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Linking gaseous and stellar gradients on simulated galaxies of the Local Group

O.F. Marioni[1,2,3] & M.G. Abadi[1,2]

[1] *Instituto de Astronomía Teórica y Experimental, CONICET–UNC, Argentina*
[2] *Observatorio Astronómico de Córdoba, UNC, Argentina*
[3] *Facultad de Matemática, Astronomía, Física y Computación, UNC, Argentina*

Contact / ornela.marioni@unc.edu.ar

Resumen / Estudios observacionales han confirmado la presencia de gradientes verticales y radiales de edad y metalicidad en nuestra galaxia. Estos gradientes son explicados generalmente como producto de la evolución interna de la galaxia causada por las migraciones de las estrellas producidas por los brazos espirales o resonancias con la barra. En nuestro trabajo, medimos los perfiles de edad y metalicidad en galaxias simuladas del Grupo Local usando las simulaciones HESTIA. Encontramos que los gradientes presentes en los perfiles radiales y verticales a corrimiento al rojo $z = 0$, están también presentes en el gas en el mismo tiempo en que se forman las estrellas. También observamos que las propiedades de las estrellas no varían significativamente desde su tiempo de formación. Esto está de acuerdo con la teoría de que las estrellas mantienen las propiedades del gas progenitor, y a medida que el gas evoluciona, se sitúa en un disco cada vez más fino soportado por rotación.

Abstract / Observational studies have confirmed the presence of radial and vertical gradients of age and metallicity in our galaxy. These gradients are generally explained as a product of the internal evolution of the galaxy caused by the migration of stars produced by spiral patterns or resonances with the bar. In our work, we measure age and metallicity profiles in simulated Local Group's galaxies using the HESTIA simulations. We find that the gradients present in the radial and vertical stellar profiles at redshift $z = 0$ are also present in the gas at the same time of star formation. We also observe that the properties of the stars do not vary significantly from their formation time. This is in agreement with the idea that the stars maintain the properties of the progenitor gas, and as the gas evolves, it is settled into a thinner centrifugally supported disc.

Keywords / galaxies: structure — galaxies: star formation — galaxies: formation — galaxies: abundances

1. Introduction

Several studies have confirmed the presence of age and metallicity gradients in the Milky Way. In particular, it is well-known that in our solar neighborhood, star ages correlate with their metallicity (Freeman & Bland-Hawthorn, 2002; Hayden et al., 2014). Near the midplane of the galaxy, the age and metallicity decrease with the radius (Boeche et al., 2013; Hayden et al., 2014). Also, these gradients are linked with the vertical scale of the disc; for a fixed radius, the vertical scale of the disc is higher for older and metal-poorer stars (Mikolaitis et al., 2014; Casagrande et al., 2016). At fixed metallicities, the vertical scale of the disc increases at larger radii, being steeper for lower metallicities (Bovy et al., 2016). These gradients were explained as a product of the secular evolution of the galaxy; radial migration, resonances with a bar, or external perturbations with satellites (see Rix & Bovy, 2013). Understanding the processes involved in the formation of these gradients can help us to comprehend what mechanisms are present in galaxy formation.

There are several galaxy formation scenarios that attempt to explain the origin of these gradients. The most popular scenario settles the initial star-forming gas on a thin disc on the midplane of the galaxy which is centrifugally supported and is enriched by stellar evolution and warmed by the galaxy's secular evolution and mergers with satellites (Rix & Bovy, 2013). In such a way that the early generations of stars occupy a thick disc with higher velocity dispersion, while the later ones continue forming on the gaseous thin disc on the midplane of the galaxy.

The opposite scenario was first proposed by Eggen et al. (1962) who suggest that the gas was initially thick and concentrated at the center of the galaxy. As the stars are formed, the gas is enriched, became thinner, and is extended on a centrifugally supported disc in the midplane of the galaxy. This scenario was discussed in several works like Bird et al. (2013); Navarro et al. (2018); Yu et al. (2022) where they study the evolution of chemical and dynamical properties of stars throughout the formation history of the galaxy. In particular, Navarro et al. (2018) found that the secular processes play a minor role in galaxy evolution and that the stars that are born from the gaseous disc maintain the properties of the progenitor gas. Following this work, we study the gradients present on a Milky Way-like galaxy from the HESTIA (Libeskind et al., 2020) simulations and analyze the correlation between gas and stars at their formation time. The first part of this work was presented on Marioni & Abadi (2021), in this paper we

