An X-ray ionized nebula around the eclipsing black hole binary M 33 X-7

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Abstract :

X-ray observations of stellar mass accreting black holes are often satisfactorily fit by various distinct spectral models. Part of this degeneracy arises from the fact that little is known about the emission in the unobservable Extreme Ultraviolet (EUV) / soft X-ray ranges, *i.e.* down to 0.05 keV. Here we study M 33 X-7, the only known eclipsing X-ray binary hosting a black hole as the compact object. We find that it is embedded in a relatively dense H II region where it excites the high-ionization He II λ4686 emission line akin to the case of the black hole binary LMC X-1 (Pakull & Angebault 1986). This line provides an independant measurement of the total number of He^{+}-ionizing photons in the 54 – 200 eV range. Therefore, we obtain important constraints on the EUV flux of an accreting black hole and are able to lift the degeneracy between the various models.

Optical observations of M 33 X-7 :

This high mass X-ray binary is located in a spiral arm of the nearby galaxy M 33, at a distance of 840 kpc. The black hole nature of the compact object was first suggested by Pietsch et al. (2004, 2006), who also identified the optical counterpart. Orosz et al. (2007) used spectroscopic observations of the O star companion to measure its radial velocity curve. They derived masses of **15.65 (±1.45) $M_\odot$ and 70.0 (±6.9) $M_\odot$** for the black hole and mass donor, respectively.

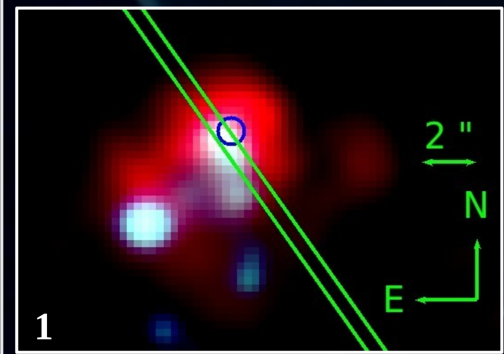

Figure 1 : X-7 is embedded in the H II region B0208f, shown here in a multi-color image (Hα in red, V in green and B in blue). Data are from the Local Group Survey (Massey et al. 2006). We use the Gemini-North GMOS observations from Orosz et al. but focus on the nebular emission around X-7. The green box delineates the position of the long-slit. The blue circle shows the Chandra position of X-7.

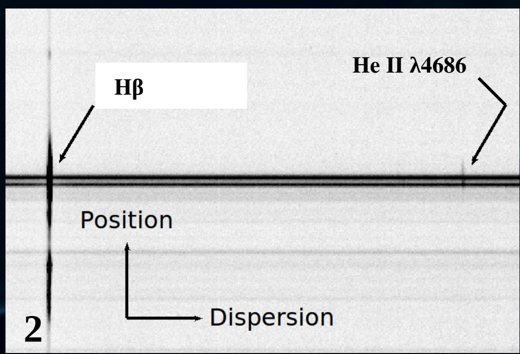

Figure 2 : Portion (~ 4880 – 4650 Å) of a 2D GMOS spectral image, showing the extended Hβ and He II λ4686 emission lines around X-7. Correcting for the finite slit width and interstellar absorption (A_V = 0.53) we measure the luminosity of the He II λ4686 line to be $2{\times}10^{35}$ erg.s^{-1}. Horizontally, the continua of two stars can be seen. The upper one is the companion of X-7, the lower one is a field star, with a separation of only 0.9 ".

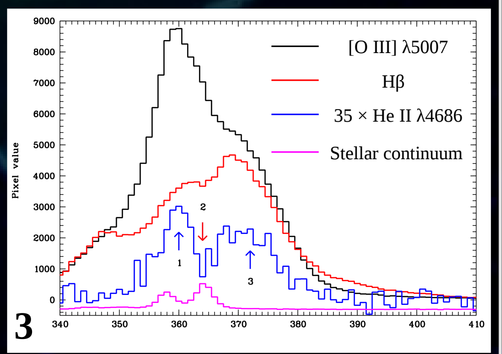

Figure 3 : Intensities of [O III] λ5007, Hβ and He II λ4686 as a function of position along the slit (here, 10 pixels = 1.45" = 6 pc). To guide the eye, the magenta curve shows the continuum of the two stars. The position of X-7 is marked by the red arrow (#2), corresponding to the upper star in Fig. 2. The shape of the He II λ4686 intensity suggests the presence of an empty "bubble" around the X-ray source with a radius of ~ 3 pc.

