Star formation histories of late-type dwarfs outside the Local Group

Monica Tosi
Osservatorio Astronomico, Via Ranzani 1, 40127 Bologna, Italy

Laura Greggio
Osservatorio Astronomico, Via Ranzani 1, 40127 Bologna, Italy

Francesca Annibali
Osservatorio Astronomico, Via Ranzani 1, 40127 Bologna, Italy

Alessandra Aloisi
STScI, 3700 San Martin Drive, Baltimore, MD, 21218 USA

Abstract. We describe the star formation histories of three late-type dwarfs located outside the Local Group: IZw18, NGC1569 and NGC1705. The results are based on the application of the method of synthetic colour-magnitude diagrams to deep HST photometric data. All the examined galaxies were already forming stars at the reached lookback time and show no evidence of long quiescent phases. The obtained scenarios are quite similar to those derived for other galaxies of this morphological type, both inside and outside the Local Group.

1. Introduction

The application of the synthetic colour-magnitude diagram (CMD) method to dwarf galaxies in the Local Group has allowed several people to infer the star formation histories (SFHs) of these galaxies with unprecedented accuracy (e.g. Tosi et al. 1991, Aparicio et al. 1996, Tolstoy & Saha 1996, Grebel 1998). It has thus been possible to understand that late-type dwarfs evolve following a gasping (Tosi et al 1991) regime of star formation (SF) rather than a bursting one. In other words, their SF occurs in long episodes of moderate activity, separated by short quiescent phases, and not in short episodes of strong activity, separated by long quiescent periods.

The natural question is what do late-type galaxies outside the Local Group do, and what is the SF regime in Blue Compact Dwarfs (BCDs), which are not present locally. BCDs have been suggested to undergo a few strong and short bursts of SF, to be so poorly evolved to represent the closest analogues to primeval galaxies and to be possible contributors to the excess of faint blue objects found in deep galaxy counts at redshifts between 0.7 and 1. Hence,
understanding whether or not their SF activity can be strong enough to allow for sufficient brightness at intermediate redshift and whether or not any of them are currently forming their first stars can have interesting cosmological implications.

In order to answer these questions, we are studying the SFHs of a number of late-type dwarfs (both BCDs and dwarf irregulars) outside the Local Group. Their individual stars have been resolved by deep Hubble Space Telescope (HST) photometry and their stellar populations can be interpreted in terms of SFH with the synthetic CMD method. So far, we have examined three prototype systems: IZw18, NGC1569 and NGC1705. IZw18 (at a distance between 10 and 14 Mpc) is the most metal poor galaxy ever observed and has often been suggested to be experiencing now its first burst of SF. NGC1569 (at 2.2 Mpc) is one of the most active starburst dwarfs, exhibiting three super star clusters, a large concentration of giant HII regions, and shells and filaments presumably related to young SN ejecta. NGC1705 (at 5.1 Mpc) is a post-starburst BCD, containing a super star cluster and showing the best observational evidence of gas outflows (galactic winds) triggered by SN explosions.

2. Application of the synthetic CMD method to IZw18, NGC1569 and NGC1705

For these three galaxies we have reduced with the highest accuracy the HST photometric data, to resolve individual stars down to the faintest possible level and derive their CMDs. Since the fainter stars, in general, are also the older ones, the deeper we succeed in measuring the stars, the longer we cover in lookback time. We have estimated the incompleteness and blending factors and the photometric errors of the data by performing artificial star tests on the actual images. Then we have applied the synthetic CMD method as described by Tosi et al. (1991) and Greggio et al. (1998).

The synthetic CMDs are constructed via Monte Carlo extractions of (mass, age) pairs, according to the assumed IMF, SF law, and time interval of the SF activity. Each extracted synthetic star is placed in the CMD by suitable interpolations on the adopted stellar evolution tracks and adopting appropriate tables for photometric conversion in the desired photometric system (the HST-Vega system for all our HST data). The absolute magnitude is converted to a provisional apparent mag by applying the (either known or arbitrary) reddening and distance modulus. The results of the artificial star tests are crucial to create reliable synthetic CMDs. First, of the synthetic stars extracted for any mag and photometric band, we retain only the fraction given by the corresponding recovered/input artificial stars. Then, the retained synthetic stars are assigned a photometric error derived from the cumulative distribution of the (output-input) mags of the artificial stars with input mag equal to the provisional apparent mag.

