INTEGRAL AND MAGNETARS

Diego Götz[1], Sandro Mereghetti[2], Kevin Hurley[3], I. Félix Mirabel[4], Paolo Esposito[2], Andrea Tiengo[2], Georg Weidenspointner[5], and Andreas von Kienlin[6]

[1]*CEA, DSM/DAPNIA/Service d'Astrophysique, Gif-sur-Yvette, France*
[2]*INAF – Istituto di Astrofisica Spaziale e Fisica Cosmica, Milano, Italy*
[3]*University of California at Berkeley, Space Sciences Laboratory, Berkeley CA, USA*
[4]*European Southern Observatory, Santiago, Chile*
[5]*Centre d'Étude Spatiale des Rayonnements, Toulouse, France*
[6]*Max-Planck-Institut für extraterrestrische Physik, Garching, Germany*

ABSTRACT

Thanks to *INTEGRAL*'s long exposures of the Galactic Plane, the two brightest Soft Gamma-Ray Repeaters, SGR 1806-20 and SGR 1900+14, have been monitored and studied in detail for the first time at hard-X/soft-gamma rays.

SGR 1806-20, lying close to the Galactic Centre, and being very active in the past two years, has provided a wealth of new *INTEGRAL* results, which we will summarise here: more than 300 short bursts have been observed from this source and their characteristics have been studied with unprecedented sensitivity in the 15-200 keV range. A hardness-intensity anticorrelation within the bursts has been discovered and the overall Number-Intensity distribution of the bursts has been determined. The increase of its bursting activity eventually led to the December 2004 Giant Flare for which a possible soft gamma-ray (>80 keV) early afterglow has been detected with *INTEGRAL*.

The deep observations allowed us to discover the persistent emission in hard X-rays (20-150 keV) from 1806-20 and 1900+14, the latter being in quiescent state, and to directly compare the spectral characteristics of all Magnetars (two SGRs and three Anomalous X-ray Pulsars) detected with *INTEGRAL*.

Key words: gamma-rays: observations; pulsars: individual SGR 1806–20, SGR 1900+14; pulsars: general.

1. INTRODUCTION

Most neutron stars (NSs) belong to two big categories: isolated NSs, where the dominant source of energy is the rotational one, and binary NSs where the accretion process dominates. The first category is mainly represented by classical radio pulsars with spin periods between 1.5 ms and 5 s, and comprises more than 1500 members. The youngest among them are also detected at higher energy. The second category is composed by several hundreds of members, which are hosted in binary systems and classified, based on the mass of their companion, as low mass (LMXB) or high mass X-ray binaries (HMXB). Many among them are transients and their rotational periods range from a few ms (the so called *recycled* millisecond pulsars) to a few hours (the longest one, ∼5 hours, recently discovered in 4U 1954+319, [25]).

Besides rotation and accretion two other sources of energy can dominate: in the "middle aged" isolated NSs thermal emission from the surface is detected in X-rays, and in LMXBs nuclear energy can be the dominant source, since they sometimes emit the so called type I X-ray bursts, whose flux reaches the Eddington limit for a NS.

Magnetars do not fit in any of the above categories. They are a peculiar class of sources, made of 11 members and 4 candidates, where the magnetic energy is the dominant one. This class is composed by Soft Gamma-Ray Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs): the reason for the different names is historical and due to the fact that they were discovered through different manifestations.

The SGRs were discovered more than 20 years ago, thanks to the fact that they emit short (∼ 0.1) and intense (10^{39}-10^{42} erg s^{-1}) bursts of high-energy radiation in the tens to ∼hundred keV energy range. They were initially considered a subclass of the Gamma Ray Bursts (GRBs), but then their recurrent behaviour and their soft spectrum (compared to GRBs) identified them as a separate class of objects. 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 "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 Tab. 1 (see, e.g., [26] for 0526–66,

[12] for 1900+14, [40, 31, 16] for 1806–20). These giant flares are today the most convincing evidence for the existence of very high ($B \sim 10^{15}$ G) magnetic fields associated with these objects [3, 39, 46], dubbed *Magnetars*. The pulsations measured during these powerful flares indicated for the first time the NS nature of these sources. The same periodicities (5–8 s) have also been confirmed in the persistent (i.e. non-bursting) emission, which is observed from SGRs in the soft X–ray range (<10 keV) [22, 13, 50], with a typical luminosity of $\sim 10^{35}$ erg s^{-1}. Spindown rates, $\dot{P}$, of the order of 10^{-11} s s^{-1} have been measured in these objects.

Table 1. Energetics of the three giant flares detected to date.

