r-Process Abundances in the EMP Star CS 31082-001

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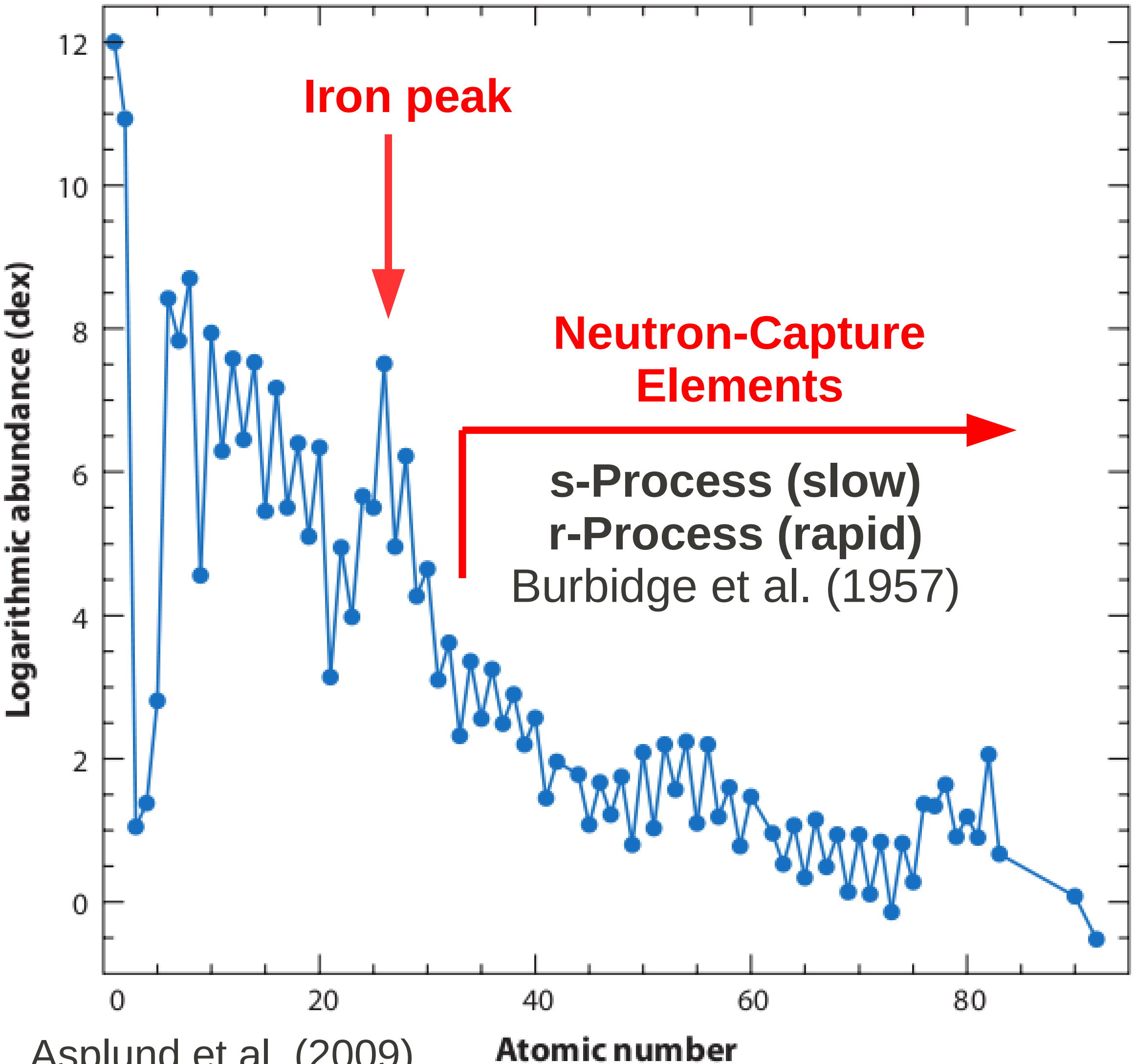
Context

- The origin of the r-process elements
- The ESO large programme "First Stars"

The EMP star CS 31082-001

- STIS/HST observations
- Abundance determinations
- Comparisons with r-process models



Asplund et al. (2009)

