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Carbon stars in the halo of the Magellanic Clouds: Identification and radial velocity data*

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Abstract. We present the current status of our ongoing cool carbon star survey in the halo of the Magellanic Clouds. Candidate cool carbon stars were identified from APM measures of pairs of UK Schmidt Telescope B_J and R survey plates. Intermediate resolution spectroscopy on the duPont Telescope, Las Campanas, was used to simultaneously verify the nature of the candidates, late M-type giants or AGB carbon stars, and to derive their radial velocity. Coordinates, finding charts and radial velocity data for 392 spectroscopically identified cool carbon stars distributed out to angular distances of 10 degrees from the Cloud optical centres are given. Radial velocities were also obtained for 133 known carbon stars in the Large Magellanic Cloud, in the inter-Cloud region, in the wing of the Small Magellanic Cloud and in a few SMC star clusters. These intermediate-age carbon stars define ideal kinematic test particles to investigate recent dynamical interactions between the Galaxy-LMC-SMC system and in particular the origin of the morphological disturbances seen in the SMC and parts of the LMC, the origin of the Magellanic Stream and the total mass of the LMC.

Key words: galaxies: Magellanic Clouds — stars: carbon — technique: radial velocities

1. Introduction

Characteristic timescales for galaxy-galaxy interactions are much shorter than a Hubble time and therefore interactions between galaxies are of vital importance for their evolution. We are fortunate in having a pair of Magellanic galaxies so close to a large spiral like our Galaxy, since the LMC-SMC-Galaxy system provides us with an ideal chance to make a detailed study of galaxy interactions and system evolution. As the Magellanic Clouds are also the only galaxies near our own with significant amounts of gas, there will also be interactions with any outer halo gaseous component of our Galaxy (cf. possible origins and development of the Magellanic Stream, Murai & Fujimoto 1980; Wayte 1991). It is also quite feasible that the distribution and the origin of at least some of the Galactic dwarf spheroidal satellites and outer halo globular clusters are intimately linked with the development of the Magellanic System (e.g. Lynden-Bell 1976; Kunkel & Demers 1976)

However, before we can fully understand these outer halo stellar systems or even the star formation, chemical evolution and kinematics internal to the LMC and SMC, we need to have a thorough understanding of the global dynamics of the Magellanic System. An essential step towards achieving this is to investigate the kinematics of a representative sample of LMC-SMC members. Throughout the last twenty years, our two nearest neighbours have been surveyed to identify numerous types of stars, of which cool AGB carbon stars are just one example. These intermediate age, extremely red giants, are a few to several Gyr old and represent the age of the majority of the stellar population of the Magellanic Clouds, making them excellent probes of the dynamics of the bulk motion of the Cloud stellar populations. Furthermore, AGB carbon stars are found not only in the inner regions of the Magellanic Clouds, but also in their "disks" and outer halos. Demers et al. (1993 - hereafter DIK) demonstrated that intermediate age AGB carbon stars can be found out to an angular distance of 10 degrees from the centre of the LMC and that they can be readily identified from sky survey photographic plates.

Previous large area surveys for Cloud carbon stars (e.g. Westerlund et al. 1978; Blanco et al. 1980; Blanco & McCarthy 1990; Rebeirot et al. 1993) have, with the exception of the SMC survey of Morgan & Hatzidimitriou

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* Tables 2 to 18 are only available in electronic form at the CDS via anonymous ftp to 130.79.128.5 or at http://cdsweb.u-strasbg.fr/Abstract.html The finding charts are available electronically via http://www.ed-phys.fr

(1995), searched areas close to the centre of the these galaxies but have neglected the low density periphery of the Clouds. These outer regions are vital to the study of the interaction dynamics of the LMC-SMC-Galaxy system. The ∼100 square degree survey by DIK in the inter-Cloud bridge region was our first attempt to remedy this situation. Feast & Whitelock (1994) obtained JHK infrared photometry of the stars listed by DIK and concluded that they were similar in age (1 to a few Gyr), colour and magnitude to stars in intermediate age clusters in the Clouds, confirming that these field carbon stars do indeed represent the intermediate age bulk population of the Clouds.

