A search for giant flares from soft gamma-ray repeaters in nearby galaxies in the Konus-*WIND* short burst sample

D. S. Svinkin,[1]★ K. Hurley,[2] R. L. Aptekar,[1] S. V. Golenetskii[1] and D. D. Frederiks[1]

[1]*Ioffe Physical-Technical Institute, Politekhnicheskaya 26, St. Petersburg 194021, Russia*
[2]*Space Sciences Laboratory, University of California, 7 Gauss Way, Berkeley, CA 94720-7450, USA*

ABSTRACT

The knowledge of the rate of soft gamma-ray repeater (SGR) giant flares (GFs) is important for understanding the GF mechanism and the SGR energy budget in the framework of the magnetar model. We estimate the upper limit to the rate using the results of an extensive search for extragalactic SGR GFs among 140 short gamma-ray bursts detected between 1994 and 2010 by *Konus-WIND* using Interplanetary Network (IPN) localizations and temporal parameters. We show that Konus-*WIND* and the IPN are capable of detecting GFs with energies of 2.3×10^{46} erg (which is the energy of the GF from SGR 1806−20 assuming a distance of 15 kpc) at distances of up to ∼30 Mpc and GFs with energies of $\lesssim 10^{45}$ erg (which is the energy of the GF from SGR 0526−66) at distances of up to ≈6 Mpc. Using a sample of 1896 nearby galaxies, we found that only two bursts, GRB 051103 and GRB 070201, have a low chance coincidence probability between an IPN localization and a nearby galaxy. We found the upper limit to the fraction of GFs among short gamma-ray bursts with fluence above ∼5×10^{-7} erg cm^{-2} to be <8 per cent (95 per cent confidence level). Assuming that the number of active SGRs in nearby galaxies is proportional to their core-collapse supernova rate, we derived the one-sided 95 per cent upper limit to the rate of GFs with energy output similar to the GF from SGR 1806−20 to be $(0.6\text{-}1.2) \times 10^{-4} Q_{46}^{-1.5}$ yr^{-1} per SGR, where Q_{46} is the GF energy output in 10^{46} erg.

Key words: gamma-ray burst: general – stars: magnetars.

1 INTRODUCTION

Soft gamma-ray repeaters (SGRs) are thought to be a special rare class of neutron stars (NS) exhibiting two types of bursting emission in gamma-rays. During the active stage, SGRs emit randomly occurring short (∼0.01–1 s) hard X-ray bursts with peak luminosities of ∼10^{38}–10^{42} erg s^{-1}. The bursting activity may last from several days to a year or more, followed by a long quiescent period. Much more rarely, perhaps once during the SGR stage, an SGR may emit a giant flare (GF) with sudden release of an enormous amount of energy ∼$(0.01–1) \times 10^{46}$ erg. A GF displays a short ∼0.2–0.5 s initial pulse of gamma-rays with a sharp rise and a more extended decay which evolves into a soft, long-duration decaying tail modulated with the NS rotation period; see Mereghetti (2013) for a detailed review.

To date, 15 SGRs have been discovered (Olausen & Kaspi 2014), 14 of which are in our Galaxy and one is located in the Large Magellanic Cloud (LMC). The first GF was detected from the LMC

on 1979 March 5 by the Konus experiment on the Venera 11 and 12 interplanetary missions (Golenetskii et al. 1979; Mazets et al. 1979) as well as by the Interplanetary Network (IPN; Barat et al. 1979; Cline et al. 1980, 1982; Evans et al. 1980). So far, only three GFs have been observed, and all of them were detected by the Konus experiments and the IPN. Two recent GFs, from SGR 1900+14 and SGR 1806−20, were preceded by a pronounced increase in bursting activity (Mazets et al. 1999; Frederiks et al. 2007a).

All of the known SGRs are rapidly spinning down X-ray pulsars with spin periods of 2–12 s and persistent X-ray luminosities of 10^{35}–10^{36} erg s^{-1}. The SGRs are thought to belong to a wider class of objects called magnetars. This class also includes anomalous X-ray pulsars (AXPs) and high-B radio pulsars; a recent catalogue lists 26 objects in the magnetar class (Olausen & Kaspi 2014). The distinction between AXPs and SGRs is blurred due to the detection of anomalously high quiescent X-ray luminosity of SGRs and the occasional bursting of AXPs. About half of the known magnetars are associated with star-forming regions or SNRs and appear to be young isolated NS. The spatial distribution of magnetars provides evidence that they are born from the most massive O stars (Olausen & Kaspi 2014). It is believed that the activity of magnetars is related

★ E-mail: svinkin@mail.ioffe.ru

to the presence of a superstrong magnetic field $\sim 10^{13}$–10^{15} G, inferred from the high spin-down rate and other evidence (Duncan & Thompson 1992; Thompson & Duncan 1995, 1996). The first direct measurement of the high spin-down rate of SGR 1806−20 by Kouveliotou et al. (1998) gave strong support to the magnetar nature of SGRs.

