Stellar Populations and Chemical Evolution of Late–Type Dwarf Galaxies

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Abstract

Some aspects of the chemical evolution of late-type dwarf galaxies are reviewed, together with their implications on some issues of cosmological relevance. A more detailed approach to model their evolution is suggested. The importance of deriving the star formation history in these systems by studying their resolved stellar populations is emphasized.

1 Introduction

People have been studying the evolution of late-type dwarf galaxies for two-three decades, but only in the last 5–6 years this has become a fashionable research field. This late interest is probably due to the circumstance that cosmologists have recently discovered that understanding the evolution of the gaseous and stellar constituents of these systems is a necessary step for a correct analysis of some important problems of cosmological relevance. The connection between late-type dwarfs and cosmology is at least three-fold: 1) given the high gas content and low metallicity of irregular and blue compact galaxies (hereinafter, Irrs and BCDs, respectively), they are the closest analogues to primeval galaxies; 2) they are the systems currently providing the safest empirical estimate of the primordial ^{4}He abundance; 3) they have been suggested 5-6 years ago (e.g. Lilly et al. 1995, Babul & Ferguson 1996) to be the local counterparts of the blue objects in excess in deep galaxy counts at intermediate redshifts.

Here I will try to summarize what can be learnt from chemical evolution models and stellar population studies of Irrs and BCDs and what this implies for these three issues of cosmological relevance. In the following discussion, I will emphasize the open questions rather than the (important) results already achieved in the field.

2 Evolution of late-type dwarfs

When a galaxy forms, after a while it begins to form stars and starts a series of cycles following in general the scheme drawn by Tinsley (1980). The stars evolve and synthesize in their interiors heavier and heavier elements, and then eject them in the surrounding medium when they lose mass and die. In this way they pollute the interstellar medium (ISM) and modify both its mass and chemical composition. In the meantime, the ISM mass and metallicity may change also for gas exchanges with adjacent regions (gas losses or accretions, or both). The next generation of stars thus form in that ISM with a different initial composition and must have therefore a slightly different evolution.

Models for galaxy chemical evolution take these phenomena into account, as well as their effects on the stellar and gaseous properties, by simplisticly parametrizing the physical mechanisms. The

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

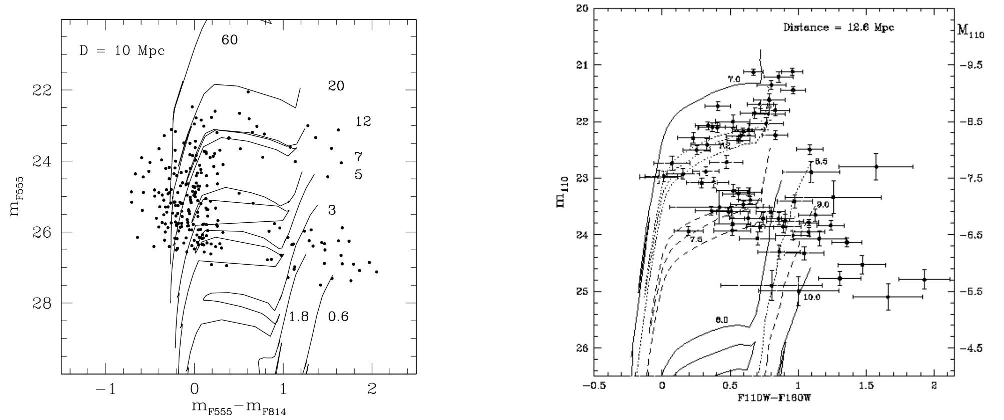

Figure 1: Optical and NIR CMD of the resolved stars in the main body of IZw18, as resulting from HST data (Aloisi et al. 1999 and Ostlin 2000, respectively). Overimposed on the optical CMD are the Padova stellar evolution tracks with Z=0.0004 (masses are indicated in $M_{\odot}$). Overimposed on the NIR CMD are the Geneva isochrones with the same metallicity.

major parameters are the star formation (SF) law, the initial mass function (IMF), the gas flows in and out of the considered region, and the quantities involved in stellar nucleosynthesis (e.g. stellar lifetimes, yields, mass loss, opacities, treatment of convection, etc.).

