The Progenitors of the Milky Way Stellar Halo

Alis Deason – Hubble Fellow UCSC
What is the “mass spectrum” of accreted dwarfs (i.e. lots of little things vs. one massive thing)

When did these accretion events happen?
Common lore – stellar halo built up from many lower mass dwarfs. **BUT** chemical properties of halo stars and surviving dwarfs don’t match up.

Tolstoy et al. 2009

**NB:** Same abundance trends seen for outer (> 15 kpc) halo stars (Battaglia et al. in prep)
A ton of ultra-faints? Or one SMC/LMC mass dwarf?
Accretion History from Halo Stars

- Dark matter halos are approximately universal (e.g. NFW).
- Stellar halo formation is a much more stochastic process:
  - Plummeting star formation efficiency in low mass dwarfs (and likely lots of scatter in stellar mass-halo mass relation).
  - Deeply embedded in dark halos (get stripped later)
- Lumpier accretion plus extremely long mixing times leads to a greater variety of stellar halo profiles.

Aquarius Stellar halos: Cooper et al. 2010
Beyond $r \sim 25$ kpc, the stellar density in the Milky Way falls off more rapidly; Sesar et al. 2011 (MSTO, CFHTLS), Deason et al. 2011 (BHB, SDSS)

Transition from in-situ dominated “inner” halo to accretion dominated “outer” halo (why doesn’t M31 have a break?)

Or linked to accretion history? (Deason, Belokurov, Evans, Johnston 2013)

Break due to build up of stars at apocenter: 1) One massive accretion event or 2) Synchronized accretion events (at similar epoch)
Full 3D velocity information is vital in order to evaluate the orbits of halo stars and, potentially, link them to a common progenitor.

Metallicity information can differentiate between different mass accretion events (more massive dwarfs have more metal-rich populations).

No knowledge of the transverse motion of distant halo stars.

Lack reliable metallicity measurements for halo stars beyond the solar neighborhood.
Select foreground MW stars in three M31 fields
3 HST/ACS Fields, multi-epoch 5-7 year baseline.
Main sequence stars in MW: potentially 10-100 kpc away.
Halo Star Proper Motions

Keck run in September 2014 to get spectra of these stars!

Besancon Galaxy model:
disk stars, halo stars

HST data:
M31, halo stars

$\sigma_l \sim 95 \text{ km/s}, \sigma_b \sim 80 \text{ km/s}, \langle v_l \rangle = v_{\text{rot}} \sim 50 \text{ km/s}$
Keck/DEIMOS Follow-up

\[ \sigma_{\text{los}} \sim 90 \text{ km/s} \]

Hot halo population (not a cold stream or TriAnd!)

\[ \mu_\alpha \text{ (mas yr}^{-1}) \]
\[ V_{\text{LOS}} \text{ (GSR) (km/s)} \]

\[ \mu_\delta \text{ (mas yr}^{-1}) \]

**Best Fit:** \( \sigma = 90 \text{ km/s} \)

Cunningham, Deason, Guhathakurta, Rockosi et al. in prep.

Also see Emily’s poster!

Triand
A “Shell” in the Milky Way halo?

\[ \beta = 1 - \frac{<V_t^2>}{<V_r^2>} \]
Sideways Stellar Motions Suggest Shell in Milky Way Halo

Illustration Credit: NASA, ESA, and A. Feild
**HST+Keck: HALO7D**

Joint HST (STScI) and Keck (UCSC) project

Emily Cunningham, Raja Guhathakurta, Connie Rockosi
Tony Sohn, Roeland van der Marel, Jay Anderson

### HST Archival Legacy Program
- Deep multi-epoch HST imaging
- Use distant galaxies as “wall paper”
- Transverse motion (derived from proper motion) of ~1000 stars in distant MW halo

### Current status:
HST Archive program approved.
20 Nights on Keck/DEIMOS (data taken 2014/15).

### Keck/DEIMOS Spectroscopic Program
- 8-32 hr integrations of ~350 halo stars with measured proper motions.
- Radial velocities
- Chemical abundances
- Fillers: exquisite spectra of ~1500 distant galaxies.
Stellar Population Ratios:  
Comparing dwarfs/GCs with halo stars

- BS and BHB populations relatively simple to isolate in dwarfs and GCs
- Little contamination from foreground (cf. RGB stars)
- In the halo, get BS-to-BHB ratio for “free” from Deason et al. 2011 analysis of SDSS photometry.
- Try to make comparison between halo and satellites as “fair” as possible (same color cuts, photometric filters, many different data sources etc.)

Big Bricks Favored over Little Bricks

- BS-to-BHB ratio in dwarfs and GCs depend on stellar mass.
- We find relatively high ratio in stellar halo (~5-6) that is inconsistent with low ratios found in GCs and ultra-faint dwarfs.
- More massive dwarfs (SGR/LMC type mass) favored as the most dominant “building blocks” of the stellar halo.
Progenitor of the Milky Way stellar halo was (likely) one massive system or a small group.

3D Kinematic and Chemical information needed in the halo:

NOW = HST+Keck, Gaia+4MOST/WEAVE;
FUTURE = LSST/HST+GMT/TMT/E-ELT.