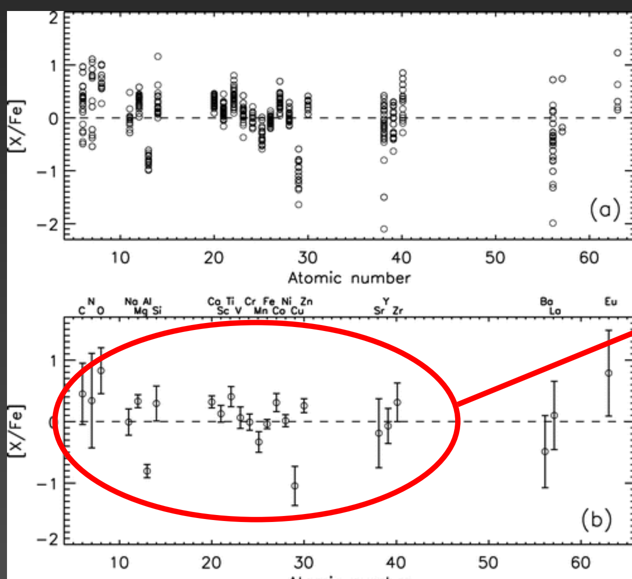
The Abundances of Metal-poor Stars in the Outer Halo of the Milky Way

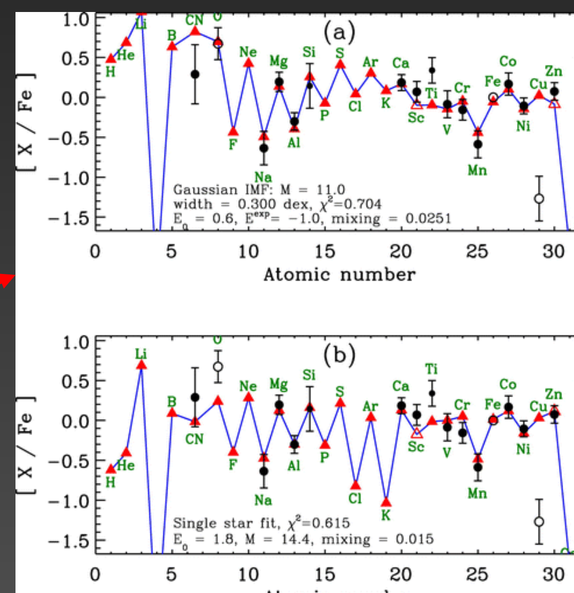
David Lai (UCSC)
Connie Rockosi, Jennifer Johnson
Mike Bolte,
and the SEGUE team

Nearby Metal-poor stars

- [Fe/H] ≤ –2.0
- A window into early star formation environments, possibly even the first stars.



