Discovery of 47-s pulsations in the X-ray source 1RXS J225352.8+624354

P. Esposito,1⋆ G. L. Israel,2 L. Sidoli,1 E. Mason,3 G. A. Rodríguez Castillo,2,4 J. P. Halpern,5 A. Moretti6 and D. Götz7
1Istituto di Astrofisica Spaziale e Fisica Cosmica - Milano, INAF, via E. Bassini 15, I-20133 Milano, Italy
2Osservatorio Astronomico di Roma, INAF, via Francisci 33, I-00040 Monteporzio Catone, Italy
3Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
4Dipartimento di Fisica, Università di Roma “La Sapienza”, p.le A. Moro 2, I-00185 Roma, Italy
5Astronomy Department, Columbia University, 550 West 120th Street, New York, NY 10027-6601, USA
6Osservatorio Astronomico di Brera, INAF, via Brera 28, I-20121 Milano, Italy
7AIM CEA/Irfu/Service d’Astrophysique, Orme des Merisiers, F-91191 Gif-sur-Yvette, France

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ABSTRACT
We report on the discovery of pulsations at a period of $\sim$47 s in the persistent X-ray source 1RXS J225352.8+624354 (1RXS J2253) using five Chandra observations performed in 2009. The signal was also detected in Swift and ROSAT data, allowing us to infer over a 16-yr baseline an average, long-term period increasing rate of $\approx$17 ms yr$^{-1}$ and therefore to confirm the signal as the spin period of an accreting, spinning-down neutron star. The pulse profile of 1RXS J2253 ($\sim$50–60% pulsed fraction) is complex and energy independent (within the statistical uncertainties). The 1–10 keV Chandra spectra are well fit by an absorbed power-law model with $\Gamma \sim 1.4$ and observed flux of $(2-5) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. The source was also detected by INTEGRAL in the 17–60 keV band at a persistent flux of $\sim 6 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, implying a spectral cut off around 15 keV. We also carried out optical spectroscopic follow-up observations of the 2MASS counterpart at the Nordic Optical Telescope. This made it possible to first classify the companion of 1RXS J2253 as a B0-III-Ve (most likely a B1Ve) star at a distance of about 4–5 kpc (favouring an association with the Perseus arm of the Galaxy). The latter finding implies an X-ray luminosity of $\sim 3 \times 10^{34}$ erg s$^{-1}$, suggesting that 1RXS J2253 is a new member of the sub-class of low-luminosity long-orbital-period persistent Be/X-ray pulsars in a wide and circular orbit (such as X Persei).

Key words: stars: emission-line, Be – stars: individual: 2MASS J22535512+6243368 – X-rays: binaries – X-rays: individual: 1RXS J225352.8+624354 (CXOU J225355.1+624336, 1WGA J2253.9+6243, IGR J22534+6243)

1 INTRODUCTION

Every time a new X-ray mission is launched, many serendipitous X-ray sources of unknown nature are usually discovered. Among them, some may suddenly become objects of interest because they display outbursts/flare or are recognised to be the X-ray counterpart of sources discovered at other wavelengths, but most of them, especially the faintest ones, can remain unidentified for years. Sometimes they are ‘re-discovered’ by the next X-ray missions or by systematic archival searches for specific signatures (such as flux variability, multiwavelength associations or pulsations).

The identification of detected sources with still unknown nature is a fundamental step towards the study of the different populations of Galactic and extragalactic X-ray sources, and can lead to surprising results. Examples are the discovery of RX J0806.3+1527, the double-degenerate ultracompact binary with the shortest known orbital period (5.4 minutes; Israel et al. 1999, Ramsay, Hakala & Cropper 2002), or the realisation of the existence of a potentially large population of ‘dormant’ magnetars (e.g. Rea & Esposito 2011 and references therein). This was also the case of the supergiant fast X-ray transients (SFXTs), a class of hard X-ray transients discovered by the INTEGRAL satellite (Seuera et al. 2005); in several cases in fact, SFXTs were found to be associated with objects listed in catalogues of faint soft-X-ray sources from past missions (mostly ASCA and BeppoSAX).