SGR	Initial Pulse Energy [ergs]	Tail energy [ergs]
0526-66	1.6×10^{44}	4×10^{44}
1900+14	$>7\times10^{43}$	5×10^{43}
1806-20	2×10^{46}	10^{44}

AXPs were identified by Mereghetti & Stella [29] as a subclass of LMXBs. Later studies (see [30] for a review) demonstrated that AXPs show no evidence for companion stars, having faint IR counterparts and lacking of orbital Doppler delays in their light curves. Two (maybe three) of them are associated with Supernova remnants, and recent evidence has been put forward for the existence of a fallback disk in 4U 0142+61 [49]. Their rotational periods are clustered in the 5–12 s range with a secular spindown of 0.05-4$\times10^{-11}$s s^{-1}. Their X-ray spectra (1-10 keV) are soft and usually modelled with the sum of a black body ($kT \sim$ 0.5 keV) and a power law (photon index, $2< \Gamma <4$), and the typical luminosities are in the range 10^{34-36} erg s^{-1}. This luminosity is much larger than the spindown one ($I\omega\dot{\omega}$), indicating that the dominant source of energy in AXPs, as in SGRs, is the magnetic one. In fact given the period and period derivative values, one expects a surface dipole magnetic field of

$$B = \left(\frac{3Ic^3P\dot{P}}{2\pi^2R^6}\right) \simeq 3.2\times10^{19}(P\dot{P})^{1/2}\ \text{G}, \quad (1)$$

where I ($\simeq 10^{45}$g cm^2) is the NS moment of inertia, and R ($\simeq 10^6$ cm) is the NS radius. The derived field values for AXPs exceed the quantum critical value of $B_Q \equiv m_e^2c^3/(e\hbar) = 4.4\times10^{13}$ G, and hence AXPs have been proposed to be also members of the Magnetar class even if this model had been developed earlier for explaining the SGR phenomenology.

The unification process of the two categories started on the base of the similar temporal and spectral behaviour at soft X-rays. But the real breakthrough was the detection of SGR-like bursts from four AXPs (1E 1048.1-5937, [5], 1E 2259+586, [20], XTE J1810–197, [52], 4U 0142+61, [21]). The Magnetar model (see [3, 39, 46, 47] for details), predicts that, if the "proto-NS" is initially spinning at ∼few ms, an efficient $\alpha - \Omega$ dynamo process can produce magnetic fields of the order of B$\sim 10^{15}$ G. Then the huge magnetic field can easily spin down the neutron star via dipole magnetic braking to periods longer than 10 s in $\sim 10^4$ years. Such a magnetic field also provides the necessary energy to power the spectacular giant flares in SGRs (at least once in an SGR lifetime), magnetically confine the trapped fireball seen in flares' tails, and power the persistent X-ray luminosity.

The new *INTEGRAL* results concerning SGRs are presented in the following sections. For a review on the low-energy (0.1–10 keV) XMM observations of SGRs see [35].

2. SGR 1806–20

SGR 1806–20 was discovered by the Interplanetary Network (IPN) in 1979 [23]. It lies in a crowded region close to the galactic centre. Kouveliotou et al. [22] discovered a quiescent X-ray pulsating (P=7.48 s) counterpart, which was spinning down rapidly ($\dot{P}$=2.8$\times10^{-11}$ s s^{-1}). If this spindown is interpreted as braking by a magnetic dipole field, its strength is $B \sim 10^{15}$ G. The source activity is variable, alternating between quiet periods and very active ones.

After a period of quiescence, SGR 1806–20 became active in the Summer of 2003 [15]. Its activity then increased in 2004, and a strong outburst during which about one hundred short bursts were emitted in a few minutes occurred on October 5 2004 [8]. Finally a giant flare, whose energy (a few 10^{46} erg) was two orders of magnitude larger than those of the previously recorded flares from SGR 0526-66 and SGR 1900+14, was emitted on December 27^{th} 2004 (see e.g. [40, 31, 16]).

Thanks to its good sensitivity *INTEGRAL* detected more than 300 short bursts from SGR 1806–20. Many of these bursts were among the faintest ever detected from these sources, and only thanks to imaging they could be studied in detail for the first time. In fact, *INTEGRAL* provided new results on them, like the discovery of a hardness-intensity anti-correlation within the bursts, see Fig. 1, and the determination of the overall Number-Intensity distribution, see Fig. 2, which can be modeled as a single power law (α=0.91$\pm$0.09) over 2.5 energy decades. These results have been presented in detail elsewhere [7, 8]. We will focus here on the SGR 1806–20 persistent emission and on the Giant Flare of December 2004.

2.1. Discovery of the persistent emission

Until 2004 spectral information on the perisistent emission of SGRs was known only below 10 keV, where the spectrum is usually well described by the sum of a power

