The Evolution of

Tidal Dwarf Galaxies

and their stellar populations

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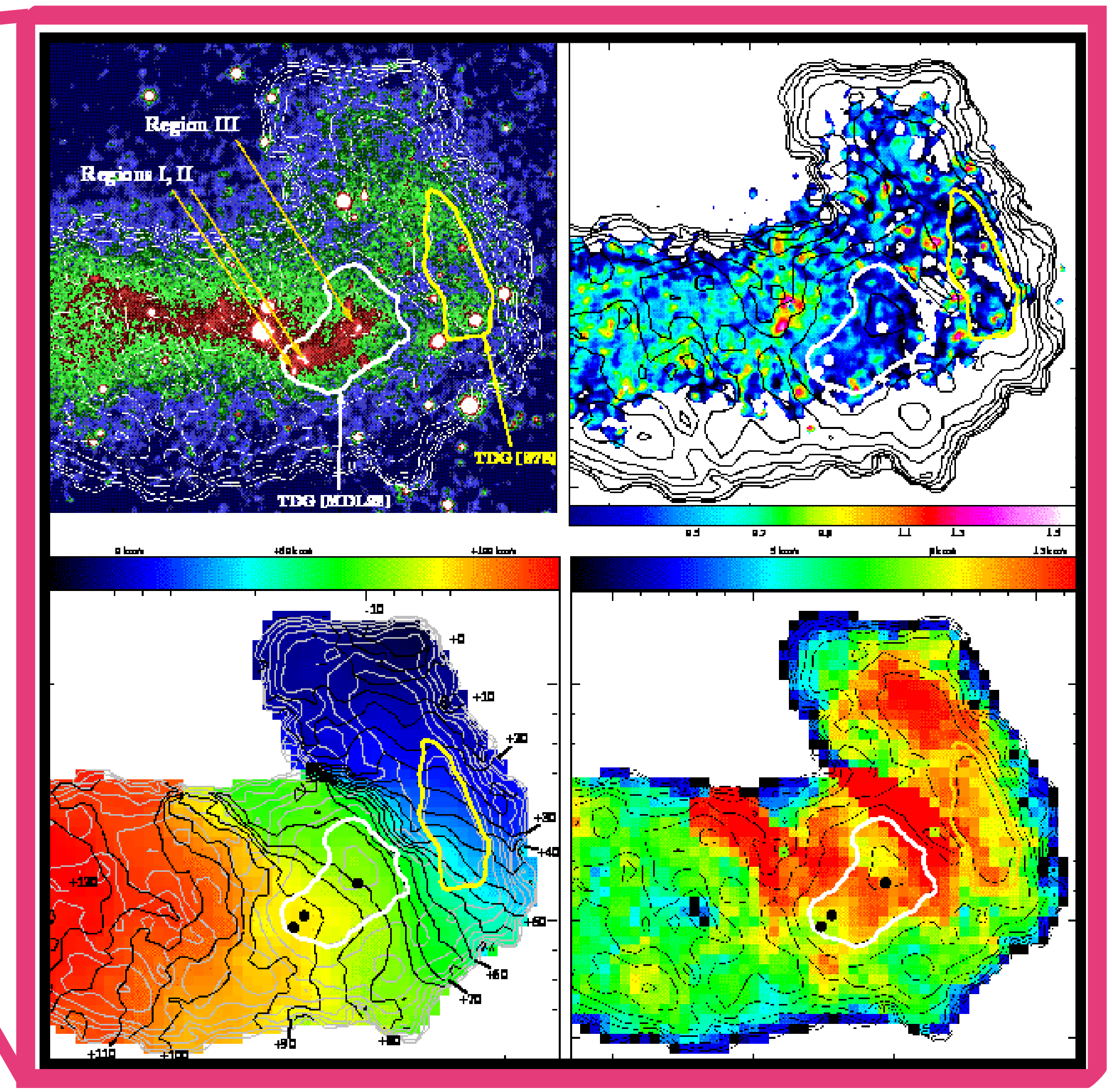
Observations

Image Credit: A. Oreshko, D. Hager

Image Credit: Jean-Charles Cuillandre, Hawaiian Starlight



Hibbard et al. (2001)

