Mem. S.A.It. Suppl. Vol. 3, 147
© SAIt 2003

Memorie della
Supplementi

Our nearest neighbour is metal-rich *

P. Bonifacio[1], L. Sbordone[2,3] and G. Marconi[3]

[1] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy
[2] Università Tor Vergata, via della Ricerca Scientifica 1, 00133 Roma, Italia
[3] European Southern Observatory, Casilla 19001, Santiago, Chile

Abstract. We report our recent results on the abundance ratios in our nearest neighbour: the Sgr dwarf spheroidal. Based on high resolution spectra obtained with UVES at the the Kueyen-VLT 8.2m telescope we measured abundance ratios for 12 giants in Sgr. The dominant population in our sample is of almost solar metallicity and characterized by an underabundance of $\alpha-$process elements with respect to iron. The lack of $\alpha-$element enhancement persists also for the most metal poor star of the sample ([Fe/H]=-0.8), suggesting a star formation which has been slow or bursting. The spectroscopic metallicity allows to resolve the age-metallicity degeneracy and we derive from the colour-magnitude diagram of the galaxy a very young age, of the order of 1 Gyr, or younger. The high metallicity and young age seem to point to a scenario in which star bursts are triggered by the passing of Sgr through the Galactic disc.

Key words. Stars: abundances – Stars: atmospheres – Galaxies: abundances – Galaxies: evolution – Galaxies: dwarf – Galaxies:individual Sgr dSph

1. Introduction

Our nearest known neighbour in the Local Group is the Sagittarius dwarf spheroidal galaxy (Ibata et al. 1994, 1995). The wide red giant branch suggests that the galaxy a dispersion in metallicity. We are conducting a study of the chemical composition of Sgr giants using high resolution spectra collected using the UVES spectrograph at the VLT-Kueyen 8.2m telescope Bonifacio et al. (2000, 2003). The sample now consists of 12 giants with previously determined radial velocity membership (Bonifacio et al. 1999; Bonifacio 1999), for which we have determined abundances of O, Mg, Si, Ca and Fe.

2. Observations and analysis

The data of Bonifacio et al. (2000) and Bonifacio et al. (2003) have been obtained with a similar spectrograph setting. The main difference being is that Bonifacio et al. (2003) used the dichroic mode DIC1 to obtain also blue spectra, which, however have not yet been analyzed. All the

Send offprint requests to: P. Bonifacio
* Based on observations obtained with UVES at VLT Kueyen 8.2m telescope in program 67.B-0147
Correspondence to: bonifaci@ts.astro.it

Table 1. Abundance ratios

Star	V	$(V - I)_0^c$	$T_{\rm eff}$ K	log g cgs	ξ kms^{-1}	[Fe/H]	[O/FeII]	[Mg/Fe]	[Si/Fe]	[Ca/Fe]
432	17.55	0.965	4818	2.30	1.3	−0.83	+0.01	−0.01	−0.06	−0.24
628	18.00	0.928	4904	2.50	2.0	−0.22	−0.16	−0.06	−0.02	−0.22
635	18.01	0.954	4843	2.50	1.8	−0.33	−0.02	−0.05	−0.14	−0.26
656	18.04	0.882	5017	2.50	1.6	−0.17	−0.18	−0.24	−0.09	−0.18
709	18.09	0.917	4930	2.50	1.5	−0.02	−0.14	−0.25	−0.21	−0.22
716	18.10	0.902	4967	2.50	2.0	−0.12	−0.16	−0.24	−0.17	−0.32
717	18.10	0.872	5042	2.50	1.3	+0.09	−0.09	−0.16	−0.15	−0.21
772	18.15	0.947	4891	2.50	1.5	−0.21	−0.11	−0.23	−0.07	−0.26
867	18.30	0.933	4892	2.50	2.0	−0.56	−0.01	−0.13	+0.01	−0.08
879	18.33	0.965	4891	2.50	1.4	−0.28	$\leq$ 0.18	−0.05	−0.07	−0.21
894	18.34	0.940	4876	2.50	1.4	−0.04	+0.11	−0.34	+0.00	−0.20
927	18.39	0.937	4880	2.75	1.2	−0.03	−0.09	−0.29	−0.10	−0.20

red arm observations were obtained with a 1” slit, which provides a resolution of about 43000. Both in the observations of 1999 and in those of 2001 we used a 2 × 2 on-chip binning and the spectral range covered is 480-680nm with a small gap around 580nm, due to the gap in the UVES red arm CCD mosaic.

