Metal-Poor Stars in the Galactic Bulge

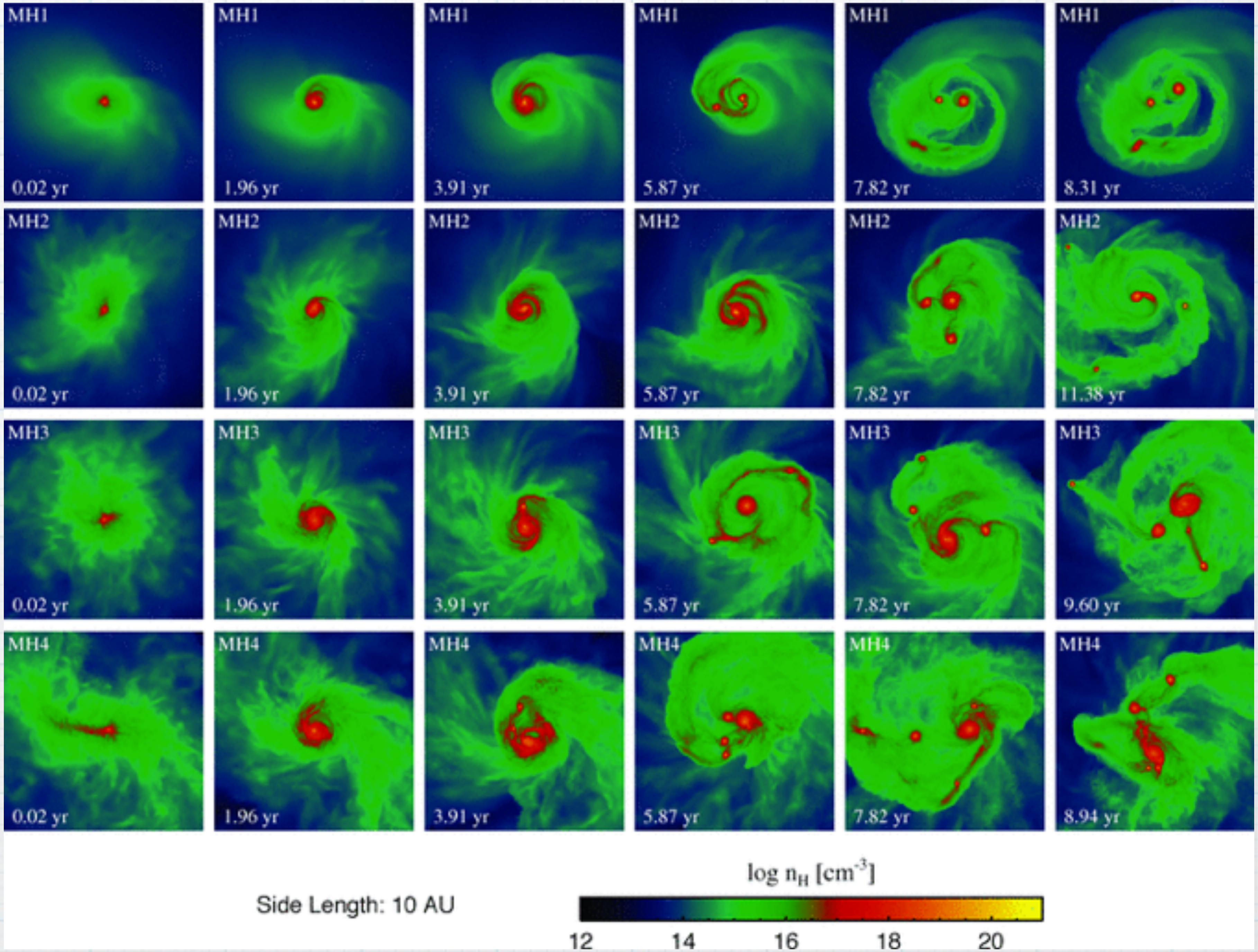
Louise Howes
Australian National University

First Star Formation

* Start with BBNS elements

* Models predict first stars form in DM halos - all massive?

* Accretion disc simulations leading to fragmentation.

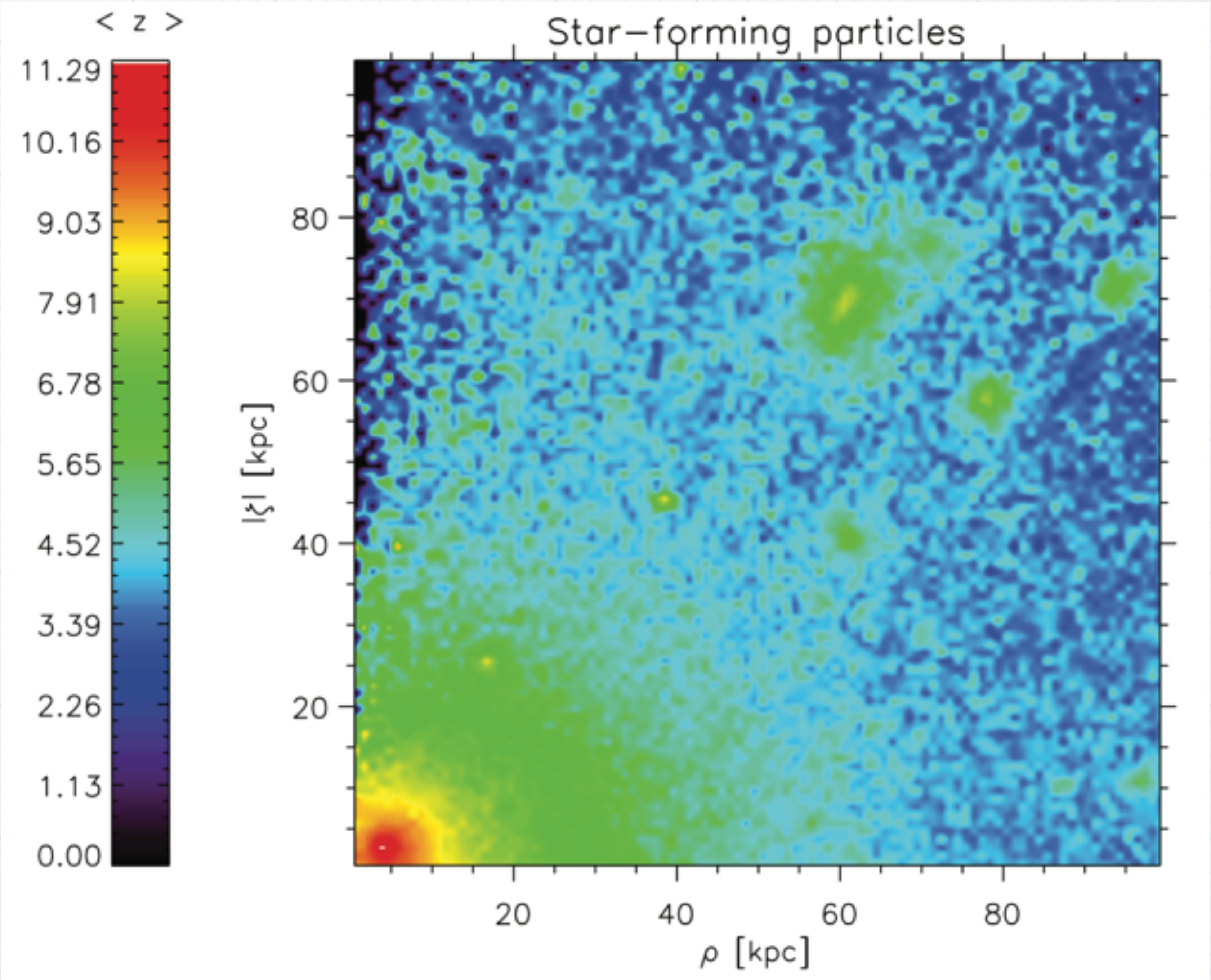


Greif et al. (2012)

First Stars in the Bulge

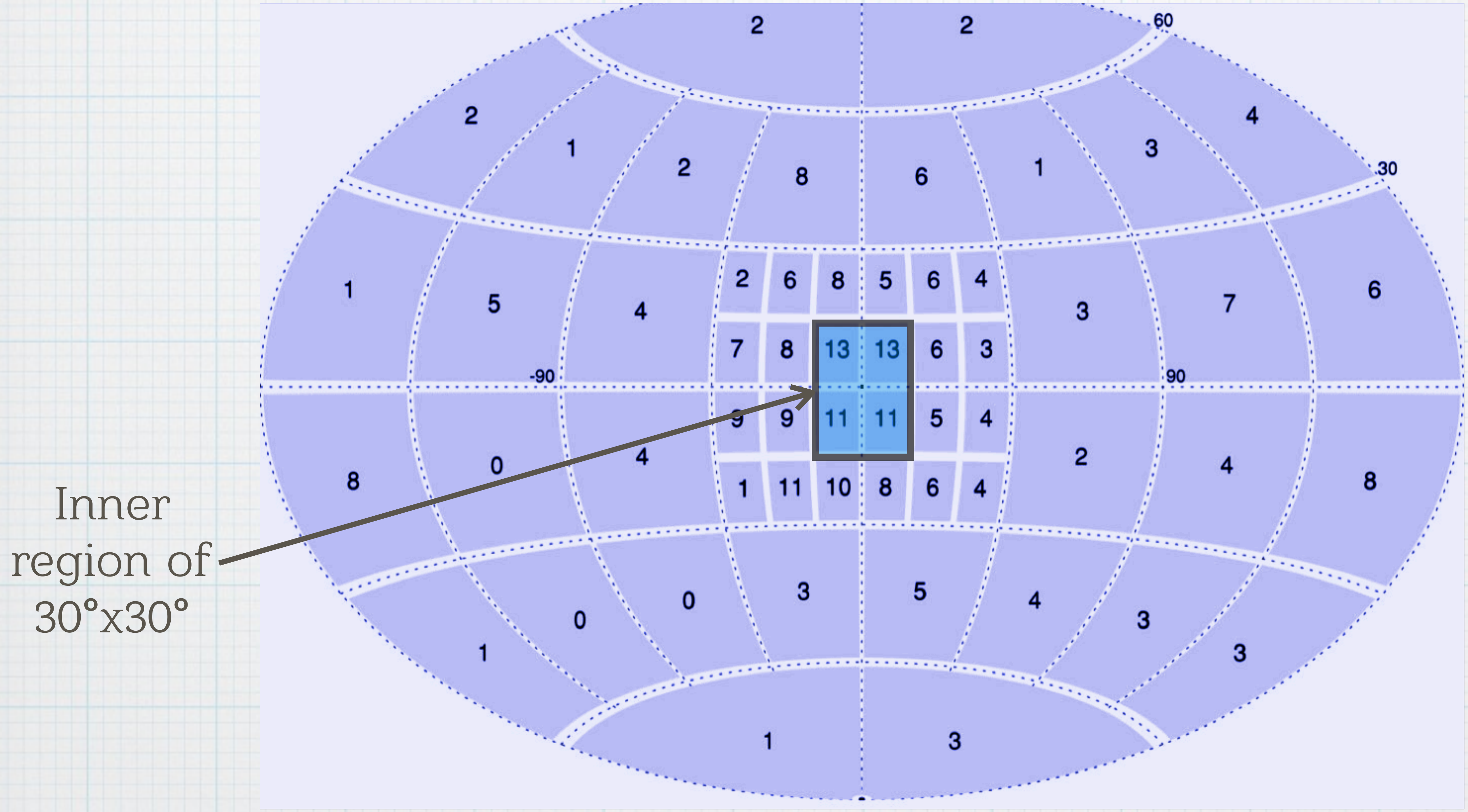
* Diemand et al. (2005):

  "If the first stars form at early epochs... then half of their remnants should be found in the bulge."



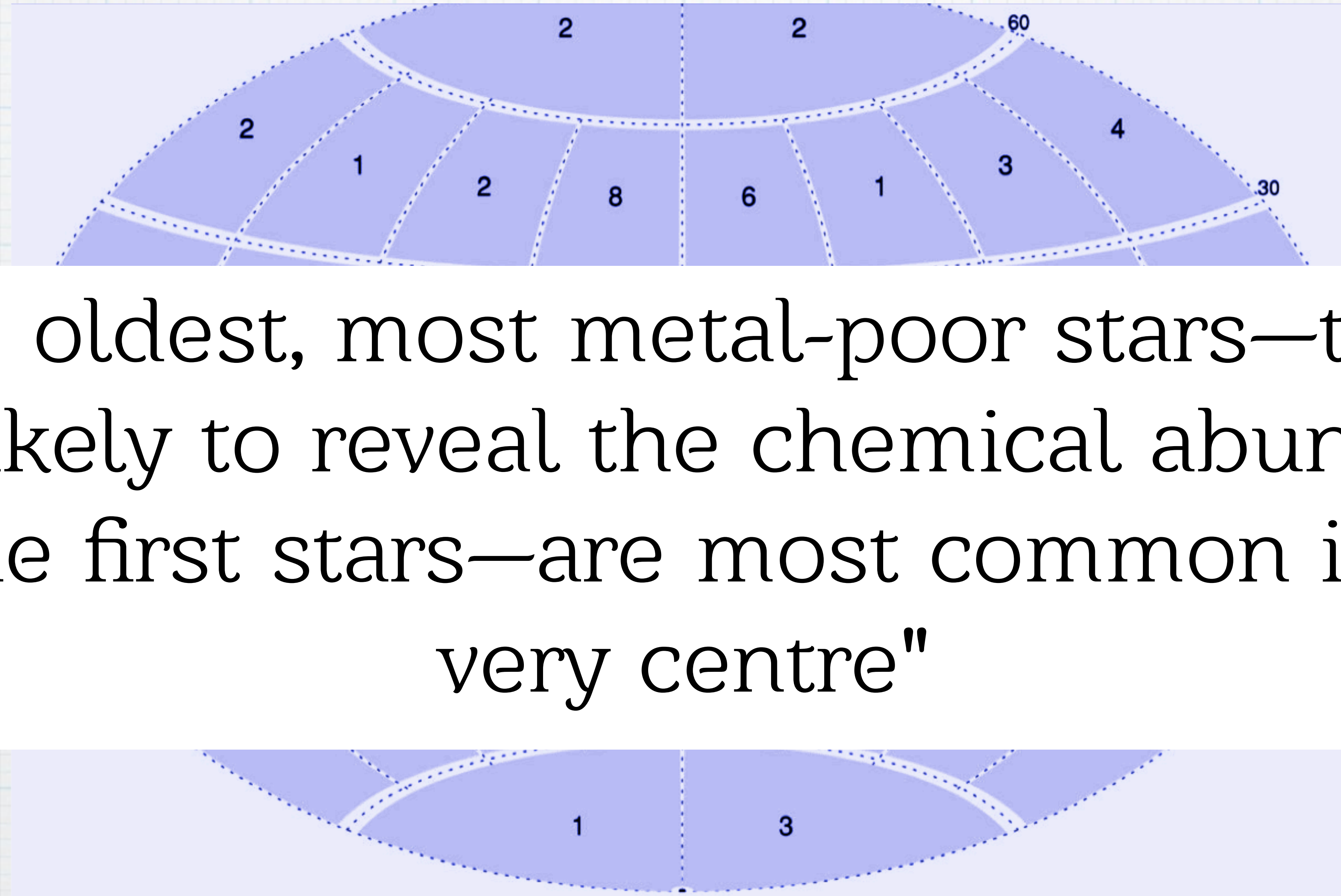
Salvadori et al. (2010)

First Stars in the Bulge



* Tumlinson (2010): Fraction of low-metallicity (EMP) stars from high redshift as a function of position on the sky. In each bin, the percentage of stars with [Fe/H] < −3 that formed prior to z = 15.

