Stars and the Milky Way in 2025+

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Gaia (ESA)
- millions of stars in the MW disk
- few 100,000s in the halo
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Gaia (ESA)
The MW Science of 2025+

The "first" stars
Where are they?
1\textsuperscript{st} or n\textsuperscript{th} generation?
How did early star formation work?

The assembly of the Galaxy
How was the halo assembled?
What is its origin?

Dark matter on small scales
Do dark matter sub-halos exist?
The shape of dwarf galaxy sub-halos?
The "First" Stars

The very first stars \((M_\star > 10M_\odot)\) are likely inaccessible to us but the lowest metallicity stars \(([\text{Fe/H}] < -3.0)\) should carry their imprint.

**J0023 + 0307**

\([\text{Fe/H}] < -6.3\)

**Issues:** They are very rare, they are (mainly) in the halo and so faint, they require high S/N spectra to study.
The "First" Stars

Ongoing surveys will help find the rare Extremely/Ultra Metal-Poor (EMP/UMP) stars: **Pristine** at CFHT, **SkyMapper** in the South, **WEAVE/4MOST** will confirm them.

*Needs:* Large number of high S/N spectra from faint stars ($16<V<20$) all over the sky for **chemical-abundance measurements**

Frebel & Norris (2015)
A chemo-dynamical decomposition of the MW

Different types of accretions events leave different traces in the MW halo

<table>
<thead>
<tr>
<th>$\mu$ (mag/arcsec$^2$)</th>
<th>$[\text{Fe/H}]$</th>
<th>$[\alpha/\text{Fe}]$</th>
<th>$v_r$ (km/s)</th>
<th>$\sigma$ (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>38 → 23</td>
<td>-2.0 → -0.5</td>
<td>-0.1 → +0.2</td>
<td>-200 → +200</td>
<td>0 → +150</td>
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</tbody>
</table>

Highest luminosity accretion events

Lowest luminosity accretion events

artificial simulations by Johnston et al. (2018)
A chemo-dynamical decomposition of the MW

[α/Fe] is a simple diagnostic of the progenitor of a halo structure

Tolstoy, Hill & Tosi (2009)
A chemo-dynamical decomposition of the MW

$[\alpha/\text{Fe}]$ is a simple diagnostic of the progenitor of a halo structure

*Is Gaia-Enceladus the remnant of a dwarf galaxy?*  
Helmi et al. (2018)
A chemo-dynamical decomposition of the MW

**Chemical Tagging:** identifying stars from the same star formation event ("cluster")

Figure 3. Same as Figure 1 except that the entire sample has been made gray and the members of the most dense $K = 256$ abundance-space cluster have been rendered as unique, prominent triangles (color is velocity rank, orientation is log $g$ rank). The lower-right plot shows this cluster (circle) in context of the other clusters (dots). This cluster, which was identified only in abundance space (six projections of which are the top six panels in this Figure), turns out to be dominated by the halo globular cluster M13. The symbol orientations and colors have no meaning; they are randomly generated—one unique color and orientation for each highlighted star—to make the points cross-identifiable across panels.

**Needs:** Very large survey with very accurate (<0.1 dex) chemical-abundance measurements
Cold streams are sensitive to the nearby passage of dark DM sub-halos

Yoon, Johnston & Hogg (2010)
Cold streams are sensitive to the nearby passage of dark DM sub-halos
Dark matter: stellar streams as seismographs

Is this what is happening to the GD1 stream?

**Issues**: sensitive to any type of perturbation — passage through the MW disk, nearby passage of GMC, clusters, dwarf galaxies, …

**Needs**: dynamical study, many streams, doing this statistically
Many streams are being discovered — they beg of a thorough dynamical study.

Ibata, Mahlan & Martin (2019)
Dark matter: the dwarf galaxies case

Are dwarf galaxy sub-halos **cusped** or **cored**? How is this affected by baryonic effects?

**Needs:** 10,000s spectra in **multiple** dwarf galaxies, over the widest possible **luminosity range**, and **coverage**
The MW Science of 2025+

The "first" stars
chemical abundances of many faint stars in the optical

The assembly of the Galaxy
chemical abundances of many faint stars

Dark matter on small scales
Very accurate velocities in large samples of stream/dwarf galaxy members from many structures
The case for M31 too

Pan-Andromeda Archaeological Survey
(McConnachie et al. 2009)
(Figure adapted from Martin et al. 2014)

MSE Survey Strategy
for M31 and M33