Physical properties of RR Lyrae variables in Galactic globular clusters and dwarf spheroidal galaxies

S Benkortem¹, N Tanakul²*, C Suwannajak², P Pattarakijwanich¹ and S Yuma¹

¹Department of Physics, Faculty of Science, Mahidol University, Bangkok, Thailand
²National Astronomical Research Institute of Thailand, Chiang Mai, Thailand
*E-mail: nahathai@narit.or.th

Abstract. We propose a tool to distinguish between Galactic globular clusters (GCs) and dwarf galaxies based on physical properties of RR Lyrae (RRL) variables in the systems. Normally, these two systems show various distinctive properties; for instance, mass, size, and luminosity. Nevertheless, these properties overlap each other in recently discovered systems. The subsequent classification between GCs and dwarf spheroidal (dSph) galaxy is ambiguous. An RRL variable is a pulsating variable star with a short period of 0.2-1 days. It is relatively easy to observe the complete period of its light curve. The age of RRL stars is typically more than 10 Gyr; therefore, they can provide information of the host system at its early stage. In this study, we provide an extensive data collection of RRLs in 96 GCs, 23 dSphs, and 10 dwarf irregular (dIrr) galaxies. Based on public catalogs, we analyze various RRL properties such as Oosterhoff dichotomy, fraction of high amplitude short period (HASP) variables, metallicity, and specific frequency of RRLs ($S_{RR}$). We examine correlations among all properties in an attempt to distinguish between GCs and dSphs.

1. Introduction

The Local Group dwarf galaxies are satellites of main galaxies, Milky Way (MW) and Andromeda (M31) galaxy. Mostly these stellar systems are distinguished from star clusters by having a substantially dynamical mass larger than the mass from the total stellar population or a dispersion in metallicities that specify by different stellar generation inside and an evidence of supernova (SN) ejecta still preserve [1-2]. To classify stellar systems as dwarf galaxies or globular clusters, one need to relatively examine these stellar systems by considering their low surface brightnesses, physical sizes, mass, or heliocentric distances from the center of host system mass. That is a distinct separation with the system as a globular cluster (GC). Due to GCs have lower mass and shorter distance from center than dwarf galaxy, also fainter in absolute magnitude of GCs include.

As a result of large optical surveys such as SDSS or Sloan Digital Sky Survey [3], Dark Energy Survey [4] and 2nd Gaia Data Release [5], the major of new discovery is a small and least luminous galaxies which are hardly detected in the past. Recent explorations have been found the ambiguous stellar systems which have to overlap in several properties; for instance, mass, size, and luminosity that indistinct between a dwarf galaxy and globular cluster (GC). These unclear systems are a problem to classify the type of stellar systems and understand the galaxy evolution.
To troubleshooting, we propose the analysis of RR Lyrae (RRL) variable stars because these are great tracers for observing chemical and dynamical properties of stellar populations that old enough to exist in the system, so RRL stars give us to understand the earliest history of galaxies. Their distinct light curves are easy to detect with a short period around 0.2 to 1 day. The RRL stars are a kind of pulsating variable stars with low mass (~ 0.6 \( M_\odot \)) and they inhabit the horizontal branch (HB) in a colour magnitude diagram (CMD) where is away at least 3 mag brighter than the main sequence turn-off that intersects the pulsational instability strip. To expanding and contracting caused by helium-burning cores hence their age must older than 10 Gyr. Additionally, RRL light curves are various types caused by the differences in a period and brightness amplitude. The fundamental mode (RRab) pulsate with a sawtooth-like light curve in period range between 0.3 to 1 day (most of them \( \geq 0.45 \) days). The first overtone mode (RRc) pulsate with nearly a sinusoidal light curve and period shorter than RRab (\( \sim 0.2 \) to 0.5 days). The last example is a double mode (RRd) variable stars which pulsate in both the fundamental and first overtone modes.

In this study, we aim to identify the physical properties of GCs and 2 types of mostly found in dwarf galaxies, dwarf spheroidal (dSph) and dwarf irregular (dIrr). We are also interested in studying the physical properties of RRL variables in those systems, to distinguish and explain more about their own stellar evolution.

