MHD simulation of stellar feedback in a filamentary molecular cloud formed by the thermal instability

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Summary

We have used the AMR hydrodynamic code, MG, to perform 3D MHD simulations of stellar feedback in a filamentary molecular cloud formed through the action of the thermal instability, with self-gravity and magnetic fields [1]. Our aim is to examine the effect of stellar wind *and* supernova feedback on the evolution of the molecular cloud. The initial condition is a 100 pc-diameter 17,000 $M_\odot$ molecular cloud best described as a corrugated sheet that in projection appears filamentary [2] and is very reminiscent of Larson's "filamentary or sheet-like structure" [3]. Geneva star tracks are employed to mechanically launch stellar winds into this structure in two separate cases: 15 $M_\odot$ and 40 $M_\odot$ stars. In both cases the stellar wind blows out away from the filamentary structure, redistributing cloud material to differing amounts. In the 15 $M_\odot$ star case, the wind forms a narrow bipolar cavity with minimal effect on the parent cloud. In the 40 $M_\odot$ star case, the greater mass and energy injected in the stellar wind leads to the formation of a large cylindrical cavity around the location of the star, through the centre of the cloud. After 12.5 Myrs and 4.97 Myrs respectively, the massive stars in these simulations explode as supernovae (SNe), introducing 10 $M_\odot$ of material and 10^{51} erg of thermal energy. In the 15 $M_\odot$ star case, where the wind cavity is almost inconsequential, the SN energy is primarily deposited into the molecular cloud surroundings over the course of 200,000 years before the SN remnant escapes the cloud. In the 40 $M_\odot$ star case, the majority of the SN energy and material rapidly escapes the molecular cloud along the wind cavity in a few tens of kyrs. In both cases cold molecular cloud material survives, with SN events compressing cloud material to higher densities, particularly so in the 15 $M_\odot$ star case, suggesting triggered star formation.

Physical Model

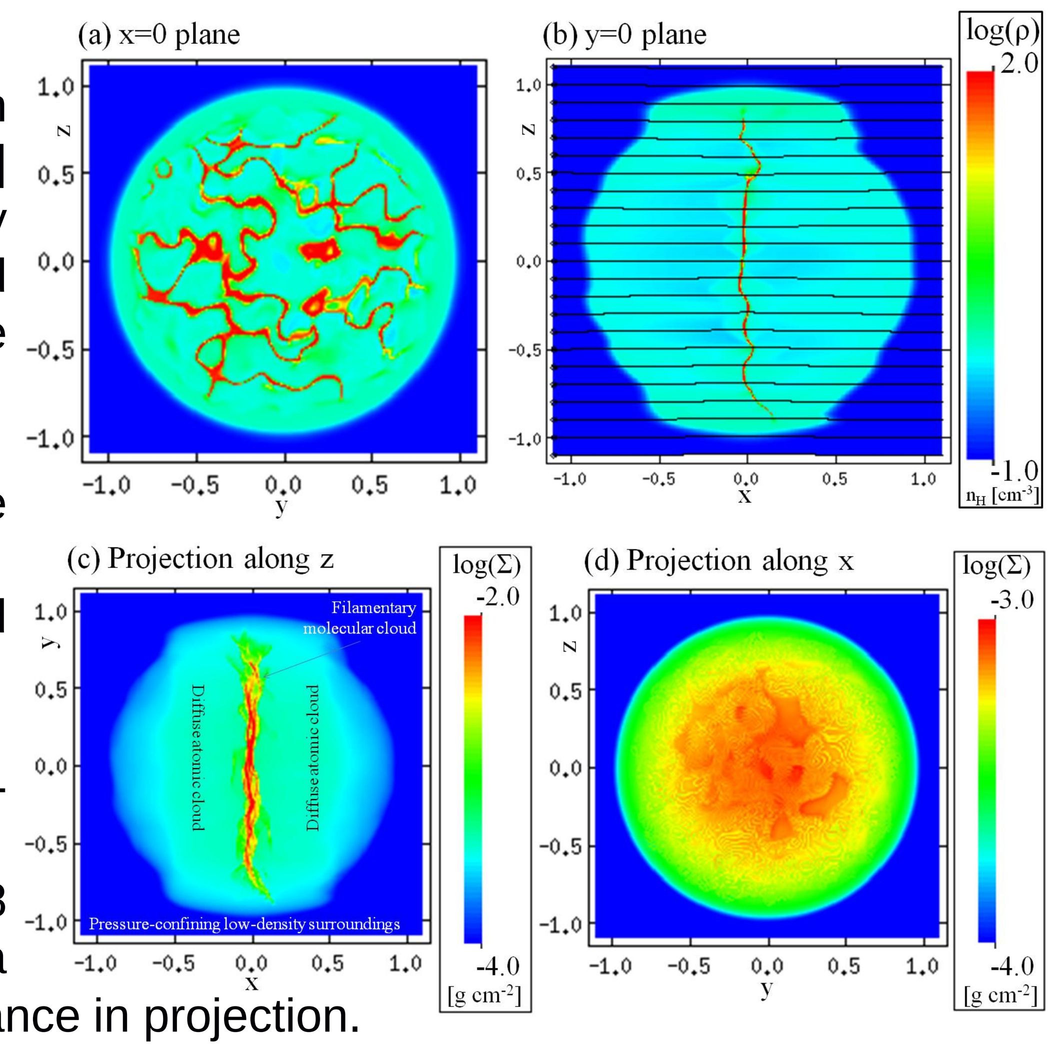
- With the aim of exploring the effect of feedback on a molecular cloud, we start from the simplest set of self-consistent physics that forms the cloud:
  - 3D MHD,
  - Self-gravity,
  - Multi-phase ISM, requiring a prescription for heating and cooling.
- In future, additions may be explored, e.g. large-scale flows or turbulence, but for now we look for a solution without recourse to extra factors.

