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Variable stars in dwarf galaxies: key tools to constrain the stellar population

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Abstract. Cepheid and RRLyrae variable stars have a key role in our understanding of Dwarf Galaxies as stellar population, metallicity tracers and distance indicators. An overview of recent results for four morphologically different cases is given: Leo I (dSph), LMC (dIrr) and M 32 (dE). In particular, the discovery of RRLyrae stars belonging to M 32 represent the only way to constrain the nature, and even presence of a stellar population ≥10 Gyrs old. Moreover, other kind of variables can provide strong constraints to the host galaxy metallicity, as the complete sample of Anomalous Cepheids now available in LMC and Leo I.

Key words. Stars: variables – Galaxy: dwarfs

1. Introduction

The resolved stellar populations in nearby galaxies allow a number of different observables which can be used to derive the full evolution of the host system. Deep colour-magnitude diagrams (CMDs), kinematics and spectroscopic abundances give different constraints that allow to recover their full Star Formation History (SFH). Complementary to these, the study of variable stars allow independent estimates of the age and the metallicity of their parent populations. This is particularly important whenever different classes of variable stars coexist in a galaxy, because it allows to trace the properties of stellar populations of different ages, provided that the pulsational and evolutionary properties or variable stars are properly classified. As a classical example, Carina is a well known dwarf spheroidal galaxy. Its variable star population has been studied in detail by Dall'Ora et al. (2003) and revealed the presence of RRLyrae stars and Anomalous Cepheids (ACs). Using this bright part of the CMD sound constraints on the galaxy SFH can be obtained. Carina hosts an old (≥ 10 Gyrs) stellar population indicated by the presence of RRLyrae stars. Furthermore, the detection of ACs suggests a very metal–poor ([Fe/H]∼-1.7 dex) environment for this galaxy. Unfortunately, ACs cannot be firmly related to a particular age, being their origin very uncertain (see Fiorentino et al., 2012c, for details). The suggestions on the SFH given by the Carina variable star population are fully supported by the accurate analysis of deep CMDs and high resolution spectroscopy available for this galaxy (Monelli et al., 2003; Fabrizio et al., 2012). Therefore, complete and homogeneous searches for vari-

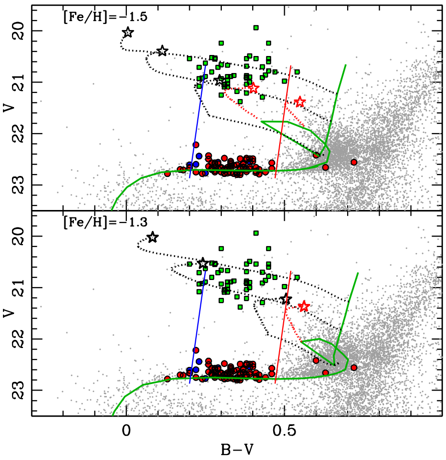

Fig. 1. Theoretical prediction for central helium-burning structures, based on scaled-solar evolutionary models from the BaSTI database (Pietrinferni et al., 2004), for the labeled values of metallicity with a fixed ΔY/ΔZ = 1.4 and a primordial helium Y = 0.23. We assumed μ_0 = 22.11 mag and E(B–V) = 0.02 mag. Blue and red solid lines represent the theoretical IS.

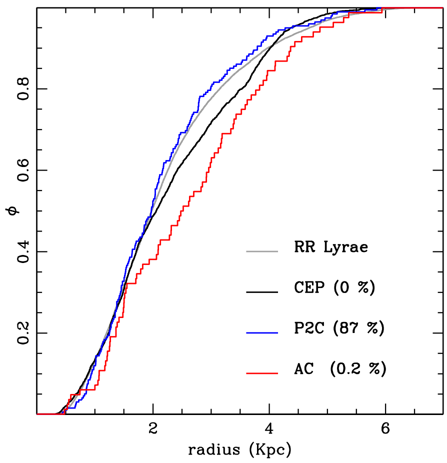

Fig. 2. Cumulative distributions for anomalous (red), population II (blue) and classical Cepheids (black), RRLyrae (grey).

able star are fundamental to complement classical stellar population studies in those cases where the observed CMD can not be accurate enough.

