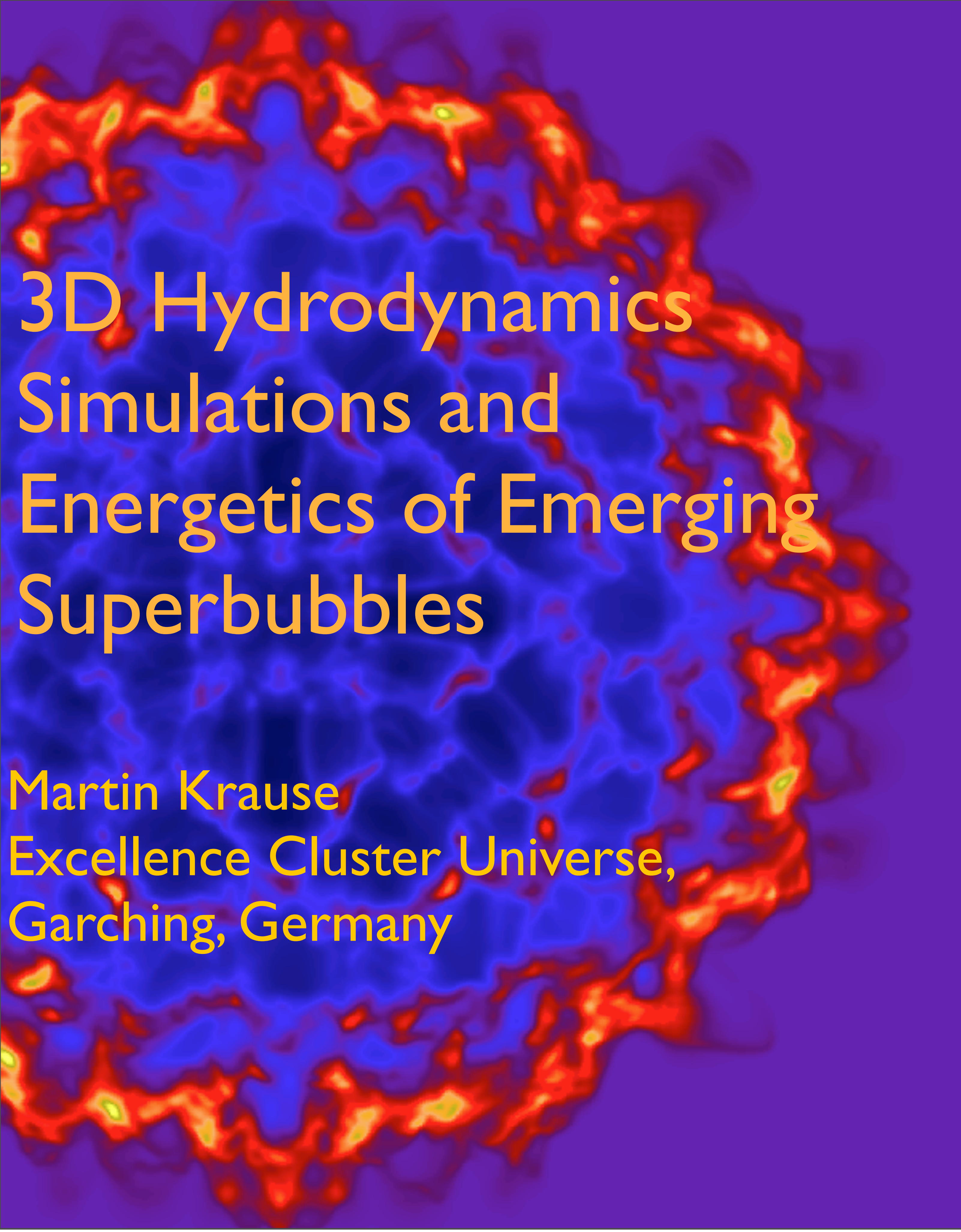

3D Hydrodynamics Simulations and Energetics of Emerging Superbubbles

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Overview

- *Introduction*
  - Superbubbles
  - The energy problem
- Hydrodynamic simulations
  - Emerging superbubble from 3 massive stars
  - Vishniac instability
  - Energetics
- Conclusions

Superbubbles

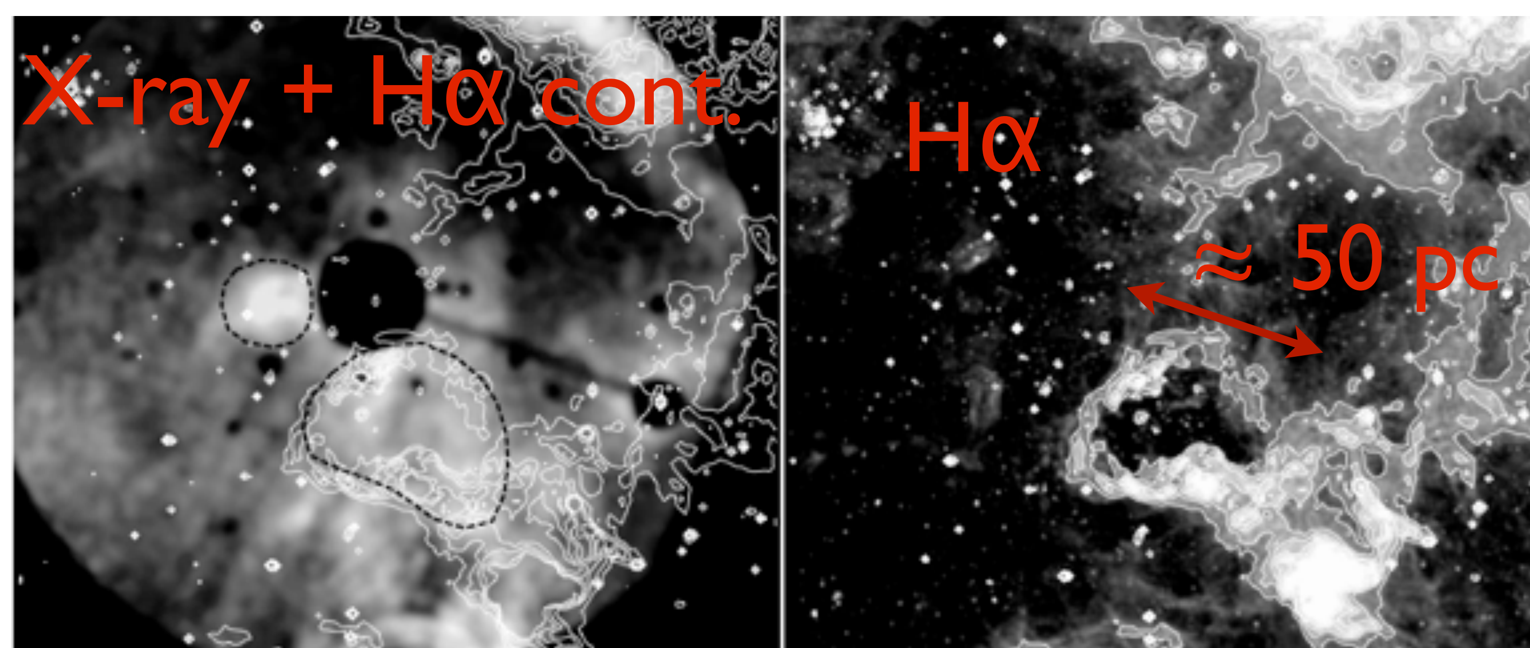
- Groups of stars (clusters / associations) combine their wind bubbles to “superbubbles”
- Superbubble expansion commonly modelled by Weaver (1977)-law:

