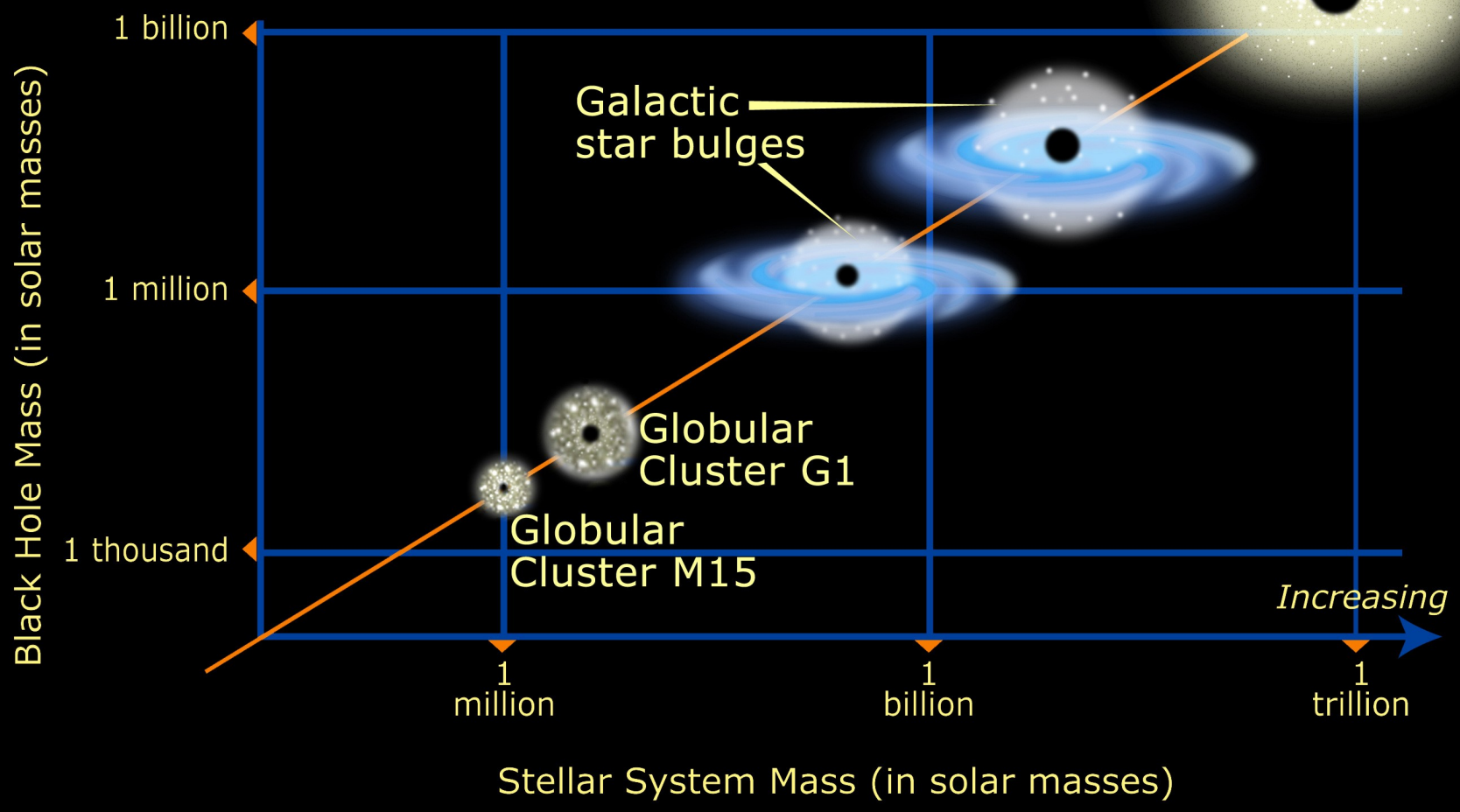
The Bulge, Building Block Globular clusters, And the Galactic Center

R. Michael Rich
UCLA

Brno Galactic Center 2026

Correlating Black Hole Mass to Stellar System Mass



Important Scales:

Galactic Nuclear Star Cluster: 5 pc

Nuclear stellar disk: 100 pc

Galactic bulge 100-1000 pc

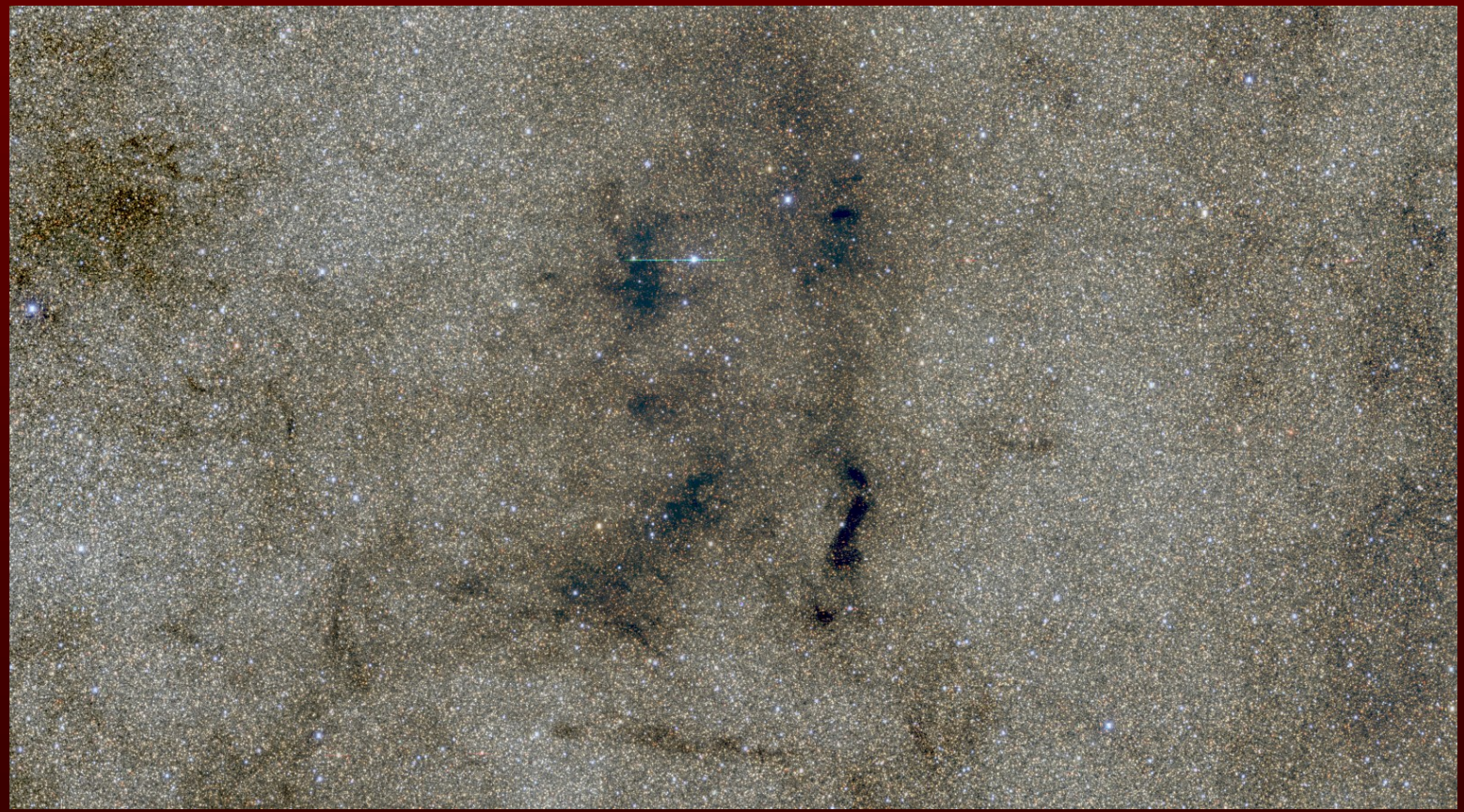
Age, abundance, kinematics, structure
Metal rich bulge is strongly barred
And shows rotation

1. Blanco DECam Bulge Survey
2. Abundances and Ages in the central parsecs
3. Other Massive Clusters
4. Future Questions

The Blanco DECam Bulge Survey: A Rubin Observatory Pathfinder

R. Michael Rich (UCLA), Co-PI

Christian Johnson, STScI, Co-PI, Tommaso Marchetti (ESO), Kathy Vivas (CTIO,NoirLab), Scott Michael & Mike Young (Indiana University), Andrea Kunder (St. Martin's U), Tomasso Marchetti (ESO) Andreas Koch (ZAH), Will Clarskon U. Mich Dearborn, Caty Pilachowski (Indiana University), Ortwin Gerhard (MPIA), Iulia Simion, Juntai Shen (Shanghai Observatory), Roberto de Propris (FINCA), Annie Robin (Besancon), Mario Soto



Blanco DECam Bulge Survey (BDBS)
LSST pathfinder (Rubin)

