Variable stars in Stellar Systems

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Abstract. We discuss in detail the pulsation properties of variable stars in globular clusters (GCs) and in Local Group (LG) dwarf galaxies. Data available in the literature strongly support the evidence that we still lack a complete census of variable stars in these stellar systems. This selection bias is even more severe for small-amplitude variables such as Oscillating Blue Stragglers (OBSs) and new exotic groups of variable stars located in crowded cluster regions. The same outcome applies to large-amplitude, long-period variables as well as to RR Lyrae and Anomalous Cepheids in dwarf galaxies.

1. Introduction

Variable stars in stellar systems such as GCs and dwarf galaxies have played a fundamental role in improving our knowledge on stellar populations (Baade 1958) as well as on the physical mechanism that drive the pulsation instability (Schwarzschild 1942). The main advantage of cluster variables when compared with field ones is that they are located at the same distance, and possibly the same reddening. Moreover, they formed from the same proto-globular cloud and therefore they have the same age, and chemical composition. Even though cluster variables present several undoubted advantages current knowledge concerning the pulsation properties of these objects is still limited. Recent estimates based on new data reduction procedures to perform differential photometry (ISIS, Alard 2000) suggest that the incompleteness factor in the detection of RR Lyrae stars is at least of the order of 30% (Kaluzny et al. 2001; Corwin & Carney 2001) in Galactic GCs characterized by high central densities. This limit is even more severe for OBSs, since the luminosity amplitude range from hundredths of a magnitude to a few tenths. Moreover, their radial distribution peaks toward the center of the cluster, and therefore ground based observations are strongly limited by crowding (Gilliland et al. 1998; Santolamazza et al.
The same outcome applies to Miras and to Semi-Regular variables in GGCs, but for a different reason, quite often they are saturated in current CCD chips. This is a real limit for metal-rich clusters of the Galactic bulge, since they lack of RR Lyrae stars or host a few of them (Pritzl et al. 2002), and the detection of Miras could supply an independent distance estimate (Feast et al. 2002).

Variable stars in dwarf spheroidal (dSph) galaxies presents several pros and cons when compared with variables in GGCs. The star formation history as well as the dynamical evolution of dSph galaxies is much more complex than for GGCs. Typically the age of stellar populations in LG dSphs ranges from a few Gyr to 12-13 Gyr, i.e. as old as stars in GGCs (Da Costa 1999). Wide photometric surveys strongly support the evidence of extra-tidal stars near several dSphs (Irwin & Hatzidimitriou 1995; Martinez-Delgado et al. 2001). The observation of these stellar debris resembles the tidal tails detected in several GGCs (Leon et al. 2000). On the other hand, dSph galaxies apparently host large amounts of Dark Matter (DM), and indeed the mass-to-light ratios in these systems range from ($M/L)_V \sim 5$ (Fornax) to $\sim 100$ (Ursa Minor). However, the scenario is still quite controversial and the evidence that dSphs present large DM central densities would suggest that they are not a large version of GGCs, since the latter present M/L ratios $\approx 1-2$. Photometric and spectroscopic data on variable stars in dSphs might supply new insights on the impact that environmental effects have on their evolutionary and pulsation properties. Unfortunately, data available in the literature are limited, since these stellar systems cover wide sky regions. The use of wide field imagers and wide field, multifiber spectrographs might overcome these problems.

In the following we discuss the impact that variables in stellar systems might have on cosmic distances and on stellar populations.

2. Variables in globular clusters

RR Lyrae stars together with subdwarf main sequence fitting are the most popular standard candles to estimate the distance to GGCs (Carretta et al. 2000; Bono et al. 2001). Both of them require accurate evaluations of cluster metal abundance, but the latter ones are more sensitive to reddening corrections (Castellani 1999). RR Lyrae stars present the non trivial advantage that individual reddening can be estimated on the basis of mean colors. During the last few years have been suggested new methods that rely on observables that do not depend at all on color excess, namely the pulsation period and the luminosity amplitude (Kovacs & Walker 2001; Piersimoni et al. 2002). Even though these pulsation parameters can be easily estimated, the accuracy of individual redenings might be affected by systematic uncertainties. Empirical evidence suggest that approximately the 30% of fundamental pulsators are affected by the Blazhko phenomenon (Kolenberg, this meeting), i.e. the light curve shows both amplitude and possibly phase modulation (Kurtz et al. 2000). The previous number fraction is supported by recent multiband investigation of RR Lyrae in NGC 3201 (Piersimoni et al. 2002) and in M3 (Corwin & Carney 2001).

