PROBING THE NUCLEOSYNTHESIS PRODUCTS OF THE FIRST STARS

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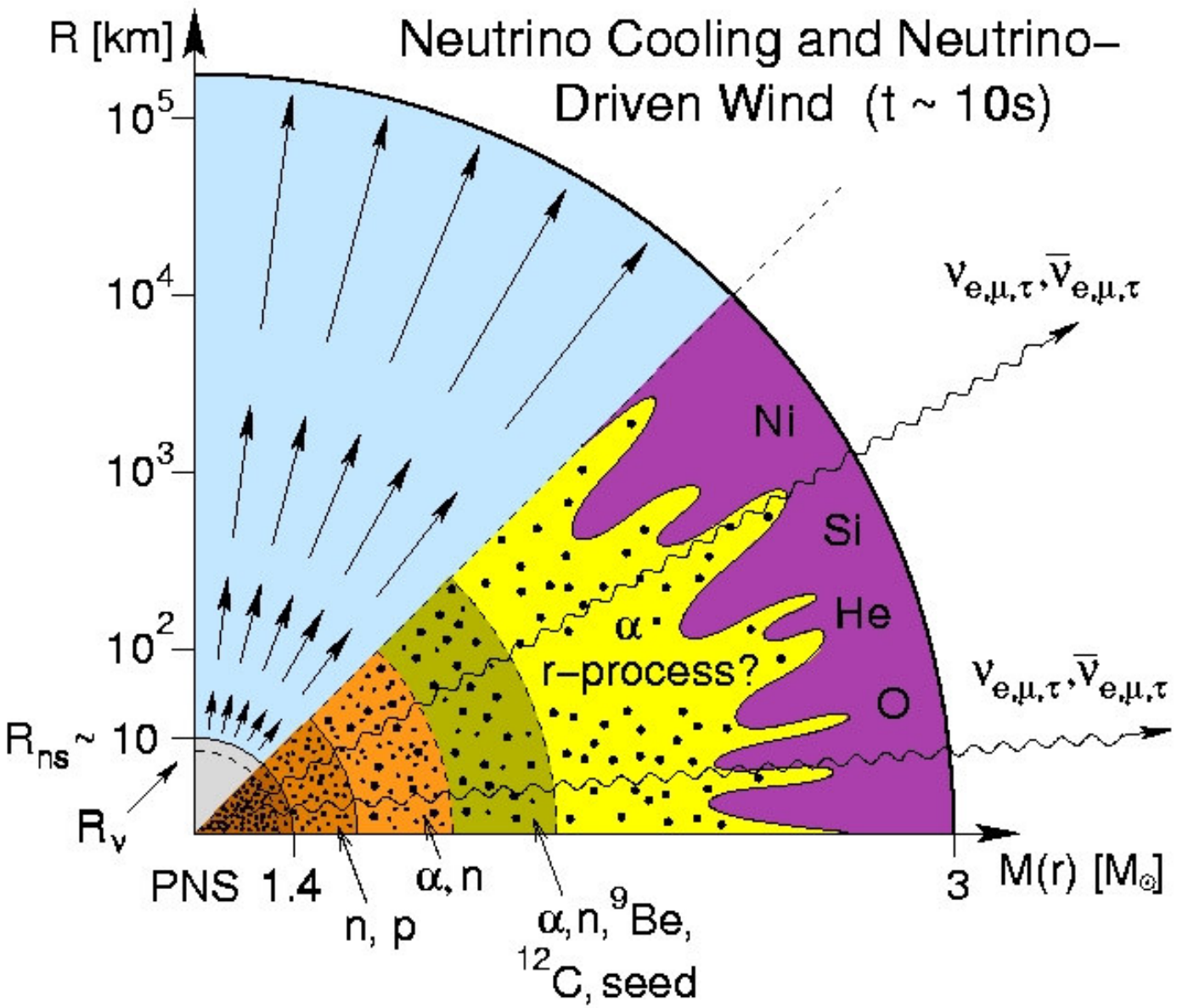
Chemical Enrichment of the Early Universe

Abundance Clues and Constraints

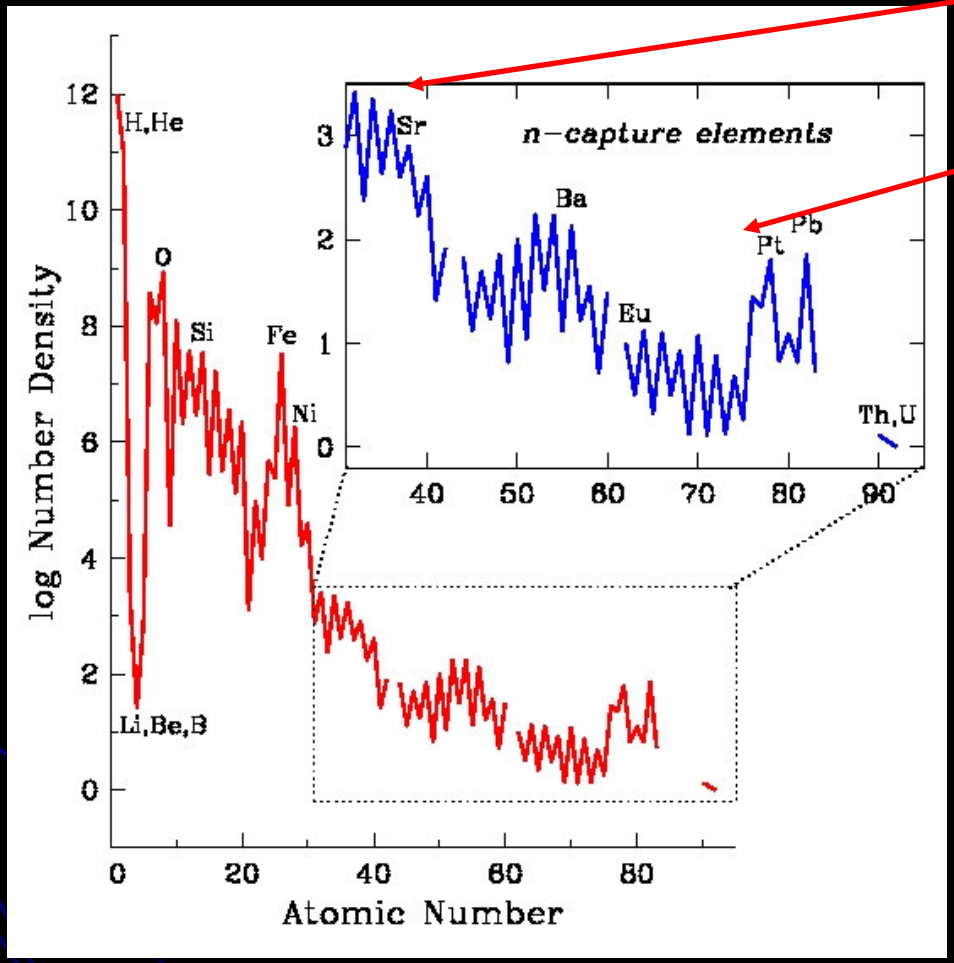
- New observations of n-capture elements in low-metallicity Galactic halo stars providing clues and constraints on:
  1. Synthesis mechanisms for heavy elements early in the history of the Galaxy
  2. Identities of earliest stellar generations, the progenitors of the halo stars
  3. Suggestions on sites, particularly site or sites for the r-process
  4. Galactic chemical evolution

Most Likely Site(s) for the r-Process

- Supernovae: The Prime Suspects
  - → Regions just outside neutronized core: (Woosley et al. 1994; Wanajo et al. 2002)
  - → Prompt explosions of low-mass Type II SNe (Wheeler, JC, Hillebrandt 1998)
  - → Jets and bubbles (Cameron 2001)
- NS & NS-BH mergers (Rosswog et al. 1999; Freiburghaus et al. 1999)


Neutrino Cooling and Neutrino–
Driven Wind (t ~ 10s)
R [km]
10^5
10^4
10^3
10^2
R_ns ~ 10
R_ν
PNS 1.4
n, p
α, n
α, n, ^9Be,
^12C, seed
3
M(r) [M_⊙]
Ni
Si
He
O
α
r–process?
ν_e,μ,τ, ν̄_e,μ,τ
ν_e,μ,τ, ν̄_e,μ,τ

