Classification of short GRBs. Merging and postmerging.

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Abstract We represent a review of the short GRBs classification problem. We took four largest GRBs catalogs: BATSE, BeppoSAX, Swift and Fermi and, as a first approximation, constructed duration distributions for short GRBs, that is GRBs shorter than 2 seconds. It turned out that on 0.1, 0.2 and 1 seconds we have statistical peaks which we associate with different types of binary mergers. The multimessenger astronomy allows us to come closer to a binary mergers analysis by gravitational-wave observations. Also we offer a new test for existence of event horizon through it.

Key words: Gamma-Ray Bursts, Binary Merges, Gravitational Waves.

1. Introduction

According to modern ideas, GRBs are classified in two types: long-soft and short-hard ones. Long-duration bursts last from 2 seconds up to a few hundreds of seconds (several minutes), with an average duration of about 30 seconds. They are associated with the collapse of massive stars in supernovas. Short-duration bursts last less than 2 seconds lasting from a few milliseconds up to 2 seconds with an average duration of about 0.3 seconds (or 300 milliseconds). These bursts are associated with binary mergers. The example of duration distribution is shown in Figure 1.

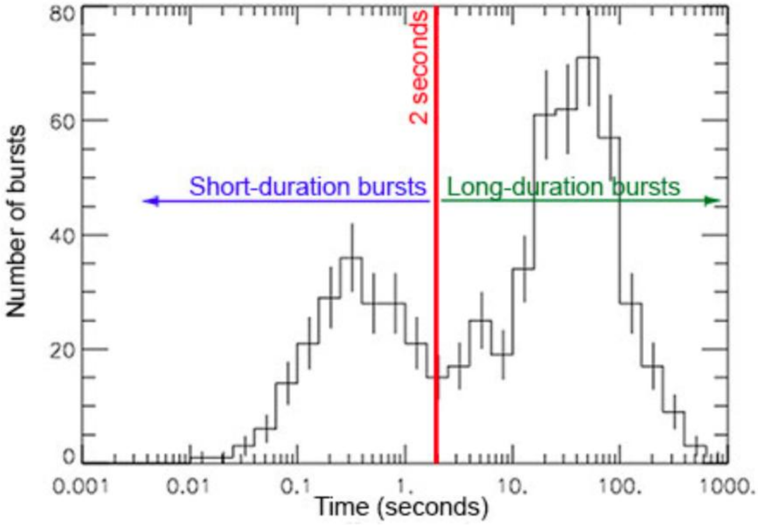


Fig1. *Graph of the time versus number of bursts for the gamma-ray bursts observed by the BATSE instrument on the Compton Gamma-ray Telescope [26].*

However, the classification can be more detailed. So, in a paper by Ruffini R. (2018) [21] seven types of the short GRBs are proposed. The separation is based on binary merges of different components. Another team of Rueda J.A. (2018) [20] introduces four subclasses of short GRBs. For example, so-called gamma-ray flashes (GRFs), that is, merges of neutron star (NS) and white dwarf (WD) have durations up to 100 seconds. In fact, this is a long GRB, but it is associated with short GRBs. Also authors note that gravitational-wave emission (GWE) must be observed in a range from 10^{-2} to 10^{-1} Hz for merges of WDs and WD with NS. The observing of GWE in the range will confirm existence of the GRFs sources and will explain its physics.

At the present time the gravitational instruments do not register GWE in the range less than 10 Hz. Figure 2 shows spectral sensitivity of modern (aLIGO) and planned (eLISA) instruments.

