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3XMM J185246.6+003317: ANOTHER LOW MAGNETIC FIELD MAGNETAR

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ABSTRACT

We study the outburst of the newly discovered X-ray transient 3XMM J185246.6+003317, re-analyzing all available XMM-Newton observations of the source to perform a phase-coherent timing analysis, and derive updated values of the period and period derivative. We find the source rotating at \( P = 11.55871346(6) \) s (90% confidence level; at epoch MJD 54728.7) but no evidence for a period derivative in the seven months of outburst decay spanned by the observations. This translates to a 3\( \sigma \) upper limit for the period derivative of \( P < 1.4 \times 10^{-13} \) s s\(^{-1} \), which, assuming the classical magneto-dipolar braking model, gives a limit on the dipolar magnetic field of \( B_{\text{dip}} < 4.1 \times 10^{13} \) G. The X-ray outburst and spectral characteristics of 3XMM J185246.6+003317 confirm its identification as a magnetar, but the magnetic field upper limit we derive defines it as the third “low-\( B \)” magnetar discovered in the past 3 yr, after SGR 0418+5729 and Swift J1822.3–1606. We have also obtained an upper limit to the quiescent luminosity \((<4 \times 10^{35} \text{ erg s}^{-1})\), in line with the expectations for an old magnetar. The discovery of this new low field magnetar reaffirms the prediction of about one outburst per year from the hidden population of aged magnetars.

Key words: pulsars: general – X-rays: stars

Online-only material: color figures

1. INTRODUCTION

Neutron stars are the relic of the supernova explosions of massive stars (Baade & Zwicky 1934). Five decades after their discovery (Hewish et al. 1968), these compact objects have appeared in many different forms. The most common are radio pulsars, usually modeled as rapidly rotating magnetic dipoles. Another important subgroup is formed by binary neutron stars, either as X-ray pulsars accreting from a companion or normal radio pulsars orbiting a companion star. Perhaps the most intriguing class among isolated neutron stars are the “magnetars,” so called because they are believed to be powered by their super strong magnetic field (see Mereghetti 2008; Rea & Esposito 2011 for recent reviews). Initially classified as anomalous X-ray pulsars and soft gamma repeaters (SGRs), it is now accepted that this is not an intrinsic distinction but rather a historical nomenclature due to the different ways they were discovered: as a steady emitter visible in X-ray surveys or during a high-energy burst or flare from a new direction in the sky. Magnetars are characterized by rotational periods in the 0.3–12 s range, period derivatives between \( 10^{-12} \)–\( 10^{-10} \) s s\(^{-1} \), X-ray luminosities of \( 10^{31} \)–\( 10^{35} \) erg s\(^{-1} \), and episodes of enhanced X-ray persistent emission either as a long-lived radiative outburst (lasting months–years) or short bursts and flares (lasting seconds–minutes). Both their steady and transient X-ray phenomena are powered by their strong magnetic fields that can stress the neutron star crust causing stellar quakes, accompanied by global magnetospheric reorganizations with the subsequent powerful high-energy emission. Eventually, shorter flares might instead be purely magnetospheric, caused by reconnection of magnetic field lines higher up in the magnetosphere (Thompson et al. 2002; Lyutikov 2003).

In 2009, a peculiar magnetar (van der Horst et al. 2010; Esposito et al. 2010; Rea et al. 2010) was discovered during an active epoch (SGR 0418+5729) as have many other members of the magnetar class, but in this case, its estimated surface dipolar magnetic field (at the equator) of \( B = 6.2 \times 10^{12} \) G (Rea et al. 2013) was rather low, more typical of a normal radio pulsar. Some years later, another “low magnetic field magnetar” was discovered (Swift J1822.3–1606 : \( B \sim 2 \times 10^{13} \) G; Rea et al. 2012; Scholz et al. 2012), again showing all of the characteristics of the outburst activity of a typical magnetar. A plausible solution to the apparent puzzle considers these objects as aged magnetars that have largely dissipated their external dipolar field but still hold a crustal/ internal field one or two orders of magnitude larger. This internal field would be responsible for the bursting activity and intense outbursts (Rea et al. 2010; Turolla et al. 2011). This scenario has been strengthened by detailed studies of the evolution of neutron stars endowed with strong magnetic fields, and applied to the two known low field magnetars (Pons et al. 2009; Viganó et al. 2013; Rea et al. 2013). Furthermore, the absorption feature observed during the outburst of the lowest field magnetar, SGR 0418+5729, if interpreted as a proton cyclotron feature, confirms a \( \sim 10^{14} \) G magnetic field in a magnetic loop close to the surface (Tiengo et al. 2013).

In this Letter, we have re-analyzed all the archival XMM-Newton observations of 3XMM J185246.6+003317 (hereafter 3XMM J1852+0033): a new transient source discovered serendipitously while undergoing an outburst in 2008 (Zhou et al. 2014). We first report on the data analysis, and in Section 5, we argue that this source is a low magnetic field magnetar and discuss the consequences of this finding in terms of the population of old magnetars and their magneto-thermal evolutionary path.

