Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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The X-ray history of WR 140 in modest comparison with the radio

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Abstract. We present the X-ray lightcurve of the canonical colliding-wind binary WR 140 from the time of the last periastron through late 1997. Variations in column density, and intrinsic and absorbed X-ray flux agree well with the expectations of colliding wind theory in which the winds from the stars are spherically symmetric.

1. Introduction

Since the 1990 Bali symposium (van der Hucht & Hidayat 1991) there have been nine X-ray spectra of WR 140 (WC7+O4-5): four *ROSAT* spectra up to the 1993 periastron passage ($\phi = 0.76$, 0.77, 0.89, 0.96); two *ASCA* X-ray spectra after the 1993 periastron passage ($\phi = 1.03$, 1.07); and three *ASCA* spectra ($\phi = 1.53$, 1.60, 1.66) as part of a six-monthly monitoring program begun by the XMEGA group.

All four 0.2–2.0 keV *ROSAT* spectra have the same shape, even at $\phi = 0.96$, though the count-rate rises steadily during the approach to periastron. All three 0.5–10 keV *ASCA* spectra at $\phi > 1.5$ have the same shape and, given the slow or absent evolution of the spectrum around most of the orbit, it is likely that these seven spectra show the X-ray spectrum in the absence of significant intrinsic absorption in either of the stellar winds.

2. Colliding-wind models look good

The spectra taken just after periastron clearly show extra absorption, similar to the level seen in lower-resolution *EXOSAT* data taken just after the last periastron passage in 1985. The absorption enhancement starts somewhere

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$0.96 < \phi < 1.007$ and is visible only until about $\phi = 1.1$. The variation in absorption and X-ray flux is very similar to that predicted in the spherically symmetric colliding wind model considered by Stevens, Blondin & Pollock (1992).

3. Variability of the Fe-K line

A remarkable feature of the *ASCA* spectra is the variablity of the Fe K-α line. The line is strongest when the WR absorption is high. If these spectra were purely a thermal phenomenon an iron line should have been observed in all the X-ray spectra, not just the most absorbed. It is also clear from the line energy that it is not emission from cold material. From an empirical point-of-view, the line's appearence could be either absorption-dependent, if it were a hot flourescent line, or luminosity-dependent. We should soon be able to distinguish between these possibilities.

A power-law model $f_\nu \propto \nu^{-\alpha}$ of the type often associated with non-thermal processes works quite well for most of the data with spectral index $\alpha \approx 1.6$. The observation of negative index radio spectra, as exemplified by the Williams, van der Hucht & Spoelstra (1994) and White & Becker (1995) radio studies, leaves little doubt of the presence of relativistic electrons and magnetic fields in WR 140 for the production of synchrotron radiation at centimetre wavelengths. These electrons should thus produce power-law radio and X-ray spectra of identical index, the ratio of whose luminosities is given by the ratio of energy densities in the radiation and magnetic fields: $(L_X/L_R) = (U_{rad}/U_B) \approx 500/B^2_{v=0}$, where the approximation has been calculated near a typical stagnation point ($v = 0$) of WR 140 at 1 AU from the O-star.

4. No evidence for a disk in the wind

We have argued elsewhere (Pollock 1998) that the WR 140 radio curves do not require a disk but are principally the result of variable absorption of two separate radio components, one identified with shocked WR material, the other with shocked O-star material. Even a single component radio spectrum is certainly steeper than $\alpha = -0.8$ and it is easy to construct a 2-component model in which the underlying spectrum has the same steep slope as the putative non-thermal X-ray spectrum.

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