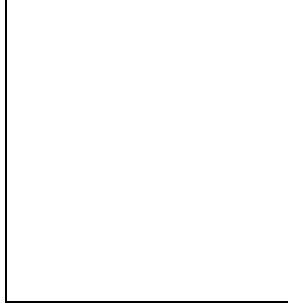


# CHEMICAL EVOLUTION OF IRREGULAR GALAXIES

Monica Tosi

*Osservatorio Astronomico, Bologna, Italy.*



## Abstract

The state-of-the-art of chemical evolution models for Irregular and Blue Compact galaxies is reviewed. The resulting scenarios for the initial mass function, the regime of star formation and the efficiency of gas outflows are described: The IMF appears to be roughly the same everywhere; the SF has possibly followed a bursting regime in BCGs and a more continuous regime in Irregulars, but with significant exceptions; galactic winds must occur in some of these galaxies, with efficiencies inversely proportional to the galaxy potential well.

## 1 Introduction

Irregular (Irr) and Blue Compact (BCG) galaxies have always had significant importance for cosmological studies. One of the major reasons for this is that they host the HII regions from which the relation between helium and oxygen,  $\Delta Y/\Delta O$ , is derived and, consequently, the primordial helium abundance  $Y_p$ . They thus provide a fundamental test for theories of Big Bang Nucleosynthesis. Moreover, these galaxies are usually poorly evolved systems and can thus be considered as fairly similar to primordial galaxies. What brings them more into fashion nowadays is, however, the circumstance that they have been recently suggested as major contributors to the excess of faint blue objects in deep galaxy counts.

To study properly all the above cosmological issues it would be necessary to know not only the current or recent evolutionary conditions of these galaxies, but also (or mostly) their conditions at the earlier epochs, which correspond to high redshifts. In the case of the Magellanic Clouds and the few other closest irregulars in the Local Group, this is feasible with sufficient accuracy, thanks to the fact that their old stars are observable and examinable in detail. For the great majority of Irrs and BCGs, however, the older stars are too faint to be individually

resolvable, and the available observational data refer only to young objects. For these galaxies one of the few ways to infer their past evolutionary conditions is from chemical evolution models. By selecting those models which are able to reproduce the observed features, one can in fact derive the most plausible scenarios for previous epochs, although with the usual caveat [31] that such scenarios may not be unique, since different models can provide predictions for the recent times in similar agreement with the available constraints, but fairly different predictions for the earlier unconstrained phases [33].

## 2 Outline of chemical evolution models

The major task and difficulty for chemical evolution models of Irrs and BCGs is to reproduce their low observed chemical abundances despite the relatively high observed star formation rates (SFR).

The theoretical parameters involved in the computation of these models are essentially three: the law of star formation (SF), the initial mass function (IMF), and the gas flows, in and out of the system. Stellar evolution and nucleosynthesis are the other important ingredients in chemical evolution models. In the following I concentrate only on the *galactic* parameters, without discussing the uncertainties on stellar evolution theories, despite the fact that the latter deserve a careful treatment as well.

A priori, the galactic parameters are free as a consequence of our ignorance on the actual physical mechanisms regulating the formation of stars and the evolution of the interstellar medium. However, the comparison with appropriate observational constraints of the model predictions based on different assumptions on the parameters leads to a significant reduction of their ranges of acceptable values.

The observational constraints usually available for most Irrs and BCGs are the gas and total masses,  $M_g$  and  $M_t$  respectively, and the chemical abundances of the elements measurable from the emission lines of HII regions, namely: He, N, O and, in a few cases, C and Fe.

Effective constraints on the SF in a galaxy come from its observed  $M_g/M_t$  and absolute element abundances. For instance, if a model assumes an excessively high or long SF activity in a given galaxy, this provides an excessively high number of formed stars, which, in turn, lead to an excessively high gas consumption and metal production. Such model thus predicts too many metals and too little gas with respect to the observed values, and this is the sign that the SF activity must be lower than adopted.

