Carbon stars in the Local Group

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Abstract. This is the unofficial proceeding of my invited review at the Ringberg Castle Workshop on "The Chemical Evolution of Dwarf Galaxies", July 28th - August 2nd, 2002, and presents an update of a similar review I gave in 1999.

The current status of carbon stars in the Local Group and beyond, is discussed. Although many carbon stars and late M-stars have been identified in Local Group galaxies, a coherent understanding in terms of the chemical evolution- and star formation history of a galaxy is still largely lacking. Although a few major new surveys have been carried out over the last three years, the observational data is still incomplete in many respects: 1) for some of the larger galaxies only a small fraction in area has been surveyed so far, 2) surveys have been conducted using different techniques, and some of the older surveys are incomplete in bolometric magnitude, 3) only for some galaxies is there information about the late M-star population, or it is sometimes unpublished even when the data is available, 4) not all galaxies in the Local Group have been surveyed, 5) especially for some of the older work insufficient data is available to determine bolometric magnitudes. I have correlated carbon star positions with the 2MASS 2nd incremental data release to obtain JHK, and bolometric magnitudes, to remedy this situation in some cases.

From the existing observations one can derive the following: the formation of carbon stars is both a function of metallicity and star-formation history. In galaxies with a similar star formation history, there will be relatively more carbon stars formed in the system with the lower metallicity. On the other hand, the scarcity of AGB type carbon stars in some galaxies with the lowest metallicity indicates that these systems have had a low, if any, star-formation over the last few Gyrs.

1. Introduction

Carbon stars are tracers of the intermediate age population in galaxies. Either they are currently undergoing third dredge-up on the (Thermal-Pulsing) Asymptotic Giant Branch (TP-AGB) – the cool and luminous N-type carbon stars –, or have been enriched with carbon-rich material in a binary system when the present-day white dwarf was on the AGB (the carbon dwarfs and CH-stars. The R-stars may be the result of a coalescing binary [McClure 1997]).

Since their spectral signature is very different from oxygen-rich and S-type stars, it is relatively easy to identify carbon stars even at large distances. In Sect. 2 the main technique to identify carbon stars is briefly discussed, and in Sect. 3 the various surveys for carbon stars in external galaxies are summarised. That section is in fact, an update of a review I gave at IAU Symposium 191 (Groenewegen 1999; hereafter G99), and here I will only refer to new results published since then, or older literature when I use it to obtain new results. Please refer to G99, and the similar review by Azzopardi (1999) for the full story. The results and some recent theoretical predictions are discussed in Sect. 4.

2. Methods

This has been discussed in some detail in G99. Briefly, the most effective method for large scale surveys of late-type M- and C-stars uses typically two broad-band filters from the set V, R, I, and two narrow-band filters near 7800 and 8100 Å, which are centred on a CN-band in carbon stars, and a TiO band in oxygen-rich stars, respectively. In an [78-81] versus $[V - I]$ (or similar) colour-colour plot, carbon stars and late-type oxygen-rich stars clearly separate redwards of $V - I \approx 1.6$. For an illustration of this, see Cook & Aaronson (1989), or Kerschbaum et al. (1999).

A caveat is that, unfortunately, not all groups adopt the same "boxes" in these diagrams to select M- and C-stars (e.g. compare Nowotny et al. 2001 and Demers et al. 2002). Furthermore, in many cases, only the photometry is published for the stars the respective authors consider to be the M- and C-stars, so its impossible to apply ones own selection criteria a posteriori. Furthermore, one usually applies the same lower-limit on the broad band colour ($(V - I)$, or $(R - I)$) to select M-stars (usually chosen to correspond to M0 and later) to C-stars, while it is known (e.g. Kerschbaum et al. 1999) that the hottest C-stars (spectral type C0) are bluer than this limit. So, applying the same lower-limit on the broad-band colour will bias against the hottest C-stars.

3. Surveys

In this section the (recent) surveys for carbon stars in external galaxies, or new results in general, are described.

The Magellanic Clouds

A huge new survey of the LMC was presented by Kontizas et al. (2001) covering about 300 sq.degree and containing 7760 objects. I used the listed R, I data to calculate the bolometric magnitude using bolometric corrections (BCs) from Costa & Frogel (1996; hereafter CF) for a reddening of $E(B - V)$ = 0.06.

Kunkel et al. (2000) present a new survey of carbon stars in the periphery of the SMC, and present B, R, and heliocentric velocities for 150 stars.

It should be mentioned that the data release of the infra-red surveys DENIS and 2MASS has allowed to identify many candidate AGB stars based on colour criteria, e.g. Egan et al. (2001), who combine 2MASS with MSX data, to suggest about 500 candidate AGB stars, or Nikolaev & Weinberg (2000) who analyse 2MASS data to find that there is a significant population of AGB stars. In the near future multi-object spectroscopy will assign spectral types and measure radial velocities for many of them.

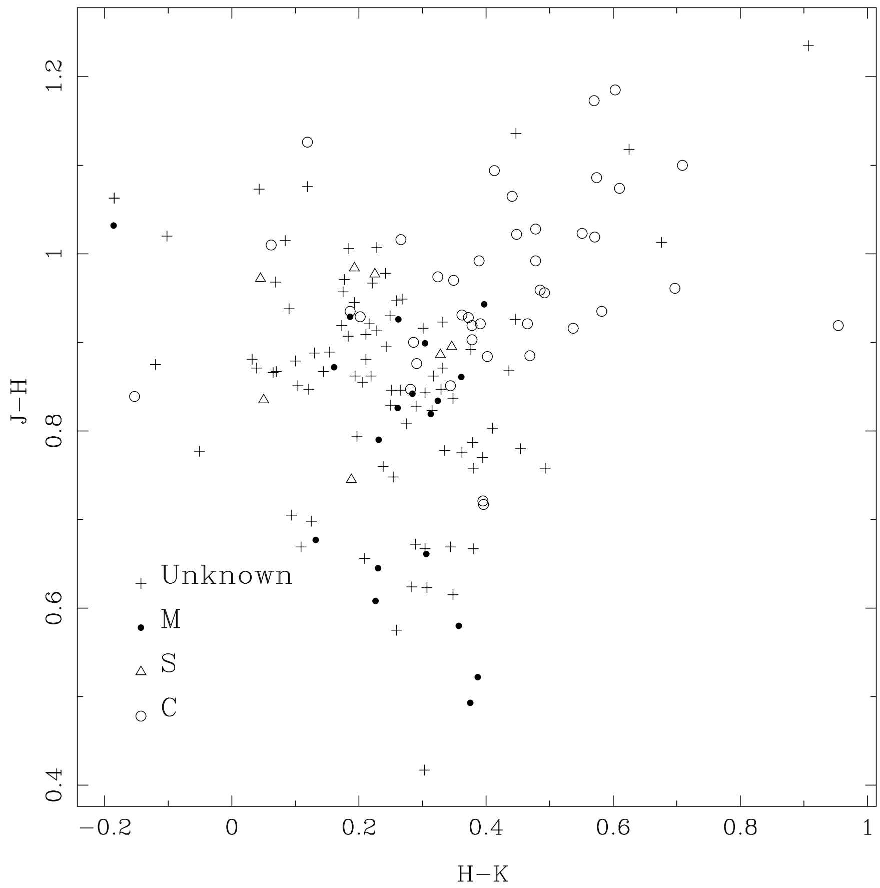

Figure 1. Colour-colour diagram of 152 stars in Fornax from Stetson et al. (1998) with 2MASS counterparts, with spectral types indicated.

