EPJ Web of Conferences **19**, 01001 (2012)
DOI: 10.1051/epjconf/20121901001

Chemical evolution in hierarchical scenarios

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Abstract. We studied the chemical properties of Milky-Way mass galaxies. We found common global chemical patterns with particularities which reflect their different assembly histories in a hierarchical scenario. We carried out a comprehensively analysis of the dynamical components (central spheroid, disc, inner and outer haloes) and their chemical properties.

1. INTRODUCTION

The formation and evolution of galaxies is an active area of astronomy with challenging questions remaining to be answered such as how disc-like galaxies such as our Milky Way could formed and survived in the current cosmological paradigm [8].

Cosmological hydrodynamical simulations have proven to be a powerful tool to tackle these questions. In the last years, numerical models and codes have been improved importantly and new physics have been included. Nevertheless, the formation of disc galaxies has been difficult to reproduce in numerical simulations since excessive angular momentum loss and very efficient transformation of gas into stars dominate the gas dynamics, producing too small discs and/or too high fraction of baryons locked into stars compared to estimations from observations. Supernova feedback has been proposed and tested as a process capable of injecting efficiently large amount of energy into the interstellar medium, regulating the transformation of gas into stars and eventually triggering mass-loaded outflows. The modellization of SN feedback has improved the description of the baryonic physics in cosmological simulations, resulting in galaxies with better defined disc components although with too large bulges compared to observations. Missing physics such as black hole feedback or numerical limitations such as resolution could be behind these problems [3].

A complementary route to test galaxy formation model is given by chemical properties. The chemical abundances of the stars and the gas combined with their dynamical properties could provide stringent constrains on galaxy formation models [4]. Requiring galaxy formation models to be able to reproduce both the dynamics and the chemical patterns of baryons can help us to underpin physics which could be missing or misinterpreted.

Motivated by these ideas, we studied the chemical properties of stars in Milky-Way mass-type galaxies simulated within the Λ-CDM cosmology, searching for particular characteristics in their assembly histories which could leave imprints in their chemical patterns. Most of our simulated galaxies has a surviving disc component although the spheroidal stellar systems are still important [9]. A detailed discussion of the results summarized in this proceeding can be found in Tissera, White & Scannapieco (2011).

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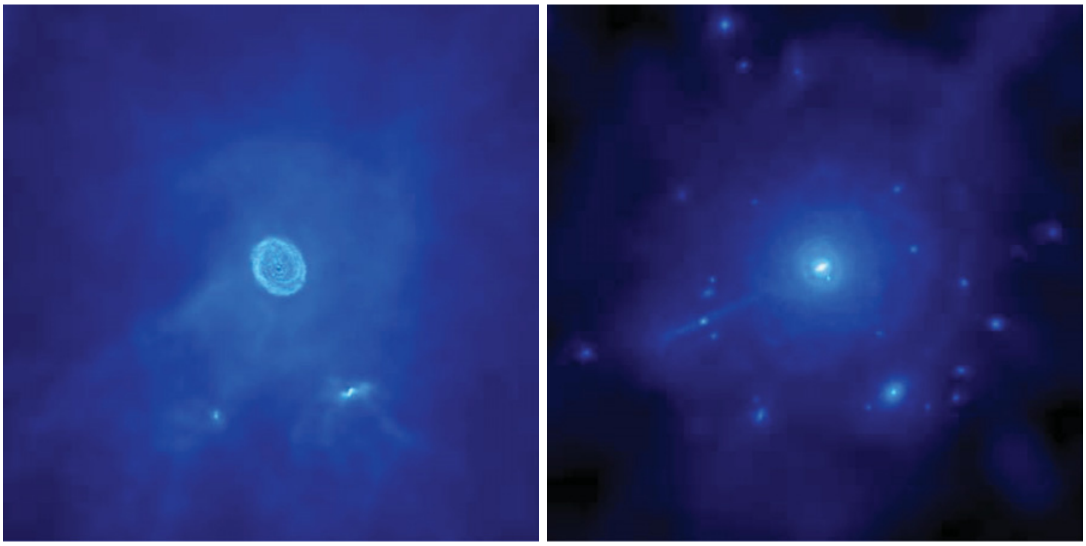

Figure 1. Projected gas (left panel) and stellar (right panel) mass maps of Aq-C-5 halo.

2. SIMULATED MILKY-WAY MASS HALOES

We used the set of eight galaxies simulated by [8]. These haloes were taken from the Millennium-II simulation [2] and assumed a Λ-CDM cosmogony with $\Omega_\mathrm{m} = 0.25, \Omega_\Lambda = 0.75, \Omega_\mathrm{b} = 0.04, \sigma_8 = 0.9, n_s = 1$ and $H_0 = 100\,h\,\mathrm{kms}^{-1}\,\mathrm{Mpc}^{-1}$ with $h = 0.73$. Dark matter particles have masses of the order of 10^6 $\mathrm{M}_\odot$ h^{-1} while initially gas particles have masses of the order of $2 \times 10^5\,\mathrm{M}_\odot\,\mathrm{h}^{-1}$. The final galaxies are resolved with around one million particles within the virial radius. This corresponds to level-5 resolution according to the original Aquarius resolution [10].

