The early chemical evolution of the Sagittarius dwarf galaxy

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University of Hertfordshire UH

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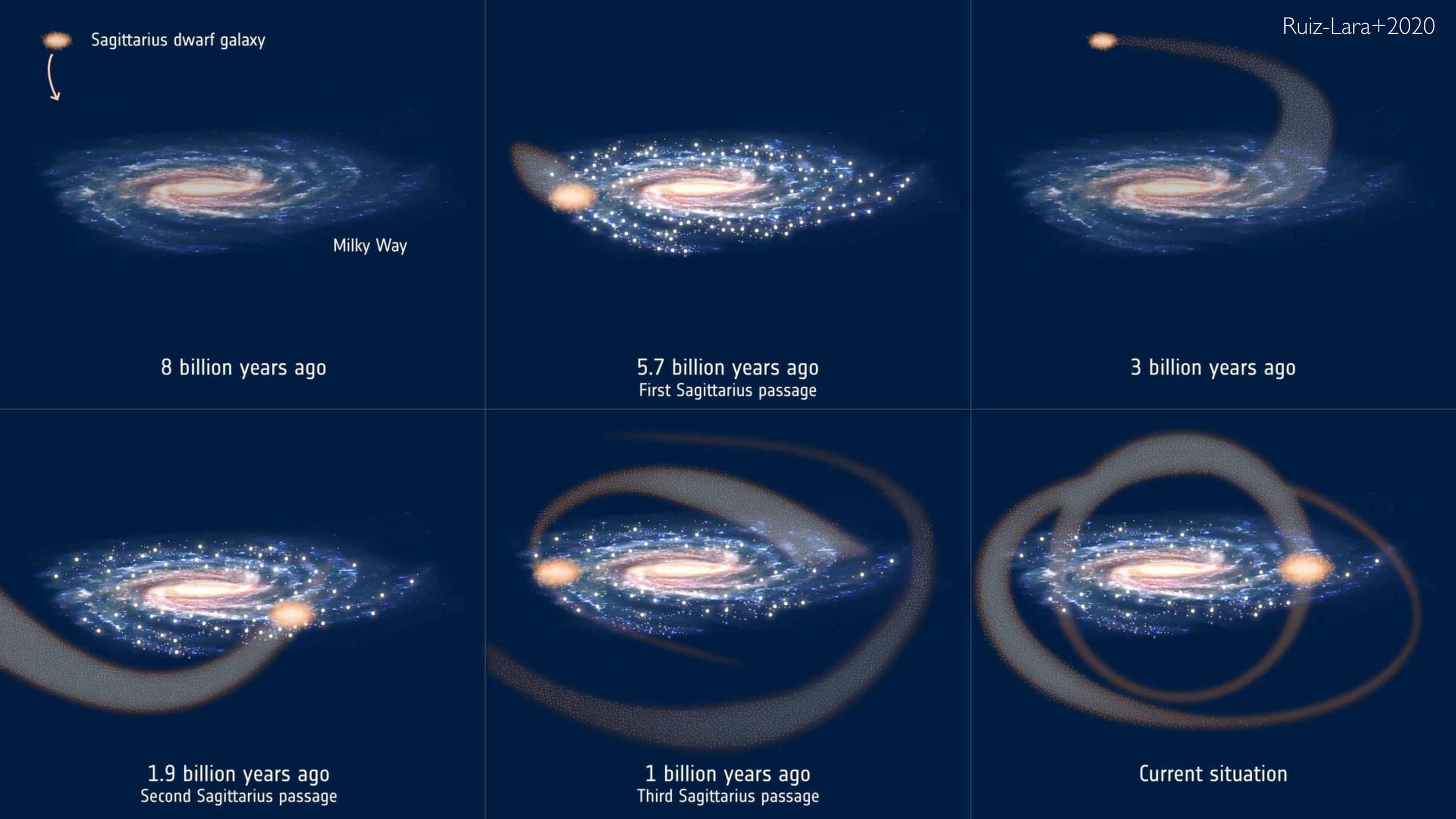
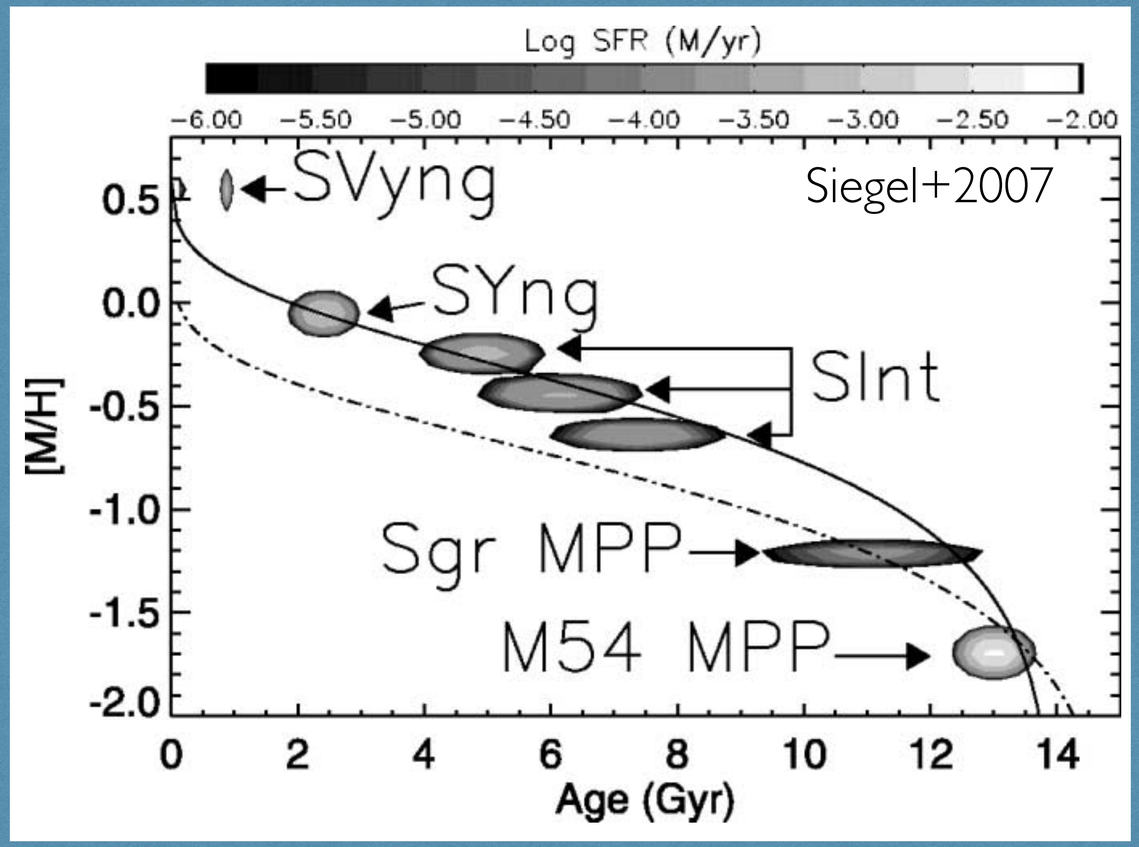

Ruiz-Lara+2020
Sagittarius dwarf galaxy
Milky Way
8 billion years ago
5.7 billion years ago
First Sagittarius passage
3 billion years ago
1.9 billion years ago
Second Sagittarius passage
1 billion years ago
Third Sagittarius passage
Current situation

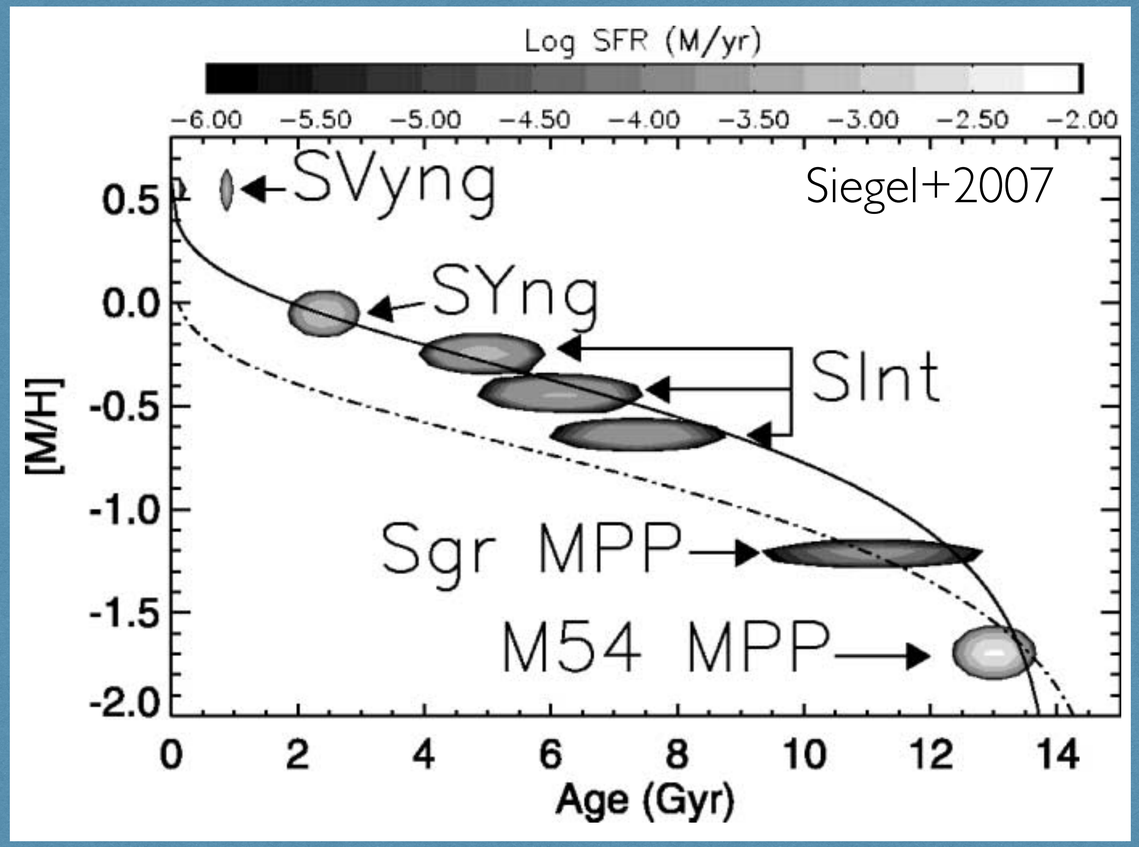
The oldest stars to explore the early chemical evolution of Sagittarius

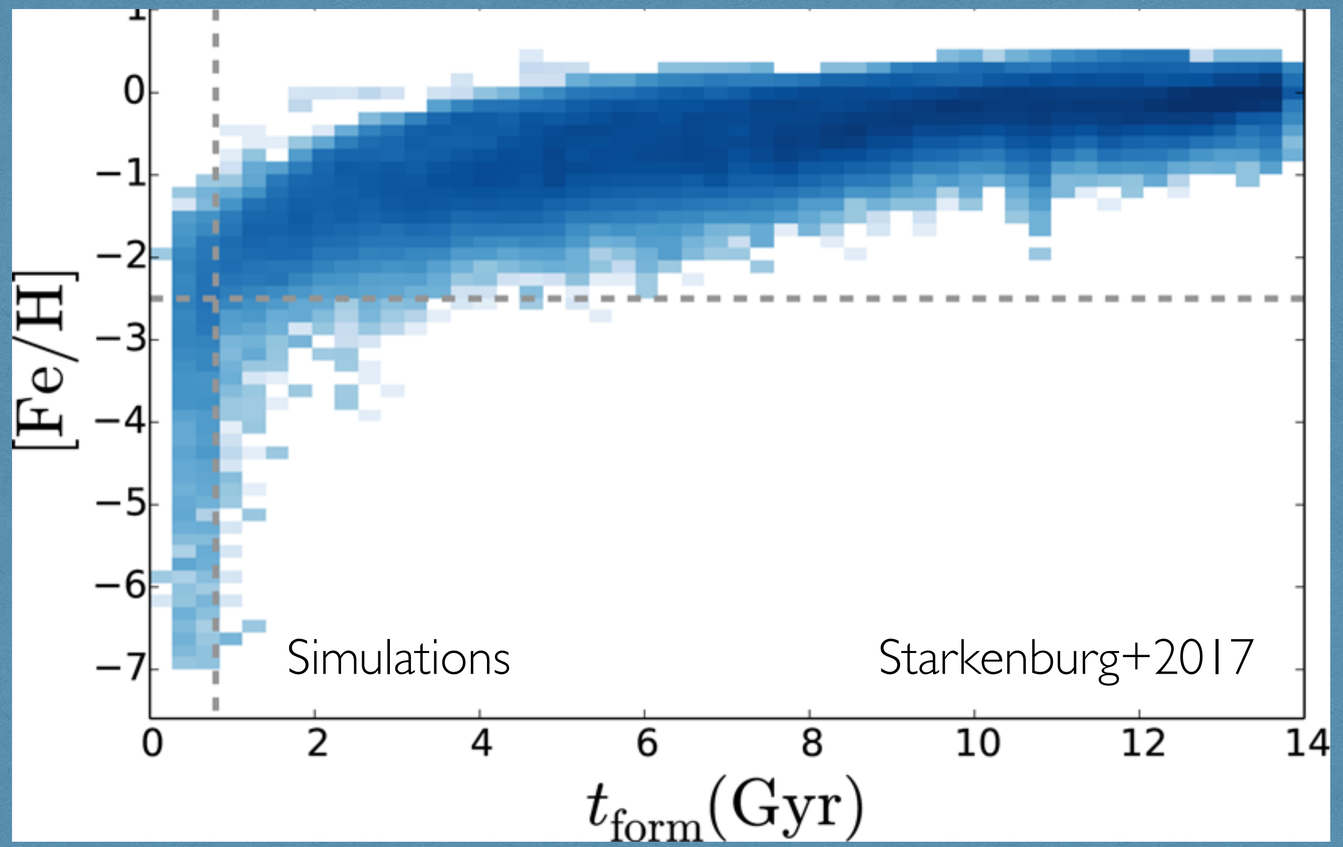


- Multiple bursts of star formation
- Old stars → glimpse into early evolution
- Precise stellar ages: difficult to measure

How to solve this problem?

Let's use metallicity to explore the oldest part of Sagittarius!

