NEW MULTISPECTRAL APPROACHES TO STUDY OF GAMMA RAY BURSTS

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The recent detections of X-ray and optical afterglows allow the independent searches for X-ray and optical counterparts of GRBs to be considered. We discuss the possible methods to detect and to investigate the GRB using their low energy emission.

1 Introduction

Recently, the Gamma-Ray Bursts (GRBs) are discovered only in gamma rays. However, nearly 90% of all GRBs detected by BeppoSAX have an X-ray afterglow, nearly 45% of detected GRBs by BeppoSAX have an optical afterglow, and nearly 40% of detected GRBs by BeppoSAX have a radio afterglow. These results justify the searches for GRBs INDEPENDENTLY at other wavelengths, especially in X-rays and in optical. This means that GRBs can be detected not only in gamma rays but at other wavelengths as well. Since the GRB emission is believed to be beamed, with opening angle increasing with wavelength and with time, the fraction of GRBs observable at longer wavelengths if compared with gamma-rays is believed to be larger.

The advantages of observing GRBs at other wavelengths can be summarized as follows: (i) larger sample and hence better statistics: the total number of detected triggers is expected to be larger, (ii) this means also better statistics of related host galaxies, redshift distributions, etc., (iii) precise astrometry and localization accuracy (if compared with gamma rays), (iv) constraints on beaming and other parameters, (v) cost effective approach, (vi) multispectral analyses in real time, better physical understanding, and (vii) the UV flashes predicted by some theories such as Protheroe and Bednarek 1999 could be detected and studied. The corresponding delays regarding GRBs could serve to study the nature of the sources. This can be addressed only by surveys, not by follow-up devices since the flashes may precede the GRBs (Protheroe and Bednarek, 1999).

2 Feasibility of Independent X-ray Searches

The independent X-ray searches for GRBs require sensitive X-ray monitoring of the sky. The X-ray telescopes in recent use however mostly have field of view (FOV) limited to 1 degree or even less. The recently designed and developed wide-field Lobster-Eye (LE) X-ray telescopes offer one very promising possibility. The FOV of 1000 deg^2 or even more is easily feasible in these devices. The recently developed prototypes of wide field X-ray telescopes of Lobster–Eye type confirm the technical feasibility of such analyses. The first prototypes of Lobster–Eye X-ray telescopes have been designed, developed and tested (Hudec et al., 2000). Both alternative approaches (Schmidt as well as Angel arrangements) of the Lobster– Eye X-ray optics have been considered and designed, resulting in various prototypes. The tests both in optical as well as in X-rays confirm the performance identical with the calculations. One module has FOV of up to 40 deg^2; more can be obtained by arrays of analogous modules. The recently available angular resolution is of order of 1 arcmin in the best case, with potential of further impovements.

The expected rate of GRBs is 1 per day, however the theoretical prediction assumes larger beaming angle in X-rays if compared with gamma rays, hence the actual rate of X-ray afteglows may be larger. The sensitivity of LE telescopes is sufficient enough to detect the recently discovered X-ray GRB afterglows. The localization accuracy of the LE telescopes is of order of 1 arcmin, substantially exceeding the recent localization accuracy of most gamma ray instruments (2 deg and more). The proposed strategy for locating GRBs upon their X-ray fading counterparts is based on a pointed two-dimensional LE telescope with FOV of 12 x 12 deg^2 and a crude positioning instrument like BATSE/CGRO. The LE telescope will be pointed immediately at the GRB crude position and stay on it for $\sim$ 24 hrs, then the sensitivity of $\sim 10^{-14} ergscm^{-2}s^{-1}$ or better may be achieved (0.5 - 3 keV energy range). This is sufficient to localize the fading X-ray GRB counterpart with the accuracy of 1 arcmin or better, as well as to obtain its light curve. The additional science of LE X-ray telescopes includes supernova explosions, high energy binary sources, AGNs, blazars, X-ray novae, X-ray flares on stars, X-ray transients, X-ray flashes etc.

