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XSS J12270-4859: the first low mass X-ray binary gamma ray source system?

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XSS J12270-4859 is an enigmatic X-ray source. While it was first classified as a possible magnetic Cataclysmic Variable (CV), our recent follow-up X-ray study with *XMM-Newton*, *RXTE*, and *INTEGRAL* has revealed a peculiar highly variable source. This source was later classified as a low mass X-ray binary (LMXB) and not as first suggested to be a CV. The X-ray emission is highly variable showing flares and intensity dips. The flares consist of flare-dip pairs. Flares are detected in both X-rays and UV range whilst the subsequent dips are present only in the X-ray band. Further aperiodic dipping behaviour is observed during X-ray quiescence but not in the UV. We found that XSS J12270-4859 is positionally compatible with the high energy *Fermi*/LAT source 1FGL J1227.9-4852 which is significant up to 10 GeV. The X- and Gamma-ray spectra suggest a continuum peaking around 1-100 MeV, which strengthens the association of the two sources. From our optical and near-IR photometry we could also detect a 4.32 hr periodicity, likely related to the binary orbit. This source could be the first gamma-ray binary of LMXB nature.

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1. Introduction

Discovered as a hard X-ray source from the *Rossi XTE* slew survey [19], XSS J12270-4859 was also detected as an *INTEGRAL* source and suggested to be a Cataclysmic Variable (CV) by [14] from its optical spectrum. From follow-up *RXTE* observations [5] proposed a magnetic Intermediate Polar (IP) type from a possible periodic variability at a 859.6 s period. This periodicity is not confirmed in optical fast photometry [17] and in a *Suzaku* X-ray observation [18]. The latter showed a peculiar X-ray variability suggesting a low-mass X-ray binary (LMXB).

In the framework of a X-ray characterization programme of hard X-ray sources we present our recent results based on XMM-Newton, RXTE and INTEGRAL satellites and on optical and near-IR photometry acquired at the INAF-REM telescope that indicate that the previous classification was not confirmed [9]. A similar result is also found from a Suzaku observation [18]. We furthermore find that XSS J12270-4859 could be the X-ray counterpart of the high energy γ-ray source 1FGL J12279-4852 that emits up to 10 GeV, thus making this source an unique object that deserves deep investigation in all energy ranges (see details in [9]).

2. The LMXB nature of XSS J12270-4859

In [9] we have presented X-ray (XMM-Newton/RXTE/INTEGRAL), UV, and optical/nIR observations of XSS J12270-4859. We also found strong indication that this source has a high energy GeV counterpart as detected by the *Fermi* satellite.

XSS J12270-4859 shows remarkably large amplitude variability from X-rays to optical/near-IR. However, we did not detect the putative 859.6 s periodicity in any data set from X-rays to UV/optical and near-IR ranges. The *XMM-Newton* X-ray light curve is characterized by short aperiodic variations consisting of flares and dips (see Fig. 1). The latter are observed during quiescence as well as immediately after the flares. This peculiar behaviour is also detected in a *Suzaku* observation [18] carried out five months before the *XMM-Newton* pointing. A re-analysis of the 2007 *RXTE* data reveals a similar behaviour as detected by *XMM-Newton* and *Suzaku* [9]. However, the reported 859.6 s period [5] is not detected in the same *RXTE* data. The broad-band X-ray spectrum is essentially featureless and is well described by an absorbed simple power law with $\Gamma \sim 1.6$. An emission feature at 6.2 keV could be present during flares. From both temporal and spectral characteristics, we therefore conclude that XSS J12270-4859 is a persistent highly variable hard X-ray source that does not share any of the typical X-ray characteristics of magnetic CVs, especially of the IP type, and any commonality of CV flares as for instance seen in AE Aqr [8] or UZ For [20] and AM Her [10]. A similar conclusion was drawn by [18].

