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Review

Soft gamma repeaters

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Abstract

The observational properties of the soft gamma repeaters are reviewed briefly, starting with the time histories and energy spectra of their bursts. The short bursts and giant flares are compared. Their quiescent emission is presented, and the context of the magnetar model is discussed.

Keyword: Stars: neutron

Contents

1. Introduction

The soft gamma repeaters (SGRs) are sporadic sources of bursts of X- and gamma-rays. In this short review, we will concentrate on their observational properties. More complete reviews can be found in Woods and Thompson (2006) and Mereghetti (2008). SGRs can remain dormant (i.e. burst-inactive) for many years; during these periods, no bursting behavior is observed, although the possibility remains that they are indeed emitting very weak bursts which are below the thresholds of most instruments. When they become burst-active, they emit relatively strong bursts at apparently random times, and it is during these periods that they are discovered. The most common type of burst has a short duration (roughly 100 ms), and a rather soft spectrum compared to those of cosmic gamma-ray bursts; a rough description of the spectrum over a limited energy range is that of a blackbody with temperature $kT_{BB} \sim 10$ keV or bremsstrahlung at a temperature of 25 keV, but see below. The isotropic energy in this type of event is about 10^{40} erg or more, and the average luminosity is $\sim 10^{41}$ erg s^{-1}. Far rarer, but more interesting, are the giant flares. These last several hundred seconds, have hard spectra extending into the MeV range at least, and display

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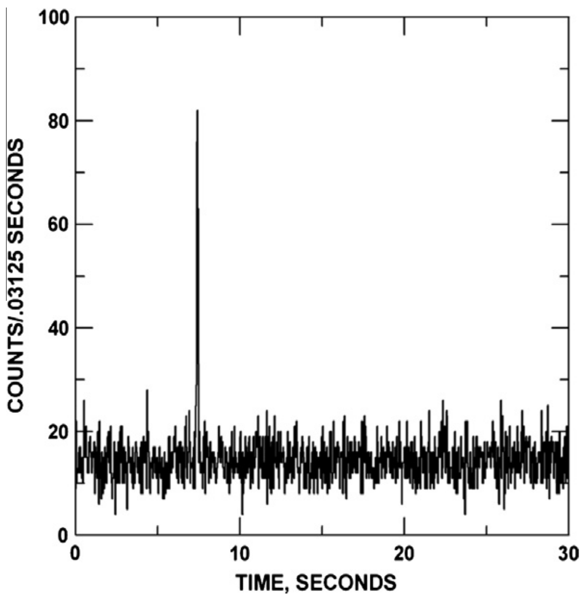

Fig. 1. A typical short burst time history. The time resolution is 32 ms, and the energy range is 25-150 keV. This was recorded with the 20 cm^2 GRB detector aboard Ulysses on 1998 May 30 from SGR1900+14. Bursts such as these are bright enough to be detected from anywhere in the Galaxy by the Interplanetary Network.

periodic emission. Their total energies exceed 10^{46} erg (Hurley et al., 2005; Palmer et al., 2005; Terasawa et al., 2005). Fig. 1 shows the time history of a typical short burst,