$$R \propto (Lt^3/\rho_0)^{1/5}$$

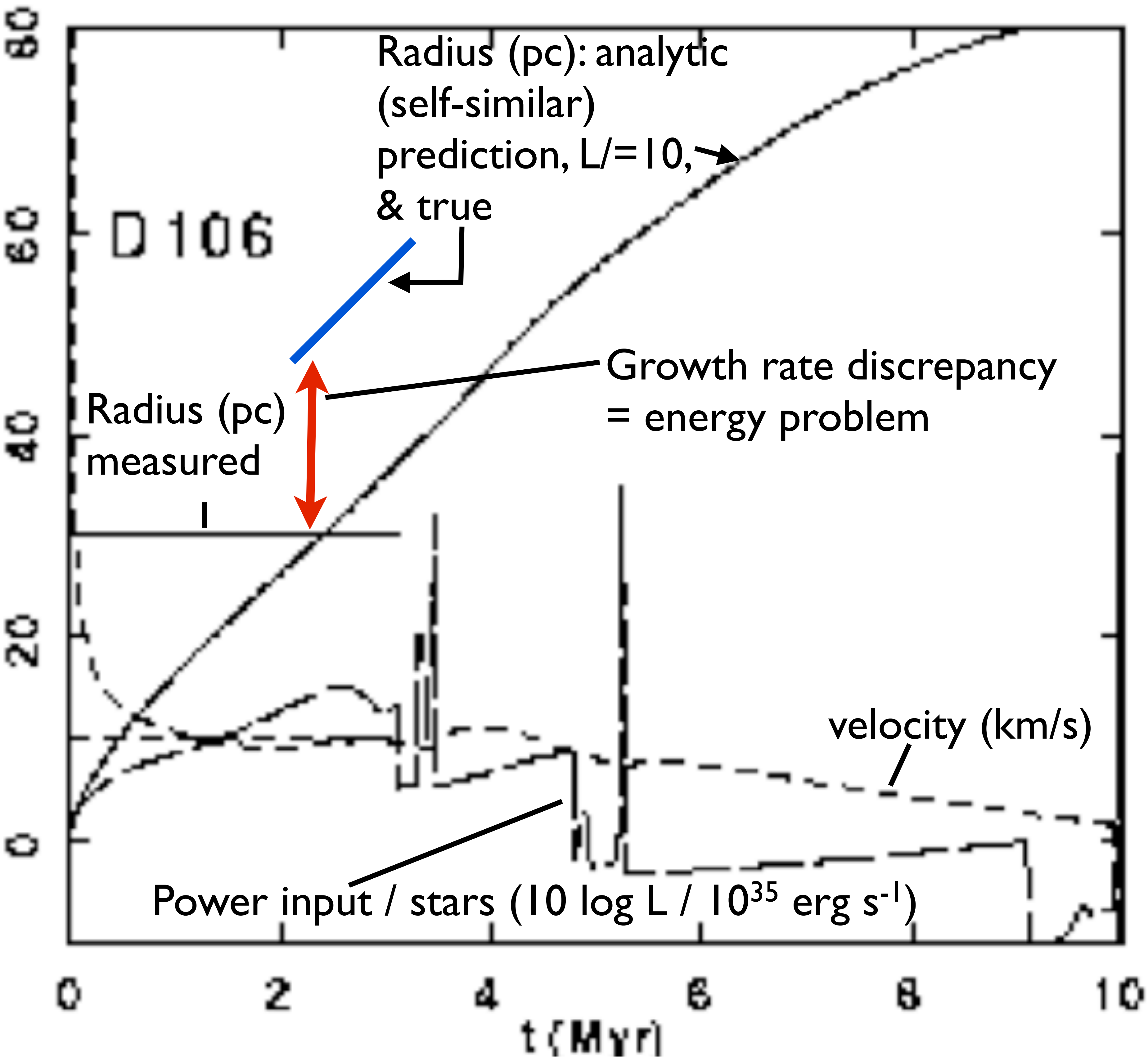
- Sizes ≈ 100pc ≈ order disk scale height
- Superbubbles may connect to halo

Top:Rosette nebula (optical, X-rays: red), Chandra homepage

Bottom X-ray + Hα of N158 in the LMC, Sasaki et al. 2011



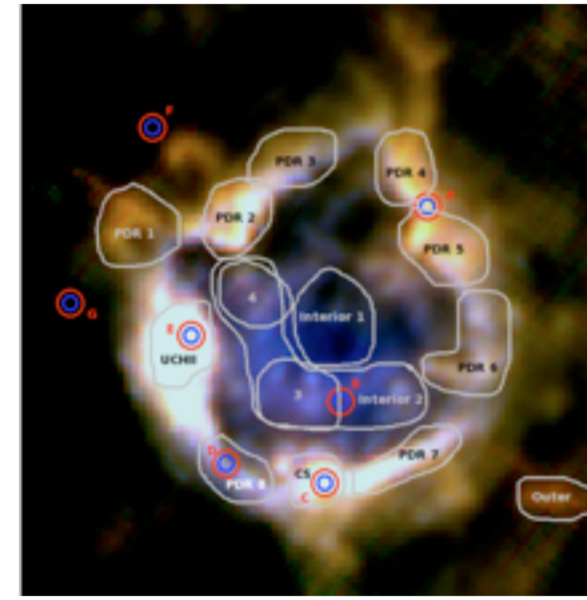
Growth rate discrepancy in superbubbles



Oey 2009

Energy problem:

- Observationally, even single bubbles are claimed to be inefficient, e.g. Garcia-Segura & Mac Low (1995), 0.5% for NGC 6888, but lack of hard evidence for a sample
- Superbubbles expand slower than expected from their stellar content (e.g. Oey & Garcia -Segura 2004)
- Explanations: cooling (shell & interior), mass loading / mixing of shocked wind w. entrained gas, evaporation of shell material, cosmic ray losses
- Galactic winds: Observations require high energy efficiency > 10% SN



⇒ We do not understand energy transfer in superbubbles.

Questions:

- What is the reason for the energy deficit in bubbles / superbubbles?
- *Losses during bubble merging?*
- $\Rightarrow$ Hydrodynamic simulations
- Confidence in theory: match observations

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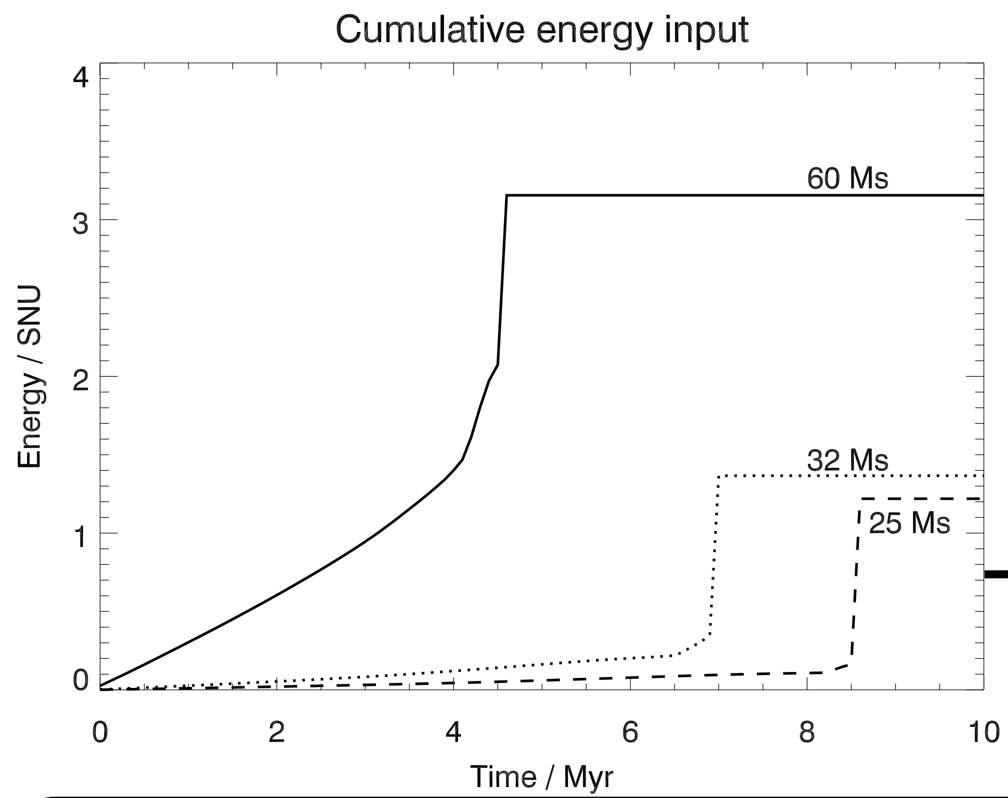


Hydrodynamic simulation

Conservation of:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = \dot{\rho}_*$$

