Bright Metal-Poor Stars from the Hamburg/ESO Survey

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Three Observational Steps to Find Metal-Poor Stars

1. Sample selection and visual inspection:
   Find appropriate candidates

2. Follow-up spectroscopy (medium resolution):
   Derive estimate for [Fe/H] from the Ca II K line

3. High-resolution spectroscopy:
   Detailed abundances analysis

Frebel et al. 2005b
HE 1327–2326

Basic and stellar parameters:
(see Frebel et al. 05, Aoki et al. 06)

- Magnitude: $B = 14.016$ mag
- Colour: $(B-V)_0 = 0.40$ mag
- Reddening: $E(B-V) = 0.06 - 0.096$

- $BVRIK$ photometry: $T_{\text{eff}} = 6180 \pm 80$K (on Alonso et al. 1996 scale)
- Proper motion is $\mu = 0.0733$ arcsec/yr
  $\Rightarrow M_V > 3.2$
  $\Rightarrow$ surface gravity: $\log g = 3.7$ or 4.5 (subgiant or dwarf)
- Metallicity: $[\text{Fe/H}] = -5.4$ (1D, NLTE corrected)

- Kinematic properties in line with “outer halo” member

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Ca K line

High-resolution Subaru/HDS spectra (taken by W. Aoki)

Double lined spectroscopic binary

Interstellar Ca

Frebel et al. (2005), Nature
Fe I Lines

Clearly detected:

Fe I 3581: 5.9 mÅ
Fe I 3859: 6.8 mÅ

Very weak lines:

Fe I 3820: 2.5 mÅ
Fe I 4045: 1.9 mÅ

=> [Fe/H] = -5.4

Frebel 05, priv. comm.
What about Fe II lines??

![Graphs showing Fe II lines at different wavelengths for different objects.](image)
Update on Fe abundance

Based on new VLT/UVES data (see Frebel et al. 06), we still have to live with the Fe I abundance…

From these new data, we find:

LTE values:

\[ [\text{FeI/H}] = -5.7 \] (subgiant and dwarf)

\[ [\text{FeII/H}] < -5.4 \] (subgiant)

\[ [\text{FeII/H}] < -5.2 \] (dwarf)

=> HE 1327-2326 certainly has \([\text{Fe/H}]< -5.0 \)]
CH 4300 Bandhead

1D LTE:

\[[\text{C}/\text{Fe}]\] = 4.1 or 3.9 for 
\[\log g = 3.7 \text{ or } 4.5\]
1D LTE:
[N/Fe] = 4.4 or 4.1 for log $g$ = 3.7 or 4.5
OH Features in the UV

\[ \text{[O/Fe]}_{1\text{DLTE}} = 3.7 \text{ but } \text{[O/Fe]}_{3\text{DLTE}} = 2.8 \text{ (subgiant)} \]

Frebel et al. 06, ApJL
1D vs 3D log ε abundances

CNO: 3D LTE
Fe: 1D NLTE
everything else: 1D LTE

based on Frebel et al. 2005, Nature 434, 871 + Frebel et al. 06
What is so Special About HE 1327–2326?

HE 1327–2326 has a very different chemical signature compared with the more metal-rich stars! So does HE 0107–5240 (Christlieb et al. 2002, 2004)

This is crucial observational information for the study of the early Universe
(New) Upper Limit on Li Abundance

Frebel & Christlieb 07, in prep.
The Lithium Riddle

Really low Li abundance!!

...other evolved stars display Li!

Primordial Li value:
- WMAP: $\log \varepsilon(\text{Li})=2.6$ (Spergel et al. 06)
- Ryan et al. value at $[\text{Fe/H}]=-3.5$: $\log \varepsilon(\text{Li})=2.0$
- Our current upper limit: $\log \varepsilon(\text{Li})<1.0$

Possible reasons for Li depletion:
- HE1327-2326 could be a fast rotator
- Accretion of Li-depleted material from binary companion

Norris 06, priv. comm

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Possible Scenarios for the Origin of the Abundance Pattern

1. By faint Pop III SN (mixing and fallback)
2. By Pop III stellar wind yields => Pre-enrichment => Pop II star
3. By several Pop III SNe
4. Binary system with mass transfer => Pop III star (unlikely...)

Big Bang (~14 billion years ago)
First generation of stars
Today

Christlieb 04, priv. comm.

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Radial Velocity Variations??

Based on Frebel et al. 2006, 638, L117

\[ \langle v \rangle = 63.7 \text{ km/s} \]
1. Meynet/Maeder/Hirschi et al.