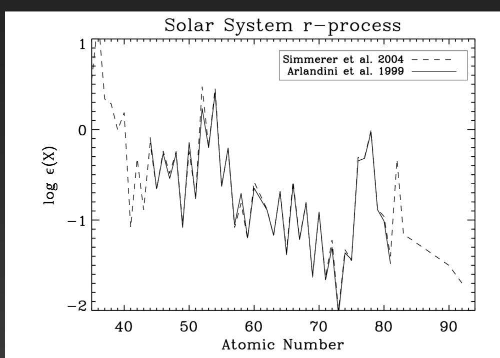
Lai et al. 2008

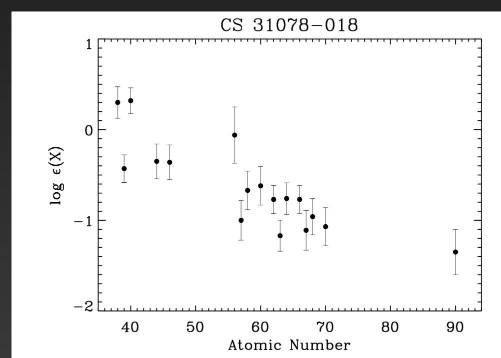


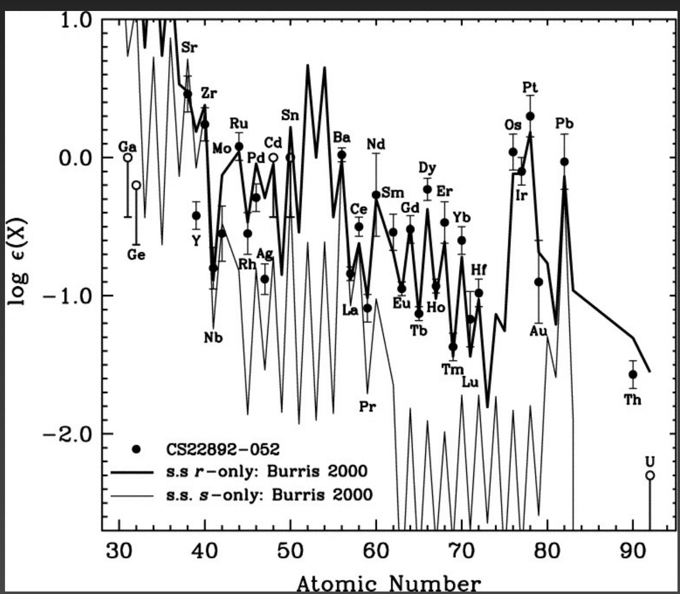
Models from Heger & Woosley (2008)

Nearby Metal-poor stars

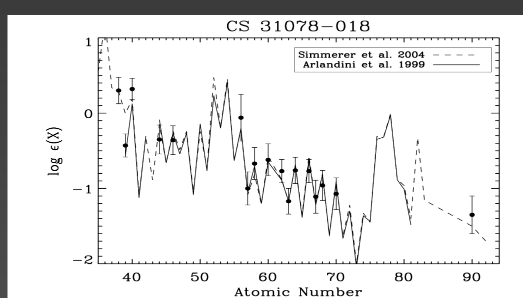
- Origin of the elements and nucleosynthesis sites.







Sneden et al. 2003



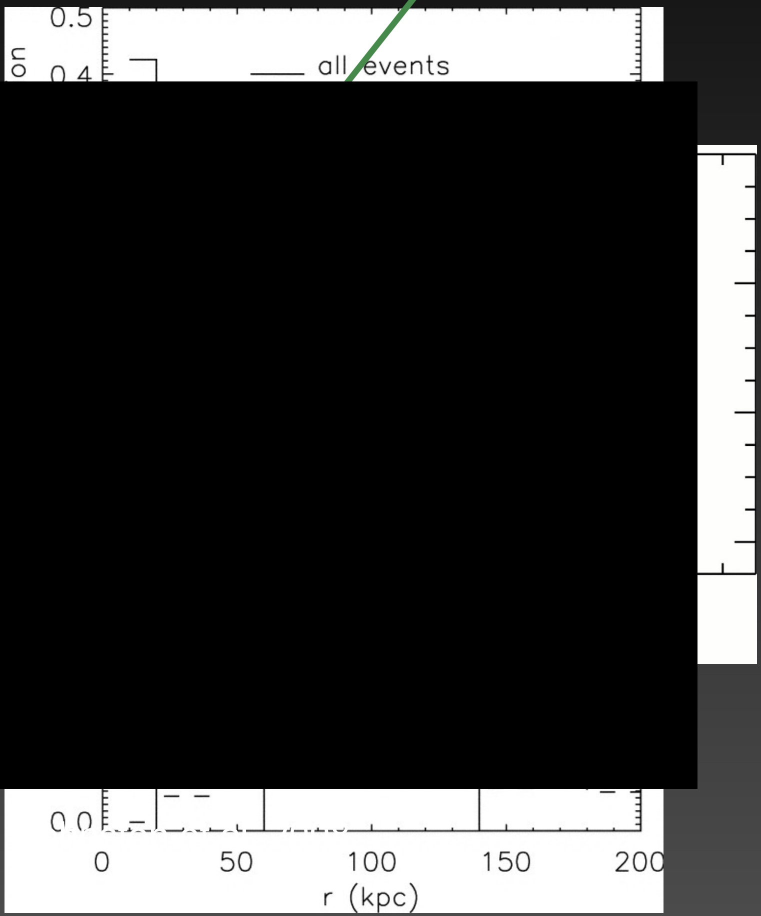
Lai et al. 2008

The origins of the stellar halo

- Recent observations:
  - Two components (Carollo et al. 2007)
  - Substructure (Bell et al. 2008, the morning session)
- The halo is a complicated place, and accretion most likely plays an important role
  - Predominately information for the outer halo has come from phase space or overall metallicities ([Fe/H]).