mass

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v}\mathbf{v}) = -\nabla p$$

momentum

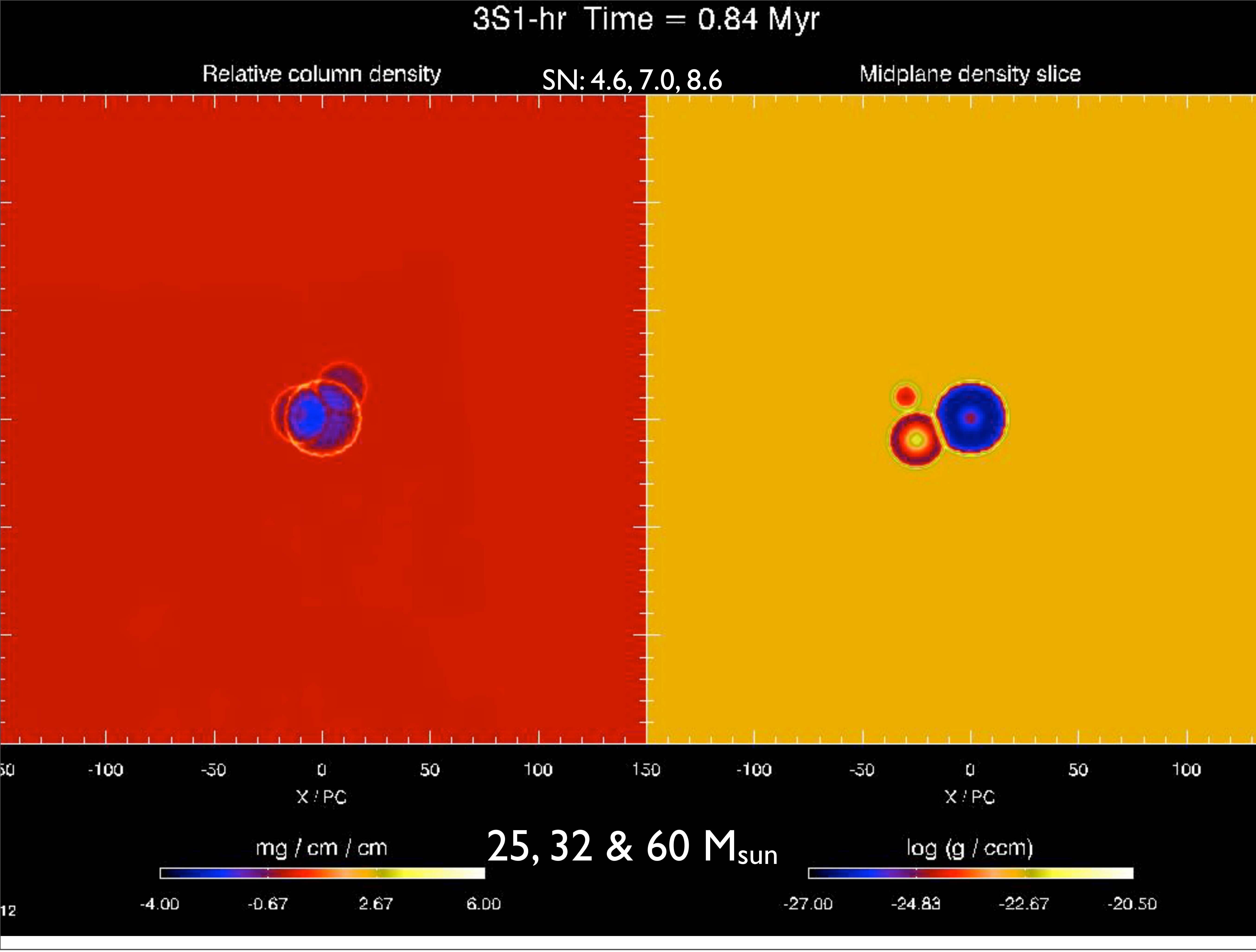
$$\frac{\partial e}{\partial t} + \nabla \cdot (e v) = -p\nabla \cdot \mathbf{v} + \mathcal{H} - \mathcal{C} + \dot{e}_*$$

energy

input / stars

thermodynamics

Codes: RAMSES & NIRVANA, 2D/3D, ||, AMR


3S1-hr Time = 0.84 Myr
Relative column density
SN: 4.6, 7.0, 8.6
Midplane density slice
-100
-50
0
50
100
150
X / PC
mg / cm / cm
25, 32 & 60 Msun
log (g / ccm)
-4.00
-0.67
2.67
6.00
-27.00
-24.83
-22.67
-20.50

