SURVEYING CARBON STARS IN THE DWARF SPHEROIDAL GALAXIES

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ABSTRACT. We have completed a blue-green Grism survey for carbon stars in the seven "classical" dwarf spheroidal galaxies. The results for six of them have been published already, while the results for the Fornax galaxy are presented here: this galaxy contains 77 carbon stars, including 30 new objects. The bolometric luminosity function of Fornax is intermediate between that of the Small and of the Large Magellanic Cloud. We will also compare these carbon stars with the fainter objects in the galactic bulge and in the galactic halo and discuss their properties in relation with the metallicity and history of star formation in the parent galaxies.

1. Introduction

Carbon stars are a very late stage in the evolution of intermediate-mass stars. Unfortunately their formation is still not well understood (Iben and Renzini 1983) although progress has been done recently (see e.g. Boothroyd and Sackman 1988 and Lattanzio 1989). There seems to exist at least three kinds of carbon stars with different origins: i) the "normal" ones which are Asymptotic Giant Branch (AGB) stars enriched in carbon brought to the surface by dredge-ups driven by helium-burning thermal pulses; ii) fainter and bluer ones which have been discovered in the galactic bulge and whose origin is not understood (Westerlund et al. 1991) and iii) dwarf carbon stars presumably resulting from mass transfer from a more massive companion at the time it was a carbon star (Dearborn et al. 1986). Observationally, there seems to be continuity between classes i) and ii), the brightest bulge carbon stars being not strikingly different from the faintest observed SMC carbon stars.

Although we are not yet able to make full use carbon stars for studying the properties of the stellar populations of which they are a part, their potential is very great as they are relatively bright and easily recognizable while their number relative to other stars is obviously very sensitive to metallicity and age. Consequently, a number of astronomers have made systematic searches for carbon stars in our Galaxy and in nearby galaxies.

2. Finding relatively blue carbon stars

We have been surveying carbon stars in the Magellanic Clouds, the dwarf spheroidal galaxies and the galactic bulge using very-low resolution field spectroscopy in the green. The spectral range (4350-5400 A) allows to recognize carbon stars from their deep absorption bands of the C_2 molecule (the Swan bands) with bandheads at 4737 and 5165 A. The observations were made at the prime foci of the ESO and of the CFH 3.6 m telescopes, equipped with wide-field correctors and a Grism or a Grens with respectively 2200 and 2000 A/mm dispersion (see Breysacher and Lequeux 1983 for more information on the technique we used). Comparison with a similar, more classical technique using the CN bands in the near-infrared shows that our

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technique is roughly equivalent for the red, bright carbon stars and more powerful for the fainter and bluer carbon stars (see McCarthy 1987 and Blanco and McCarthy 1990).

Subsequent spectroscopy is very useful for confirming the nature of the carbon star candidates found in the surveys. We have made medium-resolution spectroscopy of many of the candidates in the Fornax, Sculptor, Carina and Leo I galaxies using the ESO 3.6 m telescope with the Boller and Chivens spectrograph (long slit mode and Optopus multifiber device) or EFOSC and using the NTT with EFOSC 2. Infrared (IR) photometry has been made at the ESO 3.6 m telescope for a number of the Fornax stars. This, added to IR photometry obtained by other authors and after correcting for extinction given in the literature, allows to calculate the bolometric magnitude using a formula for the bolometric correction to the K magnitude given by Wood et al. (1983): $BC_K = 0.55 + 2.65\,(J\text{-}K)_0 - 0.67\,(J\text{-}K)_0^2$,
J and K being the magnitudes in the Johnson system (Johnson et al. 1966). Then the absolute bolometric magnitude can be calculated using distances from the literature.

