Mem. S.A.It. Suppl. Vol. 9, 351

Memorie della
Supplementi

Gamma Ray Bursts and recent Swift Results

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Longum Iter est per praecepta
Breve et efficax per exempla
Seneca

Abstract. Due to the large activity we had during these last months with the Swift satellite I started the writing of the presentation I gave at the SAIt Catania meeting only in the middle of September. The Swift satellite, however, never rested. Since then and in addition to the results I showed at the meeting in relation to the early and steep light curves observed with the XRT telescope in the 0.2 – 10 keV band, we had fundamental discoveries among which the detection and localization of short bursts and the detection of the largest redshift ever. It obviously would be improper to discuss here the most recent results but it would also be silly in such a fast evolving topics where the day by day observations show excellent results and the observer is far ahead of the theoretician, to write an article that, from the observational point of view, would be completely obsolete. The best approach here seems to be a brief description of what was presented during the meeting briefly mentioning also some of the most recent results. We remind the reader, however, that a copious literature written, and in preparation, exists so that we urge the reader to refer to the specialized articles.
This brief article will touch on the basic characteristics of the Gamma Ray Bursts (GRBs) in the Introduction (section 1) and illustrate the basic characteristics of the Swift mission in section 2. Preliminary science results will be discussed in section 3 and finally we will mention one, among many, of the main goal we plan to achieve in Cosmology via the observations of very distant GRBs.

Key words. Gamma Ray Bursts – High Energy Astrophysics – Stellar Evolution – Cosmology

1. Introduction

After the discovery by Beppo Sax that GRBs are extragalactic objects, it became clear that the energies involved were extremely high in spite of the fact that an asymmetric emission would decrease the energy, computed under the assumption of isotropy, by a large factor. The energy emitted within a few seconds by these

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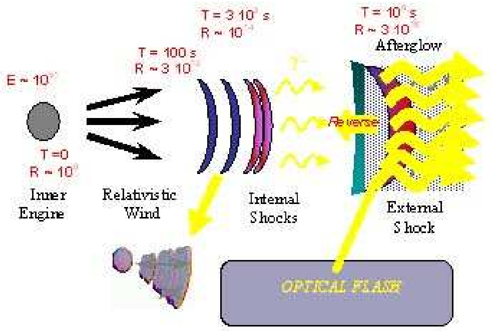

Fig. 1. Cartoon illustrating the evolution of the relativistic jets emitted by the central engine. The internal shock is believed to generate the prompt emission while the afterglow is due to the external shock following the impact of the jet with the surrounding medium, either ISM or stellar wind. The reverse shock may be related tooptical emission via inverse Compton radiation.

objects is of the order of 10^{51} 10^{52} erg Frail et al. (2001). These large energies put very strong constraints on the central engine. The only way to produce in a short time such high energies is via gravitational accretion into degenerated matter, Black Holes in particular. The observed burst as detected in the hard X ray and gamma ray pass-band is rather well understood under the fireball model proposed by Meszaros and Rees (1993). To solve the compactness problem we must invoke high relativistic motion (Paczynski (1986); Goodman (1986)). The emission of a large amount of energy on a short time scale calls for a large optical depth and all photons would have created pairs and thermalized. The observed GRB spectrum is however highly non thermal (see the excellent review by Piran et al. (1999)). In brief the concentration, in a 10^7 cm radius sphere, of large amount of radiation with a very small amount of baryons calls for a relativistic flow (Goodman 1986). The existence of relativistic jets was later observationally proved by radio observations of the Burst GRB970508 (Waxman et al. 1998). Relativistic shells with Lorentz factor about $\Gamma = 100$ move at different relativistic speed and when they clash we have the so called internal shock and the emission of the gamma radiation we observe, in the prompt emission. Subsequently the jets impacts, external shock, the external medium, either composed by material left over from the early evolution of the progenitor or by the ISM of the host galaxy and we observe what is generally known as the afterglow, Figure 1. The observations obtained during the Beppo Sax era characterized the afterglow as a mild and rather regular decay at all wavelengths, X band included. Observations of the afterglow except of a very few cases, generally started only 3 to 4 hours after the discovery of the burst. A late bump in the optical light curve was later identified as the possible signature of the presence of a supernova (Galama et al. 1998; Malesani et al. 2004). Finally detailed observations of GRB 990123, especially by the ROTSE telescope that got to the burst before the maximum, clearly showed that the peak emission occurs at different times for the various wavelengths (Akerlof et al. 1999). The detection of optical light during the prompt emission may be due to the reverse shock and the generation of inverse Compton radiation. More recently following the detection of a burst by Swift, such radiation was detected by Vestrand et al. (2005) and Blake et al. (2005). All this set of information due to the excellent theoretical work and unique observations at all wavelengths triggered by the detection of bursts by various satellites and primarily by Beppo SAX, formed the guidelines or the conceptual design of the Swift satellite and for the design of the follow up strategy that was also prepared and tested before launch.

