Variable Stars in the Local Group
ASP Conference Series, Vol. 310, 2004
Donald W. Kurtz & Karen R. Pollard, eds.

Observational properties of red variables in the LMC

M. Takeuti[1], S. Noda[2,3], F. Abe[2], I.A. Bond[4], R.J. Dodd[5,6,7], J.B. Hearnshaw[8], M. Honda[9], M. Honma[10], J. Jugaku[11], Y. Kan-ya[10], Y. Kato[2], P.M. Kilmartin[5,8], Y. Matsubara[2], K. Masuda[2], Y. Muraki[2], T. Nakamura[12], K. Ohnishi[13], M. Reid[7], N.J. Rattenbury[5], To. Saito[14], Y. Saito[2], H. Sato[15], M. Sekiguchi[9], J. Skuljan[8], D.J. Sullivan[7], T. Sumi[2,16], R. Yamada[2], T. Yanagisawa[17], P.C.M. Yock[5], M. Yoshizawa[18]

[1] *Astronomical Institute, Tohoku University, Sendai 980-8578 Japan*
[2] *Solar-Terrestrial Environment Lab., Nagoya University, Nagoya 464-8601 Japan*
[3] *Astronomical Data Analysis Center, National Astronomical Observatory, Japan*
[4] *Institute of Astronomy, University of Edinburgh, Royal Observatory, UK*
[5] *Department of Physics, University of Auckland, New Zealand*
[6] *Carter National Observatory, New Zealand*
[7] *School of Chemical and Physical Sciences, Victoria University, New Zealand*
[8] *Department of Physics and Astronomy, University of Canterbury, New Zealand*
[9] *Institute for Cosmic Ray Research, University of Tokyo, Japan*
[10] *VERA Project Office, National Astronomical Observatory, Japan*
[11] *Institute for Civilization, Tokai University, Japan*
[12] *Department of Physics, Kyoto University, Japan*
[13] *Nagano National College of Technology, Japan*
[14] *Tokyo Metropolitan College of Aeronautics, Japan*
[15] *Research Institute of Fundamental Physics, Kyoto University, Japan*
[16] *Department of Astrophysical Science, Princeton University, USA*
[17] *National Aeronautical Laboratory of Japan, Space Research Technology Center, Japan*
[18] *Department of Fundamental Astrometry, National Astronomical Observatory, Japan*

Abstract. More than 4000 stars observed in both MOA and DENIS projects showing periodic or quasi-periodic light curves are studied. Almost all Mira stars are located on the classical period-luminosity relation, and the multiplicity of the period-luminosity relation is confirmed for small-amplitude stars. The colour-magnitude diagrams based on the MOA red band, R_m, and K_S constructed for the sequences, form a single strip with small successive shifts.

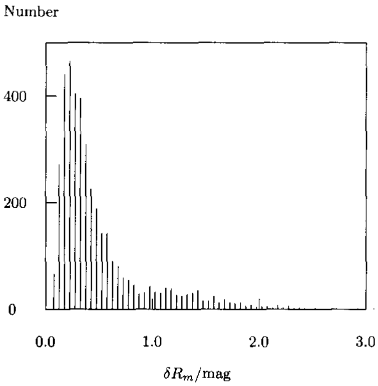

Figure 1. Frequency with the amplitude δR_m. The number of variable stars are indicated with the bin of 0.05 mag.

1. Introduction

Data on the LMC stars in the database obtained by the massive photometry carried out by the MOA collaboration, a group of Japanese and New Zealand scientists, have been analyzed to study the properties of red variables. Observations were carried out with a 61-cm reflector at the Mount John University Observatory in New Zealand from 1996 (Hearnshaw et al. 2000). In the recent series, we observed 4.4 million stars of 16 fields in the LMC together with stars of the SMC and the Galactic Bulge. For variable star study, the photometric images were analyzed using DOPHOT photometry software. The Phase Difference Minimization code was used to obtain the period and amplitude. Detailed comparison of the MOA database with the DENIS Catalogue toward the Magellanic Clouds was performed. The 2.3 years of data from 1998 August to 2001 January were investigated. We chose 4362 regular variables after excluding suspected eclipsing variables. Properties of these regular variables were reported in Noda & Takeuti (2003) and Noda et al. (2003).

2. Large- and small-amplitude components

Mira stars and semi-regular stars are defined by their amplitude: 1.0 mag in V is the threshold. Fig. 1 shows the distribution in R_m amplitude, where R_m is the brightness of the MOA red passband. The variables are divided into two groups according to their amplitude with the threshold of 0.9 mag. The small-amplitude stars are not Mira stars by the GCVS classification, and the majority are semi-regular variables (Lebzelter, Schultheis, & Melchior 2002). The distribution implies a stochastic origin for the stellar variability (Christensen-Dalsgaard, these proceedings). The large-amplitude stars are Mira stars. Such an amplitude-free distribution implies the intrinsic balance between excitation and damping, with the limit-cycle oscillation from overstability being given as another mechanism (Christensen-Dalsgaard, these proceedings).

