The Blanco DECam Bulge Survey: A Rubin Observatory Pathfinder

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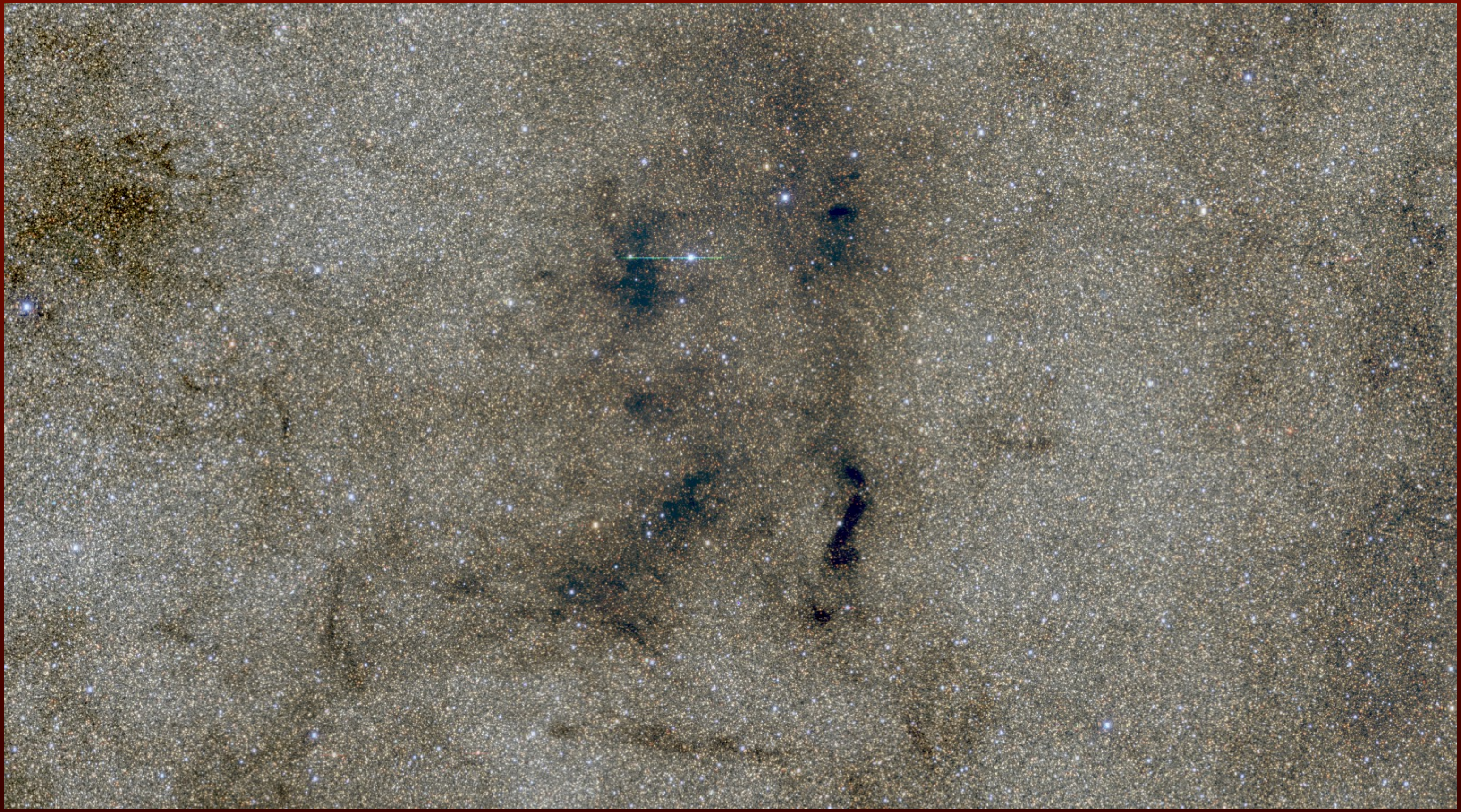


Mike at SAB meeting ca. 1980s

The Big Wheel at z=3.245 (30 kpc across) Survival to z=0?

Wang,Cantalup et al. 2024

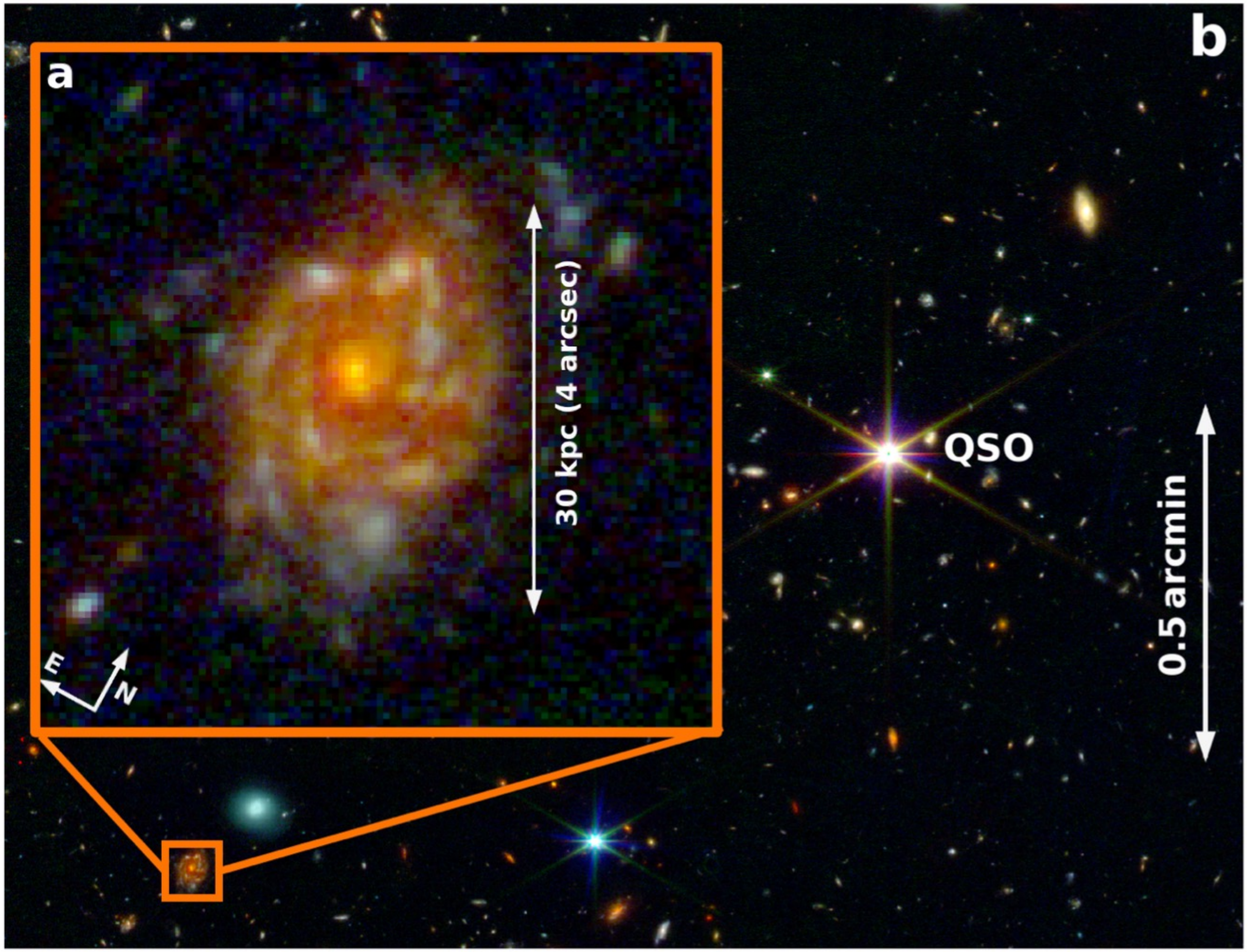
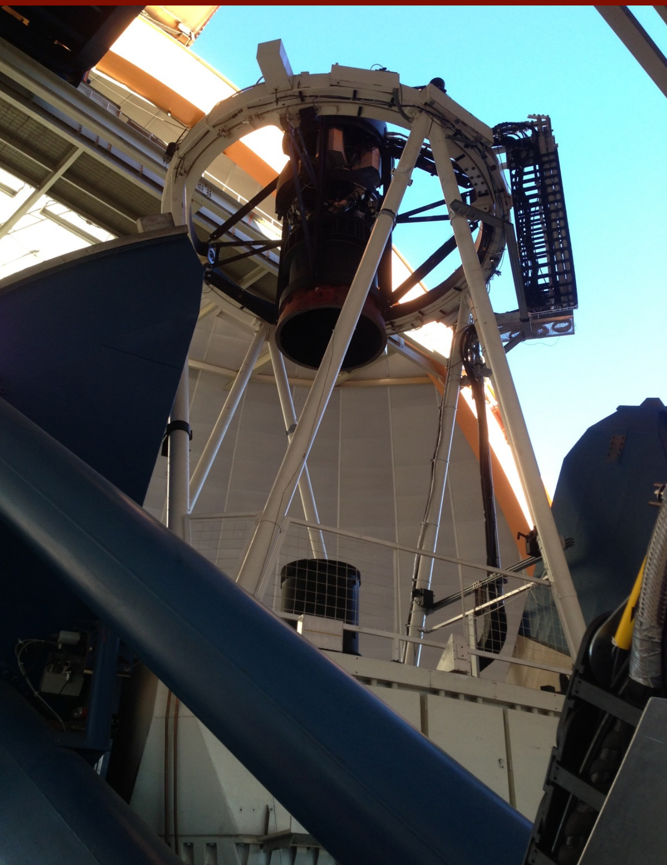


Fig. 1 Composite false-color images of the Big Wheel galaxy at $z = 3.245$ (a) and its surrounding area (b). The galaxy shows a red and compact center and a giant stellar disk extending to at least 30 kiloparsecs in diameter. The disk appears clumpy with manifest spiral structures **(a)**. The Big Wheel is located about 70 arcsec away (about 0.5 pMpc) from a bright quasar at a similar redshift **(b)**. The quasar was originally chosen as the center of the observation field. This region shows an exceptionally high galaxy number density compared to the cosmic average. The filters used to create the color image are HST F814W (0.8 μm; blue), JWST F150W2 (1.5 μm; green), and JWST F322W2 (3.2 μm; red). The disk is visible in the green and red channels but not in the blue channel.

Blanco DECam Bulge Survey (BDBS)
LSST pathfinder (Rubin). DECam has 3sq. Deg FOV



DECam on the 4m Blanco telescope

BDBS Science: *ugrizY* colors superior to JHK for metallicities- more sensitive

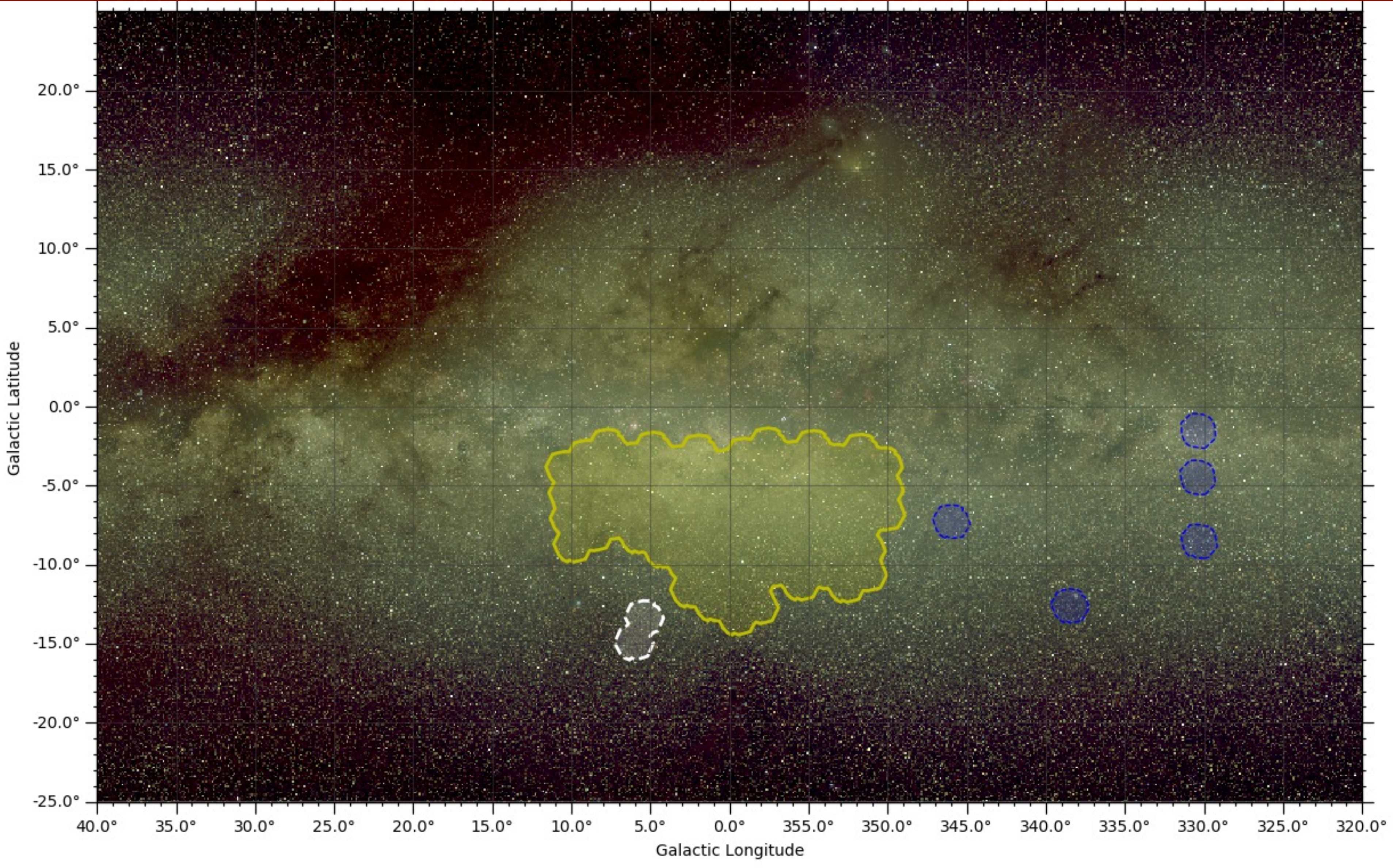
Explore spatial distribution of metallicity and age over the whole of the bulge

Use Gaia to explore abundance/kinematic correlations

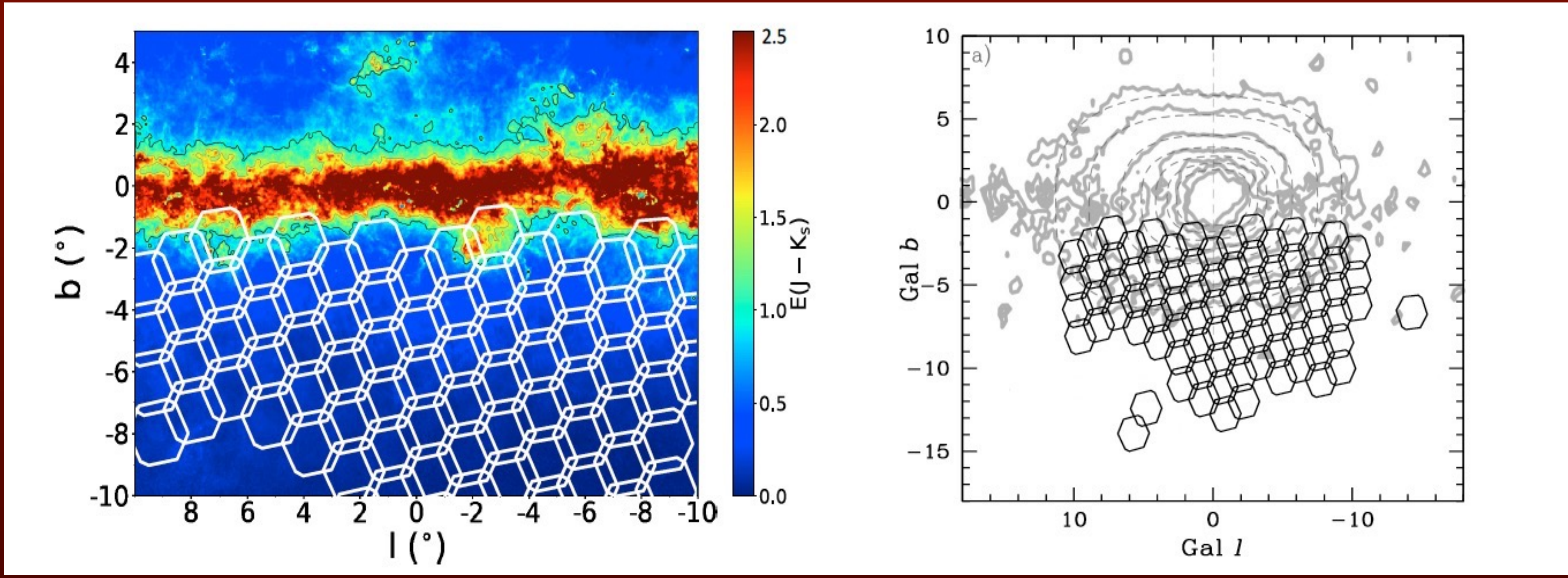
Bulge globular clusters, tidal tails

Matching to Galex and other surveys

BDBS Fields include Sgr dwarf, disk fields



BDBS survey spans most of low extinction Southern Galactic bulge, extends beyond VVV footprint



Dereddened region from Simion et al. 2017 (1x1 arcmin)- Left

Calibration and data reduction
Undertaken by a single person-
Christian Johnson (STScI)

Also finds $(u\text{-}i)_o$ vs [Fe/H] correlation

Project begins with 50 TB of data taken of 3 observing seasons, in varying photometric conditions.

