KHAGOL खगोल

IUCAA

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Neutron Stars: Isolated and in Binary Systems

Participants of the workshop on Neutron Stars: Isolated and in Binary Systems

The workshop on Neutron Stars: Isolated and in Binary Systems was held in IUCAA during July 15-16, 2000. The topics covered in this workshop included - Evolution of Neutron Stars in Binaries, the Magnetar Question, Accretion onto Neutron Stars, Magnetic Fields of the Neutron Stars, Pulsar-Strange Star Connection, Pulsar Observation at GMRT, etc. Talks were given by Sudip Bhattacharya (IIA, Bangalore), S. M. Chitre (TIFR, Mumbai), Pranab Ghosh (TIFR, Mumbai), Yashwant Gupta (NCRA, Pune), E. P. J. van den Heuvel (Univ. of Amsterdam), Sushan Konar (IUCAA), Dipanjan Mitra (RRI, Bangalore), Alak Ray (TIFR, Mumbai), Firoza K. Sutaria (IUCAA) and C. S. Shukre (RRI, Bangalore).

Congratulations to ...

Varun Sahni the recipient of Shanti Swarup Bhatnagar Award (2000) for Physical Sciences, conferrred by CSIR, India.

Yogesh Wadadekar the recipient of the Ravikumar Bhalla Award (2000), conferred by the Indian Physics Association.

Contents...

Workshop on Nuclear Astrophysics

Participants of the workshop on Nuclear Astrophysics

The workshop on Nuclear Astrophysics was held at IUCAA during September 20 - 22, 2000. There were twenty four active participants from all over the country. The topics on which lectures were delivered included Neutron Stars, Neutron Rich Nuclei, Neutron Stars and Quark Stars, Cosmic Ray, Quark Matter and White Dwarfs, Neutrino Physics and Nuclear Matter. The speakers were F.K. Sutaria (IUCAA, Pune), Rituparna Kanungo (Japan), Sushan Konar (IUCAA, Pune), Nayantara Gupta (IACS Calcutta) Somenath Chakraborty (Kalyani University, Calcutta), S.K. Singh (Aligarh Muslim University, Aligarh), V.K. Gupta (Delhi University, Delhi) Debades Banerjee (SINP, Calcutta), P.K. Raina (IIT, Kharagpur), and Hiranmaya Mishra (PRL, Ahmedabad). Somenath Chakrabarty and A. Kembhavi were the coordinators of the workshop.

Welcome to ...

Tapas Kumar Das, who has joined as a post-doctoral fellow. His research interests are Formation of Accretion Powered Cosmic Jets and Gravitational Waves.

Dipanjan Mitra, who has joined as a post-doctoral fellow. His research interests are Pulsar emission mechanism, Search for millisecond pulsars and Interstellar medium.

Amrit Lal Ahuja, **Ujjaini Alam** and **Atul Deep**, who have joined as Research Scholars.

Farewell to ...

Somak Raychaudhury who has joined (on leave from IUCAA) the School of Physics and Astronomy, University of Birmingham, U.K.

Vacation Students' Programme 2000

The 7 weeks long Vacation Students' Programme (VSP) for students in their penultimate year of their M.Sc. (Physics) or Engineering degree course was held during May 22 - July 7, 2000. Seven students participated in this programme. The participants attended about 63 lectures dealing with wide variety of topics in Astronomy and Astrophysics. They also did a project with one of the faculty members of IUCAA during this period. T. Padmanabhan was the coordinator of this programme.

Seminars

28.7.2000 Anand S. Sengupta *on* Simulation of the One Step Search Algorithm for Detection of Gravitational Waves from Inspiralling Compact Binaries; 28.7.2000 Parampreet Singh *on* Ashtekar Variables; 21.8.2000 Harvinder Kaur Jassal *on* Null Strings Near A Higher Dimensional Blackhole and 19.9.2000 Anup Rej *on* Universe as Turbulence.

