HRMOS for the Milky Way Satellites

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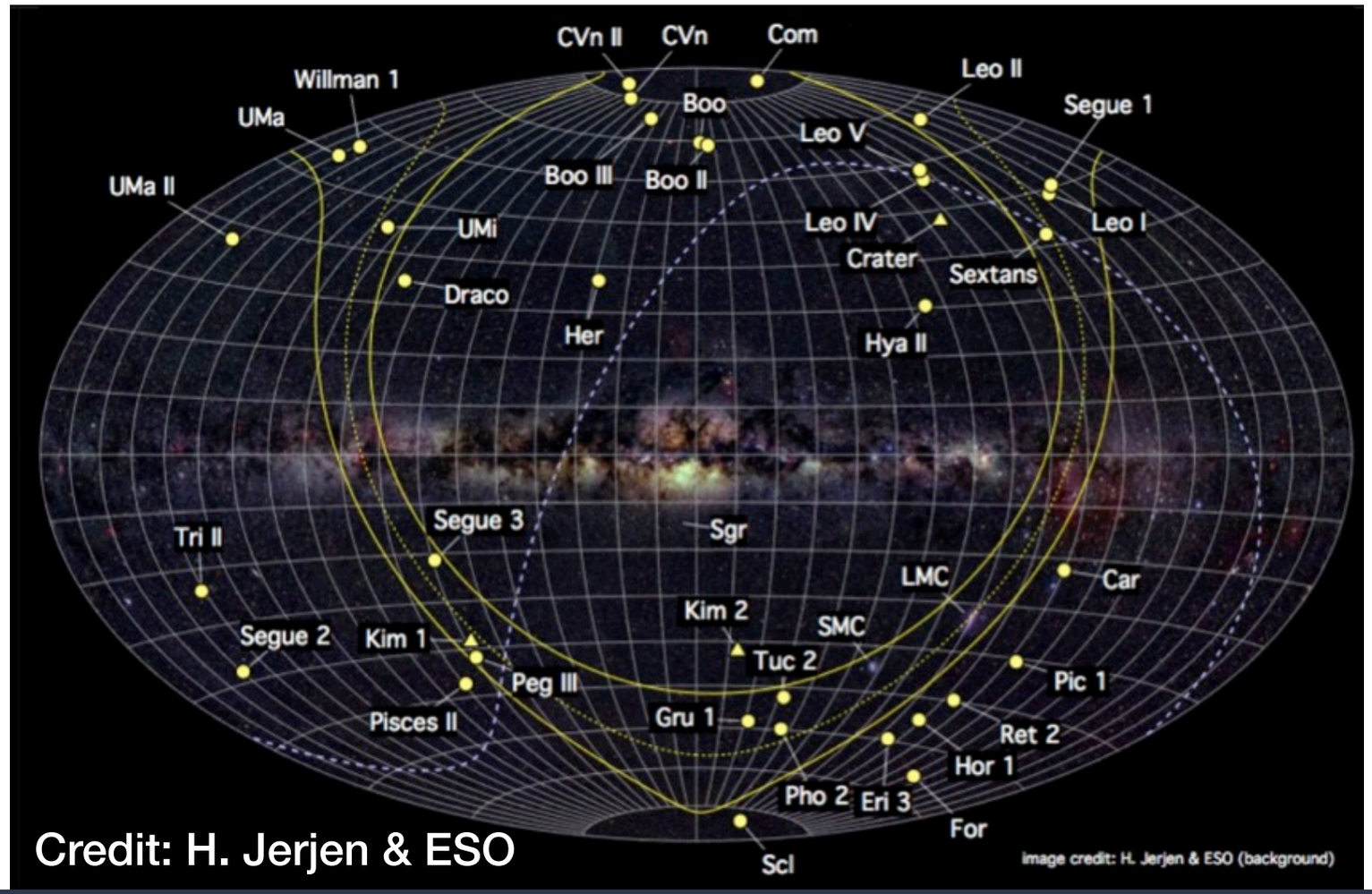
The Milky Way satellites

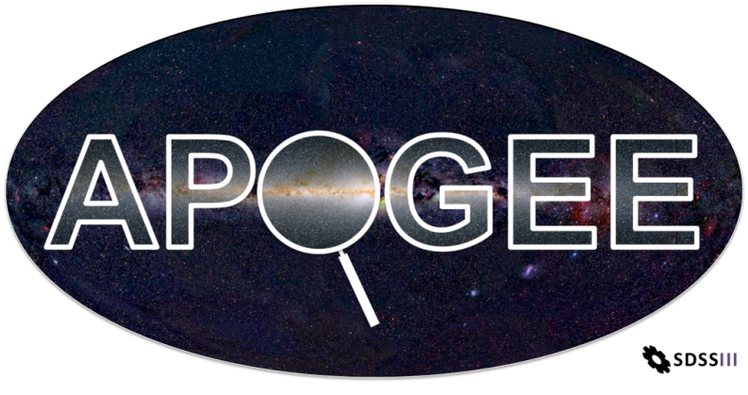
- The Milky Way has ≈50 known dwarf galaxy satellites (McConnachie 2012 + updates)
- Multiple populations of disrupted dwarf galaxies have been identified, Gaia-Enceladus, Sequoia, the Helmi streams etc.
- Key scientific questions require HR spectra of individual stars!



Credit: H. Jerjen & ESO

Planned & Proposed Surveys of Satellite Galaxies

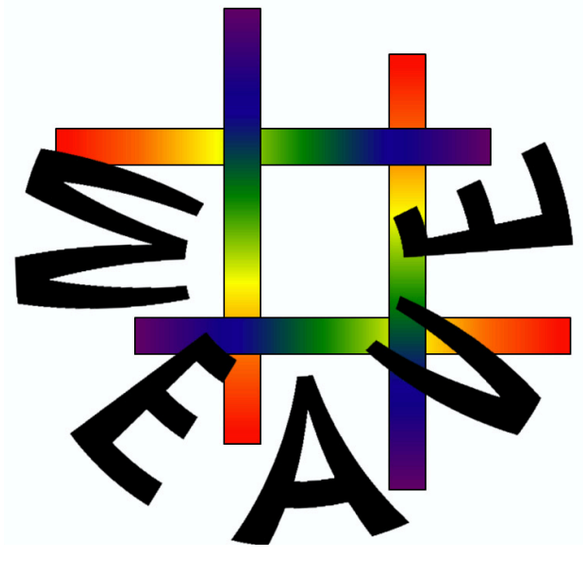
The Landscape



Recent paper by Hasselquist et al. 2021
Abundance analysis of ~10 elements
~5000 LMC/SMC stars
~1100 Sgr/Fnx stars

Talk by Oscar Gonzalez!

Will be able to target satellite galaxies in the near-infrared (LMC/SMC/Sgr)



Will include some smaller dwarf galaxies in the Northern hemisphere

Talk by Thomas Bensby!

Dedicated survey for the LMC/SMC
~576k stars

No consortium survey targets the dwarf galaxies!

4DWARFS

ESO Public Spectroscopic Survey Phase 1 LoI

4MOST survey of dwarf galaxies and their stellar streams (4DWARFS): Small but fundamental

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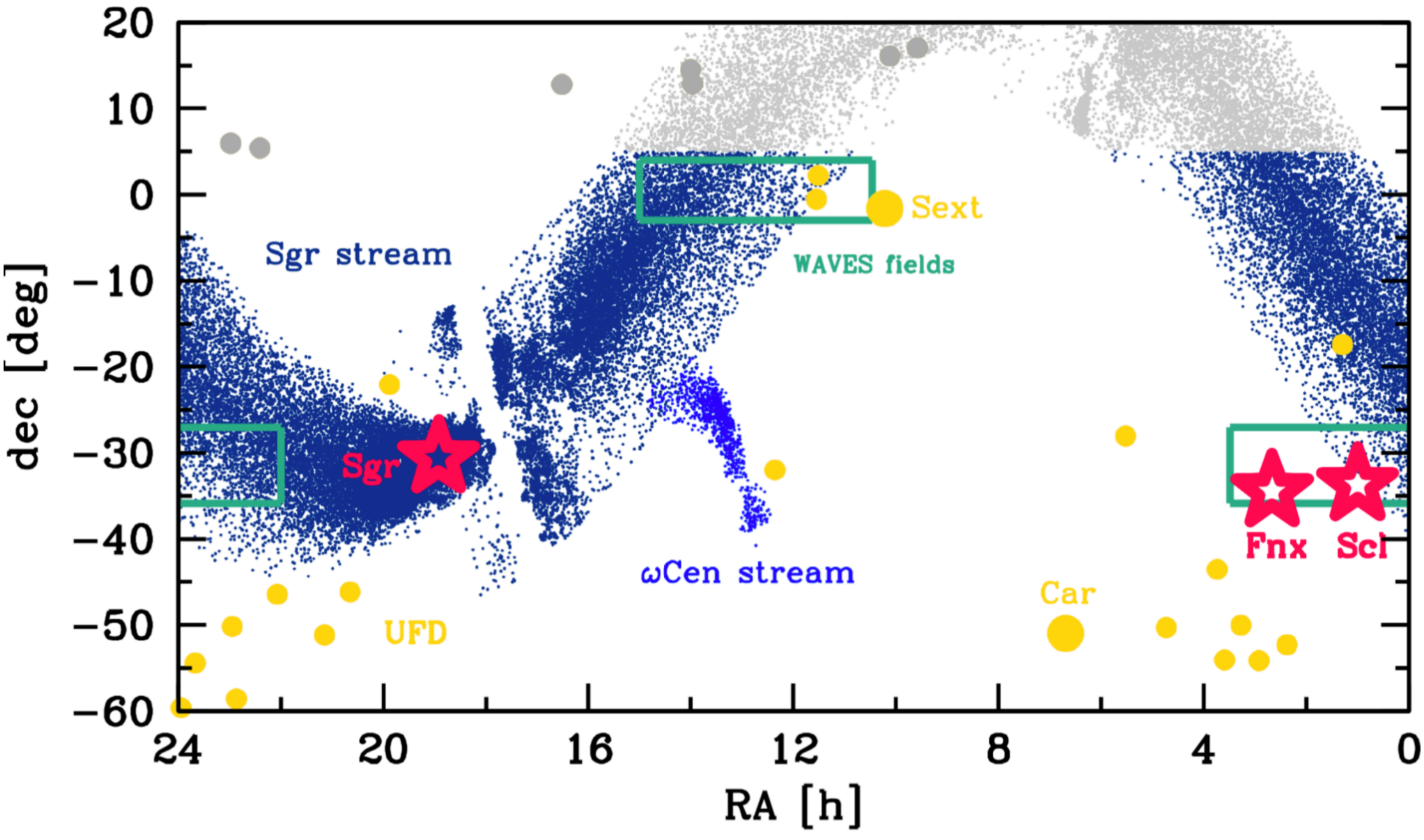
Cols: Anish M. Amarsi [3], Almudena Arcones [4,5], Giuseppina Battaglia [6,7], Sven Buder [8], Benoit Côté [9], Simon W. Campbell [10], Marius Eichler [4], Diane Feuillet [11], Andrew J. Gallagher [12], Viola Gelli [1,2], Melanie Hampel [10], Michael Hanke [13], Camilla J. Hansen [12], Sten Hasselquist [14,15], Vanessa Hill [16], Rodrigo Ibata [17], Nikolay Kacharov [12], Amanda Karakas [10], Andreas Koch [13], Karin Lind [18], Maria Lugaro [9], Davide Massari [19,20,21], Thomas Nordlander [8,22], Moritz Reichert [4], Martina Rossi [1,2], Ashley Ruiter [23], Stefania Salvadori [1,2], Ivo Seitenzahl [23], Eline Tolstoy [21], Theodora Xilaki-Dornbusch [24].

