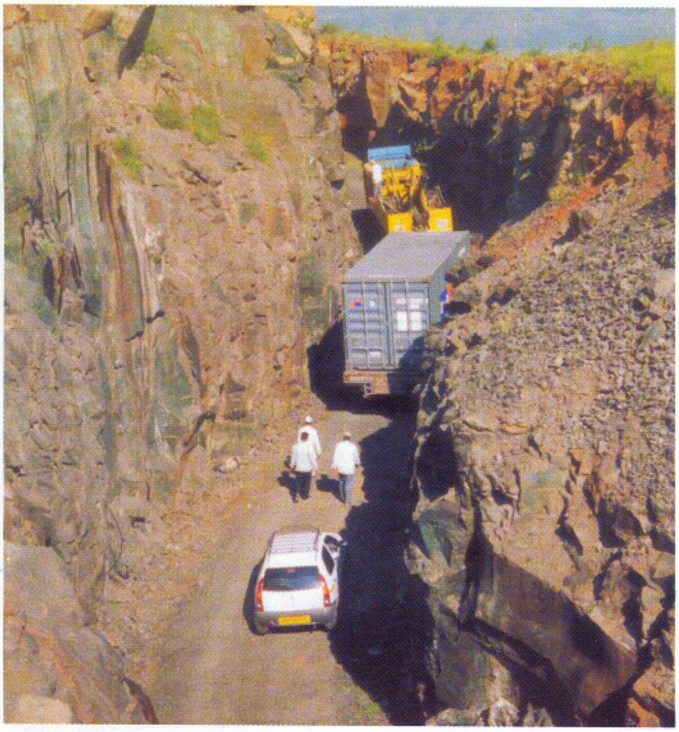
KHAGOL
खगोल

IUCAA

No. 52 / October 2002

A Quarterly Bulletin of the Inter-University Centre for Astronomy and Astrophysics (An Autonomous Institution of the University Grants Commission)

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



IUCAA Telescope parts were delivered to the site on 21.9.2002. Here is a photograph taken by Tushar Agarkar

Workshop on Field Theoretic Aspects Of Gravity (FTAG)

IUCAA will be sponsoring the third workshop in this series [The first one was held at IUCAA and the second one was organized by IMSc Chennai at Ooty]. Department of Physics, Cochin University of Science and Technology will be organizing the third workshop during January 23-29, 2003 at Kochi. Participation, by invitation, is limited to 35 persons. N. K. Dadhich (IUCAA) and V.C.Kuriakose (CUSAT) will be the Coordinators of the Workshop. Further details can be had from, nkd@iucaa.ernet.in or vck@cusat.ac.in.

Welcome to . . .

Abhijit Bhattacharyya, who has joined as a Post-doctoral Fellow under the project "Virtual Observatory - India". His research interests are Simulation of Accretion Disk of Compact Objects, Particle Dynamics, Planetary Magnetospheres, and Data Reduction and Analysis of Data from Astronomical Databases.

Ali Reza Rafiee, **Abhishek Rawat** and **Arman Shafieloo**, who have joined as Research Scholars.

. . . Farewell to

S. Sridhar, who has joined the Raman Research Institute, Bangalore as a Faculty Member.

Tapas Kumar Das, who has joined the University of California at Los Angeles, as a Post-doctoral Fellow.

Niranjan Sambhus, who has joined the Astronomy Institute, University of Basel, Switzerland, as a Post-doctoral Fellow.

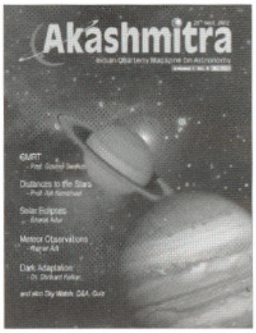
Workshop on Astronomy with Small Telescopes

A workshop on "Astronomy with Small Telescopes" will be held in IUCAA, Pune during January 6-10, 2003. Small but intelligent telescopes equipped with low cost back-end instruments, e.g., photometers, CCDs and spectrographs, which Universities and Colleges can afford to procure and maintain, can serve the purpose of providing training to M.Sc. students in Astronomy.

Contents...

The facility can also be used in carrying out a variety of research projects that require continuous monitoring. The main objective of the workshop will be to discuss various aspects of modern small size telescopes and their instrumentation, photometry and spectroscopy, and research projects that can be carried out using such a facility. The lectures will be supplemented by observational exercises using the facilities available in IUCAA. The workshop is open to University/College teachers, research scholars who are either involved in carrying out research projects using small telescopes or intend to do so in future. Postgraduate students doing project work in astronomy as the part of their course work and have strong inclination to pursue research work in astronomy are also welcome to participate in workshop. Interested persons may send their resume highlighting their level of involvement with the usage of small telescopes to S. K. Pandey, either by post at School of Studies in Physics, Pt. Ravishankar Shukla University, Raipur-492 010 or by email at ircrsu@sancharnet.in before November 10, 2002.

Akashmitra - A Magazine for Amateur Astronomers, is launched in Pune



The first issue of a quarterly magazine devoted to amateur astronomy was launched on September 22, 2002 in Pune. This magazine aims at giving information on astronomy, astrophysics and space sciences to the Indian readers and hopes to create interactive platform for amateur astronomers in India. Shreekant Kelkar, Director of National Institute of Ophthalmology and Aditya Ponkshe (Anaesthetist) who also formed an amateur astronomers association in Pune by the name 'Akashmitra' are the main brains behind the publication of this issue. Arvind Paranjpye of IUCAA is the editor of the magazine. The magazine, which will be published on the Equinoxes and Solstices, is priced at Rs 50/- per issue and the annual subscription is Rs 180/-. More details can be found at http://www.akashmitra.com.

