Mem. S.A.It. Suppl. Vol. 2, 227

Memorie della
Supplementi

Advantages of Gamma-Ray Burst Follow-up Observations from Dome-C

M. Boër

Centre d'Etude Spatiale des Rayonnements (CNRS-UPS), BP 4346, 31028 Toulouse Cedex, France e-mail: Michel.Boer@cesr.fr

Abstract. Gamma-Ray Bursts (GRBs) are the most relativistic and luminous phenomena of the Universe. Their explanation is still uncomplete, though it is agreed now that they probably originate from the collapse of massive stars at cosmological distances. They address fundamental questions in physics and astrophysics, and they can be used to probe the early universe. The follow-up of GRBs with ground based instruments, both at infrared and visible wavelengths, is crucial to understand their nature. Given the dynamics of the source, the observations should start within seconds of the explosion, and last as long as possible, i.e. hours or even days. Using the same instrument would be better for this follow-up, alleviating inter-calibration problems. Both from the point of view of the accessible sky, of the length of contiguous observations, and of the excellent infrared and far-infrared transparency, Dome-C seems one of the best location for a robotic observatory partly dedicated to the observation of Gamma-ray Burst sources.

Key words. Gamma-rays: bursts – Supernovae: Type I

1. Introduction

Discovered in the late sixties (Klebesadel et al. 1973) , gamma-ray burst sources (hereafter GRBs) remained mysterious for about 20 years. They appear as an intense emission of gamma-rays and hard X-rays, with a peak energy around 100keV, which lasts between 0.1 to 1000 seconds. They display a high level of variability, down to the sub-millisecond scale. At the limiting fluence of 10^{-8}erg.s^{-1}.cm^{-2}, their occurrence rate is about 2 per day, isotropically distributed over the sky (Fishman and Meegan 1995). This prompt event is followed by a long lasting afterglow which decreases as a power law of typical index between -1 to -2 (van Paradijs et al. 2000). GRBs have been observed at almost all wavelengths (from radio to X-rays) during their afterglow part, and at gamma-ray, X-ray and visible wavelengths for the prompt emission. Figure 1 displays the light curve of GRB 990123, showing both the prompt and afterglow parts of the GRB (Akerlof et al. 1999).

Since 1997, the cosmological origin of GRBs has been confirmed, thanks to the accurate positions given by the BeppoSAX satellite (Costa et al. 1997). Follow-up work lead to redshift measures at visible wavelengths (van Paradijs et al. 1997). With measured redshifts ranging from 0.001 to 4.5, the luminosity of these sources is about 10^{51}ergs, probably mak-

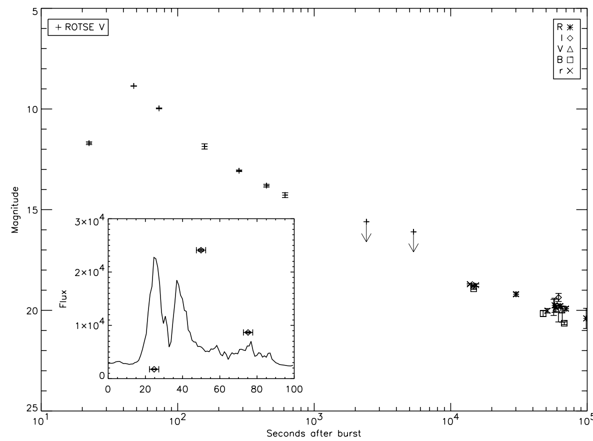

Fig. 1. Main panel: V band light curve of GRB 990123 observed by the ROTSE experiment. Inside panel, first three optical points superimposed on the BATSE gamma-ray time profile (Akerlof et al. 1999).

ing them the most luminous sources in the universe.

The fireball model (Rees and Mészáros 1992, Mészáros and Rees 1997, Panaitescu et al. 1998) has been established as a standard tool to interpret these observations. In this framework the afterglow emission is described as synchrotron and inverse Compton emission of high energy electrons accelerated during the shock of an ultra-relativistic shell with the external medium, while the prompt emission is due to the internal shocks produced by shells of different Lorentz factors within the relativistic blast wave (see e.g. Piran 1999 for a review). Both the prompt radiation and early afterglow phases provide critical information to establish the physical processes at work during the burst itself, as well as the physical conditions of the surrounding environment (Kumar and Panaitescu 2000, Kumar and Piran 2000). There is a general consensus that the fireball plasma is constituted by e^-e^+ pairs and γ-ray photons, however the ultimate energy reservoir and the detailed radiation mechanisms are still a challenge to theoretical models. Recently, the observation of GRB 030329 identified with SN 2003dh Stanek et al. (2003), lead to the conclusion that at least several GRBs come from the collapse of massive stars (Zhang et al. 2002), and that the source of the GRB may produce a supernova type Ib/c event.

