ANNA FREBEL

METAL-POOR STARS

LEPP workshop GSI, Oct 10-12

A new sample of ~20 main-sequence dwarf stars with [Fe/H]=-3 to study the distribution of Sr and Ba abundances and come other considerations

Anna Frebel

Harvard-Smithsonian Center for Astrophysics

Massachusetts Institute of Technology from 2012

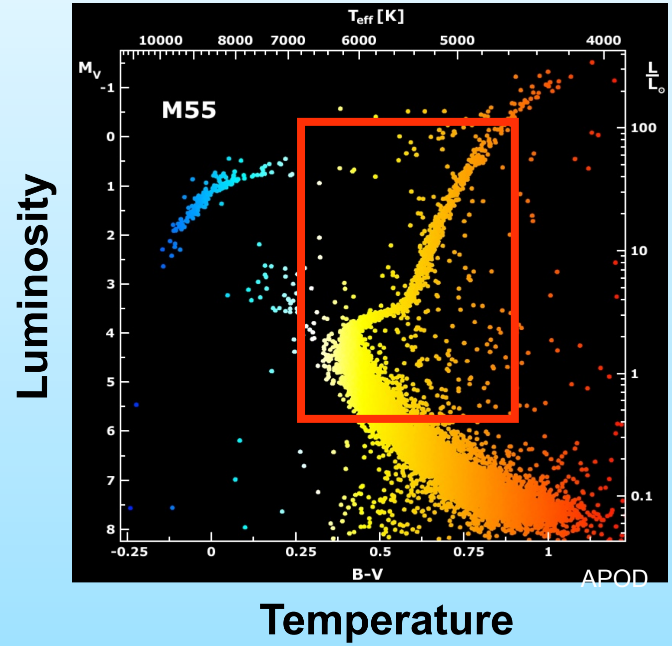
What can we learn from old halo stars?

Low-mass stars (M < 1 M⊙)
⇒ Lifetimes > 10 billion years => still around!

Using metal-poor stars to reconstruct:
- ✓Origin and evolution of chemical elements
- ✓Relevant nucleosynthesis processes + sites
- ✓Chemical + dynamical history of the Galaxy
- ✓Lower limit to the age of the Universe

... and to provide constraints
- ✓Nature of the first stars & initial mass function
- ✓Early star & early galaxy formation processes
- ✓Nucleosynthesis & chemical yields of first/early SNe
- ✓Formation of the Galactic halo
- ✓Hierarchical merging of galaxies

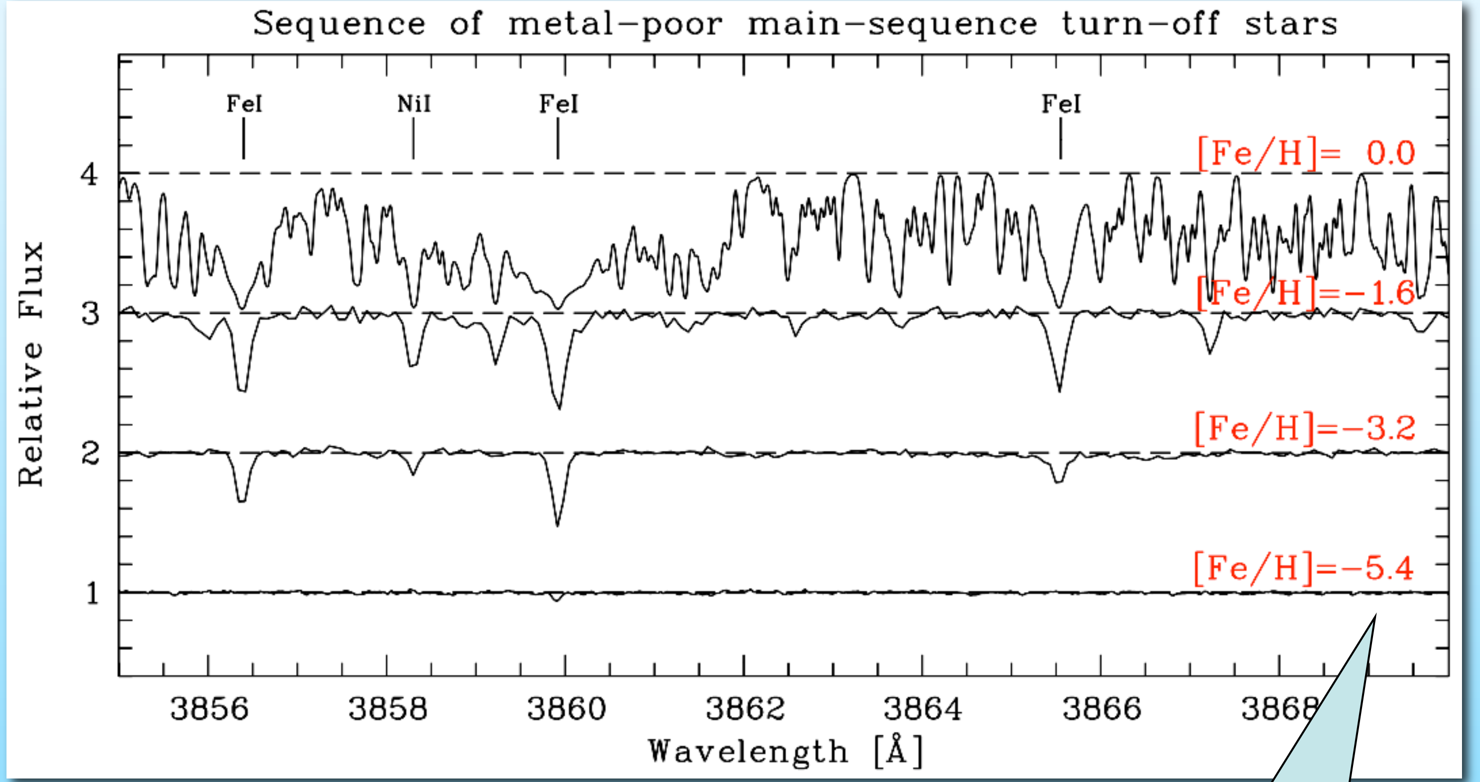
Hertzsprung-Russell-diagram



Metal-poor stars are a great tool for near-field cosmology because they are the local equivalent of the high-redshift Universe!

Taking a spectroscopic look

“Look-back time”



Galactic chemical evolution

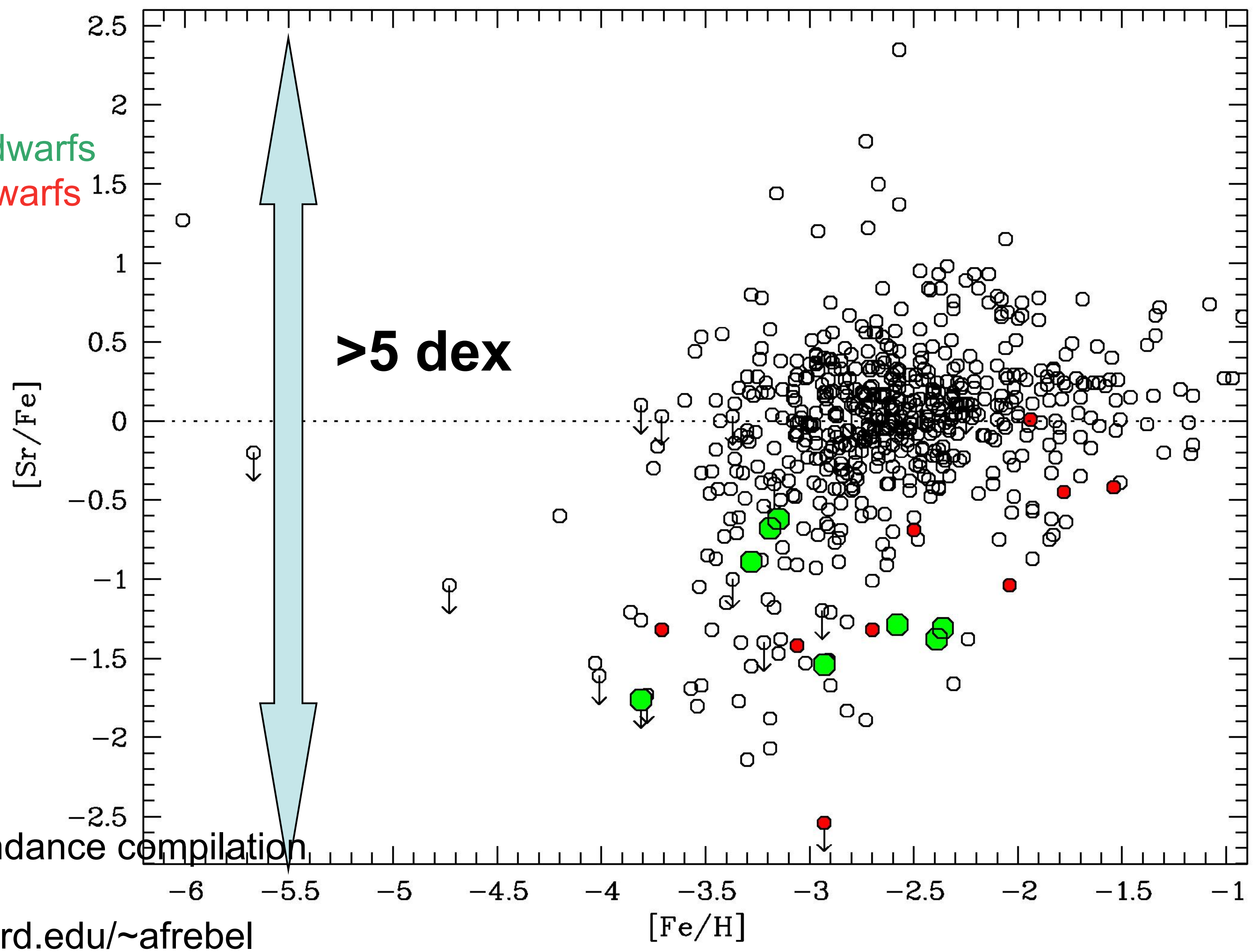
Abundances are derived from integrated absorption line strengths