- **4MOST:** Large survey facility on the VISTA 4m telescope, Paranal, field of view: 4.2 deg^2.
  - LR: 1600 fibres, 370-950nm, R~6500
  - HR: 800 fibres, 393-435, 516-573, and 610-679nm, R~20,000

4DWARFS


Sext
WAVES fields
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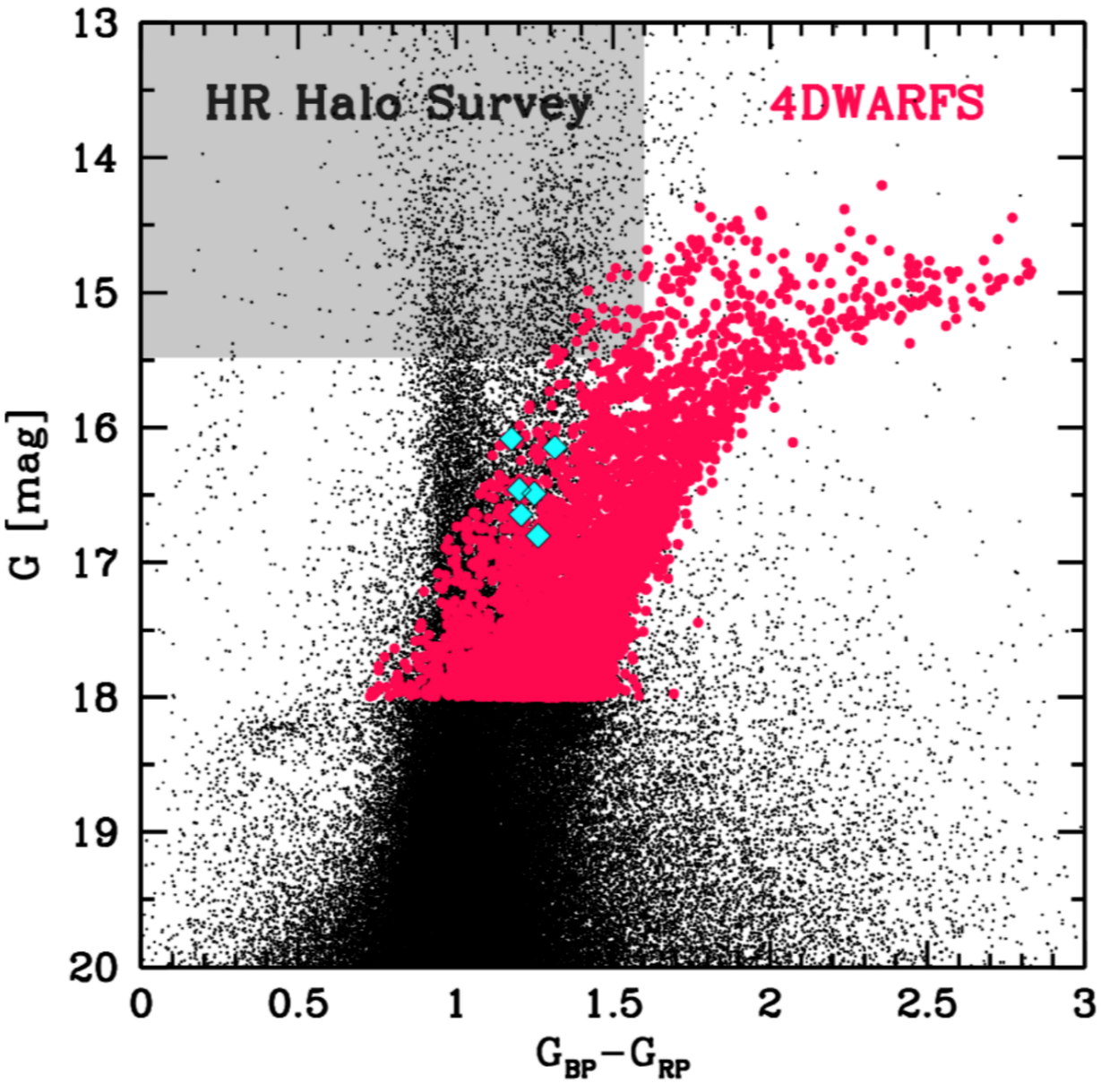
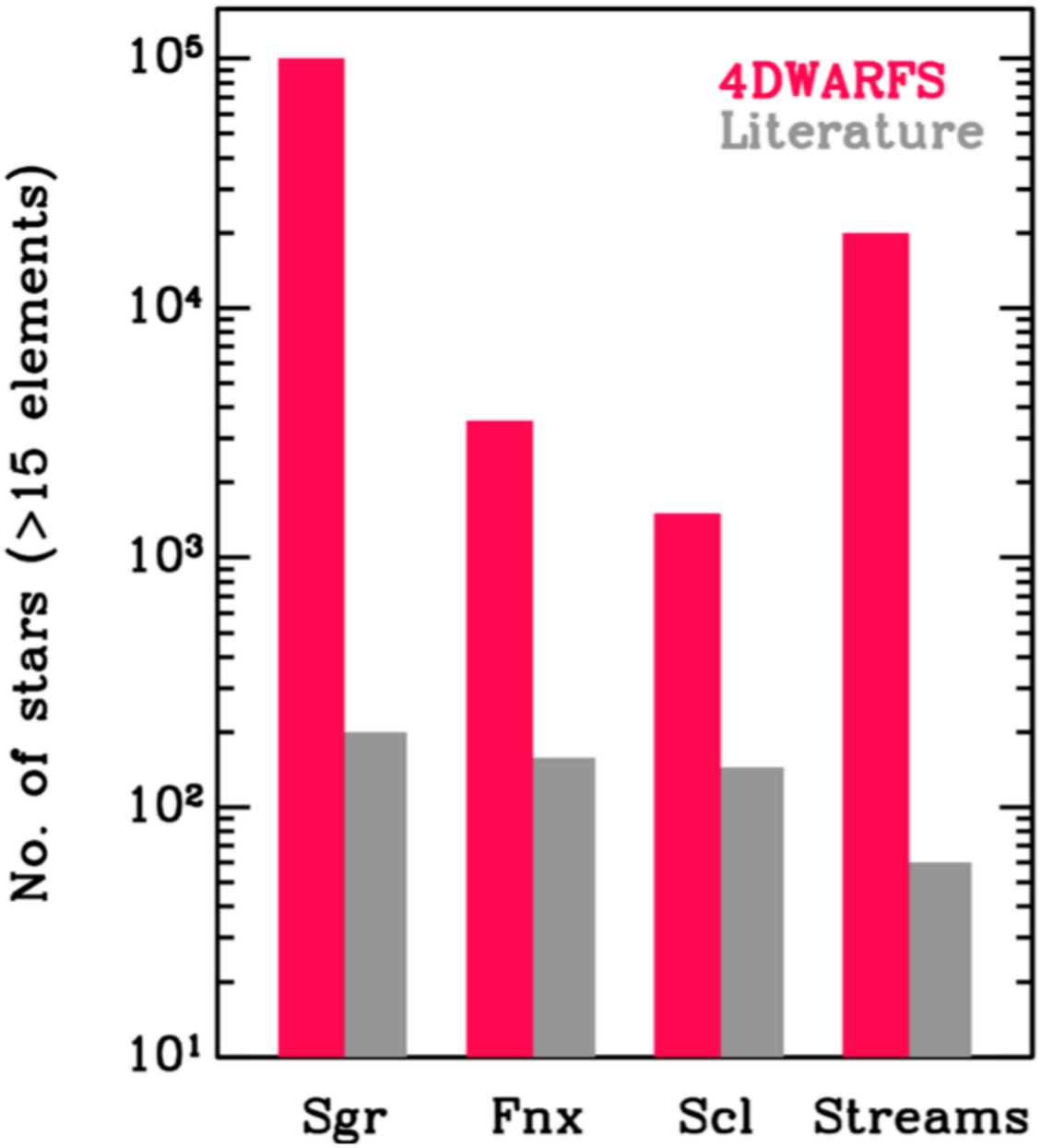
4DWARFS



Sagittarius central field (Gaia DR2)

- Chemical abundances in all dwarf galaxies in the Southern hemisphere
- Without 4DWARFS, there will be very limited coverage of Sagittarius!

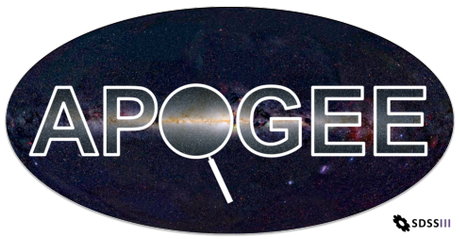
4DWARFS

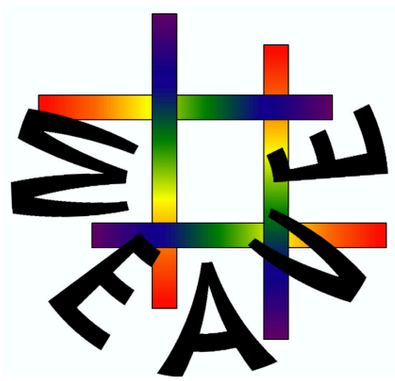


- ~120,000 stars with detailed chemical abundance measurements (>15 elements) in dwarf galaxies + the Sagittarius stream

- Currently available: <1,000

The landscape





+ 4DWARFS?

- Pressing need for high-resolution follow-up spectra!

- Especially in the blue!

