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The short gamma-ray burst – SGR giant flare connection

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Abstract

We review the notion that some extragalactic giant magnetar flares could be mistaken for short cosmic gamma-ray bursts. There are at least two general ways to approach this problem. One is statistical, while the other considers individual bursts. Both methods appear to agree that extragalactic flares can be, and indeed are, present in the short burst population, although the rate of such events remains uncertain. The statistical studies all suggest a rate of ~1–15% in the short GRB sample.

Keywords: Stars; Neutron

1. Introduction

The idea that some short gamma-ray bursts (GRBs) could actually be extragalactic giant magnetar flares is not new by any means, but the observation of the most powerful giant flare to date on 2004 December 27 revived the debate. There are various ways to approach the "how many are there?" question. One relies on the properties of the three well studied giant flares observed to date to make statistical predictions about the number of events which might be masquerading as short gamma-ray bursts. The other is to examine all the short gamma-ray bursts one by one for clues to a possible giant flare origin. Neither method is perfect or definitive; each has its advantages and limitations. In this paper I will briefly review these approaches, which I will call "statistical" and "burst-by-burst" respectively.

2. A quick review

In order to understand the approaches to the question, it is necessary to review the properties of the three closest giant flares observed to date. These are, in chronological order, the 1979 March 5 event from SGR0525-66, the 1998 August 27 event from SGR1900+14, and the 2004 December 27 event from SGR1806-20. Their properties are summarized in Table 1. Since they were all measured by different instruments, most of which were initially saturated to some degree, a precise comparison between them is not possible. However, they clearly resemble one another in their general properties. Note that no radio or optical observations of giant flares have been reported, so our knowledge of them is based on X- and γ-ray measurements.

Giant flares are the most spectacular manifestations of soft gamma repeaters (SGRs). Their time histories are characterized by a very rapid (<1 ms) rise to an intense peak lasting several hundred milliseconds, followed by a much weaker, oscillatory phase which exhibits the period of the neutron star. The spectrum of the peak is very hard and extends to MeV energies. The spectrum of the oscillatory phase is very soft ($kT_{BB} \sim 9$ keV). The most energetic giant flare to date, and the one for which the data are most complete, is that of 2004 December 27 from SGR1806-20, with an isotropic energy of roughly 5×10^{46} erg (Frederiks et al., 2007b; Hurley et al., 2005; Mereghetti et al., 2005; Palmer et al., 2005; Terasawa et al., 2005). The time history of this event is shown in Fig. 1. Viewed from a large distance, only the initial peak of a giant flare would be detectable, and it would resemble a several hundred millisecond

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Table 1
Galactic and possible extragalactic SGR giant flares, in order of increasing energy. The distances to the galactic SGRs are uncertain by about a factor of 2, so the energies are uncertain by about a factor of 4 due to distance alone.

SGR or GRB	Date	Assumed distance (kpc)	E_γ (erg)
GRB970110[a]	1997 January 10	5900 (NGC6946)	2.7×10^{44}
SGR1900+14[b]	1998 August 27	15	4×10^{44}
SGR0525-66[c]	1979 March 5	55 (LMC)	7×10^{44}
SGR0044+42[d]	2007 February 1	780 (M31)	1.5×10^{45}
SGR1806-20[e]	2004 December 27	8.7	8×10^{45}
SGR0331-1439[f]	2005 September 5	130000 (IC328)	1.5×10^{46}
SGR0952+69[g]	2005 November 3	3600 (M81)	7×10^{46}

[a] Crider (2006)
[b] Hurley et al. (1999) and Tanaka et al. (2007)
[c] Mazets et al. (1979)
[d] Mazets et al. (2008)
[e] Frederiks et al. (2007b), Hurley et al. (2005) and Terasawa et al. (2005)
[f] Levan et al. (2008)
[g] Frederiks et al. (2007a) and Hurley et al. (2010)

