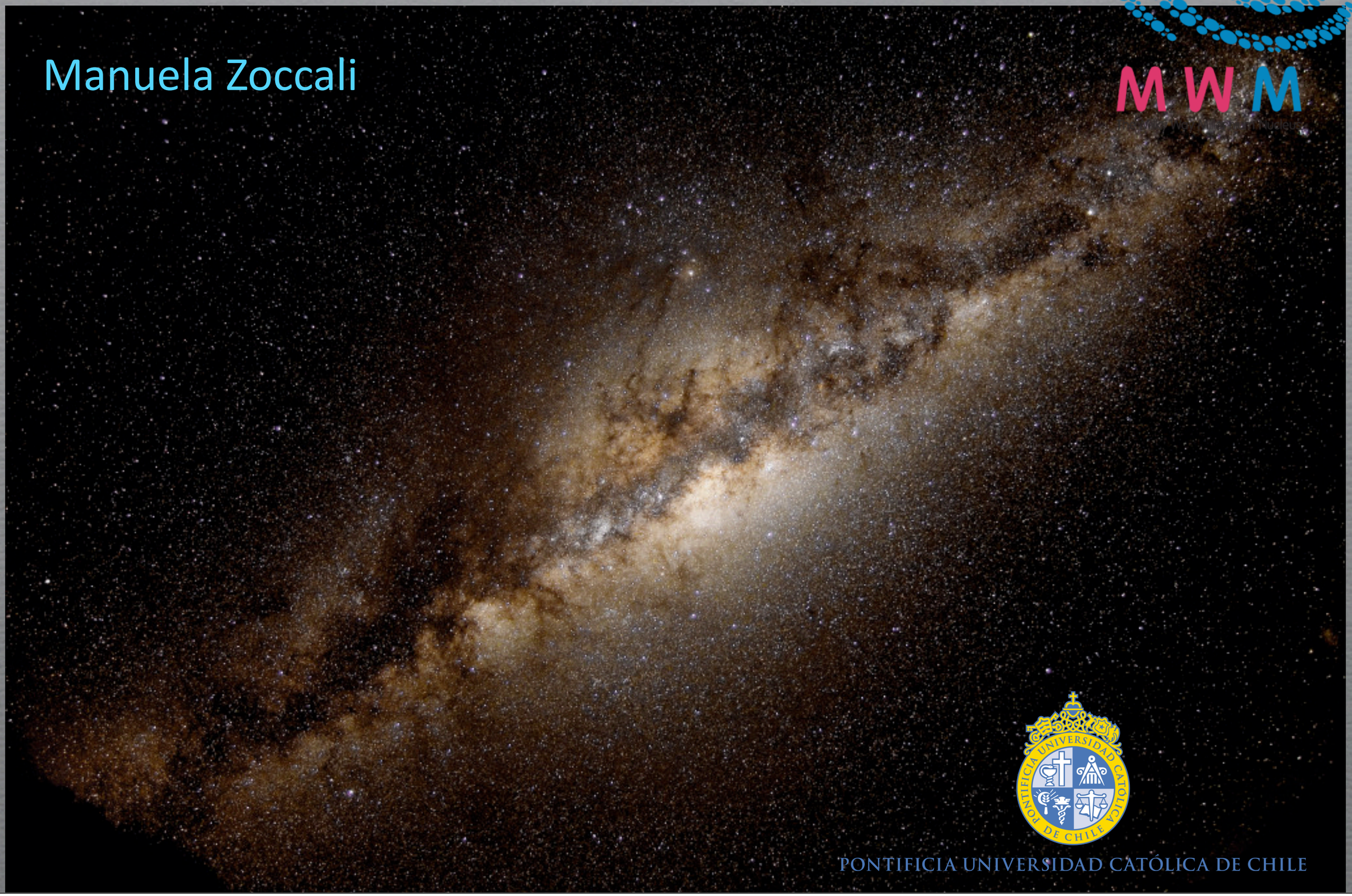
Chemical abundances in the Galactic bulge

Manuela Zoccali

MWM



PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

The question: How did the Milky Way form?
How do galaxies form?

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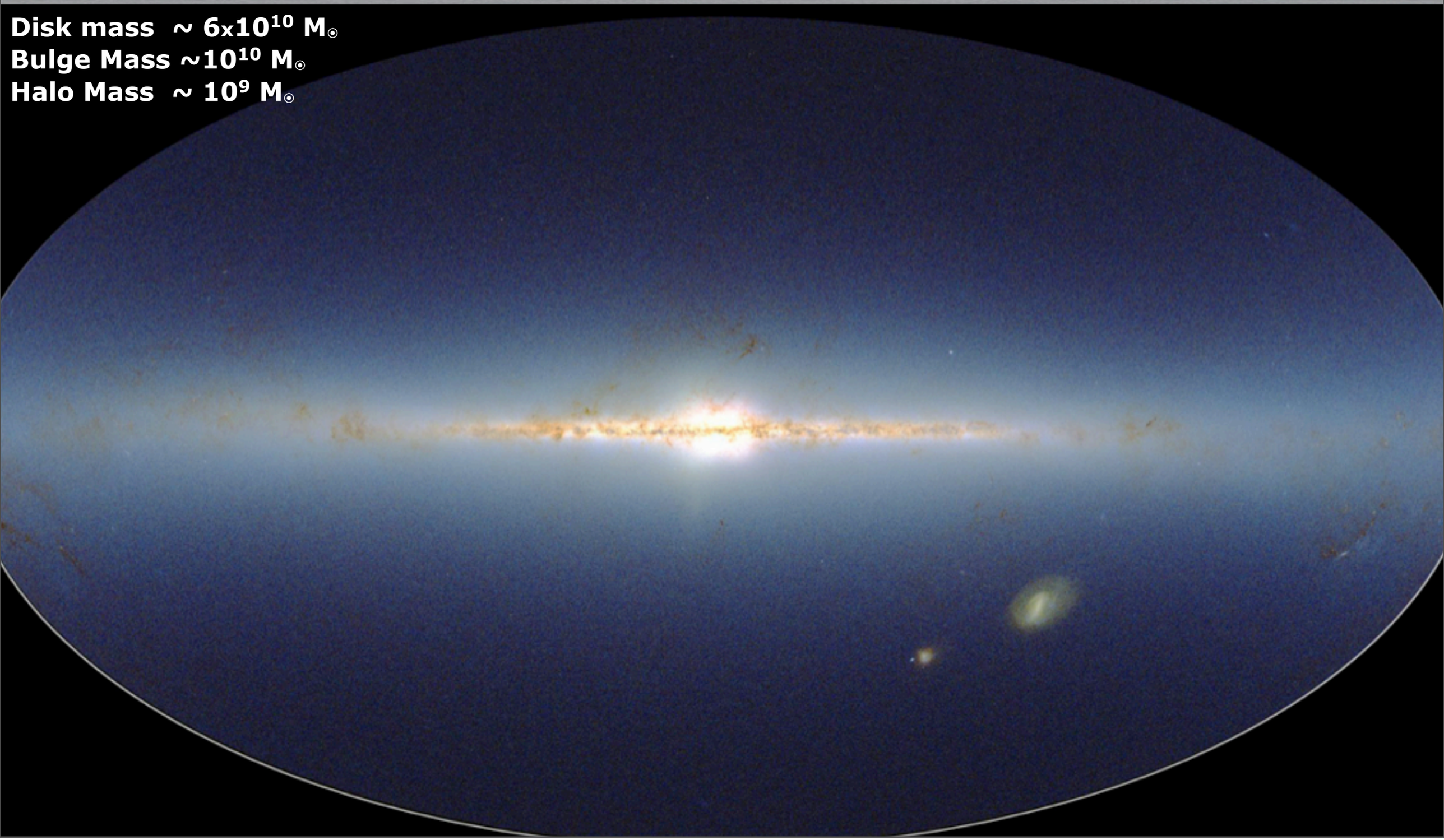
How do galaxies form?

the bulge is a massive (and old) component of the Milky Way

Disk mass ~ 6×10^{10} $M_\odot$
Bulge Mass ~10^{10} $M_\odot$
Halo Mass ~ 10^{9} $M_\odot$



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How do galaxies form?

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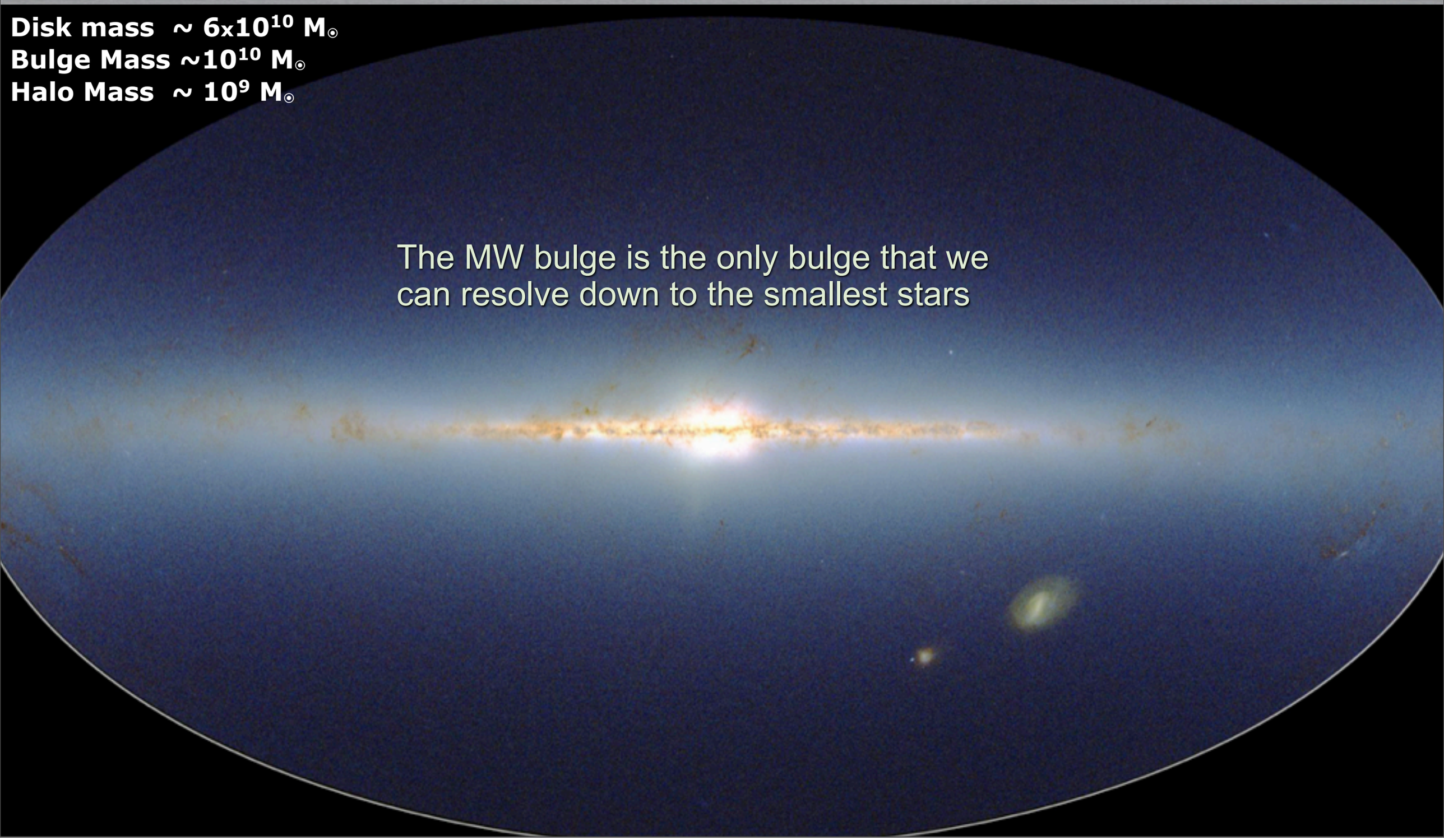
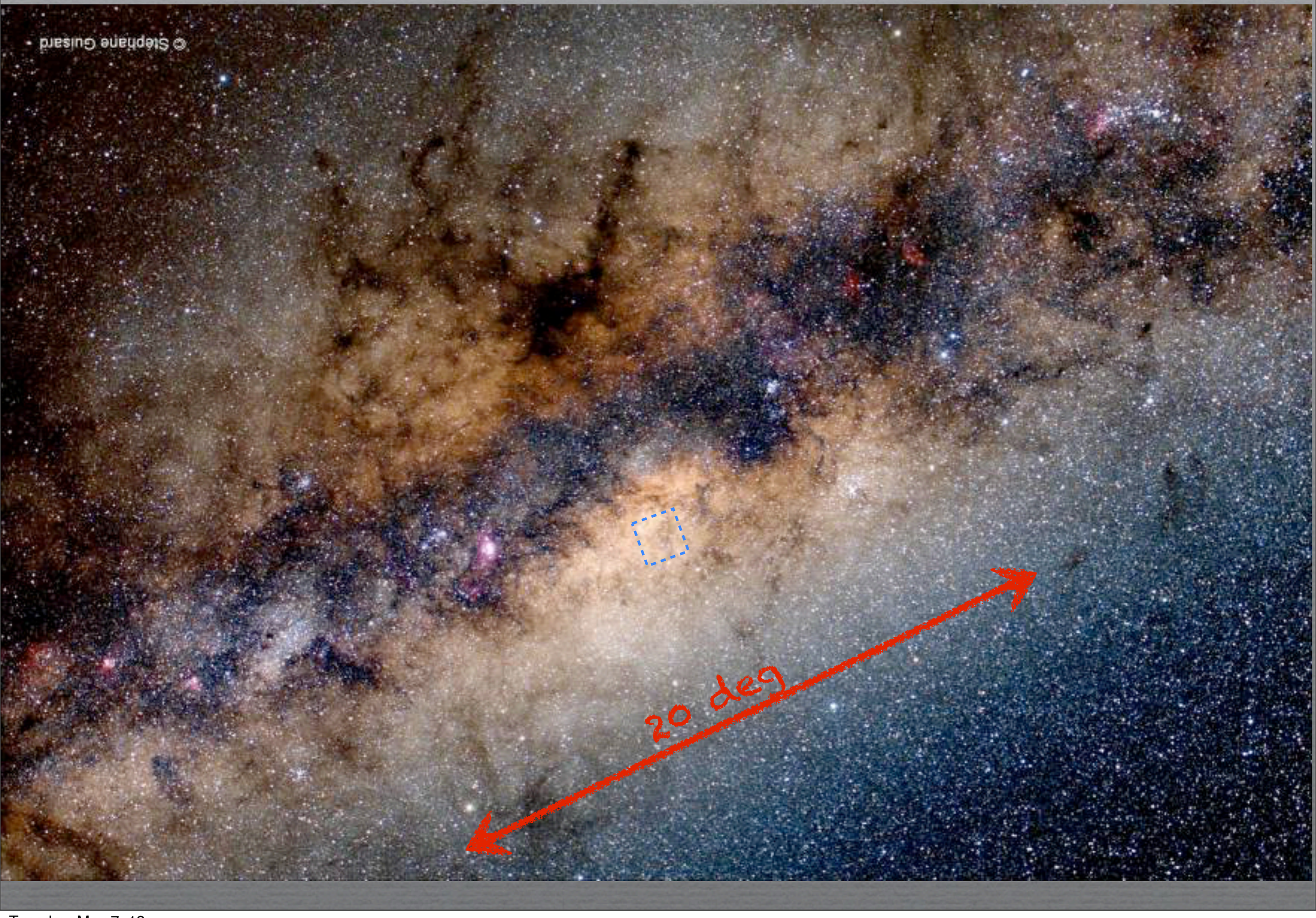
The MW bulge is the only bulge that we can resolve down to the smallest stars



The Galactic bulge



The question: How did the Milky Way form?
How do galaxies form?

