X-rays from young clusters reveal binarity of massive stars

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Abstract

We analysed the X-ray emission from massive Wolf-Rayet (WR) stars in vicinity of two young stellar clusters (Danks 1 and Danks 2) in the G305 star-forming region in the Scutum Crux arm of the Galaxy. Ten WR stars fall in the field of view of the corresponding archive *Chandra* observation. Based on the previous studies of X-ray emission from presumably single and binary WR stars, we estimate that about 60 - 66 % of the WR stars in vicinity of Danks 1 and Danks 2 are binary systems.

X-rays from Wolf-Rayet Stars

Wolf-Rayet (WR) stars are decendants from the most massive stars in the Galaxy and are divided into three subtypes: nitrogen-rich (WN), carbon-rich (WC) and oxygen-rich (WO; very rare: there are only four such objects in the Galaxy) (see [3] for a review on physical properties of WRs).

They were discovered to be X-ray sources by the ***Einstein Observatory*** ([13]) and the first systematic studies of WRs ([10]) showed that WR binaries are the brightest X-ray sources amongst them. Modern X-ray observatories (*Chandra*, *XMM-Newton*) considerably increased the number of pointed observations, thus, the number of objects with good quality X-ray data which allows establishing some general properties.

Single WRs

WN stars are clearly detected with X-ray luminosity $L_X < 10^{33}$ ergs s^{-1} as the late WN objects (WN8-9) are faint X-ray sources ([15], [16]).

WC stars have NO X-ray detection ([8], [14]), so, they are either very faint or X-ray quiet.

WO stars: the only pointed observation of such a star showed that they are X-ray sources ([9], [17]).

Binary WRs

Binary WR stars of all subtypes are X-ray sources as they are brighter than the single WR objects and their enhanced X-ray emission is assumed to originate from colliding stellar winds (CSW) of the massive binary components ([11], [2]; see [12] for a recent review on X-ray emission from interacting wind massive binaries).

X-ray based criteria for Single vs. Binary Wolf-Rayet objects

Based on the X-ray studies of WR stars, we propose the following criteria for discriminating between single and binary objects.

- WC stars: X-ray detection means a binary; non-detection means a single object.
- WN and WO stars: objects with X-ray luminosity **larger** than 10^{33} ergs s^{-1} are binaries while others are single WRs.

Massive Stars in G305 and the *Chandra* Data

G305 is a star-forming region in the Scutum Crux arm of the Galaxy. Near its centre, there are two compact stellar clusters Danks 1 and Danks 2 ([4]) with estimated age of $1.5^{+1.5}_{-0.5}$ Myr and $3.0^{+3.0}_{-1.0}$ Myr, respectively ([5]). More than ten WR stars have been identified in G305, as most of them are located in vicinity of the young central clusters ([7], [5]).

The WR stars in vicinity of the young clusters Danks 1 and Danks 2 that fell in the field of view of a *Chandra* observation (ObsID 8922) are listed in Table 1. We used the Chandra Interactive Analysis of Observations 4.7.3 data analysis software (for details, see `http://cxc.harvard.edu/ciao/`) to re-process the archive data and to extract the source and background spectra, as well as all other files needed for the X-ray analysis. Figure 1 presents the X-ray images of the studied WR stars. We note that the X-ray emission from the binary system WR 48a has been already studied in detail ([19],[20]).

Table 1: WR stars of G305 in the *Chandra* (ACIS-I) FOV

	Name (SIMBAD)	Spectral type	X-ray counts
(1)	[DCT2012] D1-5	WNLh	643 ± 27
(2)	[DCT2012] D1-1	WNLh	409 ± 21
(3)	[DCT2012] D1-2	WNLh	250 ± 18
(4)	[MVM2011b] MDM3	WN8-9	468 ± 22
(5)	[MVM2011b] MDM5	WN9	7 ± 5
(6)	[SMG2009] 845-35	WC7	(in CCD gap)
(7)	[DCT2012] D2-3	WC8	0 ± 3
(8)	WR 48a	WC8+WN8h	a lot
(9)	[SMG2009] 845-34	WC8	93 ± 10
(10))	MSX5C G305.4013+00.0170	WCL	0 ± 2

The spectral type is from [7] and [5] excepting objects (7) and (8) for which is from [21]. The X-ray emission of WR 48a, the X-ray most luminous WR star in the Galaxy (object (8) in the list), is discussed in [19] and [20]. The last column gives the net source counts and associated 1σ errors in the effective 119.5 ks ACIS-I exposure.