2. The SWIFT Mission

The main ingredients in designing the mission have been therefore accurate astrometry, multiwavelengths capability (Swift cover the range from 200 keV to 6000 Å), fast positioning on target and accurate tracking, excellent and real time communication network.

The great success of Swift, however, is not only due to the excellent instrumentation and state of the art spacecraft but also to the structure and organization that was imparted to the mission by the Executive committee we had during the study and construction phase, Gehrels (PI and chair of the committee), Chincarini, Giommi, Mason, Nousek, Wells, White. The mission consists of a satellite with state of the art payload that will be briefly described below. A data and command transmission network that is very efficient and consists of the NASA Tracking Data Relay Satellite System (TDRSS) for the immediate download and command upload transmission and of the Italian ASI ground segment at Malindi (Kenia) for the routine data download and command upload. A International team of technician and scientists take turns and have a world wide alert notification system as to know at any time what is going on with the satellite and the data and this group of scientists is ready to interpret the first information on real time. Furthermore large telescopes and teams of scientists all over the world are organized in such a way that following the alert given by the satellite and the Swift Team, they are in matter of minutes ready to point the ground based telescopes either in a robotic way or following a semiautomatic procedure. The European Southern Observatory (Chile), to make an example, has the capability to be on target with a VLT telescope, 8.2 meter of aperture, in about 7 minutes following the alert triggered by the astronomer in charge anywhere in Europe. Also in this case European teams take turn to be always on call and be ready to check and trigger the follow up observations. Trigger, furthermore, may be also send to other facilities and orbiting telescopes but these generally do not have, except for the high energy ground based facilities as MAGIC, to react in real time so that any programming is more relaxed. Indeed it is also this magnificent and very efficient International collaboration that is capable to produce the results we are witnessing and it is my opinion that such collaboration has also profound meanings that go beyond the technicalities of the today research.

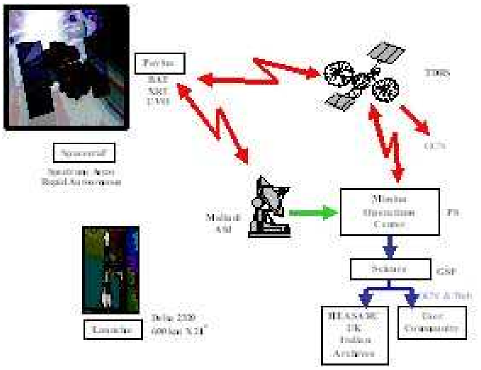

Fig. 2. Following the detection of a burst the onboard computer send the results of preliminary analysis to the Mission Operation Center at PSU via the TDRSS. Urgent commands are up loaded via the same satellite. The data and the ordinary sequence of commands are down up-loaded via the ground station located at Malindi in Kenia.