The most significant tests on the IMF are the abundance ratios of elements produced and ejected by stars of different mass. Fortunately, the few elements measurable in these galaxies are indeed produced in different stellar sites. For instance, N is produced mostly by intermediate mass stars, O only by massive stars, and Fe partly ( $\sim 1/3$ ) by SNeII and mostly ( $\sim 2/3$ ) by SNeIa. Let's assume that for a given galaxy, one adopts a too flat IMF: there will be too many massive stars with respect to lower mass ones and, consequently, overproduction of oxygen and underproduction of iron and even less nitrogen. The predicted N/O ratio will then be significantly lower and the predicted O/Fe higher than observed, a circumstance indicating that the IMF appropriate for that galaxy should be steeper than the adopted one.

Irrs and BCGs can experience both infall and outflows of gas, depending on their potential well (generally low) and on the intergalactic medium where they are imbedded. However, from the point of view of their chemical evolution, outflows have turned out to be more important than inflows, at variance with what happens in big spiral galaxies. The occurrence of galactic winds in some Irrs and BCGs was first suggested by [22] and then confirmed by several other modellers (see Table 1) as a sort of *deus ex machina* able to overcome the problem that the

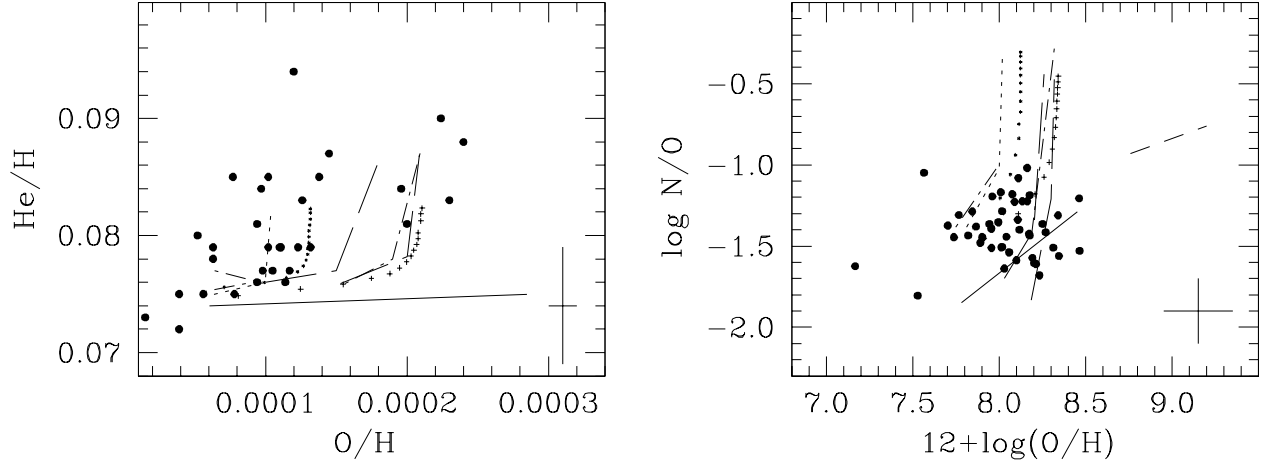


Figure 1: Left hand panel: Distribution of the helium vs oxygen abundances by number as derived from Pagel et al's (1992, [25]) observations of HII regions in Irrs and BCGs (dots) and from the predictions of Marconi et al's (1994, [21]) models. Right hand panel: Distribution of the nitrogen/oxygen vs oxygen abundances by number for the same data and models as on the left panel. The average observational error bar is shown in the bottom right corner of each panel.

models overpredicted the metal abundances of these systems for whatever combination of the other free parameters. The advantage of the winds is that they can remove the elements in excess, without significantly altering the other quantities. This obviously does not imply that galactic winds actually occur, but the comparison of the observed quantities with the predictions of models with various wind assumptions can at least tell how the outflows should be.

### 3 Description of specific models

Some years ago, we ([23] and [21]) computed a series of numerical models with the combined goals of reproducing the observed features of a large sample of Irrs and BCGs and of testing the range of acceptable values for the theoretical parameters. These models assumed a bursting mode of SF (i.e. short episodes of intense activity, separated by long quiescent phases), adopted several IMFs (with varying slope and/or upper and lower mass cutoffs), and allowed for two types of gas outflows triggered by SNeII explosions: differential winds (i.e. able to remove from the galaxy only the elements synthesized and ejected by the SNeII) or well mixed winds (i.e. able to remove from the galaxy a fraction of all the elements present in the interstellar medium around the SNe).

