Bright Metal-Poor Stars from the Hamburg/ESO Survey

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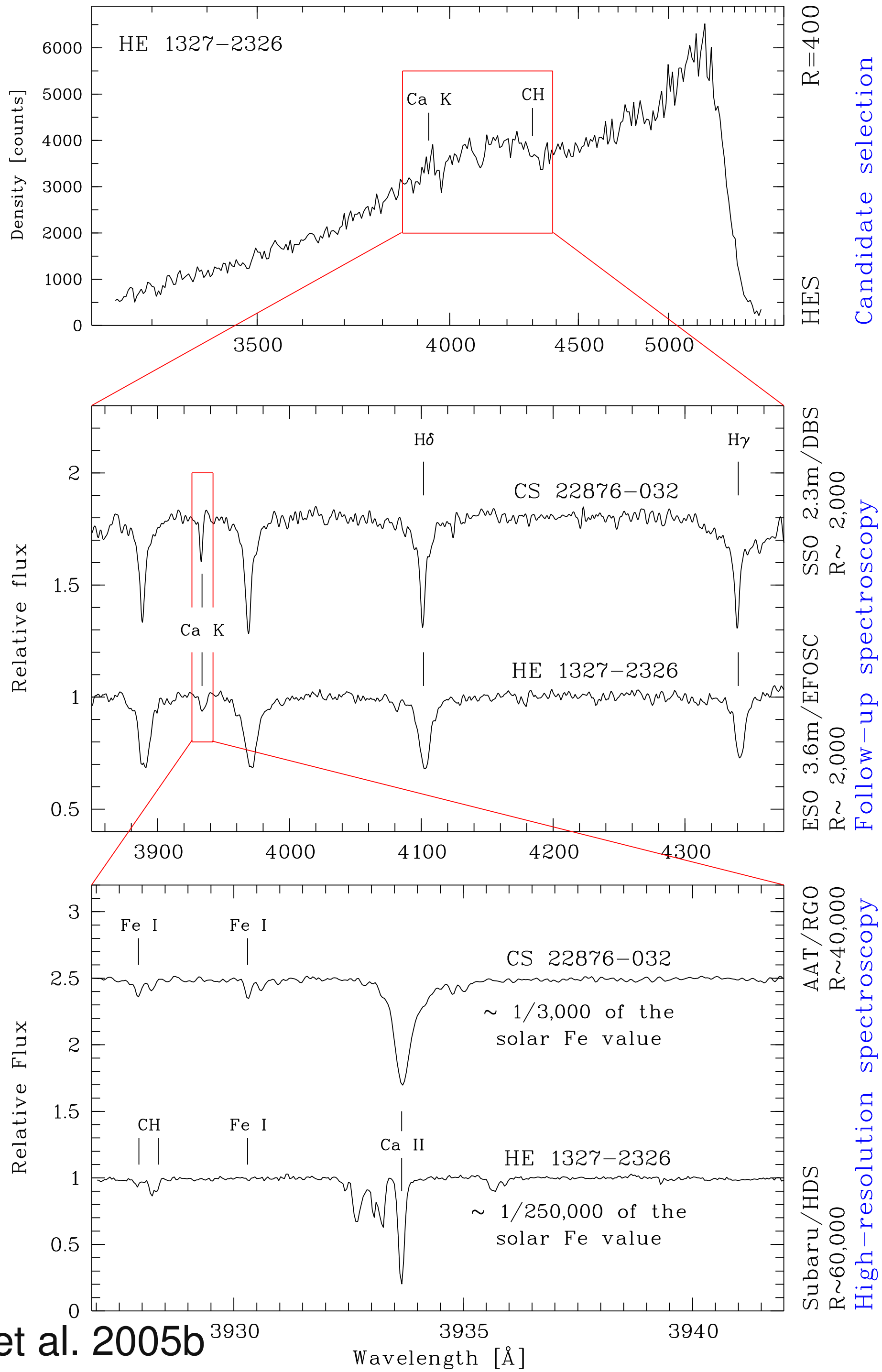
Three Observational Steps to Find Metal-Poor Stars

1. Sample selection and visual inspection:
   Find appropriate candidates

2. Follow-up spectroscopy (medium resolution):
   Derive estimate for [Fe/H] from the Ca II K line

3. High-resolution spectroscopy:
   Detailed abundances analysis



Frebel et al. 2005b

HE 1327–2326

Basic and stellar parameters:
(see Frebel et al. 05, Aoki et al. 06)

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- Magnitude: B = 14.016 mag
- Colour: $(B\text{–}V)_0$ = 0.40 mag
- Reddening: $E(B\text{–}V)$ = 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 (1D, NLTE corrected)

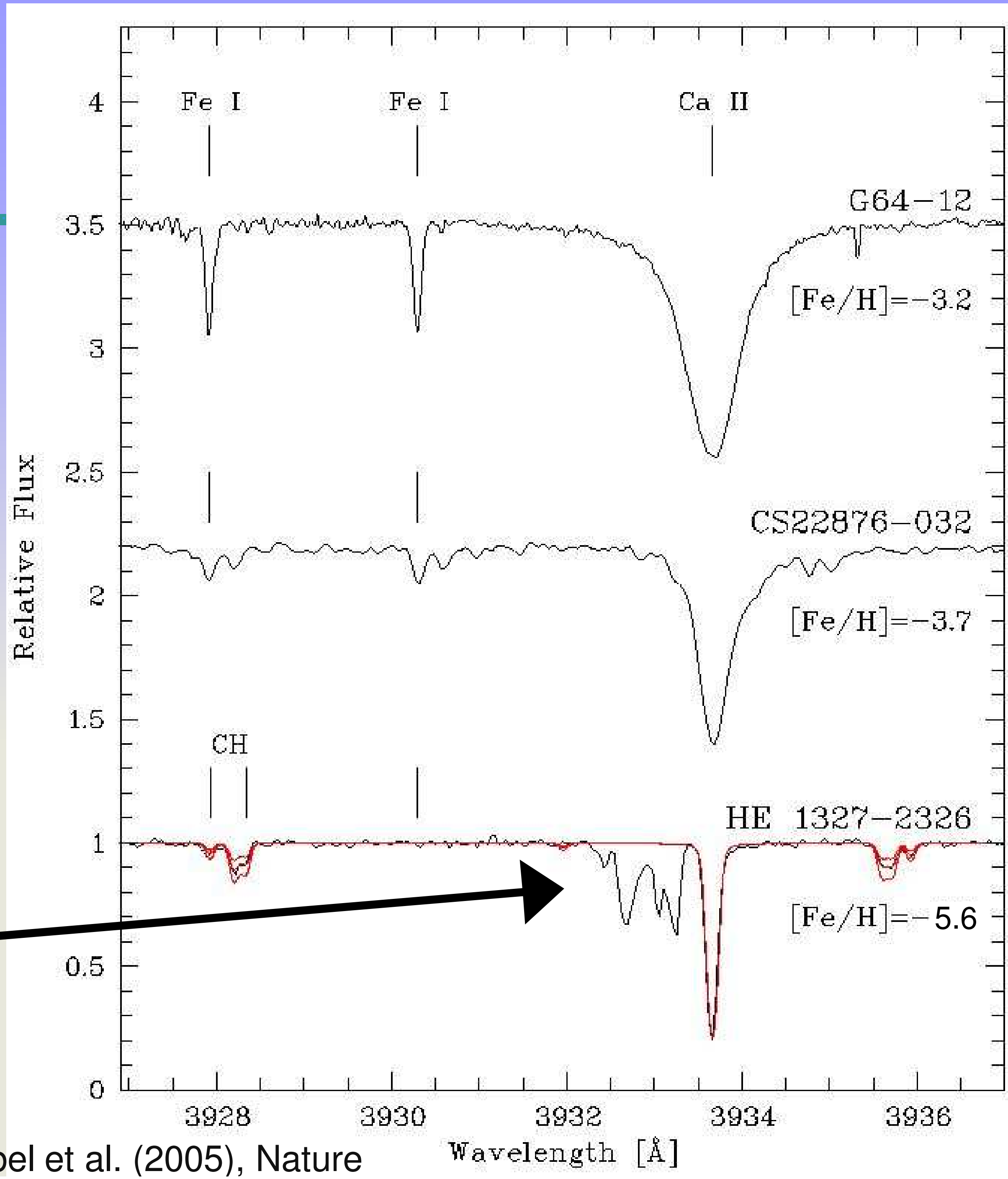
- Kinematic properties in line with "outer halo" member

Ca K line

High-resolution **Subaru/HDS** spectra (taken by W. Aoki)

