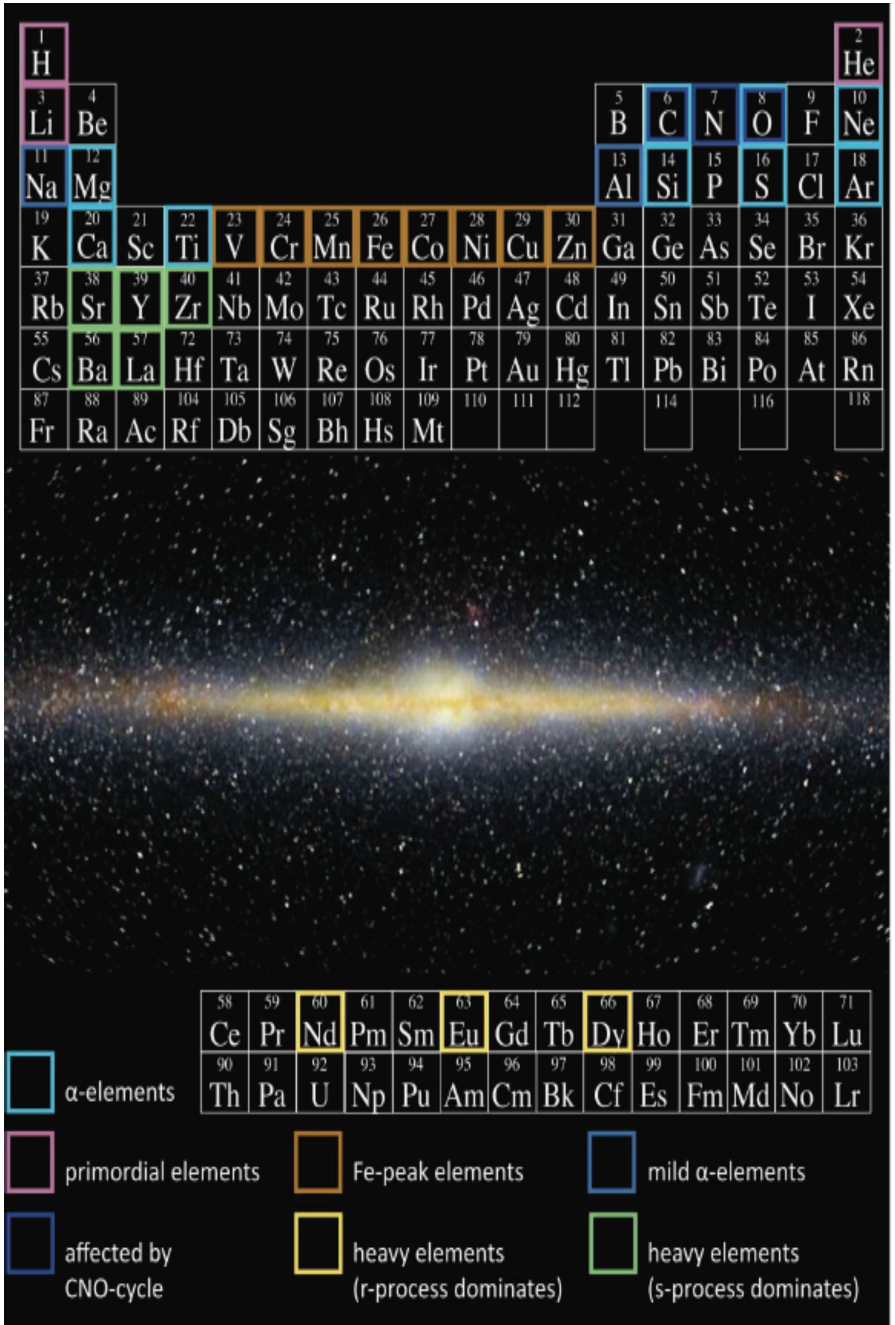
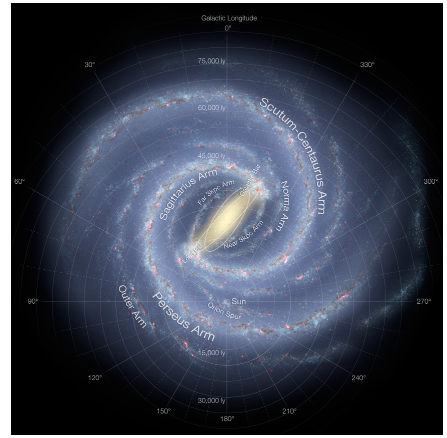
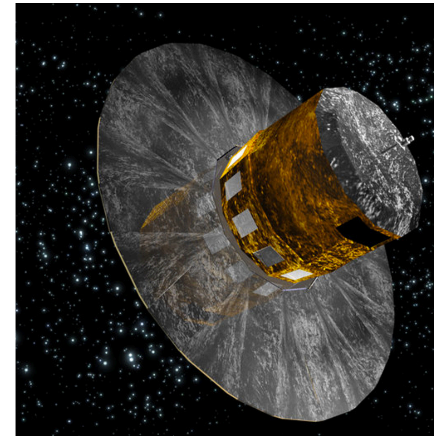






First Star Probes

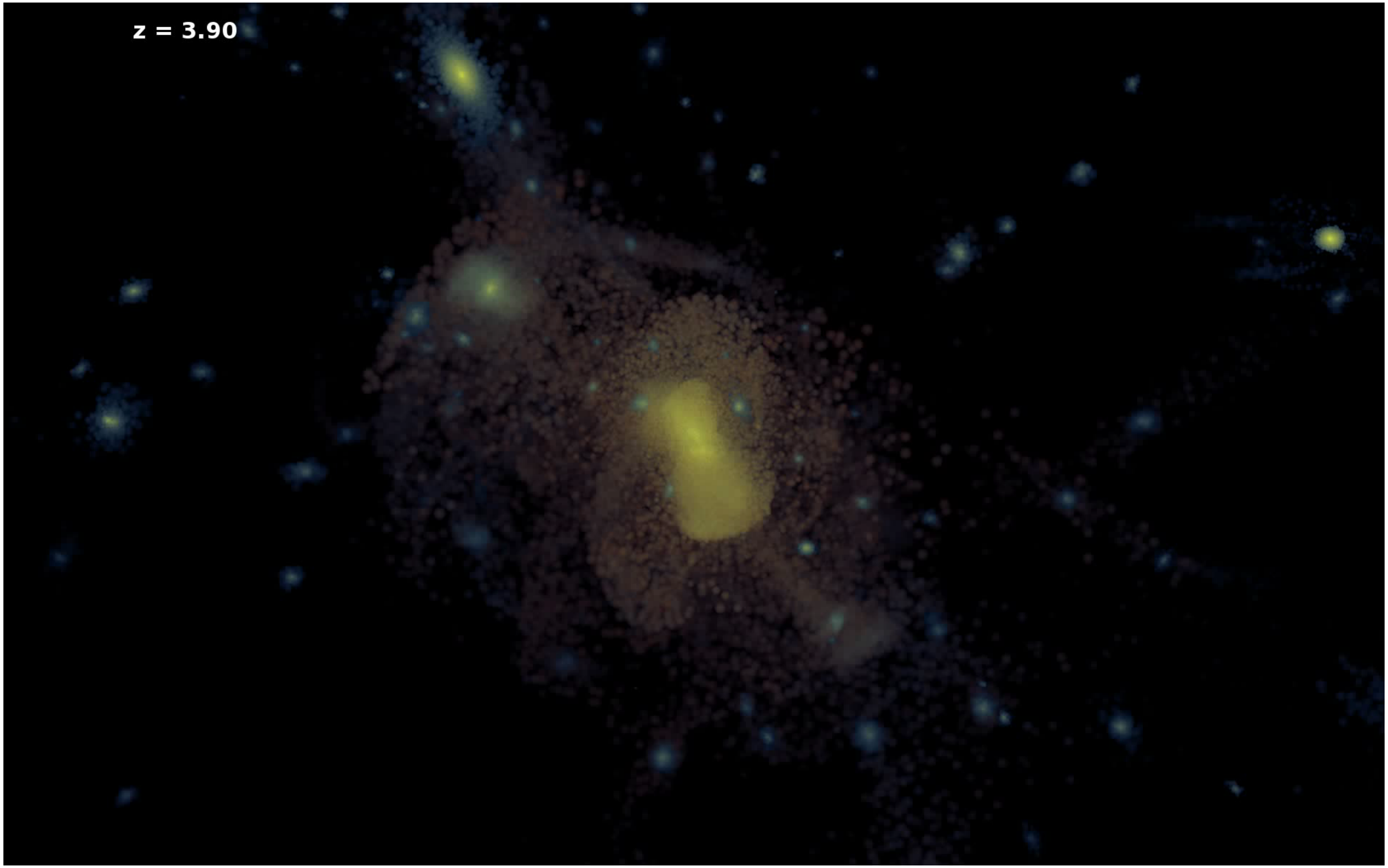
Else Starkenburg
Emmy Noether Group Leader
Leibniz-Institut für Astrophysik Potsdam (AIP)

AIP

Outline

- What do we expect?
  - Where are the most metal-poor and oldest stars in the Galaxy and what can cosmological models tell us about them?
- How do we find larger samples of CEMP (and general extremely metal-poor) stars?
  - Our probes of the First Stars
  - The *Pristine* survey
- Where are we going?
  - Preliminary and on-going work

