First Stars from Abundance Patterns in Dwarf Spheroidal Galaxies

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The DART-team

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1. Why look for First stars relics in dSph galaxies?
2. DART: a chemo-dynamical survey of nearby dSph galaxies
3. Metal-poor stars in dSph galaxies: how metal-poor can we go?
4. Metal-poor stars in dSph galaxies: abundance patterns compared to the Milky-Way halo counterparts
1. First stars in dSph?

- Hierarchical galaxy formation: small blocks form first
- dSph are the smallest galaxies directly observable in details
- Could be formed prior to reionization (Gnedin & Kravtsov 2006)? First stars in them could be responsible for (part of) the reionization and the IGM metal-enrichment (lost through efficient winds)?
- Even though the present-day nearby dSph might have evolved since the first star formation episodes, the relics (low-mass stars) of the first epochs are still observable.
1. dSph galaxies: the smallest units

CDM predictions ok at large scales, not so well at the smallest scales

What relation do dSph have to building blocks?
1. Smallest units: Mv, M, M/L

Consistent with a constant Mass $\sim$ a few $10^8 M_\odot$

(Willkinson 2006)
1. Various evolutionary paths

- **Draco**: 86 kpc
- **Ursa Minor**: 66 kpc
- **Carina**: 101 kpc
- **Fornax**: 138 kpc
- **Leo II**: 205 kpc
- **Leo I**: 250 kpc
- **Sculptor**: 79 kpc
- **Sextans**: 86 kpc
- **Sagittarius**: 24 kpc

*Age*
2. DART

Dwarf Galaxy Abundances and Radial Velocities Team

Sculptor, Fornax, Sextans, (Carina)

FLAMES multiobject spectrograph @ ESO/VLT

- HR abundances in central regions for detailed abundance analysis: 50-100* per galaxy
- LR abundances over the whole galaxy for a wider view of metallicities and kinematics of the entire system using the IR Ca triplet: 200 - 900* per galaxy
- WFI imaging over entire area of galaxies: looking for large scale spatial variations in stellar populations, and to provide spectro targets.

Sculptor: Tolstoy et al. 2004 (LR) and Hill et al. 2007 in prep (HR)
Fornax: Battaglia et al. 2006 (LR) and Letarte PhD thesis 2007 (HR)
HR abundances: Hill et al. 2007 in prep.

Sculpteur

130 candidates

HR abundances: Letarte PhD thesis 2007

Fornax

Tolstoy et al. 2003
2. GIRAFFE HR

- $P=20000 \Delta \lambda : 3 \times 20$ nm
- Measure hundred(s) of lines
- +model atmosphere

$\rightarrow$ Abundances of $\sim 15$ elements, incl. Fe, alpha-elements, neutron capture elements.
2. GIRAFFE LR: CaII NIR triplet

- $R=6000 \ 2 \text{ CaII lines } + \text{ calibration to } (V-V_{\text{HB}})$

$\rightarrow [\text{Fe/H}] \text{ estimate}$
2. Comparison LR - HR

- rms ok: ~0.15-0.2dex
- Slight systematics:
  - -0.2 at the high-metallicity end (above [Fe/H]~1)? Or simply an increase of the dispersion… Can be expected from the age-dependency of the method.
  - +0.1 at the low-metallicity end?

Battaglia et al. 2007 in preparation
3. Looking for low-Z: extent

WFI/FLAMES Sculptor dSph (650*)

Tolstoy et al. 2004, Battaglia et al. in prep.

WFI/FLAMES Fornax dSph (800*)

Battaglia et al. 2006
Metallicity distribution variation...

Sculptor (470 confirmed members)

Battaglia et al. 2007 in prep.

