Mem. S.A.It. Vol. 77, 63
© SAIt 2006

Memorie della

Red variables in globular clusters

Comparison with the Bulge and the LMC

N. Matsunaga[1], Y. Nakada[2,1], T. Tanabé[1], H. Fukushi[1], and Y. Ita[3]

[1] Institute of Astronomy, School of Science, The University of Tokyo, 2-21-1 Osawa, Mitaka, Tokyo 181-0015, Japan
[2] Kiso Observatory, School of Science, The University of Tokyo, Mitake, Kiso, Nagano 397-0101, Japan
[3] Institute of Space and Astronomical Science, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan

Abstract. We are conducting a project aimed at surveys and repeated observations of red variables (or long-period variables) in globular clusters. Using the IRSF/SIRIUS near-infrared facility located at South Africa, we are observing 145 globular clusters that are accessible from the site. In this contribution, we present our observations and preliminary results. We have discovered many red variables, especially in the Bulge region, whose memberships to the clusters remain to be confirmed. Using a sample of all red variables (both already known and newly discovered ones) in globular clusters except those projected to the Bulge region, we produce a log P-K diagram and compare it with those for the Bulge and the Large Magellanic Cloud. A prominent feature is that the bright part of overtone-pulsators' sequence (B^+ and C') is absent. We discuss its implication on the evolution of red variables.

Key words. Stars: AGB and post-AGB – Galaxy: globular clusters – Stars: Variables

1. Introduction

The study on red variables has advanced very much since Wood et al. (1998) found parallel sequences on the period-magnitude diagram as a result of the MACHO project for the Large Magellanic Cloud. Many papers have been published on the variables in the Magellanic Clouds (Ita et al. 2004a, 2004b; Kiss & Bedding, 2003, 2004; also see the contribution by Dr. Kiss in this volume). However, it is difficult to discuss the stellar evolution directly because the Magellanic Clouds contain red variables with different ages and different chemical components.

In contrast, globular clusters (GCs) are systems of single stellar population, so that we can tell the age and the initial chemical component for each variable star. Making use of this advantage, some authors have worked on the evolution of red variables in GCs. Whitelock (1986) found Mira variables and semi-regular variables in GCs define a relatively tight sequence on the log P-$M_{\rm bol}$ diagram. Bedding & Zijlstra (1998) considered the sequence as an evolutionary track, whose slope is consistent

Send offprint requests to: N. Matsunaga (e-mail: matsunaga@ioa.s.u-tokyo.ac.jp)

with an evolutionary calculation by Vassiliadis & Wood (1993). On the other hand, Perl & Tuchman (1990) theoretically examined the $\log P$-M_{bol} diagram with a staircase pattern for variables in 47 Tuc, and concluded that a switch of pulsational-mode occurs at a certain luminosity. Recently, Lebzelter et al. (2005) also proposed the switch of mode based on $\log P$-K diagram and their measurements of variations of radial velocities.

These works clearly demonstrated that GCs are good testbeds for studying the evolution of red variables. However, early surveys were not complete, and many of them were optimized to search for short-period variables such as RR Lyrae variables (Clement et al. 2001). In addition, they are mostly conducted in visible wavelength. Some red variables are undergoing heavy mass loss and holding thick circumstellar materials, which make the stars only detectable in infrared(Tanabé et al. 1997). So that we decided to conduct a near-infrared survey for red variables in GCs.

2. Observations and Preliminary Results

We started our near-infrared survey in the spring of 2002, using the IRSF 1.4 m telescope and the SIRIUS camera. They are established by Nagoya University and National Astronomical Observatory of Japan, and sited at Sutherland station of South African Astronomical Observatory. They can take three images in J-, H-, and K_{s}-band simultaneously with the $8' \times 8'$ fields-of-view. For the details of the IRSF and the SIRIUS, see Nagashima et al. (1999) and Nagayama et al. (2003).

There are 150 GCs found in the Milky Way and the neighborhood (Harris 1996). From the IRSF site, we can reach to about +30° in Declination, and we have observed such 145 clusters at least once. Until the end of 2004, we have observed 133 clusters more than 10 times and 40 clusters more than 20 times.

With data analyses for the 133 clusters, we detected variations of 58 known red variables in 30 clusters and discovered 185 red variables in 44 clusters. Detection limits of variability is typically better than 0.1 mag. Many of the newly discovered variables lie in the direction of the Galactic Bulge. 31 clusters with the new variables locate within the $|l| < 10°$ and $|b| < 10°$ region. Because the Bulge itself contains many red variables, it is important to check their memberships.

Especially, it is urgent for some peculiar objects. Among the new ones, there are very red stars, e.g. $(J - K)_0 > 3$. It is not known that such stars exist in GCs. We detected SiO maser emissions, evidences of relatively thick circumstellar materials, from four of the newly discovered variables and also from two known variables (Matsunaga et al. 2005a). The velocities of the emissions indicate five of them can be associated with GCs.

Using the near-infrared surface brightness obtained by the *COBE*/DIRBE data (Matsunaga et al. 2005b), roughly 20 % of the detected variables are considered to be associated with the GCs.

3. Discussions

3.1. The $\log P$-K diagram and comparison with the LMC

In the following, we will discuss the $\log P$-K diagram using our samples. In order to avoid the Bulge field contamination, we adopt variables whose galactic coordinates are out of the Bulge range: $|l| > 10°$ and/or $|b| > 10°$. Collecting red variables with known periods and near-infrared measurements, our sample contains 86 red variables in 29 GCs. For 27 stars among them, we detected their variations and obtained their mean magnitudes (mean of minimum and maximum); we did not detected significant variations for 50 stars; 9 stars are located too north to be observed and we just adopted the magnitudes listed in the 2MASS point source catalog.

Fig. 1 shows the $\log P$-K diagram. Filled circles for variables in metal-rich GCs ([Fe/H]> −1) and triangles for those in metal-poor ones are superposed on gray points for those in the Large Magellanic Cloud(Ita et al. 2004b). Mira variables in the metal-rich clusters obey the sequence C, and some variables are located at around the sequence

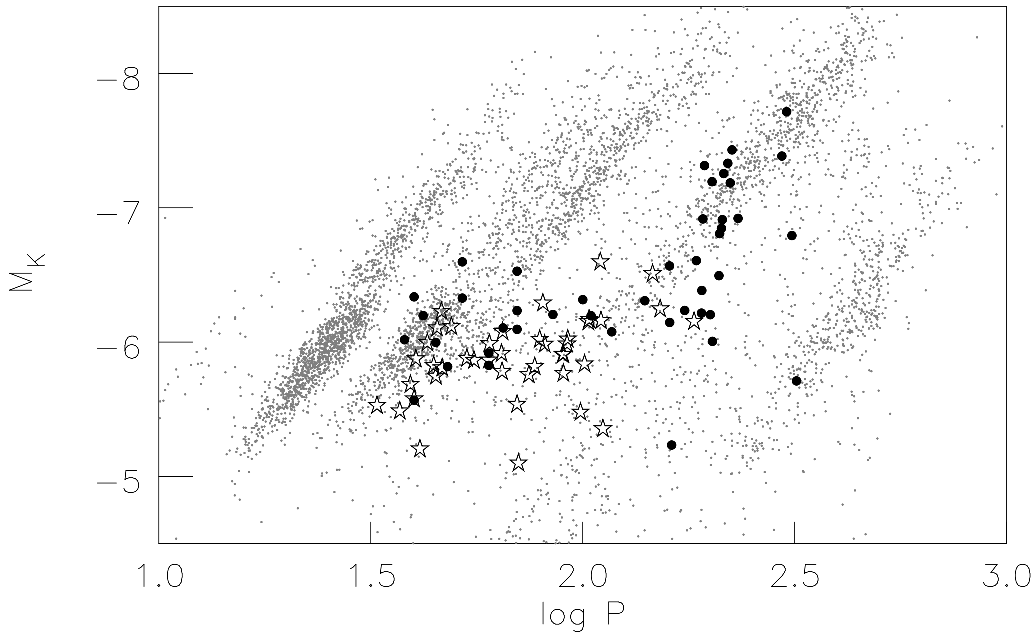

Fig. 1. The log *P*-*K* diagram. Filled circles for variables in metal-rich clusters ([Fe/H] > −1), star symbols for those in metal-poor ones, and gray points for the data of the Large Magellanic Cloud (Ita et al. 2004b).

B^- (notations for the sequences are based on those of Ita et al. 2004a). As is well known, bright Mira variables belong to only metal-rich GCs (Frogel & Whitelock 1998).

Few variables in GCs lie on the sequences A, B^+, C', and D. For variables on the sequences A and D, the periods are difficult to get. Those on the sequence A have small amplitude and irregular light curves, and ones on the sequence D have very long periods and sometimes double-periodic light curves (Wood 2000). We need massive photometric data and very careful analyses in order to conclude the absence of these sequences.

On the other hand, variables on the sequences B^+ and C' should be easier to find, at least compared with those on the sequence B^-. It is also known about GCs that all the stars brighter than the tip of Red Giant Branch (RGB) are found to be Mira variables (see Frogel & Whitelock 1998, for example). So that, we conclude this absence is a real feature of variables in GCs. Please note that this absence was utilized to propose the evolutionary track by Perl & Tuchman (1990) and Lebzelter et al. (2005). We confirmed the absence from a larger sample including many GCs.

