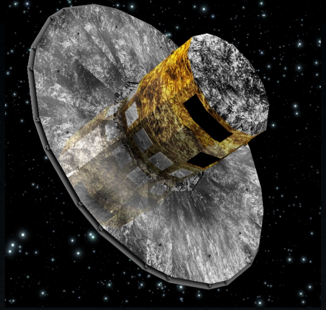

The Galactic globular clusters populations based on dynamics and chemistry

Angeles Pérez-Villegas

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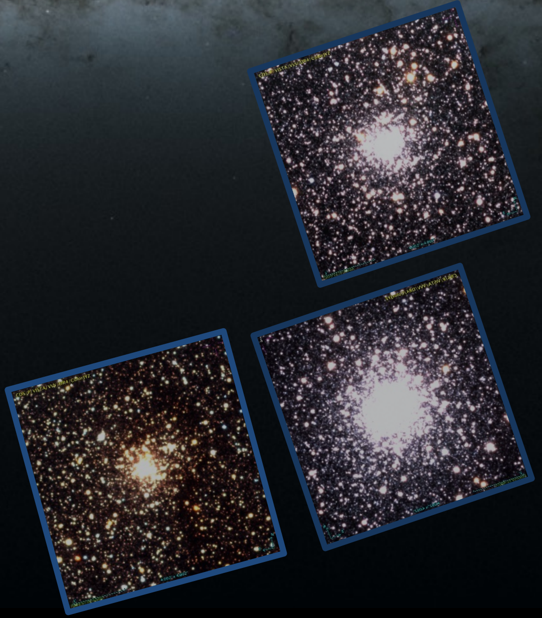
Stefano Souza (MPIA), Leandro Kerber (UESC)
Cristina Chiappini (AIP), Marica Valentini (AIP)



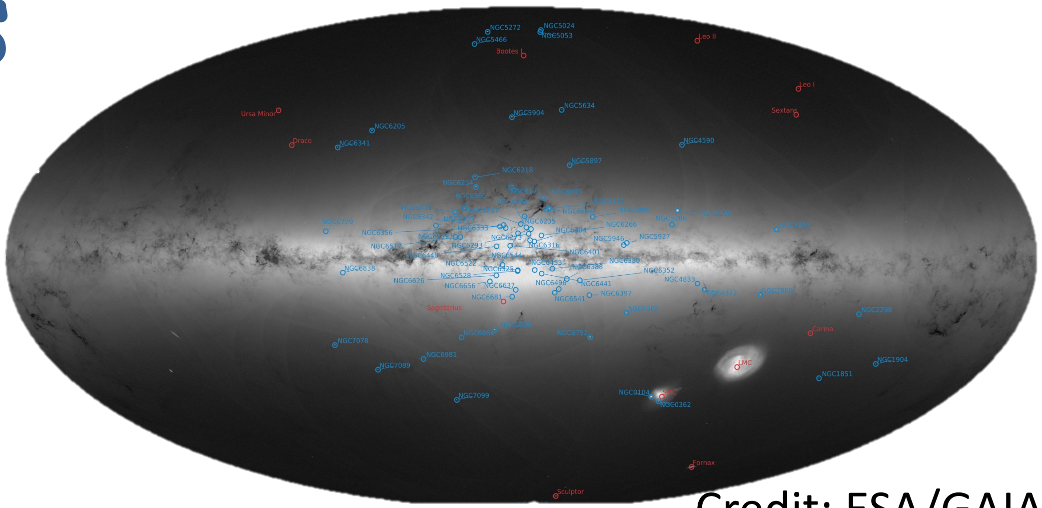
IAU Symposium 395: Stellar populations in the Milky Way and beyond

November 18th, 2024

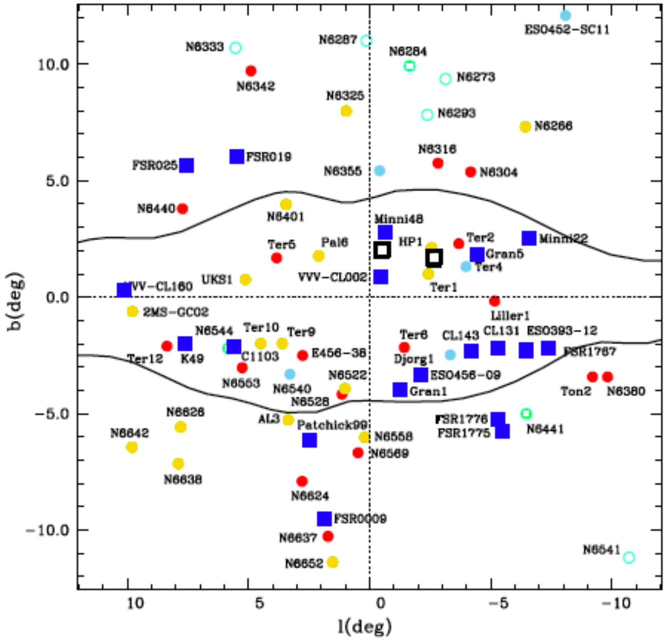
The Galactic Bulge at the crossroads, Dec 2018

Galactic globular clusters

- GCs are the most ancient stellar systems in the MW.
- The GC system follows a spheroidal distribution.
- The MW has 157 known GCs (Harris 2010).
- 200 GCs compiled by Bica+2019.
- 39 new bulge GC + 2 candidates (Bica et al. 2024)
- GCs + candidates ~ 294 objects.
- Reducing the lack of GCs with respect to M31 with ~360 GCs (Caldwell & Romanowsky 2016).
- Many of GCs will be discover with surveys such as Gaia and VVVX .