Site(s) of the Mechanisms

(main) s-Process → thermally pulsing AGB stars

(main) r-Process → high-entropy wind of core-collapse supernovae

low mass O-Ne-Mg core supernovae

merger of two neutron stars in binary systems

Observational Clues

Extremely Metal-Poor (EMP) r-Element Enhanced Stars

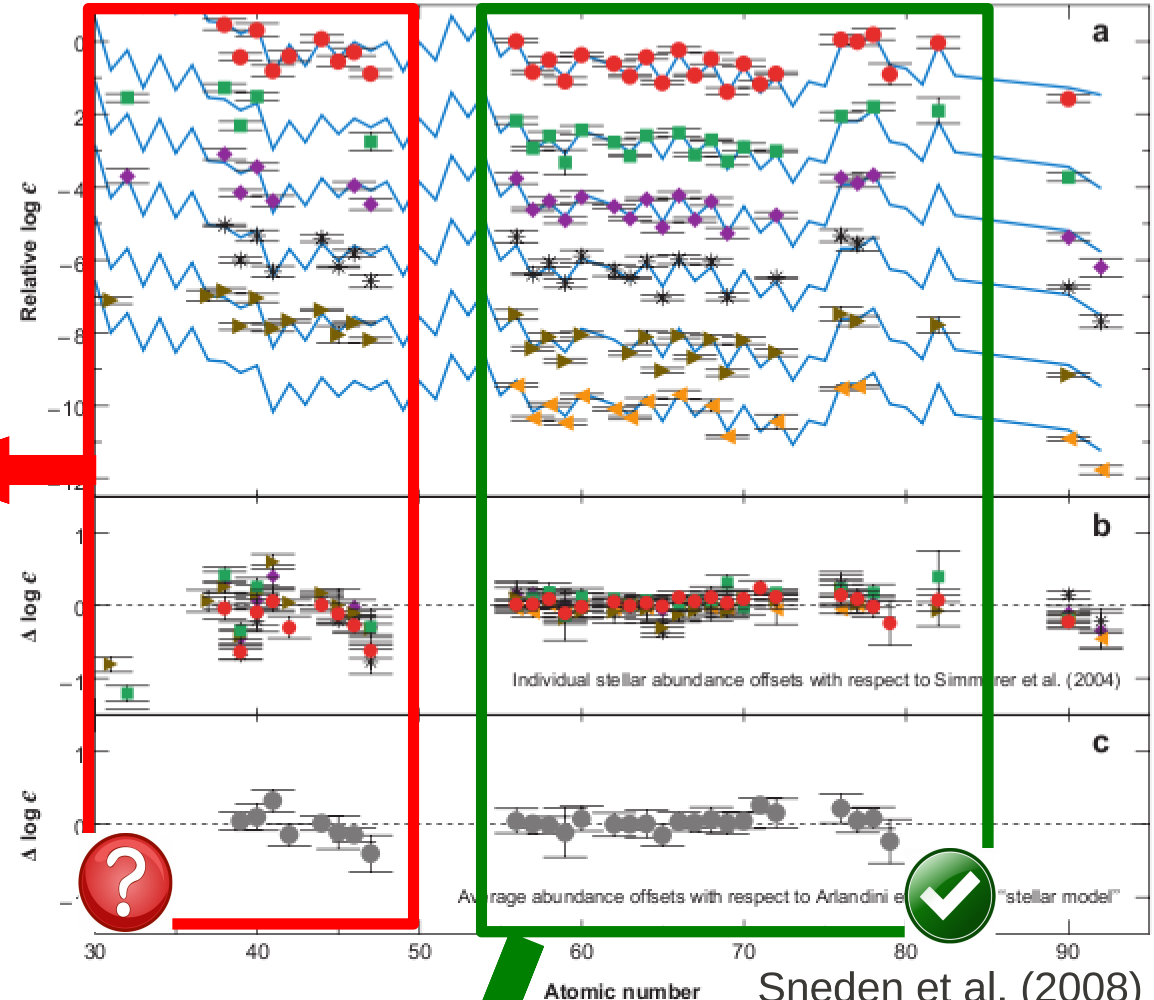
Abundance comparisons between r-process stars and the Solar System r-process values

First Peak Problem

Multiple sources of the lightest trans-Fe elements

p-process
"weak" s-process
"weak" r-process
light element primary process
νp-process
charged-particle reactions

Same or different site(s)??



Sneden et al. (2008)

- CS 22892-052: Sneden et al. (2003)
- HD 115444: Westin et al. (2000)
- BD+17°324817: Cowan et al. (2002)
- CS 31082-001: Hill et al. (2002)
- HD 221170: Ivans et al. (2006)
- HE 1523-0901: Frebel et al. (2007)

"main" r-process
Same process in the early Galaxy and in the Solar System
Universal process???

Need for more stellar observations

Important Example
The ESO Large Programme "First Stars"

First stars V - Abundance patterns from C to Zn and supernova yields in the early Galaxy*,**

First stars VI – Abundances of C, N, O, Li, and mixing in extremely metal-poor giants. Galactic evolution of the light elements*

