Nucleo-chronometry Ringberg Anna Frebel

Nucleo-chronometry of the oldest stars

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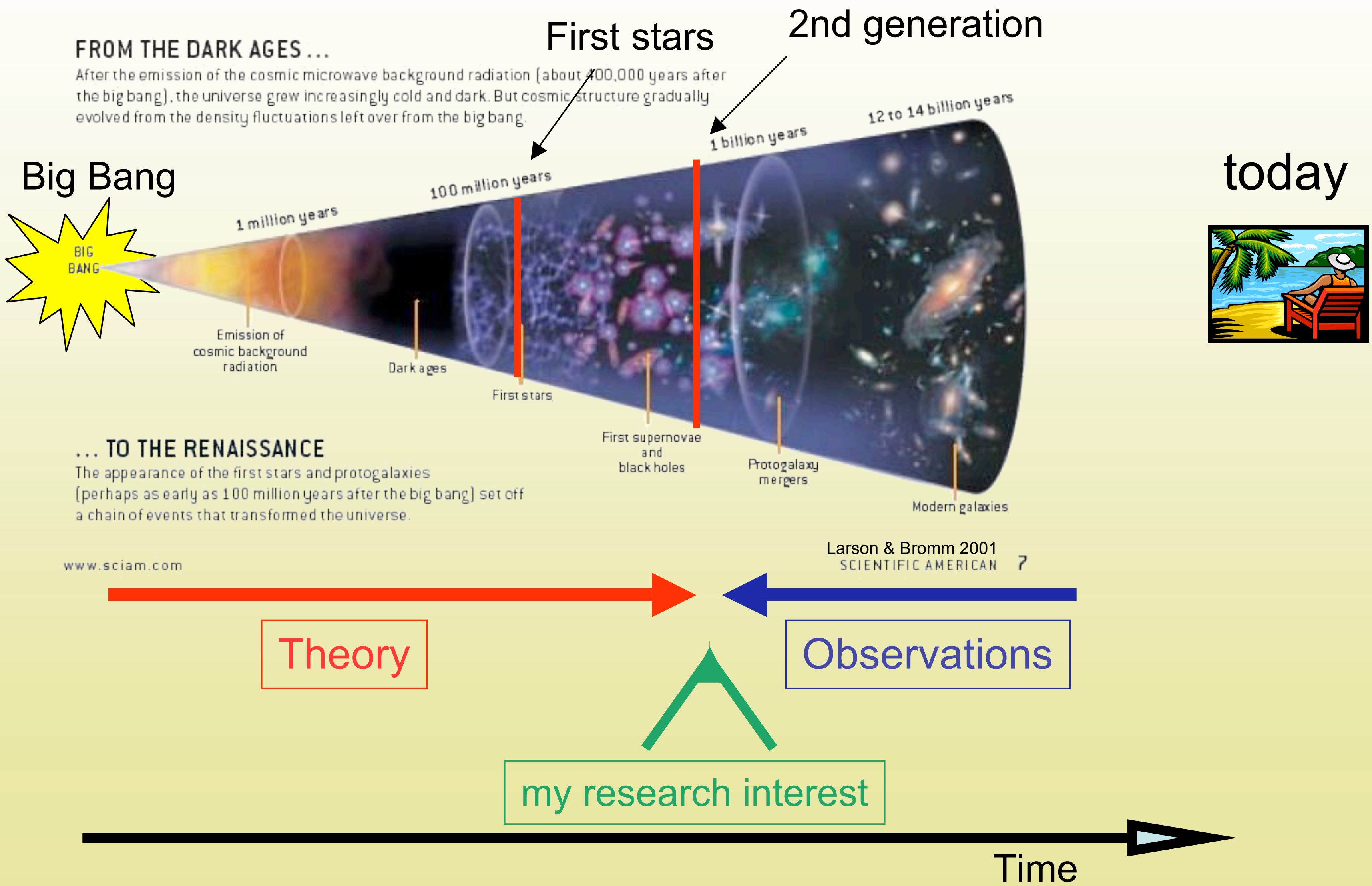
The University of Texas at Austin

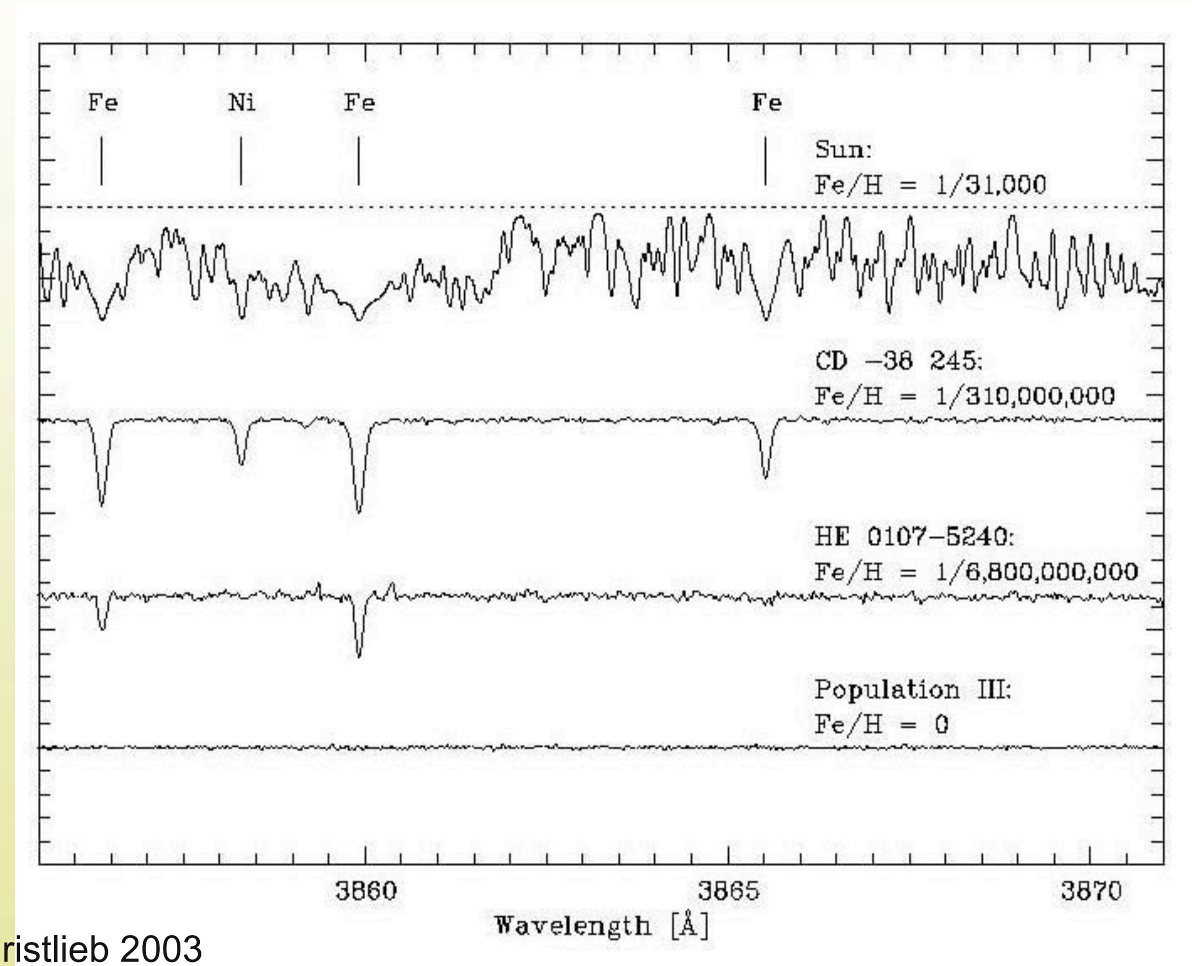
Anna Frebel   Ringberg   Nucleo-chronometry

Cosmic timeline



Spectral Comparison

"Look-back time"



Christlieb 2003

[Fe/H]=0

[Fe/H]=-4

[Fe/H]=-5.3

Pop III star
(just noise...?!?)

