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Gamma-ray bursts and the future gamma-ray missions

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Abstract. Gamma-ray bursts (GRBs) are short and intense pulses of γ-rays arriving from random directions in the sky and represent the most luminous electromagnetic explosions in the universe. They produce long–lived emission across the electromagnetic spectrum, from the X-ray band through optical to radio wavelengths. They are also potential emission sources of ultra-high energy cosmic rays, high-energy neutrinos, and gravitational waves. As stellar scale events located at cosmological distances, GRBs allow us to study the interstellar, galactic, and intergalactic medium as well as the first stars population and cosmology. I give here a short and partial report of our current understanding of GRBs and discuss the impact of the next generation of gamma-ray satellites AGILE and GLAST on GRBs science.

Key words. Gamma: observations – Gamma: gamma-ray bursts

1. Introduction

GRBs are among the most interesting sources in the universe because of the large number of fundamental information, useful to the different branches of the astrophysical research, which can be obtained studying a single class of objects. They involve stellar-scale events located at cosmological distances and their study is related to that of stellar structure and evolution, supernovae and supernova remnants. The GRBs allow us to derive important information about the properties of the interstellar, galactic and intergalactic medium and about the global star forming history of the universe. High redshift GRBs would allow us to study the earlier epochs of the universe. They could also shed light on the origin of the of ultra high energy cosmic rays and their high energy neutrinos emission may be observed by the ground detectors (e.g. ICECUBE and KM3). The gravitational radiation that may be released by a GRB may be observed for a close-by event by VIRGO, LIGO and in future by LISA. Furthermore, they are sources of both GeV and low energy radiation, and are variable on short time scales, a comparison of time of arrival of photons at different energies from a GRB could be used to test the quantum gravity measuring the arrival time difference between high and low energy photons (Amelino-Camelia et al. 1998).

The growing amount of observations and theoretical studies are opening the way to understand the physical origin and characteristics of GRBs as well as raising new questions and puzzles such as the origin of the high energy emission from GRBs observed, in the GeV band, by the Energetic Gamma-

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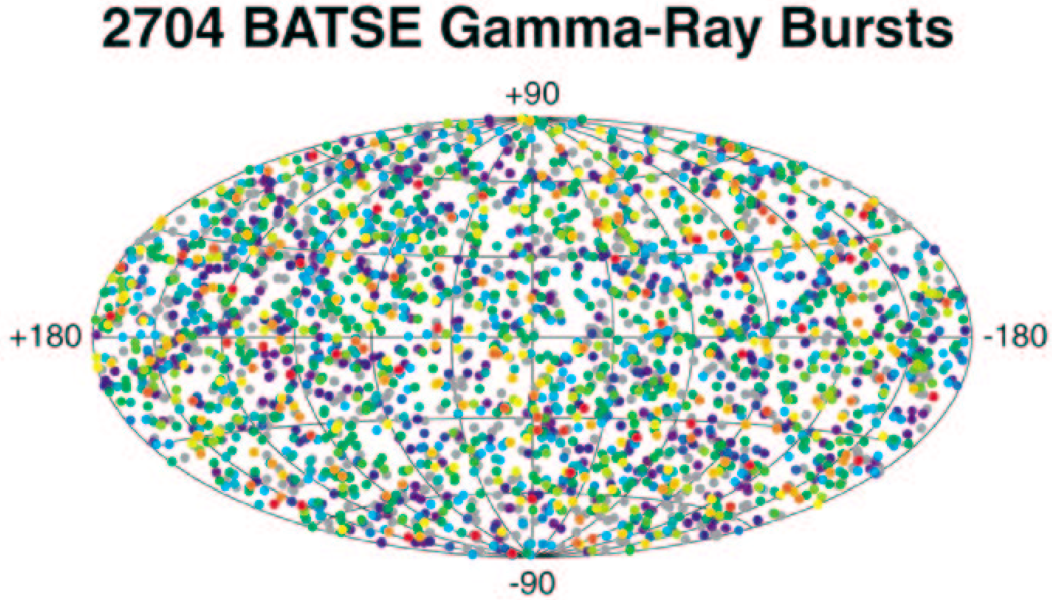

Fig. 1. The spatial distribution of the GRBs detected by BATSE

Ray Experiment Telescope (EGRET) aboard Compton Gamma-Ray Observatory (CGRO).