Vishniac instability

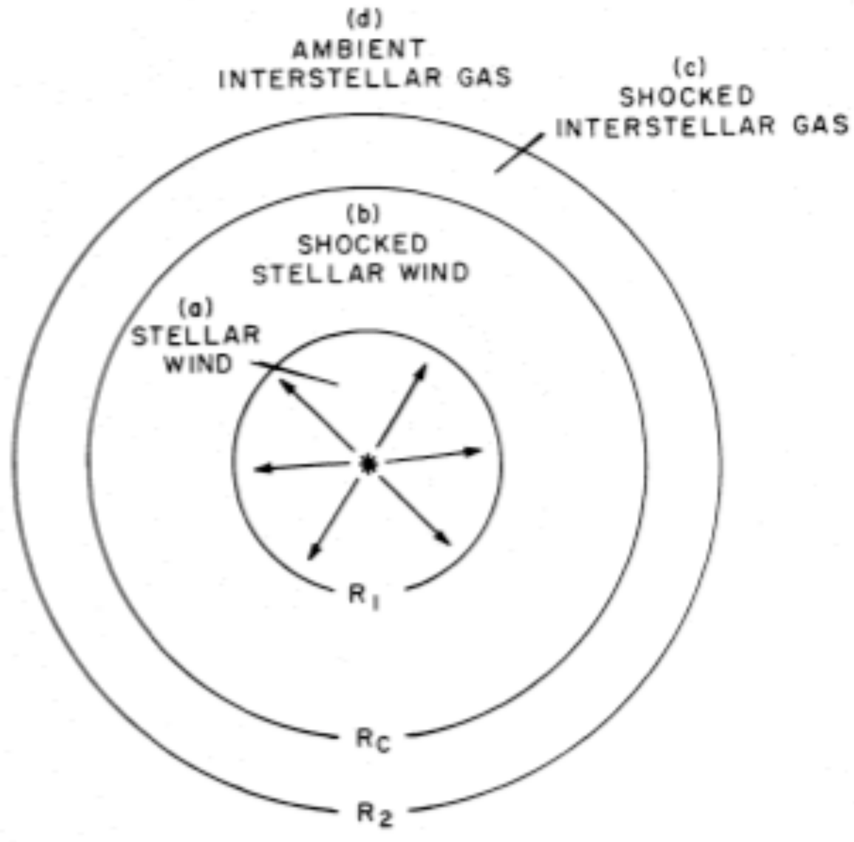
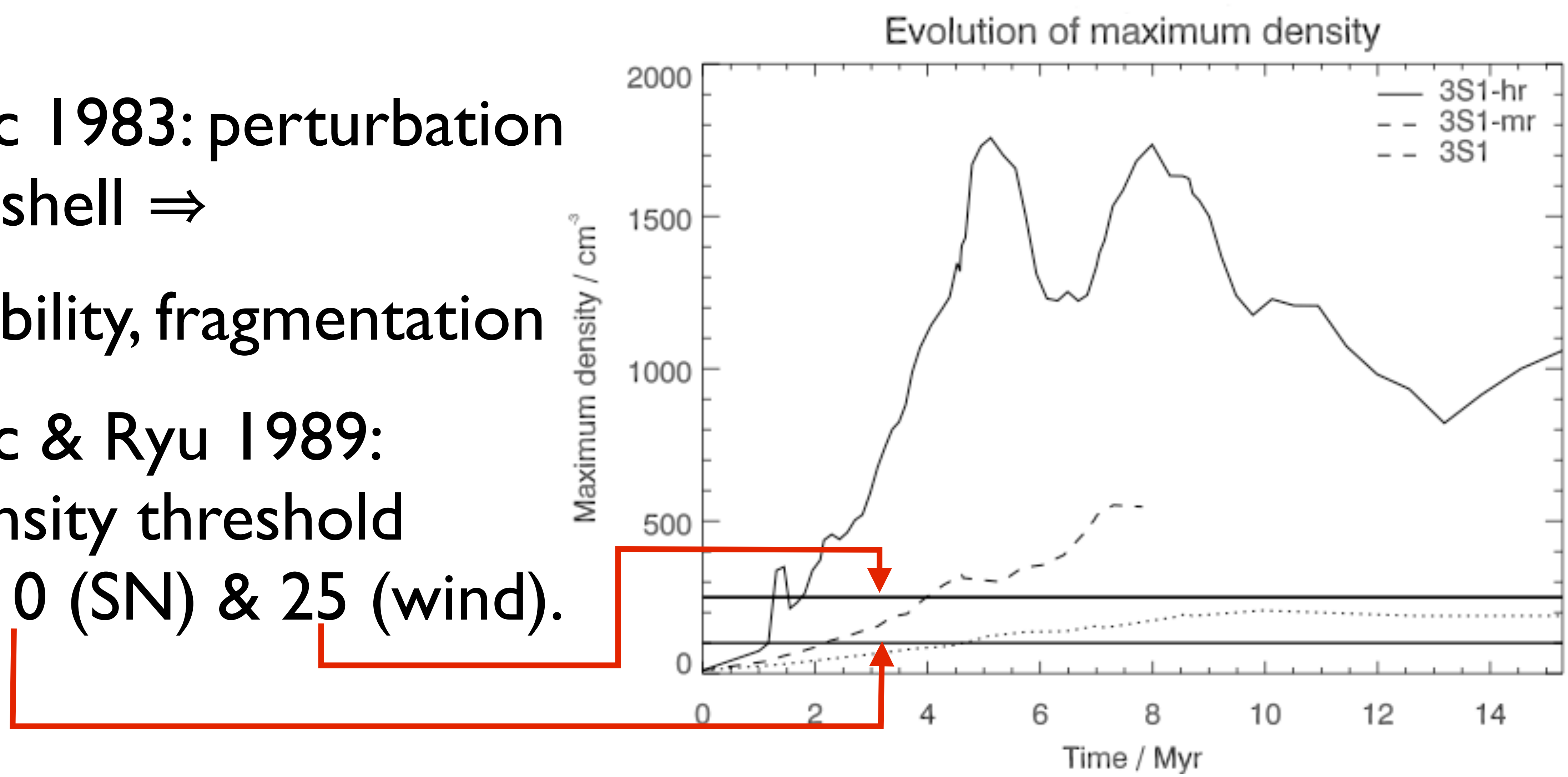
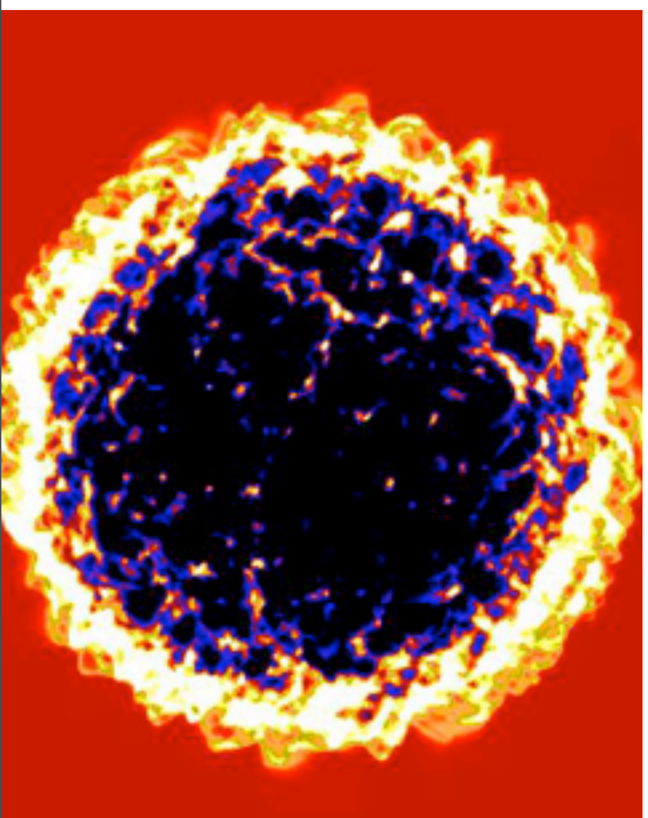


FIG. 1.—Schematic sketch indicating the regions and boundaries of the flow.

- Remember analytic wind shell models (Weaver 1977, right): shocked ISM cools ⇒ thin shell
- Vishniac 1983: perturbation to thin shell ⇒ overstability, fragmentation
- Vishniac & Ryu 1989: overdensity threshold factor 10 (SN) & 25 (wind).



