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The multi-wavelength properties of Anomalous X-ray Pulsars and Soft Gamma-ray Repeaters

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Abstract

This paper reviews the multi-wavelength properties of two groups of pulsars, the Anomalous X-ray Pulsars (AXPs) and the Soft Gamma-ray Repeaters (SGRs), that are generally interpreted as isolated neutron stars with strong magnetic fields of 10^{14}–10^{15} G. Most of these sources have now been observed at different wavelengths, from the radio band to hard X-rays. Several new members of these classes have been discovered in the last few years, due to their transient nature. The distinction between AXPs and SGRs is becoming less evident, as more observations are collected which show similar properties in all these sources.

Keywords: Neutron stars; Magnetars

1. Introduction

There are now 16 sources classified as Anomalous X-ray Pulsars (AXPs) or Soft Gamma-ray Repeaters (SGRs). All of them are characterized by X-ray pulsations with periods of a few seconds, indicating the presence of rotating neutron stars. In the last few years the distinction between these two classes has become less evident, since many similarities have been found suggesting that AXPs and SGRs are intrinsically the same kind of astrophysical objects.

Most of the sources classified as AXPs were discovered as bright pulsars in the soft X-ray range (<10 keV). The earlier data were not sufficient to distinguish them from the prevailing population of X-ray binaries powered by accretion. However, more detailed X-ray studies, coupled to deep optical/IR searches for counterparts, revealed their different nature (Mereghetti and Stella, 1995). In particular, these observations showed that the narrow period distribution, long term spin-down and soft spectrum of the AXPs were at variance with the properties of the more numerous population of pulsars in massive binaries. Furthermore, it was found that the X-ray luminosity of the AXPs was larger than the spin-down power inferred from their timing parameters (assuming they were neutron stars), thus excluding rotation-powered models.

The SGRs were instead discovered in the hard X-ray/soft gamma-ray range through the observation of bright and short bursts. These events were initially considered a particular kind of gamma-ray bursts (Laros et al., 1986; Atteia et al., 1987), with the notable properties of "repeating" from the same sky direction. When good localizations became available, it was possible to identify the X-ray counterparts of SGRs, finding that they are pulsating sources very similar to the AXPs.

The most successful model for the AXPs/SGRs involves highly magnetized neutron stars, or "magnetars" (Duncan and Thompson, 1992; Thompson and Duncan, 1995, 1996). The magnetar model was stimulated by the exceptional burst of March 5, 1979 from SGR 0526-66 and later developed to explain all the other properties of the bursting and persistent emission from SGRs and AXPs (see Woods and Thompson (2006) for a review). According to this interpretation, requiring a magnetic field up to $B \sim 10^{14}$–10^{15} G in the magnetosphere, and possibly even higher in the interior, these stars are the celestial objects with the strongest magnetic fields.

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Table 1
Multi-wavelengths detections of confirmed AXPs and SGRs (P = pulsed, D = detected, T = transient). The distances are in several cases uncertain; the table reports the values assumed in this paper. MSC = massive stars cluster. References: (1) Lamb et al. (2002), (2) Tiengo et al. (2008), (3) den Hartog et al. (2008b), (4) Israel et al. (1994), (5) Hulleman et al. (2004), (6) Kern and Martin (2002), (7) Wang et al. (2006), (8) Rea et al. (2007), (9) Leyder et al. (2008), (10) Seward et al., 1986, (11) Dhillon et al., 2009, (12) Israel et al. (2002), (13) Tiengo et al. (2005), (14) Gelfand and Gaensler (2007), (15) Halpern et al. (2008), (16) Camilo et al. (2007a), (17) Israel et al. (2009), (18) Kuiper et al. (2009), (19) Muno et al. (2006), (20) Israel et al. (2007a), (21) Sugizaki et al. (1997), (22) den Hartog et al. (2008a), (23) Testa et al. (2008), (24) Rea et al. (2005), (25) Ibrahim et al. (2004), (26) Israel et al. (2004), (27) Camilo et al. (2006), (28) Gotthelf and Halpern (2007), (29) Vasisht and Gotthelf (1997), (30) Kuiper et al. (2004), (31) Fahlman and Gregory (1981), (32) Hulleman et al. (2001), (33) Kaplan et al. (2009), (34) van der Horst et al. (2010), (35) Esposito et al. (2010), (36) Gogus et al. (2008), (37) Rea et al. (2009), (38) Aptekar et al. (2009), (39) Cline et al. (1980), (40) Tiengo et al. (2009), (41) Woods et al. (1999b), (42) Esposito et al. (2009b), (43) Esposito et al. (2009a), (44) Laros et al. (1986), (45) Kouveliotou et al. (1998), (46) Mereghetti et al. (2005a), (47) Israel et al. (2005), (48) Göğüşet al. (2010), (49) Esposito et al. (2010), (50) Mazets et al. (1979a), (51) Götz et al. (2006), (52) Hurley et al. (1999).

