Metallicity Gradients In and Chemical Fingerprinting of The Milky Way’s Halo Streams

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Abstract:
Stars have distinctive abundance patterns that reflect the unique chemical history of their parent system. In principle, therefore, “chemical fingerprinting” can help identify stars straggling in the Galactic halo. Our programs of observing through the Sgr tidal field show several large tidal structures are known to be cycling the Milky Way, including the Sagittarius (Sgr) stream and the Monoceros stream, also known as the Galactic anticenter stellar structure (GASS). The present work has focused on making the first test of the “chemical fingerprinting” concept by focussing on stars expected to be part of these, and possibly other, known streams.

Observations:
We have observed 80 M giants stars selected to be likely members of the Sgr tidal stream (see Fig. of the GASS structure, and 4 stars in the TriAnd structure, using both spatial information from Majewski et al. (2003) and Rocha-Pinto et al. (2005, 2006) and velocities from Majewski et al. (2004) and Cunha et al. (2003). These stars were observed on the SARG spectrograph (R=46000) on the TNG telescope, the Magui 4.1m echelle (R=55000) and the MIKE echelle spectrograph (R=10000) on the Clay 6.5-m telescope.

Abundance Analysis:
We adopt Houdashelt’s color-calibrated effective temperature (Houdashelt et al. 2000) in the abundance analyses, and use the LTE stellar line analysis program MOOG (Sneden 1973) for the analysis of 11 Fe lines, and other elements discussed. The model atmospheres adopted here are generated by interpolation from Kurucz (1994) grids. We treat the surface gravity (parameterized as log g, from Padova isochrones; Girardi et al. 2000), metallicity (Fe/H), and microturbulence until a consistent set of stellar and model atmosphere parameters is found. We use the spectral synthesis task in MOOG for determining the model for each star, selecting the higher Fe/H abundance set, and then use the abfnd routine for other elements (7497A and 74929A for Ti, 74979A for Fe). Some stars that have night sky-line contamination in the La line are left out of our analysis.

Exploration of the Sgr Stream:
In our first chemical abundance study of a tidal stream (Chou et al. 2006), the Sgr stream metallicity distribution function (MDF) is found to be significantly different from a medium log g (∼3.8 to 4.2) in the direction of the leading arm, and the leading arm length representing ∼ 2.5-3.0 Gyr of dynamical (i.e. tidal stripping) age, based on echelle spectroscopy of candidate M giants at different points along the tidal stream of the Sgr dwarf spheroidal (dSph) galaxy (Fig. 2). The majority of these stars are shown through “chemical fingerprinting” to have been formed in Sgr, and not the Milky Way, to the basis of unusual titanium and/or process abundances (Fig. 3-4). The MDF evolution shows direct evidence that there can be significant chemical differences between current dSph satellites and the bulk of the stars they have contributed to the halo, and suggests that there is danger in making comparisons of halo stars to Sgr giants of today. Our results also support that Sgr experienced a significant change in binding energy over the past several Gyr, which has subsequently decreased its tidal boundary across a radial range over which there must have been a significant metallicity gradient in the progenitor galaxy. In this paper, we also analyze the MDF of a moving group of M giants we previously discovered towards the North Galactic Cap (NGC) having opposite radial velocities to the infalling Sgr leading arm stars (Majewski et al. 2004), that are observed in Sgr arm and GASS stars overlapping the Sgr leading arm in this part of the sky. This conclusion invoked “chemical fingerprinting” – the NGC stars also have unusual Ti and s-process like the Sgr stream stars we found.

Exploration of the Galactic Anticenter Stellar Structure:
Clearly chemical abundances provide a means to identify member stars of halo streams. The origin of the recently identified GASS “ring”, a low latitude overdensity beyond the disk first discovered in Monoceros (Newberg et al. 2002) and spanning the second and third Galactic quadrants, remains controversial. Models include scenarios where GASS is a piece or warp of the Galactic disk (Momany et al. 2006) versus those where it represents tidal debris from the disruption of a Milky Way satellite galaxy (e.g., Rocha-Pinto et al. 2006). From preliminary analysis, the behavior of Ti and a process abundances of GASS is more like that formed in a dSph like Sgr (Fig. 3-6), which suggests that GASS is more likely the debris of a disrupted dwarf spheroid than to represent a structural component derived from the disk.

Exploration of the TriAnd overdensity:
The distant TriAnd overdensity has been little explored since its discovery (Rocha-Pinto et al. 2004, Majewski et al. 2006a), but has been proposed to be part of the Monoceros stream (Poharka et al. 2005). If TriAnd is an old piece of GASS, and it follows the Sgr paradigm, then the position of the older piece should have lower mean [Fe/H]. However, from our preliminary analysis, the mean [Fe/H] of TriAnd is −0.7 (Fig. 3-4), higher than the lowest GASS star we have observed (Fe/H)−1.0. The TriAnd stars also do not seem to have an extreme [Y/Fe] as GASS, though the sample is small (4 stars). Overall, based on its higher [Fe/H] and different abundance patterns, it appears that TriAnd is not a piece of Monoceros.

Discussion and Future Plan:
Though it is now clear that accretion of dwarf galaxies likely played a prominent role in creating the Milky Way halo (Searle & Zinn 1978), the chemical abundance patterns of current Milky Way satellites are typically very different than those of typical halo field stars, so that a clear identification of the tidal arms of dwarf galaxy halos directly by exploring chemical trends along the tails of disrupting dwarf galaxies is extremely difficult. Initial analysis on debris from the Sgr dwarf galaxy has already identified stars (e.g., Shetrone et al. 2003). Our study helps clarify the bridge from dwarf galaxy to creating the Milky Way halo (Searle & Zinn 1978), the chemical abundance patterns of Galactic stars. We also plan to repeat this analysis on the GASS system. Two locations within galaxies. Our initial abundance analysis on debris from the Sgr dwarf galaxy has already identified stars (e.g., Shetrone et al. 2003). Our study helps clarify the bridge from dwarf galaxy to creating the Milky Way halo (Searle & Zinn 1978), the chemical abundance patterns of Galactic stars.

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