Figure 1 shows the predictions of Marconi et al.'s (1994, [21]) models for the He vs O and the N/O vs O abundance ratios compared with the corresponding values derived from observational data. Models adopting no galactic wind at all are represented by the short-dashed line: even with only two bursts of SF, oxygen is so overproduced that the line falls well outside the observational ranges of both distributions (and out of the graph in the left panel) and there is no way to bring it within the empirical range of values by varying SF and/or IMF. This is why in 1985 we ([23]) introduced winds in our models. If a well mixed outflow ejecting all the elements in the same proportions is assumed (solid line in Figure 1), the predicted oxygen abundances are lower and consistent with the data, but He and N are reduced as well. It can be seen from the two panels that for nitrogen this leads to a satisfactory agreement

with the data, but helium turns out to be always underabundant and below the observational range, whatever the assumptions on the other free parameters. If, instead, a differential wind is assumed, ejecting O, but not He and N that are not produced by SNeII, we can properly reduce the O abundance without affecting too much either He or N, and predict abundances consistent with the corresponding data. By varying the wind efficiency as well as the number and/or the intensity of SF episodes, the models can span the whole observational ranges of both distributions.

By running a large number of model cases, [23] and [21] reached the following conclusions: a) each galaxy has a SF and wind history different from the others; b) for most Irrs and BCGs, the number of SF bursts does not exceed 7–10, but some can have sustained 1 or 2 bursts at most (e.g. IZw18); c) the SF bursts have short duration ( $\sim 10^8 yr$ ), whereas the inter-burst phases last several Gyrs; d) the IMF is generally universal and around Salpeter’s slope. Similar results have been recently obtained by Bradamante et al. (1998, [2]) with an updated version of the same code and are described in this volume.

It is worth emphasizing that all the computed models predict a  $\Delta Y/\Delta O$  within each individual galaxy far from being linear. Qualitatively, there is first a shallow  $\Delta Y/\Delta O$  slope when all the O produced in a burst is ejected together with the amount of He produced by massive stars; but when the lower mass stars, which are He but not O producers, start to die and to contribute to the enrichment, He goes up very quickly while O remains stable. Quantitatively, this trend is affected by the adopted efficiency of the winds and of the SF, but is the natural result of the different lifetimes of the element producers in the context of discontinuous star formation and is therefore typical of all dwarfs. Nonetheless, since the observational data on He and O refer to many galaxies with different evolutions, what can be safely derived is only the average  $\Delta Y/\Delta O$  of the whole galaxy sample. In this situation, I believe that a linear fit to the observed values remains the best statistical approach to infer the average empirical  $\Delta Y/\Delta O$ .

In 1993, Pilyugin ([27]) reached very similar conclusions on the evolutionary conditions of these galaxies with completely independent models. He assumed strongly discontinuous SF, allowed for the existence of galactic winds, and considered also the effect of the HII region self-enrichment. This phenomenon is due to the fact that when the SNe of a SF burst start to explode, they pollute only the gas of their own HII region and not all the surrounding medium; thus the HII region abundance increases while that of the interstellar medium remains unaltered. Only after a while, when the HII region mixes with the external gas and enriches it, its abundance is diluted and decreases, while that of the interstellar medium goes up. As a result of this phenomenon, Pilyugin predicts that the evolution of element abundances in HII regions has a saw-tooth shape, that appears also in the behaviour of the element abundance ratios.

By comparing his model predictions with the observed distributions of He vs O and N/O vs O, Pilyugin ([27]) found that, taken alone, the phenomenon of HII region self-enrichment is sufficient to reproduce N and O, but not He, whose predicted values as a function of N and O turned out always much lower than observed. Only by introducing differential galactic winds, was he finally able to reproduce the observed distributions of all the three elements. He also concluded that Salpeter’s IMF is appropriate for Irrs and BCGs.