	X-rays >10 keV	X-rays <10 keV	Optical	NIR	MIR	Radio	D (kpc)	N_H (cm^{-2})	Location/association	References
CXOU J0100-7211	–	P	–	–	–	–	61	6×10^{20}	SMC	1, 2
4U 0142+61	P	P	P	D	D	–	3.6	5×10^{21}		3–8
1E 1048.1-5937	D	P	P	D	–	–	9	6×10^{21}		9–13
1E 1547.0-5408	P	P, T	–	D	–	P	9	5×10^{22}	G327.24–0.13	14–18
CXOU J1647-4552	–	P, T	–	–	–	–	3.9	1.3×10^{22}	MSC	19, 20
1RXS J1708-4009	P	P	–	D?	–	–	3.8	1.4×10^{22}		21–24
XTE J1810-197	–	P, T	–	D	–	P	3.1	6×10^{21}		25–28
1E 1841-045	P	P	–	D?	–	–	8.5	2.3×10^{22}	Kes 73	29, 30, 23
1E 2259+586	–	P	–	D	D	–	7.5	1×10^{22}	CTB 109	31–33
SGR 0418+5729	–	P	–	–	–	–	2	1.1×10^{21}		34, 35
SGR 0501+4516	P	P, T	–	D	–	T	1.5	9×10^{21}		36–38
SGR 0526-66	–	P	–	–	–	–	55	5×10^{21}	LMC, N49	39, 40
SGR 1627-41	–	P, T	–	–	–	–	11	9×10^{22}		41–43
SGR 1806-20	D	P	–	D	–	T	15	6×10^{22}	MSC	44–47
SGR 1833-0832	–	P, T	–	–	–	–	10	1×10^{23}		48, 49
SGR 1900+14	D	P	–	D?	–	T	15	2×10^{22}	MSC	50–52, 23

Alternative possibilities have also been proposed. For example, models based on isolated neutron stars accreting from residual disks (Chatterjee et al., 2000; Perna et al., 2000; Alpar, 2001; Ertan et al., 2009) can explain some of the AXPs properties, but they cannot easily account for the bursts and the giant flares of SGRs. Other proposed models involve different kinds of quark stars (Xu, 2007; Horvath, 2007; Ouyed et al., 2007; Cea, 2006).

Here I describe the observational properties of the AXPs and SGRs at different wavelengths, discussing them mainly in the context of the magnetar model. A more extensive review, considering also alternative interpretations and the possible relations of AXPs/SGRs with other classes of objects, can be found in Mereghetti (2008).

2. The AXP and SGR sample

Table 1 lists all the sources that are currently considered confirmed AXPs or SGRs. Their locations and estimated distances are also indicated. The different columns show the wavelengths in which each source has been detected. Other properties of the sources are reported in Table 2. With the exception of two sources in the Magellanic Clouds, all the AXPs and SGRs are located in the Galactic plane, at distances of several kpc. Several AXPs/SGRs lie within, or close to, supernova remnants (SNRs). This is not unexpected for a population of young neutron stars, but different conclusions have been reached on the reliability of the specific associations (see, e.g., Marsden et al. (2001), Gaensler et al. (2001)). In some cases large transverse velocities are required to account for the off-center positions of the neutron stars. This was originally believed a distinguishing characteristic of SGRs, but it has not been confirmed by the observations (Helfand et al., 2007; de Luca et al., 2009). Certainly the most reliable associations are those of the few AXPs/SGRs that are located at (or close to) the center of SNRs. They are indicated in the last column of Table 1.

Three sources are likely located within clusters of massive stars (they are indicated as MSC in the last column of Table 1), suggesting that magnetars are formed in the collapse of very massive stars. The associations with SNRs and young star clusters, as well as their distribution in the Galactic plane, clearly indicate that AXPs and SGRs are a population of relatively young neutron stars.

