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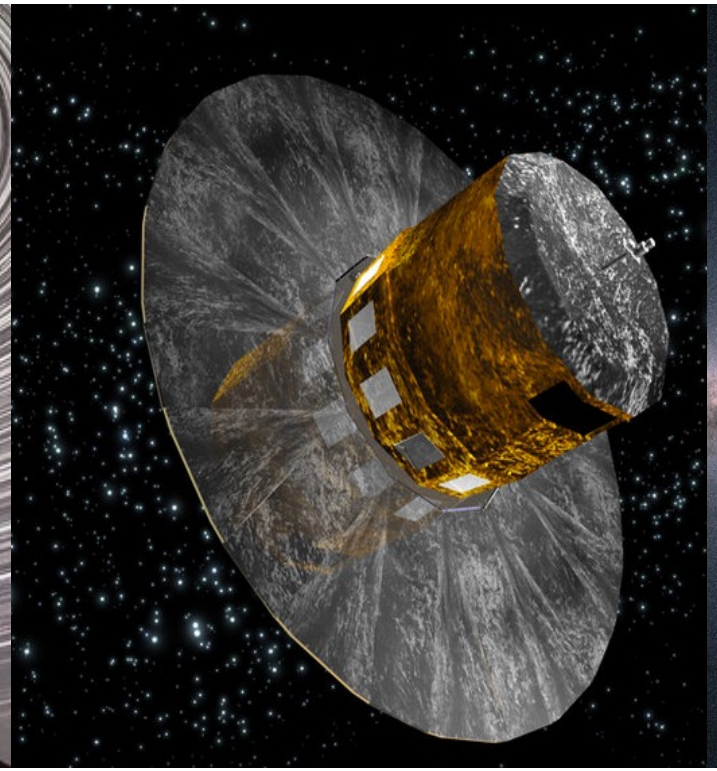
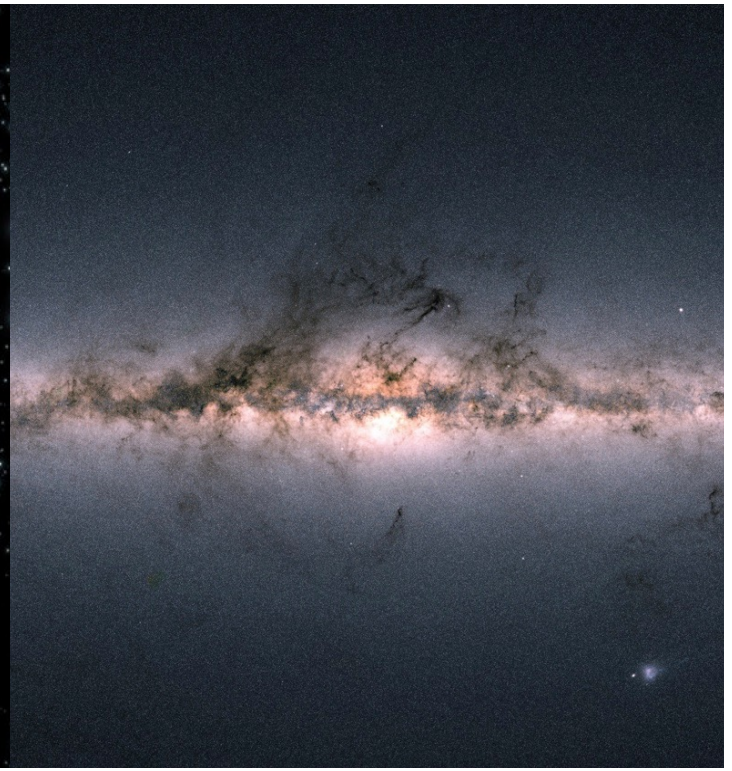
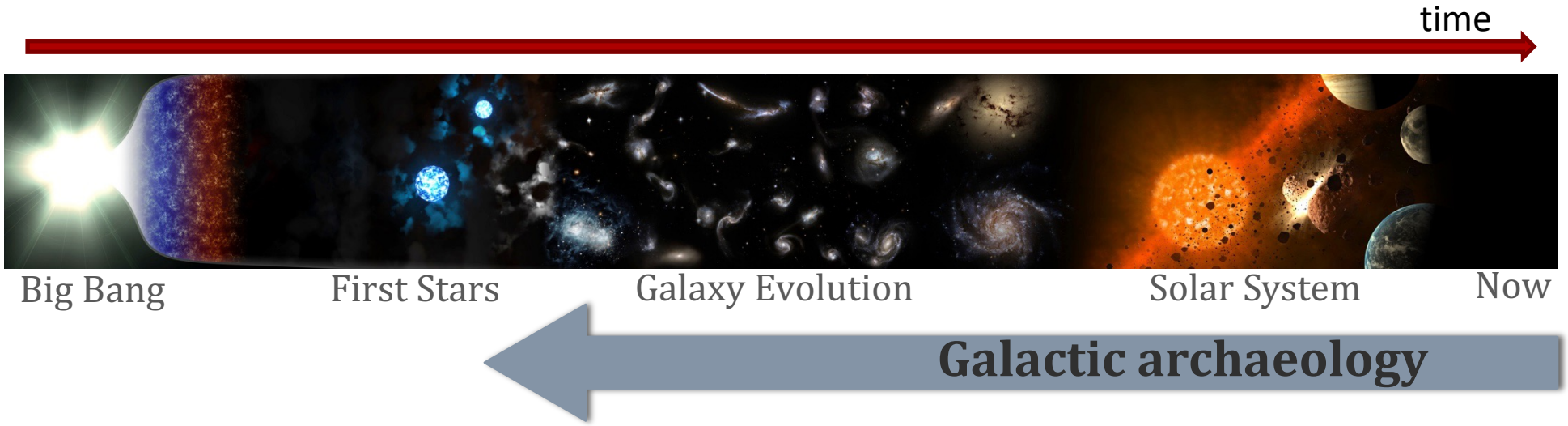
RISTINE

Galactic Archaeology to its limits - with Gaia (NIR)

Else Starkenburg

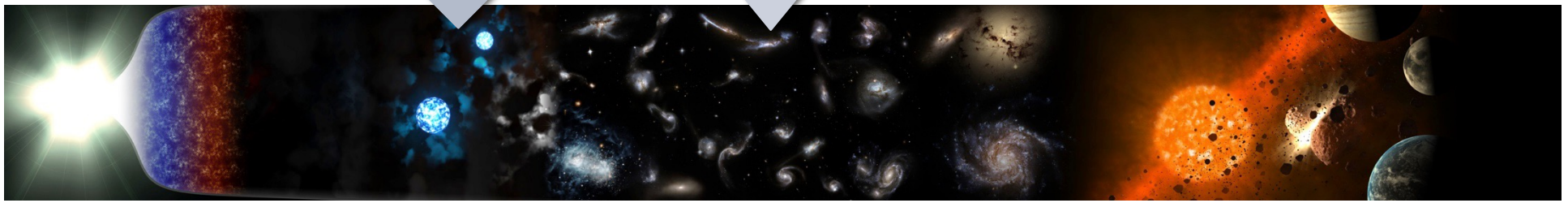
Looking at the early Milky Way using stars



