SF2A 2012
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EVOLUTION OF THE DISTRIBUTION OF BARYONS IN A SIMULATED LOCAL GROUP UNIVERSE

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Abstract. Using hydrodynamical zoom simulations in the standard ΛCDM cosmology, we have investigated the evolution of the distribution of baryons (gas and stars) in a local group-type universe. We found that physical mechanisms able to drive the gas out of the virial radius at high redshifts (such as AGN) will have a stronger impact on the deficit of baryons in the mass budget of Milky Way type-galaxies at present times than those that expel the gas in the longer, late phases of galaxy formation.

Keywords: Galaxies: Local Group, Galaxies: haloes, Dark matter, Methods: N-body simulations

1 Introduction

In the traditional picture of galaxy formation, galaxies are supposed to form when baryonic gas falls into the gravitational potential of their host dark matter halo, the distribution of dark matter is therefore expected to faithfully trace that of the baryons. However on galactic scales, observations tend to suggest that the spatial distributions of dark matter and baryons (especially in the form of gas) may display some substantial differences. In particular, it has been shown that galaxies are missing most of their baryons, – most galaxies are severely baryons-depleted relative to the cosmological fraction (see for instance Bell et al. 2003; Hoekstra et al. 2005; McGaugh 2010).

This so-called "missing baryons problem" (see Bregman 2007 for a complete review), if *real*, calls for two alternative scenarios. Either a significant part of the gas never collapsed into the gravitational potential wells of protogalaxies in the first place, or some of the gas has been expelled by galaxy formation feedback processes such as supernova winds. Hence solving the missing baryon problem may prove to be central in order to constrain galaxy formation models.

In Peirani et al. (2012), we made use of cosmological "zoom" simulations with an extended treatment of the physics of baryons to study the formation of Milky Way-like galaxies. Our aim was to characterise the relative role of supernova feedback to accretion and mergers in the evolution of the distribution of baryons for objects of such masses. But we have also tested scenarios in which a significant fraction of gas in progenitors is expelled at high redshift by more powerful sources of feedback, such as AGN associated with massive black holes. This allowed us to quantify two distinct processes which may allow us to address the so-called missing baryon problem, should it persist. The simulation of local group universe also allowed us to study the problem of the "cold" Hubble flow (see for instance Peirani 2010; Peirani & Pacheco 2006, 2008) as well as possible indirect detection of neutralino, through its γ-ray annihilation product, by FERMI satellite from our galactic halo or M31 and the dwarf galaxies (see for instance Peirani, Mohayaee & Pacheco 2004b) and theoretical models of the formation of a disc galaxy similar to the Milky Way (Peirani, Mohayaee & Pacheco 2004a).

2 Numerical Modelling

The numerical methodology used in the present paper is described in detail in Peirani et al. (2012) to which we refer the reader for more information. For the sake of clarity, we summarize the main steps below.

We analyse three cosmological zoom simulations for a ΛCDM universe using WMAP5 parameters (Komatsu et al. 2009), namely $\Omega_{\rm M} = 0.274$, $\Omega_\Lambda = 0.726$, $\Omega_b = 0.0456$, $H_0 = 70.5$ km/s/Mpc, $n = 0.96$ and $\sigma_8 = 0.812$.

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Each simulation was performed in a periodic box of side $100\,h^{-1}$ Mpc with 2×2048^3 effective dark matter and gas particles in the highest resolution region (a sphere of $7\,h^{-1}$ Mpc of radius).

The three simulations have common initial conditions whose phases are consistent with the local group but essentially differ in the quantity of energy released by SN derived from star particles i (E_i). As mentioned in Peirani et al. (2012), we consider that a fraction γ of this energy is deposited in the j^{th} neighbour gas particle by applying a radial kick to its velocity with a magnitude $\Delta v_j = \sqrt{(2 w_j \gamma E_i / m_j)}$, where w_j is the weighting based on the smoothing kernel and m_j is the mass of gas particle j. The first simulation Sim1*a* uses the standard value of $\gamma = 0.1$ while in the second one, Sim1*b*, we have considered a higher efficiency $\gamma = 1.0$ in order to investigate how our results would be affected. In the third simulation (Sim2), our aim is to study the effects of earlier high energy ejection to the ISM induced either by intermediate mass black holes or other high energy processes such as hypernovae events. For this purpose, a simple modelling was used in which a much higher efficiency ($\gamma = 50$) was considered during a very short ($\Delta t \sim 45$ Myr) at earlier times ($z \sim 8.0$) and $\gamma = 0.1$ otherwise.

