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The peculiar source XSS J12270-4859: a LMXB detected by FERMI?

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Abstract. The X-ray source XSS J12270-4859 has been first suggested to be a magnetic cataclysmic variable of Intermediate Polar type on the basis of its optical spectrum and a possible 860 s X-ray periodicity. However further X-ray observations by the Suzaku and XMM-Newton satellites did not confirm this periodicity but show a very peculiar variability, including moderate repetitive flares and numerous absorption dips. These characteristics together with a suspected 4.3 h orbital period would suggest a possible link with the so-called "dipping sources", a sub-class of Low-Mass X-ray Binaries (LMXB). Based on the released FERMI catalogues, the source was also found coincident with a very high energy (0.1-300 GeV) VHE source 2FGL J1227.7-4853. The good positional coincidence, together with the lack of any other bright X-ray sources in the field, makes this identification highly probable. However, none of the other standard LMXB have been so far detected by FERMI. Most galactic HE sources are associated with rotation-powered pulsars. We present here new results obtained from a 30 ksec high-time resolution XMM observations in January 2011 that confirm the flaring-dipping behaviour and provide upper limits on fast X-ray pulsations. We discuss the possible association of the source with either a microquasar or an accreting rotation powered pulsar.

Key words. Stars: binaries: close - Stars: individual: XSS J12270-4859, 1FGL J1227.9-4852 - gamma rays: stars- X-rays: binaries - Accretion, accretion disks

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1. The identification of XSS J12270-4859

The X-ray source XSS J12270-4859 (hereafter XSS1227) was discovered from the

Rossi XTE survey by Sazonov & Revnivtsev (2004). It was subsequently detected at energy higher than 20 keV from observations by the INTEGRAL satellite (Bird et al. 2010). An identification campaign leds to its identification with an ($m_v \sim 16$) optical star which shows Balmer emission lines typical of an accreting white dwarf (Masetti et al. 2006). Pointed observations by RXTE seemed further to consolidate the suggestion of a cataclysmic variables of Intermediate Polar (IP) when 860 sec X-ray modulation was reported, typical of IP rotations (Butters et al. 2008). However, fast optical photometry failed to confirm these pulsations (Pretorius 2009). Furthermore, the source was more extensively observed in X-rays by the Suzaku and XMM satellites (Saitou et al. 2009; de Martino et al. 2010), both observations ruling out the presence of significant X-ray pulsations. A complete account of the 2009 XMM observations is given in de Martino et al. (2010) (hereafter DDM10). The detailed observations show the source with a power-law X-ray energy distribution already more suggestive of a low-accreting X-ray binary (DDM10, Falanga et al. (2010)) but the discovery of a probable association with a high energy (E > 100 MeV) gamma-ray source makes it a very peculiar object.

2. The association with the FERMI source

Analysing our January 2009 XMM observations, we were the first to note the possible association of the source with a high energy counterpart. The first FERMI catalogue was released in Jan. 2010. The point source catalogue of the high-energy (100 MeV to 300 GeV) gamma ray sources detected by the Large Area Telescope (LAT) is based on observations of the first 11 months of the science mission. It lists a significant source 1FGL J1227.9-4852 at a distance less than 2 arcmin from XSS1227 with an associated uncertainty of 3.6 and 6.0 arcmin respectively for a 68 % and 95% confidence.

A refined position was recently provided by the second-year FERMI catalogue (Abdo et al. 2011) with the source, now labeled 2FGL J1227.7-4853 (herafter 2FGL1227). 2FGL1227 is detected at a significance of 24.3 σ with a (0.1–100 GeV) flux of $3.38\pm0.22 \times 10^{-11}$ erg cm^{-2} s^{-1} and a best fit power law photon index of 2.33±0.08 with a high energy cut-off around 4 GeV. It is at a separation with respect to XSS1227 of 2.7 arcmin with a 95% confidence uncertainty of 3.6 arcmin. The source XSS1227 is the only bright X-ray source in a (6x6) arcmin field centered around 2FGL1227 making the association quite reliable. The 2FGL1227 position is consistent with the one derived by Hill et al. (2011) who also conducted a radio survey of the error box. Three faint sources were found in the box. One is coincident with XSS1227 (to within 1 arcsec) with a flux density of 0.18 mJy at 5.5 GHz.

