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PRESENTACIÓN ORAL

Alpha-element enhancement in a Λ-CDM Universe

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Abstract. We study the chemical enrichment of elliptical galaxies using a semi-analytic model of galaxy formation combined with a cosmological N-body simulation of dark matter particles. In particular, we study the α-element abundances with respect to the iron content of galaxies. The main modification to the previous models (Cora 2006; Lagos et al. 2008; Tecce et al. 2010) was the implementation of a top heavy variable initial mass function with a theoretical basis (Weidner & Kroupa 2004, 2005, 2006; Weidner et al. 2011). We find that with a single initial mass function at all epochs the observed trend of $[\alpha/\mathrm{Fe}]$ with the stellar mass of elliptical galaxies can be hardly reproduced. We propound that a top heavy integrated galactic mass function can be a plausible solution for this problem.

Resumen. Estudiamos el enriquecimiento químico de galaxias elípticas aplicando un modelo semi-analítico de formación de galaxias a una simulación cosmológica de N-cuerpos de materia oscura. En particular, estudiamos las abundancias de elementos α respecto al contenido de hierro de las galaxias. La modificación más importante que se le hizo al modelo usado en trabajos previos (Cora et al. 2006; Lagos et al. 2008; Tecce et al. 2010) fue la implementación de una función de masa inicial variable con fundamento teórico (Weidner & Kroupa 2004, 2005, 2006; Weidner et al. 2011). Encontramos que con una función inicial de masa única para todas las épocas y condiciones en el Universo sería difícil de reproducir la tendencia observada de cocientes $[\alpha/\mathrm{Fe}]$ con la masa estelar de galaxias elípticas. Proponemos que una función inicial de masa integrada galáctica y plana para altas masas puede ser una solución plausible a este problema.

1. Introduction

The last decade has witnessed a large advance in the capacity of obtaining spectral information from large samples of galaxies in the nearby Universe, due to the realization of large spectroscopic surveys (e.g. Sloan Digital Sky Survey, SDSS; Abazajian et al., 2009), as well as direct observations of galaxies. A direct yield of the spectral analysis are the abundance ratios of different species. In particular, the abundances of alpha-elements relative to iron have been an issue of great interest because of a trend observed in the relation of these ratios with the mass of elliptical galaxies, where the more massive ones have larger values of $[\alpha/\mathrm{Fe}]$ than less massive ellipticals (Trager et al 2001; Thomas et al. 2005; Spolaor et al. 2010; Thomas et al. 2010, T10 hereafer). The α-elements are mainly products of type II supernovae (SNe II), the final stage of stars more massive than $8M_{\odot}$, with lifetimes of the order of tens of Megayears. On the other hand, type Ia supernovae (SNe Ia) are the final stage of low mass (below $8M_{\odot}$) and long lived (between 0.5 and 3 Gigayears) binary systems that produce mainly Fe and Fe-peak elements (Tinsley 1979). These different timescales for the production of $\alpha-$elements and Fe and the consequent enrichment of the gas in the interstellar medium (ISM) have been used to infer the formation time scales of the stellar populations in galaxies (Mateucci 1994; Thomas et al 2005). In this sense, galaxies with larger $[\alpha/\mathrm{Fe}]$ ratios are considered to form in a shorter time interval than galaxies with lower ratios. A priori, the observed trend of $[\alpha/\mathrm{Fe}]$ versus stellar mass could be interpreted as anti-hierarchical, because galaxies in a hierarchical scenario would be expected to grow in a bottom-up fashion, with more massive galaxies taking longer periods to build up their masses. Nevertheless, different physical explanations can be invoked to reconcile theory with observations. The aim of this contribution is to propose a variable and galactic integrated initial mass function to address this problem.

2. The Model

For this contribution we use a semi-analytic model of galaxy formation (*SAG2*, achronym for Semi-Analytic Galaxies) that is aplied to the outputs of a cosmological dark matter simulation of $67.68h^{-1}\,\mathrm{Mpc}$ side, to assign properties to the galaxies residing in the center of each dark matter halo identified in the simulation. This model is based on various former versions (Cora et al. 2006; Lagos et al. 2008; Tecce et al. 2010). For details of the semi-analytic model we refer the reader to these previous works, but it is important to note that the SAG2 model considers the feedback processes from SNe and Active Galactic Nuclei (AGNs) and has a detailed modeling of the chemical enrichment of galaxies that takes into account the stellar lifetimes (Padovani et al. 1993) and the metals contributed by the ejecta of both SNe Ia and SNII, as well as by the mass loss of low mass stars. These aspects are essential for a proper study of the chemical evolution of galaxies and, in particular, of their abundances of $\alpha-$elements with respect to the iron content achieved by them.

