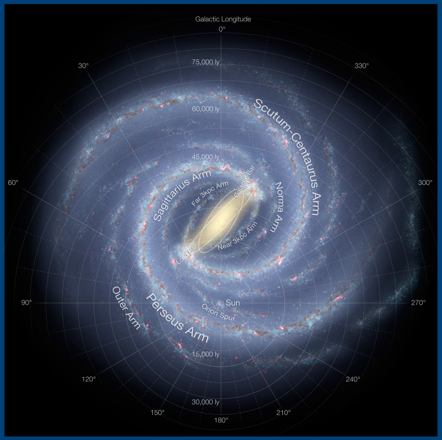
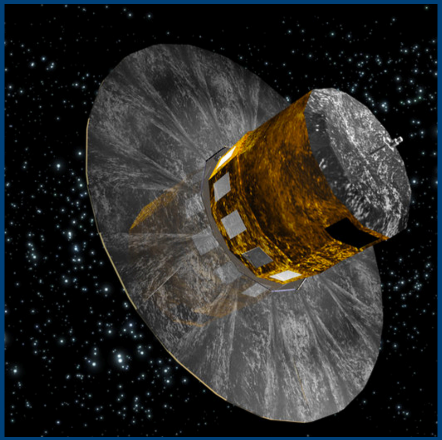
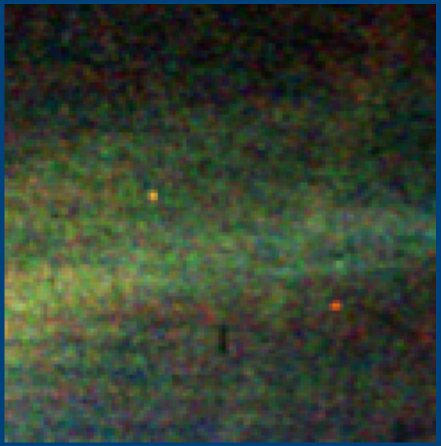
Leibniz-Institut für Astrophysik Potsdam

AIP



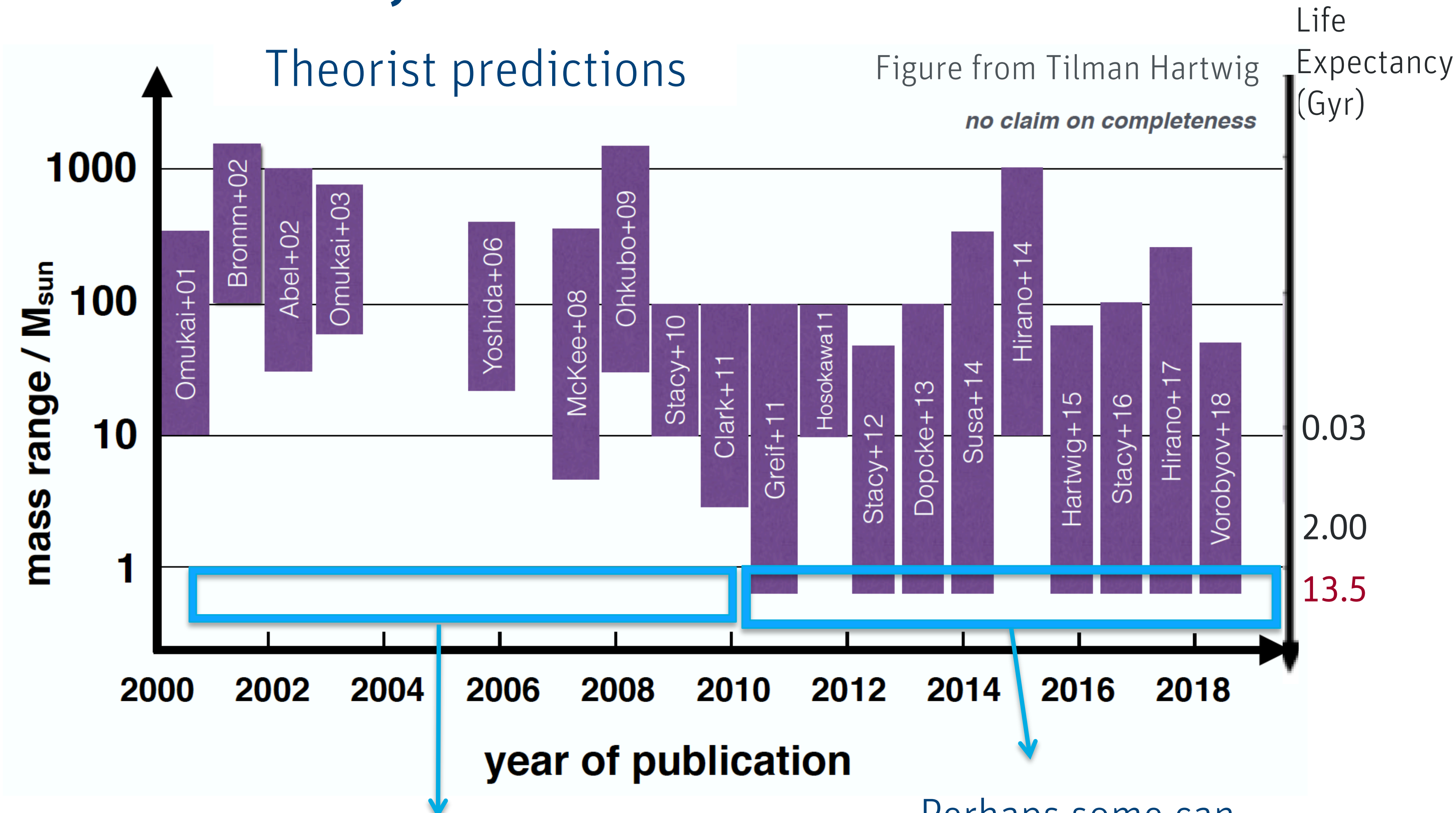




Signatures of first stars in and from dwarf galaxies

Else Starkenburg

First Stars, can we observe them?



Forget about it

Perhaps some can still be alive?

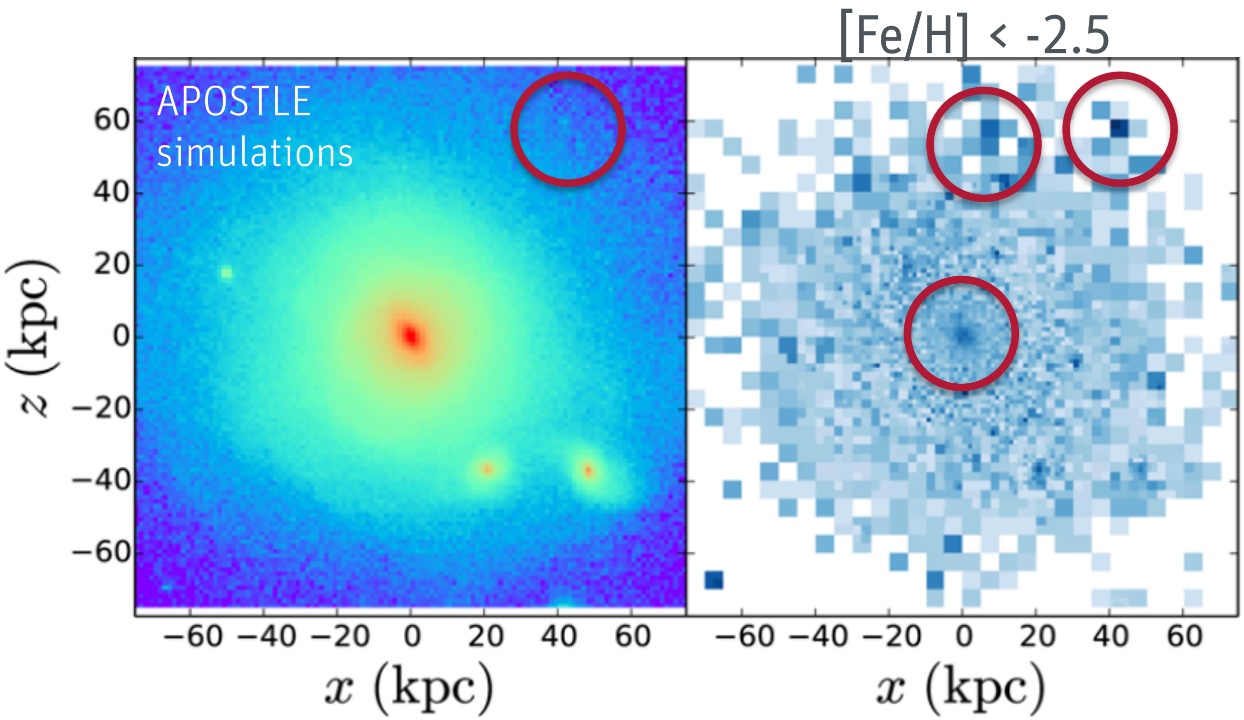
But we can also learn a lot from 2nd, 3rd, … generations

- Their chemistry tells us about early enrichment processes
  - What were the elements produced in the first generations?
  - What was the nature of their supernovae?

