Dwarf Galaxies: From the Deep Universe to the Present
Proceedings IAU Symposium No. 344, 2019
K. B. W. McQuinn & S. Stierwalt, eds.

doi:10.1017/S1743921318006270

An Analysis of M31 and its Satellite Galaxies Using RR Lyrae Variables

Nahathai Tanakul[1] **and Ata Sarajedini**[2,3]

[1]National Astronomical Research Institute of Thailand, 260 Moo 4, T. Donkaew, A. Maerim, Chiangmai, 50180, Thailand
email: nahathai@narit.or.th

[2]Department of Astronomy, University of Florida, 211 Bryant Space Science Center, Gainesville, FL 32611, USA

[3]Department of Physics, Florida Atlantic University, 777 Glades Rd, SE-43, Room 256 Boca Raton, FL 33431, USA

Abstract. RR Lyrae stars are powerful tools to study their host populations. Information such as distance, metallicity, reddening, and age can be obtained from their pulsation properties. Dwarf spheroidal (dSph) galaxies are the most common type of galaxy in the Local Group. They are found around massive hosts such as the Milky Way (MW) and M31 and are suggested to be the present-day counterparts to systems from which spheroids and stellar halos of larger galaxies were assembled. By comparing RR Lyraes in these dSphs with their host galaxies, we hope to understand more about the formation of these galaxies. In order to achieve this goal, we have analyzed six fields in M31 using archival imaging from the Hubble Space Telescope. Published data for M31, M33, and several M31 dSphs are also included. The results are then compared with those in the MW to better constrain the early history of these systems.

Keywords. stars: variables: other, galaxies: dwarf

1. Introduction

RR Lyrae (RRL) variable stars are useful tools to study stellar populations. They are low-mass ($\langle M_{\rm RRL}\rangle \sim 0.65\,{\rm M}_{\odot}$; Koopman *et al.* 1994) pulsating variable stars with helium burning cores. They are also older than ~ 10 Gyr, and therefore, provide information on their parent stellar systems at early times. From their pulsation properties, the metallicity and reddening of the stars can be determined. RRL stars can also be used measure the distance to their host system. They are relatively easy to detect since they are on the horizontal branch (HB), and at least 3 mag brighter than the main sequence turn off (MSTO). Their relatively short periods of less than 1 day and distinct light curves also make them easy to characterize. There are three types of RRLs. The ab-type pulsate in the fundamental mode with a sawtooth-like light curve. The c-type stars are first overtone pulsators with sinusoidal light curves and generally shorter periods than the ab-type. Lastly, the d-type RRLs pulsate in both the fundamental and first overtone mode. RRL stars have been extensively studied in the Milky Way (MW). In the MW globular clusters (GC), RRL populations shows two distinct sub-groups in the period-amplitude diagram, called the Oosterhoff dichotomy (Oosterhoff 1939). RRLs in Oosterhoff type I (OoI) GCs have shorter mean periods ($\sim$ 0.55 d), with a smaller ratio of c-type to total RRL stars and are more metal-rich ($-1.6\ \langle[Fe/H]\langle -1.0$), while those in Oosterhoff type II (OoII) GCs have longer mean periods ($\sim$ 0.65 d) with a larger ratio of c-type to total RRL stars and are more metal-poor ([Fe/H] $\langle -1.6$). The two Oosterhoff types occupy different regions of the period-amplitude diagram with the so-called Oosterhoff gap between them.

RRL stars in the field of the MW, unlike those in the GCs, tend to be OoI (Cacciari & Renzini 1976) and still show the Oosterhoff gap. Studies in the MW dwarf spheroidal (dSph) galaxies show that these stars tend to have an intermediate Oosterhoff type. The intermediate Oosterhoff type has also been observed in the M31 halo (Brown *et al.* 2004) and M31 dSph galaxies. However, some regions of M31 do not show this intermediate Oosterhoff type but tend to be OoI (Jeffery *et al.* 2011). What causes these differences in RRL populations? What do they imply about the early formation history of the galaxies?

2. RR Lyrae Stars in M31 dSphs

Found around massive host galaxies such as the MW and M31, dwarf spheroidal (dSph) galaxies are the most common type of galaxy in the Local Group. In the ΛCDM (Lambda cold dark matter; Universe dominated by cold dark matter with a cosmological constant Λ; Moore *et al.* 1999) theory of galaxy formation, dSphs are thought to be the present-day counterparts to systems from which spheroids and stellar halos of larger galaxies were formed.