Once the number of objects populating the whole synthetic CMD (or portions of it) equals that of the observed one, the procedure is stopped, yielding the quantitative level of the SF rate consistent with the observational data, for the prescribed IMF and shape of the SF law. To evaluate the goodness of the model predictions, we compare them with: the observational luminosity functions (LFs), the overall morphology of the CMD, its mag and colour distributions, the number of objects in particular phases (e.g. on the red giant
Star formation histories of late-type dwarfs outside the Local Group

Figure 1. IZw18: The left-hand 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. 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 text for details.

branch, RGB, on the clump, on the blue loops, etc.). A model can be considered satisfactory only if it reproduces all the features of the empirical CMDs and LFs. Given the uncertainties affecting both the photometry and the theoretical parameters (stellar evolution tracks included), the method cannot provide strictly unique results; however, it allows us to significantly reduce the range of possible interpretations of the evolutionary status of the examined region.

The application of the method to IZw18 (Aloisi, Tosi & Greggio 1999) has shown that, despite its very low metallicity, this system is not experiencing now its first SF activity. The optical CMD plotted in the left-hand panel of Fig.1 shows the clear presence of red faint objects which can be interpreted only as relatively old stars (age larger than several hundreds Myrs) on the asymptotic giant branch or RGB phases. These same stars have been measured also in the infrared by Östlin (2000) who locates them exactly in the same CMD evolutionary phase. The lookback time reached with this photometry is around 0.5 Gyr (depending on the galaxy distance which is still relatively uncertain). A model assuming a single recent burst of SF (second panel from left in Fig.1) started 10 Myr ago and still active is definitely inconsistent with the data, since it predicts no red stars, either faint or bright, and too many bright blue stars, even adopting a steep IMF (in the shown case: $\alpha = 3.0$, with the normalization where Salpeter’s slope is 2.35). Models assuming two episodes of SF (second panel from right) reproduce instead fairly well the observed stellar distribution. The best agreement is obtained with the Fagotto et al. (1994) stellar tracks with metallicity Z=0.0004, a flat IMF ($\alpha=1.5$), a first SF episode from 500 to 30 Myr ago, and a second one from 20 Myr to 5 Myr ago. The same scenario is obtained with the Geneva stellar models with Z=0.0001 (Schaller et al. 1992).

For NGC1569, the lookback time provided by the optical CMD (Greggio et al 1998) is about 0.15 Gyr, while it can reach about 1 Gyr with the infrared NICMOS data which we have only recently analyzed (Aloisi et al. 2001). Greggio et al. have thus derived the SFH of NGC1569 in recent epochs from the optical
Figure 2. NGC1705. The top panels refer to the optical data (observed CMD on the left, synthetic CMD at the center, observed and synthetic LFs on the right). The bottom panels to the infrared data (again, from left to right: observed CMD of the same objects as in the top panel, synthetic CMD from the same model as in the top panel, comparison of their LFs).

CMDs and we are planning to derive the less recent one from the infrared CMDs. The most probable scenario suggested by Greggio et al. for the recent SFH assumes an IMF slope $\alpha = 2.6$ and two episodes of SF: one from the reached lookback time up to 35 Myr ago, and a more intense one from 30 to 10 Myr ago. The quiescent phase lasts 5 Myr; had it been only 5 Myr longer it would have led to a gap in the star distribution in the blue plume, which is instead definitely absent in the observational CMD. This places a strong upper limit to the length of the quiescent phases.

