active workers only. The coordinator of this workshop is Naresh Dadhich.

Colloquia

8.8.2003 N. Mukunda on *Pancharatnam,Bargmann and Berry Phases-A historical account,* and 9.8.2003 Sushanta Dattagupta on *Dissipation.*

The Quest for Gravitational Waves

Introduction

The existence of gravitational waves (GW) was predicted by Einstein as early as 1916. Pulsar timing experiments by Hulse and Taylor led to accurate measurement of periastron time shifts in the PSR1913+16 binary pulsar system. These observations matched with the predictions of the theory of general relativity to better than 0.5%. This was the first strong indirect evidence which conclusively established the existence of GW.

GW distort spacetime, in that they change the distances between free test masses. A GW will cause a differential change in the lengths of the two arms, which is then detected as a phase difference between the optical paths of laser light in the two arms. However, these changes in lengths are exceedingly small. For example, a neutron star binary at distance of 100 Mpc will produce a differential length change of $\sim 10^{-17}$ cm. for test masses kept few kilometres apart, which is the typical length of the arm of a large scale ground-based interferometric detector.

Over the last decade or so, several laser interferometric detector projects have been commissioned: the LIGO consisting of two full length and one half length detector in US, the GEO600 in Germany, the TAMA300 in Japan, VIRGO in Italy-France, and the AIGO in Australia [1]. The goal of these instruments is to *catch* these waves *in flesh* and unravel the physics of the universe encoded in them. As of present, several of these interferometers are in advanced stages of completion and vigorous R & D efforts are in progress for improving the sensitivity of the detectors. The TAMA300 has achieved significant observation time with more than 1000 hours of observation, whereas the LIGO has had two successful scientific runs, one in August, 2002 and the second from February to April 2003. IUCAA has taken active part in the second science run and is an active participant of the Ligo Science Collaboration.

Currently, the most sensitive detectors are the LIGO detectors of the US which have crossed well below the mark of $h \sim 10^{-21}$, where h is the gravitational wave strain amplitude (see the next section for the definition of h). The instruments are sensitive in the bandwidth from few Hz ($\sim$ 10 Hz) to a few kHz having the best sensitivity around 500 Hz. In this window, the ground based interferometers will be able to observe inspiraling compact binaries of blackholes/neutron stars in their last stages before merger, non-axisymmetric rotating neutron stars and supernovae.

However, the lower limit of a few Hz of the band-width of the ground-based detector is a serious limitation to observing GW events. Applying the general theory of relativity to astronomy, physicists have realised that the most predictable and most powerful sources of GW (such as supermassive blackholes) emit GW below 10 mHz. The basic difficulty in achieving sensitivity at low frequencies below 10 Hz lies in the impossibility of screening off Newtonian time-varying gradients of the gravitational field caused by seismic activity, atmospheric disturbances, etc. The solution then is to build a detector in space. The GW space mission of the European Space Agency (ESA) and NASA of US is the Laser Interferometric Space Antenna (LISA) [2]. The goal of LISA is to observe low frequency gravitational radiation. LISA is expected to be launched in 2011. Thus, the ground and space-based detectors promise interesting and new astronomical observations/discoveries over the next several years.

Principle of GW detection

A weak gravitational wave is described by a metric perturbation $h_{\mu\nu}$ in general relativity. Typically, for the astrophysical GW sources which are amenable to detection, $h_{\mu\nu} \sim 10^{-22}$. In the transverse-traceless (TT) gauge, the $h_{\mu\nu}$ can be expressed in terms of just two amplitudes, h_+ and $h_\times$, called the 'plus' and 'cross' polarisations. If a weak monochromatic gravitational wave of + polarisation is incident on a ring of test-particles, the ring is deformed into an ellipse as shown at the top of Figure 1. Phases, quarter cycle apart, of the GW are shown in the figure. For the $\times$ polarisation, the ellipses are rotated by an angle of 45°. A general wave is a linear combination of the two polarisations.

