A&A 449, L31–L34 (2006)
DOI: 10.1051/0004-6361:20064870

Astronomy
&
Astrophysics

Magnetars as persistent hard X-ray sources: INTEGRAL discovery of a hard tail in SGR 1900+14[⋆]

D. Götz[1], S. Mereghetti[2], A. Tiengo[2], and P. Esposito[2,3]

[1] CEA Saclay, DSM/DAPNIA/Service d'Astrophysique, 91191 Gif-sur-Yvette, France
e-mail: `diego.gotz@cea.fr`
[2] INAF – Istituto di Astrofisica Spaziale e Fisica Cosmica, via Bassini 15, 20133 Milano, Italy
[3] Dipartimento di Fisica Nucleare e Teorica – Università degli Studi di Pavia, via Bassi 6, 27100 Pavia, Italy

Received 17 January 2006 / Accepted 20 February 2006

ABSTRACT

Using 2.5 Ms of data obtained by the *INTEGRAL* satellite in 2003−2004, we discovered persistent hard X-ray emission from the soft gamma-ray repeater SGR 1900+14. Its 20−100 keV spectrum is well described by a steep power law with photon index $\Gamma = 3.1 \pm 0.5$ and flux 1.5×10^{-11} erg cm^{-2} s^{-1}. Contrary to SGR 1806–20, the only other soft gamma-ray repeater for which persistent emission above 20 keV was reported, SGR 1900+14 has been detected in the hard X-ray range while it was in a quiescent state (the last bursts from this source were observed in 2002). By comparing the broad band spectra (1−100 keV) of all the magnetars detected by *INTEGRAL* (the two SGRs and three anomalous X-ray pulsars) we find evidence for a different spectral behaviour of these two classes of sources.

Key words. gamma-rays: observations – pulsars: individual SGR 1900+14 – pulsars: general

1. Introduction

Soft gamma-ray repeaters (SGRs, for a recent review see Woods & Thompson 2004) are a small group of peculiar high-energy sources generally interpreted as "magnetars", i.e. strongly magnetised ($B \sim 10^{15}$ G), slowly rotating ($P \sim$ 5−8 s) neutron stars powered by the decay of the magnetic energy, rather than by rotation (Duncan & Thompson 1992; Paczynski 1992; Thompson & Duncan 1995). They were discovered through the detection of recurrent short (∼0.1 s) bursts of high-energy radiation in the tens to hundreds of keV range, with peak luminosity up to 10^{39}−10^{42} erg s^{-1}, above the Eddington limit for neutron stars. The rate of burst emission in SGRs is highly variable. Bursts are generally emitted during sporadic periods of activity, lasting days to months, followed by long "quiescent" time intervals (up to years or decades) during which no bursts are emitted. Occasionally SGRs emit also "giant flares", that last up to a few hundred seconds and have peak luminosity up to 10^{46}−10^{47} erg s^{-1}. Only three giant flares have been observed to date, each one from a different source (see, e.g., Mazets et al. 1979; Hurley et al. 1999; Palmer et al. 2005).

Persistent (i.e. non-bursting) emission is also observed from SGRs in the soft X-ray range (<10 keV), with typical luminosity of $\sim 10^{35}$ erg s^{-1}, and, in three cases, periodic pulsations at a few seconds have been detected. Such pulsations proved the neutron star nature of SGRs and allowed to infer spin-down at rates of $\sim 10^{-10}$ s s^{-1}, consistent with dipole radiation losses for magnetic fields of the order of $B \sim 10^{14}$−10^{15} G. The X-ray spectra are generally described with absorbed power laws, but in some cases strong evidence has been found for the presence of an additional blackbody-like component with typical temperature of ∼0.5 keV (Mereghetti et al. 2005c).

The only SGR for which persistent (i.e. not due to bursts and/or flares) emission above 20 keV has been reported to date is SGR 1806−20 (Mereghetti et al. 2005a; Molkov et al. 2005). Here we report the discovery, based on observations with the *INTEGRAL* satellite (Winkler et al. 2003), of persistent hard X-ray emission from SGR 1900+14 in the 20−100 keV range.

