超低光度矮小楕円銀河 Boötes I の化学組成

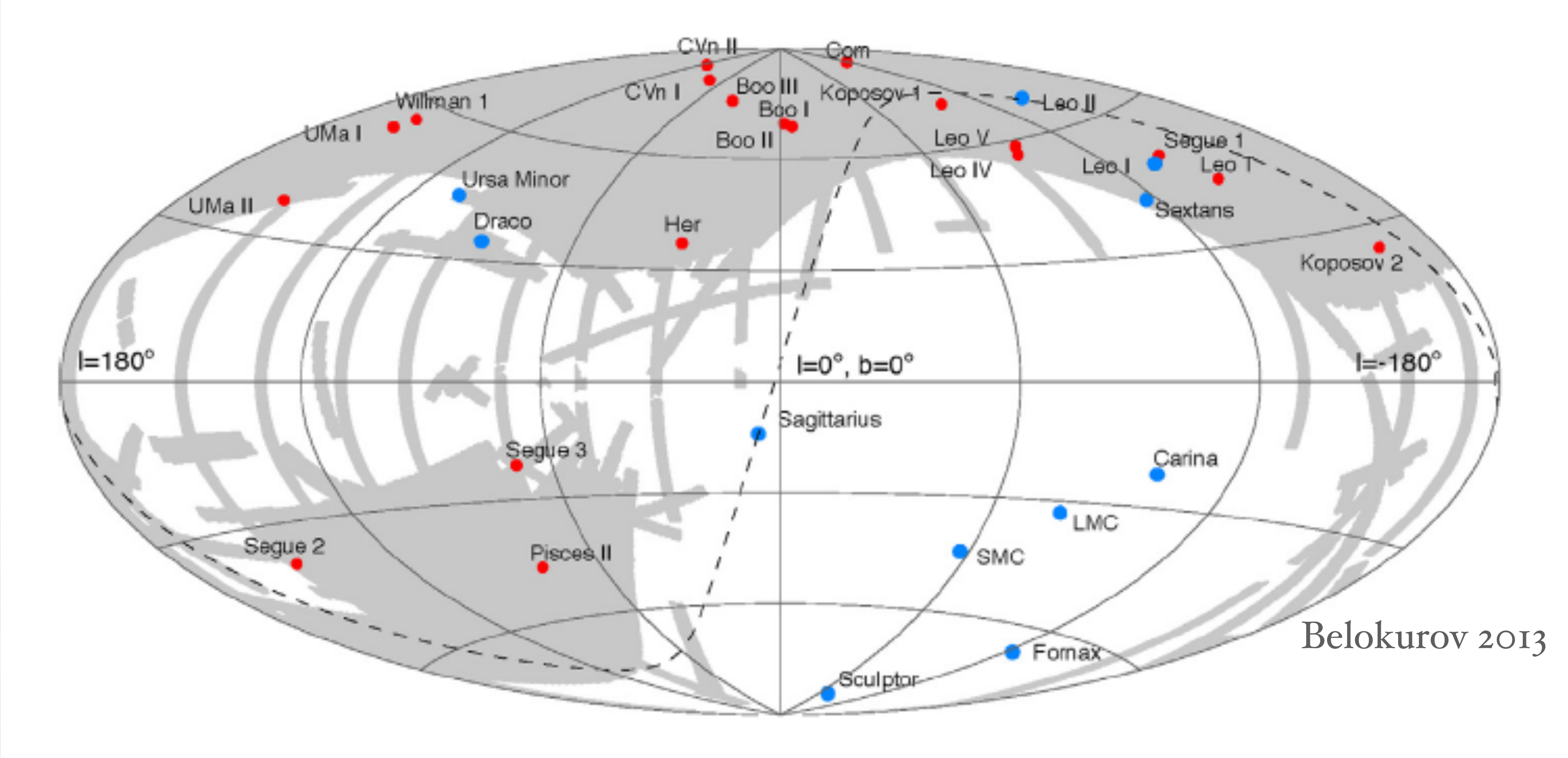
石垣美歩 (カブリIPMU/JSPS)

Co-I: 青木和光 （国立天文台）、岡本桜子 （上海天文台）、

有本信雄（国立天文台）

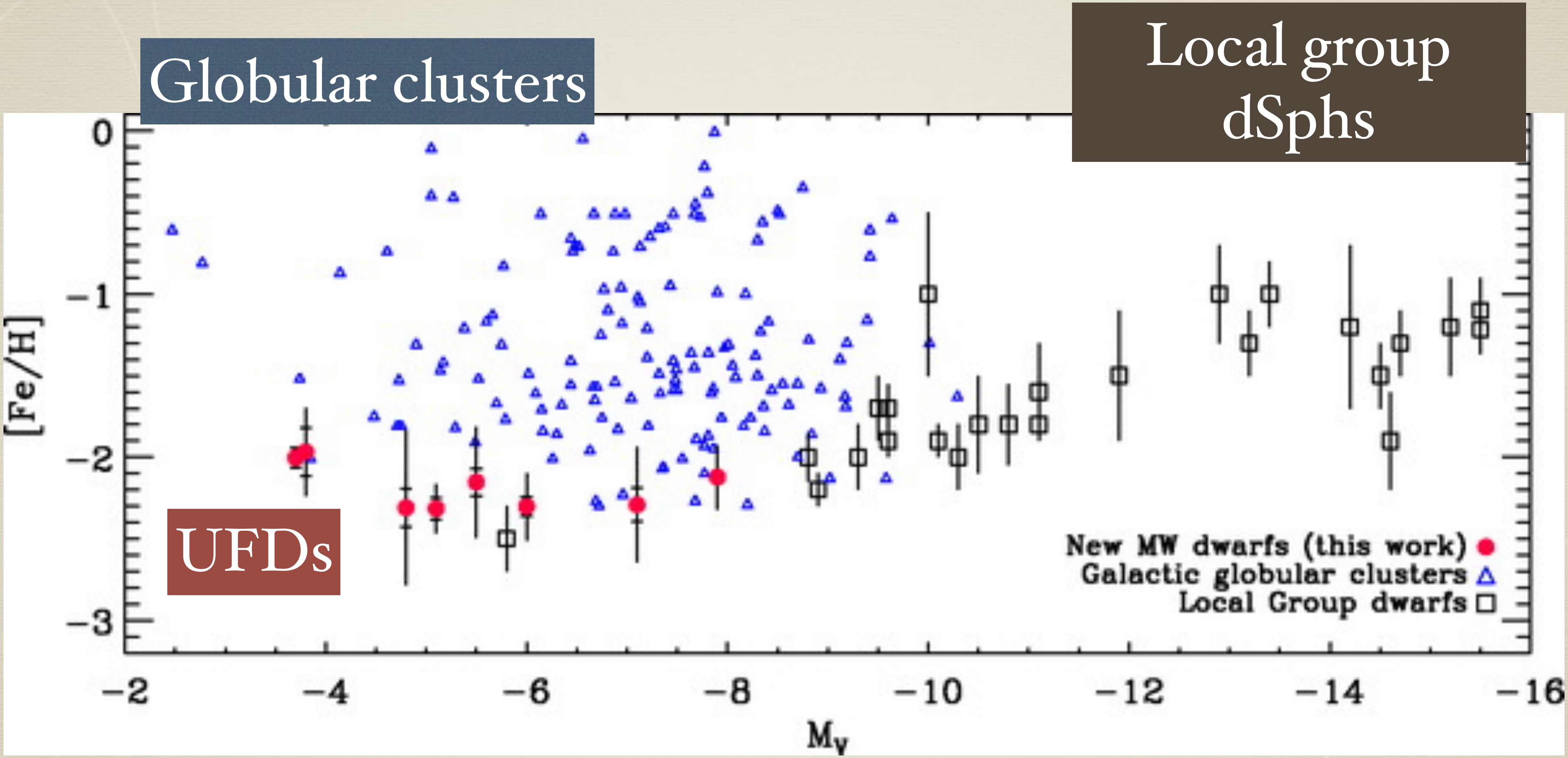
Dwarf spheroidal galaxies (dSphs) around the Milky Way