Study the build-up of the Milky Way galaxy

Find and research first generations of stars

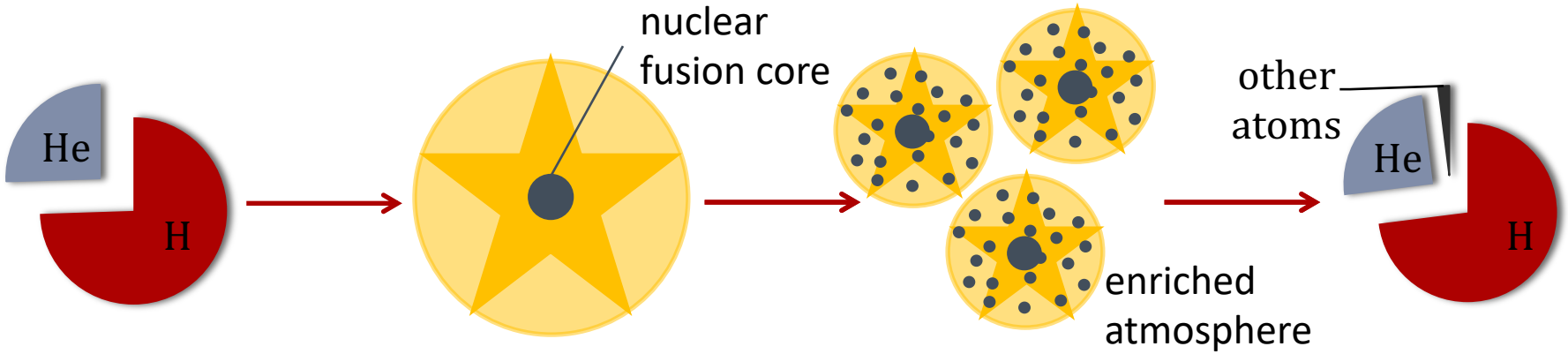
time



Big Bang | First Stars | Galaxy Evolution | Solar System | Now

Limit

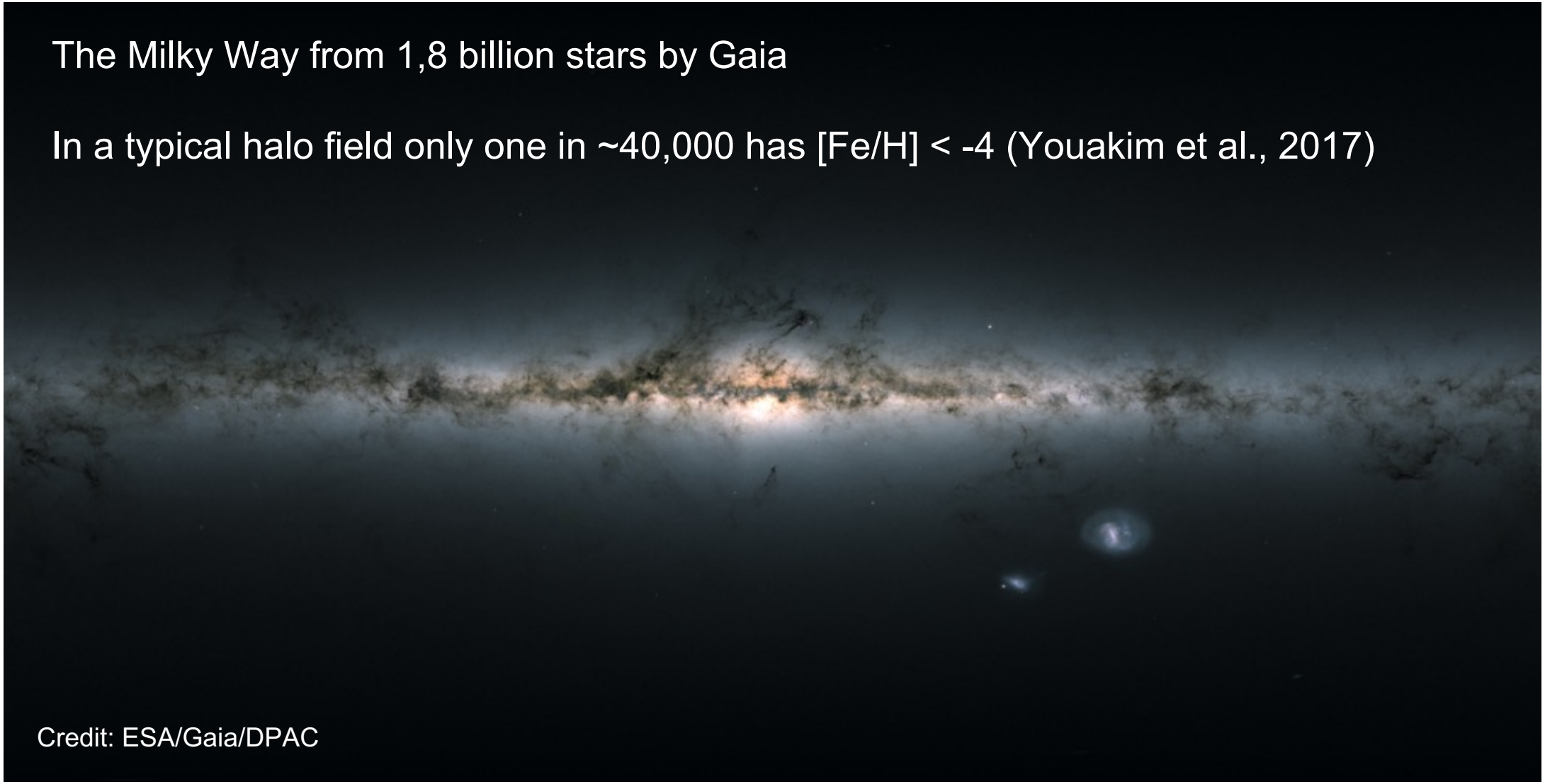
Galactic archaeology



These stars are rare

The Milky Way from 1,8 billion stars by Gaia

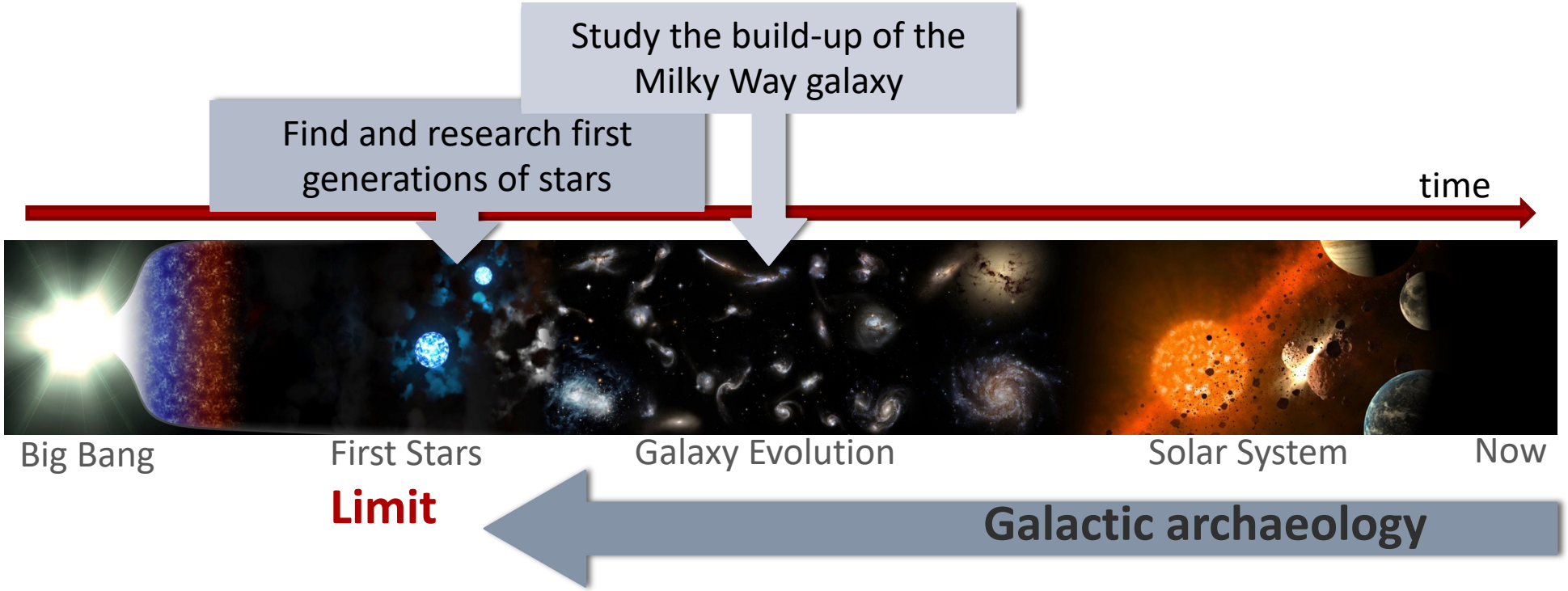
In a typical halo field only one in ~40,000 has [Fe/H] < -4 (Youakim et al., 2017)



Credit: ESA/Gaia/DPAC

This talk

- How do we discover these stars (now)
- What have we learned from their follow-up
  - Surprises in all Galactic environments!
  - A very large role for Gaia
- What is there still to come…
- What are the prospects and challenges (I see) for Gaia NIR in the future



Finding the rare, most metal-poor stars

Pre-selection, for instance:

- The **Pristine** survey
- **Gaia** BPRP spectra

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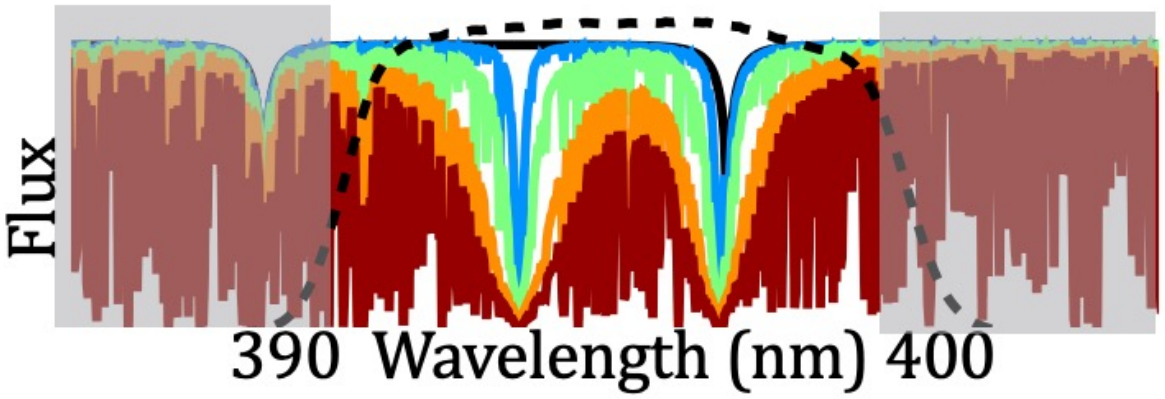
The Pristine survey

PRISTINE

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)

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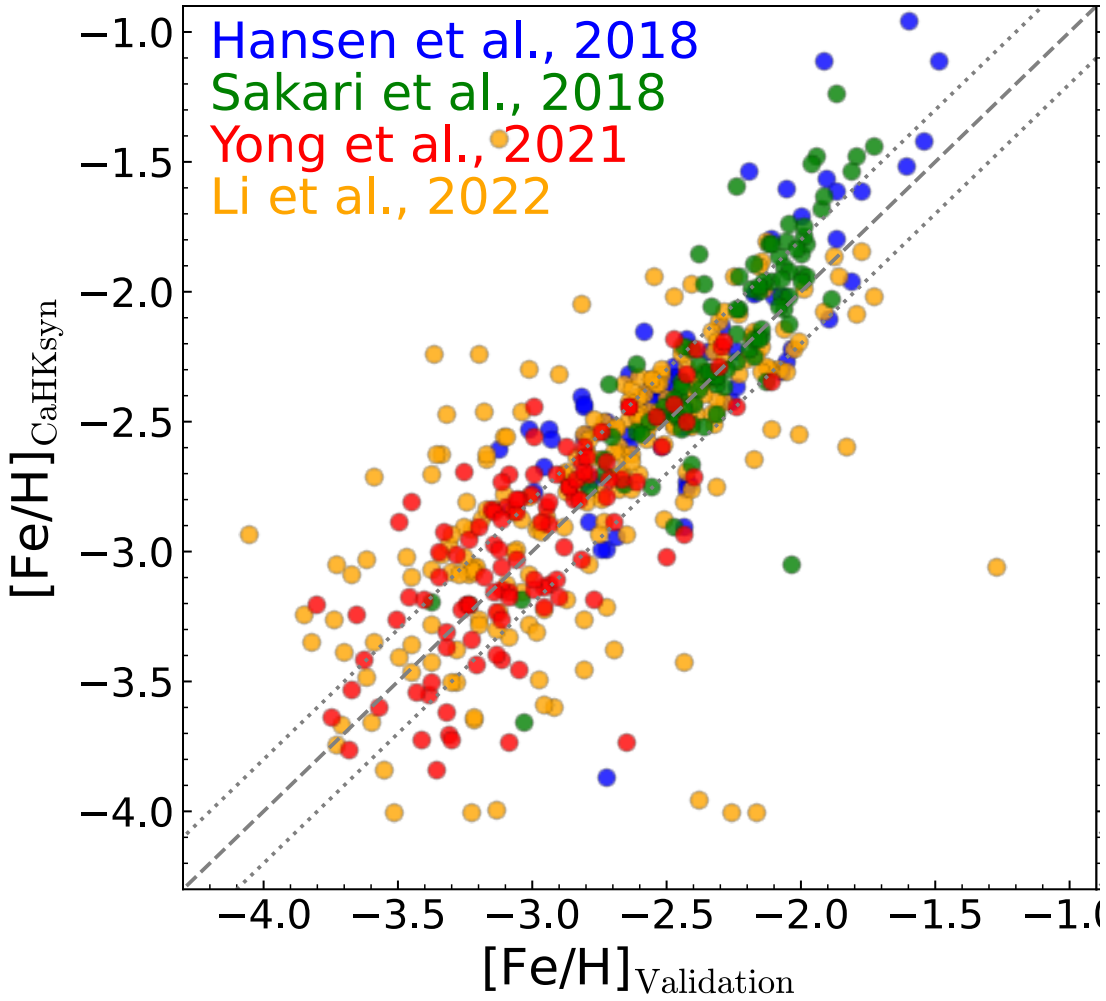
Taking the next step

