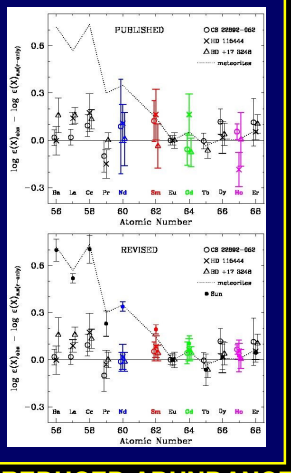
Abundance Signatures in Halo Stars: Clues to Nucleosynthesis in the First Stars

John Cowan (U. Oklahoma), Chris Sneden (U. Texas), Jim Lawler, Betsy Den Hartog (U. Wisconsin), Jason Collier (U. Oklahoma)

ABSTRACT

We are using both space-based (Hubble Space Telescope, HST) and ground-based telescopes to make extensive studies of Galactic halo stars. These stars contain nucleosynthesis products (from the rapid neutron capture process, r-process) from the earliest generations of stars – the progenitors of the halo stars. The observed stellar abundance distributions – from the lightest neutron-capture elements such as Ge, along with some of the heaviest, including Pt – are providing new clues about the earliest Galactic r-process nucleosynthesis. These in turn will help to identify the characteristics and nature of the first stars in the Galaxy.

ABUNDANCE DETERMINATIONS AND ATOMIC DATA

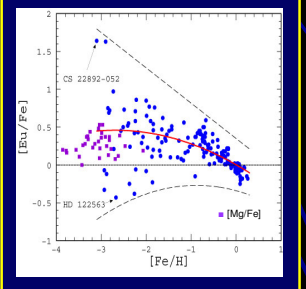


REDUCED ABUNDANCE UNCERTAINTIES:

Differences between n-capture elemental abundances in 3 halo stars and the Sun based upon older atomic data (top panel) and newer experimental data (bottom panel). Differences equal to zero, lying on the solid horizontal line, indicate perfect agreement with solar system r-process only predictions. Total solar system s- plus r-process abundances are also shown (from Lawler et al. 2004, 2006, 2007 and Den Hartog et al. 2003, 2006).

ABUNDANCE SCATTER IN THE GALAXY

Eu/Fe (and Mg/Fe) for a sample of halo and disk stars from Cowan & Thielemann 2004 (Cayrel et al. 2004). The solid red line is a least-square fit to the Eu data, the dotted line indicates a solar value and the two dashed lines are illustrative to indicate the extent of the Eu/Fe data.

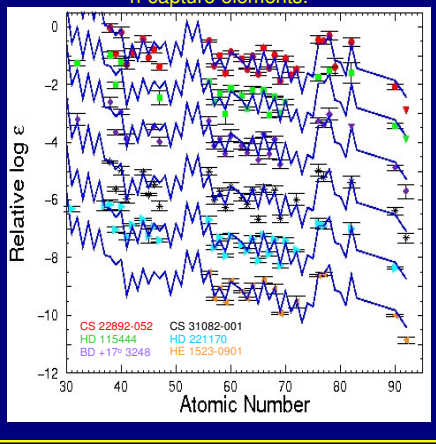


EARLY GALACTIC NUCLEOSYNTHESIS:

- Large scatter in Eu/Fe but not Mg/Fe at low metallicities and early Galactic times
- Suggests Galaxy chemically unmixed and inhomogeneous in r-process (Eu/Fe) elements, but not in α-elements (Mg/Fe)
- Further suggests different environments (e.g., stellar mass ranges) for the synthesis of these elements

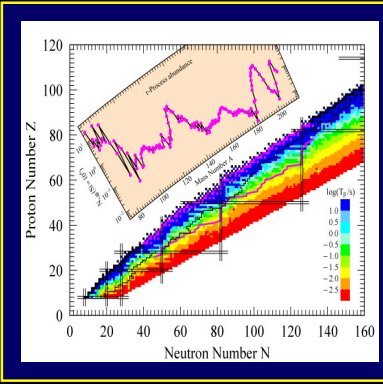
STELLAR ABUNDANCE SIGNATURES

Comparisons of neutron-capture abundance in six r-process rich Galactic halo stars. The solid lines are the scaled r-process only solar system (SS) elemental abundance curves. Note the agreement between the SS curve and the stellar curves for Ba (Z=56) and above, and the differences for the lighter n-capture elements.



