The Pristine Inner Galaxy Survey (PIGS): A chemo-dynamical investigation of the oldest and most metal-poor stars in the bulge with GRACES

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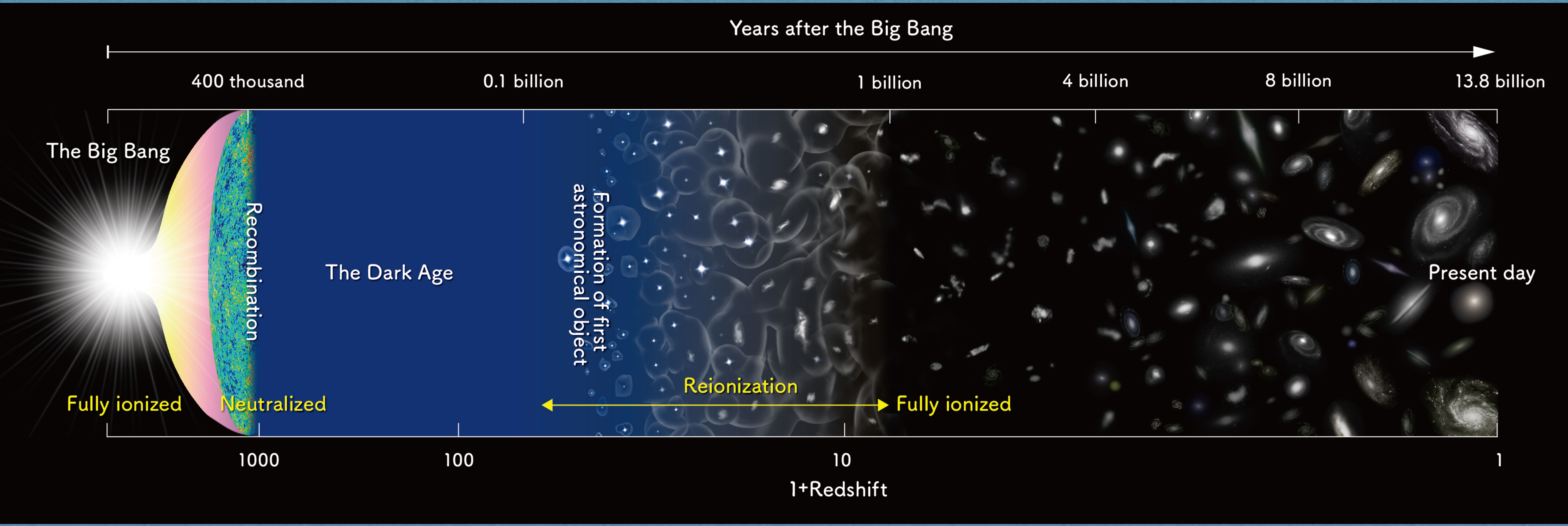
In collaboration with: Kim Venn (UVic), Anke Arentsen (ObAs), David Aguado (U. Firenze), and the Pristine survey

University of Victoria

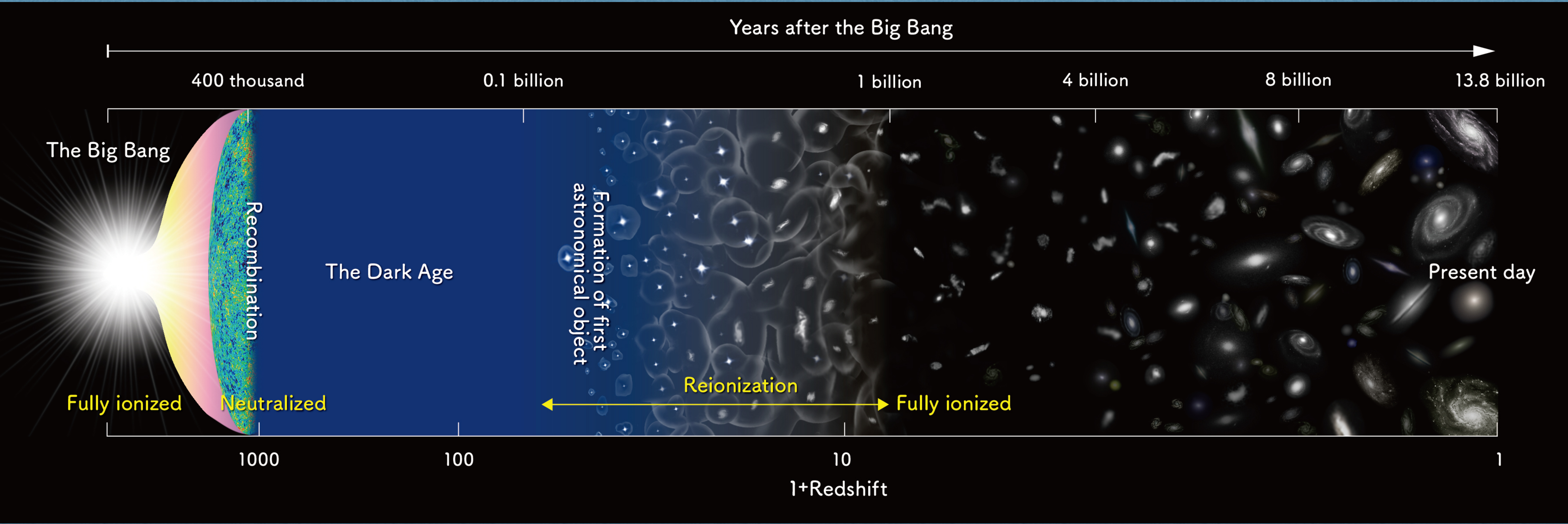
PRISTINE

Open a window into the early Universe



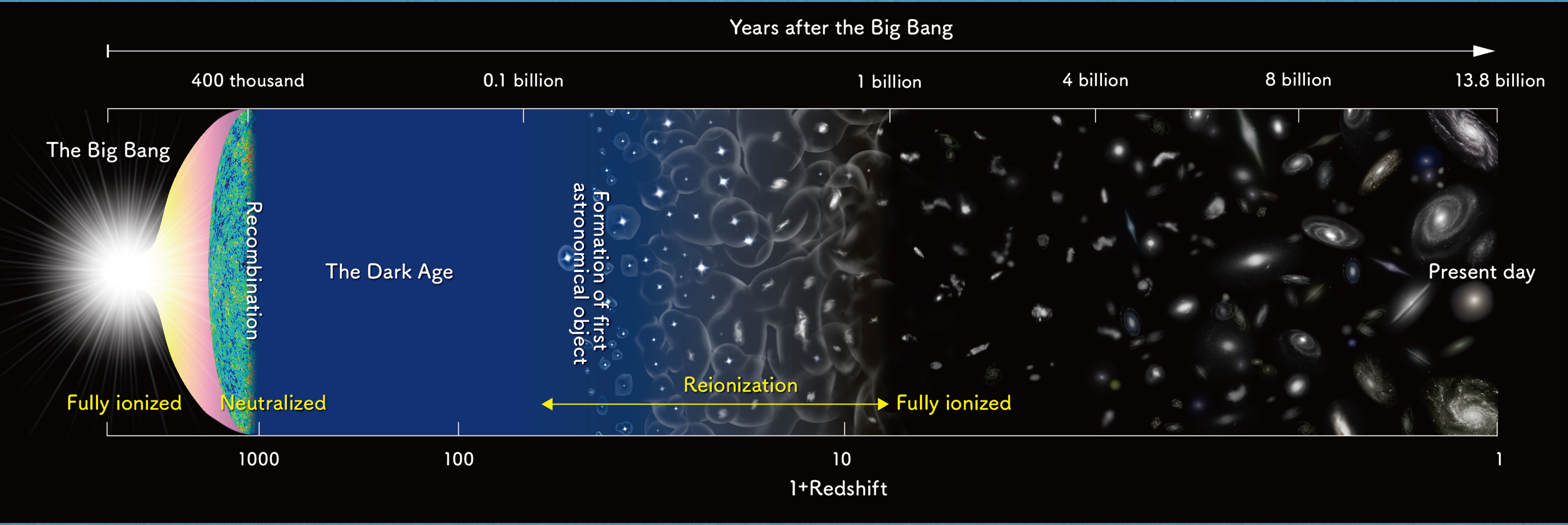
How did the first stars and first structures form and evolve?
What were their properties?

Open a window into the early Universe



Either look at high redshift or hunt for the relics/fossils

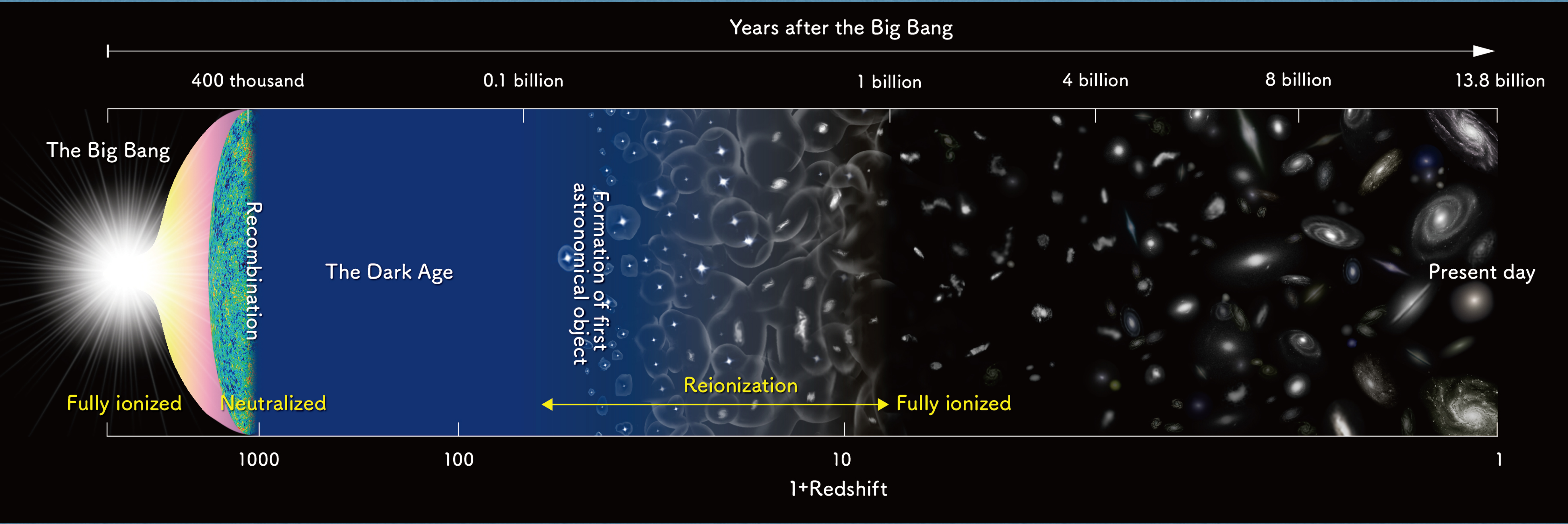
Carry the imprints of the First stars

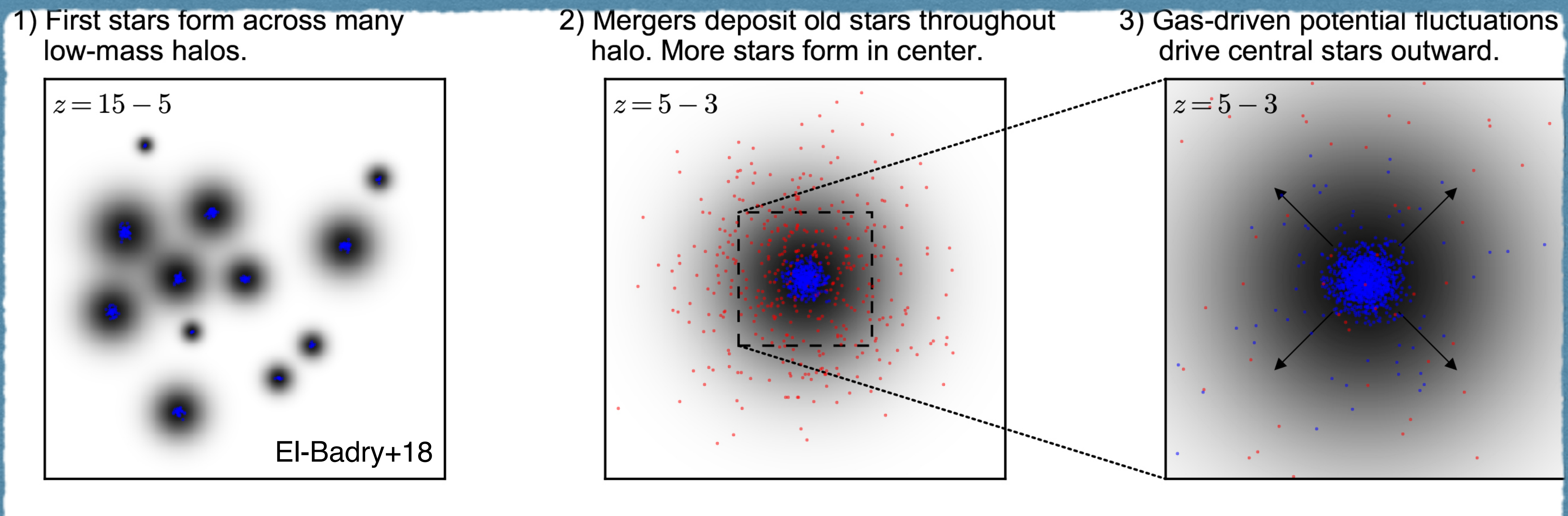


Either look at high redshift or hunt for the relics/fossils

The most metal-poor stars

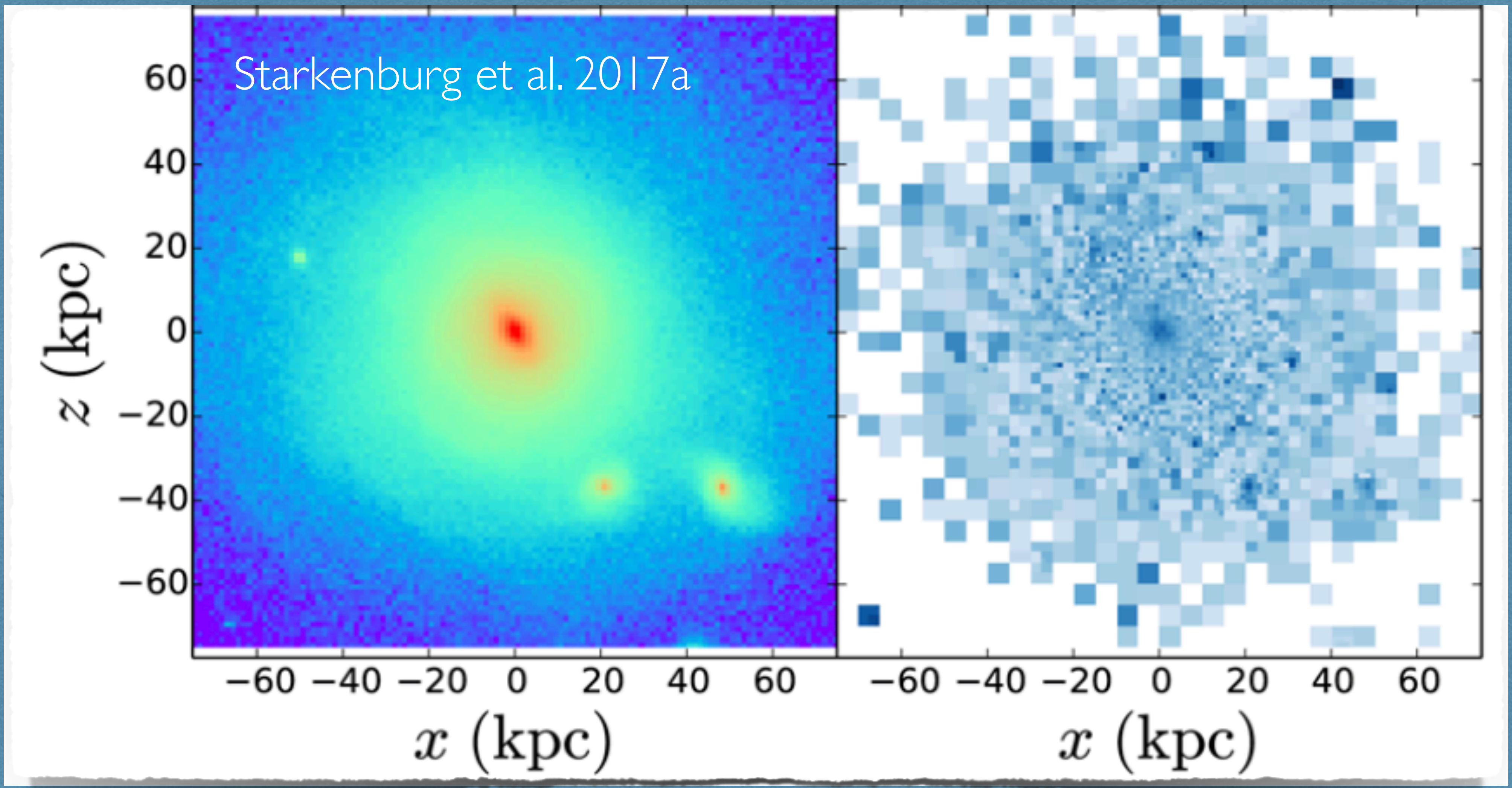
Metal-poor stars are not necessarily the First stars





Where to find the oldest and most metal-poor stars?

[Fe/H] < −2.5



Colour-coded by density

Darker with larger fraction of old stars

- ✦ Inner region (crowded by metal-rich stars, large extinction)
- ✦ In the halo ("easier" to detect)
- ✦ In satellites (faint and distant)

Where to find the oldest and most metal-poor stars?