Fig. 1 shows the suspected Blazhko RR Lyrae detected in NGC 3201. Note that secondary Blazhko periods are only available for a few GGCs such as M3.
Figure 1. Bailey Diagram for RR Lyrae stars in NGC 3201. Filled circles and triangles display fundamental and first overtone RR Lyrae. RR Lyrae that show amplitude modulations both in the B and in the V band, when compared with the amplitudes provided by Cacciari (1984, open circles), are connected with a vertical line.

Although, this pulsation feature was detected long time ago (Blazhko 1907) we still lack a firm knowledge of the physical mechanisms that drive the occurrence of such a phenomenon. Moreover, empirical data for cluster variables are poor, since they typically cover short-time intervals. This limits the use of the Bailey diagram (amplitude vs period) not only to estimate the intrinsic parameters of RR Lyrae (Bono et al. 1997) but also to estimate their individual color excesses.

This limit affects not only the detection of Semiregular (SR) and Long-Period-Variables (LPVs) but also variables along the RGB and long-period binary systems. On the other hand, the poor spatial resolution of ground based measurements and the limited accuracy hampered the detection of low-amplitude variables such as SX Phoenicis stars and BY Draconis in the innermost regions of GCs. The unprecedented amount of homogeneous and accurate time series data collected by Gilliland and collaborators to detect planets around G type stars in 47 Tuc demonstrated that current knowledge concerning cluster variables is still limited. In particular, they found a wealth of binary systems, as well as a new class of variable stars located at the base of the sub giant branch that they called “Red Stragglers” (see Table 1).

These facts further strengthen the evidence that the knowledge of periodic and aperiodic phenomena among cluster stars might be biased by selection effects (luminosity amplitudes and time resolution). Ground based observations can certainly help to overcome these limits for GGCs with low-central densities, but for high-central densities and post-core-collapse clusters the use of HST is mandatory.
Table 1. Variable stars detected in 47 Tucanae

| Class              | N\(^a\) | \(A_V^b\) mag | Period\(^c\) days | Source\(^d\) |
|--------------------|---------|---------------|-----------------|-------------|
| SRs & LPVs        | 14      | ...           | ...             | 1           |
| RR Lyrae          | 1       | \(\approx 1\) | 0.738           | 2           |
| SX Phoenicis      | 6       | 0.01-0.09     | 0.03-0.1        | 3,4         |
| Det. Ecl. Bin.    | 11      | ...           | 0.5-10          | 5           |
| W UMa             | 15      | ...           | 0.2-0.53        | 5           |
| Short-Period      | 10      | ...           | 0.1-1.5         | 5           |
| BY Draconis       | 65      | 0.001-0.04    | 0.5-10          | 5           |
| CVs               | 9       | ...           | ...             | 5           |
| Red Stragglers    | 6       | 0.003-0.12    | 1-9             | 5           |
| Red Giants        | 27      | ...           | 3-10            | 5           |
| LMXB              | 2       | \(\approx 0.05\) | 0.23-0.36       | 6           |
| MSP               | 20      | 0.004         | 0.43            | 7           |

\(^a\) Number of variables.  \(^b\) Luminosity amplitude in the V band.  \(^c\) Pulsation period.  \(^d\) Sources: 1) Fox 1982; 2) Carney et al. 1993; 3) Gilliland et al. 1998; 4) Bruntt et al. 2001; 5) Albrow et al. 2001; 6) Edmonds et al. 2002; 7) Edmonds et al. 2001.

3. Variables in dwarf galaxies

Photometric investigations of variable stars in nearby dwarf galaxies have been hampered by the reduced field of view of current CCDs. These stellar systems are characterized by low central densities and very large tidal radii (Mateo 1998). However, during the last few years wide field imagers (WFI) with fields of view of the order of 0.2-0.3 degree\(^2\) become available\(^1\). The absolute and the relative calibration of individual CCD chips is quite often challenging. Recent results concerning time series data collected with the WFI@2.2m ESO/MPI telescope seem to suggest that these thorny problems can be overcome at the level of a few hundredths of a magnitude (Monelli et al. 2002).

The number of LG dwarf galaxies for which is available a detailed census of variable stars is limited (Mateo 1998; Cseresnjes 2001; Bersier & Wood 2002). This limit applies not only to long-period and aperiodic variables but also to classical ones such as RR Lyrae (Dall'Ora et al. 2002) and δ Scuti stars (Mateo, Hurley-Keller, & Nemec 1998). The reasons why dwarf galaxies might play a crucial role in improving current knowledge on stellar populations are manifold.

i) Dwarf galaxies harbor stellar populations whose age might range from less than 1 Gyr to more than 12 Gyr, i.e. the stellar masses range from \(M/M_\odot \approx 0.1\) to \(M/M_\odot \approx 2\). Therefore they are fundamental laboratories to investigate vari-

\(^1\)In this site you can find more detailed information concerning present and future WFI
http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI
Radial Variables

able stars that are not present in GGCs such as Anomalous Cepheids (AC)\(^2\). Recent findings based on evolutionary and pulsation properties support the evidence that these objects are intermediate-mass stars during their central He-burning phase (Dall’Ora et al. 2002). However, we cannot exclude that some ACs could be the result of mass transfer in old binary systems (Renzini, MengeL, & Sweigart 1977). Moreover, dwarf galaxies might supply fundamental constraints on the accuracy of the Period-Luminosity (PL) relation of δ Scuti. In fact, these stellar systems often host both RR Lyrae and δ Scuti, and therefore independent distances may be derived to reduce the systematic uncertainties. It is noteworthy that dwarf galaxies, in contrast with open clusters, host simultaneously δ Scuti variables, i.e. young intermediate-mass stars, and OBSs, i.e. intermediate-mass stars formed via binary collision or binary merging of two old, low-mass stars (Santolamazza et al. 2001).

ii) Even though GGCs are the template of low-mass population II stars, the HB morphology is affected by the second parameter problem. This means that two GGCs with the same metal abundance might have quite different stellar distributions on the ZAHB. Dwarf galaxies supply the unique opportunity to test whether the dynamical history somehow affects the HB morphology.

iii) The number of GGCs that host sizable samples of RR Lyrae is limited, while dwarf galaxies with old stellar populations present large samples of RR Lyrae. This means that they can be soundly adopted to constrain the accuracy of theoretical predictions concerning the topology of the instability strip.

To investigate in more detail the last point, Fig. 2 shows the number fraction between first overtones and the total number of RR Lyrae as a function of the mean fundamental period. Data plotted in this figure show that a few dwarf galaxies such as Carina, Draco, and Leo II (see data listed in Table 2) can be hardly classified as Oosterhoff type I ($<P_{ab}> \approx 0.55$) or Oosterhoff type II ($<P_{ab}> \approx 0.64$) clusters. They present mean $<P_{ab}>$ values that are typical of Oo type II clusters, but the ratio between $RR_c$ and total number of RR Lyrae is more typical of Oo type I ($N_c/(N_{ab}+N_c) \approx 0.2$) than of Oo type II ($N_c/(N_{ab}+N_c) \approx 0.5$) clusters. On the other hand, Ursa Minor present a mean metallicity quite similar to Draco ($[Fe/H] = -2.2 \pm 0.1$ vs $[Fe/H] = -2.0 \pm 0.1$, Mateo 1998) but the mean $<P_{ab}>$ value and the number ratio of $RR_c$ variables is typical of Oo type II clusters. Unfortunately, the number of dwarf galaxies in which have been identified mixed-mode variables is still limited and no firm conclusion concerning their occurrence can be drawn.

