Structure of the Milky Way:
Unusual Fossil Relics

by José G. Fernández-Trincado
Universidad Católica del Norte (Chile)

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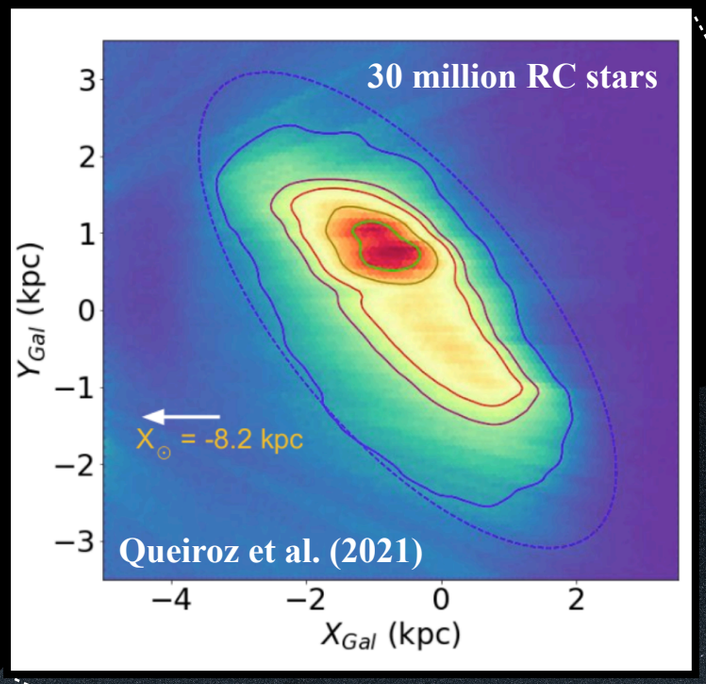
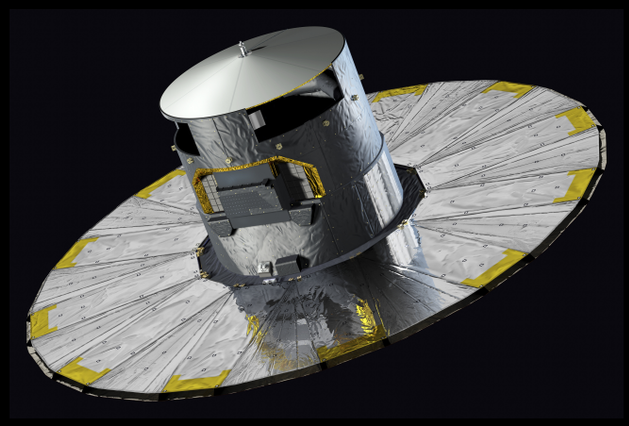
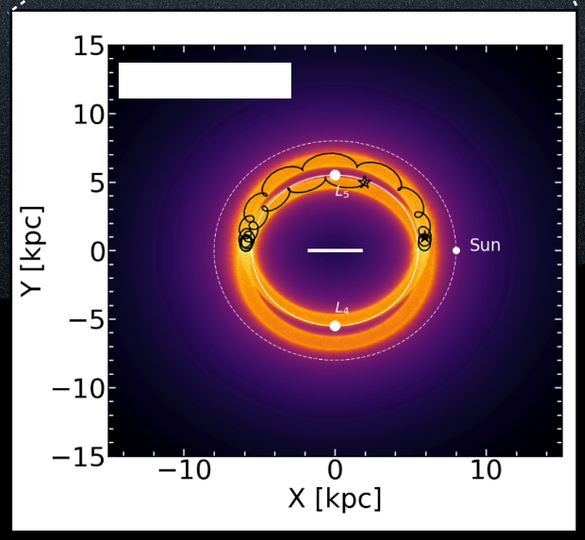
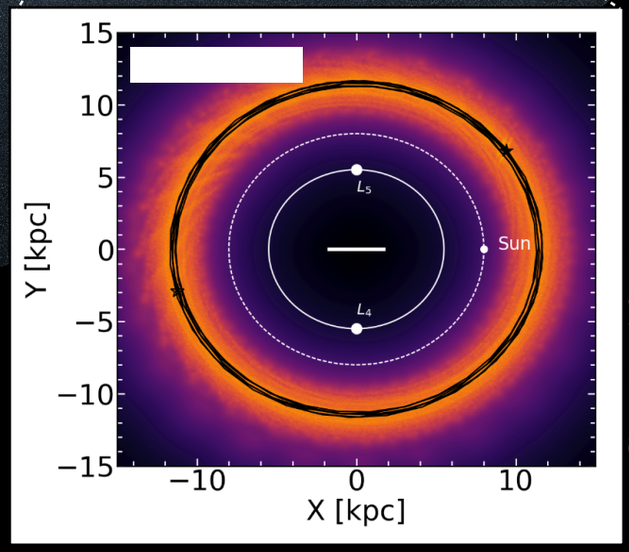




Credit: ESA/Gaia/DPAC, CC BY-SA 3.0 IGO

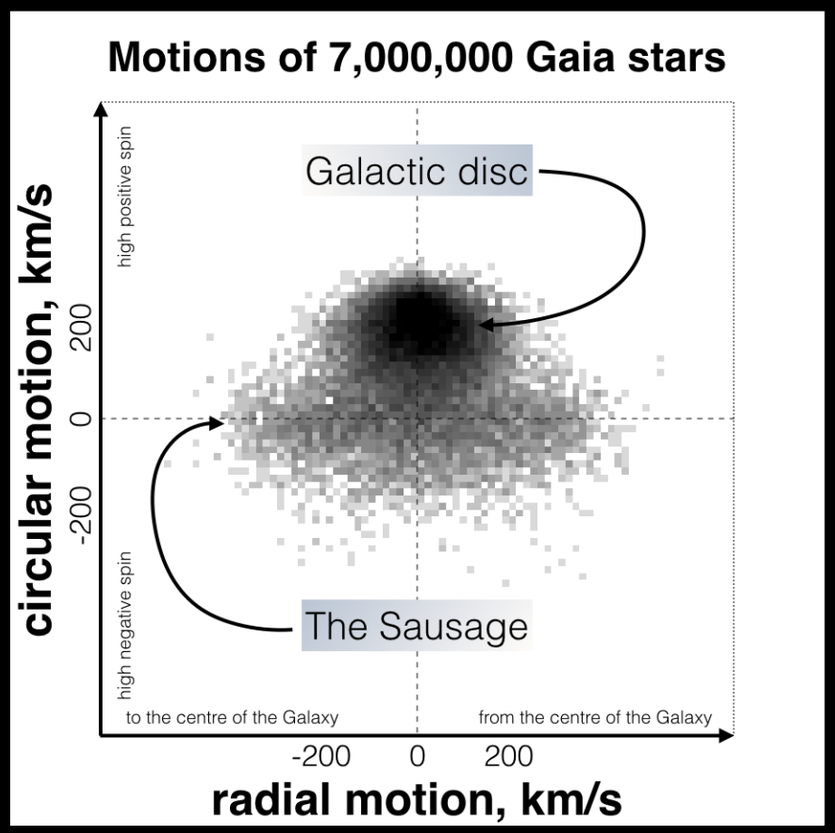




GravPot16 galaxy model

OC's: Guerço et al. in prep.

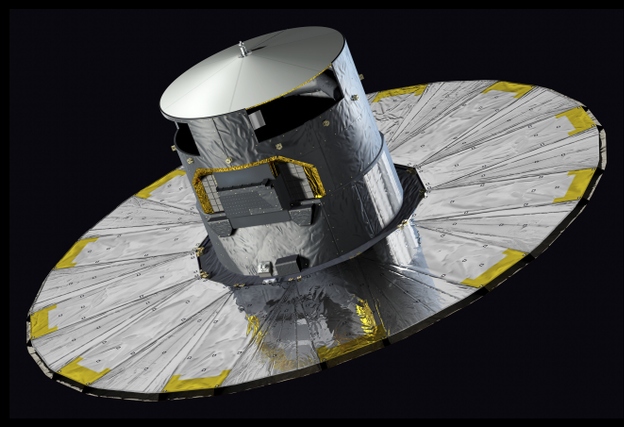
Violent past



Credit: V. Belokurov (Cambridge, UK and CCA, New York, US) and Gaia/ESA

***Gaia*-Sausage:** Belokurov et al. 2018, MNRAS, 478, 611

***Gaia*-Enceladus:** Helmi et al. 2018, Nature, 563, 85



Cause: ***Gaia*-Sausage/Enceladus**

Effect: **Likely the plash**

see Belokurov et al. 2020, MNRAS, 494, 3880 - AND-
Amarante et al. 2020, ApJL, 891, L30 (different view)

Credit: René van der Woude, Mixr.nl

Mix of stellar populations: Including Chemically unusual Stellar debris

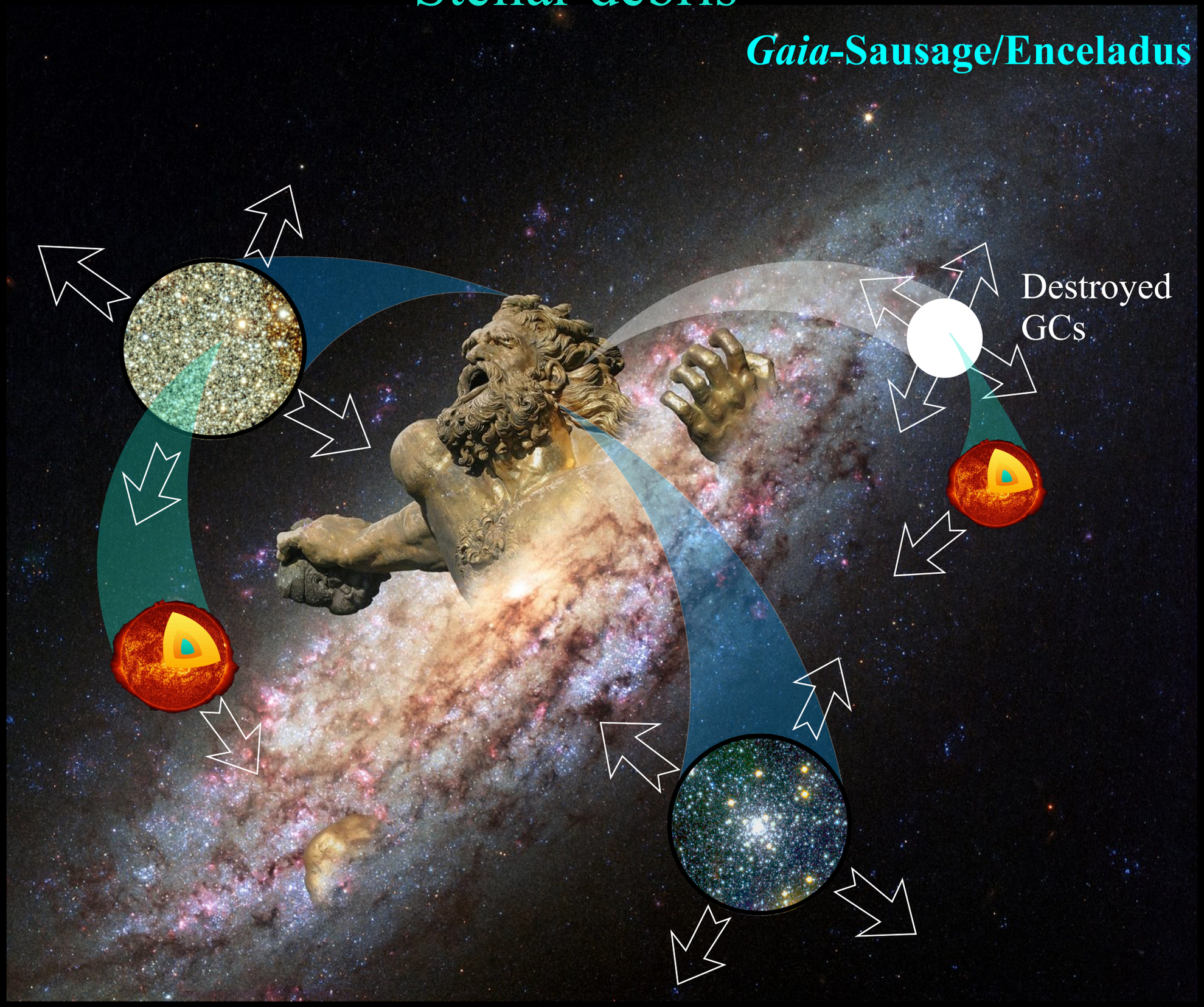
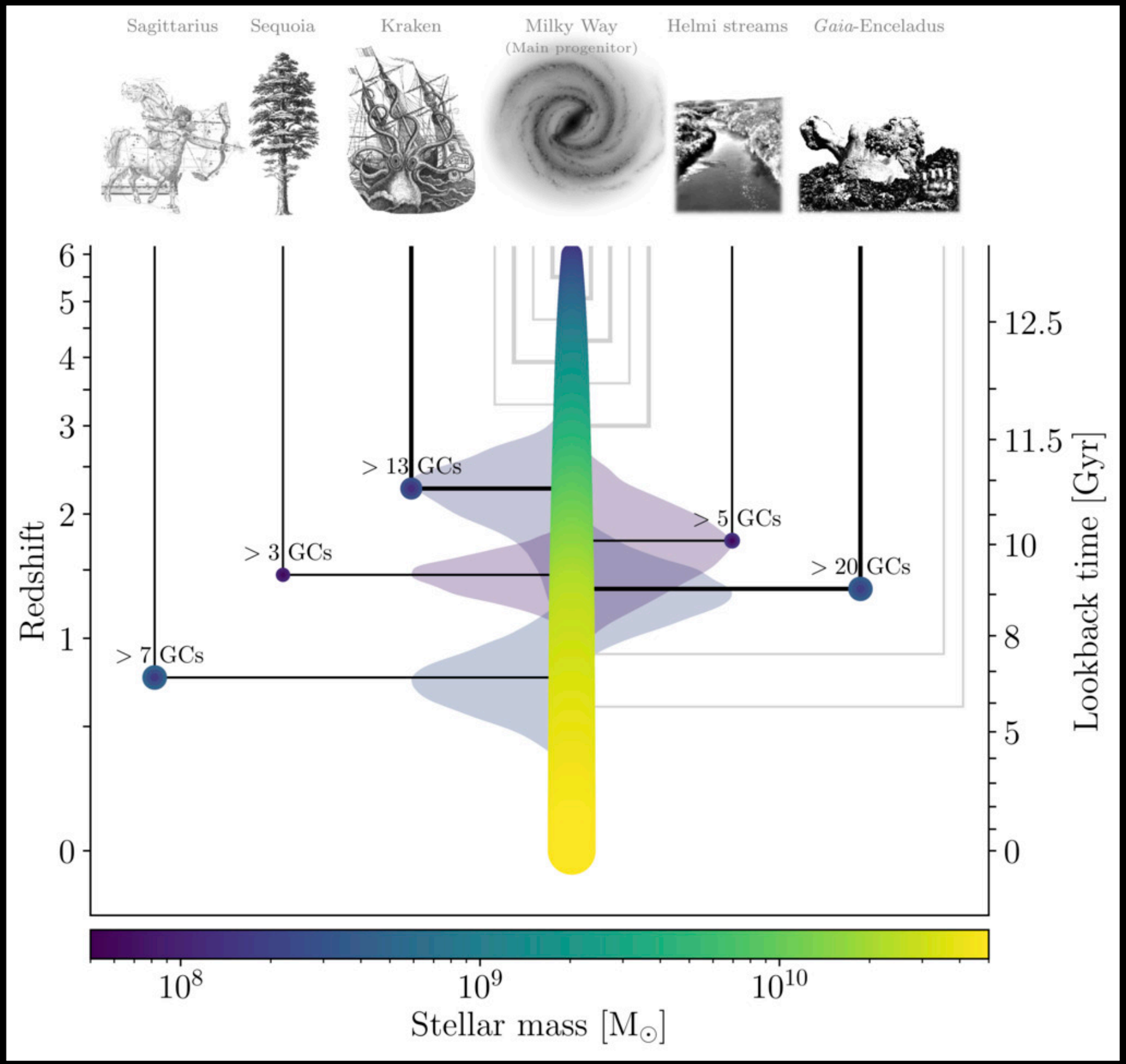


