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The observation of Gamma Ray Bursts with AGILE

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Abstract. After the demise of the EGRET experiment aboard the satellite-borne *Compton Gamma-Ray Observatory*, the observation of Gamma Ray Bursts in the gamma-ray band is advancing thanks to the *AGILE* and *Fermi* satellites. In this presentation we discuss the features of some of the most interesting bursts detected so far by *AGILE* and we show the upper limits in the gamma-ray band of the non-detected events.

Key words. Gamma-ray burst: general

1. Introduction

The EGRET instrument aboard the *Compton Gamma Ray Observatory* detected just a handful of GRBs above 100 MeV in its lifetime of about ten years. The GRBs, belonging to the class of long events, showed peculiar and distinctive features but the whole sample lacked common properties. For example, the noticeable GRB 940217 showed an extended emission of gamma-rays, detected more than 5000 s after trigger (Hurley et al., 1994). In some GRBs (e. g. GRB 930131) the spectrum in the 1 MeV - 1 GeV band is modelled by a single powerlaw, while others (e. g. GRB 941017) show additional components. It is worth recalling that the EGRET observations of GRBs were obtained before the discovery of the afterglow at lower energies (Costa et al., 1997), thus the redshift of the burst was not known.

2. The AGILE instrumentation

AGILE (Tavani et al., 2008, 2009), was launched on April 2007 and is a small scientific satellite of the Italian Space Agency (ASI), devoted to the observation of the Sky in the hard X-ray and gamma-ray energy bands. The *AGILE* payload is composed of two imagers, built "in series" and with co-aligned fields of view (FoV): the hard X-ray monitor SuperAGILE (Feroci et al., 2007), sensitive in the 18 – 60 keV energy band with a field of view of $\sim$ 1 sr and an angular resolution of 6 arcmin, and the Gamma Ray Imaging Detector (Prest et al., 2003, Bulgarelli et al., 2010, GRID), sensitive in the energy band from 30 MeV to few GeV with a field of view

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⋆ AGILE Team: G. Barbiellini, F. Fuschino, A. Giuliani, F. Longo, M. Marisaldi, M. Trifoglio, A. Argan, A. Bulgarelli, P. Caraveo, P.W. Cattaneo, A. Chen, E. Costa, G. Di Cocco, I. Donnarumma, Y. Evangelista, M. Galli, F. Gianotti, C. Labanti, I. Lapshov, F. Lazzarotto, P. Lipari, S. Mereghetti, A. Morselli, L. Pacciani, A. Pellizzoni, F. Perotti, P. Picozza, M. Pilia, M. Prest, G. Pucella, M. Rapisarda, A. Rappoldi, P. Soffitta, M. Tavani, A. Trois, S. Vercellone, V. Vittorini, C. Pittori of ~ 2.5 sr and a point spread function ranging between 3.5° (at 100 MeV) and 1.5° (at 1 GeV). The GRID also contains a non-imaging Minicalorimeter (MCAL, Labanti et al., 2009), that can independently detect transient events at MeV energies in an almost all-Sky field of view, with maximum sensitivity at an angle of roughly 90° off-axis with respect to the satellite boresight.

Both SuperAGILE and MCAL are equipped with on-board triggering algorithms (see Del Monte et al. (2007) and Fuschino et al. (2008) respectively) developed to detect transient events such Gamma Ray Bursts (GRBs) and Terrestrial Gamma-ray Flashes (TGFs). Dedicated telemetry packets are introduced in the data stream to downlink the trigger information, that is handled by a dedicated ground software (Trifoglio et al., 2010). Since the beginning of the *AGILE* operations, SuperAGILE and MCAL are active members of the InterPlanetary Network (IPN[1]).

On November 2009 *AGILE* suffered a malfunction to the reaction wheel and, after that time, the satellite is working in a spinning operative mode, with an angular velocity of ~ 0.8° per second around the axis pointed toward the Sun and scanning ~ 70 % of the Sky every orbit. In pointing operative mode the localization rate of SuperAGILE was ~ 1 GRB per month and it is now reduced of a factor of 2 – 3 in spinning mode. The MCAL detection rate is ~ 1 GRB per week and, since the instrument does not produce images, the rate is not affected by the spinning operative mode.

3. Observations of Gamma Ray Bursts with AGILE

3.1. GRB 080514B

The long GRB 080514B is the first GRB detected in gamma rays after EGRET and is characterised by an extended emission above 30 MeV, lasting until ~ 30 s after trigger and containing ~ 66 % of the photons. Just ~ 33 % of the gamma rays are simultaneous to the prompt emission in hard X-rays, whose duration is about 7 s (see Giuliani et al., 2008, for the detailed data analysis). The fluence of GRB 080514B measured by the GRID is consistent with the extrapolation of the Band function that fits the spectrum accumulated by Konus-Wind between 20 keV and 5 MeV (see Golenetskii et al., 2009). A photometric measure of the redshift at $1.8^{+0.4}_{-0.3}$ is provided by Rossi et al. (2008).

