Supernova Feedback and Galaxy Formation

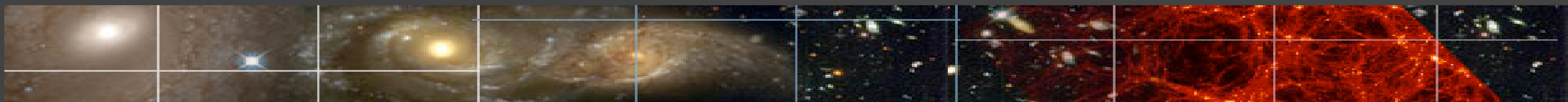
Cecilia Scannapieco & Patricia B. Tissera

Institute for Astronomy and Space Physics, Argentina

&

Simon White & Volker Springel

Max-Planck Institute for Astrophysics, Germany



The study of the Formation and Evolution of Galaxies requires to be able to follow the evolution on the structure in large scale, which is mainly determined by **gravitation,** and to describe the action of other processes such as **gas cooling, star formation, stellar evolution**, etc.

↓

- Smooth Particle Hydrodynamics simulations are one of the most popular techniques to study galaxy formation.

- Radiative cooling → gas cools down and forms cold and dense clumps
- Star formation → cold and dense clumps are transformed into stars
- SN feedback → regulate star formation, IGM enrichment, etc.
  → different implementation have been proposed.

↓

SN Feedback model within Gadget2

Patricia B. Tissera

Astrofísica Numérica

Multiphase Medium Problem:

Nearby gaseous clouds with very different densities are smoothed.

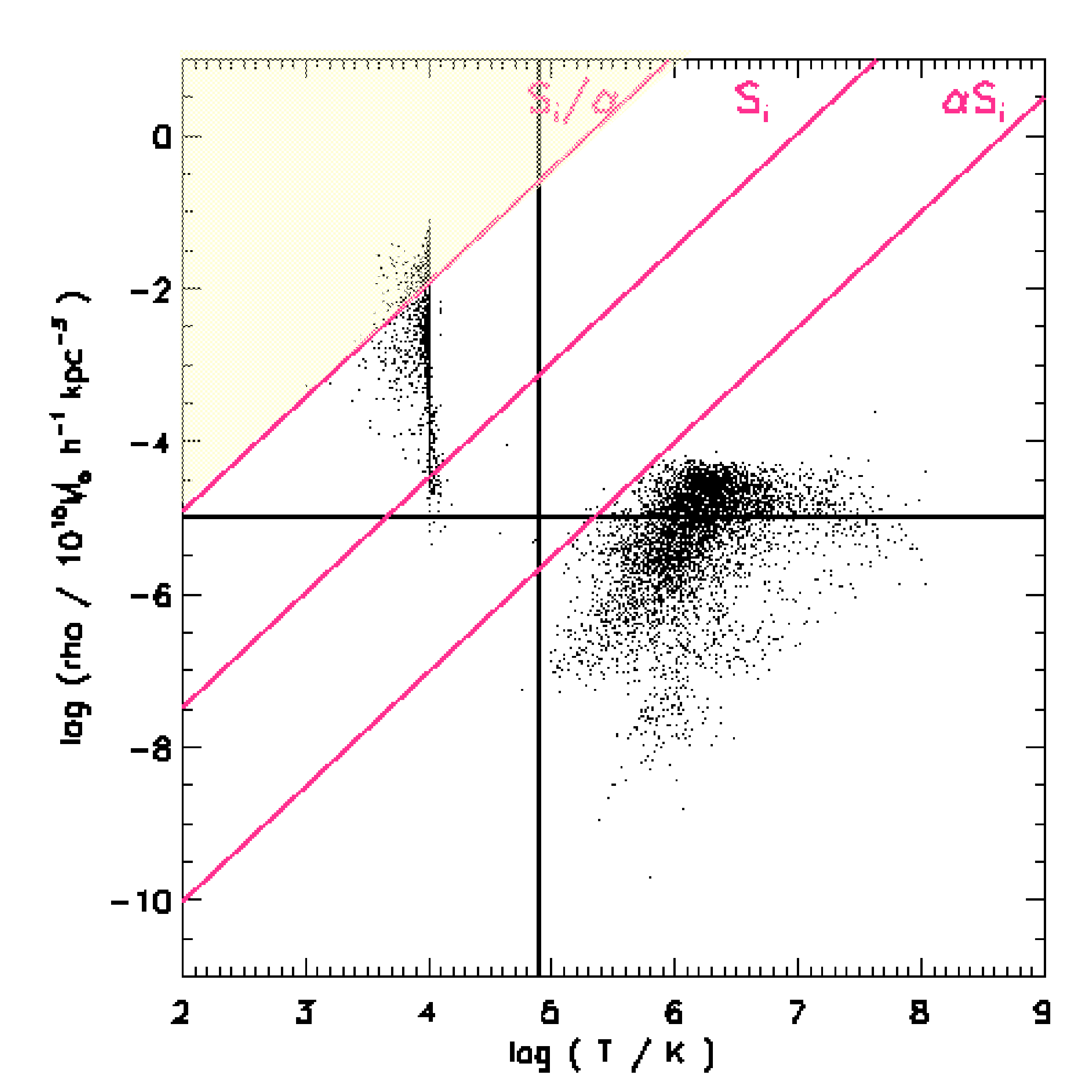
- works against the coexistence of cold clumps and hot gas.
- artificially boost the cooling rate of hot gas close to dense cold media (e.g. Shapiro et al. 1996; Ritchie & Thomas 2000; Springel & Hernquist 2002)

Our approach is based on Pearce et al. (1999, 2001) and Marri & White (2003).

Decoupling Model:

- hot gas is prevented to interact with colder material.
- particle j decouples from those particles i if $S_i > \alpha S_j$, where S is the entropy of a gas particle.
- non shock

Patricia B. Tissera



Patricia B. Tissera

Astrofísica Numérica

Isolated Disc Galaxy Test

Idealized Initial Conditions:

- **A spherical grid with superposed dark matter and gaseous particles is perturbed giving rise to a $\rho \sim r^{-1}$ profile.**
- **The sphere is initially in solid body rotation with angular momentum characterized by a spin parameter of $\lambda \approx 0.1$.**
- **Both the gas and the dark matter components are resolved with 9000 particles.**
- **The tests correspond to a 10^{12} M_o h^{-1} (h=0.7) system with 10% of baryonic mass.**

Fraction of gas in the different media defined as:

HOT GAS: $T \geq 8 \times 10^4$ K

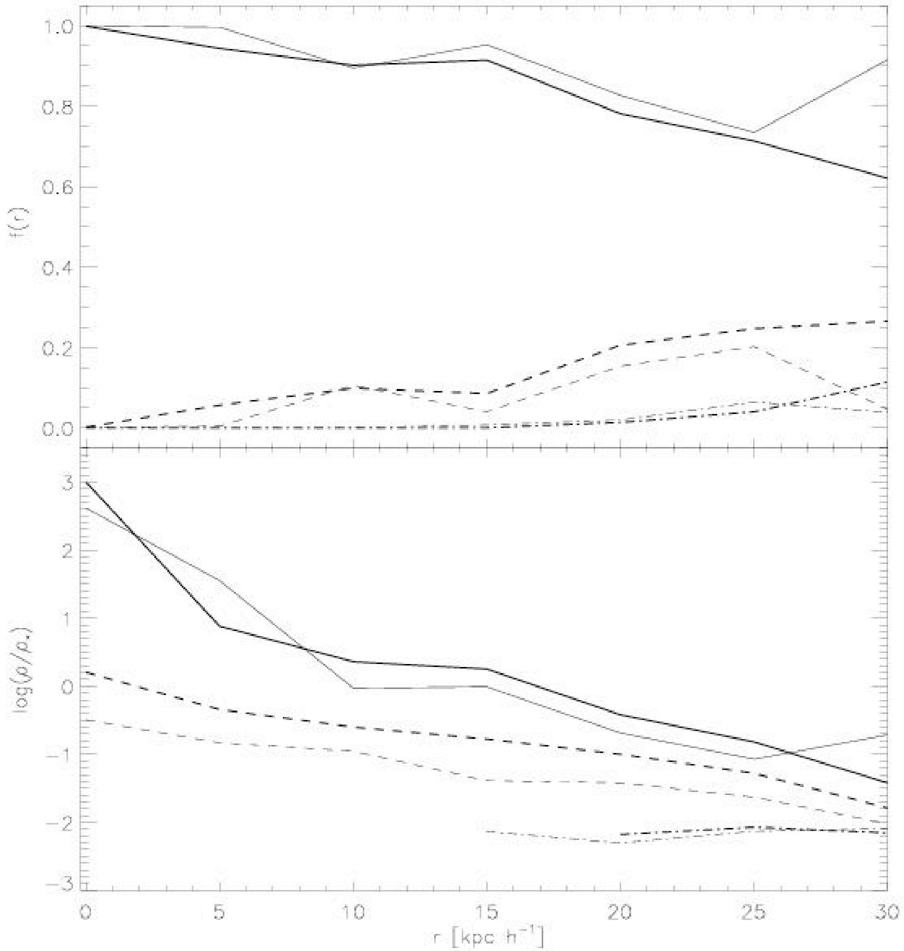
WARM GAS: $T < 8 \times 10^4$ K and $\rho < 0.1\, \rho_*$

COLD GAS: $T < 8 \times 10^4$ K and $\rho \geq 0.1\, \rho_*$

Patricia B. Tissera

Astrofísica Numérica

The Decoupling Scheme



Patricia B. Tissera

Supernova Feedback Model

- mimics the effects without introducing scale-dependent parameters
- is coupled to the decoupling medium.
- is able to transport cold gas and enriched material from the star forming regions into the halo.