$[Fe/H] = \log(N_{Fe}/N_H)_* - \log(N_{Fe}/N_H)_\odot$

equals 1/250,000th of the solar Fe abundance

Current situation: Strontium

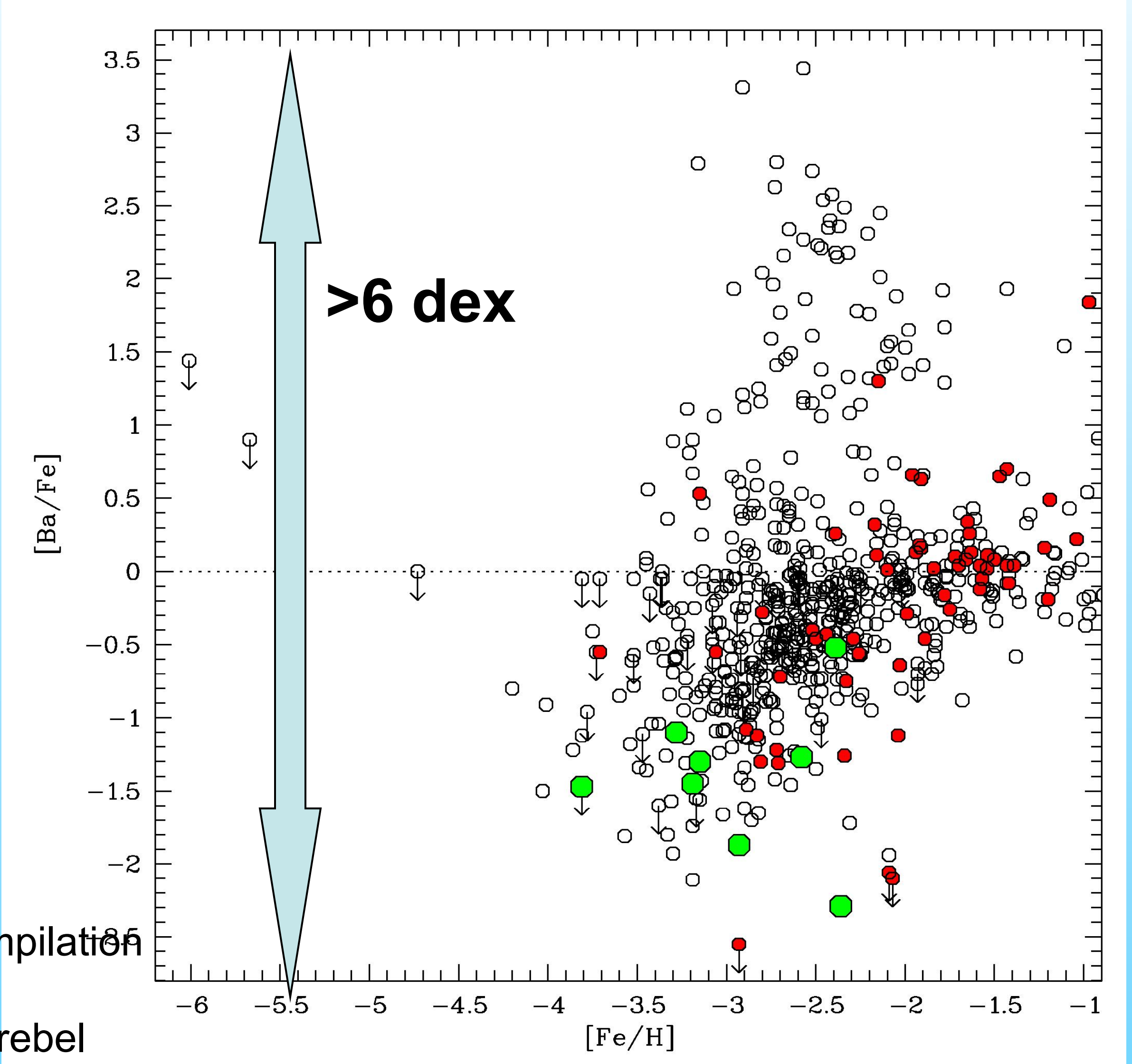
O: halo stars
●: ultra-faint dwarfs
●: classical dwarfs



based on abundance compilation
of Frebel 2010
www.cfa.harvard.edu/~afrebel

Current situation: Barium

O: halo stars
●: ultra-faint dwarfs
●: classical dwarfs



based on abundance compilation of Frebel 2010
www.cfa.harvard.edu/~afrebel

Current situation

Why is there such a large (5-6 dex) spread?

What causes it?

More than one origin/nucleosynthesis procsses?
=> Likely

We don't understand..

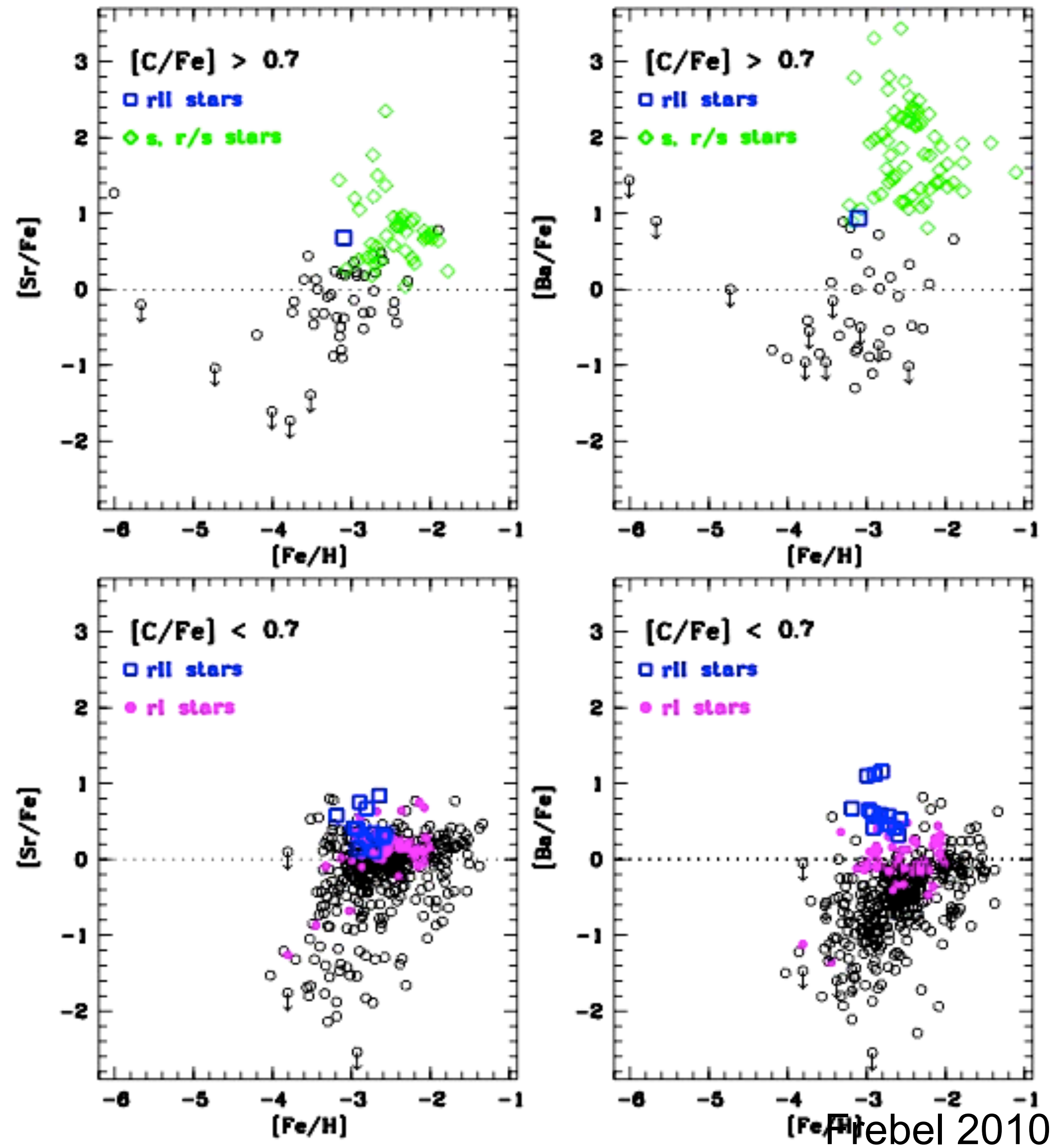
Maybe more data can help!

Dissecting abundance plots

Sr Ba

Carbon-enhanced objects ([C/Fe] ≥ 0.7)

Other halo stars (s-, rs-mostly eliminated)



Frebel 2010

For [Fe/H] –2.6, the s-process significantly contributes neutron-capture material (see Simmerer et al. 2004).

Below [Fe/H] ~ –3.0, the evolution is dominated by r-process or non-s enrichment (?)

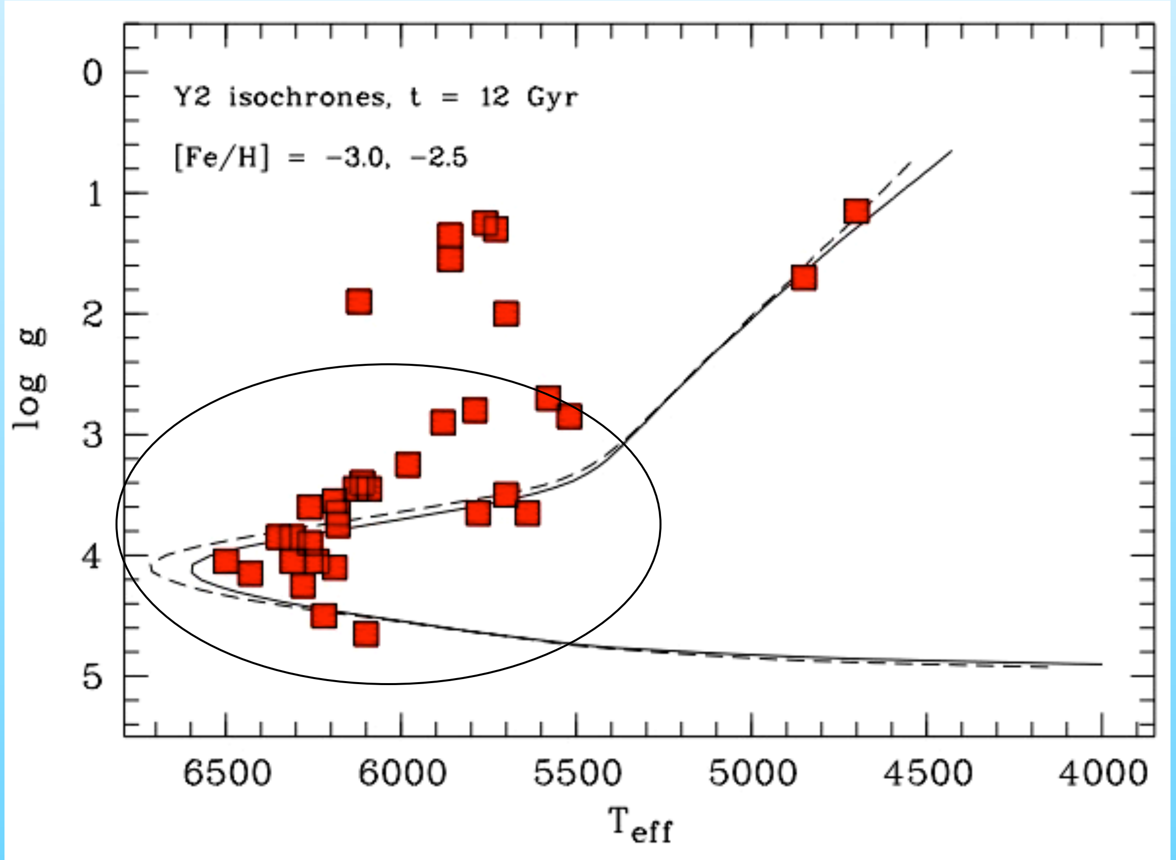
New sample

- Magellan observations, Feb 2009 - Mar 2011
- Study unevolved main-sequence stars that are all very similar in light element abundances