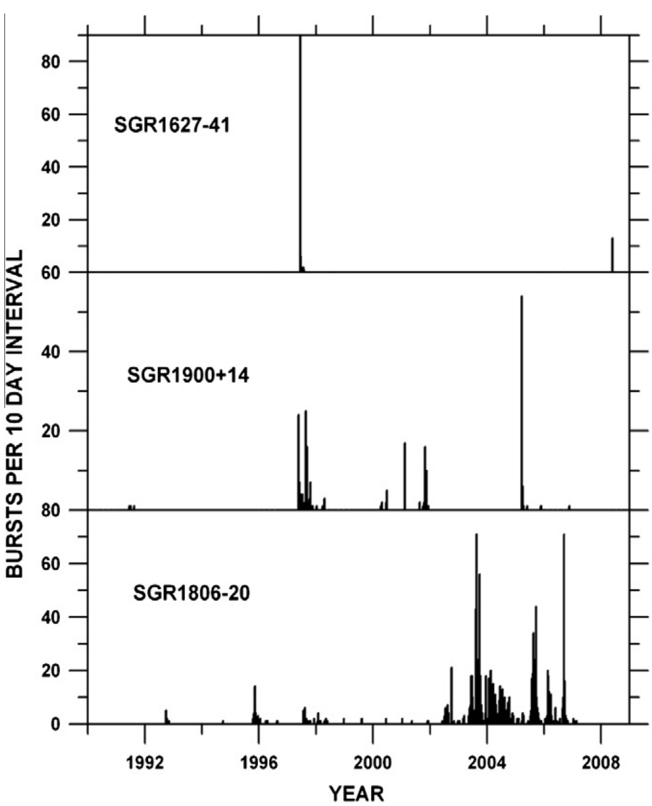

Fig. 2. The bursting activity of 3 SGRs, from the least active at the top, to the most active at the bottom. The number of short (~100 ms duration) bursts per 10 day interval is shown.

and Fig. 2 illustrates the bursting activity of 3 SGRs over a 17 year period.

In Fig. 3, the broadband energy spectrum of a short burst is shown. The best fit is a two blackbody model, with kT=3.4 keV from 1 to 10 keV, and kT=9.3 keV from 15 to 150 keV. If these fits and temperatures are interpreted literally, they imply emitting areas with radii of 14 and 2 km at 10 kpc, respectively, that is, slightly larger than the surface area of a neutron star, and about equal to its polar cap area.

The most spectacular manifestations of SGRs are the giant flares. Three have been observed to date; no SGR has been observed to emit more than one, but statistical arguments suggest that they could occur perhaps every 30 years on a given SGR. They are extremely intense: the isotropic gamma ray energies reach over 10^{46} erg, and the flux at Earth is 1 erg cm^{-2}. This makes them third only to supernovae and cosmic gamma-ray bursts in their intensities, albeit a distant third, since SNe and GRBs release over 10^{51} erg. They have very hard energy spectra, which have been observed up to 10 MeV. They create transient radio nebulae and produce dramatic ionospheric disturbances at Earth. Their energetics suggest that they should be detectable in nearby galaxies (indeed, the March 5 1979 burst from SGR0525-66 originated in the LMC), and there is evidence that they have been detected from M81 and M33 (Frederiks et al., 2007; Mazets et al., 2008; Hurley et al., 2010). Fig. 4 shows the time history of a giant flare, and Fig. 5 compares giant flare and short burst energy spectra.

2. Quiescent emission

The SGRs are quiescent, periodic X- and gamma-ray sources (e.g. Kouveliotou et al., 1998; Götz et al., 2006). Even in the absence of bursting activity, this quiescent emission is always present, although it varies in intensity. It has now been measured for most SGRs from around 1 keV to over 100 keV. Fig. 6 shows the broadband spectra of two SGRs and 3 anomalous X-ray pulsars. In general, these spectra can be described by a blackbody below 10 keV, and a power law above 15–20 keV. In some cases (e.g. SGR1806-20), the power law photon spectral index would imply a divergent energy output if there were no spectral cutoff. However, the cutoff energies have not been measured yet. Their low energy X-ray luminosities are in the 10^{34} – 10^{36} erg s^{-1} range. The SGRs display period derivatives in the range 10^{-10} to 10^{-11} s s^{-1}, which means that, like the anomalous X-ray pulsars, their X-ray luminosities are greater than can be attributed to spin-down alone. This is one reason why their behavior is often interpreted in the context of the magnetar model (Thompson and Duncan, 1995, 1996), that is, they are assumed to be neutron stars whose magnetic energy dominates all other sources (surface magnetic fields of 10^{13} G and above).