Double lined spectroscopic binary

Interstellar Ca



Frebel et al. (2005), Nature

Fe I Lines

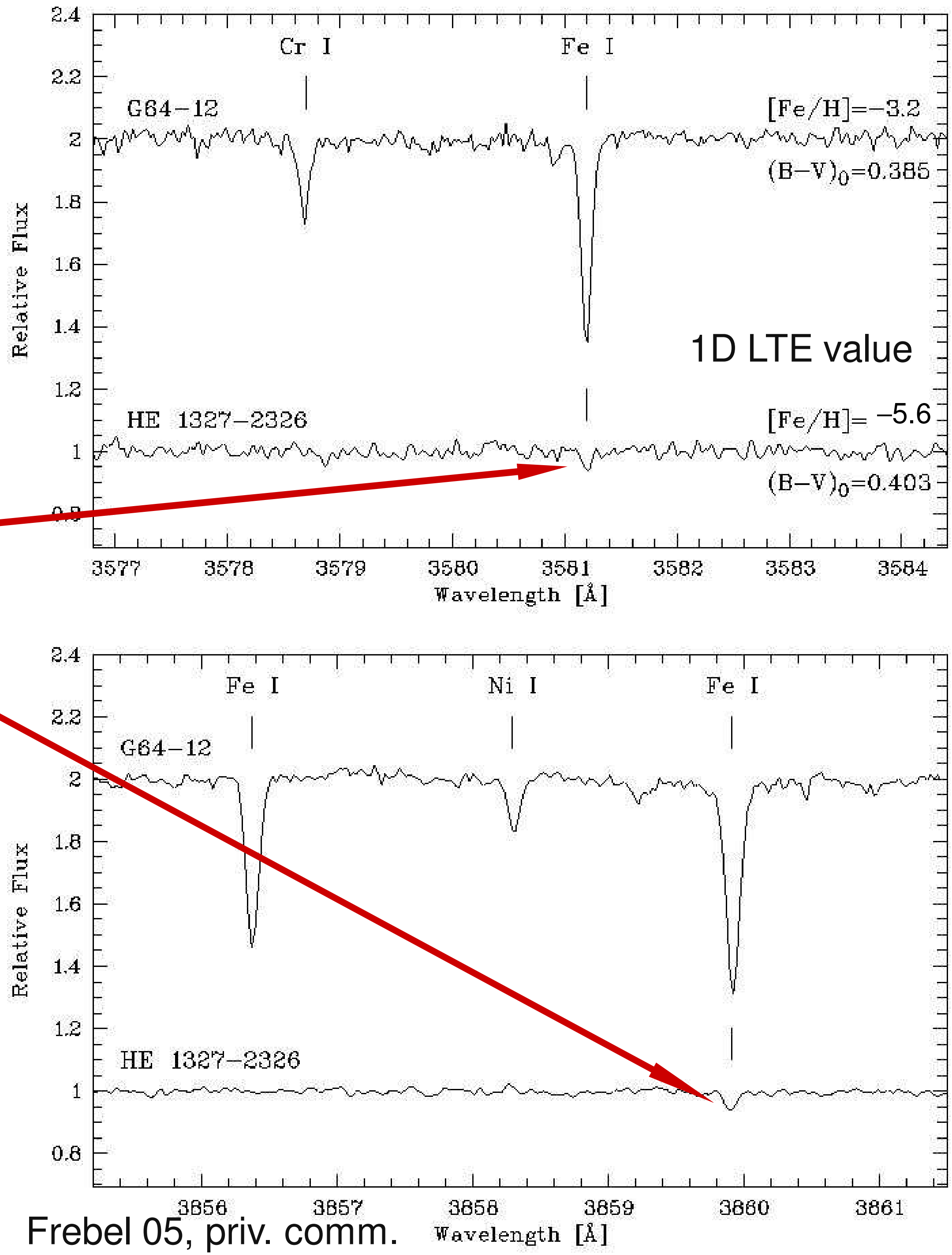
Clearly detected:

Fe I 3581: 5.9 mÅ
Fe I 3859: 6.8 mÅ

Very weak lines:

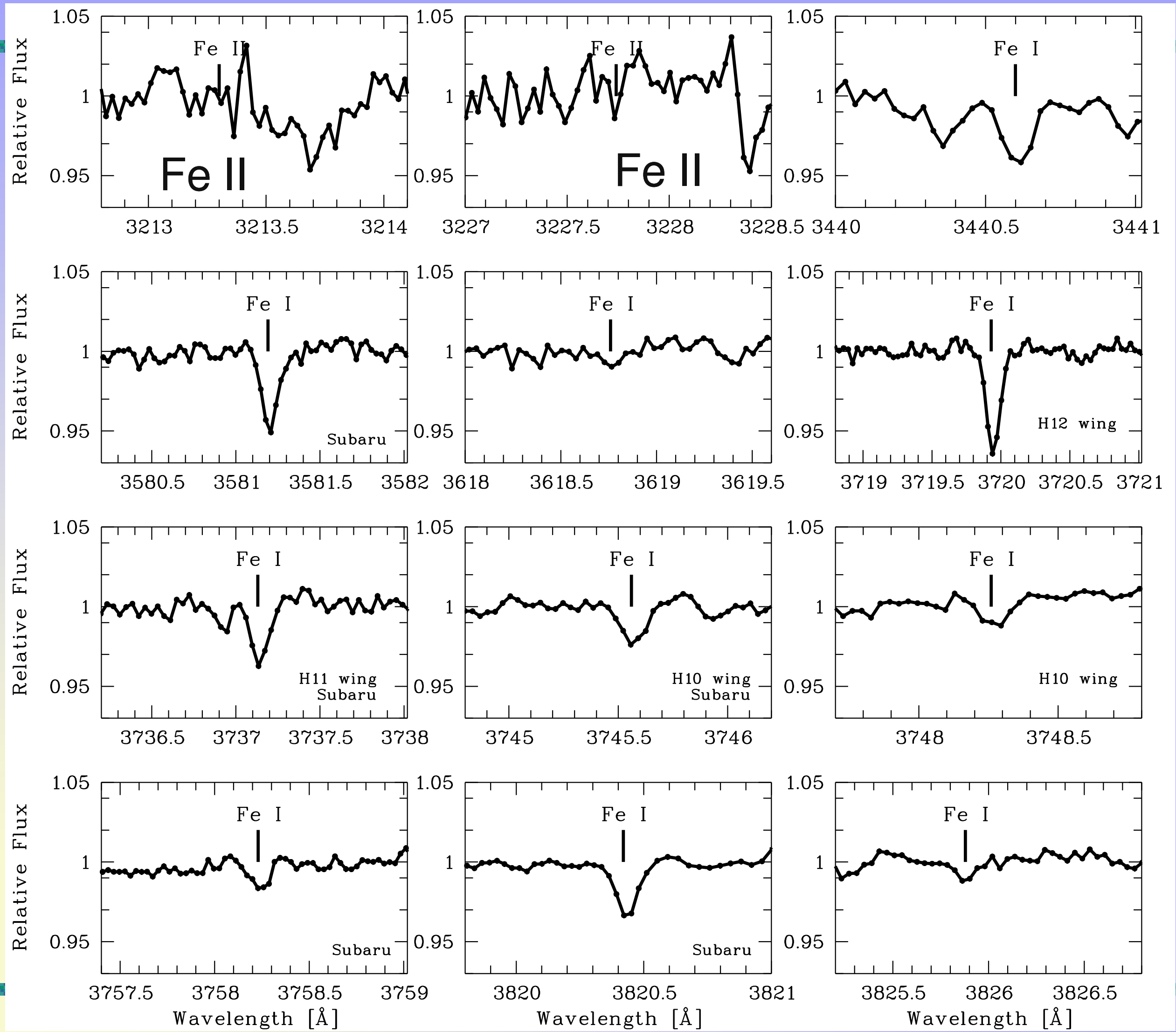
Fe I 3820: 2.5 mÅ
Fe I 4045: 1.9 mÅ

=> [Fe/H] = -5.4



Frebel 05, priv. comm.

What about Fe II lines??



Frebel & Christlieb 07, in prep.

Update on Fe abundance

Based on new VLT/UVES data (see Frebel et al. 06), we still have to live with the Fe I abundance…

From these new data, we find:

LTE values:

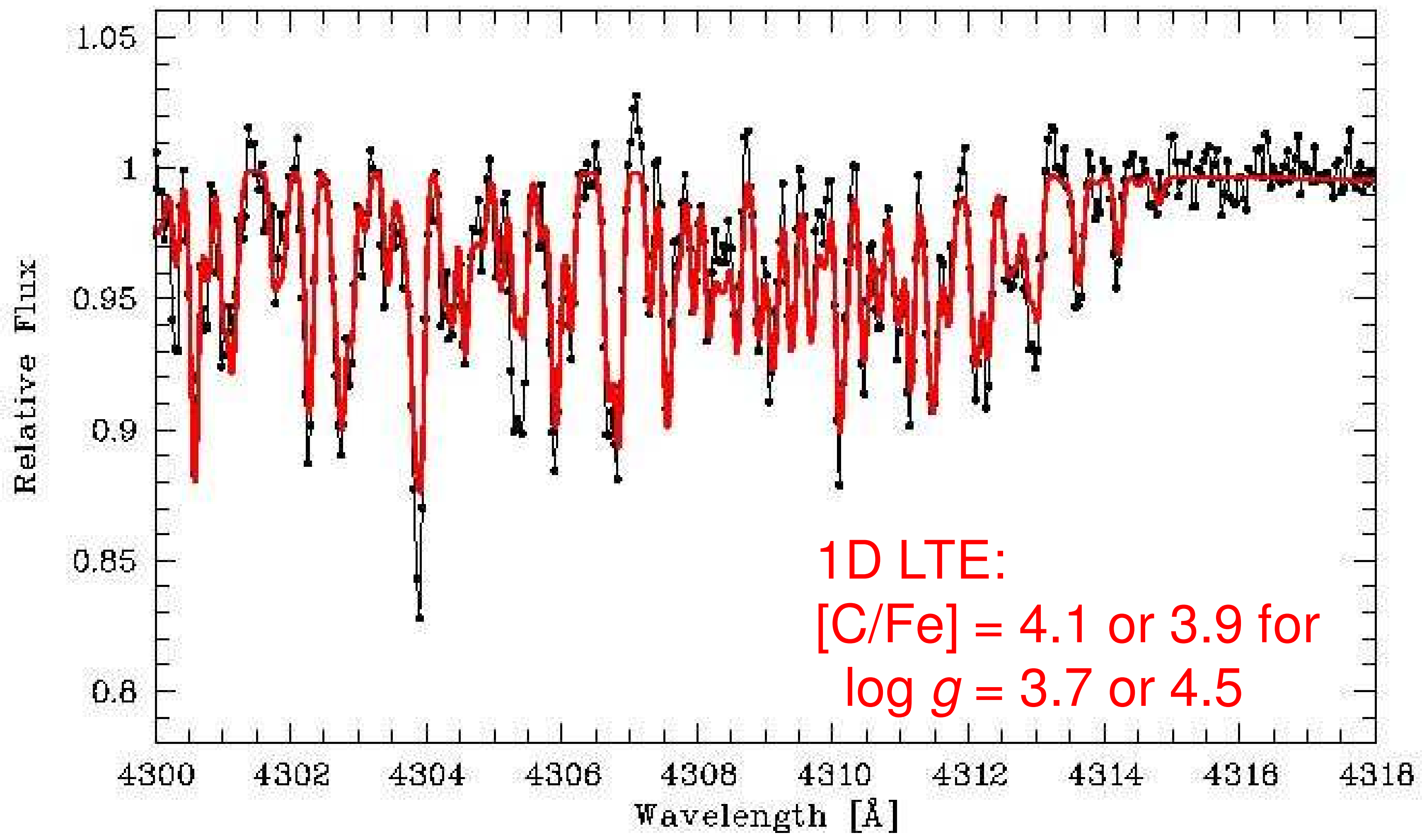
[FeI/H] = –5.7 (subgiant and dwarf)

[FeII/H] < –5.4 (subgiant)

