Probing Colliding Wind Binaries with High-Resolution X-ray Spectra

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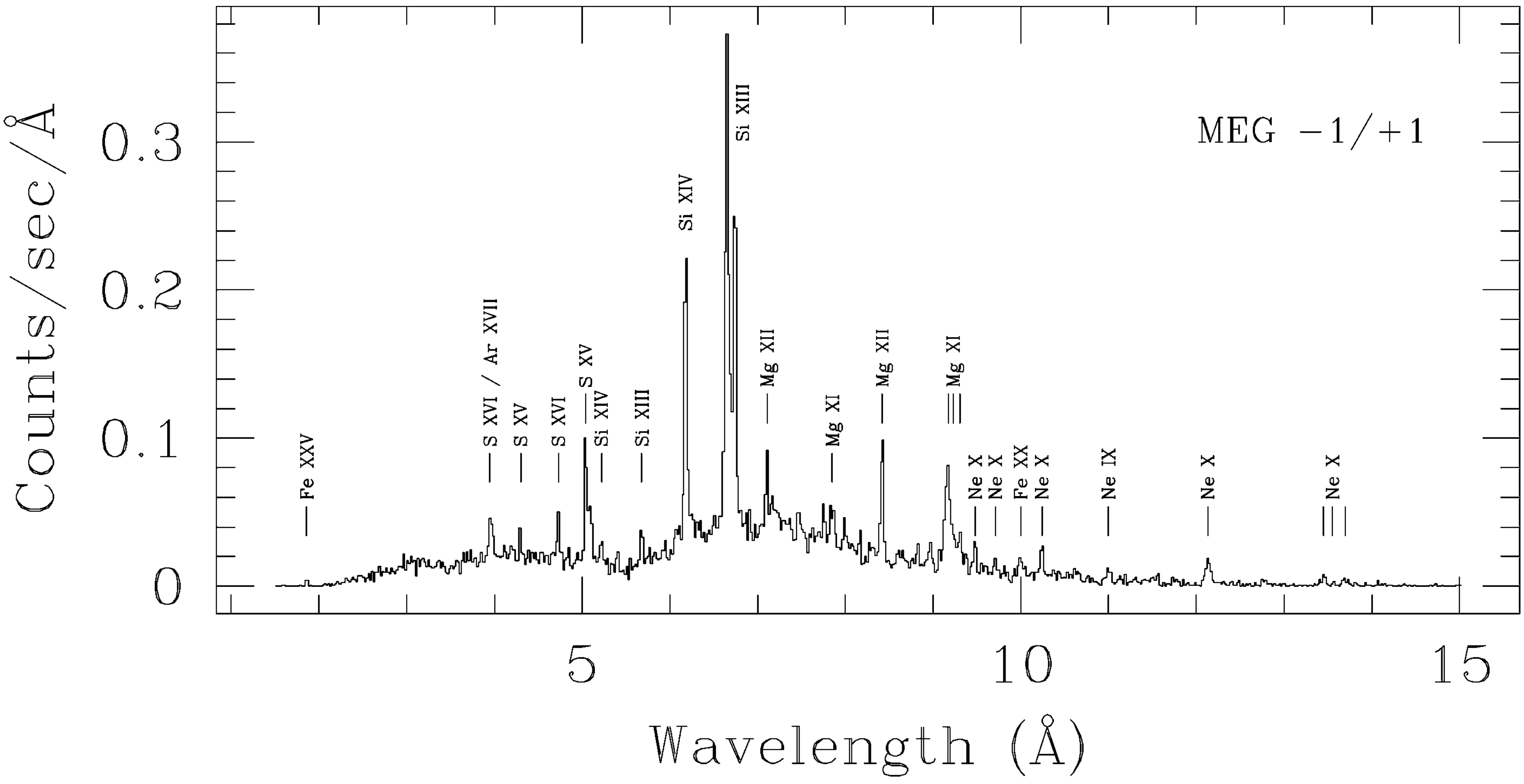
Importance of high-resolution X-ray spectra

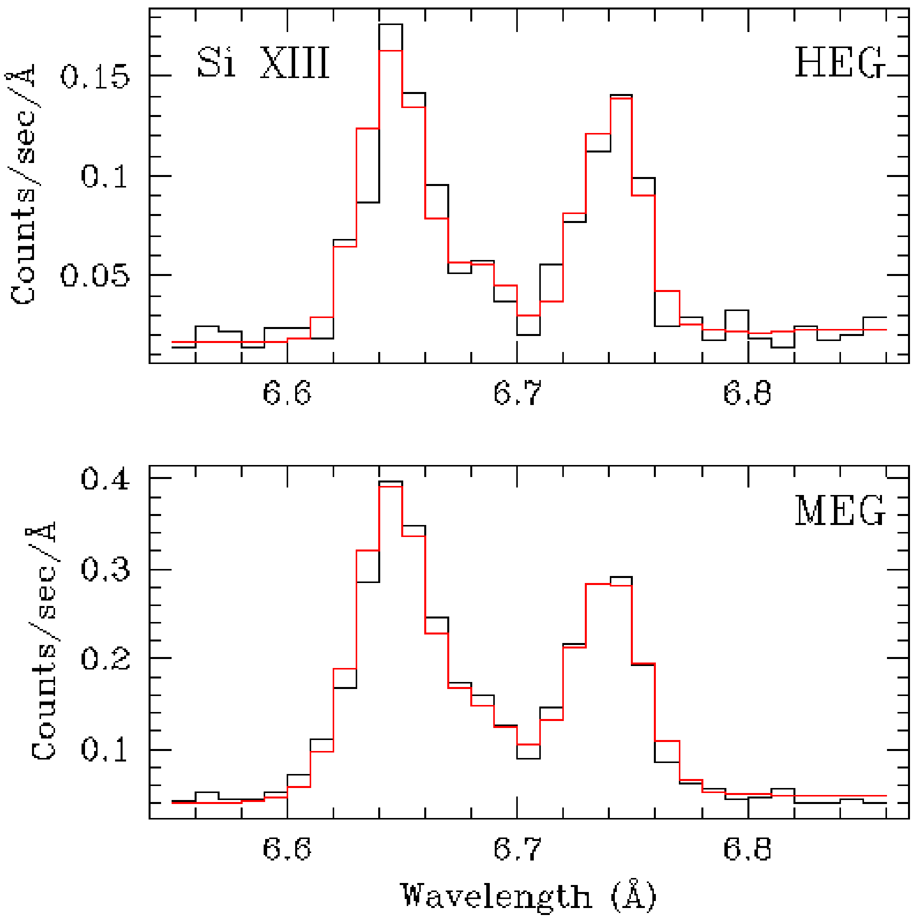
- *Chandra* & *XMM-Newton* gratings can resolve line shifts/widths down to a few hundred km s^{-1}
  - Probe dynamics of wind-wind collision
- Forbidden-intercombination-resonance (*f*-*i*-*r*) triplets from He-like ions
  - Diagnostics of electron density, UV radiation field & temperature
- New insights into location, geometry, structure and dynamics of wind-wind collision

