Soft gamma repeaters and starforming galaxies

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ABSTRACT

We propose that the best sites to search for SGRs outside the Local group are galaxies with active massive star formation. Different possibilities to observe SGR activity from these sites are discussed. In particular we searched for giant flares from M82, M83, NGC 253, and NGC 4945 in the BATSE data. We present a list of potential candidates, however, in our opinion no good candidates alike giant SGR flares were found. Still, hyperflares similar to the one of 27 December 2004 can be observed from larger distances. From the BATSE data we select 5 candidates coincident with the galaxies Arp 299 and NGC 3256 which have very high rate of star formation, and propose that they can be examples of hyperflares; however, this result has low statistical significance.

Key words: gamma rays: bursts —

1 INTRODUCTION

Sources of soft gamma repeaters (SGRs) are one of the most puzzling types of neutron stars. Now at least four of them are known in our Galaxy and in the Large Magellanic Cloud (we refer to Woods & Thompson (2004) for a recent summary of all properties of SGRs). SGRs show three main types of bursts:

- weak bursts, \( L \lesssim 10^{41} \) erg s\(^{-1}\);
- intermediate bursts, \( L \sim 10^{41}-10^{43} \) erg s\(^{-1}\);
- giant flares, \( L \lesssim 10^{45} \) erg s\(^{-1}\).

Weak bursts are relatively frequent. About several hundreds were detected from 4 sources during \( \sim 25 \) yrs, i.e. the average rate is about 1 per month per source. However, these bursts appear in groups during periods of activity of a SGR. Duration is very short, \( \sim 0.1 \) s. Intermediate bursts have typical durations \( \sim \) few seconds and are much more rare. These two types of bursts will not be discussed below.

Giant flares (GFs) are very rare. Only four GFs were observed (however, some authors do not include the burst of SGR 1627-41 on June 18 1998 into this list as it is slightly weaker then the others and shows a different pulse structure). These flares are extremely energetic. Typical duration of the initial spike is about one second or smaller. The rate of GFs is very uncertain as only four were detected, usually it is assumed to be just \( (1/20-1/30) \) yrs\(^{-1}\) per source. The latest GF detected on 27 December 2004 was suggested to be a representative the forth class of bursts – “supergiant flares” or “hyperflares” (HFs). It exceeds previous GFs in the energy release by two orders of magnitude, and below we consider this kind of events separately as they can be observed from larger distances, and potentially can contribute to short-hard GRBs detected by BATSE and other satellites (see Nakar et al. (2005); Hurley et al. (2005) and references therein).

Being very interesting objects SGRs are very rare, probably due to a short life cycle, \( 10^4 \) yrs, which can be connected with a short duration of a magnetar activity. It would be very important to detect these sources outside the Local group of galaxies to increase the sample. Especially it is interesting to understand the birth rate of SGRs and the fraction of NSs which appear as these sources. Any solid data (even upper limits) on the number of GFs and HFs detected from outside of the Local group can help here a lot.

Here we want to discuss a possibility to observe SGRs outside the Local group of galaxies (for previous discussions of extragalactic SGRs see Duncan (2001) and recent e-prints by Nakar et al. (2005); Hurley et al. (2005)). Detection of such objects can give an opportunity to estimate a fraction of NSs which appear as SGRs on larger statistics. In this short note \(^1\) we mainly focus on regions of active starformation.

We will discuss two approaches to find GFs and/or HFs from sources outside the Local group:

- Close-by (\( \lesssim 10 \) Mpc) galaxies with high star formation rate should give the main contribution for detection of GFs. However we should consider this kind of events separately as they can be observed from larger distances, and potentially can contribute to short-hard GRBs detected by BATSE and other satellites (see Nakar et al. (2005); Hurley et al. (2005) and references therein).

- Few galaxies with extreme values of star formation rate are the best sights to search for rare HFs.

\(^1\) This is just a brief discussion note, it is submitted only to the ArXiv, and should be refered by its astro-ph number. More elaborated results will be presented elsewhere (Popov, Stern in prep.).
2 GIANT FLARES FROM LOCAL GALAXIES IN THE BATSE CATALOGUE

As it is discussed by Heckman (1998) inside 10 Mpc about 25% of starformation is due to only four well known galaxies: M82, NGC 253, NGC 4945, and M83 (see Table 1). As probably BATSE could detect GFs similar to the prototype event of 5 March 1979 [Mazets et al. 1972] only from short distances ($\lesssim 3$-5 Mpc), the contribution of these four galaxies can be even more important. The main idea which we put forward here is the following: close-by galaxies with high present day star formation rate are the best sites to search for SGRs outside the Local group.