The key to GW detection is the very precise measurement of small changes in distance. For laser interferometers, this is the distance between pairs of mirrors hanging at either end of two long, mutually perpendicular vacuum chambers. GW passing through the instrument will shorten one arm while lengthening the other (this is shown schematically in the ring of particles in Figure 1). By using an interferometric design, the relative change in length

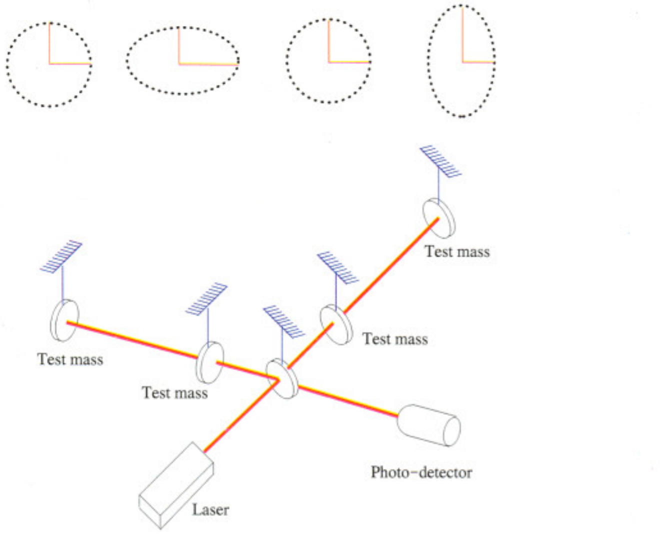

Figure 1: A circular ring test particles is deformed into an ellipse by an incident GW. Phases, quarter of a cycle apart are shown for the + polarisation. The length change in the interferometric arms is also shown schematically. Below, a schematic diagram of an interferometer is drawn.

of the two arms can be measured, thus signalling the passage of a gravitational wave at the detector site. At the bottom of Figure 1 a schematic of the interferometer is depicted. If the change in the arm-length L is δL, then,

$$\delta L \sim hL, \tag{1}$$

where h is a typical component of the metric perturbation.

For a GW source, h can be estimated from the well-known Landau-Lifschitz quadrupole formula. The GW amplitude h is related to the second time derivative of the quadrupole moment (which has dimensions of energy) of the source:

$$h \sim \frac{1}{r} \frac{G}{c^4} E^{\text{kinetic}}_{\text{nonspherical}}, \tag{2}$$

where r is the distance to the source, G is the gravitational constant, c the speed of light and $E^{\text{kinetic}}_{\text{nonspherical}}$ is the kinetic energy in the *nonspherical* motion of the source. If we consider $E^{\text{kinetic}}_{\text{nonspherical}}/c^2$ of the order of a solar mass and the distance to the source ranging from galactic scale of tens of kpc to cosmological distances of Gpc, then h ranges from 10^{-17} to 10^{-22}. These numbers then set the scale for the sensitivities at which the detectors must operate.

Interferometric detectors

There are a host of noise sources in interferometric detectors which contaminate the data. At low frequencies there is the seismic noise. The seismic isolation is a sequence of stages consisting of springs/pendulums and heavy masses. Each stage has a low resonant frequency about a fraction of a Hz. The seismic isolation acts as a low pass filter, attenuating high frequencies, but low frequencies get through. This results in a 'noise wall' at low frequencies at around 10 Hz. At mid-frequencies upto a few hundred Hz, the thermal noise is important and is due to the thermal excitations both in the test masses - the mirrors - as well as the seismic suspensions. At high frequencies, the shot noise from the laser dominates. This noise is due to the quantum nature of light. From photon counting statistics and the uncertainty principle, the phase fluctuation is inversely proportional to the square root of the mean number of photons arriving during a period of the wave. Long arm lengths, high laser power, and extremely well-controlled laser stability are essential to reach the requisite sensitivity.

Figure 2 shows the strain sensivity for the LIGO Louisiana Observatory (LLO) [3]. The design sensitivity as well as the experimental results of the science run (S2) are shown.