Sagittarius dwarf galaxy

The total number of known carbon stars is 26, with an estimated total of about 100 (Whitelock et al. 1999). JHK photometry is listed for 11 of them in Whitelock et al. (1996). I correlated all 26 of them with 2MASS, finding 14 matches, 9 also with photometry in Whitelock et al. (1996). The object with the largest difference in K, is the object classified by Whitelock et al. (1999) as a Mira, actually the first confirmed Mira-type variable in a dwarf spheroidal. The bolometric magnitudes for the 16 stars are calculated adopting $E(B-V)$ = 0.15 and BCs from Bessell & Wood (1984; hereafter BW84).

Fornax dwarf galaxy

Azzopardi et al. (1999) lists a total known number of 104, with an estimated total of 120.

Demers & Irwin (1987) identify 30 long-period variables but none with Mira-type amplitudes. Bersier & Wood (2002) give a list of 85 candidate LPVs.

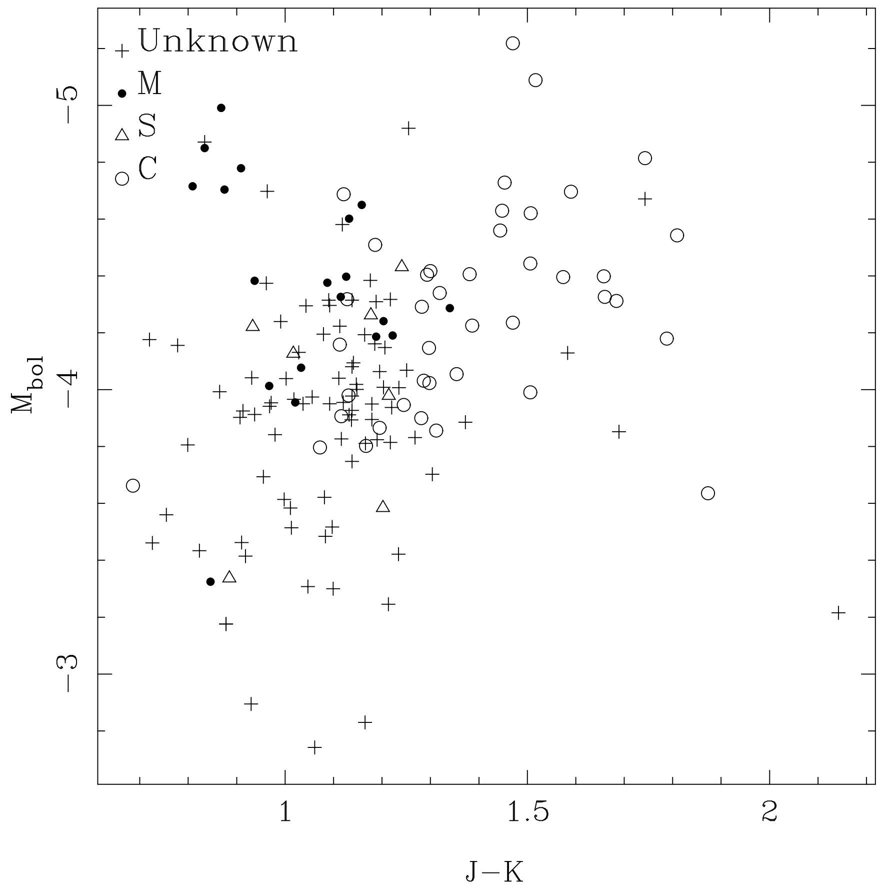

Figure 2. Colour-magnitude diagram for the stars from the previous figure.

Stetson et al. (1998) present a list of 161 candidate luminous red stars in a field of 1274 sq.arcmin based on B and R exposures. Cross-identifications with Demers & Kunkel (1979), Westerlund et al. (1987) and Lundgren (1990) are also given.

Demers et al. (2002) consider the 2MASS observations in the direction of Fornax and the LMC and use a selection in $J - K$ to identify 5 new candidates, and confirm 21 known carbon stars in Fornax.

I took the coordinates from Stetson et al. and made a correlation with the 2MASS catalogue in 2 steps. First using a search radius of 2 arcsec, finding 140 matches. Plotting the offsets between the input coordinates and the 2MASS coordinates revealed that there is an offset of 0.66 arcsec in RA and 1.10 arcsec in Dec. In a second pass, the Stetson et al. coordinates were corrected for this offset, and a search radius of 1.5 arcsec was used. 152 matches were found, with an rms in the difference between 2MASS and input coordinates now 0.42 arcsec in RA and 0.32 arcsec in Dec. This sub-sample of 152 stars contains 41 C-, 7 S- and 19 M-stars. Bolometric magnitudes are calculated adopting a reddening $E(B - V)$ of 0.020, and BCs to the K magnitude from BW84.

Figure 1 and 2 show the colour-colour and colour-magnitude diagram for these 152 red stars with 2MASS counterparts. From both diagrams it is clear that the carbon stars stand out from the M- and S-stars, a feature that is well known and related to

Table 1. $(R-I)_0$ and $(V-I)_0$ colours of M-stars (with no mass loss) derived from the spectra in Fluks et al. (1994)

Type	$(R-I)_0$	$(V-I)_0$	Type	$(R-I)_0$	$(V-I)_0$
M0	0.82	1.63	M1	0.94	1.79
M2	1.02	1.90	M3	1.16	2.07
M4	1.38	2.34	M5	1.70	2.77
M6	2.00	3.21	M7	2.24	3.64
M8	2.27	3.94	M9	2.38	4.21
M10	2.52	4.36			

the different molecular absorption features in the NIR. The carbon stars are on average more luminous than the M- and S-stars. Note that the two reddest stars seem to have a relatively low luminosity again. This is likely to be an artifact, since these red colours are influenced by circumstellar reddening because of mass loss, and hence a simple BCs formulation to obtain $M_{\rm bol}$ may become inaccurate.

