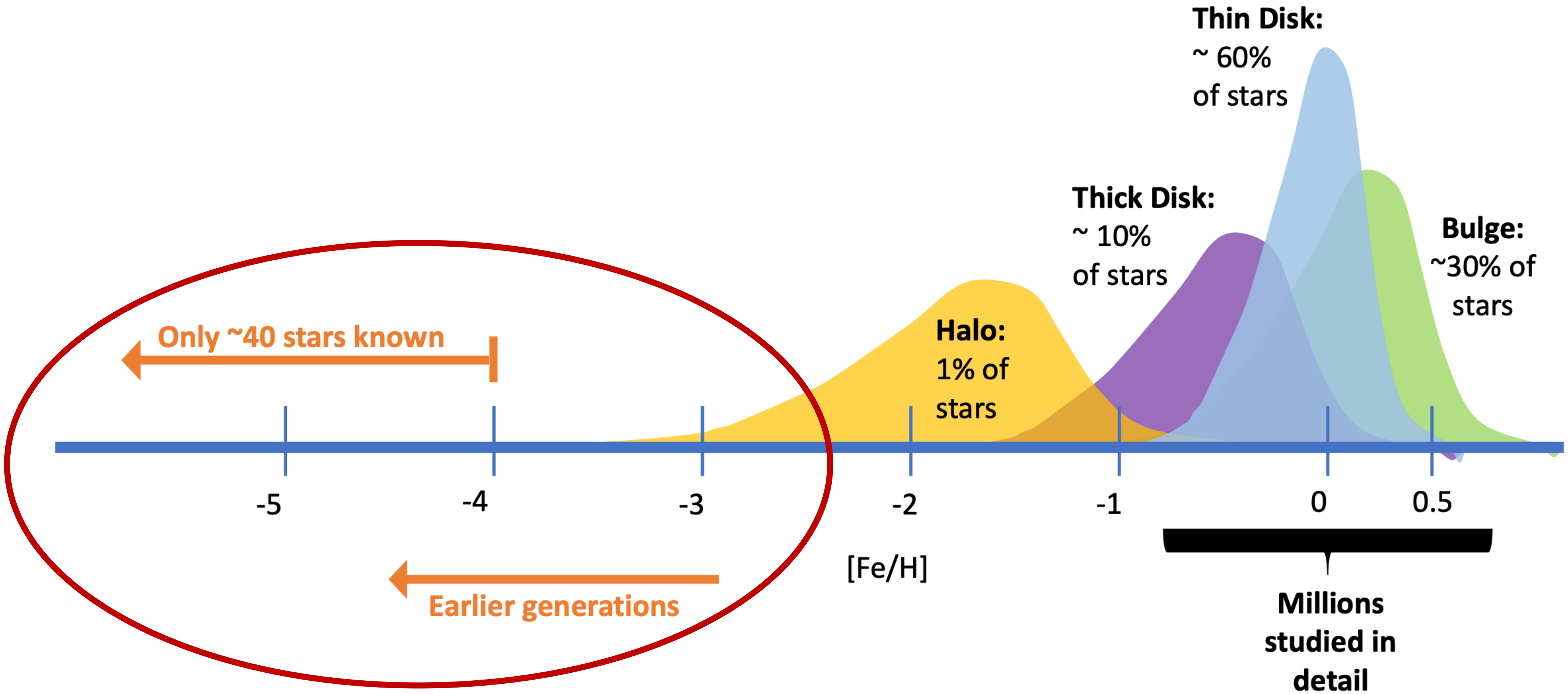
The Pristine survey

Else Starkenburg – University of Groningen

Artist impression of a high-redshift galaxy star-forming.
Credit: ESO

Galactic Archaeology to its limits

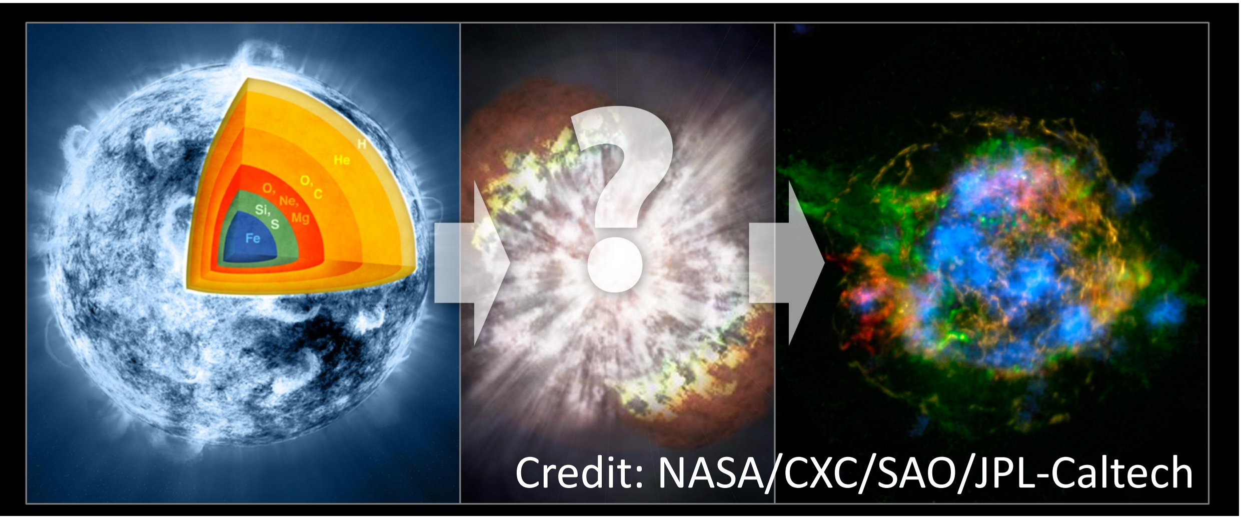
Milky Way history is very incomplete at very early times