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 to attend any of these courses, they may contact : The Coordinator, Core Programmes, IUCAA.

Ranjeev Misra

Rapid Temporal Behaviour of Black Holes and Neutron Star Systems

X-ray binaries are black holes and neutron star systems, which are accreting matter from a regular star. These systems are variable on a wide range of timescales ranging from months to milli-seconds. Like other astrophysical objects, a detailed analysis of their temporal variability is crucial to the understanding of the geometry and structure of these enigmatic high energy sources. Moreover, it is expected that a study of the rapid variability of these sources will eventually be used to test the General Theory of Relativity in the strong gravity regime.

A comprehensive (but slightly outdated) introduction to X-ray binaries is given in Chap. 13 of [1]. *The High Energy Astrophysics Science Archive Research Center*, HEASARC, maintains an up to date web-site on RXTE for both the general and scientific audience (http://heasarc.gsfc.nasa.gov/docs/xte/xtegof.html). The interested researcher (or even an amateur scientist) can learn how to analyze RXTE data by following the step-by-step procedures given in the web-site ("The RXTE Cookbook" and the "ABC of RXTE"). The learning process may take less than a couple of months but one requires a fairly fast link ($>$ 100 kbytes/sec) and a hard disk larger than 10 GB. Note that even now, a large number of RXTE data which is available to the public, remains unanalyzed. The important observational results and theoretical implications from RXTE pertaining to X-ray binaries are reviewed in a scientific (but easily readable) review [2]. However, for more details and for recent (later than 2000) results, the reader has to consult the journal papers which are cited in this summary. Wherever applicable the corresponding preprint number in the server http://xxx.lanl.gov/archive/astro-ph is also given.

1 X-ray binaries

Early rocket experiments in the sixties had discovered that our galaxy contains discrete X-ray point sources. However, it was the first astronomy satellite, *Uhuru*, which revolutionized our understanding of these sources. *Uhuru* was able to give much better position accuracy and measure their rapid temporal variability. The main observational results of this satellite were:

- Most of the X-ray sources are highly variable in timescales of milli-seconds.
- Many of the sources had an optical counter-part and hence, were confirmed to be binary systems, with regular (optical) stars orbiting an optically invisible star.
- The optical identifications led to better distance estimations and hence, it was confirmed that these sources are extremely bright with luminosities ranging from $10^{36} - 10^{38}$ ergs/sec.

The rapid variability of these sources implied that the emitting regions were small ($< c\Delta T \approx 300$ km). This unusual small size and high luminosity (10^{38} erg/sec $\approx 100,000$ Solar luminosities) ruled out nuclear power as the source of their energy. These systems were clearly a far more efficient energy powerhouse than the regular stars. Even prior to these observations, there was already speculation that accretion of matter onto compact objects (neutron stars and black holes) would be a powerful and compact source of energy. Thus, it was natural to conclude that X-ray binaries harbour black holes/neutron stars, which are accreting matter from a regular stellar companion.

Observationally, it was (and it still is!) difficult to distinguish between black hole and neutron star systems. A standard, but not direct, method is to estimate the mass of the compact objects. Since there is a strict upper limit to the mass of a neutron star ($M < M_{cr} \approx 3M_\odot$), any system with a mass higher than this would imply the presence of a black hole. It is possible to estimate the mass of a compact object using the orbital period of the binary and by measuring the Doppler velocity of the companion star. Solving for the dynamics of the two stars in a binary with these information, leads to an upper limit on the mass of the compact object. Cygnus X-1 was the first binary for which such a mass estimate turned out to be larger than $3M_\odot$ and hence it became the first black hole candidate. Since then the masses of compact objects in several binary systems have now been estimated to be larger than $3M_\odot$ and these systems are now called black hole systems [3]. These are now called black hole "systems" instead of black hole "candidates" since there have been many other indirect evidence (although none of them is as compelling as the mass estimation) that indicate that they are indeed systems harbouring black holes.

The mounting evidence that X-ray binaries could be accreting compact objects gave a new impetus to theoretical research. It was pointed out by [4] that gas flowing onto a compact object from a binary companion would have too much angular momentum to flow radially and instead an accretion disk with nearly Keplerian orbits and small radial velocities, would form. The standard theory of accretion disks was developed by [5], wherein, it was self-consistently assumed that the disk was geometrically thin and each radii radiated a black body emission equal to the energy dissipated by the viscous forces. The structure of the disk was computed using steady state hydro-dynamic equations with the expectation that the predicted time independent spectra may be compared with time-averaged spectra from X-ray binaries. Several satellites with increasing levels of sophistication (e.g., Ariel-5, HEAO-1, HEAO-3, Ginga) were launched to measure the time-averaged spectra in a broad (2-100 keV) band. One of the most important results of these experiments was that the time-averaged spectra of black hole (and most neutron star) systems cannot be adequately described by the standard accretion disk model. An additional and sometimes dominant, high energy ($\approx 10 - 50$ keV) spectral component was observed. Clearly the standard theory had to be modified to take this observation into account.

