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Stellar populations and star formation histories in late-type dwarfs

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Abstract. Studies of the resolved stellar populations in nearby systems are crucial to understand galaxy evolution. Here, we summarize how the interpretation of the colour-magnitude diagrams of field stars in late-type dwarfs inside and outside the Local Group has allowed us to infer their star formation histories and put useful constraints on the evolution of this type of galaxies.

Key words. stellar populations, colour-magnitude diagrams, star formation history, galaxy evolution

1. Introduction

If we aim at understanding the evolution of galaxies of whatever morphological type, we need to follow two distinct and complementary approaches. On the one hand we must develop theoretical models of galaxy formation, of chemical and of dynamical evolution, and, on the other hand, we must collect as many and as accurate as possible observational data to constrain the models. In particular we need to acquire reliable data on the chemical abundances, masses and kinematics of the galactic components (gas, stars, dark matter), the star formation (SF) regimes, the stellar initial mass function (IMF). It is specially important to derive information on the actual behaviours of SF and IMF, since they are usually adopted as free parameters in the models. Hence, putting stringent observational constraints on them can let us avoid unrealistic modeling. In galaxies close enough to let us resolve their individual stars, most of the information on the above quantities can be derived by observing their resolved stars. To infer the SF regime and history of resolved stellar populations, the best tool is their colour-magnitude diagram (CMD), because it shows the signature of their evolutionary status.

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2. The synthetic CMD method

To derive the SF history of dwarf galaxies, several years ago Laura Greggio and myself developed a method (Tosi et al. 1991; Greggio et al. 1998) based on the comparison of empirical and synthetic CMDs. The synthetic CMDs are created via MonteCarlo extractions on homogeneous sets of stellar evolution tracks. They take into account all the theoretical parameters (IMF, age, metallicity, small number statistics, etc.), must contain the same number of stars as the observational CMD (or portions of it), and

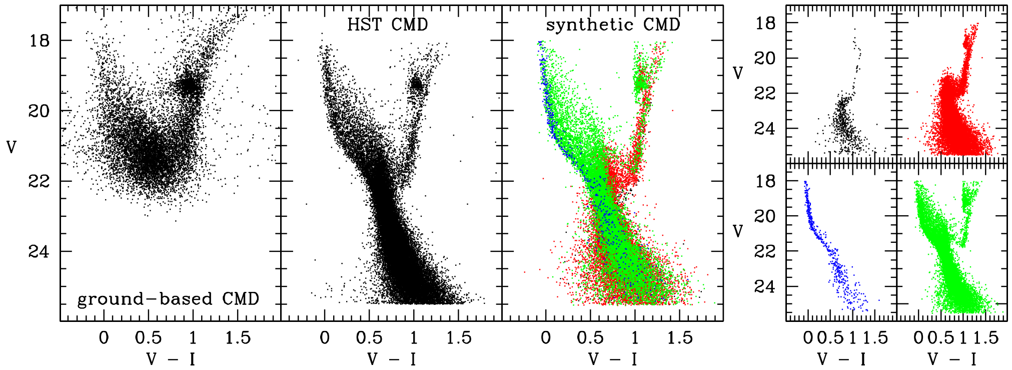

Fig. 1. CMDs of one field of the LMC bar. Left-hand panel: ground based CMD from the 1.5 m Danish telescope (Clementini et al. 2003). Second panel from left: CMD of the same field as derived by Smecker-Hane et al. (2002) from HST/WFPC2 photometry; third panel from left: from the Coimbra experiment, synthetic CMD by Tosi, Greggio & Annibali (2002). Right-hand panel, the synthetic CMD of the previous panel splitted in its four episode components, from the oldest to the youngest one clock-wise from the top-left panel.

must be affected by the same photometric error, incompleteness and blending factors. Hence, a combination of theoretical parameters is acceptable only if the resulting CMD reproduces all the features of the observational one: morphology, colours, luminosity functions (LF), number of stars in specific evolutionary phases. The comparison between empirical and synthetic CMD allows us to evaluate whether or not the parameter combination of the latter is acceptable. By checking all the combinations we can derive the epoch, duration, intensity of the SF episodes, number of episodes and quiescent intervals, IMF, metallicity.

Since this is a statistical approach, we cannot pretend to get unique solutions for the SF history of the examined region, but we can strongly reduce the range of possible scenarios.