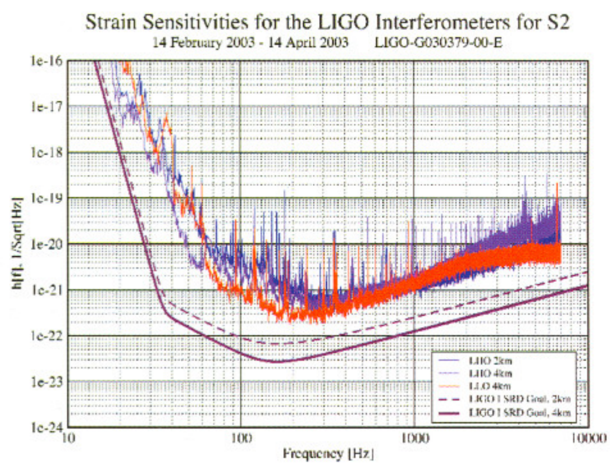

Figure 2: The goal sensitivities of the LIGO detectors and the noise curves obtained from the recent science run (S2) are shown.

Five interferometric detectors (perhaps six including AIGO) will be in operation soon. It is advantageous to have a network over a single detector, because (i) we can improve on the confidence in detection by coincidence analysis, (ii) ascertain the location of a GW source, and (iii) obtain polarisation information of GW.

GW sources and extracting the signals from noise

Several types of GW sources have been envisaged, which could be directly observed by Earth-based detectors (see [4] and references therein for recent reviews): (i) Burst sources – such as binary systems consisting of neutron stars and/or blackholes in their in-spiral phase or merger phase; supernovae explosions – whose signals last for a time much shorter, between a few milli-seconds and a few minutes, than the typical observation time; (ii) stochastic backgrounds of radiation, either of primordial or astrophysical origin, and (iii) continuous wave sources – e.g., rapidly rotating non-axisymmetric neutron stars – where a weak sinusoidal signal is continuously emitted.

Inspiraling binaries have been considered highly promising sources, not only because of the enormous GW energy they emit, but also because they are such 'clean' systems; the inspiral waveform can be computed accurately to several post-Newtonian orders adequate for optimal signal extraction techniques such as matched filtering to be used. In the past decade, IUCAA has focussed on the design, validation and implementation of search algorithms for inspiraling binaries. Hierarchical search algorithms have been designed and are being improved to reduce the cost over a flat search [5].

Another important burst source of GW is the supernova. It is difficult to reliably compute the waveforms for supernovae, because complex physical processes are involved in the collapse and the resulting GW emission. This limits the data analysis and optimal signal extraction.

Continuous wave sources pose one of the most computationally intensive problems in GW data analysis. A rapidly rotating asymmetrical neutron star is a source of continuous gravitational waves. Long integration times, typically of the order of a few months or years are needed to build up sufficient signal power. Earth's motion around itself, the sun and the moon Doppler modulates the signal, the Doppler modulation being dependent on the direction of the GW source. Thus, coherent extraction of the signal whose direction and frequency are unknown is impossibly computationally expensive. However, targeted searches are computationally viable, for example, if the direction to the source is known. In this context, LMXBs are extremely interesting candidate sources for Earth-based detectors. Several systems would be detectable by enhanced LIGO operating in the narrow-band configuration.

To detect stochastic background, one needs a network of detectors, ideally say two detectors preferably identically oriented and close to one another. The signal is extracted by cross-correlating the outputs.

Laser Interferometric Space Antenna: LISA

The lower (floor) limit of a few Hz of the bandwidth of the ground-based detectors is a serious limitation to observing GW events. The floor limit is due to our inability to shield against gravity gradient noise arising from seismic activity, atmospheric disturbances and also because of the technological limitations on long armlengths due to earth's curvature. The solution is a detector in space.

LISA is a collaborative ESA/NASA mission. It will consist of three drag-free space-craft - spacecraft shielded from buffeting by solar wind and radiation pressure - in heliocentric orbits following 20° behind the earth. They will form an equilateral triangle with sides 5×10^6 km inclined at an angle of 60° with earth's orbital plane.

