Dwarf Galaxies: From the Deep Universe to the Present
Proceedings IAU Symposium No. 344, 2019
K. B. W. McQuinn & S. Stierwalt, eds.

doi:10.1017/S1743921318006804

A wide angle chemical survey of the Sagittarius dwarf Spheroidal galaxy

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Abstract. We present the status of an ongoing project to map the detailed chemical abundances of stars across the main body of the Sagittarius dwarf Spheroidal galaxy (Sgr dSph). The Sgr dSph is the closest known dwarf galaxy, and is being tidally destroyed by its interaction with the Milky Way (MW), leaving behind a massive stellar stream. Sgr dSph is a chemically outstanding object, with peculiar abundance ratios, clear center-outskirts abundance gradients, and spanning more than 3 orders of magnitude in metallicity. We present here detailed abundances from UVES@VLT spectra for more than 50 giants across 8 fields along the major and minor axes of Sgr dSph, and 5 more outside the galaxy main body, but possibly associated to its stellar stream.

Keywords. galaxies: abundances, galaxies: dwarf, (galaxies:) Local Group, Galaxy: halo, Galaxy: abundances

1. Introduction

The Sagittarius dwarf Spheroidal galaxy (Ibata *et al.* 1995) is the closest dSph to the Sun (26.3 kpc Monaco *et al.* 2004), and is being tidally destroyed by its interaction with the Galaxy, while moving on a quasi-polar, short period orbit around it, and losing its stellar content on a prominent stellar stream, multiple wrappings of which can be observed across the whole sky (Majewski *et al.* 2003; Law & Majewski 2010). The still-bound Sgr dSph "main body" extends several degrees along the major axis (Majewski *et al.* 2003), its center of mass corresponding to the massive globular cluster NGC 6715 (M54, Bellazzini *et al.* 2008), with 4 more clusters being by now confirmed members of the Sgr dSph system: Terzan 7, Terzan 8, Arp 2, and Palomar 12 (Sbordone *et al.* 2005, 2007, and references therein), while two more, NGC 5634 and NGC 5053, are suspected, of being also associated to it (Sbordone *et al.* 2015; Tang *et al.* 2018; Bellazzini & Ibata 2018).

Sgr dSph hosts in its core a young (age $<$ 2GYr), metal rich ([Fe/H]$\geqslant$0) stellar population, characterized by a number of chemical oddities, including underabundant α elements, underabundant Na, and high [Ba/Y], [La/Y] ratios (Sbordone *et al.* 2007; McWilliam *et al.* 2013, and references therein). Many of these properties are shared to different degrees with other dSph in the Local Group (Tolstoy *et al.* 2009).

2. Observations, analysis, and results

Most detailed chemical studies of the Sgr dSph main body have been restricted to a tiny area in the core, within, and immediately outside of M54. We thus started a study

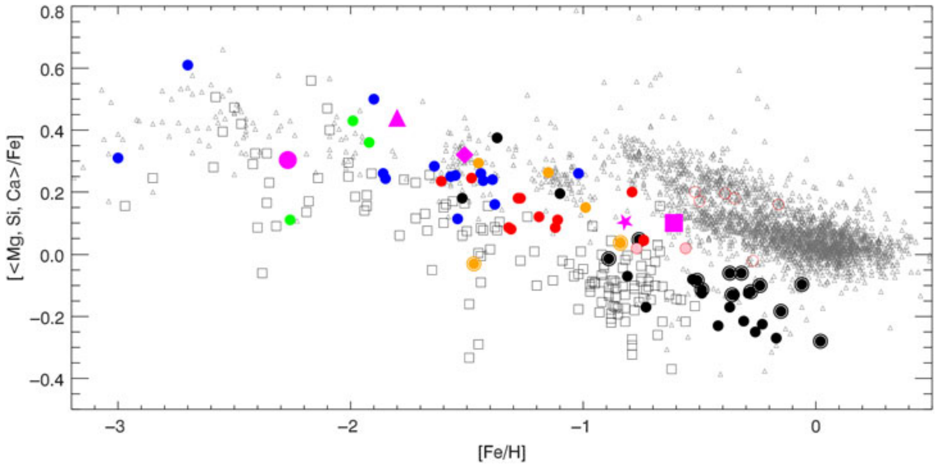

Figure 1. The [α/Fe] ratios, plotted as the average of [Mg/Fe], [Si/Fe], and [Ca/Fe] for our data and a number of comparison samples. See text for details.