Our current survey is essentially an extension of the DIK work making full use of available UK Schmidt Telescope (UKST) sky survey plates. An example of a typical colour-magnitude diagram (CMD), that can be constructed from UKST $B_{\rm J}$ and R survey quality material, is shown in Fig. 4 of Irwin et al. (1990). These passbands are particularly good for an AGB carbon survey because the colour at the tip of the giant branch $B_{\rm J} - R \gtrsim 2.4$, equivalent to $B - V \gtrsim 2$, lies redward of Galactic foreground contamination or any other possible population. Apart from photometric errors throwing a small number, $< 10\%$, of Galactic stars into the sample, virtually all the selected candidates are either late-M giants in the Clouds or cool AGB carbon stars. M-dwarfs in the solar neighbourhood have colours barely bluer that the quoted limit above. Dwarf stars made up about one third of the non-carbon stars found. The carbon star candidates, identified from their red colour, were then spectroscopically confirmed. During the course of the survey nearly one thousand spectra were obtained. They are of sufficiently good quality to derive accurate radial velocities (± 5 km/s) for a large number (> 500) of carbon stars. Radial velocities for these intermediate-age carbon stars (and for the Cloud late-type M giants) define ideal kinematic test particles to investigate recent dynamical interactions between the Galaxy-LMC-SMC system and in particular the origin of the morphological disturbances seen in the SMC and parts of the LMC, the origin of the Magellanic Stream and the total mass of the LMC. These will be the subject of future papers; in the remainder of this paper we briefly describe the survey rationale and present coordinates, finding charts and radial velocities for the carbon stars observed.

2. Observations

2.1. Photographic survey

The newly identified carbon stars, presented here, were found by estimating the magnitudes of stars present on IIIaJ and IIIaF UK Schmidt sky survey plates. The plates were measured using the APM facility (Kibblewhite et al. 1984) and the image lists for each pair were combined to produce a catalogue of magnitudes and $B_{\rm J} - R$ colours for each field. The instrumental magnitudes were internally mapped to a "linear" magnitude scale using the technique described by Bunclark & Irwin (1983). These instrumental magnitudes were then transformed into R and $B_{\rm IIIaJ}$ by making use of the known properties of the foreground Galactic stellar population and the presence (in most fields) of a well defined red horizontal branch/clump due to the Cloud population. We have successfully used this so-called "internal calibration" technique on many occasions where no standards are directly available for calibration, see for example Irwin et al. (1990). This method of calibration is reliable at the $0.1 - 0.2$ magnitude level and is more than adequate for selecting candidate carbon stars from the broad swathe of AGB stars easily visible in most fields (see for example Fig. 4 of Irwin et al. 1990). For two of the fields surveyed in DIK we had of the order of 100 calibration stars available per field which provided an independent check of this methodology and colour transformation equations given below.

To facilitate comparison with other carbon star surveys, it is possible to define a transformation from the R, $B_{\rm J}$ system to the B, V system using simple equations such as the ones given by Demers & Irwin (1991):

$$B - V = 0.75(B_{\rm J} - R)$$

$$V - R = 0.55(B - V),$$

Candidate Cloud carbon stars were selected from stars with $B_{\rm J} - R$ redder than $\sim$ 2.4, and bounded by $14 < R < 17$ with the exact colour boundary varying by ± 0.1 from field to field in order to minimise the likely foreground contamination. A $B_{\rm J} - R$ colour of 2.4 corresponds to $B - V = 1.85$, i.e. equivalent to selecting spectral types later than about M 5.

The UKST fields surveyed up to the end of 1994/95 season are listed in Table 1. The F number refers to the ESO/SERC atlas field descriptors. The last three fields do not coincide with ESO/SERC field centres, and are the fields from the DIK pilot study. Figure 1 shows the location of the carbon stars identified in the fields of Table 1, together with the plate boundaries. Particularly toward the inner parts of the LMC/SMC not all of the candidates were followed up, since we were mainly interested in obtaining good spatial coverage around the Clouds rather than an exhaustive list of carbon stars. However, that caveat notwithstanding, all candidates in the periphery regions were followed up since we wanted as a byproduct of the survey to find the extent of the intermediate age population of the Clouds. The WORC and LMC stars, given in Tables 16 and 17, are not plotted. These stars are much closer to the LMC centre.