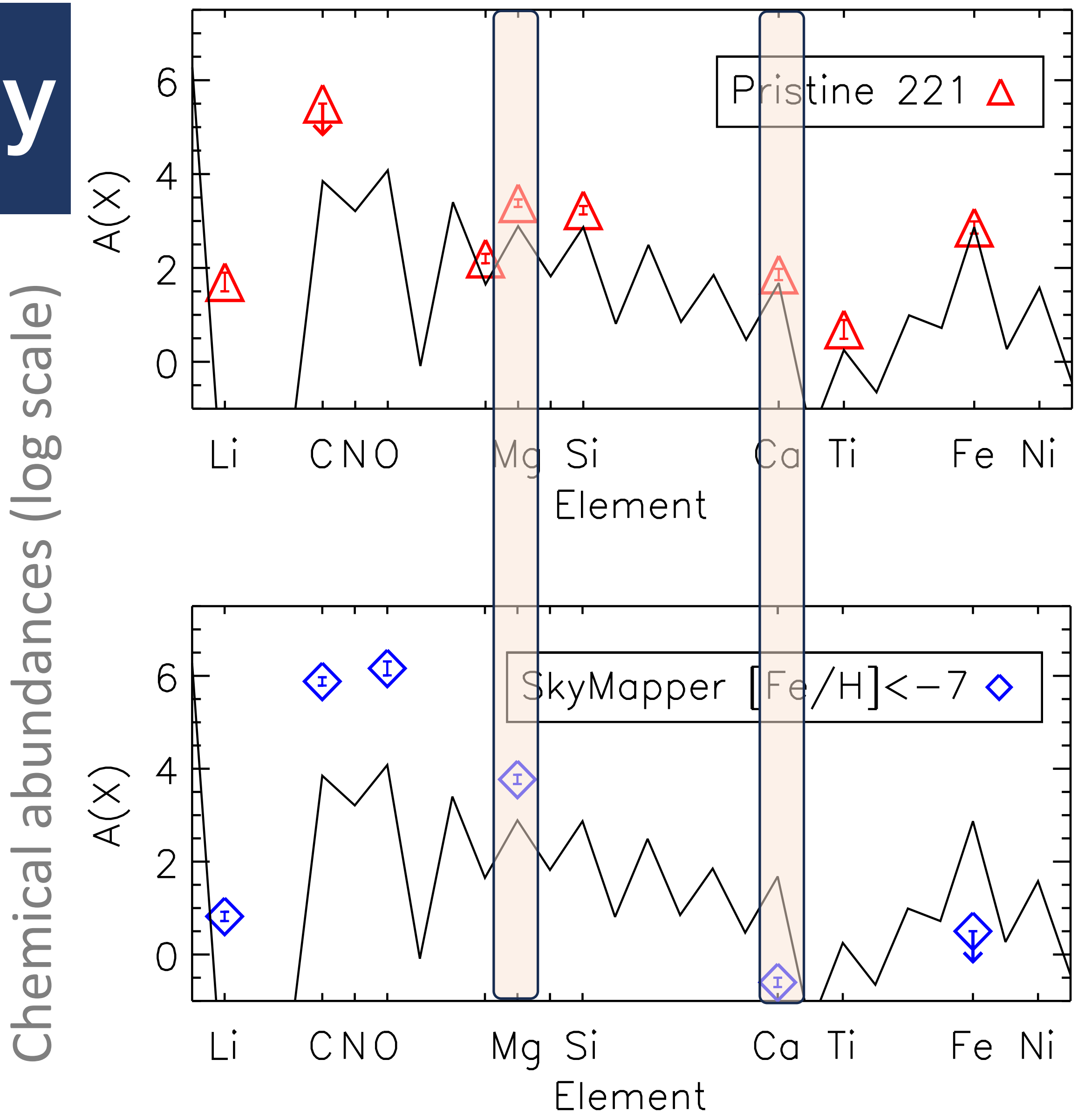


Galactic Archaeology

Early chemical evolution: Where abundances are excitingly different

- Different types of Supernovae





Abundances from Starkenburg et al., 2018
& Nordlander et al., 2017

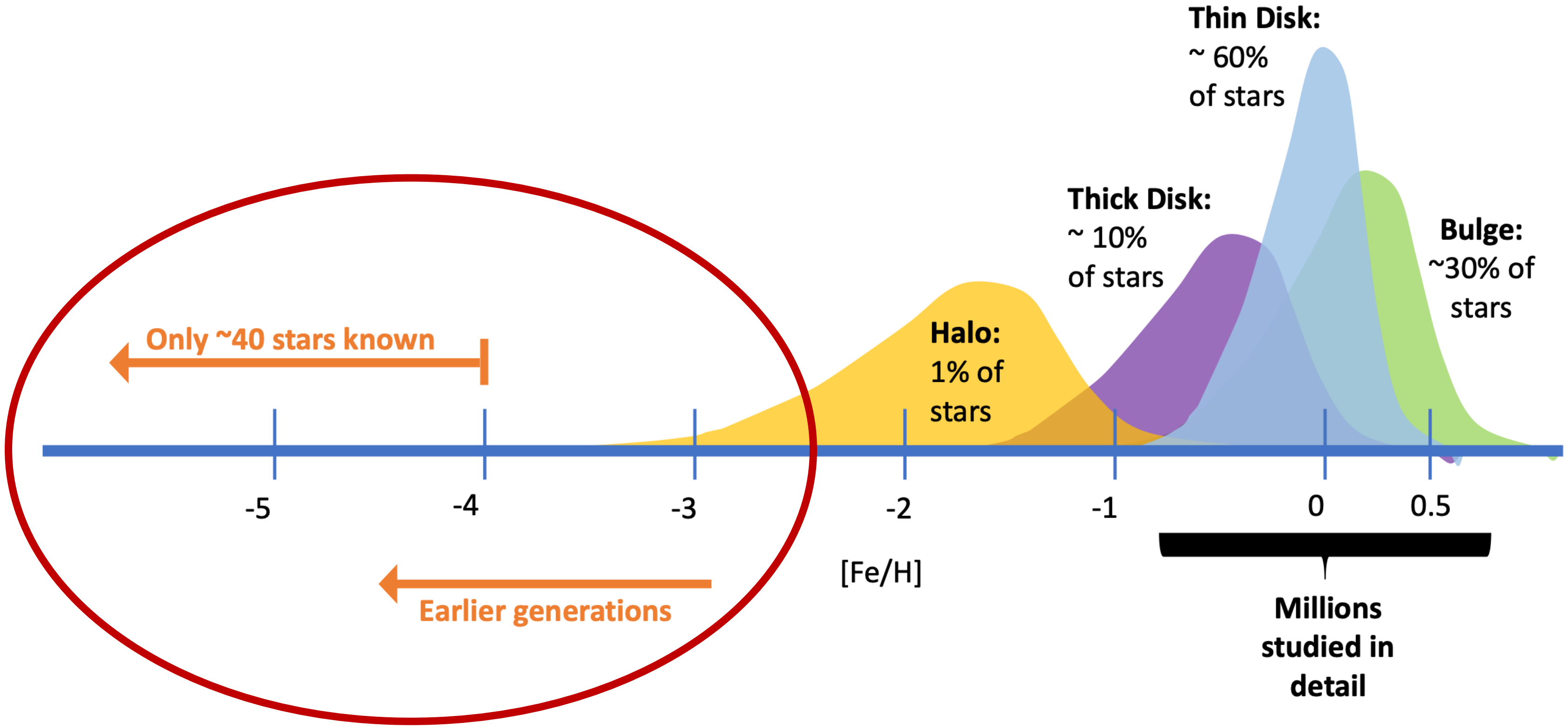
Galactic Archaeology to its limits

Milky Way history is very incomplete at very early times

Step 1:

Finding these rare stars

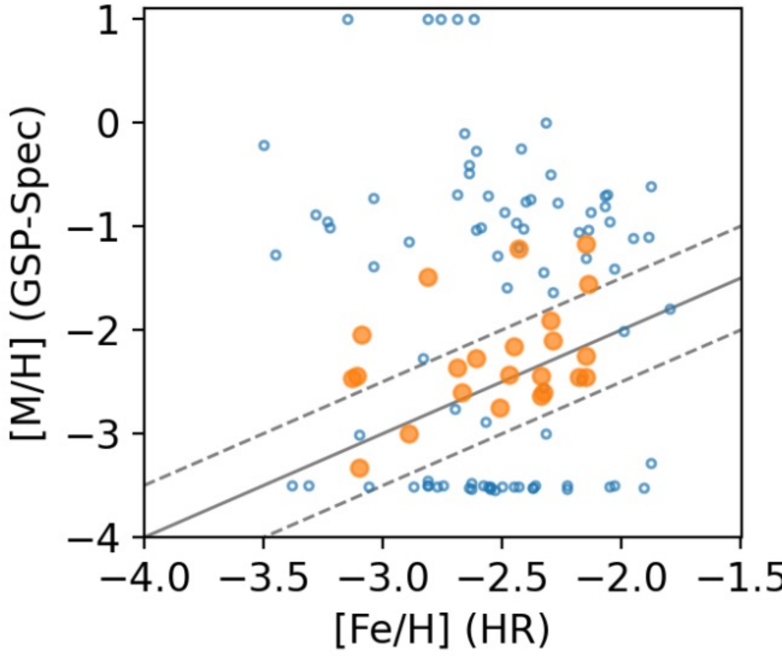
- Serendipitously in very large spectroscopic surveys
- Targeted, with narrow-band, like:
  - The Pristine survey
  - Gaia XP spectra

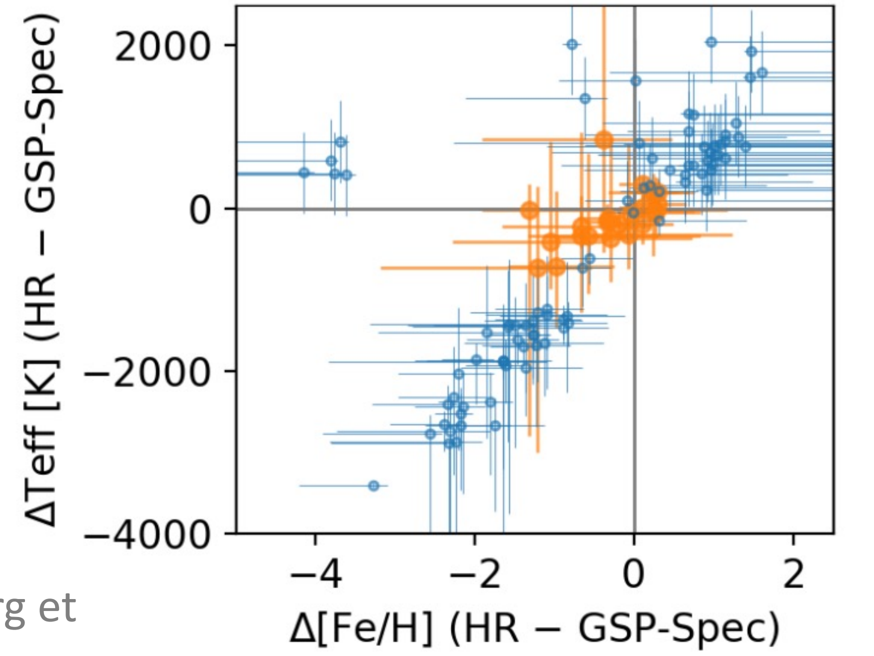


Going through "the trash"

(of the spectroscopic surveys)

- Spectra of extremely metal-poor stars can be:
  - Mistakingly classified as hot stars
  - Mistakingly classified as noisy
  - "No lines to fit" – no solution
- Many thanks to all the careful flags in the survey results!
  - These are typically bright, interesting targets





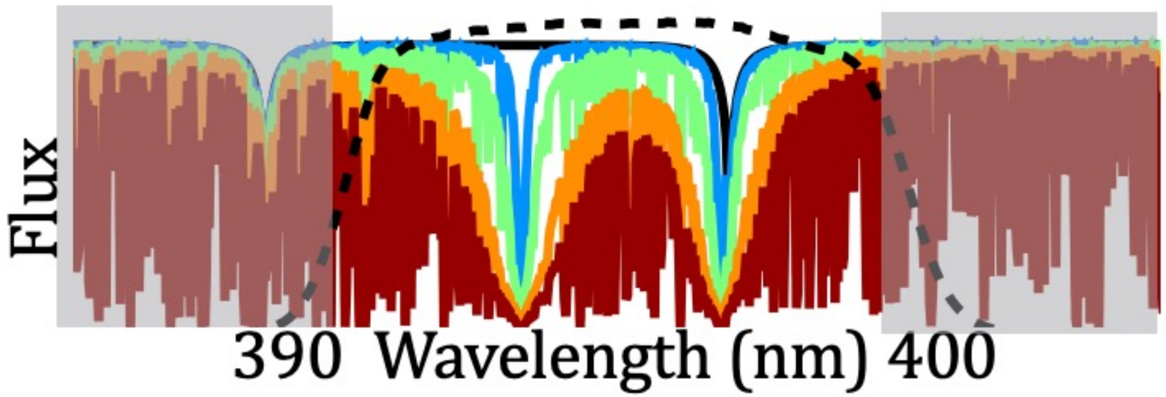
- LAMOST
  - Arentsen et al., 2023
- Gaia RVS
  - Matsuno et al., 2024; Viswanathan et al., 2024
- APOGEE
  - Montelius et al., in prep.

Matsuno, Starkenburg et al., 2024

The Pristine survey

Starkenburg, Martin et al., 2017

The Pristine measurement



Solar element pattern

[Fe/H] = -1

[Fe/H] = -2

[Fe/H] = -3

No heavy elements

Relative brightness in Pristine
(compared to Gaia data)

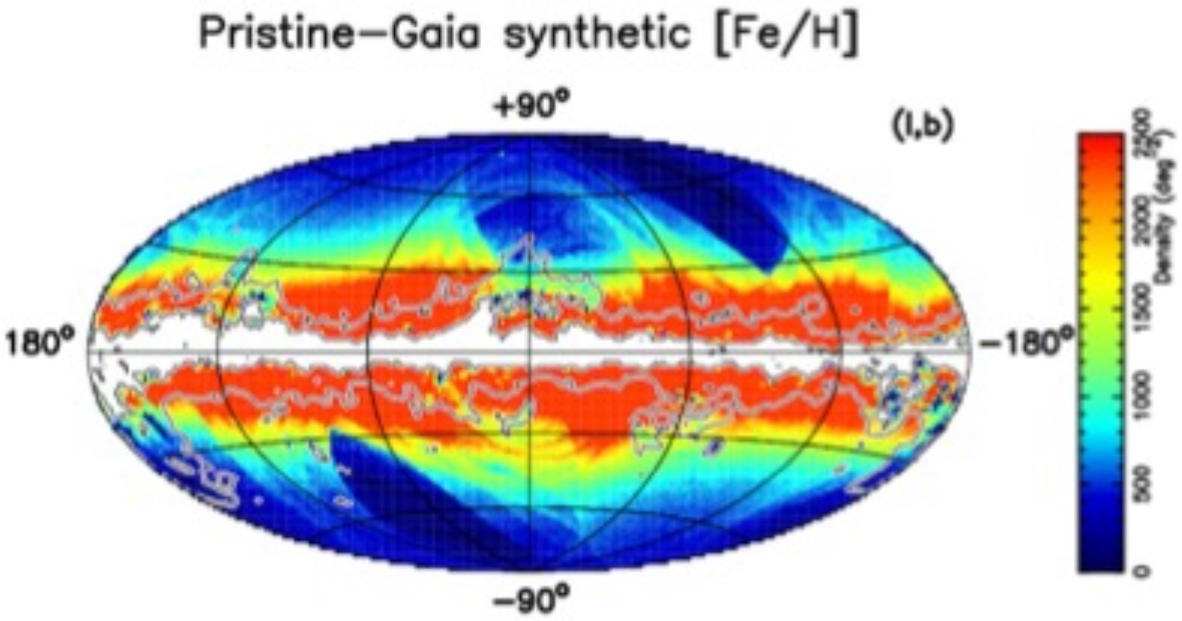
Who is Pristine?

