The puzzling symbiotic X-ray system 4U1700+24

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Symbiotic X-ray binaries (SyXBs) form a tiny subclass of Galactic low-mass X-ray binaries (LMXBs) characterized by a red giant star (generally of spectral type M) which loses matter to a compact object, most likely a neutron star (NS), via stellar wind, or (less frequently, as in the case of GX 1+4) Roche lobe overflow. Only seven confirmed members are currently known, while for other candidates like 1RXS J180431.1-273932, follow-up observations allowed us to exclude the SyXB nature. However, according to stellar population synthesis studies, between 100 and 1000 of these objects are expected to be in the Galaxy (although one should note that about half of the SyXBs were later found to be either spurious objects).

The SyXB subclass started gaining some attention from the scientific community in the last decade only and X-ray studies of these sources are still quite sporadic, with only a handful of objects having been explored in this spectral window. One of these sources is 4U 1700+24. It was discovered as a relatively bright X-ray object, with variability on both long-term timescales (months to years) and short-term timescales (tens to thousands of seconds). This characteristic suggested that the source might be an accreting system. Garcia et al., [1] proposed the bright late-type star V934 Her as the optical counterpart of 4U 1700+24 on the basis of its position and the detection of emission lines in its ultraviolet spectrum. This association was later confirmed by Masetti et al. [2] with a *Chandra* X-ray satellite observation that provided a localization of the source with subarcsecond precision.

X-ray spectroscopy of the source, obtained over the last decades, shows a continuum typical of accreting LMXBs, with a thermal component probably originating on or near the accretor and a Comptonized emission detected up to 100 keV. In particular, Masetti et al. (2002) [3] examined the X-ray spectroscopic properties of the source using data collected with several satellites over 13 years, from 1985 to 1998. After this study, Tiengo et al. (2005) published a paper on the X-ray behaviour of 4U 1700+24: the authors analysed an observation collected with the *XMM*-Newton satellite in 2002 and found an emission feature at ≈ 0.5 keV and an emission line at $\simeq 0.64$ keV which was possibly identified as the red-shifted O VIII Ly-α transition.

No further investigations on the X-ray spectroscopic behaviour of 4U 1700+24 have been performed since then; however, three more *XMM*-Newton pointings performed in 2003 and seven Swift/XRT observations made in 2010 and 2012 are publicly available but still unpublished. We have undertaken an analysis of these data, together with an independent examination of the 2002 observation in order to have a uniform analysis of the whole *XMM*-Newton and Swift/XRT data sets concerning 4U 1700+24. After reducing the *XMM*-Newton and Swift/XRT data with standard methods, we performed a detailed spectral and timing analysis. We found that the feature observed at $\simeq 0.5$ keV is possibly an artifact due primarily to the instrumental oxygen edge, while we confirm the existence of a red-shifted O VIII Ly-α transition in the high-resolution spectra collected via the RGS instruments.

We also searched in the range $5-35$ Å for the most intense lines of He-like ions of oxygen: the transitions between the $n=2$ shell and the $n=1$ ground state shell as the resonance line, $\mathbf{r}:\ 1s^2\ ^1S_0-1s2p\ ^1P_1$, the two inter-combination lines (often blended), $\mathbf{i}:\ 1s^2\ ^1S_0-1s2p\ ^3P_{2,1}$, and the forbidden feature, $\mathbf{f}:\ 1s^2\ ^1S_0-1s2s\ ^3S_1$. However, because of the poor statistics of the RGS data, a blind fit procedure to the RS data around the O VII complex with a model constituted by a power law and three Gaussians (with all the parameters free, except the relative distances among the lines and the continuum power law index) did not converge. Hence, we fixed the centroid energy of the interested lines to that expected by the atomic physics after correcting for the average red-shift previously found. Interestingly, the RGS data show the existence (although with a small signal-to-noise ratio) of emission lines in the positions where the O VII complex lines are expected: this makes us confident that the line identified at $\simeq 0.19$ Å is the O VIII Ly-α transition red-shifted (on average) by $\simeq 0.009$.

