PROBING THE NUCLEOSYNTHEIS PRODUCTS OF THE FIRST STARS

J. J. COWAN
University of Oklahoma

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)
Solar System Abundances

Focus On Individual Elements: Nd

Focus On Individual Elements: Ho


Working our way through the Periodic Table!
CS 22892-052 Abundances

Cowan et al. (2004)

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

Germanium

Platinum

57 elements observed. More than any star except the Sun.
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 ($Z \geq 56$) 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

Relative Flux

Wavelength (Å)

Pt I

Ge I

CS 22882-062
HD 115444
HD 122553
Ge Abundances in Halo Stars

\[ [\text{Ge}/\text{H}] = \log_{10}(\text{Ge}/\text{H})_{\text{star}} - \log_{10}(\text{Ge}/\text{H})_{\text{sun}} \]

Ge \propto Fe

JC et al. (2004)
Ge vs. Eu in Halo Stars

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

![Graph showing Zr vs. Eu abundances](image)

Zr and Eu are positively correlated (Zr ∝ Eu) as seen in the graph. The 
[Zr/Fe] vs. [Eu/Fe] plot displays a clear linear relationship, indicating a
consistent abundance ratio between Zr and Eu across the studied
objects.
N-Capture Element Correlations

Pt vs. Eu

[Pt/Fe] vs. [Eu/Fe]

CS 22892–52
115444
122563

Pt $\propto$ Eu
N-Capture Element Correlations

Os Trends with Metallicity

Os \propto \text{Eu}
N-Capture Element Correlations
Eu Abundance Scatter in the Galaxy

JC & Thielemann (2004)
Os-Pt & Eu correlated and show similar scatter with [Fe/H]

N-Capture Element Abundance Trends

Ge & Zr Show little Scatter.

RARE

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