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Binaries and early Galactic chemical evolution

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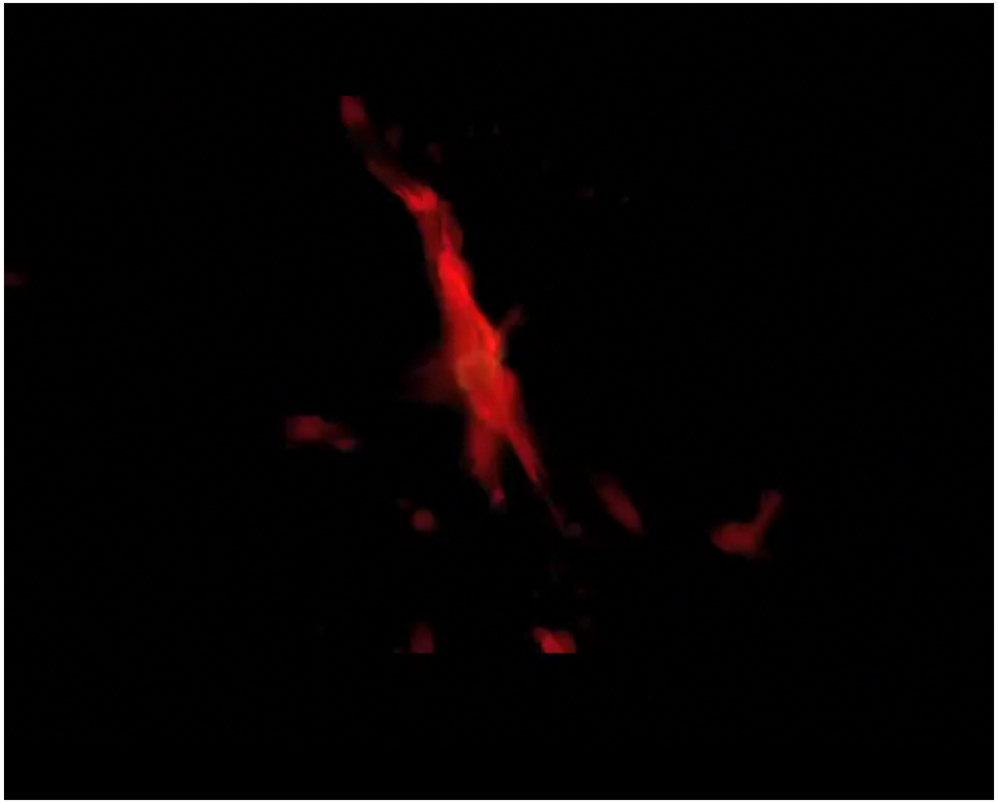
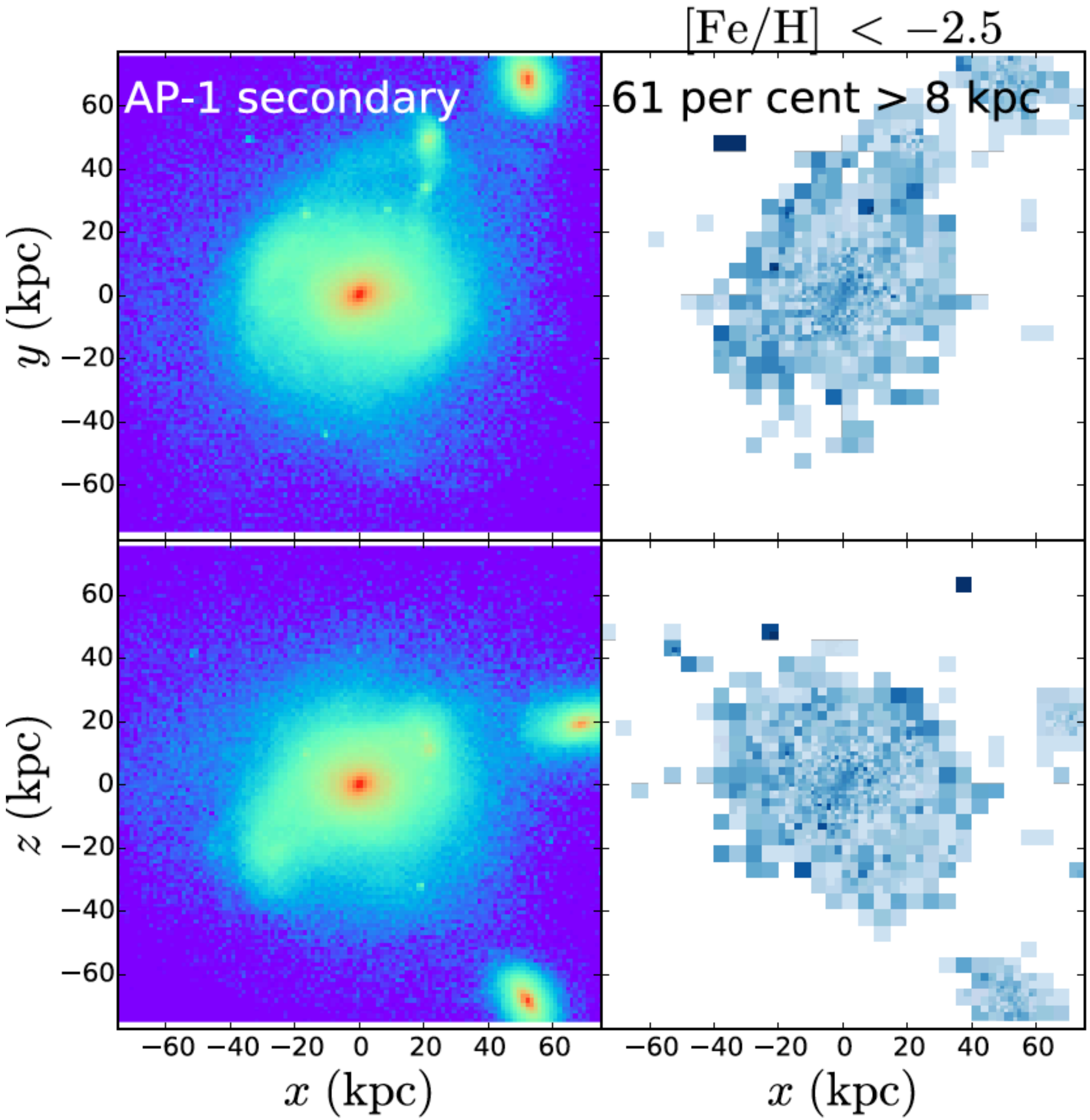
First Stars

- Ending the Universe's Dark Ages
  - Filling the Universe with light and ionizing radiation
  - The start of chemical complexity
- What were their properties?
  - Were they more massive?
    - Collapsing cloud has greater mass, but fragmentation unknown
  - Is a First Star still out there?



Movie "First Light" Wise, Abel, Kaehler, 2009



Coloured by density

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

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., et al., 2017

Observations: The most iron-poor

- Christlieb et al., 2002
- Frebel et al., 2005
- Norris et al., 2007
- Caffau et al., 2011
  - Re-defined the metallicity floor
- Hansen et al. 2014
- Keller et al., 2014

- FGK stars in different stages of chemical evolution – they do not make the Carbon themselves
  - Clue to the First Stars?