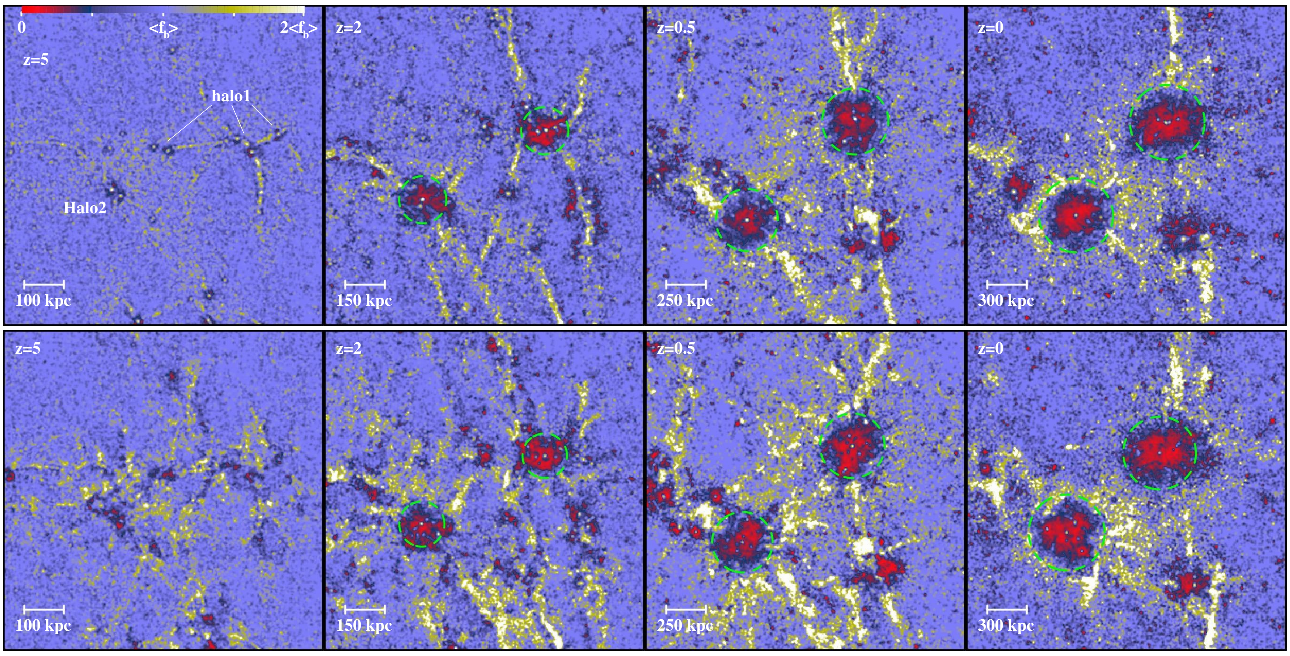

Fig. 1. The projected baryonic fraction at $z = 5$ (first column) $z = 2$ (second column), $z = 0.5$ (third column) and $z = 0$ (fourth column) from Sim1*b* (first line) and Sim2 (second line). Dashed circles show virial radii. High f_b value regions are clearly visible around galaxies (or proto-galaxies) and in the filaments. This trend seems to be more pronounced in *Sim*2 although the difference between the two simulations is vanishing at low redshift.

3 Spatial distribution in the simulated LG

Fig. 1 shows the projected distribution of baryons in our LG type universes derived from Sim1*b* and Sim2 and at four specific epochs (i.e. $z = 5, 2, 0.5$ and 0). We clearly see that the evolution of the distributions of baryons and dark matter do not follow the same trend. Indeed, the regions of the universe in red and dark blue correspond to regions where the baryonic fraction is lower than the universal value. And those specific regions are mainly located around the forming protogalaxies or galaxies at each redshift, while in the very inner part of dark matter haloes, f_b is higher. This is an expected result: due to cooling, the gas collapses to the center of haloes where stars can be formed. However, note that the size of these “red” cavities increases over time which suggests that the fraction of gas that has collapsed to the center of the halo is not immediately replaced by some fresh gas from its vicinity.

Note also, at high and low redshift, the existence of relative high baryon content regions which are located either in the filaments or beyond the virial radii. Such anisotropic distribution seems to be more pronounced in Sim2 relative to Sim1*b*. If the high baryon fractions in filaments can be understood by the dissipative nature