Chandra observation of γ^2 Velorum (WC8+O7.5)



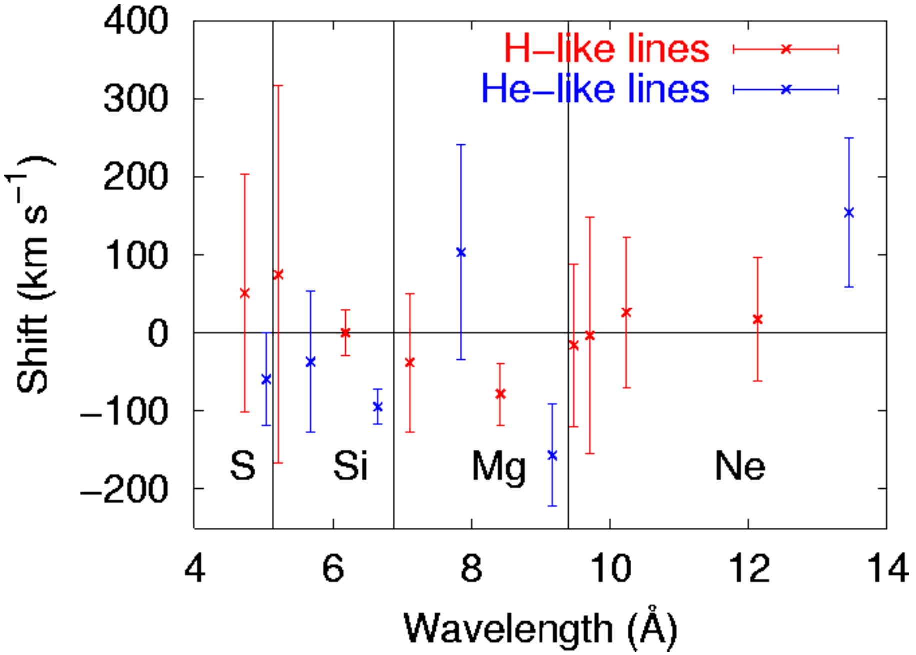
Observation length: 65 ks

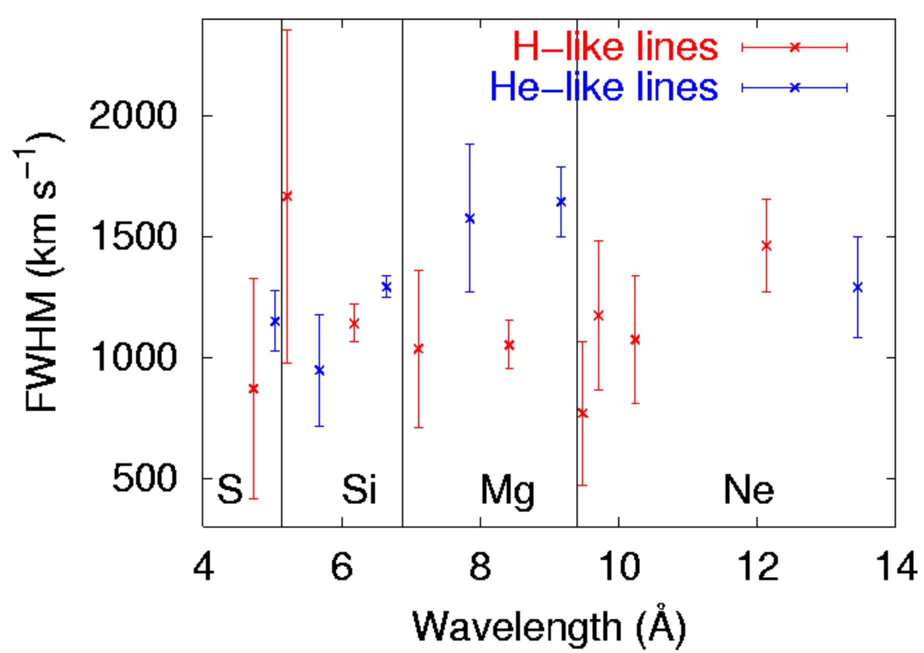
γ^2 Velorum (2) – Line fitting procedure



- Select narrow wavelength range around line of interest
- Fit to line using Gaussian line profile(s)
- Measure line centroid shifts and line widths

γ^2 Velorum (3) – Line fitting results





- Lines generally unshifted
- Mean FWHM = 1200 km s^{-1}
- No correlation with ionization potential or wavelength

γ^2 Velorum (4) – Geometrical model for line profiles

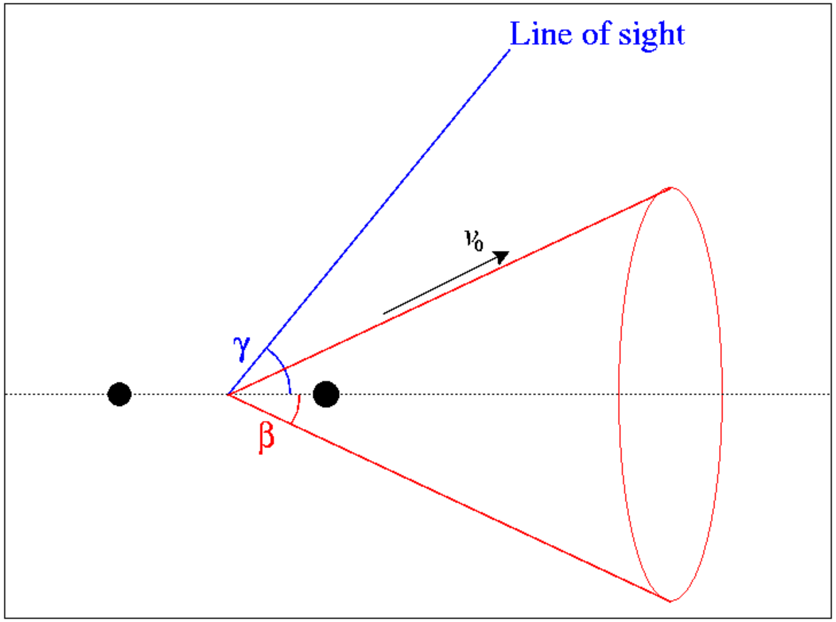
- Assume X-ray emission region is a conical surface
- Line centroid shift:

$$v = -v_0 \cos\beta \cos\gamma$$

- Line width:

$$\mathrm{FWHM} = v_0 \sin\beta \sin\gamma$$

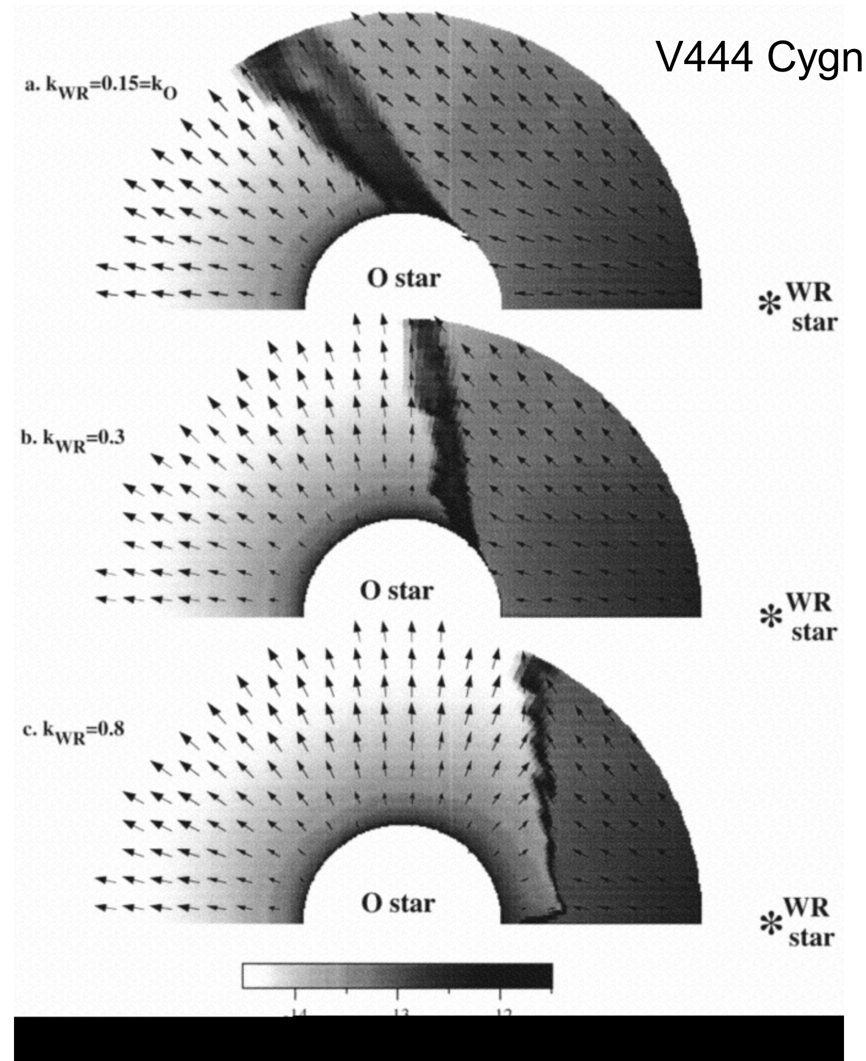
- γ well-known from orbit
- Find that $\beta > 85^0$
- Evidence of sudden radiative braking?



γ^2 Velorum (5) – sudden radiative braking

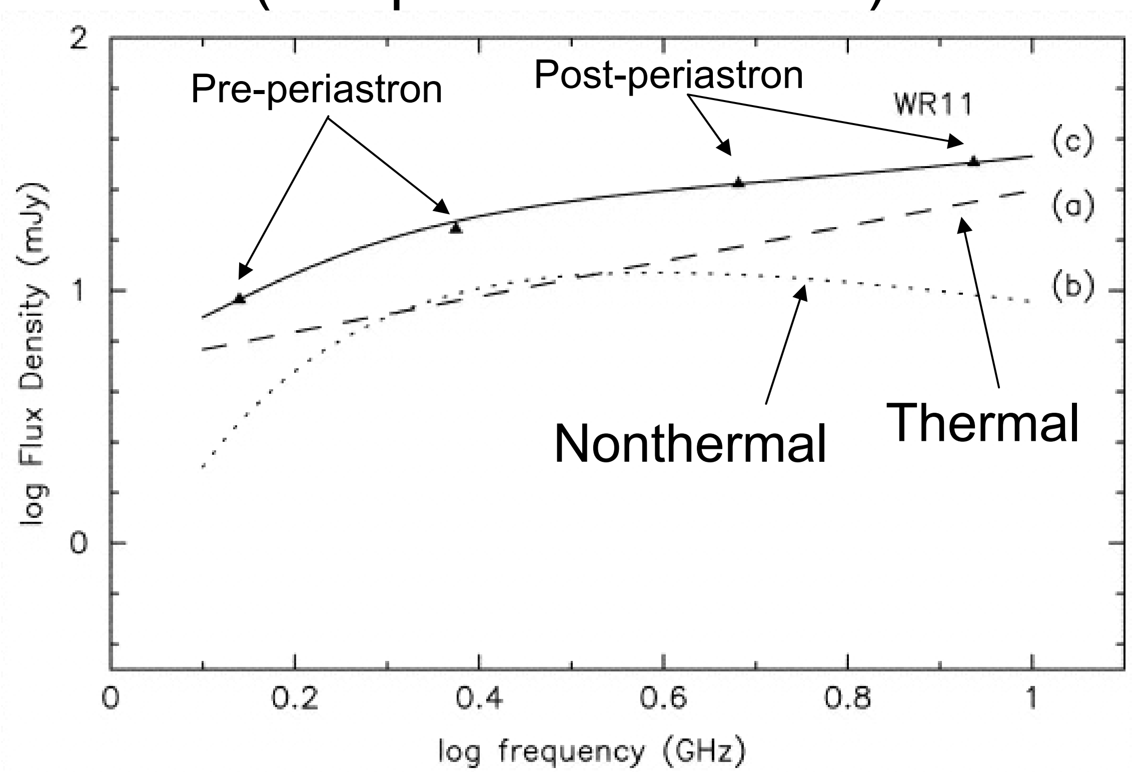
(Owocki & Gayley 1995; Gayley et al. 1997)

- Wind of WR star rapidly decelerated as it encounters O star radiation field
- Increases shock opening angle
- Alters Mach number of wind-wind collision
- As well as affecting X-ray emission, may also affect nonthermal radio emission
  - Spectral index depends on electron energy distribution, which depends on shock compression ratio
  - Variability of nonthermal radio flux depends on shock opening angle (absorption effects)