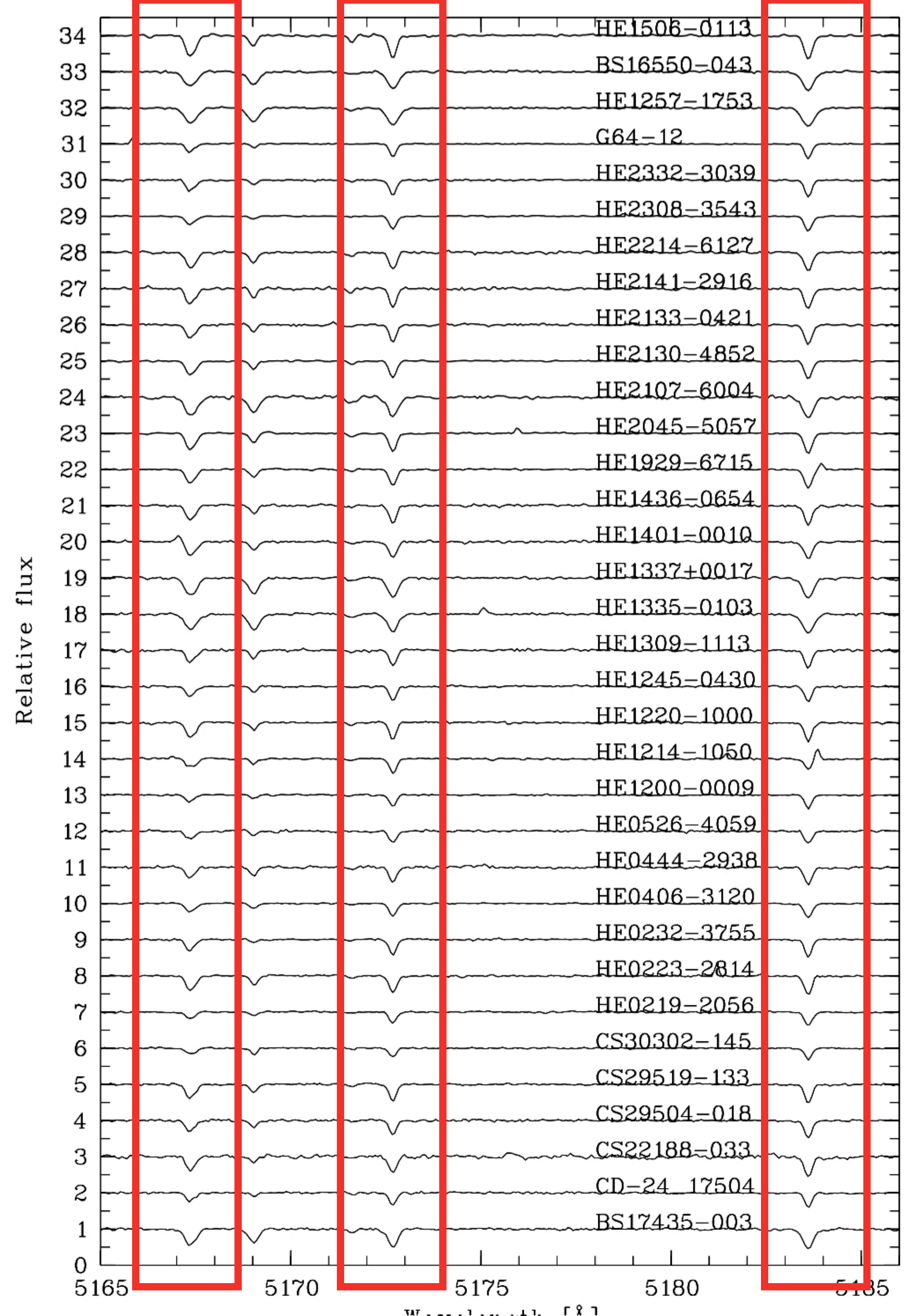
Frebel et al. 2012

- 34 total, but we caught a bunch of horizontal branch stars and 2 giants => 21 near MS-TO dwarf stars (19 stars are new)

- Is there a Sr and Ba spread?