Chemical evolution models for Irrs and BCDs have been computed by several groups in the last twenty years (e.g. Matteucci & Chiosi 1983, Matteucci & Tosi 1985, Pilyugin 1993, Marconi et al. 1994, Carigi et al. 1995, Larsen et al. 2000, Recchi et al. 2001). The combination of the predictions of these models with the information on the evolution of Irrs and BCDs from other kinds of studies have interesting consequences on the three issues of cosmological relevance mentioned in the Introduction.

2.1 Irrs and BCDs as almost primeval galaxies ?

Back in 1973, Searle et al. suggested that the blue colors, low metallicities and high gas fractions of BCDs could be self-consistently explained only if these systems either are experiencing now their first episode of SF activity or have a very discontinuous SF regime, dominated by short intense bursts separated by long quiescent phases (see e.g. the top right-hand panel in Fig.5).

Almost thirty years later, however, no convincing case of galaxy at its first SF experience has been found yet: all the systems for which sufficiently deep photometry exists reveal the presence of stellar populations as old as the maximum lookback time allowed by the photometric depth (see also Schulte-Ladbeck, this volume). Even IZw18, the most metal-poor galaxy ever discovered, when imaged with HST, has been recognized to contain stars at least a few hundreds Myr old. Aloisi et al. (1999) have shown that the colour-magnitude diagram (CMD) derived from optical WFPC2 photometry of IZw18 contains several faint red stars (see left panel in Fig.1) which can only be objects in the asymptotic giant branch (AGB) phase of low and intermediate mass stars and must, therefore, have ages between a minimum of 200-300 Myr up to a few Gyrs. Exactly the same conclusion has been independently reached by Ostlin (2000) on the basis of near-infrared Nicmos imaging (right panel in Fig.1).

Since lack of evidence is certainly not evidence of lack, this result does not exclude that really young galaxies do exist, but clearly restricts their possible number to a small fraction of the known late-type dwarfs. If Searle et al. (1973) were right, then, the vast majority of BCDs should have a bursting mode of SF. This was indeed suggested by many chemical evolution models (e.g. Matteucci & Tosi 1985, Pilyugin 1993), which confirmed that the best way to reproduce simultaneously colours, chemical abundances and gas fractions of BCDs (and possibly of Irrs) was to have only a

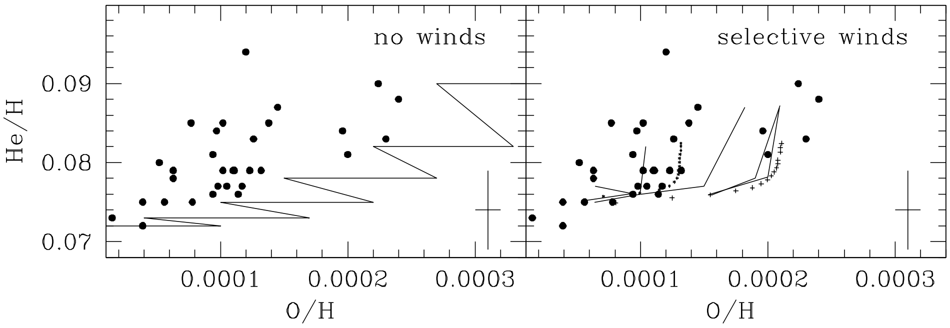

Figure 2: Distribution of the helium vs oxygen abundance as derived from HII regions (dots) in late-type dwarfs and as predicted (curves) by chemical evolution models (Pilyugin 1993 on the left panel, Marconi et al. 1994 on the right panel).

few (7–10, at most) episodes of strong SF activity, with long quiescent intervals. This conclusion has however been questioned by more recent models (e.g. Carigi et al. 1995, Legrand 2000) suggesting that continuous SF regimes, with very low rates, could account equally well for the observed features.

