X-Rays from V723 Mon are due to Optical Loading in Swift XRT

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Abstract

V723 Mon was recently reported to be hosting the nearest (d = 460 pc) candidate black hole by Jayasinghe et al. An X-ray detection was claimed based on deep Swift XRT observations with a luminosity of $L_X \approx 8 \times 10^{29}$ erg s^{-1} or $L_X/L_{Edd} \approx 10^{-9}$. Here we show that the X-ray photons detected by Swift XRT are due to optical loading from the bright (V = 8.3 mag) star. Using events in the 2–10 keV energy band, where optical loading does not strongly contribute, we find a 3σ upper-limit on the unabsorbed 2–10 keV X-ray flux of $F_X < 2.8 \times 10^{-14}$ erg cm^{-2} s^{-1}, corresponding to a luminosity $L_X < 7.2 \times 10^{29}$ erg s^{-1} at a distance of 460 pc or $L_X/L_{Edd} \lesssim 2 \times 10^{-9}$ for a $M \approx 3M_\odot$ black hole.
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1. Introduction

V723 Mon is a variable red giant star that was found to be in an almost circular binary orbit with a "dark" companion having a period of 59.9 days (Jayasinghe et al. 2021; J+21, hereafter). The star has a mass of $M \approx 1M_\odot$ and is of K0/K1 III spectral type, although previously a spectral type of G0 II was suggested (Houk & Swift 2000; J+21). V723 Mon lies at a Gaia EDR3 distance of 460 ± 7 pc with a luminosity of $L \approx 165L_\odot$ and a reddening, $E(B-V) \approx 0.1$ (Gaia Collaboration et al. 2021; J+21). Using high-resolution optical spectra, radial velocity curves, and optical lightcurves, J+21 have concluded that the system is close to edge-on (i = 87°) but shows no eclipses. The mass function, in combination with the orbital inclination, places a lower-limit on the mass of the companion of M > 3.04 ± 0.06 $M_\odot$. Furthermore, J+21 found no evidence for a luminous stellar companion and ruled out both single and binary main sequence companions based on the measured spectral energy distribution and the limits on the eclipses, leading them to suggest that the companion may be a black hole in the mass gap.

In an independent analysis taking into account tidal deformations and tidal locking Masuda & Hirano (2021) largely agreed with the conclusions of J+21, but reported a slightly lower mass of the compact object $M_{\rm CO}$ = 2.95 ± 0.17 $M_\odot$. Masuda & Hirano (2021) also noted that periodic (with $P/P_{\rm bin}$ = 3) radial velocity residuals remain after accounting for the binary motion and attribute them to the tidal deformation of the red giant whose rotation is synchronized with the binary orbit.

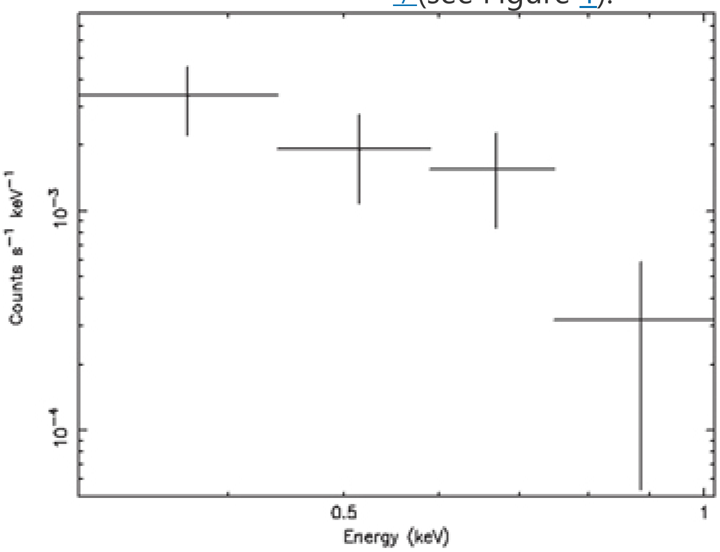
The source was observed for about 19.6 ks with the Neil Gehrels Swift Observatory (Gehrels et al. 2004) and an X-ray detection was claimed, having a position consistent with that of V723 Mon. The source was claimed to be detected with 18.5 ± 4.9 net counts in the 0.3–2.0 keV energy range, suggesting a soft spectrum (J+21). To explain the X-ray counterpart J+21 considered the possibility of accretion onto the BH or chromospheric activity of the rapidly rotating red giant. Here we show that this X-ray emission is actually due to optical loading caused by the optically bright (V = 8.3) stellar companion in the system. We then derive upper limits on the source's X-ray flux in the 2–10 keV energy band, where optical loading has little to no effect.