Folding the X-ray emission modulo the neutron star period gives the light curve shown in Fig. 7, for

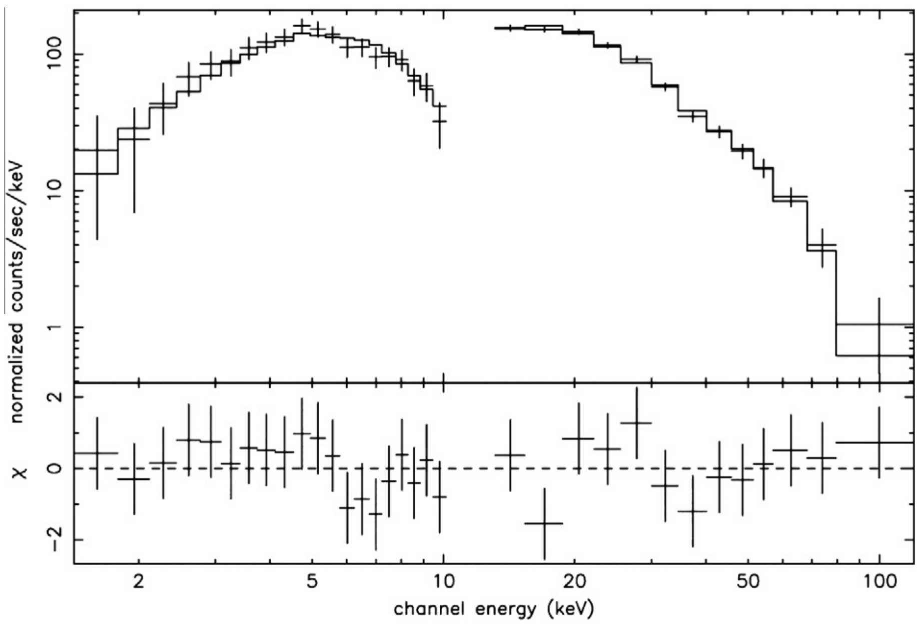

Fig. 3. From Feroci et al., 2004. BeppoSAX MECS and PDS fits to a short burst from SGR1900+14 with a two blackbody function. Reproduced by permission of the AAS.

SGR1900+14. The light curve is far from a simple sinusoid. It has numerous interpulses, and its shape is time-variable. In the magnetar model, the interpretation is that we are observing hot spots on the neutron star surface which are the result of a multipolar field. The poles evolve and move with time as the magnetic field stresses the surface, causing the light curve to change.

Table 1 gives some of the SGR physical properties. In this table, the surface magnetic field strength is calculated from the measured period and its derivative, and the estimated radius and moment of inertia of the neutron star. Because the period and period derivative are time-variable (the spindown is irregular, and is loosely related to the bursting activity - see Woods et al., 2002, 2006), B can only be calculated approximately.

3. The strange case of 1E1547-5408

One of the newest members of the SGR club was initially thought to be an anomalous X-ray pulsar. 1E1547 was proposed as a magnetar candidate by Gelfand and Gaensler in 2007, and eventually classified as an AXP. In January 2009, however, it was observed to burst by Fermi (Connaughton and Briggs, 2009). Although this is not unheard of for an AXP, the bursts that it emitted were far more SGR-like than AXP-like. Thus it is tempting to simply say that this source was initially misidentified. However, it would be the only SGR to have a persistent radio counterpart, and one of only two that can be argued to be associated with a supernova remnant. This object, more than any other, raises the question of the true differences between AXPs and SGRs, and their significance. The big-