3. Multi-wavelength properties

3.1. Soft X-rays

All[1] the confirmed AXPs and SGRs are pulsating sources in the classical X-ray band. Their pulse profiles have generally a single (or sometimes two) broad peak(s)

[1] The rotation period and period derivative of the transient SGR 1627-41, that could not be found during its 1998 outburst, have been recently discovered thanks to an XMM-Newton ToO during a new outburst of the source (Esposito et al., 2009b,a).

Table 2
Main properties of the AXPs and SGRs. Fluxes are not corrected for the absorption. Luminosities are corrected for the absorption. B = burst(s), GF = Giant Flare. References: (1) Lamb et al. (2002), (2) McGarry et al. (2005), (3) Tiengo et al. (2008), (4) Israel et al. (1994), (5) Gavriil et al. (2008), (6) Dib et al. (2007), (7) Rea et al. (2007), (8) Seward et al. (1986), (9) Mereghetti (1995), (10) Tiengo et al. (2005), (11) Gavriil et al. (2002), (12) Dib et al. (2009), (13) Esposito et al. (2008), (14) Mereghetti et al. (2009), (15) Muno et al. (2007), (16) Israel et al. (2007a), (17) Rea et al. (2005), (18) Israel et al. (2007b), (19) Dall'Osso et al. (2003), (20) Dib et al. (2008), (21) Gotthelf and Halpern (2007), (22) Woods et al. (2005), (23) Bernardini et al. (2009), (24) Gotthelf et al. (2002), (25) Morii et al. (2003), (26) Woods et al. (2004), (27) Gavriil et al. (2004), (28) Kaspi et al. (2003), (29) Gogus et al. (2009), (30) Rea et al. (2009), (31) Enoto et al. (2009), (32) Mazets et al. (1979b), (33) Mazets et al. (1999), (34) Tiengo et al. (2009), (35) Mereghetti et al. (2006a), (36) Esposito et al. (2009b), (37) Esposito et al. (2009a), (38) Palmer et al. (2005), (39) Mereghetti et al. (2005c), (40) Woods et al. (2007), (41) Göğüşet al. (2010), (42) Esposito et al. (2010), (43) Mazets et al. (1979a), (44) Woods et al. (1999a), (45) Mereghetti et al. (2006b).

	Period (s)	$\dot{P}$ (10^{-11} s s^{-1})	B (10^{14} G)	Flux [2–10 keV] (10^{-11} erg cm^{-2} s^{-1})	L_X [0.5–10 keV] (erg s^{-1})	Bursts Flares	Glitches	References
CXOU J0100-7211	8.02	1.9	4	0.013	2×10^{35}	–	–	1–3
4U 0142+61	8.69	0.2	1.3	6	3×10^{35}	B	G?	4–7
1E 1048.1-5937	6.45	1–10	2.6–8.1	0.5–4	$(0.9–7) \times 10^{35}$	B	G	8–12
1E 1547.0-5408	2.07	2.3	2.2	0.02–7	3×10^{33} to $\sim 10^{36}$	B	–	13, 14
CXOU J1647-4552	10.6	0.09	1	0.01–4	7×10^{32} to $\sim 10^{35}$	B	G	15, 16
1RXS J1708-4009	11.0	2.4	5.2	2–3	$(1.5–2.5) \times 10^{35}$	–	G	17–20
XTE J1810-197	5.54	0.8–2.2	2.1–3.5	0.05–8	8×10^{32}–1.310^{35}	B	–	21–23
1E 1841-045	11.77	4.1	7	1.6	4×10^{35}	–	G	24, 25, 20
1E 2259+586	6.98	0.048	0.6	1–4	$(1–4) \times 10^{36}$	B	G	26–28
SGR 0418+5729	9.1	–	–	1	1.3×10^{34}	B	–	29
SGR 0501+4516	5.7	0.7	2	0.13–4	$\sim 10^{33}$ to $2.4\ 10^{34}$	B	–	30,31
SGR 0526-66	8.05	6.5	5.7	0.05	$\sim 10^{36}$	B, GF	–	32–34
SGR 1627-41	2.59	1.9	2.2	0.006–1.2	$\sim 10^{33}$ to 2×10^{35}	B	–	35–37
SGR 1806-20	7.6	8–80	8–25	1–3	$(0.5–1.4) \times 10^{36}$	B, GF	–	38–40
SGR 1833-0832	7.56	0.28	1.5	<0.004–0.4	$(<0.01–1) \times 10^{35}$	B	–	41, 42
SGR 1900+14	5.2	5–14	5.1–8.6	0.4–1	$(2–5) \times 10^{35}$	B, GF	G?	43–45

with pulsed fractions from ~10% to ~90%. The profiles are energy-dependent, with the pulsed fraction increasing in the hard X-ray range. Variations related to the source state of bursting/flaring activity have also been observed.