Leo I dwarf galaxy

The total number of known carbon stars is 23. Demers & Battinelli (2002) use the narrow-band filter technique to find 7 new carbon stars. The number of M0+ stars they estimate to be 15 (foreground corrected), and based on the expected colours of M-stars I estimated that the number of M2+, M3+ and M5+ stars is 13, 10 and 1, respectively. This (and similar estimates described below for other galaxies) is based on colours derived from the M-type spectra of Fluks et al. (1994), as listed in Table 1. Demers & Battinelli (2002) give R, I for all 23 stars, and I calculated bolometric magnitudes assuming $E(B-V)$ = 0.02 and BCs from CF.

Recently, Menzies et al. (2002) surveyed a field of 7.2 arcmin square in the inner part of Leo I in JHK. They find all 21 known and suspected carbon stars in the field, but also identify 3 very red objects (and a fourth in a nearby field), which, based on their colours, are possibly carbon stars undergoing mass loss.

Sculptor dwarf galaxy

I took the coordinates from Azzopardi et al. (1986) and correlated them with 2MASS to find a match in all cases. For the 2 stars with IR photometry listed in Frogel et al. (1982) the agreement is excellent. Bolometric magnitudes are calculated assuming $E(B-V)$ = 0.02, and BCs from BW84. The number of stars available to calculate the LF is therefore increased from 2 to 8.

Leo II dwarf galaxy

The total known number of certain carbon stars is 8. Azzopardi et al. (2000) state they found 2 new ones, without providing further details.

I extracted the coordinates for the 6 certain and 1 candidate carbon stars in Azzopardi et al. (1985), and cross-correlated them with 2MASS, to find 6 matches (all but ALW 5). The K-magnitudes for ALW 4 and 6 agree to with a few hundredth of a magnitude with those listed in Aaronson & Mould (1985), the difference in the sense Aaronson & Mould minus 2MASS is 0.1 mag for ALW1, –0.18 for ALW3 and –0.36 for ALW7, possibly indicating they are variable. I determined the bolometric magnitude for ALW2, and removed the star DH 260 in Aaronson & Mould (1985), which I

Table 2. The carbon star census

Name	D (kpc)	M_V (mag)	[Fe/H]	N_C	Area (kpc^2)	Factor[a]	N_M
M31	770	–21.2	0.0	243	12.3	47	789 (5+)
Galaxy		–20.6	0.0	81	1.0	700	C/M $\approx$ 0.2[b]
M33	840	–19.0	–0.6	15	0.20	790	5 (5+), 60 (0+)
LMC	50	–18.1	–0.6	1045	4.8	11	1300 (5+)
				7750	300.		
NGC 205	815	–16.4	–0.8	7	0.33	40	4 (5+), 17 (0+)
SMC	63	–16.2	–1.0	789	5.4	4	180 (5+)
				1707	12.2		
NGC 6822	490	–16.0	–0.7	904	4.5	1.0	941 (0+)
IC 1613	720	–15.3	–1.3	195	7.8	1.0	35 (5+), 300 (0+)
WLM	930	–14.4	–1.5	14	0.28	8	0 (5+), 6 (0+)
SagDSph	24	–13.4	–1.0	26	7.2	4	
Fornax	138	–13.1	–1.3	104	1.35	1.0	4 (5+), 25 (2+)
Pegasus	955	–12.4	–1.1	40	1.04	1.0	77 (0+)
SagDIG	1060	–12.3	–2.5	16	0.58	1.0	1 (0+)
Leo I	250	–11.9	–2.0	23	0.45	1.0	1 (5+), 15 (0+)
And I	790	–11.9	–1.5	0			
And II	680	–11.8	–1.5	8			1 (0+)
Aquarius	950	–10.9	–1.9	3	0.18	1.0	1 (0+)
And III	760	–10.3	–2.0	0			
Leo II	205	–10.1	–1.9	8	0.47	1.0	
Sculptor	79	–9.8	–1.8	8	0.65	1.0	40 (2+), 0 (5+)
Phoenix	400	–9.8	–1.8	2	0.40	1.0	
Sextans	86	–9.5	–1.7	(0)			
Carina	100	–9.4	–2.0	11	0.31	1.0	
Tucana	870	–9.3	–1.8	0	0.22	1.0	
Ursa Minor	69	–8.9	–2.2	7	0.58	1.0	
Draco	82	–8.6	–2.0	6	0.50	1.0	
NGC 2403	3390	–20.4	0.0	4	2.0	125	7 (0+)
NGC 300	2170	–18.7	–0.4	16	3.2	31	23 (0+), 6 (5+)
NGC 55	1480	–18.0	–0.6	14	2.8	12	6 (5+)

[a]. Ratio of the area of the galaxy on the sky (taken from the NED catalog) and the survey area.
[b]. In the solar neighbourhood.

inadvertently had included in 1999 in the luminosity function of this galaxy, but is not a carbon star.

Phoenix dwarf galaxy

Martinez-Delgado et al. (1999) present I-band photometry of the two known carbon stars that agrees very well with the values in Van de Rydt et al. (1991).

Carina dwarf galaxy

Azzopardi et al. (1999) list 11 carbon stars, which is two more than listed in G99, but no details are given.

Ursa Minor dwarf galaxy

The total number of known carbon stars is 7. Armandroff et al. (1995) confirm the 1 certain and 1 candidate carbon star in Azzopardi et al. (1986, and references therein), and find 2 new ones. Shetrone et al. (2001) do follow-up spectroscopy of red stars and

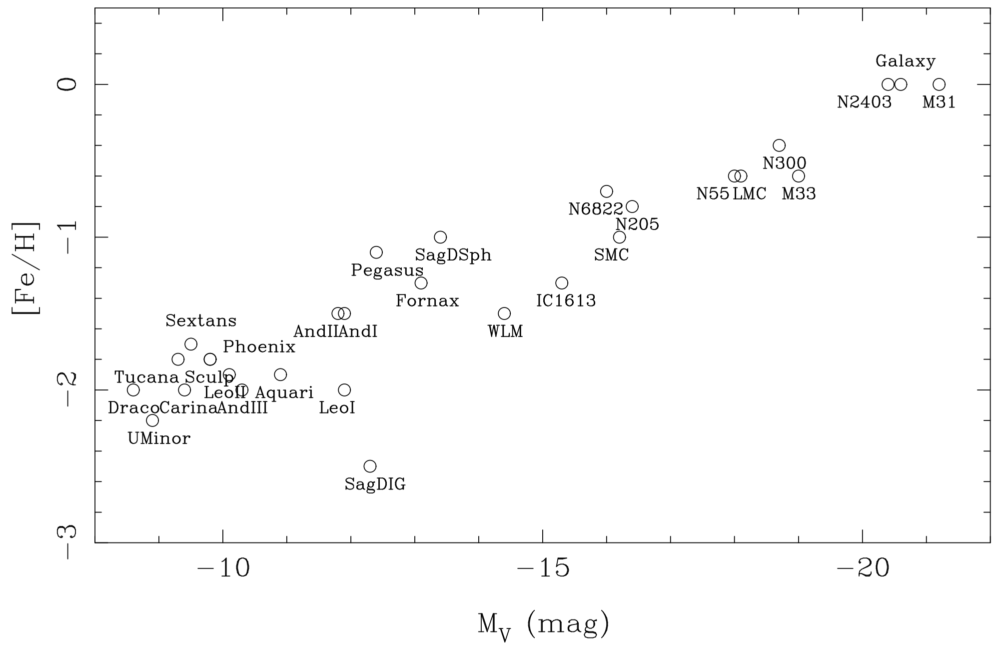

Figure 3. Metallicity versus $M_{\rm V}$ of the galaxies discussed here.

find 3 new carbon stars to bring the total to 7. They list B, V photometry for all. I correlated these 7 using the positions in Shetrone et al. with 2MASS and found a match within 1 arcsec in 6 cases, of which 5 have good photometry in J and K. A reddening of $E(B-V)$ = 0.032 is adopted to compute $m_{\rm bol}$ with BCs from BW84.

Draco dwarf galaxy

The total known number of carbon stars is 6. Armandroff et al. (1995) confirm the 3 certain and 1 candidate carbon star in Azzopardi et al. (1986, and references therein), and find one new one. Shetrone et al. (2001) do follow-up spectroscopy of red stars and find a sixth carbon star. B, V photometry is listed for all. Draco is not yet observed by 2MASS. Margon et al. (2002), in a search for "Faint High Latitude Carbon Stars", identify three known carbon stars in SDSS data.

M31

From Brewer et al. (1995, table 8), and the expected colours of M-stars (Table 1), I estimated the number of M0+, M2+, M3+, M5+, M6+ stars to be 5254, 4887, 3920, 789 and 223, respectively.

A new survey was presented by Nowotny et al. (2001) for one field of 5.3x5 arcmin (unvignetted area) in between fields 3 and 4 of Brewer et al. (1995). They find 61 carbon stars and 507 M0+ stars. Since no colour information for the M-stars is given, no spectral subdivision according to colour can be made. The C/M ratio and the number of objects per unit area found by Nowotny et al. (2001) are very similar to those found by Brewer et al. (1995) for their flanking field no 4.

M33

The colours of the M-stars in Cook et al. (1986) were inspected and I estimated the number of M0+, M2+, M3+, M5+, M6+ stars to be 60, 34, 26, 5, 2.

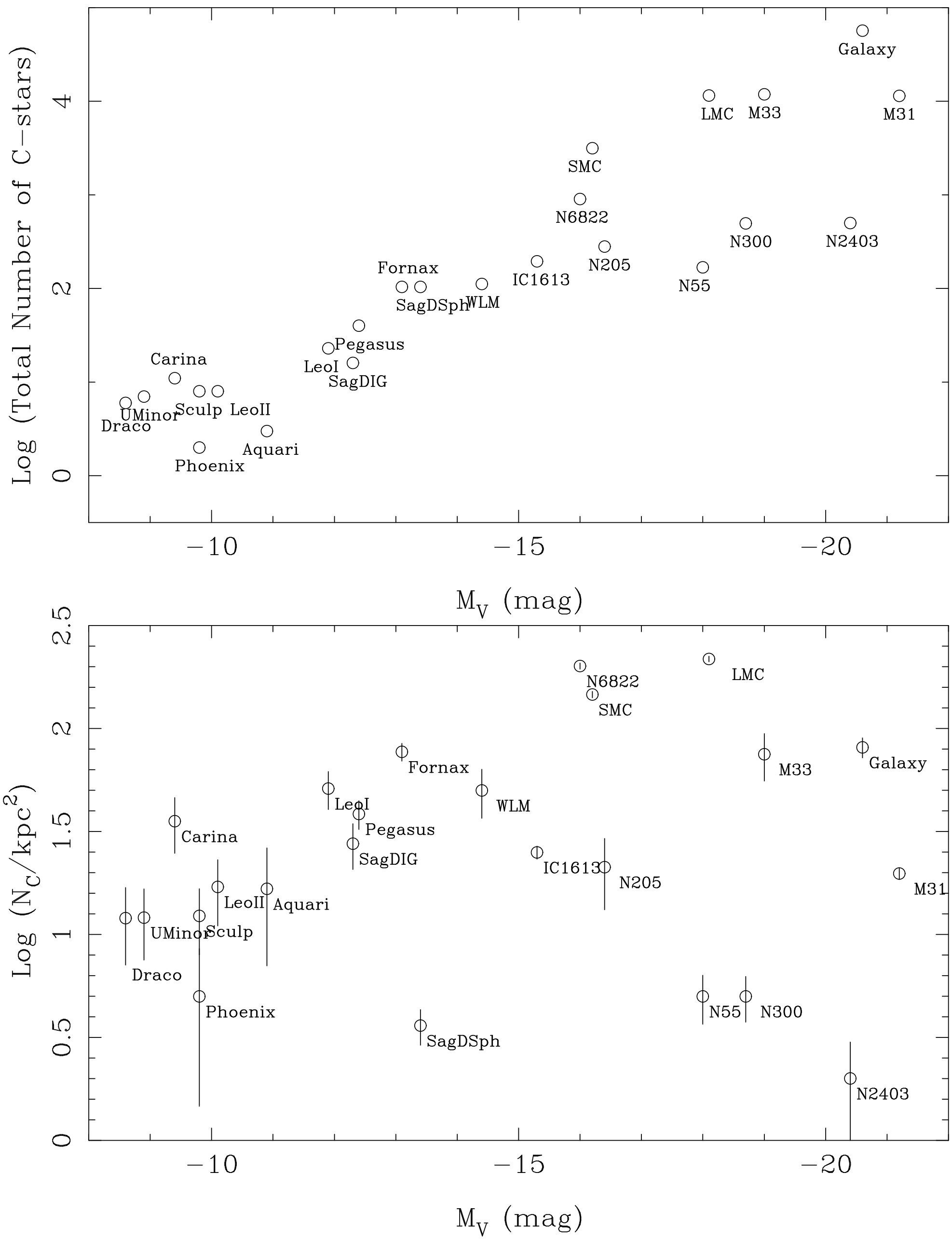

Figure 4. Total number of carbon stars and surface density of carbon stars versus $M_{\rm V}$. No correction for inclination effects has been made.