When we started working in this field, the CMDs were obtained from relatively small, relatively old telescopes, such as the 1.5m Danish and the 2.2m ESO/MPI in La Silla (Ferraro et al. 1989; Tosi et al. 1991) or the 2.5m INT in the Canary Islands (Gallart et al. 1996). When the first CMDs resulting from HST photometry became available, they appeared impressively deeper and tighter than the previous ones (see e.g. Fig. 1) and triggered so much interest on the synthetic CMD method, that many new groups developed their own procedures to apply it [e.g. Tolstoy & Saha (1996)]. To check if the scenarios resulting from the approaches of different groups are consistent with each other, Carme Gallart set up a very interesting experiment which was held in 2000 (Skillman & Gallart 2002) in Coimbra (Portugal). Each participating group was given the empirical CMD of a field on the bar of the LMC as derived by Smecker-Hane et al. (2002) from HST-WFPC2 photometry (second panel from left in Fig. 1) and the catalogue of the artificial star test kindly performed by A. Dolphin to get photometric errors, incompleteness and blending factors. A referee (E. Skillman) was in charge of comparing the results of the different groups and of summarizing them all. About ten groups participated (Gallart, Aparicio & Bertelli 2002; Rizzi et al. 2002; Cole, Smecker-Hane & Mandushev 2002; Dolphin 2002; Valls-Gabaud & Hernandez 2002; Holtzman 2002; Harris & Zaritsky 2002; Tosi, Greggio & Annibali 2002). The experiment was very successful, because the various scenarios turned out to be indeed consistent with each other, thus giving support to the method reliability, and because we had the opportunity to compare the different procedures with each other and evidentiate strengths and weaknesses of each one. The SF regime in that LMC field turned out to have been fairly continuous over the whole Hubble time, with no apparent interruptions (at least at more recent epochs when time resolution is higher), but with significant ups and downs in the SF rate (see the filled histogram in the right-bottom panel in Fig. 4). This SF history is significantly different from that presented by Pagel & Tautvaisiene (1998) for LMC clusters, represented in Fig. 4 by the empty histogram. This difference reveals how important it is to derive the SF history of both cluster and field stellar populations in as many galactic regions as possible.

3. The SF histories of late-type dwarfs

Nowadays the SF history has been inferred in more or less detail for all the late-type dwarfs in the Local Group. As reviewed e.g. by Grebel (1998), all these galaxies show what we (Tosi et al. 1991) defined as a *gasping* SF regime (i.e. long episodes of moderate SF activity, possibly separated by short quiescent phases), rather than a bursting one (short and intense episodes of SF activity, separated by long quiescent phases).

Local Group galaxies are obviously the best ones to accurately derive the SF history back to the oldest epochs. In more distant galaxies, crowding and magnitude limit make the fainter/older stars increasingly difficult to resolve and, correspondingly, the look-back time reachable by the photometry is increasingly short (ranging between a few 10^9 yr to a few 10^8 yr). None the less, we have to study galaxies also outside the Local Group, because we do know that not all the morhological types are present in the Group. Indeed, ellipticals and blue compact dwarfs (BCDs), i.e. the most and the least evolved galaxies can be found only outside it.

Our group is studying a number of external late-type dwarfs of particular interest: NGC1569, a dwarf irregular at 2.2 Mpc, with particularly strong SF activity, three super-star-clusters, and evidence of galactic winds (De Marchi et al. 1997; Greggio et al. 1998; Aloisi et al. 2001; Origlia et al. 2001), NGC1705, a BCD at 5.1 Mpc, with one super-star-cluster and evidence of galactic winds (Tosi et al. 2001; Annibali et al. 2003), IZw18, a BCD at 10-14 Mpc which is the most metal-poor galaxy discovered so far (Aloisi et al. 1999), and a few more, still to be observed with the HST/ACS.

The case of NGC1705 is particularly instructive, because the photometry was deep and good enough to let us resolve its stars from the most central regions to the extreme outskirts. We have thus been able to divide the galaxy in 8 roughly concentric regions, all sufficiently populated by individual stars, and derive the SF history of each region. Figure 2 shows the CMDs of the various regions: it is apparent that young massive stars are concentrated at the center and their percentage rapidly decreases outwards, while faint red stars are increasingly visible towards the outer regions. The latter circumstance does not necessarily imply that old stars are absent at the center, it simply means that crowding is too severe there to let us resolve them. In the outer regions, where crowding is definitely not a problem, the CMDs present a well defined upper portion of the red-giant branch (RGB), whose tip is also very well defined and allowed us to accurately derive the galaxy distance (Tosi et al. 2001).