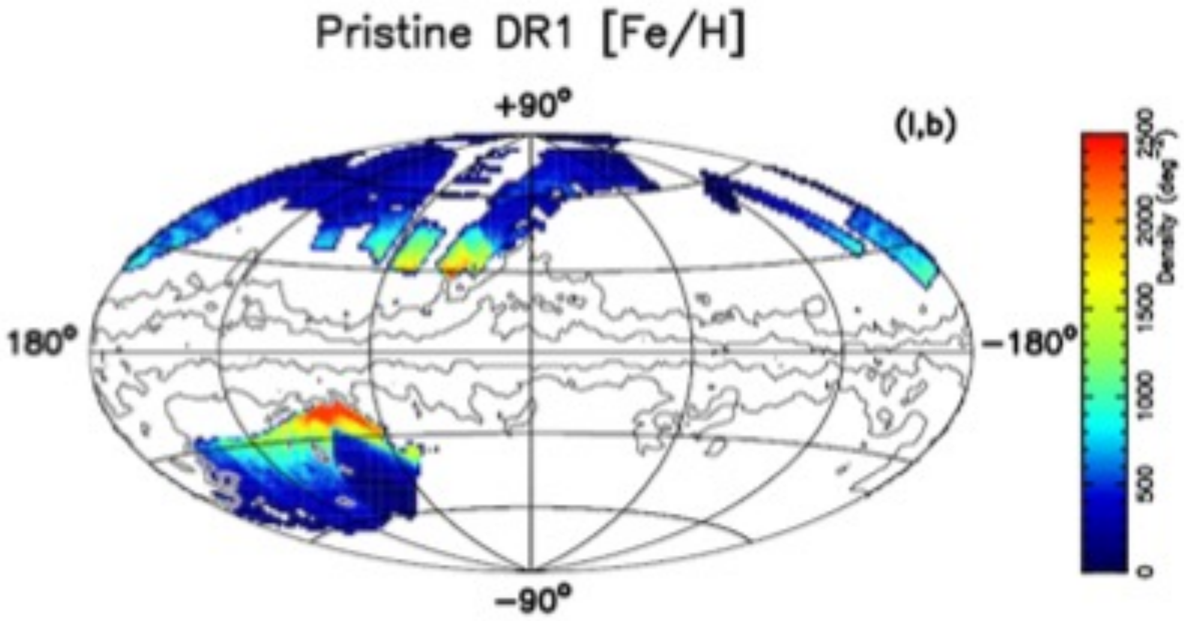
PIs: Else Starkenburg & Nicolas Martin
PhD students: Manuel Bayer, Spencer Bialek, Amanda Byström, Emma Dodd, Isaure Gonzalez Rivera, Jaclyn Jensen, Aroa del Mar Matas Pinto, Martin Montelius, Samuel Rusterucci, Akshara Viswanathan, Sara Vitali
Postdocs & staff:
David Aguado, Carlos Allende Prieto, Anke Ardern-Arentsen, Piercarlo Bonifacio, Elisabetta Caffau, Raymond Carlberg, Patrick Côté, Raphaël Errani, Sebastien Fabbro, Emma Fernández-Alvar, Morgan Fouesneau, Patrick Francois, Jonay González Hernández, Felipe Gran, Stephen Gwyn, Vanessa Hill, Rodrigo Ibata, Pascale Jablonka, Georges Kordopatis, Carmela Lardo, Linda Lombardo, Nicolas Longeard, Romain Lucchesi, Khyati Malhan, Lyudmila Mashonkina, Tadafumi Matsuno, Alan McConnachie, Camila Navarrete, Julio Navarro, Ruben Sanchez-Janssen, Mathias Schultheis, Federico Sestito, Salvatore Taibi, Guillaume Thomas, Eline Tolstoy, Kim Venn, Karina Voggel, Kris Youakim, Zhen Yuan

Pristine started in 2015 taking data with a CaHK filter on the Canada-France-Hawaii-Telescope – to date 40+ papers
(Building on a long history of CaHK, see also talks of Ting Li, Wako Aoki, Anirudh Chiti)

Pristine Data Release 1

Martin, Starkenburg et al., 2024





Based on Gaia XP

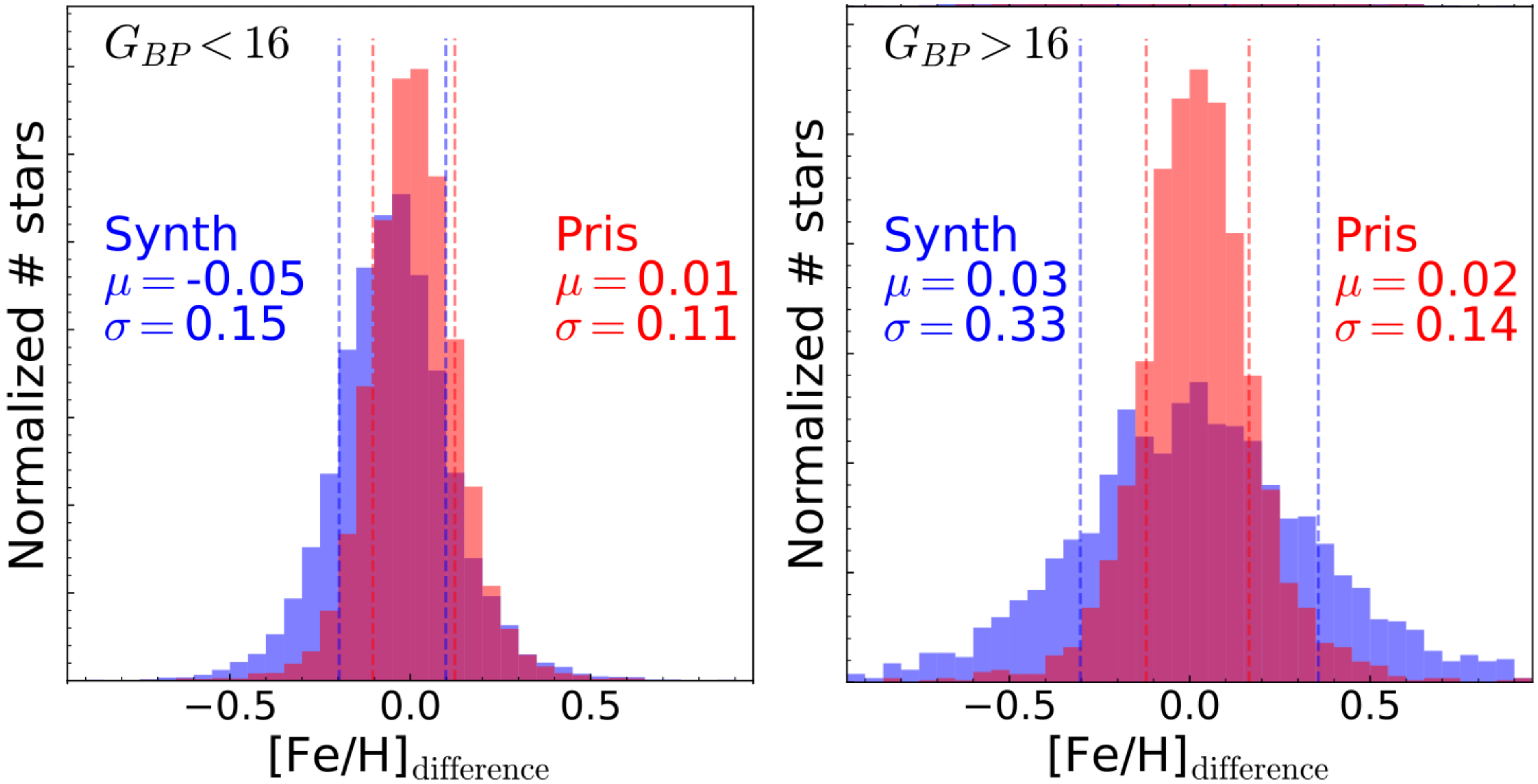
Based on Pristine CaHK

Complementary to catalogues by e.g., Andrae et al., 2022, 2023; Zhang et al., 2023; Bellazzini et al., 2023

Pristine Data Release 1

Martin, Starkenburg et al., 2024

- Difference in quality at the fainter end ($G_{BP} > 16$)



Low-metallicity stars

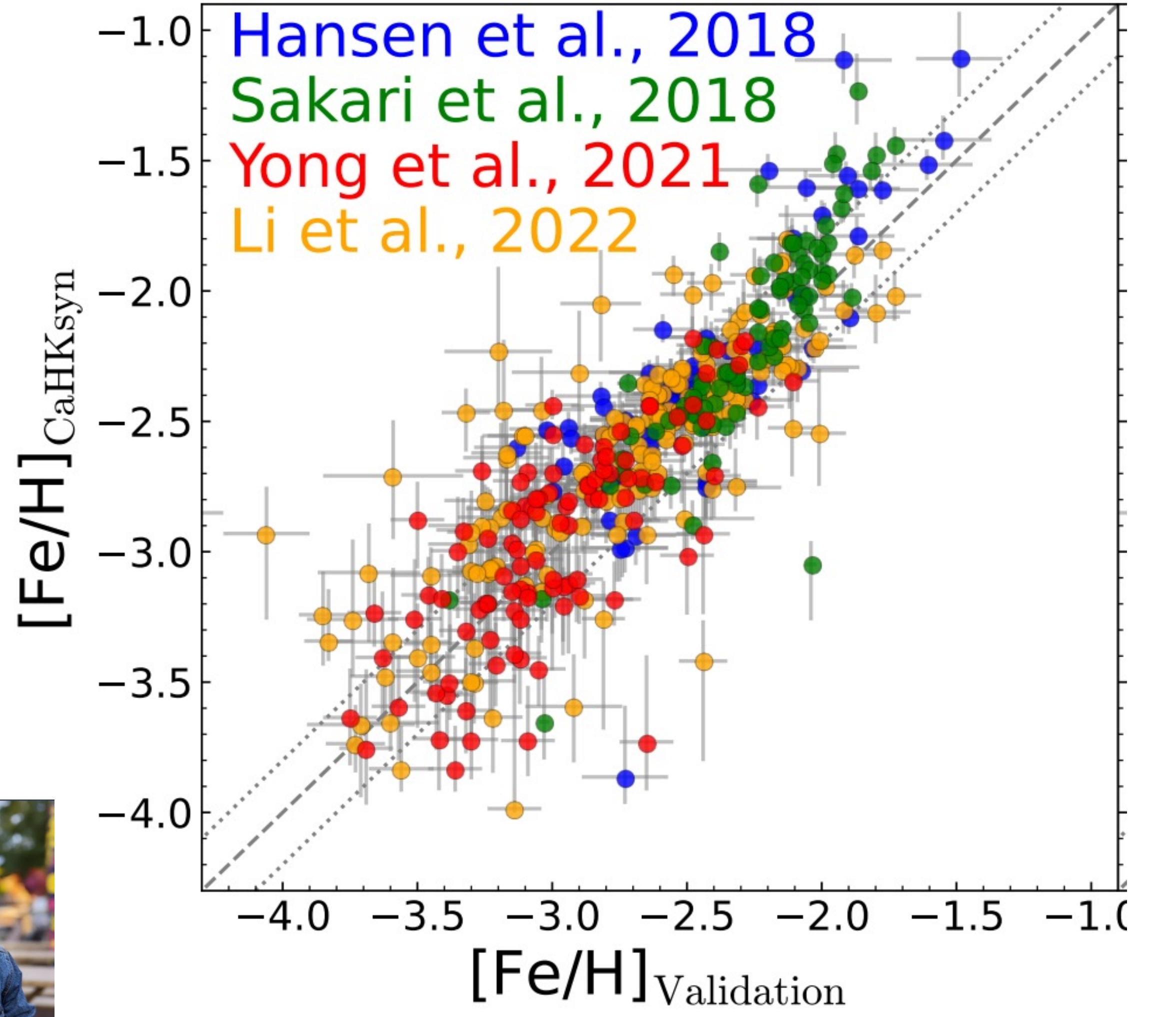
Works well until extremely low-metallicity regime

- Dataset (+ Pristine data) released Martin, Starkenburg et al., 2024

Our own follow-up

- Great success rates
    - 77% and 38% in finding stars with [Fe/H]<-2.5 and -3.0 (Viswanathan et al., 2024)