There were two basic models for the origin of the hard X-rays. First, it was proposed by [6] that the inner regions of the standard disk, being unstable, would get converted into a hot, geometrically thick region, where hard X-ray photons would be produced by inverse Compton scattering. On the other hand, it was suggested in [7] that the hard X-rays were produced (again by inverse Compton scattering) in a corona lying on top of the cold accretion disk. For neutron stars, the presence of a hard surface gives rise to additional complexities, since the boundary layer between the disk and the star could also be a dominant source of radiation. Moreover, if the magnetic field of the neutron star is large, the magnetic pressure may disrupt the accretion flow and matter may be channeled into the magnetic polar caps of the star. These ideas have been developed into more sophisticated and self-consistent accretion disk theories for black holes and neutron star systems (e.g., [8]). However, despite the advances in X-ray satellite technology and in accretion disk theory over the last two decades, the structure and geometry of accretion disks in X-ray binaries remains mostly uncertain.

It became quite apparent that a study of the temporal behaviour of X-ray binaries was required to supplement the time-averaged data. Such a study was expected to provide insights into the radiative mechanisms and structure of the accretion disks around the compact object. Moreover, it was possible that these sources have distinct high frequency (rapid variability) signatures, which could be used to probe the strong gravity of the compact objects. The *Ginga* satellite had already observed interesting temporal behaviour of some X-ray binaries but these were low frequency ($0.1 - 10$ Hz) phenomena. There was a need for a dedicated satellite to observe and quantify the rapid ($\approx$ kHz) variability.

2 Rossi X-ray Timing Explorer

The Rossi X-ray Timing Explorer (RXTE) was launched on December 30, 1995 and is still functioning. RXTE features unprecedented time resolution ($\approx$ 100 micro-seconds) and is primarily designed to explore the variability of X-ray sources. The mission carries three scientific instruments, the Proportional Counter Array (PCA), the High Energy X-ray Timing Experiment (HEXTE) and an All-Sky Monitor (ASM). While the PCA and HEXTE are pointed instruments and the ASM covers nearly 80% of the sky (per orbit) and is used to detect unusual X-ray activity and the appearance of transient X-ray sources. The PCA is the main scientific instrument to measure rapid temporal variability and most of the important scientific results were obtained from it.

The PCA is an array of five proportional counters with a total collecting area of 6500 square cm. Each proportional counter has five layers (three Xenon, one Propane veto and one Xenon veto). It can detect photons within an energy range of 2-60 keV with a resolution of around 18% at 6 keV. The most remarkable feature of this detector is the time resolution of 1μsec, although for most practical situations it is used with a resolution of 64μsec or larger.

3 X-ray Timing Data Analysis

After a fair amount of processing the raw data from the PCA, it can be converted into a light curve for different energy bins. A light curve is the variation of the count rate ($\approx$ no. of photons/sec) as a function of time. A typical light curve extracted from RXTE extends to $T \approx 3000$ sec and has a time resolution of $\Delta T = 125\mu$sec. It is convenient to analyze and interpret the timing data in the frequency domain. Thus, the extracted light curve is Fourier transformed numerically by using standard routines like the Fast Fourier Transform (FFT). The resulting Fourier transform $H(f)$ is obtained for frequencies $f < f_N = 1/2\Delta T$ (where f_N is called the Nyquist frequency) and has a frequency resolution $\Delta f = 1/T$. The power spectrum, $P(f) = 2|H(f)|^2$, is a measure of the variability at a given frequency. The error introduced in the power spectrum due to the discrete nature of the light curve is always independent on the length T and resolution ΔT! [9]. To circumvent this problem, the light curve is divided into N smaller segments and the power spectrum of each segment is independently computed. Finally, the resulting power spectra are averaged. This process reduces the error by $1/N$ but increases Δf by the same factor.

Apart from the power spectrum for different energy bins, one can also obtain the coherence and the time lag between different energy bins. The coherence function measures what fraction of a light curve is related linearly to another light curve. If the coherence is high (i.e., nearly unity), then one can measure a time-lag (if any) between the two light curves. In X-ray binaries, often the coherence is high between light curves of two different energy bins and (quite non-intuitively) the time-lag between them is in general a function of frequency. However, this is not very surprising, since there are several physical processes (e.g., waves in a disk, inverse Compton in a in-homogeneous plasma, coherent flares [10]) which give rise to frequency dependent time-lags.

4 Main Observational Results and Theoretical Implications

If a light curve has a strong sinusoidal signal in it, the power spectrum will exhibit a sharp spike (theoretically a δ function) at the corresponding frequency. Such a feature has been discovered by RXTE for two kinds of neutron star systems. In both cases the frequency of the feature is identified with the spin frequency of the star and such a sharp peak (i.e., a coherent oscillation) is taken to be a signature of the hard neutron star surface as opposed to the event horizon in a black hole. The first milli-second X-ray pulsar (SAX J1808.4-3658) was observed by RXTE to have a period of 2.5 msec [15]. Traditional, X-ray pulsars (with spin periods of seconds) were known to be highly magnetized accreting neutron star systems where the accretion is collimated unto the magnetic polar cap which is misaligned with the rotation axis. Hence emission from the polar cap is viewed from different angles as the star rotates. However, for a milli-second X-ray pulsar, the magnetic field cannot be too strong (otherwise the accreting matter will not be able to overcome the centrifugal barrier). The magnetic field for this system should not form a classical dipole structure and it is not clear why this source is observed as a milli-second X-ray pulsar. Recently (in April, 2002), a second such pulsar was discovered [18] which highlight the important science that is still being done using RXTE, seven years after it's launch.

