A common trend in the chemical evolution of Local Group dwarf spheroidals and Damped Ly α systems

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Abstract

We compare chemical abundances of Local Group dwarf spheroidals, obtained from recent UVES/VLT observations, and of high redshift Damped Lyman α systems (DLAs), corrected for dust effects. We focus, in particular, on the abundance ratio between α-capture elements and iron, α/Fe, a well known indicator of chemical evolution. Comparison of the data in the plane α/Fe versus Fe/H shows a remarkable similarity between the dwarf spheroidals and the DLAs, suggestive of a common trend in their chemical evolution. At any given metallicity these two distinct types of astronomical targets show α/Fe ratios systematically lower than those of Milky Way stars. In terms of chemical evolution models, this suggests that, on average, dSph galaxies and DLA systems are characterized by lower, or more episodic, star formation rates than the Milky Way.

1 Introduction

With the advent of 10-m class optical telescopes equipped with high resolution spectrographs, Local Group dwarf galaxies may now be observed on a star by star basis and abundance ratios measured with sufficient accuracy for probing their chemical evolution (see e.g. Shetrone et al. 2001). With the same type of instrumentation, detailed abundances can be obtained at high redshift for the class of quasar absorbers with highest HI column density, the Damped Lyman alpha (DLA) systems (see e.g. Prochaska et al. 2001). Evidence is accumulating that these absorbers originate in the interstellar gas of high redshift galaxies. Study of their abundances can be used to compare their chemical evolution properties with those of local dwarfs. In the hierarchical bottom-up scenario for galaxy formation, dwarf galaxies are the basic building blocks out of which larger galaxies are assembled. If this picture is correct, one expects to find a significant fraction of dwarf galaxies when looking at the high redshift Universe. Comparing the chemical abundances of local dwarfs with those of high redshift DLAs may provide clues in favour or against this scenario. In this contribution we compare abundances in Local Group dwarf spheroidals, described in the next section, with those DLA systems, described in Section 3.

2 LG dwarf spheroidals

We obtained abundances of Local Group galaxies using the UVES spectrograph fed by the Kueyen-VLT 8.2m ESO telescope. For two giants in the Sgr dSph galaxy we determined the detailed abundances using the UVES commissioning data (Bonifacio et al. 2000). Recently we have increased the sample by analysing ten more giants Bonifacio et al. (2003). The spectra have a resolution Δλ/λ ≃ 43000 and cover the range 480–680 nm. Each star was observed repeatedly and the final S/N ratio on the coadded spectrum was in the range 20–40 at 530 nm. Some examples of spectra are shown in Fig. 1. Effective temperatures were derived from the (V − I)0 colour of Marconi et al. (1998), through the cali-
Figure 1: Spectral region around the Fe I 616.5 nm and Ca I 616.6 nm lines for two stars of the Sgr dSph galaxy and for a comparison giant star of the Hyades.

The abundances were derived mainly from equivalent widths using the WIDTH code (Kurucz 1993), although some lines were treated with spectrum synthesis SYNTHE code (Kurucz 1993). In both cases ad hoc model atmospheres were computed with the ATLAS code. The surface gravities were adjusted to satisfy the iron ionization equilibrium, and were all around log g = 2.5, as expected from the location of the stars in the colour-magnitude diagram and the comparison with theoretical isochrones.

Two main results can be derived from our sample of 12 giant stars: (1) the Sgr dSph galaxy hosts a relatively metal-rich population, which in fact dominates our sample; (2) the α/Fe ratio is solar or sub-solar, even for the most metal-poor star of the sample, star # 432 with [Fe/H]=−0.83 and [α/Fe]∼ −0.1. This chemical pattern is clearly distinct from what observed in Milky Way stars of comparable metallicity. Both results can be seen in Fig. 2, where we plot the ratio [α/Fe] = 0.5 × ([Mg/Fe]+[Ca/Fe]) versus [Fe/H] for the twelve stars of our sample (solid circles) and for Milky Way stars (crosses). In Fig. 2 we also plot the same ratios measured in stars of other 7 Local Group dwarf spheroidals (open circles), collected from the literature (Shetrone et al. 2001, 2003). All together, the data of the 8 dwarf spheroidals show a remarkable continuity in the [α/Fe] versus [Fe/H] plane.

