γ^2 Velorum: combining interferometric observations with hydrodynamic simulations

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Studying stellar winds through colliding wind binaries

Different stars, evolutionary stages $\rightarrow$ different winds

Massive stars (O, B, WR) $\rightarrow$ Radiation pressure on lines

- $v_\infty \simeq 2000\,\mathrm{km\,s^{-1}}$
- $10^{-8} M_\odot\,\mathrm{yr}^{-1} < \dot{M} < 10^{-4} M_\odot\,\mathrm{yr}^{-1}$
- Temperature$\simeq$ 30-70kK

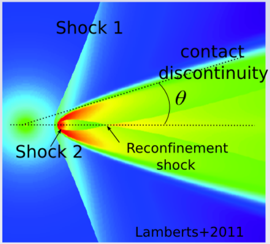
Why study colliding stellar winds?

- Winds important for stellar evolution
- Winds important for interstellar medium
  - Chemical enrichment
  - Energy injection comparable to supernova explosion
- Large fraction of massive stars are in binary systems

Observational clues and open questions

- thermal X-ray emission
- line variability (IR→ X-rays)
- non-thermal radio emission
- infrared emission if dust

→ wind structure at given distance



Questions

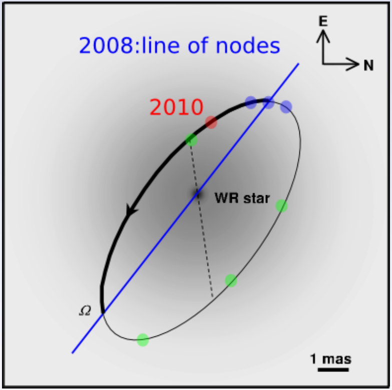
- Explain structure of CWB (radiative effects, instabilities...)?
- Explain variability ?
- Explain dust formation (too hot, too much UV...) ?

The binary γ^2 Velorum

closest WR star: WC 8 + O6
P=78 d, e=.3, i=65^o

- Radio obs: $\dot{M}_{WR}$
- IR : no dust production
- optical/UV: detection of wind collision region, probably with radiative braking (StLouis+1993; DeMarco+2002)
- X-rays: high T shocked region (Willis+1995;Henley+2005)

Most observations dominated by WR wind

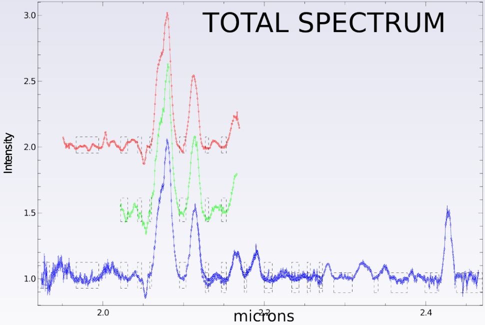


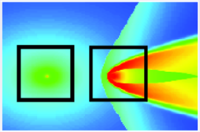
Observed orbital phases (Millour, Lamberts,+ in prep)

First interferometric data

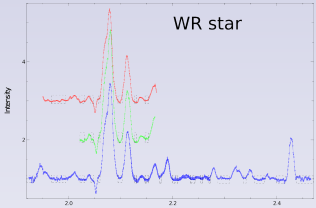
AMBER/VLTI observations: J, H, K bands, $\Delta\lambda_{max}/\lambda = 12000$.
low resolution full orbital coverage+high resolution, high SNR data
Provides spatial information: brightness ratio, angular sizes (continuum + lines), isolation of O-star spectrum

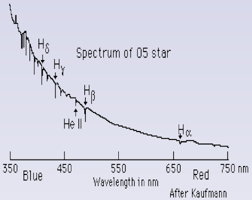
(Millour, Lamberts,+ in prep)

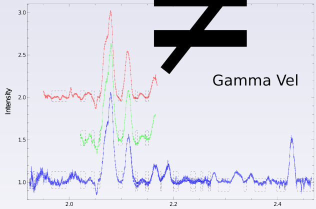




Interferometric data







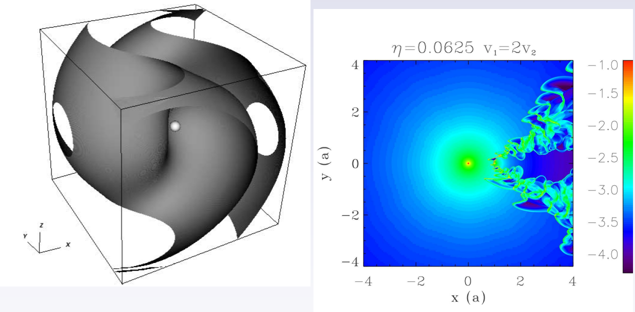
Model with WR and O with not sufficient

$\rightarrow$ wind collision region?