Solar System Abundances

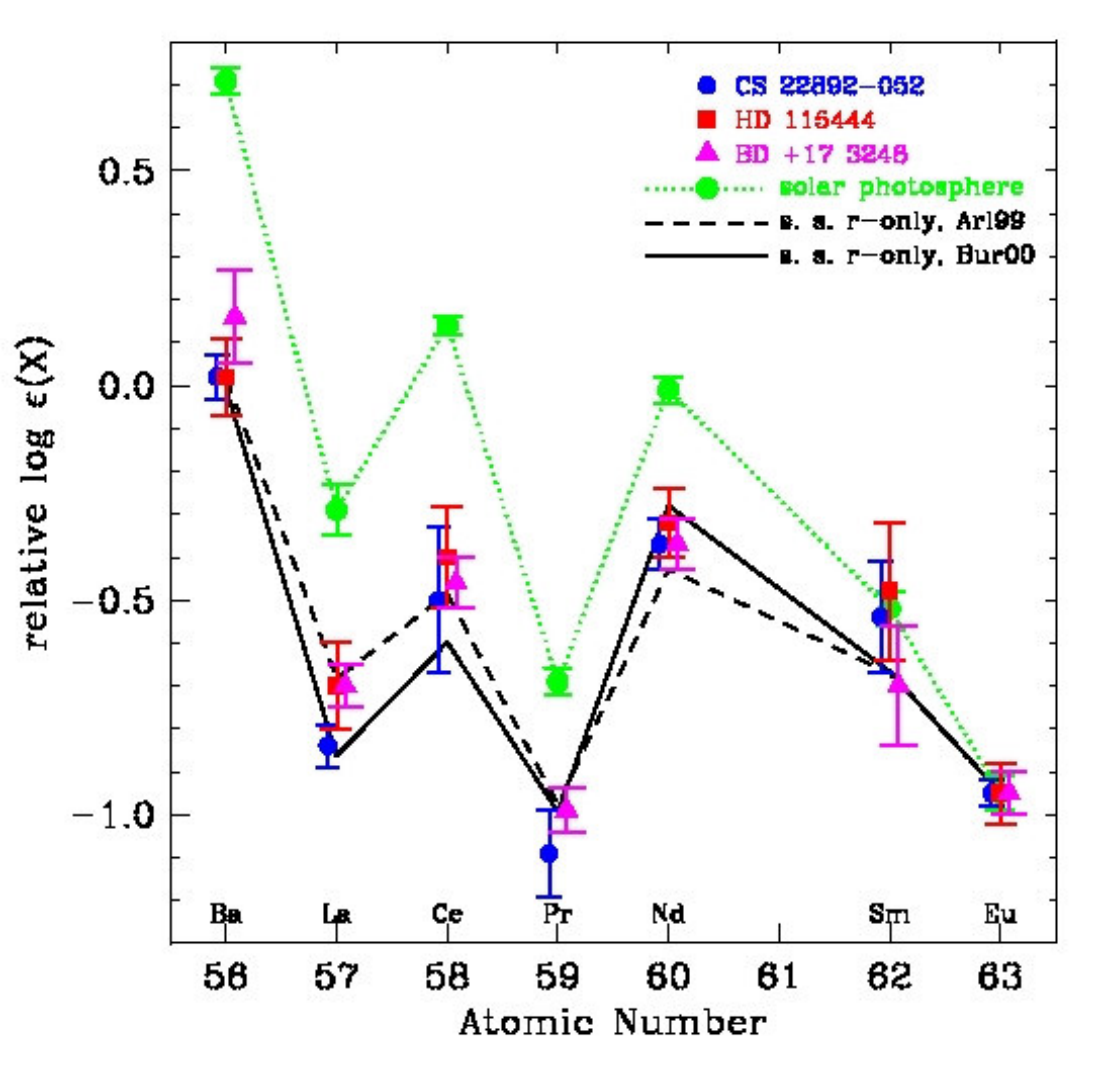


Ge, Zr

Os, Pt

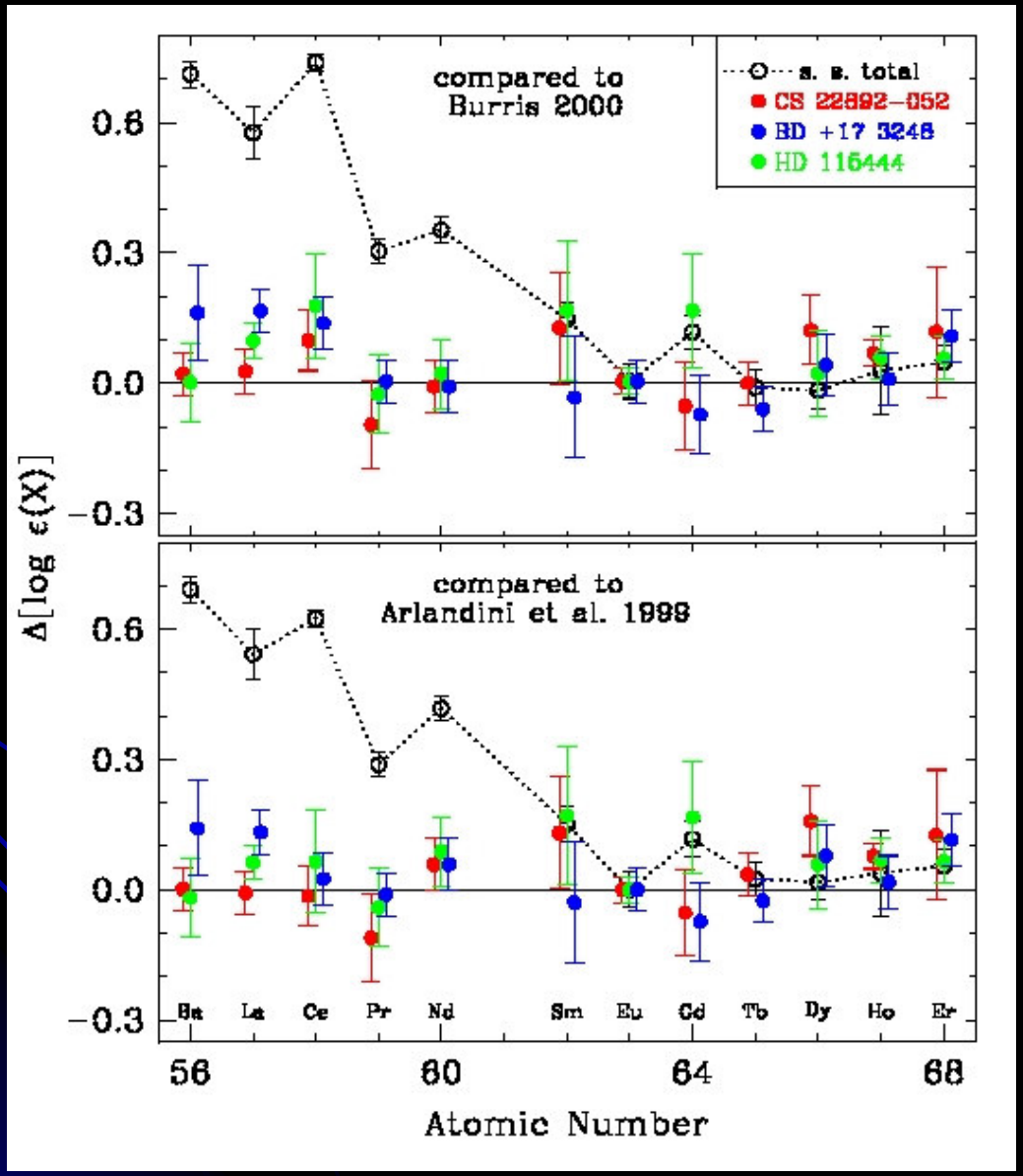
Sneden & JC (2003)

Focus On Individual Elements: Nd



New experimental atomic physics data.
Den Hartog et al. (2003).

Focus On Individual Elements: Ho

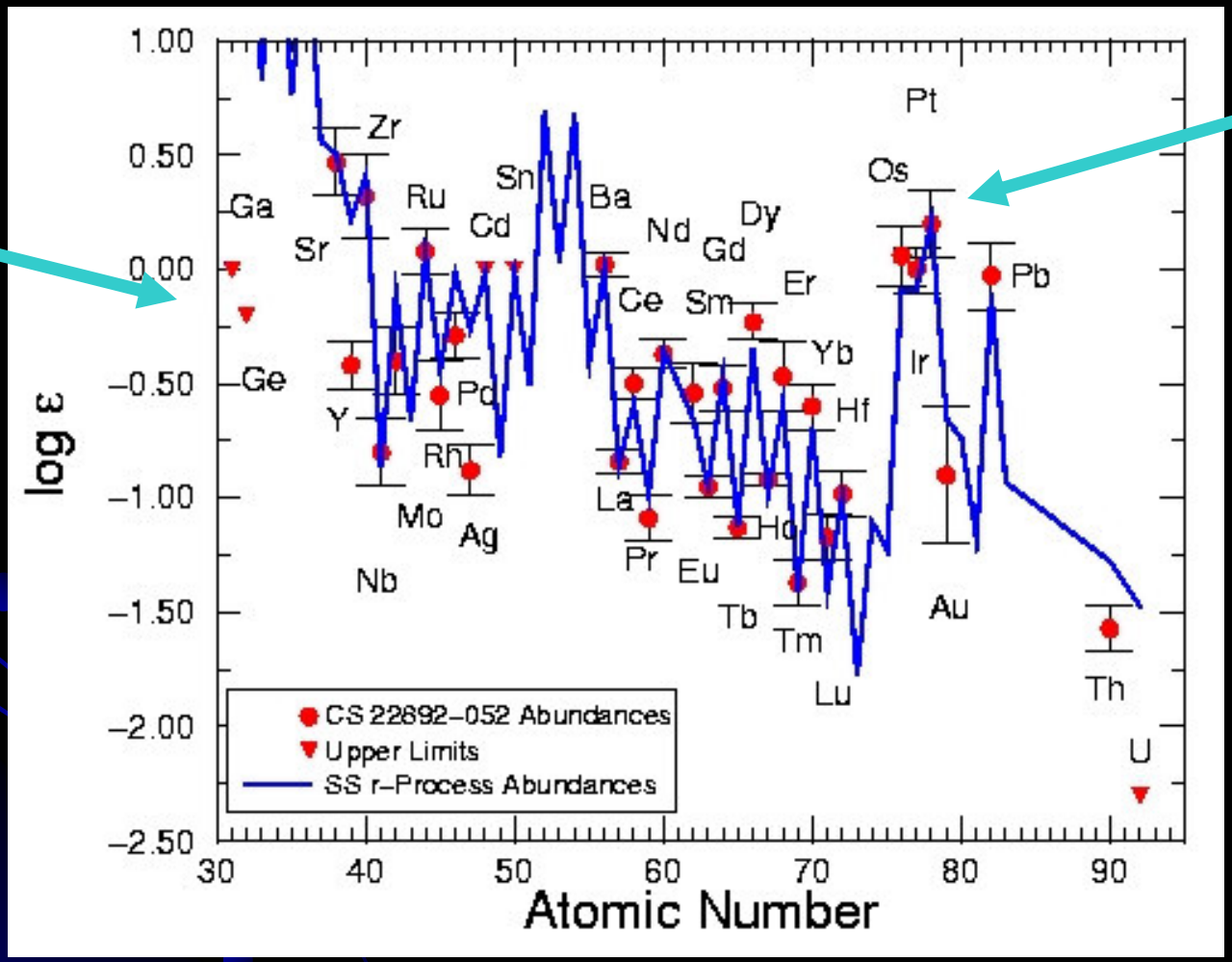


New experimental atomic physics data. Lawler et al. (2004).

Working our way through the Periodic Table!

CS 22892-052 Abundances

Cowan et al. (2004)



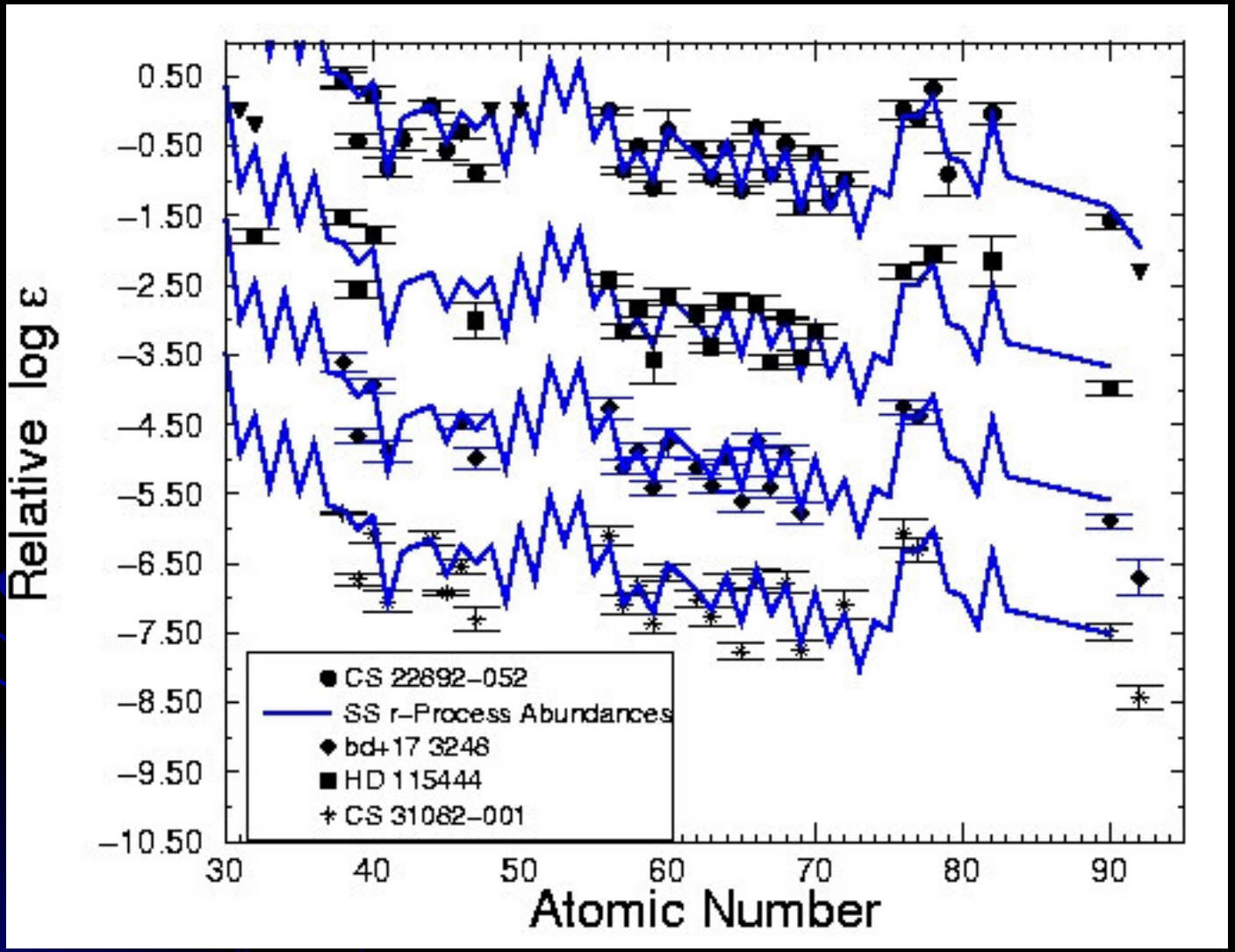
Germanium

Platinum

57 elements observed. More than any star except the Sun.

$$\text{Log } \varepsilon(A) = \log_{10}(N_A/N_H) + 12$$

Halo Star Abundances



4 r-process rich stars

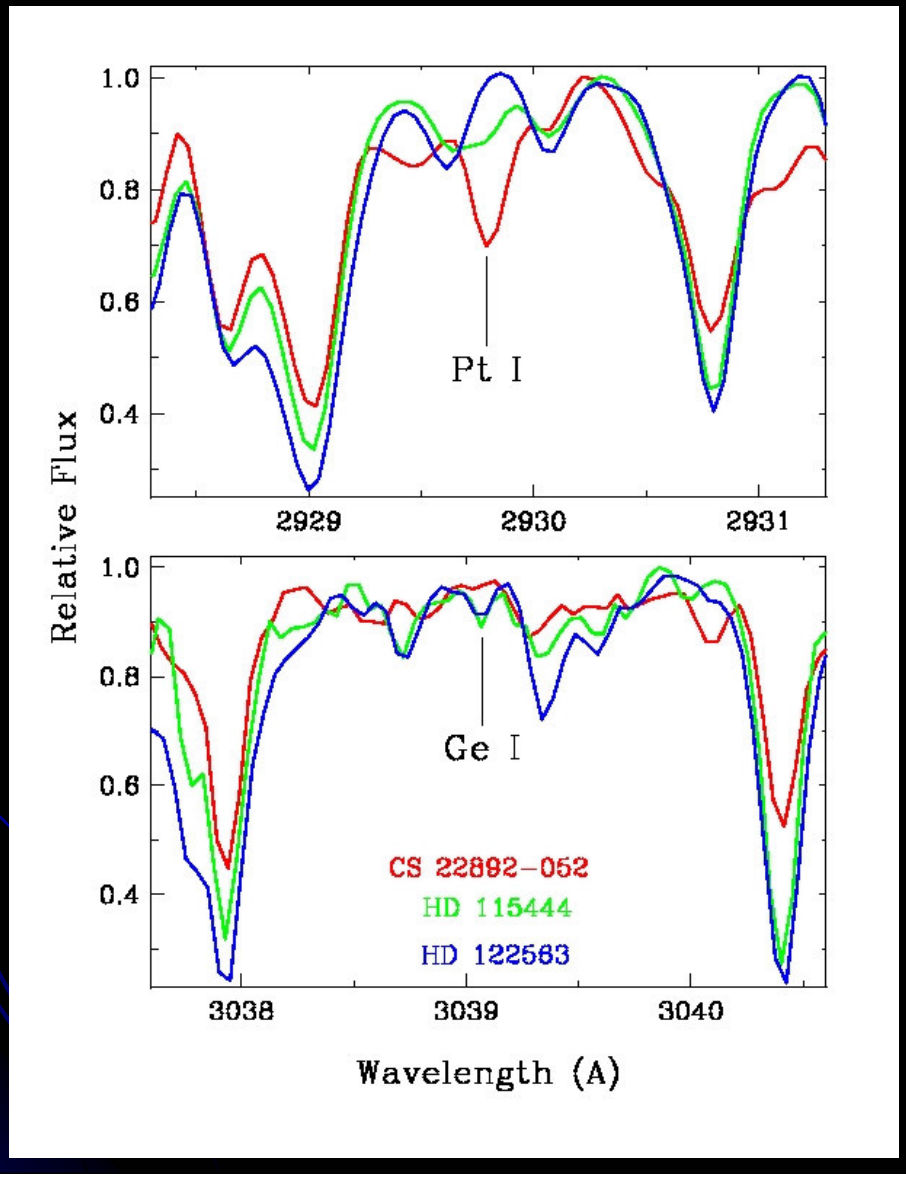
Light n-Capture Elements: Evidence for a Second r-process ?

- Only recently any detections of elements, Z = 40-50
  → Best evidence CS 22892-052
- Heavier element (Z ≥ 56) abundances seem to follow SS r-process curve, not so for the lighter elements
  → Same pattern appears in several other r-process rich stars
- Two separate sites (Wasserburg, Busso & Gallino): strong and weak r-process (2 types of SNe or SNe and NS mergers) or
- One site (different epochs or regions)

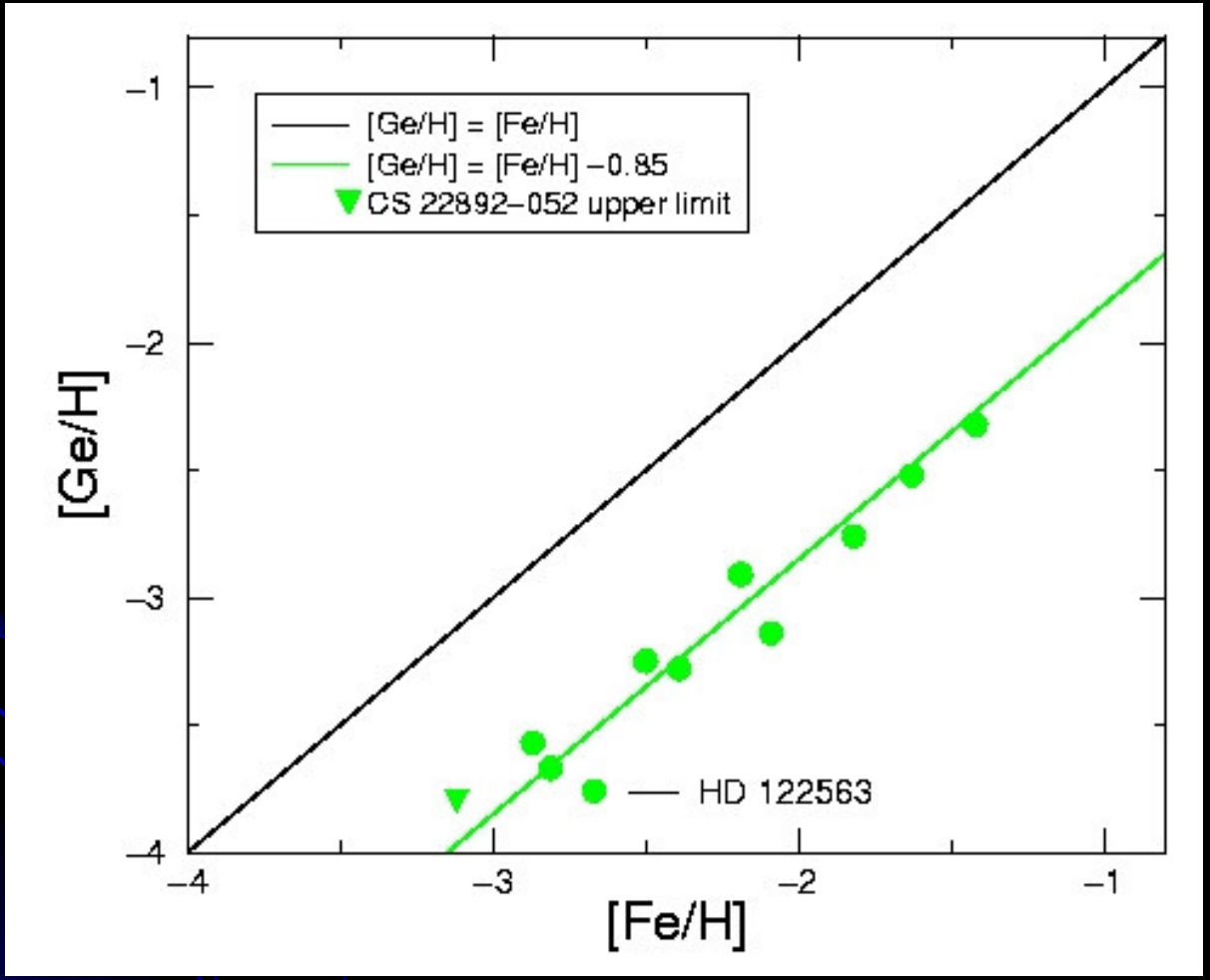
New HST Abundance Observations

- Dominant transitions for elements such as Ge, Os and Pt in NUV requires HST
- New abundance determinations of these elements (and Zr) in 11 metal-poor halo stars
- Attempt to identify abundance trends and correlations