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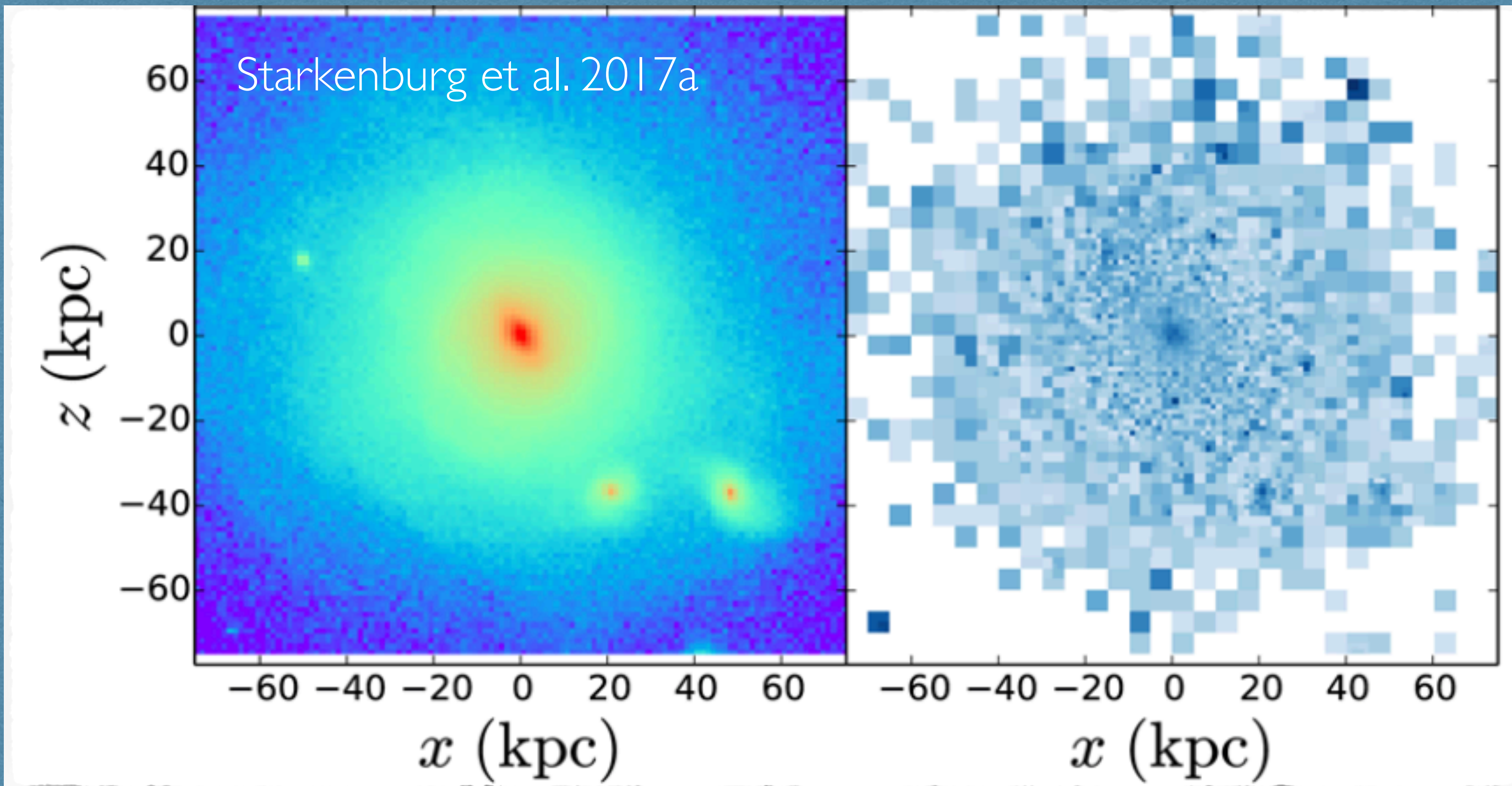


Colour-coded by density

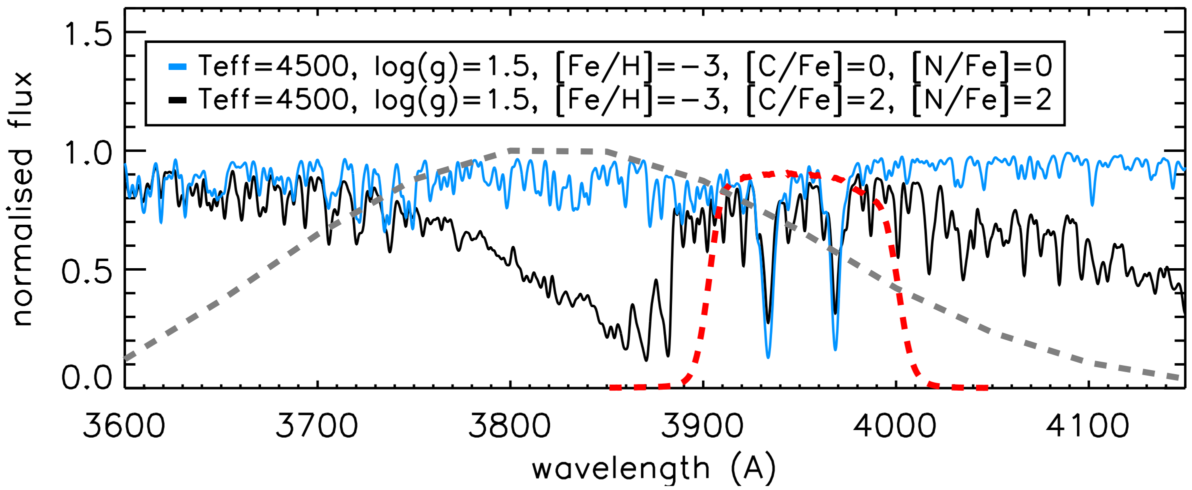
Darker with larger fraction of old stars

- ✦ Inner region (very crowded)
- ✦ In the halo ("easier" to detect)
- ✦ In satellites (faint and distant)

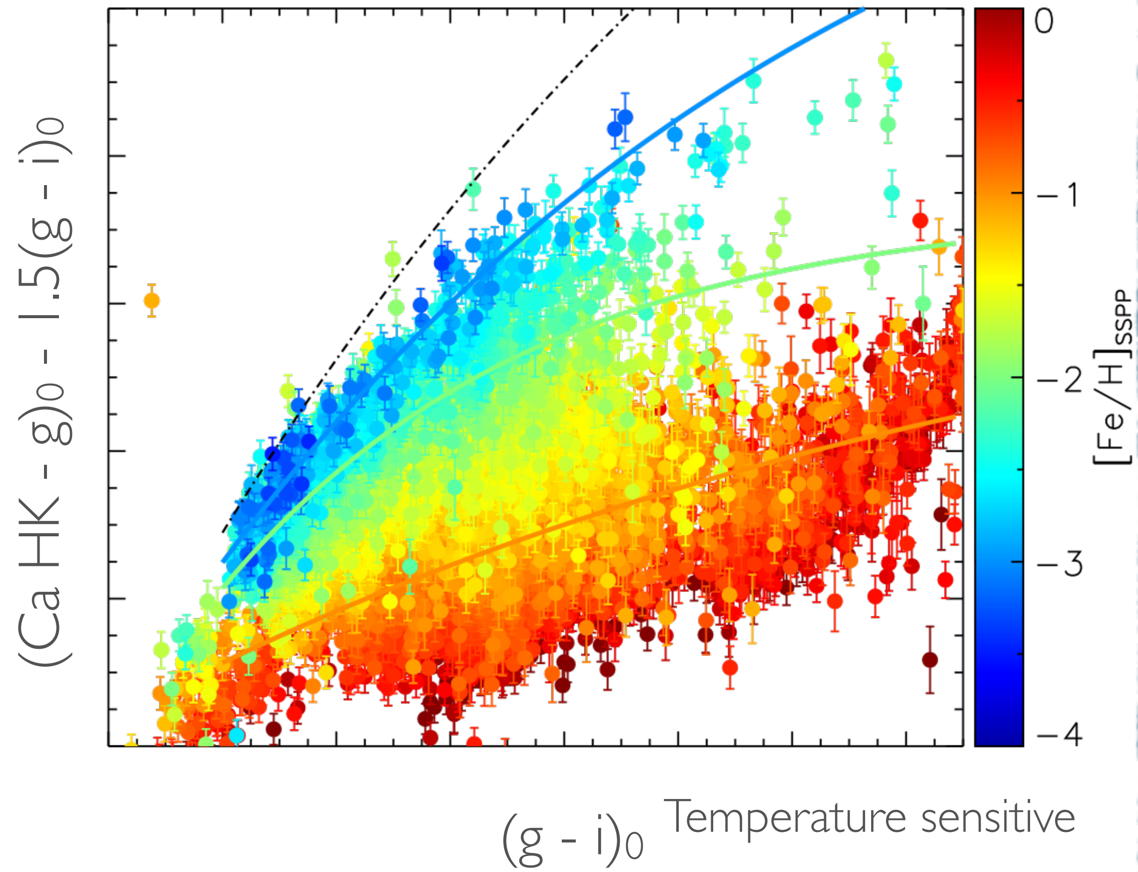
The most metal-poor stars are informative on the chemical evolution of their birth regions

Photometric [Fe/H] from the Pristine Ca H&K filter

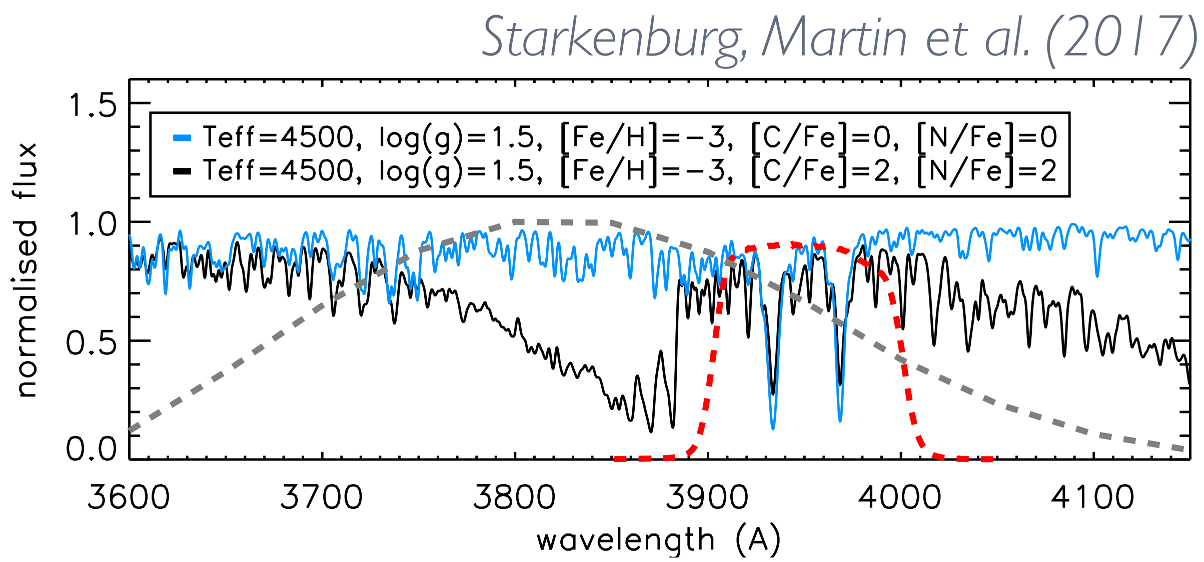
Starkenburg, Martin et al. (2017)

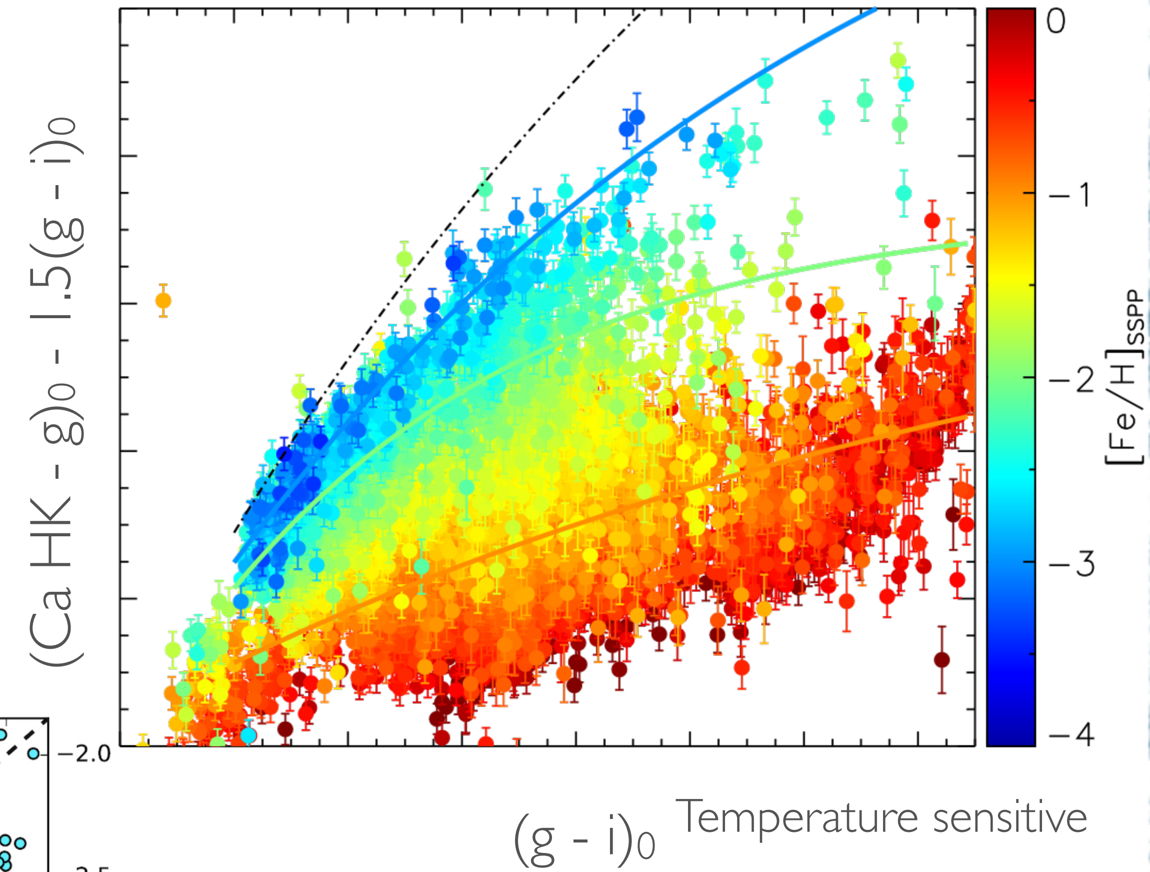


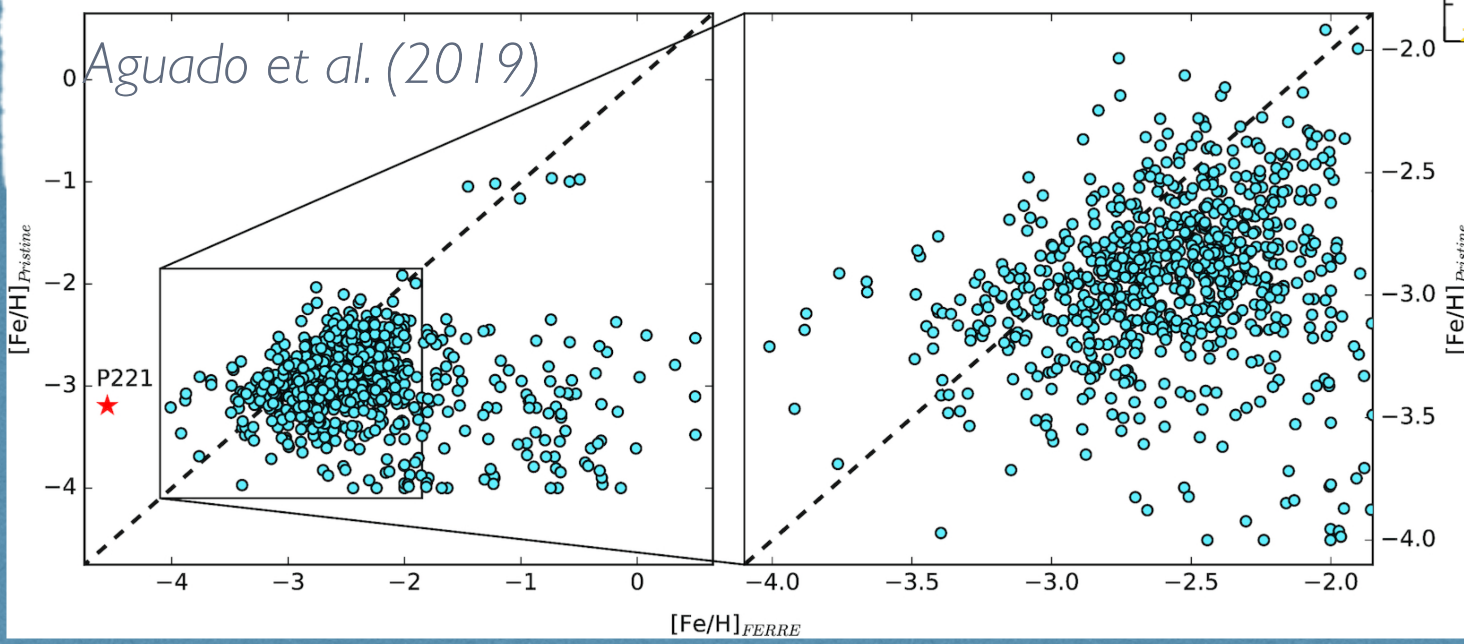
Ca H&K is a proxy for [Fe/H]
used by various surveys



The efficiency of the Pristine Ca H&K filter

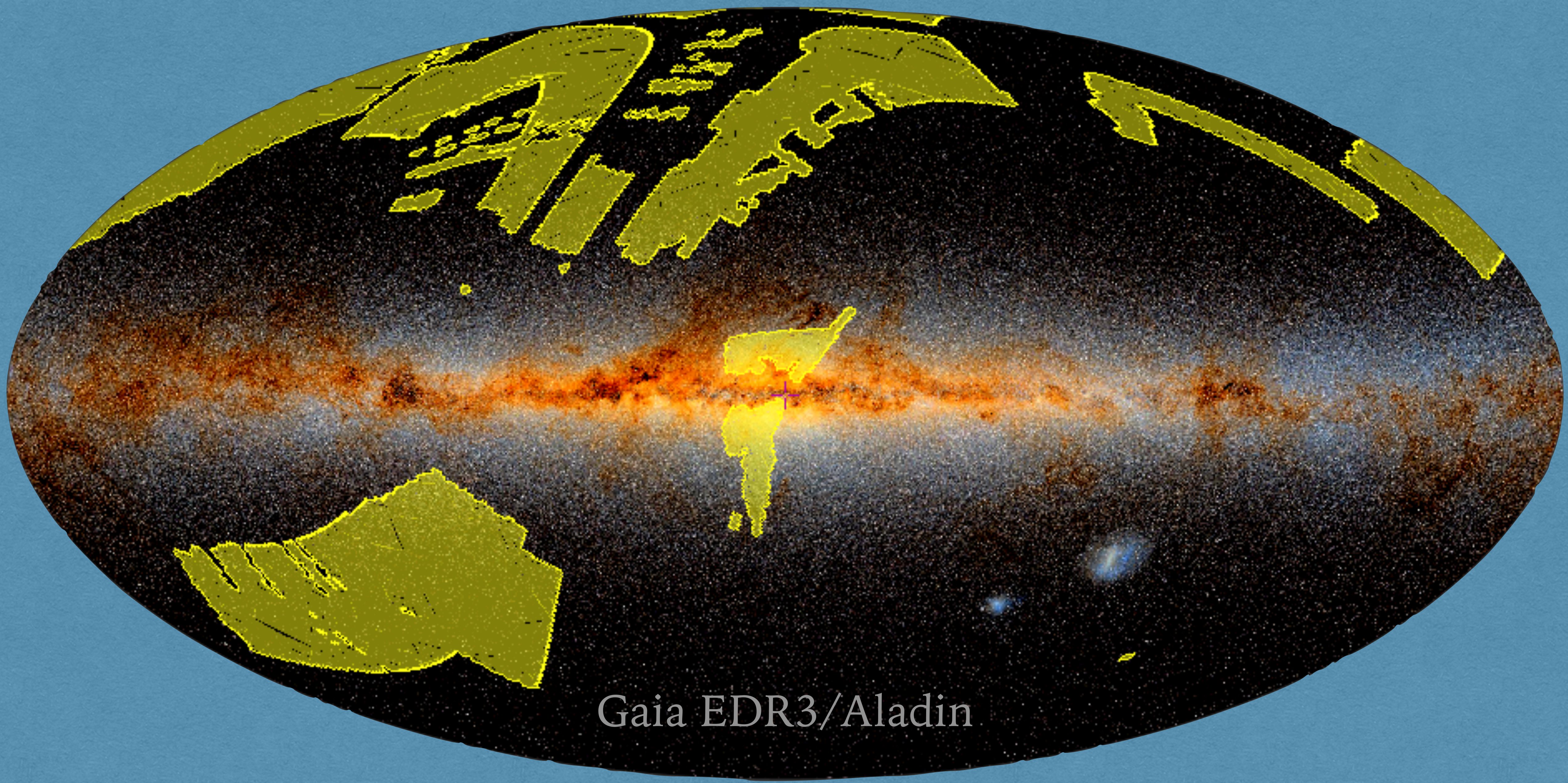






- 56% of stars with $[Fe/H]_{phot} < -2.5$ have $[Fe/H]_{spec} < -2.5$
- Much higher efficiency than previous surveys (HK~3% for EMP)