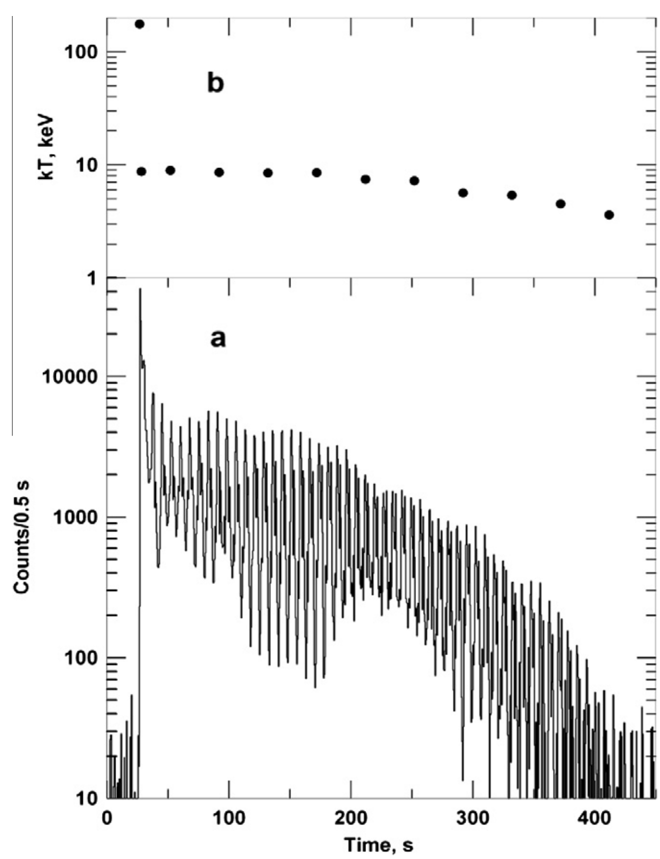

Fig. 4. From Hurley et al. 2005. Bottom panel: the time history of the giant flare from SGR1806-20, as observed by the RHESSI spacecraft in the 20 to 100 keV energy range. Giant flare time histories all display a fast rise, a very intense peak, and a periodic decay with the rotation period of the neutron star. Top panel: the spectral temperature as a function of time. Note the very hard spectrum (kT = 175 keV) at the start.

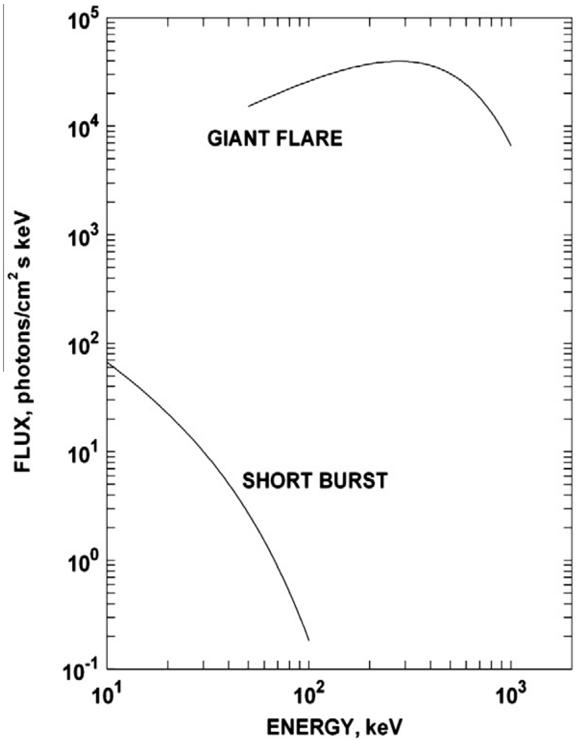

Fig. 5. The energy spectra of short bursts and giant flares compared. The giant flare spectrum is a 175 keV blackbody, which was observed in the initial pulse of the SGR1806-20 giant flare (Hurley et al. 2005). The short burst spectrum is an optically thin thermal bremsstrahlung function with a 25 keV temperature; this is an approximation which works over a limited energy range.

