The ULX NGC 1313 X-2: an optical study revealing an interesting behavior

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Abstract. We present a summary of our ongoing efforts to study one of the brightest ultraluminous X-ray source, NGC 1313 X-2. Despite a large coverage in the X-rays, much of the information we have about the source and its environment comes from optical wavelengths. Here, we report on the properties of the stellar environment, and the differences in the optical counterpart between our two observing epochs (2003–2004 and 2007–2008). We summarize our ongoing program designed to look for radial velocity variations in the optical spectra and for photometric variability.

Keywords: X-ray binaries – Black Holes – Accretion disks - OB stars association
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INTRODUCTION

Ultraluminous X-ray sources (ULXs) are extragalactic X-ray sources that are not at the nucleus of their galaxy, emitting well above the Eddington limit of a 10 M⊙ black hole \( L_X \sim 10^{39} \text{ erg s}^{-1} \) if we assume that they emit isotropically. An important question is whether they contain intermediate mass black holes (e.g. [1]), whether they are beamed [2], or if they are rather normal X-ray binaries with super-Eddington emission [3].

NGC 1313 X-2 has been extensively studied in X-rays (e.g. [4]), and is also one of the best ULX studied in the optical wavelengths (Grisé et al. [5] and references therein). The recent announcement of a periodic signal in the HST/WFPC2 optical lightcurve of X-2 was interpreted [6] as the orbital period. But despite huge observational efforts, the main parameters of the ULX system remain unknown.

RESULTS

Stellar environment

Near the ULX, we highlighted [5] two groups of (a few) young stars, spread out over \( \approx 200 \text{ pc} \), and hence more similar to an OB association (or more likely, two separate associations close to each other) rather than to a bound cluster. They clearly stand out in brightness and colors over the surrounding old population. There are no other similar groups of young stars in this region of the galaxy, nor are they connected to spiral arm features. The reason for this recent, localized episode of star formation is unclear, but the ULX is clearly associated with this young population.
We estimate \cite{5} that the largest association of young stars has an age \( \approx 20 \) Myr and a stellar mass \( \approx 5 \times 10^3 M_\odot \). The ULX optical counterpart (\( V \sim 23 \) mag) appears as one of the brightest stars in the association, without any obvious color or brightness anomaly. Using standard stellar evolutionary tracks, we constrain its mass to be \( \lesssim 12 M_\odot \); or even less, if the accretion disk is significantly contributing to the source luminosity. We estimate older ages for the stellar association than reported in previous work \cite{7}, and, correspondingly, lower stellar masses (see \cite{5} for more details).

**Optical counterpart**

Optical spectra of the ULX counterpart taken in 2003–2004 reveal characteristic high-excitation emission lines, including a broad He\( \text{II} \) \( \lambda 4686 \) line (\cite{8}, Grisé et al, in prep.). Such broad line usually comes from the accretion disk around the black hole, thus confirming the association with the X-ray source. We detected \cite{8} a significant velocity variation of this line (\( \Delta v = 380 \pm 30 \) km s\(^{-1} \)) between two spectra taken at a 3 weeks’ interval (Figure 1, left panel). If this variation reflects the orbital motion of the black hole, we can rule out the presence of an intermediate-mass black hole with \( M \gtrsim 50 M_\odot \). Our recent (2007–2008) spectroscopic campaign on the VLT revealed a decrease of the relative flux in the He\( \text{II} \) line (Figure 1, right panel). The line is no longer resolved, and the equivalent width has decreased from \( \approx 10 \) Å to \( \approx 3 \) Å. This affects the detection of the line in individual spectra, especially those taken in non-optimal seeing conditions; thus, it will make it very difficult to constrain the radial velocity curve.

Another significant finding of our work is the short-term optical variability of the ULX counterpart during the 2003–2004 campaign \cite{5}, by up to \( \approx 0.2 \) mag, on timescales of hours and days (Figure 2, left panel). This is detected both in the HST/ACS and in the VLT/FORS1 datasets from 2003–2004, and even more evident in the combined dataset. There is no evidence of periodicity. This suggests that the variability is not due to ellipsoidal variations. Instead, it may be caused by varying X-ray irradiation of the donor star and (more likely) a stochastically-varying contribution from the accretion disk. Our new photometric follow-up seems to confirm this interpretation and suggests that the source has entered a different “state”, with a mean optical luminosity at a low level consistent with the lowest luminosity of the earlier study (Figure 2, right panel). The X-ray flux of X-2 about this epoch was also much lower than the long-term average. The optical flux is consistent with being constant during the 2007–2008 observations, in contrast with the short-term variations in 2003–2004. These findings suggest a lower accretion rate and/or lower radiative efficiency of the ULX, reflected both in the optical and X-ray flux. In particular, we are investigating how the decrease in the X-ray flux may reduce the He\( \text{II} \) \( \lambda 4686 \) line emission from the irradiated accretion disk and companion star.

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FIGURE 1. Left: radial velocity variation of the HeII $\lambda$4686 line of the optical counterpart of X-2. The two spectra ($2 \times 20$ minutes of exposure time each) show a clear, resolved line (intrinsic FWHM $\sim 10$ Å) and display an interesting variation of $380 \pm 30$ km/s around the systemic velocity of the nebula that surrounds the ULX. Right: combined spectrum observed in 2007–2008 ($9 \times 45$ minutes of exposure time) showing an unresolved HeII line (intrinsic FWHM < 5 Å) with a drop in the equivalent width of a factor $\approx 3.5$.

FIGURE 2. X-ray (top) and B-band (bottom) light curve of the ULX counterpart between 2003 November 22 and 2004 February 22 (left) and between 2007 October 21 and 2008 March 8 (right). The optical light curve comes from VLT/FORS1 and HST/ACS data. Note that the X-ray flux (unabsorbed) is taken from [9] for the left plot and from [10] for the right plot.

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