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

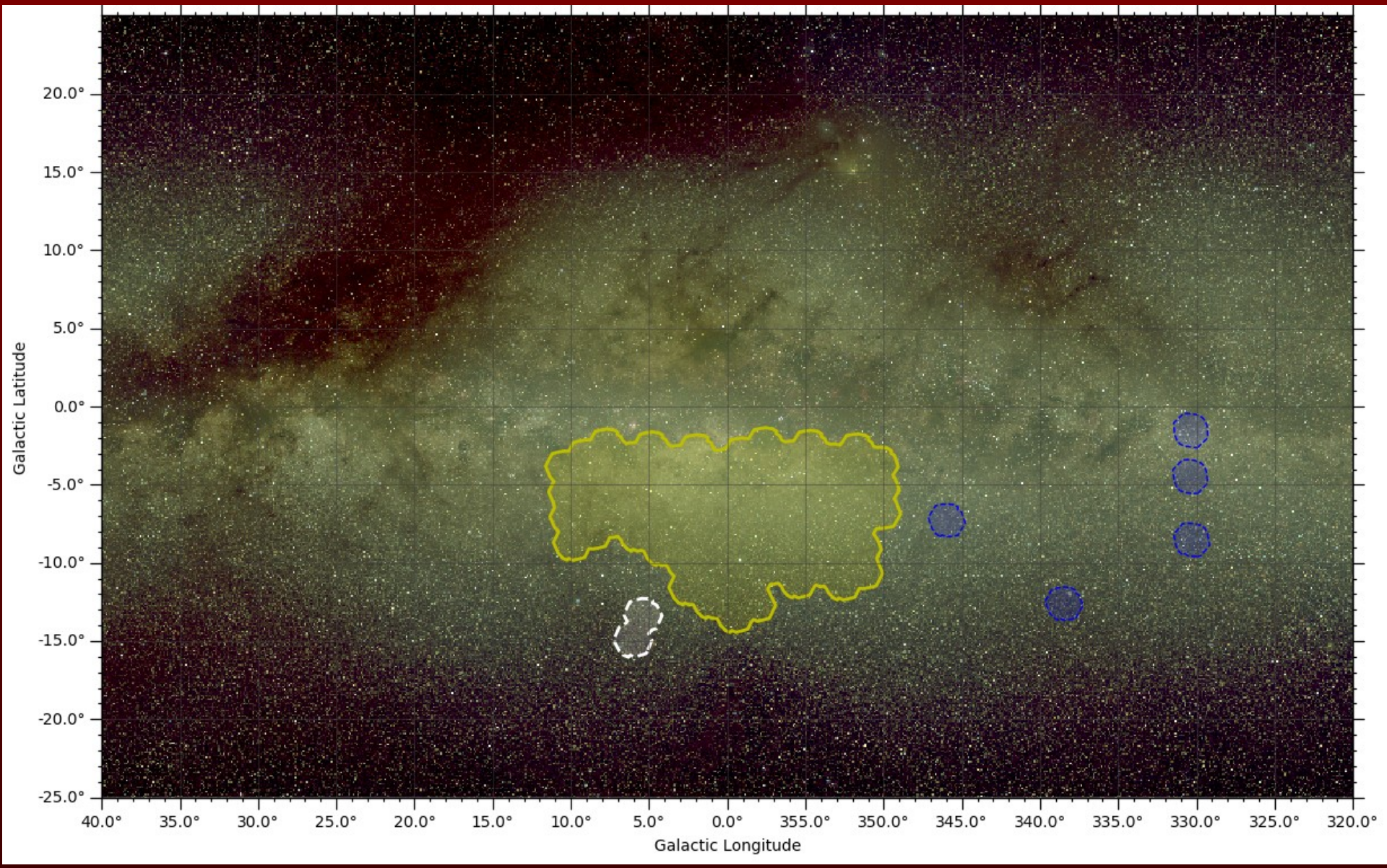
Explore metallicity distribution, age controversy over the whole of the bulge

Use Gaia to explore abundance/kinematics correlations

Bulge globular clusters, tidal tails

Matching to Galex and other surveys

BDBS Fields include Sgr dwarf, disk fields



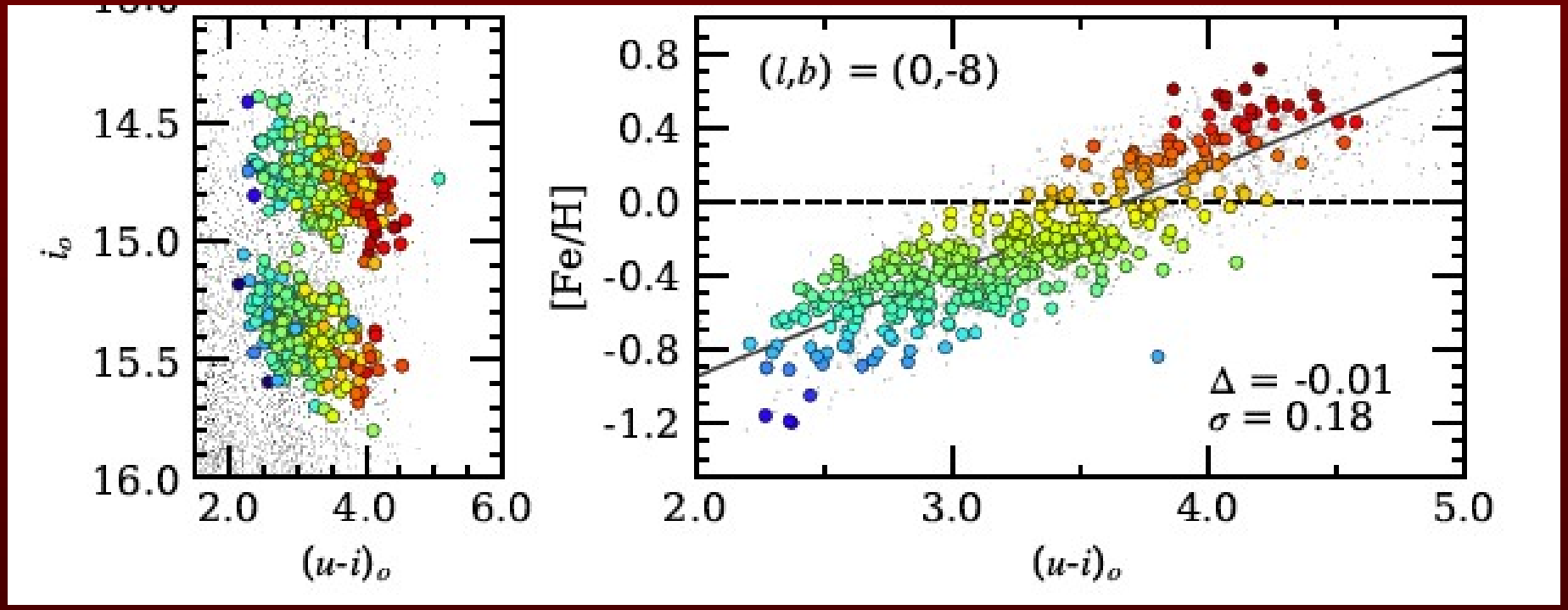
Calibration and data reduction
Undertaken by a single person-
Christian Johnson (STScI)

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

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

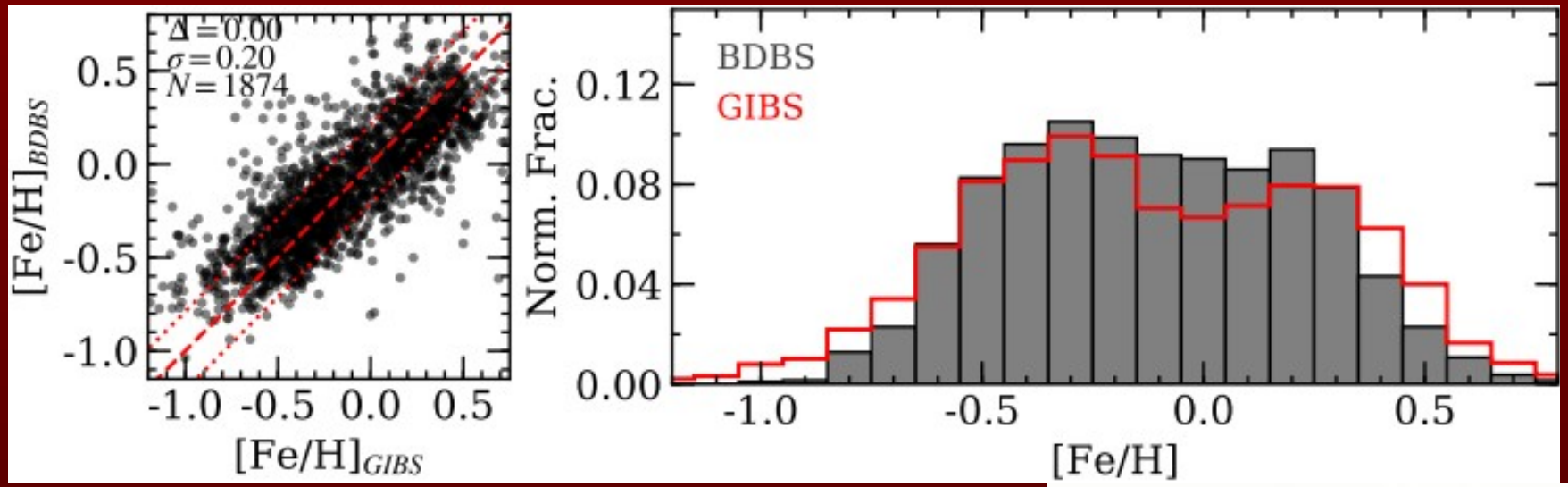
Leads photometric calibration and reduction using daophot+allstar psf photometry- but over this massive dataset.

Calibrate using red clump stars with measured abundances.
Matching to existing Ca triplet abundances (Zoccali et al. 2017) gives *u-i* vs [Fe/H]

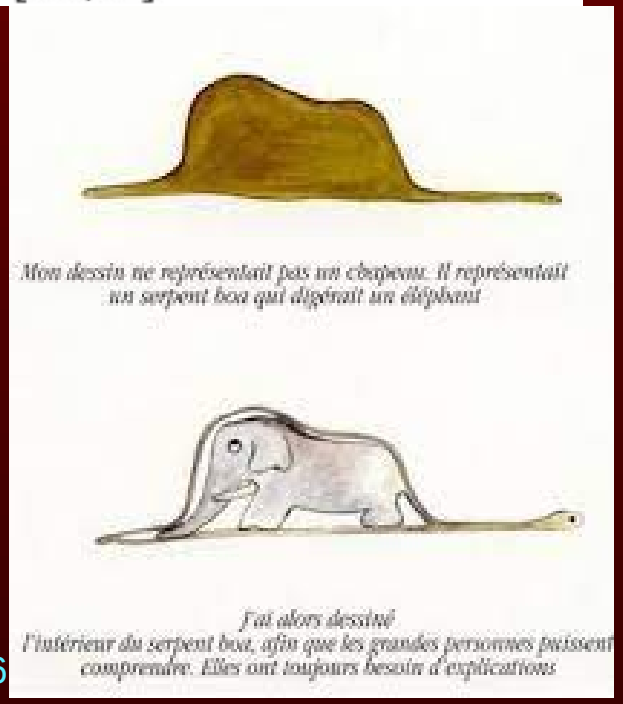


Johnson, Rich et al. (BDBS II) 2020

Another comparison with Zoccali et al. 2017
Note that we confirm a multimodal abundance distribution