- Their kinematics inform us on the early build-up of the Galaxy

- Their distribution constrains star formation physics
  - Simulation results change with changing star formation & feedback (see f.i., El-Badry et al., 2018 & Starkenburg et al., 2017)
  - Are the present-day dwarf galaxies similar to the Galaxy at the earliest times?
  - Also possible to test different cosmologies

The oldest and most metal-poor stars Where can they be found?



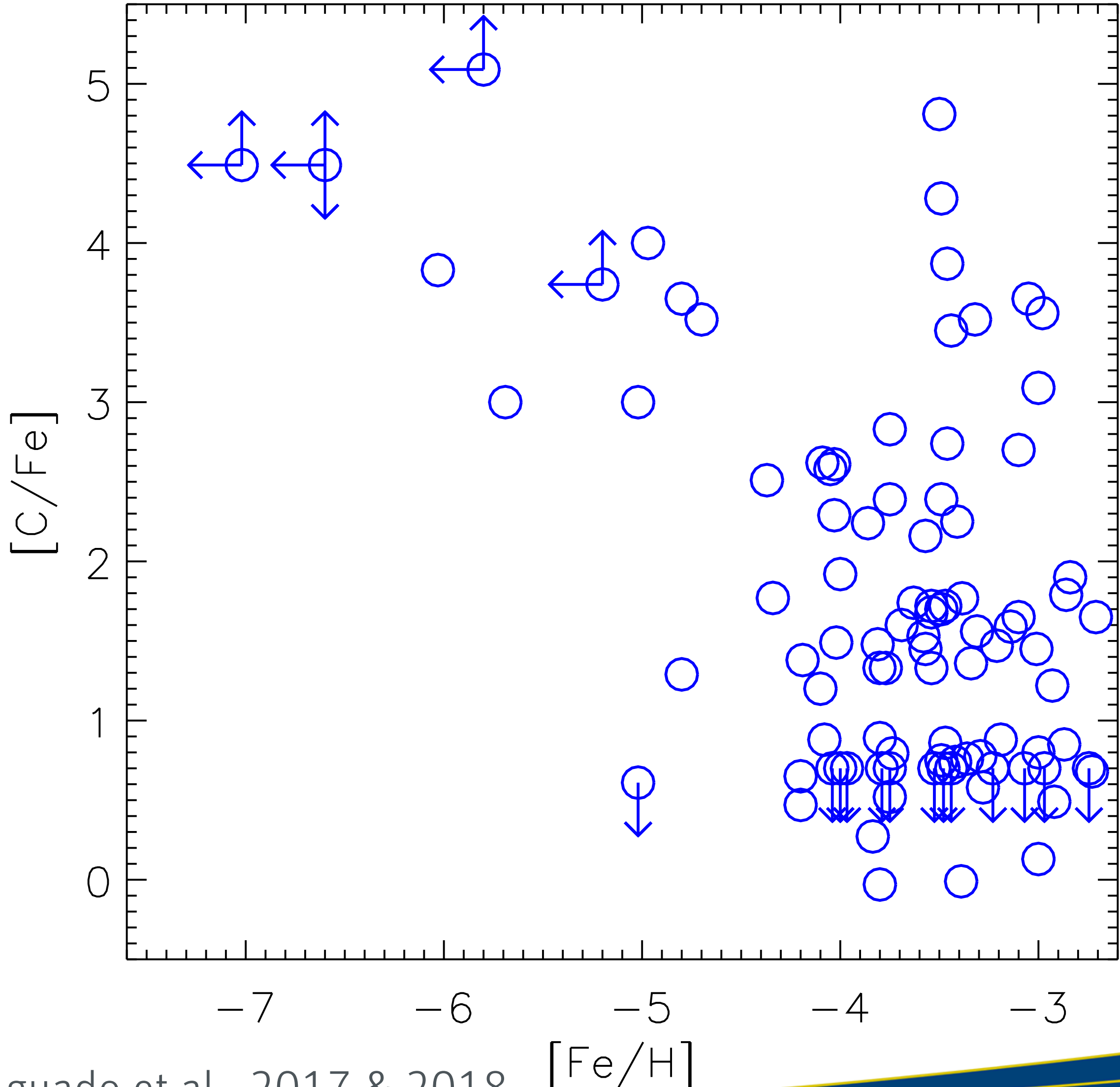
Colour-coded by density

Darker with larger fraction of old stars

- Where to look?
  - In the outskirts
  - In the center
  - In the satellites
  - Chemical evolution proceeds on different timescales in different environments

Extremely metal-poor stars in the Galaxy

- Approaching the "metallicity floor"?
  - Only 14 known [Fe/H] < -4.5
- Carbon seems important
  - Several sub-populations (Spite et al., 2013, Yoon et al., 2016,2019)
- Needle in a haystack
  - 1 in 80.000 halo stars are [Fe/H] < -4 (Youakim et al., 2017)
  - Also big surveys only find a few



