RR LYRAE STARS AND NOVAE IN THE MAGELLANIC CLOUDS

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ABSTRACT

RR Lyrae variable stars and classical novae can be used very effectively for locating and studying the old stellar populations in the Magellanic Clouds. RR Lyrae stars are found in large numbers in both Clouds at about 19^m. Apart from the concentrated searches within Cloud clusters, intensive surveys for field variables have so far been made in four areas, each about 1° square. Novae have the advantage of being as bright as 10^m at maximum light. They can be detected with small telescopes and surveys have covered almost the entire area of each Cloud. Needs and prospects for future surveys are discussed. Both types of object are suitable for investigating the early chemical composition of the Clouds and its subsequent enrichment with heavy elements. Studies of the old populations in the Clouds are reinforcing the view that, while some stars in the Magellanic Clouds are as old as any in our Galaxy, the major bursts of star formation came along comparatively recently.

INTRODUCTION

The Magellanic Clouds are the closest independently evolving galaxies in which star formation is going on today. Stellar birth, evolution and decay have been proceeding for at least 10^{10} years with little or no interchange of matter with the Galaxy and it is through the study of the oldest stars that we can hope to obtain insight into the early history of these two systems. The two types of variable star which I am discussing here are by no means the only old stars in the Magellanic Clouds but they do have the advantage of being easy to identify and isolate for detailed study. They are both suitable for investigating the early chemical composition of the Clouds and the subsequent enrichment with heavy elements from evolving stars. Studies of the space distribution give us information about the early star formation in each system. Distance checks can also be made which are useful in that they derive from an older population than that most

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commonly used for calibration purposes.

RR LYRAE STARS

i) Surveys

RR Lyrae stars were first detected in the Magellanic Clouds by Thackeray (1951, 1958). As Thackeray (1974) pointed out in a later review "the impact of these discoveries was twofold. Firstly, it proved that the Clouds contain old populations as well as the conspicuous young Population I... Secondly, the fact that the variables appeared at 19th magnitude instead of the expected 17.5 confirmed Baade's 1952 revision of the distance scale." In the initial discovery in the Small Magellanic Cloud (SMC), 3 variables were found in the cluster NGC 121 and 3 in the surrounding field outside the cluster boundaries. RR Lyraes are faint, but, as highly evolved stars of low mass, they can be confidently assigned ages of the order of 10^{10} years. Their presence marks out the location of a very old stellar population.

Almost all searches to date have been centered on Magellanic Cloud clusters. This has been largely because sequences of known stellar magnitudes are preferentially found in such places but also because of the interest in studying variable stars within the clusters themselves. Following the initial discovery, Thackeray found variables in the Large Magellanic Cloud (LMC) cluster NGC 2257 (Alexander 1960). A large number of clusters in both Clouds have now been searched for RR Lyrae stars. The present situation is discussed by Graham and Nemec (this volume).

Surveys for field variables had to wait for the availability of wide photographic fields with large telescopes. (Graham 1975, 1977) took advantage of the $1° \times 1\overset{\circ}{.}5$ field of the CTIO 1.5m telescope to search intensively two fields, one around NGC 121 (SMC) and another around NGC 1783 (LMC). A total of 143 variables were found showing that RR Lyrae stars are indeed abundant in the Clouds. Photographic plates also exist for two similar fields, one between NGC 361 and NGC 362 (SMC) and the other, about NGC 1835 (LMC). So far these have been examined in only a cursory manner.

The main conclusions of the Graham studies were as follows:

1) The mean apparent magnitudes seem to cluster closely about a single value. In the LMC, the time averaged $<\overline{V}>$ and $<\overline{B}>$ are $19\overset{m}{.}2$ and $19\overset{m}{.}6$ while in the SMC $<\overline{V}>$ and $<\overline{B}>$ are $19\overset{m}{.}6$ and $20\overset{m}{.}0$.

2) ab type variables with large amplitudes and periods less than $0\overset{d}{.}45$ are rare or absent in both Clouds although such stars are relatively common in the solar neighborhood.

3) The space density in each field is about 15 RR Lyrae stars $(kpc)^{-3}$. It is greater than that found in the Galactic halo but of the same order as that found in the solar neighborhood.

4) A preliminary survey of the two additional fields revealed that there does not appear to be a strong concentration of RR Lyrae variables towards the central region of either Cloud. In the SMC, the RR Lyraes concentrate preferentially to the west of the main body of bright stars. A similar conclusion was drawn by Brück (1980) from faint stars counts of the old population in general.