2.1. The spacecraft, the payload and communication system

As I said the spacecraft and the payload were designed to maximize the science return. To do this we had to design a spacecraft that had to move and stabilize in a very short time, matter of seconds. Thanks to Spectrum Astro which designed and constructed the spacecraft we have a fantastic machine, it takes tens of seconds to be on target with the narrow field instruments after detection. This is essential to monitor the evolution of the burst since the very beginning not only with the Burst Alert Telescope (BAT) but also with the X Ray Telescope (XRT) and UltraViolet Optical Telescope (UVOT). Indeed these are the instruments of the payload. BAT continuously monitors 1.4 steradian of the sky (Half coded Field of View). Soon after detection of a GRB (the detection and alert algorithm are very sophisticated tools to allow a characterization of the event and immediate automatic decision by the on board computer) the onboard computer sends the coordinates of the event, together with a set of parameters characterizing the burst, to the ground via the TDRSS, Figure 2. The accuracy of the position will be of about a few (4 – 5) minutes of arc and only imagery will be possible. At the same time it will instruct the spacecraft to point the target in order to allow the acquirement of the target by the two narrow field instruments. It will take a couple of minutes for XRT to send to ground the position with accuracy better than 5 seconds of arc. Again position and relevant information will be transmitted to the Ground immediately. Note that at this point it could be possible to point medium and large telescopes also for spectroscopy. Finally, and within 15 – 20 minutes, UVOT will be capable of transmitting a very accurate astrometry and also a card of the field. On the other hand we are often capable to search for the counterpart pointing large telescopes using the BAT information and try to immediately detect the optical counterpart by detecting a unknown source with decaying luminosity. XRT is sensitive in the energy range 0.2 – 10 keV, has a field of view of 23 minutes of arc with an effective area of 110 cm^2. Information can be obtained for sources in the range (Photon Counting Mode) from 2 10^{-14} to 2 10^{-11} erg cm^{-2} s^{-1}. UVOT consists of a 30 cm Ritchey – Chretien telescope sensitive in the range of 1700 to 6500 Angstrom. It will reach a magnitude B=24 in 1000 s integration using white light. A filter wheel host filters and 1 grism. For more details see Gehrels et al. (2004).

3. Preliminary science results

Thanks to a continuous coverage of the burst by the XRT the data showed very clearly since the first set of observations three effects: 1) a very steep decay during the first few hundreds seconds of the decay, 2) a break in the light curve where the slope of the curve changes from mild to steep, Campana et al. (2005), and 3) the presence of flares of various intensity. The main characteristics of the observed light curves without flares and with an observed redshift have been plotted in Figure 3 where all the curves have been plotted in the rest frame (Chincarini et al. 2005). The very steep initial slope, Type 1 light curve, is not completely understood and it is not yet clear whether it is due to the afterglow decay or to the decay of a flare of which we missed the rising phase. While this latter possibility may be unlikely due to the fact that in the rest frame we begin to observe the afterglow soon after the trigger (about 30 seconds later), it can not yet be completely disregarded. The expected relation between the temporal decay index and spectral index is universal for synchrotron emission from spherical fireballs (or jets with an opening angle much larger than the relativistic beaming scale), and is given by α=2+β (Kumar and Panaitescu 2000) where $F_\nu \propto t^{-\alpha} \nu^{-\beta}$. The typical value of β is about 0.5 – -1., the maximal decay index could be $\alpha \sim 3$. If the decay is steeper than 3, as may be the case for GRB 050319, we possibly have to argue for a highly collimated jet. Since there is no material at high latitudes, the luminosity would drop faster. In the case of GRB 050319 we may be able, as stated, to decrease the slope by using a t_0 that is different from the trigger time. Note, however, that even assuming a t_0 coincident with the end of the BAT prompt emission (an extreme that is physically untenable) we have a slope $\alpha = 2$.