First Stars in the Bulge



“The oldest, most metal-poor stars—those most likely to reveal the chemical abundances of the first stars—are most common in the very centre"

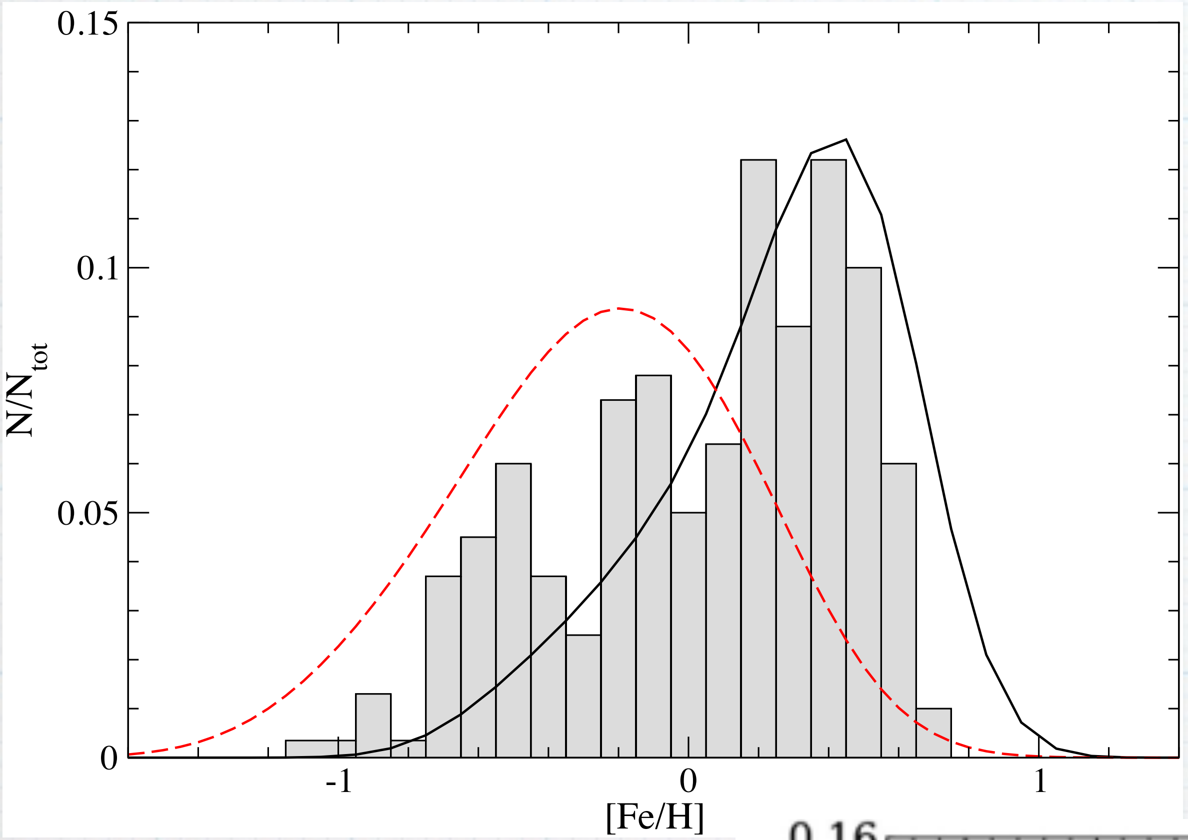
“

* Tumlinson (2010): Fraction of low-metallicity (EMP) stars from high redshift as a function of position on the sky. In each bin, the percentage of stars with [Fe/H] < −3 that formed prior to z = 15.

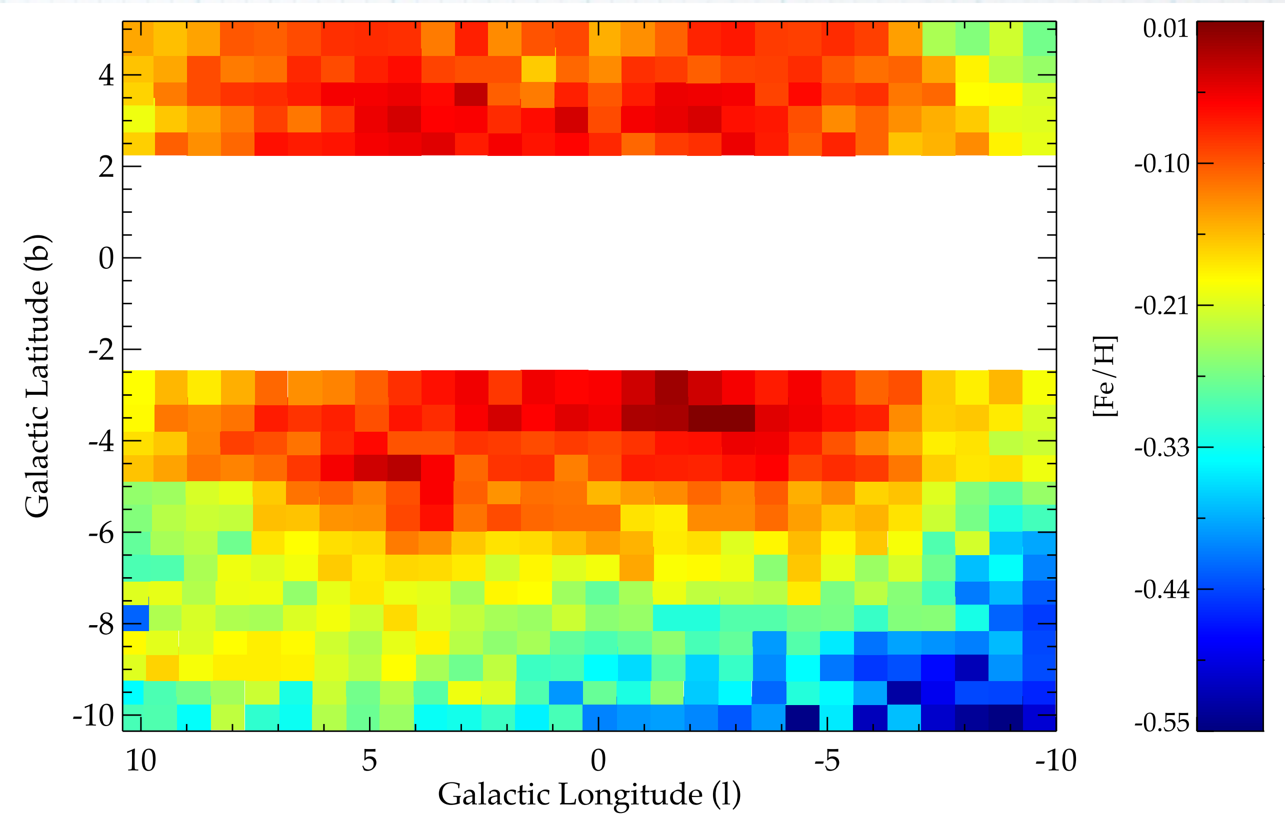
Looking in the Bulge

* Practically very difficult to look in the bulge for these - issues of dust extinction and distance.
* Must search through 10,000 bulge stars to find 10 with [Fe/H]<-2 (numbers from Ness et al. (2013)).

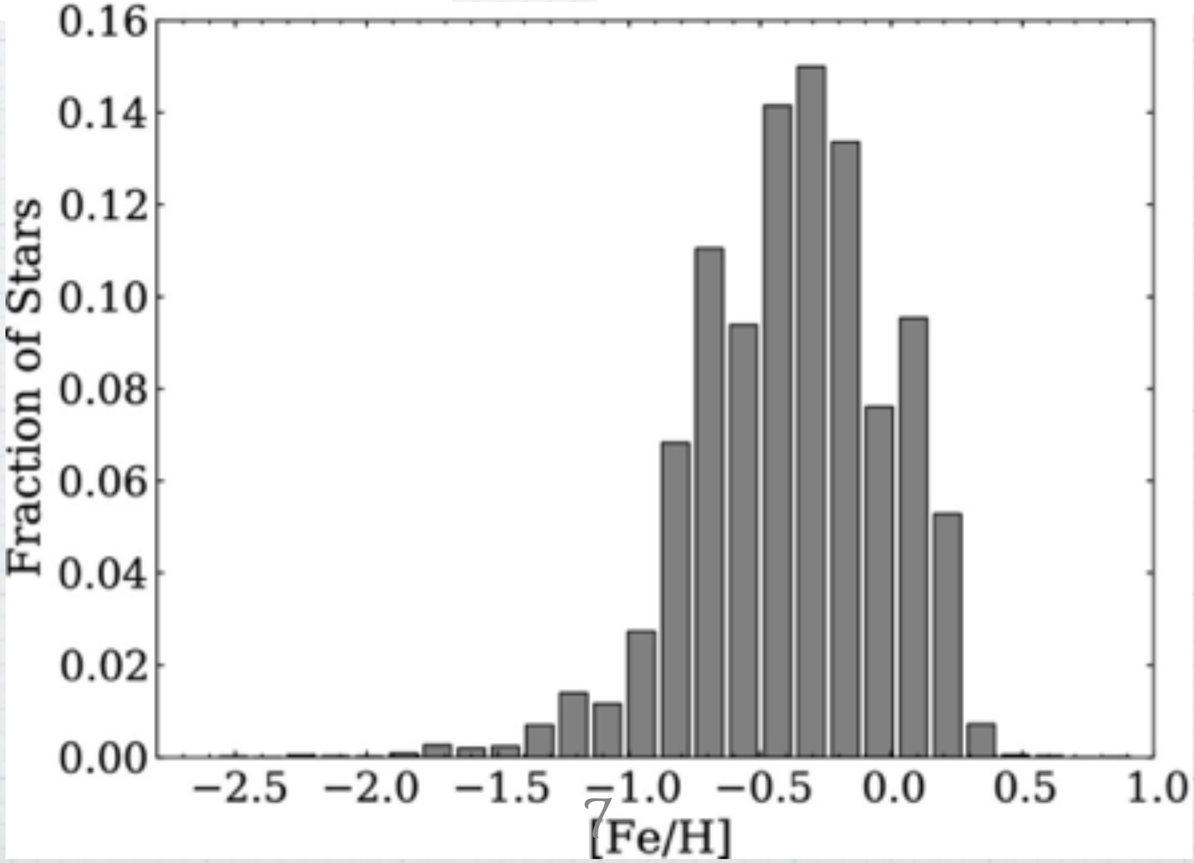
The Bulge MDF



Grieco et al. (2012)



Gonzalez et al. (2013)



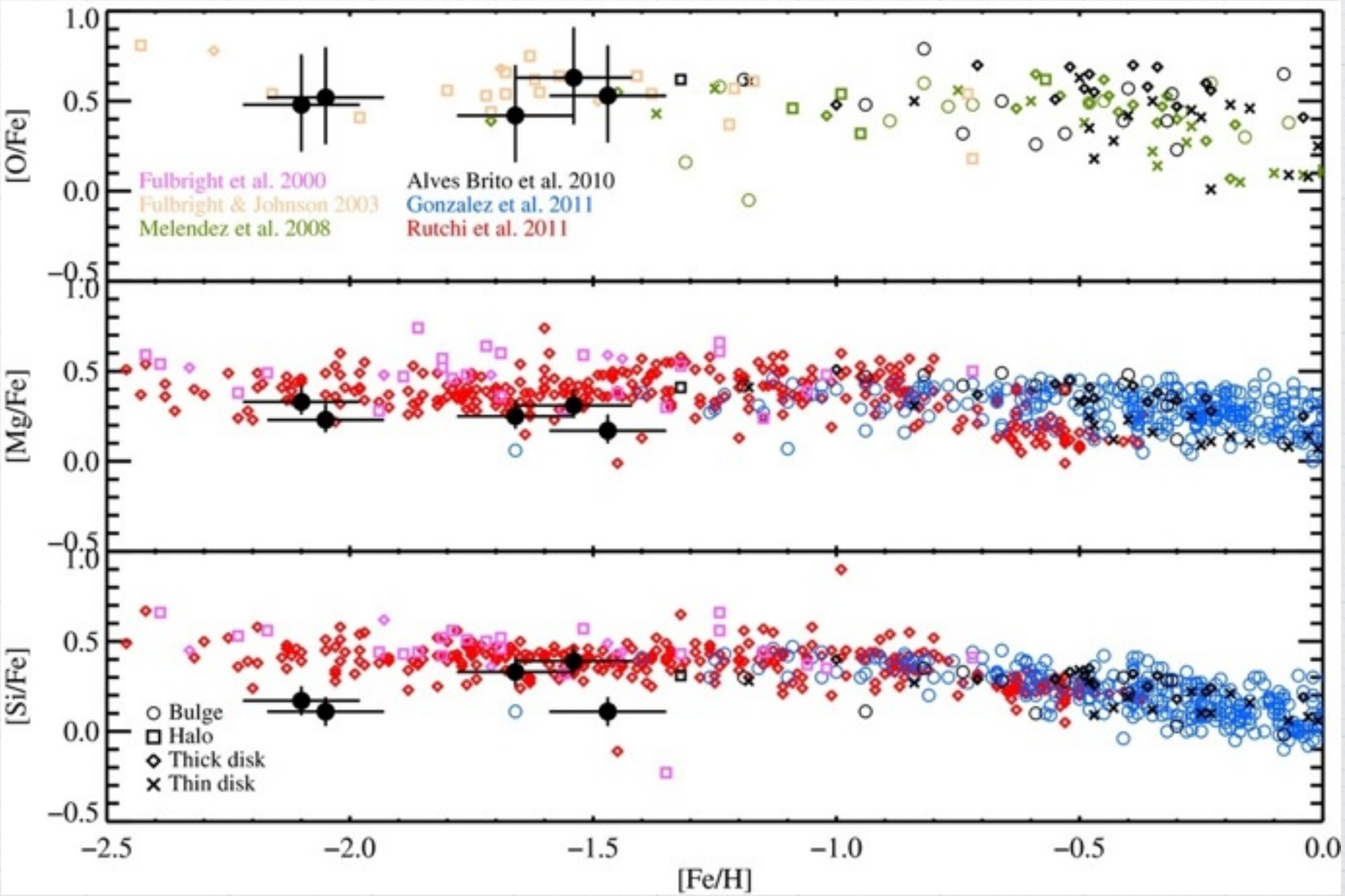
Ness et al. (2013)

The APOGEE survey

- Observed 2403 bulge stars, found five with [Fe/H] < -1.6.