Supernova (SN) rates presented in the table are approximate ones as there are no estimates better than a factor of 2-3 precision. $^2$ We collected data from different papers. For example, the rate for NGC253 is taken from Engelbracht et al. (1998) (see also Pietsch et al. 2001). In the following we will use the conservative intermediate values: 0.4, 0.2, 0.2, and 0.1 for M82, NGC 253, NGC 4945, and M83 correspondently. In comparison with the Galactic rate of SN, these galaxies have significant enhancement (roughly 12, 6, 6, and 3 times correspondently), so we can expect proportionally higher number of SGRs (and GFs from them). With the galactic rate $\sim 4$ flares in 25 years, for BATSE (4.75 years equivalent of all-sky coverage) we can expect roughly 8-9 GFs from M82, 4-5 GFs from each of NGC 253 and NGC 4945, and 2 GFs from M83 (it total about 20 GFs from four galaxies during the BATSE life cycle).

It is useful to check if in the BATSE catalogue$^3$ there are potential SGR-candidates in these four galaxies. We have to look for short bursts with $T_{50}$ at least less than 2 seconds (the burst from SGR 1627-41 was longer than initial strong spikes from three other SGRs). Another criterium is fluence. Taking into account large distances to host galaxies we do not expect SGR candidates to be bright (expected fluences $\lesssim 10^{-7}$ erg cm$^{-2}$). Then we have to select only relatively soft bursts, as GFs are softer than typical GRBs$^4$.

All GRBs for which at least one of the four galaxies appears inside the error box are given in Table 2. For each burst we give its number, coordinates, error box radius, $T_{50}$ and $T_{90}$, maximum fluence (maximum among four channels), and softness (the ratio of the 1st to the 3rd channel). Coordinates and error box radii are given in degrees.

| Name   | Distance, Mpc | SN rate per year |
|--------|---------------|------------------|
| M 82   | 3.4           | 0.1-0.6          |
| NGC 253| 2.5           | 0.1-0.3          |
| NGC 4945| 3.7          | 0.1-0.5          |
| M 83   | 3.7           | 0.1-0.5          |

2 Note, that distances are also uncertain, but the precision for them is much better.

3 http://cossc.gsfc.nasa.gov/batse/

4 A hard tail in the spectrum of 5 March event starts at $E > 430$ keV [Golenetskii et al. 1979], so it doesn’t influence the third channel with $100 < E < 300$ keV; see also fig. 14.8 in [Woods & Thompson 2004].

3 HYPERFLARES FROM VIRGO AND FROM GALAXIES WITH EXTREME STARFORMATION RATES

The situation with HFs (like the 27 Dec 2004 one) is quite different as the BATSE maximum detection distance for such events is larger by about an order of magnitude. Having a limiting distance $\approx 50$ Mpc we can roughly estimate a number of GFs and HFs from this volume. We assume that this number can be scaled from the galactic one using the number of galaxies or the starformation rate (SFR). Inside 50 Mpc we can use several estimates. For example, Duncan (2001) uses the following expression to obtain an estimate of a number of galaxies similar to the Milky Way: $N_{gal} = 0.0117 h_5^3 R_{50}^2$. For $R = 50$ Mpc we obtain about 1500 galaxies. So, for 4.5 years of observation we can expect nearly 800 GFs and about 200 HFs assuming 3 GFs and 1 HF observed in the Milky Way in 25 years. Similar estimates can be obtained using estimates of Brinchmann et al. (2004) and Gallego et al. (1995). Brinchmann et al. (2004) provide the following value for SFR density at $z = 0.1$: $0.01915 M_\odot /yr/Mpc^3$. Inside 50 Mpc it gives $\approx 10^4 M_\odot /yr/Mpc^3$. SFR for the Milky way is estimated to be few solar masses per year. So, the ratio is about few thousands. Gallego et al. (1995) estimate SFR in star-forming galaxies for $z \lesssim 0.045$ as $0.013 M_\odot /yr/Mpc^3$. It gives $\approx 6800 M_\odot /yr/Mpc^3$ inside 50 Mpc. All three estimates are in good correspondence. So, having one HF in $\sim 30$ years in our Galaxy we can expect few hundreds HFs during the BATSE lifetime potentially detectable by this satellite.

The largest structure up to $R \sim 50$ Mpc is the Virgo cluster of galaxies [see Binggeli et al. 1987 for all details about the cluster]. It includes about 1300 galaxies (including 130 spirals). BATSE should be able to detect HFs from Virgo cluster as fairly strong bursts. It is important to estimate an expected number of GFs and HFs from Virgo. However, there are several galaxies with significantly enhanced starformation. So, roughly we can estimate that the SFR in Virgo is about few hundreds time larger than in our galaxy. We can expect up to one hundred HFs during the BATSE lifetime if we assume the rate in the Galaxy about 1 in 30-40 years.

