Eta Carinae: X-ray Line Variations during the 2003 X-ray Minimum, and the Orbit Orientation

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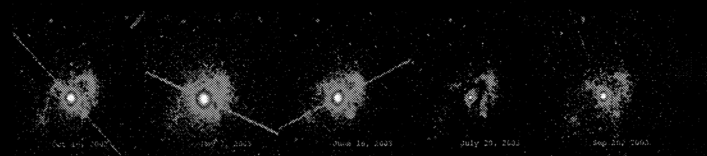


The observations: 5 HETGS 100 ksec pointings (AO4) near the X-ray minimum/periastron passage of Eta Car in mid-2003, plus an earlier (AO1) pointing near apastron.

Why this is Important:

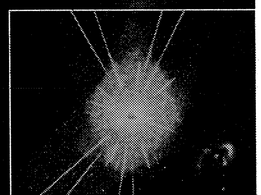
⇒The future evolution of Eta Car will be dramatic: a supernova (or hypernova) + black hole

⇒ The evolution is highly contingent on mass and angular momentum changes and instabilities

⇒ The presence of a companion can serve to trigger instabilities and provide pathways for mass and angular momentum exchange loss

X-rays as a Key Diagnostic

- X-ray temperatures trace pre-shock wind velocities
- periodic X-ray variability traces the orbit
- *X-ray line variations traces the flow & orientation of shocked gas*



500 ksec merged HETGS 0th order image; inset: Chandra "true color" X-ray image (red: 0.1-0.5 keV; green: 0.5-1.0 keV; blue: 1.0-10.0 keV) and HST WFPC2 image (courtesy N. Smith and J. Morse)

- X-rays are generated in the shock where the massive, slow wind from Eta Car smashes into and overcomes the thin, fast wind from the companion

$$\dot{p}_{wind,\eta}/\dot{p}_{wind,c} = \frac{\dot{M}_\eta V_{\infty,\eta}}{\dot{M}_c V_{\infty,c}}$$

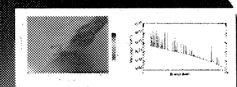
force balance determines which wind dominates

$$L_x \propto n^2 v \propto \frac{\dot{M}^2}{D}$$

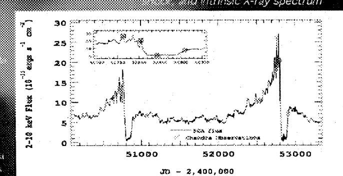
Intrinsic X-ray luminosity varies as the square of the density

$$L_{x,obs} \propto L_x e^{-\sigma N_H}$$

Observed flux is proportional to intrinsic flux modified by absorption

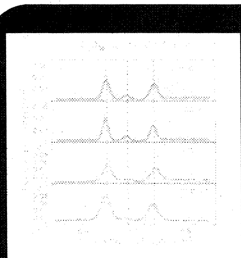


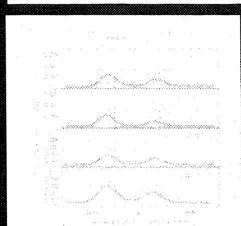
Numerical hydro model of Eta Car CW shock, and intrinsic X-ray spectrum

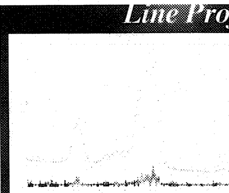


RXTE lightcurve of Eta Car, with times of Chandra observations

Line Profile Variations from the HETG:



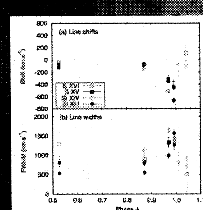




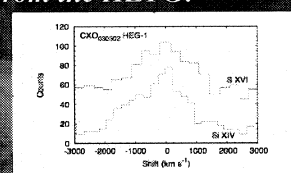
Helium-like lines

Left: the variation of the Si XIII triplet from phase=0.528 (near apastron) to phase=0.992 (just before X-ray minimum, near periastron). The R ratios are consistent with the low density/low photoexcitation limit, although the lines broaden and become more blue-shifted near periastron.

Above: the Fe XXV triplet blend shows increasingly strong "red wing" near



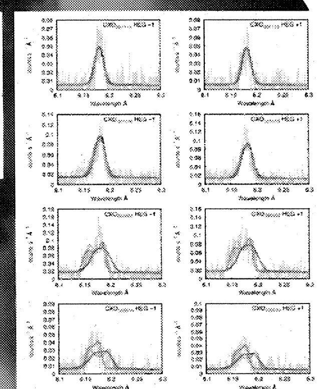
Variations in shifts and widths; lines in gray are contaminated by the CCE (Hamaguchi et al., 2007, ApJ, in press



Hydrogen-like lines

Left: the variation of the Si XIV vs. phase. The lines broaden and shift in centroid velocity. The lines show the profiles from the model described below.

Above: Comparison of the Si XIV and S XVI lines at phase=0.97, near X-ray maximum



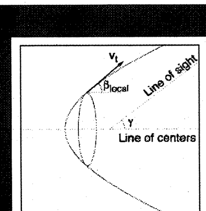
Profile colors: Corcoran et al. (2001, ApJ 547, 1034); Smith et al. (2004, ApJ, 610, L105); Henley et al. (2007, ApJ, submitted)

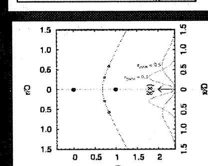
A Model of the Colliding Wind Flow

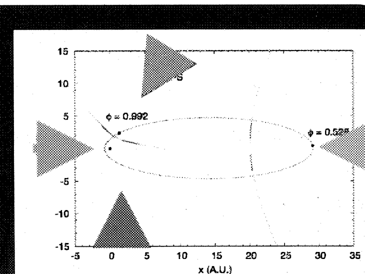
We modeled the collding wind flow as a series of cylindrically-symmetric rings using:

- the Canto, Raga and Wilkin (1996) wind-wind interaction geometry, with a scale factor to describe the Canto et al. flow velocity in each ring
- emissivity given by $\varepsilon(v) \propto [v_t^2 \sin^2\beta_{local} \sin^2\gamma - (v + v_t \cos\beta_{local} \cos\gamma)^2]^{-1/2}$
- line luminosity vs. position x along the shock based on hydrodynamical models $l(x) = \frac{4}{\sqrt{\pi}\, x_{peak}^3} L_{line}\, x^2\, e^{-(x/x_{peak})^2}$

where x_{peak} is the peak of the emission, and L_{line} the total line luminosity. The line profiles for 3 longitudes of periastron are







Lines pf sight for 4 longitudes of periastron: Corcoran et al. (2001, ApJ 547, 1034); Smith et al. (2004, ApJ, 610, L105); Abraham et al. (2005, MN, 364, 922); Henley et al. (2007, ApJ, submitted)