HRMOS for Satellite Galaxies: The Science

Science Cases

First stars

Delayed nucleosynthetic processes

Hierarchical Galaxy formation

Stellar binaries in smaller galaxies

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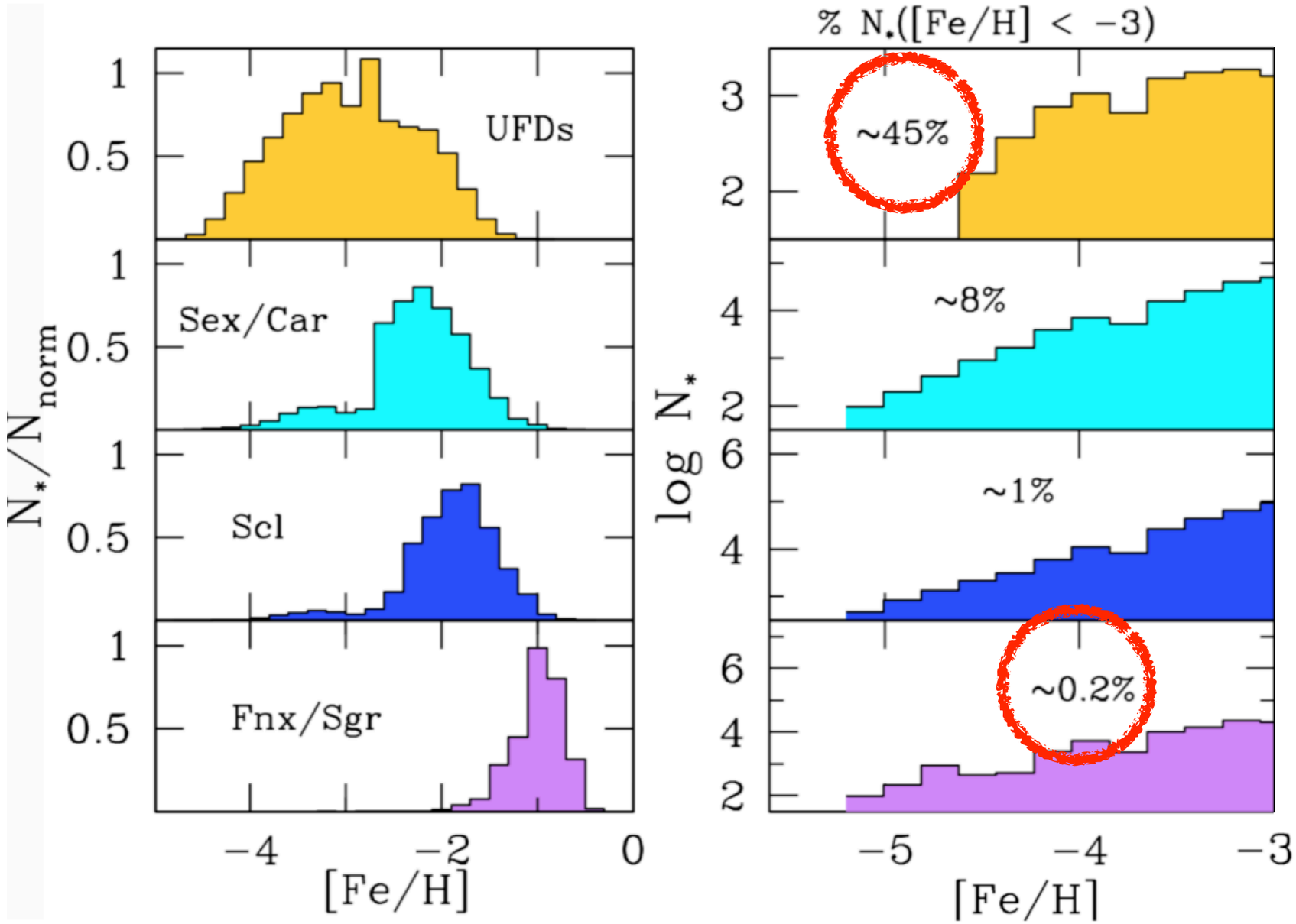
First stars: Low Z tail

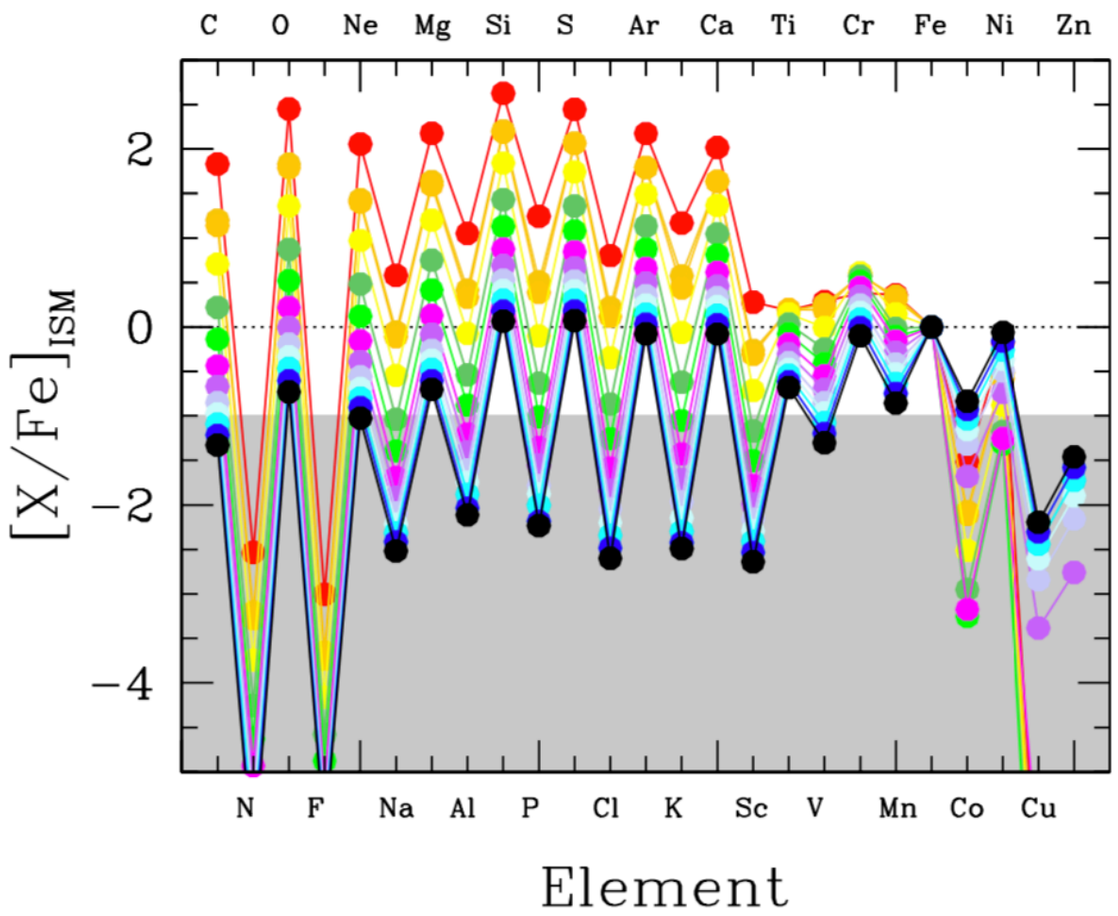


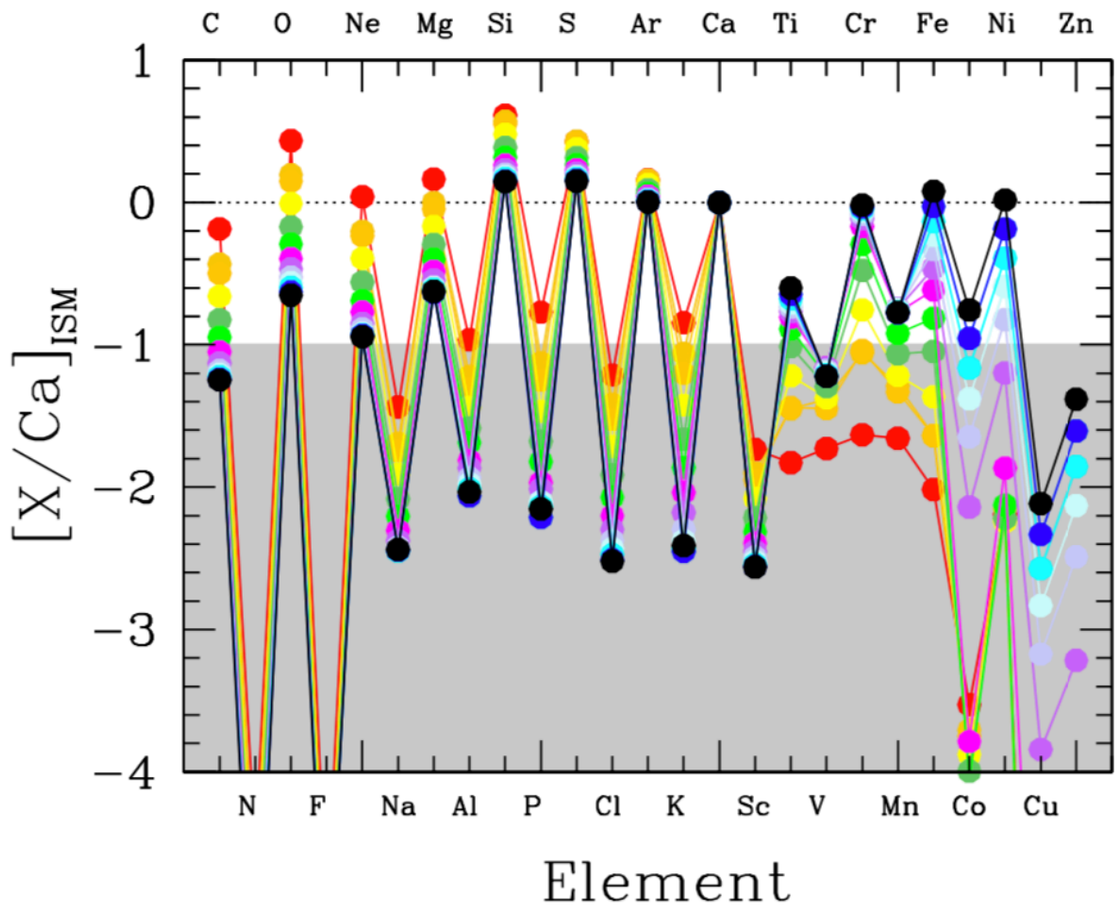
- Predictions based on a statistical, data-calibrated cosmological model for the hierarchical build-up of the Milky Way and its dwarf satellite galaxies.