γ^2 Velorum (6) – ATCA radio observations

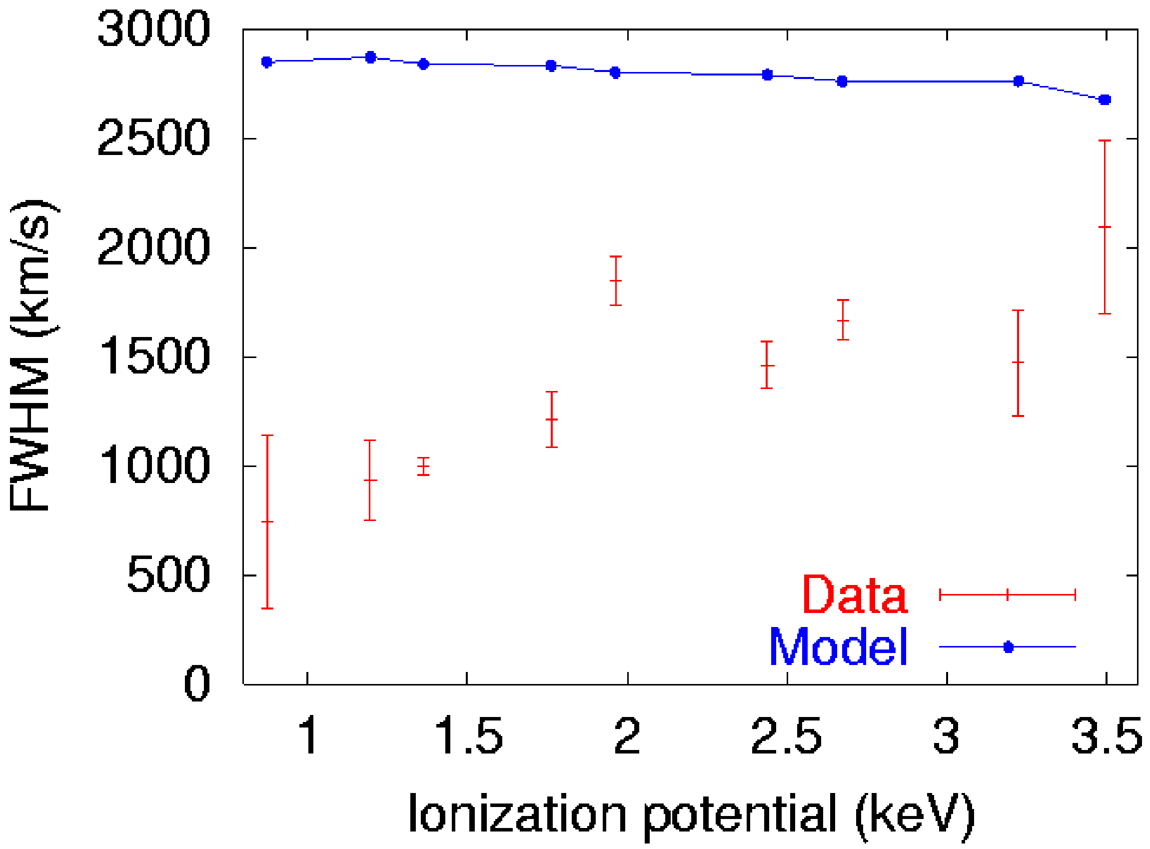
(Chapman et al. 1999)

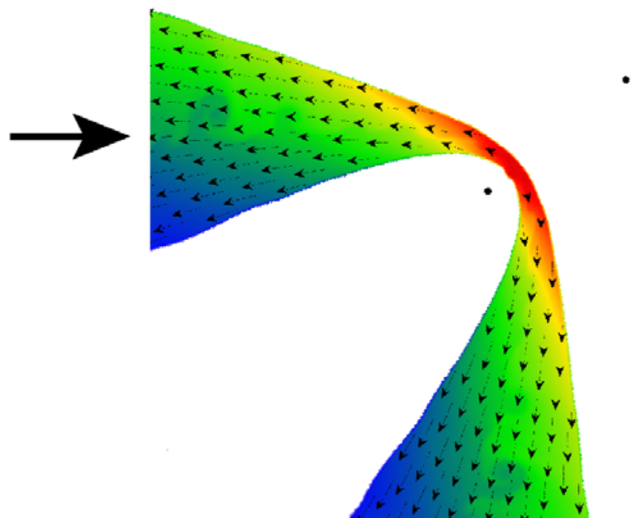


- Modelled using thermal + nonthermal emission
- Data taken at different orbital phases
- Optical depth for nonthermal emission varies throughout orbit (depends on shock opening angle)
- Better orbital coverage (Dougherty et al.) shows no evidence of nonthermal emission

WR 140 (WC7 + O4.5)

Chandra grating data (Pollock et al., in prep.)





- Correlation between line widths and ionization potential
- Disagrees with predictions of numerical model
- Evidence of non-equilibirum ionization?
  (Higher-excitation ions originate in faster-moving gas further from line of centres)

WR 140 (2)

Spherical or disk-like winds?

- X-ray emission modelled assuming spherical winds
- White & Becker (1995) unable to explain radio light curve using spherical winds
  - They suggest that the WR star’s wind is disk-like
- Model of X-ray emission lines disagrees with *Chandra* observation
  - Maybe X-ray emission lines can be explained by a disk-like WR wind
- Radio emission – need to consider thermal + nonthermal emission
  - Maybe radio emission can be explained by spherical winds
- More detailed modelling of X-ray & radio required
- More spectral information from radio would also be useful

Conclusions

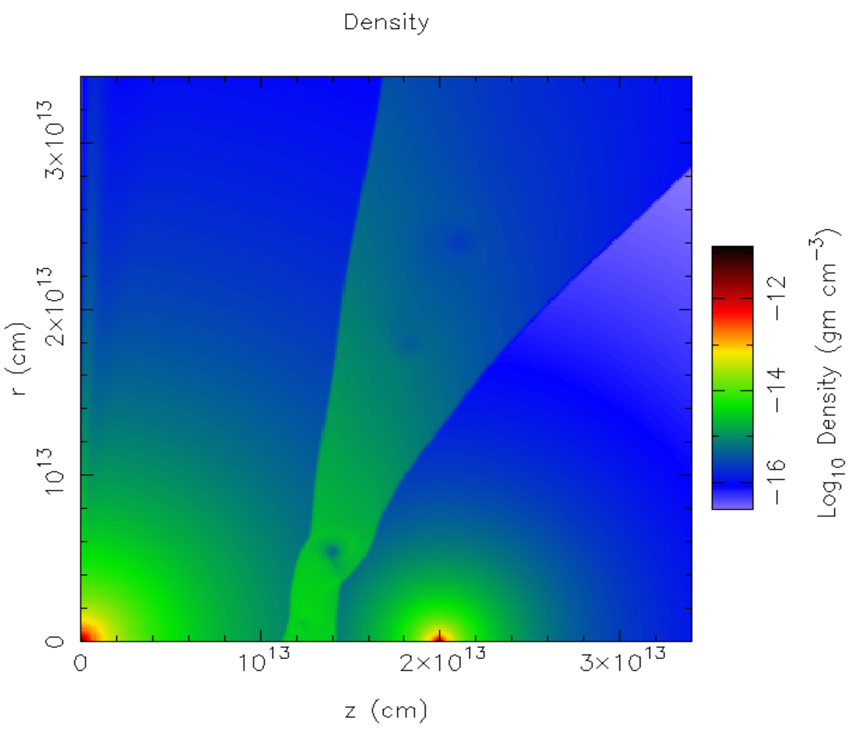
- High-resolution X-ray spectra probe structure & dynamics of wind-wind collision
- Provides information on shock geometry
- Shock opening angle influences variability of nonthermal radio emission