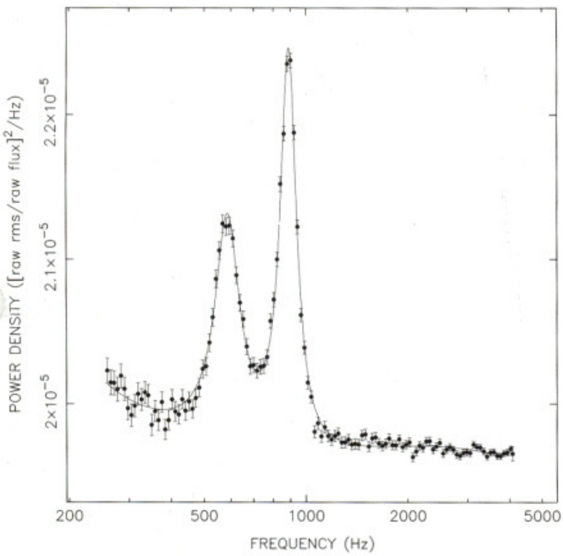


Figure 1: The power spectrum of the neutron star source, Sco X-1 showing two kHz QPO. Adapted from astro-ph/000167 [2].

Clear high frequency (≈ 500 Hz) signals have also been detected in neutron star systems exhibiting Type-1 X-ray bursts [16]. Type 1 X-ray bursts are thermonuclear runaways in the accreted matter on a neutron-star surface (see [17] for a review). In the initial phase, when the burning front is spreading, the energy generation is inherently very anisotropic and this anisotropic emission from a spinning neutron star leads to a periodic signal at the neutron star spin frequency. Such burst oscillations have now been detected in at least six sources. The luminosity and frequency of the bursts puts constrain on the size of the neutron star, which is then useful in determining the neutron star equation of state.

The power spectrum of several X-ray binaries often display broad Gaussian like features. These are called Quasi-periodic Osculations (QPO). A sinusoidal signal in the light curve will give rise to a broad feature in the power spectrum if the frequency of the signal varies during the time of the observation. Alternatively, if a signal's amplitude exponentially rises and falls in a characteristic time t_d, i.e., if

$$S(t) \propto \sin(\omega_o t)\exp(-|t - t_o|/t_d), \quad (1)$$

then the resultant power spectrum will be a Lorentzian (i.e. $P(f) \propto 1/(1 + ((f - f_o)/\sigma)^2)$ with a frequency width $W_f \approx 1/t_d$.

While low frequency $(0.1 - 10$ Hz) QPO had already been observed by the *Ginga* satellite, RXTE detected high frequency $(300 - 1100$ Hz) kHz QPO in X-ray binaries. For neutron star systems, these QPO were often observed in pairs, i.e., two QPO were detected simultaneously (Fig. 1). The frequencies of these QPO varied from 300 to 1100 Hz, but the difference between the two, $\Delta f = f_1 - f_2$ was initially thought to be constant at the spin frequency of the neutron star. However, more detailed analysis showed that Δf is also varied although the variation was less than the variation in the QPO frequencies. It was also found that the kHz QPO frequencies are often correlated with the frequencies of the low-frequency QPOs.

A broad range of theoretical ideas have been proposed to explain the phenomenology of kilohertz QPO. In these models, one of the frequencies is generally identified as the Keplerian frequency of the innermost orbit of an accretion disk. The sonic point model [11] identifies the second frequency as the beat of the primary QPO with the spin of the neutron star. In the general relativistic precession/apsidal motion models [12], the primary frequency is the Keplerian frequency of a slightly eccentric orbit, and the secondary is due to the relativistic apsidal motion of this orbit. On the other hand, in the two oscillator model [13], the secondary frequency is due to the transformation of the primary (Keplerian) frequency in the rotating frame of the neutron star magnetosphere. The strength (weakness) of these models lies in their ability (or inability) to predict the variation of the frequency separation with the kilohertz QPO frequency and the variation of their frequency with other low frequency QPO observed in the source (see [2] for a comparison of recent observations with model predictions). However, these dynamic models generally do not address how these oscillations affect, or couple to, the radiative processes which finally give rise to the oscillations seen in the X-ray spectra. The observed energy dependent features of the QPO, namely the strength of the QPO vs. photon energy (fractional root mean square, or RMS, vs. energy) and the phase lag of fluctuations at different photon energies relative to variations at a reference energy, are expected to depend primarily on the radiative mechanism and its coupling to the dynamic behaviour of the system. Despite recent work to interpret this energy dependent behavior [14], a unified model for kilohertz QPO, which self-consistently incorporates both the dynamical and radiative mechanisms, remains illusive.

