Formation of Super Star Cluster Winds

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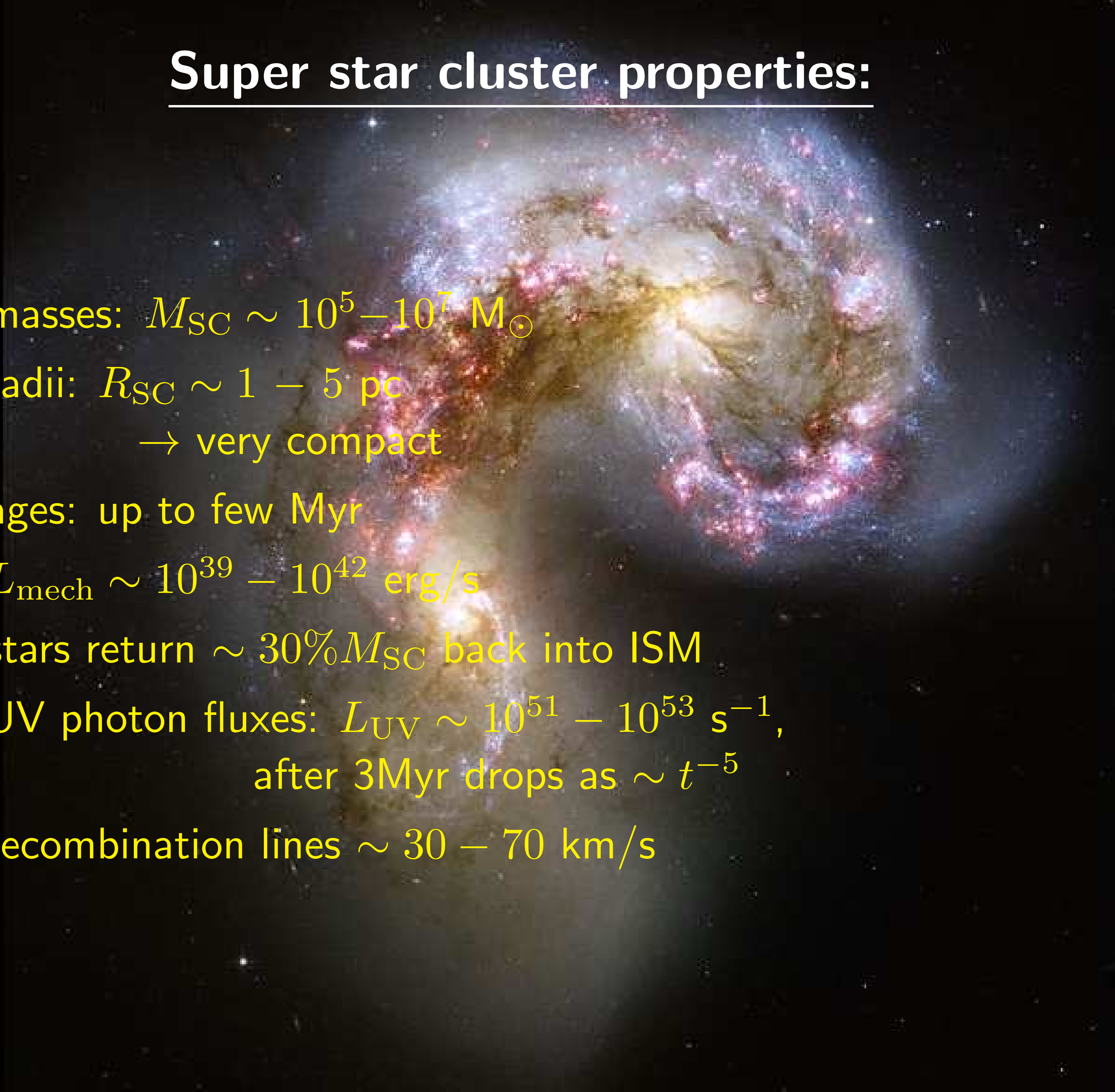
Outline:

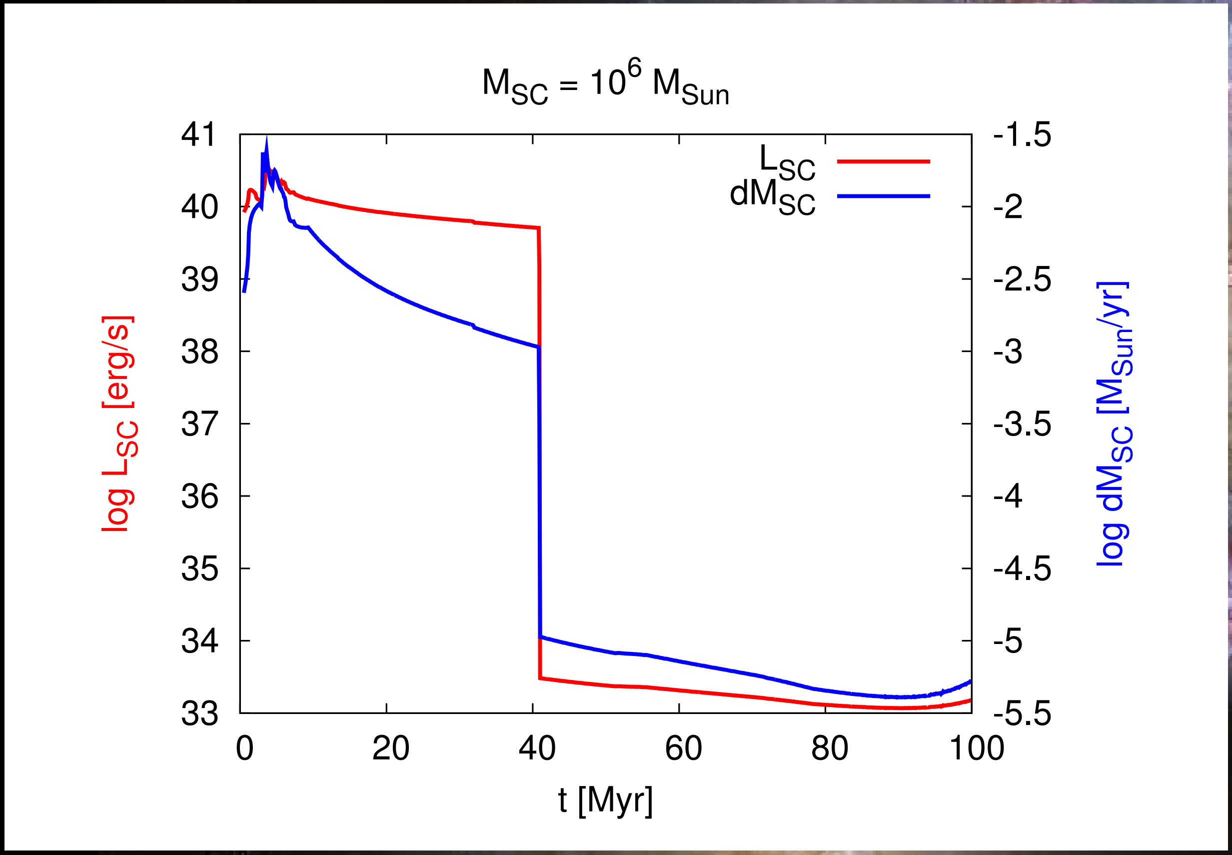
1. **Observations (nice pictures downloaded from web ;)**
2. **Models with uniform mass/energy input**
3. **Bimodal regime - secondary SF**
4. **Line profiles from repressuring shocks**
5. **Models with individual sources**
   → meassuring heating efficiency



Super star cluster properties:

- masses: $M_{\rm SC} \sim 10^5$–10^7 M$_\odot$
- radii: $R_{\rm SC} \sim 1 - 5$ pc
  $\rightarrow$ very compact
- ages: up to few Myr
- $L_{\rm mech} \sim 10^{39} - 10^{42}$ erg/s
- stars return $\sim 30\% M_{\rm SC}$ back into ISM
- UV photon fluxes: $L_{\rm UV} \sim 10^{51} - 10^{53}$ s^{-1},
  after 3Myr drops as $\sim t^{-5}$
- recombination lines $\sim 30 - 70$ km/s

Super star cluster properties:



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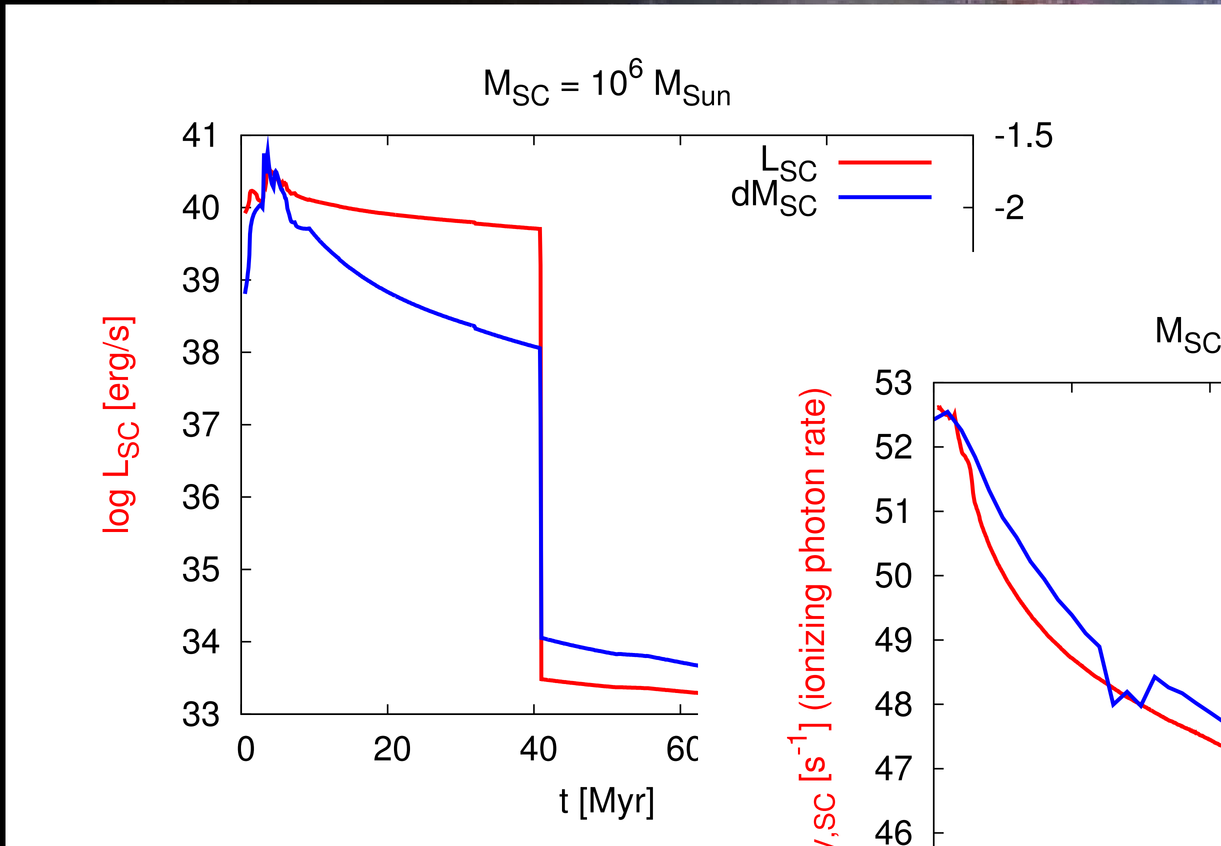
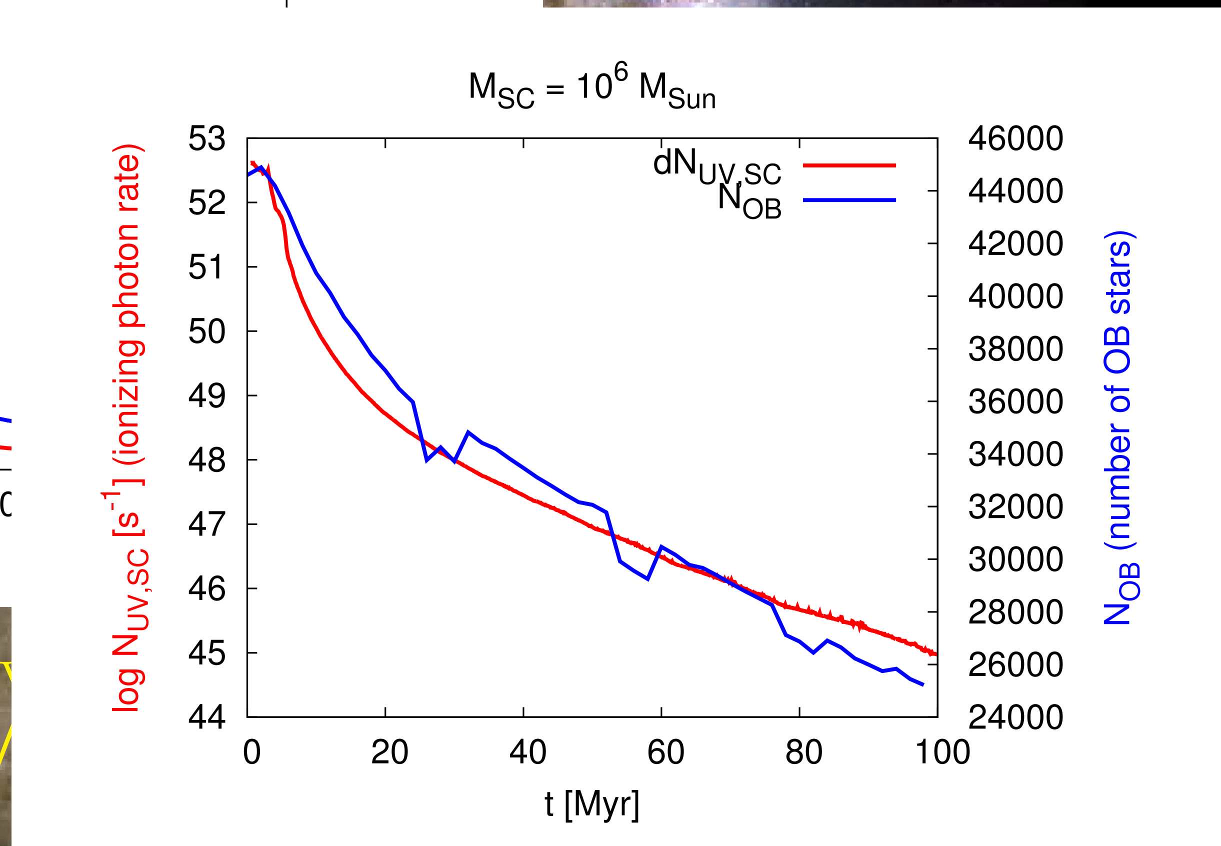
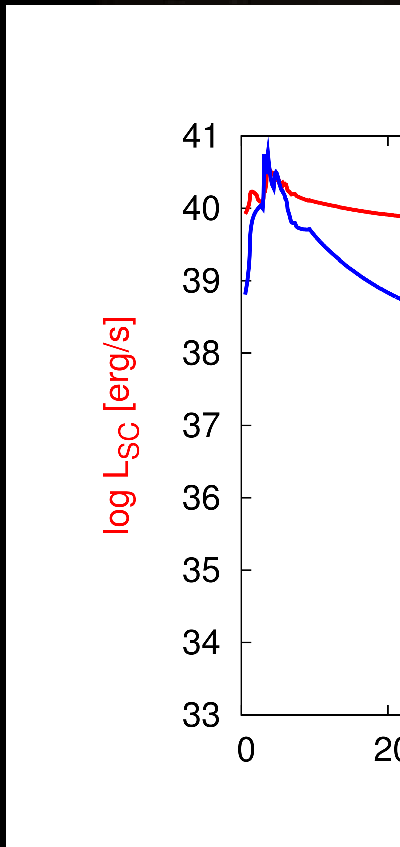
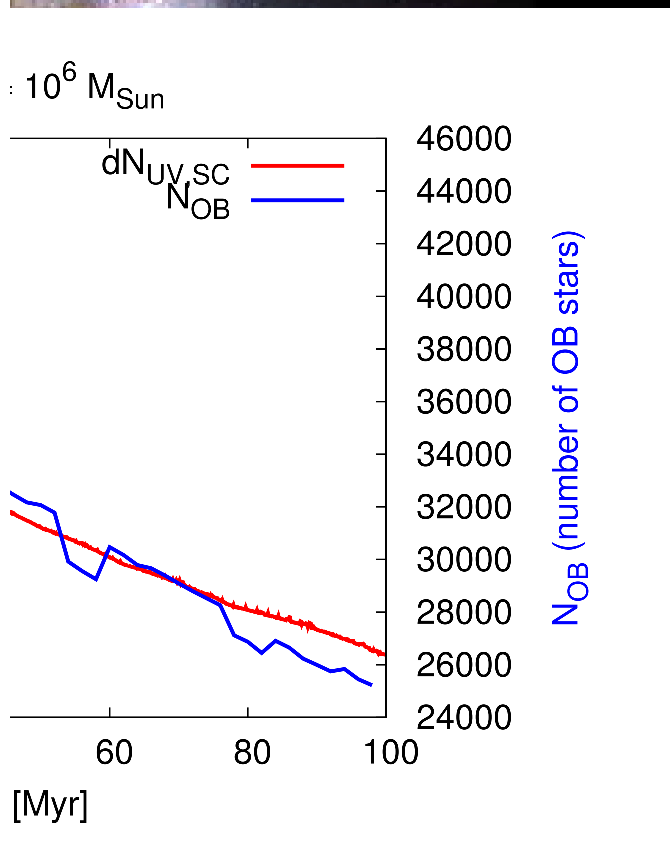




- UV photon fluxes: L_{UV} … after 3M…
- recombination lines ∼ 50 − 70 km/s

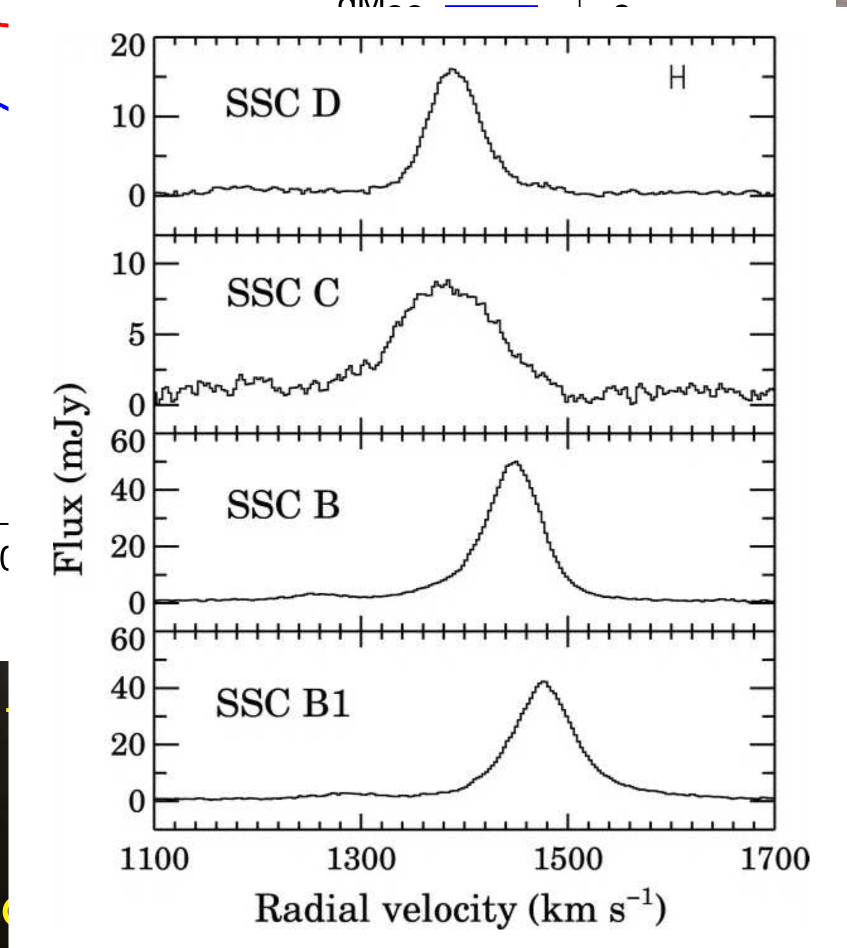
Super star cluster properties:





- UV photon

- recombinati



Gilbert & Graham (2007)

SSCs in our backyard

- R136 in LMC (30 Doradus)
- $M \sim 2 - 8 \times 10^4$ M$_\odot$, $R \sim 0.5$ pc, age~ 2 Myr
- bubbles, filaments - Tarantula nebula

Credit: N. Walborn (STScI) et al., WFPC2, HST, NASA

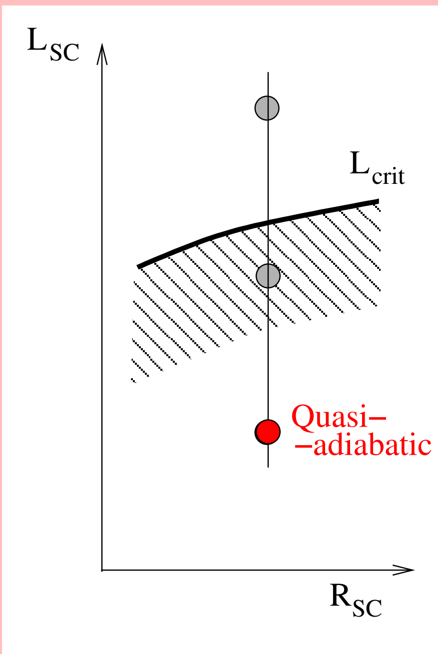
- MW: Arches, Quintuplet, NGC3603, Westerlund 1:
- $M \sim 10^5$ M$_\odot$, $R \sim 0.3$ pc, age$\sim 3.5 - 5$ Myr

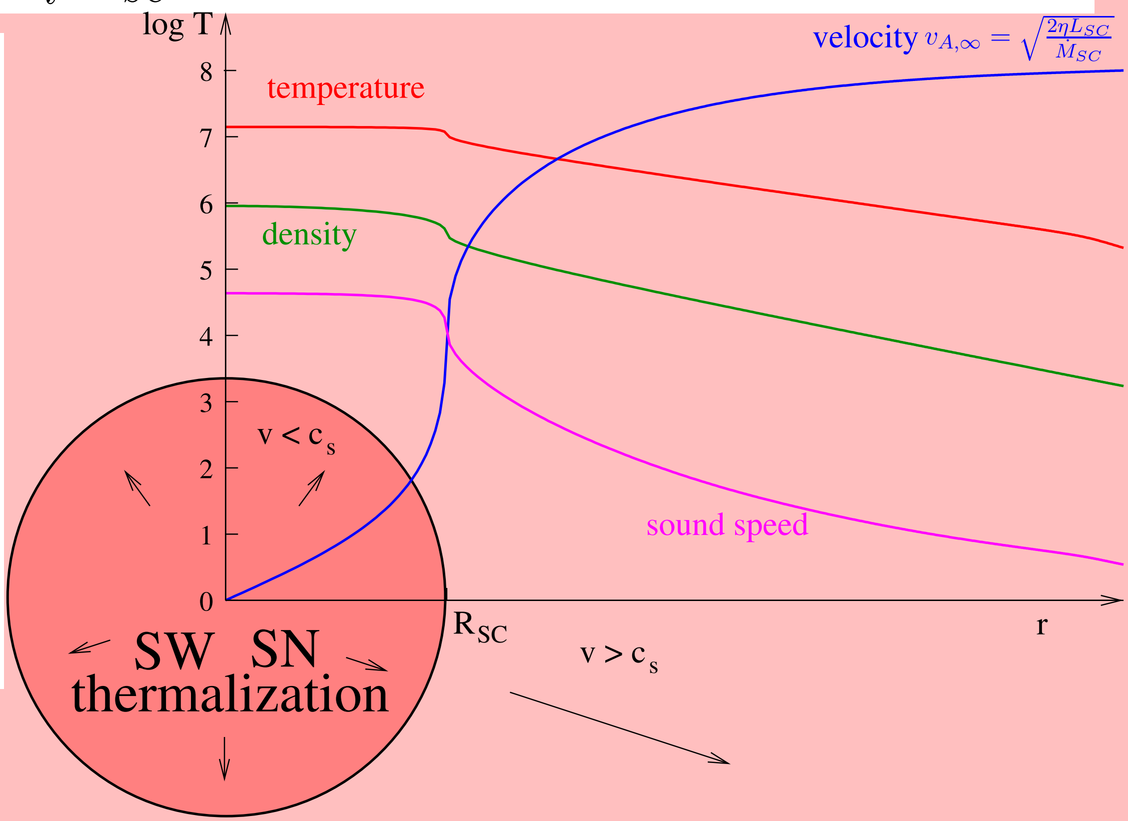
Physical model

Chevalier & Clegg (1985)