2.1. A top heavy-integrated initial mass function

In this work, we modify the semi-analytic model SAG2 considering a new scheme of star formation, that includes a top heavy integrated galactic initial mass function (Top heavy IGIMF, Weidner et al. 2011). The Top heavy IGIMF is a modification of the IGIMF developed during the last decade (Weidner & Kroupa, 2004, 2005, 2006) with an extra assumption, i.e, the clusters more massive than $10^5 M_{\odot}$ form stars with a more top heavy IMF. The final adopted Top heavy IGIMF can be translated in

$$\xi(m) = k \begin{cases} m^{-\alpha_1} & , m_{\mathrm{low}} \leq m < m_0, \\ {m_0}^{-\alpha_1} \left(\frac{m}{m_0}\right)^{-\alpha_2} & , m_0 \leq m < m_1, \\ {m_0}^{-\alpha_1} \left(\frac{m_1}{m_0}\right)^{-\alpha_2} \left(\frac{m}{m_1}\right)^{-\alpha_{\mathrm{IGIMF}}} & , m_1 \leq m < m_{\mathrm{max}}, \end{cases} \tag{1}$$

where $m_{\rm low}$ is equal to $0.1M_{\odot}$, $m_0 = 0.5M_{\odot}$, $m_1 = 1.3M_{\odot}$, $m_{\rm max}$ is $100M_{\odot}$, $\alpha_1 = 1.3$, $\alpha_2 = 2.35$ and $\alpha_{\rm IGIMF}$ is a variable slope that depends on the star formation rate (SFR) of the galaxy at the time of formation. Larger SFRs give rise to shallower slopes. k is a normalization constant, so that $\int_{m_{\rm low}}^{m_{\rm max}} \xi(m)\, m\, {\rm d}m = 1$.

3. Results and discussion

We present the results regarding the dependence of α-enhancement with stellar mass for both our reference model and the model with the Top heavy IGIMF implemented as described in section 2.1. The former considers a Salpeter IMF; the free parameters involved in the formulae that describe different physical processes are calibrated to reproduce typical observational constrains at $z = 0$ (e.g., luminosity function, mass-metallicity of gas, black hole mass-bulge mass relation, etc.). These same set of parameters are used in the modified version of SAG2 to analyze the impact of the Top heavy IGIMF on the chemical properties of galaxies. In figure 1 we show the $[\alpha/{\rm Fe}]$ ratios vs. the logarithm of the stellar mass of elliptical galaxies in the model. For comparison, we plot the data obtained by Trager et al. (2001) as shown in Arrigoni et al. (2010), and the linear fit to the sample of red sequence galaxies from Thomas et al. (2010). For comparison, we divide our sample in active and passive galaxies. We follow Kimm et al. (2011) to define active galaxies in terms of the specific SFR at $z = 0$; we estimate this quantity averaging the SFR over the last four snapshots of the simulation, that is, up to redshift $z = 0.08$. We can see that, in the case of a Salpeter IMF, model results do not follow the relationship between $[\alpha/{\rm Fe}]$ ratios and masses of galaxies as indicated by observational data, pointing that it is difficult to reconcile model and observations with a classical approach of IMF. On the other hand, the model with a Top heavy IGIMF is more consistent with the observed trend, although a great scatter is present in the results. We find that, in both models, the active and passive galaxies occupy the same regions in the plot, while Thomas et al. (2010) found that active galaxies, mainly present in low density environments and with renewed star formation, migrate in the diagram to lower $[\alpha/{\rm Fe}]$ ratios because the stars in these galaxies form from iron enriched gas from SNIa. These results show that there are caveats in the modeling of the star formation histories of galaxies, although one can reproduce other observated relations at $z = 0$. The evolution of galaxies strongly depend on the combination of star formation and feedback processes, both from SNe and AGNs, and a better understanding of these aspects and their proper modeling are needed to reproduce the $\alpha - element$ enhancement in a Λ-CDM Universe, which constitute an excellent constrain for any model of galaxy formation.

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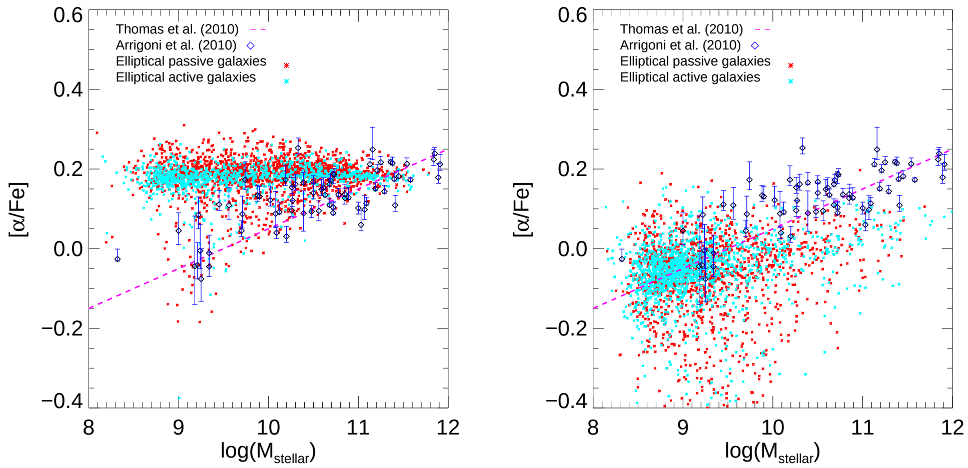

Figura 1. *Left:* $[\alpha/\mathrm{Fe}]$ vs. $log(M_{stellar})$ for elliptical galaxies in the reference model . Blue and red asterisks correspond to active galaxies and passive galaxies, respectively. Blue diamonds are data from Trager et al. (2000) as shown in Arrigoni (2010). The magenta dashed line is a linear fit to the sample of red sequence galaxies from Thomas et al. (2010).
Right: Same as in the left panel but for the model with a Top heavy IGIMF.

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