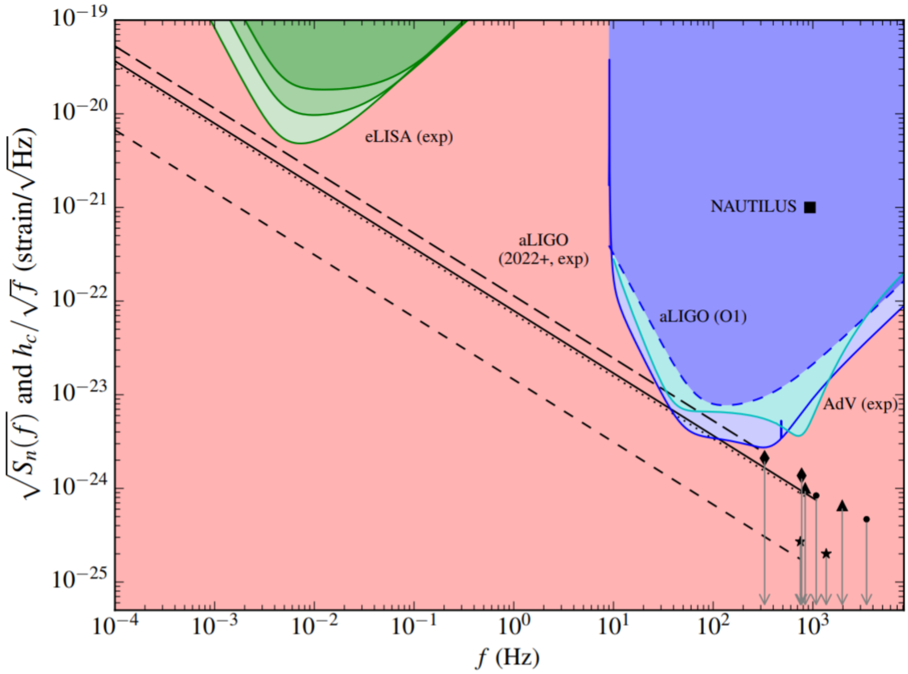


Fig2. *Spectral sensitivity of aLIGO and eLISA gravitational instruments from [22].*

2. Data

We considered four samples without any selections:

- 1234 BATSE GRBs [19];
- 1143 Swift GRBs [12];
- 1028 BeppoSAX GRBs [10];
- 2378 Fermi GRBs [18].

3. Duration analysis

The BATSE GRBs duration distribution in higher resolution is represent in Figure 2a. When the hard gamma-range is included in the histogram of the GRB duration T_{90}, we start seeing features at durations of 0.1-0.5 and 1 second. In our opinion, these features are related to the physics of a GRB source, that is, to different morphology of binary systems. From Figure 2b it is seen that the operating range of the Swift satellite smoothes out the distribution of short GRB durations, however there is still an indication of presence of features at 0.3 and 1 second regions. At the same times the BeppoSAX sample in Figure 2c shows a monotone rate with the strongly marked peak at 1 second. The most interesting result is shown in Figure 2d for the Fermi extended catalog. The distribution allows distinguishing between three peaks at 0.2, 0.5 and 1 seconds.

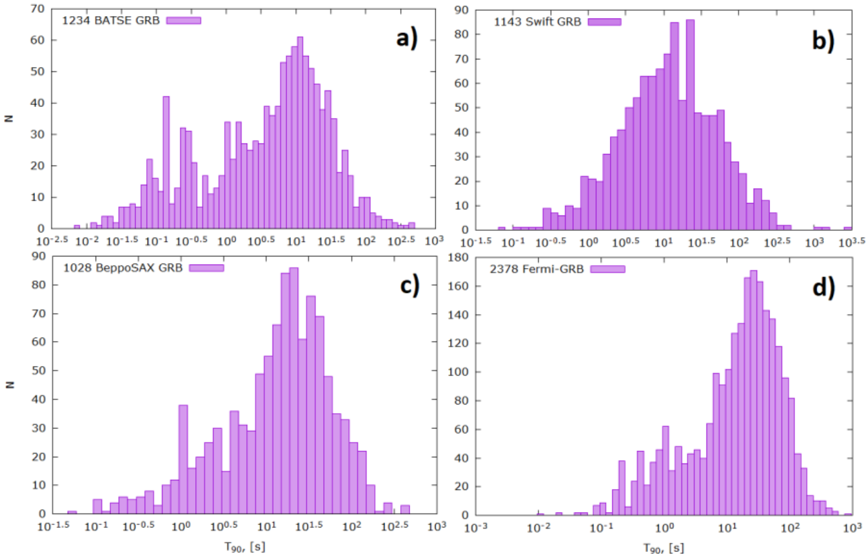


Fig3. *The GRBs duration distributions.*

For more strait result we summed the duration diagrams up to 2 second except of Swift. For this an equal duration steps were taken and all distributions were normalized on the Fermi GRBs number. The result is shown in Figure 4. According to integral result the peaks have duration T_{90} about 0.1, 0.2 and 1 seconds.