Figure modified from René van der Woude, mixr.nl (background image)

Past Accretion Events

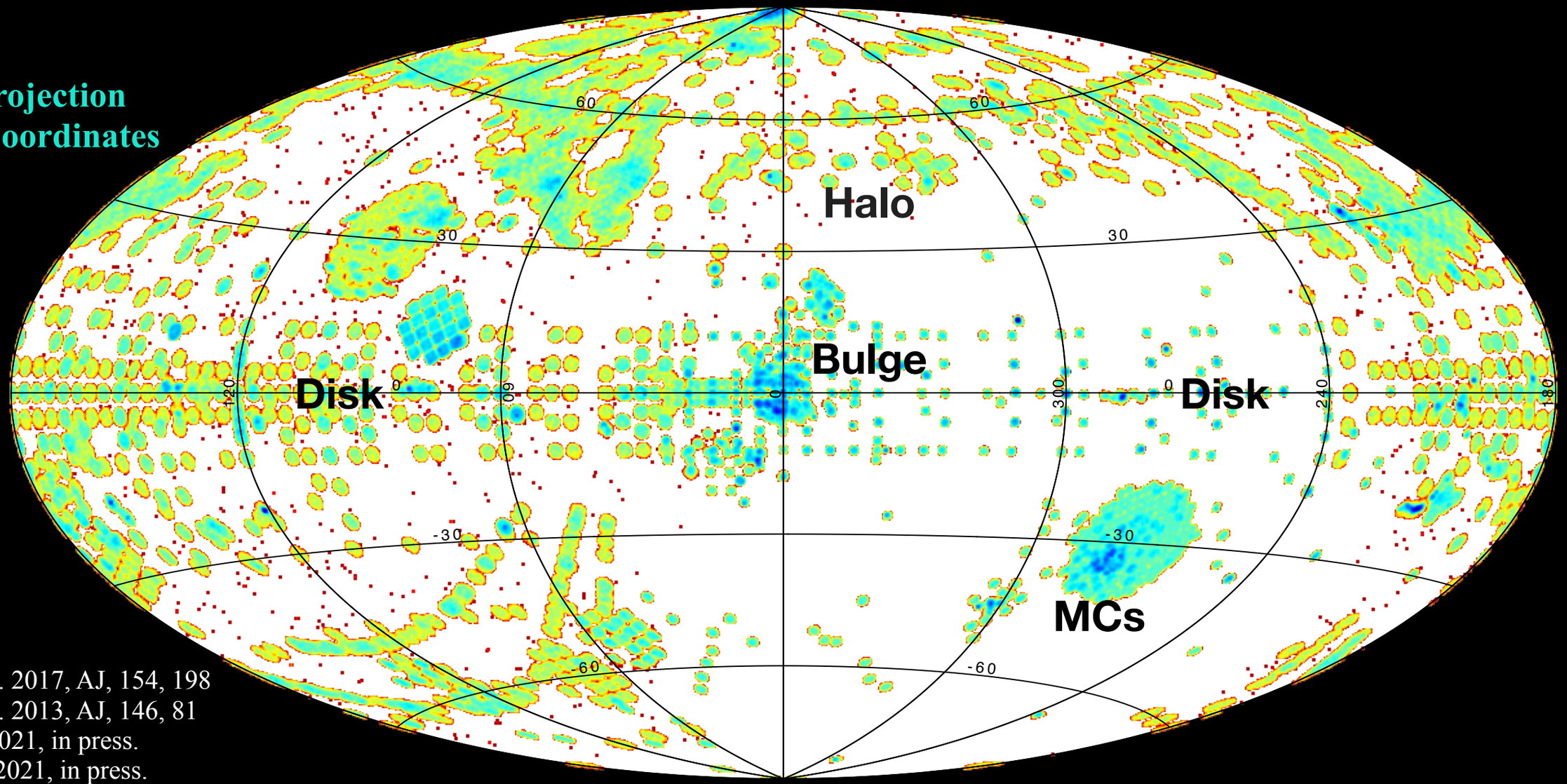


J. M. Diederik Kruijssen et al. 2020, MNRAS, 498, 2472-2491

APOGEE: The **A**pache **P**oint **O**bservatory **G**alactic **E**volution **E**xperiment survey

- Near-infrared survey / *H*-band **(1.5 — 1.7)** μm
- ~ **700 000** Stars **(SDSS DR17)**
- S/N > 70
- Radial Velocity error: 0.1 km s^{-1}
- Teff +/- 100 K; log *g* +/- 0.1 dex; [Fe/H] +/- 0.04 dex; abundances +/- 0.1 dex

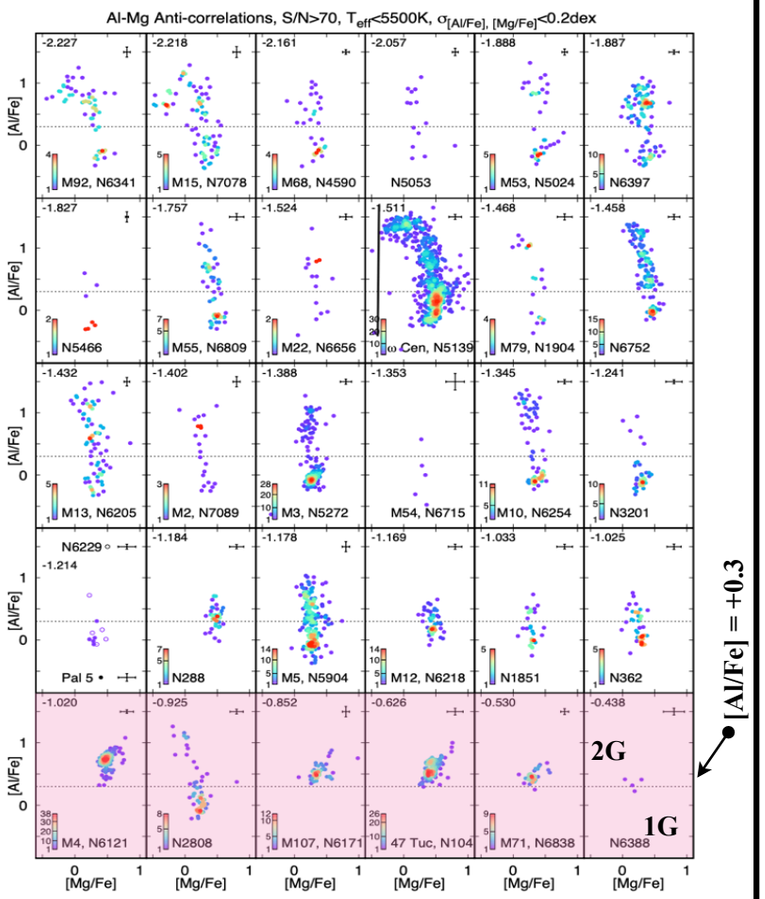
Aitoff projection
Galactic Coordinates



Zasowski et al. 2017, AJ, 154, 198
Zasowski et al. 2013, AJ, 146, 81
Beaton et al. 2021, in press.
Santana et al. 2021, in press.

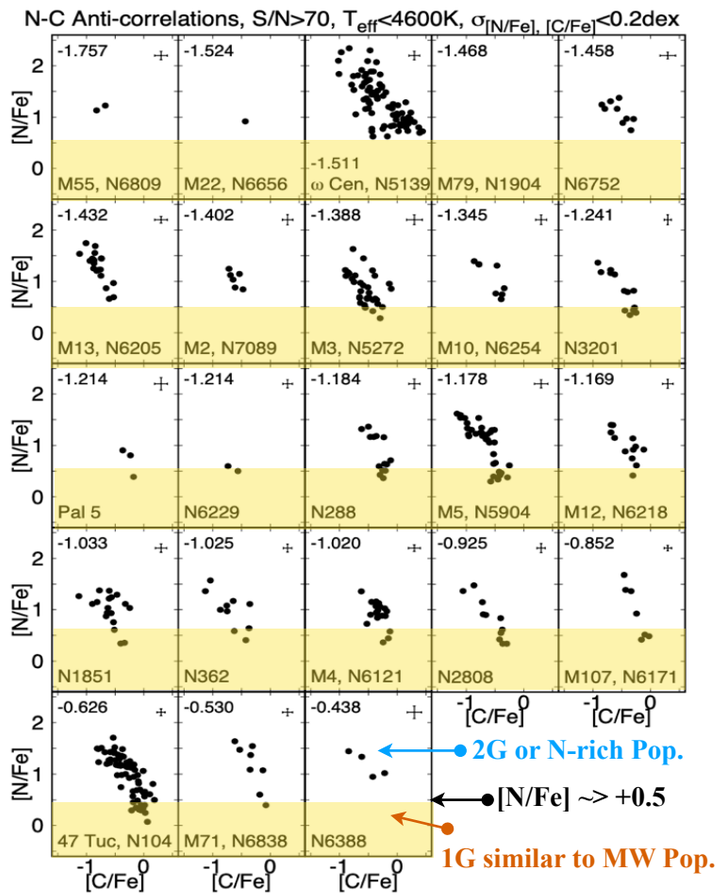
Key Chemical Species in GCs:
Multiple-population Phenomenon

Al-Mg plane



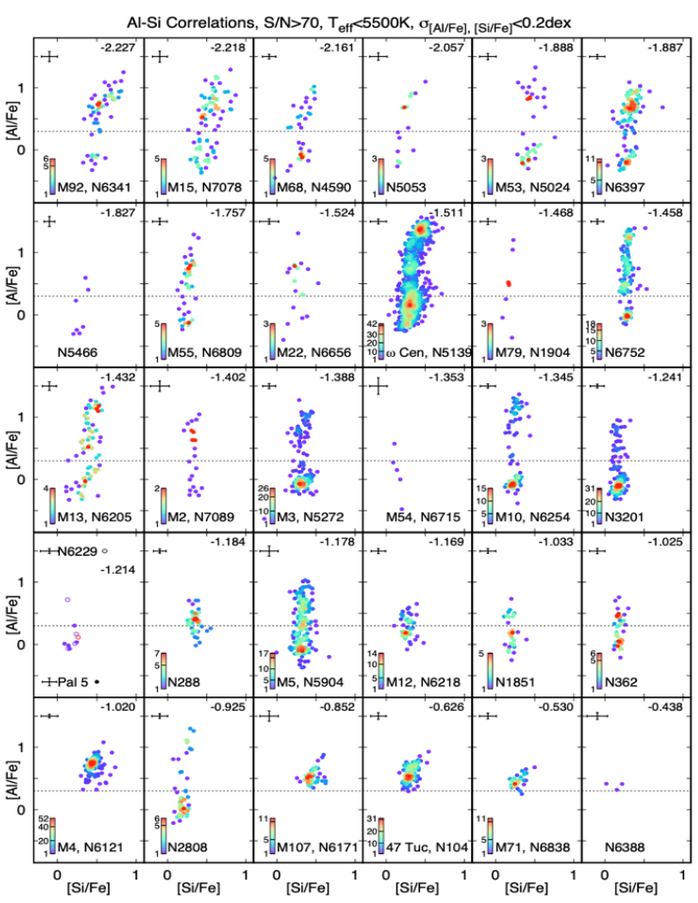
anticorrelation

N-C plane



anticorrelation

Al-Si plane



correlation

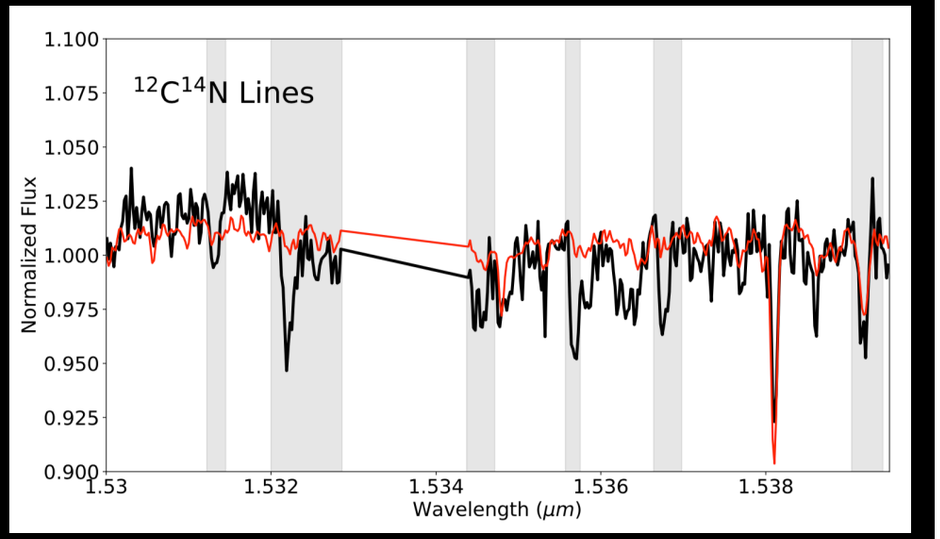
Schiavon et al. 2017, MNRAS, 466, 1010-1018
Nataf et al. 2019, AJ, 158, 14

