Simulations of Galaxies and Baryonic Physics

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Introduction

Observed baryons account only for a small fraction of what the ΛCDM model predicts.

Including some dark baryons and more precise baryonic physics in galaxy simulations could help solve problems the ΛCDM model encounters at galactic scales in simulations: unrealistic density cusps, too small discs and too numerous satellites. It is also interesting to study the morphology of galaxies dependence on the implementation of physics processes.

We use Gadget-2 [4], a TreeSPH particle code, to which we add physical processes implementations: star formation, cooling and feedback from supernovae.

Baryonic Physics

Star formation

We implement a stochastic star formation. At each time-srep, a gas particle can spawn a star with a probability:

$$p = \frac{m_g}{m_*}\left(1 - e^{-\frac{\Delta t}{t_*}}\right)$$

A gas particle of initial mass m_g can spawn N stars of mass $m_* = m_g/N$ during simulations. Star formation occurs above a set density threshold.

Supernovae feedback

We include kinetic feedback from supernovae. Each new star particle of mass m_* inputs an energy $E_{\rm SN} = 0.5\epsilon_{\rm SN} m_*$ where $\epsilon_{\rm SN} = 10^{49}{\rm erg.M}_\odot^{-1}$ is the SN energy per formed solar mass and we assume 50% of the SN energy is radiated away. Each neighbour i of a new star particle 0 receives an energy weighted by the distance:

$$E_i = \frac{W(|\mathbf{r_{i0}}|, h_0)}{\sum\limits_{ngb\ k} W(|\mathbf{r_{k0}}|, h_0)} E_{\rm SN} \qquad (1)$$

If the feedback is only kinetic, the particle is given a velocity kick $\sqrt{\frac{2E_i}{m_i}}$.

Cooling

We take the metal-dependent cooling functions of Sutherland and Dopita [5] above 10^4K and reproduce the Maio et al [3] cooling functions due to metals (FeII, OI, SiII, CII) from $10\,$K to 10^4K.

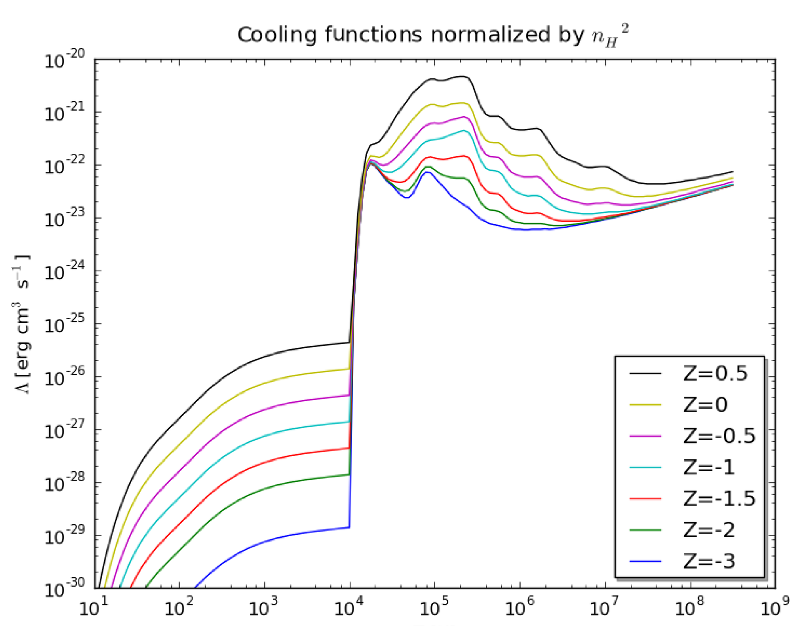

Figure 1: Cooling functions from Maio and Sutherland and Dopita. Z=0 is the solar metallicity.

We take H_2 cooling functions of Glover et al [1] that include collisions of H2 with H atoms, He atoms and H_2 molecules, and HD cooling functions from Lipovka et al [2] (HD is a more efficient coolant than H_2 due its dipolar moment). The LTE cooling functions were computed from quantum data.

We implemented an implicit thermal evolution scheme in Gadget.

Sb Galaxy Simulation

Galaxy model

We simulate an isolated Sb galaxy with the following components:

- Stellar and gaseous discs ($M_* = 4.61\times10^{10}\,{\rm M}_\odot$ and $M_g = 9.21\times10^{9}\,{\rm M}_\odot$) have a Miyamoto-Nagai density profile. They both have an initial Toomre parameter $Q = 1$.
- Stellar bulge and DM halo ($M_B = 1.11\times10^{10}\,{\rm M}_\odot$ and $M_H = 1.71\times10^{12}\,{\rm M}_\odot$) have a Plummer profile.

The galaxy initial rotation curve maximum is $200\,{\rm km\,s^{-1}}$.

