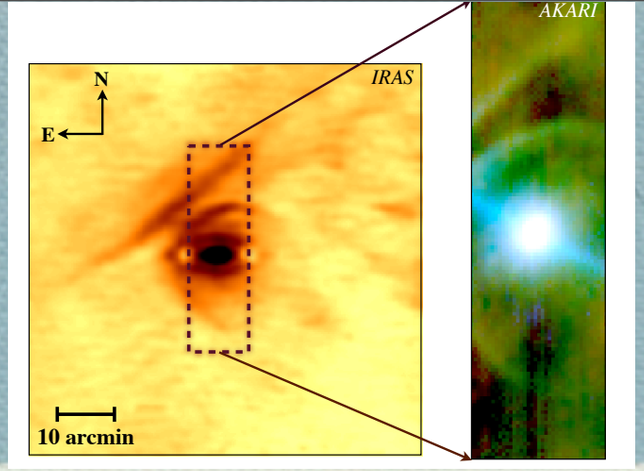

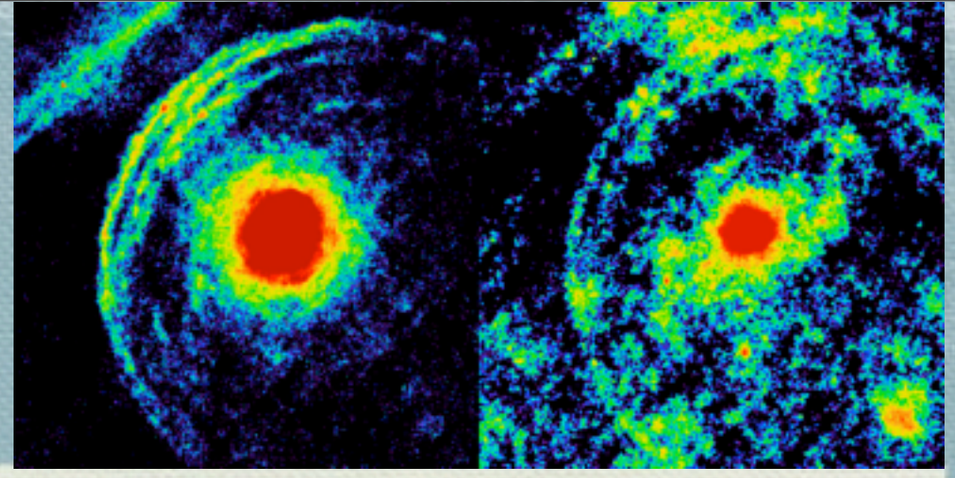

Double bow shocks around young red supergiants

Application to Betelgeuse

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Argelander-Institut für Astronomie

Unterstützt von / Supported by
Alexander von Humboldt Stiftung/Foundation

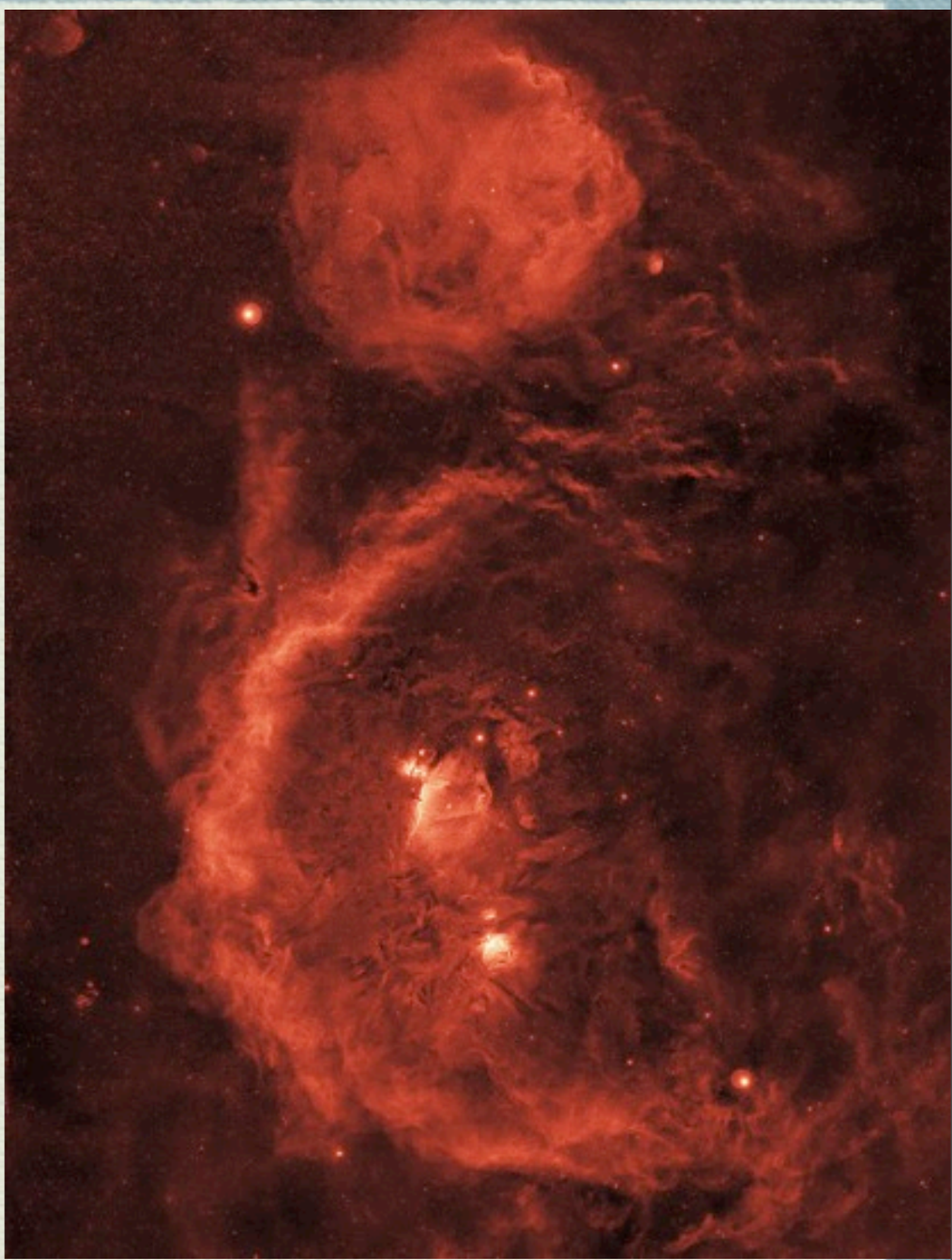
DFG Priority Program 1573
ISM-SPP
Interstellar Medium

Outline

- Betelgeuse and it's circumstellar medium (CSM).
- Constant wind models (Mohamed, Mackey & Langer, 2012).
- Predictions of/problems with constant wind model.
- Evolving wind model (Mackey et al, submitted).
- 2D simulations of runaway blue supergiant (BSG) star evolving to a red supergiant (RSG).
- Comparison to Betelgeuse.