3 Damped Ly α systems

The most widely measured α/Fe ratio in DLA systems is Si/Fe, since both Si and Fe have several unsaturated transitions redshifted into the optical range (e.g. Prochaska et al. 2001). The Si/Fe ratios in DLAs can be significantly enhanced due to dust depletion and their interpretation in terms of chemical evolution requires a preliminary correction from dust effects (Vladilo 1998).

Recently we have presented a new method aimed at correcting interstellar abundances for dust depletion, taking into account possible variations of the chemical composition of the dust (Vladilo 2002). The method can be applied to interstellar measurements in galaxies with non solar composition and, in particular, to DLA systems. The method requires a determination of the column densities of Fe, Zn, and the element X for which the ratio X/Fe must be corrected. A guess of the intrinsic Zn/Fe ratio in the system is also required. The method has been tested in the SMC, where the interstellar ([Si/Fe],[Fe/H]) data show a large scatter (Welty et al. 2001) and differ from the typical stellar SMC values (Russell & Dopita 1992) as a consequence of dust depletion, which is known to affect the interstellar measurements. As shown in Fig. 3, the application of the method to the interstellar measurements brings together all the interstellar and stellar data of the SMC. This result indicates the importance and the validity of the dust correction method.

In Fig. 2 we plot the ([Si/Fe], [Fe/H]) data in DLA systems corrected for dust (triangles). The original measurements are based on spectra collected with the Keck and the VLT telescopes (see references in Vladilo 2002). The dust corrected data in Fig. 2 have been obtained assuming that the intrinsic Zn/Fe in
DLAs is slightly oversolar, $[\text{Zn}/\text{Fe}]=+0.1$ dex, as observed in Milky Way stars (Gratton et al. 2003). Should the intrinsic $\text{Zn}/\text{Fe}$ ratio be solar, the corrected $[\text{Si}/\text{Fe}]$ ratios would be lower by $\approx 0.1$ dex.

From Fig. 2 one can see that the $([\alpha/\text{Fe}], [\text{Fe/H}])$ data of DLAs follow the same trend shown by dwarf spheroidals of the Local Group.

4 Discussion

The distribution of the $([\alpha/\text{Fe}],[\text{Fe/H}])$ data points in Fig. 2 has several implications concerning the chemical evolution properties of dSph galaxies of the Local Group and DLA systems.

The remarkable continuity between our data points of the Sgr dSph (solid circles in Fig. 2) and the data of the other dSph galaxies collected from the literature (open circles) suggests that dwarf spheroidals lie on a similar evolutionary path, but some are more evolved than the others.

The similarity between local dwarf spheroidals (circles) and high redshift DLA systems (triangles) indicate that these two distinct types of objects share a common evolutionary path. This result is robust against variations of the input parameters in the dust correction procedure.

An origin of low redshift ($z \leq 1$) DLA systems in dwarf, compact and low surface brightness galaxies, with little contribution from spirals, was indicated by imaging studies (Le Brun et al. 1997; Rao & TURNSHEK 1998). The present analysis of abundance ratios indicates that also at high redshift ($z \geq 1.5$) most DLA systems behave similarly to local dwarfs as far as the chemical evolution is concerned. The $[\alpha/\text{Fe}]$ values tend to decrease with metallicity for each class of objects considered in Fig. 2 (dSph stars, Milky Way stars, DLA systems). Chemical evolution models can explain such a decrease in terms of a time delay between an early enrichment due to type II SNe, rich in $\alpha$-capture elements, and a subsequent enrich-
ment due to type Ia SNe, rich in Fe-peak elements (see e.g. Calura et al. 2003). The decrease of $\alpha$/Fe is predicted to be faster for galaxies with high rates of star formation and slower for galaxies with low rates, or episodic star formation. In this context the lower $\alpha$/Fe values of dSph stars and DLA systems, compared to those of Milky Way stars at the same level of metallicity, may reflect a difference in the star formation rate, the Milky Way having been characterized by a higher or more continuous star formation rate than dSph galaxies and DLA systems.