Millions of metallicities from u-i photometry



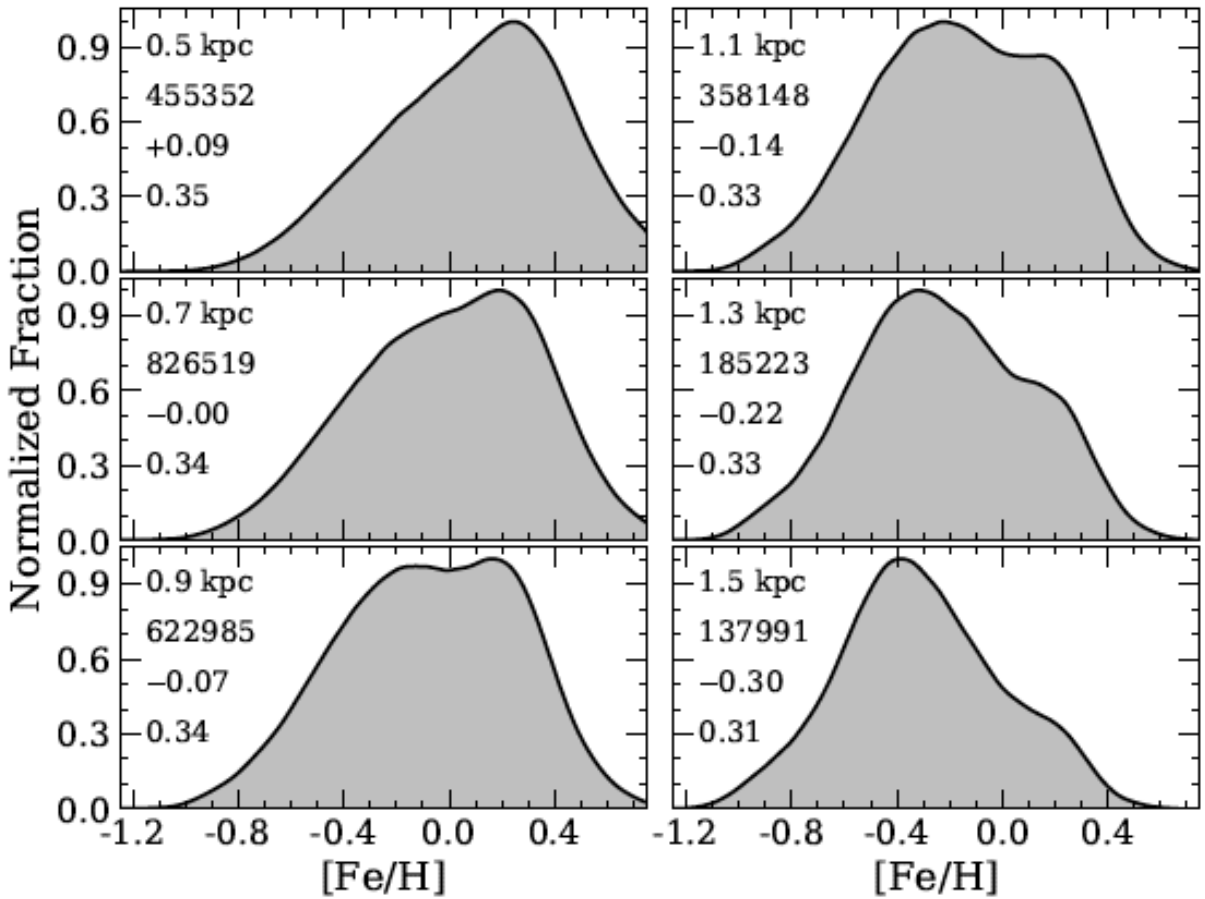
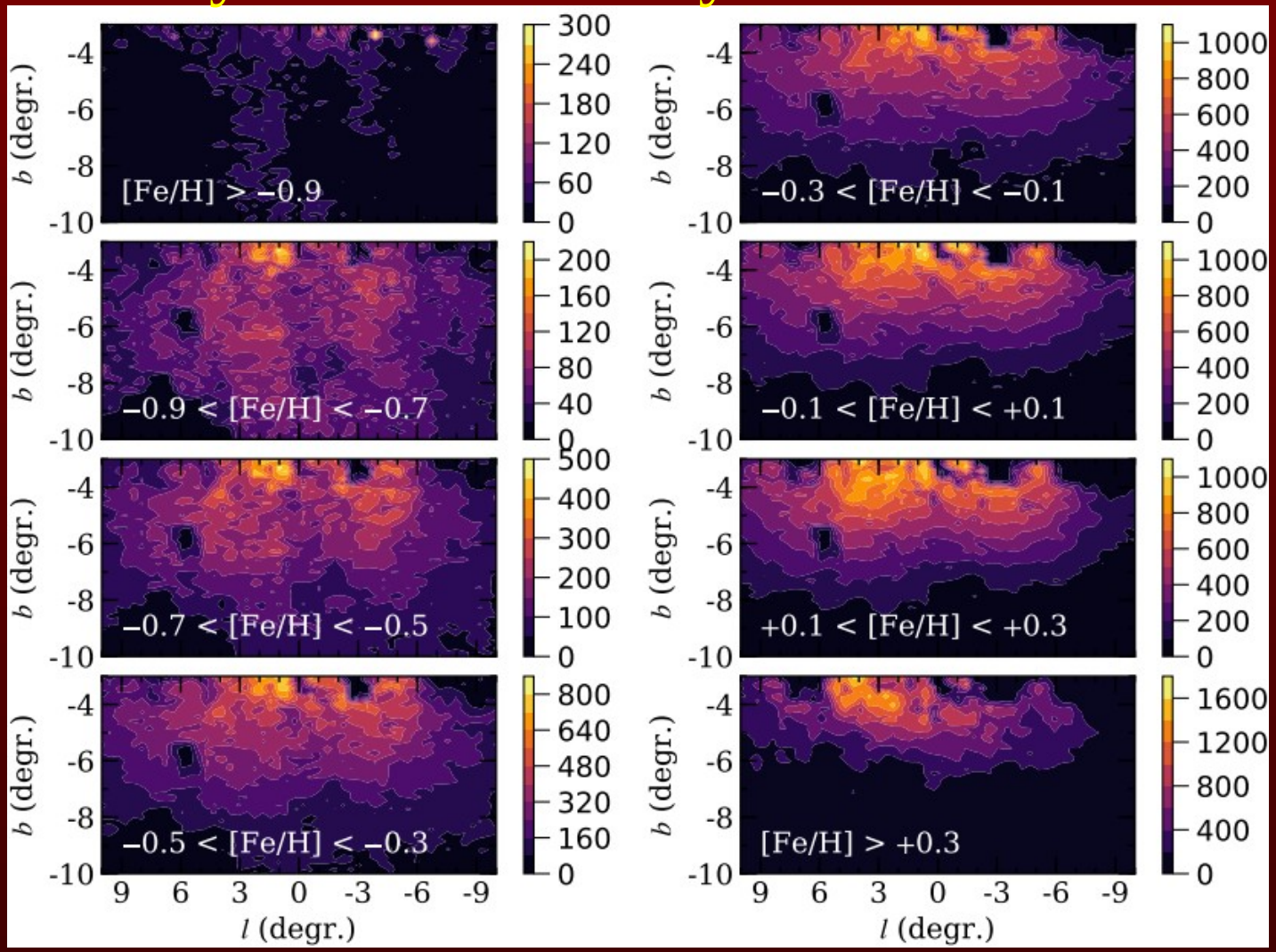


Figure 12. Similar to Figure 11, red clump metallicity distribution functions are shown as functions of distance from the Galactic plane (|Z|). Each slice encompasses all longitudes but only includes Z values ± 0.1 kpc from the values given in each panel. The results are qualitatively in agreement with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

By physical Distance Above The plane

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



Rich +2020, Johnson, Rich+ 2020, 2022

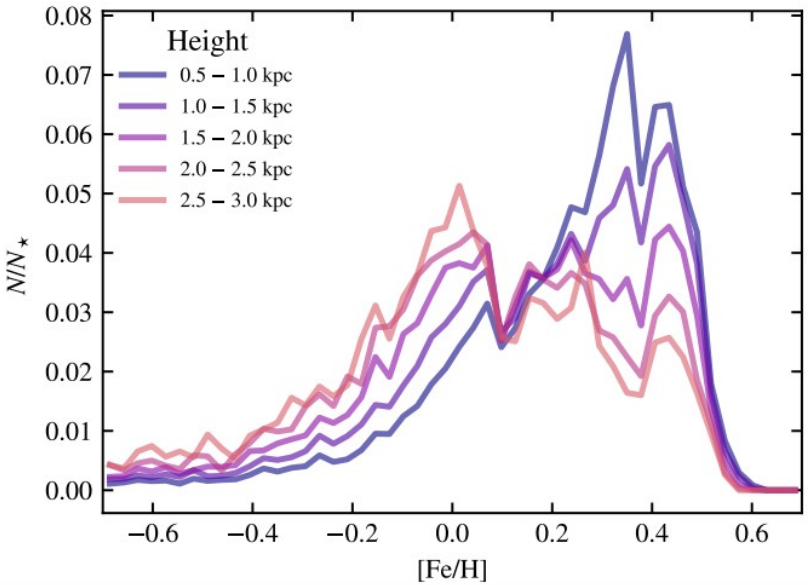
Vintergatan cosmological hydrodynamical simulation

VINTERGATAN simulation
(Agertz et al. 2021)

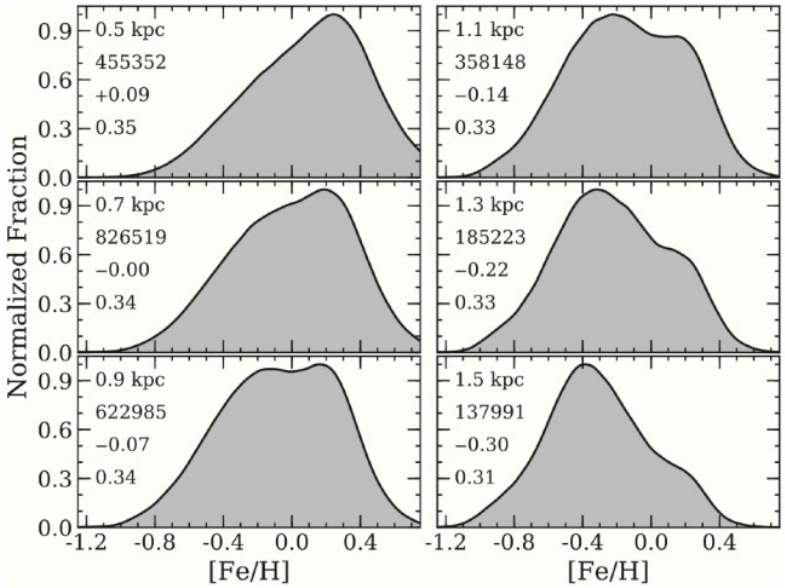
Simple test!