Leads photometric calibration and reduction using daophot+allstar psf photometry- but over this massive dataset.

Blanco DECam Bulge Survey Papers

The Blanco DECam Bulge Survey. I. The Survey Description and early results
Rich, Johnson et al. 2020 MNRAS 499, 2340

Blanco DECam Bulge Survey. II. Project performance, data analysis, and early science results Johnson, C.I., Rich, R. M. et al. 2020 MNRAS 499 2357

DEcam Opens a New Window on the Galactic Bulge 2021 Mirror, 2, 56
Johnson, C. et al.

Blanco DECam Bulge Survey (BDBS) III. A new view of the double red clump in the Milky Way bulge through luminosity and color distribution
Lim, D., Koch-Hansen et al. 2021 A&A, 647, 34

Blanco DECam Bulge Survey (BDBS) IV. Metallicity Distributions and bulge structure from 2.6 million red clump stars Johnson, C. I., Rich, R. M. et al. 2022 MNRAS 515, 1469

BDBS papers continued

Blanco DECam Bulge Survey (BDBS) V. Cleaning the foreground populations from Galactic bulge colour-magnitude diagrams using Gaia EDR3, Marchetti, T., Johnson, C.I. et al. 2022 A&A, 664, 124

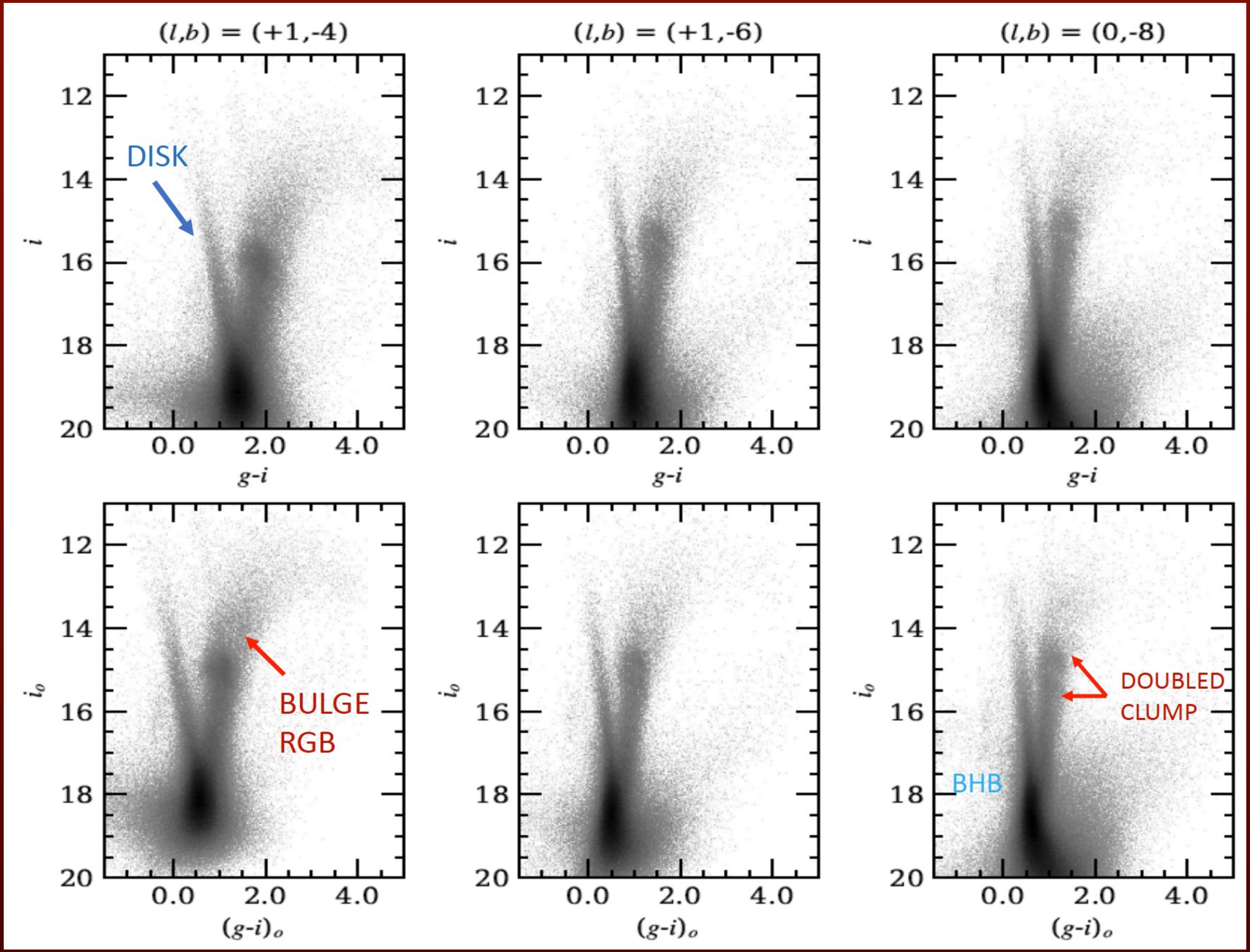
Blanco DECam Bulge Survey (BDBS) VI. Extinction Maps toward Southern Galactic Bulge Globular clusters Kader, J.A. et al. 2023 ApJ, 950 126

The Ages of Galactic Bulge Stars with Realistic Uncertainties Joyce, M. et al. 2023 ApJ 946, 7.

Blanco DECam Bulge Survey (BDBS). VII. Multiple Populations in Globular Clusters of the Galactic Bulge 2022, ApJ 940,76.

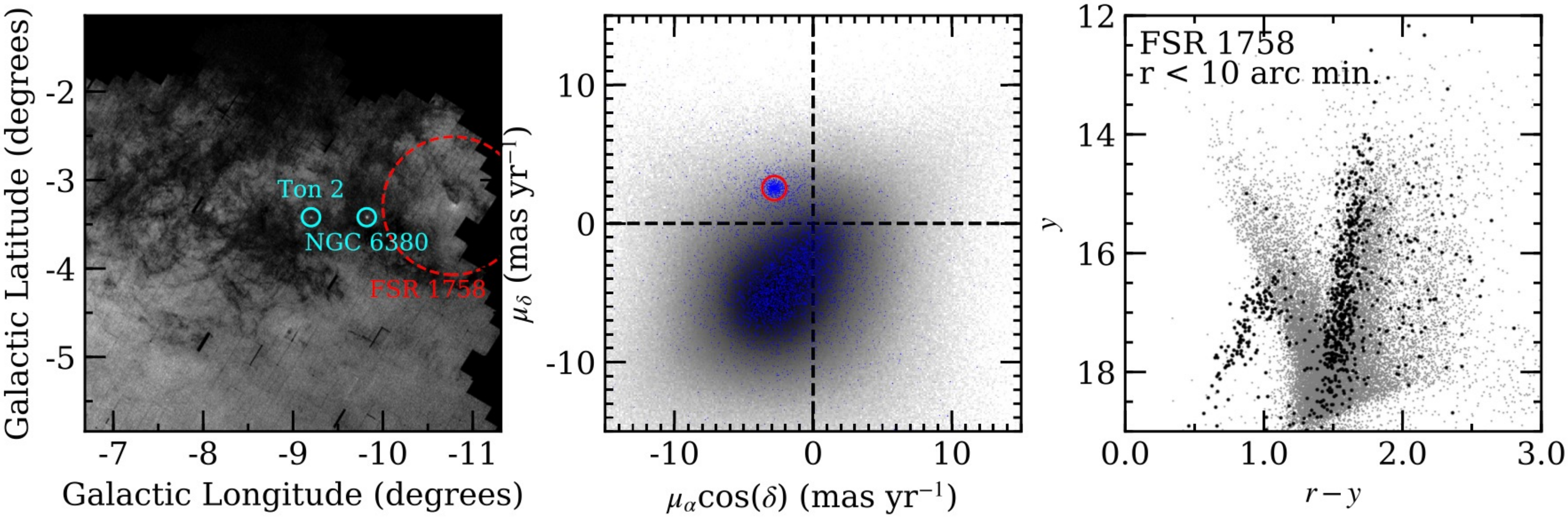
The Blanco DECam Bulge Survey (BDBS) VIII. Chemo-kinematics in the southern Galactic bulge from 2.3 million red clump stars with Gaia DR3 proper motions Marchetti, T., Joyce, M., Johnson, C.I., Rich, R. M. et al. 2024 A&A, 682, 96

Calibrated, dereddened CMDs over whole bulge



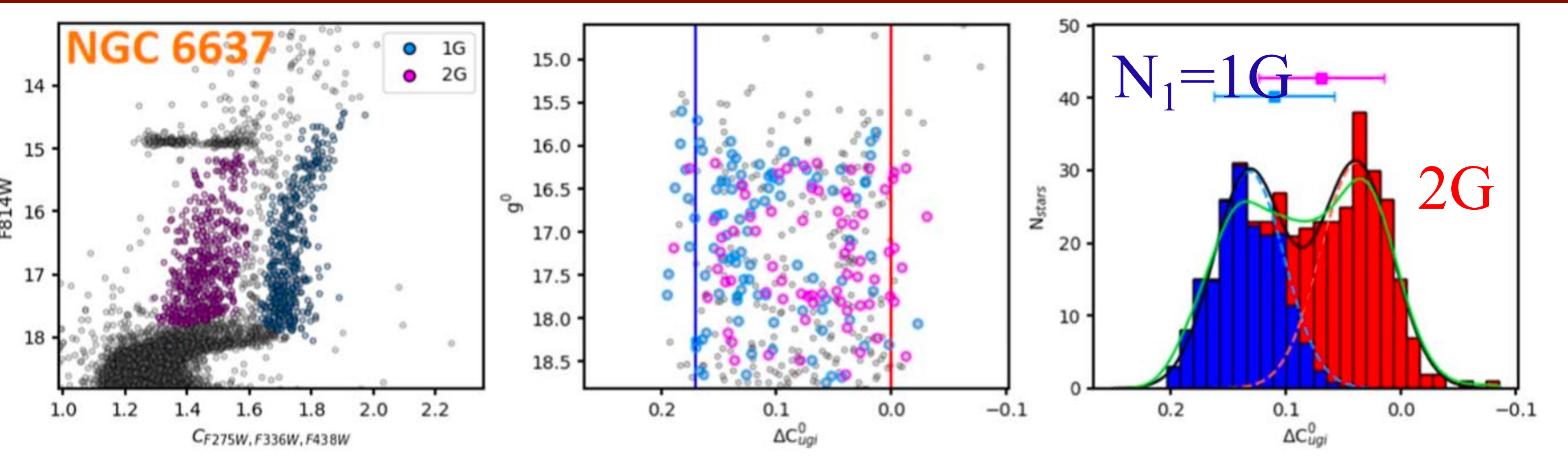
Rich, Johnson et al. 2020

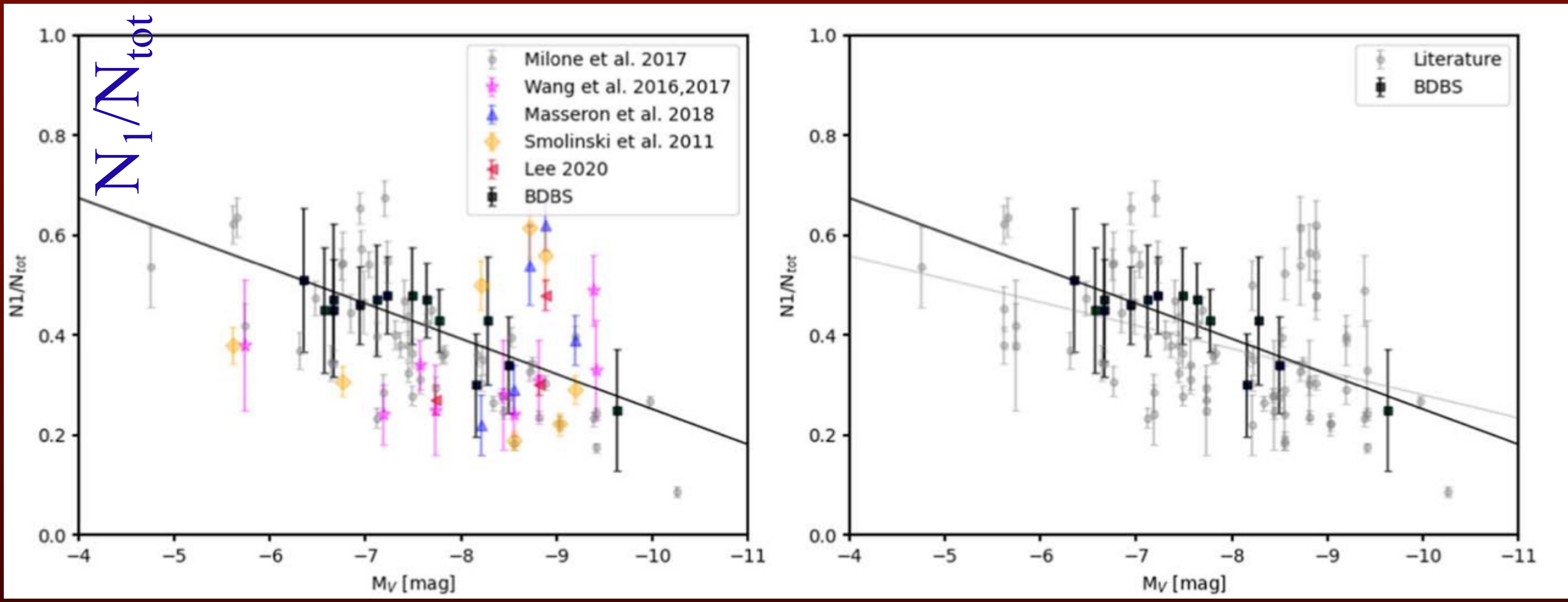
Gaia matching makes BDBS a Powerful globular cluster discovery machine