Final comment:

- Line emission generally considered to be thermal, but ions may also be excited by collisions with nonthermal electrons
- If relative abundance of nonthermal electrons is large, they will have to be included in the models

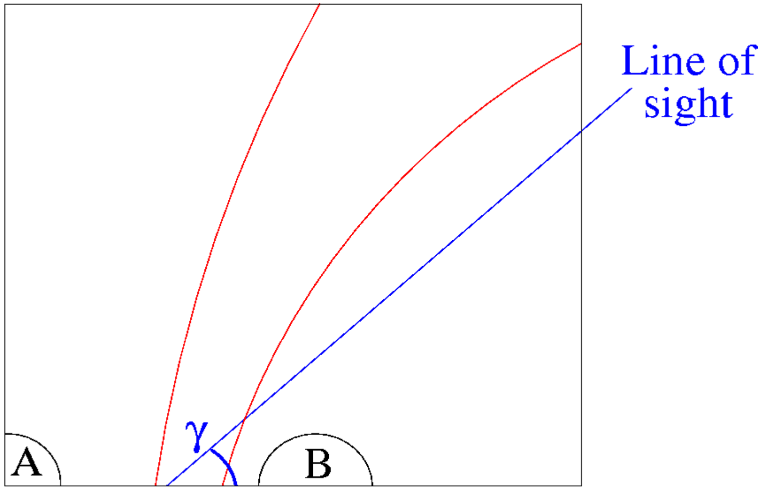
Modelling X-ray line profiles from CWBs

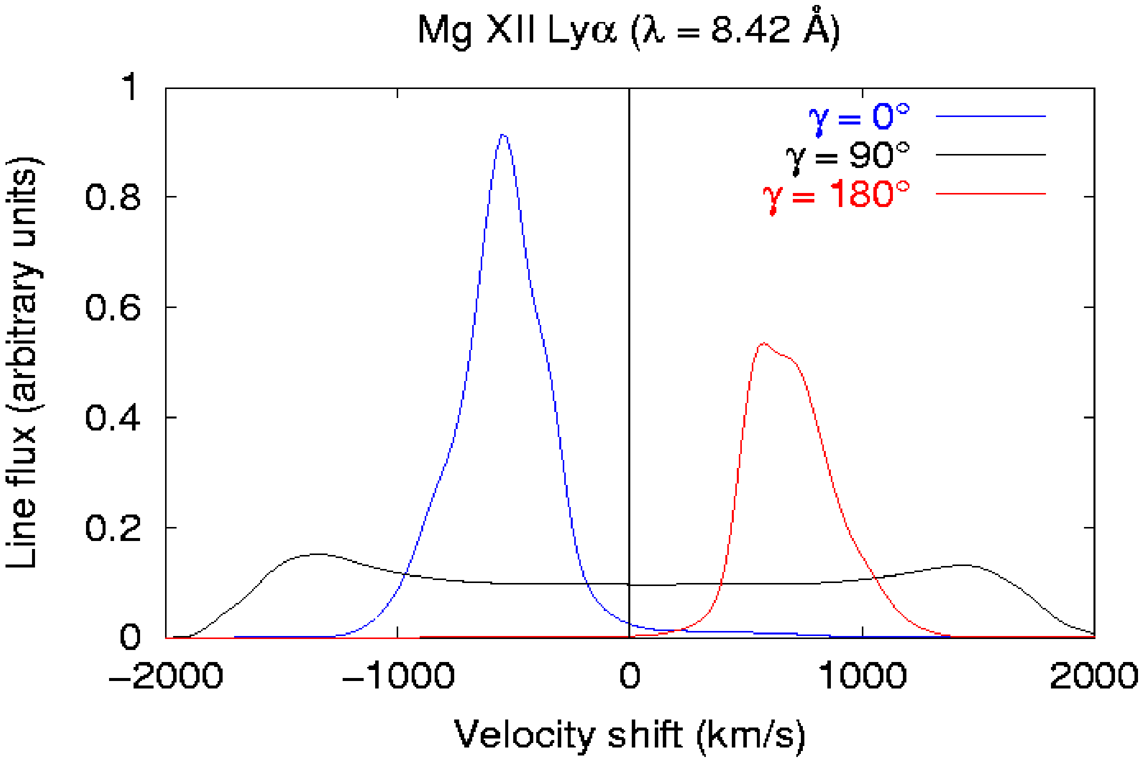
(Henley, Stevens & Pittard 2003)



- Line profile calculations based on hydro simulations
- Each grid cell produces Gaussian line profile
- Width of Gaussian depends on temperature
- Height of Gaussian depends on temperature, density and optical depth
- Sum over whole grid to get the observed profile

Orbital variability of X-ray line profiles





γ^2 Velorum (WC8+O7.5) – Basic parameters

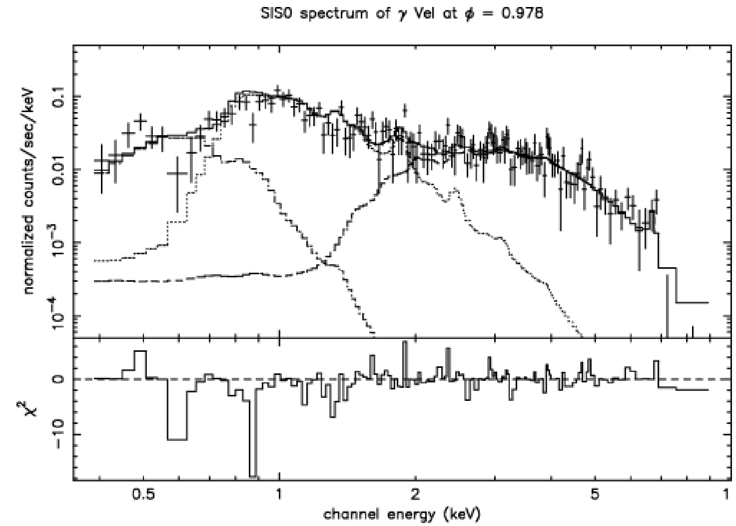
- Distance = 258 pc (*Hipparcos*)