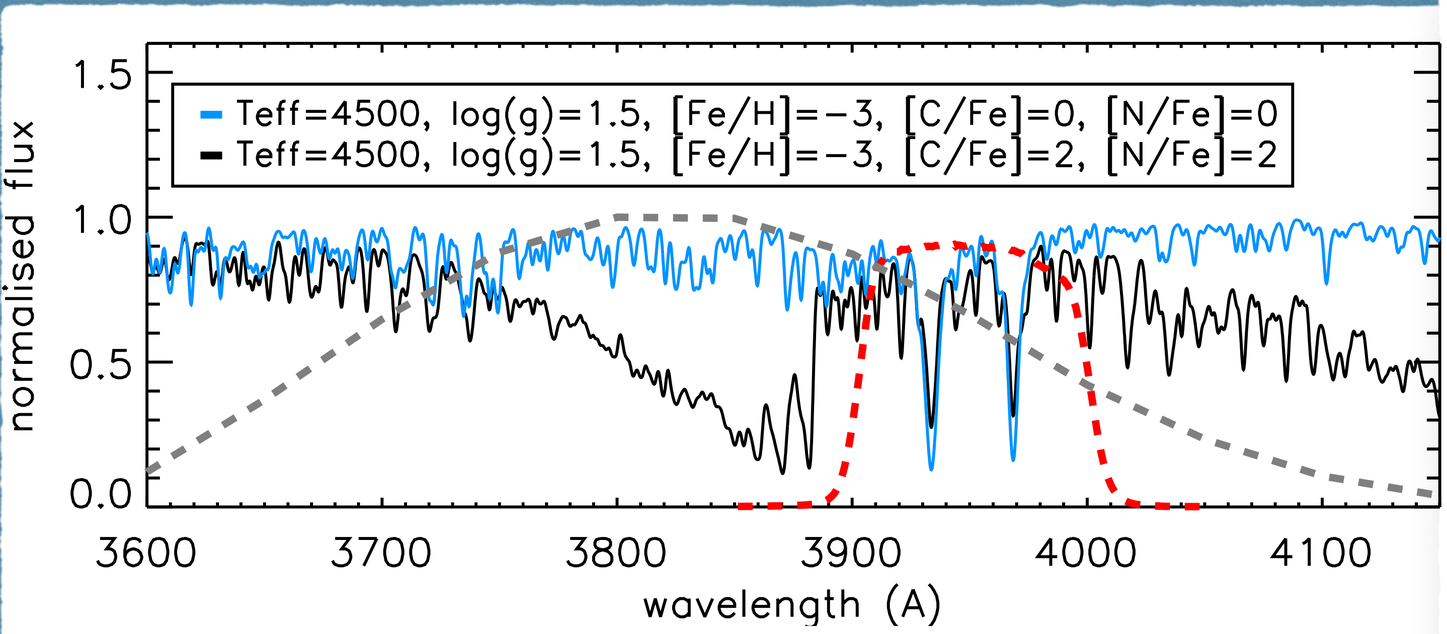


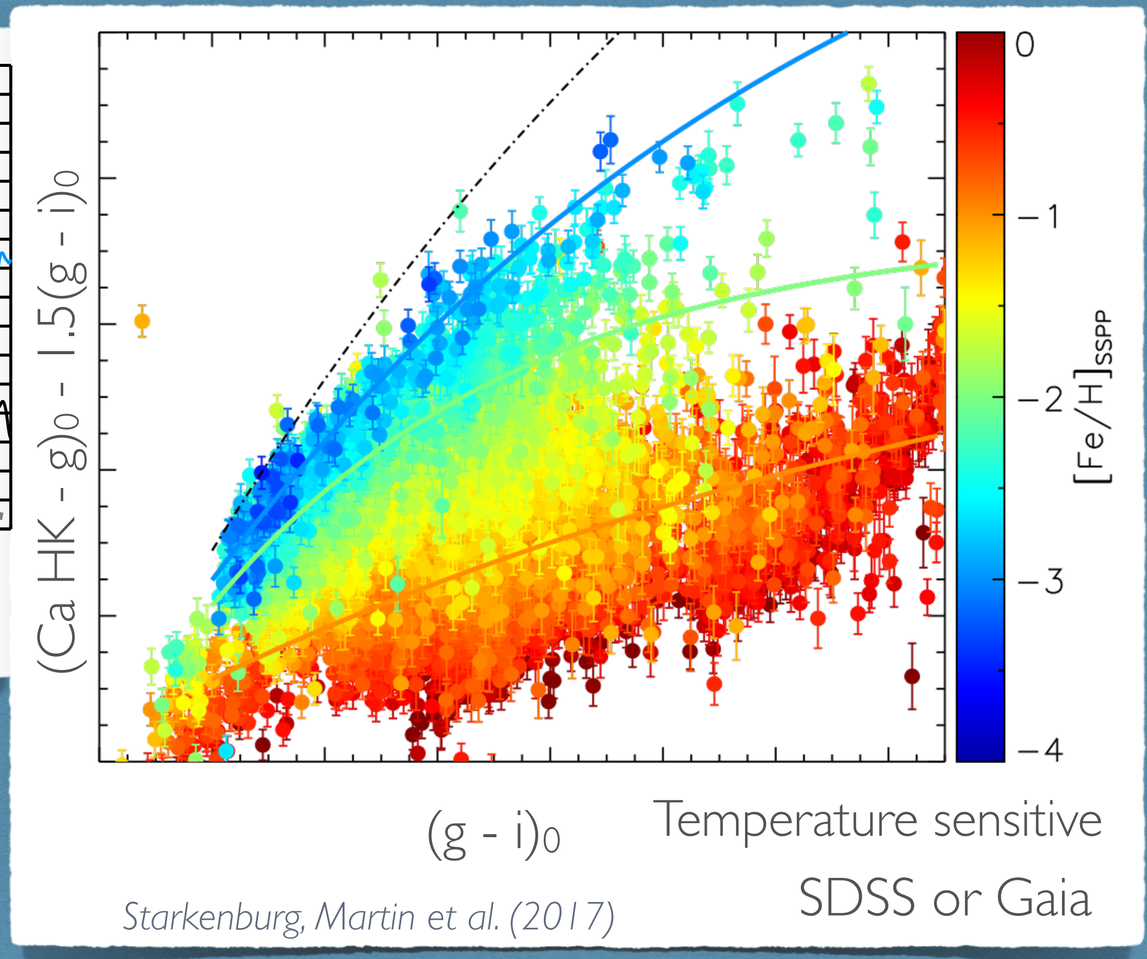


- Precise stellar ages are difficult to measure
- The most metal-poor stars are the oldest stars
- Metallicity is easier to measure than stellar ages!

Very MP: [Fe/H] < -2
<1/100 Sun's metal content

A very efficient way to select the most metal-poor stars

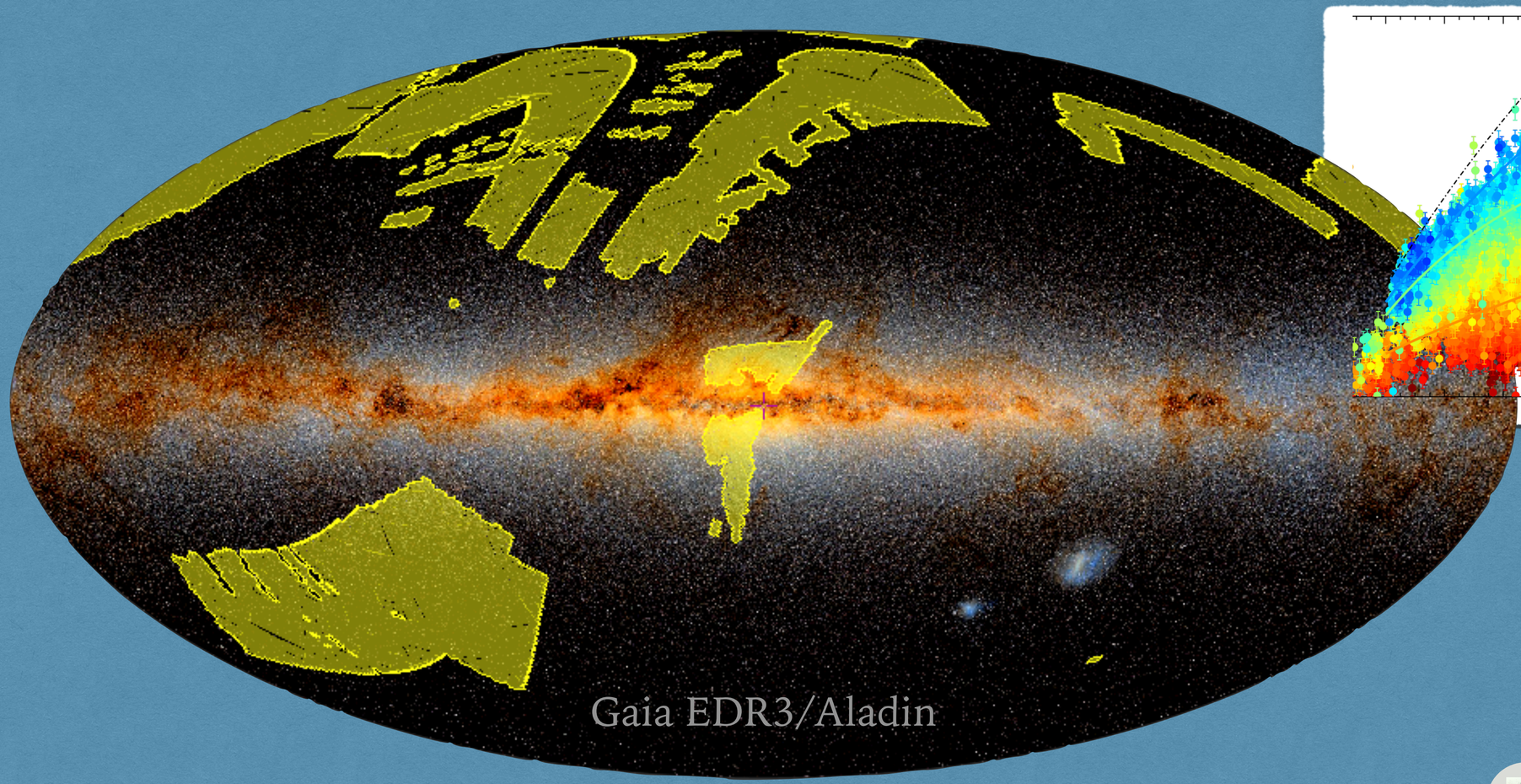


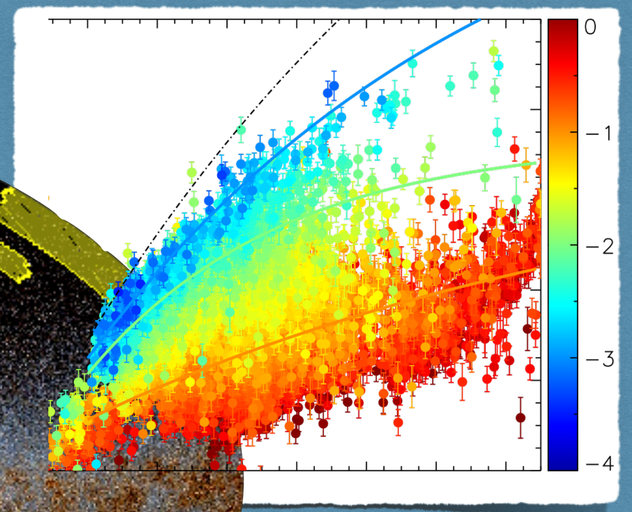


- Narrow Ca HK band sensitive to metallicity
- Ca HK + broad-band photometry
- Colour - colour space to derive photometric metallicities

PRISTINE

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

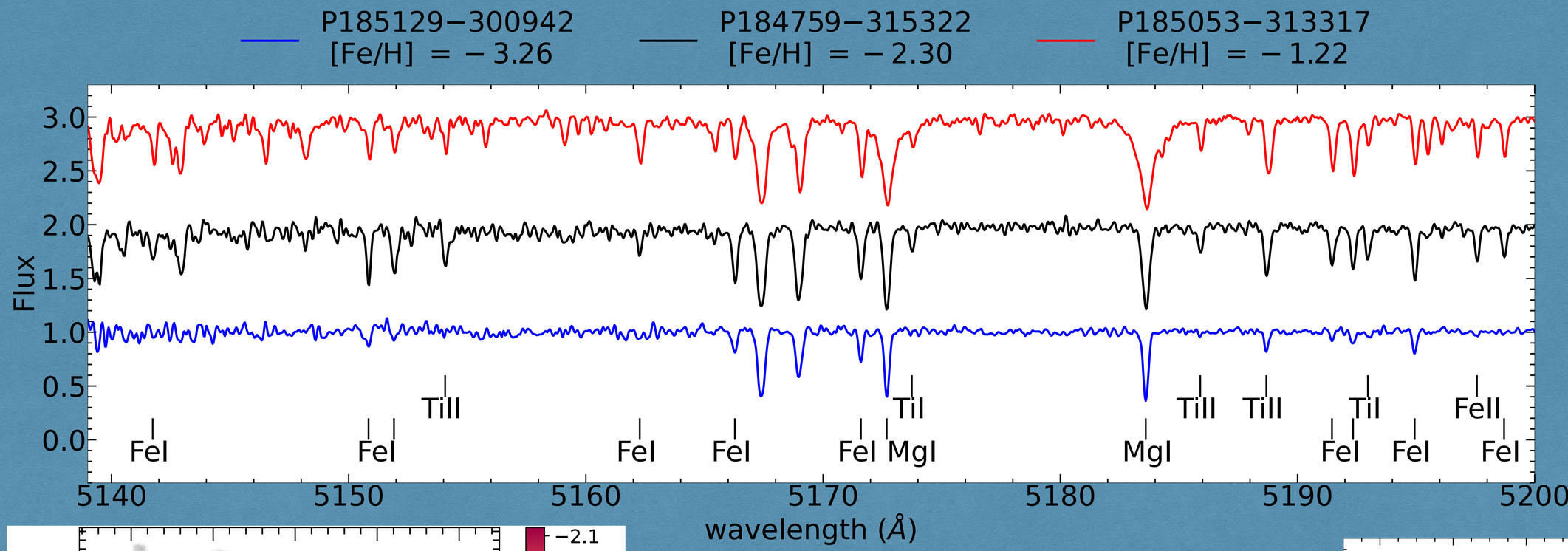


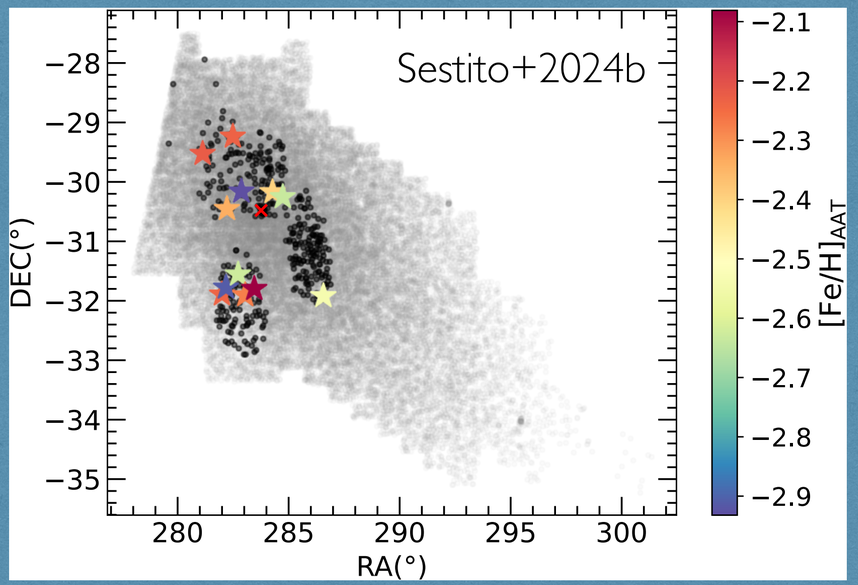


Pristine: ~6500+ deg^2 (still observing)