Carigi et al. (1995, [3]) computed somewhat different models for a sample of Irrs and BCGs, since they assumed that the SF in these systems is continuous and follows a law similar to that normally attributed to the solar neighbourhood. They also adopted differential galactic winds and tested various IMFs. As major constraints for their models they considered three observational quantities: the  $\Delta Y/\Delta O$  relation, the C/O ratio and the (Z-C-O)/O ratio (where Z is the total metallicity). Carbon is a useful element to model, since it is produced mainly by intermediate mass stars, but also by massive stars. Before the advent of the Hubble Space

Telescope no reliable measures of C in extragalactic HII regions were available and Carigi et al. were the first who could use such data. Carigi et al. found that the only models able to simultaneously reproduce all these constraints are those assuming an age of the galaxies of at least 10 Gyr, a high efficiency of the winds and a steep slope of the IMF at the low mass end. In particular, they suggested that 23% of the SN ejecta should be lost forever through the wind and that the slope of the IMF for  $M \leq 0.5M_{\odot}$  is  $-2.25$ , i.e. similar to the extrapolation of Salpeter's, but quite steeper than that attributed to solar neighbourhood stars (e.g. [17]).

**Table 1.** Chemical evolution models.

year	authors	objects	IMF	SF mode	galactic winds
1979	Lequeux et al	Irr+BCG	–	episodic	–
1983	Matteucci & Chiosi	Irr+BCG	variable ?	episodic	present ?
1985	Matteucci & Tosi	Irr+BCG	no variations	episodic	necessary
1993	Pilyugin	Irr+BCG	no variations	episodic	selective
1994	Marconi et al	Irr+BCG	no variations	episodic	selective
1995	Carigi et al	Irr+BCG	steeper at low m	continuous	selective
1995	Kunth et al	IZw18	standard	1–2 short episodes	selective
1991	Gilmore & Wyse	LMC	no variations	2 episodes	no
1993	Russel & Dopita	MC	steeper	cont or episodic ?	no
1995	Tsujimoto et al	MC	steeper if no wind	cont or episodic ?	could be
1996	Pilyugin	LMC	no variations	2 long episodes	selective
1998	Pagel & Tautvaisiene	MC	standard	2 long episodes	non selective

Table 1 provides a chronological overview of the conclusions that can be found in the literature for the IMF, SF mode and galactic winds in irregulars of various types. All these results are derived from the comparison of chemical evolution models predictions with the observed galactic features.

Table 1 shows that most of the results derived by different authors are in agreement with each other. It is interesting to notice, however, that what is found from studies of the two Magellanic Clouds (MC) is somewhat different from what is found for dwarf Irrs and BCGs. For instance, the episodes of SF activity in the MC are several Gyr long, whereas those attributed to BCGs are at least one order of magnitude shorter. Galactic winds appear absolutely necessary in dwarfs, whereas there is no obvious need in the MC. Is this difference real or artificial, and due for instance to the fact that the MC are known in more details ? And, if real, is it due to the fact that BCGs behave differently from Magellanic Irrs and large samples are dominated by BCGs, or to the fact that the LMC is much more massive and large than average Irrs ?

With these questions in mind, the results from Table 1 can be summarized as follows:

- The IMF is in general the same everywhere, with slope around Salpeter's; which means flatter than that in the solar neighbourhood for high mass stars and steeper for very low mass stars.
- Differential galactic winds are necessary but with varying efficiencies, inversely proportional to the galactic mass, so that in massive galaxies like the LMC they may be absent.
- The SF is probably discontinuous, but the significance of the discontinuity remains to be assessed, specially in bigger galaxies like the LMC.

To have a better insight of the issues related to the galactic winds and to the SF mode, it is worthwhile to examine these aspects in some further detail.