We have recently reduced V, I, J, H HST images of NGC1705 (Tosi et al. 2001) and found from the resulting CMDs that there is an age radial gradient, with the younger stars strongly concentrated in the central regions and the older stars dominating the outer regions; a result common to Local Group dwarfs. Thanks to the quality of these data, the lookback time is 10-15 Gyr, despite the high distance of this galaxy. We have already simulated (Annibali et al. 2001) the CMD of the inner field, observed in all the four bands. To reproduce all the observed features of the CMDs and LFs of this region (see Fig.2), we need to assume several episodes of SF: a roughly constant activity from the reached lookback time to 1 Gyr ago, another one from 1000 to 50 Myr ago, a more intense episode started 50 Myr ago and still active, and a short burst active only between 15 and 10 Myr ago. The SF rates of these episodes are still very
Star formation histories of late-type dwarfs outside the Local Group

3. The SFH of galaxies outside the Local Group

Fig. 3 shows the SF rate per unit area as a function of time derived in our three galaxies from the best synthetic CMDs. Only NGC1569 shows what can be defined as a real intense burst. In fact, even if we do not have yet quantitative results on its SF at ages older than 0.15 Gyr, we do know that its mass \((3.3 \times 10^8 \text{M}_\odot)\) does not allow for such gas consumption rates to last longer than 1 Gyr, at most. The other two galaxies have SFHs quite similar to those inferred by various groups for Local Group Irregulars (see Grebel 1998 and references therein): long episodes of moderate activity with only a few, short interruptions, back to the reached lookback time. We must emphasize that exactly the same scenario has been obtained for the other BCDs which have been examined with the synthetic CMD method by others. The left-hand and central panels at the bottom of Fig. 3 show for instance the SFH inferred by Schulte-Ladbeck et al. (2001) and Schulte-Ladbeck et al. (2000) for the BCDs IZw36 and Mrk178, respectively.

The results presented here can be generalized if we take into account all the CMD analyses of late-type dwarfs available in the literature.
• No evidence has been found so far of long interruptions in the SF activity, neither in irregulars nor in BCDs;
• Only very few dwarfs show strong SF bursts, like NGC1569;
• No galaxy forming now its first stars has been found yet: all the examined systems were already active at the reached lookback time.

This implies that:

a) the late-type dwarfs outside the Local Group have a gasping SF regime like those inside it;
b) there is no obvious difference in the SFH of BCDs and irregulars;
c) only a few dwarfs may have had bursts of SF as strong as required to contribute to the excess of faint blue galaxies at intermedirat redshifts.

**Acknowledgments.** We warmly thank Regina Schulte-Ladbeck for interesting conversations and for having provided her results in suitable format. This work has been supported by the Italian ASI (grant ARS-99-44) and MURST (Cofin2000).

**References**

Aloisi, A., Clampin, M., Diolaiti, E., Greggio, L., Leitherer, C., Nota, A., Origlia, L., Parmeggiani, G., Tosi, M. 2001, AJ, 121, 1425
Aloisi, A., Tosi, M., Greggio, L. 1999, AJ, 118, 302
Annibali, F., Aloisi, A., Greggio, L., Leitherer, C., Tosi, M. 2001, in Dwarf Galaxies and their Environment, ed. K.S. de Boer, R.J. Dettmar, U. Klein (Aacher: Shaker), in press
Aparicio, A., Gallart, C., Chiosi, C., Bertelli, G. 1996, ApJ, 469, L97
Fagotto, F., Bressan, A., Bertelli, G., Chiosi, C. 1994, A&AS, 105, 29
Grebel, E.K. 1998, IAU Symp.192, p.1
Greggio, L., Tosi, M., Clampin, M., De Marchi, G., Leitherer, C., Nota, A., Sirianni, M. 1998, ApJ, 504, 725
Östlin, G. 2000, ApJ, 535, L99
Pagel, B.E.J. & Tautvaisiene, G. 1998, MNRAS, 299, 535
Schaller, G., Schaerer, D., Meynet, G., Maeder, A. 1992, A&AS, 96, 269
Schulte-Ladbeck, R.E., Hopp, U., Greggio, L., Crone, M.M. 2000, AJ, 120, 1713
Schulte-Ladbeck, R.E., Hopp, U., Greggio, L., Crone, M.M., Drozdovsky, I.O., 2001, AJ, 120, 1713
Tolstoy, E. & Saha, A. 1996, ApJ, 462, 672
Tosi, M., Greggio, L., Marconi, G., Focardi, P. 1991, AJ, 102, 951
Tosi, M., Sabbi, E., Bellazzini, M., Aloisi, A., Greggio, L., Leitherer, C., Montegriffo, P. 2001, AJ 122, 1271