The discovery of coherent X-ray pulsations, in particular, is a key element to understand the nature of a source. The Chandra ACIS Timing Survey at Brera And Rome astronomical observatories (CATS@BAR) is a project aimed at the exploitation of Advanced CCD Imaging Spectrometer (ACIS; Garmire et al. 2003) data, allowing us to infer over a 16-yr baseline an average, long-term period increasing rate of $\approx$17 ms yr$^{-1}$ and therefore to confirm the signal as the spin period of an accreting, spinning-down neutron star. The pulse profile of 1RXS J2253 ($\sim$50–60% pulsed fraction) is complex and energy independent (within the statistical uncertainties). The 1–10 keV Chandra spectra are well fit by an absorbed power-law model with $\Gamma \sim 1.4$ and observed flux of $(2-5) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. The source was also detected by INTEGRAL in the 17–60 keV band at a persistent flux of $\sim 6 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, implying a spectral cut off around 15 keV. We also carried out optical spectroscopic follow-up observations of the 2MASS counterpart at the Nordic Optical Telescope. This made it possible to first classify the companion of 1RXS J2253 as a B0-III-Ve (most likely a B1Ve) star at a distance of about 4–5 kpc (favouring an association with the Perseus arm of the Galaxy). The latter finding implies an X-ray luminosity of $\sim 3 \times 10^{34}$ erg s$^{-1}$, suggesting that 1RXS J2253 is a new member of the sub-class of low-luminosity long-orbital-period persistent Be/X-ray pulsars in a wide and circular orbit (such as X Persei).
2 OBSERVATIONS AND DATA REDUCTION

2.1 Chandra

Chandra imaged the position of 1RXS J2253 five times in 2009 (see Table 1) in a campaign devoted to a portion of the Cepheus OB3 molecular cloud (see Allen et al. 2012). The data were acquired with the ACIS instrument in Very Faint imaging (Timed Exposure) mode (time resolution: ~3.2 s).

The data were reprocessed with the Chandra Interactive Analysis of Observations software (CIAO, version 4.4) using the calibration files available in the Chandra CALDB 4.4.8 database. The scientific products were extracted following standard procedures, adopting extraction regions of ~6–25 arcsec radii (depending on the off-axis angle, around 15 arcmin in most pointings) for the source counts. In particular the spectra, the spectral redistribution matrices and the ancillary response files were created using SPECEXTRACT. For the timing analysis, we applied the Solar system barycentre correction to the photon arrival times with Axbary.

2.2 Swift

Swift serendipitously observed 1RXS J2253 in two contiguous observing periods to follow the afterglow of the gamma-ray burst GRB 060421 (Goad et al. 2006). The net exposure of the X-ray Telescope (XRT; Burrows et al. 2005) data was 73.0 ks in photon counting (PC; full imaging, time resolution: ~2.5 s) mode and 1.8 ks in windowed timing (WT; one-dimensional strip readout, time resolution: ~1.8 ms) mode; since the observation was pointed at GRB 060421, only the PC data can be used to study 1RXS J2253 (see Table 1). The Ultraviolet/Optical Telescope (UVOT; Roming et al. 2005) observed the field simultaneously with its optical and ultraviolet (UV) filters (see Table 5).

The Swift data were processed and screened with standard procedures and quality cuts using ftools in the HEASOFT (version 6.12) software package and the calibration files in the 2012-04-02 CALDB release. The XRT photon arrival times were corrected to the Solar system barycenter with BARCORR. The XRT source counts were extracted within a 20-pixel radius (one XRT pixel corresponds to 2.36 arcsec). For the X-ray spectral fitting, the ancillary response files were generated with XRTMKARF accounting for different extraction regions, vignetting, point-spread function corrections, and dead, hot or warm pixels (Moretti et al. 2005). The UVOT photometry was performed with the UVOTSOURCE task, which calculates the magnitudes through aperture photometry.

