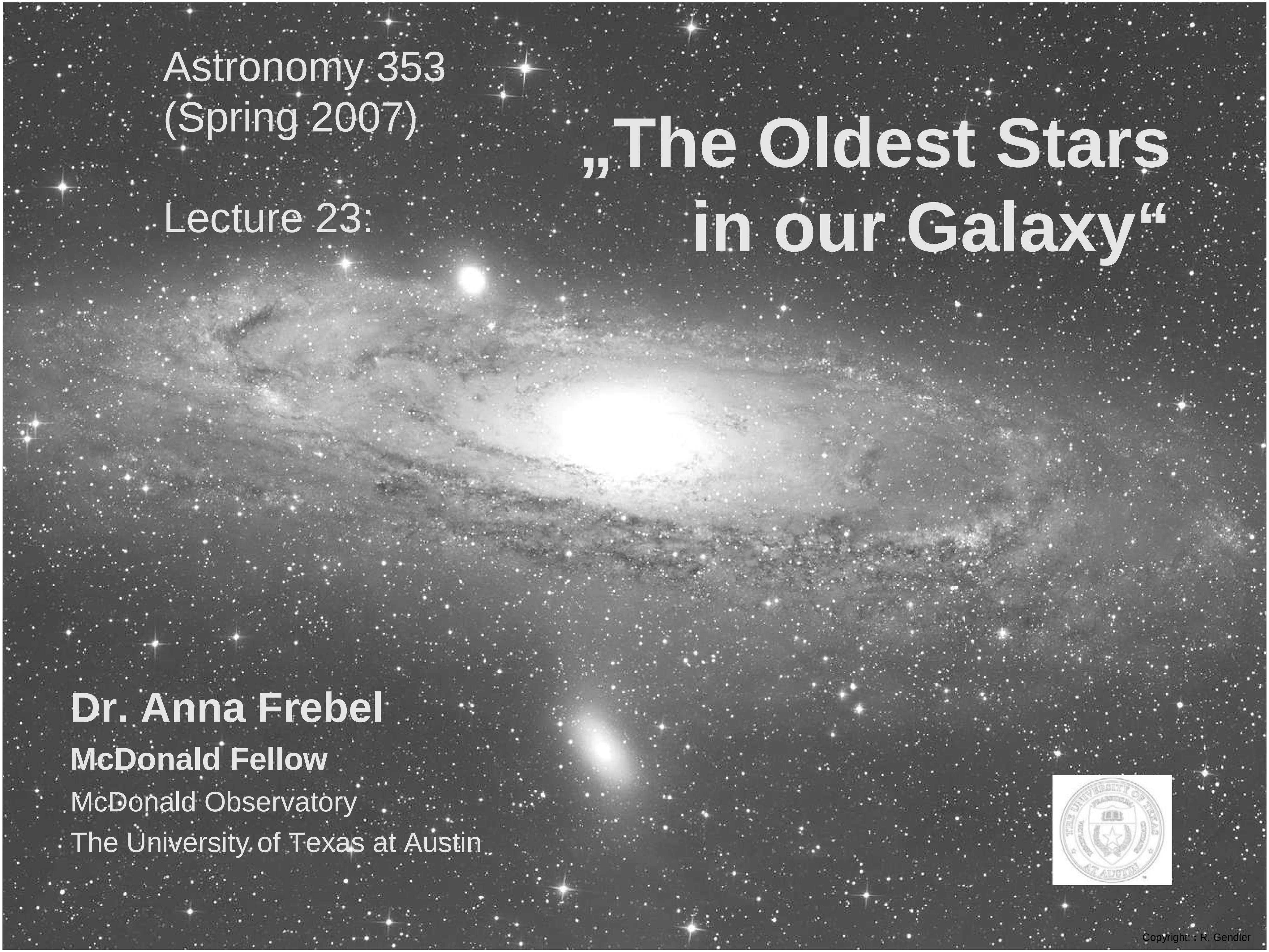
Astronomy 353
(Spring 2007)

Lecture 23:

„The Oldest Stars in our Galaxy“



Dr. Anna Frebel
McDonald Fellow
McDonald Observatory
The University of Texas at Austin

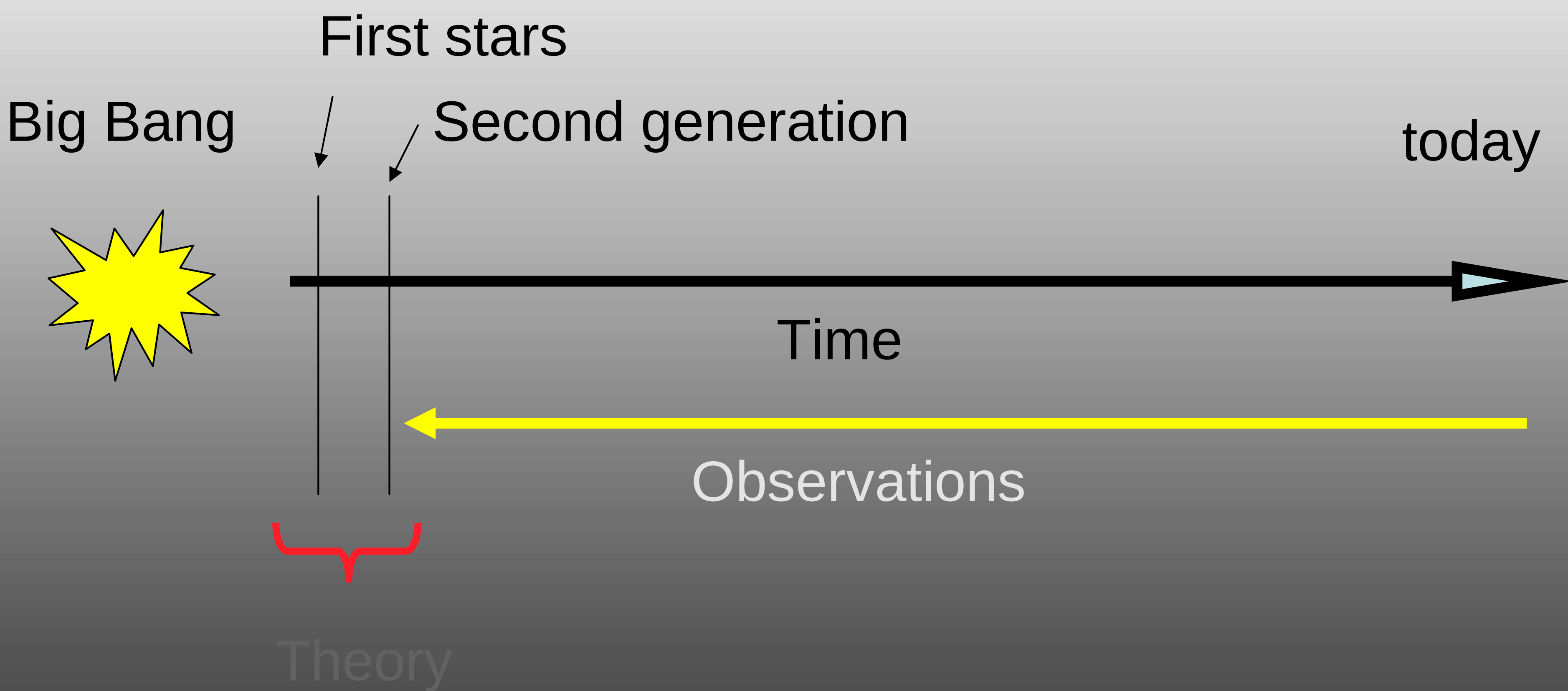
Recap

- Formation of the first stars
- Stellar deaths

Q: What is left from the early Universe
that we can still observe today?

A: A lot..! We call this near-field cosmology

Cosmic timeline



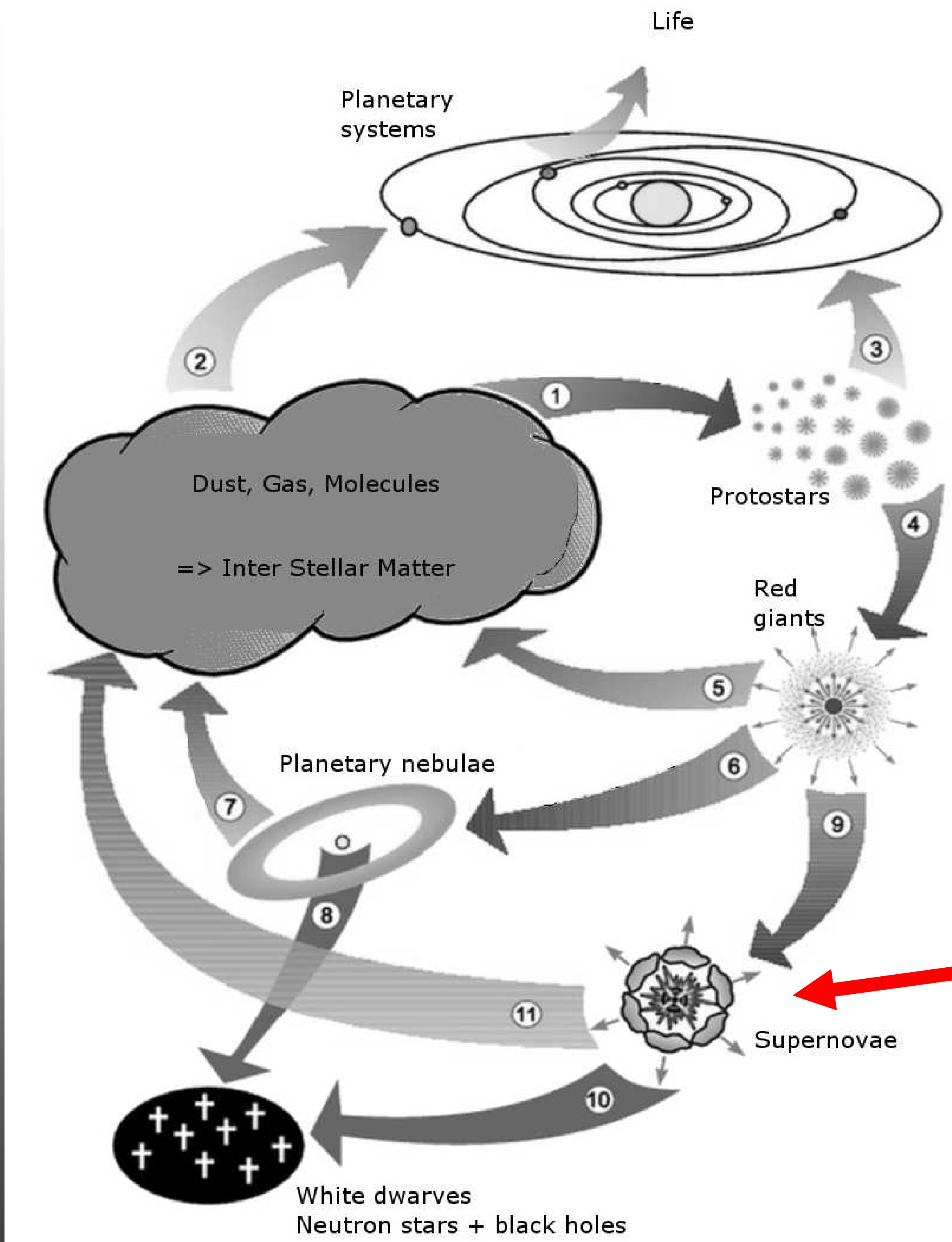
We are Children of the Stars…!

- Elements are produced in stars and supernovae
- Successive built up of heavy elements in the Universe through "cosmic recycling"

=> Old stars contain fewer elements (e.g. iron) than younger stars

=> We look for the stars with the least amount of elements heavier than H and He!

Cosmic recycling



Zentrum fuer Astronomie und Astrophysik, TU Berlin

Heavy elements are produced here!