- Lowest found have [Fe/H] = -2.1.

- Found lower alpha abundances than thick disc.



The EMBLA Survey

- Extremely Metal-poor BuLge stars with AAOmega
- The first dedicated search for metal-poor stars in the Galactic bulge, part of the collaboration between SkyMapper and Gaia-ESO.

Australian National University

- Louise Howes
- Martin Asplund
- Stefan Keller
- David Yong
- Mike Bessell
- Anna Marino
- David Nataf

UNIVERSITY OF CAMBRIDGE

- Andy Casey
- Clare Worley
- Gerry Gilmore

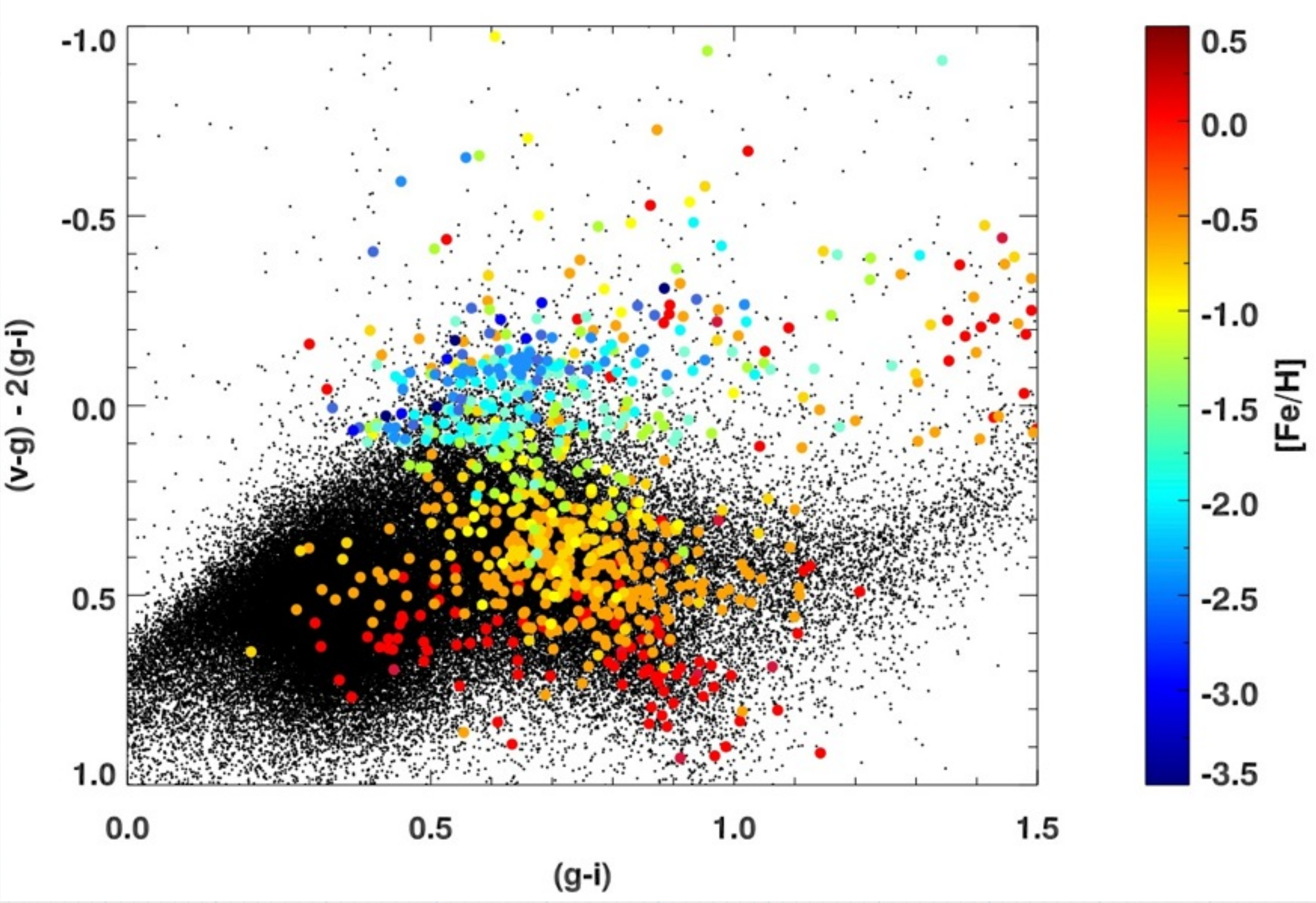
UPPSALA UNIVERSITET

- Karin Lind

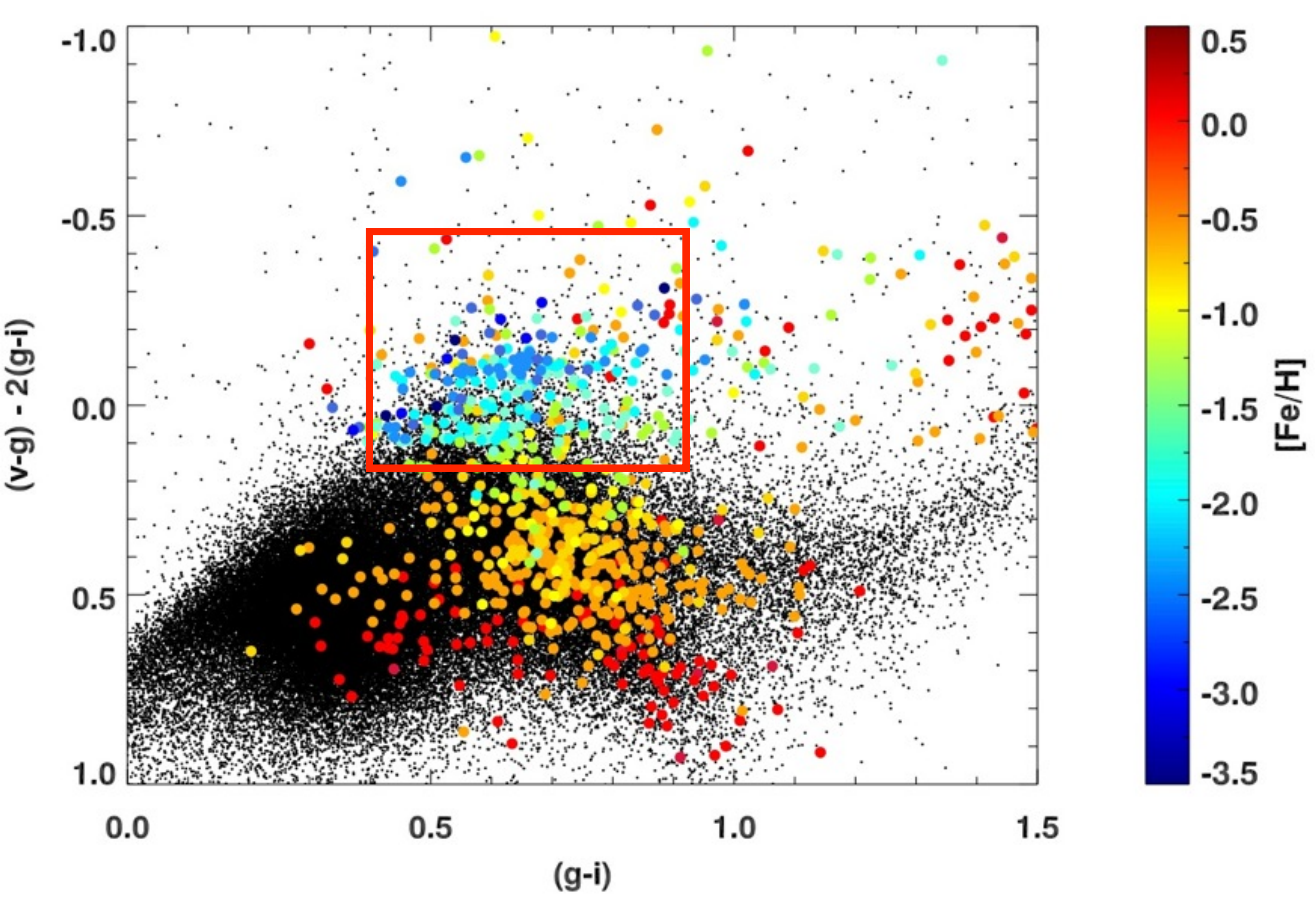
Surveying with SkyMapper

* 1.35m wide-field survey telescope.
* 32 CCDs covering a 2.34°x2.40° field of view.
* Six optical filters, based on the ugriz system.
* The extra filter, v, is designed to be metallicity sensitive.