2.2. The spectroscopic observations

On all but three out of 23 nights between August 18th, 1991 and January 5th, 1995 slit spectra were obtained with

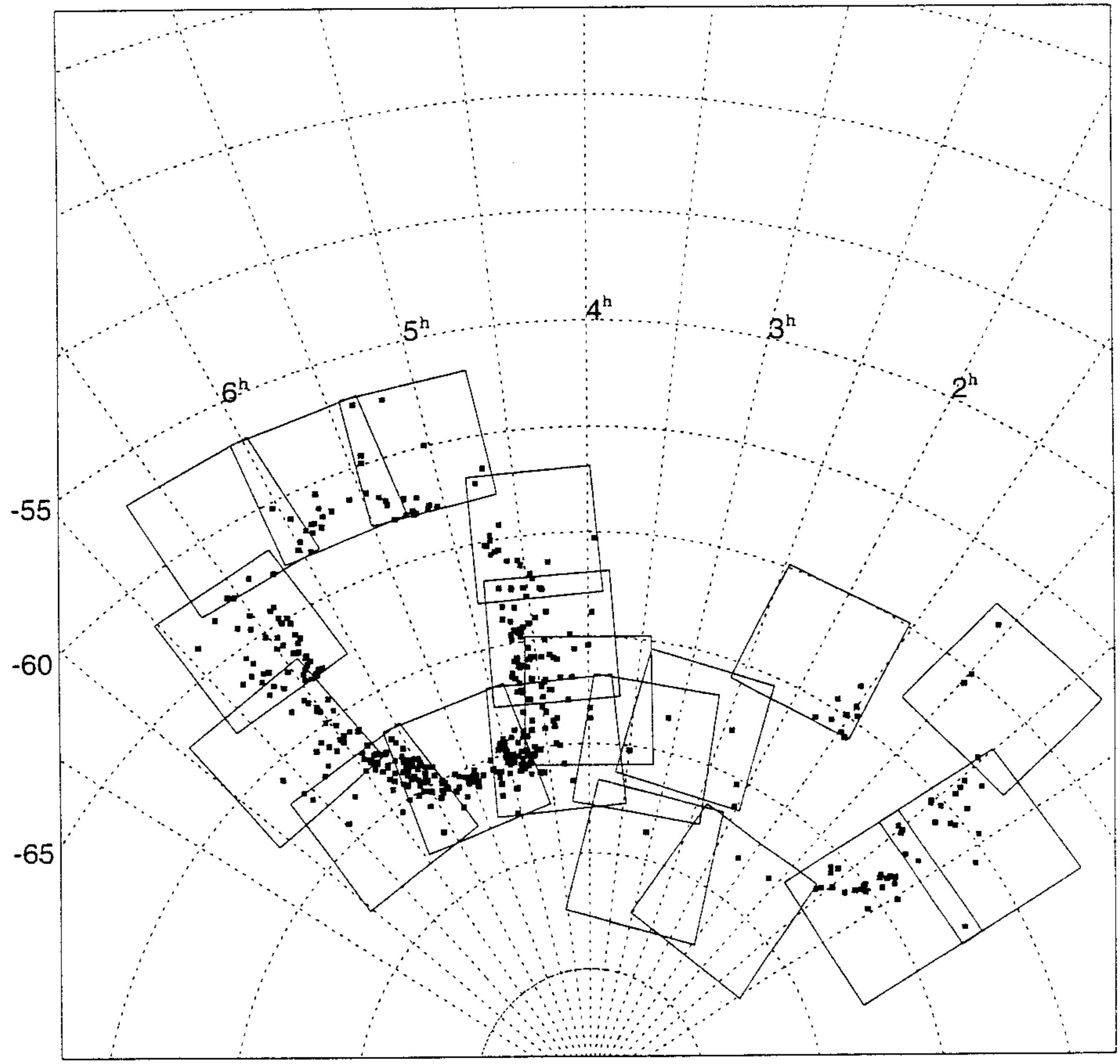

Fig. 1. Distribution of the newly identified carbon stars. Candidates were selected to have colours $B_{\rm J} - R > 2.4$ and $14 < R < 17$ and were spectroscopically confirmed as Cloud carbon stars. Toward the inner parts of both the SMC and LMC not all candidates were followed up

the MODular spectrograph (MODspec) on the duPont 2.5 m telescope. A Boller and Chivens spectrograph was briefly used early in January 1992 but abandoned after showing a lesser throughput. With a 831/7500 grating MODspec covered the range $7500 < \lambda < 9259$ Å at a resolution of 2.8 Å FWHM with a CRAF 1024×1024 thick CCD sporting 12 μm pixels, and 0.66 arcsec per pixel spacing along the slit. Trials at higher dispersions with a lower efficiency 1200/7500 grating were abandoned after two nights, to maintain the higher discovery rate. Slit widths of one arc-second were used throughout the survey. Exposure times varied between 120 s and 1200 s, with 60 percent taken at 180 s. The longest exposures were reserved for a class of carbon stars showing only weak CN bands, identified by the symbol "wk C" in the tables. It is quite likely that many of these wk C stars could be late-type M giants rather than carbon stars, although spectra of much longer integration times would be required to unambiguously assign types. We have left these objects in the tables because of the uncertainty of their nature and