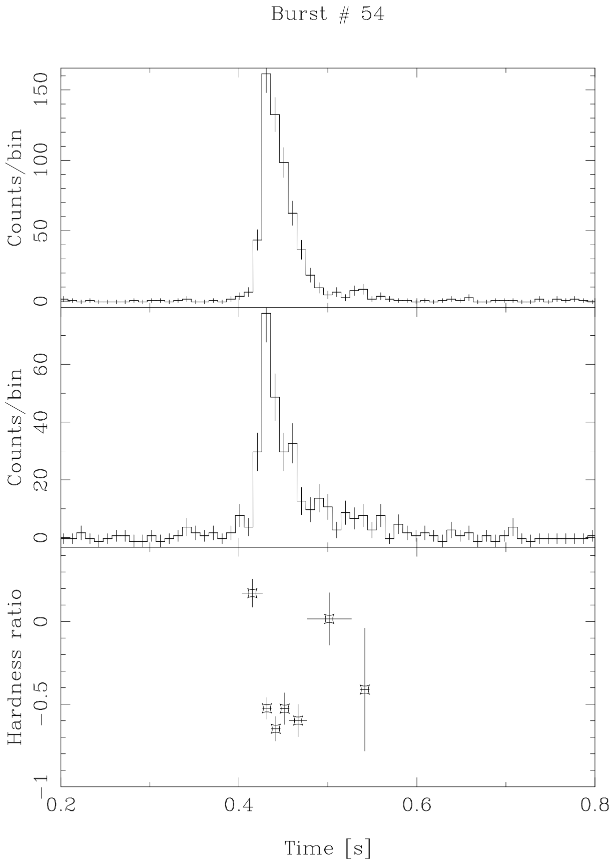

Figure 1. IBIS/ISGRI light curves in the soft (20-40 keV, upper panel) and hard (40-100 keV, middle panel) energy range and hardness ratio (lower panel) for a short burst from SGR 1806–20.

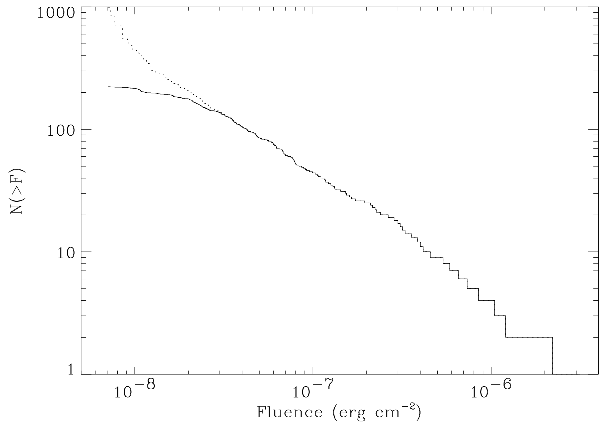

Figure 2. Number-intensity distribution of all the bursts detected by INTEGRAL in 2003 and 2004. The continuous line represents the experimental data, while the dashed line represents the data corrected for the exposure. From [8].

law component and a black body (see e.g. [32]). In 2005 two groups reported independently the discovery with *INTEGRAL* of persistent hard X-ray emission originating from SGR 1806–20 [33, 37].

INTEGRAL showed that the spectrum above 20 keV is rather hard, with a photon index between 1.5 and 2.0 (see Fig. 3) and extends up to 150 keV without an apparent cutoff. It connects rather well with the low energy (< 10 keV) spectrum [32], and the intensity and spectral hardness are correlated with the degree of bursting activity of the source [33, 8] (see Fig. 4) and with the infrared flux [19]. Our group is continuously monitoring the hard X-ray flux of SGR 1806–20, and the long term light curve of the source is shown in Fig. 5. As can be seen, the

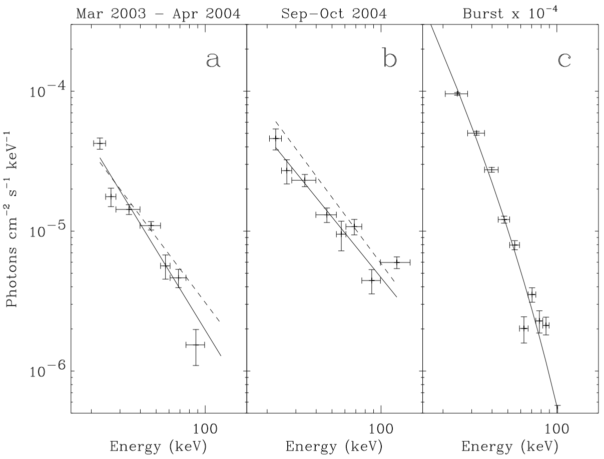

Figure 3. IBIS/ISGRI spectra of SGR 1806–20. a) persistent emission March 2003-April 2004, b) persistent emission September-October 2004, c) one burst (scaled down by a factor 10^4). The solid lines are the best fits (power laws in a) and b), thermal bremsstrahlung in c)). The dashed lines indicate the extrapolation of power-law spectra measured in the 1–10 keV band with XMM-Newton *[32]. From [33].*