Stars at $R_{\rm gal} < 2$ kpc
"inner galaxy/bulge"

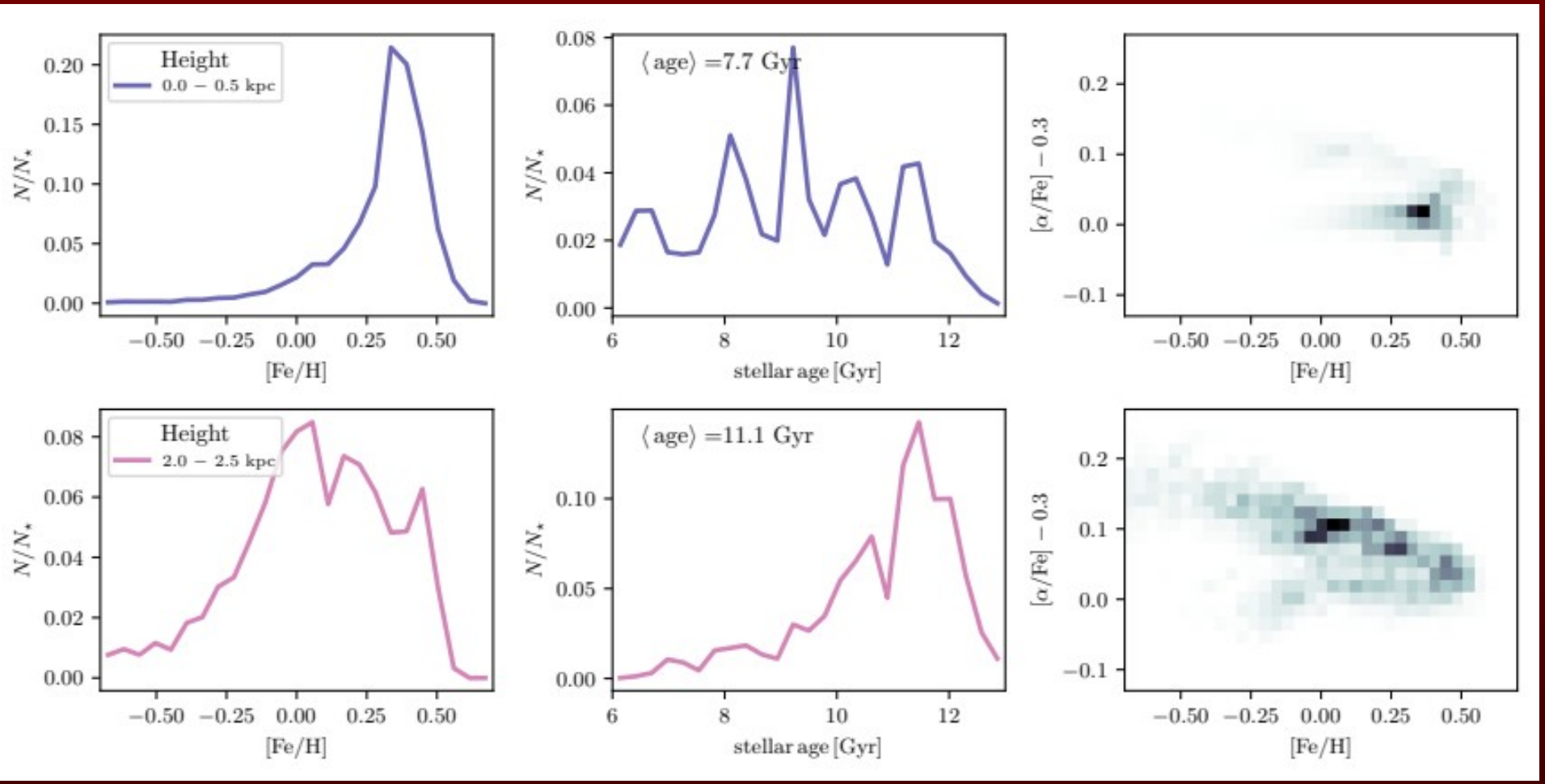
[note: precise [Fe/H]-values will not compare to the Milky Way, but trends (may) matter]



Johnson et al. (2022)



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, Ryde et al. in prep

Age Controversy

Proper motion cleaned color-magnitude diagrams using HST

Require greater ages of 10 Gyr

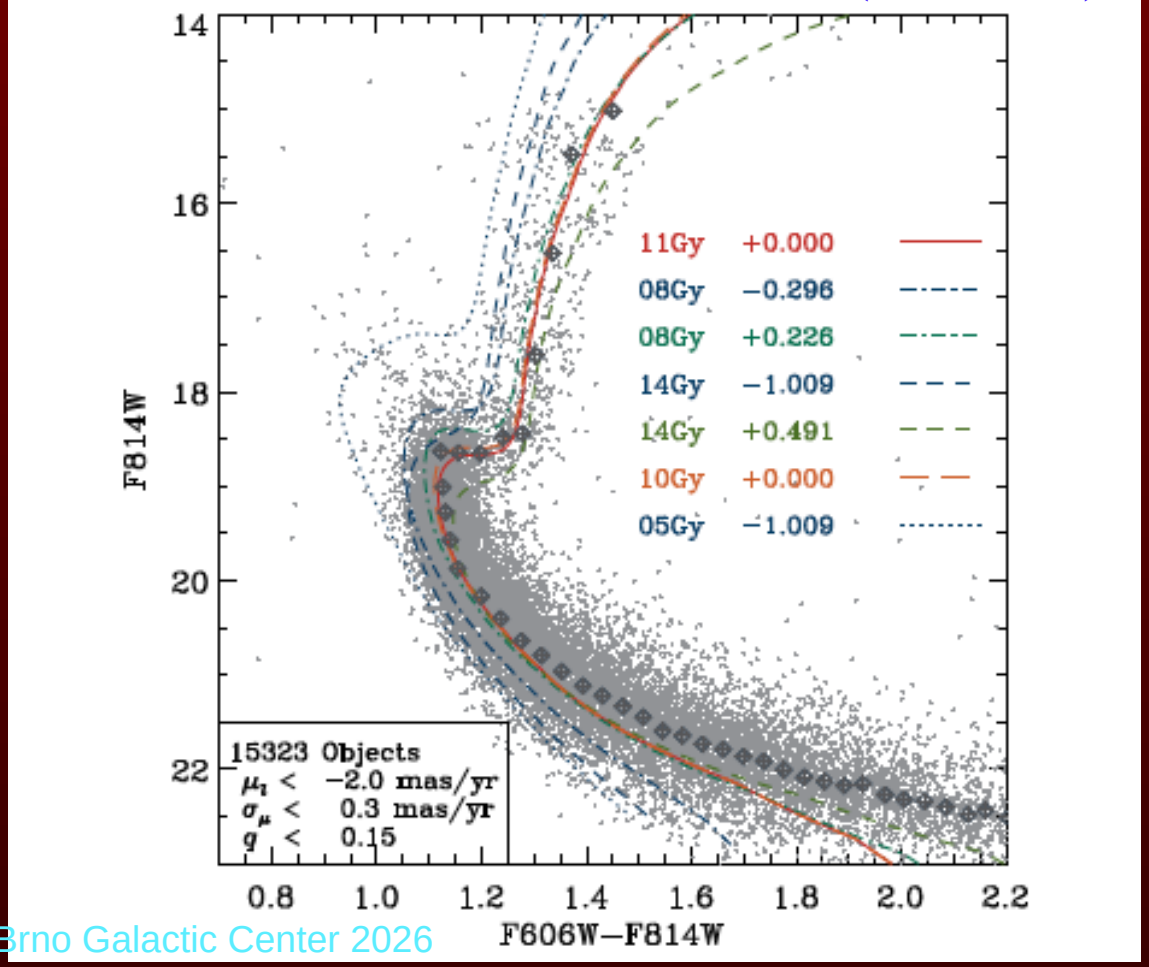
Clarkson et al. 2008

Renzini+18

Also asserts old Bulge based on luminosity functions

Bensby +17 find Dramatically younger ages

Clarkson et al. (2008, 2011)



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

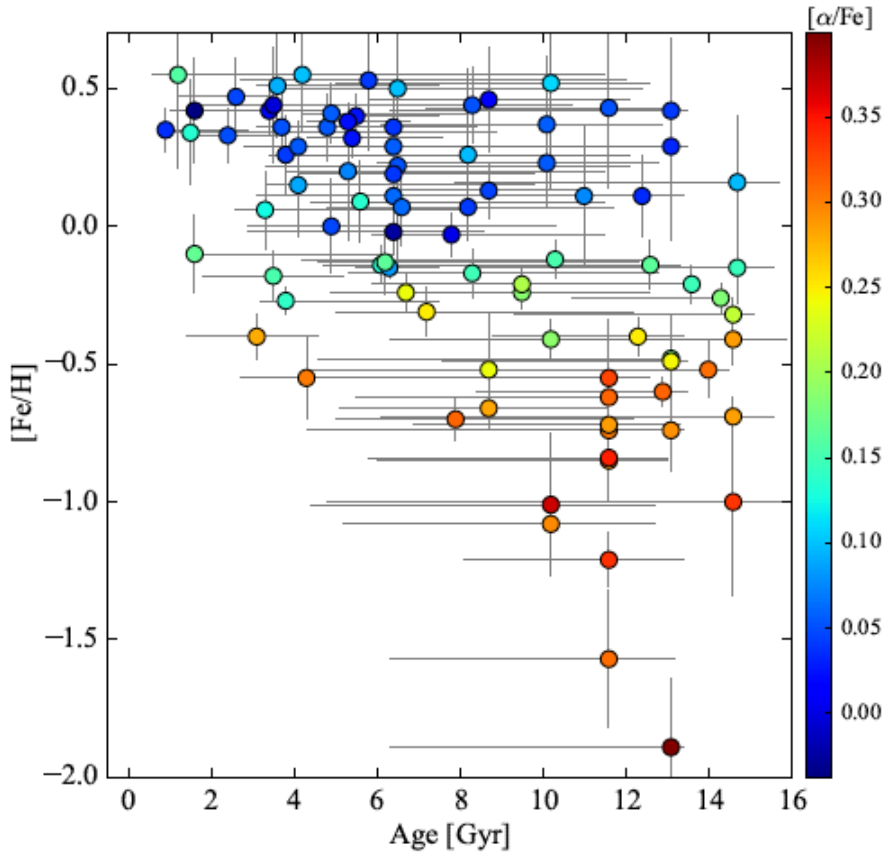


Fig. 13. Age versus [Fe/H] for the microlensed dwarf sample. The stars have been colour-coded according to their level of α-enhancement (as shown by the colour bar on the right-hand side).