Literature compilation from Aguado et al., 2017 & 2018

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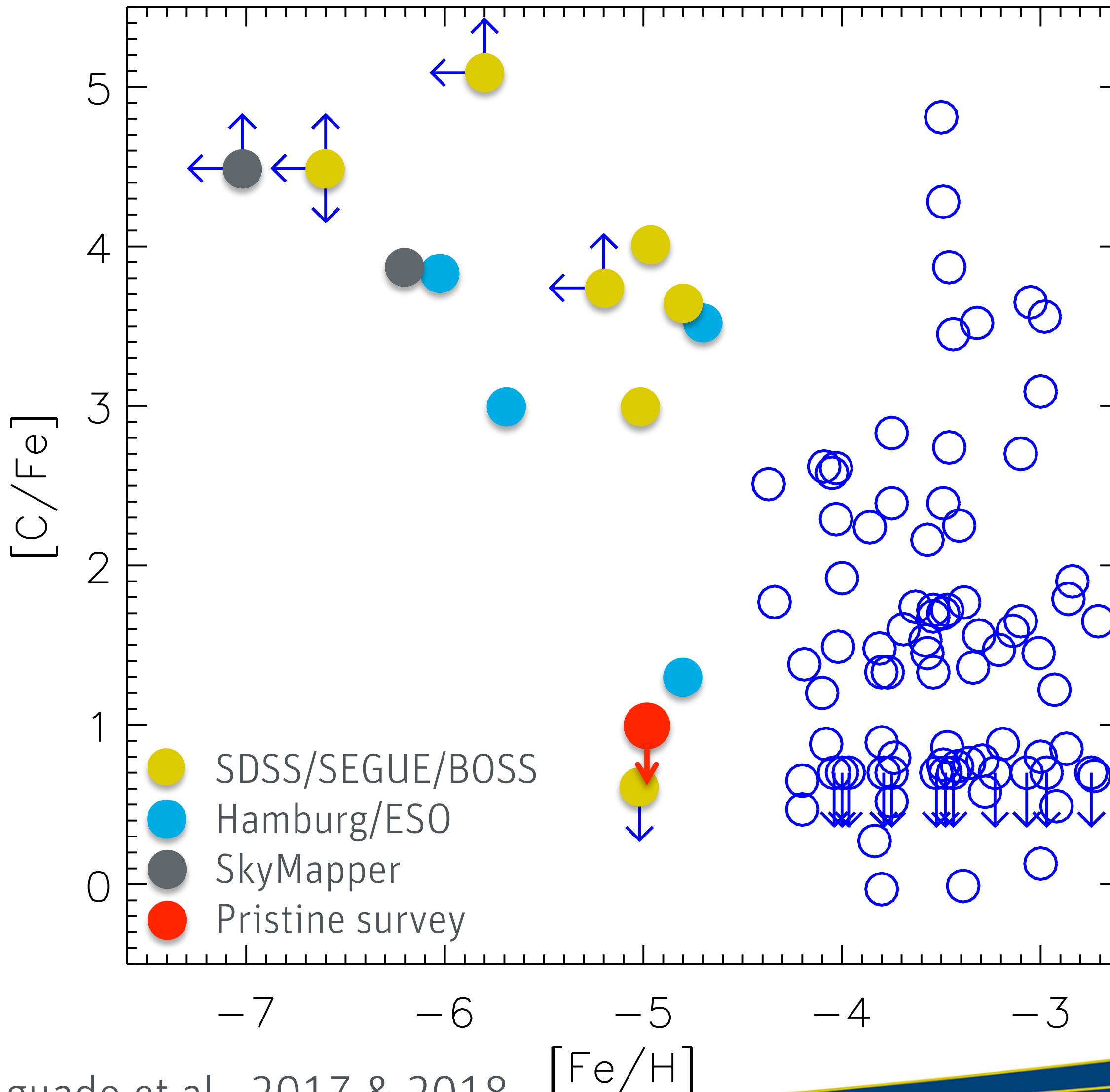
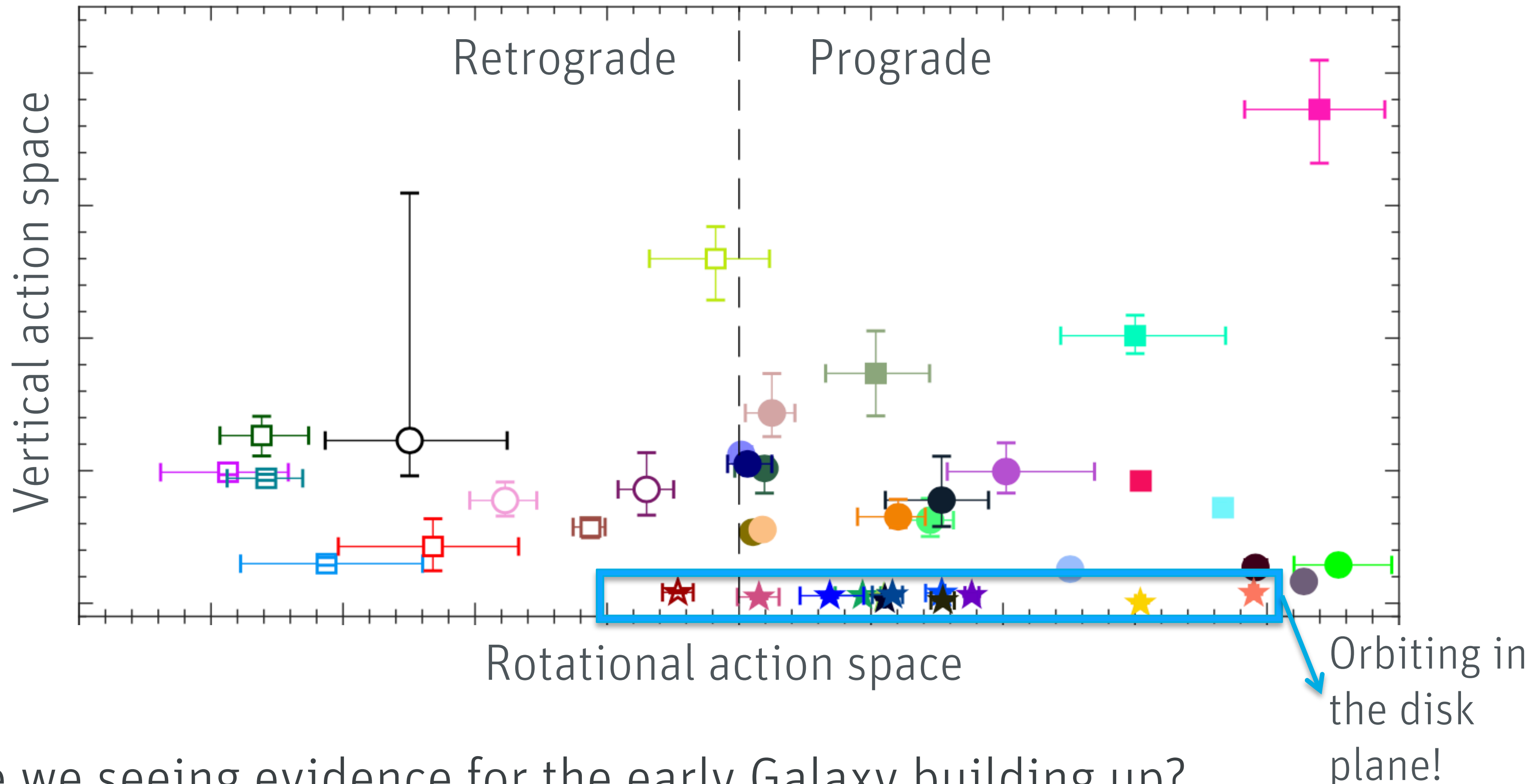


Literature compilation from Aguado et al., 2017 & 2018

+ Starkenburg et al., 2018 + Nordlander et al., 2019

Tracing the build-up of the early Galaxy

- Motions of the most metal-poor stars

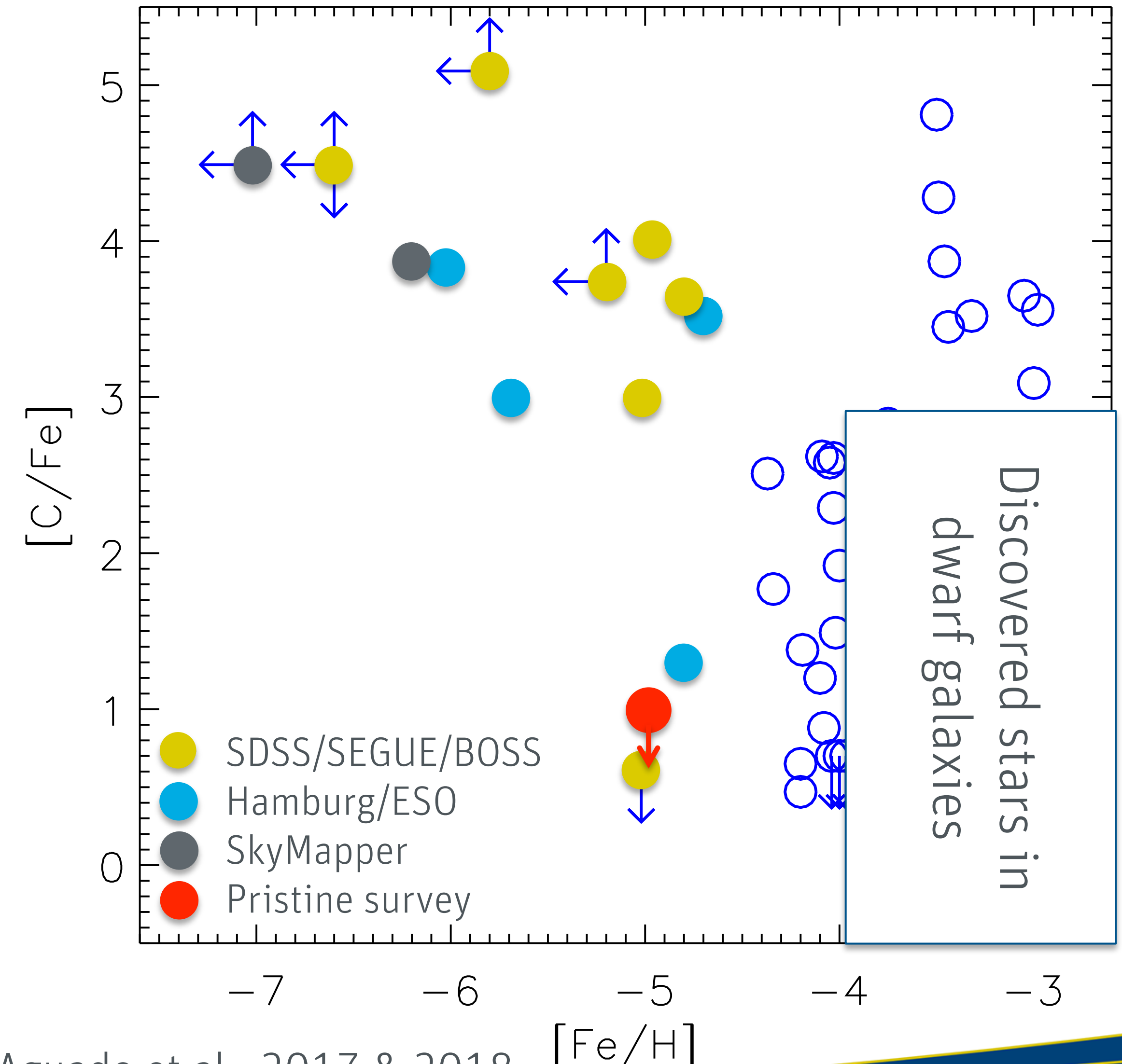


- Are we seeing evidence for the early Galaxy building up?