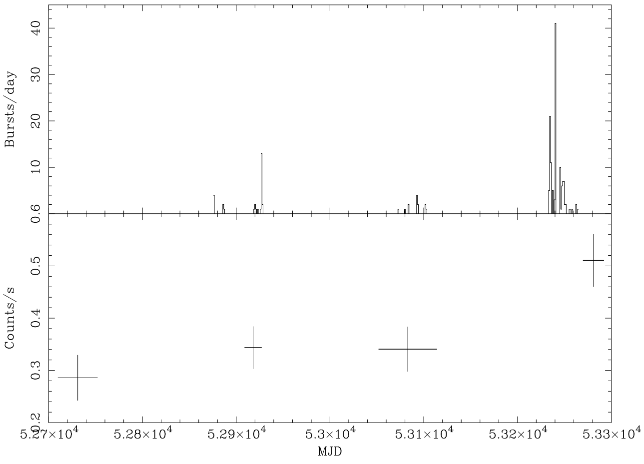

Figure 4. Upper Panel: histogram of the number of bursts per day detected with the third Interplanetary Network (IPN). Lower Panel: IBIS/ISGRI count rate in the 20-60 keV band. From [33].

persistent flux increased in 2003 and 2004 up to the giant flare (which is marked with a vertical line in the plot), and then decreased in 2005.

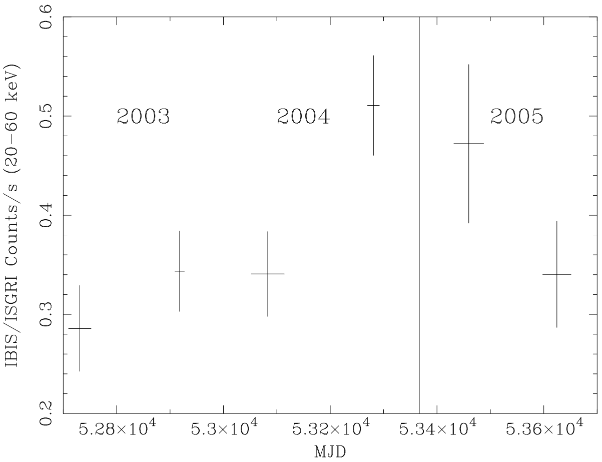

Figure 5. Long term light curve of SGR 1806–20, as measured with IBIS. The vertical line represents the time of the giant flare of December 27 2004.

These results support the twisted magnetosphere model developed by Thompson et al. [47], in which a twisted internal magnetic field provides source for helicity of the magnetosphere by shearing the NS crust. The currents, present in the twisted magnetosphere, produce hard spectral tails by resonant cyclotron scattering. In turn the twisted field produces stronger braking than a simple dipole, increasing the spindown rate, as measured by *XMM* in SGR 1806–20 [32]. At the same time stresses in the crust increase, causing a higher rate of bursts. In the end the giant flare is associated with a major magnetic field reconfiguration, which produces changes in the light curve and spectrum of the SGRs (see below).

2.2. The Giant Flare of December 27 2004

A giant flare from SGR 1806–20 was discovered with the *INTEGRAL* gamma-ray observatory on 2004 December 27 [2], and detected with many other satellites (e.g. [40, 16, 45]). The analysis of the SPI-ACS data (>80 keV) of the flare, presented in [31], showed that the giant flare is composed by 3 components: an initial spike lasting 0.2 s, followed by a ∼400 s long pulsating tail, modulated at the neutron star period of 7.56 s, and a possible high-energy afterglow. The initial spike was so bright that it saturated the ACS, so we could derive only a lower limit on its fluence, which turned out to be two orders of magnitude brighter (10^{46} ergs, see e.g. [45]) than the previously observed giant flares from SGR 1900+14 [12], and SGR 0526–66 [26]. The energy contained in the tail (1.6×10^{44} ergs), on the other hand, was of the same order as the one in the pulsating tails of the previously observed giant flares, see Table 1.

By folding the ACS light curve at the best period for several cycles, one can appreciate how the pulse profile changes with time during the giant flare itself, see Fig. 6, indicative of changes in the magnetic field configuration.

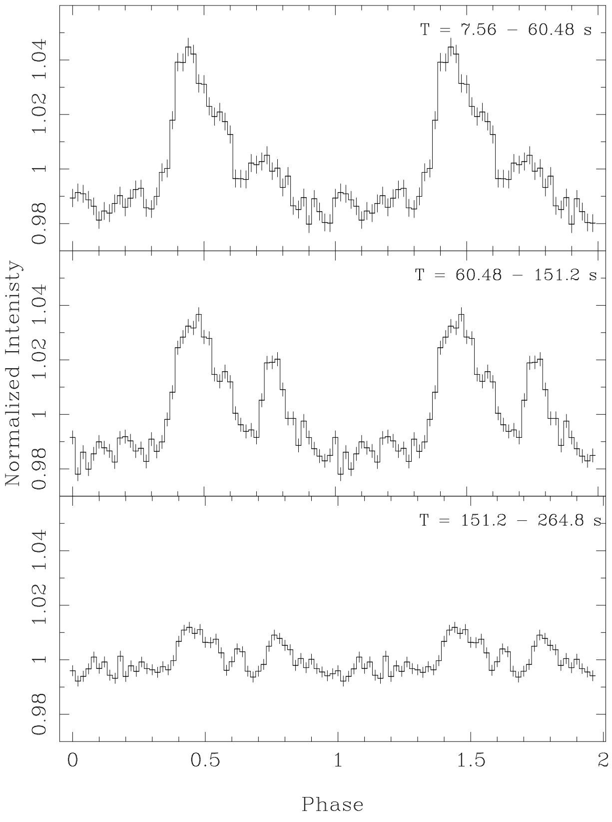

Figure 6. Averaged pulse profile of the tail of the giant flare, obtained by folding the data in three time intervals at spin period of 7.56 s. From [31]

