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# Slowly cooking galaxies

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**Abstract**

Recent spectroscopic observations of IZw 18 have revealed homogeneous abundance throughout the galaxy and several observations of other starburst galaxies have shown no significant gradient or discontinuity in the abundance distributions within the HII regions. I thus concur with Tenorio-Tagle G., 1996, AJ 111, 1641 and Devost D., Roy J.R., Drissen L., 1997, ApJ 482, 765, that these observed abundance homogeneities cannot be produced by the material ejected from the stars formed in the current burst and result from a previous star-formation episode. Metals ejected in the current burst of star formation remain most probably hidden in a hot phase and are undetectable using optical spectroscopy. Combining various observational facts, for instance, the faint star-formation rate observed in low surface brightness galaxies, Van Zee L., Haynes M.P., Salzer J.J., Broeils A.H., 1997c, AJ 113, 1618. I propose that a low and continuous star-formation rate, occurring during quiescent phases between bursts, is a non negligible source of new elements in the interstellar medium. Using a spectrophotometric and chemical evolution model for galaxies, I investigated the star formation history IZw 18. I demonstrate that the continuous star formation scenario reproduces all the observed parameters of IZw 18. I discuss the consequences of such a quiet star-formation regime. © 2000 Published by Elsevier Science B.V.

*Keywords:* Galaxies; ISM; IZw 18; Enrichment of ISM

## 1. Introduction

Understanding galaxies' formation and evolution is one of the most challenging issues of modern astrophysics. In this field, low-mass dwarfs and irregular galaxies have progressively reached a particular place. Indeed, in hierarchical clustering theories, these galaxies are the building blocks of larger systems by merging (Kauffman et al., 1993; Pascarelle et al., 1996; Lowenthal et al., 1997). Moreover, as primeval galaxies may undergo rapid and strong star-formation events (Partridge & Peebles, 1967), nearby dwarf starburst galaxies or Blue Compact Galaxies (BCDG) of low metallicity can also be considered as their local counterparts. Therefore, the study of low redshift starbursts is of major interest for our understanding of galaxies' formation and evolution.

During a starburst, the massive stars produce and eject metal-rich gas into the interstellar medium, but the timescale for chemical enrichment is far from being constrained. Is the process so quick that the newly synthesized elements are immediately detectable in H II regions? Is there a time delay between the release of nucleosynthesis products and the chemical pollution of the star-forming regions? Answering these questions is crucial for the interpretation of the abundances measurements in star-forming galaxies and their chemical evolution.

Kunth & Sargent (1986) first proposed that metals produced in a burst of star formation are likely to very quickly enrich the surrounding H II region. If true, the present burst in IZw 18 alone could account for its observed metallicity (Kunth et al., 1995) and this would explain why no galaxy with a metallicity lower than that of IZw 18 has ever been found,

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despite extensive searches (Terlevich, 1982; Terlevich et al., 1991; Masegosa & Moles, 1994; Izotov et al., 1994; Terlevich et al., 1996).

Recently, Roy & Kunth (1995) argued that the newly synthesized elements cannot be dispersed over scales larger than a few hundred parsecs in a timescale $\leq$100 Myr, predicting that abundance discontinuities should be observed in young starburst galaxies between the central H II regions (‘auto-enriched’ by the massive ionizing stars) and more external regions that are relatively free of recent chemical pollution. However, recent observations of IZw 18 (Van Zee et al., 1998; Legrand et al., 1999) revealed a homogeneous abundance throughout the galaxy (HII and HI) and several studies of other starburst galaxies ((Kobulnicky & Shillman, 1997) and references therein) have shown no significant gradient or discontinuity in the abundance distributions within the HII regions. This suggest that the metals produced in the current burst are invisible in the optical and remain hidden in a hot X-ray-emitting phase, as discussed by Tenorio-Tagle (1996), Devost et al. (1997), Kobulnicky & Shillman (1997) and Pilyugin (1999). An important consequence of this is that the observed metals in IZw 18 and other starbursts come from previous star-formation events whose nature has to be specified.

On the other hand, it is easy to show that the current star-formation rate (SFR) in starburst galaxies cannot be maintained over a long time without consuming most of the gas and producing excessive enrichment. It is thus generally assumed that the star-formation history of these objects is made of a succession of bursts separated by rather long quiescent periods, during which they are likely to appear as low-surface brightness or quiescent dwarf galaxies. However, even among these objects, none has been found with a star formation equal to zero (Van Zee et al., 1997c). All of them present very low, but non zero, SFRs. Indeed, this is a strong indication that star formation at a very low level occurs even between bursts and that the metallicity continues to increase slightly during these periods. This led Legrand et al. (1999) to propose the existence of a small but rather continuous SFR during the lifetime of galaxies and to suggest that this regime of star formation can alone be responsible for the observed metals in IZw 18. Preliminary results (Legrand & Kunth, 1998) seem to agree with this hypothesis.