Hunting for the most metal-poor star @ CFTH/MegaCam



Pristine footprint: ~6200 deg^2 (June last year, still increasing)

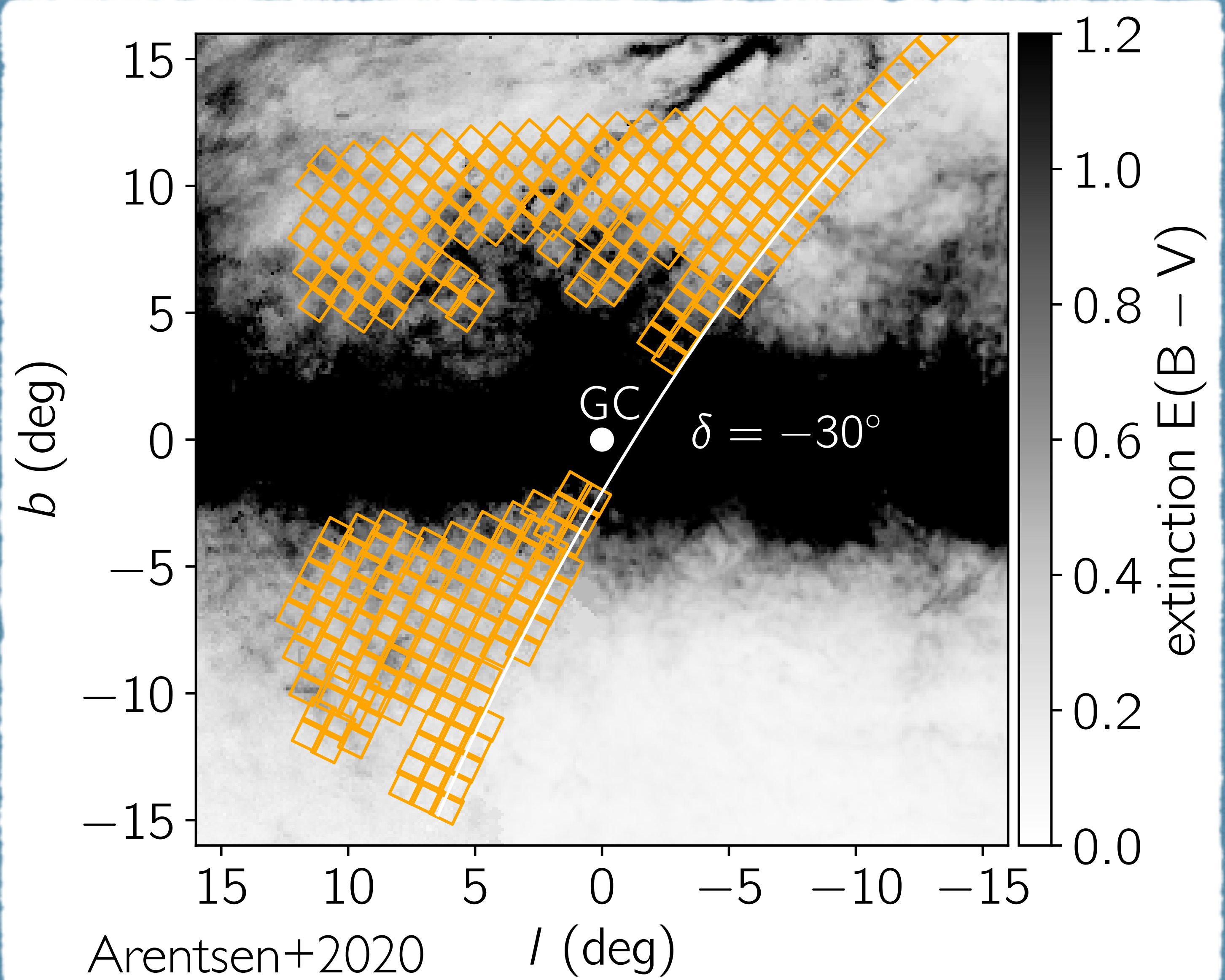
PIGS footprint (bulge + Sagittarius dSph): ~300 deg^2

The low/medium res spectroscopic follow-up

AAT/AAOmega+2dF
(400 fibres in a 2-degree field)

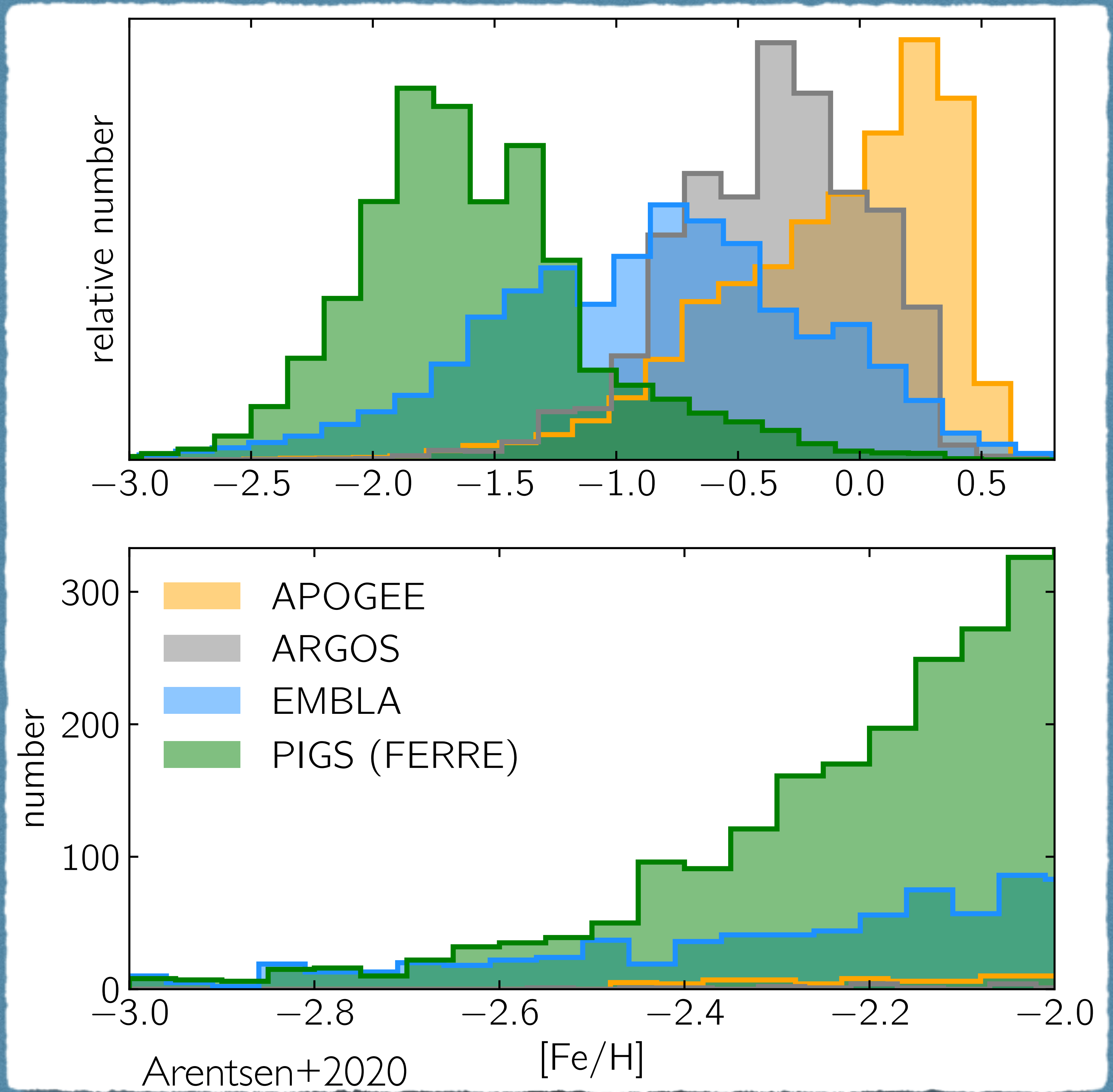
R~1300 blue (3800-5600 Å)
R~11000 red (8400-8800 Å, CaT) simultaneously

~12000 spectra



Arentsen+2020

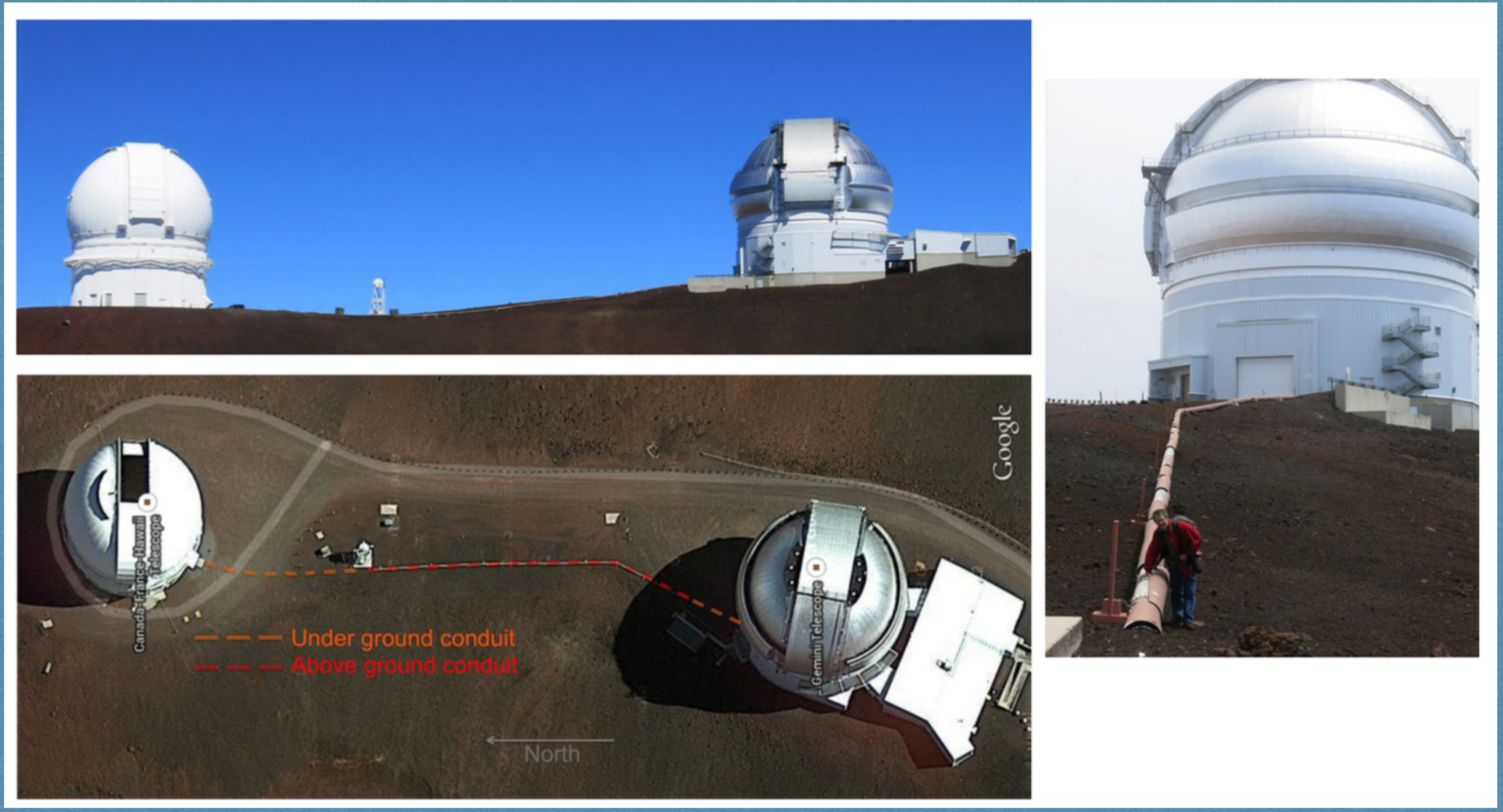
Exploring the most metal-poor tail of the inner galaxy



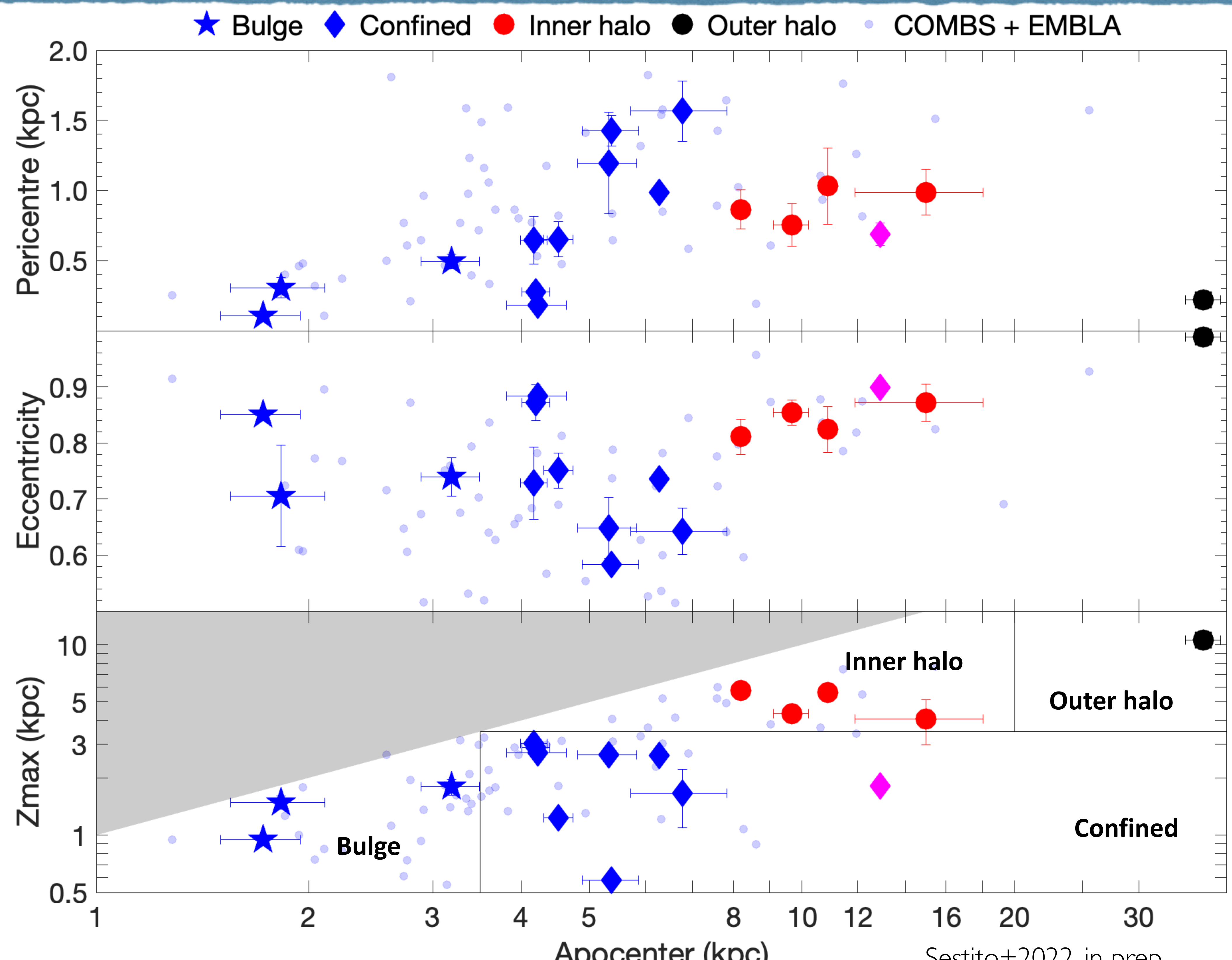
GRACES @ Gemini North (and CFHT)

Gemini Remote Access to CFHT ESPaDOnS Spectrograph (GRACES):
Large collecting area of the Gemini North 8.1m
+
The high resolving power and efficiency of ESPaDOnS