And I,II,III

Cote et al. (1999) took spectra of red stars in And II and confirm one new carbon star, and give V, I photometry. Da Costa et al. (2000) quote a V-magnitude fainter by 0.2 mag for this object. However, since the list of Cook et al. remains unpublished it is unclear whether this star is in their list already. Bolometric magnitudes are available

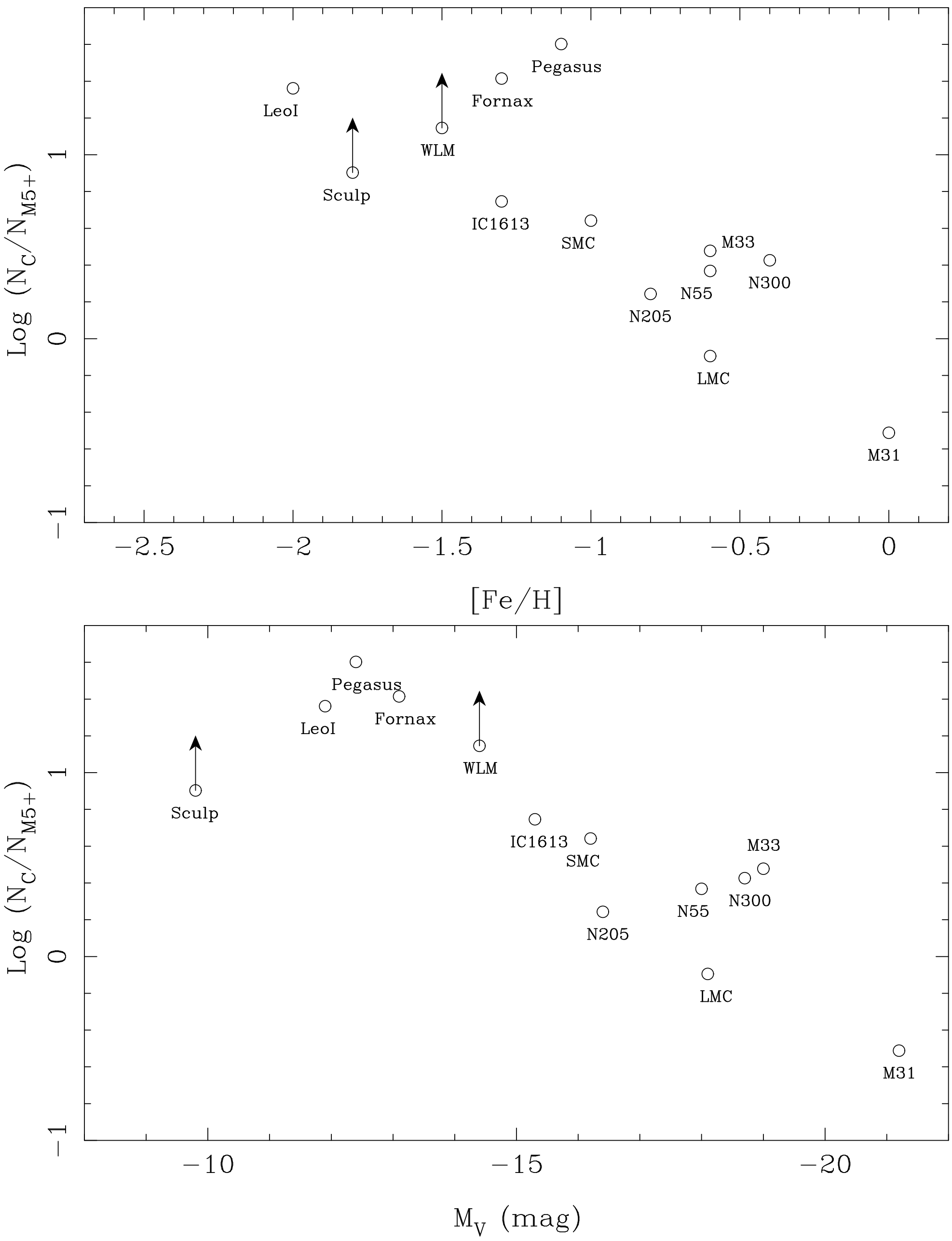

Figure 5. Log of the number ratio of carbon stars to late M-stars versus metallicity and $M_{\rm V}$.

for 2 certain C-stars, one based on IR photometry (Aaronson et al. 1985b), and the other calculated by me using the average of the two available V data points, $V-I$ from Cote et al. (1999), assuming $E(B-V)$ = 0.06, and BCs from BW84.

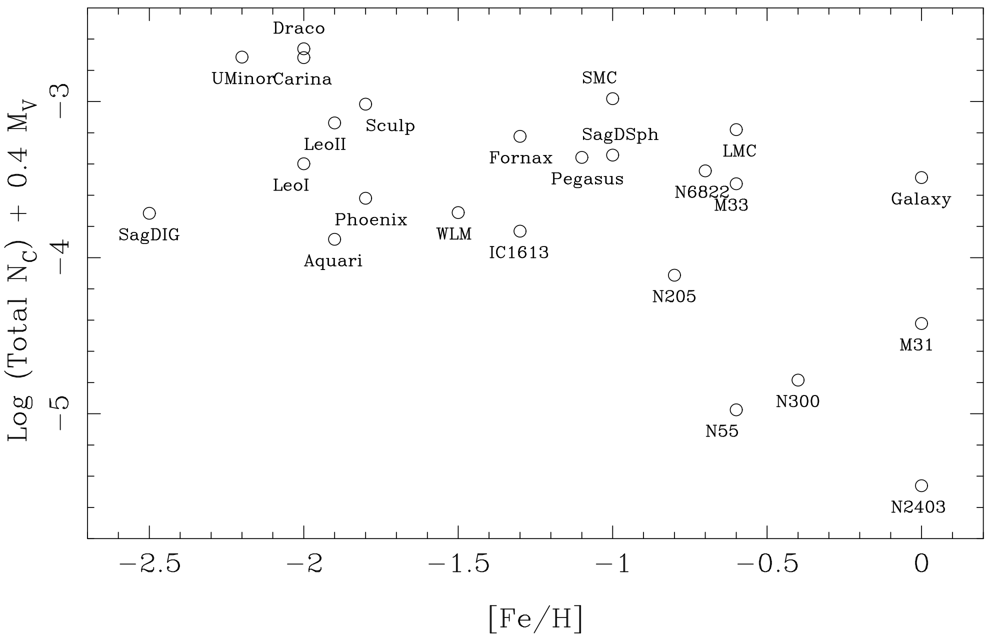

Figure 6. Log of the number of carbon stars over total visual luminosity versus metallicity.

NGC 6822

A new survey using the narrow-band filter technique was presented by Letarte et al. (2002), covering the whole galaxy and identifying 904 carbon stars. A similar number of M-stars with colours corresponding to spectral type M0 and later was identified. Unfortunately no information is given on the number distribution of M-stars as a function of colour (spectral type). I took their R, I data, and calculated the bolometric magnitudes adopting $E(B-V)$ = 0.24 and BCs from CF.

Sagittarius DIG

A new survey using the narrow-band filter technique was presented by Demers & Battinelli (2002), covering the whole galaxy. They found 16 carbon stars. The foreground contamination is so strong that no useful estimate of the number of M stars could be made. I took their R, I data and reddening ($E(B-V)$= 0.05) and the BCs from CF to estimate the bolometric magnitudes.