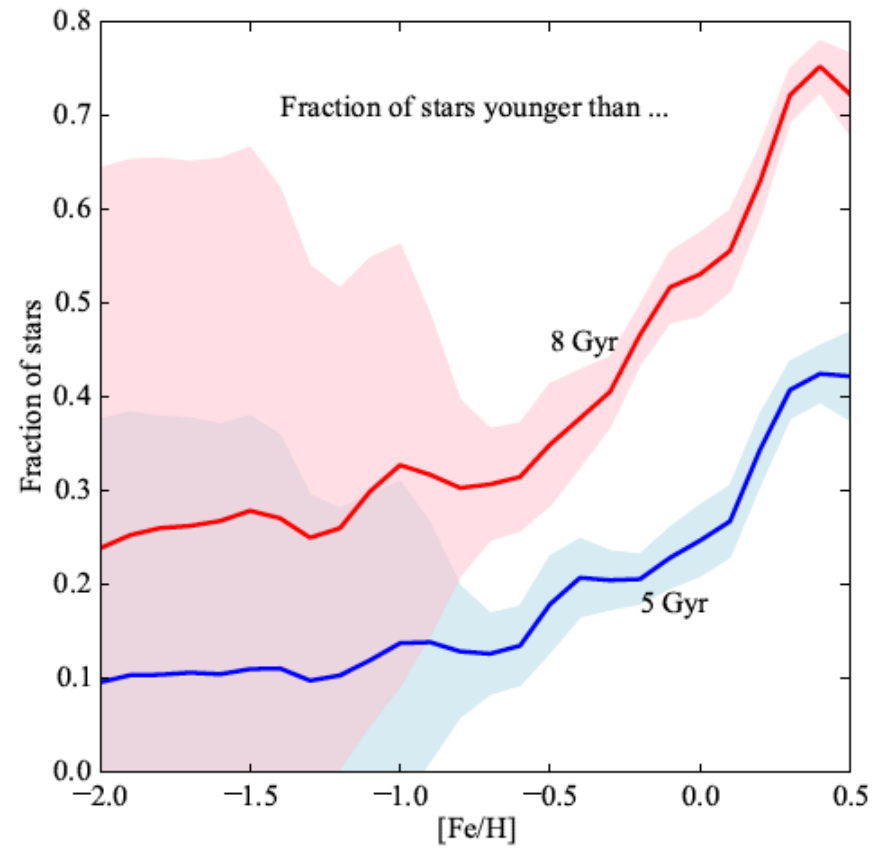
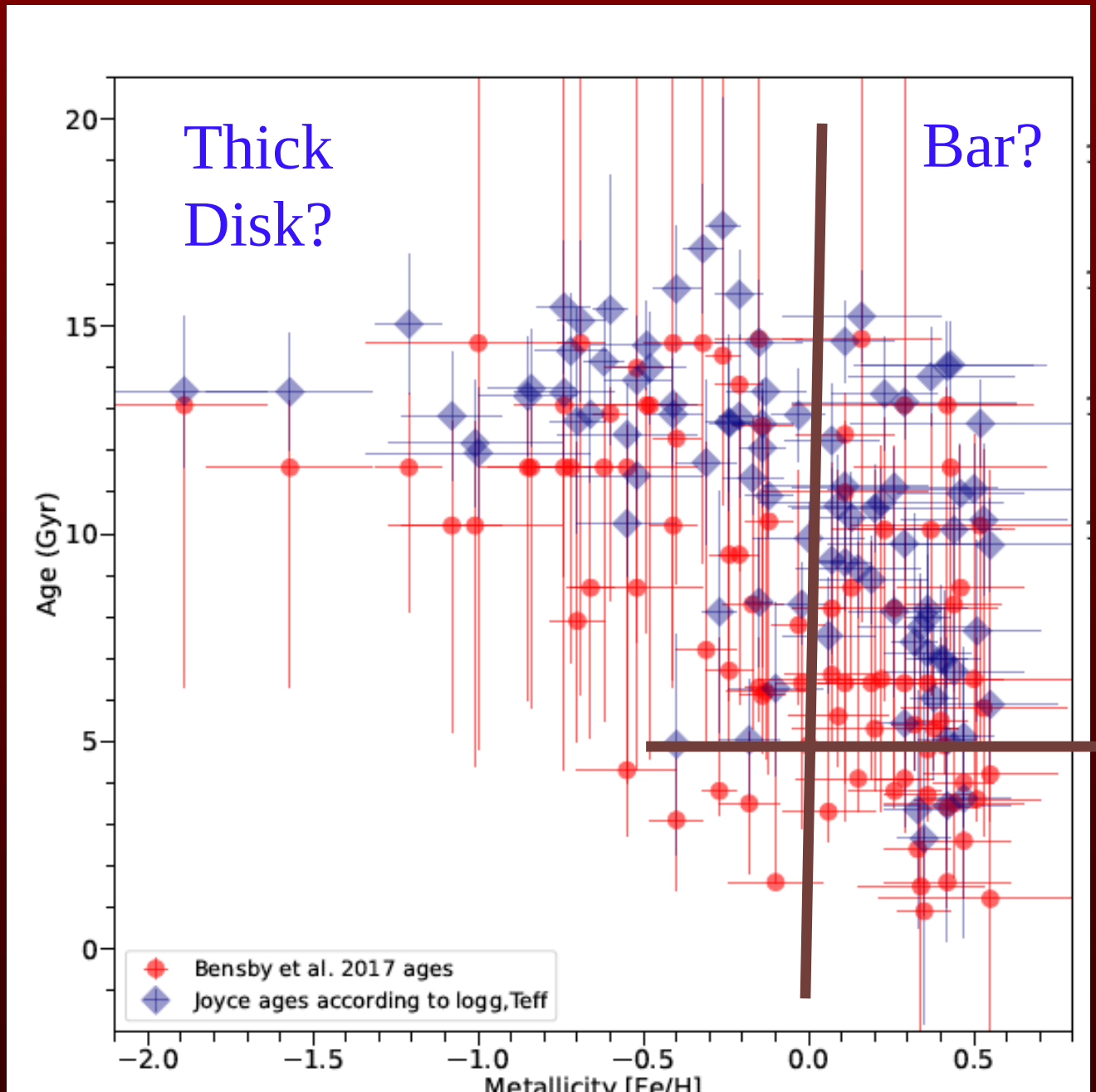


Fig. 14. The fraction of stars younger than 5 Gyr and 8 Gyr, respectively, at different metallicities. The thick blue and red lines represent the mean values from 10 000 age-metallicity distributions where individual ages and metallicities have been re-sampled using the [Fe/H] uncertainties and the individual 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 function (see Appendix C). For each sample of 90 stars the fraction

Joyce, Johnson, Marchetti, Rich et al. 2023



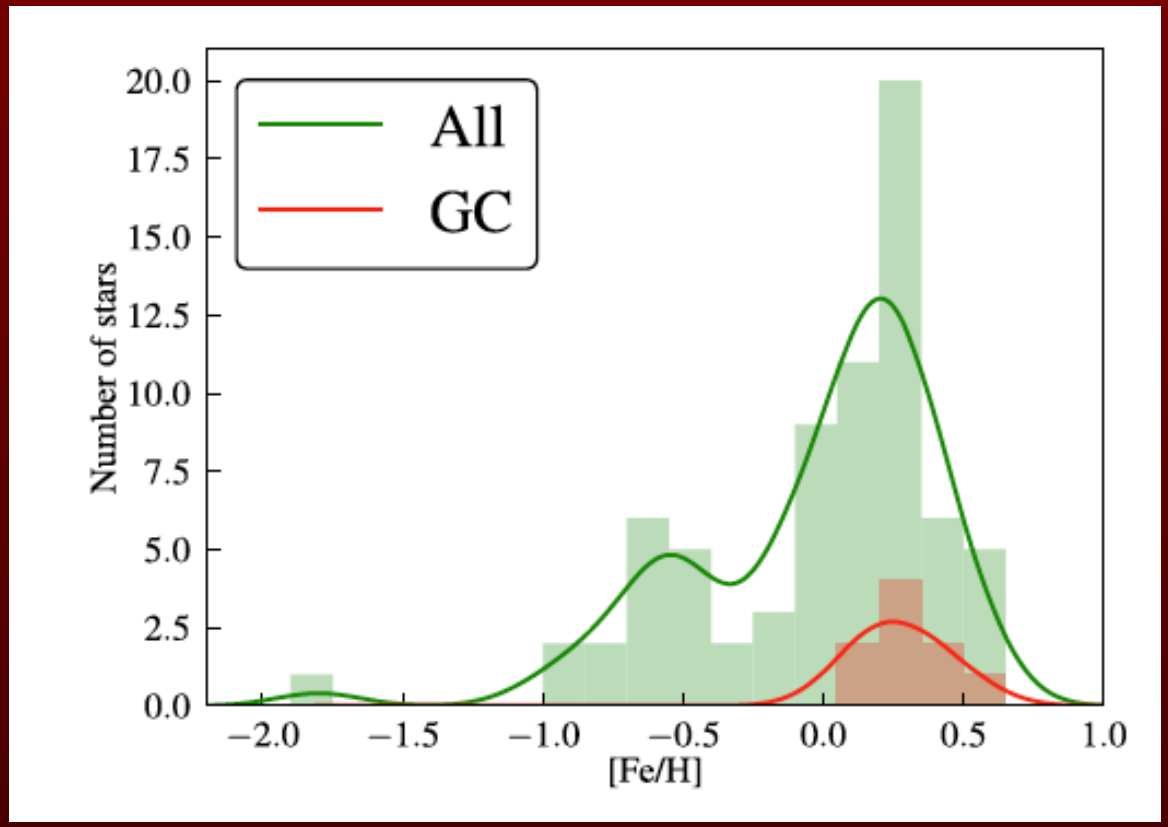
Ages:

New Result:

We find very few stars < 5 Gyr

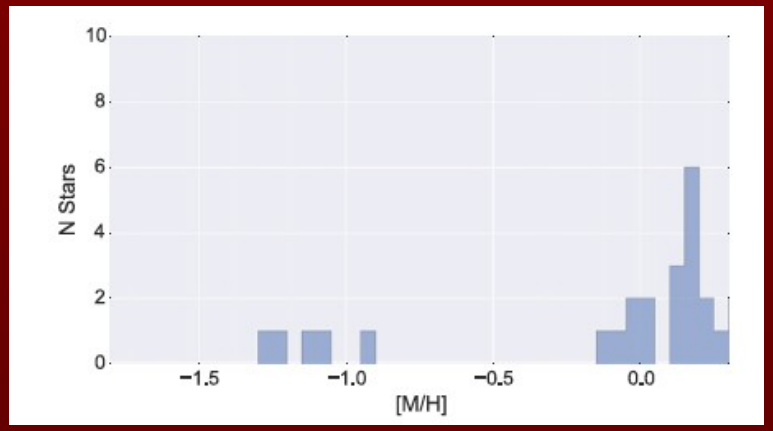
10+/-3 Gyr

Compare to bulge at ~100pc



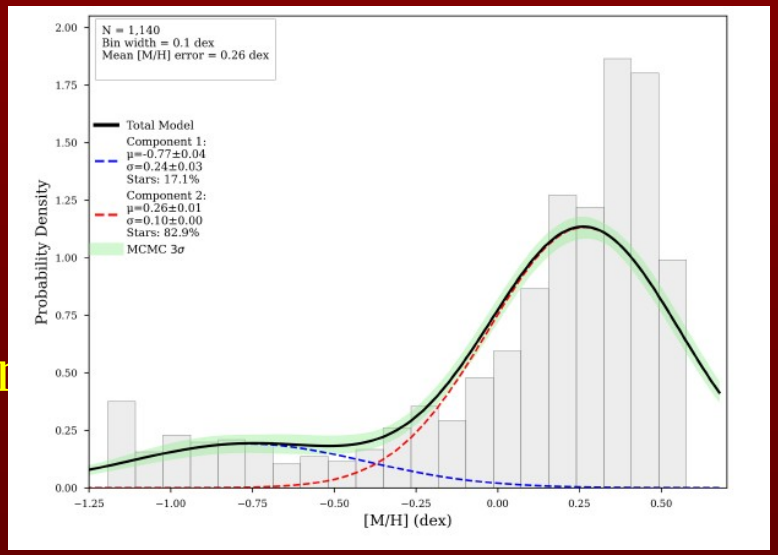
Nandakumar et al. 18, 22

Relating the nucleus to the bulge



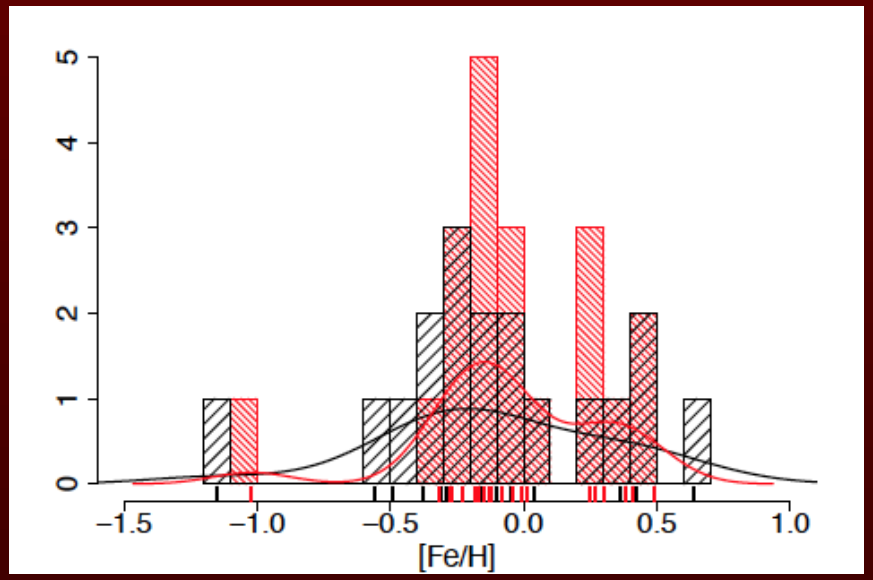
Do+2015

Metal poor
metal rich



Schultheis et al. 2026

Nucleus has an old population (RR ab stars) < 18% (Hui, Schodel+2017)

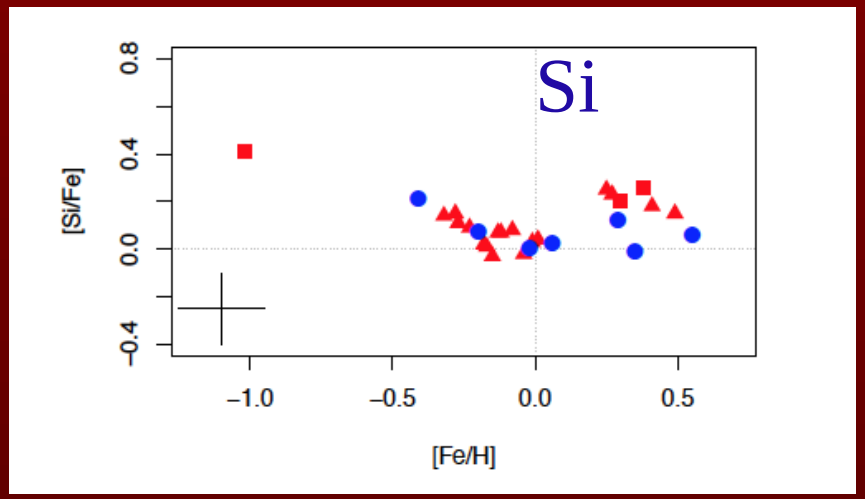


Rich+2017 highres
Thorsbro+2020

Bayesian Modeling gives age 5+/- 3 Gyr Chen,Do+22

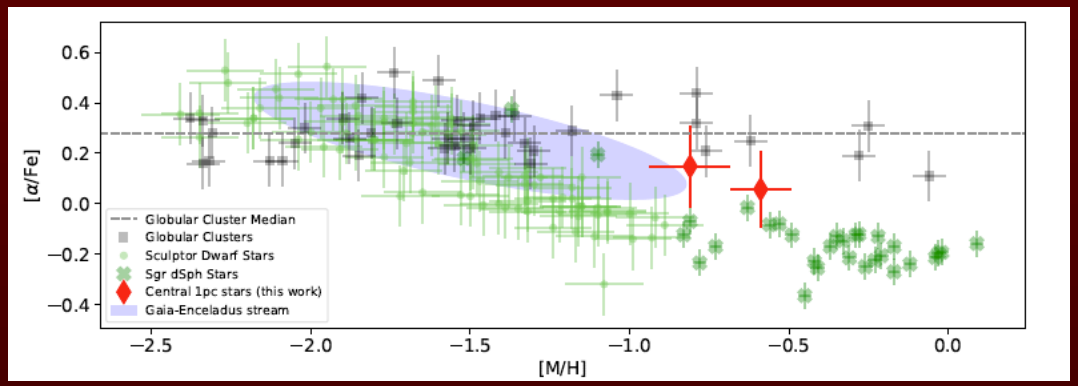
Composition inner po

High alphas (Type II Sne)



Thorsbro et al. 2020

.. Other bulge surveys find no evidence for dSph contribution Johnson+2014



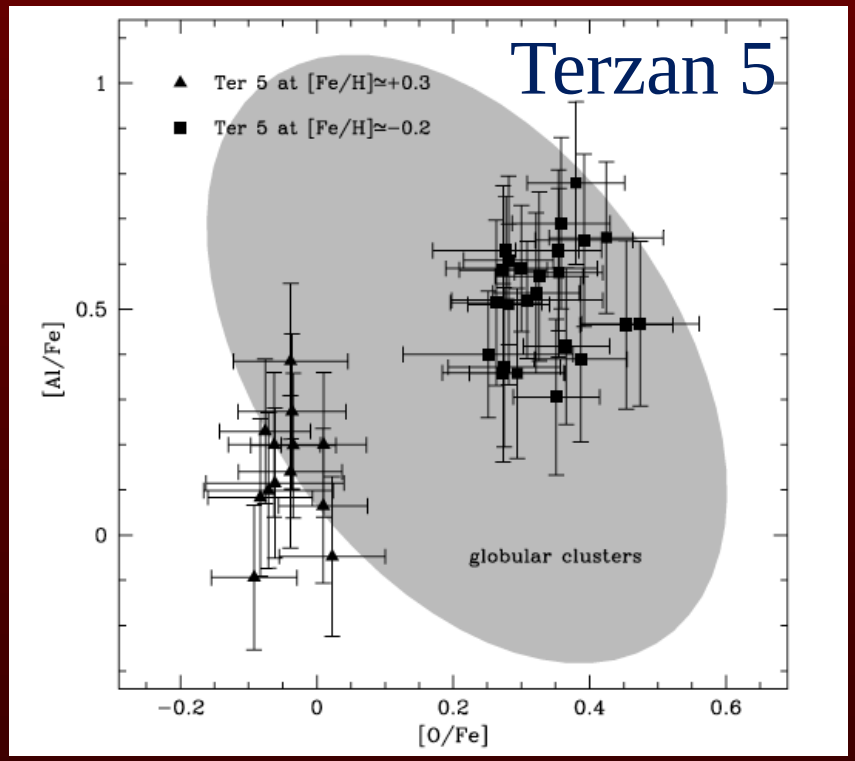
Bentley et al. 2023 dSph stars?