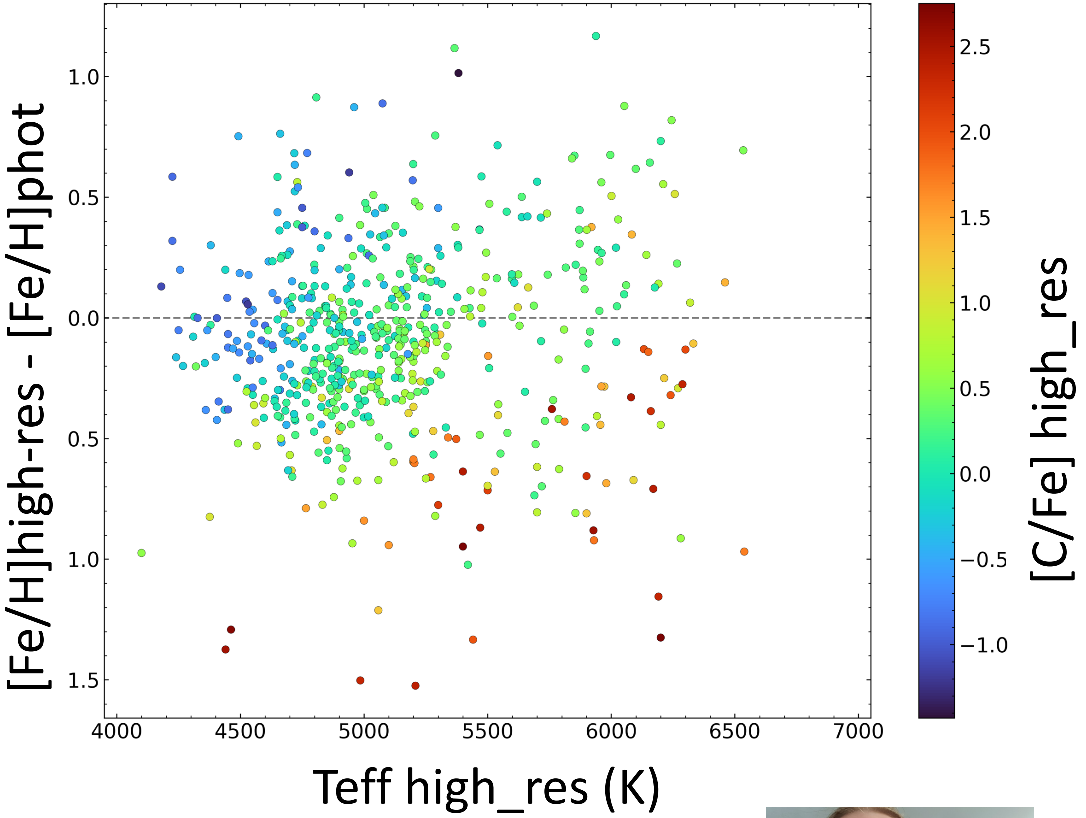
Martin, Starkenburg et al., 2024



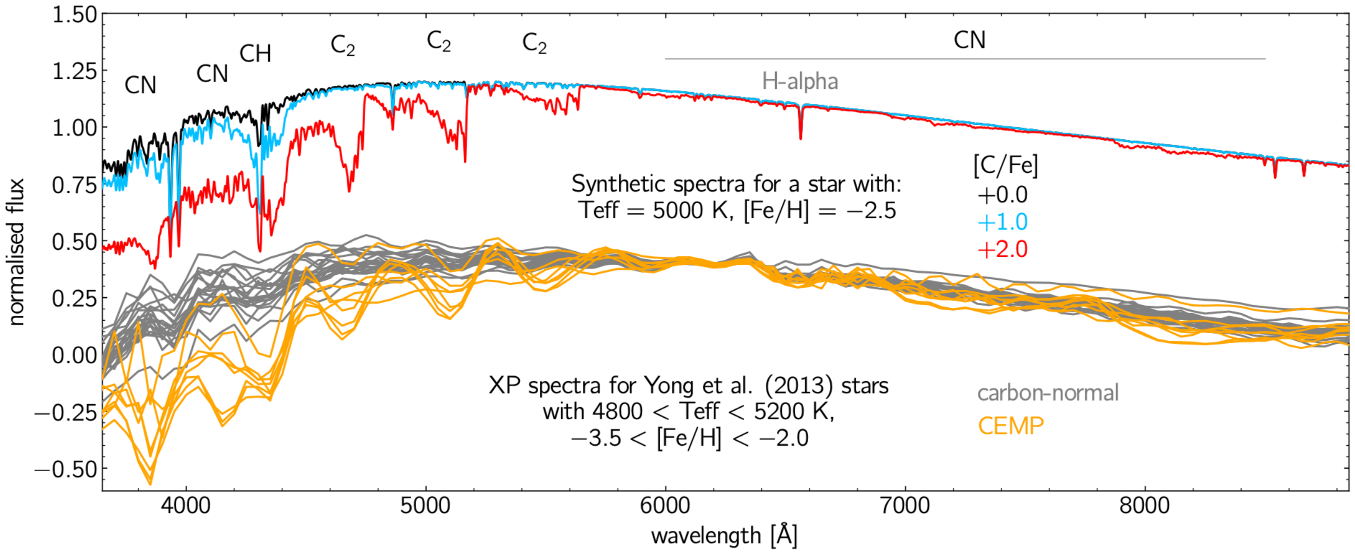
Akshara Viswanathan

What are we missing?

We know we are missing the most extreme carbon-rich and cool stars



- A more careful selection of targets is needed



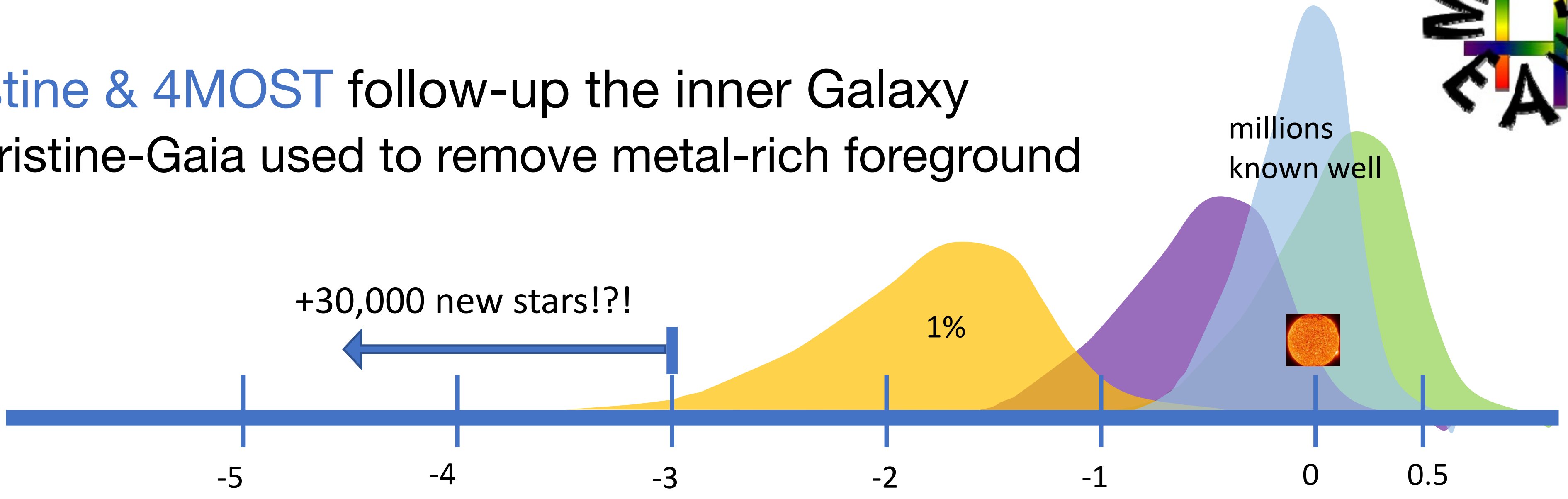
Credit: Martin Montelius

Ardern-Arentsen et al., 2024,
see also Lucey et al., 2023

Big leap straight ahead

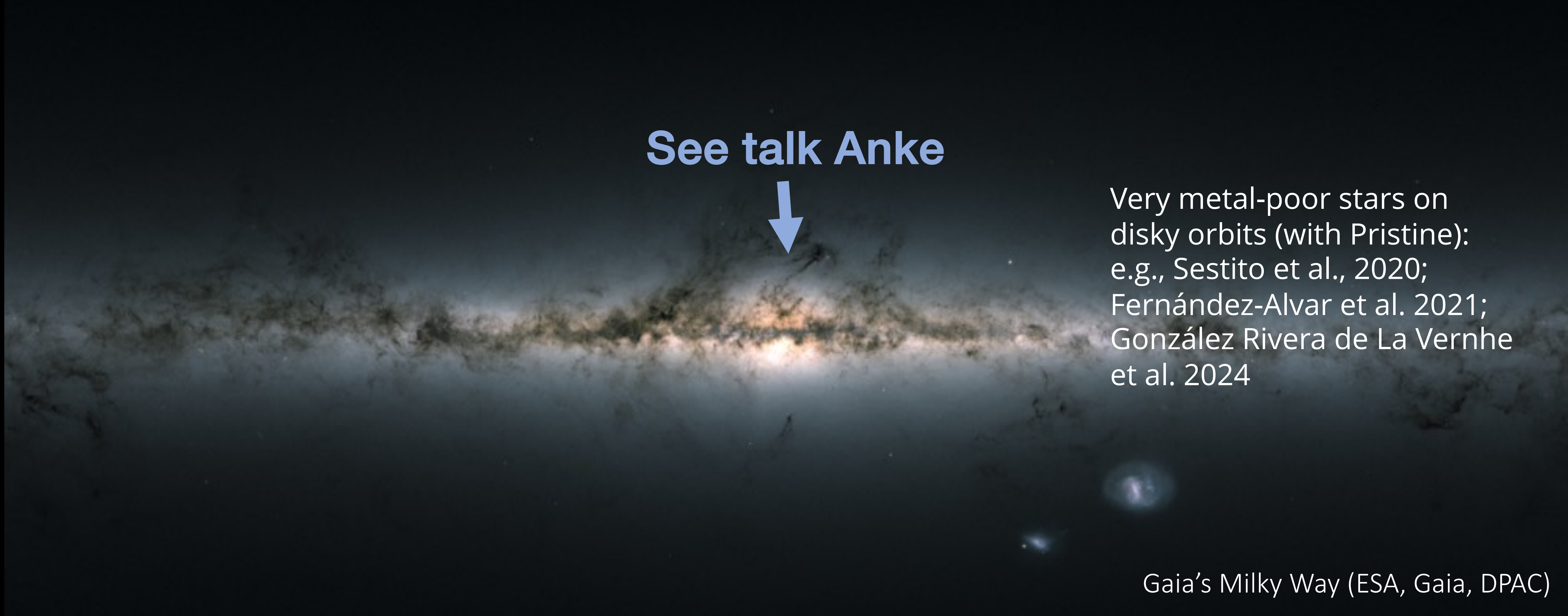
Metal-poor Targets

- Pristine & WEAVE agreement:
  - Spectroscopy for extremely metal-poor star candidates
  - Homogeneous study > 30,000 stars
    - Increase samples > 10-fold
- Pristine & 4MOST follow-up the inner Galaxy
  - Pristine-Gaia used to remove metal-rich foreground