Achieved through a 270m fiber from Gemini North to CFHT

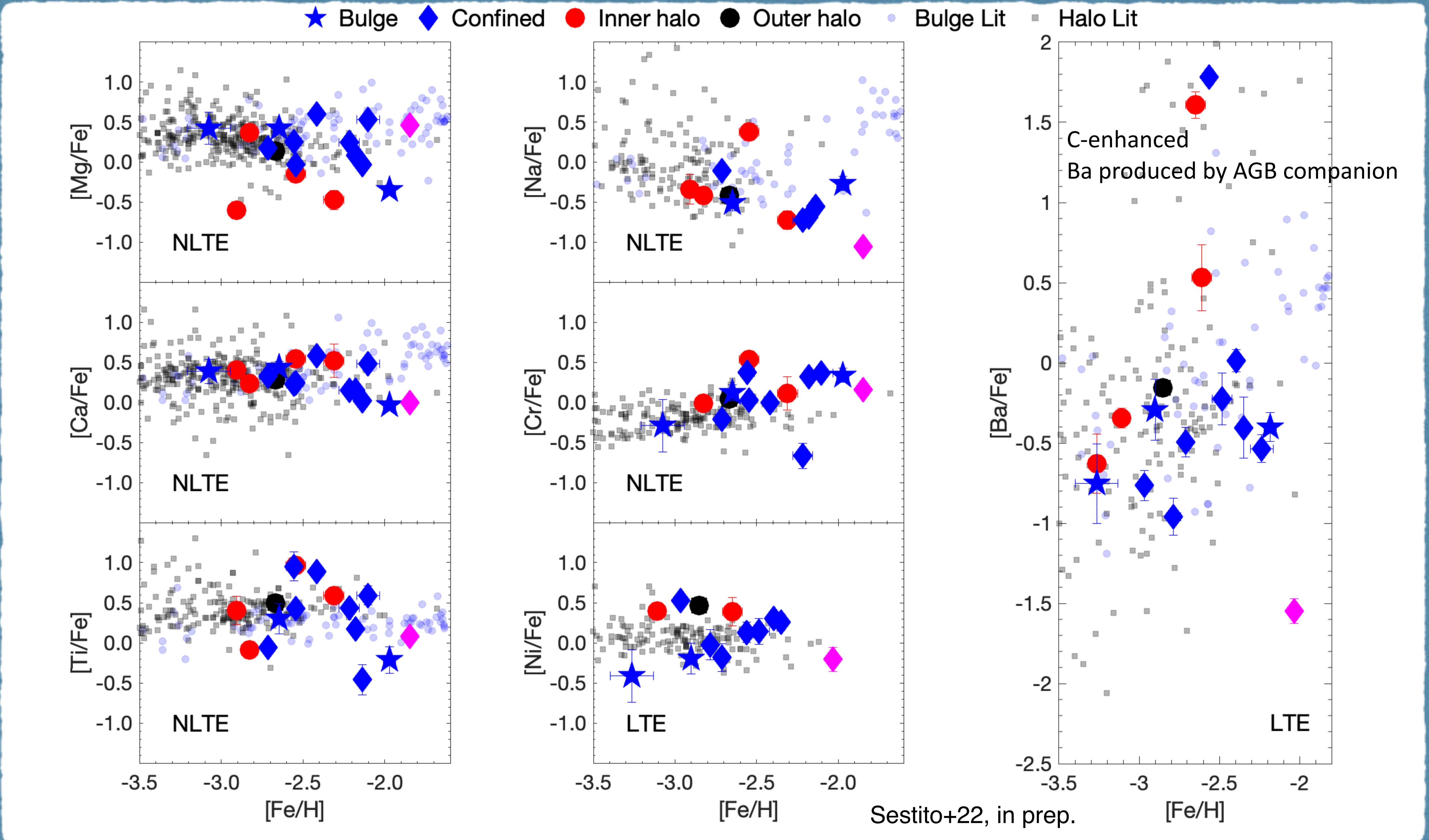


The kinematical revolution in the Gaia era



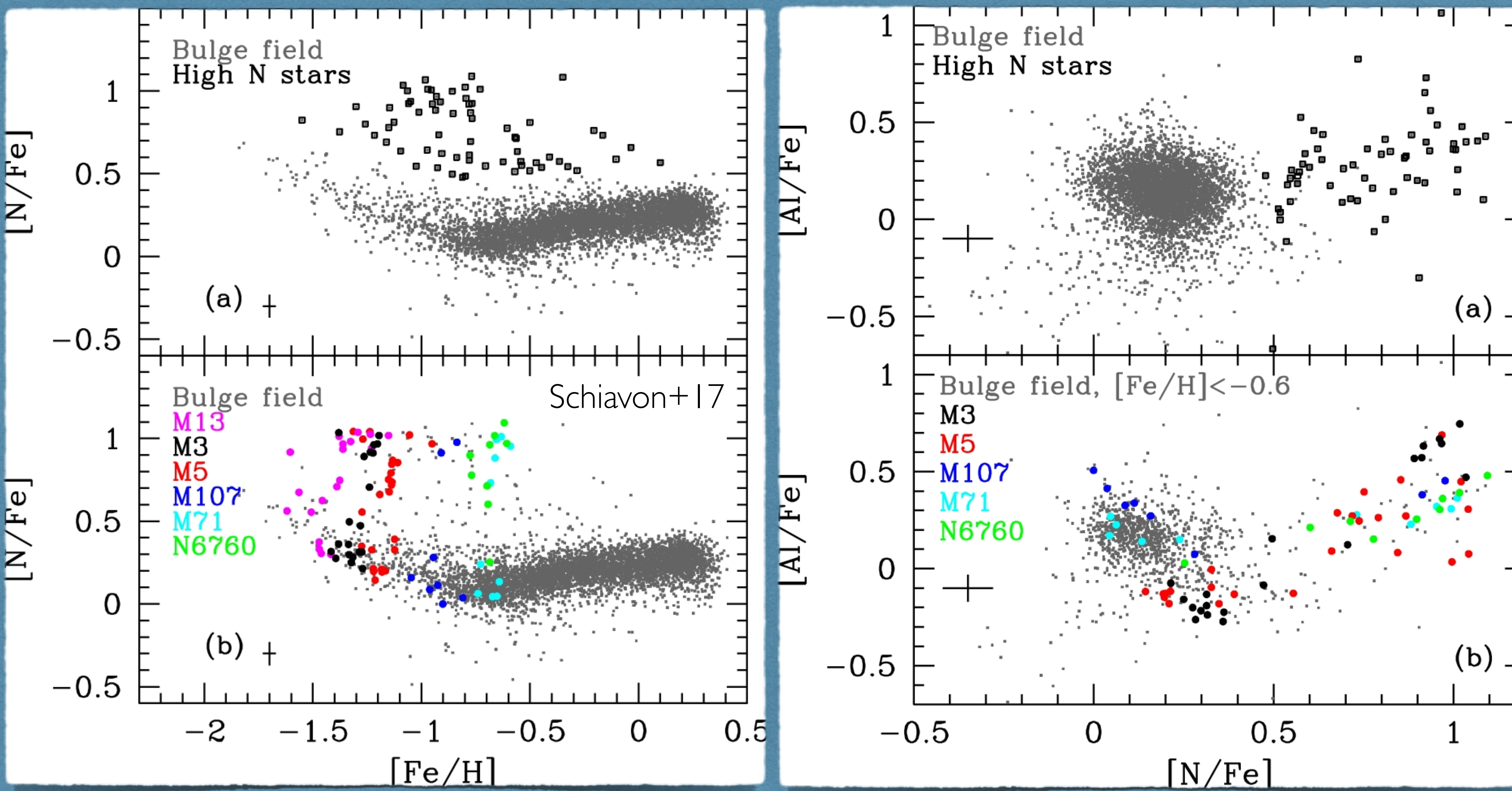
Sestito+2022, in prep.

No difference with the halo: confirmation of the hierarchical assembly of the Milky Way



Low-mass systems merged together at early times forming the proto-Galaxy and providing pristine stars, gas, and dark matter

The connection with the second generation stars from globular clusters



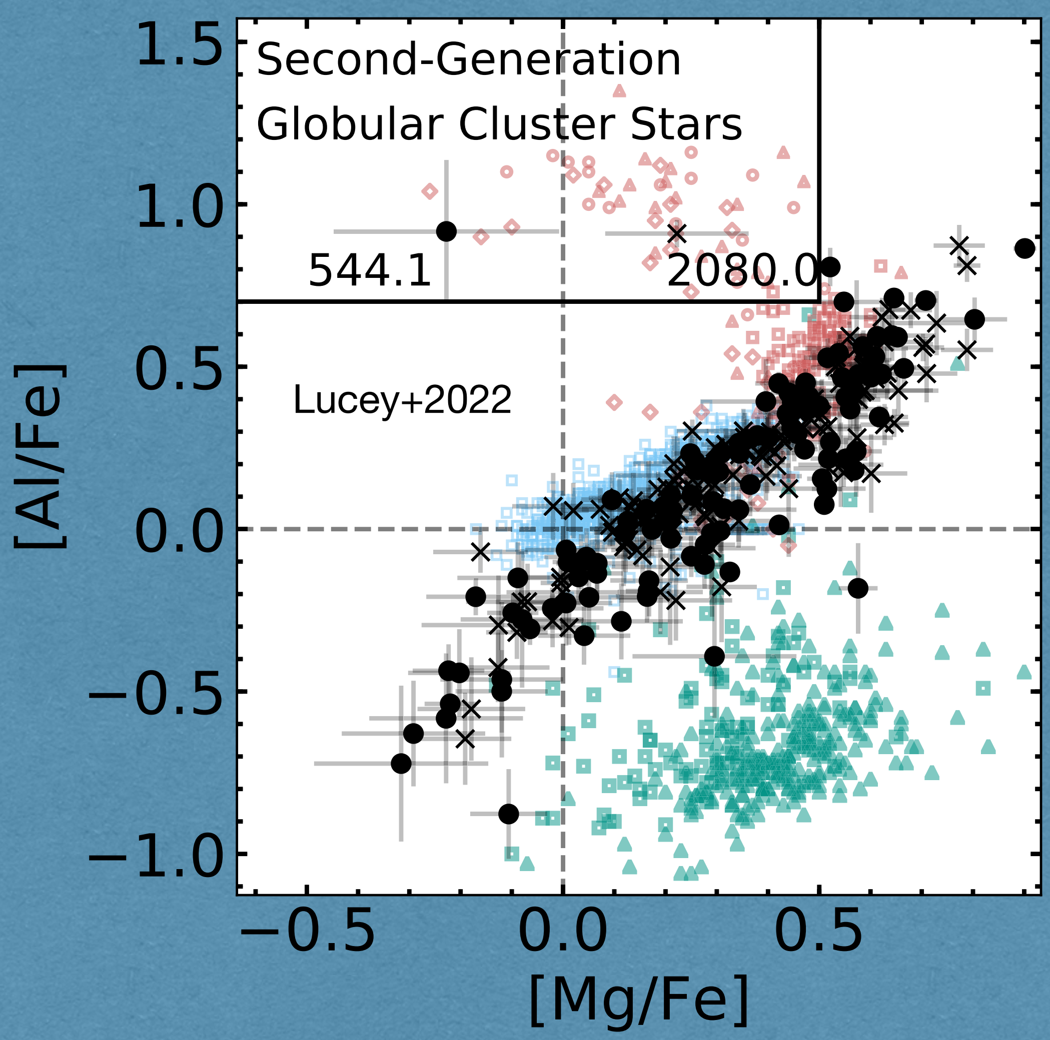
The N-rich stars are connected to the II generation stars from GCs

Ancient and dissolved GCs might constitute up to 25% of the building blocks of the inner galaxy

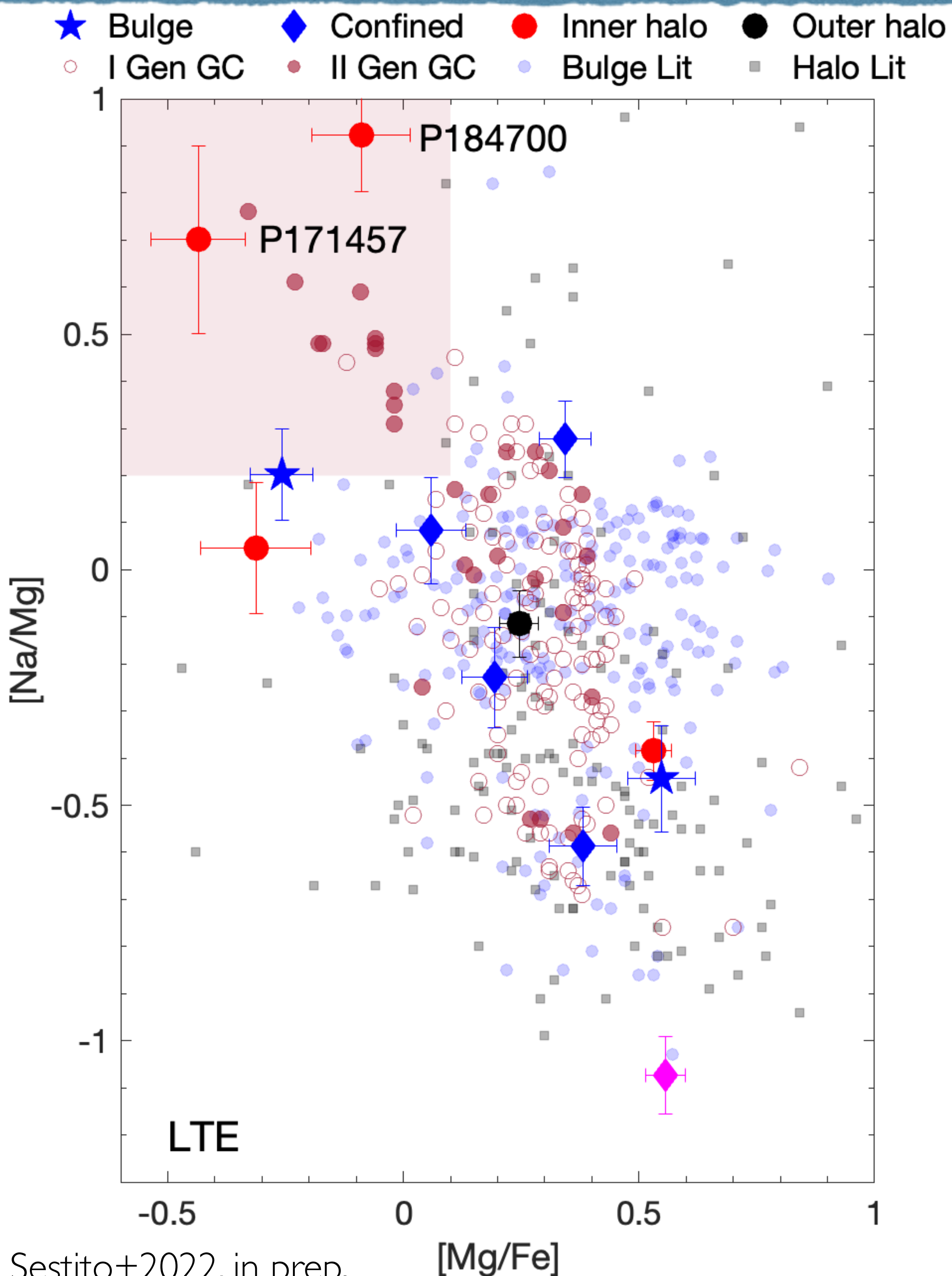
The connection with the second generation stars from globular clusters

Can we do the same with GRACES?
Only using Na and Mg

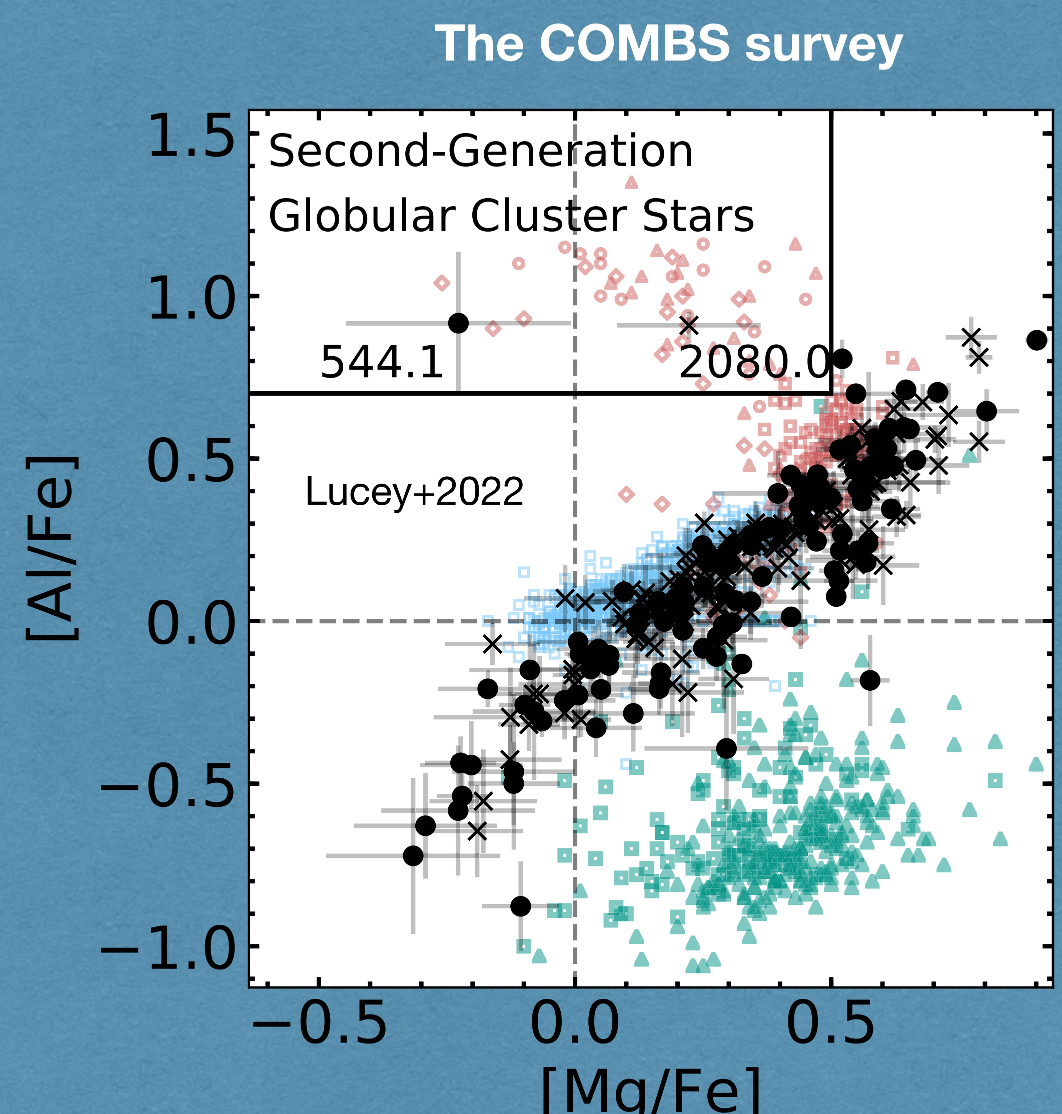
The COMBS survey



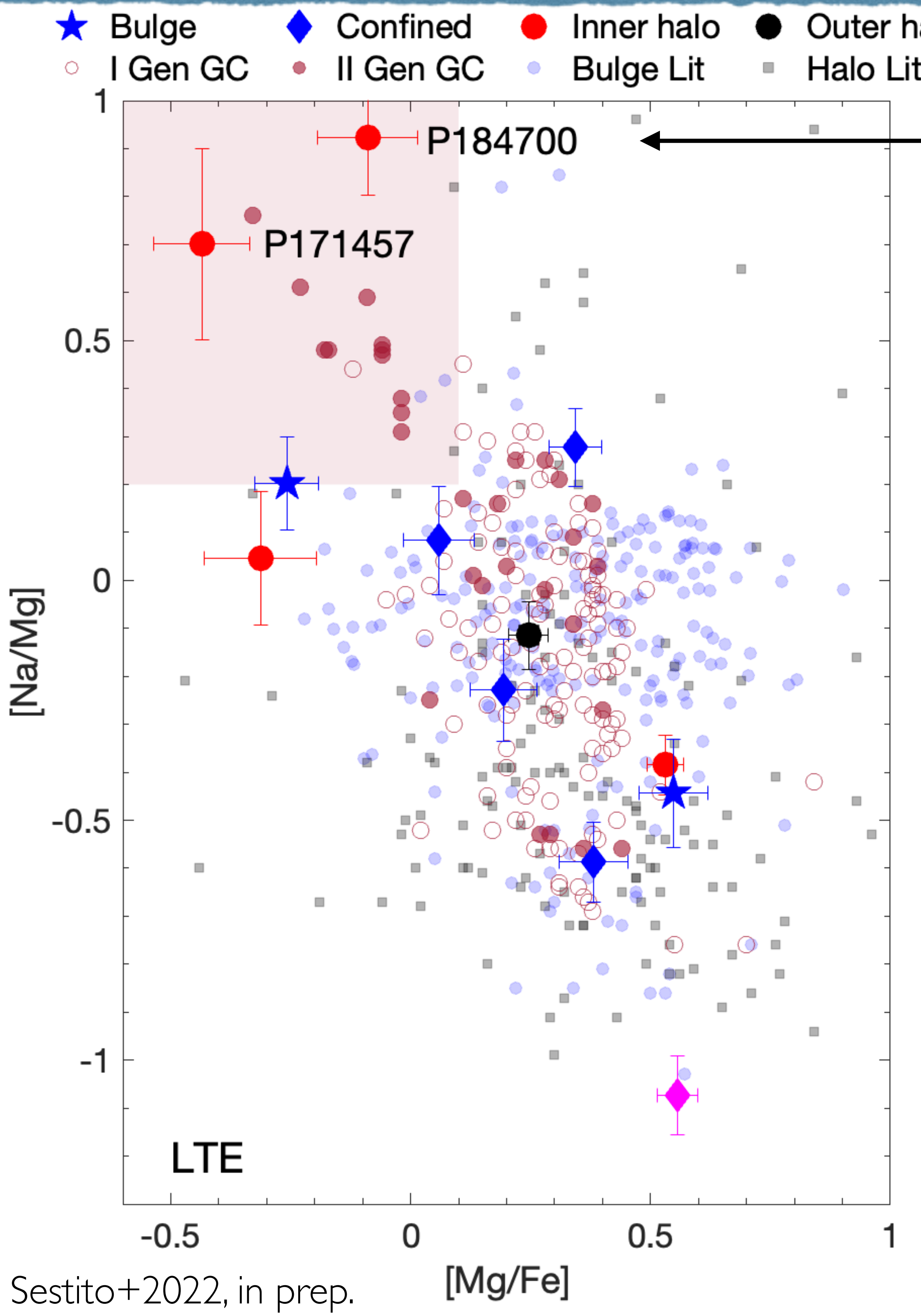
The connection with the second generation stars from globular clusters



Sestito+2022, in prep.