Classical dwarf galaxies

Bottom-up

Dark matter dominated

(Isolated) self-enrichment

Tidal dwarf galaxies

Top-down

No dark matter content

Pre-enriched material

Self-gravitating objects

Cover the same mass range

Classical dwarf galaxies

Tidal dwarf galaxies

Bottom-up

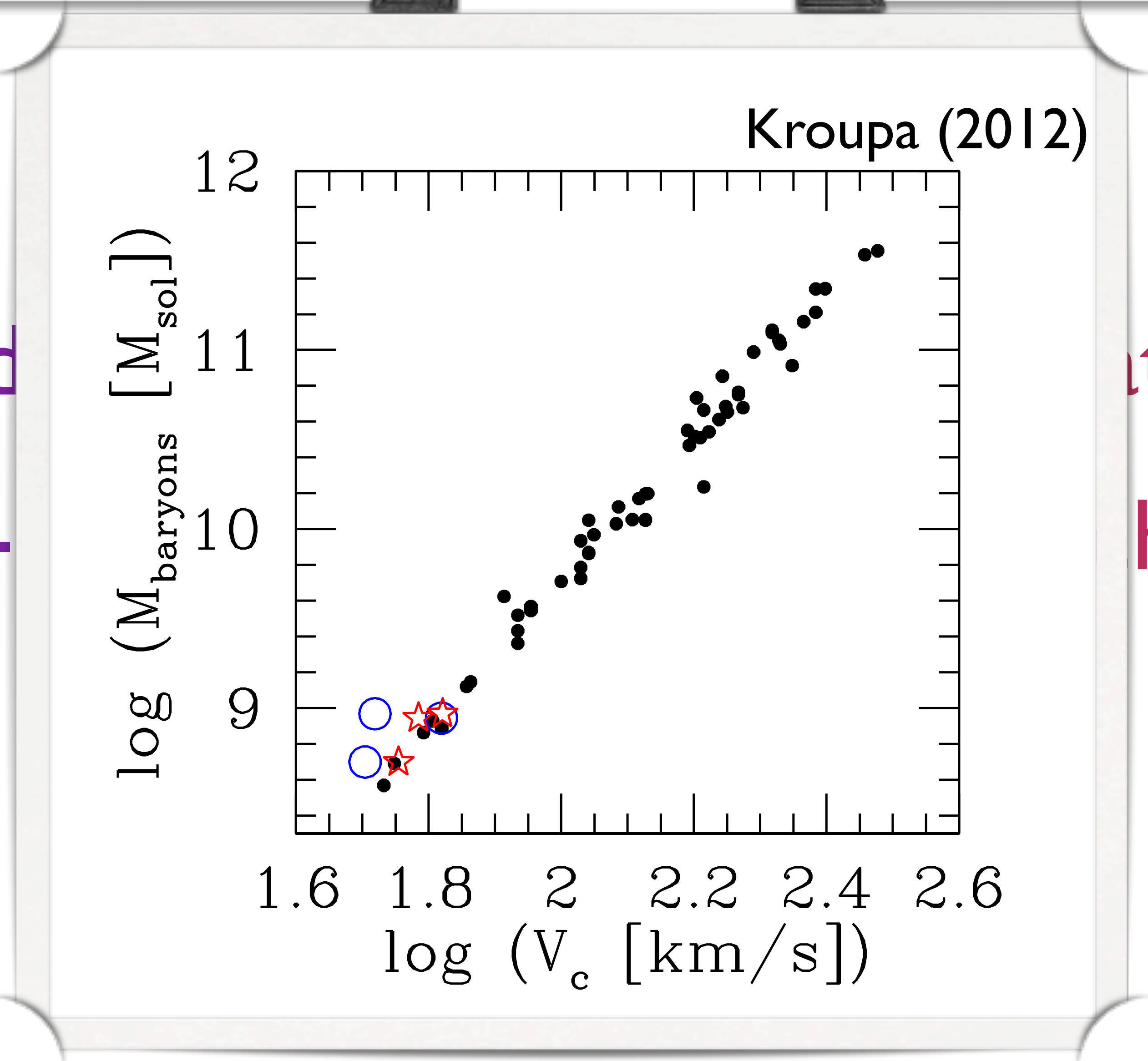
Dark matter d

(Isolated) self-

Top-down

tter content

hed material



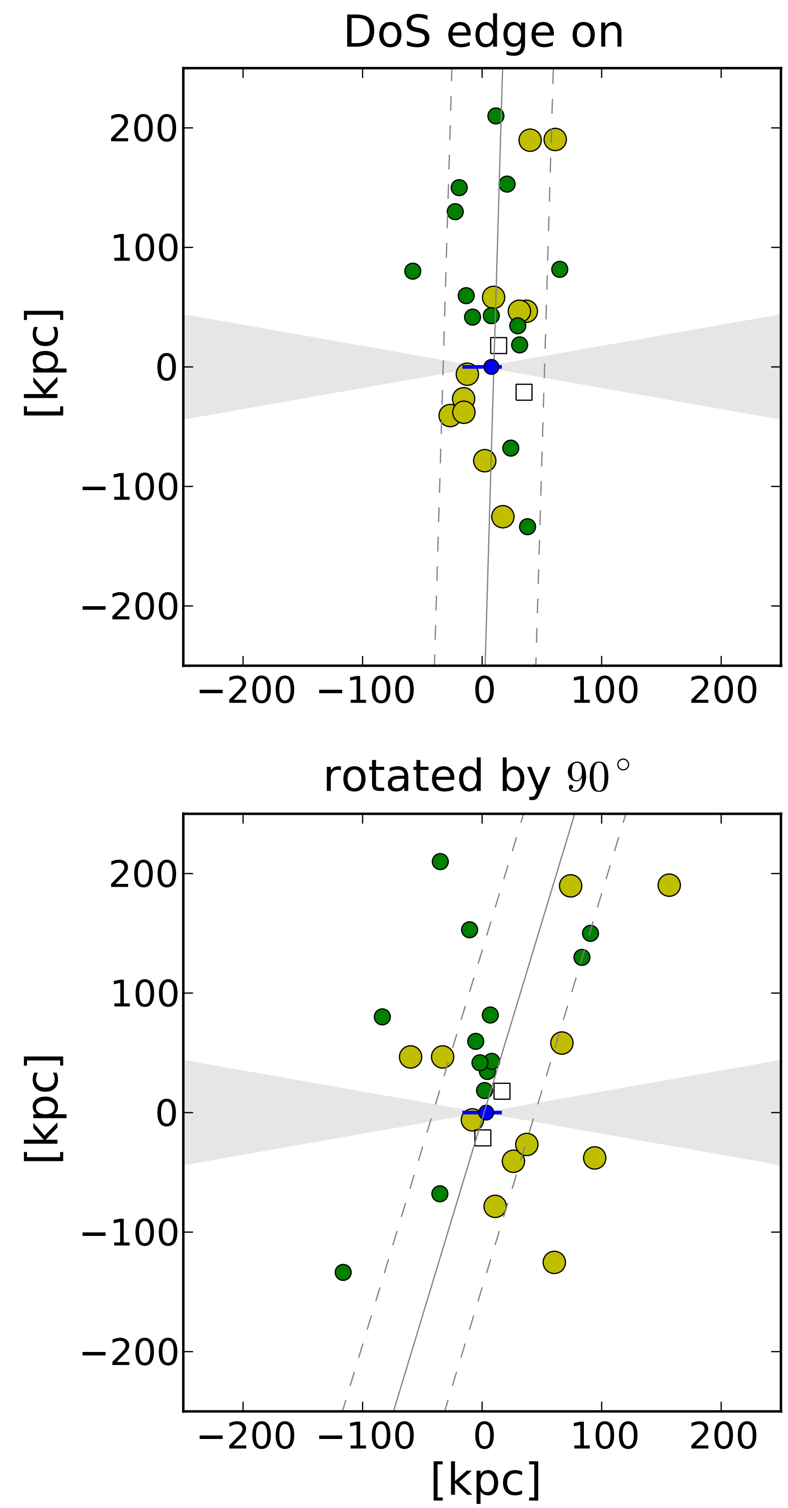
Cover the same mass range

Share the same baryonic TF-relation

Motivation

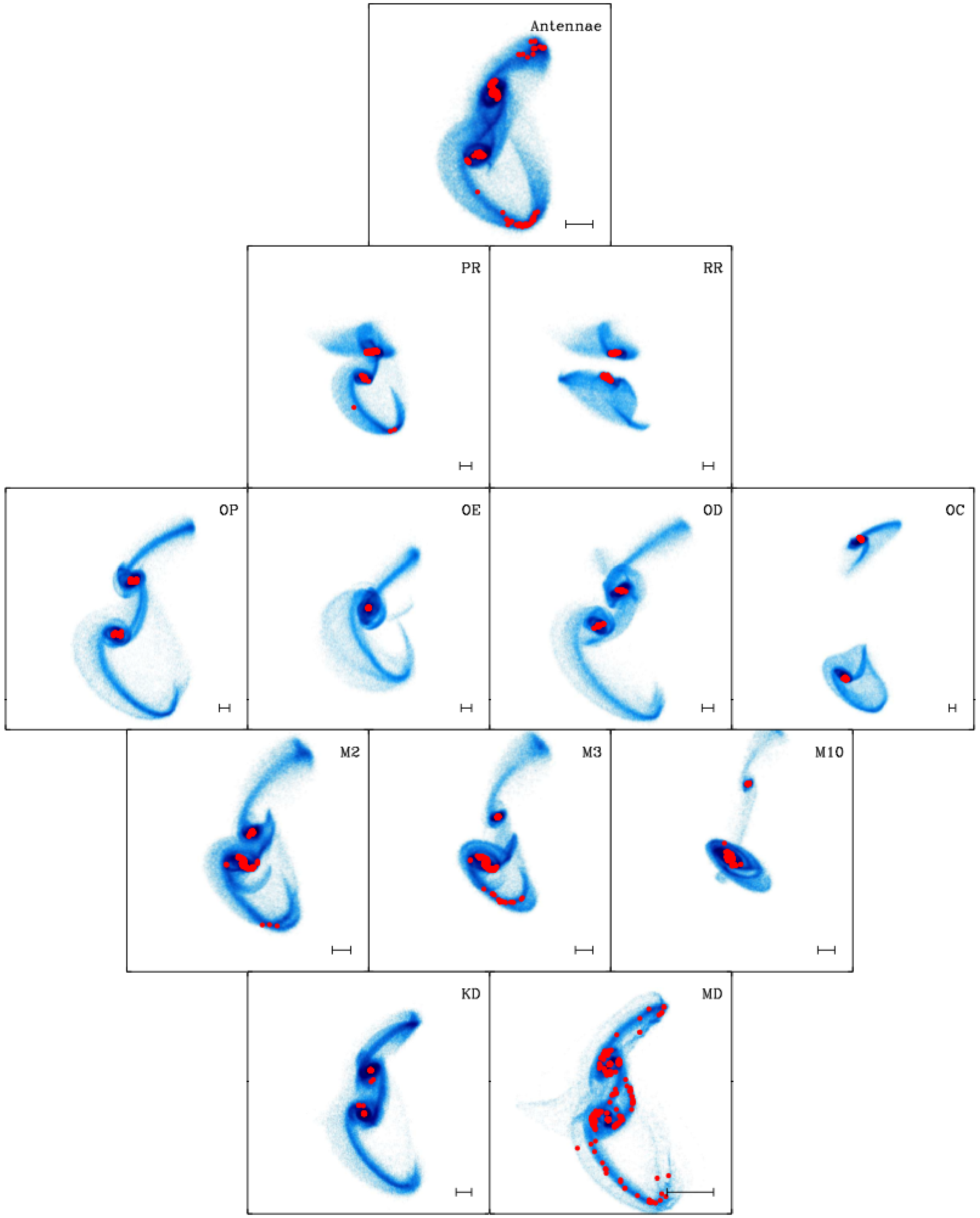
- ✗ *Dwarf Galaxies*
  - ✗ *Total Number*
  - ✗ *Spatial Distribution*
  - ✗ *Circular Velocities*

Springel et. al. (2005)

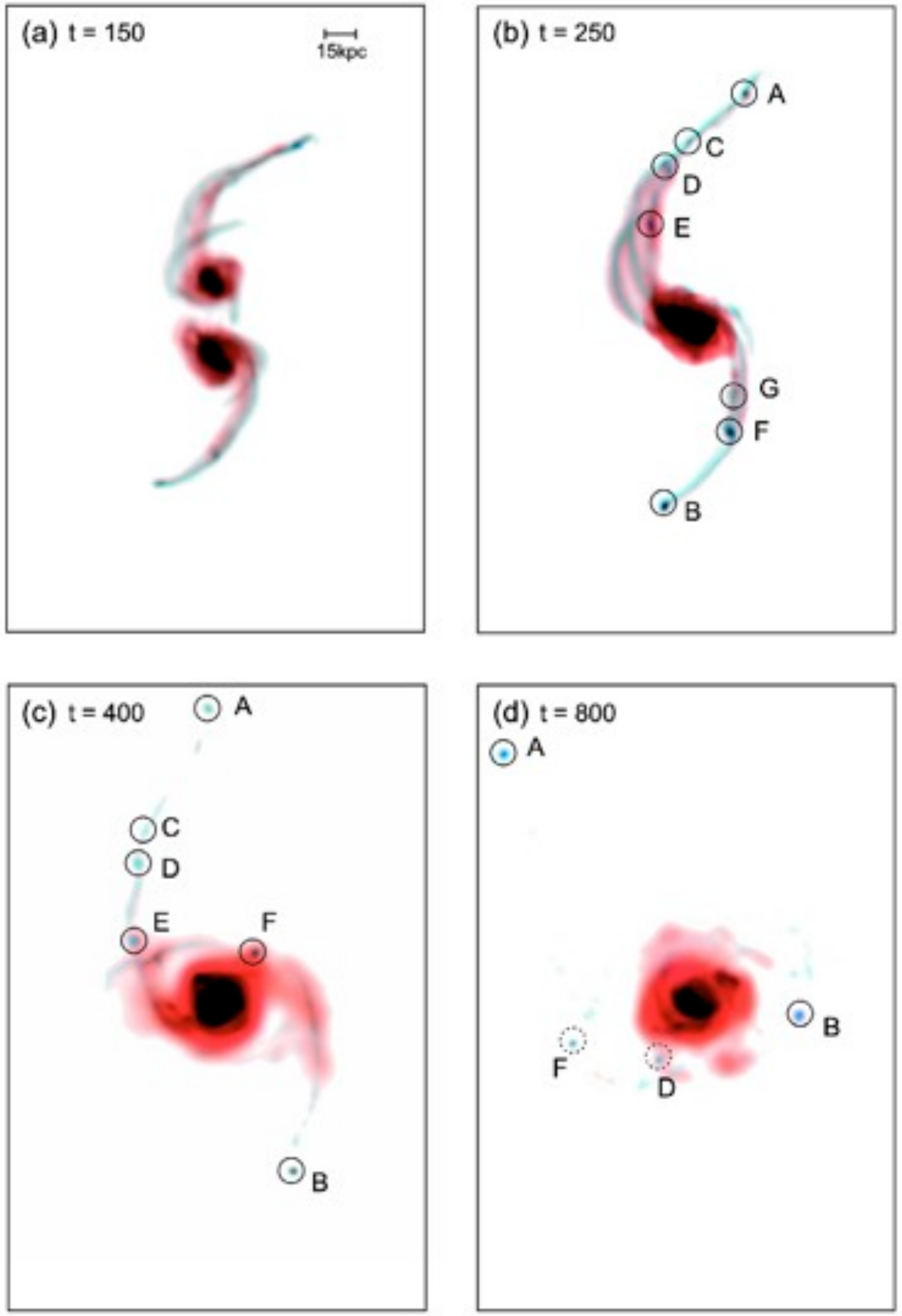


Kroupa et al. (2010)

Simulations

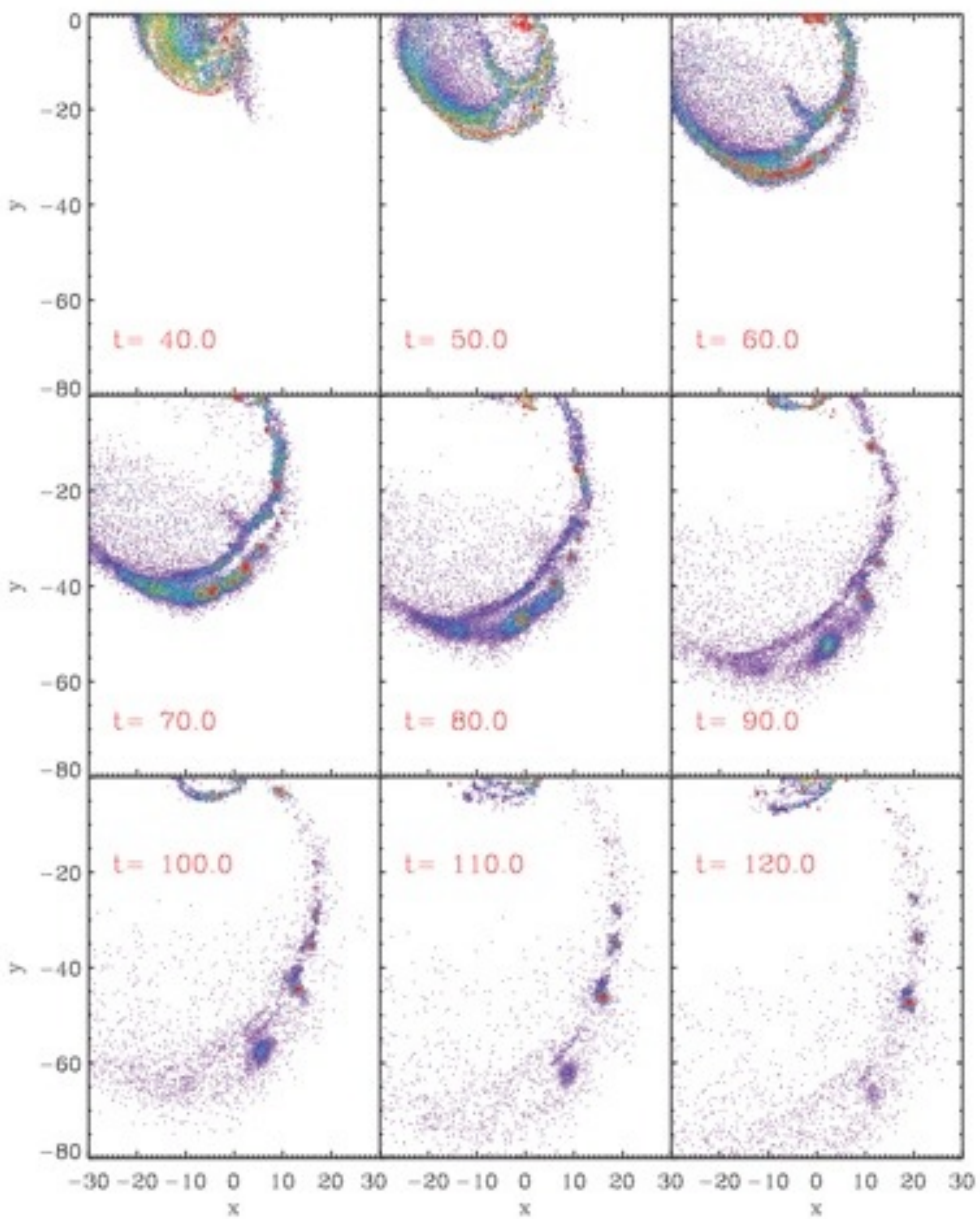


Renaud et al. (2009)

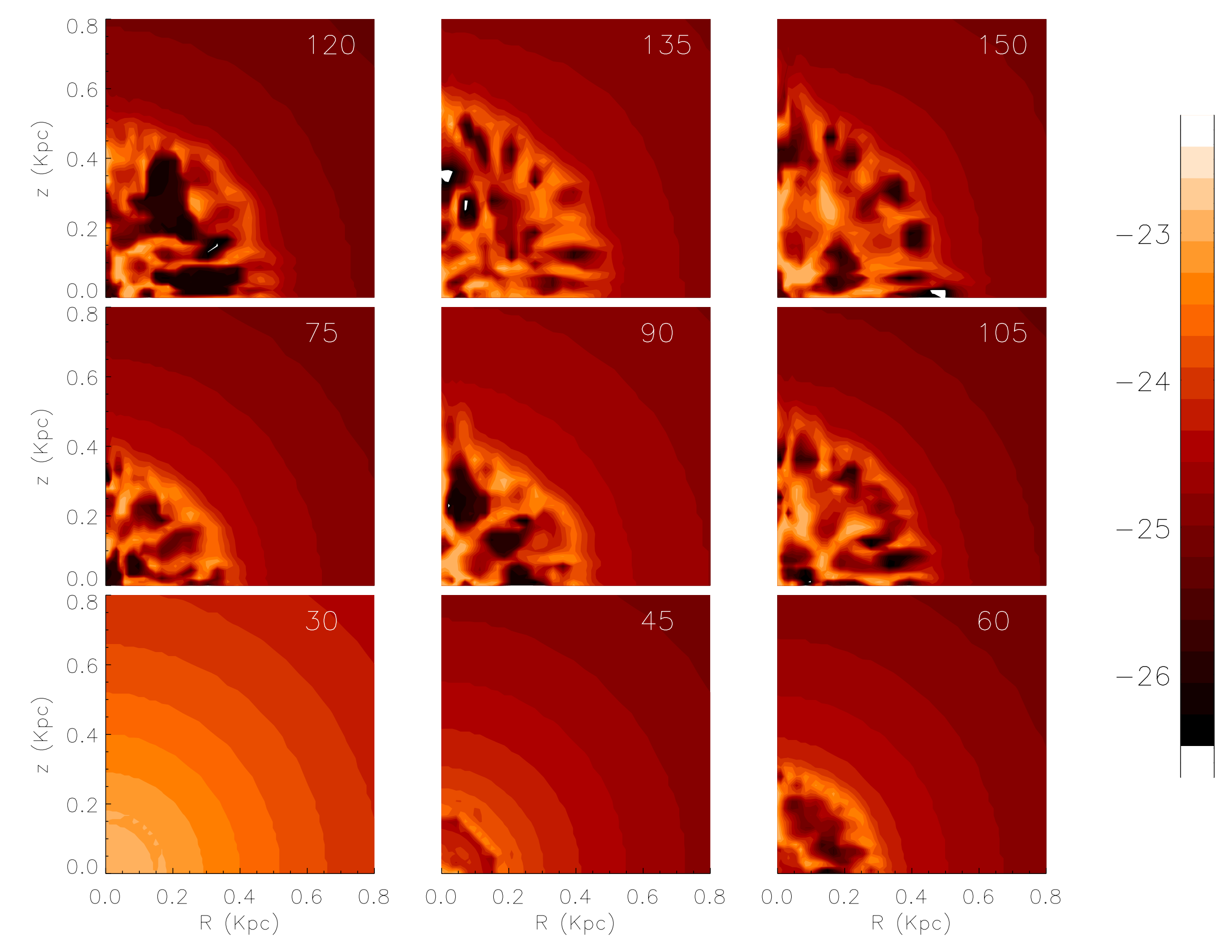


Bournaud & Duc (2006)