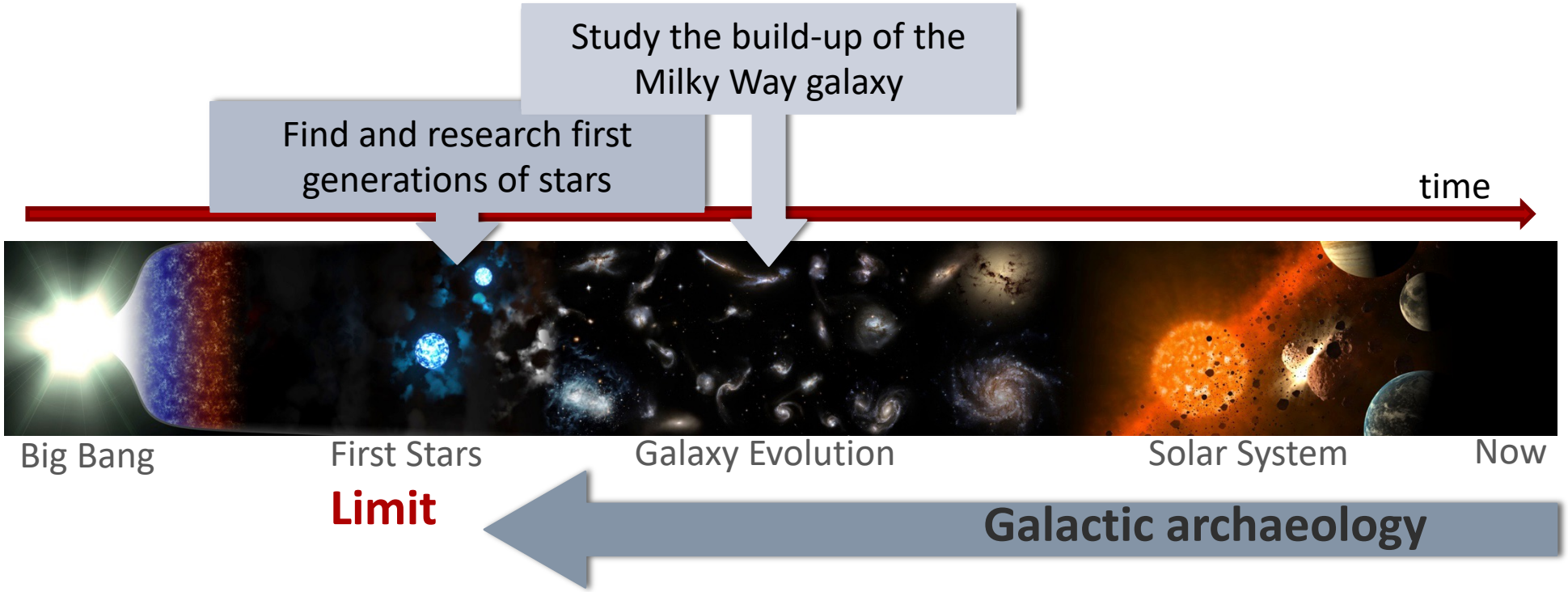
Martin, Starkenburg et al., in prep.

Applying our method to Gaia spectrophotometry from BP/RP

- Less deep …
  - … but all-sky

- Input catalogues for upcoming highly-multiplexed spectrographs
  - WEAVE (low-res + high-res)
  - 4MOST halo & bulge surveys





Finding the rare, most metal-poor stars

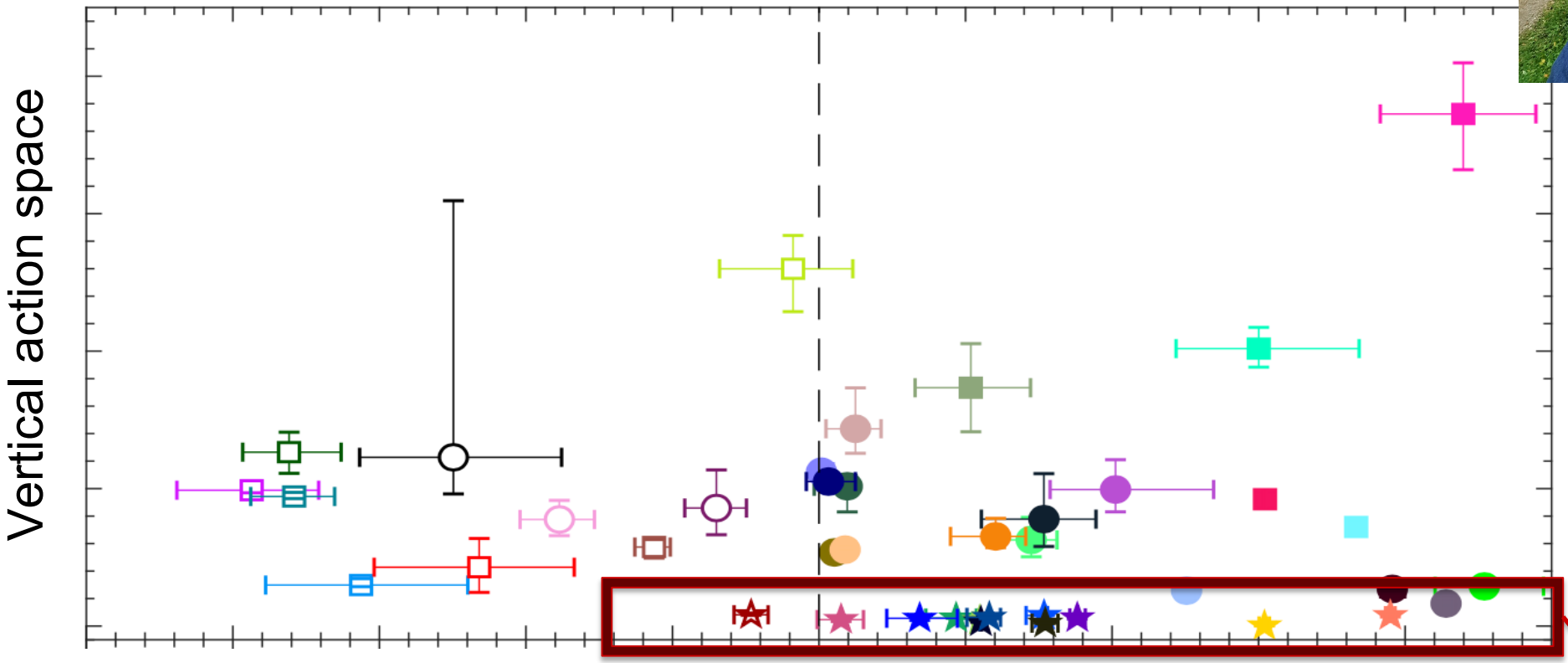
- The **Pristine** survey
- **Gaia** BPRP spectra

Distribution & kinematics

- **Gaia**
- Spectroscopy

Federico Sestito

Orbits of [Fe/H] < -4 stars



Sestito et al., 2019

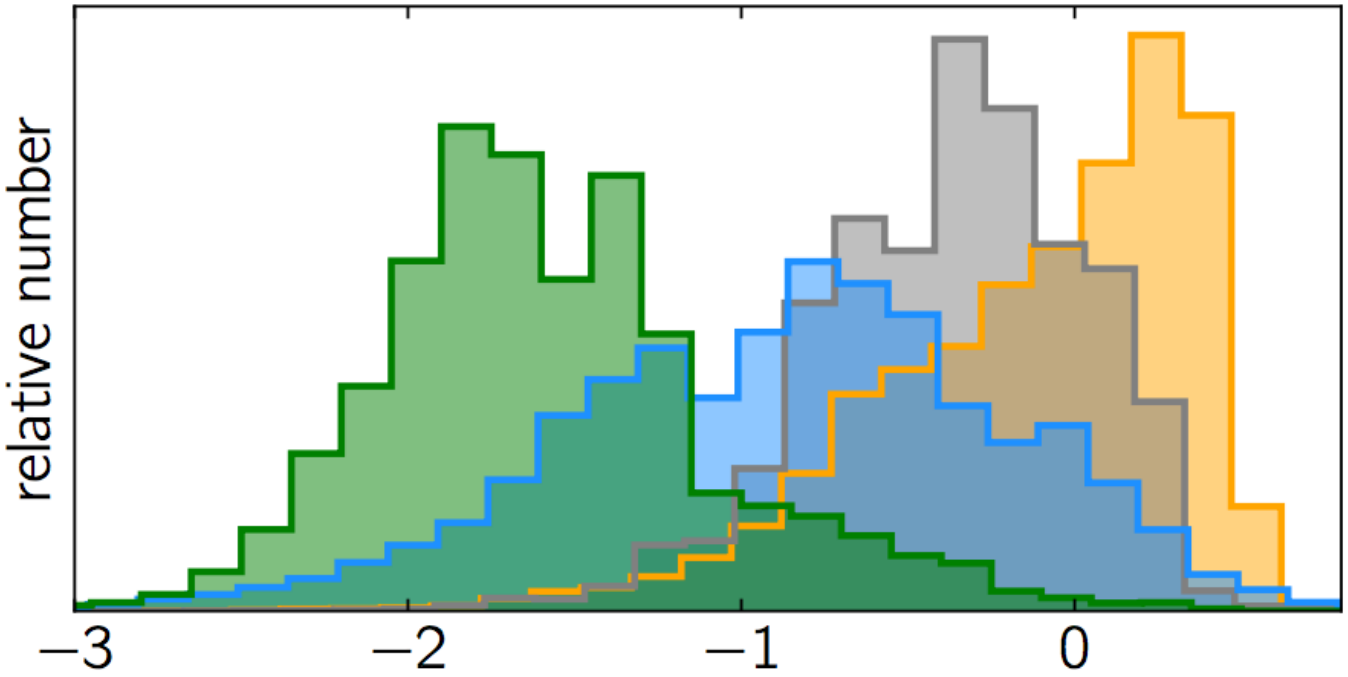
Orbiting in the disk plane!

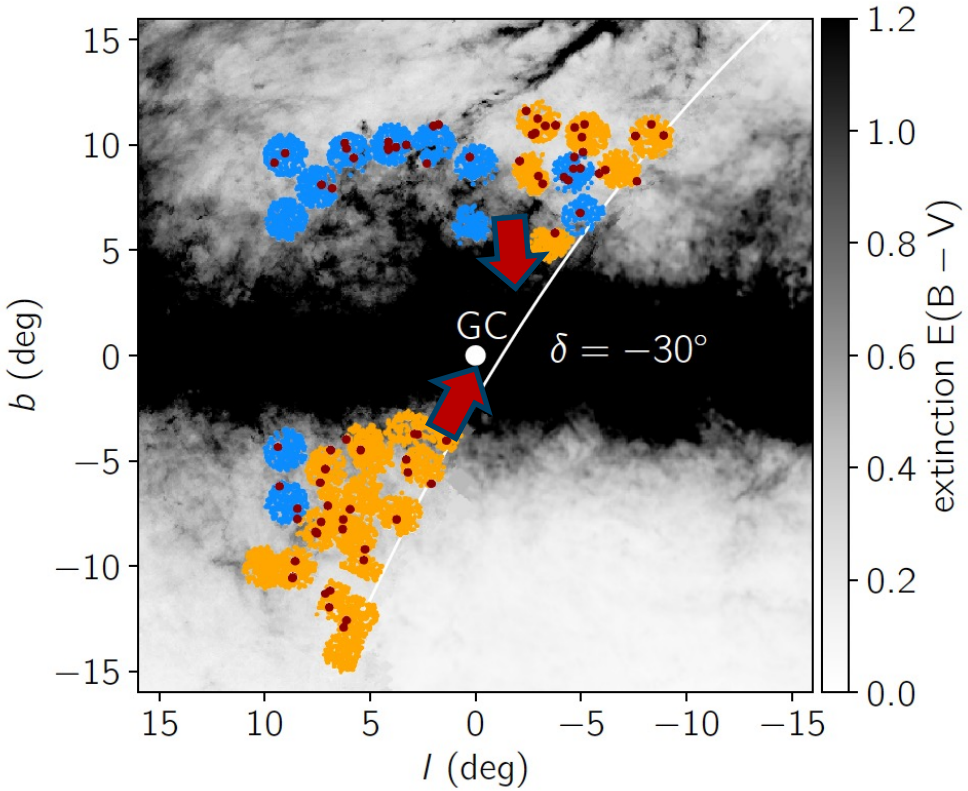
Qualitatively, we do see this in simulations

