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 WN-6 stars have been detected, but data are sparse for later WN-7 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 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.

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).

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). CCO 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 WN 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 X-ray 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).

4 Wolf-Rayet Binaries
High-resolution X-ray grating spectra have been obtained for a few binaries such as γ² Vel (WC6 + O7.5; Fig. 3) and WR 140 (WC7 + O4.5). CCO spectra have been obtained of WR 147 (WN8 + OB; Fig. 2). These spectra stringently test shock models.

Wind Shocks: Spectral features in γ² 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 CCO X-ray spectra, but suggest a revision of adopted mass-loss parameters may be needed (Skinner et al. 2007; Zhekov 2007).

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 WN - 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?

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