Numerical techniques

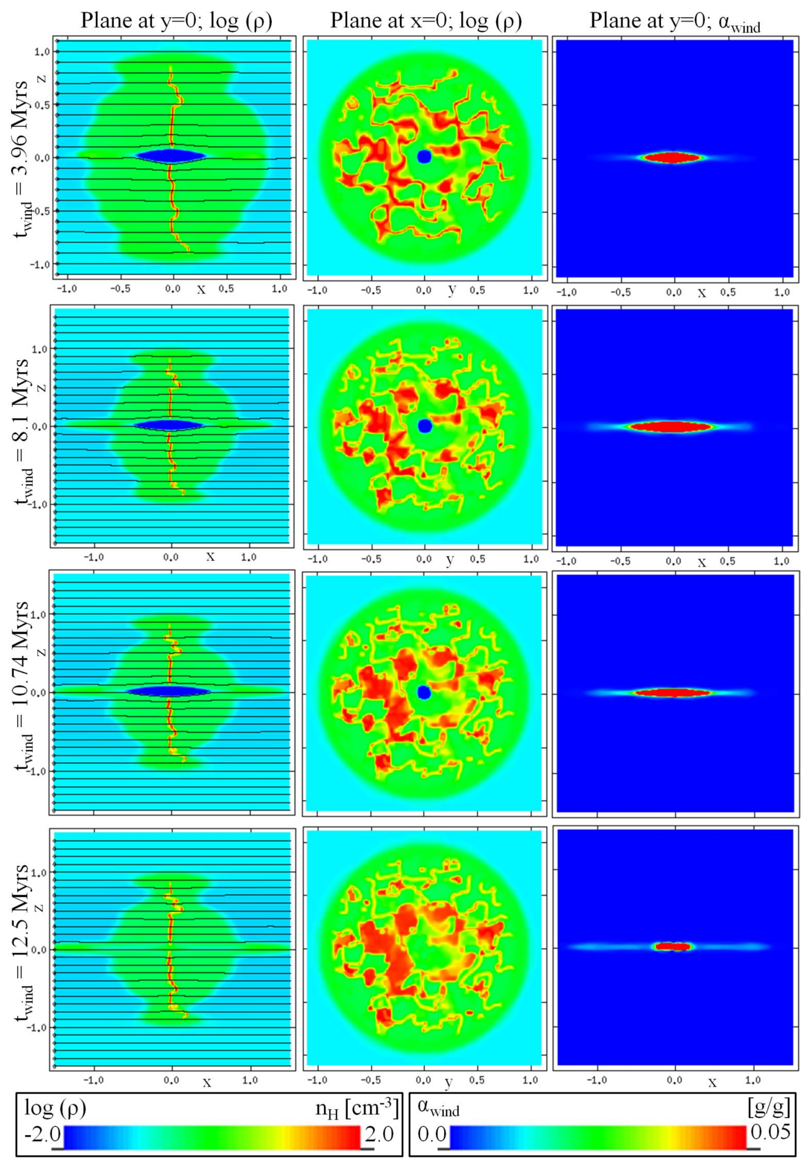
- Magnetohydrodynamic version of MG with self-gravity.
- Parallel, upwind, conservative, shock-capturing scheme.
- Adaptive mesh refinement in this case uses a coarse base grid (4x4x4) with 7 (or more) levels of AMR to achieve a resolution up to 512^3.
  - Why the wide range? Efficient computation of self-gravity.
- Realistic heating and cooling methods.
  - Of key importance as it is the balance of these that establishes the initial condition and defines the consequent evolution.
- Heating: $\Gamma = 2\times10^{-26}\,\mathrm{erg\ s^{-1}}$, independent of ρ and T for now.
- Multi-stage cooling, in order to apply for the molecular cloud formation (down to 10K) and stellar feedback (up to 10^9 K):
  - Low T (<10^4 K) [4,5]: $\dfrac{\Lambda(T)}{\Gamma} = 10^7 \exp\left(\dfrac{-1.184\times10^5}{T+1000}\right) + 1.4\times10^{-2}\sqrt{T}\exp\left(\dfrac{-92}{T}\right)$
  - Between 10^4 K and 10^8 K we have used CLOUDY 10.00 rates [6],
  - Above 10^8 K a MEKAL curve has been used.
- Establishes thermal equilibrium pressure and temperature by $\rho^2\Lambda = \rho\Gamma$.

Forming the molecular cloud

- The initial condition is taken from our previous work [2] which focussed on the study of filamentary molecular cloud formation under the influence of the thermal instability [7].
- 100 pc-diameter diffuse cloud
- n_H=1.1cm^{-3} ±10% - in the thermally unstable regime.
- Threaded by magnetic field along the x-axis.
- For β=1.0, B_0=1.15 μG
- Pressure equilibrium with low-density surroundings.
- Stars are injected after 38.8 Myrs, when the cloud has a corrugated sheet-like appearance in projection.