Rarity of binaries in globular clusters

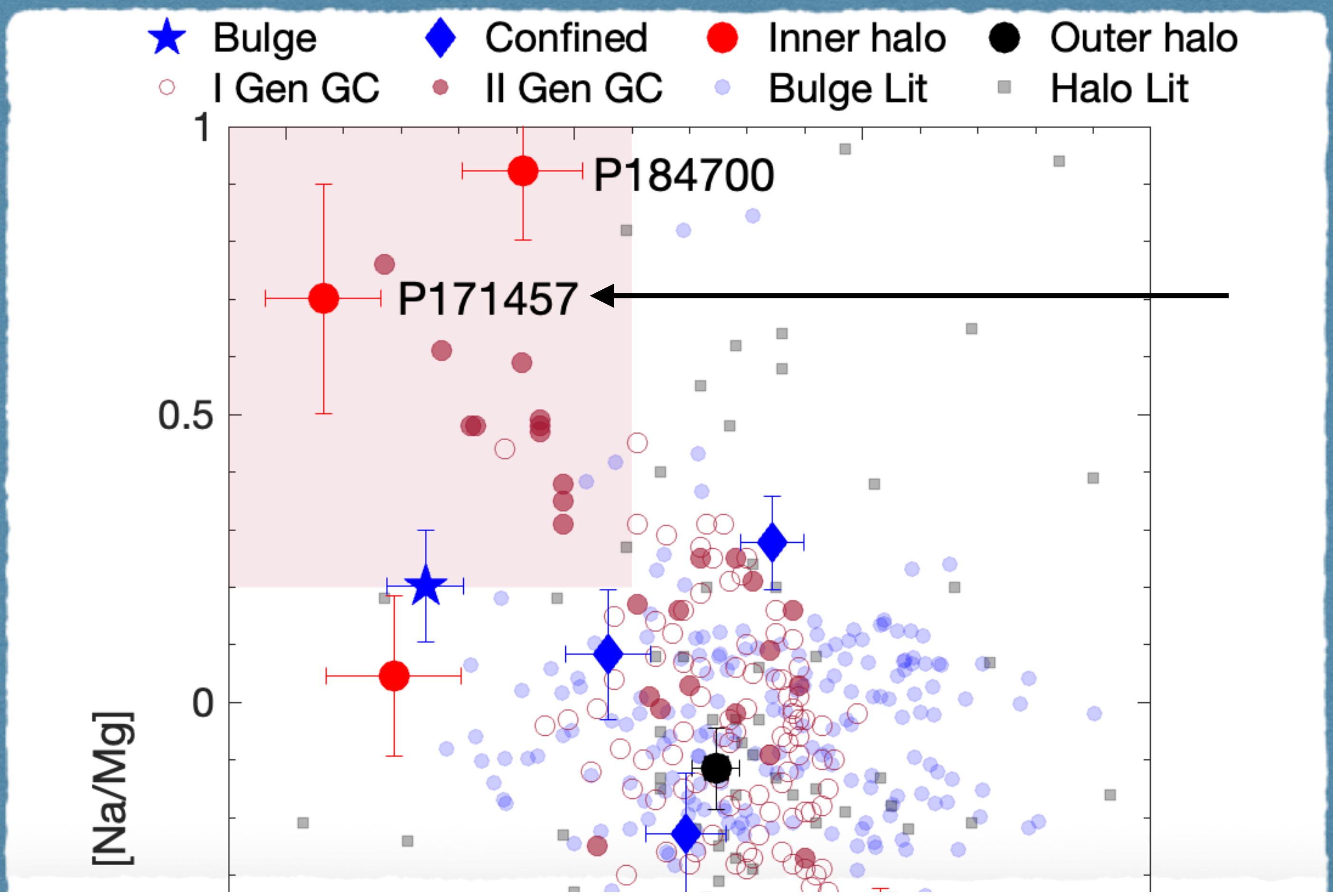


Sestito+2022, in prep.

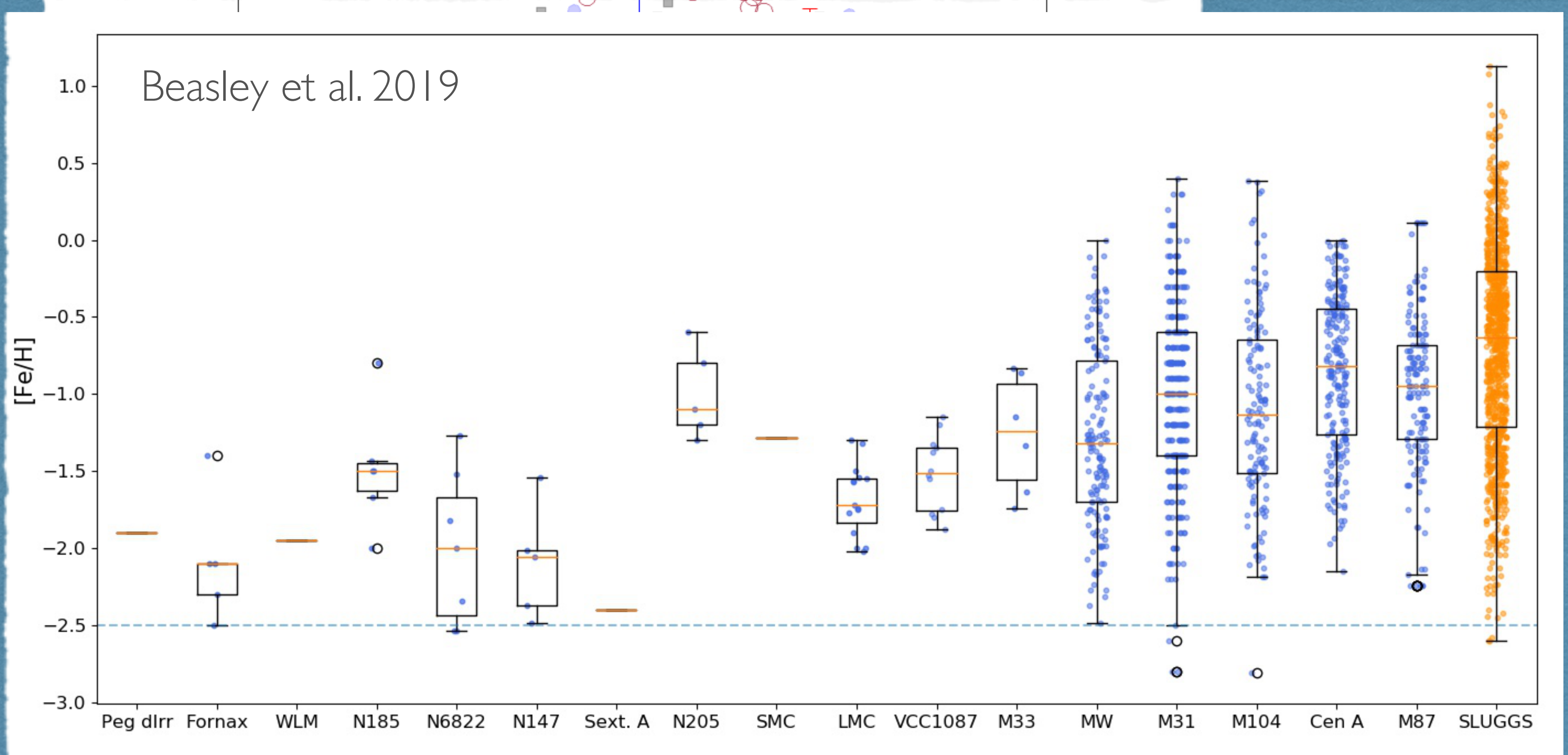
- ✦ C-enhanced
- ✦ Polluted by an AGB companion
- ✦ Na might be enhanced too.
- ✦ What about Mg?

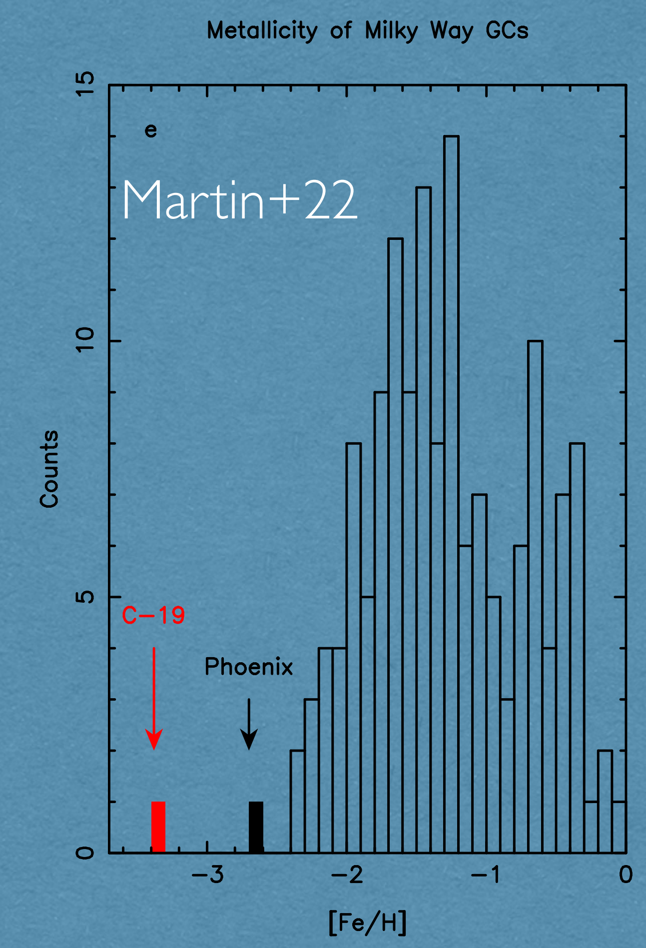
It is very rare to find such a star in GCs, since the rarity of binaries in high density regions (e.g. D'Orazi+10, Milone+12).

[Fe/H]~—3.2: Challenging the metallicity floor, again!



- ✦ Challenge the "Metallicity floor" for GCs
- ✦ [Fe/H] ~ to C-19, the most MP structure in the MW (Martin+22, Nature)





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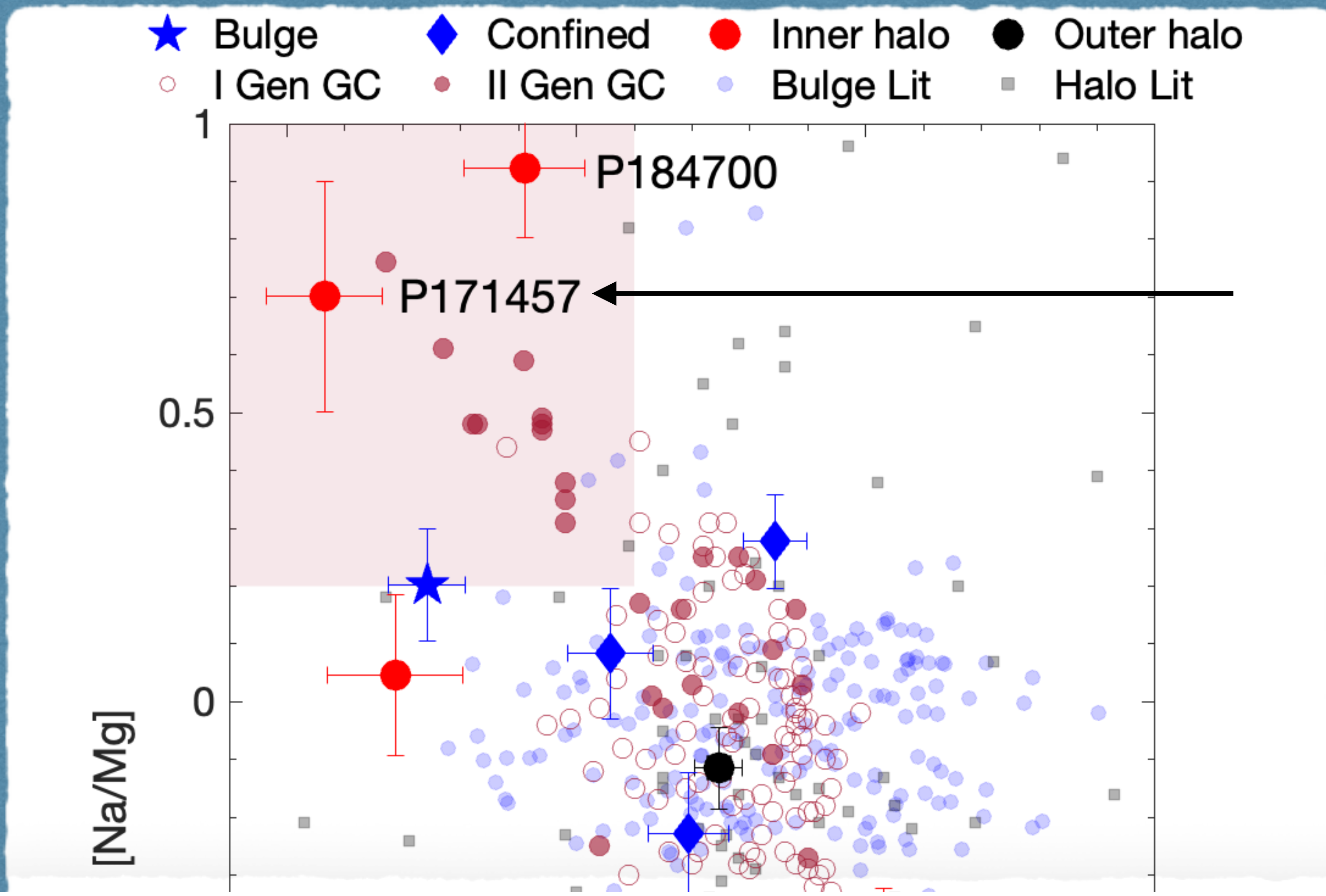
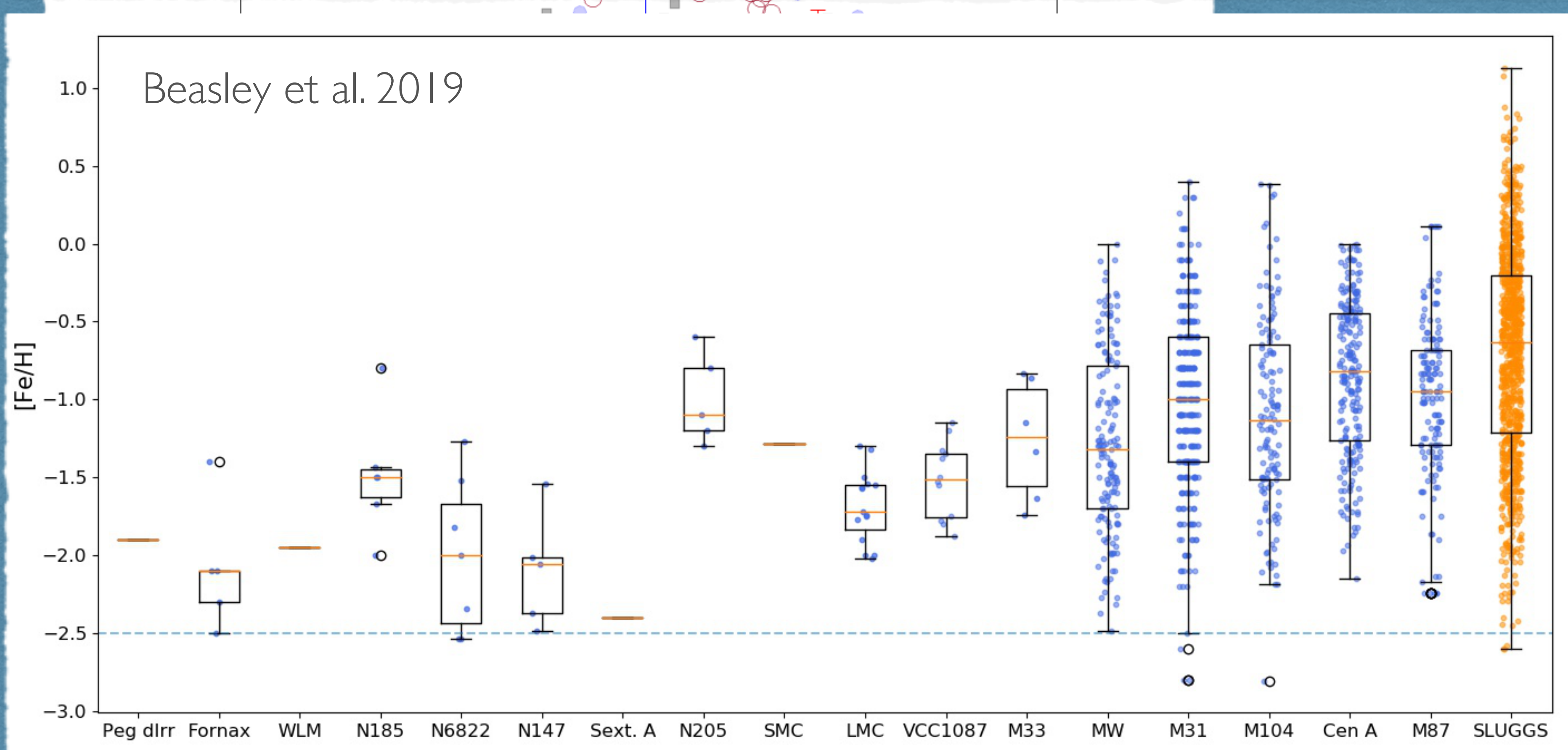
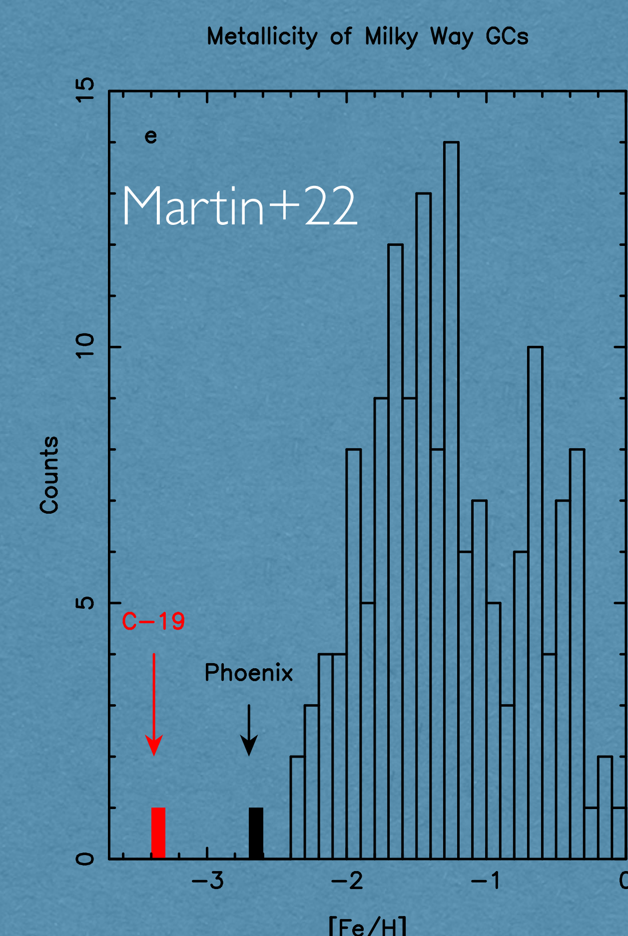
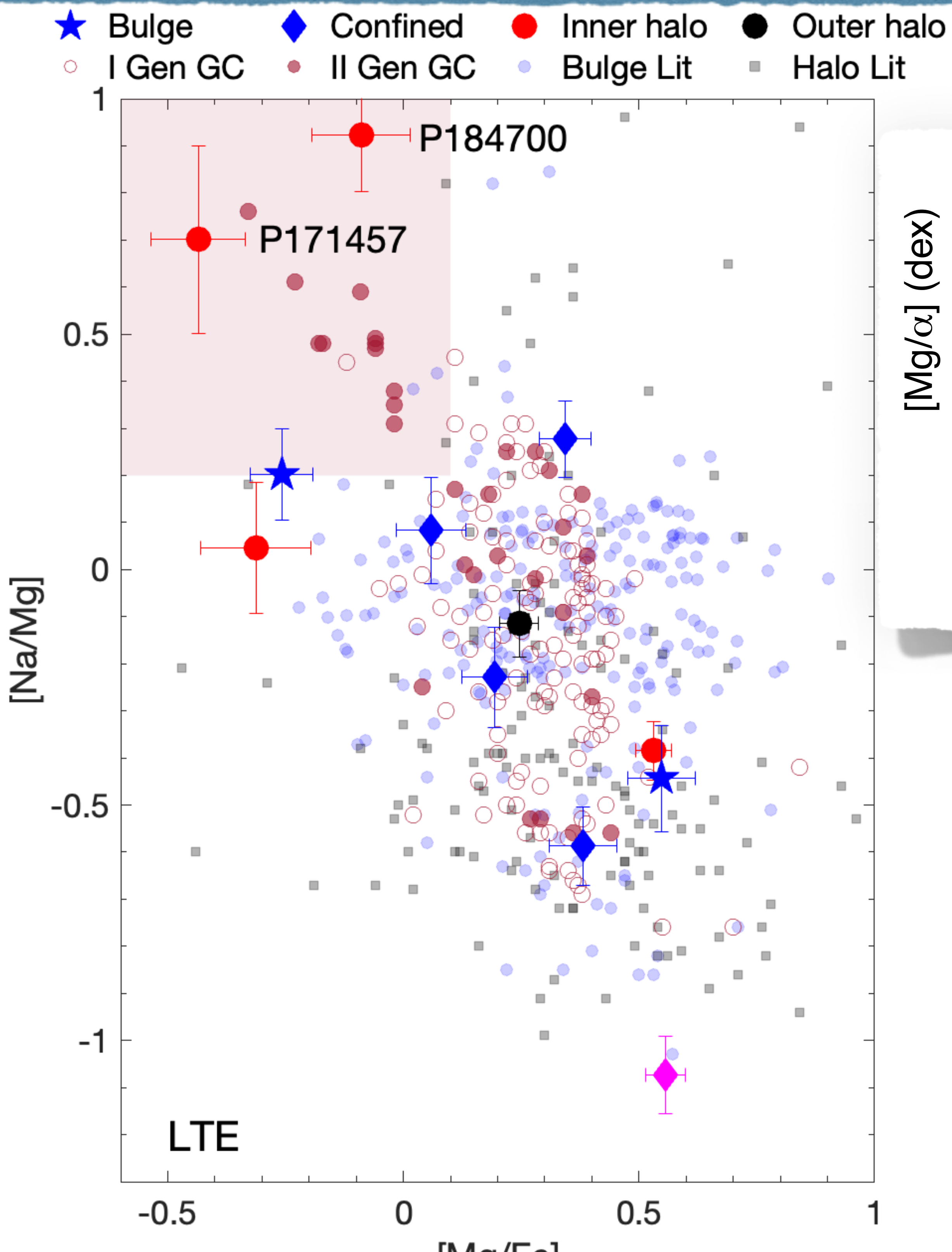


