Feedback vs cold flows

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Cosmological hydrodynamic simulations of galaxy formation.

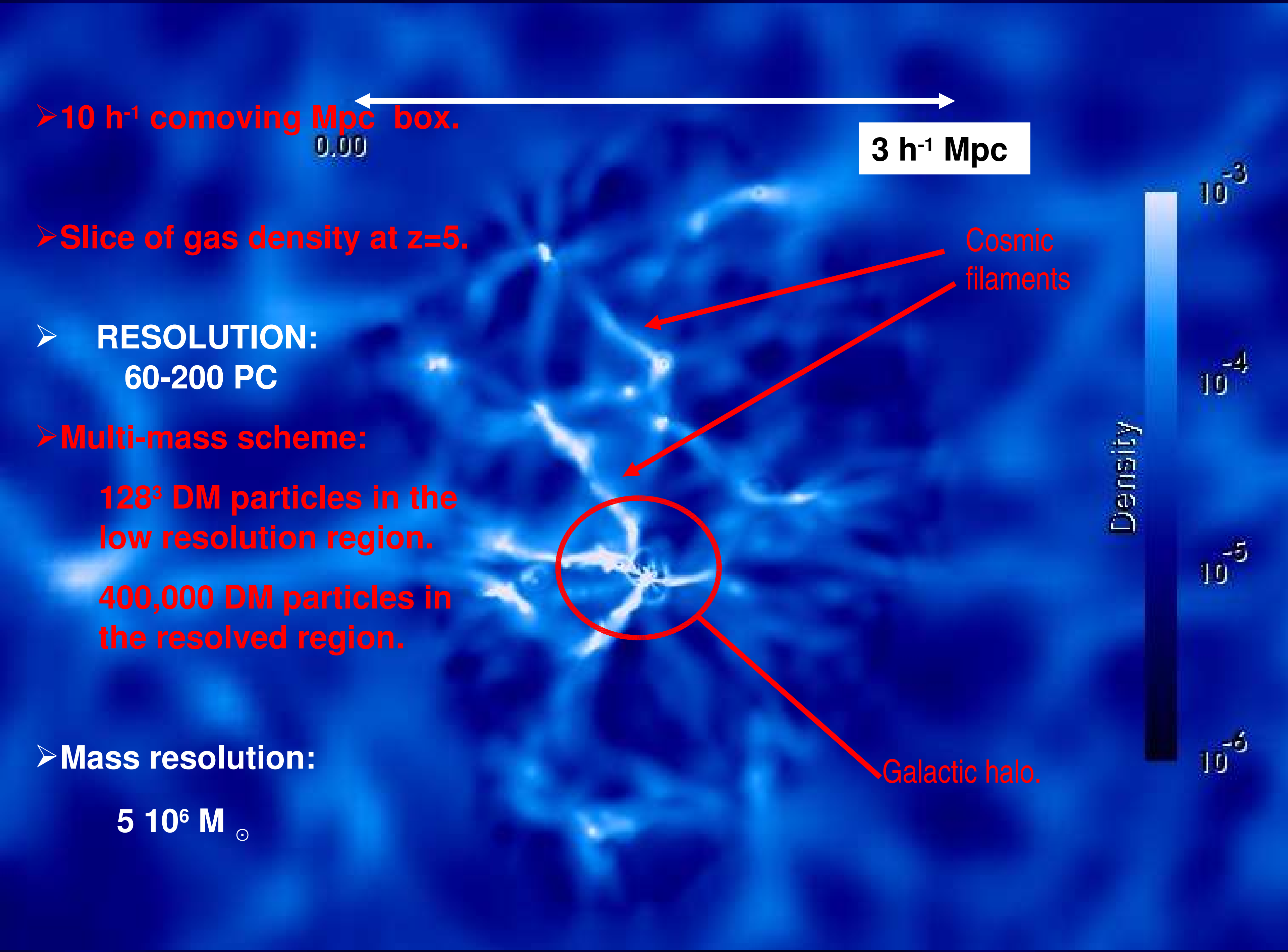
- Goal: To simulate the formation of a MW-type galaxy in a cosmological context.
- HYDRO+N-body ART code (Kravtsov et al 2002)
  - Eulerian code.

- 10 h^{-1} comoving Mpc box.
- Slice of gas density at z=5.
- RESOLUTION: 60-200 PC
- Multi-mass scheme:

  128^3 DM particles in the low resolution region.

  400,000 DM particles in the resolved region.
- Mass resolution:

  $5\ 10^6\ M_\odot$



Outline

- Code and physics involved.
- Some results and open questions.

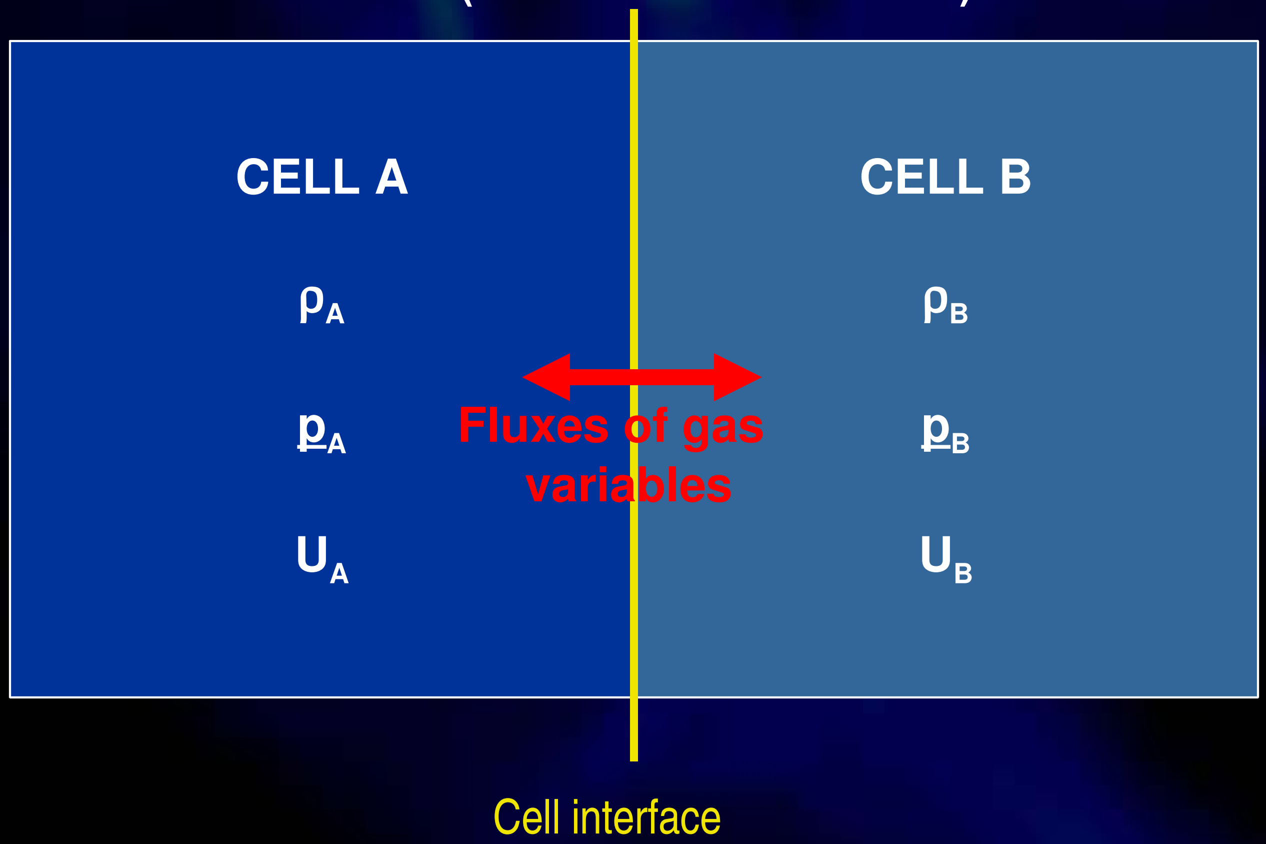
Adaptive Refinement Tree (ART) N-body + gasdynamics code

- Dark matter dynamics:
  - Collisionless N-body problem → Gravity.

- Gas dynamics:
  - Collisions, shocks, …

Gasdynamics

- Riemann solver. (Khokhlov 1998)



Radiative cooling

- Atomic and molecular hydrogen cooling.
- Cooling of a plasma with a given metallicity:
  - Tabulated Cooling rates from CLOUDY (Ferland 1998) for given…
    - Hydrogen density.
    - Temperature.
    - Metallicity.
    - UV background intensity.
  - Cooling rates depend on the local conditions of the gas.

Heating rates

- Compton heating.