2. Observations and data analysis

We analysed data obtained with ISGRI (Lebrun et al. 2003), the low-energy detector of the IBIS (Ubertini et al. 2003) coded mask telescope. IBIS/ISGRI is an imaging instrument covering a wide field of view (29° × 29° at zero sensitivity, 9° × 9° at full sensitivity) with unprecedented sensitivity and angular resolution (∼12′) in the hard X/soft γ-ray energy range

---

[⋆] Based on observations with INTEGRAL, an ESA project with instruments and the science data centre funded by ESA member states (especially the PI countries: Denmark, France, Germany, Italy, Switzerland, Spain), Czech Republic and Poland, and with the participation of Russia and the USA.

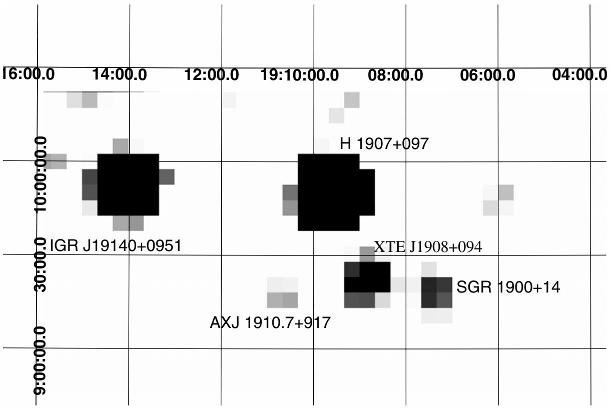

Fig. 1. IBIS/ISGRI image of the SGR 1900+14 field in the 18−60 keV energy range. The other detected sources are the high-mass X-ray binary (HMXB) IGR J19140+0951 (Rodriguez et al. 2005), the black hole candidate XTE J1908+094 (in't Zand et al. 2002), the HMXB pulsar H 1907+097 (Makishima et al. 1984), and the weak unidentified source AXJ 1910.7+917 (Sugizaki et al. 2001).

(15 keV−1 MeV). These excellent imaging performances are essential, especially in crowded Galactic fields, to avoid source confusion, which affected most previous experiments operating in this energy range.

From the *INTEGRAL* public data archive we selected all the observations pointed within 10° from the position of SGR 1900+14. The resulting data set consists of 1033 pointings, yielding a total exposure time of ~2.5 Ms. The observation period, during which the source was observed discontinuously, spans from March 6th 2003 to June 8th 2004. We used version 5.1 of the Offline Scientific Analysis (OSA) Software provided by the *INTEGRAL* Science Data Centre (Courvoisier et al. 2003).

After standard data processing (dead time correction, good time-interval selection, gain correction, energy reconstruction), we produced the sky images of each pointing in the 18−60 keV range. These individual images were summed to produce a total image, a portion of which is shown in Fig. 1. A source with count rate 0.18 ± 0.02 counts s^{-1} is detected with a significance of 9σ at coordinates (J2000) RA = $19^h07^m25^s$, Dec = $+09°18'34''$. The associated error circle, with a radius of $\sim 3'$ (Gros et al. 2003) contains the position of SGR 1900+14 (Frail et al. 1999). No other catalogued X-ray sources are present in the error circle. We therefore associate the detected source with SGR 1900+14.

We found marginal evidence for a long term flux increase by splitting the data in two parts (March to May 2003 and November 2003 to June 2004) and producing two images of approximately equal exposure. SGR 1900+14 had a count rate of 0.14 ± 0.03 counts s^{-1} in the first period and of 0.25 ± 0.03 counts s^{-1} in the second one.