Credit: ESA/GAIA

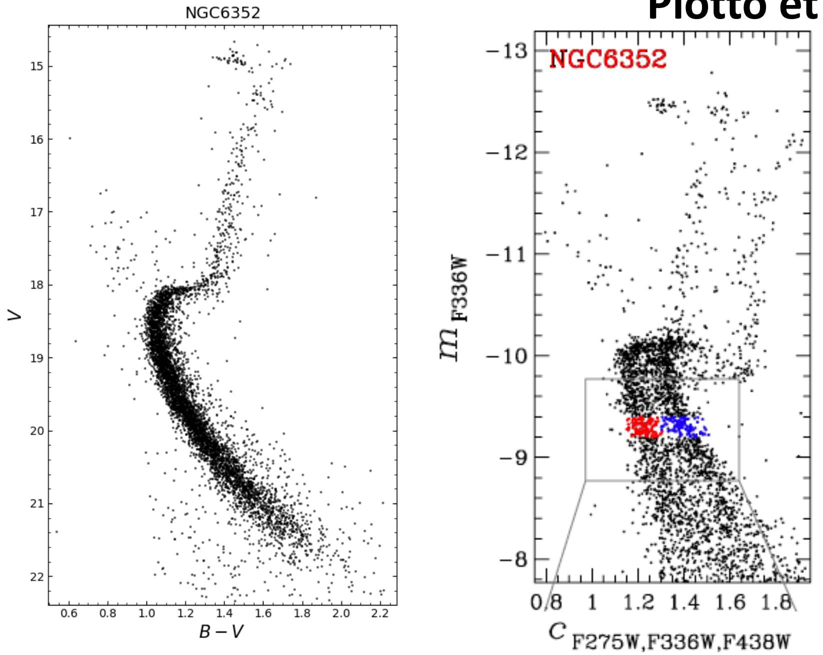


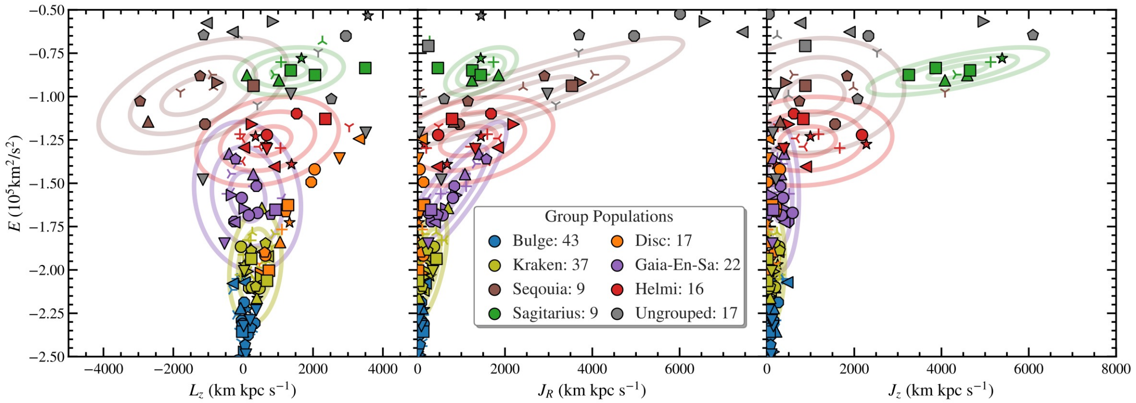
Bica et al. 2024

Why do we study globular clusters?

- As individual objects:
  - Laboratories to study the stellar evolution.
    - Stars with ~same age and ~chemical composition but different masses.
    - Multiple stellar populations.
- As a system:
  - They provide a fossil record of the dynamical and chemical condition during the Galaxy formation.