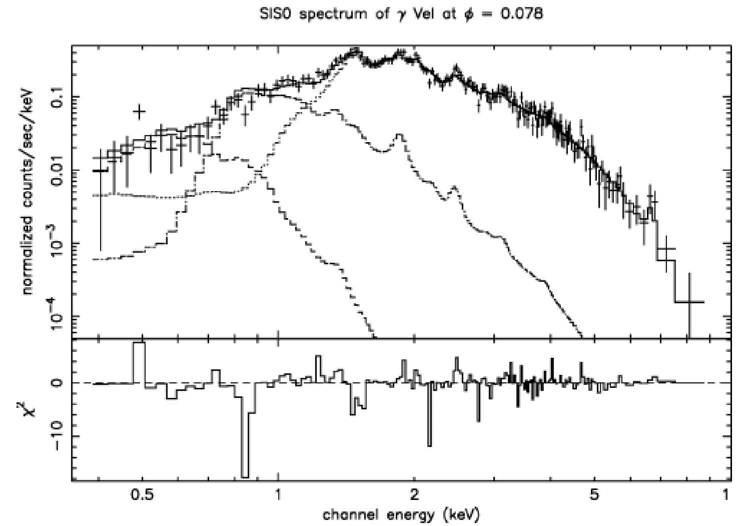
  [Evidence that it may be further away: 400 pc (Pozzo et al. 2000)]
- Period = 78.53 days, e = 0.326, i = 63^0

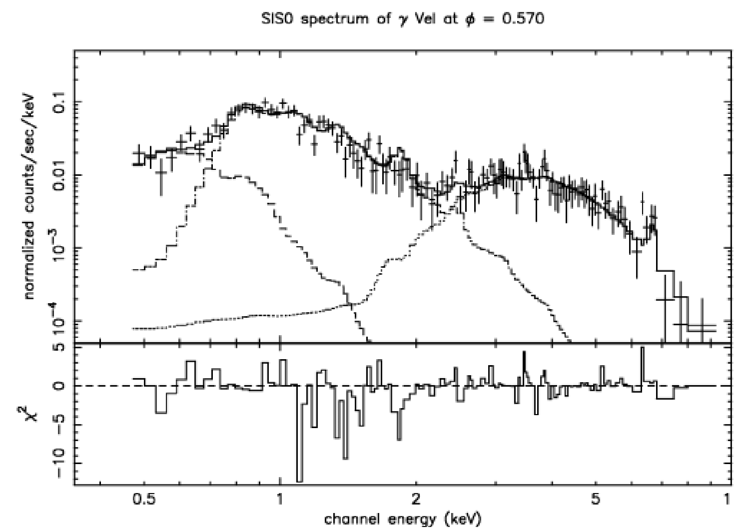
  (Schmutz et al. 1997, de Marco & Schmutz 1999)
- $L_X = 1.1 \times 10^{32}$ erg s^{-1} (absorbed)
- $L_X = 16 \times 10^{32}$ erg s^{-1} (intrinsic)

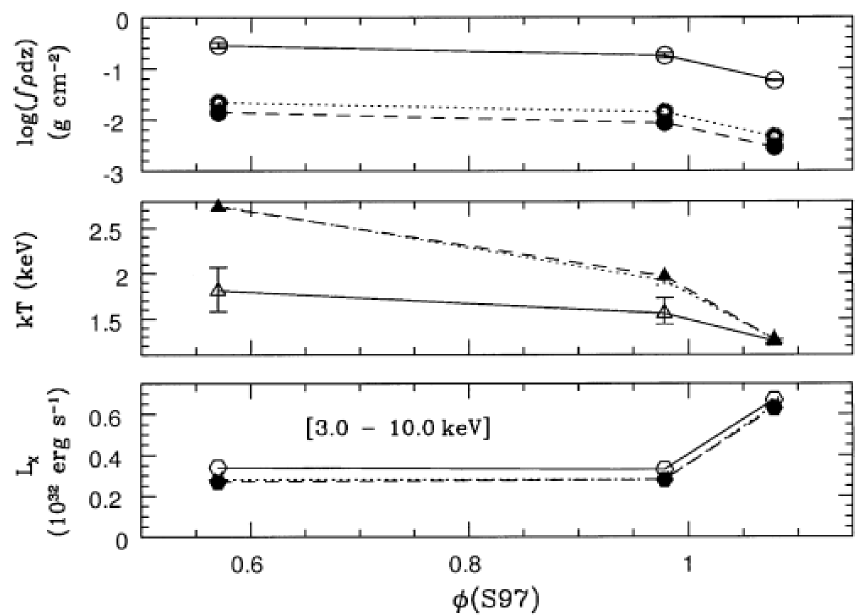
γ^2 Velorum – *ASCA* data

(Stevens et al. 1996, Rauw et al. 2000)