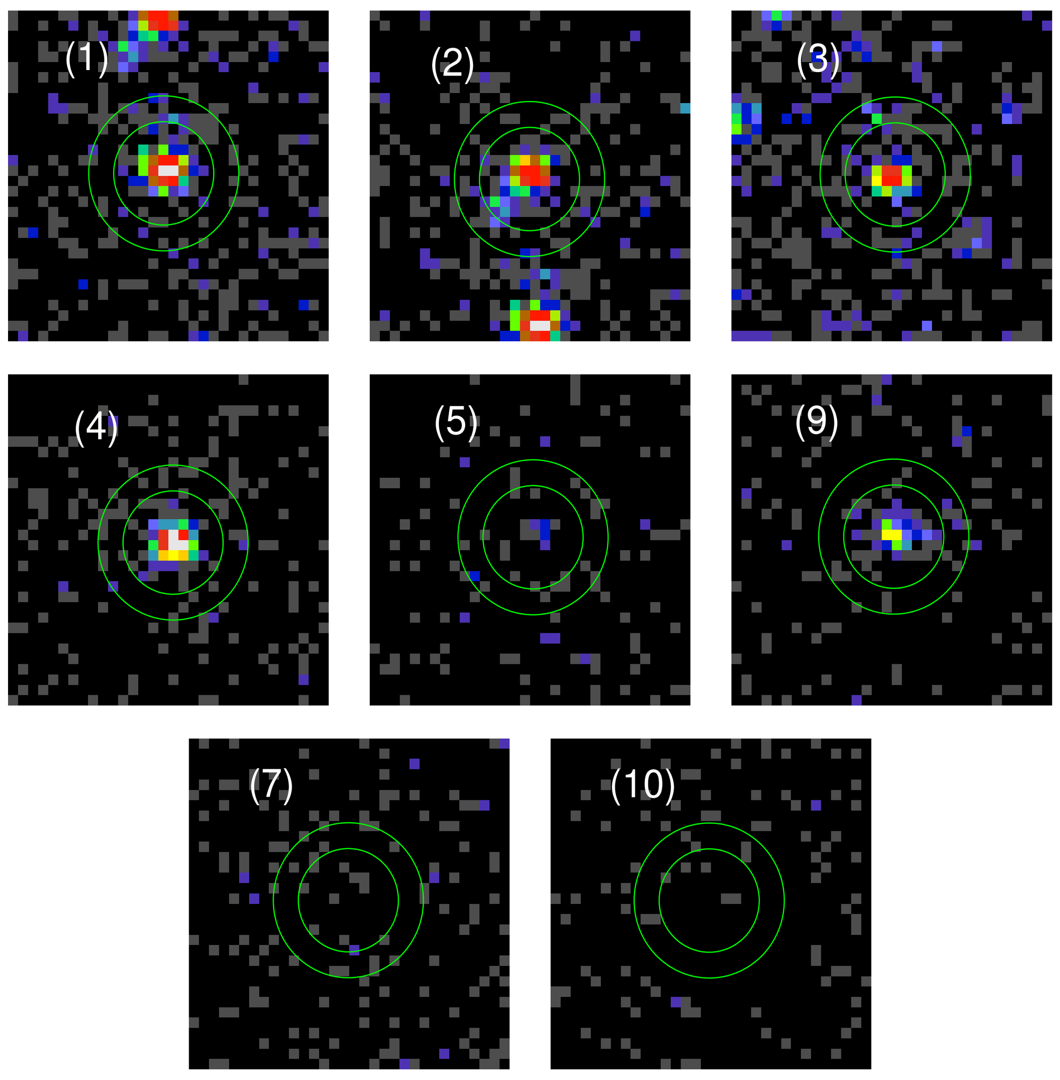

Figure 1: Raw *Chandra* ACIS-I (ObsId 8922) images of the WR stars in G305. The inner circle (2.″5 size) marks the source extraction region while the adjacent annulus denotes the background extraction region for each object. Image labels correspond to the object number in Table 1.