Gamma Ray Bursts in the Afterglow Era

The Gamma-Ray Burst (GRB) phenomenon was discovered more than a quarter century ago, but had remained a mere curiosity until two major leaps were taken in the last decade [2]. First, the Burst and Transient Source Experiment (BATSE) aboard Compton Gamma Ray Observatory (CGRO) made the detection of GRBs a routine affair – it detected over 2700 bursts until CGRO was brought down in June 2000 – and localised them within a few degrees, making possible the study of their space distribution. Second, the Italian-Dutch satellite BeppoSAX discovered X-ray *Afterglows* of GRBs, and using them obtained arcminute-scale localisation of a couple of dozen bursts over the last three years. Discovery of afterglows has revolutionised GRB astronomy. It has enabled multiwavelength follow-up all the way from radio to X-rays. Optical follow-up has paid rich dividends: the determination of redshifts and hence distances, as well as the identification and imaging of host galaxies. Detailed afterglow light curves and broadband spectra have revealed the dynamics of GRB remnants and provided important information about the energetics of these events.

1 The Bursts in Gamma Rays

The largest compilation of the burst characteristics in Gamma Rays comes from BATSE. The revised Fourth BATSE burst catalog contains 1637 bursts [3] recorded by BATSE between 1991 April and 1996 August. A catalog including later bursts is available online [1]. The online resource also allows the viewing of burst light curves, with a time resolution up to 64 ms. Three major points can be noted from these catalogs.

- The bursts are most often multipeaked, with ~10–100 distinct peaks in each event. In strong bursts, it can be seen that these individual peaks ("sub-bursts") follow a Fast Rise and Exponential Decay (FRED) profile (fig. 1).
- The duration of bursts occupy a large range – from a few ms to ~1000 s. It appears that the bursts can be classified into two distinct categories: short (<1 s) bursts with harder gamma-ray spectra and long (>1 s, typically ~10 s) bursts with softer spectra.
- The sky distribution of bursts is to a high degree isotropic (fig. 2), implying source locations at cosmological distances.

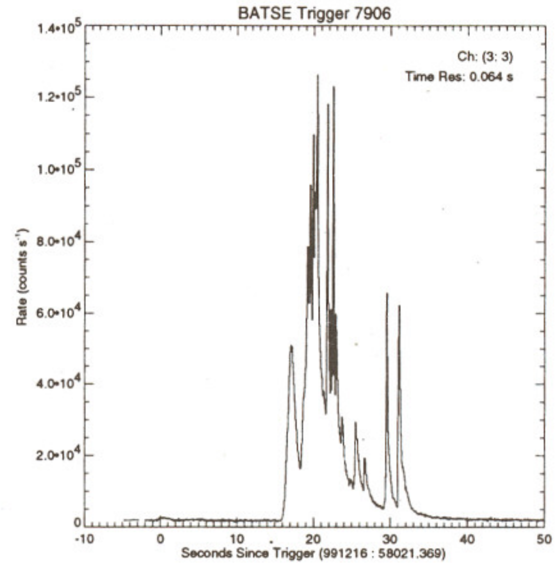

Figure 1: BATSE light curve of GRB991216 in 100-300 keV energy band. This is among the brightest bursts seen by BATSE. Note the mutipeaked nature of the event.

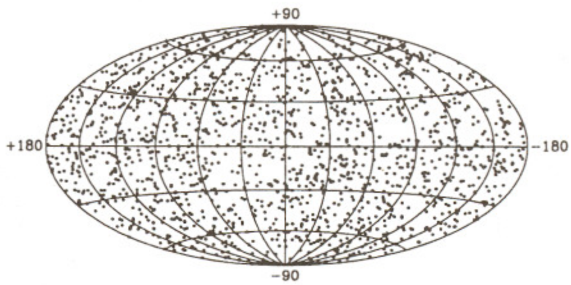

Figure 2: Sky distribution of the 1637 bursts in revised 4th BATSE catalog. Note the isotropy of the distribution. From [3].

2 Afterglows

The afterglow of a GRB appears soon after the GRB event, and is normally spotted in X-rays. The refined coordinates provided by the X-ray instruments then enable ground based optical and radio telescopes to conduct further follow-up. Unlike the GRB event itself, the afterglow is long-lived, and has a smooth light curve that exhibits a power-law decay. It is now a matter of routine to follow-up optical afterglows for several days to tens of days using ground-based telescopes. At radio wavelengths, GRB afterglows have been observed for many months.

The broadband power-law spectra of GRB afterglows and their smooth power-law light curves provide two important indications about the nature of afterglows: (i) that the emission process is non-thermal, with synchrotron radiation as the possible underlying mechanism, and (ii) that the source undergoes rapid expansion, causing the decay of luminosity. The situation is analogous to supernovae: while the burst itself is an event like the supernova, the afterglow emission comes from a phase analogous to the Supernova Remnants, which arise due to the interaction of the expanding ejecta with the surrounding interstellar (or circumstellar) medium. All timescales in a GRB, however, are much shorter than those for a standard supernova, and this is related to the extremely rapid expansion of the material.

