Stellar heavy element abundances and ages

J. J. Cowan

STELLAR HEAVY-ELEMENT ABUNDANCES AND AGES

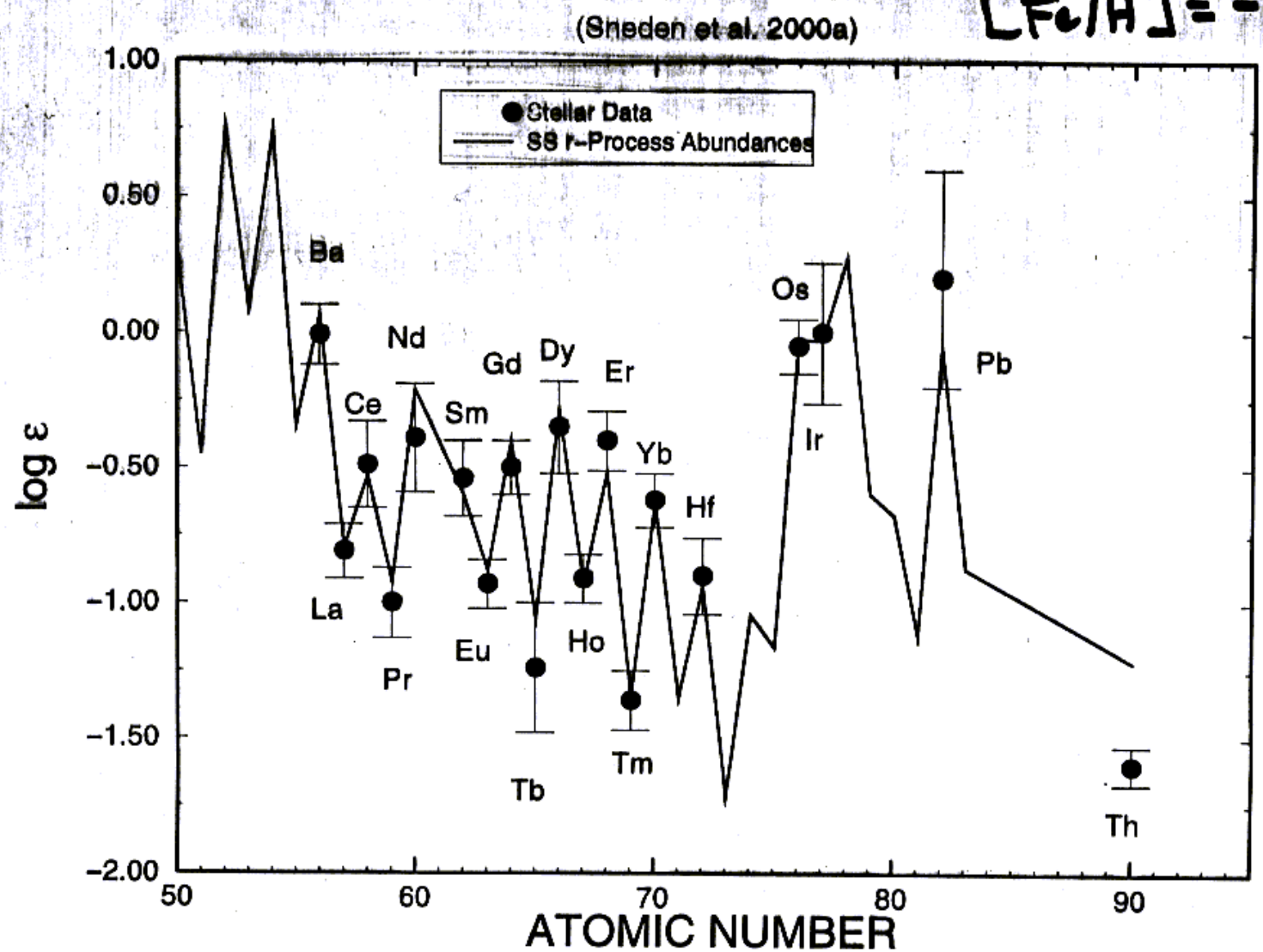
J.J. Cowan (Univ. of Oklahoma)

A Team of Observational and Theoretical Collaborators:

T. Beers (MSU)
M. Bolte, R. Kraft, G. Smith (Lick)
D. Burris (Oklahoma)
G. Fuller (UCSD)
J. Johnson (Carnegie)
K.-L. Kratz, B. Pfeiffer (Mainz)
C. Pilachowski, T. Armandroff (NOAO)
C. Sneden, R. French, I. Ivans (Texas)
F.-K. Thielemann, C. Freiburghaus (Basel)
J. Truran, S. Burles (Chicago)
J. Westin, B. Gustafsson (Uppsala)

r–Process Abundances in CS 22892–052

[Fe/H] = −3.1



$\log \varepsilon(X) = \log(N_X/N_H) + 12$

- **CS 22892–052 NOT UNIQUE, JUST WELL-STUDIED WITH LOTS OF GOOD DATA**

- **MORE DATA ON ADDITIONAL STARS NOW BECOMING AVAILABLE**

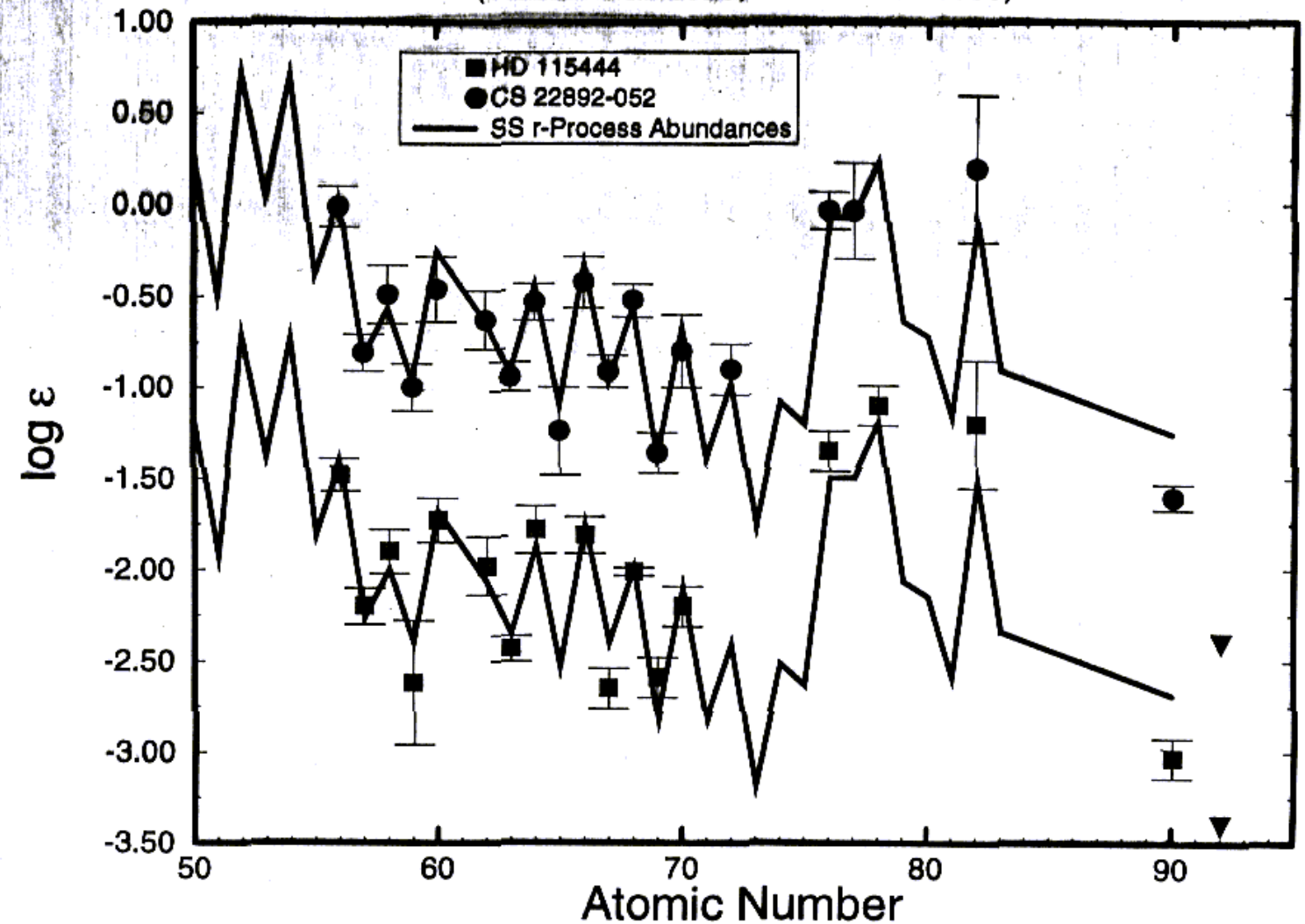
The 2nd r-process peak is currently not accessible to observations.