- Uniform UV heating due to a cosmological ionizing background. (Haardt and Madau 1996)

Star formation

- Kennicutt law. (Kennicutt 1998)

$$\dot{\ }_{stars} = \frac{{}_{gas}}{\ } \qquad \propto t_{dyn} = \frac{1}{\sqrt{4\ G\ {}_{gas}}}$$

- Density and temperature thresholds.
- Averaged star formation.
- Stellar particle → single population with a Miller-scallo IMF

Feedback due to SN II and SN Ia

- Thermal feedback.

- Metal enrichment.

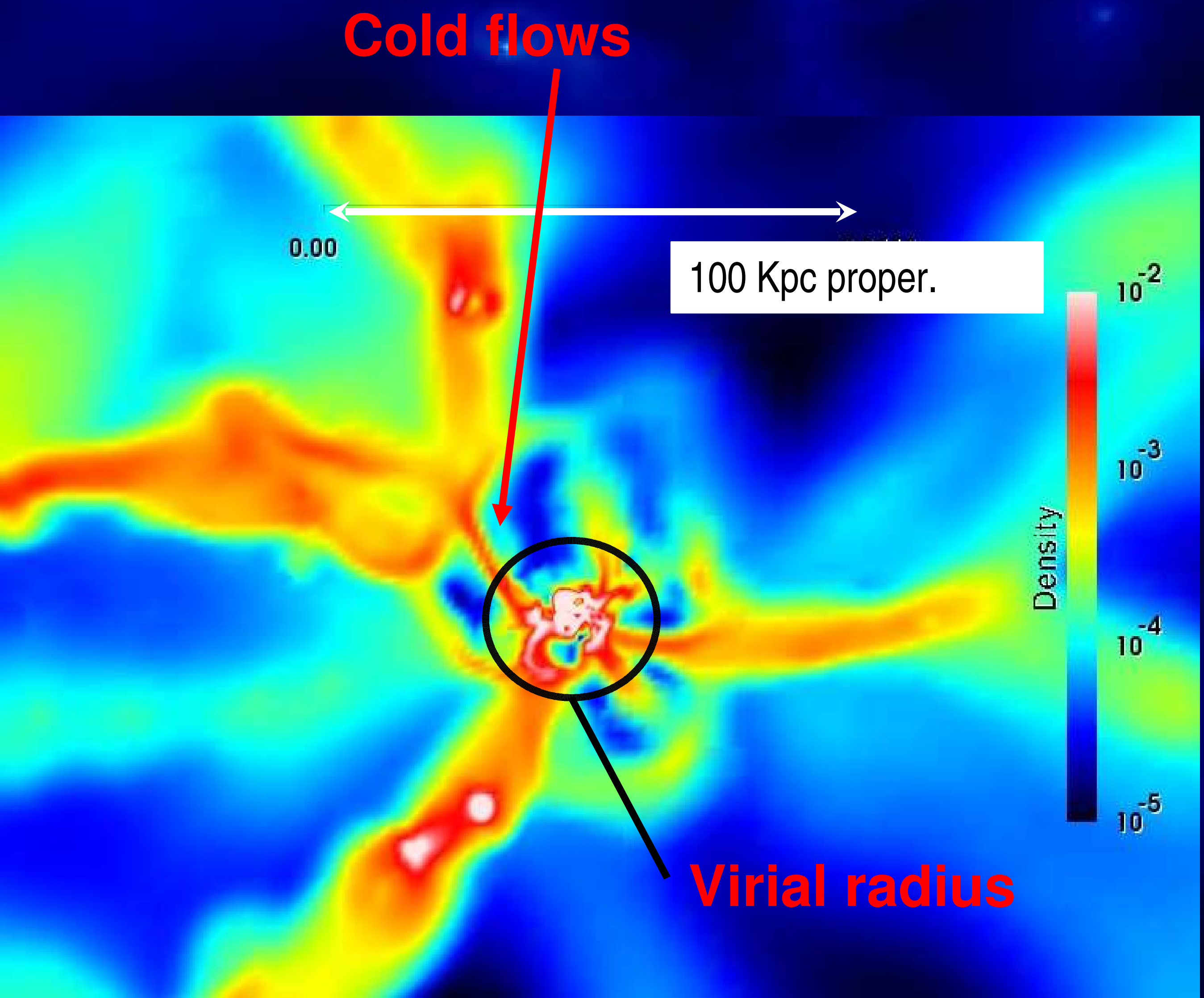
- Energy and metals are released after the typical lifetime of a massive star.

RESULTS AND OPEN QUESTIONS.

Metals ejected in SNII explosions.

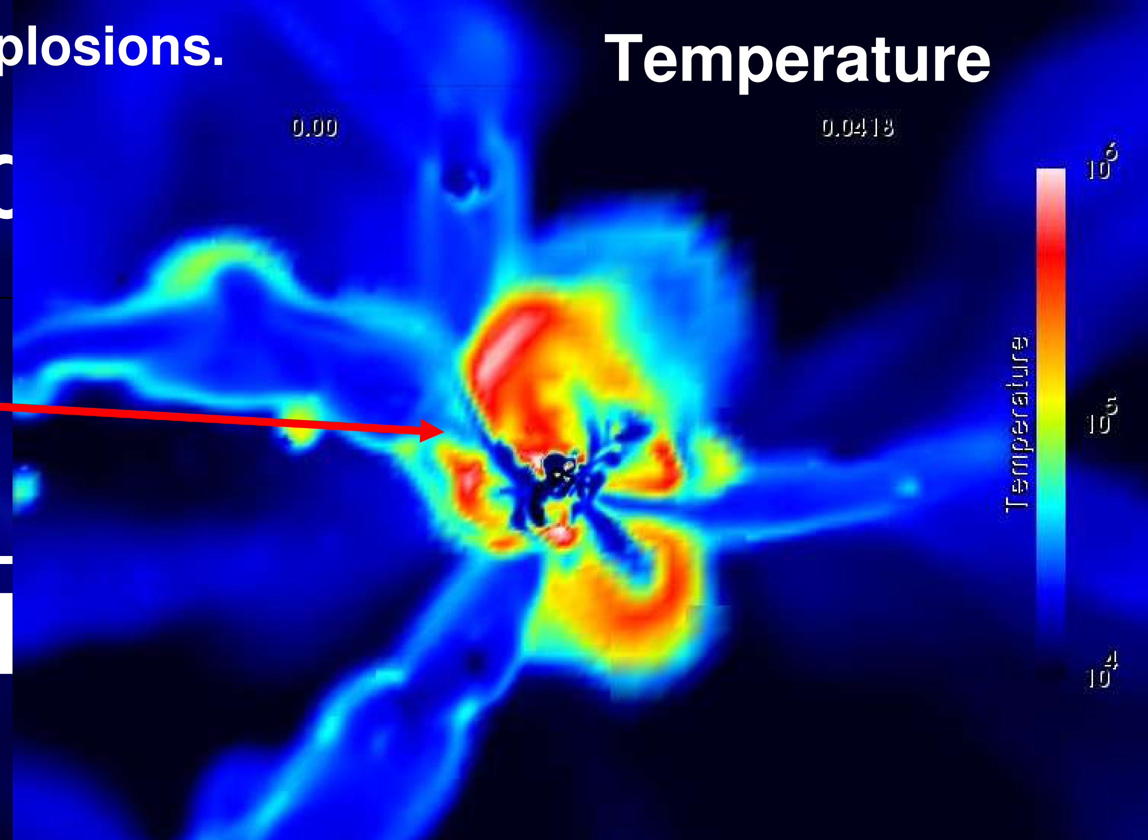
Temperature

Cold flows at z=5



- The accretion of gas is not spherical.
- Shocks.
- 150 pc of maximum resolution
- Outflows.
- Mixing of metals.

Metals ejected in SNII explosions.