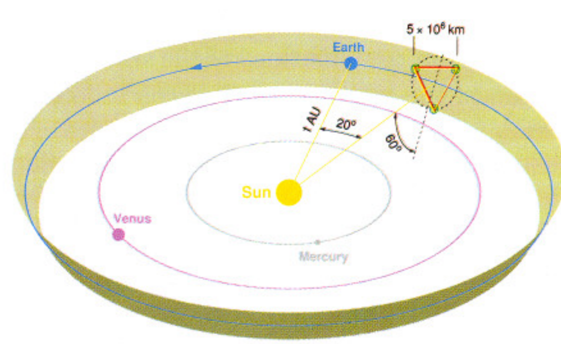

Figure 3: The orbit of LISA

Each space-craft houses two lasers (1 Watt Yag) and each laser is phase locked to its companion and to the incoming light from the distant space-craft.The space-craft rotate in a circle drawn through the vertices of the triangle and the LISA constellation as a whole revolves around the Sun. The goal of LISA is to detect and study low frequency astrophysical GW in the band 10^{-4} Hz to 1 Hz. The astrophysical sources that LISA could observe include galactic binaries, extra-galactic supermassive blackhole binaries and coalescences, stochastic GW background from the early universe. The LISA and the ground based detectors complement each other in an essential way. Since, both types of detectors have similar energy sensitivities, their different observing frequency bands will provide crucial spectral information about the source. This is as important as complementing the optical and radio observations from the ground with observations in space at submillimetre, infra red, ultra violet, X-ray and gamma-ray frequencies.

LISA data analysis differs from the data analysis for ground-based detectors in one crucial way: because the observations will be at low frequencies, the computational cost, data storage is not an important issue here. Also, the GW sources tend to be relatively strong at low frequencies, because the GW amplitude scales inversely with the frequency for a given energy. This in turn will give rise to high signal-to-noise ratios (SNR) for several GW sources. Since LISA consists of two partially independent interferometers, it can also detect stochastic background of GW produced in the early universe. The cancellation of laser phase noise is an important problem in LISA data analysis, since it is impossible to maintain equal distances between space-craft. Recently, we [6] have shown that the space of all data combinations of the six laser beams which cancel the laser phase noise is a module - the *module of syzygies* as known in the literature of commutative algebra. The module is generated by four elements. This has the important physical implication: only four data streams need be telemetered to Earth, instead of the original six streams and moreover at reduced bandwidth, because the laser frequency noise has been cancelled. Also, access to all the data combinations enables us to maximise SNR in various scenarios, optimise the directional sensitivity, etc.

Future prospects

The network of LIGO, VIRGO, GEO and TAMA will operate continuously for many years to come. It is possible that these first generation detectors might make the first detections of GW. Series of upgrades have been planned for the future. The second generation detectors will aim at increasing sensitivity and bandwidth and should come into operation after 2006. Work on third generation of detectors is being strongly pursued now. They should start operating after 2010. Each generation will improve the amplitude senstivity by an order of magnitude. In the meanwhile LISA will open the low sensitivity window and should make several detections, some with high SNR. We, therefore, expect exciting times in the next decade in gravitational wave astronomy.

References

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IUCAA-NCRA GRADUATE SCHOOL COURSES

The IUCAA-NCRA Graduate School (conducted jointly with the National Centre for Radio Astrophysics (NCRA), Pune) is divided into two semesters (four terms) spread over one year. Each term is of roughly eight weeks duration. During the Graduate School, the Ph.D. students (Research Scholars) are taught relevant advanced courses in Physics and are also introduced to courses in Astronomy and Astrophysics. The Graduate School structure is given below. The number of teaching hours is shown in brackets after each course.

Semester I, Term I, From August second week to October first week.

01. Methods of Mathematical Physics I (21)
02. Introduction to Astronomy and Astrophysics I (14)
03. Electrodynamics and Radiative Processes I (14)
04. Quantum and Statistical Mechanics I (14)

Semester I, Term II, From October third week to December second week.

05. Methods of Mathematical Physics II (14)
06. Introduction to Astronomy and Astrophysics II (14)
07. Electrodynamics and Radiative Processes II (14)
08. Quantum and Statistical Mechanics II (14)

Semester II, Term I, From January first week to February fourth week.