3. Period-luminosity diagram

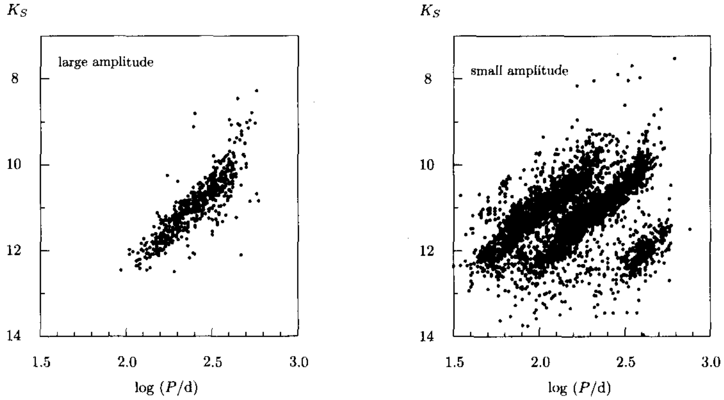

Figure 2. Period-luminosity ($\log P$, K_S) diagrams of the LMC red variables.

Fig. 2 (left) shows the period-luminosity (PL) diagram of the large-amplitude variables. Individual points must have a reasonable uncertainty in K_S because these are single-epoch K_S observations. Taking into account such an uncertainty, the large-amplitude stars are well located on the PL relation for the LMC oxygen-rich Miras presented by Feast et al. (1989). This sequence coincides with Sequence C labelled by Wood et al. (1999) in the study of the MACHO database. Several stars are found above the relation and faint stars similar to some Galactic Miras, such as χ Cyg (Bedding & Zijlstra 1998), are also found. These large-amplitude stars are AGB stars, because they are brighter than the tip of the red giant branch. The narrowness of the PL relation reveals the usefulness of this relation to measure the distance of galaxies (Noda & Takeuti 2003). The PL diagram of Mira stars of Cen A (Rejkuba 2003) shown by Feast (these proceedings) is very similar to ours.

Fig. 2 (right) shows the PL diagram of the small-amplitude variables. The strip structure found in the MACHO databases (Wood et al. 1999; Wood 2000) is clearly seen. The third strip from the right side, Sequence C, is superposed on the main strip of oxygen-rich Miras. The second strip from the right side, Sequence B, also includes many stars. A number of variables are found at the TRGB. The mean positions of two faint sequences, E and D, are fainter than AGB stars. The majority of regular variables are on Sequences B and C. The numbers of stars included in each sequence are 59, 1253, 1863, 286, and 99, from Sequence A to E respectively.

4. Properties of each sequence

The properties of each sequence were studied including their colour and the position in the LMC. The colour-magnitude diagram was studied using the colour $(R_m - K_S)$, so as to avoid the effect of chemical composition on the colour (Noda et al. 2002). 1) Sequence A is bluer and brighter than Sequence B which is bluer and brighter than Sequence C. Sequences D and E are located on the fainter extension of Sequence C. 2) Sequences A and B are found in bluer domain than Sequence C, and Sequence D is at the redder side. Sequence E extends from the fainter extension of Sequence C to the position of Sequence D. 3) Sequences A, B, and C concentrate towards the centre of the LMC, and Sequences D and E distribute more homogeneously.

Sequence D is likely to consist of pulsating red giant branch (RGB) stars because of their spatial distribution and their faintness. The majority of Sequence E stars will be also be pulsating RGB stars, but some of Sequence E stars may be Mira stars.

The difference in position on the colour-magnitude diagram found for Sequences A, B, and C suggests the enhancement of overtones. It must be plausible that the Sequence C is the lowest or fundamental mode, because it has the richest population and its members are the longest in the period. When we consider the ambiguity of the theoretical periods that come from the calculated linear periods and also the nonlinear effect on the period (see Barthes & Luri 2001), we suggest it is too early to decide on their modes. The period ratios of 1:2:4 among them implies to us the enhancement of harmonic modes. Since the plausible excitation mechanism of red variables is the coupling between convective circulation and pulsation, excitation may not be confined to a selected layer effective for overtone modes.

References

Barthes, D., Luri, X. 2001, A&A, 365, 519

Bedding, T.R., Zijlstra, A.A. 1998, ApJ, 506, L47

Feast, M.W., Glass, I.S., Whitelock, P.A., Catchpole, R.M. 1989, MNRAS, 241, 375

Hearnshaw, J.B., Bond, I.A., Rattenbury, N.J., et al. 2000, in ASP Conf. Ser. Vol. 203, The Impact of Large-scale Surveys on Pulsating Star Research, eds L. Szabados, & D.W. Kurtz (San Francisco: ASP), 203, 31

Hughes, S.M.C., Wood, P.R. 1990, AJ, 99, 784

Lebzelter, T., Schultheis, Melchior, A.L. 2002, A&A, 393, 573

Noda, S., Takeuti, M. 2003, in ASSL Vol. 283, Mass-losing Pulsating Stars and Their Circumstellar Matter, ed. Y. Nakada, M. Honma, & M. Seki (Dordrecht: Kluwer), 27

Noda, S., Takeuti, M., Abe, F., et al. 2002, MNRAS, 330, 137

Noda, S., Takeuti, M., Abe, F., et al. 2003, MNRAS, accepted

Rejkuba, M. 2003, A&A, submitted

Wood, P.R. 2000, PASA, 17, 18

Wood, P.R., Alcock, C., Allsman, R.A., et al. 1999, in IAU Symp. 191, Asymptotic Branch Stars, ed. T. Bertre, A. Lebre, & C. Waelkens (San Francisco: ASP), 151