I give here a short and partial report of our current understanding of GRBs and discuss the impact of the next generation of gamma-ray satellites AGILE and GLAST on GRBs science. For very complete reviews on GRBs researches the interested reader can consult the articles by Fishman & Meegan (1995); Piran (1999, 2005); Zhang & Mészáros (2004); Zhang (2007) and the references cited in these papers. In section, §1 the observational and global properties of GRBs are first reported, while the physical models of GRB emission mechanisms and progenitors are discussed in §2. In §3 the possible contributions of the future gamma-ray mission AGILE and GLAST to the study of the GRB phenomenon are briefly discussed.

2. Multiwavelength observations of GRBs

GRBs were first discovered in 1967 in the energy range of 0.2–1.5 MeV by the *Vela* satellites, 1973 (Klebesadel et al. 1973). Subsequently, the gamma-ray missions *Venera* 11–14, *Solar Maximum Mission*, *Pioneer Venus Orbiter* and *Ginga*, detected hundred GRBs. These observations showed the diversity and variability of the burst light curves, the existence of events lasting less than a second and power-law like spectra.

The Burst And Transient Source Experiment (BATSE) aboard the CGRO satellite, was designed to detect GRBs and study their temporal and spectral characteristics with a greater resolution than the previous experiments. BATSE detected GRBs at a rate of about 1 per day. The thousands of GRBs observed by BATSE were isotropically distributed (Fig. 1), strongly suggesting their cosmological origin. The distribution of the durations of the bursts observed by BATSE is bimodal with a typical values of 20 s for long bursts and 0.2 s for short bursts. The light curves are very irregular and with a different number of apparently distinct and generally asymmetric pulses having different widths (milliseconds or less). For the majority of the bursts, the continuum non-thermal spectra is well described by a smoothly-joining broken

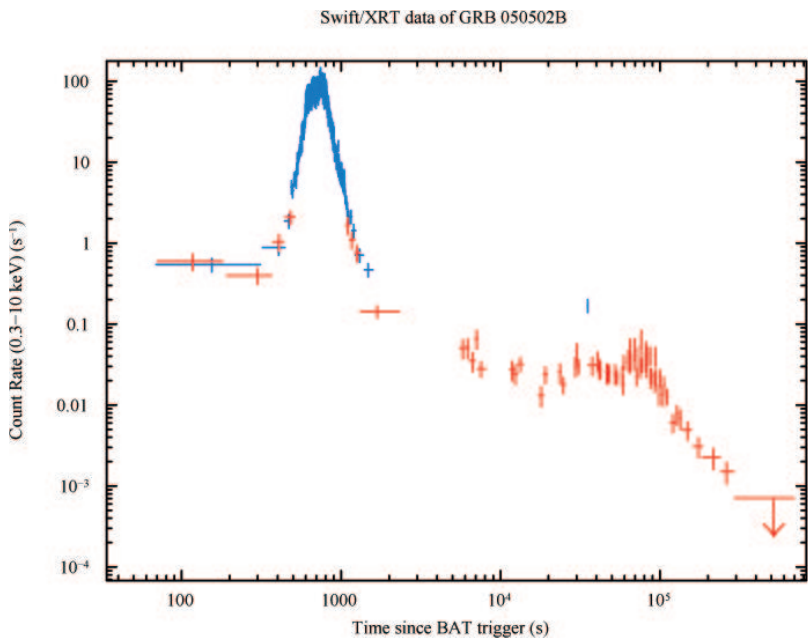

Fig. 2. Swift XRT curve for 050502B

power law, the "Band-function" (Band et al. 1993).