To perform a spectral analysis we produced the summed images, corresponding to the three time periods mentioned above, in five energy bands (18−25, 25−35, 35−60, 60−100, and 100−200 keV). We extracted the SGR 1900+14 spectra using the source count rates obtained from these images and rebinned the IBIS/ISGRI response matrix in order to match our five energy channels. This spectral extraction method, which we tested successfully with data also from the Crab nebula, is particularly suited for weak sources that cannot be detected in the individual pointings. Before fitting, we added a systematic error of 5% to the data, to account for the uncertainties of our spectral extraction method and of the response matrix. In all cases a rather steep power law gave good results (see Table 1). No signal was detected above 100 keV, but owing to the small statistics we could not establish the possible presence of a spectral break at high energies.

Table 1. Fluxes (20−100 keV) and spectral parameters derived for SGR 1900+14 with IBIS/ISGRI during the whole observation and during its parts (see text). All the errors are at 1σ for one parameter of interest.

	Flux $[10^{-12}$ erg cm^{-2} s$^{-1}]$	Photon index
Average spectrum	15 ± 3	3.1 ± 0.5
Spring 2003	10 ± 3	4.0 ± 1.0
2003/2004	20 ± 3	3.1 ± 0.6

3. Discussion

SGR 1900+14 is the second SGR for which persistent hard X-ray emission extending to ~100 keV has been detected, the other being SGR 1806–20 (Mereghetti et al. 2005a; Molkov et al. 2005). The spectrum of SGR 1900+14 in the 20−100 keV range, with photon index $\Gamma = 3.1 \pm 0.5$, is softer than that of SGR 1806–20, which, in the last few years has been the most active SGR. In the latter source the photon index varied from $\Gamma = 1.9 \pm 0.2$, measured in the period March 2003−April 2004, to $\Gamma = 1.5 \pm 0.3$ in September−October 2004, when the burst rate increased (Mereghetti et al. 2005a) before the emission on December 27, 2004 of the most powerful giant flare ever observed from a SGR (Palmer et al. 2005; Hurley et al. 2005; Mereghetti et al. 2005b). Positive correlations between the bursting activity, the intensity and hardness of the persistent emission, and the spin-down rate, as have been observed in SGR 1806–20 (Mereghetti et al. 2005c), are expected in magnetar models involving a twisted magnetosphere (Thompson et al. 2002), since all these phenomena are driven by an increase of the twist angle.

The soft spectrum of SGR 1900+14 is possibly related to the fact that this source is currently in a quiescent state. Short bursts were observed from this source with BATSE (Kouveliotou et al. 1993), *RXTE* (Göğüş et al. 1999) and other satellites (e.g. Feroci et al. 2004; Aptekar et al. 2001) in the years 1979−2002. SGR 1900+14 emitted a giant flare on August 27, 1998 (e.g. Hurley et al. 1999), followed by less intense "intermediate" flares on August 29 1998 (Ibrahim et al. 2001) and in April 2001 (Guidorzi et al. 2004; Lenters et al. 2003). The last bursts reported from SGR 1900+14 were observed with the Third Interplanetay Network (IPN) in November 2002 (Hurley et al. 2002). No bursts from this source were revealed in all the *INTEGRAL* observations from 2003 to 2005.

Table 2. High-energy spectral parameters of Magnetars as measured by *INTEGRAL*. The distances are taken from Woods & Thompson (2004) and references therein.

Source	Exposure time [Ms]	Obs. start UTC	Obs. end UTC	Photon index	20−100 keV luminosity [10^{34} erg s^{-1}]	Distance [kpc]
SGR 1900+14	2.5	2003-03-06	2004-06-08	3.1 ± 0.5	40 ± 8	15
SGR 1806–20	2.0	2003-03-12	2003-10-15	1.8 ± 0.2	124 ± 11 (35 ± 3)	15 (8)
4U 0142+61	0.33	2002-12-28	2004-06-09	1.3 ± 0.4	5 ± 0.5	3
1E 1841–045	1.5	2003-03-10	2004-05-02	1.5 ± 0.2	26 ± 2	7
1RXS J170849.0–400910	1.8	2003-02-01	2004-04-20	1.4 ± 0.4	7 ± 1	5