$3+1$ parameters: $\underbrace{L_{SC}, \dot{M}_{SC}}_{\text{given by } M_{SC}}$ $, R_{SC}, \eta$ - themalization efficiency

$\eta \lesssim 0.1$ in M82-A1 (Silich et al., 2007)

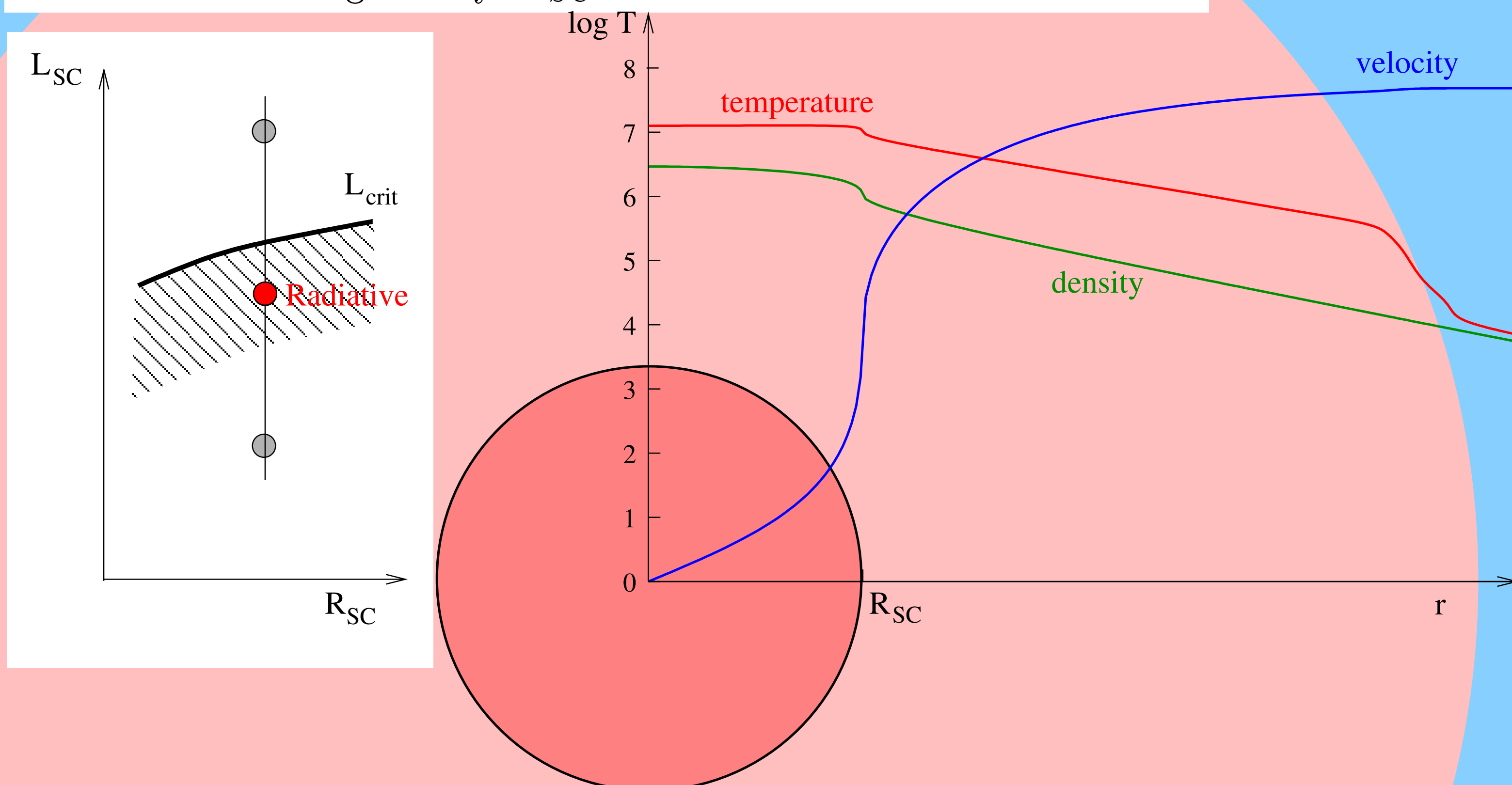




Physical model

Silich et al. (2004)

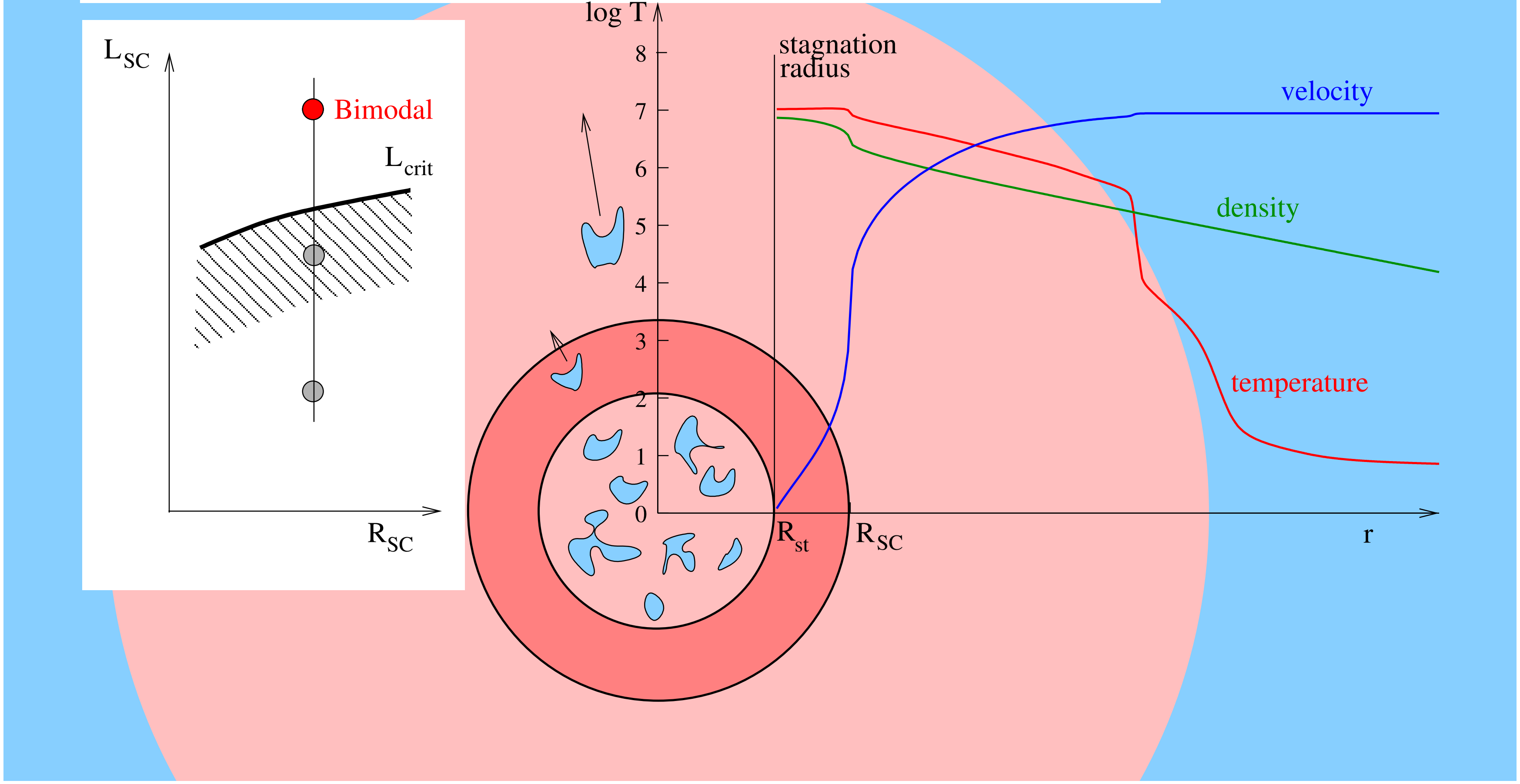
$3+1$ parameters: $\underbrace{L_{SC}, \dot{M}_{SC}}_{\text{given by } M_{SC}}$, R_{SC}, η - themalization efficiency



Physical model

Tenorio-Tagle et al. (2007)

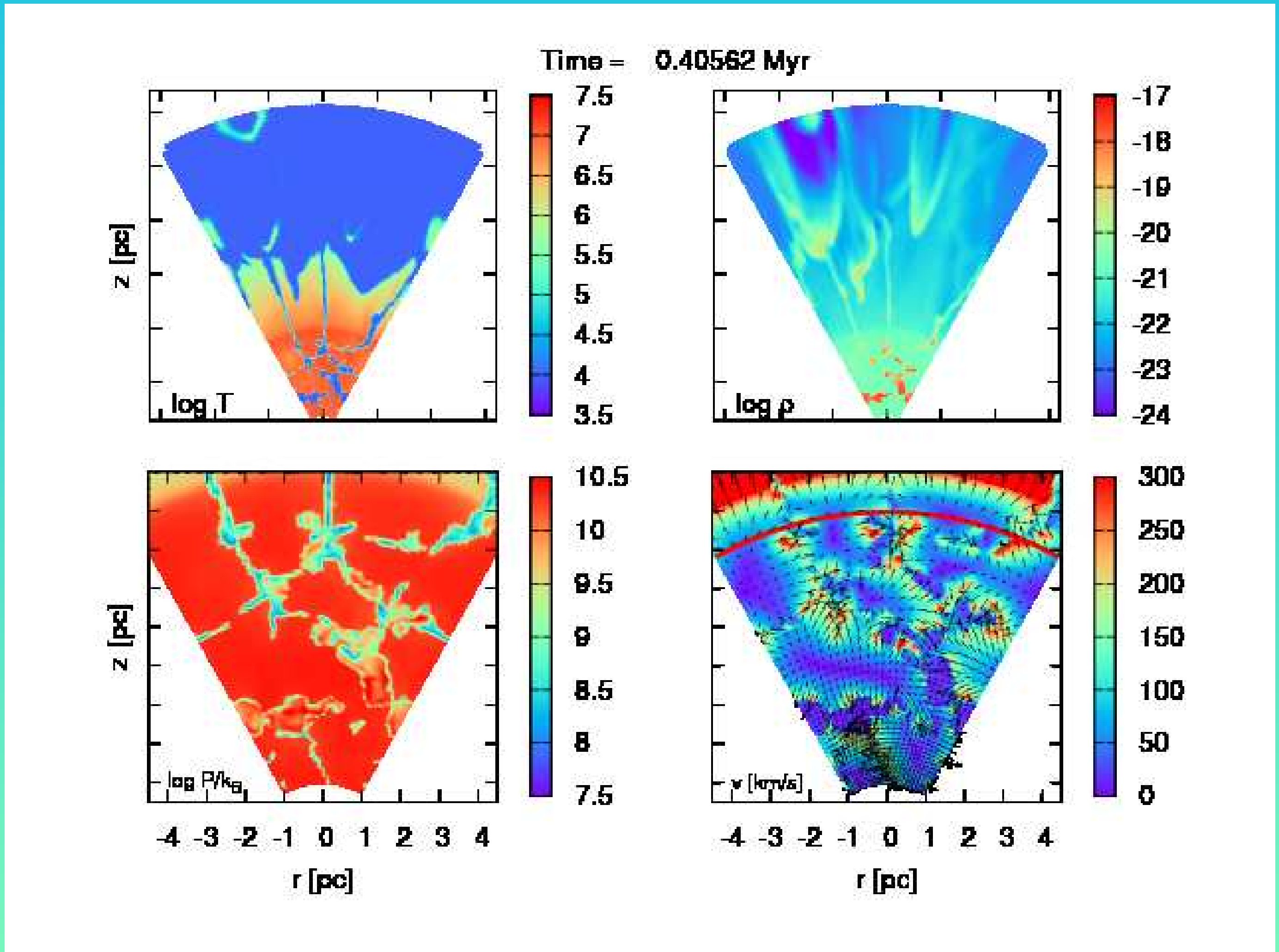
$3 + 1$ parameters: $\underbrace{L_{SC}, \dot{M}_{SC}}_{\text{given by } M_{SC}}$, R_{SC}, η - themalization efficiency