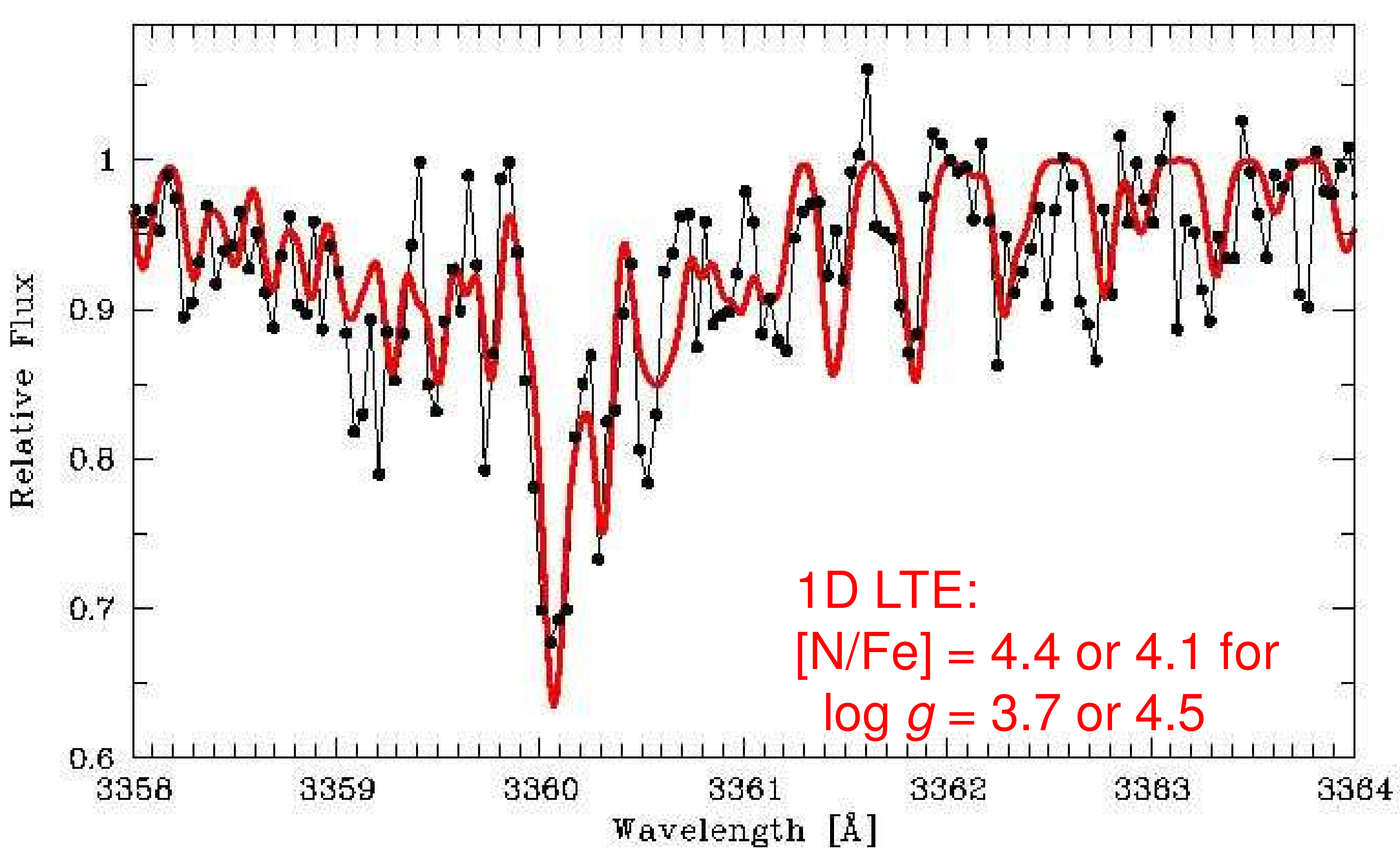
[FeII/H] < –5.2 (dwarf)

=> HE 1327-2326 certainly has [Fe/H]<-5.0 !!

