RR Lyraes in the Magellanic Clouds

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Abstract

Recent work on the Magellanic Cloud RR Lyrae stars is reviewed. The absolute magnitudes of LMC RR Lyraes, when calibrated from a distance modulus of 18.5 mag, disagrees with the Galactic calibration. The revised distance scale makes distances greater, and ages younger, within our galaxy. Field star studies show that the "halo" population of the LMC is very similar to that of our own Galaxy outside of the solar circle. This result supports a Searle and Zinn model of galaxy formation.

1. Introduction

RR Lyraes in the Magellanic Clouds (MC) are important for a number of reasons. Perhaps the two most important are as follows: RR Lyraes are important standard candles, and via their calibration of the luminosity of the main-sequence turnoff of Galactic globular clusters, they allow ages to be determined for the oldest recognizable component of our Galaxy. The MC, in particular the LMC, is the best place for comparing the RR Lyrae luminosity calibration with those for other standard candles. Secondly, the field RR Lyraes map the distribution of the oldest MC population, and together with the oldest LMC clusters we can compare their properties with the halo stars and clusters of our own galaxy. This can give important clues as to how the Galaxy and the MC originally formed, and together with abundances and kinematics, can map out the chemical and dynamic evolution in the first few Gyr after formation.

In this review I concentrate on progress made since my review of the same subject at IAU Symposium No. 148 (Walker 1991).

2. RR Lyrae absolute magnitudes

RR Lyraes are known in seven LMC clusters (NGC 1466, 1786, 1835, 1841, 2210, 2257, and Reticulum). Walker (1992a) summarizes his CCD photometry for 182 variables in these clusters, from which mean magnitudes, metal abundances, and reddenings are derived. These results are summarized in Table 1, together with data from various studies of the field RR Lyraes. We tabulate (1) location of the field, (2) distance in degrees of the LMC clusters from the LMC center, from Suntzeff et al. (1992), (3) metallicity, except where noted, determined from the RR Lyraes themselves, (4) reddening, generally a mean of several methods, (5) number of RR Lyraes, (6) intensity mean V magnitude, (7) and (8) refer to the references and notes attached to the table. For NGC 1466, NGC 1841, and Reticulum color-magnitude

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Table 1.

Summary of the Photometry of Magellanic Cloud RR Lyrae Variables

Location (1)	Radius (2)	[Fe/H] (3)	E(B-V) (4)	N(RR) (5)	<V> (6)	Ref (7)	Notes (8)
LMC							
NGC 1466 cluster	8.4	-1.8	0.09	38	19.33	W5	
NGC 1786 cluster	2.5	-2.3	0.07	9	19.27	WM2	1
NGC 1835 cluster	1.4	-1.8	0.13	33	19.37	W6	
NGC 1841 cluster	14.9	-2.2	0.18	22	19.31	W3	
NGC 2210 cluster	4.4	-1.9	0.06	9	19.12	W1	
NGC 2210 cluster	4.4		0.08	10	19.19	HN	2,3
NGC 2257 cluster	8.4	-1.8	0.04	39	19.03	W2	
Reticulum cluster	11.4	-1.7	0.03	32	19.07	W4	
NGC 1466 field				3	19.5	K	4
NGC 1783 field		-1.6:	0.06:	73	19.2	G2	5
NGC 1841 field				2	19.35	K	4
NGC 2210 field		-1.8	0.08	52	19.26	HN	
NGC 2257 field			0.04	22	19.30	HNU	
NGC 2257 field		-1.8	0.04	9	19.20	W2	
Reticulum field				1	19.1	K	4
SMC							
NGC 121 cluster		-1.4:	0.04	4	19.59	WM1	6
NGC 121 field				75	19.6	G1	4
NGC 361 field		-1.5:	0.06	42	19.5	S	4,7

References: G1 = Graham (1975), G2 = Graham (1977), HN = Hazen and Nemec (1992) HNU = Hesser, Nemec and Ugarte (1976), K = Kinman et al. 1991, S = Smith et al 1992, W1 = Walker (1985), W2 = Walker (1989), W3 = Walker (1990), W4 = Walke (1992b), W5 = Walker (1992c), W6 = Walker (1992d), WM1 = Walker and Mack (1988a) WM2 = Walker and Mack (1988b).

