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Chemical feedback from SNIa in isolated galaxies

The Single Degenerate Scenario

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Abstract. The nature of the Supernova Ia progenitors remains unknown. This is a major issue for galactic chemical evolution models since both chemical and energy feedback influence the evolution of baryons. The progenitor models for the supernovae Ia available in the literature propose different shapes for the function which regulates the explosion times of the SNIa. In this work, we include for in hydrodynamical simulations the Single Degenerate scenario for supernova type Ia. We analyse the implications for the chemical enrichment of galaxies. Our best scenario can reproduce the [α/Fe] ratios for bulge-dominated type galaxies, the observed SNIa rates and the observed correlation between the the star formation and the supernova Ia rates in galaxies.

Key words. Galaxy: chemical enrichment– Galaxy: abundances – Galaxy: evolution – Galaxy: supernovae type Ia

1. Introduction

Galaxy formation constitutes a multi-scale highly non-linear process. Observations such as the galactic chemical abundances can set strong constrains on the galaxy formation models. The observed chemical patterns can relate nucleoshyntesis products coming from the stellar populations with the processes involved in the galaxy formation. This has been done both with the use of hydrodynamical cosmological simulations (Mosconi et al. 2001; Scannapieco et al. 2005; Tissera et al. 2013), and with semi-analytic models of galaxy formation (Pipino et al. 2009; Jiménez et al. 2011; Yates et al. 2013). It is well known that supernovae core collapse (SNe Type II) are produced by massive short-lived stars (M> 8 $M_{\odot}$). The residual production of these events feeds the interstellar medium (ISM) with energy and the α-elements (O, Ne, Mg, Si, S and Ca). On the other hand, the supernovae type Ia (SNIa) are the main contributors of the Fe in the Universe. The lifetime of SNIa are longer than SNII and consequence the relative enrichment of chemical element is different, impriting chemical features which can use as clocks. In this work, we present preliminary results of a extended work aim at testing the effects of using different life-time distributions for SNIa. In particular, we focus on Single Degenerate (SD) scenario. By studying of the enhancement of the α-elements relative, we learn about the time-scales in which SNIa becomes important and the efficiency of the feedback processes in galaxies.

2. The simulations: general characteristics

We use an extended version of the Tree-PM SPH code GADGET-3 (Springel 2005), which includes star formation, chemical enrichment and supernova feedback (from Type II and Type Ia). Metal-dependent cooling (Sutherland & Dopita 1993) and a multiphase model for the gas component are considered (Scannapieco et al. 2005, 2006). We refer to this model as the "Original Model" to distinguish it from the models we present here. In the Original Model, the lifetime of the binary system that explodes as a SN Ia is assumed to be in the range of $\tau_{SNIa} = [0.1, 1]$ Gyr. The number of SNIa is settle by fitting the observational range for the relative ratios of SN II and SN Ia rates from van den Bergh (1991). In all the models, the yields for SNII are taken from Woosley & Weaver (1995). For the chemical yields of SNIa, we use W7 mode by Iwamoto et al. (1999). The initial condition (IC) consists of a dark matter potential corresponding to a Navarro et al. (1997) profile with a halo concentration of c= 9. The baryonic gas phase is initially in hydrostatic equilibrium within the Dark Matter potential. The typical virial mass of the systems is $M_{200} = 10\times10^{11}$ $M_\odot$, with 10% of this mass in form of baryons. The initial number of gas particles is 50000, with a softening length for the gas of $\sim$ 200 pc. The inital gas mass particle is 3.5×10^5 $M_\odot$while the stellar mass particles is 7×10^5 $M_\odot$. This initial galaxy is composed by a bulge and a disk component. The initial gas fraction is 50%, distributed in the disc component. We notice that all the simulations show a bursty star formation rate (SFR), which ends before 1 Gyr due to the gas consumption into stars and the effects of SN feedback which ejects part of it. The final stellar mass of the galaxies is nearly the same for all the simulations, around 2.2×10^{10} $M_\odot$. By comparison of these SF histories with the ones given by the model of Pipino & Matteucci (2004), we conclude they resemble spherodal-type galaxies. And this is consistent with the fact that the gas become unstable and collapse to the central region feedback the strong starburst. Most of the new stars are centrally concentrated in forming a spheroidal component.

2.1. Including the SD in the simulations

In the SD scenario, the SNIa originate from white dwarfs (WDs) in binary systems with one C-O WD and a red (super) giant star (Whelan & Iben 1973). The WD accretes mass from the red giant through the Roche lobe, and an explosive nucleosynthesis process occurs when the WD reaches the Chandrasekhar mass. We include the formalism proposed by Matteucci & Recchi (2001) (from now, MR01), in our simulations where the SNIa rate results:

$$R_{\mathrm{Ia}}(t) = A \int_{M_{\mathrm{B,inf}}}^{M_{\mathrm{B,sup}}} dM_{\mathrm{B,sup}}\, \phi(M_{\mathrm{B}}) \times \int_{\mu_{\min}}^{\mu_{\max}} d\mu\ f(\mu) \psi(t - \tau_{M_2}) \qquad (1)$$

The star formation ψ has to be evaluated at the time $(t-\tau_{M_2})$, with τ_{M_2} being the lifetime of the secondary star and the clock for the explosion. In particular, Greggio & Renzini (1983) considered that only stars with $M \leq 8M_\odot$ could develop a degenerate C-O core, thus obtaining an upper limit $M_{BM} = 16M_\odot$ for the mass of the binary system. The adopted lower limit is $M_{Bm} = 3M_\odot$. The constant A represents a free parameter which indicates the fraction of binary systems necessary to produce SNIa relative to all the stars in the mass range 3-16$M_\odot$. This is fixed a *posteriori* to fit observed rates of SNIa at present day, for a given type of galaxy.