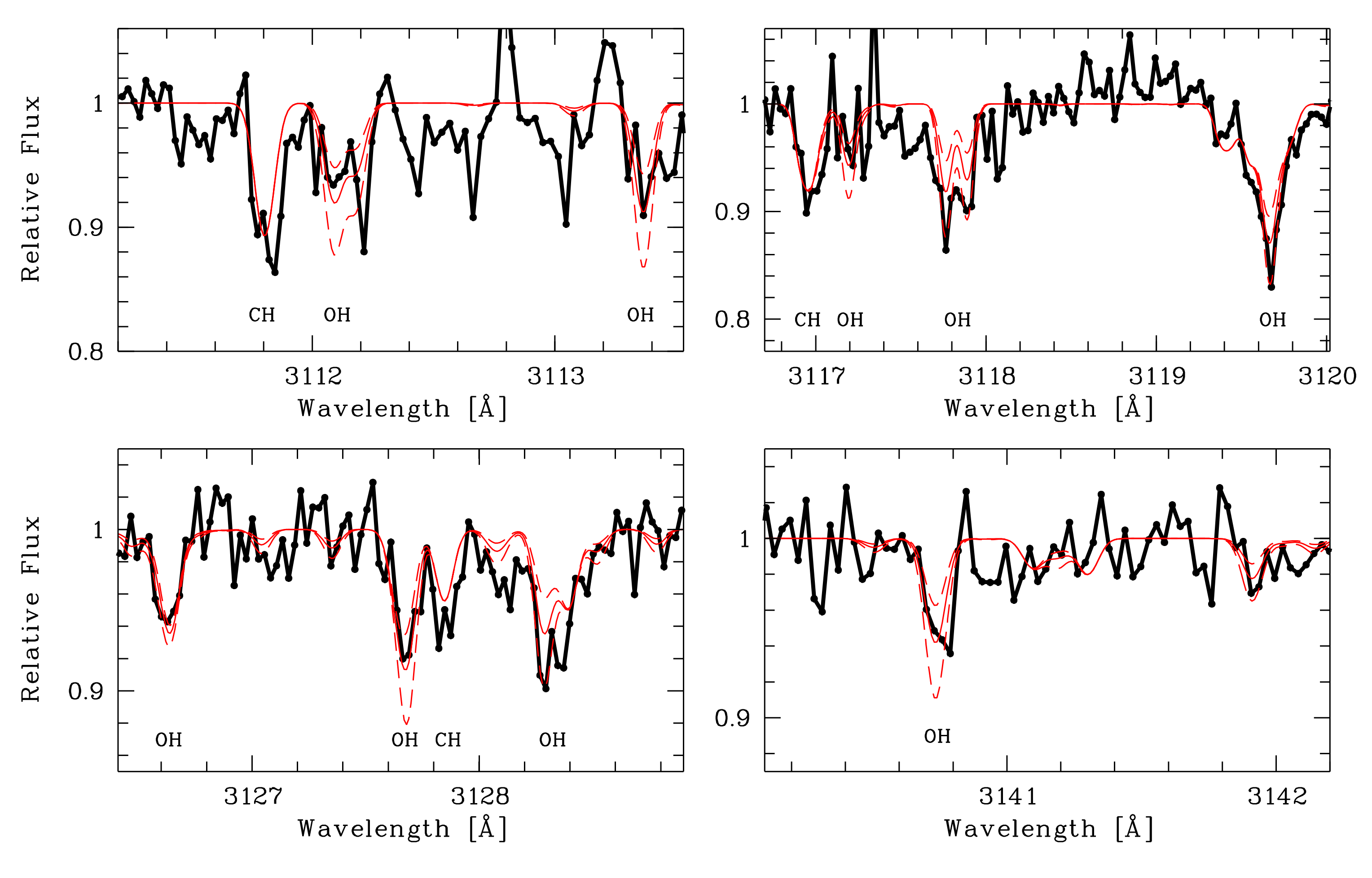
CH 4300 Bandhead



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

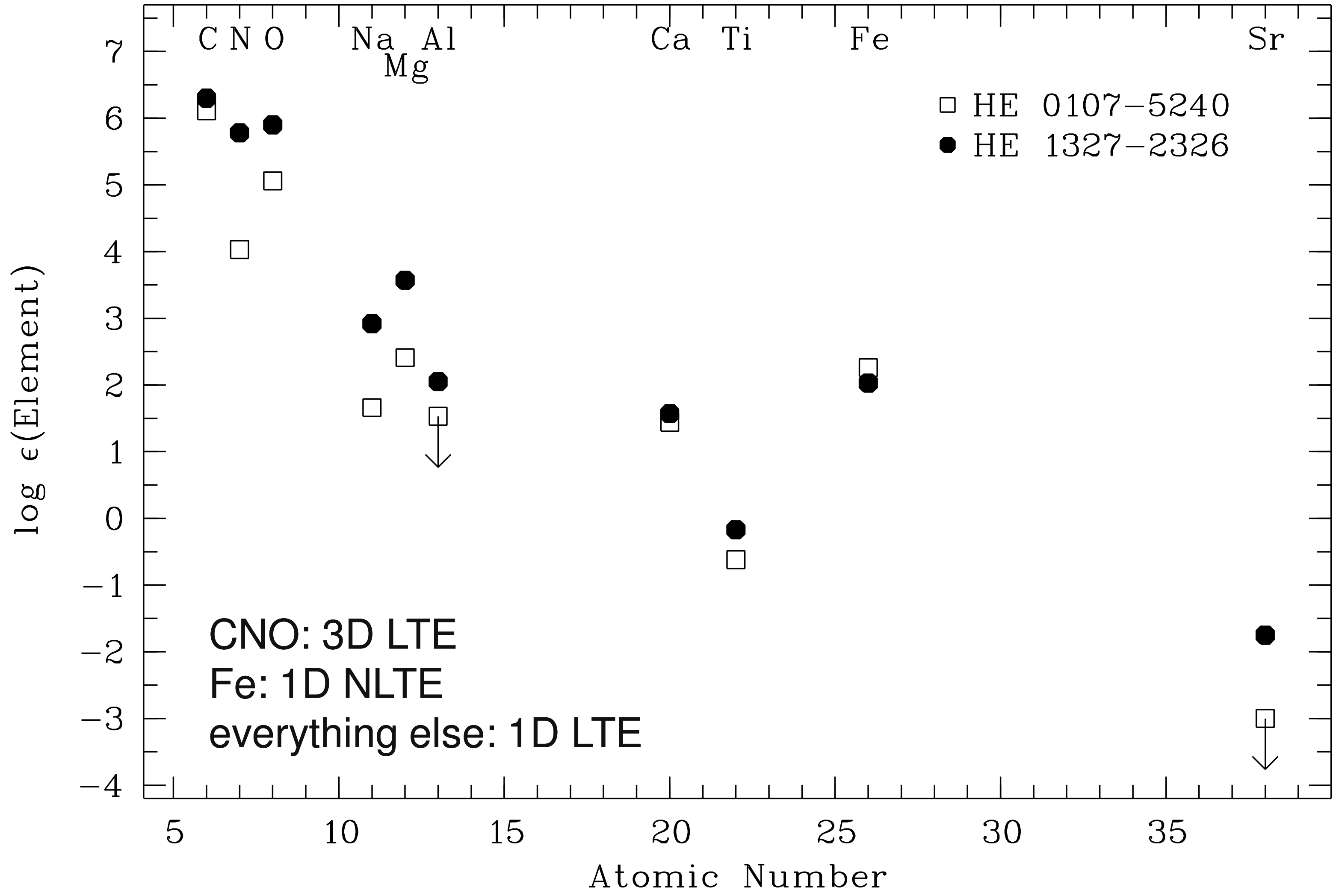
OH Features in the UV



Frebel et al. 06, ApJL

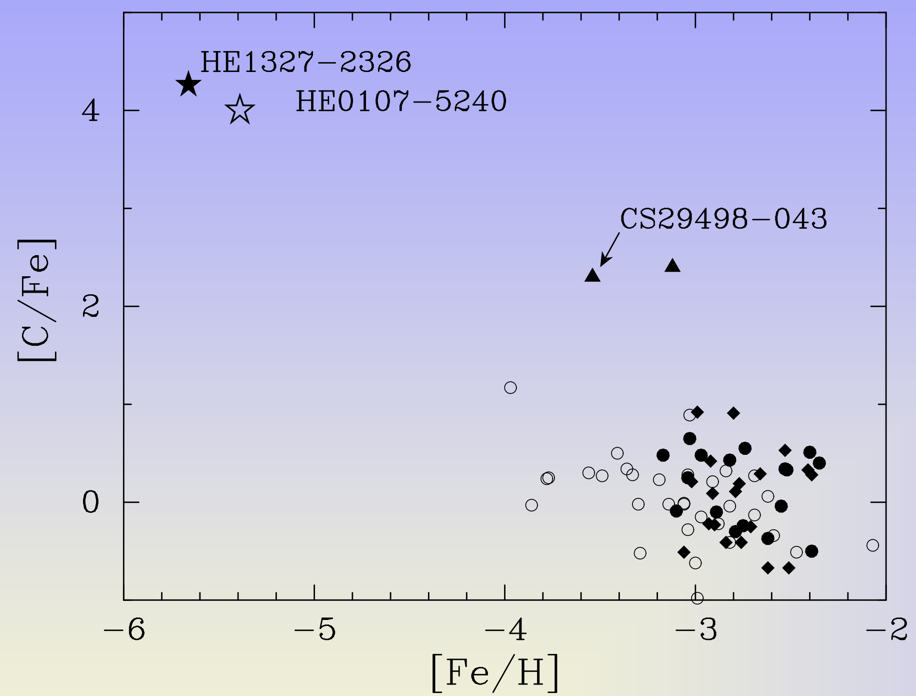
$[O/Fe]_{1DLTE}$ = 3.7 but $[O/Fe]_{3DLTE}$ = 2.8 (subgiant)

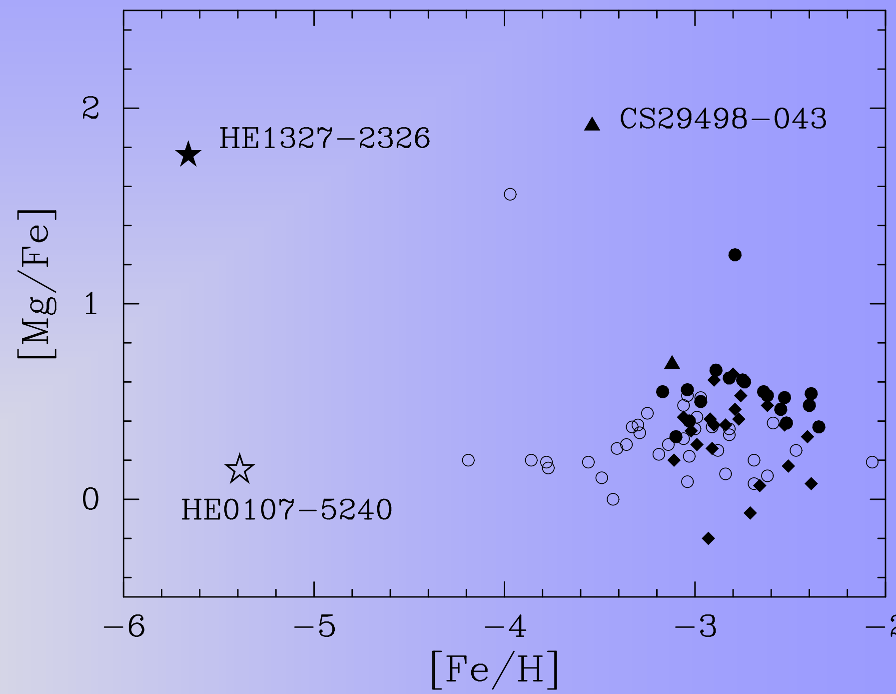
1D vs 3D log ε abundances



based on Frebel et al. 2005, Nature 434, 871 + Frebel et al. 06

What is so Special About HE 1327–2326?



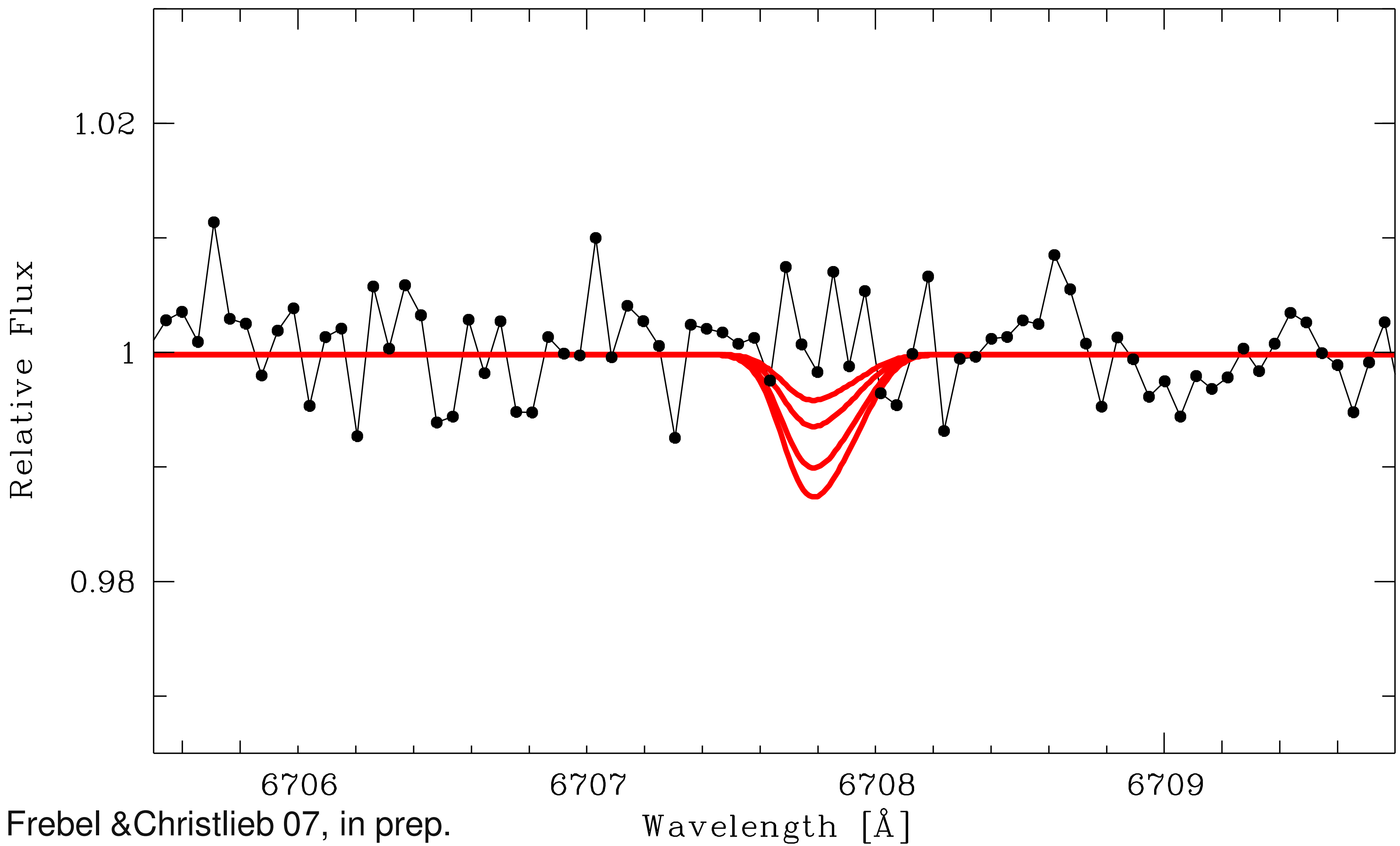


Aoki, Frebel et al. 2006

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

(New) Upper Limit on Li Abundance

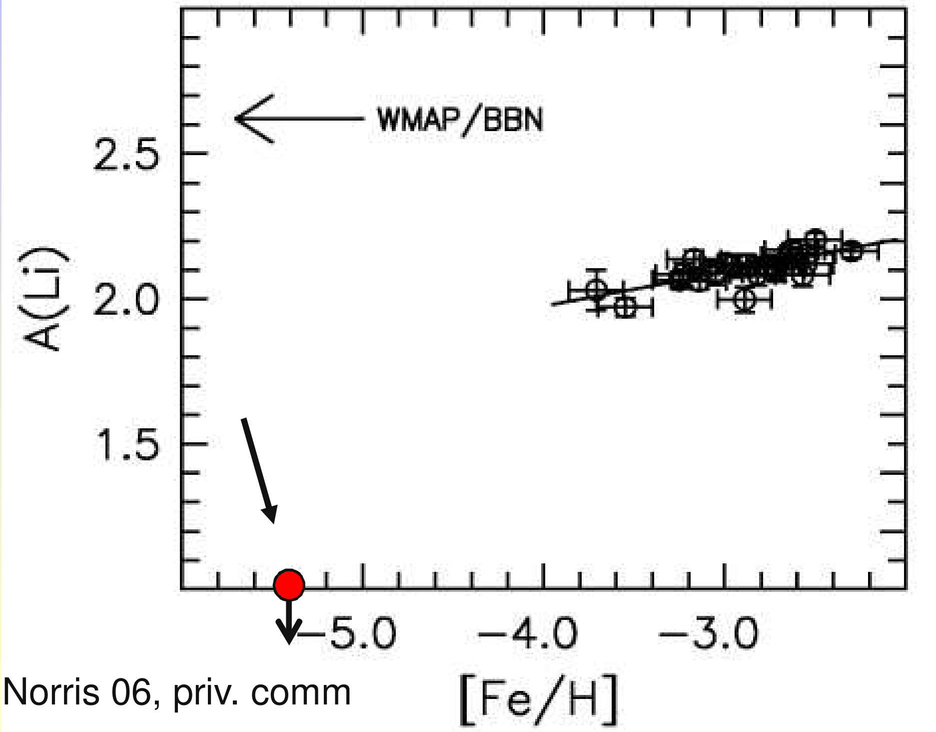


Frebel &Christlieb 07, in prep.