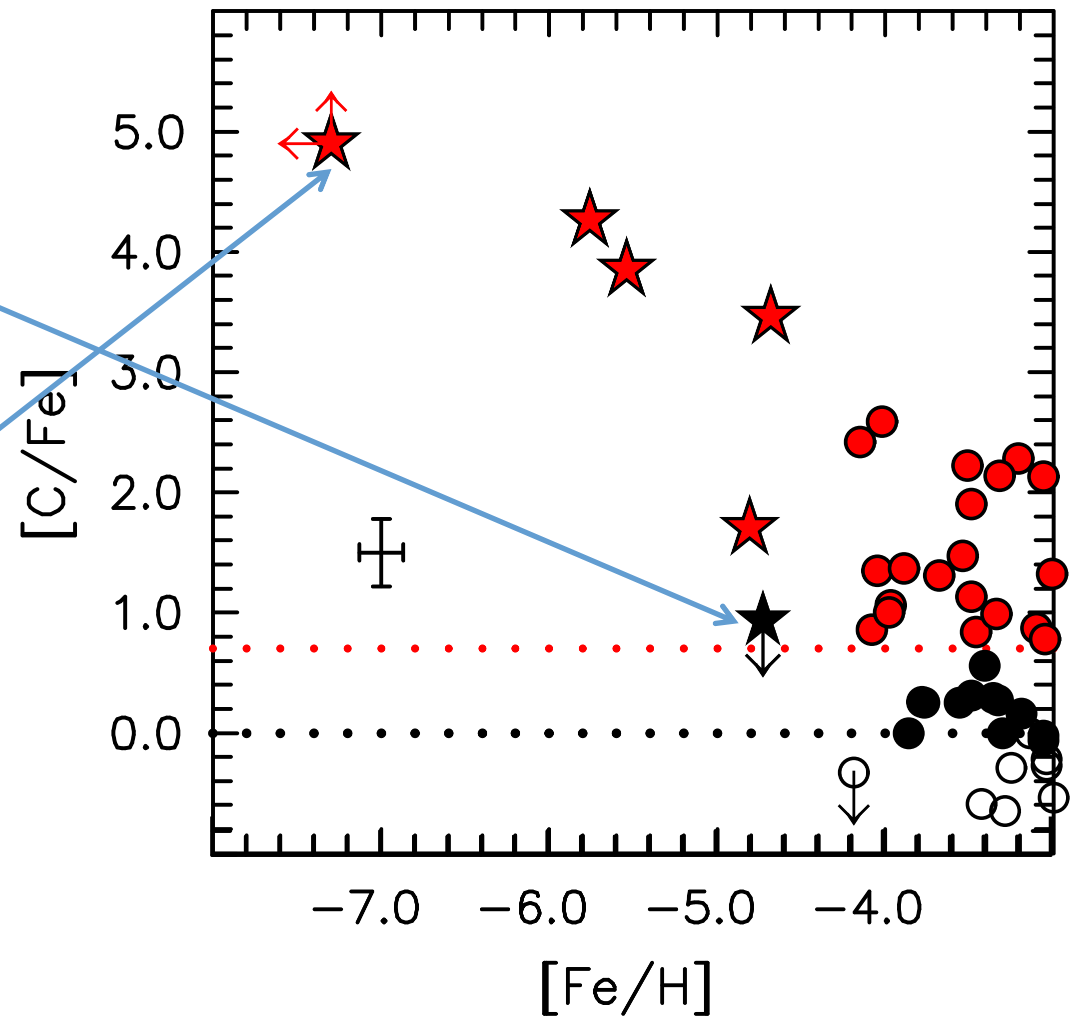
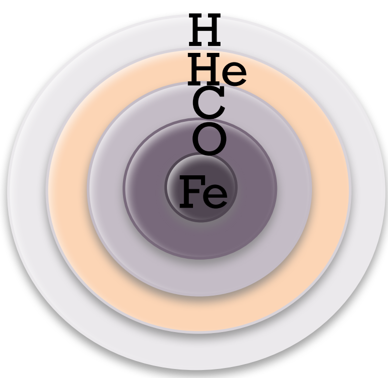
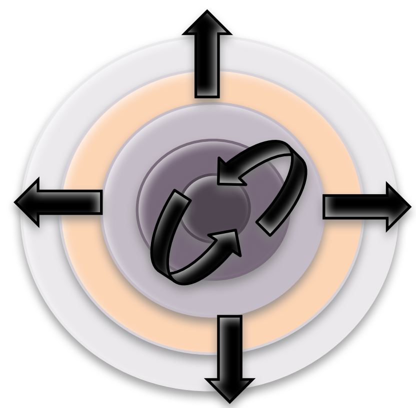


Figure from Frebel & Norris 2015

The nature of the most iron-poor stars

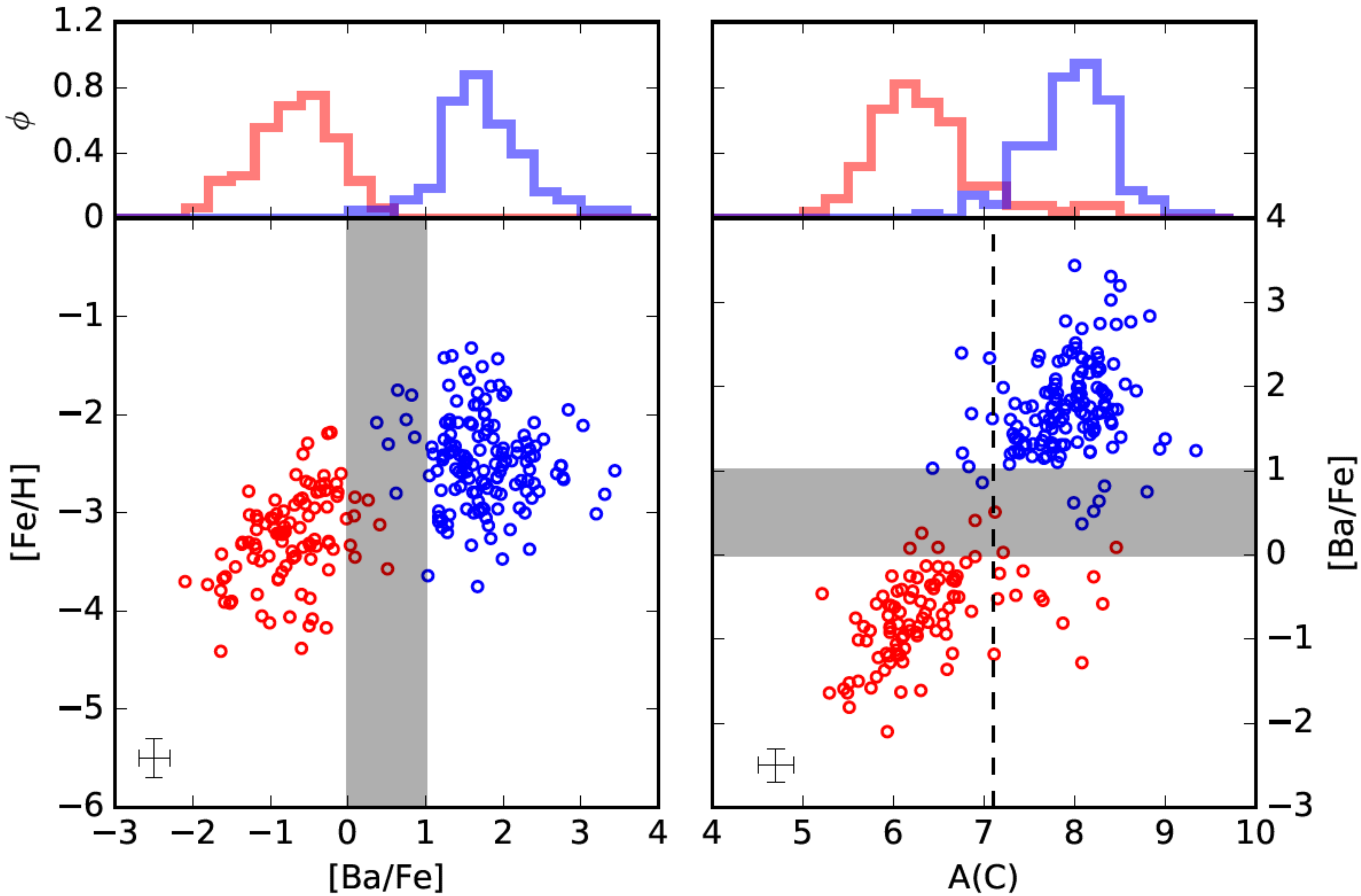
- Where does the high Carbon come from?
  - The peculiar properties of the First Stars
    - Faint (mixing & fall-back) supernovae (possibly helped by higher spin rates)





  - Transferred from a binary companion?
    - We can check by radial velocity monitoring
  - It is not high Carbon, but low Iron
    - Dust-gas winnowing – can be ruled out for some stars based on abundance pattern
      - No evidence for dust (Venn et al., 2014)