SkyMapper Photometry

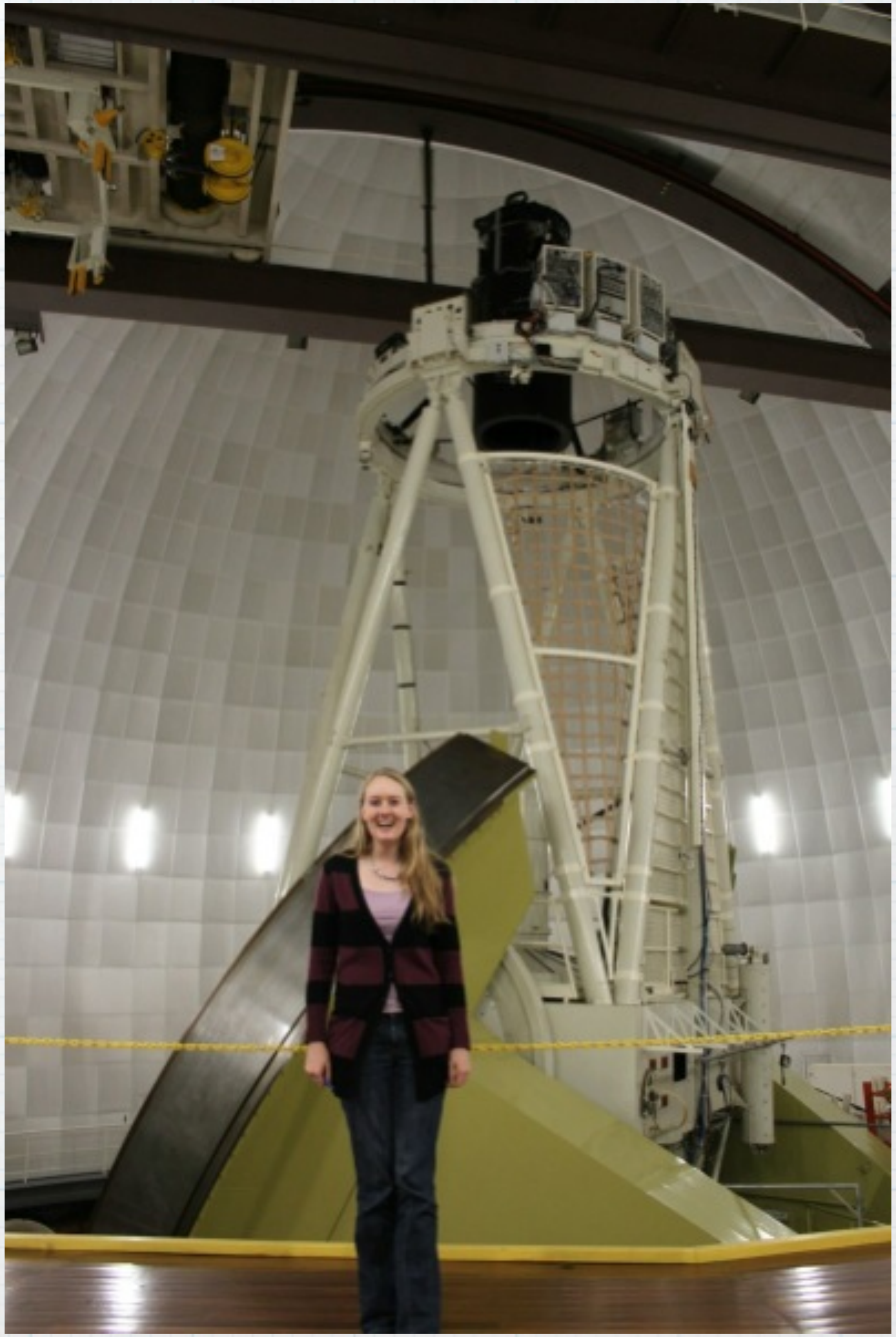


The Selection Process



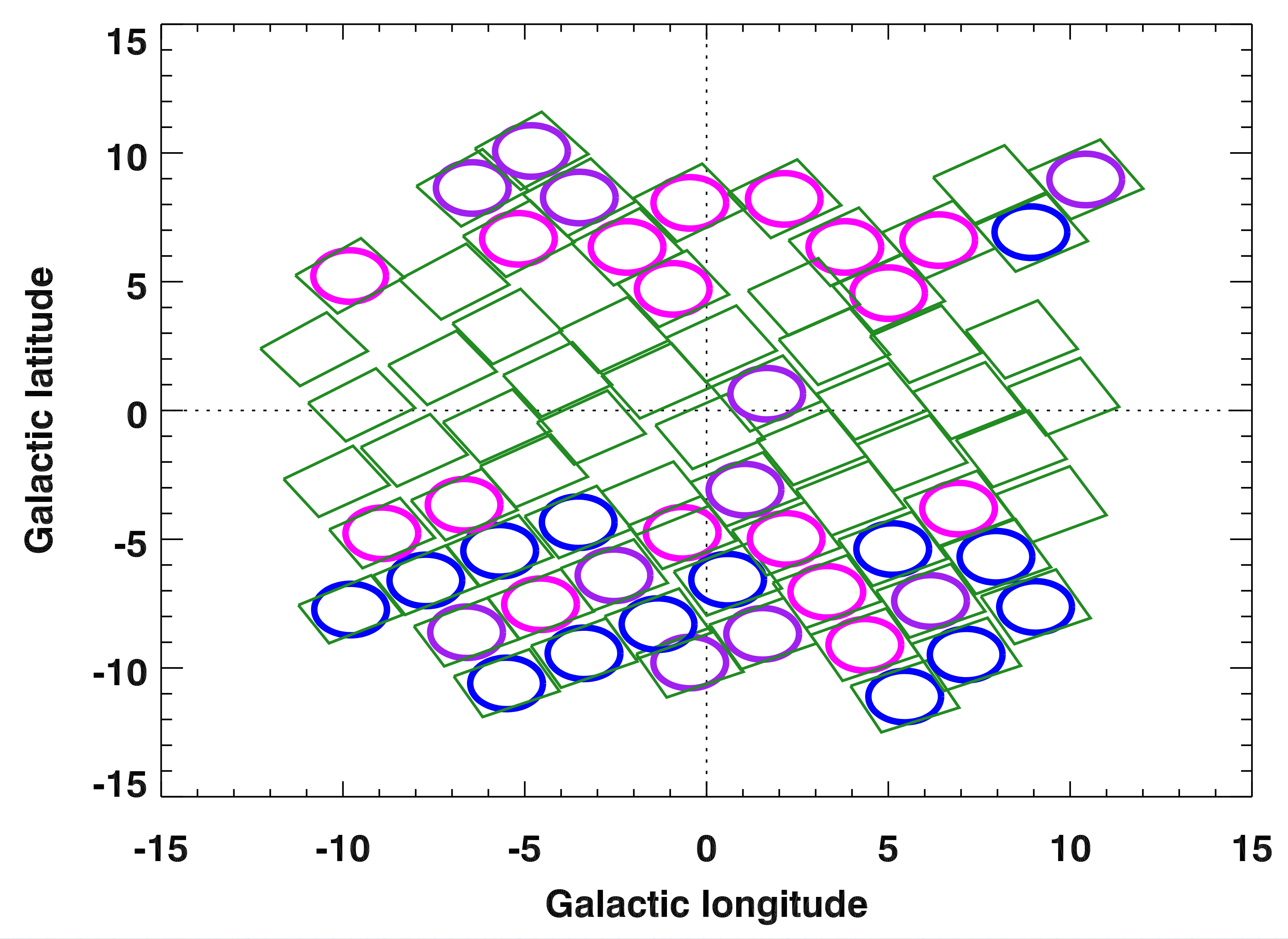
Spectroscopy from the AAT

* 3.9m telescope at Siding Spring Observatory, NSW.
* Multi-object spectrograph AAOmega has 400 fibres with a 2° diameter FOV.
* Observed ~350 stars in each field for 120 mins.
* Obtain blue spectrum (370-580nm) with R=1,300 and calcium triplet (845-900nm) with R=10,000.



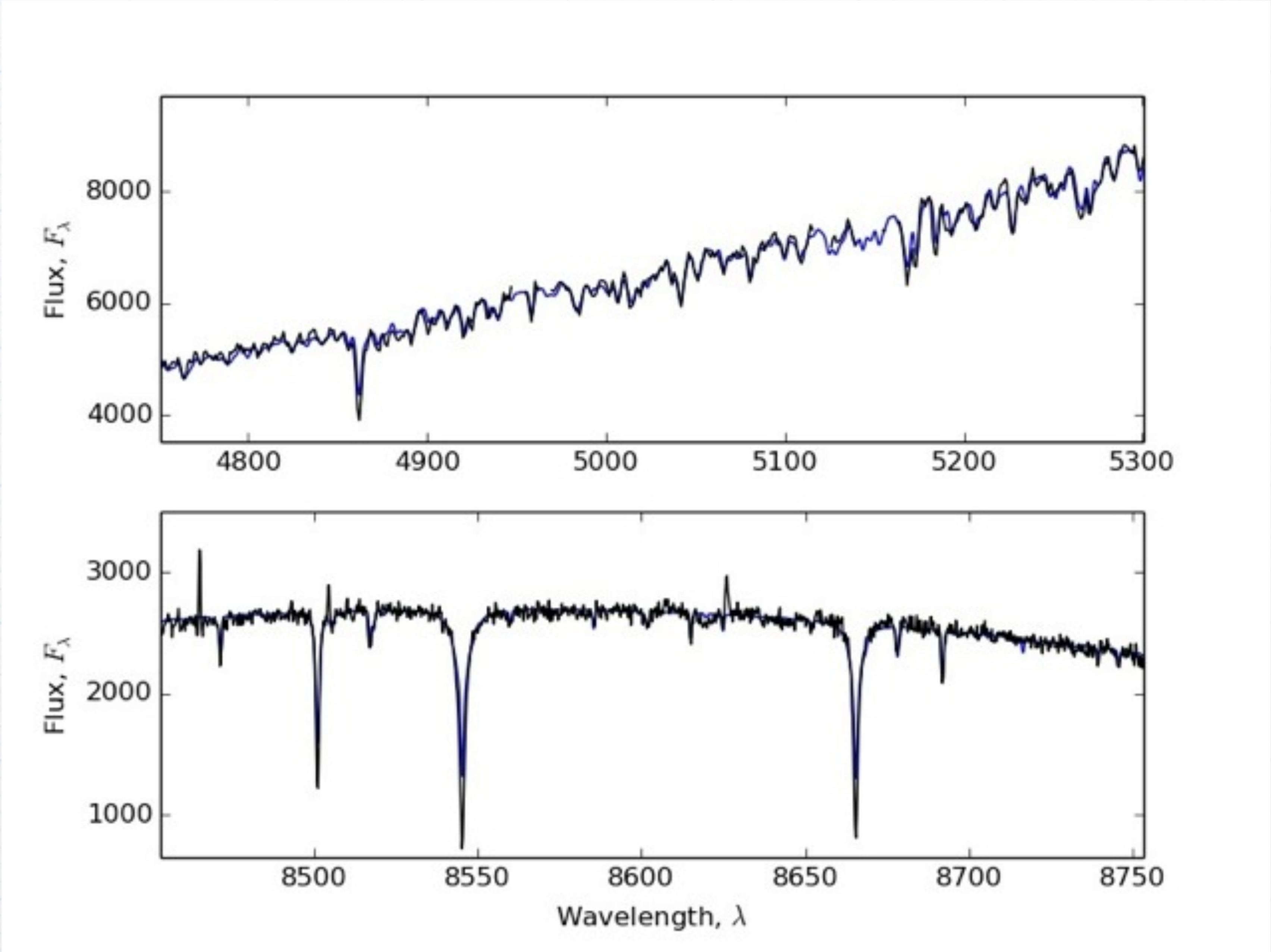
Fields Observed

* 14 fields in 2012
* 11 fields in 2013
* Final 17 fields in 2014
* In total, over 14,000 stars observed.



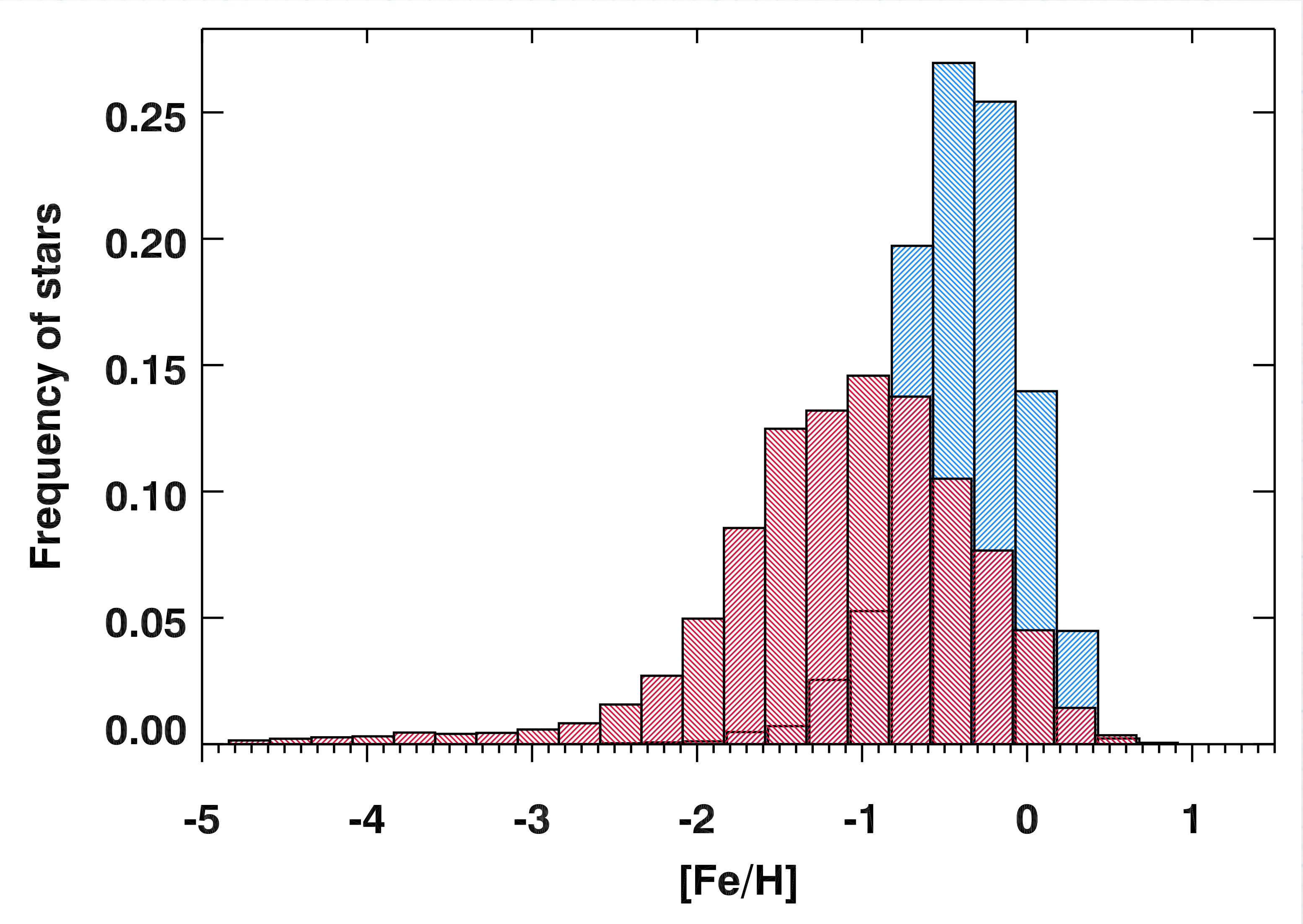
Spectroscopy from the AAT

* Parameters evaluated using **sick**: v_{rad}, T_{eff}, log(g), [Fe/H] and [α/Fe] - all calculated using MCMC to match the entire spectrum to synthetic grids.



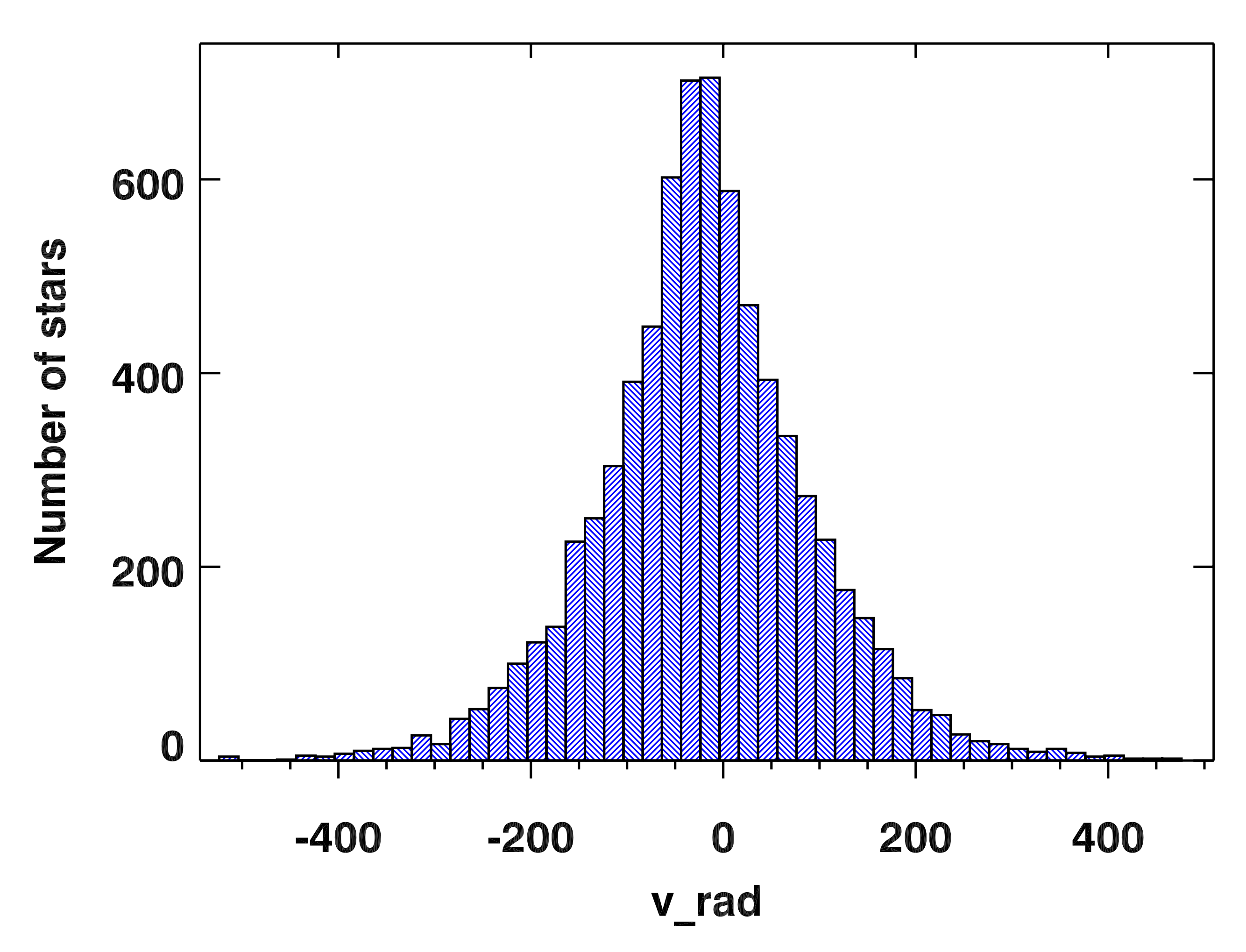
The Resulting MDF (2013)