3. The X-ray variability of XSS J12270-4859

The atypical X-ray variability of XSS1227 was first uncovered by Suzaku observations (Saitou et al. 2009) that revealed the presence of repetitive flares and numerous absorption dips with significant spectral changes. However, numerous gaps in the Suzaku data prevented an accurate study. A first continuous 35 ksec XMM observation was obtained on January 5, 2009 supplemented by additional optical photometric data (DDM10). Figure 1 shows the (0.2-10 keV) XMM light curve with the presence of three large flares of typical duration of ~ 10 min. and more than 20 absorption dips with very small residual flux. This same type of behaviour was consistently seen for the source when additional RXTE (Saitou et al. 2011) and XMM observations (de Martino et al. 2012) were obtained.

New XMM observations obtained on January 1st, 2011 reveals again more than 35 absorption dips; most of the dips being short ($\lesssim$ 3 min.) but at least three long dips are also visible with duration more than 10 min. The dips are reminiscent of the dipping LMXB sources (Diaz Trigo et al. 2006), such as EXO 0748-676 (Bonnet-Bidaud et al. 2001), but in these sources they occur at specific orbital phases and with a spectral hardening that is not ob-

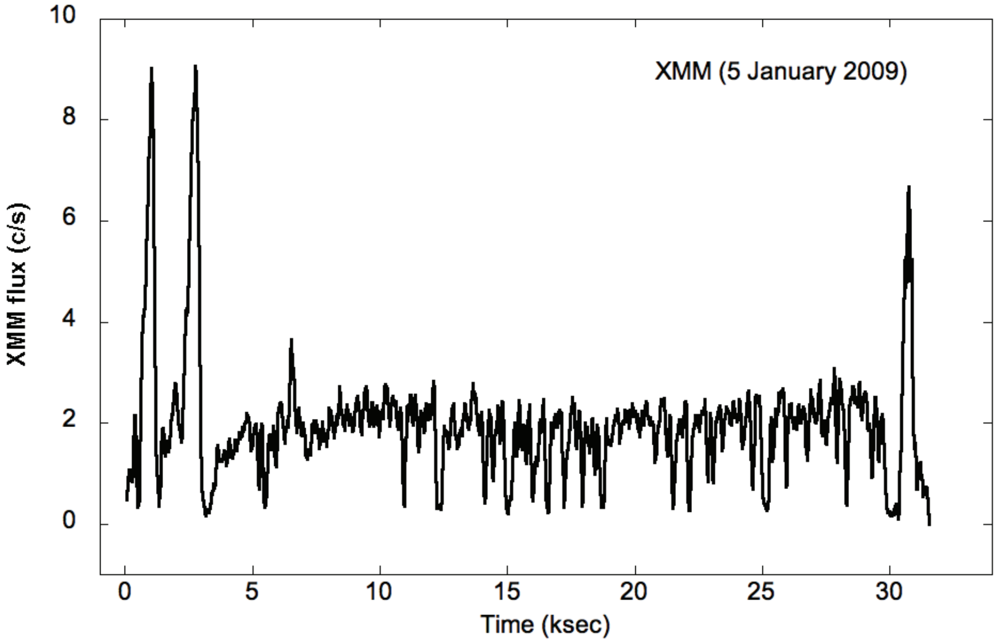

Fig. 1. The (0.2-10) keV light curve of XSS1227 obtained with XMM on 5 January 2009. Repetitive absorption dips are clearly visible all through the observations with also three large (~ 5-10 min.) flares.

served in XSS1227 (see below). Three (~ 5-fold) flares with duration ~ 5-10 minutes are also present at the end of the observations. These flares are similar to those observed previously. Showing much longer timescales and a rather a-typical "inverted" shape with a slow rising and a sharp drop, they are quite different from the typical bursts seen among other X-ray binaries.

