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*Beppo*SAX observations of SGR 1806–20

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Abstract. We have observed with the BeppoSAX satellite the quiescent counterpart of the Soft Gamma-ray Repeater SGR 1806–20. Observations performed in October 1998 and in March 1999 showed that this pulsar continued its long term spin-down trend at an average rate of $\sim$8 10^{-11} s s^{-1} while its flux and spectrum remained remarkably constant between the two observations, despite the soft gamma-ray bursting activity that occurred in this period. We also reanalyzed archival ASCA data, that when compared with the new BeppoSAX observations, show evidence for a long term variation in luminosity.

Key words: stars: individual: SGR 1806-20 – stars: neutron – gamma rays: observations – X-rays: stars

1. Introduction

Soft gamma-ray repeaters (SGRs) are remarkable transient events characterized by brief (< 1 s) and relatively soft (peak photon energy $\sim$20–30 keV) bursts of super-Eddington luminosity. Only four (or possibly five) SGRs are currently known (see, e.g., Hurley 2000). Soon after the discovery of the first three SGRs, the fact that they were all located within, or very close to, young supernova remnants (Vasisht et al. 1994, Kulkarni & Frail 1993), and the 8 s periodicity observed during the famous 1979 March 5 event from SGR 0525–66 (Mazets et al. 1979), suggested that SGRs involve some form of impulsive release of energy from a neutron star. This was recently confirmed with the discovery of periodicities in the 5–8 s range in the persistent X-ray counterparts of SGR 1806–20 and SGR 1900+14 (Kouveliotou et al. 1998, Hurley et al. 1999a), as well as in the bursting emission from SGR 1900+14 (Cline et al. 1998).

The quiescent X–ray counterpart of SGR 1806–20 was discovered with the ASCA satellite (Murakami et al. 1994) within the radio nebula G10.0–0.3, most likely a supernova remnant (Kulkarni & Frail 1993). Until recently, SGR 1806–20 was thought to be associated to a luminous blue variable (LBV) star located in the non-thermal core of the radio nebula (van Kerkwijk et al. 1995). Flux variability and a change in the nebular morphology on a timescale of a few months, were also detected from the central part of the radio nebula and thought to be related to the activity from SGR 1806–20 (Frail et al. 1997). However, a more precise localization of this SGR (Hurley et al. 1999b) has shown that its position is incompatible with the LBV, which is probably responsible for the non-thermal radio emission, but may be unrelated to SGR 1806–20.

Previous X–ray observations of SGR 1806–20 in the 1–10 keV energy range were obtained with the ASCA satellite by Sonobe et al. (1994). These authors reported a 2–10 keV luminosity of $\sim 10^{35}$ erg s^{-1} (for d=10 kpc) and the following spectral parameters: photon index α_{ph} = 2.2$\pm$0.2, N$_H$ = (6$\pm$0.2)$\times 10^{22}$ cm^{-2} and kT = 6.5$\pm$1.5 keV, N$_H$ = (5.2$\pm$0.2)$\times 10^{22}$ cm^{-2} in the case, respectively, of a power law and of a thermal bremsstrahlung fit.

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2. Observations and data analysis

The BeppoSAX observations of SGR 1806–20 were performed in October 1998 and in March 1999 (see Table 1 for details). Most of our results were obtained with the Medium Energy Concentrator Spectrometers (MECS) instrument that covers the $\sim$ 1.6–10 keV energy range.

The MECS (Boella et al. 1997) is based on three position–sensitive gas–scintillation proportional counters placed in the focal plane of grazing incidence telescopes, providing images over a nearly circular field of view with $\sim 28'$ radius. The MECS is characterized by a total (three telescopes) effective area of $\sim$150 cm^2 at 6 keV, a relatively good angular resolution (50% power radius of $\sim 75''$ at 6 keV, on-axis) and a moderate energy resolution (FWHM $\sim 8.5\sqrt{6/\mathrm{E_{keV}}}$%). Due to a failure in one of the MECS units, only two of them were available at the time of our observations.

The target was clearly detected on axis in both observations, with a net count rate in the two MECS units of $\sim$0.1 counts s^{-1}.

2.1. Spectral analysis

We describe the spectral results obtained in the 1.6–10 keV range by using only the MECS instrument. We verified that the inclusion of the data from the LECS instrument (Parmar et al. 1997), that extends the energy range down to $\sim$0.1 keV, did not significantly change the results of the fits. In fact the combi-

Table 1. Summary of the BeppoSAX observations of SGR 1806–20

Obs.	Start/Stop UT	Exposure time[a] (ks) MECS/LECS	Count rate[b] (counts s^{-1})	Period (s)
A	1998 Oct 16 12:30 / 17 10:38	30.8 / 10.7	0.102±0.002	7.48175 ± 0.00016
B	1999 Mar 21 4:37 / 22 16:26	56.7 / 18.2	0.103±0.001	7.48271 ± 0.00003

[a] Net exposure time in the MECS instrument.
[b] Net count rate in 2 MECS units.

Table 2. Summary of the MECS spectral results

Obs.	Pow Law photon index	Absorption 10^{22} cm^{-2}	χ^2/dof	2–10 keV Flux absorbed	2–10 keV Flux unabsorbed (erg cm^{-2} s^{-1})
A	1.91 ±0.17	5.9±0.8	1.31 / 88	1.03 10^{-11}	1.56 10^{-11}
B	1.98 ±0.12	6.5±0.6	0.76 / 132	1.06 10^{-11}	1.68 10^{-11}
A+B	1.95 ±0.10	6.3±0.5	0.98 / 223	1.045 10^{-11}	1.64 10^{-11}
Obs.	Bremmstrahlung Temperature (keV)	Absorption 10^{22} cm^{-2}	χ^2/dof	2–10 keV Flux absorbed	2–10 keV Flux unabsorbed (erg cm^{-2} s^{-1})
A	$11.7^{+4.9}_{-2.8}$	5.0±0.6	1.34 / 88	1.02 10^{-11}	1.44 10^{-11}
B	$10.6^{+2.5}_{-1.8}$	5.5±0.5	0.808 / 132	1.05 10^{-11}	1.53 10^{-11}
A+B	$11.0^{+2.1}_{-1.6}$	5.35±0.35	1.02 / 223	1.04 10^{-11}	1.50 10^{-11}

Errors are at the 90% c.l. for a single interesting parameter.

nation of its smaller effective area, shorter exposure times (see Table 1) and high absorption gives a small statistics in the LECS data for SGR 1806–20. For both observations, the MECS counts for the spectral analysis were extracted from a circle of 4′ centered at the source position and the background spectra were estimated from a concentric circular corona with radii ∼5′ and 10′. In fact the observations of standard background fields are not adequate in this case due to the presence of a substantial diffuse emission from the Galactic plane.

The spectra were equally well fit with a power law (α_{ph} ∼2) or with a thermal bremsstrahlung (kT∼11 keV) absorbed by the interstellar medium (N_H ∼6×10^{22} cm^{-2}). A blackbody spectrum gave unacceptable results (Obs A: χ^2 = 1.7 / 88 dof, Obs B: χ^2 =1.26 / 132 dof). Since the results of both observations were consistent with the same spectral shape and flux, we also performed a joint analysis of both observations to further restrict the uncertainties in the spectral parameters under the assumption of a constant source. All the derived parameters are reported in Table 2.

The observed flux for the power law best fit is ∼ 10^{-11} erg cm^{-2} s^{-1}in the 2–10 keV energy range. In the following we assume a distance of 15 kpc, based on the work by Corbel et al. (1997). After correcting for the effect of the interstellar absorption, this corresponds to an emitted luminosity of ∼4×10^{35} erg s^{-1} (2–10 keV).