A ∼0.2 s long small burst was detected in the ACS data 2.8 s after the initial spike, see Fig. 7. It is superposed on the pulsating tail and has no clear association with the pulse phase. This burst is produced by the reflection by the Moon of the initial spike of the giant flare. In fact this delay corresponds to the light travel time between *INTEGRAL*, the Moon, and back. A similar detection was reported with the *Helicon-Coronas-F* satellite [28].

The most striking feature provided by the *INTEGRAL* data is the detection of a possible early high-energy afterglow emission associated with the giant flare. At the end of the pulsating tail the count rate increased again, forming a long bump which peaked around t∼700 s and returned to the pre-flare background level at t∼3000-4000. This component decays as $\sim t^{-0.85}$, and is shown in blue in Fig. 8, while the overall long term background trend is shown in yellow, and the giant flare itself in red. The association of this emission with SGR 1806–20 is discussed in [31]. The fluence contained in the 400-4000 s time interval is approximately the same as that in the pulsating tail. With simple gamma-ray burst afterglow models based on synchrotron emission one can

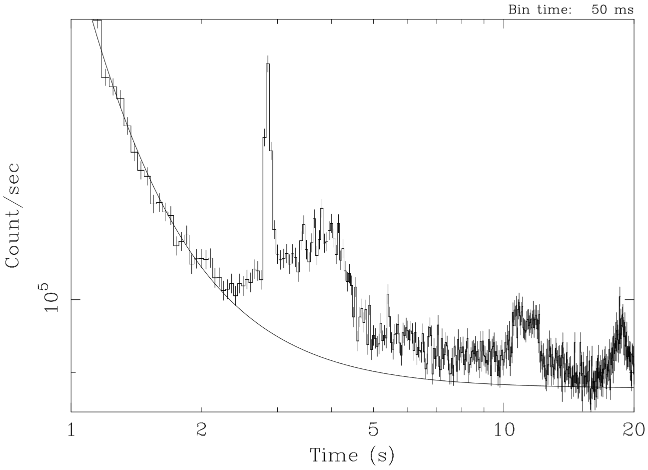

Figure 7. SPI-ACS light curve of the giant flare of SGR 1806–20, binned at 50 ms. The Moon reflection component is clearly visible at t∼ 2.8s. Note that the initial part of the flare is not shown.

derive the bulk Lorentz factor Γ from the time t_0 of the afterglow onset: $\Gamma \sim 15(E/5\times 10^{43}\ \mathrm{ergs})^{1/8}(n/0.1\ \mathrm{cm}^{-3})^{-1/8}(t_0/100)^{-3/8}$, where n is the ambient density. This is consistent with the mildly relativistic outflow inferred from the radio data [10].

3. SGR 1900+14

SGR 1900+14 was discovered in 1979 [27] when it emitted 3 bursts in 2 days. Since then short bursts were observed from this source with BATSE, *RXTE* and Interplanetary Network satellites in the years 1979-2002. SGR 1900+14 emitted a giant flare on August 27 1998 (e.g. [12]), followed by less intense “intermediate” flares on August 29 1998 [17] and in April 2001 [24]. The last bursts reported from SGR 1900+14 were observed with the Third Interplanetay Network (IPN) in November 2002 [14]. No bursts from this source were revealed in all the *INTEGRAL* observations from 2003 to 2005, but Swift has detected renewed activity in 2006 [41].

3.1. Discovery of the persistent emission

Using 2.5 Ms of *INTEGRAL* data, Götz et al. [9] reported the discovery of persistent hard X-ray emission. This emission extended up to ∼ 100 keV, but with a softer spectrum compared to SGR 1806–20, having a photon index of 3.1±0.5. Also the luminosity is dimmer in this case, being $\sim 4\times 10^{35}$ erg s^{-1}, a factor of three lower than SGR 1806–20. This is probably due to the fact that SGR 1900+14 was observed in a quiescent state. In fact a possible detection of a high-energy component in *SAX* PDS data is reported by Esposito et al. [4] during an active state of the source after the giant flare of August 1998. In that case the hard tail was brighter and harder ($\Gamma \sim 1$). The *INTEGRAL* observations spanned March 2003 to June 2004, and did not include the recent reactivation of the source in March 2006 [41], when the source emitted a few tens of regular bursts plus an intense burst series, lasting ∼30 s [42], reminiscent of the October 5 2004 event from SGR 1806–20. We recently analysed the *INTEGRAL* data spanning from August 2004 to March 2006, and found that the hard X-ray flux of the source flux did not increase up to a few weeks before its reactivation. This indicates that the reactivation was not triggered by a flux increase, at least on the time scale of a few months sampled by *INTEGRAL*.