Supernova Feedback:

Chemical Feedback & Energy Feedback

The Chemical Feedback

The chemical model is based on the work of Mosconi et al. (2001).

Chemical Production

Metal Ejection

Metal-dependent Cooling Rates

Patricia B. Tissera

Energy Feedback

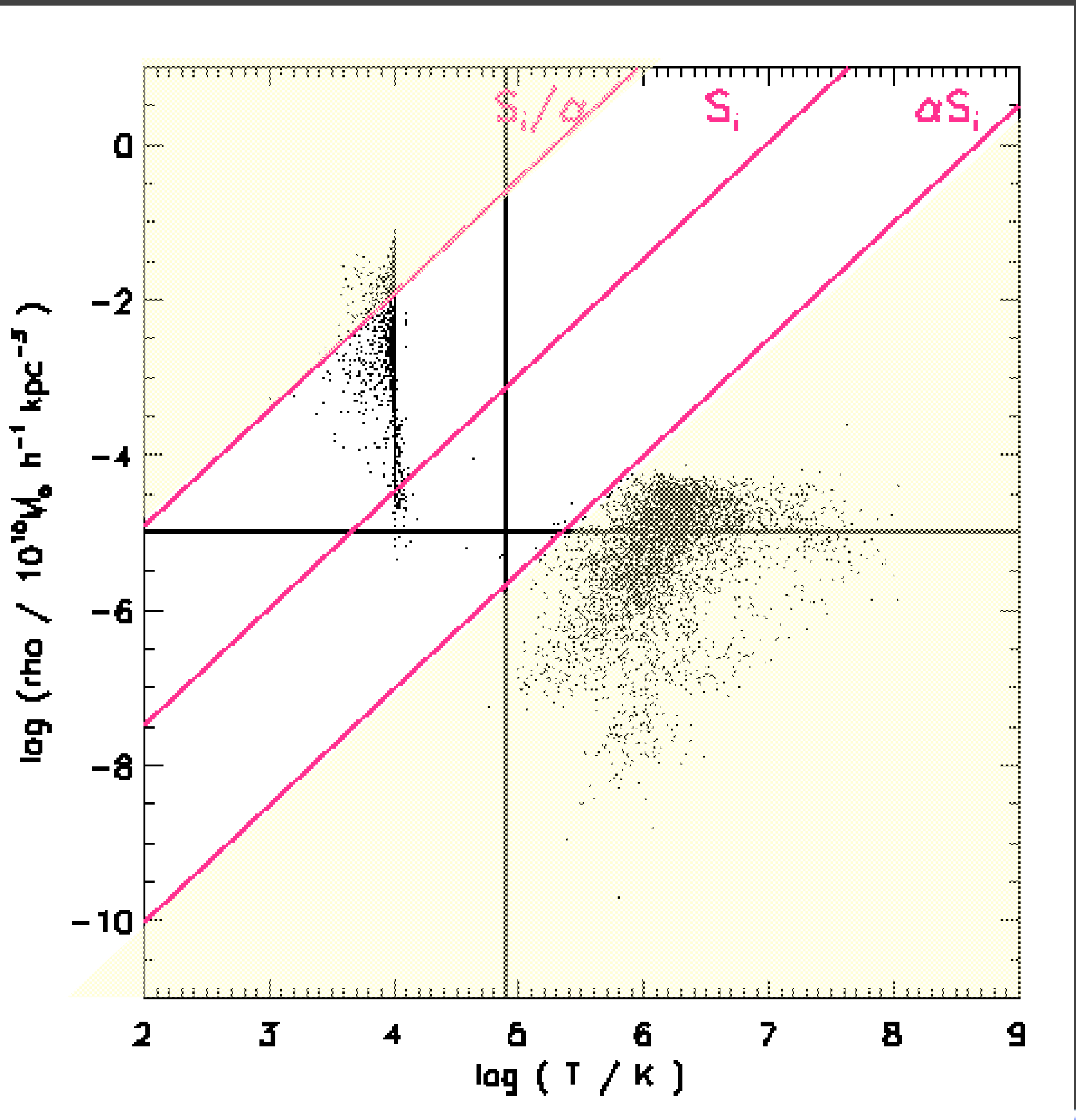
- SN energy (10^{51} ergs per SN) released by a *star particle* is distributed within its gaseous neighbours.
- The Cold-Diffuse neighbours of a *star particle*:

  $T < 8 \times 10^4$ K and $\rho > 0.1\ \rho^*$

  f_{cold} → cold and dense neighbours

  $1-f_{cold}$ → diffuse neighbours

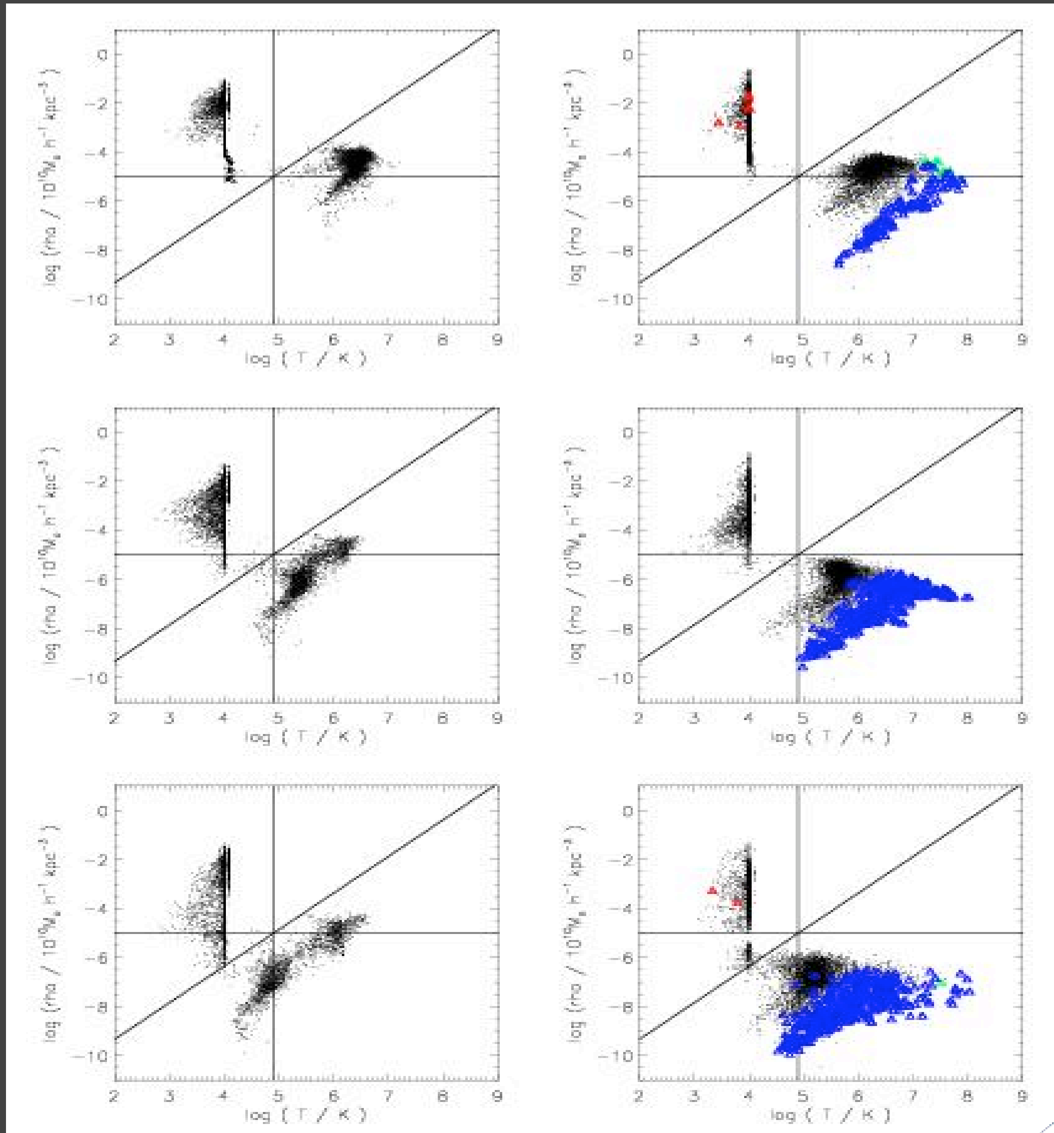
- Diffuse neighbours thermalize the energy "instantaneously".
- Cold neighbours accumulates it in a Reservoir until it is high enough to ensure that the *gas particle* will join "its own hot phase" according to the decoupling scheme → Promoted particles.