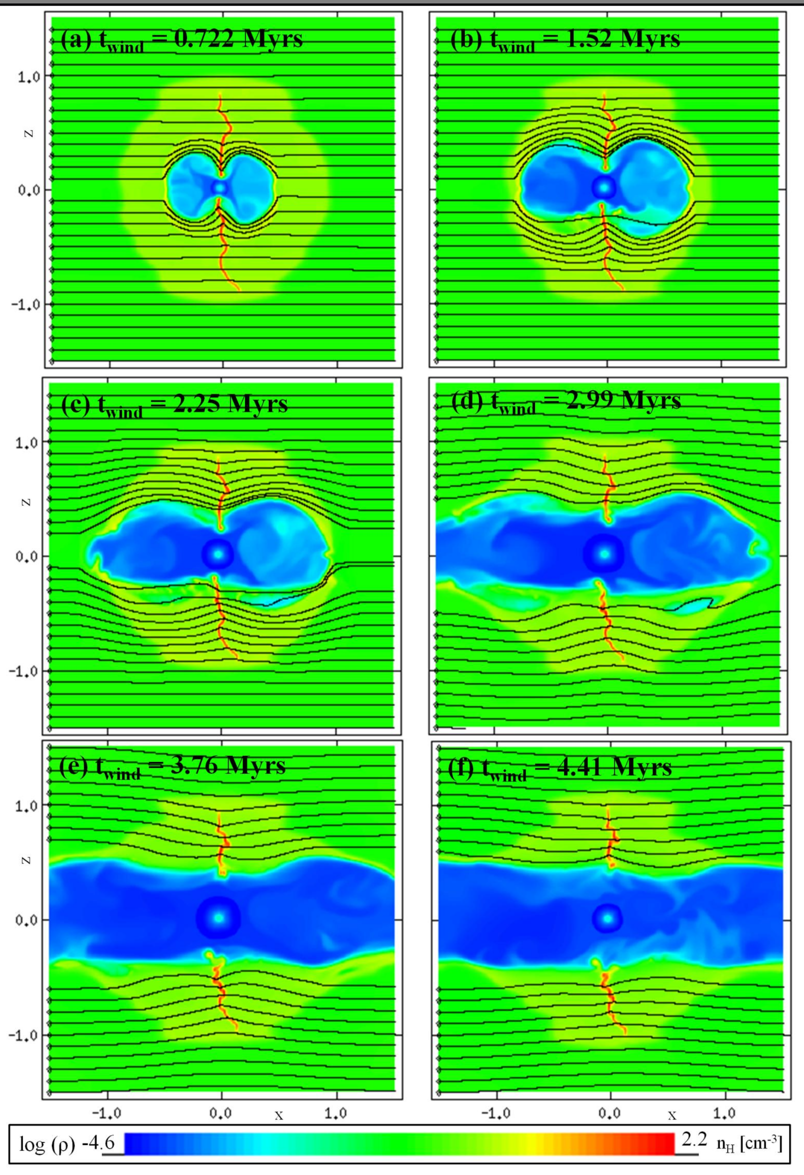


15 $M_\odot$ star – wind phase



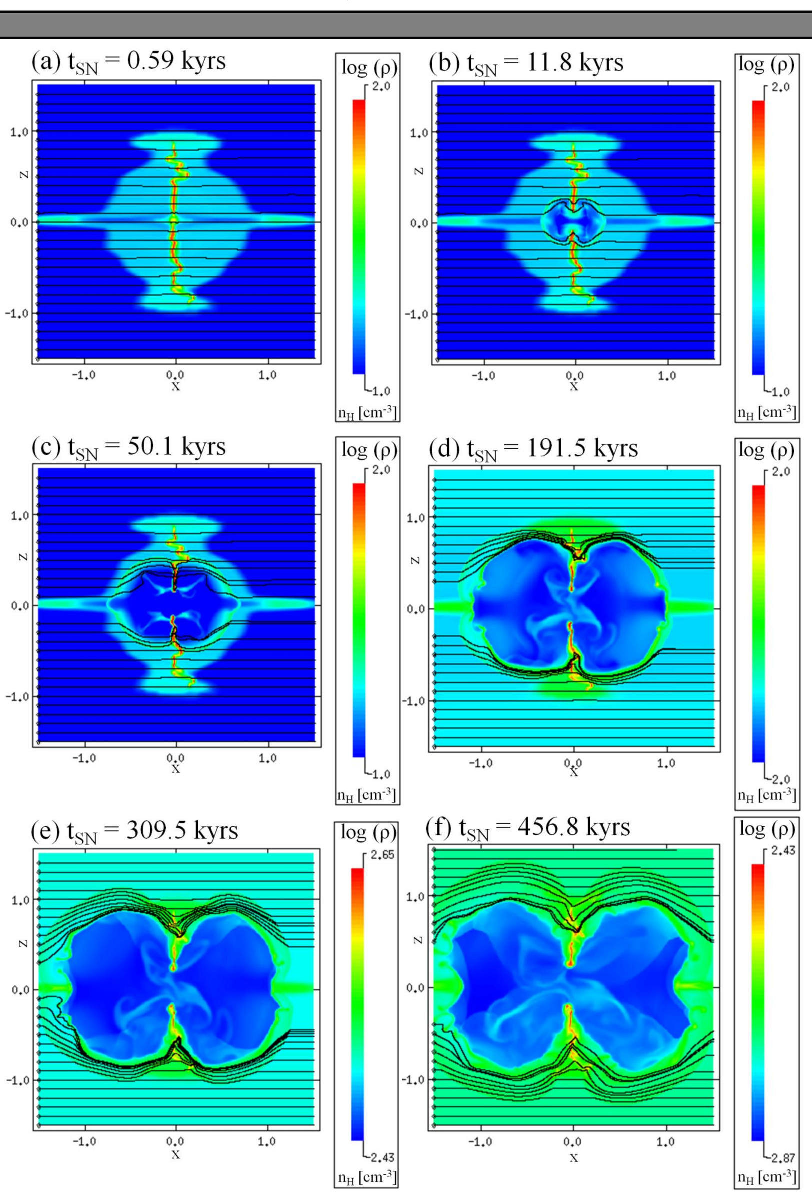
- Low mass-loss rate and low wind power have minimal impact.
- Small, local cavity, refilled during the RSG wind phase.

