The General Assembly of Galaxy Halos: Structure, Origin and Evolution
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Reconstructing the Accretion History of the Galactic Halo Using Stellar Chemical Abundance Ratio Distributions

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Abstract. In this study we tested the prospects of using 2D chemical abundance ratio distributions (CARDs) found in stars of the stellar halo to determine its formation history. First, we used simulated data from eleven "MW-like" halos to generate satellite template sets of 2D CARDs of accreted dwarf satellites which are comprised of accreted dwarfs from various mass regimes and epochs of accretion. Next, we randomly drew samples of $\sim 10^{3-4}$ mock observations of stellar chemical abundance ratios ([α/Fe], [Fe/H]) from those eleven halos to generate samples of the underlying densities for our CARDs to be compared to our templates in our analysis. Finally, we used the expectation-maximization algorithm to derive accretion histories in relation to the satellite template set (STS) used and the sample size. For certain STS used we typically can identify the relative mass contributions of all accreted satellites to within a factor of 2. We also find that this method is particularly sensitive to older accretion events involving low-luminous dwarfs e.g. ultra-faint dwarfs — precisely those events that are too ancient to be seen by phase-space studies of stars and too faint to be seen by high-z studies of the early Universe. Since our results only exploit two chemical dimensions and near-future surveys promise to provide $\sim 6-9$ dimensions, we conclude that these new high-resolution spectroscopic surveys of the stellar halo will allow us (given the development of new CARD–generating dwarf models) to recover the luminosity function of infalling dwarf galaxies — and the detailed accretion history of the halo — across cosmic time.

Keywords. Galaxy: abundances – Galaxy: evolution – Galaxy: formation – Galaxy: halo – Galaxy: stellar content – galaxies: dwarf – galaxies: stellar content – methods: statistical – stars: abundances

1. Brief Introduction

What is the nature, evolution, and origin of the Galactic halo? Observations of the Galactic halo support the theory that accreted dwarf galaxies built up (most) of the halo over time via hierarchical merging (Searle & Zinn 1978). If so, then what is the merger history of the MW halo? If hierarchical merging of satellites constitutes the prevailing mode of building the stellar halo as suggested by both observations (see above) and simulations (N-body, SPH, AMR, etc. — both with & without gas; see, e.g., Bullock & Johnston 2005 and Cooper *et al.* 2010), then devising a way to recover its accretion history may be paramount to a better understanding galactic evolution. It may also place further constraints on the nature of dark matter halos (see, e.g., Diemand & Moore 2011).

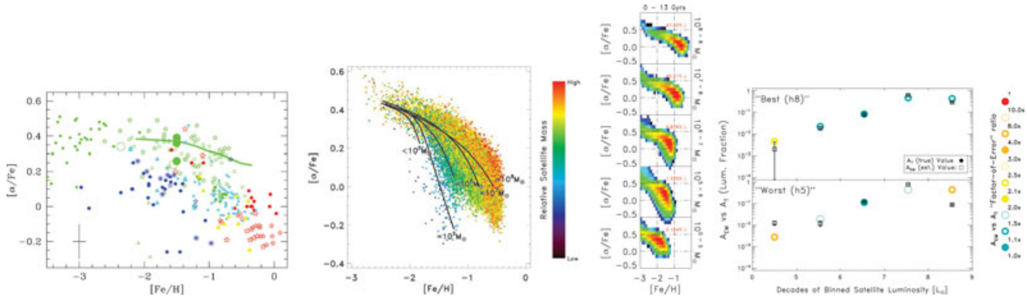

Figure 1. *Left*: Plot is a reproduction of Figure 12 from Geisler *et al.* (2007). *Middle-left*: Plot of [α/Fe] vs. [Fe/H] for $\sim 3 \times 10^4$ "star particles." Each particle is color-coded to represent the relative stellar mass/luminosity of its parent satellite. *Middle-right*: Plot of 1×5 STS in the $t_{acc} - M_{sat}$ plane. *Right*: Plot of 1×5 AHP.

In this work we apply a method that leverages "statistical chemical tagging" (e.g., Schlaufman *et al.* 2012) via the expectation-maximization (EM) algorithm on chemical abundance data from the Bullock & Johnston (2005) simulations (also see Robertson *et al.* 2005 and Font *et al.* 2006) which substantially expands on the idea that Unavane *et al.* (1996) introduced nearly two decades earlier. Unlike stars born in the same cluster, stars born in the same dwarf galaxy do not necessarily share the same chemical composition. However, pioneering studies in the past decade have shown that stars in different dwarfs do have distinct (while overlapping) chemical abundance ratio distributions (CARDs; see, e.g., Geisler *et al.* 2007 and references therein). Hence, the CARD of the Galactic halo should, in theory, reflect the relative number of halo progenitors that were accreted with different galactic masses and accretion epochs.

2. Some Models & Results

The four panels of Figure 1 represents the basic approach and results of the study. The CARDs from observations (*left*) are similar to CARDs from the simulations (*middle-left*). The CARDs of the accreted satellites in the simulations can be marginalized over accretion time to produce the satellite template set (STS) displayed (*middle-right*). Finally, the EM algorithm can be applied to the simulation data using the STS to estimate the accretion history profile (AHP) shown (*right*). Full details of the method, models, and results are provided in Lee *et al.* (2015).

References

Bullock, J. S. & Johnston, K. V. 2005, *ApJ* 635, 931

Cooper, A. P. , Cole, S. , Frenk, C. S. , White, S. D. M. , Helly, J. , Benson, A. J. , De Lucia, G. , Helmi, A. , Jenkins, A. , Navarro, J. F. , Springel, V. , & Wang, J. 2010, *MNRAS* 406, 744

Diemand, J., & Moore, B. 2011, *Adv. Sc. Lett.* 4, 297

Font, A. S.,Johnston, K. V.,Bullock, J. S., & Robertson, B. E. 2006, *ApJ*

Geisler, D., Wallerstein, G., Smith, V. V., & Casetti-Dinescu, D. I. 2007, *PASP*

Lee, D. M.,Johnston, K. V.,Sen, B., & Jessop, W. 2015, *ApJ* 802, 48

Robertson, B., Bullock, J. S., Font, A. S., Johnston, K. V., & Hernquist, L. 2005, *ApJ* 632, 872

Schlaufman, Kevin C., Rockosi, Constance M., Lee, Young Sun, Beers, Timothy C., & Prieto, Carlos Allende, Rashkov, Valery, Madau, Piero, Bizyaev, Dmitry 2012, *ApJ* 749, 77

&Searle, L. & Zinn, R. 1978, *ApJ* 225, 357

&Unavane, M. and Wyse, R. F. G., & Gilmore, G. 1996, *ApJ* 278, 727

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