The 3rd r-process peak, Os-Pt, is accessible using HST.

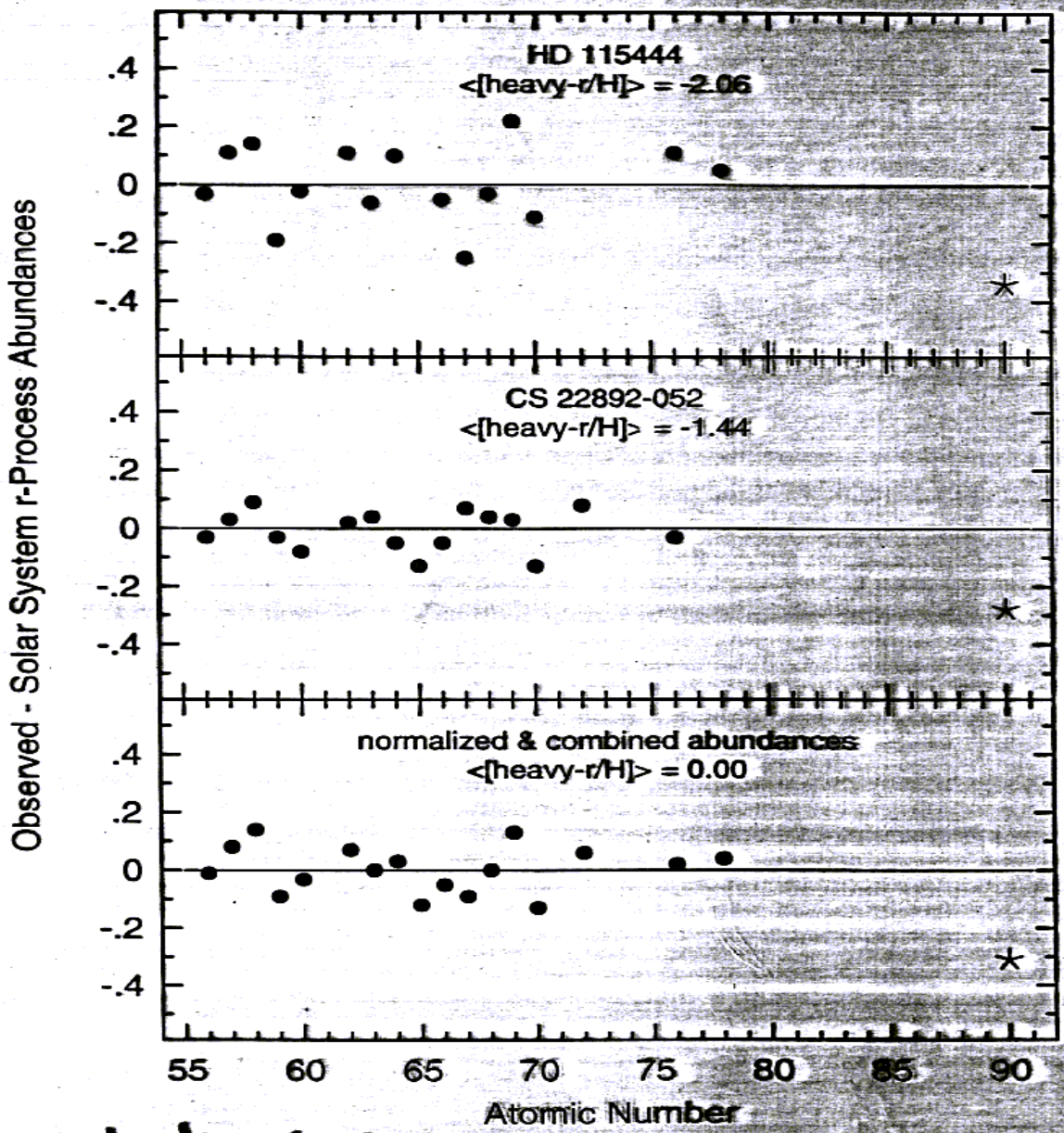
- **DATA FROM THESE OTHER STARS SUGGEST A PATTERN SIMILAR TO THAT SEEN IN CS 22892–052**

r-Process Abundances in Halo Stars

(Westin et al. 2000; Truran et al. 2000)