40 $M_\odot$ star – wind phase



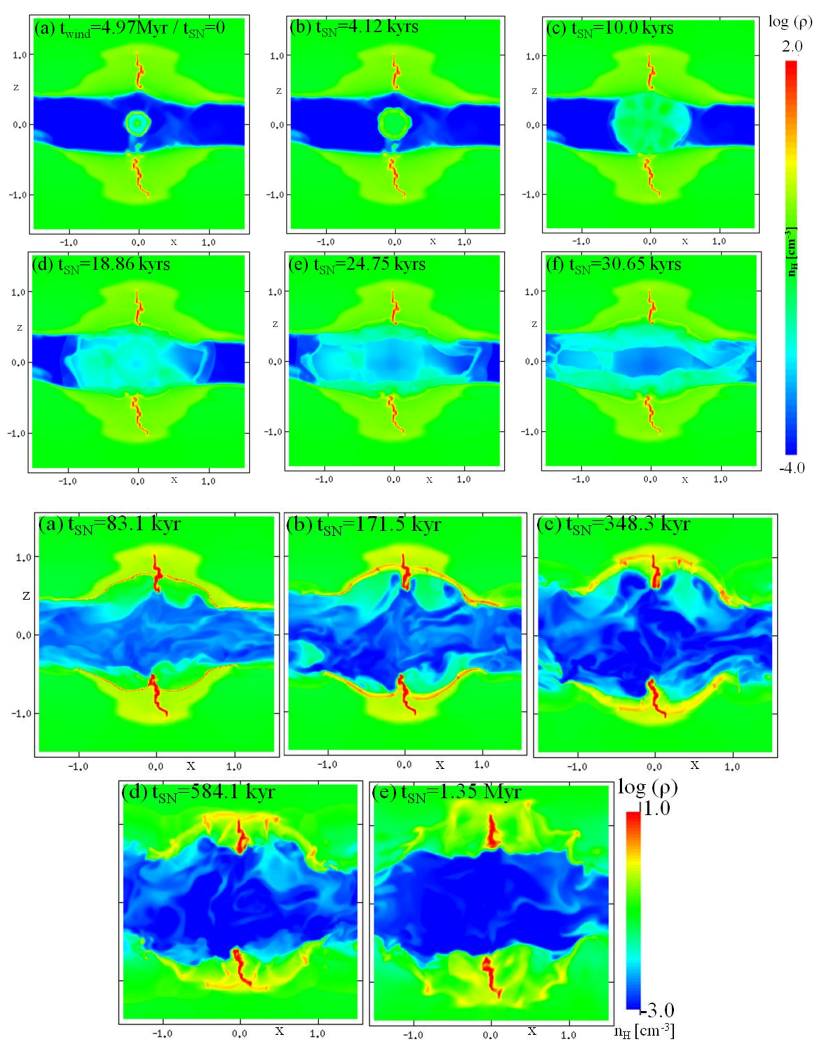
- Significant impact: large bipolar cavity evolves into cylindrical tunnel.
- Much of the wind material flows out.
- B fields intensified by factor 3-4.