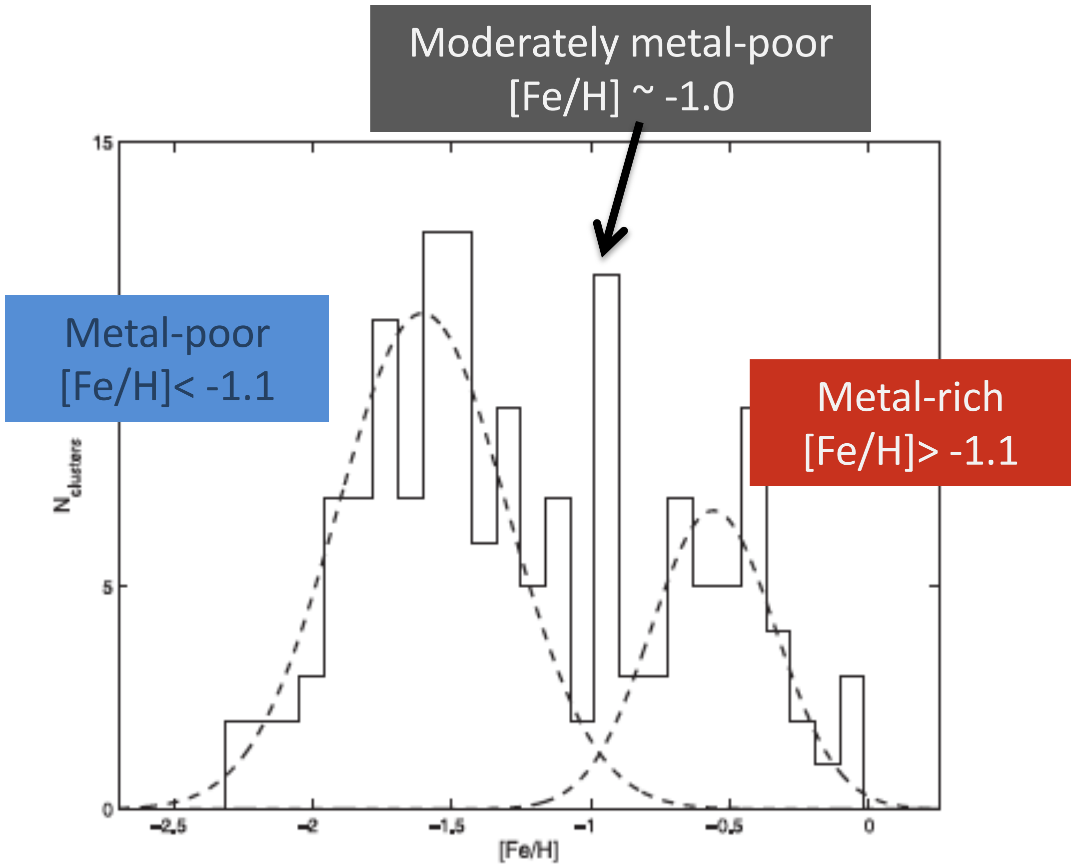
Piotto et al. 2015

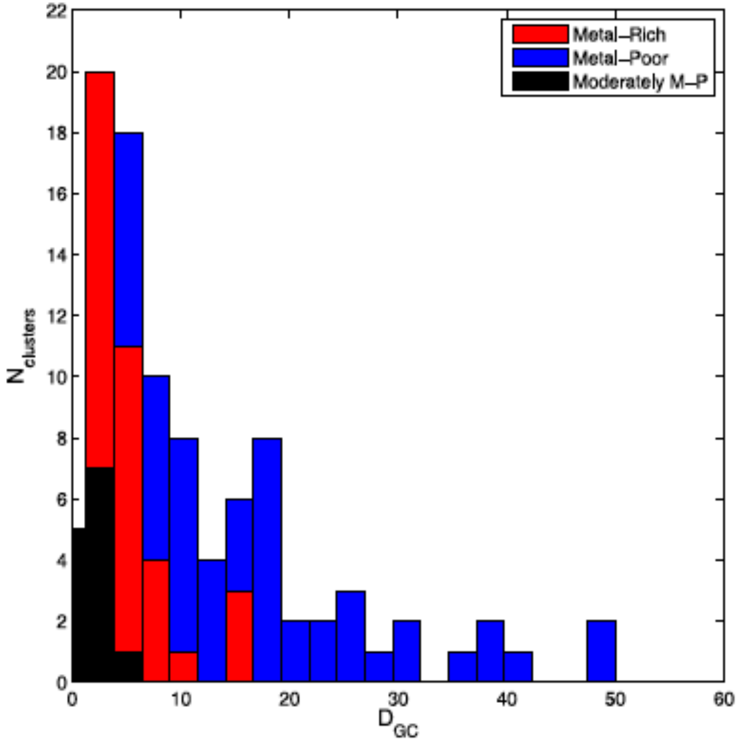




Callingham et al. (2022)