Comparison to observations



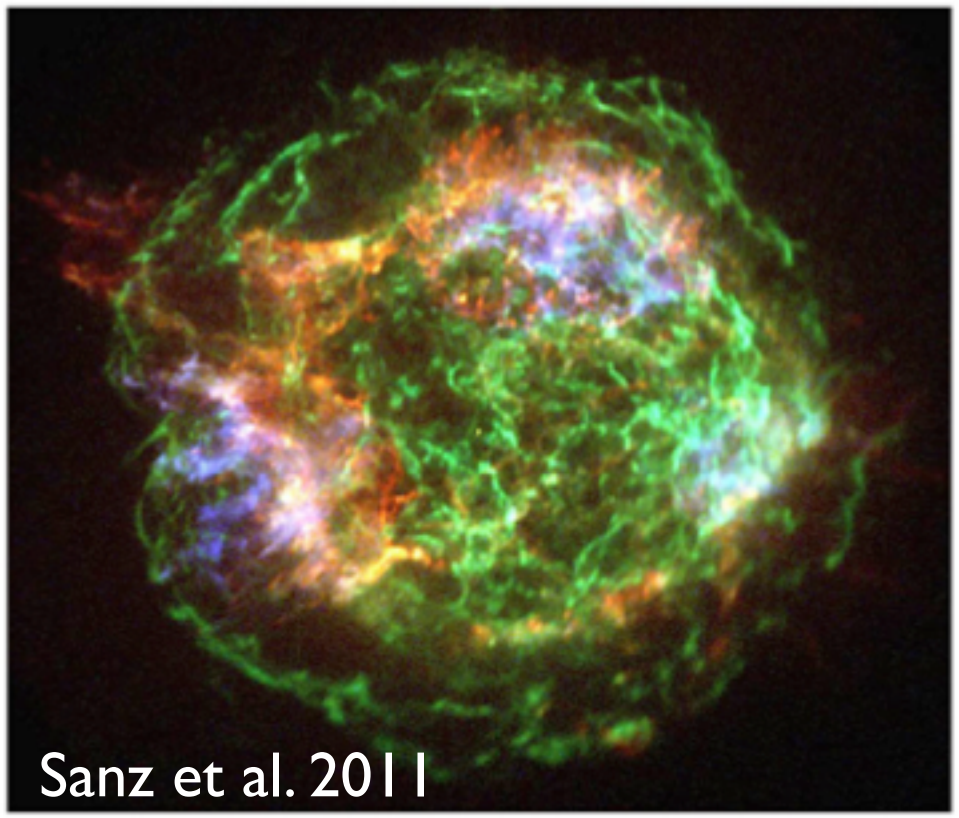
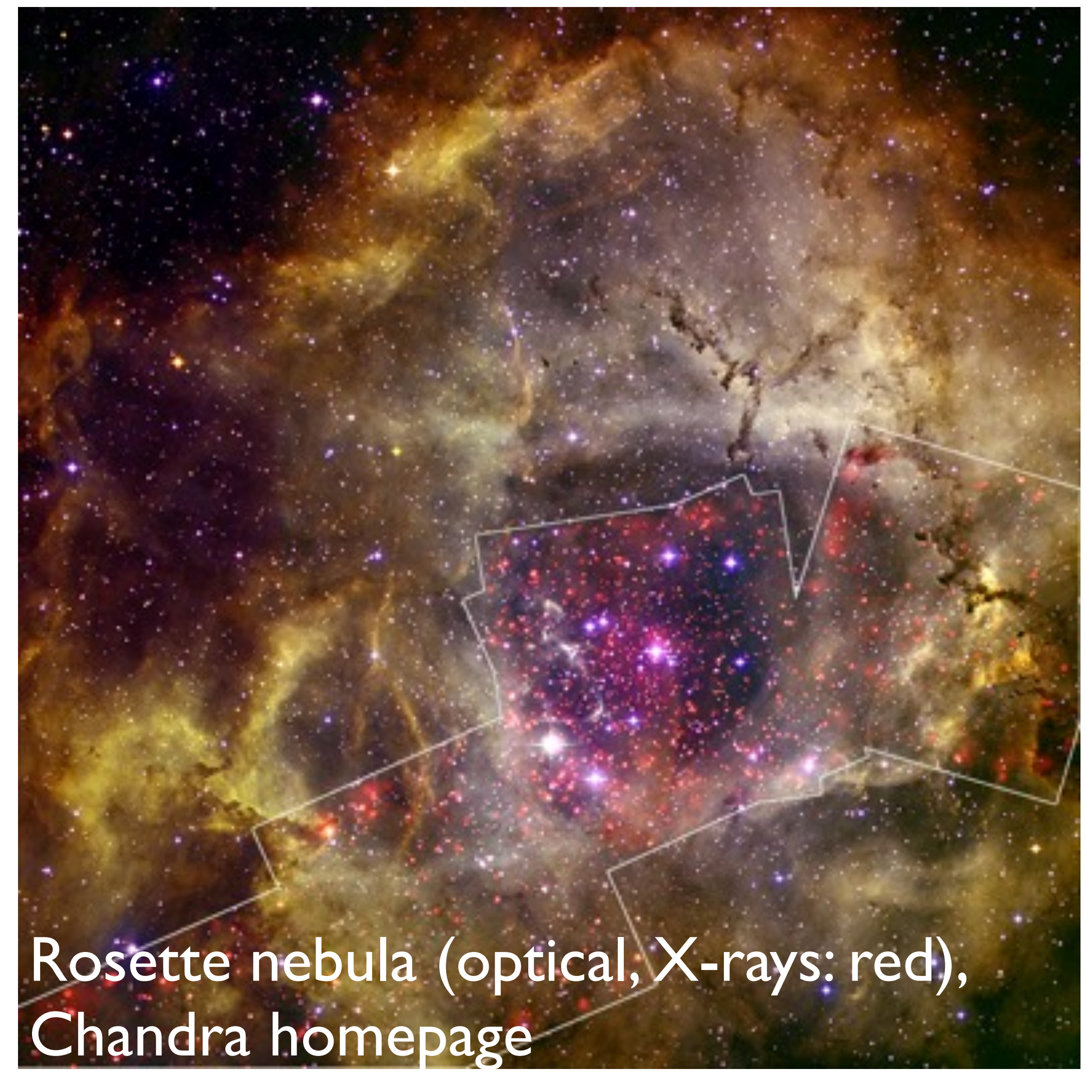
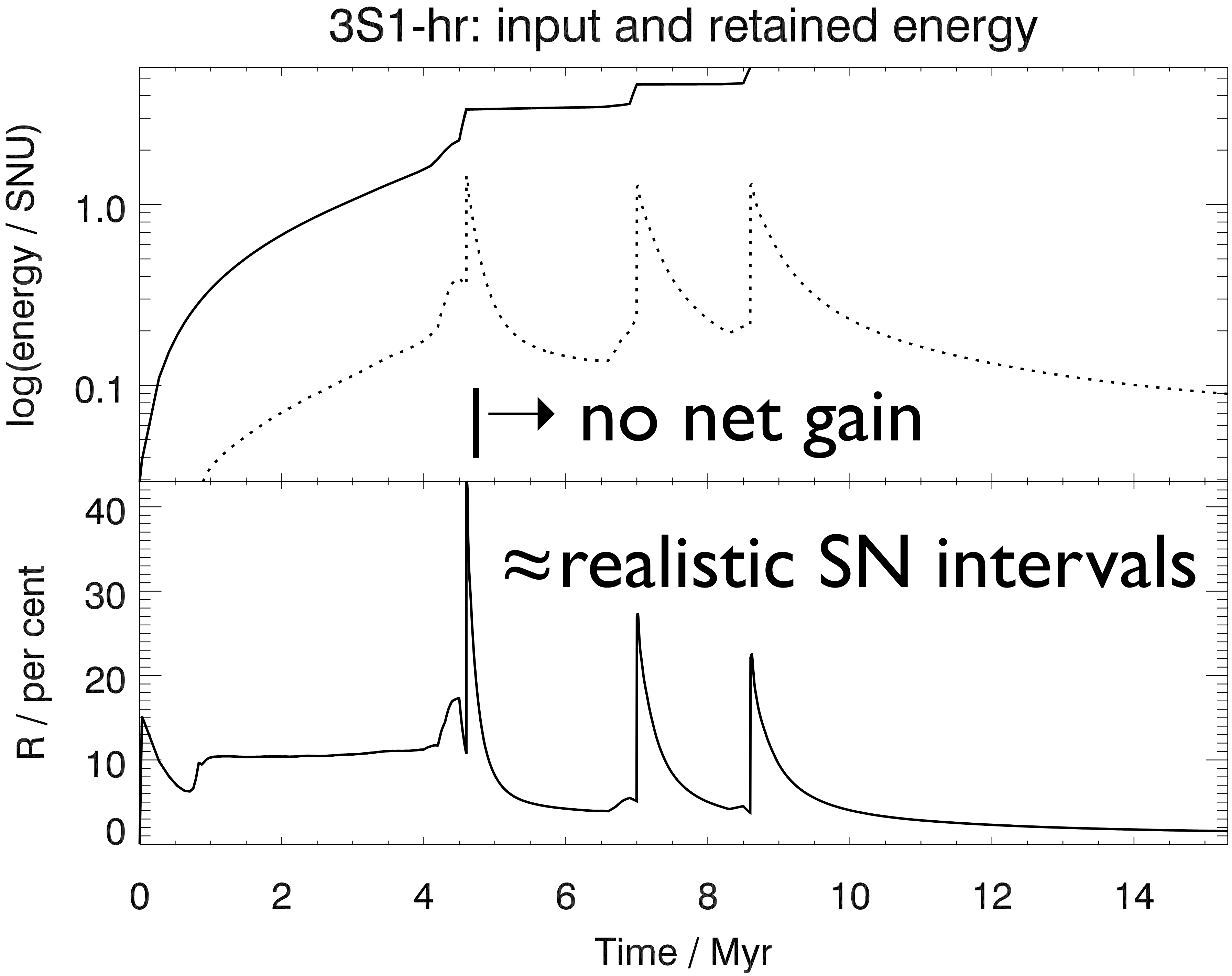


