

Are the Bulge C – stars related to the Sagittarius dwarf galaxy?

II. Metallicity – a link with the galactic disc

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Abstract. The photometric estimate of the metallicity and the age of the Azzopardi et al. (1991) carbon stars (Ng 1997) is revised to respectively $Z \simeq 0.004$ and ~ 0.1 Gyr. Under the hypothesis that the carbon stars are located at a distance related to the Sagittarius dwarf galaxy, the broad velocity dispersion of the stars can only be explained if they were formed out of Galactic material during a recent crossing of the Sagittarius dwarf galaxy through the Galactic plane.

Key words: stars: carbon – stars: evolution – galaxies: individual: Sagittarius dwarf – galaxies: interactions

1. Introduction

The near-IR colours and medium-low resolution spectra (Azzopardi et al. 1991 – hereafter referred to as ALRW91, Tyson & Rich 1991 – hereafter referred to as TR91, Westerlund et al. 1991) obtained for the so-called ‘bulge’ carbon stars, identified by Azzopardi et al. (1985, 1988), show similarities with the low- to medium bolometric luminosity SMC carbon stars. The main difference is that the galactic carbon stars are photometrically bluer and that they have spectroscopically stronger NaD-doublets.

The radial velocities together with the direction in which these stars are located suggest a Bulge membership. In addition, a high metallicity for the Bulge lead TR91 and Westerlund et al. (1991) to suggest that the stars should be old and possess a mass of about $0.8 M_{\odot}$, while evolutionary calculations (Boothroyd et al. 1993, Groenewegen & de Jong 1993, Groenewegen et al. 1995, Marigo 1998, Marigo et al. 1996ab) demonstrate that the initial mass of carbon stars in general has to be at least $\sim 1.2 M_{\odot}$ ($t \lesssim 4$ Gyr) for both $Z=0.004$ and $Z=0.008$. Furthermore, the initial mass increases towards higher metallicity (Lattanzio 1989). The ALRW91 C-stars are a mystery (Lequeux 1990, TR91, Westerlund et al. 1991, Chiosi et al. 1992, Azzopardi 1994), because they are in bolometric luminosity about $2^{m:5}$ too faint to be regarded as genuine AGB (Asymptotic Giant Branch) stars, if located in the metal-rich Bulge.

The serendipitous identification of the Sagittarius dwarf galaxy (SDG) was made by Ibata et al. (1994, 1995). The $\sim 2^{m:5}$ difference of the distance modulus between the dwarf galaxy and the Galactic Centre at 8 kpc lead Ng & Schultheis (1997, hereafter referred to as NS97) to suggest that the ALRW91 C-stars could actually be located at the distance of the dwarf galaxy. Its presence was unknown at the time when the C-stars were identified and a different location could solve the standing question about the origin of the ‘bulge’ carbon stars.

Ng (1997, 1998) analysed the possibility that the ALRW91 C-stars are related to the SDG. With this hypothesis there is no need of exotic stellar evolutionary scenarios to explain these stars. Ng demonstrated that the photometric sequence of the ALRW91 C-stars is not exceptional, but comparable with the sequence found for the SMC. The estimated metallicity and age were respectively $Z \simeq 0.008$ and $0.1 - 1$ Gyr.

The organisation of the paper is that Sect. 2 begins with an overview about the age and metallicities of the various populations identified in the SDG. Sect. 3 deals with the improvement of the photometric metallicity and age estimates of the ALRW91 C-stars. In Sect. 4 additional constraints are obtained from the velocity dispersion. In Sect. 5 it is further argued that the present position of the C-stars does not violate any of the reliable observational constraints. The discussion continues in Sect. 6 with additional tests to verify independently the results summarized in Sect. 7.