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

What can we learn from metal-poor stars?

$M < 1\ M_\odot$; lifetimes > 10 Gyr; turnoff stars and giants

----

Metal-poor stars are “fossils” of the early Universe
- the origin and evolution of the elements
- the involved nucleosynthesis processes

⇒ ideal tracers of the chemical evolution of their host galaxy
- ⇒ chemical history
- ⇒ dynamical history
- ⇒ galaxy formation and evolution

Near-field cosmology
- abundance patterns provide constraints on the first SN yields
  => the first stars
- easily accessible local equivalent of the high-redshift Universe

B²FH

REVIEWS OF
MODERN PHYSICS

Volume 29, Number 4 October, 1957

Synthesis of the Elements in Stars*

E. Margaret Burbidge, G. R. Burbidge, William A. Fowler, and F. Hoyle

Kellogg Radiation Laboratory, California Institute of Technology, and Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California

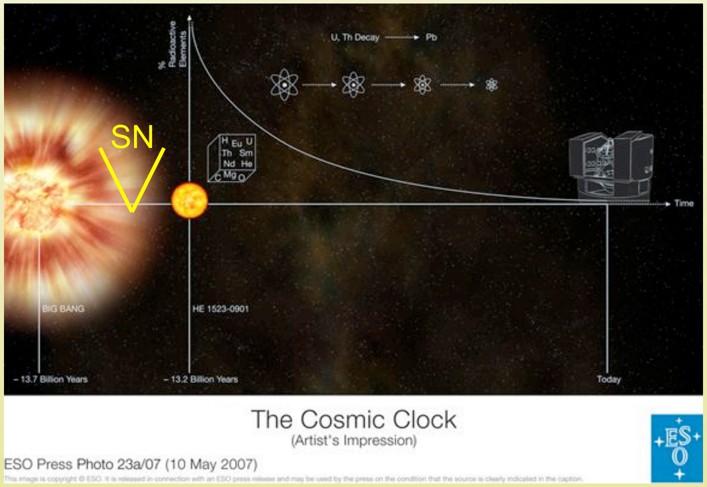
E. *r* Process

The outstanding piece of observational evidence that this takes place is given by the explanation of the light curves of supernovae of Type I as being due to the decay of Cf^{254} (Bu56, Ba56), together with some other isotopes produced in the *r* process. Further evidence can be obtained only by interpreting the spectra of Type I supernovae, a problem which has so far remained unsolved.

... there are old stars with r-process signature being discovered!

r-Process Enhanced Stars
(rapid neutron-capture process)

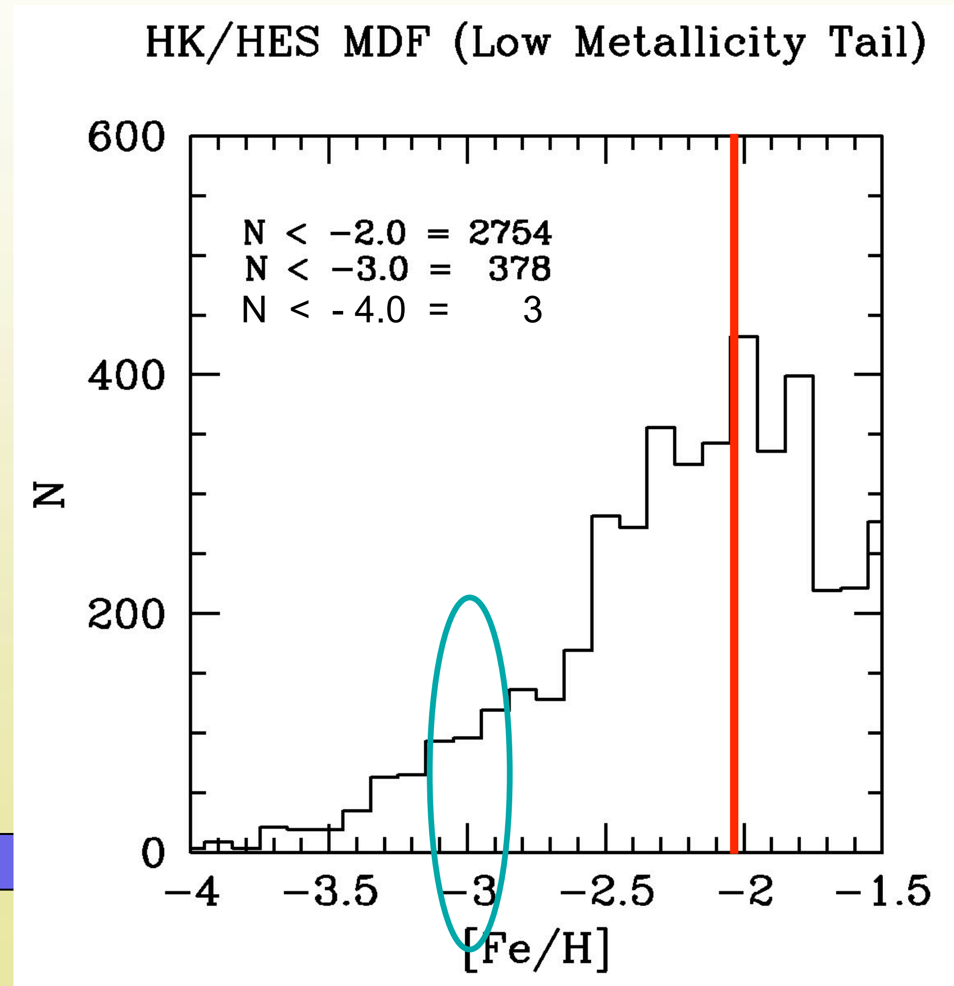
- Responsible for the production of heavy elements
- Most likely production site: SN type II => pre-enrichment
- Chemical “fingerprint” of previous nucleosynthesis event
- ~5% of metal-poor stars with [Fe/H] < – 2.5 (Barklem et al. 05) => Only ~12 stars known so far with [r/Fe] > 1.0



- **Nucleo-chronometry**: obtain stellar ages from decaying Th, U and stable r-process elements (e.g. Eu, Os, Ir)