Betelgeuse

- H-alpha map of Orion (right).
- D~200pc, (2nd?) nearest RSG to sun.
- Proper motion implies v~30-35km/s, moving to ~Northeast.
- Mass ~11-20 Msun. Teff ~3300K. (e.g. Neilson+2011).
- Has bow-shock and “bar” upstream (IRAS -- Noriega-Crespo+,1997).
- Size similar to the full moon.



Bow Shock and Bar

1997AJ....114..837N

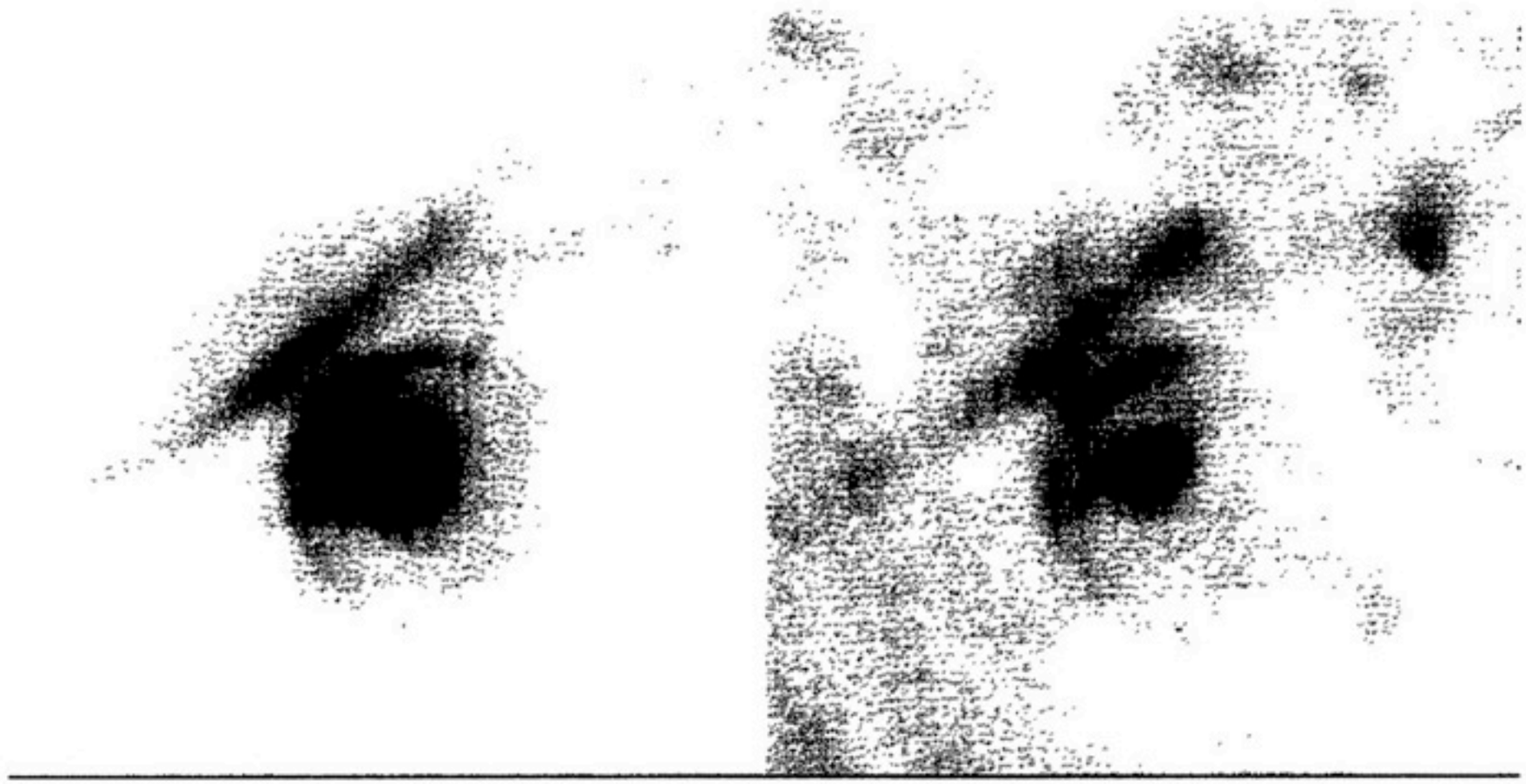
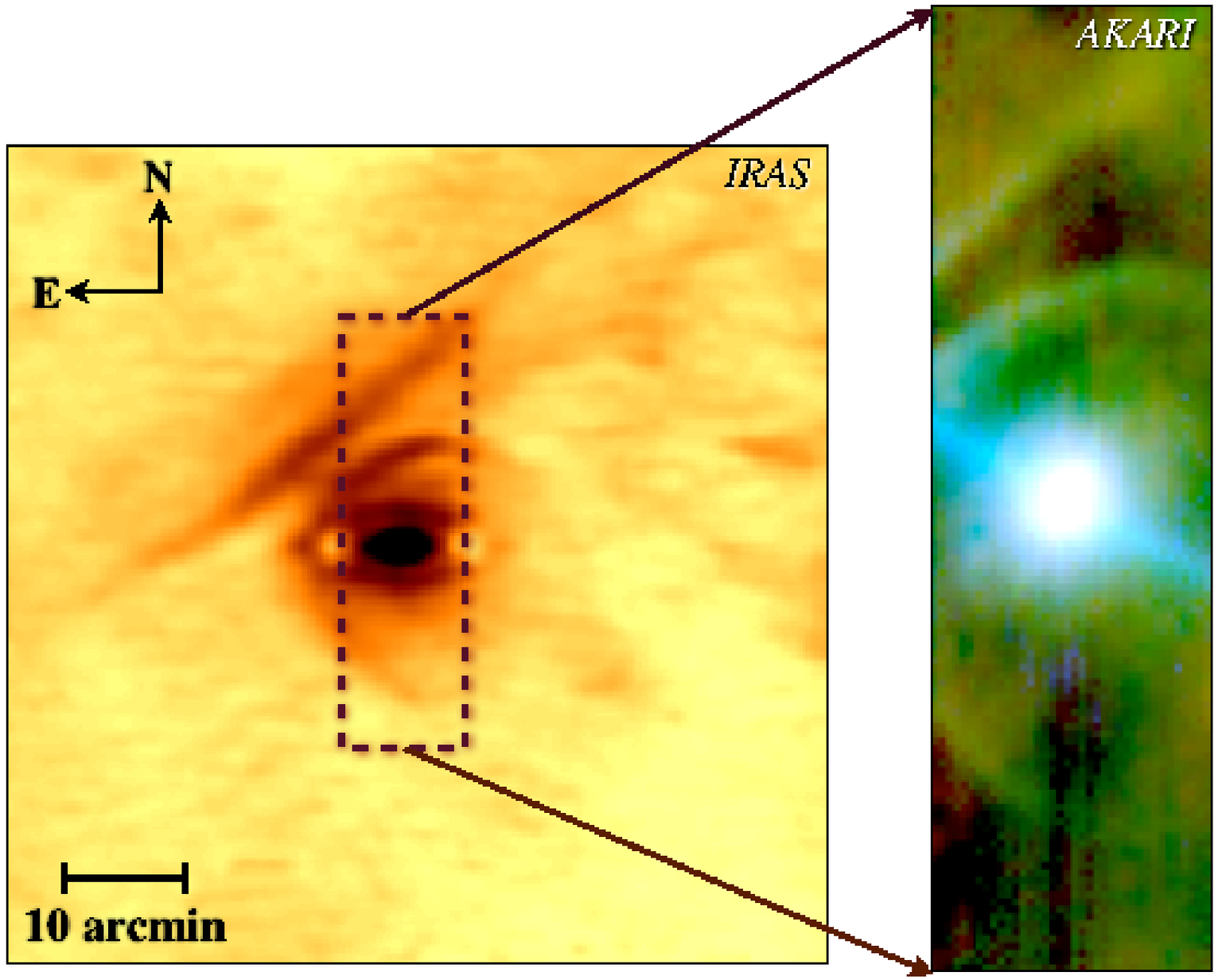