2. Sagittarius dwarf galaxy: age and metallicity

The photometric metallicity estimates made for the SDG thus far depend heavily on the assumed age. The values for $[Fe/H]$ range from -0.5 to -1.8 dex. According to Ibata et al. (1997) the mean age (10–12 Gyr) and metallicity ($[Fe/H] = -1.5$) adopted is a trade-off, such that the age conveniently allows for the presence RR Lyrae and carbon stars. The age range is acceptable for the RR Lyrae stars, but it is inconsistent with the evolutionary calculations for the carbon stars mentioned in Sect. 1.

Preliminary results, based on HST WFPC2 data, reported by Mighell et al. (1998) yielded $[Fe/H] \simeq -0.4$ for a 4 and 6 Gyr population¹. The presence of an even younger population could

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¹ A (small) revision of the age and metallicity is expected in the final results (Mighell 1998)

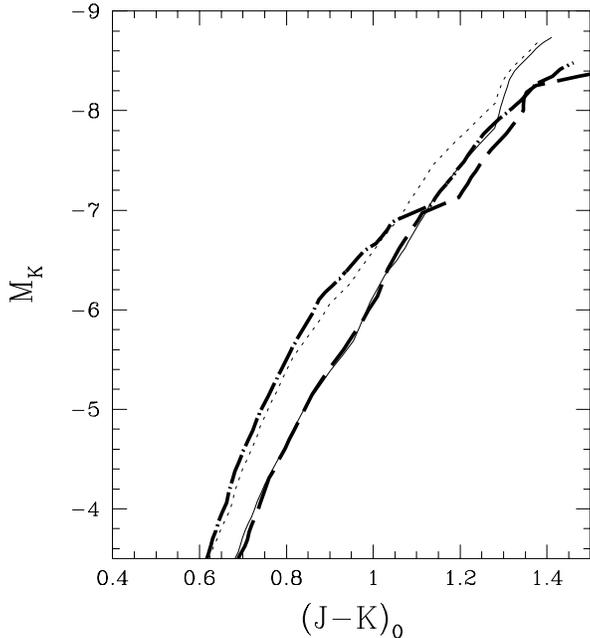


Fig. 1. A comparison between isochrones of 1 Gyr with and without dusty envelopes (carbon grain mixture B; Bressan et al. 1998). A dotted and a solid line are used for the dust free envelopes for $Z=0.004$ and $Z=0.008$; for respectively the same chemical compositions a dot, long dashed and a long dashed line are used for the isochrones with dusty envelopes

not be established due to the small solid angle covered by the WFPC2.

3. Isochrones: metallicity and age

3.1. Calibration

The photometric calibration of the AGB-phase of the isochrones is a cumbersome process. Ng (1997) gave in his analysis no consideration to the possibility that the photometric estimate of the metallicity might have been too high, which could be due to the uncertainties of the various transformations applied. In particular, the photometric calibration of the AGB-phase of the isochrones in the ESO photometric system (Bouchet et al. 1991). The photometric calibration of this phase was not specifically based on carbon stars. The dusty atmospheres of carbon stars should result in redder colours for a particular metallicity and NG (1997) LIKELY OVERESTIMATED THE METALLICITY OF THE ALRW91 C-STARS.

3.2. Metallicity from ‘dusty’ isochrones

Preferably one ought to calibrate correctly the AGB phase for the carbon stars. Unfortunately, an empirical calibration cannot be established in the ESO photometric system, because not enough data is available. An indication of the correction to be applied to the metallicity estimated by Ng (1997) for the ALRW91 C-stars can be obtained from the relative shift between the isochrones with and without dusty envelopes computed by Bressan et al.

(1998; mixture B with amorphous carbon grains) for the SAAO photometric system (Carter 1990). The shift is the same for the ESO photometric system.