A comparison with the previous results reported by Sonobe et al. (1994) for the October 1993 ASCA observation seems to indicate that during the BeppoSAX observations the spectrum of SGR 1806–20 was slightly harder and the luminosity higher. Though the evidence for a spectral variation is only marginal and can probably be accounted for by systematic uncertainties related to the comparison between different instruments, the significant luminosity change (a factor ∼2) deserves a more accurate analysis owing to its important implications for the nature of SGR 1806–20. We therefore reanalyzed the public ASCA data obtained from the HEASARC/GSFC on-line archives using the latest available response matrices.

2.2. Reanalysis of ASCA data

We analyzed the ASCA GIS data of the October 1993 observation. The data consist of two observations carried out on October 10 and 20. The spectra were accumulated from circular regions with radii 6′ centered on the source position and rebinned in order to have at least 25 counts for each energy channel. As for the BeppoSAX data, we estimated the background spectra from a source free region in the same observation to properly take into account the contribution from the galactic plane X–ray emission. The power law model gave a very good fit without evidence for variations between the two ASCA observations. Combining the two data sets, we derive the following best fit values: α_{ph} = 2.25±0.15, N_H = (6.0±0.5)×10^{22} cm^{-2}, unabsorbed flux (1.32±0.06)×10^{-11} erg cm^{-2} s^{-1}in the 2–10 keV energy range. The values for the spectral index and absorption are similar to those of Sonobe et al. (1994), but we derive a slighlty greater flux, closer to the value measured with BeppoSAX.

2.3. Timing analysis

The times of arrival of the MECS counts used in the spectral analysis were converted to the Solar System Barycenter and used in the timing analysis. The data were first analyzed with a standard folding technique and phase fitting was subsequently

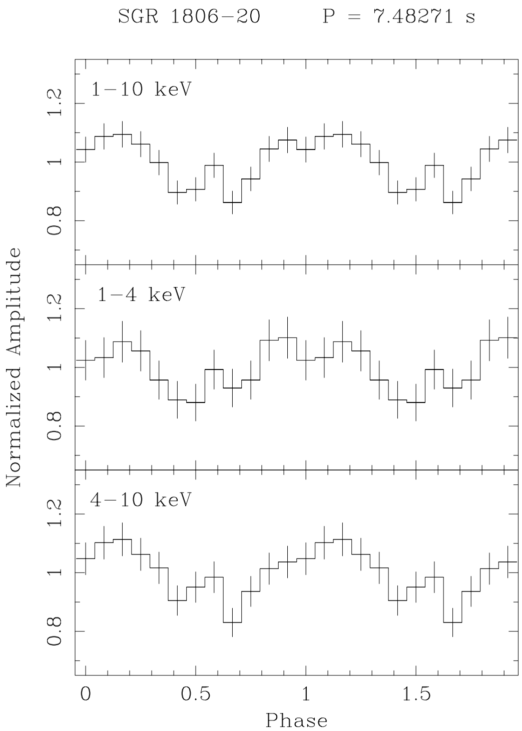

Fig. 1. MECS light curves of SGR 1806–20 folded at the best period of the 1999 observation.

used to refine the estimate of the pulse period. The derived values are reported in Table 1. The light curve obtained in the longer observation (1999) is shown in Fig. 1 for different energy ranges. No significant variations in the shape of the folded light curve are visible as a function of time and/or energy band.

3. Discussion

Soft Gamma-ray Repeaters are usually interpreted in the context of the so called "Magnetar" model (Duncan & Thompson 1992; Thompson & Duncan 1995) which is based on isolated and strongly magnetized (B $\gtrsim 10^{14}$ G) neutron stars. In this model the magnetic field is the main energy source, powering both the persistent X–ray (and particle) emission and the soft gamma-ray bursting activity. This involves internal heating, due to the magnetic field dissipation, and the generation of seismic activity. The latter is responsible for the soft γ-ray bursts, when the magnetic stresses in the neutron star crust shake the magnetosphere and accelerate particles.