Patricia B. Tissera

Astrofísica Numérica

Energy Feedback: Promotion



Patricia B. Tissera

Astrofísica Numérica

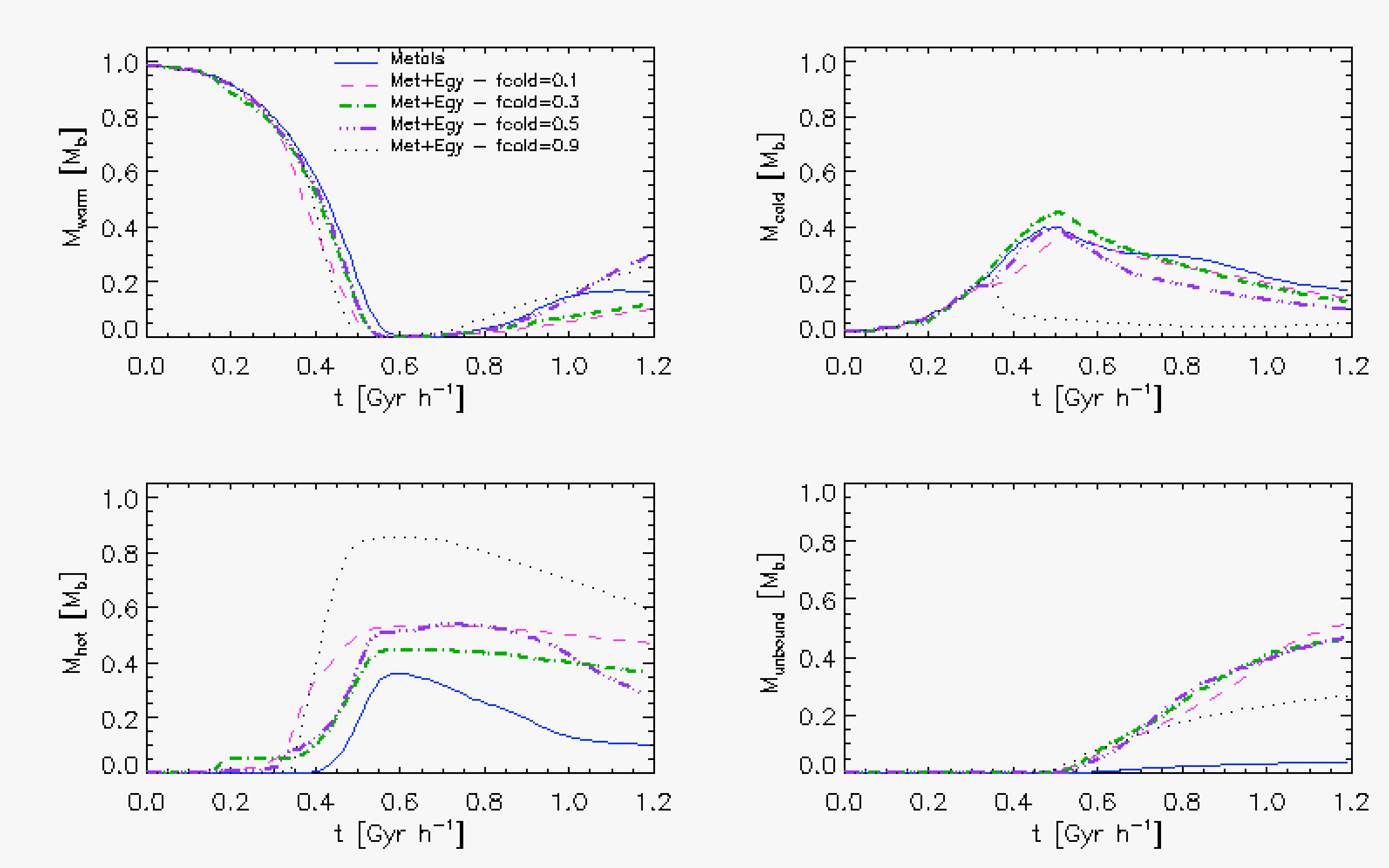
Energy Feedback

- SN energy (10^{51} ergs) released by a star particle is distributed within its gaseous neighbours.
- The Cold/Diffuse neighbours of a star particle:
  $T < 8 \times 10^4$ K and $\rho > 0.1\ \rho^*$

  f_{cold} → cold and dense neighbours
  $1\text{-}f_{cold}$ → diffuse neighbours

- Diffuse neighbours thermalize the energy "instantaneously".
- Cold neighbours accumulates it in a Reservoir until it is high enough to ensure that the gas particle will join "its own hot phase" according to the decoupling scheme → Promoted particles.

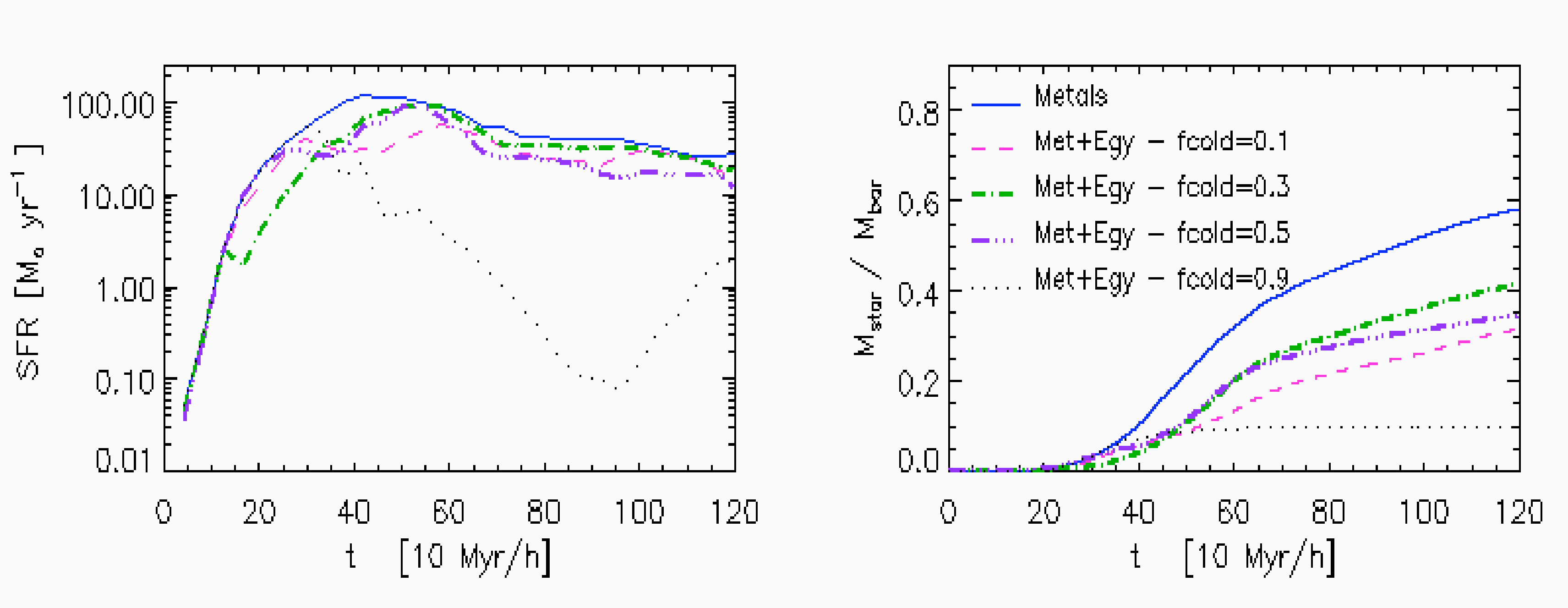
Feedback: varying Fcold ….