Oral contribution

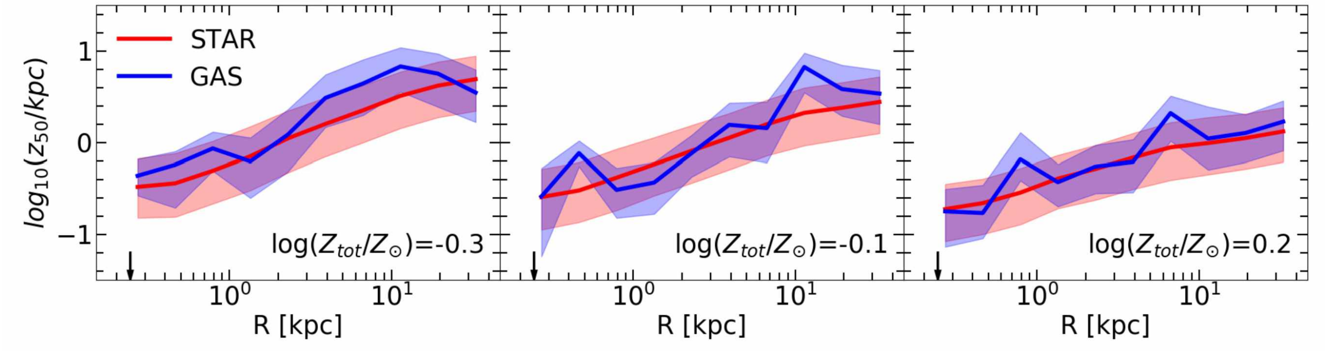

Figure 1: Half-mass high scale profile vs the cylindrical radius for three fixed metallicities. In red is the profile for stars at $z = 0$ and in blue is the profile for the gas at the star formation time. The time for each bin in the gas profile was selected using the characteristic age of the stars at that radius with that metallicity. The black arrow on each panel indicates the softening length. The shadowed regions correspond to the 25 and 75 quartiles.

continue the study of the most massive galaxy of the simulation.

2. Simulations

As mentioned in the previous section, we analyze a Milky Way-like galaxy from the HESTIA (Libeskind et al., 2020) simulations. These simulations are a set of hydrodynamical zoom-in constrained simulations. They used observational data as restrictions on their initial conditions to reproduce in the best way possible the Local Group of galaxies. They are runned with the AREPO code (Springel, 2010; Pakmor et al., 2016), using the galaxy formation model from Grand et al. (2017) and the cosmological parameters of Planck Collaboration et al. (2014): $\sigma_8 = 0.83$, $H_0 = 100h\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$, $h = 0.667$, $\Omega_\lambda = 0.682$, $\Omega_M = 0.270$ and $\Omega_b = 0.048$. In the high-resolution volume, the final mass and spatial resolution achieved are $m_{dm} = 1.5 \times 10^5\ \mathrm{M_\odot}$, $m_{gas} = 2.2 \times 10^4\ \mathrm{M_\odot}$ and $\epsilon = 220$ pc (see Libeskind et al., 2020, for more details). We analyze the most massive halo of the high-resolution region of the 17_11 simulation of HESTIA set (see Table 1 on Libeskind et al., 2020). The virial mass, stellar mass, and virial radius of the selected galaxy are $M_{vir} = 2.60 \times 10^{12}\ \mathrm{M_\odot}$ and $M_{star} = 1.1 \times 10^{11}\ \mathrm{M_\odot}$ and $R_{vir} = 290.0$ kpc respectively. The virial radius is defined as the radius where the density drops to $200\rho_{crit}$. The total mass enclosed by this radius is named as the virial mass and the stellar mass is computed inside $0.15r_{vir}$.

3. Analysis and results

This work is a continuation from Marioni & Abadi (2021), where we analyzed the gradients present in age and metallicity of stars at $z = 0$. Now, we continue the analysis for stars at all times and add the study of gaseous gradients and their correlation with the stellar ones.

In Fig. 1, we can see the half-mass high-scale profile of stars (red line) and gas (blue line) for three fixed metallicities. The stellar profiles are measured at $z = 0$, while the gas is measured at the formation time of these stars. To measure the gas profile, we calculate the characteristic age of the stars at a fixed metallicity in each radial bin. Then, we measure the gas profile at the formation time of these stars in the corresponding radial bin. From the figure, we can see, in each panel, that the gas profile correlates well with the stellar profiles. Both curves are inside the errors of each other [⋆]. The reader can notice that in the three panels, always the gas is noisier than the stars, this is because of the hydrodynamical nature of the gas itself. For each panel, we can see that the vertical profiles increase with the radius independently of the metallicity. Moreover, we see that the vertical scale of the disc is higher for stars (or gas) of lower metallicities.

On the other hand, if we look at the stars at $z = 0$ and compare themselves at their formation time we obtain the results of Fig. 2. In this figure, we show the vertical and metallicity profiles of stars at $z = 0$ (dashed lines) and the same stars at their formation time (solid lines). From the *top row*, we see that the vertical scale of the disc increase with the radius being higher for older stars; i.e. the newer formed stars are born nearest the midplane. From the *bottom row*, we can see that the metallicity profiles decrease with the radius and the slope is steeper for older stars. Also, we can notice that older stars have lower metallicities. From all panels, we see that the profiles of stars do not change significantly from their formation to $z = 0$. These results suggest that the stars do not evolve meaningfully from their formation and they maintained the properties of the progenitor gas.