Solid circles: [Fe/H]=−6.6 with rotation
stars: HE 1327−2326
Solid triangles: [Fe/H]=−6.6 without rotation
empty triangles: G77−61

$\nu_{\text{ini}}=800\text{km/s}$

$M_{\odot}=60M_{\odot}$

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2. Tominaga/Iwamoto/Umeda/Nomoto et al.

Tominaga et al. 2007
3. Chieffi & Limongi

[Graph showing [X/Fe] values for different elements (C, N, O, Na, Mg, Al, Si, K, Ca, Ti, Cr, Mn, Co, Ni, Zn).]

Chieffi & Limongi, priv. comm.
HE 1523–0901

Basic and stellar parameters:

(see Frebel et al. 07)

- Magnitude: $B = 12.1$ mag
- Colour: $(B-V)_0 = 0.70$ mag
- Reddening: $E(B-V) = 0.02$

- $BVRIJHK$ photometry:
  $T_{\text{eff}} = 4630 \pm 70K$ (on Alonso et al. 1996 scale)
- Surface gravity: $\log g = 1.0$ (ionisation equilibrium)
  => red giant
- Metallicity: $[\text{Fe/H}] = -3.0$
Abundances of HE 1523–0901

Frebel et al. (2007), in prep.
r-Process Enhanced Stars

(rapid neutron-capture process)

• Responsible for the production of heavy elements

• ~5% of metal-poor stars with \([\text{Fe/H}] < -2.5\) (Barklem et al. 2005)
  => Only ~12 stars known so far with \([\text{r/Fe}] > 1.0\)

• Chemical “fingerprint” of previous nucleosynthesis event

• Possible production sites:
  SN type II, neutrino-driven winds

• Nucleo-chronometry:
  w/ Th, U and stable r-process elements (e.g. Eu, Os, Ir)
Th II Line 4019Å

Frebel et al. (2007), in prep.
U II at 3859Å

Frebel et al. (2007), ApJL, 660, 117
The r-Process Pattern

Very good agreement with scaled solar r-process pattern for Z>56

Frebel et al. (2007), ApJL, 660, 117

HE 1523-0901

scaled solar r-process pattern

decayed Th,U
What Chronometers have been used so far?

Age estimates can be obtained from a comparison of an observed abundance ratio of a radioactive element (such as Th, U) to a stable r-process element (such as Eu, Os, Ir) and a theoretically derived initial production ratio.

Th/Eu: “most commonly” used chronometer
- Th is “relatively easy” measurable in r-process stars
- “famous” example: CS22892-052: 14-15Gyr; Sneden et al. 96,03

U/Th: Uranium so far only confidently measured in one star
- CS31082-001: U/Th: ~14Gyr (Cayrel et al. 01, Hill et al. 02);
- one known with tentative, one with detection (Hill et al. 2007, in prep.)

⇒Ultimate goal: Use as many chronometers as possible (+ beat down any errors...)!
The Age of HE 1523–0901

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Age</th>
<th>$\sigma_{\text{obs},\text{Teff, log g, vmicr, PR}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th/Eu</td>
<td>11.5</td>
<td>3.3/3.4/0.6/0.6/5.6</td>
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<tr>
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<td>10.7</td>
<td>3.3/2.8/5.6/0.0/5.6</td>
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<tr>
<td>U/Th</td>
<td>13.0</td>
<td>2.9/0.4/0.9/0.4/2.2</td>
</tr>
</tbody>
</table>

**Age:**

average 13.2 Gyr

Frebel et al. (2007), ApJL, 660, 117
Words of wisdom...

Chicago Airport, some advertisement...
That’s why :-) 

- Bright HES stars with $[\text{Fe/H}] < -2.5$ are currently being observed with high-resolution to reveal further astrophysically interesting objects.

- The survey discovered HE 1327–2326 which is the new record holder for the most iron-poor star known ($[\text{FeI/H}]_{\text{NLTE}} = -5.4$). Several promising scenarios reproduce the abundance pattern.

- HE 1523–0901: A new r-process enhanced star with a U detection. For the first time, a star’s age could (consistently) be derived from all three available chronometer pairs. The age is 13.2 Gyr.

- Outlook @ UT: A new metal-poor stars observing program with the Hobby-Eberly-Telescope “The chemical compositions of our Galactic Halo” (w/ Chris Sneden, Carlos Allende Prieto and others) w/ targets from SDSS/SEGUE, HKII & bright HES samples.
References

Bright metal-poor HES stars:
Frebel et al. 2005b, IAU Symp 228, astro-ph/0509658

HE 1327-2326:
Frebel & Christlieb 2007, in preparation

HE1523-0901:
Frebel et al. 2007, in preparation

Other: