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: $5 \times 10^6 \, M_\odot$
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 $\rightarrow$ Gravity.

- Gas dynamics:
  - Collisions, shocks, …
Gasdynamics

- Riemann solver. (Khokhlov 1998)

CELL A

\[ \rho_A \]
\[ p_A \]
\[ U_A \]

CELL B

\[ \rho_B \]
\[ p_B \]
\[ U_B \]

Fluxes of gas variables

Cell interface
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)

\[ \dot{\text{stars}} = \frac{\text{gas}}{t_{\text{dyn}}} \propto \frac{1}{\sqrt{4G_{\text{gas}}}} \]

- Density and temperature thresholds.
- Averaged star formation.
- Stellar particle \(\rightarrow\) 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.
• The accretion of gas is not spherical.
• Shocks.
• 150 pc of maximum resolution
• Outflows.
• Mixing of metals.

Cold flows at z=5

Metals ejected in SNII explosions.
The accretion of gas is not spherical.

- Shocks.
- 150 pc of maximum resolution.
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Metals ejected in SNII explosions.

Cold flows

Temperature

Cold flows

100 Kpc proper.

Temperature

Cold flows

100 Kpc proper.

Temperature

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The accretion of gas is not spherical.

- Shocks.
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Temperature

z=5
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

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

\begin{align*}
\text{z}=1.5 \\
R_{\text{vir}}=100 \text{ Kpc} \\
M_{\text{vir}}=4 \times 10^{11} \text{ M}_{\odot}
\end{align*}
Evolution of cold flows

• Temperature distribution of the same halo at different redshift.

Cold flows are moving out as the system grows.

\[ z = 0.8 \]
\[ R_{\text{vir}} = 200 \text{ Kpc} \]
\[ M_{\text{vir}} = 10^{12} \, M_\odot \]
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.

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

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

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.

Resolution of 60 pc

Resolution of 120 pc

Rotation curve of the stellar population.
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

$Z = 3.7$

20 Kpc

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.
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 ?