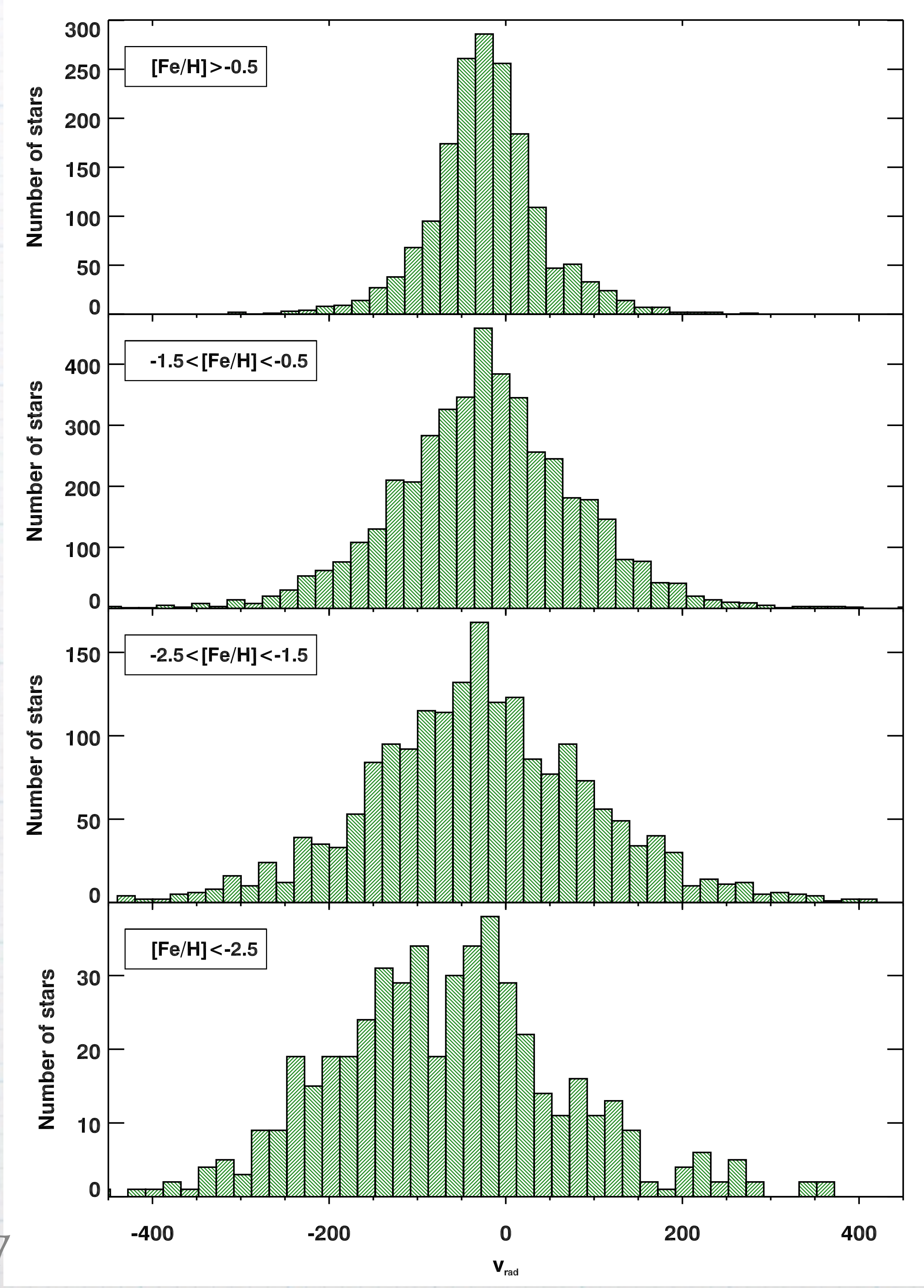
* We have found a significantly more metal-poor population than an unbiased survey.
* Over 50% have [Fe/H] < -1.
* Up to 50 stars with [Fe/H] < -3.
* No previous star found in the bulge below [Fe/H] = -3.



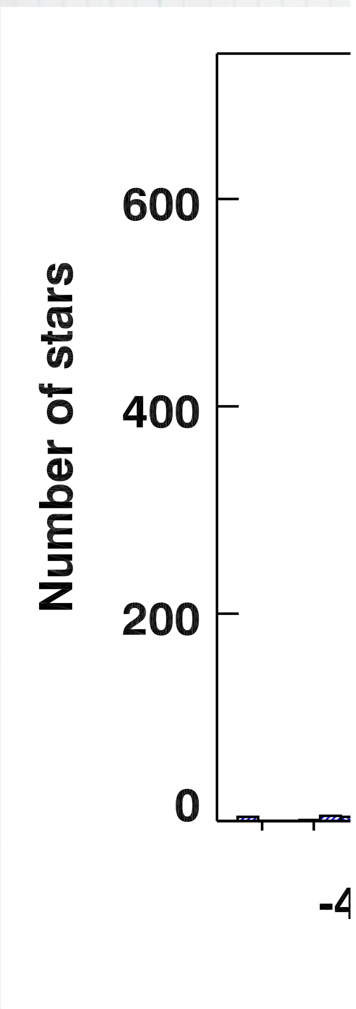
* Red: our survey
* Blue: data from ARGOS survey

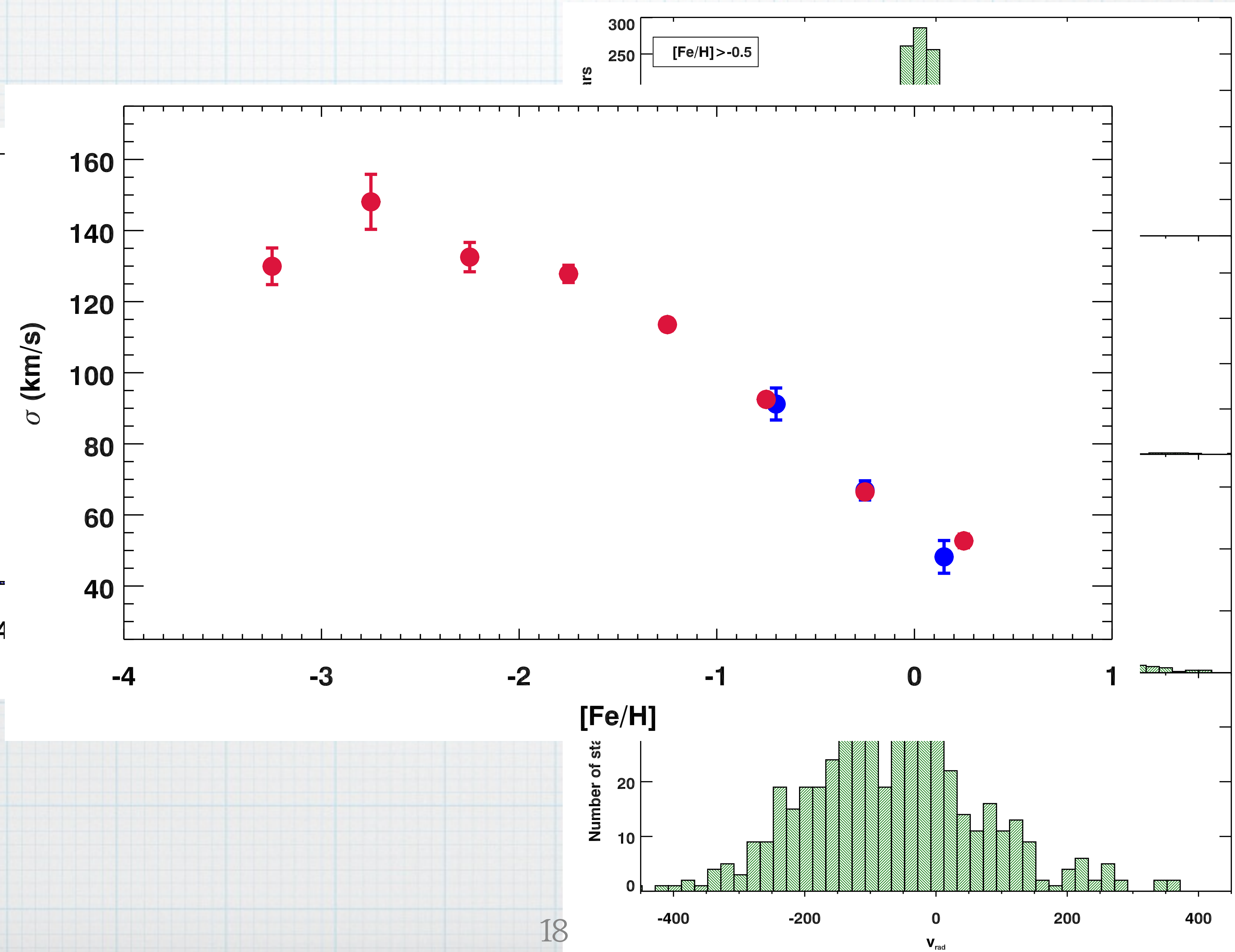
Velocity Dispersion





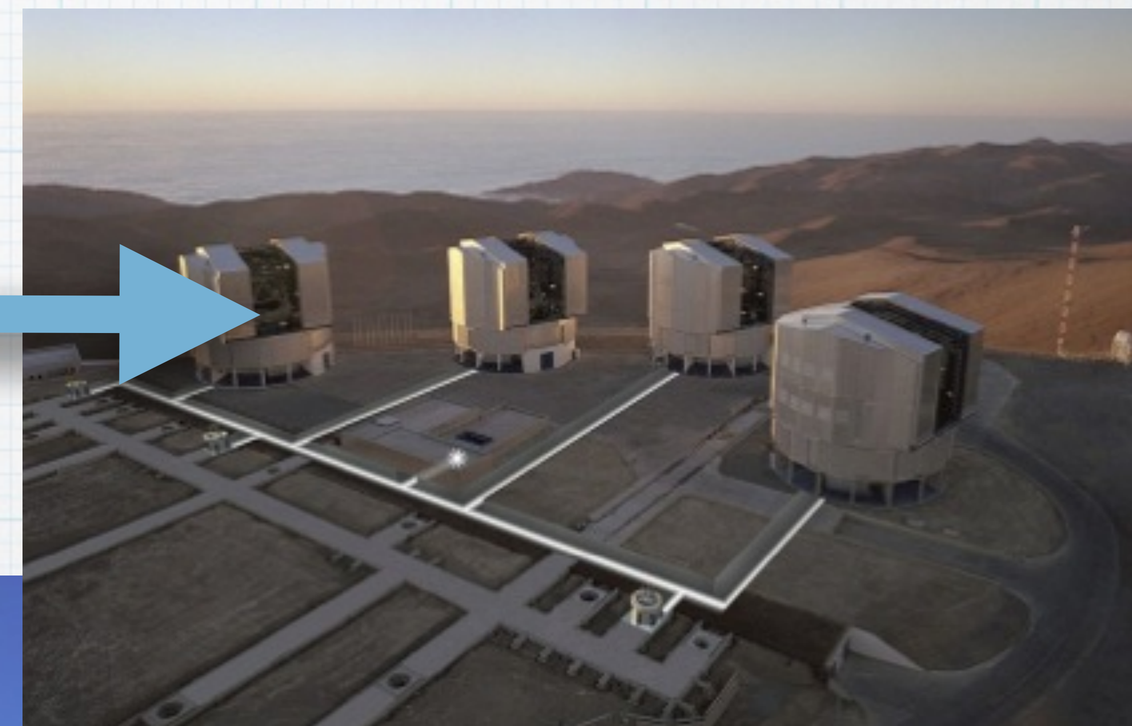
Velocity Dispersion





Follow-up with High-Resolution Data

Gaia-ESO survey



VLT

Magellan

Stars from Gaia-ESO iDR2

Our data:

Gaia-ESO (bulge)

Gaia-ESO (halo)

Bulge data:

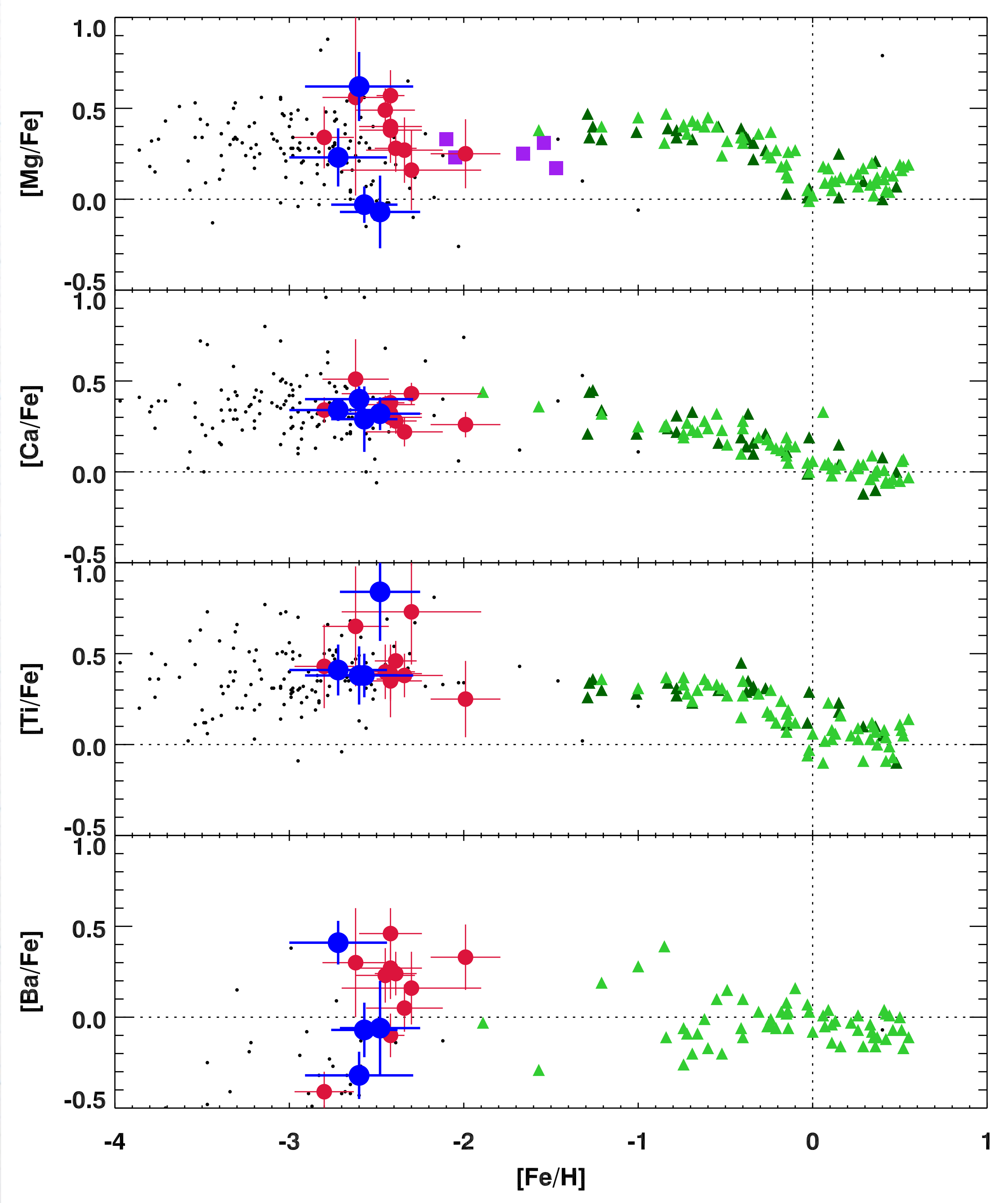
García Pérez et al. (2012)

Alves-Brito et al. (2012)

Bensby et al. (2013)

Halo data:

Yong et al. (2013)



Results from 2014

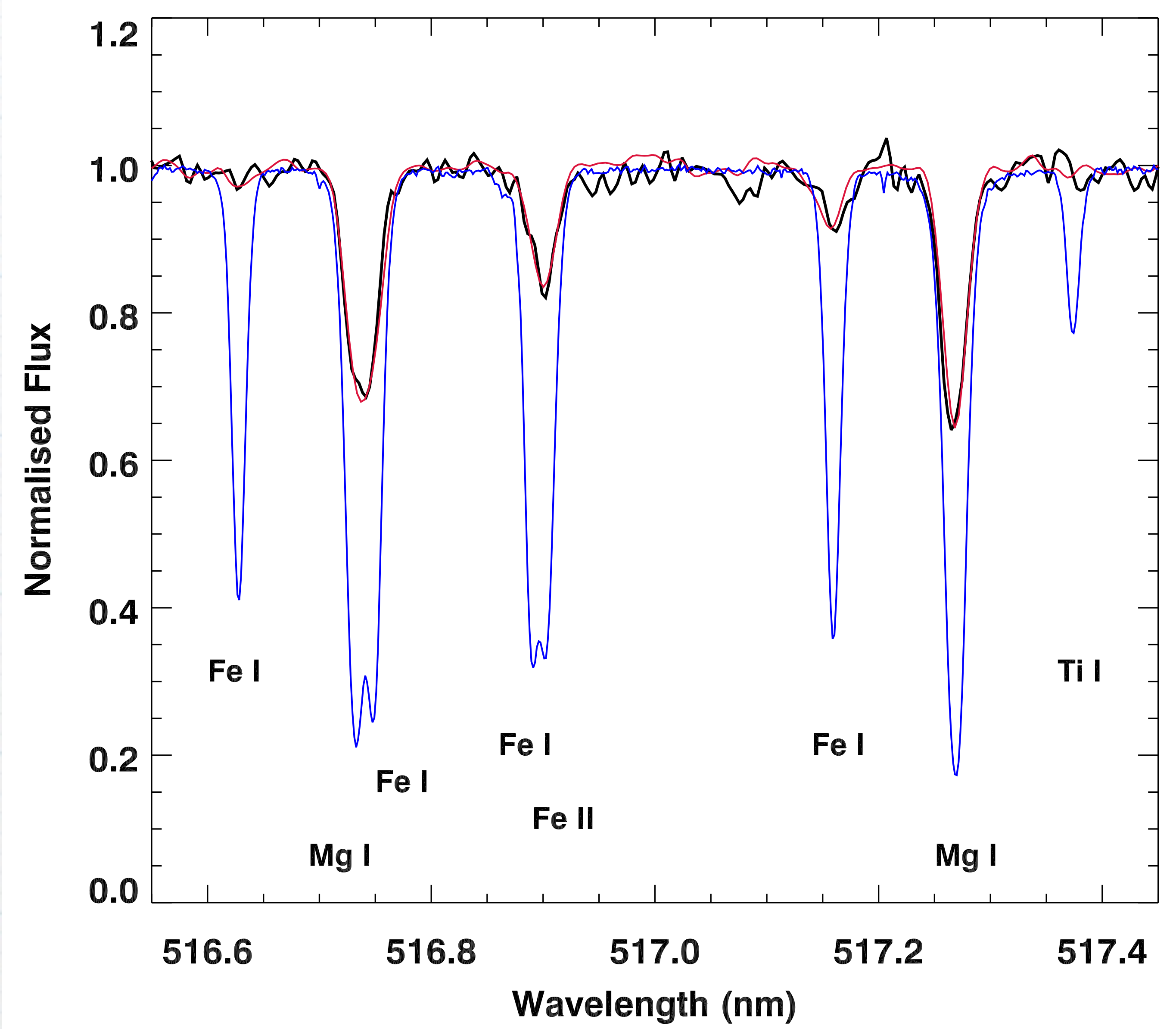
* 23 stars observed on Magellan
* 8 stars observed on the VLT
* ~10 stars observed with GES

Results from 2014

* 23 stars observed on Magellan
* 8 stars observed on the VLT
* ~10 stars observed with GES
* Measured: Li, O, Na, Mg, Al, Si, K, Ca, Sc, Ti, Cr, Mn, Ni, Zn, Sr, Y, Zr, Ba, La, Eu.

Lowest metallicity in the Bulge?

* Observed star 2156-228, similar to the halo star CD 38-245 with preliminary estimated parameters:
  * $T_{eff} = 4500K$
    $\log(g) = 1.24$
    $[Fe/H] = -4.23$



Alpha Elements - Ca, Ti

Our data:

Magellan

Gaia-ESO

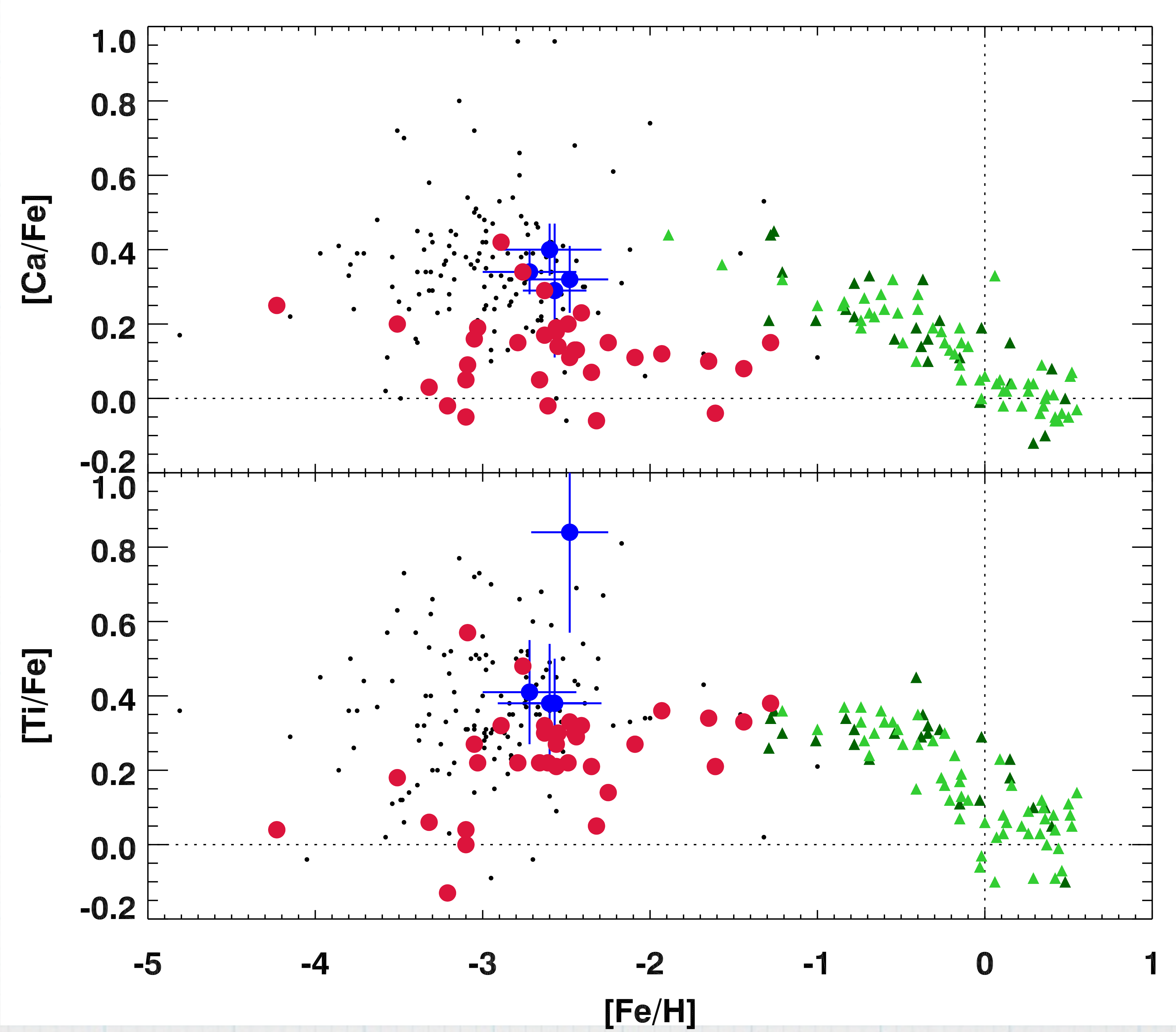
Bulge data:

Alves-Brito et al. (2012)

Bensby et al. (2013)

Halo data:

Yong et al. (2013)



Alpha Elements - Ca, Ti

Our data:

Magellan

Gaia-ESO

Mean Ca
abundance = 0.15

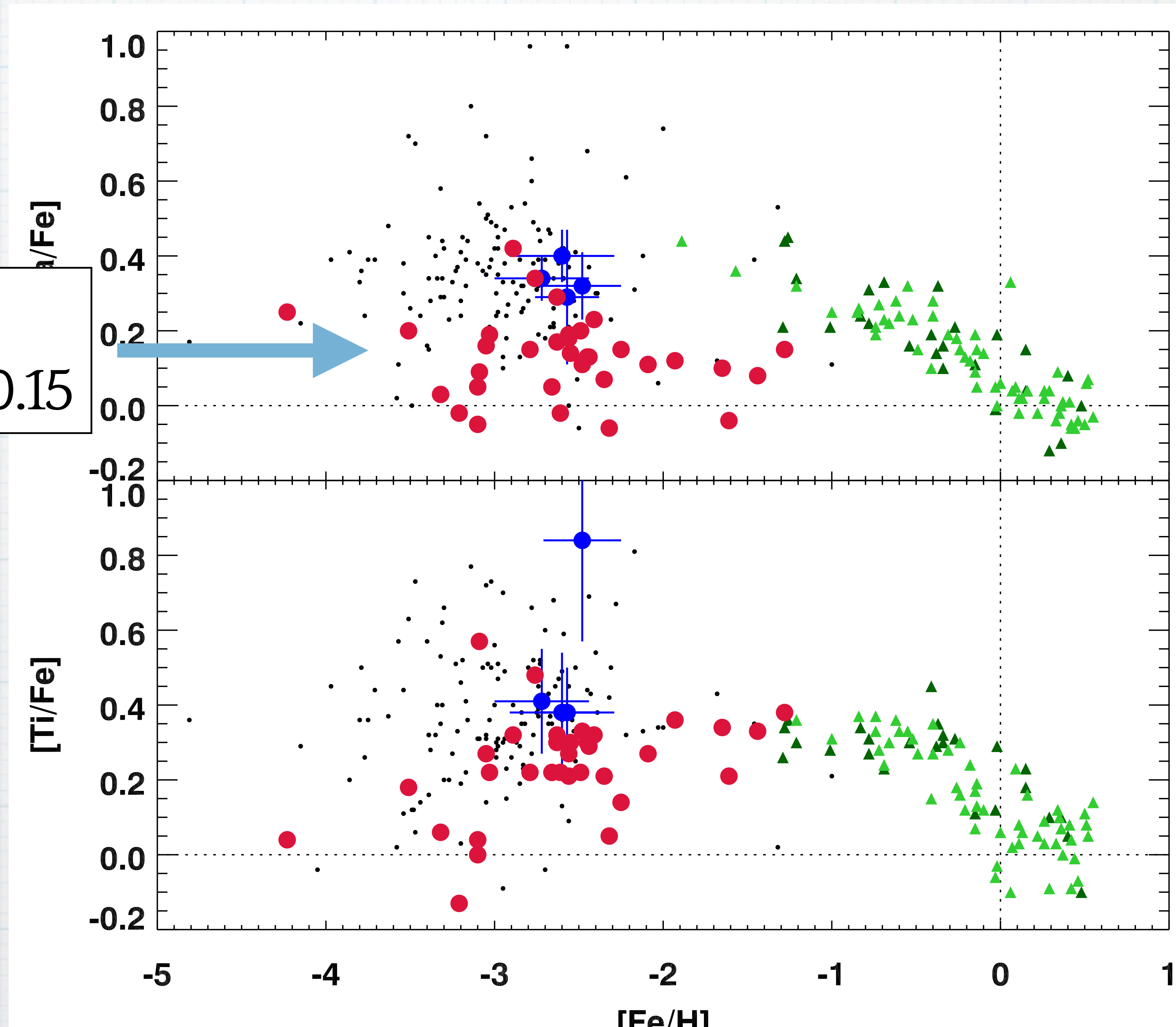
Bu

Alves-Brito et al. (2012)