Pristine Inner Galaxy Survey (PIGS): bulge + Sagittarius ~600 deg^2

The MIKE high-resolution spectroscopic follow-up

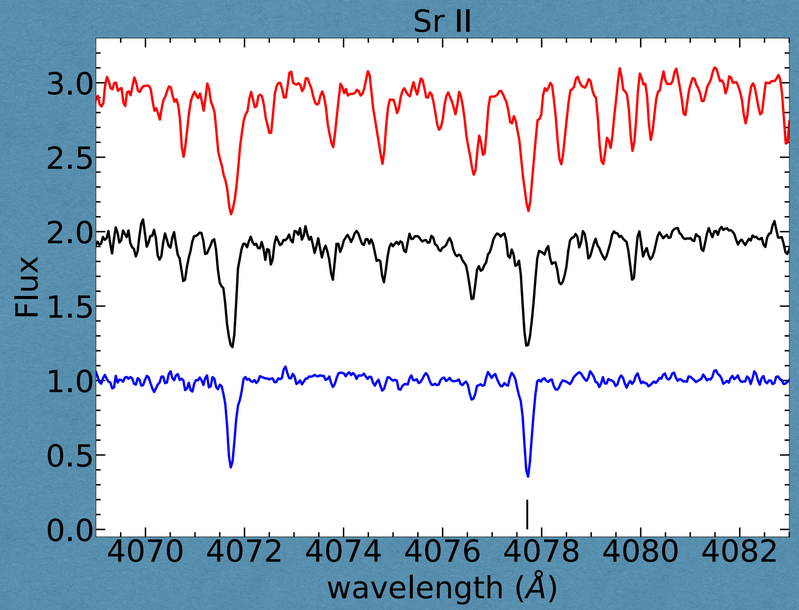




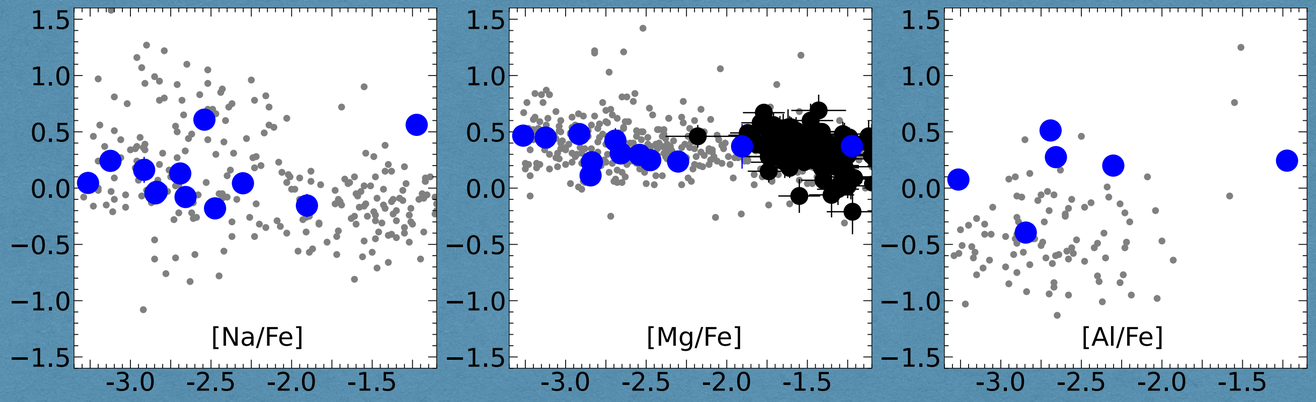
Chemical abundances

for ~19 species

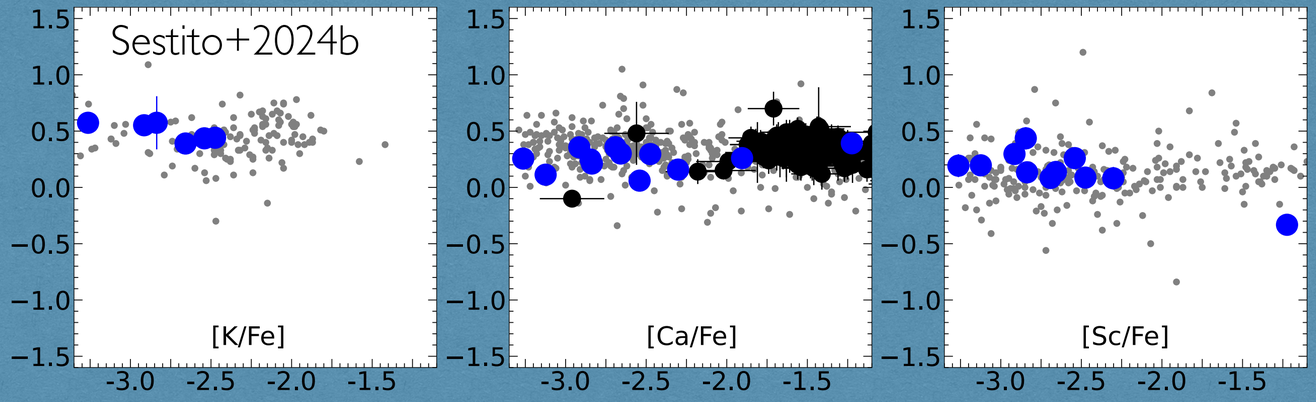
in 12 stars



The unexplored very metal-poor part of the Sagittarius core

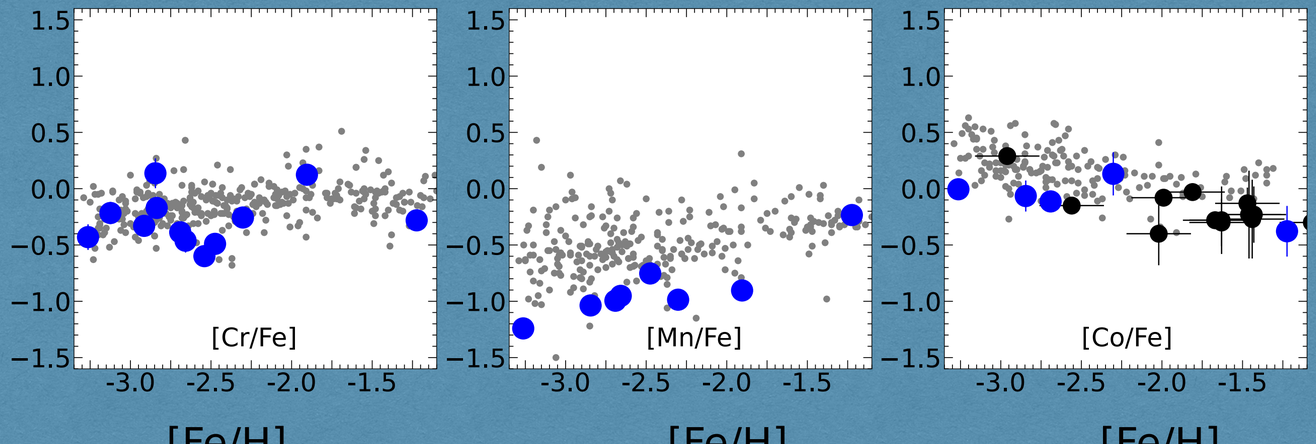


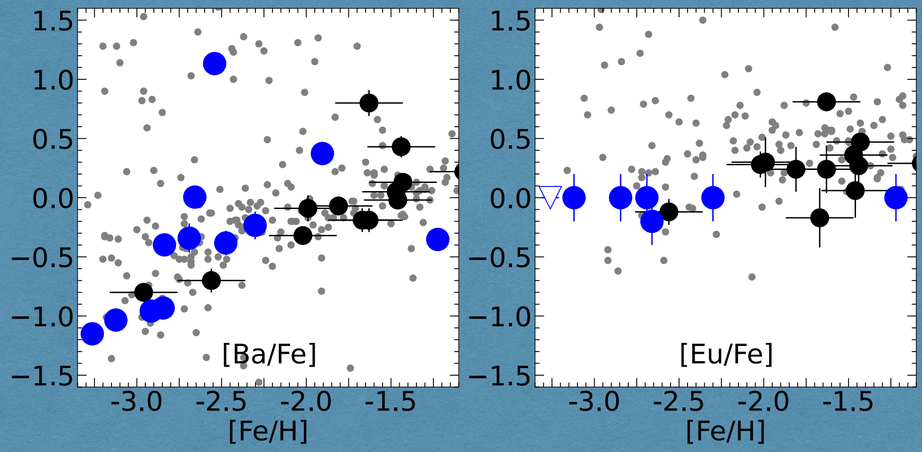
Very MP: [Fe/H] < -2
Extremely MP: [Fe/H] < -3



