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

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 change, and instabilities.
- The presence of gas temperature over 2 million Kelvin and provides potential for mass and angular momentum exchange lines.

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 expose short-term evolution of the outflow.

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=0.932 (just before X-ray minimum, near periastron). The R ratios are consistent with the low density/low photoionization limit, although the lines broaden and become more blue-shifted near periastron. Above: the Fe XVII triplet blend shows increasingly strong "red wing" near

Hydrogen-like lines

Left: the variation of the Si XIV vs. phase. The lines broaden and shift in contrast velocity. The lines show the profiles from the model described below. Above: Comparison of the Si XIV and S XIV lines at phase=0.97, near X-ray maximum.

A Model of the Colliding Wind Flow

We modeled the colliding 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:

  \[ \frac{\dot{E}}{\dot{M}} = \frac{1}{\epsilon} \left( \frac{\rho_1}{\rho_2} \right)^{1/2} \]

- line luminosity vs. position x along the shock based on hydrodynamic modeling:

  \[ L_x = \frac{1}{\epsilon} \left( \frac{\rho_1}{\rho_2} \right)^{1/2} \]

where \( \rho_1 \) is the peak of the emission, and \( L_\infty \) the total line luminosity. The line profiles for 3 longitudes of periastron are