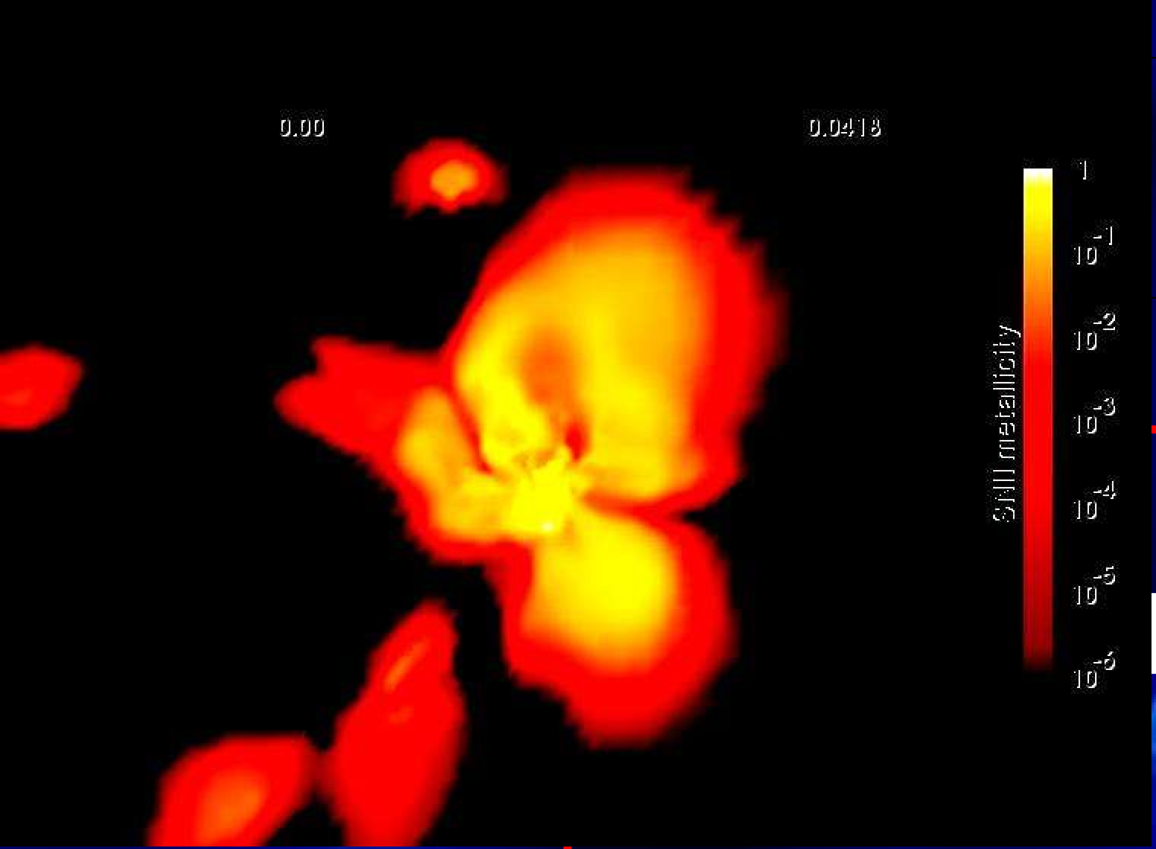


Cold flows

- 150 pc of maximum resolution
- Outflows.
- Mixing of metals.

Temperature

z=5



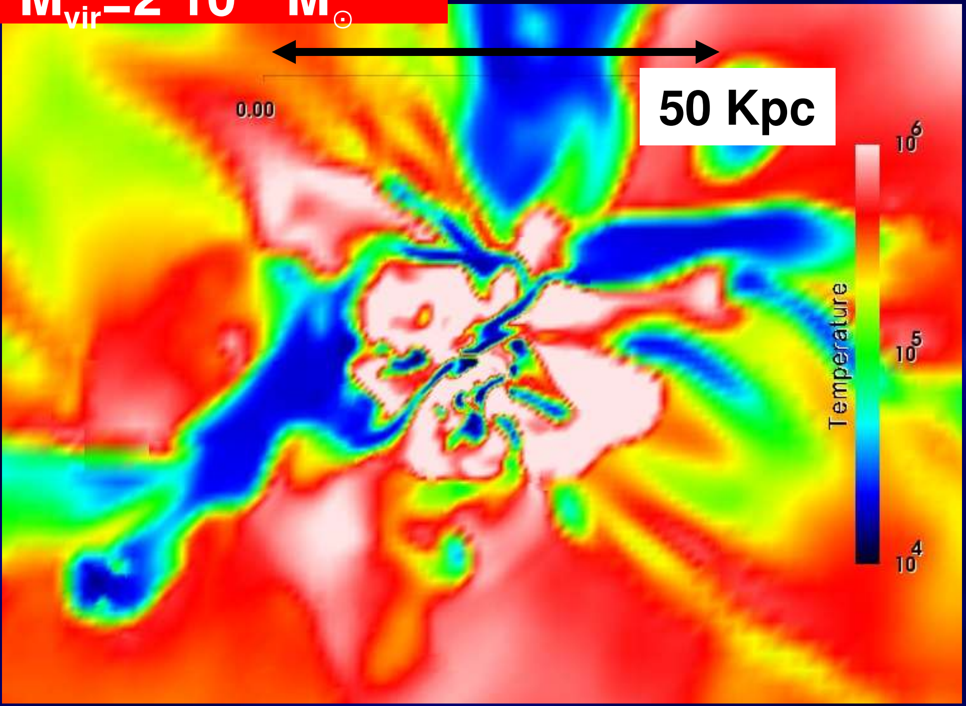
- The accretion of gas is not spherical.
- Shocks.
- 150 pc of maximum resolution
- Outflows.
- Mixing of metals.

$z=2.5$

$R_{vir}=50$ Kpc

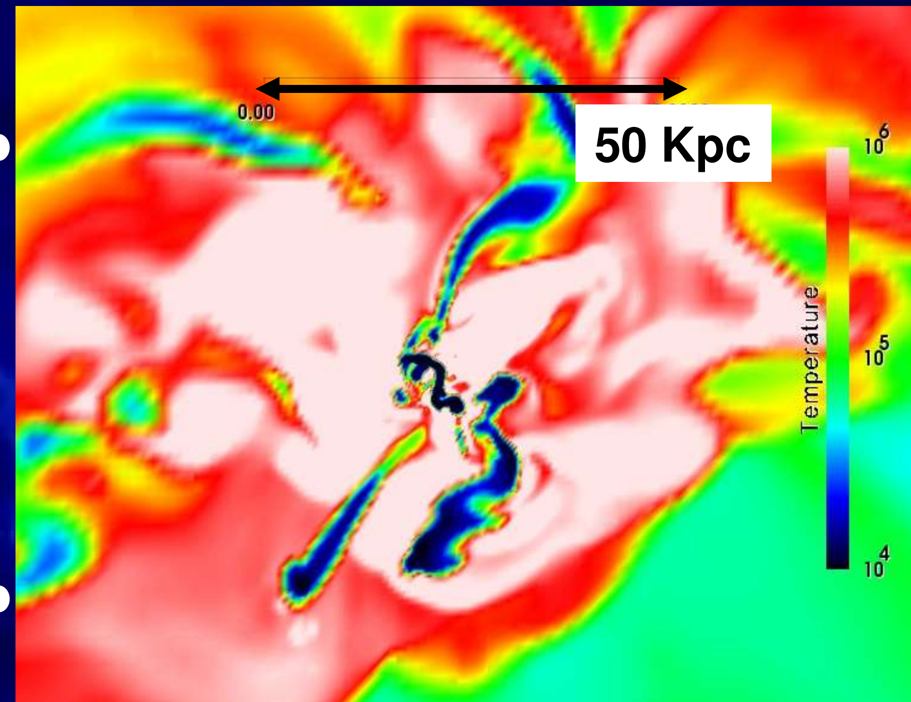
$M_{vir}=2\ 10^{11}\ M_\odot$

Evolution of cold flows



- Temperature distribution of the same halo at different redshift.
- Cold flows are moving out as the system grows.

Evolution of cold flows



- out as the sys
  grows.

z=1.5

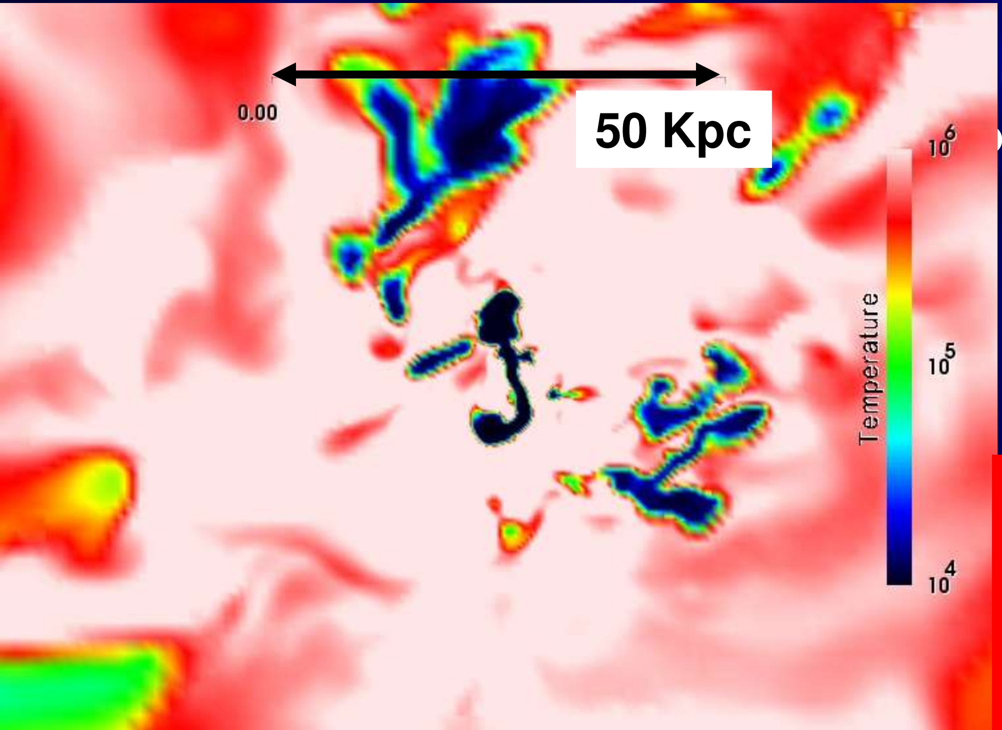
R_{vir}=100 Kpc

M_{vir}=4 10^{11} $M_\odot$

Evolution of cold flows

- Temperature distribution of the same halo at different redshift.