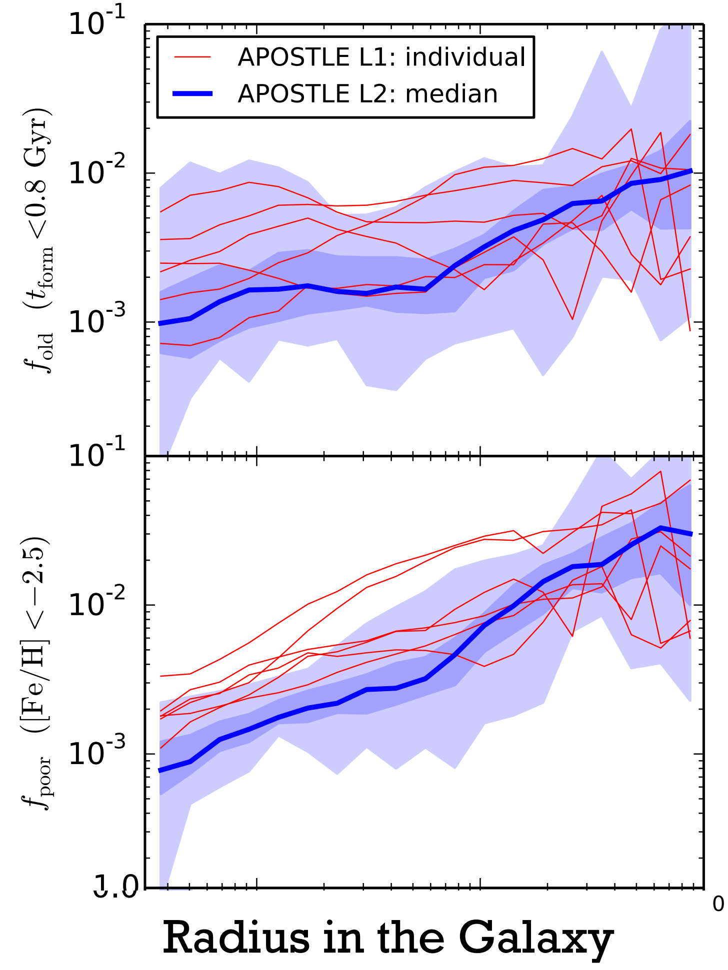
Does this show the history of our Milky Way?



Credit: J. Helly, A. Cooper, S. Cole and C. Frenk (ICC), based on simulation data from The Virgo consortium and software by V. Springel

Where are the metal-poor stars?

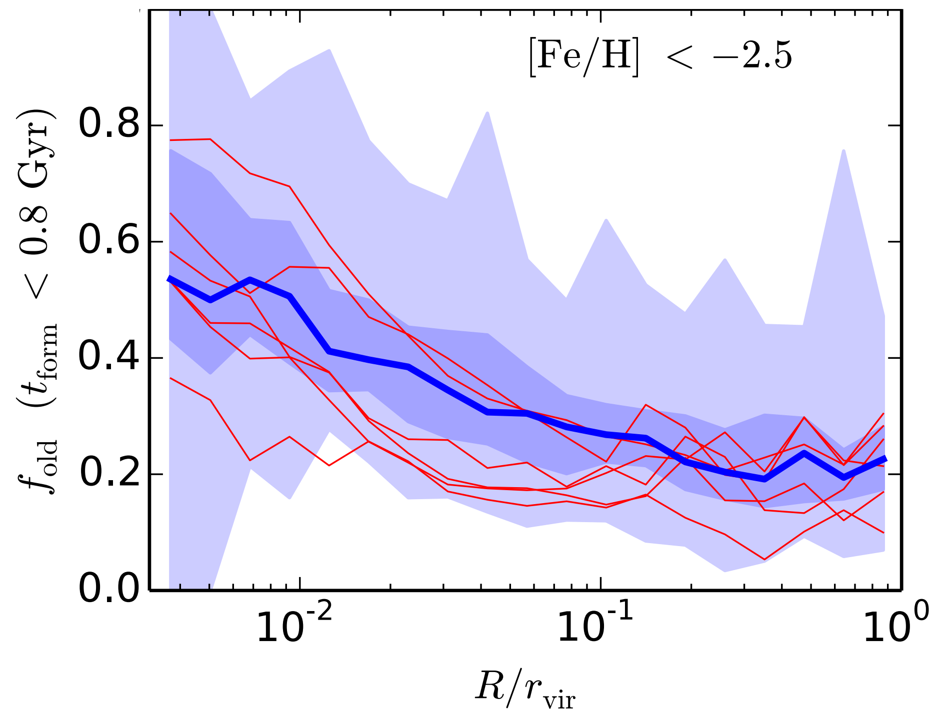
- Where do we expect to find them today?
- There are more old stars in the halo
- There are more metal-poor stars in the halo
  - Using the APOSTLE simulations
  - 12 Local Groups
  - High-resolution
  - Full hydrodynamics



Starkenburg, E., Oman K. et al., 2017a

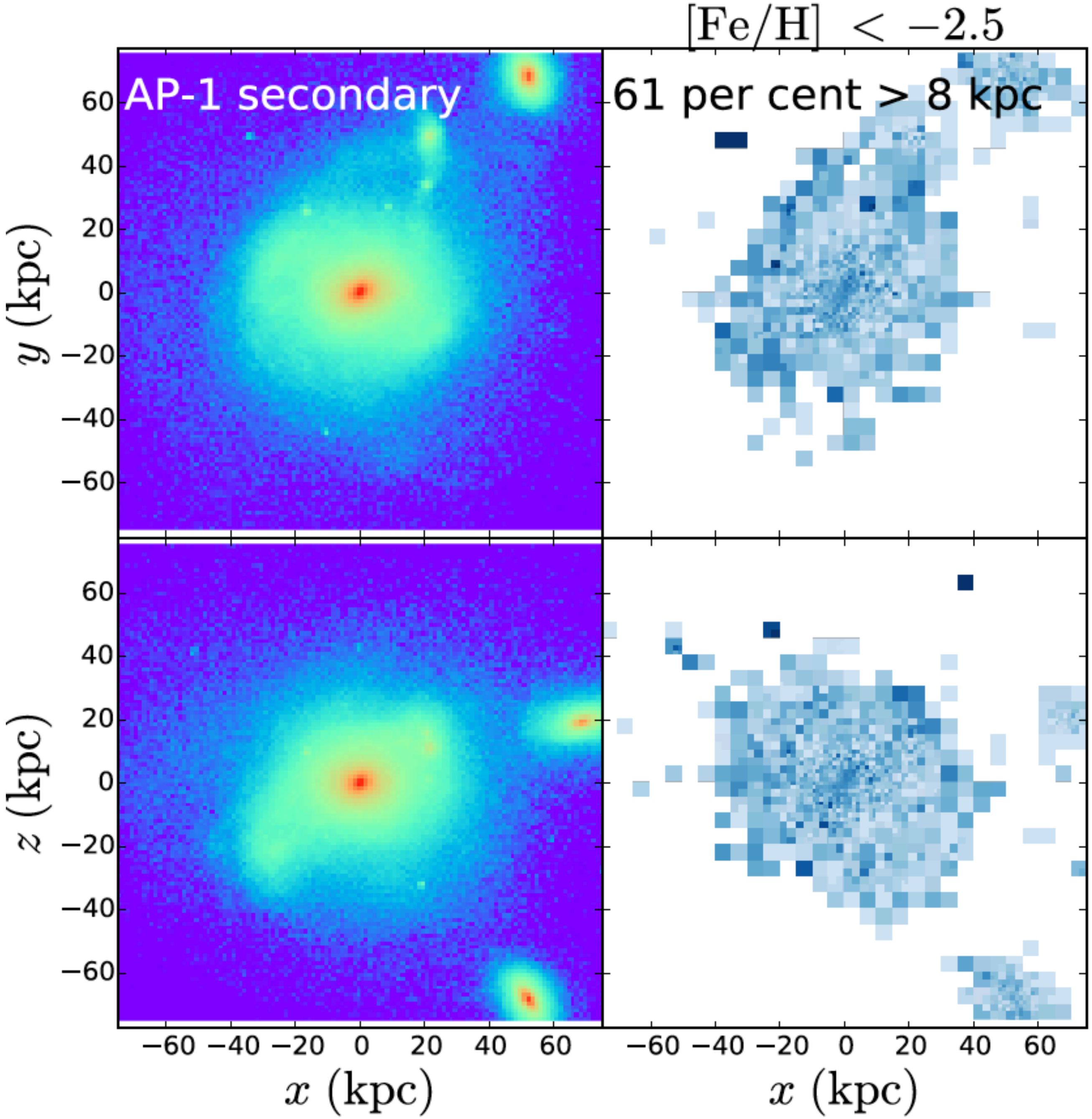
Where are the first (generations) stars?

- Where do we expect to find them today?
- There are more old stars in the halo
- There are more metal-poor stars in the halo
  - but not all of them are really old
  - if you discover a metal-poor star in the inner Galaxy, it is very likely to be old



Starkenburg, E., Oman K. et al., 2017a

s?