Further arguments would show that the expansion is ultra-relativistic, with bulk Lorentz factor $\Gamma \gg 1$. The first evidence comes from the rapid variability timescale of the burst, $\delta T \sim 10$ ms. Interpreted non-relativistically, this would imply a source size $\leq c\delta T \sim 3000$ km. If the observed gamma-ray photons were to come from such a small volume, however, the local optical depth for these photons to produce pairs by $\gamma\gamma \rightarrow e^+e^-$ process would turn out to be $\tau_{\gamma\gamma} \sim 10^{13}$, so these photons should not have escaped in the first place! This contradiction can be resolved by appealing to relativistic expansion: the observed time scale δT then corresponds to a time $\Gamma^2\delta T$ in the frame of the emitting plasma, and the energies of individual photons are reduced by a factor Γ at the point of emission. These two factors reduce $\tau_{\gamma\gamma}$ below unity for the observed photons if $\Gamma \geq 100$ [4]. Other arguments in favour of relativistic expansion come from direct observations - for example, the angular size of the afterglow has been inferred to increase superluminally from radio scintillations [10].

3 Blast Wave Dynamics

The ultra-relativistically expanding ejecta will obviously drive a shock in the external medium. As this, blast wave expands and entrains matter from the surroundings, the dynamics will gradually come to be dominated by the swept-up matter. Ultra-relativistic expansion demands that the ejected mass is small: $M_0 \approx E_0/\Gamma_0 c^2 \approx 10^{-4} M_\odot (E_0/10^{52}\text{ erg})(\Gamma_0/100)^{-1}$, where E_0, Γ_0 are the blast energy and the initial bulk Lorentz factor respectively. The swept-up mass M_s has a thermal energy $(\Gamma - 1)M_s c^2$ after being shocked, so the inertia equivalent of swept-up matter is ΓM_s. As a result, swept-up matter begins to dominate dynamics when $M_s \geq M_0/\Gamma_0$, following which the blast wave begins to decelerate significantly.

In case of supernovae, where the expansion is fast but non-relativistic ($v \sim 10^4$km/s), the deceleration of the blast wave coincides with the start of the Supernova Remnant (SNR) phase. Deceleration aids the formation of turbulent cells, which can amplify local magnetic fields and accelerate electrons to relativistic energies, causing synchrotron emission to build up [7]. A fraction ($\sim 10^{-2}$) of the postshock thermal energy can be pumped by turbulence into magnetic field and relativistic particles. A very similar situation obtains in GRBs–as the blast wave decelerates, the afterglow appears. The major difference between the two cases are (i) relativistic shocks are more efficient particle accelerators, so the fraction ϵ_e of postshock thermal energy going into relativistic electrons could be larger, and (ii) the time scales are much shorter, because (a) much less mass needs to be swept-up for the deceleration to start, (b) the expansion, at nearly the speed of light, takes a much shorter time, and (c) the time measured by an earthbound observer is shortened by a factor Γ^2 due to Doppler effect. Thus the ~ 200 y time needed for an SNR to develop gets compressed, in case of GRBS, into a few minutes for the afterglow emission to begin.

It may well be that the material ejected at the GRB event is not isotropic but is collimated into jets of opening angle, say, θ_{j0}. Unlike spherical blast waves, the material here will expand not only radially, but also sideways. The jet opening angle will have the following behaviour: $\theta_j = \theta_{j0} + v_l/c\Gamma$, where the lateral expansion speed v_l would lie between $c/\sqrt{3}$ and c. Clearly, once deceleration brings Γ down to $< 1/\theta_{j0}$, lateral expansion will dominate the evolution, causing the dynamics to differ strongly from the spherical case [6].

In general, the complete evolution of the decelerating blast wave can be obtained from the following set of equations [4, 6, 5]:

$$\frac{d\Gamma}{dm} = -\frac{\Gamma^2 - 1}{M}, \quad \frac{dM}{dr} = \frac{dm}{dr}[\Gamma - \epsilon(\Gamma - 1)], \quad \frac{dm}{dr} = \Omega r^2 \rho(r)$$

where $\rho(r)$ is the mass density of the external medium, Ω the solid angle into which the ejecta are expanding, dm is the rest mass swept-up and M is the total mass including internal energy. $\epsilon = 0$ corresponds to an adiabatic shock and $\epsilon = 1$ to a fully radiative shock. $\rho(r) =$ constant would represent expansion into a uniform-density interstellar medium, and $\rho(r) \propto r^2$ would represent a circumstellar wind medium.