to identify and analyze chemically Sgr dSph members on a number of fields along the major and minor axis of the Sgr dSph main body.

The fields were imaged and followed up via low-resolution spectroscopy (Giuffrida *et al.* 2010,B), to derive suitable member candidates, that were reobserved with FLAMES@VLT (Pasquini *et al.* 2000). We present here only the results from the fibers linked to the red arm of UVES@VLT (Dekker *et al.* 2000), observed in the 480nm-680nm spectral range at a resolution of R=47000. Together we reanalyzed the core stars presented in Monaco *et al.* (2005) and the ones in Sbordone *et al.* (2007). Some of the Giraffe targets that were confirmed as low metallicity members were reobserved with UVES in slit mode (Hansen *et al.* 2018), and are also included here. Finally, five MW Halo stars, identified in the Gaia ESO survey (GES, Gilmore *et al.* 2012) as having kinematical and chemical characteristics compatible with an accreted origin (Ruchti *et al.* 2015), were also observed with UVES. Two of them are positionally compatible with a membership in the Sgr stream. All the spectra were analyzed homogeneously by means of the MyGIsFOS code (Sbordone *et al.* 2014), employing the latest set of atmosphere models and atomic/molecular data from GES (Heiter *et al.* 2015), although heavy element abundances for the Hansen *et al.* (2018) sample were not derived by means of MyGIsFOS.

In Fig. 1 we present the results for the [α/Fe] ratios versus [Fe/H] for the Sgr dSph data together with a few comparison samples. Small open grey triangles represent the UVES MW sample from the 3rd GES public data release and Cayrel *et al.* (2004). Open black squares are stars in other Local Group (LG) dSph (Venn *et al.* 2004; Geisler *et al.* 2005; Letarte *et al.* 2006; Letarte 2007; Koch *et al.* 2008). Large magenta symbols are average values for globular clusters associated with Sgr dSph: square, Terzan 7 (Sbordone *et al.* 2005); star, Palomar 12 (Sbordone *et al.* 2007); diamond, M54 (Carretta *et al.* 2014); triangle, Arp 2 (Mottini *et al.* 2008); circle, Terzan 8 (Carretta *et al.* 2014). Other filled circle symbols refer to the Sgr dSph data presented in this work. Core samples: black with outline, Sbordone *et al.* (2007), black simple, Monaco *et al.* (2005). Ouskirts samples: red, FLAMES-UVES data; blue, UVES slit data (Hansen *et al.* 2018). Green, NGC 5634 and 5053 (Sbordone *et al.* 2015). Finally, the orange symbols represent the five Halo stars derived from Ruchti *et al.* (2015), the two outlined being the ones comparible with the Sgr stream.

The Sgr dSph appears here to follow a trend broadly common to all the LG dSph: they display lower [α/Fe] than the MW stars of similar metallicity. This is interpreted as the