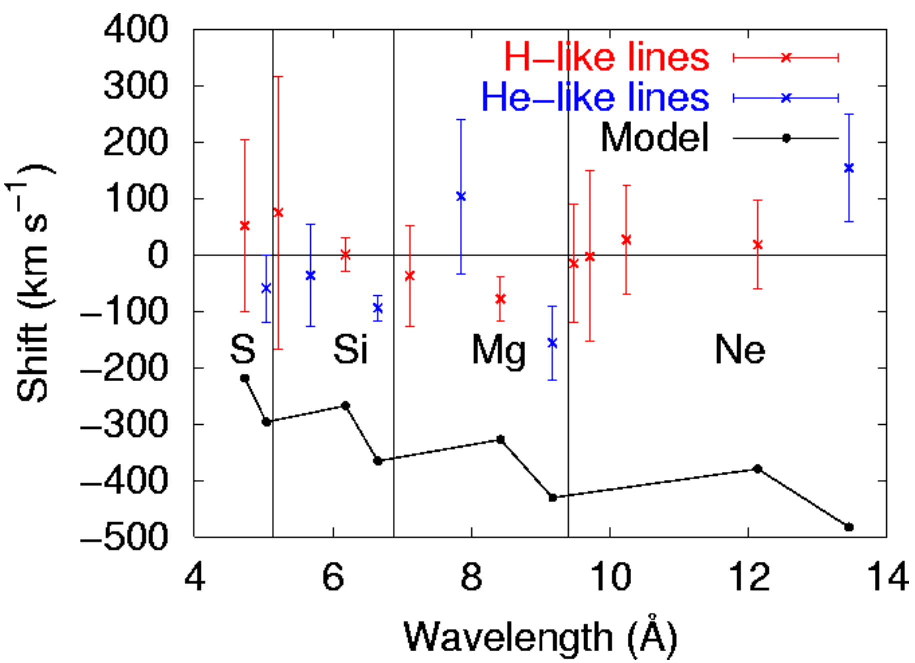


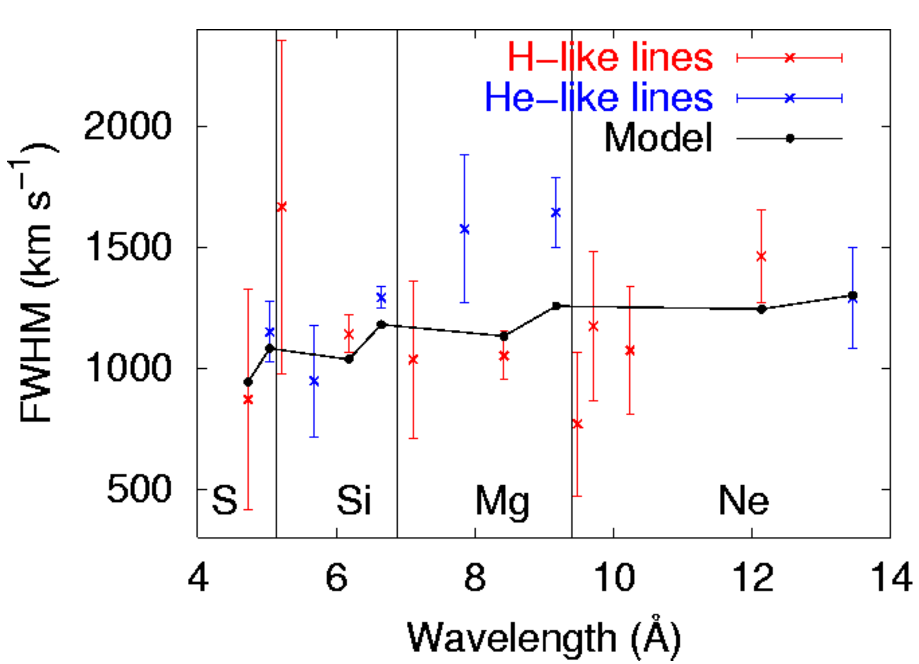


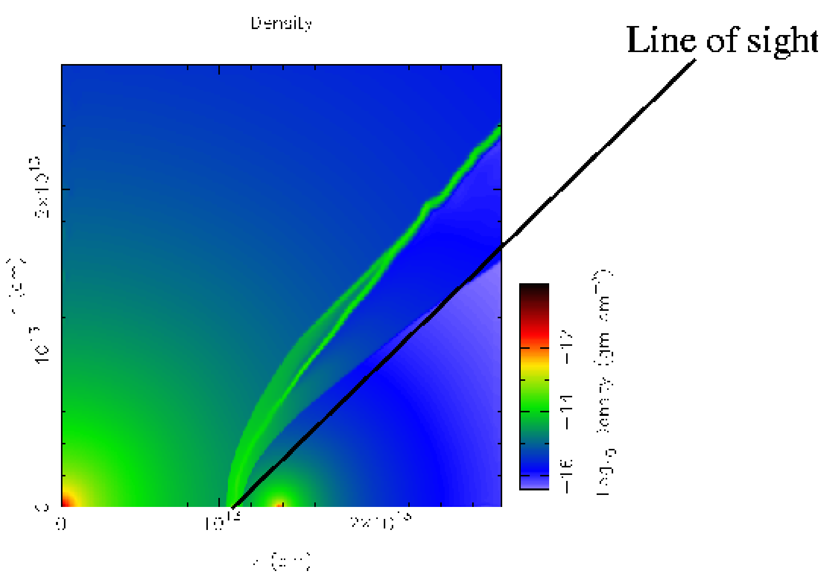




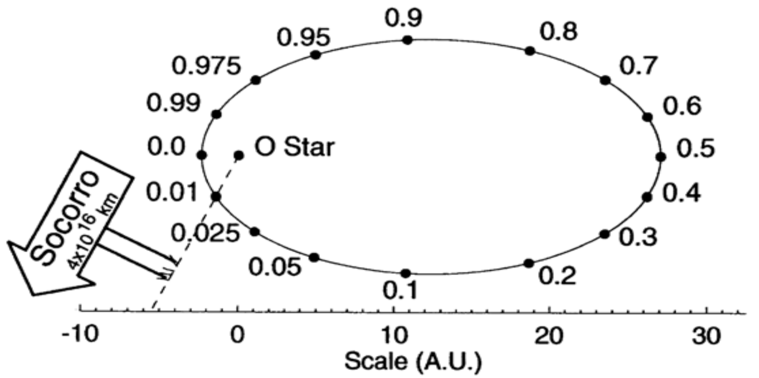
γ^2 Velorum – Line profile modelling

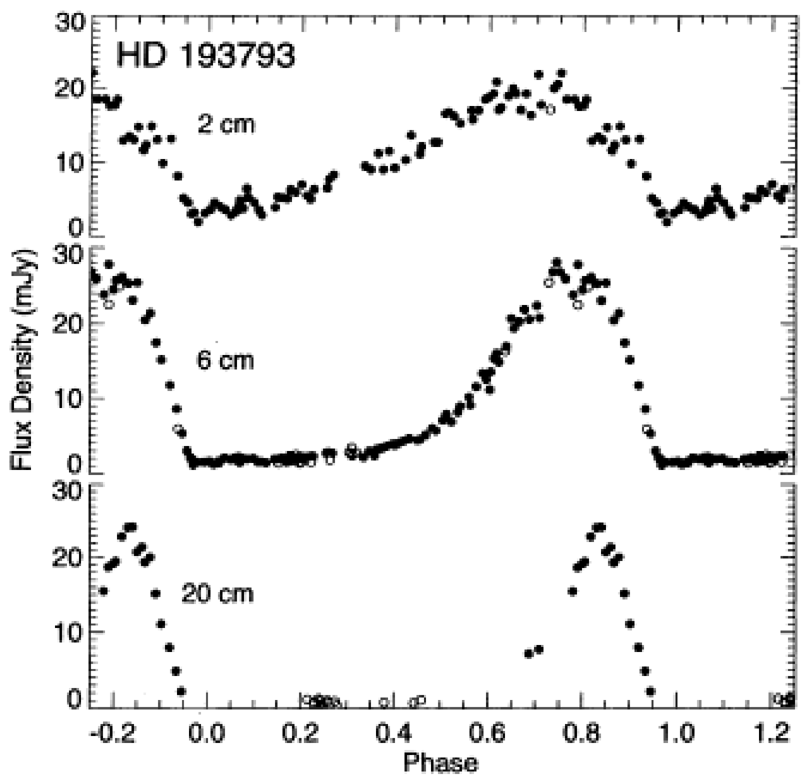


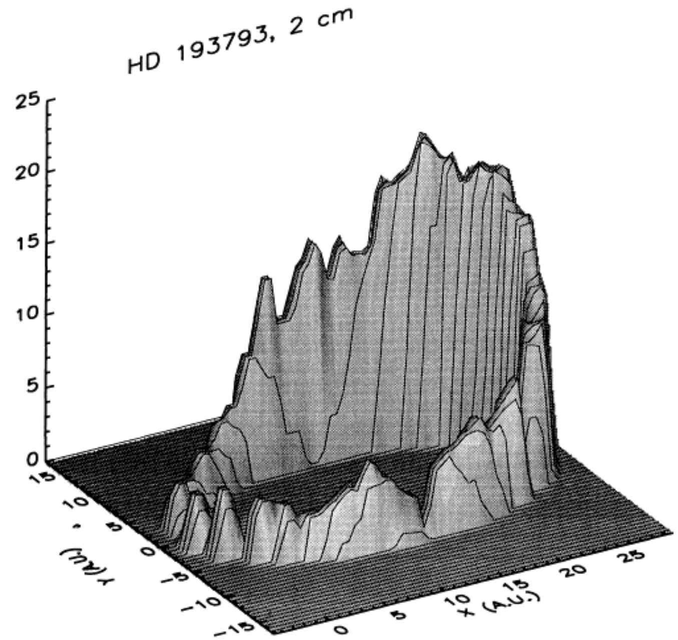


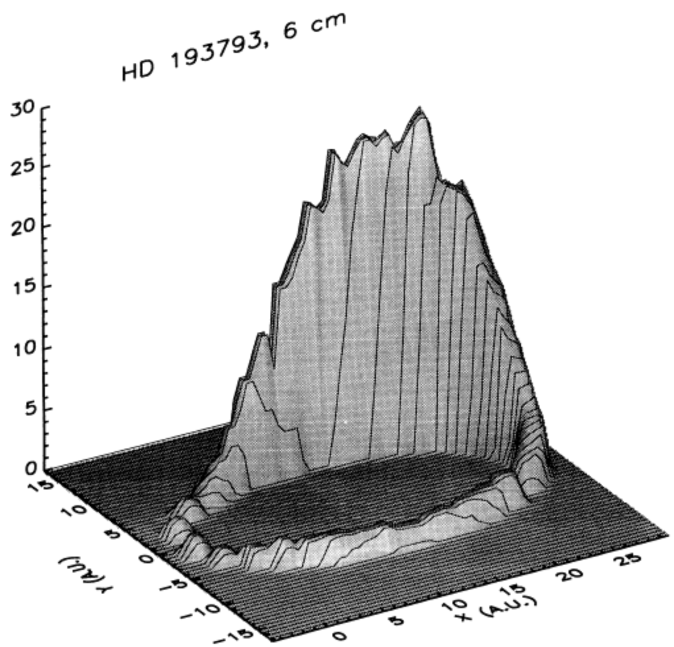


WR 140 VLA observations (White & Becker 1995)