- Classical dSphs
- Ultra-faint dSphs (UFDs)



Belokurov 2013

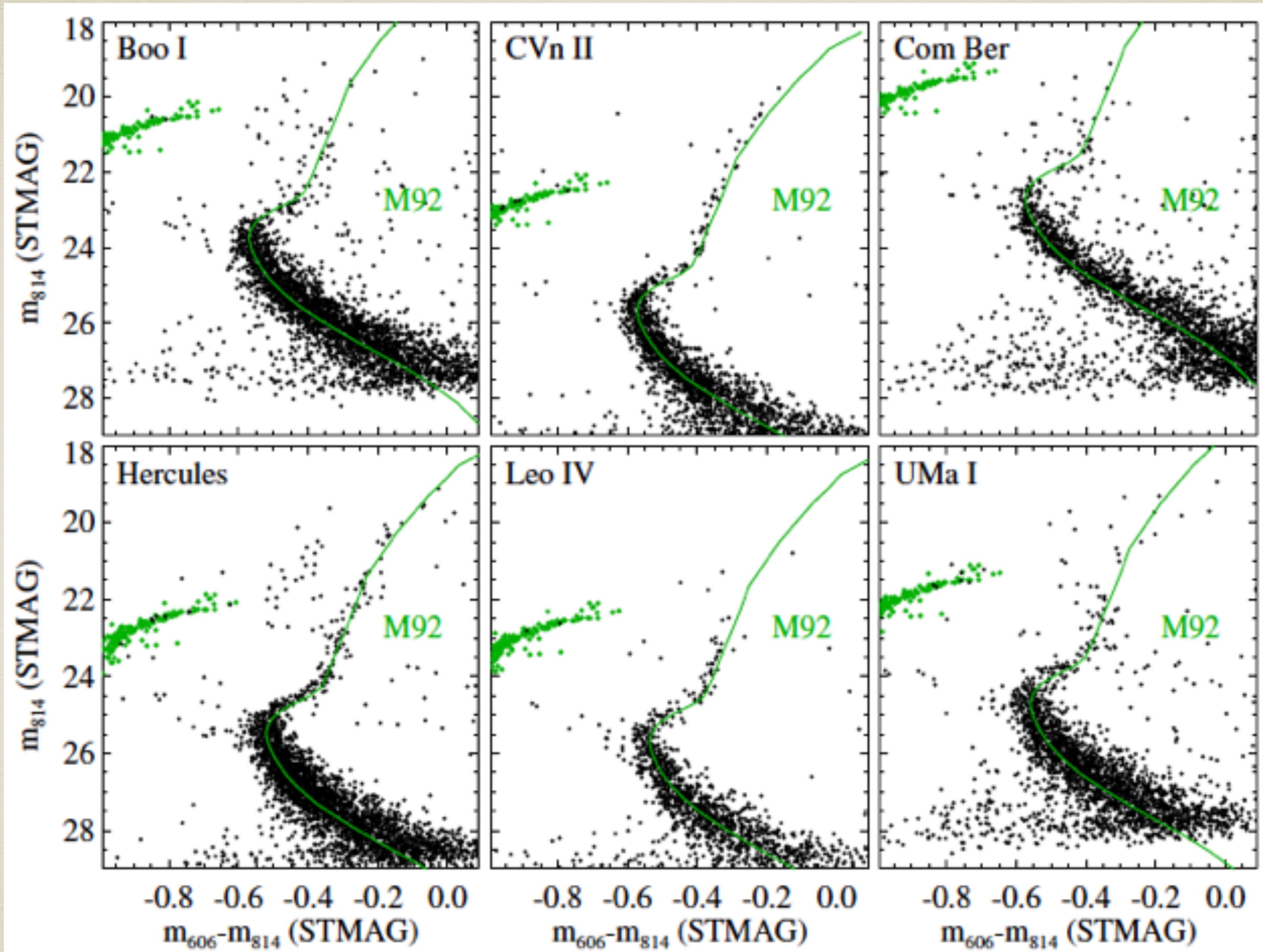
Luminosity vs. metallicity of UFDs



Simon & Geha 2007

* Low luminosity and very metal-poor

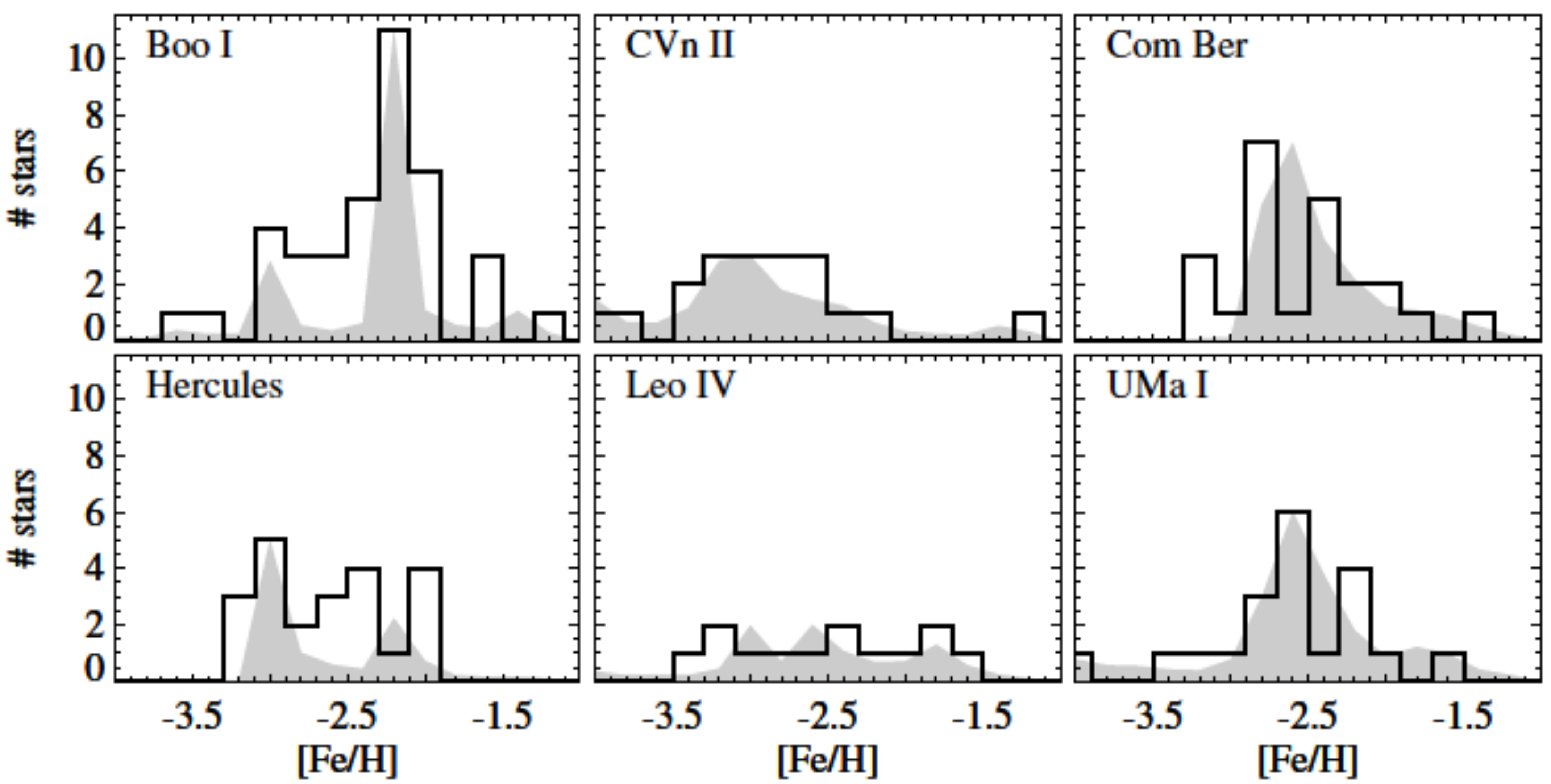
Stellar population in UFDs



Brown et al. 2014

* Very old, small scatter in age⟹ Short duration of star formation

Metallicity distribution in UFDs



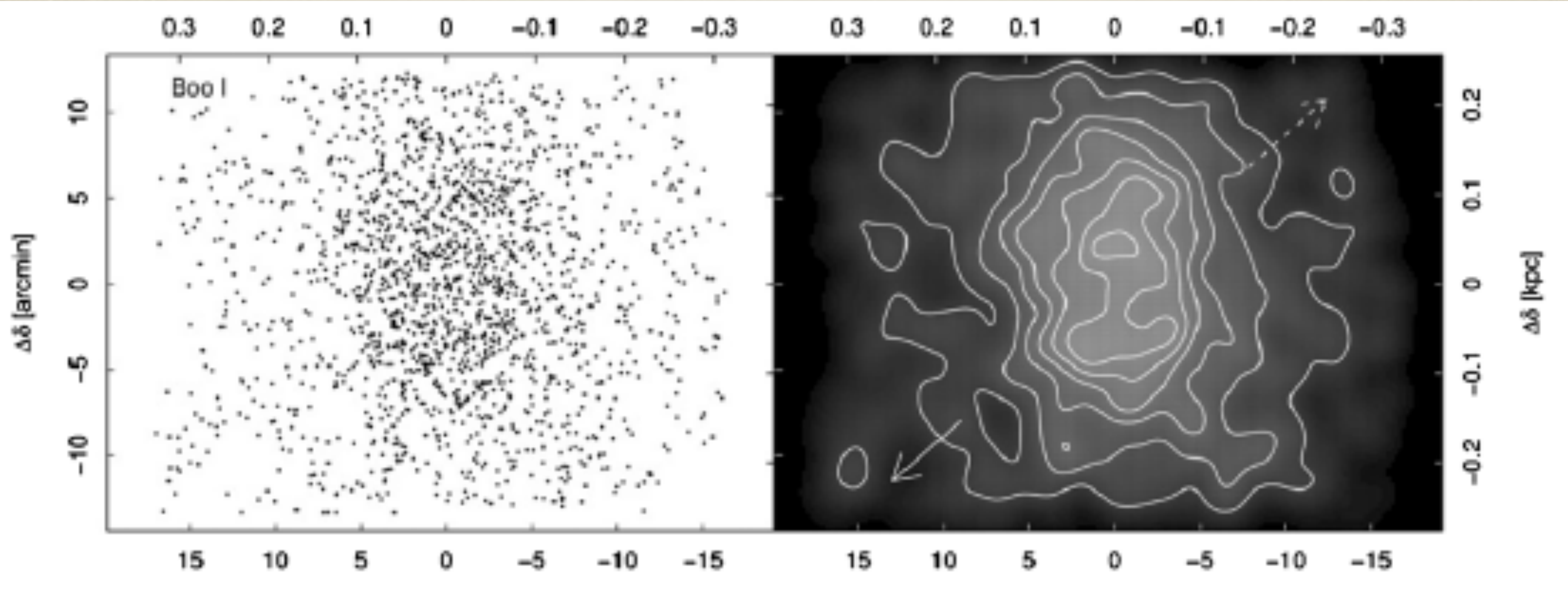
Brown et al. 2014

* ~ 1 dex spread in [Fe/H] ⇒ Complex star formation history