Adopted from Salvadori, Skúladóttir & Tolstoy 2015

First stars: PISN

- The mass distribution of first zero-metallicity stars is very uncertain, but is likely more top-heavy than in present day star formation.
- Stars in mass range ~150-260 $M_\odot$ are expected to end their lives as pair-instability supernovae, with very distinctive yields

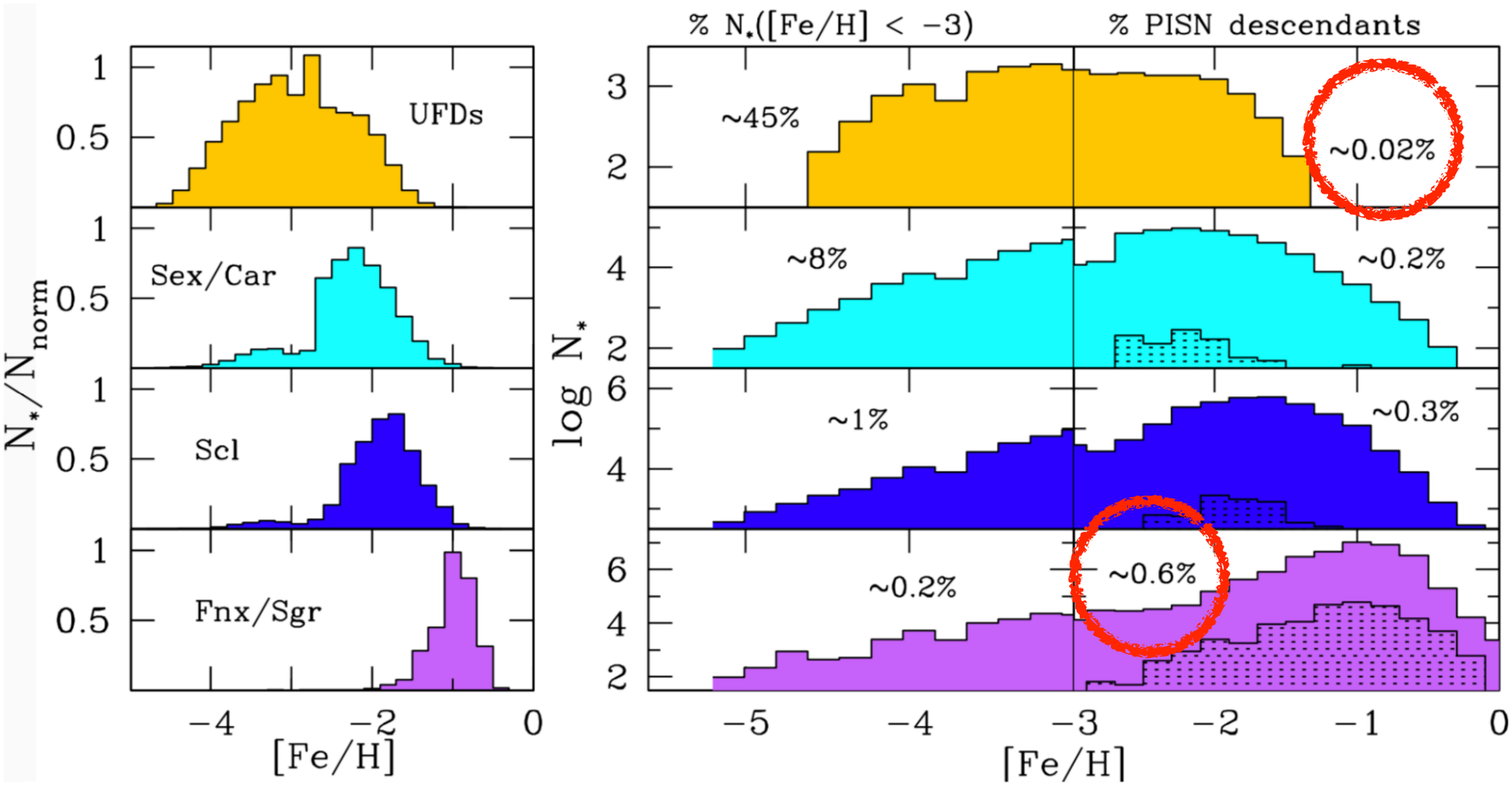




Salvadori+19

First stars: PISN

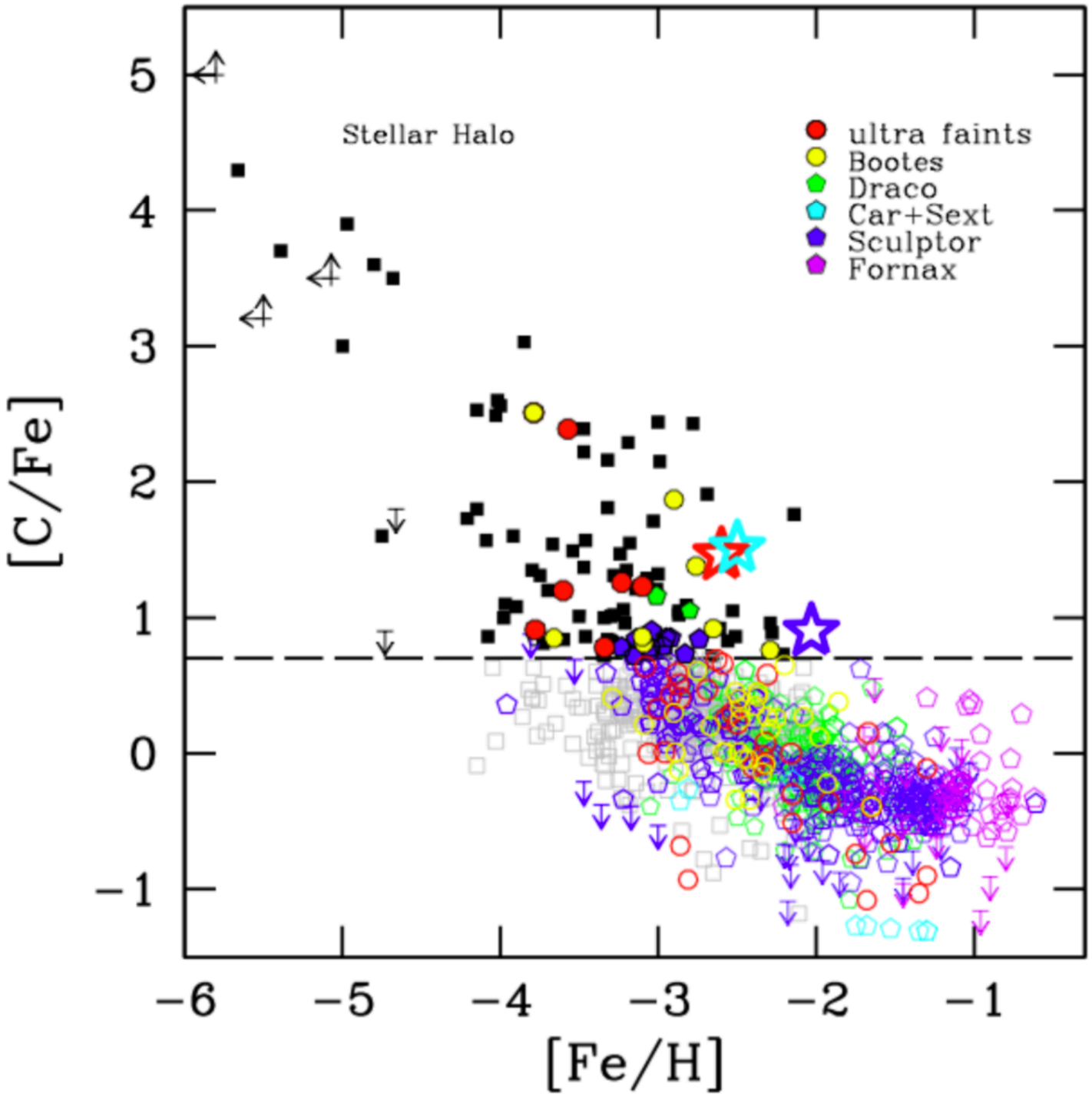
- The fraction of PISN descendants predicted to be larger in dwarf galaxies compared to the Milky Way
- HR spectra are needed to confirm and characterise final candidates



Salvadori, Skúladóttir+ in prep

First stars: CEMP-no stars

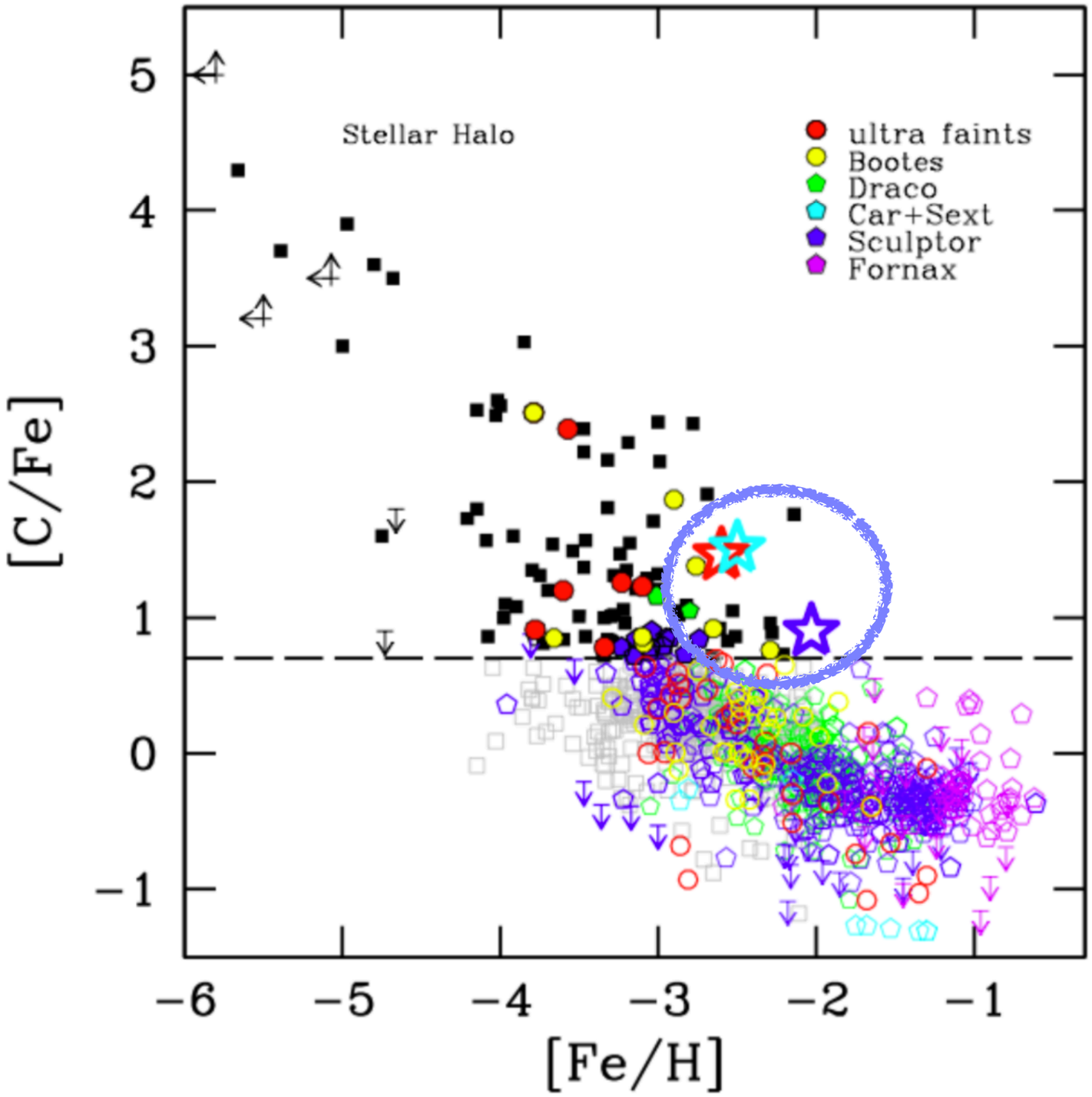
- CEMP-no stars believed to be bonafide second generation stars.
- Lack of CEMP-no stars in dwarf spheroidal galaxies?