The Lithium Riddle

Really low Li abundance!!

...other evolved stars display Li!



Norris 06, priv. comm

Primordial Li value:

- WMAP: log ε(Li)=2.6 (Spergel et al. 06)
- Ryan et al. value at [Fe/H]=–3.5: log ε(Li)=2.0

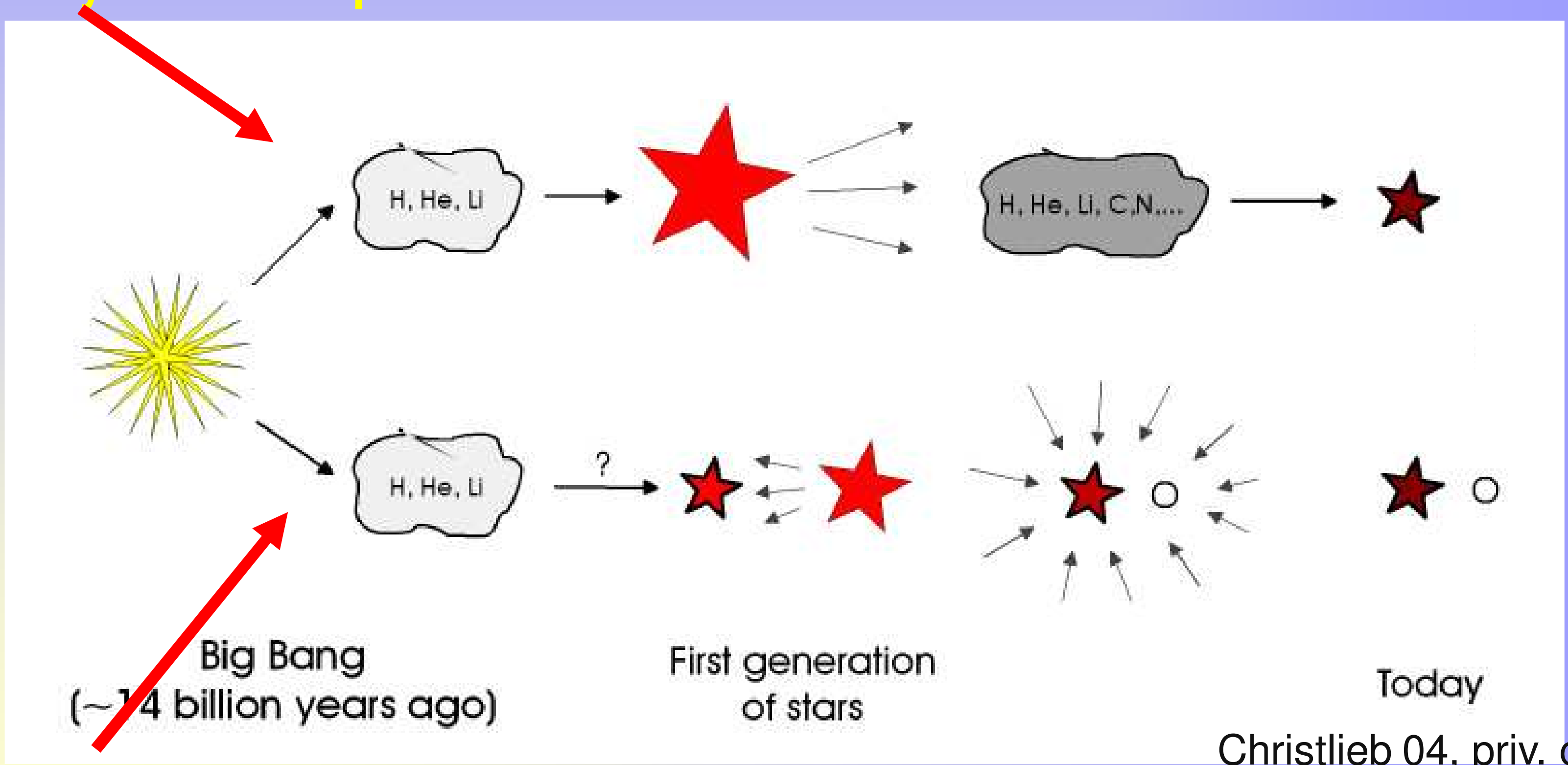
- Our current upper limit: log ε(Li)<1.0

Possible reasons for Li depletion:

- HE1327-2326 could be a fast rotator
- Accretion of Li-depleted material from binary companion

Possible Scenarios for the Origin of the Abundance Pattern

1. By faint Pop III SN (mixing and fallback)
2. By Pop III stellar wind yields => Pre-enrichment => Pop II star
3. By several Pop III SNe

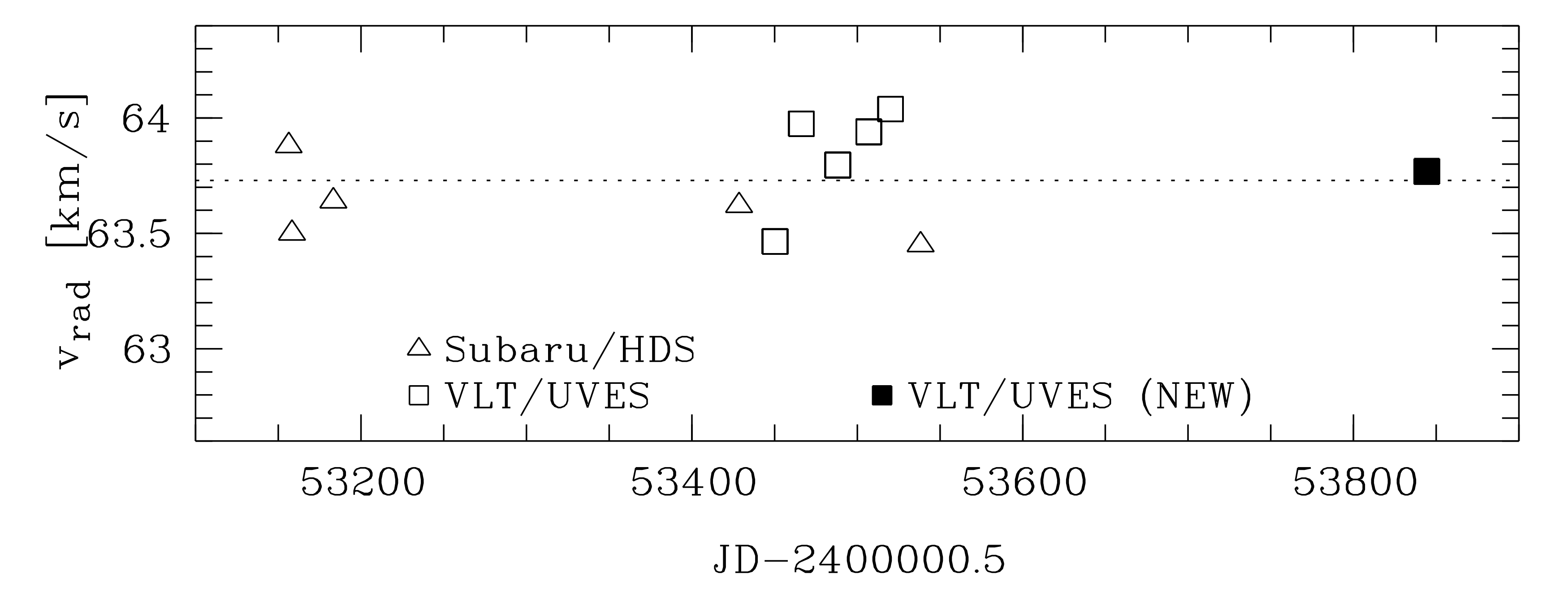


Christlieb 04, priv. comm.

4. **Binary system with mass transfer => Pop III star (unlikely...)**

Radial Velocity Variations??