For black hole systems, initially the power spectrum was thought to be well fitted by broken power-laws with two characteristic break frequencies, at ≈ 1 and ≈ 10 Hz. However, a re-interpretation of the data showed that the data would be better fit by three (sometimes four) very broad ($\Delta f \approx f$) Lorentzians. In this interpretation, the temporal behaviour of black hole systems was due to broad low frequency periodic oscillations. However, the light curve in different energy bands was found to be coherent and had a frequency dependent time-lag, which suggests that either the fluctuations are produced by waves in the accretion disk or due to correlated flaring activity on the disk corona [10]. Recently, a true high frequency QPO ($\Delta f < f$) was discovered in a black hole system [19] (Fig. 2). The QPO frequency (450 Hz) was higher than the Keplerian frequency of the last stable orbit for a

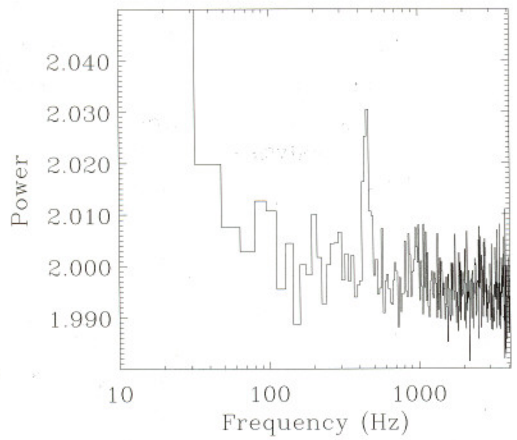


Figure 2: The power spectrum of the black hole system, GRO J1655-40 showing the ≈ 450 Hz QPO. Adapted from astro-ph/00014487 [19].

non-spinning black hole with the same mass. This may imply that the black hole may be rapidly spinning. Like for neutron stars, the origin of these high frequency QPO is largely unknown although their high frequency implies that they are caused (or at least influenced) by the strong gravity near the black hole.

5 Summary

RXTE has opened a new window that allows us to study the rapid (≈ kHz) variability of X-ray binaries. These millisecond phenomena must be affected (or even be caused) by the strong gravity of the compact object. However, detailed theoretical modeling of these sources is difficult and the simple interpretations put forward remain inconclusive. The present challenge is to develop innovative and self-consistent models which should be confirmed by hydro-dynamic and radiative computations. Such a model (or models), which might be developed in a couple of years, would need to be tested using more advanced observations. Keeping this in mind, there are proposals now to develop a much larger (≈ 10 m^2 area) instruments in the next decade. The Indian X-ray satellite, ASTROSAT (expected to be launched in 2005), will carry among other instruments, a proportional counter array similar to the one in RXTE, but with much better high energy coverage. Thus, these advanced future observations will help the ongoing theoretical research with the hope of unlocking the secrets of these enigmatic sources.

References

[1] S. L. Shapiro and S. A. Teukolsky: *Black Holes, White Dwarfs and Neutron Stars*, (John Wiley & Sons, New York, 1983).

[2] M. van der Klis: Annual Review of Astronomy and Astrophysics; **38**, 717 (2000). (astro-ph: 0001167).

[3] J. A. Orosz: *Inventory of Black Hole Binaries*, Invited talk at IAU Symp. 212, (2002). (astro-ph: 0209041)

[4] K. H. Prendergast and G. R. Burbidge: Ap.J., **151**, L83 (1968).

[5] N. I. Shakura and R. A. Sunyaev, *Astron. Astrohys*, **24**, 337, (1973).

[6] S. L. Shapiro, A. P. Lightman and D. M. Eardley, Ap.J., **204**, 187 (1976).

[7] E. P. Liang and R. H. Price, Ap.J., **218**, 427 (1977).

[8] F. Haardt and L. Maraschi, Ap.J., **380**, L51 (1991); R. Narayan and Yi, Ap.J., **428**, L13 (1994); R. Misra and F. Melia, Ap.J., **467**, 405 (1996); S. K. Chakrabarti,, Ap.J. , **484**, 313 (1997).

[9] W. H. Press, S. A. Teukolsky, W. T. Vellerling and B. A. Flannery, *Numerical Recipies*, (Cambridge University Press, Cambridge 1986);

[10] R. Misra, Ap.J., **529** L95 (2000); X. M. Hua, D. Kazanas and L. Titarchuk, Ap.J., **428**, L57 (1997); J. Poutanen and A. C. Fabian, Mon. Not. R. Astr. Soc., **306**, L31 (1999).

[11] M. C. Miller, F. K. Lamb, and D. Psaltis, Ap.J., **508**, 791 (1998).

[12] L. Stella, and M. Vietri, Phys. Rev. Lett., 82, 17 (1999).

[13] V. Osherovich, and L. Titarchuk, Ap.J., **522** L113 (1999).

[14] M. Bottcher and E. P. Liang, Ap.J., **511**, L37 (1999); L. Nobili *et. al.*, Ap.J., **538**, L137 (2000); H. C. Lee, R. Misra and R. Taam, Ap.J., **549**, 229 (2001).

[15] R. Wijnands and M. van der Klis, Nature **394**, 344 (1998).

[16] T. E. Strohmayer *et. al.*, Ap.J., **469**, L9 (1996).

[17] W. H. G. Lewin, J. van Paradijs and E. P. J. van den Heuvel,. *X-Ray Binaries* (Cambridge University Press, Cambridge)

[18] C. B. Markwardt, J. H. Swank, T. E. Strohmayer, J. J. M. Zand, J. J. M. and F. E.Marshall, Ap.J., **575**, L21 (2002)

[19] T. E. Strohmayer, Ap.J., **552**, L49 (2001) (astro-ph/0104487); T. E. Strohmayer, Ap.J., **554**, L169 (2001) (astro-ph/0105338).

IUCAA Preprints

Listed below are the IUCAA preprints released during July - September 2002. These can be obtained from the Librarian, IUCAA (library@iucaa.ernet.in).

