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Derivation of star formation histories through deep color-magnitude diagrams: the dependency on stellar evolution models

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Abstract. We review the state of the art of the derivation of star formation histories from color-magnitude diagrams reaching the oldest main sequence turnoffs. From the observational point of view, high quality CMDs are being obtained for galaxies over virtually the whole Local Group. However, the retrieval of star formation histories from these data using the synthetic color magnitude diagram technique heavily relies on stellar evolution model predictions. We discuss the main systematic differences that are found among the stellar evolution libraries most heavily used for this purpose, and the effect that these differences have on the resulting star formation histories.

Key words. Stars: stellar evolution – Galaxies: stellar populations – Galaxies: star formation histories

1. Introduction

A color-magnitude diagram (CMD) reaching the oldest main sequence (MS) turnoffs (TO) is the best tool to retrieve a detailed and reliable star formation history (SFH) for a galaxy. In this case, information on the distribution of ages and metallicities can be obtained directly from the MS locus, which is the best understood phase of stellar evolution from the theoretical point of view. It is also the one in which the location of stars shows the highest sensitivity to age differences. The *range* of ages and metallicities present can be determined simply through comparison with theoretical isochrones. However, to **quantitatively** determine the SFH (star formation rate and metallicity as a function of time, *plus* an estimate of the IMF and the characteristics of the binary stars population), it is necessary to compare the observed density distribution of stars

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with that predicted by stellar evolution models Gallart et al. (2005a). This is usually done through the computation of synthetic CMDs and the simulation of observational errors in them (e.g. Gallart et al. 1999).

From the observational point of view, this field of research has reached considerable ripeness. Most of the Local Group (LG), to a distance of approximately 1 Mpc, is accessible for this kind of observations, and important LG galaxy samples have been observed. The nearest objects, i.e. the Milky Way satellites, are best observed using ground based facilities, which afford the necessary depth while providing a large wide field coverage to sample most (or a significant fraction) of their stellar populations, which allows to study the stellar population gradients on them (e.g. Majewski et al. 1999; Hurley-Keller et al. 1999; Aparicio et al. 2001; Carrera et al. 2002; Monelli et al. 2003; Lee et al. 2003). Particularly important challenges are imposed, however, by the Magellanic Clouds (e.g. Noël & Gallart 2007; Gallart et al. 2004; Zaritsky, Harris & Thompson 1997) due to their huge apparent size. In the case of more distant LG objects, basically the M31 system *plus* M33, and the isolated dwarf galaxies, the oldest MS TO can be reached using the ACS on board of the HST. Several HST large programs have been approved to obtain these kind of data, with spectacular results (e.g. the LCID[1] project: see Gallart et al. 2006; Monelli et al., and Monelli, Bernard et al. these Proceedings; M31: Brown et al. 2006). In this context, obtaining similar quality observations of a representative sample of dSph galaxy satellites of M31 would be particularly interesting in order to compare the SFHs of two different satellite systems among themselves and with those of a sample of isolated dwarf galaxies. This would provide key insights on the effects of environment in dwarf galaxy formation and evolution.

The other necessary ingredient to retrieve SFHs are stellar evolution models. In this paper, we will focus on the discussion of the differences between current stellar evolution libraries and the systematics that these may imply on the derived SFHs.

[1] Local Cosmology from Isolated Dwarfs. This project (HST P.ID. 10505 and 10590) has obtained deep CMDs reaching the oldest MS TO in five isolated Local Group galaxies. See http://www.iac.es/project/LCID/

2. Stellar evolution libraries: the systematic differences

Gallart et al. (2005a) analyzed how well current stellar evolution models reproduce the properties of the CMDs of simple stellar populations and made extensive comparisons between the predictions of several of the most complete and widely used stellar evolution libraries. This allowed them to assess how much model dependent are the results of interpreting a CMD using stellar evolution models. In this contribution we will concentrate on the MS phase and both summarize their findings and present some new considerations.

Gallart et al. (2005a) found (see their Figure 2) that all the analyzed models, except the overshooting version of the BaSTI library (Pietrinferni et al. 2004), reproduce the same MS TO magnitude, M_V^{TO}, with similar ages for the whole age range. The BaSTI overshooting models require significantly larger ages, at intermediate age, to reproduce the TO luminosity of the other sets. For example, isochrones of 0.8 and 3 Gyr are required to reproduce the $\simeq$ 0.5 and 2 Gyr old TOs. The difference disappears both for older ($\simeq$ 14 Gyr) and younger ($\simeq$ 0.1 Gyr) ages. A closer examination of the intermediate-age discrepancy between the BaSTI and the other models (Girardi et al. 2000 in particular, see Figure 3 of Gallart et al. 2005a and Figure 1 of Aparicio et al. in these Proceedings) indicates that the mass-luminosity relation for intermediate-age stars is quite similar between BaSTI and Girardi et al. (2000), since two evolutionary tracks of identical mass occupy very similar loci in the CMD. However, the respective TO ages are substantially different: 1.75 and 1.26 Gyr respectively, for a mass of 1.9 $M_\odot$ and Z=0.001. In analyzing a given stellar population, the BaSTI overshooting models imply, therefore, in addition to an older age, a more populated MS for given magnitude and star formation