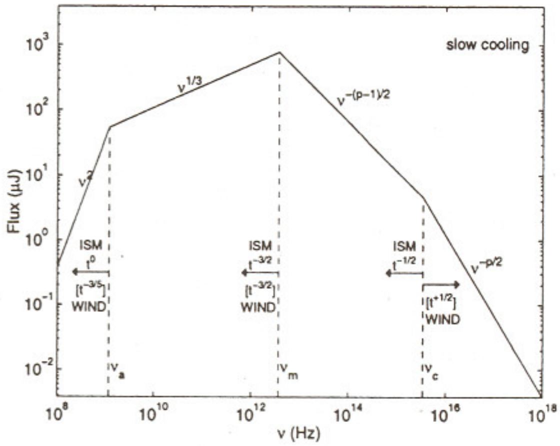

Figure 3: Predicted radiation spectrum of a GRB afterglow in the adiabatic expansion phase (from [8])

4 Afterglow Emission

Once the dynamics of the blast wave is known, the synchrotron emission from the afterglow can be easily calculated, assuming a constant fraction ϵ_e of the postshock thermal energy to go into relativistic electrons with a power-law energy distribution ($N(\gamma_e) \propto \gamma_e^{-p}$, where γ_e is the Lorentz factor of the electrons), and a fraction ϵ_B into magnetic field. The minimum energy in the electron distribution is $\gamma_m \approx \epsilon_e \Gamma(m_p/m_e)$, m_p, m_e being the mass of a proton and of an electron respectively. This energy will correspond to a low-frequency break in the synchrotron spectrum, at a frequency ν_m. Another break frequency of importance is ν_c, the cooling frequency. Electrons responsible for emission above ν_c suffer strong energy losses due to synchrotron radiation. If $\nu_c < \nu_m$, the situation is called "fast cooling", since all electrons are cooling rapidly. If $\nu_c > \nu_m$, as is more often the case, then the majority of electrons suffer no significant energy loss. This case is called that of "slow cooling". A typical synchrotron spectrum expected in the adiabatic slow cooling case is displayed in fig. 3. Apart from ν_c and ν_m, the figure includes a break at ν_a due to Synchrotron self-absorption. The figure also displays the time evolution of the spectrum.

One would notice from the figure that in the range $\nu_m < \nu < \nu_c$ which, for a typical afterglow, includes the optical band, the light curve is predicted to be a power law, with a decay index of $\frac{3}{4}(p-1)$ for expansion in a uniform Interstellar Medium. This is indeed found to be the case in afterglows that have had both broadband spectra and light curves measured well. Interestingly, after a period of a few days, optical light curves, in most cases, show a steeper decline. This can be attributed to the lateral expansion of ejected material, which was initially confined to a small cone. The light curve in this case is expected to steepen to t^{-p} asymptotically. GRB 990510 presented the first clear-cut evidence of this, leading to an estimate of the jet opening angle $\theta_{j0} \sim 5°$ [9]. However, in some afterglows the amount of light curve steepening may not quite be in accord with this prediction [11].

5 Energetics and Origin

Burst energies inferred from the measured burst fluence, the observed redshift and the degree of collimation determined from light curves are typically of order $\sim 10^{52}$ erg. The two major models proposed to explain the origin of GRBs, namely, (1) the merger of two neutron stars or a neutron star and a black hole [12], or (2) the collapse of the core of a very massive star directly forming a black hole (hypernova) [13], can certainly release gravitational energies larger than this, but the details of how the energy is tapped and converted to kinetic energy and radiation remains poorly understood. A promising mechanism to generate the multi-peaked burst of gamma-rays is a series of internal shocks in the expanding ejecta, but the efficiency of this process still remains questionable [4].