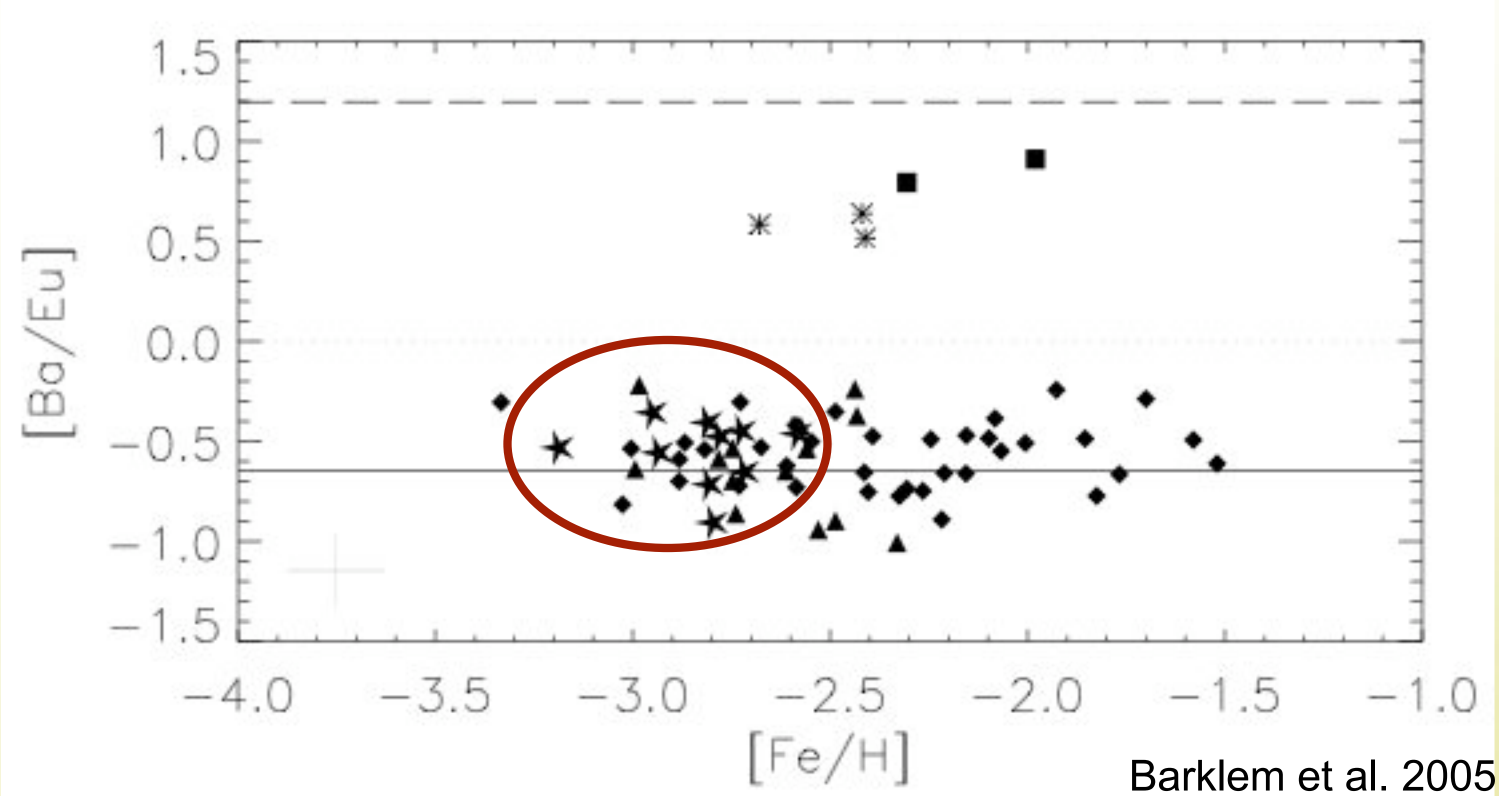
Halo Metallicity Distribution Function

Plus
HE0557-4840, [Fe/H] = -4.8
HE0107-5240, [Fe/H] = -5.3
HE1327-2326, [Fe/H] = -5.4



Beers et al. 2005

Where are r-rich stars?



Barklem et al. 2005

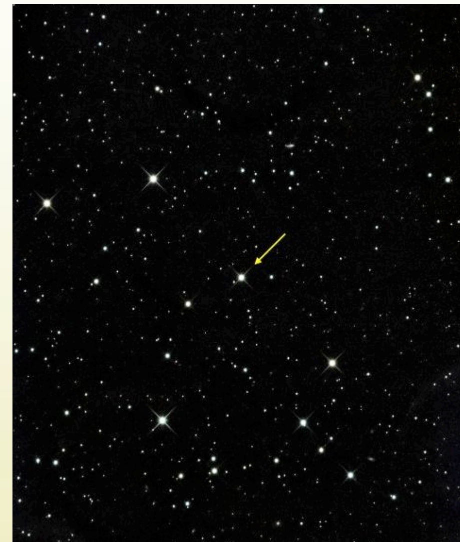
Rapid Nucleosynthesis Evidence: HE 1523-0901

Basic and stellar parameters:

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

- Effective temp.: $T_{eff} = 4630 \pm 70$K
- Surface gravity: $\log g = 1.0$ (red giant)
- Metallicity: [Fe/H] = −3.0

- Frebel et al. 2007, ApJ 660, L117
- Frebel et al. 2008, in prep.



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We made no. 5!