HOT GAS: T ≥ 8 x 10^4 K WARM GAS: T < 8 x 10^4 K and ρ < 0.1 ρ_*

COLD GAS: T < 8 x 10^4 K and ρ ≥ 0.1 ρ_*

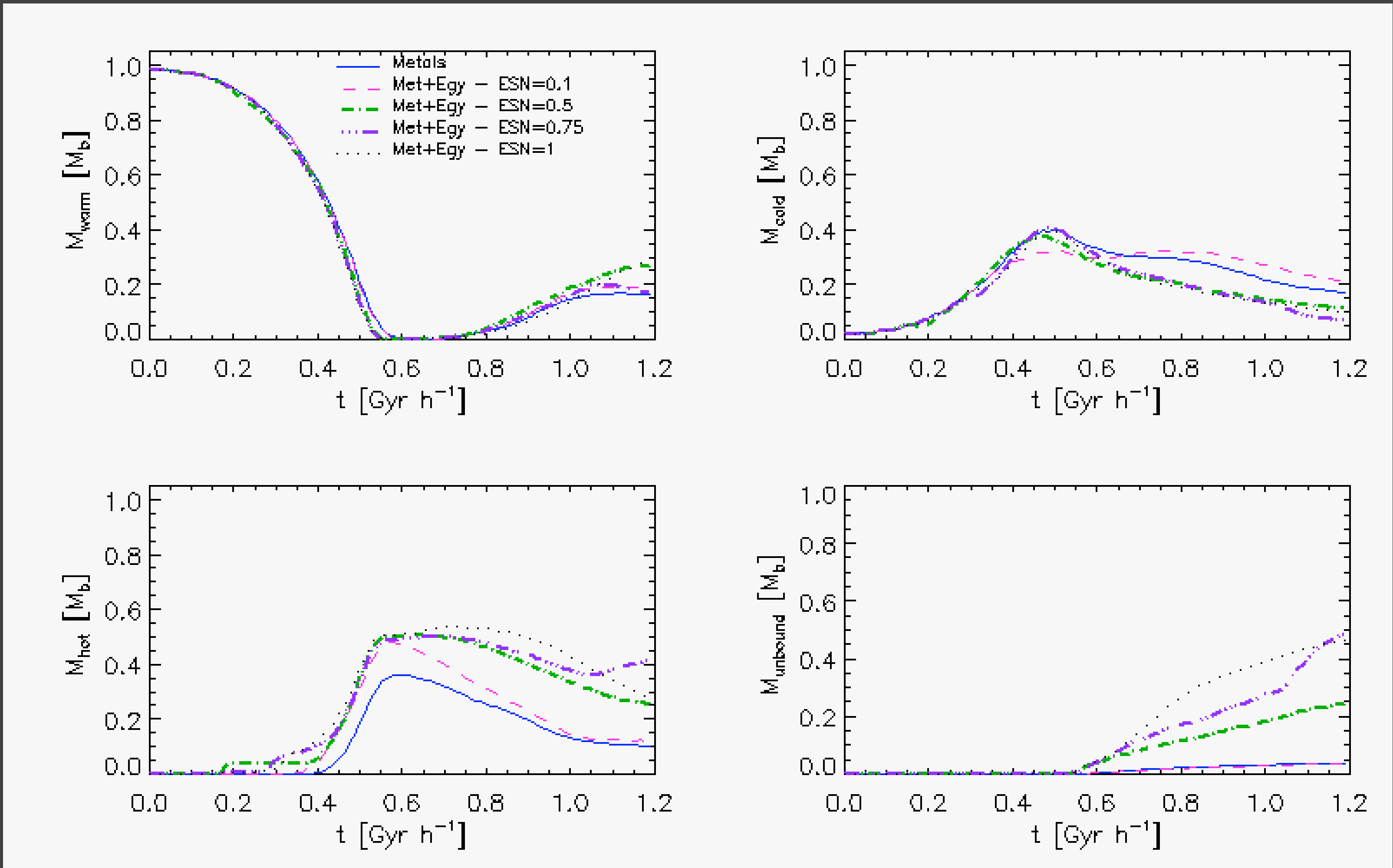
Feedback: varying Fcold ….



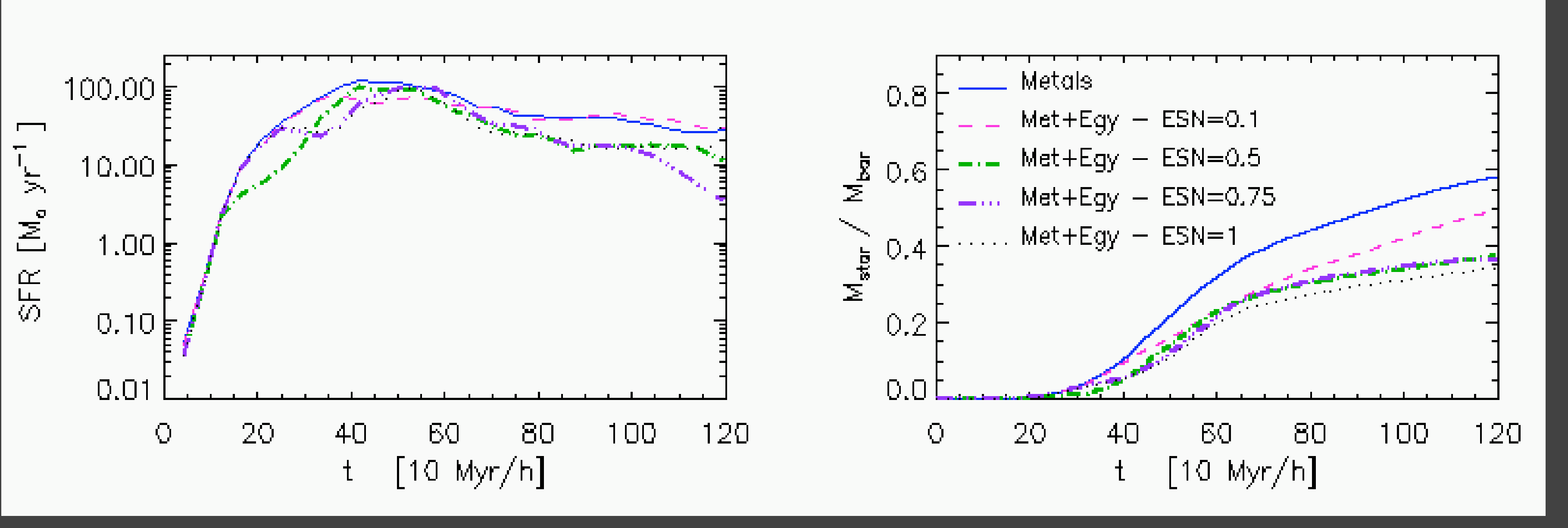
HOT GAS: $T \geq 8 \times 10^4$ K WARM GAS: $T < 8 \times 10^4$ K and $\rho < 0.1\ \rho_*$

COLD GAS: $T < 8 \times 10^4$ K and $\rho \geq 0.1\ \rho_*$

Feedback: varying ESN ….



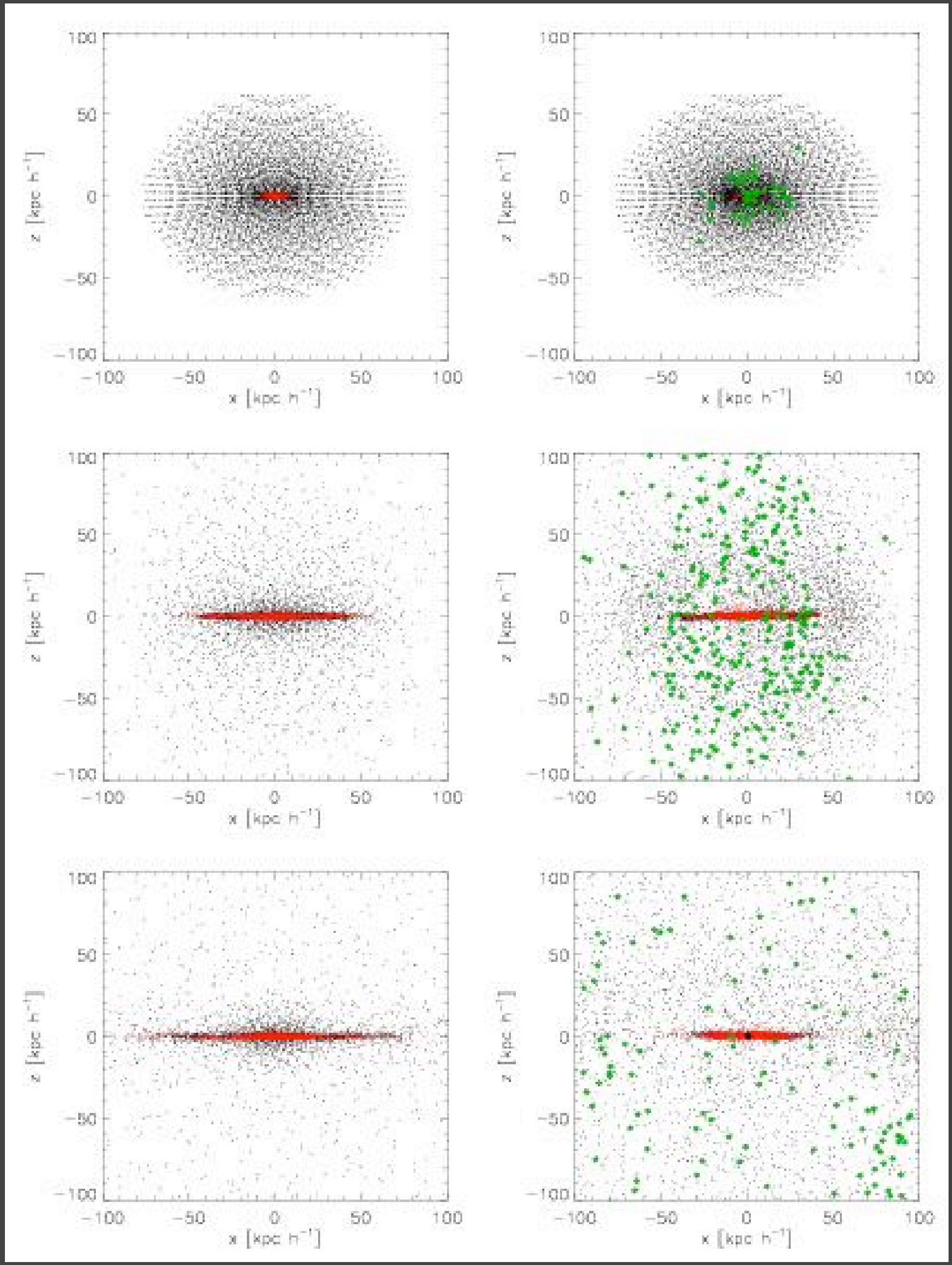
Feedback: varying ESN ….

