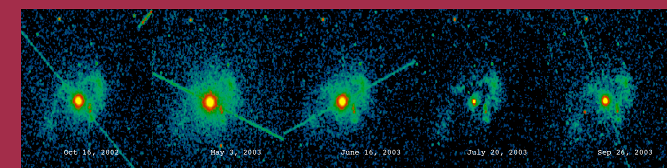
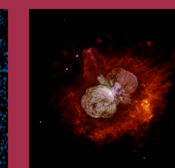
Eta Carinae: X-ray Line Variations during the 2003 X-ray Minimum, and the Properties of the Shocked Plasma

M. F. Corcoran[1,2], K. Hamaguchi[1,3], D. Henley[4], K. Ishibashi[5], J. M. Pittard[6], T. Gull[1], R. Petre[1], Augusto Damineli[7]
[1]NASA / Goddard Space Flight Center, [2]Universities Research Association (USRA), [4]The University of Birmingham, [5]MIT, [6]The University of Leeds, [7]IAGUSP
E-mail: corcoran@barnegat.gsfc.nasa.gov



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.


WFPC-2 image of Eta Car (courtesy N. Smith and J. Morse)

The Main Questions:

a) Is Eta Carinae, one of the Galaxy's most massive, luminous and unstable stars, one star or two?

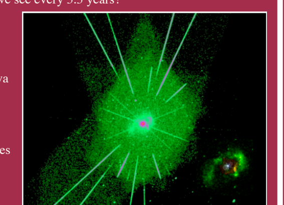
b) What causes the apparently clocklike spectral variations we see every 5.5 years?

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


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 as a Key Diagnostic

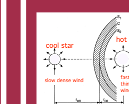
- X-ray temperatures diagnose pre-shock wind velocities
- periodic X-ray variability diagnose orbit
- X-ray line variations diagnose flow & orientation of shocked gas

A Colliding Wind Primer

- 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



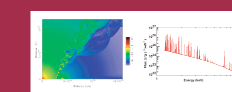
$$L_x \propto n^2 v \propto \frac{\dot{M}^2}{D}$$

Intrinsic X-ray luminosity varies the square of the density x volume

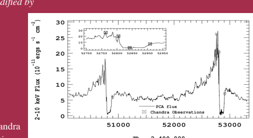
$$L_{x,obs} \propto L_x e^{-\sigma N_H}$$

Observed flux is proportional to intrinsic flux modified by absorption

The X-ray minimum must occur near periastron, and is probably caused by occultation of the shock by the wind from Eta Car, or an intrinsic decline in the 2-10 keV emission from the shock

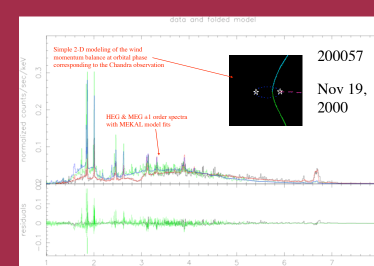


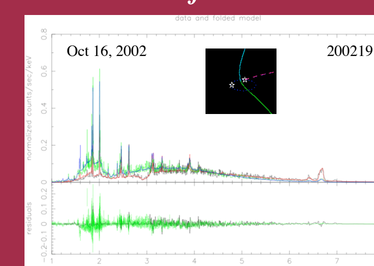
Numerical hydro model of Eta Car CW shock, and intrinsic X-ray spectrum

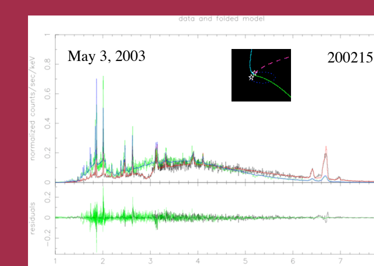


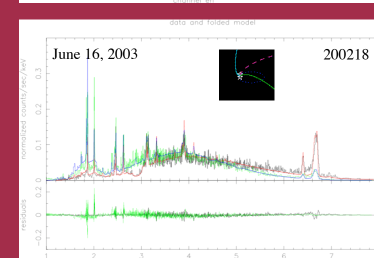
RXTE lightcurve of Eta Car, with times of Chandra observations.

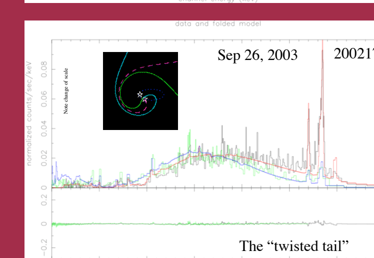
Spectral Variations from the HETG:

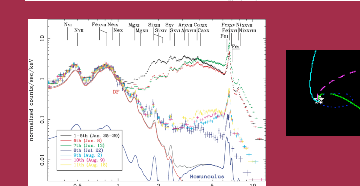


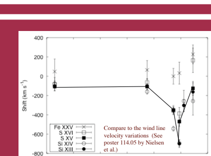


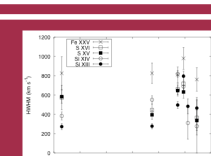


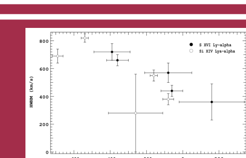


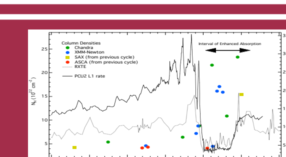



XMM/EPIC spectra before and during the Minimum (see poster 114.03 by Hamaguchi et al.)



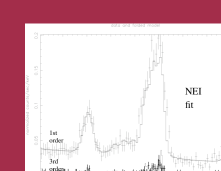






Highlights:

- Significant variations were seen in the centroid velocities of the strong, resolved emission lines, except (perhaps) for the FeXXV He-like line, similar to the variation seen in the He I wind lines (Nielsen et al.)
- There seems to be a good correlation between the line centroid variation and the line width
- Significant increases in column density were seen through the minimum
- Excess emission between the FeXXV K line and the Fe I fluorescent line is visible near the X-ray minimum but not very apparent near apastron



Interpretation:

- In the colliding wind binary model, the line centroid velocities represent the flow of the shocked gas in the observer's line of sight, modified by the orbital motion of the companion. The highest velocity flow is seen in the 0.97<φ<0.99 interval, which suggests that the aberrated shock cone is pointing towards the observer at this phase. This constrains the orientation of the orbital semi-major axis.

There is no obvious interpretation of the change in X-ray line profiles in any single-star mass ejection model.

- The emission redward of Fe XXV probably indicates that the amount of plasma which is not in ionization equilibrium increases near periastron. NEI plasma was also detected in the colliding wind binary WR 140 by Pollock et al.