FIG. 1. The 60 μm (left) and 100 μm (right) enhance resolution *IRAS* images of α Orionis. The field is approximately one degree.

- IRAS discovery image: 60 micron (left), 100 micron (right).

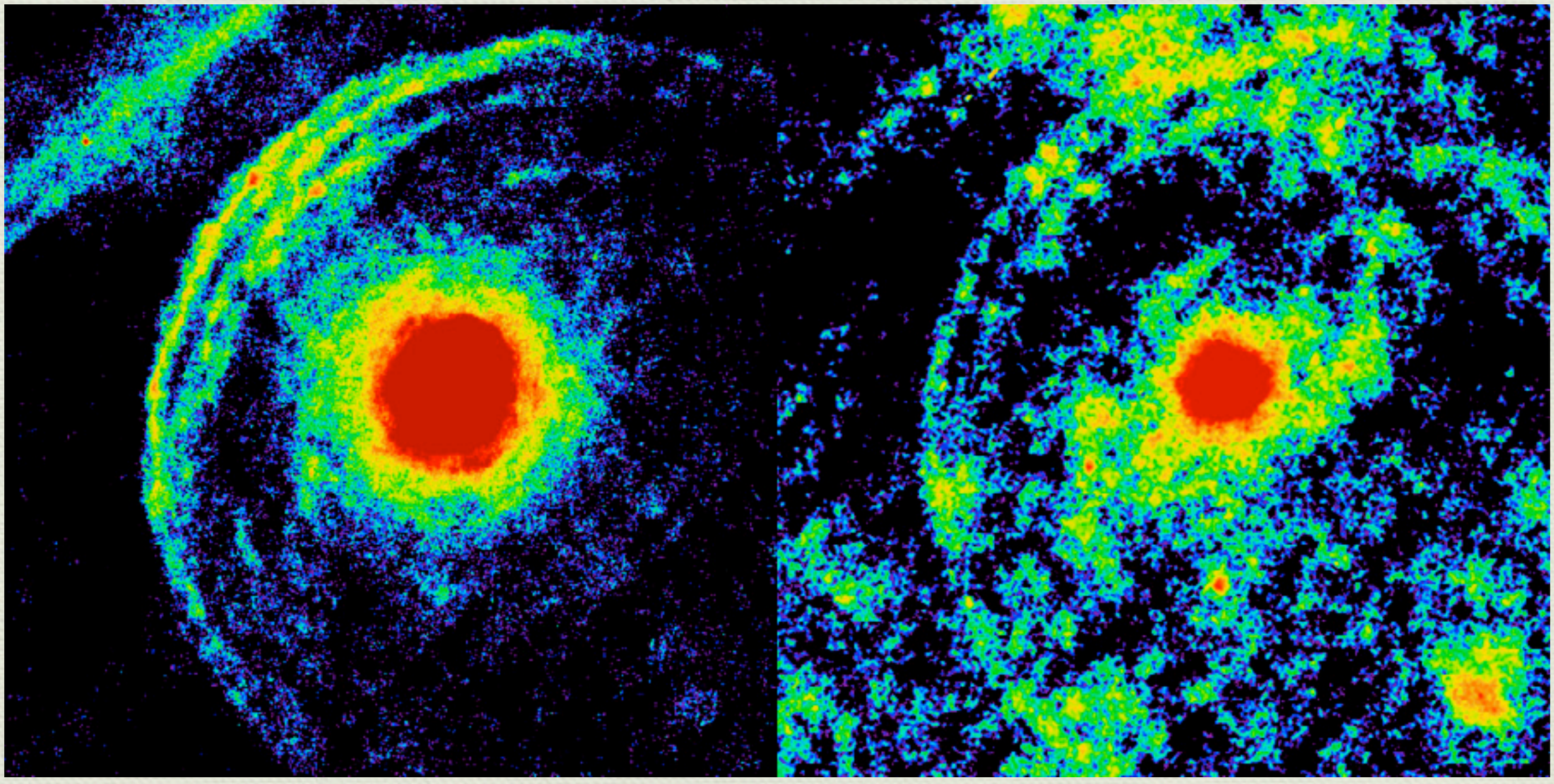
Bow Shock and Bar

- Heavily processed IRAS image (right), note scale!
- Later observed with AKARI (Ueta+,2008,PASJ).
- Higher resolution, smaller FOV.
- Bow-shock has M~0.0033 Msun, based on AKARI flux.