The narrow period distribution, that played a role in recognizing the anomalous nature of these sources, has been only slightly extended with the now triplicated sample of objects. Its significant difference with respect to the period distributions of accreting pulsars and rotation-powered pulsars, both of which span several orders of magnitude, is thus confirmed.

The period derivatives span a larger range, from $\sim 5 \times 10^{-13}$ to $\sim 8 \times 10^{-10}$ s s^{-1}. Adopting the usual dipole spin-down formula ($B = 3.2 \times 10^{19}\ (P\dot{P})^{1/2}$ G), the observed timing parameters give magnetic fields in the range from 6×10^{13} to 2.5×10^{15} G (see Fig. 1 and Table 2). Significant variations in $\dot{P}$ have been observed in several sources, in some cases up to one order of magnitude on timescales of weeks to months (Gavriil and Kaspi, 2004; Woods et al., 2007). The variations in $\dot{P}$ and in the pulse profiles indicate that the magnetospheres of these sources are subject to significant changes, affecting the spin-down efficiency and the radiative properties. This is in accord with the magnetar theory.

Many of the well monitored AXPs showed also the occurrence of glitches, as indicated in Table 2. These are sometimes associated to changes in the emission properties, especially when strong bursting activity or large flares occur (see, e.g. Dib et al. (2008), and references therein). Crustal fractures caused by magnetic stresses are a likely mechanism at the basis of such phenomena. However, there is also evidence for glitches not accompanied by bursts, and the observations are too sparse to unambiguously correlate glitches and radiative variations. The study of glitches, as in the case of radio pulsars, could provide crucial information on the star's internal structure, but this is complicated by the dynamical configuration of the AXPs/SGRs magnetospheres. Furthermore it is not at all clear that glitches in radio pulsars and magnetars have the same origin.

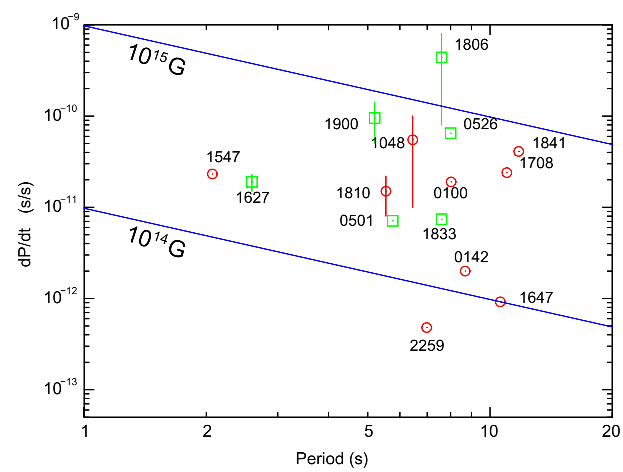

Fig. 1. $P - \dot{P}$ diagram for AXPs (red circles) and SGRs (green squares). The vertical lines associated to some sources indicate the observed range of variability in $\dot{P}$. The lines indicate the dipolar magnetic fields inferred assuming that the spin-down is entirely due to the emission of dipole radiation, $B = 3.2 \times 10^{19}\ (P\dot{P})^{1/2}$ G. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

