Massive Stars Near and Far
Proceedings IAU Symposium No. 361, 2024
J. Mackey, J. S. Vink, & N. St-Louis, eds.
doi:10.1017/S1743921322002265

Phase-resolved spectroscopic analysis of the eclipsing black hole X-ray binary M33 X-7

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Abstract. We present a detailed spectroscopic analysis of the only known eclipsing high mass X-ray binary with a black hole companion, M33 X-7. We obtained the first UV spectra of the system accompanied by X-ray observations, taken at three key orbital phases. We performed a detailed analysis of X-Ray, UV, and archival optical spectra using stellar atmosphere models which shed light on the interaction of the stellar wind with the black hole. Our new analysis suggests a large reduction in component masses compared to previous results. Our one-dimensional calculations confirm that the photoionization by the X-ray radiation can significantly change the ionization structure and diminish the wind accelerations. For this system standard wind-fed accretion scenario alone cannot explain the observed X-ray luminosity, indicating an additional mass overflow towards the black hole. Our evolutionary models suggest that the system is transitioning towards a common envelope stage in which both components merge.

Keywords. X-rays: binaries, black hole accretion, stars: fundamental parameters, stars: winds, outflows

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To understand the complex behaviour of High Mass X-ray binaries (HMXBs) with black hole (BH) companions, detailed knowledge of the massive star donors is essential. However, only a few such systems are known so far. To remedy this situation, we performed a multi-wavelength phase-resolved analysis of the extragalactic HMXB M33 X-7. This eclipsing BH HMXB is reported to contain a very massive O supergiant donor and a massive black hole in a short orbit (Orosz et al. 2007; Pietsch et al. 2006). However, previous spectroscopic analyses were limited to plane-parallel models which are optimized for hot stars with no significant wind.

Using phase-resolved simultaneous *HST*- and *XMM-Newton*-observations, we trace the interaction of the stellar wind with the BH. The UV resonance lines show the Hatchett-McCray effect with a large reduction in absorption strength when the BH is in the foreground due to the strong X-ray ionization (see Fig. 1). Our comprehensive spectroscopic investigation of the donor star (X-ray+UV+optical) yields new stellar and wind parameters for the system that differ significantly from previous estimates. In particular, the masses of the components are considerably reduced to $\approx 38 M_{\odot}$ for the O-star donor and $\approx 11.4 M_{\odot}$ for the black hole (see comparison in Fig. 2a). The O giant is overfilling its Roche lobe and shows surface He enrichment.

The derived mass-loss rate of the donor is in good agreement with the Vink et al. (2001) prediction assuming a high depth-dependent microclumping. By incorporating observed X-ray luminosities in models corresponding to different orbital phases, we were able to reproduce the spectral variations at three phases with the same stellar and wind parameters. We investigated the wind driving contributions from different ions and the

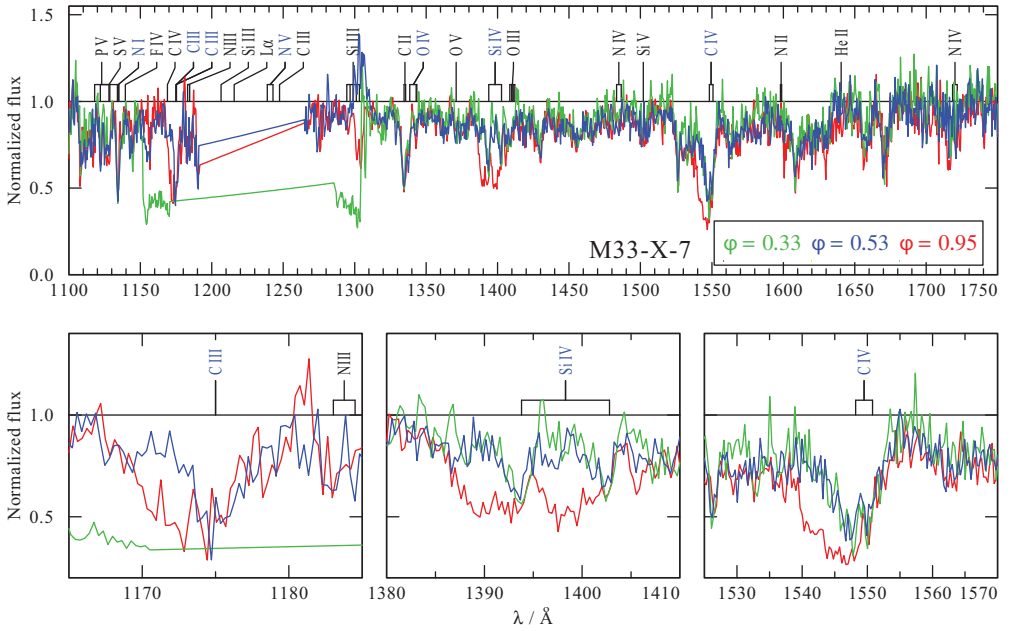

Figure 1. Comparison of HST/COS spectra of M33 X-7 taken during different orbital phases. The observed line variations are due to the Hatchett-McCray effect.

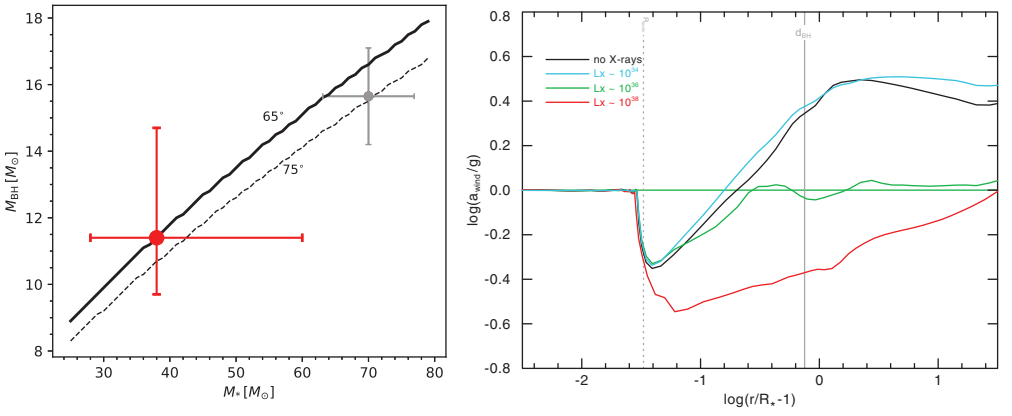

Figure 2. (a) Component masses in the M33 X-7 derived in this work (red) compared to previous values (grey) from Orosz et al. (2007). (b) Comparison of normalized wind acceleration for models including different amounts of X-rays.

changes in the ionization structure due to X-ray illumination. Towards the black hole, the wind is strongly quenched due to strong X-ray illumination (Fig. 2b). For this system, the standard wind-fed accretion scenario alone cannot explain the observed X-ray luminosity, pointing towards an additional mass overflow, in line with our acceleration calculations. The classical distinction between wind-fed and Roche-lobe overflow systems becomes meaningless for our system. Our investigations on wind driving and the impact of X-rays in M33 X-7 can be also applied to other high luminosity HMXB systems in general.

We computed binary evolutionary tracks for the system using MESA. Currently, the system is transitioning towards an unstable mass transfer phase, resulting in a common envelope of the black hole and the O-star donor.

https://doi.org/10.1017/S1743921322002265 Published online by Cambridge University Press

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https://doi.org/10.1017/S1743921322002265 Published online by Cambridge University Press