09. Astronomical Techniques I (14)
10. Galaxies : Structure, Dynamics and Evolution (21)
11. Extragalactic Astronomy I (21)

Semester II, Term II, From March second week to May second week.

12. Astronomical Techniques II (14)
13. Interstellar Medium (14)
14. Extragalactic Astronomy II (14)
15. Topical Course (for earlier batch of students) (< 21)
16. Project Work (During May - July).

Syllabus for the Graduate School Courses

1. The courses are designed, emphasizing the aspects which are directly relevant to Astronomy and Astrophysics. It is assumed that unnecessary repetition of material which is already taught at M.Sc. is avoided.

2. The syllabus provides enough avenues for topics which are of "local interest" to be included in the graduate school. This is necessary so that graduate students coming out of IUCAA/NCRA, not only have a comprehensive grasp of the A & A but are also aware of the key research areas in which these two institutions are concentrating at present.

If any of the Research Scholars from Indian universities/colleges are interested in attending any of these courses, they may contact : The Coordinator, Core Programmes, IUCAA.

Seminars

4.7.2003 Sverre Aarseth on *N-Body simulations*; 17.7.2003 Sukanta Panda on *Signatures of low scale gravity in ultra high energy cosmic rays*; 28.7.2003 J. Maharana on *Duality and integrability of two dimensional string effective action*; 7.8.2003 Kandaswamy Subramanian on *Primordial magnetic fields and CMB anisotropies*; 11.8.2003 Ali Reza Rafiee on *Super massive black holes and sersic's parameter n*; 11.8.2003 Abhishek Rawat on *Quasar host galaxies*; 11.8.2003 S. Sridhar on *Turbulent mixing and pulsar scintillation*; 14.8.2003 Amir Ahmad on *Helium-rich subdwarf B stars - where do they come from?*; 27.8.2003 Arman Shafieloo on *An examination of quintessence models for an accelerating universe*; 28.8.2003 Gora Mohanty on *The violent universe : Gamma-ray astrophysics in the new millennium*; 8.9.2003 Ani Thakar on *SDSS data release 1 and virtual observatory development;* and 11.9.2003 Ranjeev Misra on *The effect of non-thermal protons on the high energy spectra of blackhole binaries.*

Workshop on Galaxies: Structure and Dynamics

A workshop on *Galaxies : Structure and Dynamics* is being organized at the Astronomy Department, Osmania University, Hyderabad during January 6- 9, 2004. The workshop will cover observational and theoretical topics and will be suitable for research students and other persons working in these areas. Those interested in attending the workshop may contact the Coordinator, Najamul Hasan, (hasan@iucaa.ernet.in), L-38, Osmania University Quarters, Osmania University, Hyderabad 500 001, Andhra Pradesh.

Visitors during July - September 2003

Tulsi Dass, M. Sami, A. Pradhan, Gargi Shaw, K.N. Iyer, L. Sriramkumar, M. Sinha, M. Bagchi, V. Gopisankara Rao, A. Nigavekar, P. Janardhan, Ali Shojai Baghini, Fatima Shojai Baghini, P. Hasan, S. Panda, P.N. Pandita, J. Maharana, S. Sridhar, Arnab Rai Choudhuri, L. Chaturvedi, Ved Prakash, P. Prakash, S. Dattagupta, N. Mukunda, R. Rajaraman, K.N. Pathak, A.K. Gupta, J.A.K. Tareen, V.N.R. Pillai, N. Saha, D. Dhar, P.S. Naik, K. Shanthi, Ninan Sajeeth Philip, M.A. Sharmila, Rahumathunnisa, Tarun Deep Saini, S. Bhattacharya, G. Mohanty, K.P. Harikrishnan, A. Thakar, V.B. Bhatia, Subinoy Das, D. B. Vaidya, K.S.V.S. Narasimhan, S. Sahayanathan, R. Sinha, D. Lohiya, S.N. Hasan, Suresh Chandra, S.K. Pandey, S. Rastogi, A. Pathak, C.D. Ravikumar, T. Fernandez, V.S. Cholin, Nalini Kaku, P. Rajaratnam, N.K. Lohani, A. Gupta, and Z. Turakulov

About 125 people from India and abroad participated in the workshop on Provocative Universe held during June 30 to July 4, 2003.