Stellar Archaeology I

Some definitions:
Metals = concerns all elements, except hydrogen and helium
Metal-poor star = Star with fewer metals than the Sun
==

- Population I: Metallicity similar to that of Sun; young disk stars

- Population II: Lower metallicity (metal-poor); old halo stars

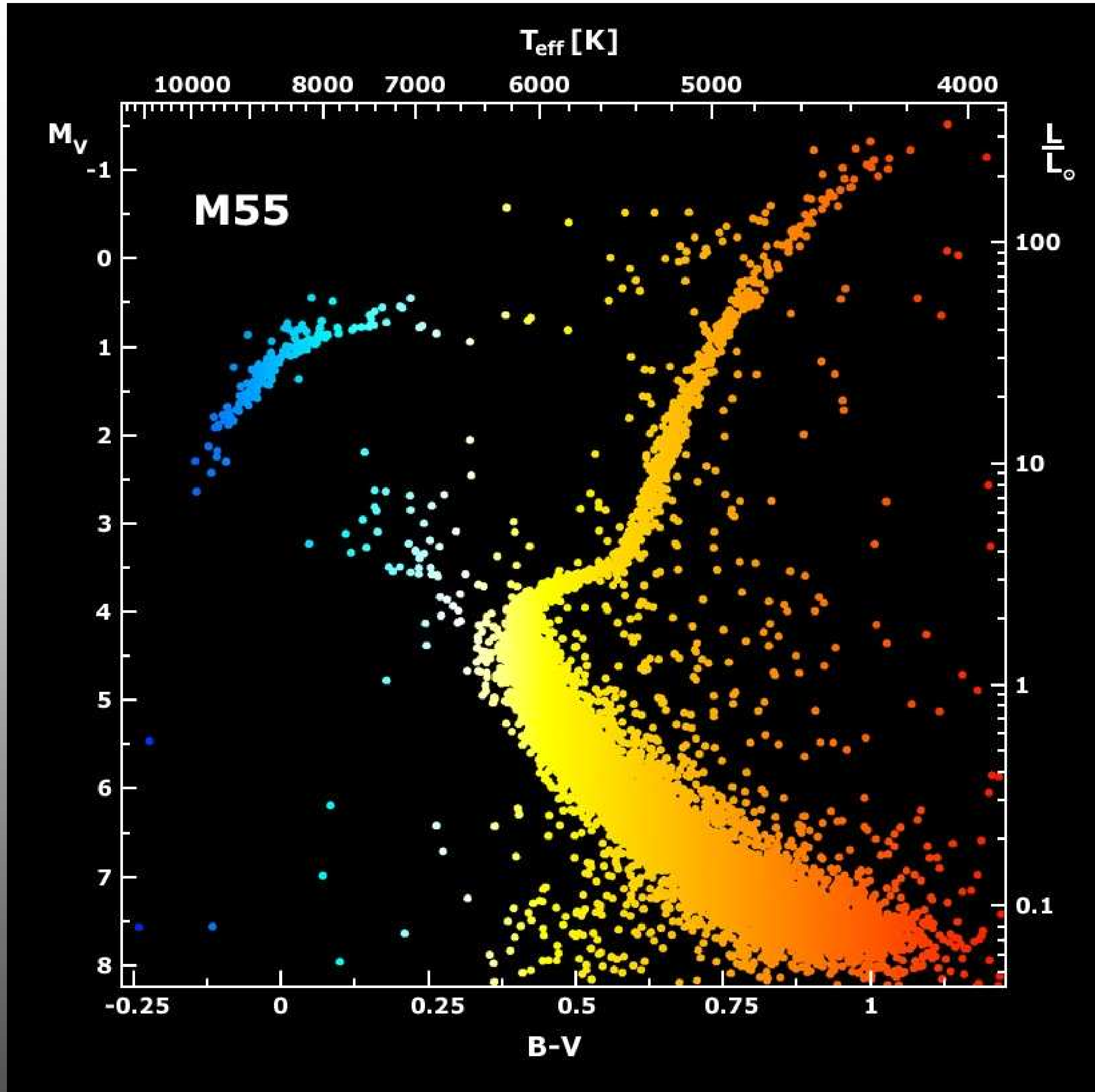
- Population III: Theoretical poplulation; the very first generation of stars that formed after the big bang

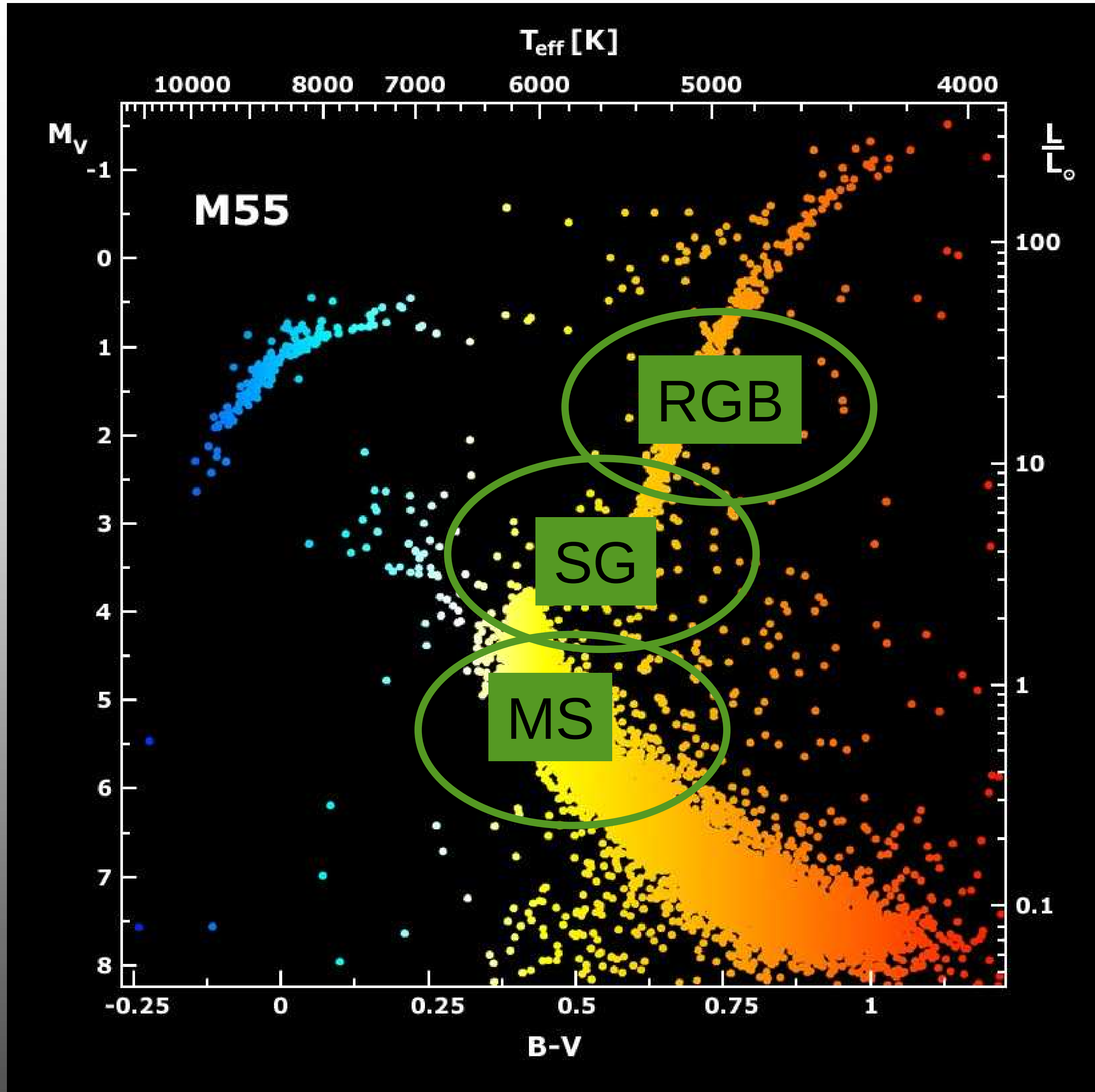
Stellar Archaeology II

Why are metal-poor stars interesting?

- Chemical evolution of the Galaxy from the Big Bang until today
- “Snapshots of the early Universe”
- Nucleosynthesis processes can be studied
- Models of the first stars can be tested
- They are the **“closest relatives”** to the First Stars

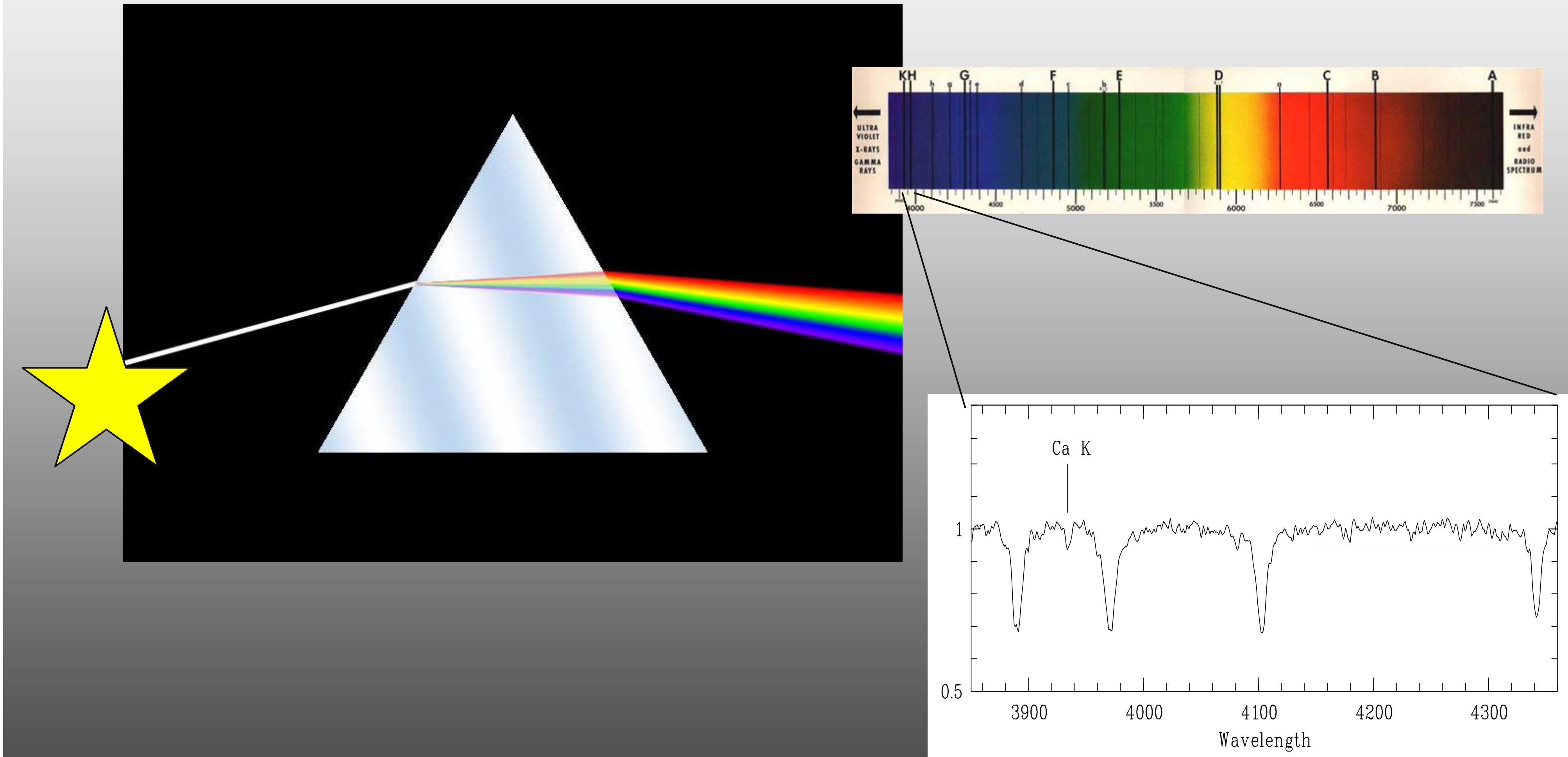
=> **Near-field cosmology**: they connect us to the high-redshift Universe


M55
T_eff [K]
10000
8000
7000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
L/L_⊙
100
10
1
0.1
-0.25
0
0.25
0.5
0.75
1
B-V

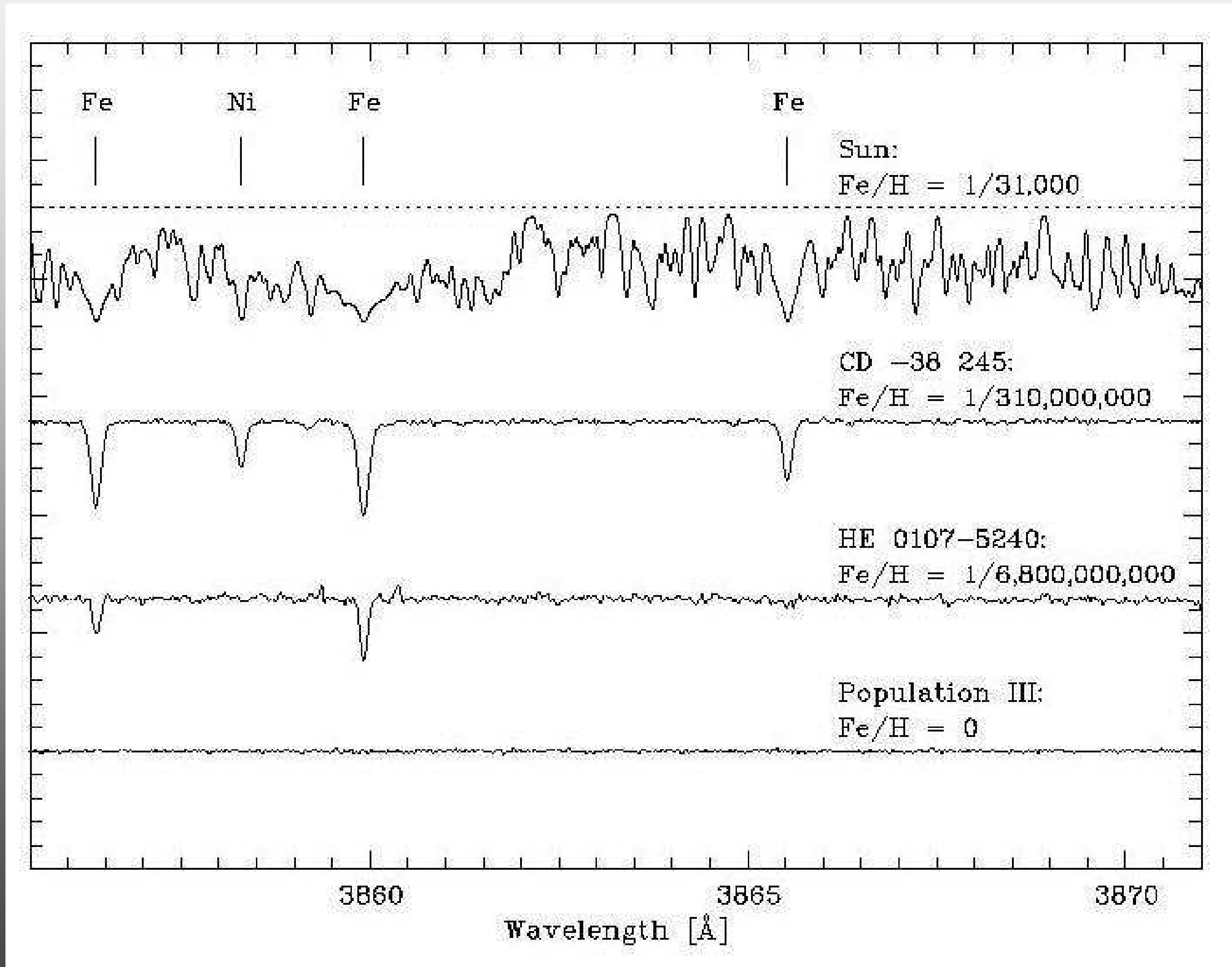


M55
T_{eff} [K]
10000
8000
7000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
$\frac{L}{L_\odot}$
100
10
1
0.1
RGB
SG
MS
-0.25
0
0.25
0.5
0.75
1
B-V