A comparison of the hard X-ray luminosity of the two SGRs is subject to some uncertainties due to the unknown distances of these sources. For SGR 1900+14 a distance of 15 kpc has been derived based on its likely association with a young star cluster (Vrba et al. 2000). For this distance the average flux of about 1 mCrab corresponds to a 20−100 keV luminosity of 4 × 10^{35} erg s^{-1}. The distance of SGR 1806–20 is more controversial. If also this source is at ~15 kpc (McClure-Griffiths & Gaensler 2005), its hard X-ray luminosity would be at least three times larger than that of SGR 1900+14. On the other hand, for a distance in the 6.4 to 9.8 kpc range, as derived from the latest radio measurements of the afterglow of SGR 1806–20 giant flare (Cameron et al. 2005), the two SGRs would have about the same luminosity.

Hard X-ray persistent emission (>20 keV) has recently been detected from another group of sources, the Anomalous X-ray Pulsars (AXPs, Mereghetti & Stella 1995), which share several characteristics with the SGRs and are also believed to be magnetars (see Woods & Thompson 2004). Hard X-ray emission has been detected from three AXPs with *INTEGRAL*: 1E 1841−045 (Molkov et al. 2004), 4U 0142+61 (den Hartog et al. 2006) and 1RXS J170849−400910 (Revnivtsev et al. 2004). The presence of pulsations seen with RXTE up to ~200 keV in 1E 1841−045 (Kuiper et al. 2004) proofs that the hard X-ray emission originates from the AXP and not from the associated supernova remnant Kes 73. The discovery of (pulsed) persistent hard X-ray tails in these three sources was quite unexpected, since below 10 keV the AXP have soft spectra, consisting of a blackbody-like component (kT ~ 0.5 keV) and a steep power law (photon index ~3–4).

In order to coherently compare the broad band spectral properties of all the SGRs and AXPs detected at high energy, we analysed all the public *INTEGRAL* data using the same procedures described above for SGR 1900+14. Our results are summarised in Table 2 and in Fig. 2 where the *INTEGRAL* spectra are plotted together with the results of observations at lower energy taken from the literature (see figure caption for details). For SGR 1806–20 we considered only the *INTEGRAL* data obtained from March to October 2003, in order to exclude the more active period observed in 2004. We did not introduce any normalisation factor between the different satellites and some discrepancy between the soft and hard X-ray spectra might be ascribed to source variability since the observations were not simultaneous. Nevertheless, even considering these uncertainties, some indications can be drawn from the plotted spectra. Namely, in the three AXP a spectral hardening above ~10−20 keV is required (as already noted, e.g. by Kuiper et al. 2004), while at hard X/soft γ-rays the spectra of the two SGRs tend to be softer than the ones measured at low energies. The fact that the spectral break in SGR 1900+14 is more evident than in SGR 1806–20 could be also due to the different state during which the two sources have been observed, with the former in complete quiescence and the latter in a low level of activity. All the three AXPs, on the other hand,

