Radiation Hydrodynamics Simulations of Interstellar and Circumstellar Bubbles

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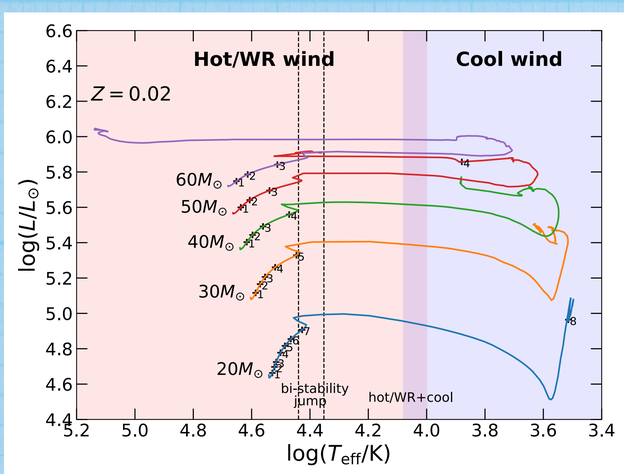
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* To study the physical structures of interstellar bubbles, we calculate time-dependent mass-loss rates and wind velocities using 1D stellar evolution models and then import these data into 2D radiation hydro simulations.

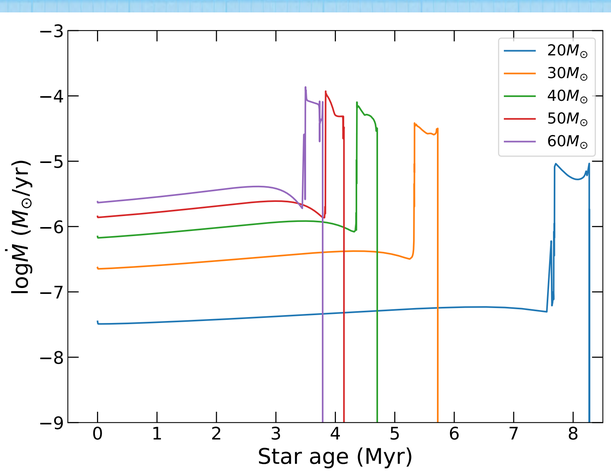
1D stellar evolution simulations

Ou et al. (2023), ApJ, 944, 34

- A grid of 1900 stellar models of different initial masses and metallicities
- Facility: MESA stellar evolution code (Paxton et al. 2011, 2013, 2015, 2018, 2019)