The clues:

- The bulge structure and kinematics

  spheroid? bar? boxy? peanut?
  orbits help understanding where did stars came from

- The bulge age

  all stars coeval? age gradient?

- The bulge chemical content

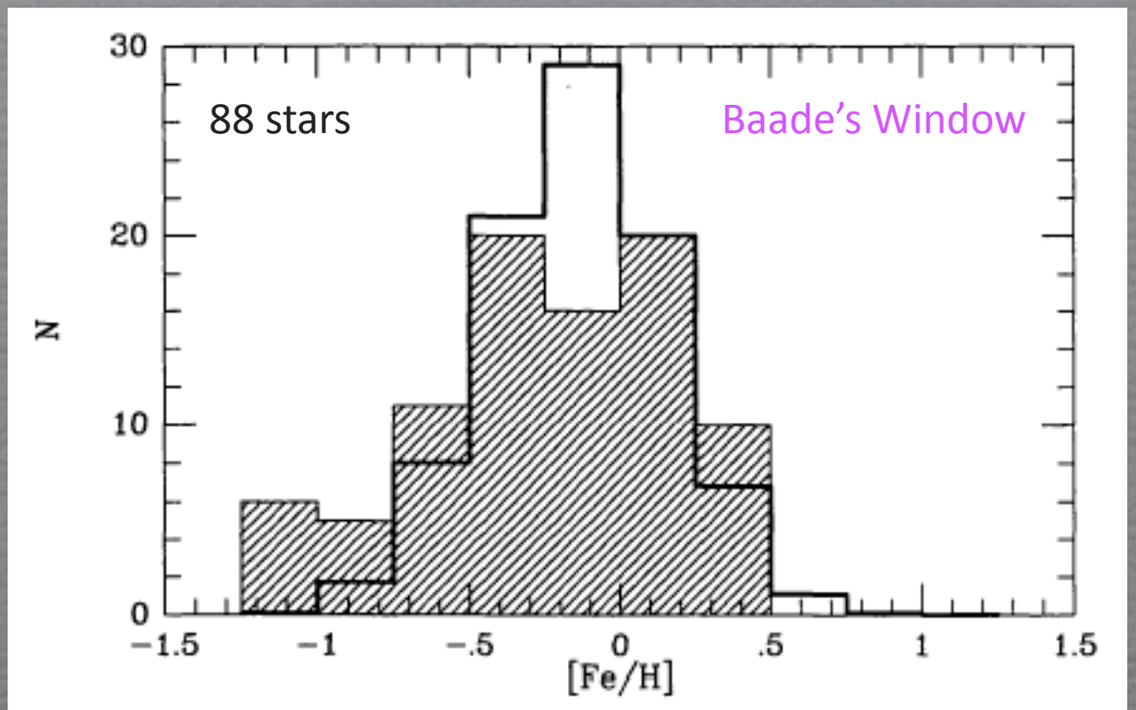
  metallicity distribution
  metallicity gradients
  kinematics and metallicity
  element ratios → formation timescale
  comparison with inner/outer thin/thick disk

Chemical abundances in the Galactic bulge

from high resolution spectra

McWilliam & Rich (1994)

11 calibrating stars at R=17,000



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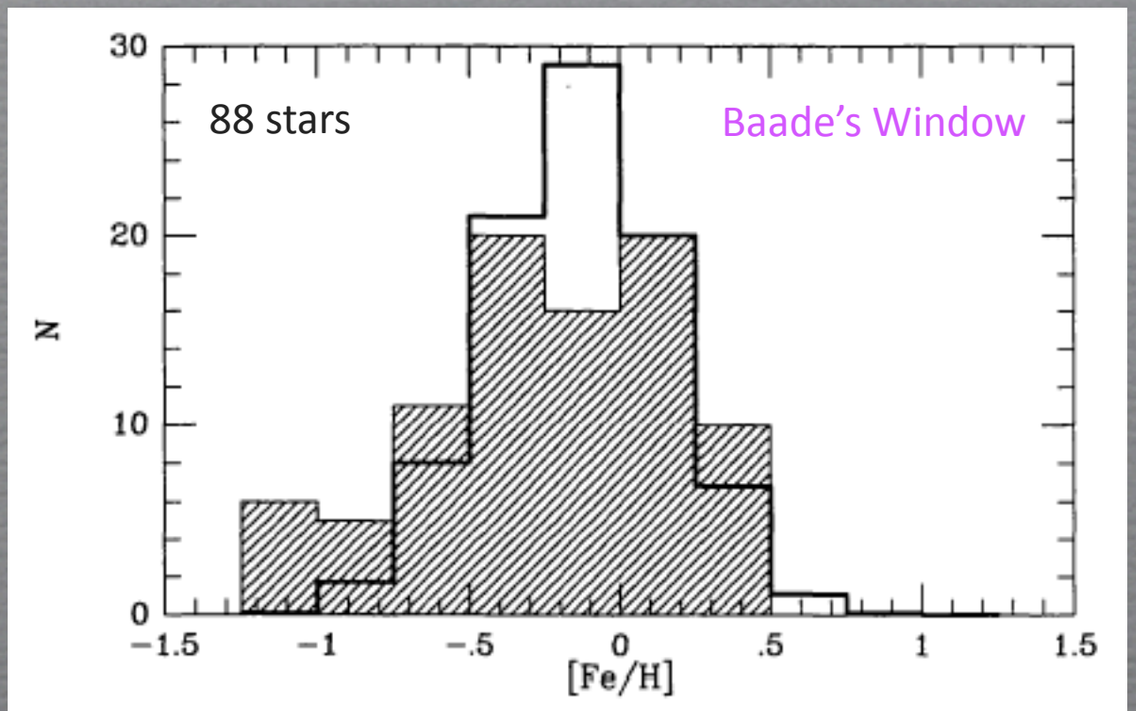
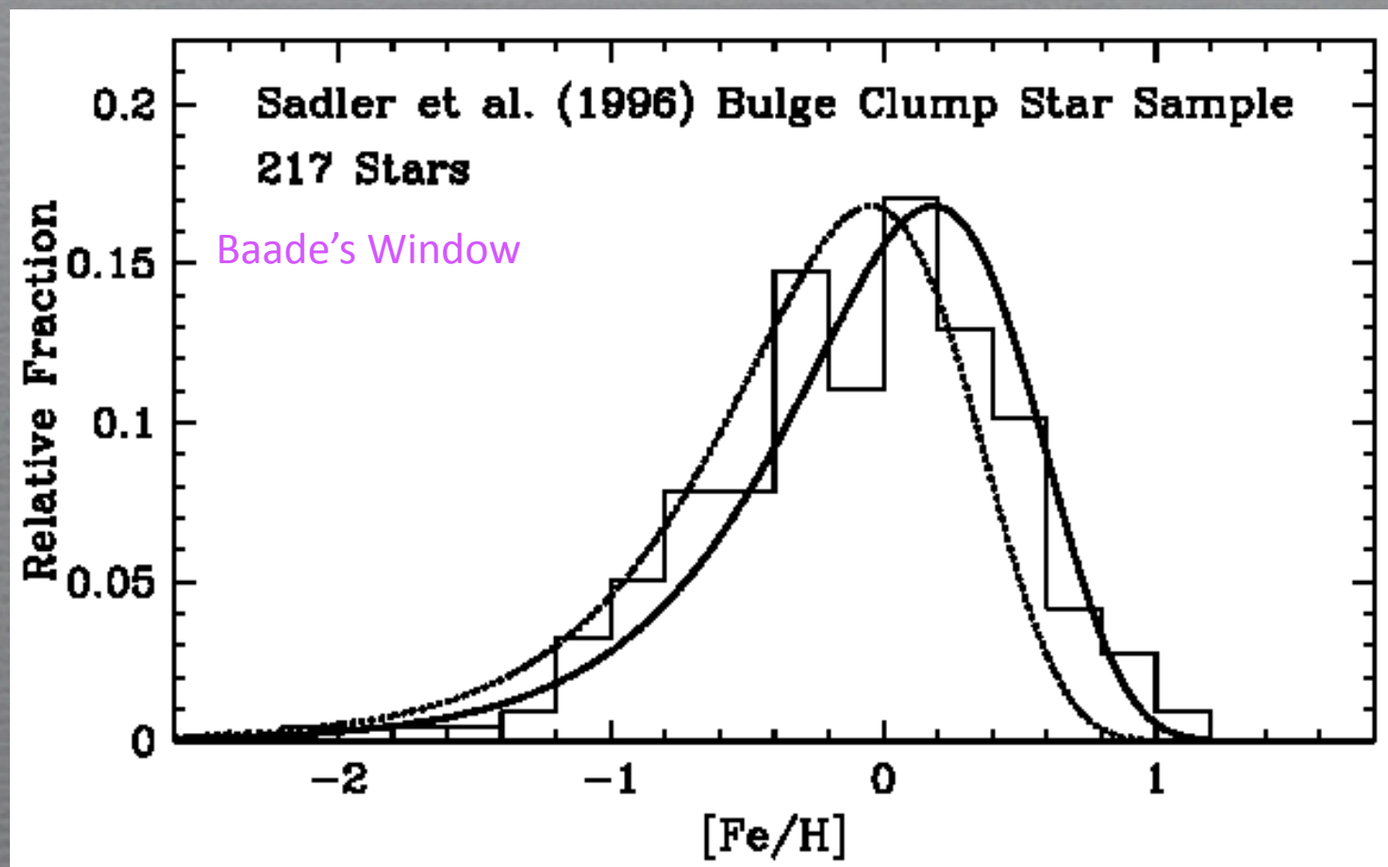


Fulbright et al. (2006)

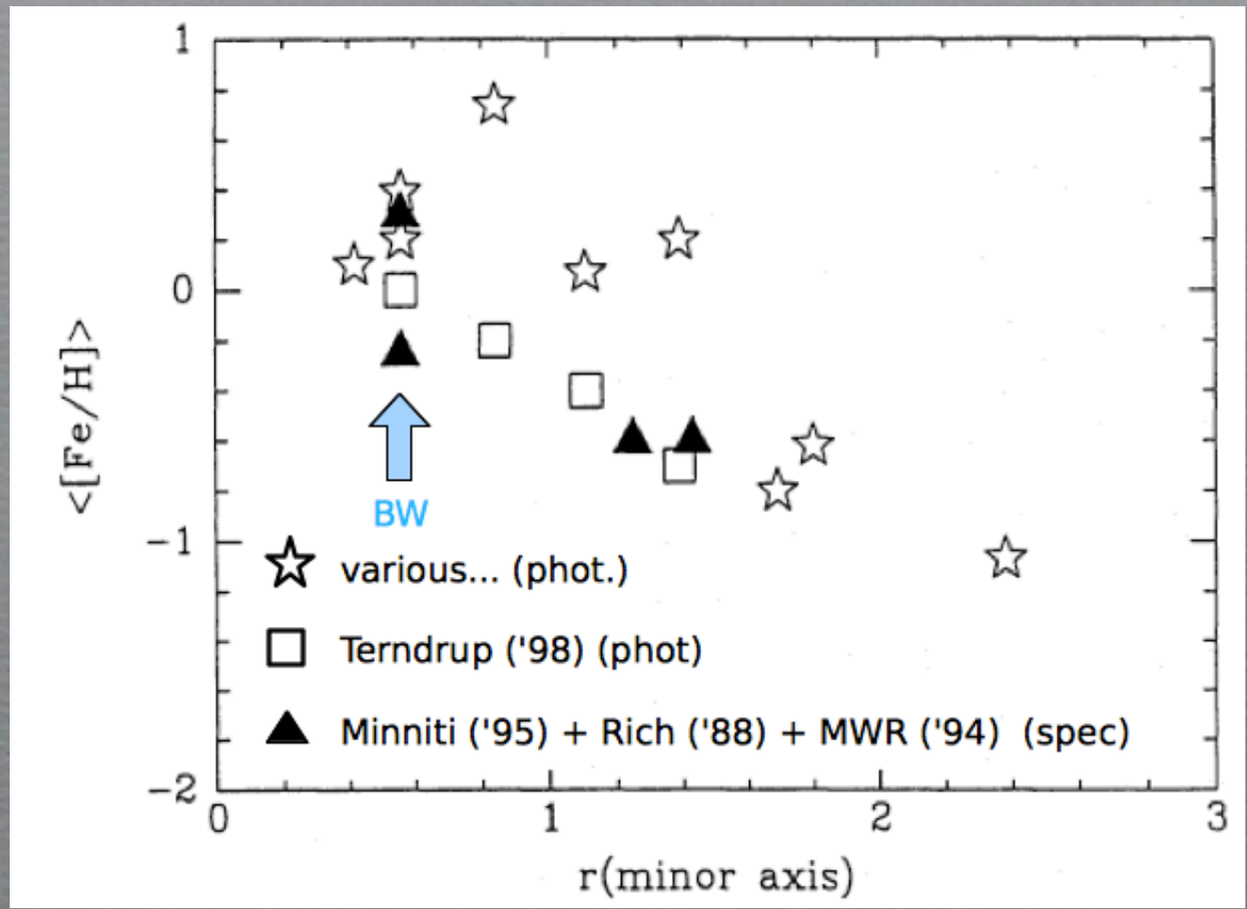
27 calibrating stars at R=60,000



radial metallicity gradients

physical intuition: radial gradient = dissipational collapse

Minniti et al. (1995)