Making a rainbow



Spectral Comparison



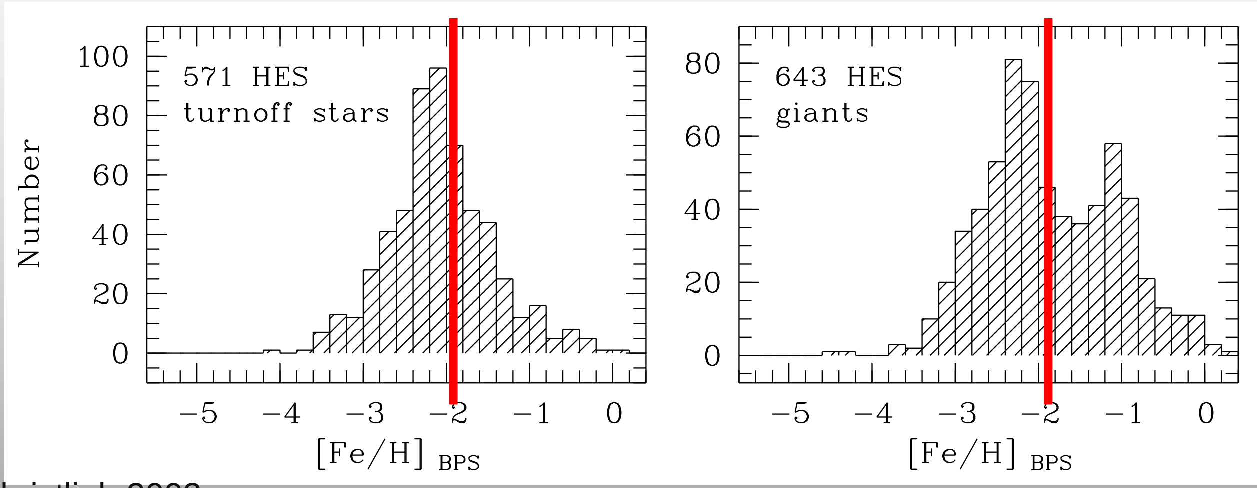
[Fe/H]= 0

[Fe/H]= −4

[Fe/H]= −5.3

[Fe/H] = - ∞

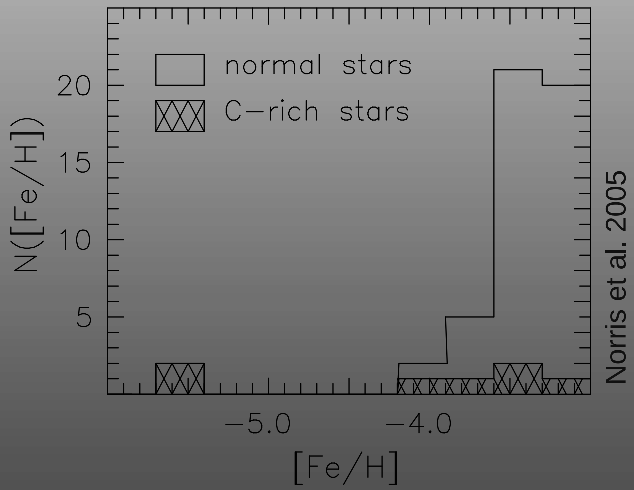
The Metallicity Distribution Function



Christlieb 2003

Hamburg/ESO survey (faint):

Christlieb and collaborators



~15 stars with [Fe/H]< –3.5

No stars with –4 <[Fe/H]<–5

Only two stars with [Fe/H]<–5.0

What [Fe/H] means to me:

Stars with metal contents much less than the Sun

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

[Fe/H] = 0: solar composition

[Fe/H] ~ – 1: boring…

[Fe/H] ~ – 2: good for statistics

[Fe/H] ~ – 3: … interesting!

[Fe/H] < – 4: Oooh my GOD !!!!!!!!! J

How many metal-poor stars do we know??

- –2.0 < [Fe/H] < –1.0: very many
- –3.0 < [Fe/H] < –2.0: many
- –3.5 < [Fe/H] < –3.0: ~300
- –4.0 < [Fe/H] < –3.5: ~15
- –5.0 < [Fe/H] < –4.0: 1 (yet unpublished)
- –6.0 < [Fe/H] < –5.0: 2 …

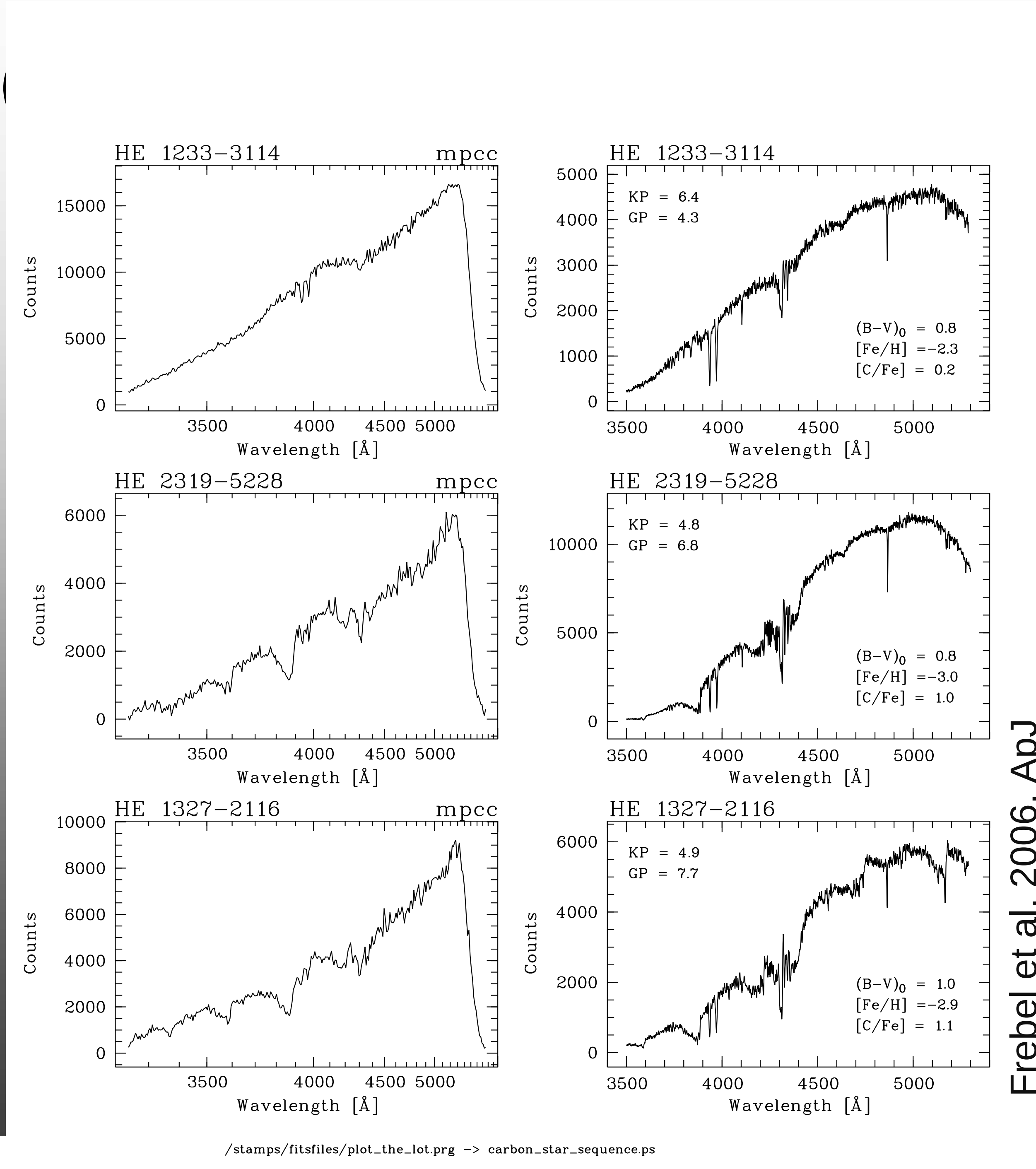
All those elements...

- The Elements Song

  by Tom Lehrer

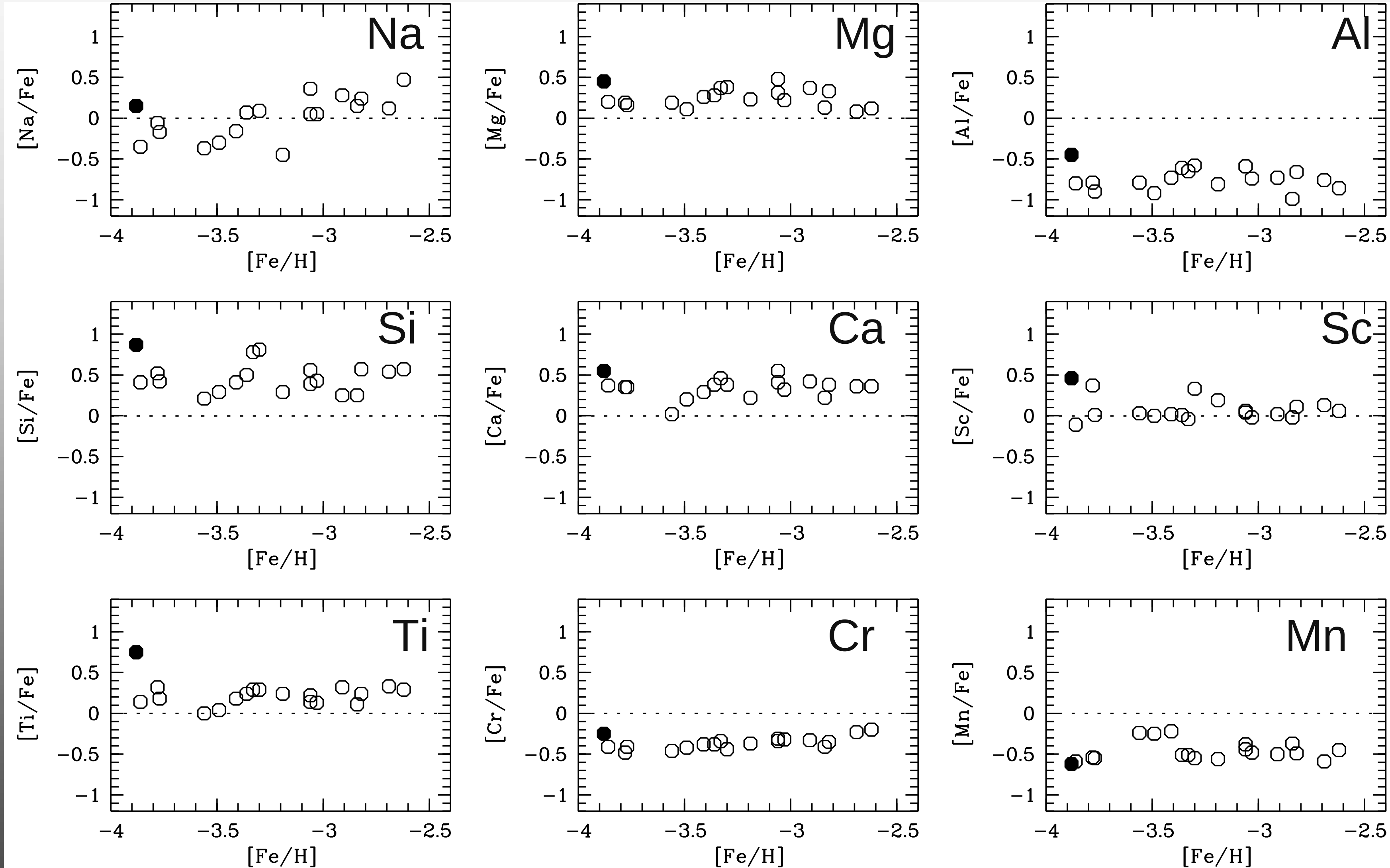
http://louhi.kempele.fi/~skyostil/archive/dump/flash/elements.swf