2.3 ROSAT

The position of 1RXS J2253 occurred within the ROSAT Position Sensitive Proportional Counter (PSPC; Pfeffermann et al. 1987) field of view in four pointings carried out between July 1992 and June 1993. However, owing to large off-axis angles and/or short duration, in three out of the four observations the exposures provide too few photons for meaningful analyses. The only observation useful for timing and spectral analysis was carried out in June 1993 (obs. ID RPS500321N00, see Table 1) for an effective exposure time of ~18 ks.

The event lists and spectra for 1RXS J2253 and the background were extracted from circles of ~1 arcmin radius. The solar system barycentre correction to the photon arrival times was applied with the ftools tasks BCT and ABC. For the spectroscopy, we used the spectral redistribution matrix PSPCBBR256.RMF, while the ancillary response file was generated with PCARF.

2.4 Nordic Optical Telescope

1RXS J2253 was observed at the 2.5-m Nordic Optical Telescope (NOT) equipped with the Andalucia Faint Object Spectrograph and Camera (ALFOSC) on 2012 December 26 and 30. We used the grism N.7 and slit of 0.5 arcsec, covering the wavelength range ~3800–6800 Å at a resolution of 4.4 Å or ~237 km s$^{-1}$ . We obtained four spectra per night, each of 900 s exposure time. The observations had attached arc-lamp exposure and flat field.

The data were reduced using IRAF (Tody 1993) packages and

1 See [http://www.mporzio.astro.it/gianluca/resultss.html] for the analogous Swift project, Swift Automatic Timing Analysis of Serendipitous Sources at Brera And Roma astronomical observatories (SATANASS@BAR).

2 See Poole et al. (2008) for an overview of the UVOT photometric system and Best et al. (2011) for the most updated zero-points and count rate to flux conversion factors.

3 As measured on the sky emission lines.
3 TIMING ANALYSIS AND RESULTS

The inspection of the X-ray light curves showed evidence of moderate variability on a time-scale of a few ks. The root-mean-square (rms) fractional variation (defined as the rms variation normalised by the average count rate) was 52 ± 5% in observation Swift7000, and 47 ± 6% in Swift7001 (measured in 1–10 keV light curves, bin size of 500 s). In the Chandra observations (1–10 keV, 500 s bin size) it was, in chronological order, 22 ± 4% (obs. 9920), 34 ± 4% (10811), 29 ± 4% (10812), 33 ± 4% (10810), and 23 ± 4% (9919). For the ROSAT observation 500321 we could only place an upper limit of ~40% (3σ c.l.) for bin sizes from 0.5 to 5 ks (1–2.4 keV).

As anticipated, ~46.7-s coherent pulsations from 1RXS J2253 were found within the CATS@BAR project using the whole Chandra dataset. Fig. 1 shows the discovery periodogram where two peaks, corresponding to the fundamental (ν1 = 1/P ≈ 0.0214 Hz) and the second (ν2 = 1/(2P)) harmonics, stand well above the significance threshold. For the analysis of the coherent period that follows, the photon arrival times were transformed to Barycentric Dynamical Time (TDB) using the 2MASS coordinates of the optical/infrared counterpart listed in Table 1.

The signal is easily detectable also in the 2006 Swift dataset (since the two observations were contiguous, we treated them as a single one), where we measured by the Z2 test (e.g. Buccheri et al. [1983]), which optimises the pulsation power, a period of 46.6145(5) s. The pulsed fraction (defined as (M − m)/(M + m), where M and m are the observed background-subtracted count rates at the peak and at the minimum, respectively) of the folded profile (Fig 1) is 45 ± 5 percent in the 1–10 keV range.