The spectra of each star were coadded and abundances determined from equivalent widths using the WIDTH code (Kurucz 1997). Effective temperatures were derived from the $(V - I)_0$ colour through the calibration of Alonso et al. (1999), we adopted the reddening $E(V - I) = 0.22$, $A_V = 0.55$ and a distance modulus $m - M = 16.95$ from Marconi et al. (1998). For each star we computed a model atmosphere using version 9 of the ATLAS code (Kurucz 1997) with the above derived $T_{\rm eff}$. We initially adopted log g = 2.5 for all stars, estimated from the location of the stars in the $(V-I)_0, M_v$ diagram, and then verified it with the FeI/FeII ionization equilibrium, for a few stars the adopted log g was slightly changed.

The derived abundances are listed in Table 1.

3. Results and discussion

Inspection of Table 1 suggests that the majority of the stars in our sample is metal-rich with $-0.5 \lesssim$ [Fe/H] $\lesssim 0.0$ and that the total observed spread is of the order of 1 dex. Photometric estimates of the metallicity found in the literature are significantly lower than our measurements (Marconi et al. 1998; Ibata et al. 1997). Comparison of the colour-magnitude diagram (CMD) of Sgr with isochrones in the above metallicity range imply that the metal-rich population is also young with an age of the order of 1 Gyr or perhaps even less. The existence of a young population is supported by the presence of a ”Blue Plume” in the CMD which would be the Main Sequence counter part of the stars observed on the Red Giant Branch (RGB). The number of Blue Plume stars is scarce, yet it seems far too large to be ascribed to Blue Stragglers only. Radial velocity measurements of the Blue Plume

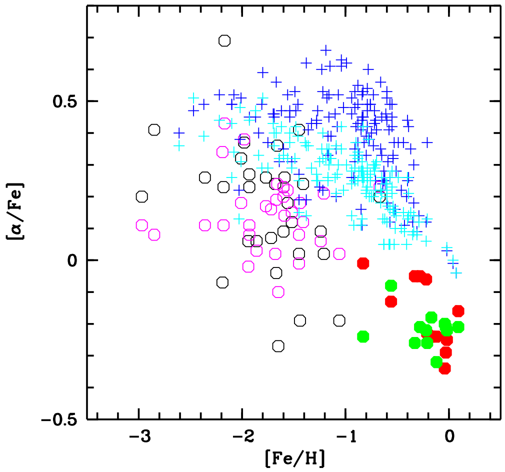

Fig. 1. The [Fe/H], [α/Fe] diagram: the red filled hexagons is [Mg/Fe] for our sample of stars in Sgr, the green filled hexagons is [Ca/Fe] for the same stars, black open hexagons is [Mg/Fe] for the stars in the Local Group dSphs, Draco, Ursa Minor, Sextans from Shetrone et al. (2001) and Carina, Sculptor, Fornax and Leo from Shetrone et al. (2003), magenta open hexagons is [Ca/Fe] for the same stars; [Mg/Fe] for Galactic stars from Gratton et al. (2003) is displayed as blue plus signs, while [Ca/Fe] for the same stars is displayed as cyan × signs.

will allow to ascertain if it effectively belongs to Sgr or not.

If we assume that there is a sizeable young population in Sgr the discrepancy between spectroscopic and photometric metallicity may be understood as an age bias. Marconi et al. (1998) used Galactic Globular clusters of known metallicity as a reference. Since these are an old population (of the order of 12 Gyr) the RGB is shifted towards bluer colours, with respect to a younger population of the same metallicity, this introduces a bias towards lower metallicities. This fact has already been noticed by Cole (2001) who used the slope of the RGB in an IR colour magnitude diagram, to estimate the metallicity of Sgr.

The abundance ratio of α elements to iron for all the stars in our sample, is slightly sub-solar or solar (within errors), even for the most metal-poor stars. In Fig. 1 we show the [Mg/Fe] and [Ca/Fe] ratios for our sample of Sgr stars together with the same ratios for stars in other Local Group dwarf Spheroidals (dSphs) (Shetrone et al. 2001; Shetrone et al. 2003) and in Galactic stars (Gratton et al. 2003). The impression conveyed from Fig 1 is that the dSphs lie on the same chemical evolutionary path and that this path is distinct from that followed by Galactic stars.

A value of the α to iron ratio lower than what found in Galactic stars of similar metallicity can occur if the galaxy is characterized by a low or bursting star formation rate (Marconi et al. 1994). In such cases the Type Ia supernovae have time to evolve and explode, enriching the gas mainly in iron, *before* a new generation of massive stars, which explode as Type II supernovae, enriches the gas in oxygen and other α elements. If this is the correct interpretation of the low α to iron ratios found in LG dSphs it is not clear why *all* the observed galaxies should be characterized by low or bursting star formation rates; especially considering that these galaxies span a range of five magnitudes in M_V from the most luminous (Sgr $M_V \sim -13.8$; van den Bergh 1999) to the faintest (Draco $M_V \sim -8.6$;van den Bergh 1999) .

