Hard X-ray variability of Magnetar's Tails observed with INTEGRAL

D. Götz*, S. Mereghetti†, K. Hurley**, P. Esposito†,‡, E. V. Gotthelf§, G. L. Israel¶, N. Rea‖, A. Tiengo†, R. Turolla††,‡‡ and S. Zane‡‡

*CEA Saclay, DSM/Dapnia/Service d'Astrophysique, F-91191, Gif sur Yvette, France
†INAF–Istituto di Astrofisica Spaziale e Fisica Cosmica Milano, via Bassini 15, I-20133 Milano, Italy
**University of California at Berkeley, Space Sciences Laboratory, Berkeley CA 94720-7450, USA
‡University of Pavia, Department of Nuclear and Theoretical Physics and INFN-Pavia, Pavia, Italy
§Columbia Astrophysics Laboratory, Columbia University, 550 West 120th Street, New York, NY 10027, USA
¶INAF–Osservatorio Astronomico di Roma, Via Frascati 33, I-00040 Monteporzio Catone (Roma), Italy
‖University of Amsterdam, Astronomical Institute "Anton Pannekoek", 1098 SJ, Amsterdam, The Netherlands
††University of Padua, Department of Physics, via Marzolo 8, 35131 Padova, Italy
‡‡Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Droking Surrey, UK

Abstract. Magnetar's persistent emission above 10 keV was recently discovered thanks to the imaging capabilities of the IBIS coded mask telescope on board the *INTEGRAL* satellite. The only two sources that show some degree of long term variability are SGR 1806–20 and 1RXS J170849.0–400910. We find some indications that variability of these hard tails could be the driver of the spectral variability measured in these sources below 10 keV.

In addition we report for the first time the detection at 2.8 σ level of pulsations in the hard X-ray tail of SGR 1806–20.

Keywords: pulsars; magnetars; hard X-rays
PACS: 97.60.Gb; 98.70.Rz

INTRODUCTION

Anomalous X-ray Pulsars (AXPs) and Soft Gamma-Ray Repeaters (SGRs) are two small classes of sources that are believed to be magnetar candidates, namely isolated neutron stars with magnetic fields larger than the quantum critical value $B_{QED} \sim 4.4\times10^{13}$G. For a review of this class of objects see [1].

They share some common properties like a long spin period in the range of P=2–12 s, a large period derivative of $\dot{P}$=10^{-13}–10^{-10} s s^{-1}, and a typical X-ray luminosity of $L_X \sim 10^{34}$–10^{36} erg s^{-1}. This luminosity is well above the rotational energy losses, and is believed to be powered by the decay of the huge magnetic field.

Since the spectra below ∼10 keV are rather soft, the first *INTEGRAL* detections above 20 keV of very hard high-energy tails associated with these objects came as a surprise [2, 3, 4, 5, 6, 7]. The spectra flatten ($\Gamma \sim 1$, where Γ is the photon index) above 20 keV and the pulsed fraction of some of them reaches up to 100% [2]. The discovery of these hard tails provides new constraints on the emission models for these objects since their luminosities might well be dominated by hard, rather than soft, X-rays.

In this paper we will focus on the timing properties and long term variations of two magnetar candidates, 1RXS J170849.0–400910 and SGR 1806–20, as measured by IBIS/ISGRI [8, 9] on board the *INTEGRAL* satellite [10].

1RXS J170849.0–400910

1RXS J170849.0–400910 was discovered during the *ROSAT* all sky survey. The measure of its period [11], period derivative [12] and general X-ray properties [13], made it an AXP member. Interesting results have been reported by [14], who claimed a correlation between the soft X-ray flux and spectral hardness, with a marginal evidence of the highest and hardest spectra being correlated with the AXP glitching activity [15, 16, 17]. This correlation has recently been confirmed by [18], [19], and [17] using further *Chandra*, *Swift*/XRT and *RXTE* data, but always focusing on a limited energy interval (i.e. below ∼ 10 keV).