In the 1997 the *Beppo*SAX satellite detected for the first time the X-ray afterglow after some hours from a prompt GRB emission detected by BATSE (GRB 970228, Costa et al. 1997). The accurate position provided by *Beppo*SAX allows the measurement of the redshift for GRB 970508. This confirmed the cosmological origin of the GRBs.

Long GRB afterglows were observed (several hours after the gamma-ray detection) in the X-ray, the optical/infrared and the radio bands. In each band, the light curve shows a temporal power-law decay behavior. The initial rising branch of the light curve was detected for the first time in the optical in GRB 990123 by the ROTSE robotic telescope (Akerlof et al. 1999). This remarkably bright optical flash, combined with the redshift of $z \geq 1.6$ measured from the afterglow observations for this event resulted in a total isotropic emitted energy estimated to be $> 10^{54}$ ergs. This enormous energy raised some concerns, and contributed to the recognition of the idea that GRBs emission may be collimated.

The X-ray and optical light curve of some afterglows showed a break or steepening, which is supporting the idea that the GRB emission is collimated in a jet outflow. In this scenario the break occurs when the edge of the jet becomes visible. The introduction of the jet in the GRB structure has the advantage to reduce the total energy flux needed to explain a GRB from $\sim 10^{54}$ to $\sim 10^{51}$ ergs. Another important discovery was the association of the GRB980425 with SN1998bw, a peculiar Type Ib/c supernova. However, about the 40% of the X-ray afterglows were not detected also in the optical. This raised the question about the origin of these "dark" GRB.

The HETE-2 satellite characterized a new class of sources called X-ray flashes (XRF) that were already discovered by *Beppo*SAX and allows the first well established connection between a GRB and a supernova (GRB 030329/SN 2003dh at $z = 0.168$).

A new era in GRBs study started with the Swift satellite (Gehrels et al. 2004), launched

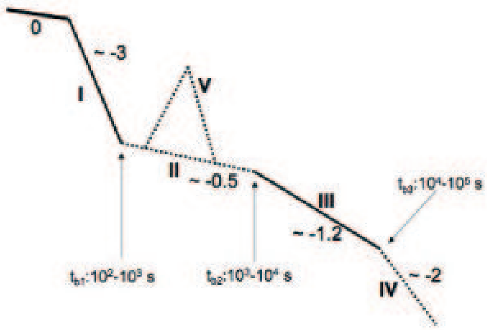

Fig. 3. A schematic X-ray GRB light curve

in November 2004. Swift is able to localize the afterglows emission starting from minutes after the burst, during the transition phase from the prompt to the afterglow emission. The satellite has onboard three instruments: the wide-field Burst Alert Telescope (BAT), which detects bursts and provides an approximate position and two narrow-field instruments: the X-ray Telescope (XRT) and the UV/Optical Telescope(UVOT).

Swift is detecting GRBs at a rate of about 2 per week, of these about the 90 % were detected by XRT and followed within less than about 5 minutes from the trigger (see, e.g., Fig. 2), while about the 30% were detected also with UVOT.

An important results from Swift was the detection of the long burst GRB 050904 at $z = 6.29$ that is at end of the "dark ages" of the universe, when started the reionization of the intergalactic medium. On average the redshifts of the GRBs detected by Swift are higher than those detected by *Beppo*SAX.

Another of the major discoveries of Swift is the identification of a new multi-component X-ray afterglow paradigm. In general all the light-curves can be composed of several or all of the five component reported in Fig. 3, of these only component III and IV were detected in the pre-Swift era. One of the more intriguing new feature present in the GRB light curve is the possible presence of one or multiple flares (component V in Fig. 3, see also Fig. 2) during the decay phase. The origin of this component as well as that of the components I and II is still unclear. A new question raised by Swift concerns the origin of the late GRB afterglows temporal breaks both achromatic and chromatic. Also, Swift discovered and characterized the short GRB afterglows, which allowed the identifications of host galaxy shedding light on the possible progenitors.