Metallicity distribution function of GCs in the Milky Way

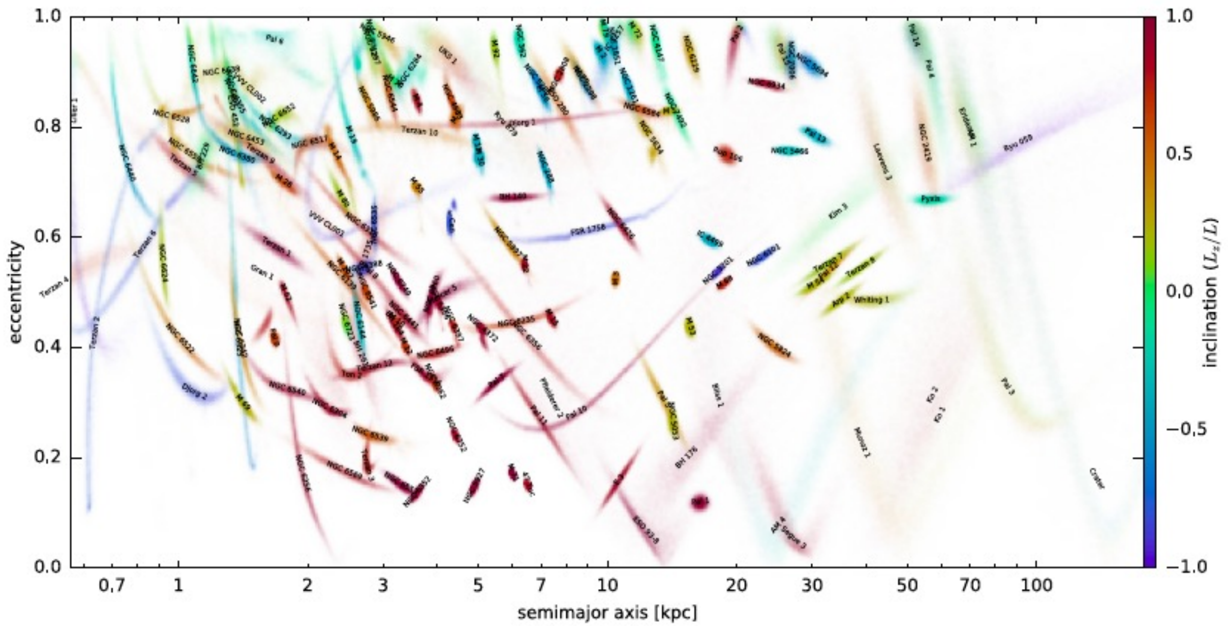




Rossi et al. 2015

Proper Motions from Gaia

- Accurate absolute mean proper motions for 166 MW GCs (Vasiliev & Baumgardt 2021).
- Homogeneous method.
- Errors < 0.05 mas/yr.
- Even for the GCs associated to the bar/bulge region.



Vasiliev & Baumgardt 2021

Perfect timing for orbital analysis of GCs

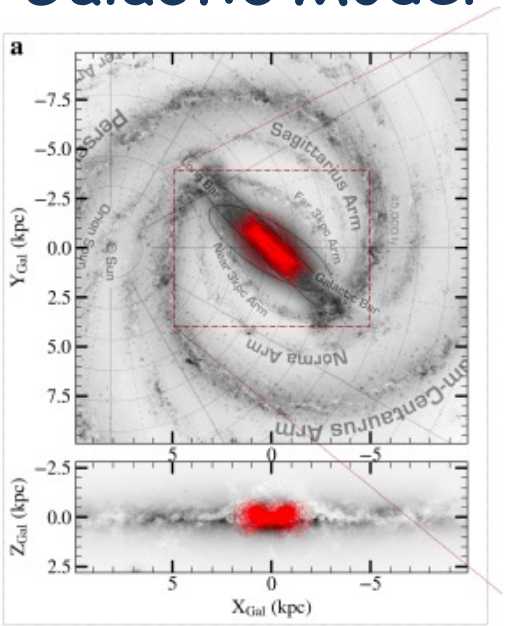
Ingredients to the orbital analysis

1. **Observational parameters:**

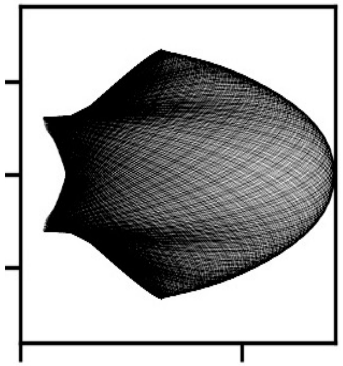
R.A. & DEC + [$d_\odot$ + RV + PMs] = 6D phase-space vector