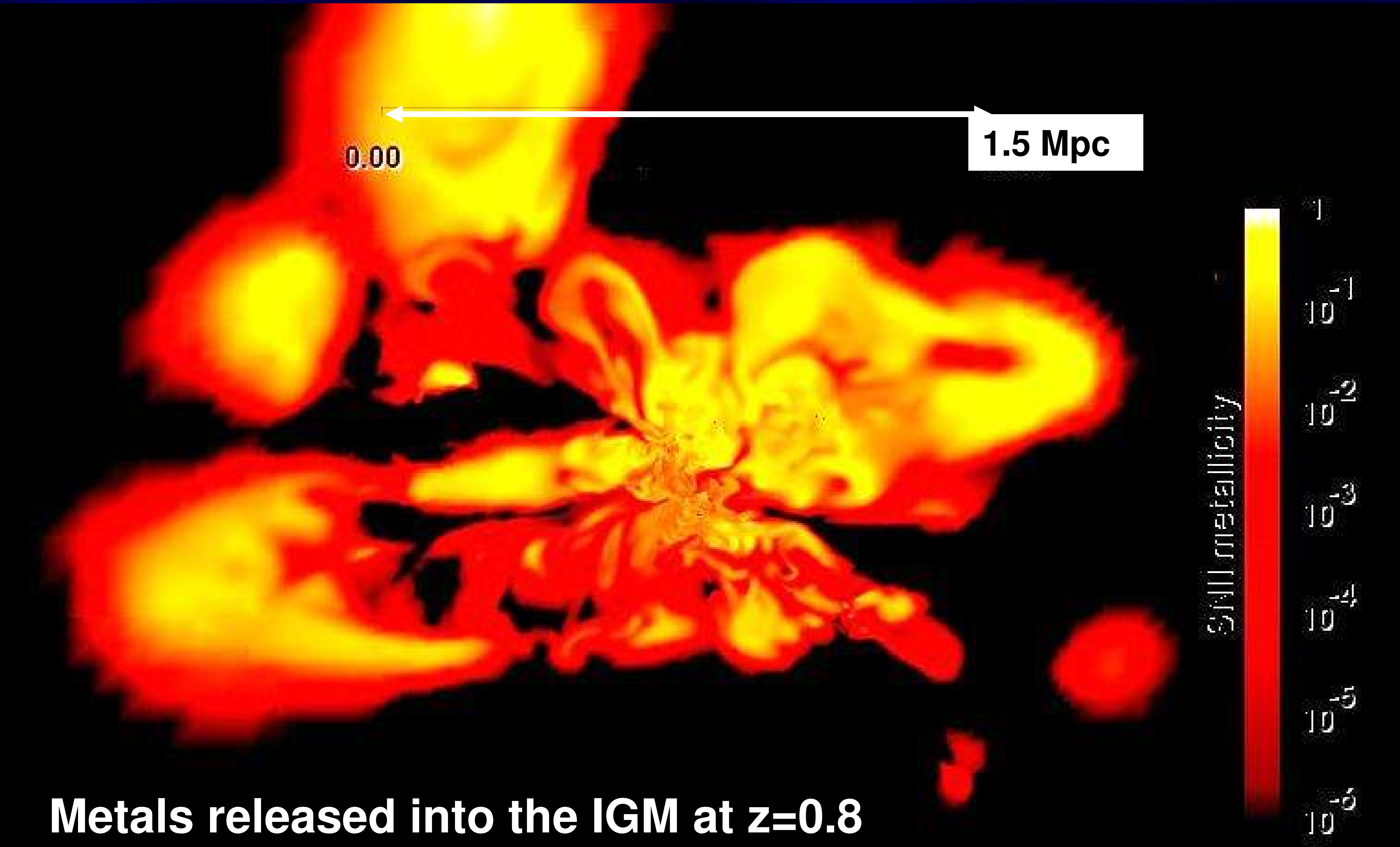
- Cold flows are moving out as the system grows.