Salvadori, Skúladóttir & Tolstoy 2015

First stars: CEMP-no stars

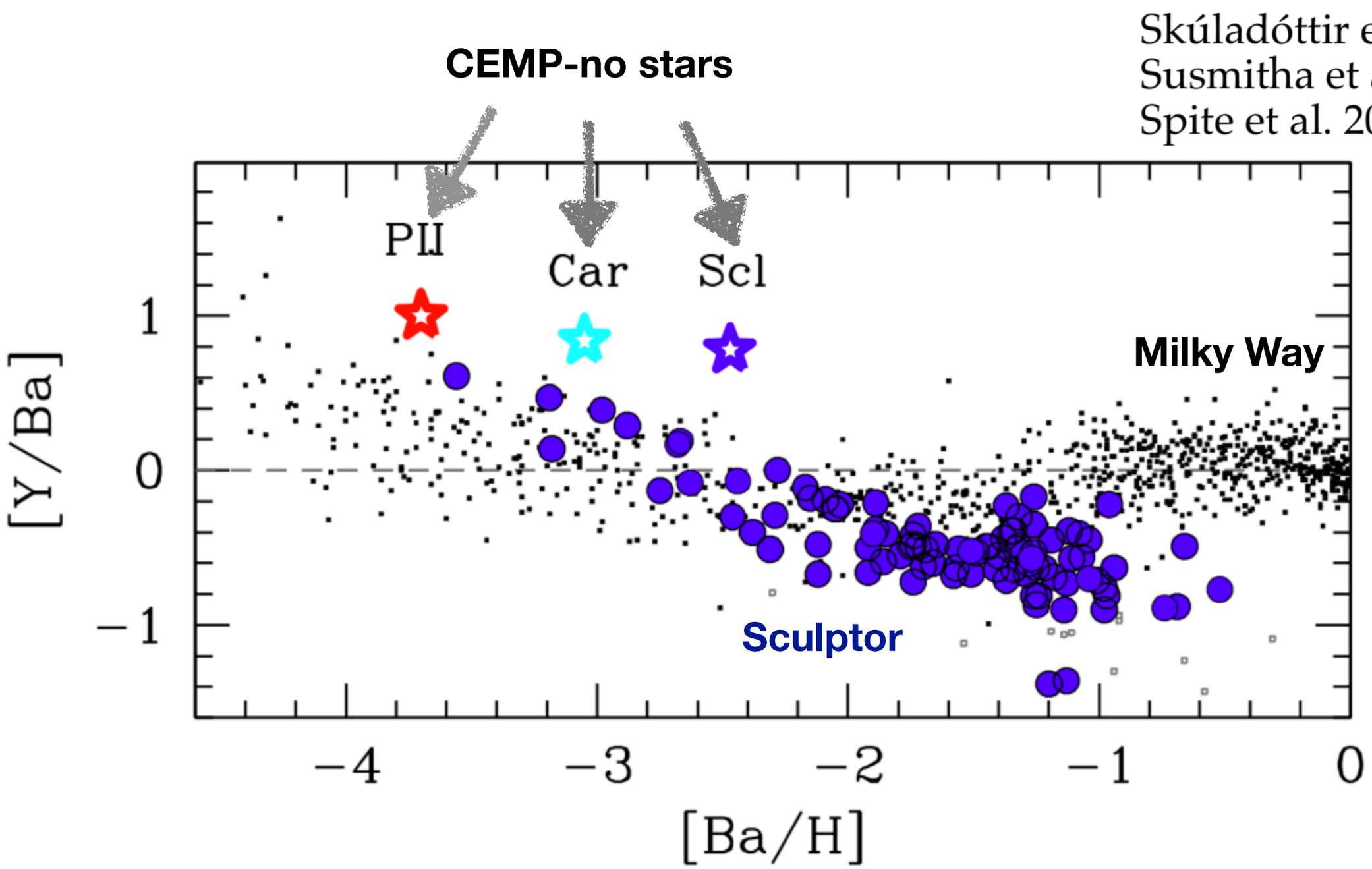
- CEMP-no stars believed to be bonafide second generation stars.
- Lack of CEMP-no stars in dwarf spheroidal galaxies?
- **The ones that we do find are weird.**



Salvadori, Skúladóttir & Tolstoy 2015

First stars: CEMP-no stars

Skúladóttir et al. 2015
Susmitha et al. 2017
Spite et al. 2018



- CEMP-no stars in dwarf galaxies show high [Y/Ba] ratios!

Based on Skúladóttir et al. 2020

Science Cases

First stars

Delayed nucleosynthetic processes

Hierarchical Galaxy formation

Stellar binaries in smaller galaxies

Delayed processes

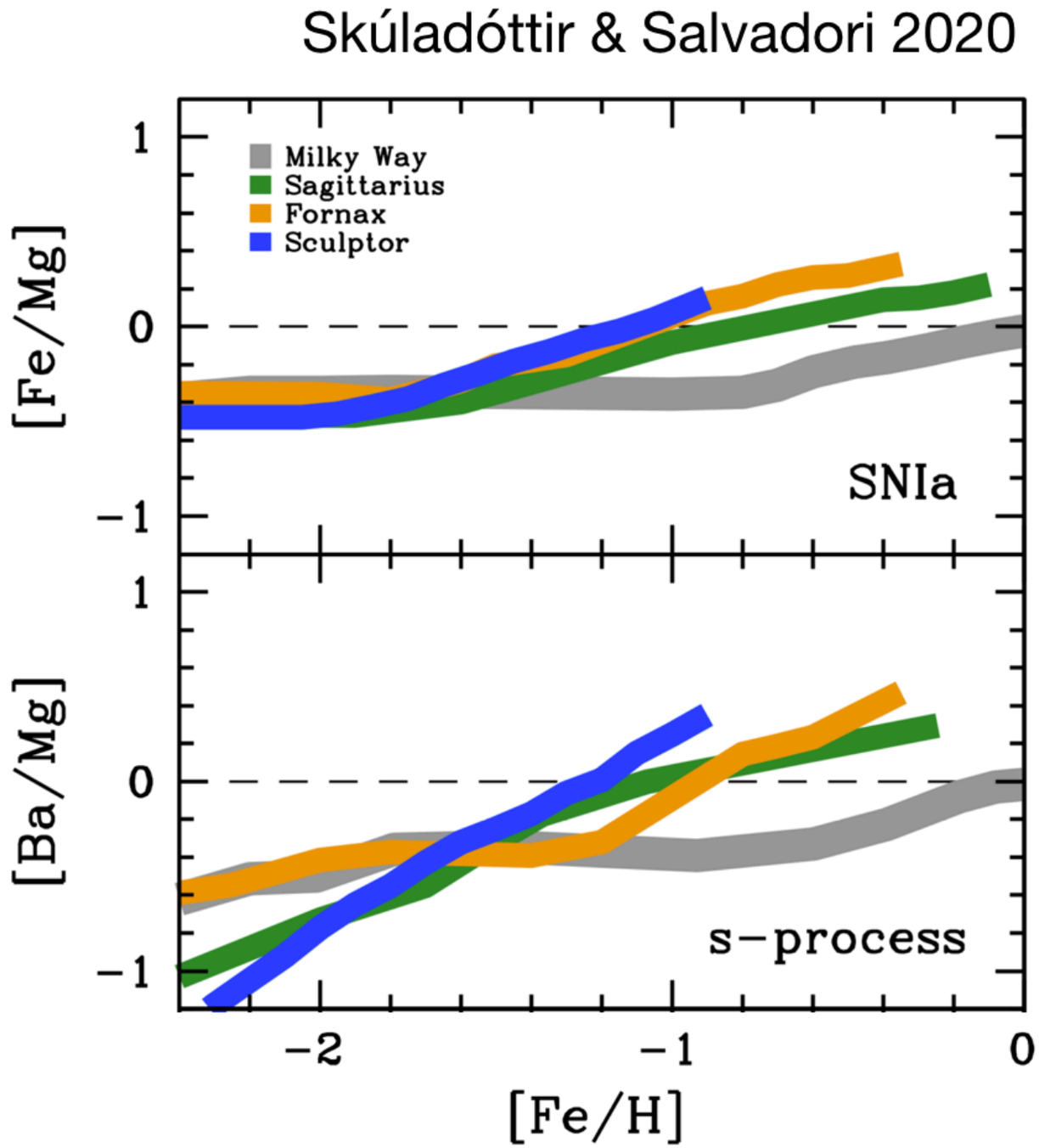
Mg almost exclusively made by core collapse SN