Due to the enormous luminosity of the initial pulse, GFs can be detected from SGRs in nearby galaxies. In this case, the initial pulse will be indistinguishable from a short gamma-ray burst (GRB). The rate of SGR GFs and their fraction among short-duration GRBs are important quantities for the understanding of the GF mechanism in the framework of the magnetar model. A limit on the fraction of SGR GFs among short GRBs was estimated in several studies (Lazzati, Ghirlanda & Ghisellini 2005; Palmer et al. 2005; Nakar et al. 2006; Popov & Stern 2006; Ofek 2007) to be $\sim$1–15 per cent; see Hurley (2011) for a detailed review. Two extragalactic GF candidates have been reported and localized by the IPN: GRB 051103 in the M81/M82 group of galaxies (Ofek et al. 2006; Frederiks et al. 2007b; Hurley et al. 2010) and GRB 070201 in the Andromeda galaxy (Mazets et al. 2008; Ofek et al. 2008). However, Hurley et al. (2010) argued that GRB 051103 is unlikely to be an SGR GF in the nearby Universe, mostly due to its extreme peak luminosity of approximately 4.7×10^{48} erg s^{-1}, assuming that it was from an SGR in the M81/M82 group, which is a factor of 10 brighter than the peak luminosity of the GF from SGR 1806−20, which is $(2$–$5) \times 10^{47}$ erg s^{-1} assuming a distance of 15 kpc.

A recently published catalogue of IPN localizations of Konus-*WIND* short GRBs (Pal'shin et al. 2013) contains localizations of 271 short GRBs detected by Konus-*WIND* during its almost 16 yr of continuous full-sky observations. This catalogue allows us to search for GF candidates in the largest well-localized short GRB sample.

In Section 2, we discuss the Konus-*WIND* and IPN sensitivity to GFs. In Section 3, we provide a nearby galaxy sample and discuss its properties. We present in Section 4 the search for Konus-*WIND* short GRBs that spatially coincide with the nearby galaxies and estimate the fraction of GFs among short GRBs. In Section 5, we use results of this search to derive upper limits on the GF rate. Finally, in Section 6 we give concluding remarks.

2 THE KONUS-*WIND* AND IPN SENSITIVITY TO GFs

The Konus-*WIND* instrument (Aptekar et al. 1995) consists of two identical omnidirectional NaI(Tl) detectors. The detectors are mounted on opposite faces of the rotationally stabilized *WIND* spacecraft. Each detector has an effective area of $\sim$80–160 cm^2 depending on the photon energy and incidence angle. Konus-*WIND* has two operational modes: background and triggered. The triggered mode is initiated when the number of counts on one of two fixed time-scales, 1 s or 140 ms, exceeds a preset value. This value is defined in terms of a number of standard deviations above the background ($\approx$9σ). There is a single background measurement period of 30 s duration before the trigger interval. The initial pulse of a GF from a distant galaxy can trigger Konus-*WIND* on the 140 ms time-scale.

Among the three detected GFs, only one, from SGR 1806−20, has well-estimated initial pulse spectral parameters. The parameters were derived using the detection of the flare radiation reflected from the Moon (Frederiks et al. 2007a). The initial pulse spectrum of this GF is well described by a power law with an exponential cutoff [dN/d$E \sim E^{-\alpha}\exp(-E/E_0)$] with
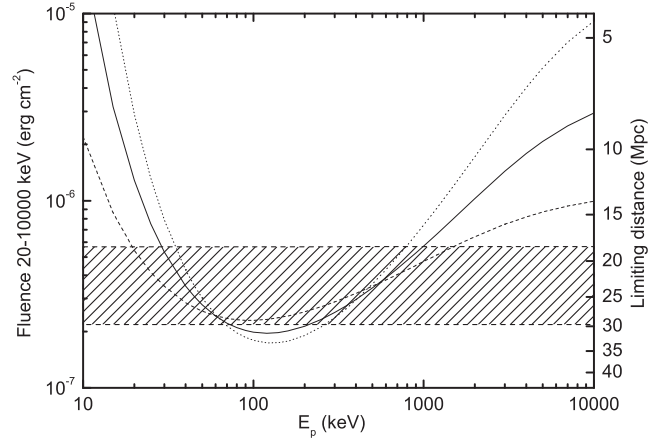