AXPs spectra below 10 keV have been often fitted with two-components models: either a steep power law (photon index ∼3–4) plus a blackbody ($kT \sim 0.5$ keV), or two blackbody components with different temperatures. The latter choice is probably to be preferred (Halpern and Gotthelf, 2005) because the blackbody plus power law fits result in interstellar absorption values higher than those independently estimated in other ways. In addition, the power law components, extrapolated to lower energies, exceed the flux of the near infrared and optical counterparts (unless a drastic, and possibly un-physical, cut-off in the power law component is invoked). However, from a purely observational point of view, it is impossible to discriminate between these two possibilities in the Galactic AXPs and SGRs, due to the high interstellar absorption (see Fig. 2) that severely suppresses their flux below ∼1 keV. This is not the case for the two sources in the Magellanic Clouds that are much less absorbed. While the spectral analysis of SGR 0526-66 is complicated by the presence of soft X-ray emission from the surrounding supernova remnant N49 (Tiengo et al., 2009), XMM-Newton data of CXOU J0100-7211 indicate that the power law plus blackbody model can be rejected with high confidence, while a good fit to the spectrum is obtained with the sum of two blackbody components (Tiengo et al., 2008). As shown in Fig. 3 the spectrum of this source can be significantly detected down to 0.2 keV.

In recent years considerable effort has started in the analysis and interpretation of the AXPs and SGRs spectra, in an attempt to progress from purely phenomenological fits to more physical models. The presence of a relatively dense plasma in magnetospheres with a twisted configuration (Thompson et al., 2002) is expected to affect the emergent spectrum through resonant Compton scattering (RCS) of the thermal photons emitted by the underlying neutron star's surface. A simplified model, based on a semi-analytical treatment of these effects (Lyutikov and Gavriil, 2006), has been systematically applied to several

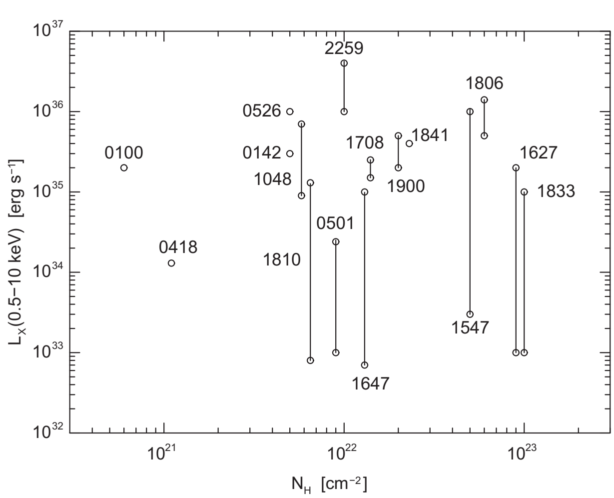

Fig. 2. X-ray luminosity versus absorption for the AXPs and SGRs. Several transient sources have large luminosities variations.

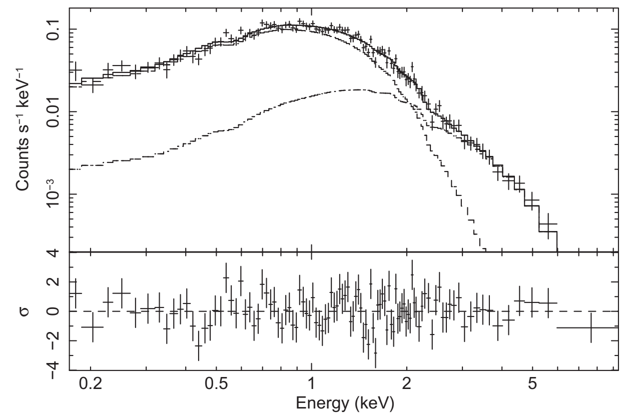

Fig. 3. X-ray spectrum of the AXP CXOU J0100-7211 fitted with two blackbody components (from Tiengo et al. (2008)). The small absorption ($N_H \sim 6 \times 10^{20}$ cm^{-2}) allows in this case to clearly reject fits with a blackbody plus power law model.

magnetar candidates (Rea et al., 2008). This showed that at $E < 10$ keV the RCS can replace the blackbody plus power law model, but in most sources an additional power law is still required to fit the hard X-ray tails. More realistic 3-D simulations have also been performed to compute the magnetar's spectral models (Fernández and Thompson, 2007; Nobili et al., 2008b,a) and quite successfully applied to the spectra of several magnetar candidates (Zane et al., 2009).

3.2. Hard X-rays

One of the main results of the INTEGRAL satellite has been the discovery of persistent hard X-ray emission from AXPs and SGRs. Previous detections of these sources above ∼20 keV were limited to the bursts and flares from SGRs.[2] Hard X-ray tails, extending to ∼150 keV have been seen both in AXPs (Kuiper et al., 2004; den Hartog et al., 2008b,a) and SGRs (Mereghetti et al., 2005a; Götz et al., 2006; Rea et al., 2009). The luminosity in the hard X-ray range is comparable to, and in some cases higher than, that in the soft X-ray band. The evidence of a substantial luminosity at high energies has radically changed our picture of the emission from these sources.