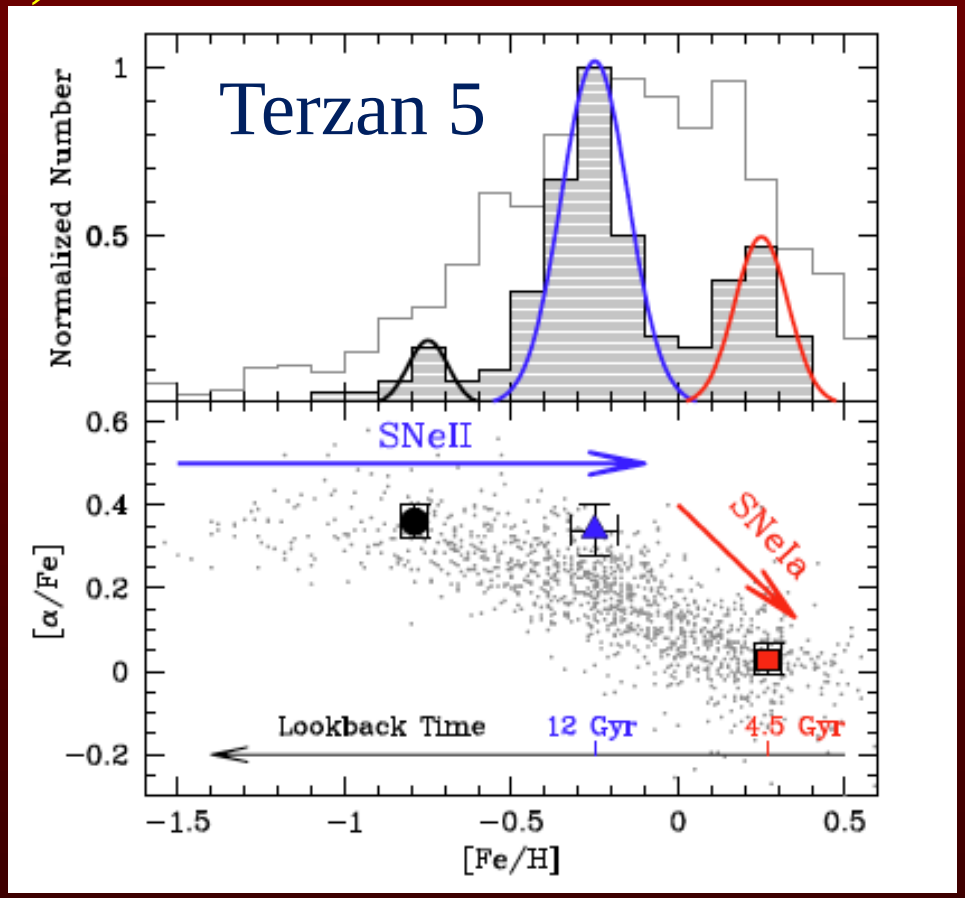
Is the central cluster a remnant "building block"?

Massive Clusters as 10^9 Msun "bulge building blocks"?
that are ~10^7 Msun today NO IMBH CONFIRMED IN ANY GAL CLUSTER

Terzan 5, Liller 1 - Both ~ 10^6 Msun Both have age, abundance ranges!
NSC is ~6e6 Msun (Fritz et al. 2014)