Figure 1. Dependence of the 140 ms fluence (20 keV–10 MeV) and the limiting distance (d_{max}), assuming $Q = 2.3 \times 10^{46}$ erg, on GF spectral parameters E_p and α: $\alpha = 1$ (solid line), $\alpha = 1.5$ (dashed line), $\alpha = 0.5$ (dotted line). The limiting distance for bursts with $E_p \sim 250$–1000 keV is in the range $\sim$18–30 Mpc (dashed region).

$\alpha = 0.73^{+0.47}_{-0.64}$ and $E_0 = 666^{+1859}_{-368}$ keV (or the νF_ν spectrum peak energy $E_p = (2 - \alpha)E_0 = 850^{+1259}_{-303}$ keV), see also Terasawa et al. (2005). Two other GFs are characterized by only rough estimates of E_p: $\sim$400–500 keV (SGR 0526−66; Golenetskii et al. 1979; Mazets et al. 1979) and >250 keV (SGR 1900+14; Hurley et al. 1999; Mazets et al. 1999).

Assuming that all the initial pulse energy is released during the short trigger time-scale (140 ms), we calculated the minimum fluence S_{min} in the 20–10 000 keV band which produces a 9σ increase in the count rate in the 50–200 keV energy range using forward folding of an incident photon spectrum through the detector response matrix. For calculations, we used an average background count rate of 400 counts s^{-1} in the 50–200 keV energy range.

We found that S_{min} strongly depends on the burst spectral hardness (E_p and α). The known E_p range of about 200–1000 keV corresponds to $S_{min} = (2.1$–$5.7) \times 10^{-7}$ erg cm^{-2} (Fig. 1). Then, the corresponding limiting detection distance was calculated as $d_{max} = \sqrt{Q/(4\pi S_{min})}$, where Q is the GF energy output.

The IPN (Hurley et al. 2013) is a set of gamma-ray detectors on board several spacecraft orbiting the Earth, Mars, and Mercury. The IPN allows near-continuous, all-sky coverage and provides accurate sky locations determined by triangulation between the spacecraft in the network using GRB photon arrival times. Each pair of spacecraft constrains the GRB position to an annulus on the celestial sphere, and the intersection of two or more annuli forms an error box. Depending upon the spacecraft involved, the error box areas can vary from square arcminutes to thousands of degrees.

We investigated the dependence of the IPN error box area on the Konus-*WIND* fluence (20–10 000 keV) over the 140 ms interval with the highest count rate and found no prominent correlation (Fig. 2). So, the IPN sensitivity to short GRBs in terms of the error box area does not depend on the Konus-*WIND* burst fluence. Therefore, S_{min} can be taken as the IPN sensitivity to short GRBs.

The distance estimates for SGR 1806−20 range from about 6 to 19 kpc (Tendulkar, Cameron & Kulkarni 2012); the most recent analysis of Svirski, Nakar & Ofek (2011) gives the range 9.4–18.6 kpc. The isotropic energy release of the initial pulse of the GF from SGR 1806−20 ($Q = 2.3 \times 10^{46}d_{15}^2$ erg) implies a limiting distance $d_{max} = (18$–$30) \times d_{15}$ Mpc, where $d_{15} = d/15$ kpc and d is the distance to SGR 1806−20. The range of d_{max} corresponds
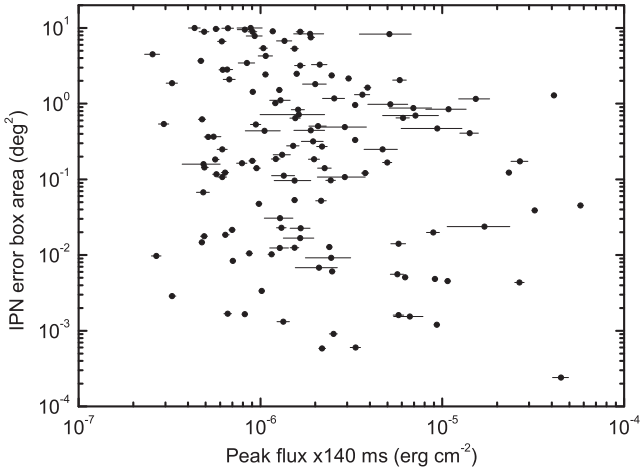
Figure 2. IPN error box area versus Konus-*WIND* fluence (20–10 000 keV) over the 140 ms interval with the highest count rate.

to the S_{min} range. Less intense GFs with $Q \approx 1 \times 10^{45}$ erg (like the 1979 March 5 GF from SGR 0526−66) can be detected up to $d_{max} = (3.8\text{-}6.3)Q_{45}^{0.5}$ Mpc, where Q_{45} is the GF energy output in 10^{45} erg.