2D hydro simulations

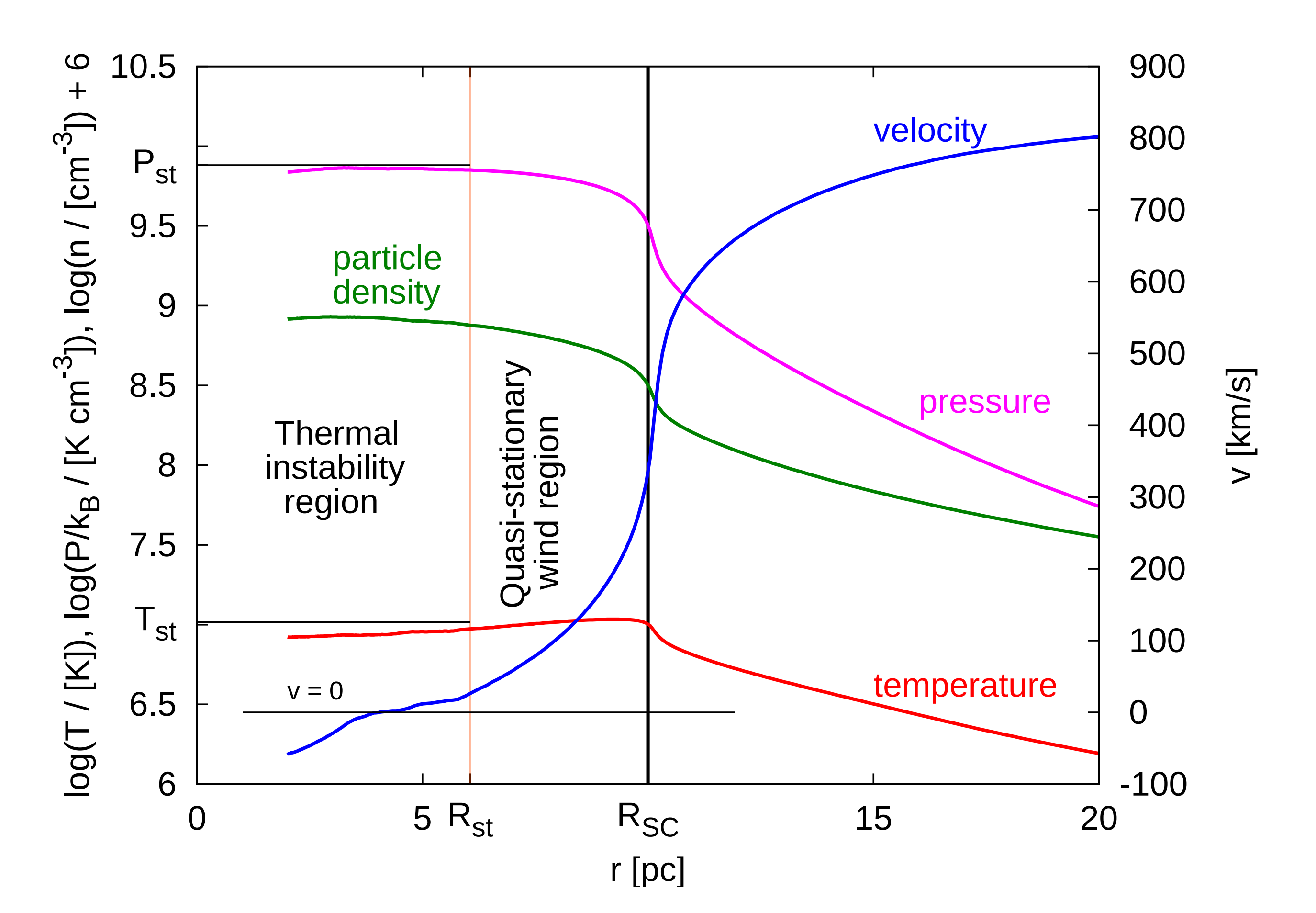
Wünsch et al. (2008)

- ZEUS, Rθ coords, open **both** R-boundaries, periodic θ-boundary
- $R_{SC} = 10$ pc, $L_{SC}/L_{\rm crit} = 20$, $\eta = 1.0$, 600×224



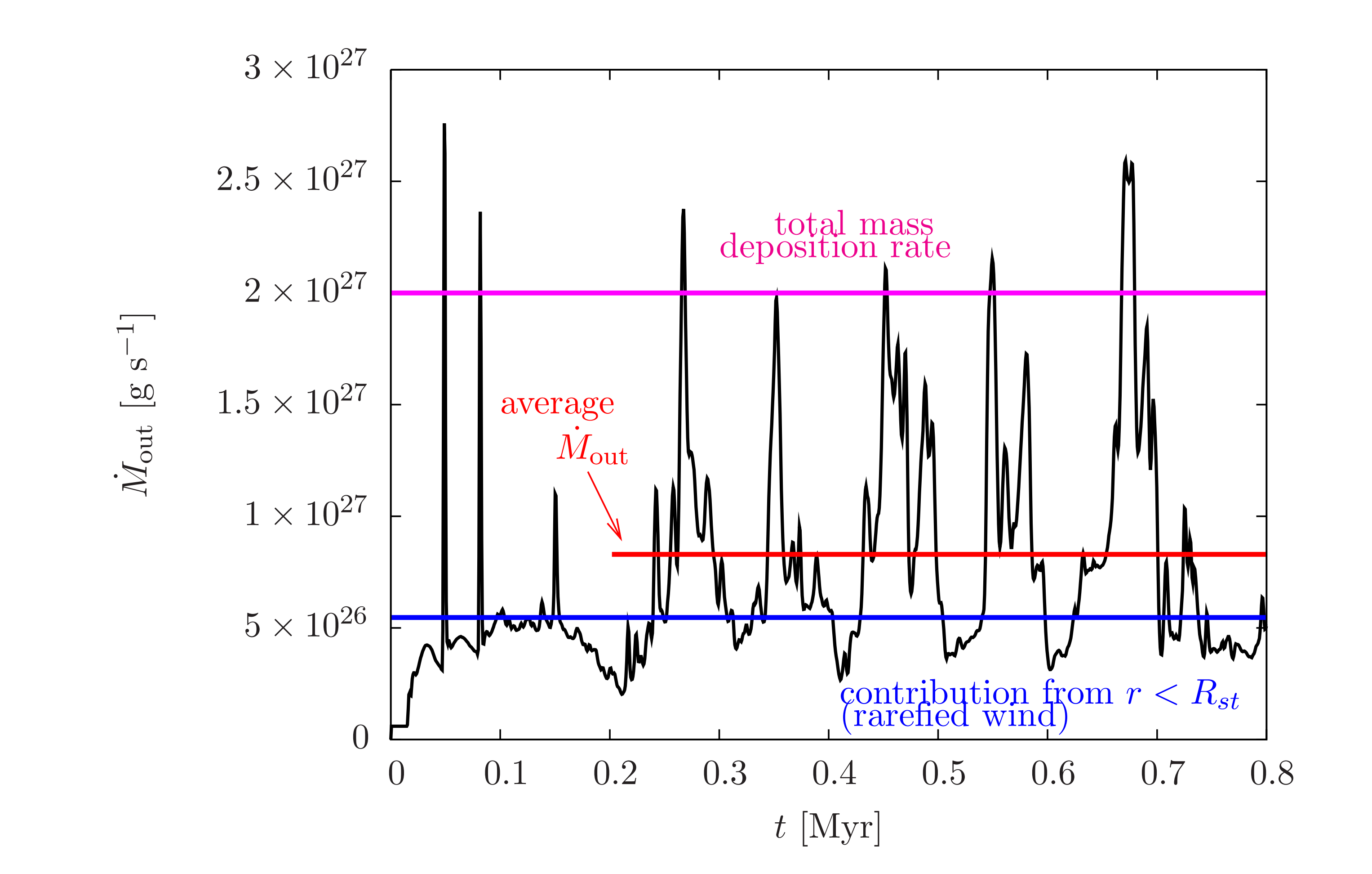
Internal structure of SSC in bimodal regime

- radial profiles averaged over θ and $t = 0.4 - 0.8$ Myr
- $v = 0$ slightly below R_{st} (due to passing clumps)
- $P = \text{const}$ for $r < R_{st}$ (in agreement with semi-anl. value)