Star formation possibly affected by cosmic reionization and chemical enrichment via supernovae of the first stars

Boötes I

Okamoto et al. 2012

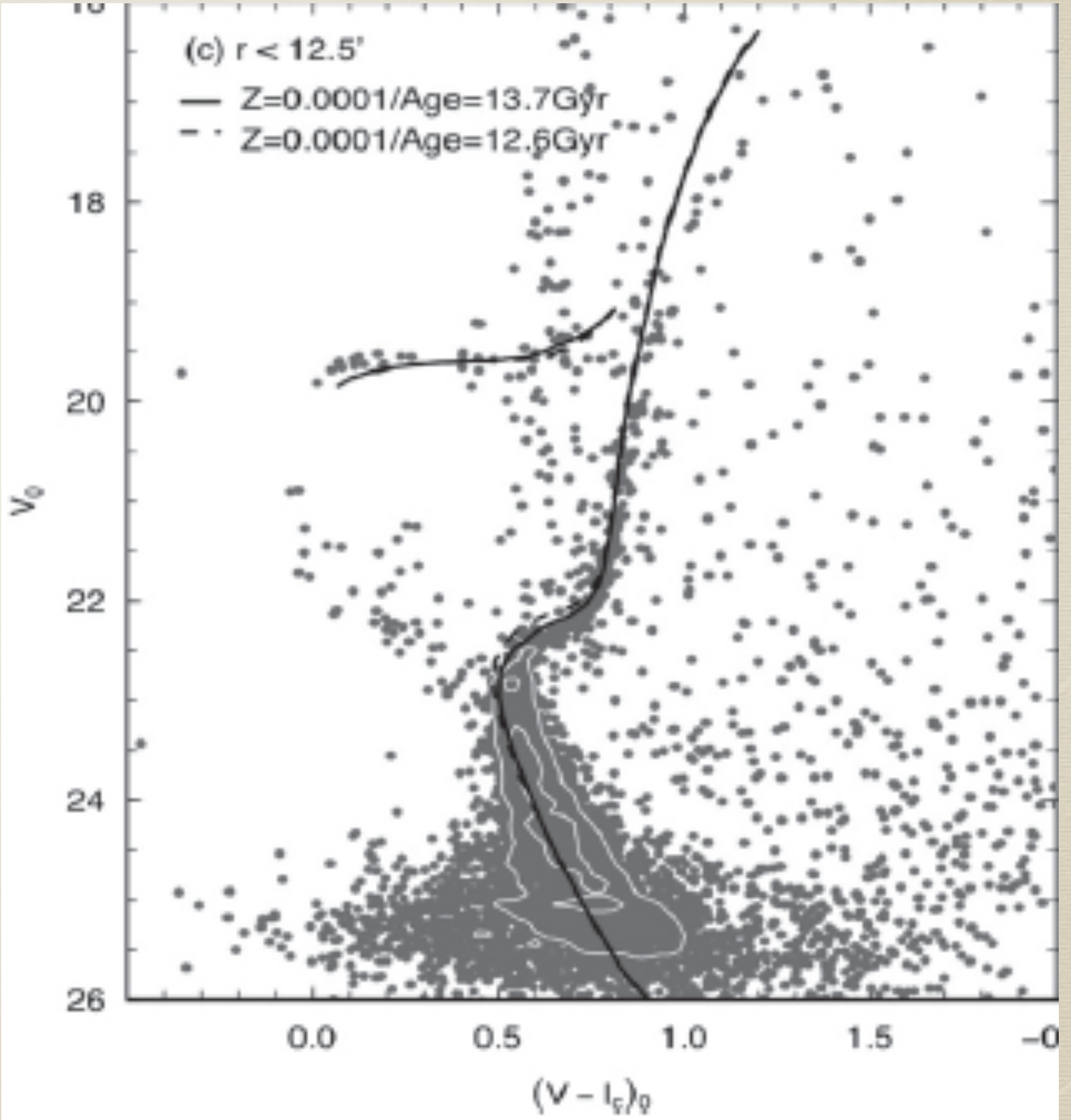


* Discovered in SDSS DR5 (Belokurov+06)
* $D_{\odot}$= 66kpc
* Stellar mass ~ $10^4 M_{\odot}$
* Dynamical mass ~ 10^6 $M_{\odot}$

Color-magnitude diagram of Boötes I

* Old stellar population with age>13 Gyr (Okamoto et al. 2012, Brown et al. 2014)
* Majority of stars (>80%) formed before z~ 6 (Brown et al. 2014)