Fig. 1 indicates that in the thermally pulsing (TP) AGB phase the $Z=0.004$ ‘dusty’ isochrone with a K -magnitude brighter than $M_K \simeq -7^m0$ is comparable to the $Z=0.008$ non-dusty isochrone. The isochrones start to diverge from each other when the superwind phase sets in at $M_K \simeq -8^m2$. The transition from the E-AGB (early-AGB) to the TP-AGB phase is likely smoother than presently modeled for the isochrones². Improvements are however beyond the scope of this paper. For our purpose Fig. 1 sufficiently demonstrates that the metallicity of the carbon stars in the TP-AGB phase are overestimated with non dusty isochrones. It is therefore argued that THE PHOTOMETRIC METALLICITY ESTIMATED BY NG (1997) FOR THE ALRW91 C-STARS SHOULD BE REVISED DOWNWARD TO $Z \simeq 0.004$.

3.3. Age

Low metallicity carbon stars with an extended carbon envelope might be confused with stars with less extended envelopes, which are either older but have the same metallicity or younger/same age and metal-richer. In addition, the envelope of the carbon star is enriched progressively during each thermal pulse. As a result the star becomes metal-richer (redder) after each thermal pulse for virtually the same age, i.e. the metallicity enrichment takes precedence over aging. The red edge of the carbon stars in the $(K, J-K)$ CMD, see Fig. 2b (Ng 1997), is therefore due to metal enriched carbon stars with the same age and initial metallicity as those found at the blue edge. This implies that the upper age limit of 1 Gyr given by Ng (1997) for the ALRW91 C-stars is wrong.

THE AGE OF THE ALRW91 C-STARS IS ABOUT 0.1 GYR³.

4. The velocity dispersion of the carbon stars

The broad velocity dispersion of $\sigma_{RV} = 113 \pm 14 \text{ km s}^{-1}$ (TR91) of the ALRW91 C-stars is apparently comparable with a Galactic Bulge dispersion. A Galactic Bulge membership leads to the mystery outlined in Sect. 1 and the question arises if there is an alternative explanation for the velocity dispersion, which does not imply a Bulge membership. In the following

² Inclusion of the long-lived subluminal stage for carbon stars (Boothroyd et al. 1993, Marigo 1998) would give in the K -magnitude range -5^m0 to -7^m0 a still unaccounted, but comparable redward shift of the dusty isochrones. At fainter luminosities the amount of the redward shift of the isochrone, if any, is unknown. An additional complication is that the envelope is chemically enriched during the TP-AGB phase. The enrichment of the envelope has also not been included in the generation of the isochrones.

³ Note that the present results suggest that the ALRW91 C-stars and the carbon stars in the Fornax dwarf spheroidal galaxy (Stetson et al. 1998) have a comparable age, but a different metallicity.

sub-sections various alternatives related to the Sagittarius dwarf galaxy are explored.

4.1. Are they member of the Sagittarius dwarf galaxy?

The average heliocentric radial velocity of the SDG stars is $V_R = 140 \pm 2 \text{ km s}^{-1}$, which corresponds in galactocentric coordinates with 172 km s^{-1} and a dispersion of $\sigma_{RV} = 11.4 \pm 0.7 \text{ km s}^{-1}$ (Ibata et al. 1995, 1997). The average radial velocity of the ALRW91 C-stars is $V_R = -44 \pm 20 \text{ km s}^{-1}$.

It is immediately evident from both the average velocities and their dispersion that the majority or even all of the ALRW91 C-stars cannot be member of the SDG.

Numerical calculation (see Edelsohn & Elmegreen 1997, Johnston et al. 1995 and Velázquez & White 1995) indicated that the velocity dispersion of the SDG stars does not change significantly on approaching and after crossing of the Galactic plane. Johnston et al. also demonstrated for moving groups with stars stripped from the dwarf galaxy, that their radial velocities change but that they do maintain a small velocity dispersion.

THE ALRW91 C-STARS CANNOT BE MEMBER OF THE SDG, NOR CAN THEY BE A TIDALLY STRIPPED MOVING GROUP.