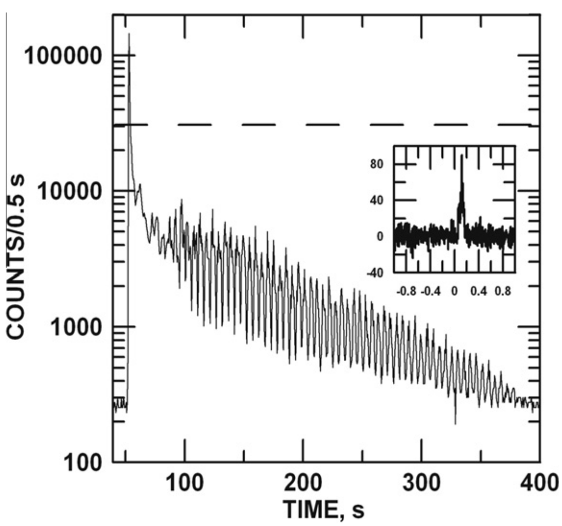

Fig. 1. The RHESSI time history of the 2004 December 27 giant flare from SGR1806-20. The dashed line indicates approximately where the background level of a detector might be relative to this burst, if it were observed from a large distance, leaving only the initial spike detectable. The event might then resemble the one in the inset.

long, hard-spectrum GRB. For example, using the estimates of Terasawa et al. (2005), and assuming a distance of 15 kpc for SGR1806-20, the photon flux and fluence of the peak would be 56 photons $cm^{-2}\,s^{-1}$ and 4.5×10^{-6} erg cm^{-2} at 10 Mpc, respectively. The energetics of giant flares thus make it a virtual certainty that such events can be detected in distant galaxies; by some estimates, the initial spike could be detected to 100 Mpc with a large detector, but the simple detection of this component alone is just a necessary, but not sufficient condition for its correct identification. Recognizing these events as giant flares and demonstrating their origin beyond a reasonable doubt are difficult. The reasons are first, that short gamma-ray bursts tend to have time histories which resemble the initial peaks of giant flares. Second, the short GRBs, like giant flares, tend to have hard energy spectra. Third, the oscillatory phase of a giant flare contains several orders of magnitude less energy than the peak. Scaling down the numbers above results in an event which is all but undetectable, at least in the energy range above about 20 keV; detailed calculations have been reported in Hurley et al. (2010). And finally, associating the localization of a burst with a nearby galaxy will always involve a probability argument based on *a posteriori* statistics, which can be misleading.

Some other facts to keep in mind are first, that no SGR has been observed to emit more than one giant flare so far. Statistical arguments suggest that each SGR could emit perhaps one every 30 years or so, but this is far from certain. Another is that the distances to most SGRs are poorly known. Uncertainties of a factor of 2 are common, and this contributes a factor of 4 to the energetics; other effects, such as detector saturation, increase this factor. Another way of stating this is that the number–intensity relation for SGR giant flares is very uncertain.

Since many studies are based on assumptions about the energy of the 2004 December 27 giant flare, it is also essential to keep in mind that the estimates of its distance vary widely. Bibby et al. (2008) favor 8.7 kpc, but distances up to 15 kpc have been used in the past.

3. Statistical methods

Here we will outline the results of various studies using different statistical approaches to the question.

3.1. Lazzati et al.

Lazzati et al. (2005) noted that one measurement of the spectrum of the giant flare from SGR1806-20 found a good fit to a blackbody function (Hurley et al., 2005). They examined the spectra of 76 short GRBs observed by BATSE for evidence of a blackbody shape, and found only three events which satisfied this criterion. Their conclusions were that either

- up to 4% of the short bursts could be attributed to SGR giant flares, or
- the energies of the galactic giant flares may have been overestimated (for example, if the distances were overestimated), or
- the rate of galactic giant flares has been overestimated.

A cautionary note to keep in mind is that the spectrum of the giant flare from SGR1806-20 was measured by many instruments, using many different methods (Boggs et al., 2007; Frederiks et al., 2007b; Hurley et al., 2005; Palmer et al., 2005), and while they all agreed on the hardness of the spectrum, there was no general agreement on the best-fitting spectral shape. So the restriction of the study to events with blackbody spectra may be too limiting.

3.2. Nakar et al.

Nakar et al. (2006) searched for nearby galaxies in the error boxes of six short-duration hard-spectrum GRBs.

They found none, and concluded that either

- <15% of BATSE short/hard GRBs were SGR giant flares, or
- SGR giant flares can be much more energetic than previously thought, and therefore more distant, or
- SGR giant flares are actually much more rare than suspected, and possibly occur only once in a magnetar's lifetime, or
- the distance to SGR1806 is smaller than previously thought, so the energy of the 2004 December 27 event is smaller than what was estimated.

