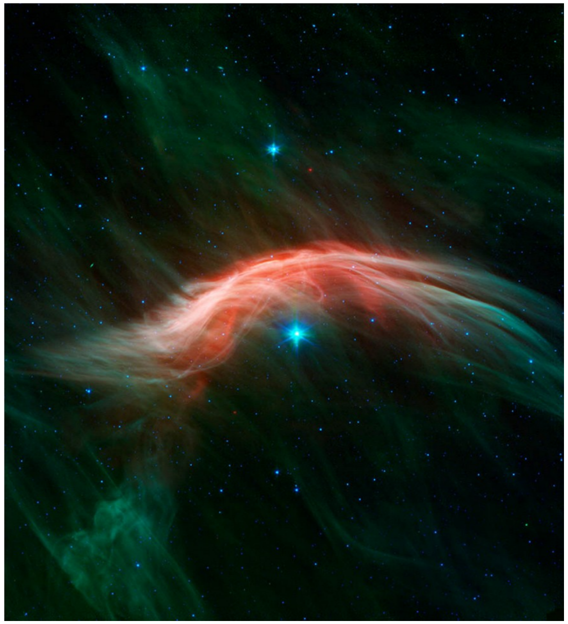
The circumstellar medium of runaway massive stars

Dominique M.-A. Meyer

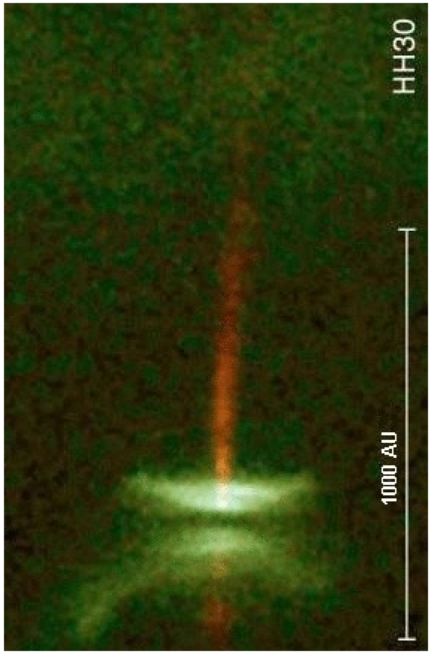
ZetaOphiuchi © Wise/Nasa/Caltech

The circumstellar medium



Bow shock

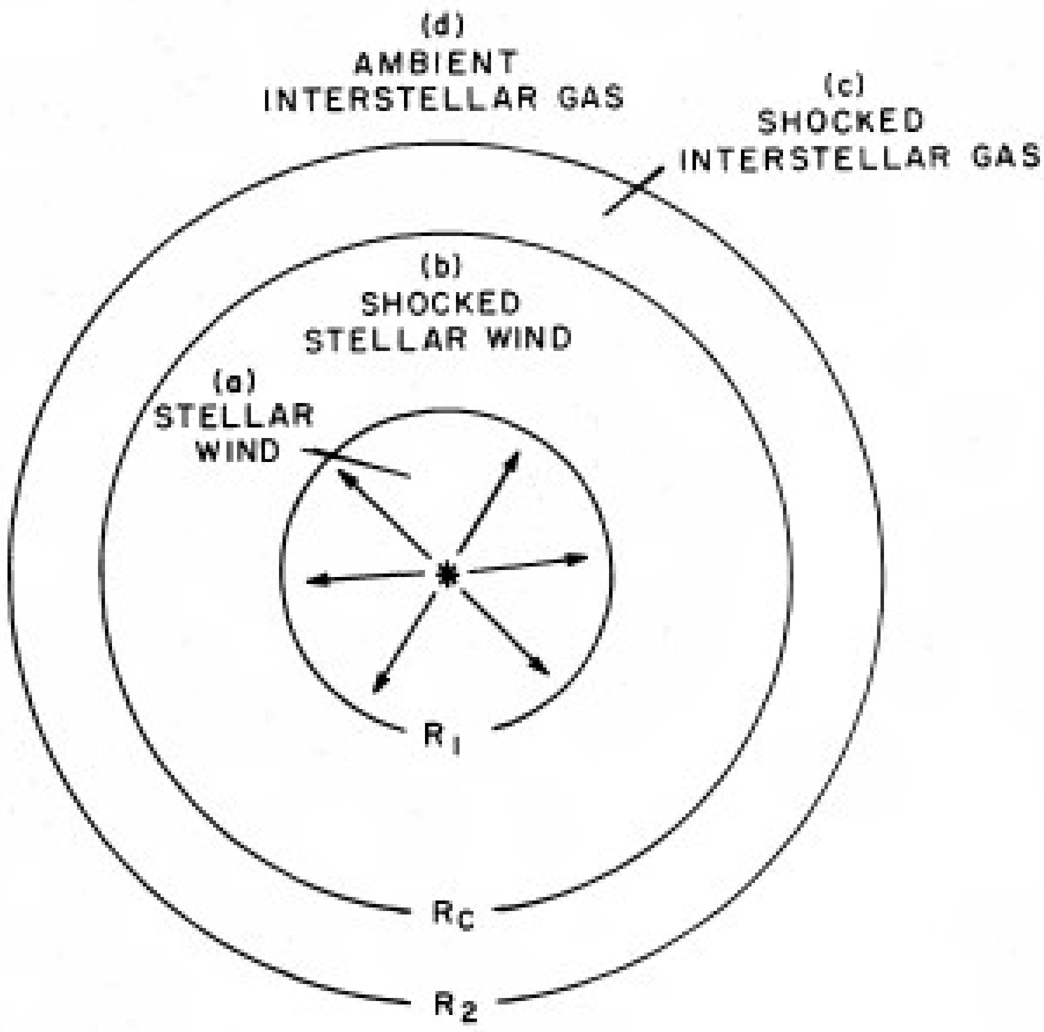
Bubble



Disc

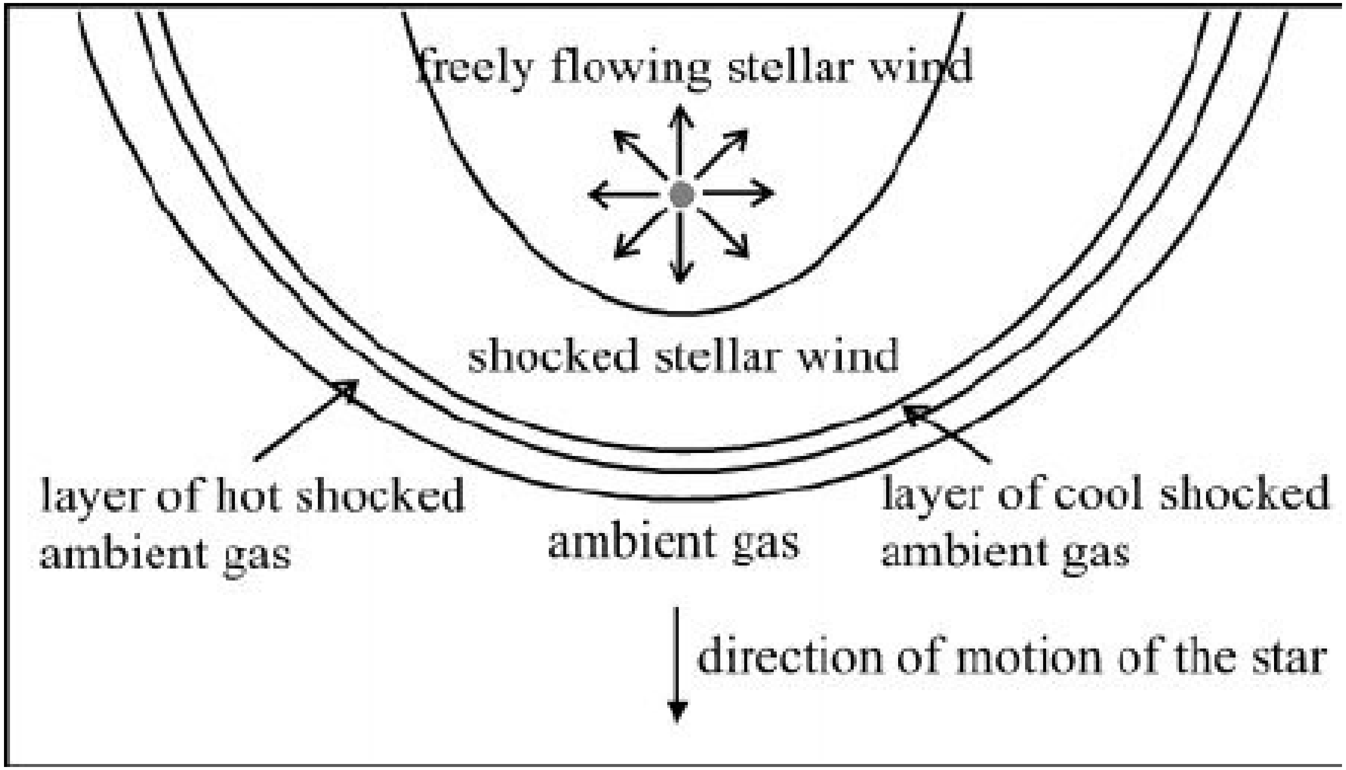
The part of the interstellar medium constituting the close surroundings of stars and influenced by their feedback.

Stellar wind bubbles



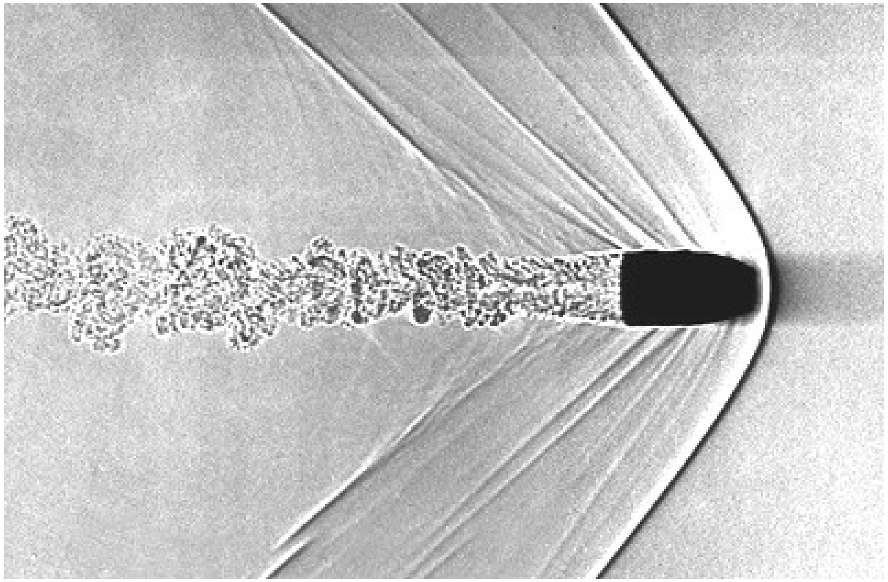
Weaver et al. (1977)

Stellar wind bow shocks

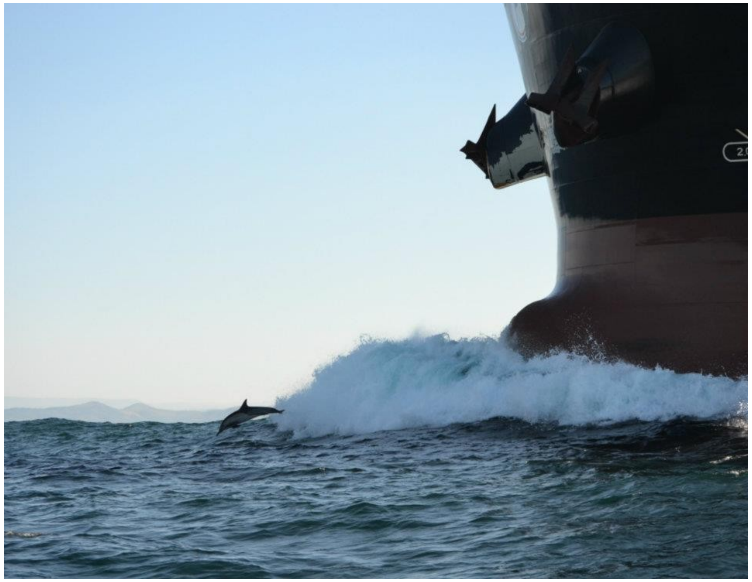


Kaper et al. (1997)

