X-ray Emission from Wolf-Rayet Stars

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Abstract

We present an overview of recent X-ray observations of Wolf-Rayet (WR) stars with XMM-Newton and Chandra. Observations of several WC-type (carbon-rich) WR stars without known companions have yielded only non-detections, implying they are either very feeble X-ray emitters or perhaps even X-ray quiet. In contrast, several apparently single WN2-6 stars have been detected, but data are sparse for later WN7-9 stars. Putatively single WN stars such as WR 134 have X-ray luminosities and spectra that are strikingly similar to some known WN + OB binaries such as WR 147, suggesting a similar emission mechanism.

1 X-rays from WR Stars: Overview

WR stars are the evolutionary descendants of massive O stars and are losing mass at very high rates. They are in advanced nuclear burning stages, approaching the end of their lives as supernovae. Strong X-rays have been detected from several WR binary systems, which are thought to originate (at least partially) in a colliding wind shock between the two binary components. Much less is known about the X-ray emission from single (non-binary) WR stars, but theoretical models predict that they should emit soft X-rays (kT $<$ 1 keV) via shocks that are set up by instabilities in their supersonic line-driven winds. We have recently detected X-ray emission from two putatively single WN stars, and both show hard emission that is not anticipated if their X-rays originate in radiative wind shocks. No single WC star has so far been detected in X-rays.

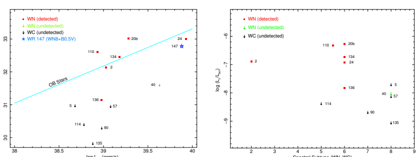

FIGURE 1: *Left*: L_x versus L_{bol} for single WR stars. The WN binary system WR 147 is also shown for comparison. The WR star number is shown next to each data point. The solid line is the regression fit for OB stars detected in the *ROSAT* All-Sky Survey (Berghöfer et al. 1997). L_{bol} from Hamann et al. 2006 (AA, 457, 1015). *Right*: L_x/L_{bol} versus spectral subtype. There are no existing X-ray detections of single WC stars or of single WN stars later than WN6.

2 Single Carbon-rich WC Stars

- Sensitive X-ray observations have now been obtained of five putatively single WC stars with *XMM* and *Chandra*. All are of spectral type WC5 or later. Surprisingly, none is detected (Fig. 1).
- The most stringent upper limit is from a 19 ksec *Chandra* observation of the WC8 star WR 135 (Skinner et al. 2006). Upper limits on L_x/L_{bol} are $\sim$100 times below that of detected O stars and other WR stars (Fig. 1).
- The observed sample is small, but results so far suggest that WC stars are X-ray quiet.
- Where are the X-rays? If they are produced in shock regions close to the star in the wind acceleration zone, as appears to be the case for some O stars (e.g. σ Ori AB, Skinner et al. 2008) then they may be totally absorbed by the metal-rich WC wind.

3 Single Nitrogen-rich WN Stars

- Sensitive X-ray observations have now been obtained of several putatively single WN2-6 stars with *XMM* and *Chandra*. All but one were detected (Fig. 1). CCD spectra exist (Fig. 2), but no grating spectra have been obtained of single WN stars due to low count rates.
- Observations of later WN7-9 stars are sparse. The WN8h star WR 40 was undetected by *XMM* (Gosset et al. 2005; see also Fig. 1). Are WNL stars X-ray sources? We don't yet know.
- Putatively single WN stars such as WR 2 and WR 134 show high-temperature plasma in *Chandra* ACIS spectra (Fig. 2). This is not expected if their emission arises solely in radiative wind shocks.
- X-ray luminosities of several single WN stars are as large as some WR binaries (Fig. 1). If these stars are indeed single, the belief that single WR stars are less-luminous than WR binaries is probably incorrect (but subject to distance uncertainties).

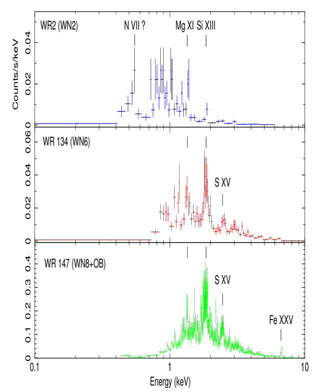

FIGURE 2: Chandra ACIS CCD X-ray spectra of putatively single stars WR 2 (WN2; A_V = 1.52 mag) and WR 134 (WN 6; A_V = 1.41 mag). X-ray absorption below 1 keV is stronger in WR 134 than in WR 2, despite similar A_V. Both stars show high-temperature plasma (kT $\geq$ 3 keV) and high-T emission lines, at odds with a purely radiative wind shock origin. A strong N VII line may be present in WR 2. Bottom panel shows the XMM PN spectrum of the binary WR 147 (A_V = 11.2 mag) for comparison (Skinner et al. 2007).

4 Wolf-Rayet Binaries

- High-resolution X-ray grating spectra have been obtained for a few binaries such as γ^2 Vel (WC8 + O7.5; Fig. 3) and WR 140 (WC7 + O4-5). CCD spectra have been obtained of WR 147 (WN8 + OB; Fig. 2). These spectra stringently test shock models.
- **Wind Shocks**: Spectral features in γ^2 Vel (Skinner et al. 2001; Schild et al. 2004) imply line formation far from the star, perhaps in colliding wind shocks.
- **Models**: Colliding wind models of WR 147 roughly reproduce XMM CCD X-ray spectra, but suggest a revision of adopted mass-loss parameters may be needed (Skinner et al. 2007; Zhekov 2007).

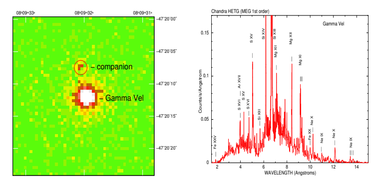

FIGURE 3: *Left:* Chandra zero order ACIS image of γ^2 Vel. The WC8+O7.5 system is unresolved. A faint companion lies 4.8$''$ to its north. *Right:* Chandra HETG grating spectrum (MEG, 1st order) of γ^2 Vel (Skinner et al. 2001).

5 Open Questions

- Are *all* single WC stars X-ray quiet? Are dense metal-rich winds responsible for the absence of X-ray detections of WC stars?
- Are late-type single WN7 - WN9 stars X-ray emitters?
- Why do the X-ray spectra of putatively single stars like WR 134 (WN6) so closely resemble known binaries such as WR 147? Does WR 134 have an optically faint companion?
- Do other processes besides colliding winds contribute to the X-ray emission of luminous WR+OB binaries?

References & Acknowledgment

Berghöfer, T. et al. 1997, A&A, 322, 167
Gosset, E. et al. 2005, A&A, 429, 685
Schild, H. et al., 2004, A&A, 422, 177
Skinner, S. et al., 2001, ApJ, 558, L113
Skinner, S. et al., 2006, Ast. Space Sci., 304, 97
Skinner, S. et al., 2007, MNRAS, 378, 1491
Skinner, S. et al., 2008, ApJ, 683, 796
Zhekov, S., 2007, MNRAS, 382, 886

This work was supported by NASA grants NNG05GA10G & GO8-9008.