CARBON AND LATE TYPE M STARS AS POPULATION INDICATORS

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The discovery of different ratios of carbon (C-type) to oxygen stars (M type) in the direction of the central regions of our own and the nearest galaxies, the Large and Small Magellanic Clouds, is the result of surveys made by Blanco, Blanco and Hoag (unpublished) who observed Baade's Window near NGC 6522 in the direction of our Galaxy's nuclear bulge and by Blanco, Blanco and McCarthy (in press) who observed selected regions in the center of the Large and Small Magellanic Clouds. We have observed each of these central regions with a combination of a grating and prism set in the converging beam of the prime focus of the CTIO 4 meter telescope (Hoag 1976). We used Eastman IV-N plates hypersensitized with silver nitrate solution; the spectral plates were exposed through a Wratten 89 filter for 60 min. We limited our spectral survey to M type stars later then M5 and to the carbon stars, using the criteria of Nassau and colleagues (1949). Thus far no S type stars have been discerned in central regions of the LMC or SMC at the dispersion used (2300 Å/mm).

The results for Baade's Window, a region 0.12 sq degree in area near NGC 6522 ($\alpha=18^h02^m$, $\delta=-30^\circ\!.0$) are shown in Fig. 1. We note near $m_c=12^m\!.6$ a maximum in the frequency of M stars found; this value combined with an adopted distance modulus from the work of Oort and Plaut (1975) of $15^m\!.4$ leads to a mean infrared absolute magnitude

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M_i, of $-2^m\!.8$. With an assumed intrinsic (V-I) color of $+3^m\!.6$ this corresponds to a mean visual absolute magnitude for the M giants in the nuclear bulge region of approximately $+1^m\!.0$. There is only one C star observed in this region.

In Fig. 2 we present the counts according to m_i of late type stars for 3 central regions in the LMC. Each of these regions are 0.12 sq. deg. in area. They include the optical center ($\alpha=5^h24^m\!.5$, $\delta=-59^\circ\!.8$), the radio center ($\alpha=5^h20^m\!.2$, $\delta=-68^\circ\!.9$) and a region we have denoted Bar-west ($\alpha=5^h08^m\!.9$, $\delta=-68^\circ\!.9$) studied also by Tifft and Snell (1971). In the LMC the observed maximum frequency of late M stars occurs near $m_i=14^m\!.1$. Thus with an assumed distance modulus of $18^m\!.6$ we find a mean infrared absolute mag. $M_i=-4^m\!.6$ and a corresponding $M=-1^m\!.0$. This confirms the earlier findings by Blanco and McCarthy (1975) who used a thin-prism with the Curtis Schmidt at CTIO in a study of late type M stars. The more abundant carbon stars also show a maximum near $m_i=14^m\!.0$ in central regions of the LMC.

In Fig. 3 we display counts of late type stars grouped in magnitude intervals for the two SMC areas at $\alpha=0^h49^m\!.5$, $\delta=-73^\circ\!.4$ and at $\alpha=1^h00^m\!.0$, $\delta=-73^m\!.2$. Four late M stars were discovered in these regions, too few for a meaningful discussion of their mean absolute magnitudes. The 135 C stars show a maximum concentration near $m_i=14^m\!.4$.

One of the surprising results of this study is the apparent difference in the mean absolute magnitude derived for M giants in the nuclear bulge of our Galaxy ($M_V=+1^m\!.0$) and in the direction of the central regions of the LMC ($M_V=-1^m\!.0$). We note obvious uncertainties in the mean (V-I) colors of late type M stars. The results shown by Clube and Dawe (1978) at this Symposium point up the possibilities of revisions in the distance modulus to the Clouds and galactic center. Nonetheless the difference of 2 magnitudes in mean visual absolute magnitudes of late M stars in the two galaxies is striking.

Perhaps more puzzling in the present observations of late type stars is the difference in the three galaxies of the ratios of the two different kinds of cool stars discussed here: the carbon and late type M stars. Outstanding is the almost complete absence of carbon stars in the nuclear bulge of the Galaxy and the corresponding lack of late type M stars in the central regions of the Small Magellanic Cloud, with a 2:1 ratio of carbon to late M stars in the cool population of the Large Cloud. Parallels with population indices concerning an ordering in terms of decreasing metallicity are most attractive. Studies by Gascoigne (1969), Payne-Gaposchkin(1971), Sanduleak, MacConnell and Hoover (1972), Oort (1971), Graham (1974) and Hagen and van den Bergh (1974) have pointed out differences between the LMC, SMC and the Galaxy.