4.2. Are they formed during crossing the disc?

4.2.1. In the galactic anti-centre direction?

If the SDG is moving towards the galactic mid-plane (Edelsohn & Elmegreen 1997 and references cited therein) then the most recent crossing occurred in the direction of the galactic anti-centre. At the present position this should have resulted in a small velocity dispersion similar to the one of the SDG stars. The broad velocity distribution of the C-stars does not support the possibility that these stars have been dragged along the SDG orbit from the anti-centre to its present position.

THE ALRW91 C-STARS WERE NOT FORMED IN THE GALACTIC ANTI-CENTRE DIRECTION.

4.2.2. On the recent approach towards the disc?

Hydrodynamical calculations of the interaction of the SDG with a gaseous H I disc by Ibata & Razoumov (1998) indicate that on approach of the SDG part of the H I layer is first pulled out of the disc due to the attractive influence of the dwarf galaxy. The temperature and density of the gas is at this stage not favourable to turn part of the gas into stars. This will change when the SDG gets nearer to the midplane and part of the material is compressed to densities high enough to sustain star formation. The SDG is located at about 6 kpc out of the Galactic midplane. This is too far away to invoke star formation.

THE ALRW91 C-STARS ARE NOT FORMED ON APPROACH OF THE GALACTIC MIDPLANE.

4.2.3. On a recent crossing?

Star formation could be invoked from the material residing in either the SDG and/or near the impact spot in the Galactic disc, when the SDG is nearby the galactic plane and crosses it. Stars formed from SDG material are SDG members and can be ignored in this discussion (see Sect. 4.1). Near the Galactic plane the SDG starts to compress the material that it pulled out from the disc earlier on its approach (see Sect. 4.2.2). Star formation is mainly triggered during and after the crossing of the Galactic plane⁴.

The SDG pushes material out of the Galactic disc. A small fraction of the newly formed stars is dragged along the orbit, while the majority of the material together with some young stars is moving away from the SDG. Part of these young stars are moving with different velocities towards us while another part of the stars are moving away from us. As a consequence, the distribution of radial velocities is considerably broader than expected from a SDG membership alone. The resulting distribution can even mimic a Bulge-like velocity dispersion.

Fig. 2 gives a schematic view of this process. If the motion of the dwarf galaxy is perpendicular to the galactic plane then the resulting radial velocity distribution after crossing the galactic plane will be symmetric around zero. The situation sketched in Fig. 2 implies that more stars will be found moving towards us, thus giving a negative value for the average radial velocity.

A RECENT STAR FORMATION EVENT, INDUCED BY THE CROSSING THROUGH THE GALACTIC PLANE OF THE SDG, CAN ACCOUNT FOR BOTH THE AVERAGE RADIAL VELOCITY AND THE VELOCITY DISPERSION OF THE ALRW91 C-STARS.

5. Motion

5.1. Which direction?

The models of the SDG orbit indicate (see Fig. 11 Ibata et al. 1997 and references cited therein), together with the *preliminary* proper motion reported by Irwin et al. (1996), that the SDG is moving towards the galactic mid-plane. On the other hand, the ALRW91 C-stars appear to form the evidence that the SDG already crossed the galactic mid-plane. Furthermore, the Ibata et al. orbit at low galactic latitudes appears to be inconsistent with the position obtained from RR Lyrae stars, see Fig. 4 and Sect. 5.2. A study of the Galactic globular cluster Palomar 5

⁴ According to Ibata & Razoumov (1998) there is substantial heating only in disc shocks and tidal tails which follow the SDG into the halo. They did not consider in their calculations star formation in the disc shocks and the tidal tails. However, their number density-temperature diagram (their Fig. 4) suggests that, following generally adopted star formation scenarios (see for example Carraro et al. 1998a and references cited therein), part of their gaseous material ($\log T \simeq 2-4$) should have been converted into stars. Moreover, their Fig. 2b indicate that just after the collision a combination of gaseous and stellar material is scattered in all directions. A detailed analysis of the radial velocities of the scattered material should confirm the feasibility of the scenario outlined above.