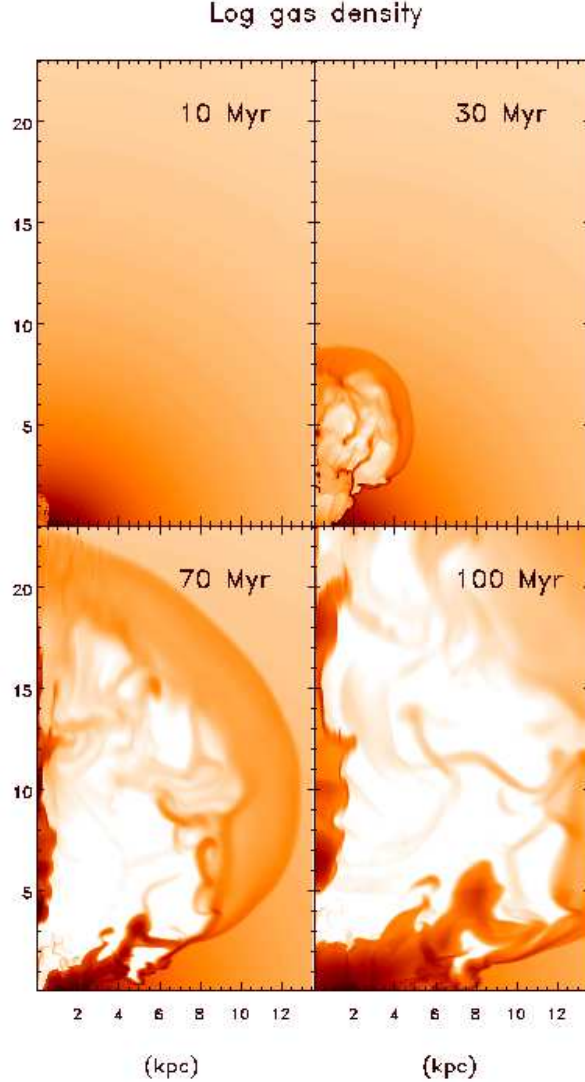


Figure 2: Distribution of the gas density in NGC1569 resulting from SN explosions as predicted by the hydrodynamical models by D’Ercole and Brighenti (1998, [5]). The galaxy major axis  $x$  is in abscissa, the vertical axis  $z$  in ordinate, and both are expressed in kpc. See text for details.

## 4 Galactic winds

From the chemical evolution models described in the previous section, it appears that galactic winds are necessary to explain the evolution of most, but not all, irregulars. These were model results with no previous support on either observational or theoretical ground. In the last few years, however, there has been an increasing evidence in favour of the wind occurrence both from observations and from theory. First of all, the high velocity filaments observed in  $H_\alpha$ , UV and X-rays in several galaxies (e.g. NGC1569, NGC1705, NGC4449, IZw18, [36], [24], [4]) have all been interpreted in terms of gas escaping from the parent galaxy. Moreover, winds are theoretically predicted by hydrodynamical studies of the SN ejecta in the interstellar medium typical of Irrs and BCGs (e.g. [6], [20], [5]).

D’Ercole and Brighenti ([5]) are currently performing a detailed study of the hydrodynamics of the SN ejecta in NGC1569. They have adopted the literature values for  $M_g = 1.1 \times 10^8 M_\odot$  and  $M_t = 3.3 \times 10^8 M_\odot$  ([16]) and for the recent  $SFR = 0.5 M_\odot yr^{-1}$  ([11]). This SF implies that approximately 30000 SNe have exploded during 30 Myr, ejecting  $\sim 10^6 M_\odot$  of their own gas.

They have then numerically followed the fate of these  $10^6 M_\odot$  of gas in the interaction with the interstellar and intergalactic media. Figure 2 shows the results of their computations for the distribution with galactocentric distance of the gas density. The various grey levels correspond to the gas density in logarithmic scale, in the sense that the darker, the denser (and white indicates empty regions). The model predictions are illustrated at four different epochs after the beginning of the SF activity: 10 Myr in the top left panel, 30 Myr (i.e. 20 Myr after the previous plot) in the top right panel, 70 Myr in the bottom left panel, and 100 Myr in the bottom right panel.

A few million years after the onset of the SF activity, the SNe start to explode, so that at 10 Myr (top left panel) the whitening of the blowing bubble is already distinguishable toward the galactic center, while the remaining gas of the galaxy still maintains the original distribution. At 30 Myr (i.e. at the end of the SF episode) the superbubble has already been able to go through the galaxy and to expand in the surrounding medium, thus creating (top right panel) the typical filamentary distribution observed in NGC1569 and other Irrs. At 70 Myr, the energy input has stopped since 40 Myr and part of the escaped gas is already falling back into the galaxy, as visible from the dark condensations at the sides of the superbubble in the bottom left panel. At 100 Myr the situation has eventually settled down, with some gas having definitely left the galaxy and the rest having fallen back. From these models, the estimated amount of gas returning into the galaxy is  $10^5 M_\odot$ , i.e. only 10% of that blown out by the SNe; the remaining 90% is lost forever. Notice that what is lost is only gas from the SN ejecta, not from the interstellar medium, thus supporting the differential wind case suggested by many chemical evolution models. The total amount of matter escaping from NGC1569 is only 1/100 of its  $10^8 M_\odot$  gas mass.