The highest measured redshift of a GRB is 3.4. If this is taken to indicate that observed bursts occur out to a redshift at least ~ 6 [14], then the inferred event rate per galaxy works out to be $\sim 10^{-8}\ \mathrm{yr}^{-1}(\Omega_{\mathrm{jet}}/10^{-2})^{-1}$ or less. This is much smaller than the average rate computed for either neutron star merger or massive star collapse events. It appears, then, additional conditions must be fulfilled for a GRB event to occur, one of them possibly being the limiting of the ejected mass to a very small value.

One discriminator between the two models above would be the burst environment. A double neutron star binary will in general travel a long way from its birthplace before merger occurs, while a massive star will remain close to it. If GRBs in general are closely associated with star forming regions (of which, some evidence appears to be emerging from HST imaging) then the latter would appear more favourable.

One must note that due to BeppoSAX trigger criteria, all afterglow follow-ups have so far been for the long, soft bursts. It is possible that the short, hard bursts are of a different origin. One is eagerly awaiting the launch of the High Energy Transient Explorer - II in October 2000, which will make the follow-up of this class of GRBs possible.

References

[1] Being a rapidly developing field, much of the current and archival information about GRBs is best obtained from online resources. The BATSE catalog of bursts is available from http://www.batse.msfc.nasa.gov/batse/grb/catalog/. E-mail notification of burst coordinates and follow-up observations can be obtained from GCN circulars and notices, visit http://gcn.gsfc.nasa.gov/invitation.html to sign up. http://gcn.gsfc.nasa.gov/ keeps an archive of all the circulars. A page kept updated with summary of afterglow observations is at http://www.aip.de/~jcg/grb.html.

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[7] Gull S.F., 1975 MNRAS 171, 237

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[12] Eichler, D. et al, 1989 Nat 340, 126; Paczyński, B., 1991 Acta Astronomica 41, 267

[13] Paczyński, B., 1998 ApJ 494, L45

[14] Lamb, D.Q. and Reichart D.E., 2000 ApJ 536, 1: discusses cosmological issues relevant for GRBs. For discussion of possible microlensing of GRB afterglows see Garnavich et al 2000, astro-ph/0008049.

Oncoming Events from the Academic Calendar 2000-2001

November 2 - 4	**Workshop on Observations with Small Telescopes** at Bhavnagar
November 16 - 20	**Introductory School on Astronomy and Astrophysics** at Nanded
December 4 - 8	**Workshop on Solar Physics** at IUCAA
December 11 -20	**Indo-French School on Star Bursts and the Structure and Evolution of Galaxies** at IUCAA
December 21 - 23	**Workshop on Observing with IUCAA Telescope** at IUCAA
December 29	**Foundation Day**
January 8 - 12	**Astronomical Photometry and Spectroscopy** at Bangalore
January 17 - 19	**Second Level , 1st Work shop on Astronomical Photometry** at IUCAA
January 28 - 29	**Discussion Meeting on Cosmology** at Nagpur

Second Level 1st Workshop on Astronomical Photometry

Applications are invited for the second level 1st workshop on astronomical photometry to be held at IUCAA during January 17 -19, 2001.

In this workshop advanced techniques of photometric observations will be discussed. Those who had participated in the Level 1 series will be given priority and those who would like to present their observations/ results.

Applications may be sent to Arvind Paranjpye at IUCAA or by email to: arp@iucaa.ernet.in, by November 10.

IUCAA Preprints

Listed below are the IUCAA preprints brought out during July-September 2000. These can be obtained from the Librarian, IUCAA (email: library@iucaa.ernet.in).

Avijit K. Ganguly and **Sushan Konar**, *Absorption of Electro-magnetic Waves in a Magnetized Medium*, IUCAA-26/2000; **S. Shankaranarayanan**, **K. Srinivasan** and **T. Padmanabhan**, *Method of Complex Paths and General Covariance of Hawking Radiation*, IUCAA-27/2000; **R. G. Vishwakarma**, *A Study of Angular Size-Redshift Relation for Models in which Λ Decays as the Energy Density,* IUCAA-28/2000; **S.G. Ghosh** and **R. V. Saraykar**, *Higher Dimensional Radiation Collapse and Cosmic Censorship*, IUCAA-29/2000; **Boudewijn F. Roukema**, *A Counter example to Claimed COBE Constraints on Compact Toroidal Universe Models*, IUCAA-30/2000; **Boudewijn F. Roukema**, *The Topology of the Universe*, IUCAA-31/2000; **Tarun Deep Saini**, **Somnath Bharadwaj** and **Shiv K. Sethi**, *Using Gravitational Lensing to Study Damped Lyman-α Clouds*, IUCAA-32/2000.