NUV HST STIS Spectra



Ge Abundances in Halo Stars

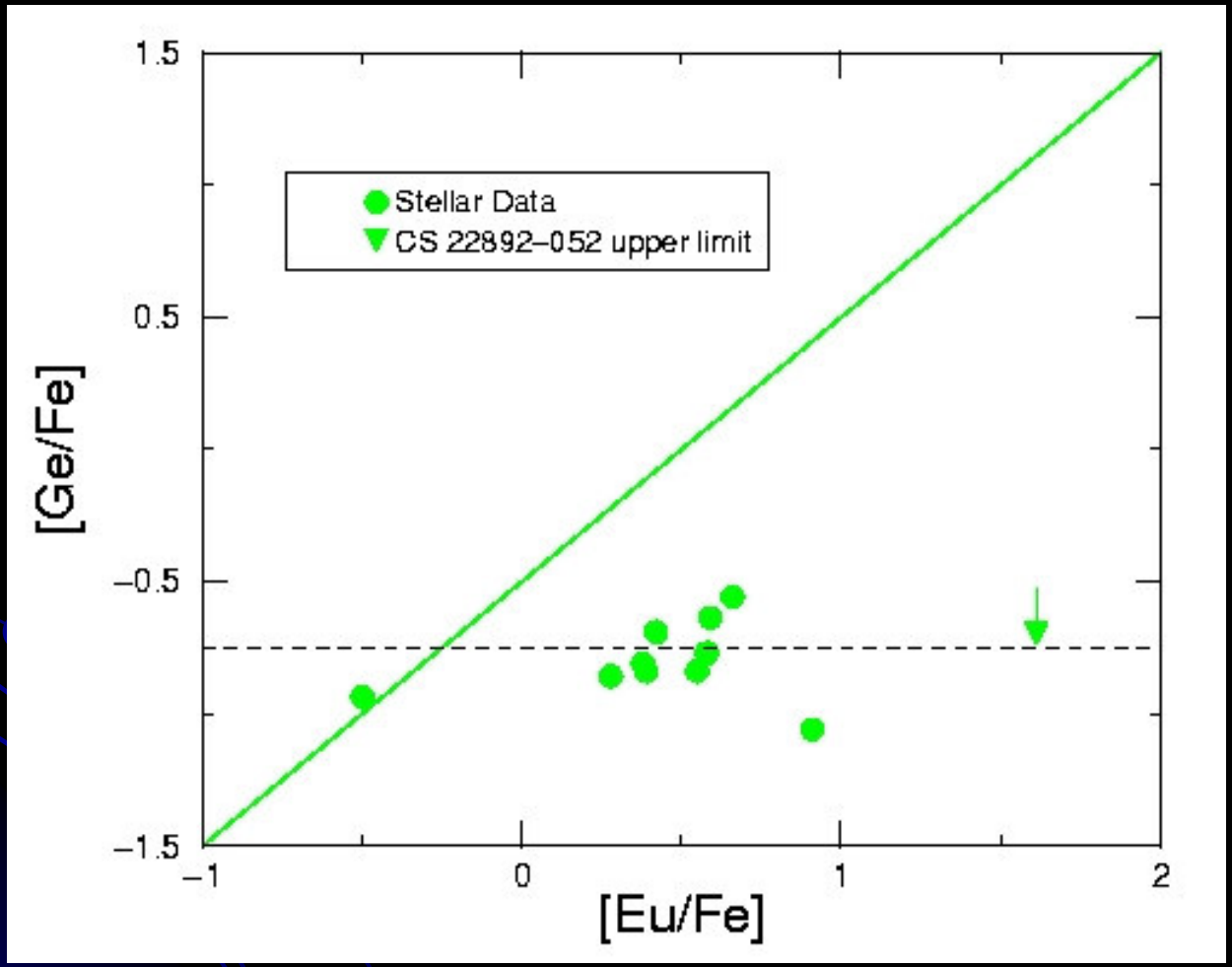


Ge ∝ Fe

JC et al. (2004)

$[A/B] = \log_{10}(A/B)_{star} - \log_{10}(A/B)_{sun}$

Ge vs. Eu in Halo Stars

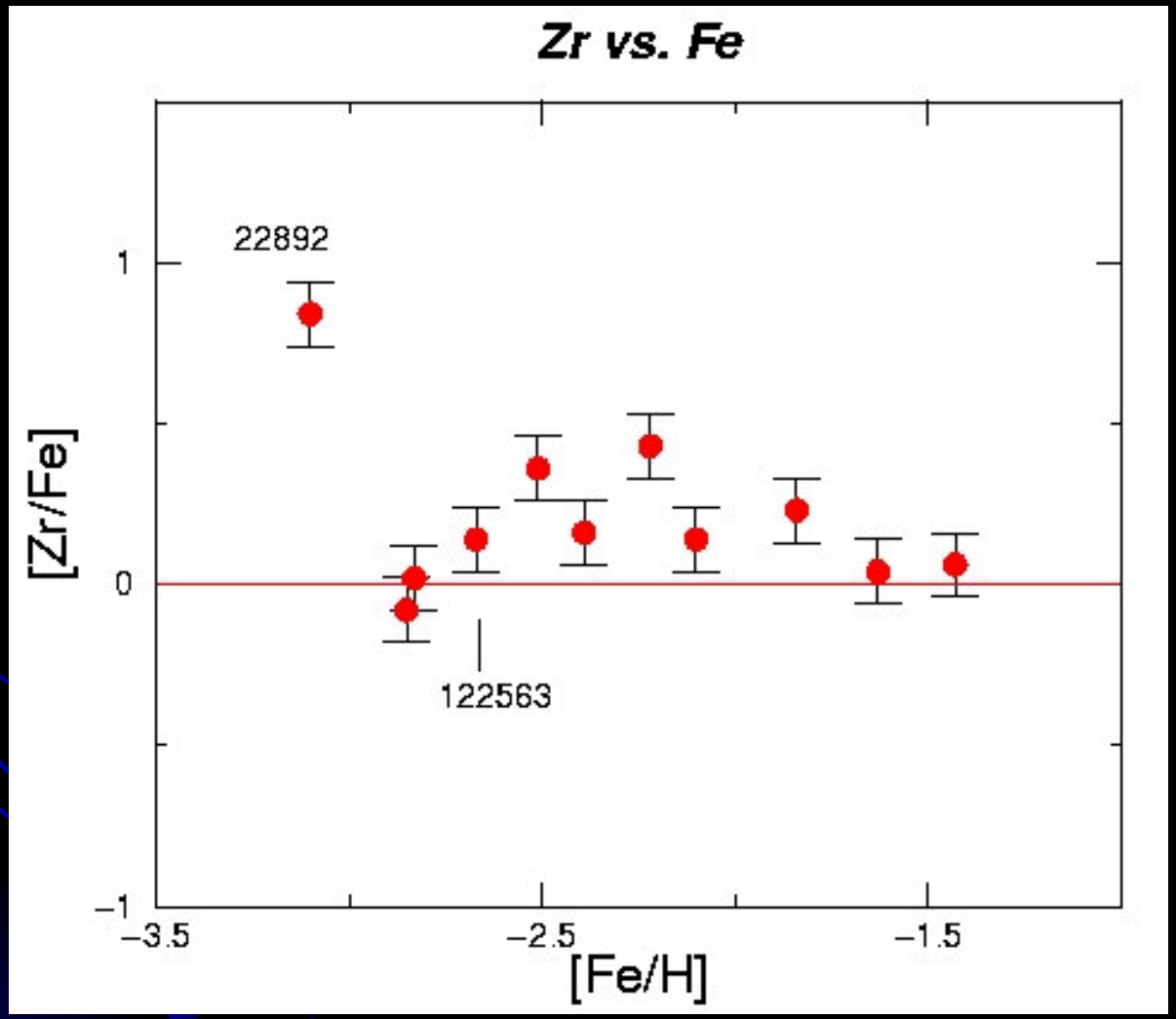


Ge $\propto$ Eu

JC et al. (2004)

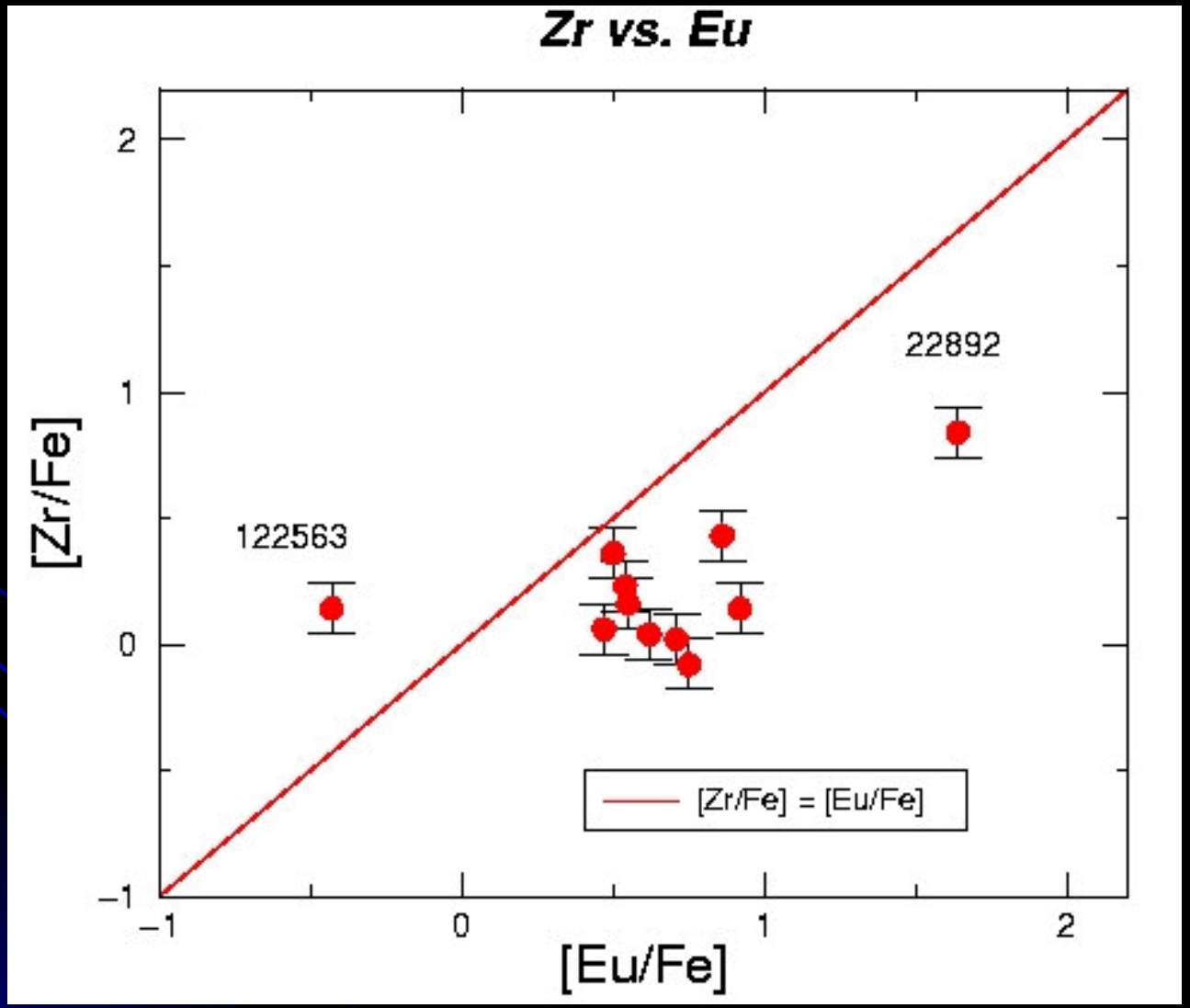
$$[A/B] = \log_{10}(A/B)_{star} - \log_{10}(A/B)_{sun}$$