$\rightarrow$ possibility to constrain large scale structure of wind if collision region well understood

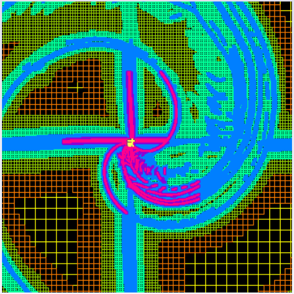
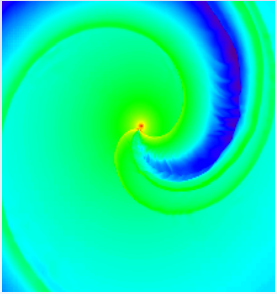
The power of hydro simulations

- Large scale, time-variable multi-D structure (e.g. Walder+2003; Lemaster+2007)
- Various instabilities (Stevens+1992; Pittard+2009)



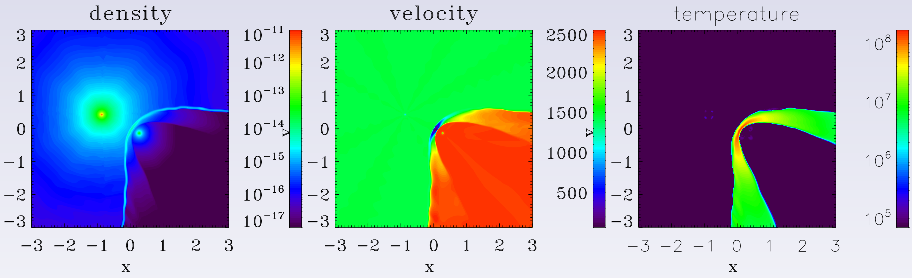
3D structure (Lemaster+, 2007) / Instabilities (Lamberts+, 2011)

RAMSES (Teyssier, 2002; Fromang et al, 2006) solves the Euler equations
Adaptive Mesh Refinement: Local increase of resolution according to gradients → well-suited for discontinuities

AMR map : $l_{min} = 7$, $l_{max} = 16$ and density map

Simulation: $L_{box} = 6a, 3D, N_{max}$=$512^3$, with cooling and orbital motion

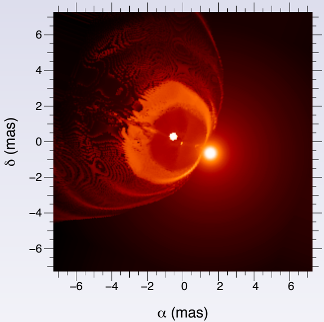


(Millour, Lamberts + in prep)

Limited development of instabilities
Cooling important in WR wind

Collision region emission 2 μm

Postprocessing: free-free emission and absorption



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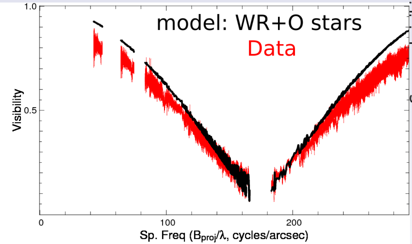
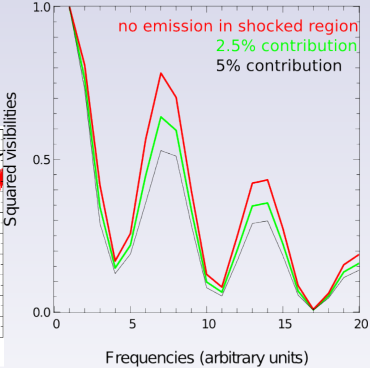
Shocked structure contributes to continuum emission

Visibility curves

Visibility → spatial extension of system





(Millour, Lamberts + in prep)

Estimates of visibility depend on contribution of wind collision region → consistent with observations

Conclusions

To remember

- γ^2 Vel closest WR binary$\rightarrow$ ideal target
- Combining interferometric observations with hydro model $\rightarrow$ confirm presence of colliding wind region

To do

- Complete visibility study
- Study line emission
- confirm radiative braking
- constrain WR wind at large distance