By applying to each region the synthetic CMD method, we (Annibali et al. 2003) have inferred their SF histories, summarized in Fig. 3. There. the SF rate per unit area is plotted as a function of age. It can be seen that, except for the innermost region, where crowding does not allow us to reach old look-back times, all the regions have been forming stars since at least 5 Gyr. On average, the SF appears to have been rather continous: There are evidences for interruptions in the SF activity, but always shorter than a few Myr or tens of Myr, at least in the age range where we do have this time resolution (i.e. in the last 1 Gyr or so). Quiescent phases of 100 Myr or longer would have appeared as gaps in the empirical CMDs of stars younger than 1 Gyr, and such gaps are absent. The SF history of NGC1705 shows three striking features: one is the burst occurred in the central regions 10–

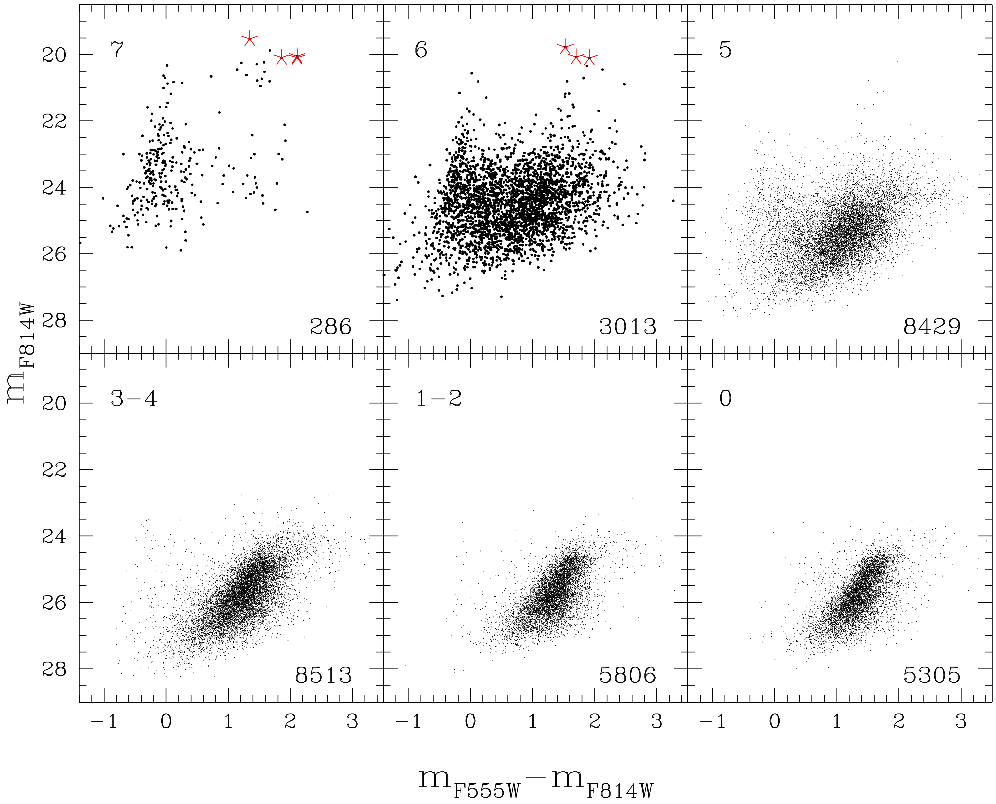

Fig. 2. CMDs of concentric regions of the BCD galaxy NGC 1705, as derived from HST/WFPC2 photometry (Tosi et al. 2001). The number in the top-left corner of each panel indicates the region, from the central one (7) to the outermost (0). The number of resolved stars in each region is shown in the bottom-right corner. Asterisks represent possible star clusters.