Johnson, Rich et al. 2020

FSR 1758 is shown to be a metal poor globular cluster



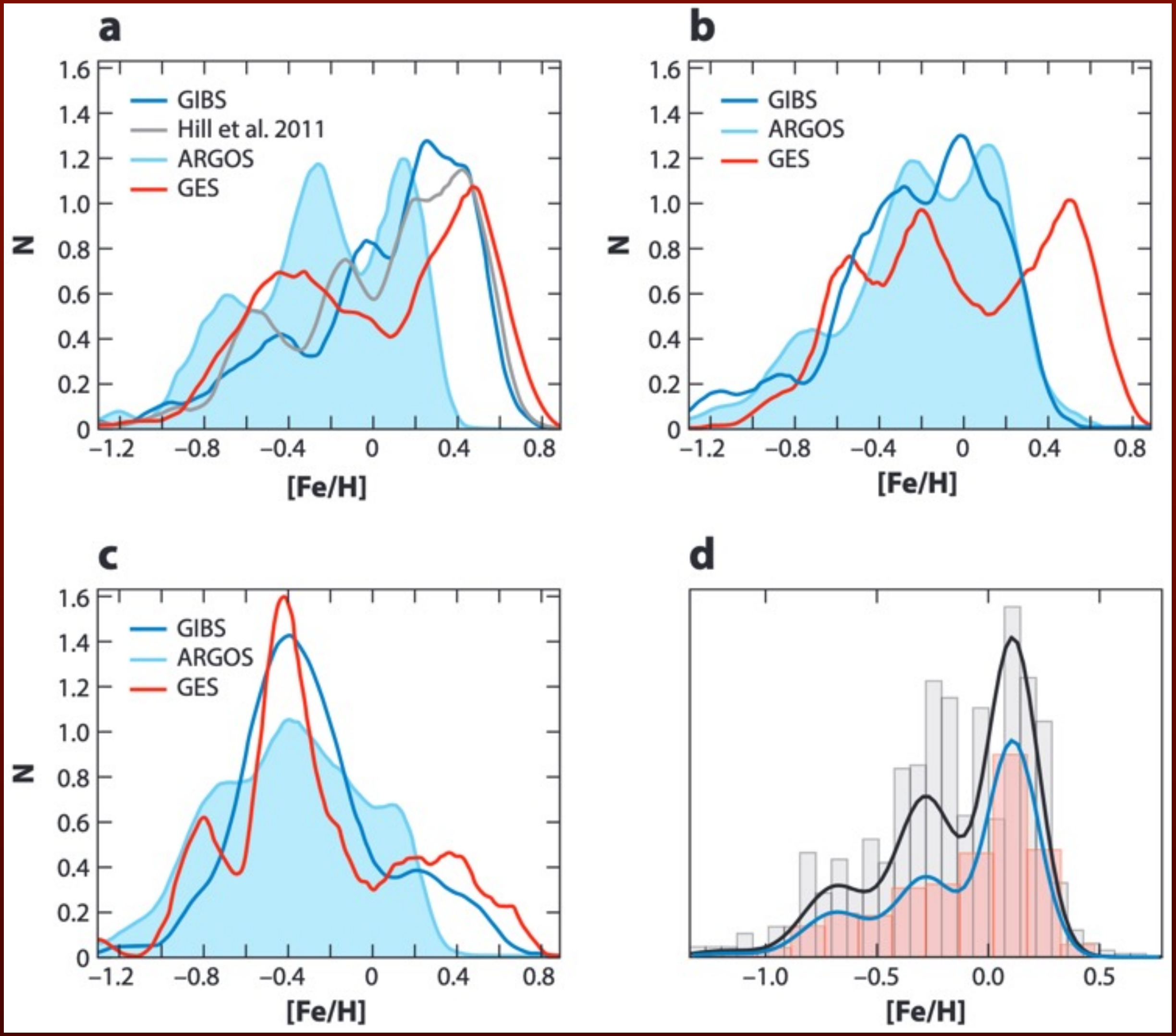


M_V

IAUS395

Kader, BDBS et al. 2022, 20223

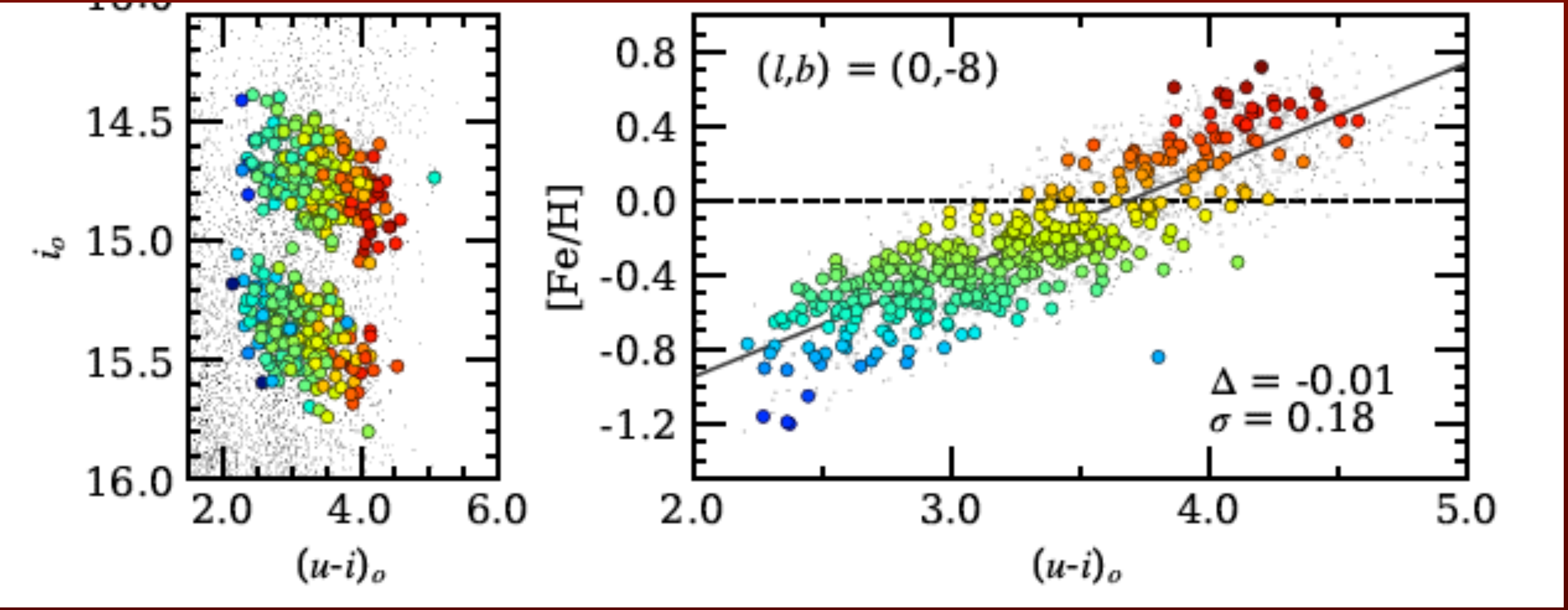
Abundance distributions are not in agreement – neither in number of peaks nor their location.



Barbuy et al. 2020

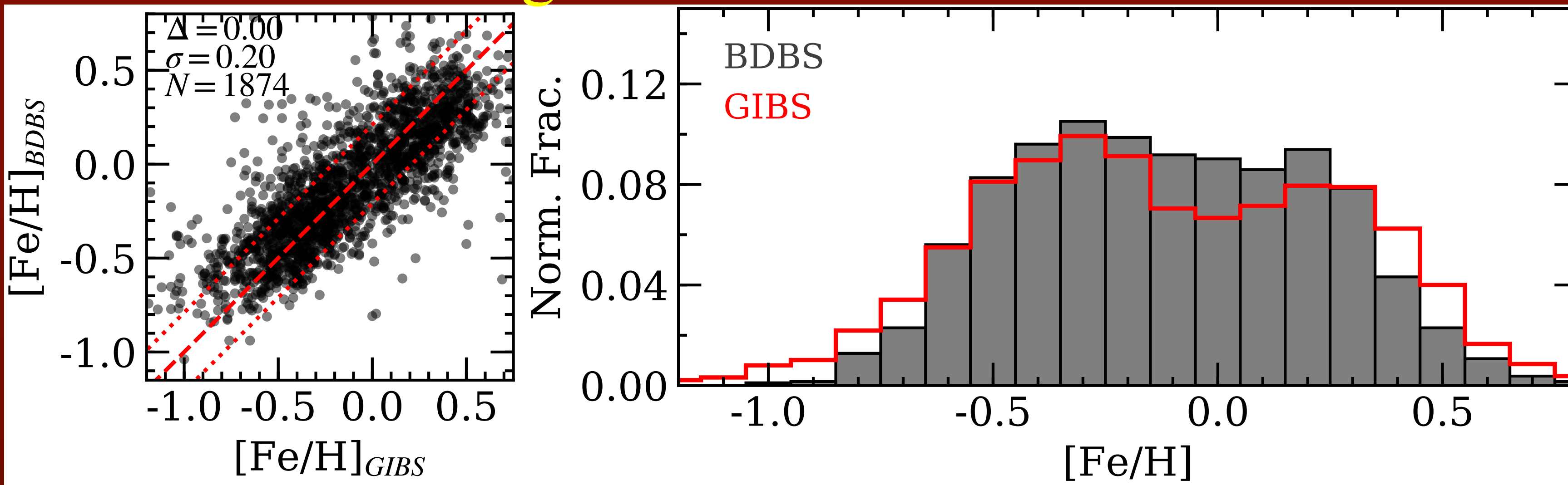
Calibrate $(u\text{-}i)_o$ using red clump stars with [Fe/H] derived from high resolution spectroscopy and CaT

(Zoccali et al. 2017) gives *u-i* vs [Fe/H]



Johnson, Rich et al. (BDBS II) 2020

Another comparison with Zoccali et al. 2017
we confirm them global “bimodal” abundance distribution

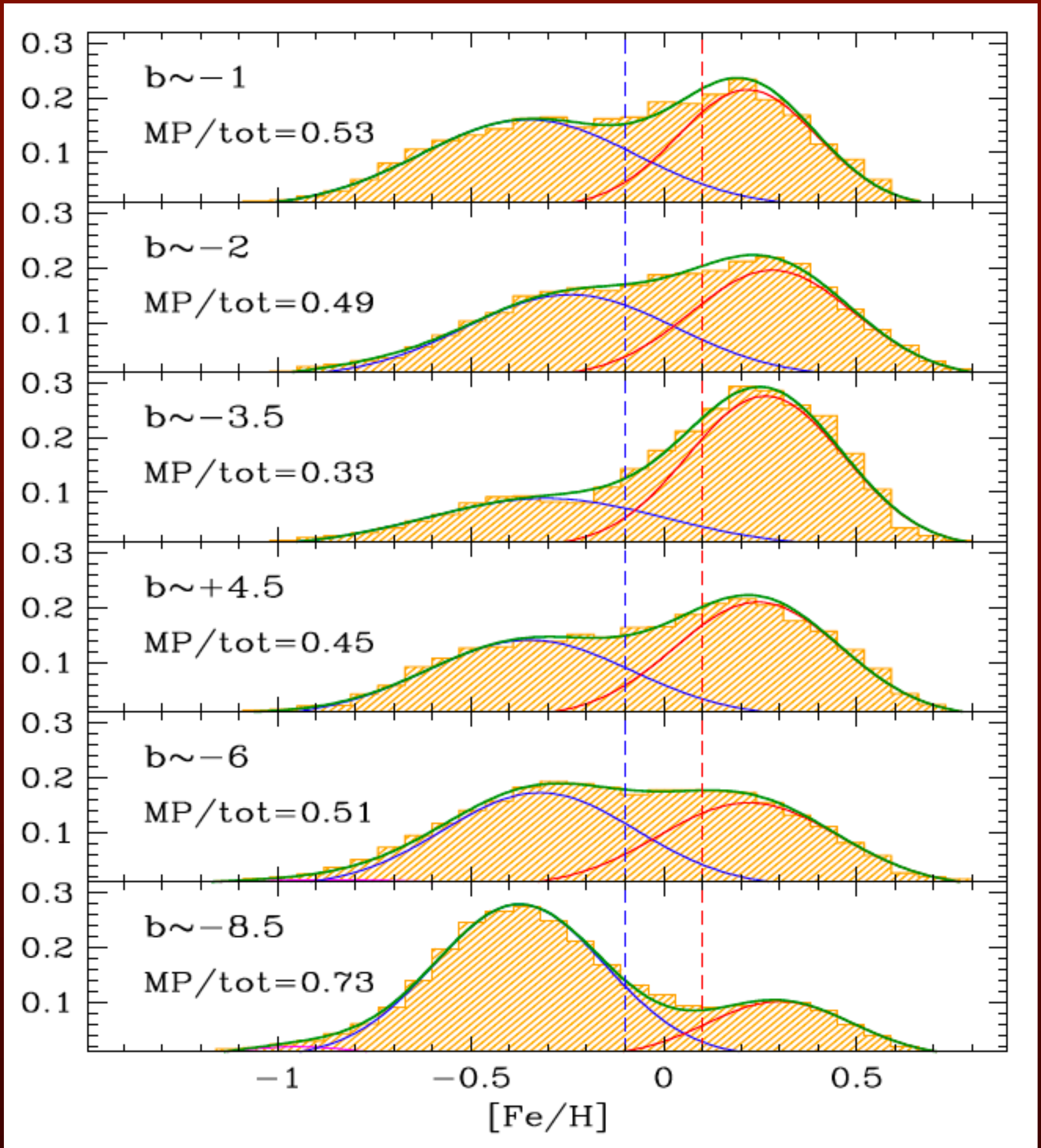


2.6 million red clump metallicities from u-i photometry

Catalog is published in Johnson et al. 2022

Detailed distributions complex

Zoccali et al. 2017 fit 2 gaussians but find a rising fraction of metal poor stars at low latitude.



BDBS and other studies (see Nandakumar et al. 2018, etc) do not confirm this.