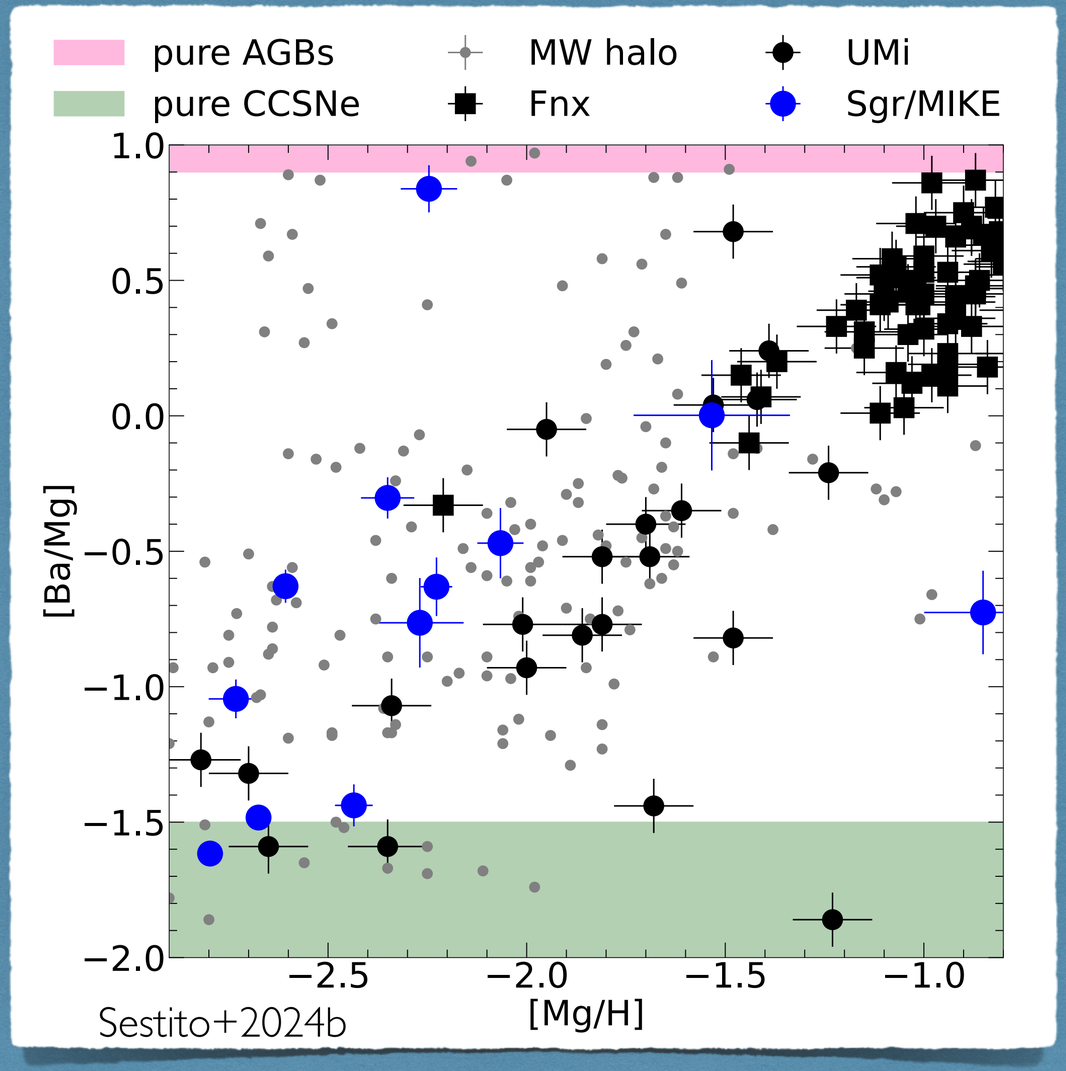
+ C, Si, Ti, Ni, Zn, Sr, and Y

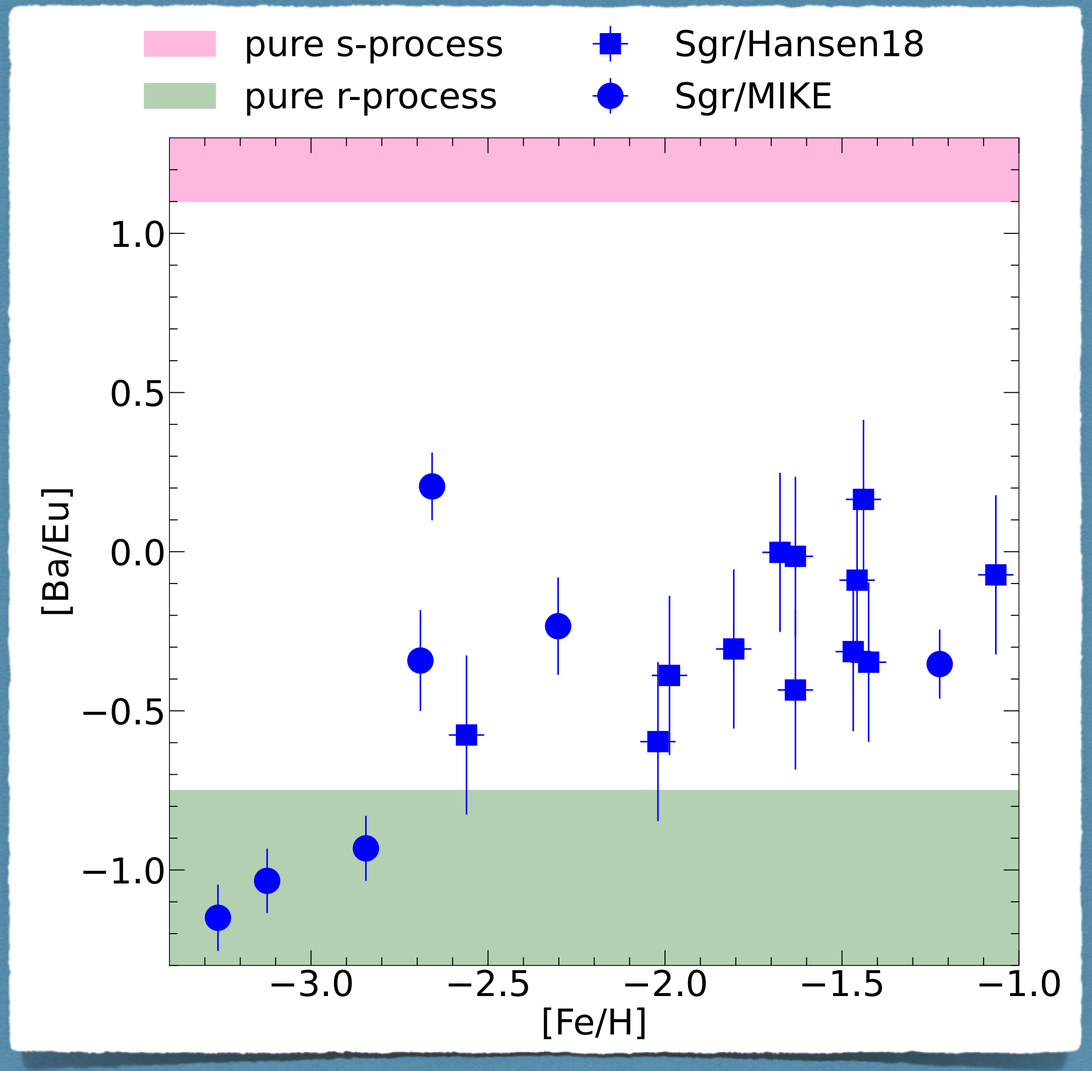
MW Halo
Sagittarius Literature
Sagittarius PIGS/MIKE





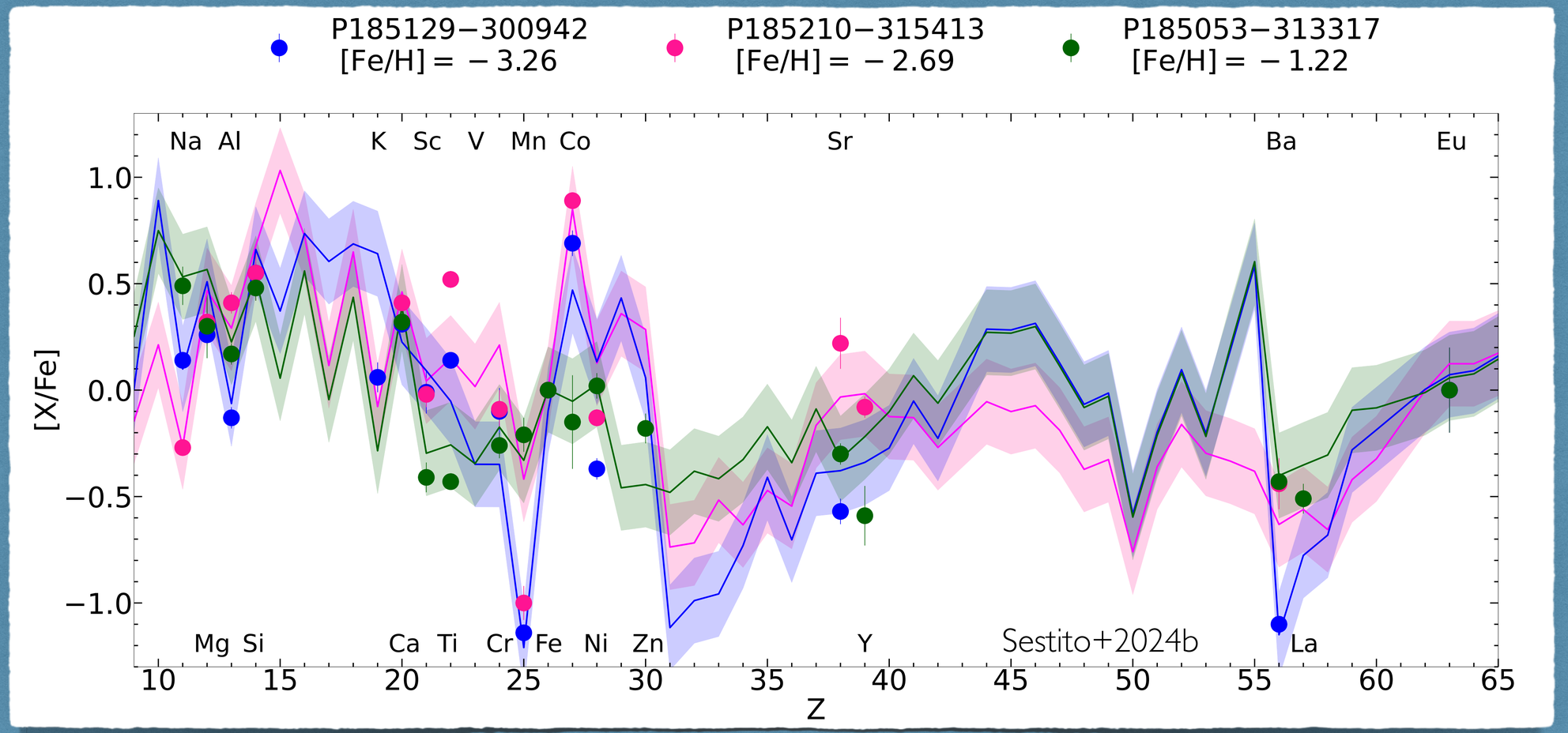
rapid- and slow-processes diagnostics





r-processes alone cannot explain the rise in these ratios: AGB are needed

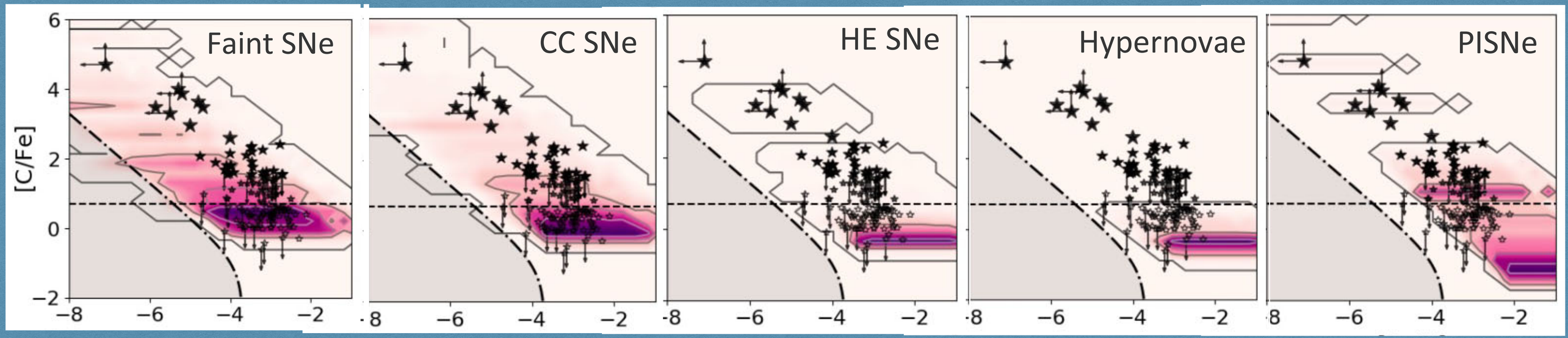
Recipe for the most metal-poor stars in Sagittarius



- Light elements up to Fe-peak: high-energy supernovae up to 70 Msun
- Neutron-capture elements: compact binary merger, fast-rotating stars, asymptotic giant branch stars
- No SNe Ia at [Fe/H] < -2

Carbon as a tracer of the supernovae energy

Energy: lower —> higher

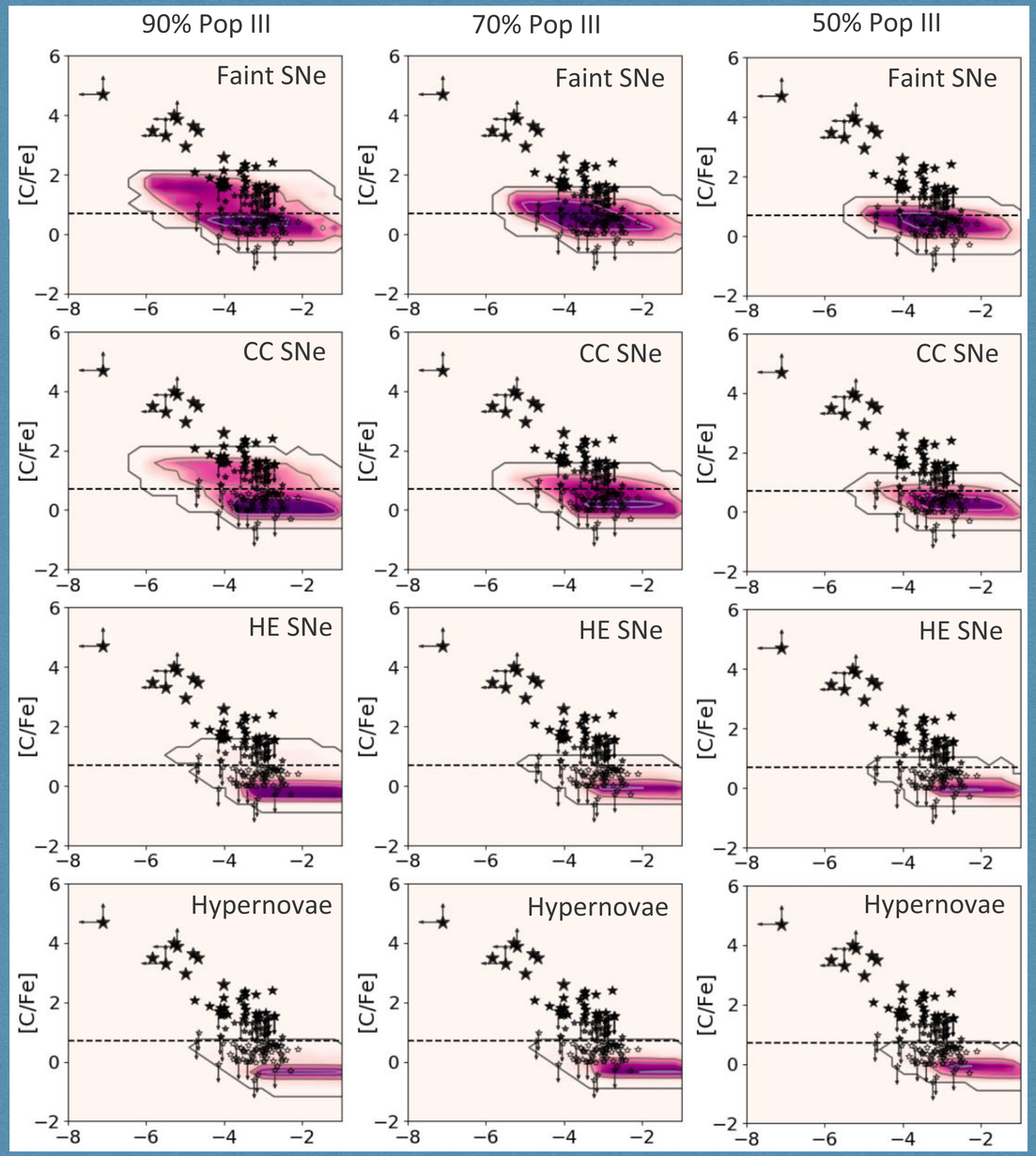


Vanni+2023

The higher the energy, the lower the [C/Fe] in system

Yields from Heger & Woosley

Metals in SNe II: lower → higher



Energy:
lower
↓
higher

Vanni+2023

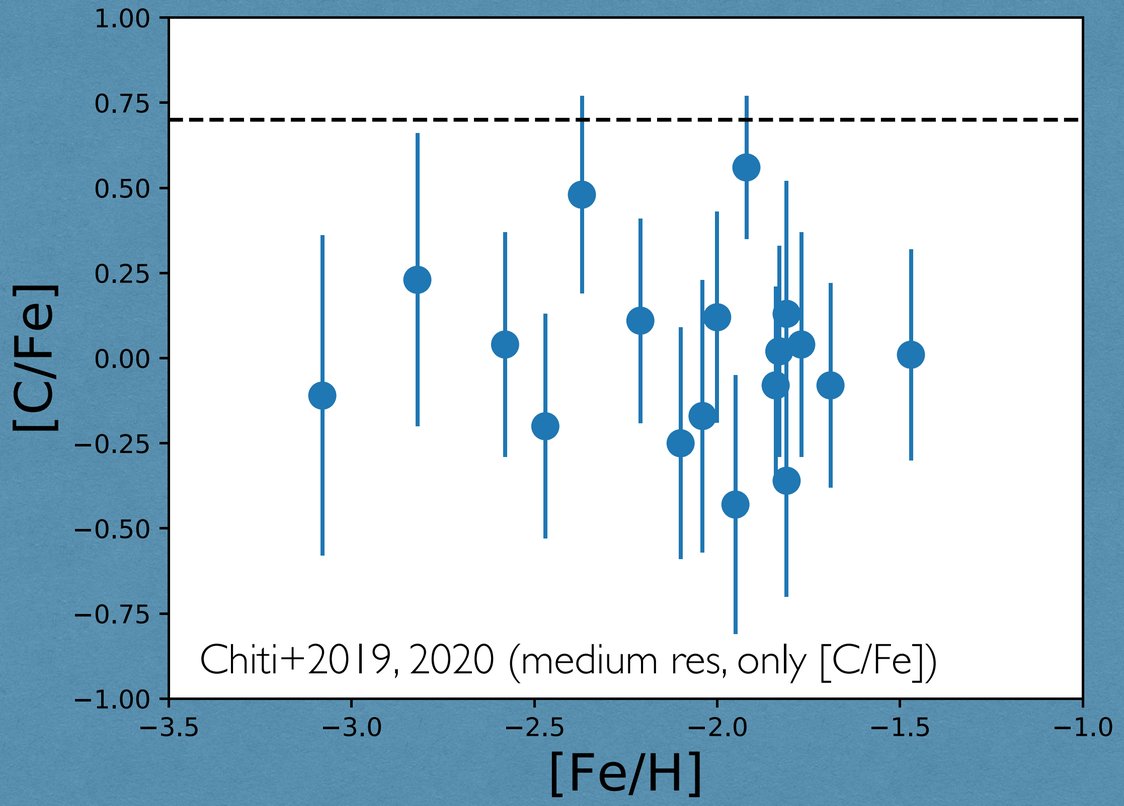
The lower the Pop III Sne II fraction,
the lower the [C/Fe]