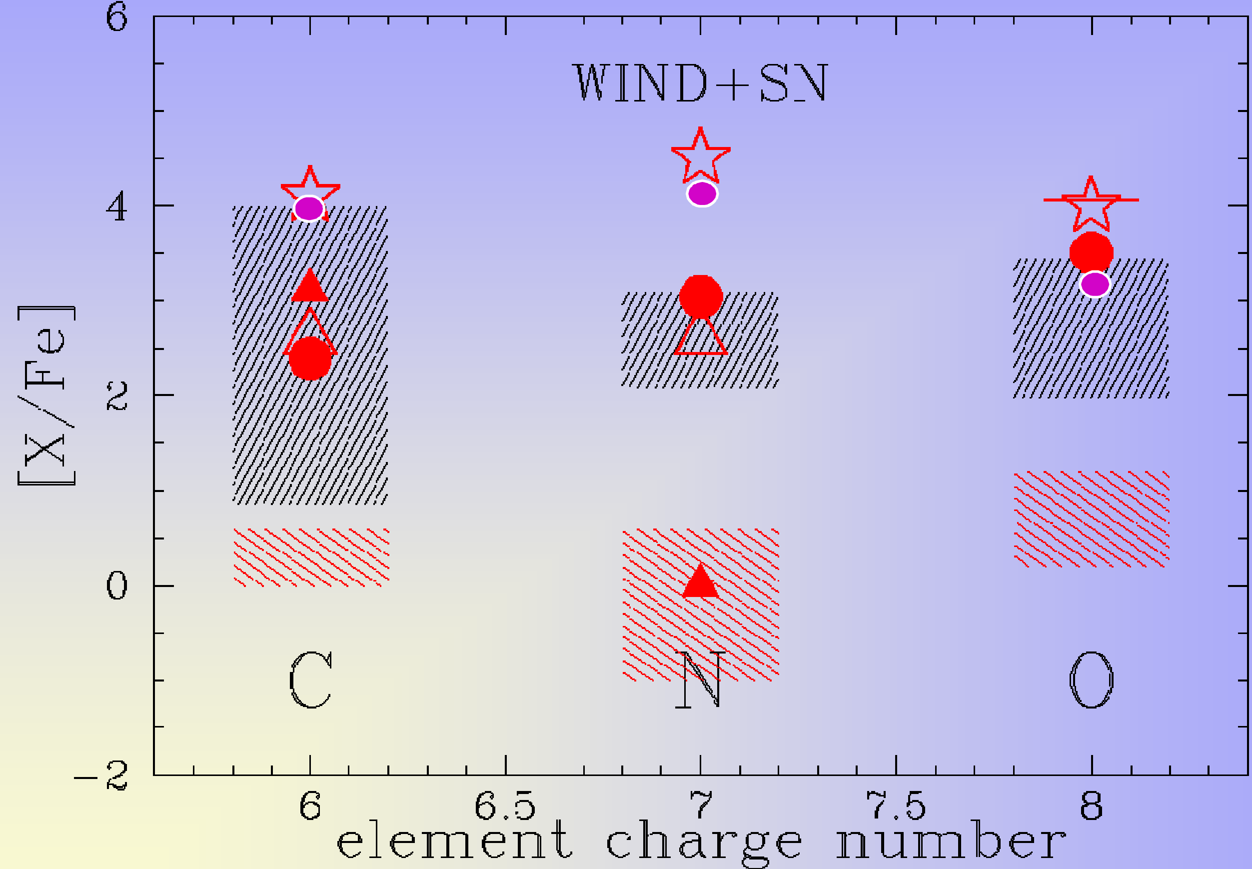
May-Jun 2004 Mar-Jul 2005 Apr 06



based on Frebel et al. 2006, 638, L117

<v> = 63.7 km/s

1. Meynet/Maeder/Hirschi et al.



Meynet et al. astro-ph/0510560

$60M_\odot$

v_{ini}=800km/s

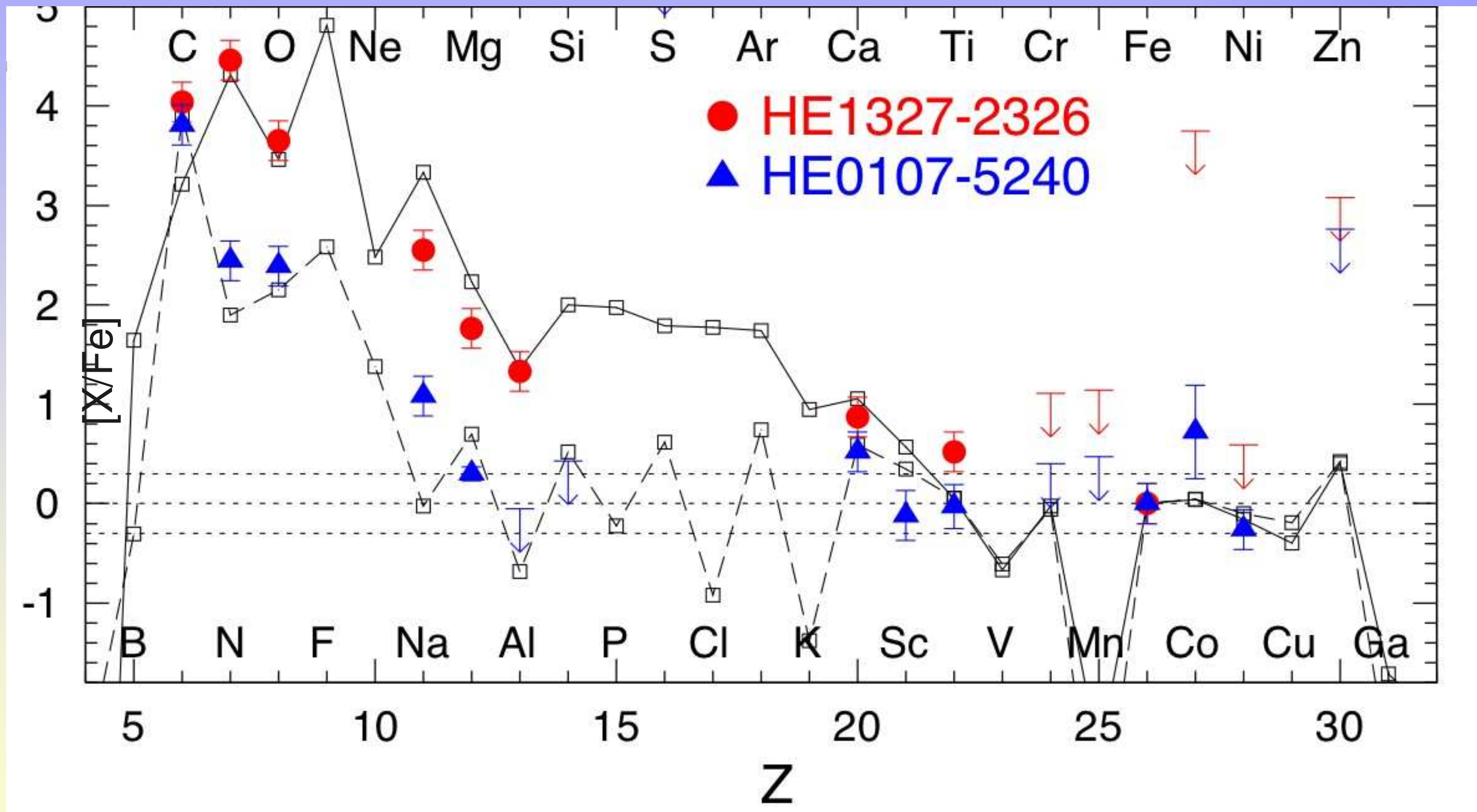
Solid circles: [Fe/H]=–6.6 with rotation

Solid triangles: [Fe/H]=–6.6 without rotation

stars: HE 1327–2326

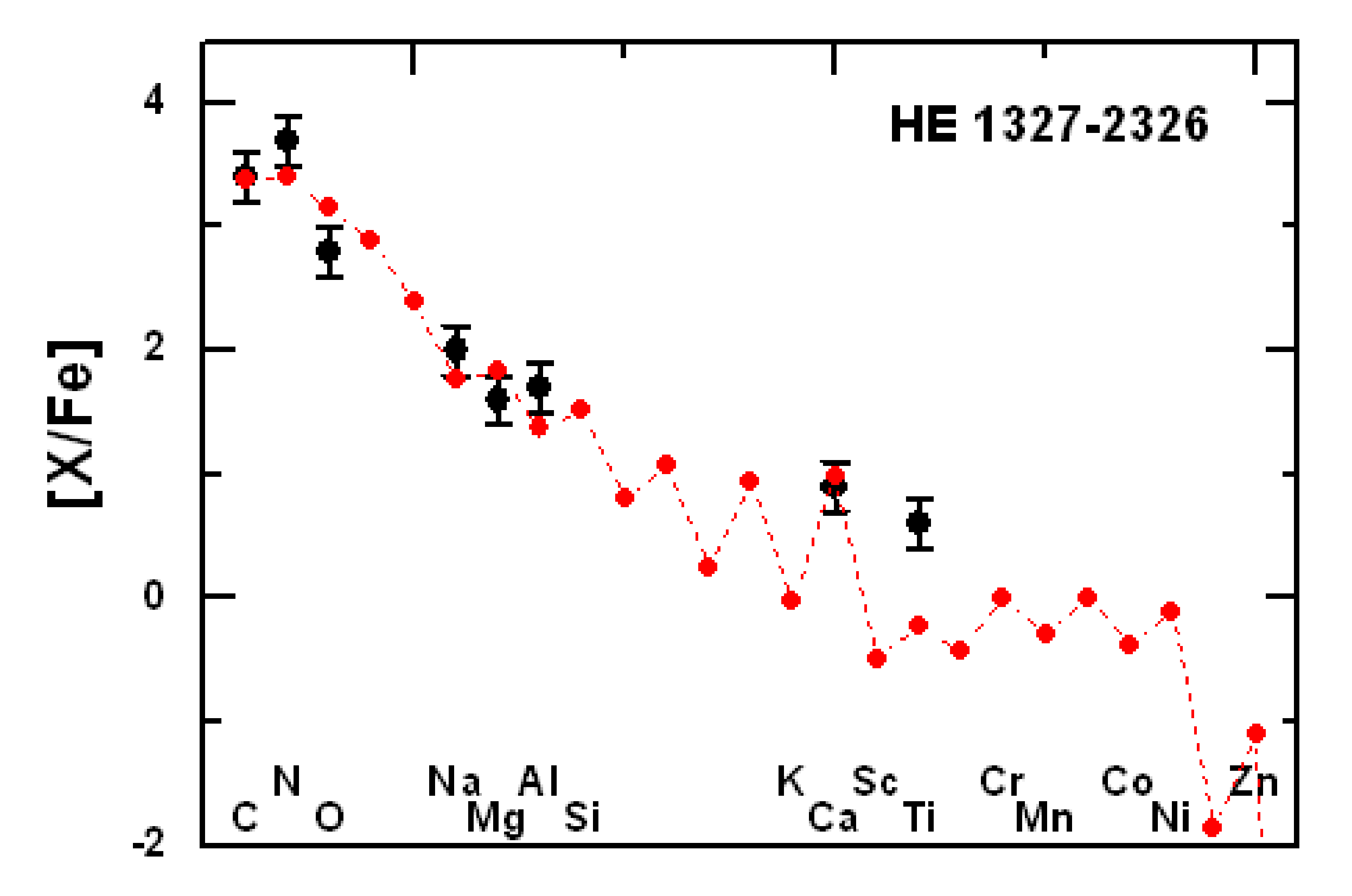
empty triangles: G77-61

2. Tominaga/Iwamoto/ Umeda/Nomoto et al.



Tominaga et al. 2007

3. Chieffi & Limongi



Chieffi & Linomgi, priv. comm.