Bow shocks are ubiquitous



Bullet



Ship

Plane

Behind a bow shock/wave is a wake

Duke in Bodensee

Guadeloupe's island

Some runaway stars have observed bow shocks

K-Cassiopeiae, NASA/Spitzer

Mira, NASA/JPL-Caltech

Z-Ophiuchi, NASA-Caltech/WISE team

We observe and model the wind nebulae of massive stars to know:

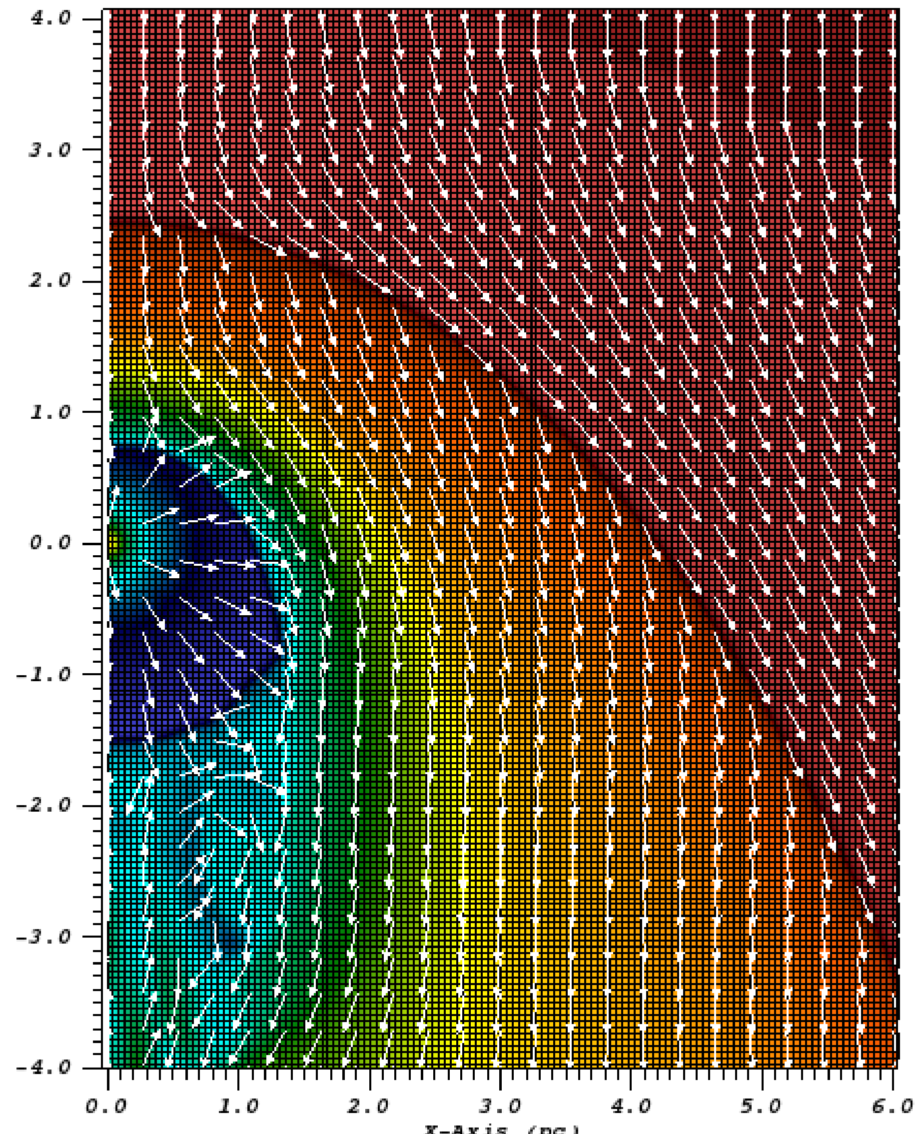
- the stellar wind properties,
- their ambient medium properties,
- the feedback of massive stars and their subsequent supernovae.

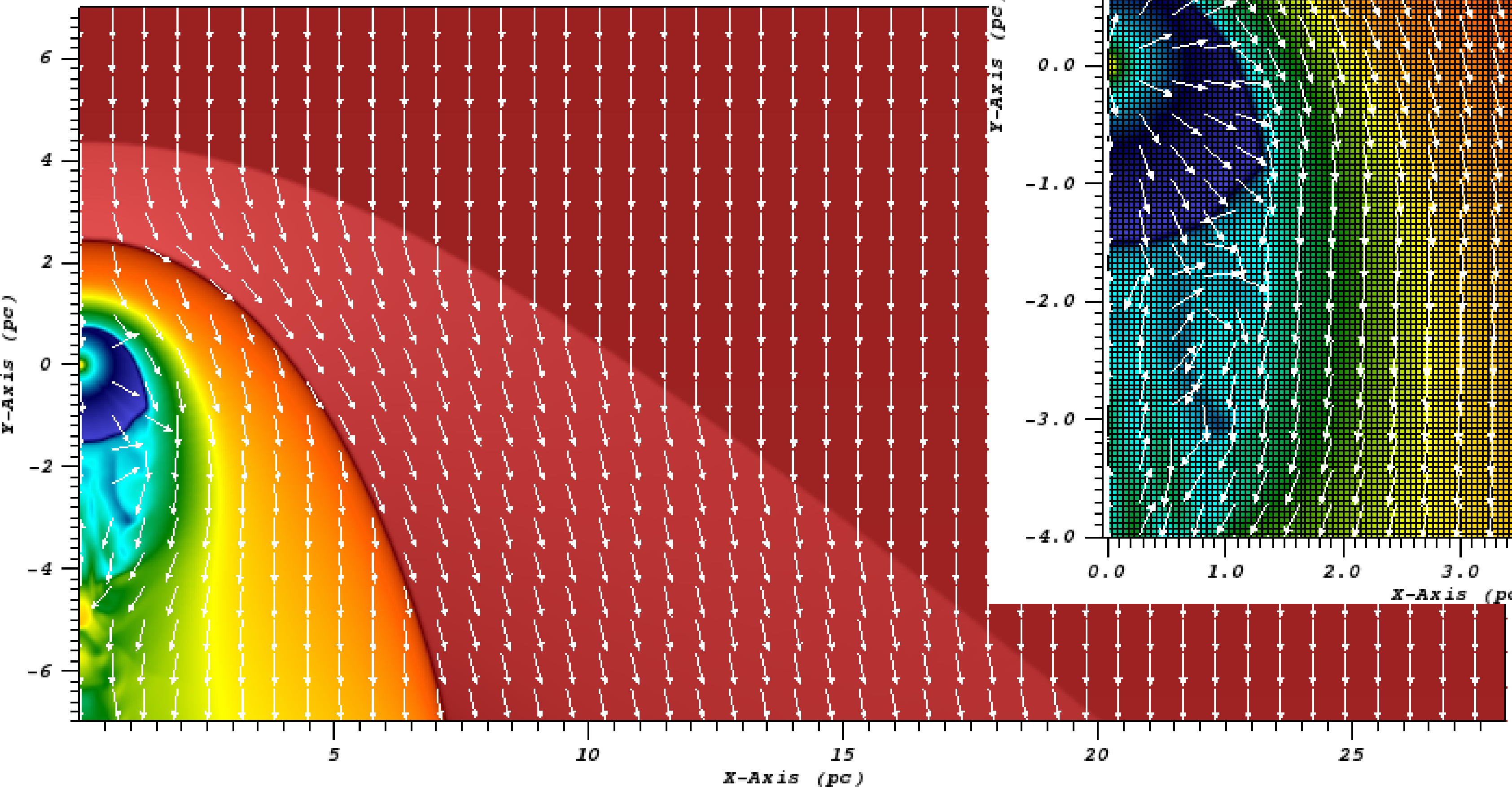
2.5D modelling with PLUTO

- 2D axi-symmetric hydrodynamical models,

  PLUTO code (Mignone et al. 2007, 2012),
  Optically-thin cooling, heating,
  Thermal conduction,

- Evolving stellar winds (Brott et al. 2011),



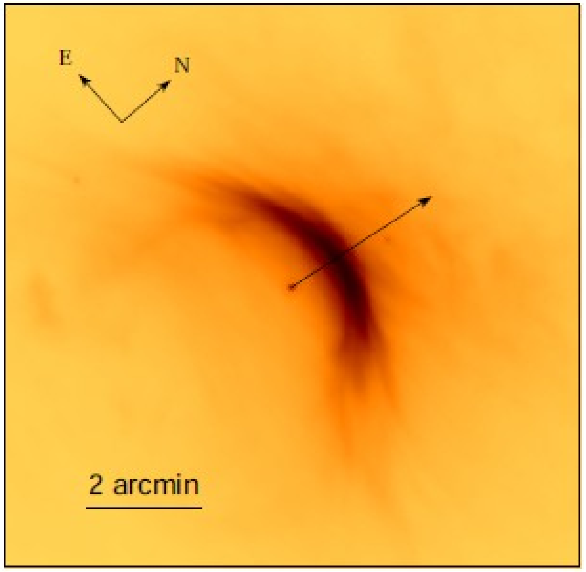


Bow shock of hot runaway stars

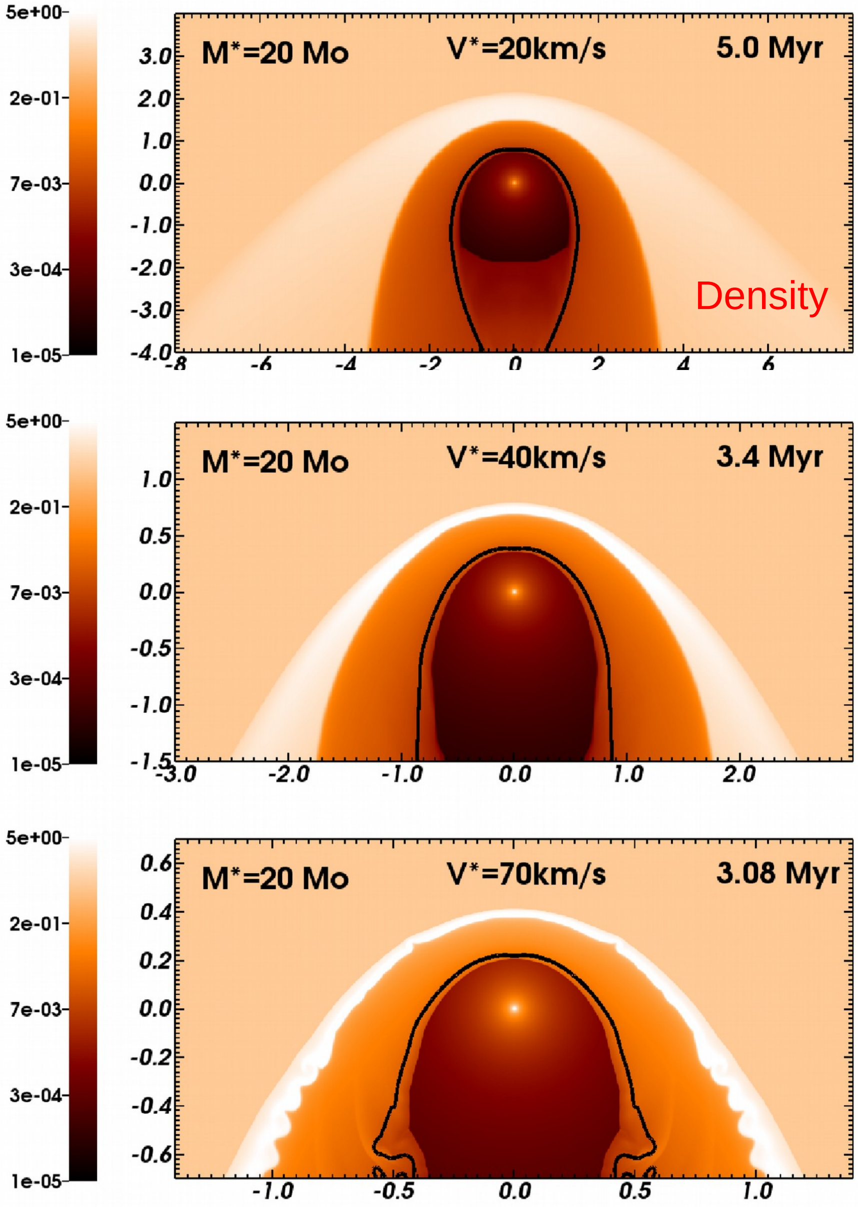
- 2D axi-symmetric hydrodynamical models,

