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The importance of multispectral band observations of Gamma–Ray Bursts

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Abstract. Gamma–Ray Bursts are one of the best examples to show how multiwavelength observations can help in our understanding of the universe. Gamma–Ray Bursts were a mystery for more than thirty years, during which they could be observed only in the hard X–ray/soft γ–ray band. Nowadays, bursts are observed from the gamma–ray to the optical frequencies and a completely new phenomenon, the afterglow, is observed down radio frequencies. This extension of the band led to a much deeper understanding of the bursts. The importance of the multiwavelength observations that drove us to our present understanding of the bursts will be shown, as well as the possible new observations that are foreseen to clarify some obscure points of the burst and afterglow astrophysics.

Key words: Gamma–ray bursts

1. Introduction

Gamma–Ray Bursts (hereafter GRBs) have puzzled astronomers for more than thirty years. The main reason for this difficulty in their understanding was that the bursts could be observed only at gamma–ray energies, and only for the few seconds of their duration. For this reason it was not even possible to measure their distance, and hence their energy budget. This led to the development of an enormous number of different theories, with the burst emission associated to nearby events, happening in the solar system itself, or to cosmological phenomena, with the burst located at the edge of the observable universe. Thanks to the breakthrough of the Italian–Dutch satellite *Beppo*SAX (Boella et al. 1997), we now observe the burst and their afterglows in the whole electromagnetic spectrum. For this reason, we now know much more about GRBs and their astrophysical properties.

In Sect. 2 our present understanding of GRBs will be described, underlining the importance of multiwavelength observations. In Sect. 3, I will describe some open questions and how they can be addressed in different observational bands.

2. History

Since their accidental discovery made by the Vela satellites (Klebesadel et al. 1973), GRBs have been observed by a variety of experiments in gamma–rays for more than thirty years. Among these experiments, the most important was BATSE, on board the *Compton*GRO satellite. BATSE observed the largest sample of GRBs known so far, in an energy ranging from few keV up to $\sim$ 1 MeV. The two more important results obtained by BATSE were the isotropy of the GRB explosions in the sky and their inhomogeneity (see the BATSE catalog and references therein: Paciesas et al. 1999). BATSE, in fact, showed that the 2702 events detected are one of the most evenly distributed samples in the sky. On the other hand, the distribution of the peak fluxes does not follow the Euclidean $-3/2$ slope, showing that the GRB events are not uniformly distributed in distance. This may be due either to the fact that GRBs are a local phenomenon or, or the contrary, that they are at cosmological distances. In the latter case, the non homogeneity of the sample is due to the variation of the proper volume of the universe with redshift. For this reason, after several years of BATSE observations, two leading models for the description of GRBs were available: galactic GRBs, related to phenomena taking place on the surface of neutron stars, and cosmological GRBs. In addition, the observations of BATSE showed the necessity of relativistic motions taking place in order to override the compactness problem (see Piran 1999 for a review), defining the so–called "fireball model".

After the launch of the Italian–Dutch satellite *Beppo*SAX, the situation changed dramatically. *Beppo*SAX, in fact, was capable to observe the burst in soft X–ray with a coded mask camera, localizing it in real time within a circle of several arcminutes. In a few hours, in addition, the satellite was moved, pointing the narrow field instruments (MECS and LECS, hereafter NFI) to the GRB position. These X–rays telescopes, with a much higher sensitivity, detected for the first time X–ray emission coming from the GRB location in the sky, $\sim$ 6 hours after GRB 970228 (Costa et al. 1997). This emission, predicted in the framework of the fireball model (Meszaros & Rees 1997), is now known to be a very common feature of GRBs and called "afterglow". In addition to the discovery of the X–ray afterglows, the NFI provided the optical community with a position for the afterglow with an accuracy of $\sim 1'$, enabling to point the bigger optical telescopes looking for an optical transient associated to the GRB. This led to the discovery of the optical afterglow (van Paradijs et al. 1997) and, subsequently, of the radio afterglow (Frail et al. 1997). These observations were a dramatic confirmation of the fireball model (Wijers et al. 1997), even allowing for the measurement of the fireball radius (Frail et al. 1997), but still the distance of the bursts was unknown.