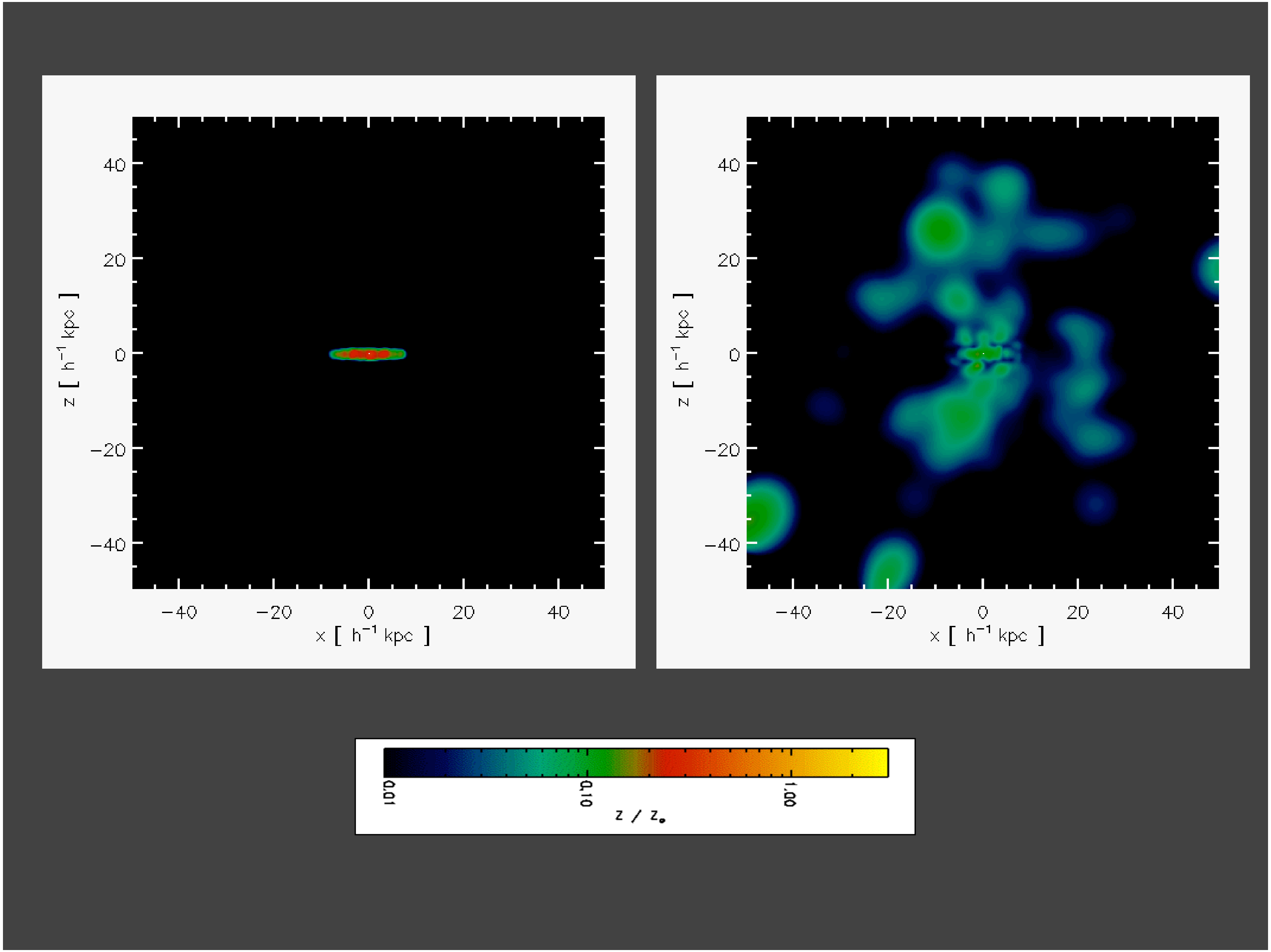


Promoted Particles transport material from the cold and dense central clump into the halo.

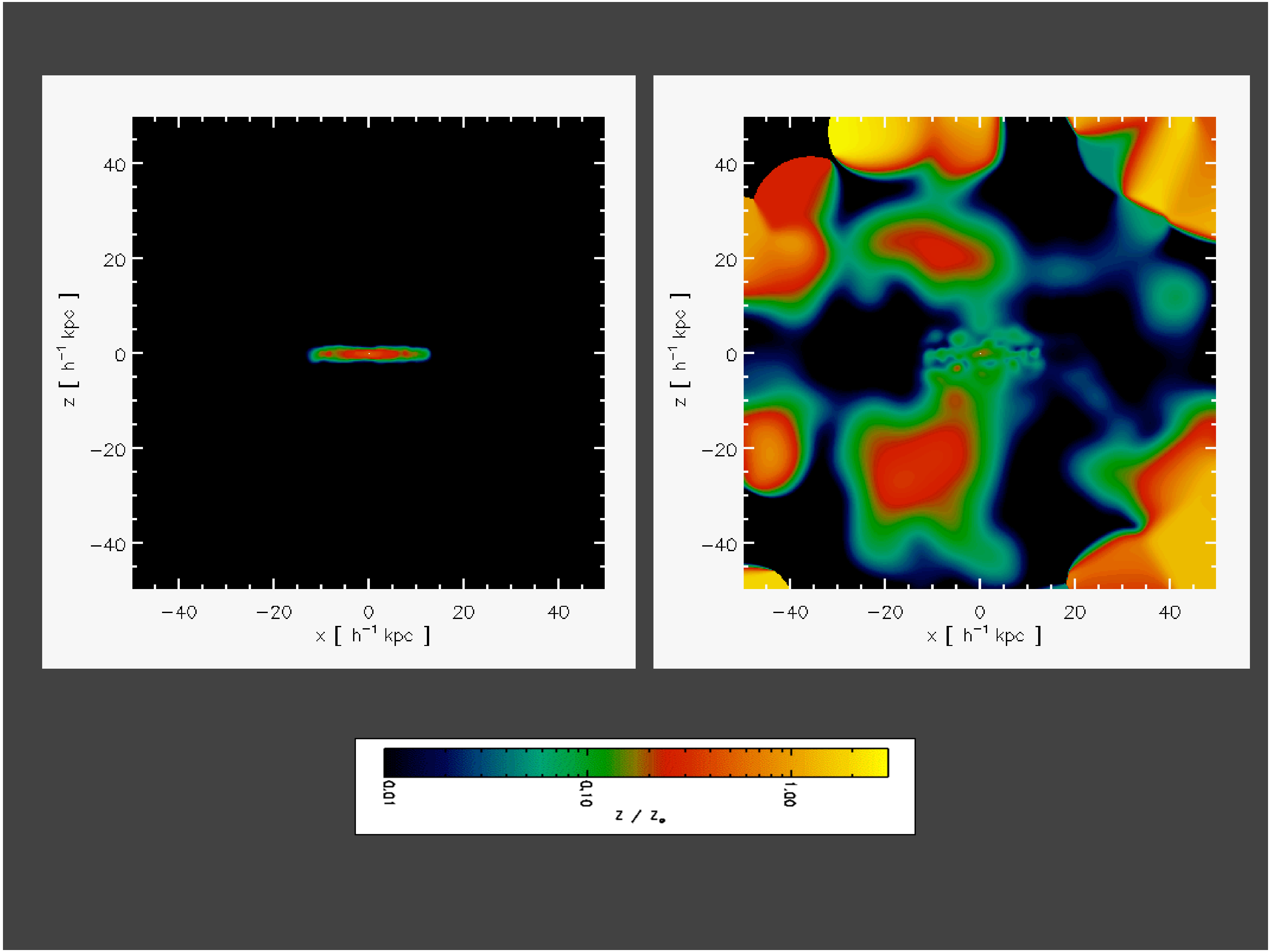
Chemical elements are transported by the Promoted Particles.

Depending on the fcold used, the chemical abundances of the multiphase medium and the stars will change.

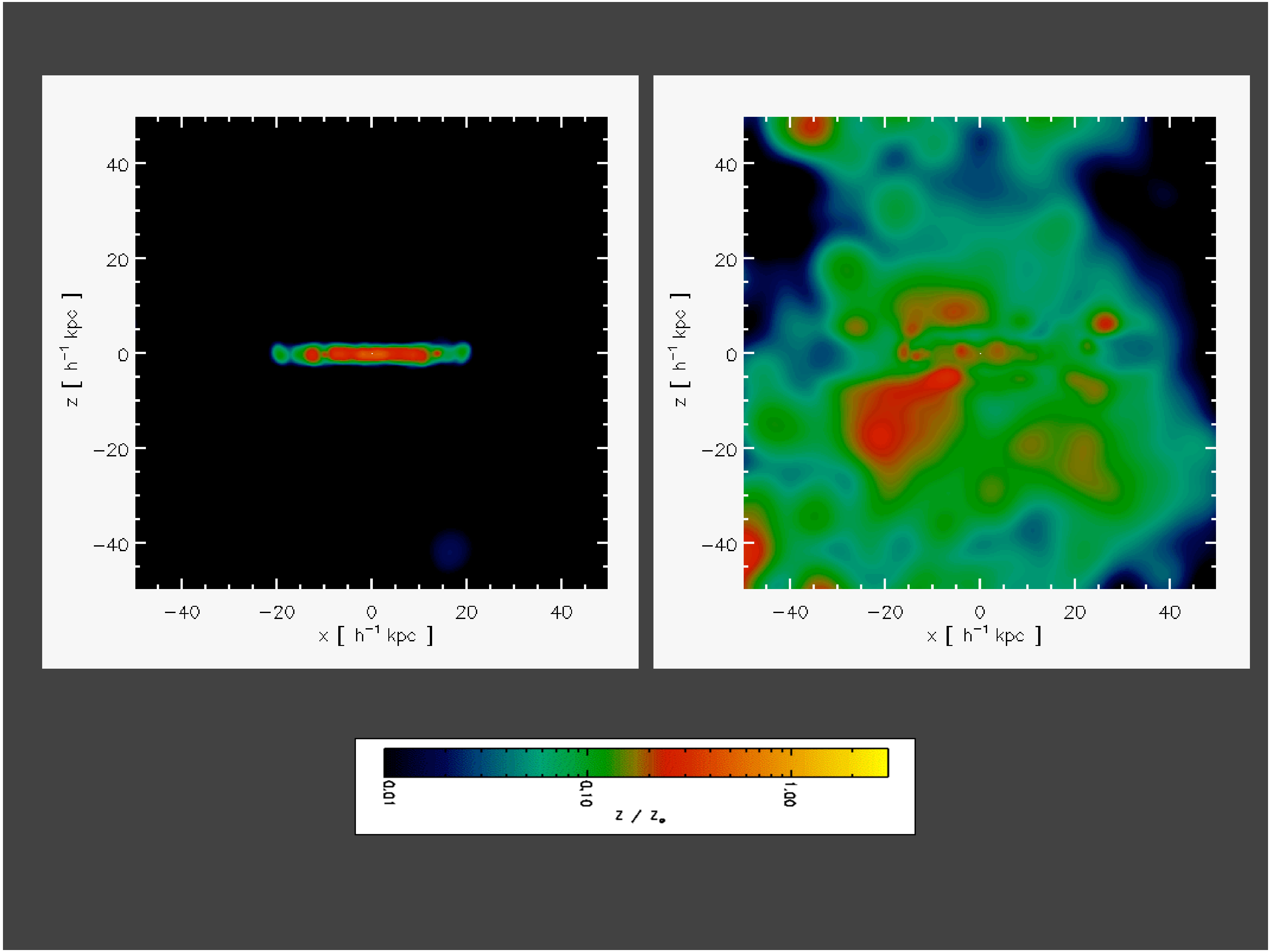


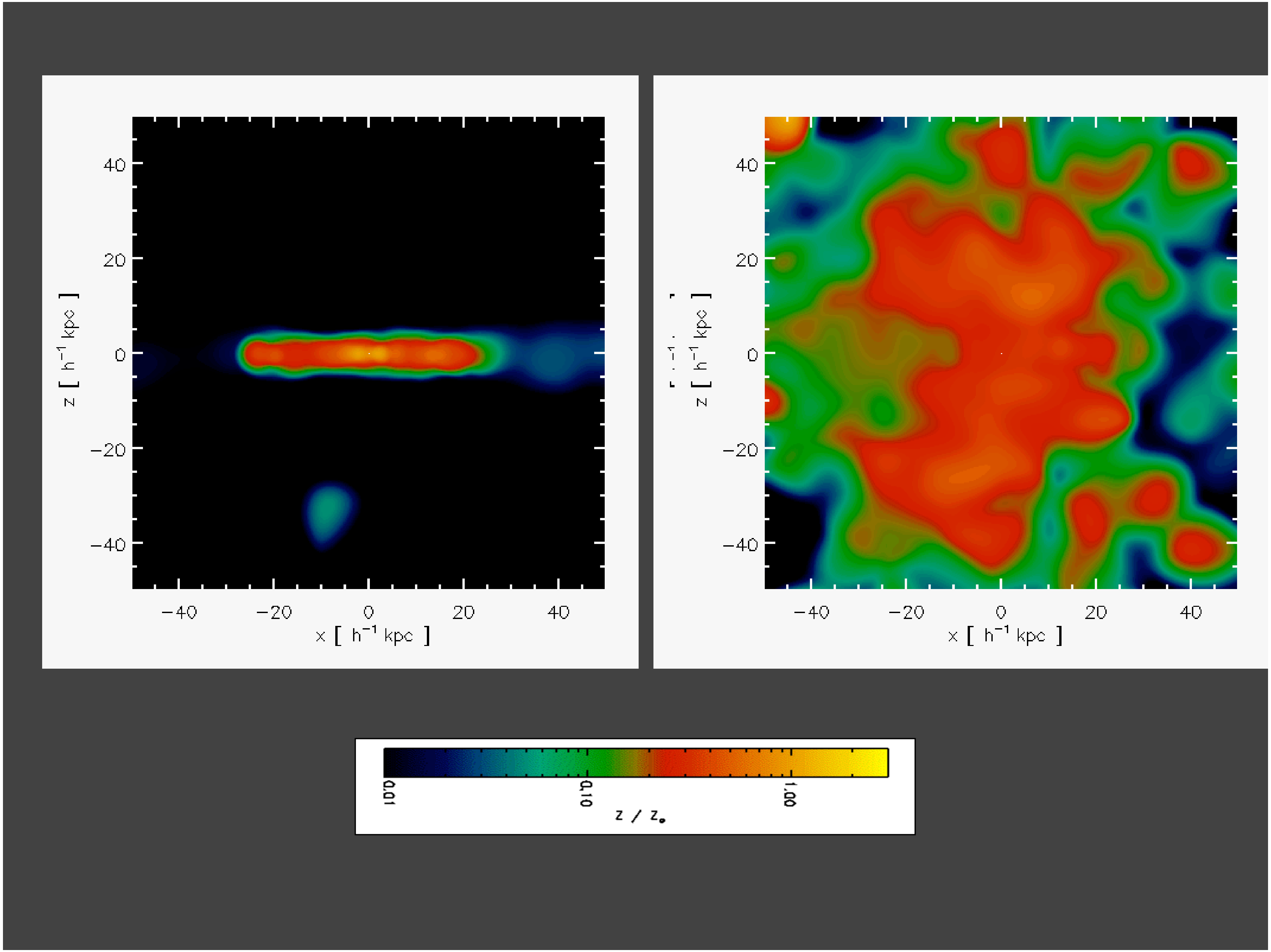


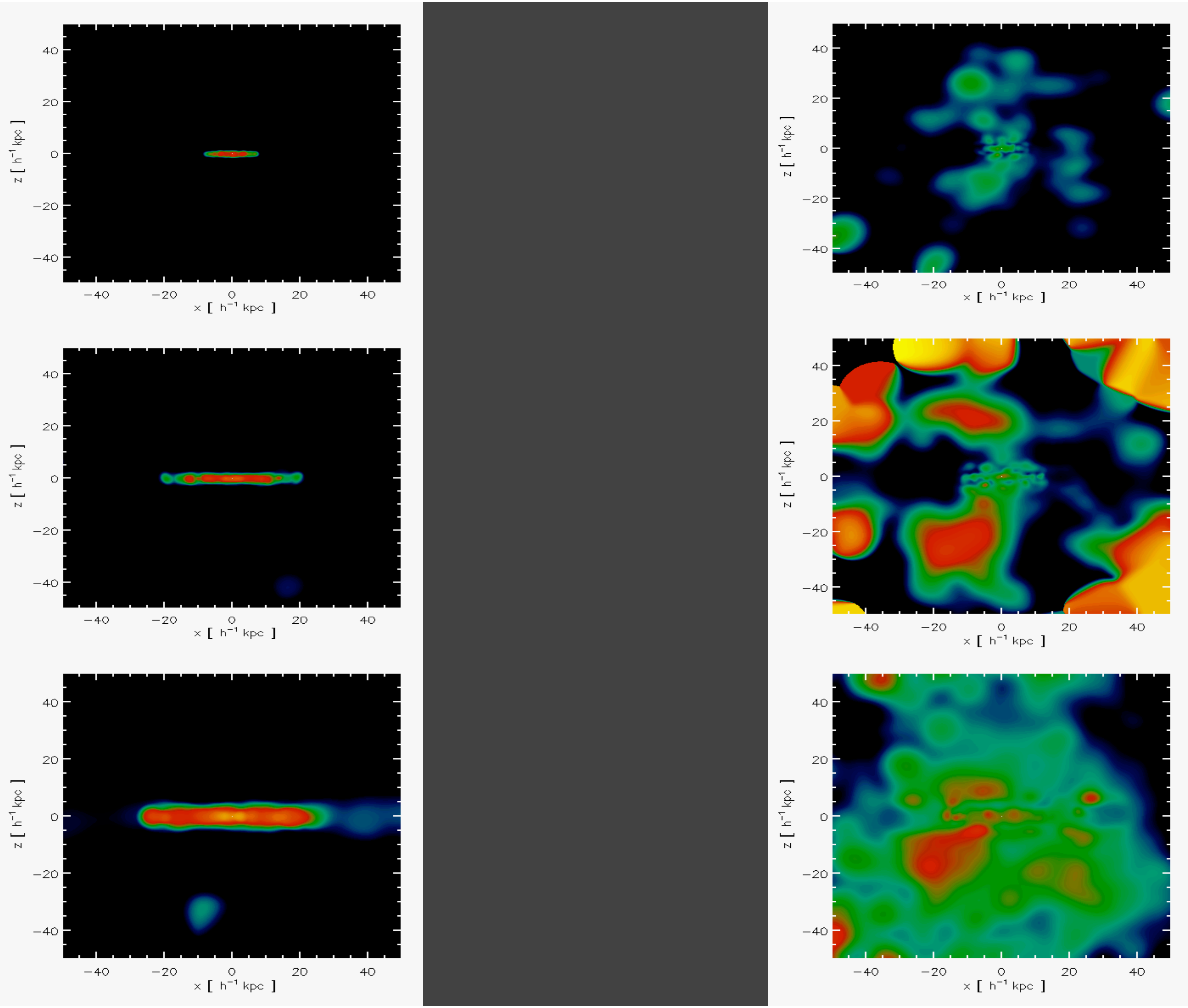
z [h⁻¹ kpc]
x [h⁻¹ kpc]
z / z☉



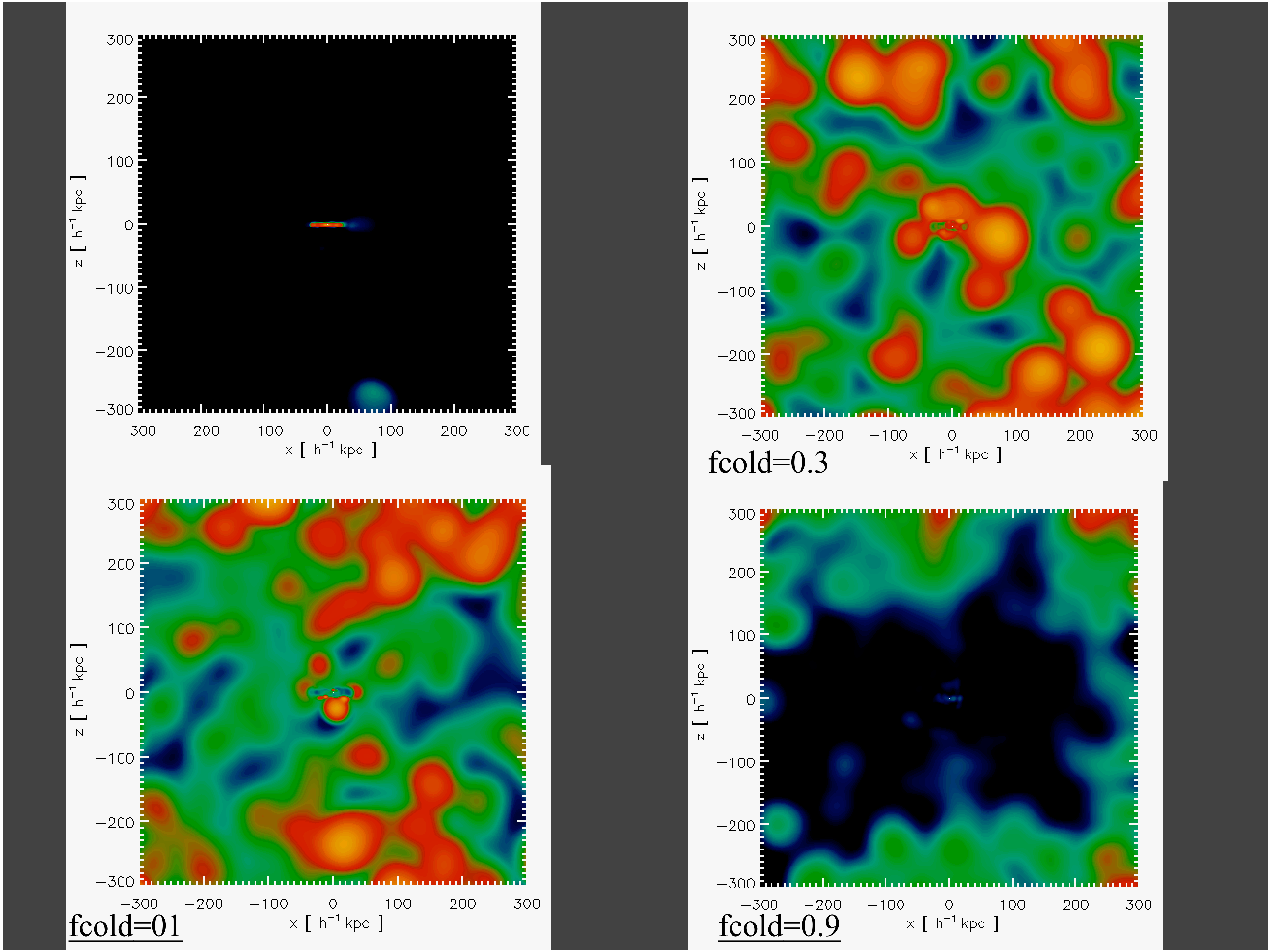
40
20
0
−20
−40
z [h^{-1} kpc]
x [h^{-1} kpc]
0.01
0.10
1.00
Z / Z$_\odot$


40
20