The situation of 60% of the GRB afterglows which are not observed at optical wavelengths (called *dark GRBs*) is not clear. As it has been shown Boër and Gendre (2000), the optical flux is not correlated with the intensity of the X-ray afterglow, nor with the distance. Generally speaking the absence of an optical transient associated with a GRB can be attributed to four, non exclusive, reasons, namely 1) the distance of the source, though this is obviously not the general case, 2) the absorption of the visible light by a dense medium (*i.e.* dust), 3) the rapid decay of the optical afterglow, and 4) the intrinsic faintness of the source at long wavelengths (*i.e.* optical, NIR...). Few reports of near IR and optical non-detection of GRB afterglows show, that hypothesis 2 is not the main reason (see *e.g.* GRB 010214 Piro 2001 and subsequent GCN circulars[1]. In the absence of rapid simultaneous X-ray and optical mea-

[1] Available at the following URL: http://gcn.gsfc.nasa.gov/gcn/other/010214.gcn3

surements, hypotheses 3 and 4 are difficult to evaluate.

The fact that GRBs are produced by a collimated highly relativistic fireball has for interesting consequence that as the Lorentz factor decreases, and as the fireball expands sideway, long wavelength emission may be seen at higher angle with respect to the direction of expansion. In other word, it should be possible to observe radio to visible emission from wider angles, while the gamma and X-rays remains not visible because they are strongly focussed. This means that a vast amount of so-called *orphan* afterglows should be detectable, possibly associated with SN events, in a wide angle coverage sensitive survey. In addition, it is possible that the Lorentz factor within the fireball is not uniform, leading to both prompt and afterglow orphans (Piran and Nakar 2003)

In summary the study of GRBs presents several interesting aspects, the following list being certainly not exhaustive:

- The GRB phenomenon still lacks a complete explanation. What is the full spectrum of short, hard GRBs? Beside X-ray flashes, are they other types of transient events connected to the fate of massive stars? Are neutron star mergers still a good explanation of short events? What is the actual connection with SNs, and in which cases do we observe both a SN and GRB event? How to measure the collimation angle of the fireball, and the distribution of Lorentz factors? What is the GRB energetics, how the energy is transported, and how are thermal X-rays suppressed?
- GRBs are good candidates for the production of high energy particles. High energy neutrinos may be observed by the AMANDA and/or ANTARES detectors, and more probably by their more sensitive followers ICECUBE and KM3. Gravitational radiation may be released and observed for a close-by event by VIRGO. GRBs are still good candidates for the production of the ultra high-energy cosmic-ray events, which are about to be studied in details by the AUGER experiment.
- Because GRBs are produced at cosmological distances, are sources of both GeV and low energy radiation, and are variable on small scales, they may be used to test the quantum gravity, comparing the arrival time difference between high and low energy photons (Amelino-Camelia et al. 1998)
- GRBs are also bright sources even when they are at high redshifts. They may be used as a probe for the early universe. They sample the SFR, they probably originate partly from Pop. III stars, they may be used to probe the diffuse matter in the host galaxy and toward the observer. GRBs are also one of the most promising probes for the study of the re-ionization and Lymman alpha clouds.

In the following we present several advantages of Dome-C as a site for follow-up observations

2. Why and what to observe from Dome-C

Several quantities have to be measured for GRBs: the light curve, both during the prompt event and the afterglow. The former inform us on the activity of the inner engine, and on the internal, as well as reverse shock formation. The later is directly connected to the interaction of the fireball with the interstellar medium or matter coming from a previous wind phase of the progenitor. Especially important are the various transitions. The transition between the prompt and afterglow phases are directly connected to the surrounding medium density and distribution. Equally important is the observation of the transition between the adiabatic and radiative phases of the afterglow (Boër and Gendre 2000). This implies both rapid differential photometry at the beginning of the burst, on the order of 1 second, and the follow-