First stars VII - Lithium in extremely metal poor dwarfs*,**

VIII. Enrichment of the neutron-capture elements in the early Galaxy*

Astronomy & Astrophysics

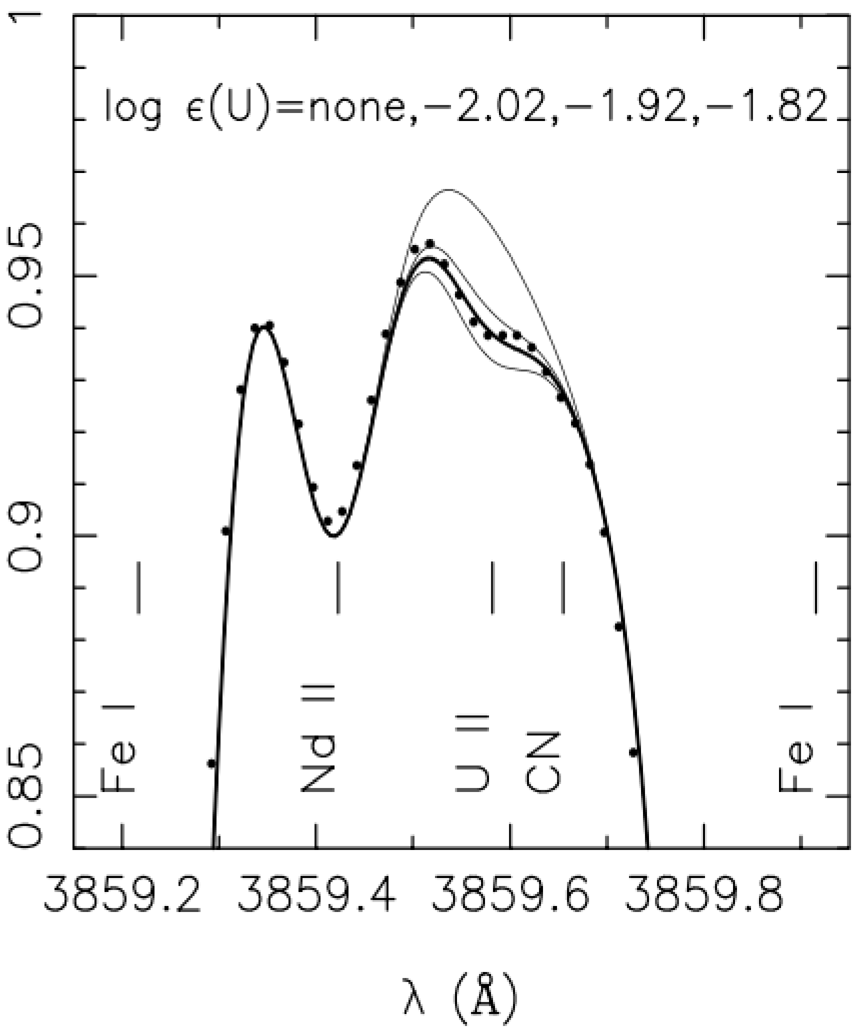
15 articles
2002 – 2011

+ Several others...

First stars. I. The extreme r-element rich, iron-poor halo giant CS 31082-001

Implications for the r-process site(s) and radioactive cosmochronology*

V. Hill[1], B. Plez[2], R. Cayrel[3], T. C. Beers[4], B. Nordström[5,6], J. Andersen[6], M. Spite[1], F. Spite[1], B. Barbuy[7], P. Bonifacio[8], E. Depagne[1], P. François[3], and F. Primas[9]



Actinide Boost

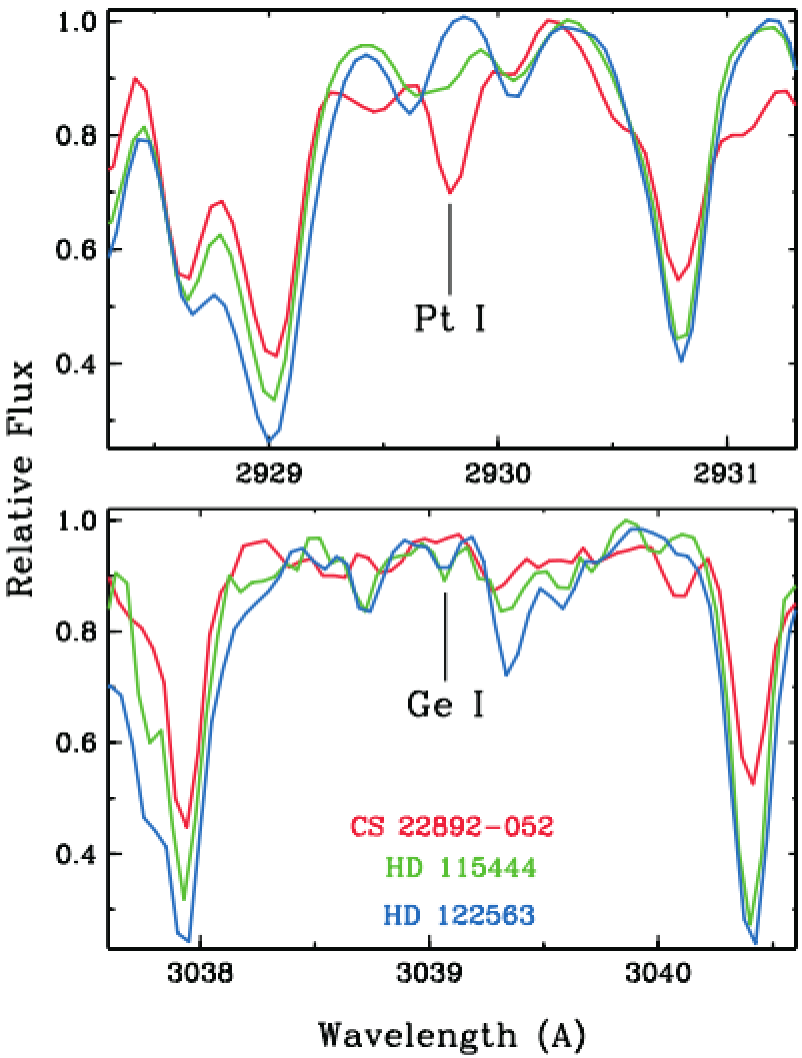
Th and U enhanced relative to the general r-process level