15 $M_\odot$ star – SN phase



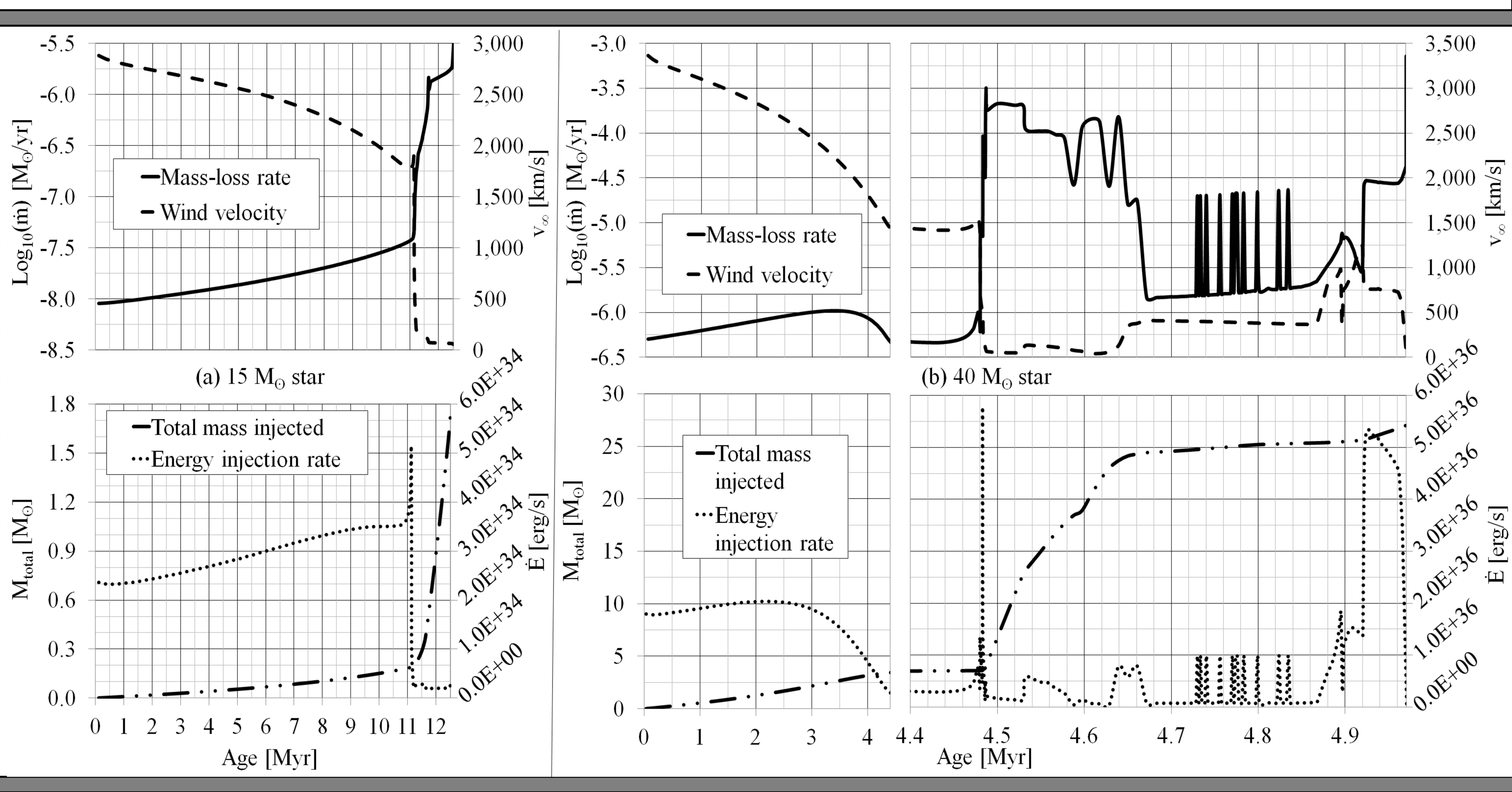
- SN expansion hindered by the high density corrugated molecular cloud.
- The high density filamentary structure is ablated by the SNR.