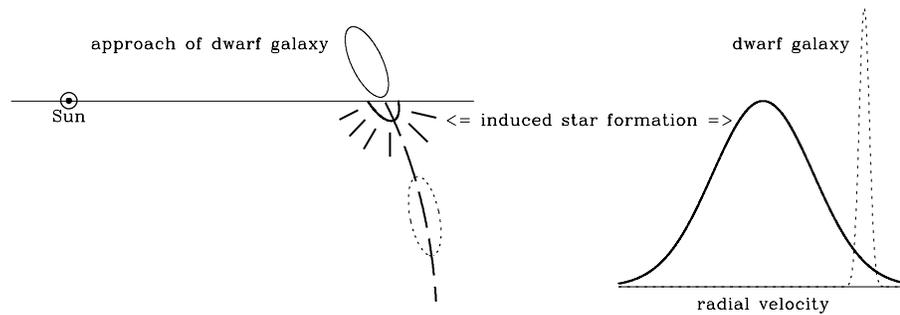


Fig. 2. Schematic view of the broad, bulge like, radial velocity distribution for the material from an induced star formation event, caused by the crossing from a dwarf galaxy through the Galactic mid-plane. Note that the majority of the new material will not be moving along the dwarf galaxy orbit. The dotted ellipse and the dotted line indicate respectively the current position and radial velocity (not on scale) for the dwarf galaxy

(Scholz et al. 1998) indicates further that the cluster is moving in the opposite direction⁵ with respect to the Ibata et al. orbital motion of the SDG.

Instead of looking for alternative explanations for the apparent contradictions, one should consider an independent determination of the proper motion with a zeropoint tied to one or more distant galaxies.

Recognizing that the present contradiction about the direction of motion of the SDG will not be solved until *definite* proper motions are available, and considering that reasonable grounds are given to use a lower weight for the *preliminary* value of the proper motion reported for the SDG, I assume for the remaining part of the paper that THE SDG IS NOT MOVING TOWARDS THE GALACTIC MIDPLANE, BUT CROSSED IT RECENTLY.

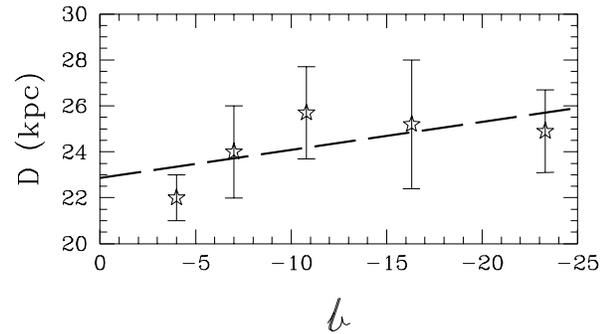


Fig. 3. The distance from RR Lyrae stars to the Sagittarius dwarf galaxy as a function of galactic latitude. The assumed RR Lyrae luminosity is $M_V = 0^m.6$. The long dashed line is determined from an unweighted least-squares fit and yields: $D(\text{kpc}) = 22.83 - 0.12b$.

5.2. Where did the last crossing occurred?

The impact position at the galactic mid-plane is obtained from an unweighted least-squares fit through the distances determined for the SDG from RR Lyrae stars (Alcock et al. 1997, Alard 1996, NS97, and Mateo et al. 1995&1996)⁶ as a function of the galactic latitude.

Fig. 3 displays the distances from the RR Lyrae stars as a function of galactic latitude. An unweighted least-squares fit gives $D(\text{kpc}) = 22.83 - 0.12b$. One thus obtains 22.8 kpc for the distance towards the disc impact position of the SDG. Adopting a Solar galacto-centric distance of $R_0 = 8.0$ kpc (Paczynski & Stanek 1998, Wesselink 1987) implies that THE CROSSING OF THE SDG THROUGH THE GALACTIC PLANE OCCURRED BEHIND THE GALACTIC BULGE AT 14.8 KPC FROM THE GALACTIC CENTRE.

