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Star formation histories in nearby galaxies

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Abstract. The colour-magnitude diagrams of resolved stars in nearby galaxies allows us to infer their star formation histories and put useful constraints on galaxy evolution. Here we briefly summarize our current knowledge on the star formation histories of galaxies in the Local Group and beyond.

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

1. Introduction

To understand the evolution of galaxies it is necessary both to develop theoretical models of galaxy formation, of chemical and of dynamical evolution and to collect accurate observational data to constrain the models. Of particular importance is to acquire reliable data on the chemical abundances, masses and kinematics of the galactic components (gas, stars, dark matter), on the star formation (SF) regimes, and on the stellar initial mass function (IMF). Since SF law and IMF are usually adopted as free parameters in the models, putting stringent observational constraints on their actual behaviours can let us avoid spurious model results.

In nearby galaxies where individual stars can be studied with ground or space-based photometry and spectroscopy, most of the information on the above quantities can be derived from field and cluster stars observations. To infer the SF regime and history of resolved stellar populations, the best tool is their colour-magnitude diagram (CMD), because it brings the signature of their evolutionary status.

2. The synthetic CMD method

To derive the SF history of dwarf galaxies, several years ago a few groups (Tosi et al. 1991; Gallart et al. 1996; Tosltoy & Saha 1996) have independently developed a method based on the comparison of empirical and synthetic CMDs.

Our synthetic CMDs (Tosi et al. 1991; Greggio et al. 1998) 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.), they must contain the same number of stars as the observational CMD (or portions of it), and must be affected by the same photometric error, incompleteness and blending factors. Hence, a combination of theoretical parameters is ac-

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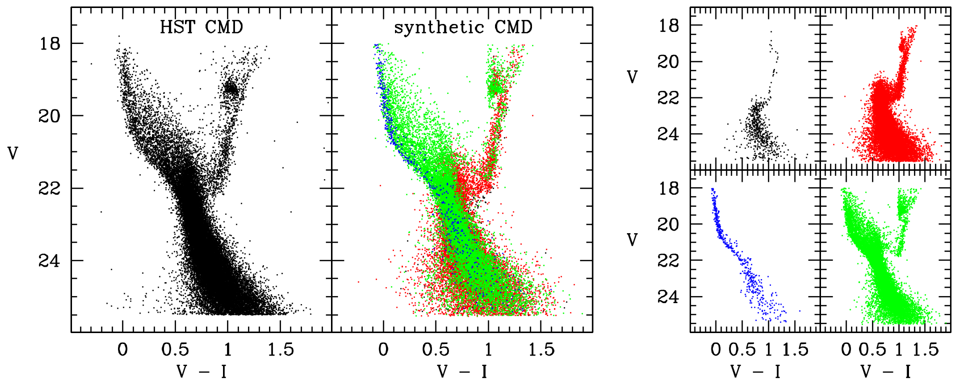

Fig. 1. CMDs of one field of the LMC bar. Left-hand panel: CMD derived by Smecker-Hane et al. (2002) from HST/WFPC2 photometry; central panel: synthetic CMD by Tosi et al. (2002). Right-hand panel, the synthetic CMD of the previous panel splitted in its four episode components, from the oldest to the youngest one clock-wise from the top-left panel.

ceptable only if the resulting CMD reproduces all the features of the observational one: morphology, colours, luminosity functions, number of stars in specific evolutionary phases. The comparison between empirical and synthetic CMDs 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.

3. The SF histories of Local Group galaxies

The synthetic CMD method nowadays has been applied by several groups to many dwarf galaxies (both late- and early-type) of the Local Group and will be soon applied to the spirals as well.

Fig.1 shows for instance the empirical CMD of one field in the LMC bar, obtained by Smecker-Hane et al. (2002) from HST/WFPC2 observations, that was adopetd by about ten groups [(Skillman & Gallart 2002) and references therein] to independently derive its SF history. The CMD in the central panel of Fig.1 and those on the right-hand panels are those synthetized by our group (Tosi et al. 2002). The resulting SF history of this field is shown in the right-bottom panel in Fig.5 (filled histogram) and is clearly different from that derived by Pagel & Tautvaisiene (1998) from LMC clusters, represented in Fig.5 by the empty histogram. At variance with the cluster history, the SF regime in the LMC bar field has been fairly continuous over the whole Hubble time, with no apparent interruptions (at least at more recent epochs where time resolution is higher), but with significant variations in the SF rate. This difference shows how important is to derive the SF history of both cluster and field stellar populations in as many galactic regions as possible.