http://www.edu/cyberpg.com/IEC/elementsong.html



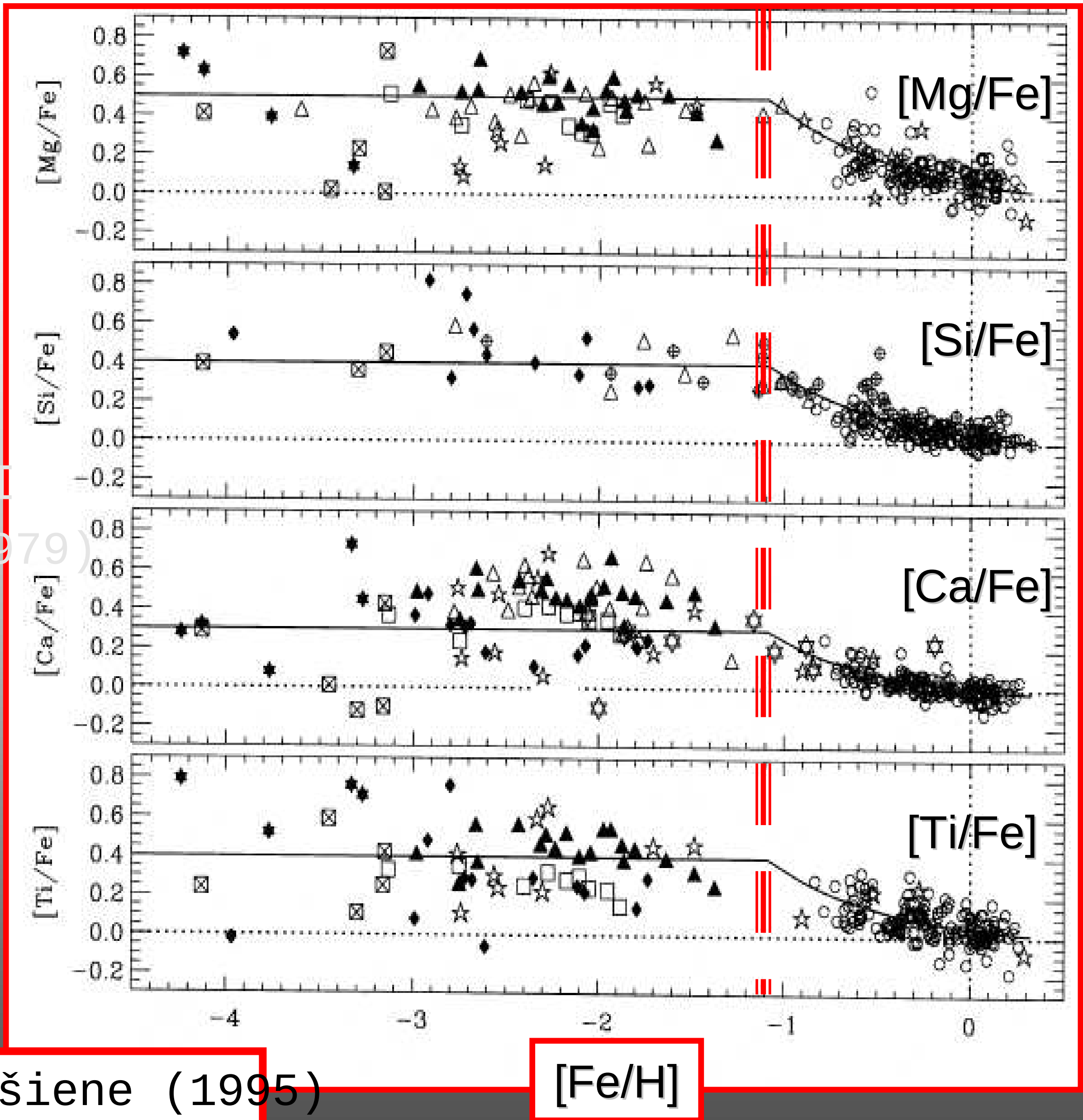
Frebel et al. 2006, ApJ

“Normal” Metal-Poor Stars



Frebel et al. (2006), ApJ in press

Standard picture:
iron-rich ejecta
from SNe Ia
super-posed on
pre-existing
material
(e.g. α-elements)
produced in SNe II
(see e.g. Tinsley 1979)



Pagel & Tautvaišiene (1995)

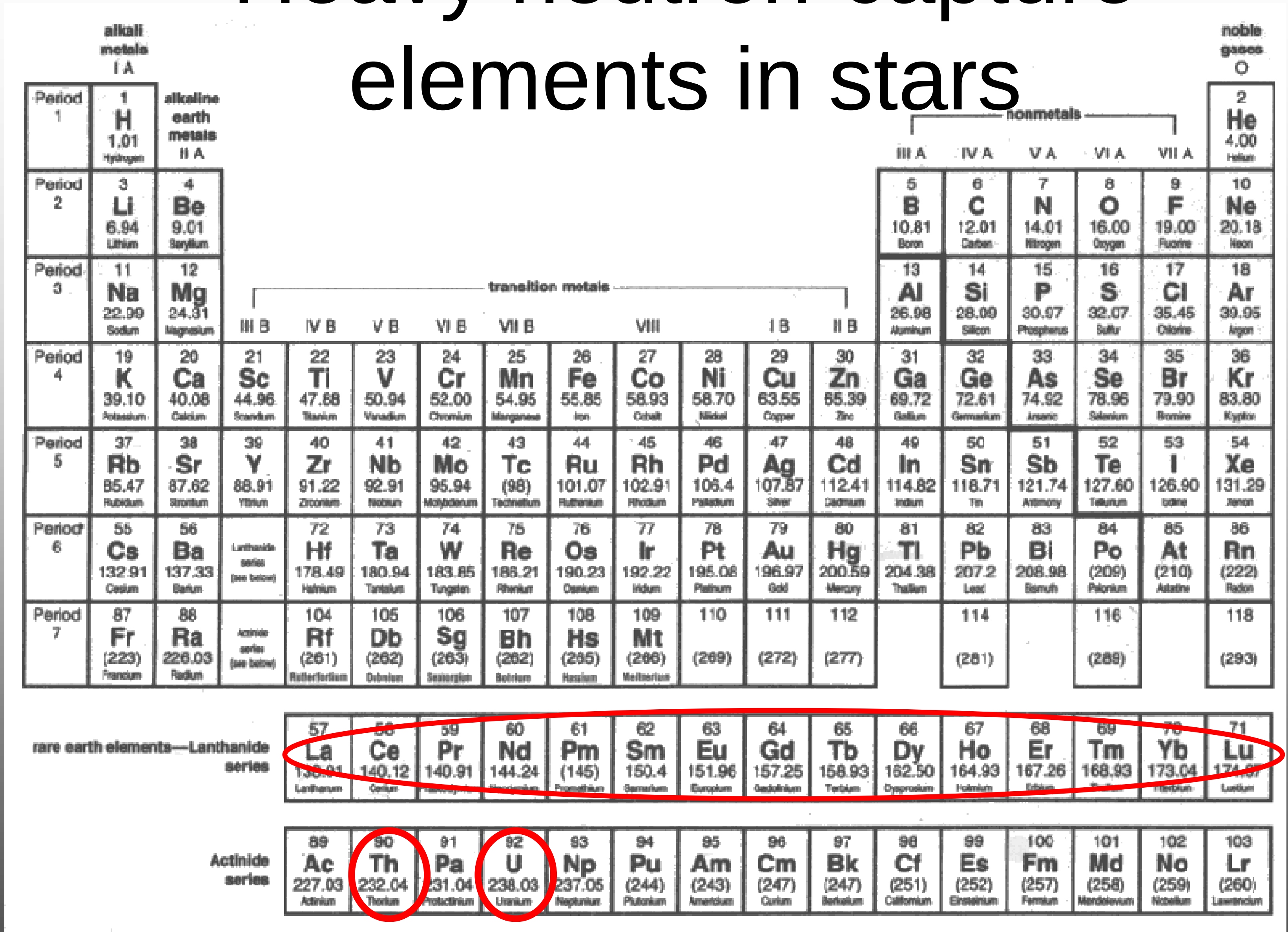
<- more pristine ~ older

r-Process Element Enhanced Stars

(rapid neutron-capture process)

- Responsible for the production of heavy elements
- Only ~12 stars known that display strong neutron-capture lines associated with the r-process
- Chemical “fingerprint” of one previous nucleosynthesis event
- Nucleo-chronometry: age measurements from radioactive elements Th, U and stable r-process elements (Eu, Os, Ir)

Heavy neutron-capture elements in stars



HE 1523-0901

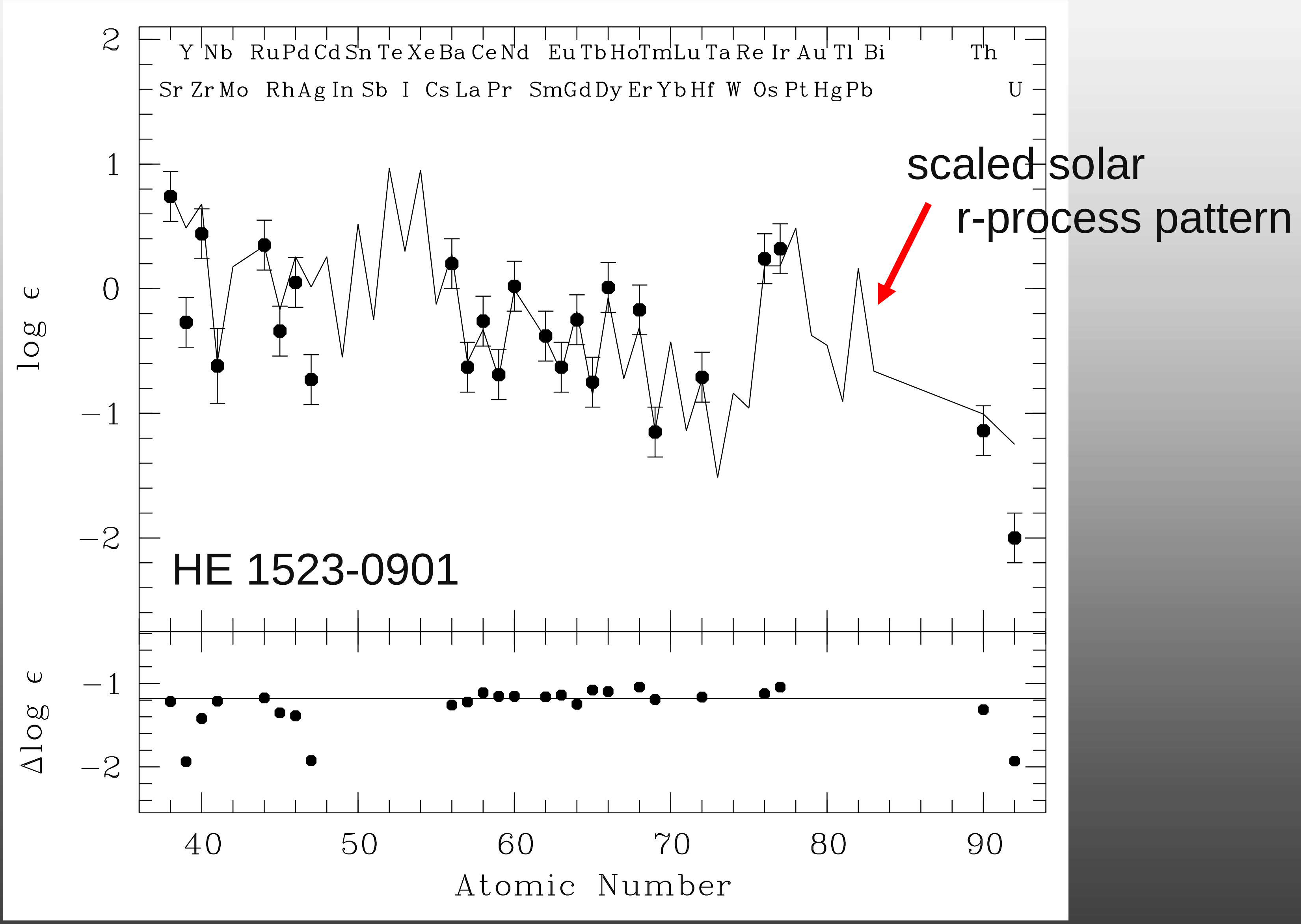
5. HE 1523−0901

Basic and stellar parameters:

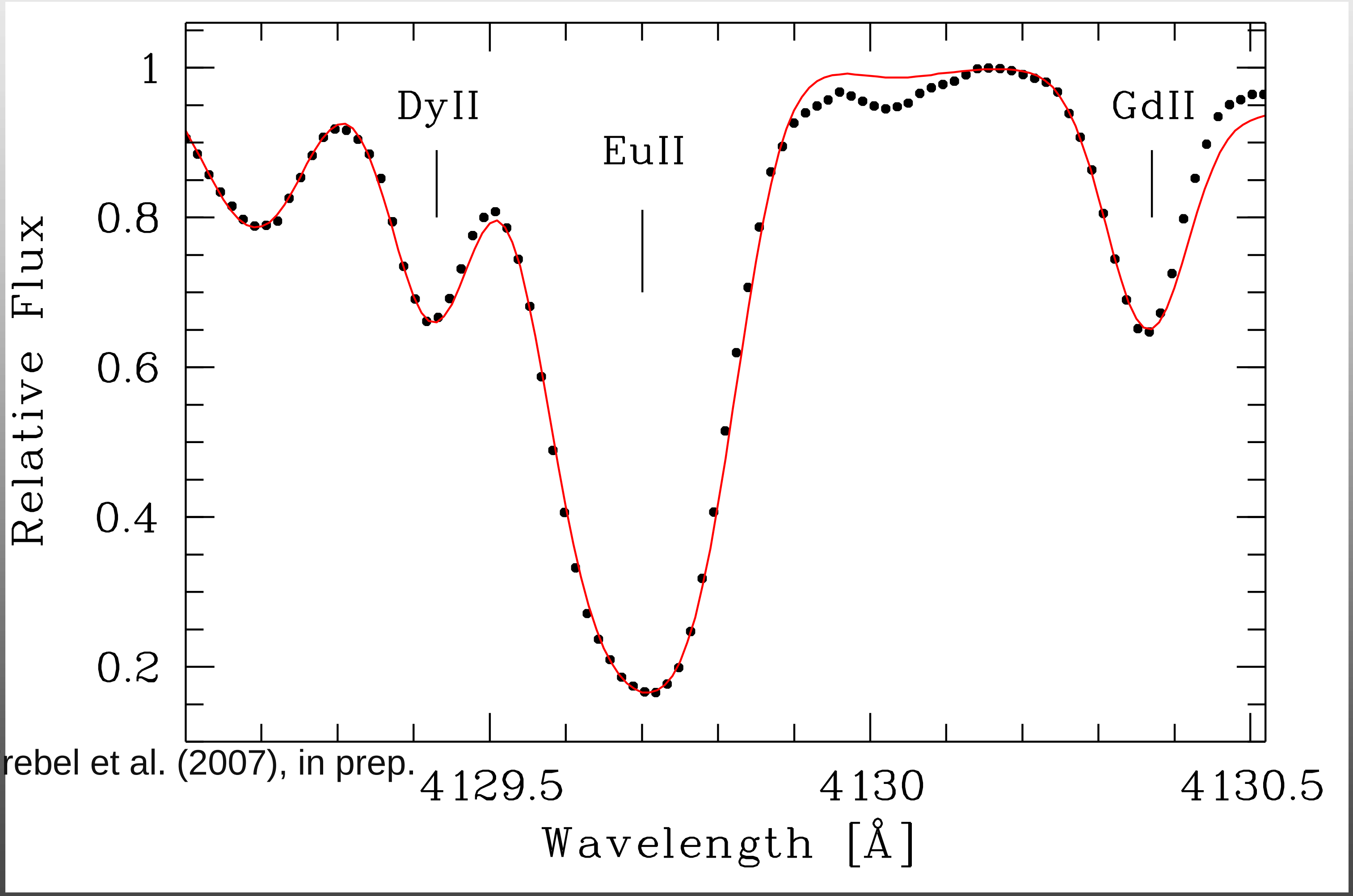
- Magnitude: B = 12.1 mag
- Colour: $(B-V)_0$ = 0.70 mag
- Reddening: $E(B-V)$ = 0.02

- *BVRIJHK* photometry: T_{eff} = 4630 ± 70K (on Alonso et al. 1996 scale)
- Surface gravity: log g = 1.0 (ionisation equilibrium)
  => red giant
- Metallicity: [Fe/H] = −3.0

The r-Process Pattern

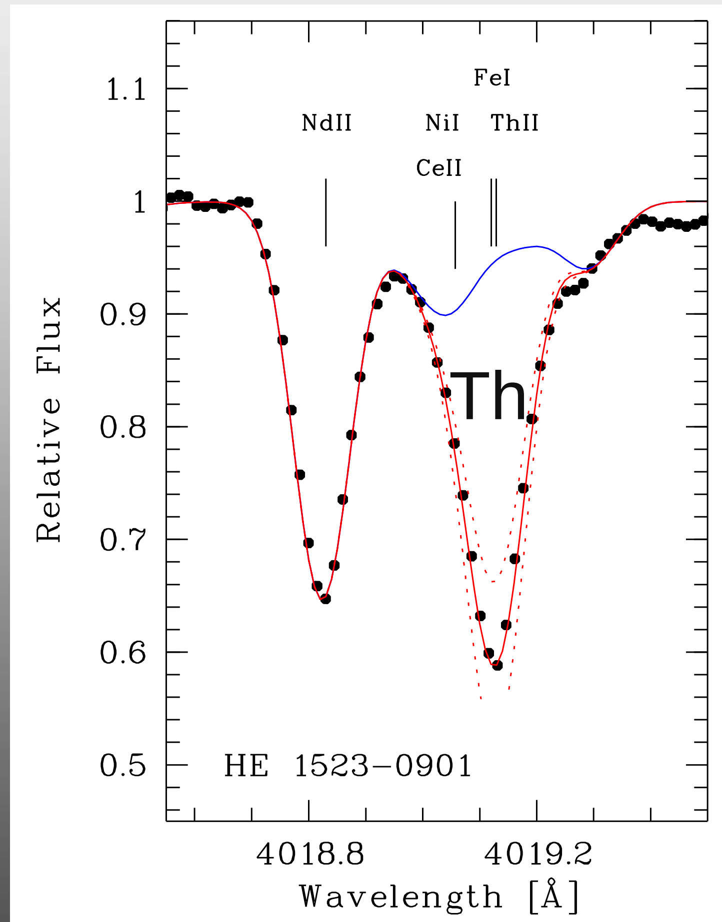


Abundances of HE 1523−0901



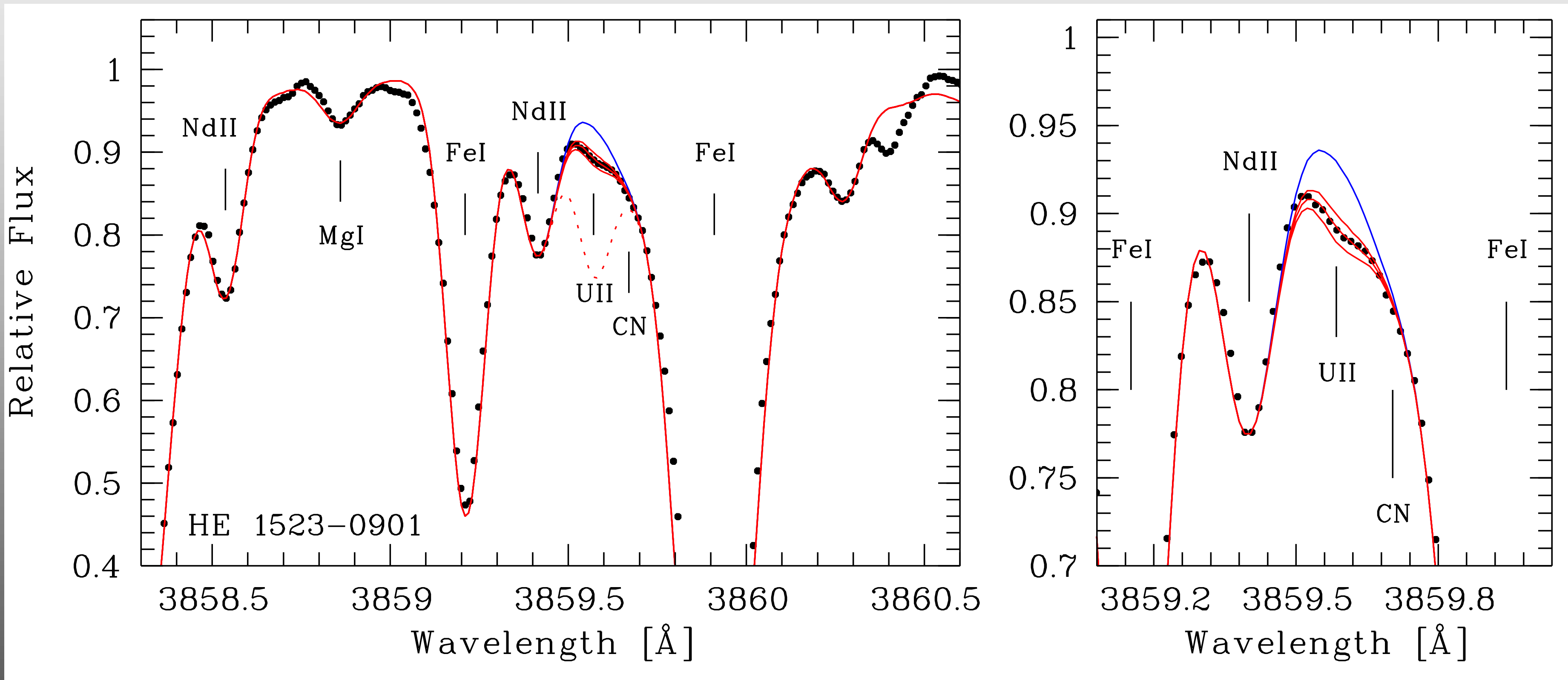
Frebel et al. (2007), in prep.

Th II Line 4019Å



Frebel et al. (2007), in prep.

U II at 3859Å



Frebel et al. (2007), ApJL in press

Nucleo-Chronometric Age Dating

Age estimates can be obtained from a comparison of an observed abundance ratio of a radioactive element (such as Thorium, Uranium) to a stable r-process element (such as Europium, Osmium, Iridium) and a theoretically derived initial production ratio.

$$\Delta t = 46.8 * (\log (Th/r)_0 - \log (Th/r)_{obs})$$

$$\Delta t = 14.8 * (\log (U/r)_0 - \log (U/r)_{obs})$$

$$\Delta t = 21.8 * (\log (U/Th)_0 - \log (U/Th)_{obs})$$

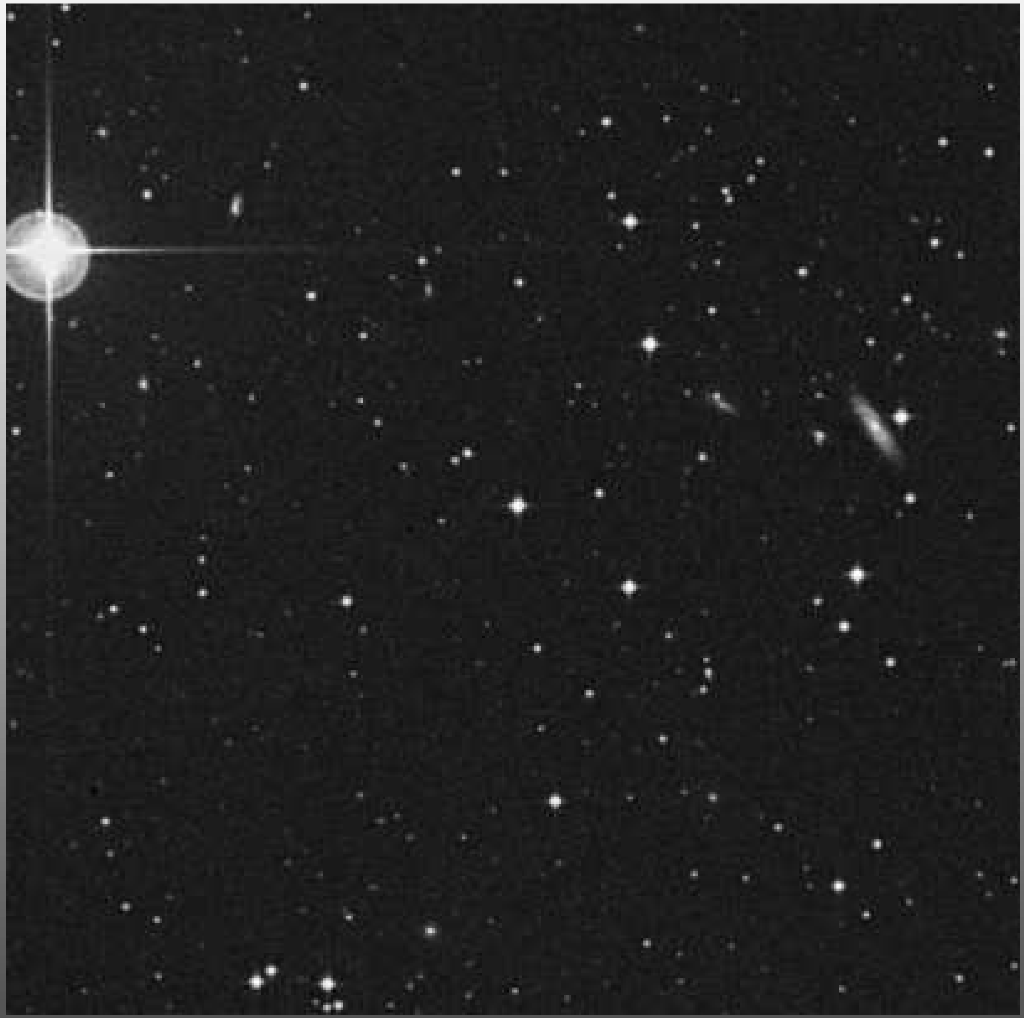
The Age of HE 1523−0901

Ratio	Age
Th/Eu	11.5 ±4.7
Th/Os	10.7 ±4.7
Th/Ir	15.0 ±4.7
U/Eu	13.2 ±2.2
U/Os	12.9 ±2.2
U/Ir	14.1 ±2.2
U/Th	13.0 ±3.3
average	**13.2±1.1±2.0 Gyr**