Simulations



Wetzstein et al. (2007)



0.8 x 0.8 kpc

Recchi et al. (2007)

Tidal dwarf galaxy simulation:

- Flash basics
- Radiative cooling
- Stellar feedback
- Orbit
- Star formation / IMF
- Initial conditions

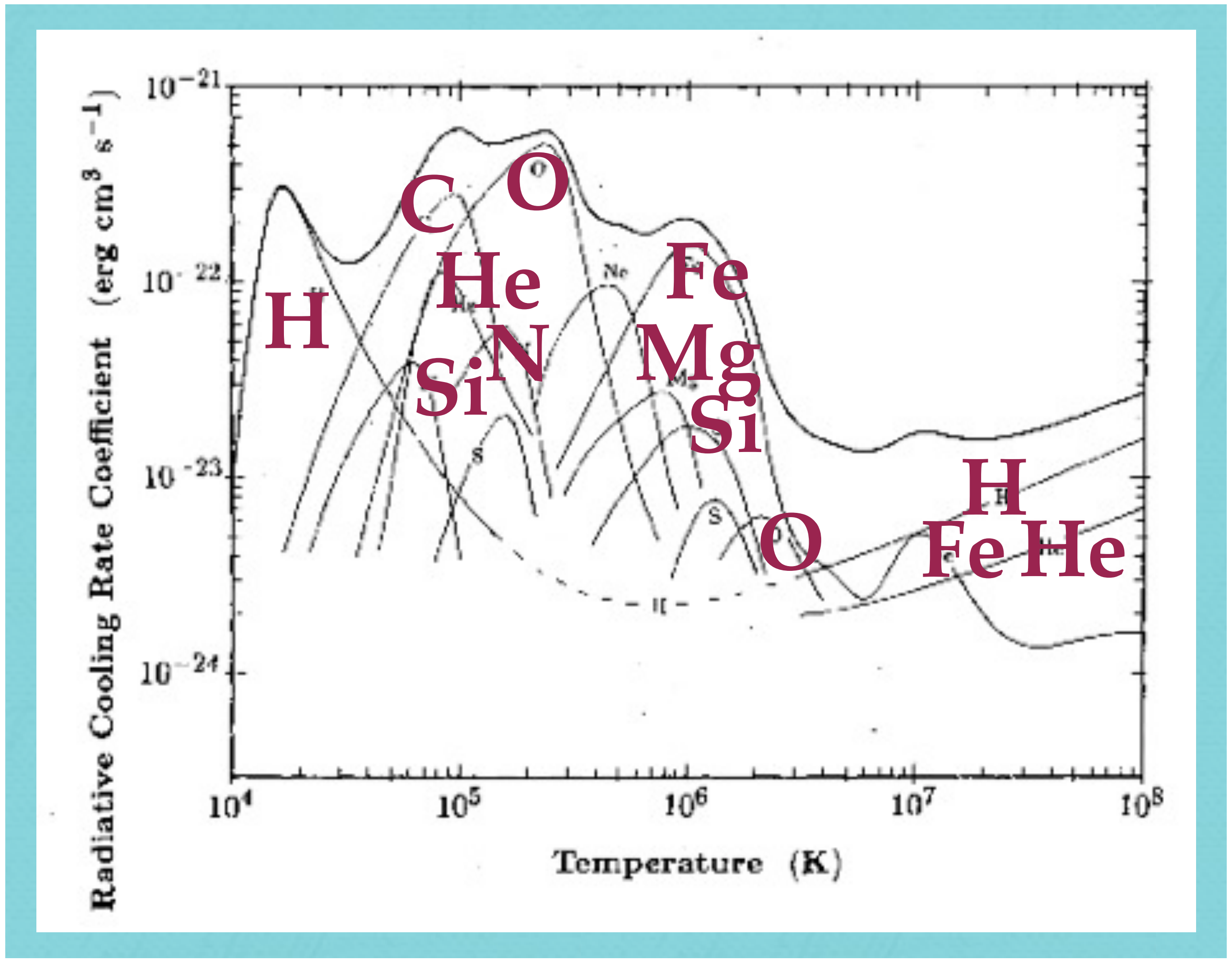
Flash basics

- University of Chicago
- Version 3.3
- Modified unsplit hydro solver (N. Mitchell)
- Multigrid Poisson Solver
- Adaptive mesh refinement
- Very well parallelized
- Particle module (PM)

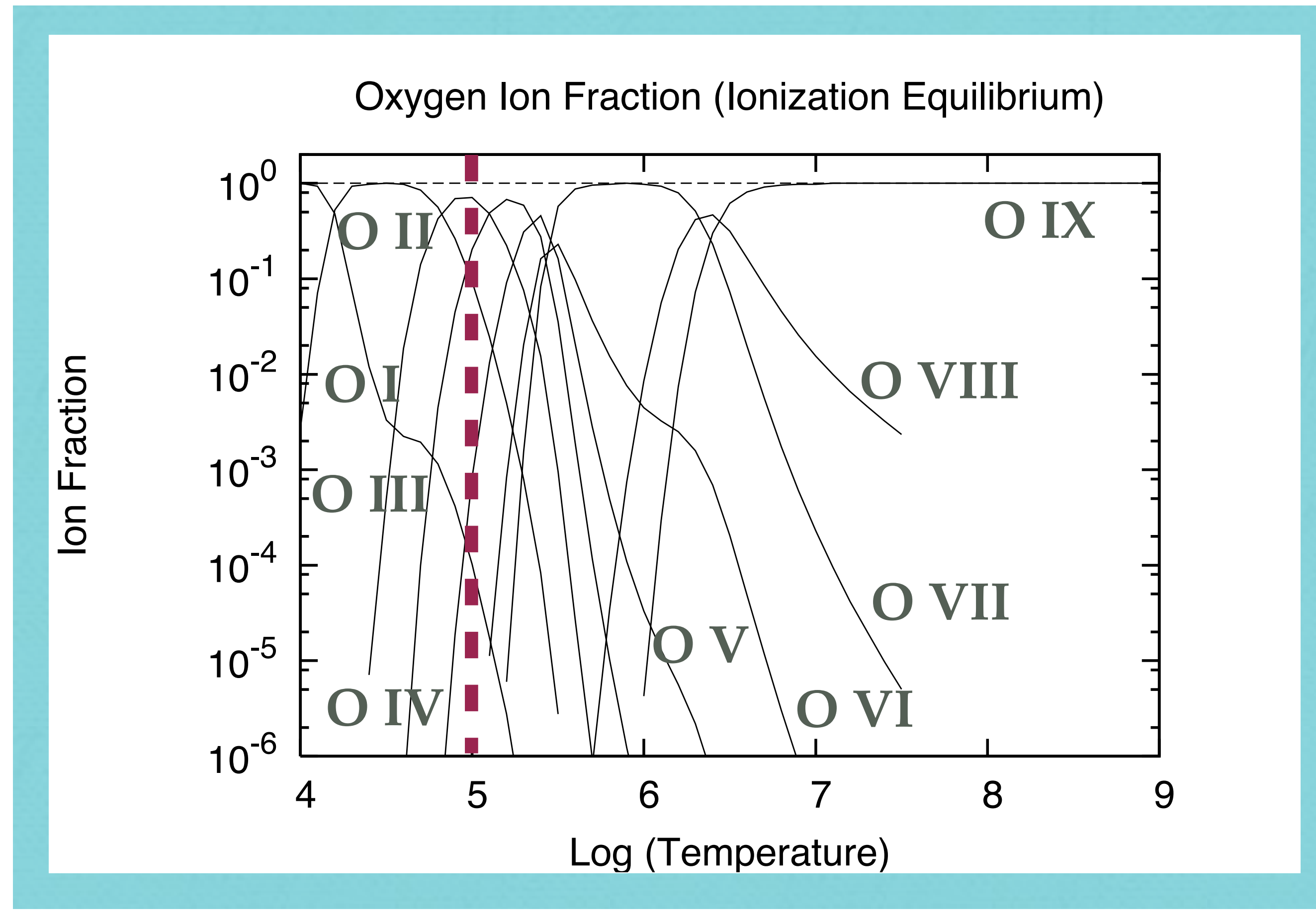
Flash Center
for computational science

Radiative cooling

Cooling



Böhringer & Hensler (1989)

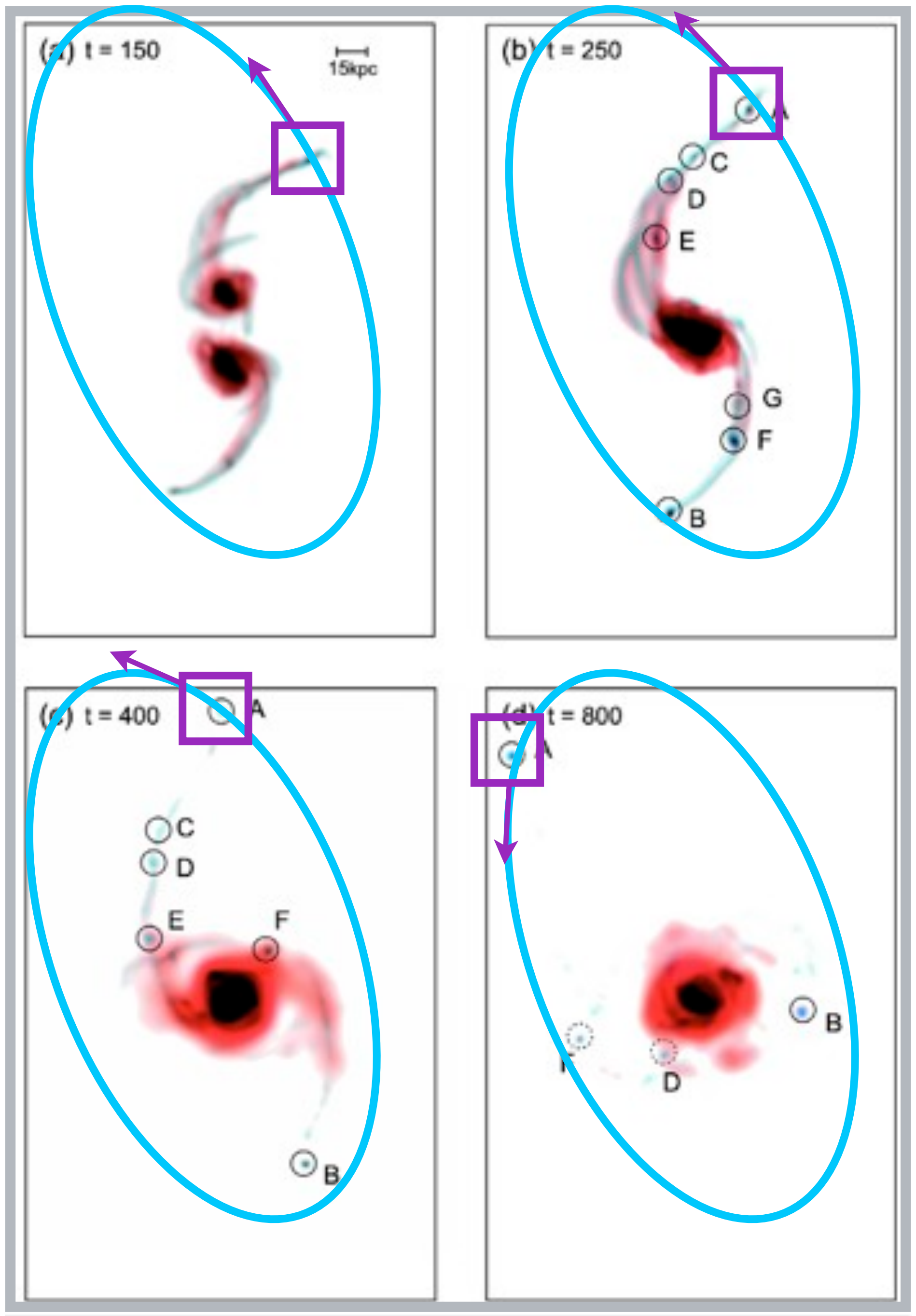


Arnaud & Rothenflug (1985)

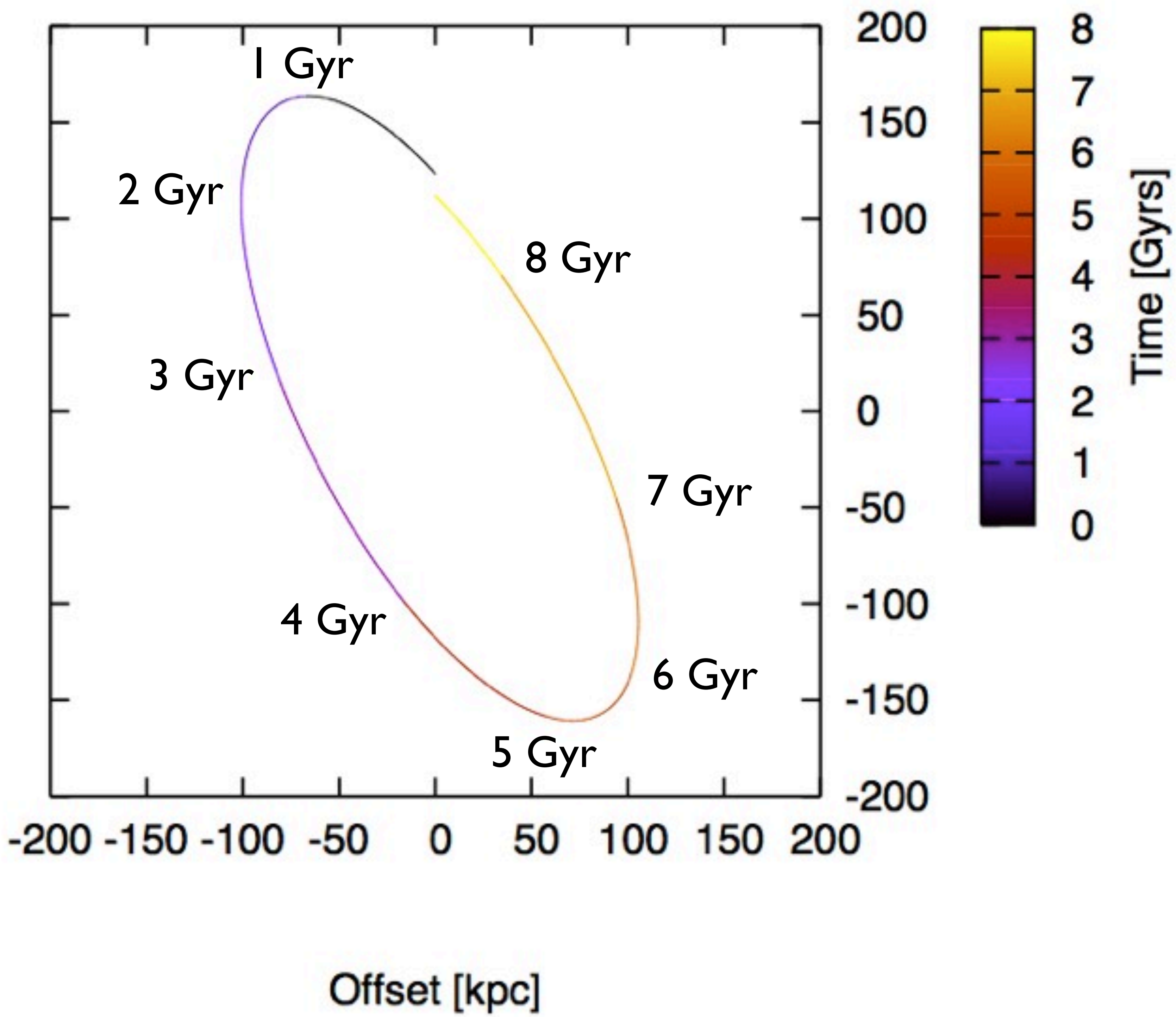
Implicit radiative cooling routine for FLASH

Orbit

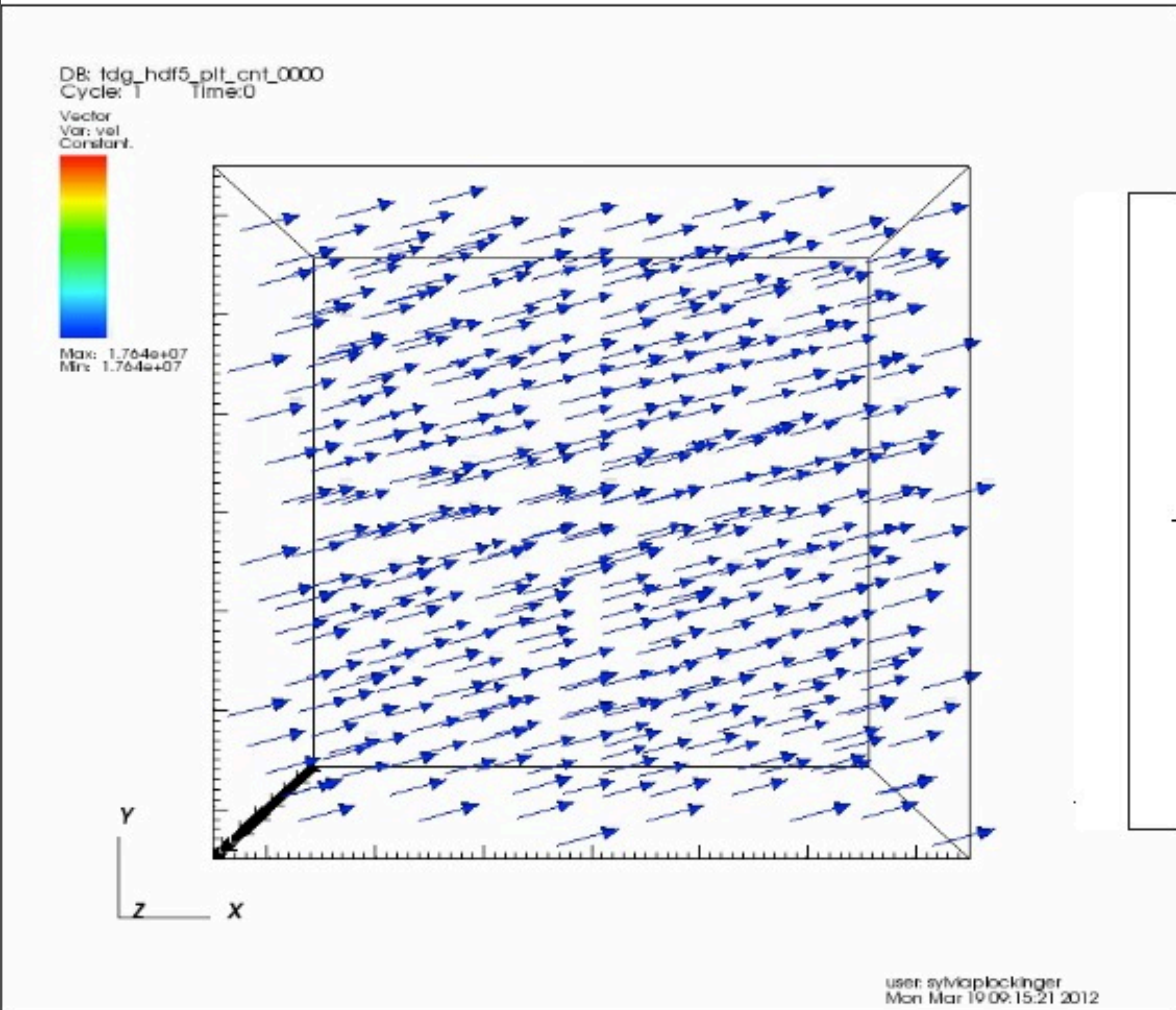
Orbit

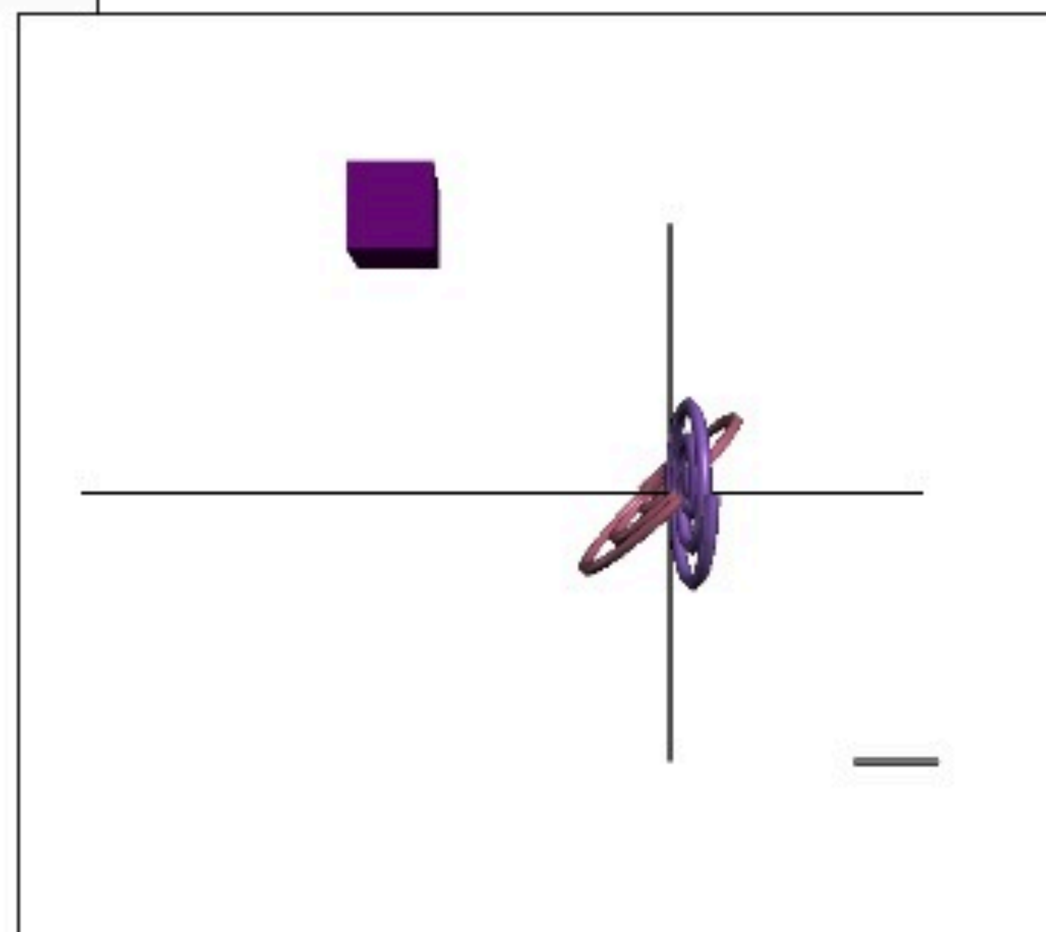


Bournaud & Duc (2006)



