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 $\gamma^2$ Velorum (WC8+O7.5)

Observation length: 65 ks
γ² 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
$\gamma^2$ Velorum (3) – Line fitting results

- Lines generally unshifted
- Mean FWHM = 1200 km s$^{-1}$
- No correlation with ionization potential or wavelength
$\gamma^2$ Velorum (4) – Geometrical model for line profiles

- Assume X-ray emission region is a conical surface
- Line centroid shift:
  \[ \nu = -\nu_0 \cos \beta \cos \gamma \]
- Line width:
  \[ \text{FWHM} = \nu_0 \sin \beta \sin \gamma \]
- $\gamma$ well-known from orbit
- Find that $\beta > 85^0$
- Evidence of sudden radiative braking?
γ² 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)
\( \gamma^2 \) 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
Correlation between line widths and ionization potential

Disagrees with predictions of numerical model

Evidence of non-equilibrium 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

Mg XII Lyα (λ = 8.42 Å)

Line of sight

Velocity shift (km/s)

Line flux (arbitrary units)
\( \gamma^2 \) Velorum (WC8+O7.5) – Basic parameters

- Distance = 258 pc \((\text{Hipparcos})\)
  
  [Evidence that it may be further away: 400 pc \((\text{Pozzo et al. 2000})\)]

- Period = 78.53 days, \(e = 0.326, i = 63^\circ\)
  
  \((\text{Schmutz et al. 1997, de Marco & Schmutz 1999})\)

- \( L_X = 1.1 \times 10^{32} \text{ erg s}^{-1} \) (absorbed)

- \( L_X = 16 \times 10^{32} \text{ erg s}^{-1} \) (intrinsic)
$\gamma^2$ Velorum – ASCA data
(Stevens et al. 1996, Rauw et al. 2000)
$\gamma^2$ Velorum – Line profile modelling

- H–like lines
- He–like lines
- Model

![Graph showing line profile modelling results for $\gamma^2$ Velorum with shifts and FWHM measurements for different elements like S, Si, Mg, and Ne across a wavelength spectrum.](image)
WR 140 VLA observations (White & Becker 1995)
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