For the Younger Minds - 6

T. Padmanabhan

Estimate the rate of precession of the Equinoxes.

Answers to the questions which appeared in Khagol - July 2003

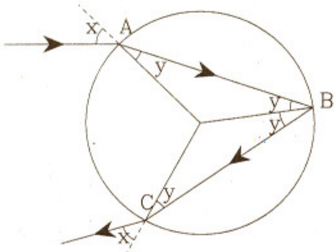

Figure 1

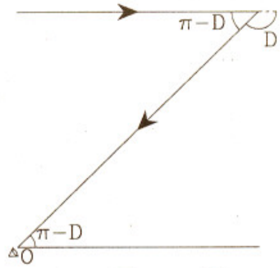

Figure 2

Figure 1 shows the path of a light ray through a spherical droplet of water, which leads to the formation of a (primary) rainbow. The ray incident at A gets refracted; part of the light is reflected at B which is again refracted at C. The angles x and y are related by $\sin x = n \sin y$ where n is the refractive index of water. The direction of the ray changes by $(x - y)$ at A, by $(\pi - 2y)$ at B and by $(x - y)$ at C thereby undergoing a total deviation $D(x) = 2x - 4y + \pi$.

The net effect of the water droplet is to deviate a ray of light as shown in figure 2, where the incident direction of ray is taken to be horizontal. The angle of incidence x will be different for droplets of water at different locations and, in general, D will change with x. There is, however, one particular angle x_c at which $(dD/dx) = 0$. At this critical value, the deviation $D = D_c$ is stationary with respect to x and one sees an enhancement of several rays travelling towards the same direction after going through the water droplets. This will lead to a rainbow in the sky located on the semicircular rim of a cone with vertex at O and semi vertical angle $(\pi - D_c)$. Elementary calculation now gives $\cos^2 x_c = (1/3)(n^2 - 1)$. Taking the refractive index for $\lambda = 400$ nμ to be $n_{400} = 1.3440$ and for $\lambda = 700$ nμ to be $n_{700} = 1.3309$, we find that $x_c = (58.77°, 59.54°)$ and $y_c = (39.51°, 40.36°)$ for the two wavelengths, leading to $(\pi - D_c) = (40.51°, 42.38°)$. Thus, the primary rainbow is at about 41° and its angular width is about 1.87°. [Challenge: Provide a suitable definition and then estimate the relative brightness of a rainbow.]

Visitors Expected

October: Sukanta Daw, Manjari Bagchi; D.W. Deshkar, Science College, Nagpur; Koshy George, PRL, Ahmedabad; S. Pote, Science College, Nagpur; S. G. Ghosh, Science College, Nagpur; K.S. Sastry, Osmania University; B. Ishwar, B.R.A. Bihar University, Muzaffarpur; S. Bhowmick, Barsat Govt. College, Kolkata; R. Tikekar, Sardar Patel University, Vallabh Vidyanagar; S. Chaudhuri, Gushkara Mahavidyalaya, Burdwan; S. Ray, Barsat Govt. College, Kolkata; S. N. Hasan, Osmania University; P. Hasan, Osmania University and K. Jotania, M.N. College, Visnagar, Gujarat.

November: A. Omont, IAP, France; E. van den Heuvel, University of Amsterdam; B. Schutz, Max Plank Institute, Germany; S. R. Choudhury, Delhi University; U.C. Joshi, PRL, Ahmedabad; T.P. Prabhu, IIA, Bangalore and P. Khare, Utkal University, Bhubaneswar.

December: N. Katz, University of Massachussets; Yogesh Mathur, Nagendra Kumar Chauhan and E. Spiegel, UK

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IUCAA, Post Bag 4, Ganeshkhind,
Pune 411 007, India

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Fax (020) 569 0760

email: publ@iucaa.ernet.in

Web page : **http://www.iucaa.ernet.in/**