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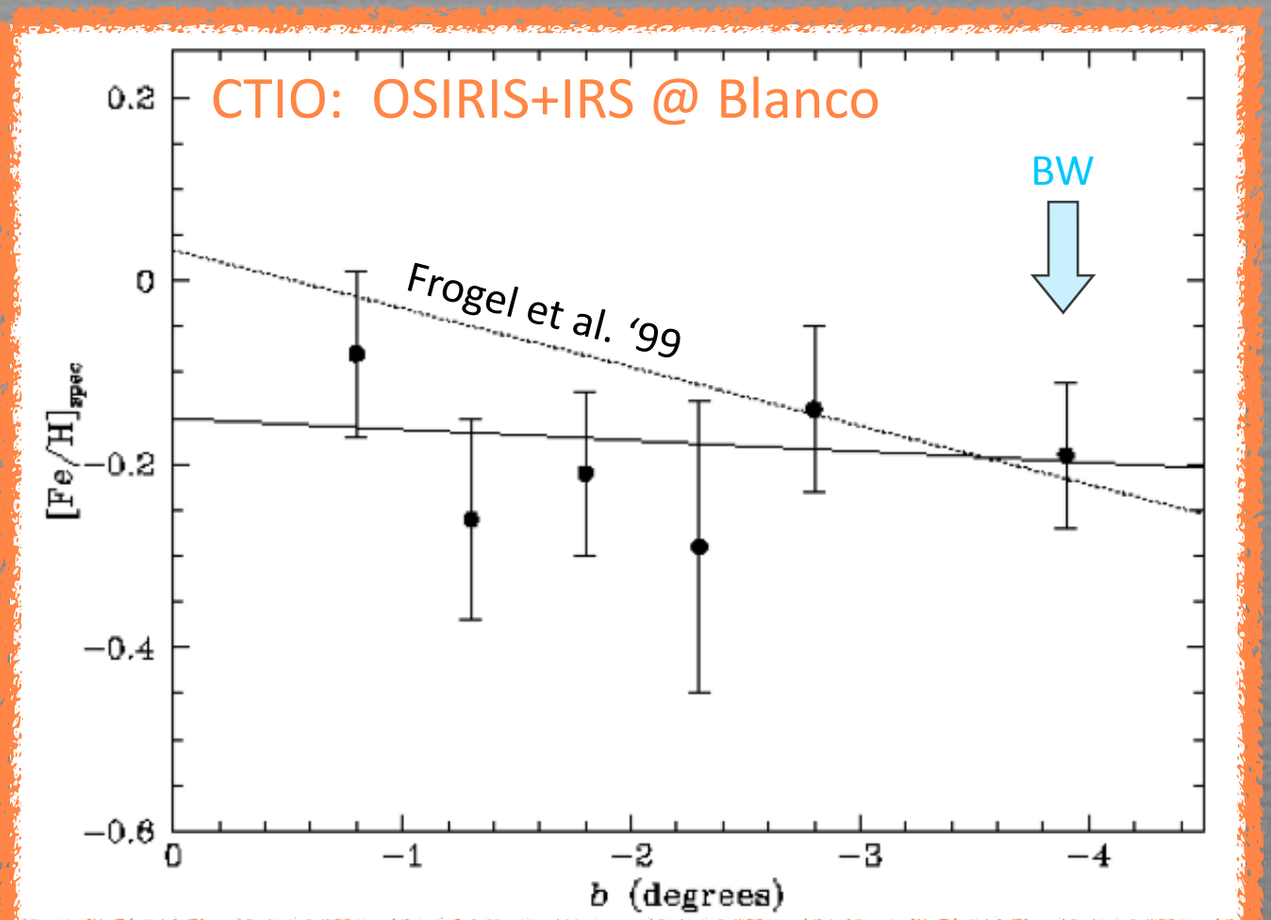
Ramírez et al. (2000)



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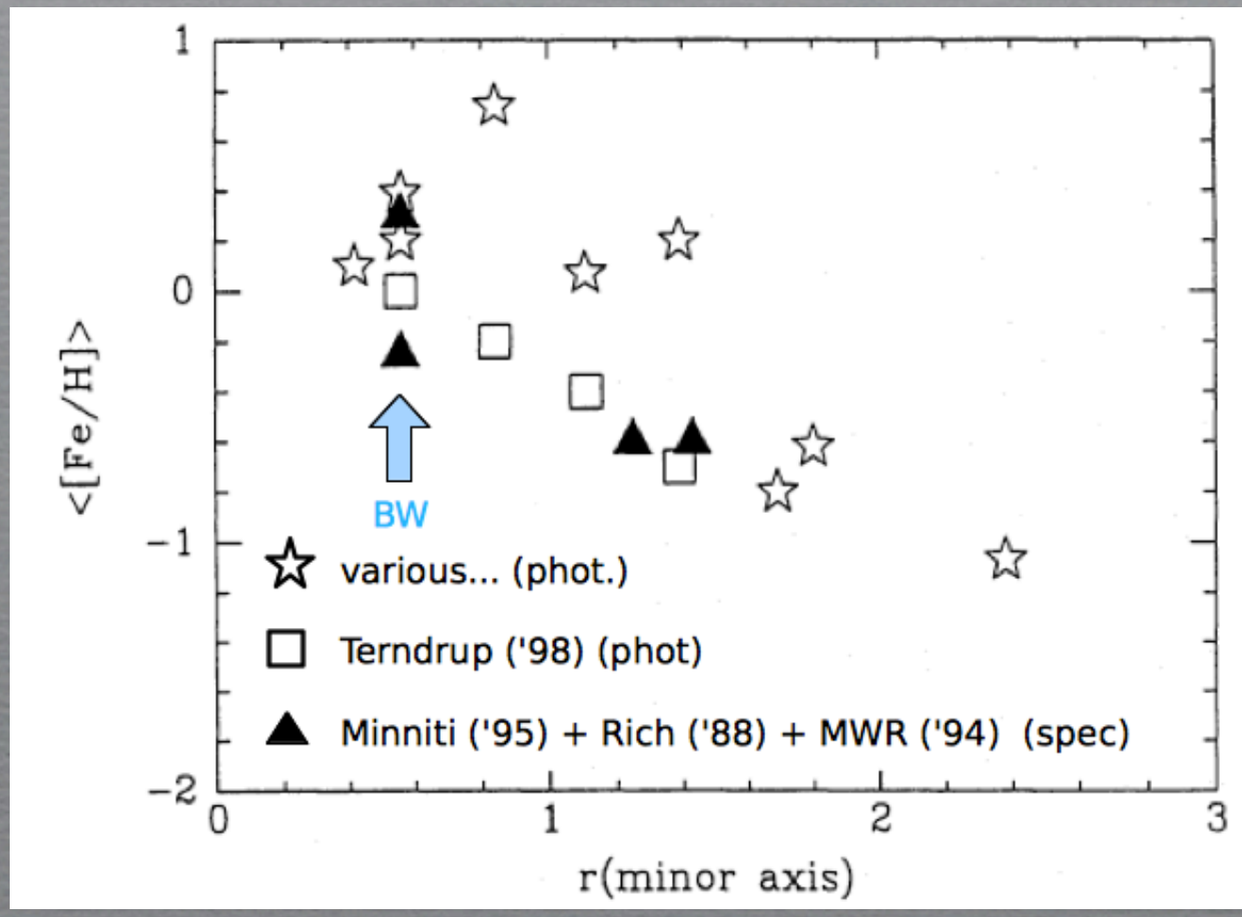
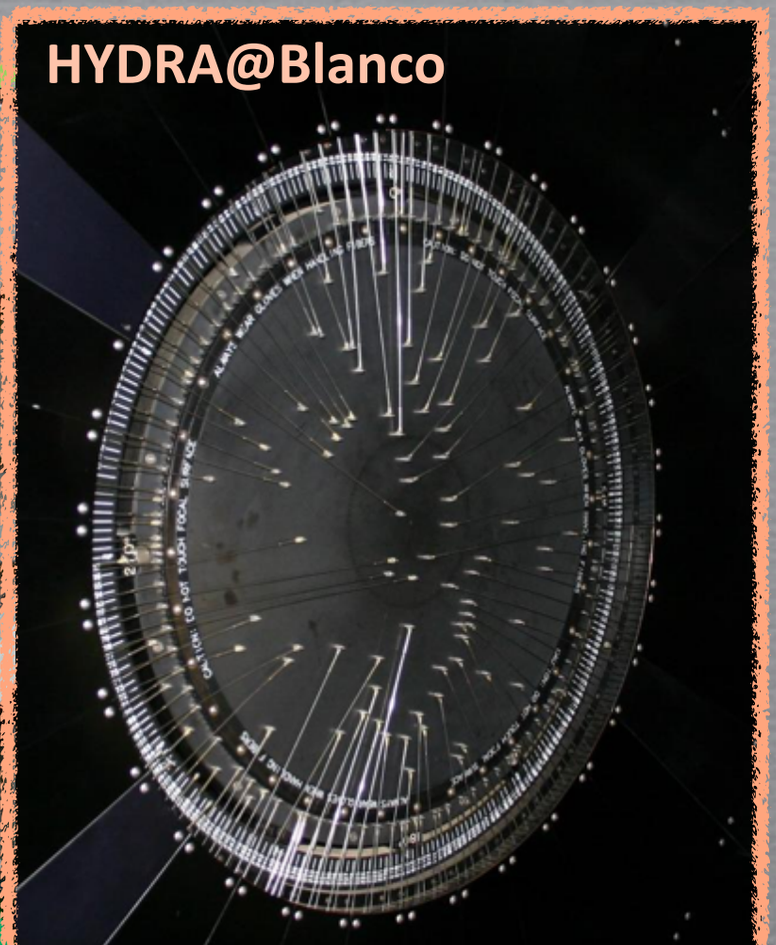