For Sgr, however, there is a very natural explanation for a bursting star formation history. The orbit of Sgr is polar (Ibata et al. 1997) with a period of about 1Gyr and intersects the Galactic per orbit. The gas-dynamical simulations of Ibata & Razoumov (1998) suggest that the passage of Sgr through the Galactic disc is responsible for its warping and could possibly have affected the star formation history of the outer Galactic disc. One can therefore expect that these events have a similar effect on Sgr, with star bursts in Sgr triggered by its passage through the Galactic disc. The young population we find would then be the outcome of the last passage. The viability of this suggestion needs to be verified with dedicated dynamical simulations. A possible difficulty is the present-day lack of any detectable gas in Sgr (Burton & Lockman 1999). Quite unexpectedly the star burst scenario provides also a simple explanation for the Bulge C stars "mystery". The C stars observed in the direction of the Bulge and Sgr are about 2.5 mag too faint to be on the tip of the Asymptotic Giant Branch, where the carbon-star phenomenon is believed to take place (Blanco et al. 1978; Azzopardi et al. 1988). Ng (1997) suggested that these stars are in fact related to Sgr, rather than to the Bulge and thus have a distance modulus which is exactly 2.5 mag larger, solving the apparent paradox. The sample of C Bulge stars of Azzopardi et al. (1991) cannot belong to Sgr, since their radial velocities do not support membership. They could however be stars formed in the starburst triggered in the Galactic disc, at the location where it was disturbed by the passage of Sgr (Ng 1997, 1998). On the other hand also the starburst in Sgr would produce some stars which, in due time, evolve to be C stars, and these would explain the established Sgr C-stars (Ibata et al. 1995) and the candidates (Whitelock et al. 1996; Ng & Schultheis 1997), if confirmed.

We consider firmly established the existence of a sizeable population which is relatively metal rich, although it is not yet clear what is the fraction of the Sgr stars belong to it. This places Sgr out of the metallicity – luminosity relation which seems to hold for LG galaxies (van den Bergh 1999): Sgr is underluminous for its metallicity. In a similar way we consider established the fact that the ratio of α elements to iron is subsolar or solar.

We believe likely that the evolution of Sgr has been significantly affected by its interaction with the Milky Way, whether through the above proposed scenario of starbursts triggered by its passage through the Galactic disc, or otherwise. We expect new light on Sgr will be shed by the campaign which we are conducting using FLAMES at VLT (Pasquini et al. 2002).

References

Alonso, A., Arribas, S., & Martínez-Roger, C. 1999, A&AS, 140, 261

Azzopardi, M., Lequeux, J., & Rebeirot, E. 1988, A&A, 202, L27

Azzopardi, et al. 1991, A&AS, 88, 265

Blanco, B. M., Blanco, V. M., & McCarthy, M. F. 1978, Nature, 271, 638

Bonifacio P. 1999, in "From extrasolar planets to cosmology: the VLT Opening Symposium", J. Bergeron & A. Renzini eds, Springer-Verlag, Berlin, p. 338

Bonifacio P., Pasquini L., Molaro P., Marconi G., 1999 Ap&SS, 265, 541

Bonifacio P. et al. 2000, A&A, 359, 663

Bonifacio P., Sbordone L., Marconi G., Pasquini L., Hill V., 2003, A&A, submitted

Burton, W. B. & Lockman, F. J. 1999, A&A, 349, 7

Cole, A. A. 2001, ApJ, 559, L17

Gratton, R. et al. 2003, A&A in press, astro-ph/0303653

Ibata, R. A., Gilmore, G., & Irwin, M. J. 1994, Nature, 370, 194

Ibata, R. A., Gilmore, G., & Irwin, M. J. 1995, MNRAS, 277, 781

Ibata, R. A. & Razoumov, A. O. 1998, A&A, 336, 130

Ibata, R. A. et al. 1997, AJ, 113, 634

Kurucz, R. L. 1993, CD-ROM 13, 18

Marconi G., Matteucci F., Tosi, M. 1994, MNRAS, 270, 35

Marconi, G. et. al. 1998, A&A, 330, 453

Ng, Y. K. 1997, A&A, 328, 211

Ng, Y. K. 1998, A&A, 338, 435

Ng, Y. K. & Schultheis, M. 1997, A&AS, 123, 115

Pasquini, L. et al. 2002, The Messenger, 110, 1

Shetrone, M. D., Côté, P., & Sargent, W. L. W. 2001, ApJ, 548, 592

Shetrone, M. at al., 2003, AJ, 125, 684

van den Bergh, S. 1999, A&A Rev., 9, 273

Whitelock, P. A., Irwin, M., & Catchpole, R. M. 1996, New Astronomy, 1, 57