The soft and constant spectrum of SGR 1900+14 is possibly related to the fact that this source is still in a rather quiescent state.

4. COMPARISON WITH THE ANOMALOUS X-RAY PULSARS

Hard X-ray persistent emission (>20 keV) has recently been detected with *INTEGRAL* also from the Anomalous X-ray Pulsars. It has been detected from three AXPs with *INTEGRAL*: 1E 1841–045 [36], 4U 0142+61 [11] and 1RXS J170849–400910 [44]. The presence of pulsations seen with RXTE up to ∼200 keV in 1E 1841–045 [18] proves 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. Our results are shown in Fig. 9, where the *INTEGRAL* spectra are plotted together with the results of observations at lower energy taken from the literature (see figure caption for details).

As can be seen, AXPs generally present harder spectra than SGRs in hard X-rays. In particular, for the three AXPs, a spectral break is expected to occur between 10 and 20 keV in order to reconcile the soft and the hard parts of the spectrum. On the other hand, SGRs present a softer spectrum at higher energies, also implying a break around 15 keV (especially for SGR 1900+14), but in the opposite sense with respect to the AXPs. The fact that the spectral break is more evident in SGR 1900+14 could be due to the fact that its level of activity was much lower during our observations, compared to SGR 1806–20. All three AXPs, on the other hand, can be considered being in a quiescent state since no bursts were been reported from them during the *INTEGRAL* observation.

The magnetar model, in its different flavours, explains this hard X-ray emission as powered by bremsstrahlung photons produced either close to the neutron star surface

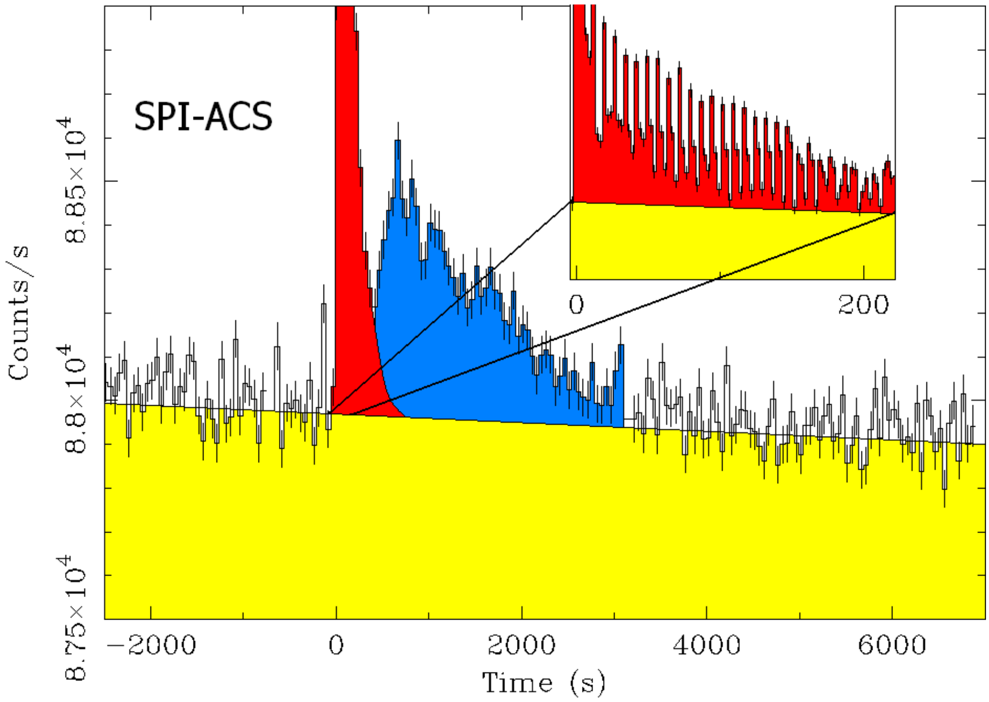

Figure 8. Light curve of the Giant Flare of December 27 2004 as measured with SPI-ACS above 80 keV. The light curve is binned at 50 s, and hence the pulsating tail is not visible (it is visible in the inset where the light curve is binned at 2.5 s). (yellow: instrumental background, red: Flare tail, blue: high-energy afterglow, see text)

or at a high altitude ($\sim$ 100 km) in the magnetosphere [47, 48]. The two models could be distinguished by the presence of a cutoff at $\sim$ 100 keV or $\sim$ 1 MeV. Unfortunately current experiments like *INTEGRAL* are not sensitive enough to firmly assess the presence of the cutoffs and hence to distinguish between the two models.

5. CONCLUSIONS

Thanks to *INTEGRAL*, and in particular to its imager IBIS, we have been able to study most of the magnetars' phenomenology with unprecedented sensitivity at high energies. One of the most striking results is the discovery, which was particularly unexpected for AXPs, of the persistent hard X-ray emission. This discovery, which can be considered one of the most important *INTEGRAL* results, represents a new important input for theoreticians who started to include it in the magnetar model (see e.g. [1]).