Pegasus

A new survey using the narrow-band filter technique was presented by Battinelli & Demers (2000), covering the whole galaxy. They found 40 carbon stars for their preferred reddening of $E(B-V)$ = 0.03. The C/M ratio they quote appears to be in error however. Based on their Figure 4, I count 19 M-stars in the area of approximately 5.6 sq.arcmin they define as the foreground area, and 116 M-stars in the 11.4 sq.arcmin covered by Pegasus. This implies there are 11.4/5.6 $\times$ 19 = 39 foreground stars in the area covered by Pegasus, and hence the C/M ratio is 40 /(116 - 39) = 0.52, and not 0.77. Assuming that 57% of all M-stars in the field are foreground, I estimated the number of M0+, M2+, M3+, M5+, M6+ stars in Pegasus to be 77, 30, 17, 1, 0, respectively. I calculated the bolometric magnitude using the BCs from CF.

Aquarius

A new survey using the narrow-band filter technique was presented by Battinelli & Demers (2000), covering the whole galaxy. They found 3 carbon stars. The foreground contamination is such that no reliable estimate for the C/M ratio can be made. I calculated the bolometric magnitude using the BCs from CF, and a reddening of $E(B-V)$ = 0.03.

Tucana

A new survey using the narrow-band filter technique was presented by Battinelli & Demers (2000), covering the whole galaxy. They found no carbon stars.

IC 1613

A new survey, covering the whole galaxy, using the narrow-band filter technique is presented by Albert et al. (2000). They identify 195 carbon stars, and, considering the foreground contamination, about 300 stars of spectral type M0 and later. Assuming the same fraction of foreground contamination as for all M-stars, I estimated from their Figure 5, that there are approximately 35 M5+ and 2 M6+ stars. I took their R, I data, and calculated the bolometric magnitudes assuming $E(B-V) = 0.03$ and BCs from CF.

Kurtev et al. (2001) identify the first known Mira in IC 1613, with a period of 640 days, and an amplitude in the R-band of 2.5-3 magnitudes. Its spectral type is around M3.

WLM

The colours of the M-stars in Cook et al. (1986) were inspected and I estimated the number of M0+, M2+, M3+, M5+ stars to be 6, 3, 3, 0.

NGC 55

I corrected an error in the distance and $M_{\rm V}$ in G99. The colours of the M-stars in Pritchet et al. (1987) were inspected and the number of M3+, M5+ stars is estimated to be 7 and 6.

NGC 300

Richer et al. (1985) identify 25 M-stars (with an estimated 2 foregound objects) with observed colours $V-I \approx 1.9$ and assume all to be of spectral type M5+. Using Table 1, I estimated the number of stars in NGC 300 with spectral type M1+, M2+, M3+, M5+ to be 23, 21, 15, 6, respectively.

For the Sextans dwarf galaxy, NGC 205 and NGC 2403 there has been no new information on the carbon star population since G99.

Table 2 summarises the number of known carbon stars in external galaxies. Local Group members not explicitly mentioned have never been surveyed for C-stars. The last three entries are galaxies outside the Local Group. Listed are the adopted distance, absolute visual magnitude, metallicity (these three parameters come from Mateo (1998) and van den Bergh (2000)), number of known carbon stars, the surface area on the sky of the respective survey, the ratio of the area of the galaxy on the sky (taken from the NED catalogue) and the survey area, and the number of late-type M-stars, when known (the symbol '3+' meaning stars of spectral type M3 and later, etc.). The entry for the number of carbon stars in our galaxy is the local surface density of TP-AGB stars by Groenewegen et al. (1992).

Table 3. The carbon star luminosity function. Galaxies are ordered by decreasing $M_{\rm V}$

Name	$M_{\rm bol}^{\rm max}$ (mag)	$M_{\rm bol}^{\rm min}$ (mag)	$M_{\rm bol}^{\rm mean}$ (mag)	spread (mag)	$N_{\rm all}$	$N_{\rm M_{bol} > -3.5}$
M 31	−6.13	−3.34	−4.31	0.50	243	16
NGC 2403	−6.05	−5.89	−5.97	0.08	4	0
NGC 300	−5.93	−4.68	−5.39	0.41	13	0
LMC	−8.01	−1.33	−4.67	0.61	7650	378
NGC 55	−4.98	−3.37	−4.40	0.51	9	1
NGC 205	−5.14	−4.04	−4.50	0.44	7	0
SMC	−8.17	−1.62	−4.33	0.81	1626	226
NGC 6822	−6.48	−3.65	−5.00	0.44	904	0
IC 1613	−6.34	−3.48	−4.94	0.56	195	2
SagDSph	−4.37	−3.11	−3.81	0.40	16	5
Fornax	−5.22	−3.64	−4.28	0.36	41	0
Pegasus	−5.59	−4.05	−4.68	0.37	40	0
SagDIG	−5.66	−4.48	−5.08	0.31	16	0
Leo I	−5.38	−3.32	−4.59	0.47	23	1
And II	−4.11	−3.24	−3.68	0.62	2	1
Aquarius	−5.12	−4.71	−4.89	0.21	3	0
Leo II	−4.26	−3.20	−3.75	0.37	6	1
Sculptor	−4.49	−2.71	−3.22	0.57	8	7
Phoenix	−3.71	−3.55	−3.63	0.11	2	0
Carina	−4.85	−3.14	−4.30	0.61	6	1
Ursa Minor	−2.90	−2.04	−2.60	0.33	6	6
Draco	−3.62	−2.92	−3.27	0.35	3	2

4. Discussion

Figure 3 shows the well-known correlation between metallicity and absolute visual magnitude. The interpretation being that the more luminous galaxies are also the more massive ones that have had more gas mass available to transform into stars and enrich the interstellar medium. There is a clear outlier, SagDIG, but several research groups find a similar low metallicity for this galaxy (see discussion in Momany et al. 2002)

Figure 4 shows the number of carbon stars in a galaxy versus $M_{\rm V}$ represented in two ways. First, the total number of C-stars in a galaxy was estimated by simply multiplying the known number by the ratio of total surface area of a galaxy to the survey area. As for some galaxies the survey area is less than a few percent, this correction factor can be quite large (and uncertain). To circumvent this, the bottom panel shows the surface density of carbon stars in the particular survey. The drawback of this approach is that it does not take into account the spatial variation of the density of carbon stars within a galaxy. In neither approach did I correct for the fact that we do not see these galaxies face-on. Some interesting things can be noticed. There is a clear relation between the (estimated) total number of C-stars and $M_{\rm V}$, and there seems to be a maximum surface density of about 200 kpc^{-2} averaged over a galaxy. In both plots