The evolution of the X-ray events is rather similar consisting of flare-dip pairs where the duration and intensity of flare and associated dips appear correlated. While no spectral changes are observed during flares with respect to quiescence, the spectrum hardens during the post-flare dips. A dense ($N_H = 6.1 \times 10^{22}$ cm^{-2}) absorbing material covering about $\sim$ 86% of the X-ray source is required to fit these dips. This is suggestive of a flow of cool material appearing after the flares. These flares also occur in the UV but with longer duration. The UV variations lag by more than 300 s the X-ray ones. The UV flux gets bluer during the flares than in quiescence. It is then possible that large amplitude, long term variations first affect the outermost parts of an accretion disc that are cooler

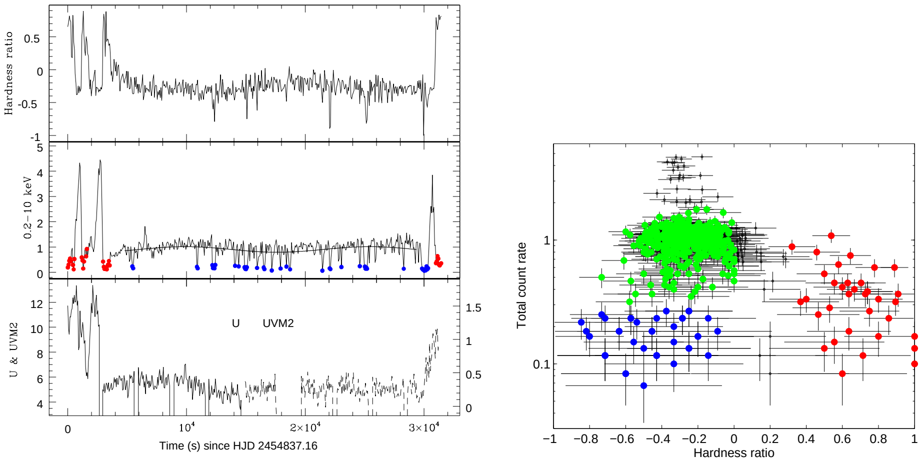

Figure 1: *Left*: *Bottom:* OM-*U* (solid line) and OM-*UVM*2 (dashed line) background subtracted light curves. Ordinates at the left report the OM-*U* count rate and at the right the OM-*UVM*2 band count rate. Gaps are due to the OM fast mode windows. *Middle panel:* EPIC-MOS (MOS1 and MOS2) combined light curve in the 0.2-10 keV band. A sinusoidal function at a period of 244.5 min is also shown. Red points refer to hard dips whilst blue points refer to soft dips that are reported below (see also text). *Top:* Hardness ratio defined as [H-S/H+S] between 2–10 keV and 0.2–2 keV bands from combined EPIC-MOS light curves. A bin size of 60 s is adopted for clarity in the three panels. *Right*: Diagram of total MOS intensity versus hardness ratio in the 0.2–2 keV and 2–10 keV bands. Green points represent quiescence (not reported above for clarity), red points are the dips observed after the flares and the blue points represent the dips observed during quiescence. Flares are denoted with black points.

and then propagate towards smaller radii. The UV decay is delayed suggesting that the UV is also affected by reprocessing of X-rays after the flare.

Pronounced aperiodic X-ray dips are observed when the source is in quiescence with no significant spectral changes. On the other hand, no dips are detected in the UV band suggesting that they originate from random occultations by material very close to the X-ray source.

New optical and near-IR photometry reveals large amplitude (up to 50%) variability. A periodicity at 4.32 hr is derived from the optical data. The modulation at this period is single peaked in the optical whilst it is double-humped in the near-IR band. A marginal evidence of a low (4%) amplitude variability at this period is also found in the X-ray and UV ranges. If this period is linked to the orbital binary period it implies that XSS J12270-4859 is a LMXB. The near-IR double humped modulation could then be due to ellipsoidal variations from the non-spherical low-mass donor star. The amplitude is determined by the orbital inclination angle i of the binary [11]. If it is indeed the case the binary inclination: $i \gtrsim 60^{\circ}$. On the other hand eclipses are not observed suggesting $i < 75^{\circ}$.