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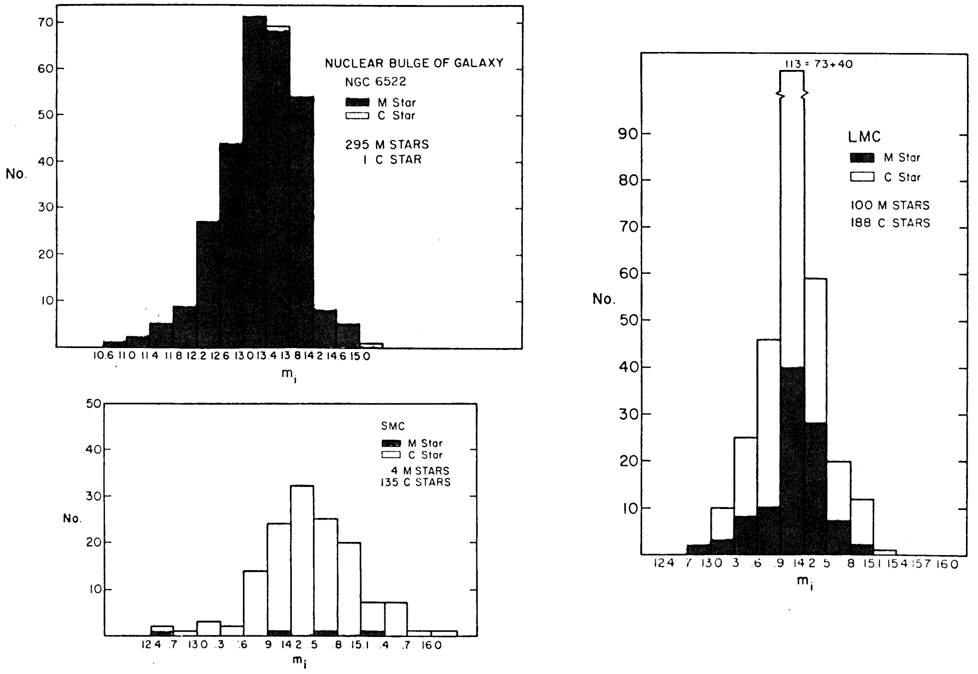

Figs. 1-3. Number of late type giants. 1, Nuclear bulge of the Galaxy; 2, Central region of LMC; and 3, Central region of SMC.

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DISCUSSION

BIDELMAN: Strictly speaking, carbon stars are defined by the presence of C_2 bands. What you have found are stars showing strong infrared bands of CN, which may or may not be the same thing. There are other types of objects that show strong infrared CN.

McCARTHY: Our findings are based on low dispersion combination prism-grating plates. Certainly higher dispersion spectra are required and multicolor photometry will be of great value. Our survey reaches to $m_i = 18\overset{m}{.}5$ and to a visual mag near 21^m During our observations we have secured besides the spectral plates enough direct plates to allow positional measures and magnitude determinations for charting and identification. We don't have enough plate material for precision photometry or for variable star work. When charts are published all observations will be welcomed.

PEERY: Do you know what types of carbon stars you are observing, e.g., variability characteristics such as long-period variability, or irregular variable carbon stars?

McCARTHY: At present we have a list of 280 carbon stars plus positional data (derived by Mrs. B. Blanco) and magnitude data. Our collection of direct plates is not extensive, but we can now compare our list with existing catalogues and data books for stars in the clouds. These correlations are an important next step and all suggestions of colleagues will be most welcomed.

PEL: I would like to make a radio-astronomical remark. Although radio astronomy is generally of little use in the study of the HR diagram, there is one possibility that not all stellar astronomers may be aware of: the 18-cm, OH maser-emission from long-period variables. The radio-sensitivities are good enough to observe such masers throughout the whole Galaxy, and maybe also in the Magellanic Clouds. It seems that OH-maser M stars are always oxygen-rich, and never carbon-rich. Furthermore, there are very interesting indications of correlations of the radio properties with stellar properties such as the period. I would like to urge the optical astronomers to put more effort into the identification and study of the known radio masers at optical and infrared wavelengths, and I would like to suggest that radio astronomers, particularly at Parkes, search carefully for OH masers in globular clusters and in the Magellanic Clouds.

McCARTHY: Thank you for this suggestion. It should prove most helpful and once our charts and positional and photometric data are published could be most effective in verifying and explaining our findings.

SCHLESINGER: Do you have any information on space densities? The reason for asking is that some of your results, in particular, the increase in ratio of C/M stars going from the Galaxy to the Small Cloud, could be connected with the trend in metal abundance, decreasing from the Galaxy to the Small Cloud. When heavy element abundance goes down the Hayashi track is shifted to the blue. So some stars that would appear at M5-M9 in the Galaxy would not get as red in the clouds, but would be shifted to earlier spectral types

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and not be caught in your survey. The change in ratio of C stars to M stars could then be a change in the number of M stars.

McCARTHY: Preliminary calculations by Blanco of the space density for the late M stars observed in the direction of the galactic nuclear bulge leads to about 35 stars per 10^6 pc^3 which is roughly 250 times the density observed for these stars in the solar neighborhood. The first magnitude estimates for the C and M stars in the LMC and SMC are just completed and so we can soon derive ratios for these.