M31-G1 2e4Msun IMBH



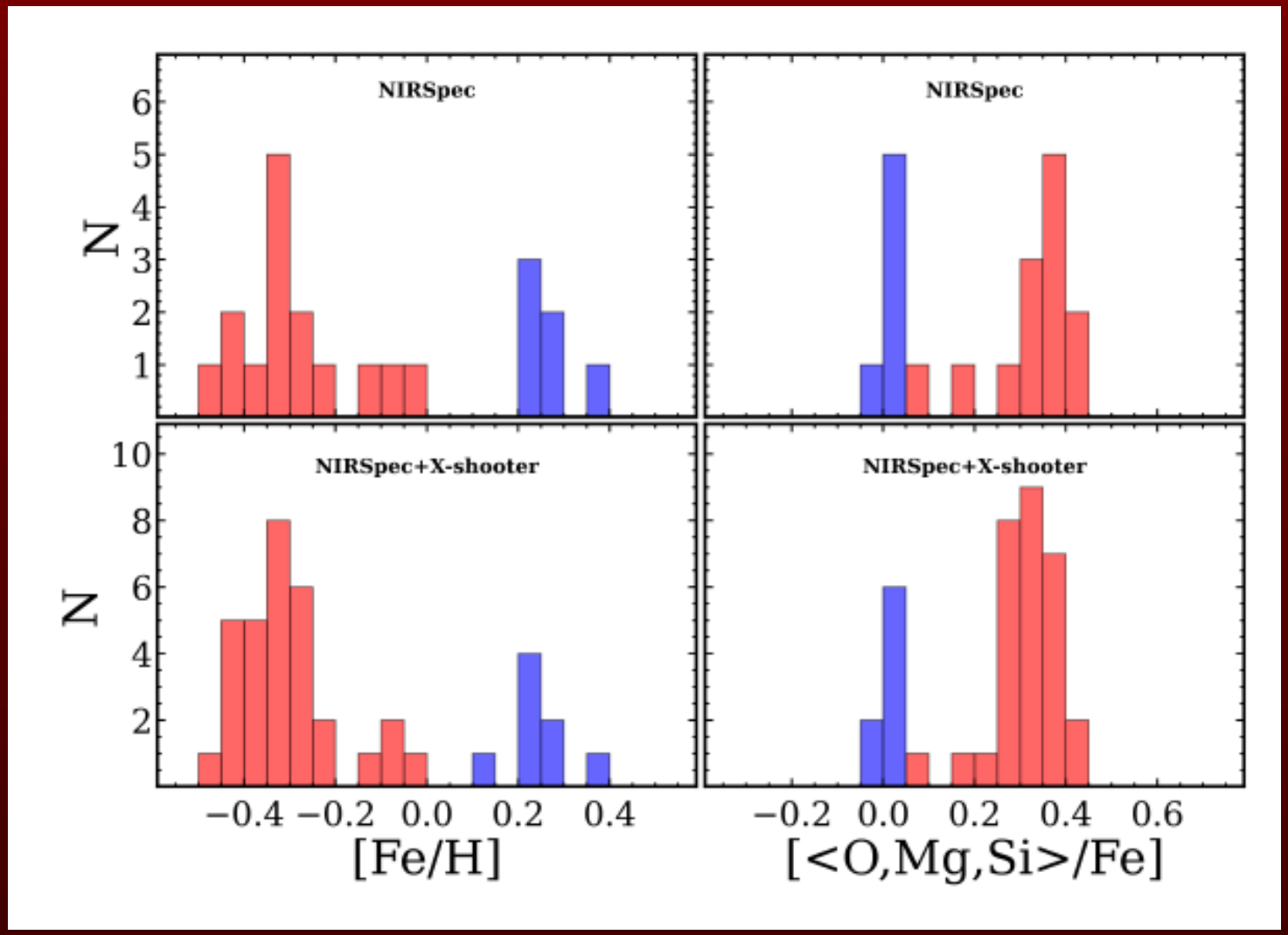


Origlia, Rich +11

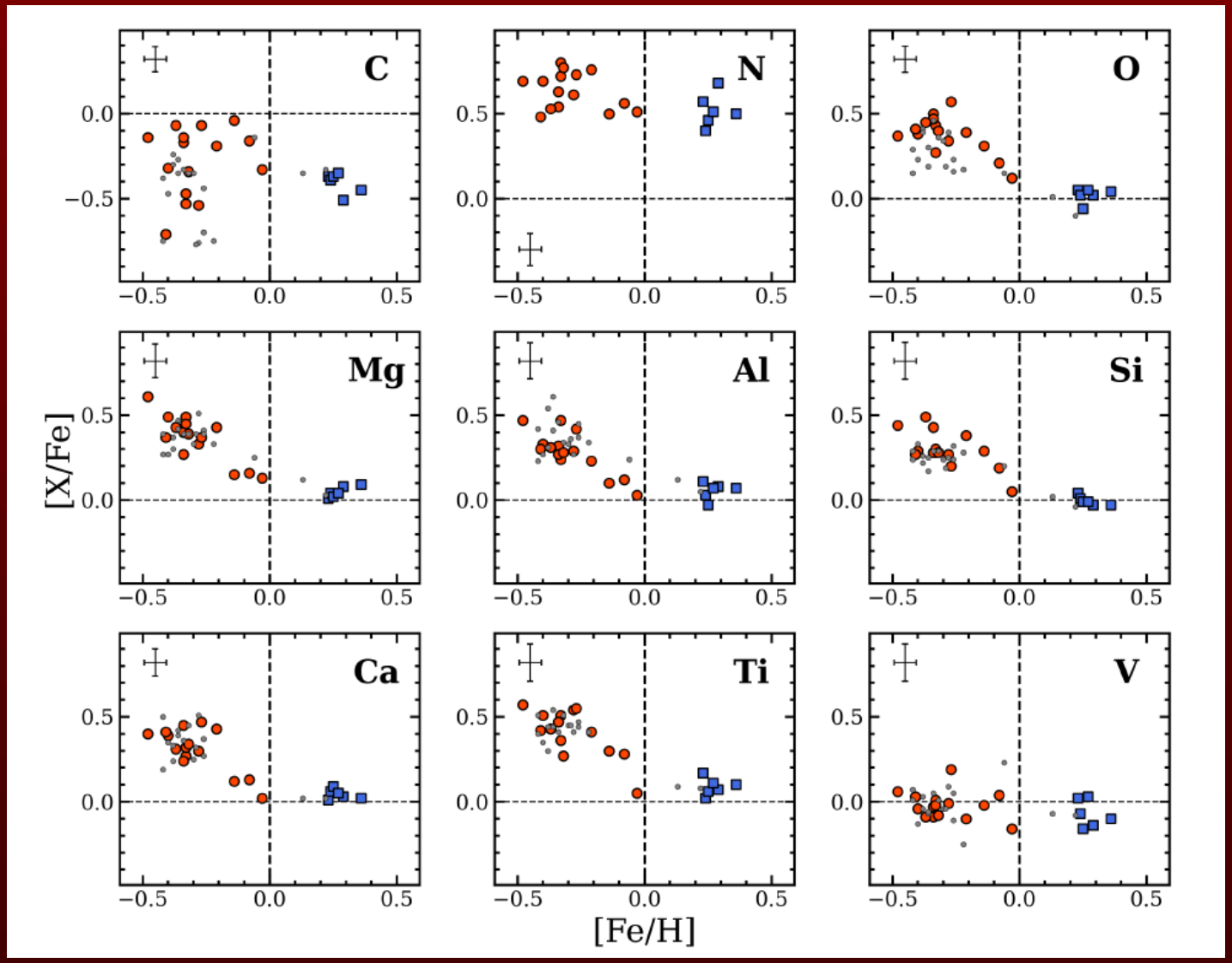
Ferraro+2016

Liller 1

Fanelli et al. 2024 A&A

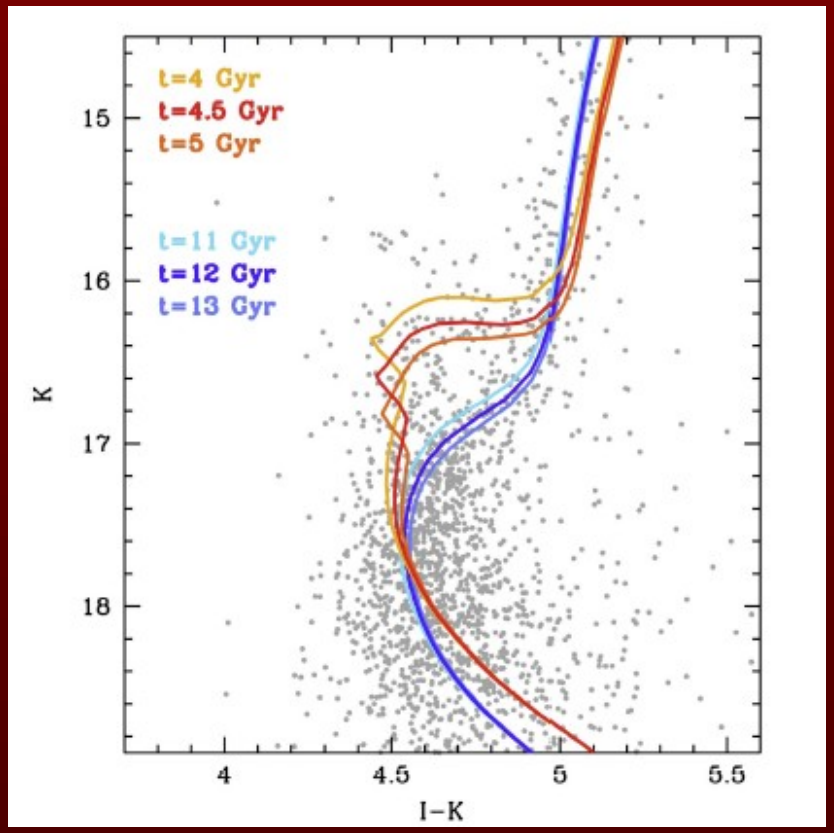


Liller 1 abundance trends



Age, abundance range

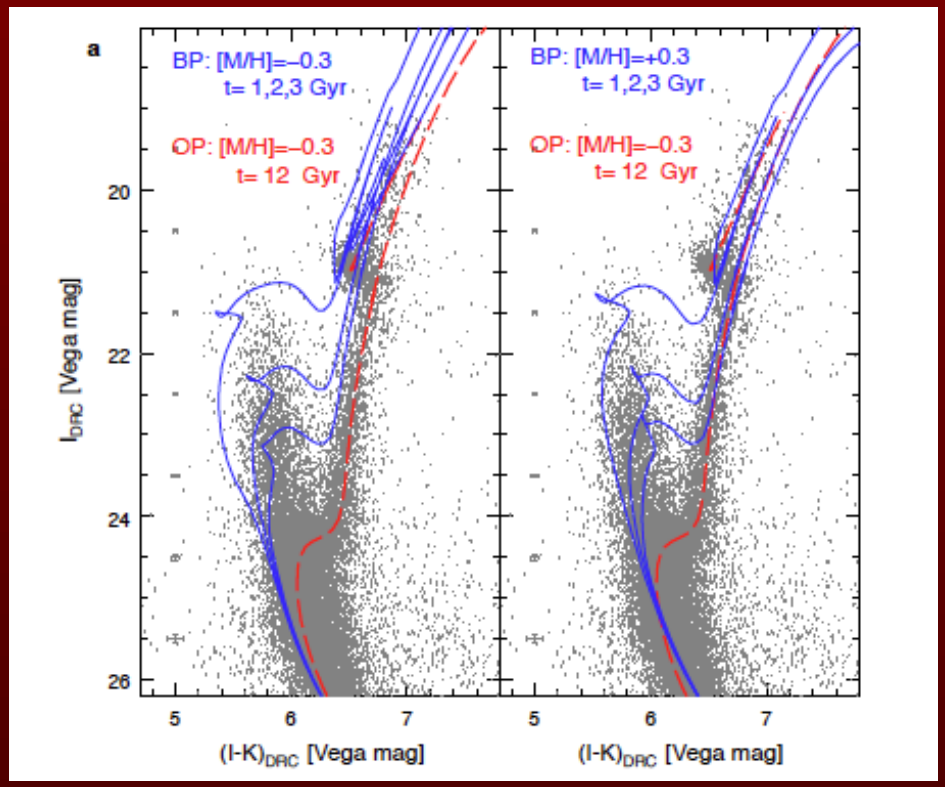
Terzan 5



Ferraro+2016

2e6 Msun, 34 msec pulsars

Liller 1



Ferraro+ 2020, 2023

2e6 Msun

Origin of the NSC still unclear

Clear bursts of SF

HST+JWST data- Ter 5

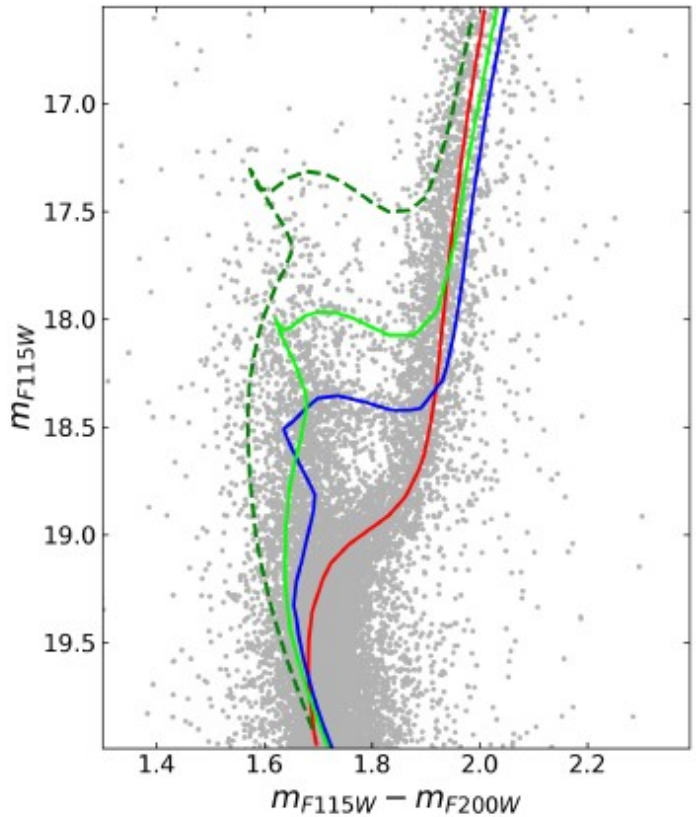
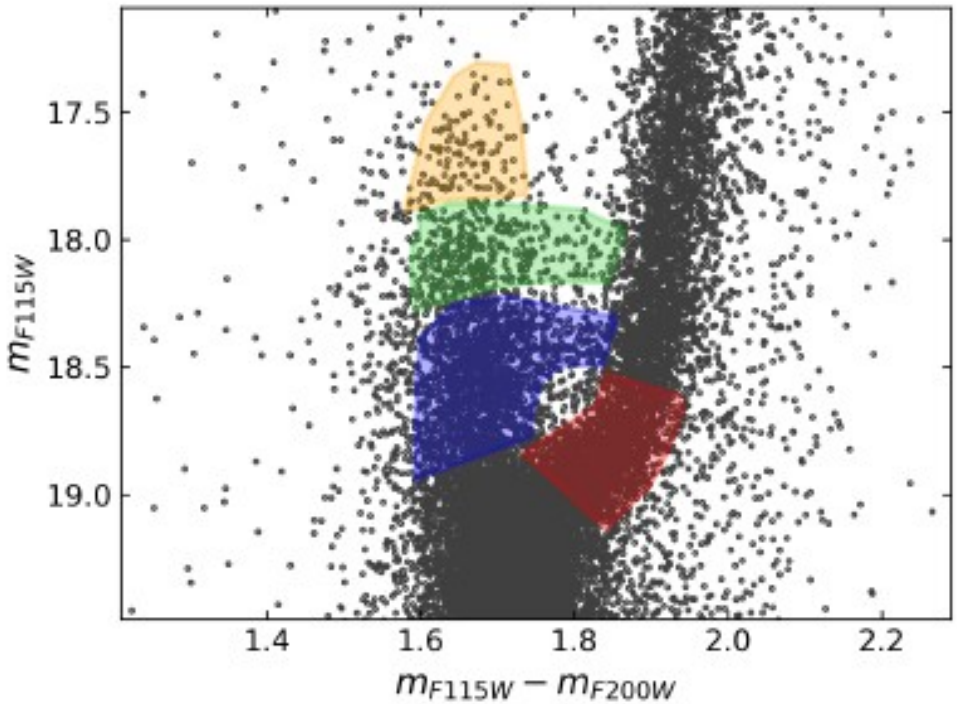


Fig. 10: NIR CMD of Terzan 5 as in Fig. 9, with the solid lines tracing the 12.5, 4.7, and 3.8 Gyr old sub-populations discussed in text (red, blue, and green color, respectively), and the dashed line corresponding to an isochrone of just the 2.5 Gyr, which is needed to encompass the entire extension of the blue plume.



Discovery of a young Population in Ter 5

Zullo et al. 2026 A&A in prep

Origin of Nuclear Star Cluster?

Intrinsic origin is unlikely because of difficulty forming stars near Sgr A*

An abundance gradient, if confirmed, might favor an intrinsic origin

Elevated alphas seen nowhere else also would favor intrinsic

“Building block” clusters have age, abundance range – attractive option

NSC, NSD may be dominated by older stars (see Nogueres Lara et al, poster by Salvo Guajardo this meeting

Conclusions

The abundance distribution of the central pc is similar to the bulge and inner bulge

But, NSC may have elevated alphas at high Fe/H-not seen elsewhere (see also Nishiyama, Thorsbro this meeting)

Need very precise [Fe/H], composition, age for NSC stars

Similarities, differences vs. Ter 5, Liller 1 but <u>no BH in any other cluster</u>

<u>Many aspects of SgrA*- cluster remain unique</u>!