Quiet but still bright: XMM-Newton observations of the soft gamma-ray repeater SGR 0526–66

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ABSTRACT

SGR 0526–66 was the first soft gamma-ray repeater (SGR) from which a giant flare was detected in March 1979, suggesting the existence of magnetars, i.e., neutron stars powered by the decay of their extremely strong magnetic field. Since then, very little information has been obtained on this object, mainly because it has been burst-inactive since 1983 and the study of its persistent X-ray emission has been hampered by its large distance and its location in a X-ray bright supernova remnant in the Large Magellanic Cloud. Here we report on a comprehensive analysis of all the available XMM-Newton observations of SGR 0526–66. In particular, thanks to a deep observation taken in 2007, we measured its pulsation period (P = 8.054±0.0002 s) 6 years after its latest detection by Chandra. This allowed us to detect for the first time a significant reduction of its spin-down rate. From a comparison with two shorter XMM-Newton observations performed in 2000 and 2001, we found no significant changes in the spectrum, which is well modelled by an absorbed power-law with N_H = 4.6^{+0.7}_{-0.5} \times 10^{21} \text{ cm}^{-2} and \Gamma = 3.27^{+0.07}_{-0.04} \text{.} \ The high luminosity (\sim 4 \times 10^{35} \text{ erg s}^{-1}, \text{ in the 1–10 keV energy band}) still observed \sim 23 years after the latest detection of bursting activity places SGR 0526–66 in the group of bright and persistent magnetar candidates.

Key words: ISM: individual: N49 – stars: neutron – supernova remnants – X-rays: individual: SGR 0526–66 – X-rays: stars.

1 INTRODUCTION

On 1979 March 5, an extremely bright gamma-ray burst (GRB), followed by a >60 s long tail pulsating at a period of 8.1 ± 0.1 s, was detected by many spacecrafts (Mazets et al. 1979). The event was localized within the young (~5,000–10,000 years old) supernova remnant (SNR) LHA 120–N49 (N49) in the Large Magellanic Cloud (LMC; Cline et al. 1982). These properties indicated that the burst was emitted by a young neutron star, leading Duncan & Thompson (1992) and Paczynski (1992) to propose the existence of neutron stars with magnetic fields of \sim 10^{15} G, that were called magnetars. The detection of many weaker bursts from the same direction in the following 4 years indicated that the March 5 event was not a typical GRB, but an exceptional outburst from a small class of sources which had been just discovered and called soft gamma-ray repeaters (SGRs). Indeed the 1979 March 5 event was the first “giant flare” observed from a SGR. Only two other such events have been observed in the following years, each one from a different SGR (Hurley et al. 1999, 2005).

Up to now, only six SGRs have been discovered (plus a few candidates). They are characterised by the emission of short bursts of gamma-rays during sporadic periods of activity. In addition, they are also observed as pulsating X-ray sources with periods in the 2–9 s range and persistent luminosities up to \sim 10^{36} \text{ erg s}^{-1}. The magnetar model was developed to explain both their bursting and persistent emission (Thompson & Duncan 1995) and later extended (Thompson & Duncan 1996) to the interpretation of the anomalous X-ray pulsars (AXPs). These are a group of 9 X-ray sources (plus...
2 OBSERVATIONS AND DATA ANALYSIS

SGR 0526–66 was observed by *XMM-Newton* on 2007 November 10 for about 70 ks. The field containing SGR 0526–66 had already been observed by *XMM-Newton*, with shorter exposure times, on 2000 July 8 and on 2001 April 8. In the 2000 observation SGR 0526–66 was ∼6′ off-axis, while in the other observations it was on-axis. We concentrate here on the analysis of the data collected with the EPIC instrument, which is composed by a PN [Strüder et al. 2001] and two MOS X-ray cameras [Turner et al. 2001], sensitive in the 0.2–15 keV energy range. Details on the instrument settings (optical blocking filter and operating mode) for each observation are listed in Table 1. For the longest observation we used also the data collected by the Reflection Grating Spectrometer (RGS, den Herder et al. 2001), which worked in parallel to the EPIC instrument and had a net exposure time of 71 ks for each of its two units (RGS1 and RGS2). This high resolution spectrometer is sensitive in the 0.35–2.5 keV energy range.

All the data were processed using the *XMM-Newton* Science Analysis Software (SAS version 8.0.0) and the calibration files released in August 2007. The standard pattern selection criteria for the EPIC X–ray events (patterns 0–4 for PN and 0–12 for MOS) were adopted. The RGS analysis followed the standard selection criteria as well. Response matrices and ancillary files for each spectrum were produced using the SAS software package and the XSPEC version 11.3.1. All errors reported in the following analysis are at 1 σ.