5 A st
unc
HE 1523–0901, an 11th-m
of the oldest stars known:
0901 formed about 500 m
Studies of the cosmic r
verse's first stars fired up a
Bang. Astronomers think
ping the scales at hundred
"The lifetime of the ve
hundred million years," sa
tory in Texas. At the ends
supernovae and seeded th
iron, so important for pla
the universe until then.
To learn about the firs
the Milky Way's oldest sta
iron. That's where HE 152
also contains the greatest
found. "Very few stars dis
"I'm looking at a rare sub
Because uranium deca
keeper. Better yet, the spe
other natural "clocks" — t
pium. "We can now use se
ments, not just one as in t
Frebel. It's this fact that m
Theorists provide a sta
these "clock" elements the
a handle on how hot and mas-
helps constrain state-of-the-art
nly now are computers getting
nulations," says Frebel. "But the
servations, and the old stars
s to the puzzle."
ar fires, the Sun's birth lay 9
take a bit of poetic license and
our galaxy? "Well," Frebel says,
n the truth."
RE, is one of the oldest stars
t lies 7,500 light-years away in
star's 13.2-billion-year age
smic clock" elements. ESO
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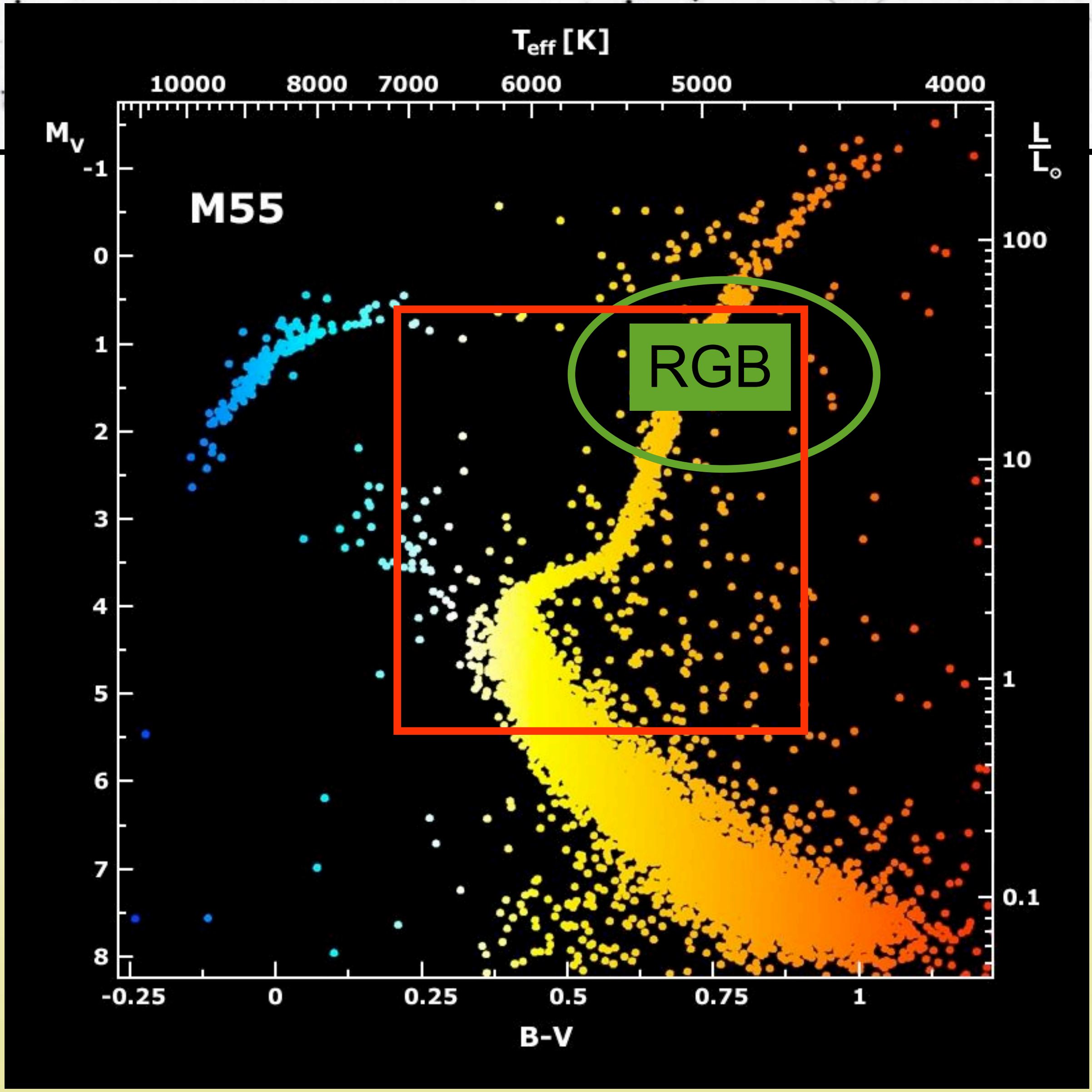
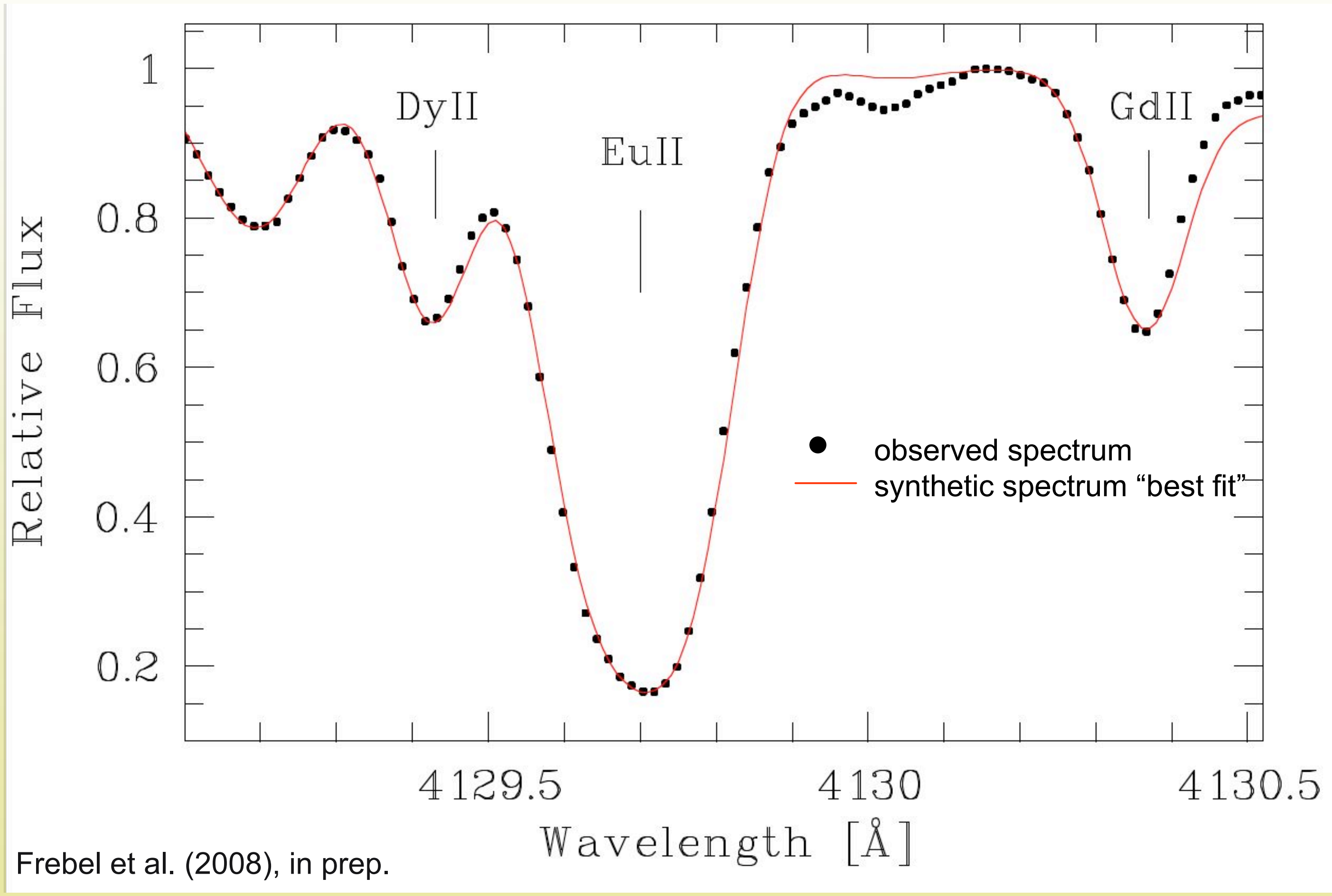
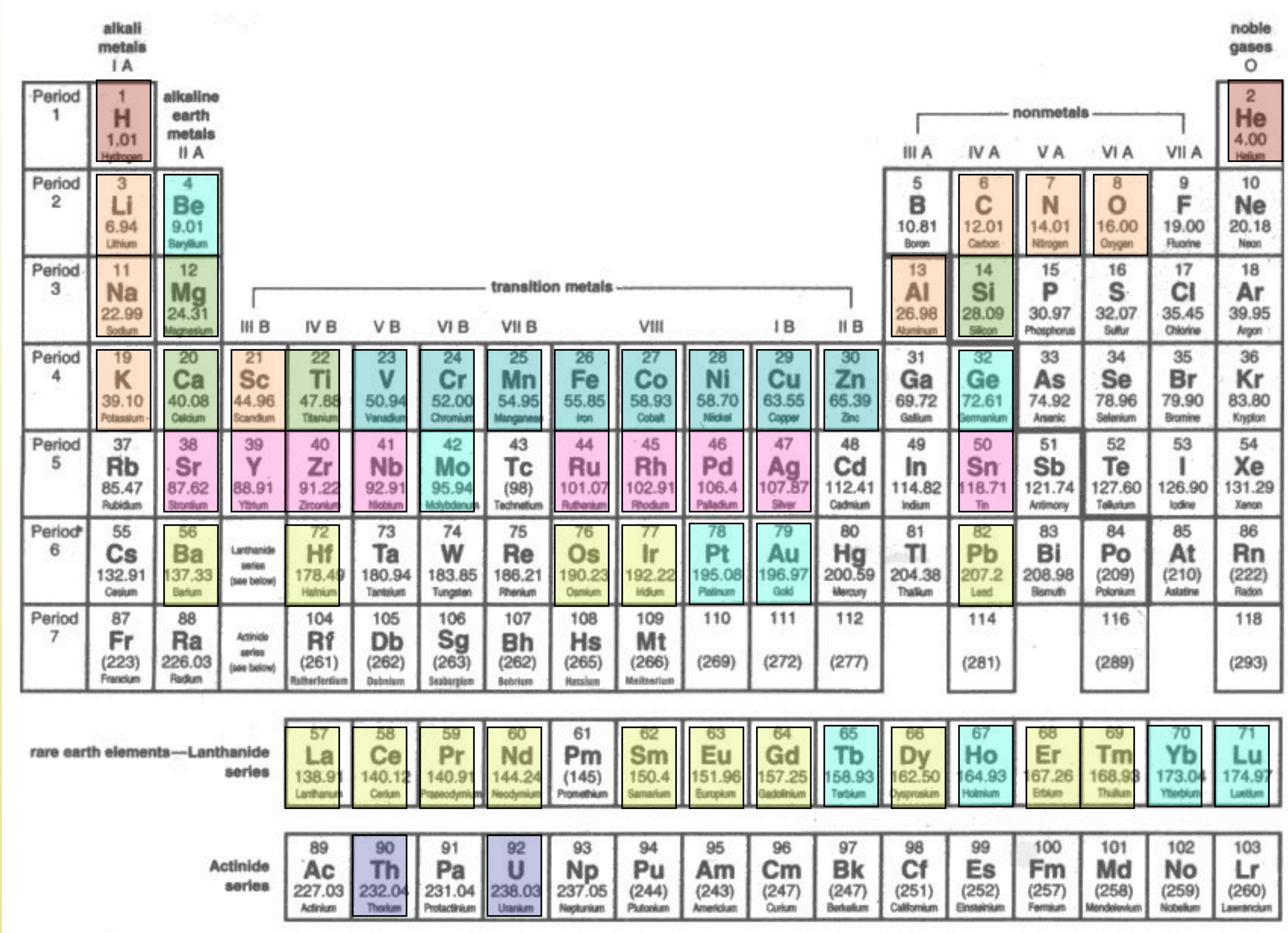