Notes: (1) Suntzeff et al. (1992) tabulate [Fe/H] = -1.87 from spectroscopy o RGB stars. For all other clusters the RR Lyrae-derived [Fe/H] values agree wit those from spectroscopy of RGB stars to within 0.1 dex.
(2) V32 which has <B>=20.32 has not been included in the mean.
(3) Another 33 cluster variables have been discovered (Nemec and Hazen, in prep.
(4) <V> derived from <B>, not directly measured.
(5) G77 V magnitude scale found to be correct by Blanco and Blanco (1986), bu B requires a correction of -0.2 mag.
(6) [Fe/H] from Stryker, Da Costa and Mould (1985).
(7) Of the 42 stars, 22 have periods determined.

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diagrams extending to the main-sequence turnoff were prepared by combining several of the frames used for measuring the variables. All the clusters are metal poor, with mean $[Fe/H] = -1.9$. If a distance modulus of 18.5 mag for the LMC is assumed, then the RR Lyraes have mean $< M_V >= 0.45$. Since the old clusters which contain the RR Lyraes are fairly evenly distributed across the face of the LMC, correcting individual distances for some assumed LMC geometry has very little effect on the mean. Given that the LMC modulus quoted above is probably reliable to within 0.15 mag, the relatively bright absolute magnitude found for the RR Lyraes is not consistent with the galactic RR Lyrae calibration (from statistical parallaxes and Baade-Wesselink analyses) by some 0.3 mag., especially now that the slope of the RR Lyrae magnitude-metallicity relation is generally accepted to be in the range 0.15-0.20. Since the galactic RR Lyraes, via the globular clusters, are used to calibrate both distances and ages within our galaxy, the new LMC calibration will increase distances (eg R_0 of 8.5 kpc rather than 8.0 kpc) and reduce ages (the oldest globular clusters are now no more than 15 Gyr old, fitting VandenBerg and Bell (1985) isochrones to the main-sequence turnoff) within our Galaxy. Some support for this brighter calibration is provided by the LMC Mira variables, for which the zeropoint can be calibrated in the same way as for the RR Lyraes. These in turn calibrate the metal rich galactic globular clusters which happen to contain Mira variables. This calibration agrees with the new RR Lyrae calibration if the slope of the magnitude-metallicity relation is 0.17.

3. Field RR Lyraes in the LMC

Studies of field RR Lyraes in the LMC are in almost all cases based upon photographic surveys. For the more recent work the photometric calibrations are based on CCD sequences thus giving confidence that no gross systematic errors exist in the magnitude scales. In addition, much of the later work is based on CTIO 4m plates rather than 1.5m plates. The plate limit of the 1.5m telescope is such that the earlier surveys (eg Graham 1975, 1977) are seriously incomplete for RRc stars.

Hazen and Nemec (1992) have found 52 new field RR Lyraes near the LMC cluster NGC 2210. The mean period $< P_{ab} >= 0.576 \pm 0.057$ day lies between that of Oosterhof groups I and II in our galaxy, and is also similar to that found for LMC field RR Lyraes near the LMC clusters NGC 1783 and 2257. The mean metallicity is about $[Fe/H] = -1.8$, within the errors similar to the mean metallicity found for the old clusters. There is some evidence for a gradient in abundance between the (inner) NGC 1783 field, via the NGC 2210 field to the outer NGC 2257 field, based on mean periods and period-amplitude plots. Given that the NGC 1783 field results (Graham 1977) are seriously incomplete for low amplitude stars, this result must be treated with caution.

Kinman et al. (1991) found four new type-ab field RR Lyraes in the direction of NGC 1466, and a possible field variable near Reticulum. They then fitted exponential and King models to all available LMC field RRab results, and calculated a central surface density of about 200 stars per square degree. By associating each RR Lyrae

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(RRab and RRc) with a halo globular cluster population of absolute visual magnitude -4.74 (Suntzeff, Kinman and Kraft 1991), and assuming a mass-to-light ratio of 1.6, they found that the field halo stars make up about 2% of the mass of the LMC, a figure close to that for our Galaxy. In addition, they found that period-frequency distributions are similar for the LMC field variables and those in the outer halo of the Galaxy. Finally, the surface density ratio of the older long-period variables to RR Lyraes (old-disk to halo) is within a factor of two of that in our own Galaxy at the solar circle. All these results suggest that the efficiency of the first few Gyr of star formation in the Galaxy and the LMC was comparable.