Despite these optimistic predictions no anisotropy in distribution of short GRBs or any correlations with known type of objects were found. Here we want to adress another possibility — observations of HFs by BATSE from particular galaxies outside the Virgo cluster. Of course, this large

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volume \((R \lesssim 50 \text{ Mpc})\) cannot be dominated by few star-forming galaxies, nevertheless, some peculiar objects can be considered as important targets to search for HFs from extragalactic SGRs. In the Universe there is a small amount of galaxies with extreme SFR – “supernova factories”. They have core collapse SN rate up to two orders of magnitude higher than in the Milky Way. Up to the limiting distance of detection of a HF by BATSE there are two prominent objects of that kind: Arp 299 \cite{Neff_2004} and NGC 3256 \cite{Lipari_2004}. We propose to look for HF candidates in the direction of these two galaxies.\(^5\)

\(^5\) Hurley et al. \citeyear{Hurley_2005} suggested that flares even stronger than the one of Dec 27 can be expected from younger SGRs. Without any doubts the best place to look for them are these two galaxies (and objects similar to them).

### Table 2. GRBs coincident with SF galaxies

| Trigger number | \(\alpha\) | \(\delta\) | Error box | \(T_{50}\), s | \(T_{90}\), s | Maximum fluence | Softness |
|----------------|-----|-----|----------|--------|--------|----------------|---------|
| M82            |     |     |          |        |        |                |         |
| 2054           | 164.33 | 66.15 | 17.91    | —      | —      | —              | —       |
| 2160           | 150.84 | 68.81 | 2.15     | 11.072 | 123.136 | —              | —       |
| 2660           | 157.28 | 70.08 | 3.02     | 6.464  | 16.896  | 79.451e-08    | 0.613   |
| 2821           | 124.84 | 60.59 | 13.53    | 0.152  | 0.392  | 67.355e-09    | 0.122   |
| 3118           | 117.57 | 80.37 | 34.15    | 0.136  | 0.232  | 18.628e-08    | 0.059   |
| 3915           | 96.66  | 65.27 | 61.91    | 0.080  | 0.200  | —              | —       |
| 6219           | 170.66 | 70.18 | 9.54     | 1.856  | 2.752  | 1.1506e-07    | 0.014   |
| 6255           | 148.68 | 60.79 | 12.71    | —      | —      | —              | —       |
| 6488           | 155.76 | 76.41 | 9.94     | 1.152  | 2.240  | 6.3462e-07    | 0.333   |
| 6547           | 155.18 | 62.23 | 13.58    | 0.029  | 0.097  | 1.0350e-07    | 0.129   |
| 7297           | 140.07 | 76.39 | 9.53     | 1.141  | 6.5662e-07 | 0.050   |
| 7552           | 137.56 | 65.9  | 6.15     | 11.648 | 63.296  | 5.8479e-07    | 1.122   |
| 7970           | 136.87 | 64.49 | 8.48     | 0.157  | 0.387  | 6.0876e-08    | 0.343   |
| M83            |     |     |          |        |        |                |         |
| 1485           | 202.01 | -29.98 | 9.65    | —      | —      | 50.284e-08    | 0.501   |
| 1510           | 198.84 | -34.35 | 7.29    | —      | —      | —              | —       |
| 2349           | 203.15 | -31.88 | 6.19    | 1.696  | 4.032  | 21.409e-08    | 0.426   |
| 2384           | 203.8  | -18.21 | 17.81   | 0.128  | 0.192  | 84.657e-09    | 0.309   |
| 2596           | 211.51 | -27.07 | 19.74   | —      | —      | —              | —       |
| 2756           | 209.39 | -23.16 | 9.65    | —      | —      | —              | —       |
| 5444           | 199.44 | -31.51 | 4.94    | —      | —      | —              | —       |
| 6447           | 191.44 | -36.6  | 14.77   | 0.256  | 1.024  | 6.0229e-08    | 0.159   |
| 6708           | 206.73 | -29.7  | 3.02    | 3.904  | 12.160 | 1.0452e-06    | 0.051   |
| 7361           | 204.17 | -28.29 | 7.28    | 0.960  | 1.856  | 7.8501e-08    | 0.121   |
| 7385           | 203.02 | -27.81 | 3.59    | —      | —      | —              | —       |
| 8076           | 199.39 | -29.98 | 7.39    | 0.075  | 0.218  | 3.1075e-07    | 0.072   |
| NGC 253        |     |     |          |        |        |                |         |
| 2140           | 9.08  | -24.03 | 4.34    | 6.784  | 19.072 | 48.766e-08    | 1.070   |
| 2312           | 14.72 | -33.56 | 8.93    | 0.112  | 0.272  | 45.113e-08    | 0.082   |
| 2325           | 12.7  | -24.78 | 13.55   | 16.448 | 22.528 | 39.642e-08    | 0.218   |
| 3908           | 11.56 | -27.25 | 7.96    | 5.344  | 13.920 | 59.805e-08    | 0.203   |
| 6135           | 9.06  | -22.84 | 8.79    | 1.856  | 4.032  | 1.4354e-06    | 0.119   |
| 6648           | 10.26 | -26.97 | 2.52    | 24.512 | 88.384 | 1.7639e-06    | 0.061   |
| 6918           | 4.86  | -30.74 | 13.24   | —      | —      | —              | —       |
| 7551           | 13.78 | -24.45 | 3.75    | 53.248 | 119.616 | 6.8409e-07    | 1.665   |
| NGC 4945       |     |     |          |        |        |                |         |
| 108            | 201.31 | -45.41 | 13.78   | 1.280  | 3.136  | 14.604e-07    | 0.259   |
| 1167           | 209.4 | -45.74 | 10.04   | 7.552  | 24.576 | 22.754e-08    | 0.330   |
| 2405           | 197.74 | -44.32 | 11.28   | 25.088 | 64.014 | 83.646e-08    | 0.155   |
| 2800           | 200.29 | -47.94 | 15.92   | 0.320  | 0.448  | 35.153e-08    | 0.072   |
| 3895           | 189.39 | -47.72 | 6.99    | 0.384  | 0.768  | 42.483e-09    | 0.135   |
| 6447           | 191.44 | -36.6  | 14.77   | 0.256  | 1.024  | 6.0229e-08    | 0.159   |