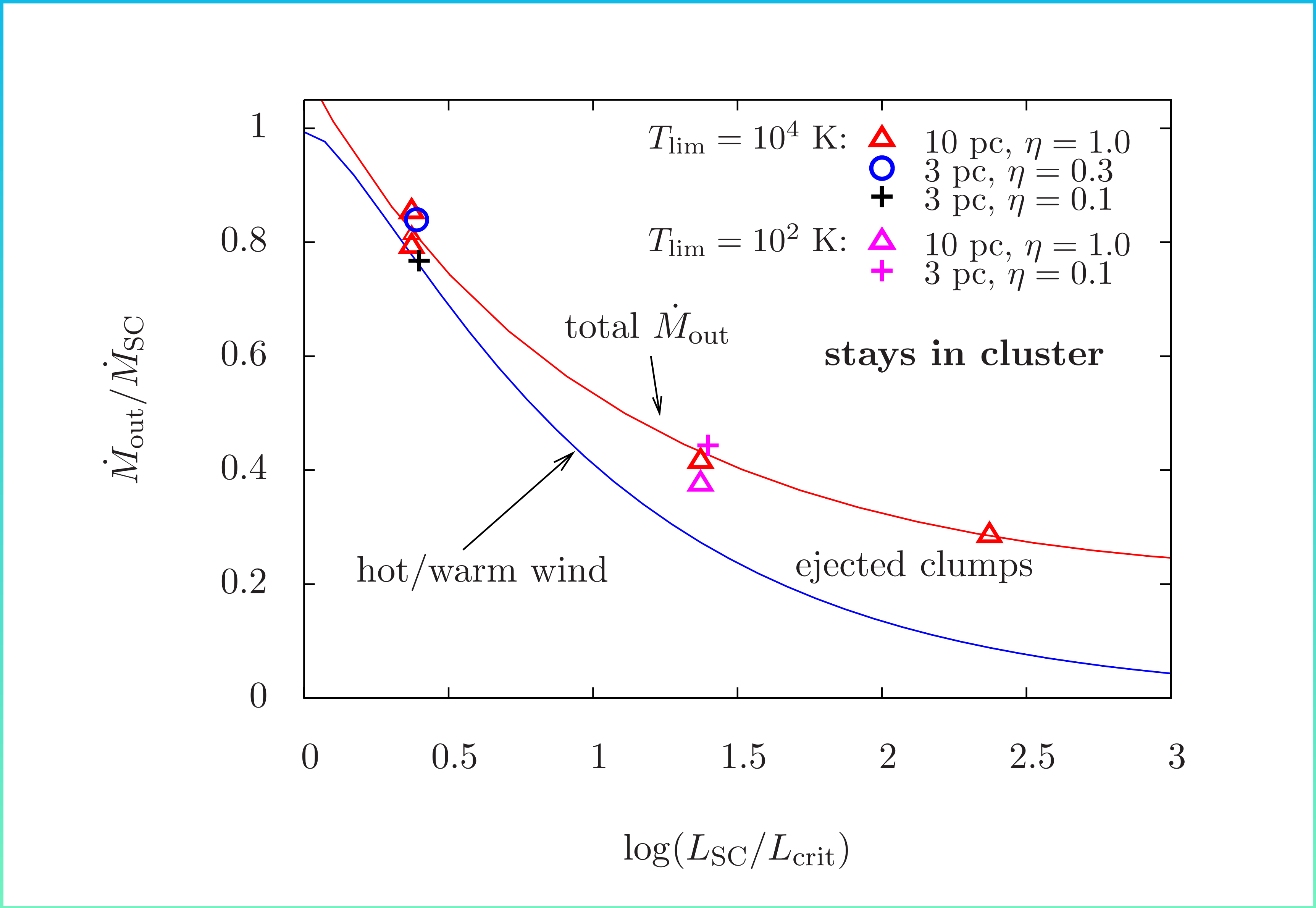


Outflow from the cluster as a function of time

- two component outflow: 1. rarefied originaly hot wind
  2. dense clumps

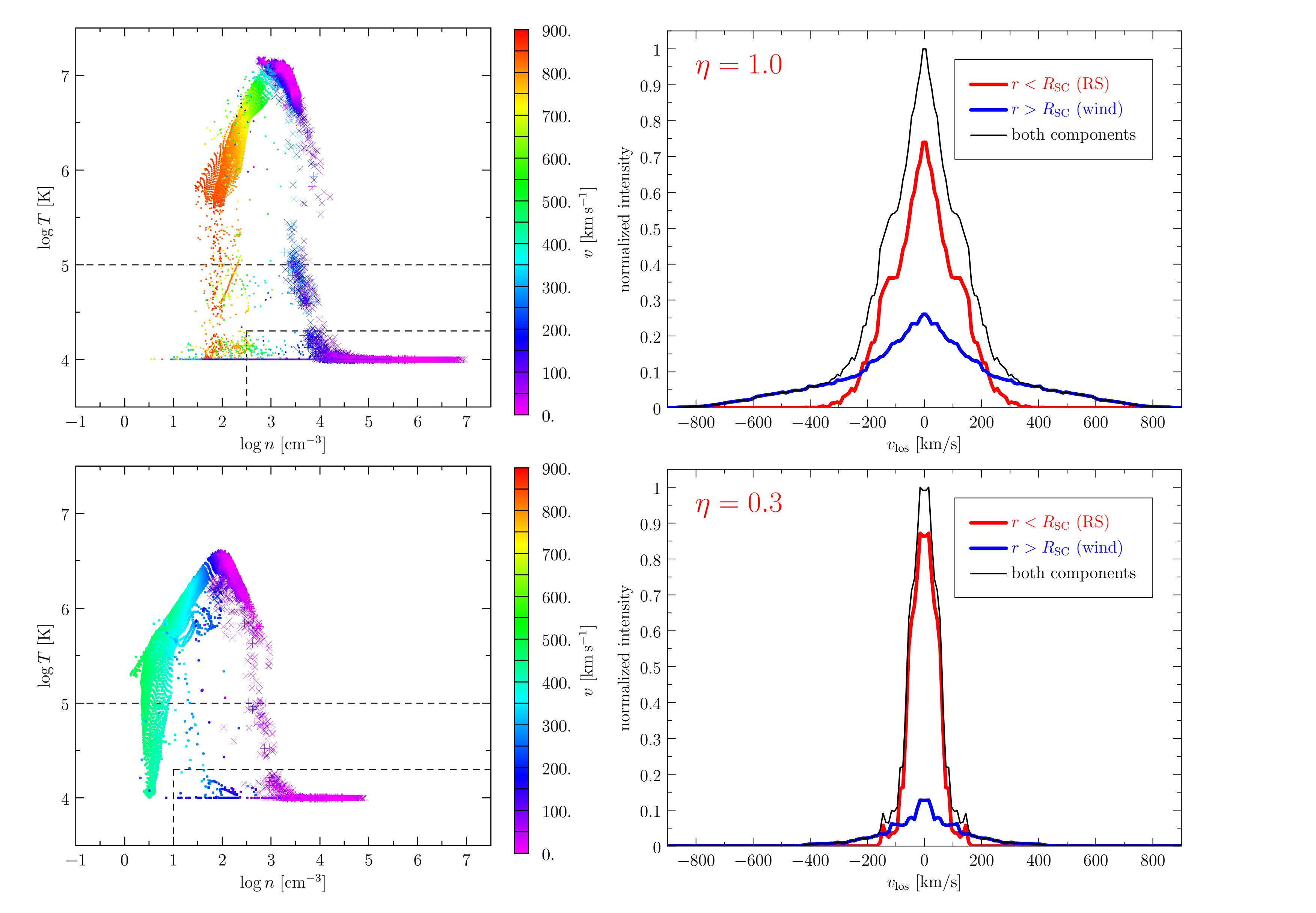


Outflow from the cluster for different models

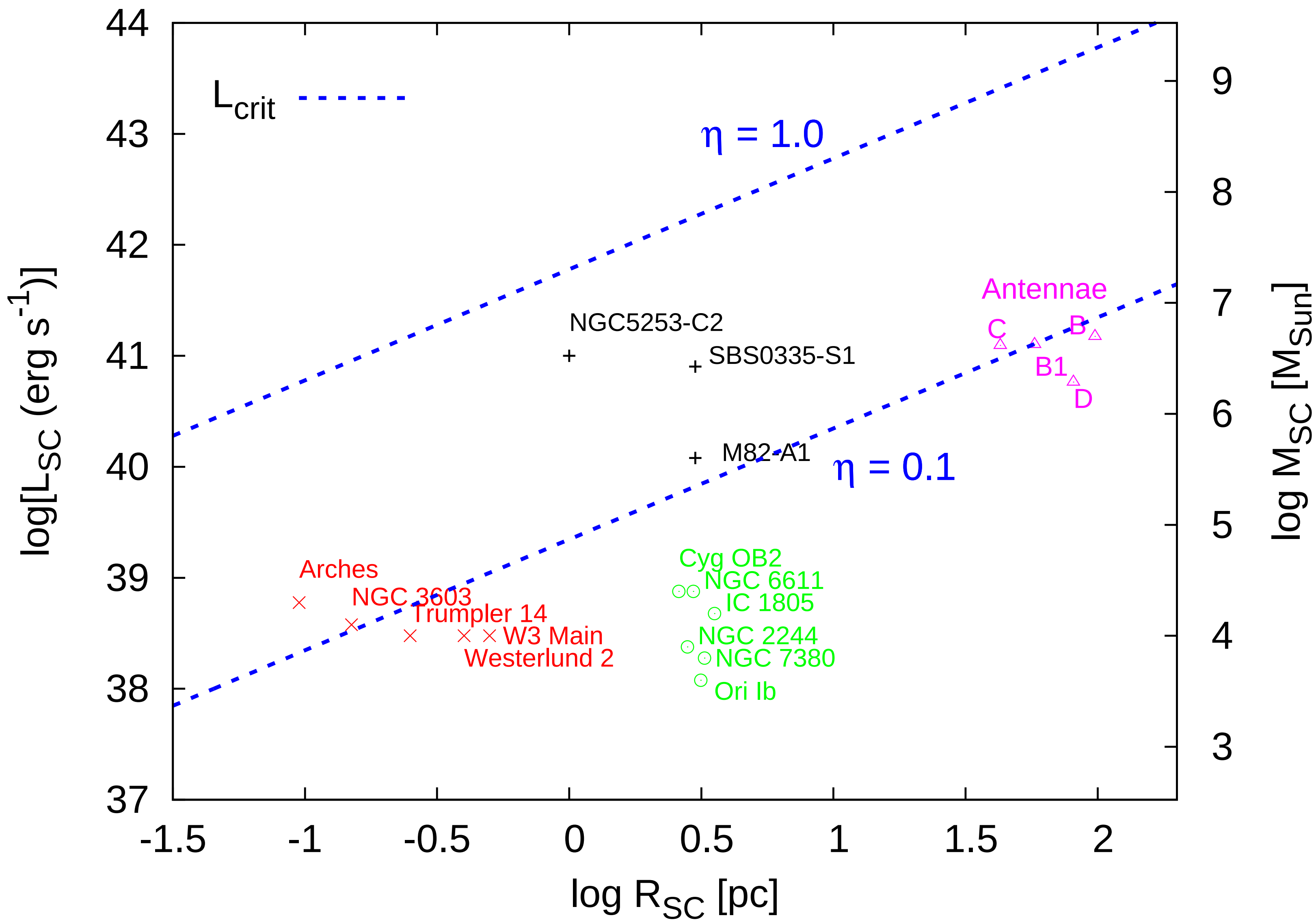


Supersonic recombination lines widths

Tenorio-Tagle et al. (2010)