2. A sample of dwarf galaxies

Leo I dSph galaxy: Leo I is a dwarf spheroidal galaxy that just stop to transform gas into stars as suggested by a careful study of its SFH (Gallart et al., 1999) using HST data and assuming a quite low metallicity, i.e. [Fe/H]=-1.7 dex. In particular, this study suggests that a very strong episode of star formation happened about 8 Gyr ago and stopped only few hundreds Myr ago. A complementary study of variable stars carried out by Hodge & Wright (1978) confirms the very low metal content classifying a large sample of bright variables as ACs. Lately, the presence of an old stellar population has been confirmed by the detection of RRLyrae stars by Held et al. (2001). However, this scenario seems to be at odd with recent spectroscopic analysis of more than 150 RGB stars made by Bosler et al. (2007) and Gullieuszik et al. (2009) that, measuring the Ca triplet lines, revealed much higher metallicity, i.e. [Fe/H]∼-1.35 ± 0.20 dex. This is in quite good agreement with recent medium resolution spectroscopy of 850 RGB stars that provided a mean metallicity of [Fe/H]∼ -1.43±0.33 dex (Kirby et al., 2011).

Recently, Fiorentino et al. (2012b) presented a new and more complete search for variable stars using an extensive sample of archival data collected with ground based telescopes. This sample is very complete at the Cepheid luminosity level ($V \sim 21$ mag) and the light curves have a good temporal coverage. The final sample consists of 37 Cepheids and more than 100 RRLyrae, 90 out of them with well defined period. A portion of the full CMD is shown in Fig. 1. The whole CMD goes well below the MSTO and a detailed SFH study is in progress. The classical instability strip for ACs (Marconi et al., 2004; Fiorentino et al., 2006) is also shown and it is in perfect agreement with the observed colours. In order to properly interpret and classify the detected sample of Cepheids we have plotted the central helium ignition loci of stars with masses from 0.5 to 3

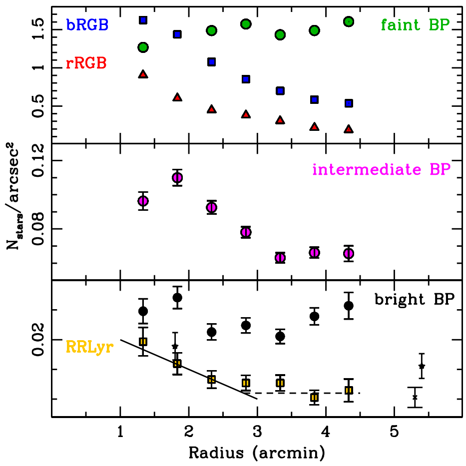

Fig. 3. The variation of the fraction of stars with the distance from the centre of M 32 for different selected stellar populations. Namely, the blue (bRGB) and red (rRGB) portion of the RGB, the bright (bBP) and faint (fBP) Blue Plume and the RRLyrae stars.

$M_{\odot}$ for two assumed metal contents, [Fe/H]=–1.3 and –1.5 dex.

In fact, in this region of the CMD both short period classical and ACs are expected. Given that the different pulsation classification depends on their evolution, we have also shown the central helium burning evolutionary paths till the end of the helium in the core (stars) for structures which ignite the helium in a degenerate core (red) that produce ACs and in a quiescent way (black) that produce classical Cepheids. A very low metallicity has to be assumed to let degenerate structures enter into the IS forming ACs, whereas blue loop stars cross the IS at higher luminosity forming CCs. When we move to higher metallicity, [Fe/H] > –1.3 dex, degenerate structures become redder and fainter and do not cross the IS anymore. Thus, only classical Cepheids are expected. This scenario is characterized by the transition mass that is the last mass showing a helium core with electron degeneracy. This mass is not depending on the adopted metallicity and is around 2.1 $M_{\odot}$.