High-Res multi-fibre spectrographs

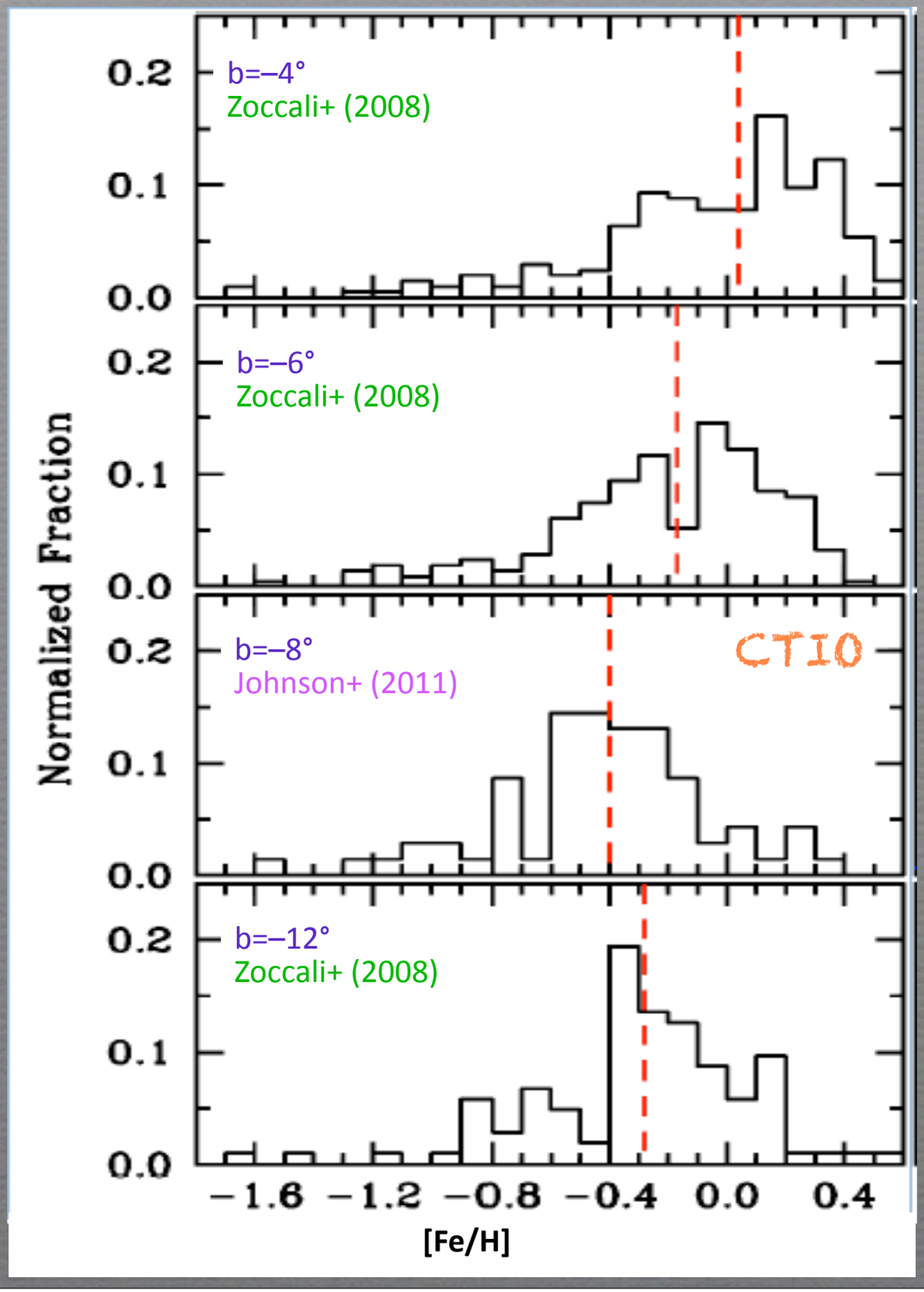
FLAMES@VLT

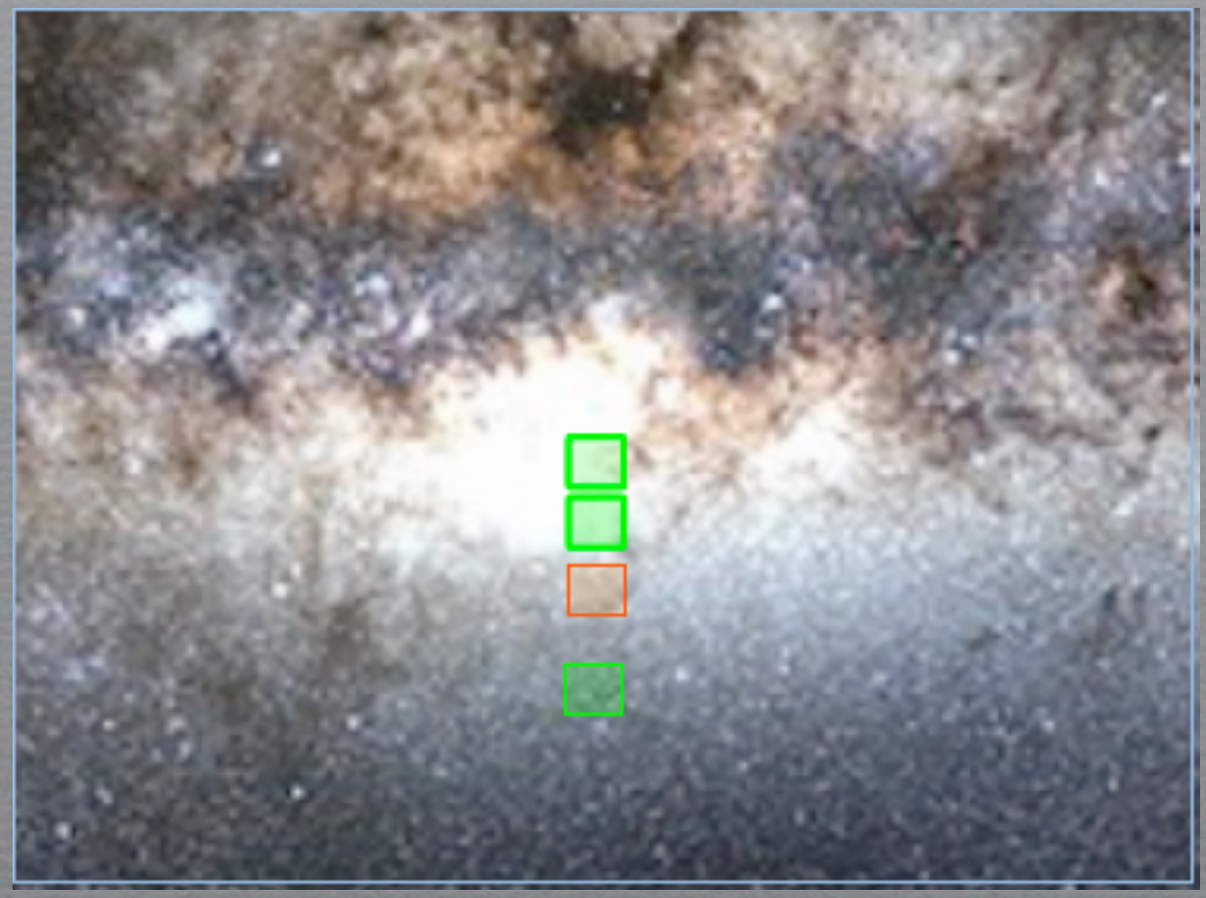
HYDRA@Blanco

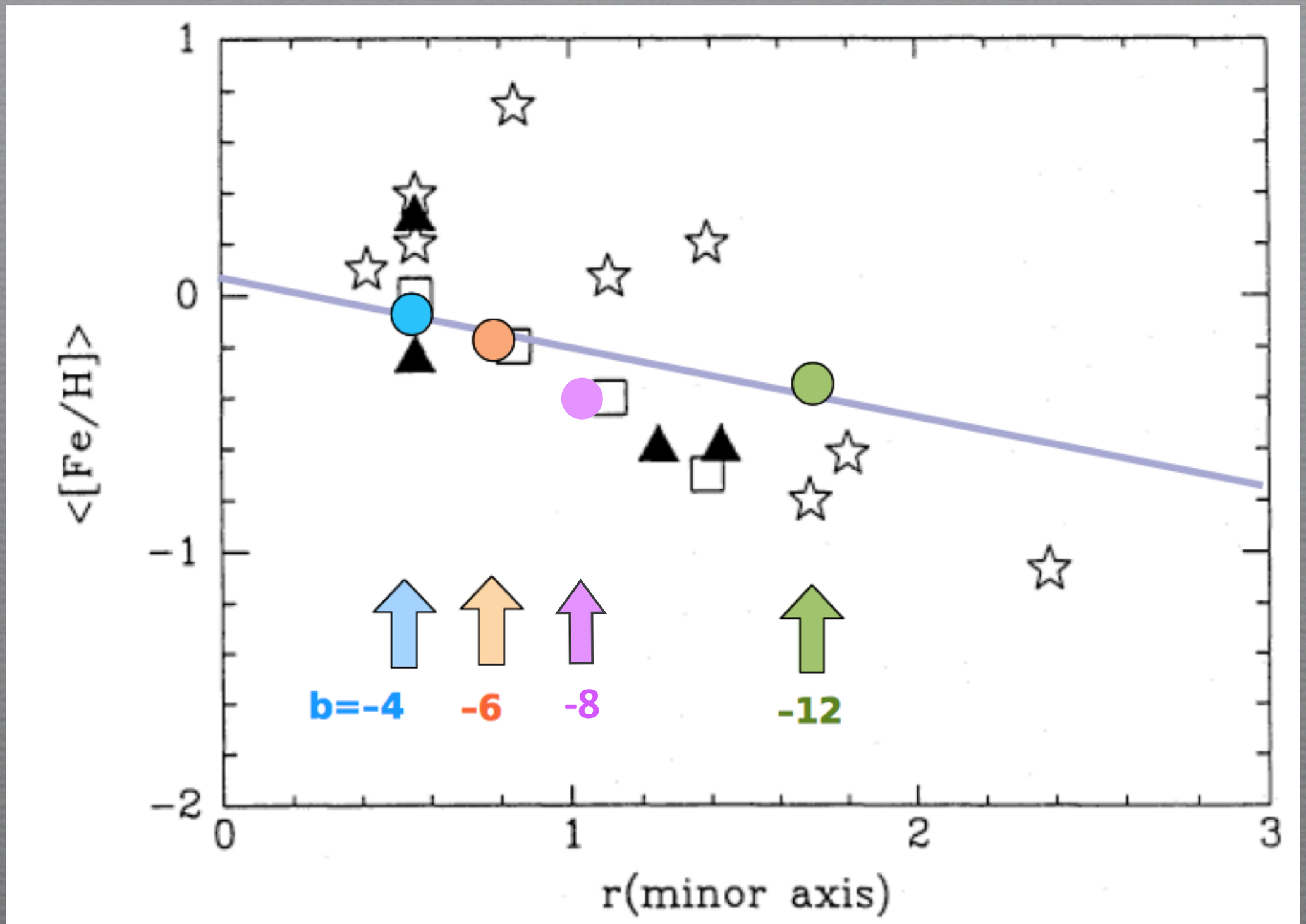


2dF@AAT

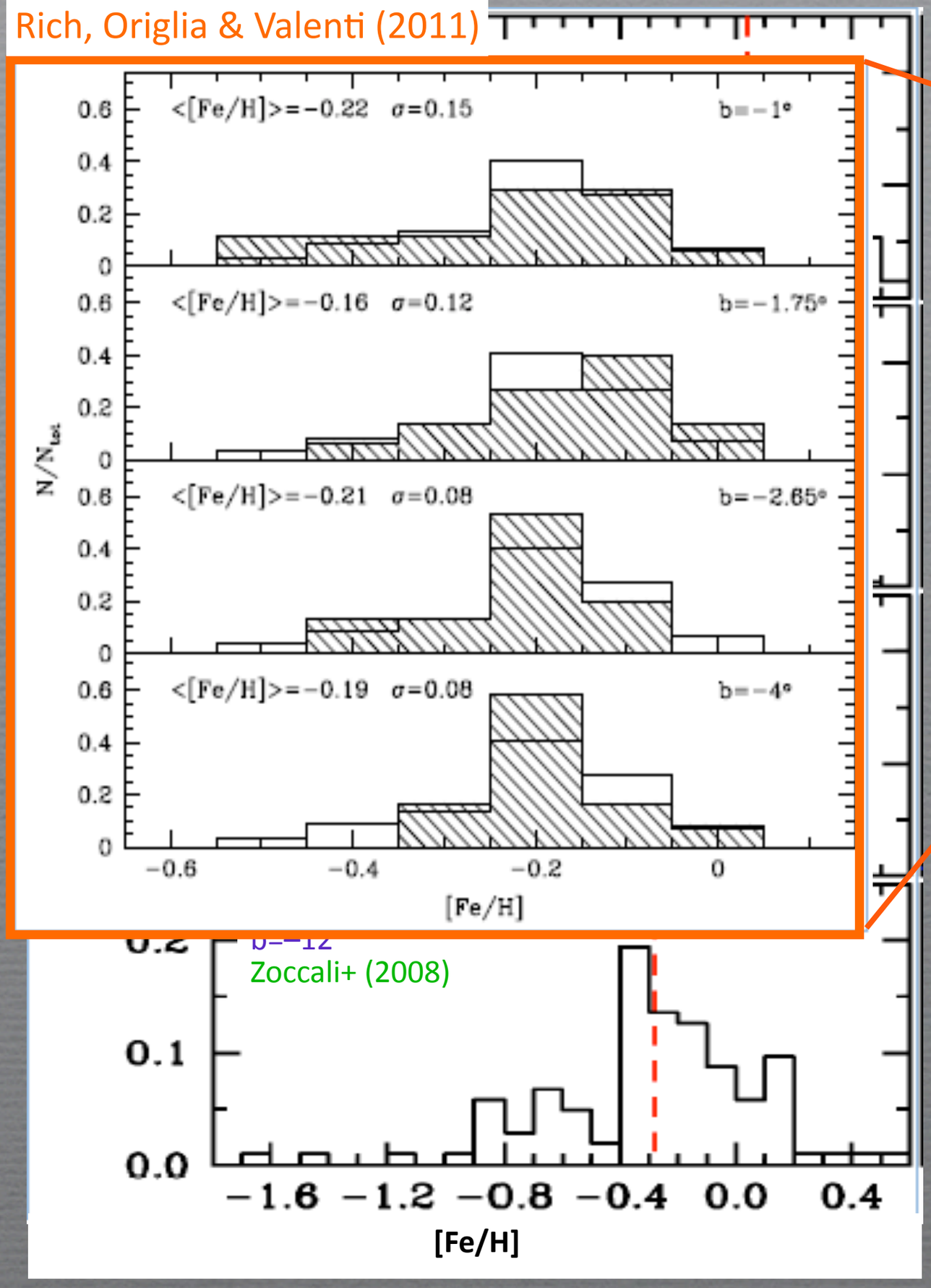
Bulge Metallicity Distribution Function





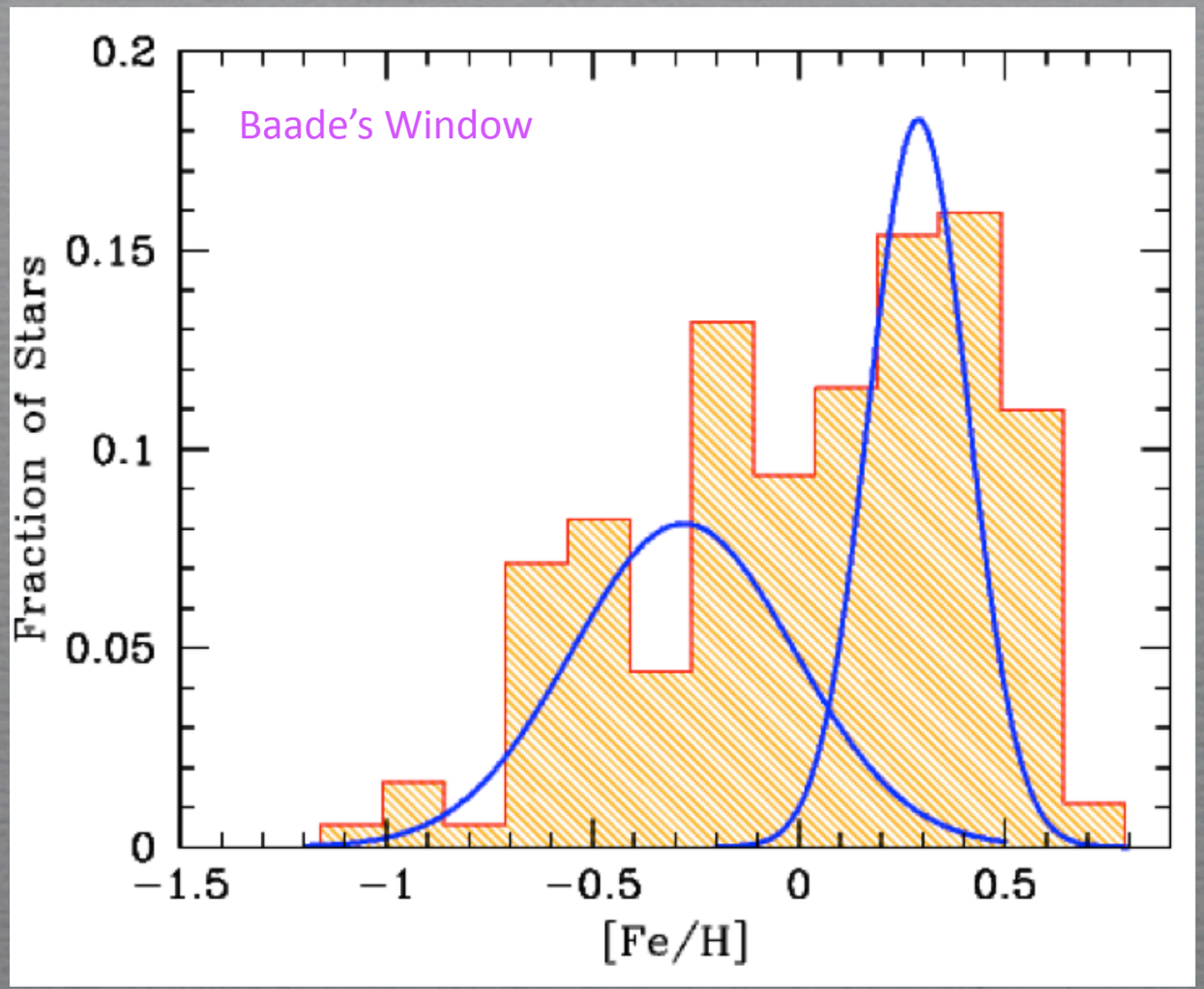

1
0
−1
−2
0
1
2
3
<[Fe/H]>
r(minor axis)
b=-4
-6
-8
-12