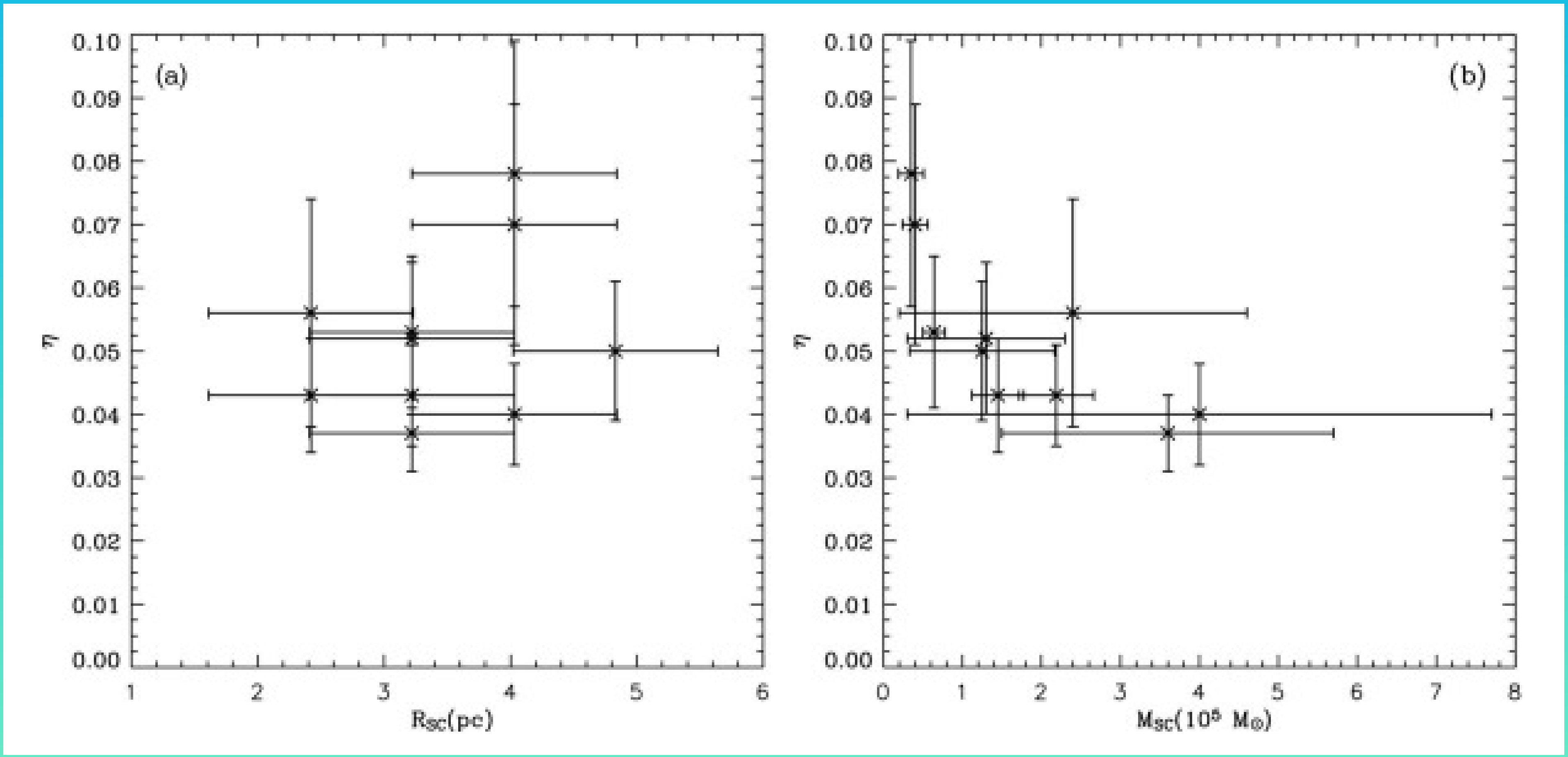


Critical luminosity and observed clusters



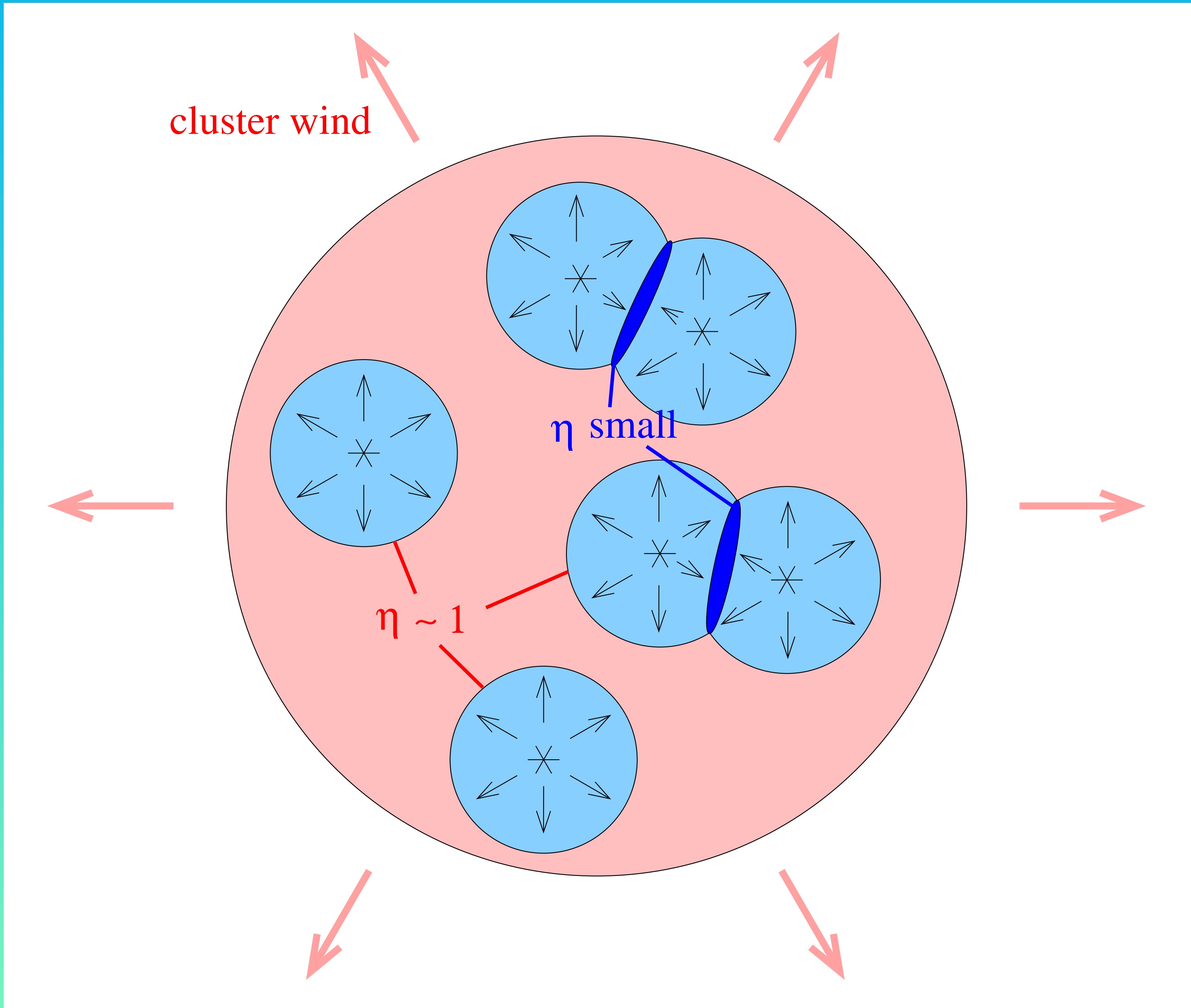
Heating efficiency in clusters in M8

Silich et al. (2009)

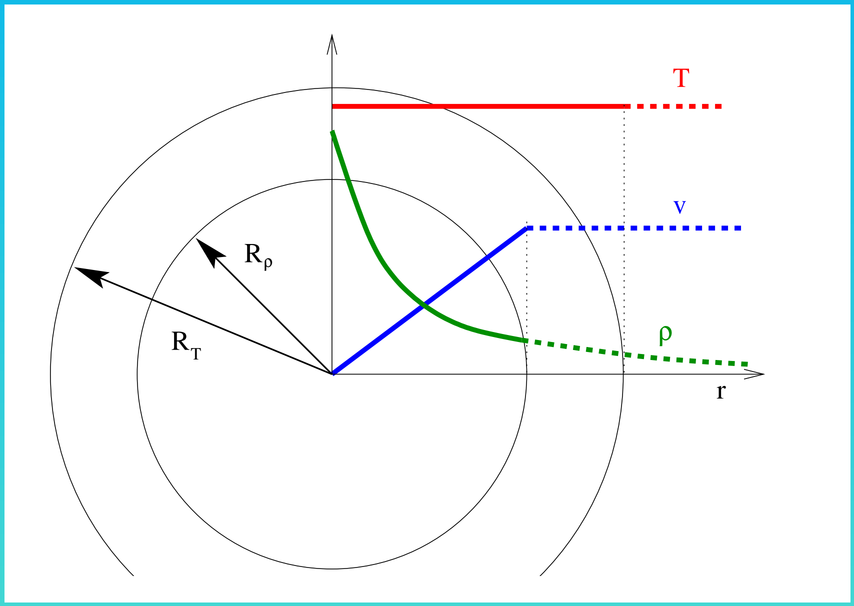


- η measured for 10 clusters in M82
- from sizes of HII regions, $\eta \lesssim 10\%$

Model for heating efficiency



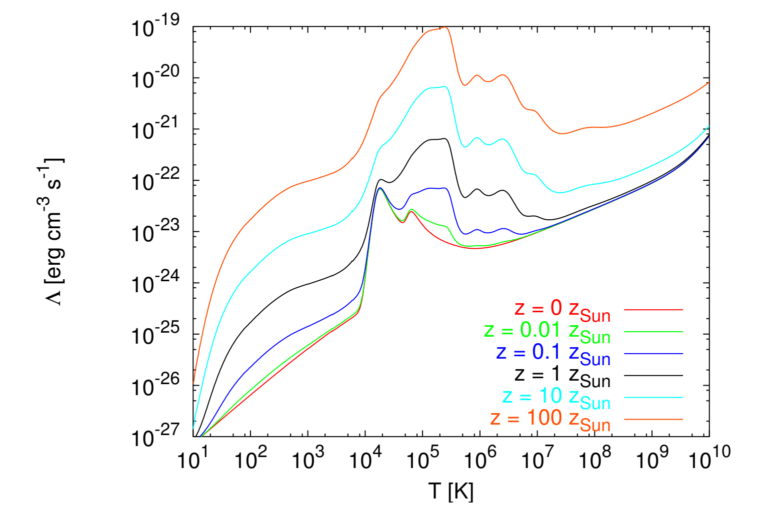
Flash model with individual sources



- Flash3.2, standard ppm Rieman solver (the unsplit solver crashes)
- Energy source: $\dot{m}$, v, T, R_ρ, R_T
- for $r < R_\rho$: $v \propto r$, $\rho \propto r^{-2}$
- for $r < R_T$: $T = \mathrm{const}$

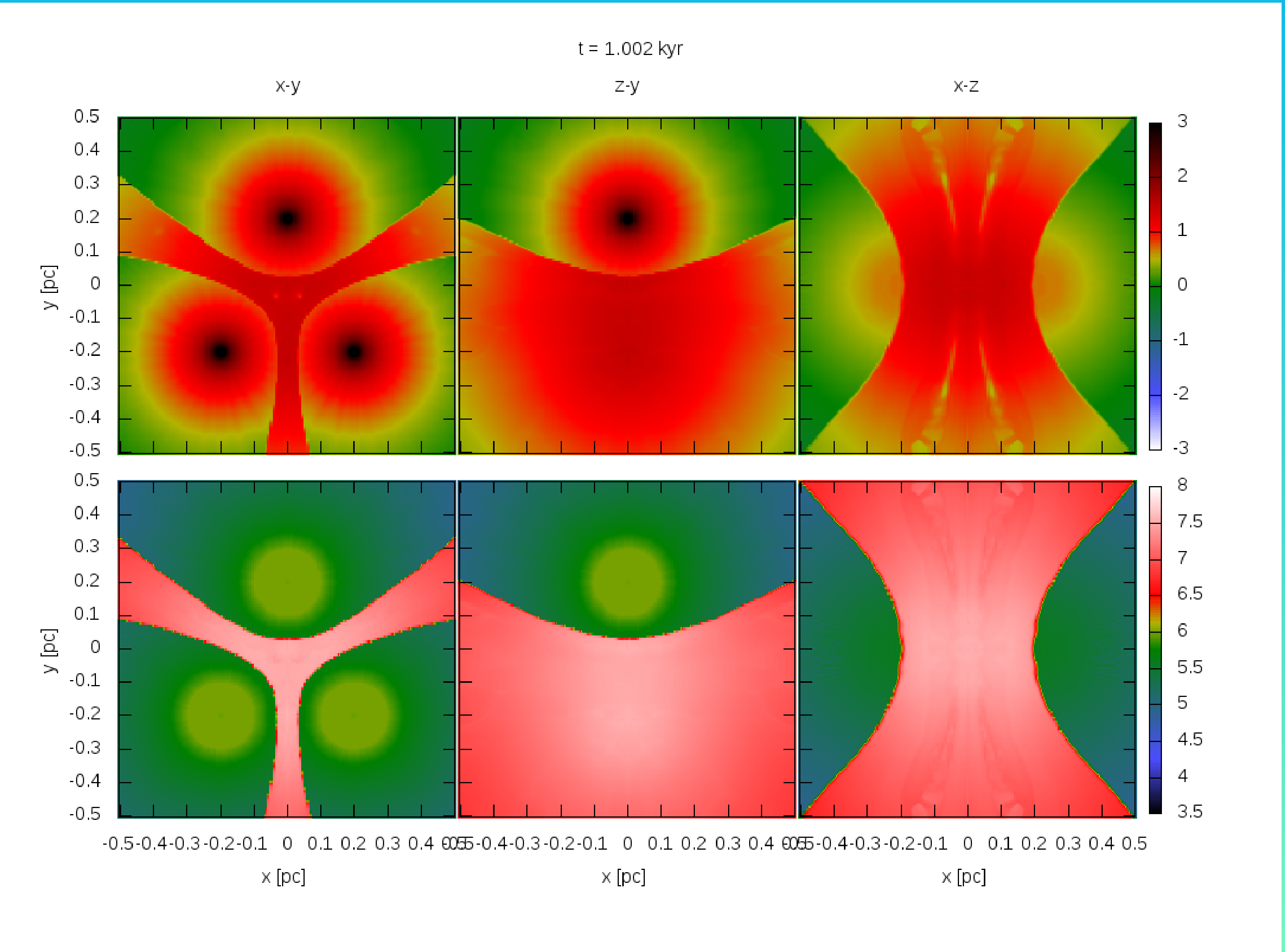
Cooling:

- time-step controlled by cooling
- limit on the minimum timestep $dt_{\mathrm{min}} \sim dt_{\mathrm{hydro}}/3$
- substeps

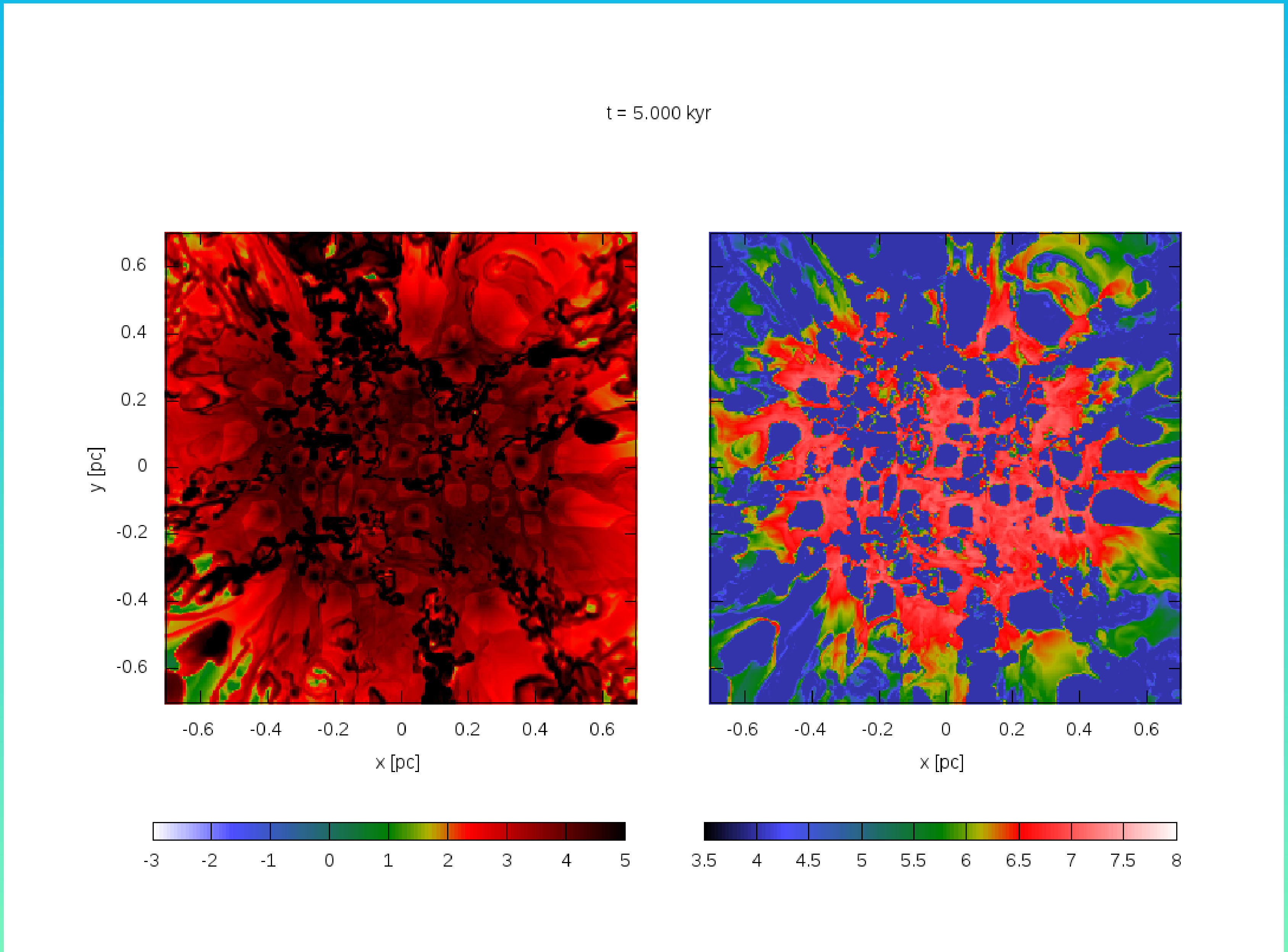


Plewa (1995)