3. The number and luminosity functions of carbon stars in the dwarf spheroidal galaxies

The results for Sculptor, Carina, Leo I, Leo II, Draco and Ursa Minor have been presented by Azzopardi et al. (1985, 1986). These surveys should be essentially complete. Preliminary results for the Fornax dwarf spheroidal galaxy are presented here. Fornax contains 77 carbon stars: 30 new ones and 47 already known (Azzopardi, Lequeux and Muratorio 1992). We have added 13 carbon stars in the areas searched for by Blanco and McCarthy (Frogel et al. 1982) and by Westerlund et al. (1987) using near-infrared Grism technique. 20 carbon stars have been found outside these areas, 3 of which, belonging to the list of the very red giants discovered by Demers and Kunkel (1979) in the Fornax galaxy, were previously classified as carbon stars by Aaronson and Mould (1980) and Lundgren (1990). Note that the stars designated as "Ctm" by Aaronson and Mould (1980) and by other authors have not been considered as carbon stars. Although medium-resolution spectroscopy has not been secured yet for all stars, the list should be essentially complete at least for "normal" carbon stars (stars of the other categories are too faint to have been detected). Table 1 summarizes the results for the carbon stars in the dwarf spheroidals; for comparison it also contains estimates for the Magellanic Clouds (field carbon stars, the census in the clusters being certainly incomplete), the galactic bulge and the galactic halo.

Table 1. Census of field carbon stars in local group galaxies

Galaxy	Candidates (our surveys)	Candidates (previous)	Confirmed by spectroscopy	Estimated total nb.	References
Fornax	77	47	53	77	1, 2, 3, 4, 5, 6
Leo I	19	1	18	19:	7, 8, 9
Carina	11	6	9	11	7, 8, 10, 11
Sculptor	8	3	8	8	3, 4, 7, 8
Leo II	7	4	5	7	7, 9
Draco	4	3	3	4	8, 12
Ursa Minor	1	1	1	1	8, 9
Sextans	0	0	0	0	13
LMC	-	849	?	11000	14, 15
SMC	1707	860	?	3100	14, 16, 17
Gal. Bulge	34	0	34	-	18
Gal. halo	-	10	10	-	19, 20, 21

Note that we do not take into account the CH star K = SOC 215 in Ursa Minor (Zinn 1981).
References to Table 1: (1) this paper and Azzopardi et al. 1992; (2) Aaronson and Mould 1980; (3) Frogel et al. 1982; (4) Richer and Westerlund 1983; (5) Westerlund et al. 1987; (6) Lundgren 1990; (7) Azzopardi et

al. 1985; (8) Azzopardi et al. 1986; (9) Aaronson et al. 1983; (10) Cannon et al. 1981; (11) Mould et al. 1982; (12) Aaronson et al. 1982; (13) Irwin et al. 1990; (14) Blanco and McCarthy 1983; (15) Blanco and McCarthy 1990; (16) Rebeirot et al. 1992; (17) Azzopardi and Rebeirot 1991; (18) Azzopardi et al. 1991; (19) Margon et al. 1984; (20) Mould et al. 1985; (21) Green et al. 1991.

As discussed by Richer and Westerlund (1983) and Azzopardi, Lequeux and Westerlund (1985) there is some correlation between the number of carbon stars per unit luminosity and the absolute luminosity of the parent galaxy, and also a trend with metallicity, the number of carbon stars per unit luminosity increasing with decreasing absolute luminosity and decreasing abundance. The new data do not change these conclusions. However their interpretation is difficult because the galaxies we consider presumably have different histories of star formation, and also because there is a correlation between absolute luminosity and metallicity which does not allow to disantangle the different possible effects.

Table 2 presents the bolometric luminosity functions for the galaxies or parts of galaxies in our sample, together with the adopted extinctions and distance moduli. The bolometric magnitudes have been calculated in an homogeneous way as explained in Section 2. Most of the samples are incomplete in the sense that all discovered carbon stars do not have the IR photometry necessary to calculate the bolometric magnitudes, but we do not think that the results are strongly biased by this incompleteness.