Table 1. UK Schmidt fields surveyed

Field	RA (1950)	Dec
F013	1^h30^m	$-80°00'$
F014	3^h00^m	$-80°00'$
F028	2^h48^m	$-73°36'$
F031	3^h18^m	$-75°00'$
F032	4^h24^m	$-75°00'$
F033	5^h30^m	$-75°00'$
F034	6^h36^m	$-76°00'$
F050	0^h00^m	$-70°00'$
F055	4^h20^m	$-70°00'$
F058	6^h56^m	$-70°00'$
F079	0^h44^m	$-65°00'$
F084	4^h24^m	$-65°00'$
F087	6^h36^m	$-65°00'$
F119	5^h04^m	$-60°00'$
F120	5^h42^m	$-60°00'$
F121	6^h20^m	$-60°00'$
IDK 1	2^h48^m	$-73°36'$
IDK 2	4^h00^m	$-73°00'$
IDK 3	2^h00^m	$-68°00'$

because their velocities indicate that the majority have a high probability of being Cloud members and hence provide additional useful kinematic constraints.

Although HD 16115 was the only template star observed, a set of ten program stars was observed on most of the nights as a means of controlling the internal velocity system. Six of these are in common with the work of Hardy et al. (1989) and with Blanco et al. (1980), and another four (DIK 01, DIK 02, DIK 03 and DIK 08) from the Inter Cloud Region (ICR). Fe-Ar lamp spectra were obtained with every stellar spectrum. In the course of the survey a number of additional stars were reobserved for a variety of motives. Some stars showed unexpected velocities, occasionally more than 50 km s^{-1} different from the expected values. Such stars were observed three times, to permit discarding velocity variables or bad measurements. Other repeat observations occurred fortuitously, as candidates appearing on more than one search list. Table 19 summarizes data statistics of stars observed four or more times, including the ten internal velocity controls. The table shows that two of the "control" stars in common with Hardy et al. (1989) and Blanco et al. (1980) are velocity variables: Wing-4 (Blanco 13) and Wing-5 (Blanco 26). 75 stars were observed at least three times, and almost half were observed twice. In all, 1340 pair comparisons allowed setting velocity offsets for any given night to within 1.8 km s^{-1} of the adopted mean for the entire data set. The heliocentric velocity (v) system of our data differs from that of Hardy et al. (1989) in the sense: $v(\mathrm{Hardy}) - v(\mathrm{thispaper}) = 7.2 \pm 2.0$ km s^{-1}. Eliminating the two velocity variables from the list reduces the difference to 6.2 ± 2.6 km s^{-1}.

Radial velocities were determined using a cross-correlation technique adapted to the heterogeneous nature of the data (containing a mix of various carbon types) and to the presence of telluric features contaminating portions of the spectral range. Early trials relied exclusively on the CN bands at 7910, 8100, and at 8320 Å. Later trials led to partly masking the 8100 and 8320 Å CN bands, and adding a spectral region centered on the Ca triplet (from 8480 to 8700 Å), thereby avoiding telluric contamination and adding metallic lines useful with spectra with weak CN features. These windows were given a trapezoidal shape to minimise the effects of accidental contributions from window edges ("ringing" in FFT jargon). The windows finally adopted for the work here reported cover from 7780 to 8128 Å and Fe, Ti, and Ca lines from 8138 to 8690 Å. Prior to correlation the data were high-pass filtered with an Ormsby zero phase shift filter that begins attenuating features longer than 30 Å, completely suppressing those longer than 60 Å. The mix of carbon types encountered produced correlation functions containing odd terms so that the method of Tonry & Davis (1979) no longer yields reliable error estimates. The presence of the odd terms is seen in an asymmetry of the correlation function about the zero-lag peak; its origin in the data (as opposed to noise) is indicated by its systematic repetition in well-exposed spectra of certain stars, and has led to an independent method for estimating observational errors, described below.