[1] `http://www.ssl.berkeley.edu/ipn3/`

The most striking feature of GRB 080514B is the fact that the arrival times of the high energy photons detected with the AGILE/GRID do not coincide with the brightest peaks seen in hard X-rays. Three photons are concentrated within 2 s at the beginning of the burst, while the next ones arrive only after the X-ray emission has returned to a level consistent with the background (7 s after trigger). It is important to remark here that the number of photons in the initial 2 s is not limited by instrumental dead time effects, as was the case for some of the EGRET GRBs, for which only a flux lower limit could be measured from the brightest peaks. X-ray and optical/NIR observations indicate that the afterglow properties of GRB 080514B are similar to those of other bursts (Rossi et al., 2008).

3.2. GRB 090401B

The long GRB 090401B has important differences with respect to the other GRBs observed by AGILE. In fact the majority of the gamma ray photons (~ 68 %) are detected during the prompt phase and only a small fraction (~ 32 %) is found in the extended emission. It is worth mentioning that the prompt phase in hard X-rays has a duration of about 10 s while the gamma ray extended emission lasts for about 25 s. GRB 090401B has been also localised by *Swift*, that rapidly observed the afterglow with a delay of only ~ 80 s. Up to now only for two GeV-bright GRBs, GRB 090401B and 090510, *Swift* observed the prompt emission and afterglow, with a delay as small as ~ 100 s. More details about the data analysis of GRB 090401B will be reported in a forthcoming paper (Longo et al., in prep.).

3.3. GRB 090510

The short GRB 090510, localized by *Swift* and observed by *AGILE* (Giuliani et al., 2010) and *Fermi* (Ackerman et al., 2010), presents a clear delayed and extended emission of gamma rays. In fact the prompt emission, as detected in hard X-rays by the MCAL, lasts for about 0.2 s and no photon is simultaneously detected by the GRID. The onset of the gamma ray emission is at the end of the prompt phase and lasts for about 0.8 s. The same result is provided by Fermi/LAT, that detected the majority of the emission above 100 MeV after the end of the prompt phase. Only the rise of the gamma-ray emission is observed simultaneously to the prompt phase.

An important feature of GRB 090510 observed by *AGILE* is the spectral evolution. In fact, during the prompt emission, the spectrum of the burst can be modelled with a cutoff powerlaw with a photon index of 0.6 ± 0.3, the cutoff energy at 2.8 ± 0.9 MeV and a fluence of 1.8×10^{-5} erg cm^{-2} in 0.5 - 10 MeV. After the onset of the gamma ray emission, the model becomes a powerlaw without cutoff and the photon indices, 1.6 ± 0.1 (0.5 - 10 MeV) and 1.4 ± 0.4 (25 - 500 MeV) are fully consistent, thus indicating a single powerlaw. The redshift of GRB 090510 is 0.903 as reported by De Pasquale et al. (2010).

3.4. GRB 090618

The long GRB 090618 has been localised by Swift (Schady et al., 2009) and also by SuperAGILE (in a consistent position) and detected by the MCAL (Longo et al., 2009). GRB 090618 is characterised by a remarkable fluence of $(3.2 \pm 0.6) \times 10^{-5}$ erg cm^{-2}, measured by MCAL in the energy band between 350 keV and 100 MeV. The burst has a steep spectrum in the same energy band, with a photon index of 3.16 (Longo et al., 2009) by MCAL and is not detected in gamma-rays by the GRID. A timing and spectral study of the peaks in the prompt emission of the GRB (26 – 1000 keV) has been performed with the RT-2 experiment aboard the Coronas-Photon satellite and a systematic softening of the spectrum with time is found (Rao et al., 2011).

The light curve of the afterglow in X-rays (Swift/XRT) and optical (B, V, R, I) shows an achromatic break at 0.50 ± 0.11 days, consistent in the various energy bands (Cano et al., 2010). After the end of the steep phase, commonly detected in the Swift/XRT observations, the X-ray afterglow (corrected for foreground and host n_H absorption) and the optical afterglow can be fitted with a broken powerlaw and show similar decay indices: $\alpha_1 = 0.79 \pm 0.01$ in X-rays and $\alpha_1 = 0.65 \pm 0.08$ in optical (consistent at 2.0 σ), $\alpha_2 = 1.74 \pm 0.04$ in X-rays and $\alpha_1 = 1.57 \pm 0.07$ in optical (consistent at 2.4 σ). The spectroscopic redshift of GRB 090618 is 0.54 (Cenko et al., 2009, Fatkhullin et al., 2009). In a dedicated paper (Cano et al., 2010) the host and GRB contribution were subtracted from the optical data and a supernova was found, with lightcurve peaking at $\sim$ 20 to 30 days after the prompt emission and similar in brightness and evolution to SN1998bw. All the details of the follow-up in X-rays, optical and radio are reported by Cano et al. (2010).