z=0.8

R_{vir}=200 Kpc

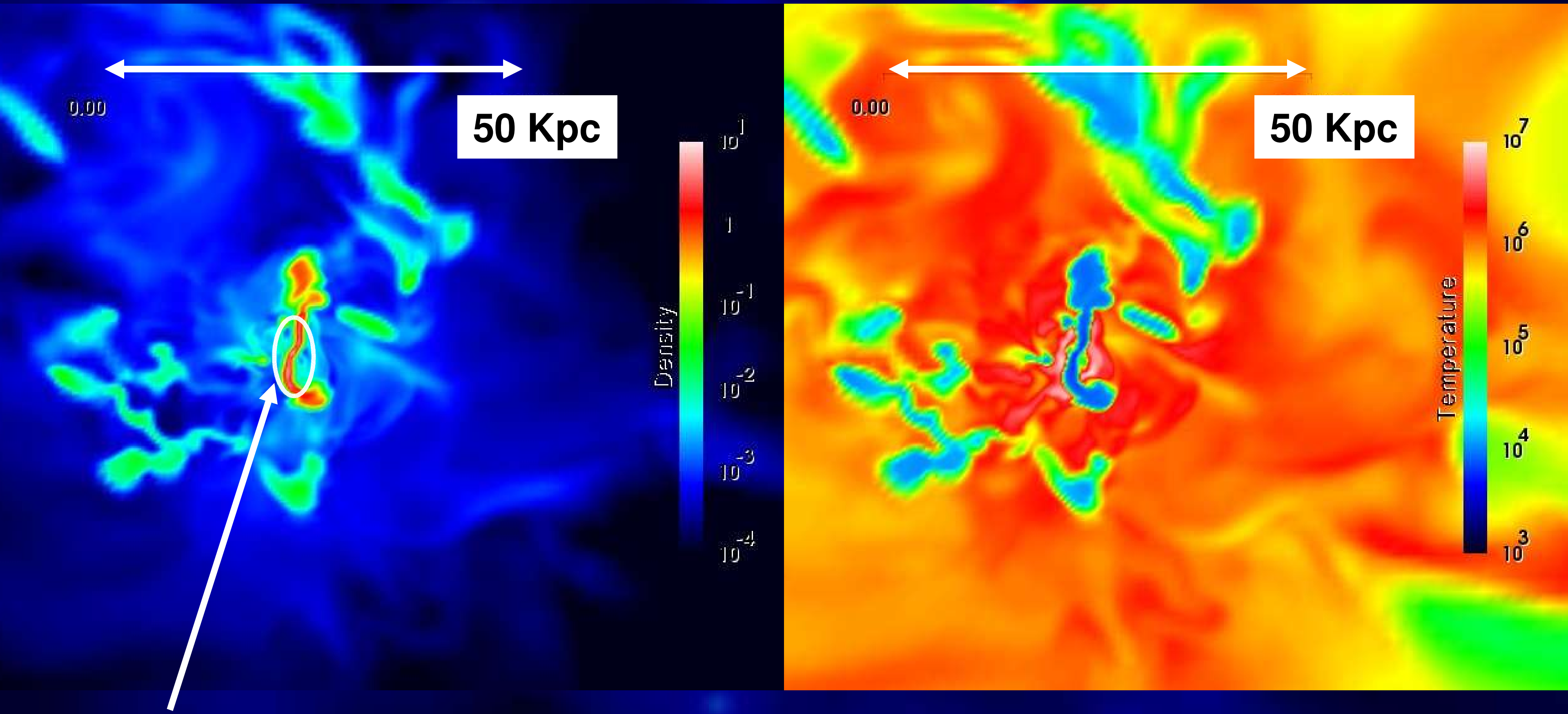
$M_{vir}=10^{12}\ M_{\odot}$



Metals released into the IGM at z=0.8

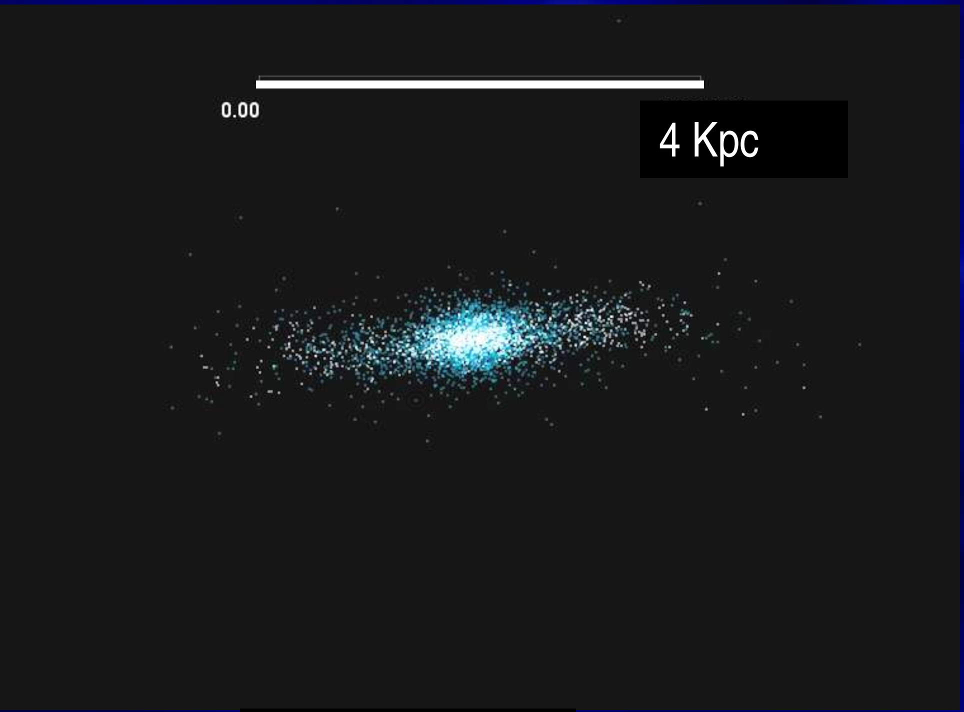
SN-driven outflows can release a significant amount of metals into the IGM

A extended disk at z=0.8

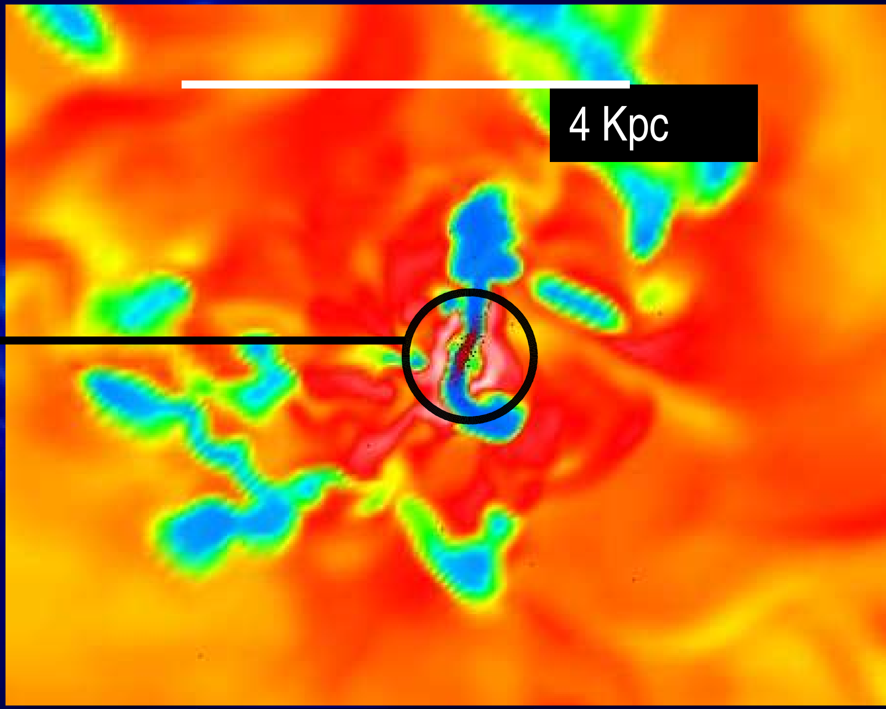


Edge-on view of a gaseous disk with 4 Kpc radius and 1 Kpc thick.

Extended stellar disk.



Edge-on view

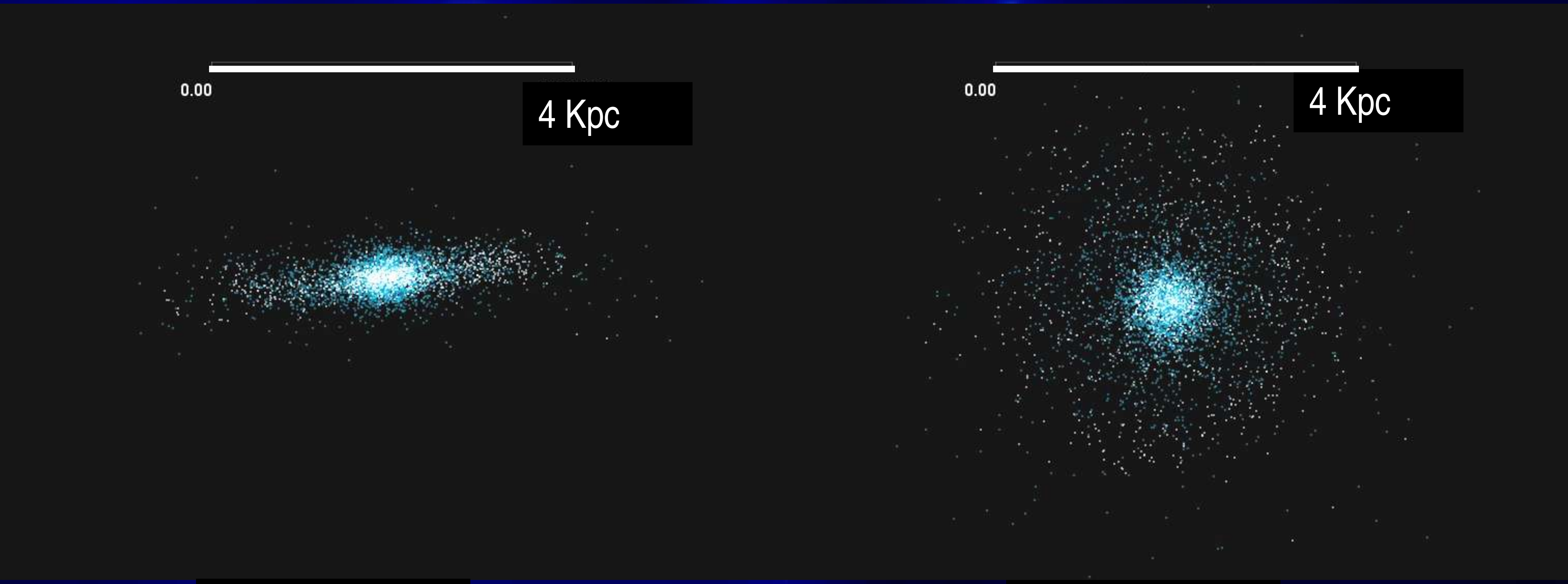


Face-on view

Stars younger than 2 Gyr form a stellar disk with a radius of 2 Kpc and 1Kpc thick.

The inner disk is already in place at z≈ 1.

Extended stellar disk.

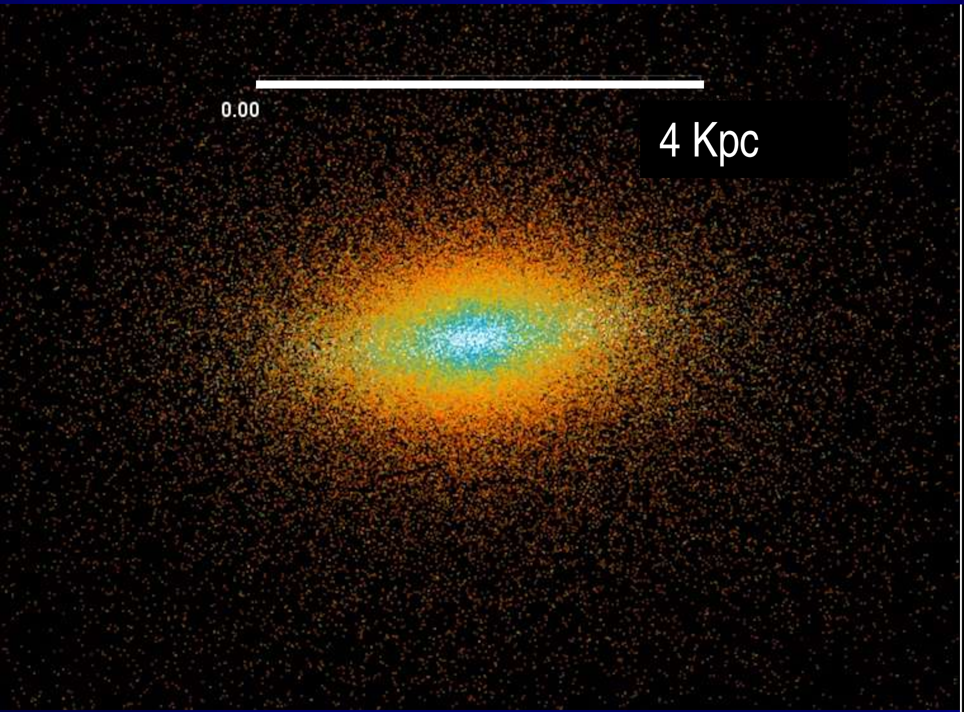


Edge-on view Face-on view

Stars younger than 2 Gyr form a stellar disk with a radius of 2 Kpc and 1Kpc thick.

