POPULATION II IN THE MILKY WAY GALAXY AND THE LMC

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Abstract.
The RR Lyrae and globular cluster populations are used to study the Pop II in the Galaxy and the LMC. The metallicity gradient in the Galaxy changes abruptly at the position of the solar circle. The statistics of field RR Lyraes imply that the Pop II field population is older towards the Galactic center. The density of RR Lyraes in the solar neighborhood implies a luminous mass density of $6.4 \pm 1.8 \times 10^{-5} M_{\odot}$ pc^{-3} for the Galactic halo. The total luminosities (M_V) for the Galactic and LMC halos are -18.4 and -15.1, and the ratio of globular cluster to luminous Pop II mass is 0.02 in both cases. The agreement of this ratio in two systems with very different tidal fields argues against the formation of the field population as the disruption of many smaller systems.

1. Introduction

Clues to the formation of galaxies lie in the characteristics of the oldest population of stars, traditionally called Population II after Baade. This ancient population remains today as a ghost-like remnant of the proto-galaxy, and through a study of the kinematics and chemistry of its constituent stars, we can gain insight into the initial conditions for galaxy formation.

The studies of the Pop II in the Galaxy rely primarily on two types of samples: *local* samples in the solar neighborhood; and *in situ* samples. Both samples suffer from the extreme low density of Pop II stars. A recent estimate for ratio of the density of young and old disk stars to Pop II stars is 1200 (Gilmore and Wyse 1985). The local sample technique gets around this problem by sampling stars based on proper motion and radial velocity data. This approach was pioneered by Eggen, Sandage, and collaborators (Eggen, *et al.* 1962), and Schmidt (1975), and later extended by Carney and collaborators (Carney and Latham 1987). The main disadvantage of this approach is the kinematical bias of the sample selection. For example, the sample of stars discovered by Morrison, Flynn, and Freeman (1990) which have low abundances but disk-like kinematics are selected against in local samples.

The *in situ* selection is hampered by the difficulty of picking out the Pop II objects from the tremendous number of local field stars. The globular cluster sample does not have this problem, but there are only a limited number of clusters ($\sim$ 120), and there is no guarantee that the stars in globular clusters have the same history as the field population. Indeed, there is evidence that in M87 the cluster and field spheroid populations are different (Strom, *et al.* 1981). Other evidence that the cluster stars are different than the halo field is the radial gradient in CN-band strength seen in 47 Tuc giants (Paltoglou 1990) and the paucity of field giants (at [Fe/H] $\sim$ -1.6) with strong CN bands (Langer, *et al.* 1991).

In order to select stars in the *in situ* samples, some property must be used to weed out the local disk stars. Various attempts to select out the Pop II sample have used metallicity indices based on zero-proper motion stars selected by color

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(Friel 1988), objective dispersion spectra (Ratnatunga and Freeman 1989, Preston, Shectman, and Beers 1991), and variable stars (Kinman 1965). These latter two approaches have their disadvantages also in that stars selected are biased in terms of metallicity.

In this short contribution, I will summarize the nature of the Pop II in the Galaxy and the LMC, using the RR Lyrae giants as probes of the density and metallicity. RR Lyraes are arguably the stellar constituent with the most precisely determined spatial densities of any class of stars. This is because the blue amplitudes for the fundamental pulsators (RRab) are typically 0.8 mag or greater, which is large enough that simple blink techniques can discover them. Whether a star at the red giant branch tip becomes an RR Lyrae is a poorly understood function of primarily age and metallicity, and also a host of other parameters. But by relying on the RR Lyraes in globular clusters, where the underlying stellar population is much better understood, we can convert the RR Lyrae number densities in the field into precise properties of the field stars in general.

2. The Galaxy

The metallicity and density distribution for the RR Lyraes discovered in the Lick Astrographic survey by Kinman are discussed in Suntzeff, Kinman, and Kraft (1991) (SKK). This sample of 171 stars, which includes the RR Lyraes discovered by Saha (1984), has [Fe/H] measured from ΔS , with an accuracy of $\sim$ 0.15 dex. The distribution is plotted as a function of galactocentric distance in Figure 1. One can see that there is both a real scatter of about 0.3 dex in [Fe/H] at any galactocentric distance, and that the abundance gradient changes abruptly at the solar circle. As discussed in SKK, the globular cluster abundance, when weighted by the total number of RR Lyraes in each cluster, shows the *same* average metallicity distribution over all galactocentric distances as the field stars.

We can convert the spatial distribution of field RR Lyraes into total *luminous* mass distribution by calculating the average number of RR Lyraes per unit luminosity in globular clusters and assuming the typical M/L for clusters is 2. In SKK, we calculate the average N_{RR} (the number of RR Lyraes in a cluster scaled to M_V=–7.5) at various radial bins, and use this to integrate the density distribution of field RR Lyraes from 1 to 35 kpc. The total Pop II luminosity, luminous mass outside of 1 kpc, and a summary of the cluster properties are given in Table 1. The local space density of RR Lyraes implies a luminous mass density of $6.4 \pm 1.8 \times 10^{-5} M_{\odot}$ pc^{-3} for the Pop II in the solar neighborhood.