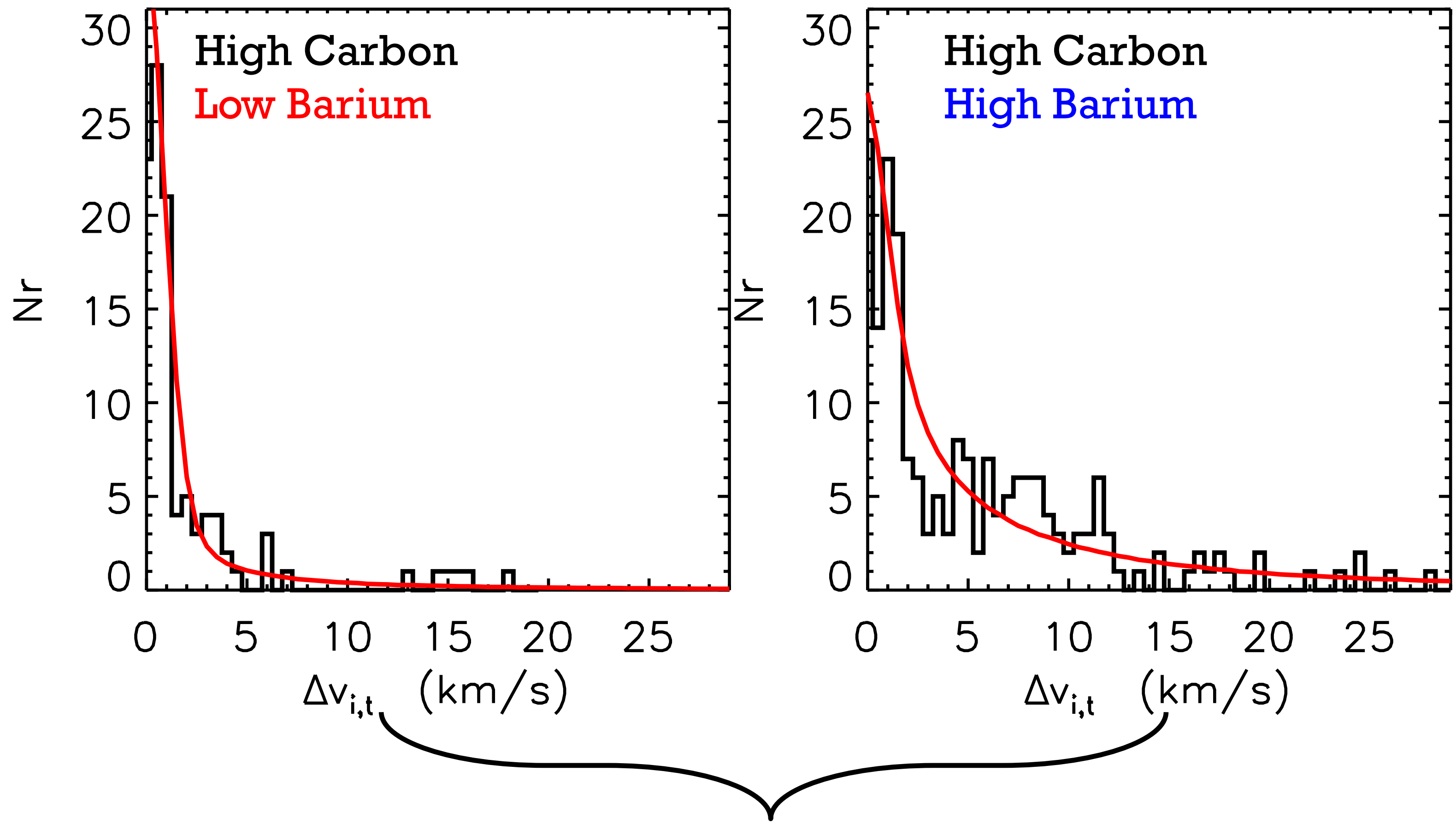
Different Carbon-rich stars



Yoon et al., 2016

Binaries?

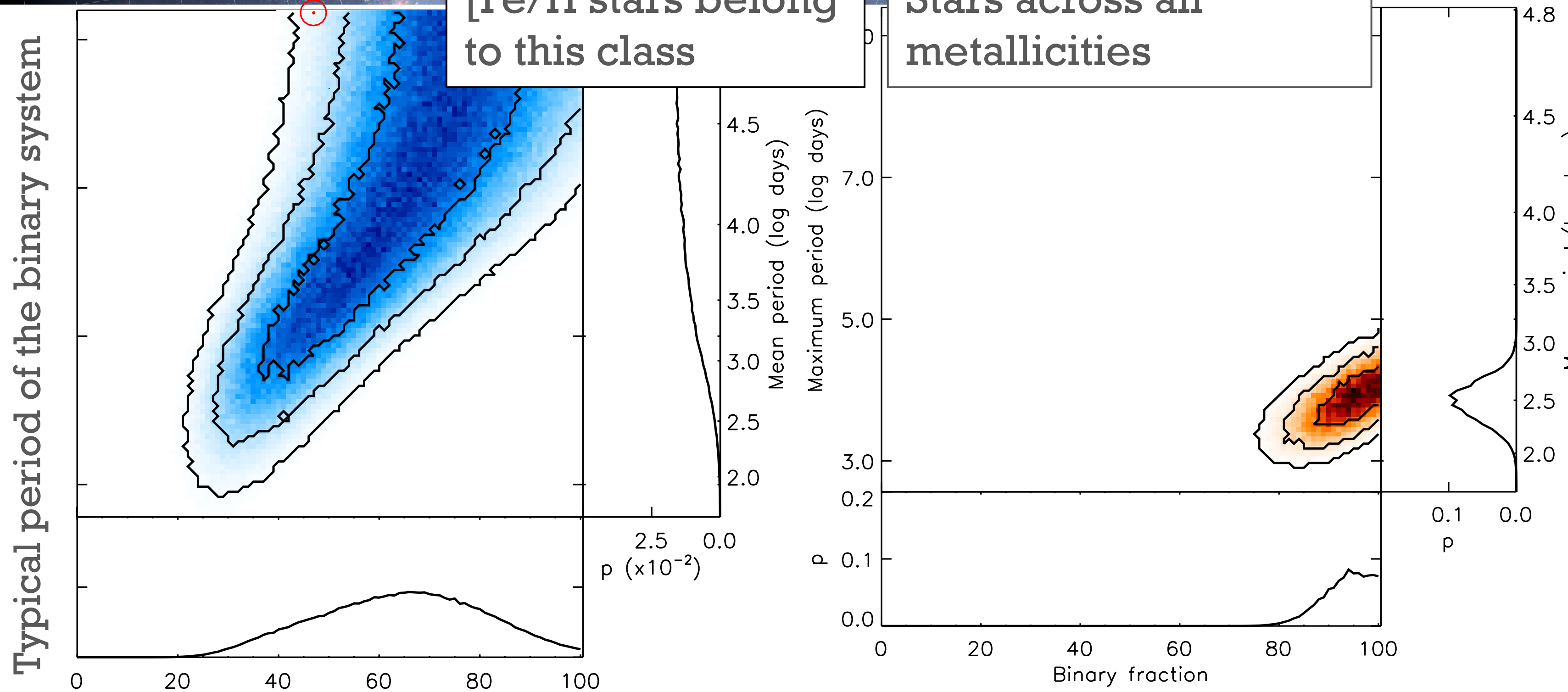
Starkenburg, Shetrone, McConnachie & Venn, 2014



Different formation scenario

Data from HET + literature (Lucatello et al., 2005 for CEMP-s)

Binaries?



High Carbon
Low Barium
Many of the lowest [Fe/H stars belong to this class

High Carbon
High Barium
AGB star polluted.
Stars across all metallicities

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Similar conclusions reached by T. Hansen et al., 2015, 2016 and Jorissen et al., 2016 from years of monitoring