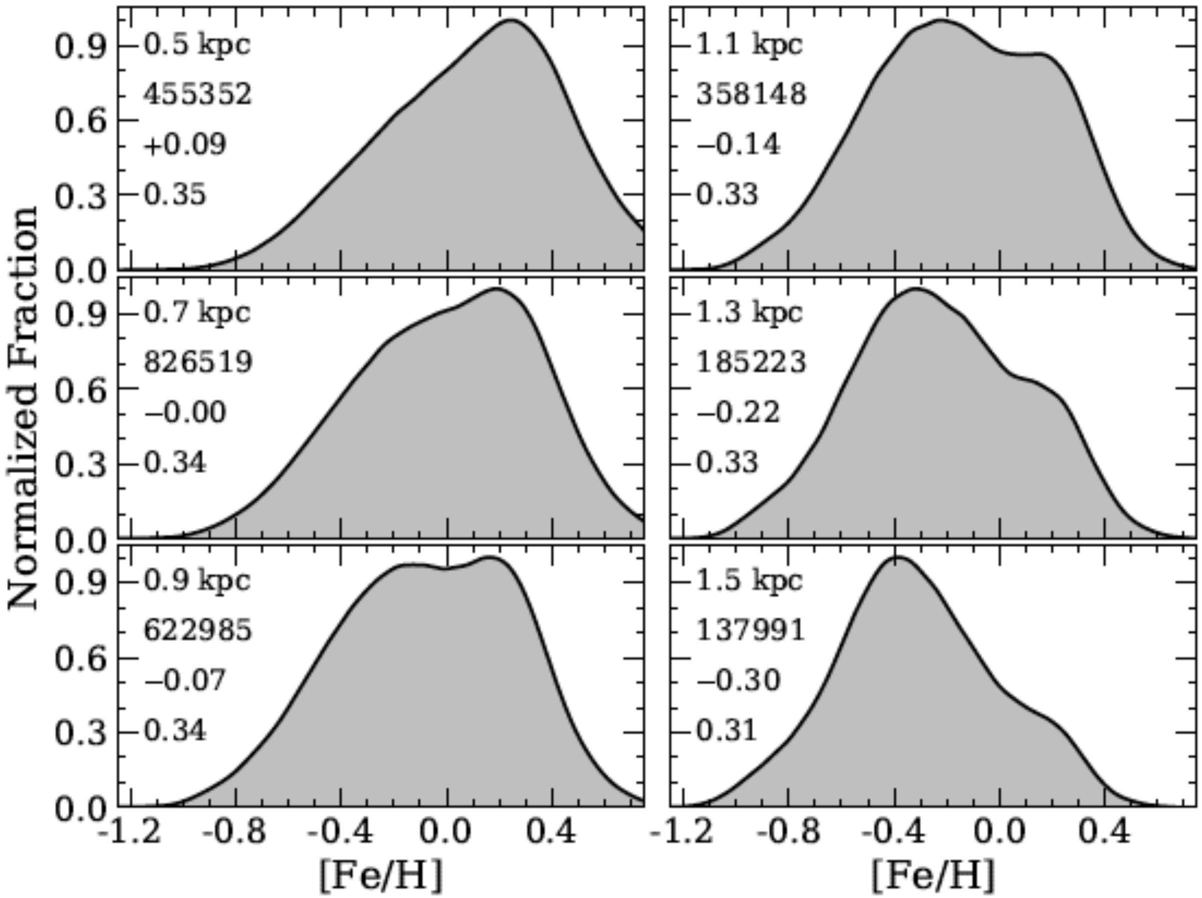
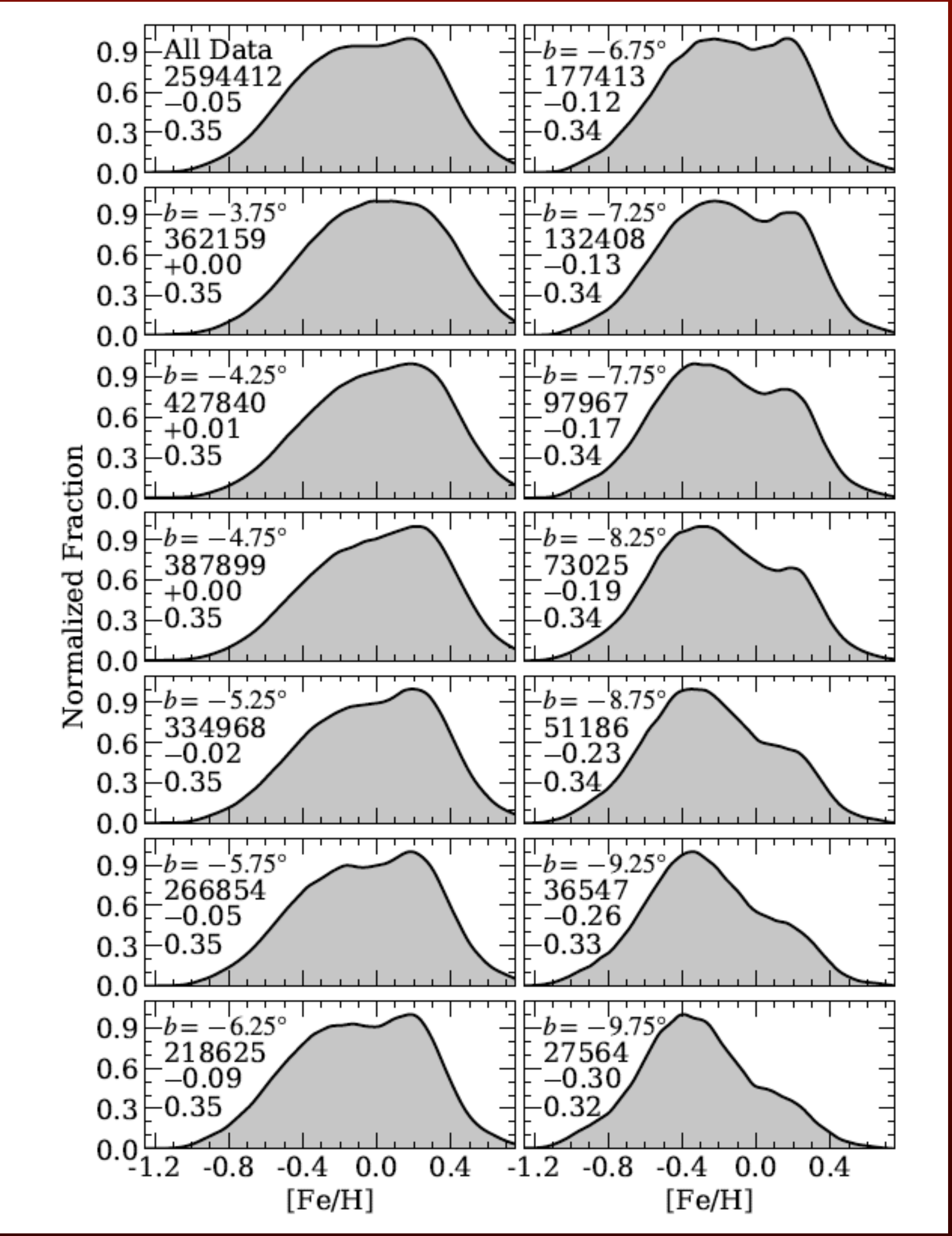


Figure 12. Similar to Figure 11, red clump metallicity distribution functions are shown as functions of distance from the Galactic plane (|Z|). Each slice encompasses all longitudes but only includes Z values ± 0.1 kpc from the values given in each panel. The results are qualitatively in agreement with those of 11; however, the various peaks are sharper and the field closest to the plane appears strongly unimodal.

Abundance distribution

By physical Distance Below The Galactic plane

Note: these are not gaussian.



Bulge abundance distribution consists of metal rich "one zone" like

And a different distribution at higher latitude

The more metal poor distribution may reflect the thick disk or an early era of mass loading and winds.

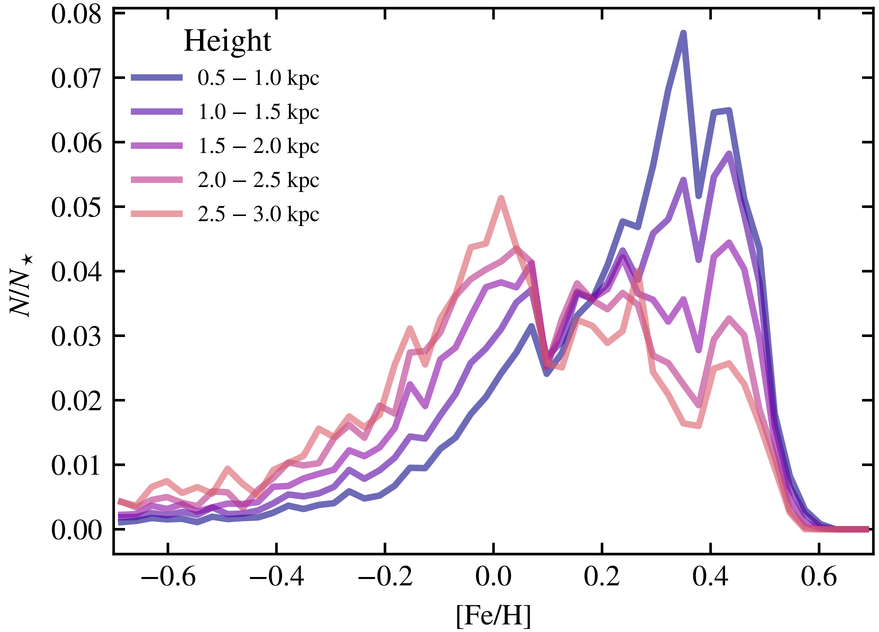
Johnson et al. 2022

Vintergatan cosmological hydrodynamical simulation

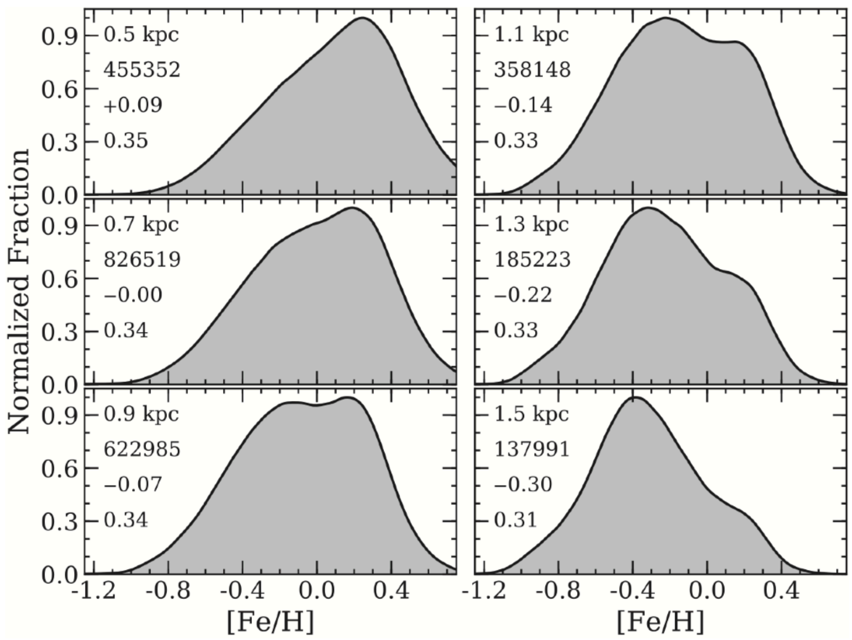
VINTERGATAN simulation
(Agertz et al. 2021)

Simple test!
Stars at $R_{\mathrm{gal}} < 2$ kpc
“inner galaxy/bulge”

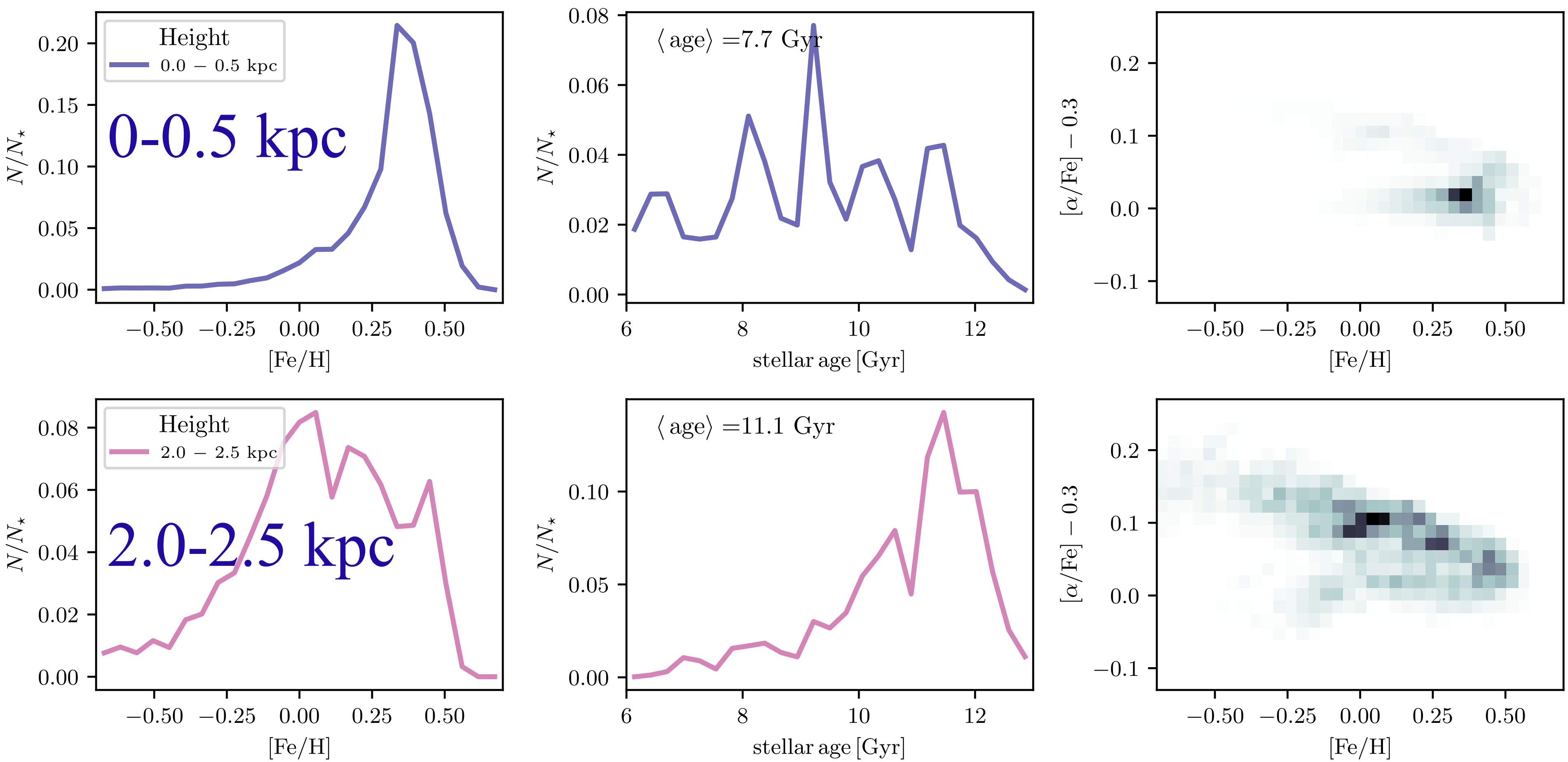
[note: precise [Fe/H]-values will not compare to the Milky Way, but trends (may) matter]



Johnson et al. (2022)



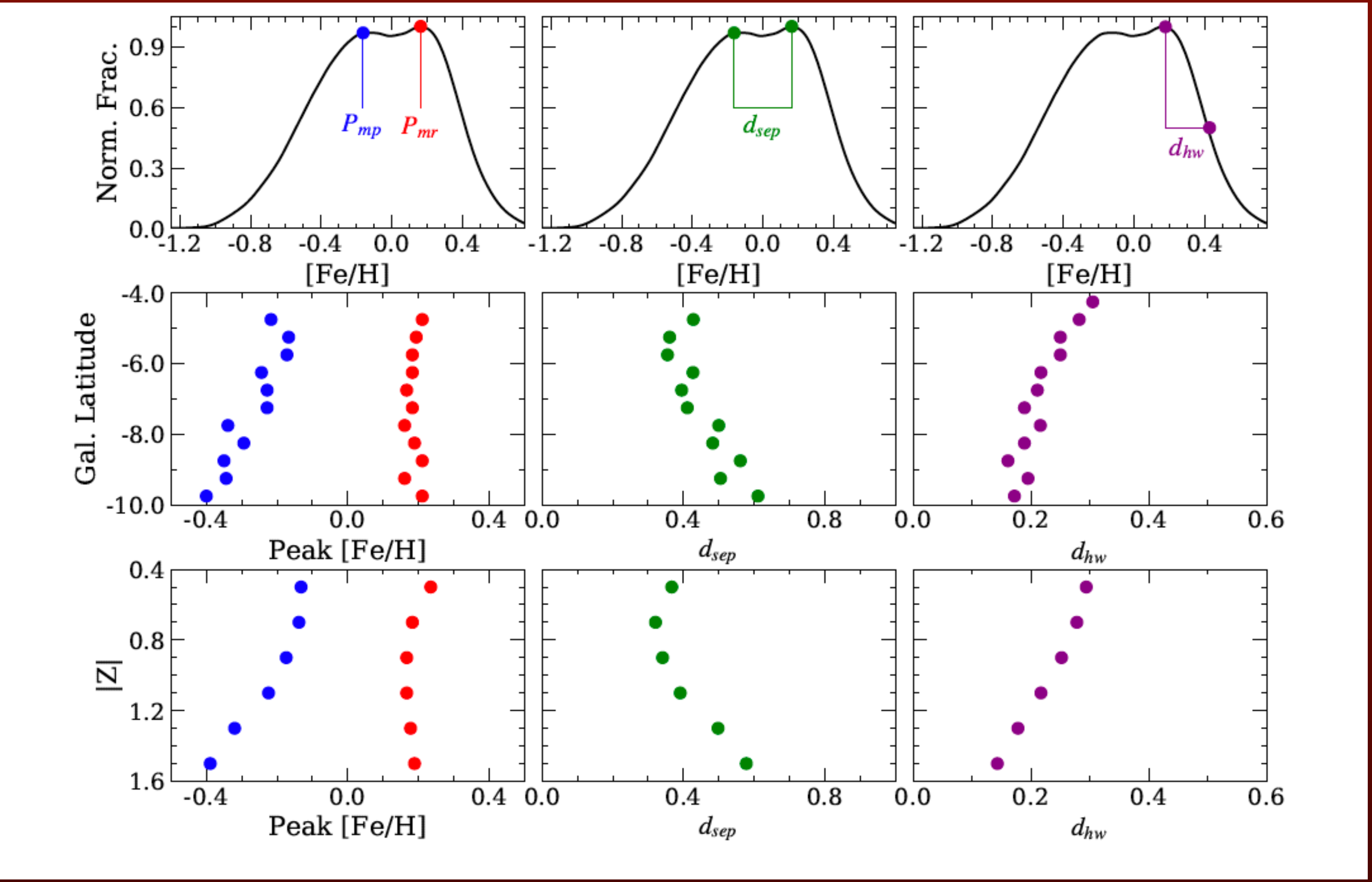
Cosmological hydrodynamical simulations: The metal rich stars may have a greater age spread, multi bursts; Away from the plane the population is older and peaks subsolar