Zr as a Function of Metallicity



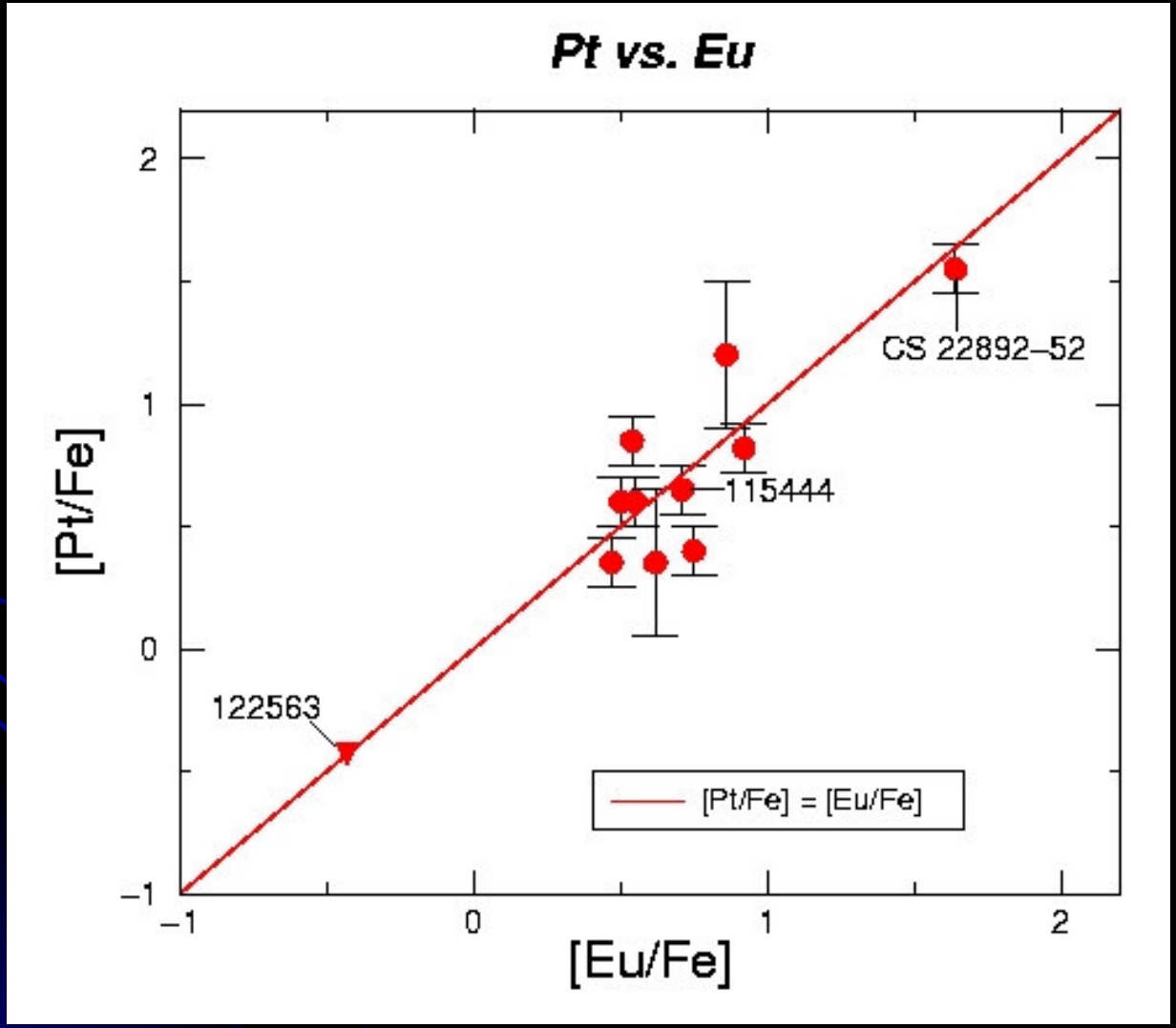
Zr independent of [Fe/H], as shown already by Travaglio et al. (2004).