Recent studies of RRLs in M31 dSphs include, for example, Monelli *et al.* 2016, Cusano *et al.* 2015, Cusano *et al.* 2013. By studying RR Lyrae stars in these dSphs and their host galaxy, we can obtain information on their early formation history.

From previously published data, we have compiled all RR Lyrae properties in each dSph galaxy and constructed the period-amplitude diagrams of all the M31 dSph fields. From the Bailey diagrams, we can see that the majority of M31 dSph RRLs tend to be between OoI and OoII or Oosterhoff intermediate with some OoI RRLs. This is the same as RRLs in the MW dSphs.

Recent study by Fiorentino *et al.* (2015) suggested that the fundamental mode RRL in most of their MW dSphs were lacking in High Amplitude Short Period (HASP) variables. These HASP stars are defined as those with $P \lesssim 0.48$ days and $A_V \geqslant 0.75$ mag. These HASP RRLs are common in the MW halo and globular clusters. They further studied these HASP RRLs in 18 globular clusters hosting more than 35 RRL each and found that the metallicity seems to be the main parameter since RRL in the HASP region are only present in globular clusters that are more metal-rich than $[\mathrm{Fe/H}] \sim -1.5$. We found that most of our dSphs are also lacking RRLs in the HASP regions. To confirm that metallicity is the main parameter affecting the lack of RRLs in the HASP region, we plot the fraction of RRLs in HASP region against the mean metallicity as shown in Figure 1. We can see that the more metal-rich galaxies do have a higher fraction of stars in the HASP region.

3. Comparison Between RRLs in M31 and its Satellites

To compare the properties of RRL in M31 dSphs with those in M31 itself and M33, we plot the period-amplitude diagram of each region as shown in Figure 2. To examine the Oosterhoff type of RRLs in each region, we plot the distribution of the period difference of each RRL from each Oosterhoff type. From this, we find that RRLs in M31, M33 and more massive M31 dSphs tend to be OoI, while the less massive M31 dSphs tend to be OoI and Oosterhoff intermediate. This difference, and the fact that M31 dSph RRLs tend to be lacking in the HASP region, suggests that systems similar to the present dSphs do not appear to be the main building-blocks of the halo. This observation can also be seen in the Milky Way (Fiorentino *et al.* 2015).

4. Conclusion

From the properties of RR Lyrae stars, we found that the majority of M31 and M33 RRLs are of OoI while those in M31 dSphs are of Oosterhoff intermediate. The main

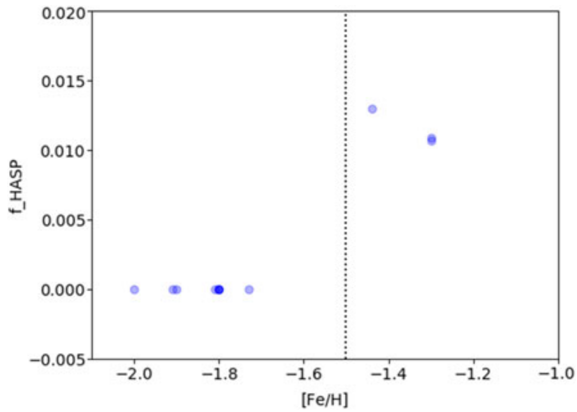

Figure 1. The fraction of RRL in the HASP region, plotted against the mean metallicities of each dSph. The vertical line indicates the metallicity of –1.5.

