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Age and metallicity gradients in simulated galaxies of the Local Group

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Resumen / Presentamos resultados preliminares sobre la presencia de gradientes radiales y verticales en edad y metalicidad de galaxias simuladas similares al Grupo Local, utilizando la nueva generación de simulaciones hidrodinámicas de alta resolución *HESTIA*. Este conjunto de simulaciones utiliza datos observacionales, como restricción en sus condiciones iniciales, para simular el entorno local. Analizamos los halos más masivos de una de estas simulaciones. Estudiamos las distribuciones de edad y metalicidad de estas galaxias y encontramos presencia de gradientes verticales y radiales. Estos gradientes muestran que la población estelar más vieja y menos metálica tiene una escala vertical más alta que la población de estrellas más joven y más metálica. La escala vertical aumenta hacia las afueras de la galaxia y esta tendencia se observa en todos los bines de edad estelar. Este tipo de gradientes son observados también en la Vía Láctea, analizar su origen puede ayudarnos a comprender la historia de formación de nuestra galaxia.

Abstract / We present preliminary results regarding the presence of radial and vertical gradients in age and metallicity of simulated Local Group-like galaxies, using the new generation of high-resolution hydrodynamical zoom-in simulations *HESTIA* (High-resolution Environmental Simulations of The Immediate Area). These set of simulations use observational data, as constraint in their initial conditions, to simulate the local environment. We analyzed the most massive halos of one of these simulations. We studied the metallicity and age distributions of these galaxies and found the presence of vertical and radial gradients. These gradients show that the older and less metallic population have a higher vertical scale, than the younger and more metallic population of stars. The vertical scale increase to the outskirts of the galaxy and this trend is seen for all stellar ages. This kind of gradients is seen also in the Milky Way, analyzing their origin can help us to understand the formation history of our galaxy.

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

1. Introduction

It is well known that galaxies and in particular, the Milky Way, present well-established radial and vertical gradients on their structures. In particular, in the solar neighbourhood, age of stars correlates with their metallicity (Freeman & Bland-Hawthorn, 2002; Hayden et al., 2014). In the midplane of the Galaxy, the average of age and metallicity of stars decreases when increasing the radius (Boeche et al., 2013; Hayden et al., 2014). At a fixed radius, the vertical scale of the disc increases when we look older or lower metallicity stars (Mikolaitis et al., 2014; Casagrande et al., 2016). The vertical scale of the disc depends on the radius, becoming steeper at smaller radii (Hayden et al., 2014). If we look at a fixed metallicity, it is found that the vertical scale of stars increases towards the outskirts, these are the well-known flares. These flares depend on metallicity, being more pronounced to lower metallicity (Bovy et al., 2016).

Historically, these gradients were interpreted as part of the internal evolution of the Galaxy, produced by process like radial migration generated by spiral patterns, resonance with a bar, perturbations brought about interactions with satellites, among others. Understanding the origin of these gradients can help us to understand the process involved on galaxy formation. Some models about the origin of these gradients are present in the literature. One of these models suggests that the gradients arise as the result of the gradual enrichment of the gaseous disc that initially settles thick but as the gas transform into stars, it becomes thinner and settles on centrifugal equilibrium in the midplane of the galaxy. Other model considered to explain these gradients presents the opposite idea. It could be that, in fact, the secular processes play a minor role on the evolution of the galaxy and the properties of stars that form in the galaxy depend only on the properties of the progenitor gaseous disc.

This work is an extension of the work of Navarro et al. (2018) where they use a isolated Milky Way-like galaxy of the *APOSTLE* simulations. They found that the gas at the epoch of star formation presents similar properties of the stars of that age. The stars that born on a certain epoch do not evolved so much since their formation, taking the spotlight off the secular evolution model of galaxy formation.