External tidal field



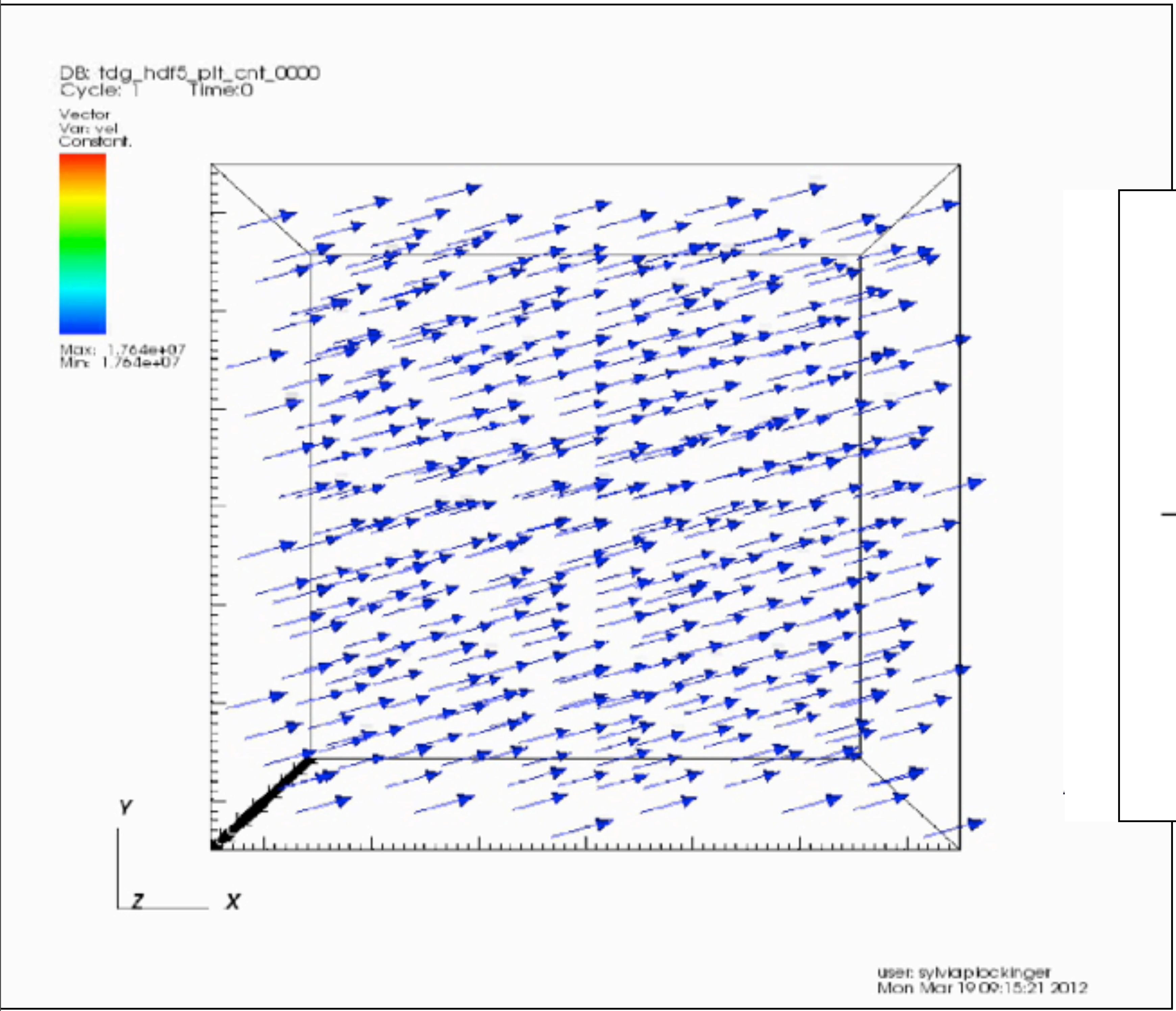


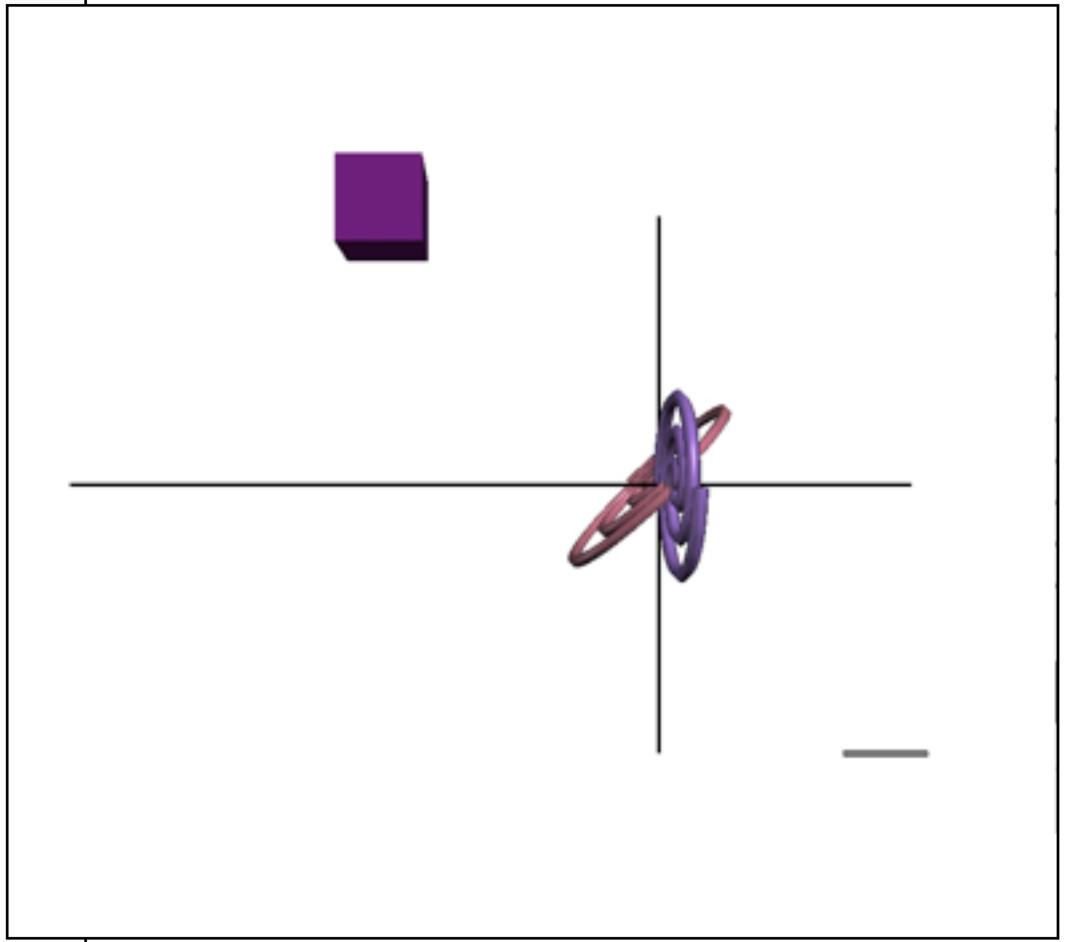
Orbit

External tidal field

Orbit

External tidal field



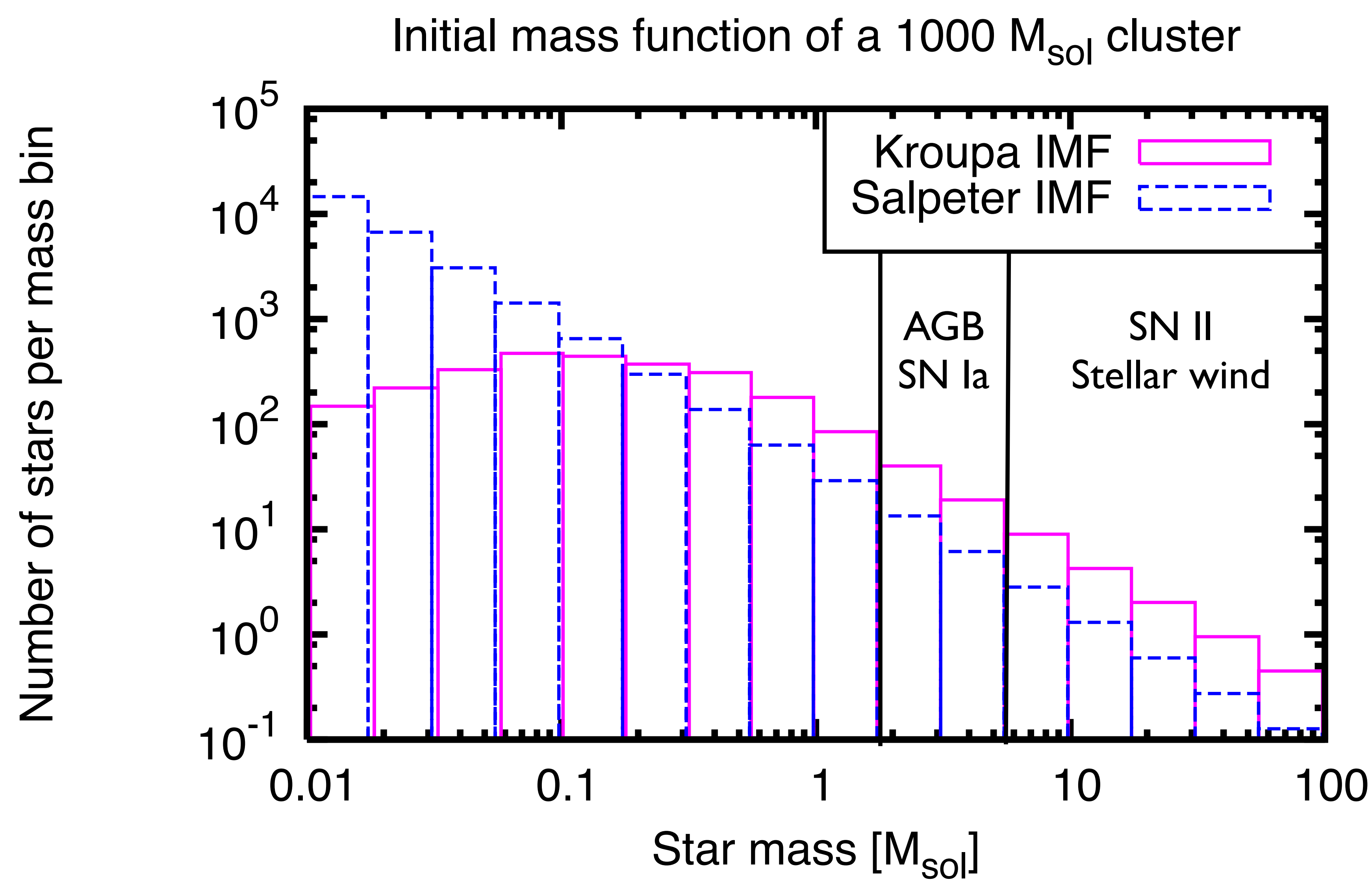


Selfregulated star formation

Stellar birth function:

$$\Psi(g,T) \quad = \quad C_n g^n e^{-T/T_s}$$

Köppen, Theis & Hensler (1995)

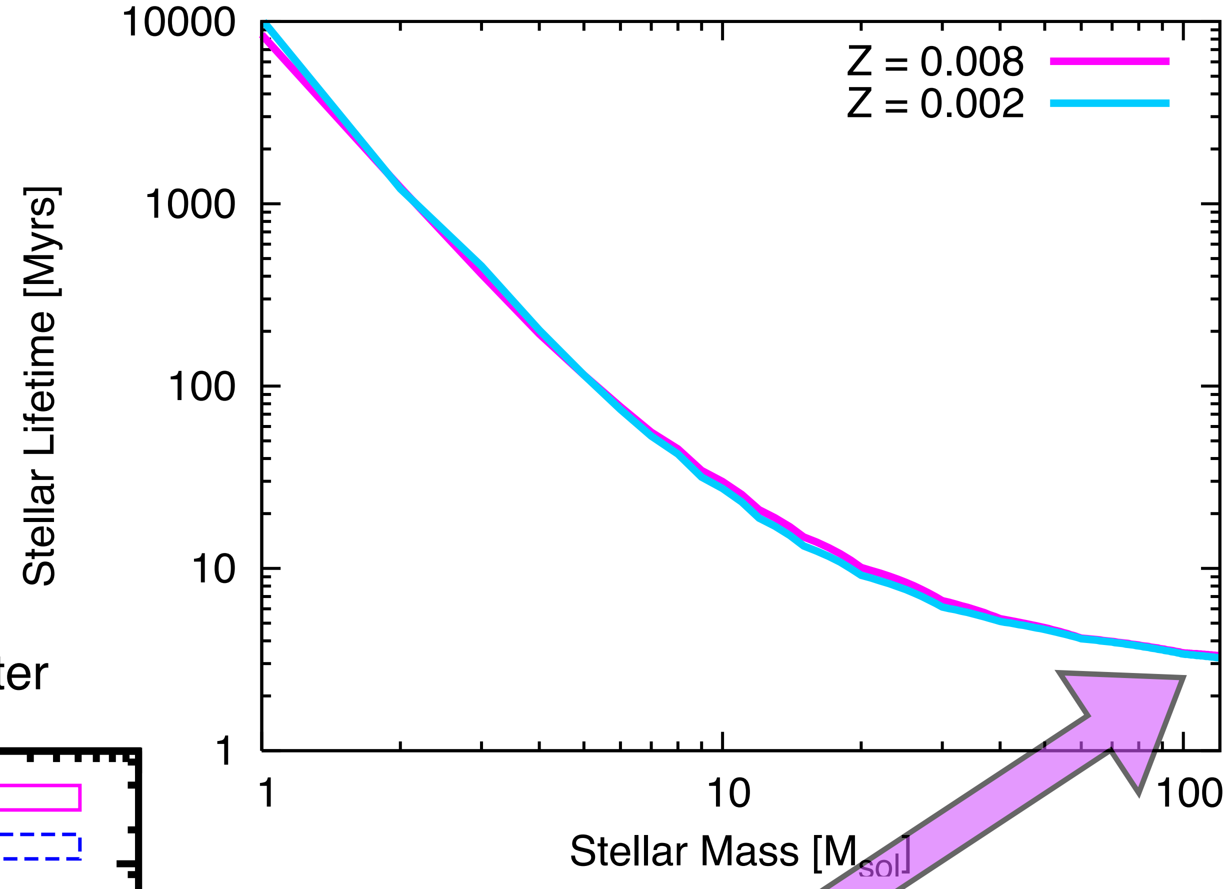


Stellar Feedback

Wind: $$\left.\frac{\partial e_{th}}{\partial t}\right|_{OB} = \frac{1}{2}\dot{m}v_\infty^2 + \eta_{Ly}L_{Ly}(m)$$