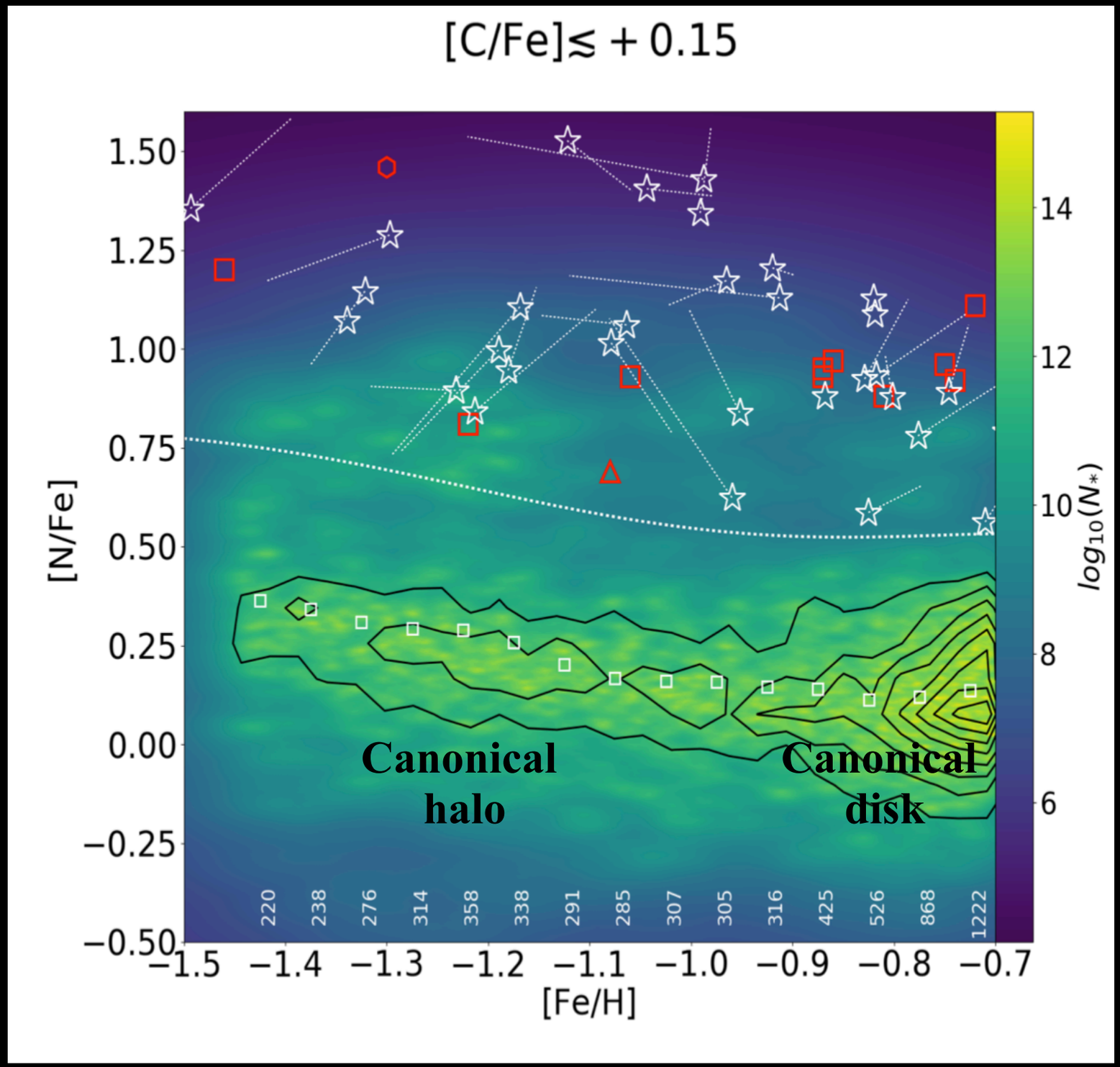
Masseron et al. 2019, A&A, 622, A191
Mészáros et al. 2015, AJ, 149, 153

Mészáros et al. 2020, MNRAS, 492, 1641-1670
Mészáros et al. 2021, MNRAS, 505, 1645-1660

N-rich Stars: A new population in the Milky Way bulge, disk, and inner/outer halo

- Fernández-Trincado et al. 2016, ApJ, 833, 132
- Martell et al. 2016, ApJ, 825, 146
- Schiavon et al. 2017, MNRAS, 465, 501-524
- Fernández-Trincado et al. 2019, A&A, 631, A97
- Fernández-Trincado et al. 2019, MNRAS,488, 2864
- Fernández-Trincado et al. 2020, MNRAS, 495, 4113

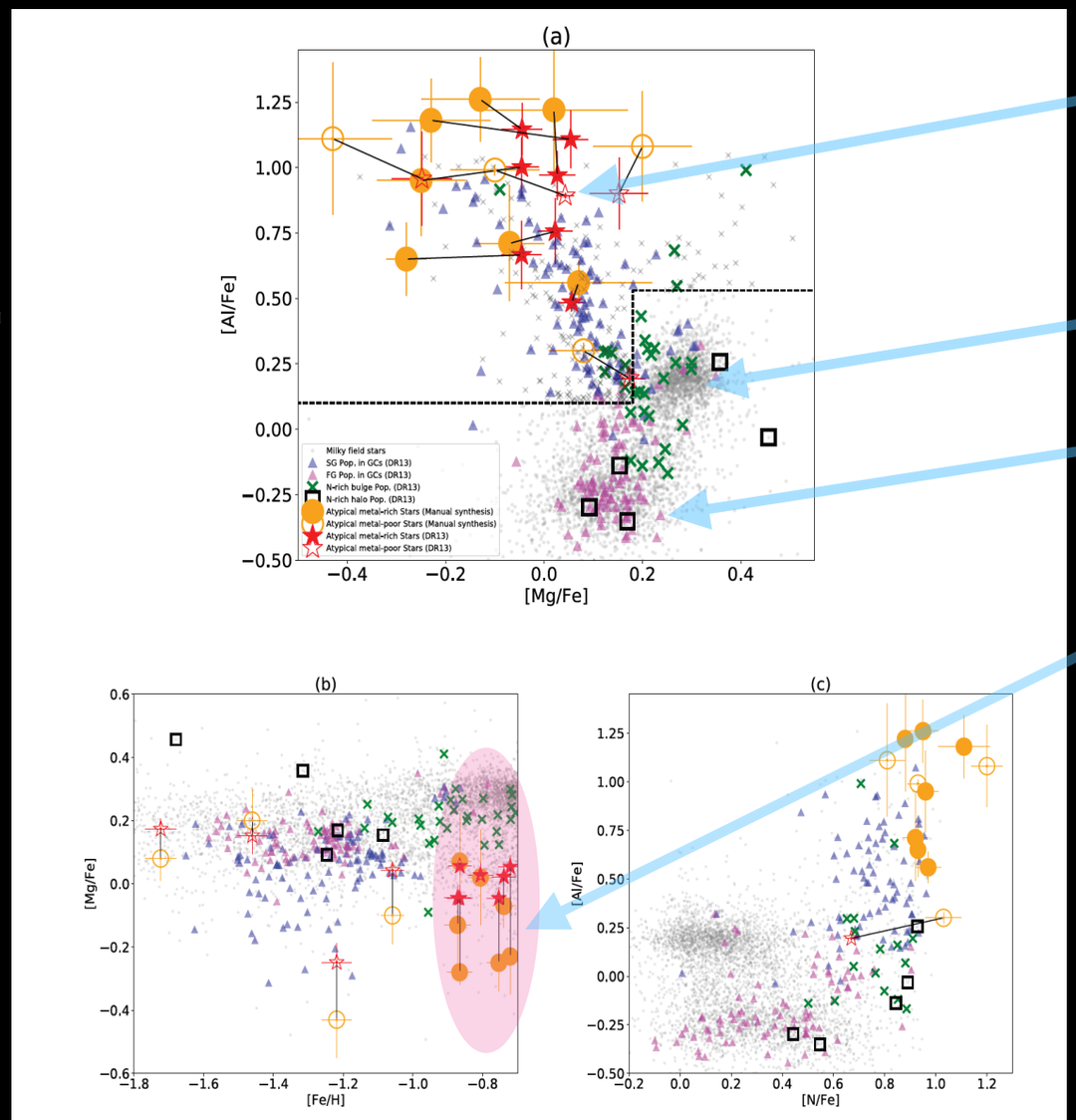




N-rich Stars with Extra-galactic Origins

- ✦Low Magnesium makes they **unlikely linked to Galactic Globular Clusters**
- ✦High Aluminum enrichment makes they **unlikely linked to Dwarf Galaxy debris**
- ✦Retrograde orbits suggest a probable link with **disrupted Globular Clusters**
- ✦**Absence of radial velocity** variation: Difficult to support pollution by stellar winds from a binary companion