In the case of the ROSAT/PSPC data, considering the ~13 years elapsed between ROSAT and Swift observations, we carried out a period search in an interval set by a period derivative ± ˙P, assuming a maximum spin-up/down intensity | ˙P | = 5 × 10−8 s−1. A significant peak (6.4σ c.l. in about 103 trial periods) was found in a Z2 periodogram at a best period of 46.406(5) s (see the folded profile in Fig 1). The corresponding pulsed fraction is 65 ± 11 percent (0.1–2.4 keV).

For each ACIS observation listed in Table 1 we extracted source photons in the 1–10 keV band using an aperture of radius 10′′ or 20′′ as appropriate. We used the Z2 test to measure the pe-
The minimum phase coincides with that of the normalised pulse profiles of 1RXS J2253. Both profiles have been aligned so that the minimum phase coincides with that of the Chandra minimum in Fig. 2.

Table 3. Chandra ephemeris of 1RXS J2253.

| Parameter                              | Value                                |
|----------------------------------------|--------------------------------------|
| R.A. (J2000.0)°                       | 22°53'55.12'                        |
| Decl. (J2000.0)°                       | +62°43'36.8'                        |
| Epoch of ephemeris (MJD TDB)           | 54954.00050                         |
| Valid range of dates (MJD)             | 54937–54959                         |
| Frequency, \( f \) (Hz)               | 0.02142536(2)                       |
| Frequency derivative, \( f \) (Hz s\(^{-1}\)) | -6.1(4) \times 10^{-13}          |
| Period, \( P \) (s)                   | 46.673666(4)                        |
| Period derivative, \( \dot{P} \) (s s\(^{-1}\)) | 1.33(9) \times 10^{-9}            |

The TDB epoch of pulse minimum (phase 0.5) is MJD 54954.00050.

The fit period derivative, \( \dot{P} = 1.3 \times 10^{-9} \) s s\(^{-1}\), may have contributions from both secular spin-down and orbital acceleration, as we show here. The long-term spin-down rate is \( \approx 5.3 \times 10^{-10} \) s s\(^{-1}\) (Fig. 3). This is only \( \approx 40\% \) of the \( \dot{P} \) required to fit the series of Chandra observations, which means that orbital acceleration contributes to the Chandra timing over 22 days. The kinematic effect may be estimated assuming \( M_c = 1.4 M_\odot \) for the neutron star in a circular orbit around a Be star companion (see Sect. 5.1) of mass \( M_c = 20 M_\odot \). The contribution of acceleration to \( \dot{P} \) is

\[
\dot{P}_k = 1.4 \times 10^{-8} \left( \frac{P_{\text{orb}}}{100 \text{ d}} \right)^{-4/3} \left( \frac{M_c}{20 M_\odot} \right)^{1/3} \left( \frac{P}{46.7 \text{ s}} \right) (1 + q)^{-2/3} \sin i \sin \phi, \tag{1}
\]

where \( q = M_c/M_\star \) is the mass ratio, \( i \) is the inclination of the binary, and \( \phi \) is the orbital phase of the companion. Evidently, the orbital period \( P_{\text{orb}} \) is significantly longer than the 22 day span of the Chandra observations because the observed \( \dot{P} = 1.3 \times 10^{-9} \) s s\(^{-1}\) is small and constant to within \( \approx 10\% \) over this interval. Eq. 1 also implies that \( P_{\text{orb}} < 800 \) days in order to provide the required acceleration. While orbital acceleration may account for the Chandra measured \( \dot{P} \), the monotonic increase in spin period between ROSAT, Swift, and Chandra timings over 16 years cannot be due to orbital motion, since the total observed range in period is \( \Delta P \approx 0.27 \) s, while the kinematic effect provides only

\[
\Delta P_k = -0.019 \left( \frac{P_{\text{orb}}}{100 \text{ d}} \right)^{-1/3} \left( \frac{M_c}{20 M_\odot} \right)^{1/3} \left( \frac{P}{46.7 \text{ s}} \right) (1 + q)^{-2/3} \sin i \cos \phi \text{ s}. \tag{2}
\]