T_eff [K]
10000
8000
7000
6000
5000
4000
M_V
L/L☉
M55
RGB
B-V
-0.25
0
0.25
0.5
0.75
1
100
10
1
0.1

What elements can we see in HE 1523-0901?



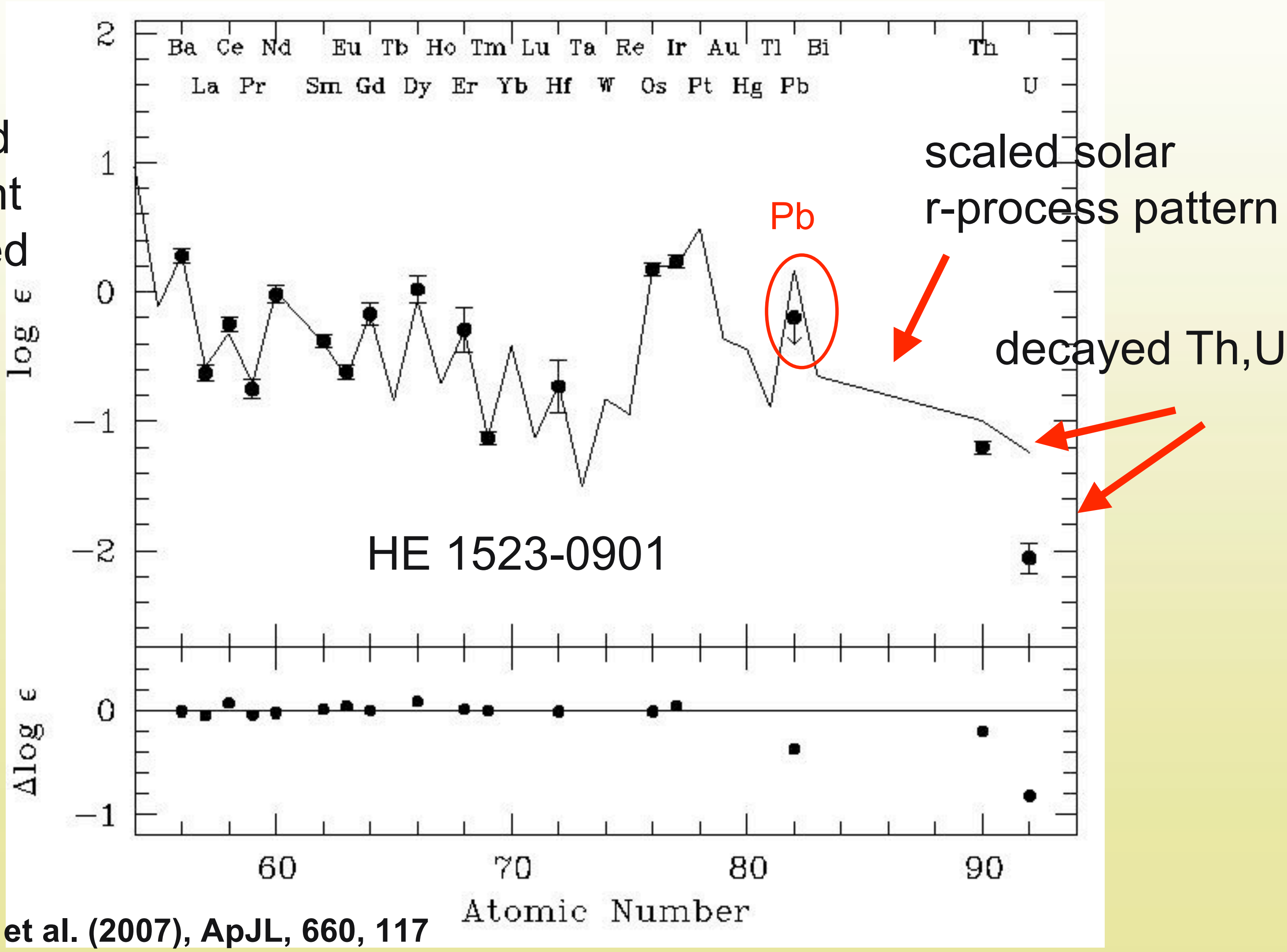
Lanthanides or rare earth elements: i.e. Eu, Gd, Dy