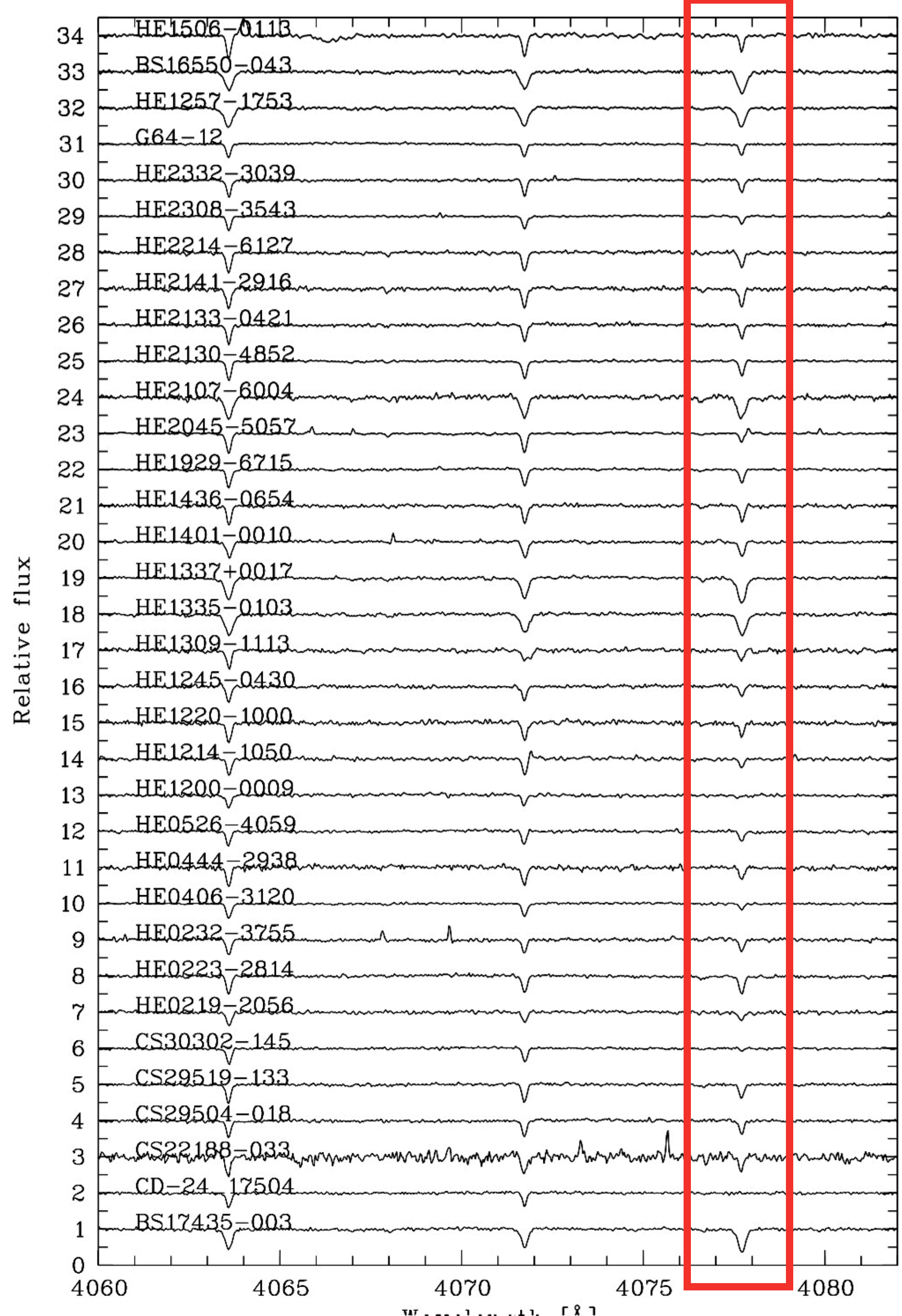


Mg @5170A



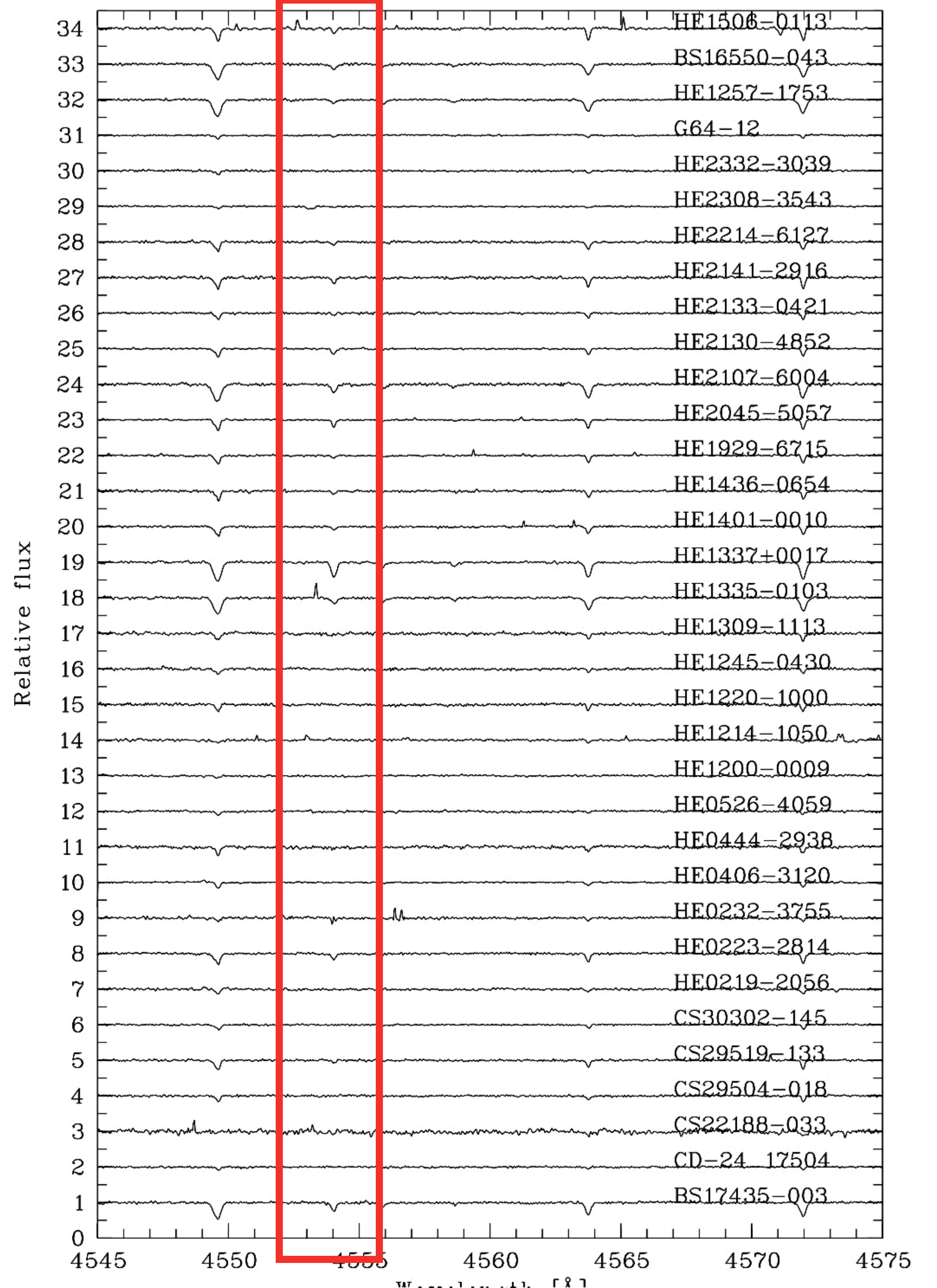
Frebel et al. 2012

Sr @4077A

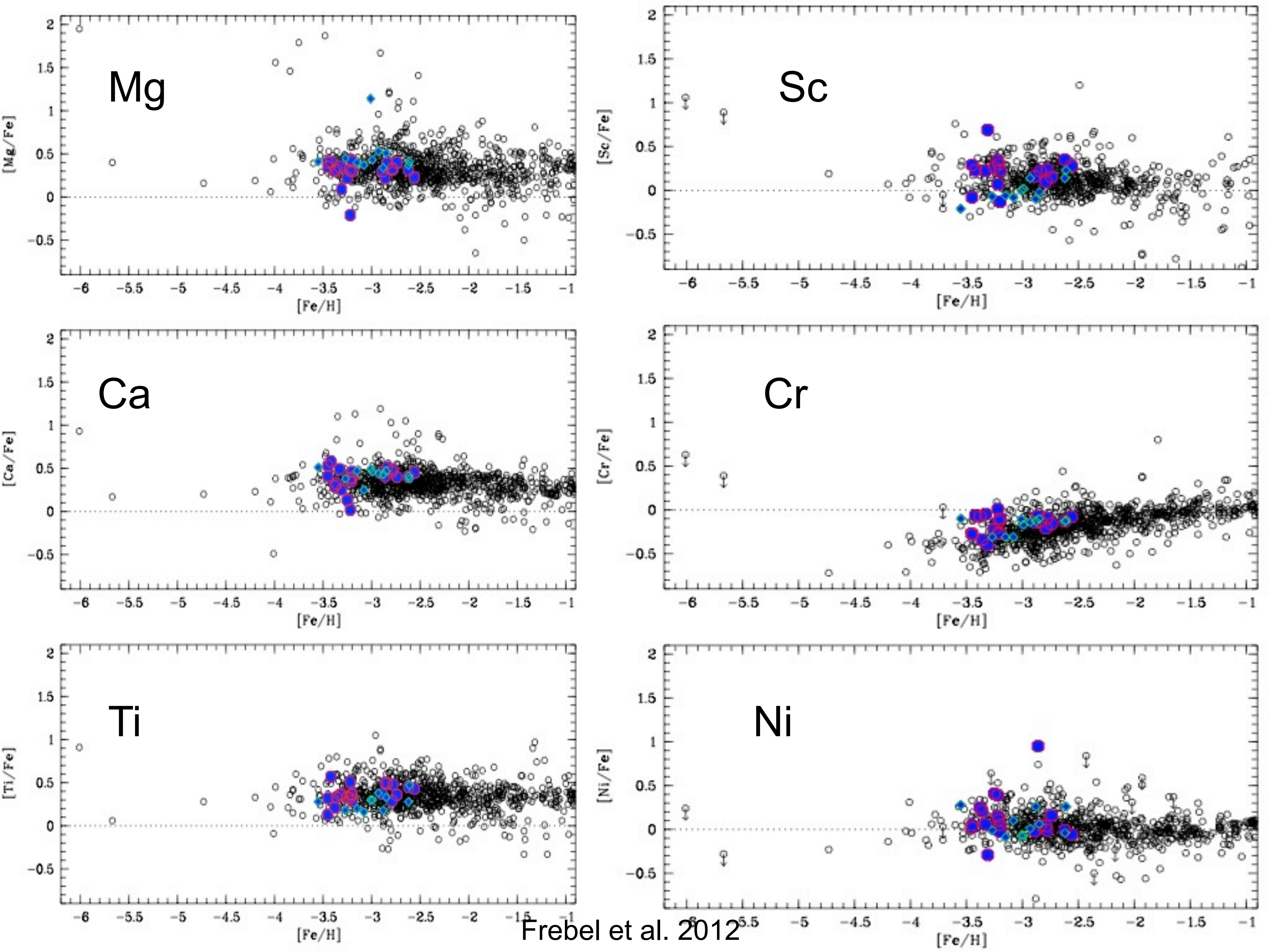


Frebel et al. 2012

Ba @4554A



Frebel et al. 2012



Frebel et al. 2012

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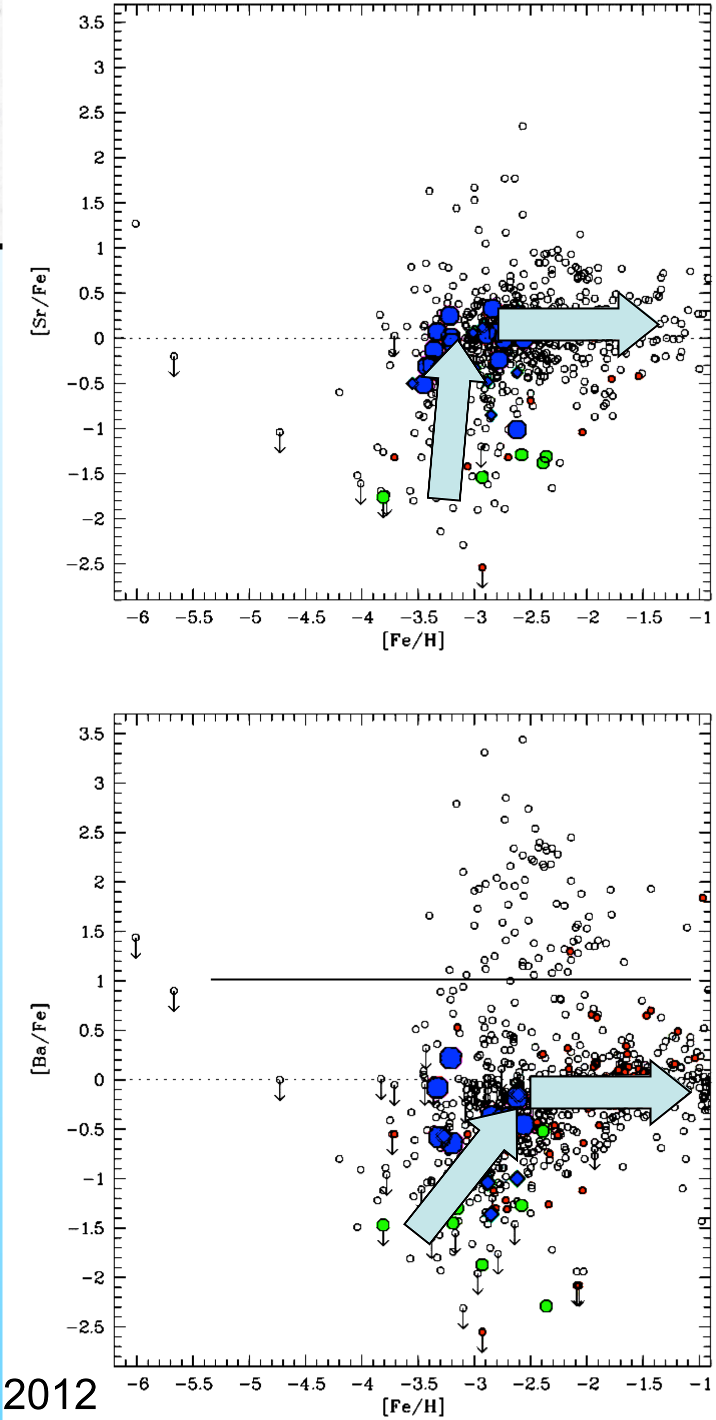
METAL-POOR STARS

Sr and Ba!

- Dwarf galaxy abundances are much lower than average!
- Why do halo stars have so much more?
- => Dwarf gal. abund. may provide constraints on first stars nucleosynthesis and individual yields (?)
- How did chemical evolution proceed from there?



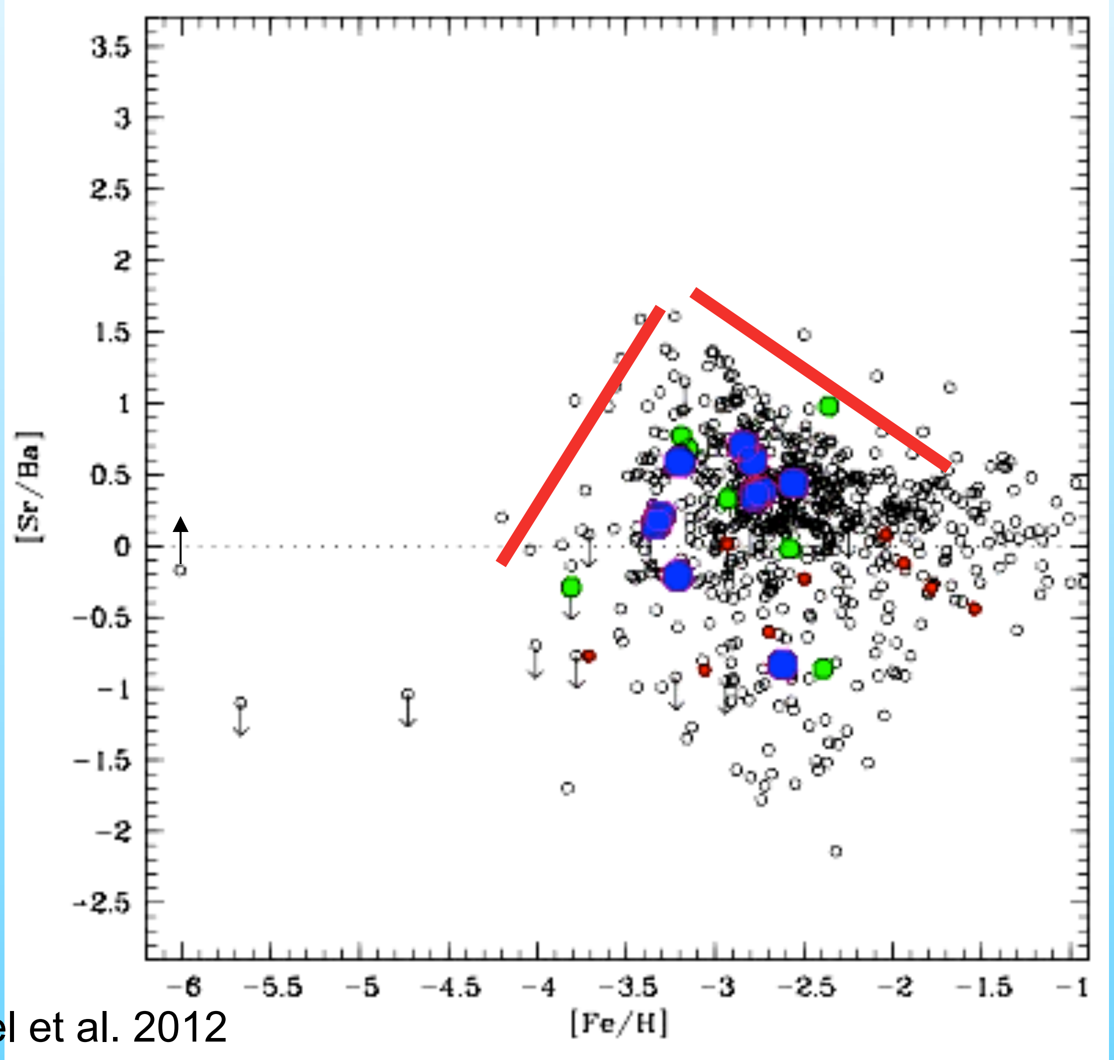
Frebel et al. 2012

Sr/Ba ratio

Clear-cut envelopes for Sr/Ba ratio?