Supernovae type Ia

~60% of Fe in the Sun

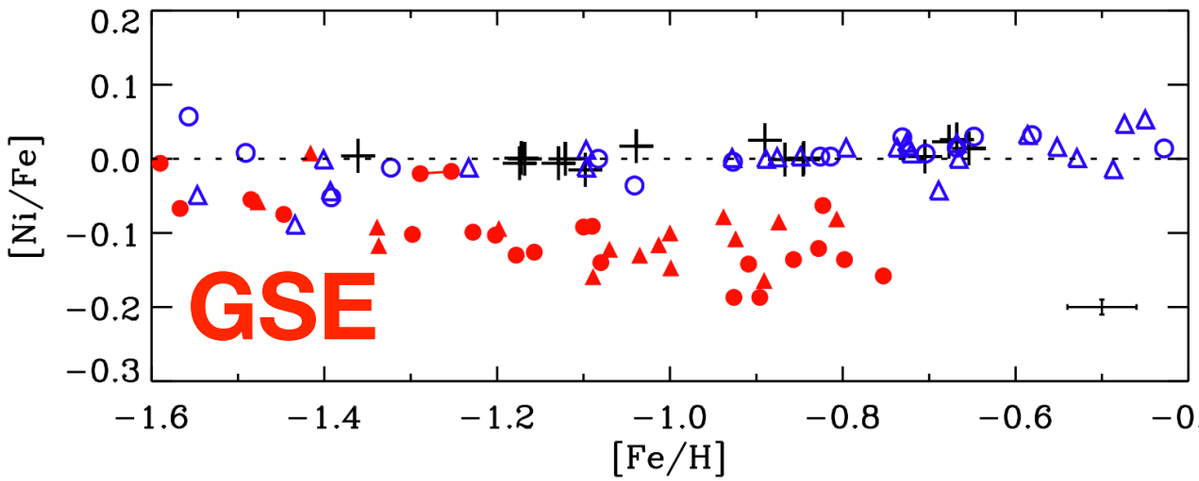
AGB stars

~85% of Ba in the Sun



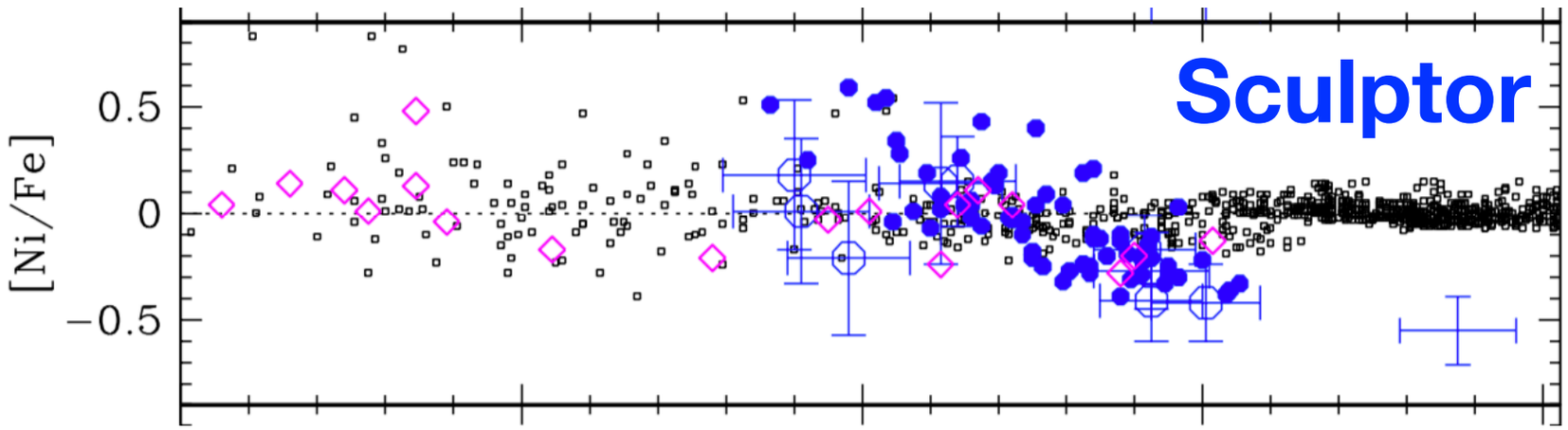
Supernovae type Ia

Supernovae type Ia in some dwarf galaxies seem to be devoid of Ni!



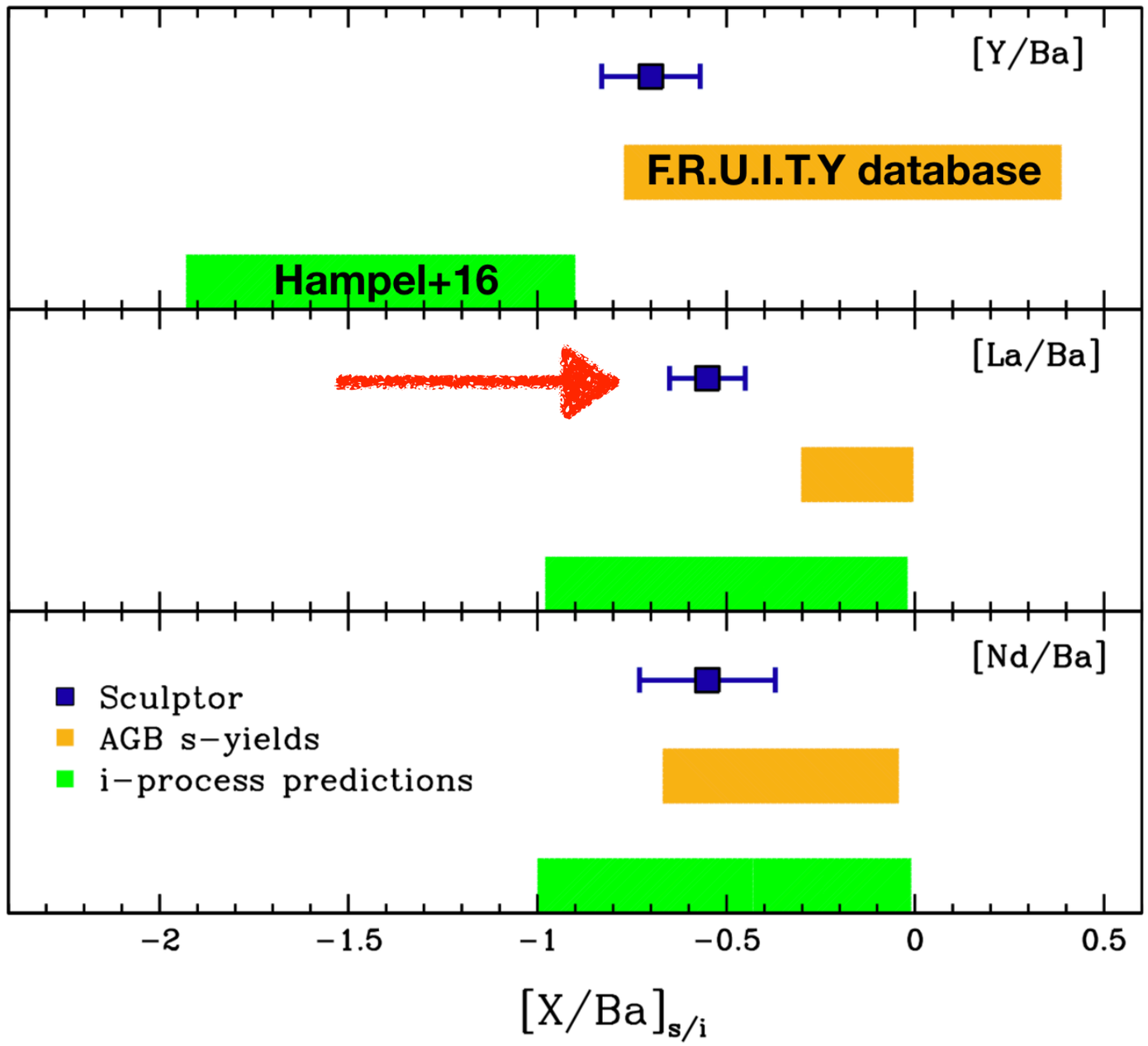
Nissen & Schuster 2010
Also see e.g. Sanders et al. 2021
(The next talk!)

Hill et al. 2019
Also e.g. Kirby et al. 2019,
Reichert et al. 2020



Evidence for Sub-Chandrasekhar SNIa?

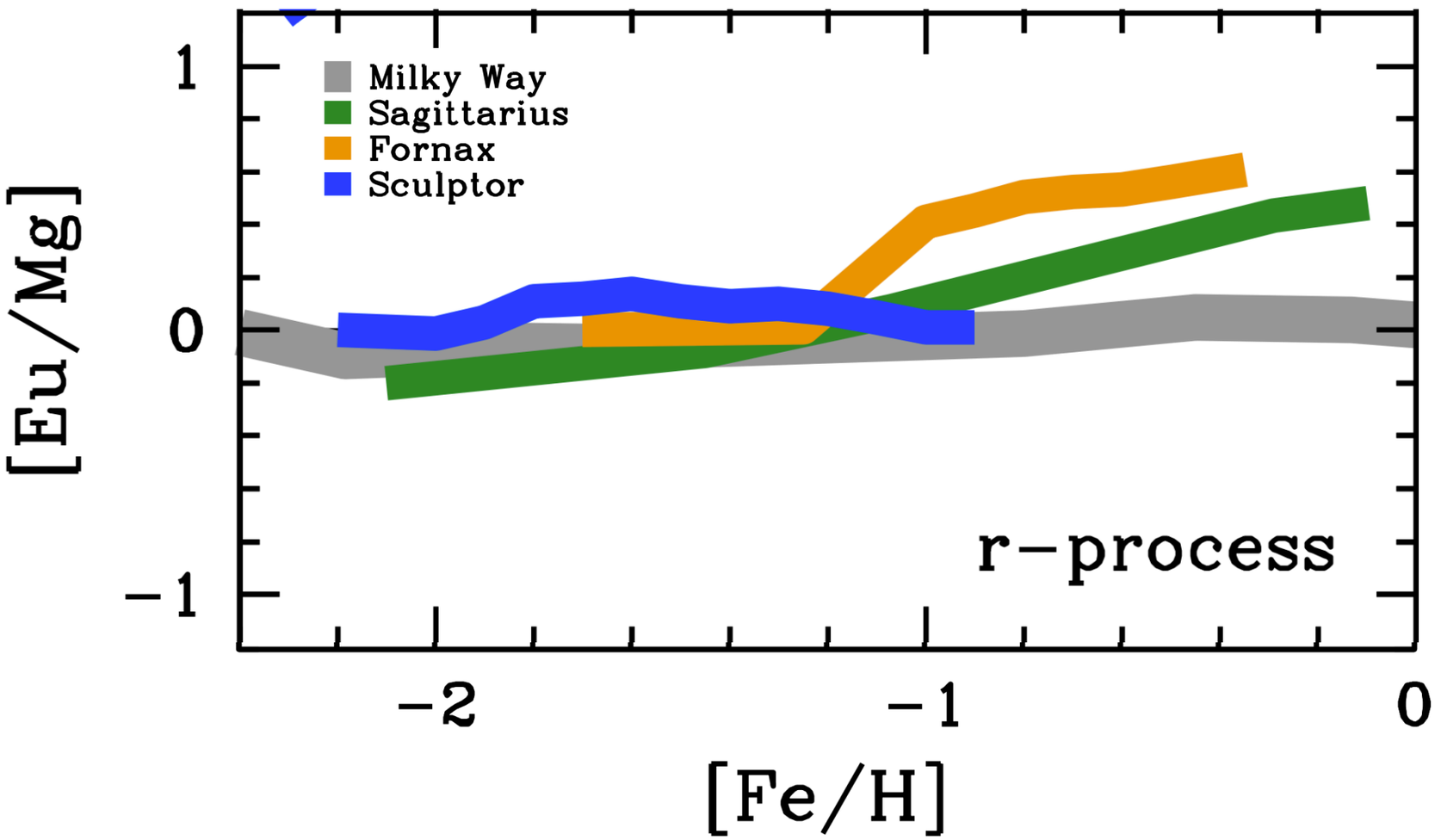
Importance of the i-process



The low [La/Ba] in Sculptor suggests significant i-process contribution

Based on Skúladóttir et al. 2020

The r-process



The r-process

~94% of Eu in the Sun

- Two distinct r-process sites are able to explain all the data: a quick source (comparable to ccSN) and a delayed source, ≳4 Gyr (Skúladóttir & Salvadori 2020)
- **Dwarf galaxies are key to understand the r-process!**
- **HRMOS necessary!**