Metallicity is not always a clock.

Analysis of the APOSTLE hydrodynamical simulations of Loal Groups:

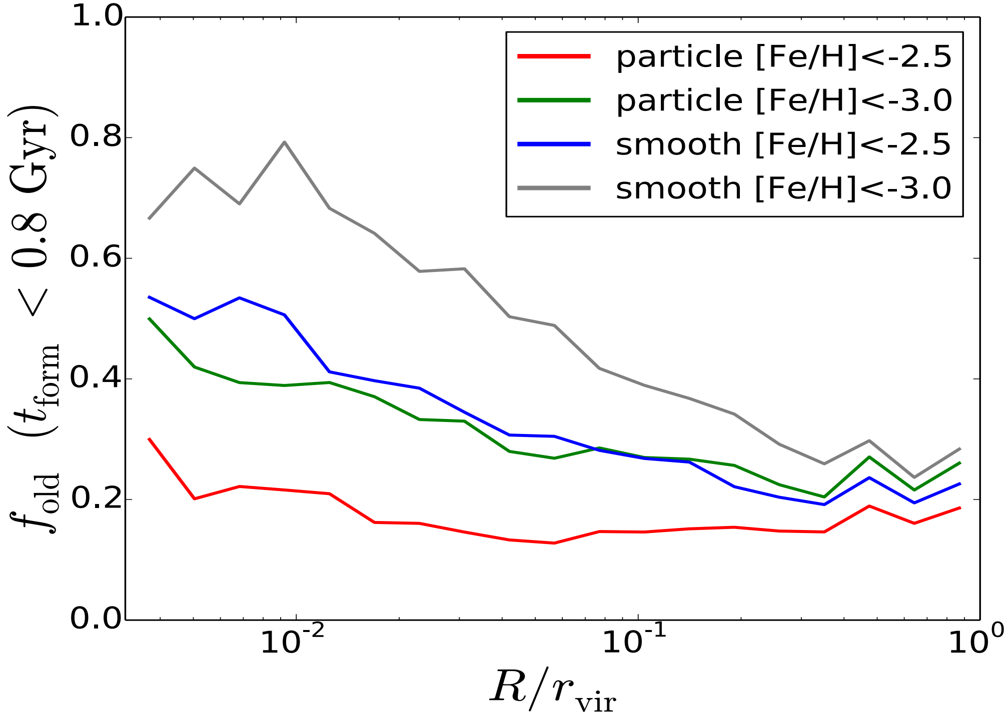
- Inner Galaxy and substructures are a very promising place to find the oldest stars!
  - Both bound and unbound

Starkenburg, E., Oman K., et al., 2017a

Coloured by density

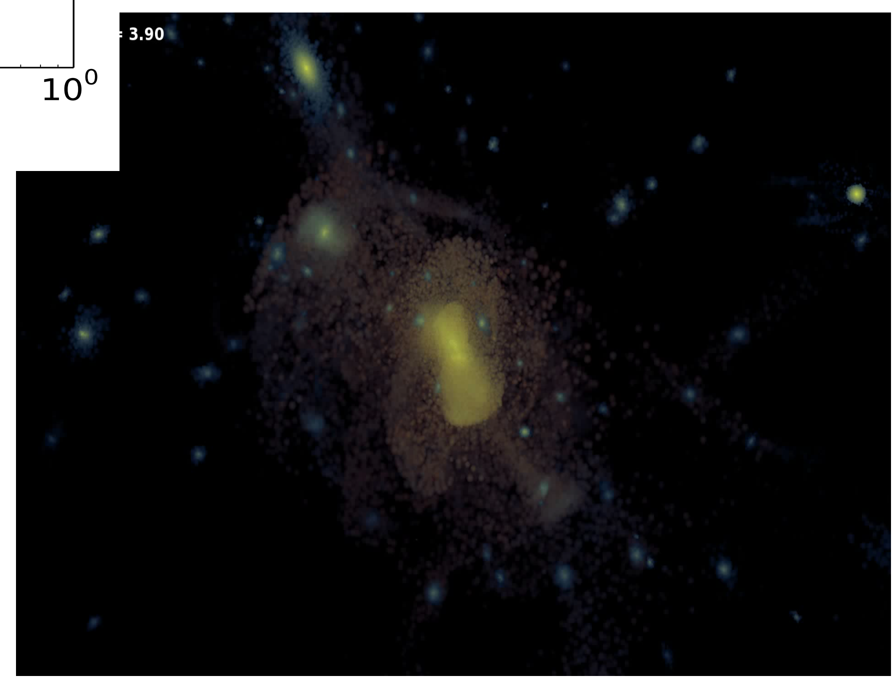
Coloured by % old stars (< 0.8 Gyr after Big Bang)

Where are the first (generations) stars?



Starkenburg, E., Oman K., et al., 2017a

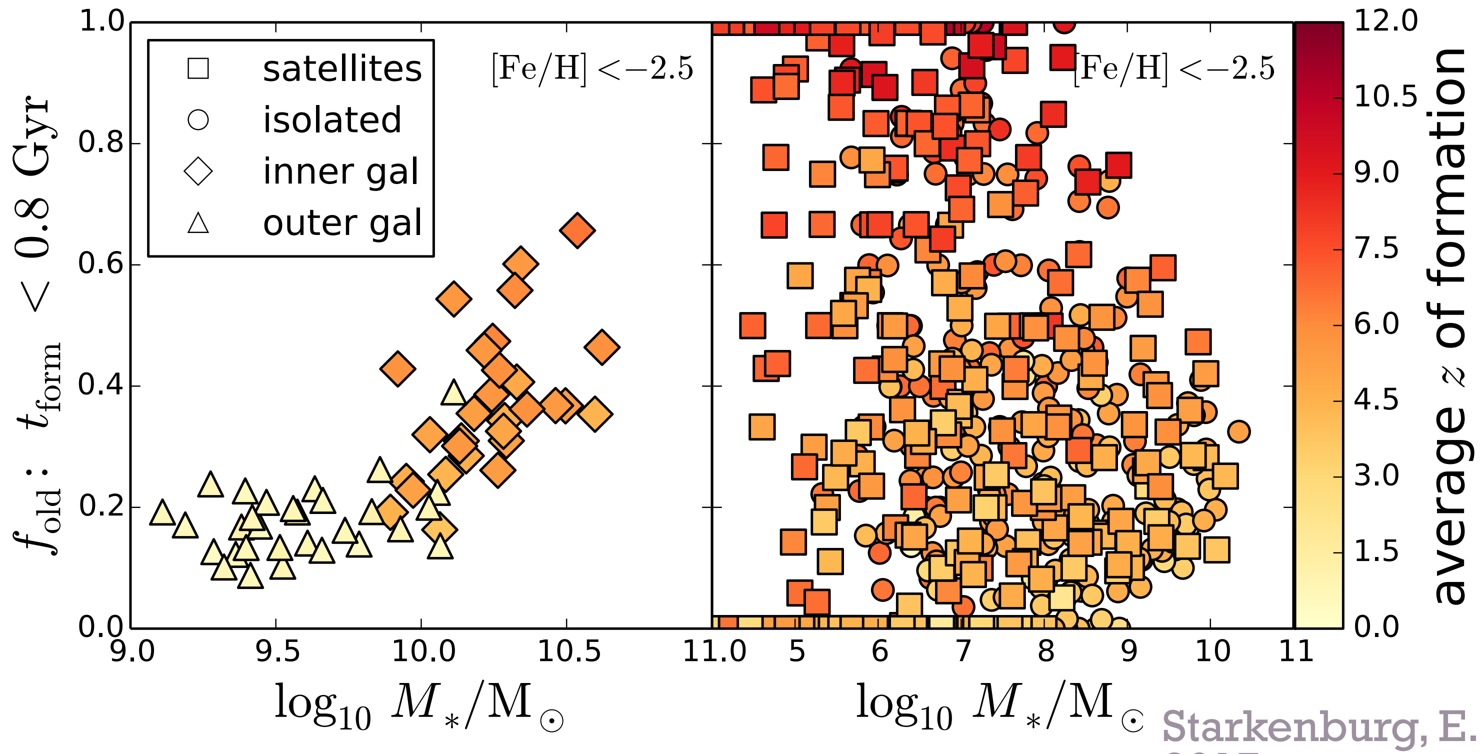
Credit: J. Helly, A. Cooper, S. Cole and C. Frenk (ICC), based on simulation data from The Virgo consortium and software by V. Springel



- The history of the Galaxy is messy
  - Are they all in the center?
- Be careful with quantitative results, they depend heavily on the metal-mixing recipe in the simulations

Where are the first stars?

- Dwarf galaxies are also good to hunt for the oldest stars
  - They are very interesting systems!