3 Feasibility of Independent Optical Searches

The recent detection of optical afterglows and optical transients of gamma ray bursts allows to consider the optical ground-based independent detection of these phenomena. The optical surveys achieving limiting magnitudes better than 19...23 for stars and/or 10 for 1 min exposures may detect OAs and OTs of GRBs. This opens the possibility of independent optical searches. These searches must be of large field of view and sufficient sensitivity i.e. CCD surveys and/or deep patrol plates are suitable.

3.1 The influence of the beaming

It is expected that sources emit jets from which the gamma ray emission is more beamed than the subsequent optical afterglow radiation due to the deceleration of the jet by the ambient gas and the corresponding decline in its relativistic beaming with time (Rhoads 1997). Because the shift to lower frequencies accompanies the shift to lower bulk Lorentz factor, the minimum solid angle into which the transient can radiate increases with time. A jet geometry hence implies a higher rate of OAs detection. If bursts are highly collimated, the gamma rays will radiate into a small solid angle, the optical light into a larger one, and radio into a still larger one. On the other hand, if the bursts emit isotropically, no OAs unaccompanied by GRBs are expected. The ratio of transients detected hence allows the ratio of the mean solid angle into which transients radiate to be estimated. The GRBs rate is known already, and the OA rate with characteristics typical for the observed OAs can be estimated by present and future sky survey programs.

The number of optically selected OAs could be greater than the number of gamma-ray selected GRBs by a factor of $(\gamma_o/\gamma_a)^2$ where the γ_o is the initial Lorentz factor, the initial gamma-ray emission is beamed to an angle of about $(\gamma_0)^{-1}$ and the afterglow emission is produced when the fireball has been decelerated to a modest Lorentz factor γ_a. Since typical bursts have $\gamma_0 \leq 10^{2-3}$ (e.g. Fenimore et al. 1993, Woods and Loeb 1995) while the optical afterglow emission occurs at $\gamma_a \sim 10^{1-2}$, hence this could boost the expected OAs rates by up to four orders of magnitude (we will call this boosting factor).

3.2 The estimated rates of OAs and OTs in real experiments

The recent digitization of deep sky patrol plates as well as CCD surveys provide valuable input data for these searches.

Optical Transients (prompt emission). The observed rate of GRBs (by BATSE) is about 1 GRB/day. The assumed beaming factor is 1 ... 10 (no more since the time after GRB is small), hence the boosting factor amounts to 1 ... 100. The estimated actual GRB fraction with OTs is 0.01 - 1 (brighter than mag 12). Then the estimated OT rate represents 0.01 - 100 OTs/day for the whole sky sphere, i.e. 2.5 x 10^{-7} .... 2.5 x $10^{-3} deg^{-2}$. Example: astrograph plate (100 deg^2) is expected to exhibit 2.5 x 10^{-5} ... 2.5 x 10^{-1} OTs per plate.

Optical Afterglows (delayed emission). In this case, the assumed beaming factor is 1 ... 100, i.e. the estimated boosting factor amounts to 1 ... 10 000. The actual GRB fraction with OAs (brighter than mag 23) can be, using the events observed so far, estimated as 0.5 and/or 0.05 (OAs brighter than mag 18). Then the estimated OA rate amounts to 0.5 ... 5 000 OAs/day for the whole sky sphere (lim mag 23) or 0.05 ... 500 OAs/day for the whole sphere (lim mag 18). This means 1 x 10^{-5} .... 1 x $10^{-1} deg^{-2}$ (lim mag 23) and 1 x 10^{-6} ... 1 x 10^{-2} (lim mag 18), not in contrast with results obtained by plate searches. Example: UKSTU plate with an area of 41 deg^2:4 x 10^{-4} ... 4 objects per plate (23 mag limit) and/or 4 x 10^{-5} ... 4 x 10^{-1} objects per plate (18 mag limit).