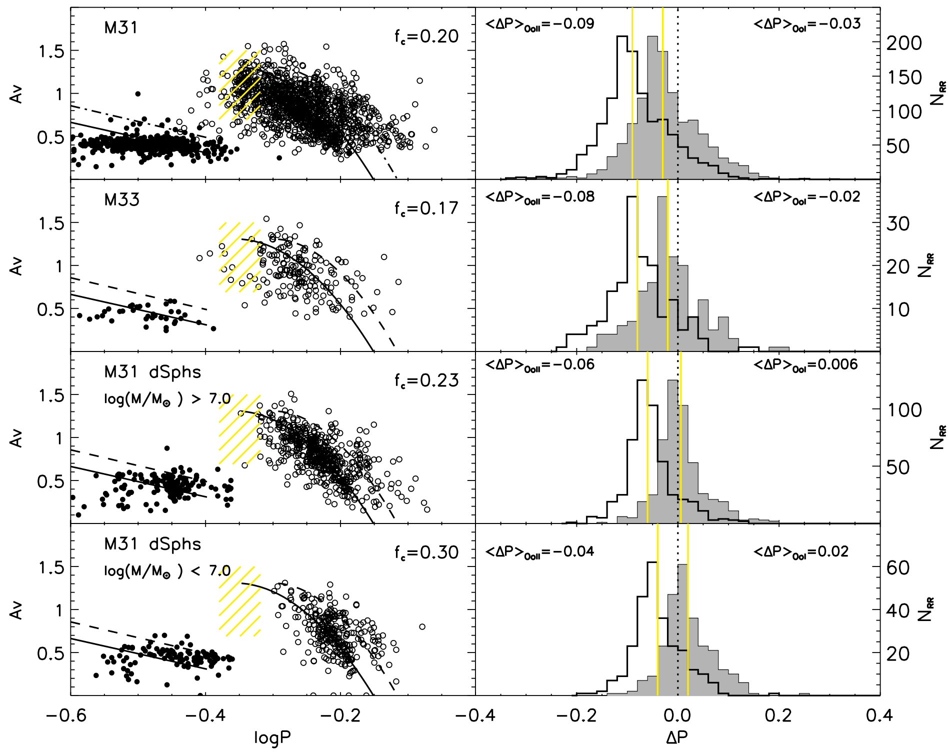

Figure 2. This figure shows pulsation properties of different regions. The left panels are the period-amplitude diagrams of RRL stars in M31, M33, more massive M31 dSphs and less massive M31 dSphs. The lines show the locations of RRL stars in Oosterhoff I (solid lines) and Oosterhoff II (dot-dashed lines) clusters. The yellow area designates the region of the HASP RRLs. The right panels show the distribution of the difference in period of each RRL from each Oosterhoff type. The gray histograms are the difference from OoI, while the white histogram are from OoII. The yellow vertical lines show the mean difference.

https://doi.org/10.1017/S1743921318006270 Published online by Cambridge University Press

parameter affecting these Oosterhoff types is likely to be metallicity. Metallicity also plays a role in the lack of RRLs in HASP variables in M31 dSphs. This difference in the properties of RRLs between their parent galaxy and satellites, as well as the lack of RRLs in the HASP region in dSphs can also be observed in the Milky Way. Therefore, systems like these dSphs are unlikely to be the main building blocks of the M31 and Milky Way halo.

References

Brown, T. M., Ferguson, H. C., Smith, E., Kimble, R. A., Sweigart, A. V., Renzini, A., & Rich, R. M. 2004, *AJ*, 127, 2738

Cacciari, C., & Renzini, A. 1976, *A&A*, 25, 303

Cusano, F., Clementini, G., Garofalo, A., Cignoni, M., Federici, L., Marconi, M., Musella, I., Ripepi, V., Boutsia, K., Fumana, M., Gallozzi, S., & Testa, V. 2003, *ApJ*, 779, 7

Cusano, F., Garofalo, A., Clementini, G., Cignoni, M., Federici, L., Marconi, M., Musella, I., Ripepi, V., Speziali, R., Sani, E., & Merighi, R. 2015, *ApJ*, 806, 200

Fiorentino, G., Bono, G., Monelli, M., Stetson, P. B., Tolstoy, E., Gallart, C., Salaris, M., Martínez-Vázquez, C. E., & Bernard, E. J. 2015, *ApJ*, 631, 976

Jeffery, E. J., Smith, E., Brown, T. M., Sweigart, A. V., Kalirai, J. S., Ferguson, H. C., Guhathakurta, P., Renzini, A., & Rich, R. M. 2011, *AJ*, 141, 171

Koopman, R. A., Lee, Y. W., Demarque, P., & Howard, J. M. 1994, *ApJ*, 423, 380

Monelli, M., Martínez-Vázquez, C. E., Bernard, E. J., Gallart, C., Skillman, E. D., Weisz, D. R., Dolphin, A. E., Hidalgo, S. L., Cole, A. A., Martin, N. F., Aparicio, A., Cassisi, S., Boylan-Kolchin, M., Mayer, L., McConnachie, A., McQuinn, K. B. W., & Navarro, J. F. 2016, *ApJ*, 819, 147

Moore, B., Lee, Y. W., Demarque, P., & Howard, J. M. 1994, *ApJ*, 423, 380

Oosterhoff, P. T. 1939, *The Observatory*, 62, 104

Zorotovic, M., Catelan, M., Smith, H. A., Pritzl, B. J., Aguirre, P., Angulo, R. E., Aravena, M., Assef, R. J., Contreras, C., Cortés, C., De Martini, G., Escobar, M. E., González, D., Jofré, P., Lacerna, I., Navarro, C., Palma, O., Prieto, G. E., Recabarren, E., Triviño, J., & Vidal, E., 2010, *AJ*, 139, 357