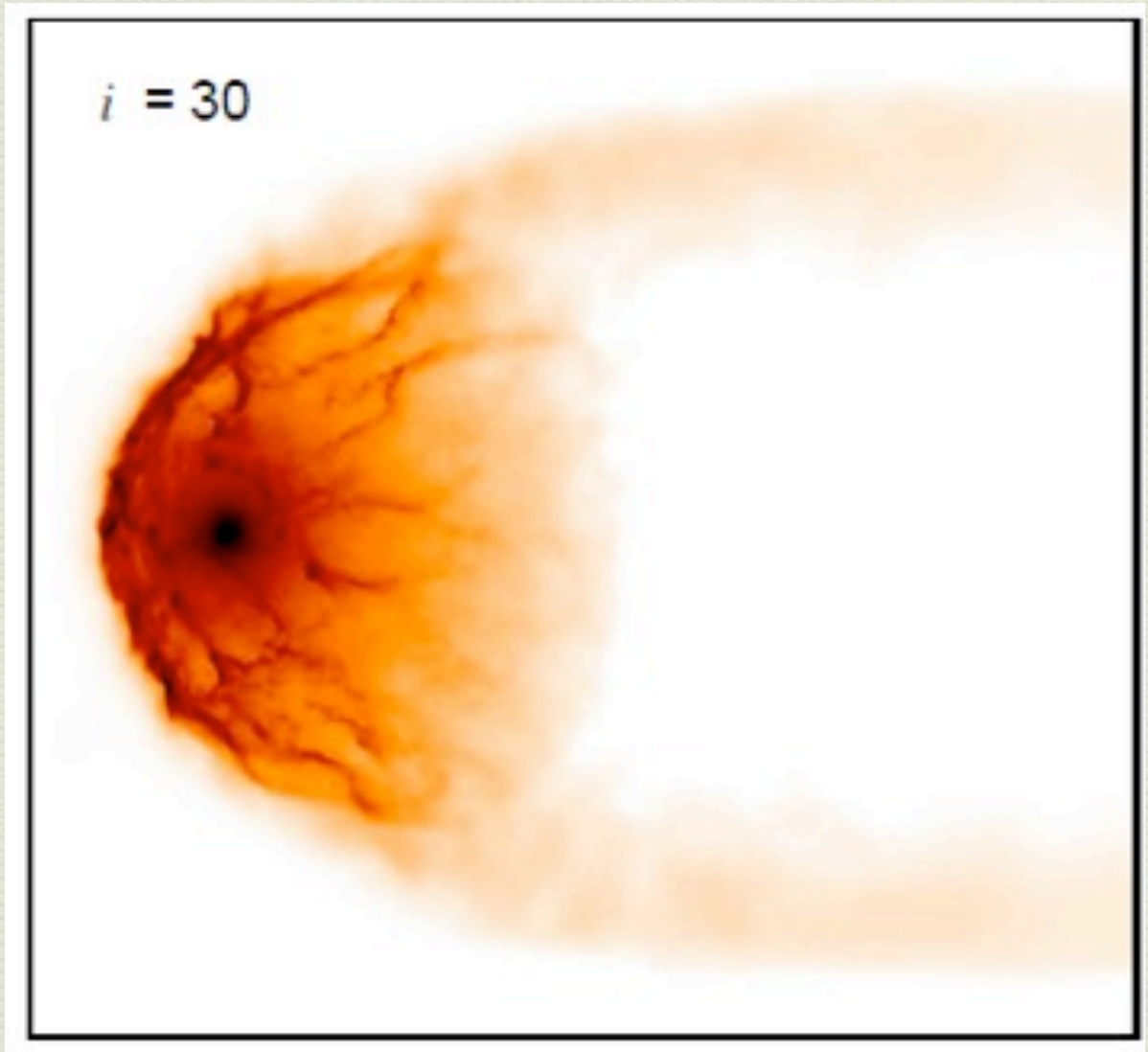
Bow Shock and Bar

- Herschel 70 + 100 micron (Cox+, 2012,A&A,537,A35).
  Bow shock mass estimated at <1e-3 Msun.



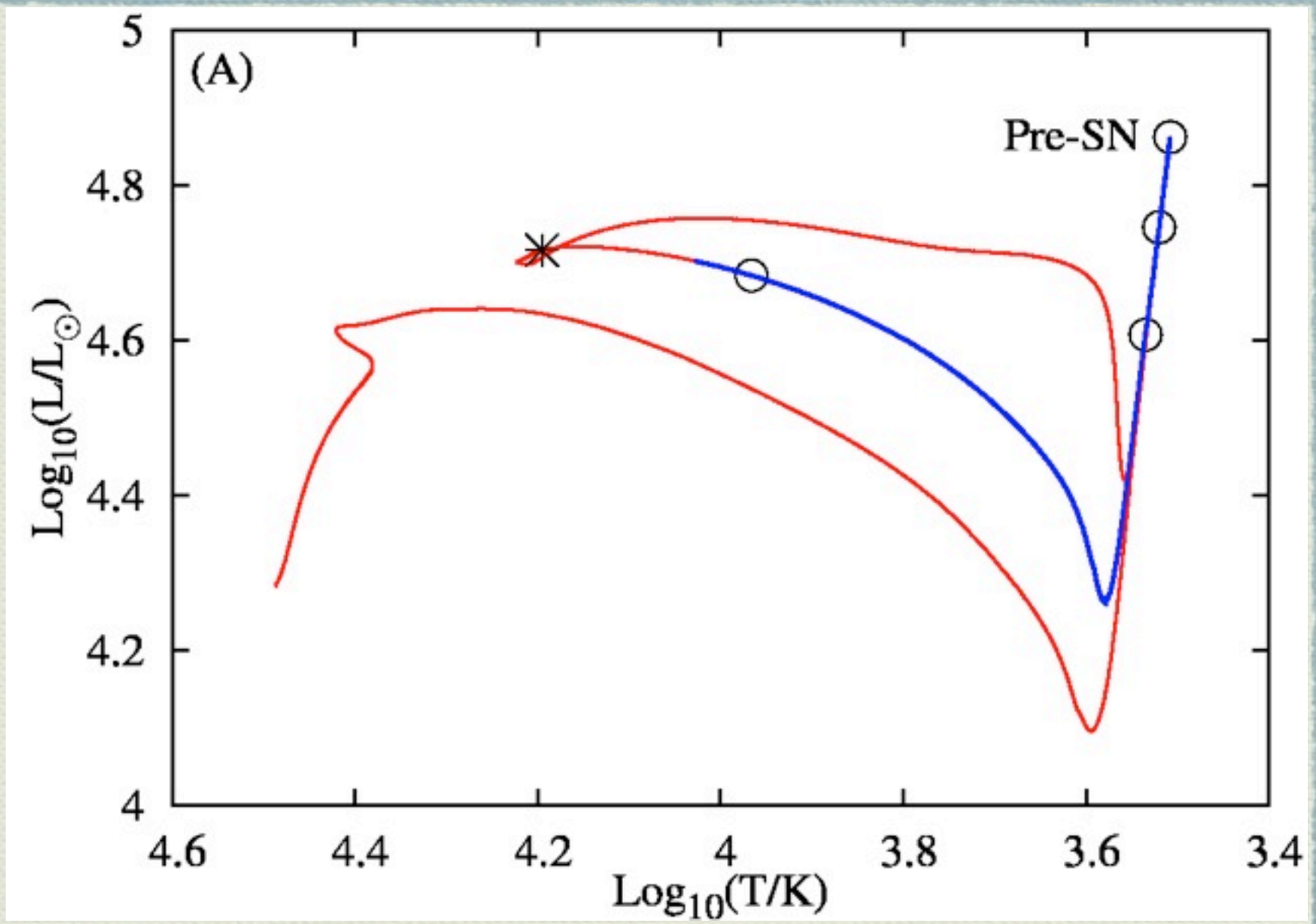
Mohamed, Mackey & Langer (2012, A&A, in press)

- 3D SPH simulations of constant RSG wind interacting with ISM flowing past star, generating bow shock.
- Different ISM densities, stellar space velocities.
- Bow shock is clumpy and unstable, and mass is >0.1 Msun in steady state.
- If M=0.0033 Msun, bow shock must be <30,000 yrs old.
- Even younger with Herschel mass.



