Extremely Metal-Poor Stars in Dwarf Galaxies around the Milky Way

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Sextans A galaxy (Subaru Telescope)
The local group of galaxies consists of two giant galaxies (Milky Way and M31) and smaller ones, most of which are dwarf galaxies.

Dwarf galaxies are possible survivors of the building blocks of the giant galaxies.
Local Group Galaxies

courtesy of S. Okamoto
Dwarf galaxies around the Milky Way

courtesy of S. Okamoto
Photometric study for individual stars in dwarf galaxies

→metallicity and ages (star formation history)

Draco (82kpc)

Okamoto et al. 2008
Luminosity-Metallicity Relation of Dwarf Galaxies

![Graph showing the Luminosity-Metallicity relation of dwarf galaxies.](Diagram)
Extremely Metal-Poor (EMP) Stars in Dwarf Galaxies around the Milky Way

(1) Chemical abundance trends of “luminous” dwarf galaxies compared with Milky Way halo

(2) EMP stars in “faint” dwarf galaxies

(3) Metal-poor stars in Ultra-Faint Dwarf Galaxies

• $[\text{Fe/H}] = \log(n[\text{Fe}]/n[H]) - \log(n[\text{Fe}]/n[H])_{\text{sun}}$
• EMP stars: $[\text{Fe/H}] < -3$ (or -2.5)
(1) Chemical abundance trends of "luminous" dwarf galaxies

• Chemical abundances of bright red giants are measurable for nearby dwarf galaxies (<100kpc).

• The chemical evolution and the relation to the Milky Way formation can be studied from the chemical composition if the origins of elements are known.

example: $\alpha$/Fe ratio (e.g. Mg/Fe)

$\alpha$: type II supernovae: short timescale of contributions to enrichment

Fe: type Ia supernovae: longer timescale
[α/Fe] in dwarf galaxies and the Milky Way

Low α/Fe are found in dwarf galaxies in general

Tolstoy et al. (2009, ARAA)
Implications of $\alpha$/Fe in Dwarf Galaxies

- Low $\alpha$/Fe stars at high metallicity
- Decreasing trend at lower metallicity

$\rightarrow$ Large contributions of type Ia supernovae even at low metallicity (?)

This idea is (partially) supported by trends of neutron-capture elements.
Neutron capture element Ba in dwarf galaxies

$[\text{Ba/Fe}]$

$[\text{Eu/Fe}]$

Tolstoy et al. (2009, ARAA)
(2) Metal-Poor Stars in “Faint” Dwarf Galaxies

How is the chemical abundances of EMP stars in dwarf galaxies?

Helmi et al. (2006)
Chemical abundance analysis of Sextans stars with Subaru/HDS

Aoki et al. 2009

- A part of study by the DART projects

- High resolution follow-up for candidate extremely metal-poor stars discovered with VLT/FLAMES (Helmi et al. 2006)

- Subaru/HDS observations (P.I.: N. Arimoto)
  May 2005 + Jan. 2007
  $R=40,000$, 4400-7200A
  Exposures : 1-6 hours, $S/N=20-45$

- $T_{\text{eff}}$ from V-K colors
$\alpha$/Fe of Sextans EMP stars:
Most stars show low Mg/Fe ratios
Sextans EMP stars

[Ca/Fe] is also low

[Mg/Ca] is similar to (or slightly lower than) that of field stars

Aoki et al. 2009
Why is the $\alpha$/Fe of Sextans EMP stars low?

- Not the abundance anomaly as found in globular clusters (no Na abundance anomaly is found)

- **Large contributions of type Ia supernovae (SN Ia)?** However, contributions of SN Ia is not expected in $[\text{Fe/H}]<-2.5$. No contribution of intermediate-mass stars is found in Ba (=AGB products).

- **Different Initial Mass Function (IMF)?** ... small contribution of very massive (>20M$_\text{sun}$) stars?
\( \alpha/Fe \) in relatively faint dwarf galaxies: 
\([Mg/Fe]\) in Sextans, Ursa Minor, Draco

![Plot showing [Mg/Fe] vs [Fe/H] for Sextans, Ursa Minor, and Draco.]

- **Sextans**: Aoki et al. (2009)
- **Sextans**: Shetrone et al. (2001)
- **Draco**: Cohen et al. (2009)
- **Ursa Minor**: Sadakane et al. (in prep)
- **Ursa Minor**: Shetrone et al. (2001)
α/Fe in relatively faint dwarf galaxies:
[Ca/Fe] in Sextans, Ursa Minor, Draco

- Sextans: Aoki et al. (2009)
- Sextans: Shetrone et al. (2001)
- Draco: Cohen et al. (2009)
- Ursa Minor: Sadakane et al. (in prep)
- Ursa Minor: Shetrone et al. (2001)
The Neutron-Capture Element Ba in the Faint Dwarf Galaxies Sextans, Ursa Minor, and Draco

→ Large scatter as found in Milky Way halo stars
→ Increasing trend appears at slightly higher metallicity (?)
α/Fe in relatively faint dwarf galaxies (Sextans, Draco and Ursa Minor)

α/Fe ratio trends are significantly different between the three relatively faint dwarf galaxies, even though they have similar luminosity (similar stellar mass).

What does determine the α/Fe in dwarf galaxies?

No clear answer ....

cf. the trend of neutron-capture elements seems to be similar to the Milky Way halo.
(3) Metal-Poor Stars in Ultra-Faint Dwarf Galaxies (UFDG)
Discoveries of EMP stars in Ultra Faint Dwarf Galaxies → a high fraction of EMP stars?

A red giant with $[\text{Fe/H}]=-3.7$ in the UFDG Bootes I

Norris et al. (2010)

$[\text{Fe/H}]=-4.2$

$[\text{Fe/H}]=-3.7$

$[\text{Fe/H}]=-3.1$
Are $\alpha$/Fe trends in UFDG similar to Milky Way halo stars?

The sample is too small, and the quality is not sufficient, to derive clear conclusions...

- **Bootes:** This work (preliminary)
- **Bootes:** Norris et al. (2010)
- **Leo IV:** Simon et al. (2010)
- **ComBar, UMa II:** Frebel et al. (2009)
- **Her:** Koch et al. (2008)
The neutron-capture element Ba in Ultra Faint Dwarf Galaxies

Neutron-capture elements are under-abundant even in [Fe/H] > -2.5.
Future prospects

- Diversity of chemical nature of dwarf galaxies → systematic studies for individual galaxies are necessary
- Ultra Faint Dwarf Galaxies are important as possible survivors of building blocks of the Milky Way halo.

Fainter stars in fainter galaxies will be studied with next generation larger telescopes

*Okamoto et al. 2008*
Thirty Meter Telescope (TMT)

The construction site was decided to be Hawaii. The first light is planned in 2018.