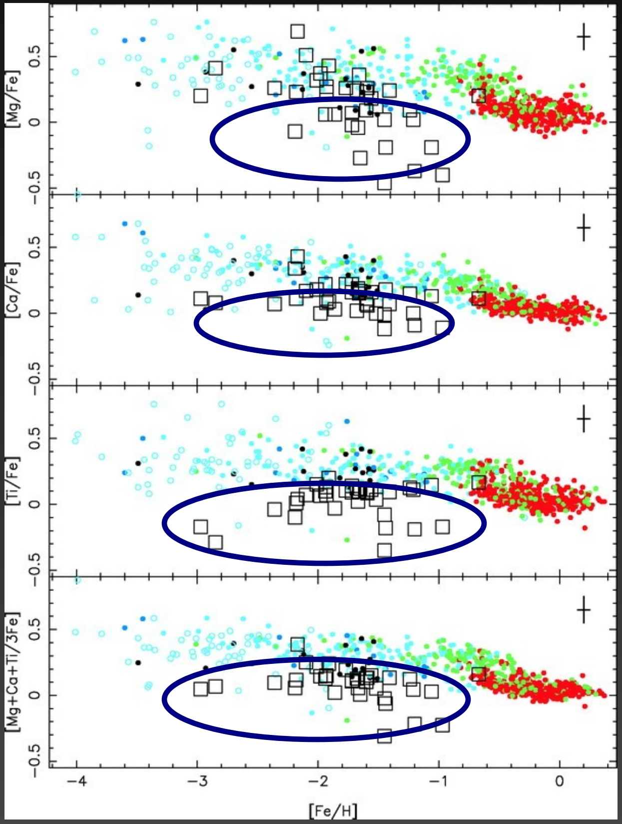
The Role of Stellar Abundances

- Different stellar formation envir[redacted] reflec[redacted]
- Signa[redacted] forma[redacted] the a[redacted]
  - C[redacted] c[redacted] s[redacted] p[redacted]

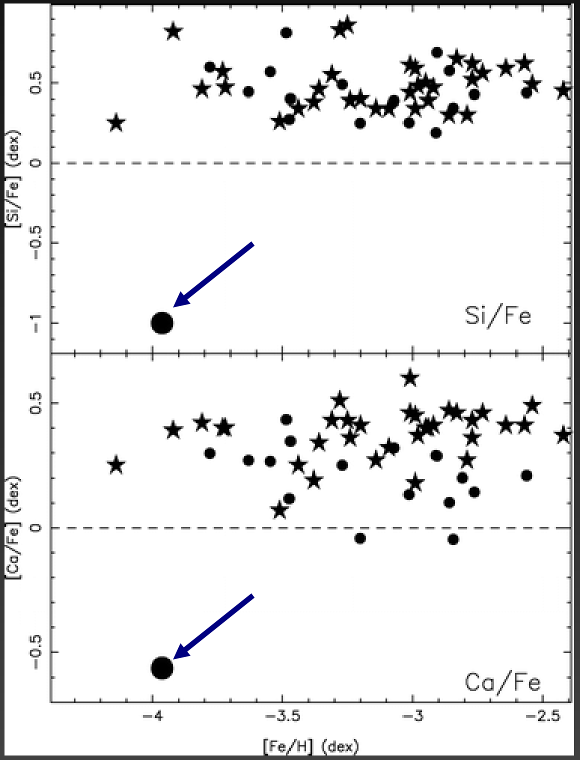


Bullock & Johnston 2005

Nearby halo stars and dSph abundances



Venn et al. 2004



Cohen et al. 2007 (see also Fulbright 2000 and 2002, Ivans et al. 2003, Aoki et al. 2007)