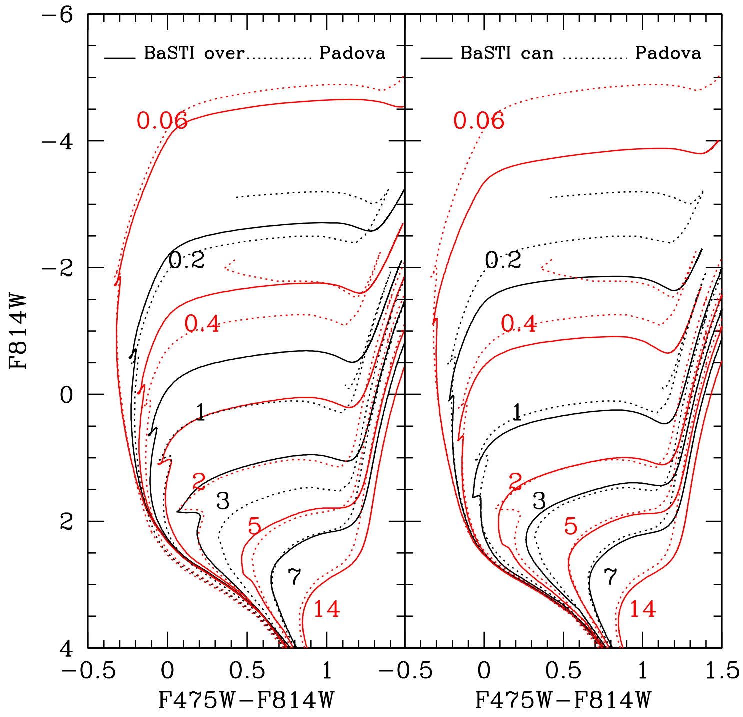

Fig. 1. Comparison between the BaSTI and Girardi et al. (2000) isochrones of metallicity Z=0.001. Left panel: BaSTI overshooting set. Right panel, BaSTI canonical set.

rate, since stars of the same mass and luminosity have longer lifetimes.

Pietrinferni et al. (2004) investigated the possible origin of this discrepancy and concluded that only a fraction of it is related to differences in the overshooting treatment, the remaining having to be ascribed to the input physics. Another version of the comparison discussed above is shown in Figure 1, where isochrones for ages 0.06, 0.2, 0.4, 1, 2, 3, 5, 7 and 14 Gyr from both the Girardi et al. (2000) and the BaSTI library have been represented (in the case of BaSTI, the overshooting set has been represented in the left panel and the canonical set in the right panel). The already described behaviour can be observed in the left panel: at intermediate-age, the isochrones of the BaSTI library are brighter for the same age (see, for example, that the 2-3 Gyr old BaSTI isochrones coincide with the 1-2 Gyr old Padova library). The differences are small or disappear for ages older than ≃ 5 Gyr and younger than ≃ 0.1 Gyr old. The discrepancy is much smaller (and in the opposite sense), when comparing the Girardi et al. (2000) isochrones with the canonical BaSTI set (Figure 1, right panel). In this case, the differences are substantial only for ages younger than ≃ 1 Gyr. This last comparison may indicate that the *canonical* physics of the BaSTI library, currently the most up to date among the different model sets (see Table 1 of Gallart et al. 2005a), imply a larger size of the core for intermediate mass stars, similar to the size of the core of the overshooting Girardi models, for example. This possibly indicates that the amount of overshooting required in the BaSTI library may be smaller than in the other libraries. It would be interesting to test in detail this possibility through a comparison with empirical con-