Sestito, Longeard, Martin, Starkenburg et al., 2019

Extremely metal-poor stars in the dwarfs

- Not yet into the ultra metal-poor regime
  - Sampling or pre-enrichment?

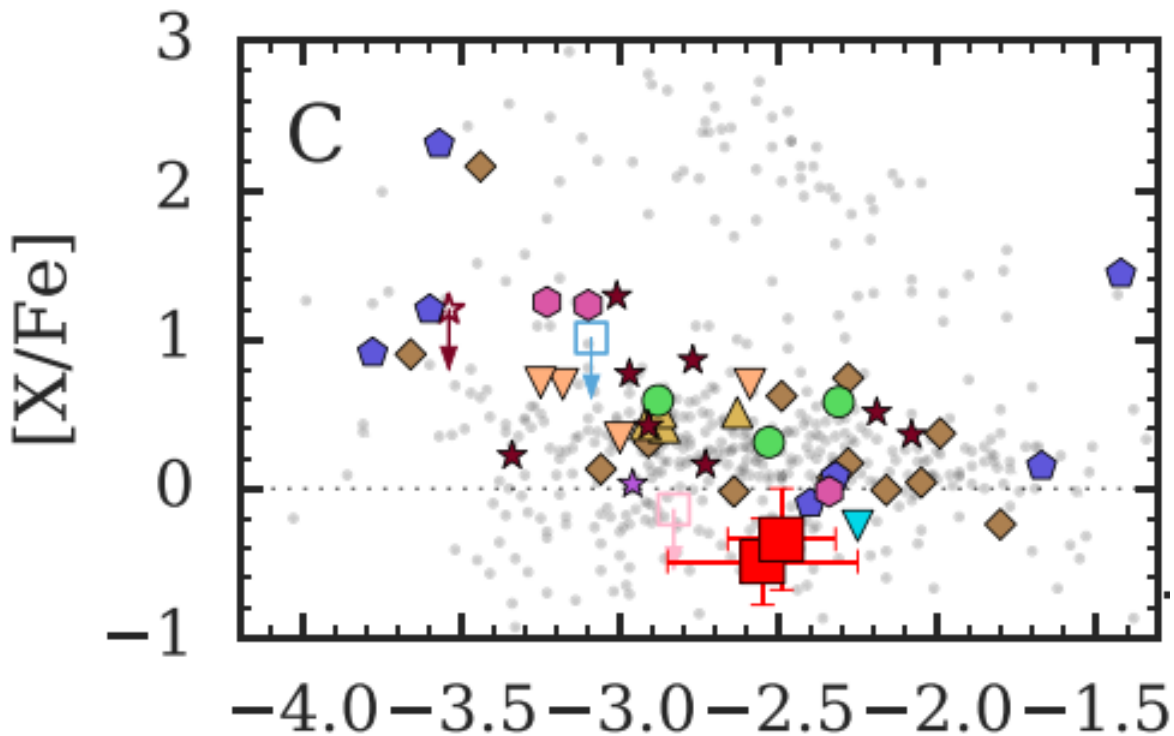


Literature compilation from Aguado et al., 2017 & 2018

+ Starkenburg et al., 2018 + Nordlander et al., 2019

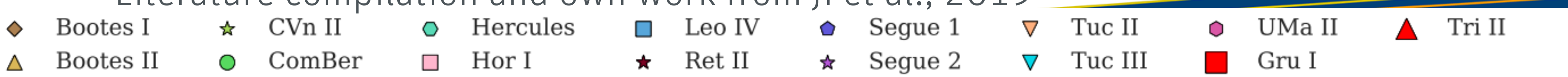
Extremely metal-poor stars in the dwarfs

- Not yet into the ultra metal-poor regime
  - Sampling or pre-enrichment?
- Testbeds for all possibilities in chemical evolution
  - r-process
- Metal-poor population more halo-like
  - But also more scatter in abundance patterns
  - The same, or different?



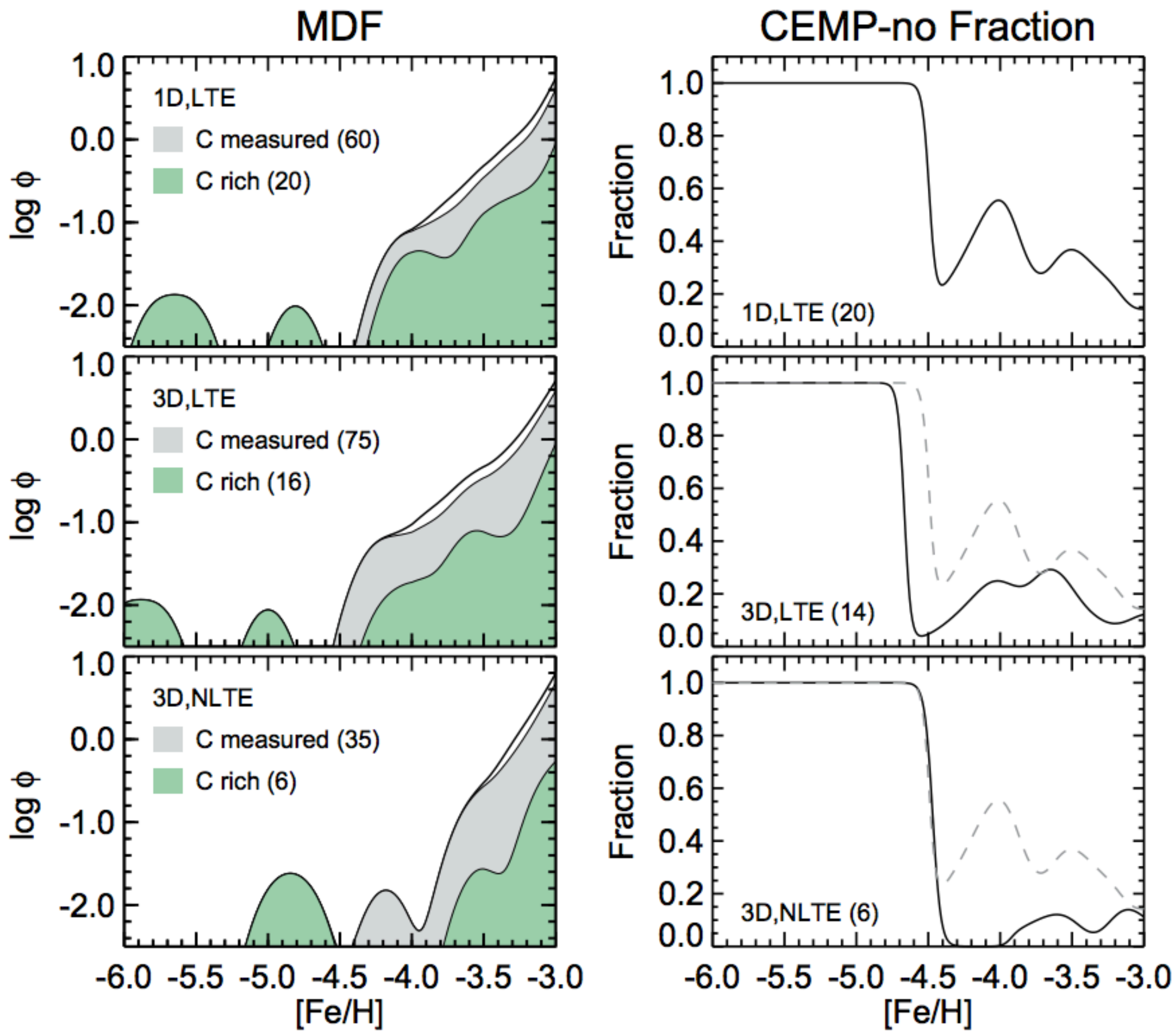
See upcoming talks!