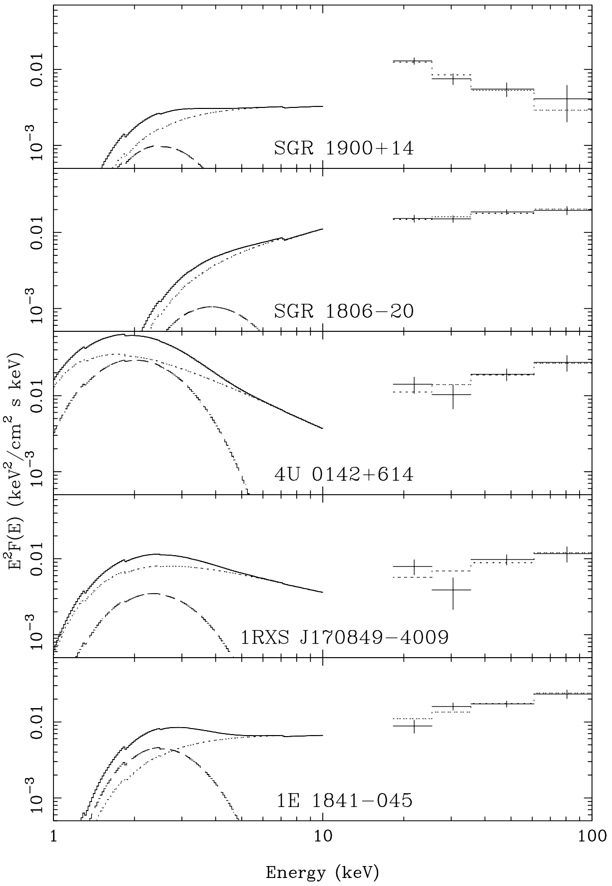

Fig. 2. Broad band X-ray spectra of the five magnetars detected by *INTEGRAL*. The data points above 18 keV are the *INTEGRAL* spectra with their best fit power-law models (dotted lines). The solid lines below 10 keV represent the absorbed power-law (dotted lines) plus blackbody (dashed lines) models taken from Woods et al. (2001) (SGR 1900+14, during a quiescent state in spring 2000), Mereghetti et al. (2005c) (SGR 1806–20, observation B, when the bursting activity was low), Göhler et al. (2005) (4U 0142+614), Rea et al. (2005) (1RXS J170849–4009), and Morii et al. (2003) (1E 1841−045).

can be considered in a quiescent state since no SGR-like bursts have ever been reported from any of them.

4. Conclusions

We have discovered persistent emission in the 20−100 keV range from SGR 1900+14. Its spectrum is softer than that of the only other SGR with persistent emission at these energies, SGR 1806–20. This difference is possibly due to the different activity state of the two sources since SGR 1900+14 was detected while it was quiescent from the point of view of bursting emission, contrary to the case of SGR 1806–20.

Examining the broad band spectra of magnetars in the 1−100 keV range, a notable difference between SGRs and AXPs appears. While in SGRs the hard tails at higher energies are softer than the power law components measured below 10 keV, in all the AXPs there is evidence for a spectral hardening between the soft and hard X-ray range.

In the framework of the magnetar model the persistent hard X-ray emission can be powered either by bremsstrahlung photons produced in a thin layer close to the neutron star surface, or at ∼100 km altitude in the magnetosphere through multiple resonant cyclotron scattering (Thompson et al. 2002; Thompson & Beloborodov 2005). The two models can be distinguished by the presence of a cutoff at ∼100 keV or at ∼1 MeV. Unfortunately the current *INTEGRAL* observations can just firmly asses the presence of the high energy emission in magnetars, but cannot fully rule out the presence of spectral breaks at high energies. Longer exposure times and/or observations with more sensitive high-energy instruments are required to discriminate between the two models.

Acknowledgements. D.G. acknowledges support from the French Space Agency (CNES). ISGRI has been realized and maintained in flight by CEA-Saclay/DAPNIA with the support of CNES. This work has been partially supported by the Italian Space Agency and by the MIUR under grant PRIN 2004-023189.