Different mechanisms have been proposed to explain these high-energy tails. Thompson and Beloborodov (2005) discussed two possibilities in the context of the twisted magnetosphere model: bremsstrahlung from a thin turbulent layer of the star's surface heated to $kT \sim 100$ keV by magnetospheric currents and synchrotron emission from mildly relativistic pairs produced at a height of ∼100 km above the neutron star. Compton scattering in high magnetic fields has also been considered (Harding and Daugherty, 1991; Gonthier et al., 2000). Baring and Harding (2007) invoked upscattering of soft thermal

[2] In retrospect, it seems that some detections of persistent emission could have been present also in earlier data (e.g., Esposito et al., 2007).

photons, emitted from the star surface, by relativistic electrons threaded in the magnetosphere as a possible explanation for the hard X-rays. Different groups are working to extend to high-energy the physical spectral models developed for the X-ray band.

3.3. Near infrared

The search for optical/IR counterparts of AXPs and SGRs is complicated by the high interstellar absorption suffered by these sources, as well as by the crowding of their locations in the Galactic plane. Identifications have been more successful in the near infrared (NIR), where counterparts have been secured (or proposed) for most of the sources. In general, the counterparts are selected based on their unusual colors compared to field stars and/or some evidence of variability.

All the (candidate) counterparts of AXPs/SGRs are very faint, clearly inconsistent with the presence of high-mass companions and in most cases also ruling out the possibility of low mass companion stars. The counterparts have NIR fluxes which lie above the extrapolation of the blackbody components measured at X-rays. Most of them showed some variability. The X-ray and NIR flux variations do not always correlate (Rea et al., 2004; Hulleman et al., 2004; Durant and van Kerkwijk, 2006; Israel et al., 2005; Hulleman et al., 2004; Testa et al., 2008), although there is a tendency for increased optical/NIR emission during the outbursts of transient AXPs and SGRs (see, e.g., Kaspi et al., 2003; Rea et al., 2004).

These results point to possibly different origins for the X-ray and optical/IR emission. For example, the optical/IR could be non-thermal coherent emission from plasma instabilities above the plasma frequency (Eichler et al., 2002), in which case it would be probably pulsed and polarized. Unfortunately most counterparts are too faint to test these predictions with the current facilities.

3.4. Mid infrared

4U 0142+61 has been detected in the mid infrared (MIR) band with the Spitzer Space Telescope (Wang et al., 2006). The emission observed at 4.5 and 8 μm has been interpreted as evidence for a residual disk of debris from the supernova, irradiated and heated by the magnetar's X-ray flux. In this scenario the disk is "passive", i.e. it does not contribute to the X-ray emission by accretion.[3] The emission from 4U 0142+61 seems to vary less in the MIR than in the K band (Wang and Kaspi, 2008). This might be due to structural changes in the inner part of the disk, not affecting the external regions where the MIR emission takes place. More frequent sampling is required to assess this possibility.

Spitzer detected at 4.5 μm also 1E 2259+586 (Kaplan et al., 2009), while only upper limits could be obtained for XTE J1810-197, 1RXS J1708-4009 and 1E 1048.1-5937 (Wang et al., 2007, 2008). In the latter source, the upper limits are sufficiently deep to exclude the presence of a disk similar to that of 4U 0142+61.

A different phenomenon was discovered in longer wavelengths observations of SGR 1900+14: images obtained at 16 and 24 μm led to the discovery of an elliptical structure with a size of about 30″ surrounding the SGR (Wachter et al., 2008). These authors speculate that the ring marks the boundary of a dust-free region produced by a giant flare emitted by SGR 1900+14 and now irradiated by the hot massive stars of the nearby cluster. The flare might be that observed from this source in August 1998 or an earlier, more powerful one.