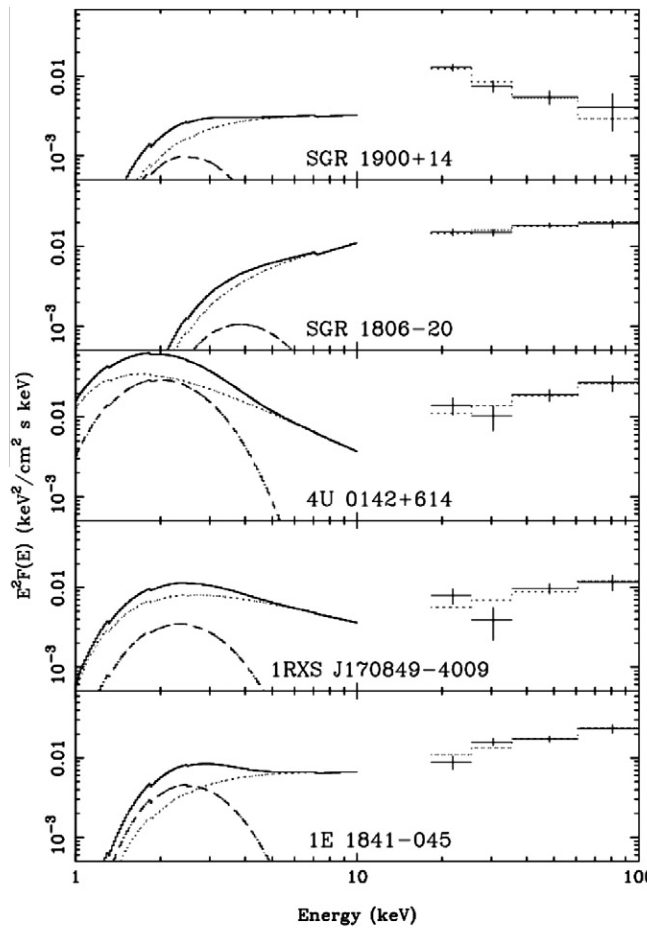

Fig. 6. From Götz et al. 2006. Broadband $\nu - F\nu$ spectrum of two SGRs and 3 AXPs. A blackbody fit describes the spectrum below 10 keV, and a power law describes the spectrum above 20 keV. All the high energy spectra have been measured by INTEGRAL-IBIS. Reprinted by permission of Astronomy and Astrophysics.

gest difference seems to be the method of their discovery: AXPs via their quiescent emission, and SGRs via their bursts. Yet AXPs are observed to burst, and SGRs have quiescent X-ray emission whose properties are similar to those of AXPs. It is tempting to downplay the differences between the two, and simply to place them both in the "magnetar" family, with similar DNA, but different appearances.

4. Hosts and progenitors

The host of SGR0525-66 is almost certainly the N49 optical supernova remnant in the LMC (Evans et al., 1980). 1E1547-5408 lies close to the center of the galactic radio supernova remnant G327.24-0.13 (Gelfand and Gaensler, 2007). Other SGR-SNR associations are less certain. SGR0501-4516 lies outside the supernova remnant HB9 (Gaensler and Chatterjee, 2008), and may have been ejected from it after acquiring a kick velocity. This idea is testable, because the proper motion of the X-ray counterpart can be measured within a few years. Two SGRs are probably in massive star clusters. SGR 1900+14 lies along the line of sight to a cluster of about 13 massive stars with ages 1-10 Myr (Vrba et al., 2000), and SGR1806-20 lies along the line of sight to a cluster of about 12 stars with ages 3-5 Myr (Fuchs et al., 1999). Bibby et al. (2008) have estimated that the progenitor of the latter SGR must have had a mass of about 48 solar masses. Large progenitor masses are not a requirement of the magnetar model. In the cases of the SGR-SNR associations, the progenitor masses could be considerably less; any star that can produce a core-collapse supernova is probably adequate. Table 2 outlines what is known about hosts and progenitors.

5. Counterparts

All the SGRs have persistent X-ray counterparts. At other wavelengths, the situation is less clear. Most SGRs lie in the galactic disk and are heavily obscured, so no detectable optical counterparts to them are expected. However, at least one SGR has a near-infrared counterpart. Kosugi et al. (2005) and Israel et al. (2005) have identified a faint, variable NIR counterpart to SGR1806-20. Although the IR magnitude varies roughly with bursting activity and with the persistent X-ray flux (the measurements were not exactly simultaneous), the IR flux is not an extrapolation of the X-ray flux. In the case of