B. C. Paul and R. Tikekar, *A core-envelope model of compact stars*, IUCAA-31/2002; Anirudh Pradhan and Iotemshi I., *Bulk viscous solutions to the field equations and the deceleration parameter-revisited*, IUCAA-32/2002; Banibrata Mukhopadhyay, *Description of pseudo-Newtonian potential for the relativisitic accretion disk around Kerr black holes*, IUCAA-33/2002; Monika Sinha, Jishnu Dey, Mira Dey, Subharthi Ray and Siddhartha Bhowmick, *Stability of strange stars (SS) derived from a realistic equation of state*, IUCAA-34/2002; S. G. Ghosh, S.B. Sarwe and R. V. Saraykar, *Collapsing perfect fluid in self-similar five dimensional space-time and cosmic censorship*, IUCAA-35/2002; Celine Peroux, Patrick Petitjean, Bastien Aracil and R. Srianand, *A new measurement of zinc metallicity in a DLA at z ~ 3.35*, IUCAA-36/2002; Pia Mukherjee, Tarun Souradeep, Bharat Ratra, Naoshi Sugiyama and Krzysztof M. Gorski, *OVRO CMB Anisotropy measurement cosntraints on flat - Λ and open CDM cosmogonies*, IUCAA-37/2002; T. Roy Choudhury and R. Srianand, *Probing the dark ages with redshift distribution of GRBs*, IUCAA-38/2002; S. G. Ghosh and D. W. Deshkar, *Non-spherical collapse of a radiating star*, IUCAA-39/2002; Banibrata Mulhopadhyay and Ranjeev Misra, *Pseudo-Newtonian potentials to describe the temporal effects on relativistic accretion disks around rotating black holes and neutron stars*, IUCAA-40/2002; Sushan Konar, *Neutrino propagation in a weakly magnetized medium*, IUCAA-41/2002; Pia Mukherjee, Ken Ganga, Bharat Ratra, Grace Rocha, Tarun Souradeep, Naoshi Sugiyama and Krzysztof M. Gorski, *CMB anisotropy constraints on flat-Λ and open CDM cosmogonies from DMR, UCSB South Pole, Python, ARGO, MAX White Dish, OVRO and SuZIE data,* IUCAA-42/2002.

IAGRG - 2002

The 22nd Meeting of the Indian Association for General Relativity and Gravitation (IAGRG) would be held at IUCAA during December 11-14, 2002. We are expecting good participation from the GR and astrophysics community within India as well as some international participants. For up to date information, please visit the meeting web site at http://www.iucaa.ernet.in/~iagrg02, where online registration and abstract submission facilities are also available. The scientific programme will be posted at the same site. Please register as early as possible to help us plan and organize the meeting smoothly.

Seminars

16.07.2002 Pavan Chakraborty on Spectropolarimetry at VBT; 18.7.2002 N. D. Hari Dass on Emergence of the microcanonical distribution from a pure quantum state; 2.8.2002 Hum Chand on Probing the time variation of fine structure constant using QSOs absorption lines; 2.8.2002 Amir Hajian on Statistical isotropy of the cosmic microwave background anisotropy and 23.9.2002 A. A. Zdziarski on Spectral correlation in accreting black holes.

Visitors Expected October to December 2002

October:

A. Ray Chaudhuri, Indian Institute of Science, Bangalore; M. Whittle, University of Virginia, USA; R. Ramakrisha Reddy, Sri Krishnadevaraya University, Anantapur; S. Mukherjee, North Bengal University, Darjeeling; K.S. Sastry, Osmania University, Hyderabad; A. Pradhan, Hindu Degree College, Ghaziabad; B.C. Paul, North Bengal University, Darjeeling; P. Shawhan, Caltech, USA; J. Dey, Maulana Azad College, Kolkata; M. Dey, Presidency College, Kolkata; M. Sinha, Presidency College, Kolkata; A. Sen, Assam University; I. Aotemshi, Nagaland; P. Joarder, VECC, Kolkata; Avas Khugaev, Tashkent; S.N. Paul, Serampore Girls College; T. Subba Rao, S.K. Univ., Kurnool; Hasi Ray, IIA, Bangalore; T.P. Singh, TIFR, Mumbai; T. R. Govindarajan, IMSc, Chennai.

November:

G.S. Khadekar, Science College; Hasi Ray, Indian Institute of Astrophysics, Bangalore.

December:

A. Shukurov, University of Newcastle-upon-Tyne, UK; Albert Lazzarini, LIGO Lab., California Inst. of Technology, USA.

Workshop on Large-scale Structures and the CMBR

This workshop will be held at the Department of Physics and Astrophysics, University of Delhi during November 16 - 20, 2002.

The workshop will consist of two to three lectures on the topics; Structure Formation, Gravitational Lensing and Large-scale Structures, Cosmological Constant and the Dark Energy, CMBR Anisotropy and Polarization and FRW Universe. The speakers are J. Bagla, D. Narasimha, T. Padmanabhan, K. Subramanian and T. R. Seshadri. Limited financial assistance is available for participants from Universities.

Please contact **T. R. Seshadri,** Local Coordinator, Department of Physics and Astrophysics, University of Delhi, Delhi - 110 007. Email: trs@physics.du.ac.in for further details.

For the Younger Minds - 2

T. Padmanabhan

(1) A compact, empty, region in the three dimensional space has a gravitational field $\mathbf{g}$ which is constant in space and time. This field is generated by matter outside this region. One simple configuration which will lead to such a constant, uniform, gravitational field is a plain sheet of matter which is unbounded in two directions. This is not very realistic, since it requires infinite amount of matter. Find another configuration of matter involving only finite amount of mass which is capable of producing a constant, uniform gravitational field in a finite region of space.

