PoS PROCEEDINGS OF SCIENCE

GRB 080407: an ultra-long burst discovered by the IPN

V. Pal'shin*
Ioffe Physical Technical Institute of the Russian Academy of Sciences, St. Petersburg, 194021, Russian Federation
E-mail: val@mail.ioffe.ru

K. Hurley
U.C. Berkeley Space Sciences Laboratory, 7 Gauss Way, Berkeley, CA 94720-7450, U.S.A.
E-mail: khurley@ssl.berkeley.edu

J. Goldsten
Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723, U.S.A.
E-mail: john.goldsten@jhuapl.edu

I. G. Mitrofanov
Institute for Space Research, Profsojuznaja 84/32, Moscow 117997, Russian Federation
E-mail: imitrofa@space.ru

W. Boynton
Univeristy of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, U.S.A.
E-mail: wboynton@gamma1.lpl.arizona.edu

A. von Kienlin
Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse, Garching, 85748 Germany
E-mail: azk@mpe.mpg.de

J. Cummings
NASA Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, U.S.A.
E-mail: jayc@milkyway.gsfc.nasa.gov

M. Feroci
INAF/IASF-Roma, via Fosso del Cavaliere 100, 00133, Roma, Italy
E-mail: Marco.Feroci@iasf-roma.inaf.it

R. Aptekar, D. Frederiks, S. Golenetskii, E. Mazets, D. Svinkin
Ioffe Physical Technical Institute of the Russian Academy of Sciences, St. Petersburg, 194021, Russian Federation
E-mail: aptekar@mail.ioffe.ru, fred@mail.ioffe.ru, golen@mail.ioffe.ru, mazets@mail.ioffe.ru, svinkin@mail.ioffe.ru

D. Golovin, M. L. Litvak, A. B. Sanin
Institute for Space Research, Profsojuznaja 84/32, Moscow 117997, Russian Federation
E-mail: dimamsu@mail.ru, max@cgrsmx.iki.rssi.ru, sanin@mx.iki.rssi.ru

PROCEEDINGS OF SCIENCE

C. Fellows, K. Harshman
Univeristy of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, U.S.A.
E-mail: cfellows@lpl.arizona.edu, karl@lpl.arizona.edu

R. Starr
Physics Department, The Catholic University of America, Washington, DC 20064, USA
E-mail: richard.starr@gsfc.nasa.gov

A. Rau, X. Zhang
Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse, Garching, 85748 Germany
E-mail: arau@mpe.mpg.de, zhangx@mpe.mpg.de

V. Savchenko
ISDC Data Centre for Astrophysics, Ch. d'Ecogia 16, 1290, Versoix, Switzerland
E-mail: Volodymyr.Savchenko@unige.ch

S. Barthelmy, N. Gehrels, H. Krimm, D. Palmer
NASA Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, U.S.A.
E-mail: scott@milkyway.gsfc.nasa.gov, gehrels@lheavx.gsfc.nasa.gov, krimm@milkyway.gsfc.nasa.gov, palmer@lanl.gov

E. Del Monte, M. Marisaldi
INAF/IASF-Roma, via Fosso del Cavaliere 100, 00133, Roma, Italy
E-mail: delmonte@iasf-roma.inaf.it, marisaldi@iasfbo.inaf.it

We present observations of the extremely long GRB 080704 obtained with the instruments of the Interplanetary Network (IPN). The observations reveal two distinct emission episodes, separated by a $\sim$1500 s long period of quiescence. The total burst duration is about 2100 s. We compare the temporal and spectral characteristics of this burst with those obtained for other ultra-long GRBs and discuss these characteristics in the context of different models.

Gamma-Ray Bursts 2012 Conference -GRB2012,
May 07-11, 2012
Munich, Germany

*Speaker.

1. Observations

The first emission episode of GRB 080704 was detected at about 74529 s UT (20:42:09). It shows the bright initial pulse followed by two weaker pulses – see Fig. 1. The total duration of the episode is ~160 s. The whole episode was observed by Konus-Wind, INTEGRAL-SPI-ACS, and Swift-BAT (out FoV). The initial pulse was also detected by AGILE (SuperAGILE & MCAL), Mars Odyssey (GRS & HEND), and MESSENGER (GRNS).

The second episode was detected at about 76000 s UT (21:06:40), i.e. ~1500 s after the onset of the burst. It shows two broad pulses with a total duration of ~400 s and a weaker emission before the pulses – see Fig. 1. Both pulses were detected by INTEGRAL-SPI-ACS, Swift-BAT (out FoV), and MESSENGER (GRNS). The first pulse is also seen in the HEND data (numerous noisy spiked, followed it, have been removed, so the second pulse can not be seen). Unfortunately this episode was seen by Konus-Wind only in the housekeeping data (80–360 keV range, 3.68 s resolution) due to data readout after the trigger on the initial pulse, so no spectral data are available for this episode.