Evolving wind model

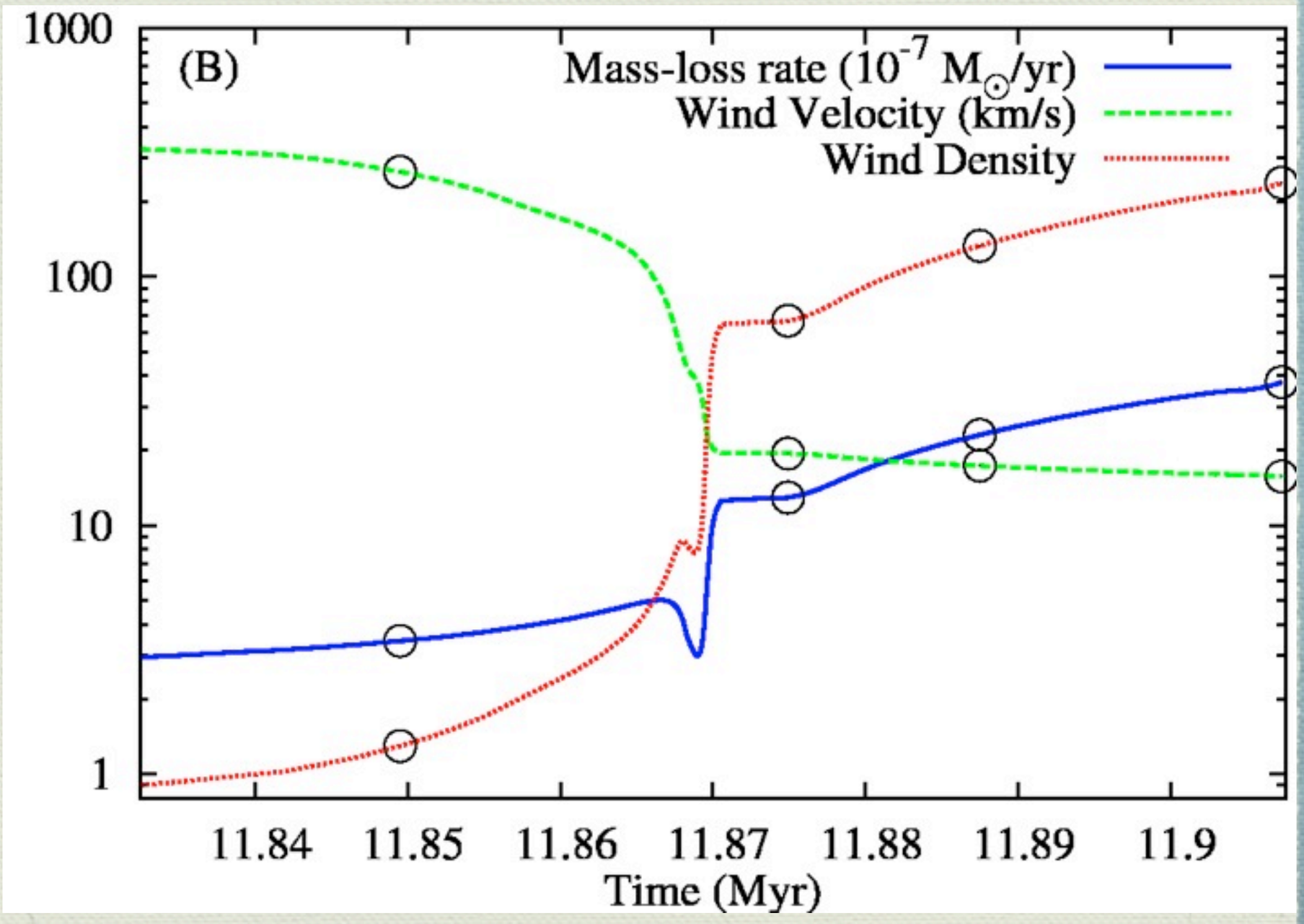
- 15 Msun model from Bonn stellar evolution code.
- Computed to have RSG properties similar to Betelgeuse (see Neilson+2011).
- Simulation starts at 11.4 Myr (shown by asterisk)



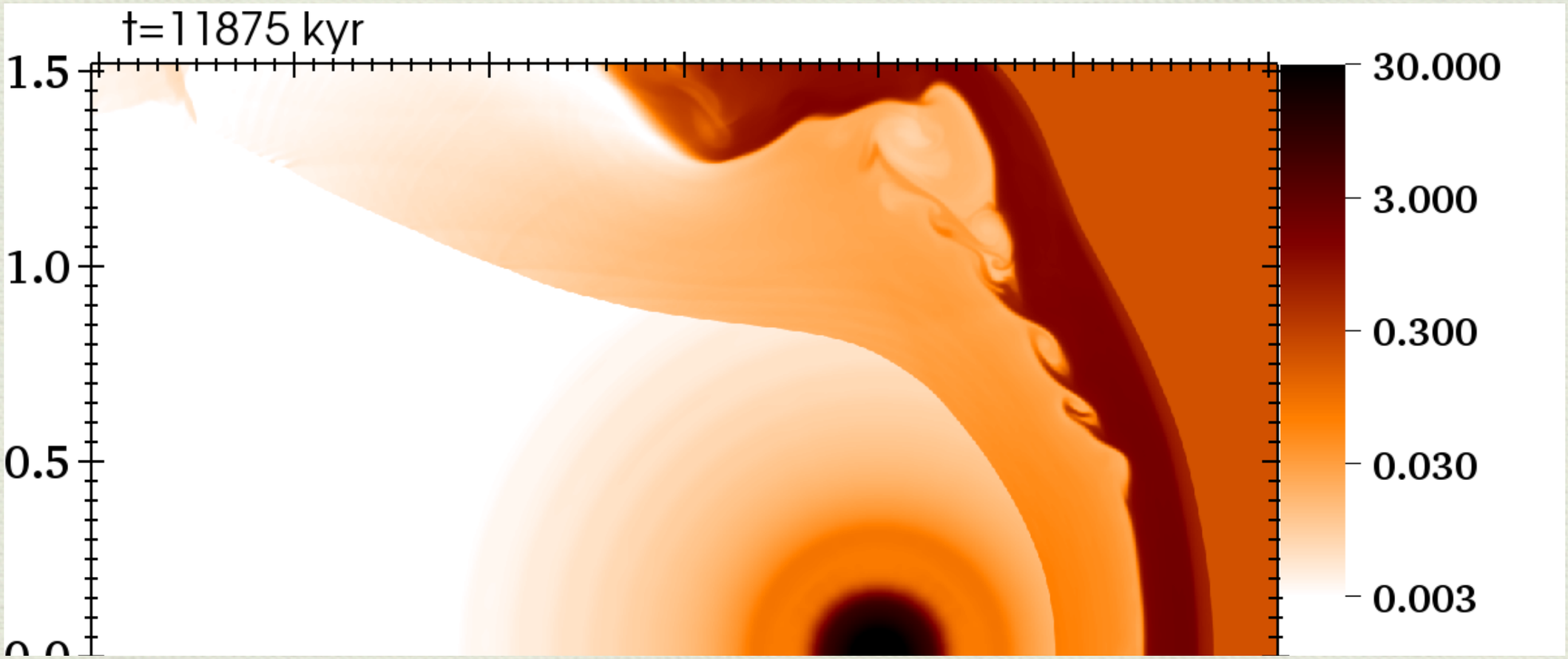
- Blue section is last 75 kyr (t=11.832 - 11.907 Myr).