3.5. Optical

4U 0142+61 and 1E 1048.1-5937 have been detected as periodic sources in the optical band. In both sources optical pulsations are clearly visible (Kern and Martin, 2002; Dhillon et al., 2009) with the same period and approximate phase of the X-rays, but with a larger pulsed fraction. According to the magnetar model, optical pulsed emission is expected from non-thermal magnetospheric processes, while in models involving residual disks the optical modulation could come from reprocessing of the X-ray pulses in the disk. In the latter case it is unlikely (although not impossible for some particular geometry) to have a larger pulsed fraction in the optical than in the X-rays and the same phase alignment in the two wavebands. The detection of optical pulses has thus been considered to support the magnetar interpretation, but a possible alternative explanation is discussed in Ertan and Cheng (2004).

The origin of the optical emission is unclear, since several processes are in principle available in the neutron star magnetospheres. These include coherent plasma emission (Eichler et al., 2002), synchrotron emission from relativistic electrons, cyclotron emission from ions, and curvature radiation (Beloborodov and Thompson, 2007).

3.6. Radio

Two very different kinds of radio emission have been observed in AXPs/SGRs: variable emission due to the ejection of relativistic matter after the giant flares, and pulsed emission in the two transient AXPs, XTE J1810-197 and 1E 1547.0-5408.

Transient radio emission was first detected after the 1998 giant flare of SGR 1900+14 (Frail et al., 1999), and interpreted as evidence for relativistic matter ejection. This was confirmed by the much more extensive radio observations that followed the exceptionally bright giant flare of SGR 1806-20 (Gaensler et al., 2005; Cameron et al., 2005; Granot et al., 2006; Mereghetti et al., 2005b). In this case the evolution of the radio emission could be studied

[3] A different interpretation of the multi-wavelength data from this source in terms of an active disk is given in Ertan et al. (2007).

for more than one year. The proper motion of the source in the initial phases clearly demonstrated the anisotropy of the mass ejection, within a solid angle of ∼0.5–1 sterad. Other parameters could be estimated by modelling the source expansion and flux temporal evolution at different frequencies. Although the data can be fitted with different jet models, that differ in the physical and geometrical details, the evidence for an anisotropic ejection of 10^{24}–10^{25} g of mildly relativistic matter (Lorentz factor $\Gamma\sim$ a few) is well consolidated.

Searches for radio pulsations have been carried out for several AXPs and SGRs (Burgay et al., 2006b), but only two cases gave positive results. Radio emission from the transient XTE J1810-197 was discovered in 2004, about one year after the start of the X-ray outburst of this source (Halpern et al., 2005). Further observations showed it to consist of bright (>1 Jy), highly linearly polarized pulses at the neutron star rotation period (Camilo et al., 2006). Radio pulsations at 2.07 s[4] were reported also from 1E 1547.0-5408 (Camilo et al., 2007a). Both sources are transients, suggesting that the mechanisms responsible for the pulsed radio emission in some magnetars might be related to their transient nature. However, no radio pulsations were seen in the other transient AXP, CXOU J1647-4552, after its September 2006 outburst (Burgay et al., 2006a), nor in the transient SGR 1627-41 (Esposito et al., 2009a), which is in many respects very similar to 1E 1547.0-5408 (Mereghetti et al., 2009).

The radio properties of the two AXPs showing radio pulsations differ in several respects from those of radio pulsars: their flux is highly variable on daily timescales, their spectrum is very flat with $\alpha > -0.5$ (where $S_\nu \propto \nu^\alpha$), and their average pulse profile changes with time (Camilo et al., 2007b,a, 2008). Such differences probably indicate that the radio emitting regions are more complex than the dipolar open field lines along which the radio emission in normal pulsars is thought to originate.

4. Conclusions

AXPs and SGRs have attracted increasing interest in the latest few years and contributed to change our vision of isolated neutron stars. Their number has more than doubled with the discovery of several transients, that now outnumber the original sample of “steady” sources. Future observations will further increase the number of known AXPs/SGRs, both with the detection of new transients and with the discovery of new examples among the large number of poorly studied, faint X-ray sources.

As magnetar candidates, these sources offer the unique possibility to study physical processes in extremely high magnetic fields. Their X-ray spectral and timing properties are well explained by the magnetar model, at least in their general aspects. However, the complexity of the involved physics and the unknown details of the geometry, make difficult to model in a self-consistent way all the data and extract relevant and robust information. X-ray polarimetry, that will be available with future instrumentation, will play a crucial role in the study of these sources.

[4] This was the first evidence for a periodicity in this source; pulsations were subsequently found also in X-rays.

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