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Table 3. GRBs coincident with extreme SF galaxies

| Trigger number | α     | δ      | Error box | T₅₀, s | T₉₀, s | Maximum fluence |
|----------------|-------|--------|-----------|--------|--------|----------------|
| Arp 299        | 2265  | 180.2  | 59.57     | 8.32   | 0.256  | 0.456          |
|                | 3118  | 117.57 | 80.37     | 34.15  | 0.136  | 0.232          |
|                | 6547  | 155.18 | 62.23     | 13.58  | 0.029  | 0.097          |
| NGC 3256       | 2372  | 161.1  | -36.01    | 8.84   | 0.072  | 0.256          |
|                | 2485  | 173.45 | -40.09    | 18.39  | 0.128  | 0.176          |

Knowing a SN rate in a given galaxy we can obtain an estimate of a HF rate. In the Galaxy only one HF in 30 years was observed. (By the way it is roughly coincident with the core collapse SN rate.) The SN rates in Arp 299 and NGC 3256 are about 1 per year. So, we can expect about 1 HF per year from each of them. During the BATSE lifetime few such events can be expected.

The fluence for the 27 Dec event was estimated in Hurley et al. (2005) as 1.36 erg cm⁻². The distance is about 15 kpc. For 40 Mpc (distance to Arp 299 and NGC 3256) we can expect fluences about 10⁻⁷ erg cm⁻².

In the BATSE catalogue ⁶ we looked for short GRBs with known timing and fluences coincident with Arp 299 and NGC 3256. On the whole (among 2704 GRB coordinates of which we used) error boxes of 12 appeared to be coincident with Arp 299 and 6 with NGC 3256. From these set five short hard bursts with known fluences were selected (Table 3): three from the direction of Arp 299 (for one another very short burst – the trigger number 3915 – fluences are not given) and two from NGC 3256 (however, another burst with the trigger number 6278 can be a possible candidate). All five GRBs look like short spikes in the BATSE data. We propose that these 5 GRBs can be good candidates to be HFs. Of course, some amount of events can be coincident with these galaxies by chance, and such a probability is not low.⁷ Still, we think that our finding is worth discussing. Future and present day missions with better angular resolution (like Swift and, probably, Integral and HETE) can shed light on the association of short GRBs with galaxies with high SFR.

4 CONCLUSIONS

We discussed the connection between SGRs and starforming galaxies. Our suggestion is that few well know galaxies with large SFR are the best candidate sites to look for SGR flares. For the case of GFs we especially mention such close-by galaxies as M82, M83, NGC 253, NGC 4945. For HFs we point to “supernova factories” Arp 299 and NGC 3256.

We found 5 candidates (3 in the direction of Arp 299 and 2 in the direction of NGC 3256) which can be HFs.

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⁶ http://cossc.gsfc.nasa.gov/batse/
⁷ For example, three bursts with large error boxes – 3118, 3915 and 6547 – appeared to be coincident both with M82 and Arp 299; and 6447 with M83 and NGC 4945.
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