  PLUTO code (Mignone et al. 2007, 2012),
  Optically-thin cooling, heating,
  Thermal conduction,

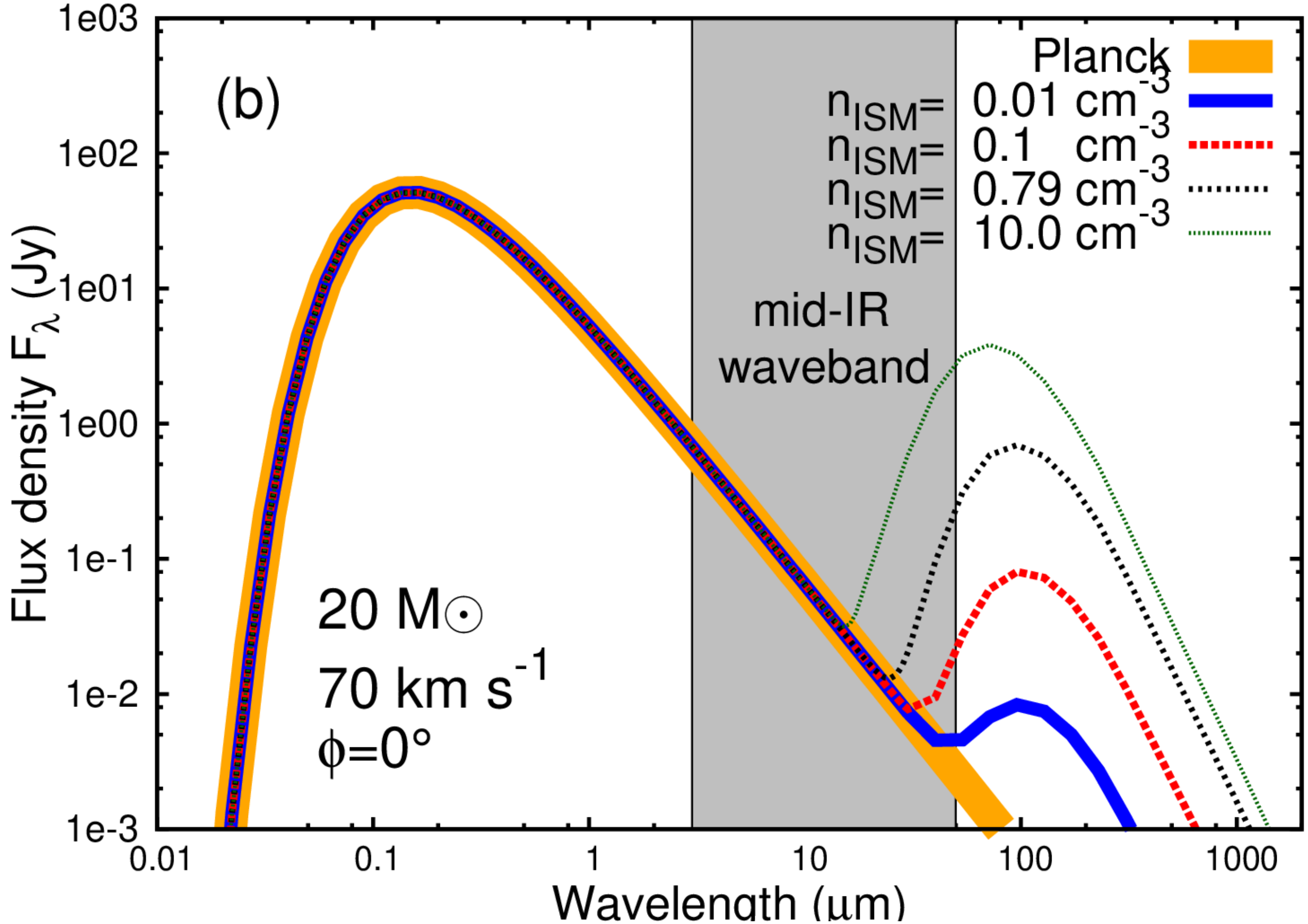
- Evolving stellar winds (Brott et al. 2011),



Vela-X1 (*Spitzer*)
Gvaramadze et al. 2011



Influence of the ambient medium density

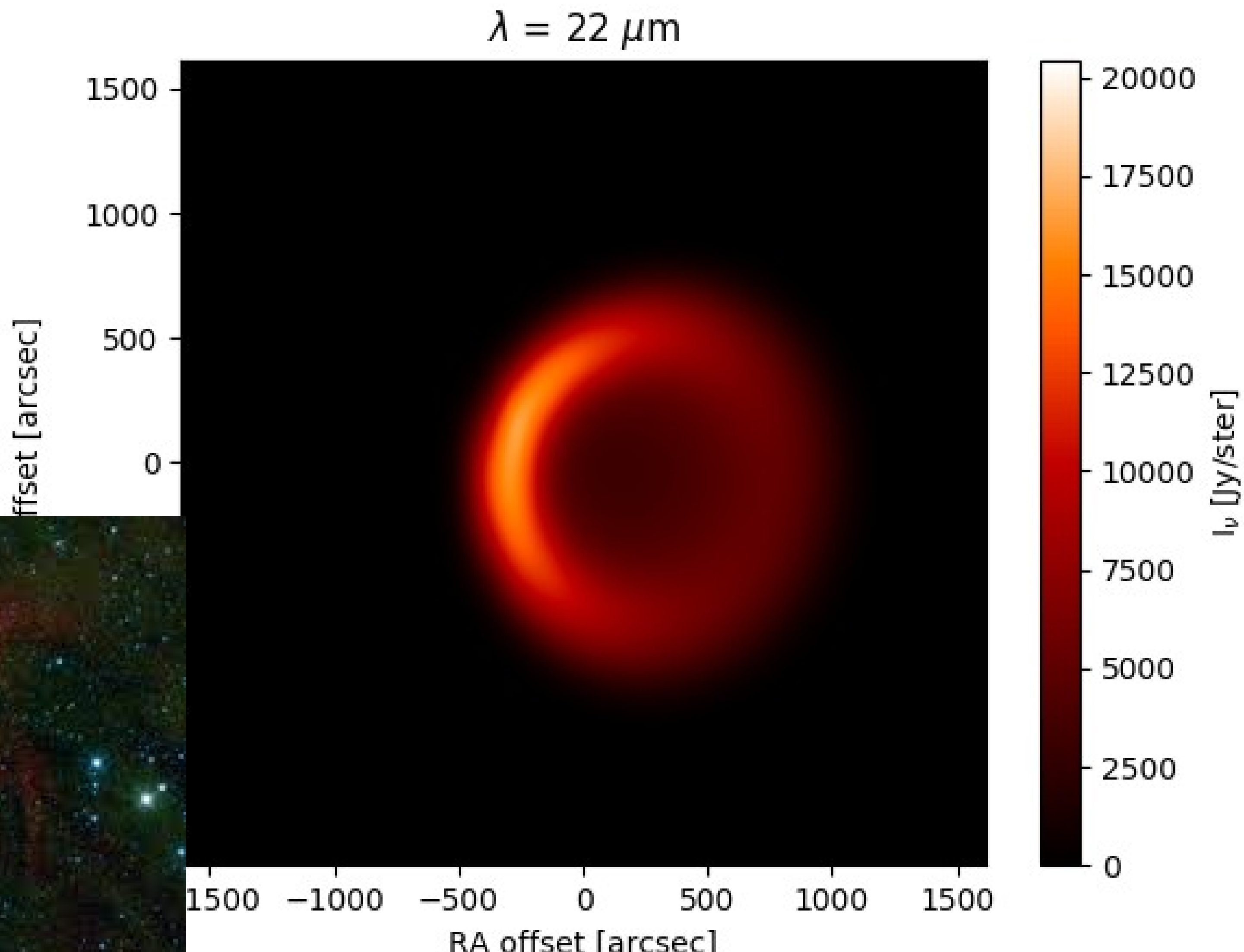


Meyer & van Marle (in prep.)

RADMC-3D (Dullemond)

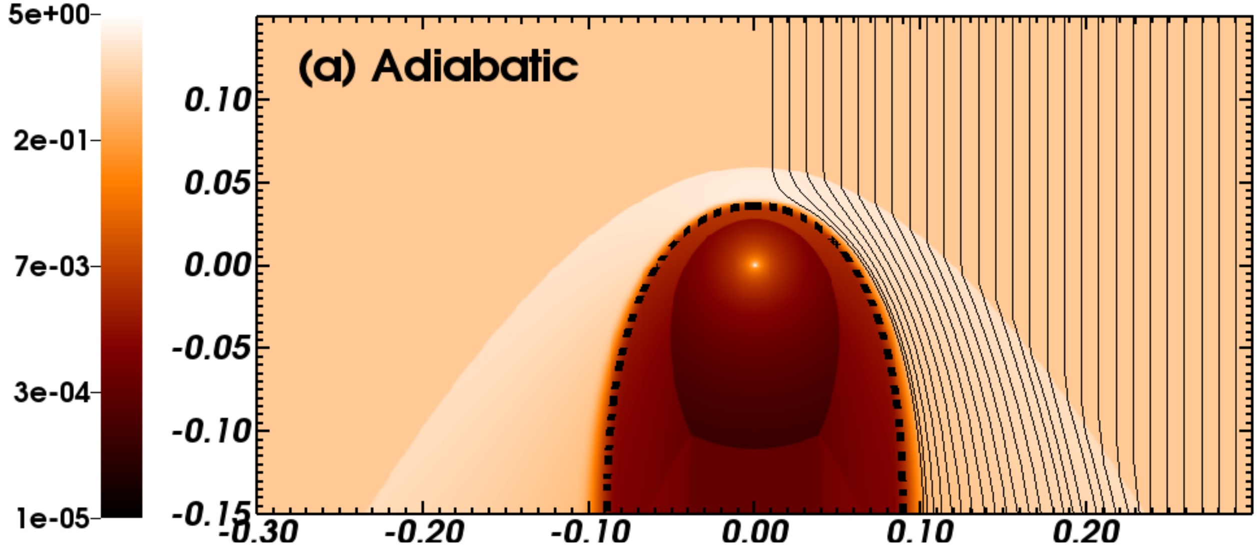
Synthetic 22 micron IRAS image of a stellar wind bow shock