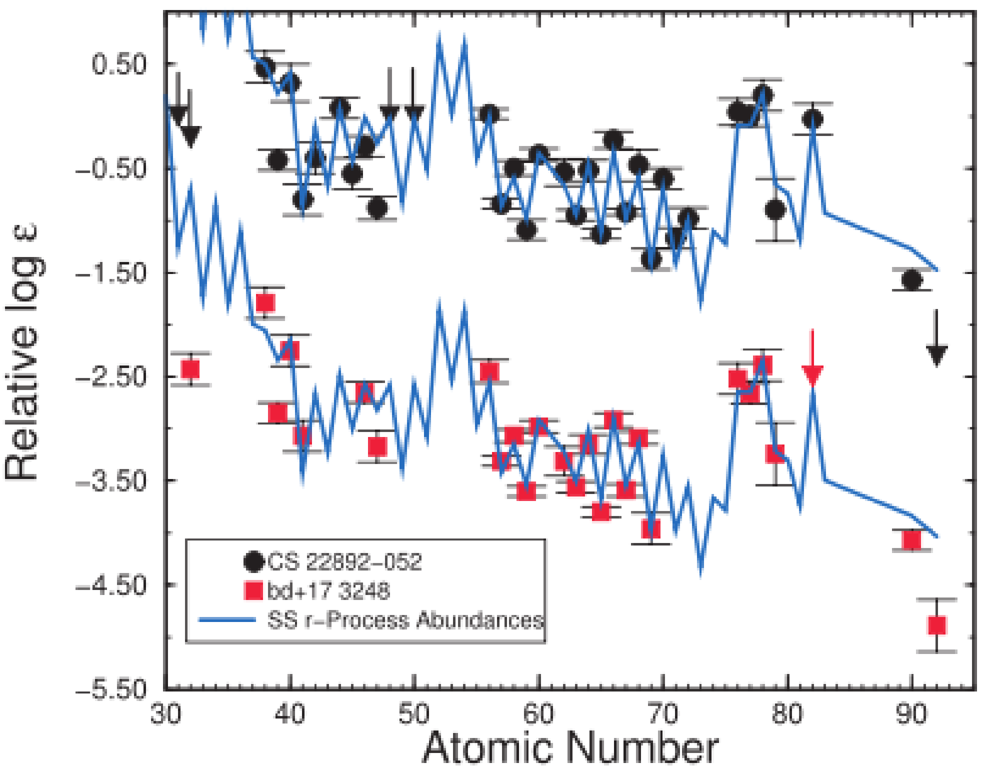
the actinides had a **different nucleosynthesis history** than the stable third-peak elements

a new piece at the problem of the r-process elements

in addition...

UV observations





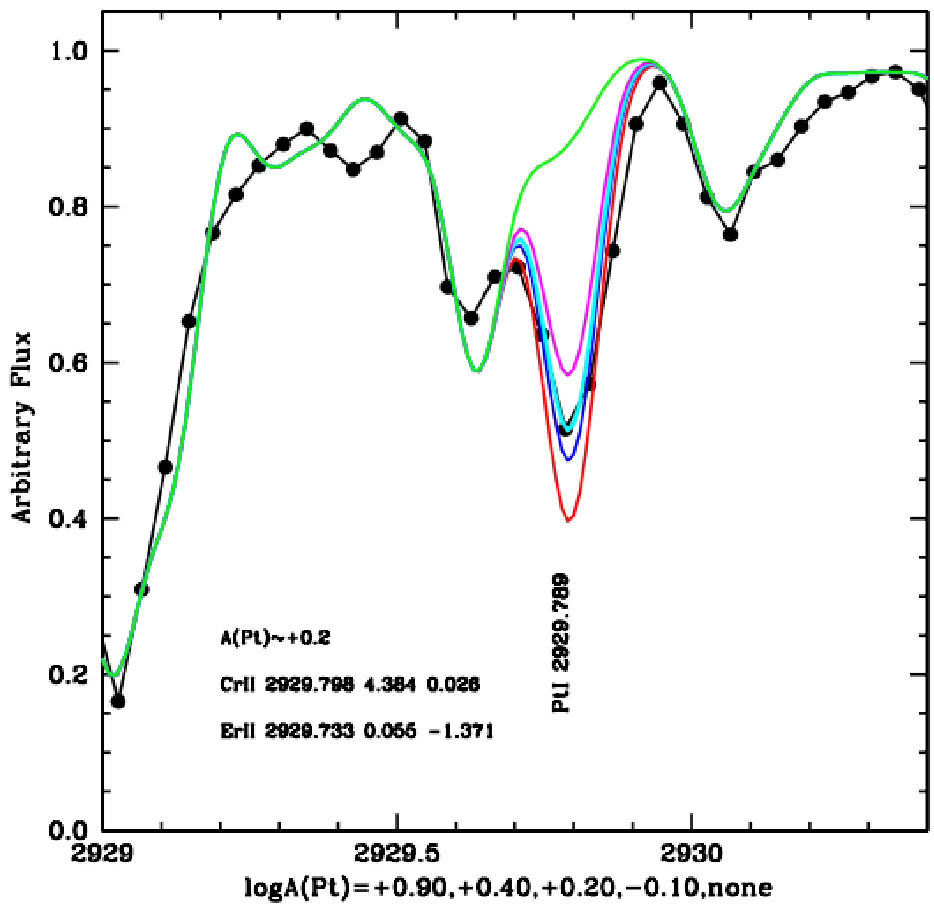
UV observations are crucial to examine the full range of the n-capture elements