2. XMM-NEwTON DATA ANALYSIS

3XMM J1852+0033 was observed several times with XMM-Newton (Jansen et al. 2001). Data have been processed using SAS version 13, and we have employed the most updated calibration files available at the time the reduction was performed (2013...
November). The source was detected serendipitously only in the Metal Oxide Semiconductor (MOS) cameras (Turner et al. 2001; see Table 1) in the 2008 and 2009 observations. The MOS1 and MOS2 cameras were set up in full frame mode, with a timing resolution of 2.6 s. We have applied standard data screening criteria in the extraction of scientific products. Source photons were extracted from a circular region with a radius of 40″, and a similar circle was used for the background, in the same CCD of the source. We used the same extraction region to estimate the count rate upper limit for the four observations of the source in quiescence (see Table 1). Our spectral analysis was restricted to photons having PATTERN $\leq$ 12 and FLAG = 0. All photon arrival times have been referred to the solar system barycenter (TDB time system and DE200 ephemeris).

3. OUTBURST

3.1. Timing Analysis

Timing analysis was performed using the phase-fitting technique (details on this technique can be found in Dall’Osso et al. 2003), and using all “outburst” data listed in Table 1 (both from the MOS1 and MOS2 cameras when available). We merged the photon arrival times of some contiguous pointings (2008 September 19–29, with a 0.5–10 keV observed flux of $\sim 4.2 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ (see also Figure 2), (2) red—2008 October 10 (MOS2) at a flux of $\sim 2.8 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$, (3) blue—2009 March 16–25 (MOS1 and MOS2) at $\sim 6 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$, and (4) green—2009 April 4–22 (MOS1 and MOS2) at $\sim 5 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ (note that some observations have been merged to increase the accuracy in the phase determination).

(A color version of this figure is available in the online journal.)

Figure 1. Left: 3XMM J1852+0033’s pulse phases derived with fitting a sine function the pulse profile folded with a trial period (see text for details, and below for the color code definition). The phase evolution in time is fitted with a linear function. The residuals with respect to our best phase-coherent solution are reported in the lower panel, in units of seconds. Right: pulse profiles in the 0.3–10 keV energy range. From top to bottom they refer to: (1) black—MOS2 observations performed between 2008 September 19–29, with a 0.5–10 keV observed flux of $\sim 4.2 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ (see also Figure 2), (2) red—2008 October 10 (MOS2) at a flux of $\sim 2.8 \times 10^{-12}$ erg s$^{-1}$ cm$^{-2}$, (3) blue—2009 March 16–25 (MOS1 and MOS2) at $\sim 6 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$, and (4) green—2009 April 4–22 (MOS1 and MOS2) at $\sim 5 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ (note that some observations have been merged to increase the accuracy in the phase determination).

In almost all cases, the use of the fundamental harmonic alone was sufficiently accurate. In Figure 1, we plot the phases at which the fundamental sine function fitted to the pulse profile is equal to zero.

The time evolution of the phase can be described by a relation: $\phi = \phi_0 + 2\pi(t - t_0)/P - \pi(t - t_0)^2P^2$. A linear fit of the resulting pulse phases, by assuming the initial trial period reported above, gives a reduced $\chi^2_r \sim 2$ for 8 degrees of freedom (dof hereafter). The inclusion of a quadratic term in the phase modeling, corresponding to a first period derivative component, was not significant in our data with a 3σ (two parameters of interest, p.o.i) upper limit on the period derivative of $P < 1.4 \times 10^{-13}$ s s$^{-1}$ and a reduced $\chi^2_r \sim 2.2$ (for 7 dof; see also Figure 1). The resulting best-fit solution corresponds to a spin period of $P = 11.55871346(6)$ s (90%
The mean source count rate). In time with an average value of \( \sim \) during the outburst decay. The pulsed fraction is relatively stable observations during the outburst phase of 3XMM J1852+0033. The stabilization was already observed in other low-B magnetars. That we caught the outburst at a late time, and a pulse profile consistent within errors with those of Zhou et al. (2014). We have performed the spectral analysis using all of the observations during the outburst phase of 3XMM J1852+0033 reported in Table 1, and data from both the MOS1 and MOS2 cameras when available. Spectra from the 2008 observations were grouped to have at least 50 counts per bin, while for the 2009 observations, we required at least 30 counts per bin. The rebinning was made with special care in order not to oversample the instrument spectral resolution by more than a factor of three. We used XSPEC 12.7.1 for the spectral fitting. Our results are consistent within errors with those of Zhou et al. (2014). We report in Figure 2, the evolution of the spectral parameters and of the 0.5–10 keV observed flux for a phabs*bbody*rad spectral model (\( \chi^2 = 1.1 \) (1049 dof); \( N_{\text{H}} = 1.32(5) \times 10^{22} \text{ cm}^{-2} \). Similar to Zhou et al. (2014), we find a tiny excess flux at energies higher than 6 keV which is not properly modeled by a single blackbody model alone (although this is not influencing the goodness of the \( \chi^2 \)). Using a resonant cyclotron scattering (RCS) model (Rea et al. 2008), this excess is instead well accounted for (note, however, that the RCS has two additional free parameters) by the nonthermal sinusoidal modulation divided by the mean source count rate.