We also observed a modulation of the centroid energy of the line on short time scales (a few days) and discuss the observations in the framework of different scenarios. If the modulation is due to the gravitational red-shift of the neutron star, it might arise from a sudden re-organization of the emitting X-ray matter on the scale of a few hundreds of km. Alternatively, we are witnessing a uni-polar jet of matter (with typical velocity of $1000-4000$ km s^{-1}) possibly emitted by the neutron star in an almost face-on system. The second possibility seems to be required by the apparent lack of any modulation in the observed X-ray light curve. We also note also that the low-resolution spectra (both *XMM*-Newton and Swift/XRT in the $0.3-10$ keV band) show the existence of a black body radiation emitted by a region (possibly associated with the neutron star polar cap) with typical size from a few tens to hundreds of meters. The size of this spot-like region reduces as the overall luminosity of 4U 1700+24 decreases.

A red-shift of the O VIII Ly-α line in the range $0.002-0.013$ (see the estimated values given in Table 3 in Nucita et al. [4]) can be explained as due to the gravitational red-shifted photons emitted by a plasma blob at distance R from an object with mass M, i.e. $\Delta\lambda/\lambda = 1/(g_{00})^{0.5}-1$ with $g_{00} = 1-2GM/Rc^2$. As can be seen, the possibility that 4U 1700+24 hosts a white dwarf can easily be ruled out because, for the typical values of white dwarf mass and radius ($M \simeq 1$ $M_\odot$ and $R \simeq 2\times10^4$ km), the expected gravitational red-shift is a factor of 10 (or more) lower than the observed value. This supports the idea that 4U 1700+24 is a neutron star that accretes matter from a red giant star. Assuming a neutron star mass of $\simeq 1.4$ $M_\odot$ in the 4U 1700+24 binary system, the detected red-shift range corresponds to the gravitational red-shift of a photon emitted at a distance of $160-1000$ km from the central object, i.e. consistent with the value previously found when analyzing the 2002 *XMM*-Newton observation. Furthermore, a close inspection of Fig. 2 in Nucita et al. (2013) allows to conclude that the red-shift of the O VII Ly-α line is variable on a time scale of a few days. In particular, the red-shifts estimated for the central observations 0151240301 and 0151240201 are $\simeq 0.004$ and $\simeq 0.012$, respectively. Since these estimates differ from the average red-shift value by more than $3-5\sigma$, we are confident that the effect is real. Excluding Doppler contributions due to the orbital motion of any blob of plasma around the neutron star (as the associated signatures would be different to the observations presented here), we conclude that we are witnessing the re-organization of matter at a distance of a few hundred kms around the accreting object. An alternative picture would be a jet of matter (with typical velocity of $1000-4000$ km s^{-1}) possibly emitted away by the neutron star in an almost face-on system. The alternative condition seems to be required by the apparent lack of any periodicity and/or modulation (as we have verified via a Lomb-Scargle analysis) in the observed X-ray light curve. However, the puzzling lack of any blue-shifted component implies the necessity of an ad-hoc geometry to explain the observations or one could invoke a uni-polar jet emitted by the neutron star.

Based on these facts, we prefer a scenario in which the mass coming from the M-type companion stellar wind is captured directly onto a small zone of the NS surface. The X-ray photons emitted are reprocessed by a blob of matter at a few hundreds kms far from the NS surface so that the output emission features are gravitationally red-shifted.

REFERENCES

1. M.R. Garcia, M.R., et al., ApJ, 267 (1983) 291.
2. N. Masetti, et al., 2006, A&A, 453 (2006) 295.
3. N. Masetti, et al., 2002, A&A, 382 (2002) 104.
4. A.A. Nucita, et al., 2014, in press on A&A (2014).