The broad-band (0.2-100 keV) XMM and INTEGRAL combined spectrum of XSS1227 is found featureless and well described by a weakly absorbed power law with a photon index of $\Gamma_{ph} \sim 1.7$ and an hydrogen column density $\sim 1 \times 10^{21}\,\mathrm{cm}^{-2}$ consistent with the interstellar extinction. The source does not show any significant Fe line commonly seen in accreting white dwarfs. There is no apparent cut-off up to 100 keV and the derived X-ray luminosity is $L_X \sim 5 \times 10^{33}\,(d/1\mathrm{kpc})^2\,\mathrm{erg\,s}^{-1}$. Time-resolved X-ray spectroscopy also clearly shows that the flares and dips in general are accompanied by no significant spectral change. However the flares are usually followed by a dip than can be described with severe absorption $N_H \geq 6.1 \times 10^{22}\,\mathrm{cm}^{-2}$ (see DDM10).

There is at present no definitive measure of the orbital period of the system. The best indication has come so far from our V and J optical photometry that shows a significant modulation at a period of ~ 4.3 h. A marginal evidence of a low (4%) amplitude variability at this period is also found in the X-ray and UV ranges (DDM10). This periodicity has still to be confirmed by upcoming optical spectroscopy but seems to be a good indication of a LMXB.

4. The high energy spectrum

The association with 2FGL1227 means that the source has an emission extending up to the GeV range rather atypical for LMXBs. The combined XMM-INTEGRAL-FERMI spectrum is shown in Fig. 2 as Energy Density Spectrum (SED) to better show where the peak energy is released. With a power-law index changing from 1.7 (X-rays) to 2.3 (VHE), the maximum flux will be expected around 1 MeV.

Table 1. Source comparison

Source	PSRJ1023	XSS1227
Pulse	1.67 ms	?
Orbit	4.75 hr	4.3 hr ?
Radio Flux	6 mJy	0.2 mJy
Optical (V)	15 – 17.4	15.8 – 17.3
X-ray flux	$4.6\ 10^{-13}$	$4.5\ 10^{-11}$
Spectrum (PL)	1.3 – 1.7	1.7
Pulsation	Yes (11%)	(< 30%)
γ flux	$5.5\ 10^{-12}$	$4.1\ 10^{-11}$
Spectrum (PL)	2.9	2.3
Lγ (1kpc)	$6.5\ 10^{32}$	$4.9\ 10^{33}$
Ratio Lγ/L_X	12	0.9

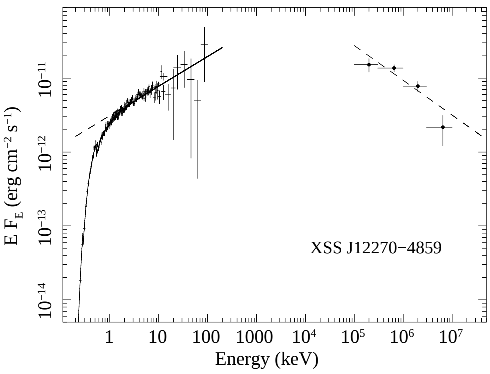

Fig. 2. The composite XMM-Integral-Fermi energy density spectrum (from (de Martino et al. 2010)).

There is a significant energy released above 100 MeV with a ratio L_X(0.2-100keV)/L_γ(0.1-100GeV)=0.9. The FERMI light curve shows that the source is persistent at VHE with no significant flaring activity to within the statistical uncertainty. Very few X-ray binaries have been so far detected by FERMI. In the last two-year catalogue, 1873 sources are detected of which 127 can be considered as being firmly identified and 1170 as being reliably associated with counterparts. Among the firm identifications, 83 are pulsars, 28 are AGN, 6 are SNR, 4 are HMXB, 3 are Pulsar-wind nebulae, 2 are normal galaxies, and one is a nova (Abdo et al. 2011). Among the HMXBs, all sources are long-period (P> 3d) massive systems apart from the microquasar candidate Cyg X-3 (P=0.2d) that is only transitorily detected. Formal associations with low- mass X-ray binaries are reported for three 2FGL sources but all three are located in globular clusters, and the observed emission can be readily explained by the combined emission of millisecond pulsars. 2FGL1227 could be therefore the first LMXB emitting at high energies.