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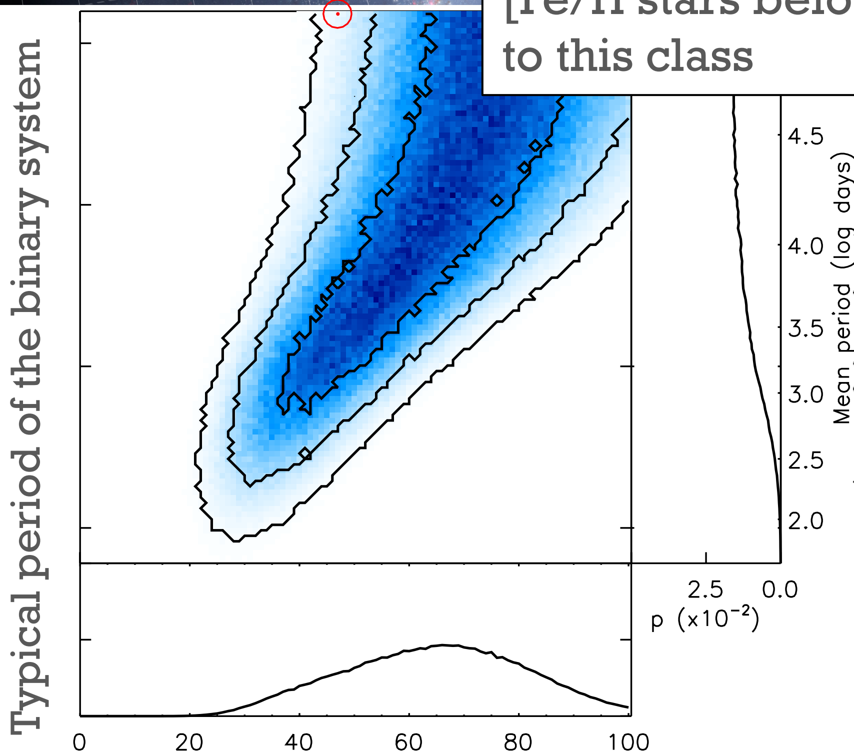
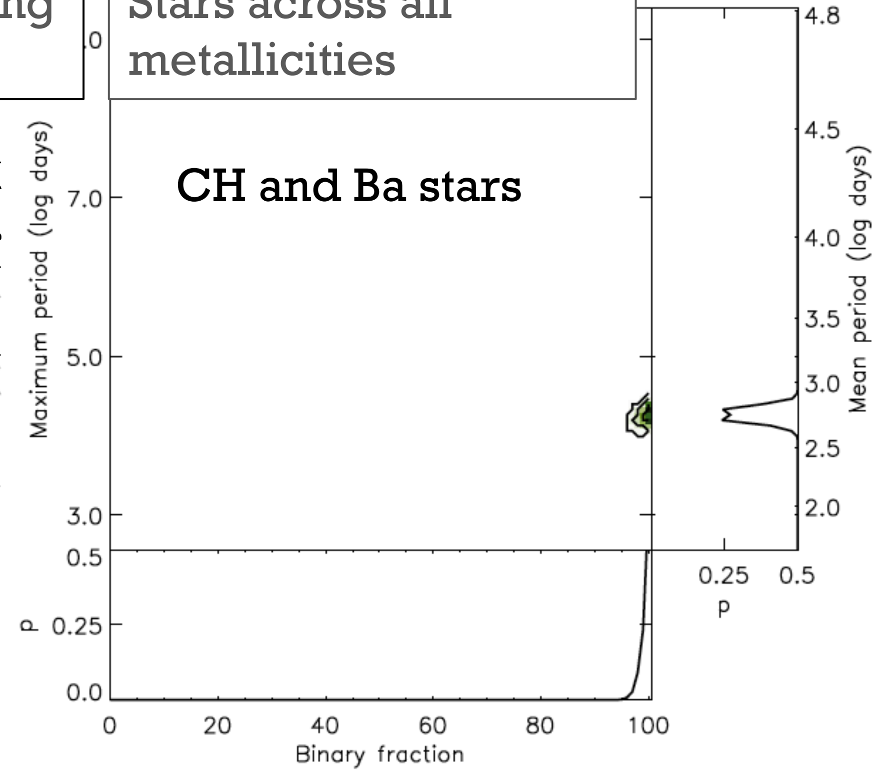




Data from HET + literature for CEMP-no

Different formation scenario

Lucatello et al., 2005 for CEMP-s; McClure & Woodsworth 1990; McClure 1997 for CH and Ba stars

Similar conclusions reached by T. Hansen et al., 2015, 2016 and Jorissen et al., 2016 from years of monitoring

R-stars – high-metallicity counterparts?

(the "R"-classification hereby refers back to the R, N system of Cannon & Pickering (1918) and should not be confused with stars rich in r-process material).

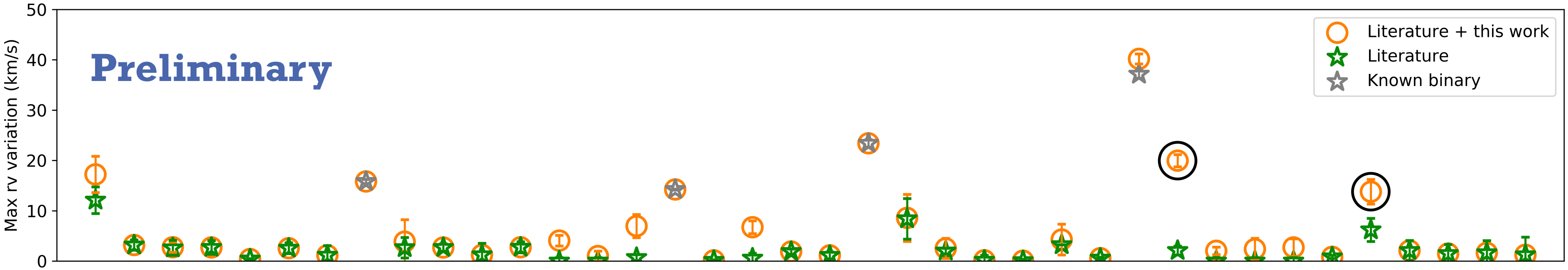
- C-rich, but not s-process enhanced
- Only giants

- **No binaries at all!** Much unlike any other stellar population
  - Also not rapidly rotating (McClure 1997)
- They are **not** the high-metallicity analogues of (all) CEMP-no stars
  - Some are binaries
  - Some are sub-giants and dwarfs
- Close binaries that have merged?
  - Merger event has mixed C from helium-core into the atmosphere
  - (Izzard et al., 2007)

Some CEMP-no stars **are** binaries

- Can they tell us about binarity in the early Universe?
  - Binarity > 7/38 (18%)

Anke Arentsen



Arentsen et al., in prep.

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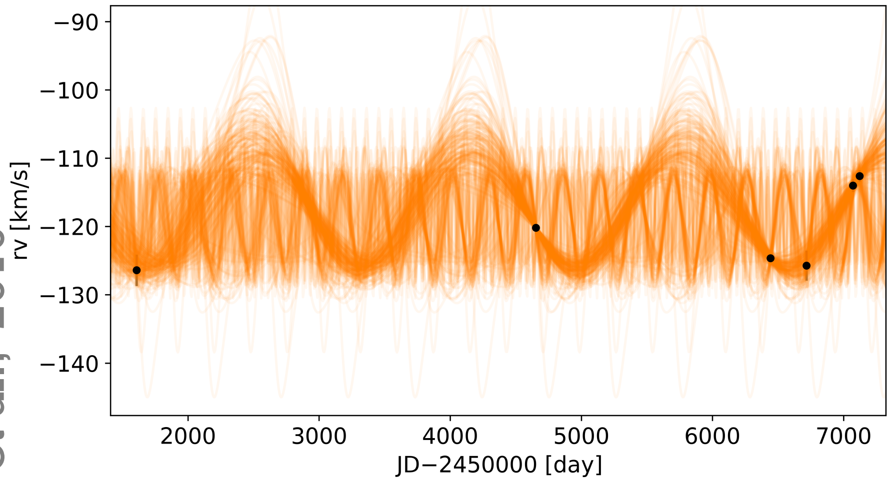
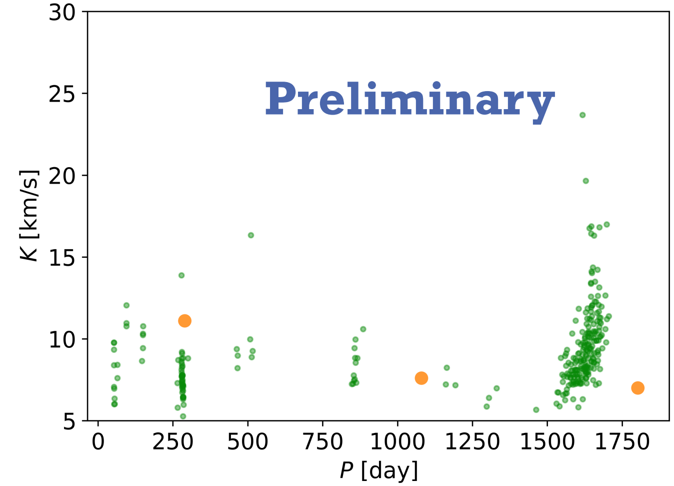
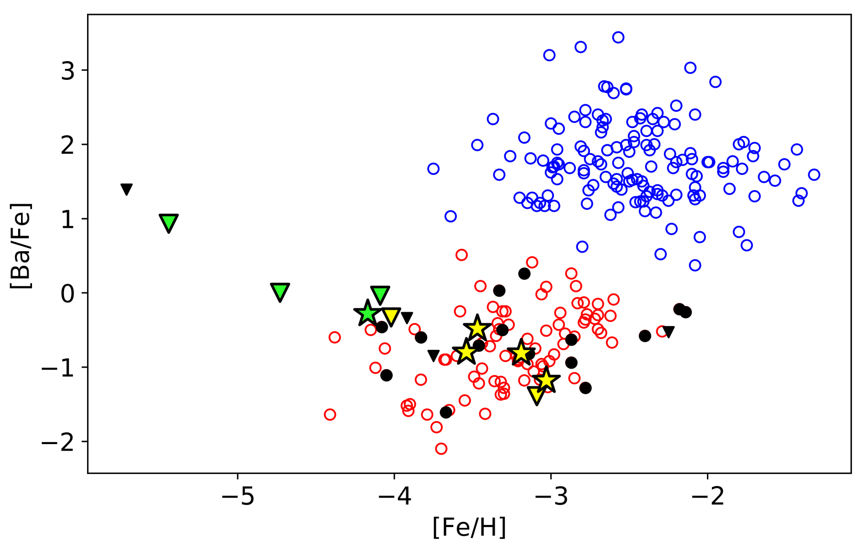