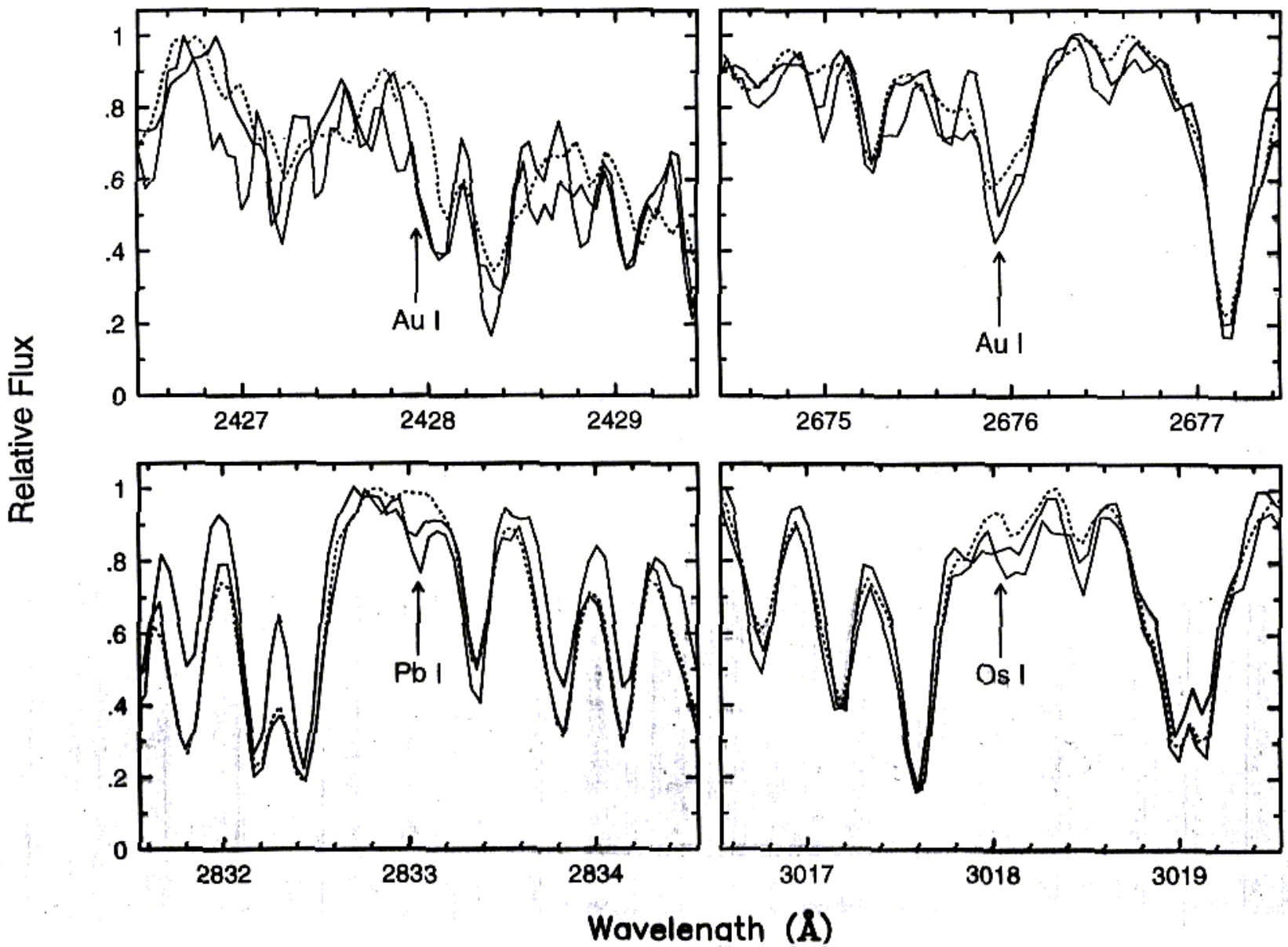


Abundance Comparisons

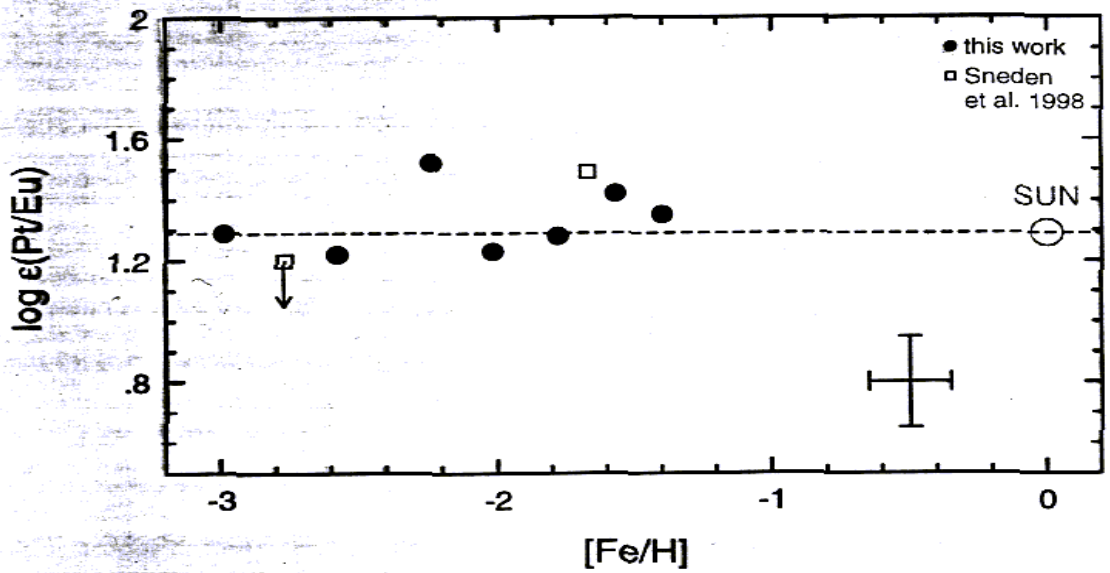


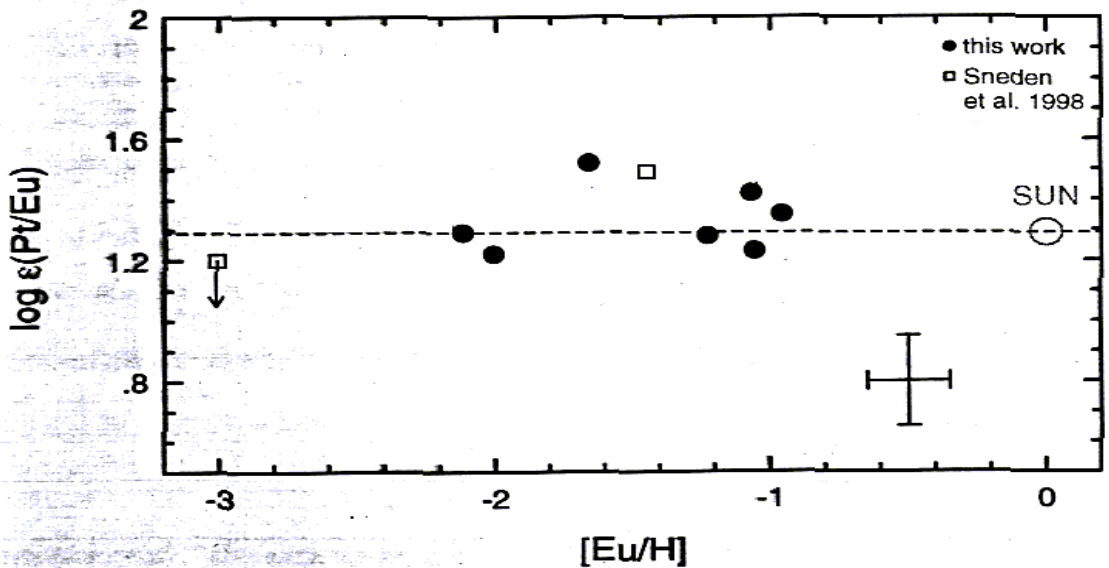
Westin et al. (2000)

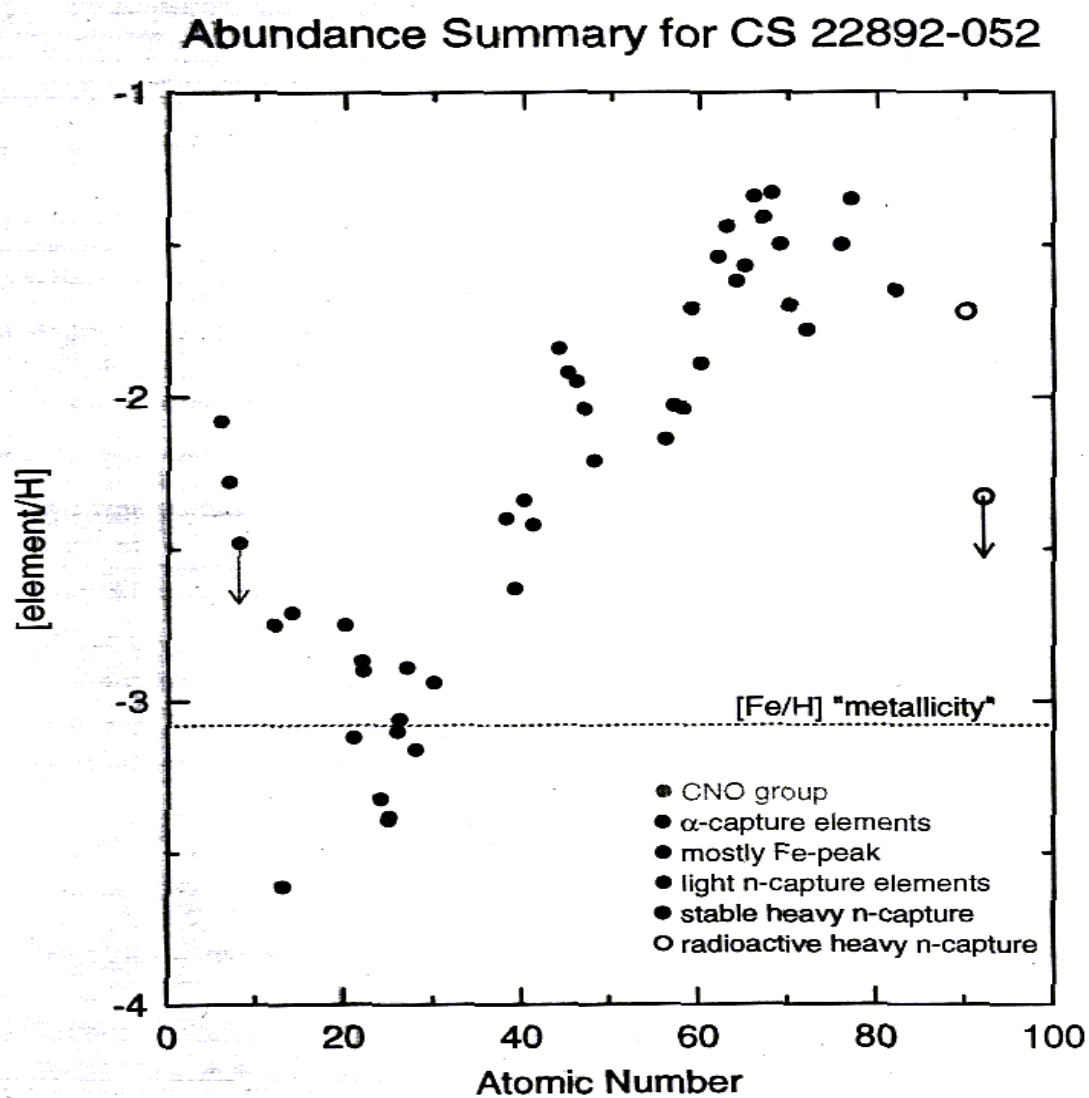
Neutron-Capture Elements in HST Spectra



Pt/Eu Ratios as a Function of "Metallicity"