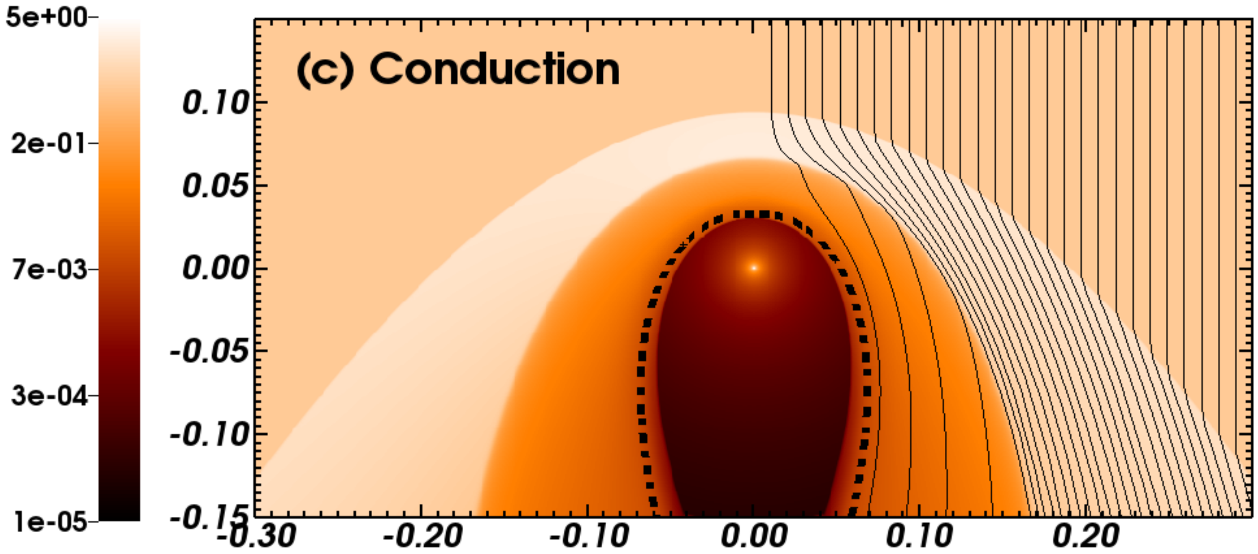
RADMC-3D (Dullemond)



Alpha Cam (NASA)

Electronic thermal conduction makes bow shock larger

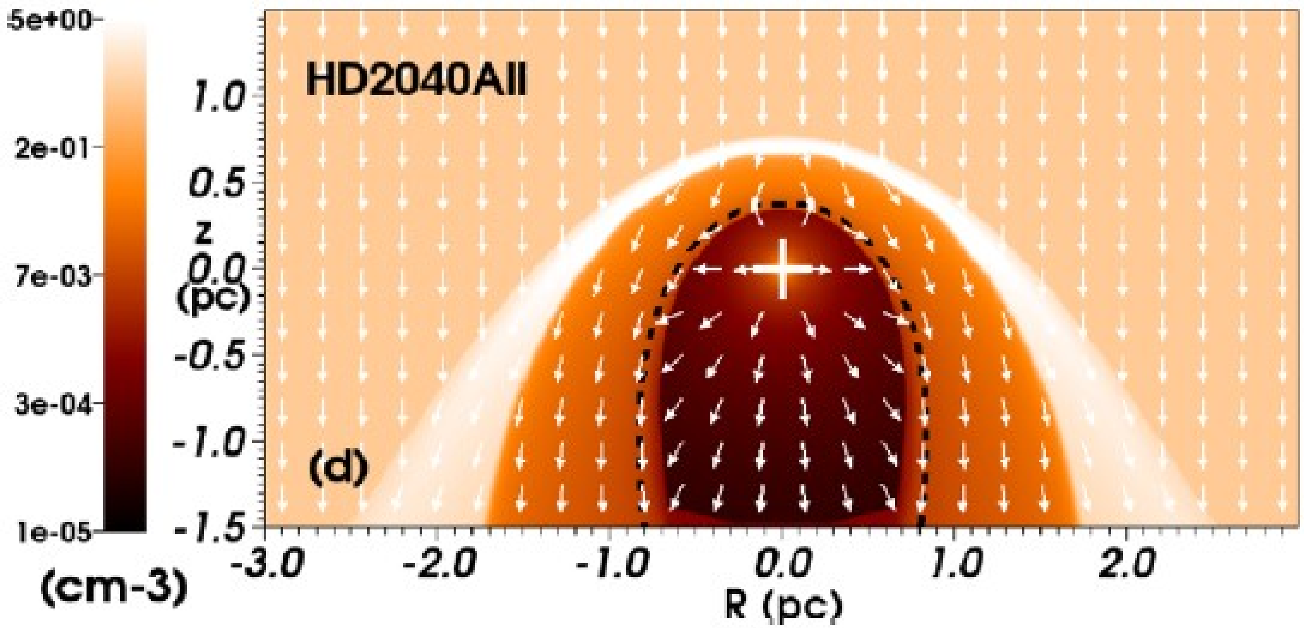


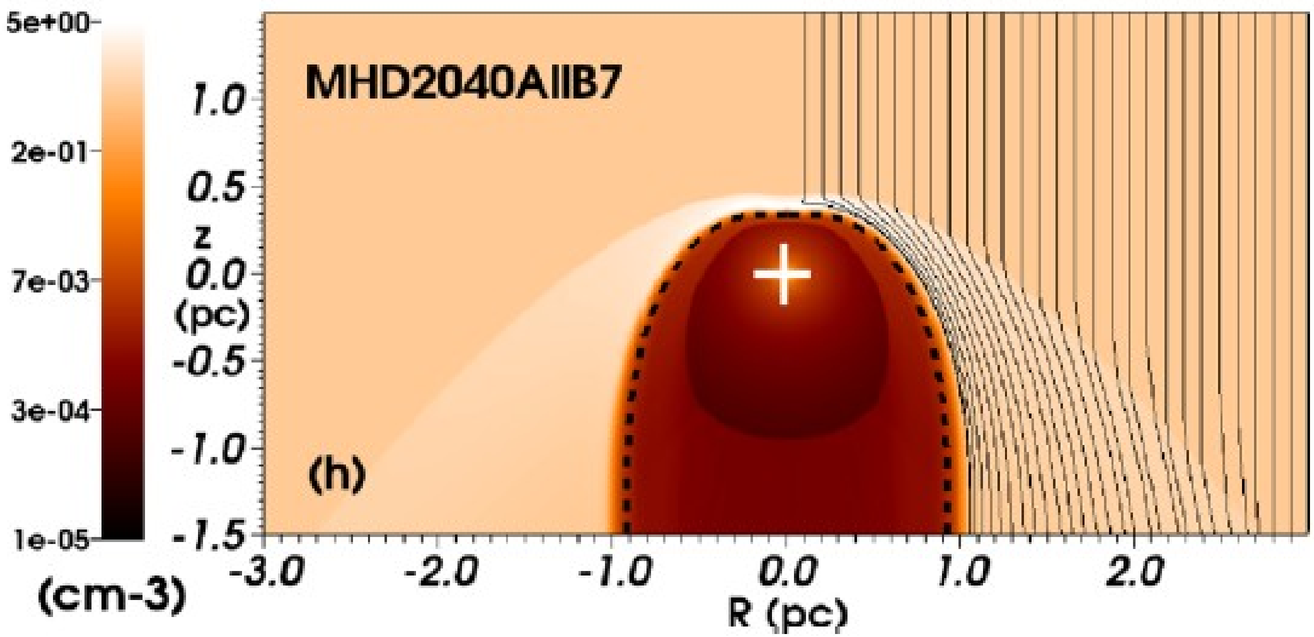


$$\boldsymbol{F}_{\mathbf{c}} = \kappa \nabla T$$

$$R(0) = \sqrt{\frac{\dot{M} v_{\mathrm{w}}}{4\pi \rho_{\mathrm{ISM}} v_{\star}^{2}}}$$