⁵ The work of Scholz et al. demonstrates how the direction of space motion in Galacto-centric terms changed with respect to the results from the *preliminary* proper motion reported by Schweitzer et al. (1993).

⁶ Alcock et al. estimated the distance by scaling the $2^m.2$ difference between the Bulge and SDG, assuming implicitly $R_\odot = 8$ kpc. The remaining distances were determined with an adopted RR Lyrae luminosity: Alard, NS97, and Mateo et al. (1995) adopted $M_V = 0^m.6$, while Mateo et al. (1996) used $M_V = 0^m.8$. The latter gives an inhomogeneity in the distances. There is no reason to assume that the luminosity of the SDG RR Lyrae stars is different at various galactic latitudes. The distance of 27.3 kpc obtained by Mateo et al. (1996) was therefore adjusted to 24.9 ± 1.8 kpc.

5.3. Are the carbon stars related to the Galactic disc?

A consistency check is made for the suggestion that the SDG already crossed the Galactic plane and triggered a star formation event in the Galactic disc (Sect. 4.2.3). Such an event would imply that the disc metallicity at impact position has to be comparable with the photometric determination of the metallicity of the ALRW91 C-stars. To determine the disc metallicity at impact position one has to take the radial dependence of $[\text{Fe}/\text{H}]$ into account. Carraro et al. (1998b) determined from open clusters the radial metallicity gradient in different age ranges. For the clusters younger than 2 Gyr a present day gradient of $-0.063 \pm 0.013 \text{ dex kpc}^{-1}$ was obtained. For all clusters in the sample the average gradient is $-0.085 \pm 0.008 \text{ dex kpc}^{-1}$. The normalization at the Solar position is respectively $-0.18 \pm 0.12 \text{ dex}$ and $-0.15 \pm 0.08 \text{ dex}$. The disc metallicity at the crossing position thus obtained is $[\text{Fe}/\text{H}] = -0.61 \pm 0.20$ ($Z \simeq 0.0050$) or $[\text{Fe}/\text{H}] = -0.73 \pm 0.10$ ($Z \simeq 0.0035$) with respectively the present day and the average radial metallicity gradient.

Irrespective of the present day or average metallicity gradient it is estimated that THE DISC METALLICITY AT THE CROSSING POSITION IS $Z \simeq 0.0045 \pm 0.0010$. WITHIN THE UNCERTAINTIES THE GALACTIC DISC METALLICITY AT THE IMPACT POSITION IS THE SAME AS METALLICITY OF THE ALRW91 C-STARS (Sect. 3.2).

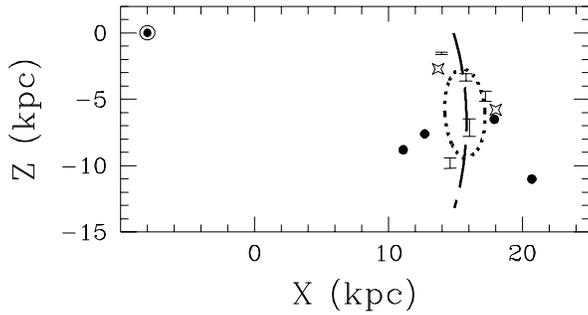


Fig. 4. The course (long dashed line) of the Sagittarius dwarf galaxy (dotted ellipse) projected on the $x - z$ plane. The Sun (\odot) is positioned at $(-8, 0)$. The error bars indicate the average location of the RR Lyrae stars displayed in Fig. 3. Skeletal crosses are used for two carbon stars (one Mira variable, see Whitelock 1998; one semiregular variable, see NS97 and Schultheis et al. 1998), and filled dots are used for the four globular clusters associated with Sagittarius dwarf galaxy (Da Costa & Armandroff 1995, Ibata et al. 1997)

5.4. Are the carbon stars near Sagittarius dwarf galaxy?

Another point to examine is how far the ALRW91 C-stars have moved from the impact since the crossing through the Galactic plane of the SDG. The C-stars were accelerated out of the Galactic midplane to their present average radial velocity of -44 km s^{-1} . In 0.1 Gyr they could have traveled about 4.4 kpc towards us. The actual distance traveled is considerably less, say $\sim 2.2 - 3.1$ kpc, because the C-stars had a considerable smaller velocity in the past. The traveled distance is within the 10% – 15% uncertainty of the 22.8 kpc distance to the impact position.