15 Myr ago, when the SSC also formed and when the observed galactic wind is supposed to have originated; the second is the quiescent phase with no SF anywhere in the galaxy right after such burst, probably due to the hot gas shocks and winds caused by the explosions of the burst supernovae; and the third is the new, even stronger, SF activity occurring everywhere in NGC1705 (but much higher in the inner regions) in the last 2 Myr. This latter event puts interesting constraints on the cooling timescales of the gas heated by the supernovae generated in the previous burst and on the modeling of SF processes.

SF histories qualitatively similar to that described here for NGC1705 have been derived by us also for NGC1569 and for IZw18 and by other people for other BCDs, also observed with HST and studied with the synthetic CMD method. Table 1 lists all the BCDs outside the Local Group whose SF history has been inferred with this method. Figure 4 shows the resulting diagrams of the SF rate per unit area vs time for some of the BCDs and for two representative irregulars: NGC1569 and the LMC. It is interesting to note that the galaxy with stronger SF activity is the dwarf irregular, NGC1569, the only one with a rate comparable to the 1 $M_{\odot} yr^{-1}$ required by Babul & Ferguson

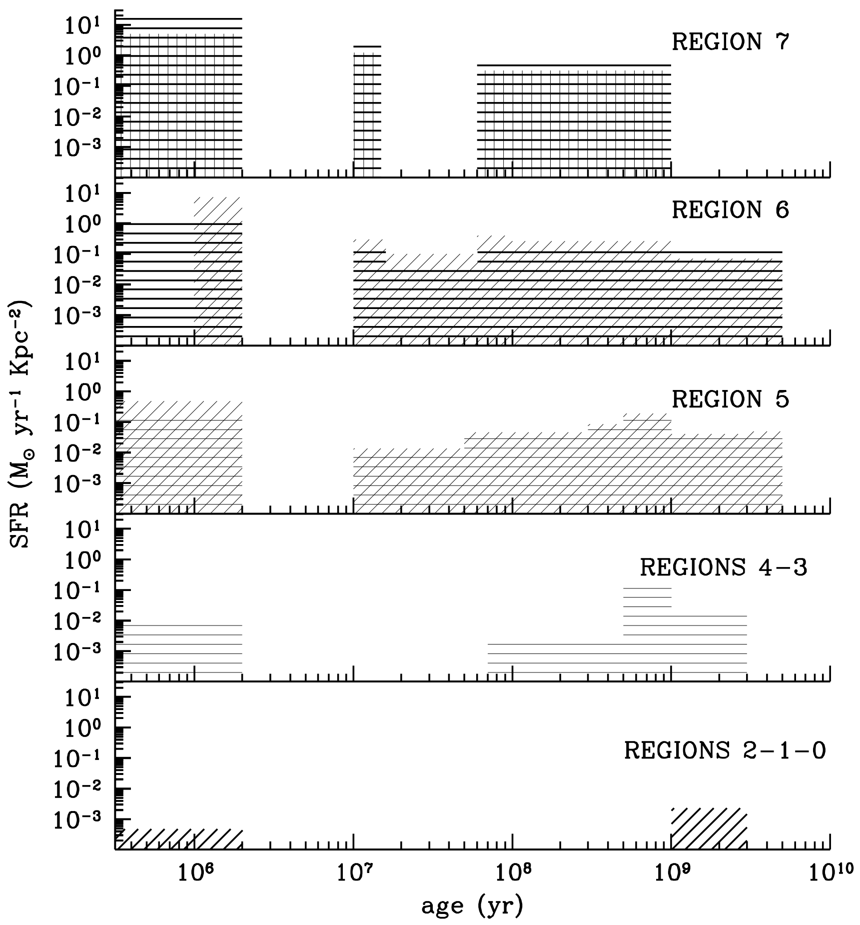

Fig. 3. SF rate per unit area as a function of age of the various regions of NGC1705, as derived from the application of the synthetic CMD method to the diagrams of Fig. 2 by Annibali et al. (2003). Notice that both axes are on logarithmic scale. The different inclination angles of the histogram filling show the SF history derived assuming different IMF slopes: Horizontal lines refer to Salpeter's IMF (i.e. exponent α=2.35), vertical lines to α=2.2, and slanted lines to α=2.6.