MHD kills heat transfers in bow shocks

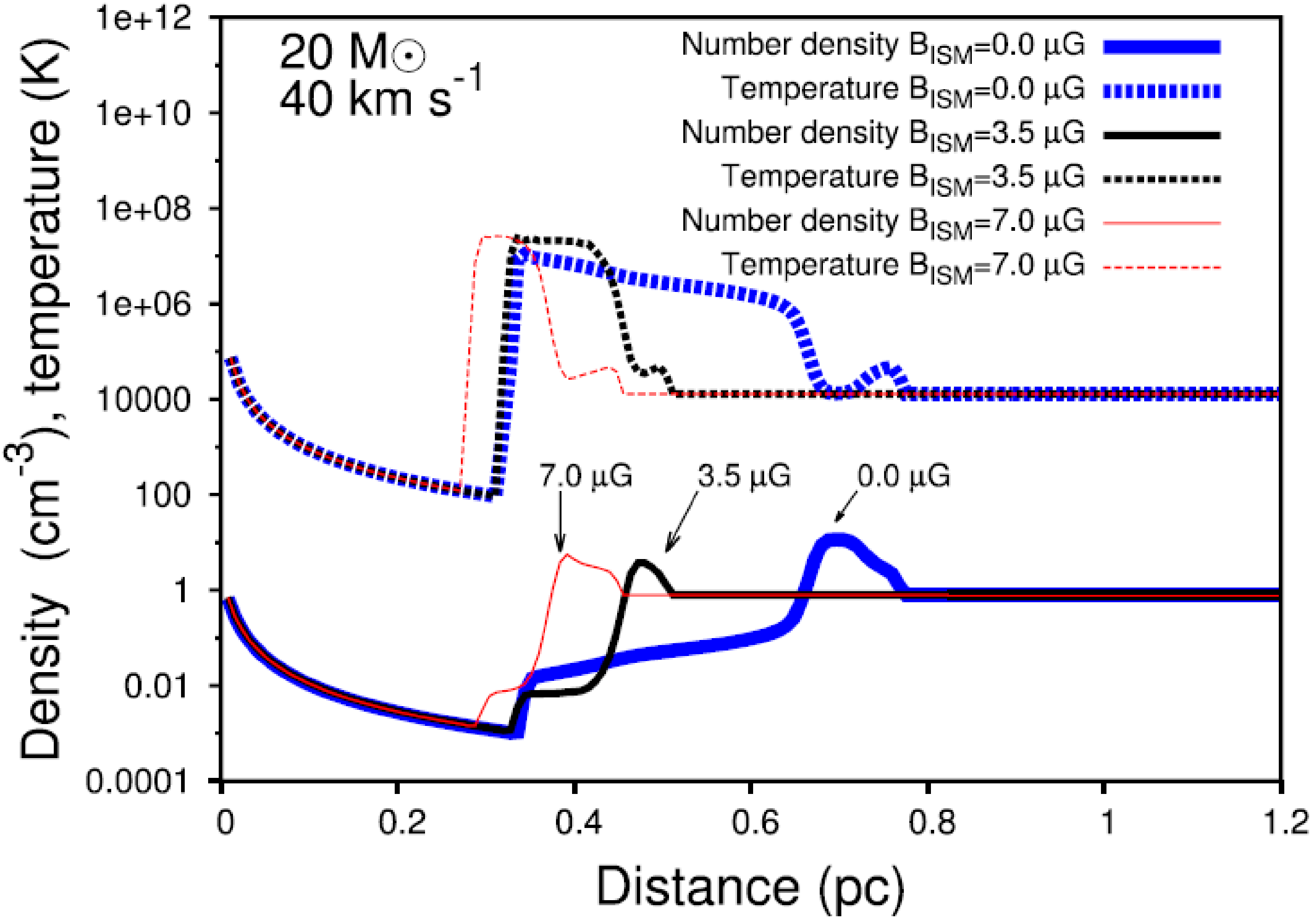




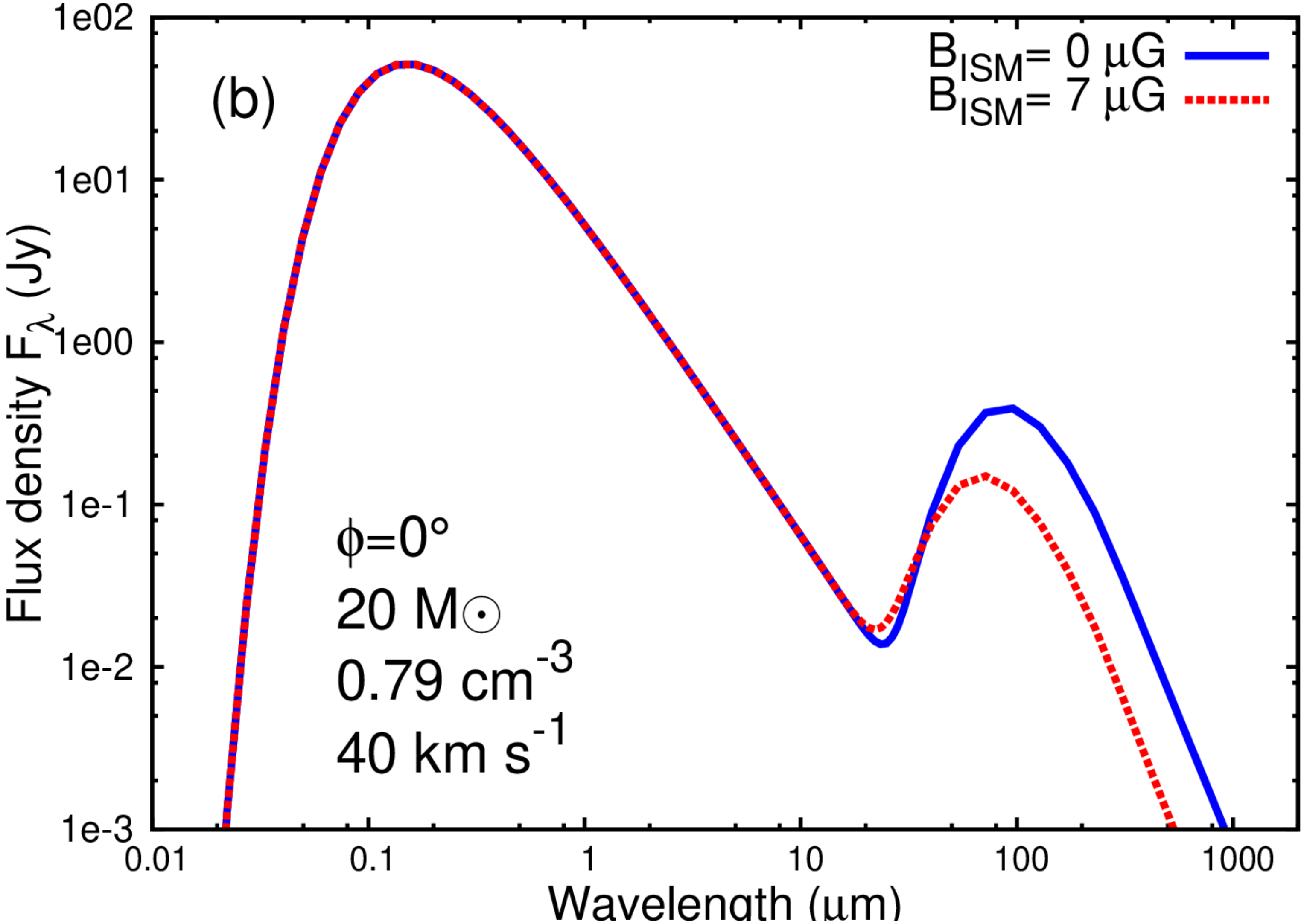
$$R(0) = \left(\frac{2\dot{M} v_{\mathrm{w}}}{B_{\mathrm{ISM}}^2 + 8\pi \rho_{\mathrm{ISM}} v_{\star}^2} \right)^{1/2}$$

$$\boldsymbol{F}_{\mathbf{c}} = \kappa_{||} \hat{\boldsymbol{b}} (\hat{\boldsymbol{b}} \cdot \nabla T) + \kappa_{\perp} (\nabla T - \hat{\boldsymbol{b}} \cdot \nabla T)$$

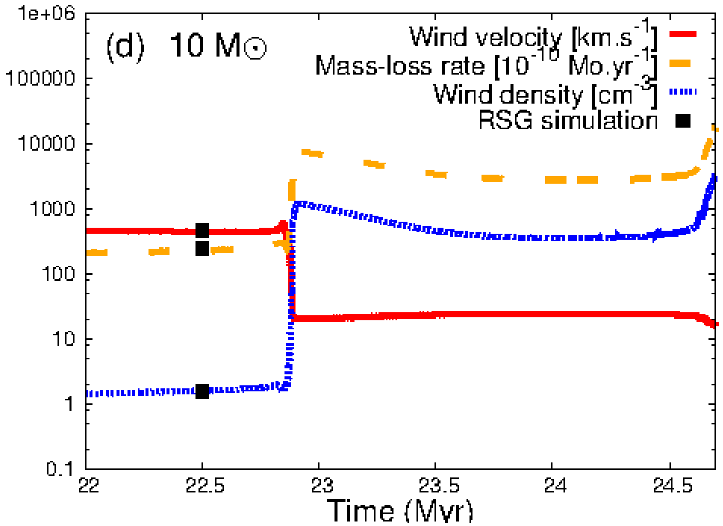
Effect of ISM magnetization



SEDs of MHD bow shocks

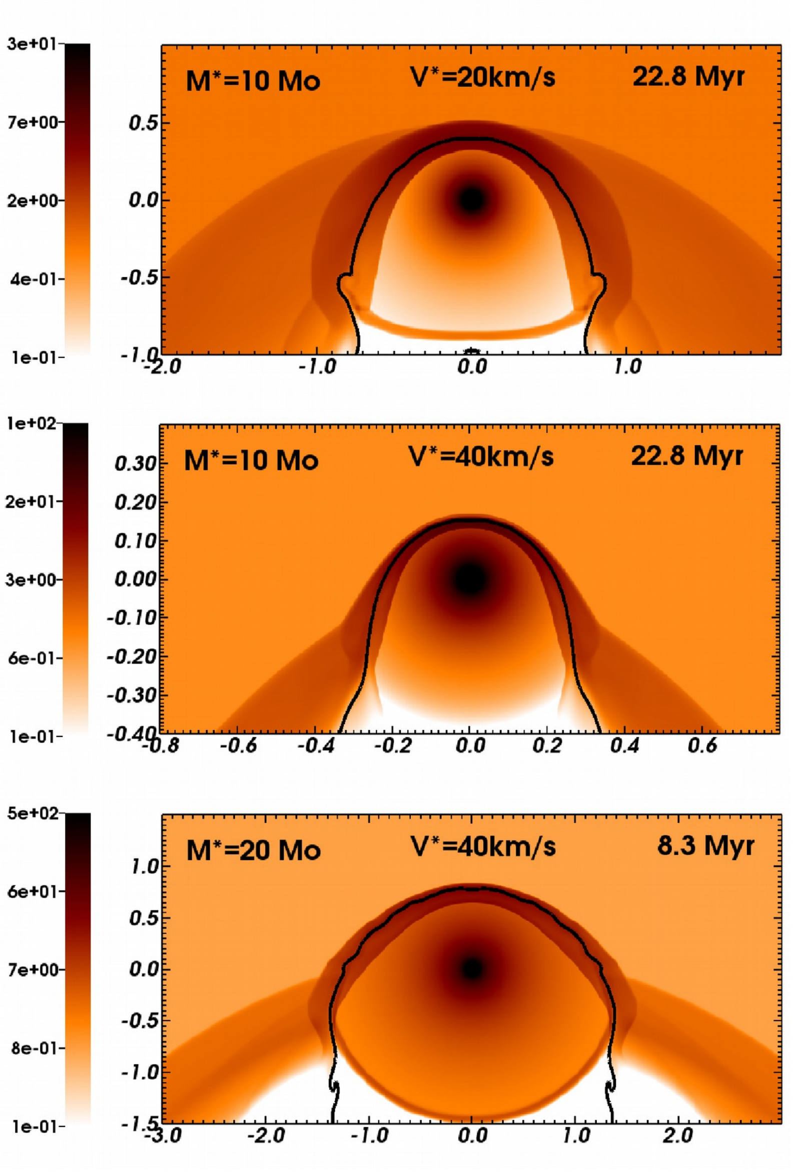


Stellar phase transition



Napoleon's hat

David (1801)

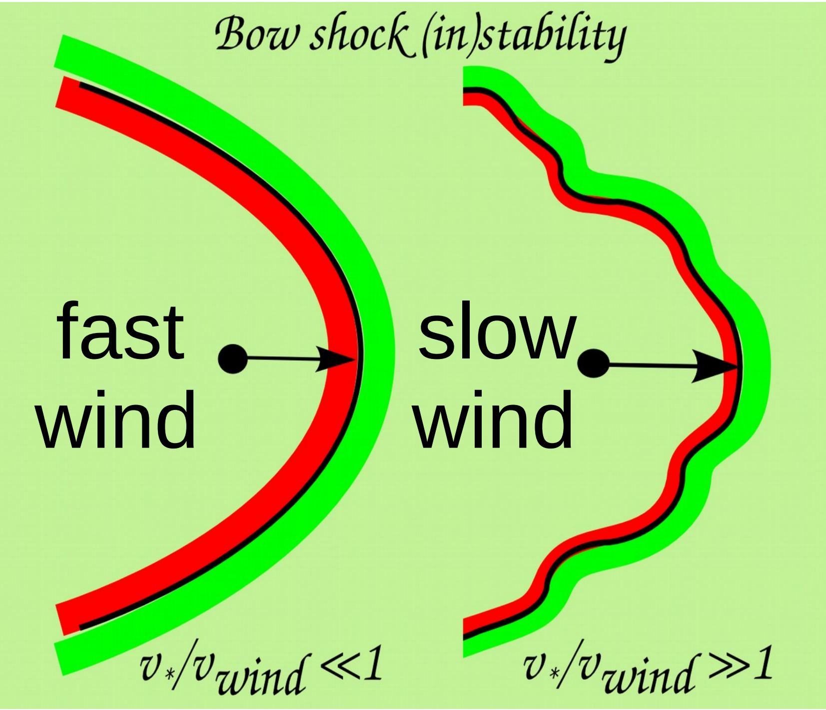


See Meyer et al. (2014b)