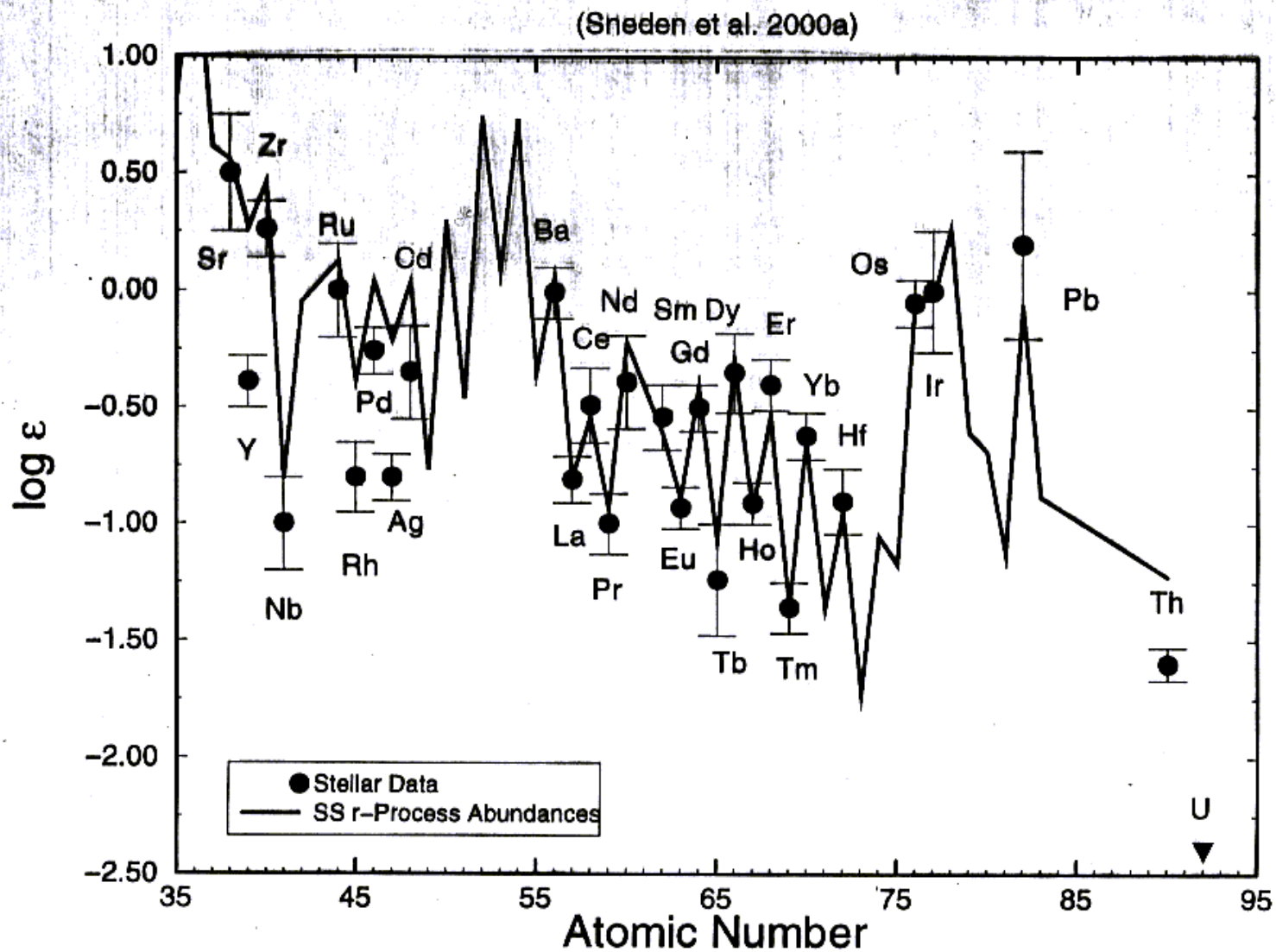




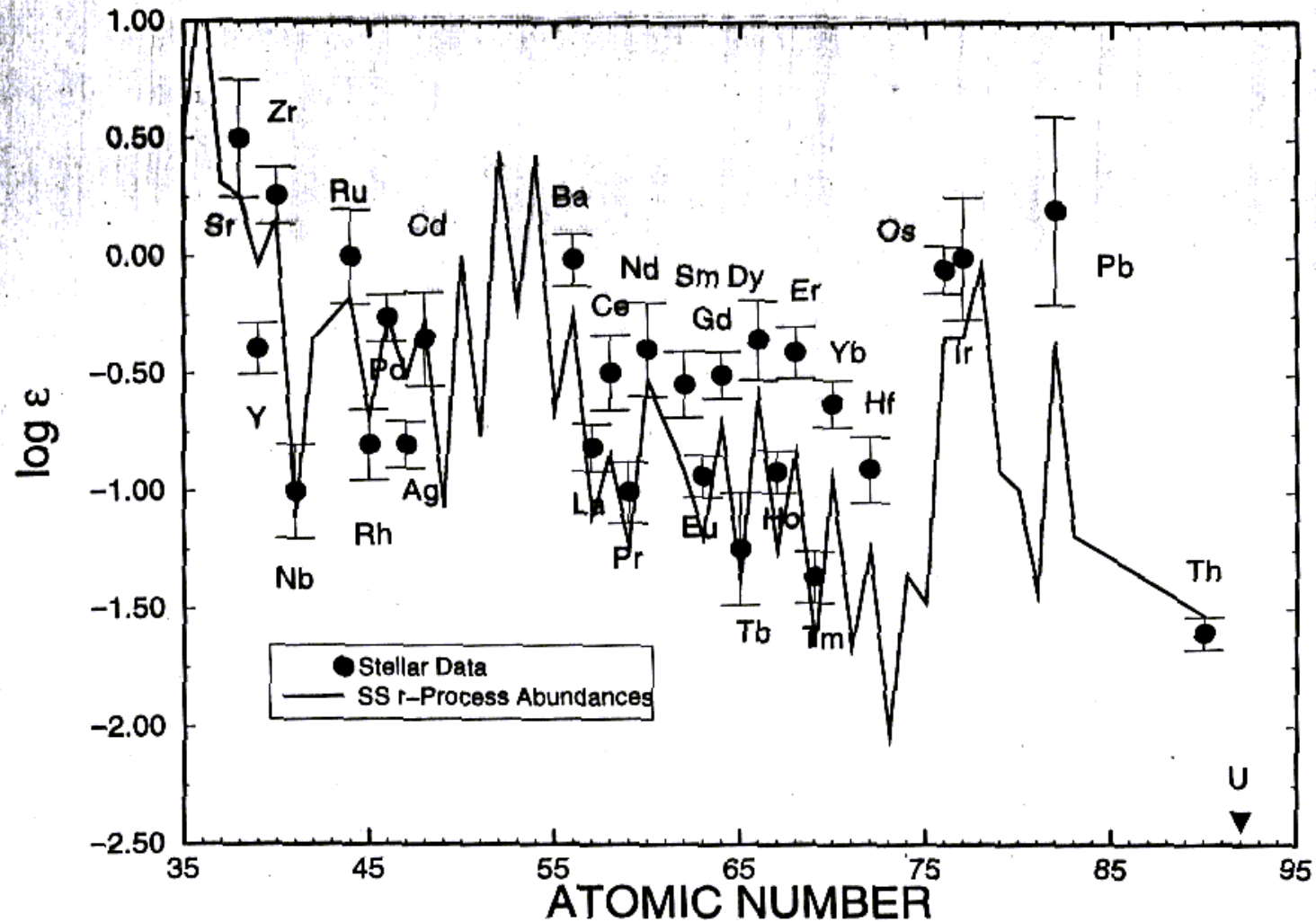


Sneden + JC (2000)