- Challenge the "Metallicity floor" for GCs
- [Fe/H] ~ to C-19
- [Fe/H] < —3 structures can form in the early Universe
- EMP stars are rare, EMP structures would be more rare
- Disrupted by tidal forces

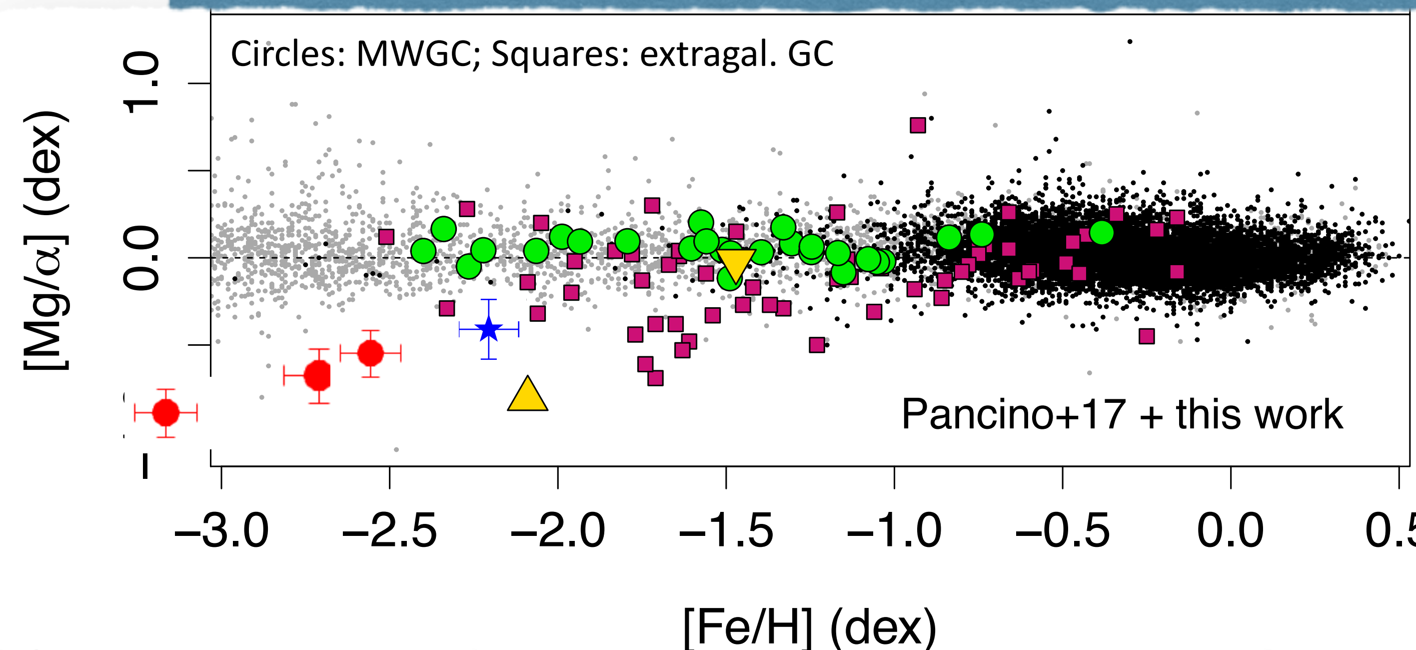




Ancient GCs are different from the MW ones?

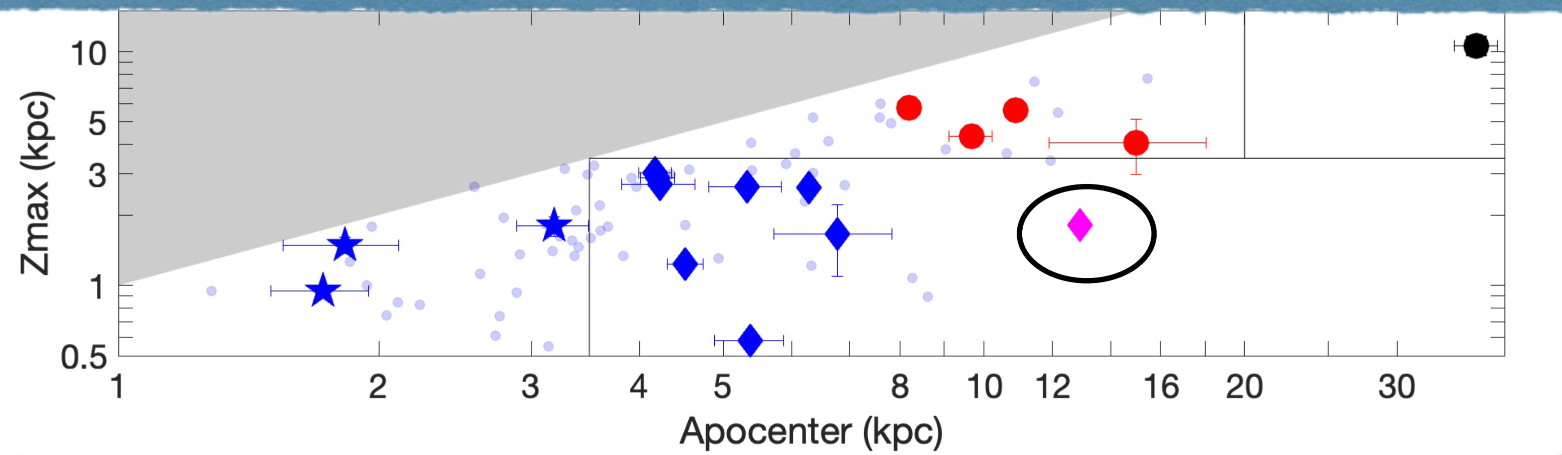


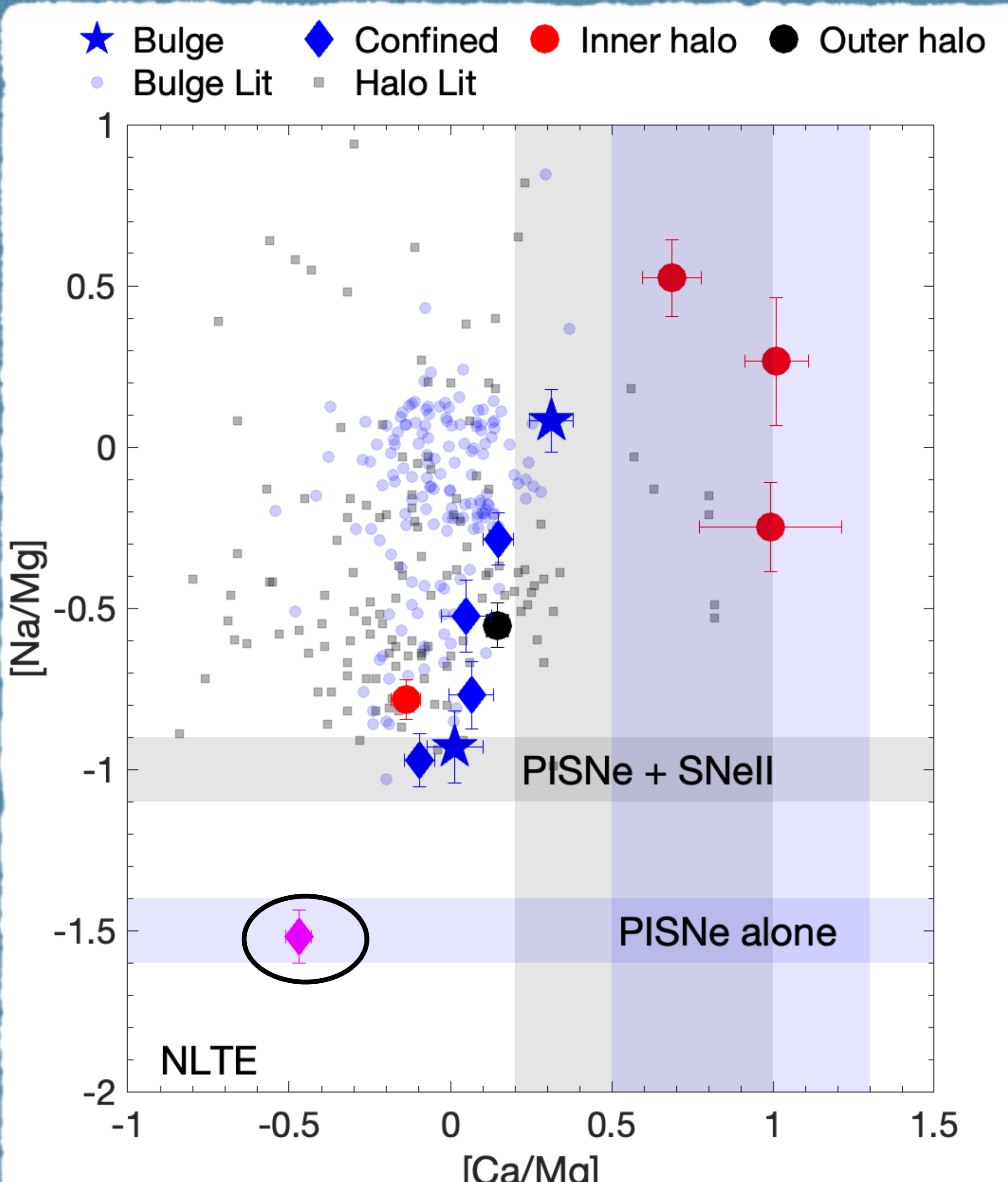
Sestito+2022, in prep.



If these stars were formed in accreted and dissolved GCs, this would indicate a different formation and evolution path than the GCs observed in the MW.