X-ray Spectra and Binarity of Massive Stars in G305

For analysis of the X-ray spectra of the WR stars in vicinity of Danks 1 and Danks 2, we made use of version 12.9.2 of XSPEC ([1]). The spectra were re-binned to have a minimum of 10 X-ray counts per bin. We fitted the spectra with models of absorbed X-ray emission from optically thin plasma in collisional ionization equilibrium. For the objects with better photon statistics (source counts > 400), we used models with two-temperature plasma with individual X-ray absrption. For the other objects, we adopted models with absorbed one-temperature plasma emission. For non-detected objects, we used the latter model with fixed plasma temperature of 1 keV and X-ray absorption that corresponds to the average optical extinction towards Danks 1 and Danks ([5]), if the Gorenstein conversion is adopted ([6]), to match the 1σ upper limit on the observed count rate.

Figure 2 presents the X-ray spectra of detected WR stars and brief comments on individual objects follow (also, see Table 2).

(1) The X-ray spectrum of this WNLh star was fitted with X-ray emission from a two-component plasma (kT = 0.7 and 2.6 keV) which shared the same absorption of $N_H = 2.6 \times 10^{22}$ cm^{-2} ($\rightarrow A_V = 11.7$ mag). The value of its X-ray luminosity is a sign of binary system. Also, we note that opposite to this the single objects of WNL type are faint X-ray source ([16]) as is the case of object (5) in the list.

(2) As for the previous object, the same was valid for this WNLh star but the thermal component had different X-ray absorptions: kT = 0.34 and 1.27 keV and $N_H = 3.4$ and 5.8×10^{22} cm^{-2}, respectively. The latter correspond to optical extinction $A_V > 15$ mag.

(3) The quality of the spectrum of this WNLh star was lower, thus, we adopted a one-temperature model (kT = 0.6 keV; $N_H = 2.8 \times 10^{22}$ cm^{-2} ($\rightarrow A_V = 12.6$ mag). Similarly to objects (1) and (2), its X-ray properties are typical for binary system.