Few months later, *Beppo*SAX was triggered by GRB 970508. An X–ray and an optical afterglow were detected and a series of absorption features were discovered in the spectrum of the optical afterglow. These features were consistent with absorption by an intervening galaxy at the redshift of $z = 0.834$ (Metzger et al. 1997). There are now more than 20 measured GRB redshifts, both from absorption and emission lines, and all are cosmological, ranging from $z = 0.43$ (GRB 990712, Vreeswijk et al. 2001) to $z = 4.50$ (GRB 000131, Andersen et al. 2001), with the exception of GRB 980425, possibly associated to SN1998bw, at redshift $z = 0.008$ (Galama et al. 1998).

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Since the beginning of the "afterglow era", several dozens of GRBs have been detected and analyzed, giving us more insight in the GRB physics and support to the fireball internal/external shock scenario (Piran 1999). In the January of 1999, a particularly bright burst was detected by BATSE and *Beppo*SAX simultaneously and, only 12 seconds later, by a robotic optical telescope (ROTSE). ROTSE detected an optical transient associated with the prompt emission of GRB 990123, reaching the peak magnitude $V \sim 8$ 42 seconds after the GRB trigger (Akerlof et al. 1999). This optical emission is now interpreted as the consequence of the shock driven by the interstellar medium in the fireball (Sari & Piran 1999) and is a further confirmation of the fireball model.

3. Future Prospects

Despite the quantity of data from the broad band follow–up of bursts and afterglows, still some basic questions of the GRB astrophysics are open.

The progenitor The first obscure point in the GRB picture is the nature of the progenitor, i.e. the astronomical object that produces the explosion and the fireball than we then observe as a GRB. Two competing model exist. In the first model, the GRB explosion is due to the collapse of a binary system made by two compact objects: two neutron stars or a neutron star and a black hole (Eichler et al. 1989). In the second model, the burst explosion is associated to the final evolutionary stages of massive stars, which produce the GRB instead of (or simultaneously with) a supernova explosion (Woosley 1993, Paczynski 1998). The two models cannot be distinguished by means of the GRB properties, since the fireball completely erases the properties of the engine that generated it (Piran 1999). It was however realized that the two types of progenitors produce GRBs in very diverse environments: low density interstellar medium in the first case and dense star–forming clouds for the second. With the information that comes from multiwavelength observations of the afterglows, we have now many indications of the association of GRBs with dense regions and star forming galaxies. In fact, host galaxies are detected in many of the bursts with optical afterglow and some of them show evidence of enhanced star formation (Hogg & Fruchter 1999). In addition, some bursts have fast decaying afterglows, which can be interpreted as due to the fact that the fireball is expanding in a stellar wind instead of a uniform molecular cloud (Chevalier & Li 1999).

Recently two crucial observations seem to firmly establish a link between the bursts and Supernovae (SNe). It has been observed that in some optical afterglows, after an initial phase in which the lightcurve strictly follows the fireball prediction, the optical transient decays slower than expected. In GRB990326 (Bloom et al. 1999) and in GRB 970228 (Reichart 1999; Galama et al 2000), a rebrightening was observed $\sim$ 30 days after the GRB explosion. This rebrightening is consistent with the contribution of a type Ic SN that exploded simultaneously with the burst. In the X–ray band, on the other hand, iron emission lines have been discovered in several afterglows (Antonelli et al. 2000, Piro et al. 2000). These lines can be produced only if the GRB is exploding in particularly dense regions, metal enriched and close to the burst (Lazzati et al. 1999a), like young supernova remnants (Vietri & Stella 1998). The explanation of these lines raised a controversy between the possibility of producing them with simultaneous star and burst explosions (Rees & Meszaros 2000) or with a two step explosion (Vietri et al. 2001), with the burst following the SN with several months of delay. More recently, an absorption feature has been detected in the X–ray prompt emission of GRB 990705 (Amati et al. 2000). This feature, if confirmed, would necessarily imply a dense iron enriched medium at few light days from the GRB (Lazzati et al. 2001a). Such a scenario would however conflict with the supernova signatures in the optical lightcurves described above, which require a simultaneous GRB and SN explosion. More optical and X–rays observations are needed to clarify this point.