We also revised the optical spectrum presented in [14] and confirm the equivalent widths of major Balmer emission lines. We note however that due to the low spectral resolution, the He II (4686) line is blended with C III (4650). We then measure E.W. (He II)=4$\pm$1$\AA$, thus being much weaker than previously measured. Hence, the H_{β} and He II E.W. ratio, when compared to that of CVs and LMXBs [21] locate XSS J12270-4859 between the two object class locii. Furthermore the X-ray

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to optical flux ratio ranges between 48 (flares) and 17 (quiescence). This value is larger than that of CVs and magnetic systems and lies in the low value range of LMXBs.
If XSS J12270-4859 has an orbital period of 4.3 hr the donor is expected to be a low mass star with $M_2 \sim 0.3$-$0.4\,M_\odot$ e.g., [12] of spectral type between ∼M3.1-M3.3 and with an absolute near-IR J band magnitude $M_J \sim 6.7$ mag [12]. The faintest measured J-band magnitude of XSS J12270-4859 (16.9 mag), when corrected for interstellar absorption, A_J=0.12 mag, obtained using the derived hydrogen column density from X-ray spectra, would imply a distance d $\gtrsim$ 1.1 kpc, if the near-IR emission is totally due to the secondary star. This minimum distance could be consistent with the presence of near-IR ellipsoidal variations. Also, the source is located at $\sim 13^o$ in galactic latitude and, if it is in the galactic disc, its distance should not be exceedingly large. The X-ray bolometric luminosity is then $L_X \gtrsim 6 \times 10^{33}\,\mathrm{erg\,s^{-1}}$ suggesting a LMXB accreting at a low rate.

The present analysis therefore favours XSS J12270-4859 as a peculiar, low-luminosity LMXB. Its flaring characteristics, consisting of flare-dip pairs are reminiscent of the type II bursts observed in the bursting pulsar GRO J1744-28 [16] or in the Rapid Burster [13]. However in these sources the energetics and timescales are much different as well as the spectral dependence of their associated dips. GRO J1744-28 could be more similar to XSS J12270-4859 , as the bursts (giant and small) do not show significant changes in spectral shape and show a good correlation between burst fluence and flux deficiency in the associated dips [16]. However during the post-flare dips, GRO J1744-28 shows no spectral changes and the burst fluence is related to the time when the source is in the persistent quiescent state. This is not the case of XSS J12270-4859 . The Rapid Burster, instead shows different spectral behaviour during the post-flare dips as well as the pre-flare ones [13]. Hence, XSS J12270-4859 could share common properties with type II bursts of the above sources, but with some differences.
Type II bursts are believed to be due to instabilities in the accretion disc that produce a rapid accretion onto the compact object depleting a reservoir in the inner disc regions. This is replenished immediately after the burst, thus producing a flux depression that does not affect the X-ray spectrum. However, type II bursts have not always the same morphology. For instance SMC X-1, a high mass X-ray binary, does not show post-flare dips e.g., [15]. Given the few sources known so far we cannot exclude that XSS J12270-4859 is a type II low-level bursting source. Its UV activity starts before that in the X-rays. Also, the timescale of UV and X-ray flares is longer than that observed in the type II bursters and of the order of the free fall time $t_{ff} \gtrsim 603\,(M_1/M_\odot)^{-1/2}$ s from the Roche-lobe radius of the compact object ($R_{L,1} \gtrsim 0.66\,R_\odot$ for $q = M_2/M_1 \leq 0.8$, for a P_{orb}=4.32 hr and $M_2 \gtrsim 0.3 - 0.4 M\odot$). The further presence of a partial (almost total) covering absorber during the post-flare dips could be the result of the replenishing of a larger portion of the accretion disc. This could be corroborated by the relatively long (∼300–600 s) post-flare dips.
While dips during quiescence are observed in many LMXBs such as EXO 0748-676 [4] or 4U 1916-05 [6], these occur at specific orbital phases and are accompained by a hardening of the source due to absorption of matter from the outer rim of the disc. XSS J12270-4859 is hence different from the LMXB dippers.
Type II bursters and LMXB dippers are known to harbour a neutron star being either pulsars (SMC X-1 and GRO J1744) or also showing type I bursts, as the Rapid Burster, that are a signature of thermonuclear flashes on a neutron star. With the present data it is not possible to establish whether the compact object in XSS J12270-4859 is a pulsar.