Starkenburg, E., Oman K., et al. 2017a

Observations

We would like a statistical sample of these stars across all Galactic environments

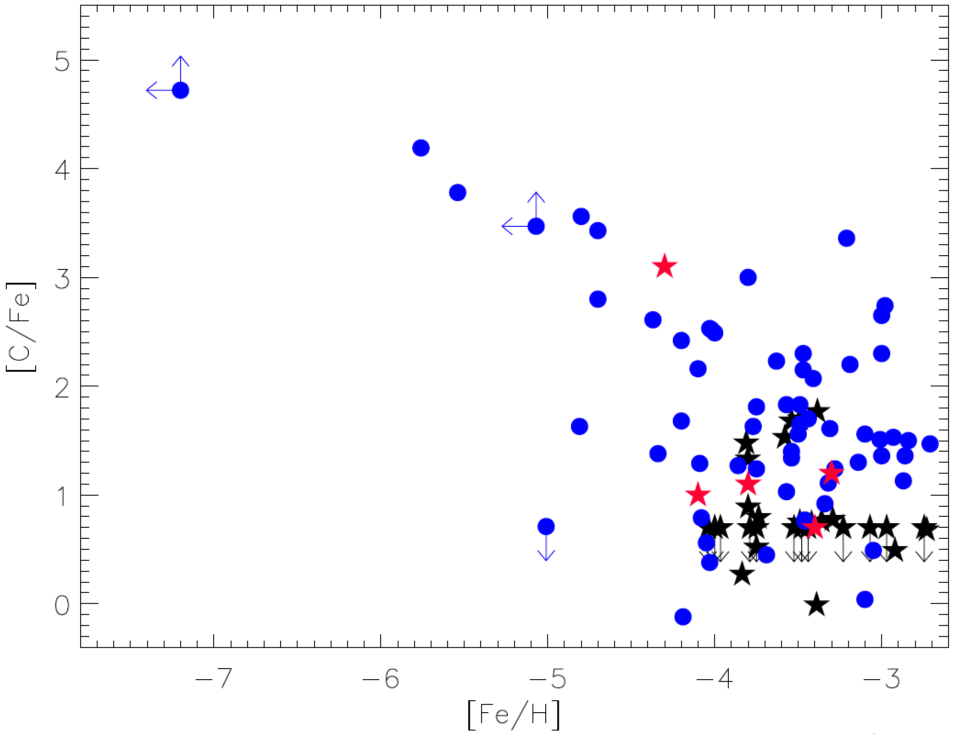
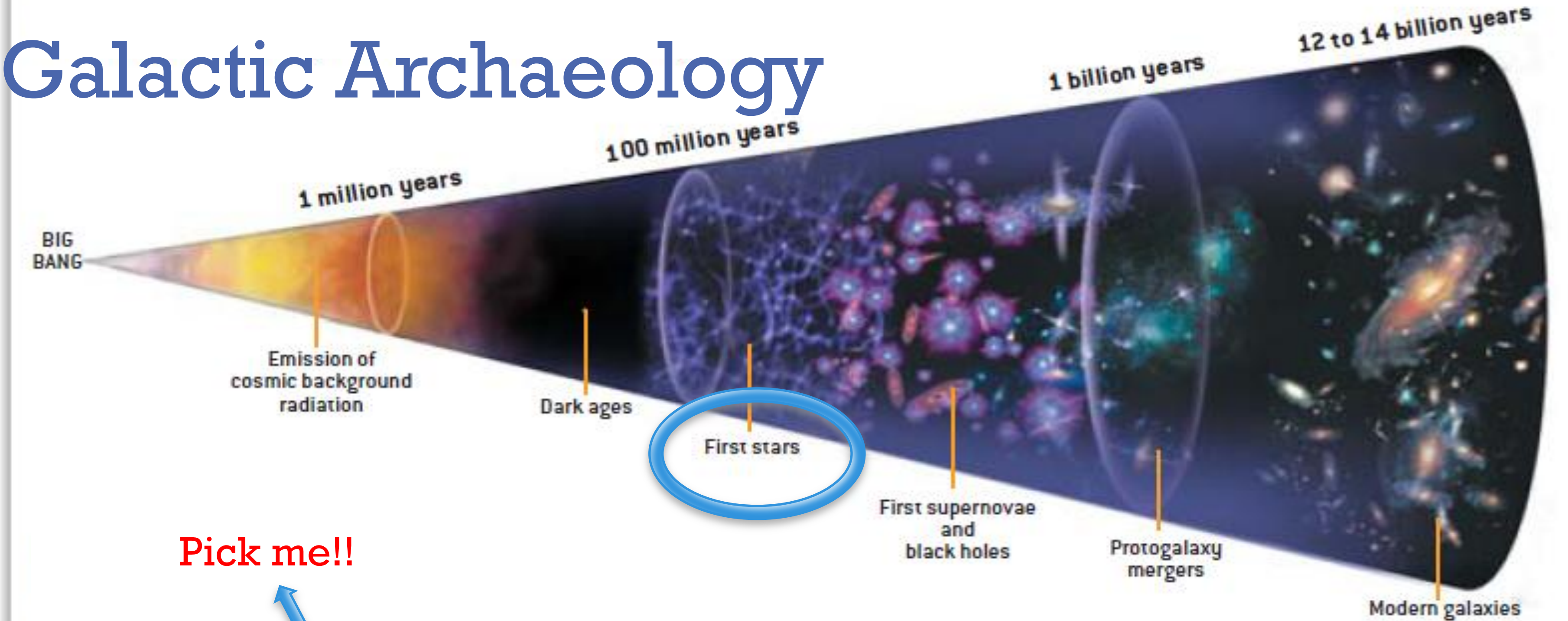
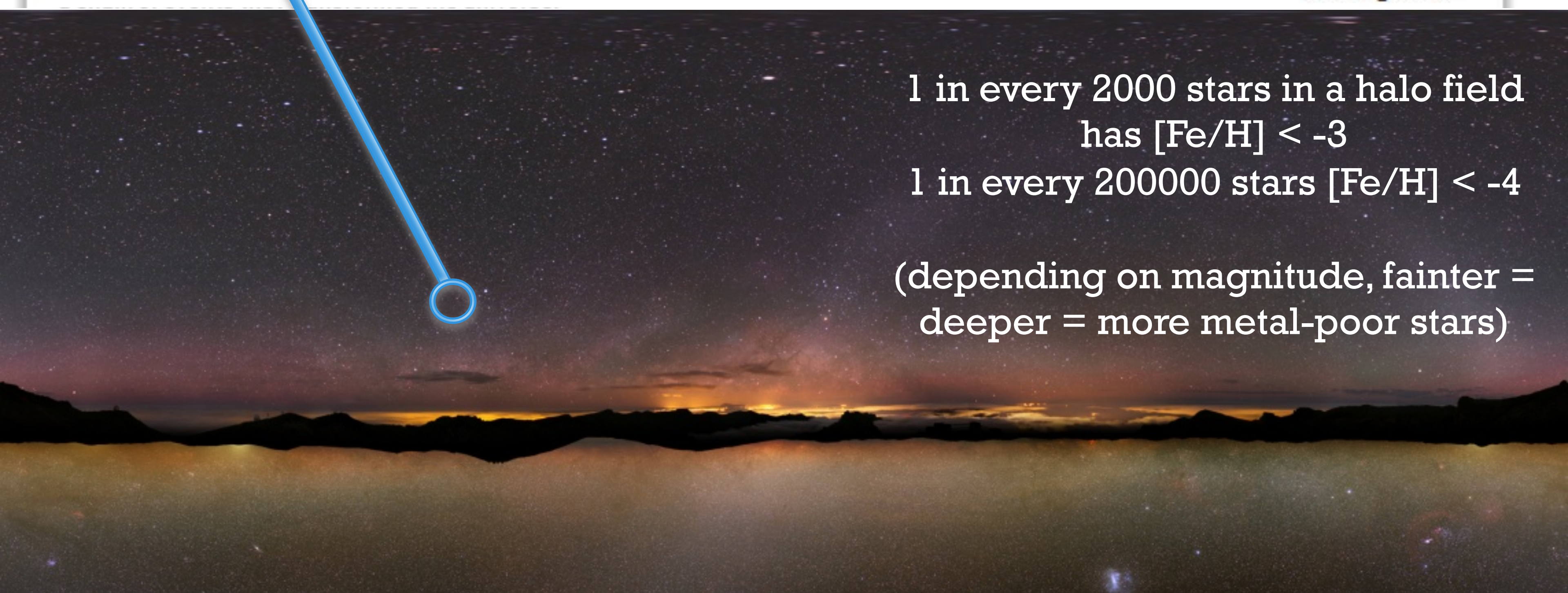


Figure from Aguado et al., 2017

Galactic Archaeology



Pick me!!