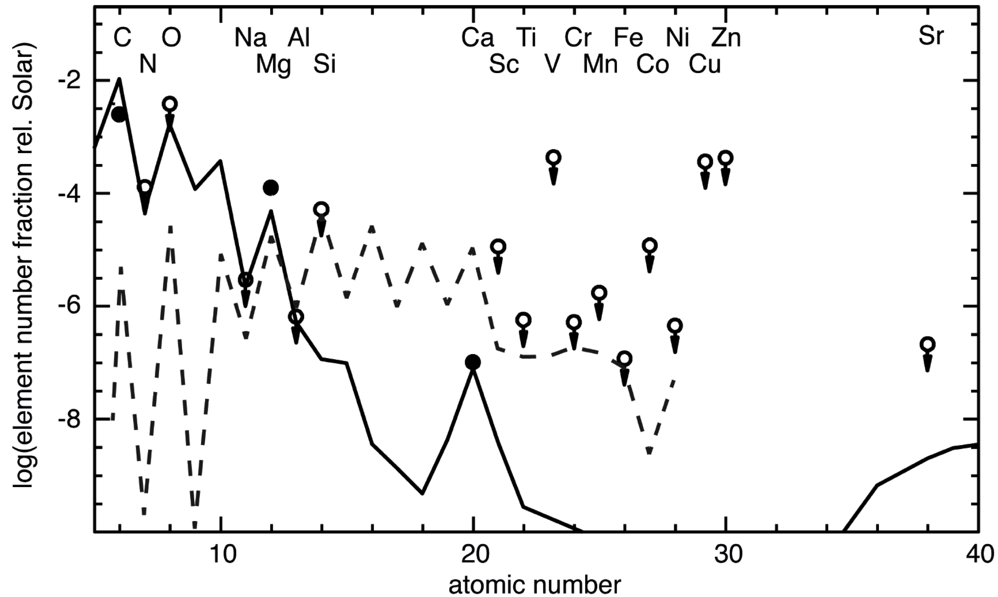




Arentsen et al., in prep. + previous measured Hansen et al., 2016

Broad strokes picture

- CEMP-s stars are low-metallicity CH and Ba stars
  - AGB donor
- CEMP-no stars trace early star formation, high abundances of light elements
- But…
  - Many individual stars are puzzling
  - Do these signatures vary as a function of Galactic environment?

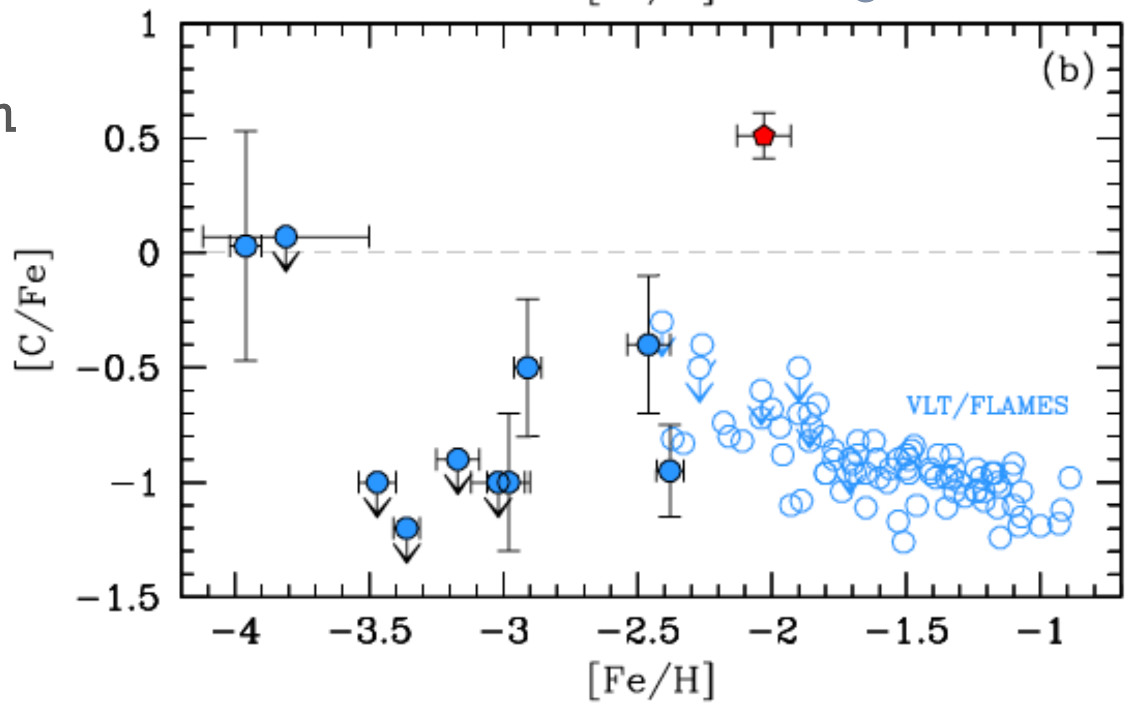


The [Fe/H] < -7 star. Imprint from a 60 solar mass First Star?
(Keller et al., 2014)

Universality?

- What about CEMP stars in dwarf galaxies?
- Sculptor:
  - In samples of 100s of stars
  - 1 CEMP-no star
    - Skuladottir et al., 2014
  - Several CEMP-s stars
    - Geisler et al., 2005
    - Kirby et al., 2015
    - Lardo et al., 2016
    - Salgado et al., 2016
- Segue I:
  - 7 red giant branch stars studied
  - 3 CEMP-no stars &1 CEMP-s star
    - Norris et al., 2010
    - Frebel et al., 2014

Skuladottir et al., 2014; Starkenburg et al., 2013

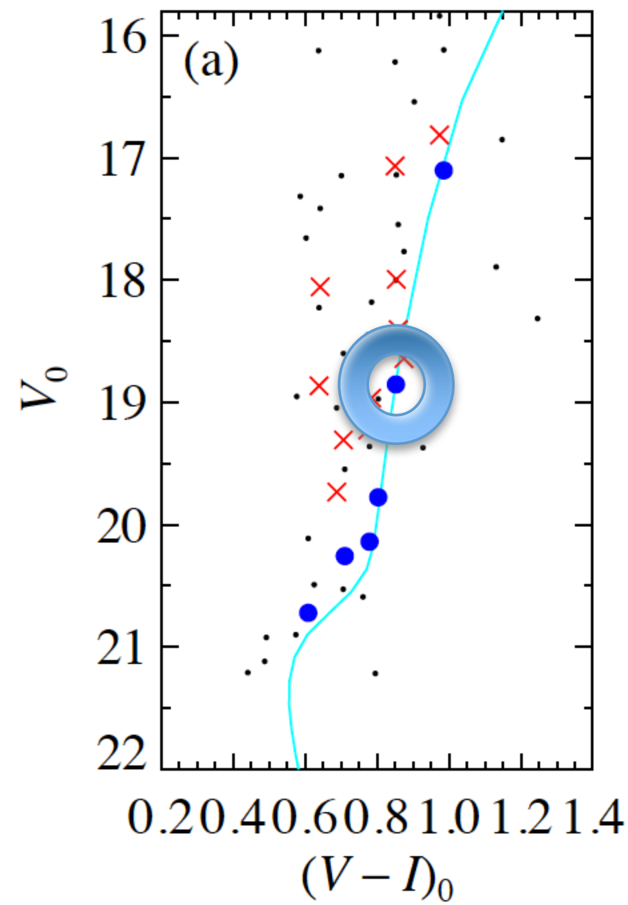


Small samples at low metallicities

Careful with selection effects

Universality?

- What about binaries in dwarf galaxies?
  - Binary fractions 0.14-0.69 (Minor et al., 2013)
  - 0.3-0.34 in Leo II (Spencer et al., 2017)



Binaries are also very important in the faintest systems to understand the dark matter mass

(the most dark matter dominated?)

Kirby et al., 2015, see also Martin et al., 2016 & Venn, Starkenburg et al., 2017

TRIANGULUM II: NOT ESPECIALLY DENSE AFTER ALL

Evan N. Kirby[1], Judith G. Cohen[1], Joshua D. Simon[2], Puragra Guhathakurta[3], Anders O. Thygesen[1], Gina E. Duggan[1]

Accepted to ApJ on 2017 March 8

Universality?