2G-like Abundance Patterns with Possible Extragalactic Origins



Fernández-Trincado et al., 2017, ApJL, 846, L2

GCs populations/debris

and unexplained objects

Canonical (thick) disk

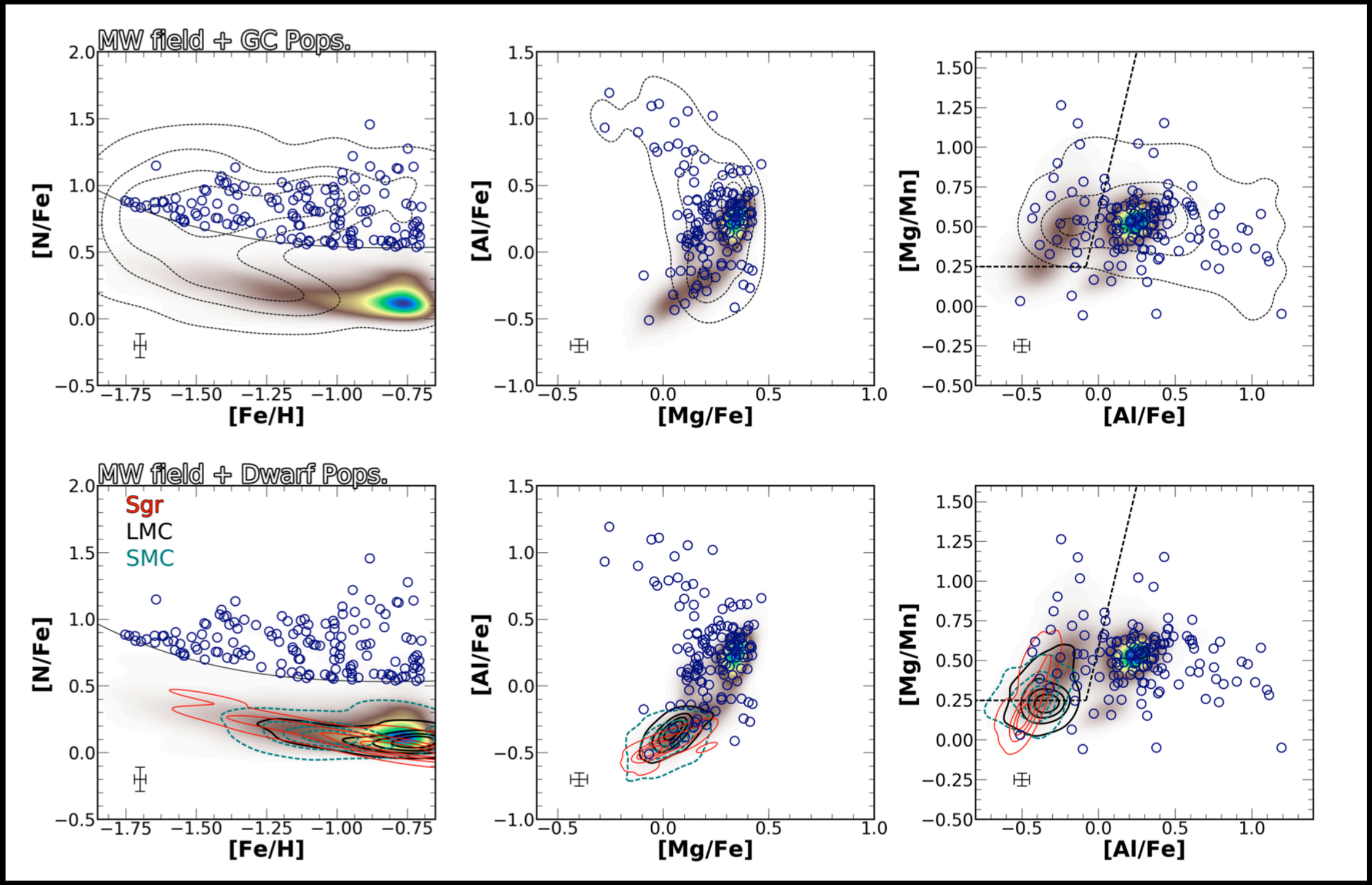
Canonical/Accreted Halo

NOT Galactic GCs with [Mg/Fe] < 0 in **[Fe/H] > -1.0**

~11 N-rich Stars toward the inner Stellar Halo

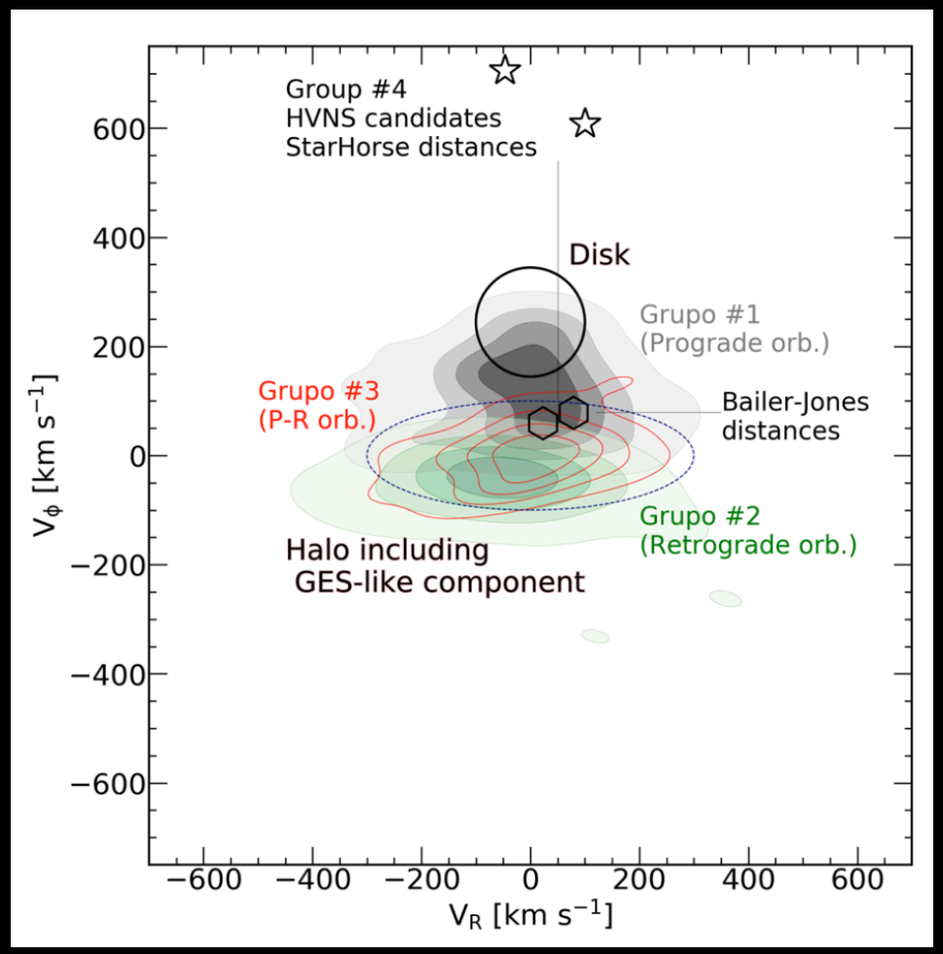
[C/Fe] < +0.15 dex

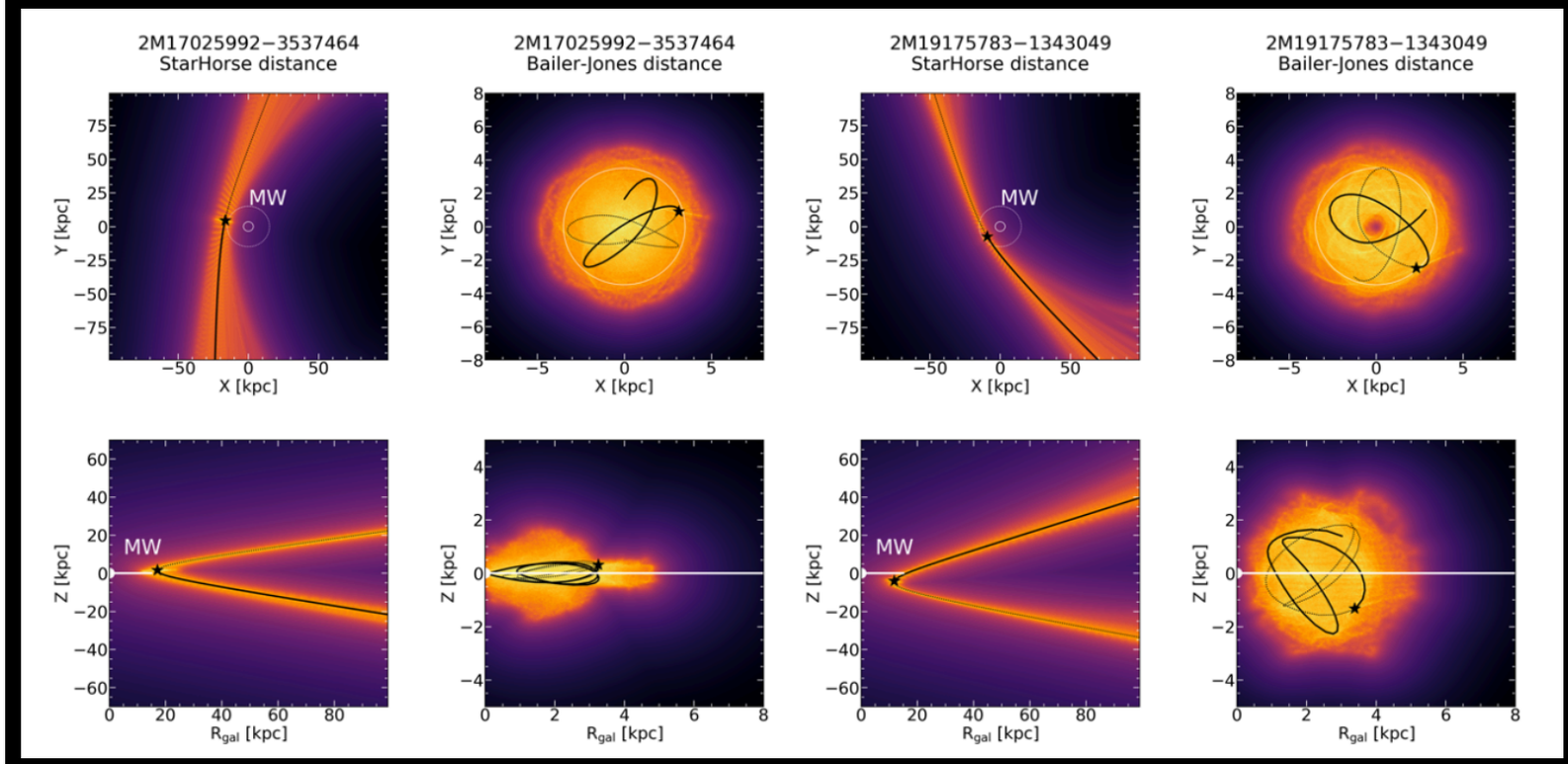
Large census of N-rich stars (Bulge+Disk+Halo): 412 unusual giant stars



Fernández-Trincado et al. 2022, A&A, 663, A126

Large census of N-rich stars (Bulge+Disk+Halo): 412 unusual giant stars

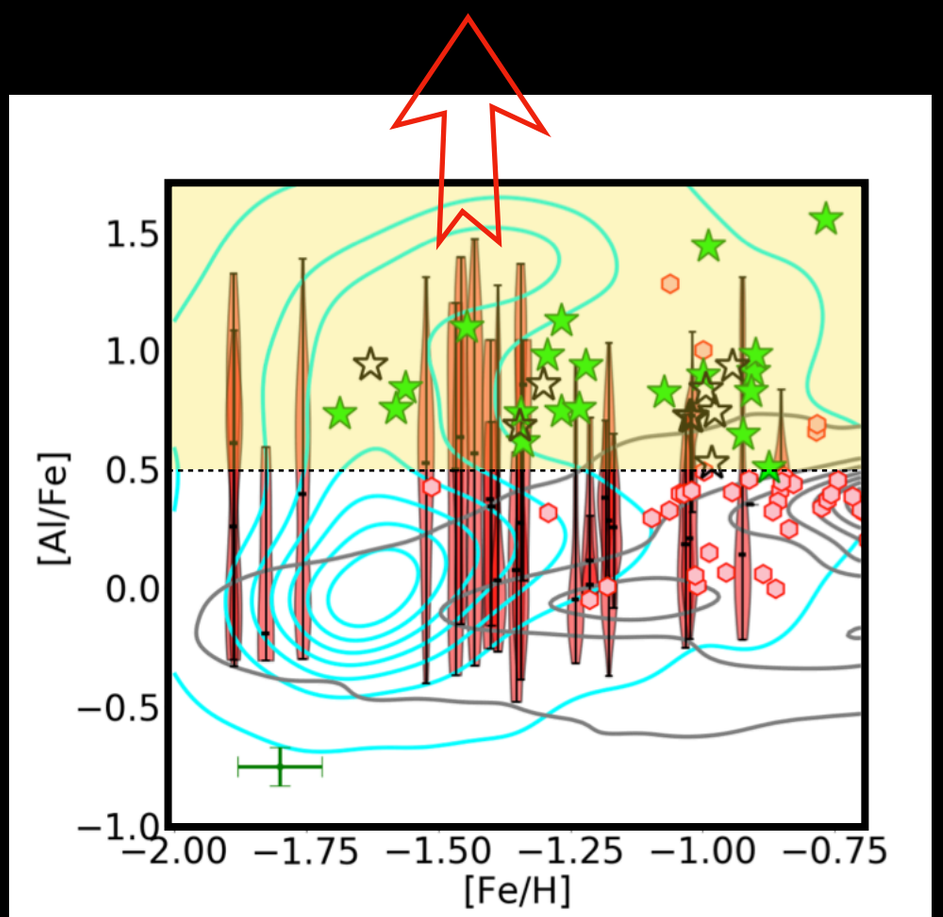


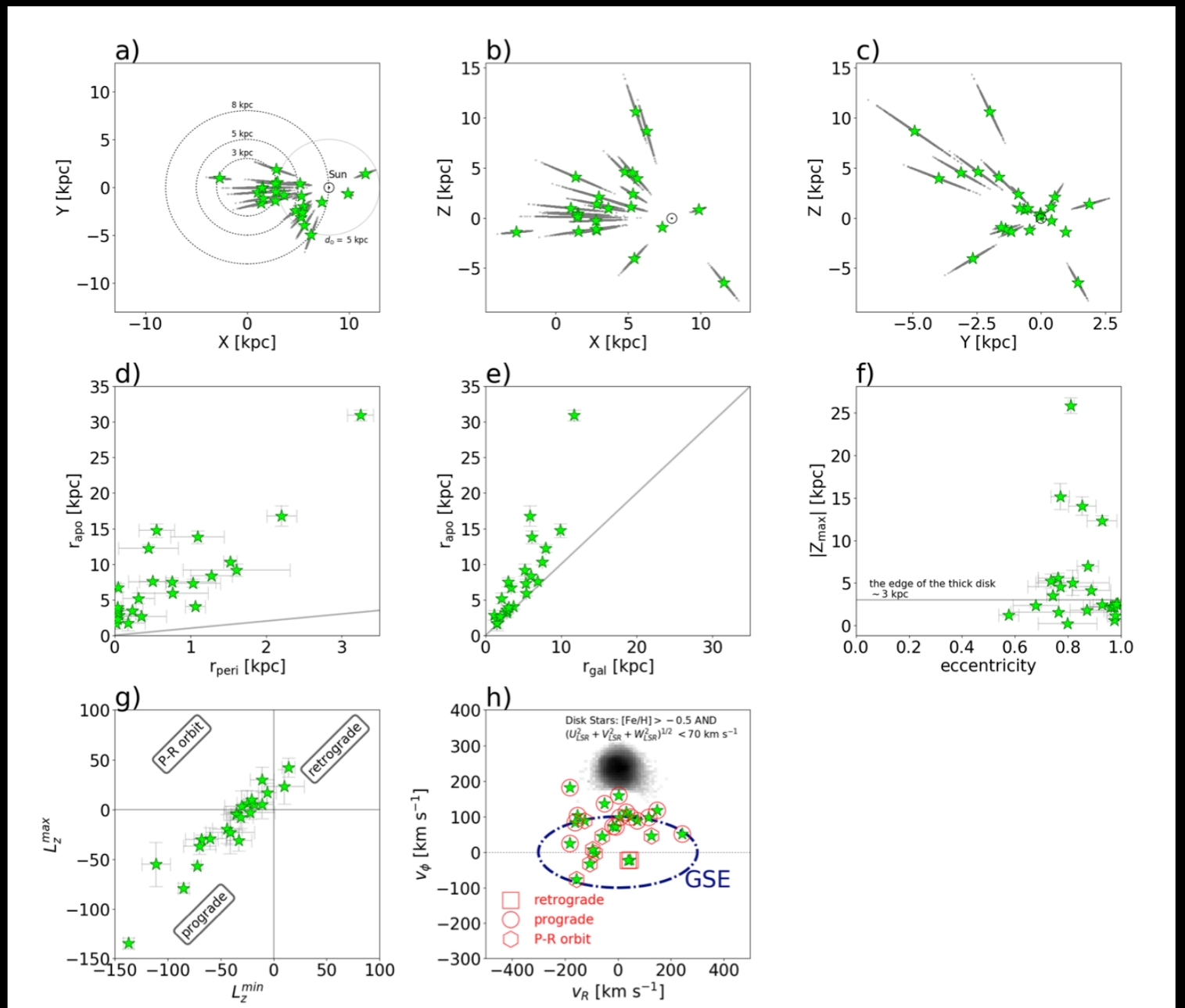


Fernández-Trincado et al. 2022, A&A, 663, A126

Discovery of a Population of Aluminium-enriched metal-poor stars buried in the Galactic Bulge