Stellar Wind Properties

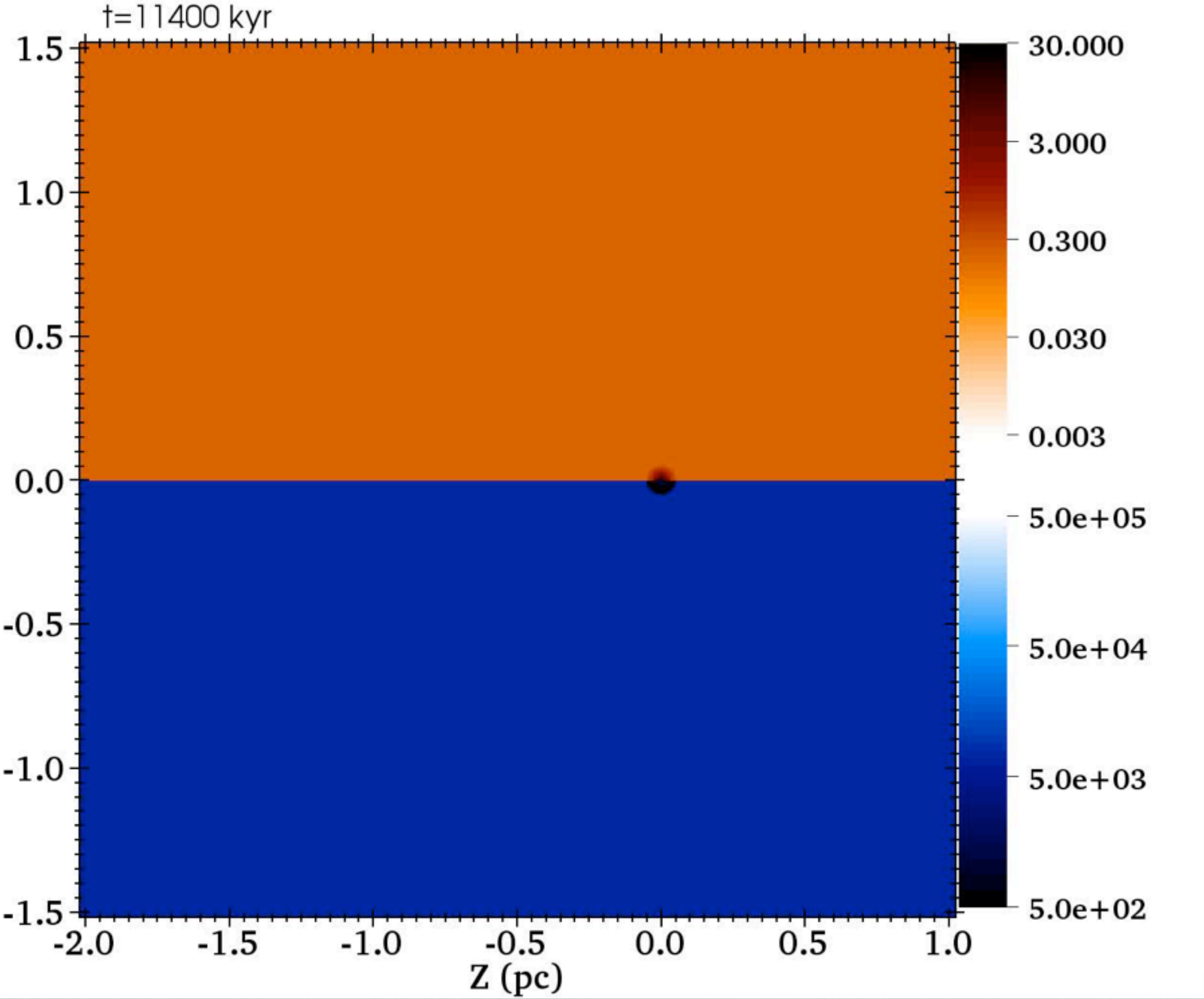
- Last 75 kyr of evolution (blue region of previous plot).
- Mdot, V_w, and wind density plotted.
- Kink is due to luminosity dip.