Also, the fact that short bursts evolve with time is a new feature that has to be considered with care within the magnetar model: up to now no clear explanation has been provided for this.

The large number of detected short bursts from SGR 1806–20 allowed us a good determination of the shape and slope of their Number-Intensity distribution, showing that a single power law holds over 2.5 orders of magnitude. The faint end of the distribution represents the faintest bursts ever detected at these energies.

In addition, the fact that SGR 1806–20 has been particularly active during the last years, also emitting a once-in-a-lifetime event such as the giant flare (and its possible high energy afterglow), has allowed observations of relatively rapid changes of the bursting and persistent emission of a Magnetar and to interpret them with the evolution of a very strong and complicated magnetic field, confirming the magnetic field as the dominant source of energy in Soft Gamma-Ray Repeaters and Anomalous X-ray Pulsars. Our group will continue the monitoring program of SGRs in order to better understand these peculiar objects.

ACKNOWLEDGEMENTS

DG acknowledges the French Space Agency (CNES) for financial support. 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. ISGRI has been realized and maintained in flight by CEA-Saclay/DAPNIA with the support of CNES.

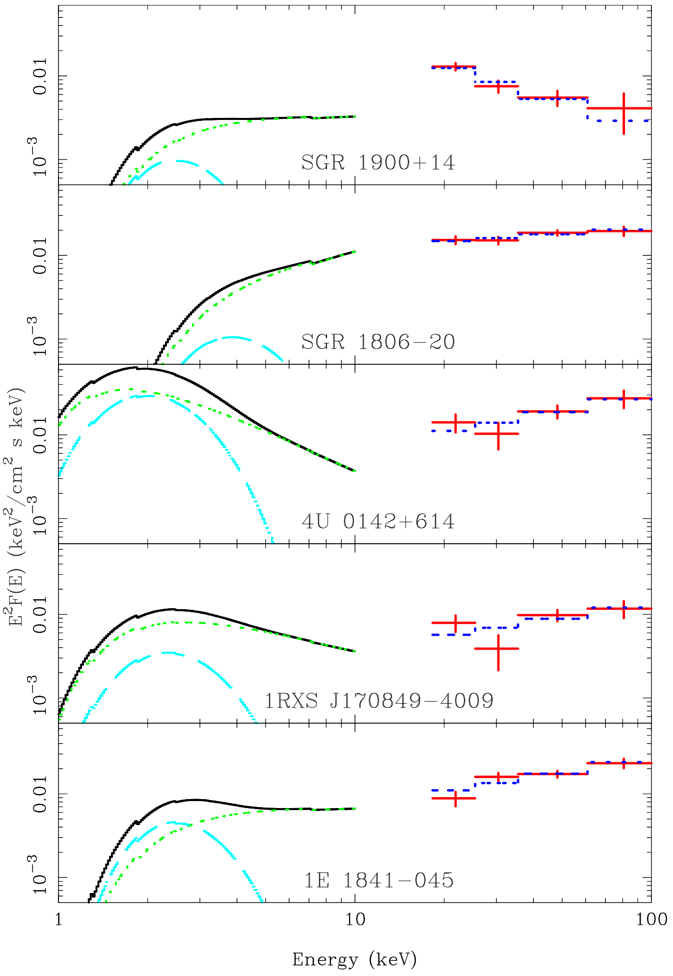

Figure 9. Broad band X–ray spectra of the five magnetars detected by INTEGRAL . The data points above 18 keV are the INTEGRAL spectra with their best fit power-law models (dotted lines). The solid lines below 10 keV represent the absorbed power-law (dotted lines) plus blackbody (dashed lines) models taken from [51] (SGR 1900+14, during a quiescent state in spring 2000), [32] (SGR 1806–20, observation B, when the bursting activity was low), [6] (4U 0142+614), [43] (1RXS J170849–4009), and [38] (1E 1841–045). From [9].

REFERENCES

[1] Belobodorov, A. M., 2006, Proc. “Isolated Neutron Stars: from the Interior to the Surface”, astro-ph/0608372

[2] Borkowski, J., Götz, D., Mereghetti, S., et al., 2006, GCN, 2920

[3] Duncan, R.C., & Thompson, C., 1992, ApJ 392, L9

[4] Esposito, P., Mereghetti, S., Tiengo, A., et al., 2006, A&A, in press, astro-ph/0609078

[5] Gavriil, F., Kaspi, V.M., & Woods, P.M., 2002, Nature, 419, 142

[6] Göhler, E., Wilms, J., & Staubert, R., 2003, A&A 433, 1079

[7] Götz, D., Mereghetti, Mirabel, F.I., & Hurley, K., 2004, A&A 417, L45

[8] Götz, D., Mereghetti, S., Molkov, S., A&A, 2006a, 445, 313

[9] Götz, D., Mereghetti, S., Tiengo, A., et al., 2006b, A&A 449, L31

[10] Granot J., Ramirez-Ruiz, E., Taylor, G. B., et al., 2006, ApJ 638, 391

[11] den Hartog, P. R., Hermsen, W., Kuiper, L., et al., 2006, A&A, in press, astro-ph/0601644