Halo and dwarf galaxy star have the same Sr/Ba ratios

=> same nucleosynthesis process(es) at work?



Frebel et al. 2012

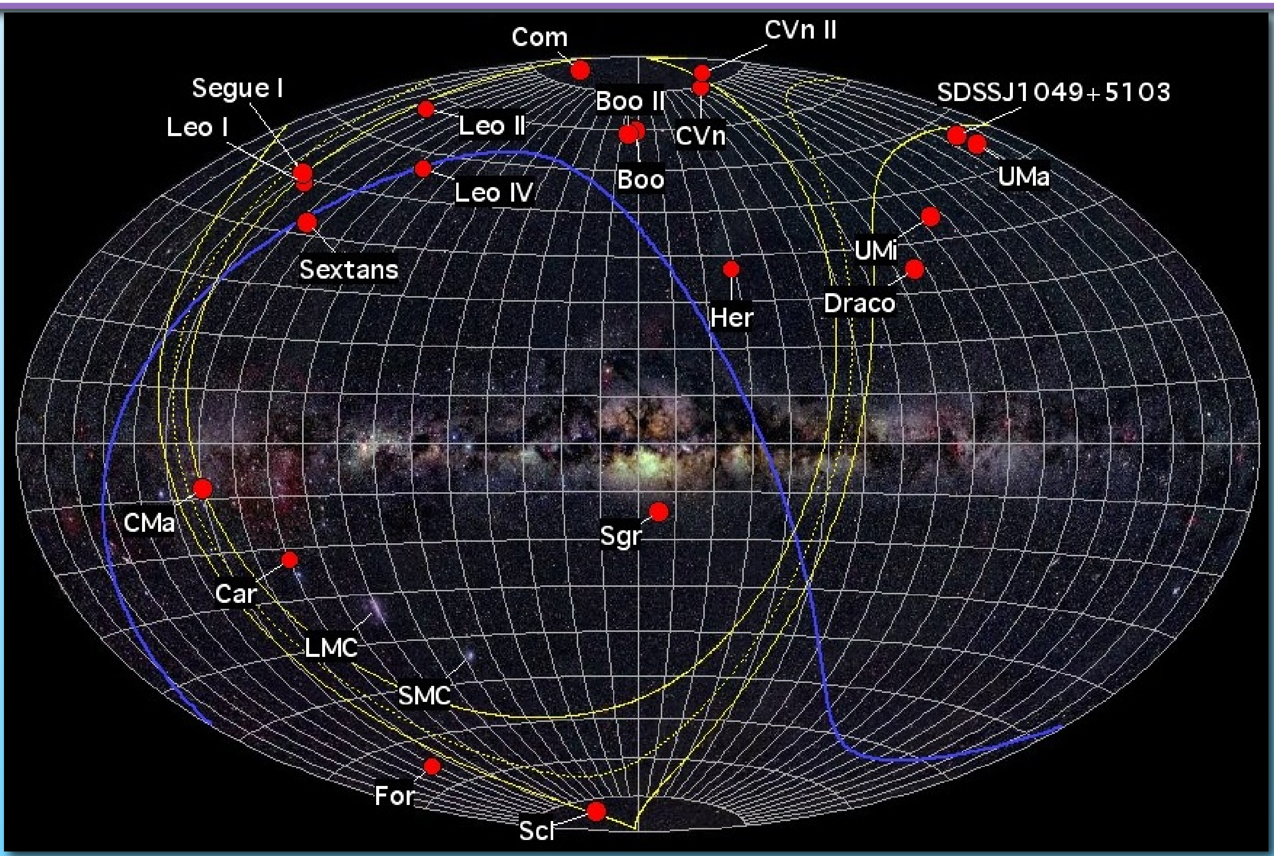
Pre-Conclusion

- Clear evolution in Sr and Ba, although different: what processes could provide this?
- Halo and dwarf galaxy stars show different behavior (on average, although low N stats.)
- Dwarf galaxy abundances provide unique insight into early chemical enrichment and nucleosynthesis!
- Understanding those first may shed some light into the halo “mess” following the hierarchical assembly
- But d ata hard to acquire because stars are very faint!

The Milky Way's satellites

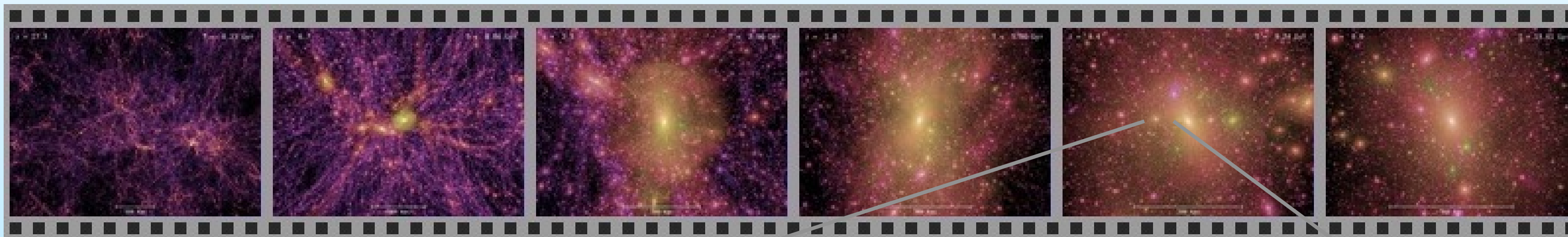
Dwarf galaxies are useful tools to study star formation and chemical evolution, early galaxy formation and the build-up of the Milky Way

dSph = gas poor dwarf galaxies dIrr = gas rich dwarf galaxies



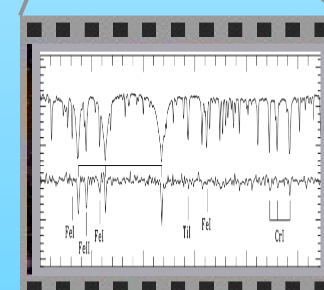
Using dwarf galaxies to study the nature of small halos

In the 'dark matter' world: λCDM hierarchical structure formation model



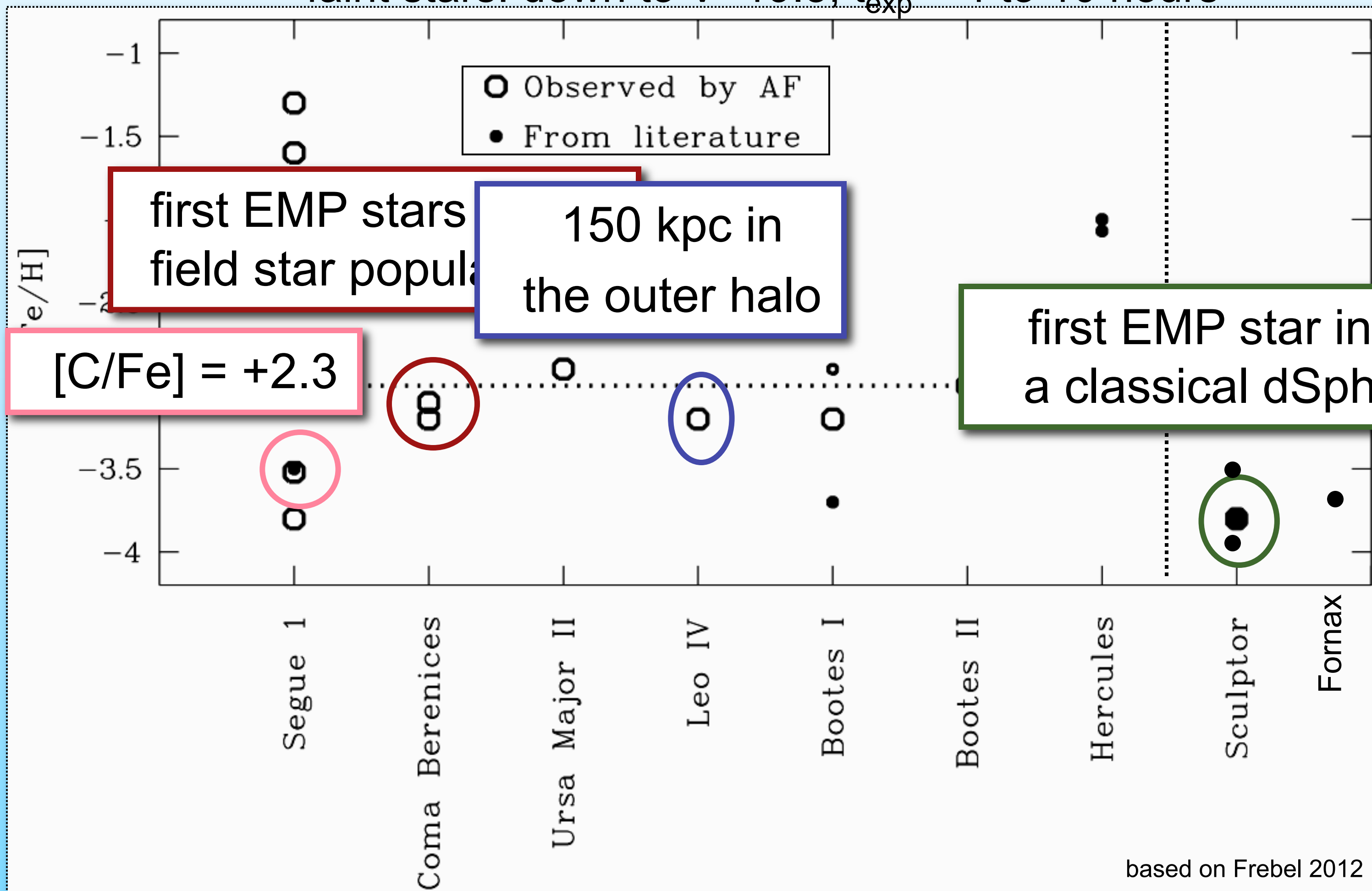
In the 'luminous' world: Comprehensive understanding of galaxy formation

Spectroscopic observations of stars and streams (=luminous matter)