Fig. 1 The remnant from a supernova in Cassiopeia, which exploded ~300 years ago. The distance to this SNR is ~3.4 kpc, and the diameter of this remnant is ~10 light year (~3 pc). Image from Chandra telescope (http://rst.gsfc.nasa.gov, section 20, Novae and Supernovae)

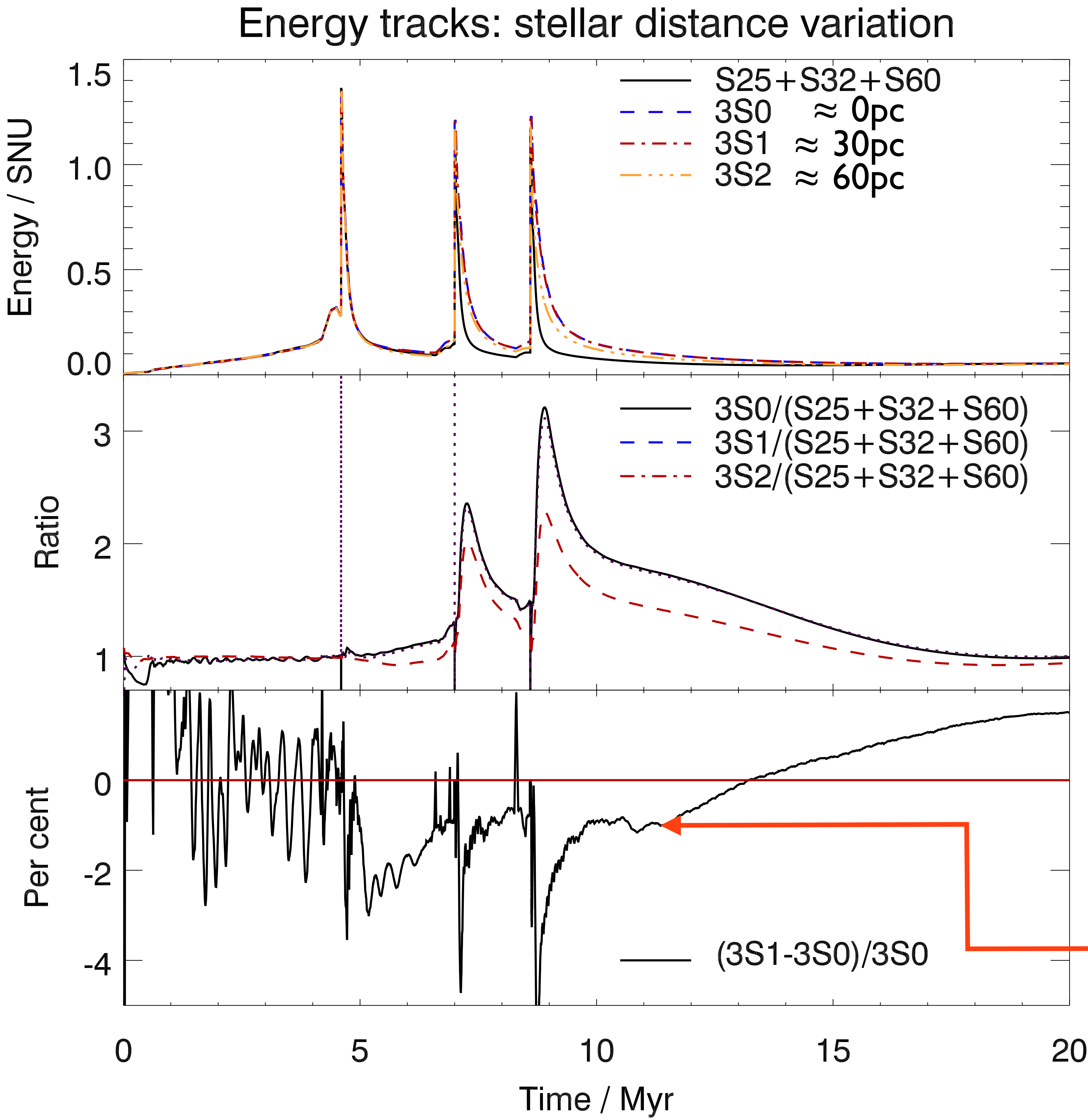


- Vishniac instability creates thick shell (from thin on) + filaments, sim: ≈ 20% outer radius
- Churchwell et al (2006): 322 bubbles, thick=20-40%