I will present here new results I obtained (detailed calculations can be found in Legrand, 1999) using a spectrophotometric and chemical evolution model in order to constrain the past star-formation history of IZw 18. In particular, I will show how the continuous, low star-formation regime proposed by (Legrand et al., 1999) can account for the observed metallicity in IZw 18. Finally, I will discuss the consequences of such a star-formation regime.

## 2. Modeling the past star formation history of IZw 18

### 2.1. The model

In order to investigate the star-formation history of IZw 18, I used the spectrophotometric model coupled with the chemical evolution program ‘STARDUST’, which was described by Devriendt et al. (1999). The main features of the model can be found in (Legrand, 1999). I used a typical IMF, described as a power law, in the mass range 0.1–120 $M_\odot$

$$\phi(m) = a.m^{-x} \tag{1}$$

with a constant index $x$ of 1.35 (Salpeter, 1955). Two regimes of star formation were investigated:

A continuous star formation during the lifetime of the galaxy. The SFR is low and is directly proportional to the total mass of available gas.

Bursts of star formation during which all of the stars are formed in a rather short time.

The model provides us with both the abundances and the spectra at each time.

### 2.2. Continuous SFR

As all of the galaxies containing gas are known to have a non-zero SFR, Legrand et al. (1999) proposed the existence of a faint but continuous SFR during the lifetime of the galaxies. In order to constrain this SFR, I used the model described previously. Assuming that the present burst in IZw 18 is the first one in the history of this galaxy, but that this object has undergone a faint but continuous SFR during its lifetime, I adjusted the continuous SFR to reproduce the observed oxygen abundance after 14 Gyrs. I found that a continuous SFR of $10^{-4}\, g\, M_\odot\, \mathrm{yr}^{-1}$, where $g$ is the fraction of gas (in mass) available in

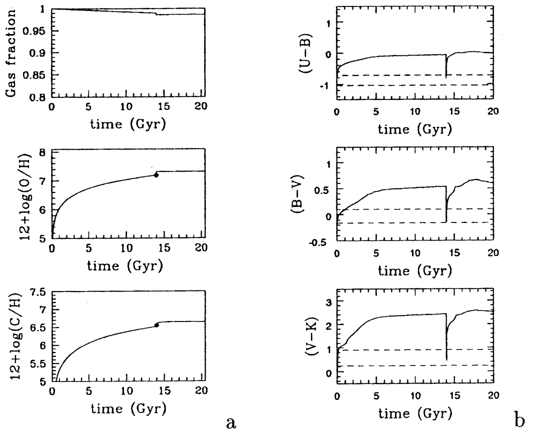


Fig. 1. (a) Time evolution of the gas fraction, oxygen and carbon abundances for the continuous SFR model with a Salpeter IMF. The dots represent the measured abundances (for O and C, respectively (Skillman & Kennicutt, 1993; Garnett et al., 1997)). (b) Evolution of colors (U–B, B–V, V–K). The dashed lines delimit the zone of compatibility between the model and the observations. The colors (corrected for the nebular contribution) are from Salzer (1998) for (U–B) and (B–V), and from Thuan (1983) for (V–K).

the galaxy, can reproduce the observed oxygen abundance in IZw 18 after 14 Gyrs. In order to reproduce the present colors, I added a burst with the characteristics of the current one, as given by Mas-Hesse & Kunth (1999). We have to keep in mind that the metals produced by this burst are not yet visible, so the metal measurements trace the metallicity **before** the burst. The results of this model are presented in Fig. 1.

One can see that, within the error bars, this model can reproduce all of the observations. The fraction of gas consumed remained very low, thus *g* is always close to 1 and the SFR is rather constant.

## 3. Generalization and consequences

Assuming that this continuous SFR occurs sporadically throughout the galaxy, the homogeneity of the abundances (within the NW region but also between NW and SE regions) is a natural outcome of this model, with the rather uniform spatial distribution of the formed stars and the long time evolution ensuring a homogeneous mixing of the metals. The physical processes that could support such an extended star formation have to be precise. Indeed, as in LSBG, the mean density seems to remain under the critical threshold of instability for star formation (Toomre, 1964; Cowie, 1981; Kennicutt, 1989; Van Zee et al., 1997c). However, the HI halo is certainly not monolithic or static, but is formed of many small clouds. When these clouds collide, the density should increase and could exceed the threshold locally. A study of the processes that could be responsible for this star-formation regime is planned.