0
−20
−40
z [h^−1 kpc]
x [h^−1 kpc]
0.01
0.10
1.00
Z / Z⊙


z [h⁻¹ kpc]
x [h⁻¹ kpc]
−40 −20 0 20 40
0.01
0.10
1.00
Z / Z⊙

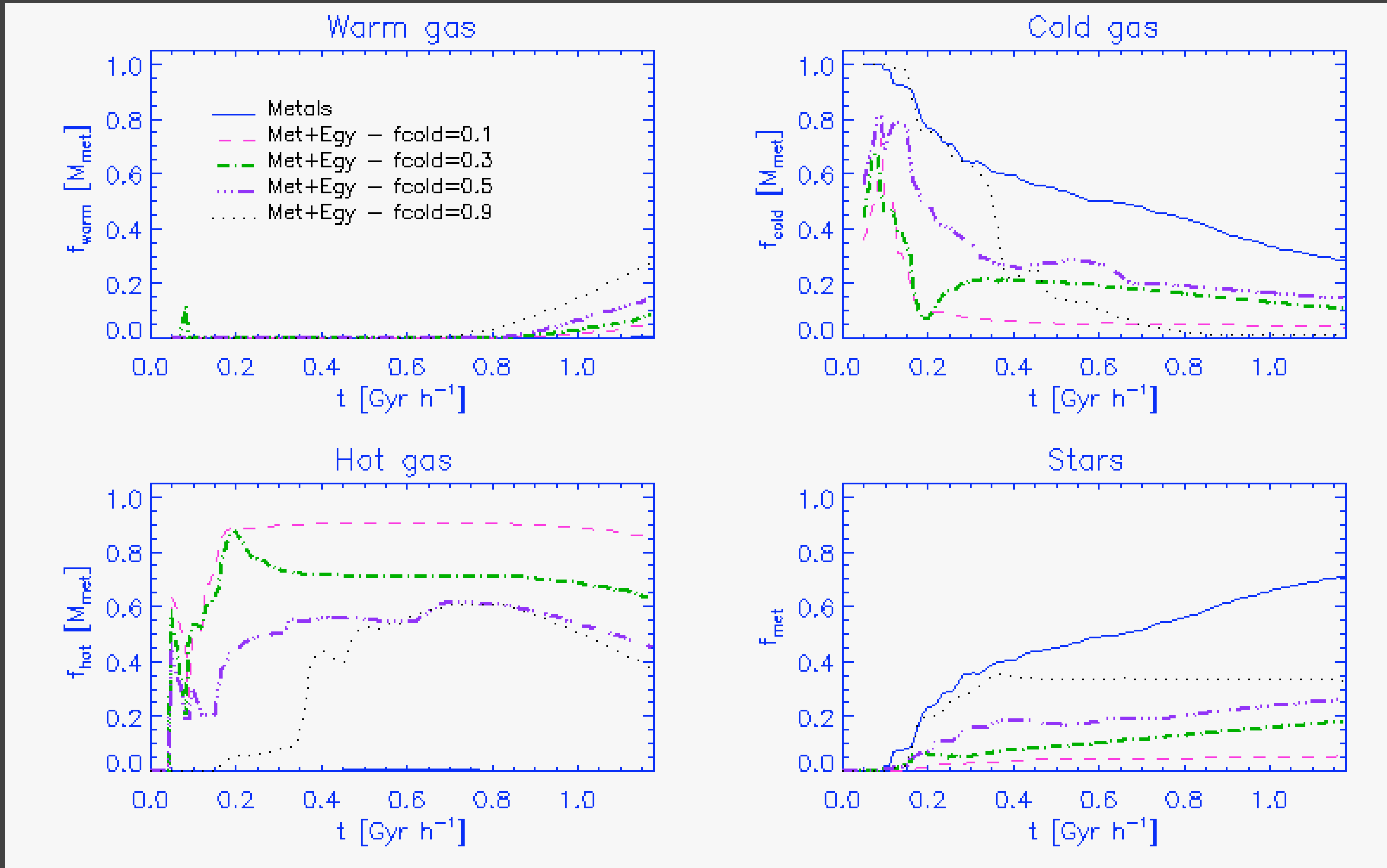


40
20
0
−20
−40
z [h−1 kpc]
−40
−20
0
20
40
x [h−1 kpc]



fcold=0.3
fcold=01
fcold=0.9
x [h^{-1} kpc]
z [h^{-1} kpc]

