Reconstructing the Stellar Accretion History of the Galactic Halo:

A future constraint on the nature of dark matter via statistical chemical tagging

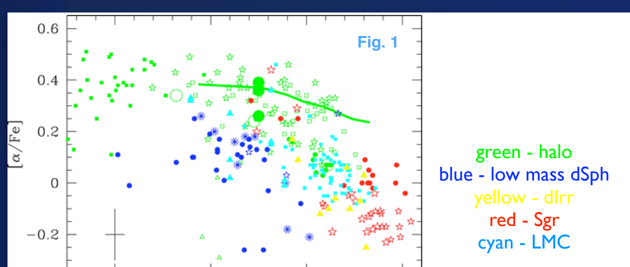
Duane M. Lee[1,2], Kathryn V. Johnston[2], Bodhisattva Sen[3], Will Jessop[3]

1 PIFI Post-doctoral Fellow, Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences

2 Department of Astronomy (Columbia U.) 3 Department of Statistics (Columbia U.)

Motivation:

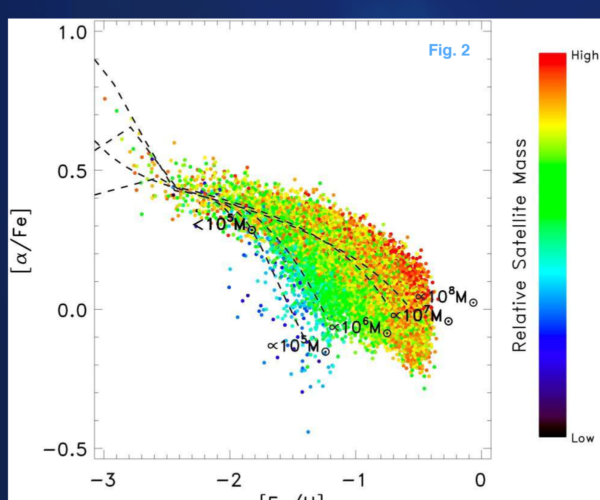
- **Observations of the Galactic halo support the theory that accreted dwarf galaxies built it up over time via hierarchical merging** (Newberg et al. 2002; Majewski et al. 2003; Belokurov et al. 2006)
- Observations of stellar populations in nearby dwarf galaxies has led to the "cusped vs. cored" central density debate over the state of dark matter (DM) in these systems (e.g., de Blok 2010, Peñarrubia et al. 2012)
- **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), **then devising a way to recover its accretion history profile (AHP) would place further constraints on the nature of DM in dwarf galaxies** (see, e.g., Diemand & Moore 2009)



(data compilation from Geisler et al, 2007)

Observations vs. Simulations + SAMs:

- A compilation of observations (Fig. 1) given in Geisler et al. (2007) unveil the **potential for "statistical chemical tagging" of past dwarf galaxy accretion** into the Galactic halo (see, e.g., Schlaufman et al. 2012)
- **Mock observations of stellar chemical abundances (Fig. 2) generated from the semi-analytic chemical evolution models (SAMs)** of Robertson et al. (2005) and implemented in the Bullock & Johnston (2006) accreted halo simulations by Font et al. (2006) **show remarkable similarities to the observational data in Figure 1**



Mixture Modeling of the Halo:

- Chemical abundance ratio distributions (CARDs) are generated from the mock stellar abundances in the ~1500 model dwarf galaxy simulations across 11 halo realizations
- **Satellite template sets (STS) are created from binning models by time of accretion and satellite mass/luminosity** (e.g., Fig. 3) — STS are labeled by # of time bin × # of mass bins (see abstract for details)
- **Each STS is then used** in conjunction with the expectation-maximization (EM) algorithm **to analyze ~10,000 mock observations of each halo realization generating an AHP for each of them**

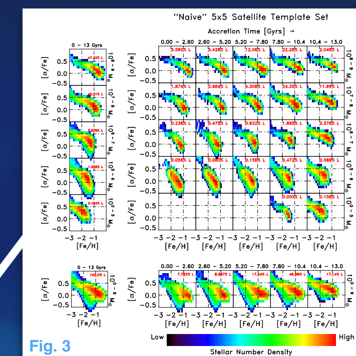


Fig. 3

Results I - Individual AHPs:

- Figs. 4 - 7 show **EM estimates (open black symbols)** and their respective **true values (colored donuts)** where the **colors = their FoE (see legends)**
- 1x5 STS (Fig. 4) represents the LF for all acc. satellites for 5 mass scales (i.e., one acc. time bin)
- 5x1 STS (Fig. 5) represents the acc. time function for all acc. satellites for 5 time epochs (i.e., one mass bin)
- **1x5 STS EM est. show remarkable agreement** for all mass bins while the 5x1 STS do considerably worse
- **Differences in 1x5 vs. 5x1 STS EM est. performance are due to their relative degeneracies in CARD-space** (see left and bottom of Fig. 3)