4. New Field Star Surveys

Two new surveys which are discovering many more RR Lyraes are underway. That of N. Reid and W. Freedman uses U.K. Schmidt 6x6 degree plates analysed by COSMOS to search for variable stars in the LMC. Although many RR Lyrae variables are being found, follow-up CCD observations centered on some of the variables has resulted in the discovery of extra candidate RR Lyraes, showing that the COSMOS/UKST survey significantly underestimates the true RR Lyrae density. From their results it appears that earlier surveys also underestimate the density of RR Lyraes, perhaps by as much as a factor of two. A paper on the variables in a field centered on NGC 2210 is near completion.

H. Smith and collaborators are studying a 1x1.3 degree SMC field near NGC 361. Their work uses CTIO 1.5m plates taken by J. Graham, on which many short-period Cepheids and RR Lyraes have been discovered (Smith et al. 1992). The surface density of the RR Lyraes is comparable with that found for the outlying NGC 121 field by Graham (1975), showing that SMC RR Lyraes are not strongly centrally concentrated. In addition, the period-amplitude relation is much the same as found for the stars in the NGC 121 field. Further observations (in B and V) are scheduled using the CTIO Curtis-Schmidt telescope using a CCD as detector.

5. Population studies

Suntzeff et al. (1992) have made a critical comparison between the LMC Population II field stars and clusters, and those in our own Galaxy. They find that the mean cluster metallicity, the absolute magnitude distribution of the clusters, and the relative numbers of RR Lyraes per unit cluster luminosity are very similar to the Galactic globular cluster population outside of the solar circle. In addition, they calculate that the total luminosities in both clusters and field stars scale as the total luminosities of the LMC and Galaxy. They conclude that the evidence strongly supports the Searle and Zinn (1978) idea that the Galactic halo originated from LMC-sized units. Further evidence for the Searle and Zinn scenario comes from ages determined from HB (horizontal branch) type, $(B-R)/(B+V+R)$ where B, V and R are the numbers of blue HB stars, RR Lyraes and red HB stars respectively. Plots as a function of metallicity, with fiducials from HB models, for various subgroups of HB stars show that there is an age gradient within our Galaxy, with the Galactic Bulge population the oldest (Lee 1992). Using the same method, Walker (1992c) finds that in the mean the LMC clusters for which the HB type can be calculated are one Gyr younger than the Galactic globular clusters outside the solar circle.

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DISCUSSION

Y.-W. LEE: I think there are two reasons why you obtained a small LMC distance modulus from your RR Lyrae analyses, compared to that of 18.5 from the Cepheids: (1). Some LMC clusters have blue HB's, and hence evolutionary effects must be taken into account (0.1 mag.). (2). The slope of the magnitude-metallicty relation which you adopted is slightly small compared to that from my models and Baade-Wesselink measurements (0.19). At $[Fe/H] = -2.0$ this difference alone would create 0.1 mag difference. A combination of (1) and (2) would explain most of the difference you suggested.

A. R. WALKER: With regard to point (1), the Lee and Demarque (1990) HB evolutionary tracks show that HB stars evolving redwards from BHB stars spend only a small fraction of their HB lifetime within the instability strip. All the LMC clusters under consideration have rather more RR Lyraes and RHB stars than expected if these stars were all highly evolved. Thus in the mean, the expected increase in brightness for the RR Lyrae sample under consideration is expected to be small, certainly much less than 0.1 mag. See also the contribution by M. Catelan (this conference). For (2), the LMC clusters containing RR Lyraes have mean metallicity 0.7 dex more metal poor than the Galactic field RR Lyraes used in the statistical parallax analyses. Increasing the slope of the magnitude-metallicity relation by 0.04 is not going to make a significant difference to the discrepancy.

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