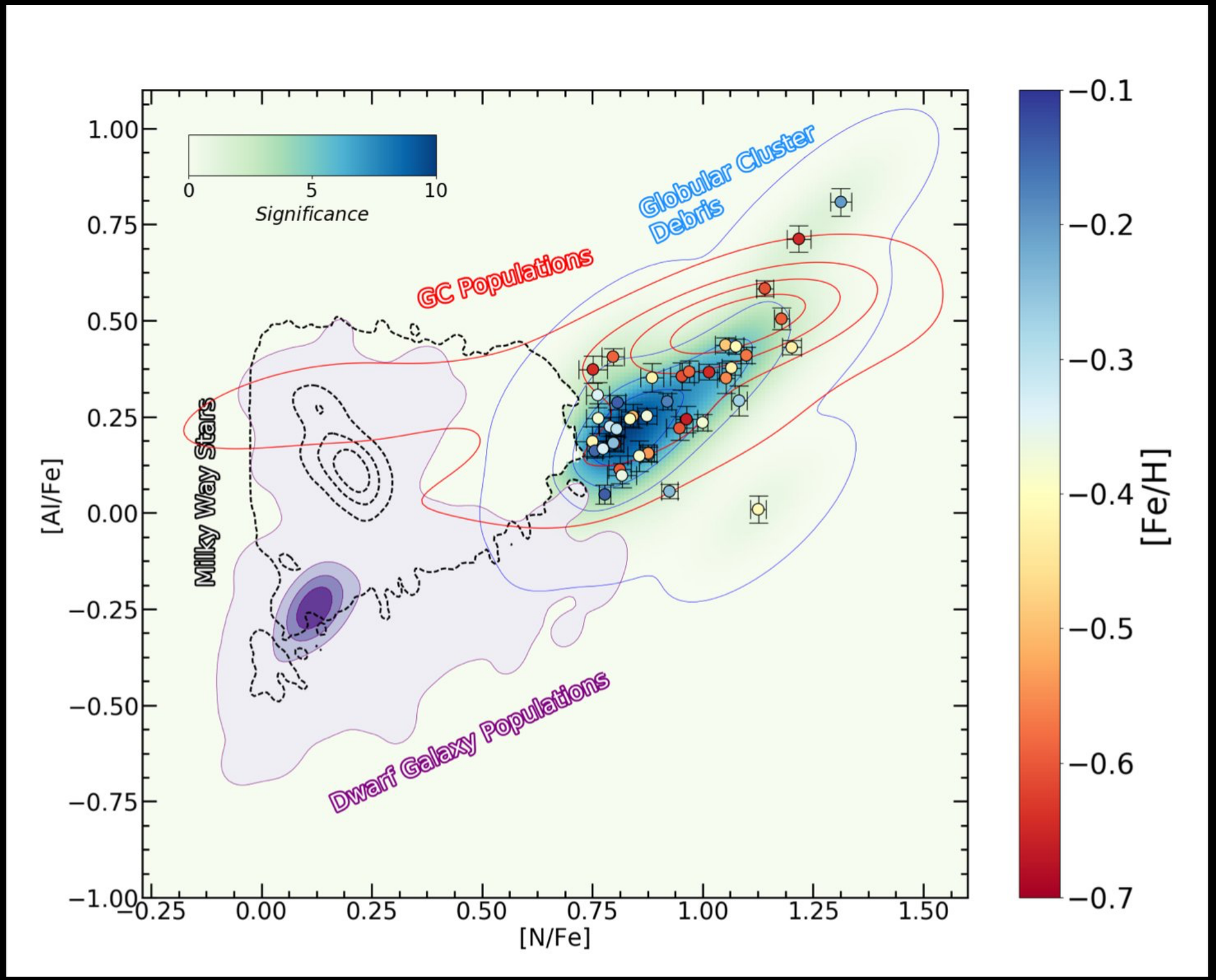
No evidence of Dwarf galaxies with **[Al/Fe] > +0.5**





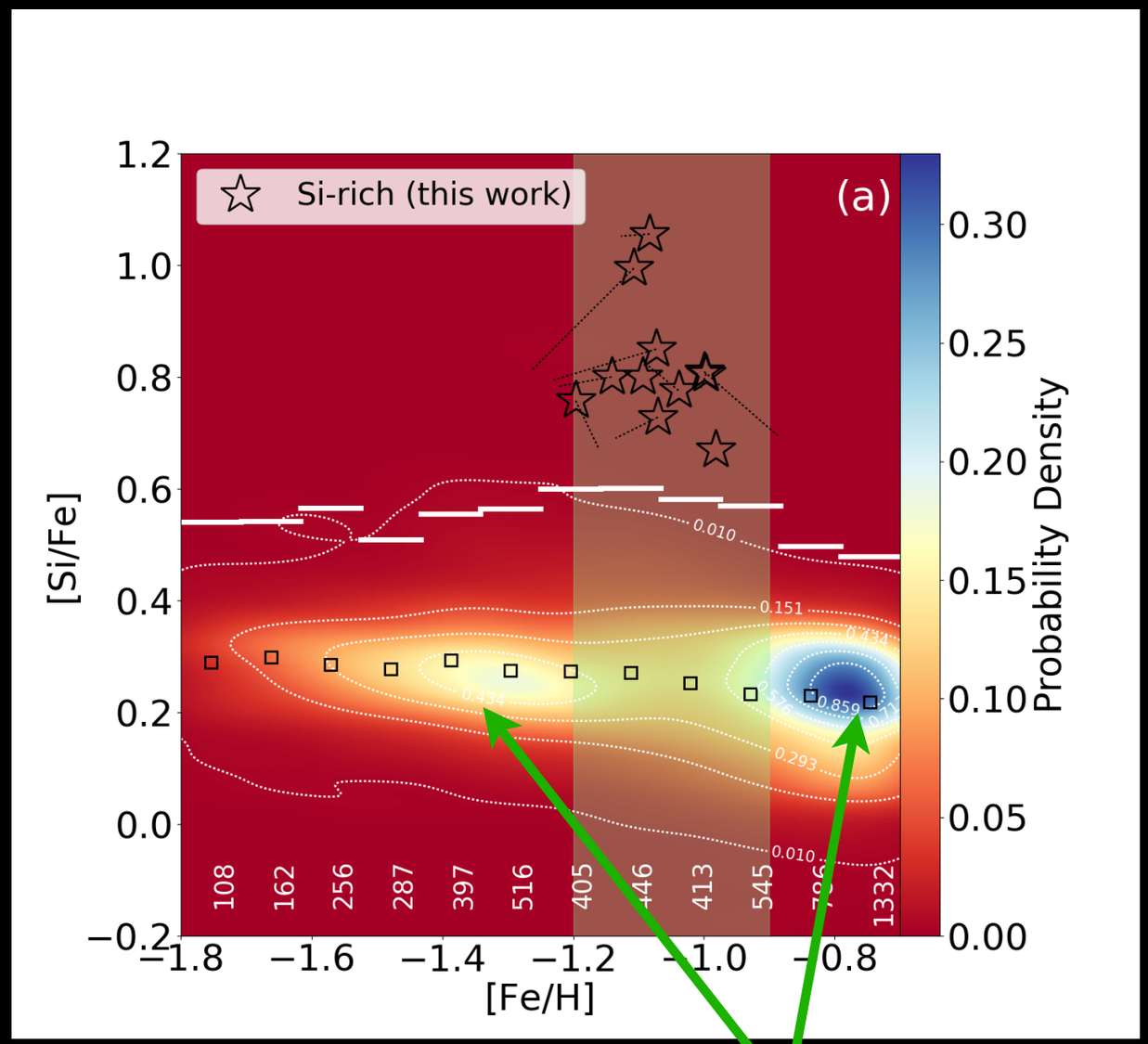
Fernández-Trincado et al. 2020, A&A Letters, 643, L4

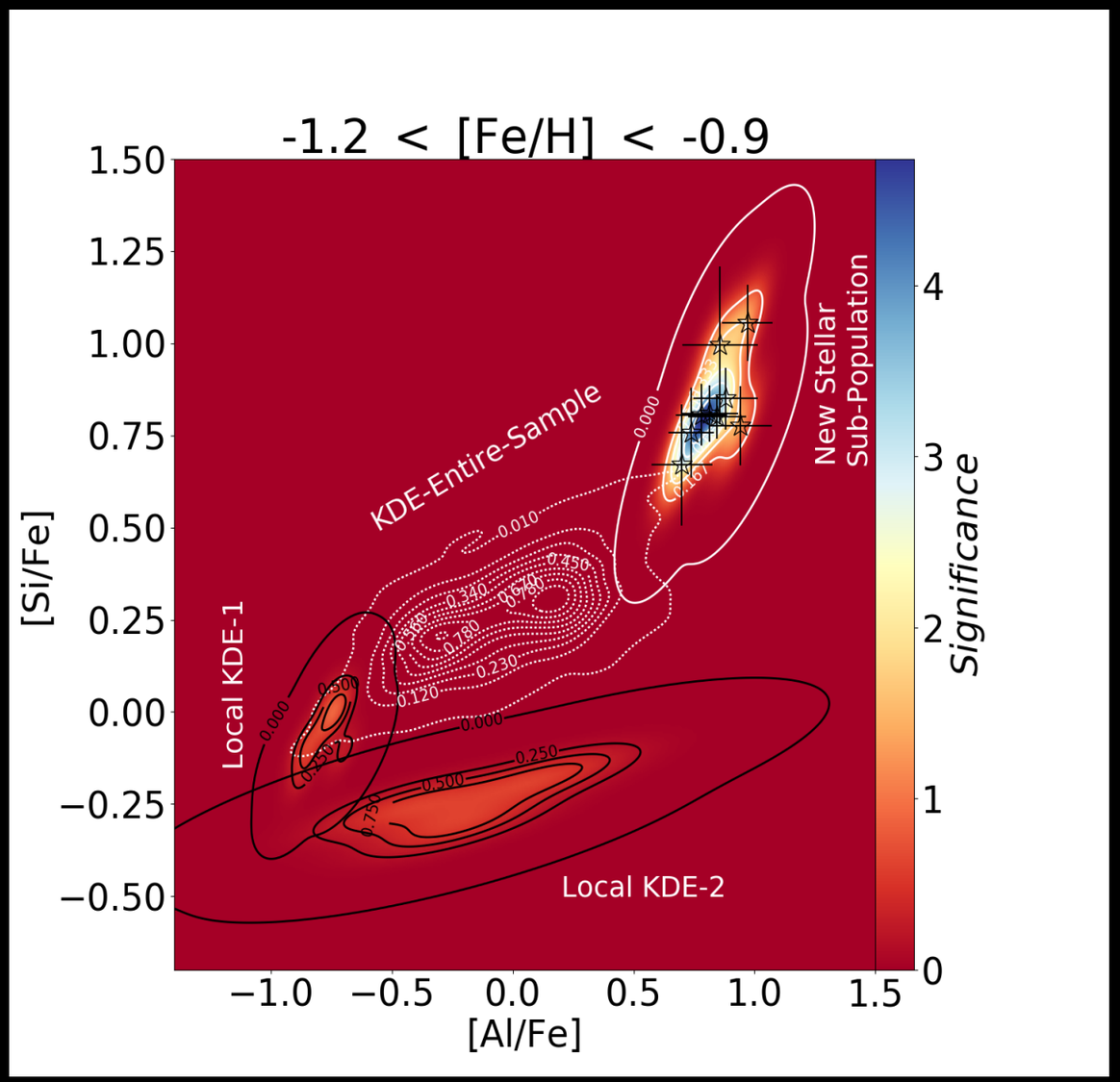
Discovery of a Large Population High-metallicity Aluminium+Nitrogen rich stars in the Inner Halo



Fernández-Trincado et al. 2021, ApJ Letters, 918, L37

Discovery of a New Sub-stellar population residing in the (inner) halo: Jurassic structure





Canonical (thick) disk & Halo

Fernández-Trincado et al., 2019, ApJL, 886, L8
Fernández-Trincado et al. 2020, A&A, 644, A83