Bensby et al. (2013)

Halo data:

Yong et al. (2013)



Alpha Elements - Mg

Our data:

Magellan

Gaia-ESO

Bulge data:

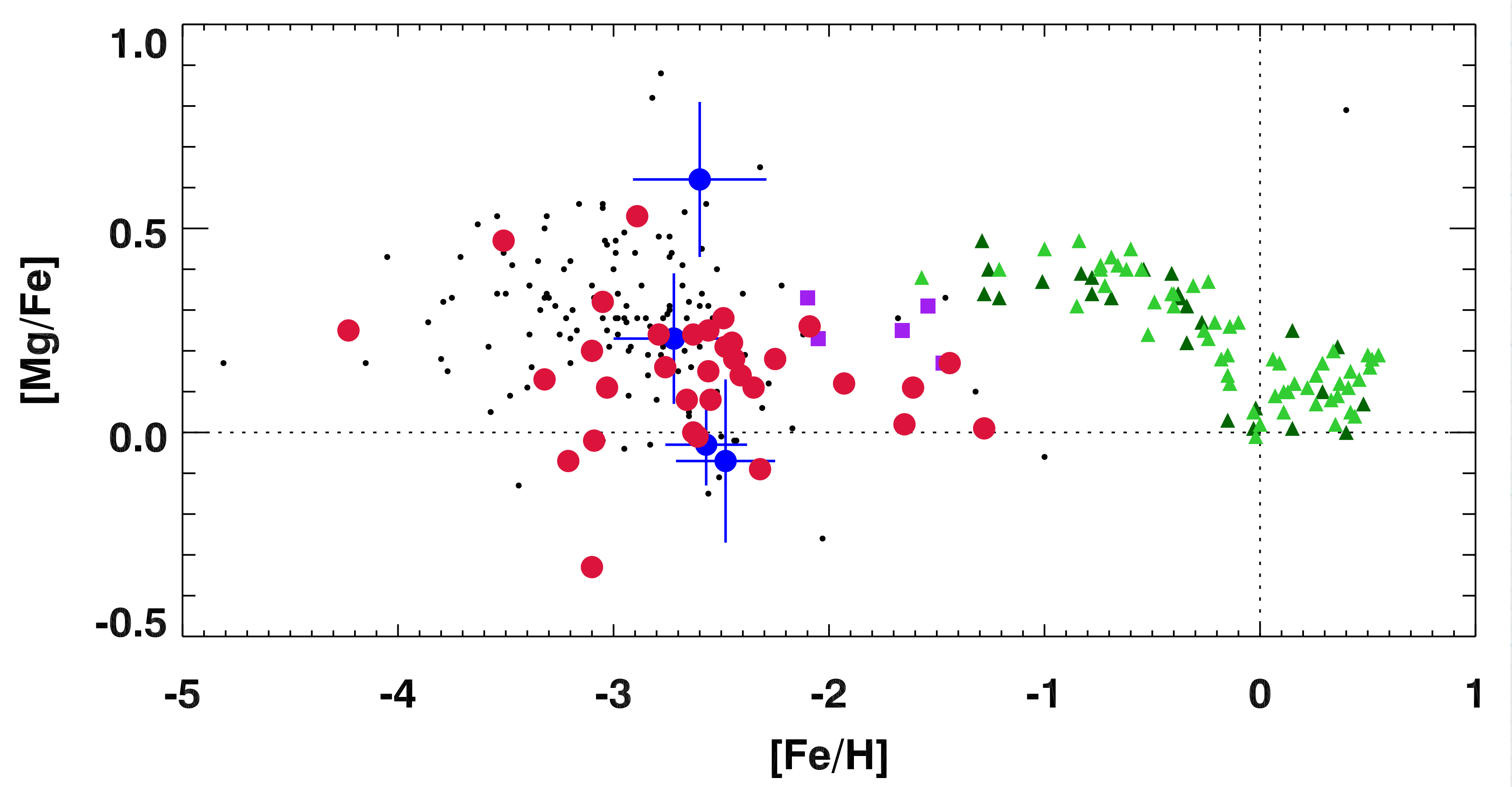
García Pérez et al. (2012)

Alves-Brito et al. (2012)

Bensby et al. (2013)

Halo data:

Yong et al. (2013)



Iron-peak Elements - Ni, Zn

Our data:

Magellan

Gaia-ESO

Bulge data:

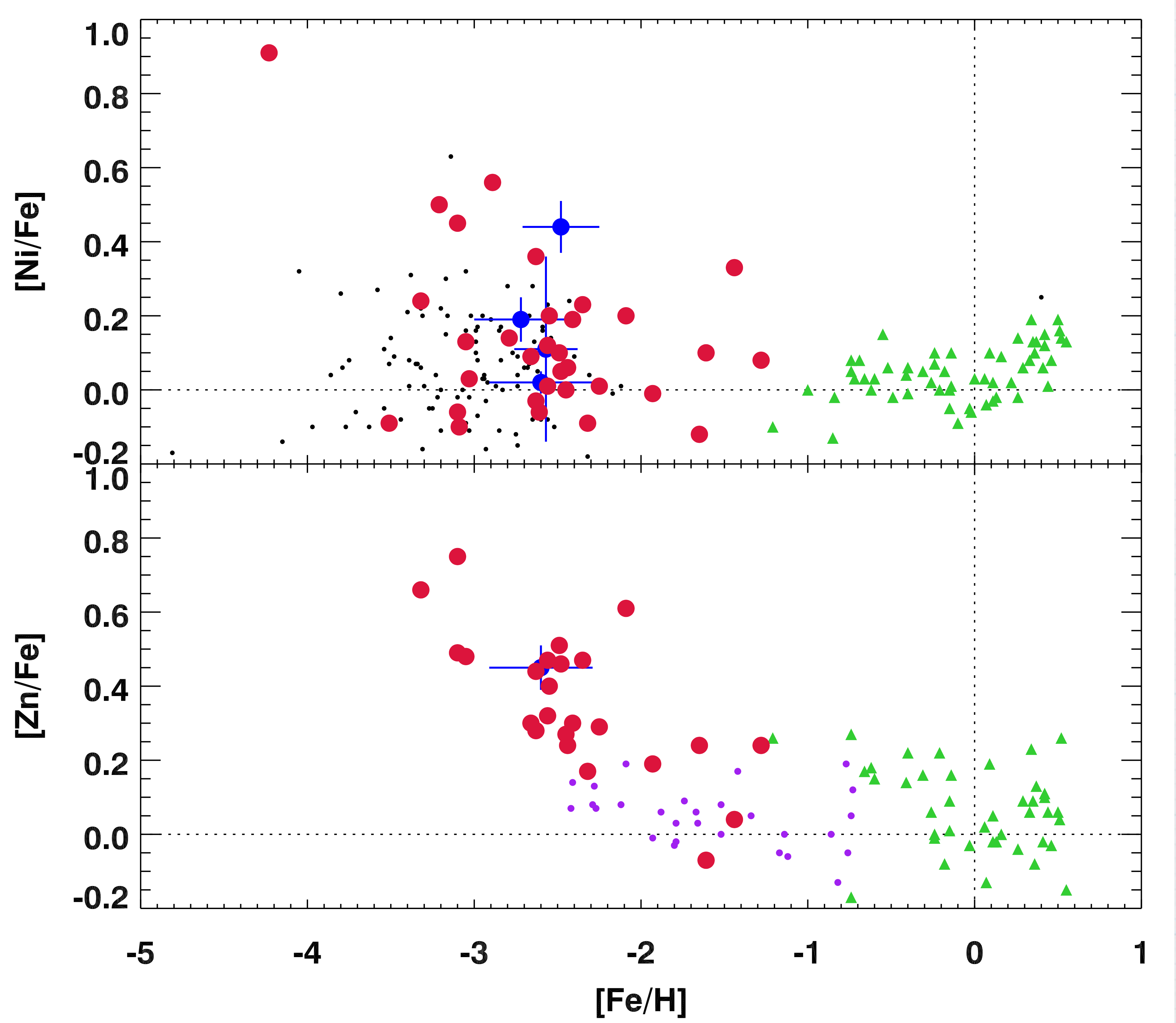
Alves-Brito et al. (2012)

Bensby et al. (2013)

Halo data:

Yong et al. (2013)

Nissen et al. (2003)



Neutron Capture Elements - Sr, Ba

Our data:

Magellan

Gaia-ESO

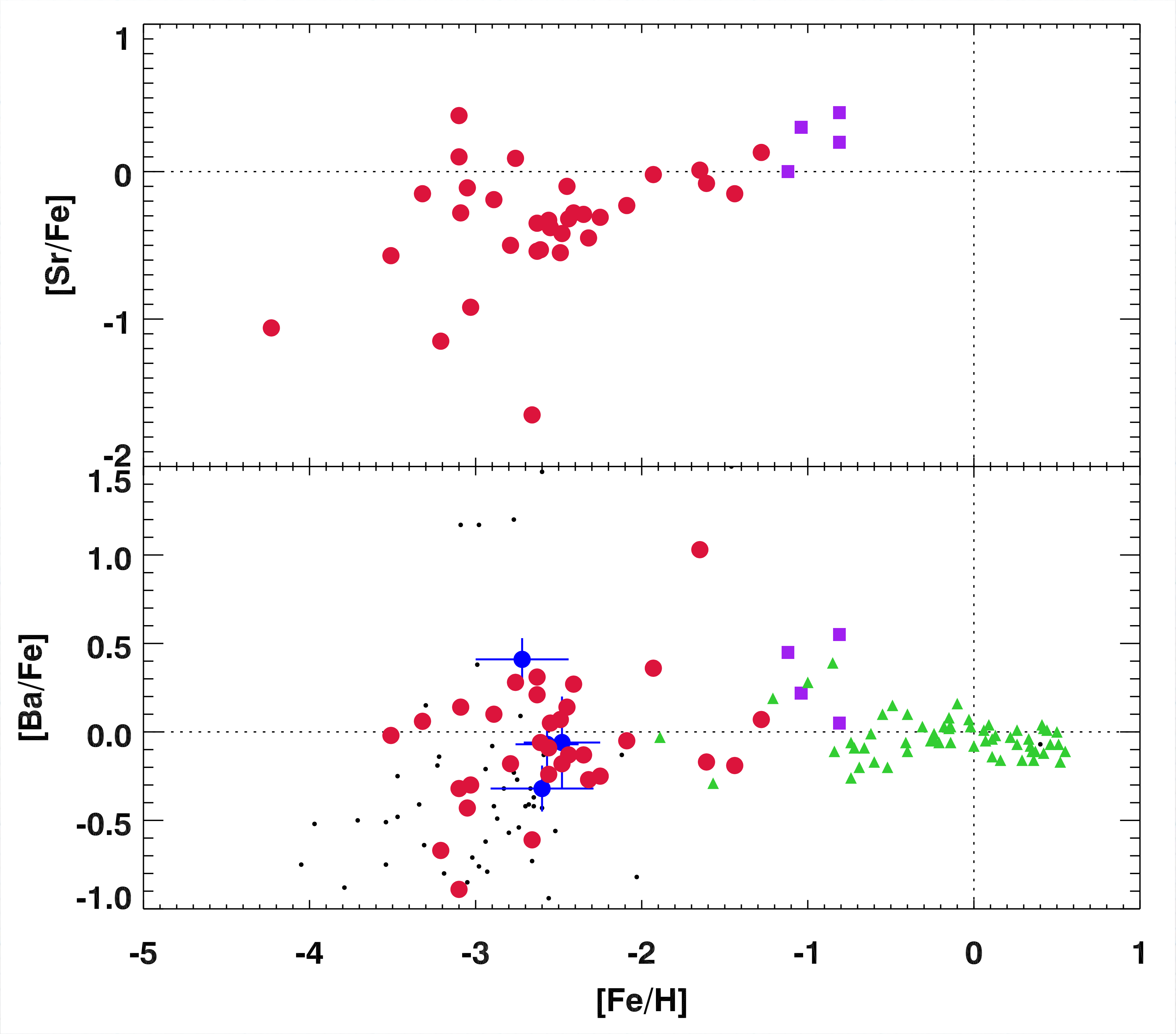
Bulge data:

Barbuy et al. (2014)

Bensby et al. (2013)

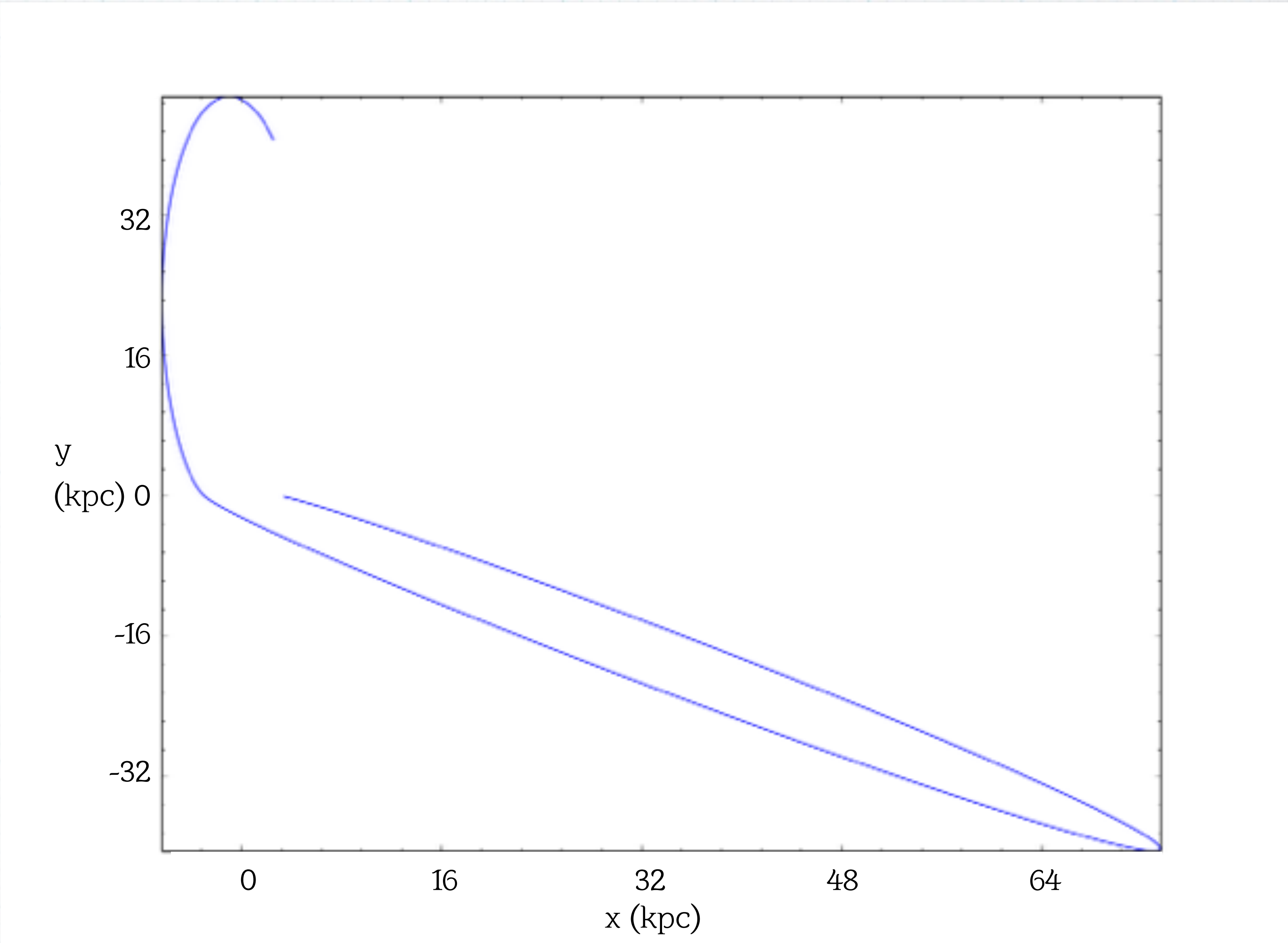
Halo data:

Yong et al. (2013)



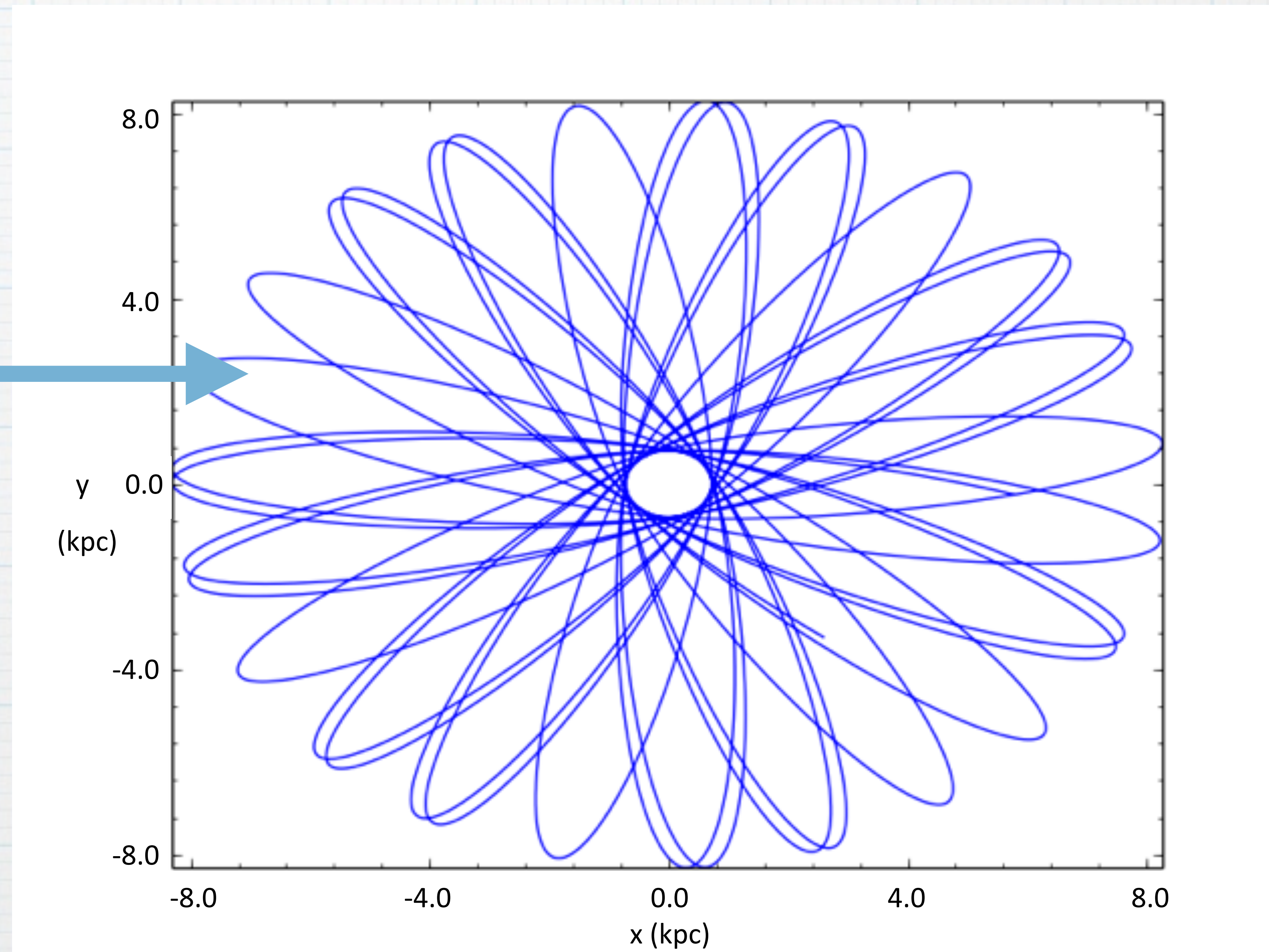
Orbiting the Bulge

- Assuming a 3-component galaxy potential: disc, halo, and bulge.
- Proper motions from UCAC4,
- Distances estimated from stellar parameters and 2MASS photometry, assuming $M \sim 0.8 M_{\odot}$.
- Roughly half have orbits like this one.



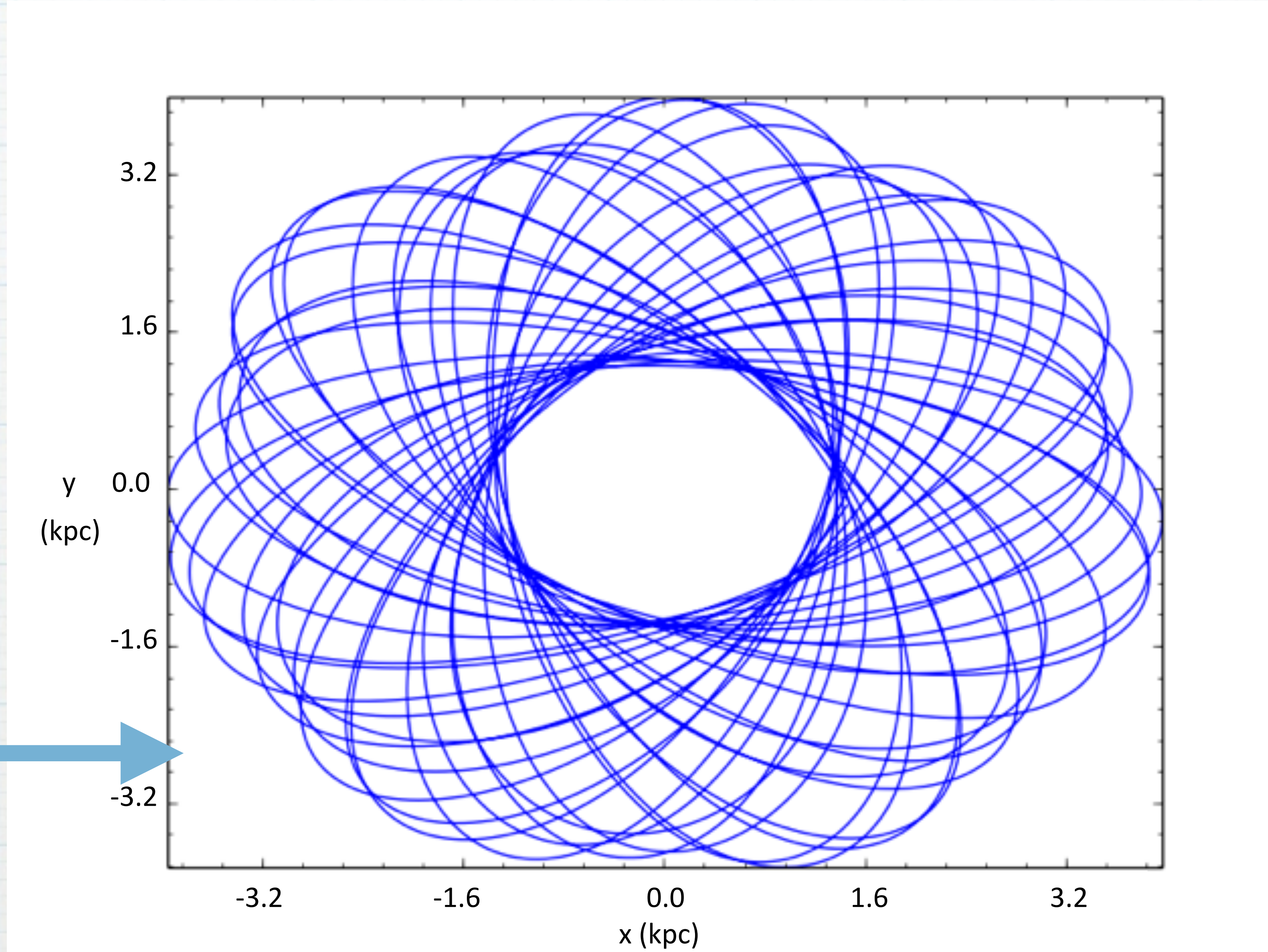
Orbiting the Bulge

* Not all have halo orbits...
* One third have orbits which remain entirely within the disc.
* About 15% have potentially bulge like orbits.



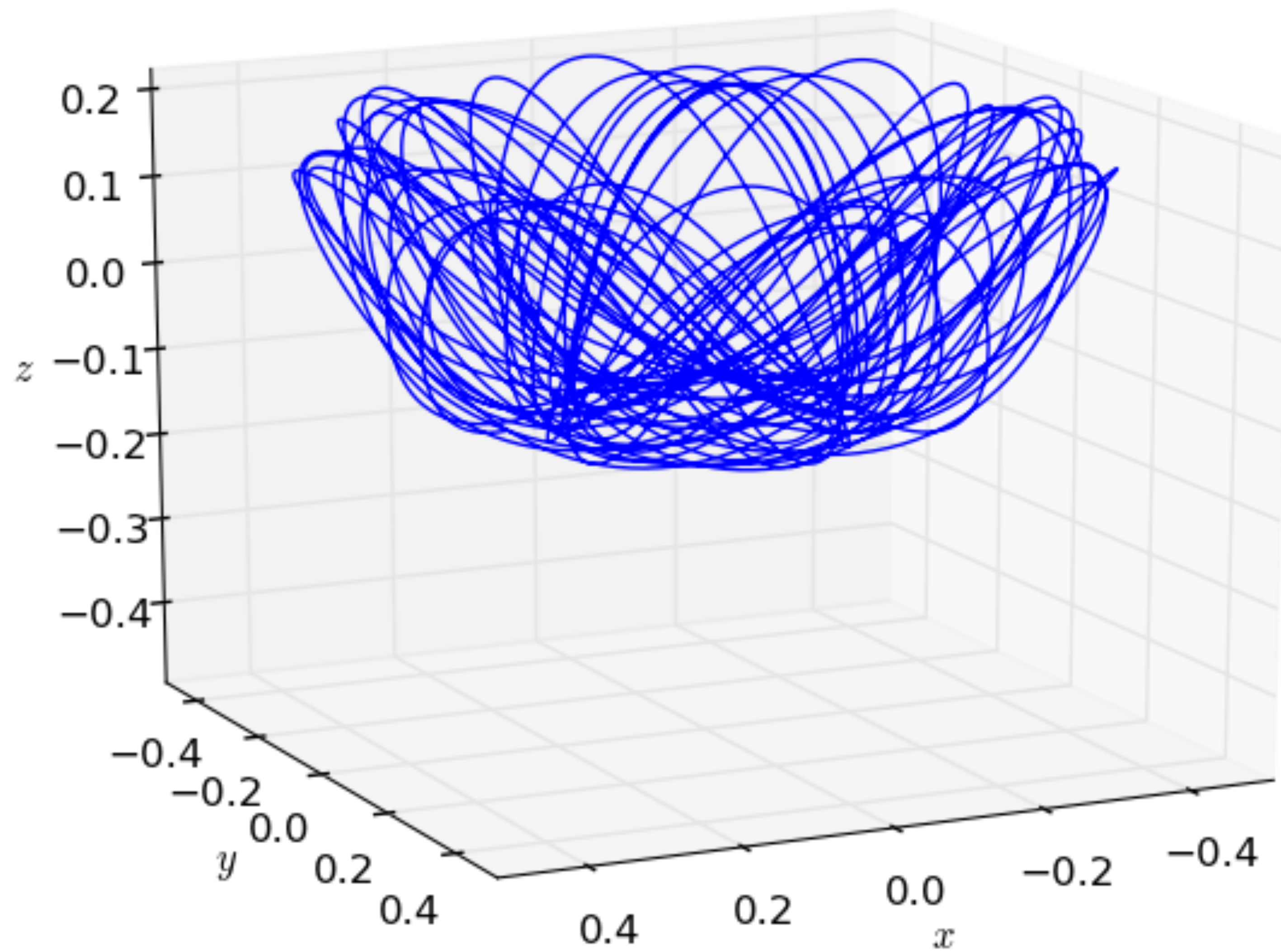
Orbiting the Bulge

* Not all have halo orbits...
* 14/37 have disc like orbits.
* 5/37 have potentially bulge-like orbits.



Orbiting the Bulge

- Not
  hal
- 14/3
  dis
  orb
- 5/37
  pot
  bul
  orb



Conclusions

* Models predict that oldest stars should lie in the bulge.
* We have found the first EMP stars in the bulge.
* Out of first 9,000 stars, we found ~4,800 stars with [Fe/H]<-1.
* >50 stars observed in high resolution, ~15 with GES.
* Interesting abundance trends.
* Not all of these stars are just passing through the bulge.