3 THE GALAXY SAMPLE

The Gravitational Wave Galaxy Catalogue (GWGC; White, Daw & Dhillon 2011) contains over 53 000 galaxies within 100 Mpc. Our initial sample includes 8112 of them within a distance 30 Mpc. The distance uncertainty in the sample ranges from 15 to 22 per cent. Using the method suggested by Ofek (2007), we estimate the completeness of the galaxy sample due to obscuration by the Galactic plane to be $\epsilon_G = 94$ per cent. Under the assumption that all SGRs are young isolated NS, we postulate that the number of SGRs is proportional to the galaxy core-collapse supernova (CCSN; SN types Ib/c and II) rate.

Following Cappellaro, Evans & Turatto (1999) and Böser et al. (2015), we assume that the galaxy's blue luminosity L_B is a good estimator of the galaxy CCSN rate $R_{SN} = kL_B$, where k is a factor depending on the galaxy type: $k_{E\text{-}S0} < 0.05$, $k_{S0a\text{-}Sb} = 0.89 \pm 0.33$, $k_{Sbc\text{-}Sd} = 1.68 \pm 0.60$, $k_{Sm,Irr,Pec.} = 1.46 \pm 0.71$, where k is given in SNu [1SNu = 1SN$(100\,\text{yr})^{-1}(10^{10}\,\text{L}_{\odot B})^{-1}$] and $\text{L}_{\odot B} = 2.16 \times 10^{33}$ erg s^{-1} is the Sun's blue luminosity. The L_B of a galaxy was calculated as $L_B = 10^{-0.4(M_B - M_{\odot B})} \text{L}_{\odot B}$, where $M_{\odot B} = 5.48$ is the Sun's absolute blue magnitude.

The initial galaxy sample contains 790 galaxies without any given L_B, so the L_B sample completeness is about $\epsilon_L = 90$ per cent. Among the 7322 galaxies with a given L_B, 2405 have an unknown morphological type. These galaxies are, on average, about 3 mag dimmer than those with a given type, and they contain less than 7 per cent of the cumulative supernova rate, so we do not take them into account. Then, we limited our final sample to 1896 galaxies with the highest R_{SN} which contain $\epsilon_{SN} = 90$ per cent of the cumulative R_{SN} and have morphological types other than E and S0. The sky surface density of these galaxies is 0.046 deg^{-2}. The cumulative supernova rate for this sample is $R_{SN} = 22.8 \pm 0.4$ yr^{-1}.

We compared the estimated volumetric R_{SN} for the 1896 galaxies with the lower limit for the local CCSN rate (distances up to 15 Mpc) derived by Mattila et al. (2012) which is $1.9^{+0.4}_{-0.2} \times 10^{-4}$ yr^{-1} Mpc^{-3}. The volumetric R_{SN} is shown in Fig. 3. The volumetric R_{SN} derived from the galaxy blue luminosity is consistent within 1σ with the
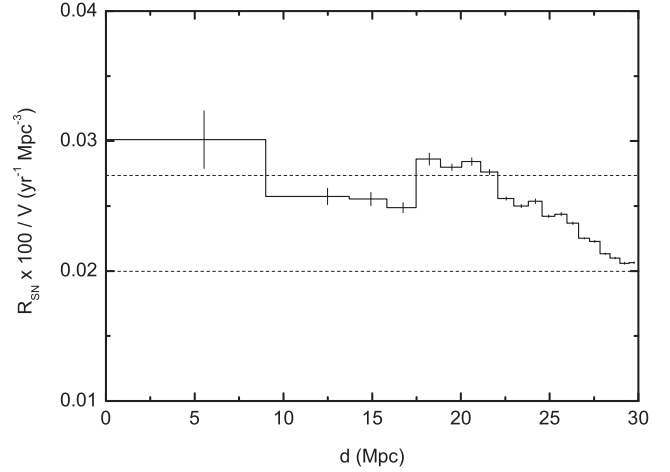