Literature compilation and own work from Ji et al., 2019



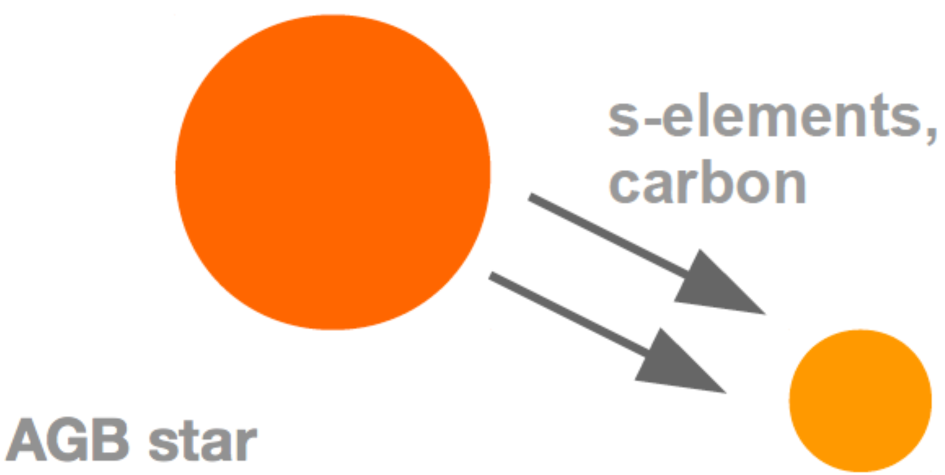
Some cautionary words on Carbon

- 3D non-LTE abundances: “Mildly” carbon-enhanced population much smaller
- Also: be mindful of stars in different evolutionary phases



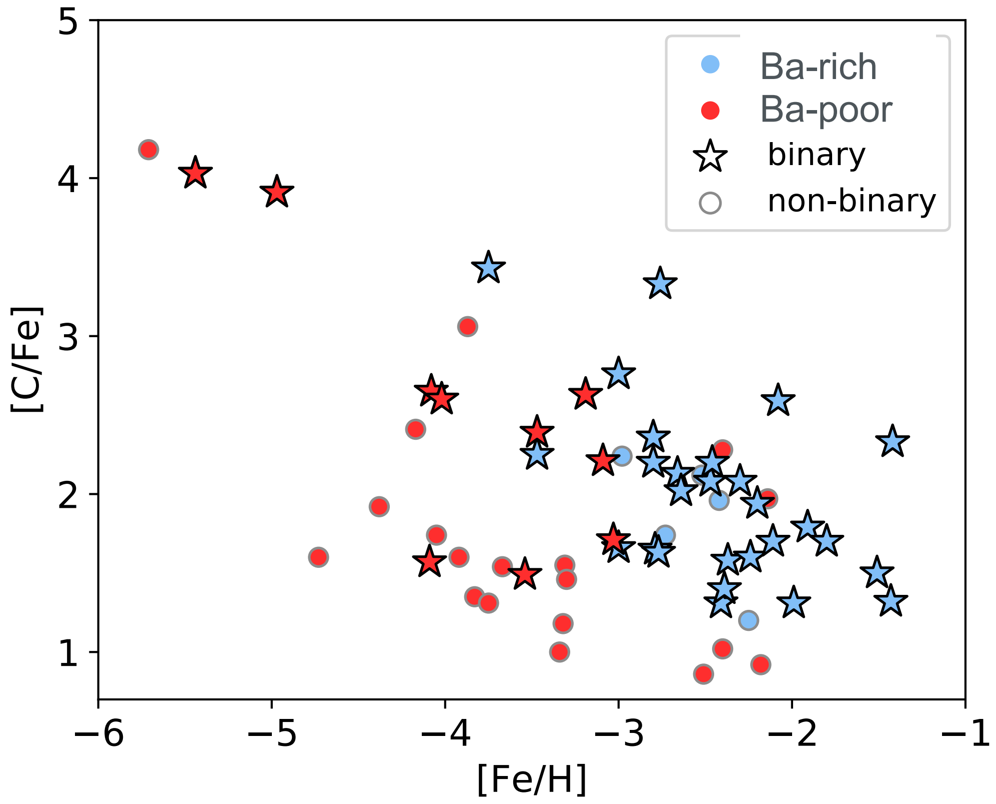
Norris & Yong, 2019

Natal versus polluted?



- Binary companions can transfer material
  - AGB pollution elevates Carbon and s-process (Barium)
- This can be checked with radial velocity monitoring (Lucatello et al., 2005, Starkenburg et al., 2014, Hansen et al., 2016a,b)

Natal versus polluted?



Arentsen, Starkenburg, Shetrone et al., 2019
Literature compilation + new data

- Radial velocity monitoring
  - Expectation: Ba-rich stars are in binaries, Ba-poor stars not
  - But…even some Ba-poor stars are in binaries!
  - We need to be careful about interpretation of their abundance patterns

Many open issues: Narrow-band filters help

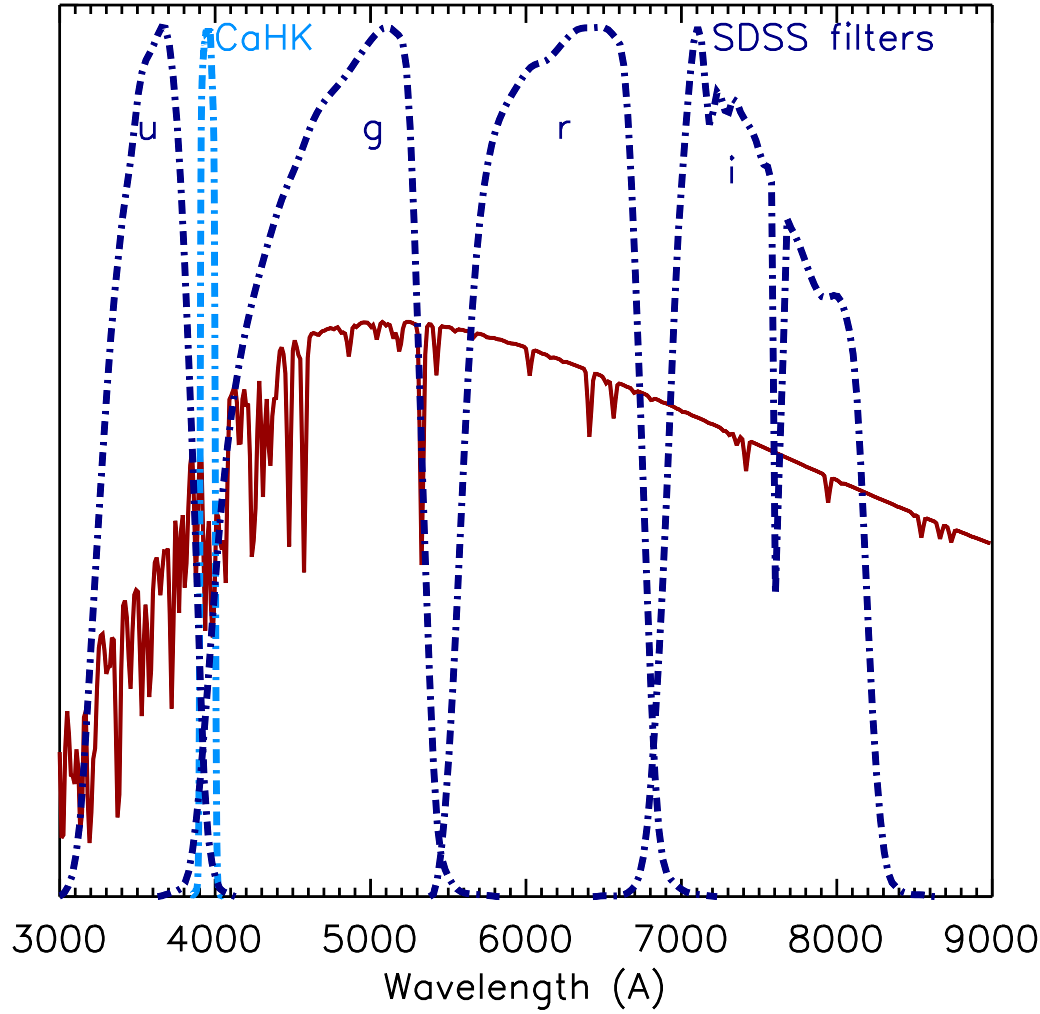
- Pristine Survey in the Northern Hemisphere