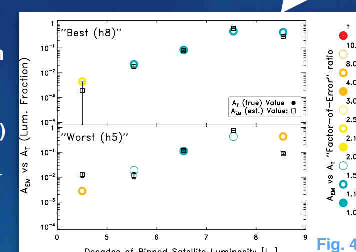


Fig. 4

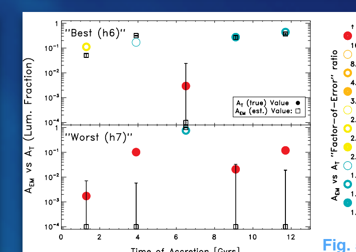


Fig. 5

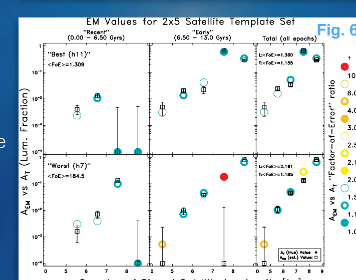


Fig. 6

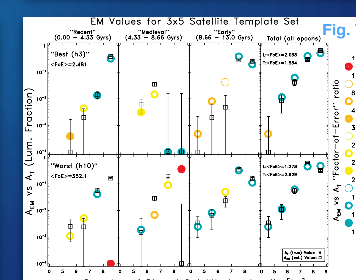


Fig. 7

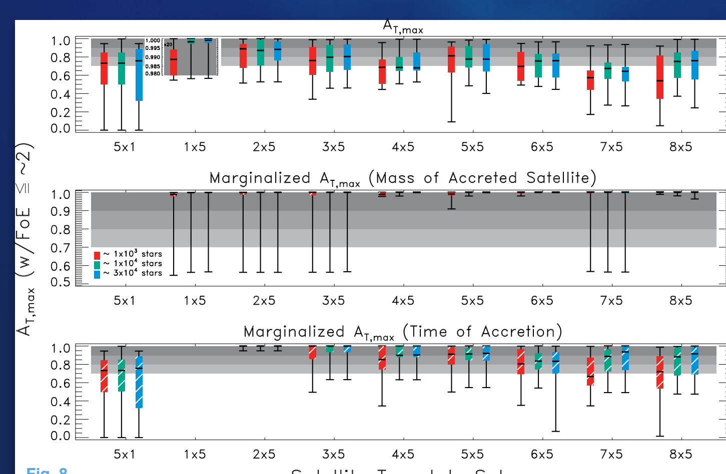


Fig. 8

Results II - $A_{T,max}$ Vs. FoE:

- **Fig. 8 summarizes the performance of our analysis** (min, max & quartiles for 11 halo results from each STS)
- Three panels show the max total of rel. contributions to the halo luminosity ($A_{T,max}$) that have FoE ≤ 2
- Top — $A_{T,max}$ w/o any marginalization of estimates in time or mass
  Middle — $A_{T,max}$ after marginalization over est. in time (i.e. one time bin)
  Bottom — $A_{T,max}$ after marginalization over est. in mass (i.e. one mass bin)
- **Fair est. from 2x5 & 3x5 STS** ("early vs. late" accretion) **for AHPs are achievable**
- **Marginalization in time and mass reveals that additional information (i.e. larger STS) can be exploited** to improve LF or acc. time estimates

Concluding Remarks:

Current/near-off surveys e.g. **APOGEE, GAIA, & GALAH + current data should provide a suitably well-mixed ~1,000 - 10,000 CARD sample to apply this technique in the next 2-3 years** (>10,000 samples may have to wait for TMT, GMT, and/or the ELT).

Short Abstract (see arXiv:1410.6166 for paper):

While some observational studies have placed limits on the quantity and nature of accreted dwarf galaxies' contributions to the Milky Way (MW) stellar halo (e.g., Unavane et al. 1996; Schlaufman et al. 2012), none has given a detailed account of their total relative contributions. In this study we test the prospects of using chemical abundances found in stars of the stellar halo to determine its formation history. To do this we utilize a statistical procedure called the expectation-maximization (EM) algorithm on ≥ 1000 mock observations of the stellar chemical abundance ratios ([α/Fe], [Fe/H]) (from Robertson et al. 2005; Font et al. 2006) found in the eleven simulated "MW-like" halos of Bullock & Johnston (2005) to recover the relative stellar mass contributions from representative accreted dwarf galaxies (templates). Here, we "naively" partitioned ~1500 accreted dwarf satellite models by their accretion times (i.e. equally separating them in time), and by assigning mass separations mainly by decades ranging from about one thousand to a billion solar masses. Using these templates we find that in most cases investigated we can recover luminosity fractions (LF) that cover ≥ 90% of the total relative stellar mass contributions (from each progenitor template) to within a factor of 2.

Goals:

- **Reconstruct the AHP of the Galactic halo from modeling its stellar CARDs**
- **Test whether ΛCDM simulations are consistent with the AHP** constructed from the chemical abundance observations **of the stellar Galactic halo**

Current & Future Plans:

- **Optimize the selection of STS** for use in analyzing the stellar halo via the EM algorithm
- **Create new models that incorporate MDYs to distribute chemical abundances in satellite dwarfs (see, e.g., Lee et al. 2013)**
- **Use model templates with real data to constrain the AHP of the Galactic halo and the nature of DM**

Contact Info:

Duane M. Lee **Email: duane@shao.ac.cn** Tel: +86 131 20731917 (CN) +1 (413) 329-6336 (US)

Address: Shanghai Astronomical Observatory, 80 Nandan Rd., Xuhui District, Shanghai, China 200030

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