3. The LMC

In Table 2 we list all the known Pop II clusters in the LMC, along with the metallicities from Olszewski, *et al.* (1991) and Suntzeff, *et al.* (1991). Kinman has estimated that the total number of field RRab stars is $\sim$ 10000. Using the average N_{RR}=12 (175 RR Lyraes in 9 clusters with ΣM_V=–10.4), we derive the total Pop II luminosity, luminous mass, and average Pop II cluster properties, which are listed in Table 1. The average properties of the two systems are quite similar, expect for the

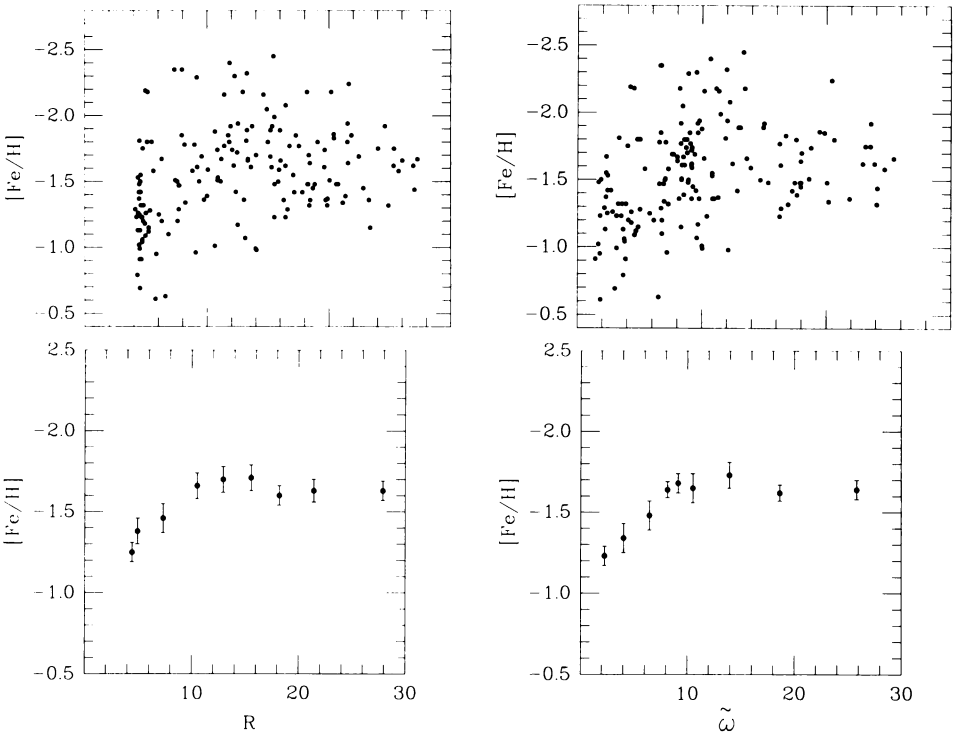

Fig. 1. The metallicity distribution of RR Lyraes in the Galactic halo plotted as a function of galactocentric distance (R) and galactocentric distance projected onto the Galactic plane ($\tilde{\omega}$). The upper panels show the individual values and the lower panels the averaged values in bins of 20. Note the abrupt change in the metallicity gradient at the solar position.

mean metallicities, which appear to reflect the trend seen in other galaxies that the more luminous galaxies have more metal-rich cluster systems.

The ratio of cluster to total Pop II mass is 0.02, which is the same as the Galaxy (SKK). It is unlikely that two galaxies, with such different tidal fields, would have the same ratio if the field stars were remnants of tidally disrupted clusters.

Finally, we note that Schommer, *et al.* (1991) have calculated that the dynamical mass of the LMC out to Reticulum is $\sim 1.3 \times 10^{10} M_{\odot}$. If we subtract off a disk mass (to 6°radius) of $\sim 3 \times 10^{9} M_{\odot}$ estimated from the exponential profile (Bothun and Thompson 1988), using the LMC luminous mass given in Table 1 we find that M(dynamical)/M(luminous) > 50. This indicates that a large amount of dark matter is present in the LMC, a result also reported by Schommer, *et al.* (1991) using the rotation curve fit to the outer clusters.

I would like to thank Dr. Tom Kinman for the communications of his results on the field RR Lyrae population in the LMC prior to publication. I also thank Bob Schommer and Ed Olszewski for a critical reading of this manuscript.