Hints that disk & (dual) halo show different ratios of C-rich populations

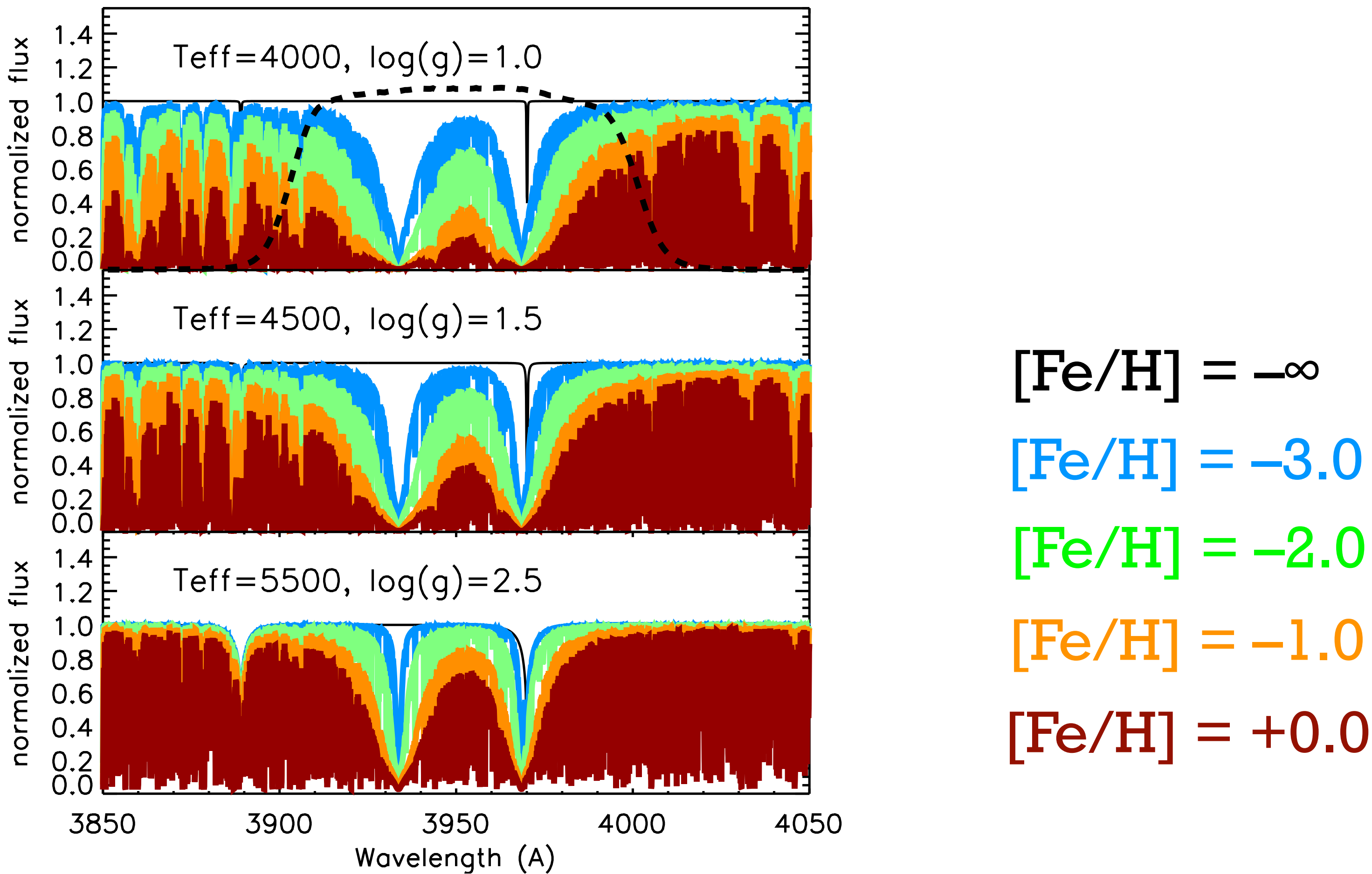
- Frebel et al., 2006, Lee et al., 2013, 2017, Carollo et al., 2014, Beers et al., 2016

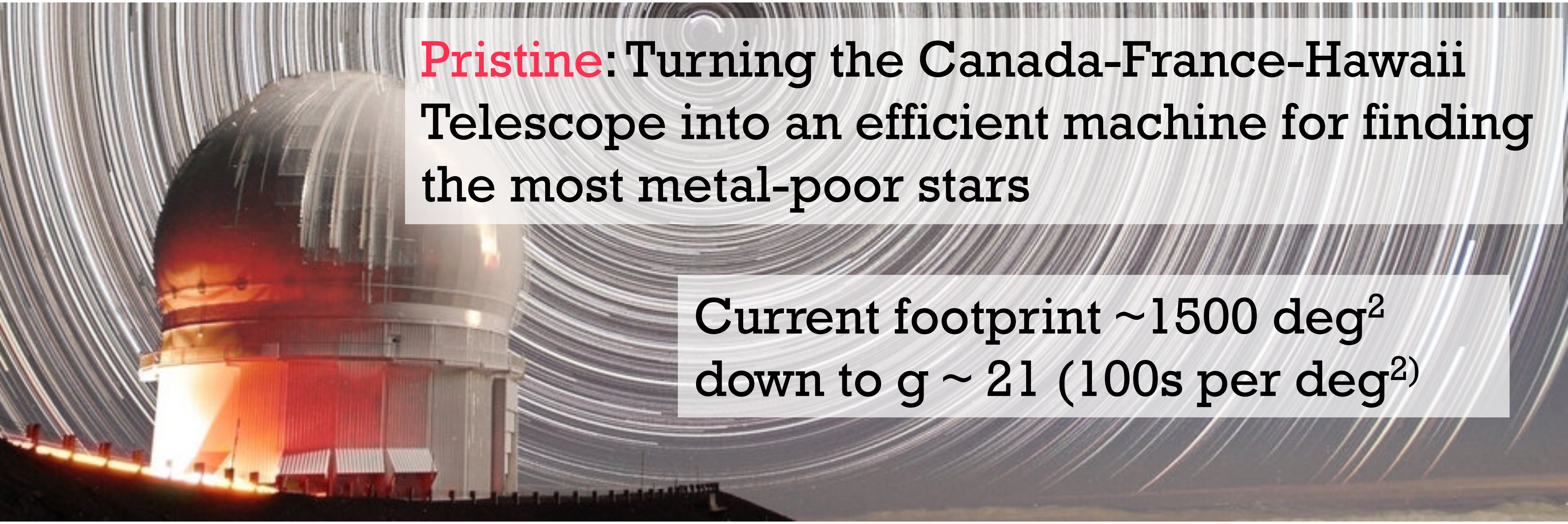
We would like large samples of these stars across all Galactic environments

Howes et al. (2016) analysed 23 stars below [Fe/H] = -2.3 including one star at [Fe/H] = -3.94 and found none of them to be Carbon-enhanced.