3.3. Popov and Stern

Popov and Stern (2006) looked for BATSE bursts from four nearby (<3.7 Mpc) galaxies undergoing star formation, and from the Virgo cluster (17 Mpc). They based their search on the assumption of a soft spectrum for the peak of the March 5, 1979 giant flare from SGR0525-66, which is not supported by all the measurements.

They found no plausible candidates, and from their results, they deduced that either

- less than a few percent of BATSE short bursts are giant flares, and giant flares are very rare (they occur perhaps once every 1000 years on a given magnetar, rather than once every 30 years), or
- the distance to SGR1806-20, and therefore the energetics of the December 27, 2004 event, have been overestimated.

However, if their assumption of a soft spectrum is relaxed, they find 10 candidates, and deduce a rate of about one giant flare every 10 years in our Galaxy.

3.4. Tikhomirova et al.

Tikhomirova et al. (2010) examined the relatively small error boxes of 34 interplanetary network short bursts, and have searched them for the presence of nearby galaxies. They found no convincing evidence for any associations, and concluded that less than 7% of the bursts could have come from the galaxies in the PCSz catalog, which they used for the search. This limit applies both to short cosmic GRBs and extragalactic SGRs.

3.5. Tanvir et al.

Tanvir et al. (2005) selected 400 bursts from the BATSE catalog with durations under 2 s. They cross-correlated their positions with those of nearby (<28 Mpc) galaxies in the PCSz catalog, and found a positive correlation. They concluded that 10–25% of short bursts originated at low redshifts ($z < 0.025$). While this does not mean that these bursts are all SGR giant flares, it leaves open the possibility that some of them could be.

3.6. Ofek

Ofek (2007) defined a sample of 47 short bursts localized by the IPN. He searched their error boxes to see if any contained one of 316 bright star-forming galaxies closer than 20 Mpc. From the results, he concluded

- that the rate of giant flares is between 0.00004 and 0.005 per year on a given SGR, and
- that over 1% of all short bursts are SGR giant flares.

These examples show that there are many ways to frame the question statistically, and many corresponding answers to it.

4. The burst-by-burst approach

A handful of short bursts have been suspected to be extragalactic SGR giant flares. These are summarized in Table 1, along with the known, nearby giant flares. Crider (2006) found evidence for a 13.8 s periodicity in the tail of the BATSE burst 970110, and suggested that it could be a giant flare in NGC6946. The Swift burst 050906 was argued to be a giant flare from IC 328 at 138 Mpc (Levan et al., 2008), based on its positional coincidence, and lack of fading X-ray and optical counterparts. The IPN burst 051103 has been discussed as a possible giant flare from M81 (Frederiks et al., 2007a; Hurley et al., 2010; Ofek et al., 2006). The evidence is tantalizing in this case because the time history looks to be about right, the energy spectrum is very hard, and the position of the event is compelling. However, the oscillatory component which is expected in a giant flare is neither detected nor detectable in this case, and the error ellipse does not contain any objects such as supernova remnants which would be expected to be present at the site of an SGR (Hurley et al., 2010). Another event, 070201, similarly has the right time history and energy spectrum to be a giant flare, and its position coincides with that of M31 (Mazets et al., 2008). The energy requirement is reasonable. In this case, there is additional evidence from LIGO, which was operating at the time and could have detected a binary merger in M31, but did not (Abbott et al., 2008). Thus if this burst did *not* originate in M31, it would have had to come from a background galaxy more distant than 3.5 Mpc (the detection limit of LIGO for binary mergers). On the other hand, if it did originate in M31, the only real possibility is that it was a giant flare, because it is not energetic enough to have been a binary merger.

5. Conclusions

The statistical studies carried out so far indicate that between 1% (Ofek, 2007) and 15% (Nakar et al., 2006) of the events in the short GRB sample could be due to SGR giant flares. However, the definitive statistical test to determine the rate of extragalactic giant SGR flares, if one indeed exists, has not been defined yet. Similarly, in the burst-by-burst approach, not all short bursts have been studied yet. Nevertheless, the two methods agree on the fact that some short bursts are quite likely to be extragalactic giant flares. A completely convincing observation of such an event would have to include the detection of the pulsating tail, which distinguishes SGR flares from cosmic bursts. This cannot be done with small detectors, because if all giant flares resemble the galactic events that have been well studied so far, this component is far too weak. However, it is within the reach of the *Swift* satellite; if a giant flare were detected by the BAT, and observed by the XRT within about a minute, the pulsations would be detectable in soft X-rays (Hurley et al., 2005).

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