NGC1569 is a Magellanic irregular with average mass and size, but outstanding SF, which implies an unusual energy release in a modest potential well. It can therefore be considered as an extreme case of high wind efficiency. However, these hydrodynamical results show that even in more normal Irrs winds of possibly lower strength may easily occur.

## 5 Star Formation Regime

It was clear right after the first studies of BCGs that their blue colours, low metallicities and high gas contents were conceivable only if these galaxies "are undergoing intermittent and unusually intense bursts of SF" (Searle et al. 1973 [30]), separated by long quiescent phases. The discovery of an underlying old population in most Irrs and BCGs (e.g. [14]) has shown that these galaxies have not started to form stars only recently, and has therefore reinforced the intermittent SF hypothesis. The same discovery, however, has also introduced some doubts over this scenario, because some of these late type galaxies seem to have formed stars rather continuously. The overall scenario that one can currently draw from the literature on chemical evolution models and stellar populations studies is that irregulars of different type may have different SF regimes. Very schematically, the situation could be the following:

- BCGs undergo bursting SF (e.g. [30], [15]);
- dwarf Irrs undergo gasping SF (e.g. [32]), with long but moderate activity separated by short quiescent phases;
- giant Irrs appear to have continuous SF (e.g. [14]), because the quiescent phases tend to be too short to be appreciable.

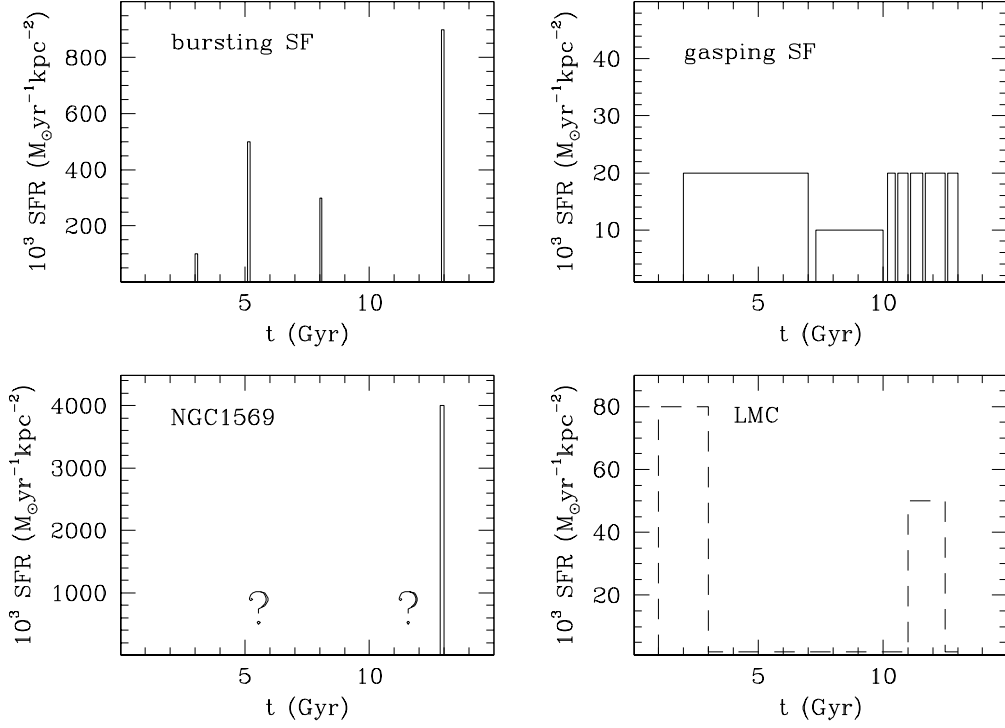


Figure 3: Star formation rate per unit area. The top panels sketch the possible scenarios for BCGs (left) and Magellanic Irrs (right). The bottom panels show the time distribution of the SF rate as estimated in NGC1569 (left, [11]) and LMC (right, [18], [28], [26]).