Narrow-band filters

- Pristine in the Northern Hemisphere
- Skymapper in the Southern Hemisphere

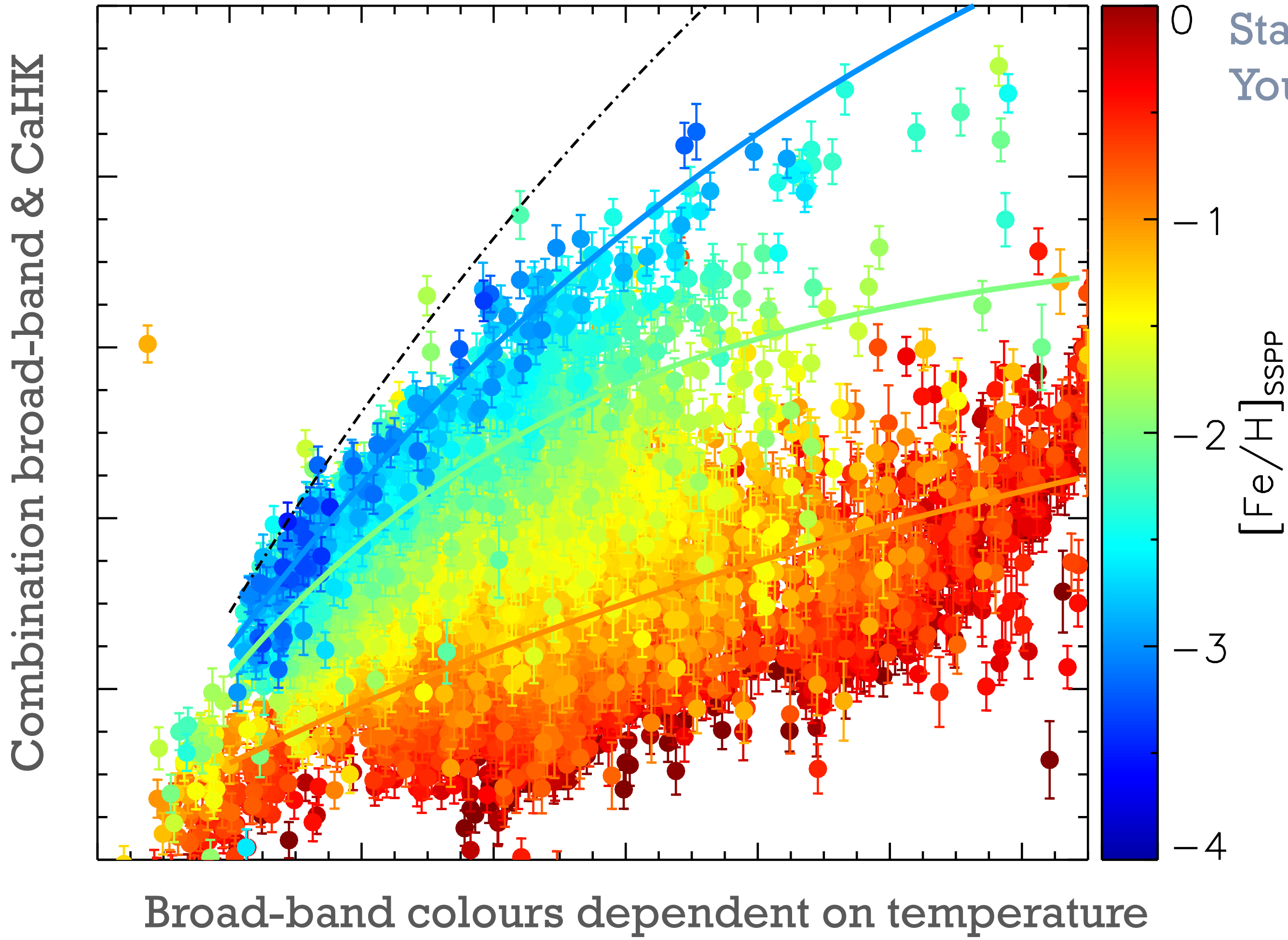




Picture credit: Jean-Charles Cuillandre

PIs: Else Starkenburg & **Nicolas Martin.**
Co-Is: David Aguado, Carlos Allende Prieto, 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, Julio Navarro, Alan McConnachie, Ruben Sanchez-Janssen, Kim Venn, **Kris Youakim**

Photometric metallicities

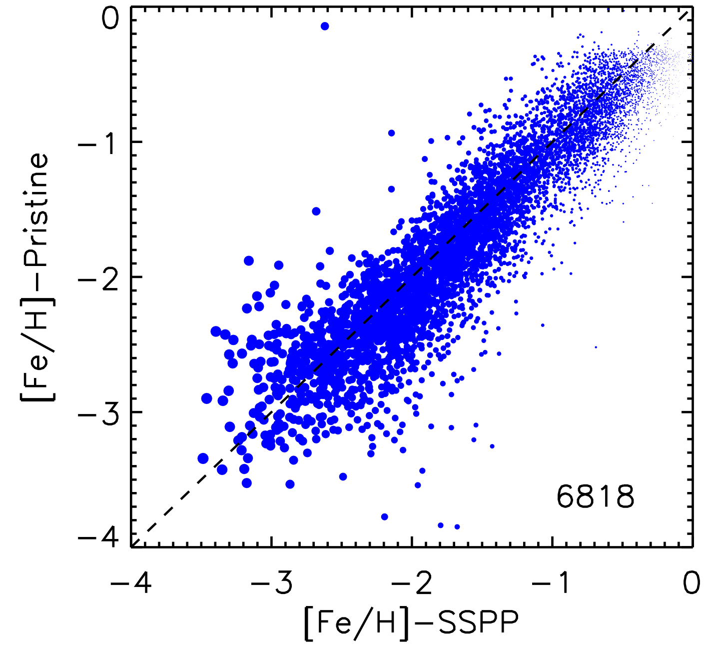


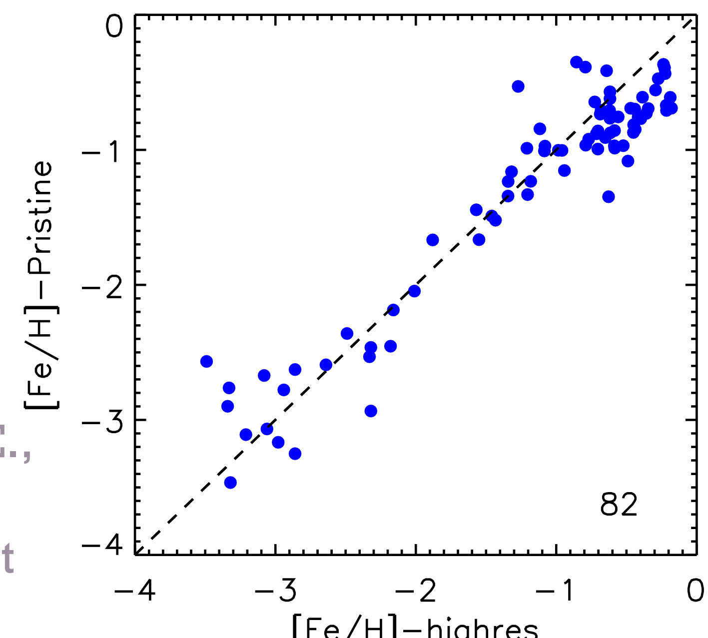
Starkenburg, Martin, Youakim et al., 2017b

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

A metallicity scale

- An rms scatter of 0.2 dex from [Fe/H] = -0.5 down to [Fe/H] = -3.0
  - We find that we have a success rate of 22% to find [Fe/H]<-3 stars (Youakim et al., 2017)
    - Previous and current surveys report 3-4% succes rates
    - Very few failures: 70% still below [Fe/H]<-2.5
- Opening up a new regime – before only accessible to spectroscopy