The chemical history of the early Galaxy

The very early generations of stars across Galactic components



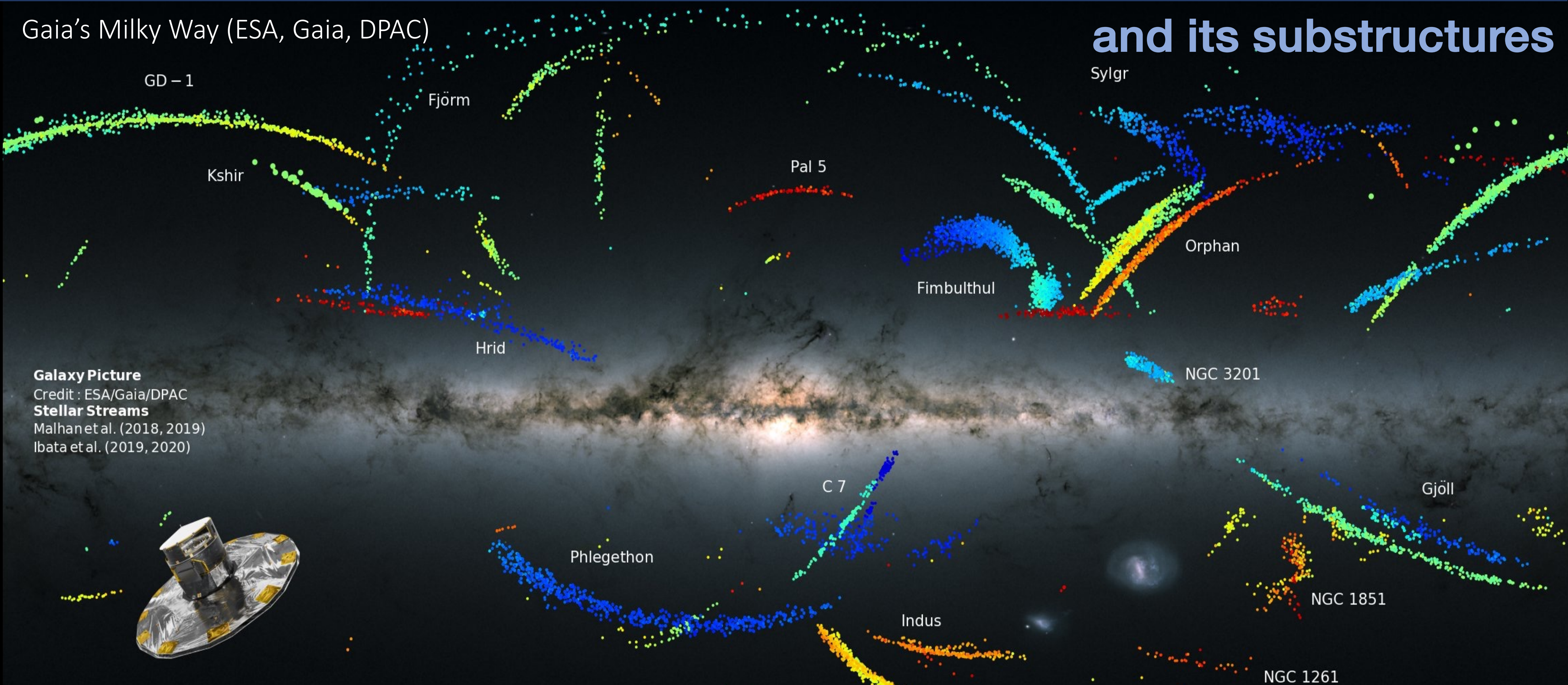
See talk Anke

Very metal-poor stars on disky orbits (with Pristine): e.g., Sestito et al., 2020; Fernández-Alvar et al. 2021; González Rivera de La Vernhe et al. 2024

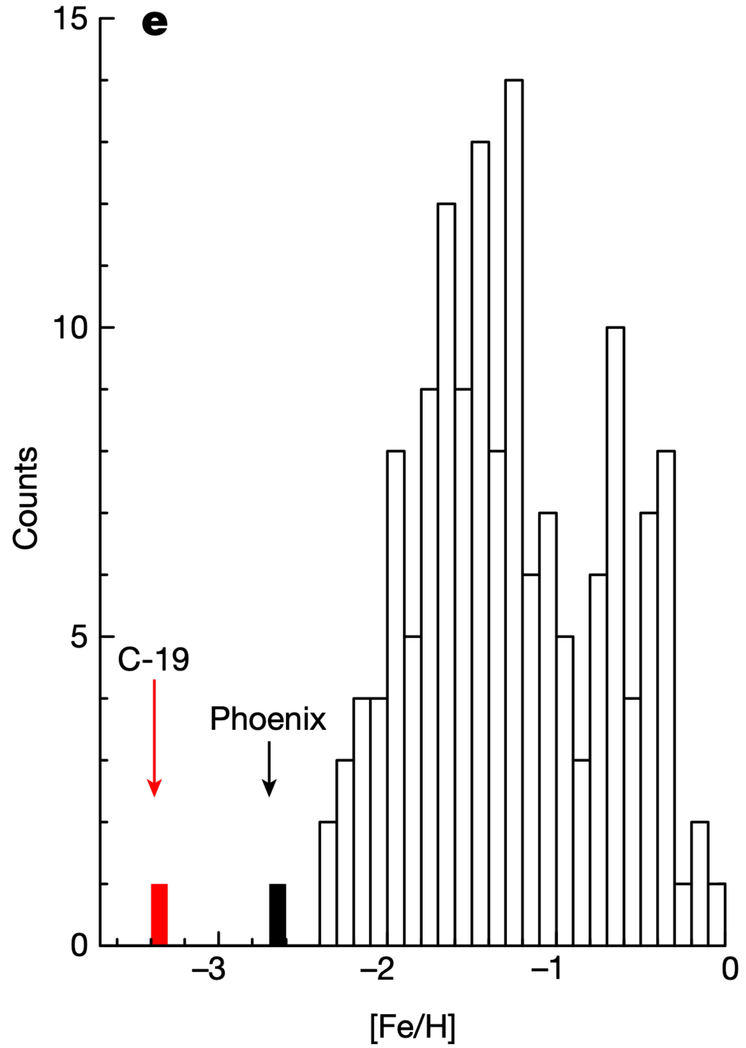
Gaia’s Milky Way (ESA, Gaia, DPAC)

The chemical history of the early Galaxy

and its substructures



Will we find more of these?



A stellar stream remnant of a globular cluster below the metallicity floor

Martin et al. (2022a, Nature 601, 45)

https://doi.org/10.1038/s41586-021-04162-2

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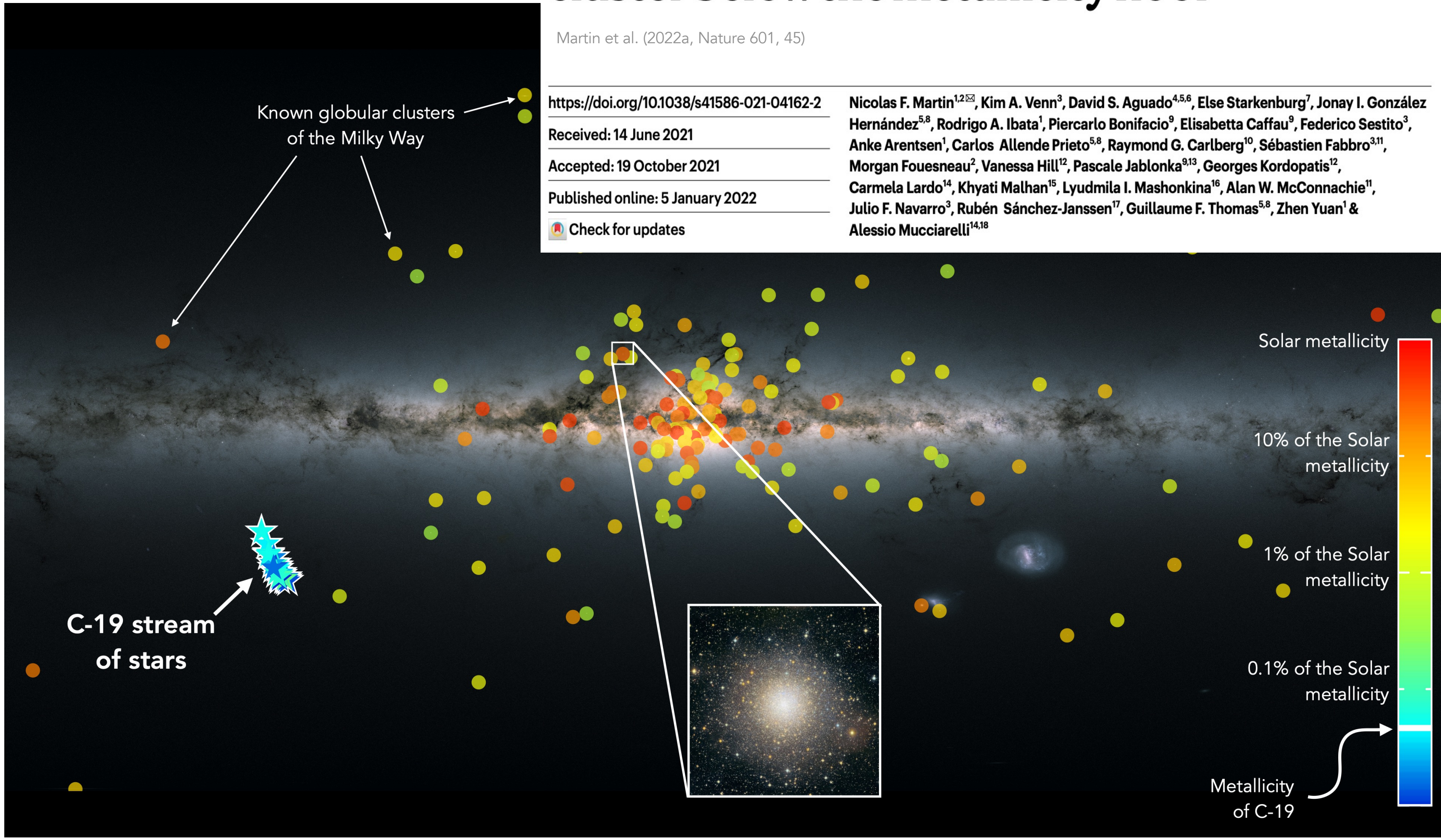
Check for updates

Nicolas F. Martin[1,2], Kim A. Venn[3], David S. Aguado[4,5,6], Else Starkenburg[7], Jonay I. González Hernández[5,8], Rodrigo A. Ibata[1], Piercarlo Bonifacio[9], Elisabetta Caffau[9], Federico Sestito[3], Anke Arentsen[1], Carlos Allende Prieto[5,8], Raymond G. Carlberg[10], Sébastien Fabbro[3,11], Morgan Fouesneau[2], Vanessa Hill[12], Pascale Jablonka[9,13], Georges Kordopatis[12], Carmela Lardo[14], Khyati Malhan[15], Lyudmila I. Mashonkina[16], Alan W. McConnachie[11], Julio F. Navarro[3], Rubén Sánchez-Janssen[17], Guillaume F. Thomas[5,8], Zhen Yuan[1] & Alessio Mucciarelli[14,18]