Physical models attempt to explain two main aspects of GRBs: what creates the non-thermal prompt gamma-ray and afterglow emission, and what is the source of their energy.The most widely accepted GRB model is the fireball-shock model (see, e.g. Rees & Mészáros 1992).

3. GRB physical models

In this model the GRBs are associated to the gravitational energy (roughly a solar rest mass) released by a catastrophic stellar event, e.g. the collapse of the core of a massive star. The release of this large amount of energy in a very compact volume (as inferred from the sub-second variability timescales of the burst and causality arguments) would give rise to a very high energy density region having a large optical depth to pair production and to the creation of a γ, $e^{\pm}$ and baryons "fireball" which in turn, would trigger a super-Eddington expansion of the fireball material. However, such a source cannot emit non-thermal emission (compactness problem). This problem can be solved assuming that the source is moving relativistically towards the observer, otherwise the GeV emission of GRBs, well above the pair-production threshold energy (0.5 MeV), should not be observed. If the ejected relativistic flow is not moving uniformly, different shells would have different velocities and shocks can form when two shells collide (internal shocks process, see Fig. 4). The shocks, which to bypass the causality and the compactness limits must be extremely relativistic (Lorentz factor $\Gamma > 100$), convert kinetic energy in internal energy of accelerated particles, which in turn emit the non-thermal observed gamma-rays (prompt) emission. As the shells keep travelling outward, they encounter the interstellar medium and go through another

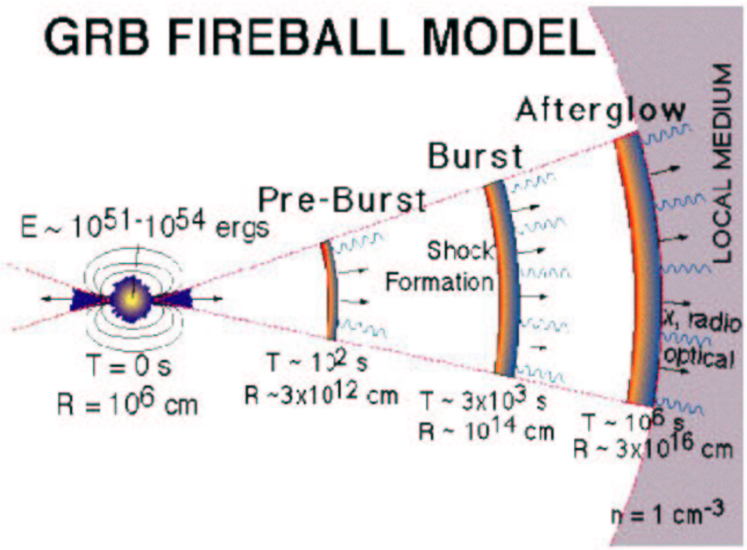

Fig. 4. A schematic view of the Fireball model

series of shocks (external shocks) responsible for afterglow emission. The emission process for both the prompt and the afterglow is synchrotron.

Concerning the GRB progenitors, the leading model is a collapsing massive star (hypernova or collapser for long GRBs), and a binary neutron star merger or neutron star black hole merger for short GRBs. Long GRBs (associated to SN Ib/c) are usually observed in young star-forming galaxy while short GRBs were observed in elliptical, irregular and star-forming galaxies.

The continuous stream of data coming from the space- and ground-based facilities are confirming the general features of the currently accepted GRB model. However many questions about both emission processes and progenitors are still opened (see e.g. Zhang 2007).

4. GRB and the AGILE and GLAST missions.

Our current understanding of GRBs derived mostly from multiwavelength observations. A further progress in GRB science is thus expected from the high energy data that will be provided by AGILE and GLAST. High energy emission was detected by EGRET in five GRBs coincident with triggers from the BATSE instrument. Although most of these detections are consistent with a Band spectrum extended to high energies, a distinct high energy component was reported in the time-dependent spectra of GRB 941017 (Gonzalez et al. 2003). An exceptional and unique event was recorded in GRB 940217. This GRB was detected by EGRET independent of BATSE trigger, with a delayed ($\sim$ 1.5 h, Fig. 5) emission and the highest energy photon of 18 GeV (Jones et al. 1996). The high energy photon can be emitted by GRBs both during the prompt and the afterglow phases. In the external shock model high energy photon can be emitted during the early afterglow phase via synchrotron and synchrotron self Compton (SSC) emission by shock accelerated relativistic electrons and protons. The proposed high energy photon emission mechanisms in the internal shocks are electron synchrotron emission, SSC of electrons, synchrotron emission of protons, photon production through π^0 decay produced