The first change of slope of the light curve, from steep to mild, occur between 200 and 1000 seconds after the trigger while the second break, when the curve passes from mild to steep again, occur at about a few thousands to 10000 seconds form the trigger time. The second break, as it is rather well known, is due to the slow down of the relativistic jet and decrease of the Lorentz actor causing a widening of the relativistic beaming angle. When such angle, $\Theta = 1/\Gamma$, reaches the opening of the Jet the intensity observed decreases due to the off jet emission we are receiving from that moment afterwards. Flares in a few cases were detected also by the Beppo SAX satellite (Piro et al. 2004). Swift showed that such flares are extremely common in the XRT light curve and in some cases the energy emitted during the flare is as high as that emitted during the prompt emission (Burrows et al. 2005). In Figure 4 we plot the brightest we observed so far to show a fast rise and steep decay governed by a power law that is characteristics also of internal shocks and due to the clashing of shells with different Lorentz factors. While we are still working on the statistics and related correlations of such flares it is evident they are present with various peak intensity and however always present the same power law morphology. They may emit as much energy as observed in the prompt emission detected by BAT, represent about 85% of the total energy emitted in the X ray afterglow or be only a few percent and almost confused with the noise.

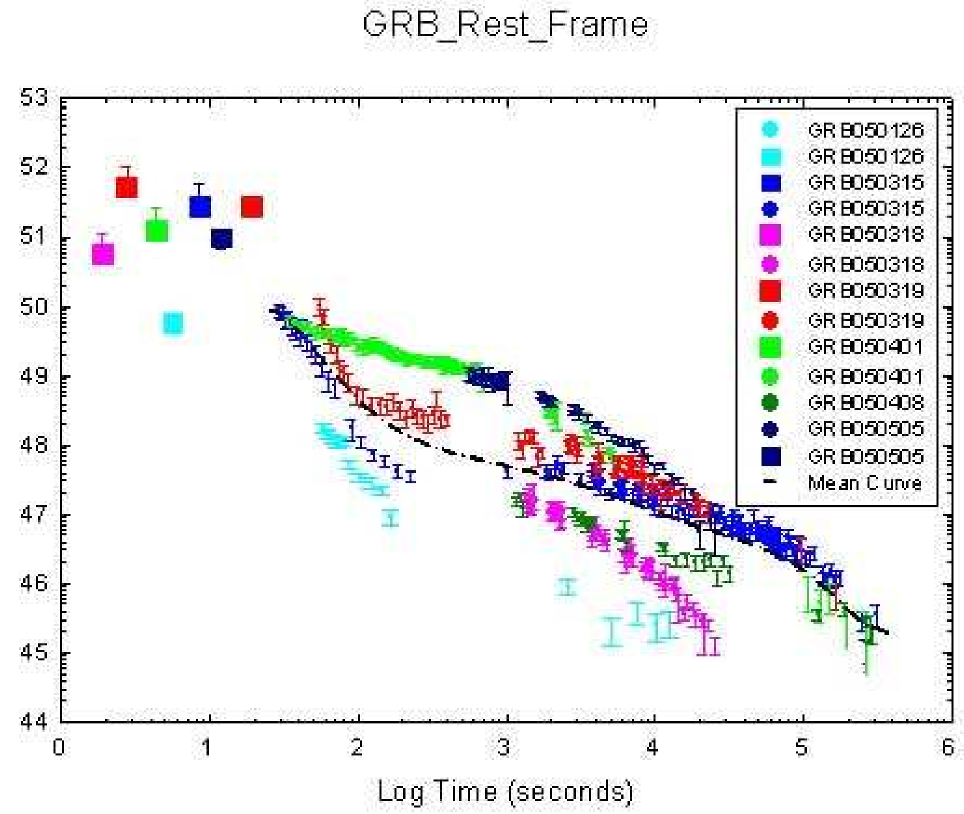

Fig. 3. The light curves have been plotted in the rest frame of each single burst. For the origin of time we used the trigger time as given by the BAT instrument. Squares refer to the mean flux observed by BAT during the burst and converted via the BAT spectrum to the energy band of XRT, circles refers to the observed flux in the band 0.2 – 10 keV. The dot dashed line is the mean curve as described in the text.