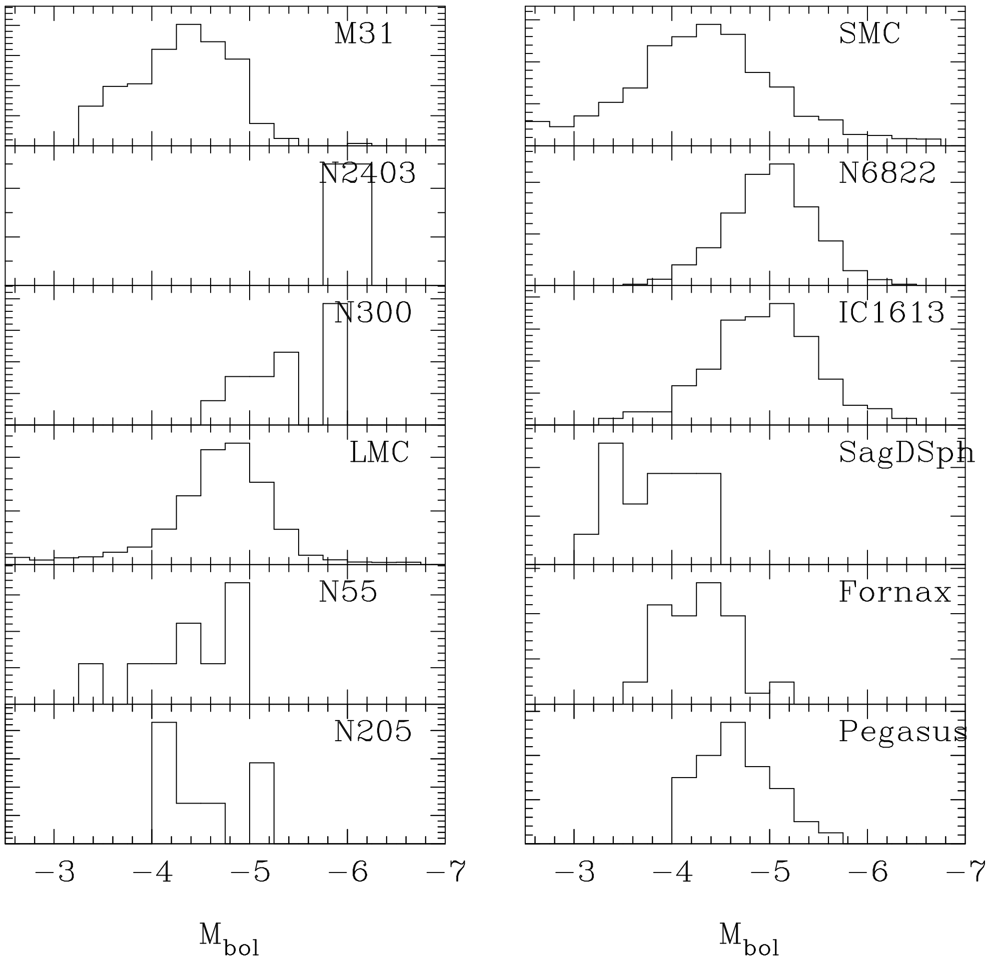

Figure 7. Luminosity functions, ordered by decreasing M_V of the galaxies, ordered top to bottom, left to right. The total number of stars plotted per galaxy is listed in column 6 of Table 3. In the case of the SMC and LMC, the lowest luminosity bin is cumulative.

NGC 55, 300 and 2403 are clear outliers. These are the most distant galaxies surveyed, and one might suppose that the surveys have been incomplete. For NGC 55 the explanation probably lies as well in the fact that we see this galaxy almost disk-on, and so both the total number as well as the surface density have been underestimated. Reddening within the galactic disk of the galaxy can also play a role. For NGC 2403 the small number of carbon stars lies in the fact that the survey has been incomplete. All 4 known C-stars have luminosities that are much higher than the average in galaxies for which we know the LF in more detail. The same is true for NGC 300. A last note of caution is that I did not try to make a distinction between carbon stars on the TP-AGB and lower-luminosity carbon stars. For example, the data for our Galaxy represents TP-AGB stars only, while on the other hand the SMC is known to contain a large fraction of low-luminosity carbon stars (see later).

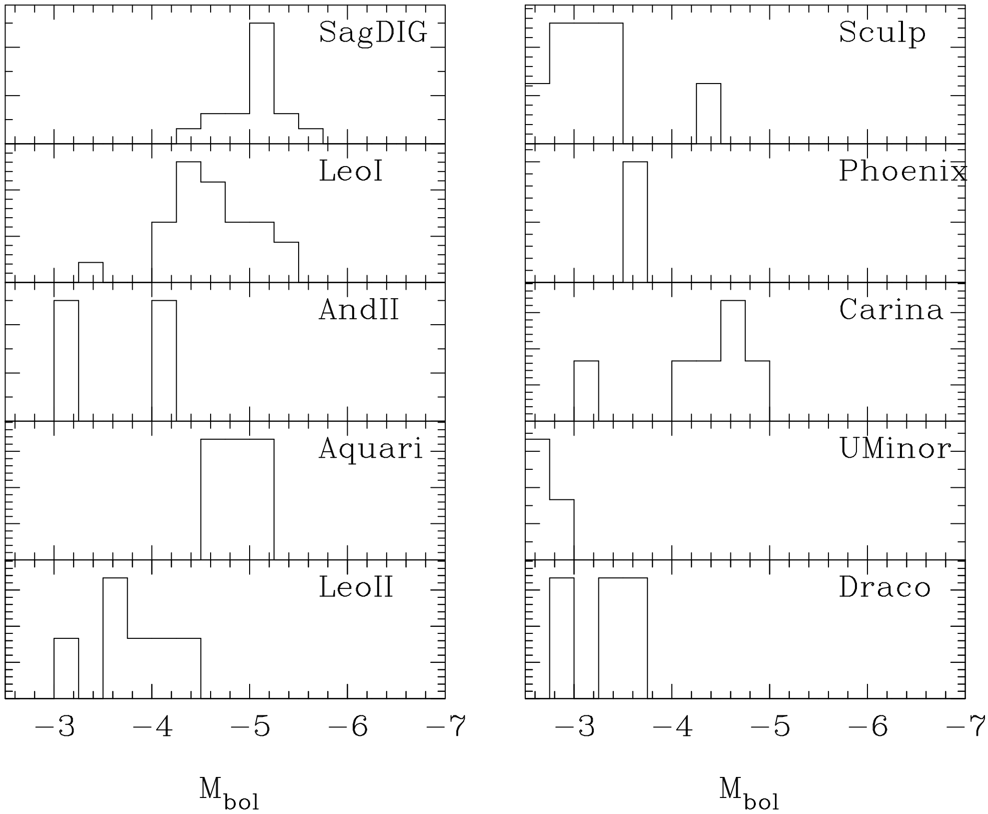

Figure 7. Continued.

Figure 5 shows the ratio of C- to late M-stars, and it confirms the well known trend (Cook et al. 1986, Pritchet et al. 1987). The interpretation is that a star with a lower metallicity needs fewer thermal pulses to turn from an oxygen-rich star into a carbon star.