If the spin-down in SGR 1806–20 is interpreted as purely due to magnetic dipole radiation losses, the observed values of P and $\dot{P}$ imply B$\sim$8 10^{14} G. Actually, this value is very likely an overestimate. In fact, the particle wind outflow, either continuous or in the form of strong episodic outbursts, also contributes significantly to the spin-down (Thompson & Blaes 1998). Harding et al. (2000) derived the relations to estimate magnetic field and spin-down age as a function of the particle wind duty cycle and luminosity. They showed that, for instance in SGR 1806–20, a dipole magnetic filed of 3 10^{13} G is derived assuming a continuous particle wind with a luminosity of $\sim10^{37}$ erg s^{-1}.

The long term period evolution of SGR 1806–20 is shown in Fig. 2 (top left panel), where our results are plotted with all the previous measurements obtained with RXTE and ASCA (Kouveliotou et al. 1998). A linear fit to all the points gives $\dot{P}$=(8.27$\pm$0.18)$\times10^{-11}$ s s^{-1}. Woods et al. (2000) reported the results of an extensive monitoring of SGR 1806–20 with the RossiXTE satellite performed from February to August 1999. The period value we measured in March is consistent with their timing solution, which however is valid only on a limited time span. In fact our first period measurement (October 1998) is inconsistent with a backward extrapolation of the RossiXTE results. It is evident that significant variations around the average linear spin-down trend are present in SGR 1806–20. According to Woods et al., the level of this "timing noise" in SGR 1806–20, is relatively larger than that expected from an extrapolation of that observed in radio pulsars.

When compared with the previous period measurements, our data show that, on a long term timescale, the period evolution of SGR 1806–20 is relatively stable, despite the bursting activity that occurred in 1997 and 1998. This is in marked contrast with the behavior of SGR 1900+14 (see Fig. 2, top right panel), that displayed much greater deviations from a constant spin-down rate. SGR 1900+14 showed two distinct periods (before and after the Summer of 1998) of nearly constant spin-down at a similar rate of $\sim$6.1 $\times10^{-11}$ s s^{-1}. The period increase from June to August 1998 could be due either to an enhanced spin-down rate related to the onset of bursting activity in June 1998 (Woods et al. 1999) or to a sudden discontinuous jump caused by the exceptional "super burst" event of August 27 (Feroci et al. 1999). Though plausible explanations for both hypothesis have been advanced in the context of the magnetar model (Thompson et al. 1999) the lack of period measurements between June 9 and August 28 does not allow to discriminate between the two possibilities.

Although no Soft Gamma-ray Bursts were detected in our BeppoSAX observations, we know that SGR 1806–20 remained active during the last three years (see, e.g., Woods et al. 2000, Hurley et al. 1999b). SGR 1806–20 was also active during the 1993 ASCA observation that allowed its identification with the steady X–ray counterpart (Murakami et al. 1994). The lack of large spin-down variations in SGR 1806–20 indicates that the presence of "normal" bursting activity is not a sufficient condition to generate a significant change in the spin-down torques. This suggests that the more likely explanation for the spin history of SGR 1900+14 is that of a discontinuous "braking glitch" due to the 27 August event.

It is also interesting to compare SGR 1806–20 and SGR 1900+14 in terms of their luminosity and long term variability properties (see Table 3 and lower panels of Fig. 2). Our new observations of SGR 1806–20 show that this source is extremely stable in terms of spectral shape, despite the evidence of a flux increase with respect to the 1993 level. All the observations of SGR 1806–20 were obtained during periods of bursting activity. Its luminosity (for d=15 kpc) is about a factor $\sim$5–6 higher than that of SGR 1900+14 during its active period of September 1998. The latter source was even fainter (a factor $\sim$3) during