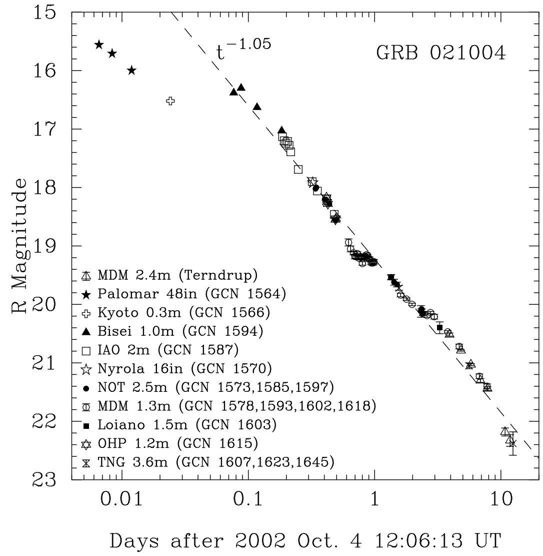

Fig. 2. Light curve of the afterglow of GRB 021004 (Halpern 2003). The dashed line is the power law fit. A continuous monitoring during the first minutes / hours of the GRB is clearly lacking.

up for hours and, whenever possible, days, in order to have accurate time series, avoiding inter-calibration problems, and displaying rapid changes in the source emission. Figure 2 displays the afterglow of GRB 021014, showing that if the decay is approximately a power law, they are large departures from it, and that transitions are not properly sampled. The dynamics in time implied by such observations is very large, a factor of about 10^5. From that point of view, Antarctica offers unique conditions of observation, because of the length of the night, which enables uninterrupted series of observations on the same event: a task limited to 1 hour at most onboard a satellite, and to few hours on other Earth sites. In addition, the good weather at dome C guaranties a very good observing efficiency. We note that at infrared wavelengths, observations may be performed almost at any time of the year, excepted close to the Sun.

The spectrum of GRBs is also an important measure. Spectral lines inform us both on the redshift of the source, on the velocity of the ejecta, and on the composition of the ejected matter, as well as the surrounding, interstellar and intergalactic diffuse matter. It is also quite important to get information on the broad band spectrum (radio - visible - X and gamma-rays) evolution along the event. This can be acquired with low resolution spectra, using filters, or monitoring both at visible and IR wavelengths. In addition, if spectroscopy is performed while the source is varying rapidly, it is necessary to get additional simultaneous photometry. Even with a modest (1m sized) instrument, some broad band spectrometry may be achieved, and photometric redshifts derived. From the point of view of measuring the dust environment of GRBs, and/or GRBs at very high redshifts, Dome-C provides unique opportunities, because of the excellent infrared properties of the site and of its access to the L and M bands.

Providing the precise location of the GRB source is of paramount importance. The first measures provided by the spacecrafts suffer errors ranging from few arcmin. to degrees. If a telescope wants to follow sources given by more than one spacecraft (e.g. SWIFT, GLAST...) it has to have a somewhat large field of view. Provided its aperture is large enough, the same observatory can be used for spacecraft alerts and for the hunt of orphan afterglows. The sensitivity is also an important point if one wants to sample rapidly the light curve, even for a bright source. The quality of Dome-C sky allows to use moderately large apertures, on the order of 1 meter. Sub-arcsec. positions can be directly used by large instruments, such as the VLT in its RRM mode, allowing a maximized scientific return.

3. Practical implementation

Several small automated telescopes, such as the TAROT experiment (Boër et al. 2001) are implemented around the world. As usual most of them are in the Northern hemisphere. Their size ranges from few centimeters to 60cm, and they are in general sensible to the visible part of the spectrum. The implementation of a new telescope, or better a set of instrument spanning the IR and visible wavelength would be a good addition to this network, providing a good coverage of the Southern sky with only one site. A 1 meter telescope such as ARAGO (Boër 2001b; Boër 2003) is a size adapted to the problem described above, and it may be used both at infrared and visible wavelengths. It will be able to make the satellite follow-up 24h a day, reaching a sensitivity of around mag. 19 in 10 seconds. Moreover, a 9 to 14 magnitude burst can be sampled at a 1s rate.

A GRB dedicated (or partly dedicated) telescope has some basic requirements: a) any alert should reach it within less than 1 second, b) it should be fully robotic and process the data in an autonomous way, and, c) it should be able to transmit rapidly the high level results of the data processing not only to other experiments on the Antarctic plateau, but also to other observatories such as ESO. Requirement a) means that the GRB observatory has to be connected with a low bandpass link to the INTERNET, since the alert consist of less than 1kB of data. An IRIDIUM or equivalent data link is enough, provided that the link can be established within a few tenth of seconds. Requirement b) is already achieved e.g. by TAROT in a fully autonomous way, and from that point of view the localization in the Antarctic seems not a big deal. Requirement c) is the most difficult one to achieve for the Antarctic. Transmitting the whole data (images, and results) seems unrealistic. However our TAROT experience show that the processing can be reliable enough to transmit only the image source list, or even the list of new, eventually flagged variable, sources. In this case, a reduced data rate link, even non permanent, is enough. However, the availability of a more rapid link to enable the transmission of few compressed images (in case of GRB occurrence) and of whole source list would be clearly a plus.