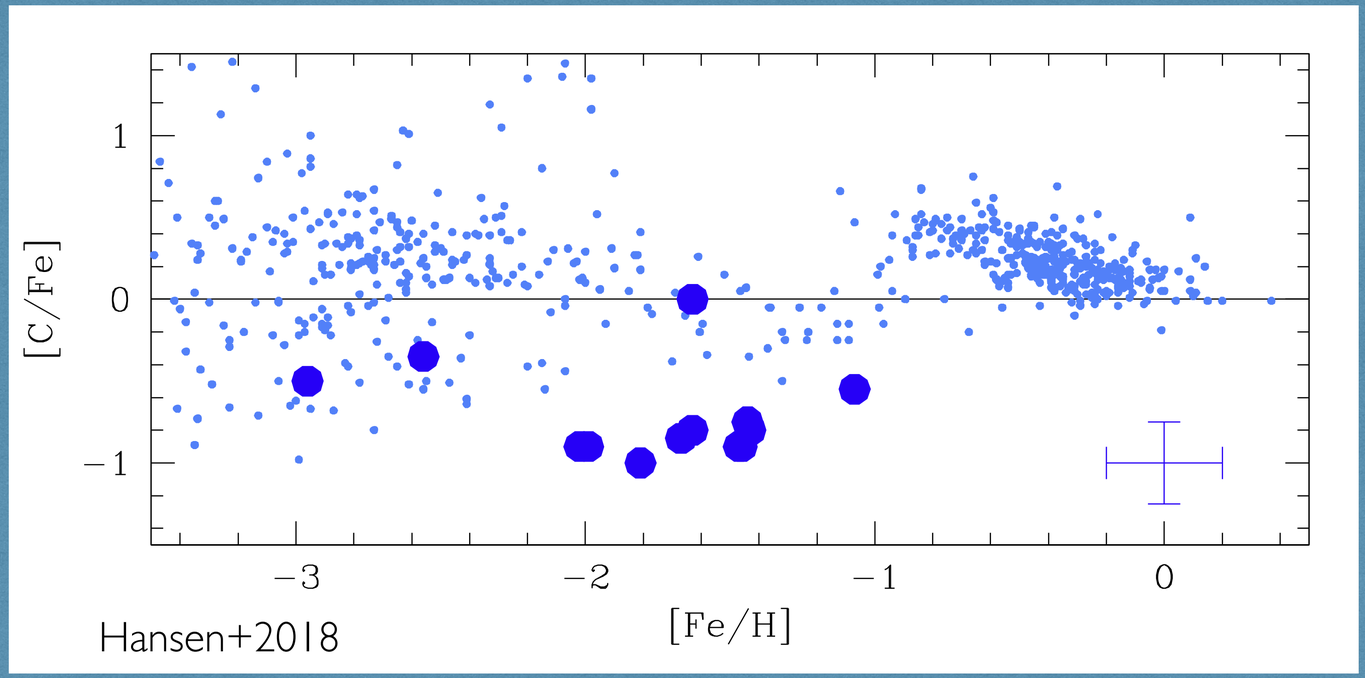
+

The higher the energy,
the lower the [C/Fe] in system

Is there any difference
between Sagittarius and the MW
in terms of Carbon?

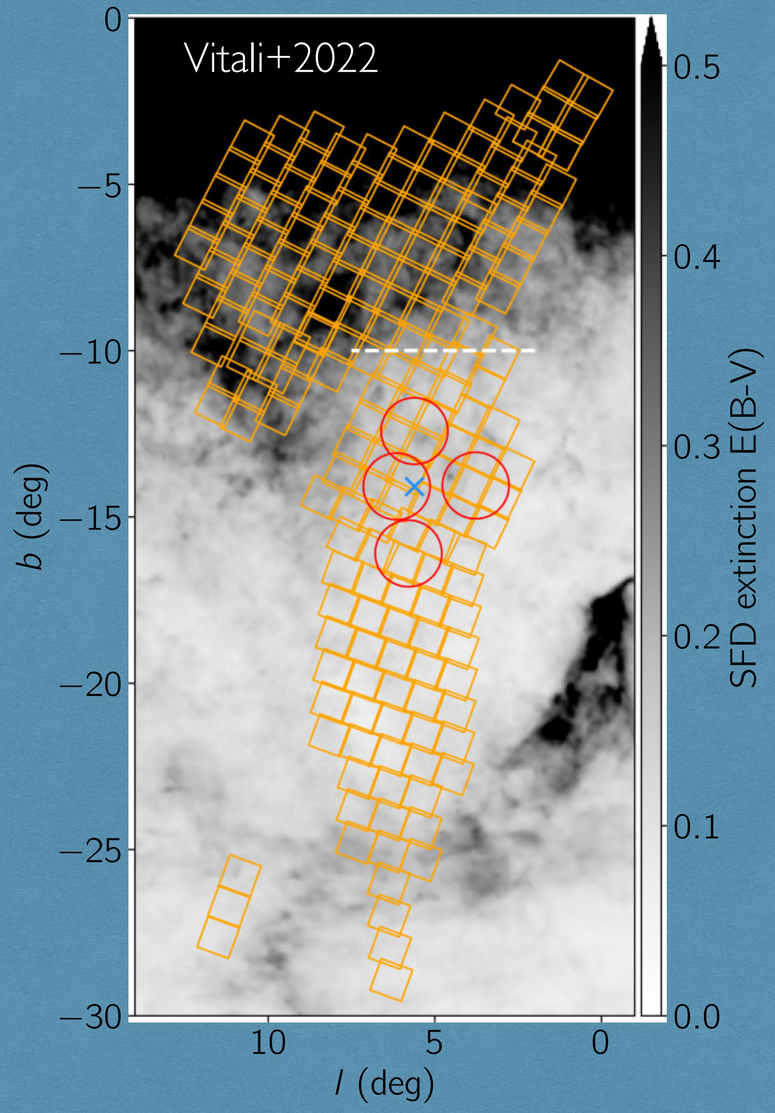
Not many stars with [C/Fe] at [Fe/H] < -1.5





How about to check the PIGS/AAT data?

The low-metallicity Sgr's core from PIGS low-/medium- resolution AAT



- 12,000 stars with radial velocity, [Fe/H], and [C/Fe]

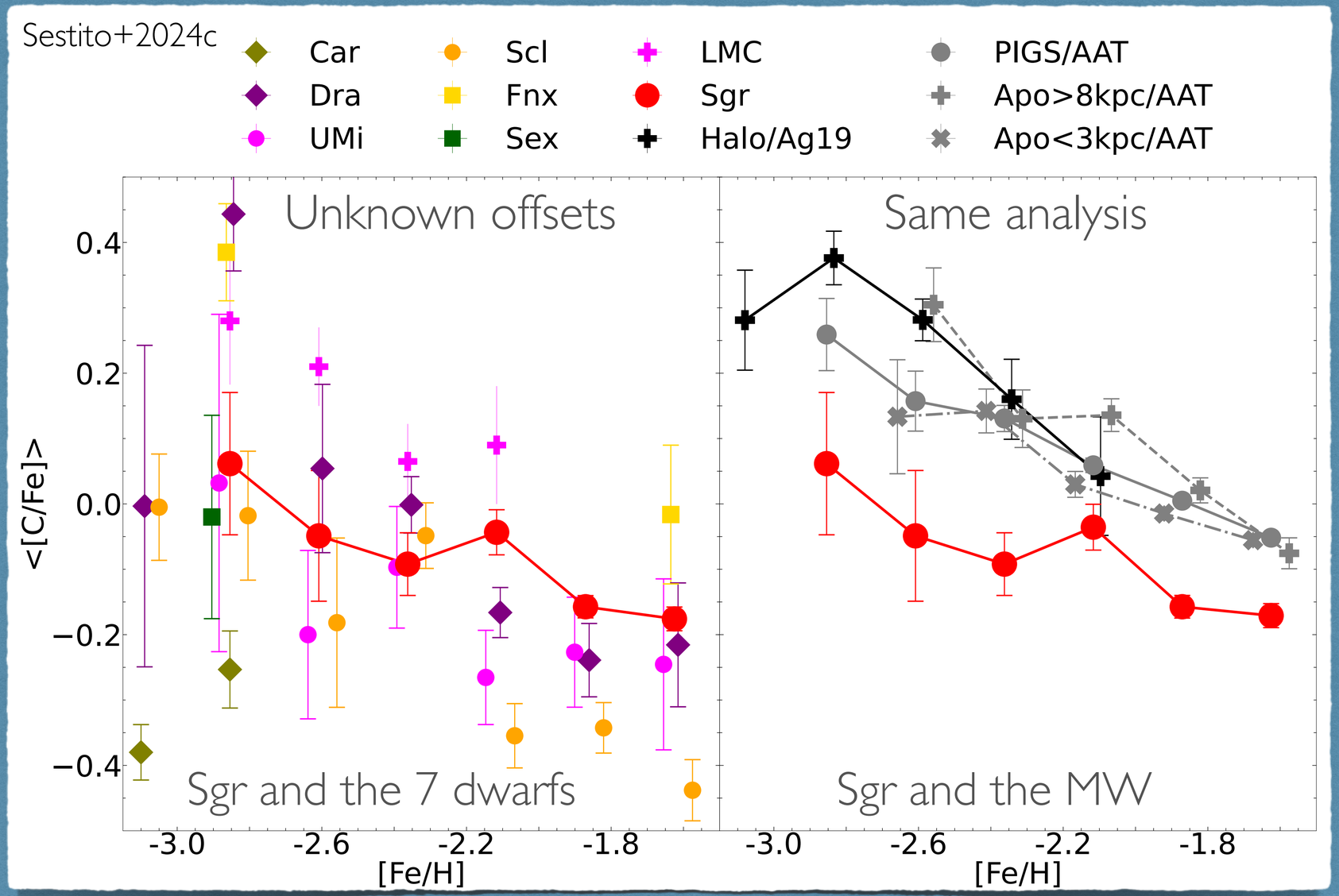
According to Gaia proper motion and AAT radial velocity:

- 835 Sgr members
- 356 Sgr members with accurate [Fe/H]< -1.5 and [C/Fe]

What can we learn from carbon?

Are there any differences respect to the MW or other dwarf galaxies?