NGC 6723

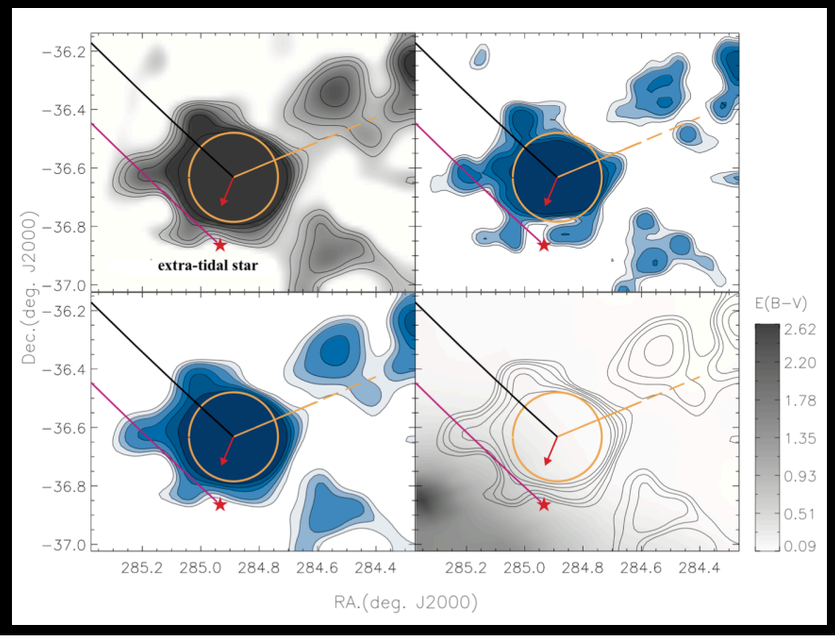
Image Credit: NASA, STScI, WikiSky

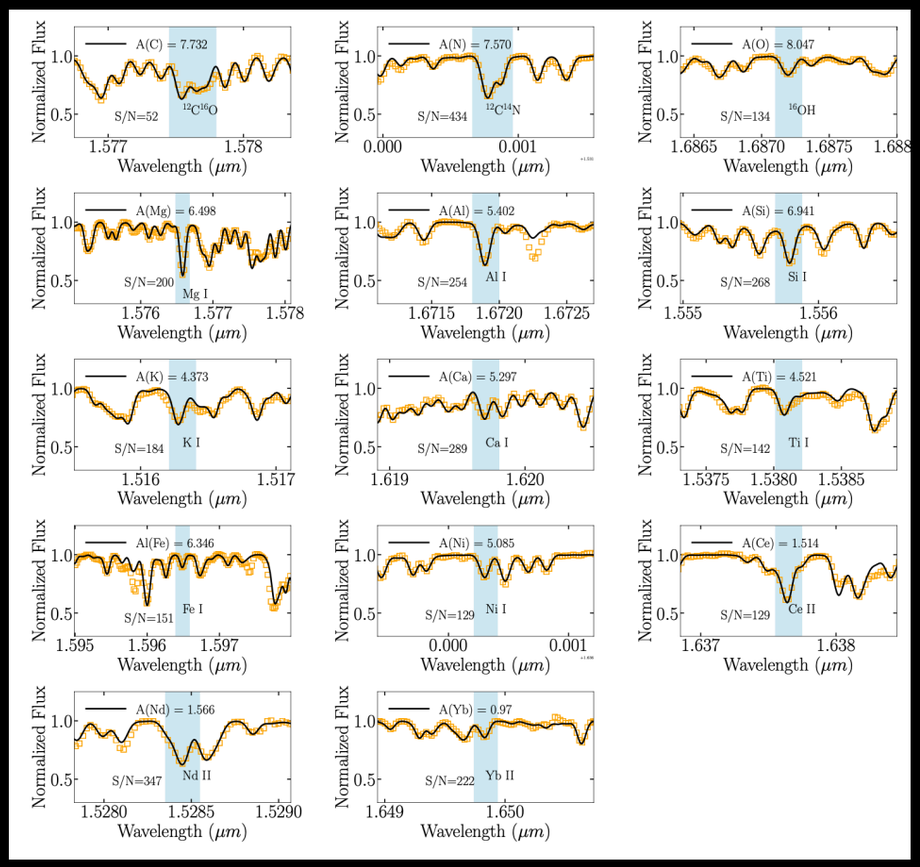
APOGEE DR16 Spectra

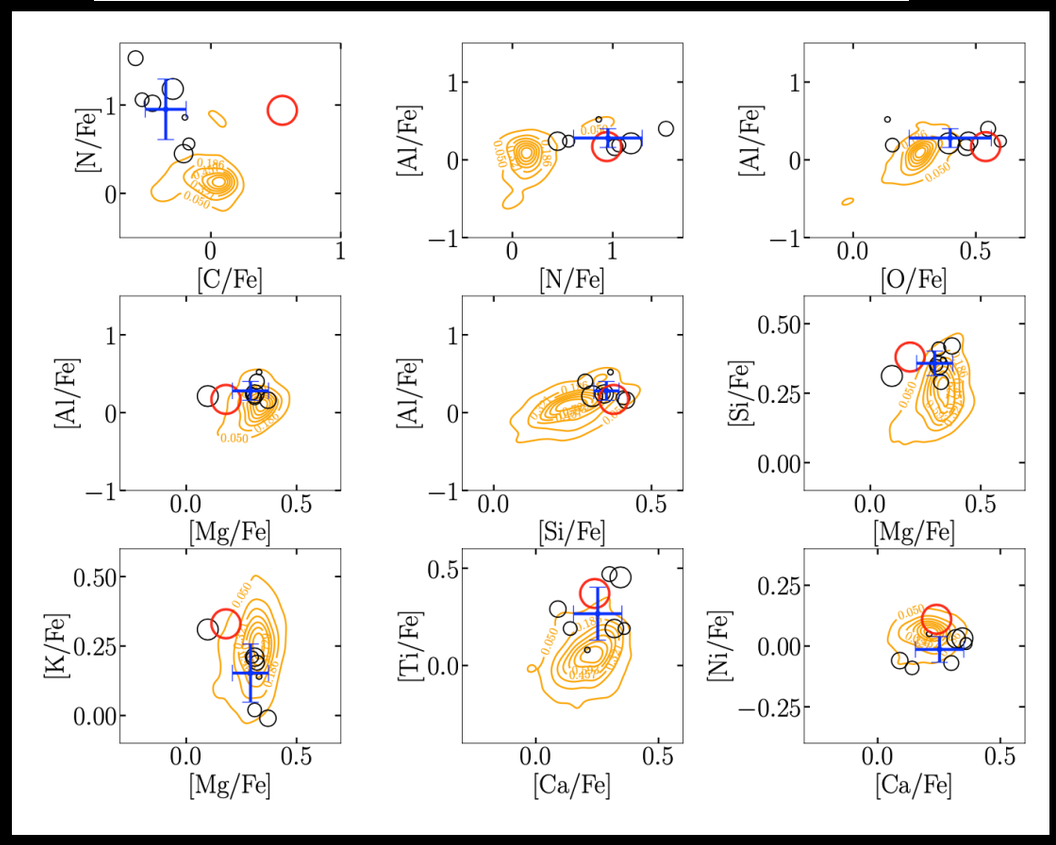
[Fe/H] = **-1.0 +/- 0.06** dex

E(B-V) ~ 0.05 mag

Extra-tidal N-rich Star



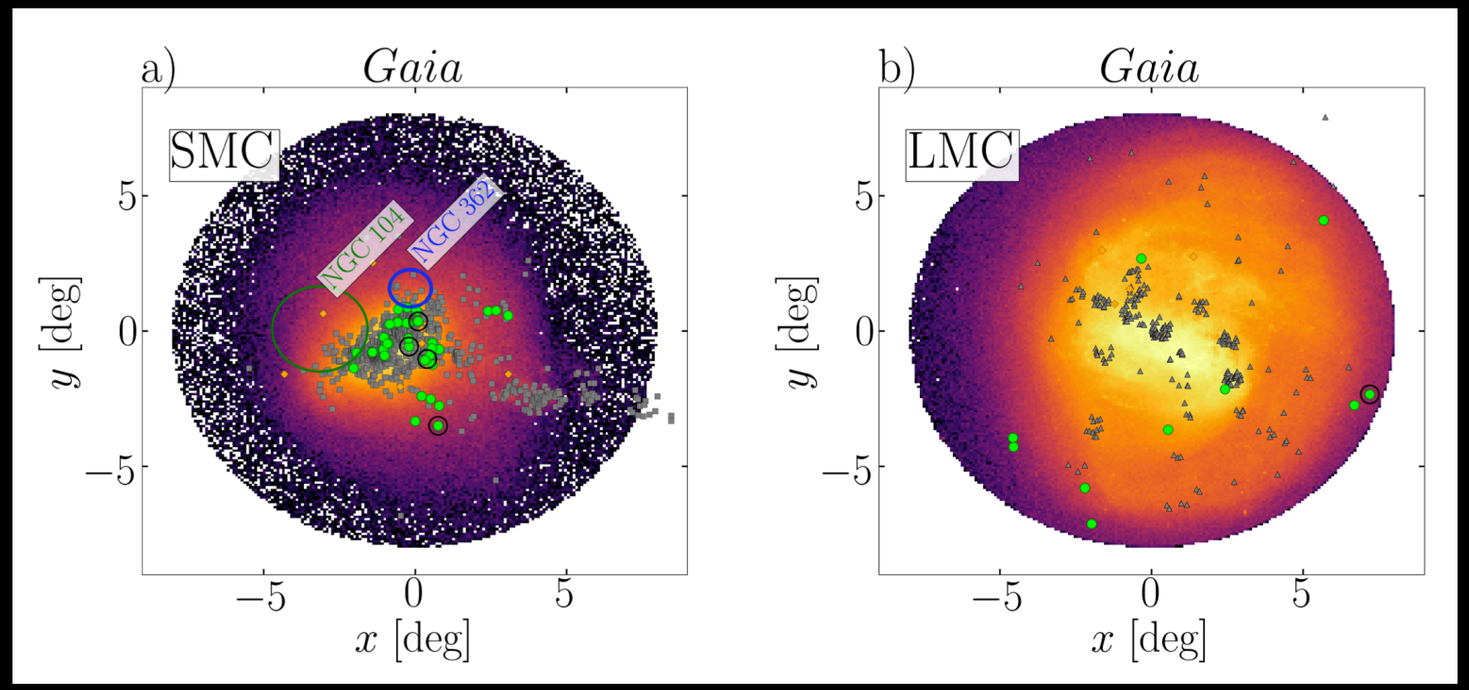


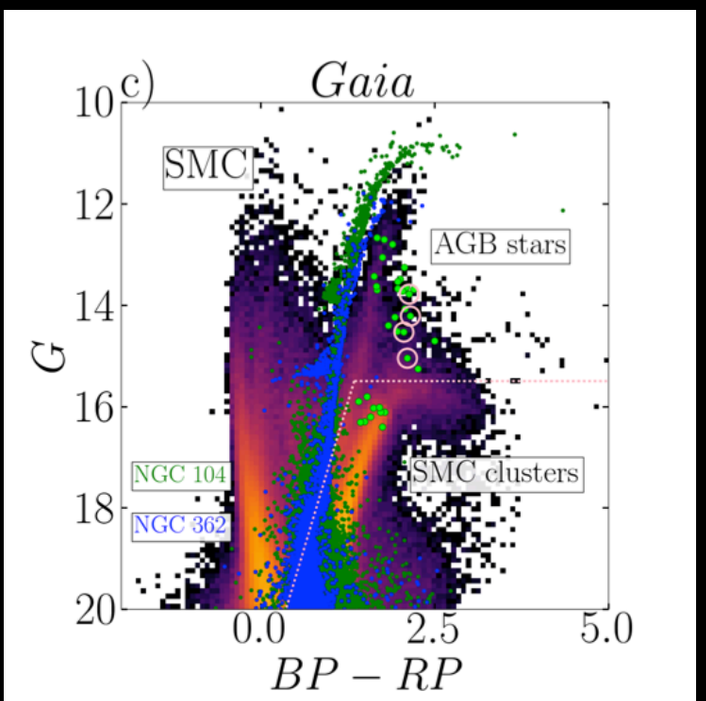


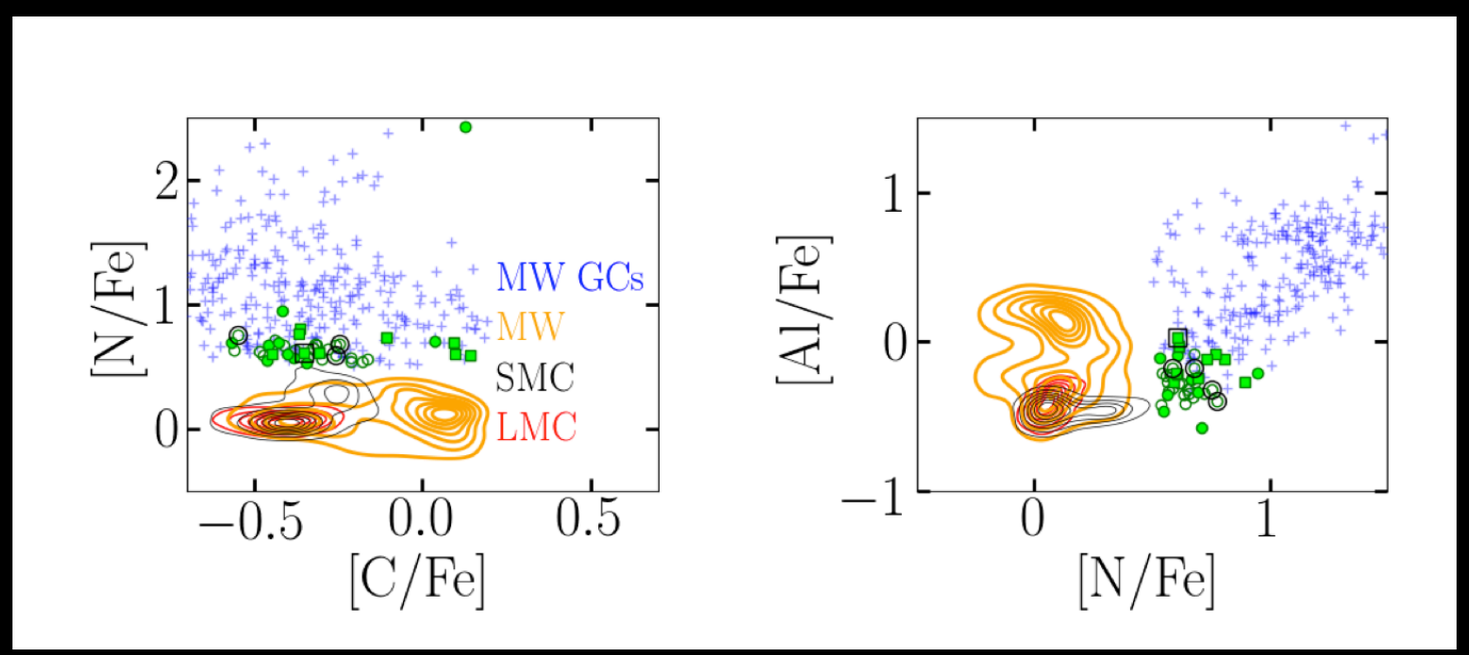
José G. Fernández-Trincado et al. 2021, A&A, 647, A64

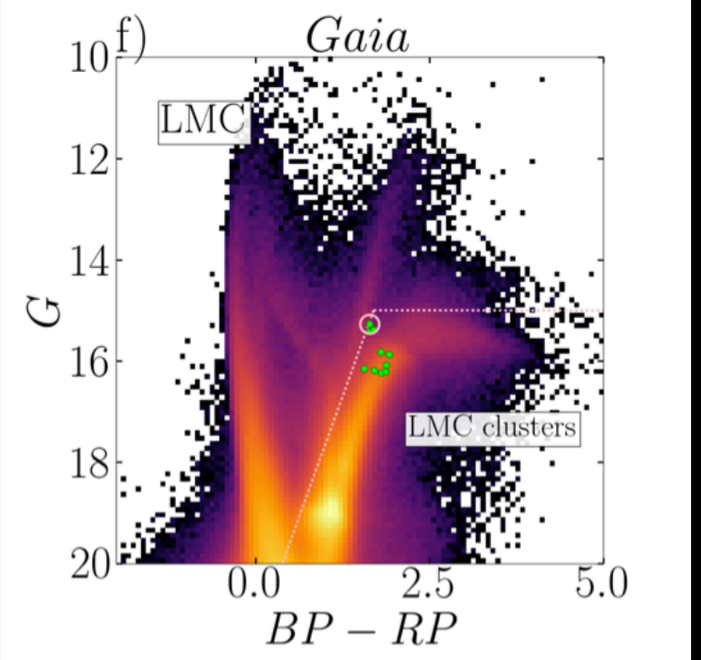
What about Dwarf Galaxies?