Rich, Origlia & Valenti (2011)



Coupling kinematics with metallicities

Hill et al. (2011) two components in the MDF



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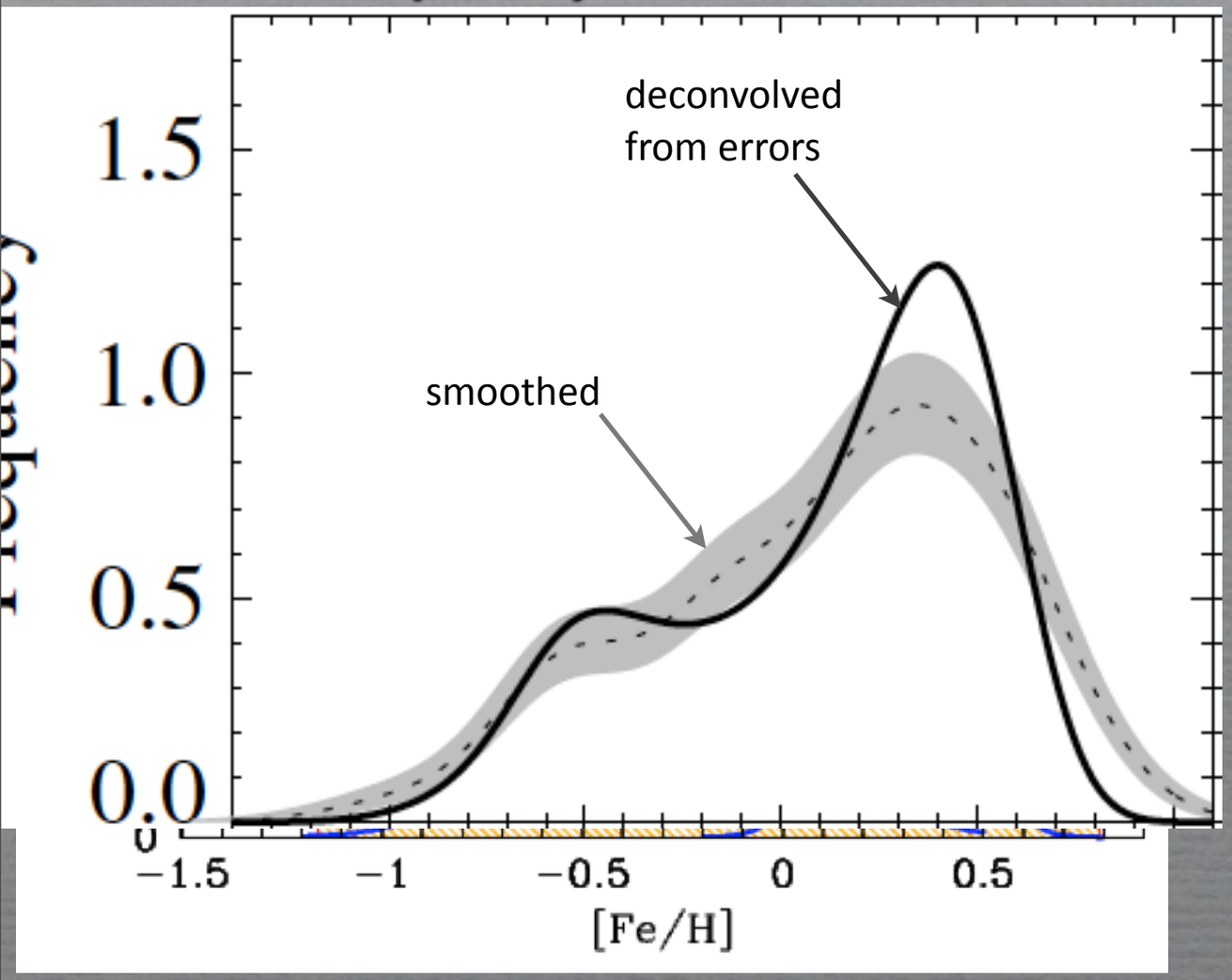

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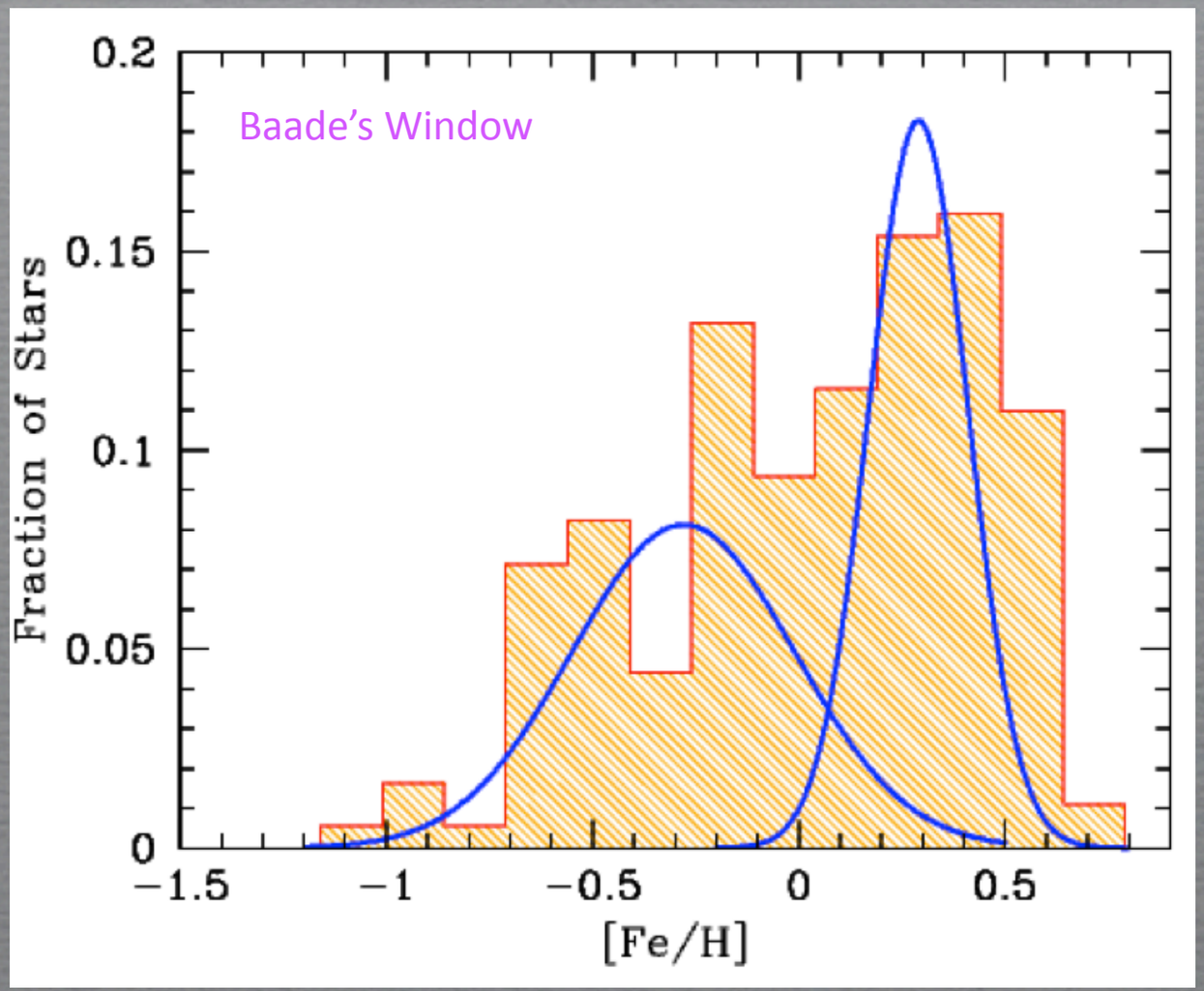
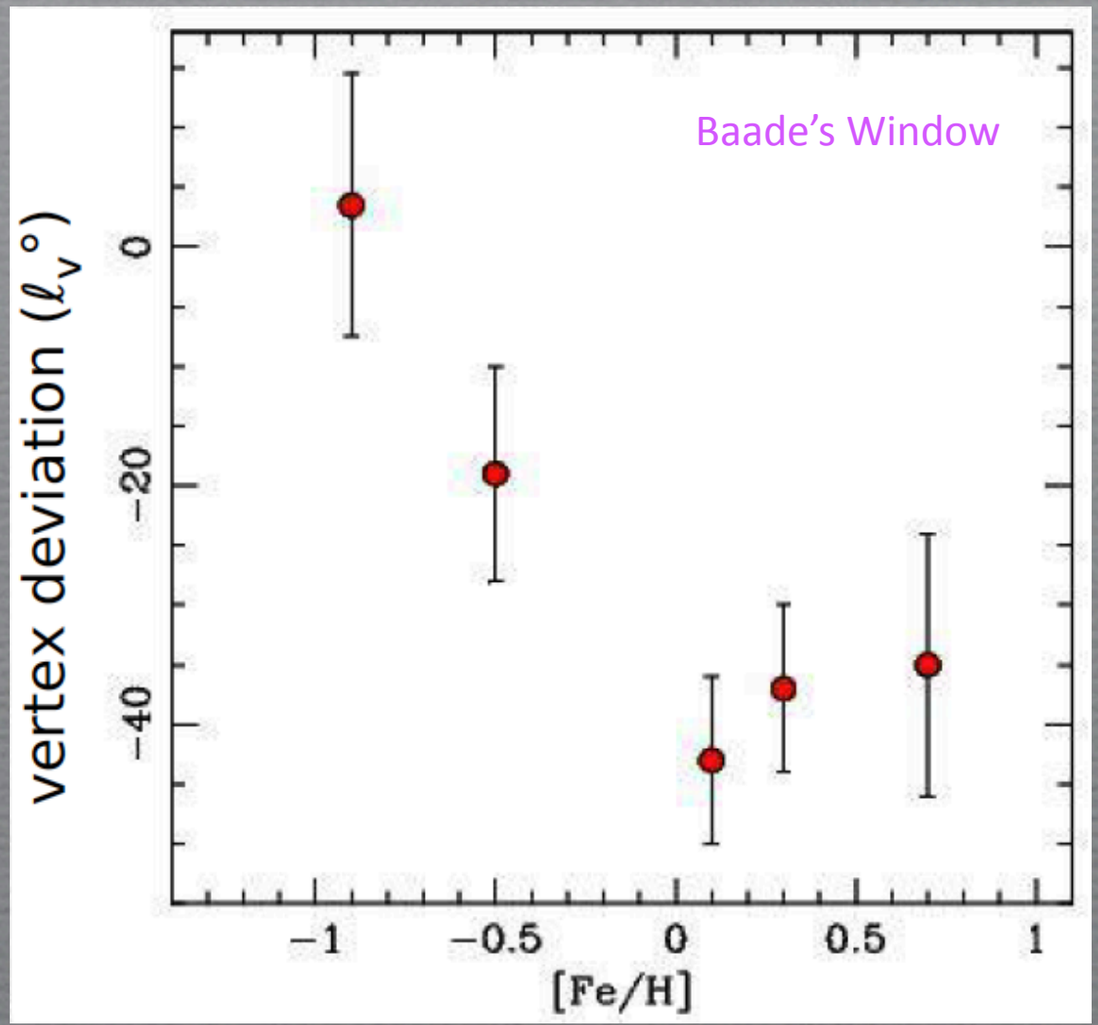


Babusiaux et al. (2010)