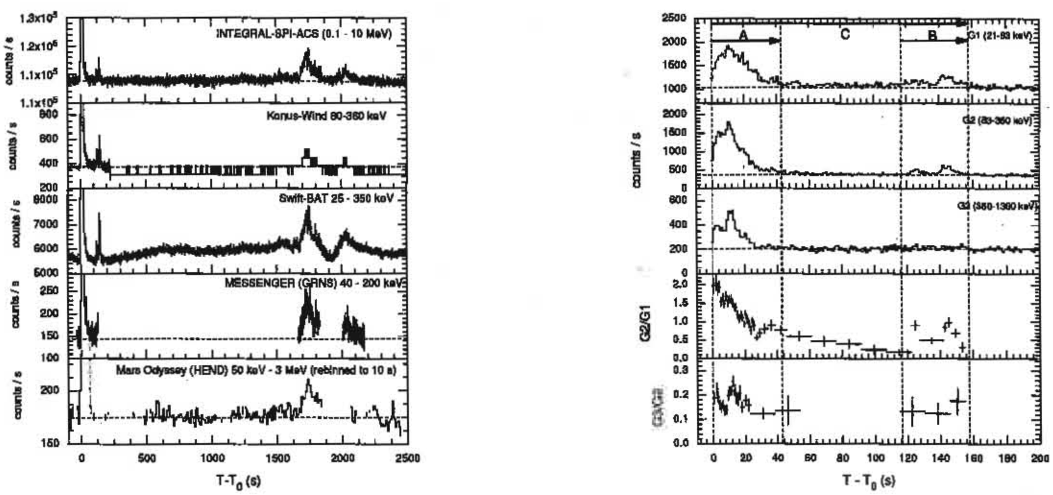

Figure 1: GRB 080407 light curve. *Left:* full lc as observed by different IPN instruments. $T_0 = T_0^*(KW)$ = 74529.471 s UT (20:42:09.471) (* – corrected for the propagation time delay; T_0(KW) – the Konus-Wind trigger time). Numerous noisy spikes have been removed from the HEND lc. *Right:* first emission episode in three energy bands and hardness ratios as observed by Konus-Wind.

2. IPN localization

We have triangulated the first episode to the rather small 3 sigma error box shown in Fig. 2 (left panel). The error box area is 582 sq. arcmin, and its maximum dimension is 2.67 deg. For the second episode we have derived the rather large 3 sigma error box shown in Fig. 2 (right panel). The error box area is 17.1 sq. deg. This box contains the small box for the first episode. The coordinates of the boxes are given in Table 1.

To estimate the probability of chance coincidence we can multiply a relative area of the large error box (that is $\Omega/4\pi$ sr = 17.1 sq. deg/ 41252 sq. deg = 4.1×10^{-4}) by the probability to have

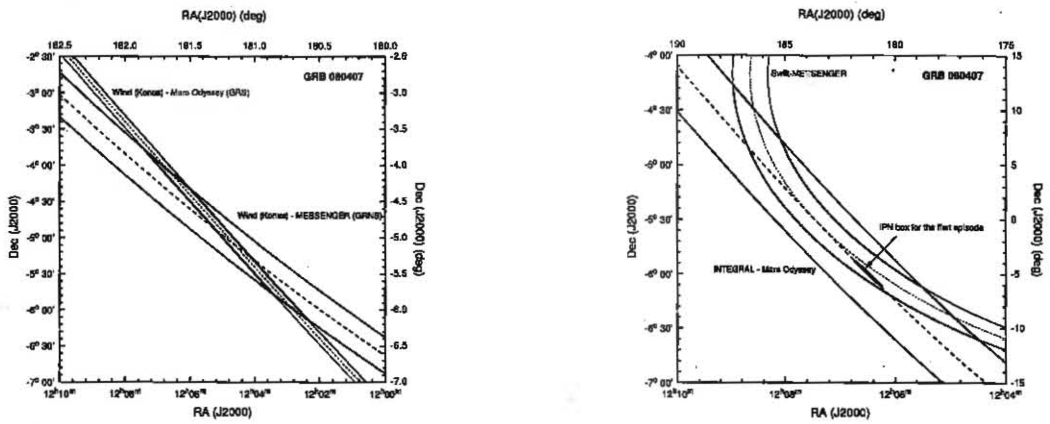

Figure 2: IPN error boxes for GRB 080407. *Left:* for the first episode. *Right:* for the second episode.