The ROSAT pulse shape, which is shown in Fig. 2, is dominated by two asymmetric peaks which are energy independent within the PSPC energy range (0.1–2.4 keV). In Fig. 3 we show the epoch-folded Chandra pulse profiles obtained using the ephemeris of Table 3. To assess the significance of the pulse shape variations through the high-count-statistics five Chandra data sets (Fig. 3).
we compared each of the folded light curves with all the others by using a bidimensional Kolmogorov-Smirnov test (e.g. Press et al. 1992). The results show that all profiles are consistent with coming from the same distribution; the most significantly different pair of profiles are those of observations 10811 and 10810, which differs at a $\sim 1.5 \sigma$ confidence level. We compared in the same way the total Chandra and Swift (Fig. 2) profiles. Taking into account the unknown relative phase alignment, the probability that they come from the same underlying distribution is about 6.1 per cent. The pulse profiles do not show dramatic shape variations with energy, but a hardness-ratio analysis suggests some spectral variability along the spin phase (see Fig. 5). In fact the emission appears to be slightly harder during the minimum-rise part of the profile than at the decline phases.

4 X-RAY SPECTRAL ANALYSIS AND RESULTS

Spectral fitting was carried out with XSPEC v.12.7 (Arnaud 1996). For each observation we extracted an average spectrum. A simple power-law model (modified for the interstellar absorption) provides an acceptable fit for all the data sets (see Table 2 for a summary of the spectral analysis). The average measured absorbing column corresponds to $\sim 1.9 \times 10^{22}$ cm$^{-2}$ and the power law is rather hard, with an average photon index $\Gamma \sim 1.4$: in the Swift and Chandra observations, the observed flux varies from $\sim 2.4 \times 10^{-12}$ to $\sim 4.5 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$.

Inspection of the energy-resolved light curves did not reveal neat spectral variations correlated with the source intensity. On the other hand, the hardness ratio analysis presented in Sect. 3 suggests some spectral variations with the spin phase. For each Chandra observation we extracted ‘soft’ and ‘hard’ spectra in two intervals chosen following the hardness ratio variations (see Fig. 5). A simultaneous fit of the spectra with an absorbed power-law model ($\chi^2 = 1.04$ for 327 dof) confirms a moderate hardening in the minimum-rise part of the profile, with an average power-law photon index $\Gamma_H = 1.26 \pm 0.06$ to be compared with $\Gamma_S = 1.4 \pm 0.1$ during the decline phases. We also produced a bidimensional histogram of the distribution of counts versus energy and phase to look for spectral features in the X-ray emission of 1RXS J2253, but none was found.

The hard-X-ray counterpart to 1RXS J2253 has been identified with INTEGRAL (IGR J22534+6243. Krivonos et al. 2013).

5 OPTICAL AND ULTRAVIOLET ANALYSIS AND RESULTS

As observed by Landi et al. (2012) and Halpern (2012), the X-ray position of 1RXS J2253 is consistent with that of the Two-Micron All-Sky Survey (2MASS, Skrutskie et al. 2006) source 2MASS 22535512+6243368 (see Table 2 for its magnitudes). The next closest source to 1RXS J2253, 2MASS 22535500+6243412, lies $\sim 4.4$ arcsec away.

Since the 2MASS sources are slightly blended in the UVOT images (see Fig. 2), we used for the photometry a small aperture radius of 2 arcsec (no attempt was made to correct for possible residual contamination from 2MASS 22535500+6243412). The source is detected with high confidence in all the UVOT filters but the $uvw2$, in which the statistical significance of the source is only at a $3.2\sigma$ confidence level. The average Vega UVOT magnitudes, calculated from the stacked images using the UVOTSOURCE tool, are reported in Table 2.

5.1 Spectral type of the stellar companion

The optical spectrum shows the presence of H$\alpha$ (equivalent width, $EW \sim -38$ Å), H$\beta$ ($EW \sim -5$ Å) and H$\gamma$ ($EW \sim -1$ Å) in the IBIS 9-year Galactic Hard-X-Ray Survey (Perseus Arm). The reported source flux in the 17–60 keV energy band is $(6 \pm 1) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. The extrapolation in this hard-X-ray band of the power-law spectrum that describes the 1–10 keV data overestimates the INTEGRAL flux by a factor $\sim 2$.