Cowan et al. (2005)

First stars

XV. Third-peak *r*-process element and actinide abundances in the uranium-rich star CS31082-001★

B. Barbuy[1], M. Spite[2], V. Hill[3], F. Primas[4], B. Plez[5], R. Cayrel[2], F. Spite[2], S. Wanajo[6,7], C. Siqueira Mello Jr.[1], J. Andersen[8,9], B. Nordström[8], T. C. Beers[10], P. Bonifacio[2], P. François[2], and P. Molaro[11]



STIS/HST Observations of CS 31082-001

the **first** abundance determination for **all measurable 3rd peak elements** for an EMP r-II star

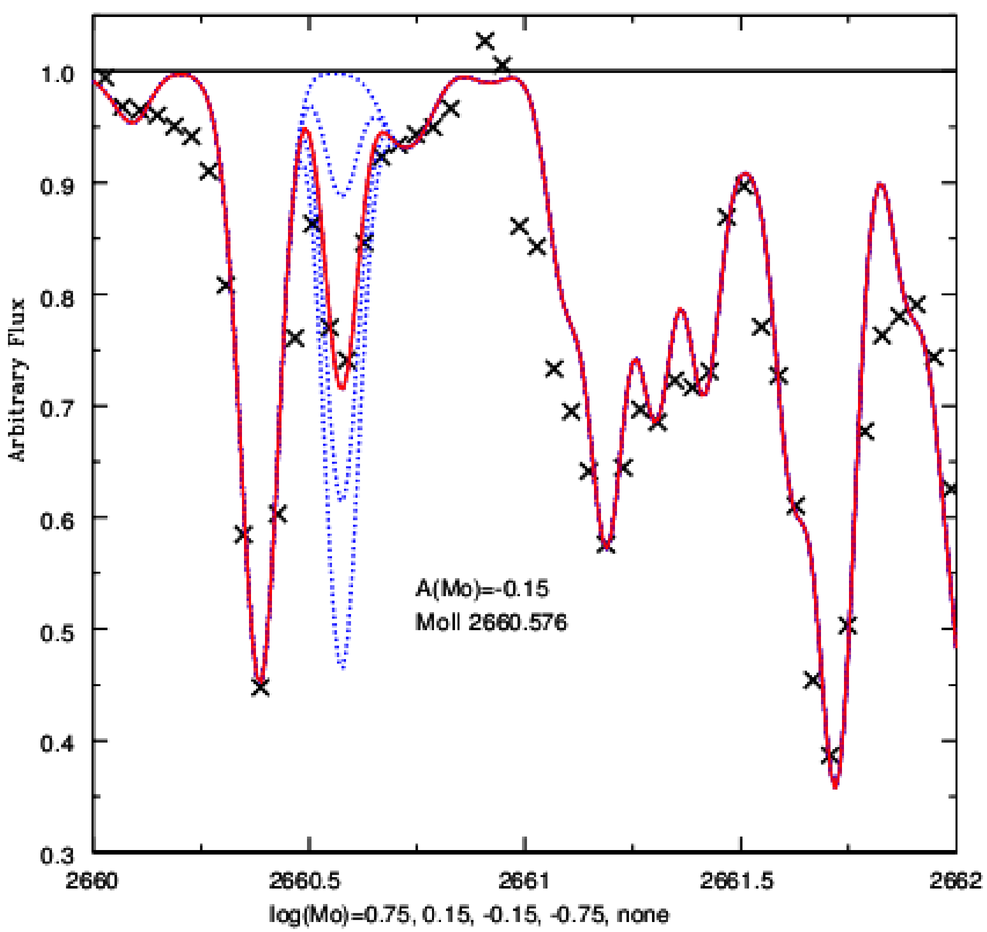
Element	Z	log $\epsilon(X)_\odot$	log $\epsilon(X)_*$ VLT	log $\epsilon(X)_*$ HST	log $\epsilon(X)_*$ adopted	log [X/Fe]$_*$ adopted
Os	76	+1.40	+0.43	–0.07	+0.18	+1.72
Ir	77	+1.38	+0.20	+0.18	+0.20	+1.72
Pt	78	+1.62	–	+0.30	+0.30	+1.46
Au	79	+0.92	–	–1.00	–1.00	+0.89
Pb	82	+1.75	-0.55	-0.65	-0.65	+0.25
Bi	83	+0.71	–	-0.40	–0.40	+1.83
Th	90	+0.17	-0.98	–	–0.98	+1.84
U	92	–0.07	-1.92	–	–1.92	+1.68

