RRL2015 – High-Precision Studies of RR Lyrae Stars
L. Szabados, R. Szabó, K. Kinemuchi (Eds.) 2016

RR Lyrae stars in the Andromeda satellite galaxies

Felice Cusano[1], Alessia Garofalo[1,2], & Gisella Clementini[1]

[1]*INAF-Osservatorio Astronomico di Bologna, via Ranzani 1, 40127, Bologna, Italy*
[2]*Dipartimento di Fisica e Astronomia-Universitá di Bologna, Viale Berti Pichat 6/2, I-40127 Bologna, Italy*

Abstract. In this contribution we summarize results on the search for variable stars and the study of the resolved stellar populations in four dwarf spheroidal satellites of the Andromeda galaxy that we have observed with the Large Binocular Cameras (LBC) at the Large Binocular Telescope (LBT).

1. Introduction

In the context of the Λ-CMD theory massive galaxies like the Milky Way (MW) and Andromeda (M31) form by accretion and merging of smaller structures (e.g. Bullock & Johnston 2005). Candidates to be the possible residual building blocks of this accretion process are the satellite galaxies observed nowadays around the MW and M31. However, some issues challenge this scenario, like, for instance, the missing satellite problem (Moore et al. 1999) or the observed alignment of a large fraction of the satellite galaxies in planar structures (see e.g. Ibata et al. 2013). In this framework, we have obtained multi-band photometric observations with the Large Binocular Cameras (LBC) at the Large Binocular Telescope (LBT) of a sample of M31 satellites (see Cusano et al. 2013) to characterize both their variable and constant star populations. The final aim of our survey is to derive hints on the formation history of the M31's satellites and relate it to the global context of merging and accretion episodes occurring in M31.

2. Observations and data reduction

Time series photometry in the B and V bands was obtained with the LBC at the foci of the LBT for four M31 satellites, namely, And XIX (Cusano et al. 2013), And XXI (Cusano et al. 2015), And XXV (Cusano et al. 2016) and And XXVII (Cusano et al., in preparation). Observations in the B band were obtained with the Blue camera of the LBC, whereas the V images were acquired with the Red camera. PSF photometry of the pre-reduced images was performed using the `DAOPHOT-ALLSTAR-ALLFRAME` package (Stetson 1987, 1994). Variable stars were identified using the variability index computed in `DAOMASTER` (Stetson 1994), then the light curves of the candidate variables were analyzed with the Graphical Analyzer of Time Series (GRATIS), custom software developed at the Bologna Observatory (see e.g. Clementini et al. 2000). Examples of light curves for two RR Lyrae stars (a fundamental-mode − RRab and a first-overtone −

RRc) and an Anomalous Cepheid (AC) that we detected in And XXV are shown in Figure 1.

Table 1. Summary of number and properties of the variable stars identified in M31 satellite galaxies

Name	N (RRab+RRc)	$\langle P_{\rm ab} \rangle$	N(AC)	$E(B-V)$	$(m-M)_0$	GpoS member	Ref
And I	72+26	0.57	1?	0.05 ± 0.01	24.49 ± 0.06	yes	1
And II	64+8	0.57	1	0.06 ± 0.01	24.11 ± 0.06	no	2
And III	39+12	0.66	4	0.05 ± 0.01	24.38 ± 0.06	yes	1
And VI	91+20	0.59	6	0.06 ± 0.01	24.55 ± 0.07	no	3
And XI	10+5	0.62	0	0.11	24.33 ± 0.05	yes	4
And XIII	12+5	0.66	0	0.15	24.62 ± 0.05	yes	4
And XIX	23+8	0.62	8	0.11 ± 0.06	24.52 ± 0.23	no	5
And XXI	37+4	0.63	9	0.15 ± 0.04	24.40 ± 0.17	no	6
And XXV	41+11	0.60	1	0.06 ± 0.04	24.62 ± 0.16	yes	7
And XXVII	55+36	0.59	1	0.09 ± 0.05	24.57 ± 0.25	yes	8

[1] Pritzl et al. (2005); [2] Pritzl et al. (2004); [3] Pritzl et al. (2002);
[4] Yang & Sarajedini (2012); [5] Cusano et al. (2013); [6] Cusano et al. (2015);
[7] Cusano et al. (2016); [8] Cusano et al., in preparation

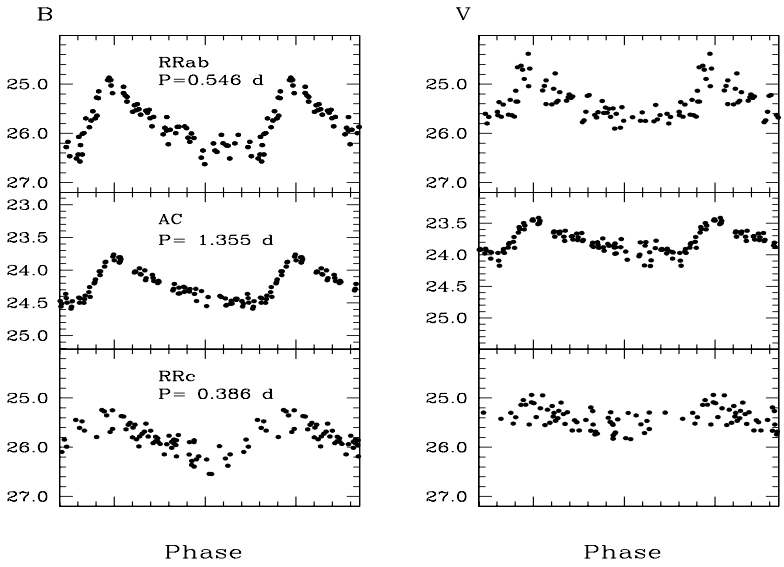

Figure 1. Light curves of a fundamental-mode (upper panel) and first-overtone (lower panel) RR Lyrae stars and of an AC (middle panel) in And XXV; *left:* in B band, *right:* in V band.

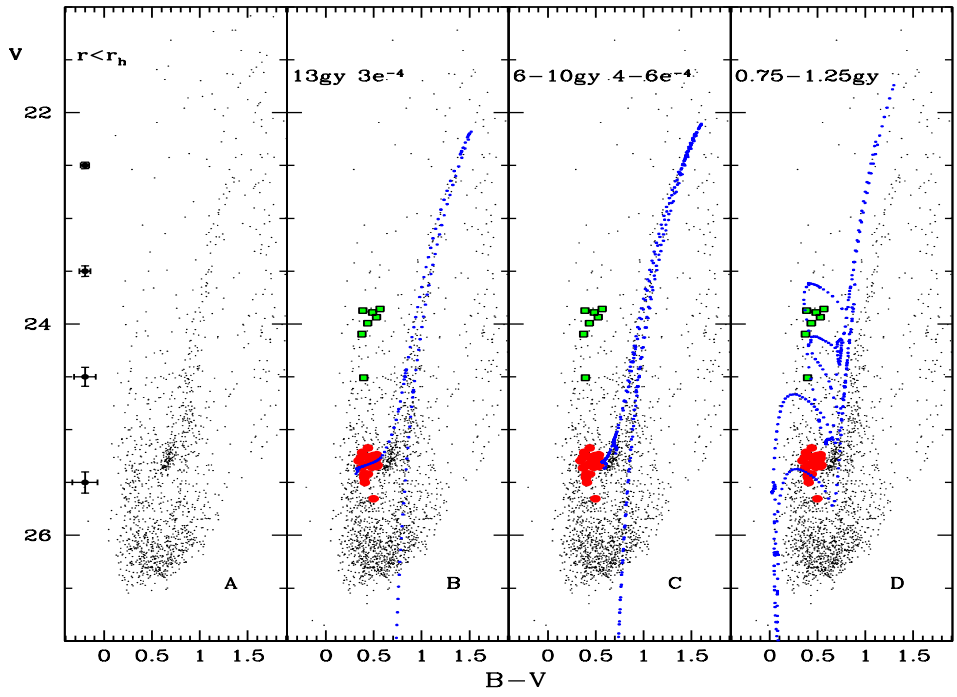

Figure 2. CMD and stellar populations in And XIX. *Panel A*: CMD of the objects in half light radius of the galaxy. *Panel B*: same as *panel A*, but the red filled circles are RR Lyrae stars, while the green filled squares are ACs. The blue dashed line is the isochrone at 13 Gyr and $Z = 0.0003$. *Panel C*: isochrones at 6 and 10 Gyr with $Z = 0.0004$. *Panel D*: isochrones at 0.75 and 1.25 Gyr with $Z = 0.0004$. The isochrones are from Bressan et al. (2012).

3. Results and conclusions

We discovered a total of 215 RR Lyrae stars and 19 Anomalous Cepheids (ACs) in the four M31 satellite galaxies observed with our program. The number and type of variable stars found in each galaxy are summarized in the last four rows of Table 1, whereas the six upper rows report the census and properties of the variable stars detected in other M31 satellite galaxies analysed so far for variability. In particular, the average period of the fundamental-mode RR Lyrae stars ($\langle P_{\rm ab} \rangle$) is given in column 3.

The M31 satellite galaxies that we have observed with the LBT can be classified as Oosterhoff Intermediate (Oo-Int) systems (see Oosterhoff 1939; Catelan 2009, for a description of the different Oosterhoff types). A comparison of the $\langle P_{\rm ab} \rangle$ values reported in Table 1, shows that the majority of the M31 satellites have Oo-Int properties, with only And III and And XIII being Oosterhoff type II (Oo II) systems. In column 7 of Table 1 we report also the membership of each galaxy to the Great plane of satellites (GpoS) discovered by Ibata et al.

(2013). The average period of the RRab stars for galaxies on and off the plane is $\langle P_{\rm ab}\rangle = 0.62 \pm 0.07$ d and $\langle P_{\rm ab}\rangle = 0.60 \pm 0.06$ d, respectively. Both populations are thus compatible with an Oo-Int classification. The number of ACs instead differs significantly among satellites and galaxies on the GpoS have very few ACs when compared to the galaxies off the plane.

Using the RR Lyrae stars we also derived independent estimates of the reddening and distance to the galaxies investigated by us. These values are summarized in columns 5 and 6 of Table 1, respectively.

Besides identifying the variable stars we also built colour-magnitude diagrams (CMDs) to characterize the stellar populations of these four satellite galaxies. We found evidence for three different stellar generations in And XIX and And XXI (see Fig. 2) and of a single old star formation burst in And XXV and And XXVII. We note that And XIX and And XXI do not belong to Ibata et al.'s GpoS, while And XXV and And XXVII lie on it. This and the different number of ACs led us to speculate on whether there might be a connection between star formation complexity/simplicity and GpoS membership.

The large field of view of the LBC allowed to accommodate in just one pointing the half light radius of each of the four galaxies we have observed with the LBT and thus study the spatial distribution of the different stellar components in each galaxy. The location of the RR Lyrae stars along with the isodensity contours of stars in selected regions of the CMD helped us to trace signatures of past and/or ongoing gravitational interactions with M31 or other dwarf galaxies. In particular, we found evidence for And XXI to be the result of a past minor merger between two dwarf galaxies.

References

Bressan, A., Marigo, P., Girardi, L., et al. 2012, MNRAS, 427, 127
Bullock, J. S., Johnston, K. V. 2005, ApJ, 635, 931
Catelan, M. 2009, Ap&SS, 320, 261
Clementini, G., Di Tomaso, S., Di Fabrizio, L., et al. 2000, AJ, 120, 2054
Cusano, F., Clementini, G., Garofalo, A., et al. 2013, ApJ, 779, 7
Cusano, F., Garofalo, A., Clementini, G., et al. 2015, ApJ, 806, 200
Cusano, F., Garofalo, A., Clementini, G., et al. 2016, submitted to ApJ
Ibata, R. A., Lewis, G. F., Conn, A. R., et al. 2013, Nature, 493, 62
Moore, B., Ghigna, S., Governato, F., et al. 1999, ApJ, 524, L19
Oosterhoff, P. T. 1939, The Observatory, 62, 104
Pritzl, B. J., Armandroff, T. E., Jacoby, G. H., et al. 2002, AJ, 124, 1464
Pritzl, B. J., Armandroff, T. E., Jacoby, G. H., et al. 2004, AJ, 127, 318
Pritzl, B. J., Armandroff, T. E., Jacoby, G. H., et al. 2005, AJ, 129, 2232
Stetson, P. B. 1987, PASP, 99, 191
Stetson, P. B. 1994, PASP, 106, 250
Yang, S.-C., Sarajedini, A. 2012, MNRAS, 419, 1362