The lack of unique scenarios from chemical evolution models of late-type dwarfs is due to the fact that we do not have yet sufficient observational data to properly constrain them. For what concerns the SF regime, the most direct way to infer it from observations is from the CMDs of systems close enough to be resolvable in single stars.

2.2 The helium–metallicity relation

The primordial ^{4}He abundance is nowadays one of the hottest issues in cosmology, due to the recent observational data (Tytler et al. 2000 and references therein) showing that primordial D was quite low, $(D/H)_p \simeq 3 \times 10^{-5}$, and, hence, either ^{4}He was high (in mass fraction $Y_p >0.24$), or the standard theories of Big Bang Nucleosynthesis are not self-consistent. The only method currently considered reliable to derive the primordial helium abundance is based on the extrapolation to zero-metallicity of the helium–metallicity relation derived from observations of HII regions in metal-poor galaxies. Since the heavy elements more reliably derived from HII regions are oxygen and nitrogen, what people actually use are the helium–oxygen and helium–nitrogen relations, inferred from a linear fit to the data (see e.g. Izotov et al. 1997).

One of the questions on this method is whether or not these relations can be taken as linear. He, N and O are synthesized in different stellar mass ranges: helium is produced by all stars, nitrogen almost exclusively by intermediate mass stars, and oxygen only by massive ones; and this implies that the timescales for their ISM enrichment are quite different from each other. This point was explicitely addressed by Pilyugin (1993) who showed with his chemical evolution models that the evolution of He with O (and with N) in a BCD is not linear but has typically a saw-tooth shape (see left-hand panel in Fig.2).

Furthermore, all chemical evolution models of these galaxies invoke the occurrence of significant galactic winds during their life, and these winds are often required to be more effective in removing elements (like oxygen) expelled from massive stars. If these differential winds occur, this also makes the behaviour of helium with oxygen non linear during the lifetime of a dwarf, as shown both by Pilyugin (1993) and Marconi et al. (1994) and illustrated in the right-hand panel of Fig.2. The questions are: Do the winds actually occur and in what percentage of Irrs and BCDs ? If they do occur, do they really remove some (which ?) elements for ever ? With what efficiency ? Several optical and X-ray observations of ionized filaments and bubbles in some Irrs and BCDs confirm that somewhere the phenomenon does take place and seem to preferentially eject alpha-elements (see e.g. Meurer et al. 1992, Sahu & Blades 1997, Hensler et al. 1998, for NGC 1705). However, hydrodynamical models of the SN ejecta in dwarf galaxies do not agree yet on the timescales or on the efficiency of the gas removal (cfr. Silich & Tenorio-Tagle 1998, D'Ercole & Brighenti 1999, Mac Low & Ferrara 1999).

In spite of the above arguments, I personally believe that a linear fit to the observed helium–oxygen and helium–nitrogen distributions derived from HII regions is the correct approach to infer the primordial ^{4}He. In fact, each data point in the empirical distribution corresponds to the final (i.e. present epoch) stage of the He–O and He–N behaviours in each galaxy, and to derive the mean initial ^{4}He one needs to average over all the possible behaviours of the whole sample of galaxies. The observed shape of the distribution suggests indeed that this is well represented by a linear fit.

2.3 Local counterparts of faint blue galaxies ?

Some authors (e.g. Lilly et al. 1995, Babul & Ferguson 1996) have suggested that starbursting dwarfs may be the local counterparts of the faint blue galaxies usually found in excess in deep galaxy counts at redshift of 0.7–1.0. To verify whether this is a likely possibility, one needs to check if most of the dwarfs have been forming stars at the epochs corresponding to that redshift (hence about 6–7 Gyr ago) and if, in case, that SF activity was strong enough (i.e. $\sim$1 $M_\odot yr^{-1}$) to guarantee the observed luminosity levels.