A building block polluted by only one low-mass supernova





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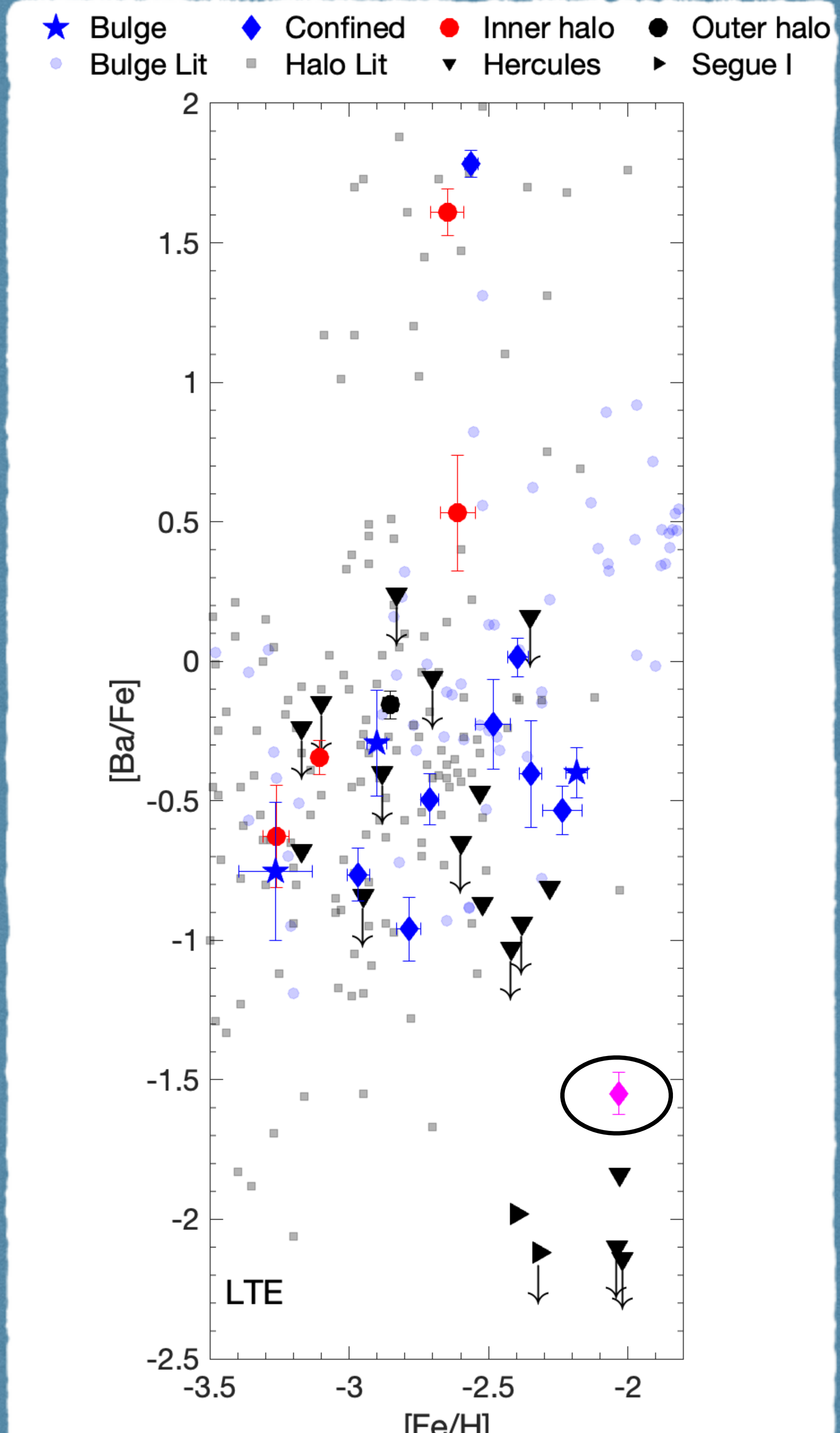
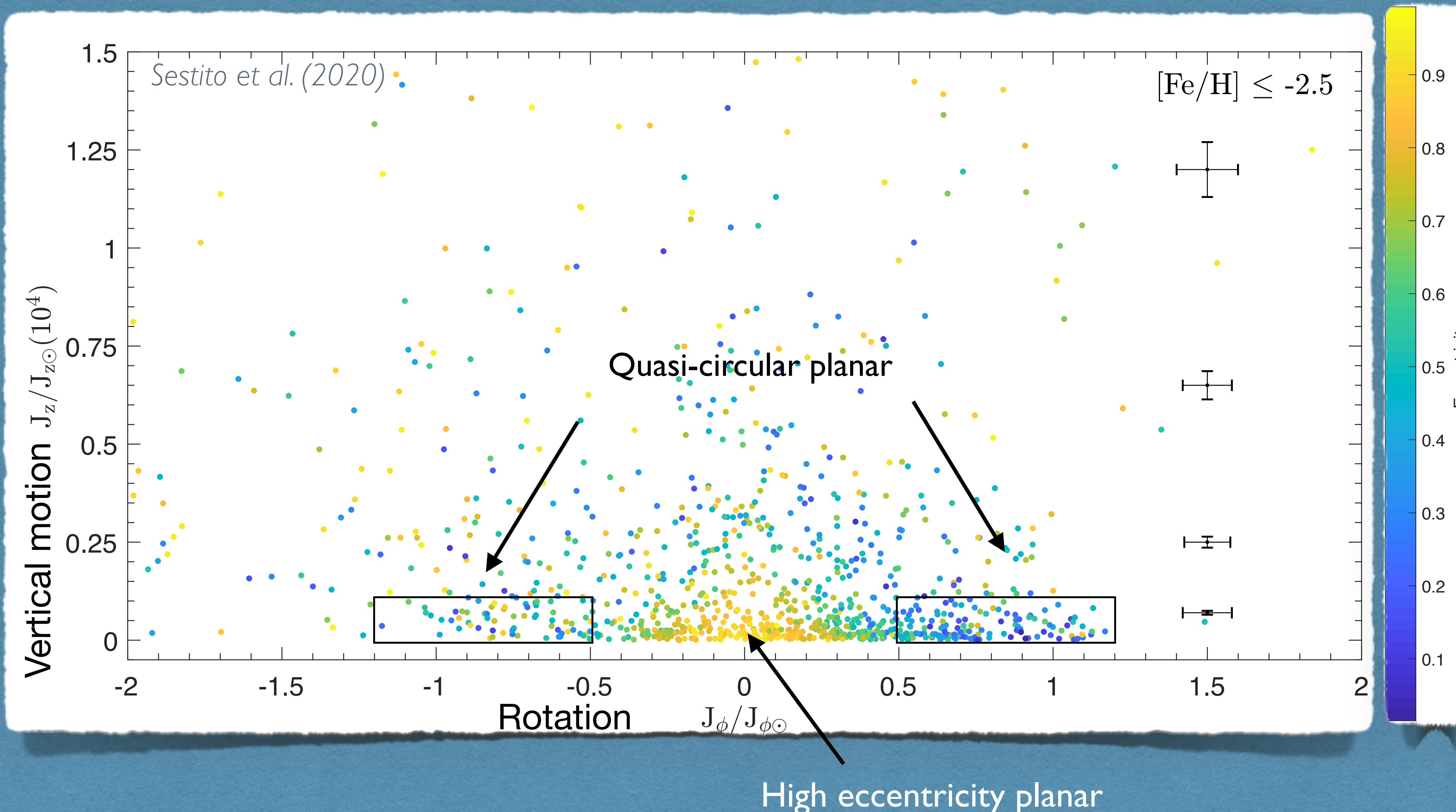


The interesting planar star: accreted early from a DG?



VMP with high eccentric planar orbits (no chemistry yet) found at all [Fe/H] (e.g. Sestito+19,20, Cordoni+21, Conroy+21).

Simulations suggest that they are accreted during the early MW assembly (Sestito+2021)

High-res is needed: Is this star part of one or multiple building blocks?

Take-home messages

➡ Very metal-poor stars (VMPs) are informative of the Milky Way assembly

➡ The majority of VMPs in the inner Galaxy is chemically similar to the halo

➡ This confirms the models of the hierarchical formation of the Galaxy

➡ Some stars are connected to II generation globular cluster stars

➡ These are also chemically similar to extragalactic GCs

➡ One star challenge the [Fe/H] floor for GCs: possibility to form EMP structures at early times

➡ The planar star suggests that one of the building blocks was similar to a UFD

➡ This has been polluted by only 1 or few low mass SNe

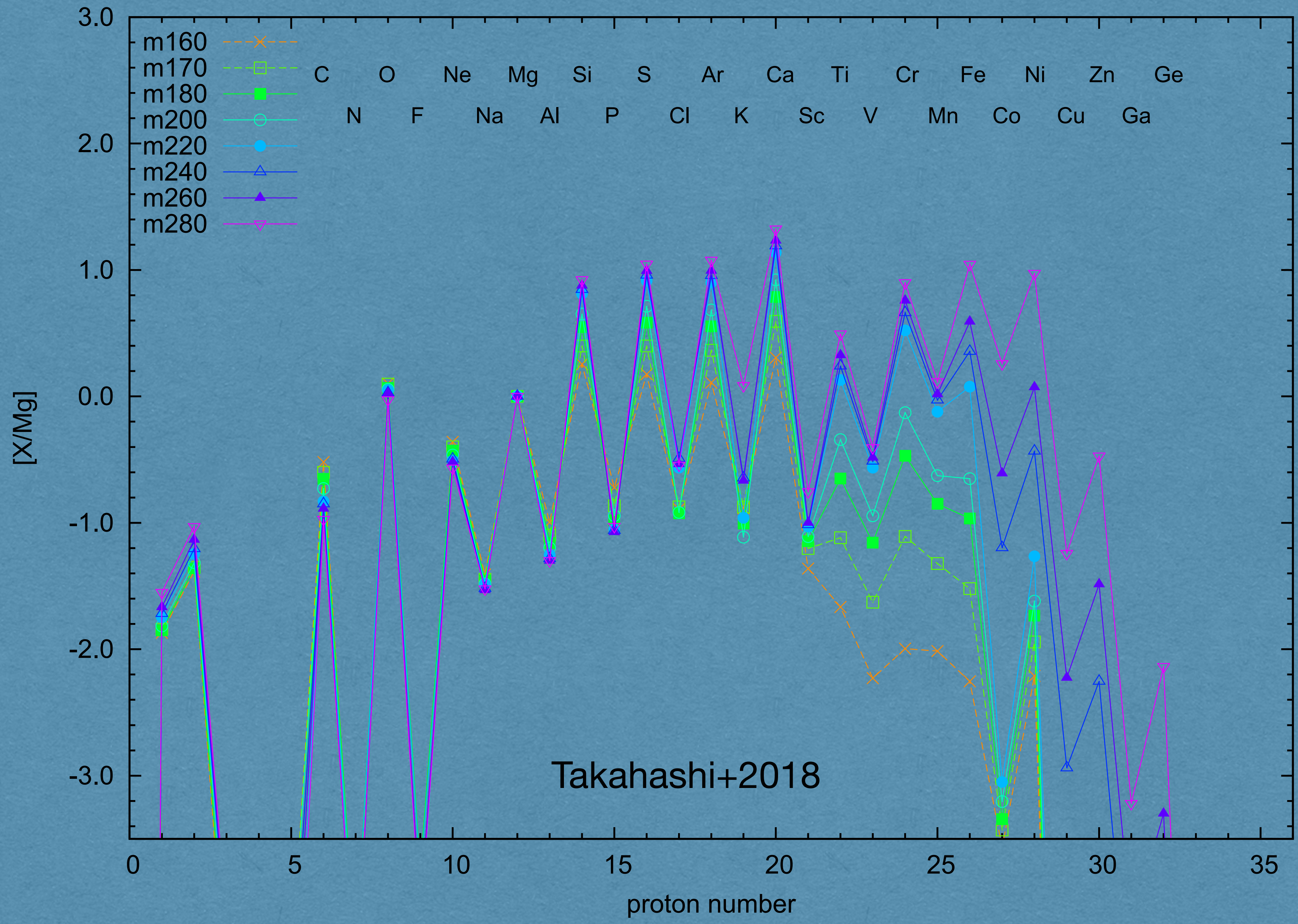
➡ Do we see a coherent planar-ish and eccentric structure accreted at early times?

UVic acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

Backup

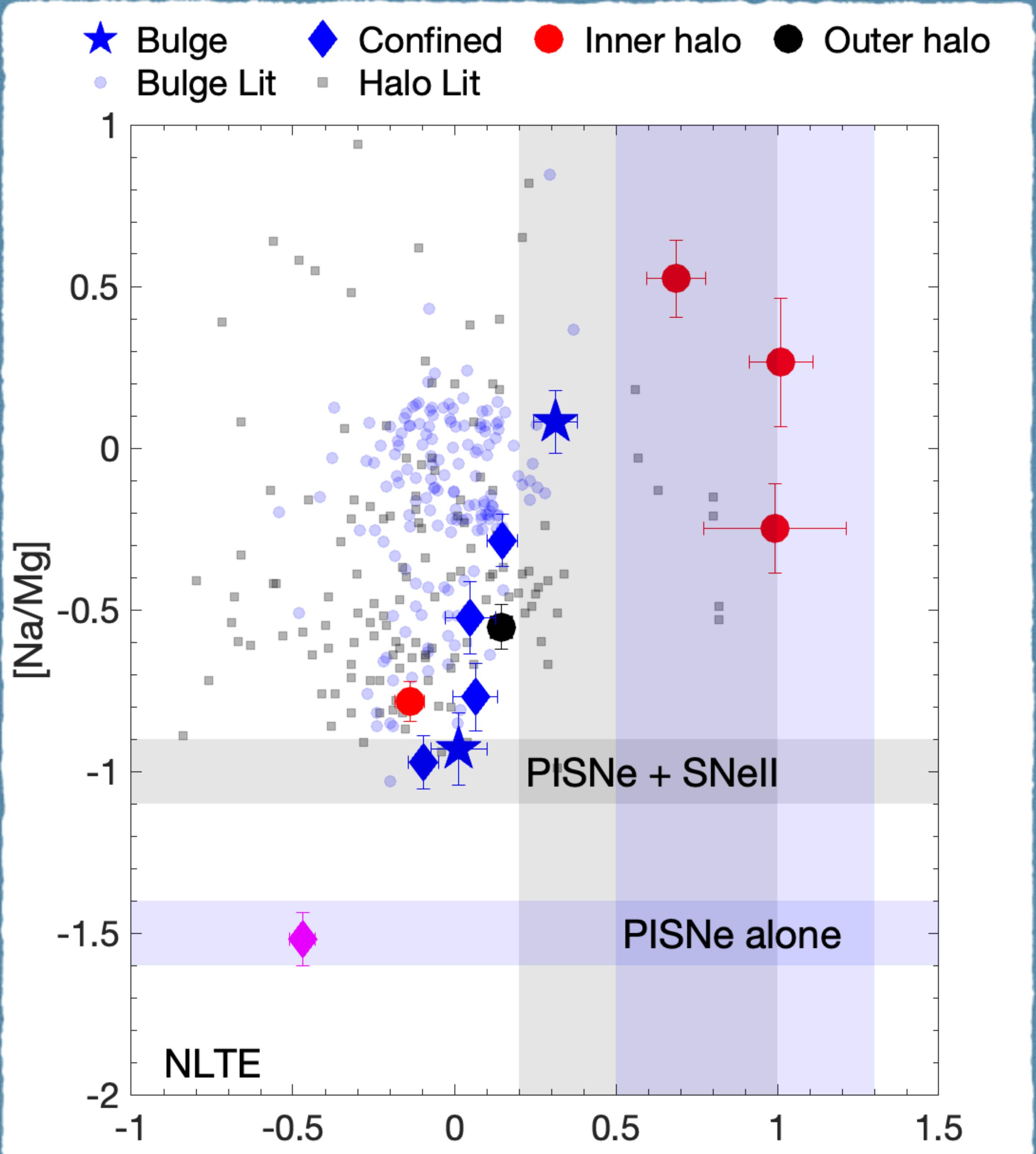
The formation site(s) polluted by Pair Instability SNe (PISNe)?

PISNe are predicted to be a common fate for the massive First Stars, therefore the next generation stars might carry the signature of PISNe



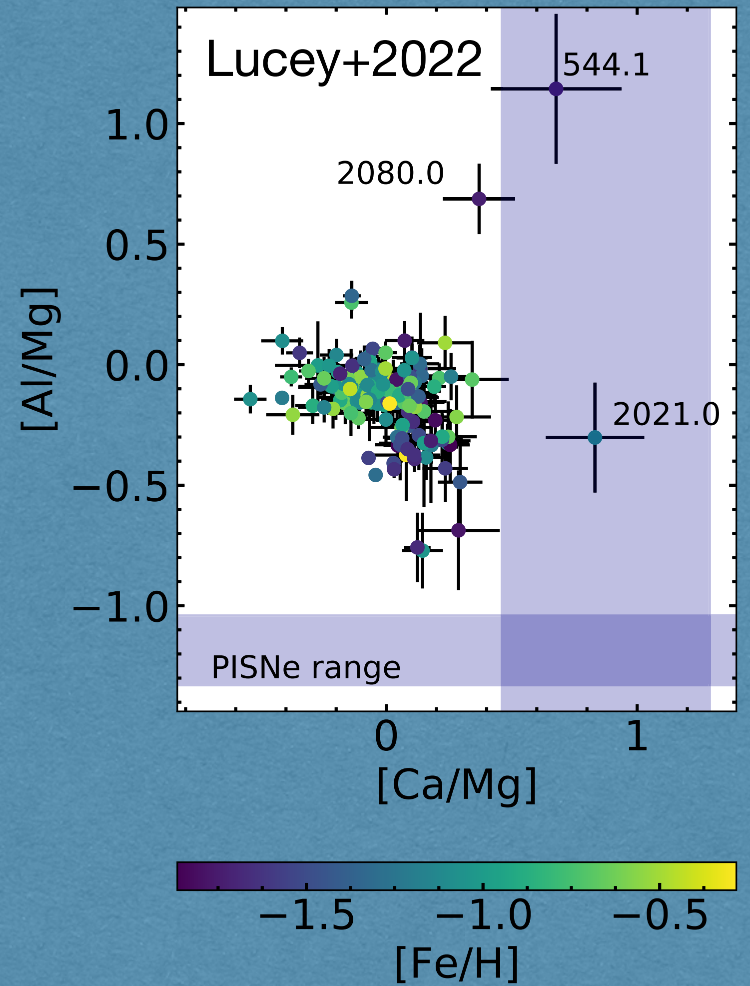
Some yields do not depend much on the PISNe mass

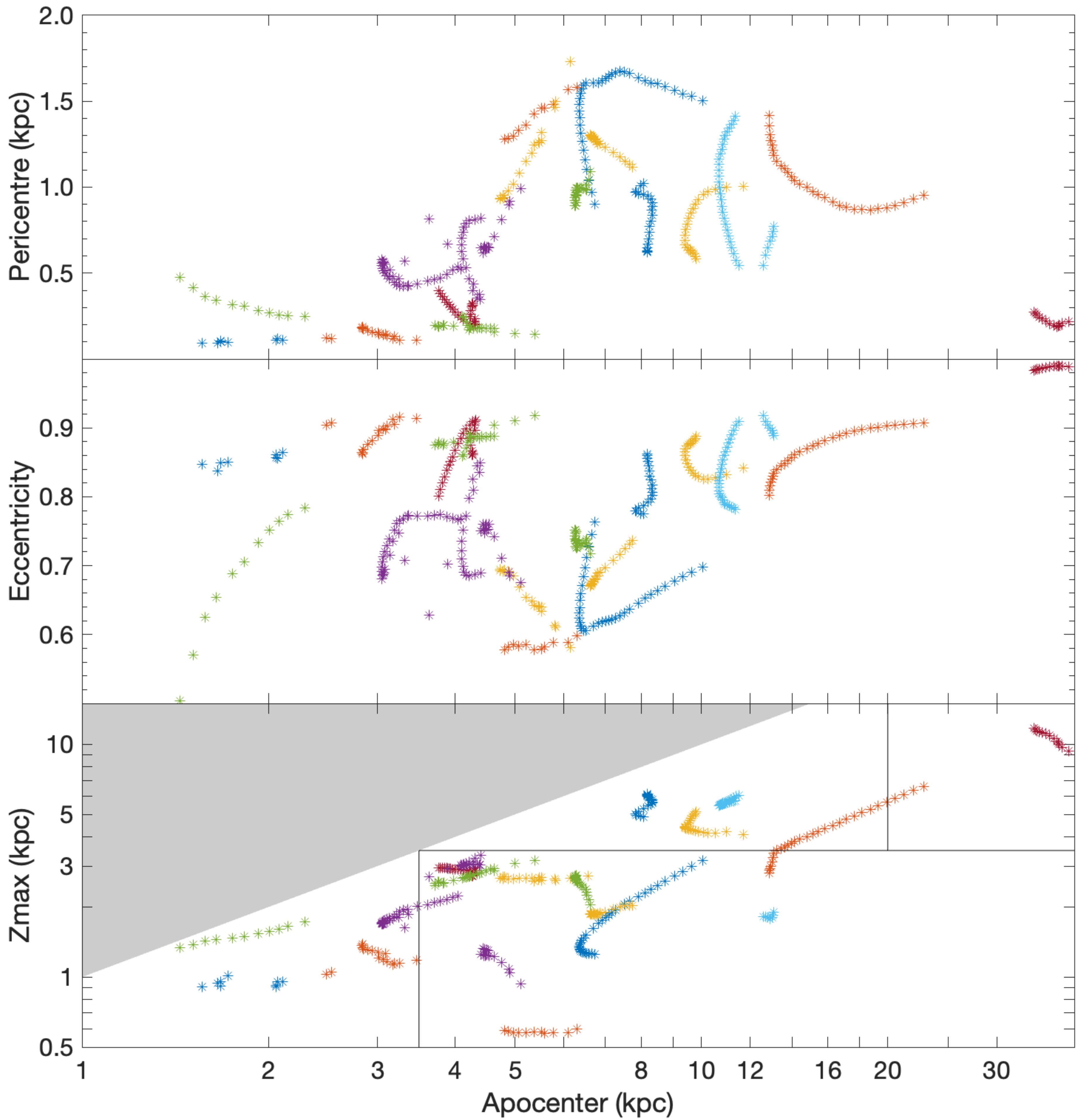
PISNe alone or PISNe + SNe? NaH!