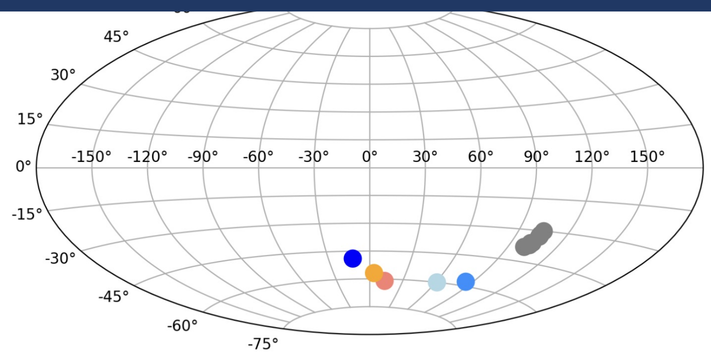


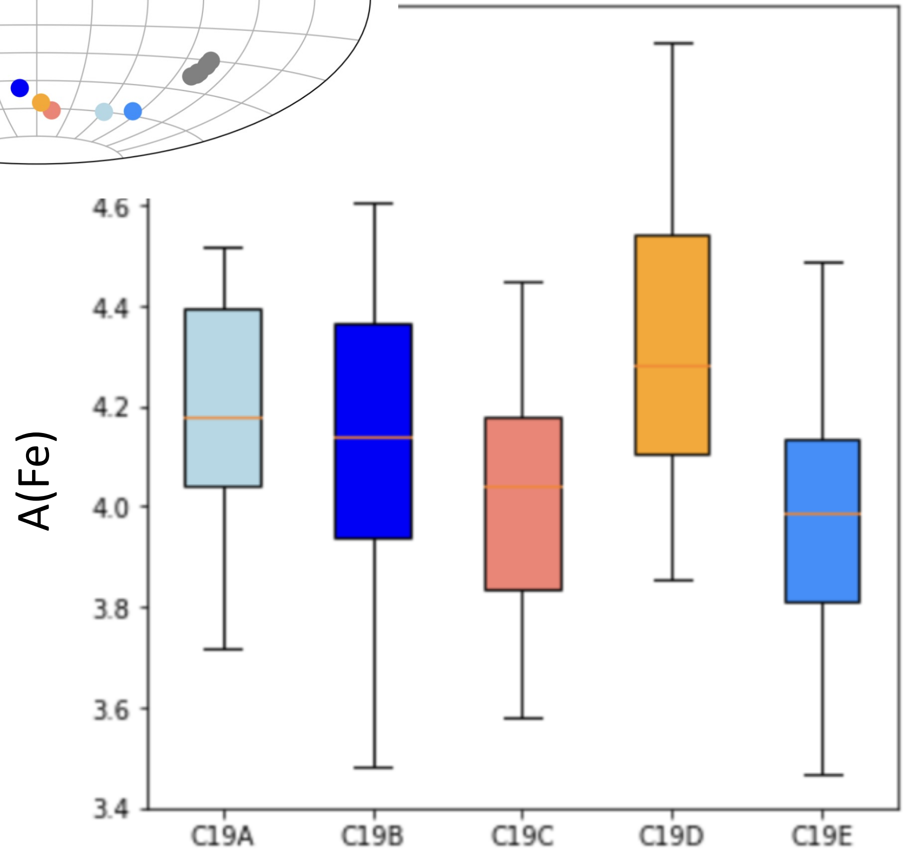
Martin, Venn, Aguado, Starkenburg et al., 2022

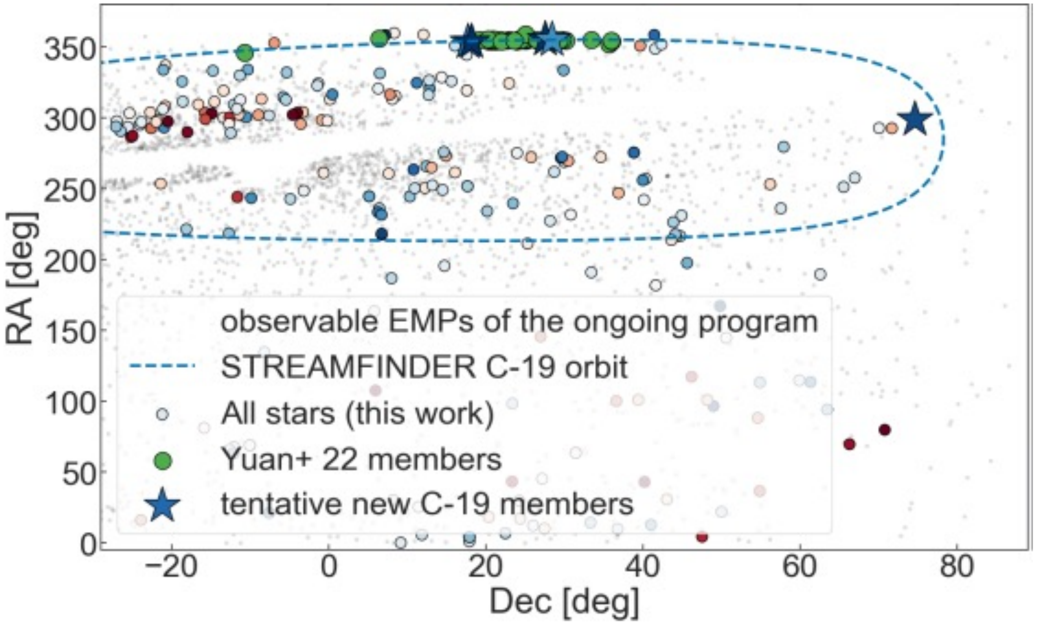
Will we find more of these?

C-19 is consistent with one metallicity

- We find more and more members further from the body of the stream



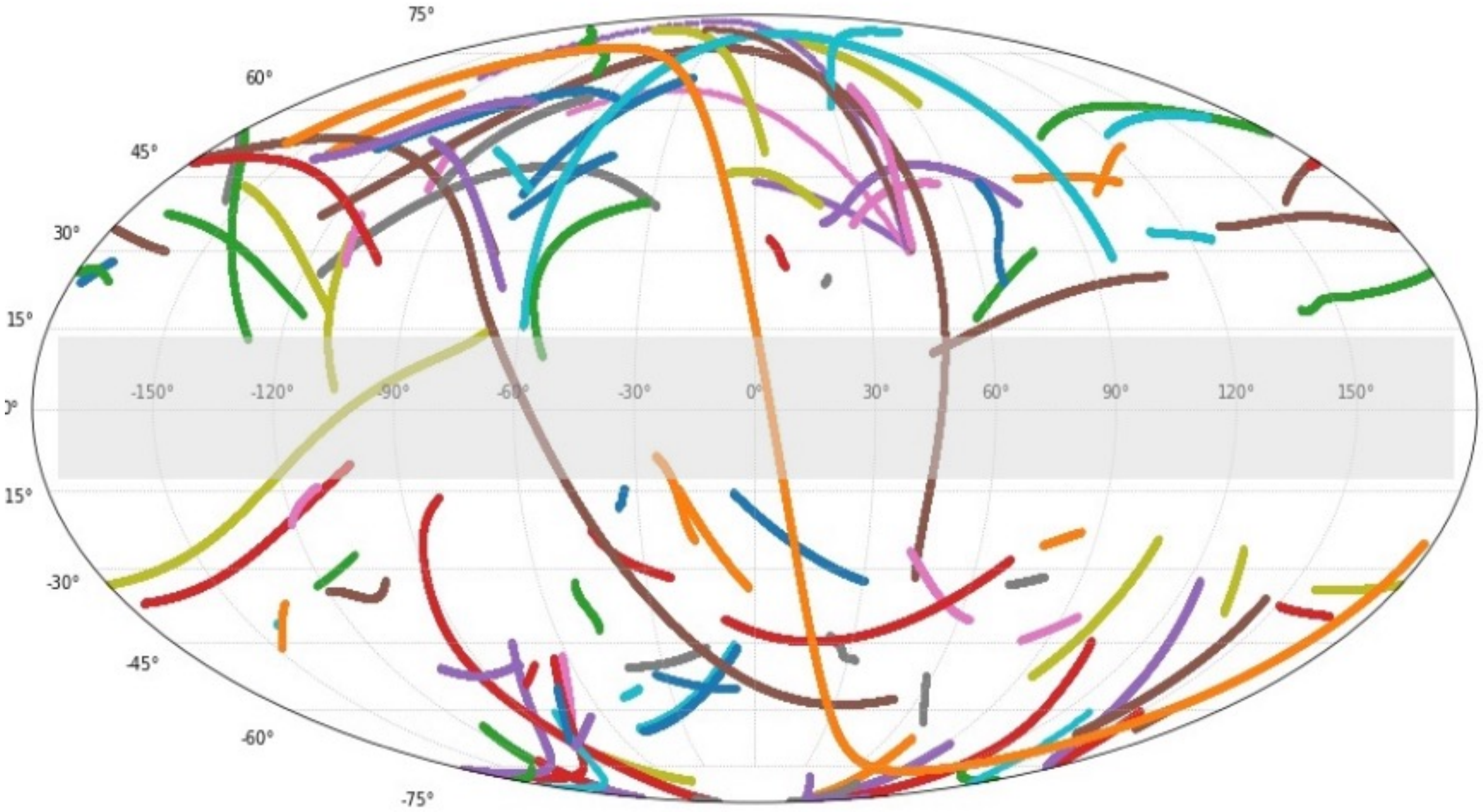


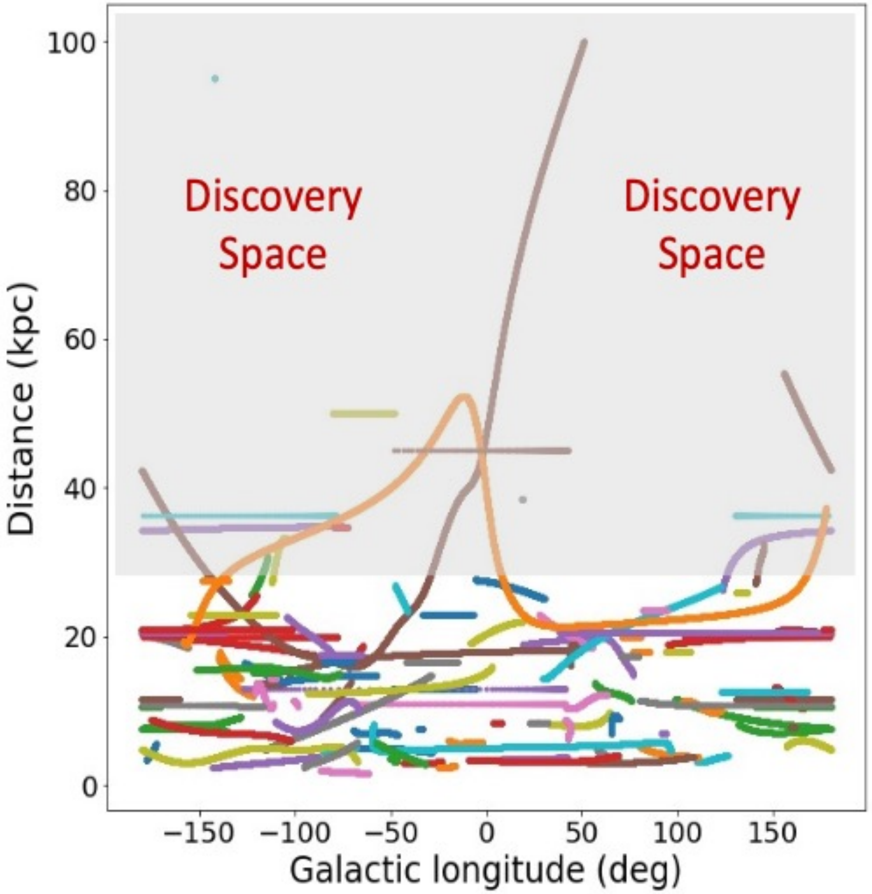


Viswanathan et al., 2024, also Yuan et al., 2022

Venn et al., in prep.

How far out can we go?