It is well known that exposure levels yielding good cross-correlation functions are often inadequately exposed to permit assigning spectral types from visual inspection. That has proved to be true in the data set here described. Observations of stars from the list of Westerlund et al. (1978) and re-observed by them later (Westerlund et al. 1991) proved mostly to be of spectral types C3 through C5. A class of stars was encountered in which the CN bands, though present, were quite weak, requiring stronger exposures to produce satisfactory correlation plots. After the early preliminary reductions it is simple to assign classification to the carbon type by looking for common features in the cross-correlation function.

2.3. The Q parameter

When ordered according to the strength of exposure, the growth of the zero-lag peak in the correlation function (normalised to unity for a correlation of the template with itself) was found to provide a reliable estimator for sequentially classifying spectra according the precision with which velocities can be measured, as shown from repeated observations. Figure 2 shows a sequence of correlation functions (cf. Tonry & Davis 1979) in order of increasing strength (roughly) of the correlation peak with respect to sidebands lying within 600 km s^{-1} on either side. The weakest spectra, assigned $Q = 0$, do not permit identifying a zero-lag peak. $Q = 1$ was assigned when a zero-lag peak could be identified, but sidebands were of nearly comparable height, or the width of the zero-lag peak was significantly broadened. $Q = 2$ was assigned when zero-lag peaks were as narrow as high quality spectra, and the two strongest sidebands lying within 600 km s^{-1} summed to more than the zero-lag peak. $Q = 3$ was assigned when the sum of these two sidebands was less than the zero-lag peak. The assignment of higher Q-values was somewhat subjective, and relied on the orderly appearance of sidebands, none with maxima greater than half the zero-lag peak. Correlation functions with Q's of 5, 6 or 7 had high zero-lag peak values > 0.3, and side-band patterns whose structure tended to repeat in other spectra; the aforementioned asymmetries. From repeat observations spectra with Q-values of 4 or greater give full precision; spectra with Q-values of 3 give useful velocities when combined with at least one additional observation of comparable quality. Q's of 2 were used to plan follow-up observations later in the program.

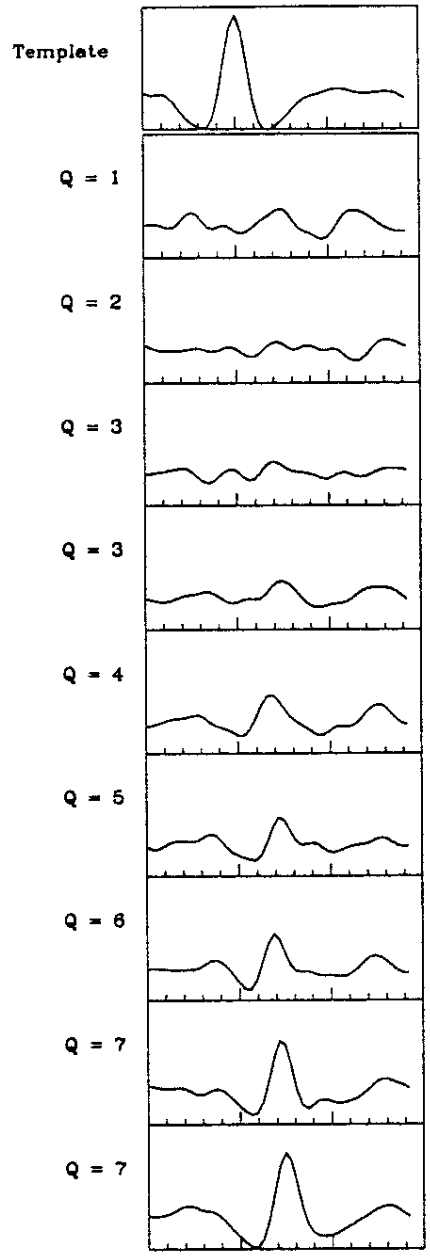

Fig. 2. Sequence of correlation functions used to assign the quality of the radial velocities. Ordinates are normalised with respect to the zero-lag peak of the template spectrum cross-correlated with itself (top panel). The small tick marks on the abscissa denote intervals of 100 km/s