We have already mentioned above that all the galaxies examined so far appear to contain stars as old as the lookback time corresponding to the faint mag limit of the available photometry. This makes it extremely probable that most of them have already been active several billion years ago. The tough question is on the intensity of the SF. Van Zee (2001) has very recently surveyed the SF histories of a large sample of distant, isolated dwarf Irrs and concludes that their SF activities are too modest and it is very unlikely that these systems could significantly contribute to the faint blue galaxy excess.

This conclusion is inevitably based on integrated properties of these distant objects. To obtain a more quantitative information, it is necessary to examine nearby systems where the SF history can be derived directly from the resolved stellar populations and a more detailed evaluation of the SF rates at different epochs can be performed.

3 SF histories from stellar populations

As discussed in the previous sections, for a correct approach to study the evolution of Irrs and BCDs and for several issues of cosmological relevance, it is of crucial importance to derive the SF history of a large number of galaxies of these types. The most direct estimate of the epochs and of the intensities of the SF activities is derivable from the CMDs, since their morpholoy is the consequence of the system evolutionary conditions. Fig.3 shows a few examples of how the CMD morphology is affected by the SF history and IMF. We thus proposed several years ago (Tosi et al. 1989, 1991) the method of synthetic CMDs to derive from the observational CMDs as much information as possible, taking into account all the incertainties related to both observations and theories. Similar procedures have been developed also by other groups (e.g. Aparicio et al. 1996, Tolstoy & Saha 1996) and are now widely applied (see also the contributions by Grebel, Schulte-Ladbeck, Tolstoy, this volume).

The numerical procedure creates synthetic CMDs, via MonteCarlo extractions on homogeneous sets of stellar evolution tracks (e.g. the Geneva or the Padova sets) of various metallicities, taking into account all the involved theoretical parameters and uncertainties (age, metallicity, IMF, SF law, stochastic effects due to small number statistics, etc.). The synthetic CMDs have the observed number of stars of the examined region and its observational uncertainties (photometric