Figure 3. Distance dependence of the local volumetric CCSN rate R_{SN}/V, where V is a volume within distance d. The solid line is R_{SN}/V for 1896 galaxies within 30 Mpc. The horizontal dashed lines denote $\pm 1\sigma$ interval for the local CCSN rate from Mattila et al. (2012), $1.9^{+0.4}_{-0.2} \times 10^{-4}$ yr^{-1} Mpc^{-3} assuming a missing CCSN fraction of 0.189.

observed CCSN rate assuming that ≈ 19 per cent of local CCSN were missed by the optical surveys. The volumetric CCSN rate shows a decline beyond ~ 22 Mpc. The decline could be the result of observational selection effects; therefore, we used the volumetric CCSN rate averaged over the distance range up to 22 Mpc, which is $(2.74 \pm 0.18) \times 10^{-4}$ yr^{-1} Mpc^{-3} [1σ confidence level (CL)], as an estimate of the CCSN rate at larger distances.

We also found an excess in the volumetric CCSN rate within ~ 10 Mpc up to $(9.3 \pm 1.6) \times 10^{-4}$ yr^{-1} Mpc^{-3} (1σ CL) within 5.1 Mpc, with only five galaxies containing 25 per cent of the total CCSN rate: PGC047885 at $d = 5$ Mpc, IC 0342 at 3.28 Mpc, NGC 6946 (Fireworks Galaxy) at 5.9 Mpc, NGC 5457 (Pinwheel Galaxy, M101) at 6.7 Mpc, and NGC 5194 (Whirlpool Galaxy M51) at 5.9 Mpc. These galaxies are the best sites to search for extragalactic GFs in addition to the previously mentioned galaxies: M82 at $d = 3.4$ Mpc, NGC 253 (Sculptor Galaxy) at 2.5 Mpc, NGC 4945 at 3.7 Mpc, and M83 at 3.7 Mpc (Popov & Stern 2006).

4 THE SEARCH FOR SGR GFS IN THE KONUS-*WIND* SHORT GRB SAMPLE

The Pal'shin et al. (2013) catalogue contains IPN localizations for 271 out of the 296 Konus-*WIND* short GRBs with a duration $T_{50} \leq 0.6$ s (Svinkin et al., in preparation). This sample contains 23 GRBs classified as short GRBs with extended emission (EE). These bursts were observed by at least one other IPN spacecraft, enabling their localizations to be constrained by triangulation. We limit our search to 140 bursts with IPN error box area less than 10 deg^2 and search for overlaps between each IPN box and galaxies from our sample. In the search a galaxy is modelled, following Ofek (2007), by a circle determined by the galaxy's major diameter from GWGC.

We found that 12 out of the 140 IPN error boxes, with a total area of 217 deg^2, overlap 20 galaxies (none of the localizations of short GRBs with EE contains a galaxy). This number is lower than that expected for chance coincidences calculated for the 140 IPN boxes (22–44 galaxies at 95 per cent CL). The confidence interval was calculated using the bootstrap approach, creating 1000 random realizations of the galaxy sample and counting the number of overlaps with the IPN boxes list for each realization. We used the

Table 1. Summary of GF search in the Konus-*WIND* short GRB sample.

Sample description	Number of boxes	Number of galaxies in boxes	Expected number of galaxies in boxes at 95 per cent CL
IPN box area <10 deg^2	140	20	22–44
IPN box area <1 deg^2	98	2	0–7
$t_r \leq 25$ ms, $T_{100} < 500$ ms, and IPN box area <10 deg^2	17	5	5–16

25th and 975th ranked values as the 95 per cent confidence interval boundaries.

Only one of these error boxes (GRB20050312_T20417[1]) overlaps the outskirts of the Virgo cluster, but the box does not contain any galaxy from our sample. The cluster was modelled with a circle centred at RA = 188°, Dec. = 12°, whose radius is 6° using the cluster parameters from Binggeli, Tammann & Sandage (1987).

We found that only two previously reported GF candidates, GRB 051103 associated with the M81/M82 group of galaxies (error box area 4.3×10^{-3} deg^2) and GRB 070201 associated with the Andromeda galaxy (error box area 0.123 deg^2), have low probabilities of chance coincidence ($P_{chance} \sim 1$ per cent). P_{chance} is the probability to find at least one galaxy in the given IPN error box. The probability was calculated in the same way as the confidence interval.