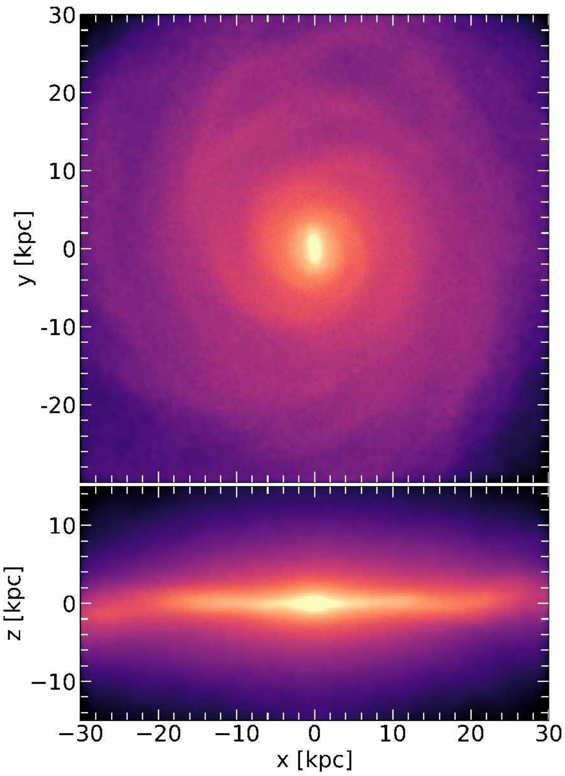

Figure 1: Face-on (*top panel*) and edge-on (*bottom panel*) views at redshift $z = 0$ of the stellar mass density distribution of the galaxy. These density maps were generated using the package Py-SPHViewer (Benitez-Llambay, 2015) of Python.

2. Simulations

For this work we use the *HESTIA* (Libeskind et al., 2020, High-resolution Environmental Simulations of The Immediate Area) simulations. These simulations are a new generation of zoom-in simulations that combine the state-of-the-art *AURIGA* galaxy formation model (Grand et al., 2017) with a modern magneto-hydrodynamic treatment of the cosmic gas with the *AREPO* code (Springel, 2010; Pakmor et al., 2016) using constrained initial conditions made of observational data to reproduce the local environment. The simulations are designed in order to reproduce, in the best way possible, the local environment with the principal neighbouring structures: i.e. a pair of galaxies analogous to Andromeda and the Milky Way living in an environment with the same conditions that we found on the Local Group, like its surrounding satellites, the Virgo cluster and the Local Void. Obtaining this conditions we can study these galaxies and understand the formation processes that take part on the evolution of our own galaxy.

These simulations use cosmological parameters of the best fit of Planck Collaboration et al. (2014): $\sigma_8 = 0.83$, $H_0 = 100h$ km s^{-1} Mpc^{-1}, $h = 0.667$, $\Omega_\lambda = 0.682$, $\Omega_M = 0.270$ and $\Omega_b = 0.048$. The final mass and spatial resolution achieved are: $m_{dm} = 1.5 \times 10^5$ M$_\odot$, $m_{gas} = 2.2 \times 10^4$ M$_\odot$ and $\epsilon = 220$ pc (see Libeskind et al., 2020, for more details).

3. Results

In this paper, we show previous results over the most massive halo of one of these set of simulations. We use the high-resolution simulation 17_11 of *HESTIA* set (see Table 1 on Libeskind et al., 2020). The virial mass, stellar mass and virial radius of the studied galaxy are, $M_{vir} = 2.60 \times 10^{12}$ M$_\odot$ and $M_{star} = 1.1 \times 10^{11}$ M$_\odot$ and $R_{vir} = 290.0$ kpc respectively. We define the virial mass as the mass enclosed on the virial radius, which is the radius where the density drops to $200\rho_{crit}$. The stellar mass is calculated inside $0.15r_{vir}$.

In Fig. 1, we show the face-on (top panel) and edge-on (bottom panel) stellar mass density projection of the galaxy. We can see that the galaxy presents a relatively thin disc with several spiral arms. On the edge-on view, we can note that the disc is flared to the outskirts.