5) There are differences between the RR Lyrae variables in each Cloud. The period distribution in the LMC resembles that found in high latitudes in the Galaxy. The period distribution in the SMC is more characteristic of the anomalous distributions found among dwarf spheroidal galaxies. The SMC also contains a small group of RR Lyraes which appear normal in all respects except that they have a mean apparent magnitude about $1\overset{m}{.}5$ brighter than the average value. In a similar LMC sample, no such variables are found.

Apart from the cluster searches described in the Graham-Nemec paper at this Symposium, intensive searches have been made in only two other fields to date, one around NGC 2257 (Hesser, Nemec & Ugarte 1980) and one around NGC 1841 (Kinman, Stryker and Hesser 1976). The latter was especially interesting as it turned up 3 normal RR Lyrae variables which lie in the general field beyond the tidal radii of both the LMC and SMC.

ii) Chemical Abundance Studies

An important study of some of the Cloud variables has been carried out by Butler, Demarque and Smith (1982). They found that RR Lyrae stars of ordinary luminosity in the LMC have $[^{Fe}/_{H}] = -1.4$ while those in the SMC have $[^{Fe}/_{H}] = -1.8$. The difference is only marginally significant but clearly demonstrates the presence of a metal poor component among the field stars of the Magellanic Clouds. Metal abundances were also determined for the overluminous SMC variables. These were found to have $[^{Fe}/_{H}] = -0.4$ and are much richer in metals than their fainter counterparts. Pulsation masses and evolutionary ages were also determined. Ages range from 2.5×10^{8} years for the overluminous stars to 14×10^{9} years for the ordinary RR Lyrae stars.

iii) Future Directions

RR Lyrae stars may be useful for mapping in depth, as well as in area, the distribution of the oldest populations in the Magellanic Clouds. Sandage (1981) has shown that, with high quality color and amplitude data, the absolute magnitude uncertainty may be reduced to the $0\overset{m}{.}1$ level thus making RR Lyraes a more precise distance calibrator than formerly thought. The advent of efficient, linear CCD detectors makes the determination of precise magnitudes and colors a far more straightforward process than with the older photographic techniques. Several observatories now have these operating on telescopes of small or moderate size.

To date, an unfortunate restriction of the surveys for RR Lyrae stars is that they have been limited to small areas of approximately one square degree. There is a great need for surveys to cover much larger areas in each Cloud and I am wondering if the time is perhaps right to be doing this with one on other of the big southern Schmidts in conjuction with automatic measuring machines. Certainly large numbers of measurements would need to be made and the key to success would be in processing the data to isolate the variable stars with RR Lyrae characteristics. Relative photometry only should be attempted at first with accurate photometry following later on carefully chosen samples.

There is hope for improvement of the basic absolute magnitude calibration for RR Lyrae stars. We depend at present on statistical parallaxes and are slowly accumulating data from the application of the Baade-Wesselink method to Galactic stars. Space astrometry should finally provide the definite zero points. Stothers (1983 preprint) has shown that a mean visual absolute magnitude $M_{<V>} = +0^{m}\!.6$ seems the best to use for now. With this value, the Graham photographic photometry gives apparent distance moduli of $18^{m}\!.6$ and $19^{m}\!.0$ for the LMC and the SMC. A correction for foreground interstellar absorption of $0^{m}\!.1 - 0^{m}\!.2$ should be taken into account to convert these values to distances. An overall uncertainty of $\pm 0^{m}\!.3$ is probably applicable. Let us hope that our efforts in the next 10 years can reduce this to no more than $\pm 0^{m}\!.1$.

NOVAE

i) Surveys

Novae have been recognized in the Magellanic Clouds since 1927 (Luyten 1927) but systematic searches have been carried out only sporadically. During their brief appearance, novae become the brightest members of the old stellar population of a galaxy. They are thought to result from post-main sequence evolution of close binary stars with components of a solar mass or less and are thus representative of a stellar population whose age is greater than 5×10^{9} years. Like RR Lyrae stars, they are good tracers of the distribution of old stars within a galaxy. The main disadvantage is that they are infrequent. (Graham 1979a) estimated a frequency of 2 or 3 novae per year in the LMC and 1 nova every 3 or 4 years in the SMC. A list of known novae is given in Table 1. 8 were discovered during a survey which was carried out between 1970 and 1979 at CTIO. Details of the observing technique were given by Graham and Araya (1971). The survey was discontinued in 1979 but we now plan to reinitiate it in a limited way during the 1983-1984 observing season. A watch is kept on the Magellanic Clouds by the University of Chile group which is conducting a systematic search for extragalactic supernovae. They found one nova in 1981 which was widely observed.