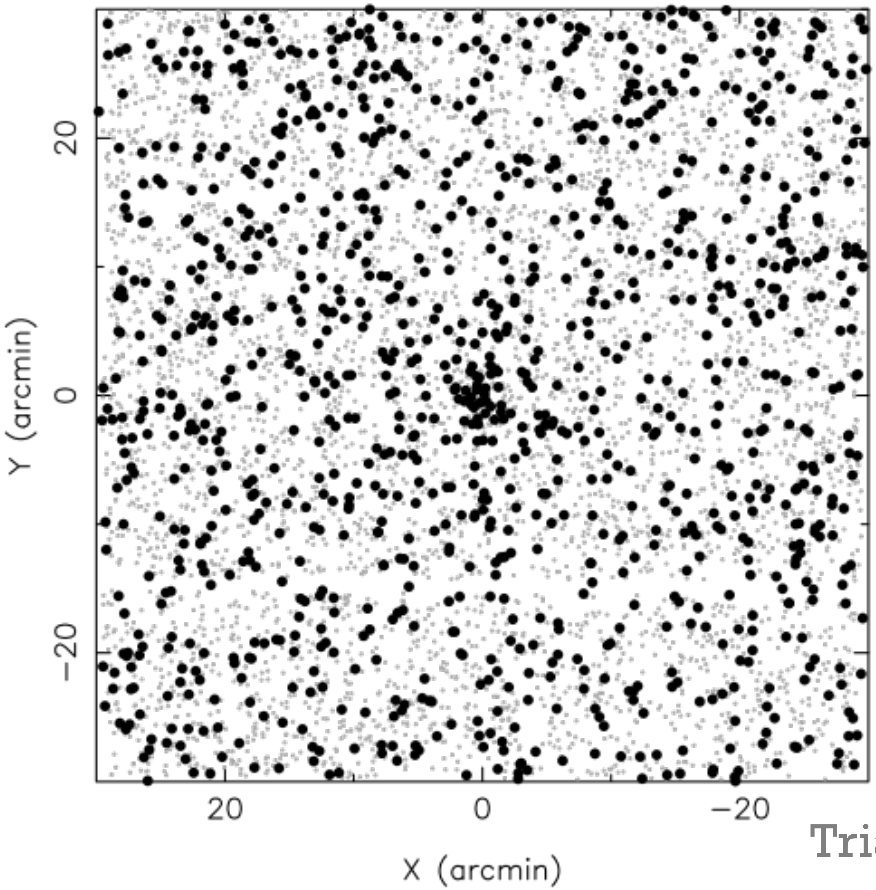




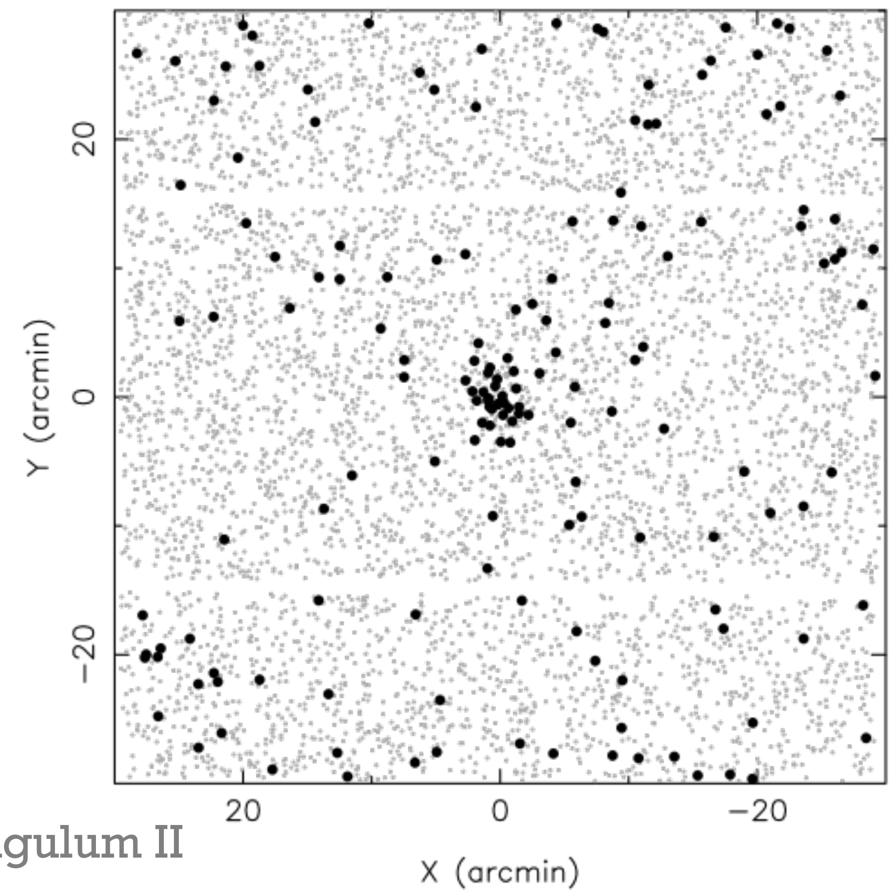
Starkenburg, E., Martin N., Youakim, K., et al., 2017b

Studying the faintest galaxies

CMD-selection candidates



Pristine-selection candidates



Triangulum II

Towards an efficient, systematic study of the MW faint dwarf galaxies with the Pristine survey

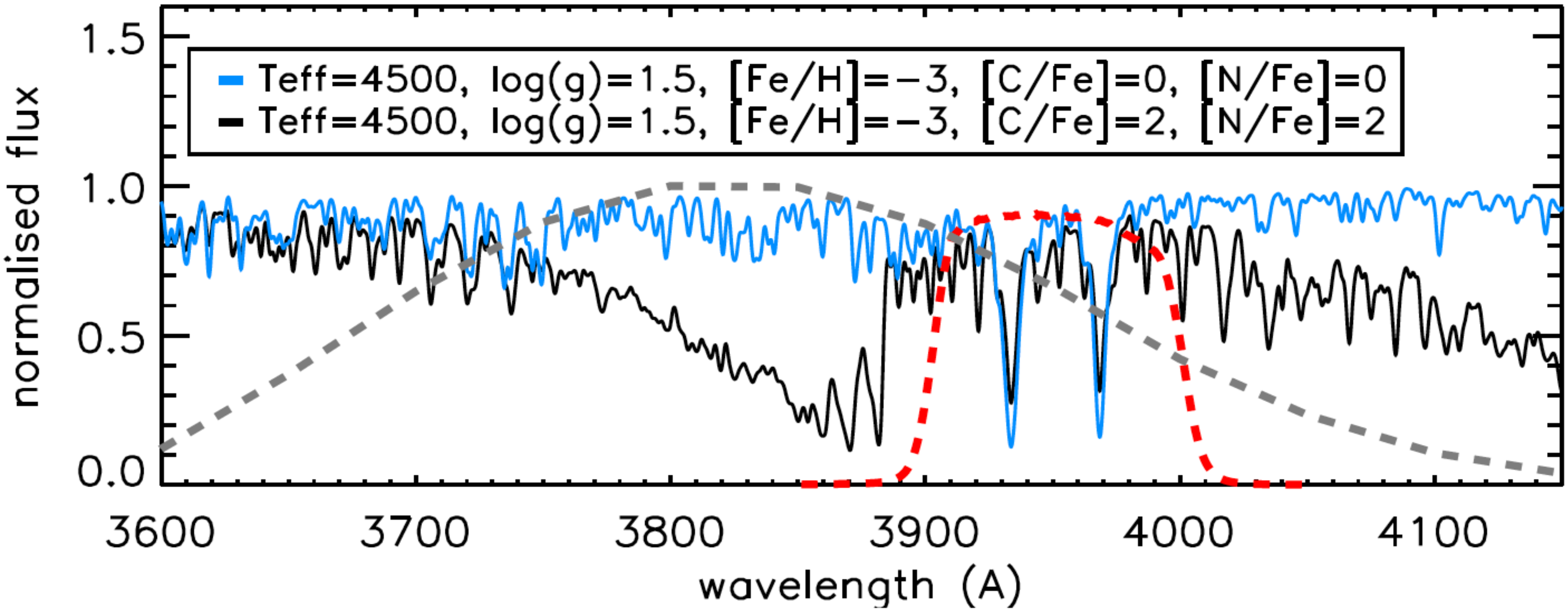
In conclusion:

- ***Oldest/most metal-poor stars*** inform us on early build-up of galaxies & First Star physics
  - Radial velocity monitoring helps to understand their nature
    - We think some stars show imprints of First Stars chemical enrichment
    - As such RV monitoring gives us a window on binary properties in the early Universe
      - Some of these stars are in binary systems

We see interesting hints of variety in C-rich populations throughout the Galaxy

- ***Metallicity decomposition of the MW from narrow-band photometry***
  - Can uncover efficiently the rare extremely metal-poor population
  - Helps studying the faintest dwarf galaxies by eliminating foreground contamination

Pristine & Skymapper



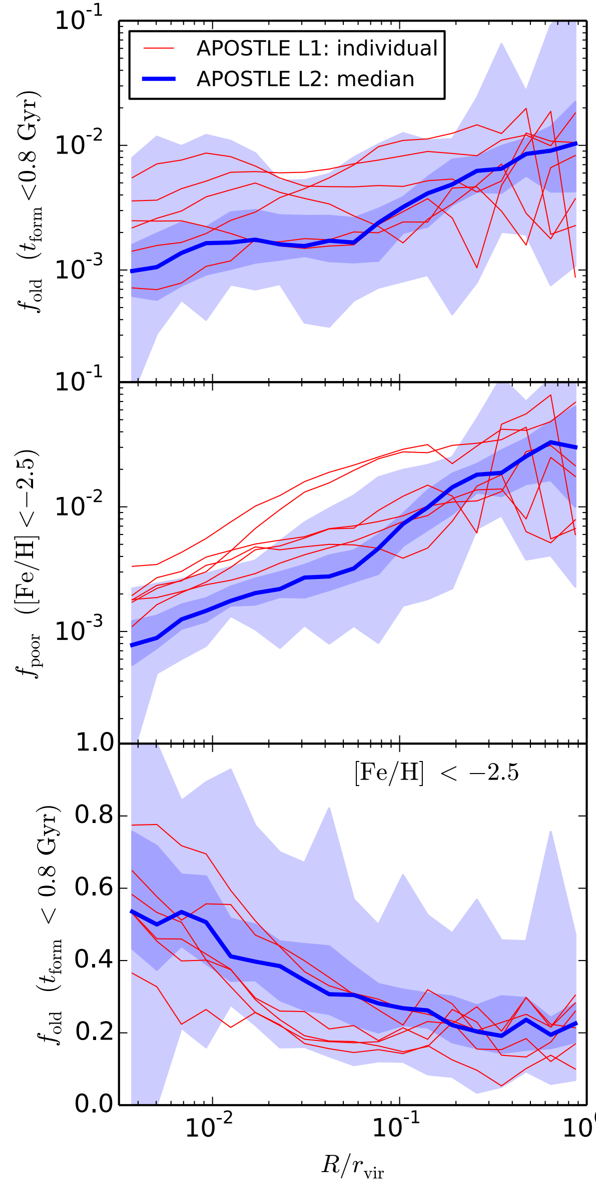
[Fe/H] = –3.0, [C/Fe] = +2, [N/Fe]=+2

[Fe/H] = –3.0

Where are the first stars?

- What do we expect in different environments?
  - More old stars in the halo
  - More metal-poor stars in the halo
    - but not all of them old
  - if you discover a metal-poor star in the inner Galaxy, it is very likely to be old
    - Quantitative measurements of this are very dependent on technique used!

- The history of the Galaxy is messy
  - Are they all in the center?



Starkenburg, E. et al., 2017