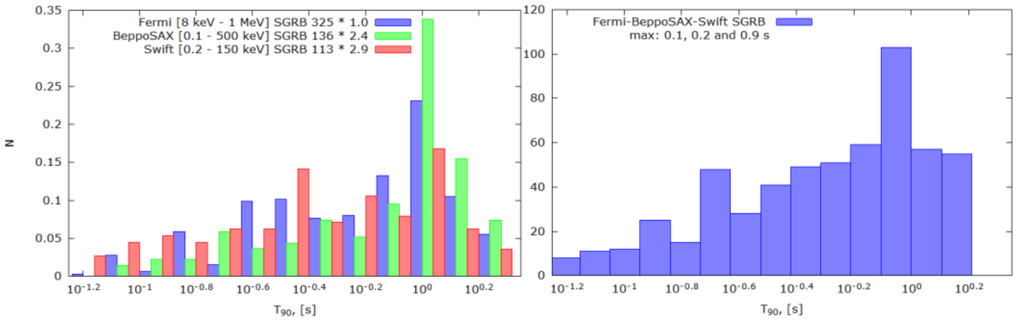


Fig4. *The short-GRB duration distributions for the catalogs (the normed on the Fermi on the left and the summed on the right).*

4. Multimessenger astronomy

In the era of mono-messenger astronomy we were getting all information about the Universe from observations of electromagnetic waves. New era of multi-messenger astronomy discovers for us such information sources as space particles, neutrino, and especially gravitational waves (GWs).

4.1 Solar neutrino

Solar neutrino of three leptonic flavors was discovered:

- Electron ν_e by Clyde Cowan & Frederick Reines in 1956 [9]
- Muon ν_μ by Leon Lederman, Melvin Schwartz & Jack Steinberger in 1962 [5]
- Tau ν_τ by DONUT at Fermilab collaboration in 2000 [1].

4.2 Supernovae neutrino

SN1987a, detected both by optical telescopes and by neutrino observatories, is probably the first example of a multi-messenger astronomical event. It was the first opportunity for modern astronomers to study the development of a supernova in great detail, and its observations have provided much insight into core-collapse supernovae [7]. There is evidences of correlation between gravitational and neutrino detectors [11].

4.3 Indirect evidence of GWs

The Hulse–Taylor binary pulsar PSR 1913+16 was discovered by Hulse Russell Alan and Taylor Joseph Hooton Jr., of the University of Massachusetts Amherst in 1974 [24]. The orbit has decayed since the binary system was initially discovered, in precise agreement with the loss of energy due to gravitational waves described by General Relativity. The ratio of observed to predicted rate of orbital decay is calculated to be 0.997±0.002 [25].

4.4 Observations of GWs

The first direct observation of gravitational waves was made on 14 September 2015 and was announced by the LIGO and VIRGO collaborations on 11 February 2016 [4]. The first observation of the coalescence of two compact objects through gravitational-wave instrument and gamma-ray telescopes is registered on 17 August 2017. The merger event has provided a signal in gravitational waves (GW170817) detected by Advanced LIGO and Advanced VIRGO, that has allowed us to localize the binary constraining a sky region of 31 deg^2 and a distance of a 40±8 Mpc. Moreover, Fermi Gamma-ray Burst Monitor has detected a short Gamma-Ray Burst event (GRB170817A) delayed by 1.7 second with respect to the merger time. Later, 15.3 hours after the trigger, the source was detected in the ultraviolet by the Swift Gamma-Ray Burst Mission [2].

5. Gravitational-wave afterglow

The recent research of GWs was made in [3]. In Figure 5 we see the waveforms of 10 gravitational events. Upper panels demonstrate relativistic modeled searches of waveform and bottom panels show unmodeled waveform searches. The frequency distribution is on the left. All unmodeled waveforms give a postmerging signal different from prediction of General

Relativity (GR) [15].