Table 2. Bolometric luminosity functions for dwarf spheroidal galaxies and other systems

System	n (C stars)	Completeness %	E(B-V)	$(m-M)_o$	$<-M_{bol}>$	$(-M_{bol})$ range
Fornax	25	32	0.02	21.0	4.6	3.7-5.6
Leo I	5	26	0.00	21.7	4.3	4.1-4.5
Carina	8	73	0.06	19.7	3.9	2.9-4.6
Sculptor	2	25	0.02	19.5	3.2	3.0-3.4
Leo II	5	71	0.00	21.7	4.0	3.7-4.4
Draco	3	75	0.03	19.4	3.1	2.8-3.5
Ursa Minor	1	100	0.02	19.3	2.9	-
LMC	74	< 1	0.05	18.5	5.1	3.7-6.4
SMC	112	< 4	0.03	18.8	4.4	2.7-5.6
Gal. Halo	7	?	0.00	-	3.2:	1.8-5.2:
Gal. Bulge	34	?	var.	14.5	1.2	-0.2-2.8

Note that the results from the galactic halo carbon stars are extremely uncertain: the distances are very poorly known, and a large fraction of these objects may be dwarfs (Green et al. 1991).

4. Discussion and conclusions

From Table 2 one can draw the following conclusions:

i) The bolometric luminosity functions of the carbon stars in the dwarf spheroidal galaxies differ somewhat from each other: those in Fornax appear to be brighter than those in Carina, Leo I and Leo II which themselves are brighter than those in the other dwarf spheroidals. One must be careful in interpreting the numbers literally, because of uncertainties in the distances and of small-number statistics. There is no obvious correlation with metallicity, that itself is poorly known, and presents a large range of values inside at least several galaxies. There is a correlation with the absolute magnitude of the galaxy, which may reflect to some extent a small-number statistical effect similar to that discussed by Schild and Maeder (1983) for the brightest stars in galaxies,

ii) The bolometric luminosity function of the Fornax galaxy is intermediate between those of the SMC and the LMC. This result cannot be appreciably biased by incompleteness, small-number statistics, etc.... It is very probably related to a different history of star formation in all three galaxies, rather than to a metallicity effect, since the metallicity of Fornax is smaller than those in both the LMC and the SMC. This property as well as property (i) deserves further studies,

(iii) The luminous carbon stars predicted by the "classical" theory of carbon star formation are not found in any of the systems we have studied. This is a major problem, already known for a long time (see e.g. Iben and Renzini 1983). There are ways out e.g. through mass loss and convective overshooting that we cannot discuss here,

(iv) We have not (yet?) found in any other system the equivalent of the low-luminosity carbon stars that we discovered in the galactic bulge. These objects are very rare in the bulge (one for several hundreds of M stars) and they are very faint, so their detection even in the nearest galaxies requires very deep low-resolution field spectroscopy (or alternatively, but less securely, deep narrow-band filter imaging). We are starting such a program in the Magellanic Clouds,

v) The status of the halo carbon stars is uncertain. Current theories open the possibility that 0.8 $M_{\odot}$ stars of low metallicities can become carbon stars. Very recently, Tsuji et al. (1991) have found that some halo CH stars have very high $^{12}C/^{13}C$ ratios, suggesting that they have been produced by the third dredge-up; however they state that these stars may be (like the halo dwarf carbon stars) binary objects which have been enriched in ^{12}C by mass transfer from a normal carbon star in the past or by some other process. More work is necessary before we understand the halo carbon stars. Globular clusters are good places for looking systematically for new candidates and we are undertaking this program.

5. References

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Discussion:

Schommer: I think the first carbon star in a dwarf spheroidal was discovered by Canterna and Schnickehooper in 1978, based on Washington photometry. Zinn showed a spectrum, confirming it to be a CH star, and Bessell and Norris called attention to the possible importance of carbon stars in dwarf spheroidal galaxies.

Da Costa: I was interested to see that there appears to be a good correlation between the luminosity of the carbon stars in the dwarf spheroidals and the age of the intermediate-age population. Fornax has the youngest intermediate-age stars and brightest carbon stars, opposite of the case for Sculptor and Draco. Difference between LMC and SMC could then be the result of different mean age for LMC and SMC as suggested by Mateo and others.

Nemec: Why are the N(C,L) for Draco and Carina excessively high, whereas that for Ursa Minor appears to be normal ? Do you think that the differences are intrinsic or due to selection effects ?

Azzopardi: Indeed the number of carbon stars per unit luminosity of the parent galaxies is larger by about a factor 4 in Carina and Draco. We do not believe that this can be due to biases in the carbon star searches. However the integrated luminosities of the dwarf spheroidal galaxies are so poorly known that the reality of the difference can be questioned.