Recently (fall 2006 and spring 2007) we performed a multi-wavelength observation campaign aimed at monitoring 1RXS J170849.0–400910 with *INTEGRAL* and *Swift* [20]. These new data, together with a re-analysis of all publicly available *INTEGRAL*, and soft X-ray observations, allowed us to investigate the timing and spectral properties of the source over a broader energy range. We discovered a long term correlation between the soft and hard X-ray emission.

The spectral parameters (fluxes and Γ) plotted in Fig. 1 have been derived by fitting all the datasets simultaneously in 1–10 keV energy range (except for *Chandra* data which were limited to 8 keV) by using an absorbed black body plus power law model. While the parameters of the power law have been left free to vary, the absorption column density, and the black body temperature have been forced to be the same for all instruments. For the details of our analysis see [21]. We found a good fit (χ^2/d.o.f. = 1188/1264 = 0.94), and the derived values were N_H=1.36(1)$\times10^{22}$ cm^{-2} , and $kT = 0.44(1)$ keV. Our new XRT observation campaign (last two points in Fig. 1) shows that the source entered a new low/soft state (similar to the one measured with *XMM-Newton* in 2003), with a flux a factor ∼1.5 lower than the one measured with XRT in 2005. By adding these new points to the long term variability study of the source, we confirm the flux-hardness correlation proposed by [14].

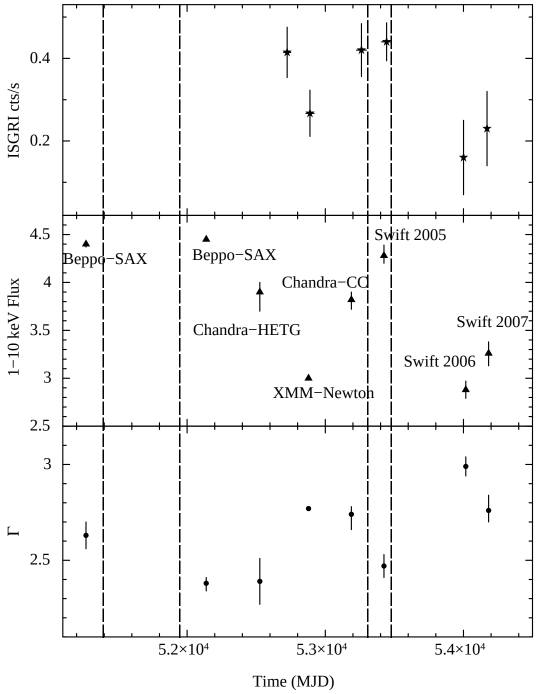

FIGURE 1. Upper panel: hard X-ray fluxes derived with *INTEGRAL*/IBIS (20–70 keV). Middle Panel: absorbed 1-10 keV fluxes in units of 10^{-11} erg cm^{-2} s^{-1} derived from recent observations of X-ray imaging telescopes as a function of time. Lower Panel: photon indices measured in the 1-10 keV energy band. Vertical lines mark the times of four observed glitches. Errors are reported at 1σ c.l. From [21].

In addition, our new hard-X data show that the long term variation in flux is correlated over more than two orders of magnitude in energy. In fact, IBIS observations taken quasi-simultaneously with the last two XRT ones indicate that the source is hardly detected above 20 keV, while the hard X-ray count rates measured before followed well the variations measured in the soft X-ray range. Unfortunately, due to the faintness of the source we could not statistically prove spectral changes at high energies, by comparing different IBIS observations.

We also tested if the spectral variations at low energies could be induced just by the variation of the high energy power law. Indeed, by fixing the spectral parameters derived from the *XMM-Newton* observations, one can fit the broad band *XMM/INTEGRAL* (2003) and *Swift/INTEGRAL* observations (2005) by simply changing the slope and normalization of the high energy power law. Unfortunately, due to the uncertainties in the intercalibration, and to the low statistic of the *Swift* data, we can not draw a firm conclusion on this point.