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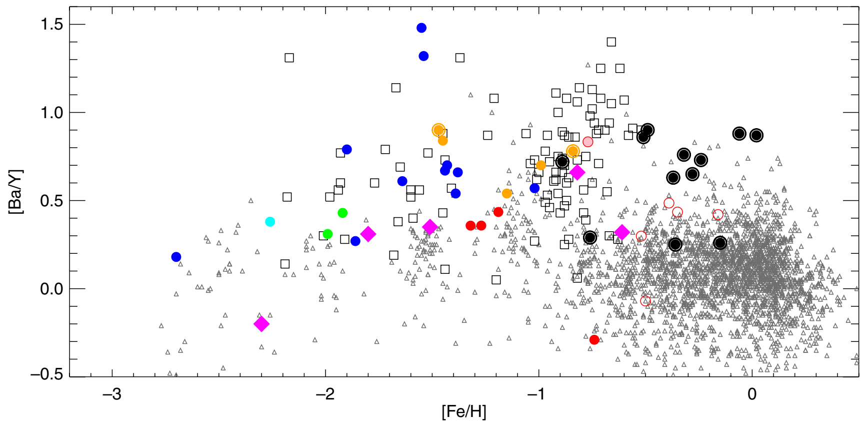

Figure 2. The [Ba/Y] ratios vs. [Fe/H] for the same samples in Fig. 1, and using the same symbols, except for the magenta Sgr dSph GC mean values, which are now all represented by diamonds.

effect of a slower chemical enrichment in the dSph compared to larger galaxies, leading to a lower average metallicity by the time SN1a begin to explode. A top-light IMF and yield loss via galactic winds might also contribute (Tolstoy *et al.* 2009; McWilliam *et al.* 2013). This difference tends to disappear at low metallicity, where in both environments SN1a have not yet begun contributing.

Three interesting characteristics of Sgr dSph can be readily seen. First, Sgr dSph appears as the most "MW-like" of all dSph in the LG, with higher [α/Fe] than its peers at each [Fe/H]. Second, an exceptionally extended metallicity range for a dSph, going at least from Fe/H]~ -3 to solar metallicity. Finally, a very clear metallicity gradient between the core and the outskirts: the black data points from Monaco *et al.* (2005) and Sbordone *et al.* (2007) all belong to the core, while the red and blue ones all come from the outer fields. It is evident that the metal rich population is all but gone as soon as one moves away from the central regions of the galaxy.

In Fig. 2 we plot the [Ba/Y] ratio versus [Fe/H]. Heavy-to-light s-process elements ratios are sensitive to the metallicity of the Asymptotic Giant Branch (AGB) stars where they are synthesized Gallino *et al.* (1998); Busso *et al.* (1999); McWilliam *et al.* (2013). Most dSph stellar populations show overabundant Ba versus Y, compared to what is found in the Milky Way. This points towards dSph s-process elements having been synthesized in relatively metal poor AGB stars. This result is broadly consistent with dSph populations having grown in metallicity slower than the MW, thus being affected by long-lived star nucleosynthesis at a lower metallicity. Sgr dSph is no exception here. It is interesting to notice that Sgr dSph presents a "low-Ba" population visible both in the core and the outskirts. These stars are confirmed members both kinematically and chemically, so that their anomaly seems to be intrinsic to the Sgr dSph nucleosynthesis.

Finally, it is apparent from their abundance ratio that at least 4 out of 5 stars extracted from Ruchti *et al.* (2015) display dSph-like chemistry, with the two Sgr stream candidate members following unambiguously the trends observed in Sgr dSph.

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Discussion

Q1: Most of the large [Ba/Y] ratios in other LG galaxies come from Fornax. They have normal Y abundances but enhanced Ba abundances. When we look at Eu abundances in Fornax, there should be some contribution by the r process. So, if we check the contribution from the r or s process for stars with large [Ba/Y] in Sgr, it would be better to check Eu or Pb abundances.

A1: The discussion of r-s process was necessarily short here. We do need to check the r-process contribution, but observationally, the high heavy-to-light s-process ratio is a clear feature in dSph stars, and Sgr is no exception.

Q2: How has SAG dSph been able to hang onto its metals being in such a precarious orbit around the Milky Way?

A2: Most likely because, pre-disruption, it was a very massive object. In fact, this is one of the arguments suggesting a high original mass for Sgr dSph.

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