Table 1: IPN localization of GRB 080407

	first episode		second episode	
	RA(2000), deg	Dec(2000), deg	RA(2000), deg	Dec(2000), deg
Center	181.151 (12h 04m 36s)	-5.110 (-5d 06' 34")		
Corner1	180.589 (12h 02m 21s)	-6.136 (-6d 08' 11")	187.413 (12h 29m 39s)	+12.295 (+12d 17' 42")
Corner2	180.851 (12h 03m 24s)	-5.789 (-5d 47' 22")	185.204 (12h 20m 49s)	+7.311 (+7d 18' 39")
Corner3	181.852 (12h 07m 24s)	-3.787 (-3d 47' 13")	178.760 (11h 55m 02s)	-6.199 (-6d 11' 56")
Corner4	181.499 (12h 06m 00s)	-4.327 (-4d 19' 38")	176.185 (11h 44m 44s)	-11.005 (-11d 00' 17")

two bursts in $t \sim 1500$ s (that is for the IPN detection rate, R, of ~250 GRBs/year (for 2008), $p = 1 - \exp(-Rt) \sim 0.012$) to get $\sim 5 \times 10^{-6}$. Multiplying this number by a total number of GRBs detected by the 3rd IPN so far (~ 6000), we get the 3% probability of observing such close (in time and on the sky) pair of IPN events for all 3rd IPN history. Actually this probability is significantly overestimated since we counted all IPN bursts, but not only bright enough detected by the least sensitive instrument in the IPN like MO HEND.

This simple estimation shows that these episodes likely belong to the same ultra-long GRB.

3. Spectral analysis and energetics

Konus-Wind spectral data from 20 to 1200 keV for the first episode were fitted by GRBM (Band) model for three specific time intervals denoted on Figure 1. The results are given in Table 2. All spectra show high-energy power-law tail with beta ~-2.3. The spectrum of the weaker pulses at ~T_0+117 s is significantly softer (in terms of E_{peak}) than the spectrum of the initial bright pulse.

Using the parameters of the time-integrated spectrum (Int. C), the calculated fluence of this episode is $(1.43 \pm 0.04) \times 10^{-4}$ erg cm^{-2}, and the peak flux is $(7.76 \pm 0.38) \times 10^{-6}$ erg cm^{-2} s^{-1} as measured from 10.4 s on a 1 s timescale (both in the 20–1000 keV).

There are no spectral data for the second episode. Comparison of the counts accumulated on several time intervals by different instruments shows that the hardness of the second episode is closer to the hardness of the weaker pulses of the first episode. Using a conversion factor of 1 SPI-ACS count = $(4.1 \pm 0.5) \times 10^{-10}$ erg cm^{-2} (obtained for the weaker pulses of the first episode; for

Table 2: Spectral parameters of GRB 080407 for three time intervals denoted on Fig. 3. All errors are at 90% CL.

Int	Tstart (s)	dT (s)	α	E_{peak} (keV)	β	χ^2/dof (prob.)
A	0	43	-1.02±0.06	325^{+29}_{-25}	$-2.43^{+0.16}_{-0.27}$	60.8/59 (0.41)
B	117	41	$-1.49^{+0.76}_{-0.37}$	114^{+77}_{-44}	-2.25(<-2.02)	48.3/59 (0.84)
C (total)	0	158	$-1.15^{+0.10}_{-0.09}$	287^{+42}_{-35}	$-2.35^{+0.20}_{-0.40}$	57.1/59 (0.54)

Table 3: Ultra-long GRBs

GRB	Tstart s UT	dT s	Fluence erg cm^{-2}	lc shape	z	E_{iso} erg	Refs.
840304	?	~1200	$\sim 2.8 \times 10^{-3}$	Two broad pulses (~200 s) + extended tail (*sim*1000 s)	-	$\sim 7.6 \times 10^{54}$ (for z=1)	[1]
971208	28092 (07:48:12)	~2500	$(2.55 \pm 0.11) \times 10^{-4}$	Single smooth FRED-like pulse	-	$\sim 6.9 \times 10^{53}$ (for z=1)	[2],[3],[4]
020410	38380 (10:39:40)	~1600	$\sim 2.8 \times 10^{-5}$	Multi-episode	≃0.5	$\sim 1.8 \times 10^{52}$	[5],[6]
060814B	37070 (10:17:50)	~2700	$(2.35 \pm 0.22) \times 10^{-4}$	Single smooth FRED-like pulse	-	$\sim 6.4 \times 10^{53}$ (for z=1)	[4]
080407	74529 (20:42:09)	~2100	$\sim 4.5 \times 10^{-4}$	Multi-episode	-	$\sim 1.2 \times 10^{54}$ (for z=1)	this work
091024	32161 (08:56:01)	~1200	$(1.13 \pm 0.12) \times 10^{-4}$	Multi-episode	1.09	$\sim 3.5 \times 10^{53}$	[7],[8],[9]

the initial pulse this factor is $(2.31 \pm 0.04) \times 10^{-10}$ erg cm^{-2} cnt^{-1}), the estimated fluence of this episode is $\sim 3 \times 10^{-4}$ erg cm^{-2}. So the total fluence of GRB 080704 is about 4.4×10^{-4} erg cm^{-2} (20–1000 keV).