Heavy neutron-capture elements in stars



The r-Process Pattern

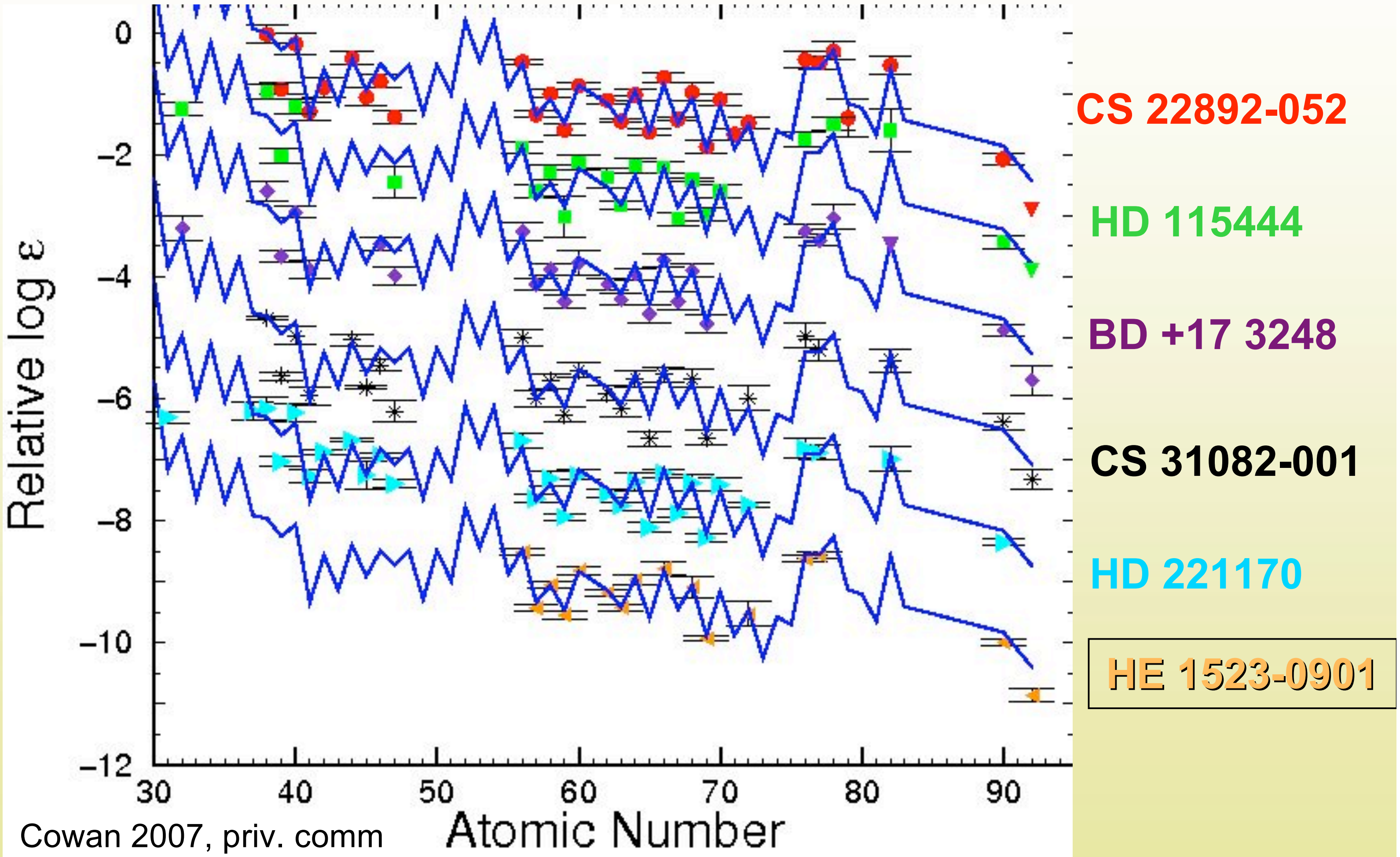
Very good agreement with scaled solar r-process pattern for Z>56



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

Anna Frebel Ringberg Nucleo-chronometry

High-precision at work



They all have the same abundance pattern, particularly in the heavy n-c elements!

Cosmo-Chronometry

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.

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

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

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

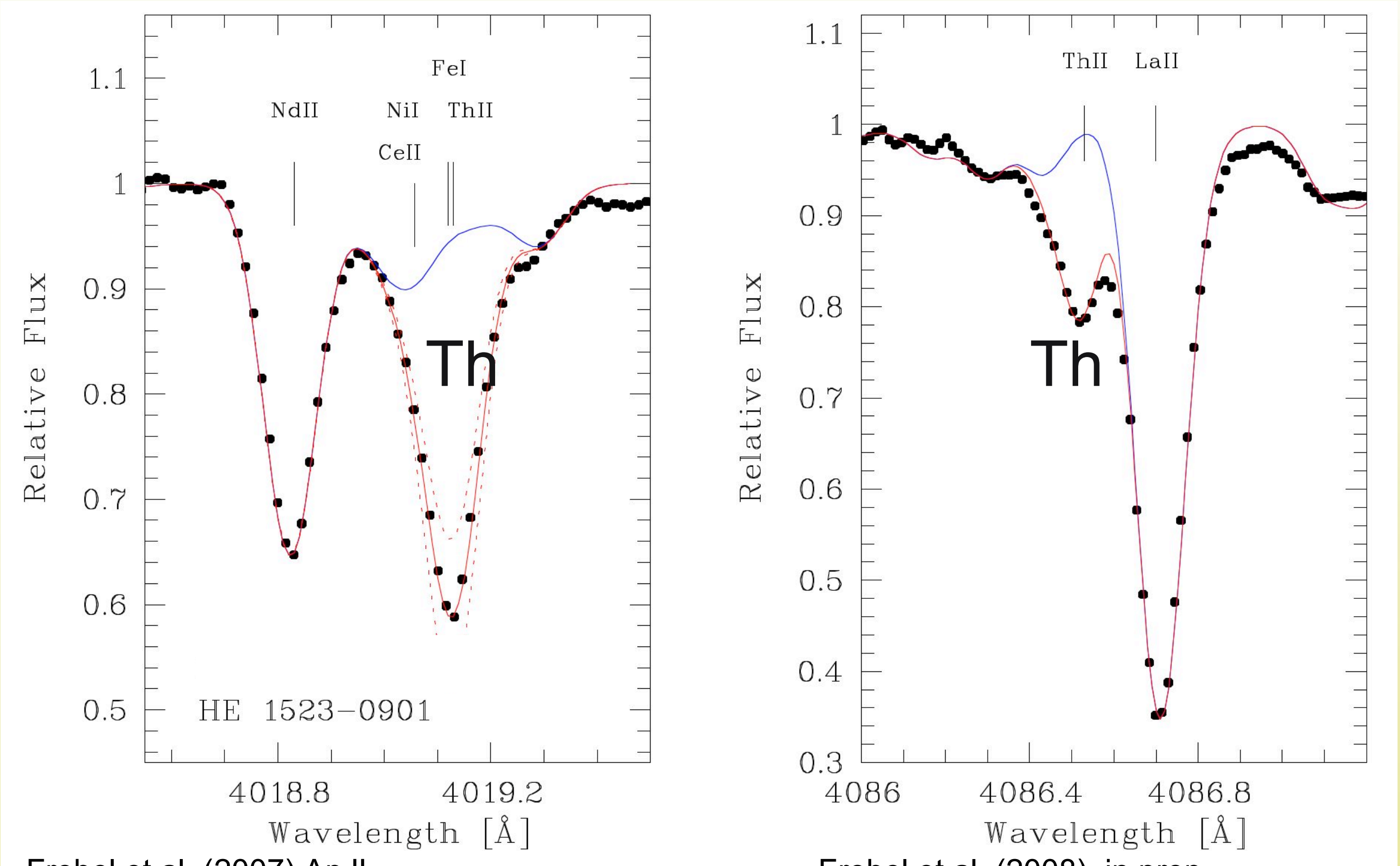
Th/Eu: “most commonly” used chronometer

- “famous” example: CS22892-052
  ~14-15Gyr; (Sneden et al. 96,03)