[C/Fe]: Sagittarius vs Milky Way vs Classical dwarfs



DGs from high-resolution

MW halo: FERRE, med res

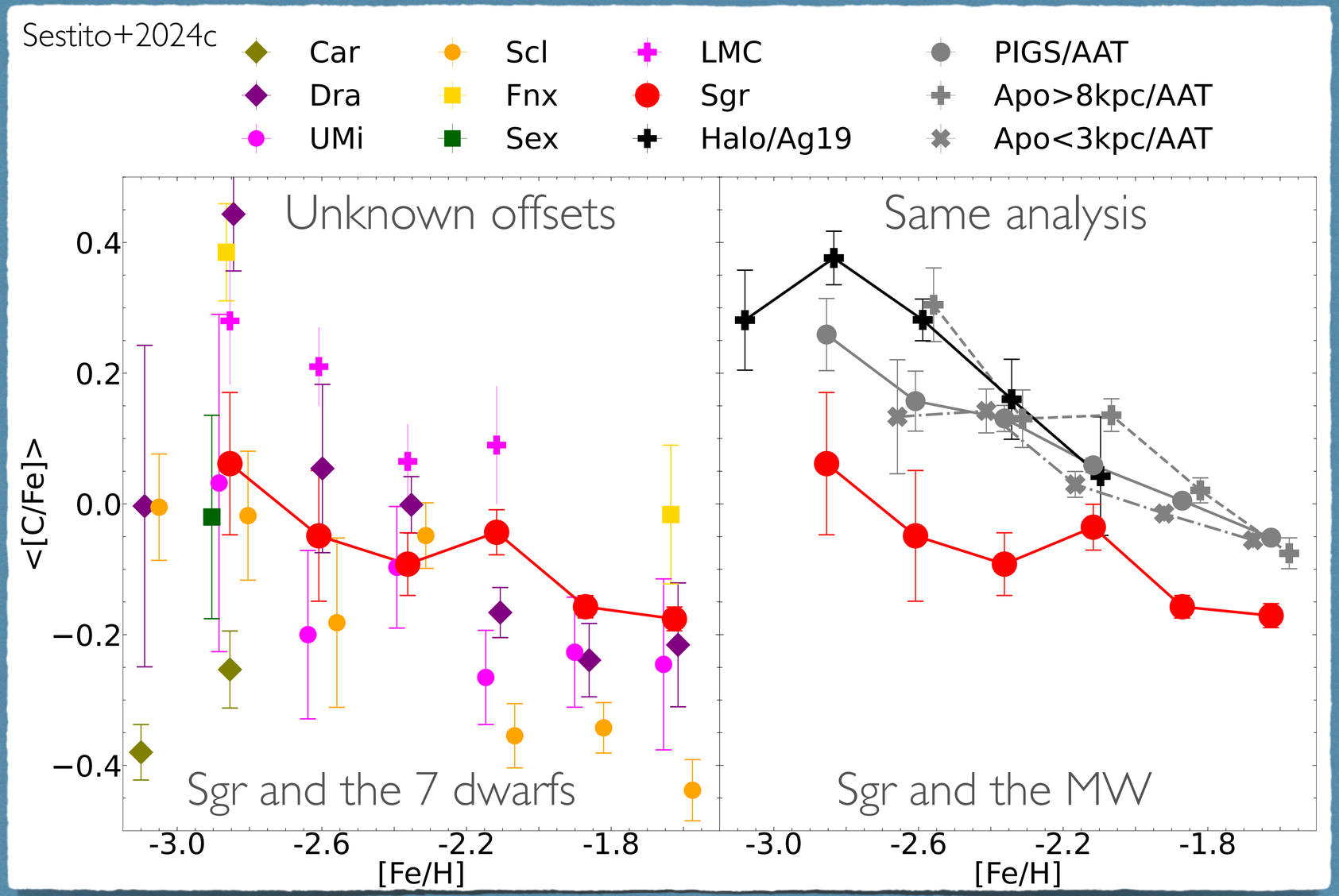
PIGS inner MW: FERRE, med res

Sgr: FERRE, med res

MW and Sgr on the same scale

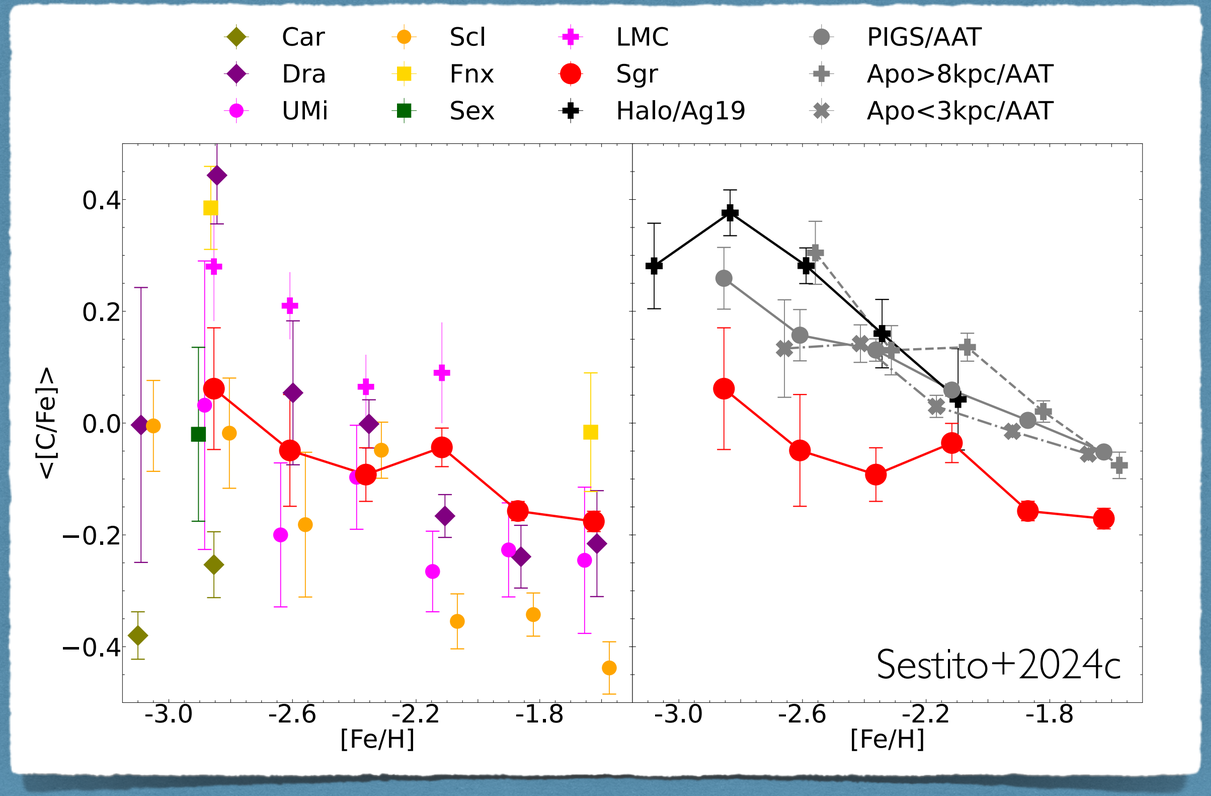
Carbon-enhanced stars ([C/Fe] > +0.7) are removed

[C/Fe]: Sagittarius vs Milky Way vs Classical dwarfs

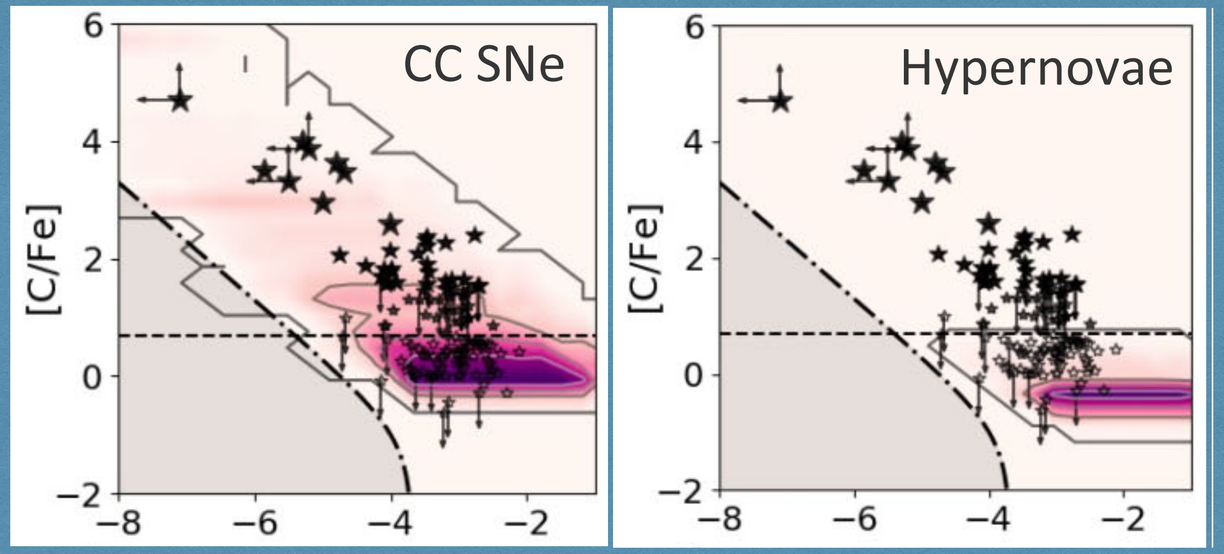


- Sgr: [C/Fe] in the ballpark of most of the DGs
- DGs: many systems have sub-solar [C/Fe]
- MW: super-solar [C/Fe]
- Sgr has a lower [C/Fe] than the MW

Is this related to different supernovae imprints between Sgr and the proto-MW?

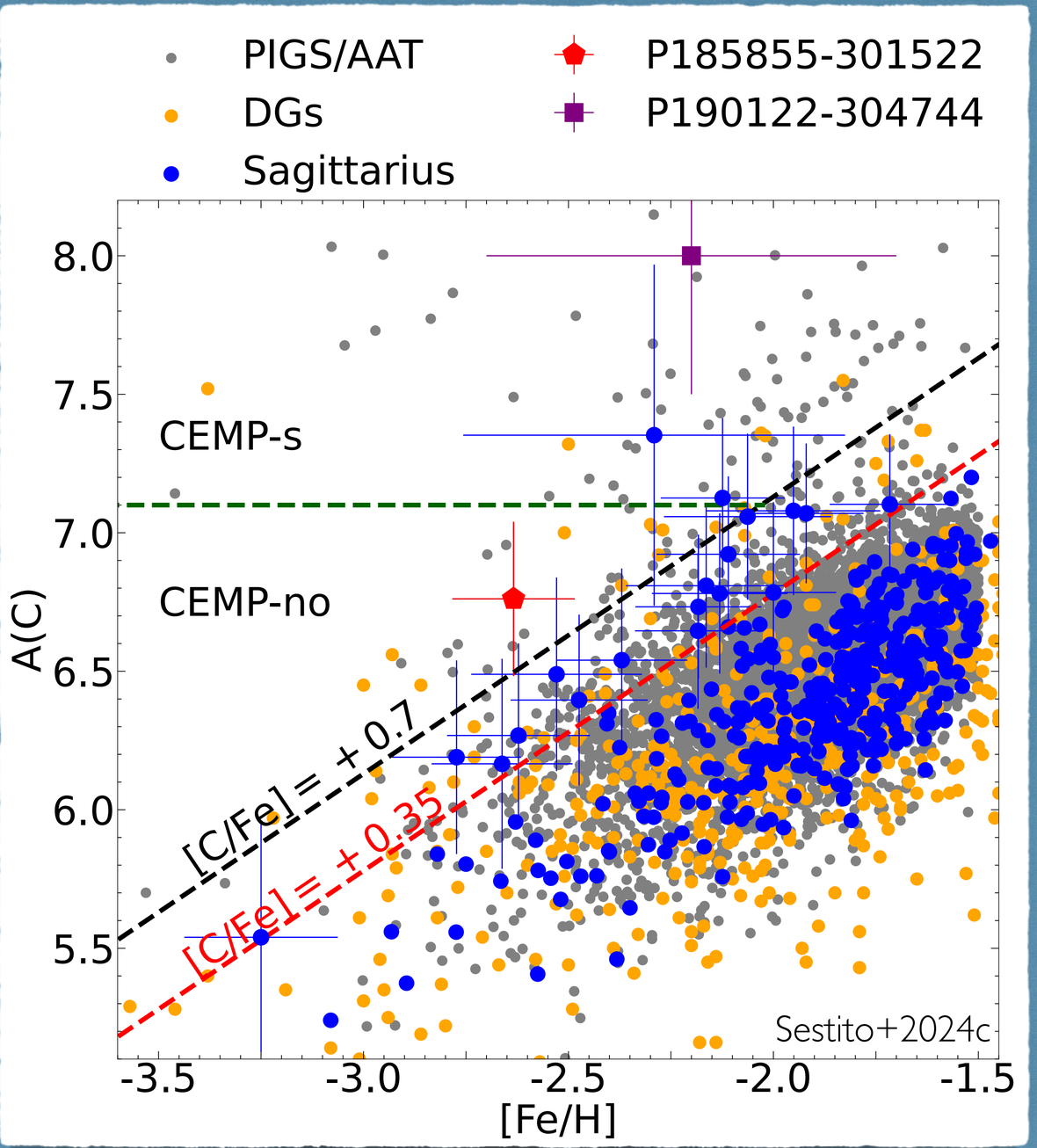


Vanni+2023



How to lower [C/Fe]	Sagittarius	proto-MW or MW building blocks
Retaining yields of most energetic events	Higher efficiency	Lower efficiency
Contribution of more metal-rich SNe II	Higher	Lower
Presence of SNe Ia at [Fe/H] <-1.5	Maybe? But not [Fe/H] <-2	Nope

Should the CEMP definition be revised?



- Lower fraction of CEMP in the DGs compared to the MW (< 5% vs ~30% for [Fe/H]<-2)
- Lower average [C/Fe] in DGs/Sgr than to the MW
- CEMP as ouliers in the A(C) or [C/Fe] distribution
- New definition to take into account the average [C/Fe] of a system
- For Sgr: CEMP when [C/Fe] > +0.35

CEMP: [C/Fe] > +0.7

CEMP-s: C from binary

CEMP-no: C from SNe

Summary of PIGS IX and X

★ Pristine/PIGS is efficient in finding MP stars everywhere in the Galaxy

★ Sgr/MIKE explore for the first time the very metal-poor part of Sagittarius' core (Sestito+2024b)

★ Imprints of high-energy, hypernovae, compact binary mergers, and AGBs

★ Sgr/AAT is the largest sample of [Fe/H] and [C/Fe] in Sgr's VMP core: ~350 stars (Sestito+2024c)

★ [C/Fe] in Sgr is lower than in MW: 1) Sgr is able to retain the yields of the most energetic events than the building blocks of the MW, 2) higher fraction of pop II SNe II in Sgr than in the MW, 3) SN Ia at -2<[Fe/H]<1.5 in Sgr ?