2.4. Completeness of the survey

The colour boundary used is targetted at finding cool carbon stars near the tip of the AGB and is specifically aimed at selecting a uniform sample of an intermediate age population. A colour of $B_J - R = 2.4$ corresponds to $B - V = 1.8$ to 1.9 and guarantees a very clean sample of Cloud stars free from significant Galactic foreground contamination. Clearly, it will not generally be sensitive to the bluer CH-type Carbon stars, which are themselves readily detectable in conventional IIIaJ prism surveys due to the strong C_2 bands blueward of the emulsion cutoff (e.g. Morgan & Hatzidimitriou 1995). Our sample is only incomplete within a degree or so of the inward limits of the survey where the number of candidates is much larger than could be observed, (e.g. fields F033, F055, F084). In such cases two search modes were adopted, with time divided roughly evenly between them. One mode was to work inwards, beginning on the periphery of the LMC and working toward the rotation center. The other approach was to start with the reddest objects in the list, and work blueward. Both methods still allow the formulating of conclusions based on the sampling statistics, which will be the subject of a later paper. However, apart from the preceding caveat we note that since all the carbon stars in our sample are cool AGB stars, because of the uniform colour limits (i.e. $B_J - R > 2.4$) imposed, they form part of a well defined survey for intermediate age cool stars.

There is considerable overlap between the processed regions from the different survey fields and we used these overlap regions to estimate the completeness of the survey for those parts of the Clouds where we have followed up all the candidates. The probability that a candidate found on one plate is also found on the overlapping area of a second plate varies from 67 percent to 90 percent, the mean being 85 percent. This efficiency shows a slight dependence on crowding.

There are three main reasons why the candidate selection will not be 100 percent complete. First, the degree of image crowding, particularly toward the inner parts of both Clouds, can be severe on long exposure UKST survey plates where the typical FWHM of stellar images is between 2 and 3 arcsec. This causes a varying fraction of the images to overlap neighbouring images making it difficult to both detect them as discrete entities and to estimate reliable magnitudes. In order to keep the number of candidates to a minimum we required images to be classified by the APM as stellar on the R plate and to be approximately stellar on the B_J plates (i.e. not obviously overlapped with neighbours). This produces a much cleaner CMD with significantly fewer outliers at the expense of losing between 5 and 20 percent (depending on the image crowding) of the real outliers. Second, the image classifier is statistical in nature and at the magnitudes of interest can misclassify up to 5 percent of the images due to faint overlapping images, spurious grain noise etc.. Finally, photographic plates suffer both from systematic, or field, errors at the $\pm$ 10 percent level, and random photometric errors ($5-10\%$) level. Of necessity this causes the colour selection, and to a lesser extent the magnitude, boundary to be somewhat "fuzzy" with respect to true colours (and magnitudes). Taken together these artefacts of selection from photographic survey material imply that we will miss between 10 and 25 percent of the true outliers in a CMD and are consistent with the number of carbon stars found in common in the overlapping regions between different fields.

In practice the estimate from the overlaping zones tends to be pessimistic because these outer regions are precisely the zones of the plate where the worst systematic effects occur and because with the benefit of the overlap between fields, at least 25 percent of the area is surveyed more than once. Consequently, our best estimate of the likely completeness of the survey is $\approx$ 80 percent.

Statistics on the "success rate" of the whole selection procedure are not straightforward to estimate because of several effects. Firstly, the fields where the AGB tip was most clearly populated, and hence defined, were precisely those fields where not all candidates were followed up. Secondly, the accuracy of the photometry, particularly the percentage of spurious outliers, depends strongly on the degree of crowding in the field. Thirdly, and related to the first two points, the ratio of the surface density of Galactic stars to Cloud stars varies strongly from field to field. Finally, the spectra were never intended to be of good enough quality to differentiate reliably between M dwarf Galactic foreground stars and M giants in either Galaxy or Clouds. However, in those fields for which we have completely sampled the candidates we can define three categories of object: Cloud carbon stars; M giants with the Cloud velocity and a miscellaneous category of leftovers. The latter category includes: otherwise bluer objects thrown into the sample by photometric errors; indeterminate spectra and M stars with velocities seemingly incompatible with Cloud membership. (Distant cool Galactic carbon stars are so rare that they are not a problem). For these completely surveyed fields, the breakdown for detecting carbon stars was $\approx 60\%$; Cloud M stars / wk C stars $\approx 20\%$; and the remainder $\approx 20\%$. The high success rate at finding bona-fide Cloud carbon stars rather than Cloud M giants is skewed by the higher proportion of LMC population surveyed, where the C star to M star ratio is much higher than for the SMC.