Status of high-resolution (R~30K) Spectroscopy of Ultra-faint dwarf galaxy stars

faint stars: down to V=19.3, t_{exp} = 4 to 10 hours

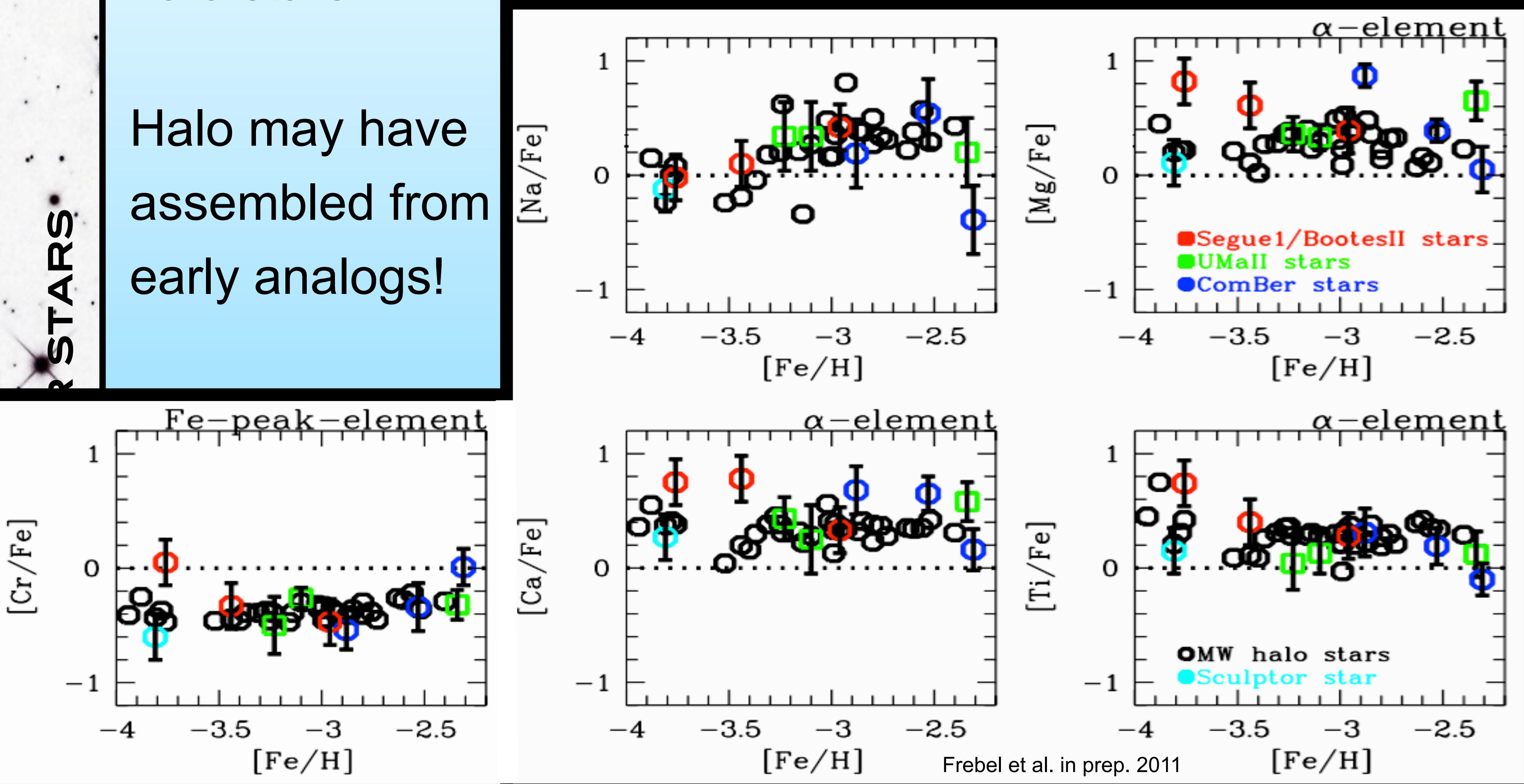


Feltzing et al 2009 Frebel et al 2010 Frebel, Kirby & Simon 2010 Frebel et al 2011a+b in prep. Koch et al. 2008 Norris et al. 2010a+b Simon et al 2010 Tafelmeyer et al. 2010

The most metal-poor stars in ultra-faint dwarfs

Agreement between dwarf galaxy stars and MW halo stars!

Halo may have assembled from early analogs!

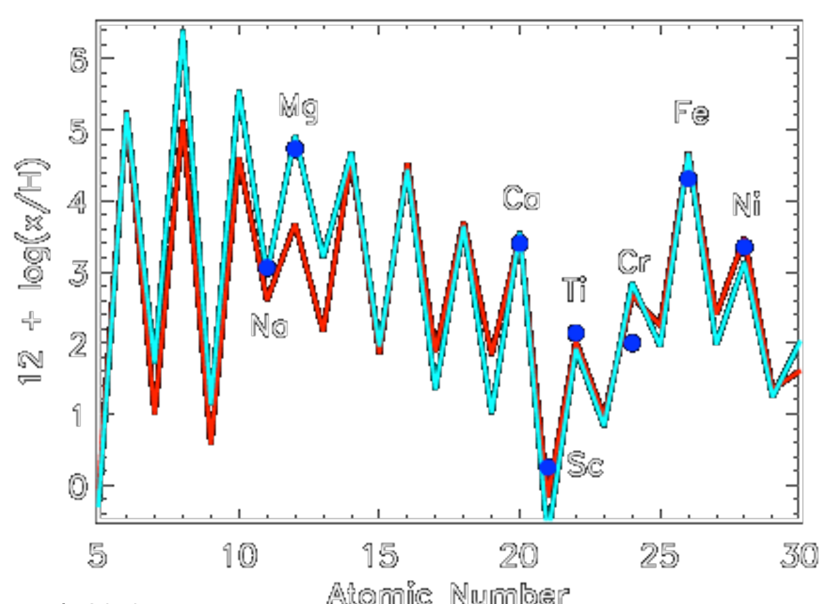


Frebel et al. in prep. 2011

The First Supernova in Leo IV

- Leo IV has a luminosity of 14000 $L_\odot$ (Sand et al. 2009)
- Total iron content of the galaxy is 0.04 $M_\odot$
- A single PopIII SN produces >0.03 $M_\odot$ of Fe (Heger & Woosley 2008)

Were *all* of the metals in LeoIV synthesized by a single star ?



Simon et al. 2010

Simon et al. (2010): observed brightest star in LeoIV with high-resolution: **[Fe/H] = -3.2** !

Leo IV abundance pattern compared to PopIII SN models

- Leo IV star
- 10 $M_\odot$, normal energy
- 50 $M_\odot$, high energy

Skymapper + Magellan

Skymapper is taking its first data now!
Will provide more metal-poor halo stars as well as more dwarf galaxies!

The chemical signature of the first galaxy

Motivation

Study the beginning of star and galaxy formation based on detailed ab-initio hydro simulations of the first stars and the assembly of the first galaxy

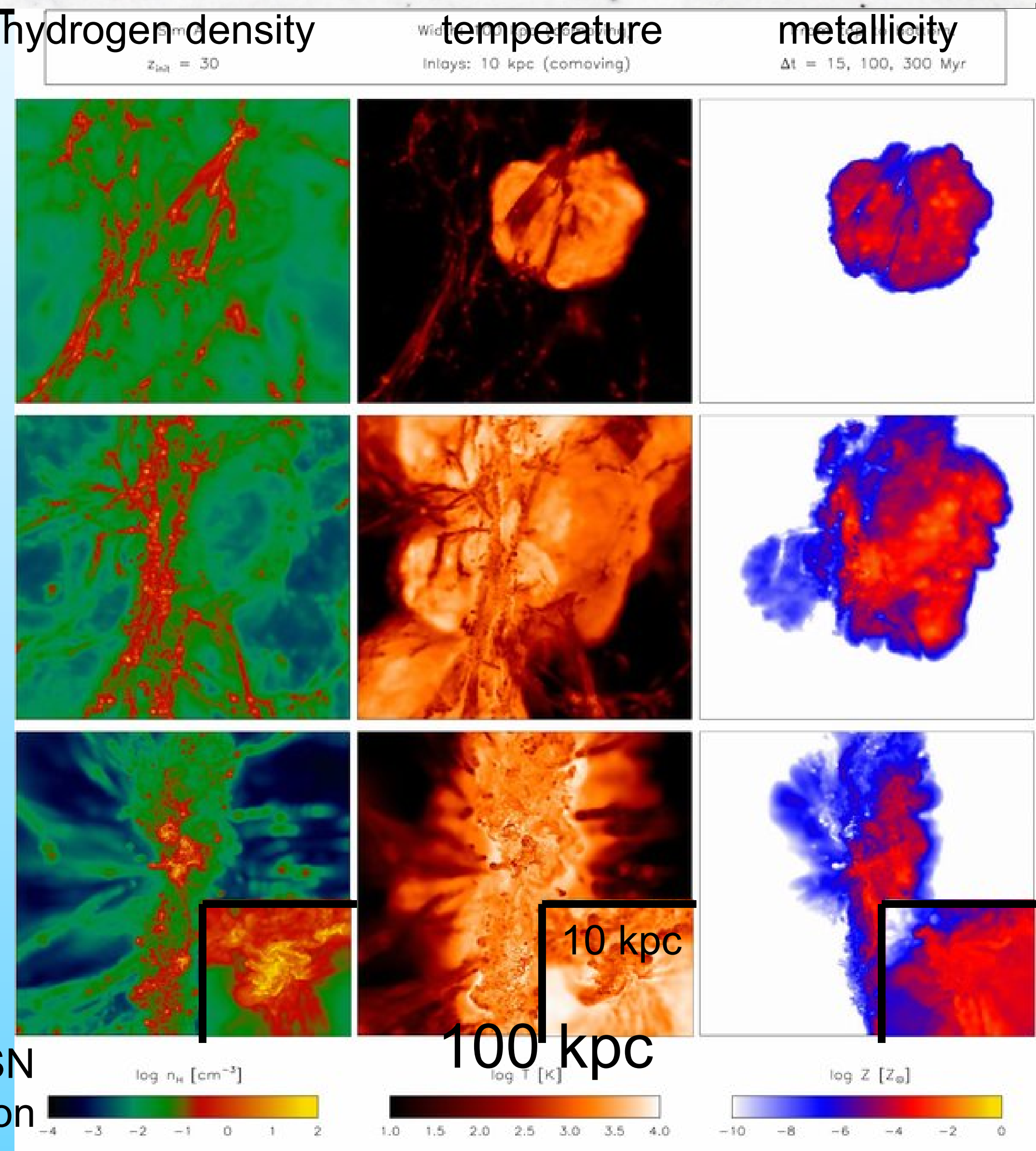
(e.g., Greif+10,11)