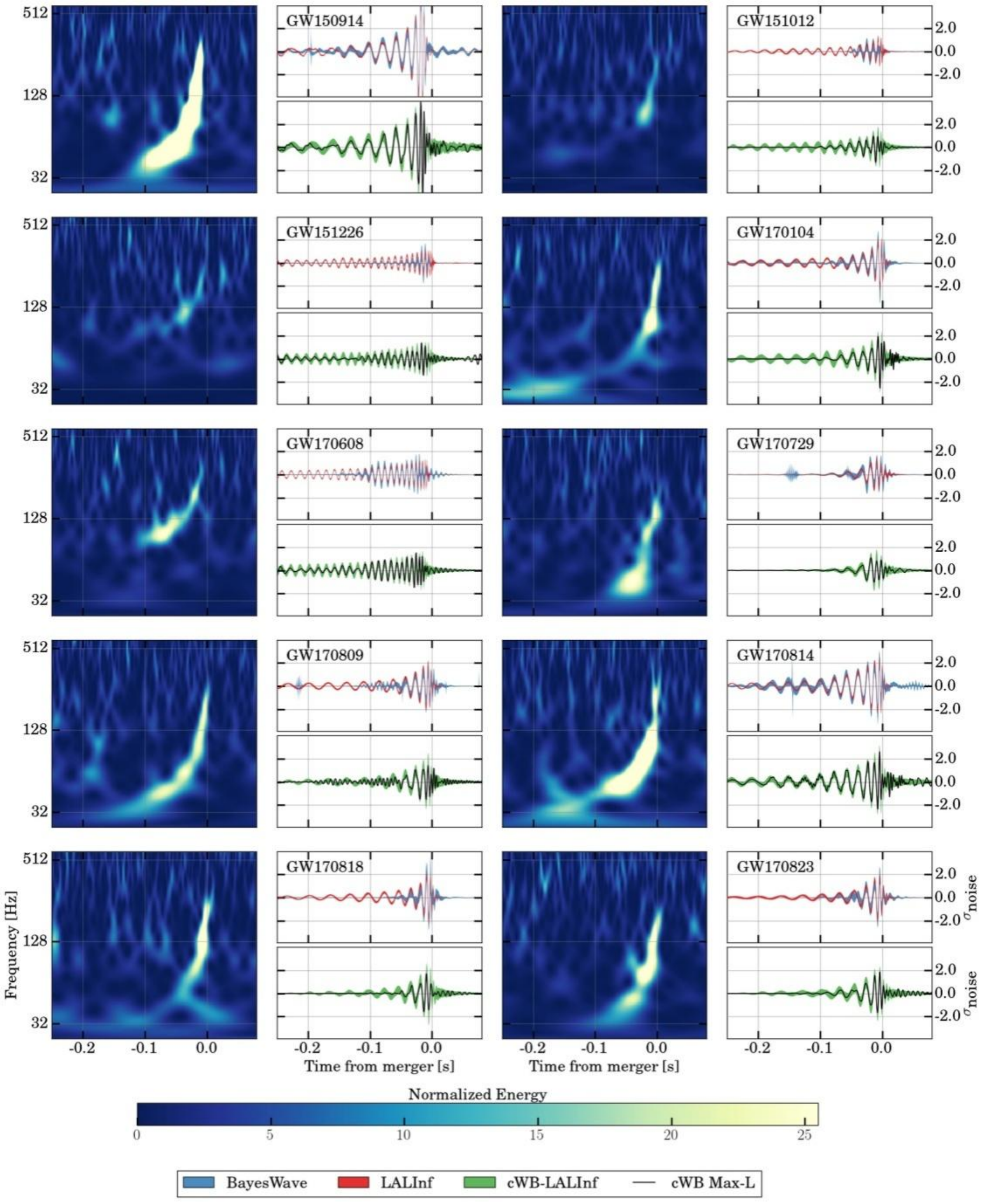


Fig5. *The waveforms of 10 gravitational events from paper [3].Upper panels demonstrate relativistic modeled searches of waveform and bottom panels show unmodeled waveform searches. On the left is a frequency distribution.*

The RCO postmerging represents a rare opportunity to test nature of merging objects. The event waveform consists of three stages: insprial motion of an RCO, merging and postmerging. In the simplest case two gravitationally related bodies with masses m_1 and m_2, moving non-relativistically in circular orbits around their common center of mass at a distance r from each other, emit gravitational waves of the next power averaged over the period:

$$-\frac{d\mathcal{E}}{dt} = \frac{32\, G^4 m_1^2 m_2^2\, (m_1 + m_2)}{5\, c^5 r^5}. \tag{1}$$