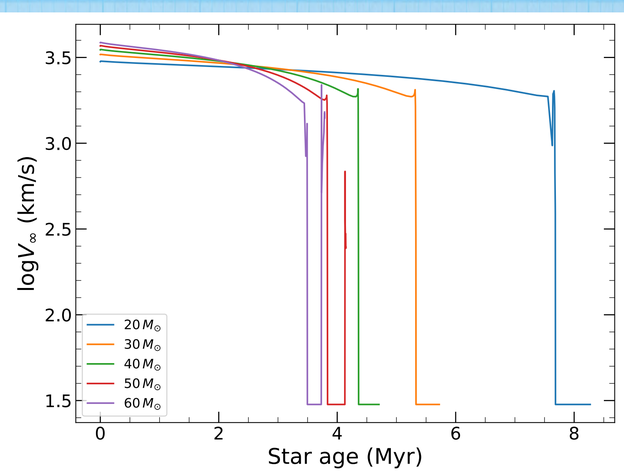


Evolutionary tracks



Mass-loss rates

Obtained from stellar models with wind recipes



Wind velocities

Derived from the escape velocities in stellar models

Main sequence
"hot wind"
Fast

↓

Red supergiant
"cool wind"
Slow

↓

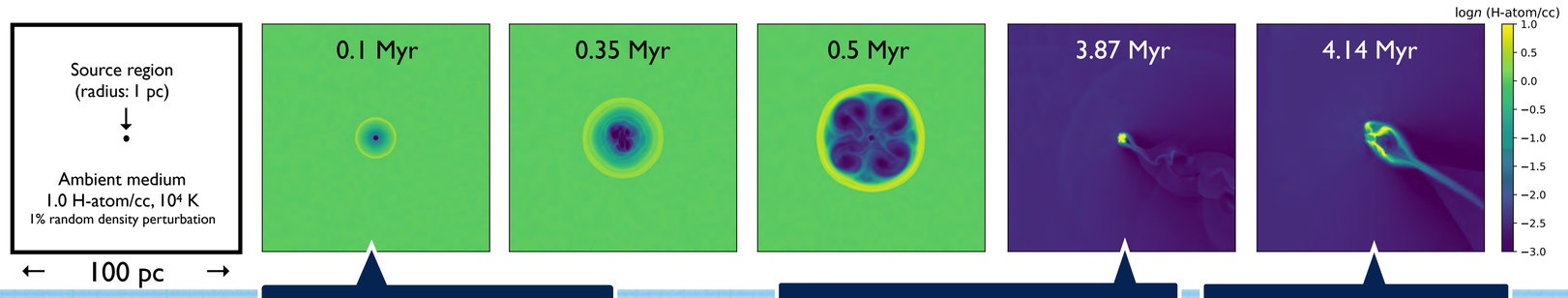
Wolf-Rayet star
WR wind
Fast

↓ Feed the *stellar winds* into the interstellar medium

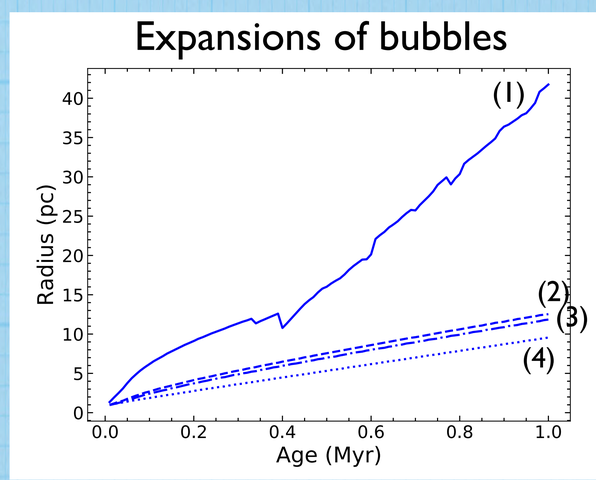
2D radiation hydrodynamics simulations

- Facility: RAMSES (Teyssier 2002; Rosdahl et al. 2013), an AMR-based RT-hydro and N-body code
- Method: establishing a source region where we add the mass, momentum and energy density of stellar wind at each timestep

A. Evolution from the main sequence



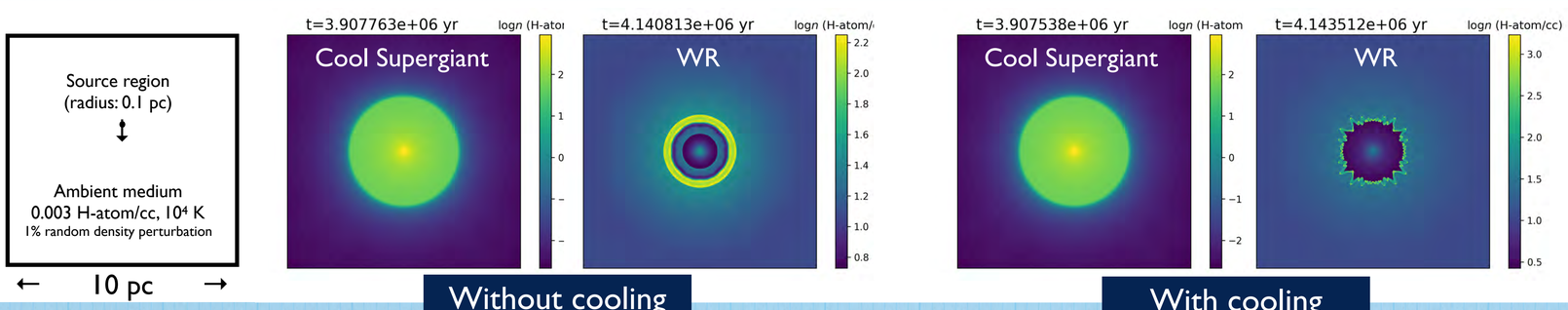
Expansions of bubbles

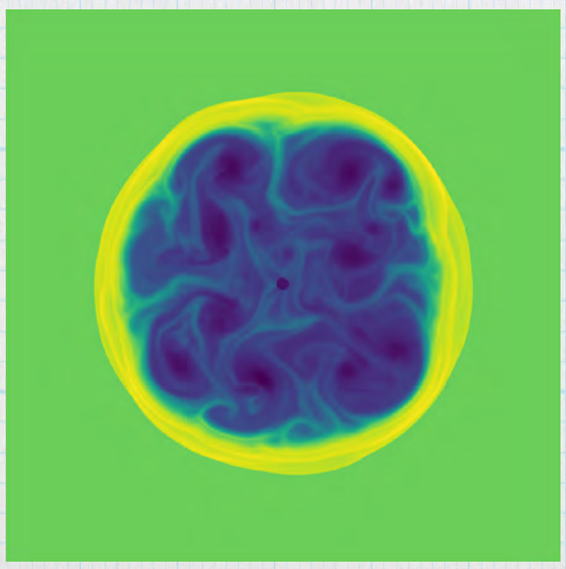


Model (1): 50 $M_\odot$, ambient density 1.0 cm^{-3}
[Instability inside the bubble is triggered]
Model (2): 50 $M_\odot$, ambient density 10 cm^{-3}
Model (3): 25 $M_\odot$, ambient density 1.0 cm^{-3}
Model (4): 25 $M_\odot$, ambient density 10 cm^{-3}

* Expansion velocities from observations: 15-20 km/s (Nazé et al. 2001; Chu 2008)

B. Post main sequence (zoom in)







Summary

We have derived mass-loss data from stellar evolution simulations and established RT-hydro models of interstellar bubbles. These models can reproduce basic nebula structures around stars during main-sequence, cool-supergiant, and WR stages. In future works, we will carry on 3D simulations and systematically study the physical factors (ambient density, stellar mass, dense clumps, cooling, etc.) that affect the evolution and structures of bubbles. These simulations can build up realistic environments of supernova explosions.

References

Chu 2008, *IAUS*, 250, 341
Nazé et al. 2001, *AJ*, 122, 921
Weaver et al. 1977, *ApJ*, 218, 377
Paxton et al. 2011, *ApJS*, 192, 3
Rosdahl et al. 2013, *MNRAS*, 436, 2188
Teyssier 2002, *A&A*, 385, 337