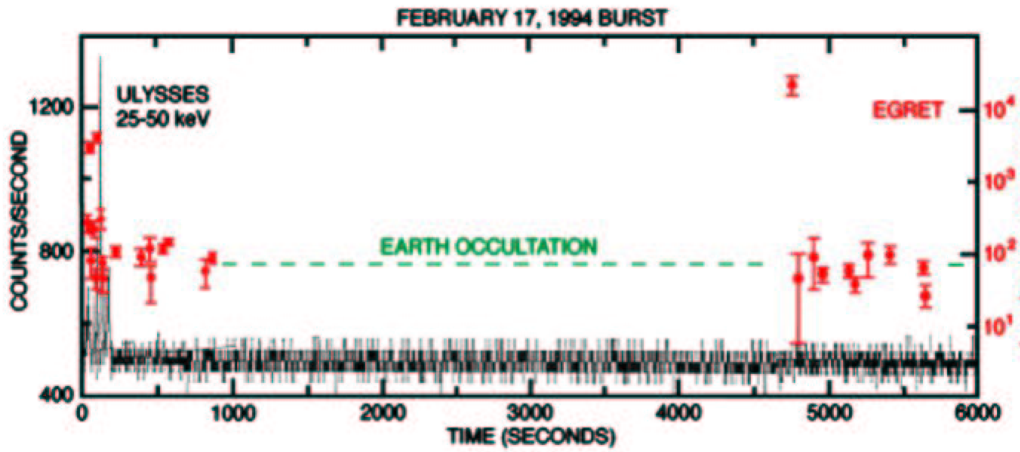

Fig. 5. The EGRET light curve of GRB 940217

in proton–photon interactions and radiations by secondary positrons produced from π^+ decays. All this models can constrained by the AGILE and GLAT data.

AGILE (Tavani et al. 2006) is an Italian Space Agency (ASI) mission launched on April 23, 2007. AGILE has a good angular resolution at γ-ray and X-ray energies and a large field of view (2.5 sr above 30 MeV, and 1 sr at 20 keV). The AGILE instruments are the Silicon strip detector for γ-ray imaging in the energy band 30 MeV – 50 GeV (the Gamma-Ray Imaging Detector, GRID), and the hard X-ray imager (Super–AGILE), sensitive in the 15–45 keV energy band (see *http://agile.iasf-roma.inaf.it* for more details). The GRB detection rate by the AGILE-GRID is expected to be at least a factor of ~5 larger than that of EGRET, i.e., 5–10 events/year). Super-AGILE will be able to locate GRBs within a few arcminutes, and will systematically study the interplay between hard X-ray and gamma-ray emissions.

The Gamma-ray Large Area Space Telescope (GLAST, Gehrels & Michelson 1999) is a new gamma-ray observatory scheduled to be launched in late 2007. It contains two instruments: the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM). The LAT will detect celestial gamma-rays in the energy range from ~20 MeV to 300 GeV with angular, energy, and time resolution that are substantially better than EGRET. GLAST will open a new window on the gamma-ray sky, exploring an uncovered region of the electromagnetic spectrum (10 GeV). GLAST–GBM is expected to detect ~200 bursts per year, of these > 60 suitable for LAT observations. GLAST–LAT will independently detect ~100 bursts. Joined LAT and GBM observations will allow us to study the relationship between GeV and keV-MeV emissions, a key point for investigating also fundamental questions on GRBs.

Therefore, in the next years the partnership among Swift AGILE and GLAST would open a new era for GRB science.

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