  ➢ Several other efforts

  (e.g., Anthony-Twarog et al., 1991,2000. Lee et al., 2013, Lim et al., 2015, Koch et al., 2016, J-PLUS survey)

  ➢ Skymapper in the South

  (Keller et al., 2014, Jacobson et al., 2015, Wolf et al., 2018)

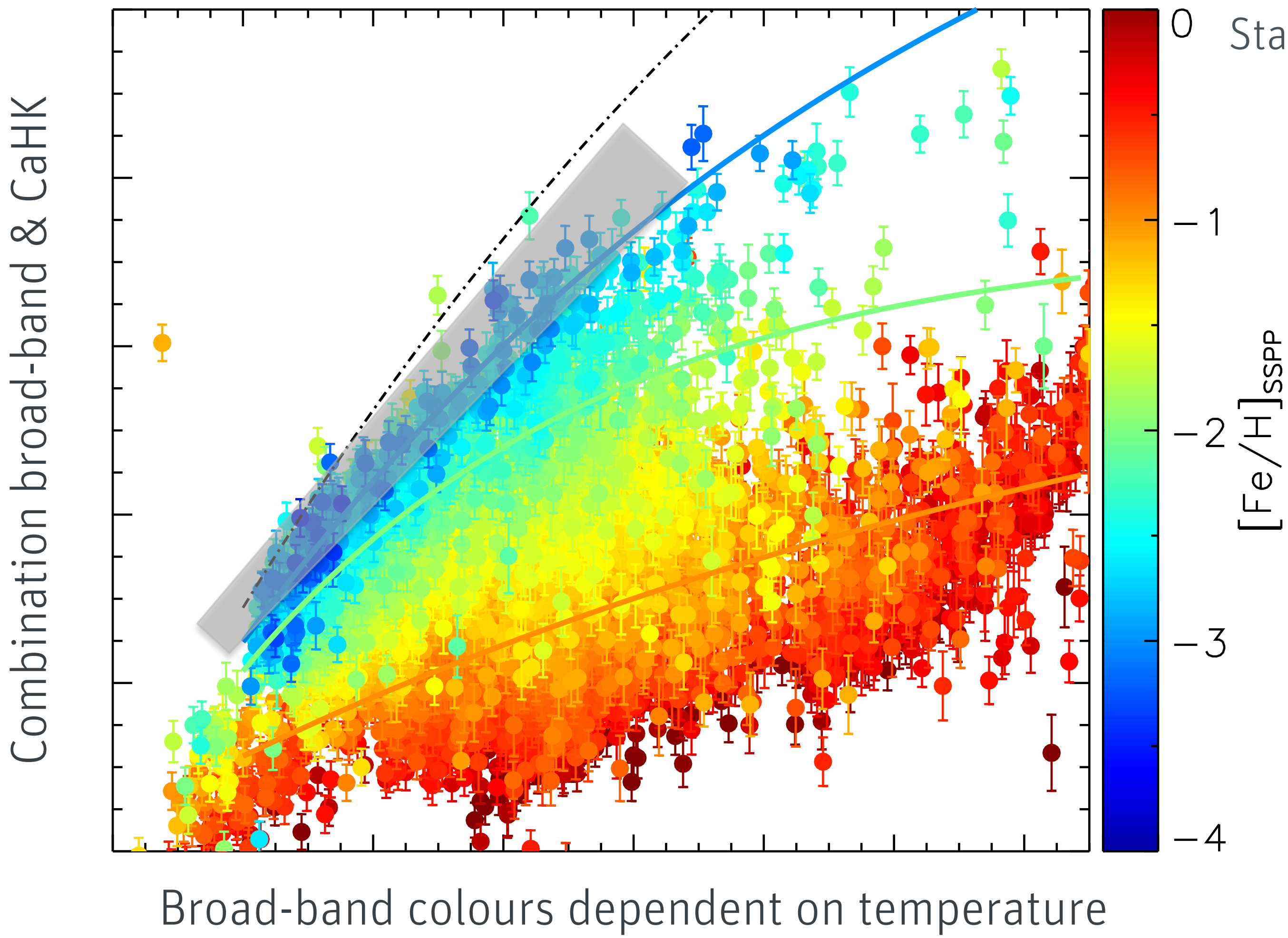


PRISTINE

PIs: Else Starkenburg & Nicolas Martin

Co-Is: David Aguado, Carlos Allende Prieto, Anke Arentsen, Edouard Bernard, Piercarlo Bonifacio, Elisabetta Caffau, Raymond Carlberg, Patrick Cote, Nick Fantin Morgan Fouesneau, Patrick Francois, Jonay Gonzalez Hernandez, Stephen Gwyn, Vanessa Hill, Rodrigo Ibata, Pascale Jablonka, Collin Kielty, Georges Kordopatis, Carmela Lardo, Nicolas Longeard, Khyati Malhan, Lyudmila Mashonkina, Julio Navarro, Alan McConnachie, Ruben Sanchez-Janssen, Federico Sestito, Guillaume Thomas, Eline Tolstoy, Kim Venn, Kris Youakim

Photometric metallicities



Starkenburg et al., 2017b

- Metallicity in colour-colour space
  - Self-calibrating through SDSS / SEGUE spectra

What we can do

- Hunt for the most metal-poor stars
  - ➢ Then perform spectroscopic follow-up

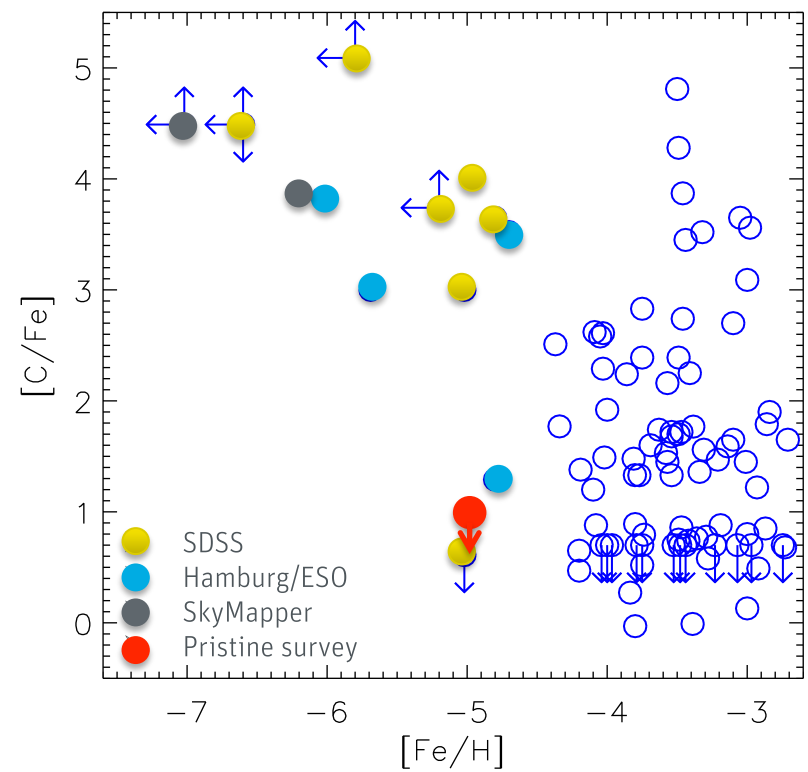
  (Starkenburg et al., 2018, see also Youakim et al., 2017, Caffau et al., 2017, Bonifacio et al., 2019, Aguado et al., 2019, Venn et al., in prep.)
- Investigate the halo metallicity distribution function

  Youakim et al., in prep.
- Quantify substructure in the Galactic halo depending on metallicity

  Youakim et al., in prep.
- Discriminate BHB stars

  Starkenburg et al., subm.
- Look at the Inner Galaxy

  PIGS survey, led by Anke Arentsen

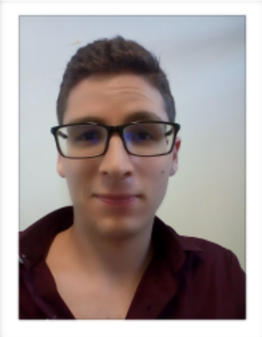


- Where to look?
  - ➢ In the outskirts ✔
  - ➢ In the center ✔
  - ➢ **In the satellites**

Survey Footprint

- Extra deep data in ultra-faint satellites
  - ➢ Data for 20 faint Northern satellites in hand
- Dwarf or globular cluster?
  - ➢ How small can a galaxy/cluster be?
  - ➢ How metal-poor?