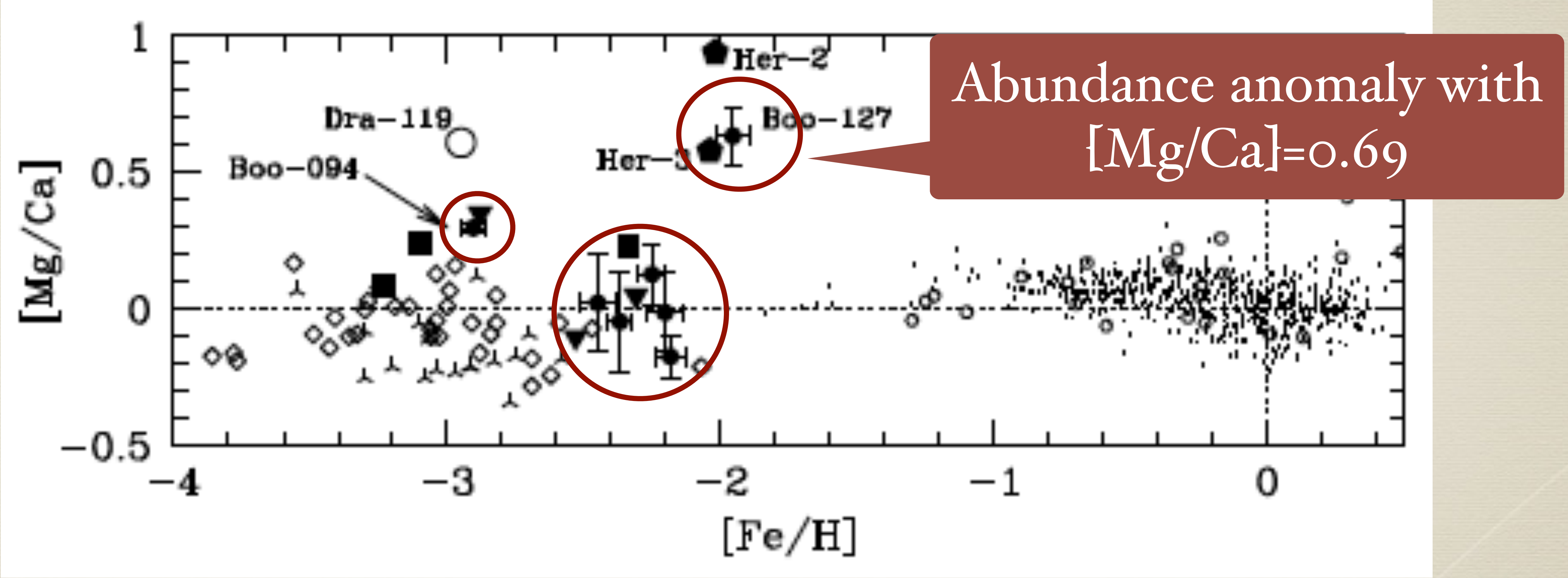
Candidate of the first galaxies or galaxies formed prior to reionization



Okamoto et al. 2012

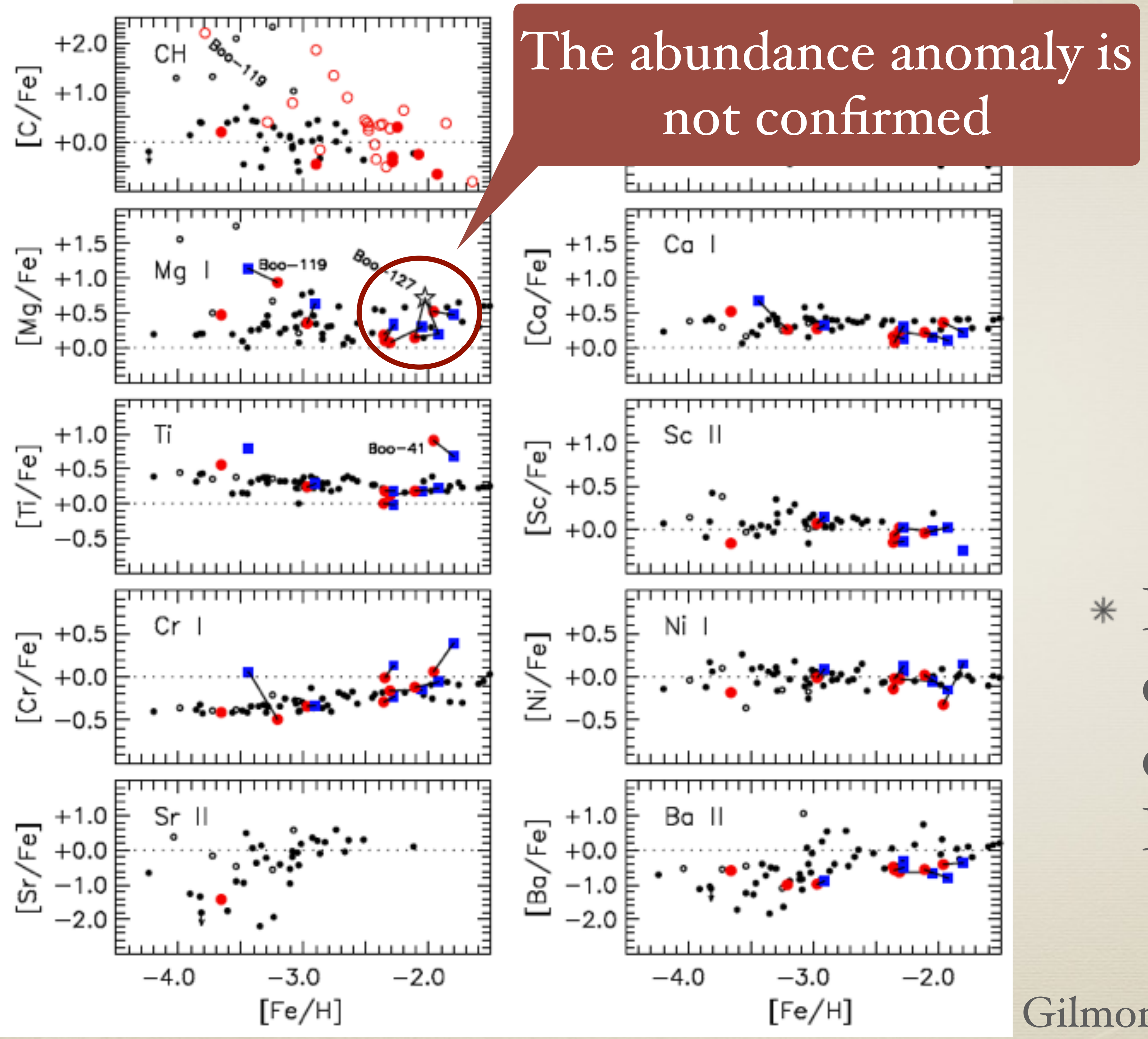
A large abundance spread in Boötes I?

Feltzing et al 2009



* Presence of a star (Boo-127) with an anomalous abundance ratio ⇒ Signature of inhomogeneous chemical enrichment

