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Dynamical and Chemical Evolution of IZw18

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Abstract: We study the effect of different star formation regimes on the dynamical and chemical evolution of IZw18, the most metal-poor dwarf galaxy locally known. To do that we adopt a two-dimensional hydrocode coupled with detailed chemical yields originating from Type II and Type Ia supernovae and from intermediate-mass stars. Particular emphasis is devoted to the problem of mixing of metals. We conclude that, under particular conditions, cooling of metals occurs with a timescale of the order of 10 Myr, thus confirming the hypothesis of instantaneous mixing adopted in chemical evolution models. We try to draw conclusions about the star formation history and the age of the last burst in IZw18.

Keywords: ISM: abundances — ISM: jets and outflows — galaxies: evolution — methods: numerical

1 Introduction

Blue compact dwarf galaxies, due to their very blue colours, compact appearance, high gas content, and low metallicities, are generally thought to be unevolved systems. Galaxies of this size are predicted to be the first virialised objects in the standard cold dark matter theories of structure formation, supplying the building blocks from which massive galaxies form through mergers.

IZw18 has been considered until recently as the best candidate for a truly 'young' galaxy (Hunter & Thronson 1995). However, recent deep colour–magnitude diagrams (CMDs), both in the optical (Aloisi et al. 1999, hereafter ATG) and in the near infrared (Östlin 2000), revealed the presence of at least two stellar populations in IZw18, the older one (an AGB population) having an age of several 10^8 yr. The relative importance of this stellar population is not clear at the moment (the spectral energy distribution of IZw18 is reproduced without any need of stars older than 13 Myr), but there is growing evidence of underlying older stellar populations (at least as old as are reachable by optical spectroscopy) in any dwarf galaxy.

This galaxy, since its discovery in 1966, has been extensively studied by many authors, and nowadays we know with reasonable accuracy the abundances in the H II (Skillman & Kennicutt 1993; Garnett et al. 1995; Izotov & Thuan 1999; among others) and in the H I regions (Aloisi et al. 2003; Lecavelier des Etangs et al. 2003); thus we can use this galaxy as a good benchmark for the study of the impact of starburst(s) on the ISM and compare the results of models with detailed observations.

2 Model

We simulate a model galaxy resembling IZw18 by means of a two-dimensional hydrocode, coupled with detailed chemical yields originating from Type II supernovae (SNeII), Type Ia supernovae (SNeIa), and winds from intermediate-mass stars (IMSs). A relevant point of these models is the so-called 'thermalisation efficiency' (i.e. the fraction of explosion energy which remains stored in the ISM and is not radiated away). SNeII explode in a medium, on average, cold and dense; therefore, during the expansion of the supernova remnant, most of the initial explosion energy can be lost due to radiative cooling. SNeIa, instead, explode with some delay, and the medium is already heated and diluted by the previous activity of SNeII. We therefore adopt a low efficiency for SNeII and a much higher value for SNeIa, according to the average density and temperature of the medium at the moment in which the two kinds of supernovae begin to explode. The assumption of a low thermalisation efficiency for SNeII, although debated (see e.g. Strickland & Stevens 2000), is the only one able to keep a large fraction of gas bound in the system at the end of the simulation, in agreement with that observed in IZw18 (see Recchi et al. 2001). In these models, abundances are calculated averaging the metal content of the cold phase (i.e. gas with $T \leq 2 \times 10^4$ K) in a region of the grid with dimensions similar to the optical part of IZw18. The details about the code and the way to insert the chemical enrichment can be found in Recchi et al. (2001).

3 Results

We consider three different star formation histories (SFHs) for IZw18: a single, instantaneous burst of star formation ('single burst' model); two instantaneous bursts of star formation separated by a quiescent period ('double burst' models); and more complex SFHs, as derived by ATG by comparing synthetic CMDs with observed ones ('continuous burst' models).

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3.1 Single Burst Models

The burst produces 6×10^5 $M_\odot$ of stars. In all the models considered, a galactic wind develops as a consequence of the energy injected during the starburst, carrying away mostly the freshly produced metals. However, due to the different explosion timescales and thermalisation efficiencies, the galactic wind is mostly triggered by SNeIa. From the chemical point of view, the products of SNeIa (mostly iron-peak elements) are ejected more easily than SNeII products (mostly α-elements); thus the net effect is to enhance [α/Fe] ratios inside the galaxy (see Figure 1, upper panels). The presence of a huge amount of iron in the intracluster medium (Renzini 1997) can be explained by these SNeIa-triggered GWs.