We then applied the search procedure to the sample of 98 bursts with IPN error box area less than 1 deg^2 (Pal'shin et al. 2013) which contains short GRBs observed by at least one *distant* spacecraft. We found that only the localizations of the two above-mentioned bursts contain galaxies.

A common feature of all known GFs is the short duration of the initial peak, $\lesssim 500$ ms, and the short rise time, $t_r \lesssim 25$ ms. Among 296 Konus-*WIND* short GRBs, 40 have $t_r < 25$ ms and a duration <500 ms. The previously discussed GF candidates GRB 051103 and GRB 070201 have $t_r = 2$ and 24 ms, respectively. We then limited our search to 17 of these bursts with IPN error box area less than 10 deg^2.

We found that 4 out of the 17 IPN boxes, with a total area of 47 deg^2, contain five galaxies. This number is consistent with that expected for chance coincidences calculated for this sample: 5–16 galaxies (95 per cent CL). Among these four bursts, only GRB 051103 and GRB 070201 have low probabilities of chance coincidence. The results for all burst samples are summarized in Table 1.

Given the product of the completeness factors $\epsilon_G \epsilon_L \epsilon_{SN} \approx 76$ per cent, and assuming that the search yielded two GF candidates among 98 well-localized Konus-*WIND* short GRBs, the upper limit to the fraction of GF among Konus-*WIND* short GRBs is less than 8 per cent (=6.296/98/0.76) at a one-sided 95 per cent CL (Gehrels 1986). Due to the whole sky coverage of the IPN, this limit can be adopted for all short GRBs with fluences above $\sim 5 \times 10^{-7}$ erg cm^{-2}. The resulting upper limit is stricter than the limit obtained in Ofek (2007).

5 THE LIMITS ON THE GF RATE

Assuming that only one GF with energy output $Q \gtrsim 10^{46}$ erg has been observed, in the M81/M82 group of galaxies, within a volume $d \leq 30$ Mpc, it is possible to calculate an upper limit to the rate of such GFs.

[1] See the burst details in Pal'shin et al. (2013).

We assume that the number of active SGRs ($N_{SGR}(d)$) in the galaxies within distance d is proportional to the CCSN rate $R_{SN}(d) = 4/3\pi d^3 r_{SN}$, where r_{SN} is the volumetric CCSN rate,

$$N_{SGR}(d) = \frac{N_{SGR,MW+LMC}}{R_{SN,MW+LMC}} R_{SN}(d). \qquad (1)$$

The Galactic CCSN rate is $R_{SN,MW} = 0.028 \pm 0.006$ yr^{-1} with a systematic uncertainty of a factor of ~ 2 (Li et al. 2011) and the LMC rate is $R_{SN,LMC} = 0.013 \pm 0.009$ yr^{-1} (van den Bergh & Tammann 1991). Hence, the total CCSN rate in MW and LMC is $R_{SN,MW+LMC} = 0.041 \pm 0.011$ yr^{-1}.

The observed rate of GFs per SGR is given by a simplified version of equation 3 from Ofek (2007):

$$R_{GF} = \frac{N_{GF,obs}}{\Delta T N_{SGR}(d_{max})}, \qquad (2)$$

where $N_{GF,obs}$ is the number of observed GF, $\Delta T = 16$ yr is the Konus-*WIND* observation time, and $N_{SGR}(d)$ is given by equation (1). To estimate an upper limit to R_{GF} in case of one observed GF, we used the 95 per cent one-sided upper limit of $N_{GF,obs} = 4.744$ (Gehrels 1986).

For the rate of GFs with energy output $Q \gtrsim 10^{46}$ erg, equation (2) gives an upper limit of $(0.6-1.2) \times 10^{-4} Q_{46}^{-1.5}$ yr^{-1} SGR^{-1}, where Q_{46} is a GF energy output in 10^{46} erg. The detection of only one GF with energy output $Q \gtrsim 10^{46}$ erg in the last 35 yr (since 1979) from SGR 1806$-$20 implies that the Galactic rate is $(0.005-1) \times 10^{-2}$ yr^{-1} SGR^{-1} ($= 1^{+4.6}_{-0.98}/35/15$) at the one-sided 95 per cent CL. This value is consistent with the upper limit derived above for the SGR 1806$-$20 distance 9.4–18.6 kpc, primarily due to the large uncertainties in both the upper limit and the Galactic GF rate.