Energetics



- Most energy radiated away
- Wind phase: >10% retained (incr. w. res, negl. direct UV)
- SN: all gone after≈ 1Myr

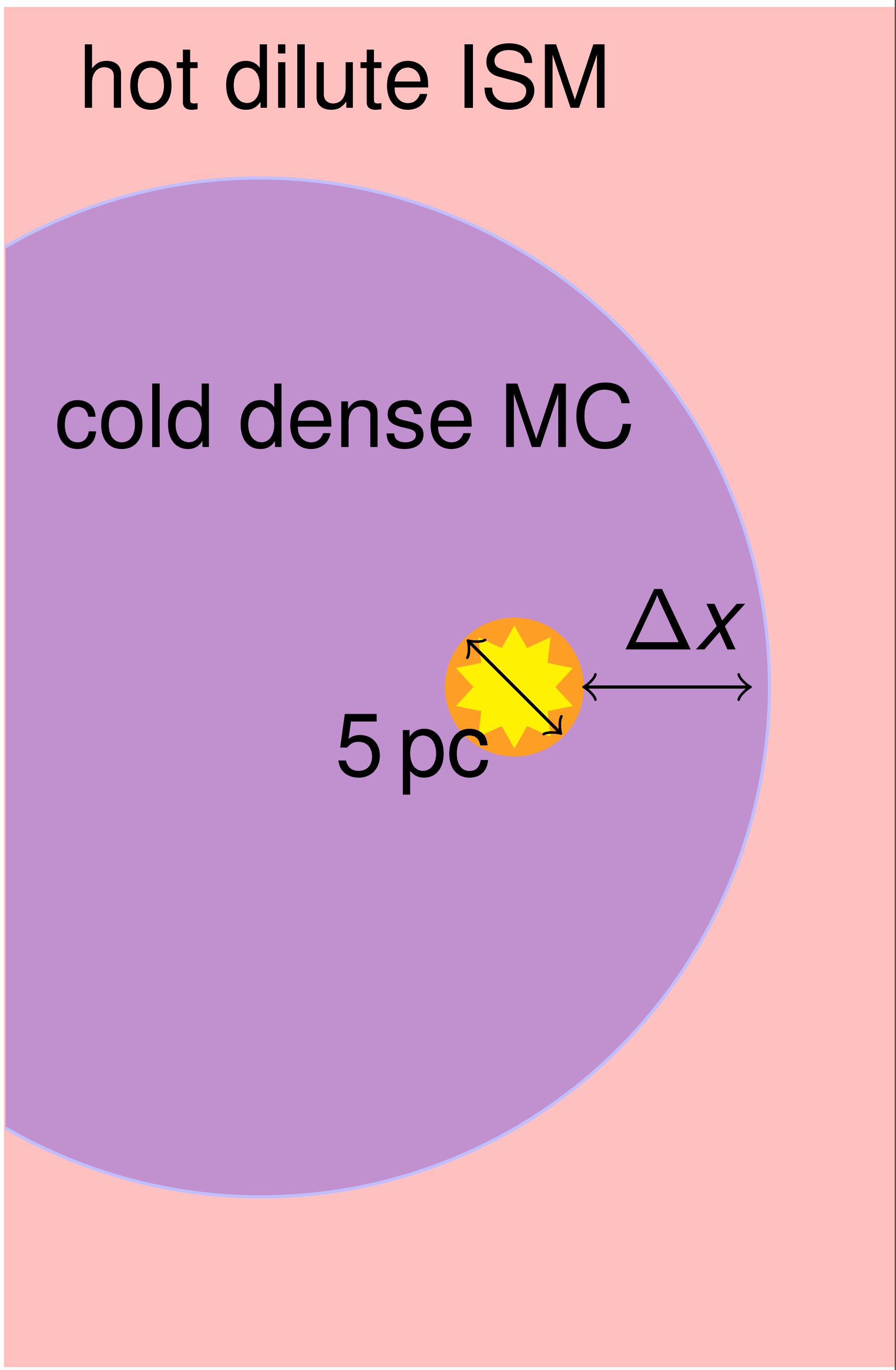


- distances: 0, inf. (sep. sims), 10s pc (3S1, 3S2)
- inf. dist: most energy radiated away
- other conf.: retain factor few more energy
- ~30pc dist ≈ 0

Energy tracks dom. by shell dynamics, merging unimportant!

Toy model for Orion OB1

- OB association
  - Population synthesis (mass loss, energy)
  - Spherical region, ø5 pc
  - Distance Δx from cloud edge
- Cold dense molecular cloud
  - $(n = 100\,\mathrm{cm}^{-3}, T = 100\,\mathrm{K})$
- Hot dilute ISM
  - $(n = 1\,\mathrm{cm}^{-3}, T = 10\,000\,\mathrm{K})$



→ Katharina Fierlinger (et. al. in prep) → **POSTER**

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- *Conclusions*
    - Vishniac instability might be responsible for large shell observed thickness & filaments inside (Caveat: ionisation)
    - Energetics: more energy into ISM if parent stars closer together
    - Bubble merging does not solve energy problem
    - Efficiency: $>\approx 10\%$ / pre-SN, consistent with observations
    - SN: dissipate in 1 Myr
    - significant differences ($\approx$ factor 2) after first SN
    - But still max eff. if distance $<\approx$ 30pc