The Extreme Ends of the Metallicity Distribution in dSph Galaxies

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Abstract. This paper reviews recent abundance results of local dSph giants. All dSph systems seem to show evidence of slow star formation rates, compared to the Milky Way, based on the most metal-rich stars exhibiting low [even-Z/Fe] ratios and high [s-process/r-process] ratios. The most metal-poor stars in the Draco, Ursa Minor, Sextans and Sculptor dSphs seem to show a split in their light even-Z, Mg and O, and the heavier even-Z, Ca and Ti, abundance ratios, where the light even-Z are halo like and the heavier even-Z elements exhibit sub-halo abundance ratios. This split remains a mystery. A review of the first dSph abundance results from FLAMES+GIRAFFE on the VLT and HRS on the Hobby-Eberly Telescope shows that the study of chemical evolution of dSph galaxies is rapidly moving out of infancy and into an era requiring very large surveys and/or targeted studies.

1 The Most Metal-rich dSph Stars

The most metal-rich stars in dwarf spheroidals (dSph) have been shown to have significantly lower even-Z abundance ratios than stars of similar metallicity in the Milky Way (MW). In addition, the most metal-rich dSph stars are dominated by an s-process abundance pattern in comparison to stars of similar metallicity in the MW. This has been interpreted as excessive contamination by Type Ia supernovae (SN) and asymptotic giant branch (AGB) stars (Bonifacio et al. 2000, Shetrone et al. 2001, Smecker-Hane & McWilliam 2002). By comparing these results to MW chemical evolution, Lanfranchi & Matteucci (2003) conclude that the dSph galaxies have had a slower star formation rate than the MW (Lanfranchi & Matteucci 2003). This slow star formation, when combined with an efficient galactic wind, allows the contribution of Type Ia SN and AGB stars to be incorporated into the ISM before the Type II SN can bring the metallicity up to MW thick disk metallicities.

Recent abundance ratio work in this field falls into two categories. The first category has been investigations into aspects of metal-poor AGB and Type Ia SN yields and their relationship to the chemical evolution in the dSph galaxies, e.g. McWilliam et al. (2003), Venn et al. (2004), McWilliam & Smecker-Hane (2005). In these works the abundances of specific elements are compared to

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1 The Hobby-Eberly Telescope (HET) is a joint project of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximilians-Universität München, and Georg-August-Universität Göttingen. The HET is named in honor of its principal benefactors, William P. Hobby and Robert E. Eberly.
predictions of yields of low metallicity SN and AGB stars. While the origins of
these elements, such as Mn, Cu and Y, may seem slightly esoteric, these types
of analyses will help constrain future models of SN yields.

The second category of dSph abundance investigations has been attempts to
gain large enough samples to accurately model the extent of the chemical evolution,
the relative contributions the Type Ia and AGB yields and to what extent
galactic winds have played a role in the chemical evolution. The new instruments
that have come on-line in the last year have increased the multiplexing capabilities
of these surveys. As an example, Figure 1 shows preliminary results from the
Dwarf Abundance and Radial velocity Team (DART) ESO large program; using
UVES FLAMES+GIRAFFE on a sample of Sculptor dSph giants, Hill (private
communication, 2005) collected nearly 100 stellar spectra, a sample larger than
all of the literature high resolution dSph surveys combined. This survey will be
able to show subtle declines and trends that the other surveys could never de-
tect. The decline seen in \([\text{Ca/Fe}]\) with increasing \([\text{Fe/H}]\) reported by Shetrone et
al. (2003) and Geisler et al. (2004) are easily detected. The spread in \([\text{Ca/Fe}]\) at
a given metallicity is being investigated by DART.