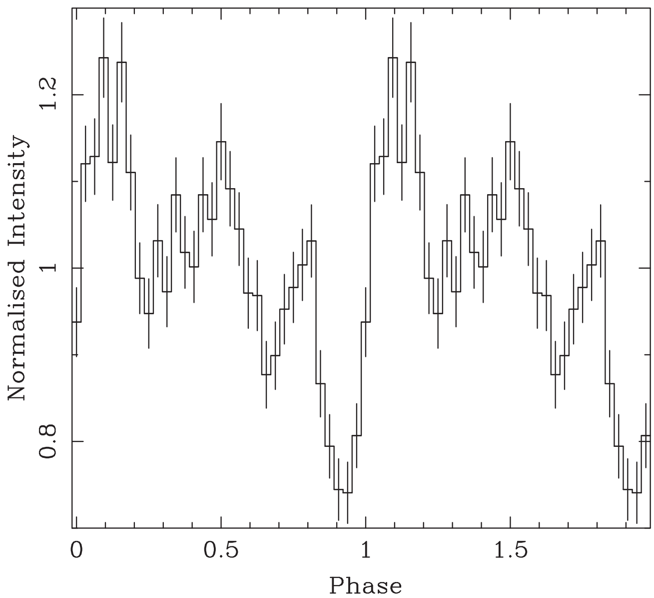

Fig. 7. The folded light curve of SGR1900+14 (Hurley et al., 1999). In the magnetar model, the complexity of the curve is explained by multipolar moments on the neutron star surface and their associated heating. The light curve is time-variable. Reproduced by permission of the AAS.

SGR0501+45, an IR source was found within the X-ray error circle (Tanvir and Varricatt, 2008), but its variability has not been definitively established, so it may or may not be the counterpart. In the radio range, only 1E1547 has a persistent counterpart, identified in surveys such as Green et al. (1999); transient radio counterparts to SGR1806-20 and 1900+14 have been observed following their giant flares (Taylor et al., 2005; Frail et al., 1999), but not at other times. These transient radio nebulae presumably consist of clouds of relativistic particles accelerated in the magnetar magnetosphere and expelled from it. Table 2 summarizes the counterparts of the SGRs.

6. How many are there?

There are 6 or 7 confirmed SGRs (depending on how one categorizes 1E1547), mostly discovered through their bursting activity. There could in principle be many more which are undiscovered because they are not burst-active. In fact, there are several unconfirmed SGRs which have burst once or twice, but went quiescent after that: examples are SGR1801-23 (Cline et al., 2000) and 1808-20 (Lamb et al., 2003). Occasionally, GRBs are proposed as possible SGRs due to their time histories, energy spectra, and/or galactic latitude; an example is GRB050906 (Levan et al., 2008). It is difficult to confirm any of these sources until and unless they are observed to repeat, and/or their quiescent emission is detected and their periods measured. However, Muno et al. (2008) have done a comprehensive study of Chandra and XMM point sources, in which they searched for periodicities and spin-down. Their study did not reveal any new candidates, and they set a limit of <540 in the Galaxy. This still leaves open the question of extragalactic magnetars. One, SGR0525-66, has definitely been observed. If magnetar giant flares reach intensities of over 10^{46} erg, they should be detectable out to distances of at least 10 Mpc, where they would look like short duration, hard spectrum gamma-ray bursts. Their positions would be consistent with those of relatively bright galaxies. Two candidates have been observed recently, one of which is possibly from M81, and the other possibly from M31

Table 1
Some SGR physical properties. The periods and period derivatives are time-variable, and therefore approximate. The luminosities are also time-variable, and the source distances are not well known, which introduces an additional uncertainty.

SGR	Giant flare?	Period (s)	Period derivative (s s^{-1})	1–10 keV luminosity (erg s^{-1})	B (Gauss)
SGR1806-20	Dec 27 2004	7.46	10^{-10}	2×10^{35}	8×10^{14}
SGR1900+14	Aug 27 1998	5.16	10^{-10}	3×10^{34}	$2–8 \times 10^{14}$
SGR0525-66	Mar 5 1979	8	7×10^{-11}	10^{36}	7×10^{14}
SGR1627-41	No	2.6	1.2×10^{-11}	10^{35}	2×10^{14}
SGR0501+45	No	5.8	5×10^{-12}	10^{34}	10^{14}
1E1547-5408	No	2.1	2.3×10^{-11}	10^{33}	2.2×10^{14}
SGRJ0418+5729	No	9.1	3×10^{-13}	10^{34}(?)	5×10^{13}

Table 2
SGR hosts and counterparts.

SGR	Radio Counterpart?	NIRCounterpart?	X-ray Counterpart?	Host	Progenitor
SGR1806-20	After giant flare (transient)	Yes	Yes	Massive star cluster?	$48M_{sol}$
SGR1900+14	After giant flare (transient)	No	Yes	Massive star cluster?	Massive star?
SGR0525-66	No	No	Yes	SNR	Normal star?
SGR1627-41	No	No	Yes	?	?
SGR0501+45	No	Maybe	Yes	SNR?	?
1E1547-5408	Yes	No	Yes	SNR	Normal star?