Mostly due to the slow expansion of the superbubble in the early phases of the evolution, the cooling of metals in the gas is very efficient, so that after a few tens of Myr most of the freshly produced metals are in a cold phase, thus detectable with optical spectroscopy. This is due to the fact that these metals spend a long time in the cavity, close to the swept-up shell. Here thermal conduction, thermal instabilities, and eddies contribute to cool the gas in the cavity and mix the two phases. These results can also depend on numerical diffusion of the code, but convergence tests (Recchi et al. 2001) let us believe that this is a robust conclusion. This justifies the 'instantaneous mixing' approximation, adopted in most chemical evolution models (see e.g. Matteucci 1996, and references therein).

We can reproduce the chemical composition and the outflow extension of IZw18 with a burst of ~31–35 Myr, depending on the adopted nucleosynthetic yields (see Figure 2, left panels). This age can hardly be accepted because of the very blue colours of IZw18, indicating a younger age.

3.2 Double Burst Models

As anticipated in the introduction, an underlying older population of stars has been discovered in IZw18. The inferred age ranges from a few 10^8 yr (ATG) to a few Gyr (Östlin 2000). We therefore simulated models with two instantaneous bursts of star formation, separated by a quiescent period.

We assume a first, weak burst of star formation (producing 10^5 $M_\odot$ of stars). This burst is not powerful enough to trigger a galactic wind. After 300 Myr, it has carved a cavity with dimensions $\sim 200 \times 100$ pc. Outside it, the ISM is almost unperturbed. In the shell surrounding the cavity, the gas is cold and very dense, thus the onset of a second burst of star formation is likely. The mass of stars produced in this second burst is $\sim 6 \times 10^5$ $M_\odot$, and the metallicity of the cold gas in the central region is 1/50 $Z_\odot$. The adopted set of yields from massive stars is from Woosley & Weaver (1995), whereas for IMSs we consider both the results of Renzini & Voli (1981) and van den Hoek & Groenewegen (1997). A single-slope initial mass function (IMF) [$\phi(m) \propto m^{-(1+x)}$] is assumed throughout the paper, but we consider two possible slopes: the classical Salpeter one ($x = 1.35$), and a flatter IMF ($x = 0.5$) as suggested by ATG in order to reproduce the CMD in IZw18 (see Recchi et al. 2002 for more details).

The impact of the second burst of star formation is rather vigorous, since a cavity has already been carved out by the previous burst. A galactic wind is created after ~20 Myr. At variance with the single burst models, the ejection efficiencies of α-elements are large and the difference from the ejection efficiencies of iron-peak elements, although still present, is much smaller. As a consequence, the [α/Fe] ratios outside the galaxy are only slightly smaller than those inside the galaxy (Figure 1, lower panels). The C, N, and O evolution of models with

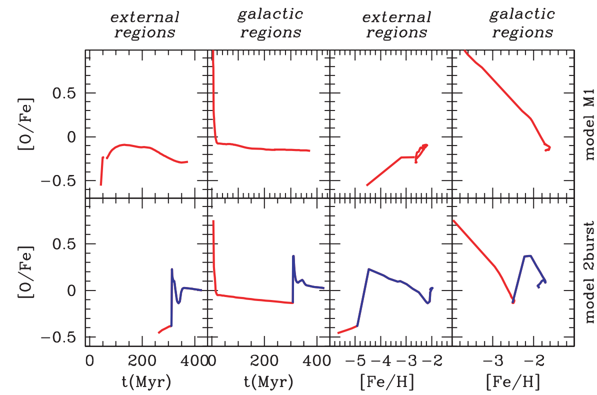

Figure 1 [O/Fe] ratios versus time and versus [Fe/H] for the single burst model (upper panels) and for the double burst one (lower panel), inside and outside the galactic region. In the lower panel, the red curve represents the evolution of the model during the first burst of star formation, whereas the blue curve is the evolution after the onset of the second burst.

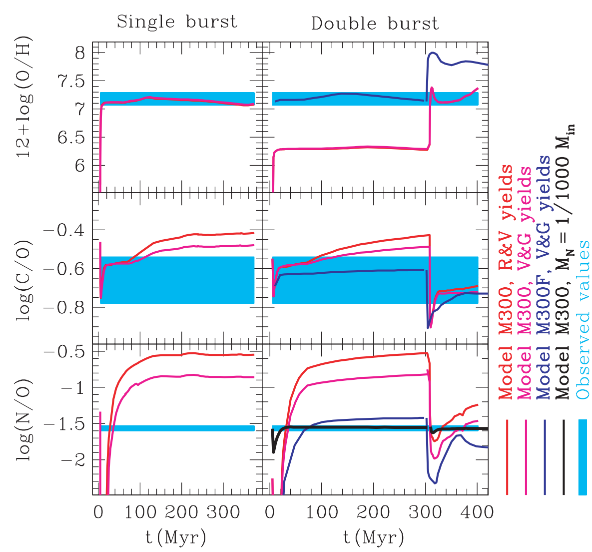

Figure 2 Evolution of O, C, and N for the single burst models (left panels) and for the double burst models with Salpeter or flat ($x = 0.5$) IMF (models M300 and M300F, respectively). Also shown (black line) is a model in which we assumed an ad hoc production of primary N in massive stars (and no production of N in IMSs). The cyan strip represents the observed values found in the literature for IZw18. Red lines represent models adopting yields from Renzini & Voli (1981), whereas magenta lines are models in which the yields of van den Hoek & Groenewegen (1997) are implemented.

different IMF slopes and different sets of nucleosynthetic yields is shown in Figure 2, right panels.