See poster Nicolas Longeard



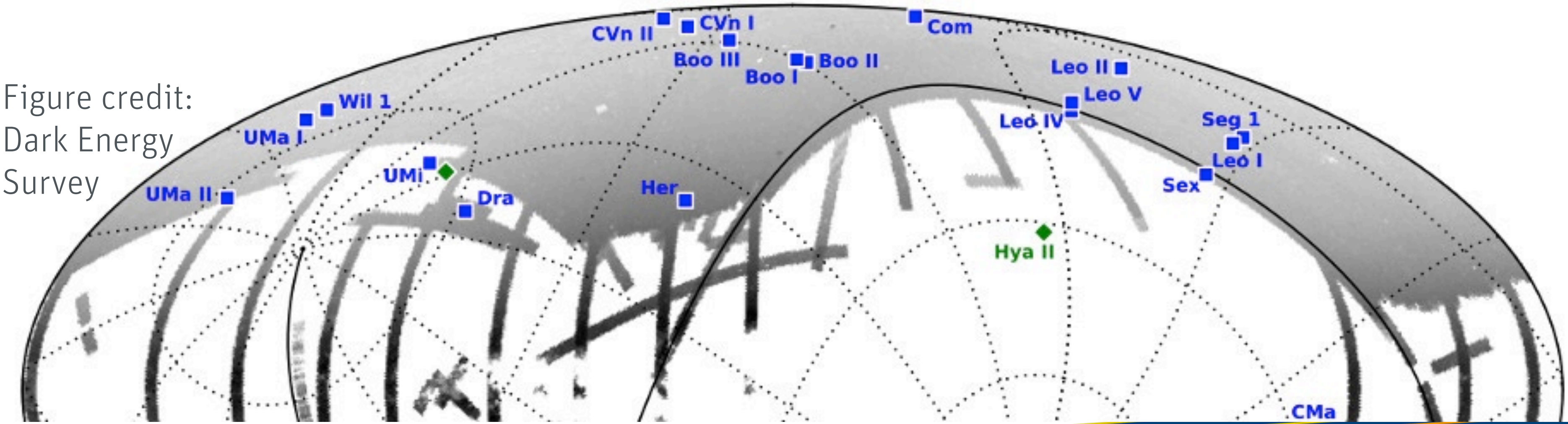
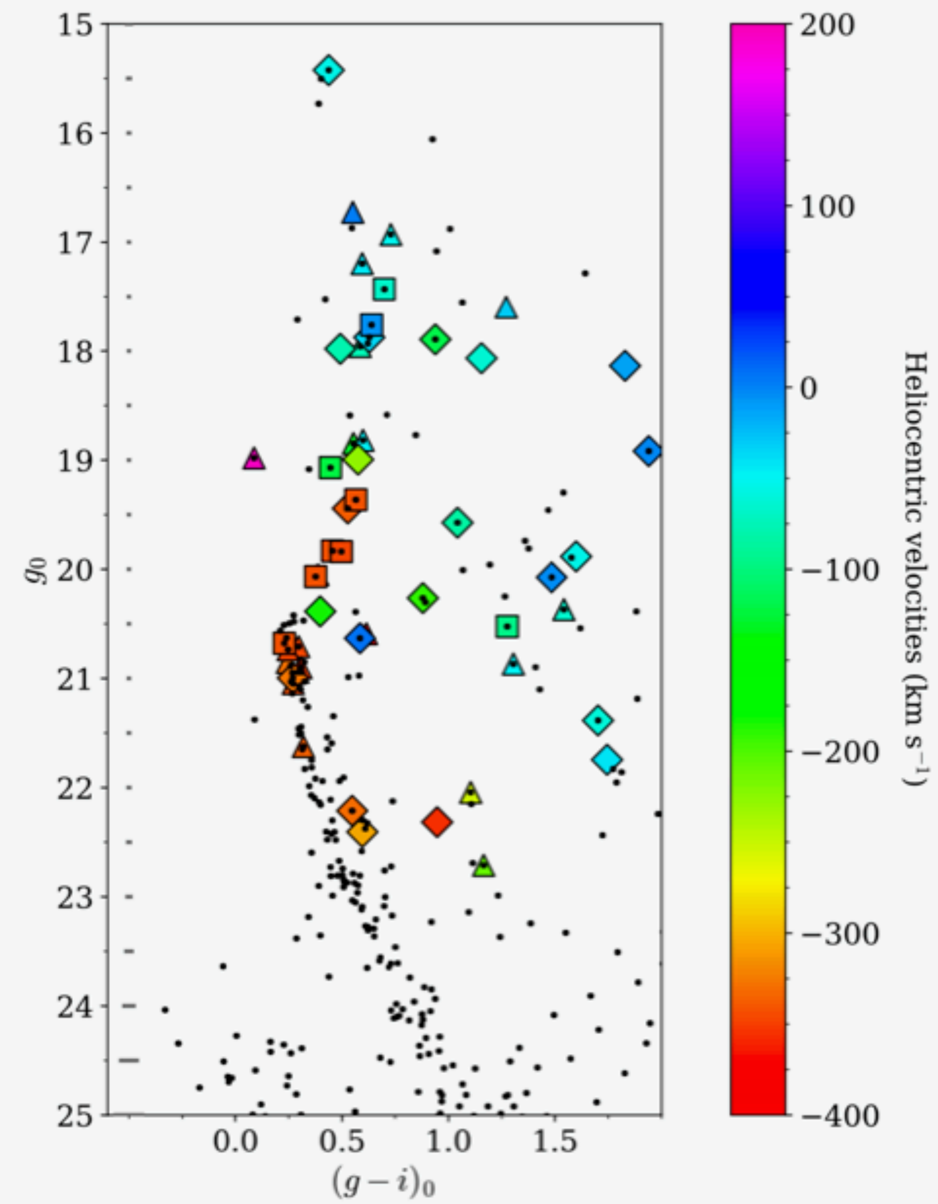


Figure credit: Dark Energy Survey

Small satellites in Pristine: Draco II

Longeard, Martin, Starkenburg et al., 2018



Tiny satellite

A bit large in size (is it disrupting?)