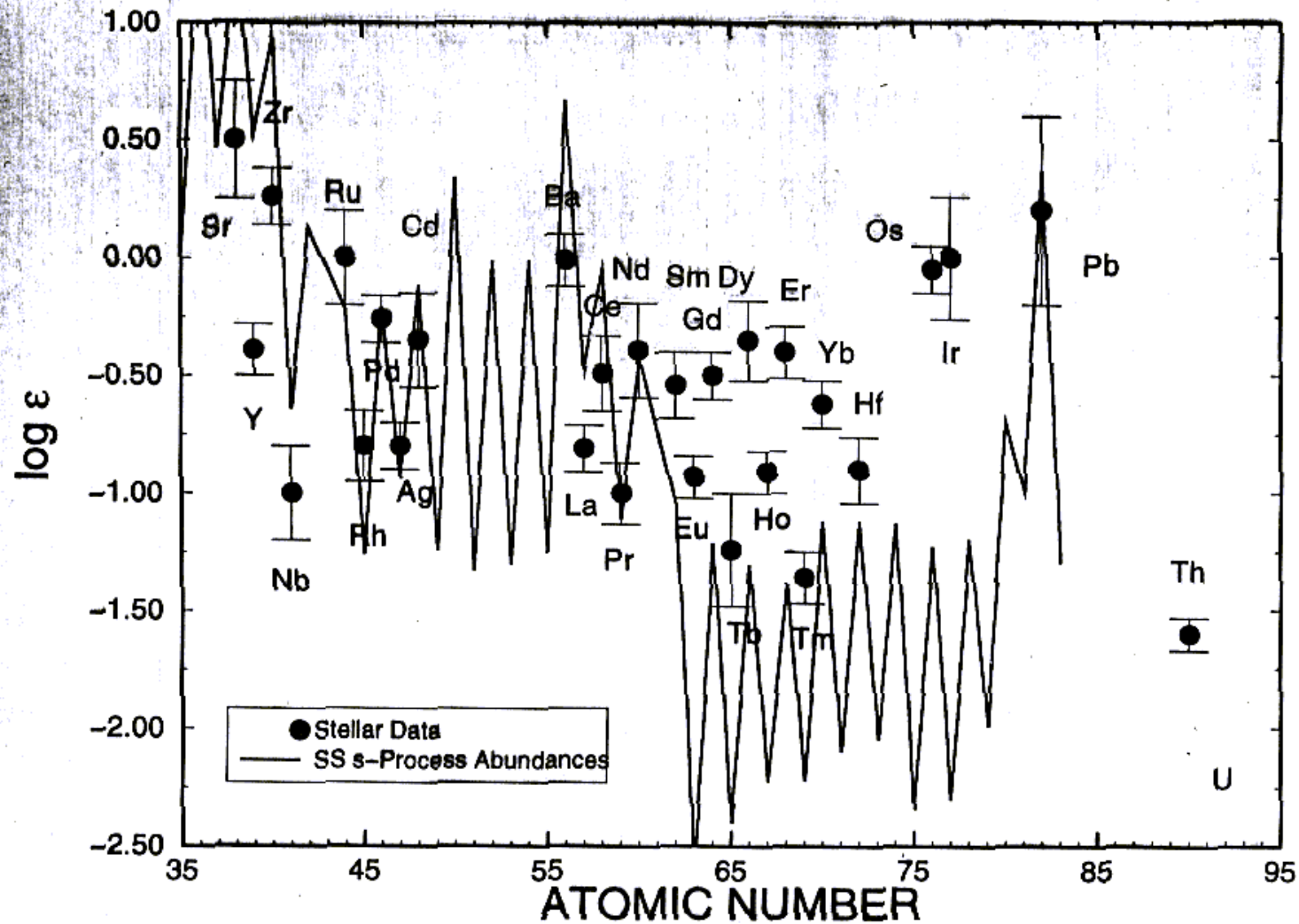
r–Process Abundances in CS 22892–052



r–Process Abundances in CS 22892–052



Abundances in CS 22892-052



NEW DETECTIONS OF NEUTRON-CAPTURE ELEMENTS IN CS 22892–052

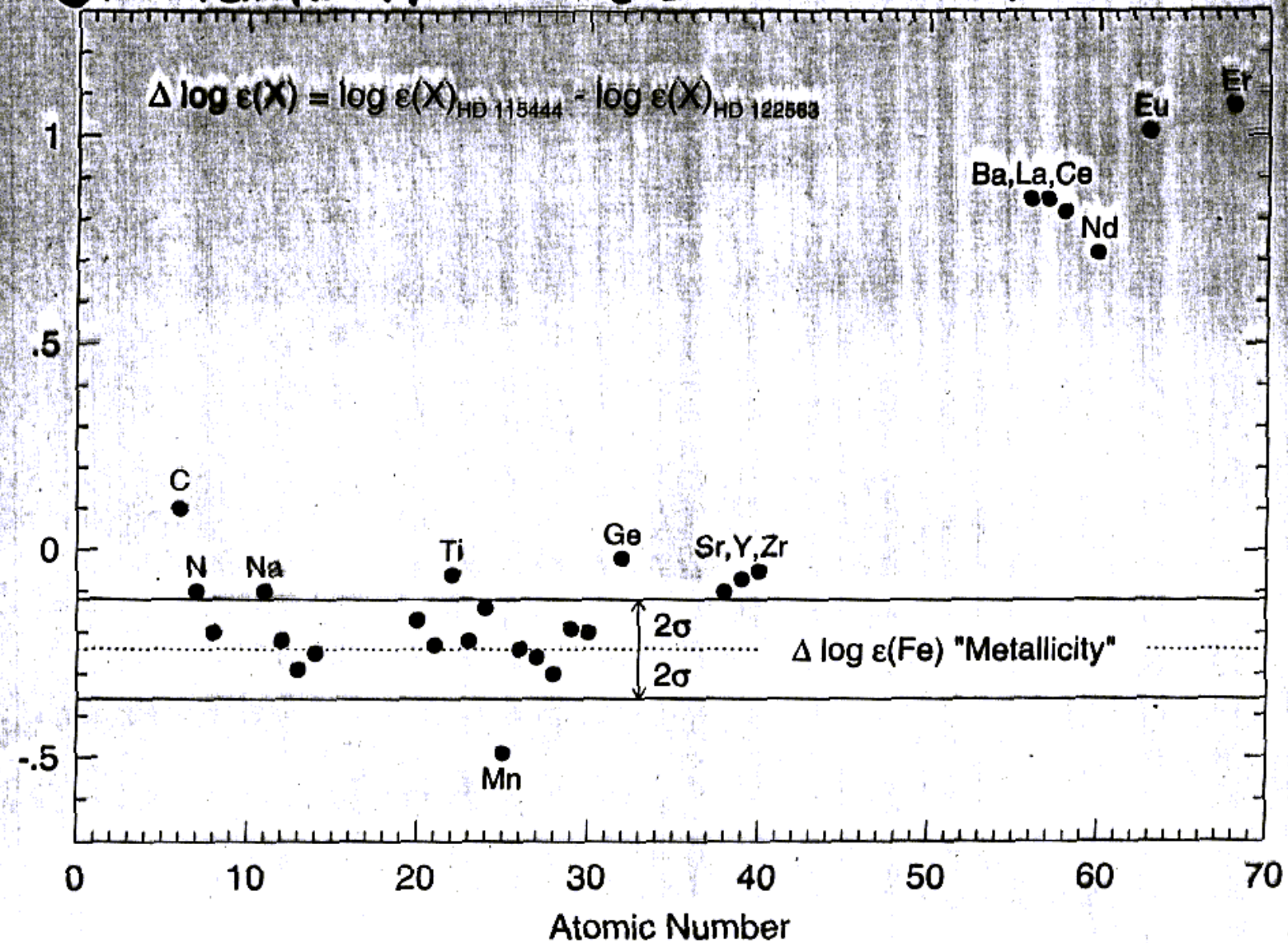
- **Elements with atomic number Z = 40-50, including niobium, ruthenium, rhodium, palladium, silver and cadmium have been detected for the first time in CS 22892–052.**

A SECOND R-PROCESS?