★ New definition of Carbon-Enhanced MP based on the <[C/Fe]> in a given system. Sgr: [C/Fe]>+0.35

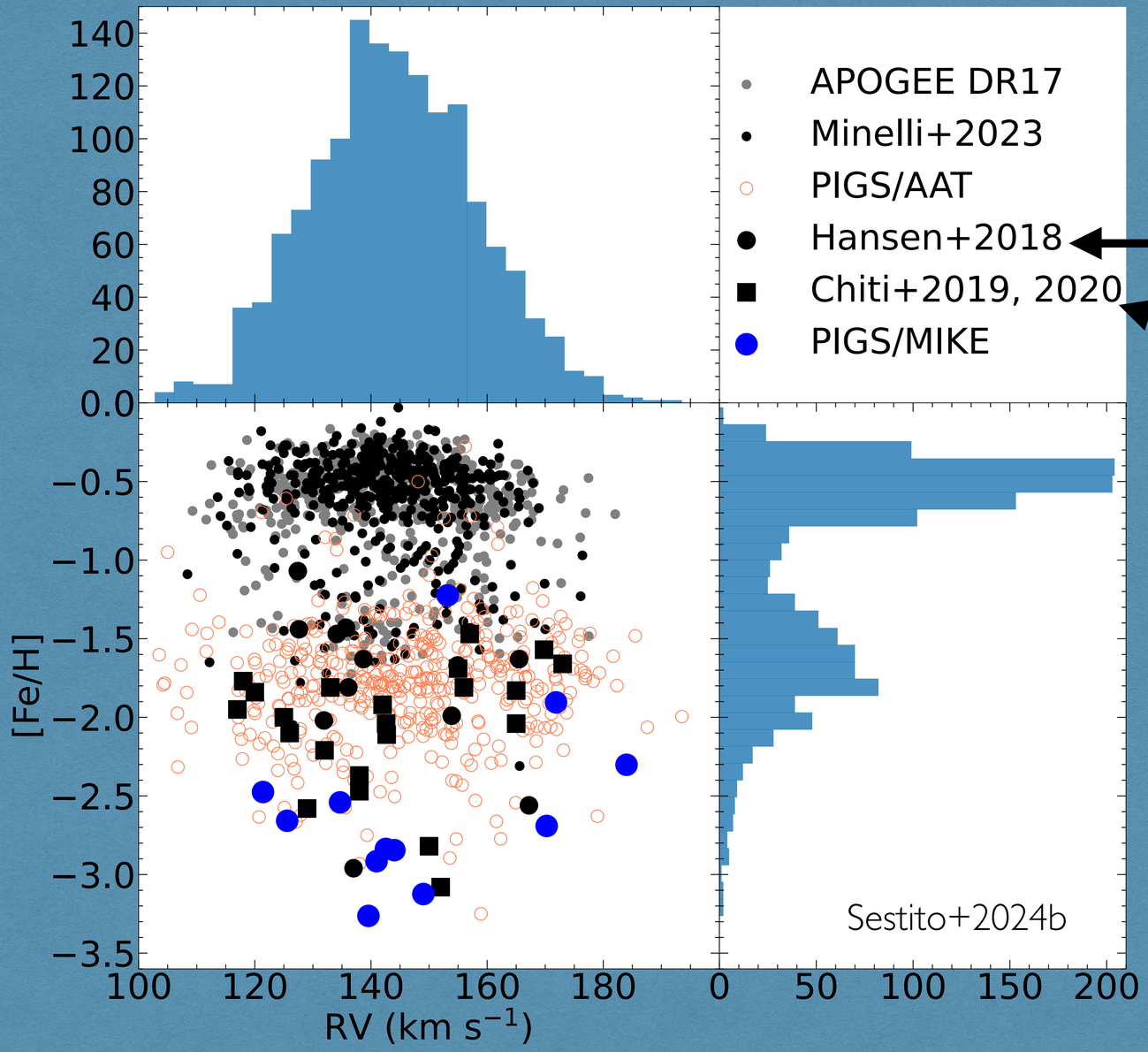
Not discussed in this talk but present in the papers:

★ Pristine is biased against extreme CEMP (from binary), OK for Carbon-normal and OK for mild CEMP

★ The systemic velocity and the velocity dispersion in Sgr are larger for MP and in the outskirts —> 1) MR disc/bar + MP halo, 2) outside-in star formation, 3) extreme tidal perturbations

Back up slides

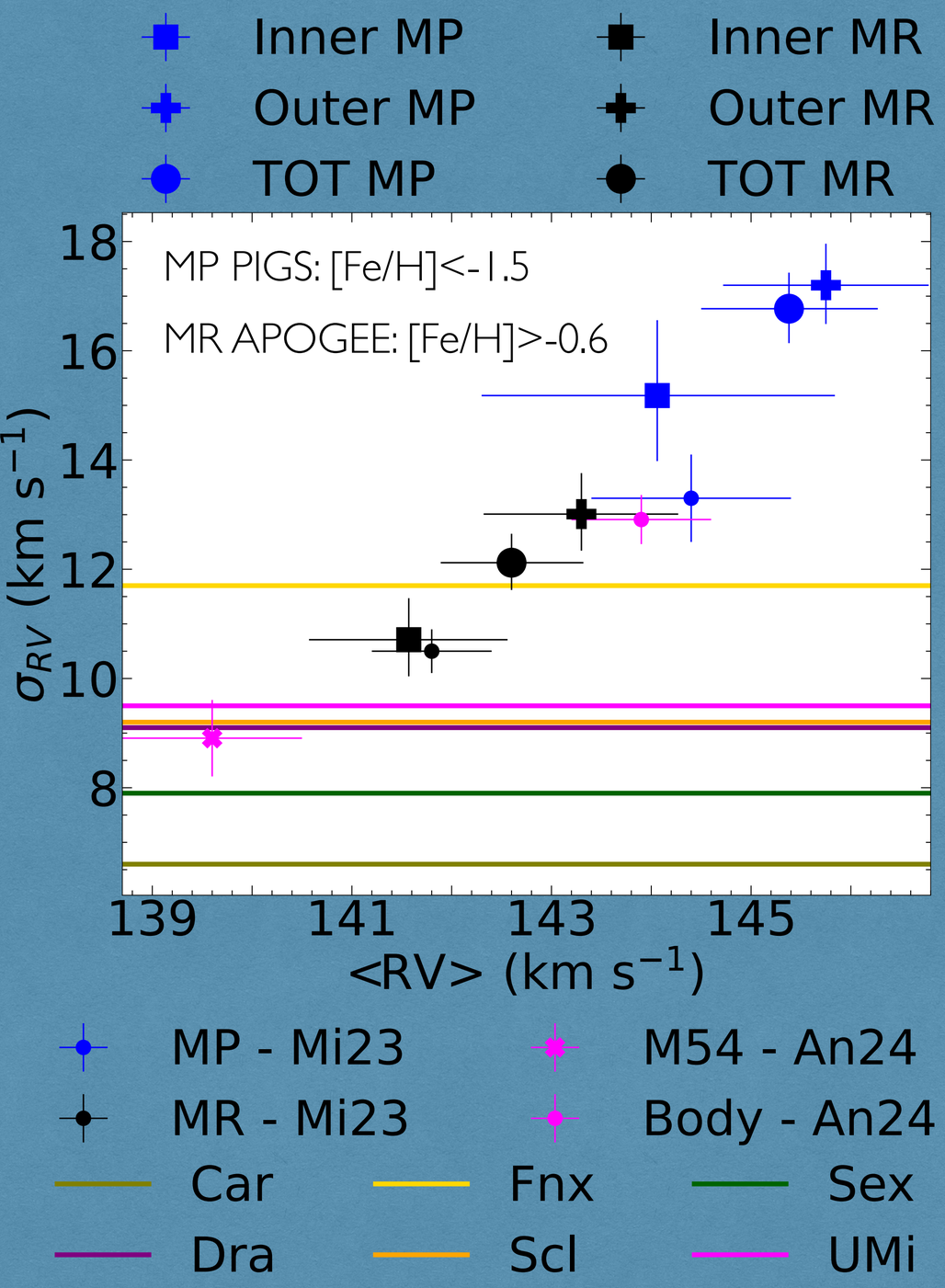
High-res MIKE spectra to explore the VMP and EMP regime



The only high-res work at VMP

Only [Fe/H] and [C/Fe]

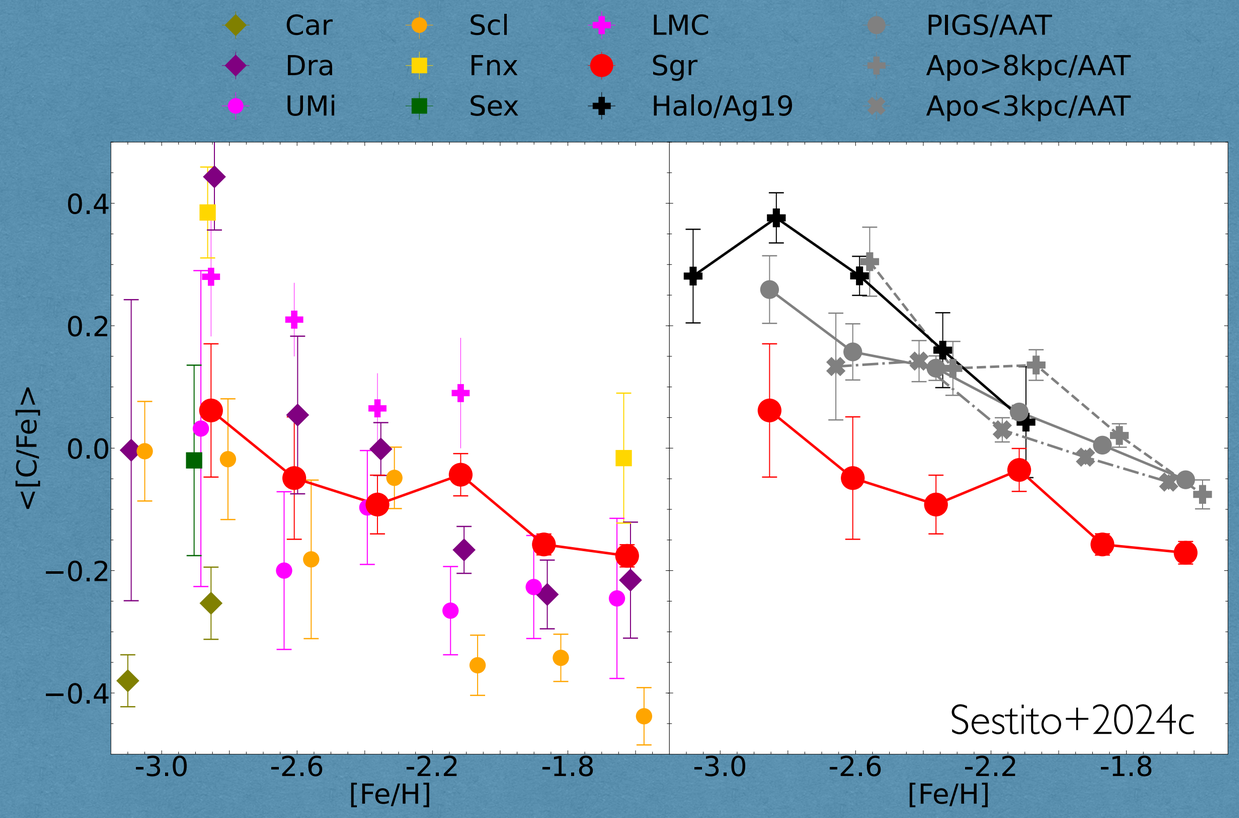
Very MP: [Fe/H] < -2
Extremely MP: [Fe/H] < -3

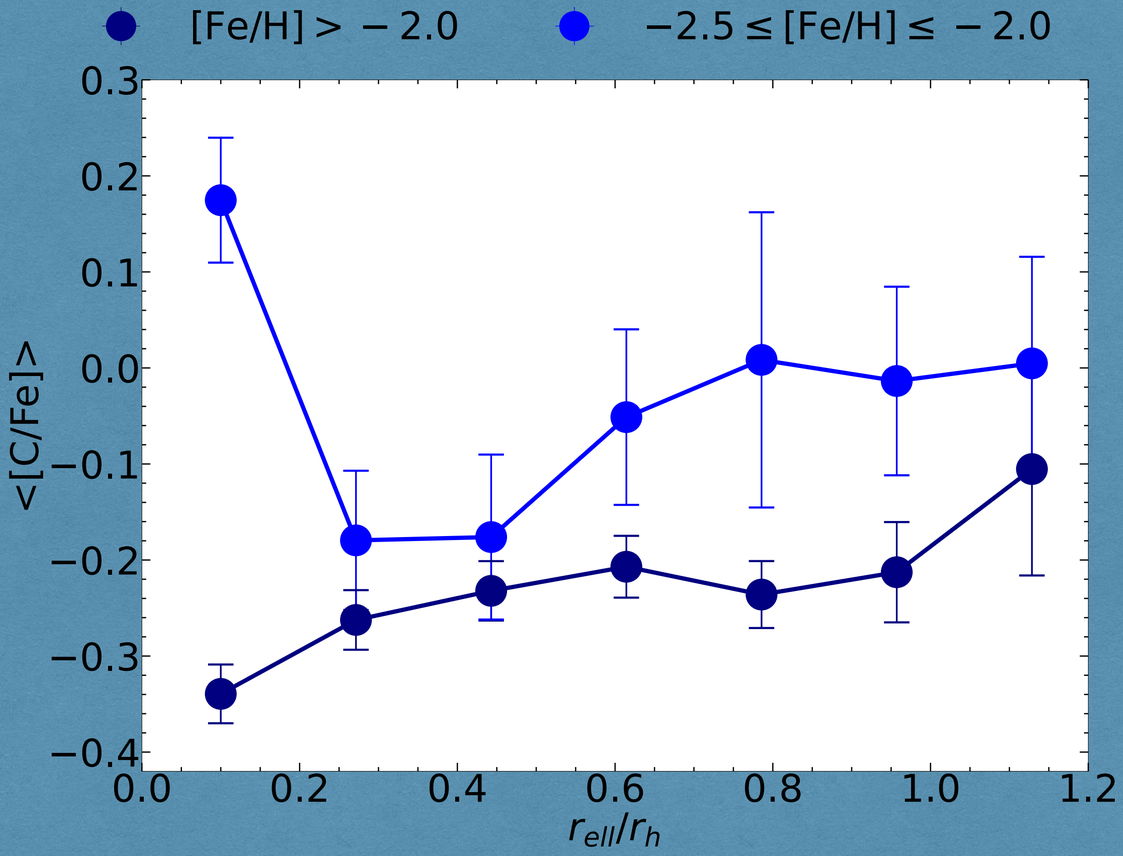


- The MP population has a larger velocity dispersion and larger systemic velocity than the MR counterpart.
- Outer stars have larger velocity dispersion and larger systemic velocity than inner stars.