Age of HE 1523-0901:

Age of the Universe: 13.7 Gyr (from WMAP, Spergel et al. 06)

HE 1327-2326



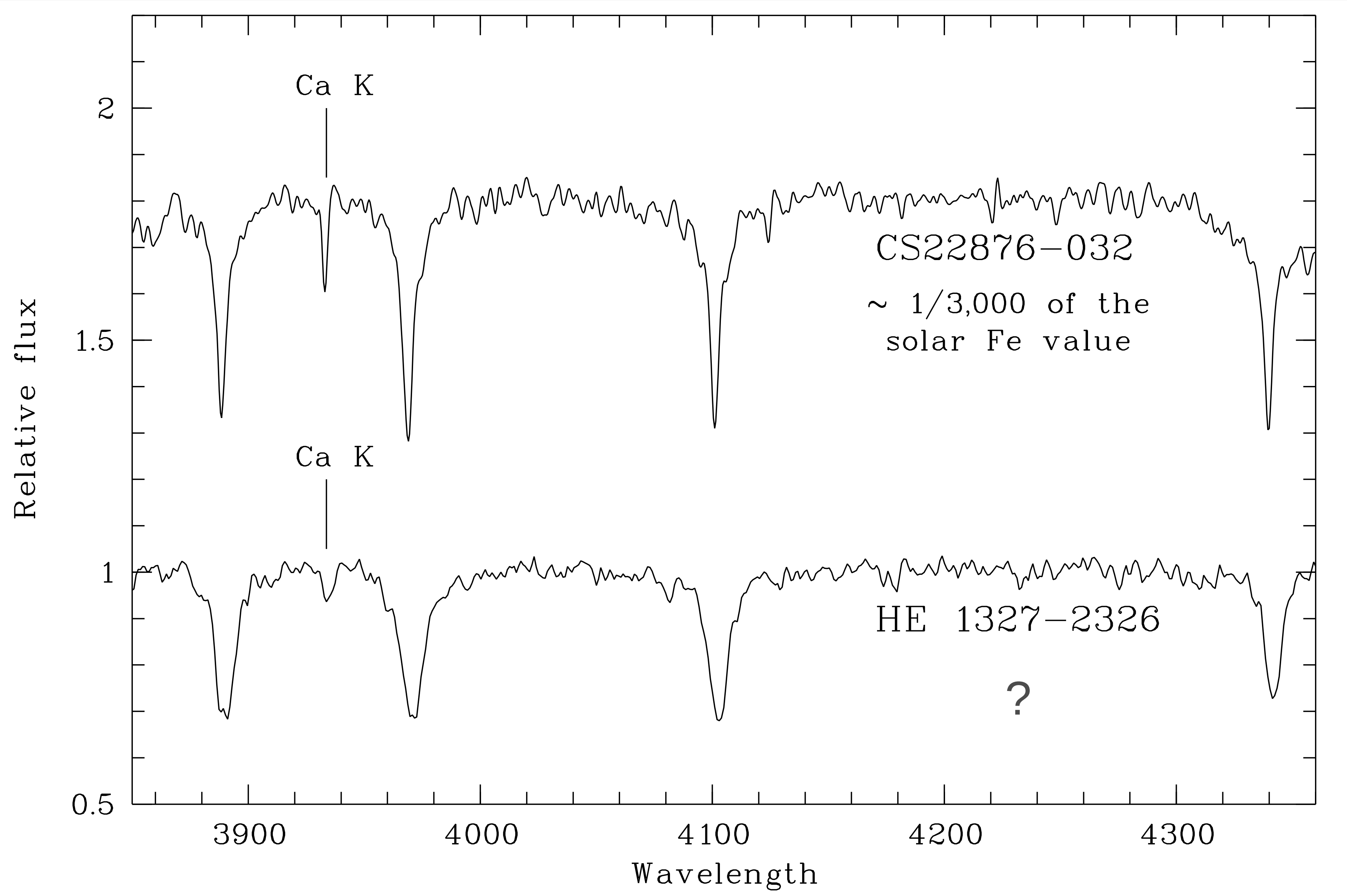
3. HE 1327−2326

Basic and stellar parameters:

- Magnitude: B = 14.016 mag
- Colour: $(B-V)_0$ = 0.40 mag
- Reddening: $E(B–V)$ = 0.06 – 0.096

- *BVRIK* photometry: T_{eff} = 6180 ± 80K (on Alonso et al. 1996 scale)
- Proper motion is μ = 0.0733 arcsec/yr
  => M_V > 3.2
  => surface gravity: log *g* = 3.7 or 4.5 (subgiant or dwarf)
- Metallicity: [Fe/H] = −5.4

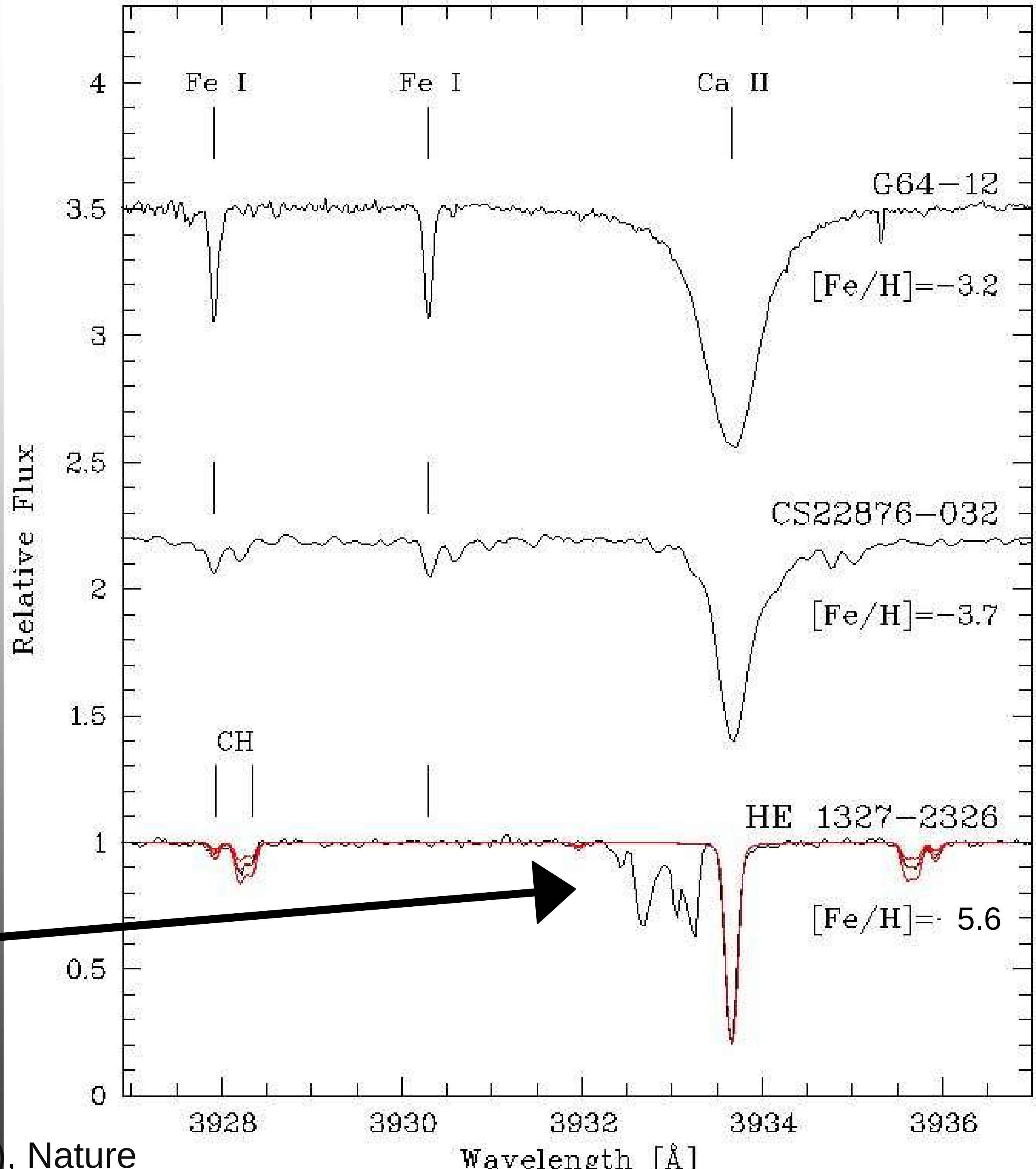
Medium-resolution spectrum



Ca K line

High-resolution
Subaru/HDS
spectra

Interstellar Ca



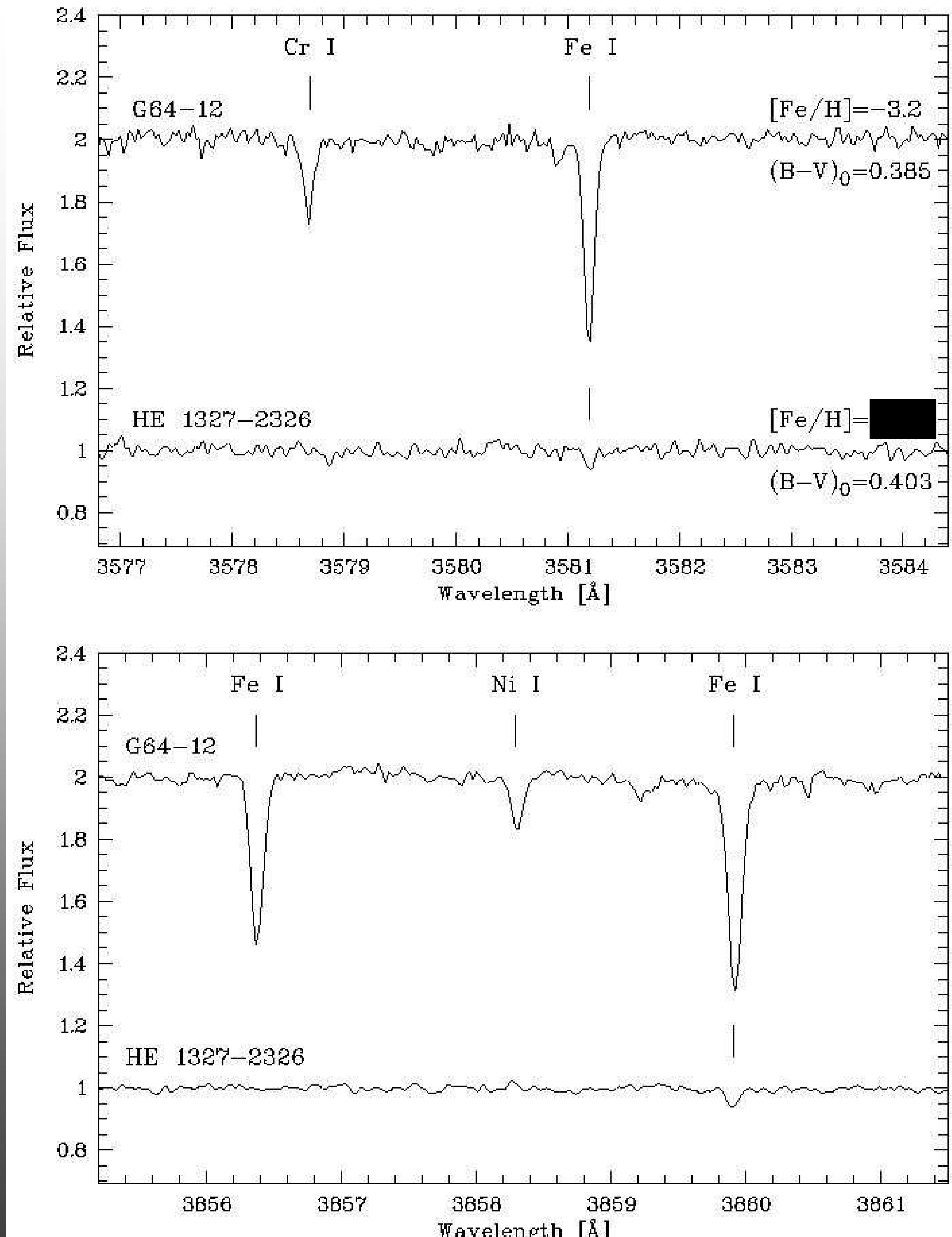
Frebel et al. (2005), Nature

Fe I Lines

The lowest iron abundance ever measured in a star:

[Fe/H] = -5.4

This number corresponds to 1/250,000 of the solar iron content!!