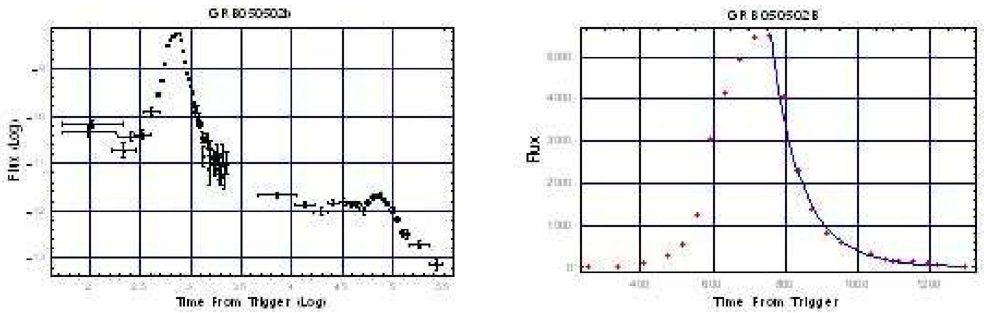

Fig. 4. Left: the light curve of GRB050502B where a very large flare is visible. The flare in linear scale is show on the right part of the figure after subtraction of the underlying type 2 light curve (mild to steep after the break). This flare account for 85% of all the energy emitted in the afterglow and decay with a power law $t^{-9.58}$. Extremely steep.

They occur at random times, as far as we know today, during the afterglow and indicate that in certain burst (not all the GRBs show flares) the central engine remain active. That is relativistic jets and clashing shells manifest with flare activity long after the prompt emission. Such flares have been detected also in one of the short bursts GRB050724 that was discovered after this meeting took place. Flares happen to be a common characteristics of Long and short bursts.

4. Conclusion and future goals

The observations of GRBs with the Swift satellite is giving us the possibility to address a broad series of interesting topics and cover almost all branches of Astrophysics, from the stellar evolution to high energy physics and cosmology. We are naturally gaining fundamental observations on the X ray, radio and optical afterglow that will lead to a deep understanding of the physics related to the internal, external and reverse shock. It is also our opinion that flares may finally lead to a better understanding on how the central engine behave. Here the real progress will be likely achieved through the detailed simulation, see for instance, but it will be fascinating to finally understand which is the mechanism acting in the central engine (Frail et al. 2001). The presence of degenerated objects and rapid rotation, likely calling for a binary progenitor, seem to be essential.

Since the time we started to design the mission and make the instruments we had in mind estimate of the redshift and the detection of very distant objects. To this end we added to the payload the UVOT which had the capability of getting a first indication of the redshift and we proposed designed and built a robotic telescope, REM (Chincarini et al. 2003), capable of detecting near infrared drop out objects and detect dropouts up to z ~ 10. Unfortunately the plan did not work since the majority of the burst we are detecting are fainter than expected and not visible by small telescope. We were forced, therefore, to change strategy and relay on larger telescopes. At the time of writing we discovered using multicolor imaging a burst at z = 6.3.

It would improper to expand on this since the discovery occurred months after the meeting. On the other hand that simply confirmed, and gave renewed impetus, to the search for high redshift objects. The discovery and the following hunt for high z bursts increase the possibility to get new data and reach a better understanding of the re-ionization epoch and of the formation of the first metal free population of stars. We do believe that at that epoch very massive stars, $M \geq 100\ M_{\odot}$, may rapidly evolve and eventually end into the supernova and GRB phenomenon. Recent simulation confirm that our plan were justified (Bromm and Loeb 2005), and indeed indicate that about 10% of the Swift detections may be related to high z objects (see also Hurley (2002) and references therein). A new and realistic challenge for Swift.

Acknowledgements. We are grateful to Dino Fugazza who helped us in preparing the manuscript and to Pawan Kumar for insightful discussions. The work is supported in Italy by funding from ASI on contract number I/R/039/04, at Penn State by NASA contract NAS5–00136 and at the University of Leicester by PPARC contract number PPA/G/S/00524 and PPA/Z/S/2003/00507. We acknowledge in particular all those member of the Swift Team at large who made this mission possible. This goes from the building of the hardware, the writing of the software, the operation at the Mission Operation Centre and the performance of the ASI ground segment at Malindi, Kenya.

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