2.1 Spectral analysis

The spectral analysis of SGR 0526–66 with *XMM-Newton* is complicated by the location of this source within the bright SNR N49, whose spatial extent (∼40″ radius) is only slightly larger than the instrumental point-spread function (the 90% encircled energy fraction for a point source is ∼40″). Rather than attempting to subtract the SNR contribution as a background component, we included it in the fits with a free normalization and a fixed spectral shape determined as explained below. To reduce the contamination from the soft X-ray emission of N49, we extracted the SGR EPIC spectrum in the 1–10 keV energy range from a circle of 10″ radius (this includes 60% of the point source counts at 5 keV). The background spectrum was extracted from a region outside the SNR, but in the same CCD as the SGR (see Figure 1).

To model the soft and line-rich spectrum of the SNR, we took advantage of the high-resolution spectra collected by the RGS instrument during the longest observation. We extracted the first order spectra from the standard region normally used for point sources, setting the centre of the SNR as source position (such a selection includes most of the photons detected from the SNR, thanks to its relatively small extension). The RGS spectral...
analysis was restricted to the 1–2 keV energy range. To model the SNR above 2 keV, we extracted a 1–10 keV PN spectrum from a 40′′ circle centred in the middle of the SNR and fitted it together with the spectra of the two RGS units. Based on the results of previous X-ray observations of N49 (Park et al. 2003; Bilikova et al. 2009), we used a model consisting of the sum of two plane-parallel shock components at different temperatures (VPSHOCK in XSPEC) both corrected for photoelectric absorption (PHABS in XSPEC). To this we added an absorbed power-law to account for the emission from SGR 0526–66. Its parameters were fixed at the best-fit values found with Chandra : $N_{\text{H}} = 5.6 \times 10^{21}$ cm$^{-2}$, $\Gamma = 3.06$, norm=$1.18 \times 10^{-10}$ s$^{-1}$ cm$^{-2}$ keV$^{-1}$ at 1 keV (Kulkarni et al. 2003). An overall normalization factor for each spectrum was also included to account for the cross-calibration uncertainties between the two RGS and the EPIC PN. A satisfactory fit ($\chi^2=2170/935$ degrees of freedom, d.o.f.) was obtained with the following parameters: $N_{\text{H}} = (1.3\pm0.3) \times 10^{21}$ cm$^{-2}$, $kT_1=0.577^{+0.005}_{-0.005}$ keV, $\tau_1 = 5.4^{+1.8}_{-0.8}$ s cm$^{-3}$, $kT_2=1.10\pm0.01$ keV, $\tau_2 = 3.0\times10^{13}$ s cm$^{-3}$, $\text{Ne}/\text{Ne}_\odot = 0.66\pm0.02$, $\text{Mg}/\text{Mg}_\odot = 0.59\pm0.01$, $\text{Si}/\text{Si}_\odot = 0.79\pm0.01$, $\text{S}/\text{S}_\odot = 1.00\pm0.04$, $\text{Ca}/\text{Ca}_\odot = 0.64\pm0.4$, $\text{Fe}/\text{Fe}_\odot = 0.45\pm0.02$. The abundances of the other elements are fixed to the Solar values (Anders & Grevesse 1989). These parameters are in good agreement with previous studies of this SNR (Park et al. 2003; Bilikova et al. 2007). The unabsorbed flux in the 1–10 keV energy range is $7.1 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ for the SNR and $1.6 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ for the SGR.

We then fitted the EPIC spectra extracted from the small region around SGR 0526–66 with an absorbed power-law plus the model of the SNR described above. All the SNR model parameters were fixed at their best-fit values, except for the normalization, in order to properly account for the unknown intensity of the SNR emission in the source extraction region. A good fit ($\chi^2 = 274.1/233$ d.o.f., see Figure 2) is obtained with a hydrogen column density $N_{\text{H}} = (4.6^{+0.7}_{-0.5}) \times 10^{21}$ cm$^{-2}$ and a photon index $\Gamma = 3.27^{+0.07}_{-0.04}$. The lack of systematic residuals in correspondence with the SNR brightest spectral lines (see Figure 3) indicates that the SNR contamination is sufficiently well modelled. The 1–10 keV (unabsorbed) flux of the power-law component is $(1.25^{+0.05}_{-0.03}) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. This corresponds to a luminosity of $4.3 \times 10^{35}$ erg s$^{-1}$ for a distance of 55 kpc.

Since no time variability is expected in the SNR contribution we can fit the SGR spectra of the older EPIC observations with the model described above, keeping the SNR model normalization fixed at the value obtained in the longest observation. The best-fit parameters for an absorbed power-law model are reported in Table 2. No spectral variability is detected and significant (>3σ) flux variations larger than ~50% among the different XMM-Newton observations can be excluded.

2 Although this fit is not statistically acceptable, a detailed modelling of the SNR emission is beyond the scope of this paper and so we did not adopt more complex spectral models.