Photoionization modeling of the nebula surrounding the X-ray source :

We perform simulations with the code Cloudy (Ferland et al. 1998). The nebula is modeled by :

- a spherical cloud,
- Z ~ 0.25 $Z_\odot$,
- an inner radius of 3 pc,
- a constant hydrogen density of 20 cm^{-3} , as derived from the Strömgren radius and L_β.

In our case the ionization parameter (log U = −1.70) is sufficiently high so that **L_{4686} is only dependent on the spectral energy distribution (SED) of the X-ray source.**

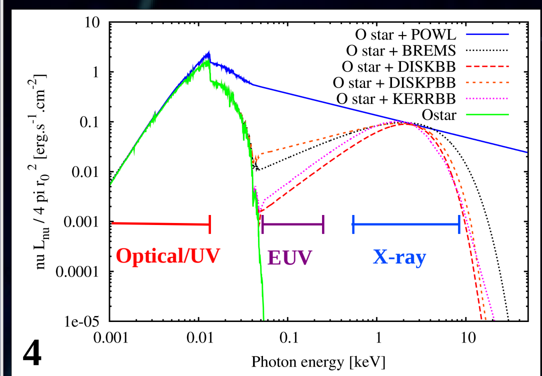

Figure 4 : SEDs used as input for the photoionization modeling. The SED of the companion star (green curve) is based on the OSTAR2002 grid (Lanz & Hubeny 2003). The SEDs of the X-ray source are those of the XSPEC model fits to the XMM data (see below) : Bremsstrahlung (black); Disk blackbody (red); p-free model (orange), i.e. a disk blackbody with T(r) α r $^{-p}$, where p is left as a free parameter (Mineshige et al. 1994); Disk blackbody model for a Kerr black hole (magenta) and power law (blue).

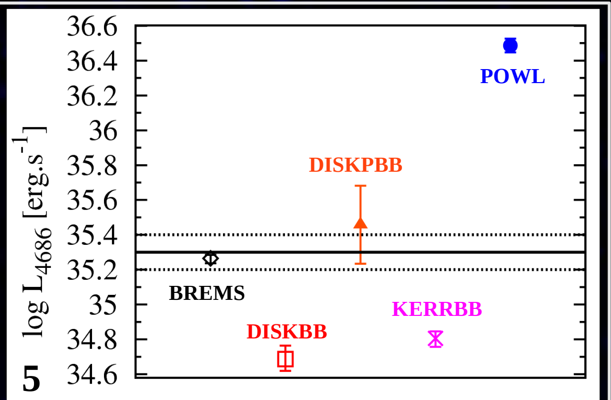

Figure 5 : Main results of the modeling
Predicted luminosities of He II λ4686 for each XSPEC model (same colors as in Fig. 4). The observed value and the 30 % errors are shown by the solid and dashed lines, respectively. A thermal bremsstrahlung with kT = 2.47 (± 0.1) keV or a p-free model, with $kTin$ = 1.13 (± 0.08) keV and p ~ 0.5 ("slim disk") yield L_{4686} in agreement with the observations. **Standard disk blackbody models cannot account for the observed 4686 Å luminosity**, because of a *too low* EUV emission. On the other hand, a power law extending down to 54 eV would produce 16 times more 4686 Å flux than actually observed.

X-ray observations :

We used XMM observations of X-7 taken between 2000 and 2004 and new data taken in 2010. We find that the spectral state of X-7 has not changed in the last few years.

ⓘ In our method, **L_{4686} measures the mean X-ray luminosity over a few He^{++} recombination timescale τ_{rec} ~ 4 500 yr.**

Conclusion and perspectives :

The modeling of the X-ray ionized nebula shows that the luminosity of the He II λ4686 line can be used to measure the extreme UV emission of a stellar mass accreting black hole. Using our optical and X-ray observations together, we can partially lift the degeneracy between existing spectral models. This work favors a slim disk and will provide important constraints for future investigations.

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Background credit : Mark A. Garlick

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