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Discovery of Extremely Metal-Poor Stars in the Ultra-Faint Dwarf Spheroidals of the Milky Way

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Discovery of Extremely Metal-Poor Stars in the Ultra-Faint Dwarf Spheroidals of the Milky Way

Evan Kirby

Marla Geha  Josh Simon  Raja Guhathakurta  Anna Frebel
Are there metallicity discrepancies between the halo and the dSphs?

- New way to measure individual-star abundances
- Discovery of stars in dSphs at [Fe/H] < -3.0
- New luminosity-metallicity relation for the Milky Way group
- Brand new metallicities for Leo I
Formation of the Halo

see also:

Chemical Discrepancy: $[\text{Fe}/\text{H}]$

Possible Explanations of Halo-dSph Discrepancy

- Late formation of the surviving dSphs
- Pre-enrichment
- Different IMF between building blocks and dSphs
- Bias-corrected halo MDF shows no discrepancy
- Ca triplet misses extremely metal-poor stars

Look for the bias-corrected halo MDF of Schörck, Christlieb, Cohen, et al. (in prep.)
Ca Triplet Metallicities

Cohen

GO89

M93

SKPL

BW

CG97

[Fe/H]_{HDS}

<\lambda W>

Ca Triplet Metallicities: Extrapolation

\[
[\text{Fe/H}]_{\text{CaT}} = -2.66 + 0.42[\Sigma \text{EW}_{\text{CaT}} + 0.64(V - V_{\text{HB}})]
\]


<table>
<thead>
<tr>
<th>$V - V_{\text{HB}}$</th>
<th>CMD</th>
<th>$[\text{Fe/H}]<em>{\text{CaT}}(\Sigma \text{EW}</em>{\text{CaT}} = 0)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.3</td>
<td>~TRGB</td>
<td>-3.55</td>
</tr>
<tr>
<td>-1.5</td>
<td>RGB</td>
<td>-3.06</td>
</tr>
<tr>
<td>0.0</td>
<td>HB</td>
<td>-2.66</td>
</tr>
<tr>
<td>+1.6</td>
<td>~MSTO</td>
<td>-2.23</td>
</tr>
</tbody>
</table>
Ca Triplet Metallicities: Extrapolation

Ca Triplet: Range of Applicability

\[
[\text{Fe/H}] = \log \left( \frac{n(\text{Fe})}{n(\text{H})} \right) - \log \left( \frac{n(\text{Fe})}{n(\text{H})} \right)_{\odot}
\]

human being

\[ [\text{Fe/H}] = -1.66 \]
\[ [\text{Ca/Fe}] = +5.88 \]

\[ 12 + \log(\text{O/H}) = +11.61 \]
\[ [\text{O/H}] = +2.68 \]
\[ [\text{Mg/Fe}] = +2.40 \]
\[ [\text{Mg/H}] = +0.74 \]
\[ [\text{C/H}] = +2.62 \]
\[ [\text{N/H}] = +2.28 \]
\[ [\text{Ca/H}] = +4.22 \]
\[ [\text{P/H}] = +4.06 \]
\[ [\text{K/H}] = +3.84 \]
\[ [\text{S/H}] = +1.69 \]
\[ [\text{Na/H}] = +2.49 \]
\[ [\text{Cl/H}] = +3.13 \]
\[ [\text{I/H}] = +2.99 \]

Jan Frodeno (Germany), 2008 Olympic triathlon gold medalist
DEIMOS Stellar Spectrum

![Stellar Spectrum Diagram]
Grid of Synthetic Spectra


see also: Lee et al., AJ, submitted, arXiv:0710.5645
Synthetic Metallicities

- DEIMOS spectra: 6300-9100 Å
- Exclude all information from the Ca triplet
- Castelli & Kurucz (& Kirby?) atmospheres: ODFNEW, no convective overshooting
- MOOG (Sneden 2008) synthesis of a large grid at different $T_{\text{eff}}$, log $g$, [Fe/H], [$\alpha$/Fe]
- $T_{\text{eff}}$, log $g$ fixed with Yonsei-Yale isochrones
- The observed spectrum is assigned the metallicity of the synthetic spectrum that best matches ($\chi^2$)
Synthetic Metallicities

Ultra-Faint dSphs

- Extremely high mass-to-light ratios
- No young stars or gas
- Some evidence of tidal disruption and stripping
- Very metal-poor, but \(~0.5\) dex spread in \([\text{Fe/H}]\)
Ultra-Faint dSphs: Individual Stellar Spectra


DEIMOS spectra from
DEIMOS vs. HIRES Metallicities

Extremely Metal-Poor Stars Found

dSphs represented:
- ComBer
- CVnI
- CVnII
- Herc
- LeoIV
- LeoT
- UMaI
- UMaII

New Ultra-Faint dSph Metallicities

Last Decade’s Luminosity-Metallicity Relation

Mateo 1998, ARAA, 36, 435
Last Year's Luminosity-Metallicity Relation

Today's Luminosity-Metallicity Relation

EK, Simon, Sohn, Guhathakurta, Majewski et al., in prep.
Immediate Future

$\alpha/Fe$ vs $\alpha/Fe_{MRS}$

Sculptor

Fornax

EK, Guhathakurta, & Sneden
This work presents the discovery of extremely metal-poor stars in the faintest dSphs.

Previously, there seemed to be a discrepancy between the metal-poor end of the Milky Way halo MDF and the luminous dSph MDFs (Helmi et al. 2006).

The luminosity-metallicity relation holds for at least four orders of magnitude in $L$.

It is possible that larger dSphs have a very small fraction of extremely metal-poor stars.

Hints of stars at $[\text{Fe/H}] < -3.0$ in Leo I.
A Close Call

Michael Phelps,
100m butterfly gold medalist

Milorad Čavić,
100m butterfly silver medalist