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Multi-band monitoring and Polarimetry of GRB afterglows with the IUCAA telescope

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Abstract. The IUCAA 2m telescope which is scheduled to be available for observations in early 2002, will initially have two instruments at its f/10 Cassegrain focii – the IUCAA Faint Object Spectrograph Camera (IFOSC) and the Near-Infrared PICNIC Imager (NIPI). Both of these instruments are planned to have polarimetric capabilities too, with the ability to measure two orthogonal polarization components simultaneously. Apart from monitoring the afterglow lightcurves, these instruments will provide the opportunity to observe afterglow linear polarization and perhaps its variation. Such observations are necessary to constrain the large number of models that have been suggested predicting afterglow polarization. Measurement of polarization will also provide a better handle in understanding the beaming nature or otherwise of GRB ejecta.

Key words: Gamma-ray bursts, Afterglows, Photometry, Polarimetry

1. Introduction

The discovery of well-localized X-ray afterglows from Gamma-ray bursts (GRBs) by the Italian-Dutch satellite *Beppo-SAX* and the subsequent detection of afterglows at other wavelengths ranging from optical to radio, were major steps forward in understanding the nature of this decades old enigmatic phenomena. Theoretical models are now able to explain a number of features in the afterglow lightcurves, which are primarily in the form of spectral/temporal breaks (see for example Sari et al. 1998, Meszaros 2001). Having achieved this broad understanding of the afterglows, attention is now turned towards a number of gaps that still remain to be filled in with details. Other contributors to this symposium have described the current state of understanding of GRBs and their afterglows and brought out a number of outstanding issues (see for example Lazzatti, Sagar etc. in this proceedings). These involve unusual afterglow properties such as steep light curve decay indices, spectral colours, possible association with other phenomena like supernovae etc.

Another recent turn around in the theoretical understanding of GRB afterglows is that they are now expected to be linearly polarized by upto a few times 10% (eg. Gruzinov and Waxman 1999). Several models have been proposed that predict a variety of signatures in terms of the fractional polarization and its variations in amount and position angle in relation to the temporal breaks in the lightcurves. Many of these models depend on beaming of afterglow ejecta – an idea which has been gaining popularity over the last few years (Rhoads 1997) – to break the isotropy of the magnetic field geometry and thereby causing net polarization. Nevertheless, observations of optical polarization have been scanty and offer little constraints to theoretical models.

In this contribution, we explore the observational opportunities that will open up for the astronomy community in India, once the IUCAA 2m telescope becomes operational. In the next section, we present the essential features of IUCAA telescope with emphasis on the planned instrument complement. In the section that follows next, we discuss various open questions related to the optical and near-IR afteglows, that still beg observational confirmations and how the above instruments can be utilized for the purpose. In the last section we summarize.

2. IUCAA Telescope and Back-end Instrumentation

The Inter-University Centre for Astronomy & Astrophysics (IUCAA) is setting up an observatory for a 2m telescope at a site called Giravali, about 80km from Pune, India. Fig. 1 shows the observatory building, which is nearing completion. The telescope itself has been built and is undergoing integration and testing at Telescope Technologies Limited, Liverpool, UK.

The primary mirror of the telescope has a pneumatic active support system, and the optical and tracking performance are specified so that the seeing limited images are not degraded by more than a fraction of an arsecond. Provided with a sensitive, off-axis acquisition and autoguiding mechanism, the telescope will be capable of quickly acquiring targets and taking long exposures with minimal effects from flexures and wind on the image quality. The telescope has a direct Cassegrain port which can handle large instruments in addition to four side Cassegrain ports suitable for smaller instruments. At present, at a time only one of the five ports can be used for observations.

The main facility instrument, which will be mounted on the direct Cassegrain port, is IUCAA Faint Object Spectrograph Camera (IFOSC). This instrument which was built as a collaboration between IUCAA and Copenhagen University Observatory, Denmark, is ready and awaiting commissioning on the telescope. IFOSC is equally capable of being used as a photometric camera in UBVRI wavelength bands as well as a spectrograph with spectral resolutions between 200 to 3700. With 10 grisms covering the wavelength range from $0.33\mu m$ to $1.15\mu m$ at different resolutions, a slit wheel which can carry seven $11'$ long slits and a sensitive 2Kx2K EEV CCD chip as detector, this instrument can cater to a wide vareity of observational demands.