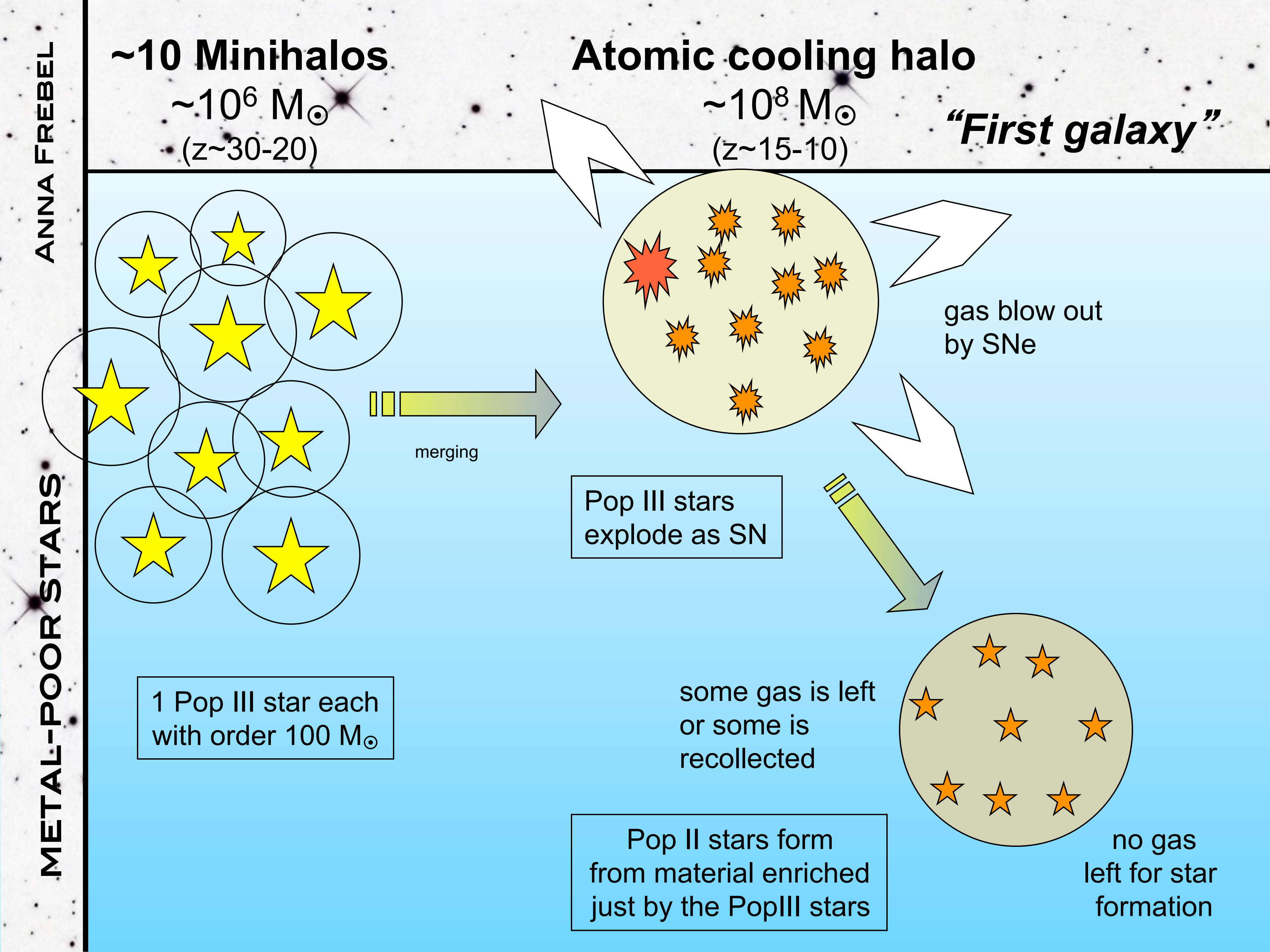
15 Myr

100 Myr

300 Myr

after the SN explosion





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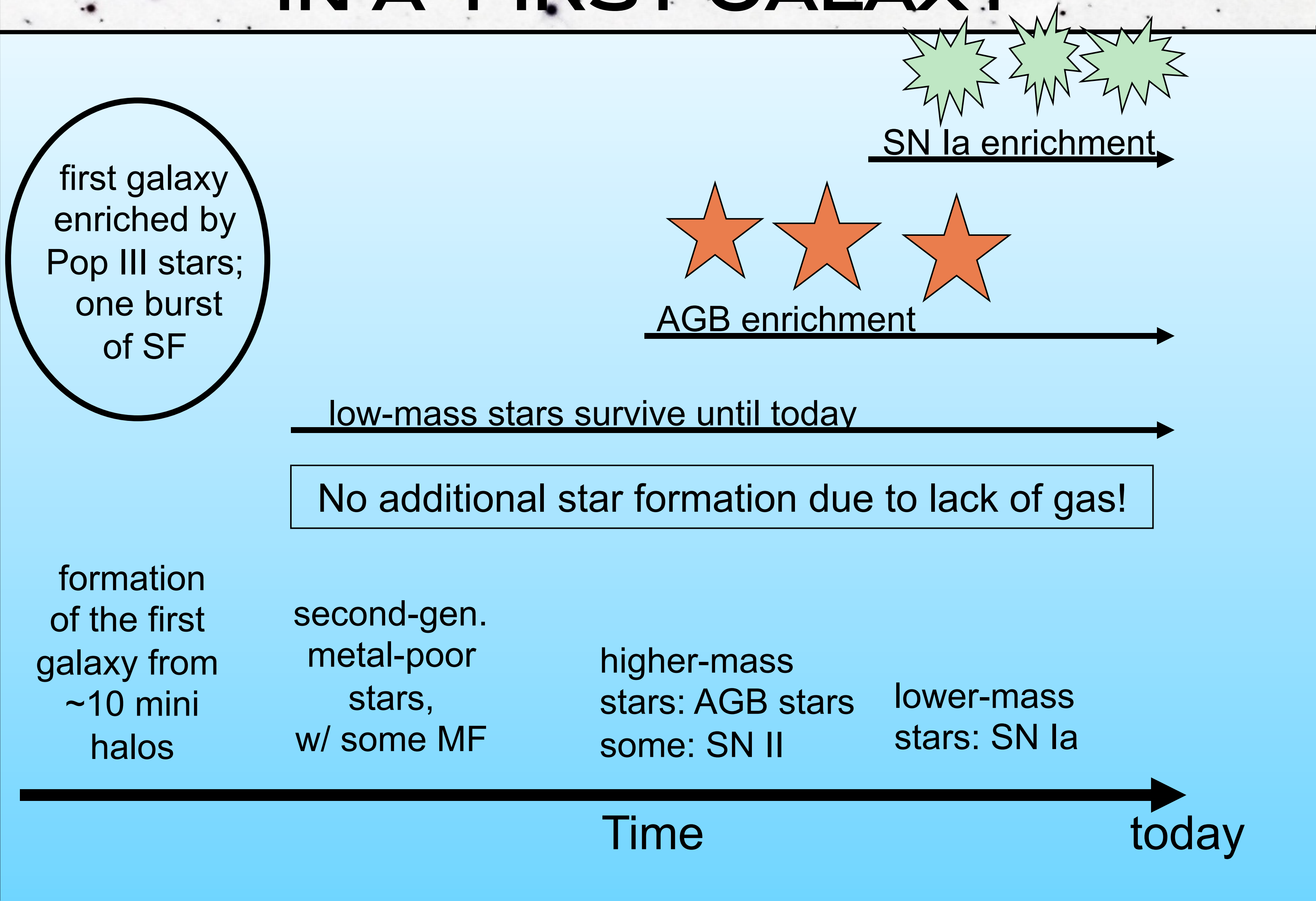
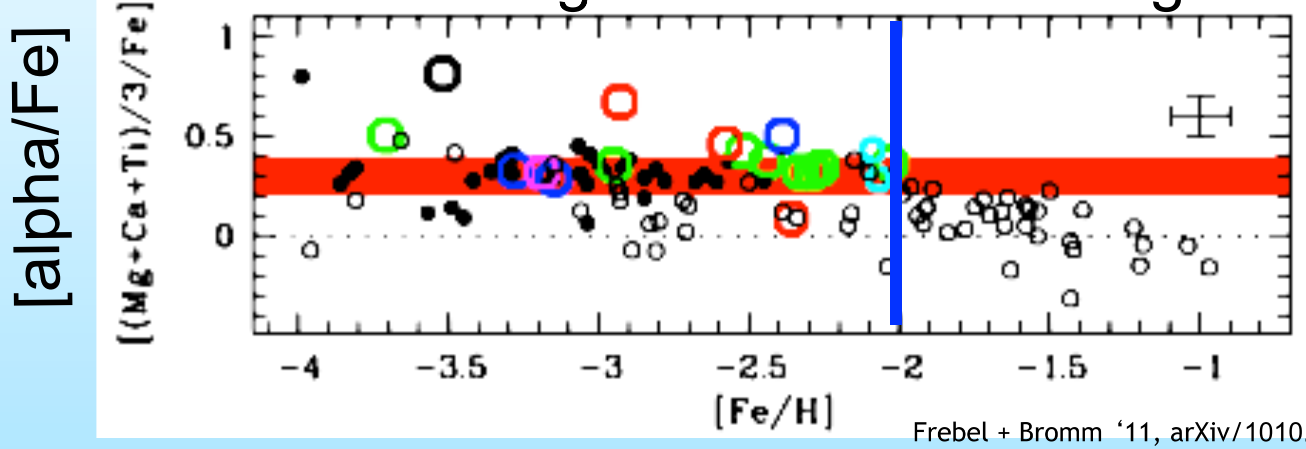
~10 Minihalos
~10^6 $M_\odot$
(z~30-20)
Atomic cooling halo
~10^8 $M_\odot$
(z~15-10)
"First galaxy"
gas blow out
by SNe
merging
Pop III stars
explode as SN
1 Pop III star each
with order 100 $M_\odot$
some gas is left
or some is
recollected
Pop II stars form
from material enriched
just by the PopIII stars
no gas
left for star
formation

ENRICHMENT CHANNEL IN A FIRST GALAXY



Abundance test!

SN II regime SN Ia regime



core-collapse enrichment level

Frebel + Bromm '11, arXiv/1010.1261

Prediction:
In a first galaxy no stars should show abundance patterns that reflect AGB or SN Ia enrichment!

AGB: can be tested with other elements

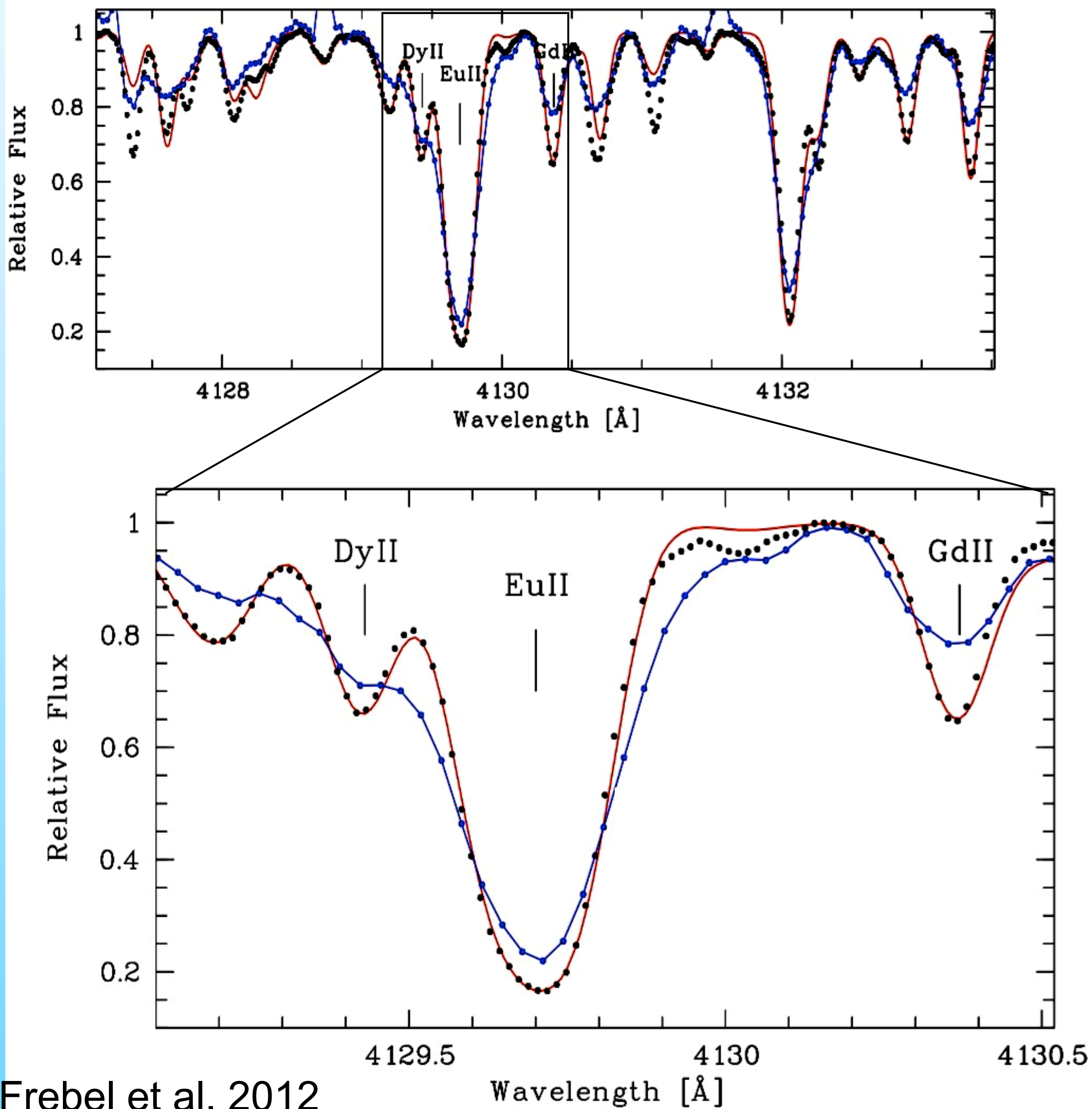
First galaxy candidates:
Ursa Major II, and also **Segue 1**
Coma Berenices, Bootes I, Leo IV