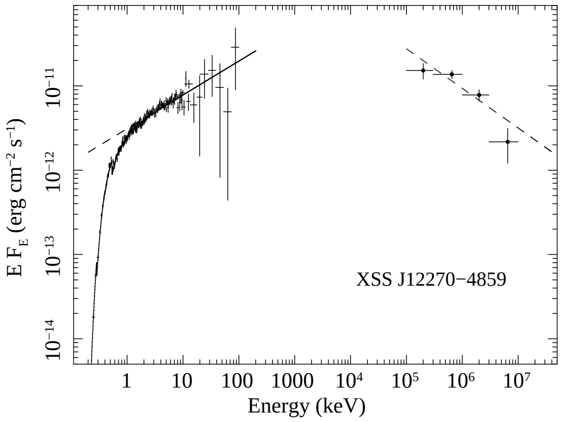

Figure 2: The broad band X-ray to high energy gamma ray spectrum combining the *XMM-Newton* EPIC-pn, the *RXTE* PCA and *INTEGRAL* ISGRI rebinned data and the *Fermi* LAT data together with their respective best fit power law models. Solid line and dashed lines represent the absorbed and unabsorbed best fit spectral models.

The *Fermi* detection in the GeV range of the source 1FGL J1227.9-4852, consistent with the XSS J12270-4859 position, may further strengthen the interpretation of a LMXB. See Fig. 2 for the broad band X-ray to high energy gamma ray spectrum. Worth noticing is that only a few X-ray binaries are detected so far with *Fermi*. In the first release of the *Fermi* source catalogue, only three are classified as High Mass X-ray Binaries (HMXB) and five as LMXBs, but among them three are associated with globular clusters, the other two are identified with the Galactic centre and the supernova remnant G332.4-00.4. The sources unambiguously identified by their periodicities are the HMXBs, 1FGL J0240.5+6116 (LS I+61^{o}303; [1]), 1FGL J1826.2-1450 (LS 5039; [2]) and 1FGL J2032.4+4057 (Cyg X-3; [3]). LS I+61^{o}303 (P_{orb}=26.5 d) and LS 5039 (P_{orb}=3.9 d) are long period systems for which the high energy gamma ray emission dominates with rather similar (0.1–100 GeV)/(0.2–100 keV) luminosity ratio of $\sim$6.8 and $\sim$6.2, respectively; while for the shorter period system Cyg X-3 ((P_{orb}=0.2 d) this ratio is at much lower value of $\sim$ 0.01-0.03 see in [9] for more details. With a value of $\sim$0.8, XSS J12270-4859 could therefore be an intermediate system between these two regimes.

It is also possible that 1FGL J1227.9-4852 is a separate confusing source, like a Geminga-like pulsar. This possibility should not be discarded until a detailed temporal analysis of the GeV emission is performed. This will allow to infer whether a flaring-type activity on similar timescale as that observed in the X-rays and/or a periodic variability, either at the putative orbital period or neutron star spin, can be detected.

We also searched for a radio counterpart in the RADIO (Master Radio) catalogue available at HEASARC archive see [9]. The only radio source within the 6' *Fermi* LAT error radius is catalogued in the Sydney University Molonglo Sky Survey, SUMSS J122820-485537 with a 843 MHz flux of 82.2$\pm$2.7 mJy. This source, also shown in Fig. 1 in [9], is found at 5.22' from 1FGL J1227.9-4852 and at 4.12' from the XSS J12270-4859 optical position. The radio positional accuracy is quite high with an ellipse uncertainty semi-major axis of 4.3" and semi-minor axis of 4.0". Hence, although within the *Fermi* LAT 95% confidence region, the association to XSS J12270-4859 is quite unsecure.

The data presented here have therefore shown that XSS J12270-4859 is a rather atypical LMXB, that might reveal a new class of low-luminosity X-ray binaries or a peculiar accretion regime. The possible association with the GeV *Fermi* LAT source 1FGL J1227.9-4852 further suggests such peculiarity. To shed light into its intriguing nature a timing analysis of the high energy emission is essential for a secure identification with XSS J12270-4859 . Also, a long-term X-ray monitoring to constrain the flaring and dipping behaviour and to infer whether this source undergoes higher states or bursts is needed as well as time–resolved spectroscopy of the optical counterpart to confirm whether the photometric period is the binary orbital period.

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