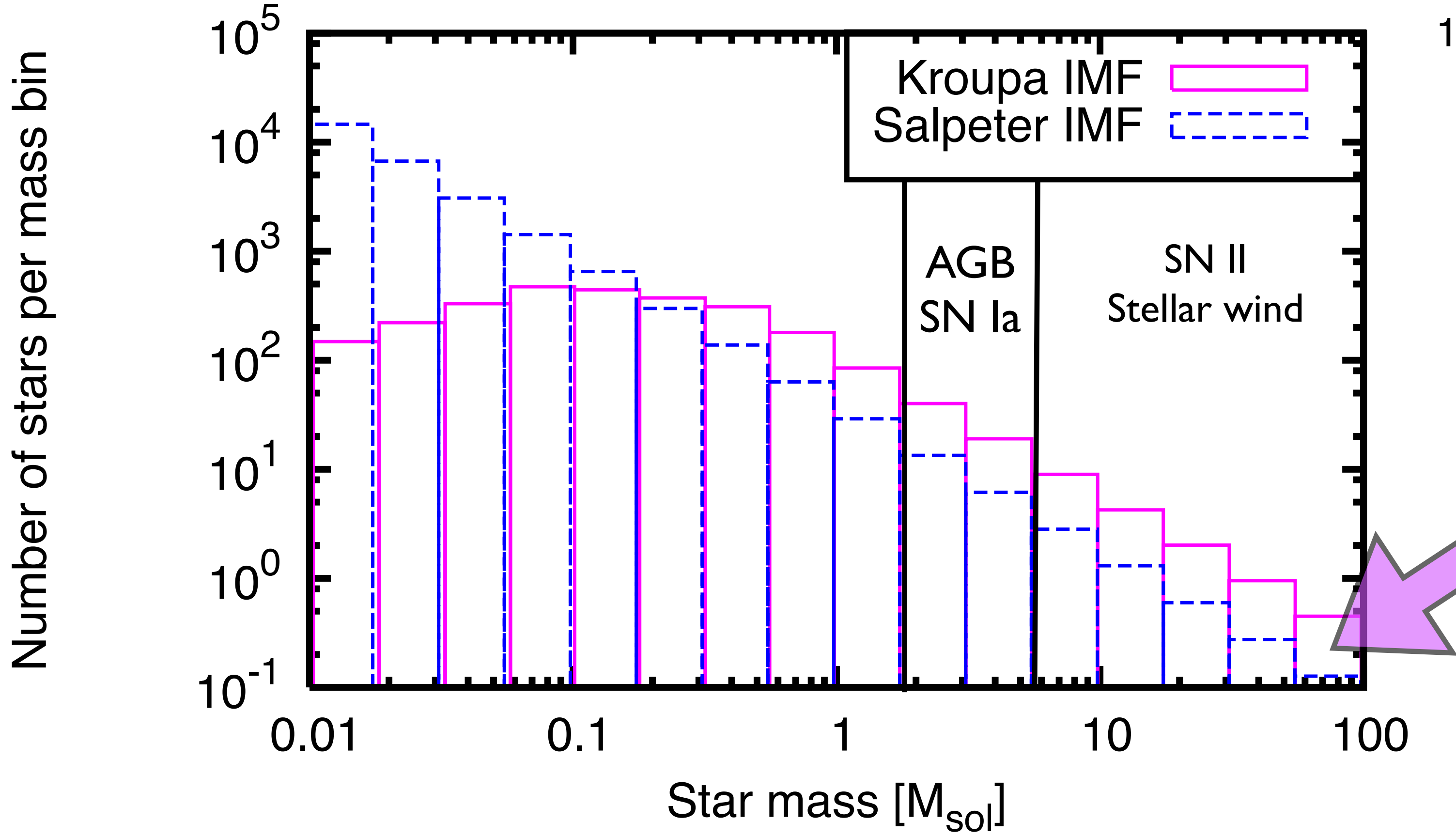
$$\begin{aligned} L_{Ly}(m) &= 10^{40}\left(\frac{m}{M_\odot}\right)^6 \text{ photons s}^{-1}\text{ star}^{-1} \\ \dot{m} &= -10^{-15}\left(\frac{Z}{Z_\odot}\right)^{0.5}\left(\frac{L}{L_\odot}\right)^{1.6} \mathrm{M_\odot\,yr^{-1}} \\ v_\infty &= 3\cdot 10^3\left(\frac{m}{M_\odot}\right)^{0.15}\left(\frac{Z}{Z_\odot}\right)^{0.08} \text{km s}^{-1} \end{aligned}$$

Theis, Burkert & Hensler (1992)



Portinari et al. (1998)

Initial mass function of a 1000 M_{sol} cluster



Stellar feedback

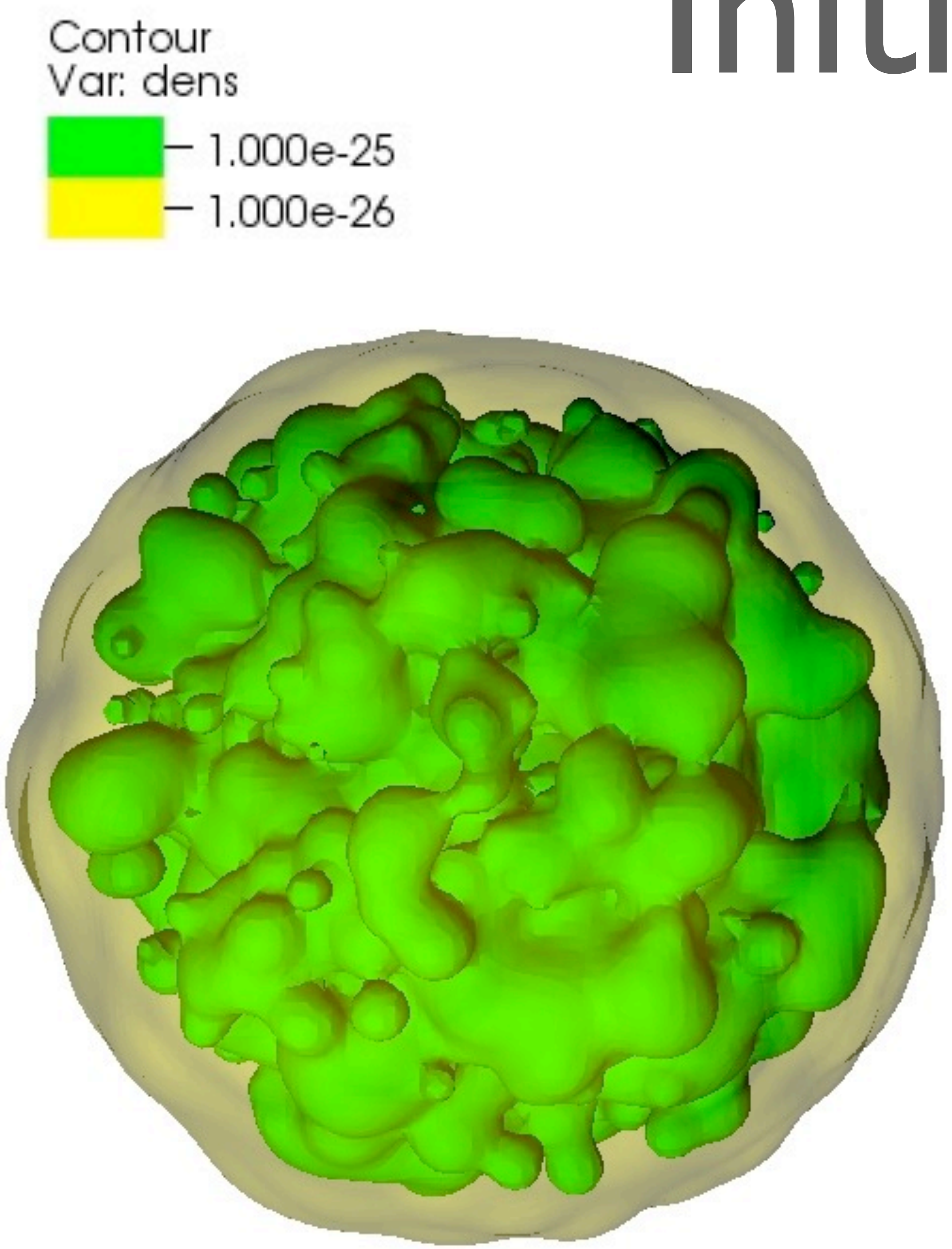
Chemistry

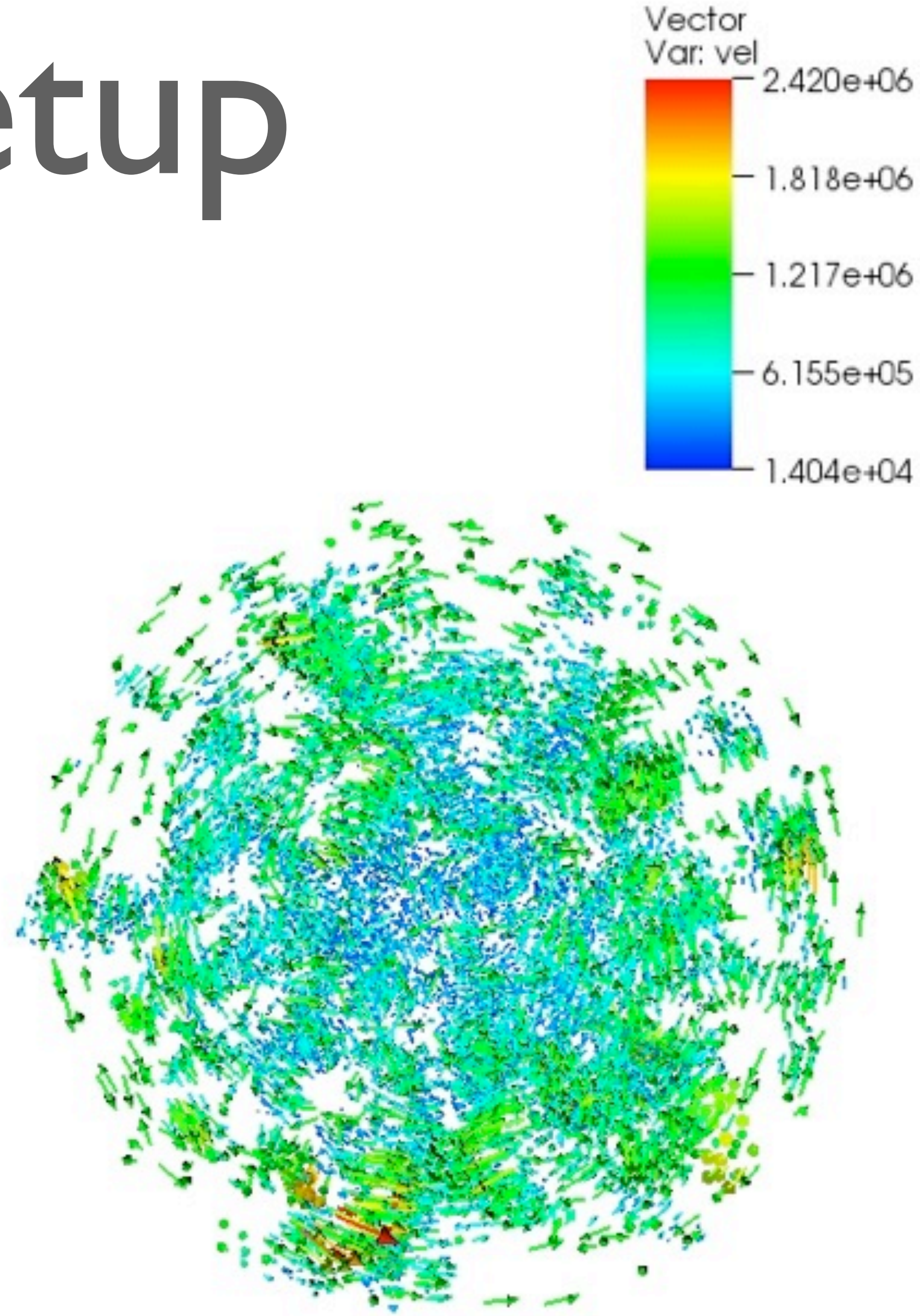
$100\ M_{sol}$ $Z = 0.004$ $100\ M_{sol}$ $Z = 0.02$