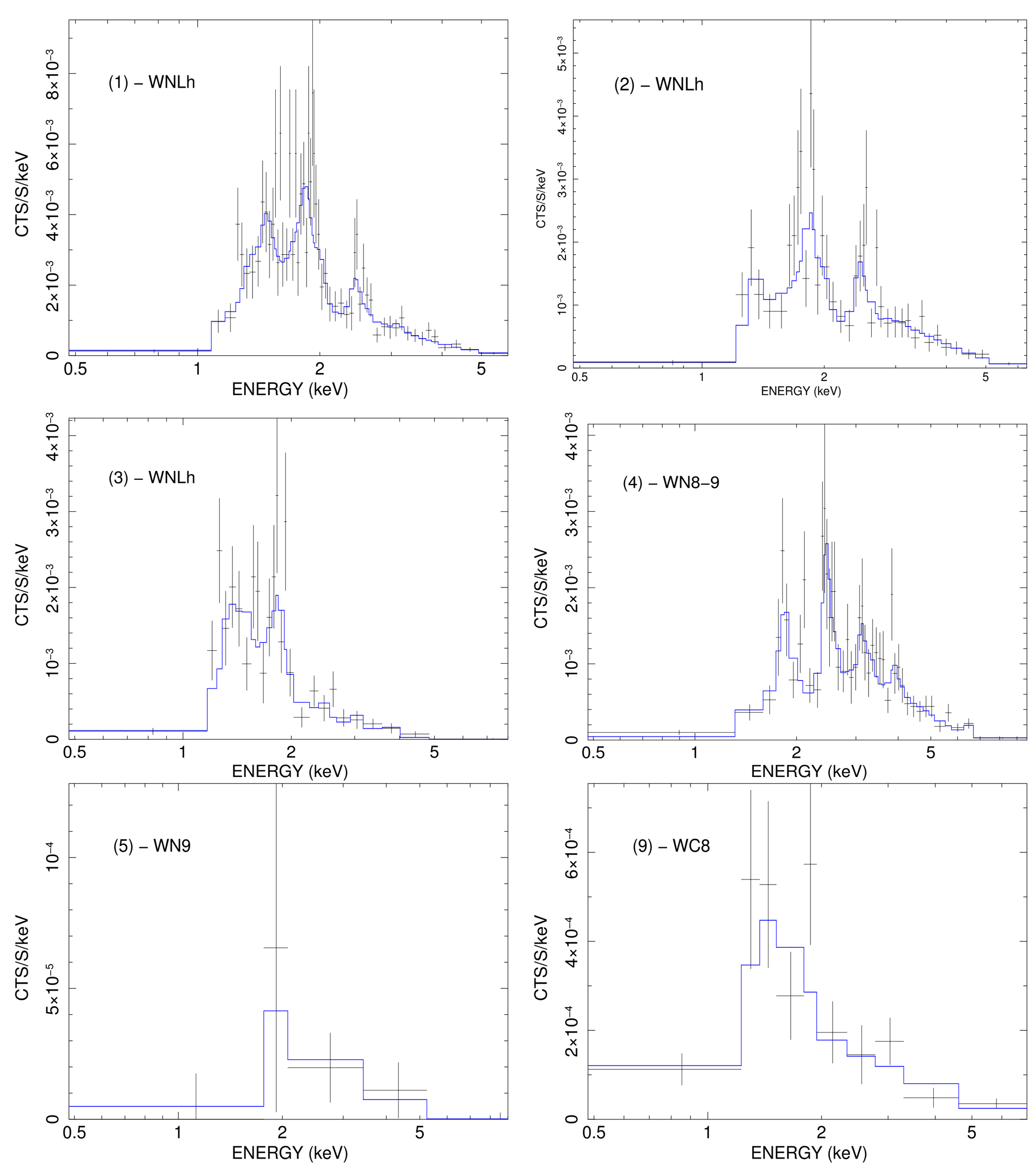

Figure 2: *Chandra* background-subtracted spectra of thei X-ray detected WR stars in G305 overlaid with the best fit model of absorbed X-ray emision from 1T or 2T optically thin plasma. Labels correspond to the object number in Table 1 followed by the object's spectral type.

(4) Another WNL star with a relatively good quality of the X-ray spectrum: model fit with kT = 0.7 and 2.7 keV; $N_H = 4.8$ and 7.7×10^{22} cm^{-2}, respectively. The latter correspond to optical extinction $A_V > 21$ mag. The value ot its X-ray luminosity indicates a binary.

(5) This is a very faint X-ray source (one-temperature spectral fit kT = 1 keV and $N_H = 5.2 \times 10^{22}$ cm$^{-2} \rightarrow A_V = 23.4$ mag) whose characteristics are typical for single WNL stars.

(6) No data: the object fell in the gap between the ACIS-I CCDs.

(7) Non-detection of a WC star signifies single WC object.

(8) WR 48a is a WC object and it is the X-ray most luminous star in the Galaxy ([19]) which is a clear sign of binary system (see also [18]).

(9) This WC star was detected and its spectrum was fitted with a one-temperature plasma model (kT = 3.6 keV; $N_H = 0.7 \times 10^{22}$ cm^{-2} $\rightarrow A_V = 3.2$ mag). We note that the X-ray absorption towards this object is relatively low (lower than the average towards Danks 1 and Danks 2 of ~ 9 mag [5]) which might be a caveat due to the low photon statistics. Nevertheless, the X-ray detection means binary system.

(10) Non-detection of a WC star signifies single WC object.

Table 2: Properties of the WR stars in G305

	Name (SIMBAD)	log L_X (ergs s^{-1})	Single or Binary
(1)	[DCT2012] D1-5	33.28	B
(2)	[DCT2012] D1-1	33.68	B
(3)	[DCT2012] D1-2	33.20	B
(4)	[MVM2011b] MDM3	33.34	B
(5)	[MVM2011b] MDM5	31.59	S
(6)	[SMG2009] 845-35	N/A	...
(7)	[DCT2012] D2-3	< 31.0	S
(8)	WR 48a	> 35.0	B
(9)	[SMG2009] 845-34	31.53	B
(10))	MSX5C G305.4013+00.0170	< 30.8	S

The values of the X-ray luminosity L_X (0.5 - 10 keV) are for adopted distance of d = 4 kpc ([4], [5]).

Conclusions

Adopting the X-ray based criteria for Single vs Binary WRs, our analysis of the X-ray emission from massive stars in G305 leads to the following conclusions.

- More than 60% (6 out of 9 objects) of the massive Wolf-Rayet stars in vicinity of the central young stellar clusters Danks 1 and Danks 2 in the star-forming region G305 are *binary systems*.
- Optical observations are needed to further support or rebut this conclusion.

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