5. Discussion

The nature of 2FGL1227 is puzzling. The identification of XSS1227 with 2FGL1227 appears quite reliable since the absence of other significant X-ray as well as strong radio sources in the field evidently excludes an alternate association with another accreting binary or a background extragalactic source. The X-ray source is consistent with an X-ray binary accreting at a rather low rate if placed at a reasonable distance less than a few kpc. At such distance, the optical magnitude excludes a massive companion and the measured (4.3h) optical modulation points instead towards a typical LMXB. The key question is therefore the origin of the VHE emission. A suggestion has been made by Saitou et al. (2011), that XSS1227 might be a microquasar accreting at very low rate with a synchrotron jet. The weak point is however that among the known microquasars, such as GRS 1915+105 or XTE J118+480, they usually show an X-ray variability much higher than XSS1227 and none emits at very high energy. The only related system, Cyg X-3, is only very transitorily detected by FERMI in specific conditions after a major radio flare and with a significant VHE flux of $L_\gamma \sim 3 \times 10^{36}\,(d/7\mathrm{kpc})^2\,\mathrm{erg\,s^{-1}}$. In view of the content of the Fermi catalogue and the high level of detection of rotation-powered pulsars, a more promising system will be a millisecond-pulsar in a LMXB such as PSR J1023+0038 as already proposed by Hill et al. (2011). Interestingly enough, this source was also initially classified as a CV candidate on the basis of an emission line optical spectrum spatially coincident with a radio source (Bond et al. 2002). Its X-ray and optical variability and line velocities clearly show an orbital period of P_{orb} = 4.75 hr but a significant change in accretion was also observed around 2002 when the optical spectrum turns to an absorption spectrum (Thorstensen & Amstrong 2005).

The discovery of a fast (1.6 msec) millisecond pulsar in the system together with the possible detection of the pulsation in X-rays suggested that, after an accretion episode, the system might have turned to quiescence with a spectrum dominated by the pulsar emission (Archibald et al. 2010). Unexpectedly, the source was detected by FERMI with a (E> 100MeV) flux of $5.5\pm0.9 \times 10^{-12}$ erg cm^{-2} s^{-1} and a power law index of 2.9±0.2 with gamma-rays originating either from the pulsar magnetosphere or a shock where accreting material interacts with the pulsar wind (Tam et al. 2010). The similarity with XSS1227 is surprising and summarized in Table 1. The two sources have similar orbits and optical flux and also very similar X-ray and gamma ray spectral shapes with only differences in flux, XSS1227 being significantly brighter in X-rays with a lower $L\gamma/L_X$ ratio.

PSR J1023+0038 is the first and only known rotation- powered MSP in a quiescent LMXB. The position of XSS1227 , at 14° high above the Galactic plane also favoured the MSP hypothesis which could be proved by the detection of millisecond pulsations. To this purpose, we asked for high-time resolution mode in our 2011 XMM observations to search for coherent signals in the frequency range 0.5-1000 Hz. Once corrected for the expected orbital smearing, no significant pulsations were found with an upper limit varying from 15 to 30% that is still well above the typical 11% fraction seen in PSR J1023+0038. Negative pulsation radio searches were also reported by Hill et al. (2011) that could also be heavily hampered by orbit smearing so that no definitive conclusion can yet be drawn.

The observed FERMI light curve, as well as our last 2011 XMM observations, confirms that XSS1227 is a rather stable X-ray and VHE source, probably accreting at a very low level. It is tempting to relate the VHE emission to the particles accelerated by a MSP pulsar as in the pulsar wind scenario, where γ-rays are generated by synchrotron radiation of the electrons (or possibly protons) accelerated in the shock with the infalling matter (Takata & Taam 2009). This scenario more naturally applied to PSR J1023+0038 where accretion may have ceased but could also possibly operate when residual accretion exists such as in XSS1227 .

6. Discussion

It is the absence of the thermal Fe line in X-rays. Otherwise, do you see two-peak profiles in optical lines as expected from disk ?

J.M. BONNET-BIDAUD: I agree with the absence of Fe line. No, we don't see two-peak profiles in optical lines but this may indicate an origin on the companion star and not in the disk.

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