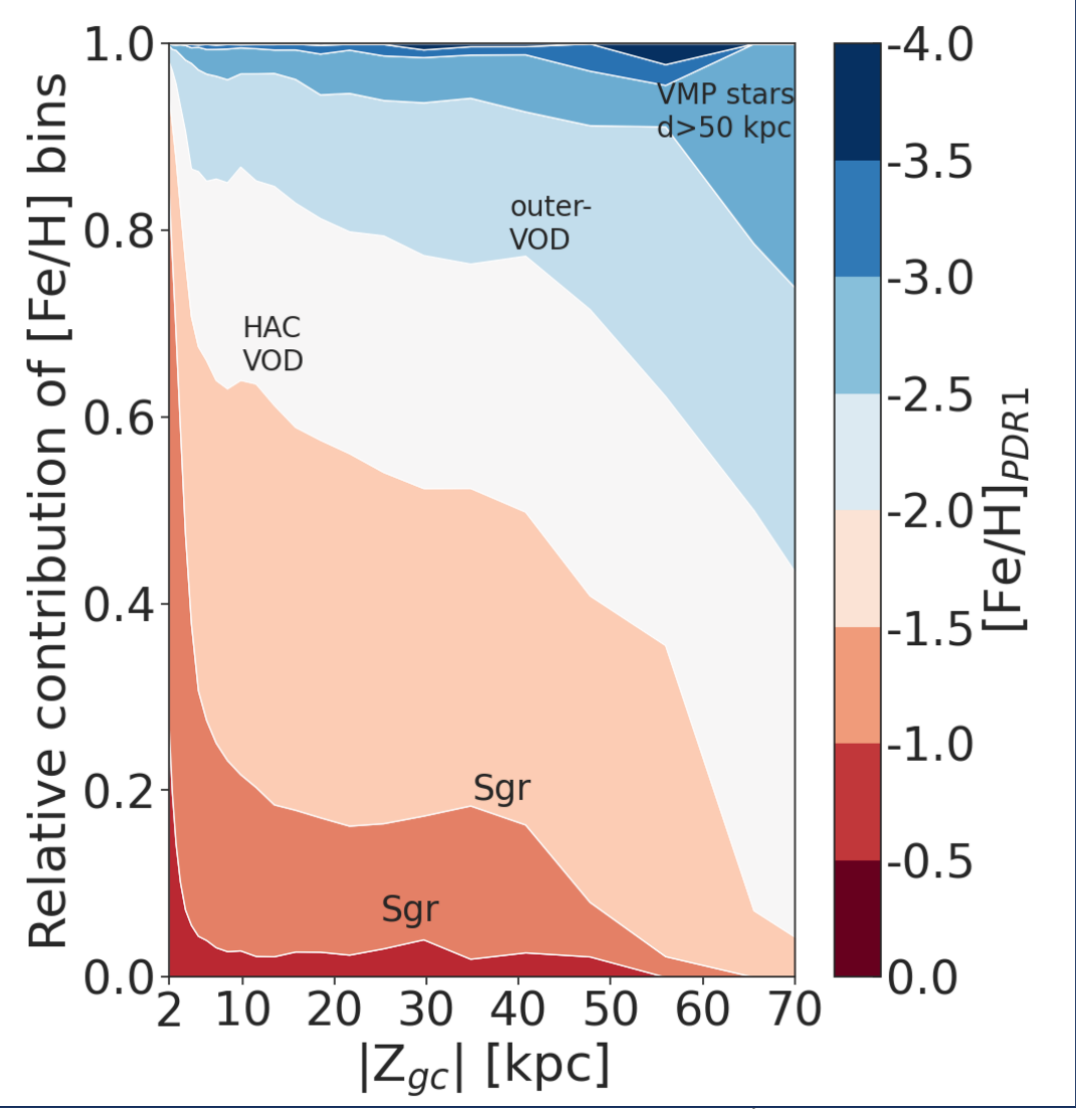


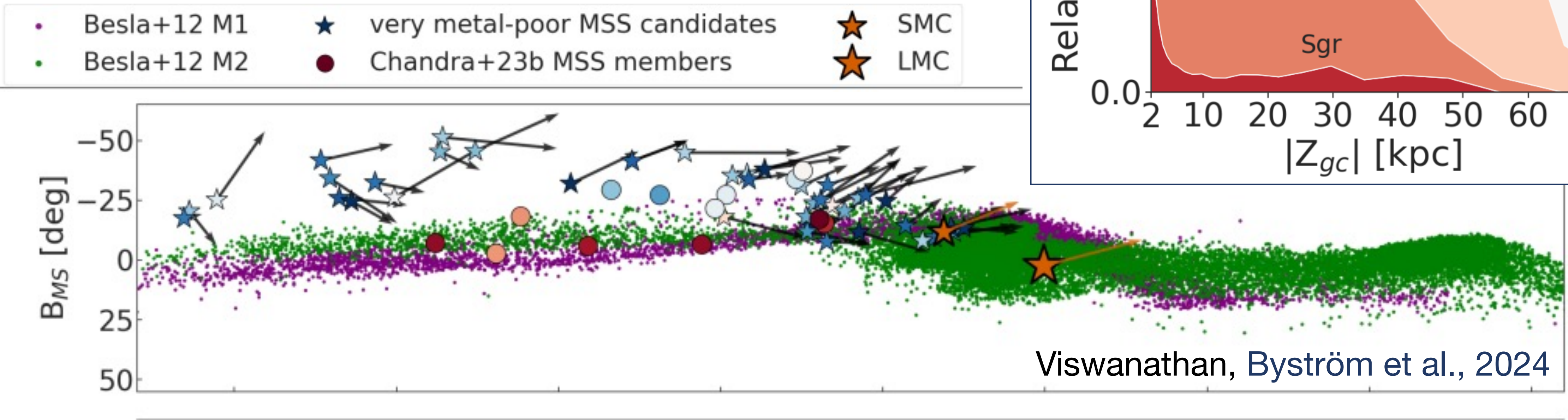
From galstreams package, Mateu, 2023

Outer Galaxy

Using red giants to trace the outer halo

- Viswanathan, Byström et al., 2024



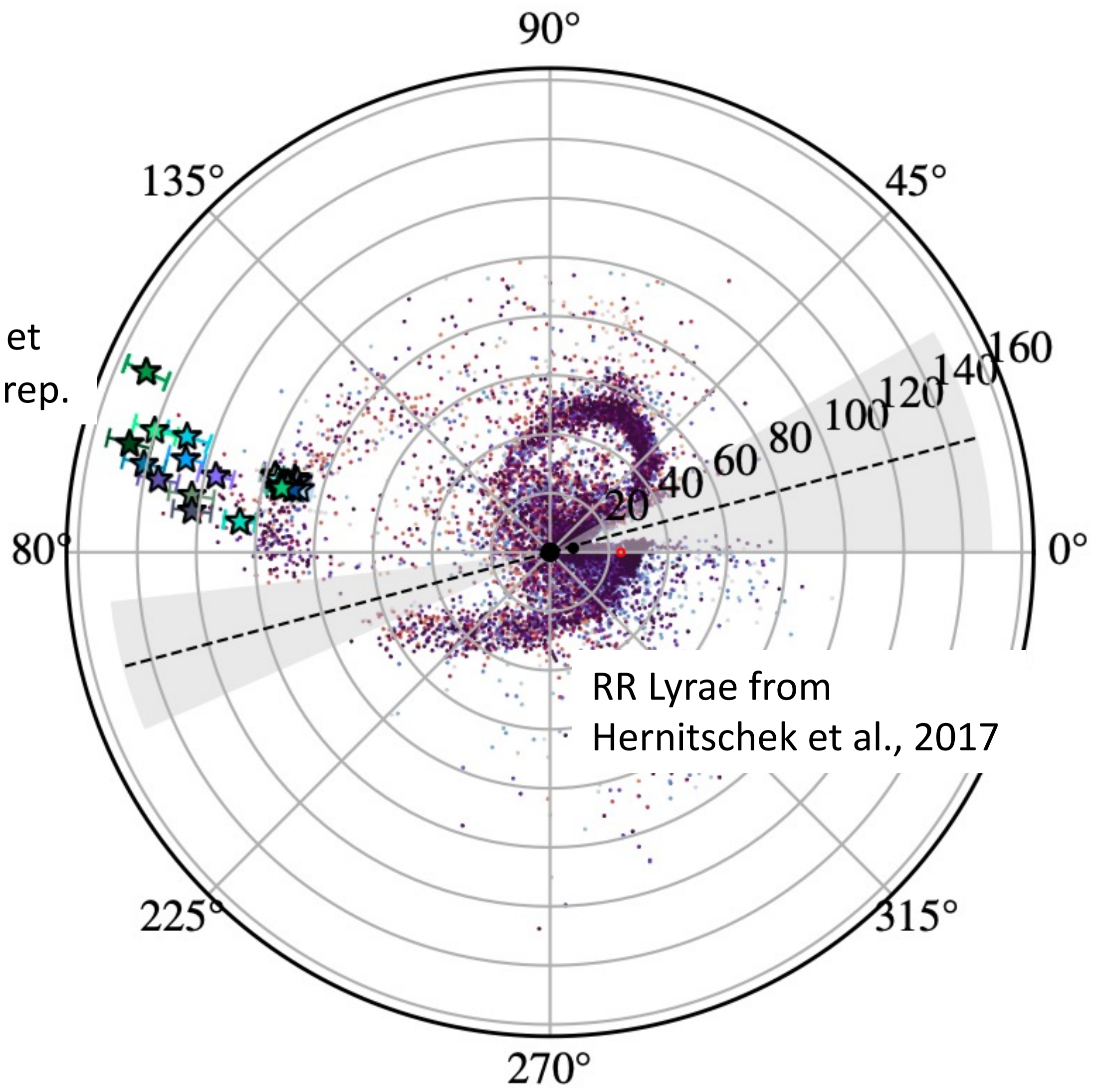


Viswanathan, Byström et al., 2024

Additional serendipitous science

Using blue horizontal branch stars to trace the outer halo through the most distant Sagittarius debris

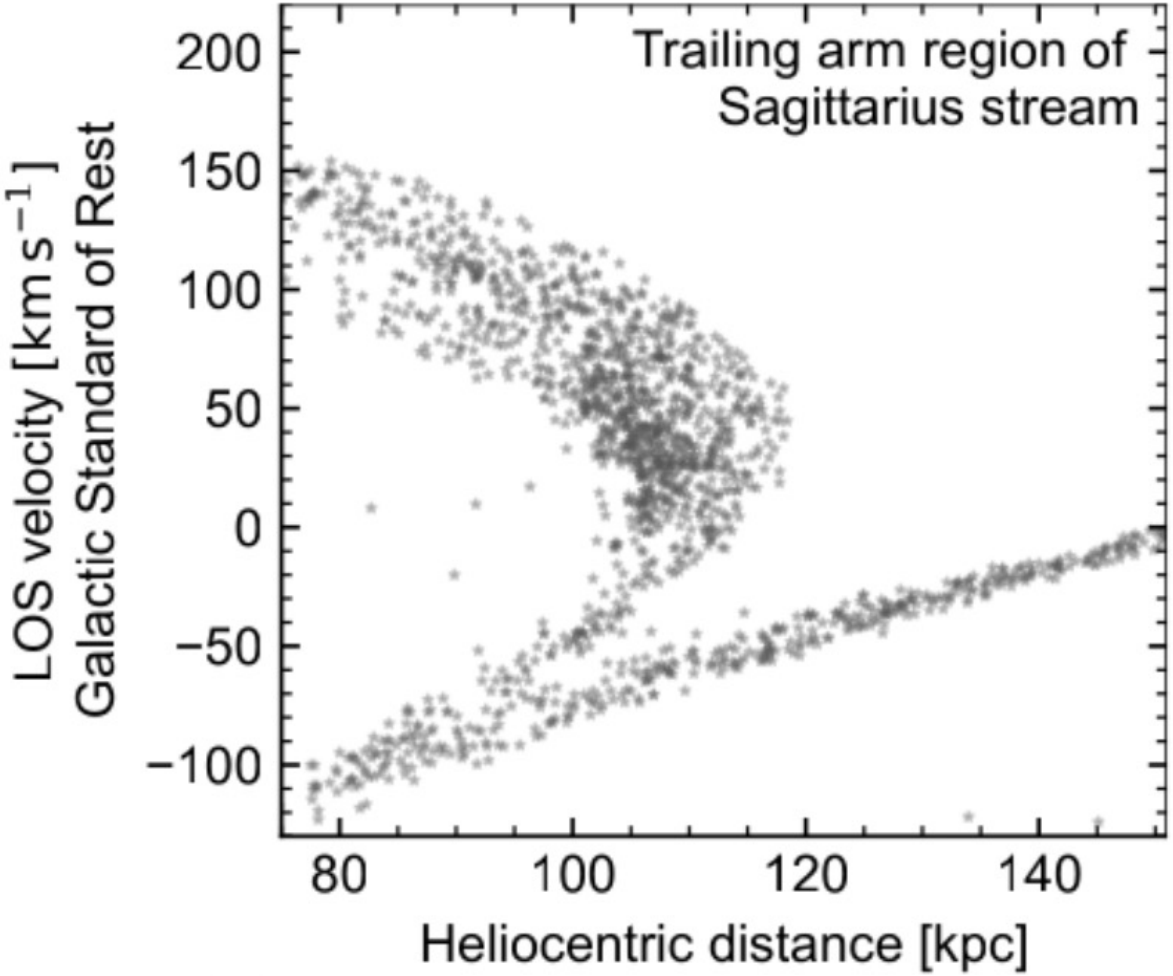
- Bayer, Starkenburg, Thomas et al., in prep.