As a result, the system loses energy, what leads to the convergence of bodies. The rate of orbital decay can be approximated by

$$\frac{\mathrm{d}r}{\mathrm{d}t} = -\frac{64}{5}\,\frac{G^3}{c^5}\,\frac{(m_1 m_2)(m_1 + m_2)}{r^3}\ , \tag{2}$$

where r is the separation between the bodies, t is the time, G is the gravitational constant, c is the speed of light, and m_1 and m_2 are the masses of the bodies. This leads to an expected time to merger of

$$t = \frac{5}{256}\,\frac{c^5}{G^3}\,\frac{r^4}{(m_1 m_2)(m_1 + m_2)}. \tag{3}$$

The merging stage is a relativistic collapse (see e.g. [17]). In the postmerging stage the GWs (gravitational-wave afterglow) emitted by an RCO rotating with period P and having ellipticity ε have the luminosity

$$L_{\mathrm{GW}} = \frac{2048\pi^6 G}{5c^5}\,\frac{I^2\varepsilon^2}{P^6}\ . \tag{4}$$

It is impossible to make an accurate estimate by formula (4), because $L_{GW} \sim \varepsilon^2$ which, generally speaking, is unknown. For the Crab Pulsar, e.g., $\varepsilon \sim 10^{-2}$, $L_{GW} \sim 10^{38}$ erg/s.

6. Discussion

In all missions (except Swift) there are peaks at short duration of T_{90}, which must indicate objects with different energies and masses, for example NS+NS. It should be noted that T_{90} may drift with a rate of redshift as an instrumental effect (e.g. Kasevski [14]). Therefore, the duration profile must be considered in different redshift ranges. This and other aspects of GRBs research requires rich redshifts and durations sample, which may appear due to the THESEUS mission. Also the GRBs duration significantly depends on instrument spectral sensitivity [8, 28]. For example, GRB 150101B has a duration of 0.018 second in the Fermi and of 0.080 second in the Swift (see Table 1 in Appendix).

Very interest results for us were obtained in the Konus-*Wind* experiment [22]. In Figure 6 the GRBs hardness-duration distribution is shown. One can see that the short-hard GRBs and long-soft GRBs distributions are localized and, cconsequently, these are two different subsamples which should be separated in the cosmological tests performed by GRBs.

According to GR there is no gravitational-wave afterglow [15]. The simulations show that GWs from the merging of objects having an event horizon are fade out quickly [27], that is, all information goes beyond measuring instruments. However, it may be a consequence of low sensitivity of gravitational-wave instruments, but not the absence of this effect. At present, there is no direct proof of existence of objects with the event horizon. It may be a collision of relativistic compact objects (RCO) with a gravitational-wave afterglow. If such an afterglow is actually observed, then the problem of existence of objects of another nature (e.g. strange quark stars) is raising and the development of appropriate physics is required. In the alternative case of gravitational-wave afterglow we can obtain important information about nature of the objects including the equation of state.

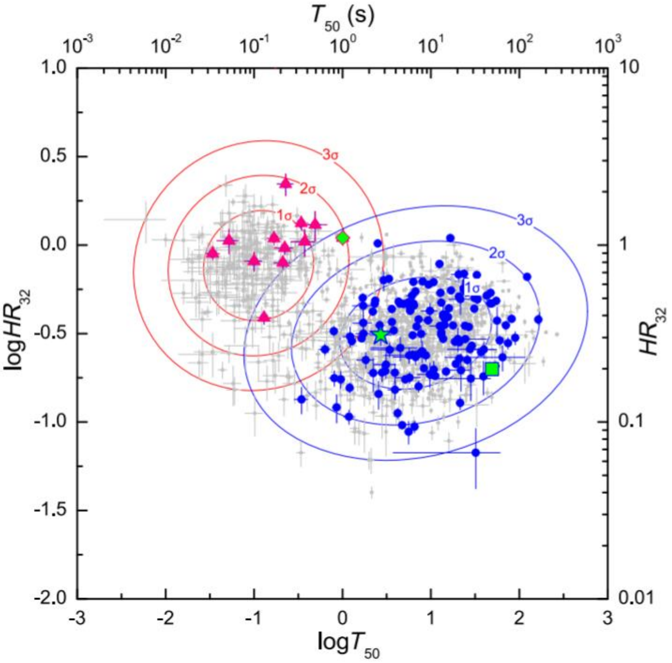


Fig6. *The hardness-duration distribution of GRBs with known redshifts detected by the Konus-Wind experiment from paper [23].*

Field gravity theories are an alternative of GR. In such field theories there is no event horizon (see e.g. [13]). Also we do not know the equation of state for a RCO with masses greater than 1-3 solar masses [29].