4. Discussion

The results presented in the previous sections bring forward the evidence that the empirical scenario for variable stars in stellar systems such as GCs and LG dwarf galaxies is far from being complete. The limit applies not only to aperiodic variables but also to long-period variables such as Miras and Semi-Regulars. The same outcome applies to RR Lyrae stars affected by the Blazhko effect.

\(^2\)Only one AC is known among GGCs (NGC 5466), see Bono et al. (1997) and Corwin, Carney, & Nifong (1999).
Figure 2. Ratio between first overtone RR Lyrae ($N_c$) and the total number of RR Lyrae versus the mean period of fundamental ($N_{ab}$) RR Lyrae. Open and filled circles show Oosterhoff type I and type II GGCs that host a sizable sample of RR Lyrae stars. Triangles refer to LG dwarf galaxies. Stellar systems in which mixed-mode pulsators have been identified are marked with an “X”. Note that mixed-mode pulsators were included among $RR_c$ variables.
Table 2. Catalogue of RR Lyrae variables in dwarf galaxies

| Name          | [Fe/H]  | σ   | [Fe/H] | N_{ab} | log(⟨P_{ab}⟩) | N_c | Source^b |
|---------------|---------|-----|--------|--------|---------------|-----|----------|
| Carina        | -2.0±0.2 | <0.1|        | 52     | -0.200        | 15  | 1        |
| Draco         | -2.0±0.2 | 0.5±0.1| 209   | -0.211 | 54            | 2   |          |
| LeoI          | -1.5±0.4 | 0.3±0.1| 47    | -0.220 | 7             | 3   |          |
| LeoII         | -1.9±0.1 | 0.3±0.1| 106   | -0.210 | 34            | 4   |          |
| Sculptor      | -1.8±0.1 | 0.3±0.05| 134   | -0.236 | 88            | 5   |          |
| Sextans       | -1.7±0.2 | 0.2±0.05| 26    | -0.219 | 7             | 6   |          |
| Ursa Minor    | -2.2±0.1 | ≤0.2|        | 47     | -0.197        | 35  | 7        |
| Sagittarius   | -1.0±0.2 | 0.5±0.1| 1906  | -0.241 | 464           | 8   |          |
| Fornax        | -1.3±0.2 | 0.6±0.1| 396   | -0.233 | 119           | 9   |          |
| Gal. Center   | ...     | ...|        | 1496   | -0.261        | 331 | 8        |
| LMC           | -1.7±0.3 | ...|        | 3499   | -0.234        | 786 | 10       |
| SMC           | -1.7     | ...|        | 75     | -0.231        | 22  | 11       |

^a Spread in metallicity; ^b Sources: 1) Dall’Ora et al. 2002; 2) Nemec 1985; 3) Held et al. 2001; 4) Siegel & Majewski 2000; 5) Kaluzny et al. 1995; 6) Mateo, Fischer & Krzeminski 1995; 7) Nemec, Wehlau & Oliveira 1988; 8) Cseresnjes 2001; 9) Bersier & Wood 2002; 10) Alcock et al. 1996; 11) Graham 1975; Smith et al. 1992.

Even though several LG dSphs present stellar populations with chemical compositions and stellar ages quite similar to stars in GCs, the RR Lyrae variables present pulsation properties that are a bridge between Oosterhoff type I and Oosterhoff type II clusters. This preliminary evidence seems to suggest that either the dynamical history and/or the chemical evolution in these stellar systems might play a role to explain this difference. In this context the use of the new wide field imagers will supply the unique opportunity to investigate on a star-by-star basis the stars and the variables in LG dwarf galaxies.

Although new theoretical frameworks have been developed to account for the occurrence of mixed-mode pulsators among RR Lyrae and OBs we still lack a comprehensive explanation of the physical mechanisms that drive the occurrence of such a phenomena. It goes without saying that new sets of full amplitude nonlinear, convective models tightly connected with evolutionary models are highly requested to constrain the region of the instability strip where these pulsators present this intriguing behavior.

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