Tolstoy et al. 2004 ApJL

Metallicity distribution variation...
3. Ubiquitous low-Z component

Various SFH and therefore MDFs, but low-Z component is ubiquitous
3. Similar low-Z tails

\[ N (< [\text{Fe/H}]) = a \times 10^{[\text{Fe/H}] + b} \]

\begin{table}
\begin{tabular}{|c|c|c|c|c|}
\hline
\text{galaxy} & \text{[Fe/H]}_0 & \chi^2 & \text{prob} & \text{N\textsubscript{stars}} \\
\hline
\text{Sculptor} & -2.90 \pm 0.21 & 1.02 & 0.998 & 10 \\
\text{Fornax} & -2.68 \pm 0.35 & 0.86 & 0.931 & 6 \\
\text{Sextans} & -2.72 \pm 0.14 & 2.0 & 0.991 & 11 \\
\text{Carina} & -2.73 \pm 0.19 & 0.44 & 0.999 & 9 \\
\hline
\end{tabular}
\end{table}
3. dSph lack the lowest-Z tail?

Milky-Way: “-4 desert”
+ 2 $[\text{Fe/H}]<-5$ stars with very high CNO

Dwarf spheroidals: “-3 desert”

$\sim x3$

6-8 stars $[\text{Fe/H}]<-2.5$ per galaxy $\rightarrow$ expect 2-3 stars $[\text{Fe/H}]<-3.0$

Beers & Christlieb 2006
Helmi et al. 2006
Salvadori & Ferrara 2006
3. Interpretation and Caveats

1) The MW building blocks formed from high-σ density peaks (Diemand et al. 2005), while dSph can arise from low-σ peaks (predicted to collapse on average at lower z: e.g., 1-σ peak of mass $10^8$ M collapses at $z \sim 4$, Qian & Wasserburg 2004). dSph could then be formed in pre-enriched gas (cf IGM metallicity of [Fe/H]~ −3 dex, Cowie & Songaila 1998)

2) The IMF could have behaved differently in Galactic building blocks and dSph at the earliest times. Ex: with a bimodal IMF, low-mass stars can form even from zero metallicity gas (Nakamura & Umemura 2001). This would then be favoured when then initial density of the gas is sufficiently large, and so this would be favoured in high-σ peaks collapsing at very early times.

• **However:**
  – CaT metallicities are extrapolated below -2.5
  – Samples are still small…. 
4. High resolution abundances

Abundance patterns are powerful to discriminate progenitors (polluters): masses, ...

Cayrel et al. 2004 + Spite et al. 2007 in prep: ~50 EMPS stars in the galactic halo
4. Abundance patterns in dSphs?

Sculptor dSph

WFI/FLAMES Fornax dSph

HR samples (also in the literature) in the center: miss the low-Z tail
n-capture elements

- Y, Ba: s-process (TP AGB) + r process
- Eu: r-process, massive stars (SNII)

At high Z:
- Ba/Fe follows distinct path: s-process very efficient in galaxies with strong SFR at younger ages (<5 Gyrs): Fnx > LMC > Scl

At low Z ([Fe/H] < -2):
- r-process dominates in dSph and MW
- Ba rise happens at higher Fe/H in dSph
- Occurrence of rII stars also at higher Fe/H?

Milky-Way:
- Compilation by Venn et al. 2004
- Francois et al. 2007 (subm.)
Conclusions

1. CaT metallicities of large sample of stars in Sculptor Fornax Sextans and Carina show that:
   a) dSph seem to lack the most metal-poor stars found in the MW halo ([Fe/H]<-3). IMF ? Late formation of dSph from pre-enriched (IGM) gaz ?
   b) Two distinct old stellar populations, chemically and kinematically

2. Abundance patterns of very metal poor stars ([Fe/H]<-2) in dSph are still very scarce, but we show that:
   a) Very Metal poor stars abundances in dSph are not significantly different from those of the metal-poor halo of the MW.
   b) The onset of the r-process might have happened at higher metallicities in dSph:
      ✓ if r-process is a clock, then it would mean that dSph enrich faster to a metallicity of -2;
      ✓ alternatively, if r-process is a baryometer, it would mean that the IMF favours lower-mass SNII in dSph)

3. Subsequent chemical evolution is distinct in each distinct galaxy (as strikingly shown by the new large samples in Sculptor and Fornax)
(near) Future work

- Obtain **precise** abundances in all the most metal-poor stars detected to date in dSph (in progress, using VLT/UVES, Subaru/HES, Magellan/MIKE).
- Continue CaT surveys to probe the (or the lack of) \([\text{Fe/H}]<-3\) stars.