U/Th: Uranium only confidently measured
in **one** star before: CS31082-001
~14Gyr (Cayrel et al. 01, Hill et al. 02);

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

Thorium II lines in HE 1523-0901



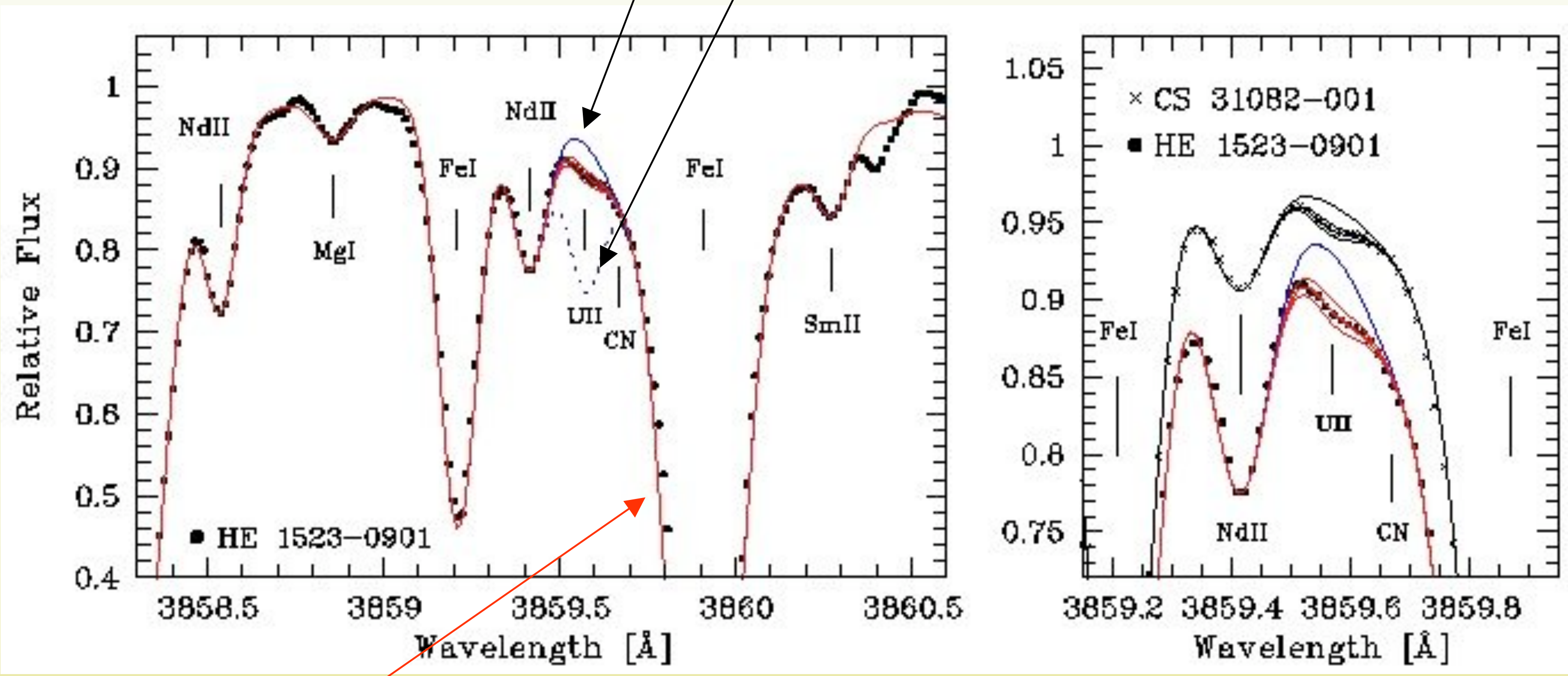
Frebel et al. (2007) ApJL

Frebel et al. (2008), in prep.

U II at 3859Å in HE 1523-0901

Synthetic spectrum that includes NO uranium

Synthetic spectrum with U abundance if it had NOT decayed



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

'Best fit' synthetic spectrum

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 of HE 1523-0901:

WMAP: 13.7 Gyr

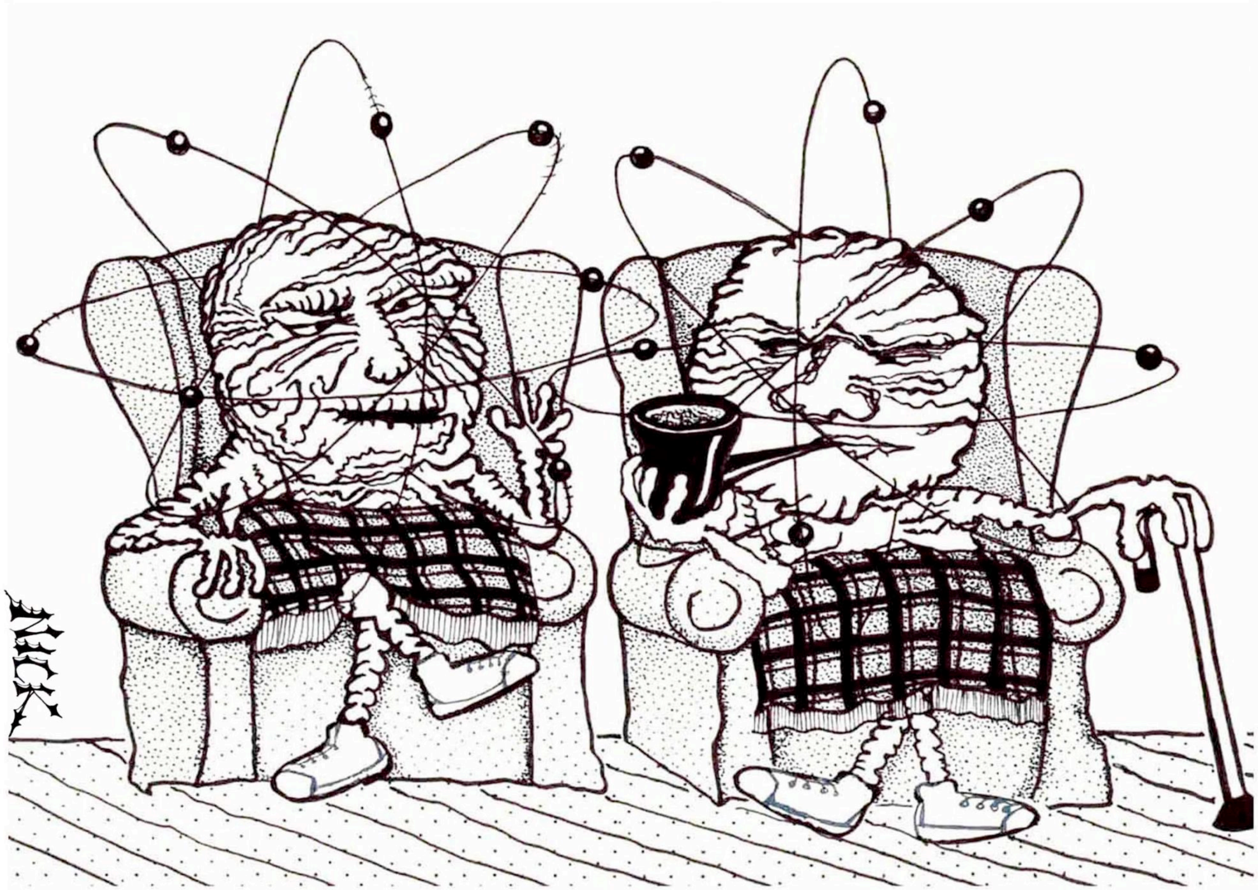
The first time **more than one** chronometer could be employed in a star to measure the age!