3.2. Spectral Analysis

We have performed the spectral analysis using all of the observations during the outburst phase of 3XMM J1852+0033 reported in Table 1, and data from both the MOS1 and MOS2 cameras when available. We have extracted all photons encircled in a 40\(^\prime\) radius around the position of the source, for the four available observations (Table 1) and both the MOS1 and MOS2 cameras when available. We have added all of the event files of the MOS1 and MOS2, created an image of the resulting merged event file, and used the Ximage sosta tool to derive a source upper limit taking into account its point-spread function correction for the off-axis position, the vignetting, and the sampling dead time. This method uses the Bayesian approach with the prior function set to the prescription described in Kraft et al. (1991). We have derived, for a total exposure time of 251 ks, a 3\(\sigma\) upper limit on the source count rate of 0.0014 count s\(^{-1}\) in the 0.3–10 keV range. With this upper limit, assuming a distance of 7.1 kpc, a 10 km radius surface emission, and an \( N_{\text{H}} = 1.32 \times 10^{22} \text{ cm}^{-2} \) (as derived in Section 3.2), we can obtain the upper limits on the surface temperature and on the bolometric thermal luminosity during quiescence of \( kT < 0.15 \text{ keV} \), and \( L_{\text{qui}} < 4 \times 10^{33} \text{ erg s}^{-1} \).

5. DISCUSSION

We have reported a phase-coherent timing solution for the newly discovered transient 3XMM J1852+0033 (Zhou et al. 2014), which underwent an outburst in 2008, and was caught serendipitously by XMM-Newton during a series of observations of the supernova remnant (SNR) Kes 79 and its central compact object CXOU J1852+0040 (Seward et al. 2003; Halpern & Gotthelf 2010). The spin period does not show any sign of Doppler shifts due to a possible companion star (and no companion star is observed in the optical or infrared bands in the available catalogs; Zhou et al. 2014). Assuming that the pulsar is isolated, its rotational properties indicate a dipolar surface magnetic field (at the equator) of \( B = 3.2 \times 10^{10}(P/P) \times 2 < 4 \times 10^{13} \text{ G} \), and the characteristic age and the rotation power are \( \tau_{c} = P/(2P) > 1.3 \text{ Myr} \) and \( E_{\text{rot}} = 3.9 \times 10^{40}P/P/3 < 3.5 \times 10^{35} \text{ erg s}^{-1} \), respectively. Despite the relatively low dipolar magnetic field, the detection of an outburst and the observed spectral characteristics confirm the magnetar nature of this transient source.

In Figure 3, we show the expected timing and luminosity evolution for isolated neutron stars born with a dipolar field intensity (at the pole) between \( B = 10^{14} \text{ G} \) and \( B = 10^{15} \text{ G} \). The expected properties are in line with the observed properties of all high-B pulsars, X-ray emitting isolated neutron stars (XINSs) and magnetars. As the right panel shows, 3XMM J1852+0033 is compatible with the expected evolution of a neutron star born with an initial dipolar magnetic field (at the pole) of \( B \sim 3 \times 4 \times 10^{14} \text{ G} \), which is now at the same evolutionary stage as the other low-B magnetars, hence about an Myr. In particular, except for the occasional outburst, the long spin period, \( P \sim 11.57 \text{ s} \), and the relatively low quiescent luminosity, \( L_{\text{qui}} < 4 \times 10^{33} \text{ erg s}^{-1} \) of 3XMM J1852+0033 (and of the other low-B magnetars SGR 0418+5729 and Swift J1823.3–1606; Rea et al. 2012, 2013; Scholz et al. 2012) would place it in the same class as the XINS, a group of nearby, thermally emitting isolated neutron stars with typical temperatures of 0.1 keV. The possibility that XINS or some of the other high-B pulsars are simply aged, less active magnetars has been proposed and tested in the last few years (see, e.g., Pons & Perna 2011; Viganò et al. 2013; Rea et al. 2013, and references therein).

In this scenario, 3XMM J1852+0033 lies on the same evolutionary track as the large group of other 6–7 neutron stars (magnetars and XINSs), perhaps indicating a common, 6 Note that the high luminosity of some young magnetars is likely to be partly due to the contribution of the magnetospheric plasma, which yields part of its kinetic energy to X-ray photons via RCS. Thus, it is hard to infer the purely thermal component in the X-ray spectrum; see Viganò et al. (2013) for details.
The quiescent luminosity is also compatible with the theoretical models, sporadical outbursts are expected to occur until a maximum age of $\approx 1$ Myr, after which the magnetic field is too weak to cause any significant crustal fracture. Thus, we find a possible association between the magnetar Kes 79 and the CCO J1852+0040. Therefore, we find a possible association between the magnetar and Kes 79 unlikely.

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