We run 4 simulations with the same IC and the implementation of the SD model of MR01,

Table 1. Characteristics of the simulated galaxies. Observed value for the SNIa rates for S0 galaxies with 3.5×10^{10} $M_{\odot}$, is 0.0011 SN/yr (Li et al. 2011)

Sim. Name	A	<SFR> [$M_{\odot} yr^{-1}$]	SNIa rates (N/yrs)
Original Model	0.0015	63	0.0001
Model 1	0.0015	83	0.002
Model 2	0.00015	60	$6.02{\times}10^{-5}$
Model 3	0.0075	84	0.0080
Model 4	0.00075	76	0.0016

varying only the value of A. The main characteristics can be seen in Table 1. We notice that the SFR is affected by the number of SNIa events occurring in the galaxies. This is expected, since the cold gas available for star formation changes accordingly with the number of SNIa explosions. Thus, we find that a large A produces many SNIa events and hence, the SF of the galaxy is halted before in comparison to those experiment with a lower A .

3. The [α-elements/Fe] for the SD scenario

It is expected that the delay on the production Fe by SNIa ejected into the ISM in relation to the rapid production of α elements by SNII, leaves a characteristic signature in the [α/Fe] vs [Fe/H] diagram (Matteucci & Recchi 2001). The main effect of the delayed Fe production in relation to the α elements produced by SNII is to create an over-abundance of O relative to Fe, until SNIa become important and the ratio [O/Fe] declines. This point is identified by a typical knee in the plot.

In Fig. 1 the average stellar mass abundance of [Fe/H] and [O/Fe] for the three of the simulated galaxies are shown. Additionally in the same figure, the Galactic bulge data by Gonzalez et al. (2011) is presented. The data are spectra of low resolution (R= 22500) for 650 bulge red giant branch (RGB) stars. It worth noting that the bulge data refer to Mg whereas the theoretical predictions refer to O. However, we are allowed to make this comparison since Mg and O behave in a similar way (see François et al. 2004). In fact, they are both formed and ejected by massive stars on short

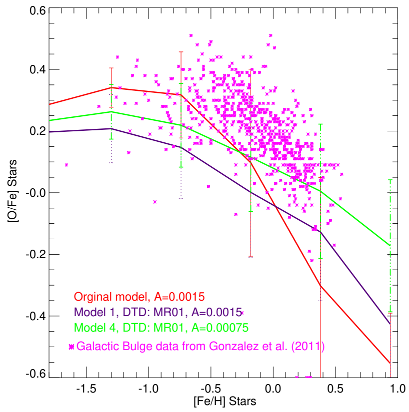

Fig. 1. [α-elements/Fe] exhibited by the Original Model and Model 4. We compare our simulations with observational data for α-elements coming from the Galactic Bulge by Gonzalez et al. (2011)

time-scales. An analysis of Fig. 1 shows that Original model fits the data only at low [Fe/H] but then it shows a knee and a rapid descent not observed in the data. This means than in the Original Model the SNe Ia were overestimated and occurred too soon. The Original Model and Model 1, which share the same value of A, produce a different curvatures, being the latter the most effective in enriching the stars, ending with a abundance of [Fe/H]> 1. Finally, Model 4 (A=0.00075) seems the best one. It does not pass exactly in the data, but this is due to the fact that we are comparing O and Mg. Here the important feature is the shape of the [α/Fe] vs. [Fe/H] relation. Interestingly, Model 4 also fits other two observables: the present

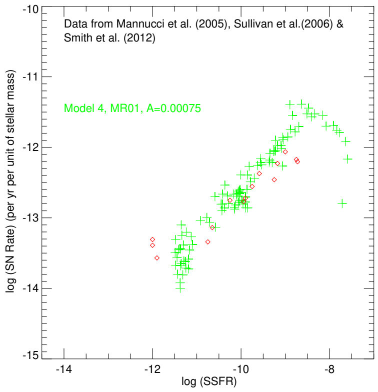

Fig. 2. Specific star formation rate (SSFR) as a function of the SNIa rate per unit of galaxy mass (SSNIaR), for Model 4. The red rhombus represent data from Sullivan et al. (2006); Mannucci et al. (2005); Smith et al. (2012). This model also fits the abundances of the Galactic bulge and the observed rates for SNIa in S0 galaxies.

time rates of SN Ia (see Table 1) and the correlation found by Sullivan et al. (2006) and Smith et al. (2012), between the SFR per unit mass of the galaxy (SSFR) and the specific SNIa rate per unit of galaxy mass (SSNIaR). The observed and simulated correlations are presented in Fig. 2, for Model 4. In a forthcoming paper, we will explore other scenarios for the SNIa progenitors.

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