Assuming that the continuous SFR occurs throughout the whole HI halo of the galaxy ($60 \times 45''$), I predict a surface brightness of the old underlying population of the order of 28 mag arcsec$^2$ in V and 26 mag arcsec$^2$ in K. These values are an upper limit (in mag arcsec$^2$); if a fraction of the metals is ejected out of the galaxy, the SFR needed to produce the observed abundances will be higher, and the total luminosity and surface brightness will be increased. Moreover, the density limit adopted for the continuous SFR is a lower limit and the region where the continuous SFR can occur may be smaller, resulting in higher surface brightness. However, the extreme faintness of the old underlying population probably explains why no strong evidence for its existence has been found in IZw 18 (Thuan, 1983; Hunter & Thronson Harley, 1995) until recently, when Aloisi et al. (1999), on reanalyzing HST archive images, found stars older than 1 Gyr. Moreover, preliminary surface-brightness profiles of IZw 18 (Fig. 2), published by Kunth & Ostlin, (1999), indicate a surface brightness of at least 28 mag arcsec$^2$ in B (may be lower) in the external parts of the galaxy (at 20$''$ from the center). These results still have to be confirmed, but they agree with our predictions.

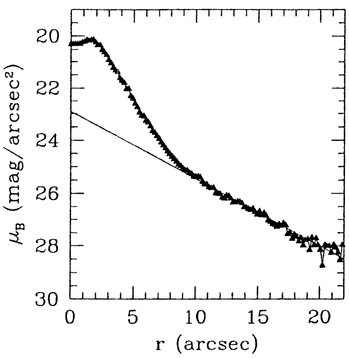


Fig. 2. IZw 18 surface-brightness profile (Kunth & Ostlin, 1999).

I also evaluated the number of massive stars ($M > 8\,M_{\odot}$) formed and determined that about 120 stars (an open cluster) are formed every 140 Myrs. This does not appear to be unrealistic.

I also compared this continuous SFR with the ones observed in LSBG and quiescent dwarfs (Van Zee et al., 1979a,b,c). As these objects have different masses, I normalized the SFR to the total HI mass observed. It appears that the continuous SFR, as predicted by our scenario, is comparable, relative to the HI mass, to the lowest SFR observed in quiescent and low surface-brightness galaxies (see (Legrand, 1999)).

If a continuous SFR exists in IZw 18, it must exist in other dwarf galaxies and, maybe, in all galaxies. If true, this explains why no galaxy with a metallicity lower than that of IZw 18 has been found and why all of the HI clouds detected by blind surveys have turned out to be associated with stars (Briggs, 1997). We can also expect that such a continuous low SFR occurs in the outskirts of spirals, at few optical radii, where the density is low. As a matter of fact, the extrapolation of the abundance gradients in these objects lead to abundances that were comparable to that of IZw 18 at radial distances of about three optical radii (Ferguson et al., 1998; Henry & Worthey, 1999). As this corresponds to the size of the halos or disks susceptible to give rise to metallic absorption in quasar spectra (Bergeron & Boisse, 1991), we can also compare the time evolution of the metallicity with the abundances measured in quasars' absorption systems. This comparison is done in Fig. 3. The abundances predicted by the model mimic the lower envelope of these measurements. If we assume that these absorption systems are associated with galaxy halos (Lanzetta et al., 1995; Tropp et al., 1997), this indicates that such a process can account for a minimal enrichment of the ISM with time.

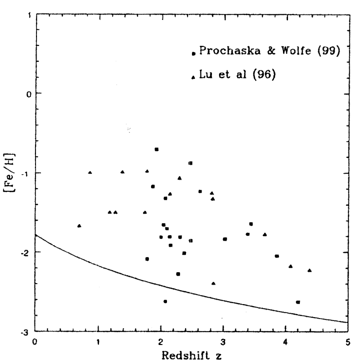


Fig. 3. Comparison of the predicted and observed evolution with redshift of the abundance [Fe/H]. The points represent the data from Lu et al. (1996) and Prochaska & Wolfe (1999) and the solid line represents the model prediction for a constant star-formation rate.

## 4. Conclusions

Various observations suggest that the metals produced by the massive stars during a burst are not immediately visible using optical spectroscopy. They should be in a hot phase, emitting in the X-ray range. Thus, the observed metals have been produced during a former star-formation event. Using the fact that we do not know any galaxy containing gas with a SFR equal to zero, I propose the existence of a low continuous SFR during the lifetime of galaxies. Using a spectrophotometric model coupled to a chemical evolution model for galaxies, I have shown that such a star-formation regime alone is sufficient to reproduce the observed metallicity of IZw 18 and can account for such observational facts as the presence of star formation in quiescent dwarfs and LSBG, the apparent absence of galaxies with a metallicity lower than that of IZw 18, the apparent absence of HI clouds without optical counterparts, the homogeneity of the metal abundances in dwarfs galaxies, the metal content extrapolations to the outskirts of spiral galaxies, and the metallicity increase with time in the most underabundant quasars' absorption systems. I thus conclude that, even if starbursts are strong and important events in the life of galaxies, their more subdued, but continuous, star-formation regime cannot be ignored when accounting for their chemical evolution.

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