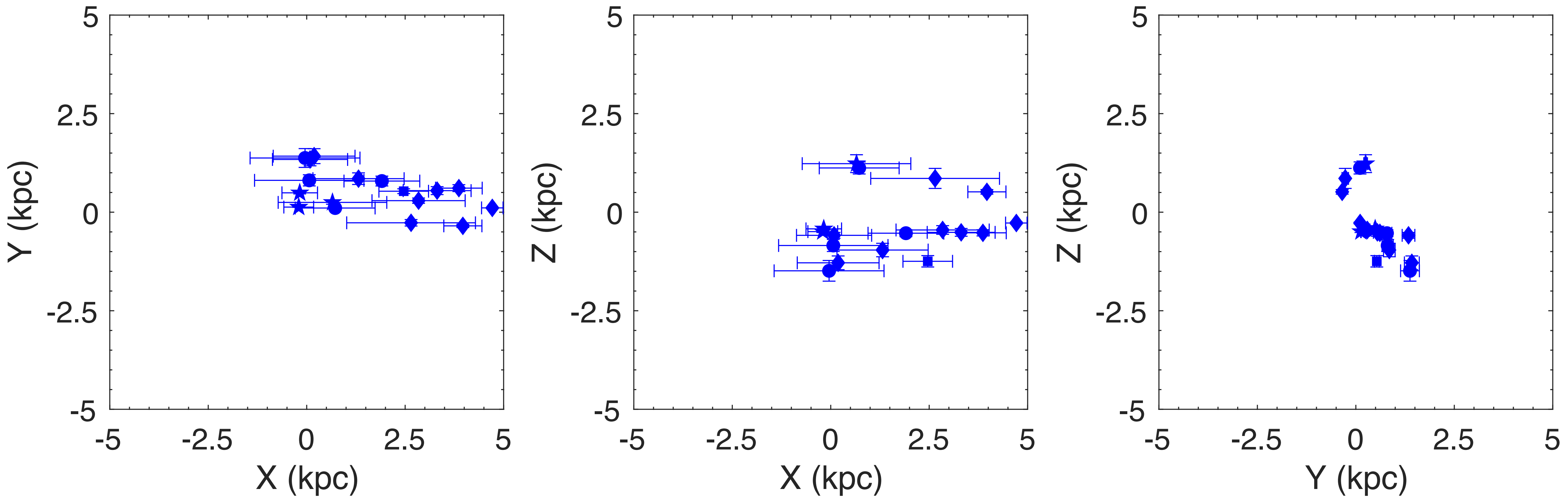
Sestito+2022, in prep.

The COMBS survey

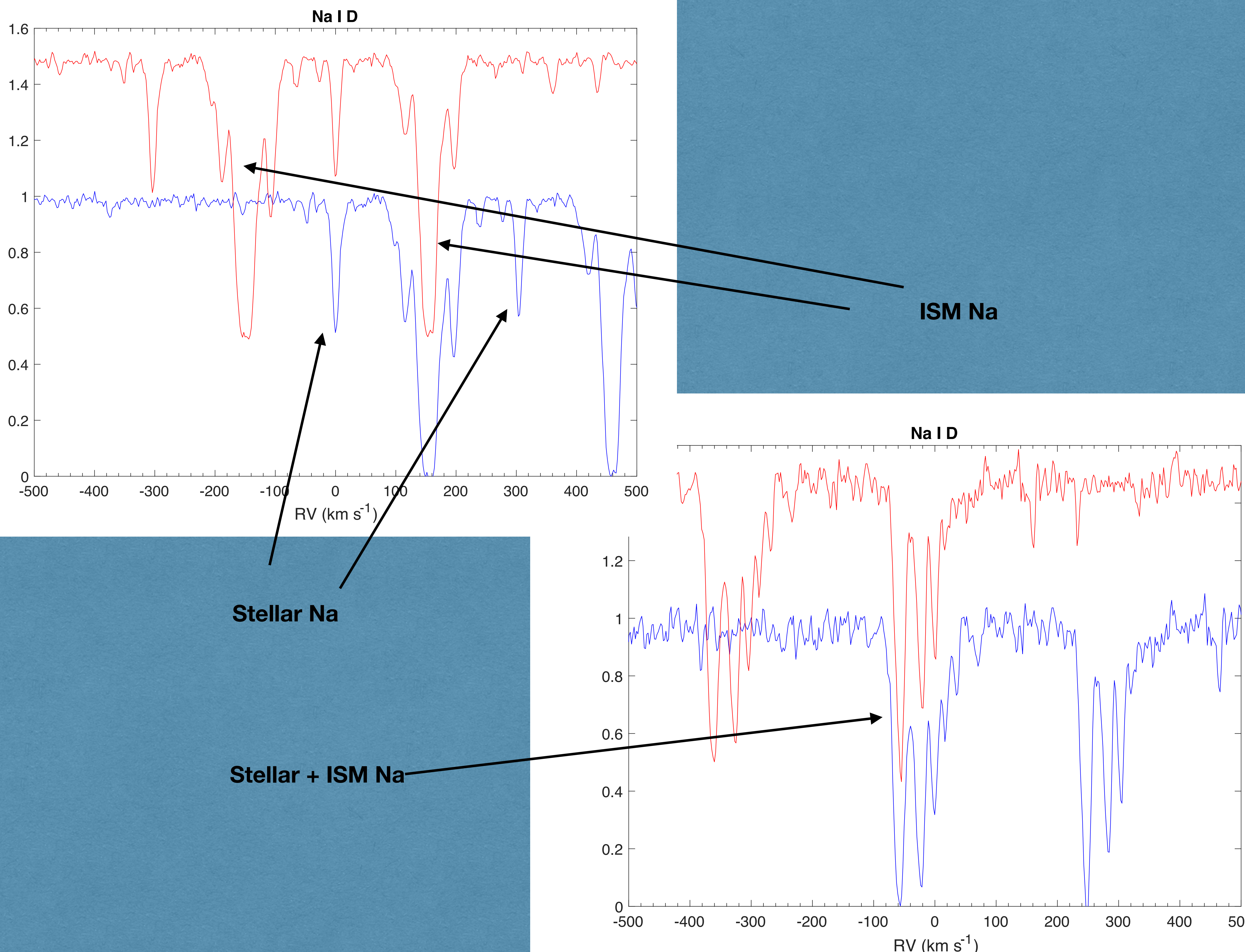




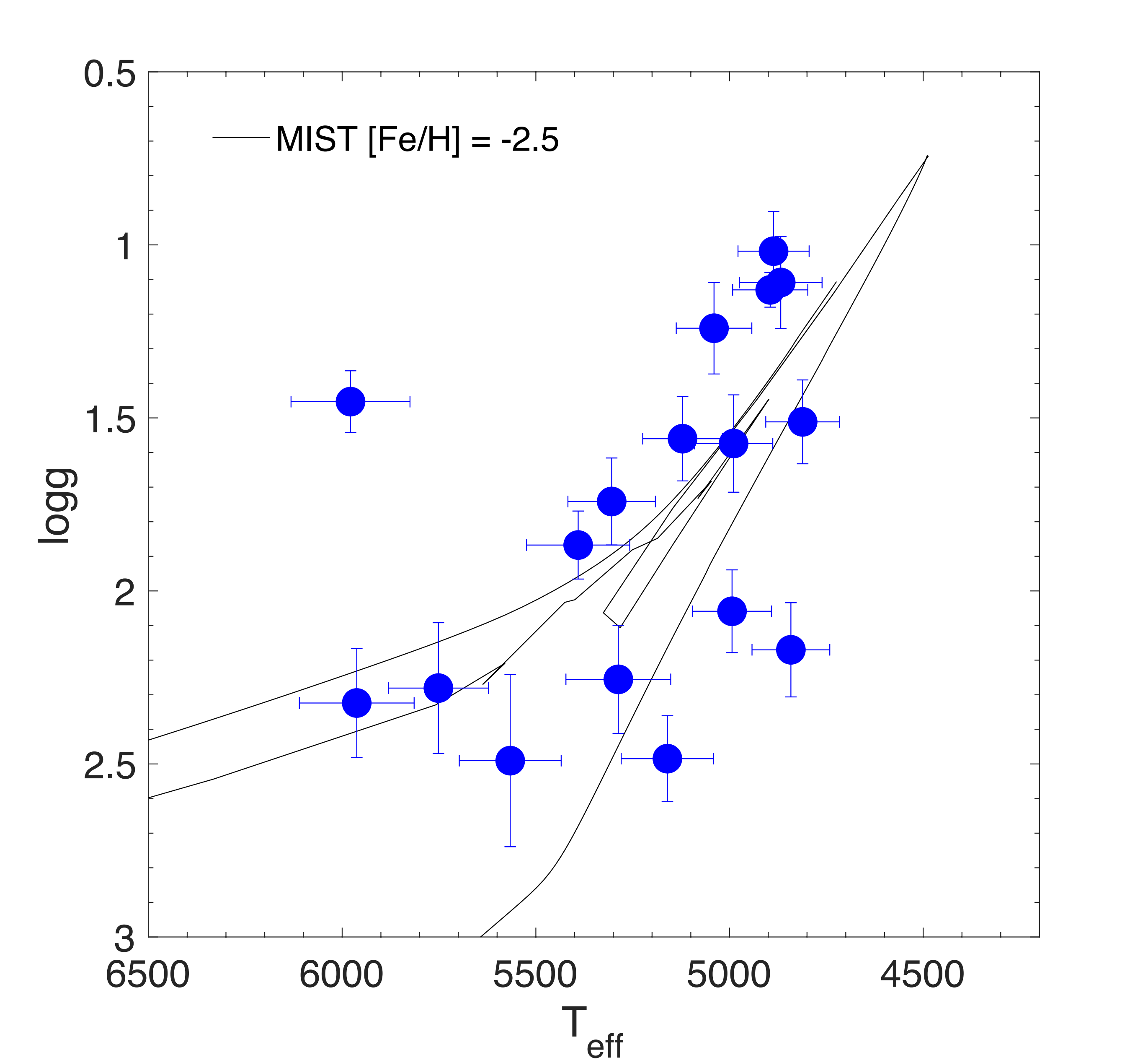
2.0
1.5
1.0
0.5
Pericentre (kpc)
0.9
0.8
0.7
0.6
Eccentricity
10
5
3
1
0.5
Zmax (kpc)
1
2
3
4
5
8
10
12
16
20
30
Apocenter (kpc)

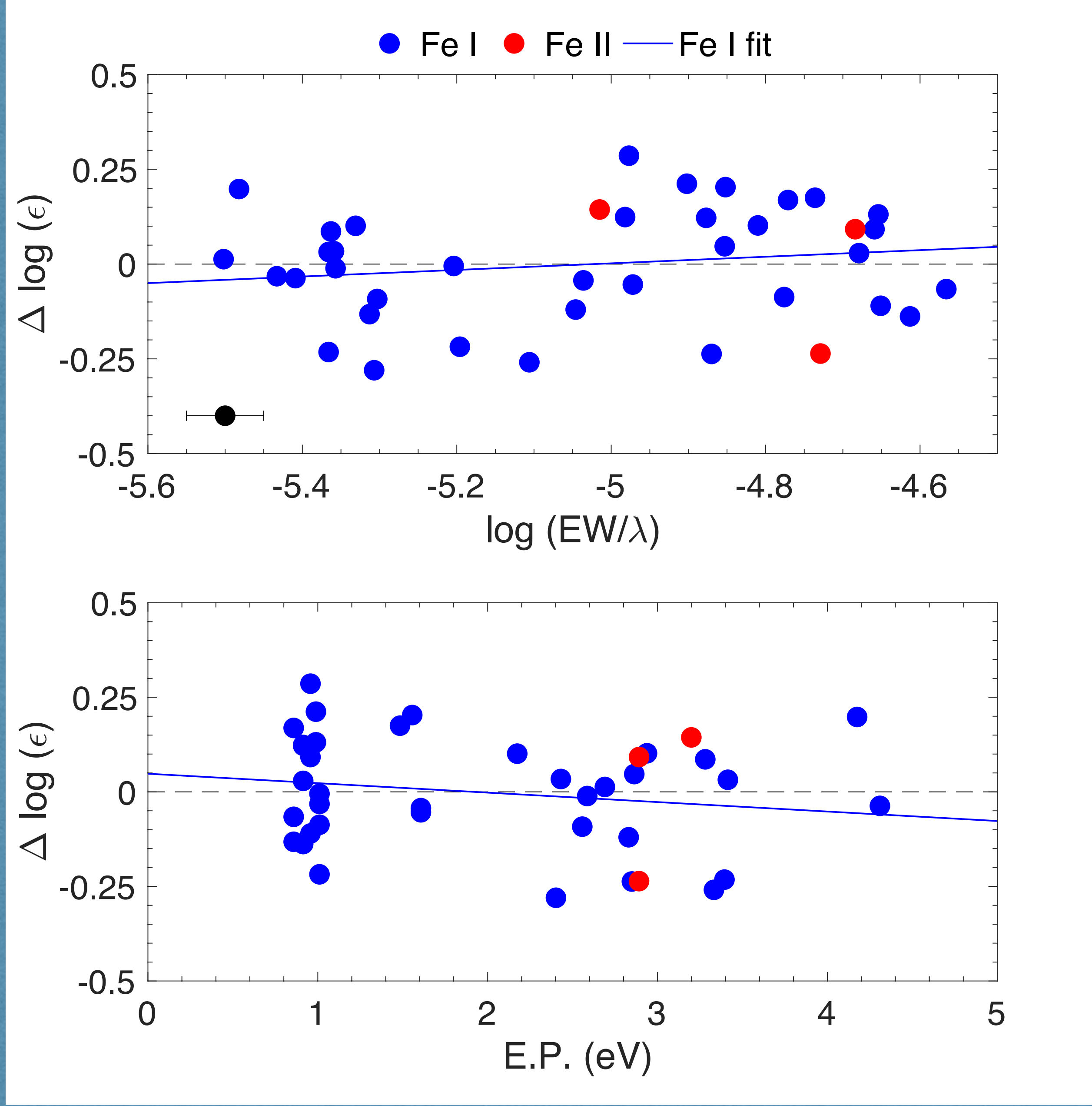


5
2.5
0
-2.5
-5
Y (kpc)
-5
-2.5
0
2.5
5
X (kpc)
Z (kpc)
X (kpc)
Z (kpc)
Y (kpc)

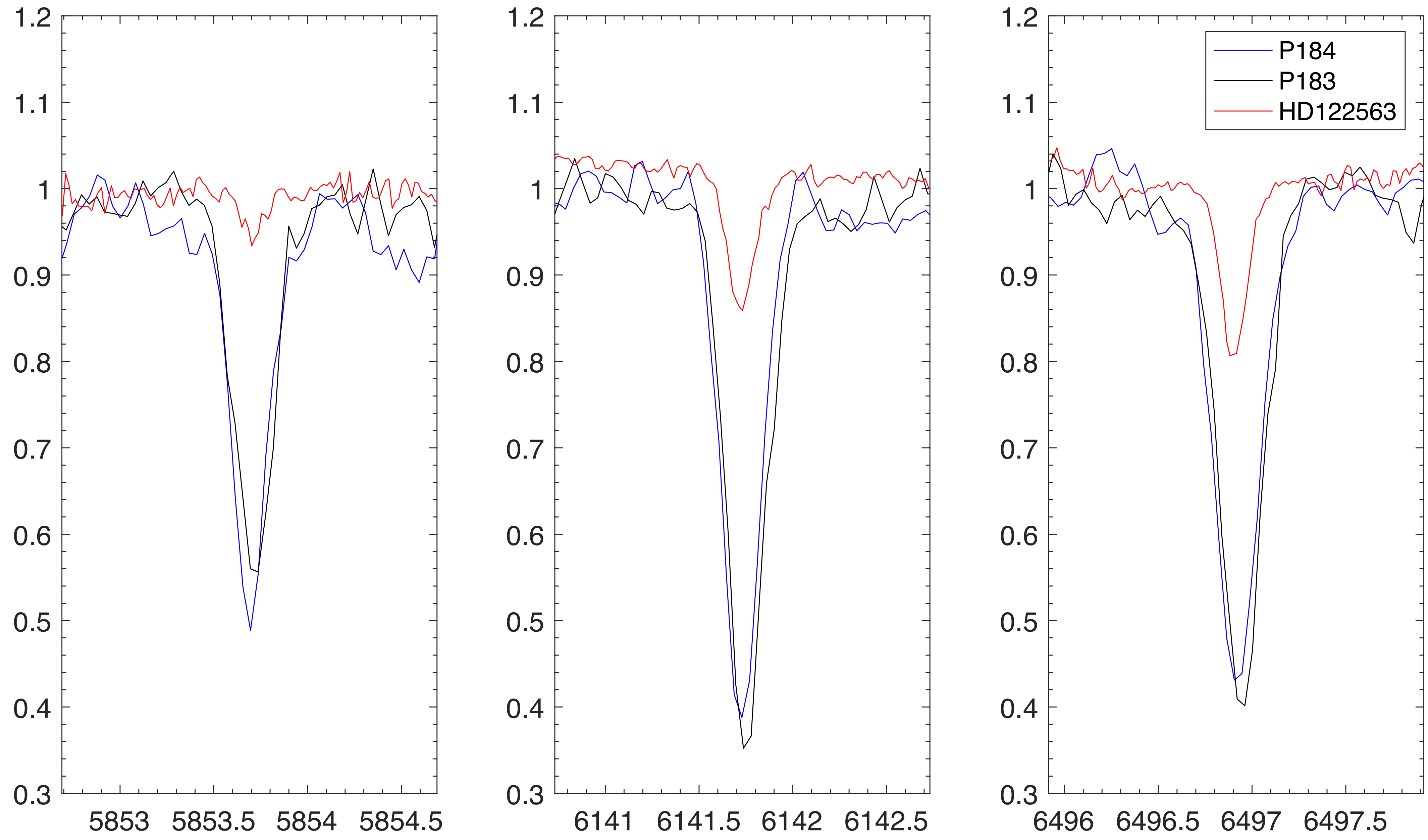


Na I D
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
RV (km s-1)
ISM Na
Stellar Na
Na I D
1.2
1
0.8
0.6
0.4
0.2
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
RV (km s-1)
Stellar + ISM Na





- ✦ Mucciarelli&Bellazzini Teff-Gaia colours relation
- ✦ Stefan-Boltzmann for logg
- ✦ Linelist for VMPs from Kielty+2021@GRACES
- ✦ EW with iraf, then Moog to get A(X)
- ✦ Check fit in Moog plots for microturbulence and temperature
- ✦ Fe I - Fe II (un)balance not applied (see Karovicova+2020)
- ✦ NLTE corrections from MPIA grid + Inspect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P184
P183
HD122563