From Sneden et al. 2003, Westin et al. 2000, Cowan et al. 2002, Hill et al. 2002, Ivans et al. 2006, Frebel et al. 2007.

NUCLEAR ISOTOPES IN NATURE

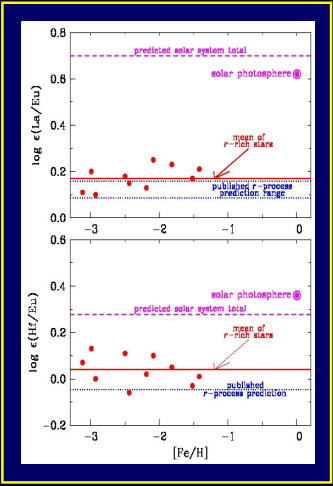


Möller, Kratz & Nix 1997, At. Dat. Nuc. Dat. Tabl., 66, 131

THE SYNTHESIS OF THE r- AND s-PROCESS ISOTOPES:

- Stable isotopes indicated by black boxes define the valley of β-stability
- s-process nuclei formed near the valley, with long durations between neutron captures, allowing for experimental data
- r-process nuclei produced far from stability – an r-process path shown by magenta line – with very short times between n-captures (colors indicate half-lives for the radioactive nuclei)
- These nuclei not, in general, experimentally measured – black line indicates extent of experimental data at that time
- Stellar and solar abundance determinations providing new clues to our understanding of the synthesis of these nuclei – particularly the sites and the astrophysical conditions for their formation

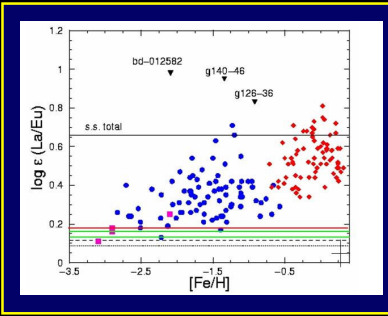
OBSERVED LA/EU AND HF/EU RATIOS IN METAL-POOR STARS



ABUNDANCE ANALYSIS:

- New atomic data refines Hf & La abundances in the Sun & 10 halo stars
- Observed ratios of La/Eu and Hf/Eu larger than previous estimates of SS r-only values
- Suggests larger contribution to Hf and La from the r-process (from Lawler et al. 2007)

OBSERVED LA/EU RATIOS AS A FUNCTION OF METALLICITY



INITIAL r-PROCESS-ONLY VALUE & ONSET OF THE s-PROCESS:

La/Eu measures the relative contribution of the s- and r-process respectively. Filled circles are halo stars, diamonds are disk stars, labelled stars are s-process rich and pink squares are r-process rich (after Simmerer et al. 2004 and Cowan & Sneden 2006). The generally upward slope of the data indicates the increasing contribution of the s-process with metallicity (and Galactic age). The dotted, dashed and green lines are various published predictions for the initial r-process only-value for La/Eu. The red line is the average observational value based upon the data shown in the top-right panel.

ACKNOWLEDGMENTS: This work has been supported by the National Science Foundations through grants AST-0307279 to JJC, AST-0607708 to CS and AST-0506324 to JEL and EADH.

REFERENCES: Cayrel et al. 2004, A&A, 416, 1117; Cowan et al. 2002, ApJ, 572, 861; Cowan & Sneden 2006, Nature, 440, 1151; Den Hartog et al. 2003, ApJS, 148, 543; Den Hartog et al. 2006, ApJS, 167, 292; Frebel et al. 2007, ApJ, 660, L117; Hill et al. 2002, A&A, 387, 560; Ivans et al. 2006, ApJ, 645, 613; Lawler et al. 2004, ApJ, 604, 850; Lawler et al. 2006, ApJS, 162, 227; Lawler et al. 2007, ApJS, 169, 120; Simmerer et al. 2004, ApJ, 617, 1091; Sneden et al. 2003, ApJ, 591, 936; Westin et al. 2000, ApJ, 530, 783