3.2. Comparison with the Bulge and its implication

We found the intermediate part of the sequence C'(or B^+) exists on the log *P*-*K* diagram for the Galactic Bulge given by Glass & Schultheis (2003; see their Fig. 7). On that sequence, there is an vacant region at the brightest part, but some variables are as bright as $M_K = -7.5$ with the distance modulus assumed to be 14.5 mag. Although it is difficult to distinguish between the sequences C' and B^+, they are bright overtone pulsators that are not found in GCs. The top of the sequence is brighter than the tip of RGB. Although there are some uncertainties about the tip of RGB for the Bulge, such as spatial depth and metallicity effects, we consider they should work on both the sequences A and B. We conclude the intermediate part is in the Asymptotic Giant Branch (AGB) phase.

It is suggested that AGB stars in the Bulge take the evolutionary track with the staircase pattern similar to that of 47 Tuc, but the luminosity at which the mode of pulsation switches is different. This can be interpreted that the variables in the Bulge have larger initial masses than those in 47 Tuc and take a brighter evolutionary track as presented by Vassiliadis & Wood (1993). The star formation history of the Bulge is still controversial, but the majority of the constituent stars have the similar ages to those of GCs(Zoccali et al. 2003). Nonetheless, their high metallicities have an effect on initial masses of the red variables. Theoretically, red giants with the high initial metallicities are expected to have the larger initial masses (Iben & Renzini 1984).

It is important to discuss GCs in the Bulge region whose metallicities are similar to the Bulge field population after confirming the memberships of variable stars. It is also interesting to investigate the $\log P$-K diagram for some massive clusters with the intermediate-age (~1 Gyr, i.e. more massive) AGB stars in the Magellanic Clouds.

4. Conclusions

We discovered many red variables in the course of our near-infrared survey toward 145 GCs. Many of the newly discovered variables lie in the direction of the Galactic Bulge. Since there is a large field population of red variables in the Bulge, it is important to check their memberships by radial velocities and proper motions.

Using the sample outside the Bulge region including both the new variables and already-known ones (86 variables in 29 clusters), we discussed the distribution on the $\log P$-K diagram. We found the absence of the bright part of the sequences C' and B^+, which was known for 47 Tuc, with more variables whose metallicities are widely spread. We also compared the distribution with that of the Bulge. It is suggested that AGB variables switch from overtone pulsators to Mira variables at a certain luminosity, which depends on stellar parameters such as initial mass and metallicity.

Acknowledgements. We are grateful to the IRSF/SIRIUS team for the well-operating instrument and their supports for our observation. Parts of our observations are kindly conducted by Dr. M. Feast, Dr. J. Menzies, Dr. P. Whitelock, Dr. E. Olivier, Dr. T. Nagata, Dr. H. Nakaya, Dr. T. Naoi, Mr. S. Nishiyama, Mr. D. Baba, and Ms. A. Ishihara. One of the authors (N. Matsunaga) is financially supported by the Japan Society for the Promotion of Science (JSPS) for Young Scientists.

References

Bedding, T. R., Zijlstra, A. A., 1998, ApJ, 506, L47
Clement, C. M., et al. 2001, AJ, 122, 2587
Frogel, J. A., Whitelock, P. A., 1998, AJ, 116, 754
Harris, W. E., 1996, AJ, 112, 1487
Glass, I. S., Schultheis, M., 2003, MNRAS, 345, 39
Iben, I., Renzini, A., 1984, Phys. Rep. 105, 329
Ita, Y. et al. 2004a, MNRAS, 347, 720
Ita, Y. et al. 2004b, MNRAS, 353, 705
Kiss, L. L., Bedding, T. R. 2003, MNRAS, 343, L79
Kiss, L. L., Bedding, T. R. 2004, MNRAS, 347, L83
Lebzelter, T., et al., 2005, A&A, 432, 207
Matsunaga, N. et al. 2005, PASJ, 57, L1
Matsunaga, N., Fukushi, H., Nakada, 2005, MNRAS, in press
Nagashima, C., et al. 1999, in Proceedings of Star Formation 1999, Star Formation, ed. T. Nakamoto (Nagoya, Japan), 397
Nagayama, T., Nagashima, C., Nakajima, Y., et al. 2003, in SPIE Vol. 4841, Instrument Design and Performance for Optical/Infrared Ground-based Telescopes, ed. M. Iye & A. F. M. Moorwood, 459
Perl, M., Tuchman, Y., 1990, ApJ, 360, 554
Tanabé, T., et al. 1997, Nature, 385, 509
Vassiliadis, E., Wood, P. R., 1993, ApJ, 413, 641
Whitelock, P. A., 1986, MNRAS, 219, 525
Wood, P. R., 2000, PASA, 17, 18
Wood P. R., Habing, H. J., McGregor, P. J., 1998, A&A, 336, 925
Zoccali, M., et al. 2003, A&A, 399, 931