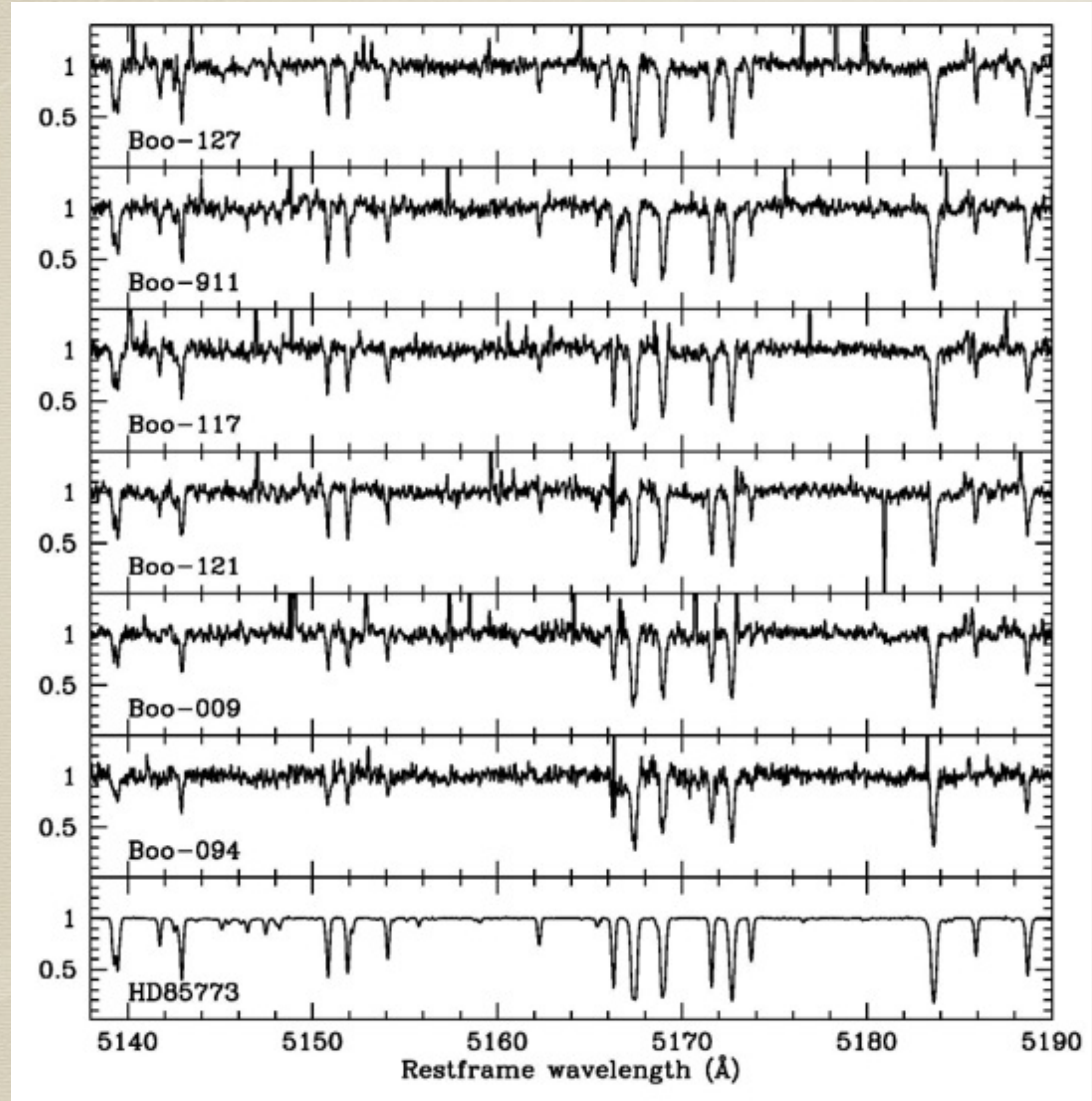
Much smaller spreads in the abundance ratios?



* Homogeneous chemical evolution in Bootes I?

Gilmore et al. 2013

Observation and analysis

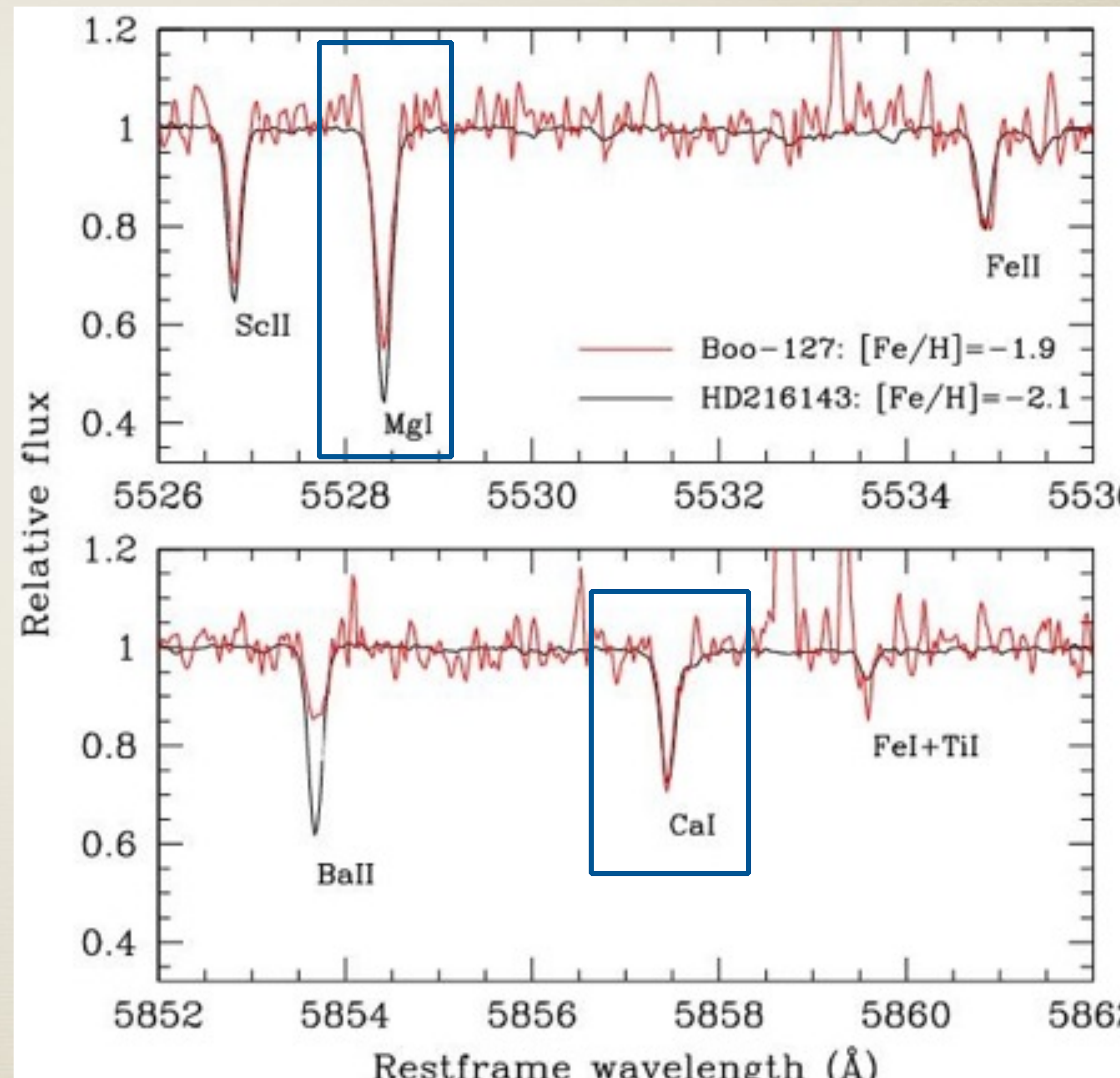


- High-res. spectroscopy with Subaru/HDS (PI:Okamoto, S.)
- λ∼4000-6000A with R~30000
- 1D-LTE abundance analysis (Aoki et al. 2009)
- Elemental abundances:
  - α-elements (e.g. Mg, Ca, Si)
  - Fe-peak elements (e.g. Cr, Ni)
  - Neutron-capture elements (Sr and Ba)

Mg/Ca anomaly in Boo-127?