2 The Most Metal-poor dSph Stars

In a closed box or leaky-box chemical evolution model the most metal-poor stars
would have formed before the majority of the Type Ia SN or the AGB stars
were significant contributors to the the ISM. Thus, the abundances of these very
metal-poor stars should be excellent surrogates of the Pop III and very metal-
poor Pop II Type II SN products held in the dSph gravitational potential. This
last point is important because if the yields of some masses of Type II SN are
lost from the dSph gravitational potential then this might significantly impact
abundance ratios found in the next generation of dSph stars.

The first papers in this field suggested that the overall alpha abundances
found in the most metal-poor dSph stars are not similar to those found in the halo. However, a more detailed analysis of the individual elements including
corrections for differences in log gf values has shown that the O and Mg abundances are consistent with those found in the MW halo, while the Ca and Ti abundances are systematically lower than those in the MW halo, see figure 1, 2
and 6 in Shetrone (2004). This can also be seen in Figure 1 which shows that
the most metal-poor Sculptor stars have \([\text{Ca/Fe}]\) ratios less than 0.2 dex while
the halo median at this metallicity is roughly 0.15 dex larger.

The difficulty with studies of the most metal-poor dSph stars is actually
finding the most metal-poor stars. Not only are these stars less numerous than
their more metal-rich counter parts, but their spatial distribution is larger than
the more metal-rich stars, e.g. Tolstoy et al. (2004), Palma et al. (2003), Har-
beck et al. (2001), Majewski et al. (1999). The use of high resolution multi-object
spectrographs such as FLAMES becomes less efficient in the search for the most-
m metallic poor stars because of the large spatial extent, rarity and huge background
contamination. For these types of studies targeting single star high resolution
spectral follow-up to photometric or low resolution surveys can be more appropriate.

One star analyzed in the Shetrone et al. (1998) survey was found to be very metal-poor but with fairly low overall-alpha abundances. Unfortunately, due to the low S/N and low metallicity many of the elements had upper limits and large error bars. This single star, Draco 119, was re-observed by Fulbright et al. (2004) with much higher S/N. They were able to confirm that the Mg abundance was halo like while the Ca and Ti abundances were lower than those found in the halo by a few tenths of dex. Even more remarkable were the upper limits found for the neutron capture elements. Fulbright et al. found upper limits for [Ba/Fe] of 1 dex lower than MW halo giants of similar metallicity, and, even more amazingly, the upper limit for [Sr/Fe] was found to be nearly 2 dex lower than similar MW giants. This begged the question: is the Draco 119 abundance pattern unique, ie, due to some strange inhomogeneous mixing event, or is this pattern found in all very metal-poor Draco stars.

A search for equally metal-poor Draco stars, using the Hobby-Eberly telescope, did not turn up any Draco giants as metal-poor as Draco 119; but it did turn up a few stars just a few tenths more metal-rich. By integrating long enough to detect the strong red Ba lines in these stars using the HRS on the Hobby-Eberly telescope, Shetrone et al. (2005) did not find extremely neutron capture poor stars, see Figure 2. The abundance pattern of Draco 119 appears to be a due to inhomogeneous mixing and is not found in all very metal-poor Draco stars.

I would like to thank Kim Venn, Andy McWilliam, Verne Smith, Jon Fulbright and the DART for preprints and invaluable discussions. I would also like to thank the NSF for support through AST-0306884; and summer REU intern John Moore and the team at the HET for their assistance in bringing these results to press.

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Fig. 1. An example of the new data sets coming available with the VLT+FLAMES. This data, from Hill (private communication, 2005) exhibits the steep decline of [Ca/Fe] with increasing [Fe/H] seen in all dSph. In addition, the most metal-poor stars do not exhibit the typical MW halo ratio near 0.3 dex.

Fig. 2. The abundance ratio of Ba from the Shetrone et al. (1998), squares, Fulbright et al. (2004), circle, and Shetrone et al. (2005), triangles shown plotted against their derived metallicities. The upper limit from Fulbright et al. (2004) is more than an order of magnitude lower than that of the slightly more metal rich Draco dSph stars or comparable metallicity MW halo stars, small symbols.