The Next Step

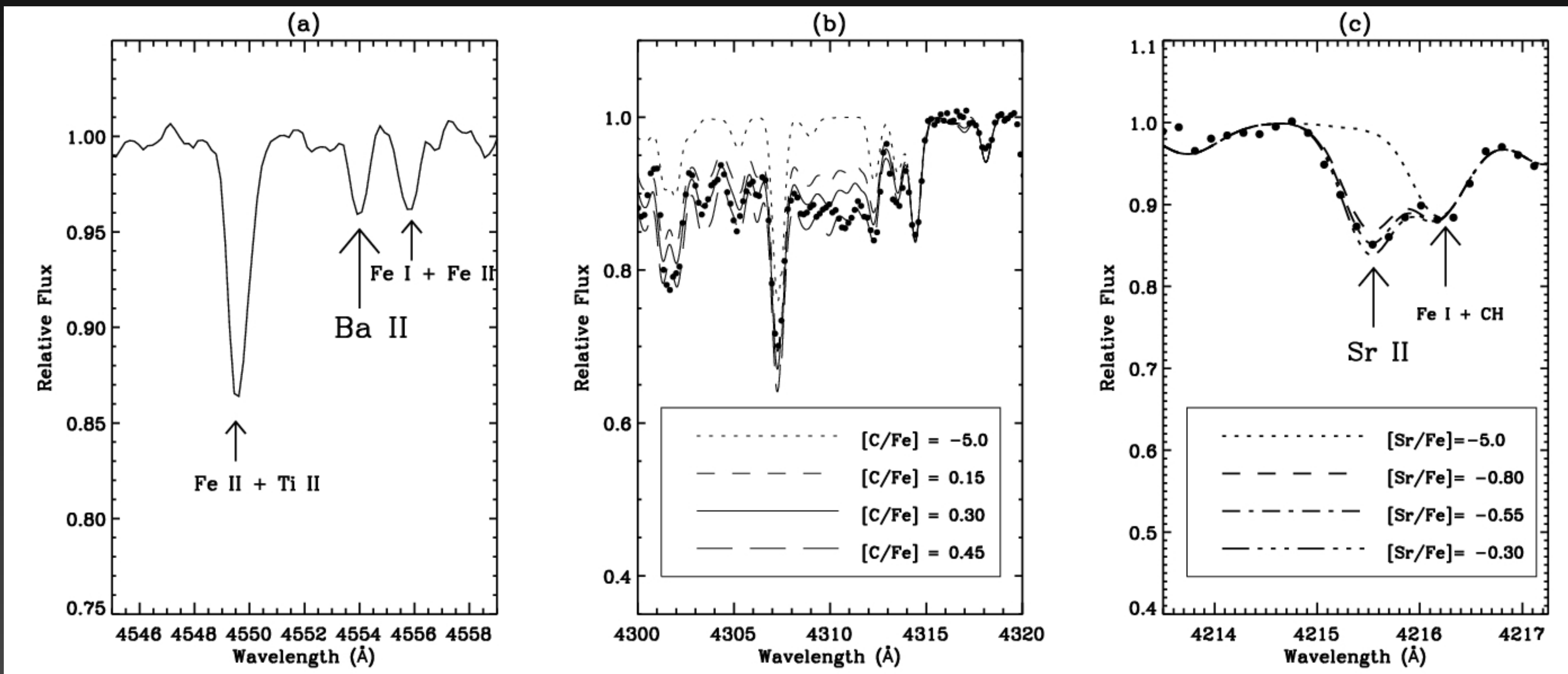
- SDSS+SEGUE +ESI v efficient survey of MP stars in the outer halo *in situ*
  - Accurate *ugriz* photometry
  - R~2000 spectroscopy
  - SEGUE Stellar Parameter Pipeline (Lee et al. 2008a,b, Allende Prieto et al. 2008): T_{eff}, surface gravity, [Fe/H] estimates