The X-ray afterglow of GRB 090618 has been also observed through high resolution spectroscopy with the MOS and RGS instruments aboard the XMM-Newton satellite (Campana et al., 2011). In the environment of the GRB the authors find a high metallicity absorbing medium ($Z \simeq 0.2\ Z_{\odot}$), with possible enhancements of S and Ne with respect to the other elements.

3.5. Upper limits of undetected Gamma Ray Bursts

The large field of view of the GRID allows to simultaneously observe about one fifth of the Sky. Significant gamma-ray emission is observed only from a small fraction of GRBs, corresponding to few events per year taking into account the *AGILE* and *Fermi* detections. Motivated by this fact we estimated the upper limits on the flux of a GRB sample localised between July 2007 and October 2009 within the GRID FoV by SuperAGILE, Swift/BAT, INTEGRAL/IBIS, Fermi/GBM and IPN. Our sample is composed of 68 bursts, of which 40 have spectral information, publicly distributed through the GCN[2] Circulars by Konus-Wind, Suzaku/WAM and Fermi/GBM.

We estimated the upper limits using a Bayesian approach and following the method proposed by Helene (1983) and Helene (1984). When available, the spectral model from the publicly available information is used to calculate the flux upper limit and to extrapolate the available flux to the energy band between 30 MeV and 3 GeV. In the other cases, we adopted for these calculations the average values measured by BATSE for the photon index of an exponential cutoff and for the high energy photon index of a Band function.

We found that the calculated upper limits are constraining the extrapolation of the spectrum for $\sim$ 10% of the GRBs. We are still investigating the consequences of such constraints on the emission models. We also searched for a delayed emission component in gamma-rays, up to 3600 s after trigger, but we did not find any significant detection. All the details and the complete analysis are reported by Longo et al. (2010)

4. Conclusions

The ongoing observation of GRBs by the *AGILE* and *Fermi* satellites is showing that only a small subsample of events emits in gamma rays. In fact, the overall detection rate of both satellites is $\sim$ 10 bursts per year, consistent with the expectations of Band et al. (2009). From the data analysis it is emerging that GRBs emitting in the GeV band are also bright at lower energy. In fact, an analysis of eleven GRBs detected by Fermi/LAT until October 2009 shows that the fluence in Fermi/GBM (8 keV – 10 MeV) of these events belongs to the highest tail of the distribution (Ghisellini et al., 2010).

From the *AGILE* and *Fermi* observations we can see that the GeV emission of GRBs takes place during the prompt phase, often with a delayed onset and extended duration. Some events have the same spectral shape from keV up to GeV energies, modelled by a single Band function (for example GRB 080514B, Giuliani et al., 2008), while in other ones the gamma-ray emission is fitted by additional components, as for example in GRB 090510 (Giuliani et al., 2010, Ackerman et al., 2010) or the *Fermi* GRB 090902B below 50 keV and above 100 MeV (Abdo et al., 2009).

Up to now the afterglow of only two GRBs detected in gamma-rays, GRB 090401B (Longo et al., in prep.) and GRB 090510 (De Pasquale et al., 2010), has been observed by *Swift* with a delay of tens of seconds after the prompt emission. In the other cases the uncertainty on the position is large or the localisation is disseminated with a delay and the afterglow is observed some hours or even days after trigger. Since the sample is small, It is still under investigation if the afterglows of GeV-emitting GRBs show significant differences with respect to the sample of "standard" afterglows (see for example Swenson et al., 2010). In our analysis we investigated the GRID data of the sample of GRBs within our field of view and we did not find any significant gamma-ray afterglow emission until 3600 s after trigger. In particular, we also checked the *AGILE* data simultaneous to flares in the X-ray afterglow but we did not find anything significant.

[2] http://gcn.gsfc.nasa.gov

5. Discussion

WOLFGANG KUNDT's Comment: When you discussed the origin of your GRBs, you interpreted redshifts as distances, and arrived at source powers some 10^{16} times larger than analogous Galactic Sources. This problem can be avoided in a Galactic interpretation.

ETTORE DEL MONTE: To me the redshift of GRBs is a clear indication of cosmological (thus extragalactic) origin.

ARNON DAR's Comment: I would like to remark here that the aterglow of Gamma Ray Bursts has been discovered by Kevin Hurley, in the observation of GRB 940217 with EGRET (Hurley et al., 1994).

LORENZO AMATI's Comment: You discussed the gamma-ray emitting GRBs as a peculiar population but they are probably just the high luminosity tail of "standard" GRBs.

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