Concluding, studying variable stars we find that the best matching theoretical scenarios are the one corresponding to [Fe/H]=–1.3 and –1.5 dex, thus learning that the metallicity can not be so metal–poor as previously believed, in fully agreement with new spectroscopic surveys. Moreover, very probably we are observing a combination of both anomalous *and* classical cepheids and that their parent population is peaked around the transition mass. This is a lucky case where the transition mass is traced making Leo I an ideal laboratory to investigate this important astrophysical parameter.

LMC dIrr galaxy: The Large Magellanic cloud is one of the most surveyed nearby Irregular galaxy, in particular it has been sub-[b!]ject of micro–lensing experiments (MACHO, OGLE). During the last few years OGLEIII (Soszyński et al., 2008) released the largest sample of variable stars ever detected in a galaxy, namely they found more than 22600 RRLyrae stars, 3000 Classical Cepheids, ~ 200 population II Cepheids (P2Cep) and ~ 80 ACs. This large sample of ACs is well separated from classical Cepheids on the basis of their light-curve morphology and their period luminosity relation, in particular in the Wesenheit plane. This is the largest sample of ACs ever detected and, interestingly enough, it is observed in a galaxy with a mean metallicity much higher then the one needed for ACs to be predicted by evolutionary theory. This large sample gives us a unique opportunity to investigate the origin of these objects. In fact, ACs can be originated by two different evolutionary channels, single intermediate star (M ~ 1.8 $M_{\odot}$) or by the coalescence of low mass star (M~0.8-0.9 $M_{\odot}$) binary system, both in very low metallicity environments. In fact they have been observed in all the dSph galaxies they have been searched for, even in those cases where an intermediate age population is not present in the galaxy (e.g., Cetus, Tucana, Draco, Ursa Minor, Sculptor and Sextans).

With this in mind, we decided to trace the spatial distribution of ACs as compared with other classes of variable stars available from OGLEIII. The cumulative distribution is shown in Fig. 2, where we compare ACs and P2Cep with young (CCs) and old (RRLyrae) variable stars. We found that the AC distribution does not follow the RRLyrae distribution nor the CC one, whereas the P2Cep one does follow the old population, as expected. This suggests that most of the ACs are not coming from the old population and thus they are likely to be the evolution of single stars, although the binary system channel cannot be completely ruled out. ACs are tracing the very metal–poor tail of the LMC metallicity distribution 1–2 Gyr ago. Only a small amount of gas was unpolluted when compared with the total mass of the galaxy, 10^5 vs 10^9 $M_\odot$, thus unlikely to be observed in spectroscopic surveys, or in statistical approached to derive the SFH. This shows the great importance of variable stars, and rare objects like ACs, to give independent constraints on the modeling of galaxies evolution.

M 32 dE galaxy: M 32 is the closest dwarf elliptical galaxy. Before the advent of Hubble Space Telescope (HST), M 32 has been mainly studied using integrated spectra. Their results suggest the presence of a predominantly intermediate age stellar population with solar metallicity. HST has given, for the first time, the opportunity to resolve M 32 into stars providing a lot of new information about this galaxy. However, even the highest spatial resolution possible with HST, i.e. HRC@ACS, does not allow to well constrain the Main Sequence Turn Off of the oldest stellar population in M 32 (Monachesi et al., 2011). The two main issues that prevent this finding are the almost "prohibitive" surface brightness of M 32 and the very high contamination level from M 31. Thus, to constrain the presence of an old stellar population in this galaxy, we have searched for bright variable stars using HRC (Fiorentino et al., 2010) and WFC (Fiorentino et al., 2012a) onboard HST. We found more than 400 RRLyrae that show a radial spatial gradient from the center of M 32. This is shown in Fig. 3, where we plot for comparison also the spatial distribution of other stellar populations, some likely belonging to M 32, as the blue (bRGB) and the red (rRGB) giant branch stars, and others likely belonging to M 31, as the bright, intermediate and faint blue Plume stars. This gradient results fully in agreement with the low–statistic RRLyrae detection, mainly due to the very small field of view of the HRC, previously found by Fiorentino et al. (2010). Concluding, this detection provides, for the first time, the presence of a purely old population in a dwarf elliptical galaxy.

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