HE 1523–0901

Basic and stellar parameters:

(see Frebel et al. 07)

- Magnitude: B = 12.1 mag
- Colour: $(B\text{–}V)_0 = 0.70$ mag
- Reddening: $E(B\text{–}V) = 0.02$

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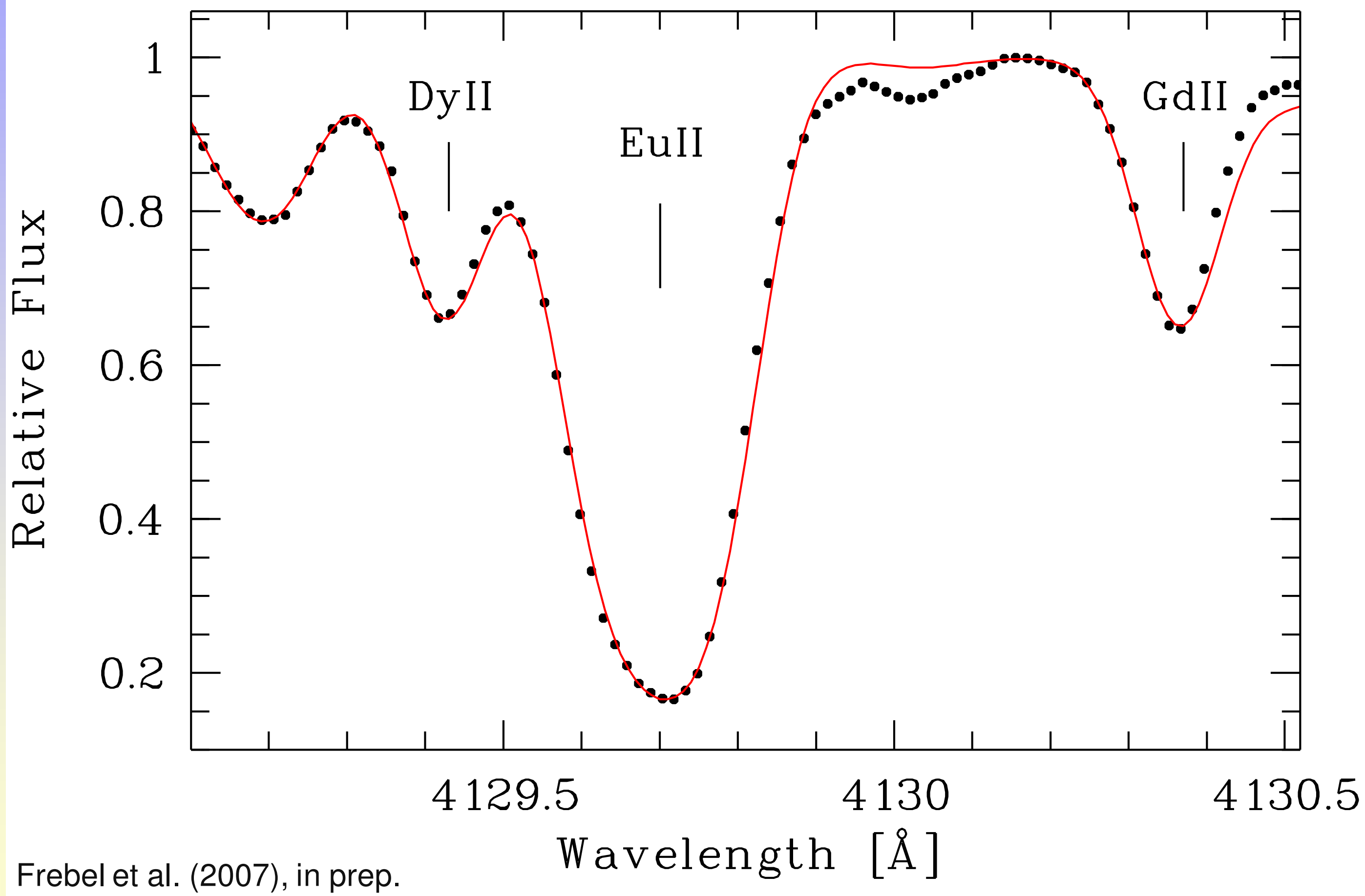
- *BVRIJHK* photometry:
  $T_{eff} = 4630 \pm 70$K (on Alonso et al. 1996 scale)
- Surface gravity: log g = 1.0 (ionisation equilibrium)
  => red giant
- Metallicity: [Fe/H] = –3.0

Abundances of HE 1523–0901



Frebel et al. (2007), in prep.

r-Process Enhanced Stars

(rapid neutron-capture process)

- Responsible for the production of heavy elements

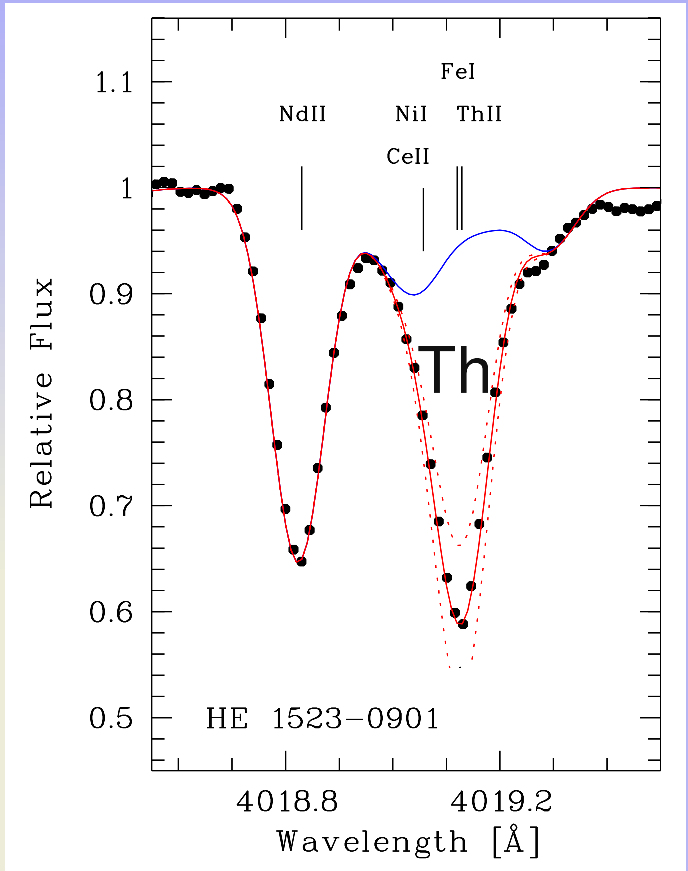
- ~5% of metal-poor stars with [Fe/H] < – 2.5 (Barklem et al. 2005)
  => Only ~12 stars known so far with [r/Fe] > 1.0

- Chemical "fingerprint" of previous nucleosynthesis event

- Possible production sites:
  SN type II, neutrino-driven winds

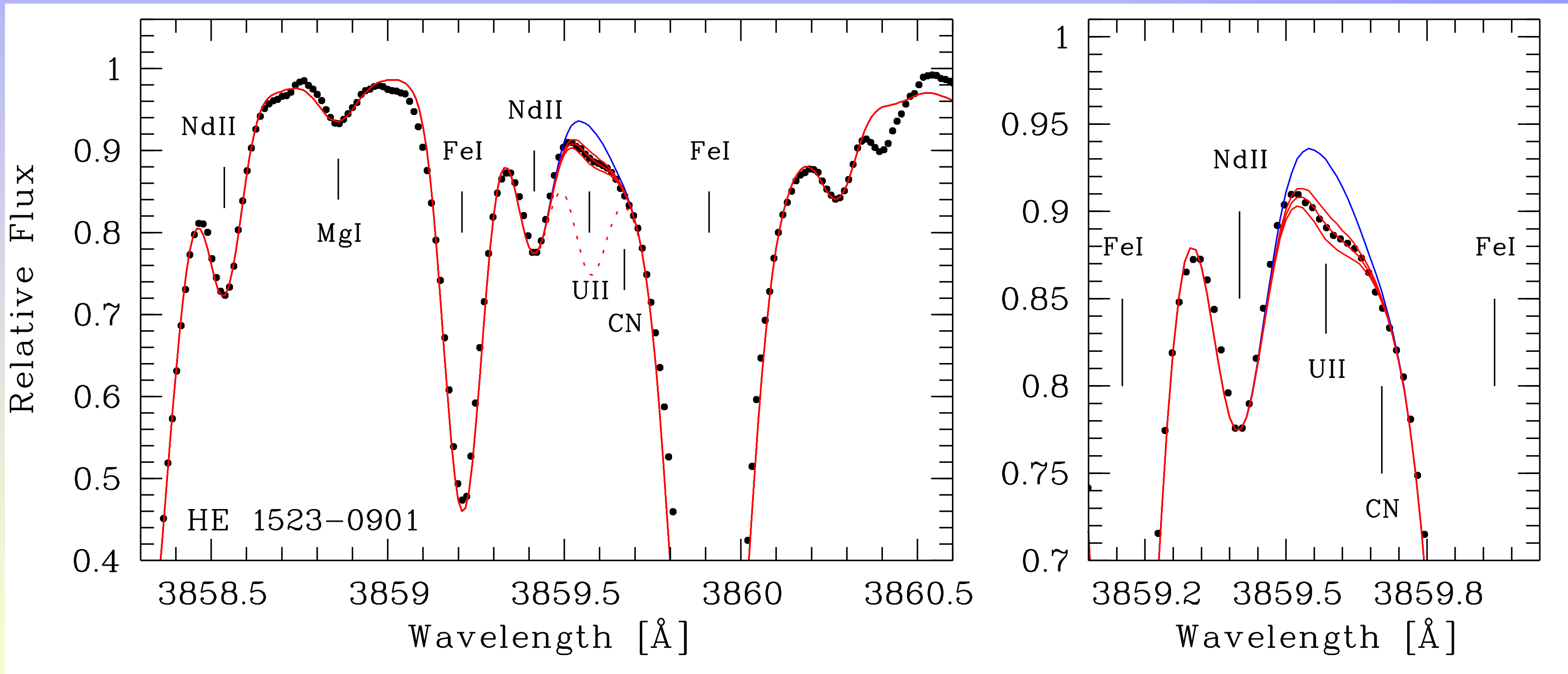
- Nucleo-chronometry:
  w/ Th, U and stable r-process elements (e.g. Eu, Os, Ir)

Th II Line 4019Å



Frebel et al. (2007), in prep.