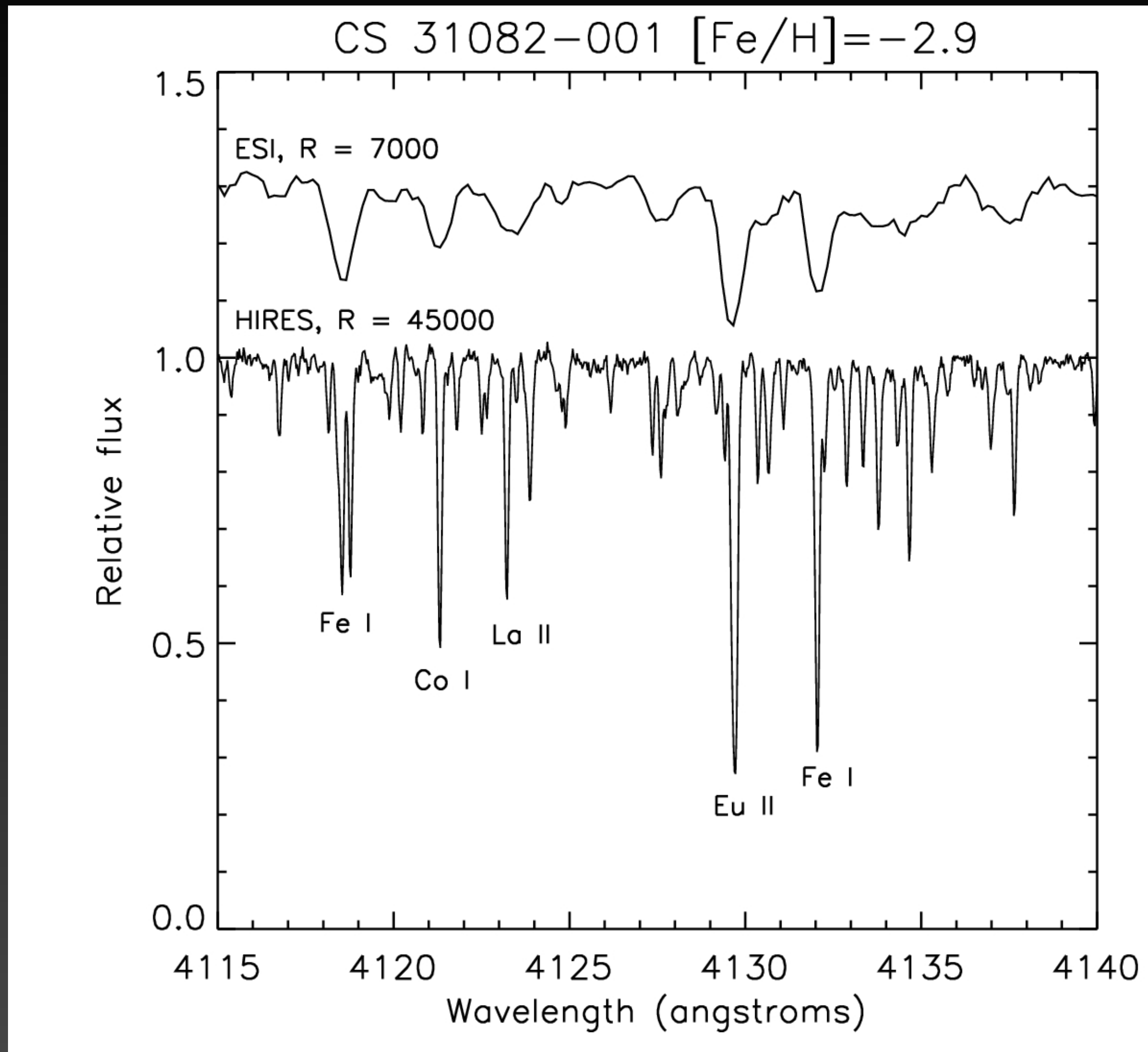
SEGUE + ESI

- ESI: Echellette Spectrograph and Imager
  - High throughput
  - R~7,000 (typical high resolution stellar abundance studies have R~20,000 to 50,000)

- We have shown that it is capable of measuring C, Mg, Ca, Ti, Cr, Fe, Sr, and Ba in metal-poor stars. (Lai et al. 2004 and 2007)