- **Abundances of the neutron-capture elements Z $\geq$ 56 (i.e. Ba and above) are consistent with the scaled solar system r-process curve (blue line) indicating that the relative elemental r-process abundances have not changed over the history of the Galaxy and further suggests that there is one r-process site in the Galaxy, at least for elements Z $\geq$ 56.**
- **Abundances of the newly determined elements from Z=40-50 in general fall below the scaled solar system r-process curve. These data seem to support the suggestion of Wasserburg, Busso & Gallino (1996) that there may be two r-process sites, with one responsible for the heavier elements (occurring on a more rapid time-scale) and a less frequently occurring synthesis producing the elements below Ba.**

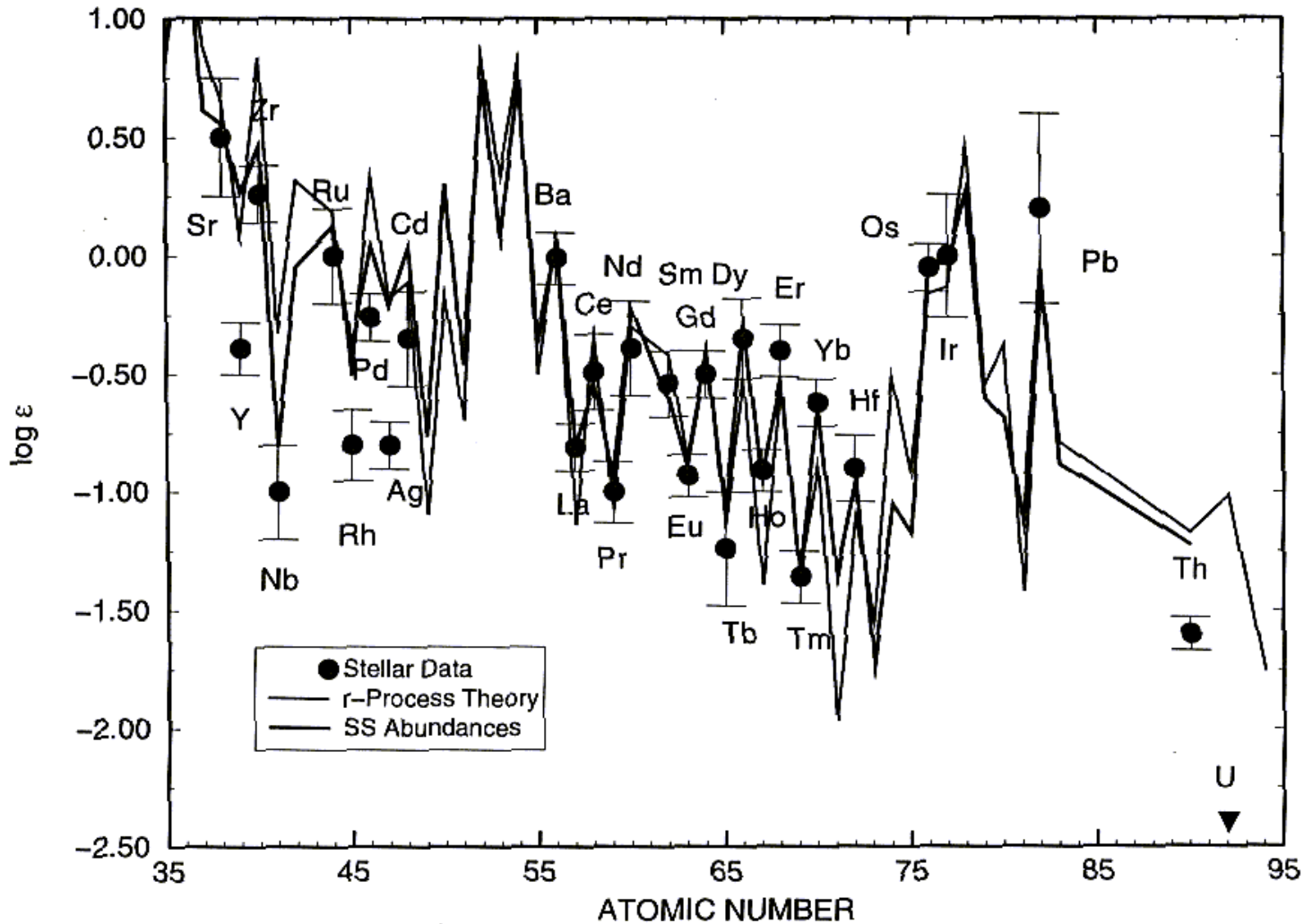
Main (or strong) R-Process + Weak

Differential Abundances in 2 Stars



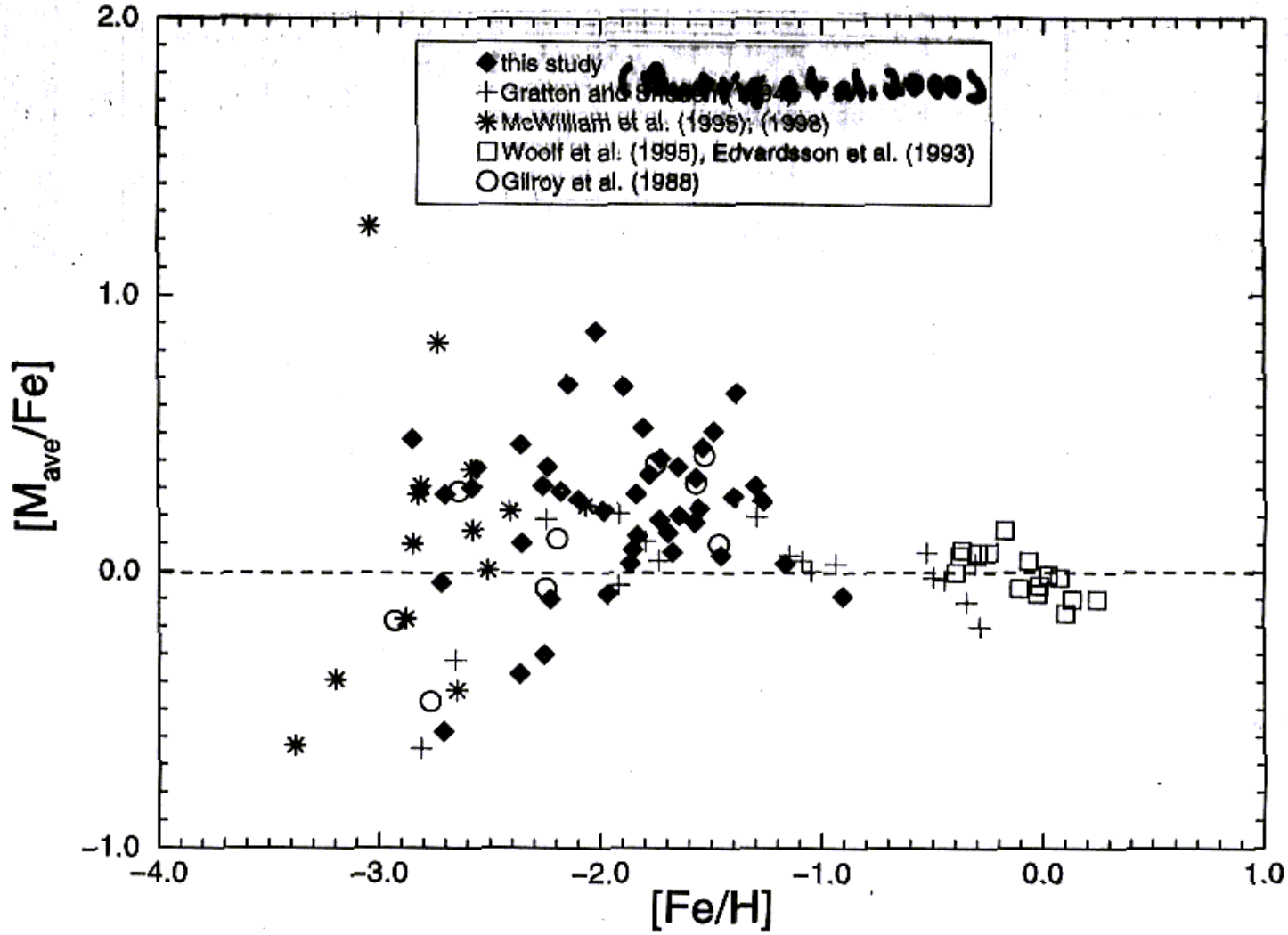
Westin et al. (2000)