The velocity dispersion of the C-stars provides further an indication about the average separation. Taking into account that the dispersion is smaller, due to a combination of turbulence and a lower velocities in the past, the separation is estimated to $\sim 5.6 - 8.0$ kpc.

This can be compared with the distance between 2 of the 4 globular clusters associated with SDG is about 10 kpc, i.e. Terzan 8 at 21.1 kpc and Arp 2 at 31.0 kpc (Da Costa & Armandroff 1995).

The distance between the two carbon stars with well determined periods⁷ is on the other hand about 5 kpc, i.e. 21.9 kpc for a carbon semiregular variable (NS97, Schultheis et al. 1998 and 26.7 kpc for a carbon Mira (Whitelock 1998). The separation between the ALRW91 C-stars is from the above consideration within acceptable limits.

THE ALRW91 C-STARS ARE STILL AT A DISTANCE RELATED WITH THE SDG.

⁷ Note that up to date no carbon semiregulars or Miras with well determined periods and luminosities have been reported, for which the period-luminosity relation unambiguously places them at a Galactic Bulge distance.

5.5. ALRW91 C-stars = SDG C-stars?

Ibata et al. (1995) identified four new carbon stars in a field skimming over the Galactic Bulge. The radial velocities of the stars confirmed their membership to the SDG. Their average $(J - K)_{0, \text{saa0}}$ colour is $1^m 40$. The average $(J - K)_{0, \text{eso}}$ colour for the ALRW91 C-stars is $0^m 85$. The colour difference indicates that there should be marked differences between the ALRW91 and the SDG C-stars⁸, because comparable colours are expected if they originated from the same star formation event.

The difference between the two groups is an indication for differences in age and metallicity. The SDG C-stars should belong to a stellar population with an age comparable or younger than ~ 4 Gyr. Only the youngest stellar population identified thus far for the SDG matches this constraint: the population has an age of 4 Gyr and a metallicity around $Z \simeq 0.008$ (Mighell et al. 1998). This is significantly different from the metallicity and age obtained for the ALRW91 C-stars: $Z = 0.004$ and 0.1 Gyr (see Sects. 3.2 & 3.3).

THE ALRW91 C-STARS \neq THE SDG C-STARS: THE SDG C-STARS ARE OLDER AND METAL-RICHER.

6. Challenges

6.1. More carbon stars wanted

It will become very important to increase the sample size of the C-stars related to the SDG. Ng (1997) argues that still a considerable number of C-stars could be found in the databases with long period variable stars from the various micro-lensing projects (see the contributions described in Ferlet et al. 1997).

The distances of these stars can be obtained from their periods and K-band luminosities. The velocity dispersion of a significant number of carbon Miras & semiregular variables located at a distance comparable to the SDG will provide an independent verification of the hypothesis that the ALRW91 C-stars are the result of an induced star formation event (see Sect 4.2.3). Note that special care should be taken to avoid mixing the older, metal-richer SDG carbon stars with the essentially younger ALRW91-like C-stars⁹

6.2. Comparison with theoretical models

The ALRW91 & the SDG C-stars offer a great opportunity to study along the same line of sight two distinct populations of carbon stars (Sect. 5.5). The distribution of both the ALRW91 and SDG C-stars ought to be compared with the theoretical models from Marigo (1998) using for each group respectively

⁸ Note that the semiregular carbon variable, mentioned in Sect. 5.4, belongs to the ‘blue’ group, while the carbon Mira is clearly related to the ‘red’ group of carbon stars.