In Fig. 2, we show the mass density projection of stars at $z = 0$ in age bins. Panels of the top show face-on views and panels on the bottom edge-on views. Each column corresponds to stars of (from left to right) 0, 4, 8 and 10 Gyr of age in a range of ± 0.5 Gyr. We can see that the younger stars live mainly in the midplane of the disc and the spiral arms of the galaxy. As we move to older stars, we can see that the region they occupy on the disc becomes more thicker around the midplane. For stars of 8 and 10 Gyr, we can see that they live near the center of the galaxy in a more triaxial region.

The main goal of this work is to understand the origin of these gradients. Studying the evolution of this galaxy, following stars and gas could bring us an important clue about galaxy formation. There are two main models to explain the settle of these gradients. The first is an inside-out scenario, i.e. the gas settles in a thin disc in the midplane of the galaxy and the stars born in this gaseous disc. As stars evolve, acquire velocity dispersion because of the secular evolution or external perturbations. Therefore, older stars live in a thicker structure, and younger stars, that did not have enough time to be disturbed, in a thin disc on the midplane of the galaxy.

The other model suggests the opposite idea: an outside-down scenario. This model proposes that the secular evolution plays a minor role on galaxy evolution. The gas, initially located on a thick disc, forms stars and these stars do not evolved so much during galaxy evolution keeping the progenitor gas properties. As the galaxy evolves, the gas becomes colder and set on a thinner disc forming new stars near the midplane galaxy.

These gradients on age are also accompanied by metallicity gradients. In Fig. 3 we show the average stellar age (top panel) and metallicity (bottom panel) distribution on the cylindrical coordinates R and z. In top panel, we can see the same trend that we see in Fig. 2. Younger stars locate near the midplane and at larger radii, while older ones concentrate at smaller radii and higher $|z|$. The color dashed lines correspond to the half-mass scale-height of stars of 4 Gyr (blue line), 8 Gyr (black line) and 10 Gyr (red line) taken in bins