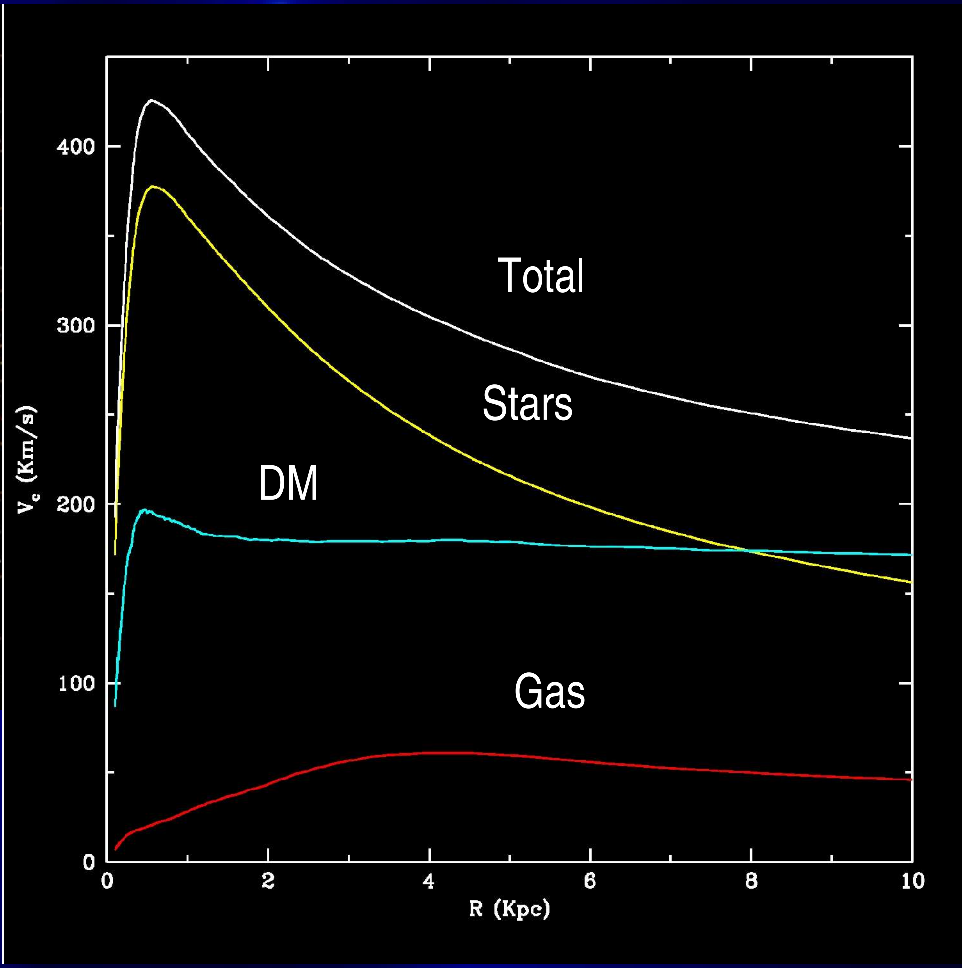
The inner disk is already in place at $z \approx 1$.

All stellar population.

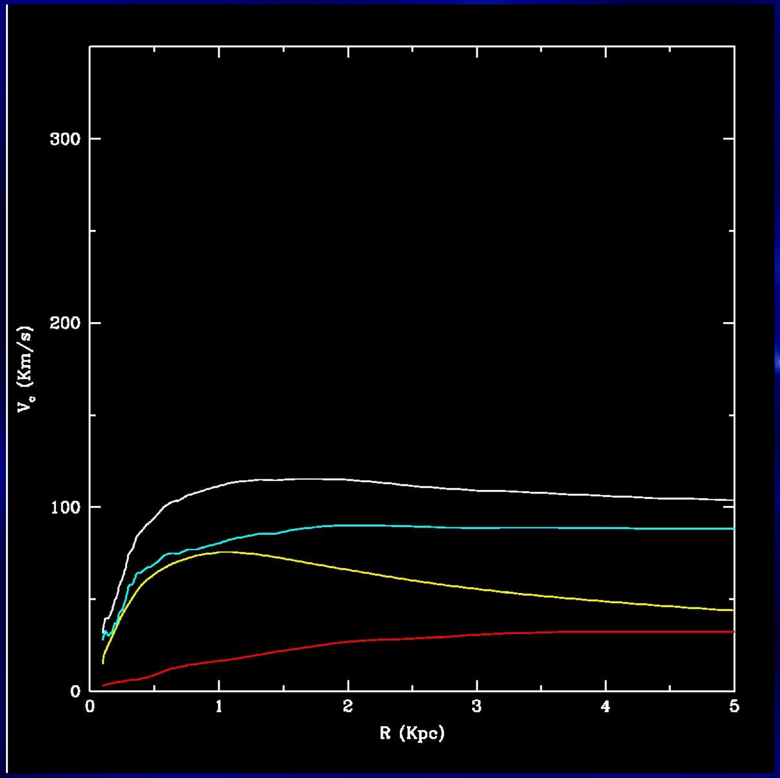


Circular velocity profiles.

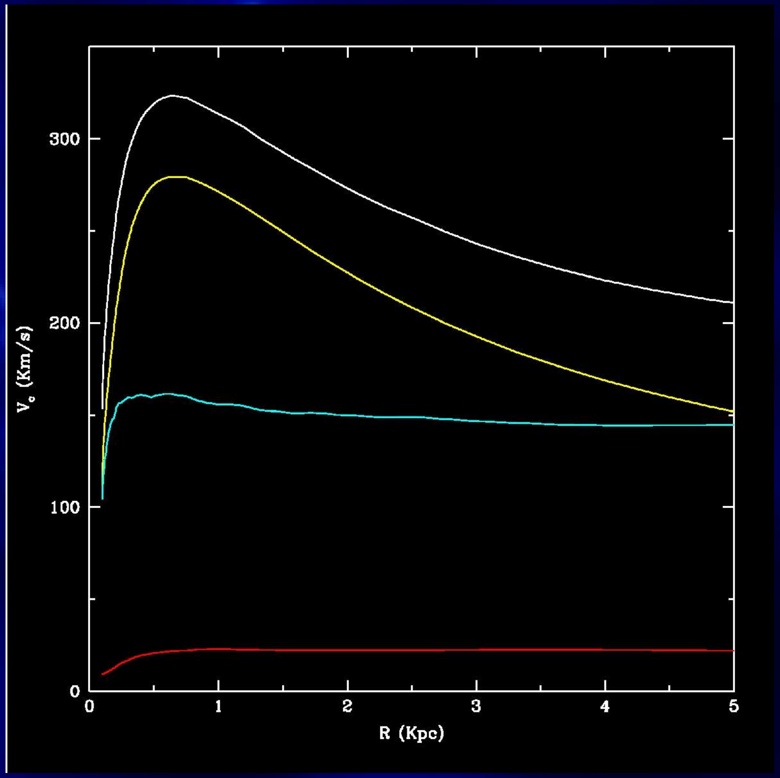
Mass distribution for different components.



What is the origin of this massive stellar core?