⁹ A very young age of ~ 0.1 Gyr for the ALRW91 C-stars would further anticipate in the microlensing databases the presence of a considerable number of Cepheids. In particular the anomalous faint Cepheids are interesting, due to a possible analogy with the former $2^m 5$ mystery of the ALRW91 C-stars.

the SMC and LMC metallicity. Moreover, the difference in metallicity and the similarity in age between the ALRW91 C-stars and those from the Fornax dwarf galaxy (Stetson et al. 1998) provides furthermore the possibility to tune the theoretical models to even lower metallicities.

Such a comparison would provide an independent verification of the age of each group of C-stars and support the assertion that the ALRW91 C-stars did form from material originating from our Galactic disc.

It is not clear what kind of event lead to the formation of the SDG C-stars ~ 4 Gyr ago. It is possibly a time-stamp of the encounter with the LMC which deflected the SDG in a closer orbit around our Galaxy (Zhao 1998). This encounter should have left in the LMC traces of a population of carbon stars with a comparable age.

6.3. Radial velocities of young stars

In Sect. 4.2.3 it is mentioned that the hydrodynamical calculations of the interaction between the SDG and the Galactic H I disc (Ibata & Razoumov 1998) provide an indication that, after a collision of the SDG with the Galactic plane, gaseous and stellar material will be scattered around in all directions. The scattering results in a small number of young stars in the CMDs from Marconi et al. (1998, see also Fig. 3 Ng 1997). A comparison of the velocity dispersion between the ALRW91 C-stars and the young stars found at a SDG related distance should provide an independent verification of the induced star formation scenario suggested in this paper.

6.4. Chemo-dynamical formation models

The models thus far consider only the gravitational interaction between the Galaxy and the SDG (Ibata & Lewis 1998, Ibata & Razoumov 1998, and Nair & Miralda-Escudé 1998), but do not take into account an encounter, induced, star formation event. Improved models should therefore be employed to trace the stars from such an event.

The SDG offers the opportunity to study in great detail encounter induced star formation events. Chemo-dynamical models (Carraro et al. 1998a, Gerritsen 1997) should be explored, which take into account the induced star formation when a SDG like object crosses our Galactic disc, to determine when star formation occurs, when carbon stars will emerge, and to determine to which extent the newly formed stars can be dragged along the orbit.

As an aside, induced star formation due to the crossing of a dwarf spheroidal galaxy through the galactic mid-plane might be one of the processes responsible for the elusive nature of the so-called halo carbon stars (see Groenewegen et al. 1997 and references cited therein). Hydrodynamical calculations of the interaction between the SDG and the Galactic H I disc (Ibata & Razoumov 1998) indicate that after a collision material from the H I disc is pulled/pushed out of the plane to ~ 10 kpc heights. i.e. comparable to the heights of the halo carbon stars. This material is partly made up out of stars (see Sect. 4.2.3)

results in a prominent signature and remains clearly visible for at least half an orbit.

7. Summary

The results obtained from the analysis by Ng (1997) of the hypothesis that the ALRW91 C-stars are located at a SDG related distance have been improved.

- The metallicity of the ALRW91 C-stars is $Z \simeq 0.004$.

- The age of the ALRW91 C-stars is ~ 0.1 Gyr.

In this paper the average velocity and the velocity dispersion of the ALRW91 C-stars were taken into consideration. They added the conditions that the stars

- cannot be member of the SDG;

- are not a tidally stripped moving group;

- were not formed on the approach of the SDG towards the Galactic midplane;

- have to be formed during a recent crossing of the SDG through the Galactic plane at about 14.8 kpc behind the Galactic Bulge.

In addition, a comparison of the near-infrared photometry between the SDG & the ALRW91 C-stars indicated that they do not originate from the same star formation event: the SDG C-stars are older and metal-richer than the ALRW91 C-stars.

The condition that the SDG must have crossed the Galactic plane will remain a point of dispute until *definite* proper motions are obtained with the HST or GAIA (Global Astrometric Interferometer for Astrophysics).

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