Figure 6 shows the ratio of the total estimated number of carbon stars over the visual luminosity of the galaxy (e.g. Aaronson et al. 1983). Most of the galaxies scatter between a value of –3 and –4, with a few outliers which are the same as noticed in Fig. 2.

Figure 7 shows the C-stars bolometric LF for the galaxies for which it could be constructed (Sect. 2); for the Magellanic Clouds see Groenewegen (1998) for details. Table 3 lists the maximum, minimum and mean magnitude, as well as the spread, calculated from the rms deviation from the mean. Also listed are the number of stars that went into the calculation and are plotted in Fig. 7, and the number of C-stars that are fainter than $M_{\rm bol} = -3.5$, the luminosity of the tip of the RGB. This is not an absolute foolproof limit between true AGB stars and binary masqueraders as (low initial mass) genuine AGB stars may have a luminosity fainter than $M_{\rm bol} = -3.5$ when experiencing the first few pulses on the TP-AGB and/or when they happen to be observed during the luminosity-dip of the thermal pulse cycle (about 10-20% of the inter pulse time). As an aside it is noted that in the case the luminosity is not conclusive about the AGB nature of an object, one could try to observe one or more Technetium lines (e.g. Abia

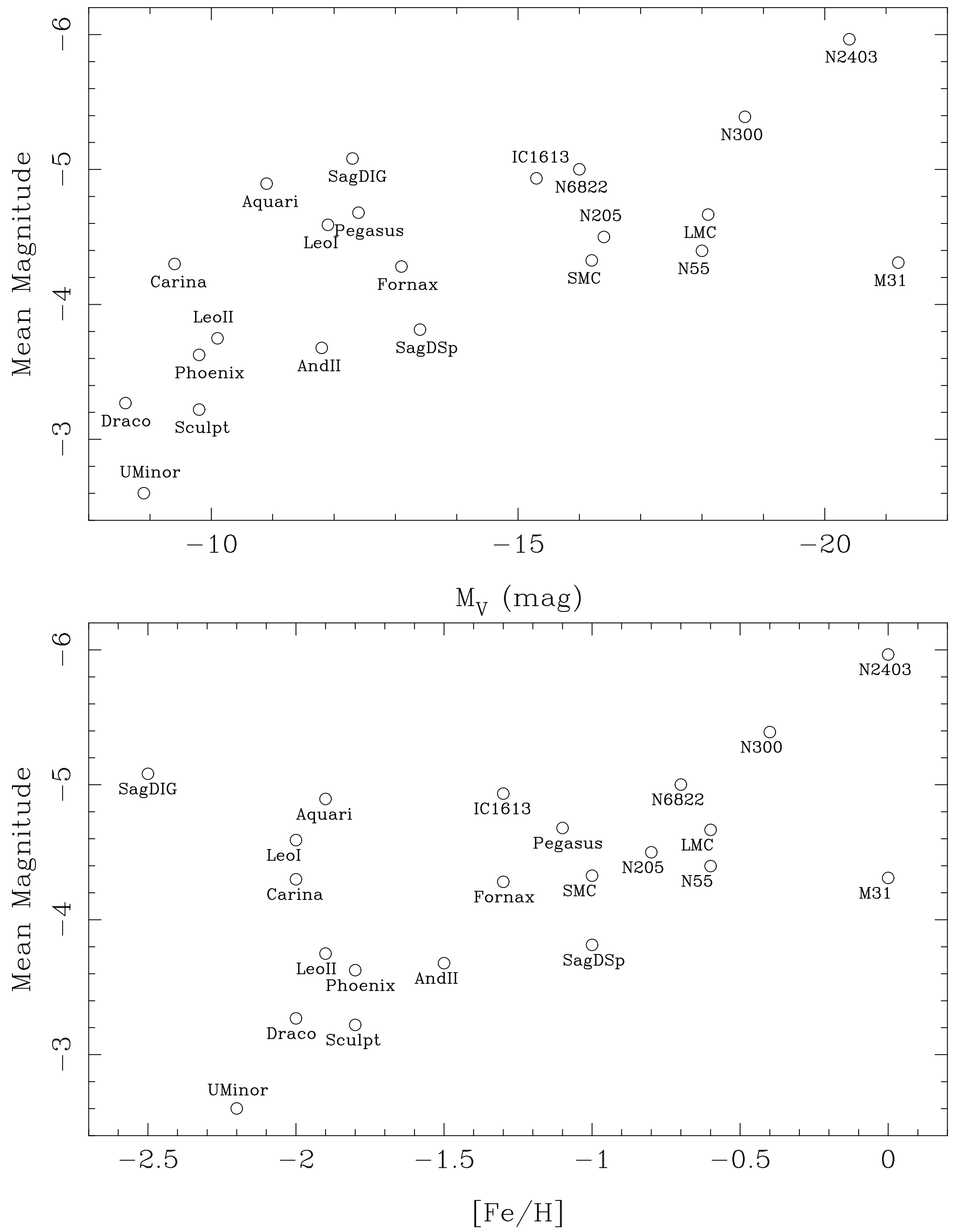

Figure 8. Mean bolometric magnitude of carbon stars versus $M_{\rm V}$ and metallicity.

et al. 2002 and references therein), as the presence of this unstable isotope indicates recent nucleosynthesis.

The data show that in well populated LFs, the mean $M_{\rm bol}$ is between –4 and –5. It also shows that the mean in NGC 300 and NGC 2403 is much higher. Unless one would invoke a large uncertainty in the distance or a burst of recent star formation, the most natural explanation lies in the incompleteness of the surveys in these distant galaxies. Finally, the data shows that in the fainter galaxies the mean magnitude increases and that a fair number of C-stars are of the low-luminosity type. This is more clearly seen in Fig. 8 where the mean magnitude is plotted. A LF which is dominated by faint carbon stars is indicative of an absent intermediate age population, and a corresponding star formation history. It is also evident that there is a considerable spread at a given metallicity or $M_{\rm V}$, inhibiting the use of the mean carbon star luminosity as a distance indicator.

In a recent paper Mouhcine & Lançon (2002) present evolutionary population synthesis models, including chemical evolution, with special focus on intermediate age populations. Their models are the first that are able to account for the observed trend in Fig. 3 adopting 'typical' SFH for Sa, Sb, Sc and Irr Hubble type galaxies. The AGB phase is included through a semi-analytical treatment of the third dredge-up, with efficiency parameters set to values that have been determined in other studies to fit the LMC carbon star LF and C/M ratio.

5. Conclusion

In principle, the overall carbon star LF and C/M ratio contains information about the star-formation rate history from, say, 10 Gyr ago (the low-luminosity C-stars in binaries) to a few-hundred Myr ago (the high luminosity tail of the LF). Its a challenge to theoretical models to use these constraints together with other data to derive the chemical evolution and star formation history of these galaxies. The models of Mouhcine & Lançon represent a first successful step in this direction.

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