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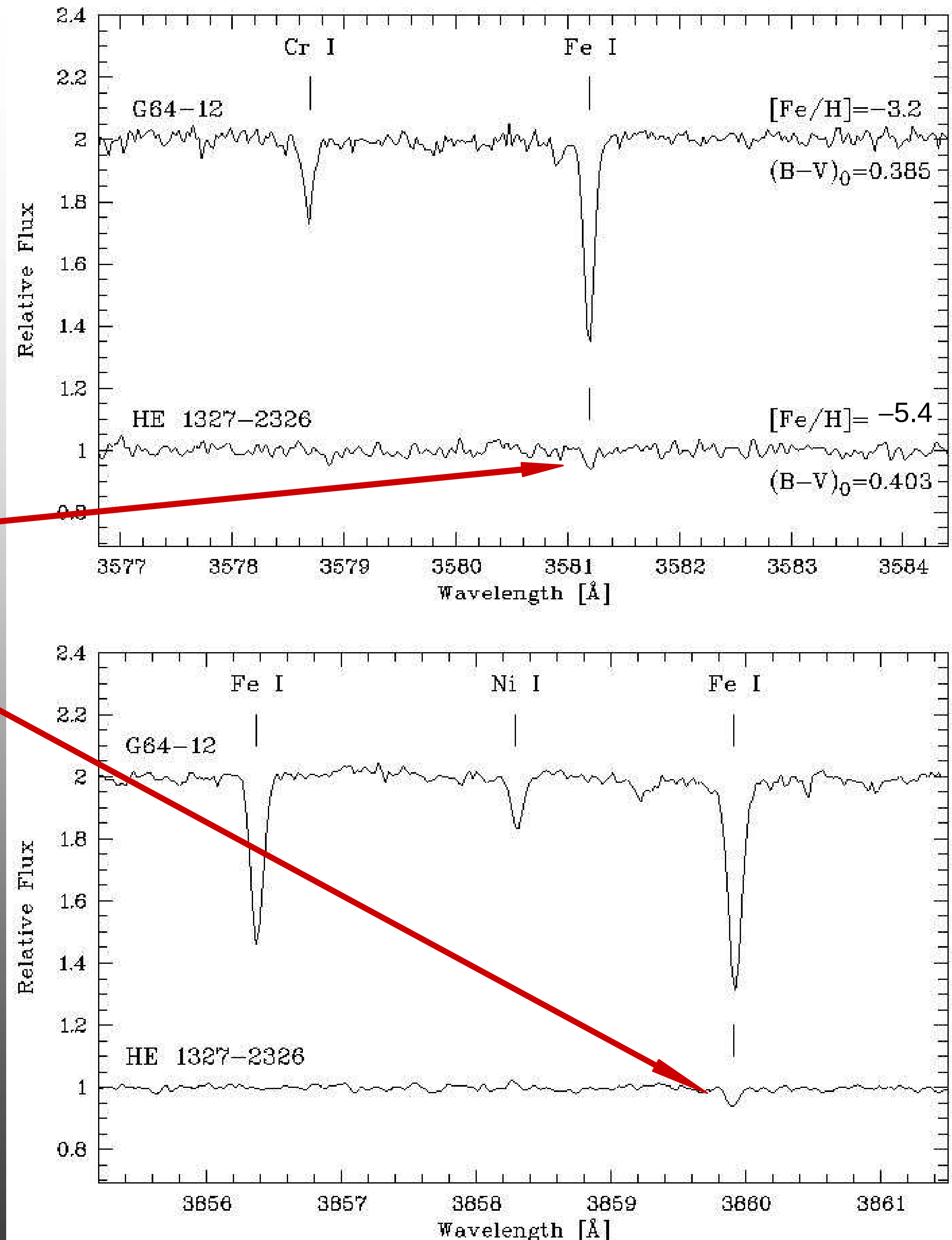
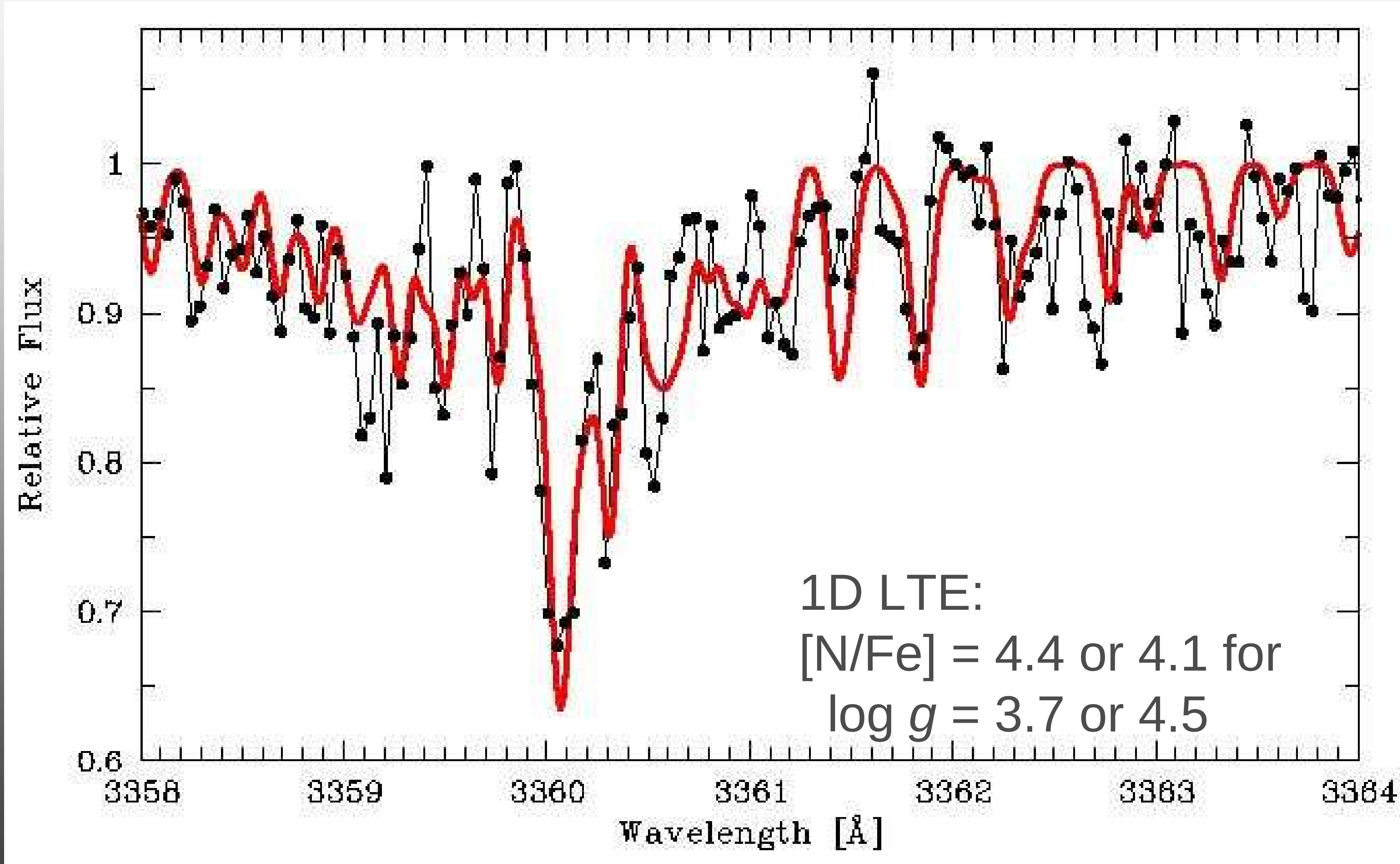
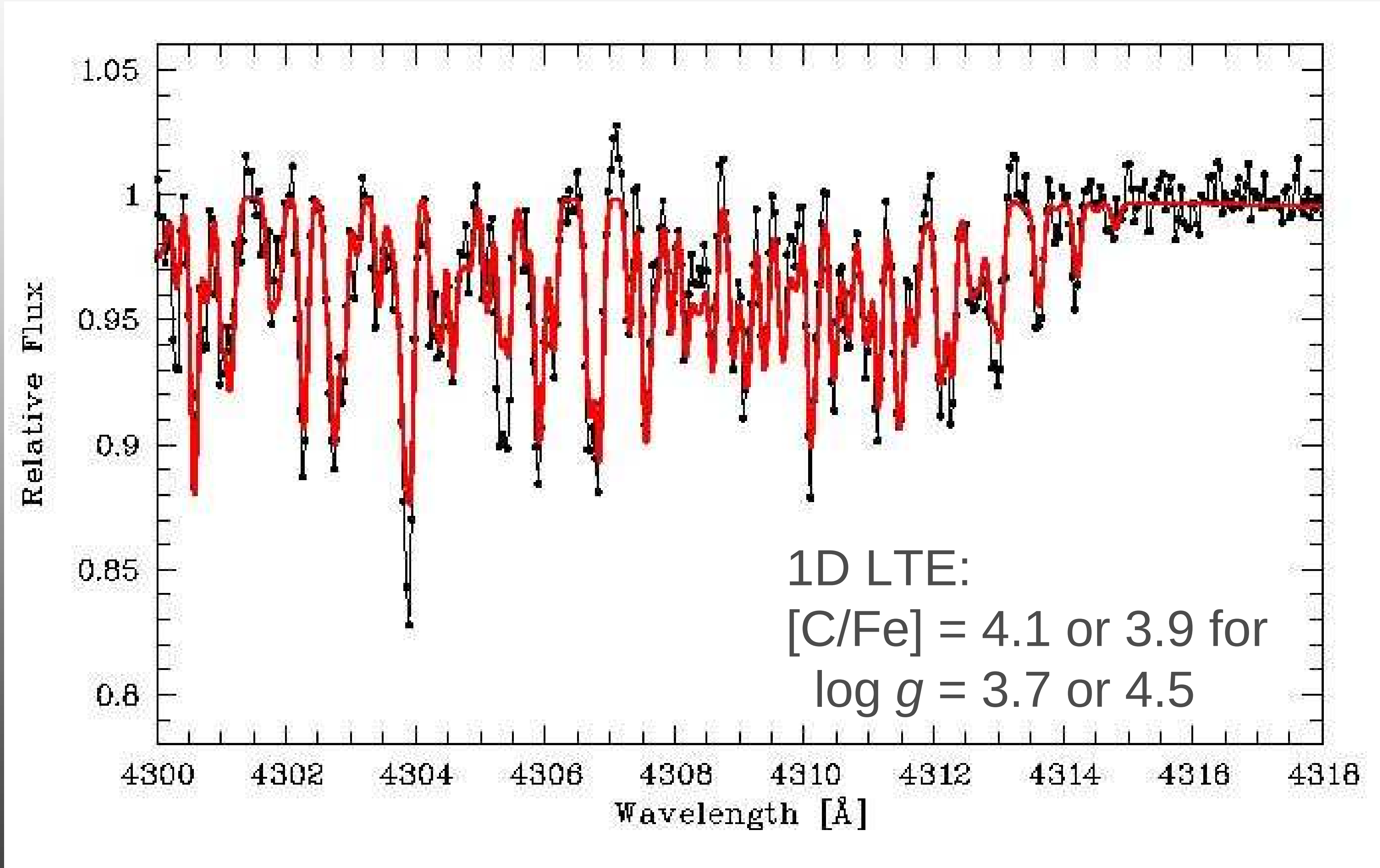


NH 3360

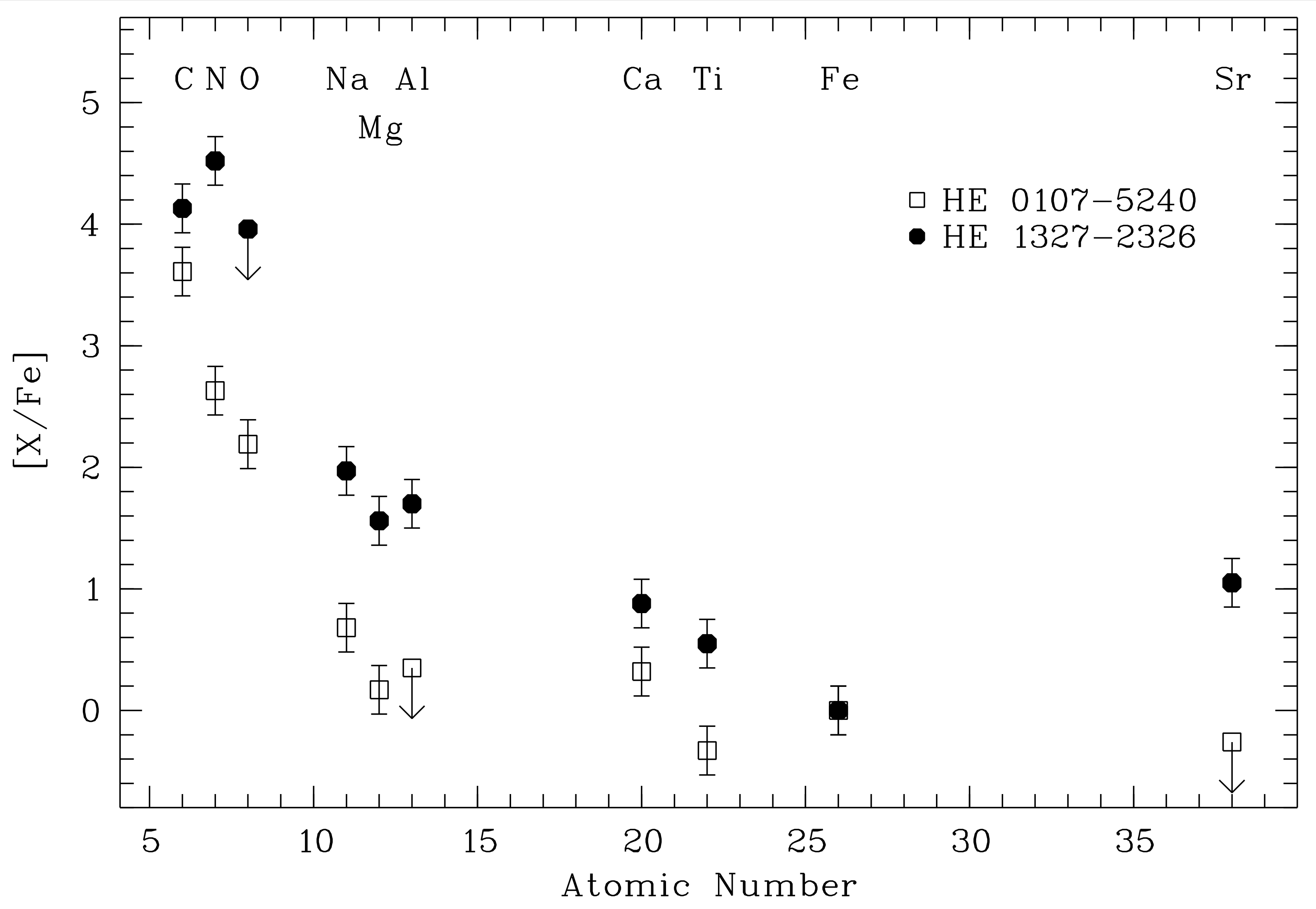


Relative Flux
1
0.9
0.8
0.7
0.6
3358
3359
3360
3361
3362
3363
3364
Wavelength [Å]
1D LTE:
[N/Fe] = 4.4 or 4.1 for
log g = 3.7 or 4.5

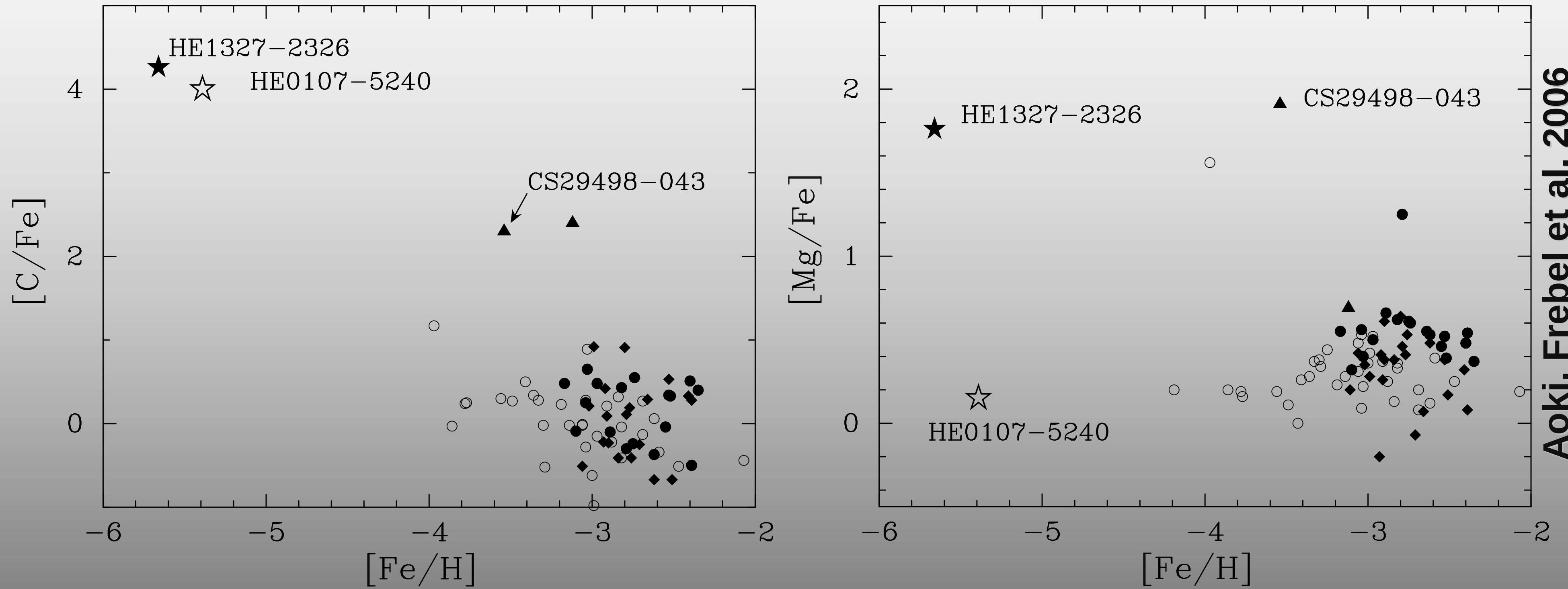
CH 4300 Bandhead



The abundance patterns of HE 1327–2327 and HE 0107–5240



What is so Special About HE 1327–2326?

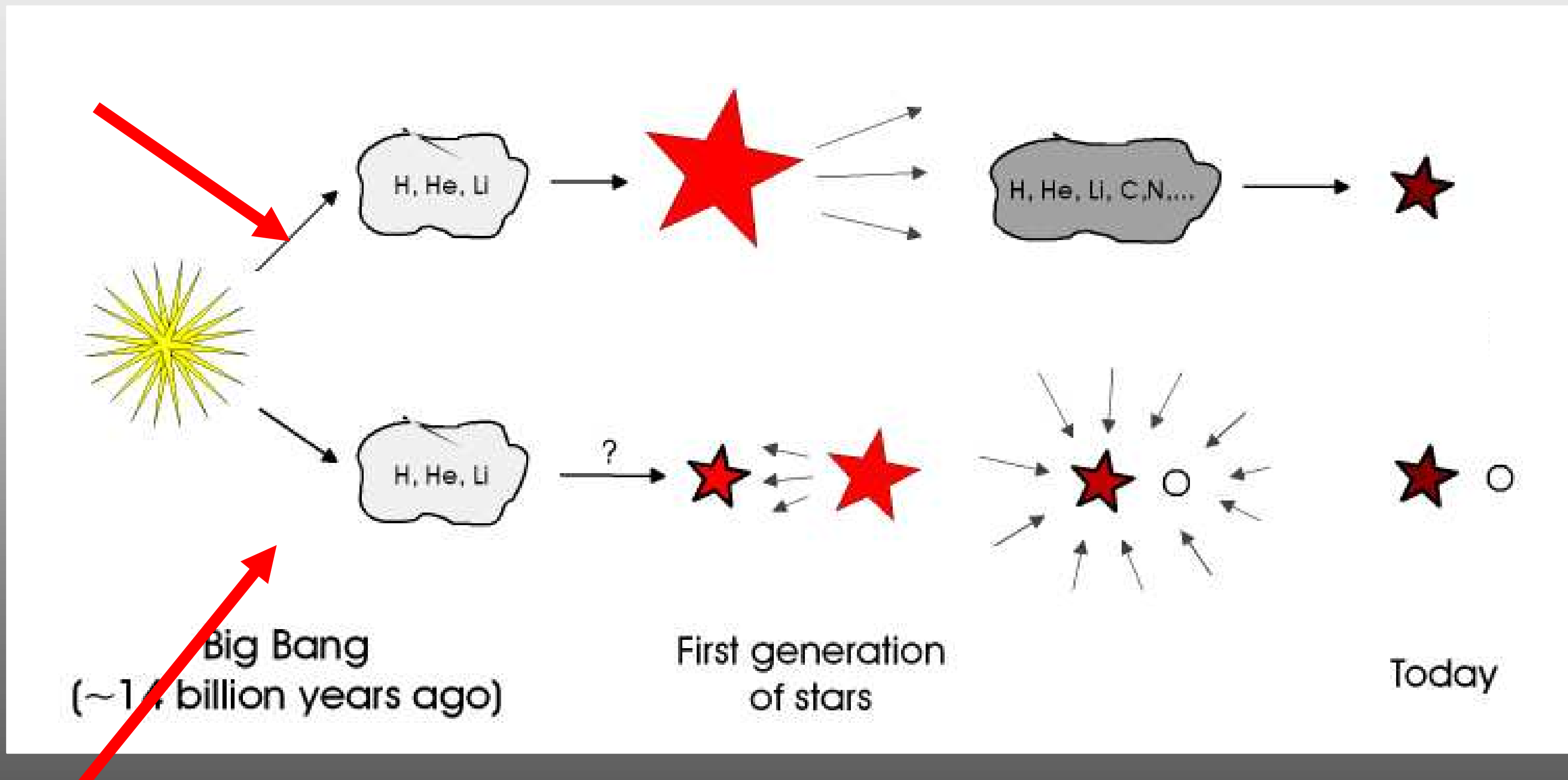


HE 1327–2326 has a very different chemical signature compared with the more metal-rich stars! So does HE 0107–5240 (Christlieb et al. 2002, 2004)

This is crucial observational information for the study of the early Universe

Possible Scenarios for the Origin of the Abundance Pattern

Pre-enrichment by Pop III SN => Pop II star



Binary system with mass transfer => Pop III star

“Chemical Compositions of the Galactic Halo”

- New program to observe metal-poor stars w/ [Fe/H]<-2.0
- Northern hemisphere
- Hobby-Eberly Telescope at McDonald Observatory

- Long-term status: 50+20 hours allocated for UT07-01,
  35 hours for UT07-02

GOAL: observe ~700 stars in ~4 years

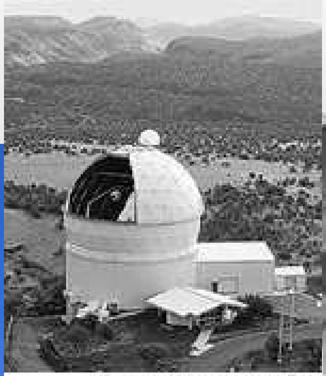
=> largest high-res database so far

The team:

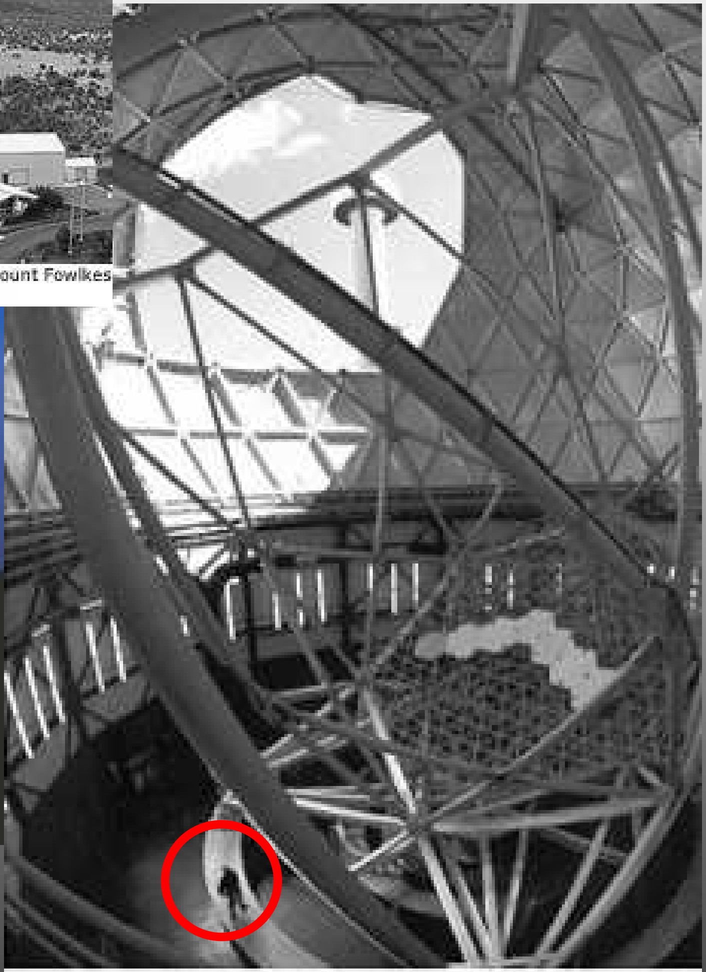
C. Allende Prieto, T. Beers, V.Bromm, J. Cowan, A. Frebel, J. Rhee, I. Roederer, C. Sneden

Hobby-Eberly-Telescope

The University of Texas at Austin -- The Pennsylvania State University -- Stanford University -- Ludwig-Maximilians-Universität München -- Georg-August-Universität Göttingen



The HET at Mount Fowlkes



A sense of scale: A man stands next to the HET

The way I observe...

I get an email in the morning:

Date: Tue, 27 Mar 2007 11:38:33 +0000(GMT)
From: Astronomer <astronomer@mcs.as.utexas.edu>
To: anna@astro.as.utexas.edu
Subject: ut...011

UT Date: 27 Mar 2007

You have data from the HET.

target numbers:
2385 2387 2398 2416 2383

...

What can we do with all those data??

- r-process rich: high Eu; s-process: high Ba, low Eu
- alpha-poor: low Ca
- C-rich stars
- [Fe/H]<-4 stars
- anything peculiar

- Statistical analyses, CEMP-frequencies, spatial distribution
- Metallicity distribution function
- More global chemical characteristics of the Galactic components

- Testing theoretical predictions

- … and more!