[12] Hurley, K., Cline, T., Mazets, E., et al., 1999, Nature 397, 41

[13] Hurley, K., Li, P., Kouveliotou, C., et al., 1999, ApJ, 510, L111

[14] Hurley, K., Mazets, E., Golenetskii, S., et al., 2002 GCN Circ. 1715

[15] Hurley, K., Atteia, J.-L., Kawai, N., et al., 2003, GCN, 2308

[16] Hurley, K., Boggs, S. E., Smith, D. M., et al., 2005, Nature 434, 1098

[17] Ibrahim, A. I., Strohmayer, T. E., Woods, P. M., et al., 2001, ApJ 558, 237

[18] Kuiper, L.,Hermsen, W., den Hartog, P. R. et al., 2006, ApJ, 645, 556

[19] Israel, G., Covino, S., Mignani, R., et al., 2005, A&A 438, L1

[20] Kaspi, V.M., Gavriil, F.P., Woods, P.M., et al., 2003, ApJ, 588, L93

[21] Kaspi, V., Dib, R., & Gavriil, F., 2006, ATel 794

[22] Kouveliotou, C., Dieters, S., Stromayer, T., et al., 1998, Nature 393, 235

[23] Laros, J., Fenimore, E. E., Fikani, M. M., et al., 1986 Nature 322, 152

[24] Lenters, G. T., Woods, P. M., Goupell, J. E., 2003, ApJ 587, 761

[25] Mattana, F., Götz, D., Falanga, M., et al. 2006, A&A, in press

[26] Mazets, E. P., Golentskii, S. V., Ilinskii, V. N., et al., 1979a Nature 282, 587

[27] Mazets, E. P., Golenetskij, S. V., & Guryan, Y. A., et al., 1979b Sov. Astr. Lett 56, 343

[28] Mazets E.P., Cline, T.L., Aptekar, R.L., et al. 2005, astro-ph/0502541

[29] Mereghetti, S. & Stella, L., 1995, ApJ, 442 L17

[30] Mereghetti, S., Chiarlone, L., Israel, G.L., Stella, L., 2002, Proc 270 WE-Heraeus Seminar, 29

[31] Mereghetti S., Götz, D., von Kienlin, A., et al. 2005a, ApJ, 624, L105

[32] Mereghetti S., Tiengo, A., Esposito, P., et al., 2005b, ApJ 628, 938

[33] Mereghetti S. , Götz, D., Mirabel, I.F., & Hurley, K., 2005c, A&A 433, L9

[34] Mereghetti S., Tiengo, A., Esposito, P., et al., 2006a, ApJ, in press,

[35] Mereghetti S., Esposito, P., Tiengo, A., 2006b, Proc. “Isolated Neutron Stars: from the Interior to the Surface”, astro-ph/0608364

[36] Molkov, S. V., Cherepashchuk, A. M., Lutovinov, A. A., et al., 2004, Astronomy Letters 30, 534

[37] Molkov, S., Hurley, K., Sunyaev, R., et al., 2005, A&A 433, L13

[38] Morii, M., Sato, R., Kataoka, J., & Kawai, N., 2003, PASJ 55, L45

[39] Paczynski, B., 1992, AcA 42, 145

[40] Palmer, D. M., Barthelmy, S., Gehrels, N., et al., 2005, Nature 434, 1107

[41] Palmer, D. M., Sakamoto, T., Barthelmy, S., et al., 2006a, ATel 789

[42] Palmer, D. M., Sakamoto, T., Barthelmy, S., et al., 2006b, GCN Circ. 4949

[43] Rea, N., Oosterbroek, T., Zane, S., et al., 2005, MNRAS 361, 710

[44] Revnivtsev, M. G., Sunyaev, R. A., Varshalovich, D. A., et al., 2004, Astronomy Letters 30, 382

[45] Terasawa, T., Tanaka, Y. T., Takei, Y., et al., 2005, Nature 434, 1110

[46] Thompson, C., & Duncan, R.C., 1995, MNRAS 275, 255

[47] Thompson, C., Lyutikov, & M. Kulkarni, S. R., 2002, ApJ, 574, 332

[48] Thompson, C., & Beloborodov, A. M. 2005, ApJ 634, 565

[49] Wang, Z., Chakrabarty, D., & Kaplan, D. L., 2006, Nature, 440, 772

[50] Woods, P. M., Kouveliotou, C., van Paradijs, J., et al., 1999, ApJ 519, L139,

[51] Woods, P. M., Kouveliotou, C., Göğüş, E., et al., 2001, ApJ 552, 748

[52] Woods, P.M., Kouveliotou, C., Gavriil, F.P., et al. 2005, ApJ, 629, 985