4. Discussion and conclusions

GRB are nowadays at the forefront of the astrophysical scientific problems. They are connected to the fate of massive stars, and thus to collapse supernovae, and are a probe of the Universe up to very large redshifts, allowing to use them for the study of a broad range of physical and astrophysical problems. These sources of photons and high energy particles, by far the most luminous and relativistic ones, are also among the promising sources of neutrinos, UHECR, and gravitational waves. They may be used to probe the most advanced physical problems, such as quantum gravity. Their study is a priority for a large number of observatory in the world. Several spacecraft are in orbit to study them (ULYSSES, HETE-2, INTEGRAL, etc.), and other missions are built or under study (SWIFT, GLAST, AGILE, ECLAIRS...). It is probable that until 2020, fast localizations will be provided from space. Moreover, other missions, such as the ESA GAIA spacecraft or the SNAP mission, though having other objectives, can lead to significant advances in the field, e.g. by the serendipitous discovery of supernovae and orphan afterglows. The continuous, quantitative follow-up of GRB sources is a scientifically rewarding task, for which Dome-C has major advantages.

Dome-C is probably the only point of the world where a 7/7d 24/24h follow-up can be performed. A coherent set of instrumentation can be installed, allowing the study of GRBs from the far infrared to the UV. Moreover, it is probable that sub-mm instrument can have GRB pointing modes, allowing the most complete and simultaneous wavelength coverage of the spectrum in the world. As pointed out in previous sections, the coverage of the infrared range could allow the use of this observatory for the whole year, albeit with pointing constraints and may be limited sensitivity. In any case, compared to the cost of developing and maintaining such a facility in space, for a limited time, Dome-C seems a very cost effective facility, with a scientific return which seems optimized compared to what can be achieved in space. On the other hand it is easy to see that a network of telescopes in the Southern hemisphere will suffer of the lack of good astronomical site for a wide range of longitude (excepted South-America, Africa and few islands), and cannot compete with Dome-C from the point of view of IR observations, a very essential point for the current problems in GRB astronomy.

As a final note, GRBs will occupy at most 10% of the time of any telescope. This means that the same instrument can study a broad range of objectives, such as performing a far infrared survey. Both objectives can be easily accommodated on a single telescope, thanks to the scarcity of GRB alerts.

We conclude repeating that the study of Gamma-ray burst from Dome-C is one of the most scientific sensitive issues for which Antarctica may bring unique data. Implementing a new instrument can be done very quickly, while, given the source brightness, its aperture remain modest.

References

Akerlof, C., *et al.*, 1999, Nat 398, 400
Amelino-Camelia, G., et al. 1998, Nat, 393,763
Boër, M., *et al.*, 1999, A&AS 138, 579
Boër, M., and Gendre, B., 2000, A&A 361, L28
Boër, M., *et al.*, 2001, A&A 378, 76
Boër, M., 2001b, A.N., 322, 343
Boër, M., *et al.*, 2002, GCNC 1408
Boër, M., this volume
Costa, E., *et al.* 1997, Nat. 387, 783
Fishman, G.J, and Meegan, C.A., 1995, ARAA, 33, 415
Halpern, J.P., *et al.*, 2003, ApJ, in press
Klebesadel, R.W., Strong, I.B., Olson, R.A., 1973, ApJ, 182, L85
Klotz, A., Boër, M., and Atteia, J.L., 2003, A&A, *in press*
Kouveliotou, C., *et al.*, 1993, ApJ 403, L101
Kumar, P., and Panaitescu, A., 2000, ApJ 541, L9
Kumar, P., and Piran, T., 2000, ApJ 535, 152
Mészáros, P., and Rees, M., 1997, ApJ 476, 232
Panaitescu, A., Mészáros, P., and Rees, M., 1998, ApJ 503, 314
Piran, T., 1999, Phys. Rep. 314, 575
Piran, T., and Nakar, E., 2003, New Astron., 8, 141
Piro, L., 2001, GCNC 932
Rees, M., and Mészáros, P., 1992, MNRAS 258, 41
Stanek, K.Z., et al., 2003, ApJ, in press
van Paradijs, J., *et al.*, 1997, Nat 386, 686
van Paradijs, J., Kouveliotou, C., Wijers, R. 2000, ARAA 38, 379
Zhang, W., Woosley S.E., MacFayden, A.I., 2003, ApJ, 586, 356