7. Conclusion

Based on last results of the GWs observations we can conclude with a high probability that any geometric gravitational theory in the postmerging stage does not work. We have very little information about this, but it is enough to make this assumption.

Our summary:

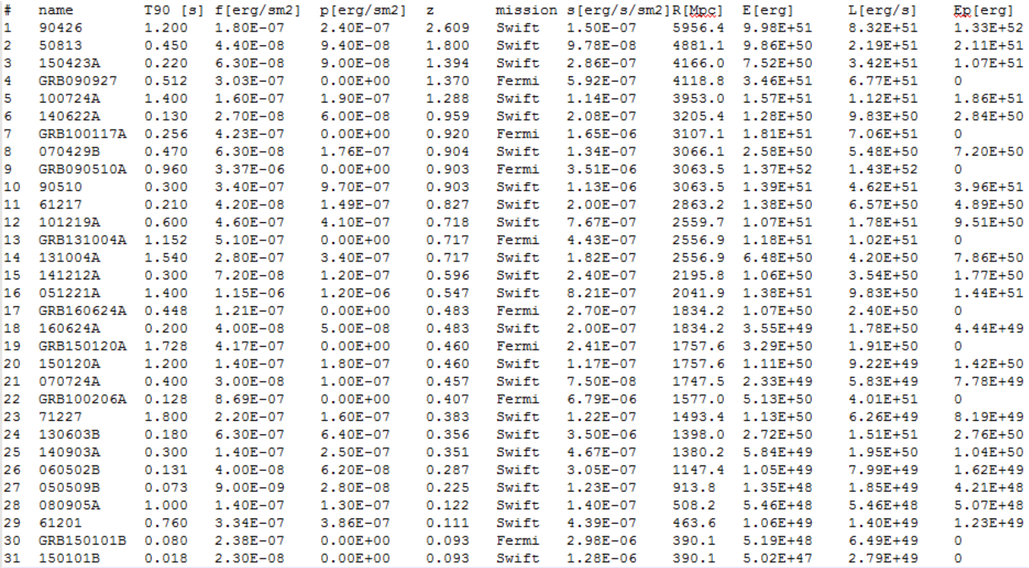
- Short GRBs are divided into subclasses by the type of merging components in binary systems. The SGRBs duration of T_{90} can reach several minutes.
- The prospects of the understanding of the RCO nature by neutron stars is a very actual problem for the modern physics.
- Progress of sensitivity in the future (or a closer burst) will allow us to see a fine

structure of the gravitational-wave afterglow signal. This method is an alternative of the Event Horizon Telescope and its cost is cheaper.

Recently, the extended emission (EE) in gravitational radiation during GRB170817A was discovered in [16]. This is possibly the first evidence of the gravitational-wave afterglow signal.