Rich, Agertz et al. 2024 in prep

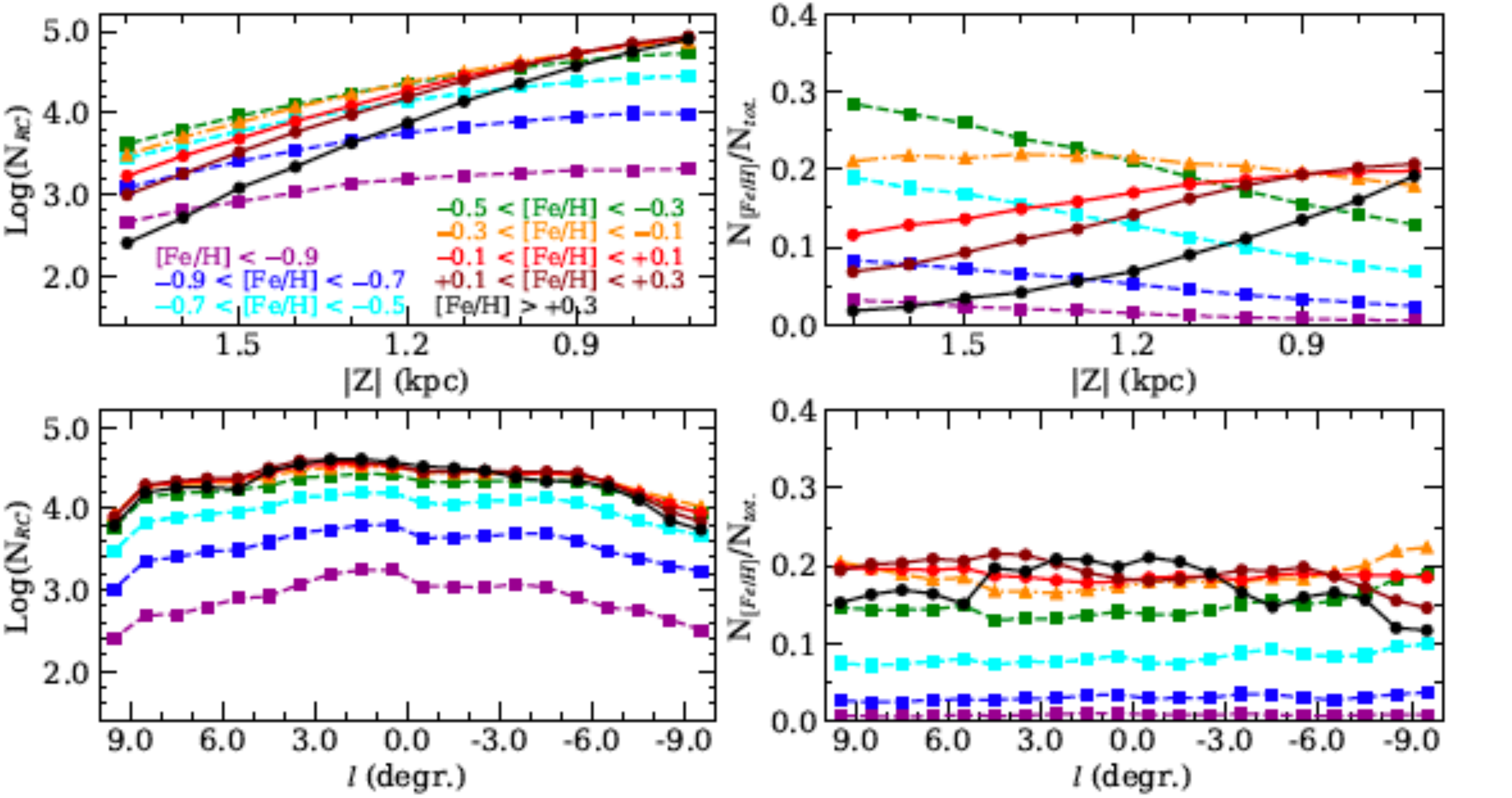
IAUS395

Metal rich component metallicity constant
Metal poor component present in the plane

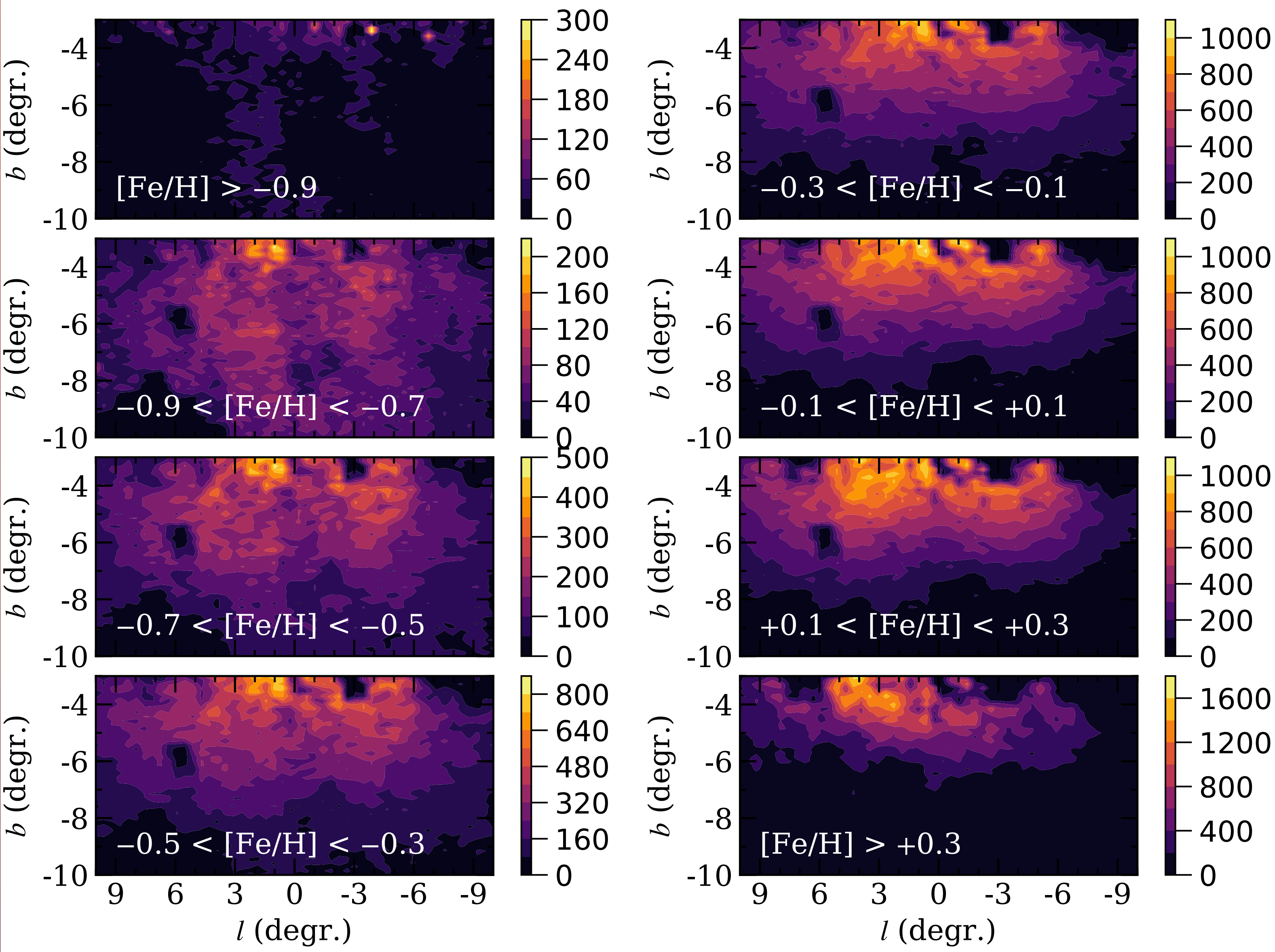


Johnson,Rich 22

Extreme vertical gradient; no radial gradients



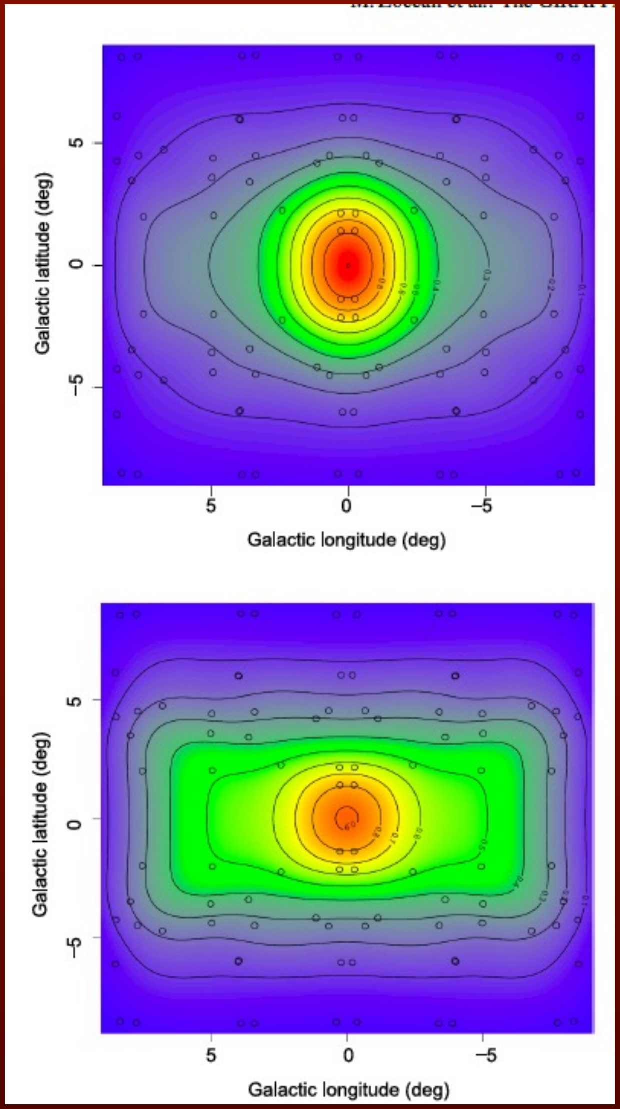
Metal rich red clump stars concentrate to the plane; no Metallicity variation radially. Detail from 2.6M stars



Rich +2020, Johnson, Rich+ 2020, 2022

[Fe/H]< 0

[Fe/H]> 0



We do not confirm this finding (Zocalli et al. 2017). However, we are not as close to the plane.

The metal poor population is not concentrated in a spheroid, and the metal rich population is more confined to the plane.

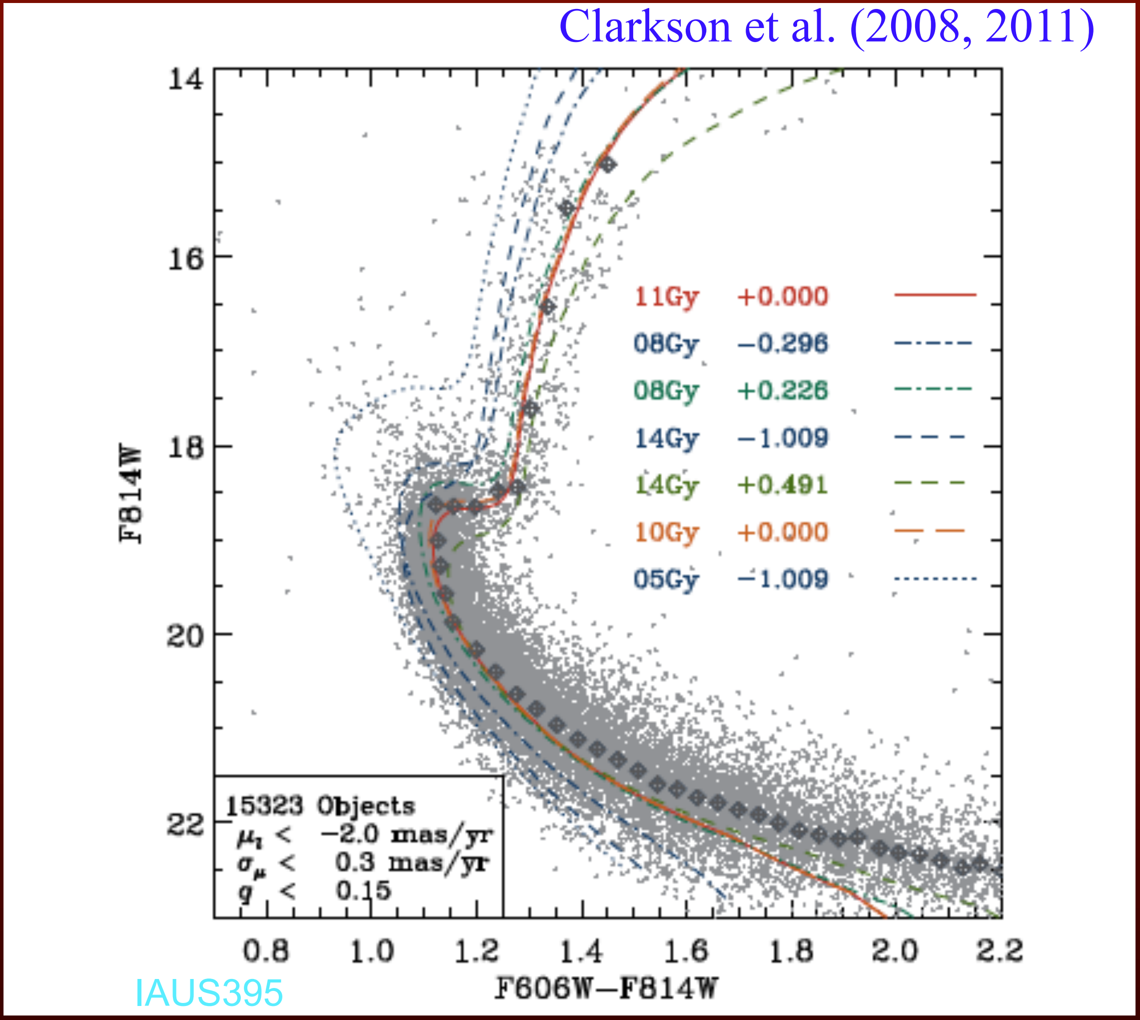
Age Controversy

Proper motion cleaned
color-magnitude diagrams using HST
Require greater ages of 10 Gyr