Portinari et al. (1998) + Marigo et al. (1996)

Initial conditions

Initial setup





Gas density

Stellar particles velocity

Initial conditions

Initial setup

$M_{TDG} = 1.96 \times 10^8\ M_{sol}$

$R_{TDG} = 3.9$ kpc

$Z_{TDG} = 0.0118 = 0.89\ Z_{sol}$

$Z_{halo} = 0.000227 = 0.017\ Z_{sol}$

500 Gaussian overdensities

Simulation Box: $(27\ \mathrm{kpc})^3$

Effective Resolution: 50 pc

Tidal dwarf galaxy simulation:

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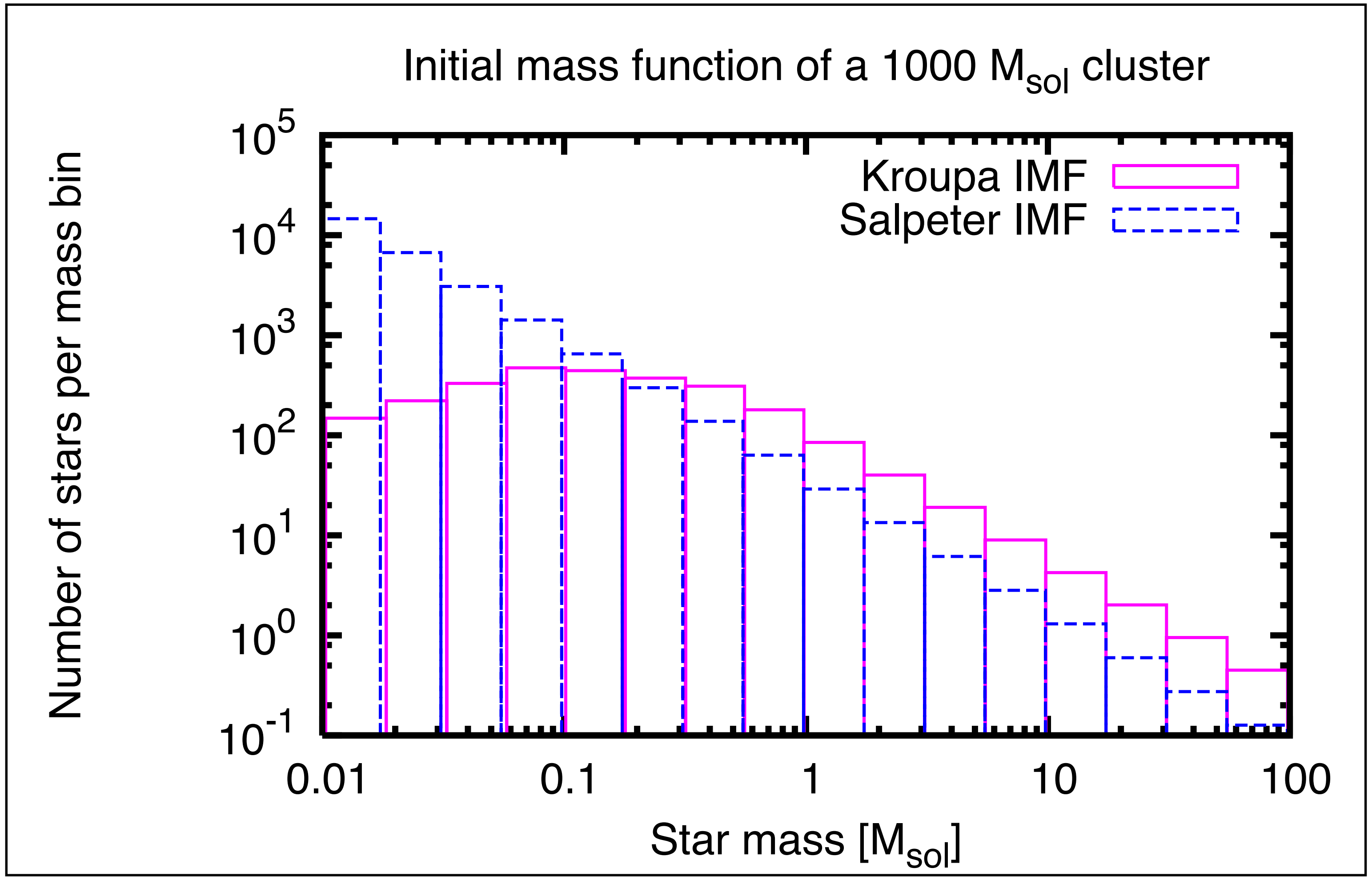
Vienna Scientific Cluster

Data Analysis

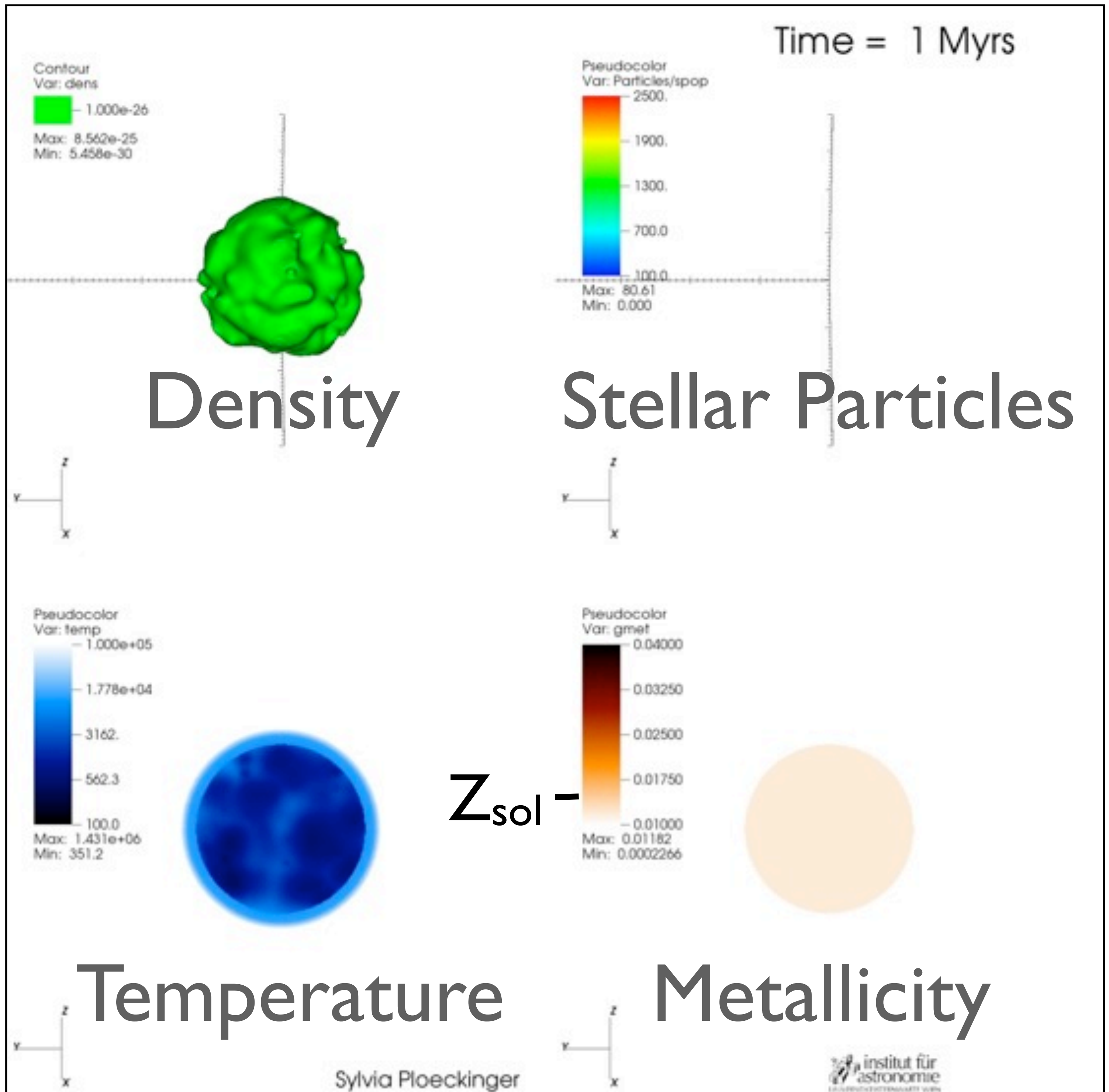
Grid and particle variables used for data analysis:

- Temperature
- Density
- 11 element abundances
- Gas metallicity

- Age
- Mass (spop + mass)
- Metallicity



Animation


Time = 1 Myrs
Contour
Var: dens
1.000e-26
Max: 8.562e-25
Min: 5.458e-30
Pseudocolor
Var: Particles/spop
2500.
1900.
1300.
700.0
100.0
Max: 80.61
Min: 0.000
Density
Stellar Particles
Pseudocolor
Var: temp
1.000e+05
1.778e+04
3162.
562.3
100.0
Max: 1.431e+06
Min: 351.2
Pseudocolor
Var: gmet
0.04000
0.03250
0.02500
0.01750
0.01000
Max: 0.01182
Min: 0.0002266
Z_{sol}
Temperature
Metallicity
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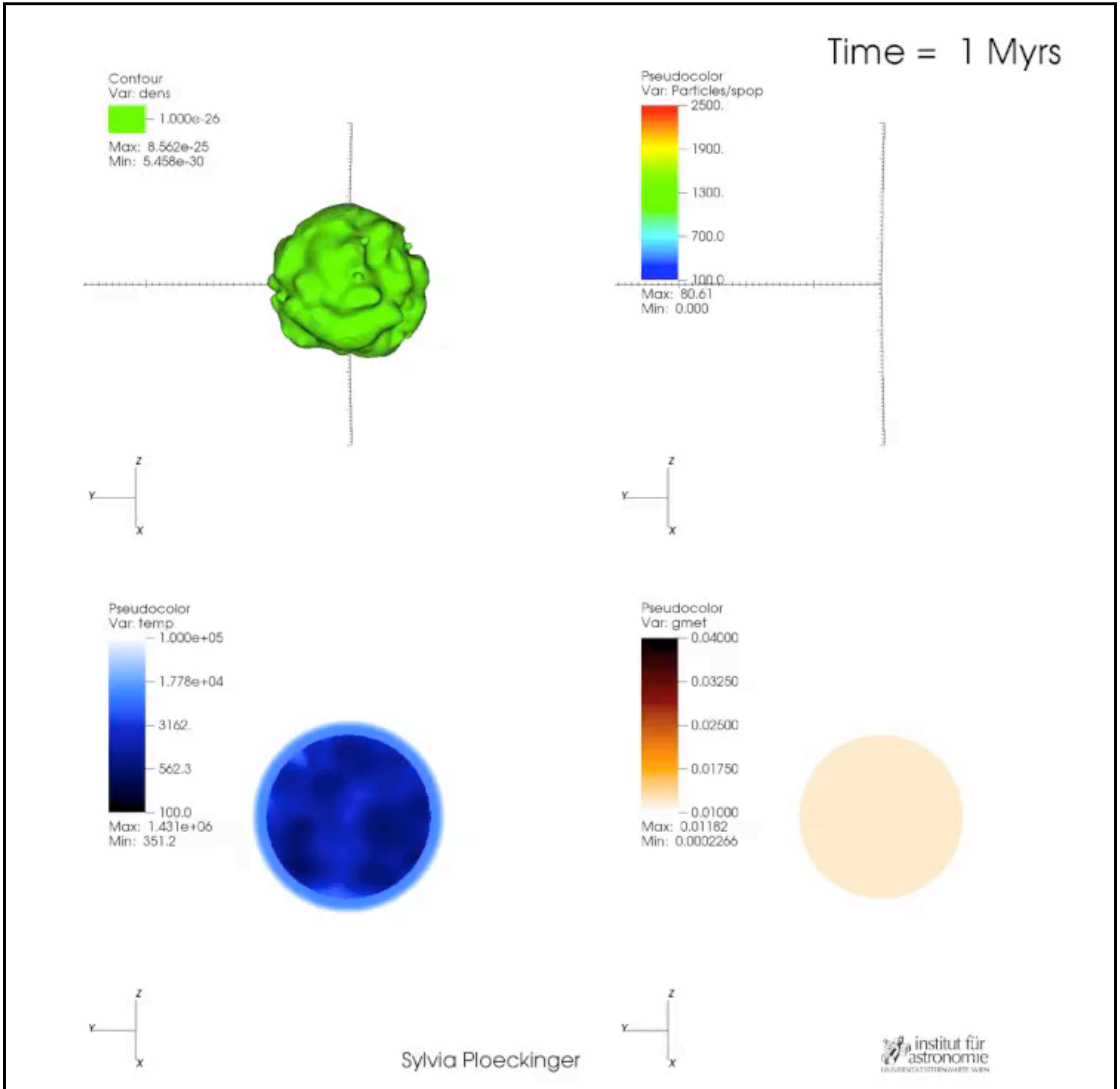
Time = 1 Myrs
Contour
Var: dens
1.000e-26
Max: 8.562e-25
Min: 5.458e-30
Pseudocolor
Var: Particles/spop
2500.
1900.
1300.
700.0
100.0
Max: 80.61
Min: 0.000
Pseudocolor
Var: temp
1.000e+05
1.778e+04
3162.
562.3
100.0
Max: 1.431e+06
Min: 351.2
Pseudocolor
Var: gmet
0.04000
0.03250
0.02500
0.01750
0.01000
Max: 0.01182
Min: 0.0002266
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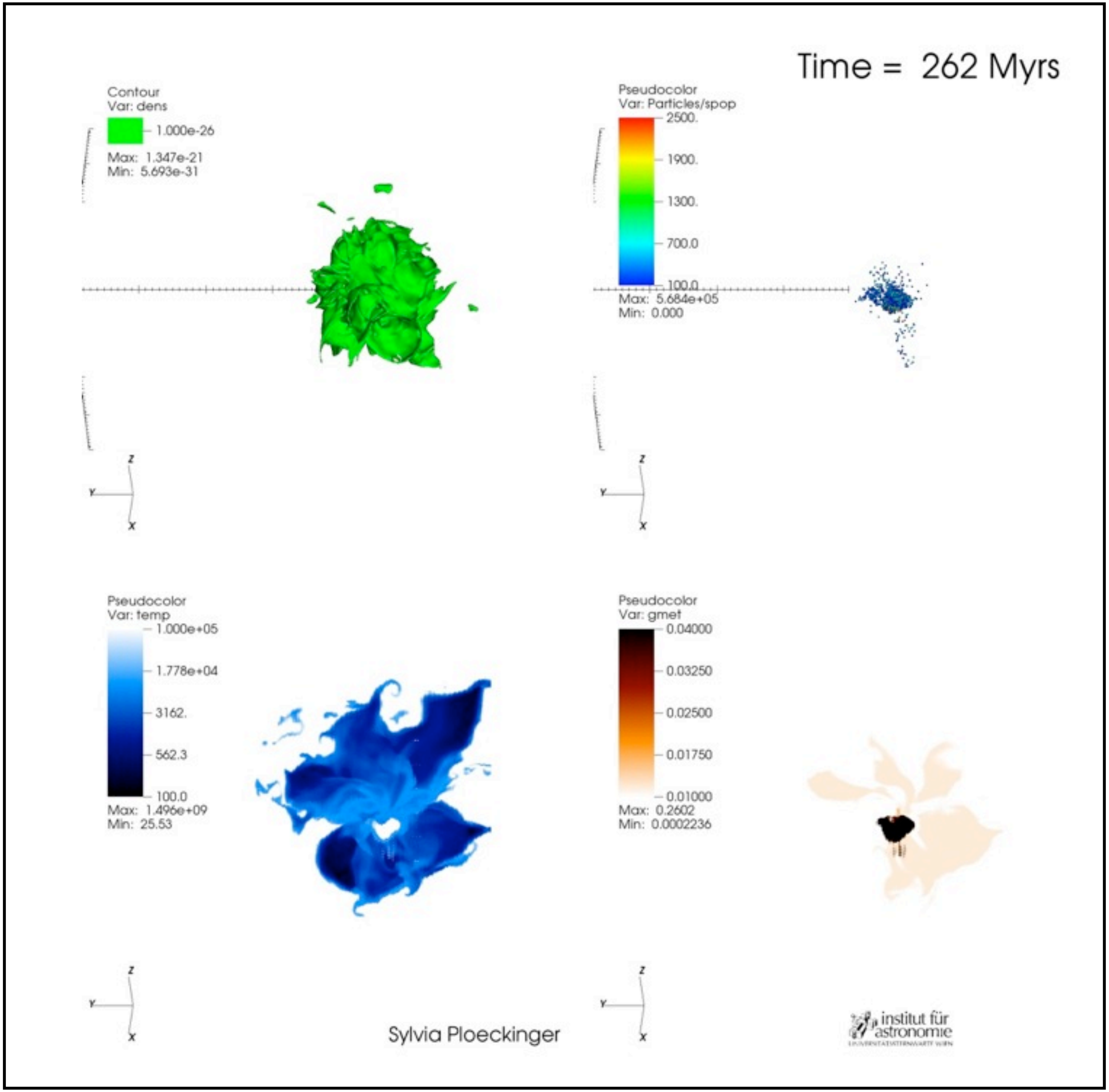
Time = 262 Myrs
Contour
Var: dens
1.000e-26
Max: 1.347e-21
Min: 5.693e-31
Pseudocolor
Var: Particles/spop
2500.
1900.
1300.
700.0
100.0
Max: 5.684e+05
Min: 0.000
Pseudocolor
Var: temp
1.000e+05
1.778e+04
3162.
562.3
100.0
Max: 1.496e+09
Min: 25.53
Pseudocolor
Var: gmet
0.04000
0.03250
0.02500
0.01750
0.01000
Max: 0.2602
Min: 0.0002236
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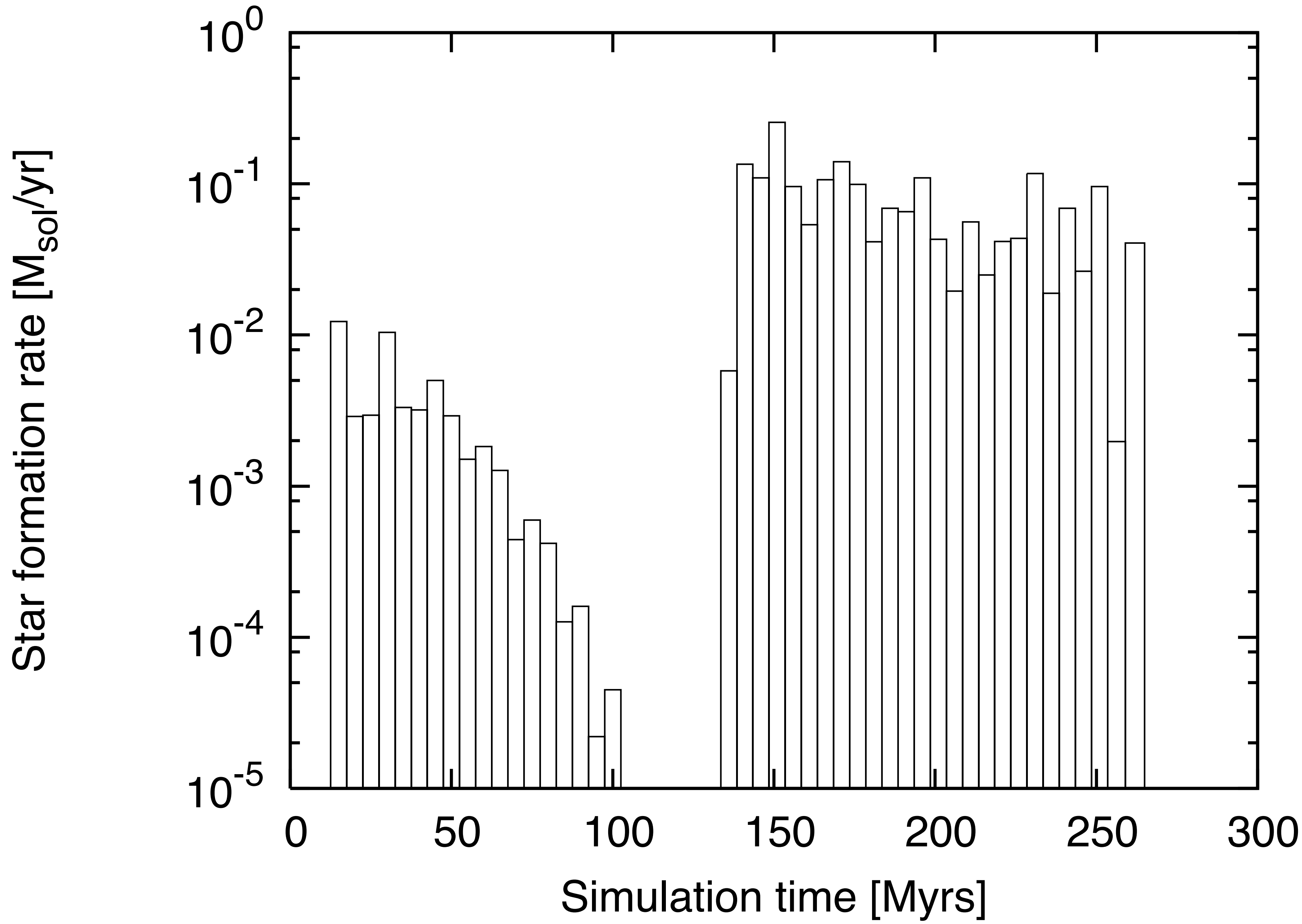
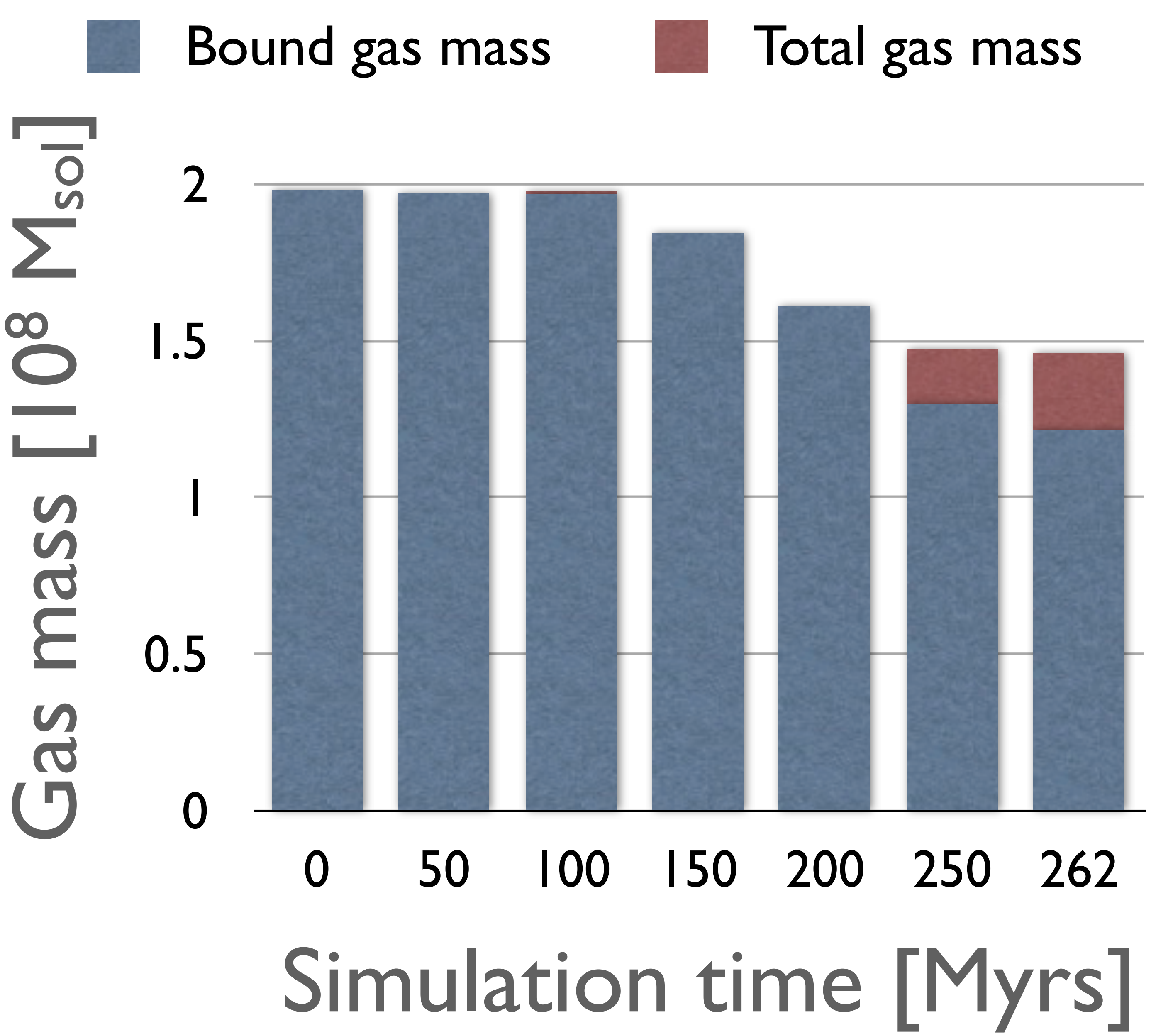
Star formation history



Stability of TDGs



Stellar mass produced in 262 Myrs:

6.1×10^7 M_{sol}

Stellar mass still present at 262 Myrs:

5.2×10^7 M_{sol}

Outlook

- Test the influence of different IMFs
- Different TDG masses (down to SSC range)
- Include initial rotation
- Mass flow
- Already simulation the formation
- Start at high z

Thank you for your attention!

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