Sestito, Buck, Starkenburg, Martin et al., 2021, similar results in Santistevan et al., 2021

The inner Milky Way

- Pristine Inner Galaxy Survey (PIGS):
  - Sample of ~1300 stars with [Fe/H] < -2.0 in this region
    - 9 with [Fe/H] < -3.0
    - More than doubling literature





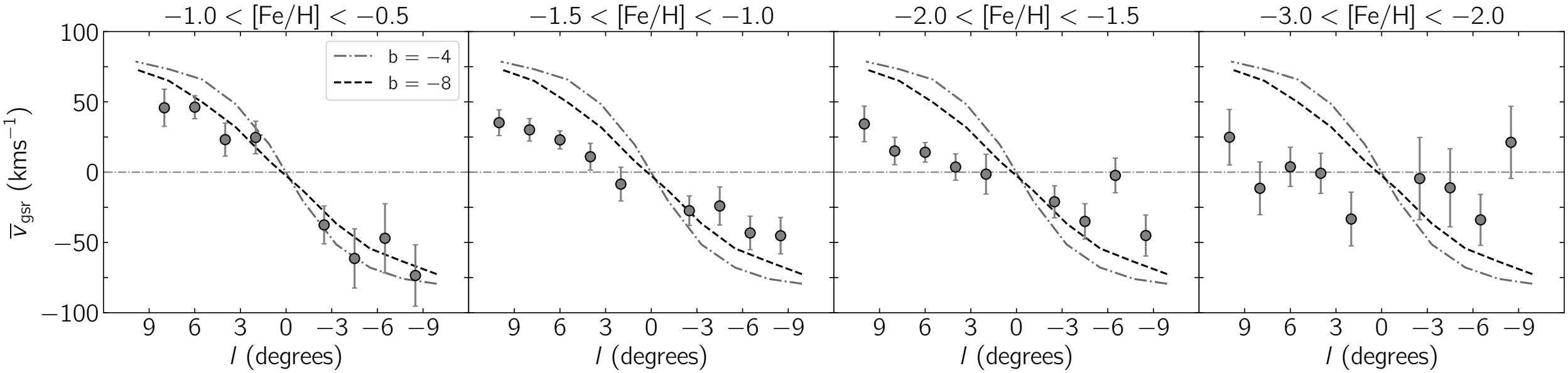
Gaia NIR

APOGEE
ARGOS
EMBLA
PIGS

Arentsen, Starkenburg et al, 2020a,b & 2021

Anke Arentsen

Different dynamics!

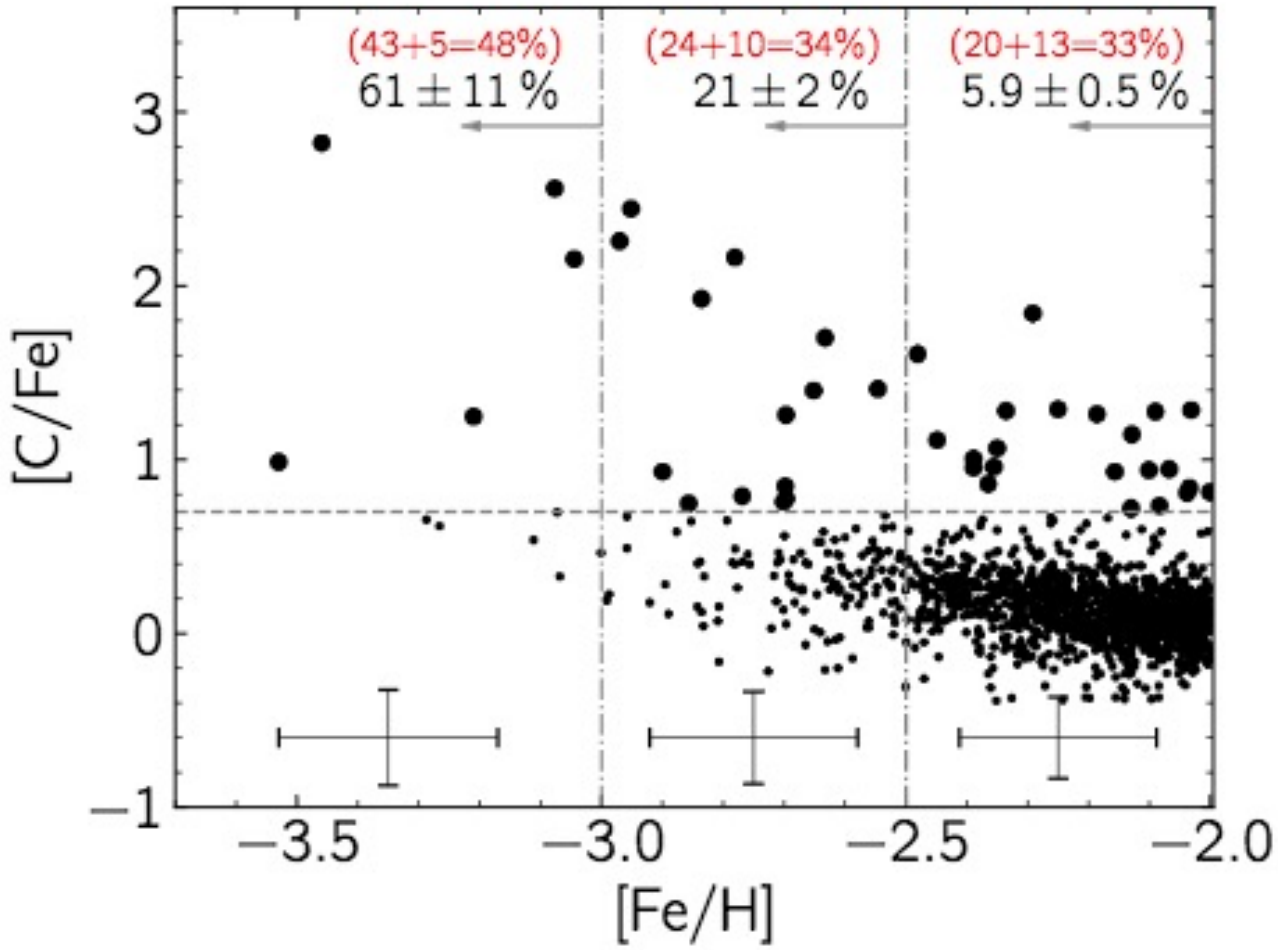


- Dynamics change with different metallicity populations
  - Rotation signal gets less and less
  - Are we seeing a classical bulge component, or the inner halo?

Arentsen, Starkenburg et al., 2020a

Different chemistry?

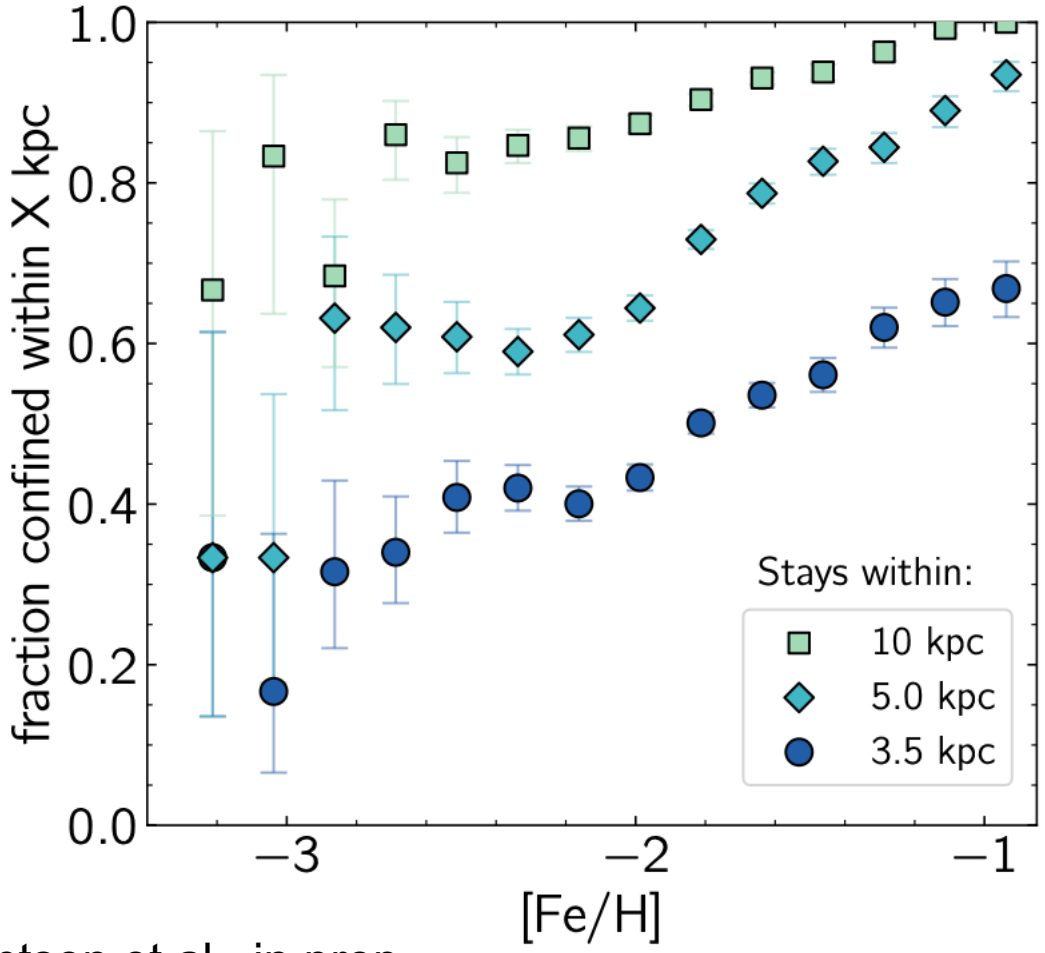
- PIGS found 62 carbon-rich metal-poor stars (only few known previously)
- Less in higher metallicity regime though…
- Signature of faster evolution?