Fig.2 shows the representative case of the dwarf spheroidal (dSph) Sculptor, studied by Rizzi et al. (in preparation). The CMD on the left-hand panel results from deep photometry acquired with the Wide Field Imager at the ESO/MPI 2.2m tele-

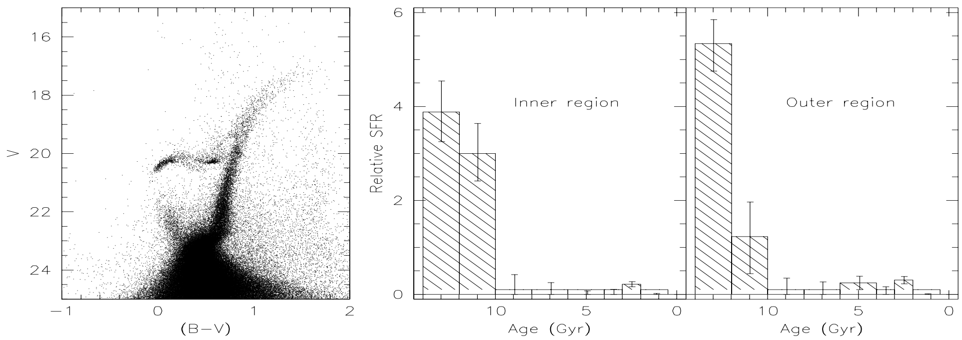

Fig. 2. The dSph Sculptor as studied by Rizzi (2002) and Rizzi et al. (in preparation). The CMD has been obtained from WFI photometry, the SF history from the synthetic CMD method.

scope (Rizzi 2002) and contains more than 100000 resolved stars. The histograms in the other two panels show the corresponding SF rate as a function of age in the inner and outer parts of Sculptor derived with Rizzi's (2002) synthetic CMD procedure. The SF histories of the two regions look fairly similar to each other, whilst the metallicities have instead to be quite different to reproduce the morphology of the red giant and horizontal branches.

Thanks to HST observations some fields in M31 have also been resolved in their individual stellar components (Bellazzini et al. 2003). Fig.3 shows four of these fields, located at different distances from the galaxy center. The SF history of these fields will be soon derived (Angeretti et al. in preparation) with the synthetic CMD method.

Several Italian groups working on stellar populations and SF history of nearby galaxies have recently organized themselves in a common effort (Cofin 2002028935) to try to understand the evolution of Local Group galaxies. This effort concerns several late-type dwarfs, like the LMC, several dSphs, like Sculptor, and M31.

4. The SF histories of galaxies outside the Local Group

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 lookback time reachable by the photometry is increasingly short (ranging between a few 10^9 yr and 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.

A few groups in the world are studying with HST observations an increasing number of BCDs. Table 1 lists the BCDs whose SF history has already been derived with the synthetic CMD method. The case of NGC1705 is particularly instructive, because the photometry was deep and good enough to let us resolve its stars from the

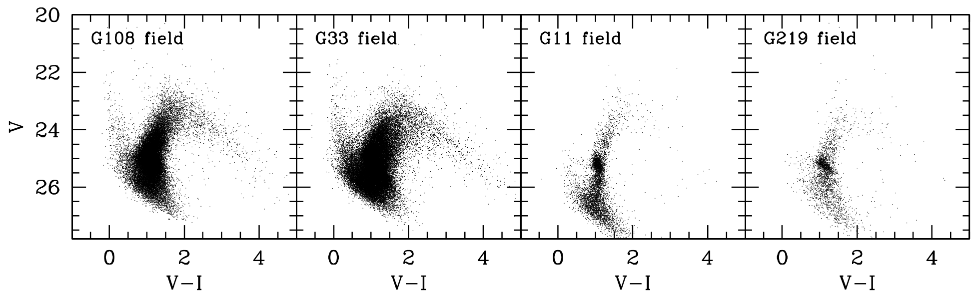

Fig. 3. CMDs of a subsample of M31 fields (Bellazzini et al. 2003). The distance of each field from the galaxy center is, respectively, 5 kpc, 13 kpc, 17 kpc, and 20 kpc, from left to right. The label in each panel indicates the globular cluster targeted with the same observations.