First Stars

XVI. STIS/HST abundances of heavy-elements in the uranium-rich star CS 31082-001⋆

C. Siqueira Mello Jr.[1,2], M. Spite[2], B. Barbuy[1], F. Spite[2], E. Caffau[2], V. Hill[3], F. Primas[4], B. Plez[5], R. Cayrel[6], S. Wanajo[7,8], J. Andersen[9,10], B. Nordström[9], C. Sneden[11], T.C. Beers[12], P. Bonifacio[2], P. François[6], and P. Molaro[13]

in preparation



1[st] and 2[nd] peak abundances

new **Ge**, **Mo, Lu, Ta, W, and Re** abundances
+
previous abundances

→ **37 detections** of n-capture elements

→ **the most complete r-II star studied**

Abundance determination

- OSMARCS LTE model atmosphere (Gustafsson et al. 2008)
- Spectrum synthesis code Turbospectrum (Alvarez & Plez 1998)

- Turbospectrum molecular line lists
- Atomic line lists from the VALD2 compilation (Kupka et al. 1999)
- Updated oscillator strengths from recent literature

- Adopted light element abundances: Hill et al. (2002), Cayrel et al. (2004), and Spite et al. (2005)
- The stellar parameters from Hill et al. (2002)

$T_{eff} = 4825 \pm 50$ K

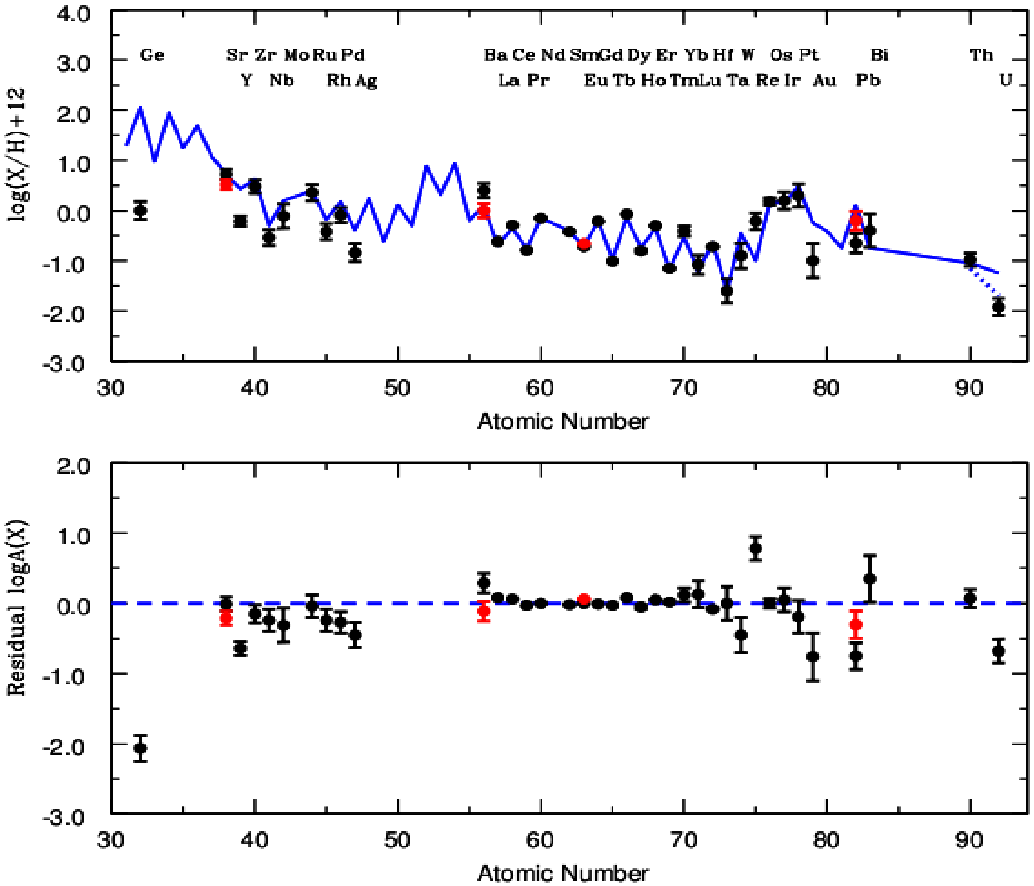
$\log g = 1.5 \pm 0.3$

$[Fe/H] = -2.9 \pm 0.1$

$v_t = 1.8 \pm 0.2$ km s^{-1}

STIS/HST
2600 - 3070 Å
S/N ~ 40 (required 45 orbits)
R = 30000

UVES/VLT
3000 - 3800 Å
S/N ~ 20 - 100
R = 75000



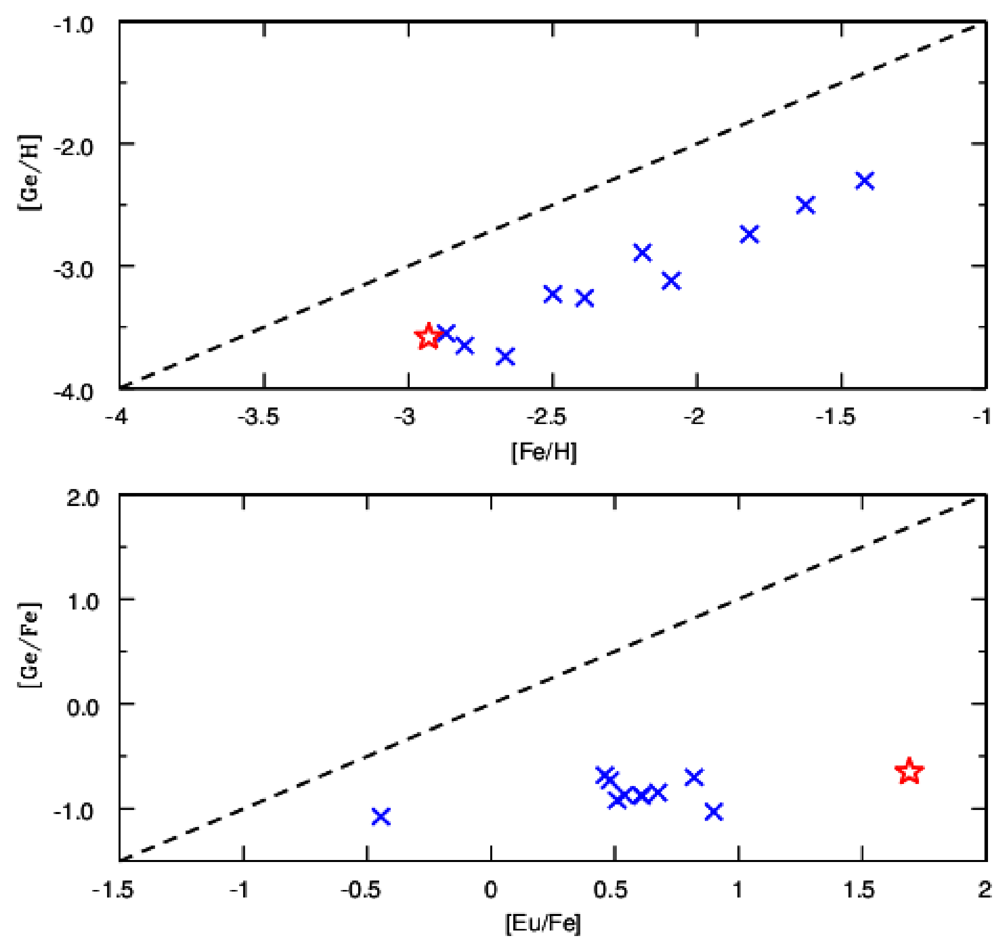
Solar r-process abundance from Simmerer et al. (2004) scaled to Eu

NLTE abundances for some elements (red dots) are compared with the LTE results

Andrievsky et al. (2009, 2011)

Mashonkina et al. (2012)