40 $M_\odot$ star – SN phase

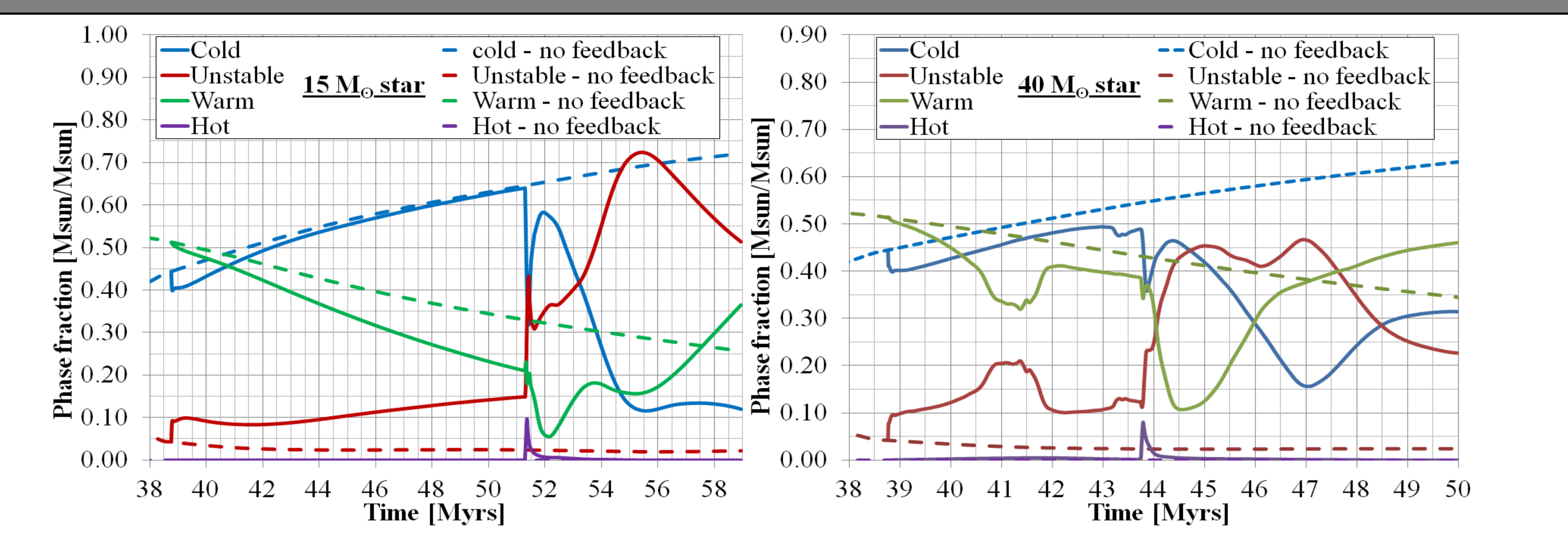


- Majority of SN energy leaves cloud along the tunnel in 30 kyrs.
- Passage through parent cloud is considerably longer: 1.35 Myrs.
- Such ring-like structures have been detected [8], with some controversy.

Stellar evolution



Fate of the molecular cloud



- Fragments of the molecular cloud survive these single star evolution scenarios, with increasing amounts of cold phase material in the 40 $M_\odot$ case.

References:

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DiRAC

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