The above scheme can be visualized in the two panels of Figure 3, where the SF rates as a function of time in BCGs (top left) and Magellanic Irrs (top right) is sketched. To allow for a more meaningful comparison, the rate of SF is normalized per unit area.

This scenario is appealing in what it supports, at least qualitatively, the hypothesis originally proposed by Gerola et al. (1980, [8]) with the theory of stochastic self-propagating SF, in which the bigger the galaxy, the more continuous the SF. In their theory, in fact, when a *cell* starts forming stars it perturbs its neighbour *cells* in such a way that these start soon to form stars as well. Since a larger galaxy size implies a higher number of adjacent *cells*, the corresponding overall SF inevitably appears more continuous, because there are higher probabilities that at any time at least one *cell* will be active.

Unfortunately, the above scenario is definitely too simplistic, when quantitatively compared with the available data on well studied galaxies. The bottom panels of Fig.3 shows, for instance, an average of the SF rates derived by various authors for the LMC ([18], [28], [26]) and NGC1569 ([15], [11]).

The LMC is one of the largest and most massive irregulars, and has most probably experienced a SF activity which is not continuous, with two major episodes separated by a long period of very low SF rate. The actual rate in the two episodes and their separation may be uncertain (see also Pagel, this volume), but all authors favour the indicated scheme.

NGC1569 is also a Magellanic irregular, but its small size and mass (e.g. [16]) classify it as a dwarf Irr. It shows the strongest SF burst ever seen in a normal galaxy, with an estimated rate of at least  $4 M_{\odot} yr^{-1} kpc^{-2}$  ([11]), one to four orders of magnitude higher than that derived for Local Group dwarf Irrs. This high activity makes NGC1569 one of the few local dwarfs satisfying the requirements of Babul & Ferguson's ([1]) model for nearby analogs of the faint blue galaxies observed at redshift around 0.5–1. The question marks in the plot indicate that



some previous star formation activity should have occurred in NGC1569, as suggested e.g. by [35] from the possible presence of Asymptotic Giant Branch stars, but it must have been very modest. It is obvious, in fact, from simple gas consumption arguments that the recent high activity cannot have taken place also in previous epochs, otherwise NGC1569 would have run out of gas long ago, whereas 1/3 of its mass is still in gaseous form. It is probable, however, that much more modest episodes of SF have occurred in the past, to justify its current metallicity and stellar content.

We thus face the situation that the prototype of giant irregulars has not the continuous SF suggested by our hypothetical scenario, and one of the best studied dwarf Irrs is not gasping at all, but has had what we would have rather taken as the paradigm of a BCG burst of SF !

## 6 Summarizing the situation ....

From the above description of the results obtained from chemical evolution models of irregulars and BCGs, I would conclude that we are now in the challenging condition of having a qualitative scenario which works acceptably well for the overall sample of late type galaxies, but is unsatisfactorily inconsistent with detailed information on important individual systems. Fortunately, in these last years we are seeing an incredible improvement in the quality of the acquired data and on the technical tools available to interpret them. I thus think that to improve our understanding of galaxy evolution, rather than to keep modelling large generic samples of galaxies, we should concentrate on single representative cases, for which all the necessary information can be obtained. In this framework, the suggested flow-chart of future evolution models would be the following, for each examined galaxy:

1) get as much information as possible on the evolutionary parameters from observations; for instance, recent IMF and SF by interpreting spectral and photometric data by means of population synthesis models (e.g. [10]) and synthetic colour-magnitude diagrams (e.g. [11]), gas flows from optical, UV and/or x-ray data (e.g. [24],[4]), etc.;

2) compute the hydrodynamics of the interstellar medium and SN ejecta in the conditions of the examined galaxy;

3) model the chemical evolution of the galaxy by including all the above data as input.

In this way, the chemical evolution models of each galaxy will be much better constrained. Once a statistically significant sample of dwarfs will be treated in this way, we will be able to draw a really self-consistent scenario for the evolution of these systems and to safely infer their average properties at high redshift.