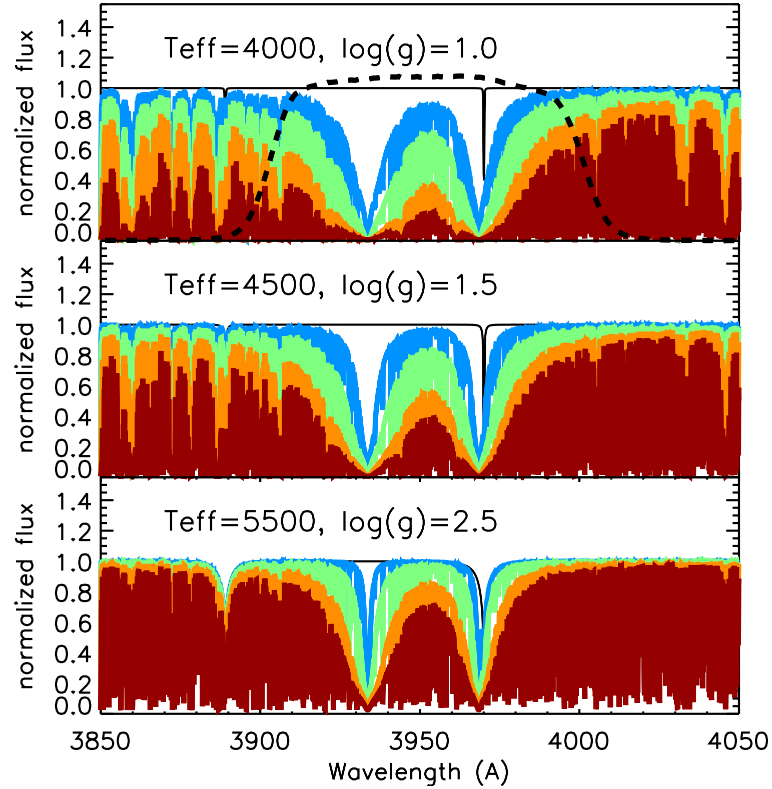


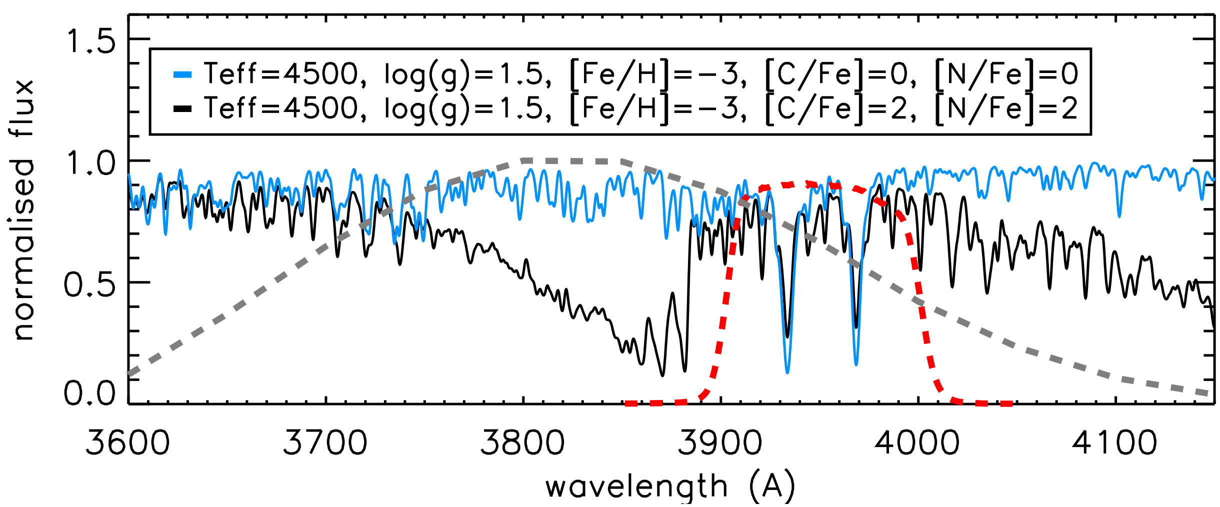
1 in every 2000 stars in a halo field has [Fe/H] < -3
1 in every 200000 stars [Fe/H] < -4

(depending on magnitude, fainter = deeper = more metal-poor stars)

(Narrow-band) filters

- Skymapper in the Southern Hemisphere - talk Gary
- Best and brightest with WISE data – Schlaufmann & Casey (2014)
- Pristine in the Northern Hemisphere





[Fe/H] = –∞

[Fe/H] = –3.0

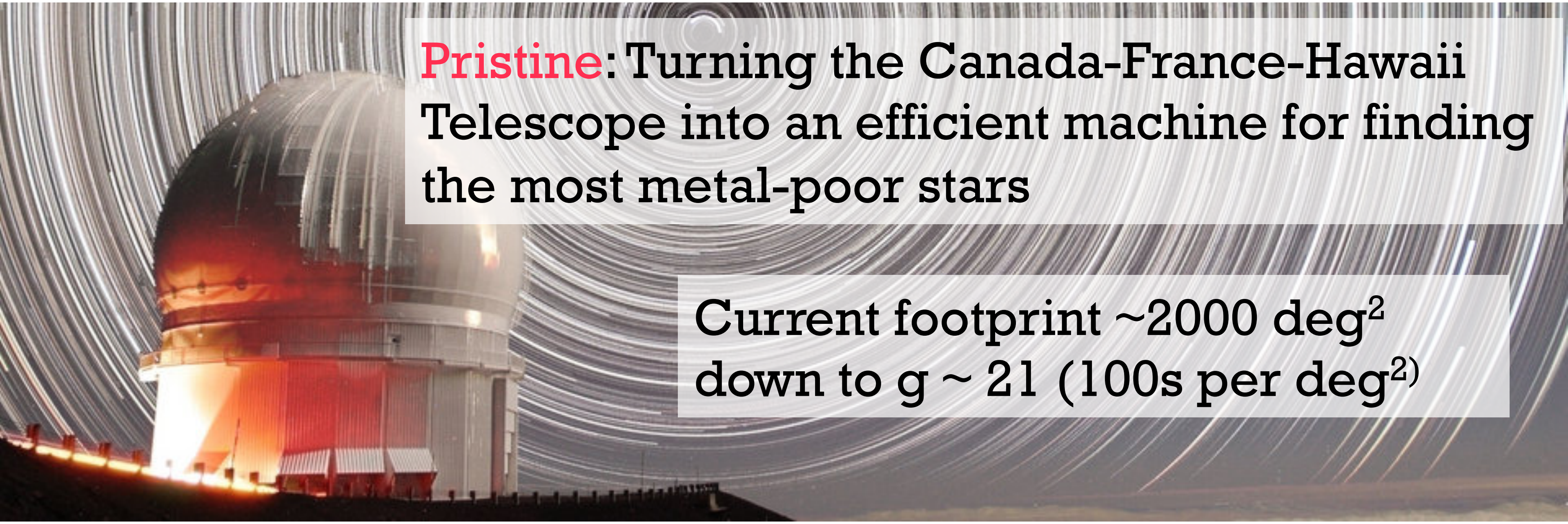
[Fe/H] = –2.0

[Fe/H] = –1.0

[Fe/H] = +0.0

[Fe/H] = –3.0, [C/Fe] = +2

[Fe/H] = –3.0



Picture credit: Jean-Charles Cuillandre

PIs: Else Starkenburg & Nicolas Martin.
Co-Is: David Aguado, Carlos Allende Prieto, Anke Arentsen, Edouard Bernard, Piercarlo Bonifacio, Elisabetta Caffau, Raymond Carlberg, Patrick Cote, Morgan Fouesneau, Patrick Francois, Jonay Gonzalez Hernandez, Stephen Gwyn, Vanessa Hill, Rodrigo Ibata,Pascale Jablonka, Collin Kielty, Nicolas Longeard, Julio Navarro, Alan McConnachie, Ruben Sanchez-Janssen, Federico Sestito, Eline Tolstoy, Kim Venn, Kris Youakim

The *Pristine* survey I: Mining the Galaxy for the most metal-poor stars*

Else Starkenburg[1]†, Nicolas Martin[2,3], Kris Youakim[1], David S. Aguado[4,5], Carlos Allende Prieto[4,5], Anke Arentsen[1], Edouard J. Bernard[6], Piercarlo Bonifacio[7], Elisabetta Caffau[7], Raymond G. Carlberg[8], Patrick Côté[9], Morgan Fouesneau[3], Patrick François[7,10], Oliver Franke[11], Jonay I. González Hernández[4,5], Stephen D. J. Gwyn[9], Vanessa Hill[12], Rodrigo A. Ibata[2], Pascale Jablonka[7,13], Nicolas Longeard[2], Alan W. McConnachie[9], Julio F. Navarro[14], Rubén Sánchez-Janssen[9,15], Eline Tolstoy[16], Kim A. Venn[14]

The *Pristine* survey II: – a sample of bright stars observed with FEROS *

E. Caffau[1,**], P. Bonifacio[1], E. Starkenburg[2], N. Martin[3,4], K. Youakim[2], A. A. Henden[5], J. I. González Hernández[6,7], D. S. Aguado[6,7], C. Allende Prieto[6,7], K. Venn[8], and P. Jablonka[9,1]

The *Pristine* survey III: Spectroscopic confirmation of an efficient search for extremely metal-poor stars*

K. Youakim[1]†, E. Starkenburg[1], D. S. Aguado[2,3], N. F. Martin[4,5], M. Fouesneau[5], J. I. González Hernández[2,3], C. Allende Prieto[2,3], P. Bonifacio[6], M. Gentile[7], C. Kielty[8], P. Côté[9], P. Jablonka[7], A. McConnachie[9], R. Sánchez Janssen[10], E. Tolstoy[11], and K. Venn[8]

What can we do?