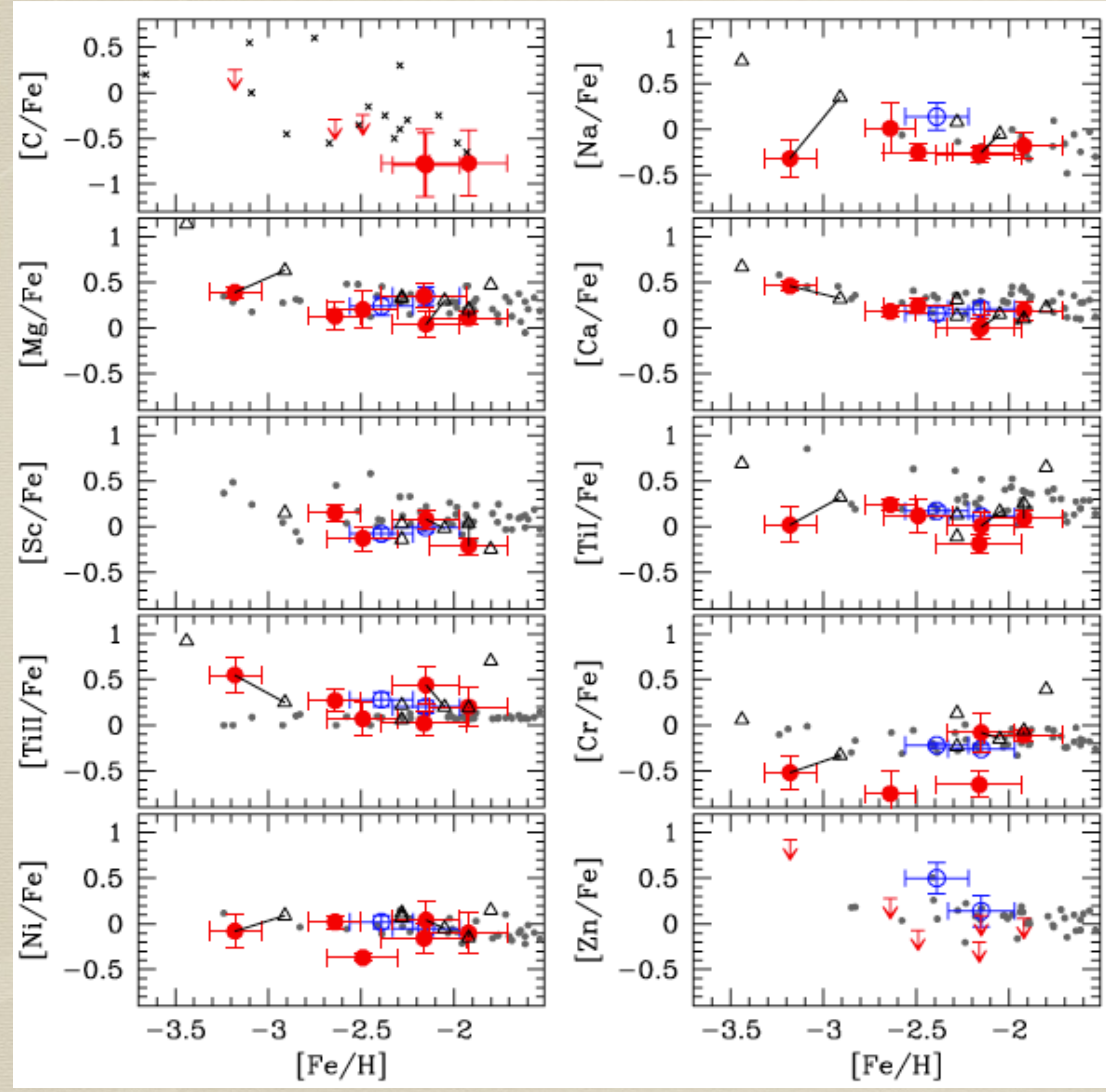
Red: Boo-127
black HD 216245 with [Mg/Ca]=0.14

- The anomaly in [Mg/Ca] (=0.69) reported by Feltzing+09 is not reproduced in this work
- Sources for the systematic errors
  - Low-signal-to-noise: errors in EWs ~20mA
  - Difference in adopted atmospheric parameters
    - Δlogg : 0.6 dex, Δvturb: 0.5 km/s
  - Difference in log gf value:
    - EWs ~ (abundance) x (log gf)



[Mg/Ca] in Boo-127 should be smaller than ~0.14 dex

[X/Fe] vs [Fe/H]: carbon to zinc

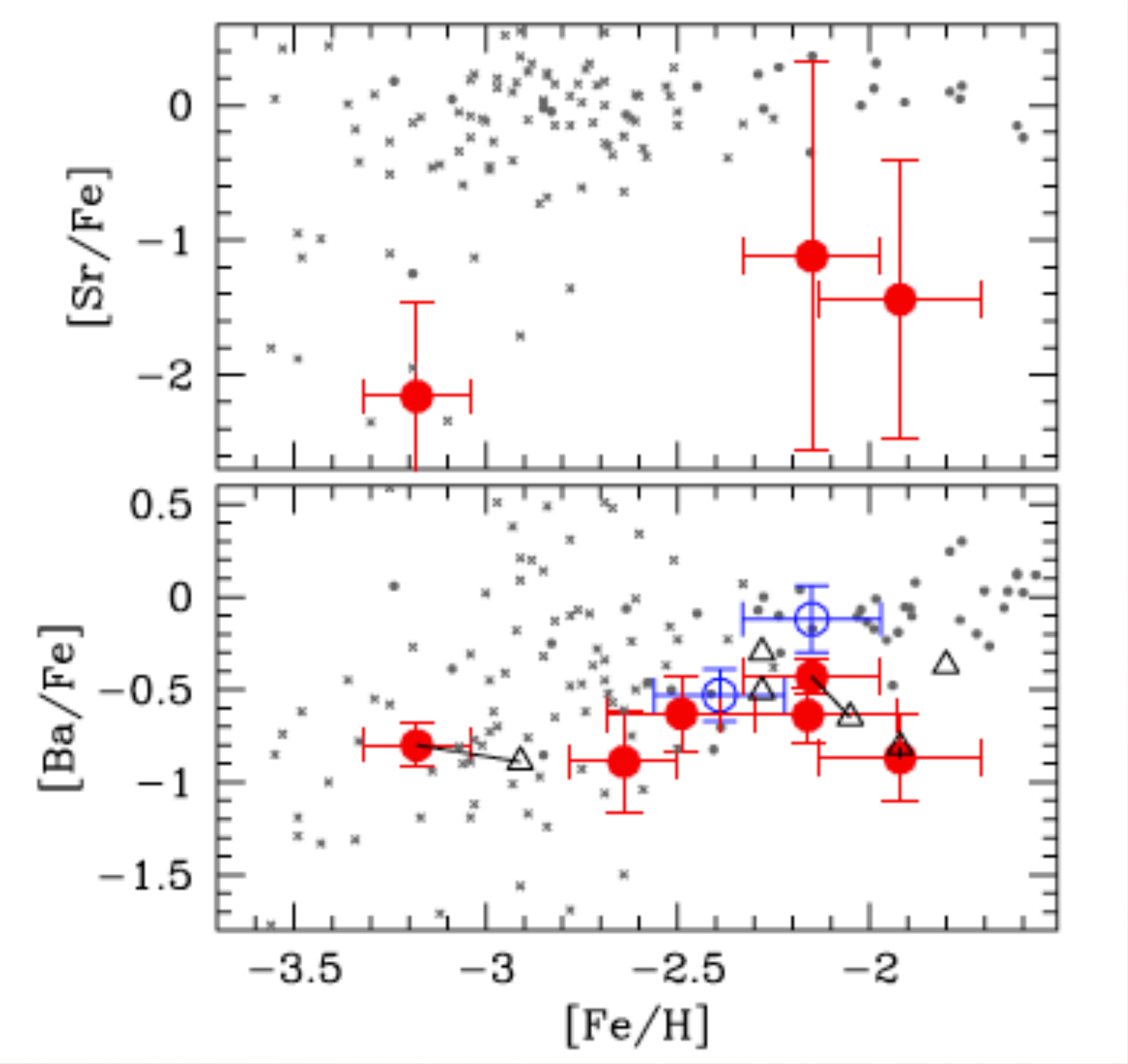


Ishigaki et al. 2014

- ● Bootes I
- ○ Comparison stars
- ・MW halo (Ishigaki+12, 13)

- Nearly homogeneous [X/Fe] over a wide metallicity range
- Similar to the Milky Way halo stars
- Decreasing [Ca/Fe] trend with [Fe/H] (probability for the null hypothesis ~ 7%)