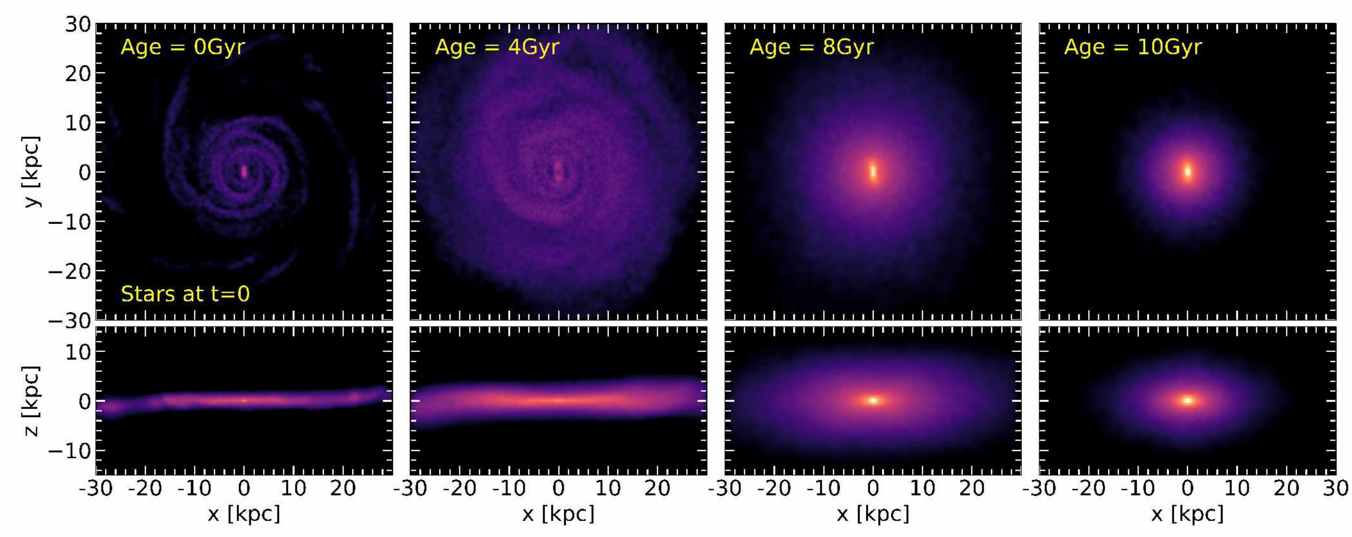

Figure 2: Stellar mass density projections of stars at redshift $z = 0$ for stars of different ages. Face-on view on the *top panel* and edge-on view on the *bottom panel*. The different columns correspond to stars of 0, 4, 8 and 10 Gyr (± 0.5 Gyr). These density maps were generated using the package Py-SPHViewer (Benitez-Llambay, 2015) of Python.

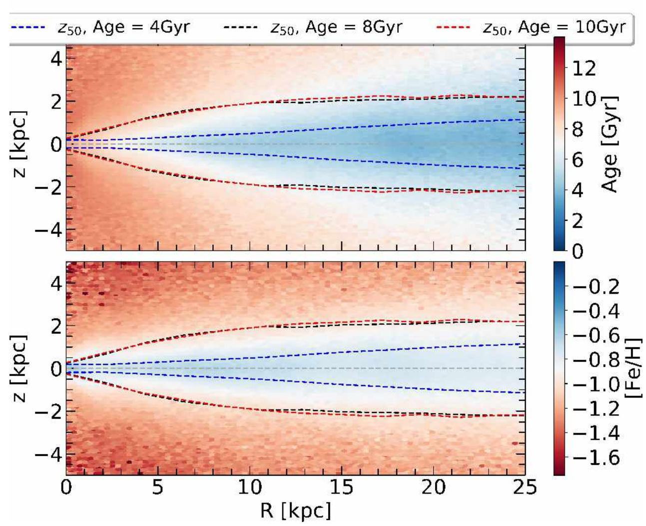

Figure 3: Average stellar age (*top panel*) and metallicity (*bottom panel*) distribution of star particles at redshift $z = 0$ in the cylindrical coordinates R and z. The color dashed lines (on both panels) correspond to the half-mass scale-height of stars of different ages: 4 Gyr (blue line), 8 Gyr (black line) and 10 Gyr (red line). The stars of different ages are selected in bins of ± 0.5 Gyr.

of ± 0.5 Gyr. We see that the half-mass scale-height of stars is growing with radius getting higher at larger radii and it is even higher for older stars. This increase of the half-mass scale-height at the outskirts shows us that the disc is flared as we can see also on the edge-on view of Fig. 1.

In the bottom panel of Fig. 3, we can see that the most metallic stars have similar distribution of younger stars; they locate near the midplane of the disc for all radii. At a fixed R, stars become more metal poor as we move away of the midplane of the galaxy and correlate with older stars too.

4. Summary and conclusions

We analyze the new set of constrained hydrodynamical cosmological simulations: *HESTIA*. These simulations reproduce a Local Group-like pair of galaxies that live in an environment similar as our Local Group neighbourhood. We present preliminary results of the analysis of the most massive halo of one of these simulations. We see that the most massive halo is a Milky Way-like galaxy with prominent spiral arms and thin disc. Besides, it presents a noticeable flared disc. We find radial and vertical gradients on age metallicity distribution according with observations. Younger and more metal-rich stars concentrate near the midplane of the galaxy having higher vertical scale at larger radii. Older and more metal-poor stars locate predominantly at smaller radii and at higher vertical scales. There are a segregation of stellar ages as we move away from the midplane of the galaxy.

In our future work, our goal is to study the behaviour of stars and gas at higher redshift to explain the origin of these gradients in *HESTIA* simulations. This study will be provide an extension of the work of Navarro et al. (2018).

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