3 More complex spectral models, which are usually used to fit magnetar spectra, were not adopted in this case due to the uncertainty of the background subtraction.

4 We also applied a second normalization factor to both the SNR and the SGR models to account for the cross-calibration uncertainties between the EPIC cameras; the maximum flux discrepancy we find between the EPIC cameras is lower than 15%.

5 The SNR contamination, evaluated from the model described in Section 2.1, is also included in the background. The error in the pulsed fraction does not include the systematic uncertainty due to the SNR contamination.

![Figure 2. EPIC PN spectrum of SGR 0526–66 collected during the longest XMM-Newton observation in 2007. The model, obtained by a simultaneous fit of the PN and MOS spectra (see the corresponding parameters in Table 2), is an absorbed power-law (green) and the sum of two plane-parallel shock components (in blue the warmer and in red the cooler one) to model the contamination from the SNR.](image-url)
sparse, the value we derived shows, for the first time, a significant decrease of the spin-down rate. This behavior is sometimes observed in magnetar candidates (see, e.g., Mereghetti et al. 2005), but some exceptions have been found (see, e.g., Gavril & Kaspi 2004). In the case of SGR 0526–66, the bursting activity is indeed very low, since no bursts have been detected since 1983. However, we note that some bursts might have been missed due to its large distance and its location in a sky region not frequently monitored by γ-ray instruments.

The X-ray luminosity measured in 2007 is ~30% lower (and the spectrum slightly softer) than that reported from the analysis of Chandra data taken in 2000 and 2001 (Kulkarni et al. 2003). However, due to the different characteristics of the instruments and additional uncertainties due to the presence of contamination from the SNR diffuse emission, we consider these changes well within the systematic uncertainties. Using the two shorter XMM-Newton observations, taken almost simultaneously with the Chandra ones, we can instead extract the spectrum and model the SNR emission in the same way as we did for the 2007 observation. In this case we are dominated by statistical errors and no significant changes in the spectral shape and source flux are detected.

The luminosity of SGR 0526–66, which can be well determined thanks to its accurately known distance, is higher than that of most magnetar candidates (see, e.g., Durant & van Kerkwijk 2006). Since this high luminosity has not substantially varied for at least several years, it is probably a long-lasting property of this magnetar rather than a transient bright state related to its past bursting activity, culminating with the giant flare of 1979 March 5.

Table 2. Best-fit spectral parameters for the three EPIC observations (see Table 1) of SGR 0526–66 in the 1–10 keV energy range. The spectral model consists of a fixed component modelling the SNR contamination (see text for details) and an absorbed power-law model for the SGR emission.

| Observation | SNR norm.a | \( N_H \) \((10^{21} \text{ cm}^{-2})\) | \( \Gamma \) | Fluxb \((10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1})\) | \( \chi^2 \) (d.o.f.) |
|-------------|------------|-----------------|------|----------------|----------------|
| A           | 0.117 (fixed) | 3.8±0.2         | 3.4±0.4 | 1.3±0.2        | 1.04 (65) |
| B           | 0.117 (fixed) | 5.3±0.6         | 3.3±0.2 | 1.3±0.1        | 0.88 (166) |
| C           | 0.117±0.002 | 4.6±0.5         | 3.27±0.07 | 1.25±0.05      | 1.18 (233) |

a Normalization factor applied to the best-fit model of the RGS and PN spectrum of the whole SNR.
b Unabsorbed flux in the 1–10 keV range.

Figure 3. Z^2 diagram of the long XMM-Newton observation (PN and MOS data in the 0.65–12 keV energy range) of SGR 0526–66 in the range used for the period search (see Section 2.2). The peak at 8.0544 s is significant at 3.2σ. Inset: The corresponding EPIC pulse profile (0.65–12 keV, not background subtracted).

The pulsation profile (shown in Figure 3) is double-peaked and the pulse fraction of SGR 0526–66 was never published before, these might be permanent properties of this source, since a non-sinusoidal modulation and a pulse fraction around 10% were also reported for the Chandra data (Kulkarni et al. 2003).

Although the period measurements of SGR 0526–66 are very sparse, the value we derived shows, for the first time, a significant decrease in the spin-down rate of this source. In the magnetar model, a reduction of the spin-down rate can be interpreted as an indication of a more relaxed state of the twisted magnetosphere and should be associated to a low rate of bursting activity, a spectral softening and a decrease of the persistent X-ray luminosity (Thompson et al. 2002). This behavior is related to intrinsic differences between the sources (e.g. magnetic field) or different evolutionary stages, this seems to support the emerging trend of separating the magnetars into transient and persistent objects, rather than in AXPs and SGRs. In this framework, SGR 0526–66 should therefore be considered a member of the persistent magnetars group.

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