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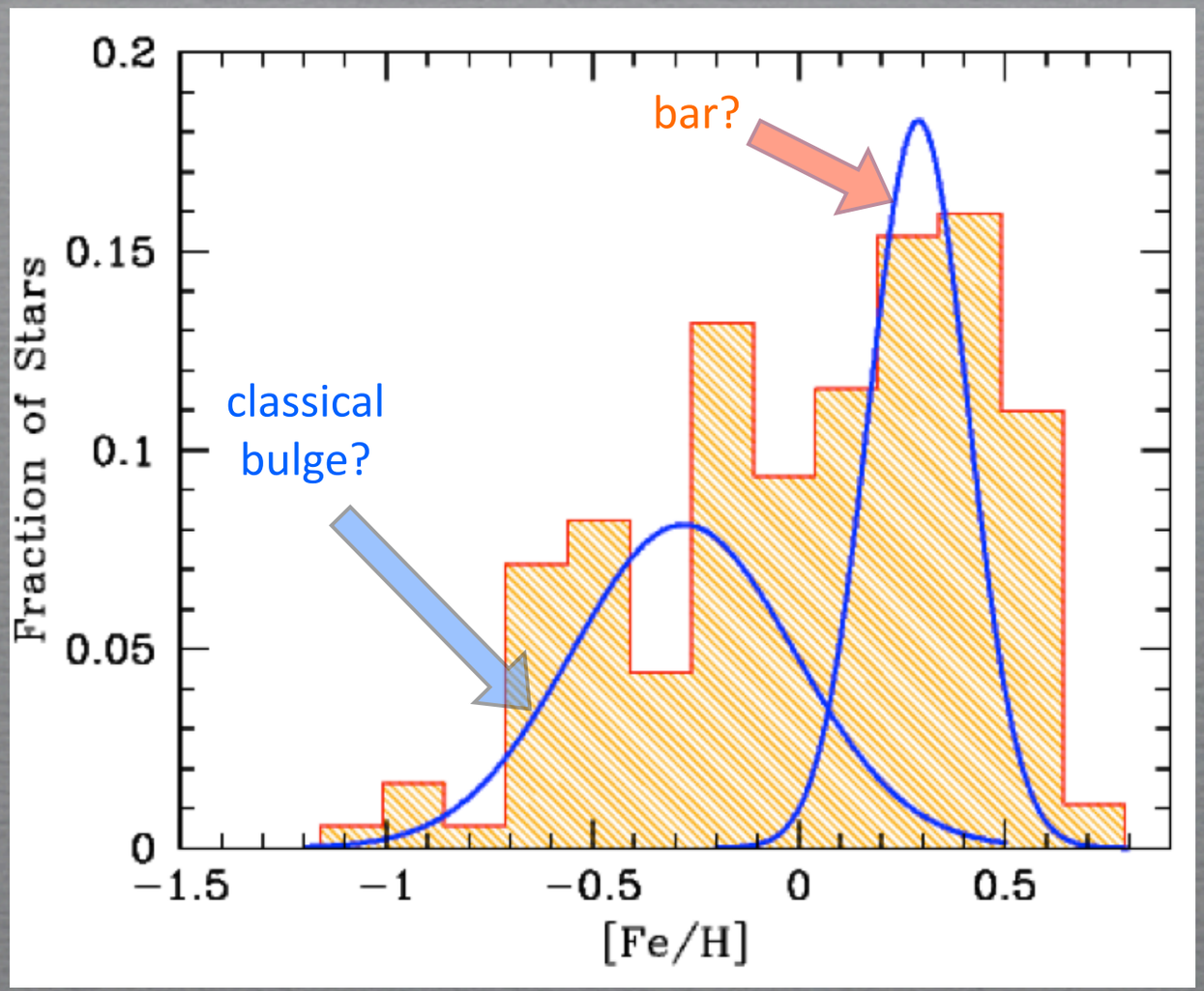
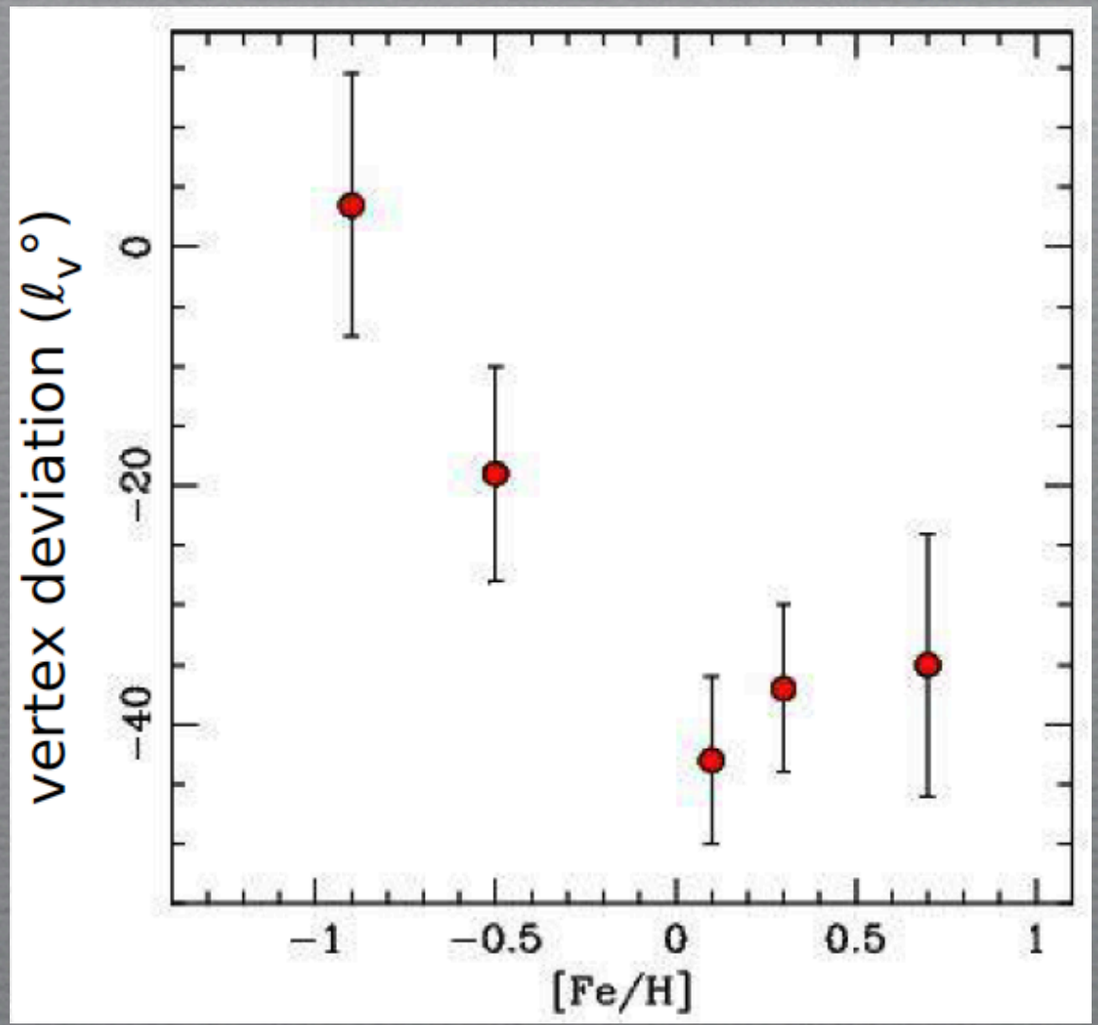
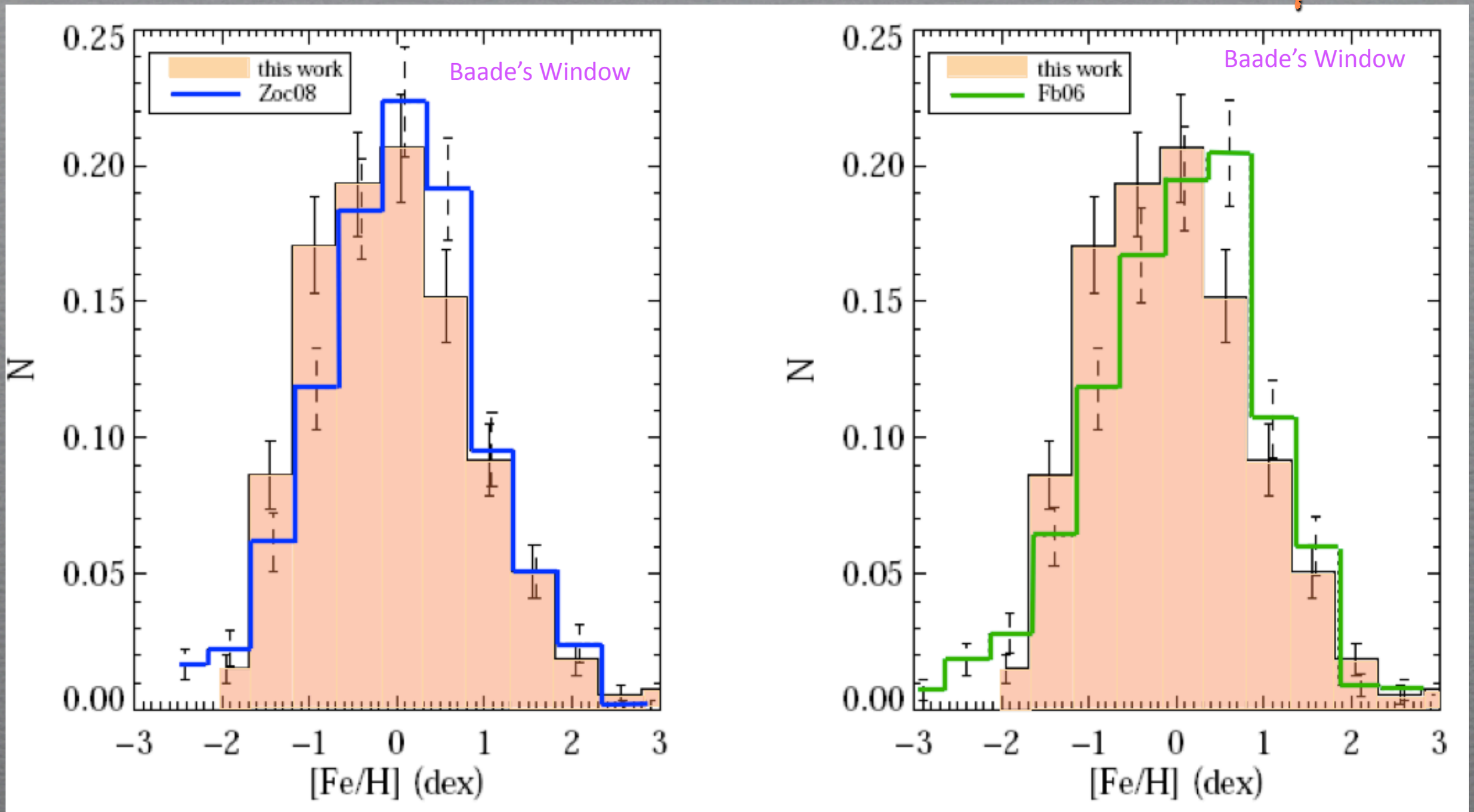


Babusiaux et al. (2010)



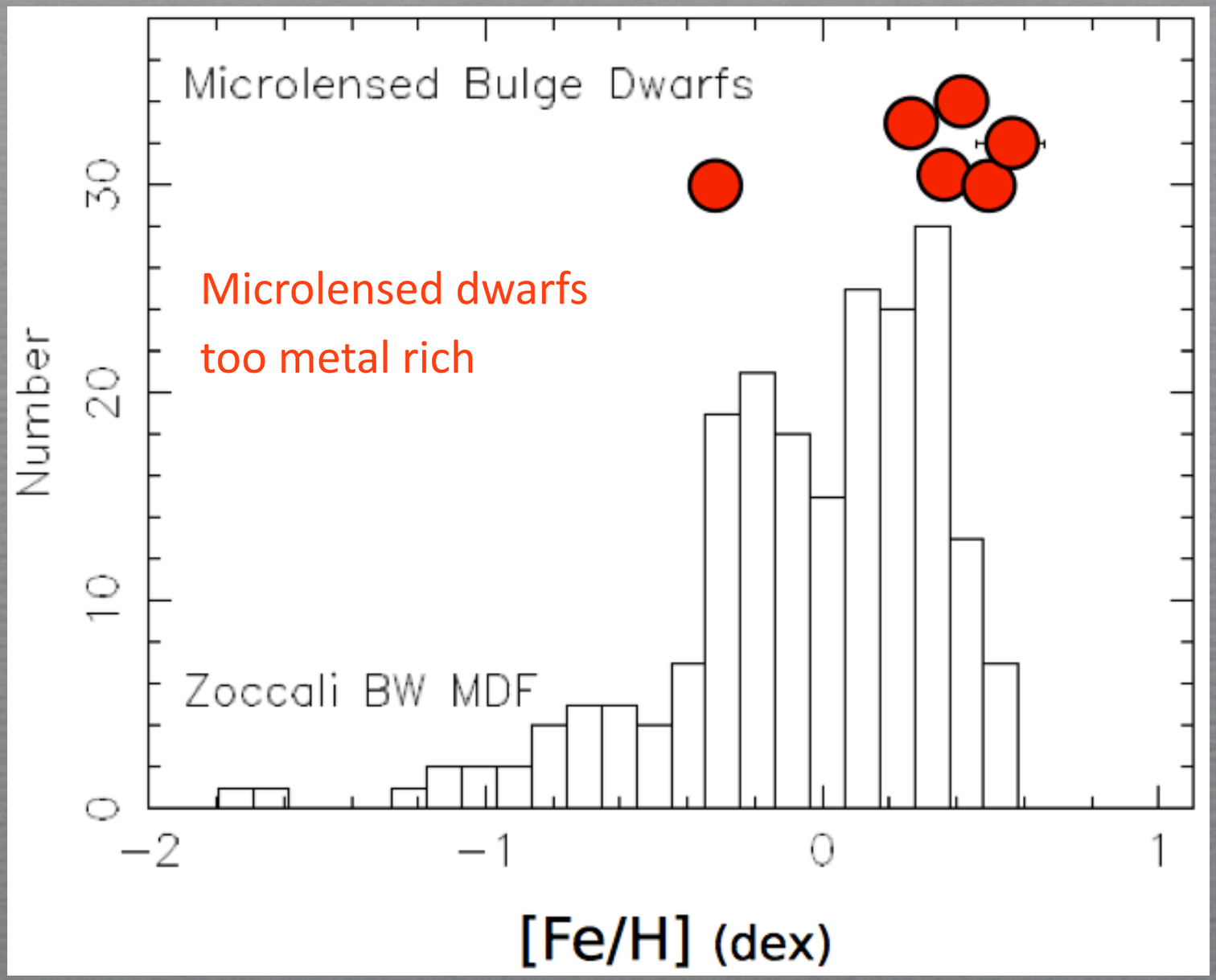
Bulge MDF with Fabry-Pérot *photometry*

Rangwala et al. (2009) CTIO 1.5m Telescope



Metallicity distribution from microlensed dwarfs

Cohen et al. (2009)