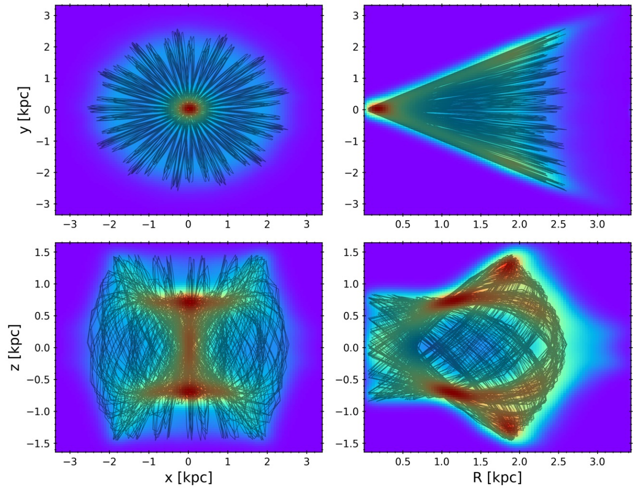
Uncertainties

2. **Galactic Model**



3. **Orbit integrations**





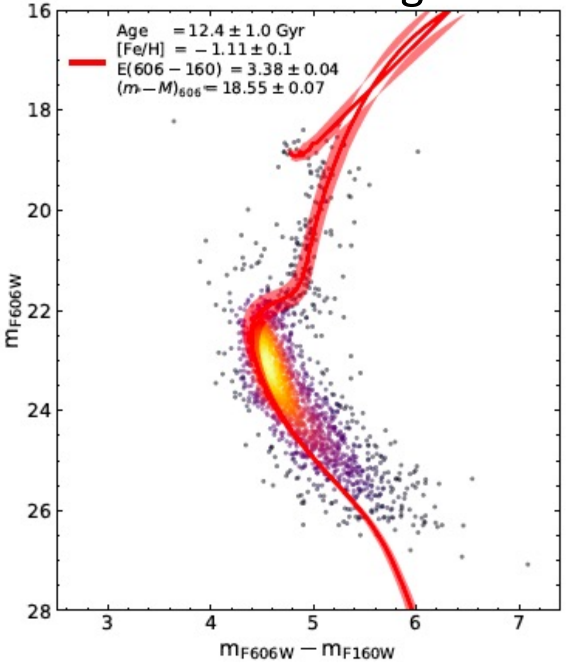
Souza et al. 2021

- *Ages*
- *Chemical information*

Chrono-chemo-dynamical analysis

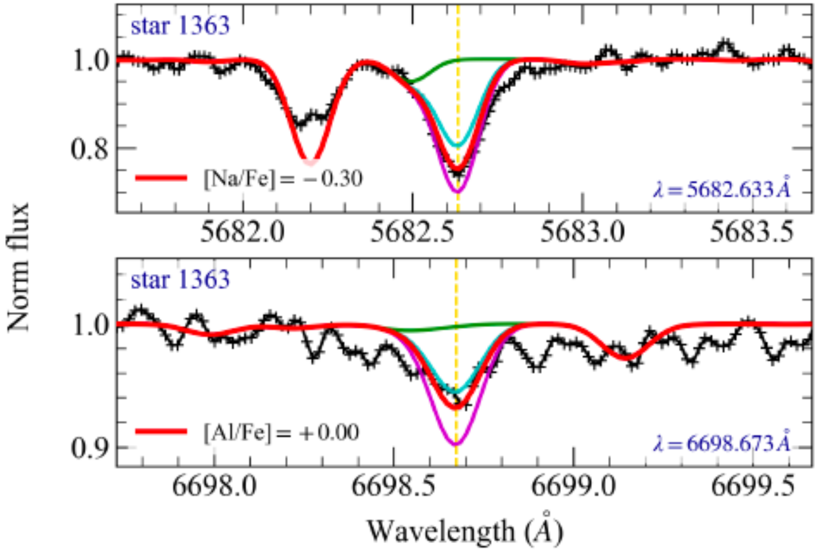
- Chrono: Ages

Isocrhone fitting



Souza et al. 2021

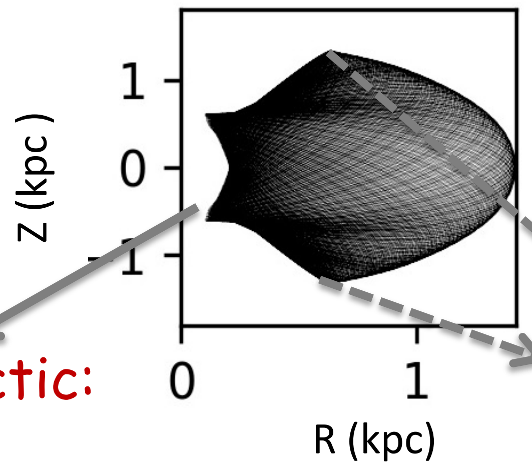
- Chemo: Abundances



Souza et al. 2023

- Dynamical: Orbital parameters