3. Description of the carbon stars found

The results of our program are presented in seventeen tables. We regroup stars of each ESO/SERC field into one table, these are Tables 2 to 14, with the exception of Table 2 where a few fields with very few carbon stars are regrouped. Star names are based on their 1950 equatorial coordinates. The format of the tables is essentially the same. The table columns give: name of star, name from our candidate list which includes the field number, equatorial coordinates, galactic coordinates, the average measured radial velocity, the radial velocity corrected for the solar motion, we use (9, 12, 7) for the solar motion and we adopt a $V_{\odot} = 225$ km s^{-1}; the quality parameter Q; the number of spectra obtained; magnitudes and colours and comments. The comment "wk" means weak carbon features, the best example being the star C0511$-$7647, although as noted earlier it is quite lkely that many of these objects are late-type M giants belonging to the Clouds rather than carbon stars.

Finding charts for the carbon stars listed in Tables 2 to 14 are available, as Postscript files, from demers@astro.umontreal.ca.

The inter-Cloud carbon stars, listed in Table 15, have been identified by Demers et al. (1993); here we list the published V magnitudes and $B-V$ colours. This table includes also a few stars from the list of Hardy et al. (1989). These stars are included in order to facilitate the comparison of their radial velocity zero point with ours. The WORC stars, given in Table 16, are taken from Westerlund et al. (1978) we have for them only an R magnitude. The LMC stars listed in Table 17 have been identified by Blanco et al. (1980) in this case, I magnitudes and $R-I$ colours are given. Finally, in Table 18 we list six carbon stars located in four star clusters of the SMC.

4. Discussion

Although uniform surveys are the most useful from the point of view of studying stellar populations, our main concern in this work was to find a series of reliable kinematic probes to investigate the complex dynamical interaction history of the Clouds; determine the mass and velocity structure of the LMC; and to investigate tidal disturbances around the outer halo of the Clouds - subjects for future papers. The magnitude and colour selection limits imposed have produced a sample of cool AGB carbon stars which are ideal probes to investigate the kinematics and spatial extent of the dominant intermediate age Cloud populations. Since all candidates in the outer halos were observed, the spatial extent of cool AGB Cloud carbon stars is well defined (cf. Fig. 1). Toward the central parts of the LMC and SMC there were too many candidates to follow up all of them. In these cases we selected subsets simply to give a dense enough sample to answer the dynamical questions above.

The complex interaction history of the Magellanic Clouds–Galaxy system poses interesting challenges to kinematic surveys. Relic signatures of previous interactions are expected to produce subtle spatially systematic and random velocity feature, at levels that require velocity probes with precision around 5 km/s. All radial velocity surveys are to some extent plagued by the same problems that contrive to make this target difficult to attain. For example: random errors from poor signal:to:noise spectra give unreliable individual velocity measures; atmospheric disturbances cause short timescale velocity variability; binary stars cause much longer timescale variability; different reference templates give different systematic offsets; alternative reduction methods often yield different results; spectra taken at different epochs exhibit peculiar systematics; and so on. Our survey is no exception and we have investigated these concerns in several ways described in Sect. 2 and summarised below.

Random errors are relatively easy to deal with and can be characterised by sufficient repeat measurements, as in Table 19. Velocity variability turned out to be more of problem than we had anticipated, with 10% and possibly as high as 20% of the sample showing evidence for both atmospheric variation and longer timescale variations indicative of of a substantial binary fraction. Long term monitoring will be necessary to address this issue further. The variable fraction is not dissimilar to the results found in many studies of velocity dispersion of giant branch members of Galactic dwarf spheroidal systems (e.g. Hargreaves et al. 1994 and references therein).

Systematic effects are much harder to quantify and we expended a considerable amount of effort to both minimise and characterise them. In the end we opted to use a single reference template for all reductions. Primarily this was possible because most of the carbon stars are of similar spectral type due to the colour selection imposed. They have compatible absorption line features (particuarly the CN bands) and the spectral rectification, prior to cross correlation, removes any "continuum" variations. Consequently a single template is adquate to determine velocities to 5 km/s for all the carbon stars analysed. Although only one RV template was used the **internal** systematic errors were minimised to the level of 2 km/s through repeat observations and pairwise matching of 75 stars. A comparison with Hardy's radial velocities showed an external systematic offset of 6 km/s, consistent with our estimates of the velocity errors.