- Search for the most metal-poor stars and try to constrain the early Universe by studying them more closely
- Study substructures as a function of metallicity
  - How much substructure do we see at different metallicities? Constraining the merging history of the Milky Way
- Study the dwarf galaxies in more detail

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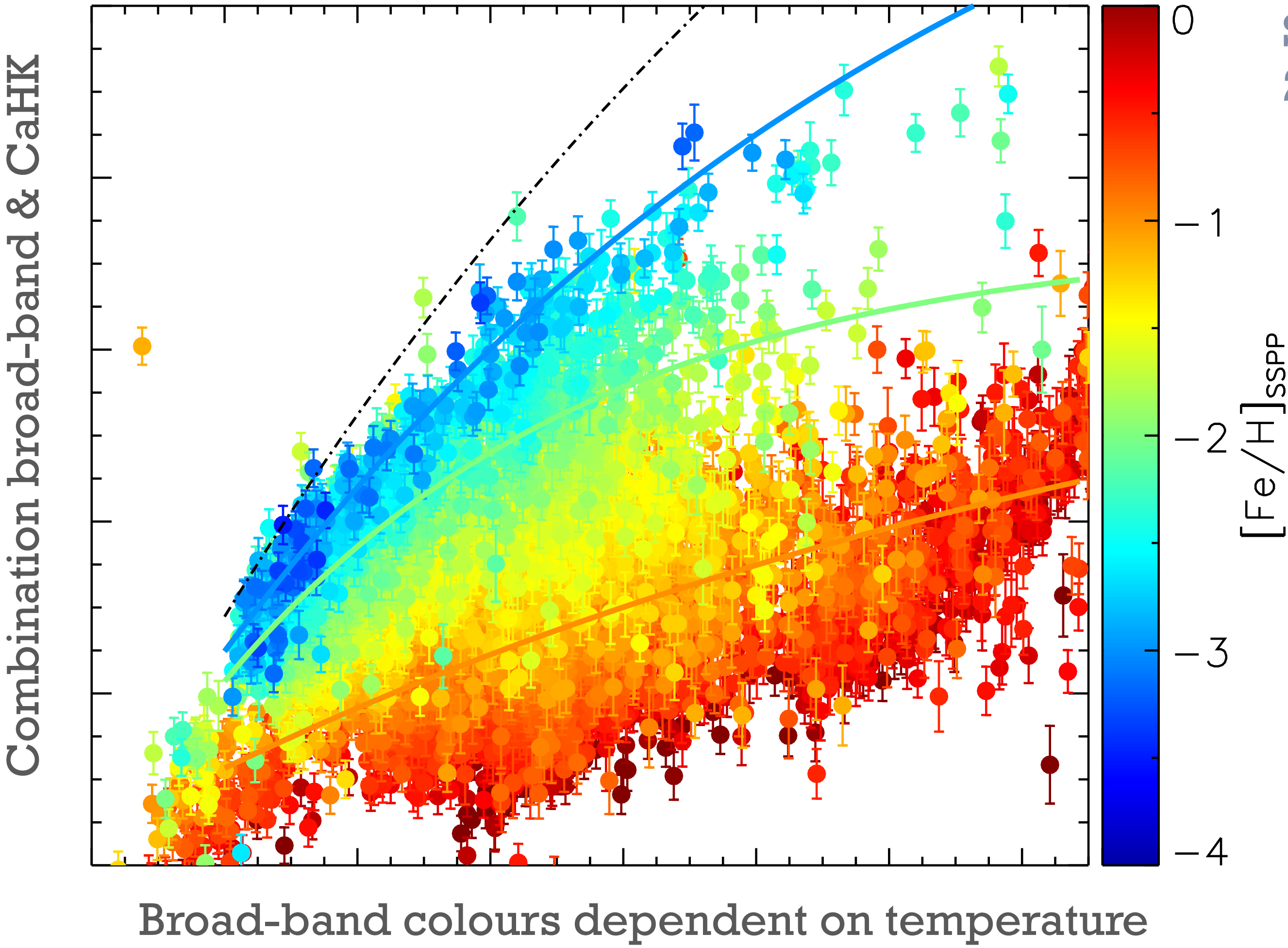
Photometric metallicities

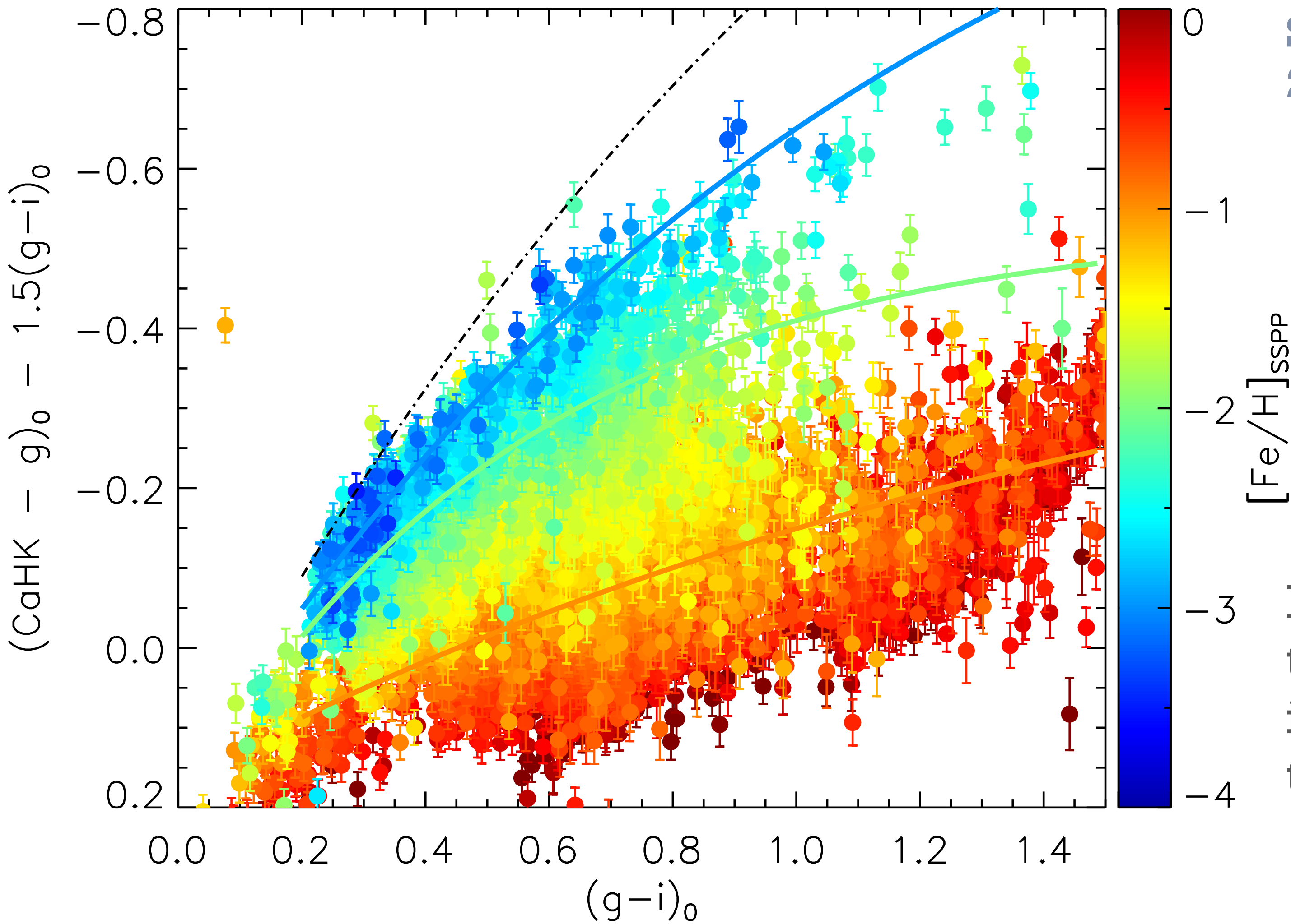


Starkenburg et al., 2017b

At the metal-poor end not very sensitive to log(g) – Gaia will help!

- Metallicity in colour-colour space
  - Calibrating with SDSS / SEGUE spectra (standing on the shoulders..)