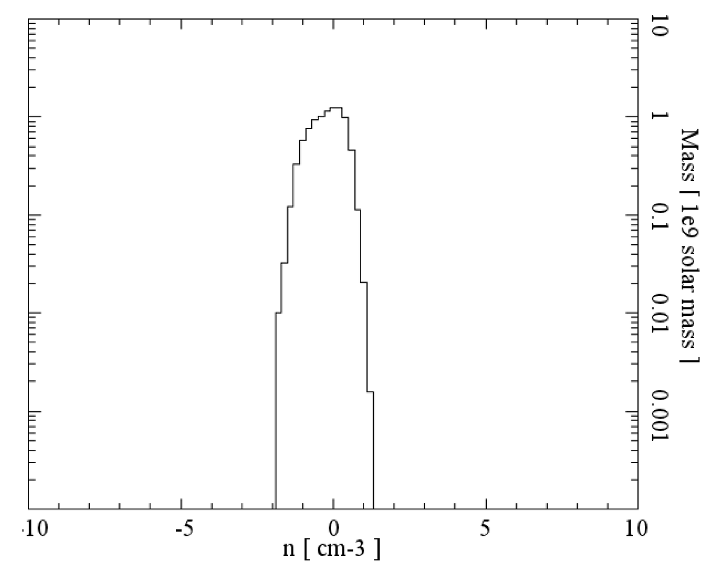

Figure 2: Initial gas density PDF

Simulation parameters

We have 120 000 particles: $m_g = 2.3\times10^5\,{\rm M}_\odot$, $m_{star} = 1.4\times10^6\,{\rm M}_\odot$, $m_{DM} = 4.2\times10^6\,{\rm M}_\odot$.
We set the gravitational softening to $\epsilon = 280\,{\rm pc}$ and each gas particle has 50 neighbours.
We set $t_* = 3.5\,{\rm Gyr}$ and a threshold density for star formation of $n_T = 10^{-1}{\rm cm}^{-3}$. We spawn 4 stars by gas particle. SNe feedback is only kinetic.
For these runs, we keep a fraction of molecular hydrogen $n_{\rm H_2} = 10^{-5} n_{\rm H}$ and a fraction of HD $n_{\rm HD} = 10^{-5} n_{\rm H_2}$. We take a fixed solar metallicity.

Simulations

We run isothermal simulations at 10^4K and simulations including cooling.