Skúladóttir & Salvadori 2020

Science Cases

First stars

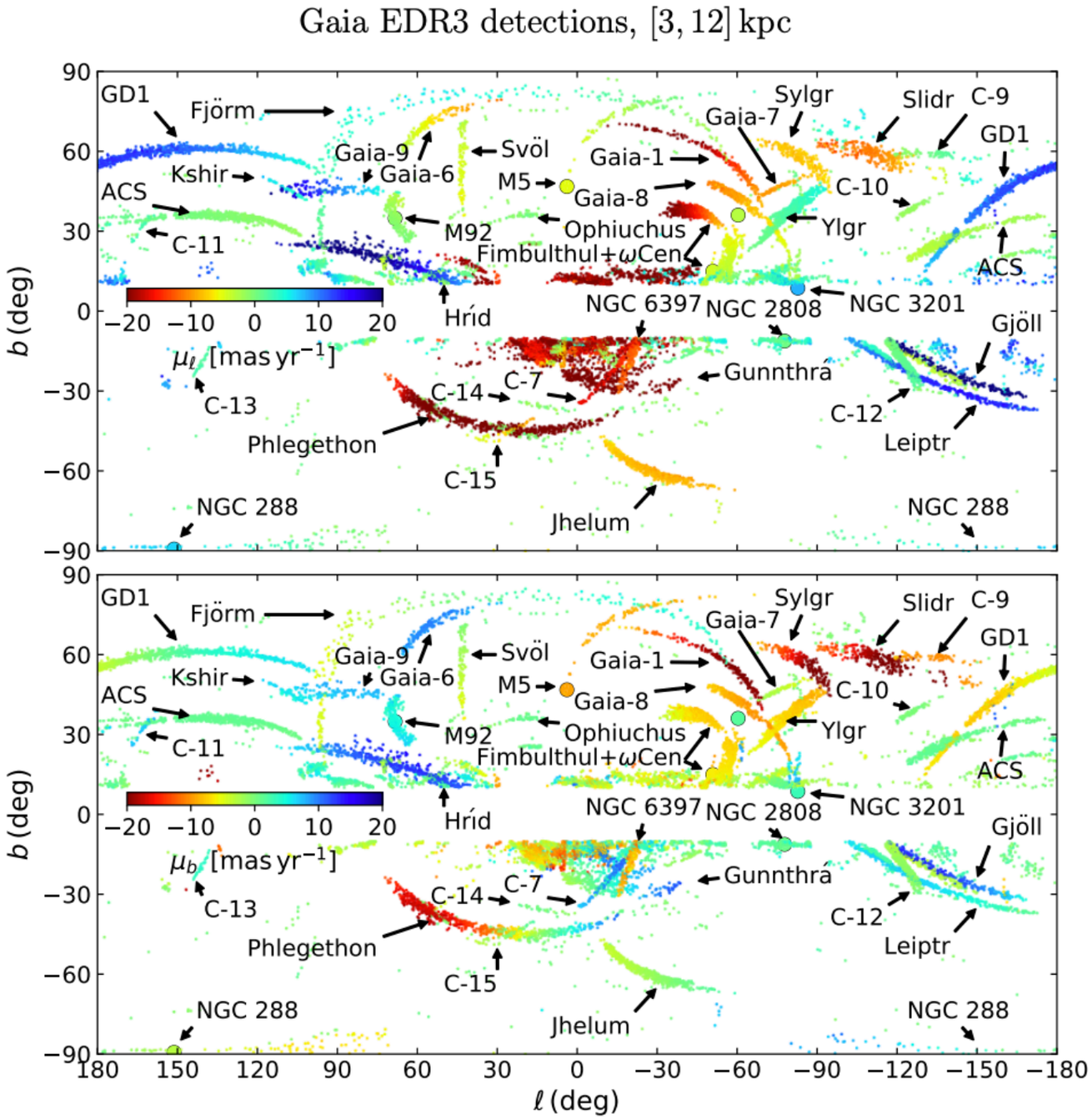
Delayed nucleosynthetic processes

Hierarchical Galaxy formation

Stellar binaries in smaller galaxies

Hierarchical Galaxy Formation

- In the current era we are discovering the accretion of our Milky Way.
- **In the next decade:** Accretion history of the satellite galaxies?

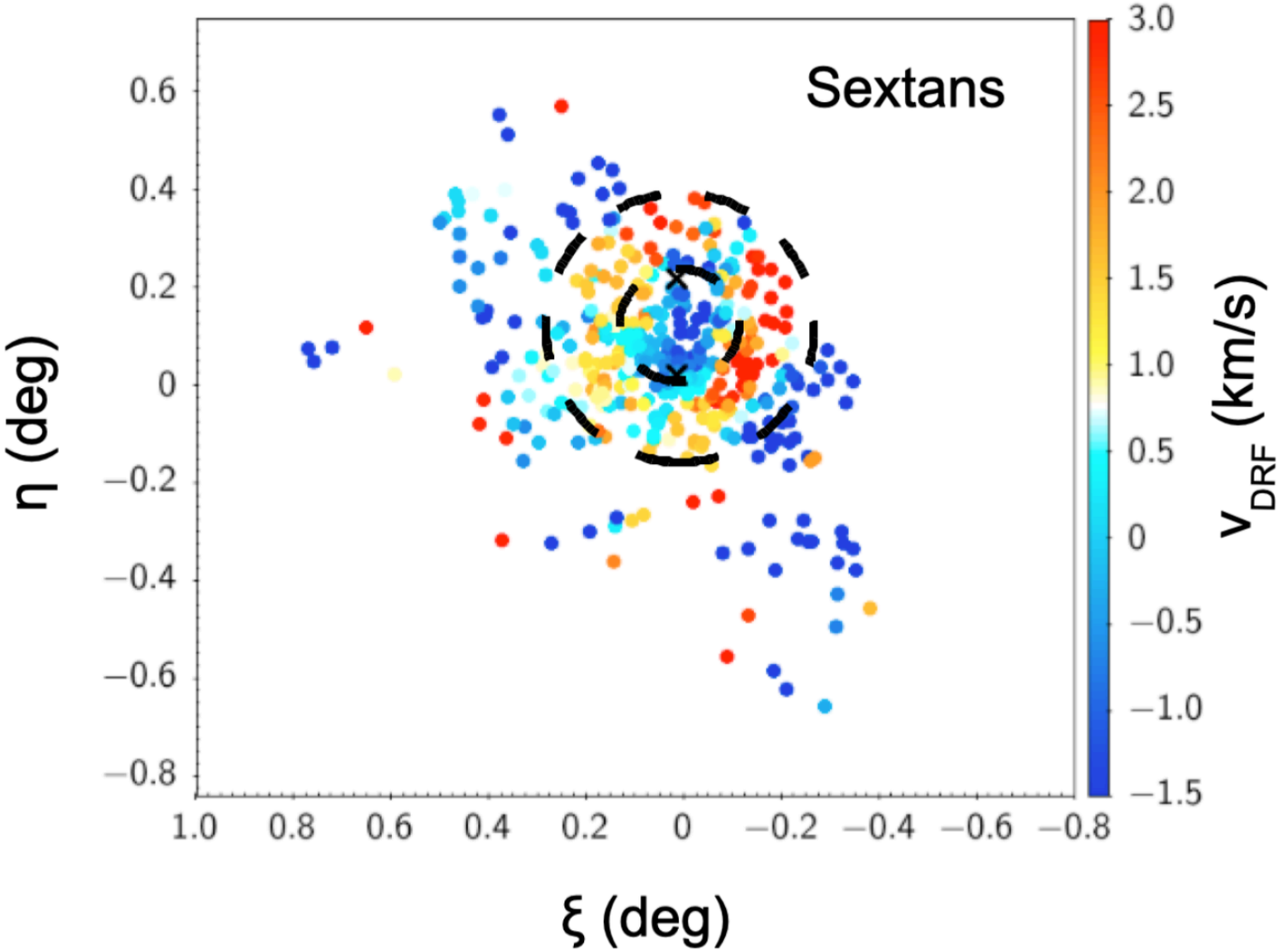


Ibata et al. 2021

Hierarchical Galaxy Formation

- Example of accretion event in Sextans
- Many such events expected to be discovered in the coming decade - will need HR follow-up!