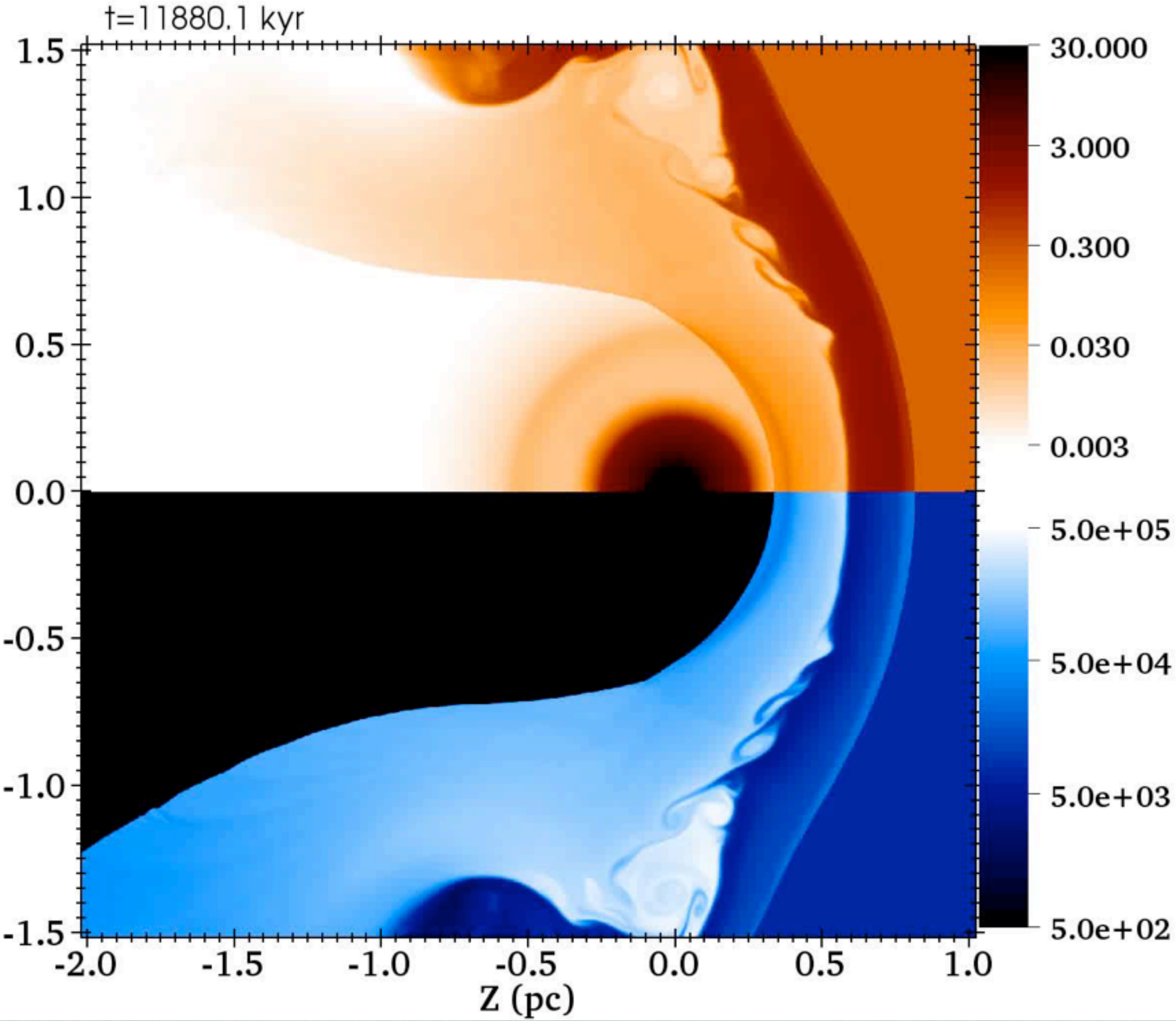


Hydrodynamical Simulations

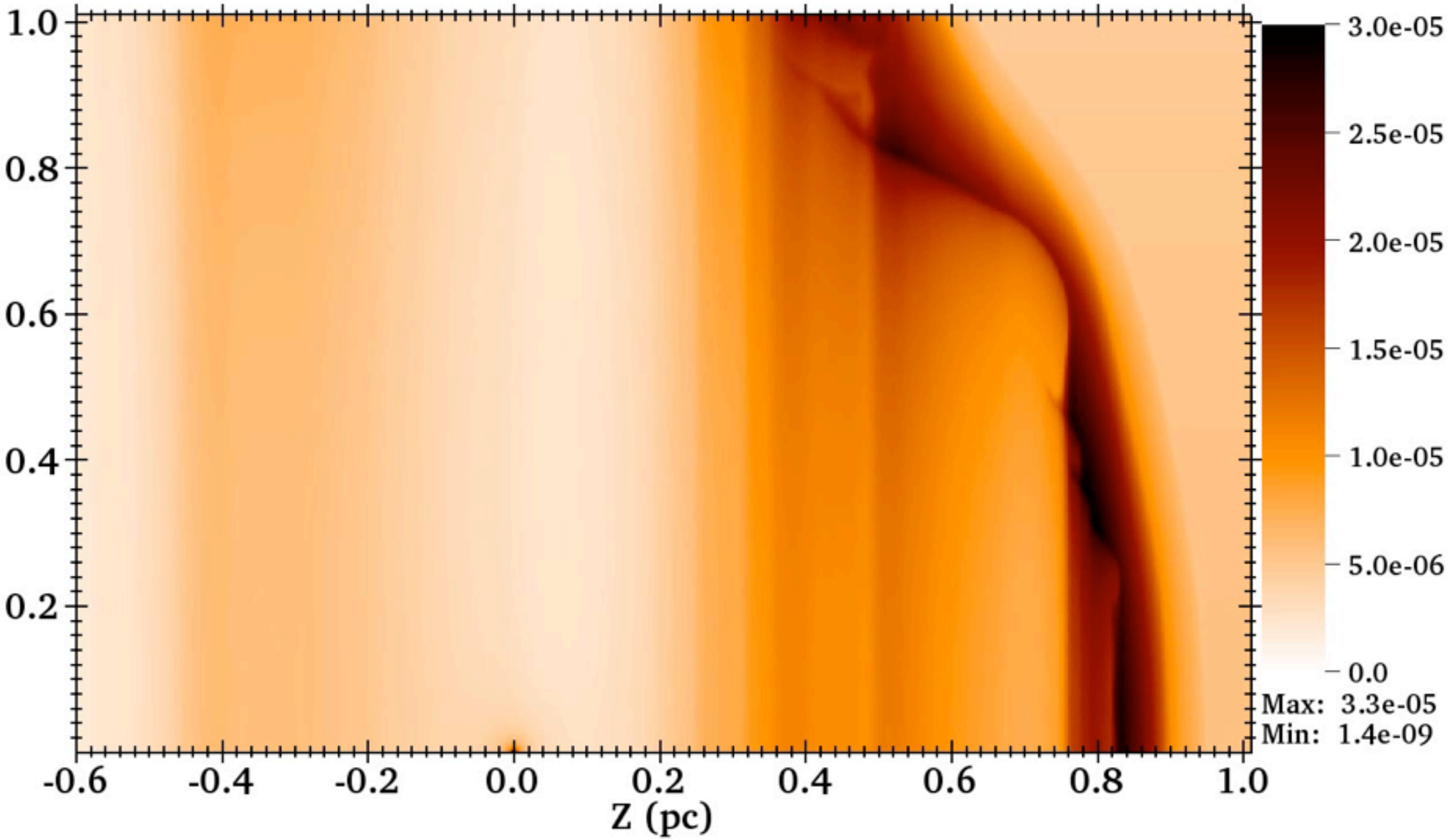


- 2D simulations of (z,R) plane with cylindrical symmetry.
- Collisional ionisation equilibrium cooling (Wiersma+2009).
- Star has V*=50 km/s, through ISM with n(H)=0.2cm-3
- Star is static on grid, ISM flows past (right to left).
- Freely-expanding wind imposed in region r<0.05 pc, following Freyer+ (2003).