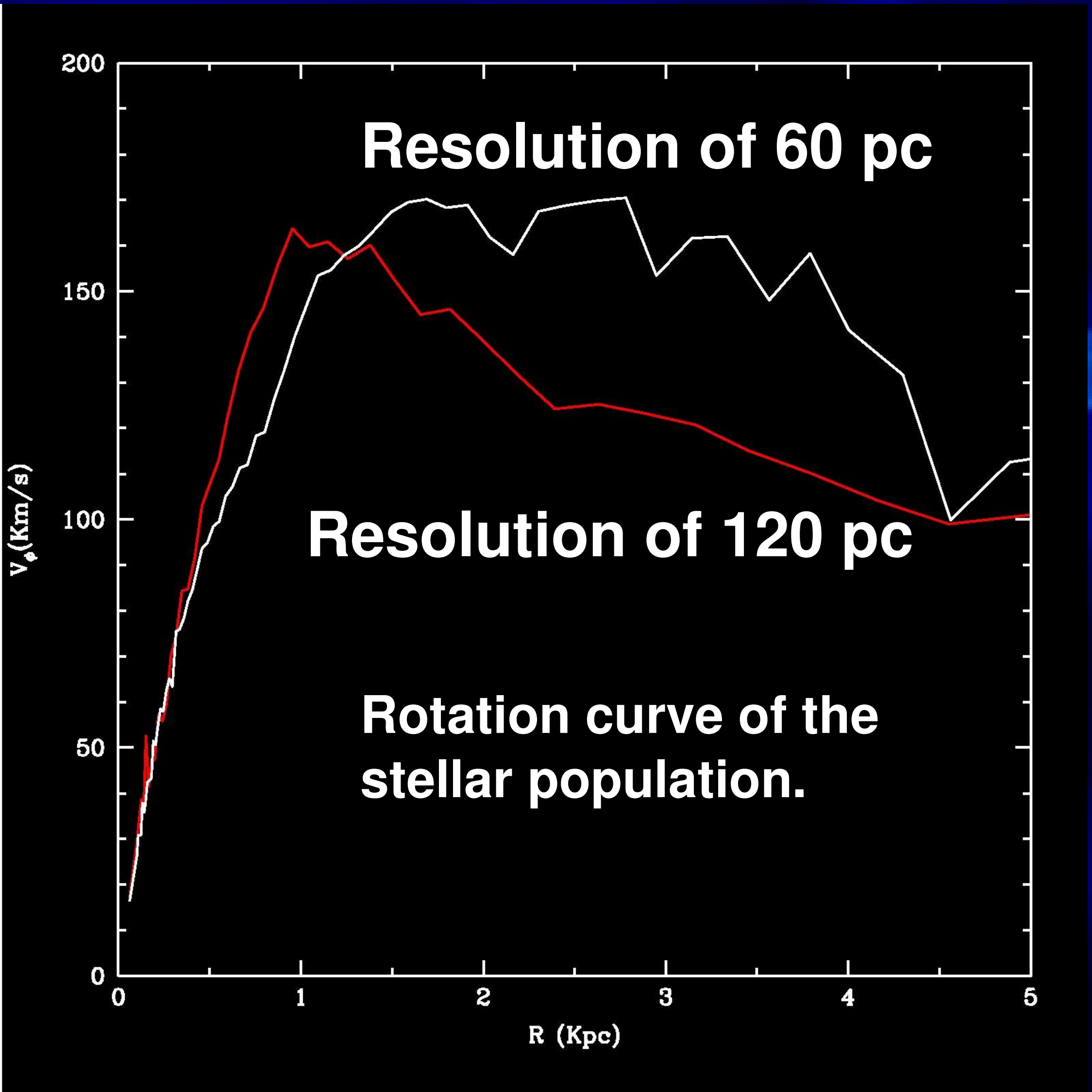


Before a major merger at z=4.



After the major merger.

Resolution effects

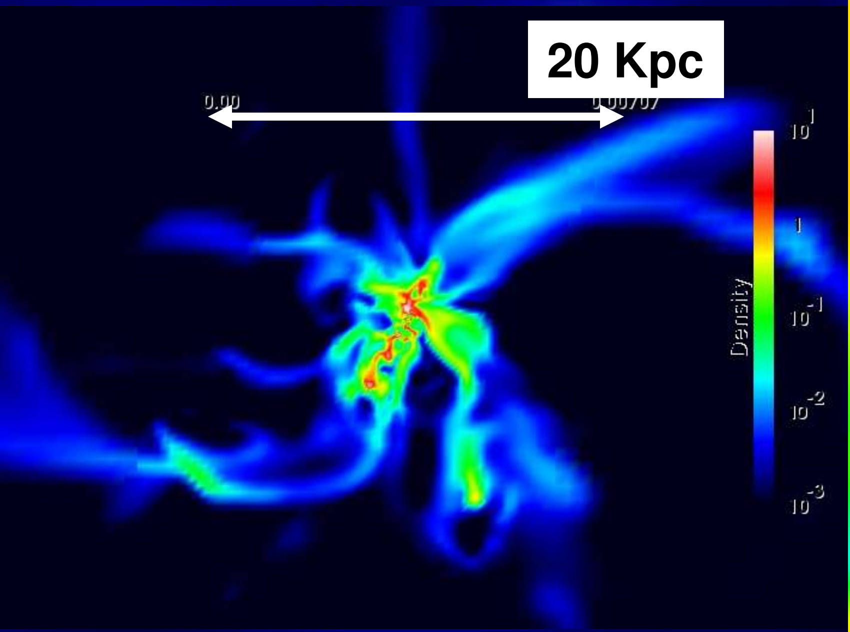


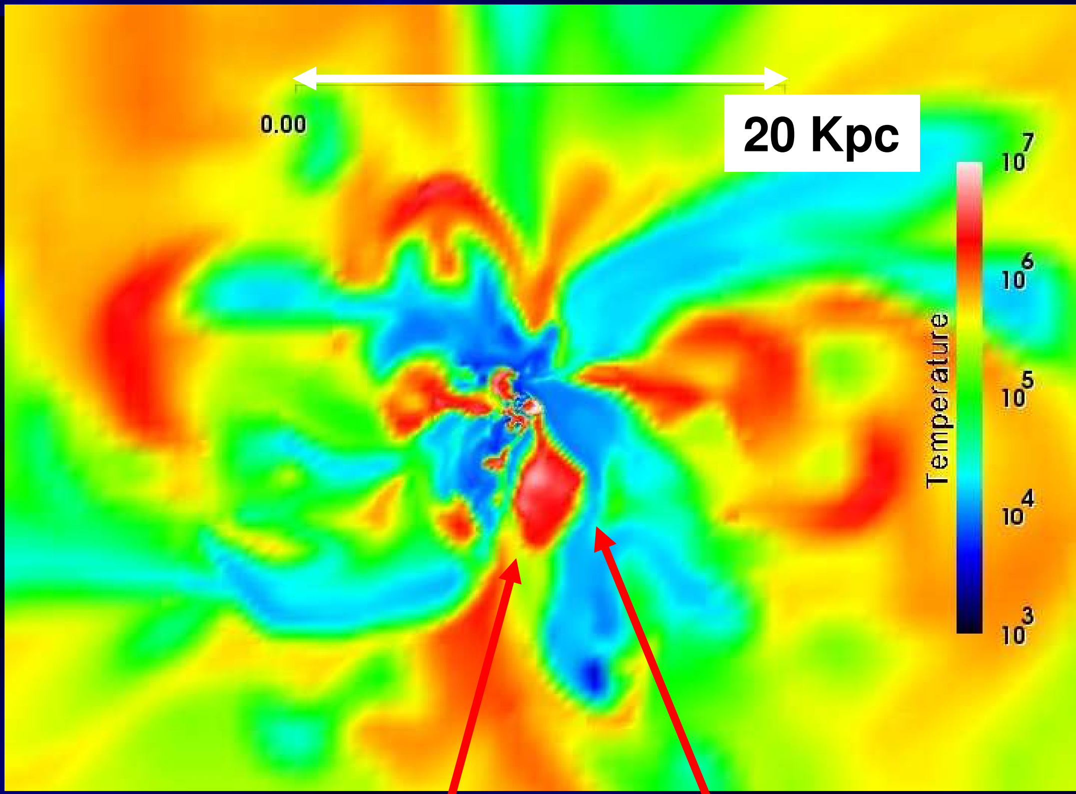
- An increase in the resolution is necessary to prevent an artificial angular momentum lost.

Feedback vs cold flows

- Is the stellar feedback able to prevent the cool gas to fall directly to the center and form a compact core?

Feedback vs cold flows





Z=3.7

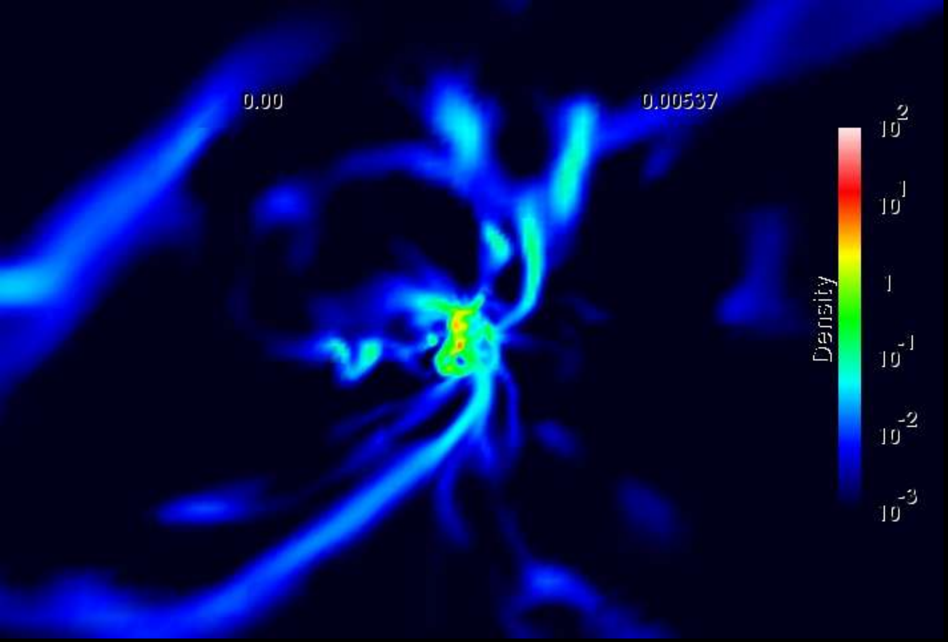
Hot outflow of dilute gas.