Apogalactic: r_{max}



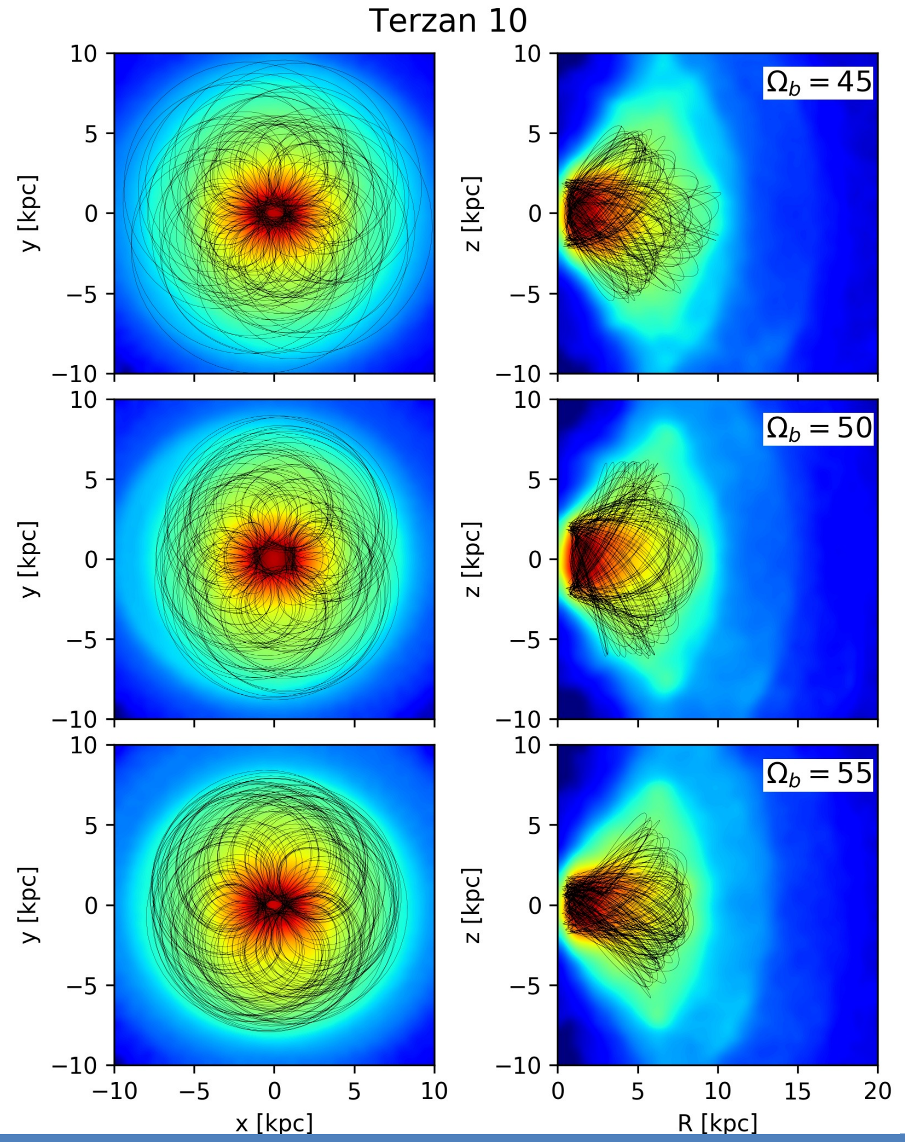
Perigalactic: r_{min}

$|Z|_{max}$

Eccentricity $e = \frac{r_{max} - r_{min}}{r_{max} + r_{min}}$

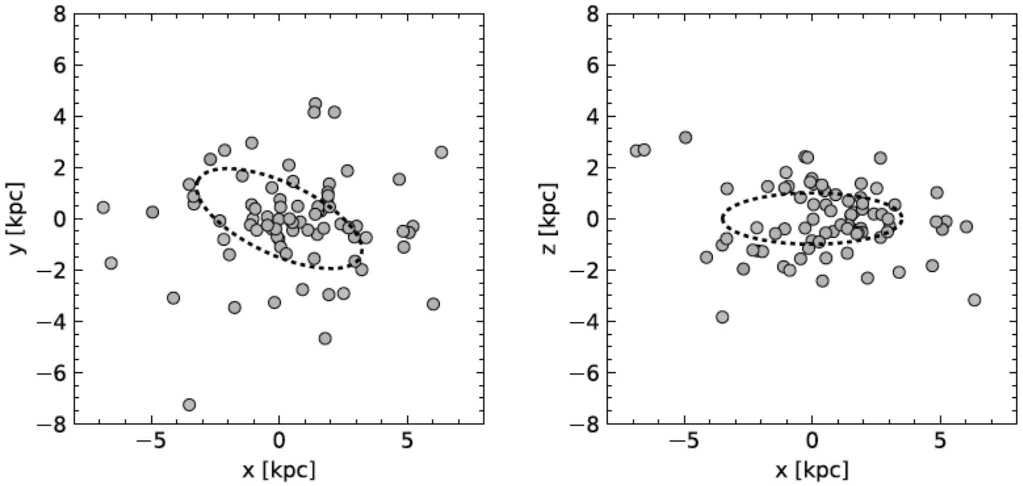
IoM→ Energy, Lz, E_J

A halo intruder in the Galactic bulge



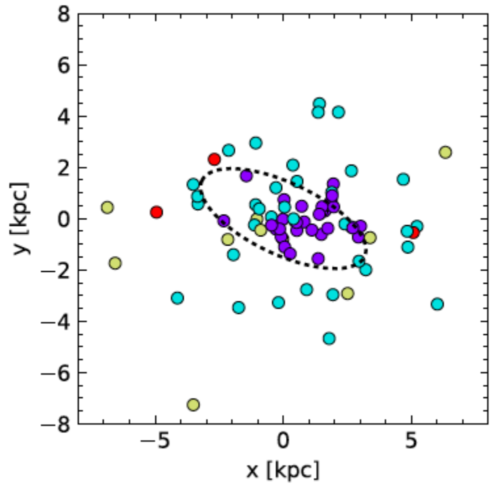
Ortolani et al. 2019

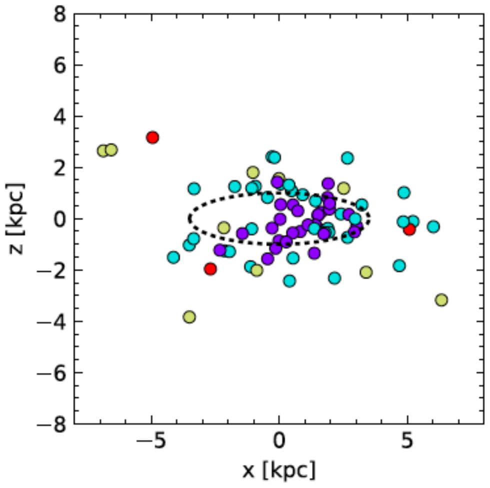
Classification of GCs using orbital parameters