Firsts tests - 2 and 3 stars

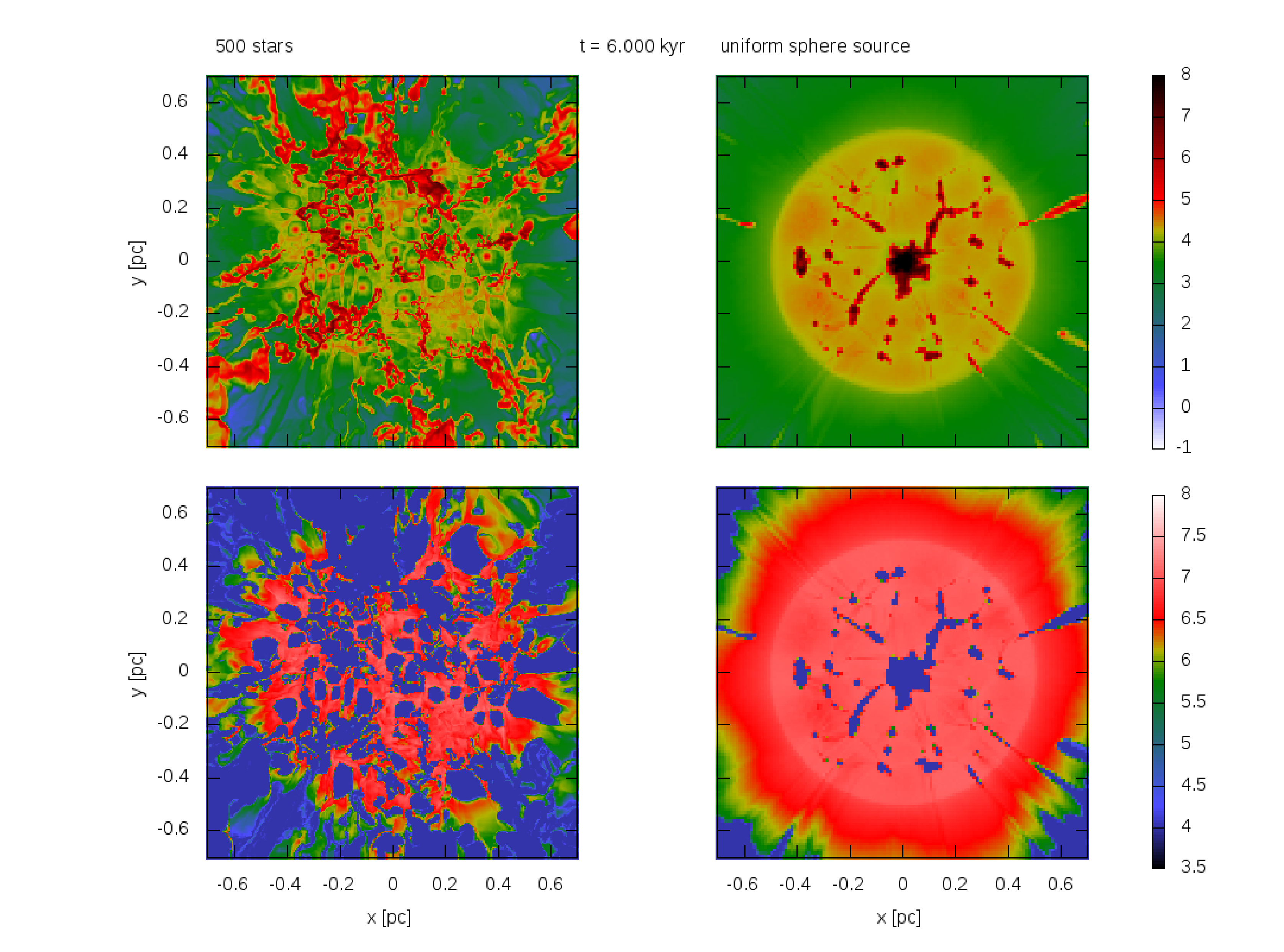


500 stars

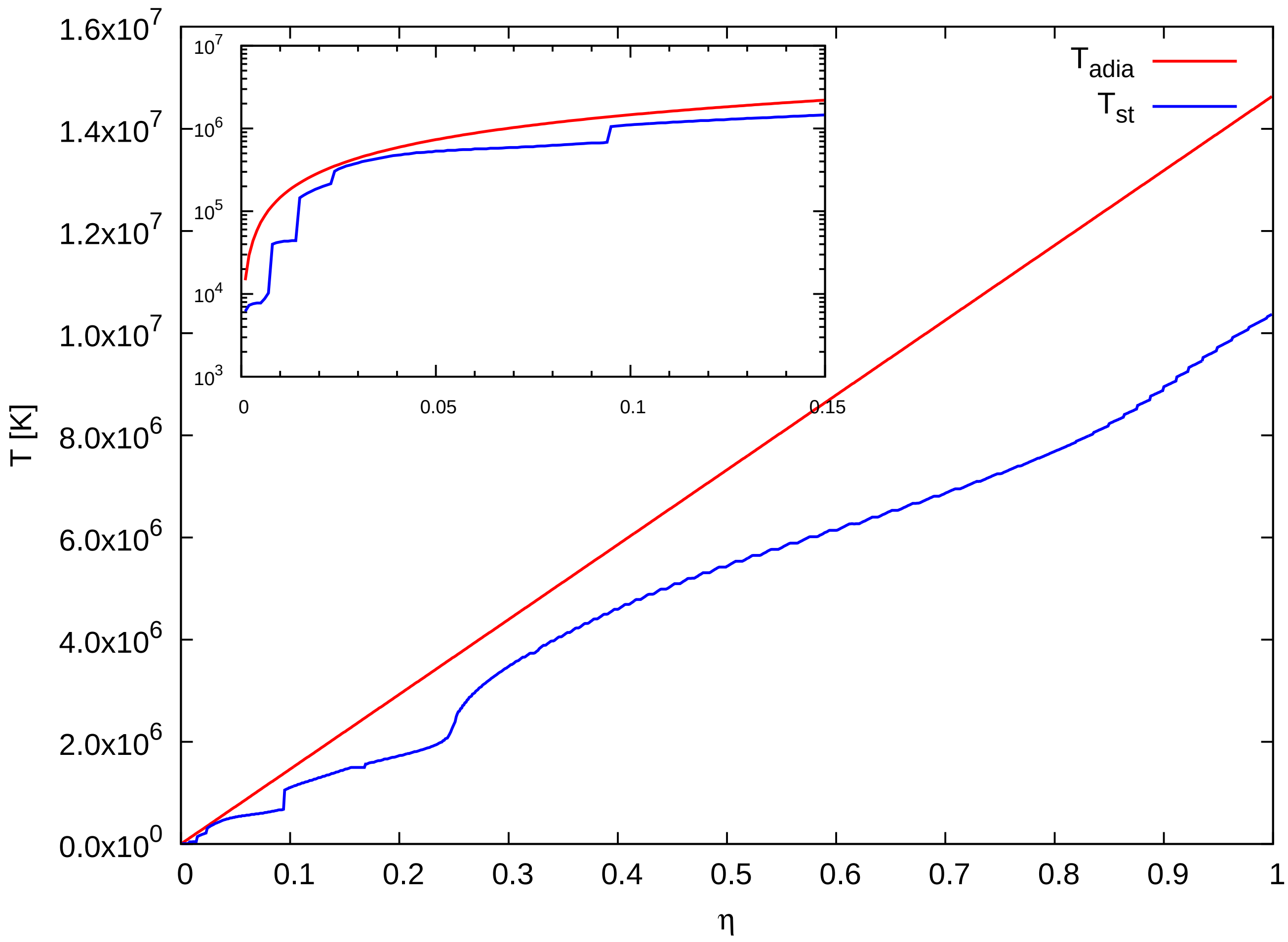


t = 5.000 kyr
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
y [pc]
-0.6 -0.4 -0.2 0 0.2 0.4 0.6
x [pc]
-0.6 -0.4 -0.2 0 0.2 0.4 0.6
x [pc]
-3 -2 -1 0 1 2 3 4 5
3.5 4 4.5 5 5.5 6 6.5 7 7.5 8