For less energetic flares with energy output $Q \lesssim 10^{45}$ erg which can be detected by Konus-*WIND* at distances up to 6.3 Mpc, assuming that one such flare was detected from the Andromeda galaxy, the implied rate upper limit is $(0.9-1.7) \times 10^{-3}$ yr^{-1} SGR^{-1} (95 per cent CL). This limit is consistent with the observed Galactic rate of $(0.05-1.4) \times 10^{-2}$ yr^{-1} SGR^{-1} (95 per cent CL).

6 SUMMARY AND DISCUSSION

We have estimated the Konus-*WIND* and IPN sensitivity to GFs and derived the limiting detection distance for GFs similar to that from SGR 1806$-$20 to be $(18-30)d_{15}$ Mpc. Less energetic flares such as those from SGR 1900+14 and SGR 0526$-$66 can be detected by Konus-*WIND* and IPN from galaxies at $d \lesssim 6$ Mpc. We searched for Konus-*WIND* short GRBs that spatially coincide with galaxies within 30 Mpc and have found that only two previously reported GF candidates have a low chance coincidence probability: GRB 051103 and GRB 070201 localized by the IPN in the M81/M82 group of galaxies and the Andromeda galaxy, respectively. We have not found any candidate GF from the Virgo cluster. Assuming that only one GF with energy output $Q \gtrsim 10^{46}$ erg was observed in the M81/M82

group of galaxies within the volume $d \leq 30$ Mpc, we obtain an upper limit to the rate of such flares to be $(0.6\text{-}1.2) \times 10^{-4} Q_{46}^{-1.5}$ yr^{-1} per SGR, where Q_{46} is the GF energy output in 10^{46} erg. This limit was calculated using the largest sample of well-localized short GRBs and is consistent with the finding of Ofek (2007). The limit implies roughly one GF with energy output $Q \gtrsim 10^{46}$ erg during the lifetime of an SGR, 10^3–10^5 yr.

For a GF with energy output of the order of the 1979 March 5 event ($Q \lesssim 10^{45}$ erg), the implied rate is nearly an order of magnitude higher $(0.9\text{–}1.7) \times 10^{-3}$ yr^{-1} SGR^{-1} (95 per cent CL). This can be interpreted to mean that more than one such GF can be observed during SGR lifetime. The measured dipolar magnetic fields of SGR 1900+14 and SGR 0526−66, 5.6×10^{14} and 7×10^{14} G, respectively (Olausen & Kaspi 2014), seem to be sufficient to power a dozen GFs with $Q \sim 10^{45}$ erg.

The upper limits we have presented contain uncertainties of about an order of magnitude which account for the uncertainty in the Galactic CCSN rate and the limiting detection distance of the IPN.

We found galaxies which are promising targets for GF observations: PGC047885, IC 0342, NGC 6946, NGC 5457, and NGC 5194, in addition to those discussed in Popov & Stern (2006).

We also derived the upper limit to the rate of bright GFs using *Swift*-BAT data. Since its launch in 2004 November, *Swift* has observed only one candidate extragalactic GF, GRB 050906 (Levan et al. 2008), with a suggested host IC 328 at ≈130 Mpc. This burst had the lowest fluence in the 15–150 keV band of all the reported GRBs, $S_{\min} = 6.1 \times 10^{-9}$ erg cm^{-2} (Sakamoto et al. 2011), and a soft spectrum described by a power-law model with a photon index of −1.7. The extrapolated energy output of the GF from SGR 1806−20 from 20 keV–10 MeV to 15–150 keV using a cut-off power-law model with $\alpha = -0.73$ and $E_p = 850$ keV yields 2.5×10^{45} erg, which corresponds to a limiting distance of 60 Mpc. The interpretation of GRB 050906 as an SGR GF in IC 328 is unlikely due to the derived *Swift*-BAT limiting detection distance.

The BAT 90 per cent sky exposure time during 2004–2010 was 7.25×10^6 s (0.23 yr) (Baumgartner et al. 2013), and extrapolation of this value to 2004–2013 gives 0.35 yr. The non-detection of a GF in the volume $d \lesssim 60$ Mpc during *Swift*-BAT operations implies a one-sided 95 per cent CL upper limit for a GF with this energy output to be $\sim 6 \times 10^{-4} Q_{45}^{-1.5}$ yr^{-1} SGR^{-1}, where Q_{45} is the GF energy output in 10^{45} erg in the 15–150 keV band. Despite BAT's high sensitivity, this upper limit is less strict than that obtained using Konus-*WIND* and IPN data due to a lower period of whole sky observations. Nevertheless, the *Swift*-BAT is a very promising mission to detect extragalactic SGR GF.