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TABLE I

Known Novae in the Magellanic Clouds

	Year	RA 1975	Dec	Centroids (1975)
SMC				
	1897	$0^h\ 59^m.1$	$-70°\ 23'$	
	1927	0 33.2	-73 24	
	1951	0 34.3	-73 06	$0^h\ 40^m.7$ $-72°\ 58'$
	1952	0 47.6	-73 39	
	1974	0 25.0	-74 10	
LMC				
	1926	5 14.9	-66 51	
	1936	5 07.4	-66 41	
	1937	5 57.2	-68 55	
	1948	5 38.6	-70 22	
	1951	5 13.0	-70 00	
	1968	5 10.4	-71 42	
	1970a	5 33.5	-70 36	
	1970b	5 36.0	-70 48	$5^h\ 25^m.0$ $-69°\ 05'$
	1971a	4 58.4	-68 08	
	1971b	5 40.6	-66 41	
	1972	5 28.8	-68 50	
	1973	5 15.5	-69 41	
	1977a	6 05.9	-68 38	
	1977b	5 05.4	-70 11	
	1978	5 05.8	-65 55	
	1981	5 32.4	-70 23	

ii) Novae as Distance Indicators

For many years it has been known that there is a tight relation between absolute visual magnitude at maximum and the rate of decline of novae. They can thus be used as good indicators of distance. The Galactic calibration is based on a comparison between the observed angular expansion of the nova shell and its radial velocity. For useful distances, good photometric coverage of a nova through maximum is essential. In the Magellanic Clouds, data of this quality is available for only two novae, both in the LMC (Ardeberg and de Groot 1973, Canterna and Schwartz 1977). Absorption corrected distance moduli of $18^m.5$ and $18^m.6$ were derived from these two studies with uncertainties of about $\pm 0^m.2$.

iii) Distributions

Figure 1 shows the surface distribution of the 5 novae known in the SMC. The numbers are small but it may be significant that, like other old populations, the known novae group preferentially on the west side of the SMC outside the main bar. In the LMC, with 16 novae now known, the statistics are better. Figure 2 shows the distribution. The most significant feature is the lack of concentration towards the crowded bar. This is not a selection effect. With the overlaps in the survey, the bar region was searched 4 times more frequently than the rest of the LMC. Figure 2 shows that the centroid of the LMC novae is significantly north of the bar and close to the center of rotation determined by Feitzinger (1980).

iv) Spectroscopy

Detailed spectroscopic observations of two novae by Canterna and Thompson (1981) and by Andrillat and Dennefeld (1983) confirm that LMC novae are basically similar to those known in our Galaxy. Subtle differences may exist. Andrillat and Dennefeld remark that, the weakness of the [O I] and [O II] lines in the 1981 LMC nova may indicate low oxygen abundance in the LMC. They point out that this interpretation may not necessarily be correct because of the wide variety of spectra one sees in novae and there is clearly a need for more examples to be studied. With systematic surveys, occasionally low dispersion spectra are obtained before maximum light. This happened with the 1978 LMC nova for which a pre-discovery objective prism plate was taken when the nova was about 5 magnitudes below maximum. (Graham 1979b). The spectrum of LMC nova 1970b is described by Havlen, West and Westerlund (1971).

v) Novae as a Source of Element Enrichment

Williams (1982) has pointed out that novae may be important contributors to the nitrogen content of galaxies. Chemical abundance analyses of old nova shells in the Galaxy have demonstrated marked enrichments of nitrogen in their envelopes. This, when combined with the known frequency of nova outbursts, suggests that novae may exceed planetary nebulae and Wolf-Rayet stars in enriching the interstellar medium with nitrogen. He suggests the possibility of checking this scheme by making abundance studies of novae and old novae shells in the Magellanic Clouds. It is a difficult job but just possible with large telescopes and currently available detectors.

EARLY STELLAR EVOLUTION IN THE MAGELLANIC CLOUDS

RR Lyrae stars and novae share the characteristic of only slight increases in surface density towards the crowded central regions of the Large and Small Magellanic Clouds. In this way, they differ from their Milky Way analogs which show strong concentrations towards the center of the Galaxy. These distributions imply that the numerous

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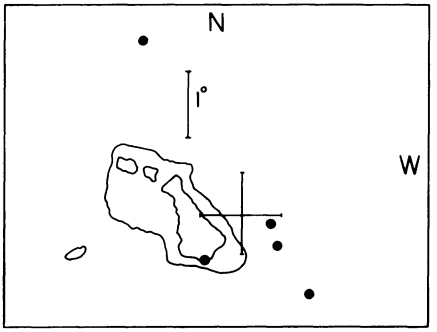

Fig. 1: Distribution of Novae in the SMC. The vertical cross marks the centroid and its extent indicates the standard error of the mean value.