2. Data and catalogue
The data in this study are obtained from main previous literature and others for a more complete properties. In table 1 we list a number of the systems that are known to contain RRL variables in detail. The main literature sources were listed in column (1) and types of system in this study which are GC, dSph, and dIrr were listed in column (2), (3) and (4), respectively.

In order to compare RRL properties between those systems we obtained raw data of each source and calculated several properties of it. All properties include absolute magnitude \( (M_v) \), metallicity from previous literature \( ([Fe/H]_{lit}) \) and empirical relation derived from RRab \( ([Fe/H]_{RRab}) \), fraction of high amplitude short period \( (f(HASP)) \) per number of total RRab which is the HASP region that defined as with \( P \leq 0.48 \) and \( A_v \geq 0.75 \) mag to focus on fundamental mode, RRab as present in Period-Amplitude diagram, distance from the center \( (D_{center}) \), and the specific frequency \( (S_{RR}) \) which is normalization of number RRL per unit absolute visual magnitude to get rid of the effect from the host system as follow:

\[
S_{RR} = N_{RR} \cdot 10^{-0.4(7.5+M_v)}
\]

Table 1. The literature source of data collection.

| Data Source | GC | dSph | dIrr |
|-------------|----|------|------|
| [6]         | 96 | -    | -    |
| [7]         | -  | 28   | 11   |
| Total       | 96 | 28   | 11   |

3. Result and discussion
The relation of RRL properties between \([Fe/H]_{lit}, f(HASP)\) and \( S_{RR} \) are illustrated as a 3D plot in the figure 1. The data in this plot does not include those with zero HASP region. We notice
the distribution of both types in each axis of RRL property. Data from GCs are various in z-axis in range 0 to almost 100. But data from dSphs are limited by $S_{RR}$ not over 20 as shown by blue plane. Consistency with data from dIrrs which are quite flat as represented by green plane. While the $f($HASP$)$ axis showed the result that GCs have a variety of distribution in $f($HASP$)$ as $[\text{Fe/H}]_{\text{lit}}$ in range -0.5 to -2.5, specifically, at $[\text{Fe/H}]_{\text{lit}} \approx 1.7$. On the other hand, the result of dSphs and dIrrs are restrict as a narrow in $f($HASP$)$.

This relation of RRL properties in three host types which are GC, dSph, and dIrr, implies that these host systems are dissimilar in the exposed RRL populations. By the determination of $[\text{Fe/H}]_{\text{lit}}$, not only the RRL properties in GCs are spread in $[\text{Fe/H}]_{\text{lit}}$ but also distribute in the axis of $S_{RR}$. Whereas RRL properties in dSphs and dIrrs are distributed in $[\text{Fe/H}]_{\text{lit}}$ with a low in $f($HASP$)$ and $S_{RR}$. It is consistent with the previous study from others which have given reason that because the GCs and dSphs have distinction in early formation histories at difference $[\text{Fe/H}]$ that affect to the display of HASP region in each systems. And the constraint in low $S_{RR}$ indicate that dSphs and dIrrs have less RRL populations than GCs by effect of n historically metallicity in early formation to become today’s RRL stars.

![Graph showing distribution of RRL properties in GC, dSph, and dIrr systems](image)

**Figure 1.** The figure shows 3D scatter plot of Metallicity from literature and $f($HASP$)$ relation as a function of $S_{RR}$. As shown in the legend, the red star represents the RRLs in GC, the blue and green symbols represent the RRLs in host system as dSph and dIrr, respectively.

4. Conclusion
We have presented a study of physical properties of RR Lyrae variables in Galactic globular clusters and dwarf spheroidal galaxies by using data from previous literature. We analyze the several properties of RRL and their host system to find the relation that distinguishes between both systems. We found that $S_{RR}$, one of the properties of RRL in two systems are dissimilar depend on unknown relation of metallicity. In addition, the $f($HASP$)$ of GCs tend to be higher than $f($HASP$)$ of dSphs and dIrrs. Our overall results agree with previous study which explains that GC and dSph are distinct in the early formation history as a result of different RRL star population. However, more data is needed to determine the exact parameter differentiating these systems.
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