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)

most central regions to the extreme outskirts (Tosi et al. 2001). We have thus been able to divide the galaxy in 8 roughly concentric regions, all sufficiently populated. By applying to each region the synthetic CMD method, we (Annibali et al. 2003) have inferred their SF histories, summarized in Fig.4. 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 lookback 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 10–15 Myr ago, when the super star cluster, located close to the galaxy center, also formed and when the observed galactic wind is supposed to have originated; the second is the quiescent phase with no SF anywhere 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 mod-

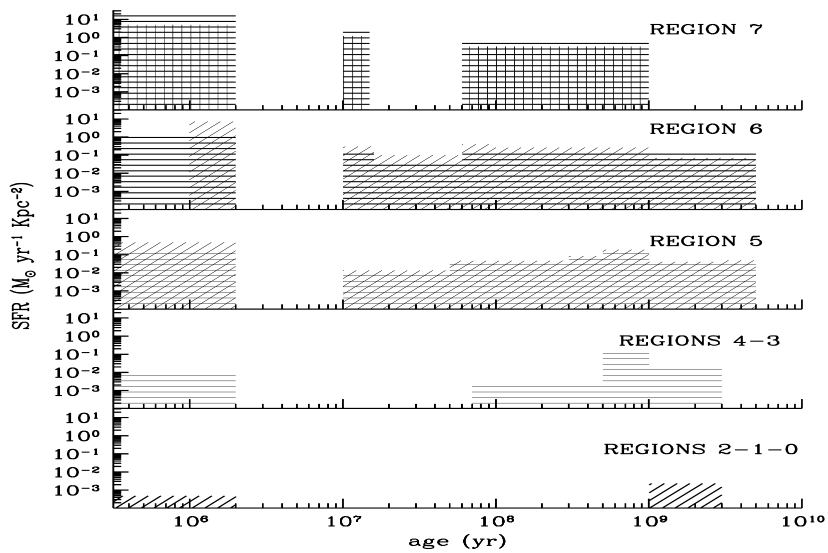

Fig. 4. SF rate per unit area as a function of age of the various regions of NGC1705 (Annibali et al. 2003). Histograms filled with horizontal lines correspond to assuming Salpeter's IMF (i.e. exponent α=2.35), vertical lines α=2.2, and slanted lines α=2.6.

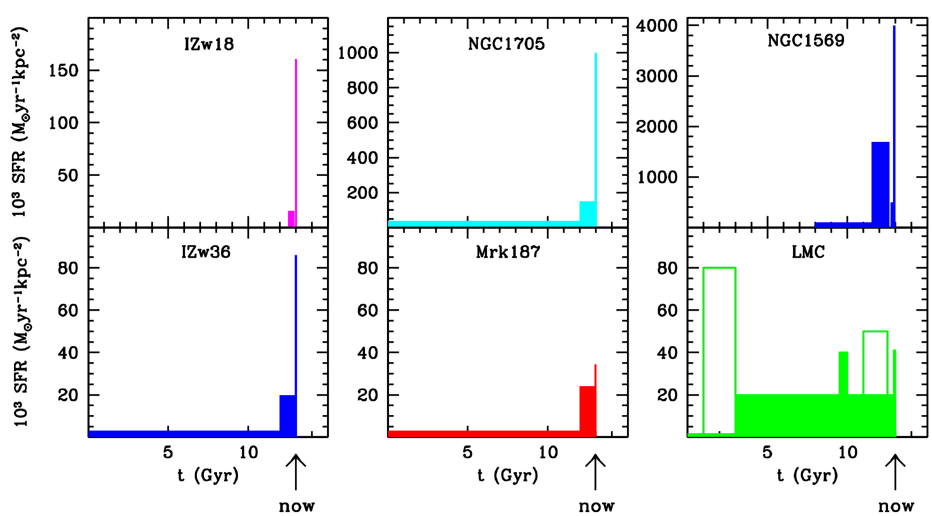

Fig. 5. SF rate per unit area as a function of time for some of the late-type dwarfs studied so far with the synthetic CMD method. Notice that IZw18, IZw36, Mrk187 and NGC1705 are classified as BCDs, while NGC1569 is classified as a dwarf irregular and the LMC as a giant irregular.

eling of SF processes. SF histories qualitatively similar to that described here for NGC1705 have been derived also for the other dwarfs of Table 1. Fig.5 shows the resulting 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. All the other dwarfs, independently of being classified as BCDs or irregulars present lower or much lower SF rates. The only apparent difference in the SF of the two types 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 ongoing bursts beyond a certain distance. From all the studies on the SF histories published so far, we can schematically summarize the following properties:

• the SF is continuous in spirals, roughly continous (gasping) in late-type dwarfs, and discontinuous (but often recurrent) in early-type dwarfs;

• no galaxy currently experiencing its first SF activity has been found yet (all the studied ones were already active at the lookback time reached by the photometry;

• 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 SF bursts.

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