Our timing analysis consisted in looking for pulsations in the IBIS data using the PCA ephemeris derived by [17]. We computed the pulse profile of the source, as a function of energy (see Fig. 1 in [21]). We found that the peak which is predominant in the soft band disappears and a secondary peak grows with energy becoming the most prominent one above ∼ 8 keV. The pulsed fraction cannot be easily derived from the PCA (a non-imaging instrument) data due to the uncertainties in the background estimation. Besides, the IBIS data are not easy to handle, because of large background variations due the to fact that the source is at different off-axis angles during the different pointings. Nevertheless, by averaging the background over the entire IBIS observations, we could measure a pulsed fraction by dividing the difference between the maximum and the minimum of the folded light curves by the count rates derived from imaging. The resulting values are: ∼25% (in the 20–60 keV band), ∼60% (60-200 keV), and ∼40% (20–200 keV). Consistent results came from our analysis of SAX/PDS archival data.

SGR 1806–20

SGR 1806–20 was discovered by the Interplanetary Network (IPN) in 1979 [22]. **(author?)** [Kouveliotou et al.] discovered pulsations (P=7.48 s) in the quiescent X-ray counterpart, which was rapidly spinning down ($\dot{P}$=2.8$\times10^{-11}$ s s^{-1}). If this spin down 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 and very active periods.

SGR 1806–20 is observed frequently by IBIS, thanks to its large field of view (29°×29°) coupled to the fact that the source lies close to the Galactic Center, one of *INTEGRAL*'s favorite targets. Thanks to IBIS high sensitivity we were able to discover and monitor its high energy flux since 2003, showing that it is correlated with the source's bursting activity, see e. g. [23]. We recently analyzed *INTEGRAL* Key Programme data, taken in fall

2006 and spring 2007. We confirm that the persistent flux has reached a level comparable with the one prior to the giant flare, see Fig. 2. Despite the flux variations all the spectra have the same slope ($\Gamma \sim 2$) in the 20-200 keV energy range, indicating that also in this case the hardening seen below 10 keV [24] could be due just to the flux variation of the underlying hard component.

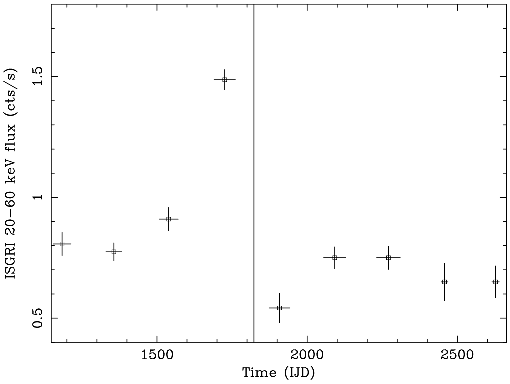

FIGURE 2. Hard X-ray persistent flux of SGR 1806–20, as measured by IBIS/ISGRI in the 20-60 keV energy range. The vertical line corresponds to the giant flare of December 27^{th} 2004. The time is expressed in INTEGRAL Julian Day (=MJD-51544)

Making use of the ephemeris recently published by [25] we folded *INTEGRAL* data of SGR 1806–20, in order to look for pulsations at high energy. For the time being we restricted ourselves to the time period preceding the giant flare where the flux is highest. Using Z^2 statistics we detected the pulsations at 2.8σ level. A folded light curve is shown in Fig. 3. Due to the complex background variations induced by the multitude of variable sources in the Galactic Center region, the determination of the pulsed fraction is particularly delicate. This work is on going, and the preliminary results indicate that the pulsed fraction of SGR 1806–20 is smaller than the one measured in the AXPs, similarly to what measured at soft X-rays.