TABLE I

A comparison of the properties of the Population II in the Galaxy and the LMC

Globular Cluster	< M_v >	σ	N	< [Fe/H] >	σ	N_{RR}	M_v
Galaxy	-7.2	1.4	102	-1.57	0.30	10-18	-13.0
LMC	-7.8	0.8	13	-1.86	0.23	12	-10.9

Population II	Mass ($M_\odot$)	M_v	
Galaxy	4×10^9	-18.4	(1 < R < 35 kpc)
LMC	1.9×10^8	-15.1	

TABLE II

The LMC population II globular clusters

Cluster	Radius(°)	[Fe/H]	n(RR)	V	E(B–V)	M_v	N_{RR}
Hodge 11	4.7	-2.06	0	11.32	0.03	-7.18	0.0
NGC 1466	8.4	-2.17	38	10.69	0.03	-7.81	28.7
NGC 1754	2.6	-1.54	...	11.20	0.07	-7.4	...
NGC 1786	2.5	-1.87	9	10.49	0.07	-8.13	5.0
NGC 1835	1.4	-1.79	31	9.52	0.10	-9.20	6.5
NGC 1898	0.6	-1.37	...	10.90	0.03	-7.6	...
NGC 1916	0.2	-2.08	...	9.88	0.07	-8.74	...
NGC 2005	0.9	-1.92	...	10.20	0.07	-8.42	...
NGC 2019	1.3	-1.81	0	10.55	0.07	-8.07	0.0
NGC 2210	4.4	-1.97	12	10.36	0.07	-8.26	5.9
NGC 2257	8.4	-1.8	31	11.48	0.04	-7.05	47.0
NGC 1841	14.9	-2.11	22	10.98	0.18	-8.00	13.9
Reticulum	11.4	-1.71	29	12.40	0.03	-6.10	105.7

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M. Edmunds: Isn't it dangerous to try and deduce total "halo" masses (or perhaps "spheroid" might be a better term) from globular clusters or RR Lyraes, since they may only trace a metal-poor component? Particularly density distributions as a function of radius may be unreliable, if applied to the whole halo.

B. Carney: In a poster, Laird, Latham, and I note that in sample of stars in retrograde Galactic orbits, which ought to define a "pure" halo sample, there are near-solar metallicity stars, but they are so rare that corrections to halo mass densities derived using RR Lyraes and globular clusters are negligible.

R. Kurucz: There is another parameter that varies with radius: the stellar accretion and loss rate from clusters. It increases inward because the collision rate increases inward. Clusters nearer the center will accrete field stars with higher abundances so there will be an apparent shift in cluster abundance with radius.

N. Suntzeff: Accretion of field stars by globular clusters would imply intra-cluster metallicity variations which are not seen.

J. Nemec: Concerning your conclusion that there is a metallicity gradient in the Galactic halo, how can you be sure that the non-zero slope seen at small $\tilde{\omega}$ in your [Fe/H] – $\tilde{\omega}$ diagram is not due to "contamination" from the thick disk or old disk component?

B. Carney: I share Bernard Pagel's concern about using one parameter to define a population - both chemistry and kinematics, at least, are necessary. You noted, in fact, that both the halo and the thick disk produce RR Lyraes. So how do you know that in the inner Galaxy your mean metallicities of RR Lyraes aren't affected by mixing stars from different populations.

N. Suntzeff: We, in fact, have used a second parameter, the *position* of the star in the Galaxy, to define the population. The RR Lyraes are an *in situ* sample that are not contaminated by the thick disk simply because the search technique finds RR Lyraes in a given solid angle to a given limiting magnitude. The volume searched (a cone) contains a negligible amount of disk and thick disk volume compared to the volume searched in the halo.

Y.-W. Lee: There is now some evidence (see my paper in this volume) that the systematic variation in HB morphology with galactocentric distance continues to vary into the center of the Galaxy. This would imply that the bulge is indeed older than the halo by ~1.5 Gyr. Other possibilities, such as high Y or high core rotation rates in the bulge, can be ruled out from the observed period distributions of RR Lyrae stars.

T. Armandroff: I'd like to call your attention to a poster by Da Costa, Zinn and myself that re-examines the question of a metallicity gradient in the halo globulars. We have determined spectroscopic abundances for stars in the very distant globulars Pal 3, 4, and 14. We find no metallicity gradient in the outer halo (R $> R_{\odot}$). A weak gradient is present inside the solar circle.

E. Bica: We have recently enlarged the sample of LMC clusters with integrated UBV photometry, in a collaboration with colleagues from Cordoba and Porto Alegre (poster in this meeting). Many new SWB Class VII clusters were detected. In particular Hodge 7 is located in the same locus as Hodge 11 or NGC 2257 in the (U-B),(B-V) diagram. Have you checked Hodge 7 for RR Lyrae stars? It would be a good candidate.

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Map of the Milky Way at 1 micron produced by the DIRBE experiment on board the Cosmic Background Explorer satellite (COBE). The nuclear Bulge is clearly visible as a flattened central structure of about one kpc size.

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