4. Conclusions

We analyzed a set of the new HESTIA simulations (Libeskind et al., 2020). These simulations reproduce a Local Group-like pair of galaxies to help us to understand the physical processes involved in the formation of our Galaxy and their neighbors. We studied the presence of vertical and radial gradients on the metallicity and age distribution of a simulated Milky Way-like

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[⋆] We take the 25 and 75 quartiles to indicate the error region.

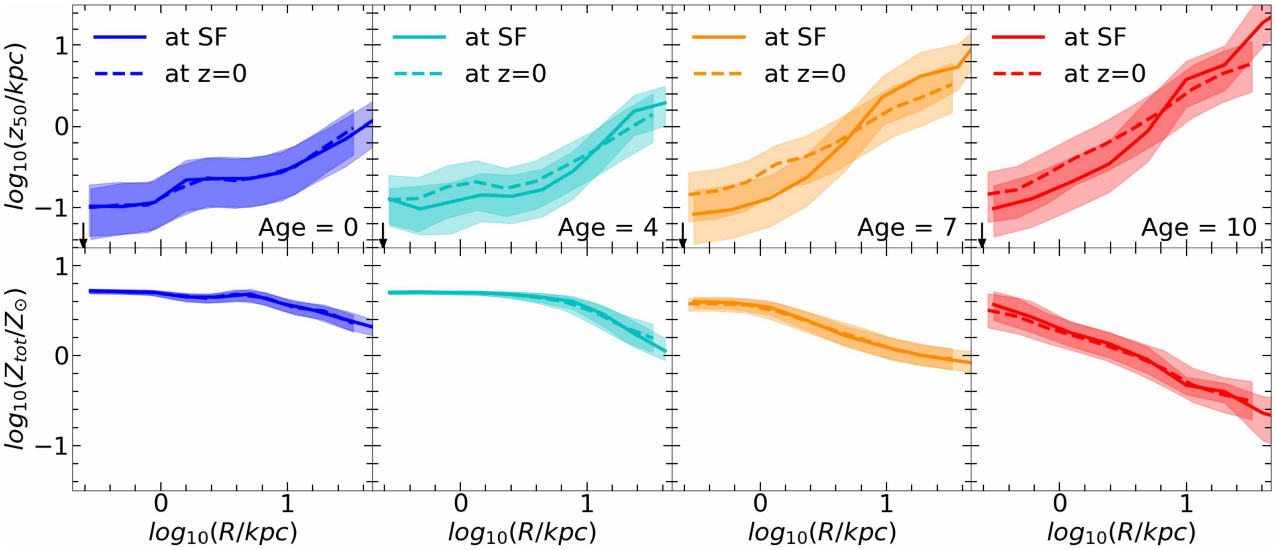

Figure 2: Half mass high scale profile (*top row*) and metallicity profile (*bottom row*) for stars at $z = 0$ (dashed line) and stars at their formation time (solid line). Each column corresponds to an age bin (±0.5Gyr). Black arrows in the *top panels* indicate the softening length. The shadowed region corresponds to the 25 and 75 quartiles.

galaxy. In a previous work (Marioni & Abadi, 2021) we have analyzed the presence of gradients in star ages and metallicities at redshift $z = 0$. Now, we compared these gradients at redshift $z = 0$ with the gas metallicity and age distribution at the time of star formation. We could find that the gradients present in stars at $z = 0$ are also present in the gas at the time of star formation. This may suggest that stars inherit the properties of the progenitor gas at their formation time and evolve very shortly thereafter, which would seem to indicate that secular evolution plays a minor role in the formation processes of these galaxies. These results are in agreement with the work of Navarro et al. (2018).

A recent study of Yu et al. (2022) where they study the dynamics and evolution of the galaxy components have arrived to the same conclusion. All this reinforces the theory of a galaxy formation scenario where the gas begins to form stars at an early age near the center of the galaxy and as it evolves it settles into an increasingly thin disk in the midplane.

References

Bird J.C., et al., 2013, ApJ, 773, 43
Boeche C., et al., 2013, A&A, 559, A59
Bovy J., et al., 2016, ApJ, 823, 30
Casagrande L., et al., 2016, MNRAS, 455, 987
Eggen O.J., Lynden-Bell D., Sandage A.R., 1962, ApJ, 136, 748
Freeman K., Bland-Hawthorn J., 2002, ARA&A, 40, 487
Grand R.J.J., et al., 2017, MNRAS, 467, 179
Hayden M.R., et al., 2014, AJ, 147, 116
Libeskind N.I., et al., 2020, MNRAS, 498, 2968
Marioni O.F., Abadi M.G., 2021, BAAA, 62, 140
Mikolaitis Š., et al., 2014, A&A, 572, A33
Navarro J.F., et al., 2018, MNRAS, 476, 3648
Pakmor R., et al., 2016, MNRAS, 455, 1134
Planck Collaboration, et al., 2014, A&A, 571, A16
Rix H.W., Bovy J., 2013, A&A Rv, 21, 61
Springel V., 2010, MNRAS, 401, 791
Yu S., et al., 2022, arXiv e-prints, arXiv:2210.03845