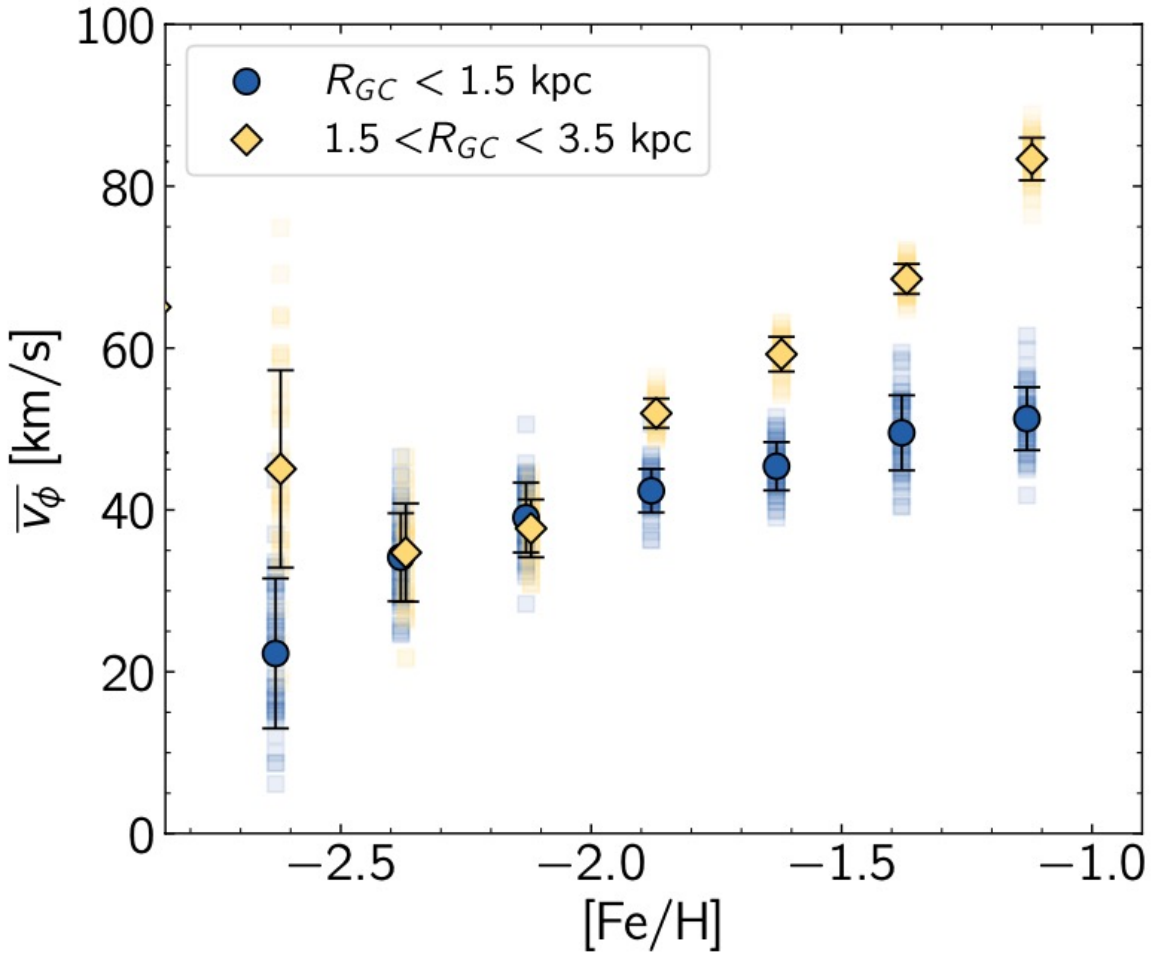


Arentsen, Starkenburg et al, 2021

Update: Do the stars also stay in the bulge?

With thanks to StarHorse (in particular, Anna Queiroz, Cristina Chiappini) also Giacomo Monari

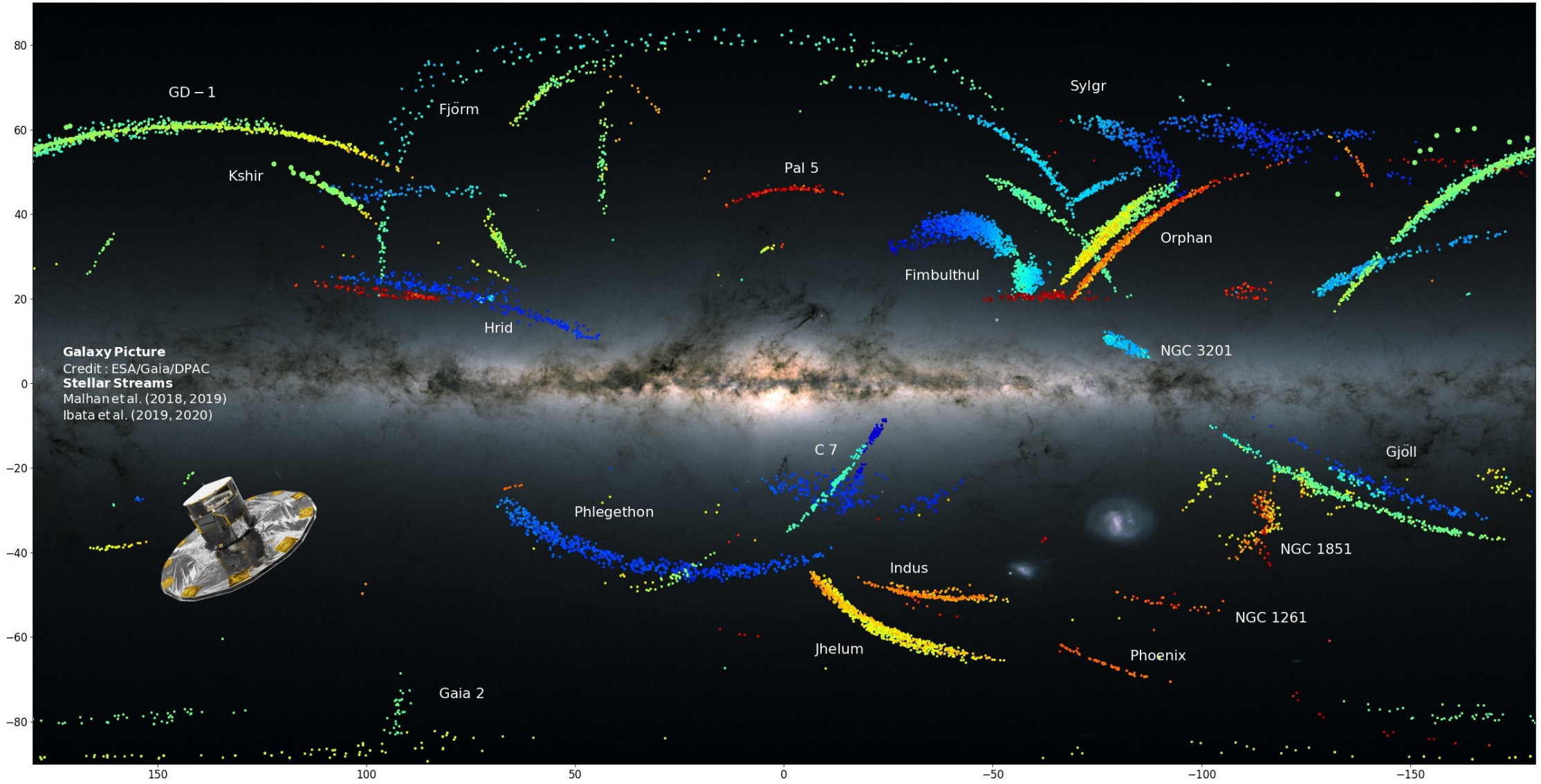




Arentsen et al., in prep.

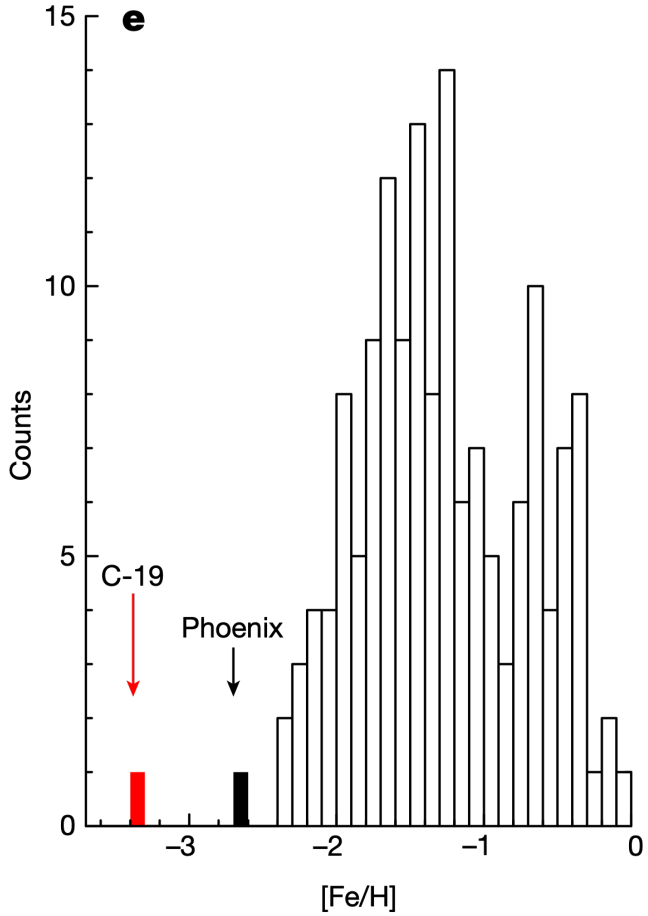
The halo: remnants of the past

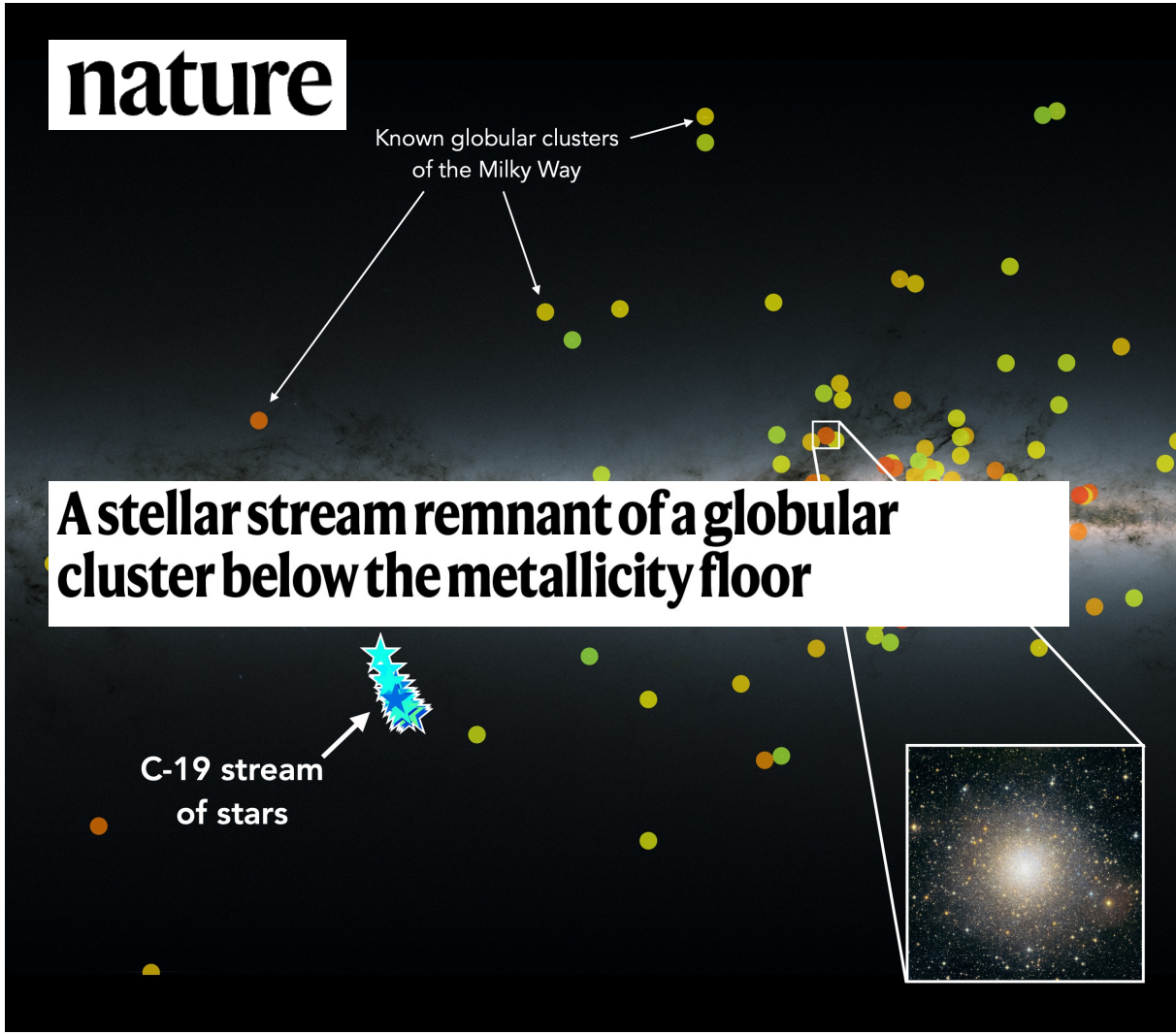
Streamfinder: using proper motions from Gaia & spectroscopy



Some very exciting streams!