References

Aptekar, R. L., Frederiks, D. D., Golenetskii, S. V., et al. 2001, ApJS, 137, 227
Cameron, P. B., Chandra, P., Ray, A., et al. 2005, Nature, 434, 1112
Courvoisier, T. J.-L., Walter, R., Beckmann, V., et al. 2003, A&A, 411, L53
Duncan, R. C., & Thompson, C. 1992, ApJ, 392, L9
Feroci, M., et al. 2004, ApJ, 612, 480
Frail, D. A., Kulkarni, S. R., & Bloom, J. S. 1999, Nature, 398, 127
Göğüş, E., Woods, P. M., Kouveliotou, et al. 1999, ApJ, 526, L93
Göhler, E., Wilms, J., & Staubert, R. 2005, A&A, 433, 1079
Gros, A., Goldwurm, A., Cadolle-Bel, M., et al. 2003, A&A, 411, L179
Guidorzi, C., Frontera, F., Montanari, E., et al. 2004, A&A, 416, 297
den Hartog, P. R., Hermsen, W., Kuiper, L., et al. 2006, A&A, in press [`arXiv:astro-ph/0601644`]
Hurley, K., Cline, T., Mazets, E., et al. 1999, Nature, 397, 41
Hurley, K., Mazets, E., Golenetskii, S., & Cline, T. 2002, GCN Circ., 1715
Hurley, K., Boggs, S. E., & Smith, D. M. 2005, Nature, 434, 1098
Ibrahim, A. I., Strohmayer, T. E., Woods, P. M., et al. 2001, ApJ, 558, 237
in't Zand, J. J. M., Miller, J. M., Oosterbroek, T., & Parmar, A. N. 2002, A&A, 394, 553
Kouveliotou, C., Fishman, G. J., Meegan, C. A., et al. 1993, Nature, 362, 728
Kuiper, L., Hermsen, W., & Mendez, M. 2004, ApJ, 613, 1173
Lebrun, F., Leray, J. P., Lavocat, P., et al. 2003, A&A, 411, L141
Lenters, G. T., Woods, P. M., Goupell, J. E., et al. 2003, ApJ, 587, 761
McClure-Griffiths, N. M., & Gaensler, B. M. 2005, ApJ, 630, L161
Makishima, K., Kawai, N., Koyama, K., et al. 1984, PASJ, 36, 679
Mereghetti, S., & Stella, L. 1995, ApJ, 442, L17
Mereghetti, S., Götz, D., Mirabel, I. F., & Hurley, K. 2005a, A&A, 433, L9
Mereghetti, S., Götz, D., von Kienlin, A., et al. 2005b, ApJ, 624, L105
Mereghetti, S., Tiengo, A., Esposito, P., et al. 2005c, ApJ, 628, 938
Mazets, E. P., Golenetskii, S. V., Ilinskii, V. N., et al. 1979, Nature, 282, 587
Molkov, S., Hurley, K., Sunyaev, R., et al. 2005, A&A, 433, L13
Molkov, S. V., Cherepashchuk, A. M., Lutovinov, A. A., et al. 2004, Astron. Lett., 30, 534
Morii, M., Sato, R., Kataoka, J., & Kawai, N. 2003, PASJ, 55, L45
Paczynski, B. 1992, AcA, 42, 145
Palmer, D. M., Barthelmy, S., Gehrels, N., et al. 2005, Nature, 434, 1107
Revnivtsev, M. G., Sunyaev, R. A., Varshalovich, D. A., et al. 2004, Astron. Lett., 30, 382
Rea, N., Oosterbroek, T., Zane, S., et al. 2005, MNRAS, 361, 710
Rodriguez, J., Cabanac, C., Hannikainen, D. C., et al. 2005, A&A, 432, 235
Sugizaki, M., Mitsuda, K., Kaneda, H., et al. 2001, ApJS, 134, 77
Thompson, C., & Duncan, R. C. 1995, MNRAS, 275, 255
Thompson, C., & Beloborodov, A. M. 2005, ApJ, 634, 565
Thompson, C., Lyutikov, M., & Kulkarni, S. R. 2002, ApJ, 574, 332
Ubertini, P., Lebrun, F., Di Cocco, G., et al. 2003, A&A, 411, L131
Vrba, F. J., Henden, A. A., Luginbuhl, C. B., et al. 2000, ApJ, 533, L17
Winkler, C., Courvoisier, T. J.-L., Di Cocco, G., et al. 2003, A&A, 411, L1
Woods, P. M., & Thompson, C. 2004, in Compact Stellar X-ray Sources, ed. W. H. G. Lewin, & M. van der Klis [`arXiv:astro-ph/0406133`]
Woods, P. M., Kouveliotou, C., Göğüş, E., et al. 2001, 552, 748