Neutron-capture elements



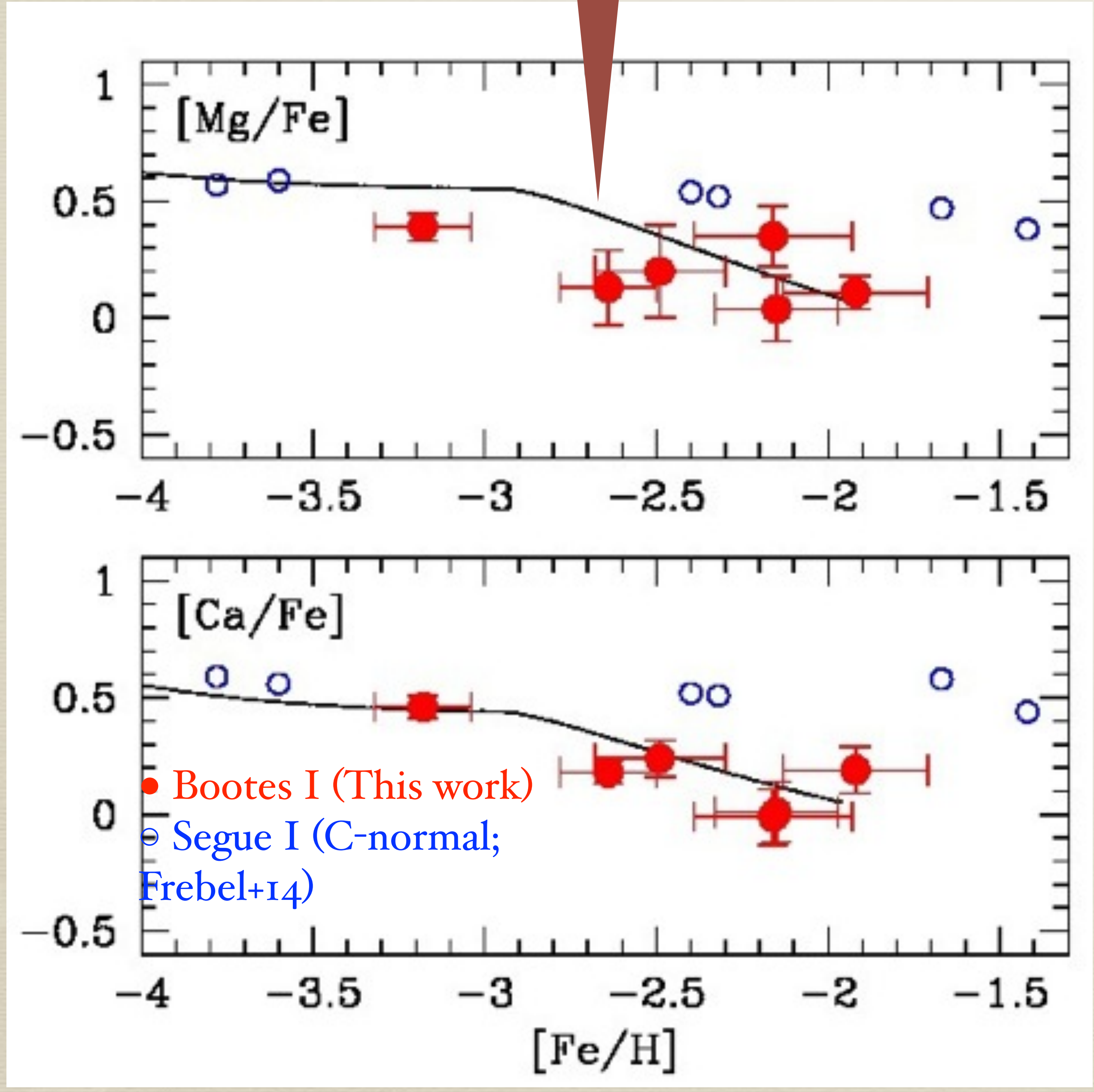
Ishigaki et al. 2014

- ● Bootes I
- ○ Comparison stars
- ・MW halo (SAGA data base)

- The lower [Sr/Fe] ratios for Bootes I compared to the MW halo stars
- Similar to other UFDs e.g. Hercules (Koch et al. 2013)

Comparison with Segue I: α elements

A simple chemical evolution model with very low SFR (e.g. Kirby+11)

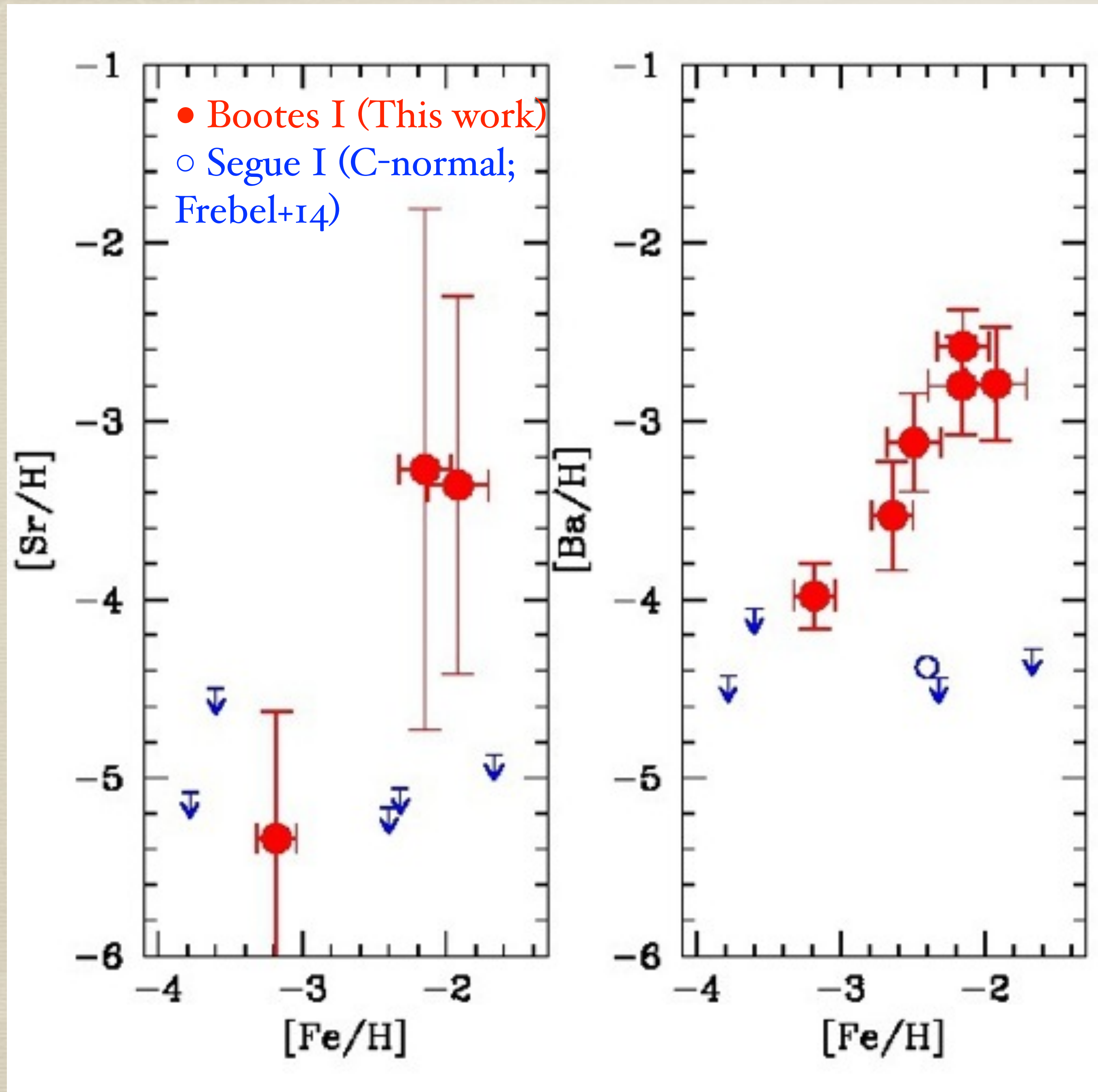


Clear differences in the abundance trends from a fainter UFD, Segue I

Bootes I:
Decreasing [X/Fe] trend with [Fe/H]:
→A signature of Fe contribution from Type Ia SNe

Segue I:
Constant [X/Fe] for a wide range of [Fe/H]
→ No contribution from Type Ia SNe

Comparison with Segue I: neutron-capture elements



Bootes I:

Increasing [X/H] trends with [Fe/H]:

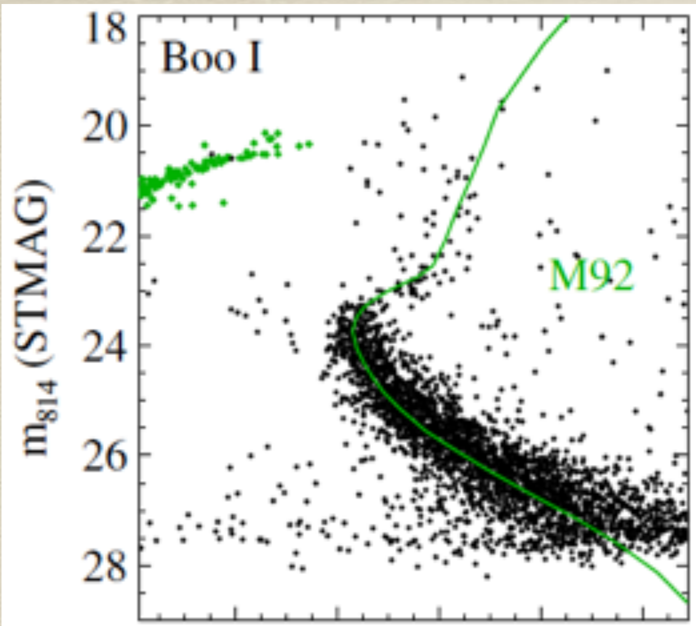
→ Continuous enrichment of Sr and Ba via r-process with Fe

Segue I:

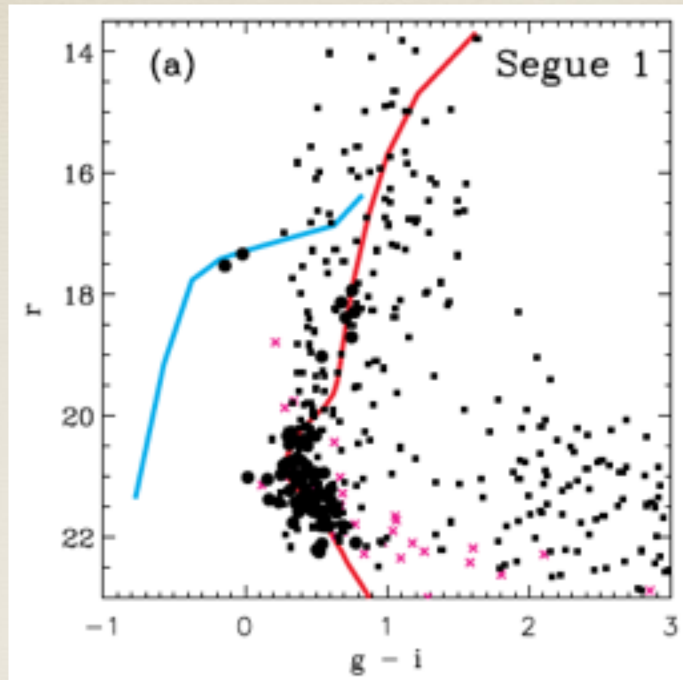
Very low upper limits in [Sr/H] and [Ba/H]

→ No significant chemical enrichment via r-process

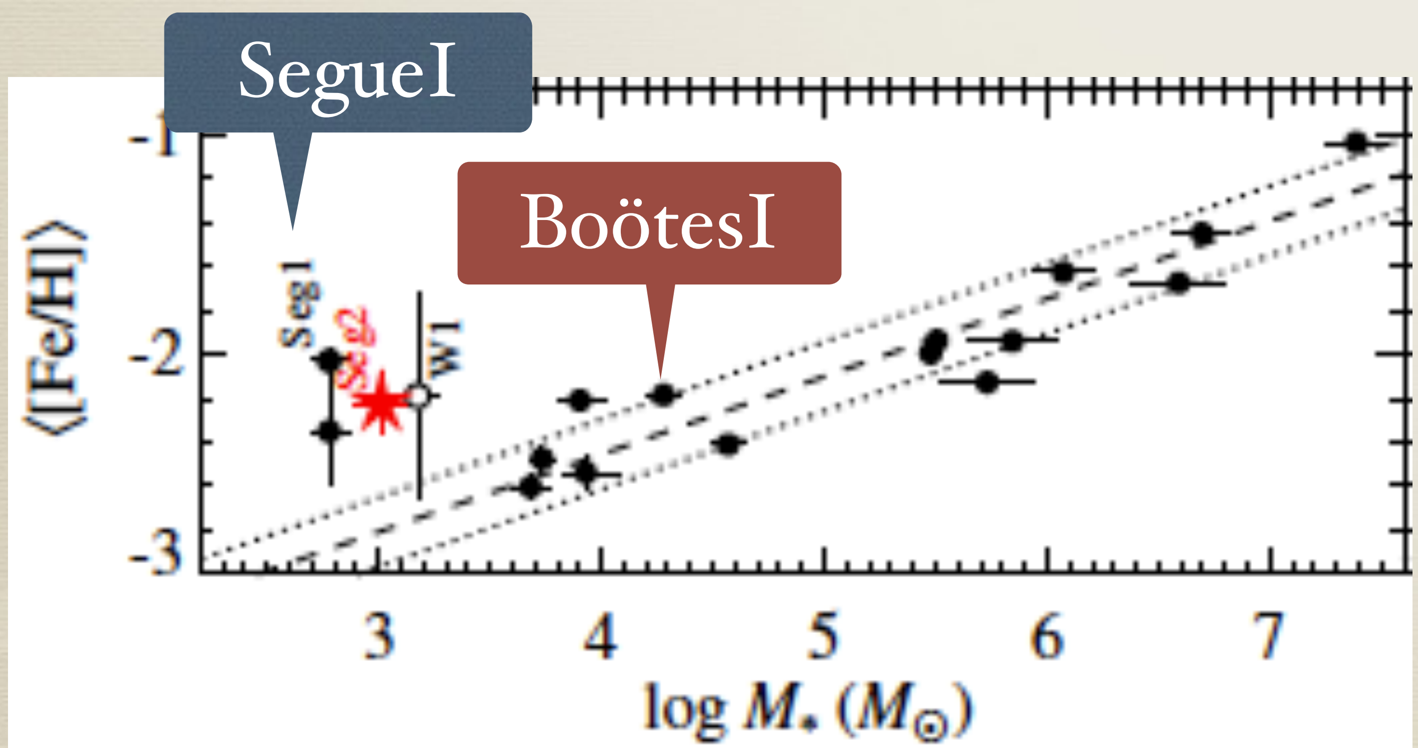
Boötes I and Segue I



Brown et al. 2014



Simon et al. 2011



Kirby et al. 2013

	Boötes I	Segue I
M	-5.8	-1.5
M	2.9×10	340
r	241	29
M [M	8.1×10	2.6×10
Signs of chemical evolution	Yes	No

Boötes I: one of the darkest galaxies in which chemical evolution with Type Ia SNe took place

Summary

* Based on the high-resolution spectra taken with Subaru/HDS, chemical abundances in the 6 giant stars in Bootes I were obtained.

* Chemical abundances the Bootes I stars are characterized by:
  * nearly homogenous abundance ratios ([X/Fe]) in the metallicity range $-3<[Fe/H]<-2$ for the most elements lighter than Zn.
  * low [Sr/H] abundances relative to the Milky Way halo stars

* The decreasing [Ca/Fe] trend with [Fe/H] suggests that Bootes I has experienced a continuous star formation with contribution from Type Ia SNe, unlike a fainter UFD Segue I

Outline

* Motivation
    * Ultra-faint dwarf galaxies (UFDs) around the Milky Way: possible remnant of the first galaxies formed in the early universe
* Analysis
    * Chemical abundance analyses of 6 giant stars in Boötes I based on the Subaru/HDS spectra
* Results
    * Homogeneous abundance ratios ([X/Fe]) for many elements lighter than Zinc
    * Lower abundances of neutron-capture elements than in Milky Way halo stars
* Discussion
    * Implications for the early chemical evolution in Boötes I