The most metal-poor stellar structure known!

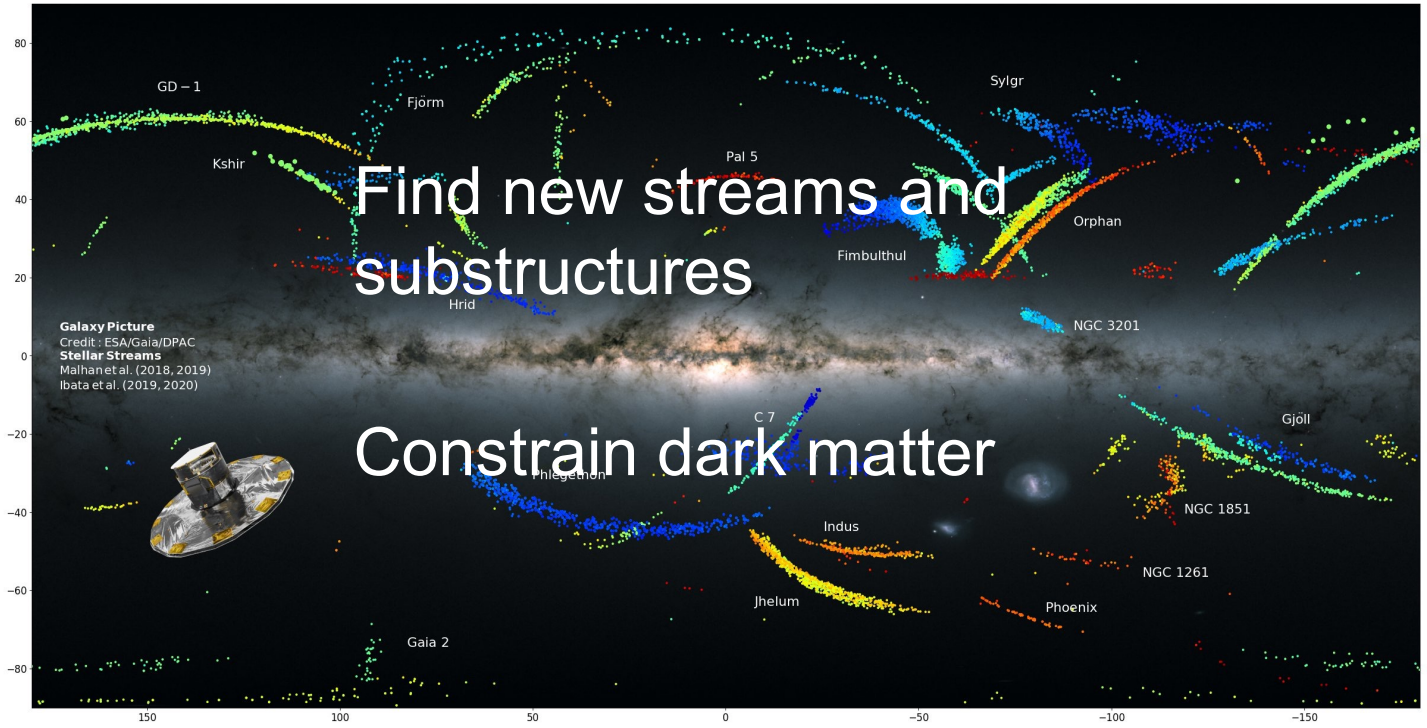




Martin, Venn, Aguado, Starkenburg et al., 2022

Moving towards the future…

- Huge step forward in this field from massively multi-plexed spectrographs
  - Low-res & high-res (R ~5000 & R ~ 20 0000)
  - Large Galactic Archaeology programs
  - Large fields of view – 1000s of fibres

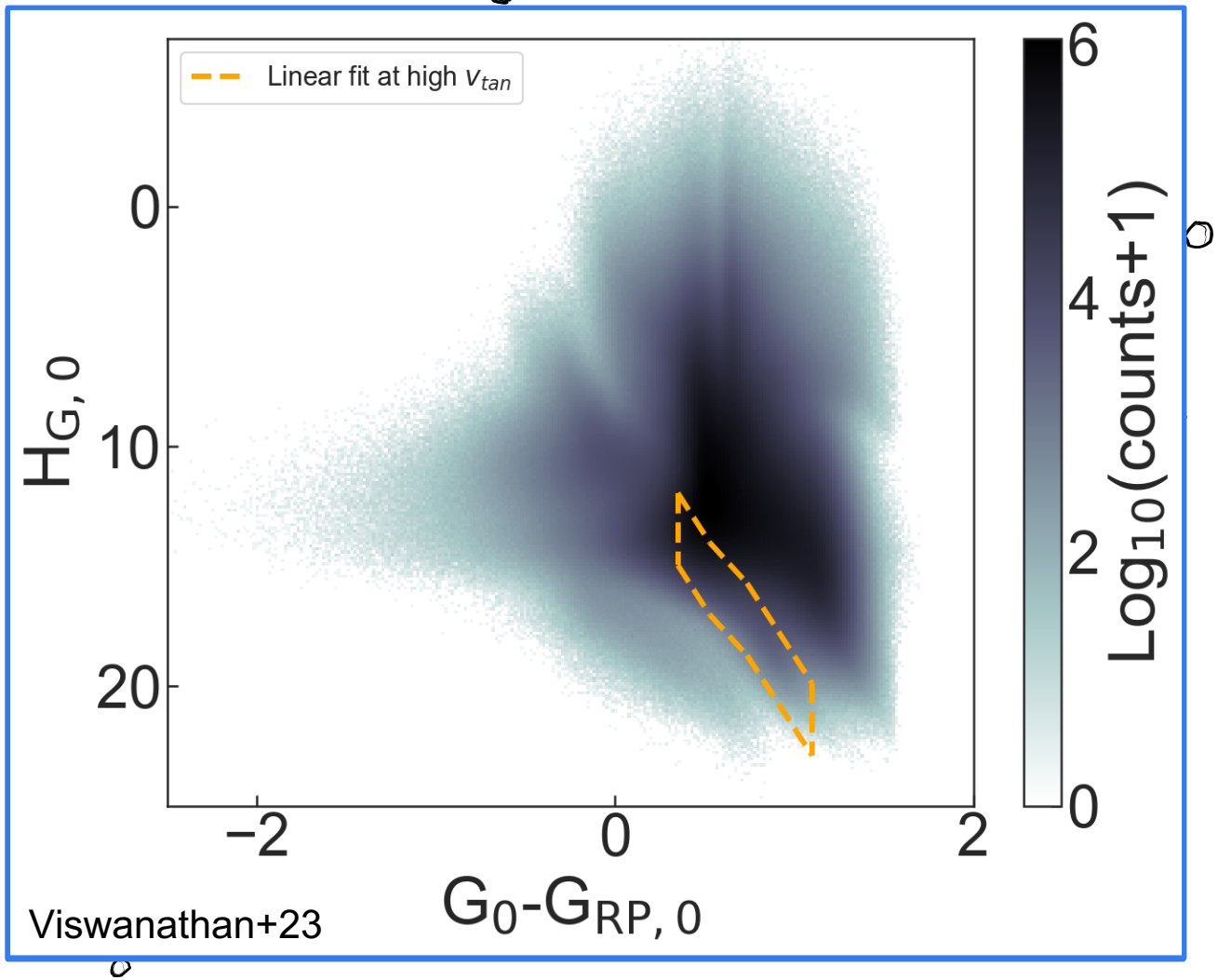


Using Reduced Proper Motion for streams

- $H_G = m_G + 5log_{10}(\mu) - 10 - A_G$
  $= M_G + 5log_{10}\left(\frac{v_{tan}}{4.74057}\right)$

- Colour versus RPM mimics an HR diagram at different tangential velocities

- High tangential velocity (200-800 km/s) population represents halo



A reduced proper motion sample

RPM sample	Max. distance	Typical distance uncertainty	Streams data released for
47 Million halo stars	21 kpc	7%	GD-1, Jhelum

Viswanathan+23, arXiv:2302.00053

Catalogue available at CDS: cat/J/MNRAS/521/2087
Codes at GitHub: astroakshara/RPM-Catalogue-Gaia-DR3

Background: Adapted from STREAMFINDER data

viswanathan@astro.rug.nl

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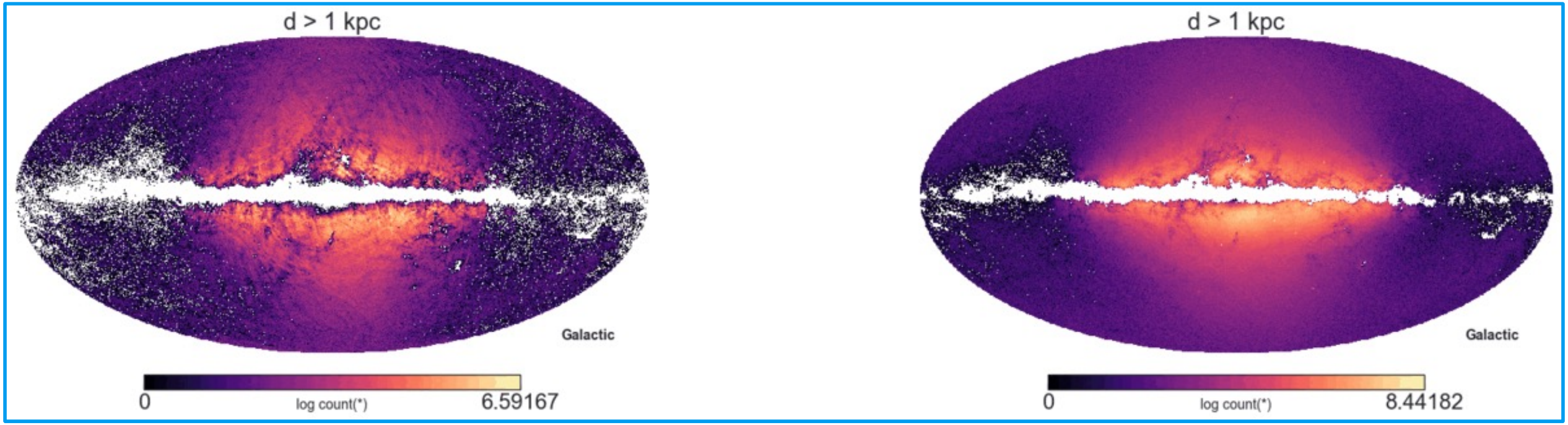
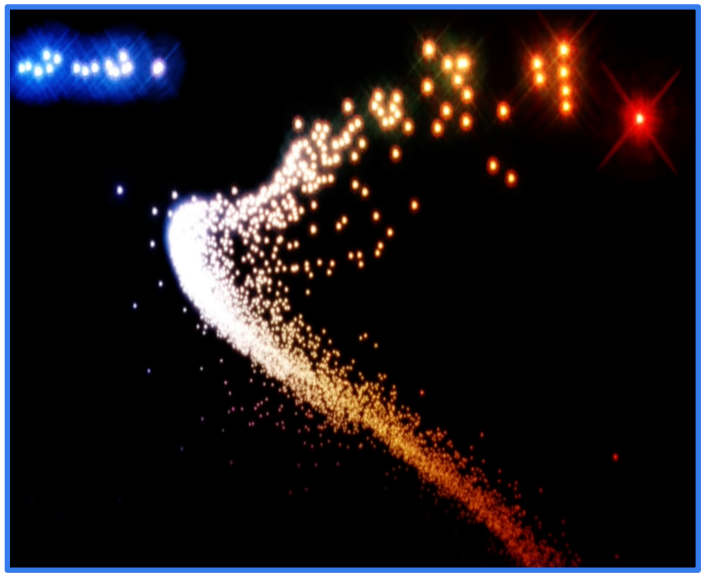