The burst emission mechanism There is a general consensus that the afterglow emission is due to synchrotron process (Meszaros & Rees 1997), supported by the afterglow spectra and lightcurves (Panaitescu & Kumar 2001) and by the detection of linear polarization (Covino et al. 1999). For the burst proper, the radiative mechanism is much less clear, and spectral problems with the synchrotron interpretation have been underlined (Ghisellini et al. 2000). Alternative processes have been proposed, such as Compton drag (Lazzati et al. 2000) and quasi–thermal Comptonization (Ghisellini & Celotti 1999), but there is not a unique scenario capable of explaining al the burst properties without a particular fine–tuning. Particularly interesting is the spectral shape in the hard gamma–ray (from hundreds of MeV to TeV), which is observationally poorly constrained. Some models that can explain the flat spectral index at low energies (e.g. the Compton drag), have difficulties in accounting for the GeV emission detected by EGRET in several bursts (Hurley 1994). Further observation, in particular in the gamma–ray and hard gamma–ray bands are required in order to clarify this open issue.

Beaming and energetics Despite we know now the redshift of many GRBs, and we know their luminosity distance, yet the total energetics of the burst is unknown by at least a factor of 100. This undertainty is due to three facts. First, we do not know the bolometric correction that we should apply to the measured flux in the soft gamma–ray band. If the marginal detection of a GRB in the TeV domain should be confirmed, the bolometric correction may be as high as an order of magnitude (Atkins et al. 2000). Second, we do not know the fraction of the kinetik energy of the fireball that is radiated. In the framework of internal shocks, this fraction may be very small (Lazzati et al. 1999b). Third, the lightcurves of many afterglows indicate that the GRB fireballs are beamed, with beaming factors as high as 1/100 of the sky (Sari et al. 1999).

Dark afterglows Even though almost all the bursts detected by *Beppo*SAX were associated with an X–ray afterglow (with the exception of GRB 990217), only ~ 40% of them have been detected in the optical (Lazzati et al. 2001b). This is not due to a shallower detection limit of the searches. The missing optical afterglow may be caused by an intrinsic weakness of the optical emission or may be undetectable because of dust absorption. The high required extinction would be an indication of the association of GRBs with molecular clouds (Paczynski 1998). Even though Galactic molecular clouds are not dense enough to obscure such a high number of afterglows (Lazzati et al. 2001b), it is possible that many GRBs explode in particularly obscured galaxies, such as the SCUBA galaxies (Ramirez–Ruiz et al. 2001) and that modification in the dust extinction curve increase the dust obscuration at high redshifts. In the case that the failed afterglow bursts are indeed intrinsically optically poor, this peculiarity has still to be understood and theoretically explained. In the other case, GRBs are extremely good probes to study the amount of obscure star formation in the universe and, thanks to their detectability at high redshift, to investigate the very high redshift universe (Lamb and Reichart 2000, Lazzati et al. 2001c). In any case, infrared and submillimeter observations are required in order to penetrate the dust obscuration and the Lymanα absorption trough.

Short bursts

Before going to the conclusion, it is mandatory to mention that all the results of multiwavelength observations described in this paper are related only to the subclass of long GRBs. GRBs, in fact, are divided in long and short on the basis of their gamma–ray duration. Bursts shorter than $\sim$ 2 seconds are considered short, while bursts longer than $\sim$ 2 seconds are considered long. Because of the triggering criteria on board the *Beppo*SAX satellite, only long bursts have been observed in the multiwavelength domain. With the HETE2 satellite, which is flying in these days, we hope to bridge the hole and to let also the short bursts in their multiwavelength era.

4. Conclusions

In the last three years the GRB fields made a quantum jump, entering the multi–wavelength domain. This vastly increased our understanding of the bursts. The X–ray observations allowed us to localize the bursts and confirmed the fireball model. Optical observations, possible only after the X–ray localization, allowed us to measure the distance of the bursts, settling a thirty years old debate: GRBs are at cosmological distances. Radio observations, in addition to their support to the fireball model, allowed us to measure the size of the fireball and confirm its relativistic expansion. Multiwavelength data, all together, allow us to model the fireball geometry and structure, do constrain the beaming angle, as well as the properties of the medium in which the bursts explode. This ambient medium, on the other hand, is the best indication of the nature of the burst progenitor. The ambient medium can be investigated also through prompt X–ray spectroscopy, enabling to understand its origin. For all these reasons, it is very important to expand the wavelength coverage of the burst and afterglows, both from the ground (radio, submm, infrared, optical, TeV) and from dedicated satellites, such as HETE2 and, in particular SWIFT, which will carry optical, UV, X–ray and soft gamma–ray instruments.

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