r–Process Abundances in CS 22892–052



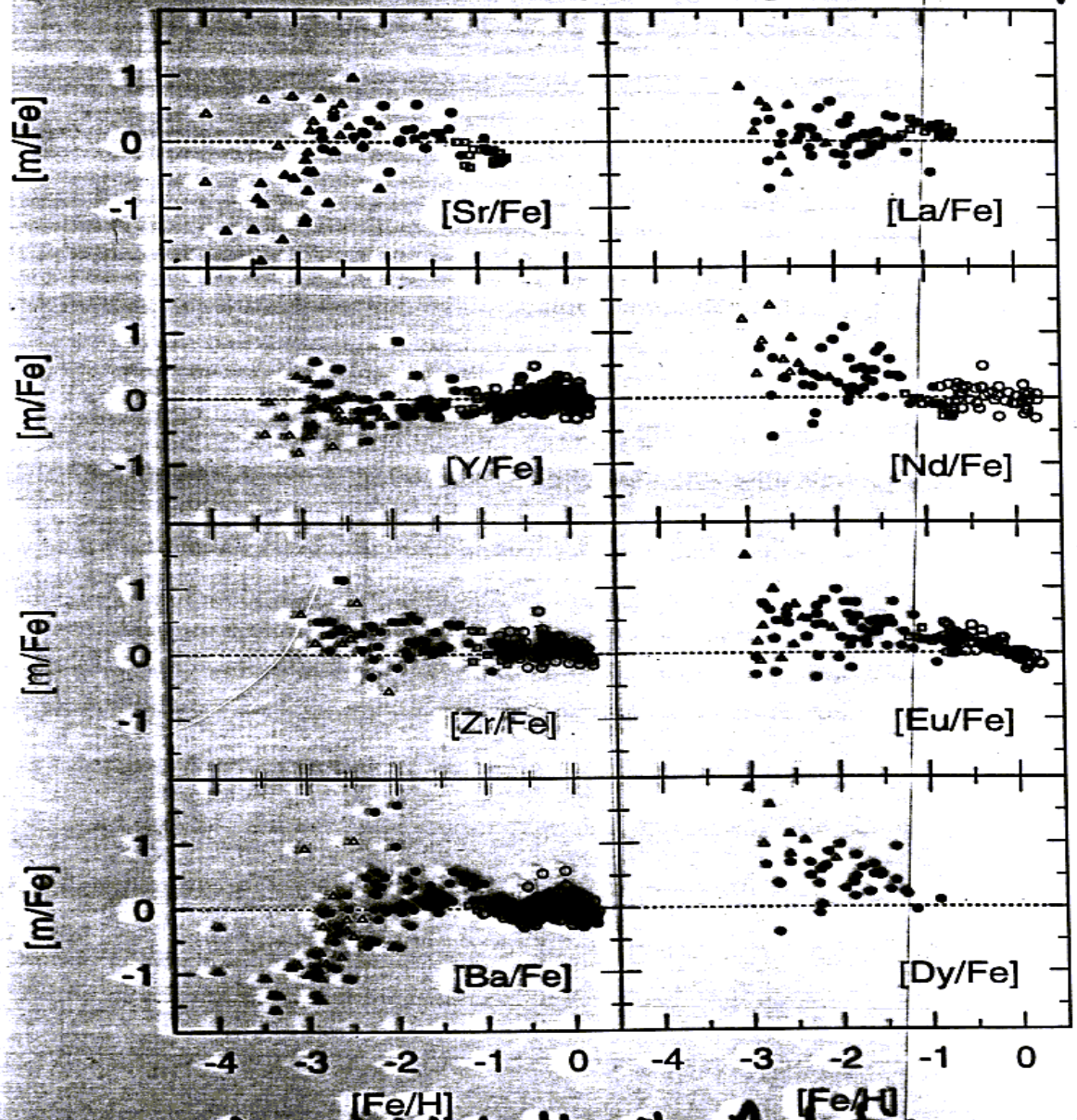
ETFSI-Q(1sq.)

Heavy Element Scatter vs. Metallicity



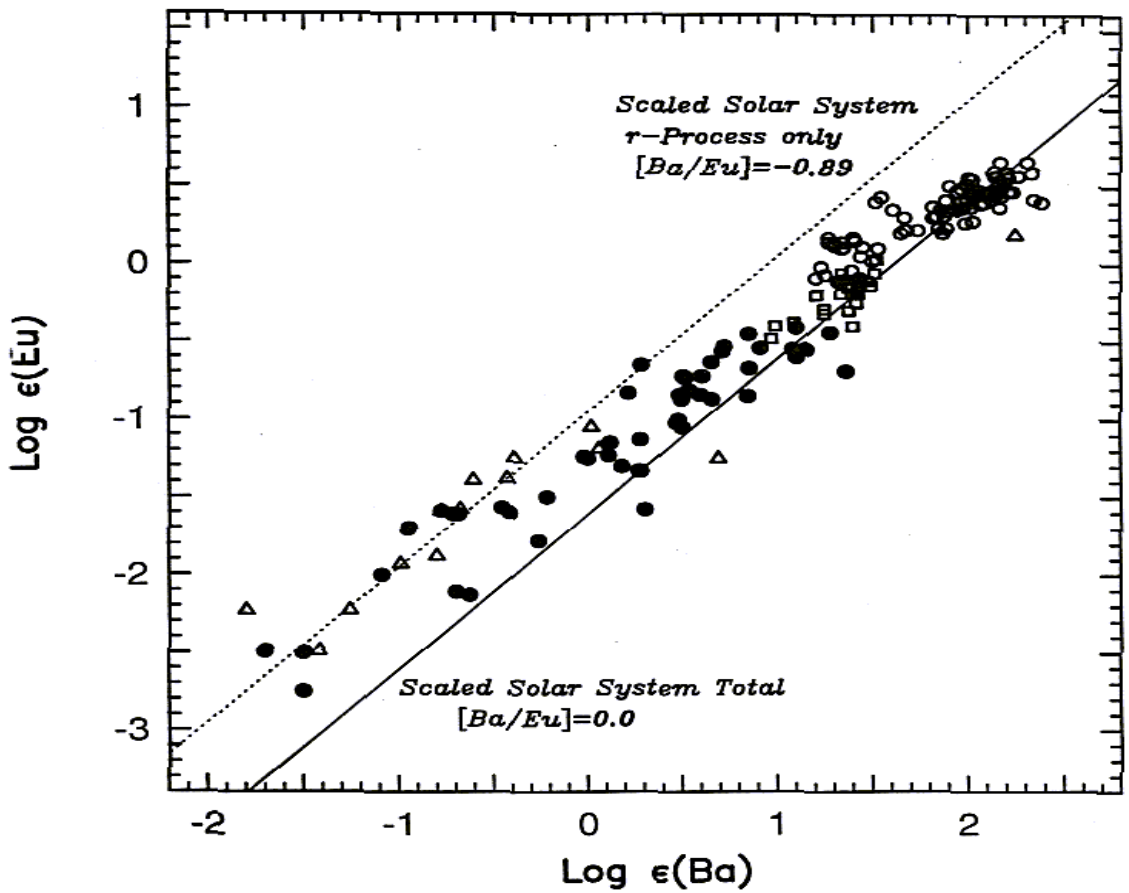
Abundance Trends vs. Metallicity

Burris et al. (2000)



Age-Metallicity Relation

r- and s-Process Trends



Burris et al. (2000)

Radioactive-Decay Age Estimates

The measured abundance of Th presents the opportunity to determine the age of CS 22892–052, by use of the known Th half-life (14.05 Gyr):

$$N_{Th}(t) = N_{Th}(t_0)exp(-t/\tau_{Th})$$

Where

$$\tau_{Th} = \frac{14.05}{ln2} = 20.27Gyr$$

- ⟹ Solar System Th/Eu (at formation) = 0.463
- ⟹ Solar System Th/Eu (today) = 0.344
- ⟹ Observed Th/Eu in CS 22892-052 = 0.219

It is important to note, that since the solar-system Th/r ratio is larger than the observed ratio in CS 22892–052 then CS 22892–052 must be older than the solar system r-process material.

Observed

Table 2. Neutron-Capture Element Abundances

Transition	log ε HD 115444	log ε CS 22892-052	log ε HD 122563
Derived Abundances			
Th II λ4019 Å	−2.1	−1.6	<−3.1
Th II λ4086 Å	<−2.2	...	...
U II λ3860 Å	<−2.5	<−2.4	...
Eu II λλ4129,4205 Å	-1.5	−0.9	−2.6
Abundance Ratios			
Th/Eu	−0.6	−0.66	<−0.5
U/Eu	<−1.0	<−1.5	...
Th/U	>+0.4	>+0.8	...

