Death of Massive Stars: Supernovae and Gamma-Ray Bursts
Proceedings IAU Symposium No. 279, 2012
P. Roming, N. Kawai & E. Pian, eds.

doi:10.1017/S1743921312013440

Observations of GRBs in the mm/submm range at the dawn of the ALMA era

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Abstract. Gamma-ray bursts (GRBs) generate an afterglow with an emission peaking in the millimetre and submillimeter (mm/submm) range during the first hours to days, making the study in these wavelengths of great importance. Here we give an overview of the data that has been collected for GRB observations in this wavelengths until September 2011. The total sample includes 102 GRBs, of which 88 have afterglow observations, and the rest are only host galaxy searches. The 22 detections cover the redshift range between 0.168 and 8.2 and have peak luminosities that span 2.5 orders of magnitude. With the start of the operations at ALMA, the sensitivity with respect to previous facilities has already improved by over an order of magnitude. We estimate that, once completed, ALMA will be able to detect ∼98 % of the afterglows.

This proceeding is based on the work published by de Ugarte Postigo *et al.* (2012).

Keywords. gamma rays: bursts, submillimeter

1. Observations and sample

During the last 3 years we have followed-up 11 GRBs (plus an additional Galactic X-ray binary, initially identified as a GRB) and discovered 2 counterparts in submm with observing programmes at APEX and SMA. This is put into context with the most complete sample of continuum observations that have been published to date of GRB afterglows and their host galaxies in the mm/submm wavelength range, covering from early 1997 until the 30th of September 2011.

The complete sample includes observations of 102 bursts, of which 88 are searches for GRB afterglows, with 22 detections. There have been specific host galaxy searches for 36 cases, although limits can be provided for the 102 bursts that have been followed. Host galaxy detections have only been achieved in four cases: GRB 000210, GRB 000418, GRB 010222 and XT 080109.

2. Afterglow models

GRB afterglows can be described, in the simplest case, using the fireball model (Sari *et al.* 1998). According to it, material is ejected at ultrarelativistic velocities through collimated jets. When this material interacts with the medium surrounding the progenitor, the accelerated particles emit a synchrotron spectrum that is characterised by three break frequencies: ν_m is the characteristic synchrotron frequency and is the maximum of the emission, ν_c is the cooling frequency, above which radiative cooling is significant, and ν_a is the synchrotron self-absorption frequency.

A reverse shock, produced inside the ejecta, can generate an additional early emission (Piran *et al.* 1999). This has been rarely observed in the optical wavelengths but is expected to have a significant contribution in the early mm/submm emission. For example, the mm detection of GRB 090423, at a redshift of 8.2, seems to show excess emission possibly due to a reverse shock.

3. Observations of individual GRBs

Multiwavelength observations of GRB afterglows are the only way to determine with precision the physics involved in the GRB and learn about the environment that surrounds it. Studies in mm/submm are especially interesting in the case of optically-dark bursts, as they allow us to access what optical observations cannot.

Optical samples of GRBs are limited by the extinction in the host galaxy that, if large, make the optical emission undetectable. The negligible effect of dust extinction in the mm/submm bands allows us to study a more complete sample. As an example we can look at GRB 051022, one of the darkest bursts detected to date, for which an optical counterpart was not found. Observations in mm wavelengths allowed us to localise and study the afterglow and host galaxy (Castro-Tirado *et al.* 2007). The other main cause for optically dark GRBs is their high redshift. In these cases the absorption produced at frequencies higher than the Lyman limit does not allow us to obtain optical detections of GRB afterglows beyond redshifts of 6. These events are important to understand the formation of the first stars in the Universe. Proof that they can be detected in the mm/submm range is the fact that, out of the three GRB afterglows observed at $z > 6$, two have been detected (GRB 050904 at $z = 6.3$, Tagliaferri *et al.* 2005, Haislip *et al.* 2006, and GRB 090423 at $z = 8.2$, Tanvir *et al.* 2009, Salvaterra *et al.* 2009).

4. GRBs in the ALMA era

Using data from the sample and assumptions based on samples at other wavelengths, we estimate the real peak flux density distribution of GRBs, from which an average peak flux density value of 0.33 mJy can be expected. Using the detection limits calculated for ALMA, we can expect that the completed observatory should be able to detect 98%. In the case of bright GRB afterglows, ALMA will be able to study spectral features and perform polarimetric studies of the afterglow, which have been out of reach until now. With ALMA we will be, for the first time, in position to undertake studies of samples of GRB host galaxies. We will be able to perform studies of the continuum emission to characterise the dust content and determine the unextinguished star formation rate of the hosts. Through the study of emission features from the host, we will be able to understand the molecular content and the chemical enrichment of the strong star-forming regions in which GRBs are found, at redshifts that go back to the epoch in which the first stars were formed.

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https://doi.org/10.1017/S1743921312013440 Published online by Cambridge University Press

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