Clarkson et al. 2008

Renzini+18
Also asserts old
Bulge based on
luminosity
functions

Bensby +17 find
Dramatically
younger ages



Bensby et al. 2017 usese log g, log T_{eff} , [Fe/H] measured from high resolution spectra of microlensed bulge stars-significant int age pop

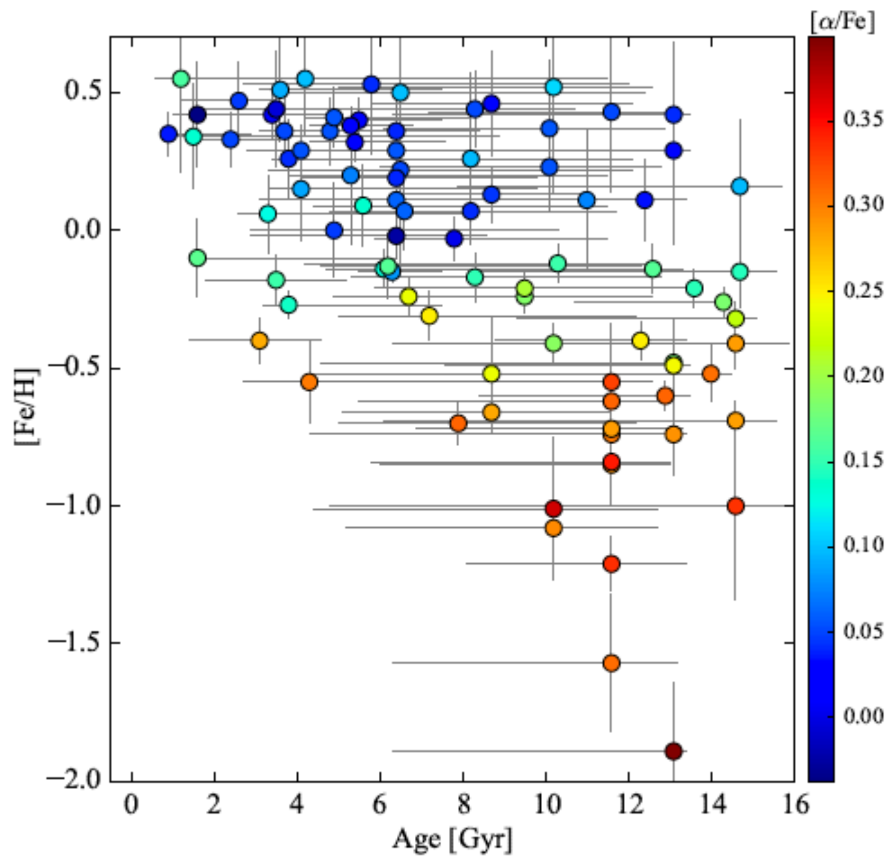


Fig. 13. Age versus [Fe/H] for the microlensed dwarf sample. The stars have been colour-coded according to their level of α-enhancement (as shown by the colour bar on the right-hand side).

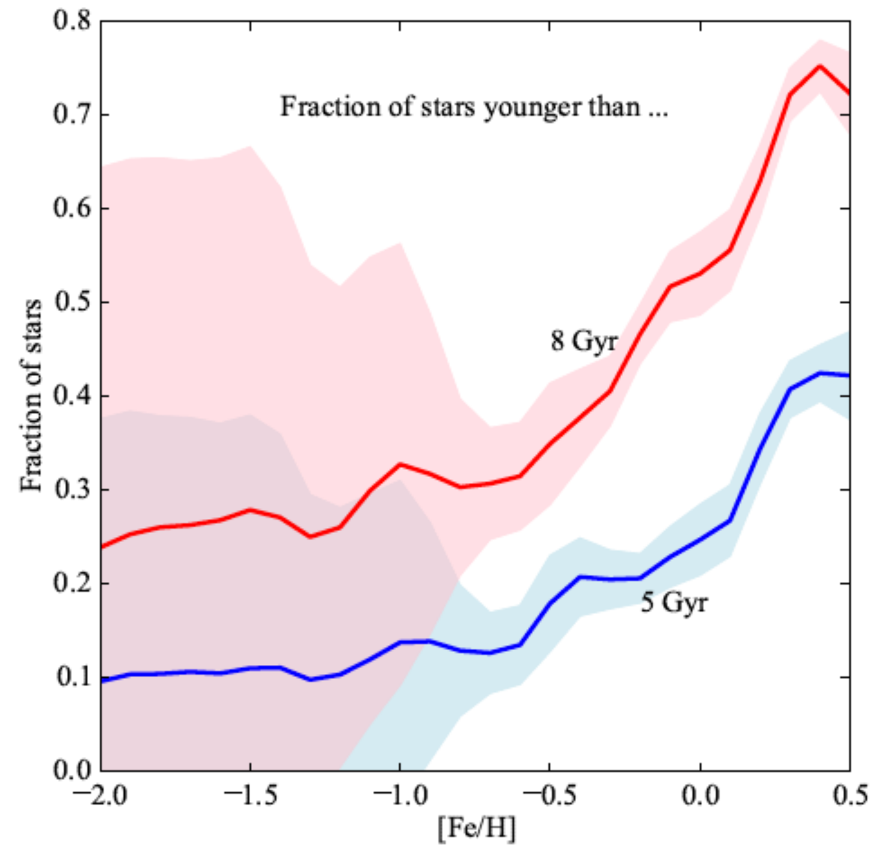
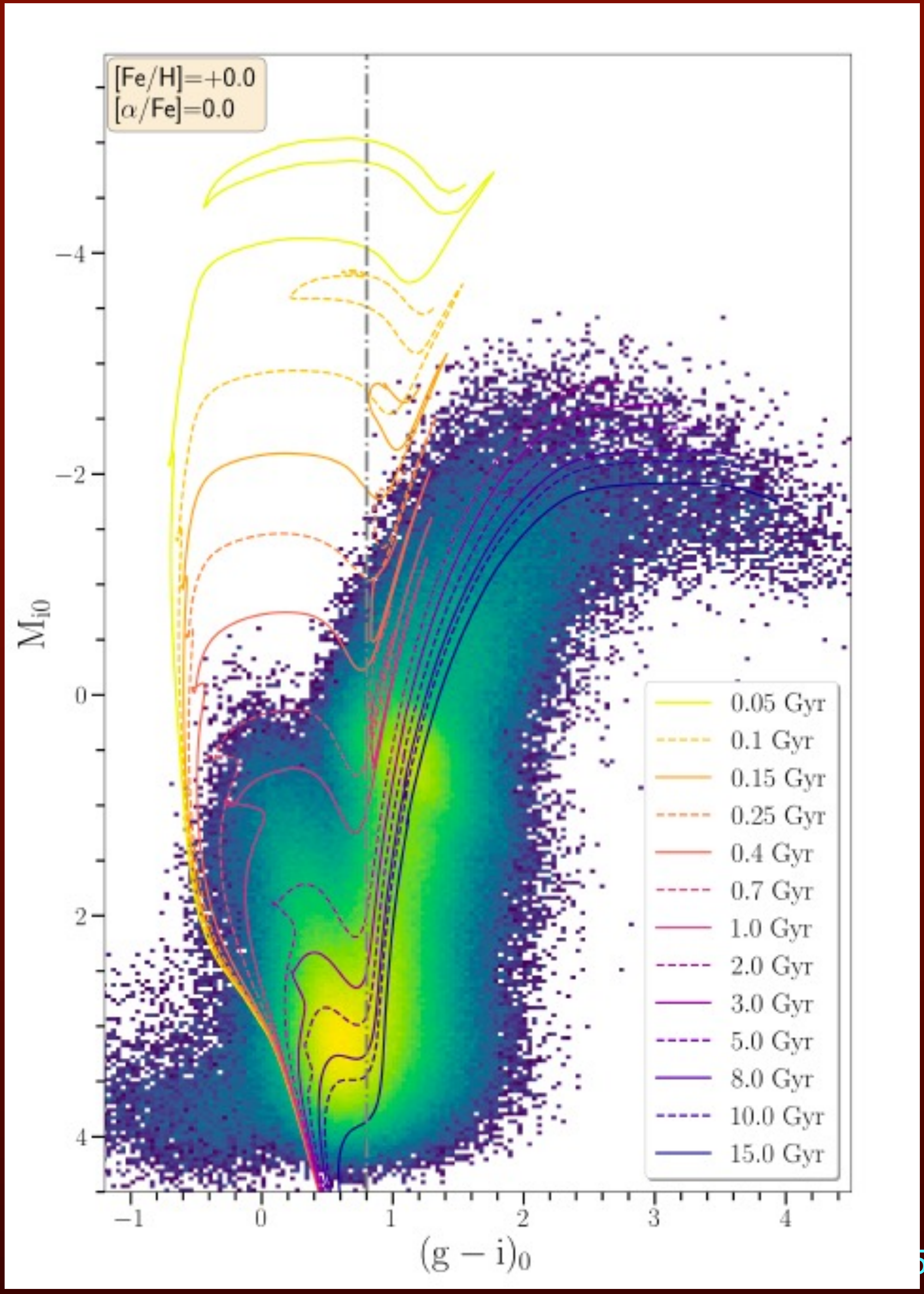


Fig. 14. The fraction of stars younger than 5 Gyr and 8 Gyr, respectively, at different metallicities. The thick blue and red lines represent the mean values from 10 000 age-metallicity distributions where individual ages and metallicities have been re-sampled using the [Fe/H] uncertainties and the individual age probability distributions (see text for more details). The shaded areas show the the formal errors of the mean (1-sigma dispersion divided by $\sqrt{N}$).

domly drawn from that star's age probability distribution func-

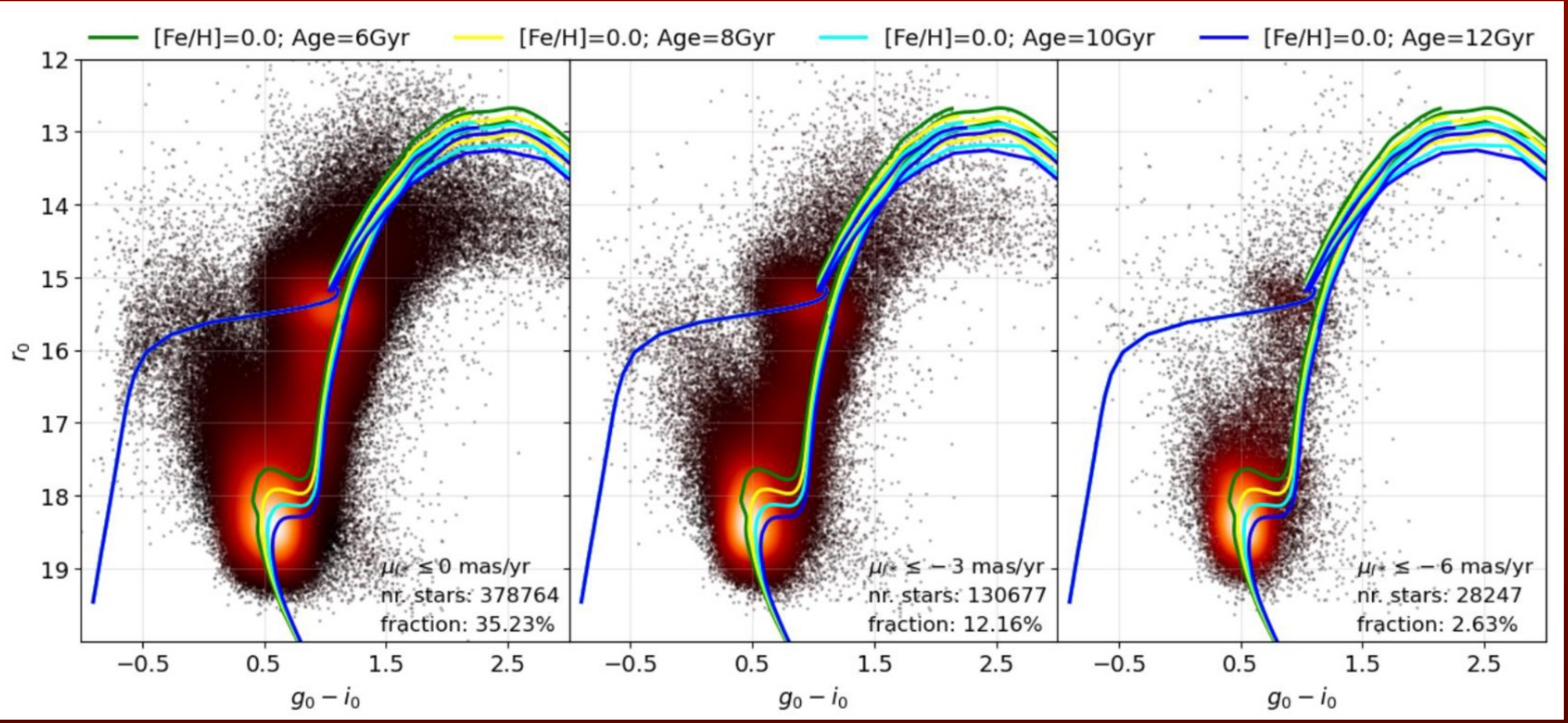


Foreground –
Cleaned full bulge
CMD
Shows no
Extensive population
<1 Gyr   Tour de Force

Marchetti et al. 2022
A&A

>100M Gaia matches

Gaia Proper motion cleaning of Saha et al. 2019 field: Similar results, but now stars < 6 Gyr ruled out