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## References

- [1] Babul, A., Ferguson, H.C., 1996, *Astrophys. J.* **458**, 100
- [2] Bradamante, F., Matteucci, F., D’Ercole, A., 1998, *astro-ph/9801131*
- [3] Carigi, L., Colin, P., Peimbert, M., Sarmiento, A., 1995, *Astrophys. J.* **445**, 98

- [4] DellaCeca, R., Griffiths, R.E., Heckman, T.M., MacKenty, J.W. 1996, *Astrophys. J.* **469**, 662
- [5] D’Ercole, A., Brighenti, F., 1998 *in preparation*
- [6] De Young, D.S., Gallagher III, J.S., 1990, *Astrophys. J.* **356**, L15
- [7] Gallagher III, J.S., Hunter, D.A., Tutukov, A.V., 1984, *Astrophys. J.* **284**, 544
- [8] Gerola, H., Seiden, P.E., Schulman, L.S., 1980, *Astrophys. J.* **242**, 517
- [9] Gilmore, J., Wyse, R.M., 1991, *Astrophys. J.* **367**, L55
- [10] Gonzales-Delgado, R.M., Leitherer, C., Heckman, T.M., Cervino, M., 1997, *Astrophys. J.* **483**, 705
- [11] Greggio, L., Tosi, M., Clampin, M., Leitherer, C., Nota, A., Sirianni, M., 1998, *Astrophys. J.* **in press**, *astro-ph/9803326*
- [12] Kunth, D., Matteucci, F., Marconi, G., 1995, *MNRAS* **297**, 634
- [13] Hodge, P., 1989, *ARAA* 27 139
- [14] Hunter, D.A., Gallagher, J.S.III, 1985, *Astrophys. J. Suppl. Ser.* **58**, 533
- [15] Hunter, D., Thronson, H.A.Jr, Casey, S., Harper, D.A., 1989, *Astrophys. J.* **341**, 697
- [16] Israel, F.P., 1988, *Astr. Astrophys.* **194**, 24
- [17] Kroupa, P., Tout, C.A., Gilmore, G., 1993, *MNRAS* **262**, 545
- [18] Lequeux, J., 1994, in *Dwarf galaxies*, G.Meylan & P.Prugniel eds (ESO, Garching DE), p.179
- [19] Lequeux, J., Rayo, J.F., Serrano, A., Peimbert, M., Torres-Peimbert, S., 1979, *Astr. Astrophys.* **80**, 155
- [20] MacLow, M. Ferrara, A., 1998, *astro-ph/9801237*
- [21] Marconi, G., Matteucci, F., Tosi, M., 1994, *MNRAS* **270**, 35
- [22] Matteucci, F., Chiosi, C., 1983, *Astr. Astrophys.* **123**, 121
- [23] Matteucci, F., Tosi, M., 1985, *MNRAS* **217**, 391
- [24] Meurer, G.R., Freeman, K.C. Dopita, M.A., Cacciari, C. 1992, *Astrophys. J.* **103**, 60
- [25] Pagel, B.E.J., Simonson, E.A., Terlevich, R.J., Edmunds, M.G., 1992, *MNRAS* **255**, 325
- [26] Pagel, B.E.J., Tautvaisiene, G., 1998, *astro-ph/9801221*
- [27] Pilyugin, L.S., 1993, *Astr. Astrophys.* **277**, 42
- [28] Pilyugin, L.S., 1996, *Astr. Astrophys.* **310**, 751
- [29] Russel, S.C., Dopita, M.A., 1993, *Astrophys. J.* **384**, 508
- [30] Searle, L., Sargent, W.L.W., Bagnuolo, W.G., 1973, *Astrophys. J.* **179**, 427
- [31] Tosi, M., 1988, *Astr. Astrophys.* **197**, 33
- [32] Tosi, M., 1994, in *Dwarf galaxies*, G.Meylan & P.Prugniel eds (ESO, Garching DE), p.465
- [33] Tosi, M., 1996, in *From stars to galaxies*, C.Leitherer, U.Fritze-von Alvensleben, J.Huchra eds, ASP Conference Series 98 299
- [34] Tsujimoto et al 1995, *MNRAS* **277**, 945
- [35] Vallenari, A., Bomans, D.J., 1996, *Astr. Astrophys.* **313**, 713
- [36] Waller, W., 1991 *Astrophys. J.* **370**, 144