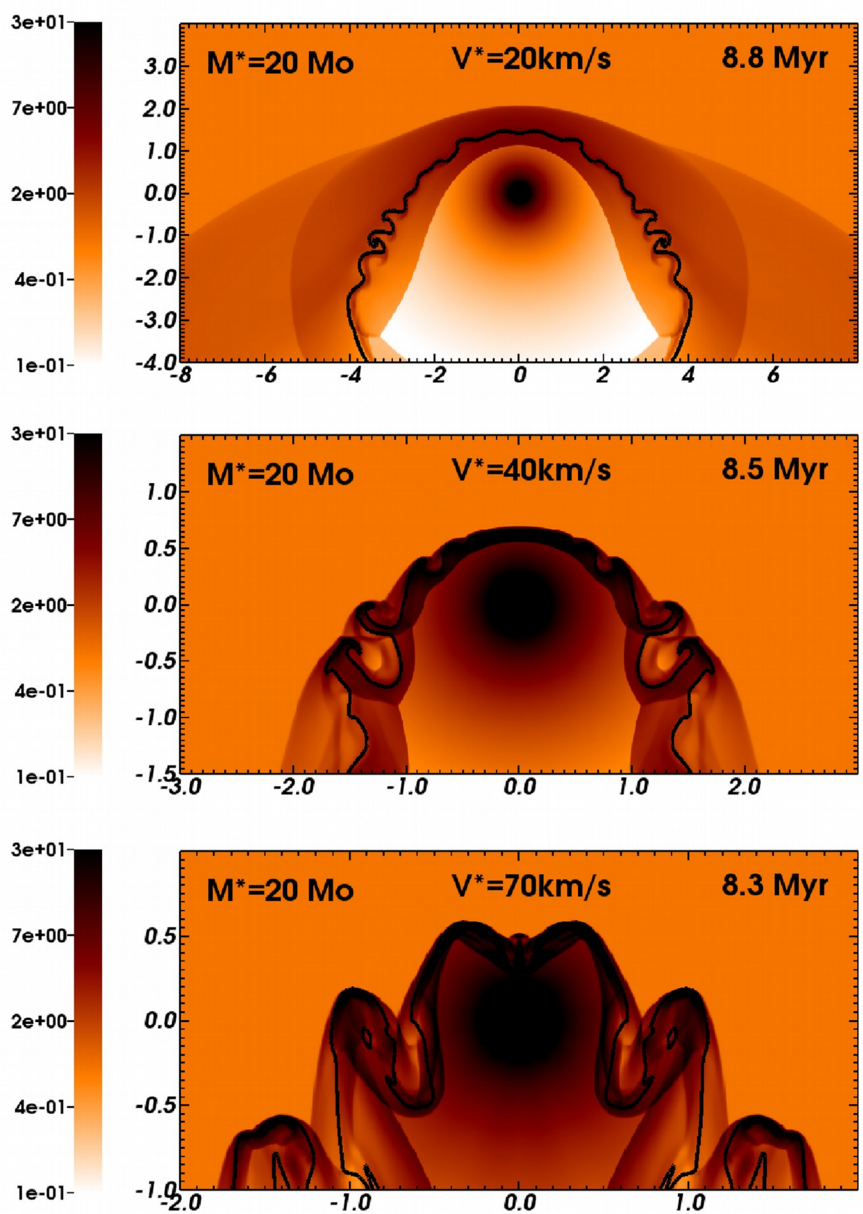
Bow shock of cool runaway stars

The bow shocks produced
by cool stars are unstable

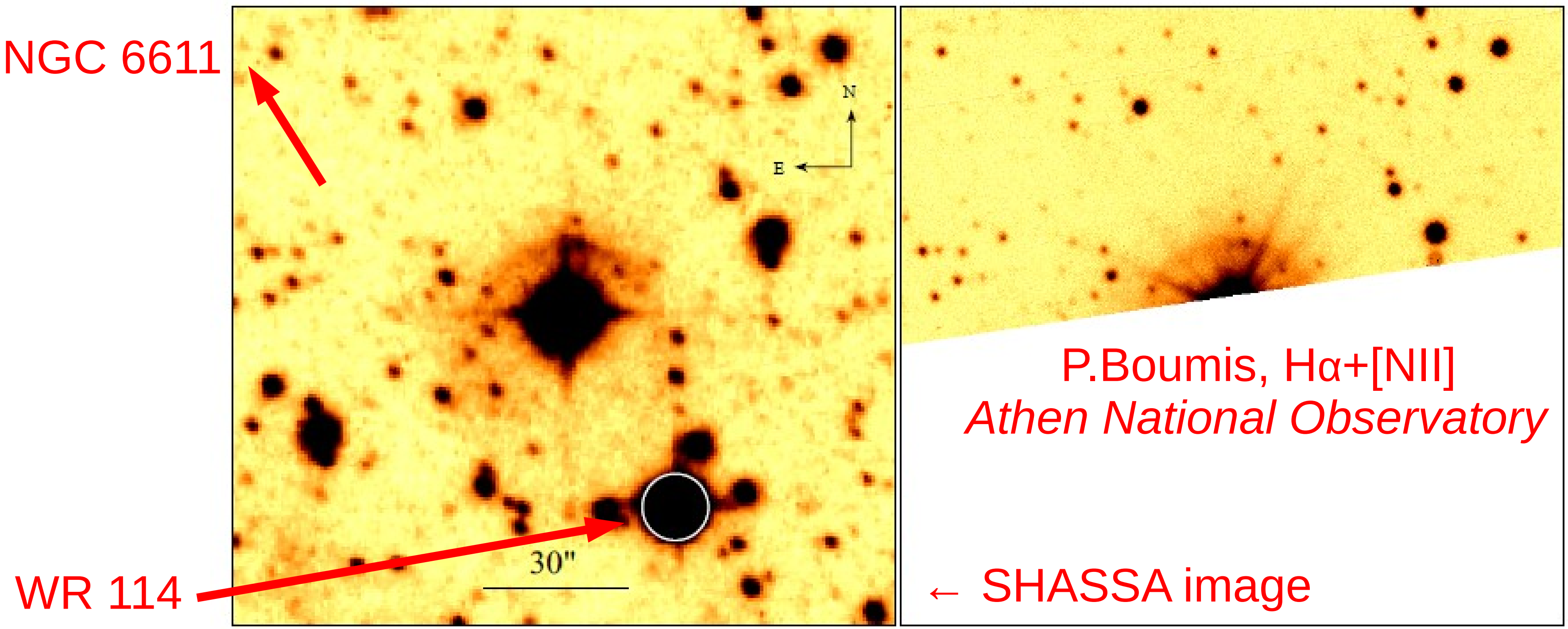
Dgani R., van Buren D.,
Noriega-Crespo A., (1996)



Scheme by Cox N., K.U. Leuven



IRC-10414 has a stable bow shock which should be unstable



V^{wind}=21 km/s but V*=70 +/- 20km/s

Gvaramadze et al. (2014)

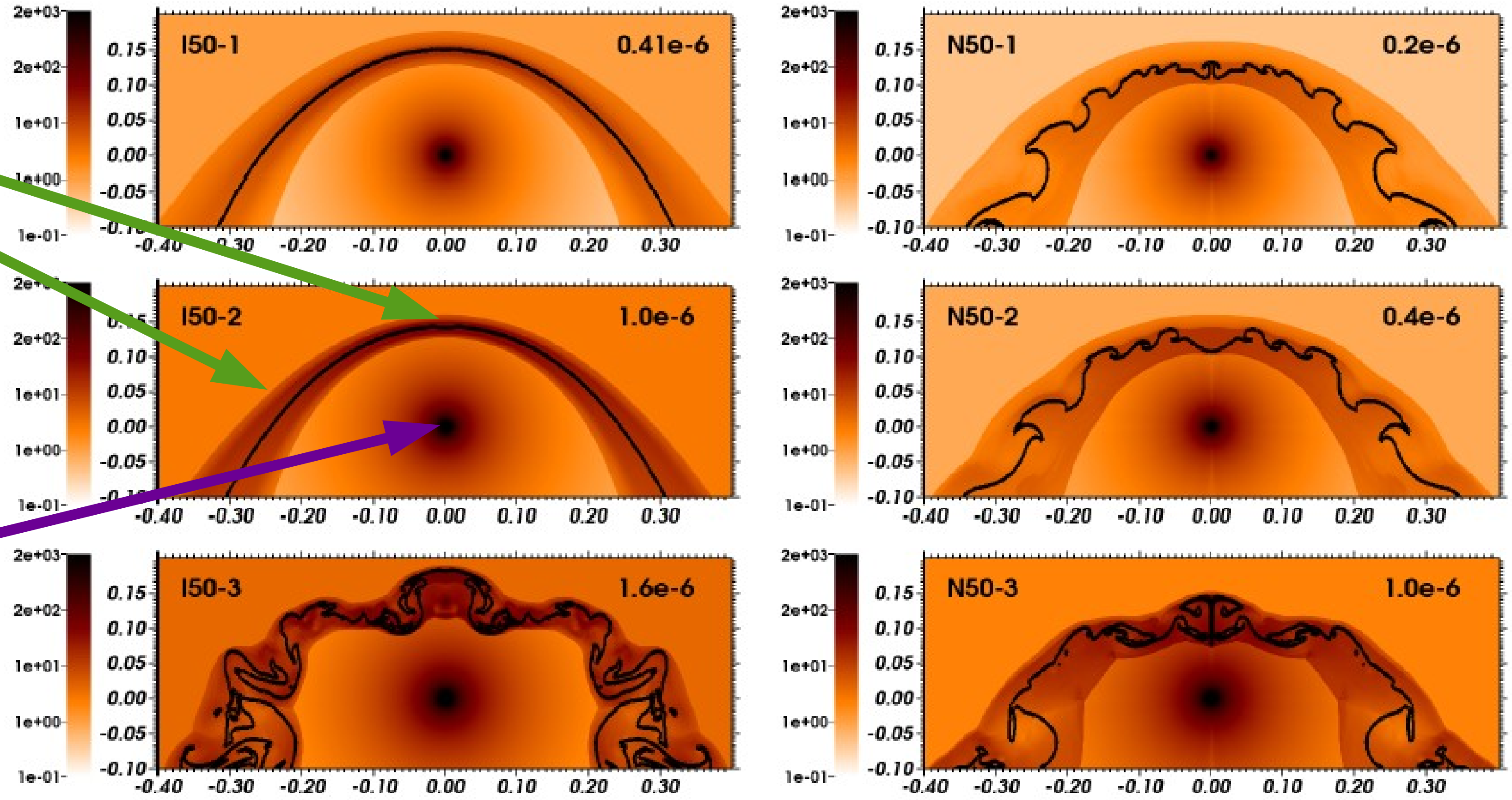
2D hydro models of IRC-10414's bow shock

Ionised wind+ISM

Neutral wind+ISM

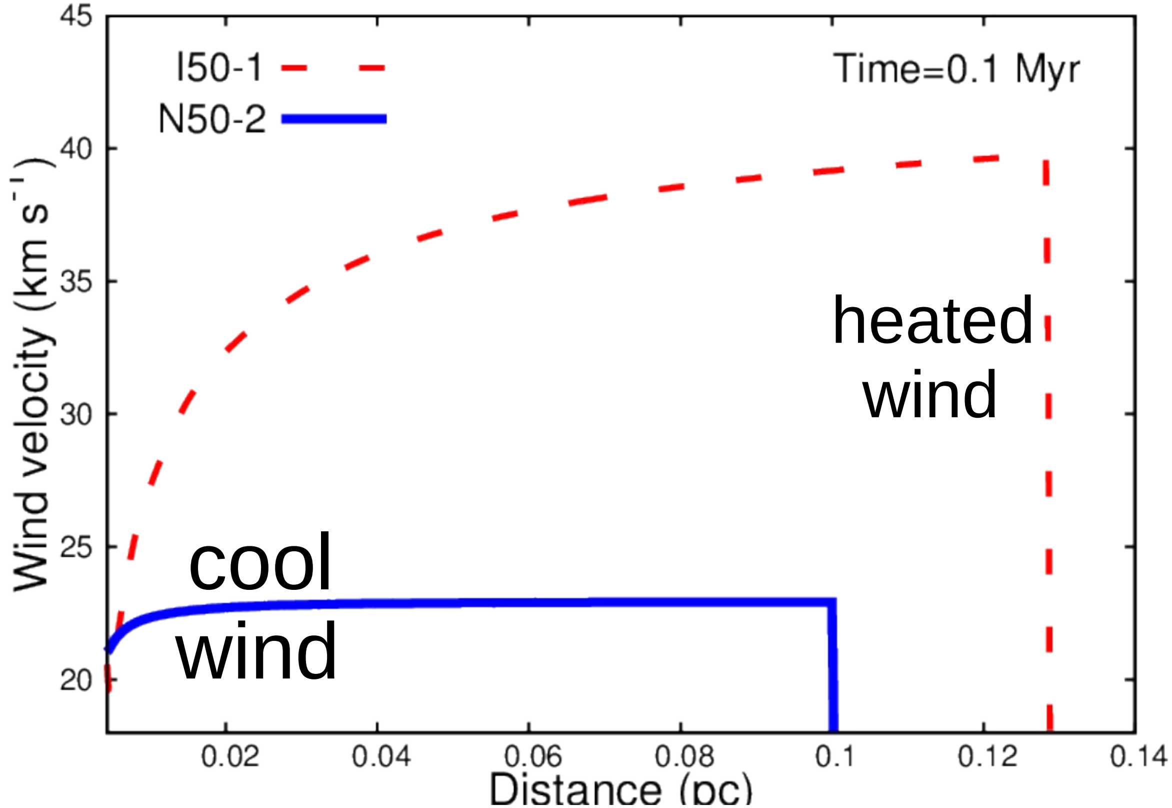
hot wind + hot bow shock

cool star



Only some ionised models are stable

The stellar wind of IRC-10414 is accelerated

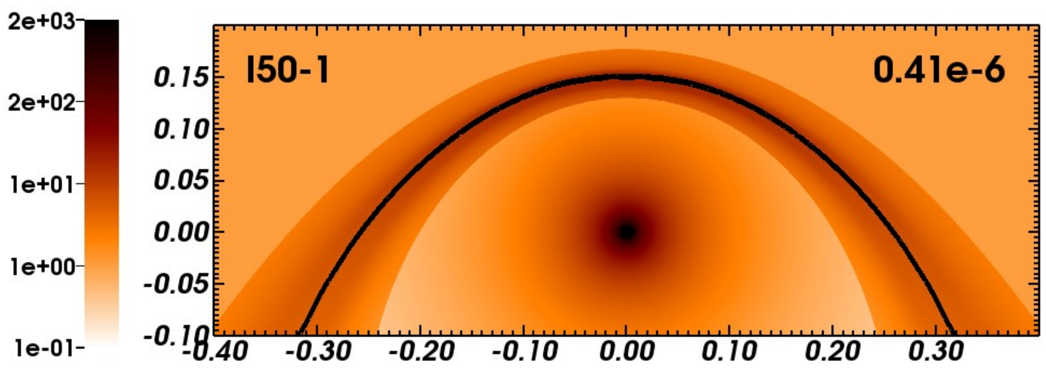


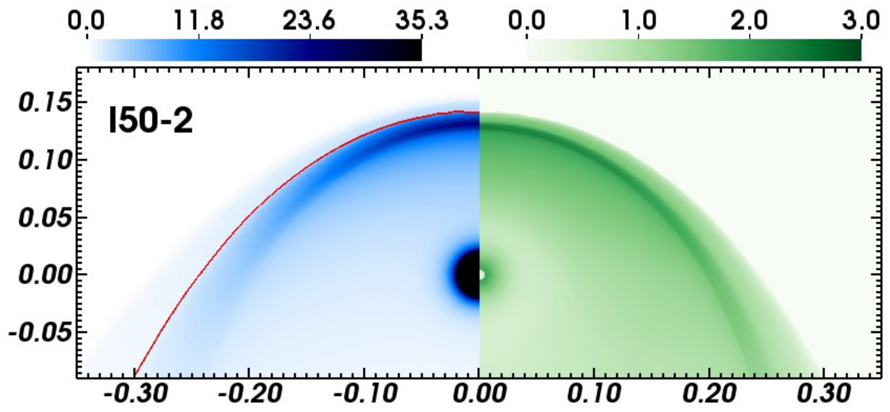
The stability criterion is fulfilled at the reverse shock

External heating $\rightarrow \Delta T \rightarrow \Delta P \rightarrow dv/dt > 0$

Constraining the properties of IRC-10414

Our best fit model's Hα+[NII] emission maps

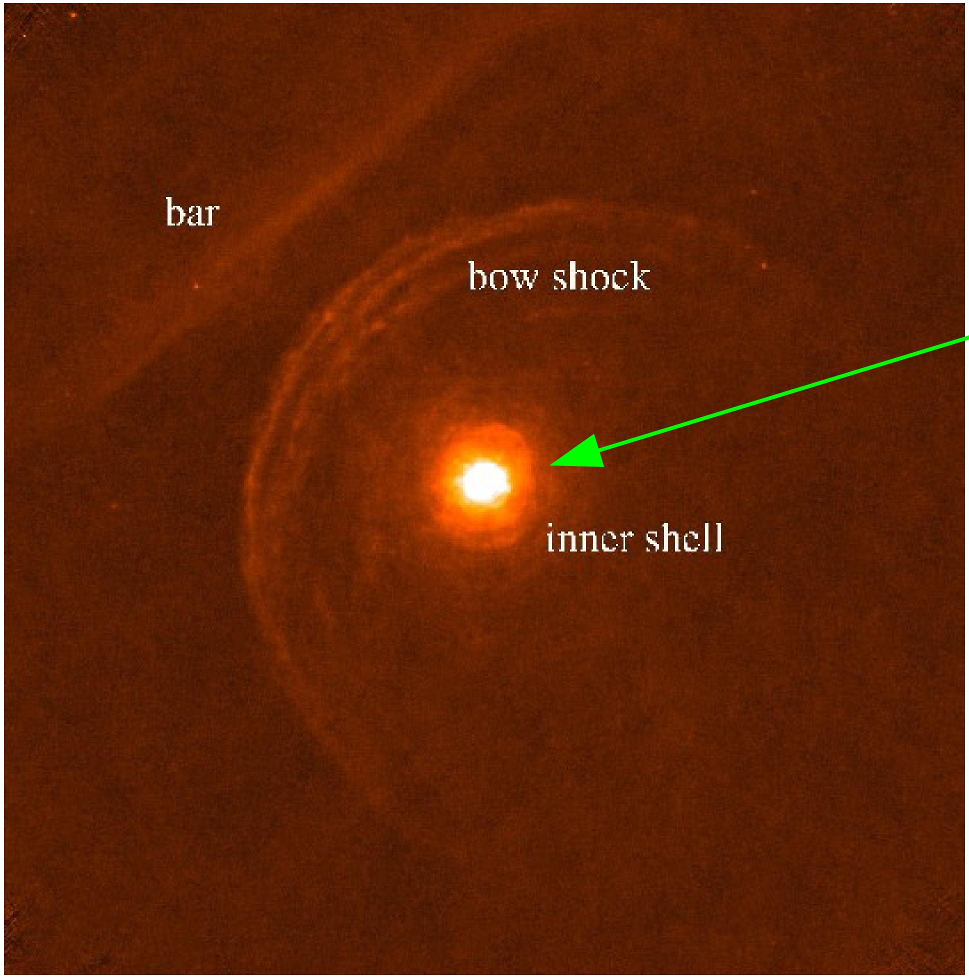




Stability	ionised wind, v*=50 km/s
Detectability	dM/dt ~ 10^{-6} Mo/yr
Opening angle	n=3.3 cm^{-3}

Ionizing Betelgeuse's cool wind explains the inner shell noticed by le Bertre T. et al. (2012)

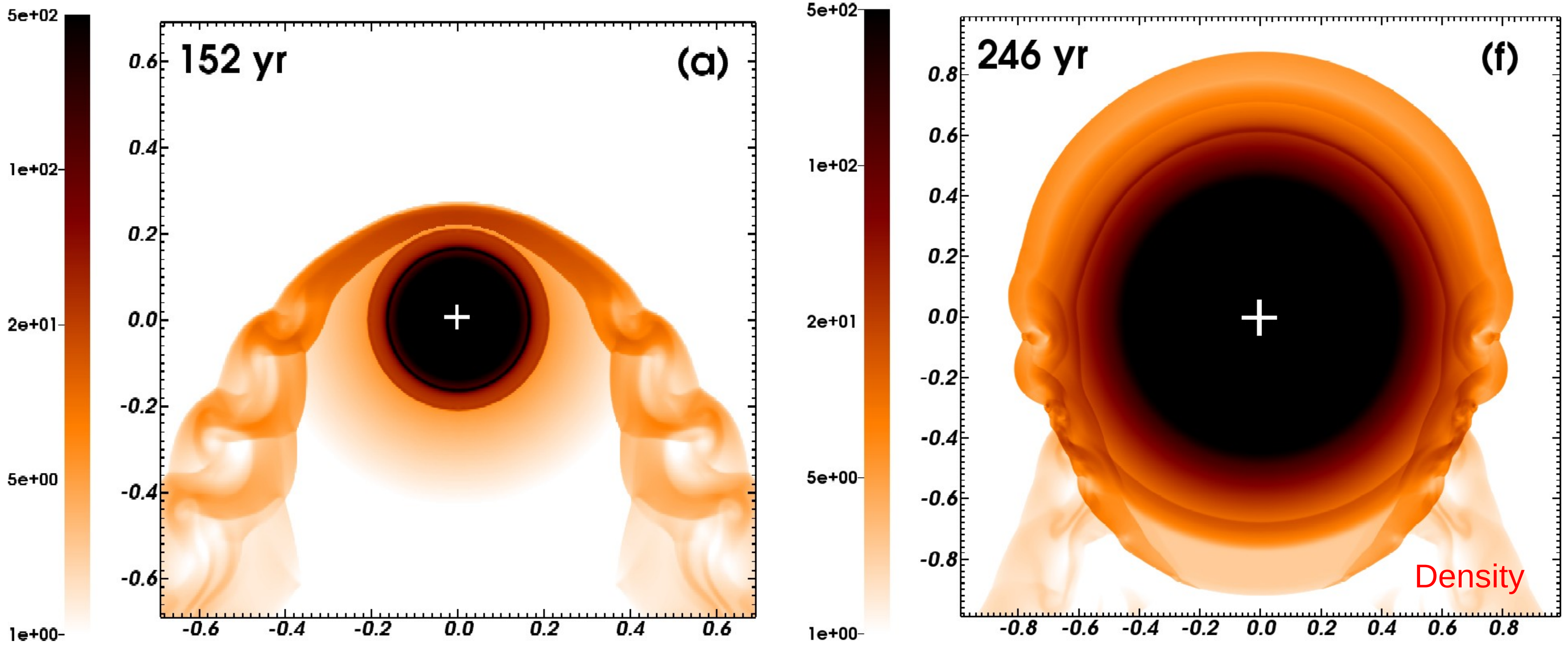
Photo-Ionised
COnfined shell



Interface
neutral/ionized
wind

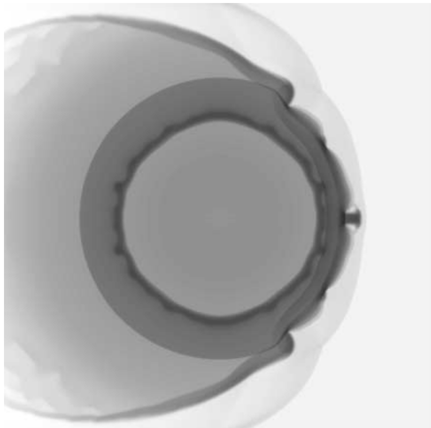
Mackey J. et al., Nature (2014)