Photometric metallicities



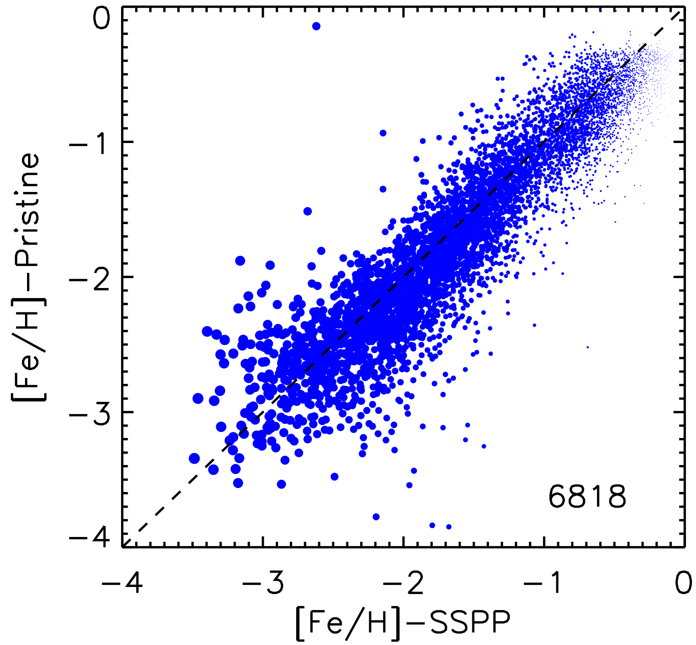
Starkenburg et al., 2017b

In selecting targets we do include stars up to the turn-off

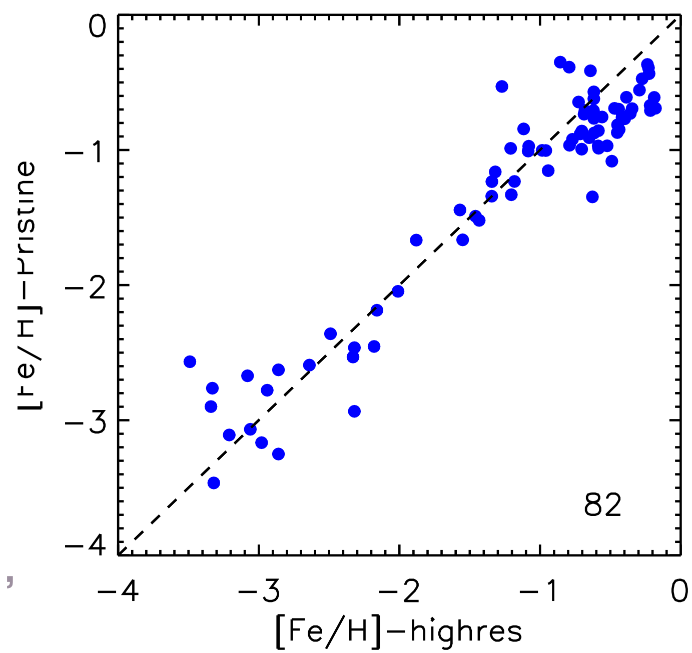
- Metallicity in colour-colour space
  - Variable stars from Panstarrs (standing on the shoulders..)

A metallicity scale

- An rms scatter of 0.2 dex from [Fe/H] = -0.5 down to [Fe/H] = -3.0



- Opening up a new regime – before only accessible to spectroscopy

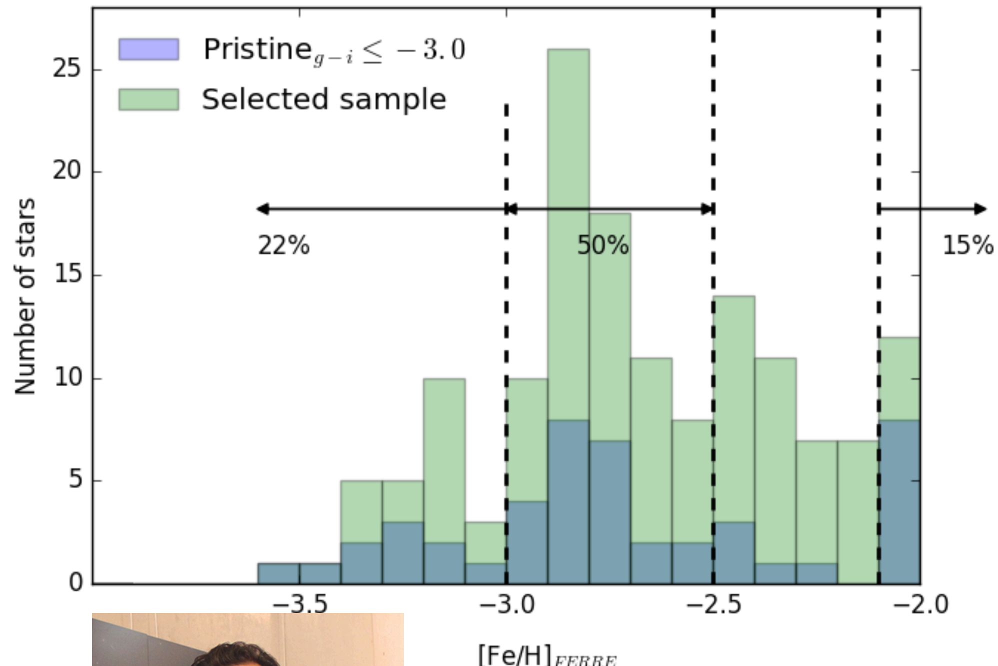


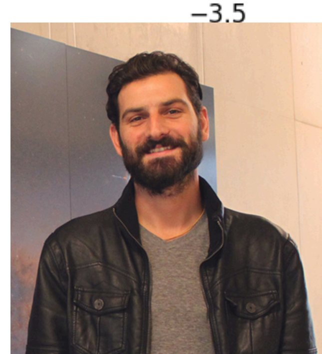
Starkenburg, E., et al., 2017b

Spectroscopic follow-up

- Follow-up in medium resolution at the Isaac Newton and William Herschel Telescope
  - Metallicities derived by the FERRE pipeline (David Aguado, Carlos Allende Prieto & Jonay Gonzalez Hernandez)

- Success rate of 22% below [Fe/H]<-3
  - Only 15% is really contaminant
  - Blind rates are 0.05%





Kris Youakim
Youakim et al., 2017

Spectroscopic follow-up

- High-resolution follow-up for individual interesting abundances
  - Venn et al., in prep.
- We are looking at going brighter than SDSS
- We expect full and homogeneous follow-up with the future WEAVE and 4MOST surveys
  - 1000(s) of fibers over the field-of-view
  - We only need 10s of fibers on the most promising objects
  - Even in low-res mode we will get a lot of information!

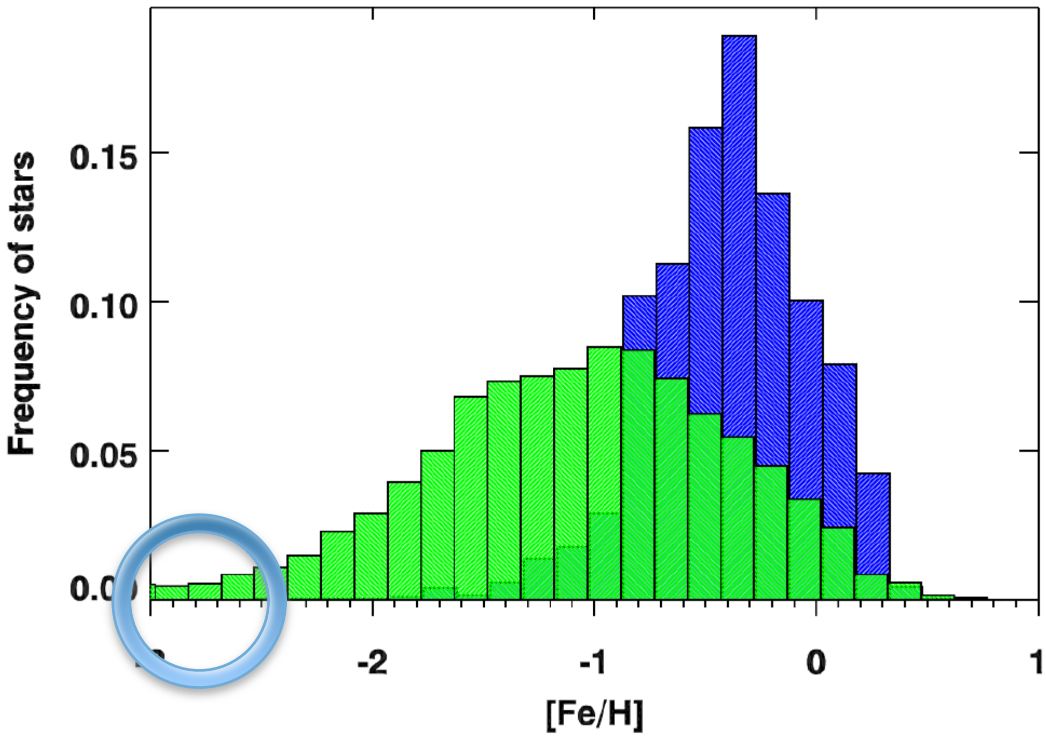
Going fainter, deeper, better (?!)