(Frederiks et al., 2007; Mazets et al., 2008; Hurley et al., 2010). These are described in more detail in another paper in this volume.

Finally, there could be manifestations of magnetars that we have not yet imagined.

7. Conclusions

All of the properties of the known and candidate SGRs are consistent with the magnetar model. However, independent evidence for this model, such as the repeatable observation of a cyclotron resonance feature, remains elusive. Such an observation would provide an independent estimate of the magnetic field strength. Alternative models, such as fall-back accretion disks (Ertan and Caliskan, 2006), or transitions in strange stars (Cheng and Dai, 2002), have been proposed, but relatively little has been written about them to date. There is also growing evidence that the distinction between AXPs and SGRs is not as meaningful as it was once thought to be, since their physical properties are so similar. Only a deeper understanding of their hosts, progenitors, and multiwavelength counterparts will resolve this issue.

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References

Bibby, J., Crowther, P., Furness, J., et al. A downward revision to the distance of the 1806-20 cluster and associated magnetar from Gemini Near-Infrared Spectroscopy. Mon. Not. R. Astron. Soc. 386, L23–L27, 2008.

Cheng, K., Dai, Z. A strongly magnetized strange star model for soft gamma-ray repeaters. Astropart. Phys. 16, 277–284, 2002.

Cline, T., Frederiks, D., Golenetskii, S., Hurley, K., et al. Observations of a Possible New Soft Gamma Repeater. SGR 1801-23. Ap. J. 531, 407–410, 2000.

Connaughton, V., and Briggs, M. AXP 1E1547.0-5408: Fermi GBM observations, GCN Circ. 8835, 2009.

Ertan, U., Caliskan, S. Optical and Infrared Emission from the Anomalous X-Ray Pulsars and Soft Gamma-Ray Repeaters. Ap. J. 649, L87–L90, 2006.

Evans, W.D., Klebesadel, R.W., Laros, J.G., Cline, T.L., et al. Location of The Gamma-Ray Transient Event of 1979 March 5. Ap. J. Lett. 237, L7–L9, 1980.

Frail, D., Kulkarni, S., Bloom, J. An Outburst of Relativistic Particles from the Soft Gamma-Ray Repeater SGR1900+14. Nature 398, 127–129, 1999.

Feroci, M., Caliandro, G.A., Massaro, E., et al. Broadband X-Ray Spectra of Short Bursts from SGR 1900+14. Ap. J. 612, 408–413, 2004.

Frederiks, D., Pal'shin, V., Aptekar, R., Golenetskii, S., et al. On the Possibility of Identifying the Short Hard Burst GRB051103 with a Giant Flare from a Soft Gamma Repeater in the M81 Group of Galaxies. Astron. Lett. 33, 19–24, 2007.

Fuchs, Y., Mirabel, F., Chaty, S., Claret, A., et al. ISO Observations of the Environment of the Soft Gamma Repeater SGR 1806-20. Astron. Astrophys. 350, 891–899, 1999.

Gaensler, B., Chatterjee, S. SGR 0501+4516: Proximity to supernova remnant HB9. GCN Circ. 8149, 2008.

Gelfand, J., Gaensler, B. The Compact X-Ray Source 1E 1547.0-5408 and the Radio Shell G327.24-0.13: A New Proposed Association Between a Candidate Magnetar and a Candidate Supernova Remnant. Ap. J. 667, 1111–1118, 2007.

Götz, D., Mereghetti, S., Tiengo, A., Esposito, P. Magnetars as Persistent Hard X-Ray Sources: INTEGRAL Discovery of a Hard Tail in SGR1900+14. Astron. Astrophys. 449, L31–L34, 2006.

Green, A., Cram, L., Large, M., Ye, T. The Molonglo Galactic Plane Survey.I. Overview and Images. ApJSS 122, 207–219, 1999.

Hurley, K., Boggs, S., Smith, D., et al. An exceptionally bright flare from SGR1806-20 and the origins of short-duration gamma-ray bursts. Nature 434, 1098–1103, 2005.

Hurley, K., Li, P., Kouveliotou, C., Murakami, T., et al. ASCA Discovery of an X-Ray Pulsar in the Error Box of SGR1900+14. Ap. J. 510, L111–L114, 1999.

Hurley, K., Rowlinson, A., Bellm, E., Perley, D., et al. A new analysis of the short-duration, hard-spectrum GRB 051103, a possible extragalactic SGR giant flare. Mon. Not. R. Astron. Soc., in press, 2010.

Israel, G., Covino, S., Mignani, R., Stella, L., et al. Discovery and Monitoring of the Likely IR Counterpart of SGR1806-20 During the 2004 Gamma-Ray Burst Active State. Astron. Astrophys. 438, L1–L4, 2005.

Kosugi, G., Ogasawara, R., Terada, H. A Variable Infrared Counterpart to the Soft Gamma-Ray Repeater SGR1806-20. Ap. J. 623, L125–L128, 2005.

Kouveliotou, C., Dieters, S., Strohmayer, T., van Paradijs, J., et al. An X-ray Pulsar With a Superstrong Magnetic Field in the Soft Gamma-Ray Repeater SGR1806-20. Nature 393, 235–237, 1998.

Lamb, D., Graziani, C., Shirasaki, Y., Atteia, J.-L., et al. SGR 1808-20 (=H2802): A Possible new SGR. GCN Circ. 2351, 2003.

Levan, A., Tanvir, N., Jakobsson, P., et al. On the nature of the short-duration GRB 050906. Mon. Not. R. Astron. Soc. 384, 541–547, 2008.

Mazets, E., Aptekar, R., Cline, T., et al. A giant flare from a soft gamma repeater in the Andromeda galaxy. Ap. J. 680, 545–549, 2008.

Mereghetti, S. The Strongest Cosmic Magnets: Soft Gamma-Ray Repeaters and Anomalous X-Ray Pulsars. Astron. Astrophys. Rev. 15, 225–287, 2008.

Muno, M., Gaensler, B., Nechita, A., Miller, J., et al. A Search for New Galactic Magnetars in Archival Chandra and XMM-Newton Observations. Ap. J. 680, 639–653, 2008.

Palmer, D., Barthelmy, S., Gehrels, N., et al. A giant gamma-ray flare from the magnetar SGR1806-20. Nature 434, 1107–1109, 2005.

Tanvir, N., Varricatt, W. SGR 0501+4516: UKIRT detection of possible infra-red counterpart. GCN Circular 8126, 2008.

Taylor, G., Gelfand, J., Gaensler, B., Granot, J., et al. The Growth, Polarization, and Motion of the Radio Afterglow from the Giant Flare from SGR1806-20. Ap. J. 634, L93–L96, 2005.

Terasawa, T., Tanaka, Y., Takei, Y., Kawai, N., et al. Repeated Injections of Energy in the First 600 ms of the Giant Flare of SGR1806-20. Nature 434, 1110–1111, 2005.

Thompson, C., Duncan, R. The Soft Gamma Repeaters as Very Strongly Magnetized Neutron Stars. I. Radiative Mechanism for Outbursts. Mon. Not. R. Astron. Soc. 275, 255–300, 1995.

Thompson, C., Duncan, R. The Soft Gamma Repeaters as Very Strongly Magnetized Neutron Stars. II. Quiescent Neutrino, X-ray, and Alfven Wave Emission. Ap. J. 473, 322–342, 1996.

Vrba, F., Henden, A., Luginbuhl, C., Guetter, H., et al. The Discovery of an Embedded Cluster of High-Mass Stars Near SGR1900+14. Ap. J. 533, L17–L20, 2000.

Woods, P., Kouveliotou, C., Gogus, E., Finger, M., et al. Large Torque Variations in Two Soft Gamma Repeaters. Ap. J. 576, 381–390, 2002.

Woods, P., Thompson, C. Soft gamma repeaters and anomalous X-ray pulsars: magnetar candidates, in: Lewin, W., van der Klis, M. (Eds.), Compact stellar X-ray sources. Cambridge University Press, Cambridge, UK, pp. 547–583, 2006.