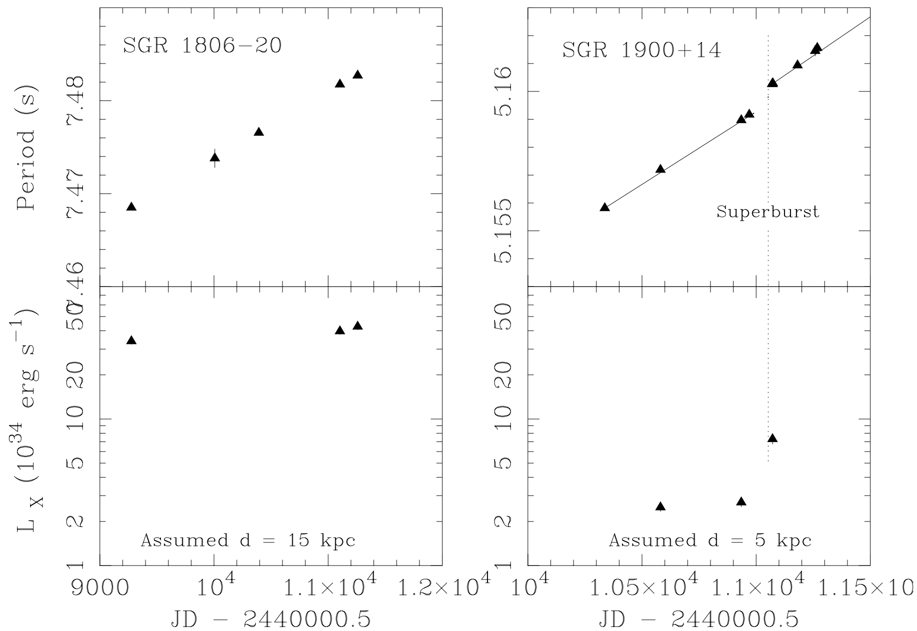

Fig. 2. Comparison between SGR 1806–20 and SGR 1900+14.The upper panels show the long term evolution of the spin period. The vertical dashed line indicates the time of the 1998 August 27 super outburst of SGR 1900+14. The unabsorbed 2–10 keV luminosities are indicated in the two bottom panels.

Table 3. Comparison between SGR 1806–20 and SGR 1900+14

	SGR 1806–20		SGR 1900+14	
Period	7.45 s		5.16 s	
$\dot{P}$	8.3×10^{-11} s s^{-1}		6.1×10^{-11} s s^{-1}	
Distance	15 kpc		5 kpc	
	ASCA October 1993[a] (Active)	BeppoSAX 1998/99[a] (Active)	BeppoSAX September 1998[b] (Active)	BeppoSAX May 1997[b] (Quiescent)
Luminosity (erg s^{-1})	3.4 10^{35}	4.2 10^{35}	7.3 10^{34}	2.5 10^{34}
Photon index	2.25	1.95	2.2	1.9
Absorption (10^{22} cm^{-2})	6.2	6.3	2.6	1.5

[a] This work
[b] Woods et al. (1999)

observations in May 1997 (BeppoSAX, Woods et al. 1999) and May 1998 (ASCA, Hurley et al. 1999a), an extended period of quiescence in which no soft gamma-ray bursting activity was detected.

4. Conclusions

New observations of SGR 1806–20 with the BeppoSAX satellite and a reanalysis of archive ASCA data have shown that this source is extremely stable in terms of long term period evolution and spectral properties. We found evidence for a luminosity variation of only ∼20% between the 1993 value and the more recent BeppoSAX observations, both obtained while the source was in an active state. This stability, despite the fact that numerous bursts have been observed in the last three years from SGR 1806–20, implies that the normal bursting activity, independent on its origin, does not significantly affect the overall (dipolar?) magnetic field configuration and/or the particle outflow stream causing the neutron star spin-down. Only exceptional events like the 27 August 1998 super outburst of SGR 1900+14 appear to cause significant jumps in the period evolution as well as a substantially increased X–ray emission.

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