(2) Two persons A and B are relaxing on a beach watching the sun set. A, who is lying on the ground sees the rim of the sun vanish below the horizon at time t_1; B, who is 6 ft tall and standing next to A sees the rim vanish at time t_2. Estimate $(t_2 - t_1)$.

Answers to the questions which appeared in Khagol - July 2002

(1a) From the symmetry of the problem, it is clear that all the particles will move towards centre of the polygon maintaining the original shape with the radius r decreasing with time. The net force on any one particle is towards the centre of the regular polygon and has the magnitude $F = (Gm^2/4r^2)\sum_{k=1}^{2n-1} \mathrm{cosec}(\pi k/2n)$. The problem, therefore, reduces to the motion of a particle under the gravitational attraction of a fixed body of mass $M(n) = (m/4)\sum_{k=1}^{2n-1}$ cosec $(\pi k/2n)$.

(1b) In the limit of $n \to \infty, m \to 0$ with $M_0 = 2nm$ remaining constant, the effective mass is obtained by summing the series $\sum_{k=1}^{2n-1} n^{-1}\mathrm{cosec}(\pi k/2n)$, and taking the limit $n \to \infty$. This sum diverges logarithmically. The same result can be obtained by computing the force at any given point P on a uniform circular ring due to the rest of the matter on the ring. Consider the force at P due to matter near a point Q such that the arc PQ subtends an angle θ at the centre of the circle. The component of the force at P towards the centre varies as [cosec $(\theta/2)$]. The total force is obtained by integrating cosec $(\theta/2)$ over θ with the limits $\theta = 0$ and $\theta = \pi$. Near $\theta = 0$, the integral diverges as $\ln\theta$. This divergence is due to the $(1/r^2)$ nature of the force.

(2) Let the effective height of the upper cone of the hour glass be H so that the volume of the sand scales as H^3. Assuming the sand flows uniformly, the time scale T must be proportional to H^3. In addition, it could depend on gravitational acceleration g, diameter d of the aperture and the density ρ of the sand. Dimensional analysis now shows that we must have $T \propto H^3 d^{-5/2} g^{-1/2}$. If we take the constant of proportionality to be of order unity, $H \sim$ few cm, $d \sim$ mm, we get $T \sim$ few minutes which appears reasonable.

For further reading: These problems and many others of similar kind are discussed in "200 Puzzling Physics Problems" by P. Gnadig, et al., Cambridge University Press 2001.

Visitors during July to September 2002

J. Pendharkar, K. Shanthi, C.D. Ravikumar, A. Parameswaran, M. Sinha, S. Bhowmick, M.K. Patil, N. Kumar, L. Chaturvedi, A.S. Reddy, R.P. Bambah, A. Nigavekar, O.P. Nigam, J. Dey, P. Prakash, C.P. Srivastava, K.N. Pathak, A. Bhatnagar, S.M. Chitre, R. Cowsik, C.L. Khetrapal, S.S. Katiyar, B. Hanumaiah, P. Chakraborty, A. Bhattacharya, N.D. Haridass, V.S. Gineesh, S. Datta, A.K. Das, N.S. Singh, B. Medhi, G. Ambika, S. Al-Mufti, N.C. Wickramasinghe, M. Wainwright, P. Rajaratnam, P.M. Bhargava, S. Shivaji, Gopisankara Rao, D.B. Vaidya, K.P. Harikrishnan, D. Singh, S. Mukherjee, V.R. Dabral, S.K. Pandey, S. Sahayanathan, S. Chatterjee, P. Baki, D. Rosario, D.V. Ahluwalia, S. Barway, D. Malquori, P.K. Srivastava, A. Pramanik, S. Bhatacharyya, P.P. Hallan, K.S.V.S. Narasimhan, A. Zdziarski J.Magri, J.Grain, U. Goswami, B.K. Sinha, Koshy George, S.S.Prasad, N. Druguet and Jermie Lasue.

Please note the change in Telephone and Fax numbers !!!

Khagol **(the Celestial Sphere) is the quarterly bulletin of IUCAA. We welcome your responses at the following address:**

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

Phone (020) 569 1414

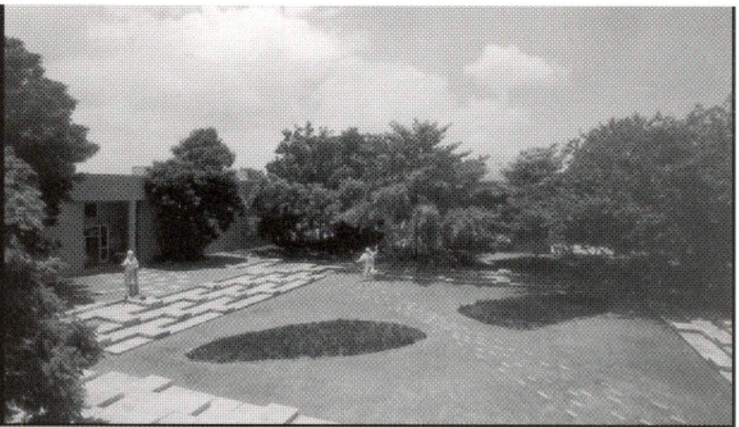
Fax (020) 569 0760

email: publ@iucaa.ernet.in

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

POST-DOCTORAL POSITIONS

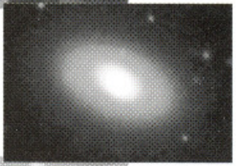
Inter-University Centre for Astronomy and Astrophysics, Pune, India



Applications are invited for post-doctoral fellowships at IUCAA, for duration which are flexible within a range of one to five years. The fellowship includes a remuneration, contingency grant, accommodation on the campus and medical benefits. Facilities required for research are provided through the general IUCAA budget. Post-doctoral fellows with excellent performance can be considered for a tenured position.