New NLTE+3D Pb abundance

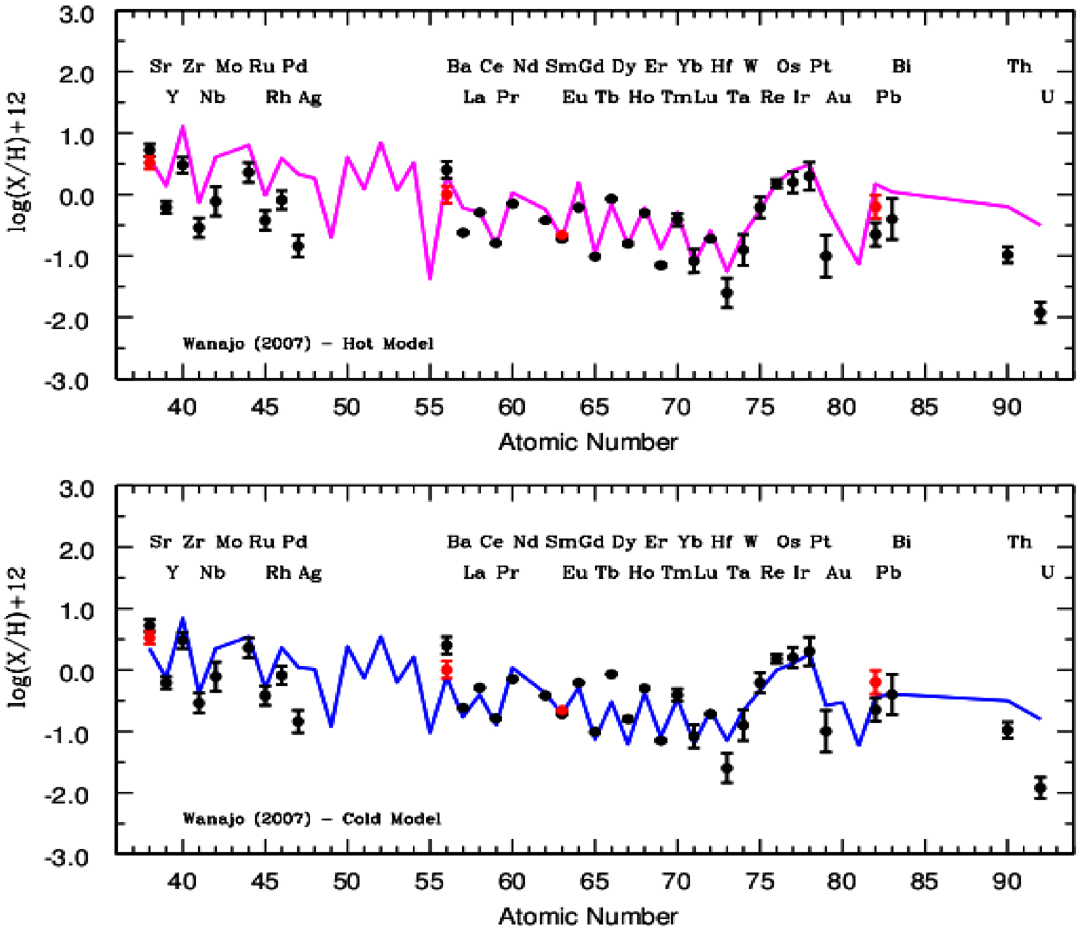


Trends of Ge

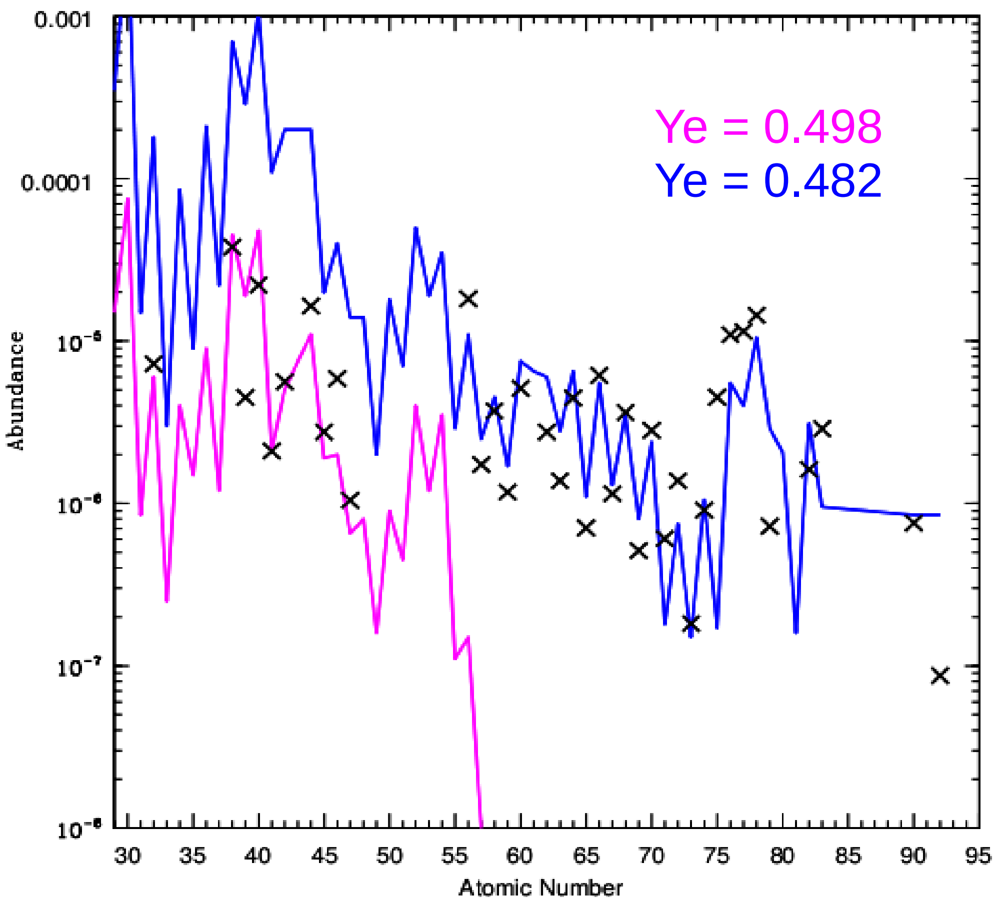
10 metal-poor stars Cowan et al. (2005)

+

CS 31082-001 (red star)



Hot (upper) and Cold (lower) models based on SN neutrino wind from Wanajo (2007)



r-process models from Farouqi et al. (2010), with different electron abundances

Results and Conclusion

New detections using the STIS/HST spectra:

→ first peak: new Ge and Mo abundances

→ second peak: new Lu, Ta, W, and Re abundances

→ third peak: new Pt, Au, and Bi abundances

New NLTE+3D Pb abundance

Comparisons between models and observations

→ combination of processes to reproduce the full range of observations