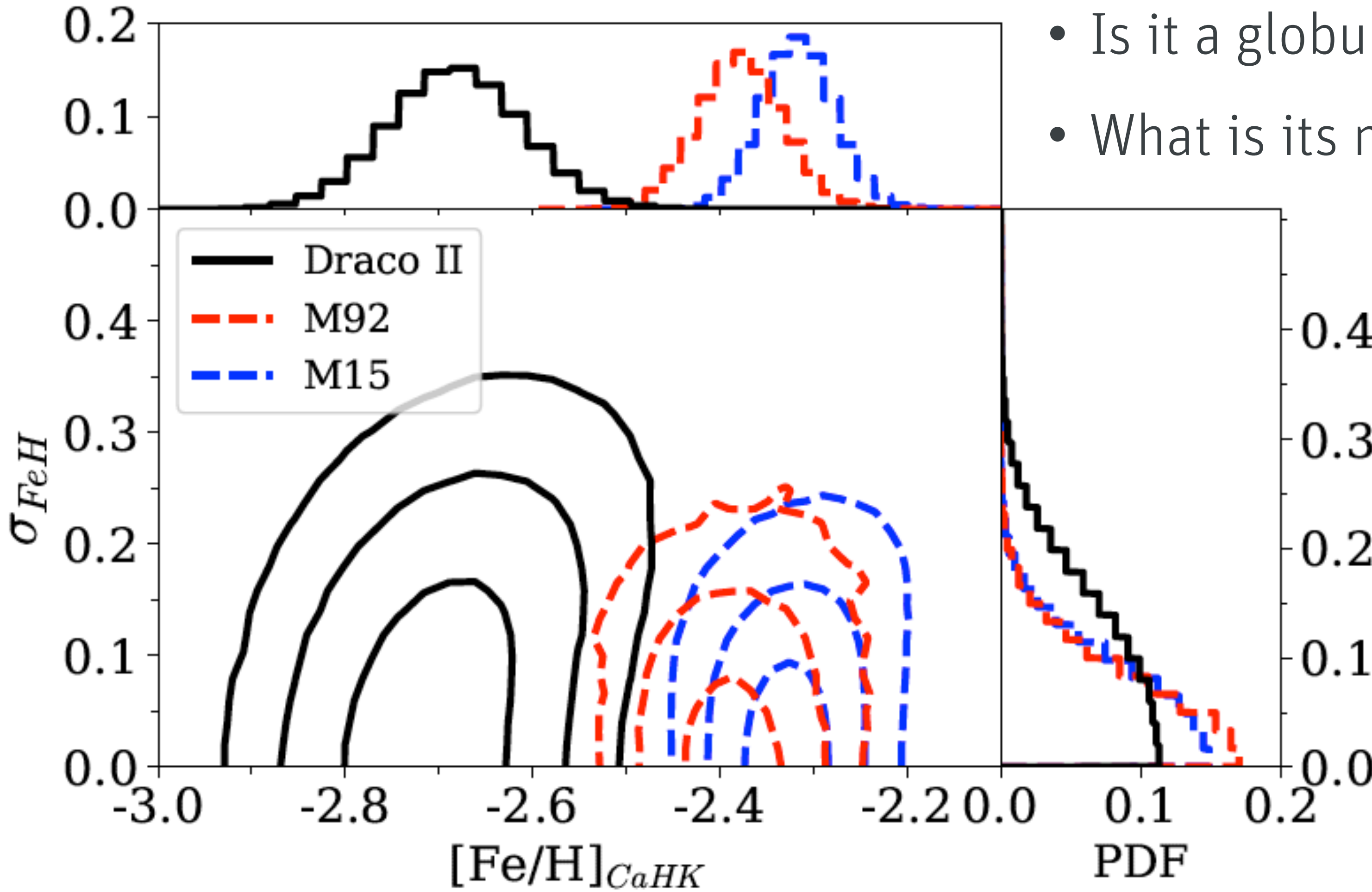
No upper RGB star found (yet)

CaHK helps selecting candidates

Velocity dispersion is small (<5.9 km/s)

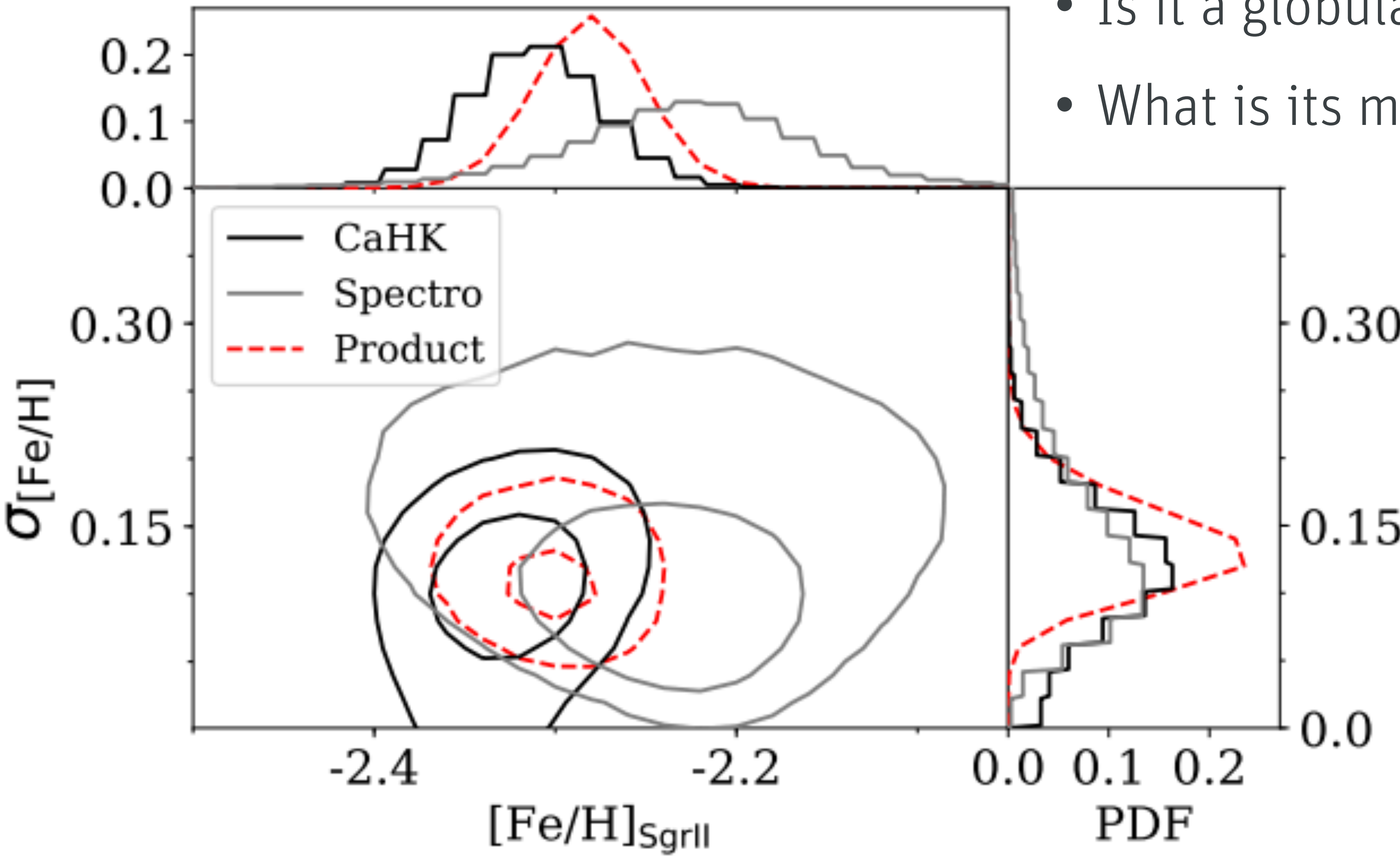
Inconclusive

Small satellites in Pristine: Draco II



- Is it a galaxy?
- Is it a globular cluster?
- What is its metallicity?

Small satellites in Pristine: Sgr II



- Is it a galaxy?
- Is it a globular cluster?
- What is its metallicity?

Longeard, Martin, Starkenburg et al., 2019

More to come!

- Extra deep data in ultra-faint satellites
  - Data for 20 faint Northern satellites in hand

- HST program (PI: Dan Weisz), 43 cycles, 18 ultra-faint dwarfs

The Metallicity Distribution Functions of Ultra-Faint Dwarf Galaxies

Investigator	Institution
Prof. Michael Boylan-Kolchin	University of Texas at Austin
Dr. Patrick Cote	National Research Council of Canada
Dr. Andrew Eugene Dolphin	Raytheon Company
Mr. Nicolas Longeard	Universite de Strasbourg I
Dr. Nicolas Martin	Universite de Strasbourg I
Dr. Mario L. Mateo	University of Michigan
Mr. Nathan Ross Sandford	University of California - Berkeley
Dr. Else Starkenburg	Leibniz-Institut fur Astrophysik Potsdam (AIP)
Dr. Matthew G. Walker	Carnegie Mellon University
Dr. Daniel R. Weisz	University of California - Berkeley

The big leap forward

We need spectroscopy to get kinematics, measure chemical abundance patterns, and study chemical evolution – multi-object spectroscopy

- We have a candidate sample of ~30.000 stars Memorandum of understanding with WEAVE
  - ➢ Bright enough for follow-up (V<18.5)
  - ➢ Success rate: 85% for [Fe/H] < -2.0

    22% for [Fe/H] < -3.0

    Youakim et al., 2017

  - ➢ More targets from SkyMapper, J-PAS etc.

In conclusion:
First Stars and their signatures

- *Oldest/most metal-poor stars* inform us on early build-up of galaxies & First Star physics

- We want to study these interesting stars at different Galactic environments and make a big leap forward in our understanding
  - What were the properties of the First Stars?
  - How did chemical enrichment proceed in various environments?
  - What is the nature of the smallest satellites of the Milky Way?