We built an IBIS/ISGRI (Ubertini et al. 2003; Lebrun et al. 2003) spectrum starting from the count rates in the 17–80 keV energy bands published by Krivonos et al. (2012) and rebinned the ISGRI response matrix in order to cope with the energy bands. A good simultaneous fit of the average 1–10 keV and INTEGRAL data ($\chi^2 = 0.95$ for 385 dof) can be obtained by using an absorbed cut-off power law (see Fig. 5). The resulting spectral parameters are absorption $N_H = (1.6 \pm 0.1) \times 10^{22}$ cm$^{-2}$, photon index $\Gamma = 1.0 \pm 0.1$, cut-off energy $E_C = 15 \pm 4$ keV, and 1–60 keV unabsorbed flux of $\approx 1.2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (the 17–60 keV flux is $\approx 5 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$). This spectrum (slope and high energy cut-off) is typical of X-ray accreting pulsars (e.g. White et al. 1983).

Figure 5. Chandra hardness ratio as function of the phase. The ratio was computed selecting soft photons in the 1–4.5 keV and hard photons in the 4.5–10 keV range. Phases are aligned with those of Fig. 2. The vertical lines and the labels indicate the phase intervals used for the phase-resolved spectroscopy (see text).

Figure 6. Broad-band soft and hard X unfolded model and (absorbed cut-off power law) spectrum ($EF(E)$) of 1RXS J2253. For clarity, we show only the Swift (black dots) and INTEGRAL (blue squares) data.
in emission (Hδ seems to be filled in while He in absorption) together with He emission lines at 6678 Å, 5875 Å and 5016 Å (the He at 4713 Å is likely filled in while He at 4471 Å is in absorption) and a number of metallic lines typical of an early B-type star of low luminosity (Fig. 8). More precisely, the absence of (or very weak) Heıı lines indicates an spectral type later than B1. Hıı lines dominate the spectrum (together with the hydrogen lines), indicating a B0 to B2 star. However, the presence of some amount of SiIıı 4552–68 Å (the identification of this lines is unclear since we see only one of the triplet transition) and the carbon blends (Cııı 4650 Å) favours the B0–Bıı spectral type. On the other hand, the weakness/absence of the oxygen and silicon lines points toward a main-sequence star, although the strength of Cııı 4650 Å might be a signature of a giant companion. We tentatively conclude that the optical counterpart to 1RXS J2253 is likely a B0V–B1V star (more likely a B1V), although a more luminous companion cannot be ruled out by present data.

Assuming typical colours of a B1V star, (B − V)0 = −0.23 (Weinert 1994), and comparing with the observed colour (B − V)obs = 1.49−1.7 (Table 5), we derived an excess colour of E(B − V) = 1.72−1.93. Assuming an absolute magnitude of Mv = −3.2 (Gray & Corbally 2009), we estimate the distance to be ∼4.5 kpc (which is consistent with the Perseus arm; e.g. Russell 2003). Similar reasoning applies for a B1ıı and a B1ııı spectral class and imply distances in the ∼14–19 kpc and ∼9–12 kpc ranges, respectively. The Galaxy edge of about 10 kpc in the direction of 1RXS J2253 rules out the possibility that the companion star is a B1ıı, while is marginally in agreement with a B1ııı spectral type (which, however, seems to be incompatible with the apparent lack of Oııı absorption lines at 4415–17 Å).

### Table 5. UVOT magnitudes, not corrected for the extinction. We also give the catalogued 2MASS infrared magnitudes

| Filter | Magnitude | Exposure (ks) |
|--------|-----------|---------------|
| V      | 15.78 ± 0.09 | 7.5 |
| B      | 17.38 ± 0.11 | 6.4 |
| U      | 17.64 ± 0.12 | 9.5 |
| uuv1   | 19.24 ± 0.13 | 15.1 |
| uuv2   | 22.34 ± 0.38 | 17.2 |
| uuem2  | 20.54 ± 0.16 | 19.2 |
| J      | 11.64 ± 0.02 | – |
| H      | 10.96 ± 0.02 | – |
| K      | 10.46 ± 0.03 | – |

6 DISCUSSION

We reported here on the discovery of 47-s spin pulses in the X-ray emission of 1RXS J2253 and on a multiwavelength and long-term (∼16 years) study of the source which made it possible to put stringent constraints on its nature. The optical spectroscopy indicates a B1-type companion, very likely a main sequence star at a distance of ∼4–5 kpc, implying that 1RXS J2253 can be classified as a massive X-ray binary located in the Perseus arm of our Galaxy. This estimated range for the pulsar distance translates into an X-ray luminosity of (2.3−3.6) × 10^34 erg s⁻¹ assuming an average flux of 1.2 × 10⁻¹¹ erg cm⁻² s⁻¹ (1–60 keV, corrected for the absorption). The X-ray emission at a level of ∼10^34 erg s⁻¹ in observations spaced by several years, strongly suggests that 1RXS J2253 is a member of the sub-class of Be X-ray pulsars where the persistent and low X-ray luminosity is driven by the accretion onto the neutron star of wind material from the massive companion in a wide (orbital period, Porb, longer than ∼30 days) and nearly circular (e < 0.2) orbit. These sources, the prototype and most luminous of which is X Persei (White et al. 1976; Delgado-Martıı et al. 2001).
La Palombara & Mereghetti (2007), were recognised by Pfahl et al. (2002) as a new sub-class of Be/X-ray binaries (XRBs), characterised by a smaller natal kick compared to classical Be/XRBs with more eccentric orbits.

The long-term pulse period changes observed in 1RXS J2253 indicate that in the years 1993–2009 the neutron star slowed down at an average rate of \( \sim 5.3 \times 10^{-10} \) s \(^{-1} \); this estimate is based, however, on determinations of the period in only three epochs and no information is available on the spin behaviour of 1RXS J2253 on shorter time-scales (a few months or less). As discussed in Sect. 2 the timing analysis of 1RXS J2253 also shows that the orbital period of the system has to be longer than \( \sim 20 \) days (and shorter than \( \sim 800 \) days). In Be/XRBs, the pulsar spin period is correlated with the orbital one (Corbet 1986), although with a large observed scatter. If the same holds also for 1RXS J2253, given the 47-s spin period, its orbital period should be around 70–80 days (Corbet 1986).

The long orbital period in 1RXS J2253 can explain the low X-ray luminosity, since it is produced by the accretion from the wind of the main-sequence early-type companion at a large orbital separation. Given that X-ray pulsations are detected in all the reported observations, 1RXS J2253 always undergoes accretion with the material channelled onto the neutron star polar caps, even at these low X-ray luminosities. In the simplest framework for wind-fed binaries, the accretion luminosity scales as \( L_X \propto M_w a^{-2} v_w^{-4} \), where \( M_w \) is the wind mass loss rate, \( a \) is the orbital separation and \( v_w \) is the wind velocity at the neutron star orbit (Davidson & Ostriker 1973). Assuming \( M_w \sim 10^{-7}–10^{-8} M_\odot \) yr \(^{-1} \) for an early-type main sequence star (Kudritzki & Puls 2000), \( v_w \sim 500–1000 \) km \( \) s \(^{-1} \), \( a \sim (5–10) \times 10^{12} \) cm, an X-ray luminosity in the range \( L_X \sim 10^{31}–10^{34} \) erg s \(^{-1} \) can be accounted for. In this scenario, a long-term spin-down behaviour, as seen in 1RXS J2253, can be explained by angular momentum removal from the rotating neutron-star magnetosphere through an extended quasi-static shell formed by the accreting matter (Shakura et al. 2012; see e.g. Davidson & Ostriker 1973; Davies, Fabian & Pringle 1979; Davies & Pringle 1981; Illarionov & Kompaneets 1990; Bisnovatyi-Kogan 1991 for other torque models for wind accretion).

A somewhat different picture can be considered based on the presence of rotationally-dominated, quasi-Keplerian discs around Be stars (e.g. Struyf 1991; Marlborough 1969; Waters et al. 1989; Hanuschik 1996; Hanuschik et al. 1996; Hummel & Hanuschik 1997; Okazaki 1997). Prompted by this, scenarios where the neutron star is capturing the matter from the dense and slow circumstellar disc have been developed to account for the outbursting behaviour of some Be/XRBs (Team, Brown & Fryxell 1988; Waters et al. 1988; Parmar et al. 1989). In particular, Okazaki & Negueruela (2001) showed that the circumstellar matter can reach the neutron star only via the inner Lagrangian point (the position of which is variable along the orbit in elliptical or moderately elliptical systems), and will therefore have a low velocity relative to the neutron star. Since such a flow (which may be said to represent the ‘decretion-disc version’ of Roche-lobe overflow) carries angular momentum, an accretion disc may be temporarily formed around the neutron star. It is therefore possible that 1RXS J2253 is accreting from a similar (but more stable) structure. Depending on the orbital parameters (orbital separation, orbital period and eccentricity) and the neutron star properties (such as magnetic field and magnetic moment axis inclination with respect to the disc), the luminosity level observed in 1RXS J2253 can be accounted for and the pulsar can show both spin-up and spin-down (Ghosh & Lamb 1979ab; Lovelace, Romanova & Bisnovatyi-Kogan 1995; Perna, Bozzo & Stella 2006).

Finally we note that 1RXS J2253 is associated with the hard X-ray source IGR J22534+6243 (Landi et al. 2012), a faint source reported for the first time by Krivonos et al. (2012) in the INTEGRAL/IBIS nine-year Galactic hard X-ray survey catalog, with an average flux of \((6 \pm 1) \times 10^{-12} \) erg cm \(^{-2} \) s \(^{-1} \) in the 17–60 keV energy range. To date (February 2013) the source sky position has

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\[^4\] If 1RXS J2253 is accreting with the same mechanism from a slower and denser wind component of the BV star, for a neutron-star magnetic field \( B \leq 10^{12} \) G and assuming typical parameters of Be decretion discs (Waters et al. 1989), a low luminosity of \( \sim 10^{34} \) erg s \(^{-1} \) can be obtained for very wide circular orbits, with \( P_{\text{orb}} \sim 300 \) days. See Delgado-Martí et al. (2001) and Doroshenko et al. (2012) for a discussion of this scenario for X Persei.

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\[\text{Figure 8. NOT/ALFOSC medium resolution (4.4 Å; 3800–7000 Å) rectified spectrum obtained for the optical counterpart of 1RXS J2253. The main identified lines are marked with solid lines and labelled. Dot-dashed lines mark further lines often used for spectral classification but absent in the spectrum.}\]
been observed by INTEGRAL/IBIS for a net exposure time of 7.5 Ms, and no bright flares nor outbursts have ever been reported, consistently with a faint persistent source. The almost constant (within a factor of ~2) X-ray luminosity (note the large uncertainty in the extrapolation of the ROSAT flux to higher energies) points to a circular, or nearly circular, orbit.

High mass X-ray binaries composed of a neutron star accreting from main-sequence companions are likely to constitute a not negligible fraction of the unidentified Galactic X-ray sources with relatively low luminosities, $L_X \lesssim 10^{35}$ erg s$^{-1}$ (perhaps a few percents but less than 10%; see e.g. [Laycock et al. 2005; Hong 2012]). Our findings suggest that 1RXS J2253 is a new member of an elusive population of persistent low-luminosity Galactic HMXBs accreting from B main-sequence donors. 

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