STELLAR POPULATIONS IN DWARF IRREGULAR GALAXIES OF THE LOCAL GROUP

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Given the uncertainties in the derivation of the current and past SFR in galaxies of any kind, the SF regime in irregulars is subject of wide debate. Since the most direct information on the stellar populations and relative histories in any system can be derived from their CMD, we have undertaken a project for accurately studying the CMDs and luminosity functions (LF) of nearby, well resolved, irregulars. The method proceeds on two tracks: a) we have developed a numerical code for Montecarlo simulations of CMDs and b) we have taken deep and accurate CCD photometry of several galaxies and derived the corresponding CMDs and LFs. The comparison of the observational data with the corresponding theoretical expectations provides several constraints on the SF history and on the IMF of the analysed objects. We do not pretend to reach unique conclusions on the evolution of irregular galaxies, but we can sensibly reduce the range of possible interpretations.

All the irregulars in our sample were selected from the DDO Catalogue and were supposed to belong to the Local Group. Detailed descriptions of the data acquisition and reduction and of the simulation code can be found in Tosi et al. (1991). In the following we briefly summarize the results relative to Sextans B, NGC 3109 and DDO 210.

Fig.1a shows the CMD of one of the two regions observed in Sextans B. This diagram contains 819 objects and its morphology is typical of all irregulars: a large dispersion of the data points, a bright blue plume, a number of bright red stars significantly lower than the corresponding number of bright blue stars. The synthetic diagram shown in Fig.1b is one of those in better agreement with the data of Fig.1a (Tosi et al. 1991). It assumes a distance modulus $(m\text{-}M)_o=25.6$ and is based on evolutionary tracks with large overshooting and low metallicity, Z=0.001 (Bertelli et al. 1986 and Greggio 1984). The adopted IMF has an exponent -2.6 (slightly steeper than Salpeter's -2.35), and the SF in the last one billion years has proceeded in two separate episodes of activity. The first from 1 Gyr to 1.5×10^8 yr ago, at the moderate rate of $2\times10^{-3}M_\odot yr^{-1}$, and the second from 1.3×10^8 yr to 3×10^6 yr ago, at an even lower rate of $1\times10^{-3}M_\odot yr^{-1}$. The cessation time of 3 million years ago may be not significant, but if the SF activity is allowed to reach the present time, bright blue stars not observed in the actual galaxy inevitably appear in the synthetic diagram.

The synthetic diagram of Fig.1b takes into account all the photometric errors, including the possible stellar blend of objects which happen to be too close in the projected plane of the CCD frames to be distinguishable from each other. This blend leads to assign spurios magnitudes and colours to the detected objects and is responsible for a large fraction of the spread in the stellar distribution on the CMD. If stellar blend is not included the same synthetic diagram becomes that of Fig.1c where the various evolutionary phases are much more separated from each other. In particular, the blue plume is now splitted into two parts: objects at the left of the vertical gap are main sequence (MS) stars, objects at its right are evolved stars at the hot edge of the blue loop evolutionary phase. This implies that the observational blue plume is populated by both MS and evolved stars. This finding

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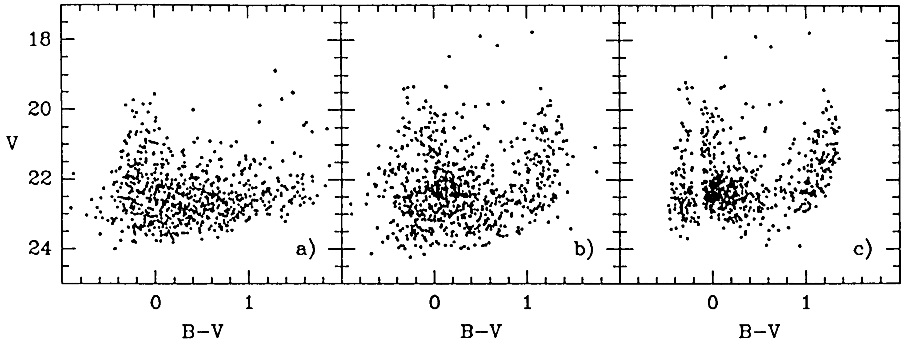

Fig.1. C-M diagrams for one region of Sextans B: a) observational, b) synthetic, c) synthetic without taking stellar blend into account.

represents a serious warning for people deriving the LF of the blue plume to infer the LF of the MS and the corresponding IMF: a safe criterion for MS selection must always be applied to avoid misleading conclusions.

The global and MS LFs of the above synthetic models are both in good agreement with the corresponding observational LFs.

