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Synchronous Observations by Ground Based Optical and X-ray Space Born Telescopes

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Abstract. Simultaneous multiwavelength observations are critically important for understanding physical and astronomical properties of many celestial phenomena. We consider simultaneous X- and γ-ray/optical observations of cosmic Gamma-Ray Bursts. An important task of optical transient observation requires continuous wide field telescope surveys. Based on available observations we discuss criteria for development of optical wide-field camera and present the automatic telescope that is being developed for the purpose of simultaneous optical observations of GRB counterparts.

1. Gamma-Ray Burst Afterglow and Optical Prompt Emission

Gamma-Ray Burst (GRB) phenomenon has been studied in γ-rays since 1967 (first publication in 1971) by space born wide field γ-ray detectors. More than 4000 events have been registered. Technology development, onboard GRB source position calculation, rapid information downlink to tracking station and the Internet, allow looking for GRB events worldwide with large optic telescopes. Since discovery of the first optical counterpart of GRB970228 (Guarnieri et al. 1997), more than 30 GRBs optical afterglows were found, and the cosmological nature of the phenomenon is proved. The typical brightness of a detected Optical Transient (OT) is about 18 mag and large telescope response time is about one day. However, response time is decreasing as more telescopes join the GRB Coordinates Network (Barthelmy et al. 1994).

Search for prompt optic emission has lead to creation of a new generation of optical telescopes—fast response wide field cameras, which can be automatically pointed to a GRB error box having been alerted by γ-ray telescopes via the network. However, in only one case was prompt optical emission successfully registered by robotic telescope: GRB990123. ROTSE was alerted via network, started observation 22 s after GRB trigger, and recorded optical emission with a maximum brightness about 8.5 mag (Akerloff et al. 1999).

2. Usefulness of Classical Approach

Even if an alert is generated, transmitted, accepted and responded to in near real time, the alerted system could not effectively record prompt emission if time delay after burst trigger is greater than duration of the burst. And the typical duration of bursts is 10 s. Indeed the necessary time to generate alert depends on brightness of the burst and its time profile in γ-ray domain: e.g., according to current trigger algorithms a slow rise burst will generate alert later than a fast rise burst; some bursts were found only in post flight analysis. Accuracy of GRB source position calculation also depends on brightness and duration of the burst; sometimes ground analysis is necessary to reduce an error-box, which also delays the start of ground based observation.

The class of short bursts and Soft Gamma-Ray Repeaters with specific duration of about 0.1 s cannot be observed by alerted system in real-time. No afterglow from short burst has been detected till now (Hurley et al. 2002). Also the optical emission preceding the burst onset (which is discussed in GRB models (Mezaros et al. 2001, Beloborodov 2001) cannot be detected by alert-based system at all. Now the detection of a prompt emission and possible optical precursor as well as variability investigation of the optical emission is a crucial point in understanding of physics of γ-ray bursts.

3. Requirements for Observation of Prompt Emission

Synchronicity. To effectively observe prompt optical emission one needs to monitor simultaneously the same area of the sky by space-born γ-ray observatories and an optical observatory. While GRB monitors do so regularly (at present the HETE-2 and IPN collaboration, consisting of Konus-Wind, Ulysses, HEND/Mars Odyssey, and GRS/Mars Odyssey, is operating in space), as far as the authors know, no one optical system is continuously monitoring the sky synchronously with space labs.

Independence. Monitoring should be independent, to avoid the need for any alerted transmission in real-time. The full data reduction and correlation with space labs could be done after observation, which additionally decreases the uptime requirements and cost of telecommunication channels.

Time scale. As opposed to the case of afterglow observations, the time resolution for prompt emission search should be near equal or better than the duration of the event. Though time scale of the optical emission may significantly differ from that of the γ-ray emission, one may estimate the specific duration of prompt emission from the only one detected, GRB990123, as 20 s. However, prompt emission duration may be different for different events. On the other hand, variability measurement requires better time resolution. Because the search strategy depends on unknown duration of the OT, and requirements for variability measurement contradict to those for search strategy, one needs to have a continuous set of frames with time exposure better than duration of the event which could be used for subsequent co-adding frames with the aim of increasing sensitivity.