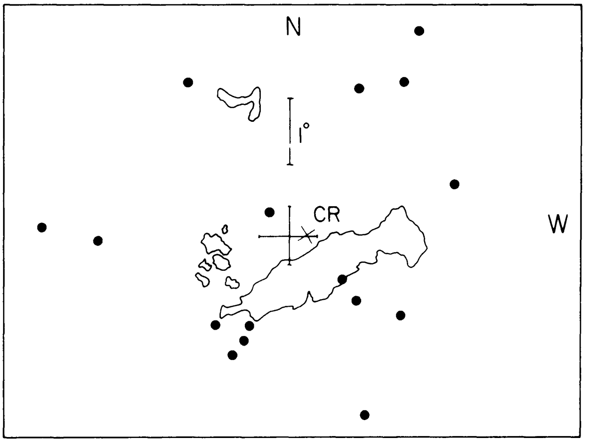

Fig. 2: Distribution of Novae in the LMC. The vertical cross marks the centroid and its extent indicates the standard error of the mean value. The diagonal cross shows the center of rotation used by Feitzinger (1980).

low mass stars in the two Magellanic Cloud bars are not sufficiently old yet to become RR Lyrae stars and novae. We cannot give an answer to the question as to whether the oldest stars in the Magellanic Clouds structurally form disk or halo-type systems. With increased samples (especially for the RR Lyrae stars) and improved calibrations, the answer could be obtained in a straightforward manner. Use of globular clusters (Freeman, Illingworth and Oemler 1983) has shown promise but is basically limited by the small number of globular clusters and the difficulty of isolating the few very old globular clusters from the large number with intermediate ages.

Oort (1971) drew attention to the fact that galaxies like the Clouds have no strong, dominating central mass concentration. The distribution of the old stellar populations seems to confirm that no major gravitational collapse with a contemporaneous major burst of star formation occurred in the early history of either Cloud. Star formation has been, in the long term, a more gradual affair. Butler et al. (1982) concluded that the SMC only now is reaching the degree of chemical enrichment which the Galaxy attained 10^{10} years ago. R.E. Williams (private communication) has pointed out another constraint. By making an account of probable abundance enhancement rates from novae, planetary nebulae and Wolf-Rayet stars, and then comparing this with the present day abundances of the interstellar medium (Cloud H II regions), he notes that the present rates cannot have occurred for longer than about 3×10^9 years. In several ways, studies of the old populations in the Clouds are leading us to accept that, while some stars in the Magellanic Clouds are as old as any in our Galaxy, the major bursts of star formation came along comparatively recently.

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DISCUSSION

Mould: After correction for an extinction of $A_V = 0.2$ from the Cepheid studies and $M_V = +0.6$, which may be an underestimate for Galactic RR Lyraes, one obtains from your $<V>$ a true distance modulus of 18.4 for the LMC, which seems to support the short distance scale of Eggen and de Vaucouleurs, rather than the 18.73 we heard earlier today. Globular cluster main sequences also seem better fitted with such a short modulus. Is there a discrepancy between the Cepheids and the RR Lyraes?

Graham: I think $A_V = 0.2$ may be a bit high, but probably the greatest uncertainty is the photometry itself. New photometry for a small sample with a CCD detector would be a very useful check. The overall uncertainty of the MC distance moduli is still about 0.2 mag.

Fall: The kinematic study of globular clusters by Freeman, Illingworth, and Oemler suggests that there may never have been a "halo" phase in the history of the LMC. In this context, the kinematics of the RR Lyrae variables would be of great interest. If they are in a disk, the velocity dispersion should be about 20 km/s or less, whereas, if they are in a spheroid, the velocity dispersion should be about 40 km/s or more. Thus, it may be possible to decide between these alternatives with only a few radial velocities.

Graham: Yes, indeed, and this should now be possible with currently available techniques.

Renzini: Let me warn the observers that one should not take for granted that if a MC globular contains RR Lyraes then its age should be virtually identical to that of Galactic globulars. Indeed, a cluster can maintain a population of RR Lyraes for some 3 to 5 Gyr, and, even more important, there is no reason to believe that the [CNO/Fe] ratio in old MC globulars is the same as in Galactic globulars. For instance, if [CNO/Fe] $\simeq$ 0 in MC old globulars, while [CNO/Fe] $\simeq$ 0.5 to 0.7 in the Galactic globulars, then the former can be several billion years younger than the latter ones, in spite of them containing RR Lyraes.

Graham: On the whole I think this unlikely for field stars in view of the radically different distributions of the RR Lyraes and intermediate age stars like carbon stars. Presumably we will be able to check it for the MC globular clusters when good color-magnitude diagrams become available.