Our position in giving now these first results has been to communicate our new findings as soon as they were reasonably ordered. We have tried to be aware of similarities with other studies of the Clouds and the Galaxy. We acknowledge the need of stellar models for late type giant stars and have deliberately avoided adopting a position regarding the history or evolution of these objects.

van den BERGH: These are very exciting results! One might think that the observed variations in N(C)/N(M) are due to changes in [Fe/H]. But probably life is more complicated that this because metal-poor clusters in the Clouds contain carbon stars at the tips of their red giant branches whereas not a single galactic globular is known to contain such stars. This indicates that N(C)/N(M) probably correlates with another parameter. It would be particularly important to find N(C)/N(M) in the galactic anti-center direction in which [Fe/H] is also thought to be low.

McCARTHY: I agree completely on the importance of studies in the direction of the anti-center and note that two Hoag grisms (with different dispersions and blazes) are now available for use at the KPNO 4 meter. Blanco, Hoag and I did not make any hypotheses in undertaking this study and were surprised at the C star anomaly and the marked difference in the absolute magnitude of M stars in the direction of galactic nucleus and in the center of the LMC.

LLOYD EVANS: Variable star surveys of the SMC carried out with the 74-inch telescope at Pretoria show that stars with the colors of carbon stars and in the magnitude range $16<V<18^m$ are mostly variable. The distribution of their periods is very similar to that of semi-regular carbon stars in the Galaxy.

McCARTHY: A most important desideratum will be the intercomparison of our C and M stars with known lists of variables. I shall be most anxious now that our positions have been determined to compare our lists with yours. We know that the domain of variable stars has been the most well explored in the Clouds and we have a legacy which extends from Pickering and Leavitt to the Gaposchkins and you and your colleagues from Pretoria. Confrontation of results should be fun.

WALBORN: The question is, what is this very interesting result telling us? I think it would be very difficult to understand the C to M ratio you find in the SMC in terms of the evolutionary interpretation given to these types in the Galaxy. I wonder if the result may be related to the decreasing metallicity from the galactic center through the LMC to the SMC. (1) If your SMC C stars correspond to the evolutionary state of Galactic C stars, where are the SMC M stars? If the first red giant phase for metal-deficient stars occurs at higher temperatures, as suggested by Dr. Schlesinger, then your red survey may be missing them in the SMC. (2) On the other hand, one can consider the possibility that your SMC "C" stars correspond to galactic M giants in an evolutionary sense. It would be interesting to have detailed spectral syntheses for cool, very metal-deficient giants, to see what the strongest spectral features in this wavelength range should be. (Dr. van den Bergh has pointed out to me that the validity of this suggestion could be easily checked with knowledge of the colors of your stars.)

McCARTHY: The results of our observations are, I believe, telling us two things: (1) The LMC M giants with mean $m_i = 14^m_.0$ and a distance modulus of $18^m_.6$ have an $M_i = -4^m_.6$ corresponding to $M_V = -1^m_.0$, similar to the usual absolute magnitude found for the solar neighborhood. The nuclear bulge M giants with a mean $m_i = 12^m_.6$ have a mean $M_i = -2^m_.8$ corresponding to $M_V = +0^m_.8$. We assume here a mean (V-I) color equal to $+3^m_.6$ and are surprised at the apparently marked luminosity difference for M giants in the LMC and in the galactic nucleus.

(2) If we order the 3 galaxies according to decreasing metallicity as indicated by the Gaposchkins, Graham and others we would list the galactic nuclear bulge, then the LMC central region and finally (the weakest in metallicity) the SMC. This reflects the same ordering in the ratio of the number of C stars to the number of late M type stars but in a reversed sense; i.e. almost no C stars are seen in the nuclear bulge where M giants abound; C stars outnumber M stars 2:1 in the LMC central areas; in the SMC practically no M stars are found and C stars are most frequent in occurence.

As is pointed out in the printed text the argument pointing to decreasing metallicity has analogues to the findings by C.P. Gaposchkin, Thackeray, M. Burbidge, S. Gascoigne and others, who emphasize the polarity of the SMC and the Galaxy with the LMC in an intermediate state.

We need now, more than ever, models for stars in this part of the HR diagram. Carbon stars remain an astrophysical enigma.

Our magnitude work is for identification purposes. We have red and infrared plates and have established that these are red stars.

HUMPHREYS: Many red stars observed in an unpublished objective-prism survey by Blanco which covers the entire LMC have been confirmed to be M supergiants. These luminous red stars are normal when compared to the supergiants in our Galaxy. Although the stars discussed by McCarthy are giants, at least the more luminous M stars do not show any evidence for differences in their properties when compared to the same stars in our Galaxy.

McCARTHY: Blanco's earlier survey is based on 4° objective prism Curtis Schmidt plates. Our thin prism work together in 1974 was also done with the Curtis Schmidt at CTIO (Nature, Dec. 1975). Blanco's first survey has many supergiants and not the giants detected in the thin prism survey or in the current study. Walter Baade once advised

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