4. Comparison with other ultra-long GRBs

Table 3 contains a comparison of the parameters of the six classical gamma-ray bursts with duration >1000 s. It does not include very long underluminous XRFs like XRF 060218, which thought to be a different phenomenon than classical GRBs. The table also does not list several ultra-long GRB candidates found in the BATSE data [11], since belonging of different emission episodes to the same burst can not be established with enough reliability.

Only a short note on GRB 840304 has been published, so it is not quite clear whether it really belongs to ultra-long GRBs and has a very large fluence.

In common these ultra-long GRBs have large fluences (except GRB 020410 which has rather moderate fluence) due to their very long durations and rather hard spectra with E_{peak} of hundreds keV. But they have quite different morphology: GRB 971208 and GRB 060814B shows a single, smooth, FRED-like pulse, whereas GRB 020410, GRB 080407, and GRB 091024 show several emission episodes separated by long period(s) of quiescence.

There is also a difference in the light curves of GRB 080407 and two other multi-episode bursts: GRB 080407 shows a bright initial pulse followed by substantially weaker pulses, whereas GRB 020410 and GRB 091024 do not demonstrate decreasing of pulse intensities with time (in contrary, the last pulse of GRB 091024 is brighter that the first one). But in all three cases the initial pulse is significantly harder than subsequent ones.

5. Summary

Only a few ultra-long GRBs (with durations > 1000 s) have been reported to date. We have presented observations of GRB 080407, probably the longest multi-episode GRB detected so far. The measured burst fluence of $\sim 4 \times 10^{-4}$ erg cm^{-2} (20–1000 keV) is among the largest observed in long GRBs.

This burst demonstrate similarities with other ultra-long bursts: long quiescent time between the episodes (~1500 s), spectral evolution from hard initial pulse to significantly softer subsequent pulses, and large fluence.

The duration of the second emission episode of GRB 080704 (that following the quiescent time) is substantially longer that the duration of the first episode that is a common feature of long GRBs. The existence of such long quiescent times may favor the dormant inner engine scenario over wind modulation models [2].

Without knowledge of the burst redshift it is not possible to determine rest frame properties of the burst, but its large fluence and high E_{peak} suggest a moderate z of ~1–2. In such a case, the rest frame burst duration of ~1000 s and the rest frame quiescence time of ~500 s can pose a problem for some central engine model in the framework of the collapsar scenario. Specifically such long durations might be hard to explain in the magnetar model of long GRBs.

The Konus-Wind experiment is supported by a Russian Space Agency contract and RFBR grant 12-02-00032a.

References

[1] Connaughton, V., et al., *GRB 971208, IAUC* **6785** (1997)

[2] Drago, A., & Pagliara, G., *Quiescent Times in Gamma-Ray Bursts: Hints of a Dormant Inner Engine, ApJ*, **665** (2007) 1227

[3] Giblin, T. W., et al., *Extended Power-Law Decays in BATSE Gamma-Ray Bursts: Signatures of External Shocks?, ApJ*, **570** (2002) 573

[4] Golenetskii, S., et al., *Konus-Wind and Konus-RF observations of GRB 091024, GCN Circ.*, **10083** (2009)

[5] Gruber, D., et al., *Fermi/GBM observations of the ultra-long GRB 091024. A burst with an optical flash, A&A*, **528** (2011) A15

[6] Klebesadel, R. W., Laros, J. G., & Fenimore, E. E. *The Unusual Gamma-Ray Burst of March 4, 1984, BAAS*, **16** (1984) 1016

[7] Levan, A., et al., *GRB 020410: A Gamma-Ray Burst Afterglow Discovered by Its Supernova Light, ApJ*, **624** (2005) 880

[8] Marshall, F. E., et al., *GRB 091024: Swift detection of a burst, GCN Circ.*, **10062** (2009)

[9] Nicastro, L., et al., *Multiwavelength study of the very long GRB 020410, A&A*, **427** (2004) 445

[10] Pal'shin, V. et al., *Extremely long hard bursts observed by Konus-Wind, AIP Conference Proceedings*, **1000** (2008) 117

[11] Tikhomirova, Ya. Yu., & Stern, B. E., *Superlong Gamma-Ray Bursts, Astronomy Letters*, **31** (2005) 291