Most of the weighting in the cross-correlation template comes from the CN bands which are strongly present in all the carbon star types in our sample apart from the Wk C/ M stars. This mitigates against template-induced systmatic effects. Tests involving splitting the template into different wavelength portions, e.g. using only the CaII triplet - clearly present in most objects - and comparing derived velocties with respect to CN-only templates, leads to systematic differences of order $2 - 3$ km/s. It is not clear how much of these small systematic shifts are due to the template, to the reduction algorithm, or to subtle atmospheric disturbances in the stars. However, since the measured systematic changes are well below 5 km/s and the random errors from repeatability measurements are of order 5 km/s we feel justified in describing the average accuracy of our measurements as 5 km/s. The question of systematic velocity differences between varying carbon star type motivated the inclusion in our spectroscopy of the large number of WORC, Blanco et al. (1980), and Hardy et al. (1989) stars. We have carried out many further tests (colour cuts, line strength cuts etc.) to look for systematic differences between perceived velocity structure for the different carbon star samples/types. Although these tests are necessarily of a coarser nature and might

Table 19. Velocity repeatibility for LMC/SMC periphery carbon stars

Name	n	$v_{\rm gc}$ km/s	σ km/s	remarks
F032-11	4	33.2	4.8	
F032-29	4	18.1	3.8	
F032-44	4	28.0	5.1	
F034-104	5	73.0	4.0	
F034-117	4	87.5	6.1	
F058-47	4	40.0	10.0	variable
F087-126	4	112.7	9.7	all Q's= 7; variable
F120-07	4	107.5	7.4	
DIK 51	4	–44.0	2.1	
DIK 46	4	44.0	7.5	
DIK 52	4	–36.8	5.3	
DIK 01	19	–16.8	5.3	
DIK 02	18	–34.8	6.0	
DIK 03	18	26.8	7.4	
DIK 08	20	–24.5	3.7	
DIK 10	6	–18.8	2.3	
DIK 13	5	65.8	7.2	
DIK 15	4	8.8	2.5	
DIK 16	4	17.9	1.6	
Wing-1	12	4.9	9.0	variable?
Wing-2	9	–20.4	4.6	$t <$Jan. 94: Note 1
	5	–5.3	4.7	$t >$Dec. 94: Note 1
Wing-3	15	5.9	4.2	
Wing-4	6	29.8	13.7	variable
Wing-5	7	9.6	11.0	variable
Wing-6	11	–7.1	6.9	

Note 1: Velocity variation monotonic over four year interval; duplicity is indicated.

involve real kinematic population differences in no cases have we seen any evidence for significant trends.

A search of the literature to confirm the radial velocities of the globular clusters (Table 18) has been nearly fruitless. There are available quite a lot of data on the LMC clusters but very few radial velocities have been published for the neglected SMC clusters. We found three radial velocities for NGC 121: two observed by Hesser et al. (1986) and one by Zinn & West (1984) and a fourth one quoted by Cohen (1983). The weighted mean of these values is 144 ± 20 km s^{-1}. This velocity is compatible with our velocity but Suntzeff et al. (1986) have published the radial velocity of one star presumed to be in NGC 121, its velocity of 126 km s^{-1} is far from our estimate. Zinn & West (1984) have also published the radial velocity of NGC 419, their value 181 ± 20 agrees well with our two radial velocities.

Morgan & Hatzidimitriou (1995) have recently published the results of a survey for carbon stars in and around the SMC, selected using visual inspection of UKST IIIaJ objective prism plates. Several of their fields overlap our survey region and hence provide an external check on our carbon star selection criteria, subject to a few caveats. For the area in common to both surveys 39 of our stars were also identified by Morgan and Hatzidimitriou. Half a dozen were not. Most of these ones are wkC stars which may be late-type M giants as we explained in 2.2. This is one of several likely reasons for these differences but the main two are: firstly our colour boundary is specific to finding cool carbon stars near the AGB tip with a $B_{\rm J} - R$ colour > 2.4. The reddest carbon stars in our sample are fainter than 19th magnitude on a IIIaJ objective prism plate and if visible at all, would appear as no more than a short stubby red object indistinguishable from late-type M stars. Secondly, our colour criteria will not in general be sensitive to CH-type Carbon stars, which are themselves readily detectable in IIIaJ prism surveys due to the strong C_2 bands blueward of the emulsion cutoff. We are therefore not surprised that the prism survey finds objects not in our sample and vice versa, that some of our redder and fainter carbon stars are not in the prism sample. Thirty nine stars are not enough to make a good comparison, when our survey will cover a larger area around the SMC a better comparison will be possible.

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