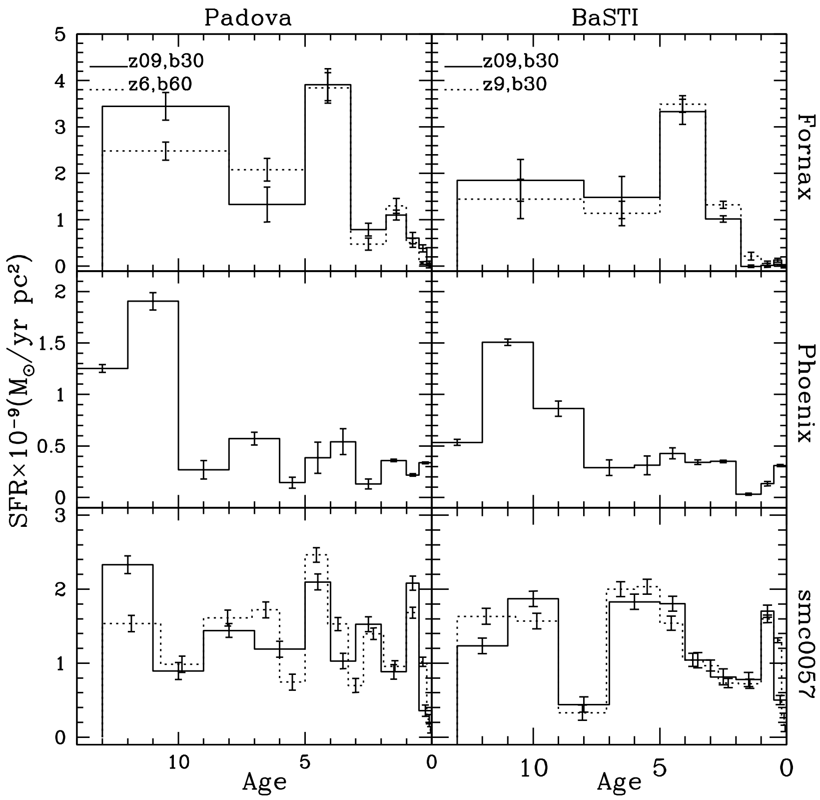

Fig. 2. Comparison of the SFHs derived for Fornax, Phoenix and a SMC field using the Padova and BaSTI stellar evolution libraries. In the case of Fornax, two SFH solutions with different assumptions for the chemical enrichment law and the binary fraction are shown for the central field, as presented by Gallart et al. (2005b). For the SMC, the SFH is that of field smc0057 presented by Noël et al. (2008). Two solutions obtained with different age binning are shown.

straints as those provided by binary stars with suitable masses for the components and open clusters.

3. The effect on the derived star formation histories.

Aparicio et al. (these Proceedings) show some tests performed using synthetic populations about the consequences that systematic differences of stellar evolution libraries have on the solutions for the SFH. These tests confirm what one may expect: the overshooting BaSTI library recovers SFHs from populations simulated with the Padova library in which the old population is less old and intense, and the population younger than $\simeq 5$ Gyr is retrieved older and less intense than the input one. This is due to the fact that the BaSTI overshooting models predict longer lifetimes in the MS phase for young intermediate-age stars, thus producing a more populated MS over that age range than the Padova models.

In Figure 2, we show the SFHs obtained for three galaxies using both the Padova library (Bertelli et al. 1994 or Girardi et al. 2000) and the BaSTI library. The details on the observations and the derivation of each of these SFHs can be obtained from Gallart et al. (2005b; Fornax), Hidalgo et al. (2008; Phoenix) and

Noël et al. (2008; SMC). In short, all CMDs reach the oldest MS TO with good photometric accuracy, and the SFHs have been derived through comparison (using different versions of the IAC-pop package, Aparicio & Hidalgo 2008) of the distribution of stars across the observed CMD with that calculated with IAC-star (Aparicio & Gallart 2004) using as input the Padova or BaSTI stellar evolution libraries, as indicated. Some (small) systematic differences between the Padova and the BaSTI solutions, in the sense indicated above, can be observed in Figure 2. In all cases, the oldest population is stronger in the Padova solutions, which also show a more important young population (younger than 2 Gyr, or 3 Gyr in the case of the SMC). Similar differences can be observed in the Tucana SFH presented by Monelli et al. (these Proceedings, their Figures 3 and 4). In the cases in which more than one SFH solution under different assumptions is shown (Fornax and the SMC), the differences among solutions obtained with the same stellar evolution library are relatively small, specially at young ages. In particular, they are smaller than the systematic differences related to the choice of stellar evolution library.

We are currently, and particularly for the LCID project, performing systematic comparisons of the results obtained using these two libraries for a number of galaxies. We are also working on improvements on our implementation of the synthetic CMD method to retrieve SFHs in order to increase the stability and accuracy of the solutions. Therefore, we hope to be able to better quantify in the future these systematic differences in the SFHs obtained using different stellar evolution libraries. We can conclude, however, that the main SFH trends are recovered consistently with different libraries.

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