Conclusion

- Large spread in Sr and Ba remains, and remains largely unexplained; new data still inconclusive
- Generic halo stars with unknown nucleosynthetic origin are only marginally helpful in this quest :(
- But dwarf galaxies can provide the means to more cleanly couple/disentangle the nucleosynthesis process to/from the actual astrophysical sites
- A large sample of r-process stars may shed some light onto the pure r-proc component of Sr and Ba and could show what the range in the elements is

New r-process star Eu @4129A

- 4250 K, log g = 0.0
- [Fe/H]=-3.2
- preliminary [Eu/Fe] ~1.1
- Low carbon => good for Th, U, etc.

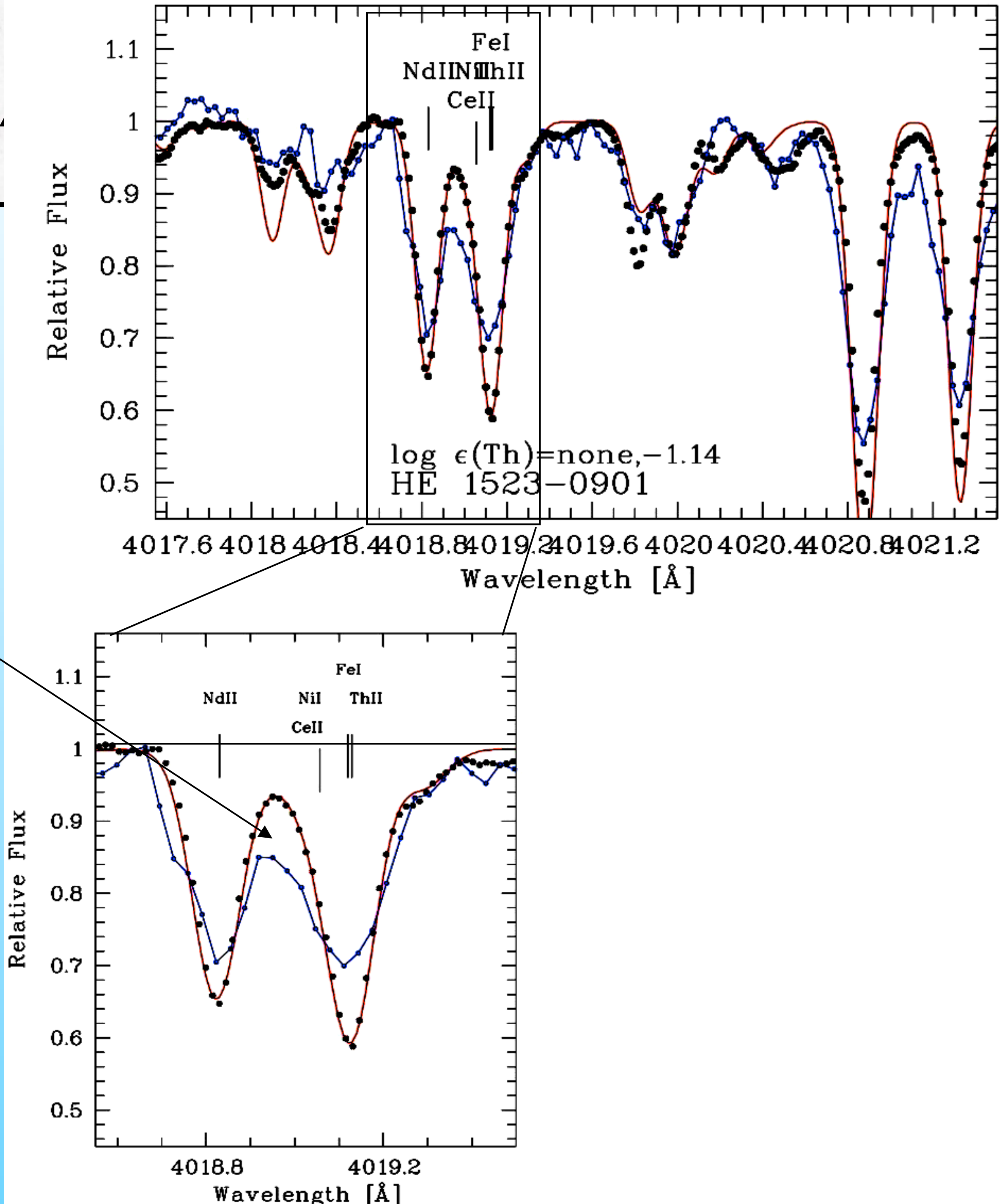


Frebel et al. 2012

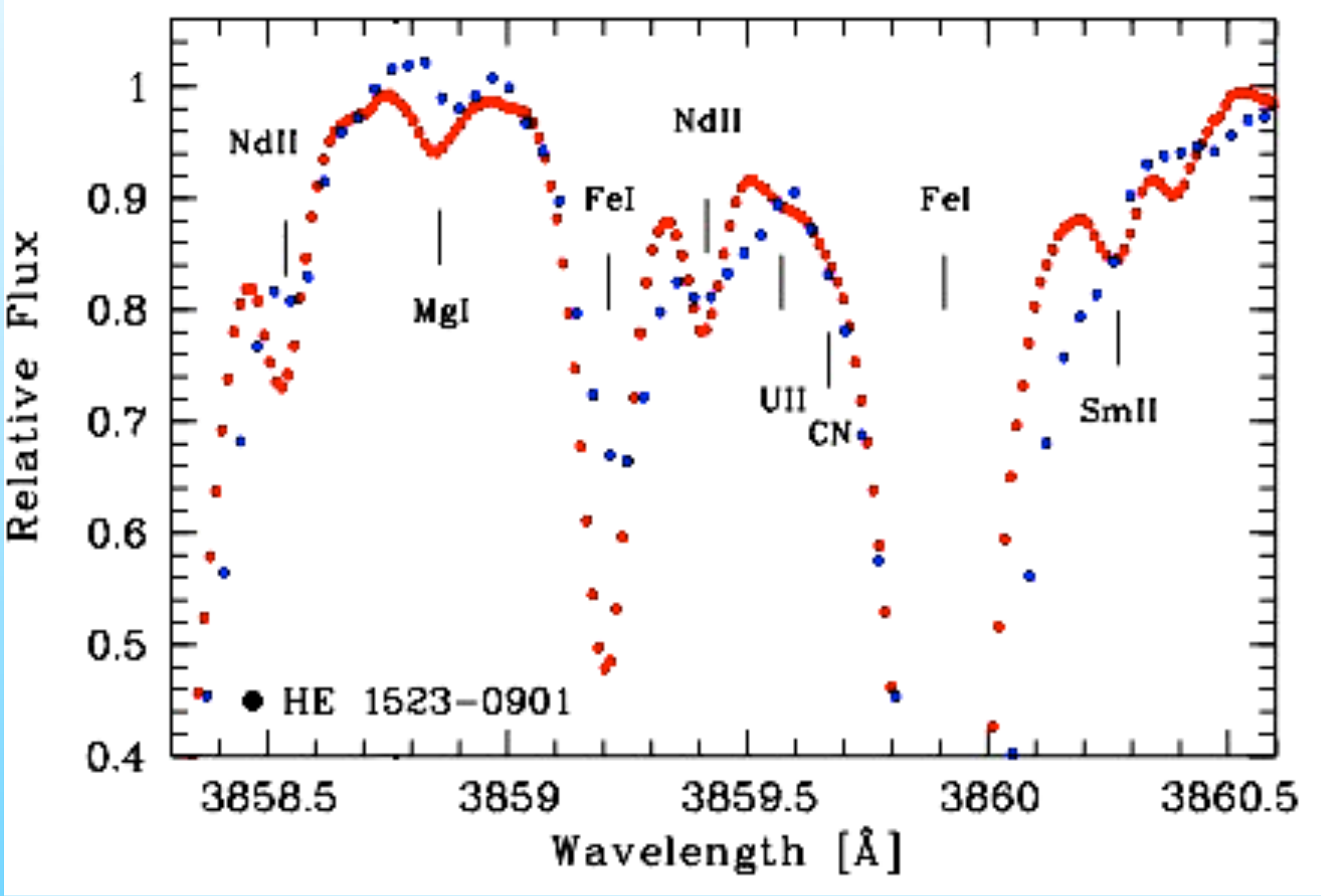
Th @4019

Lot of 13CH

Th/Eu age?
ask me in a few weeks :)



U @3859A



NdII
MgI
NdII
FeI
FeI
UII
CN
SmII
Relative Flux
Wavelength [Å]
HE 1523-0901
1
0.9
0.8
0.7
0.6
0.5
0.4
3858.5
3859
3859.5
3860
3860.5

R-process pattern

We are currently measuring hundreds of lines in both r-process stars

The abundances of the first 5 elements we measured match the solar r-process pattern well!

Another star to test whether there are any (relative) differences among light n-cap elements and compared with the solar r-process pattern -- stay tuned!

Postdoc ad

Please check my website

www.cfa.harvard.edu/~afrebel

for two postdocs job openings

1) observer: high-resolution spectroscopy, metal-poor stars, nuclear astrophysics
2) highly resolved cosmological DM simulations of Milky Way-like halos to trace the cosmological origin of the most metal-poor stars

TEXTBOOK & ABUNDANCES

Planets, Stars & Stellar Systems, by Springer
Volume 5: Editor: Gerry Gilmore; to appear in 2012

- STELLAR POPULATIONS
  Metal-poor stars and the chemical enrichment of the universe
  (by Frebel & Norris, arXiv:1102.1748)
- GALACTIC COMPONENTS
- THE NON-STELLAR GALAXY
- GALACTIC STRUCTURE AND EVOLUTION

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Abundance compilation of metal-poor stars in the literature:
~1000 stars with full chemical abundances (halo and dwarf galaxies)
See https://www.cfa.harvard.edu/~afrebel/abundances/abund.html
(as part of Frebel 2010, review on metal-poor stars)