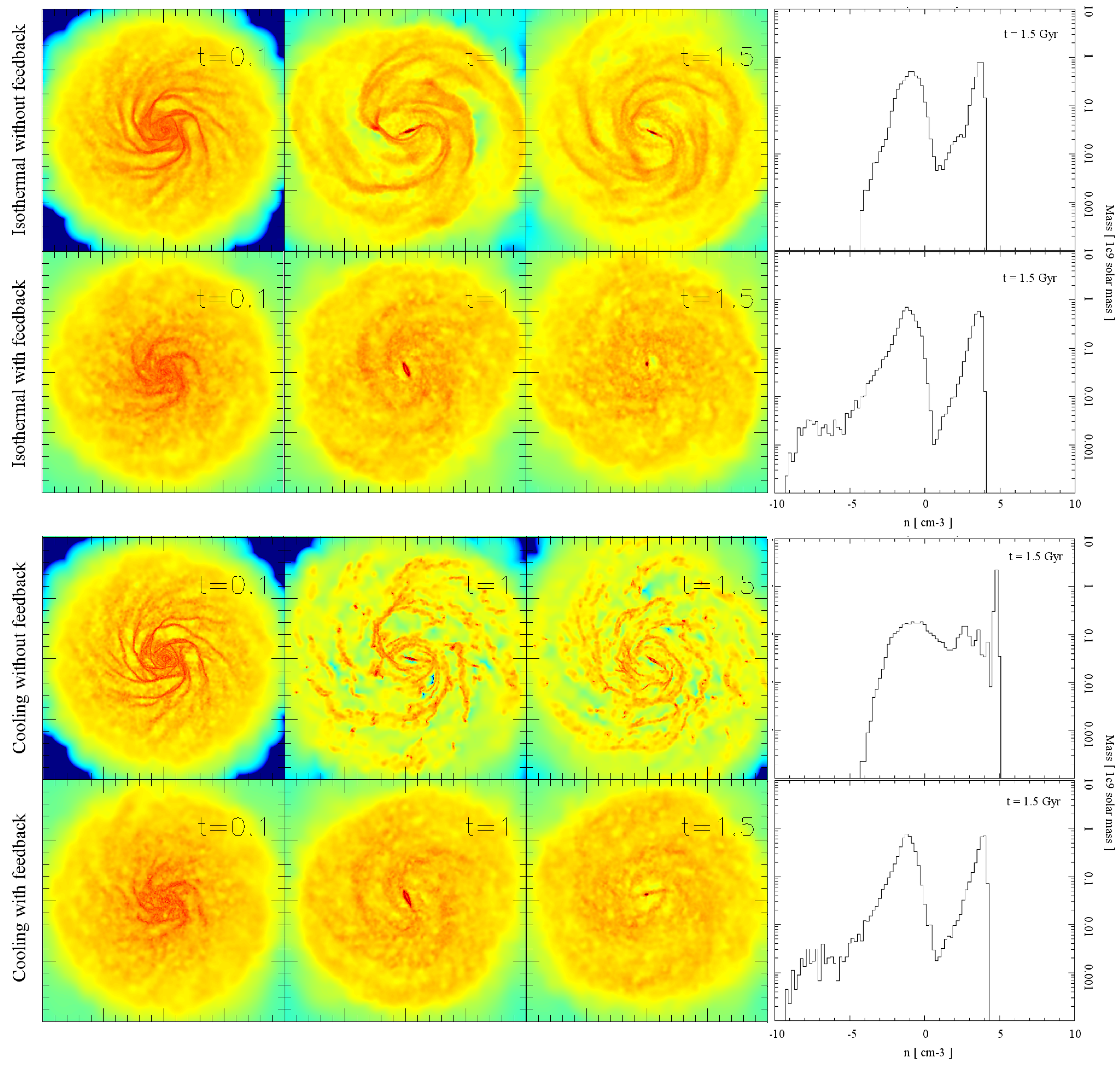

Figure 3: Boxes size is $20\,{\rm kpc} * 20\,{\rm kpc}$. Snapshots are taken at $0.5\,{\rm Gyr}$, $1\,{\rm Gyr}$ and $1.5\,{\rm Gyr}$.

Discussion

For all runs, we find the formation of two phases in the interstellar medium, a diffuse and a dense phase, which are of roughly comparable mass. Only in the cooling/without feedback run there is a continuum density distribution, with a peak in the denser possible phase. Particles pile up at the minimum allowed temperature and get denser and denser.

For the cooling+feedback run we see a dense and cold phase, and a diffuse warm phase on the temperature-density plane.

We observe the SFR is reduced in simulations with feedback.

Including feedback gives a blurrier appearance that is similar in isothermal or with cooling runs.

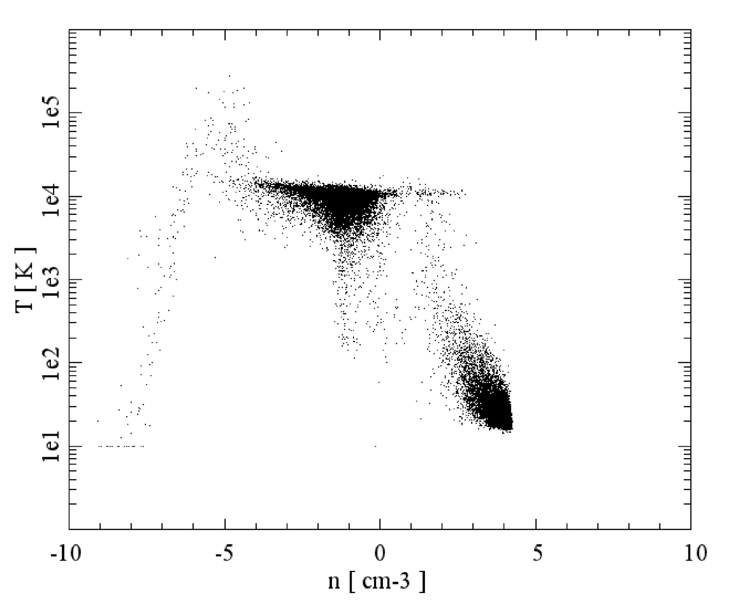

Figure 4: Temperature-density plane at t=$1.5\,{\rm Gyr}$ for the run with cooling and feedback.

Conclusion and prospects

We see the implemented feedback and cooling give a Sb galaxy morphology similar to observations, the interstellar medium being in two main phases: a dense and cold one, and a diffuse warm one.

Future work will involve higher resolution simulations with a model of the molecular hydrogen fraction depending on density and the inclusion of dark baryons in the disc.

References

[1] S. C. O. Glover and T. Abel. *MNRAS*, 388:1627–1651, August 2008.
[2] A. Lipovka, R. Núñez-López, and V. Avila-Reese. *MNRAS*, 361:850–854, August 2005.
[3] U. Maio, K. Dolag, B. Ciardi, and L. Tornatore. *MNRAS*, 379:963–973, August 2007.
[4] V. Springel. *MNRAS*, 364:1105–1134, December 2005.
[5] R. S. Sutherland and M. A. Dopita. *ApJS*, 88:253–327, September 1993.