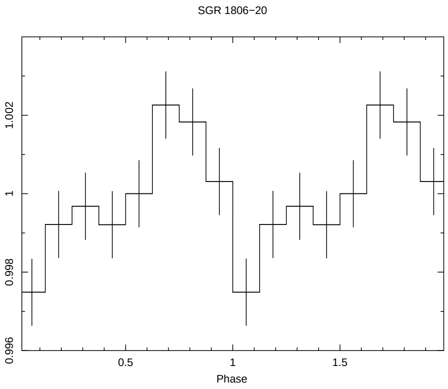

FIGURE 3. SGR 1806–20 folded light curve as measured with IBIS/ISGRI in the 20-200 keV energy band.

ACKNOWLEDGMENTS

D.G. acknowledges financial support from the French Space Agency (CNES).

REFERENCES

1. Woods, P. M. & Thompson, C., in "Compact Stellar X-ray Sources", eds. W.H.G. Lewin and M. van der Klis, Cambridge University Press, 547 (2006)
2. Kuiper, L., Hermsen, W., den Hartog, P. R. et al., ApJ **645**, 556 (2006)
3. den Hartog, P. R., Hermsen, W., Kuiper, L., et al., A&A **451**, 587 (2006)
4. Revnivtsev, M. G., Sunyaev, R. A., Varshalovich, D. A., et al., Astronomy Letters **30**, 382 (2004)
5. Mereghetti, S. , Götz, D., Mirabel, I.F., et al., A&A **433**, L9 (2005)
6. Molkov, S., Hurley, K., Sunyaev, R., et al., A&A, **433**, L13 (2005)
7. Götz, D., Mereghetti, S., Tiengo, A., et al., A&A **449**, L31 (2006)
8. Ubertini, P., Lebrun, F., Di Cocco, G., et al., A&A **411**, L131 (2003)
9. Lebrun, F., Leray, J.P., Lavocat, P., et al., A&A **411**, L141 (2003)
10. Winkler, C., Courvoisier, T.J.-L., Di Cocco G., et al., A&A **411**, L1 (2003)
11. Sugizaki, M., Nagase, F., Torii, K., PASJ **49**, L25 (1997)
12. Kaspi V.M., & Gavriil, F.P., ApJ **596**, L71 (2003)
13. Israel, G.L., Covino, S., Stella, L., et al., ApJ **518**, L107 (1999)
14. Rea, N., Oosterbroek, T., Zane, S., et al., MNRAS **361**, 710 (2005)
15. Dall'Osso S., Israel, G. L., Stella, L., et al., ApJ **599**, 485 (2003)
16. Kaspi, V.M., Lackey, J.R., & Chakrabarty, D., ApJ **537**, L31 (2000)
17. Israel, G.L., Götz, D., Zane, S., et al., A&A Letters, in press, [ArXiv: astro-ph/0707.0485] (2007)
18. Campana, S., Rea, N., Israel, G.L., et al., A&A **463**, 1047 (2007)
19. Rea, N., Israel, G.L., Oosterbroek, T., et al., Ap&SS **308**, 505 (2007)
20. Gehrels, N., Chincarini, G., Giommi, P., et al., ApJ **611**, 1005 (2004)
21. Götz, D., Rea, N., Israel, G.L., et al., A&A, in press, [ArXiv: astro-ph/0709.3712] (2007)
22. Laros, J., Fenimore, E. E., Fikani, M. M., et al., Nature **322**, 152 (1986)

Kouveliotou et al.. Kouveliotou, C., Dieters, S., Stromayer, T., et al., Nature **393**, 235 (1998)

23. Götz, D., Mereghetti, S., & Hurley, K., et al., Ap&SS **308**, 51 (2007)
24. Mereghetti, S., Esposito, P., Tiengo, A., et al., Ap&SS **308**, 13 (2007)
25. Woods, P. M., Kouveliotou, C., Finger, M.H., et al., ApJ **654**, 470 (2007)