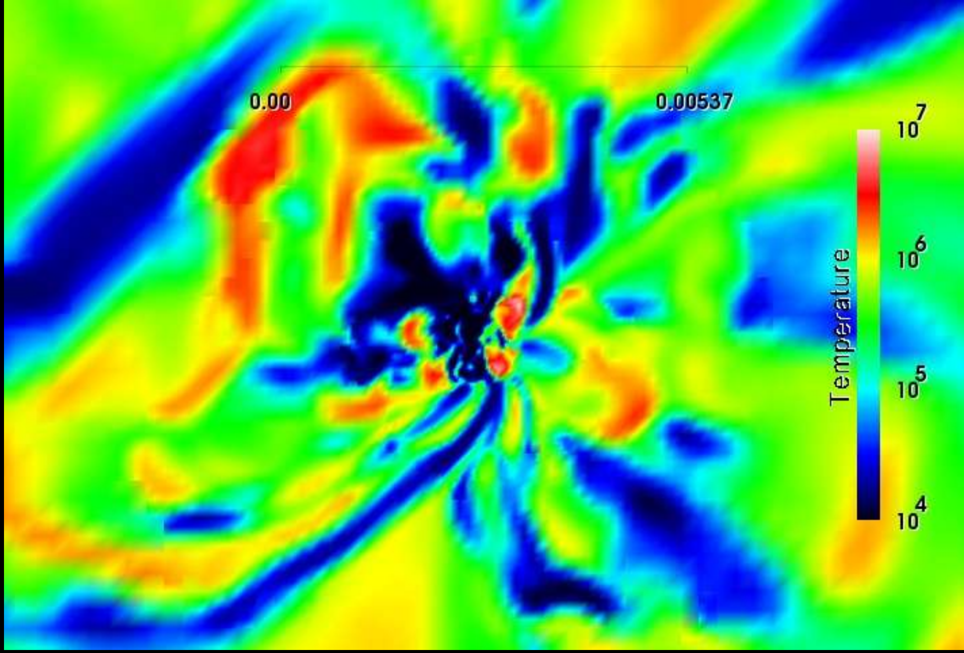
Cold inflow of dense gas.

Feedback vs cooling

- The cooling time is very short in dense regions, where stars are formed and energy is released.

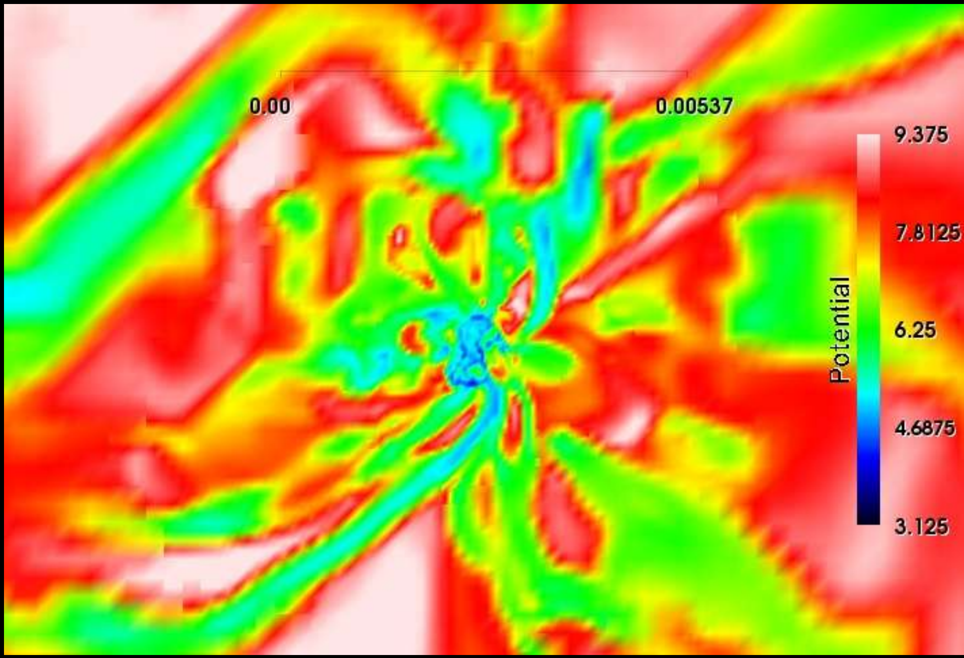
- The energy released by supernova explosions is radiated away too quickly in this regions.





- 30 Kpc in size.

Cooling time

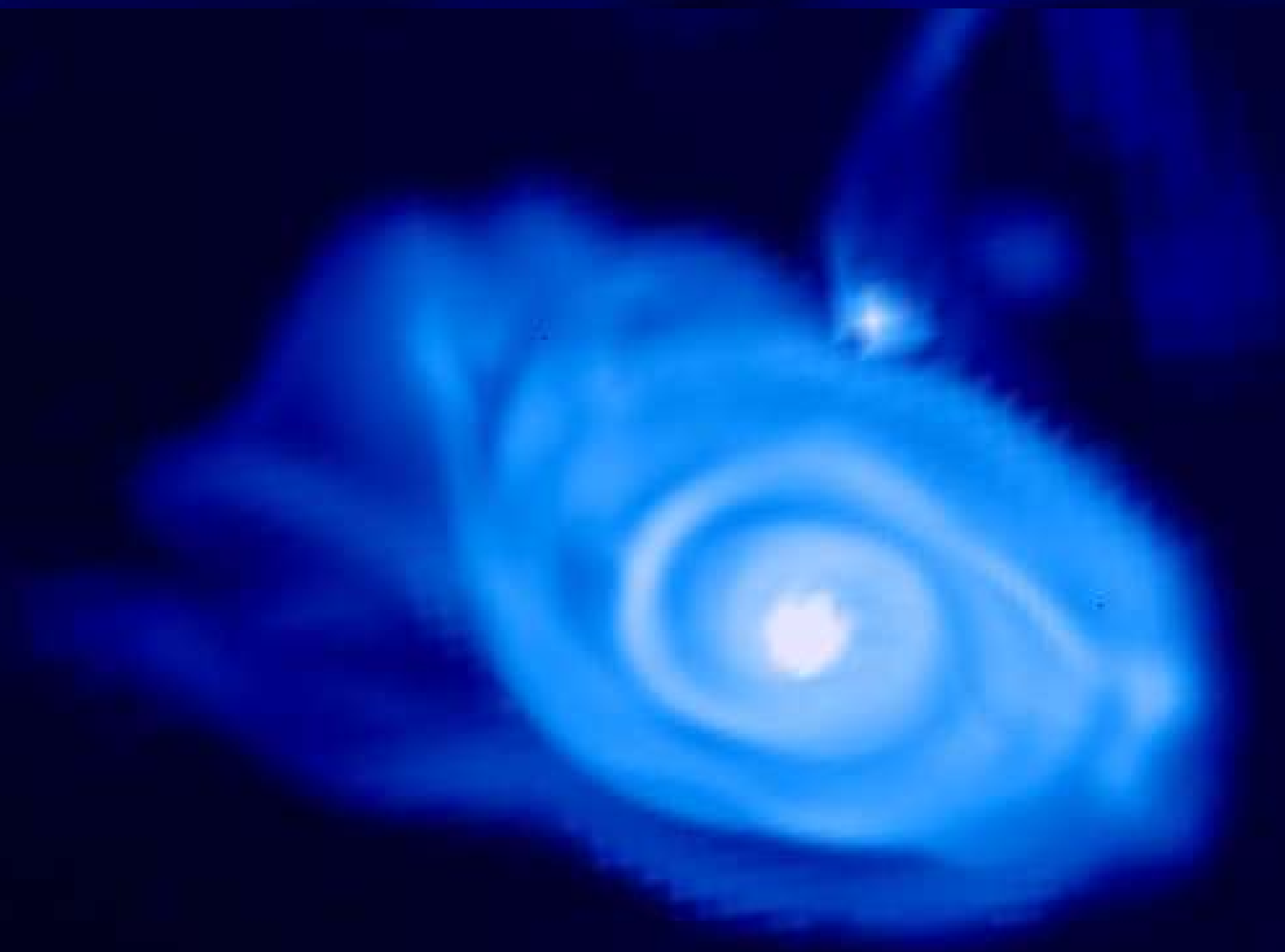


A spiral galaxy ?

- A different system with a smoother accretion history.
- 20 Kpc in size at z=0.6

Conclusions

- We follow the formation of a MW-size galaxy in a cosmological hydrodynamic simulation up to z~0.
- Cold flows accrete material to the center of the halo very efficiently and form a too massive stellar bulge.
- SN feedback can not stop this accretion.
- The cold flows are moving out as the system grows, forming a extended gaseous and stellar disk.



THE END ?