From the various simulations performed for the two observed fields that cover all Sextans B, we infer (Tosi et al. 1991) that this galaxy can be treated as a single homogeneous body because the two regions contain roughly the same stellar populations, with the same low metallicity, the same IMF slightly steeper than Salpeter's and a *gasping* regime of SF.

Fig.2a shows the CMD derived from our observations of the central region of NGC 3109. It contains 1019 stars and its overall morphology is similar to that of Sextans B. According to our analysis, which is still in a preliminary stage, the best synthetic diagram for this region is shown in Fig.2b. It is based on the same tracks as that of Fig.1b and assumes a distance modulus $(m\text{-}M)_o$=25.7 . The SF has again proceeded in two episodes, the most recent one stopped 7×10^6 yr ago. In this case we are confident that there is no on-going SF activity, otherwise there would be too many non observed bright MS stars. The IMF is incredibly flat, with an exponent of -1.2 which reminds the value suggested by Melnick (1987) for galaxies of such low metallicity. If stellar blending is not taken into account (Fig.2c) the blue plume again splits into two parts: the MS, on the left, fainter by almost one mag than the hot edge of the blue loops, a feature which can be recognized in Fig.2a as well. The predicted and observed LFs are in very good agreement.

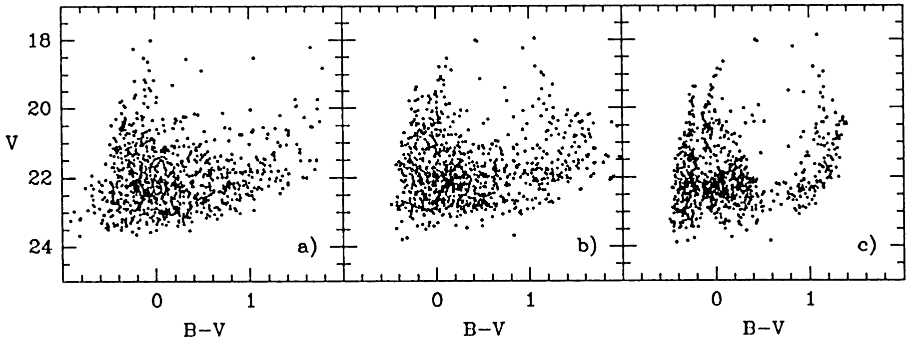

Fig.2. C-M diagrams for one region of NGC 3109: a) observational, b) synthetic, c) synthetic without taking stellar blend into account.

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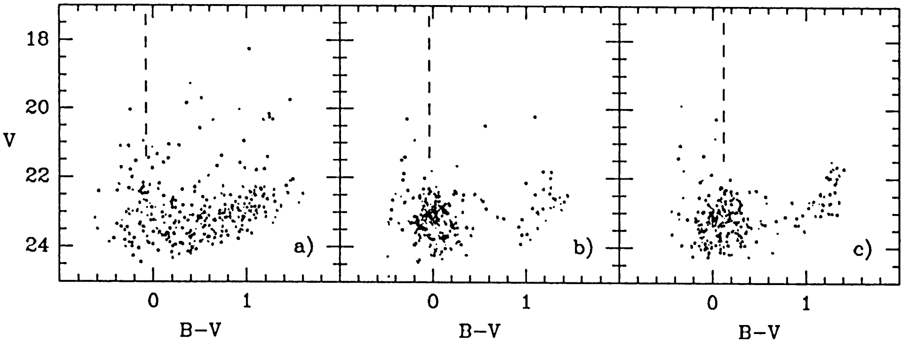

Fig.3. C-M diagrams for one region of DDO 210: a) observational, b) synthetic with $(m\text{-}M)_o$=28, c) synthetic with $(m\text{-}M)_o$=27.

DDO 210 is a highly contaminated galaxy only recently resolved in its stellar content (Marconi et al. 1990). The CMD of its central region is shown in Fig.3a. Photometric data obtained for a nearby external field allow us to infer that the stars brighter than V$\simeq$21 are most probably foreground stars, that at least half of the objects with 21$\leq$V$\leq$22 can be members of DDO 210 (including all those bluer than B-V$\simeq$0.2), and that several background galaxies contaminate the diagram below V$\simeq$21. When only probable members are considered, the usual blue plume of irregular galaxies can be better distinguished in the diagram, the location of its main body being indicated by a vertical dashed line in Fig.3a.