Discovery of Nitrogen-rich stars in the Large and Small Magellanic Clouds



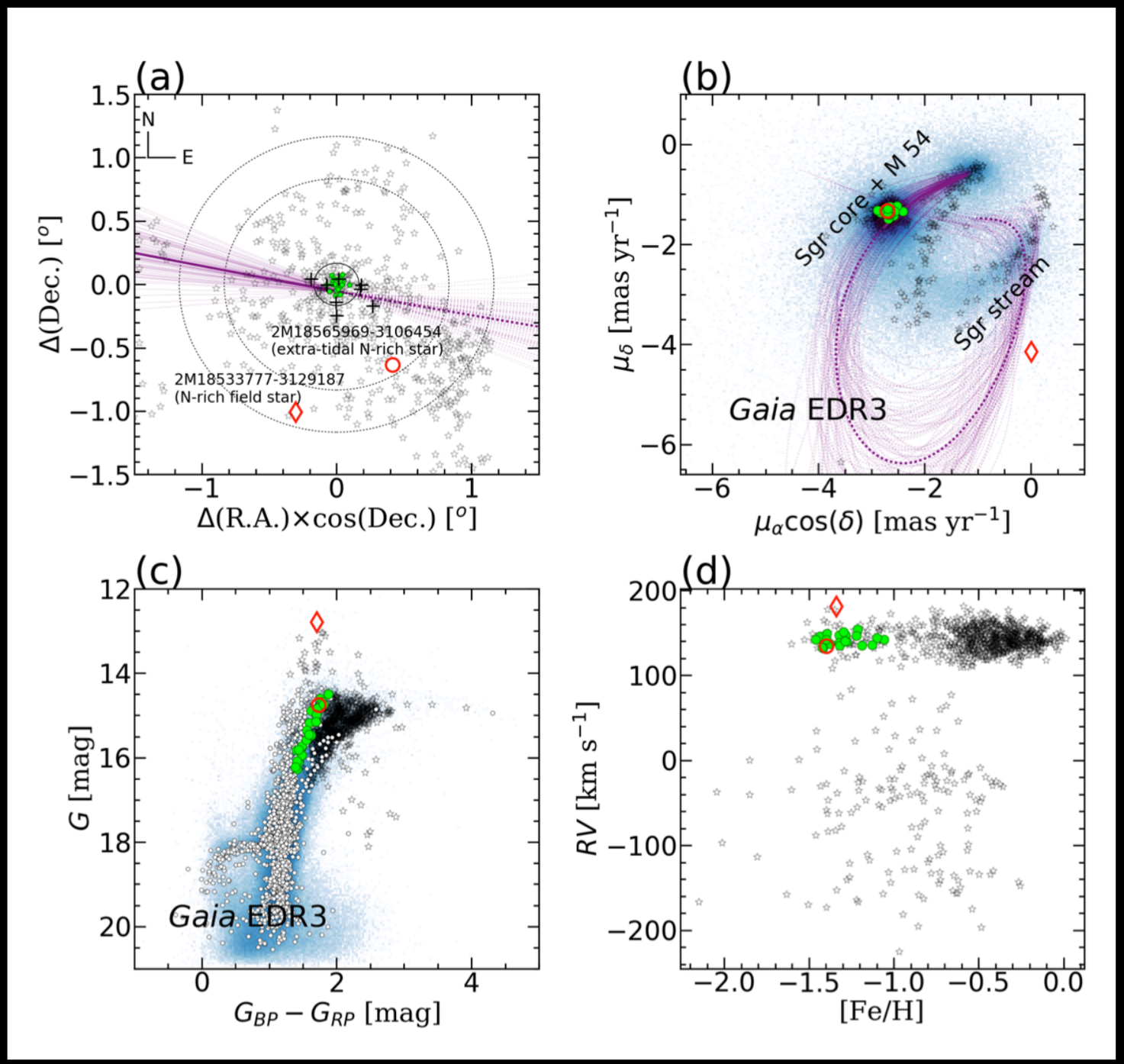


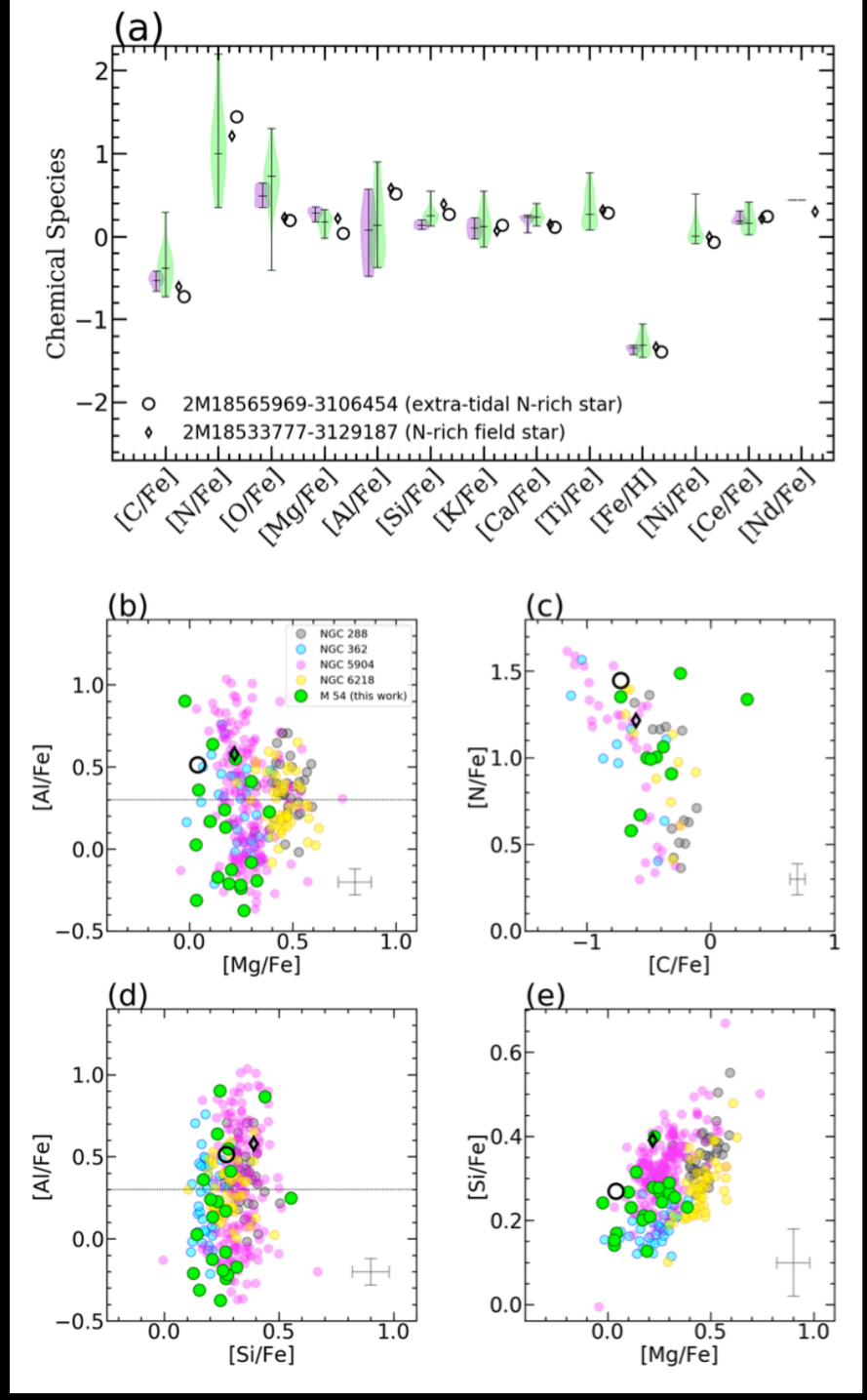




Fernández-Trincado et al. 2020, ApJ Letters, 903, L17

Discovery of Nitrogen-rich stars in the Sagittarius Dwarf Galaxy





Fernández-Trincado et al. 2021, A&A, 648, A70

About ~15% of the Milky Way halo is filled by a Zoo of Chemically unusual giants

Anomalous Metal-Poor Field Stars,
(-1.8, -0.7] dex

N-rich, > +0.5

Al-rich, > +0.5

- ***GCs-like abundance patterns***
- ***Extragalactic-like patterns***

Al-normal, < +0.5

- ***GCs/dSph-like abundance patterns***
- ***Evidence for Binary mass transfer***

N-normal, < +0.5

Si-rich, > +0.6

GC-like abundance patterns

Si-normal, < +0.6

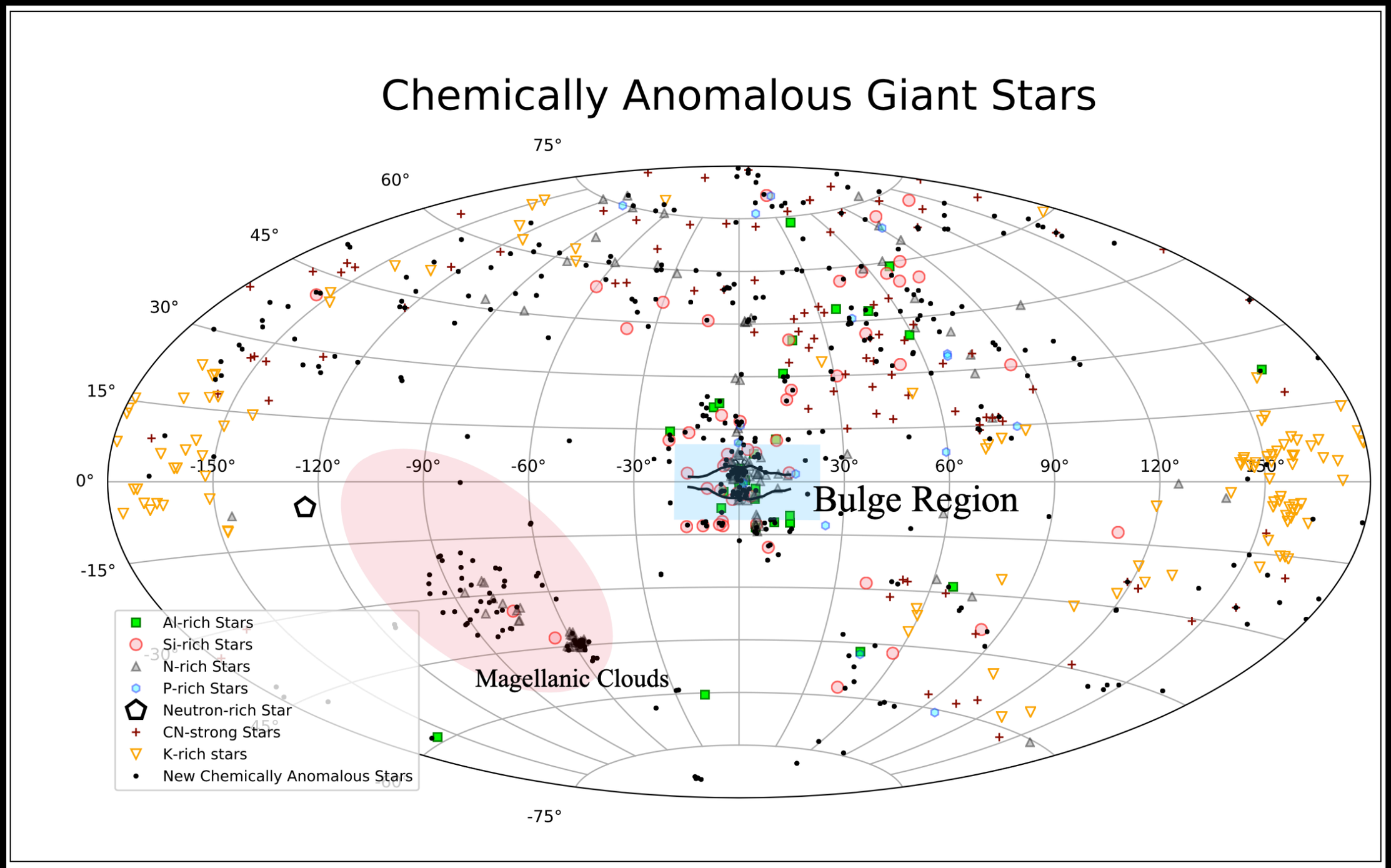
Light-Elements Galactic levels

- ✓ *Such stars may have resulted from the destruction of GC populations formed in situ and ex situ.*
- ✓ *Such stars were not perforce associated with Galactic GCs, but formed in similar environments, while never being gravitationally bound to the Gas themselves.*

What is Next?