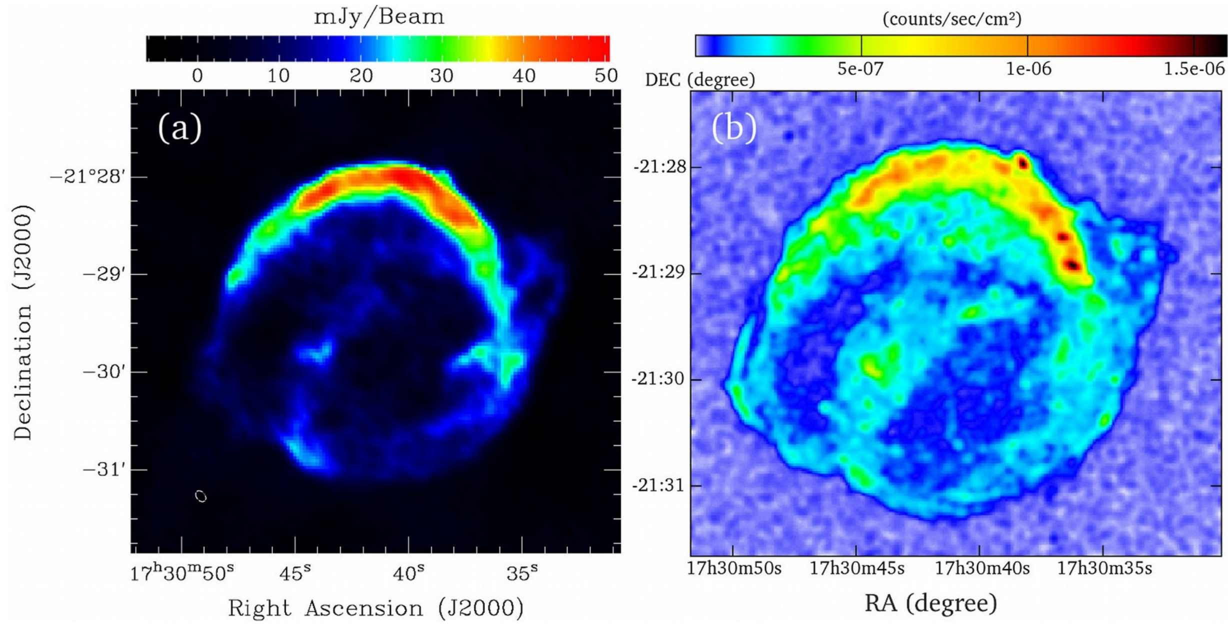
Young supernova remnants



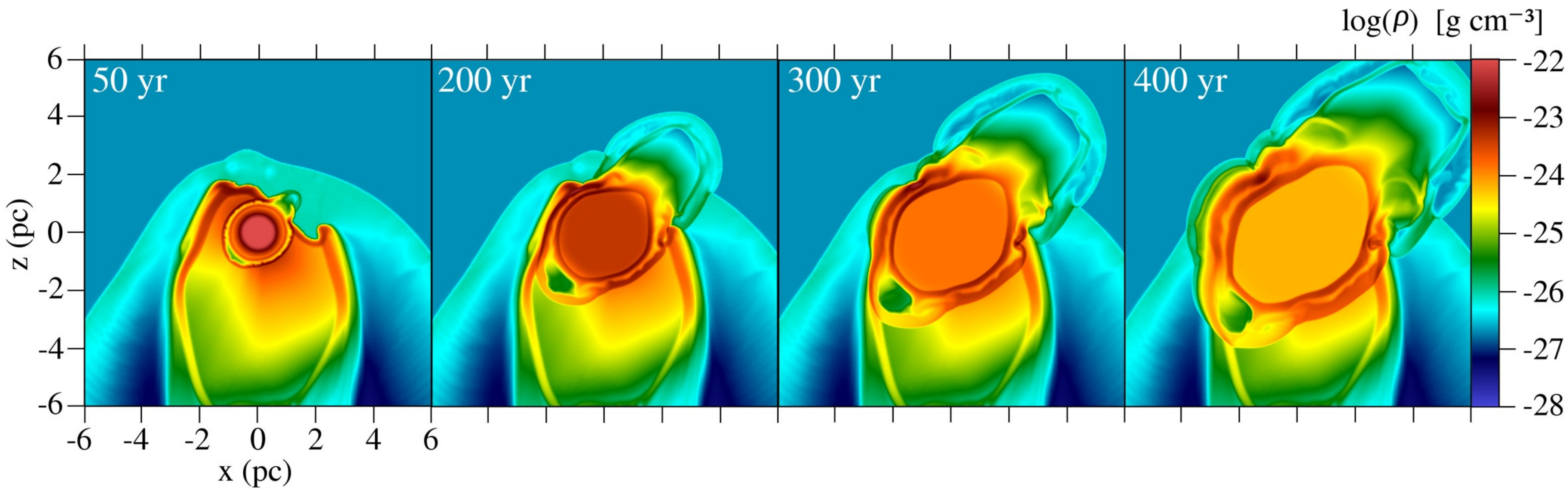
Explode inside bow shocks

Kepler supernova remnant

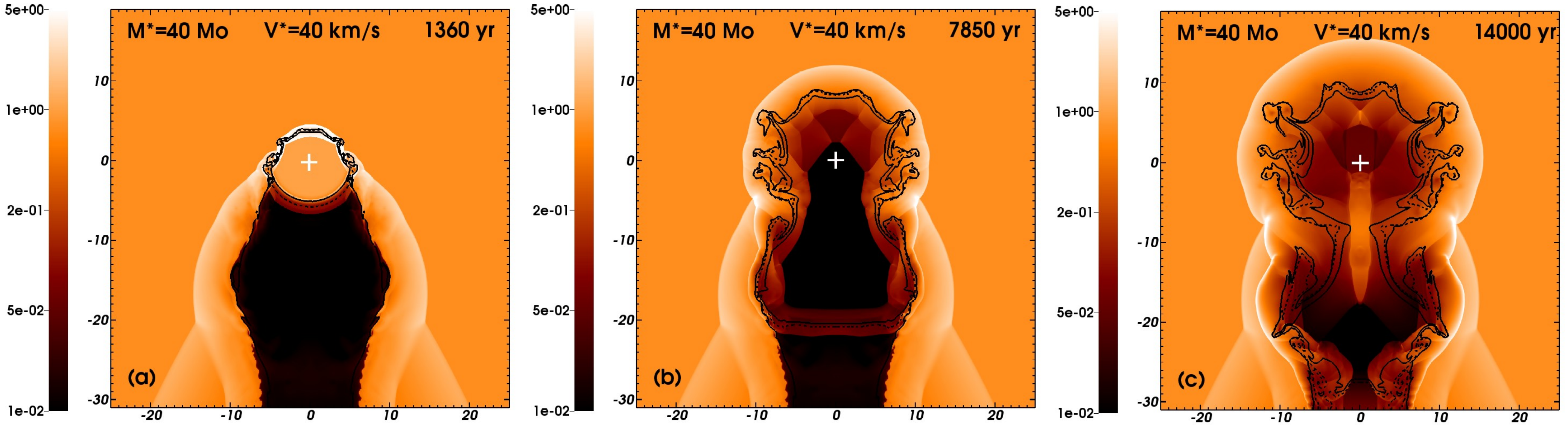




Velazquez, P. et al. (2006),
Toledo-Roy et al. (2014)



Chanelling of the shock wave

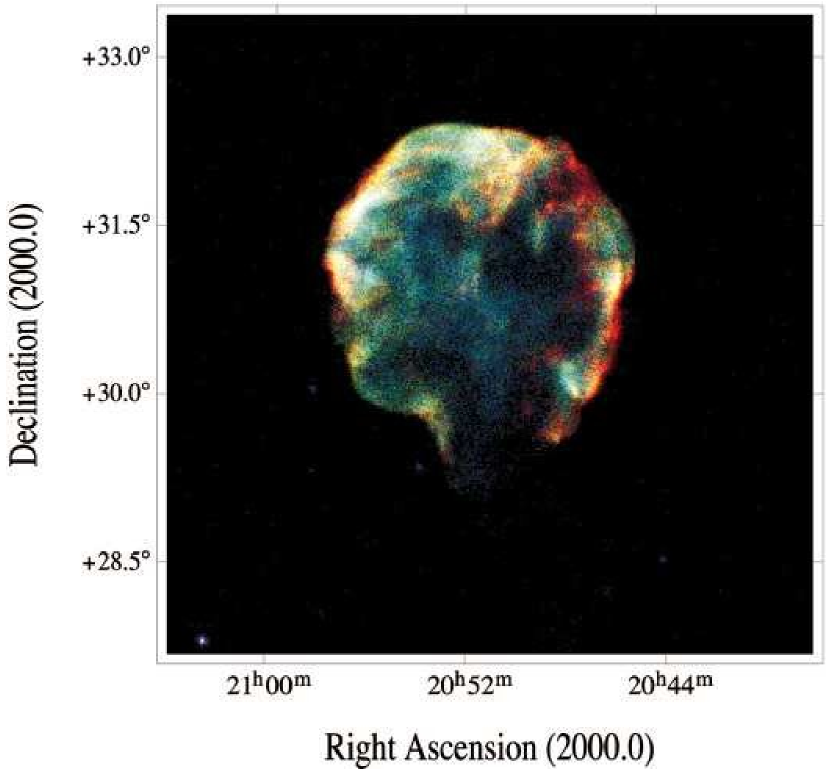


Density

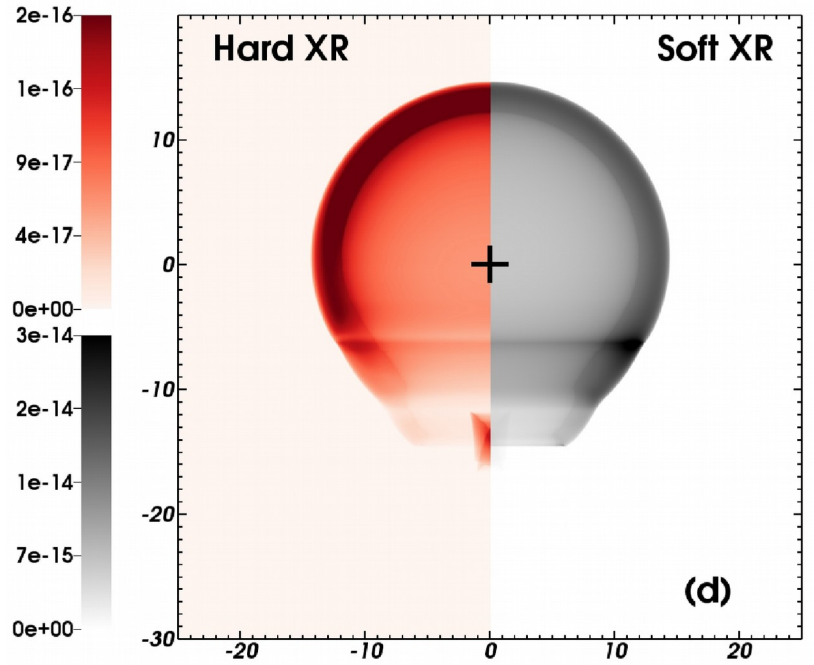
Reverberated towards the center of the explosion (upstream)

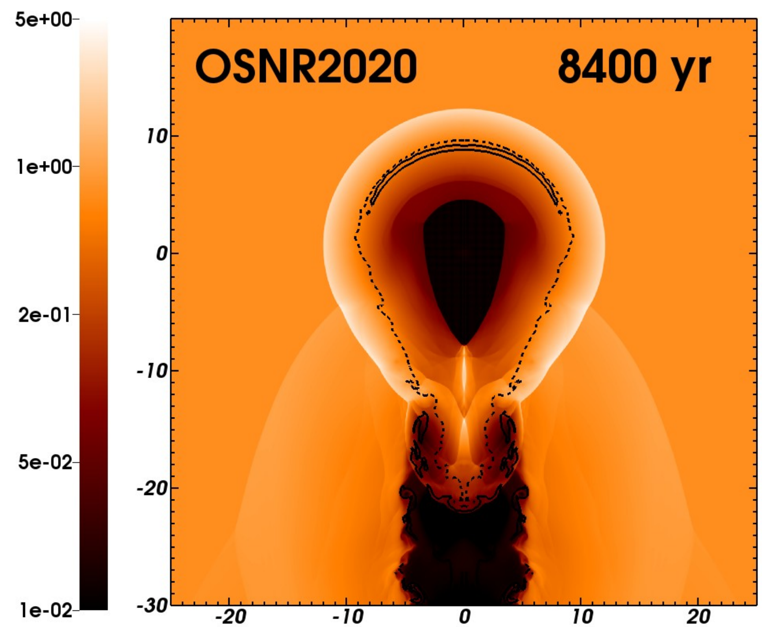
Chanelled into the bow shock (downstream)

The Cygnus loop nebula



Aschenbach et al. (1999)





Meyer et al. (2015)

Conclusions

1. The pre-supernova circumstellar medium of massive stars influence the shape of their future supernova remnants,

2. Stellar motion, ambient medium that Exotic evolutionnary phases (WR) enhances mechanism,

3. The PLUTO code (Mignone, Torino) is the tool to do this,

4. Such nebulae/remnants are the ideal objects to investigate high-energy processes,