Zr and Eu Abundances in Halo Stars



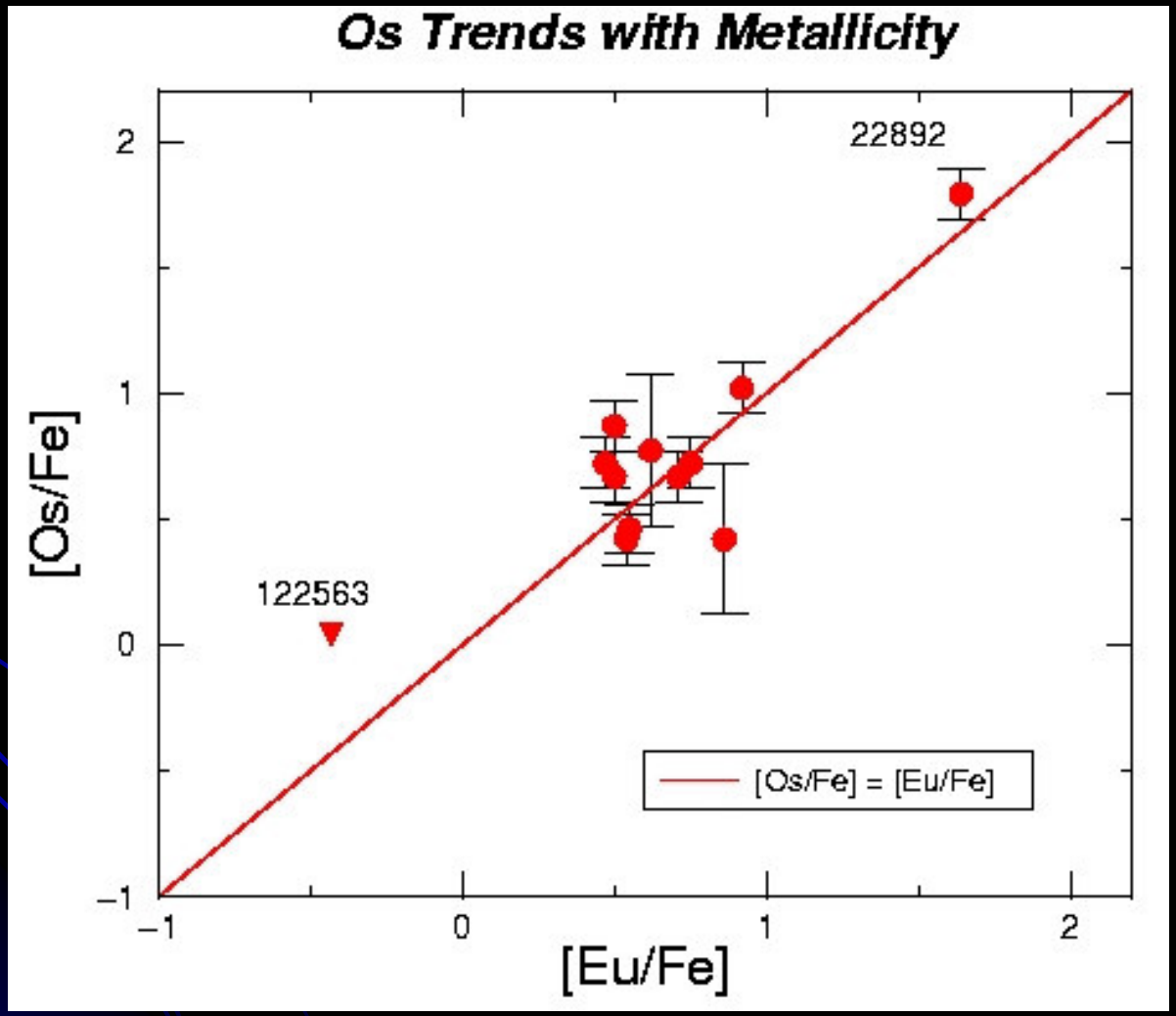
Zr ∝ Eu

N-Capture Element Correlations



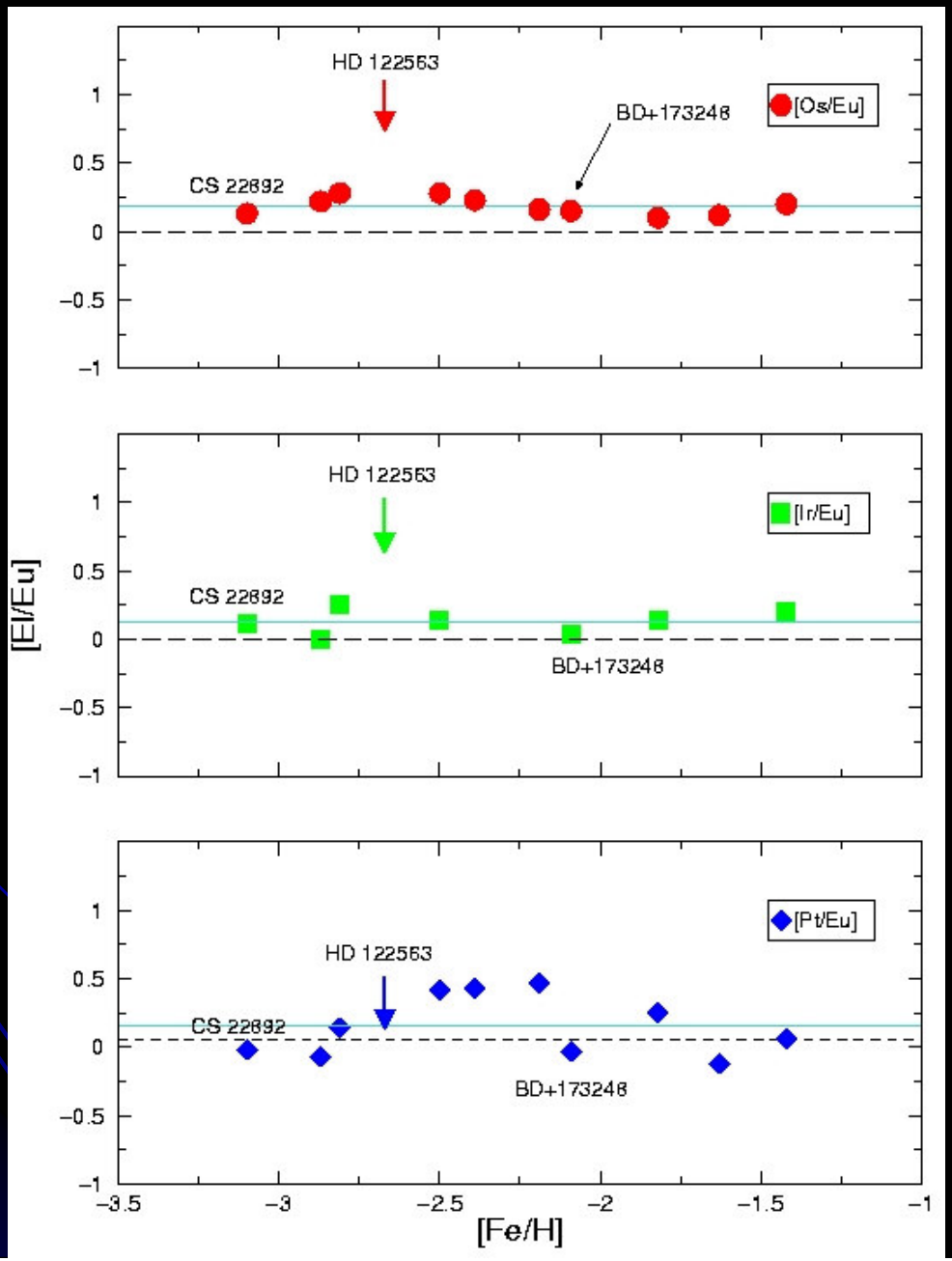
Pt ∝ Eu

N-Capture Element Correlations

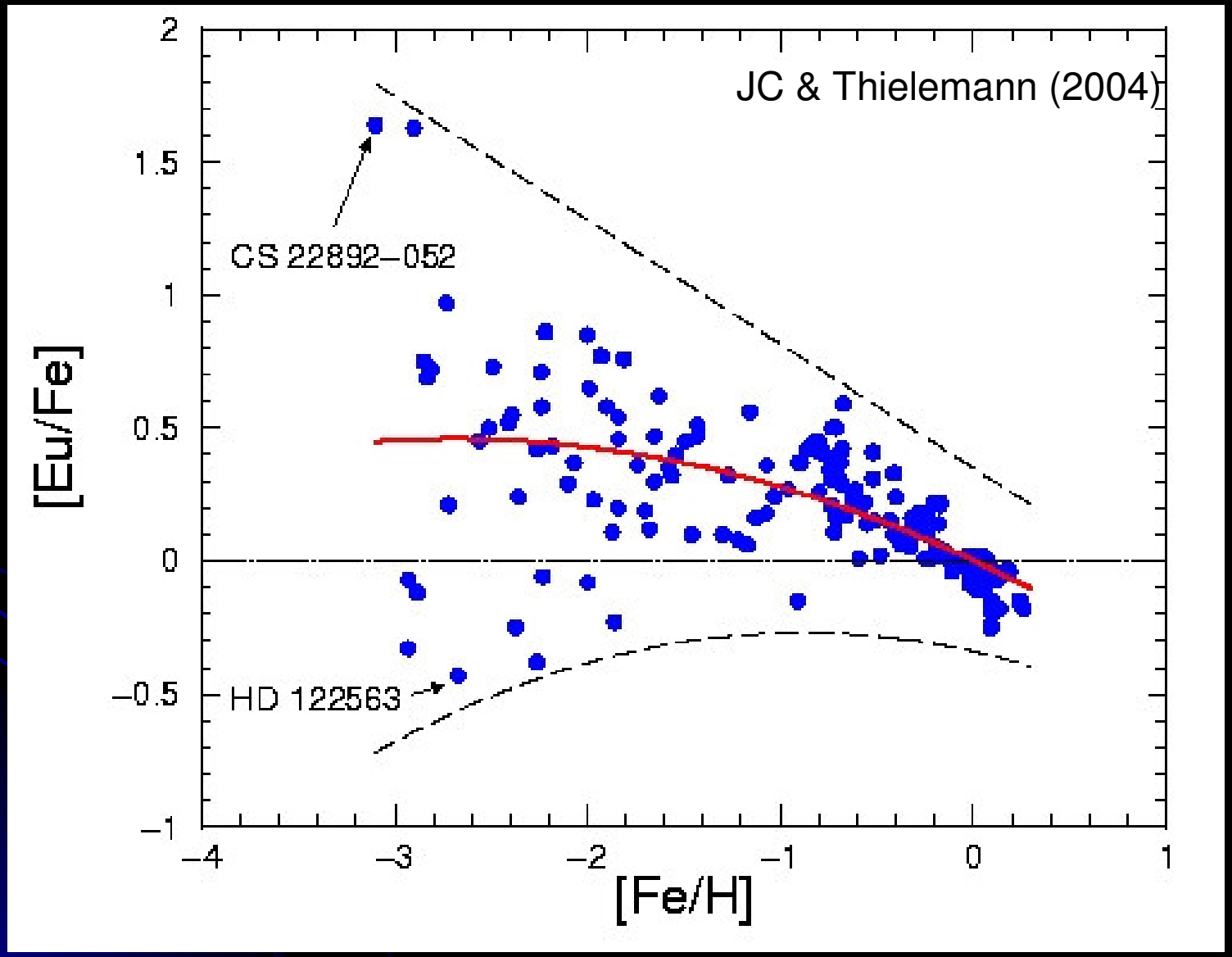


Os ∝ Eu

N-Capture Element Correlations



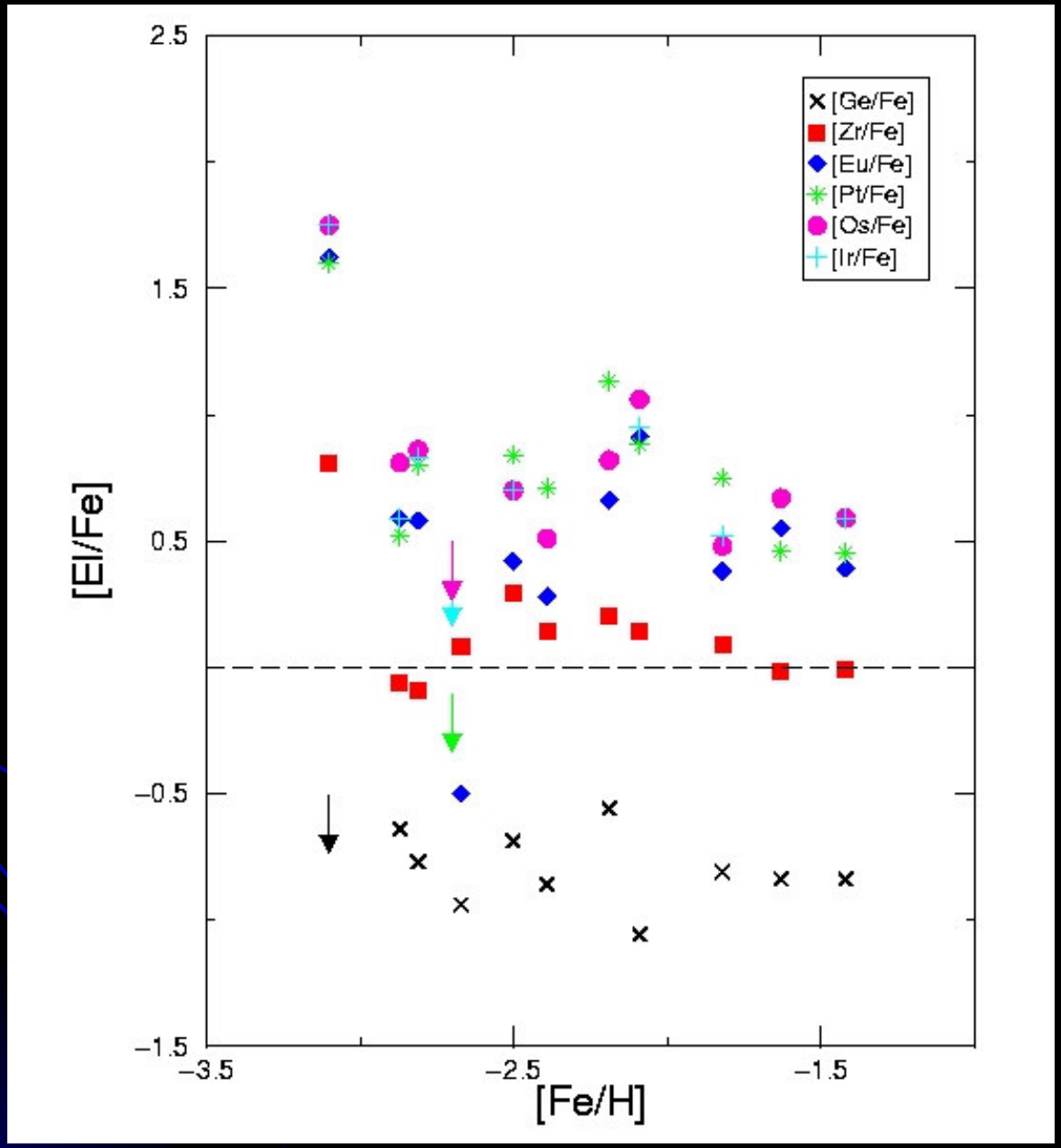
Eu Abundance Scatter in the Galaxy



N-Capture Element Abundance Trends

Os-Pt & Eu correlated and show similar scatter with [Fe/H]

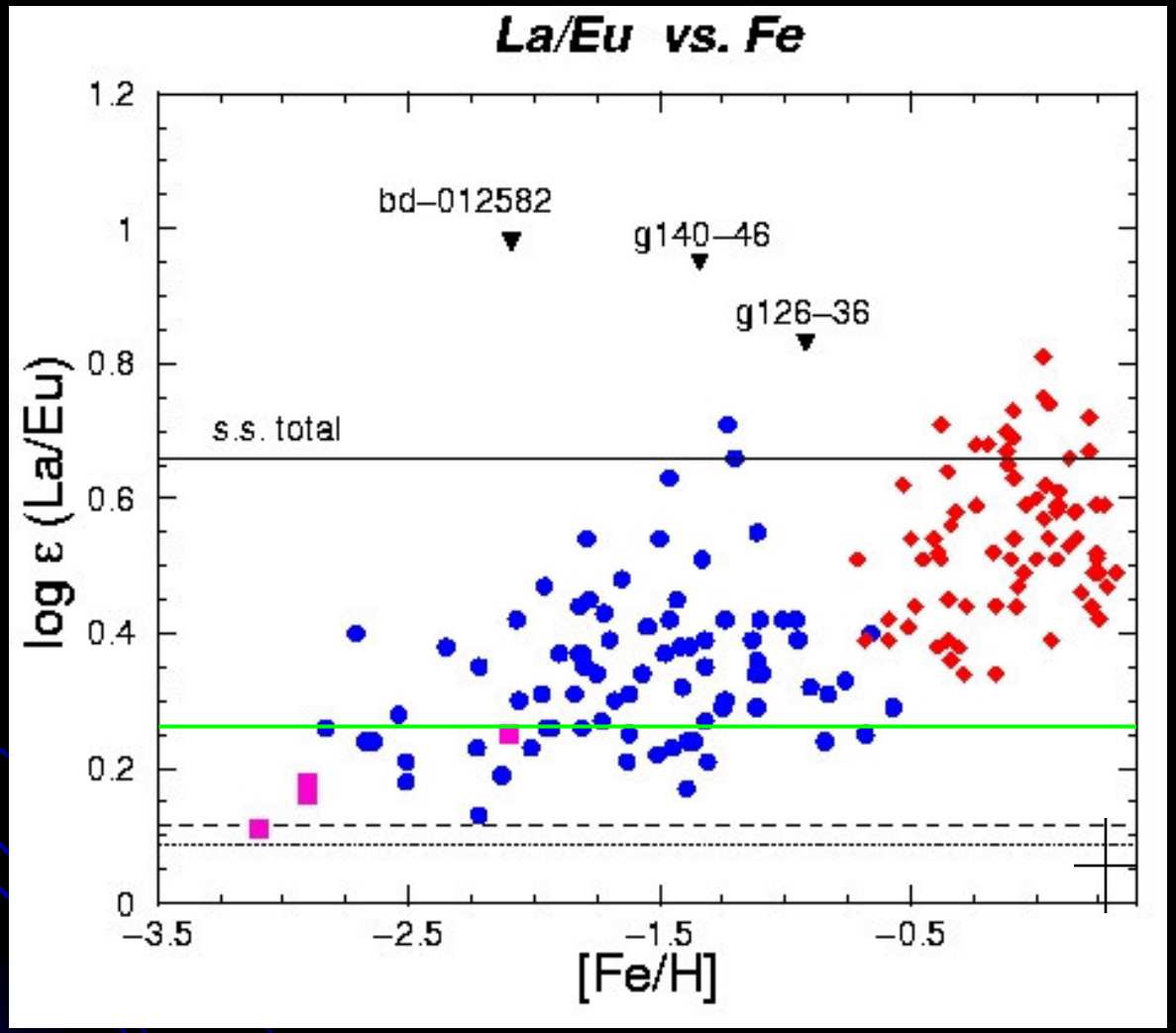
RARE



Ge & Zr Show little Scatter.

COMMON

R- and S-Process Abundance Trends



Simmerer et al. (2004)

O'Brien et al. (2003)

Burris et al. (2000)

r-process only

Some Concluding thoughts on: Element Synthesis

- Ge, thought of as an n-capture element, appears to be correlated with Fe
- Zr (like Sr & Y) complicated:
  - → not correlated with metallicity or with heavier n-capture element abundances
  - → not same origin as Eu, some primary (Travaglio et al. 2004)
- Element abundances from Z = 40-50 may be uniform in r-process rich stars, but below upper end
- Os,Ir,Pt correlated with Eu abundances

Some Concluding Thoughts on: Abundance Trends in the Galaxy

- New Os-Pt abundance values show same scatter as [Eu/Fe] at low metallicity
- New La/Eu ratios more reliable than Ba/Eu:
  1. Show scatter
  2. Only most metal-poor stars show r-process only ratio
  3. Stresses importance of nuclear measurement
  4. Some “dusting” of s-process even at [Fe/H] < -2 ?

Some Concluding thoughts on: Nucleosynthesis Early in the Galaxy

- R-process elements observed in very metal-poor halo stars
- Implies that r-process sites, earliest stellar generations,

→ rapidly evolving : live and die, eject r-process material into ISM prior to formation of halo stars

- Elements (even s-process ones like Ba) produced in r-process early in Galaxy
- Robust for heavy end :

→ places constraints on sites for the r-process