Workshop on Astronomical Spectroscopy and Photometry

A workshop on Astronomical Photometry and Spectroscopy will be held at the Department of Physics, Bangalore University during January 8-12, 2001. The workshop will deal with various theoretical and observational aspects of photometry and spectroscopy of stars and galaxies. It is primarily meant for college and university teachers of Bangalore University though a small number of interested persons from neighbouring universities would also be accommodated. Resource persons will be drawn from IUCAA, Delhi University, IIA, RRI, Bangalore University, and other institutions. Ranjan Gupta will be the coordinator from IUCAA and B.A. Kagali will be the local convener of the workshop.

Interested persons having some background in Astronomy and Astrophysics may kindly write to B.A. Kagali, Department of Physics, Bangalore University, Bangalore - 560 056.
(email : buniphy@kar.nic.in; Fax : 080-3219295)

Astronomer by Default ?

Harlow Shapley became an astronomer by accident. He arrived at the University of Missouri as a young man intent on studying journalism, but found that the buildings that would house the school were not yet finished. He was told to return the following year, which he did - only to find that the buildings were still unfinished. Rather than wait a further year he decided to take a different course. He picked up a prospectus and, in his own words, 'got a further humiliation. The very first course offered was A.R.C.H.A.E.O.L.O.G.Y. - and I couldn't pronounce it (although I did know roughly what it was about). I turned over a page and saw A.S.T.R.O.N.O.M.Y. - I could pronounce that - and here I am!'

[Source: *From: Measuring the Universe by Stephen Webb* (Springer)]

Visitors Expected

October: K.S. Sastry, Osmania University; S.M. Alladin, Osmania University; B.C. Paul, North Bengal University; Suresh Chandra, SRTMU; Lalan Prasad, MB Govt. PG College; G. Date, IMSc.; J. Maharana, IOP; A.C. Borah, Assam University; A. Raychaudhuri, University of Calcutta; J.P. Luminet, France; L.M. Saha, Zakir Husain College; H. Jassal, Delhi University; H.S. Das, Assam University; N. Rao, PRL; N. Rajasekhar Rao, MALD Govt. College; M.R. Das, Rajiv Gandhi Centre for Biotechnology; K. Bhattacharya, SINP.

Apart from the above, about 60-70 participants will visit IUCAA to attend the workshops on Automated Data Analysis and Gravity: Field Theory Aspects

November: T. Mukai, Kobe University

December: A. Beesham, University of Zululand; P. Ulmschneider, Heidelberg.

Participants of workshops on Solar Physics and Indo-French School also will be visiting IUCAA during this period.

Visitors during July - September 2000

S.N. Paul, S.K. Bhattacharya, S.K.Sahay, D.C. Srivastava, R. Nayak, N. Surchandra Singh, Suresh Chandra, V.C. Kuriakose, S. Datta, P.N. Pandita, R.T. Gangadhara, M.K. Patil, E. van den Heuvel, Ram Sagar, S. Mukherjee, A. Goyal, M.K. Das, H.P. Singh, D. Mitra, R. Ellis, S. Ray, J. Dey, R. Ramakrishna Reddy, M. Dey, S.K. Pandey, S. Bhattacharya, S. Naik, C.S. Shukre, S. Chakrabarty, B.A. Kagali, P.K. Bhattacharya, K. Mukherjee, P. Ghosh, B.S. Acharya, A. Ray, P. Majumdar, S.M. Chitre, B.B.Walwadkar, H.K. Jassal, M. Joshi, D. Singh, D.B. Vaidya, C.V. Vishveshwara, P. Petitjean, S. Mathur, C.D. Ravikumar, A. Ghosh, U. Ghosh, S.G. Pawar, P.K. Srivastava, P.J. Lavakare, M. Pandey, S. Sethi, K.R. Chatterjee, K.S.V.S. Narasimhan, J. Ehlers, A. Rej, H. Mishra, R. Dutta, B.K. Raj, N. Nag, S. Ghosh, N. Gupta, D. Bandyopadhyay, P.K. Raina, A. Giri, S. Singh, V.K. Gupta, R. Kanungo, P.K. Rath, S.K. Singh, G.P. Malik, L.K. Pande, N. Rudra, P.P. Hallan, M. Sami, B..C. Paul, S. Mukherjee.

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

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