ACKNOWLEDGEMENTS

REFERENCES

Aptekar R. L. et al., 1995, Space Sci. Rev., 71, 265
Barat C., Chambon G., Hurley K., Niel M., Vedrenne G., Estulin I. V., Kurt V. G., Zenchenko V. M., 1979, A&A, 79, L24
Baumgartner W. H., Tueller J., Markwardt C. B., Skinner G. K., Barthelmy S., Mushotzky R. F., Evans P. A., Gehrels N., 2013, ApJS, 207, 19
Binggeli B., Tammann G. A., Sandage A., 1987, AJ, 94, 251
Böser S., Kowalski M., Schulte L., Linn Strotjohann N., Voge M., 2015, Astropart. Phys., 62, 54
Cappellaro E., Evans R., Turatto M., 1999, A&A, 351, 459
Cline T. L. et al., 1980, ApJ, 237, L1
Cline T. L. et al., 1982, ApJ, 255, L45
Duncan R. C., Thompson C., 1992, ApJ, 392, L9
Evans W. D. et al., 1980, ApJ, 237, L7
Frederiks D. D., Golenetskii S. V., Pal'shin V. D., Aptekar R. L., Ilyinskii V. N., Oleinik F. P., Mazets E. P., Cline T. L., 2007a, Astron. Lett., 33, 1
Frederiks D. D., Pal'shin V. D., Aptekar R. L., Golenetskii S. V., Cline T. L., Mazets E. P., 2007b, Astron. Lett., 33, 19
Gehrels N., 1986, ApJ, 303, 336
Golenetskii S. V., Mazets E. P., Ilinskii V. N., Guryan Y. A., 1979, Sov. Astron. Lett., 5, 340
Hurley K., 2011, Adv. Space Res., 47, 1337
Hurley K. et al., 1999, Nature, 397, 41
Hurley K. et al., 2010, MNRAS, 403, 342
Hurley K. et al., 2013, in Castro-Tirado A. J., Gorosabel J., Park I. H., eds, EAS Pub. Ser. Vol. 61, The Interplanetary Network. EDP Sciences, Les Ulis, p. 459
Kouveliotou C. et al., 1998, Nature, 393, 235
Lazzati D., Ghirlanda G., Ghisellini G., 2005, MNRAS, 362, L8
Levan A. J. et al., 2008, MNRAS, 384, 541
Li W., Chornock R., Leaman J., Filippenko A. V., Poznanski D., Wang X., Ganeshalingam M., Mannucci F., 2011, MNRAS, 412, 1473
Mattila S. et al., 2012, ApJ, 756, 111
Mazets E. P., Golentskii S. V., Ilinskii V. N., Aptekar R. L., Guryan I. A., 1979, Nature, 282, 587
Mazets E. P., Cline T. L., Aptekar R. L., Butterworth P. S., Frederiks D. D., Golenetskii S. V., Il'Inskii V. N., Pal'shin V. D., 1999, Astron. Lett., 25, 635
Mazets E. P. et al., 2008, ApJ, 680, 545
Mereghetti S., 2013, Braz. J. Phys., 43, 356
Nakar E., Gal-Yam A., Piran T., Fox D. B., 2006, ApJ, 640, 849
Ofek E. O., 2007, ApJ, 659, 339
Ofek E. O. et al., 2006, ApJ, 652, 507
Ofek E. O. et al., 2008, ApJ, 681, 1464
Olausen S. A., Kaspi V. M., 2014, ApJS, 212, 6
Palmer D. M. et al., 2005, Nature, 434, 1107
Pal'shin V. D. et al., 2013, ApJS, 207, 38
Popov S. B., Stern B. E., 2006, MNRAS, 365, 885
Sakamoto T. et al., 2011, ApJS, 195, 2
Svirski G., Nakar E., Ofek E. O., 2011, MNRAS, 415, 2485
Tendulkar S. P., Cameron P. B., Kulkarni S. R., 2012, ApJ, 761, 76
Terasawa T. et al., 2005, Nature, 434, 1110
Thompson C., Duncan R. C., 1995, MNRAS, 275, 255
Thompson C., Duncan R. C., 1996, ApJ, 473, 322
van den Bergh S., Tammann G. A., 1991, ARA&A, 29, 363
White D. J., Daw E. J., Dhillon V. S., 2011, Classical Quantum Gravity, 28, 085016