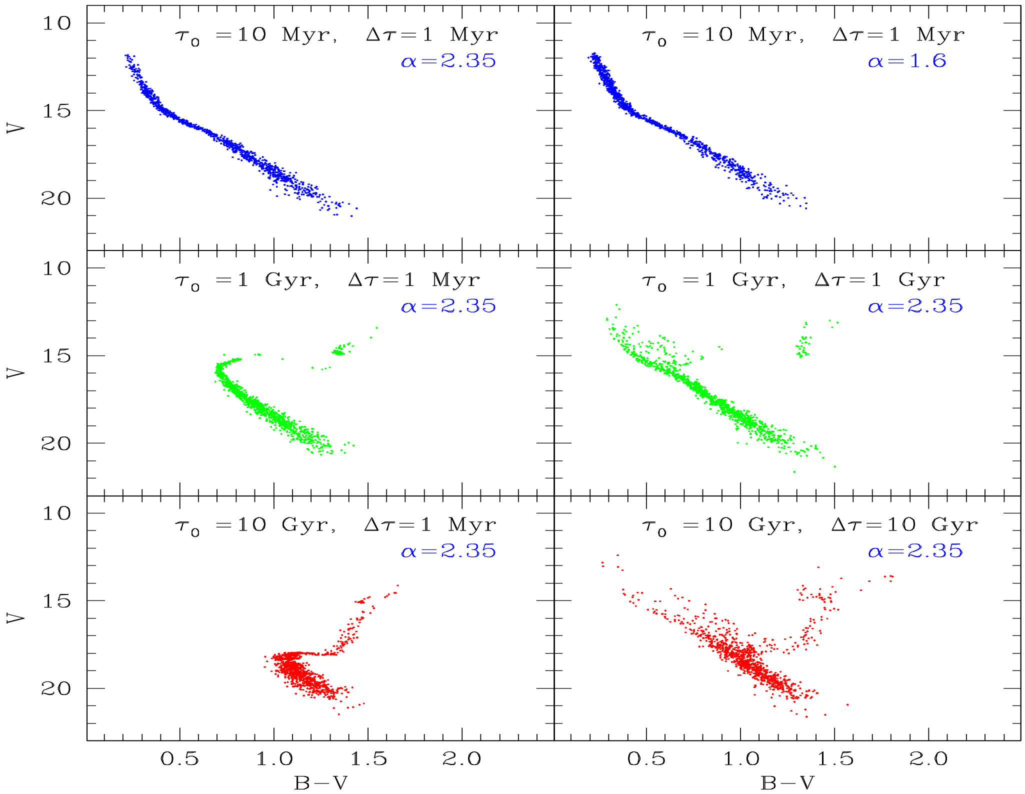

Figure 3: Synthetic CMD of a hypothetical stellar system with 1000 single stars photometrically resolved. Distance modulus, $(m-M)_0 = 12.5$, reddening, $E(B-V) = 0.45$, photometric errors and incompleteness are those derived from observations of a real Galactic open cluster (NGC 2660). The adopted stellar evolution tracks (Bressan et al. 1993) have solar metallicity. The assumed starting time (backwards from present epoch) and duration of the SF activity are labelled in each panel, together with the adopted IMF slope.

errors, incompleteness factors, blending). The latter is a very important point which requires a special accuracy during the photometric analysis. A model can be considered satisfactory only if it reproduces all the features of the observational CMD and luminosity function (LF).

By comparing all the simulated cases with the empirical CMD and LF we select those which are more consistent with them and thus derive the number, starting epoch, duration and intensity of the SF episodes, their IMF, the durations of significant quiescent intervals (if any), and hints on the most likely metallicity of the various stellar generations. In most, if not all, the cases, the results are not unique, but we can sensibly reduce the range of acceptable values of the various parameters, thus obtaining a good indication on the most likely evolution of the examined region.

We have applied the method to Local Group Irrs with ground-based observations and to more distant late-type dwarfs observed with HST (see Table 1 for a summary of the results). Fig.4 shows two cases of synthetic CMDs for IZw18: it is apparent that a single recent SF burst cannot account for the observed red stars (both faint and bright) and predicts too many too bright objects, despite the rather steep IMF. The case with two episodes is instead consistent with the observed features. The most recent application is being performed on the BCD NGC 1705 and its preliminary results are described by Annibali et al. (this volume, p. 103). Of the 8 dwarfs examined so far by our group, only NGC 1569 shows evidence for a very intense and short burst (Greggio et al. 1998), in addition to other longer, less striking episodes. All the others appear to have had a gasping SF regime, with episodes of much more moderate activity. None of them shows any evidence for

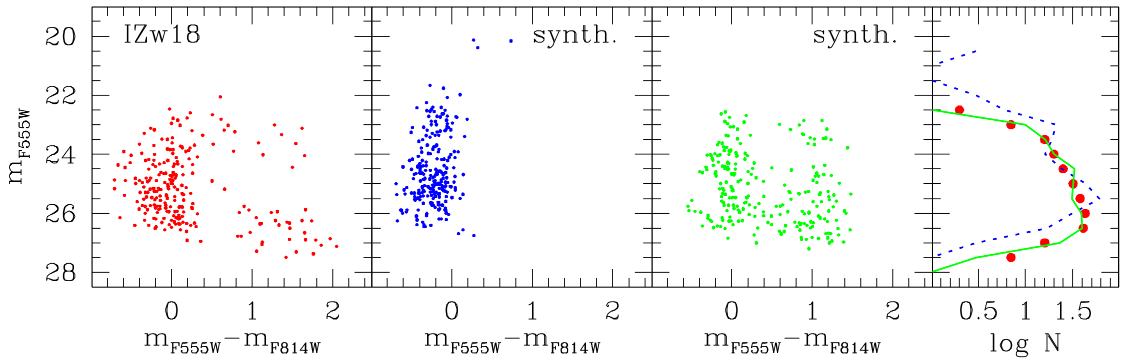

Figure 4: The case of IZw18. The left panel shows the empirical V,V–I CMD (in the HST–Vegamag system) derived from HST–WFPC2 photometry. The two middle panels show two cases of synthetic CMDs with the same number of objects, photometric error and incompleteness factors as in the empirical CMD. The left hand case refers to one single burst of SF from 10 Myr ago to the present epoch, with a steep IMF slope α=3.0. The right hand case assumes two SF episodes: one from 1 Gyr to 30 Myr ago and the other from 20 Myr to 5 Myr ago, with a flat IMF slope α=1.5. Finally, the right-hand panel presents the comparison of the LFs corresponding to the two synthetic cases (dotted line for the single episode and solid line for the two episodes) with the empirical one (dots). See Aloisi et al. (1999) for further details.

quiescent phases longer than 10^8 yr.