(1996) models to let a late-type galaxy contribute to the blue galaxy excess observed in counts at intermediate redshift. All the other dwarfs, independently of being classified as BCDs or irregulars present much lower SF rates. The only apparent difference in the SF of the two type of dwarfs is the presence of a very recent burst in BCDs. This is presumably due to selection effects that made it impossible to discover dwarfs without recent bursts beyond a certain distance.

From all the studies on the SF histories of late-type dwarfs performed so far, we can schematically summarize the main results:

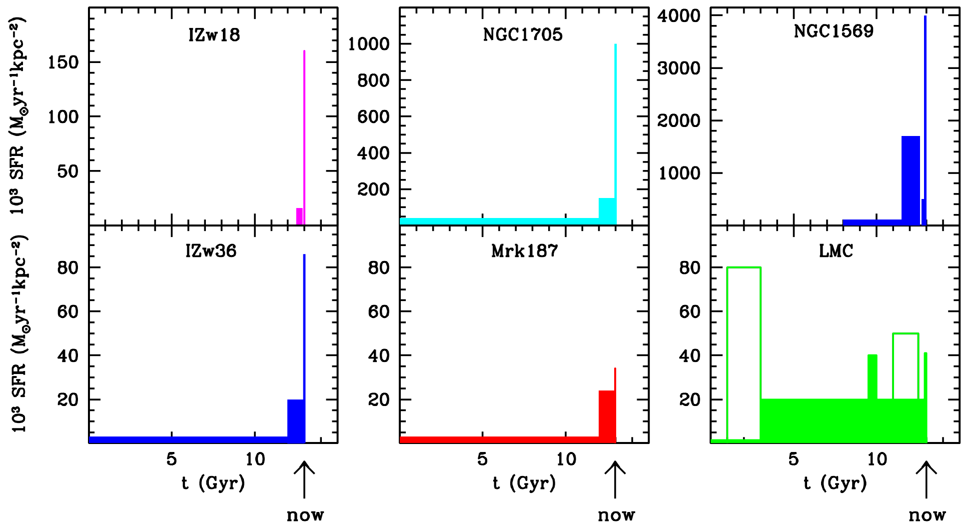

Fig. 4. SF rate per unit area as a function of time for some of the late-type dwarfs studied so far with the synthetic CMD method (see Table 1 for references). Notice that IZw18, IZw36, Mrk187 and NGC1705 are classified as BCDs, while NGC1569 is classified as a dwarf irregular and the LMC as a giant irregular.

Table 1. BCDs already studied with the synthetic CMD method

Galaxy	D (Mpc)	SFR ($M_\odot$ yr^{-1})	12+log(O/H)	Reference
I Zw 18	10-12	3-10 10^{-3}	7.18	Aloisi et al. (1999)
VII Zw 403	4.4	1.3 10^{-2}	7.69	Lynds et al. (1998)
UGCA 290	6.7	1.1 10^{-2}	?	Crone et al. (2000), (2002)
I Zw 36	5.8	2.5 10^{-2}	7.77	Schulte-Ladbeck et al. (2001)
NGC 6789	3.6	4.0 10^{-2}	7.7?	Drozdovsky et al. (2001)
UGC 5272	5.5	6 10^{-3}	7.83	Hopp et al., in prep
MrK 178	4.2	$\leq$ 10^{-2}	7.95	Schulte-Ladbeck et al. (2000)
NGC 4214	2.7	8 10^{-2}	8.27	Drozdovsky et al. (2002)
NGC 1569	2.2	5 10^{-1}	8.31	Greggio et al. (1998)
NGC 1705	5.1	1 10^{-1}	8.36	Annibali et al. (2003)

– no evidence of long interruptions in the SF activity has been found in any late-type dwarf;
– strong bursts do not seem to be frequent (NGC1569 showing the highest SF rate, followed by NGC1705 with a rate a factor of two lower);
– no galaxy currently experiencing its first SF activity has been found yet (all the studied ones were already active at the look-back time reached by the photometry);
– the SF regime seems to be a gasping rather than a bursting one in all kinds of late-type dwarfs, both in the Local Group and outside it;
– no significant difference has been found in the SF histories and in the stellar populations of BCDs and irregulars, except that the former ones have a recent SF burst.

These results suggest, in my opinion, that late-type dwarfs are unlikely significant contributors to the excess of blue galaxy counts at redshift around 0.7 – 1, and that, in spite of being poorly evolved, they should not be considered young galaxies.

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