The second facility instrument which is being designed is the Near-Infrared PICNIC Imager (NIPI). Built around the 256x256 pixel PICNIC chip (obtained on a long term loan from the Institute of Astronomy, Cambridge, UK), this instrument will have cold

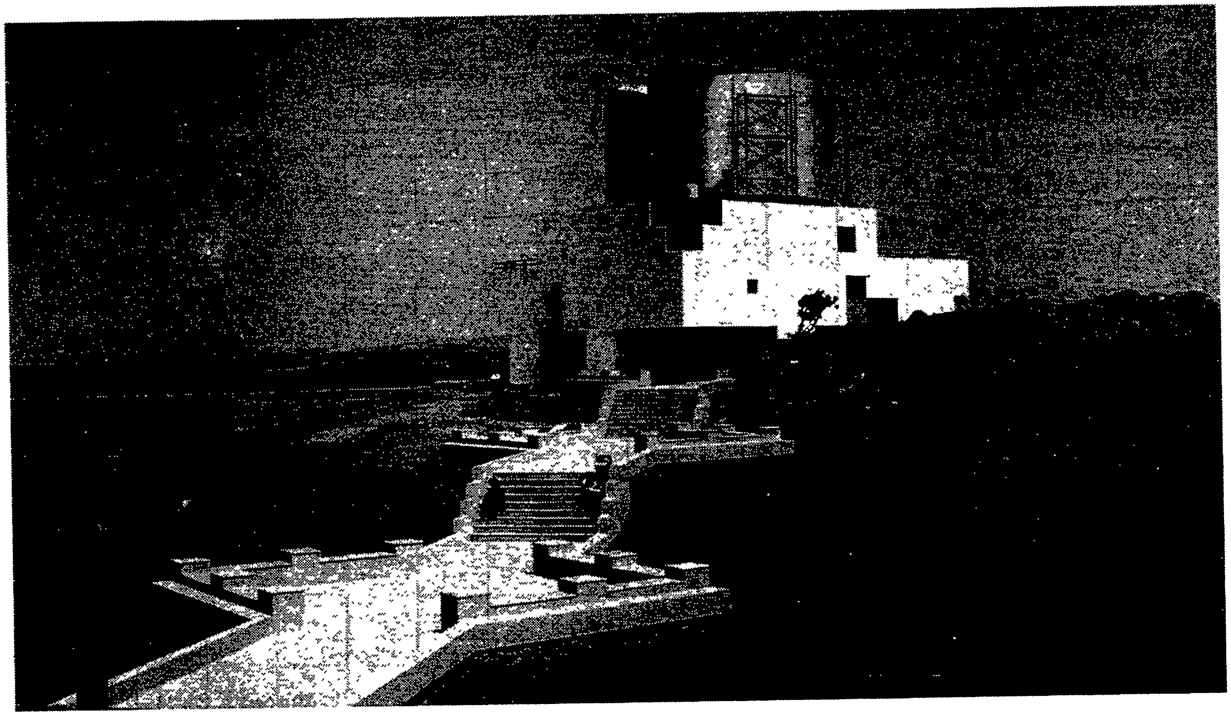

Figure 1. IUCAA Observatory site at Giravli, near Pune.

optics and filters so that it can work upto the K-band in the near-infrared. It is planned to adapt the IUCAA CCD controller for developing the data acquisition system for this instrument. The 1% photometry limits achievable in 15 minutes with NIPI are estimated to be J=18.5, H=17.7 and K=16.3 for 3 to 5 second long exposures.

IFOSC and NIPI are both planned to be provided with imaging polarimetric capability. The polarimetric technique employed, which is the same as that used in IMPOL (Ramaprakash 1998), an instrument developed earlier in IUCAA, allows two orthogonal polarization components which define a Stoke's parameter to be measured simultaneously. This eliminates measurement errors due to atmospheric scintillation, systematic sensitivity drifts, intrinsic source intensity variations etc. The rapidly fading nature of the GRB afterglows make it essential to employ this technique, if accurate polarimetry is to be achieved.

3. Challenges in GRB afterglow observations

Light curve monitoring: So far around 300 Gamma-ray bursts have been observed since the launch of the Italian-Dutch satellite *Beppo-SAX*. However, in many cases (as high as 30%), afterglows at optical wavelengths were not detected even though the X-ray afterglows were well-localized and deep follow up searches in the optical were quickly undertaken. This is surprising, given that an afterglow with an initial R-band magnitude of 16-20 and fading with a power law index of about -1.2 to -1.4, according to theoretical predictions, should be within the detection limits of ground-based telescopes for at least a few days. Extinction by dust in the host galaxy of the burst is a prime candidate suspected for making at least some of the optical afterglows vanish. High redshift ($\gtrsim$7) of the burst, foreground extinction in the Galaxy, selection effects due to intrinsic afterglow luminosity function etc. are other suggested causes. Continued efforts to monitor the lightcurve properties are necessary to understand if all, some or any of these effects are responsible for the vanishing optical counterparts.

Even in those bursts where optical afterglows were seen, many showed quite unexpected behaviours. For example, the unusual spectral colours as in GRB 980329 (Palazzi et al. 1998), GRB 990705 (Masetti et al. 2000), GRB 000301C (Rhoads and Fruchter 2001), GRB 000418 (Klose et al. 2000) etc. could give vital clues to the mystery of vanishing afterglows.

Recently, there had been claims that evidences present in the afterglow lightcurves of many GRBs, indicate a GRB-supernova connection. GRB 970228 (Galama et al. 2000), GRB 980425 (Galama et al. 1998; Kulkarni et al. 1998), GRB 990712 (Bjornsson et al. 2001) etc. have lightcurves which show such evidences. The presence of evidences for such a connection, though has not been ruled out in any of the afterglow lightcurves, neither has it been conclusively demonstrated.

The extremely high energetics ($\sim 10^{54}$ergs/s) implied by large redshifts that have been measured for some GRBs has prompted many authors to suggest that the GRB ejecta are beamed. One way of verifying this assumption is by looking for the effects of beaming in the afterglow lightcurves. In particular, if the beamed ejecta is spreading laterally, it will reach a stage when the shock front starts growing faster than that implied by the radial divergence (Rhoads 1997). This will result in a faster deceleration of the ejecta and a break in the lightcurve. The steepening of lightcurve decay to large power law indices seen in GRB 980519 (Sari et al. 1999), GRB 990123 (Kulkarni et al. 1999; Rhoads 1999), GRB 990510 (Harrison et al. 1999; Stanek et al.1999) etc. have been attributed to jet-spreading.

Polarization: Since the magnetic fields in the shocked ejecta are expected to be quite tangled up, it was thought for a long time that the afterglow emission of GRBs will be unpolarized, even though the underlying synchrotron emission mechanism is highly polarizing. However, recently Gruzinov and Waxman (1999) have shown that the net polarization in an afterglow can be non-zero if there are only a few number of coherent patches within the observable area of the shock front. On the basis of this, they predict upto a few times 10% polarization for typical afterglows. Another approach at breaking the isotropy of magnetic fields is made by assuming that the tangling up occurs mainly within the shock front while perpendicular to it there might be high level of coherence (Medvedev and Loeb, 1999). However, Gruzinov (1999) considers this assumption unrealistic and suggests that it will be more realistic to assume that the strengths of the magnetic fields parallel and perpendicular to a beamed shock front are different. He again predicts a few times 10% polarization. On the other hand, if the ejecta is beamed, the chances that the line of sight coincides with the cone axis are extremely slim. This in turn will lead to variation in the polarization and its position angle, as the ejecta becomes less relativistic and the observable area of shock surface intersects the edge of the ejecta

Two polarization peaks, differing in position angle by 90° is a distinct prediction of this model (Ghisellini & Lazzati 1999). A third peak may also be seen if the beam spreads laterally also (Sari 1999) and the line of sight towards the burst is not close to the beam axis. This peak of upto 20% polarization will have the same position angle as that of the first one.

Though theoretical models thus galore, there have been only a handful of succesful polarimetric observations till date. For GRB 990123, Hjorth et. al. (1999) put an upperlimit of 2.3% polarization. GRB 990510 was the first for which a definite polarization detection of 1.7% was made (Covino et al. 1999, Wijers et al. 1999). Rol et. al (2000) tried to measure polarization of GRB 990712 when they obtained ~2% polarization for one epoch, but their second attempt did not achieve sufficient signal to ratio to arrive at any conclusions on polarization variability. It is clear that many more observations are needed to verify/falsify the different models of polarization that have been proposed.

5. Conclusion

Observing optical and near-infrared afterglows of gamma-ray bursts still poses major observational challenges. Many of the afterglows which had been observed over the last three years or so, have thrown open many new unanswered questions. For one, it is not clear where the missing afterglows are, while for another even the ones detected, more often than not spring surprises through their behaviour. Continuing efforts in carrying out quick follow up observations of GRB afterglows are required to constrain theoretical models. The lightcurves need to be sampled at as many epochs as possible in order to monitor the passage of break frequencies through different spectral bands.

Recent predictions and subsequent verification of linear polarization in GRB afterglow lightcurves have renewed interest in this little studied effect. Measurment of polarization and its variation allow better understanding of the properties of the magnetic field that leads to synchrtron cooling of the electrons. Polarization also carries signatures of beaming of the ejecta as well as its lateral spreading, if any. Observations hitherto have been only partially successful and are not sufficient to draw any conclusions about the amount of polarization or its variability.

Thus, in spite of the fact that we can already explain a number of broad characteristics of GRB optical afterglows, there still is a long way to go.

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