Akshara Viswanathan

Gaia DR2 TO DR3

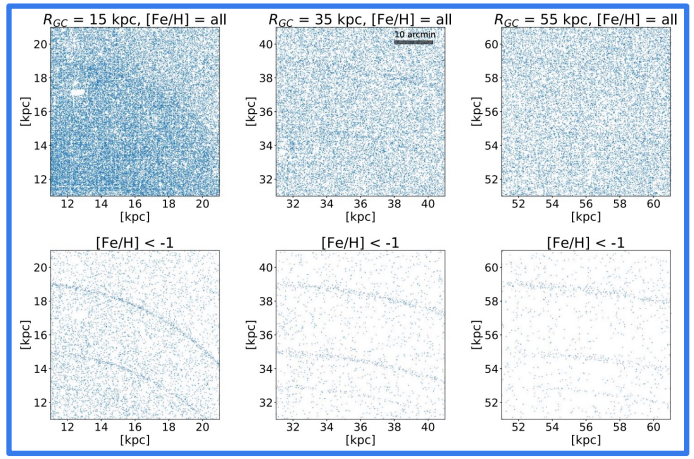
Imagine Gaia NIR!

Why Main Sequence stars?



Numerous

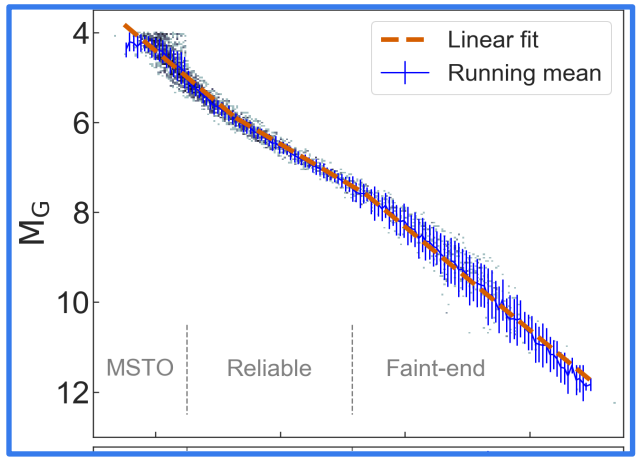
>10^2 times more common than red giants.



Pearson+19

Low surface brightness features

Because they are numerous, it allows us to probe into the faint counterpart of the streams and its features

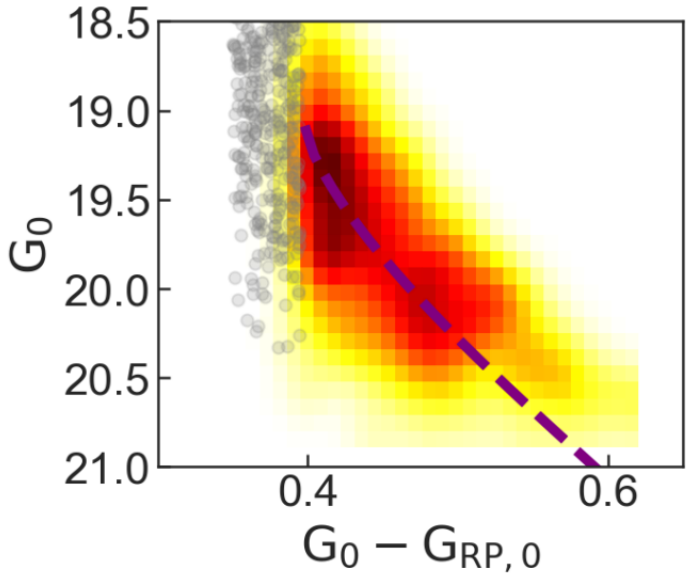


Simple distance derivation

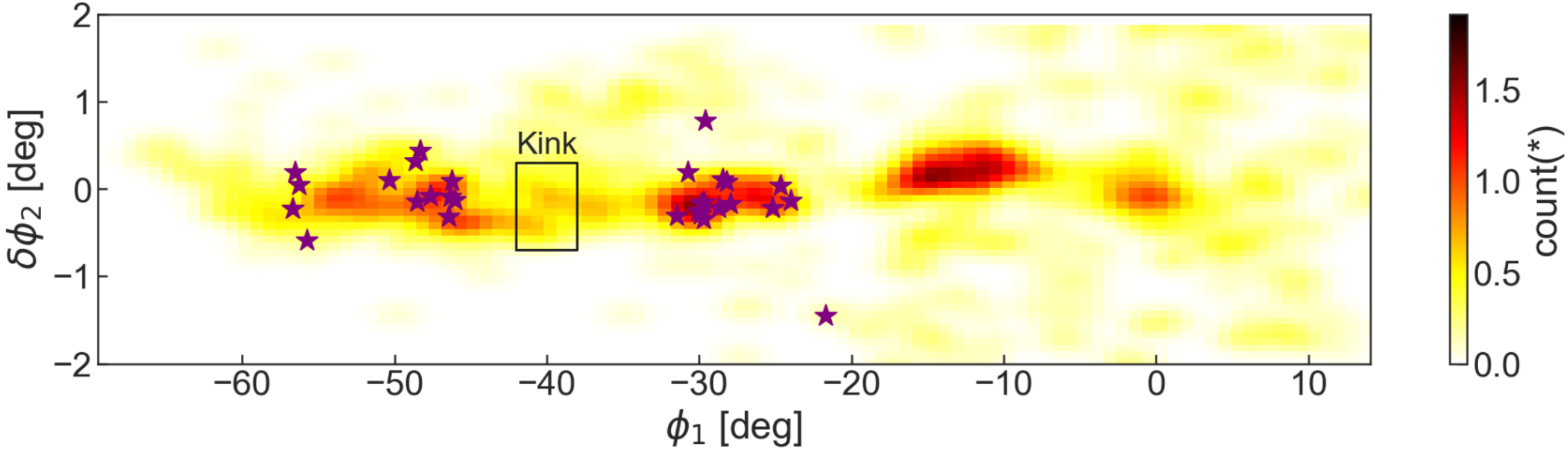
Relatively simple absolute magnitude relation as a function of colour, which can be used to calculate a photometric distance

Low surface brightness streams

- GD-1 stellar stream
  - Kinks and features better visible
- Pushing to the limits of Gaia
  - Gaia NIR reaches 1.5 – 2 mags fainter



Viswanathan+23



Low surface brightness streams

- Jhelum stellar stream
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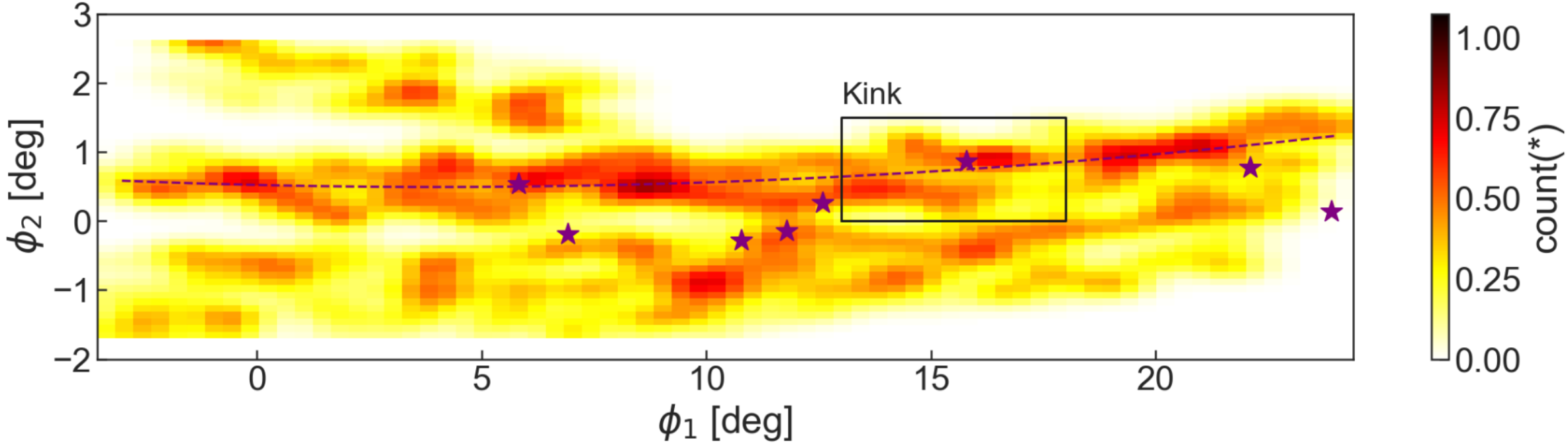
Viswanathan+23



This talk

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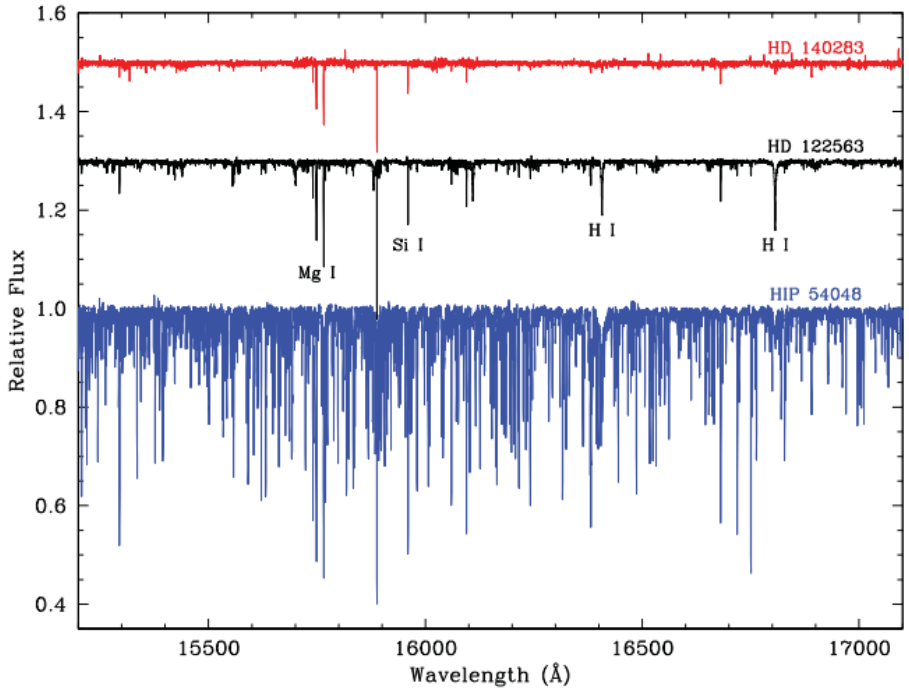
- What have we learned from their follow-up
  - Surprises in all Galactic environments!
  - A very large role for Gaia
- What is there still to come…
- What are the prospects and challenges (I see) for Gaia NIR in the future