Cicuendez & Battaglia 2018



Science Cases

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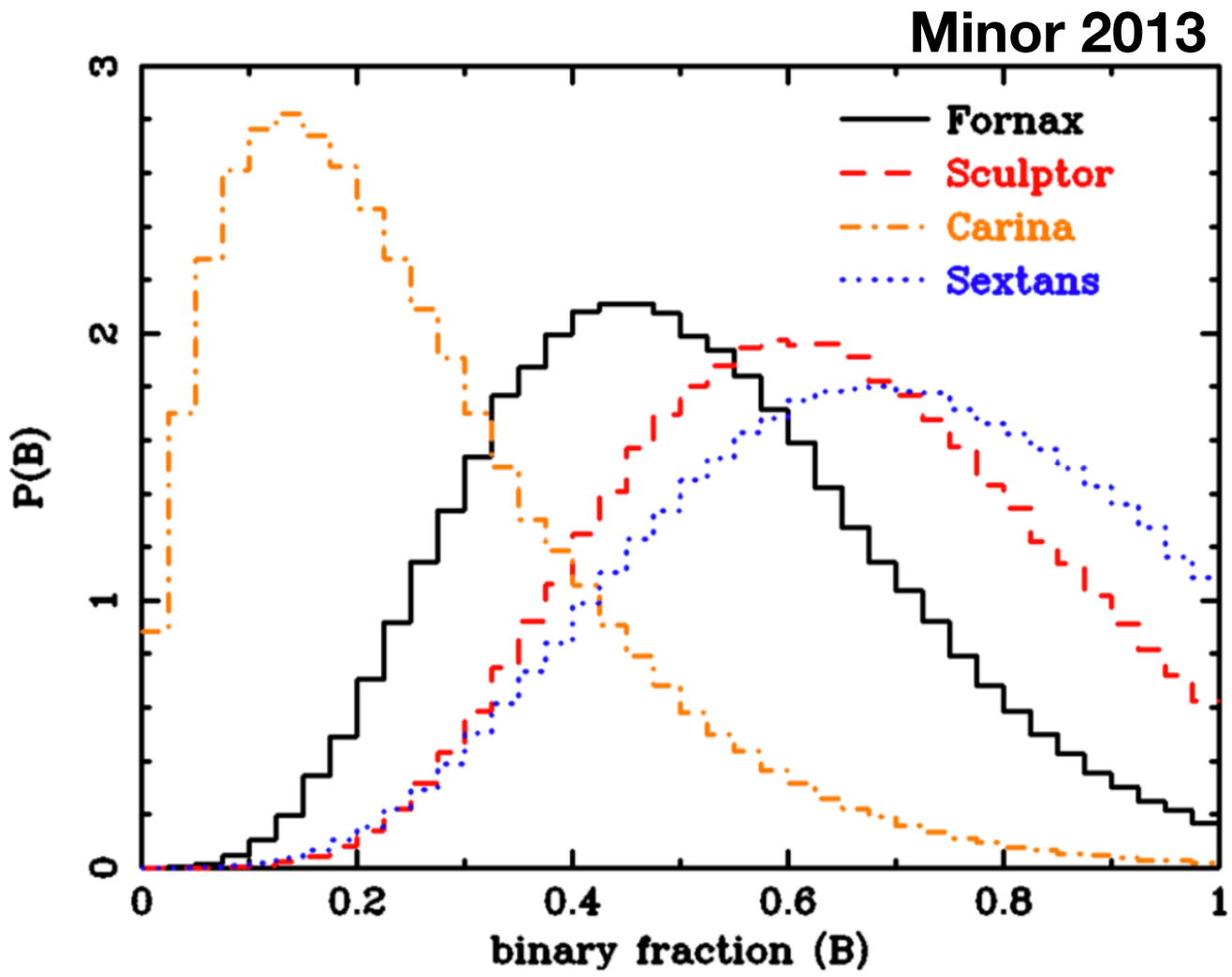
Binaries in dwarf galaxies

- Very little is known about the binary fraction and orbit distribution in the satellite galaxies

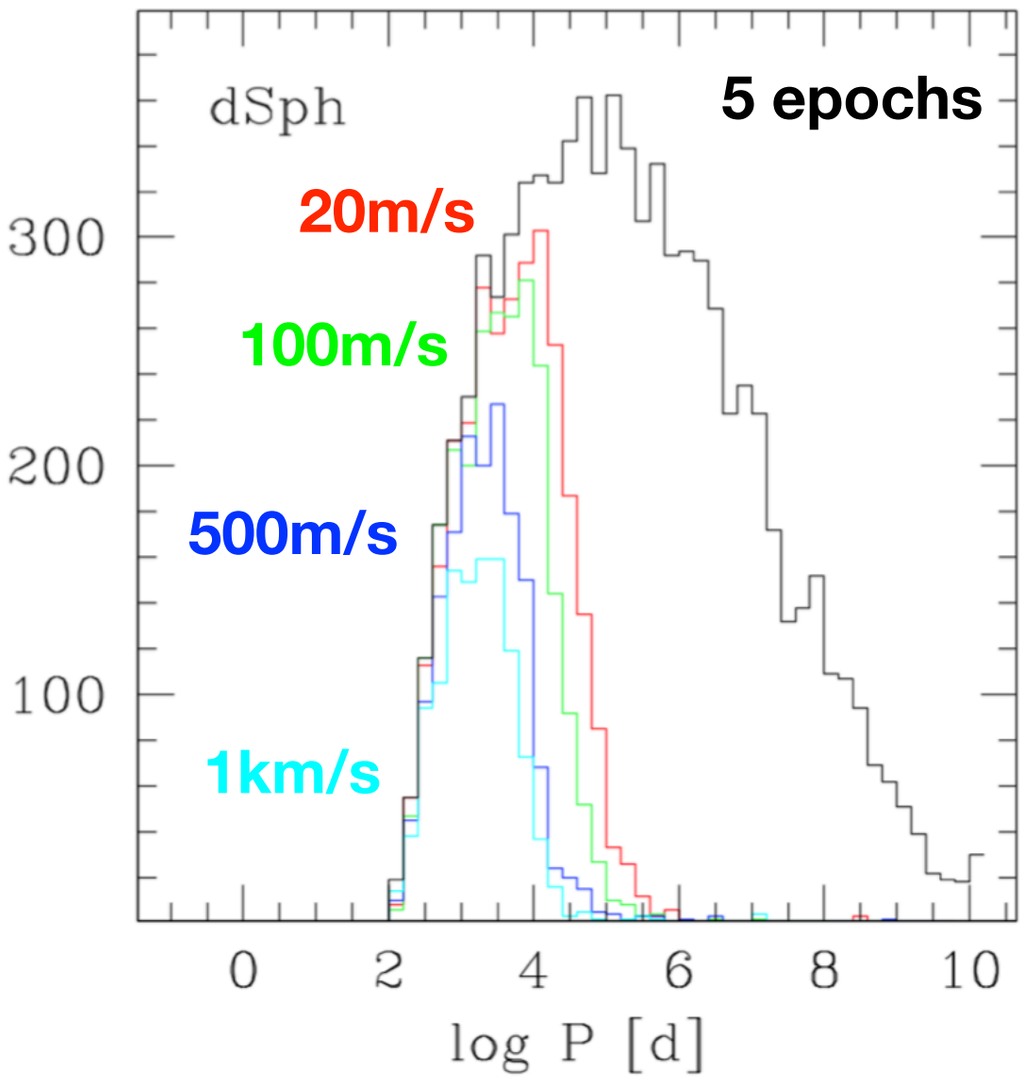


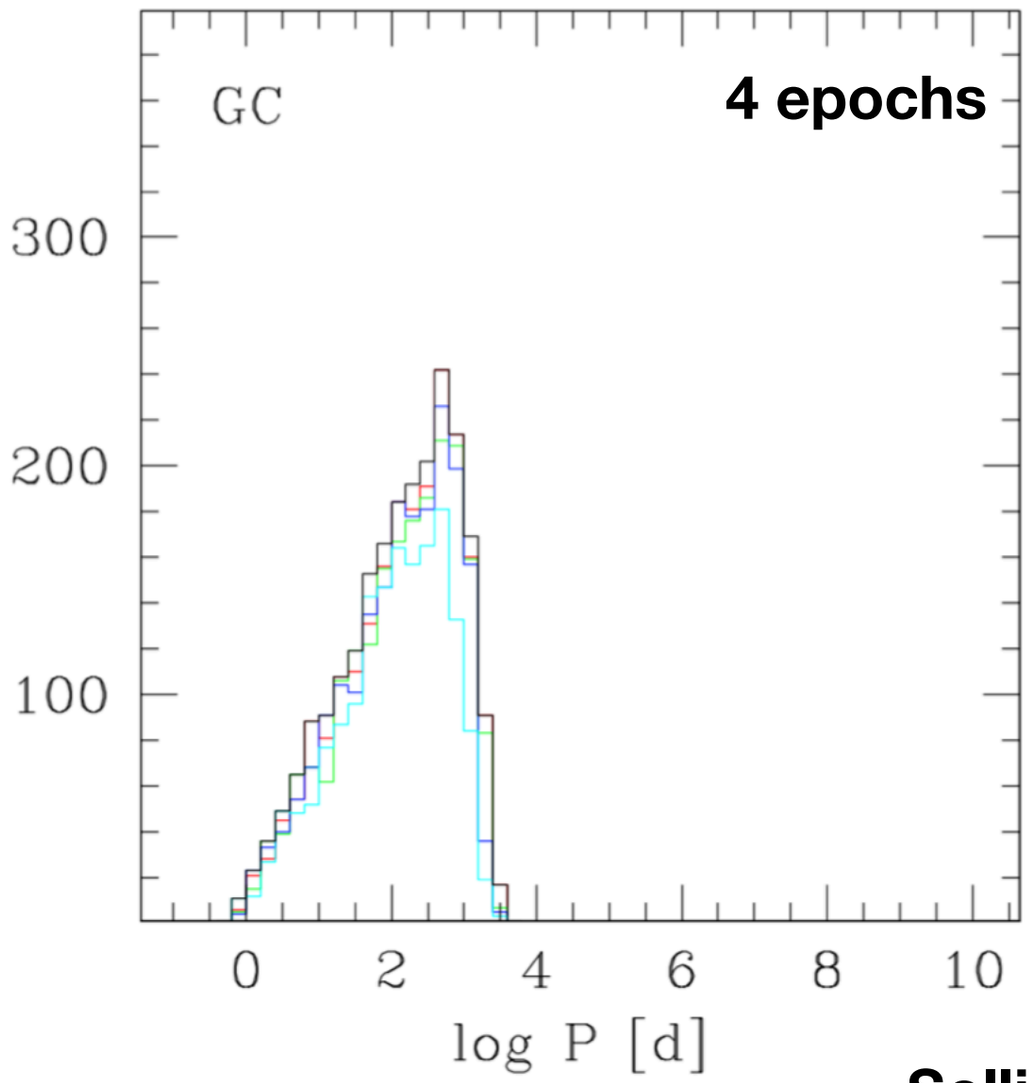
Binaries in dwarf galaxies

- Accurate binary fraction and characterization
  - Velocity dispersion - mass of the galaxy (especially important for ultra-faint dwarf galaxies).
  - Dark matter distribution
  - Dwarf galaxies are large and diffuse - binary fraction mostly unaltered.
  - Key to understand how binary fraction changes with metallicity!

Binaries in dwarf galaxies

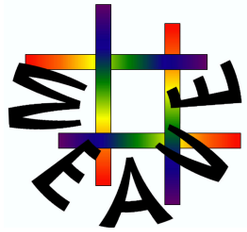
- Mock 5yr survey (Sollima)





Sollima

Conclusion: HRMOS is key!



+ 4DWARFS?

- **First stars**
- **Delayed nucleosynthetic processes**
- **Hierarchical Galaxy formation**
- **Stellar binaries in smaller galaxies**

- **Main requirements**
  - High efficiency in the blue (~380-520nm)
  - Multiplicity: ~100 objects per field
  - Ideal resolution: R~50,000