Johnson, Zoccali, Calamida et al. 2024 in prep

Re-derive ages from Bensby+17 with new isochrones

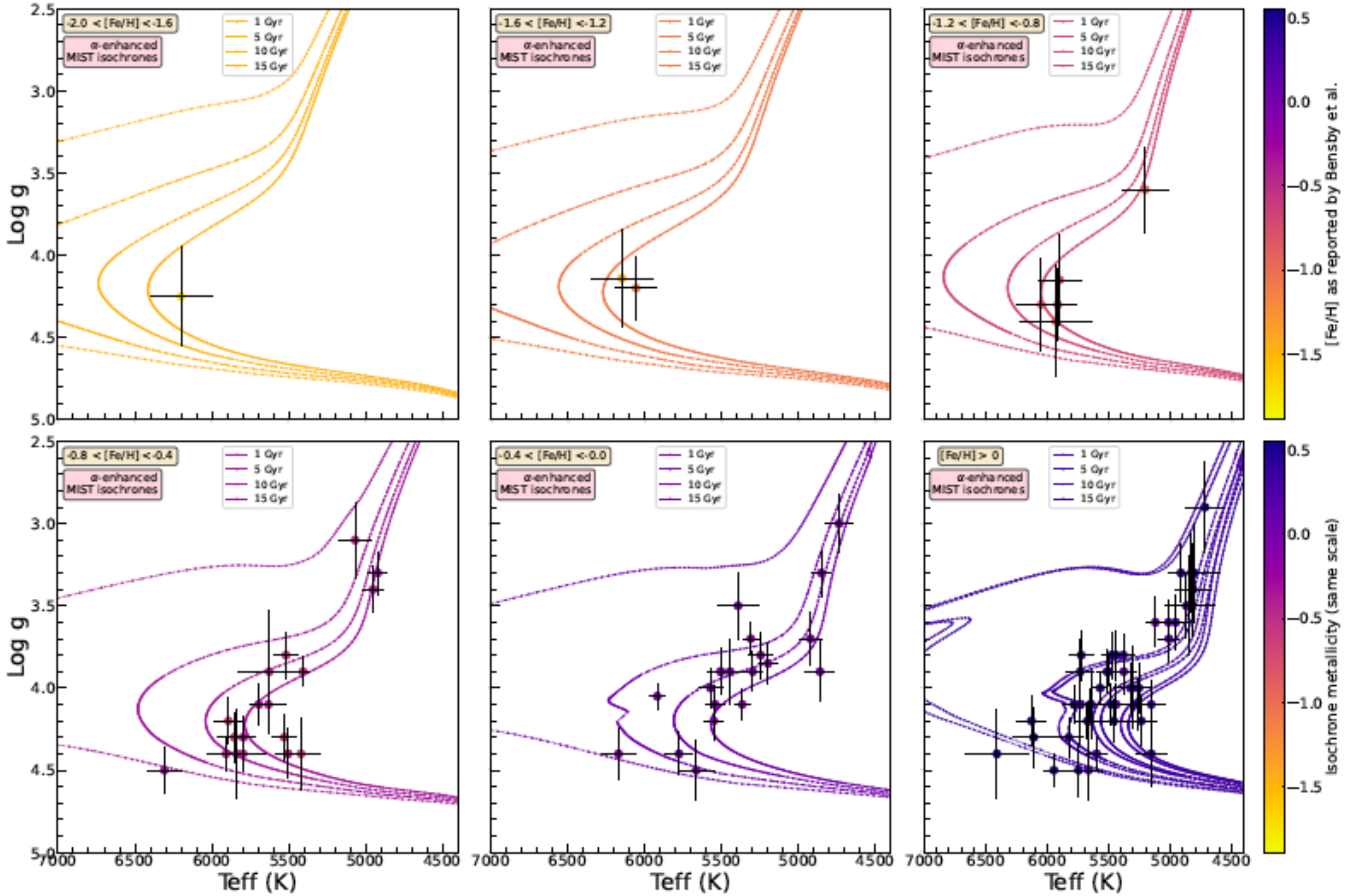
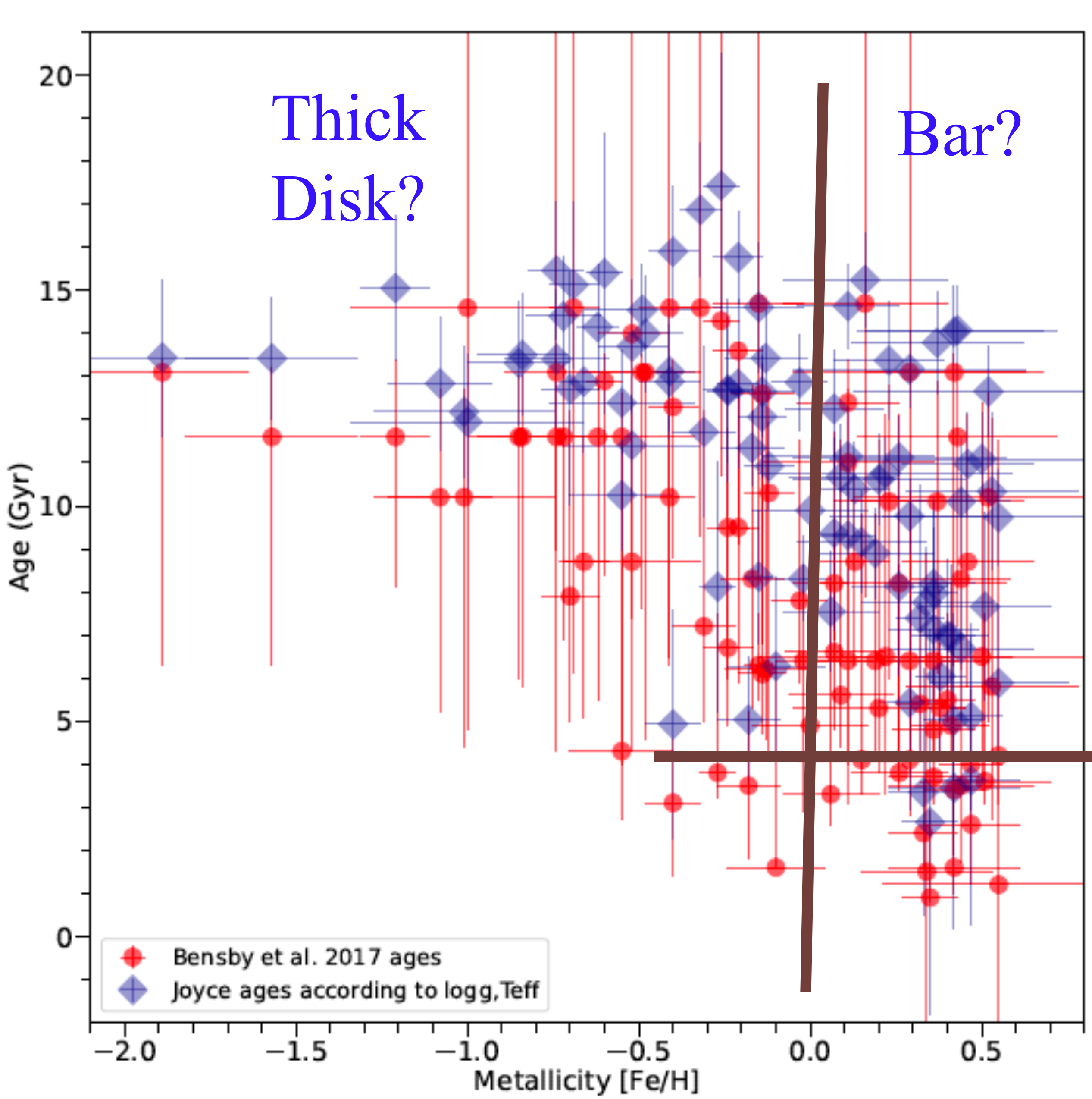


Figure 4. Same as Figure 1 but using α-enhanced MIST isochrones.

Joyce, Johnson, Marchetti, Rich et al. 2023

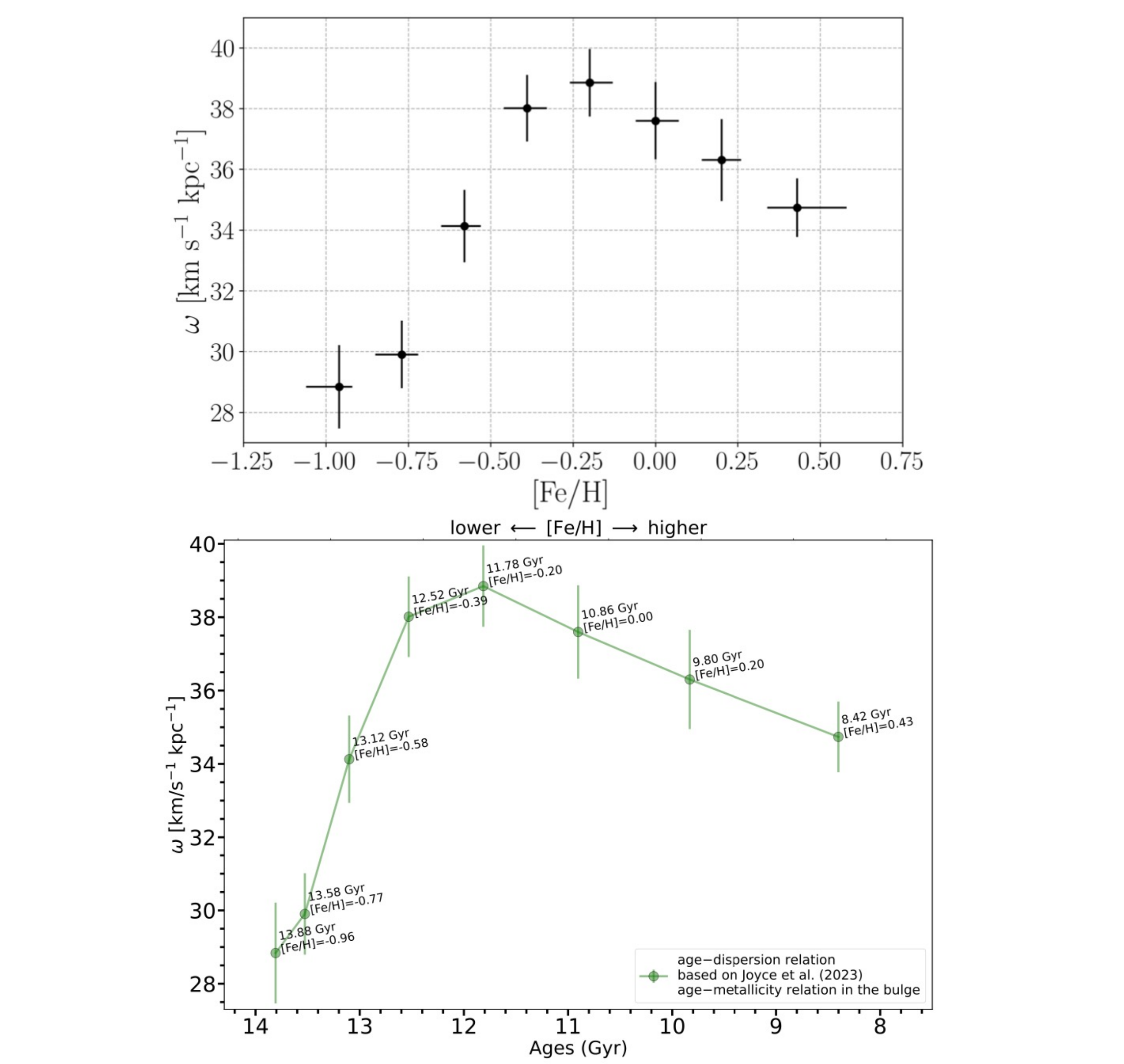


We find very few stars < 5 Gyr

10+/-3 Gyr

New Kinematics Gaia + Red clump [Fe/H]/ages

T. Marchetti et al. 2024 A&A



ω from proper motions-proxy for rotation speed

l,b proper motion correlation strong at [Fe/H]>-0.3, a bar signature.

metal rich

[Fe/H]

-0.8

-0.6

-0.4

[Fe/H]

-0.2

0.0

+0.1

>0.3

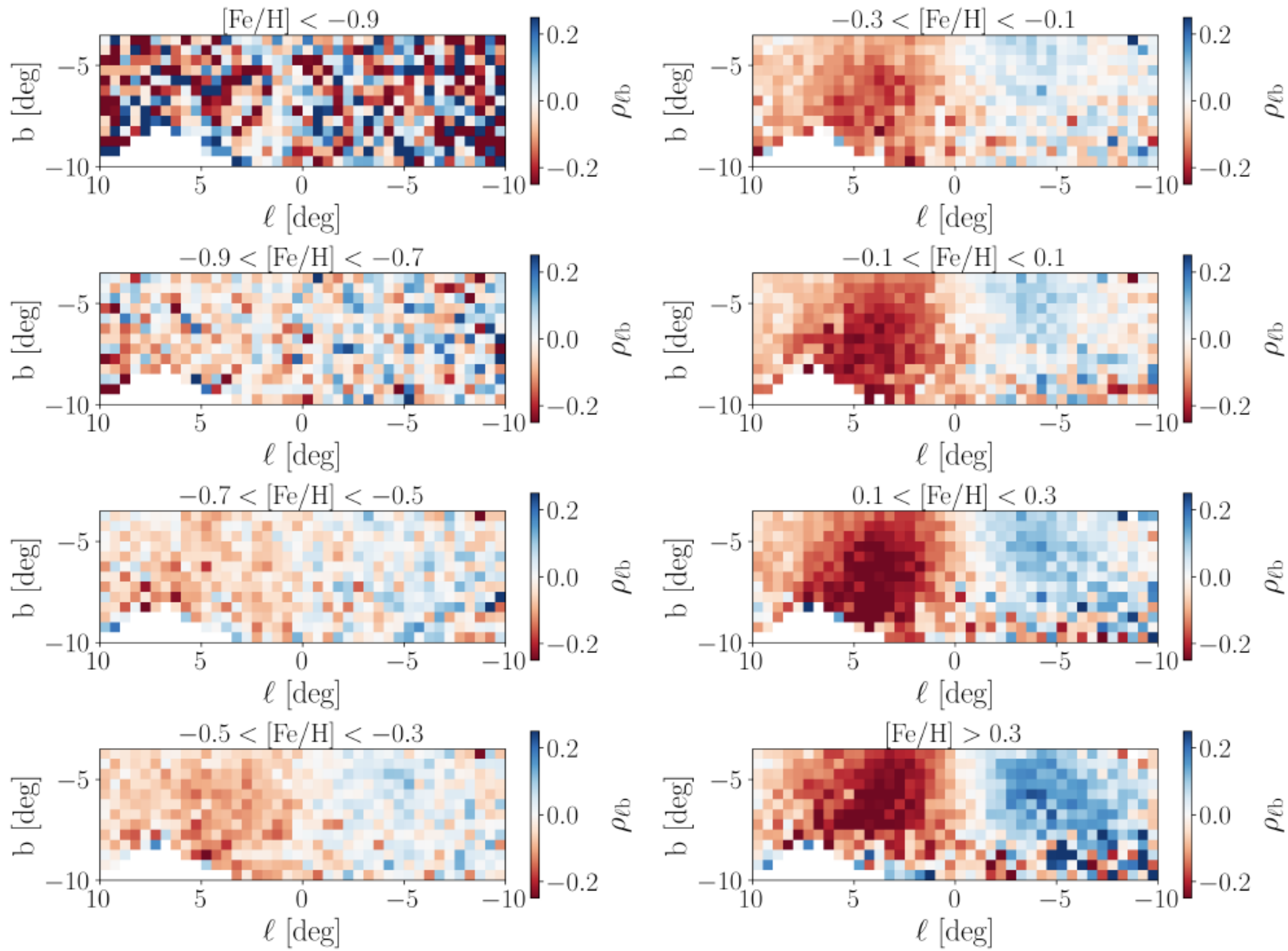
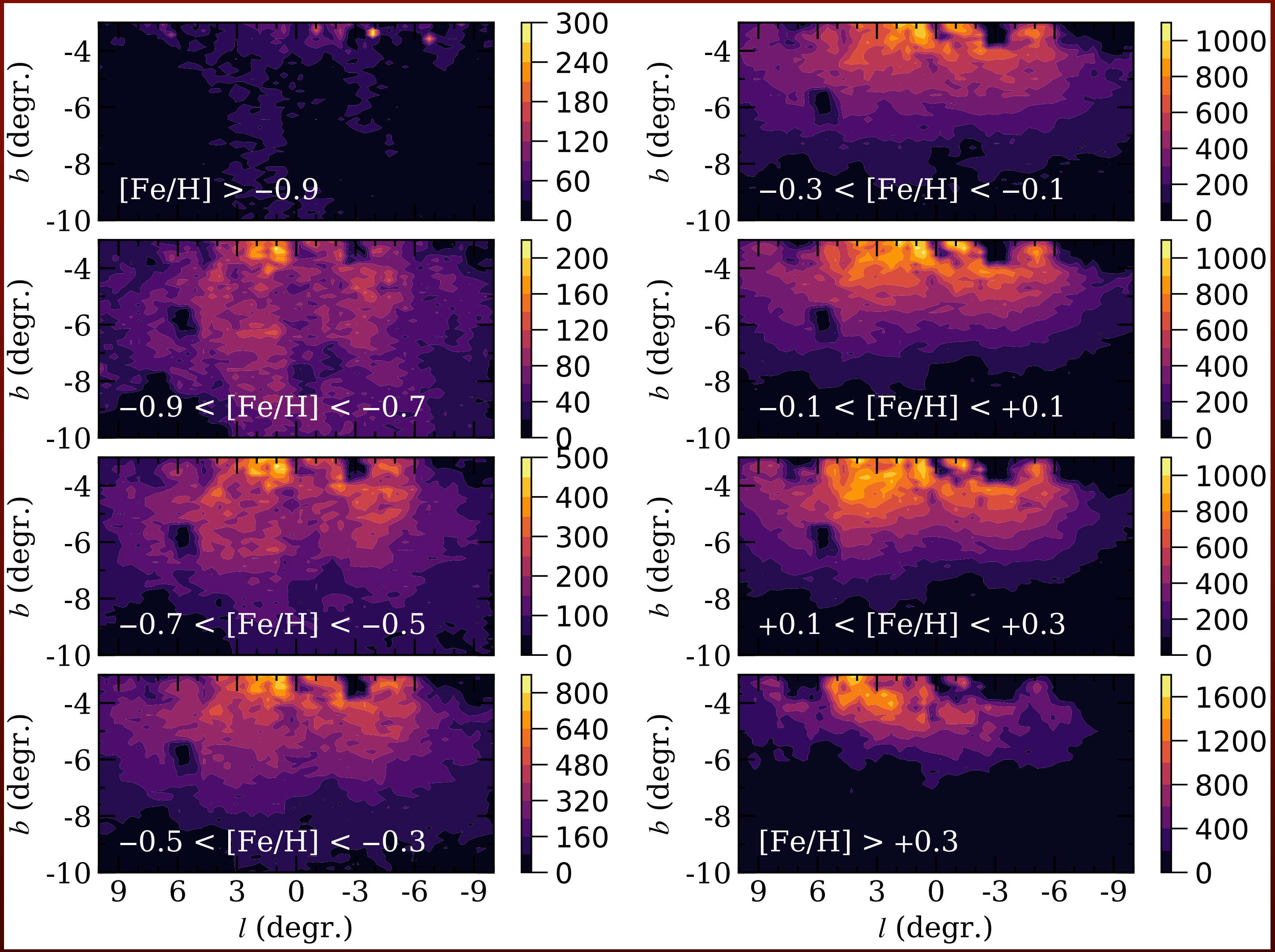


Fig. 11. Correlation between Galactic proper motions as a function of Galactic coordinates in the southern bulge, for the metallicity bins considered in this work, and in Fig. 19 of Johnson et al. (2022).