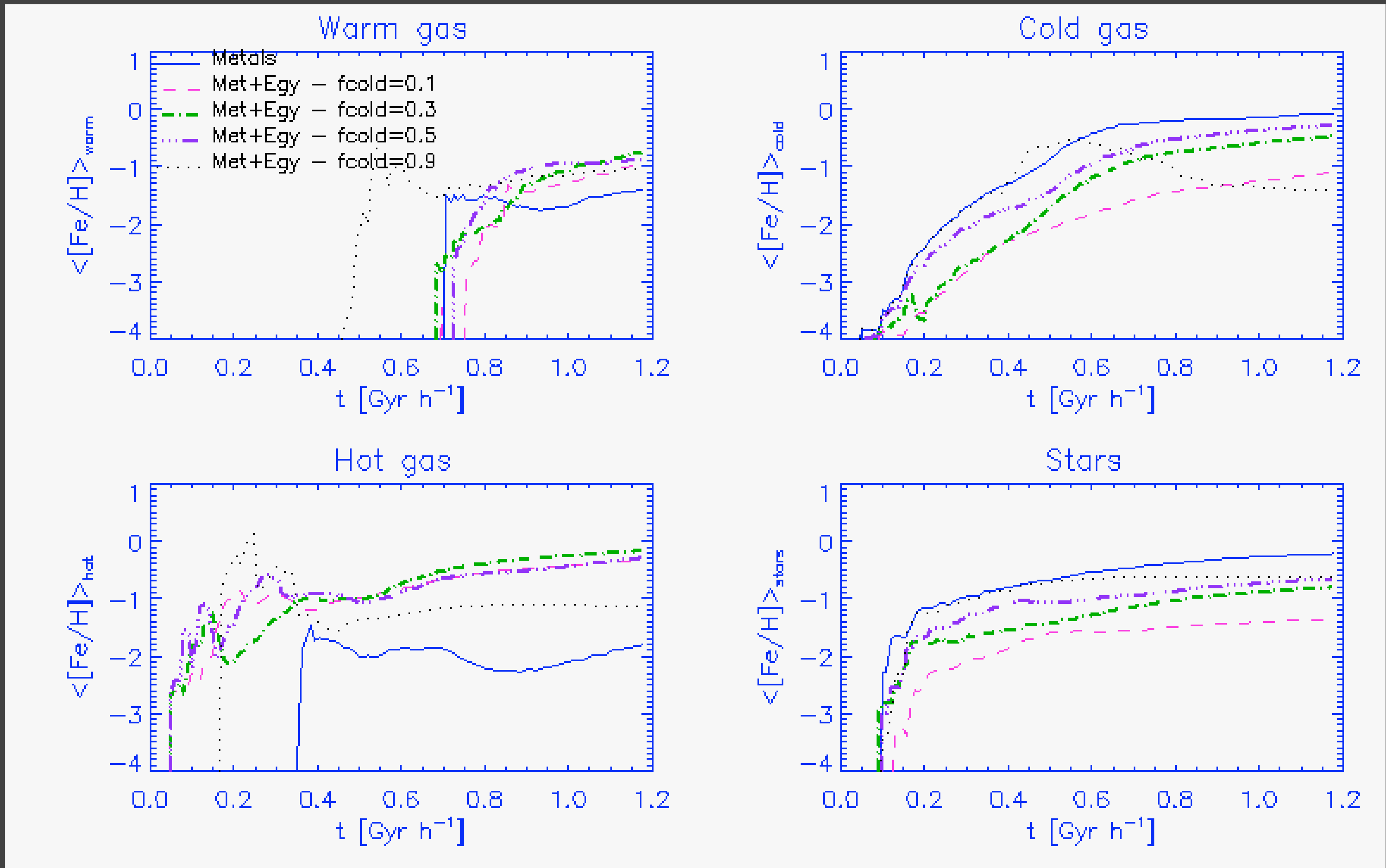
Feedback: abundances



HOT GAS: T ≥ 8 x 10^4 K WARM GAS: T < 8 x 10^4 K and ρ < 0.1 ρ_*

COLD GAS: T < 8 x 10^4 K and ρ ≥ 0.1 ρ_*

Feedback: abundances



HOT GAS: T ≥ 8 x 10^4 K WARM GAS: T < 8 x 10^4 K and ρ < 0.1 ρ_*

COLD GAS: T < 8 x 10^4 K and ρ ≥ 0.1 ρ_*

Conclusions:

- this SN model is able to transport cold, dense and enriched material into the halo.
- the star formation is regulated by ejection of SN energy.
- it has only one main free parameter.

Future work:

Simulate a Milky-Way type galaxy in order to adjust the model.

Chemical Production

Numerical space	Physical space	Need
Star particles ↔	Stellar populations	IMF (Salpeter):

SNe

long-lived stars

Type II Sne

- Produce most chemical elements (WW95)
- Typical life-times: ~ 10^6 yr

Type Ia Sne

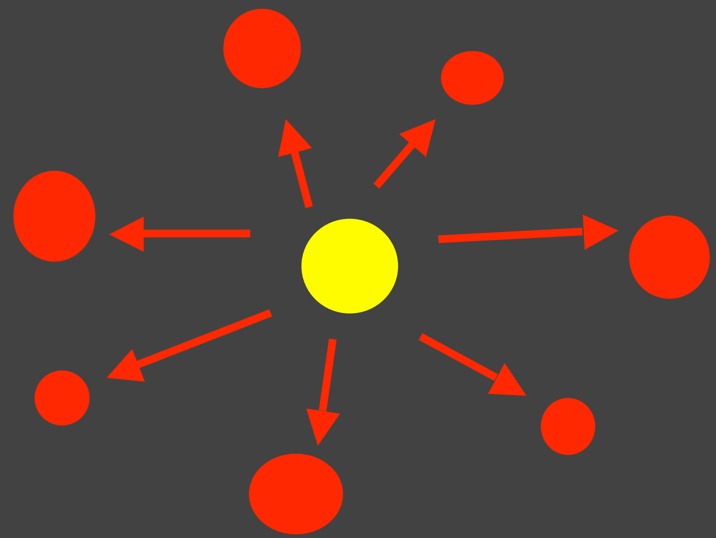
- Main source of iron (Fe)
- Typical life-times: ~ Gyr

Metal Ejection

When SN explosions take place, they distribute metals according to the SPH technique:

Exploding star particle

Gaseous neighbours



Patricia B. Tissera

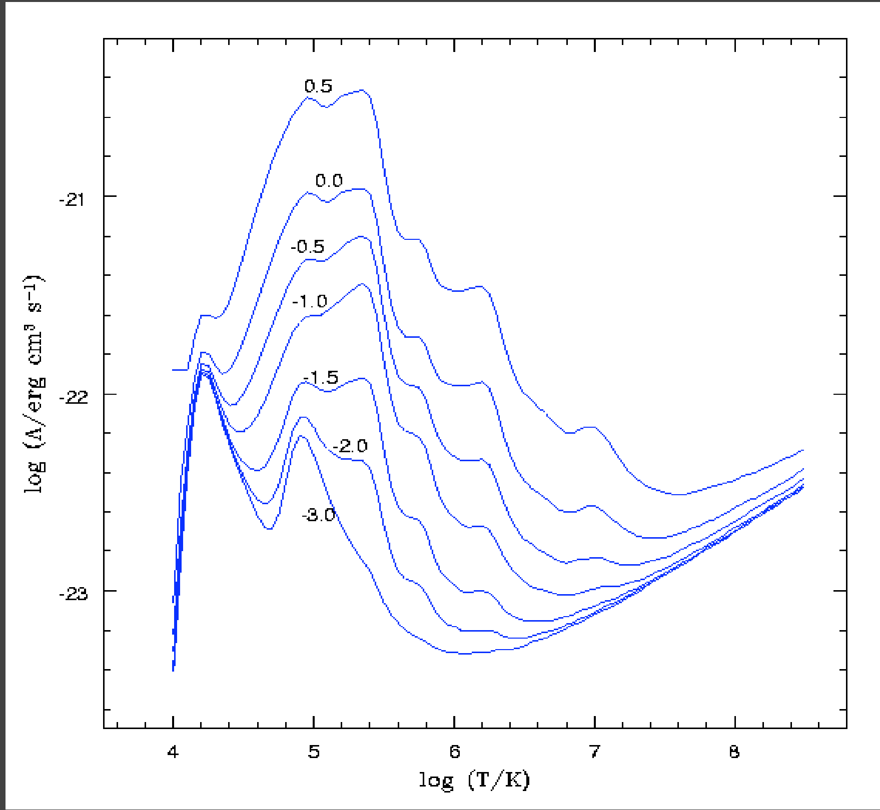
Astrofísica Numérica

Metal Dependent Cooling Rates

We use the model of Sutherland & Dopita (1993).

At T= 4 X 10^4 and ρ= ρ*:

τcool for primordial gas is 50 larger than that of [Fe/H]=0.5 gas.



Astrofísica Numérica