There are two possible evolutionary times in which the C, N, and O abundances are reproduced at the same time: shortly after the second burst (at a time of ∼4–7 Myr, depending on the model), and a few tens of Myr later (20–40 Myr with Renzini & Voli (1981) yields; 50–70 Myr with van den Hoek & Groenewegen (1997) ones). Only the first solution is acceptable, since an age estimate of a few tens of Myr is inconsistent with the colours and the spectral energy distribution of IZw18. For the model with a flatter IMF (model M300F), the only possible solution requires an extremely short burst age (∼4 Myr). Also shown (black line) is a model in which we assumed nitrogen to be produced only in massive stars. This has been suggested by Izotov & Thuan (1999) in order to explain the apparent plateau in [N/O] versus [O/H] at very low metallicities. Assuming a primary nitrogen production in massive stars, we can reproduce the N/O plateau, but the amount of nitrogen required (1/1000 of the progenitor mass) is far above the predictions of models (Woosley & Weaver 1995; Meynet & Maeder 2002, hereafter MM02). It is worth noticing that some new observations of metal-poor galaxies (Skillman et al. 2003; Pustilnik et al. 2003) show N/O ratios lying well above the plateau of log (N/O) = −1.60 found by Izotov & Thuan (1999); thus this result needs further confirmation.

3.3 Continuous Model

According to the results of ATG, we adopt a star formation constant of almost 300 Myr (with a star formation rate of $6 \times 10^{-3}\,M_\odot\,yr^{-1}$), with a second, superimposed, more vigorous burst (star formation rate $3 \times 10^{-2}\,M_\odot\,yr^{-1}$) lasting for 5 Myr. We test different IMF slopes and different sets of yields from IMSs. Model parameters are summarised in Table 1.

The resulting evolution of O, C/O, and N/O is shown in Figure 3. As can be seen from the figure, these models cannot reproduce the observed N/O ratio. This is due to the fact that the last burst of star formation is only five times more intense than the average star formation rate and lasts for only 5 Myr. The oxygen produced is not enough to compensate the nitrogen from IMSs. Only the model with a flatter IMF ($x = 0.5$) can account for the low nitrogen content, but this model overproduces oxygen.

There are indications (Chiappini et al. 2003) that the sets of yields of van den Hoek & Groenewegen (1997) overestimate nitrogen. Recent models of stellar evolution with rotation (MM02) predict less nitrogen, although they do not take into consideration the third dredge-up. A comparison of the nitrogen yields in IMSs from different authors is shown in Figure 4. The evolution of a model, in which MM02 yields are implemented, is shown in Figure 5. The nitrogen produced in this model lies close to the observed strip and the gap might be bridged by the nitrogen produced during the third dredge-up. Although we cannot constrain the age of the last burst by fitting C, N, and O at the same time, the upper panel of Figure 5 indicates an upper age of ∼15 Myr, since later on the model starts overproducing oxygen.

Table 1. Parameters for the continuous burst models

Model	Gas mass ($M_\odot$)	x (IMF slope)	IMS yields*
SR2	1.7×10^7	1.35	RV81
SR3	3.0×10^7	1.35	RV81
SV3	1.7×10^7	1.35	VG97
KR2	1.7×10^7	1.7	RV81
FV4	4.0×10^7	0.5	VG97

*RV81: Renzini & Voli 1981; VG97: van den Hoek & Groenewegen 1997.

4 Discussion and Conclusion

In this contribution, we have summarised the chemical and dynamical evolution of a model galaxy similar to IZw18, under different star formation regimes. In the framework of a single burst model, the only acceptable age of the burst ranges between ∼31 and ∼35 Myr, depending on the adopted nucleosynthetic yields. This age, however, cannot reproduce the spectral energy distribution and the colours