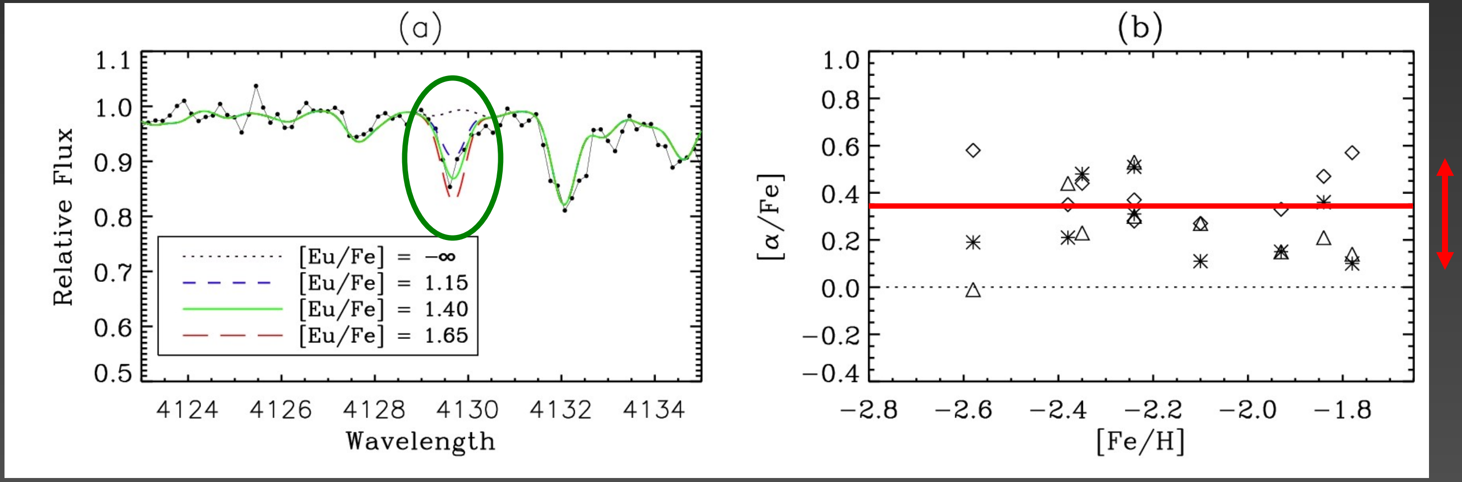
CS 22957-022, [Fe/H] = v3.0




CS 31082-001 [Fe/H]=-2.9
ESI, R = 7000
HIRES, R = 45000
Relative flux
Fe I
Co I
La II
Eu II
Fe I
1.5
1.0
0.5
0.0
4115
4120
4125
4130
4135
4140
Wavelength (angstroms)

Preliminary Results

- Nine stars at an average distance of 30 kpc
- High C-enhanced fraction: 33% have [C/Fe] ≥ 1.0
- v-abundance ratios are ‘normal’
- Discovery of one r-process enhanced star

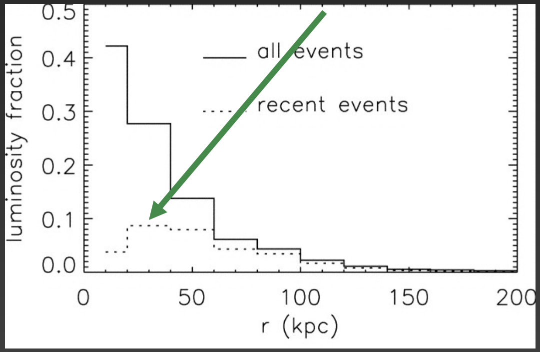


Preliminary Results

- What does this mean?
- First a caveat: this is still a very small sample…
  - But this is comparable to the number of distant stars (8 out of 249 stars with distances >20 kpc) in the HERES survey (Barklem et al. 2005).
- C-enhanced fraction of 33% vs. 20 to 25% for the highest estimates of nearby stars (Lucatello et al. 2006, Marsteller et al. 2005)
  - Possible increased role of AGB stars in these objects (see for example Tumlinson 2006).

Preliminary Results

- The v-ratios, with this small sample are still consistent with accretion scenarios.
  - May speak to the nature of the accreted substructure (e.g., Robertson et al. 2005, Font et al. 2006, Geisler et al. 2007)



Bullock & Johnston 2005

- 1 out 9 stars is highly r-process enhanced vs. 8 out of 249 of nearby stars (HERES survey).

Conclusions

- The study of stellar abundances ratios of the outer halo has important implications for Galactic halo formation scenarios.
- ESI + SEGUE is a very capable combination for this study.
  - Intriguing possible population differences, but still early.
- Stay tuned… next observing run is in two weeks.