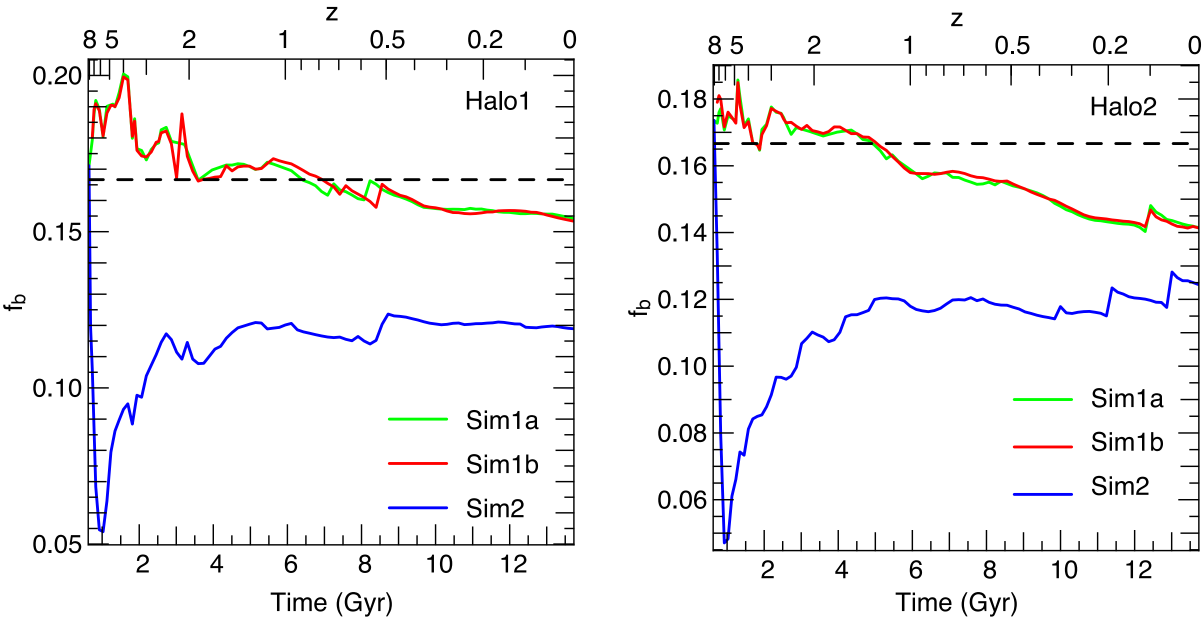

Fig. 2. The evolution of the baryonic fraction f_b estimated at the virial radius for Halo1 (left panel) and Halo2 (right panel) as a function of cosmic time. In each panel, red, green and blue lines correspond to values derived from Sim1*a*, Sim1*b* and Sim2 respectively. The horizontal dashed line corresponds to the universal fraction. Note that the early feedback model induces a lower ($f_b \sim 0.12$) baryon fraction at present time.

of gas, allowing it to cool to the dense filaments, it is crucial to characterise the mechanisms that drive high baryon content regions beyond the virial radii.

4 Cosmic evolution of fb

4.1 The effects of feedback at low redshift

The cosmic evolution of the baryonic fraction f_b estimated at the virial radius for the two main haloes is shown in Figure 2. In each of these two simulations, they follow the same trend. At high redshift, f_b is close to the universal value and sometimes is slightly higher. Cold flows provides gas to form stars. From $z \sim 3$, f_b is decreasing with cosmic time until it reaches the values of ~ 0.15 and ~ 0.14 at $z = 0$ for Halo1 and Halo2 respectively. More interestingly, no particular differences are seen in the evolution of f_b between Sim1*a* and Sim1*b*. This suggests that higher SN feedback can reduce the star formation rate (and therefore the final stellar mass) but is rather inefficient in expelling the gas outside the virial radius at high and low redshifts for massive galaxies.

4.2 The effects of feedback at high redshift

In Sim2 however, due to earlier and important eviction of gas from other potential sources of feedback (AGN, hypernovae,...) f_b reaches its lowest value $f_b \sim 0.05$ at $z \sim 6$, then increases until $z \sim 1.5$ and becomes nearly constant ($f_b \sim 0.12$) until the present time. This strongly suggests that sources of feedback acting at high redshift, even for a very short period, can have a stronger impact on the final mass budget of massive galaxies than those acting in the later and longer phases of galaxy formation.

4.3 The role of accretion of matter

The evolution of the mean baryonic fraction value f_b at the virial radius is essentially governed by the relative efficiency at which the dark matter and baryons are accreted. Indeed, the evolution of the accreted mass of both dark matter and baryons follows two different regimes: a rapid growth at high redshifts ($z \geq 1.5$) and a slower one at lower redshifts. The high f_b values at high redshift derived from Sim1a and Sim1b can be explained by the accretion of high gas-to-dark matter ratio from dense region such as filament via cold flows. But at lower redshift, f_b is decreasing due to the accretion of low gas-to-dark matter ratio material, in particular from the diffuse region. Indeed, we found that the baryonic fraction of the diffuse accreted matter (namely $f_b \sim 0.11 - 0.14$) is on the average much lower than the universal value: as the haloes become more massive, the temperature at the virial radius increases and the gas is shock-heated and this process slows down its accretion onto the halo. For Sim2, f_b reaches its lowest value ($f_b \sim 0.05$) at $z \sim 5$ right after some significant expulsion of gas. After that, there is a short phase where f_b increases because the accreted matter has a higher baryonic content (but not necessarily higher than the universal value). Then, in the late phase of evolution of each halo, f_b tends to be constant ($f_b \sim 0.12$) because the average accreted matter tends to have the same baryonic fraction value as the mean value inside virial radii.

5 Conclusions

In summary, our study indicates that in order to reach lower f_b values at $z = 0$ for Milky Way type galaxies, the eviction of cold gas by feedbacks during the first phase of galaxy formation at high redshifts proves to be crucial. If such statement is correct, numerical and observational efforts have to be focused towards characterising the respective role of each feedback process on the IGM at high redshift. But in order to achieve this goal, one must first improve the constraints of the expected energy injection to the IGM from SN, AGN, UV background (etc...) via observations.

I am grateful to the SF2A organising committee and to the Observatoire de la Côte d'Azur for the excellent organisation of the workshop. I warmly thank the chef Khaled and his wonderful team, P. de Laverny, A. Recio-Blanco, N. Nardetto and A. Crida.

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