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) is an autonomous institution under the University Grants Commission. It was set up in December 1988 amidst the picturesque surroundings of the University of Pune. IUCAA has an integrated campus which includes the academic facilities as well as residential and recreational areas. IUCAA aims at being a centre of excellence within the university sector for teaching, research and development in astronomy and astrophysics. The centre at present consists of about 35 academic members, including core faculty, post-doctoral fellows and graduate students, with potential for growth in the numbers. IUCAA has a vigorous visitor programme, involving short and long term visits of scientists from India and abroad. The centre has about 90 visiting associates from universities and colleges, who visit periodically and participate in all its activities. Further information can be obtained from the IUCAA website at http://www.iucaa.ernet.in/

Applicants should send a curriculum vitae and list of publications, and arrange for three confidential references to be sent independently. All the relevant material should reach IUCAA by November 25, 2002. Candidates will be informed of the result by January 15, 2003. Successful candidates are normally expected to commence their fellowship during 2003.



Facilities at IUCAA include a network of state-of-the-art computers, high speed internet connections, mirror sites of important databases a very well equipped instrumentation laboratory and a library with exhaustive collections of books and periodicals. A 2m optical telescope is being set up by IUCAA at a site which is about 100 kms from the IUCAA campus. The telescope will be operational towards the end of 2003.

Research Areas covered by faculty members at IUCAA include:

- Classical and quantum gravity
- Cosmology and large scale structure
- Gravitational waves
- Galactic and extragalactic astronomy
- High energy astrophysics
- Interstellar medium
- Astronomical instrumentation
- Virtual observatories

IUCAA has a vigorous observational programme in several areas. Support is available for guest observing from international facilities.

Other academic activities include a graduate school for Ph.D. students, teaching at the Master's level for students from University of Pune and other universities, schools and workshops, refresher courses for university and college teachers and a vigorous public outreach programme.

Applications and enquiries should be sent by post or e-mail to : **The Coordinator, Core Programmes, IUCAA**, Post Bag 4, Ganeshkhind Pune 411 007, India. Email : **vch@iucaa.ernet.in**

IUCAA

Inter-University Centre for Astronomy and Astrophysics
An Autonomous Institution of the University Grants Commission

Tel.	:	91-20-5691414, 5699415
Fax	:	91-20-5690760
E-mail	:	publ@iucaa.ernet.in
URL	:	http://www.iucaa.ernet.in/

ACADEMIC CALENDAR 2002 - 2003

Inter-University Centre for Astronomy and Astrophysics

(An Autonomous Institution of the University Grants Commission)

IUCAA

2002

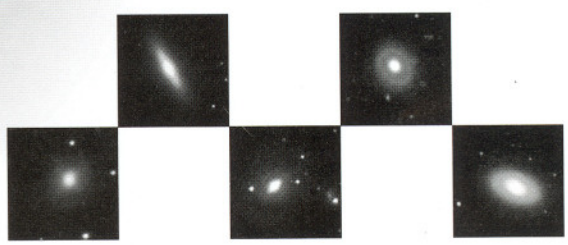
August	12	**IUCAA-NCRA Graduate School** First semester begins
October	7 - 9	**Workshop on Gravity and Astrophysics** at Mar Thoma College, Tiruvalla
October	10 - 13	**Introductory School on Astronomy and Astrophysics** at NES Science College, Nanded
October	27 - 30	**Workshop on Gravitation and Astrophysics** at Science College, Congress Nagar, Nagpur
November	16 - 20	**Introductory School on Astronomy and Astrophysics** at Siliguri College, Darjeeling
November	16 - 20	**Workshop on Large Scale Structures and the CMBR** at University of Delhi
December	11 - 14	**XXII Meeting of the Indian Association for General Relativity and Gravitation** at IUCAA
December	13	**IUCAA - NCRA Graduate School** First semester ends
December	29	**Foundation Day**

2003

January	6	**IUCAA-NCRA Graduate School** Second semester begins
January	6 - 10	**Workshop on Astronomy with Small Telescopes** at IUCAA
January	23 - 29	**Workshop on Field Theoretic Aspects of Gravity - (FTAG-III)** at Cochin University of Science & Technology, Kochi
February	28	**National Science Day**
April 14 - May 23		**School Students' Summer Programme** at IUCAA
May	9	**IUCAA-NCRA Graduate School** Second semester ends
May 19 - June 20		**Refresher Course in Astronomy and Astrophysics for College and University Teachers** at IUCAA
May 19 - July 4		**Vacation Students' Programme** at IUCAA

For further details-
Visit : http://www.iucaa.ernet.in
Or contact-

The Dean, Visitor Academic Programmes, IUCAA
Post Bag 4, Ganeshkhind, Pune 411 007, India.
Phone : +91-20-5691414 Fax : +91-20-5690760
E-mail : publ@iucaa.ernet.in



Optical images of lenticular galaxies shown were taken by S. Barway, A. Kembhavi and D. Mayya with the 2.13 m telescope of the Guillermo Haro Astrophysical Observatory, Cananea, Mexico.