Scenarios:

- Outside-in star formation
- Rotating disc/bar (MR) + Halo (MP)
- Extreme Galactic tides

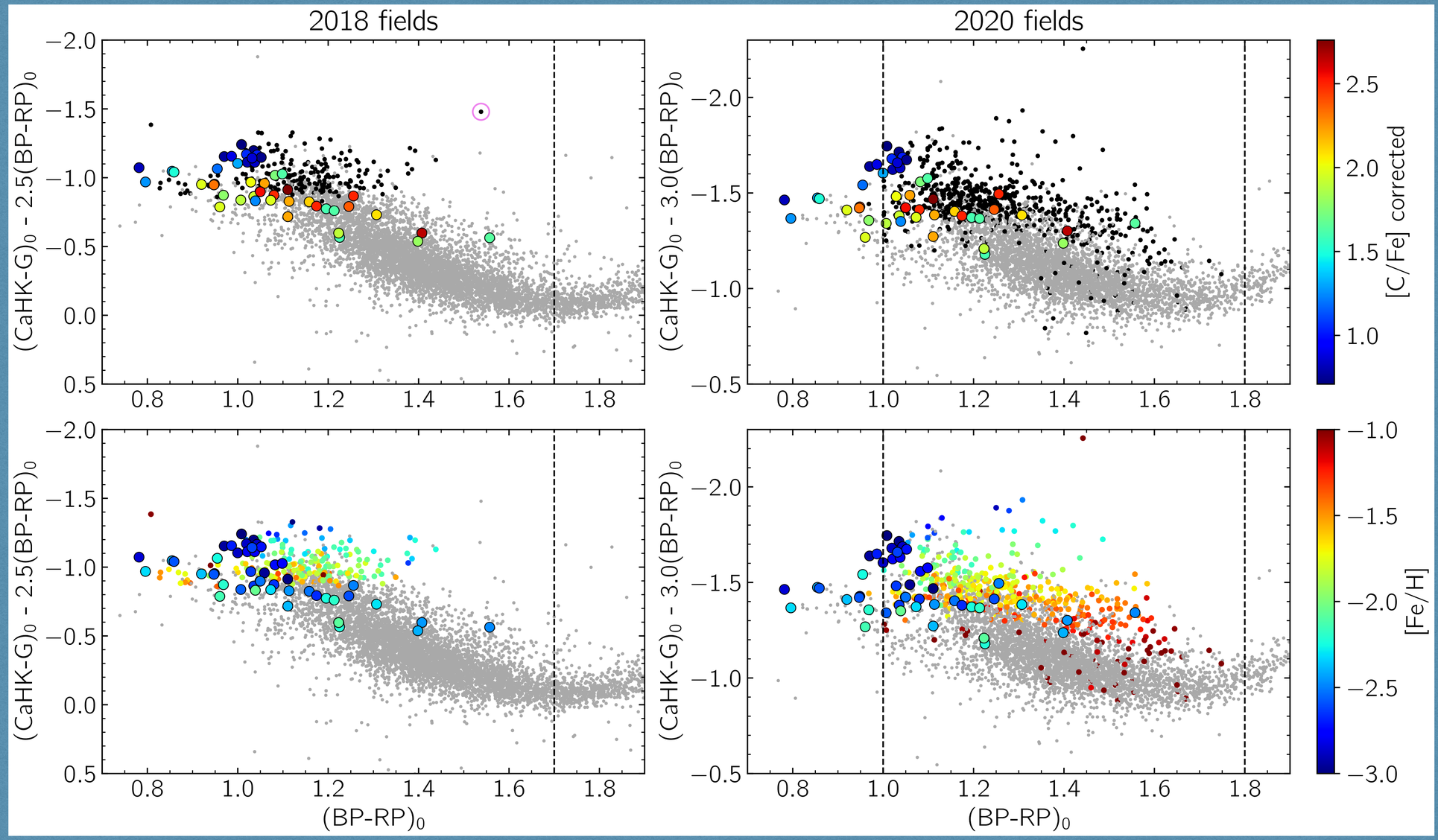




- Carbon gradient in the more MR population, not clear in the most MP
- Lower average [C/Fe] in the more MR population
- [C/Fe] gradient —> ISM not completely homogeneously mixed between the inner and outer regions?

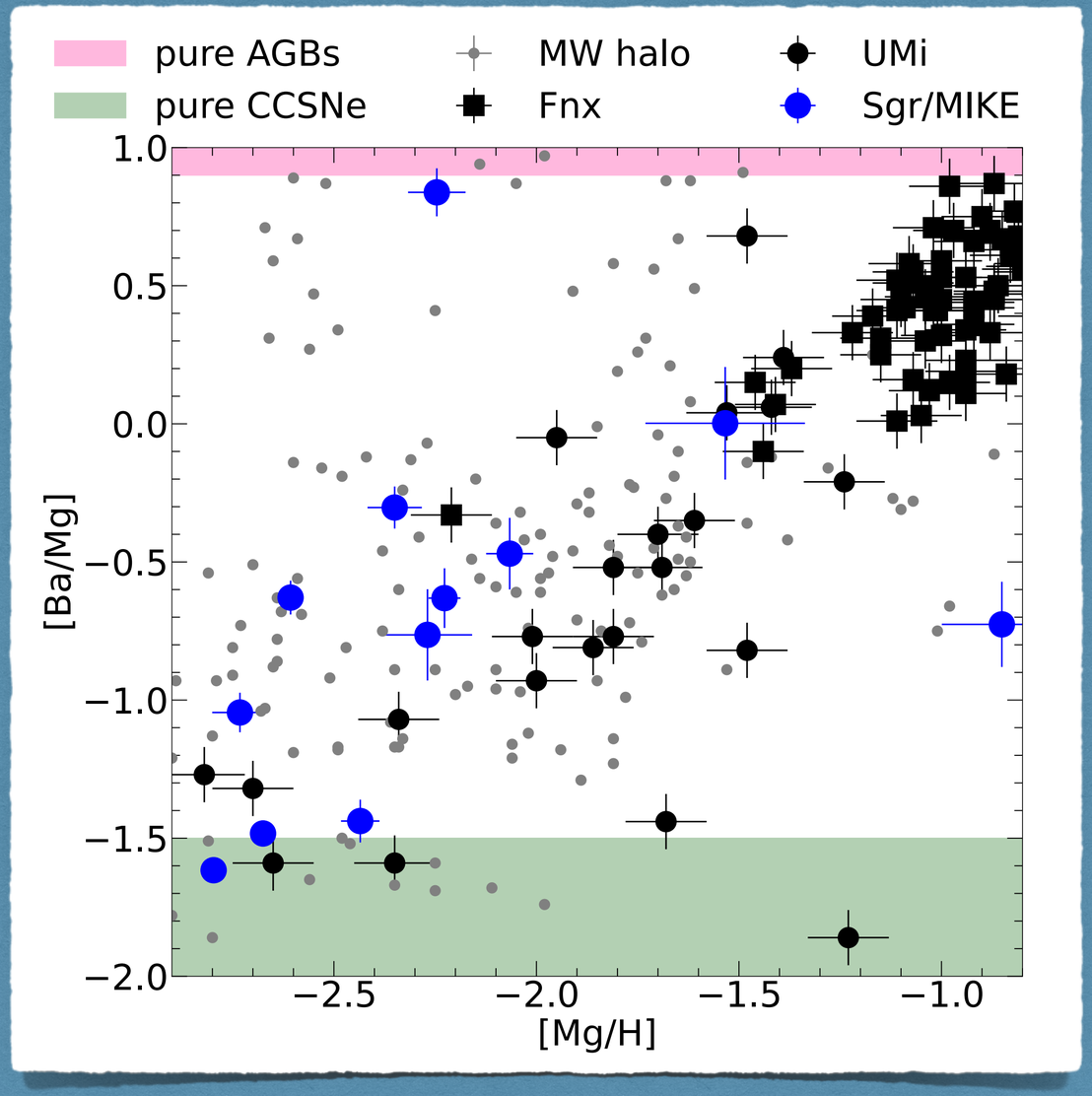
Another mechanism to lower [C/Fe] in the inner regions and more MR: type Ia supernovae

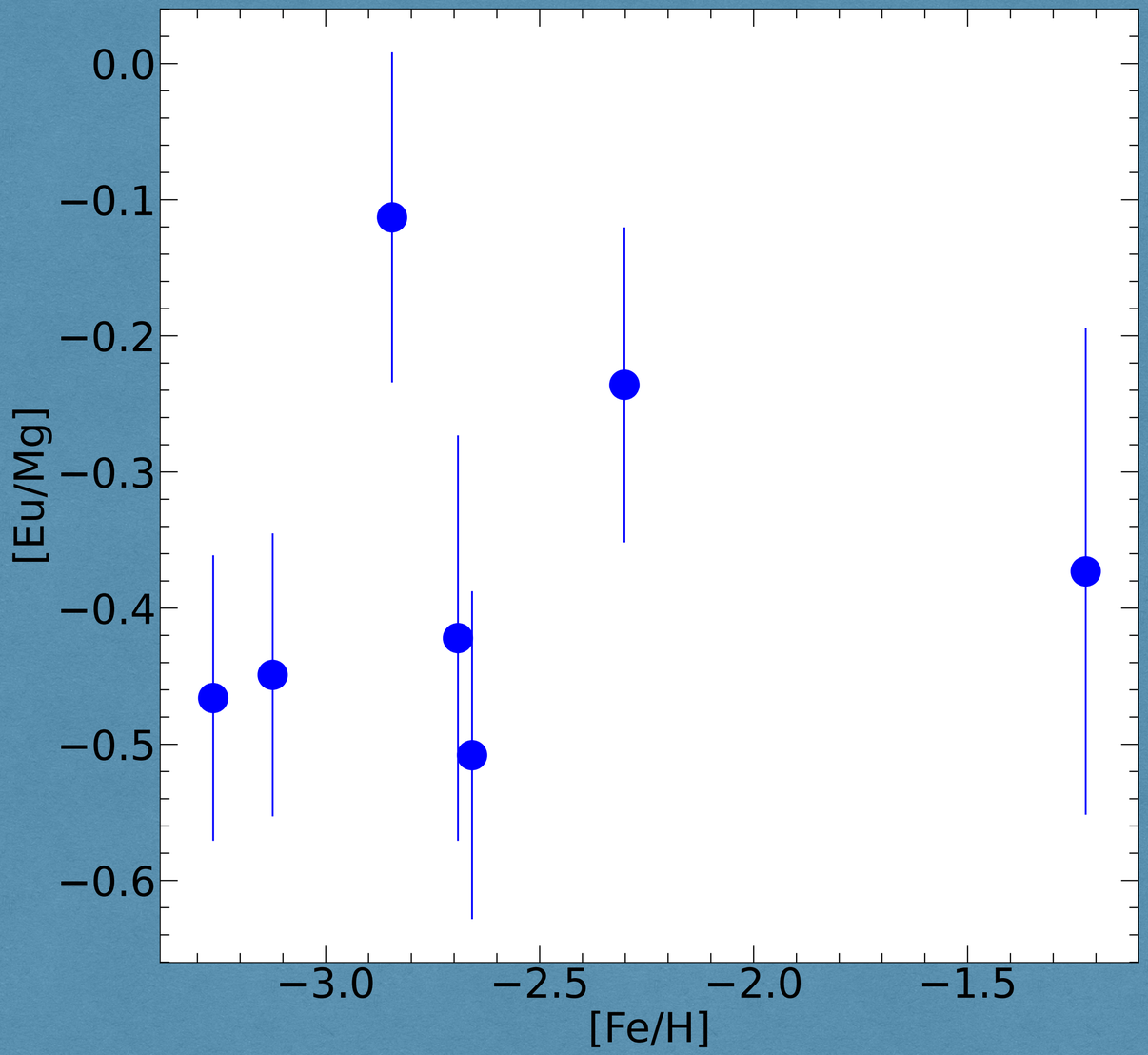
The selection effects w.r.t. CEMP stars

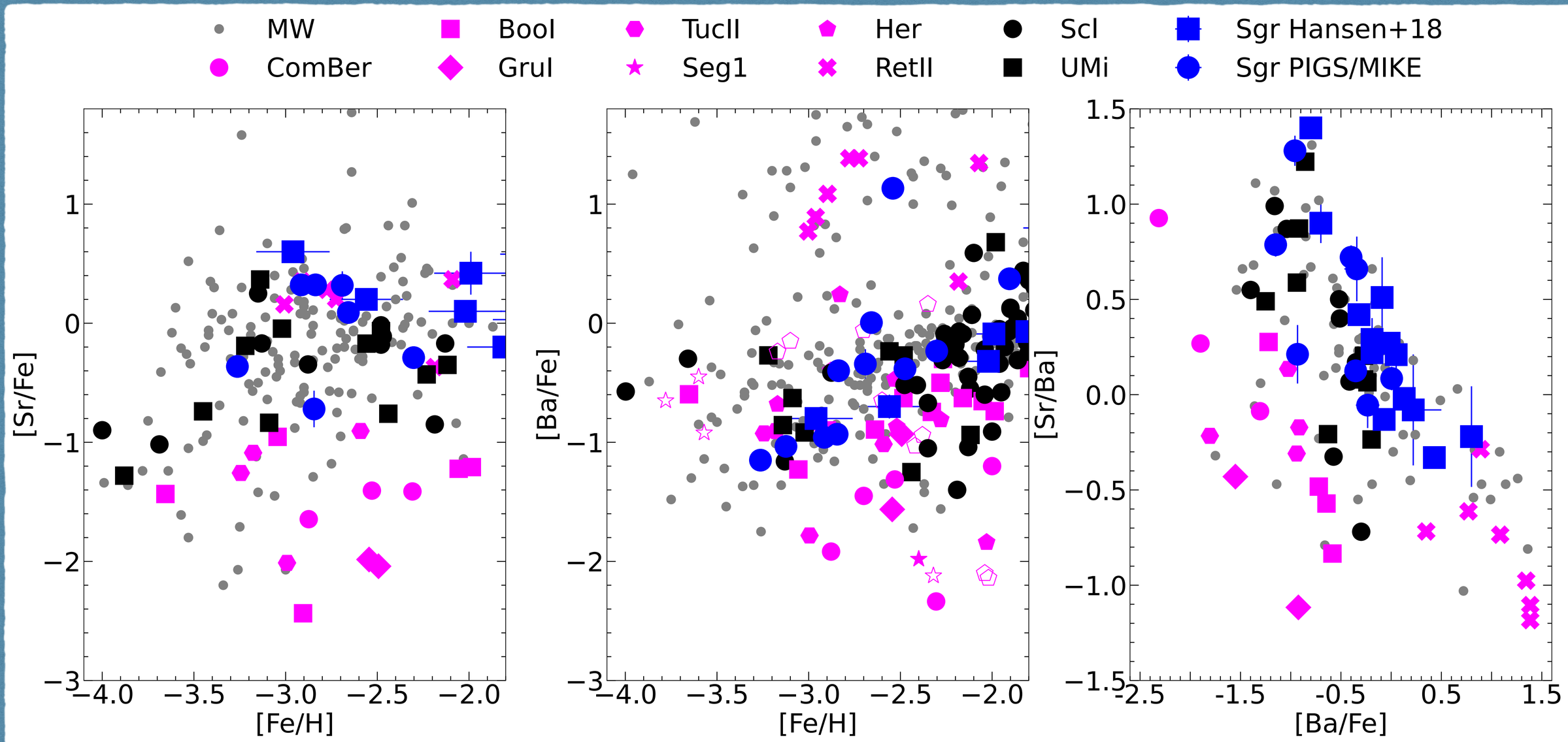


Small coloured/black: observed AAT; Large coloured: Yoon+16

Delayed rapid-processes diagnostics






MW
ComBer
Booll
Grull
TucII
Seg1
Her
RetII
Scl
UMi
Sgr Hansen+18
Sgr PIGS/MIKE
[Sr/Fe]
[Fe/H]
[Ba/Fe]
[Fe/H]
[Sr/Ba]
[Ba/Fe]