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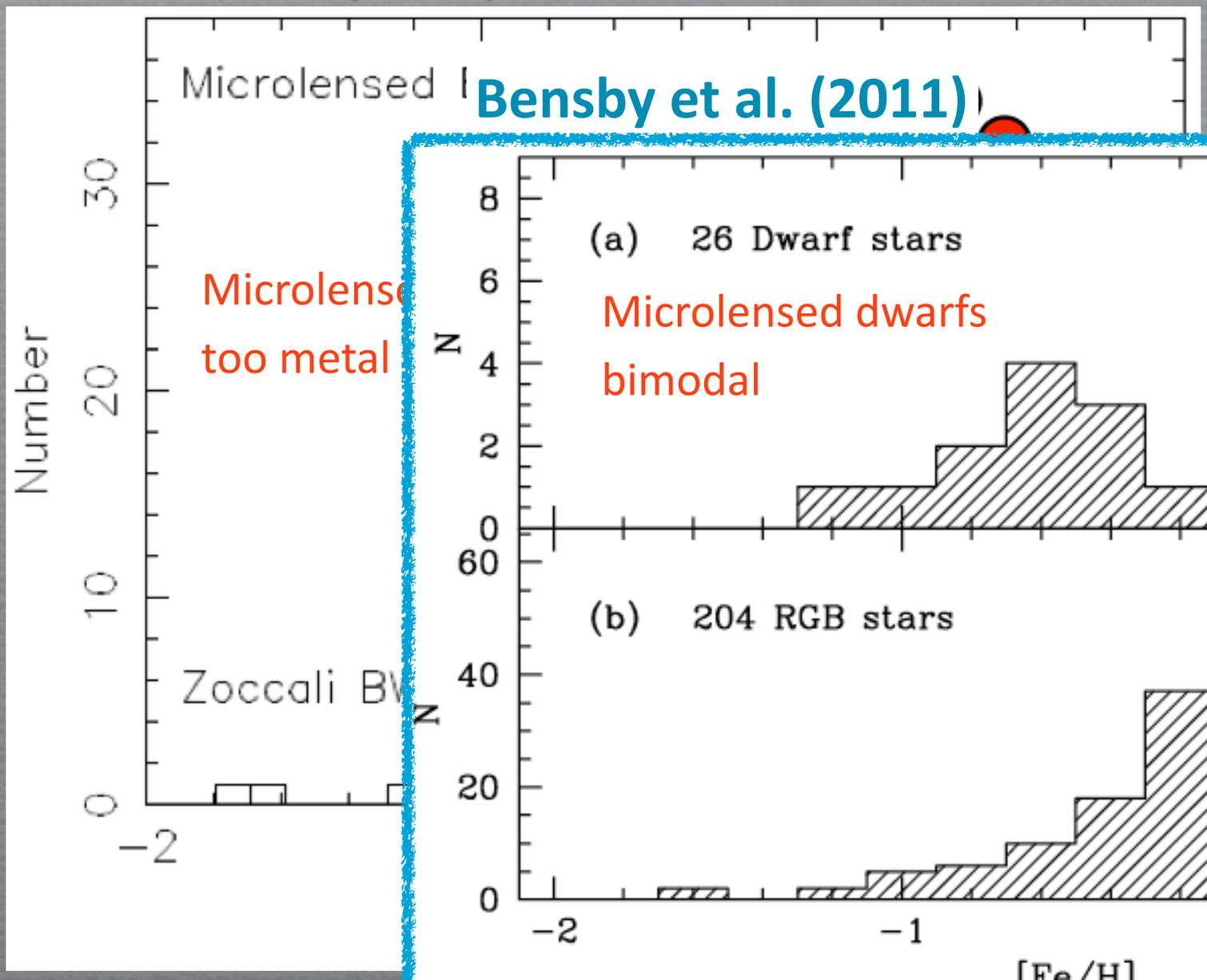


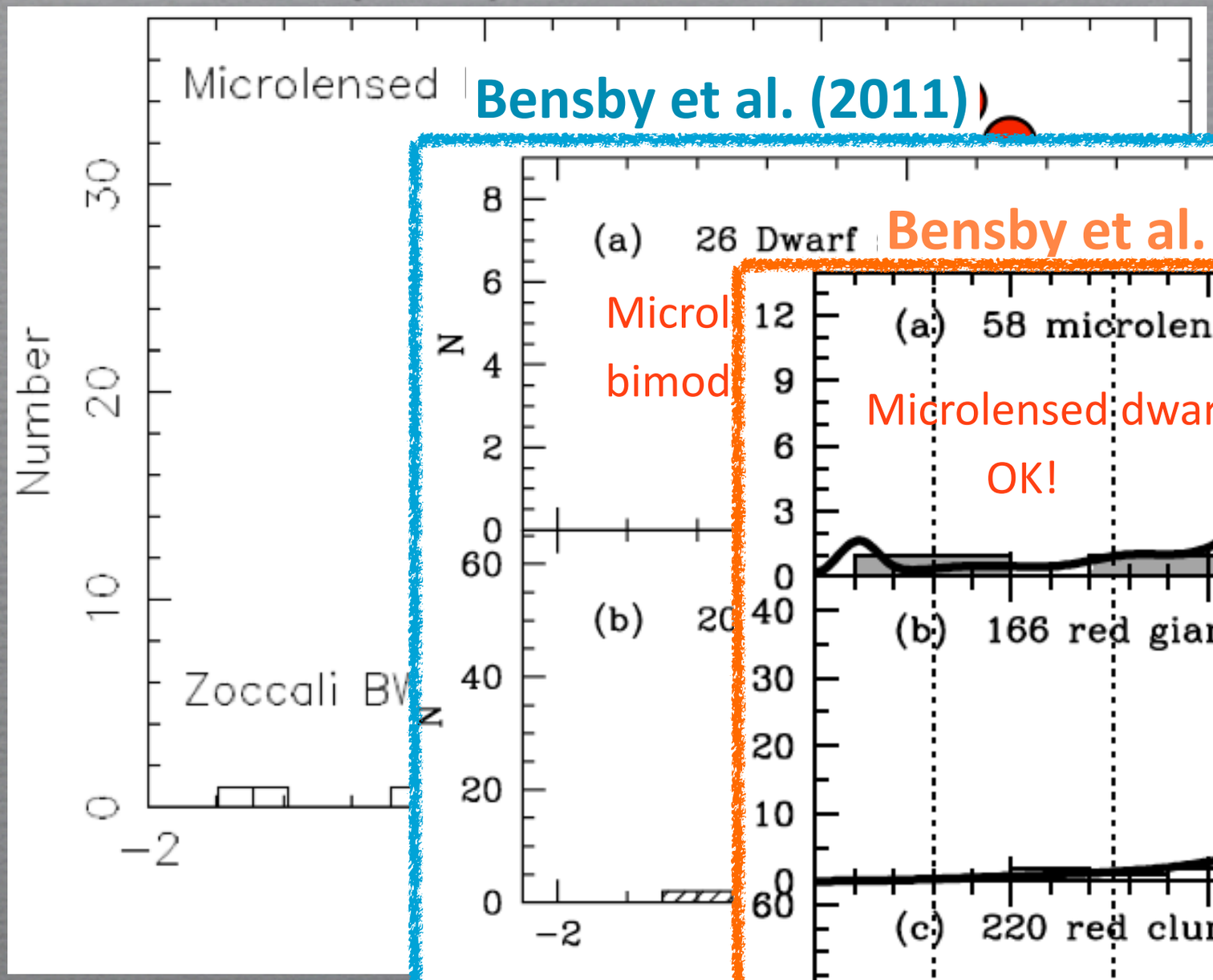
Bensby et al. (2011)

Microlense
too metal

Microlensed dwarfs
bimodal

Metallicity distribution from microlensed dwarfs

Cohen et al. (2009)



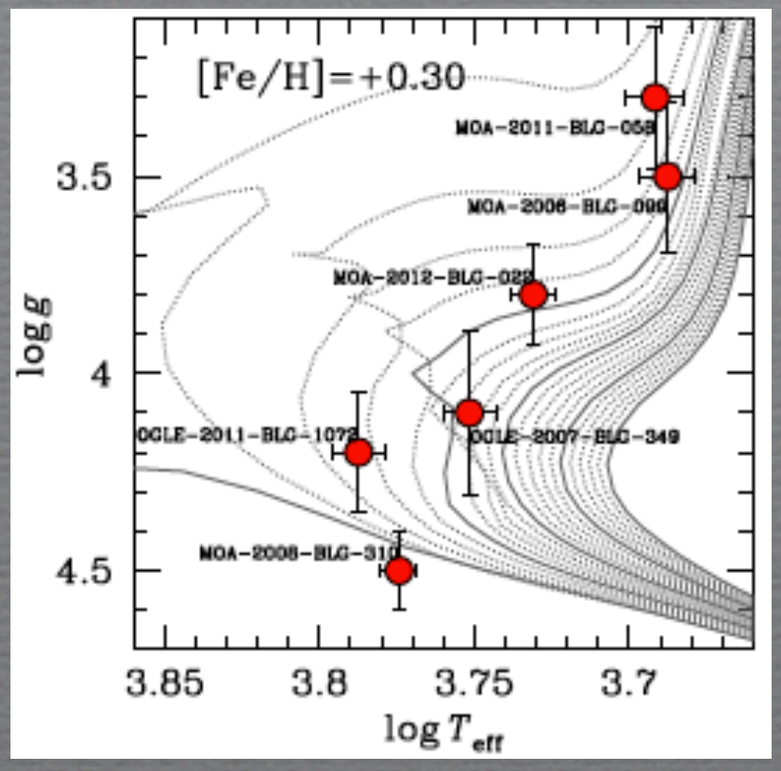
Bensby et al. (2011)

Bensby et al. (2013)

Age-Metallicity relation from microlensed dwarfs

Bensby et al. (2013)

A significant (~30%) fraction of the microlensed dwarfs have ages < 7 Gyr,
with a few as young as 1.5 Gyr.



