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Mapping the Large-Scale Structure of Colliding Wind Interaction Regions with Forbidden Emission Lines

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Introduction

Massive O and Wolf-Rayet (WR) stars have dense, fast stellar winds. When appearing in binary systems, colliding wind interactions (CWIs) lead to a variety of multi-wavelength and cyclic phenomena in both continuum and wind lines that can be used to study the binary, stellar, and wind propeties. Forbidden lines are optically lines that form at large radii in the winds, typically where the wind density is comparable to the critical density, n_c. The critical density is where collisional and radiative de-excitation rates are equal. It is also where the emissivity transitions from linear in density, to quadratic.

Forbidden Lines in Stellar Wnds

The focus here is WR+OB binaries in which the WR component is solely responsible for the forbidden line formation, owing to a combination of being of higher density, higher ionization, and/or strongly non-solar abundances (such as Ne enhancement).

Ion	λ (μm)	n_c (10^4 cm^{-3})
Ca IV	3.2	1200
Ne II	12.8	65.0
Ne III	15.6	12.6
S IV	10.5	5.6
O IV	32.6	5.2
Ne V	14.3	4.6
S III	18.7	2.1
Si III	38.2	0.13

Line emissivity:

$$j_\nu \propto \frac{n_e/n_c}{a+bn_e/n_c}$$

This ranges from $j_n \sim n$ for densities above critical (inner wind), to $j_n \sim n^2$ for low densities (outer wind).

Winding Radius:

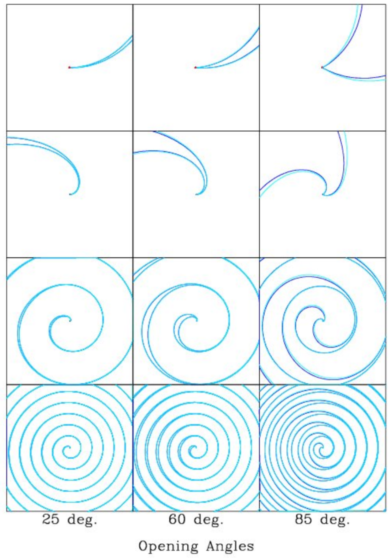
$$\frac{r_w}{a} = \frac{v_\infty}{\Omega_{orb} a}$$

This is the characteristic distance for which the rate at which the wind moves out radially equals the angular speed of the orbit.

- When r_w is large compared to the orbit size, the CWI is conical on the scale of the orbit.
- When r_w is small, spiral curvature begins close to the companion star.

Acknowledgements

This work is based on Ignace, Bessey, Price, 2009, MNRAS, 395, 962

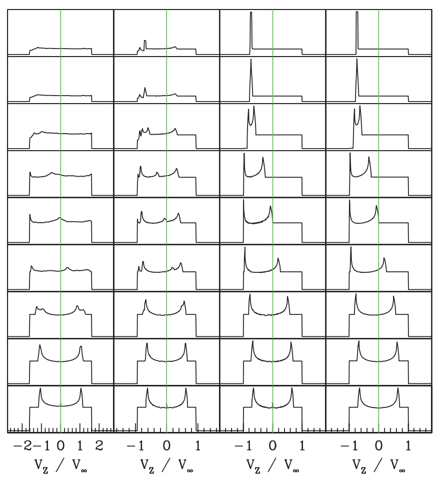


Left: Model CWIs for an eccentric binary for 3 different opening angles of the spiral. Dark and light blue demarcate the postshock "sheath" zone.

Wind and binary parameters for γ Vel.

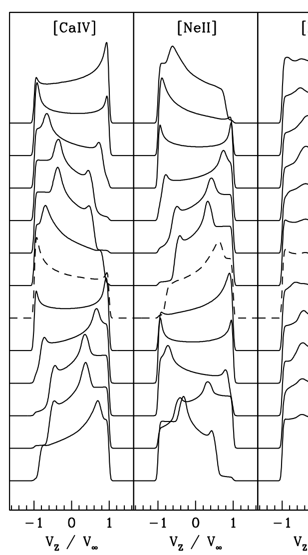
WR 11[a] = γ Vel	WC8+O7.5
$\dot{M}$	9×10^{-6} M$_\odot$ yr^{-1}
v_∞	1550 km s^{-1}
R_*	3.2 R$_\odot$
μ_e	4.5
D_{cl}	10
$n_{0,e}$	7.8×10^{11} cm^{-3}
ϵ	1/33
Orbit[b]	
d	336 pc
P	78.53 d
a	1.2 au
e	0.334
i	65°.5
Interaction region	
φ_*^c	0.28
β^d	85°
r_w	750 R_* rad°
r_w/r_c (Ca IV)	4.2
r_w/r_c (Ne II)	0.68
r_w/r_c (Ne III)	0.36
r_w/r_c (S IV)	0.13

[a] de Marco et al. (2000).
[b] North et al. (2007).
[c] T_0 = 50120.4 MJD and *ISO* data of γ Vel were obtained on T = 50 220.9836 MJD, hence the O star was at orbital phase 0.28.
[d] Henley et al. (2005).



Left: Idealized forbidden emission line profiles for a circular orbit. Column 1 for a 1 year orbit; Column 2 for 100 years; Column 3 for 10,000 years; Column 4 for a stationary binary with a strictly conical CWI. From top to bottom, the viewing inclination is 0, 2, 10, 30, 45, 60, 88, and 90 degrees.

Right: Model profile shapes with orbital variations for the indicated forbidden lines using parameters for the binary γ Vel (see table at top). The dashed line is close to an orbital phase in which the system was observed with ISO.



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