The galaxies were run with a version of GADGET-3 which includes a multiphase model for the interstellar medium and a SN feedback sub-grid scheme. The multiphase model improves the description of the gas component density and temperature distributions by allowing the co-existence of cold and dense clouds and hot and diffuse clouds. The SN feedback model is grafted within the multiphase one so that both schemes work successfully together to regulate the transformation of gas into stars and to trigger mass-loaded outflows with a strength modulated by the potential well of the haloes, without the need for mass-dependent parameters [6, 7].

Our version of GADGET-3 also includes the chemical model developed by [5] which describes the enrichment by Type II and TypeIa Supernovae. SNIa are assumed to be originated by the evolution of binary stellar systems with lifetimes in the range [0.7, 2] Gyrs while SNII are considered to take place at the end of the life of massive stars. Specific isotopes are followed in time such as ^{16}O,^{28} Si and ^{56}Fe, among others. The cooling rates of the gas component are estimated according to its metallicity.

The simulations provide us with the stellar and gas distributions and their dynamical and chemical properties as well as their evolution with time. A SUB-FIND algorithm was used to individualize the substructures with a halo, identifying the major ones as the central galaxy and the rest of them as the satellite systems. We also extracted small debris so that the stellar haloes within the virial radius correspond to the diffuse stellar components. In Fig. 1 we show the projected gas and stellar mass distributions of in one of the Aquarius haloes (Aq-C-5).

In order to individualize different dynamical stellar populations (i.e. disc, central spheroid, halo), we follow a procedure similar to that of [1], but introducing new energy-based criteria. We defined $\epsilon = J_z/J_{z,\mathrm{max}}(E)$ for each star, where J_z is the angular momentum component perpendicular to the disc

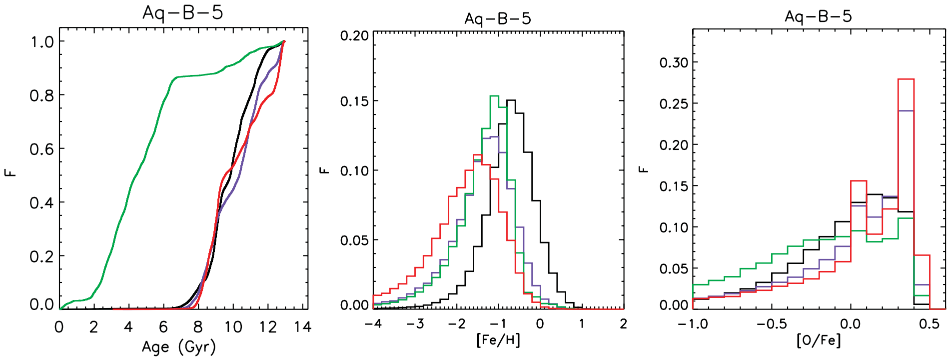

Figure 2. Cumulative stellar mass as a function of age and distributions of [Fe/H] and [O/Fe] for stars in the disc (green), central spheroid (black), inner halo (violet) and outer halo (red) of a typical Aquarius halo.

plane and $J_{z,\max}(E)$ is the maximum J_z over all particles of given total energy, E. We assumed that stars with $\epsilon > 0.65$ will be considered as part of the disc component. The central spheroids are defined by those stars more gravitationally bounded than the minimum energy of stars ($E_{\rm cen}$) with $r \geq 0.5 \times r_{\rm opt}$ where the characteristic radius $r_{\rm opt}$ is the optical radius defined as that which enclosed 83% of the baryonic mass of the main galaxy. The inner halo is determined by those stars less bounded than the E_{cen}, but more bounded than the minimum energy detected for stars with $r \geq 2 \times \mathrm{r}_{\rm opt}$ ($E_{\rm inner}$). Finally, stars with bounded energy smaller than $E_{\rm inner}$ are considered to define the outer diffuse halo. A detail description of the method together with the E-ϵ distributions for each halo can be found in [11].

3. CHEMICAL ABUNDANCES AND STAR FORMATION HISTORIES

We estimated the star formation history of each stellar component of our eight haloes and the corresponding [Fe/H] and [O/Fe] distributions. As an example, in Fig. 2 we show them for the so-called halo Aq-B-5. Other haloes show similar global chemical trends but with differences originated in their diverse formation histories. We found that, in general, the central spheroidal and the haloes are made of old stars, with ages larger than 10 Gyr, while stars in the discs are younger. It is interesting to note that the metallicity distributions of the spheroidal components: central, inner and outer haloes, are quite different even though the ages of their stellar populations are very similar. The central spheroids are more metal-rich and less α-enriched than the inner and outer haloes while between the later ones, the outer halo is the most α-enriched. This behaviour, which is in general good agreement with observations of the Milky-Way galaxies, is reflecting crucial differences between the ways these components were assembled.