Serendipitous standard candles

Using blue horizontal branch stars to trace the outer halo through the most distant Sagittarius debris

- Bayer, Starkenburg, Thomas et al., in prep.



Model predictions from Dierickx and Loeb (2017)

Serendipitous standard candles

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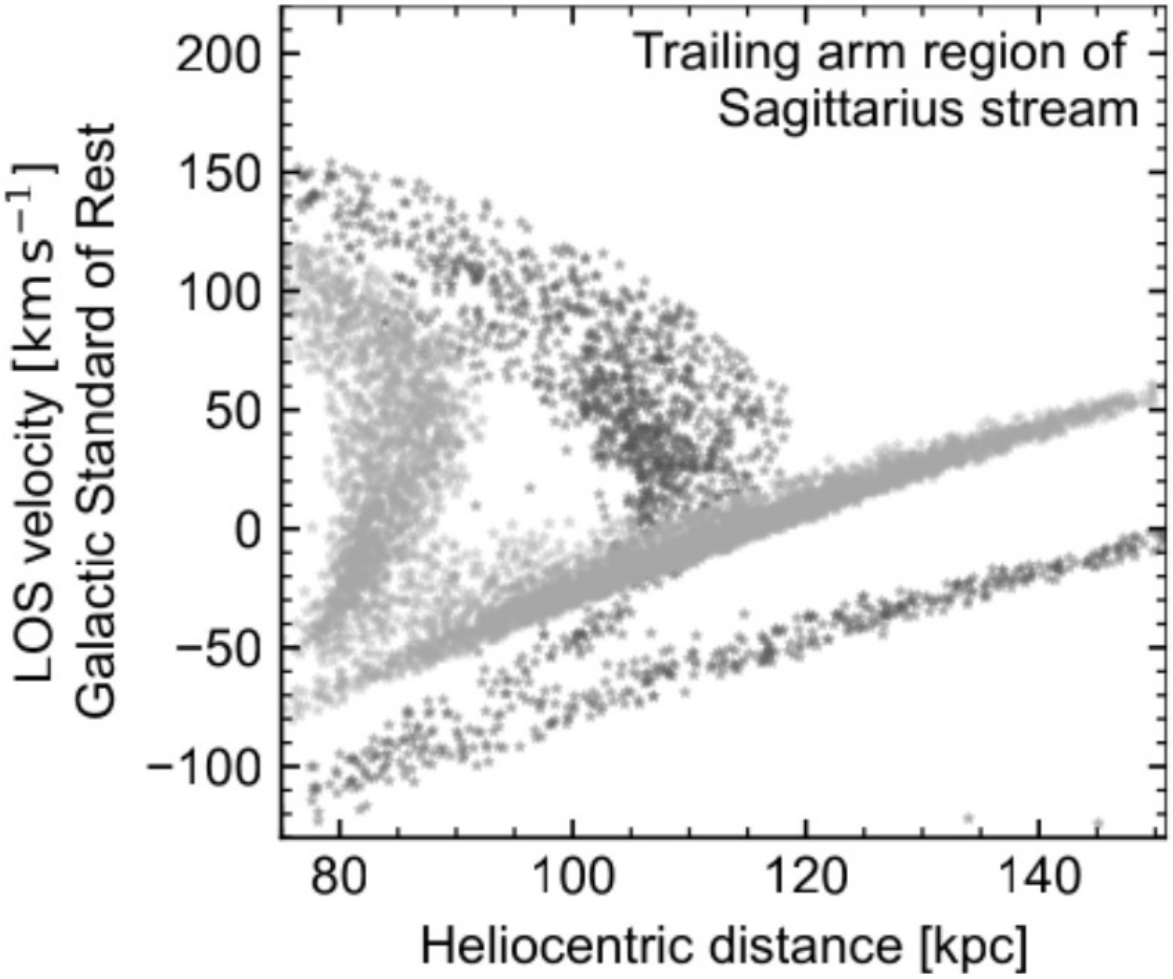
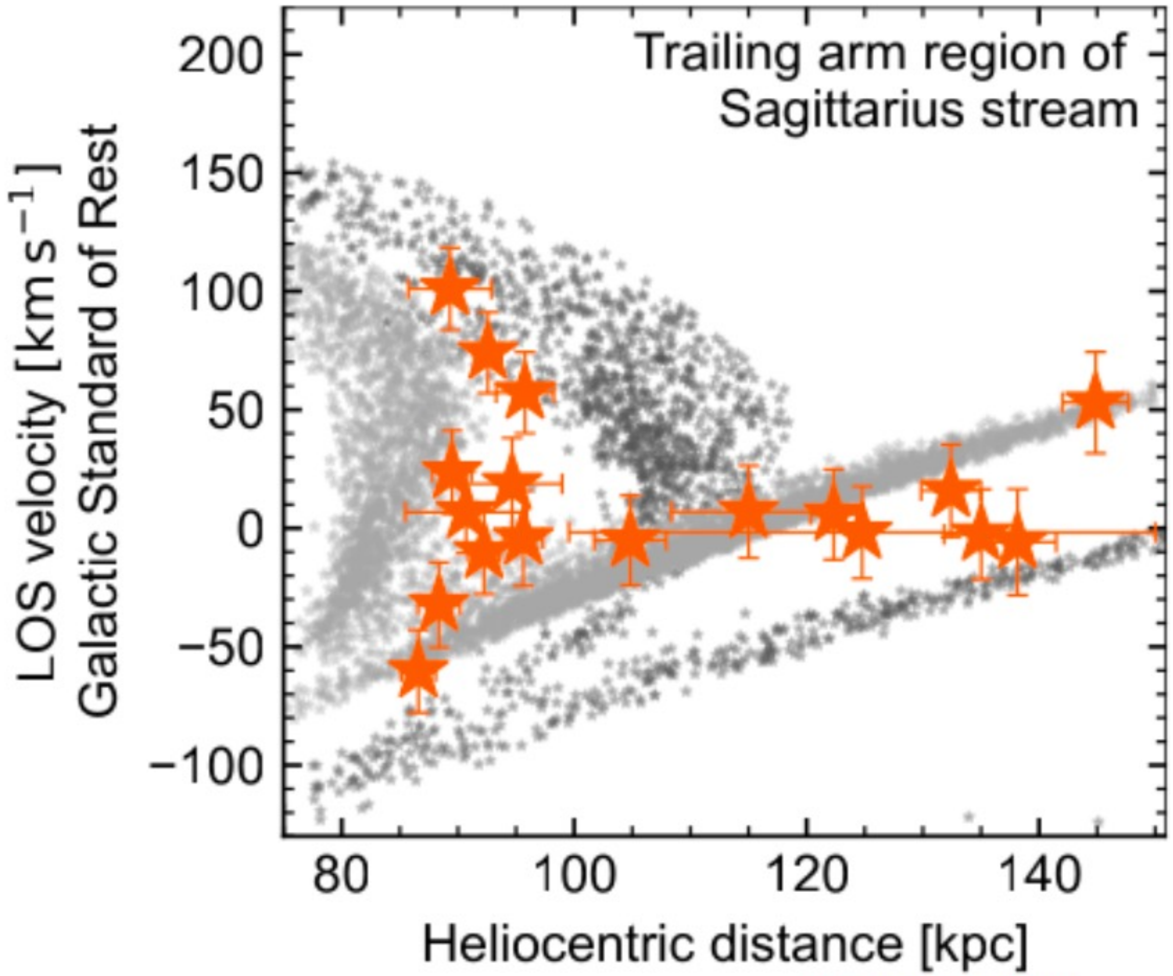


Model predictions from Dierickx and Loeb (2017) & Vasiliev et al., (2021)

Serendipitous standard candles

Using blue horizontal branch stars to trace the outer halo through the most distant Sagittarius debris



- Bayer, Starkenburg, Thomas et al., in prep.

Getting ready for the future…
to better study the past

Finding these rare stars

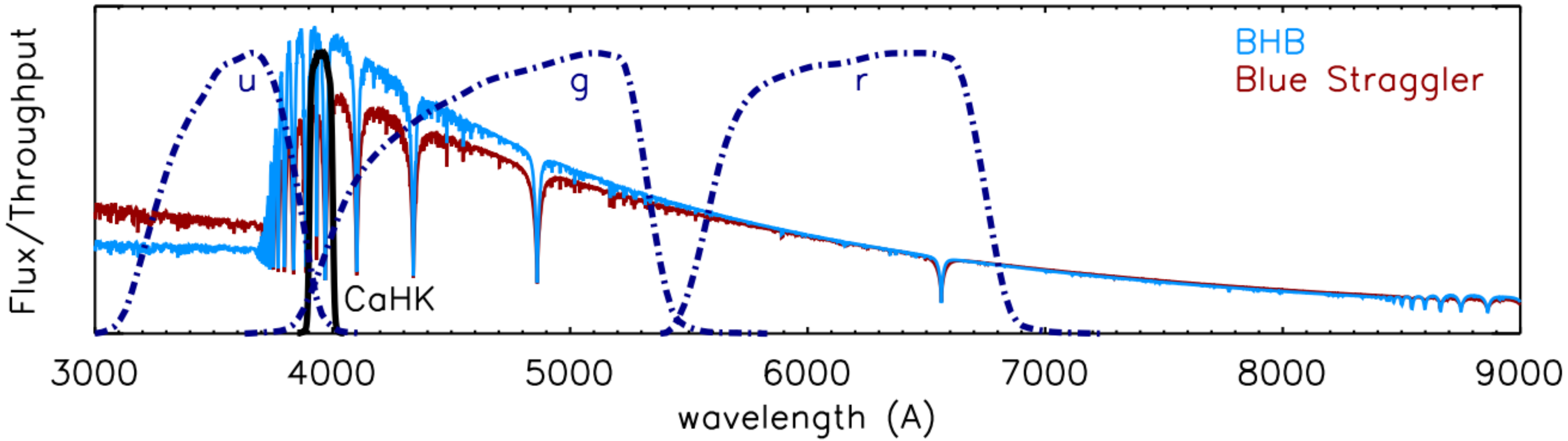
- Candidate selection
- Follow-up with WEAVE and 4MOST

Interesting physics at the metal-poor (& far) end

- Special supernovae
- Early Milky Way build-up to the outer halo
- The earliest Globular clusters?

Serendipitous science: Blue Horizontal Branch stars

- Select A-stars, but disentangle AGN, blue stragglers, main-sequence …
  - .. and genuine blue horizontal branch stars



Starkenburg et al., 2019