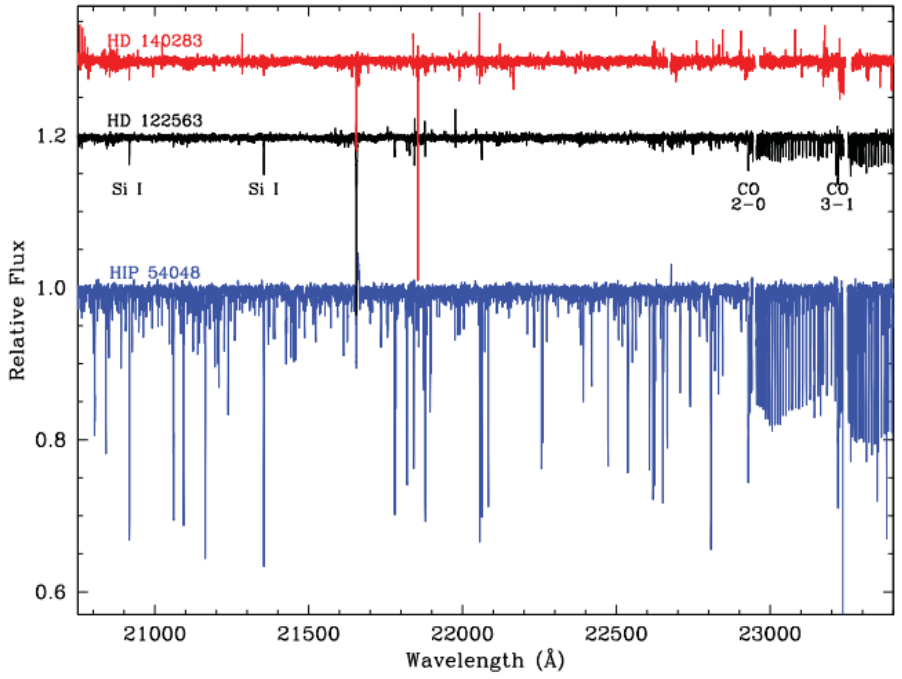
Gaia NIR – Open questions

- The power of Galactic Archaeology:

combination of astrometry and spectroscopy (and age)

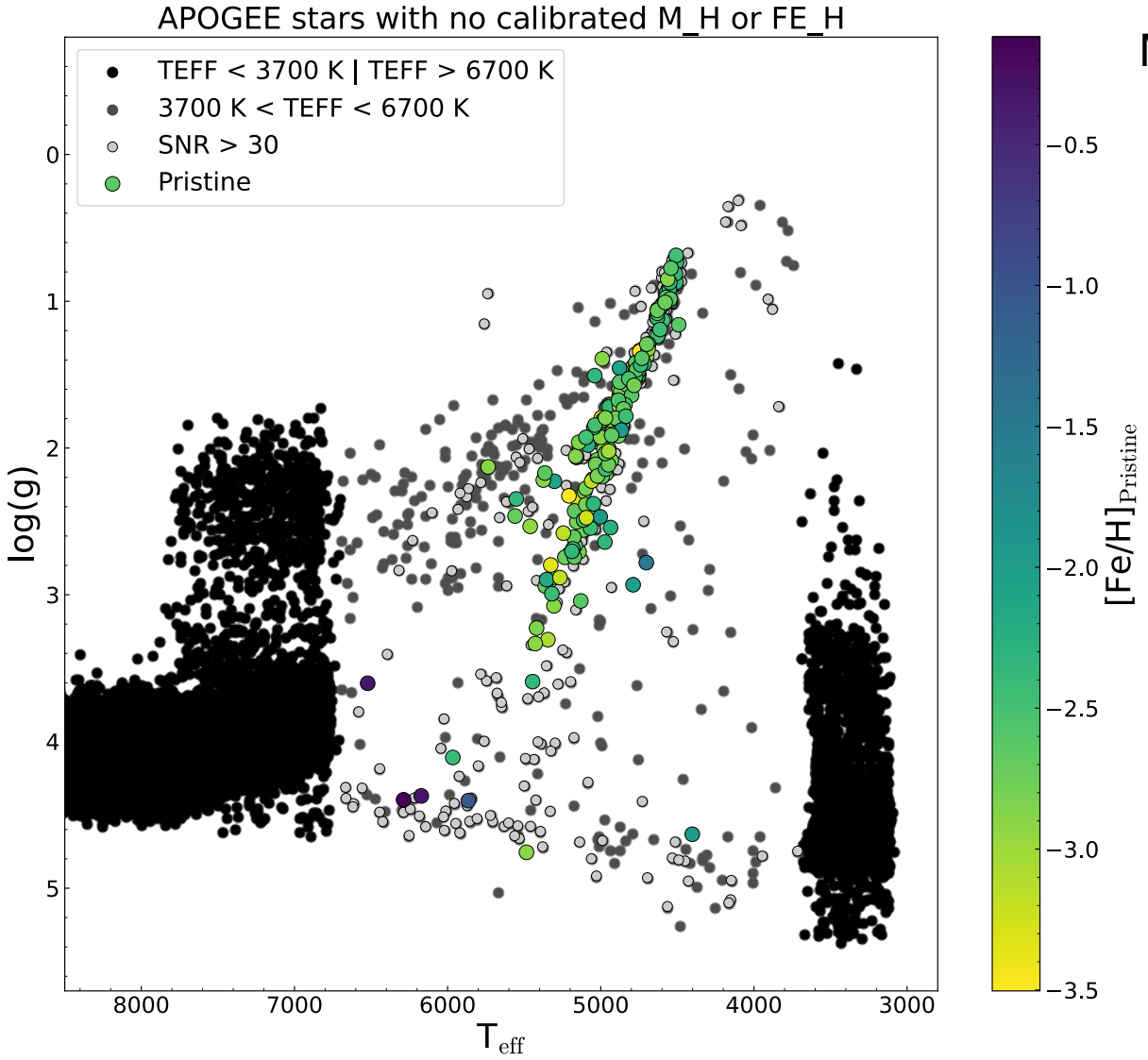
- How do we follow-up the targets Gaia NIR will uncover?
- Are metal-poor spectra in H & K interesting / sufficient?





Afsar et al., 2016

Gaia NIR – Open questions



Montelius et al., in prep.

Martin Montelius

Gaia NIR – Opportunities

- Moving into the dusty regions!
  - Better understanding populations in the disk and bulge
    - Improved parallax and proper motion

- Red faint stars in the halo
  - To map low surface brightness features
  - And long time-baselines for proper motions

- Complementing the large multi-plexed surveys

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Ready for the future …
to better study the past

Big Bang | First Stars | Galaxy Evolution | Solar System | Now

Galactic archaeology

Finding these rare stars

- The **Pristine** survey
- **Gaia** BPRP spectra

Distribution & kinematics

- **Gaia**
- **WEAVE & 4MOST**

Nucleosynthesis pattern

- Individual follow-up
- **WEAVE & 4MOST**

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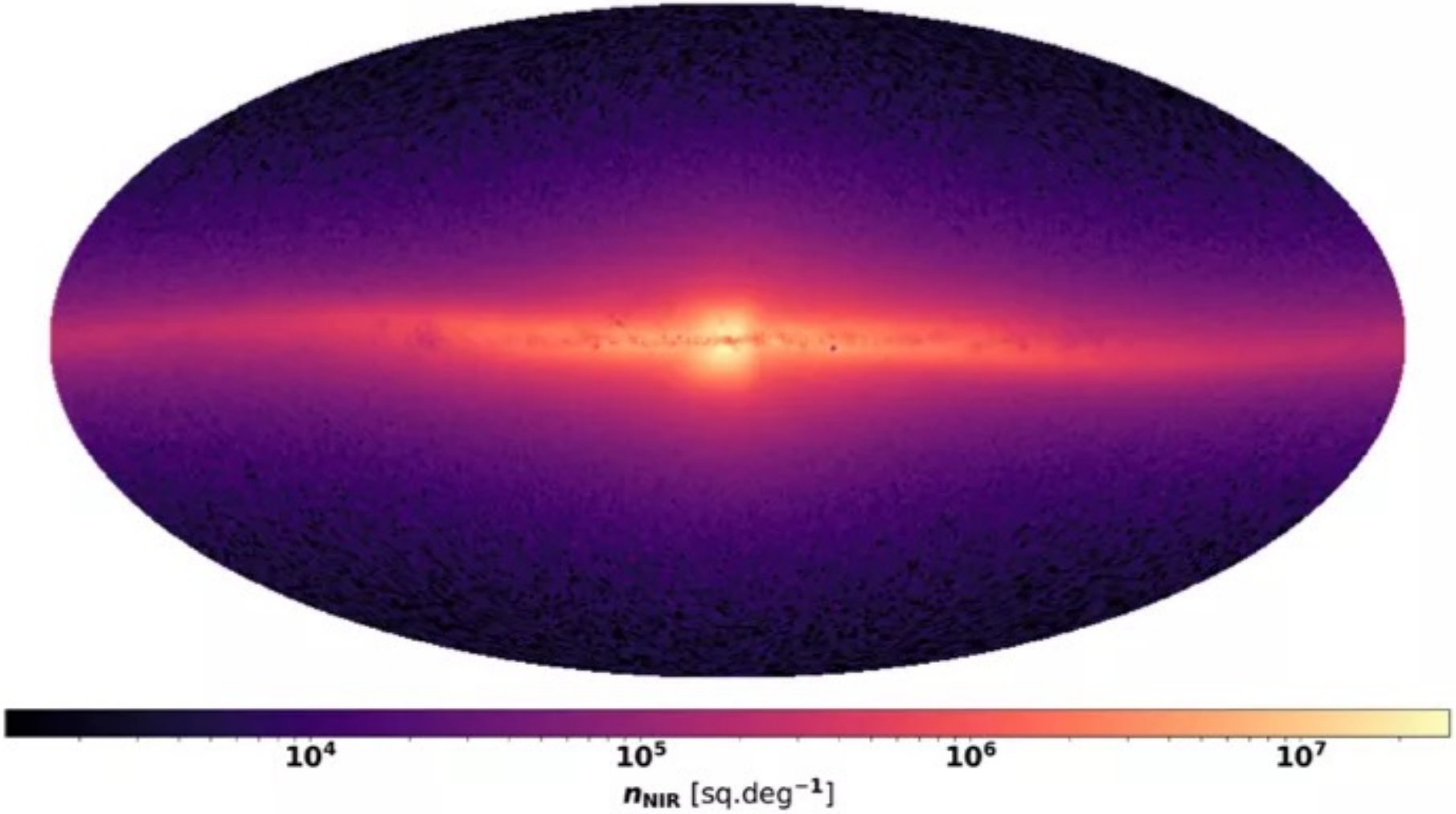

Finding these rare stars

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- **Gaia & Gaia NIR**
- **WEAVE & 4MOST & MOONS & MSE?**

Nucleosynthesis pattern

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- **WEAVE & 4MOST & MOONS & MSE?**