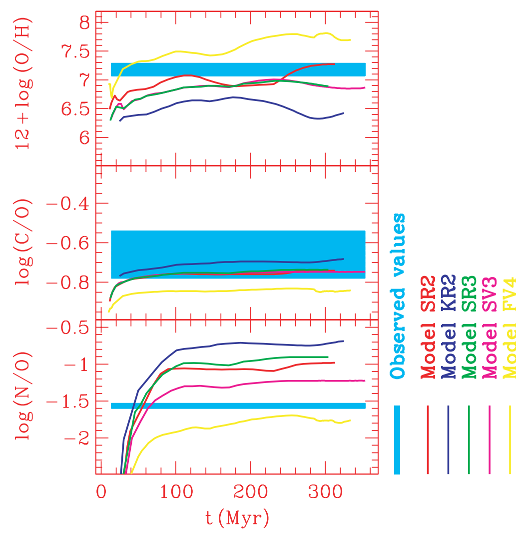

Figure 3 Evolution of O, C, and N for the continuous burst models. The parameters adopted for each model are shown in Table 1.

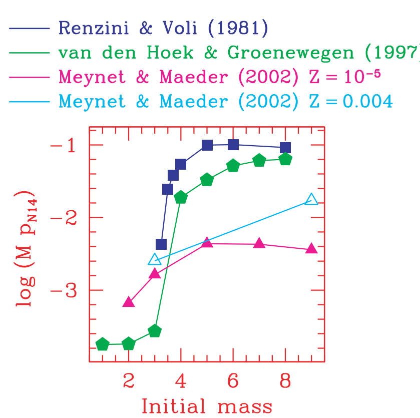

Figure 4 Nitrogen yields in IMSs from different authors.

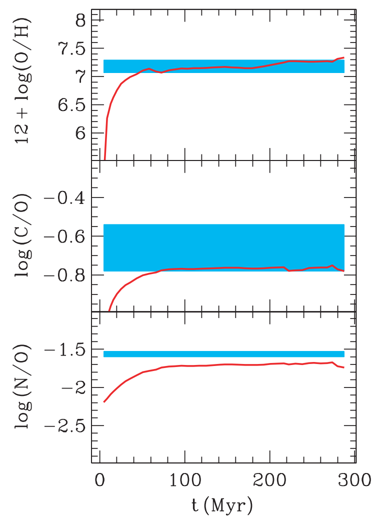

Figure 5 Evolution of O, C, N for the continuous burst models adopting MM02 yields.

of IZw18 (Mas-Hesse & Kunth 1999). Moreover, older stars have been observed in IZw18 (ATG; Östlin 2000), so the idea of a single burst is no longer tenable.

Assuming two instantaneous starbursts, separated by a quiescent period, we can reproduce the abundances and the morphology of IZw18, considering a delay of 300 Myr between the two bursts and a very young age (ranging between 4 and 7 Myr) of the second burst. Finally, for a model with a continuous starburst, we are not able to reproduce carbon, nitrogen, and oxygen at the same time, mostly because of an overproduction of nitrogen during the long-lasting episode of star formation. Only by assuming the new yields of MM02 can we reduce the nitrogen production to a level comparable to the one observed in IZw18. In order to reproduce carbon and oxygen at the same time, the last burst of star formation must be younger than 15 Myr.

By making use of the package Starburst99 (Leitherer et al. 1999) we can compute colours and magnitudes expected from our models (see details in Recchi et al. 2002). U–B colours can be reproduced only for a very young age of the second burst (between 5.3 and 11 Myr), consistent with the estimates of double burst and continuous models. B–V can be fitted only after ∼23 Myr, but this colour is heavily affected by the underlying older stellar population (impossible to simulate with Starburst99). Other independent estimates point toward a very young age of IZw18 (Martin 1996; Mas-Hesse & Kunth 1999; Hunt et al. 2003). In particular, Hunt et al. (2003), in order to reproduce the near infrared colours of IZw18, require two episodes of star formation, the first one a few 10^8 Myr ago, and another one with an age ranging between 3 and 10 Myr, in agreement with our estimates.

The other results of our models can be summarised as follows:

- In most of the cases explored, a galactic wind develops, ejecting mostly the metal-enriched gas produced during the starburst.
- The effect of SNeIa, often ignored in previous similar work, is very important in the late evolution of the galaxy, mostly because SNeIa explode in a medium which has already been heated and diluted by the previous activity of SNeII, so they can easily convert their explosion energy into thermal energy of the ISM.
- As a consequence of this large thermalisation efficiency of SNeIa, galactic winds carry away a significant fraction of iron-peak elements (mostly produced by SNeIa). The resulting [α/Fe] ratios outside the galaxy are lower than those inside. The difference between the ejection efficiencies of α-elements and iron-peak ones depends on the past star formation history of the galaxy, being maximum in the case of a single, instantaneous starburst.
- Mostly due to the low thermalisation efficiency of SNeII, the cooling timescale of freshly produced metals is short (of the order of a few tens of Myr). The 'instantaneous mixing' assumption, widely adopted in chemical evolution models, is thus acceptable.

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