"Reverse engineering"

- Assume age for star, e.g. 13 Gyr
- Take observed ratios (at face value) & calculate initial prod. ratios
- Need star(s) with many measured chronometer ratios. Only available: HE 1523-0902 so far => NEED MORE STARS!!!

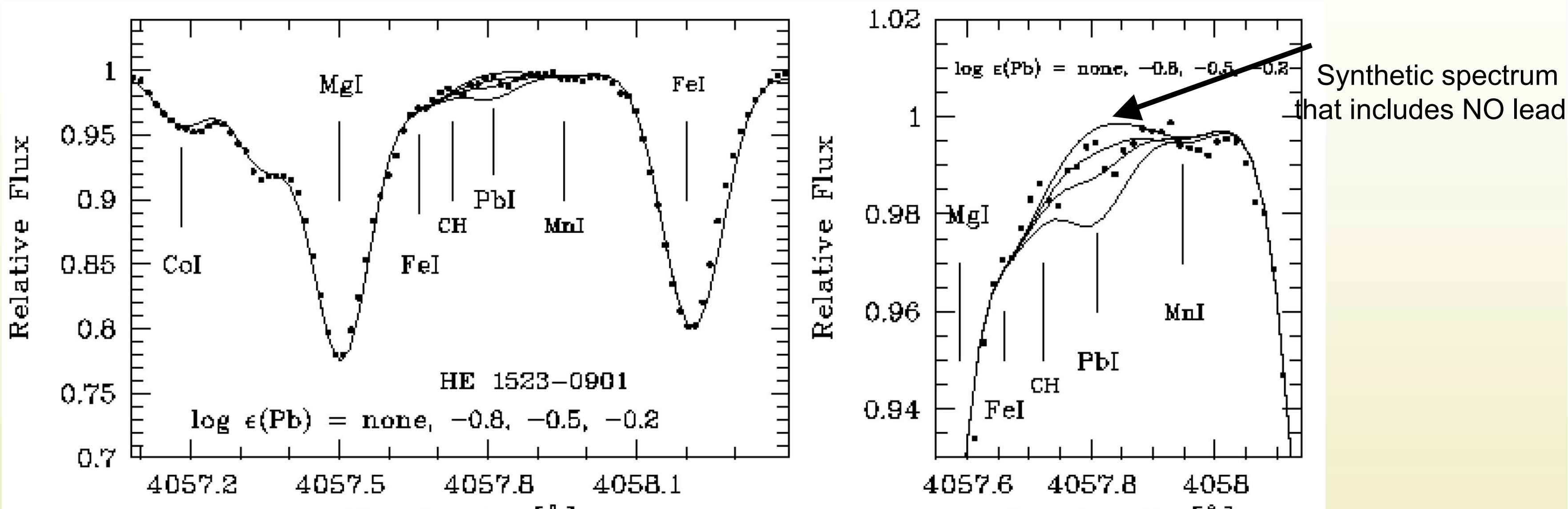
Ratio	observed ratio	derived initial prod. ratio derived from HE1523-0901	derived ages (Gyr)	stars
Th/Eu	-0.62, -0.51, -0.60, -0.60	-0.222	18.6, 13.5, 17.7, 17.7	CS 22892-052, BD 17 3248, HD221170, HD 115444
Th/Os	-1.59, -1.63	-1.022	26.6, 28.5	CS 22892-052, BD 17 3248
Th/Ir	-1.47, -1.48	-1.082	18.2, 18.6	CS 22892-052, BD 17 3248
U/Eu	-1.33	-0.562	11.4	BD 17 3248
U/Os	-2.45	-1.362	16.1	BD 17 3248
U/Ir	-2.30	-1.422	13.0	BD 17 3248
U/Th	-0.82	-0.344	10.4	CS 31082-001

At the home for old atoms...



"When I was young I used to feel so alive and dangerous! Would you believe I started life as a uranium-238? Then one day I accidentally ejected an alpha particle. Now look at me—a spent old atom of lead-206. It seems that all my life since then has been nothing but decay, decay, decay…"

Lead at 4058Å



Frebel et al. (2008) in prep.

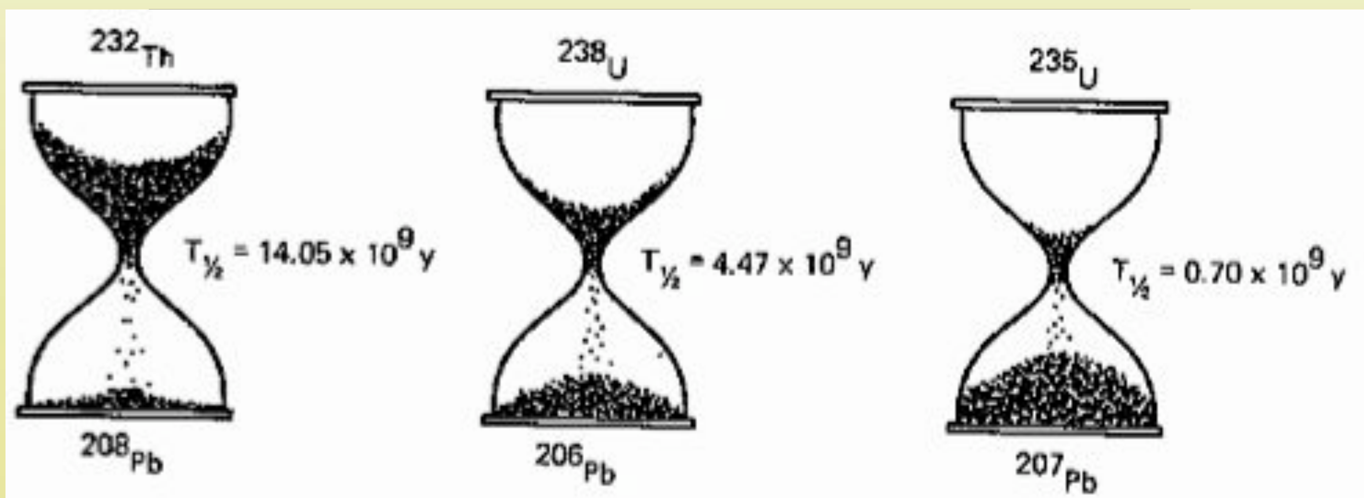
t=13.2 Gyr

$\tau(^{238}U)$=4.47

$\tau(^{232}Th)$=14.05

log ε(Th)=–1.20

log ε(U)=–2.06



Summary

- HE 1523−0901 is an ideal candidate for difficult neutron-capture line measurements, e.g., has the yet best U detection
- For the first time, all three available chronometer pairs (Th/r, U/r, U/Th) are measured in one star (7 ratios so far)
- The derived age is 13.2 Gyr; but large systematic uncertainties!
- In HE1523-0901: attempt to measure good Hf (existing data) and Pt (HST data) for Th/Hf, U/Hf and Th/Pt, U/Pt
- Reverse-engineering: use stars to obtain initial production ratio to get ages of other stars, but: we need more stars to play this game!

Thank you!

Question/comments/requests for figures? email me: anna@astro.as.utexas.edu