Slowly cooking galaxies $^{1,2}$

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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 (1996) and Devost et al. (1997) 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 et al., 1997c), 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.

Key words: Galaxies; Galaxies: ISM; Galaxies: IZw 18; Galaxies: 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

1 I thanks R.J. Terlevich for suggesting the title of this paper
2 This work is part of a PhD Thesis done at IAP (Paris) under the supervision of D. Kunth.
clustering theories these galaxies are the building blocks of larger systems by merging (Kauffmann 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 enrich very quickly the surrounding H II region. If true, the present burst in I Zw 18 could alone account for its observed metallicity (Kunth et al., 1995) and this would explain why no galaxy with a metallicity lower than that of I Zw 18 has ever been found despite extensive searches (Terlevich, 1982; Terlevich et al., 1991; Masegosa et al., 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 relatively free of recent chemical pollution. However, recent observations of I Zw 18 (Legrand et al., 1993; Van Zee et al., 1998) revealed a homogeneous abundance throughout the galaxy (HII and HI) and several studies of other starburst galaxies (Kobulnicky & Skillman, 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-rays emitting phase as discussed by Tenorio-Tagle (1996); Devost et al. (1997); Kobulnicky & Skillman (1997); Pilyugin (1999). An important consequence of this is that the observed metals in I Zw 18 and other starburst come from previous star formation event which nature have to be specified.

On the other hand it is easy to show that the current SFR in starburst galaxies cannot be maintained during 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 burst 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 star formation rate (SFR). Indeed this is a strong indication that star formation at a very low level occurs even between bursts and that the metallicity still increases 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 suggest that this regime of star formation can be alone responsible of 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. Particularly, 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 “STAR-DUST” 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 $M_\odot$

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

with constant index x of 1.35 (Salpeter, 1955).

Two regimes of star formation has been investigated:

- A continuous star formation during the lifetime of the galaxy. The SFR is low and directly proportional to the total mass of available gas.
- Bursts of star formation during which all the stars are formed in a rather short time.

The model provide us with both the abundances and the spectra at each time.
2.2 Continuous SFR

As all 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 before. 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 $10^{-4} \, M_\odot \, yr^{-1}$ where $g$ is the fraction of gas (in mass) available in 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.

We can notice that within the error bars this model can reproduce all the observations. The fraction of gas consumed remain 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; the rather uniform spatial distribution of the formed stars and the long time evolution ensuring a homogeneous mixing of the metals. The physical process which could support such an extended star formation have to be precised. 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 nor static but formed of many small clouds. When these clouds collide, the density should increase and may locally exceed the threshold. A study of the processes which could be responsible of this star formation regime is planned.

Assuming that the continuous SFR occurs throughout the whole HI halo of the galaxy (60 × 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 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, 1995) until recently when reanalyzing HST archive images (Aloisi et al., 1999) 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). This results still have to be confirmed, but it agrees with our predictions.

I also evaluated the number of massive stars ($M > 8 M_\odot$) formed to be about 120 stars (an open cluster) every 140 Myrs. This not appears unrealistic.

I also compared this continuous SFR with the ones observed in LSBG and quiescent dwarfs (Van Zee et al., 1997a,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 star formation rate exists in IZw 18, it must exist in other
dwarf galaxies, and may be, in all galaxies. If true, this explain why no galaxy with a metallicity lower than that of IZw 18 has been found and why all the HI clouds detected by blind surveys has all turned 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 radius, where the density is low. As a matter of fact, the extrapolation of the abundance gradients in these objects lead to abundances 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., 1993; Tripp et al., 1997], this indicates that such a process can account for a minimal enrichment of the ISM with time.

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-rays range. Thus the observed metals has been produced during former star formation event. Using the fact that we don't 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,
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 the model prediction for a constant star formation rate.

I have shown that such a star formation regime is sufficient to reproduce alone the observed metallicity of IZw 18 and can account for various observational facts as the 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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