Probing the most metal-poor stars in the Galactic halo & bulge

Anke Arentsen

Image credit: ESO/S. Brunier

Probing the most metal-poor stars in the Galactic halo & bulge



*MDF in the **SkyMapper/EMBLA** survey (Howes+2016) compared to the **ARGOS** survey (Ness+2013)*

~150 stars [Fe/H] < -2.5
9 stars [Fe/H] < −3.0

Almost no CEMP stars (3%)!
In the halo it is ~27% for stars with [Fe/H] < −2.0

See also Koch et al., 2016

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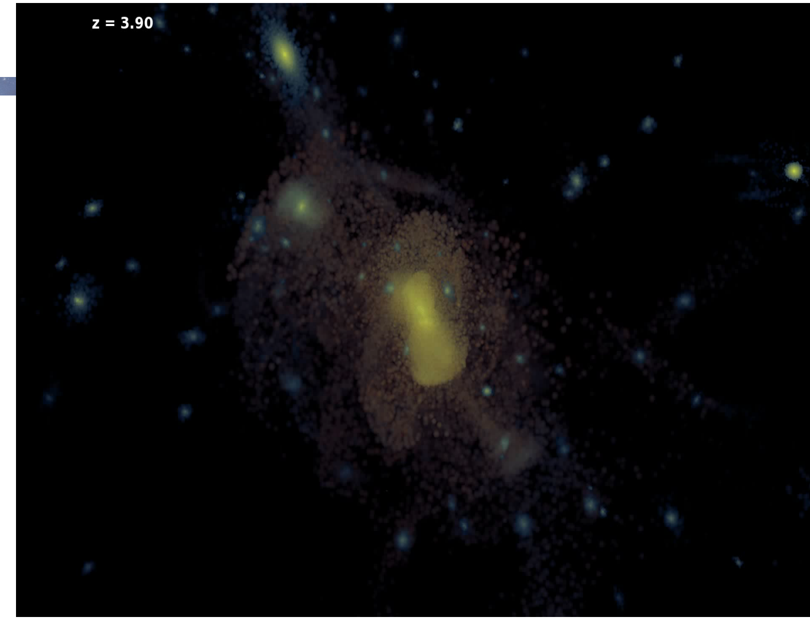
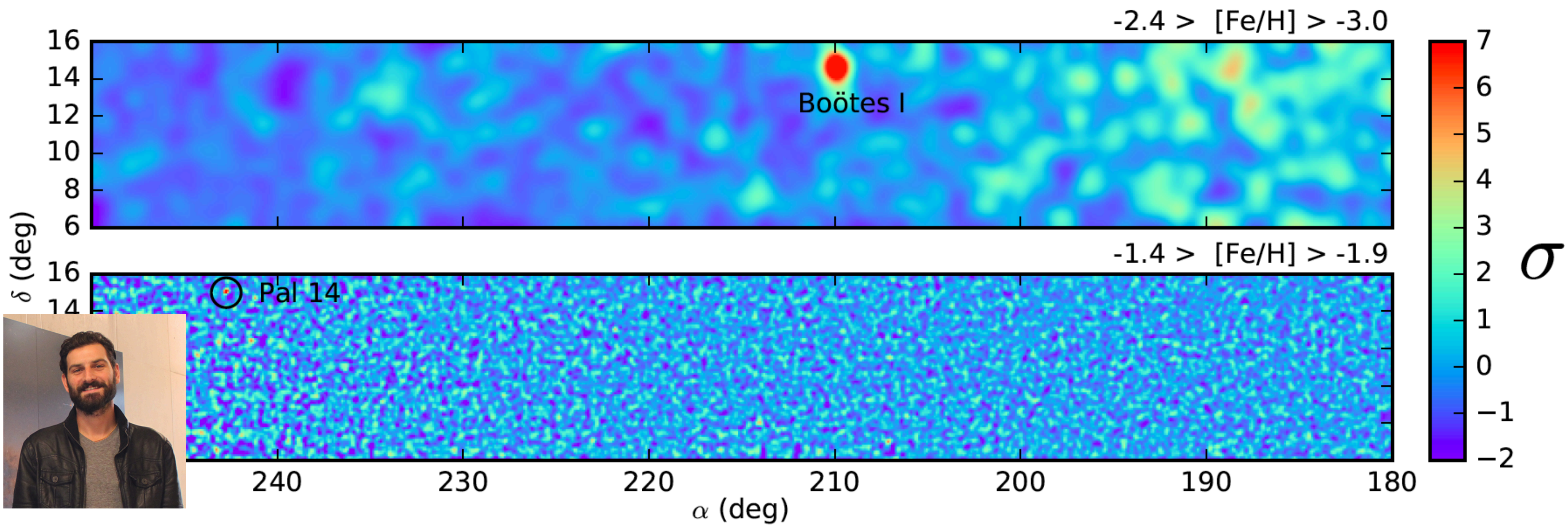
  - How much substructure do we see at different metallicities? Constraining the merging history of the Milky Way

Credit: J. Helly, A. Cooper, S. Cole and C. Frenk (ICC), based on simulation data from The Virgo consortium and software by V. Springel





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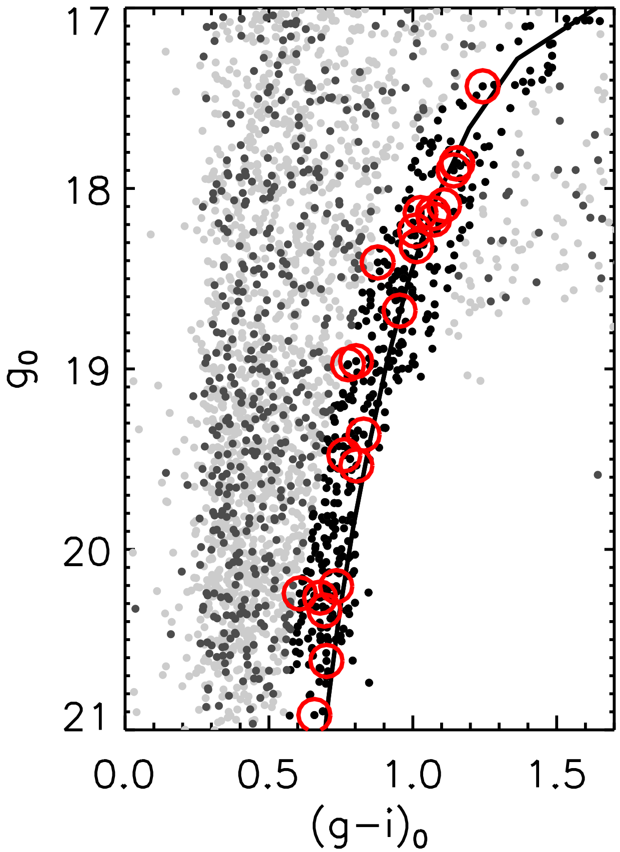
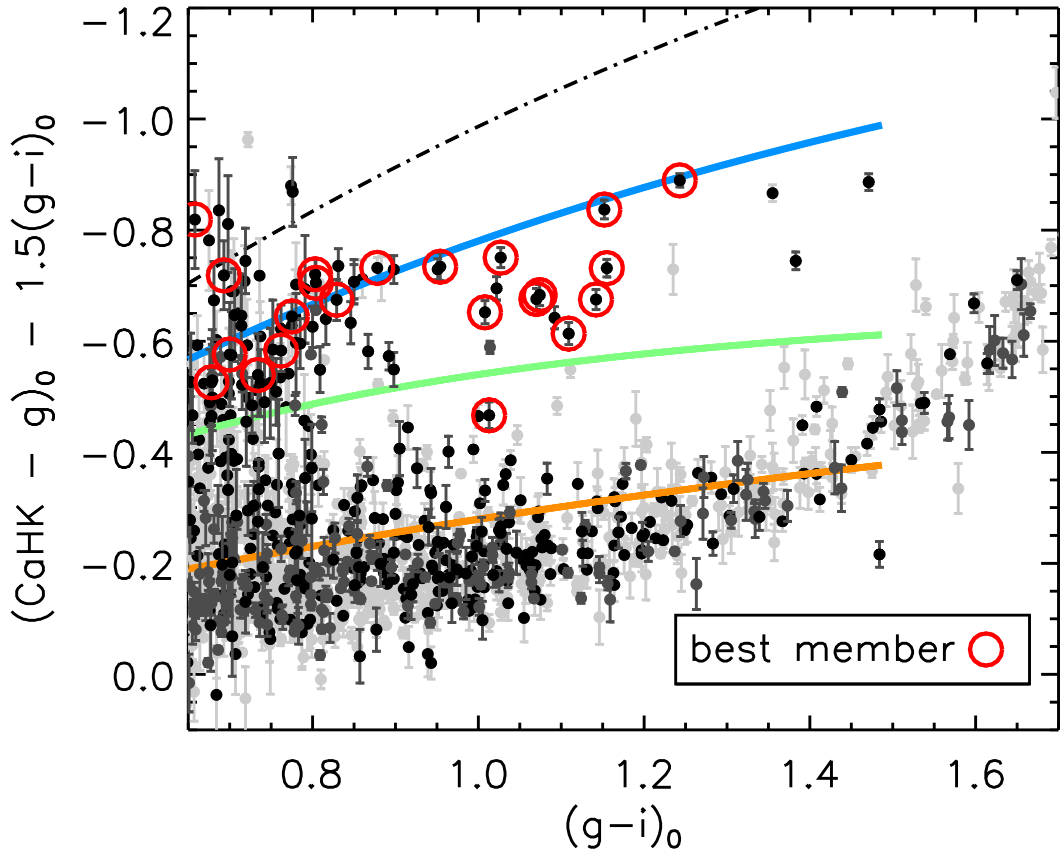
Dwarf galaxies in Pristine

Boötes I dwarf galaxy

Starkenburg E. et al., 2017b
Overplotted data from Norris et al., 2010, Koposov et al 2011





- Discriminate members and non-members, even far out of the tidal radius

In conclusion:
Mapping the Pristine Universe

- ***Oldest/most metal-poor stars*** inform us on early build-up of galaxies & First Star physics
  - We think some stars show imprints of First Stars chemical enrichment
  - We would like to understand more about their composition across various environments

- ***Metallicity decomposition of the MW from narrow-band photometry***
  - Can uncover efficiently the rare extremely metal-poor population
  - Added dimension to the MW deconstruction, even in the era of Gaia
  - Helps to study the faint dwarf galaxies