± 0.08

log

Ave. $\frac{Th}{Eu}$ (obs) = 0.234

JC et al (1997)

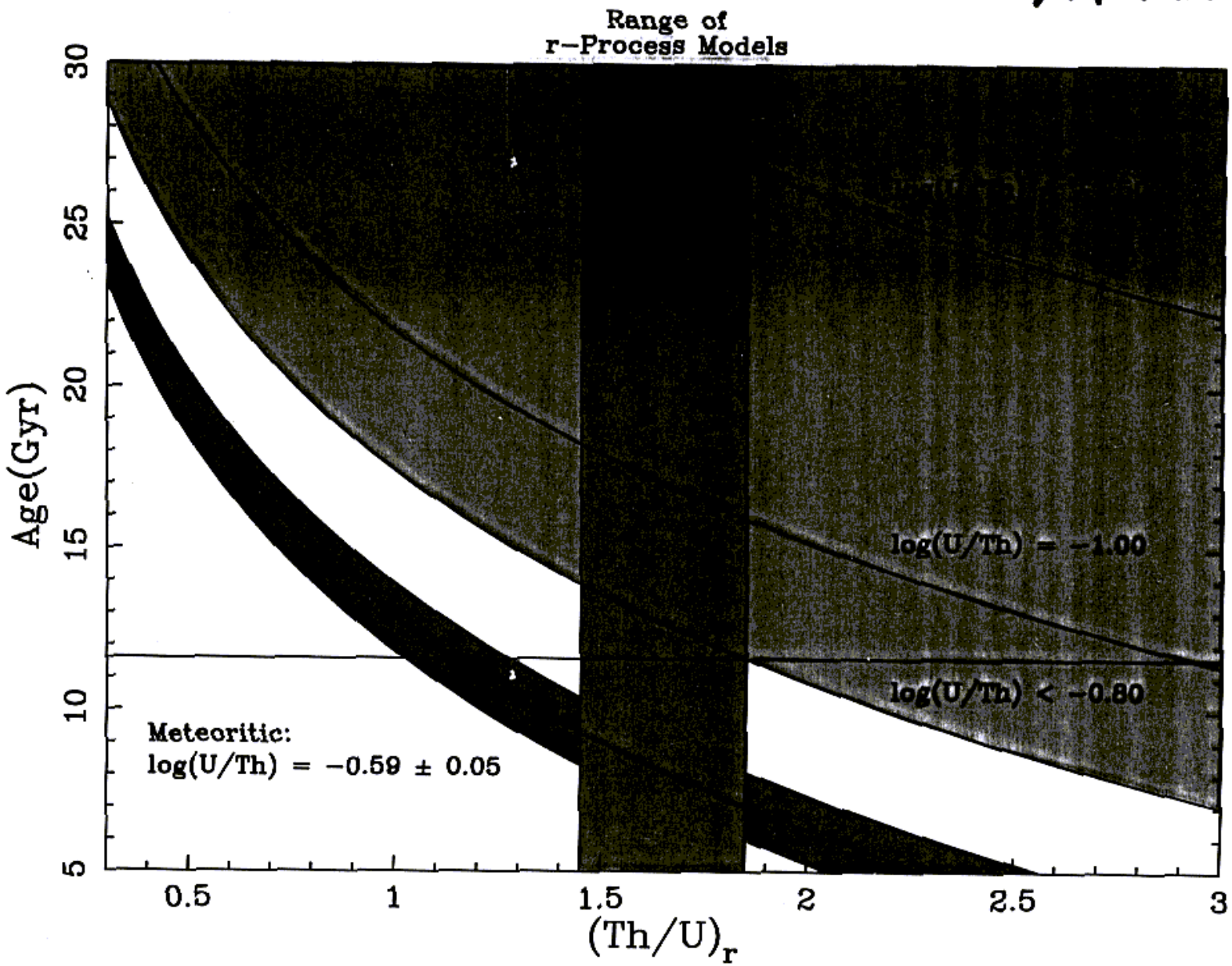
CS 22892-052
HD 115444

Table 3. Th/Eu Chronometers

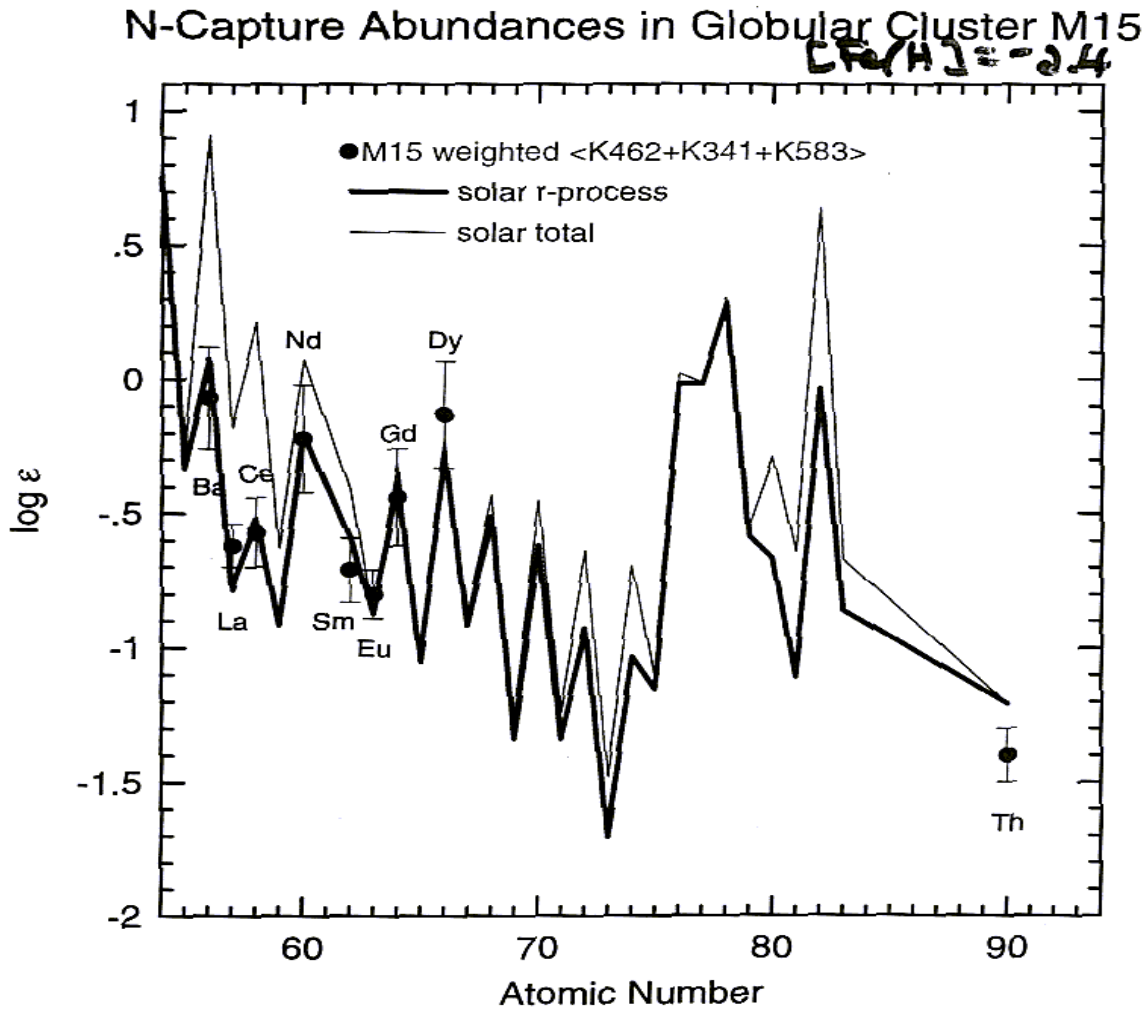
Model	$_{90}$Th	$_{63}$Eu	Zero-Decay $\frac{Th}{Eu}\Big\|_{model}$	Age [Gyrs]
Solar	0.042	0.09	0.463	13.8
FRDM	0.04280	0.02420	1.7695	41.0
ETFSI-1	0.02949	0.06041	0.4881	14.9
HFB/SkP	0.01991	0.05134	0.3879	10.2
FRDM+HFB	0.03449	0.06958	0.4957	15.2
ETFSI-Q	0.06292	0.11533	0.5456	17.1
ETFSI-Q(lsq)	0.04222	0.08788	0.4804	14.5

< Average > = 15.6 ± 4 Gyr SNIa: 14.9 ± 1.5 Gyr

Burles, Truran & JC



New Keck Observations: Sneden et al. (2000b)



<Ave. age> ~ 14 Gyr

CONCLUSIONS

- Detections of a number of elements, many for the first time, in halo (and globular) stars. We have detected almost half (!) of the periodic chart in CS 22892–052.
- Neutron-capture elements from Ge through Th show an r-process in the early Galaxy. Rapidly evolving progenitors. Supernovae? NS binaries?
- Heavy ($Z \geq 56$) n-capture elements in all halo (and globular stars) are scaled solar r-process. Lighter neutron-capture elements do not appear to fit the same distribution. Second r-process?
- Large scatter seen in n-capture elements at very low metallicity (early unmixed Galaxy).
- Abundance trends show a change from r-process to s-process at a higher metallicity (later time?) in Galaxy.
- Thorium detected in CS 22892–052, other halo stars and now globular cluster stars. Promising, independent dating technique. Puts limits on Galactic and cosmological age estimates.