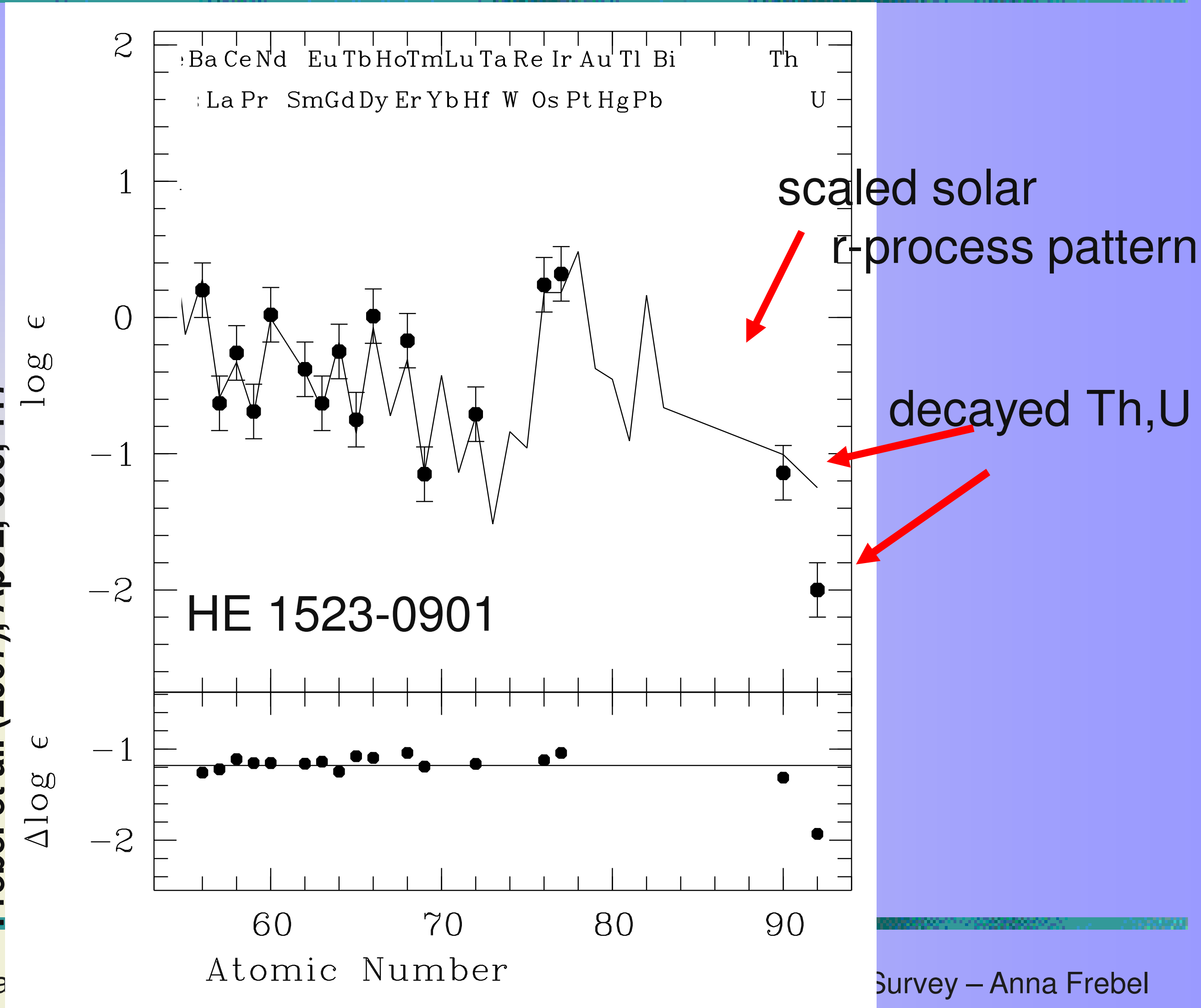
U II at 3859Å



Frebel et al. (2007), ApJL, 660, 117

The r-Process Pattern

Very good agreement with scaled solar r-process pattern for Z>56



Frebel et al. (2007), ApJL, 660, 117

What Chronometers have been used so far?

Age estimates can be obtained from a comparison of an observed abundance ratio of a radioactive element (such as Th, U) to a stable r-process element (such as Eu, Os, Ir) and a theoretically derived initial production ratio.

Th/Eu: "most commonly" used chronometer

– Th is "relatively easy" measurable in r-process stars
– "famous" example: CS22892-052: 14-15Gyr; Sneden et al. 96,03

U/Th: Uranium so far *only confidently measured in one star*

-- CS31082-001: U/Th: ~14Gyr (Cayrel et al. 01, Hill et al. 02);
– one known with tentative, one with detection (Hill et al. 2007, in prep.)

⇒Ultimate goal: Use as many chronometers as possible (+ beat down any errors...)!

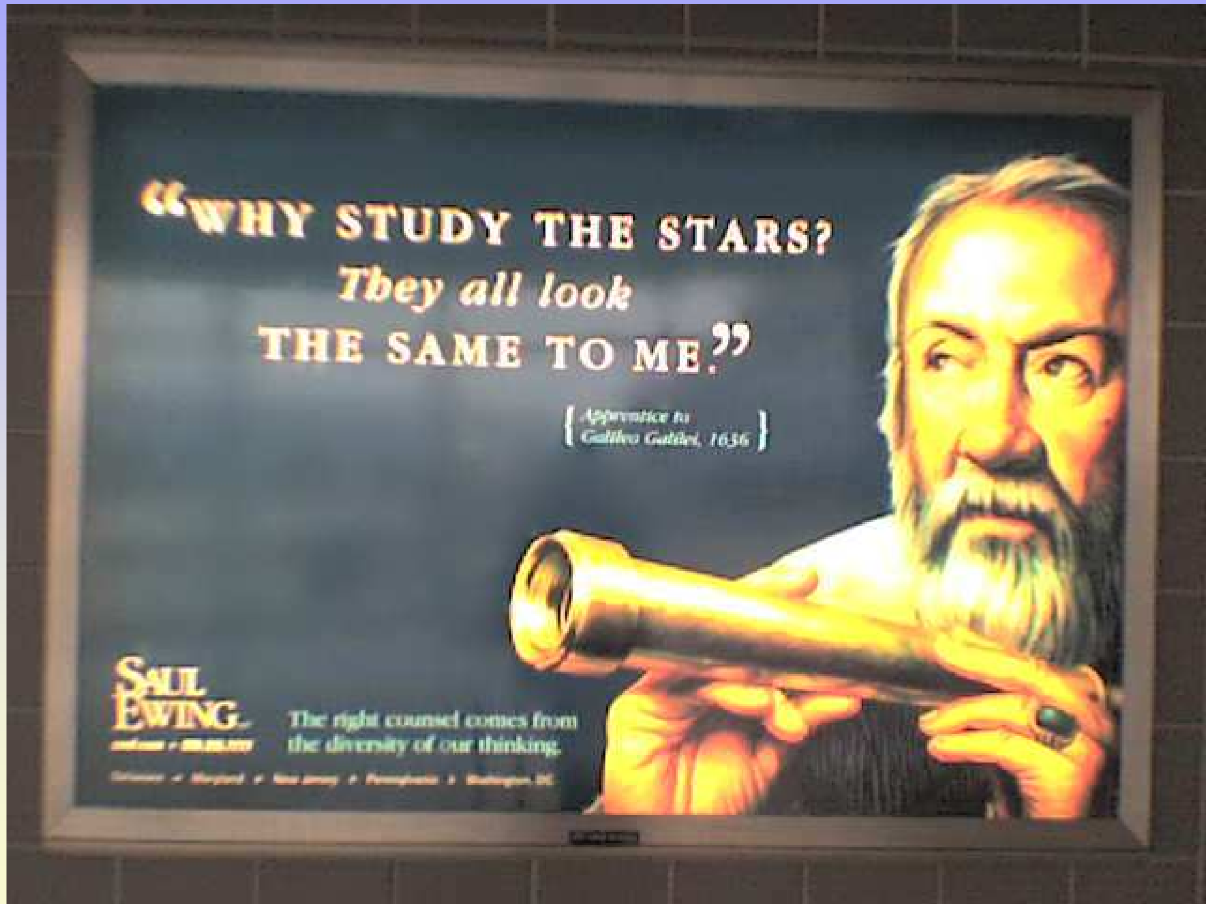
The Age of HE 1523–0901

Ratio	Age	$\sigma_{obs/Teff/log\ g/vmicr/PR}$
Th/Eu	11.5	3.3/3.4/0.6/0.6/5.6
Th/Os	10.7	3.3/2.8/5.6/0.0/5.6
Th/Ir	15.0	3.3/2.0/2.9/1.5/5.6
U/Eu	13.2	1.9/0.6/0.4/0.2/1.6
U/Os	12.9	1.9/0.6/1.2/0.3/1.6
U/Ir	14.1	1.9/0.3/0.3/0.8/1.6
U/Th	13.0	2.9/0.4/0.9/0.4/2.2
average	**13.2 Gyr**	

Age:

Frebel et al. (2007), ApJL, 660, 117

Words of wisdom...



Chicago Airport, some advertisement...

That’s why :-)

- Bright HES stars with [Fe/H] < –2.5 are currently being observed with high-resolution to reveal further astrophysically interesting objects.
- The survey discovered HE 1327–2326 which is the new record holder for the most iron-poor star known ($[FeI/H]_{NLTE} = -5.4$). Several promising scenarios reproduce the abundance pattern
- HE 1523–0901: A new r-process enhanced star with a U detection. For the first time, a star’s age could (consistently) be derived from all three available chronometer pairs. The age is 13.2 Gyr.
- Outlook @ UT: A new metal-poor stars observing program with the Hobby-Eberly-Telescope “The chemical compositions of our Galactic Halo” (w/ Chris Sneden, Carlos Allende Prieto and others) w/ targets from SDSS/SEGUE, HKII & bright HES samples

References

Bright metal-poor HES stars:
Frebel et al. 2006, ApJ, 652, 1585
Frebel et al. 2005b, IAU Symp 228, astro-ph/0509658

HE 1327-2326:
Frebel et al. 2005, Nature, 434, 871
Aoki et al. 2005, ApJ, 639, 897
Frebel et al. 2006, ApJ, 638, L17
Frebel & Christlieb 2007, in preparation

HE1523-0901:
Frebel et al. 2007, ApJ, 660, L117
Frebel et al. 2007, in preparation

Other:
Barklem et al. 2005, A&A 439,129
Meynet et al. 2006, A&A 447,623
Tominaga et al. 2007, ApJ 657, L77