2. Optical Loading in Swift XRT Data

X-ray detectors using CCDs are prone to charge build-up due to optical photons from bright sources. If an optical source is sufficiently bright and the CCD readout times are sufficiently long, enough photons can pass through the optical blocking filters to produce enough charge in the CCD pixels that the charge is similar to that produced by X-ray photons. When this occurs, X-ray detectors may spuriously record the charge due to "piled up" optical photons as an X-ray photon. This is referred to as optical loading.[4] The UK Swift Science Center[5] provides an optical loading calculator for Swift XRT (Burrows et al. 2005) photon counting (PC) mode observations. We use this tool in combination with the spectral class, type, and $T_{\rm eff}$ = 4400 K derived from J+21, to estimate the anticipated X-ray count rate due to optical loading. We use a bolometric correction factor of −0.30 or −0.36 for spectral types K0 and K1 giants, respectively (Zombeck 2006). However, we find that the estimated count rates are not strongly dependent on this factor. The estimated count rate due to optical loading is 1 count ks^{-1}, which in the 19.6 ks Swift XRT observation, corresponds to about 20 counts, which is consistent with the 18.5 ± 4.9 X-ray counts reported by J+21.

In addition to the estimate from the optical loading calculator, we also used the Build XRT Products script [6] to merge all Swift XRT observations of the source and to extract a spectrum (Evans et al. 2009

[7] (see Figure 1).



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3. New Swift XRT Data Upper-limit

The Swift XRT optical loading calculator provides only a rough estimate on the count rate due to optical loading. Therefore, to calculate the 3σ upper-limit on the X-ray flux of V723 Mon, we only use events with energies in the 2–10 keV range, as the effects of optical loading are dramatically reduced above 2 keV (see Figure 1). For simplicity we use the same source and background regions as J+21. We find there are 69 ± 8.3 counts in the 2–10 keV energy range in the circular $r = 150''$ background region, which, when scaled to the circular $r = 30''$ source extraction region area, corresponds to 2.7 ± 1.6 expected background counts. The source region contains 1 total count, which is consistent with being from the background. Following Gehrels (1986), and assuming no source counts, we find a 3σ upper limit of 6.608 counts or a count rate of 3.7×10^{-4} counts per second, accounting for the exposure map which gives an average exposure time of 17.8 ks per pixel in the source aperture. Assuming the same absorbing column density ($N_{\rm H} = 7.1 \times 10^{20}$ cm^{-2}) and photon index ($\Gamma = 2$) as J+21, we find the 3σ upper limit on the unabsorbed 2–10 keV band flux is $F_{\rm X} < 2.8 \times 10^{-14}$ erg cm^{-2} s^{-1}. This corresponds to an upper limit on the unabsorbed luminosity of $L_X < 7.2 \times 10^{29}$ erg s^{-1} for a distance of 460 pc and an Eddington luminosity ratio of $L_X/L_{Edd} \lesssim 2 \times 10^{-9}$ for a $M \approx 3M_\odot$ black hole.

4. Summary and Conclusion

Here we have shown that the X-rays detected by Swift XRT from V723 Mon are due to optical loading. The detected photons are all soft, having $E \lesssim 1.1$ keV, further supporting that they are due to optical loading. Using X-ray counts in the 2–10 keV energy range, where optical loading has little to no impact, we find an upper-limit on the unabsorbed 2–10 keV X-ray flux of $F_X < 2.8 \times 10^{-14}$ erg cm^{-2} s^{-1}, corresponding to a luminosity of $L_X < 7.2 \times 10^{29}$ erg s^{-1} for a distance of 460 pc.

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Footnotes

- 4

  See e.g., https://www.swift.ac.uk/analysis/xrt/optical_loading.php.

- 5

  See https://www.swift.ac.uk/index.php.

- 6

  See https://www.swift.ac.uk/xrt_spectra/docs.php#products.

- 7

  See https://www.swift.ac.uk/analysis/xrt/optical_loading.php.