Appendix

Table1. *A short GRBs catalog of the Swift and Fermi missions.*



#	name	T90 [s]	f[erg/sm2]	p[erg/sm2]	z	mission	s[erg/s/sm2]	R[Mpc]	E[erg]	L[erg/s]	Ep[erg]
1	90426	1.200	1.80E-07	2.40E-07	2.609	Swift	1.50E-07	5956.4	9.98E+51	8.32E+51	1.33E+52
2	50813	0.450	4.40E-08	9.40E-08	1.800	Swift	9.78E-08	4881.1	9.86E+50	2.19E+51	2.11E+51
3	150423A	0.220	6.30E-08	9.00E-08	1.394	Swift	2.86E-07	4166.0	7.52E+50	3.42E+51	1.07E+51
4	GRB090927	0.512	3.03E-07	0.00E+00	1.370	Fermi	5.92E-07	4118.8	3.46E+51	6.77E+51	0
5	100724A	1.400	1.60E-07	1.90E-07	1.288	Swift	1.14E-07	3953.0	1.57E+51	1.12E+51	1.86E+51
6	140622A	0.130	2.70E-08	6.00E-08	0.959	Swift	2.08E-07	3205.4	1.28E+50	9.83E+50	2.84E+50
7	GRB100117A	0.256	4.23E-07	0.00E+00	0.920	Fermi	1.65E-06	3107.1	1.81E+51	7.06E+51	0
8	070429B	0.470	6.30E-08	1.76E-07	0.904	Swift	1.34E-07	3066.1	2.58E+50	5.48E+50	7.20E+50
9	GRB090510A	0.960	3.37E-06	0.00E+00	0.903	Fermi	3.51E-06	3063.5	1.37E+52	1.43E+52	0
10	90510	0.300	3.40E-07	9.70E-07	0.903	Swift	1.13E-06	3063.5	1.39E+51	4.62E+51	3.96E+51
11	61217	0.210	4.20E-08	1.49E-07	0.827	Swift	2.00E-07	2863.2	1.38E+50	6.57E+50	4.89E+50
12	101219A	0.600	4.60E-07	4.10E-07	0.718	Swift	7.67E-07	2559.7	1.07E+51	1.78E+51	9.51E+50
13	GRB131004A	1.152	5.10E-07	0.00E+00	0.717	Fermi	4.43E-07	2556.9	1.18E+51	1.02E+51	0
14	131004A	1.540	2.80E-07	3.40E-07	0.717	Swift	1.82E-07	2556.9	6.48E+50	4.20E+50	7.86E+50
15	141212A	0.300	7.20E-08	1.20E-07	0.596	Swift	2.40E-07	2195.8	1.06E+50	3.54E+50	1.77E+50
16	051221A	1.400	1.15E-06	1.20E-06	0.547	Swift	8.21E-07	2041.9	1.38E+51	9.83E+50	1.44E+51
17	GRB160624A	0.448	1.21E-07	0.00E+00	0.483	Fermi	2.70E-07	1834.2	1.07E+50	2.40E+50	0
18	160624A	0.200	4.00E-08	5.00E-08	0.483	Swift	2.00E-07	1834.2	3.55E+49	1.78E+50	4.44E+49
19	GRB150120A	1.728	4.17E-07	0.00E+00	0.460	Fermi	2.41E-07	1757.6	3.29E+50	1.91E+50	0
20	150120A	1.200	1.40E-07	1.80E-07	0.460	Swift	1.17E-07	1757.6	1.11E+50	9.22E+49	1.42E+50
21	070724A	0.400	3.00E-08	1.00E-07	0.457	Swift	7.50E-08	1747.5	2.33E+49	5.83E+49	7.78E+49
22	GRB100206A	0.128	8.69E-07	0.00E+00	0.407	Fermi	6.79E-06	1577.0	5.13E+50	4.01E+51	0
23	71227	1.800	2.20E-07	1.60E-07	0.383	Swift	1.22E-07	1493.4	1.13E+50	6.26E+49	8.19E+49
24	130603B	0.180	6.30E-07	6.40E-07	0.356	Swift	3.50E-06	1398.0	2.72E+50	1.51E+51	2.76E+50
25	140903A	0.300	1.40E-07	2.50E-07	0.351	Swift	4.67E-07	1380.2	5.84E+49	1.95E+50	1.04E+50
26	060502B	0.131	4.00E-08	6.20E-08	0.287	Swift	3.05E-07	1147.4	1.05E+49	7.99E+49	1.62E+49
27	050509B	0.073	9.00E-09	2.80E-08	0.225	Swift	1.23E-07	913.8	1.35E+48	1.85E+49	4.21E+48
28	080905A	1.000	1.40E-07	1.30E-07	0.122	Swift	1.40E-07	508.2	5.46E+48	5.46E+48	5.07E+48
29	61201	0.760	3.34E-07	3.86E-07	0.111	Swift	4.39E-07	463.6	1.06E+49	1.40E+49	1.23E+49
30	GRB150101B	0.080	2.38E-07	0.00E+00	0.093	Fermi	2.98E-06	390.1	5.19E+48	6.49E+49	0
31	150101B	0.018	2.30E-08	0.00E+00	0.093	Swift	1.28E-06	390.1	5.02E+47	2.79E+49	0

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