Comparison with uniform mass/energy input

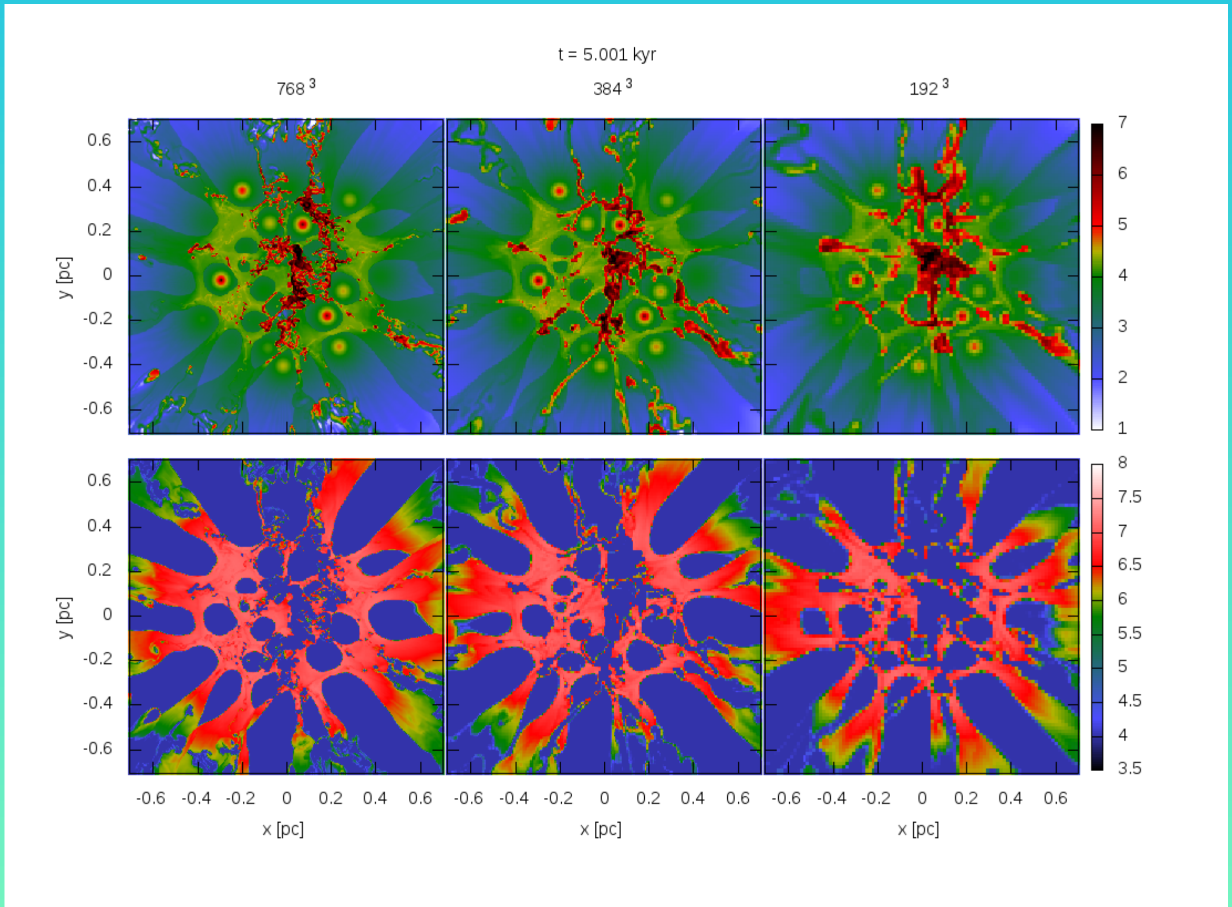


Determination of heating efficiency

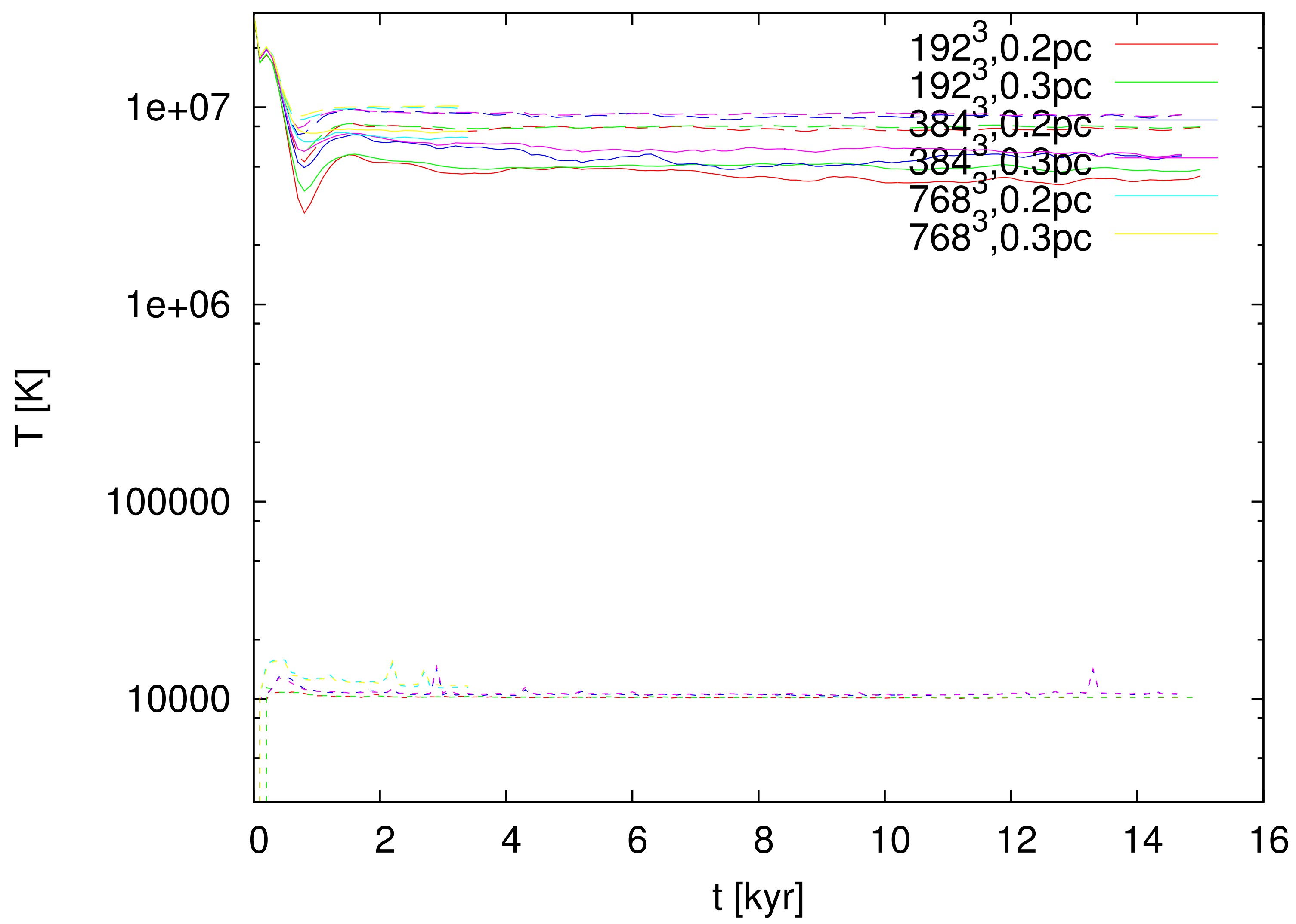


Resolution study - 100 stars

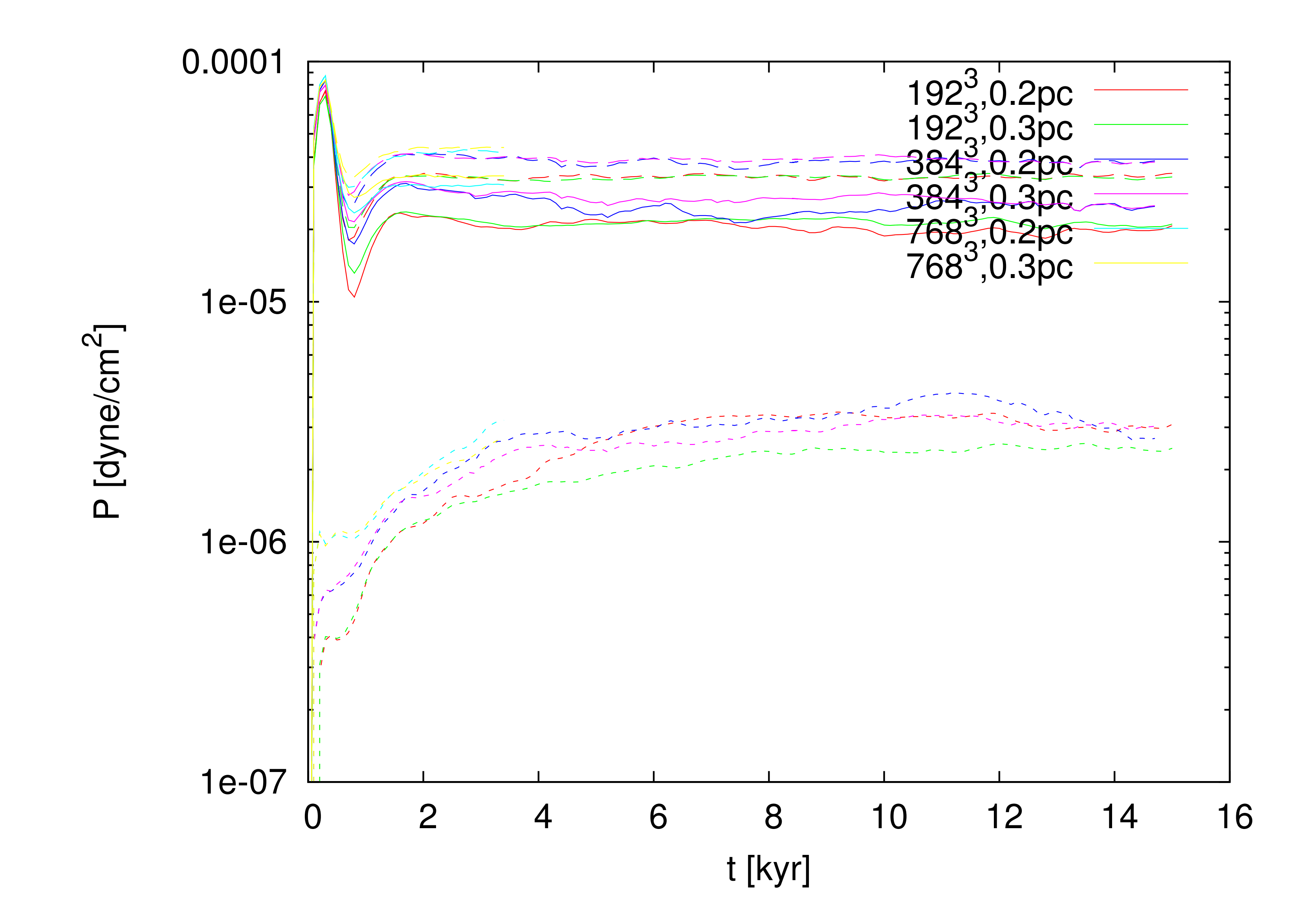
- meassured average values in spheres: 0.1, 0.2,. . . , 0.6 pc
- non-thermalized free wind excluded (velocity criterion)
- two media: warm ($T < 3 \times 10^5$) and hot ($T > 3 \times 10^5$ K)



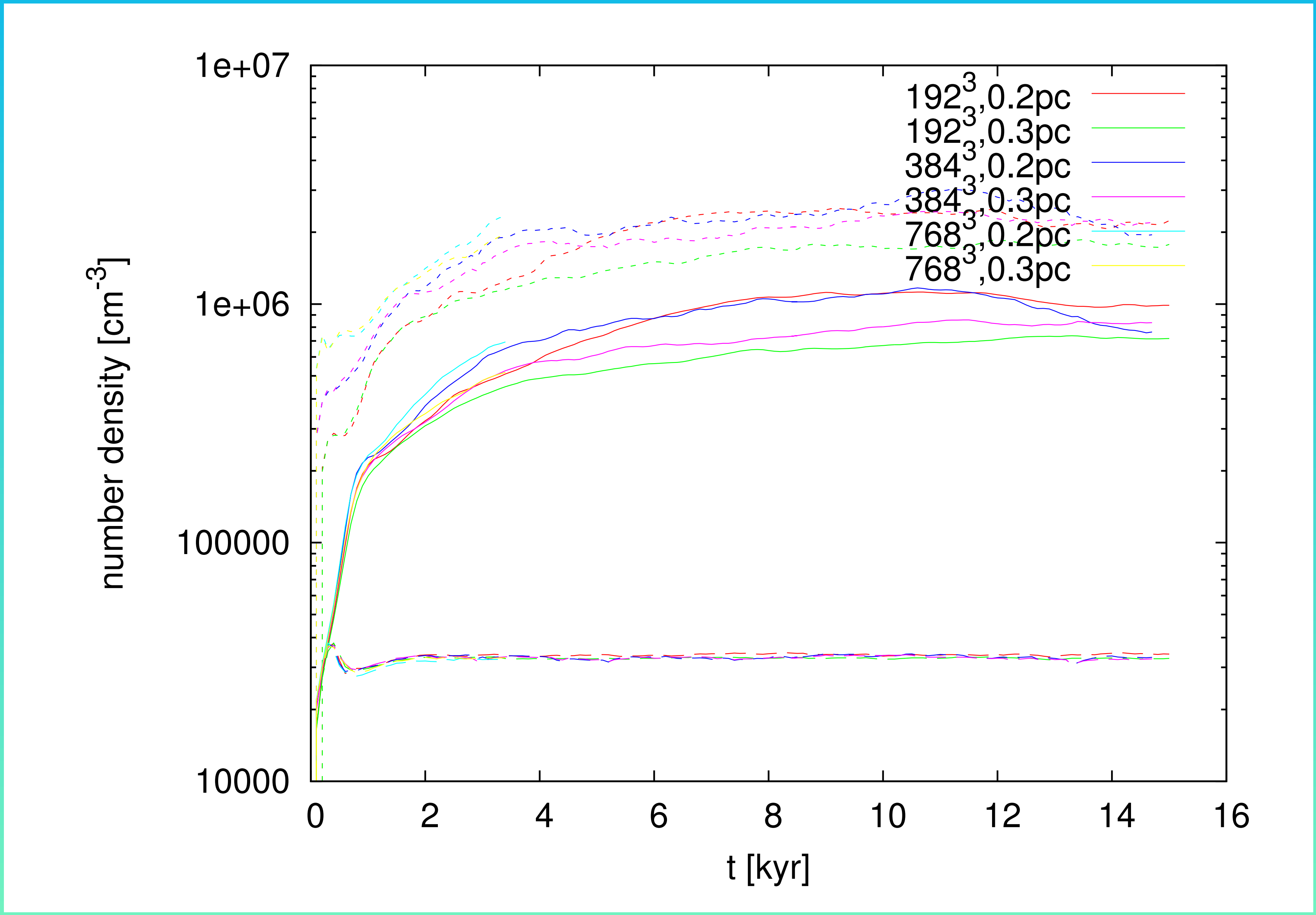
Temperature inside the cluster



Pressure inside the cluster



Density inside the cluster



Summary

- massive compact clusters evolve in the bimodal regime
  - ▹ outer quasi-stationary wind region
  - ▹ inner thermal instability region
- model of the bimodal regime:
  - ▹ predicts mass accumulated inside the cluster
    $\rightarrow$ secondary SF, multiple stellar generations
  - ▹ explains two-component supersonic line profiles
- 2D models confirm the bimodal behaviour, provide estimates on mass accumulation and line widths
- we try to use 3D models with individual stellar winds to determine the heating efficiency of the ISM inside SSCs

References

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