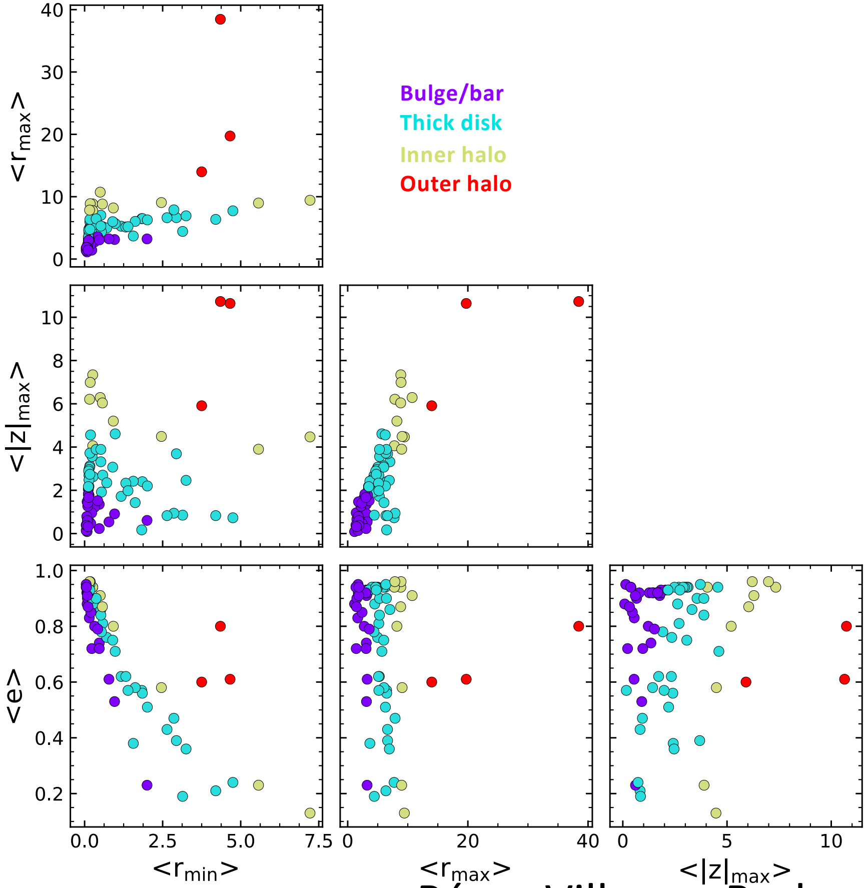


Classification of GCs using orbital parameters

- Apogalactic distance and maximum vertical excursion



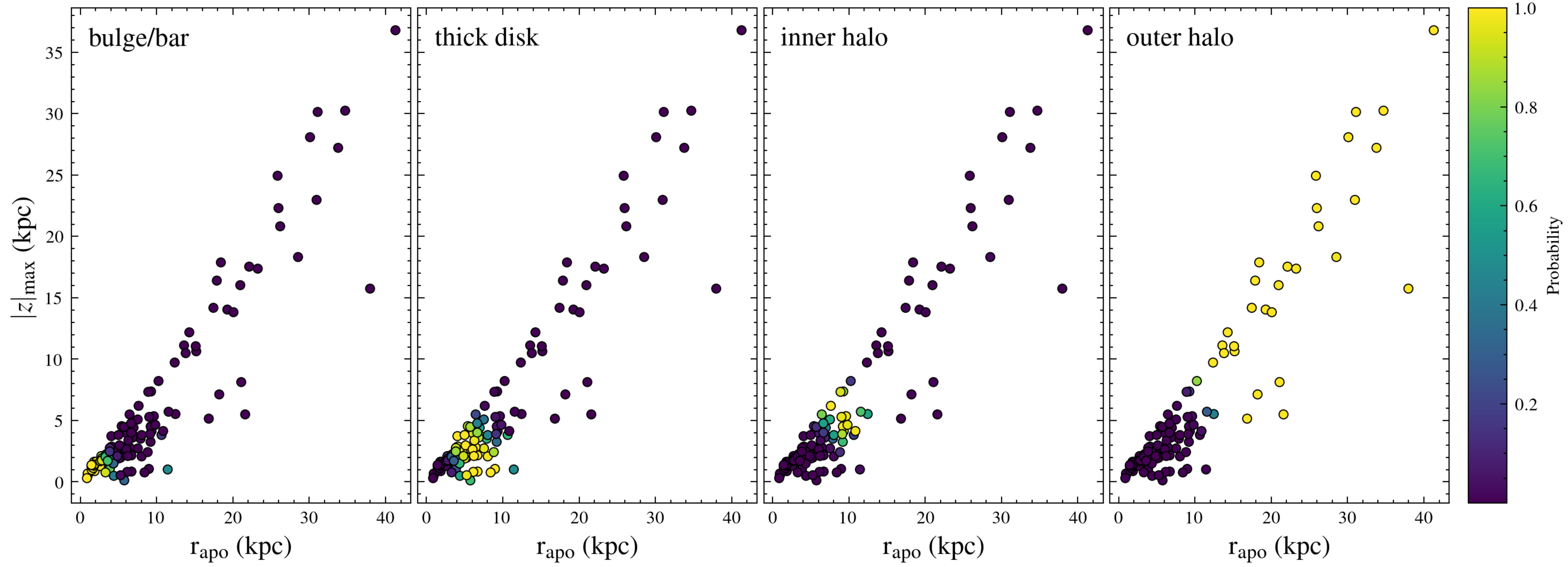




Pérez-Villegas, Barbuy et al. 2020

- ~30% of bulge GCs from Bica et al. 2016 are intruders.