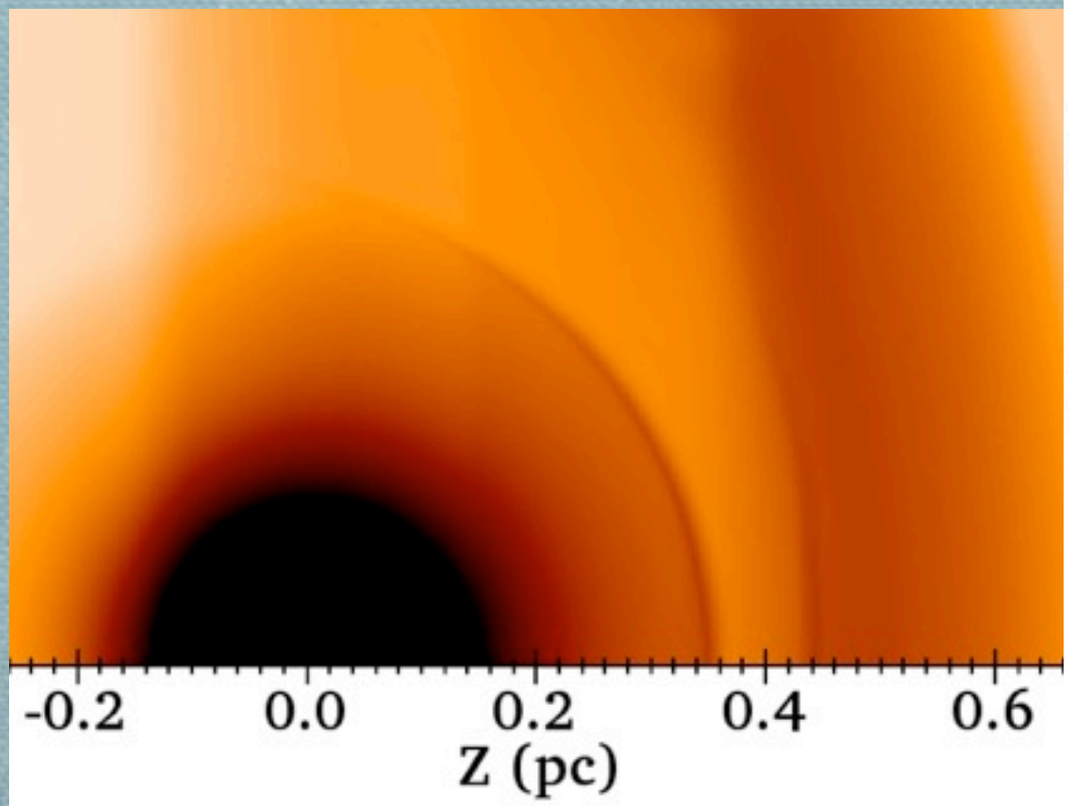

t=11400 kyr
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
Z (pc)
30.000
3.000
0.300
0.030
0.003
5.0e+05
5.0e+04
5.0e+03
5.0e+02

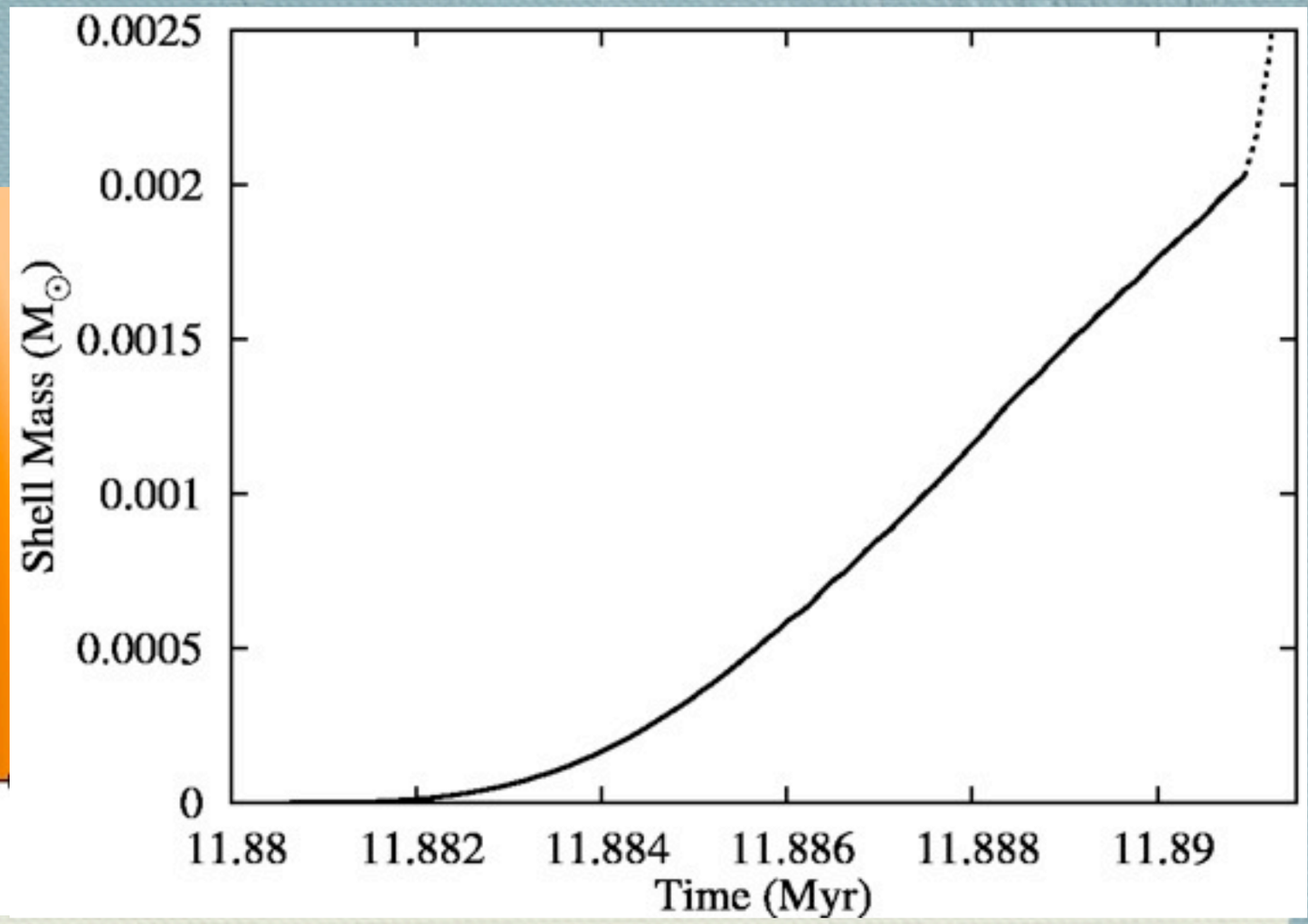

t=11880.1 kyr
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
Z (pc)
30.000
3.000
0.300
0.030
0.003
5.0e+05
5.0e+04
5.0e+03
5.0e+02

Projected Gas Density (g/cm2)



Shell Mass





- Mass of inner shell measured from simulations during time between BSG reverse-shock collapse and contact discontinuity collapse.
- Mass slightly lower than AKARI mass estimate, but within a factor of 2. Agrees with Cox+(2012) estimate.

Conclusions

- 15-20 Msun runaway stars evolving from MS/BSG to RSG can produce multiple bow shocks/shells during transition.
- Generic feature of blue-to-red transitions during evolution.
- May be visible for 50-100 kyr (depending on parameters).
- Specific model can match Betelgeuse's bow shock in terms of location (~0.3pc upstream) and mass (~0.001 Msun).
- Provides a natural explanation of the upstream bar.
- Implies Betelgeuse was recently a BSG/MS star.
- If a BSG, in our simulation it would be ~15 kyr from supernova.