4. CHEMICAL ABUNDANCES AND THE ASSEMBLY HISTORIES

We built up the merger trees and followed back in time stars in each dynamical component in order to identified if they had formed *in situ* (i.e. in the main progenitor defined as the most massive structure identified at a given time) or in smaller substructure which were later on accreted onto the progenitor. In this section, we will only talk about the diffuse stellar components since all substructures which could be individualized have been extracted.

We correlated the fraction of stars formed *in situ* and the mean [Fe/H] and mean [O/Fe] abundances of each dynamical component. We found that the larger the fraction of stars formed *in situ*, the larger the level of [Fe/H] and the lower the level of α-enhancement of these stars.

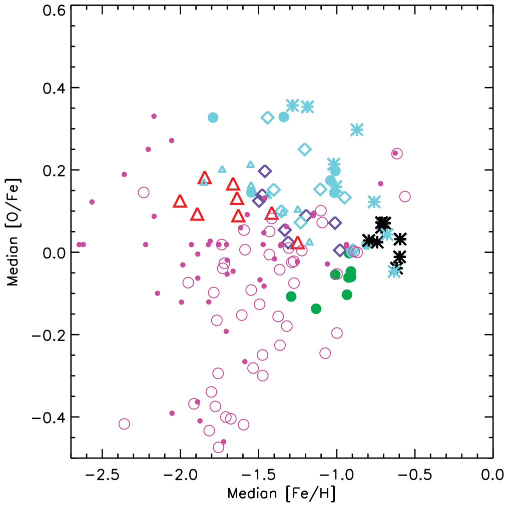

Figure 3. [O/Fe] medians versus [Fe/H] medians for stars in the four stellar components: central spheroids (black), disc (green), inner halo (violet) and outer halo (red), for stars acquired from infalling satellites (cyan) and for stars in surviving satellites (magenta) within the virial haloes.

The disc components are mainly formed inside-out and have negative metallicity gradients in agreement with observed Spirals. On average, stars in the discs have been formed in different starbursts and are clearly younger than those belonging to the spheroidal component. They have low α-enrichment, evidencing the contribution by SNIa. Most of these stars formed *in situ* with around 15% of them coming from accreted satellites. The latter ones have higher α-enrichment and show larger velocity dispersion, being more consistent with the expected properties of stars in a thick disc component.

For the central spheroids, we found that most of their stars formed *in situ*, with percentages varying between 60% and 95%. Two central spheroids out of the eight simulated ones showed an important contribution of accreted stars. We have that, in the central spheroids, the larger the *in situ* fraction of stars, the higher the mean level of α-enrichment. These stars also show high [Fe/H] abundances. Accreted stars have on average, higher α-enhanced than *in situ* ones.

Stars in the inner haloes have contribution from both *in situ* and accreted stars with relative percentages depending on details of their history of formation. As in the case of the central spheroids, on average, accreted stars tend to have higher levels of α-enhancement than *in situ* ones.

The outer haloes are formed by accreted stars. Although we identified a small fraction of *in situ* stars, a more detailed study of the mergers trees at very high redshift show that these stars were actually formed in very small substructures accreted between available snapshots. Hence, we estimated that the diffuse outer stellar haloes are fully made by old and α-enriched stars formed in satellites mainly accreted at high redshift (see Tissera et al. in preparation). There are new contributions from accreted stars with high level of [O/Fe] but these stars have been formed in larger satellites which were acquired more recently.

4.1 The masses of the accreted satellites and the abundance patterns of the dynamical components

In order to further investigate the relation between the history of formation of the dynamical stellar components of the Aquarius haloes and their abundance patterns, we correlated the mass of the disrupted satellites which contributed to each component.

We find that accreted stars in the central spheroids and discs came mainly from small substructures, except when a major mergers occured in more recent times. In the case of the stellar haloes, more massive satellites also contribute. For these components, it is clear that the larger the contribution from massive satellites, the higher the median [Fe/H] abundances and the lower the median α-enrichment. Hence, the mass function of the satellites which contributed to form the diffuse stellar haloes are also relevant to understand their chemical properties.

4.2 Surviving satellites

Surviving satellites in the dark matter haloes have stellar populations which, on average, have different chemical properties than stars in the smooth stellar haloes, since they exhibit lower α-enrichment at a given [Fe/H] abundance (see Fig. 3), in general good agreement with observations [13]. We found that these trends are the result of bursty star formation histories which allowed the subsequent enrichment by SNIa.

The evolutionary histories of the surviving satellites are different from those which were accreted to form the diffuse stellar components since the latter ones were acquired at higher redshift and as soon as they started to form stars. Larger systems which could survive within the halo, were also able to retain gas and to continue their star formation activity given rise new stars with different chemical patterns.

5. CONCLUSIONS

We studied the chemical patterns of Milky-Way mass galaxies in relation to their history of formation. Although our haloes have similar virial masses, they have different history paths which produce galaxies with different morphologies. Their stellar populations show common mean chemical trends with particularities which can be associated to differences in their assembly histories.

Our simulated galaxies show mean abundance patterns in agreement to those observed in nearby galaxies and they can be understand by studying their history of formation in a Λ-CDM.

PBT thanks the organizers of the workshop and acknowledge partial support by PICT 245 Max Planck and PIP 2009/0305.

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