Metal rich red clump stars concentrate to the plane; no Metallicity variation radially.



Johnson, Rich+ 2020, 2022

Johnson et al. 2014 Bulge has few if any dSpH

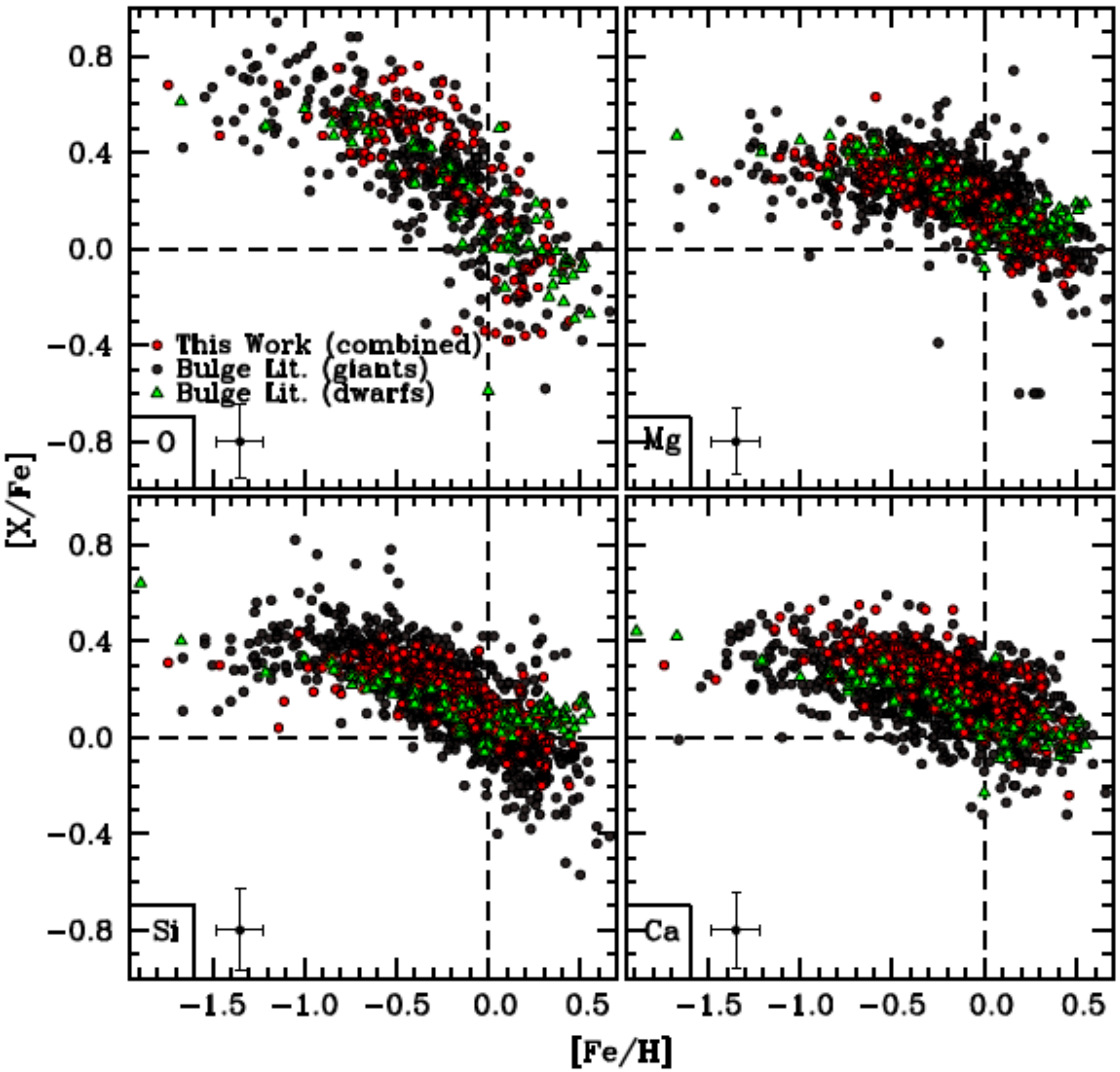


Figure 13. [X/Fe] ratios for the α–elements O, Mg, Si, and Ca plotted as a function of [Fe/H]. The filled red circles indicate abundances measured for this work (combining both fields and NGC 6553), the filled dark gray circles are abundances in bulge RGB and red clump stars from the literature, and the filled green triangles are abundances from bulge microlensed dwarfs (Bensby et al. 2013). The RGB and clump data are from McWilliam & Rich (1994), Rich & Origlia (2005), Fulbright et al. (2007), Lecureur et al. (2007), Rich et al. (2007a), Meléndez et al. (2008), Alves-Brito et al. (2010), Ryde et al. (2010), Gonzalez et al. (2011), Hill et al. (2011), Johnson et al. (2011), Rich et al. (2012), García Pérez et al. (2013), and Johnson et al. (2013a, 2013b).

(A color version of this figure is available in the online journal.)

Did some GC Stars arise from the Old Thin Disk or dSph?

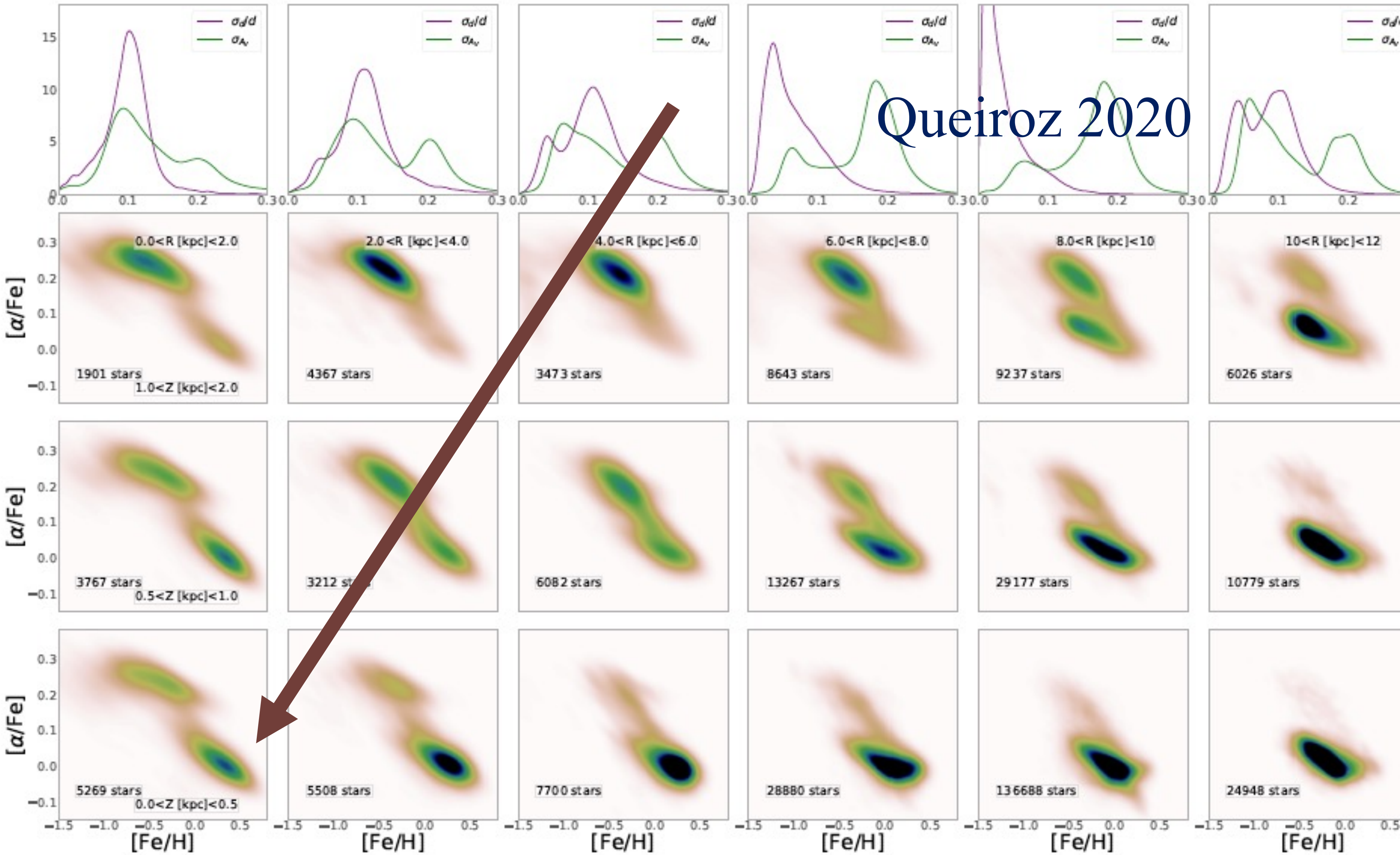


Fig. 6. APOGEE DR16 [α/Fe] vs. [Fe/H] diagrams in bins of galactocentric cylindrical coordinates, similar to the chemical maps pr in Hayden et al. (2015), but extending further into the inner Galaxy. *Top panels*: kernel-density estimates of the uncertainties distribu StarHorse extinctions and distances, for each galactocentric distance bin (including all Z_{Gal} bins).

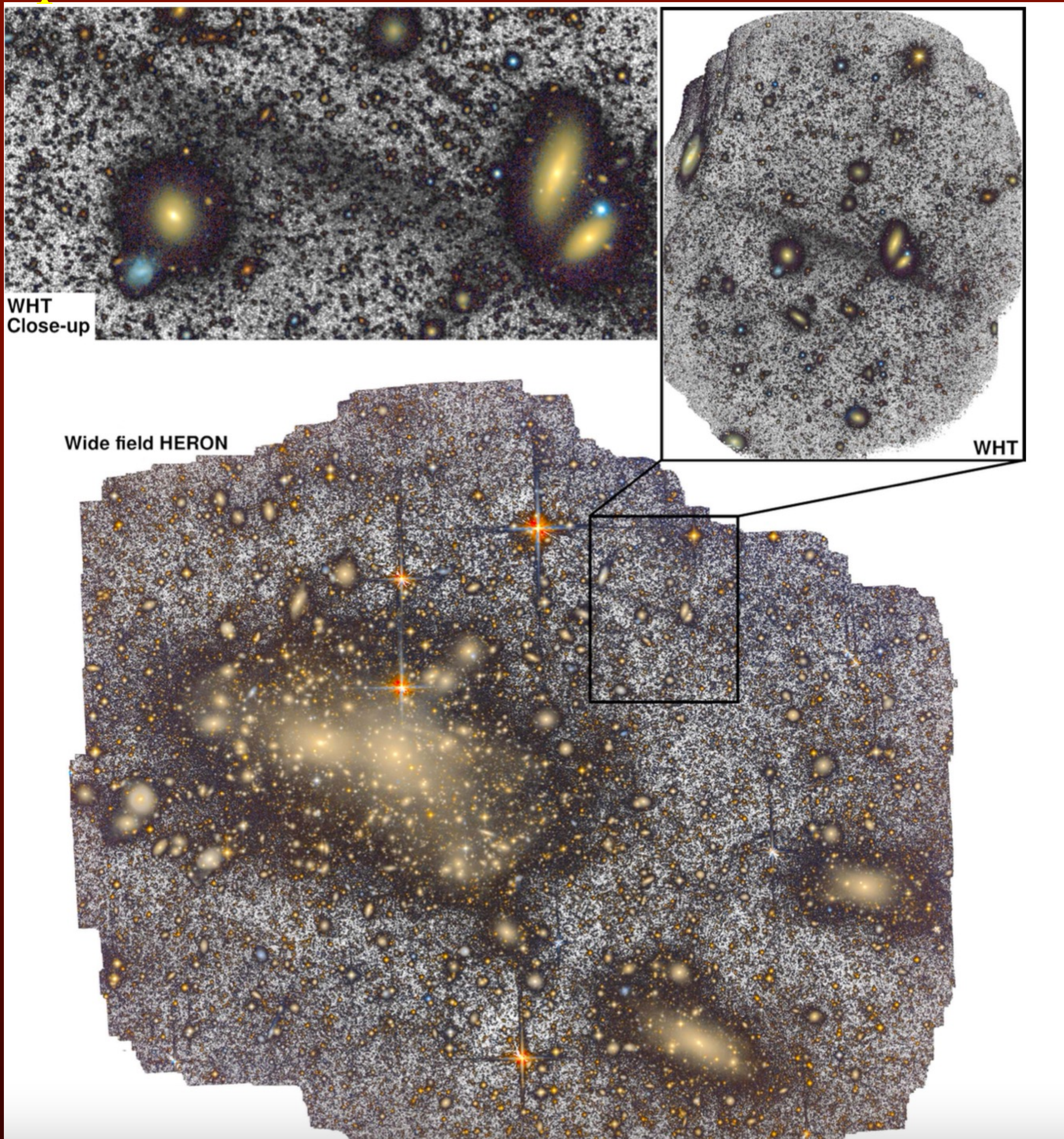
1. The ”bimodal” distribution of abundances in the bulge arises from a metal rich, plane concentrated population, and a metal poor, extended population.

2. $(u\text{-}i)_0$ not only correlates with [Fe/H] but also can be used to sort out 1 and 2 gen stars in globular clusters.

3. There may be a ~ 2-5 Gyr age range in the metal rich population; This may be consistent with Miras (Sanders, Matsunaga et al. 2024)

4. Neither an age range nor the strong metallicity gradient would consistent with a bar that has buckled from a massive disk (e.g. Shen et al. 2010). Yet the most metal rich stars are part of the kinematic bar. The disk buckling scenario is the favored scenario for the formation of the bar.

A 530 kpc stream in the Coma Cluster – ask me at break



Roman, Rich et al. 2023 A&A