5 Conclusions

We compared $\alpha$/Fe abundance ratios measured in stars of Local Group dSph galaxies, in stars of the Milky Way, and in DLA systems. The $\alpha$/Fe ratios of the Local Group include our recent measurements of 12 stars in the Sgr dSph galaxy. By adding up literature data, a total of 8 dwarf spheroidal galaxies were considered. The $\alpha$/Fe ratios of the DLA systems were corrected for dust depletion with a method recently developed by us and tested in the ISM of the SMC. The sample includes 22 DLA systems with Si/Fe data. The analysis of the data in the plane $\alpha$/Fe versus Fe/H shows a remarkable similarity between the Local Group dwarf spheroidals and the high-redshift DLA systems. This result indicates that these two distinct types of galaxies share a common trend of chemical evolution.

The similarity between high-redshift DLA systems ($z \geq 1.5$) and local dwarfs derived from the abundance analysis is in line with the results of imaging studies of low-redshift DLA systems ($z \leq 1$) which indicate that most DLA galaxies are dwarf, compact, or low surface brightness galaxies, with little contribution from spirals.

dSph stars and DLA systems have $\alpha$/Fe ratios systematically lower than those of Milky Way stars of same metallicity. In terms of the time delay interpretation of chemical evolution models, this result suggests that, on average, the dSph galaxies and DLA systems are characterized by lower (or more episodic) star formation rates than the Milky Way. This suggests that, with possible exceptions, DLAs do not represent the young stage of Milky-Way type spirals. In addition, it is unlikely that DLAs could be major building blocks out of which the proto-Milky Way was formed, considering that the vast majority of Milky-Way stars show significantly enhanced $\alpha$/Fe ratios at low metallicity.

References

Alonso, A., Arribas, S., & Martínez-Roger, C. 1999, A&AS, 140, 261
Bonifacio P., Hill V., Molaro P., Pasquini L., Di Marcantonio P., Santin P. 2000, A&A, 359, 663
Bonifacio P., Sbordone L., Marconi G., Pasquini L., Hill V. 2003, A&A submitted
Calura, F., Matteucci, F., & Vladilo, G., 2003, MNRAS, 340, 59
Gratton, R.G., Carretta, E., Claudi, R., Lucatello, S., & Barbieri, M. 2003, A&A, 404, 187
Kurucz, R. L. 1993, CD-ROM 13, 18
Le Brun, V., Bergeron, J., Boisse, P., & Deharveng, J.M. 1997, A&A, 321, 733
Luck, R. E. & Challener, S. L. 1995, AJ, 110, 2968
Marconi, G., Buonanno, R., Castellani, M., et al. 1998, A&A, 330, 453
Prochaska, J.X., Wolfe, A.M., Tytler, D., et al. 2001, ApJS, 137, 21
Rao, S.M., & Turnshek, D.A. 1998, ApJ, 500, L115
Russell, S.C. & Dopita, M.A. 1992, ApJ, 384, 508
Shetrone, M., Côté, P., Sargent, W.L.W. 2001, ApJ, 548, 592
Shetrone, M., Venn, K.A., Tolstoy, E., Primas, F., Hill, V., & Kaufer, A. 2003, AJ, 125, 684
Vladilo, G. 1998, ApJ, 493, 583
Vladilo, G. 2002, A&A, 391, 407
Welty, D.E., Lauroesch, J.T., Blades, J.C., Hobbs, L.M., & York, D.G. 2001, ApJ, 554, L75