In spite of the low number of objects and the high degree of contamination, some interesting indications can be derived from our analysis, especially on the distance modulus to this galaxy, which has never been properly evaluated. Figs 3b and 3c show the best synthetic diagrams obtained with $(m\text{-}M)_o$=28 and $(m\text{-}M)_o$=27, respectively. In both cases two episodes of SF have been considered: one, old and rather intense, has produced almost all the stars in the diagram; the second, very recent and very inefficient, is necessary to provide the few blue and bright stars of DDO 210. The comparison of the predicted with the observed B-V location of the blue plume shows that the model assuming $(m\text{-}M)_o$=28 (Fig.3b) is more consistent with the data. The shorter distance modulus, infact, implies smaller masses for the stars populating the blue plume, which are characterized by redder colours. This result is clearly independent of the adopted IMF and SF regime.

More conclusive results on NGC 3109 and DDO 210 will be presented in Greggio et al. (1991). We anticipate that in NGC 3109 different regions contain different stellar populations, as already found by Ferraro et al. (1989) for WLM, another Local Group irregular.

Our analysis performed so far suggests the following scenario:

a) The SF regime in the last one billion years in dwarf irregular galaxies seems to have proceeded in long periods of moderate activity interrupted by short quiescent intervals. This regime is clearly different from a bursting mode, where the single SF episodes are short and intense and separated by long quiescent intervals. From our simulations we exclude a time-decreasing SFR, as it would predict too many unobserved stars in late evolutionary phases, while the possibility of a constant SFR cannot be ruled out although it tends to predicts too many bright MS stars.

b) In spite of the modest SF activity proposed above, if the same *gasping* regime is extrapolated to all the galaxy lifetime the metallicity resulting from the corresponding stellar nucleosynthesis is much larger than observed in these galaxies. Diluting mechanisms able to reduce the metal content without altering the stellar content are then required. For a number of Blue Compacts (i.e. in a bursting regime of SF) Matteucci and Tosi (1985) found that galactic winds powered by SN explosions can make the proper effect; we then suggest that this mechanisms may be the way out of the problem for dwarf irregulars as well.

c) Strong deviations from a Salpeter's IMF do not seem to be required, except perhaps for one region of NGC 3109. This case, however, may depend on the adopted set of tracks. In this context we emphasize the need for homogeneous sets of stellar evolutionary models with different metallicities and overshooting parameters, which are still lacking in the literature.

Finally, we recall the *caveat* concerning the derivation of MS luminosity function: the observed blue plumes of irregulars can be largely populated by evolved stars and cannot thus be taken as representative of the pure MS.

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Discussion

Hensler. 1) If the SF has been ceased several Myrs ago, one would expect the according SNII rate to be observed. Does a hot SN-driven gas phase exists ? Does the SN rate agree well with your model ? 2) How is the WR phase taken into account ?
Tosi. 1) No SN has been detected in the 3 irregulars discussed here, which seems consistent with the low number of massive progenitors available in the models. 2) The WR phase is taken into account implicitely when computed in the adopted stellar evolution tracks.
Serrano. Did you take into account that some of the stars are binaries ?
Tosi. In the simulations shown here binaries are not included. I have included them in the simulations for galactic open clusters and I believe that they would not make much difference in the case of our dispersed CMDs.
Faber. Have the vertical gaps ever been seen in the CMDs of nearer clusters where the errors are small, and, if not, what does that mean about the accuracy of the tracks ?
Tosi. The vertical gap has never been observed. Star clusters, though, are populated by a low number of stars, so that their CMDs are dominated by stochastic effects.
Schommer. N.Caldwell and I have surveyed DDO 210 for variables, but found none. The galaxy is well resolved, and seems to have a well developed red giant branch. I think its distance might be closer to $(m\text{-}M)_o \simeq 26$. Then, it becomes an interesting transition object, like Phoenix.
Tosi. If $(m\text{-}M)_o=26$, all the stars of DDO 210 should be evolved off the MS and the turn-off definitely below the frame limit. But what could the blue bright stars of the diagram be?
Bruzual. What is the IMF upper mass limit in your simulations ? Have you found any evidence for dust in these galaxies ?
Tosi. The limit is 100 $M_\odot$. We have not checked the dust content.
Meurer. 1) Three of your galaxies have a definite tip to the blue plume which you interpret as a cessation time for the most recent SF event. Can this also be interpreted as an upper limit to the IMF ? 2) Have you done simulations of the CMDs you would get with observations done on nights of excellent seeing (say $0.3''$) with appropriate equipment ?
Tosi. 1) In order to interpret the MS tip only in terms of IMF cutoff (i.e. with on-going SF) we should assume an upper mass limit as low as 20 $M_\odot$, otherwise the blue plume would be too bright. But too many bright evolved stars would be predicted that are not observed. 2) No: the simulations are performed according to the real observational conditions.