Ongoing work on the GCs classification



25 % GCs

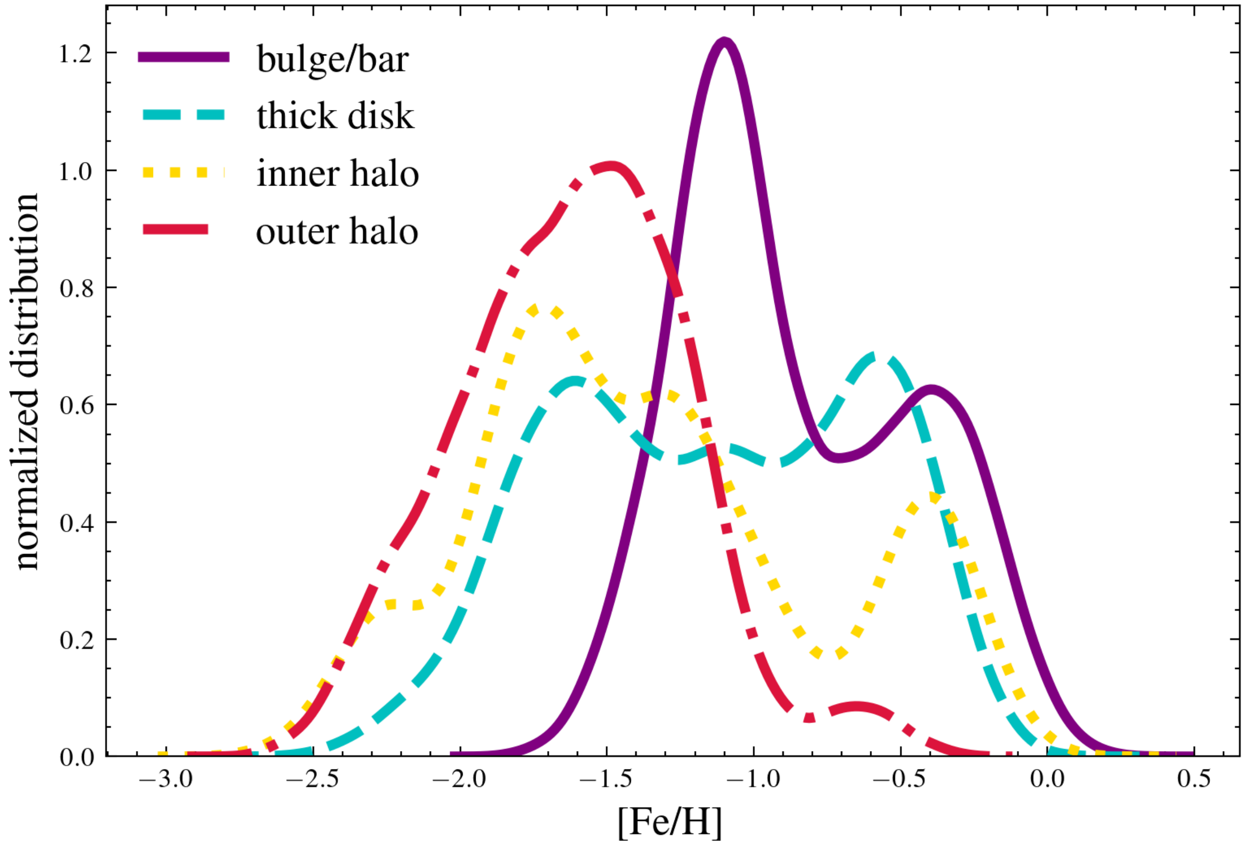
34 % GCs

12 % GCs

28 % GCs

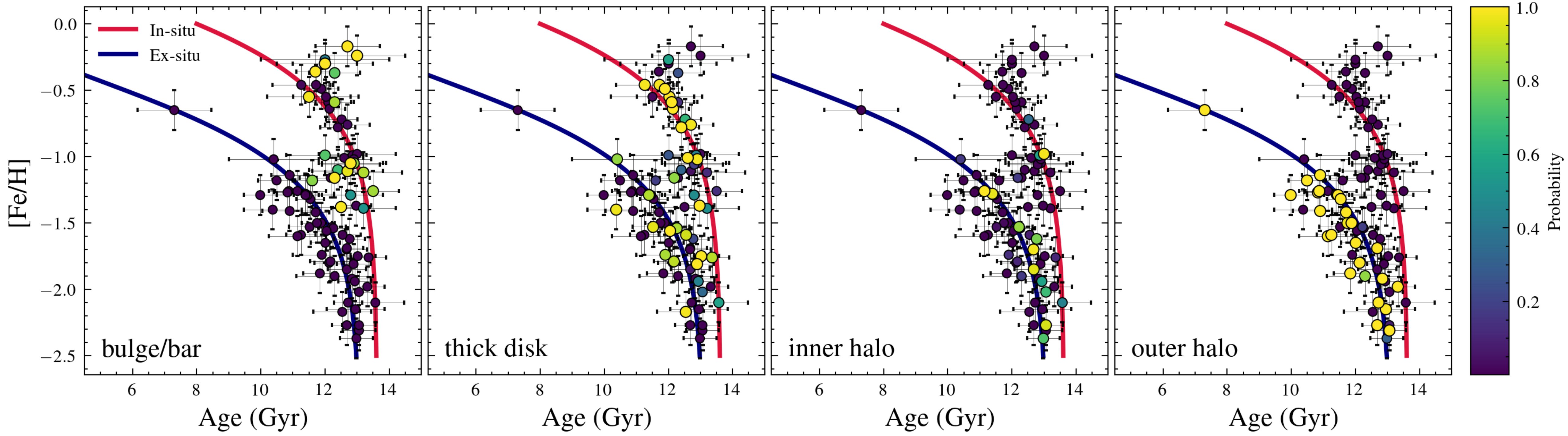
Pérez-Villegas et al. in prep.

MDF of Galactic GCs



Pérez-Villegas et al. in prep.

Age-Metalicity relation



See talk by Stefano Souza for the bulge AMR!

Pérez-Villegas et al. in prep.

Take-home message

- The MW GCs can be separated into different Galactic components: bulge/bar, thick disk, inner halo, and outer halo.
- The thick disk MDF seems to contain more thin disk population.
- The bulge/bar MDF shows a clearly peak at ~ -1.0 consistent with the fast chemical enrichment in the inner part of the Galaxy.
- Based on AMR, the GCs in the Milky Way can be separated into two groups: in-situ and accreted clusters.
- All the GCs classified as outer halo belong to the accreted component.
- The best way to analyze GCs in the context of Galaxy evolution is through chrono-chemo-dynamical studies.

¡GRACIAS!

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