Wide FOV versus sensitivity. The larger the FOV of a telescope, the larger is the probability to have in this FOV an error box of a GRB. On the other hand a more sensitive telescope has better chance to detect OT if the source of a burst is in the FOV of the telescope. In the case of searching, the probability of catch the OT is a function of the two above probabilities. Let us consider a detector with CCD matrix having fixed pixel size and number of pixels. The sensitivity S of the telescope equipped with that matrix is roughly proportional to l, $S \sim l$, where l is a filled size in degrees. (The sensitivity is defined as a detection limit with the same confidence level for the same exposure time.) The larger the FOV, the worse is the sensitivity. The cumulative distribution of OT versus their brightness may be written as $N(>S) \sim S^{-a}$, where N is a number of sources with brightness more than S. (In case of 3-dimensional Euclidean space and uniform distribution of sources it is $N(>S) \sim S^{-3/2}$.) Finally, the number of observed potential sources of OT is proportional to l^2 because of isotropic distribution of GRB. Combining these formulas one can obtain that the number of detected OT is $N \sim l^{(2-a)}$.

Strategy of prompt emission search depends on the parameter a. One can estimate the slope of $N(>S) \sim S^{-a}$ distribution by extrapolating already observed afterglow light curves backward to some standard moment of time after burst onset. The estimation gives $a = 0.7$. Of course this estimation is not fully correct due to possible bias and possible change in a power law index of OT light curve backward to the beginning of the burst. The parameter a could be estimated from theoretical predictions including cosmological nature of GRB, possible evolution of source intensity in cosmological reference frame, beaming optical emission, etc. In this case the a is varying from 0.5 to 1.5 depending on many uncertain suggestions. Because of $a < 2$ a telescope with wider FOV is more preferable.

All sky optical survey, which is widely discussed (e.g., Nemiroff & Rafert 1999; Paczynski 2001) may resolve the problem of GRB optical prompt emission and fast OT search while technological problems and limitations, including financial one, are evident. The most important factor is a large scanning time in comparison with short duration of the OT. To avoid some of the limitations and to increase the probability of synchronous coverage of the same part of the sky we propose to monitor by ground based optical system only “small” part of the sky, in particular the field of view of spaceborn X- and γ-ray telescopes. The data obtained by space lab and ground based observatory will be correlated later for joint search of transients. This approach has been already discussed (Beskin et al. 1999).

Taking into account the above requirements we have developed a low cost wide field camera ($15 \times 20^\circ$) with relatively high time resolution (0.13–10 s) which will be able to monitor FOV of current and future X-ray telescopes, in particular Wide field X-ray Camera (WXC) of HETE-2. The main components of the optical camera are: (1) Main objective: focal length 180 mm, aperture diameter 150 mm; (2) Image intensifier: photocathode S25, quantum efficiency 0.1; input fiber optic window D=80 mm, output glass window, scaling factor

4.5:1; amplification coefficient 120; (3) Adapting objective: constructed from two commercial objectives AVENIR SE2509; (4) CCD camera: commercial TV-CCD camera equipped with SONY 2/3″IXL285 matrix, 1380 × 1024 pixels, variable exposure 1/7.5–10 s, readout noise 20 e^-/pixel.

To obtain wide FOV and to use the low cost commercial CCD matrix we use image intensifier for both image scaling and compensating light loss in adapting objective. The FOV of the camera is 20°, and the spatial resolution of the system is about 50 arcsec/pixel. The spatial resolution in fast observation is less important because the precise localization can be done later by observations of the afterglow with large telescopes. Because of large readout noise of TV-CCD the sensitivity of the camera is restricted by the noise at minimum exposure time and by sky background at maximum exposures. The modeled detection level of the system is about 12.5 mag at 0.13 s exposure and about 14 mag at 1 s for a dark night. The prototype of the camera (TT600 telescope of Kosmoten observatory) is now being used for current alerted observation of GRB afterglow.

The software includes frame comparator in video processor for ion and particle events elimination, storage system management, and a buffer for frame accumulation. Frame will be accumulated in different time windows and compared in real time. According to predefined criterion the system can generate alert in case of bright transient detection. This part of the system is similar to a usual trigger scheme of γ-ray burst detectors.

We estimate the rate of successful simultaneous observation of GRB error-box with WXC of HETE-2 as 1.6 per year. More events will be investigated after correlation of weak bursts which occur in FOV of WXC but not sufficiently intense for source coordinates calculation. The same time-spatial correlation of events registered in our camera with HETE and time correlation with space born GRB detectors may help to resolve the problem of absence/presence of OT from short bursts and problem of possible GRB-orphans (GRBs which are not observed in γ-rays).

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