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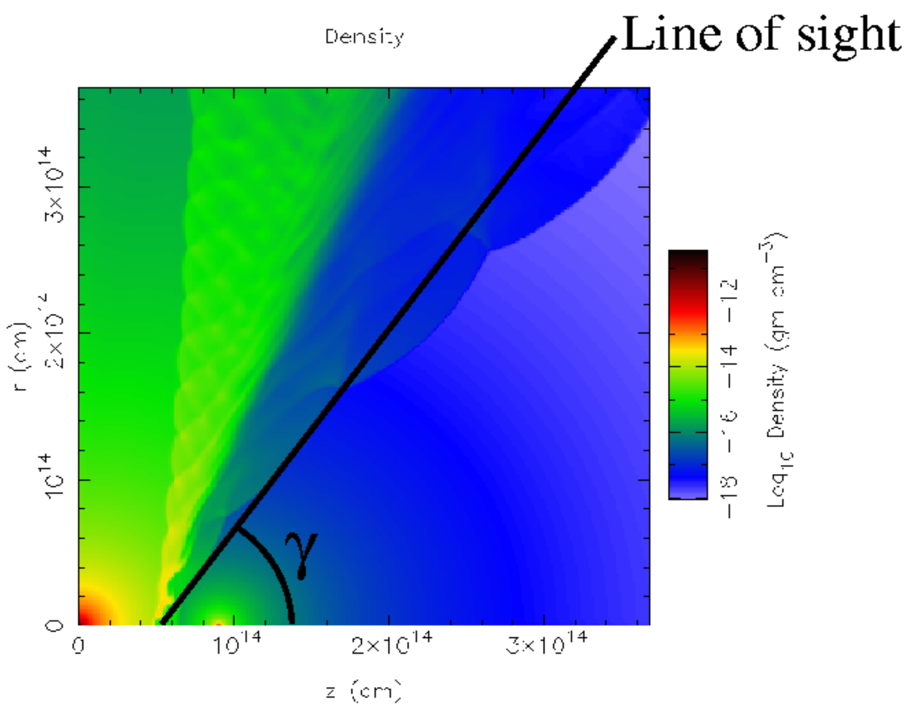

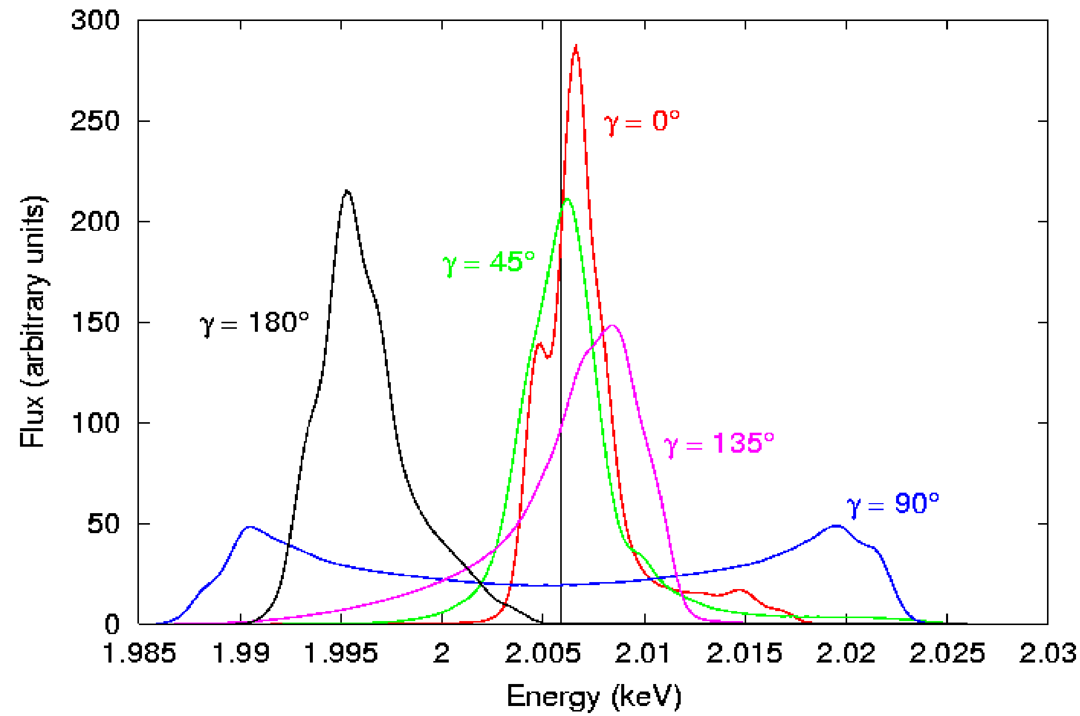

- Comparing model line profiles to set of *Chandra* grating observations
- Line shapes & variations provide important probe of shock dynamics
- Offers another tool for constraining parameters of this mysterious star