The constraints from observations (Schmidt 1999, Hudec 1999) yield $\leq$ 0.15 events/square degree (lim mag 23) implicating the boosting factor of $\leq$ 10 000 in agreement with the estimates given above. Note however that the background by supernovae (SNe), variable AGNs, variable stars, flare stars etc is higher. Depending on galactic latitude, their integrated rate may achieve $\sim$ 1 000 to 5 000 variable objects per UKSTU plate (lim mag 23).

The important question is hence how to distinguish OAs and SNe (and other background events). The following tools are available: (i) Light curve, (ii) Peak luminosity (only for objects with known redshift), and (iii) Color information. The color indices of the optical afterglows (OAs) of the GRBs represent powerful tool to search for the common properties of these events, as well as an important parameter reflecting the related physical processes (Simon et al., 2000 and 2001). The specific color indices of OAs give a hope to resolve whether the optical event is related to GRB even without available gamma-ray detection. The knowledge of colors of AOs also allows the search for interrelations among the colors, luminosities and the decay rates of the OAs (if z is known).

The recent results of the study of the colors of OAs (Simon et al. 2000, 2001) indicate that: (1) The color variations $((V-R)_0, (R-I)_0, (B-V)_0)$ during the decline of OAs are small for 0.8 days $\leq t - T_0 \leq$ 10 days (Simon et al. 2001), (2) The colors of OAs on the final decline branch concentrate at $(V-R)_0 = 0.44 + / - 0.25, (R-I)_0 = 0.50 + / - 0.25, (B-V)_0 = 0.44 + / - 0.18$ (but large scatter of $(U-B)_0$). This implies the very smooth shape of spectrum of OAs, with no bumps or strong lines within the observed I to B passbands, and (3) Concentration of the color indices implies that the intrinsic reddening (in their host galaxies) must be quite similar for all analyzed OAs (rather small) and that these GRBs are unlikely to come directly from the inner parts of the star-forming regions (maybe on our side of a star-forming region).

4 Conclusions

The X-rays and optical light represent spectral regions where the searches for GRBs seem to be feasible. The rate of GRB triggers detected at these wavelengths may be (significantly) higher than the rate of GRBs recorded in gamma-rays due to different beaming.

Results of analyses and simulations of lobster-eye X-ray telescopes have indicated that they will be able to monitor the X-ray sky at an unprecedented level of sensitivity, an order of magnitude better than any previous X-ray all- sky monitor. Limits as faint as $10^{-12} erg cm^{-2} s^{-1}$ for daily observation in soft X-ray range are expected to be achieved, allowing monitoring of all classes of X-ray sources, not only X-ray binaries, but also fainter classes such as AGNs, coronal sources, cataclysmic variables, as well as fast X- ray transients including gamma-ray bursts and the nearby type II supernovae. For pointed observations, limits better than $10^{-14} ergsec^{-1} cm^{-2}$ (0.5 to 3 keV) could be obtained, sufficient enough to detect X-ray afterglows to GRBs. The first prototypes of both Schmidt as well as Angel arrangements have been produced successfully for the first time, demonstrating the possibility to construct these lenses by innovative but feasible technologies. This makes the proposals for space projects with very wide field lobster eye optics possible.

The recent results of OAs and OTs searches also indicate that GRBs may be monitored and studied by observing their optical emissions, i.e. independently on satellite projects. It is feasible to use the recent and planned ground based optical devices to monitor OAs and OTs of GRBs. These surveys must be of wide field and high sensitivity. There is however a background of false triggers (not related to GRBs but with similar transient behavior) with poorly known statistics (for faint magnitudes). This background is due to supernovae, AGN/QSOs, stellar flares, variable stars, optical transients of unknown origin and non-astrophysical triggers. Nevertheless, tools are available to distinguish the genuine GRB triggers and the background events such as the fading profile and color information. The CCD based devices and telescopes (SLOAN, USNO, ASPA, ROTSE, OTM, BOOTES,...) are suitable for these searches, as well as the digitized plate surveys and digitized deep archival plates (e.g. UKSTU plate collection, Siding Springs Schmidt, 18 000 plates with limiting magnitude 20-23, with different filters/colors).

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