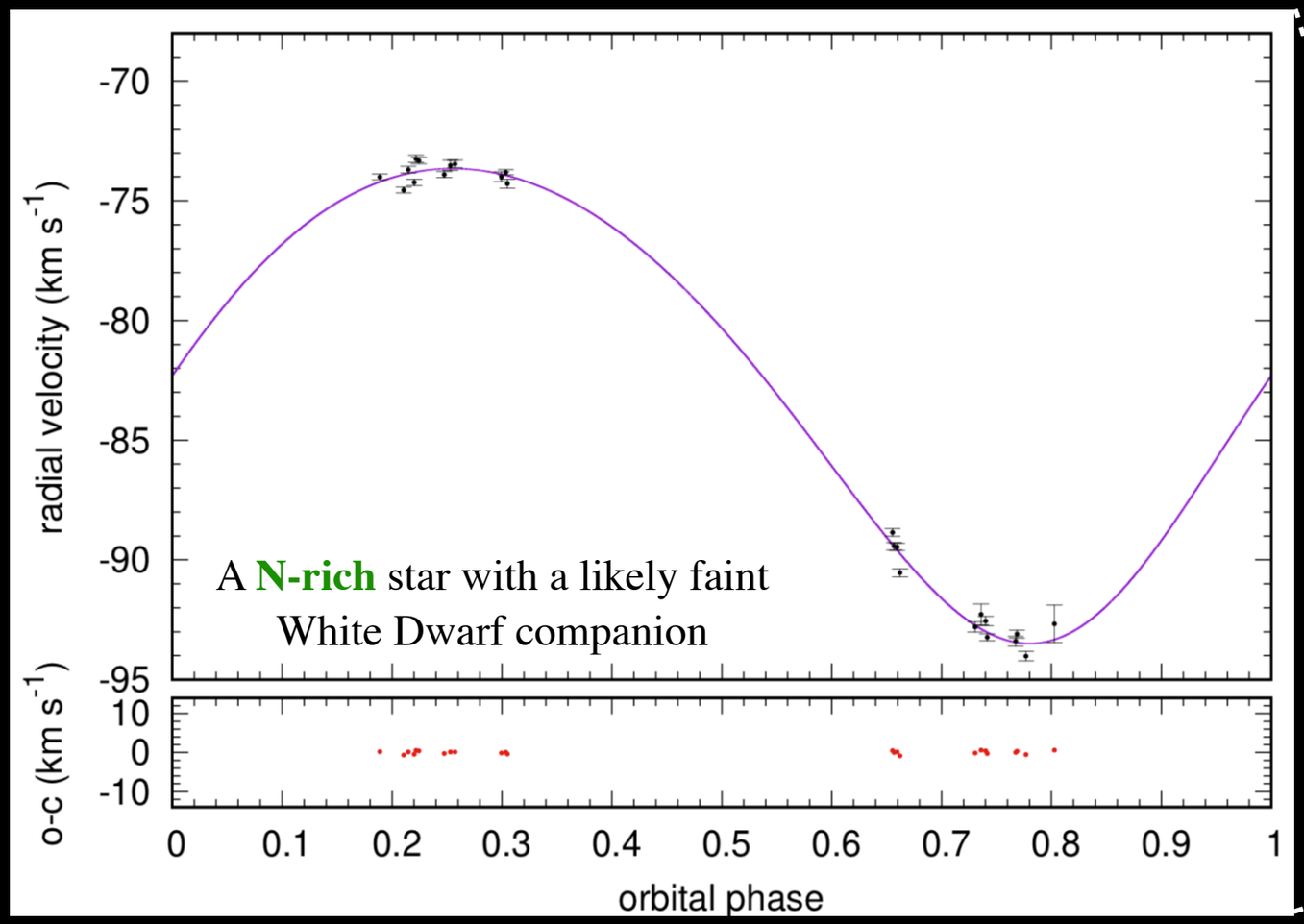
Radial velocities for chemically anomalous stars

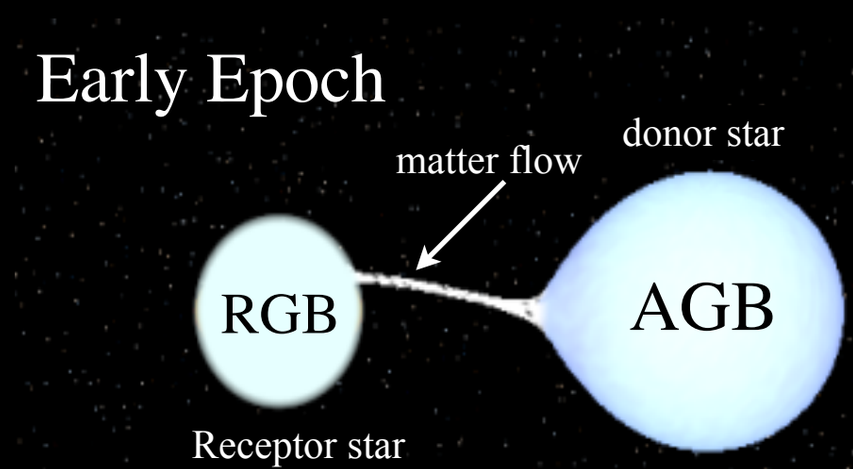
PI: José G. Fernández-Trincado

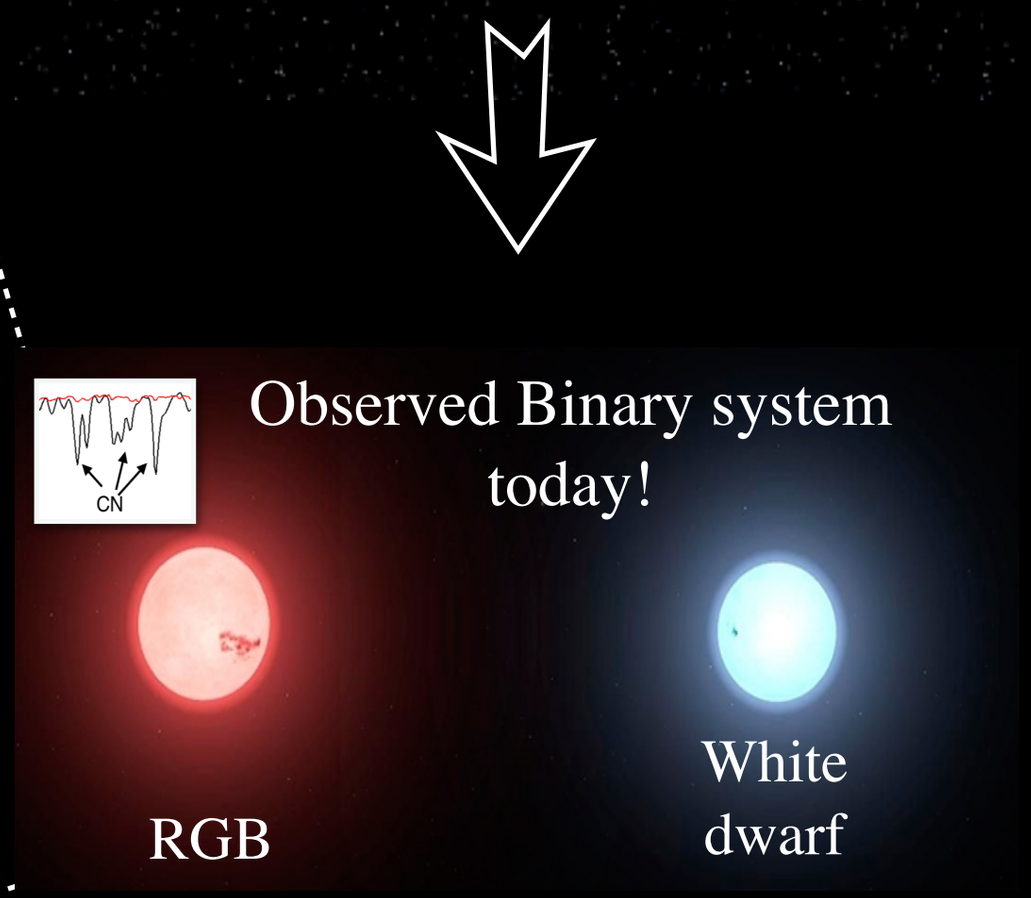


A Binary N-rich field companion of evolved star

Large variability in Radial Velocity

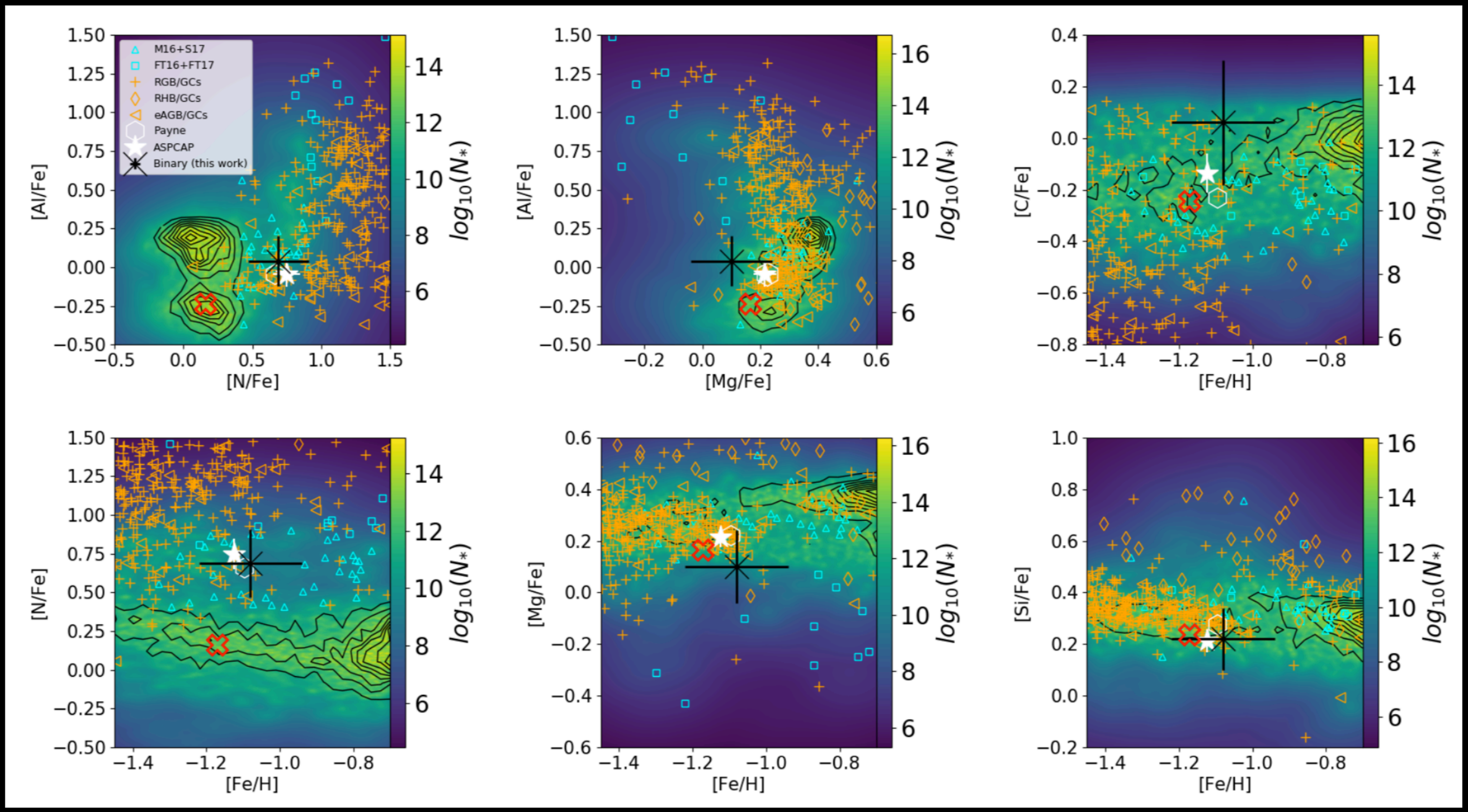






Fernández-Trincado et al. 2019, A&A, 631, A97

A Binary N-rich field companion of evolved star from the APOGEE survey



Fernández-Trincado et al. 2019c, A&A, 631, A97

SDSS-V

SDSS-V extra-tidal globular cluster stars

PI: José G. Fernández-Trincado

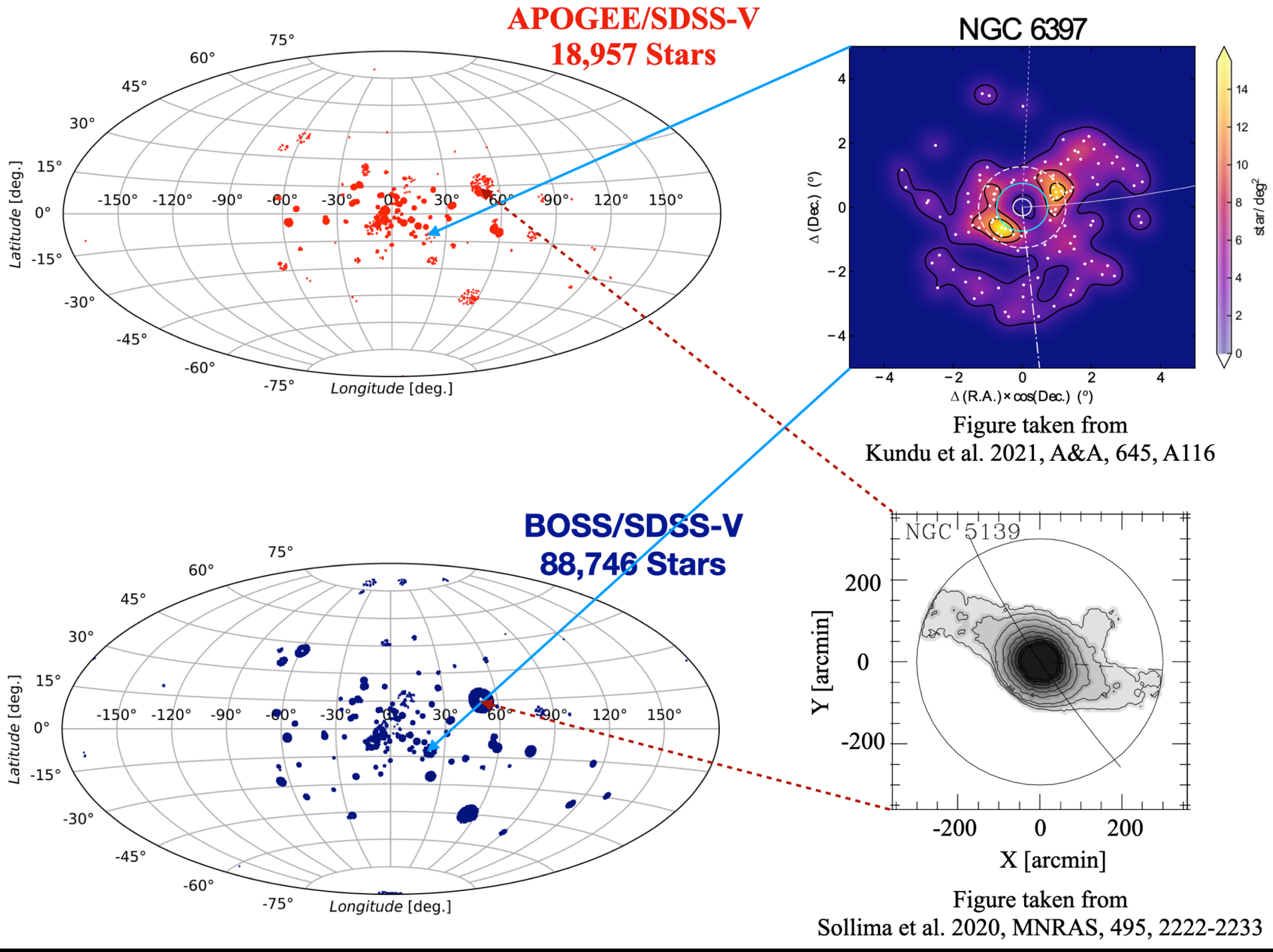


Figure taken from
Kundu et al. 2021, A&A, 645, A116

Figure taken from
Sollima et al. 2020, MNRAS, 495, 2222-2233