If we combine the results on the SF history of the late-type dwarfs studied by our group with those obtained by other groups (see e.g. Grebel 1998 for a comprehensive review of Local Group galaxies and Schulte-Ladbeck, this volume, for BCDs outside the Local Group) it is apparent that these galaxies, with very few exceptions, have had qualitatively similar SF histories. Fig.5 shows the SF histories derived in 5 galaxies: NGC 1569 is the only one which appears to follow the bursting scheme. The data available so far have not allowed yet to accurately derive its earlier activity, but the new HST photometry in the near infrared by Aloisi et al. (2001) should allow for a lookback time of, at least, a few Gyrs. In summary:

- Both Irrs and BCDs seem to have a roughly continuous or gasping SF regime, with various episodes of moderate activity and no clear sign of long periods of total inactivity.
- Only the few cases of the type of NGC 1569 have bursts with SF rates high enough to allow for the luminosity attributed to faint blue galaxies at redshift 0.7–1.
- No evidence has been found yet for dwarfs at their first SF activity.

4 Future prospects

From the above presentation, it is apparent that further studies on several issues are still required to obtain a reliable scenario for the evolution of late-type dwarfs. In particular, the SF histories and the major characteristics of the gas flows triggered by SN explosions should be examined in more details. For this reason I believe that, at present, the correct approach to model the chemical evolution of these systems would be to concentrate on single representative cases, rather than to model the overall features of a large sample of galaxies. For the chosen cases I would:

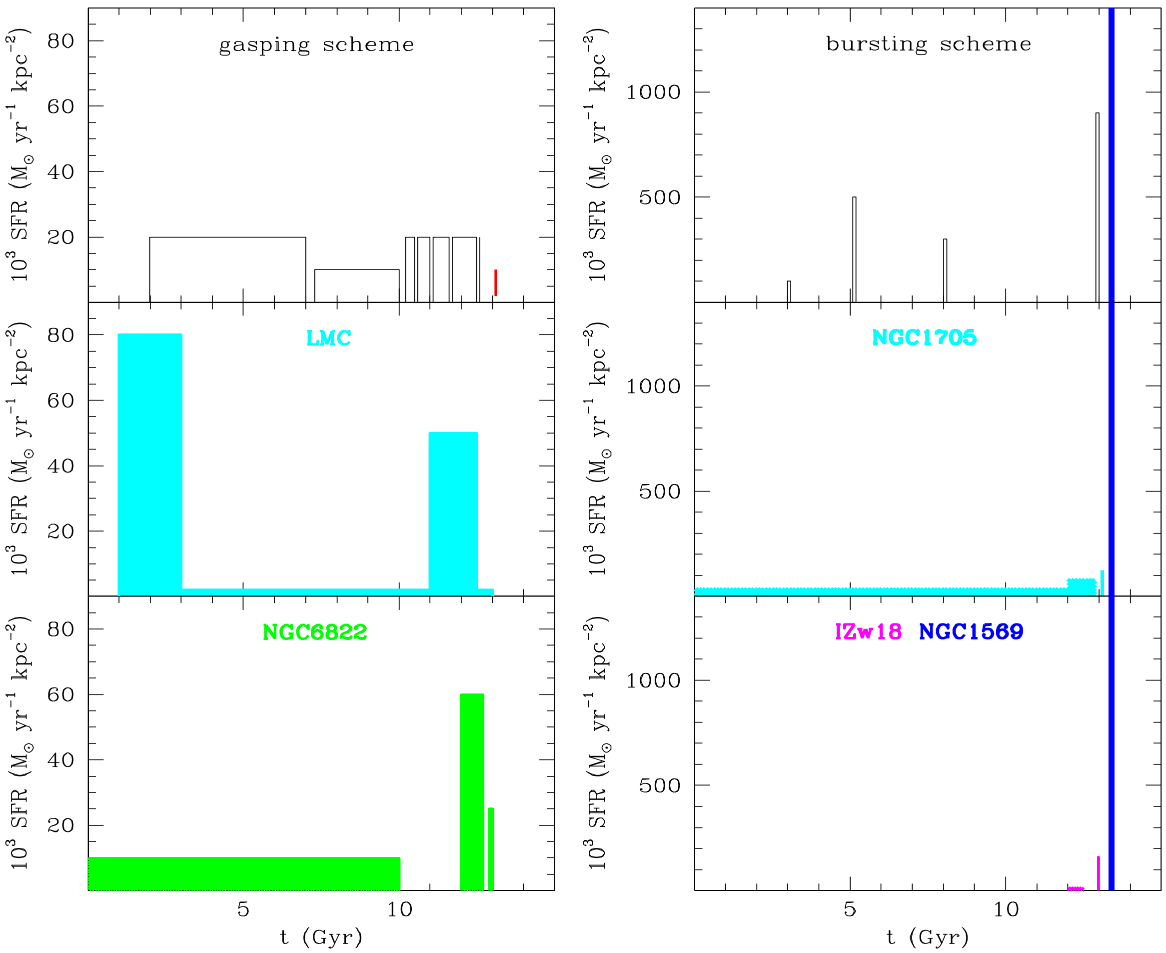

Figure 5: SF histories in late–type dwarfs. The hypothetical time behaviour of the SF rate per unit area is sketched in the top panels for the gasping (left) and bursting (right) regimes. The middle and bottom panels show the actual behaviours derived for 5 galaxies: LMC (Pilyugin 1996, Pagel & Tautvaisiene 1998), NGC 1569 (Greggio et al. 1998), NGC 1705 (Annibali et al. this volume), NGC6822 (Marconi et al. 1995, Gallart et al. 1996), IZw18 (Aloisi et al. 1999). The long spike crossing all the right-hand panels shows the striking case of NGC 1569, which has a SFR per unit area of 4 $M_\odot yr^{-1} kpc^{-2}$.

Table 1: Dwarf irregulars and BCDs in our program. Listed for each galaxy are: name, coordinates, derived distance modulus, number of resolved stars with small photometric error, and SF mode derived from the synthetic CMD method.

Name	R.A.	DEC	$(m-M)_0$	sel obj	SF mode
DDO 70 (Sex B)	09 57 23	+05 34 07	25.6	1300	gasps
DDO 209 (NGC 6822)	19 42 07	−14 55 01	23.5	1772	gasps
DDO 210 (Aquarius)	20 44 08	−13 02 00	28 ?	633	gasps
DDO 221 (WLM)	23 59 23	−15 44 06	25.0	2000	gasps
DDO 236 (NGC 3109)	10 00 48	−25 55 00	25.7	2605	gasps
NGC 1569	04 26 04	+64 44 29	26.7	801	gasps+burst
IZw18	09 34 02	+55 14 19	30.0	150	gasps
NGC 1705	04 54 13	−53 21 40	28.6	17000	gasps

- Try to get as much information as possible on the evolutionary parameters from observations (e.g. IMF and SF from populations synthesis and synthetic CMD; gas distribution and flows from multiwavelength observations; etc.);
- Compute the hydrodynamics of the ISM and SN ejecta in the conditions of the examined galaxy derived from the first point;
- Only at this point, model the chemical evolution of the examined galaxy including all the results of the previous points as input data.

Acknowledgements
I warmly thank the organizers of this enjoyable and interesting meeting for the invitation and the financial support. I sincerely congratulate them for the success of their Graduate School. This work has been partly supported by the Italian MURST through Cofin2000.

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