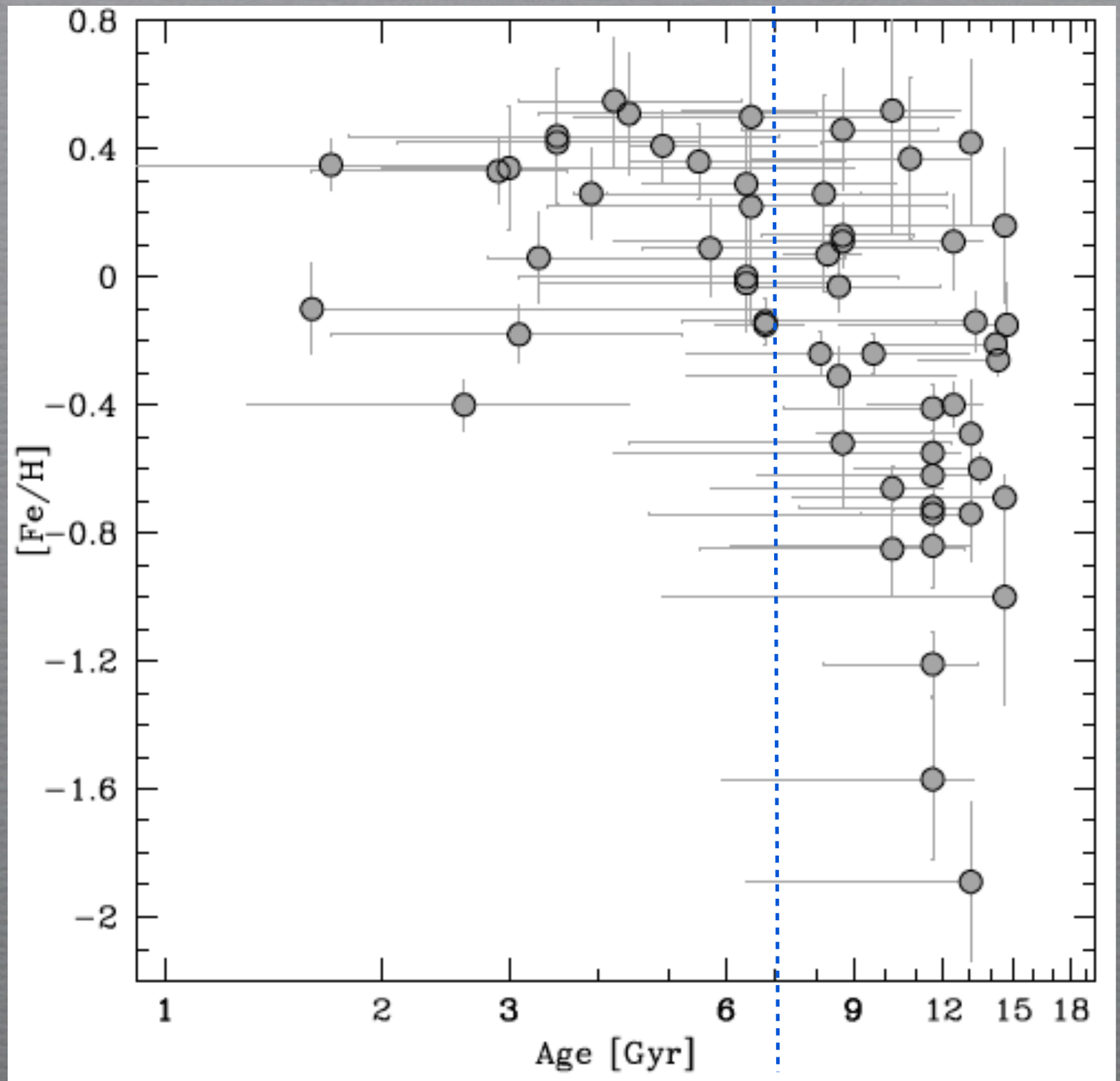


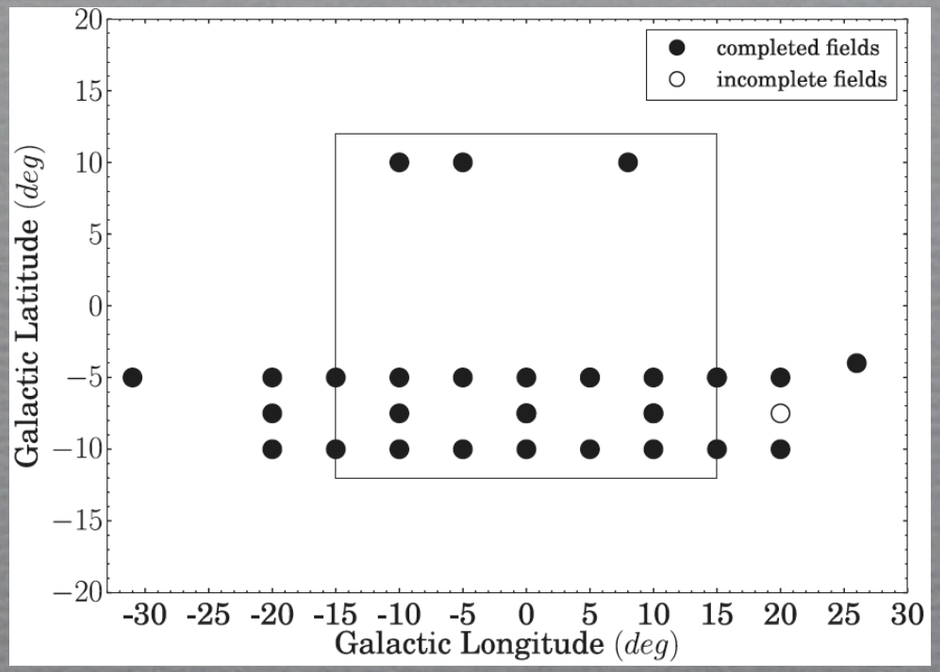
Fig. 15. Age versus [Fe/H] for the microlensed dwarf sample.

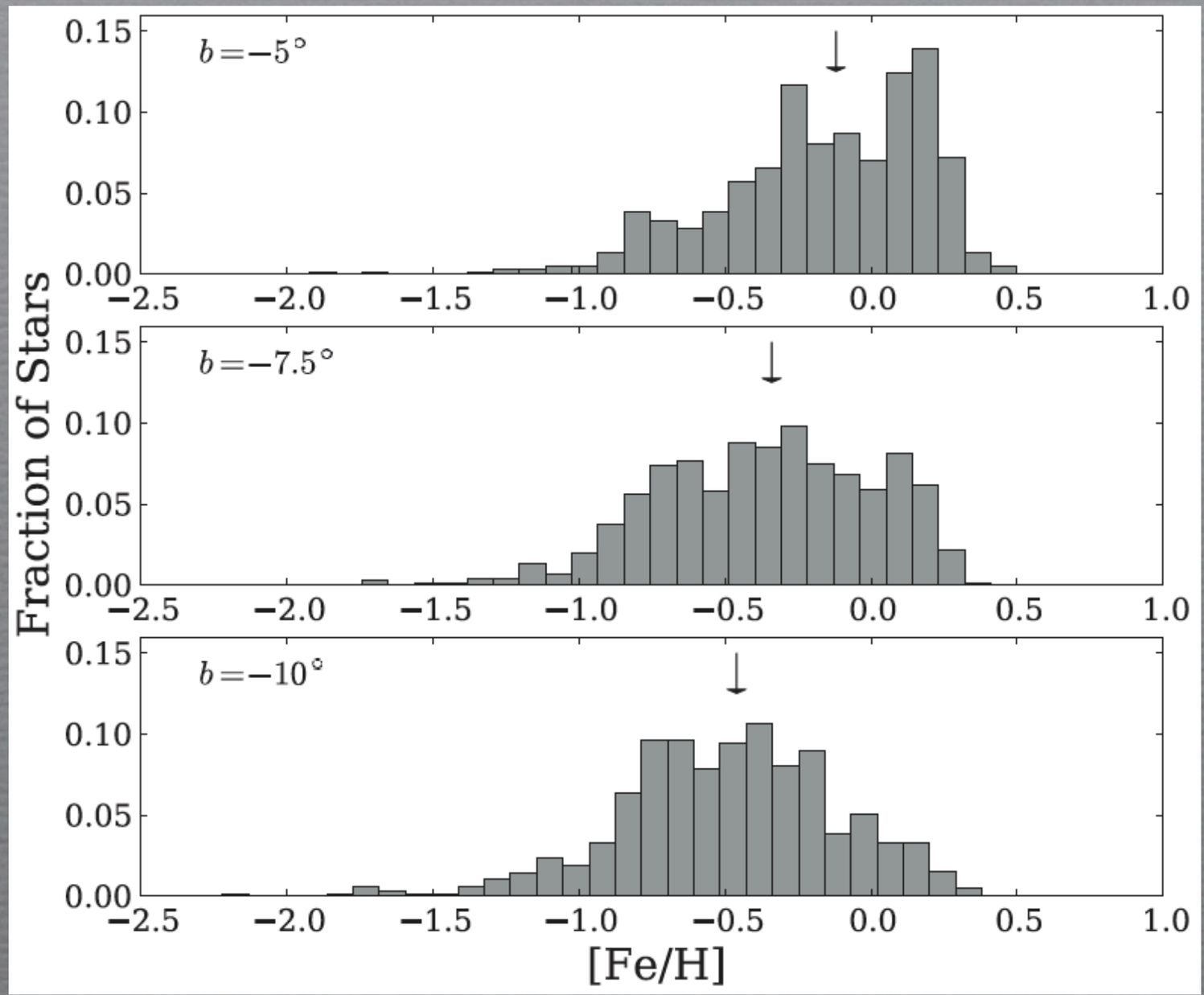
Entering The Era of Surveys

The ARGOS Survey

Freeman et al. (2012)
Ness et al. (2013a, 2013b)

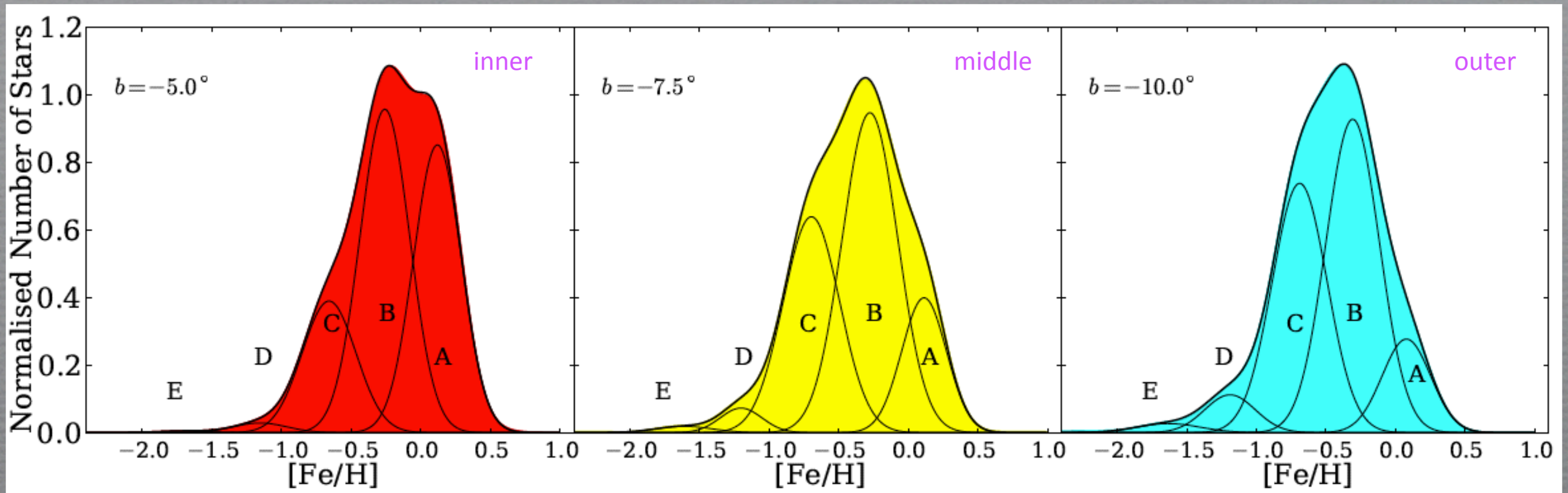
28,000 stars 14,150 stars within 3.5 kpc from the Galactic center
R=11,000





The ARGOS Survey

Ness et al. (2013a)



A: the metal rich boxy/peanut **bulge** <[Fe/H]>~+0.15

B: the vertically thicker boxy/peanut **bulge** <[Fe/H]>~−0.25

C: inner **thick disk** <[Fe/H]>~−0.70

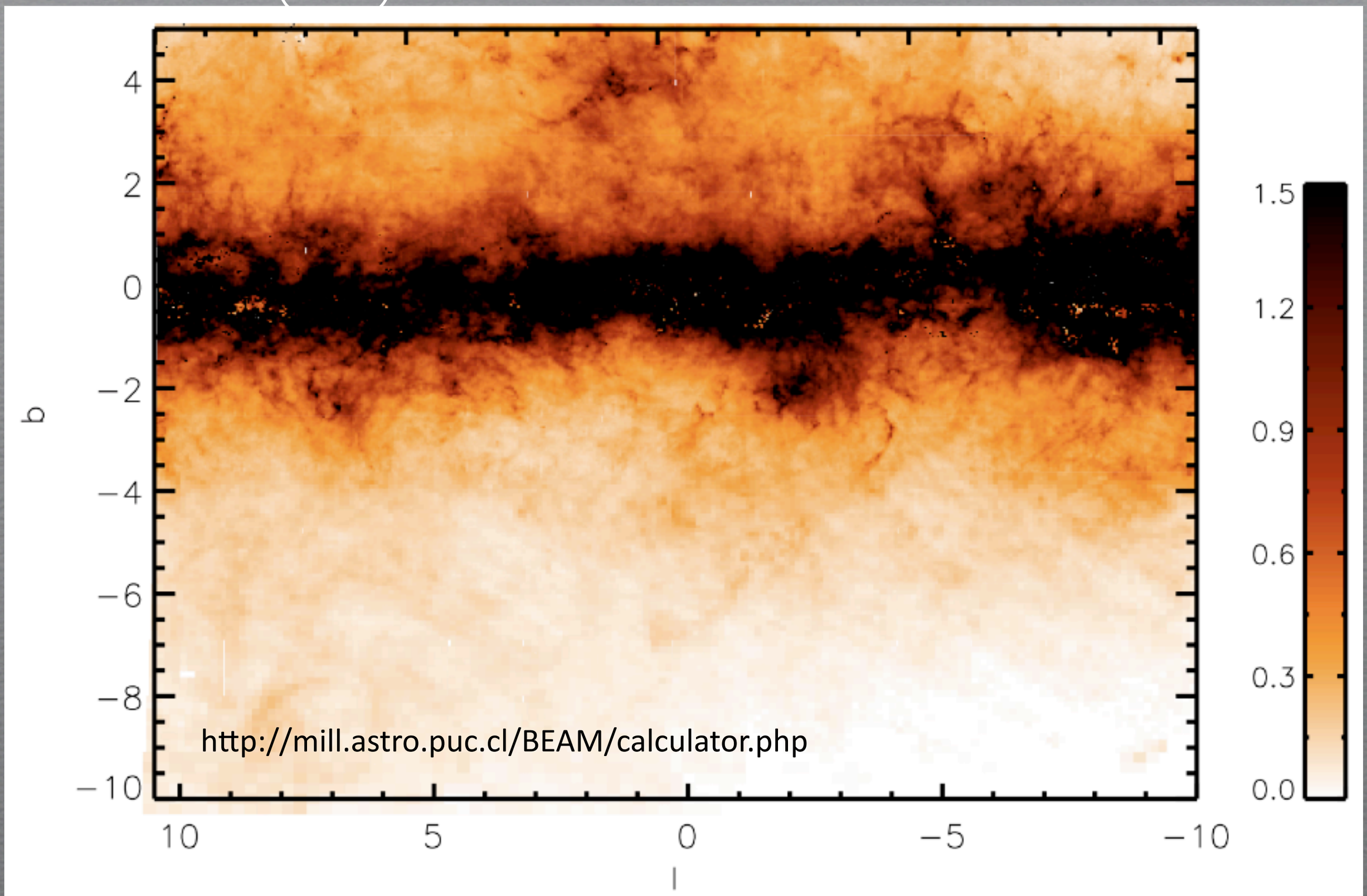
D: metal weak **thick disk** <[Fe/H]>~−1.20

E: halo

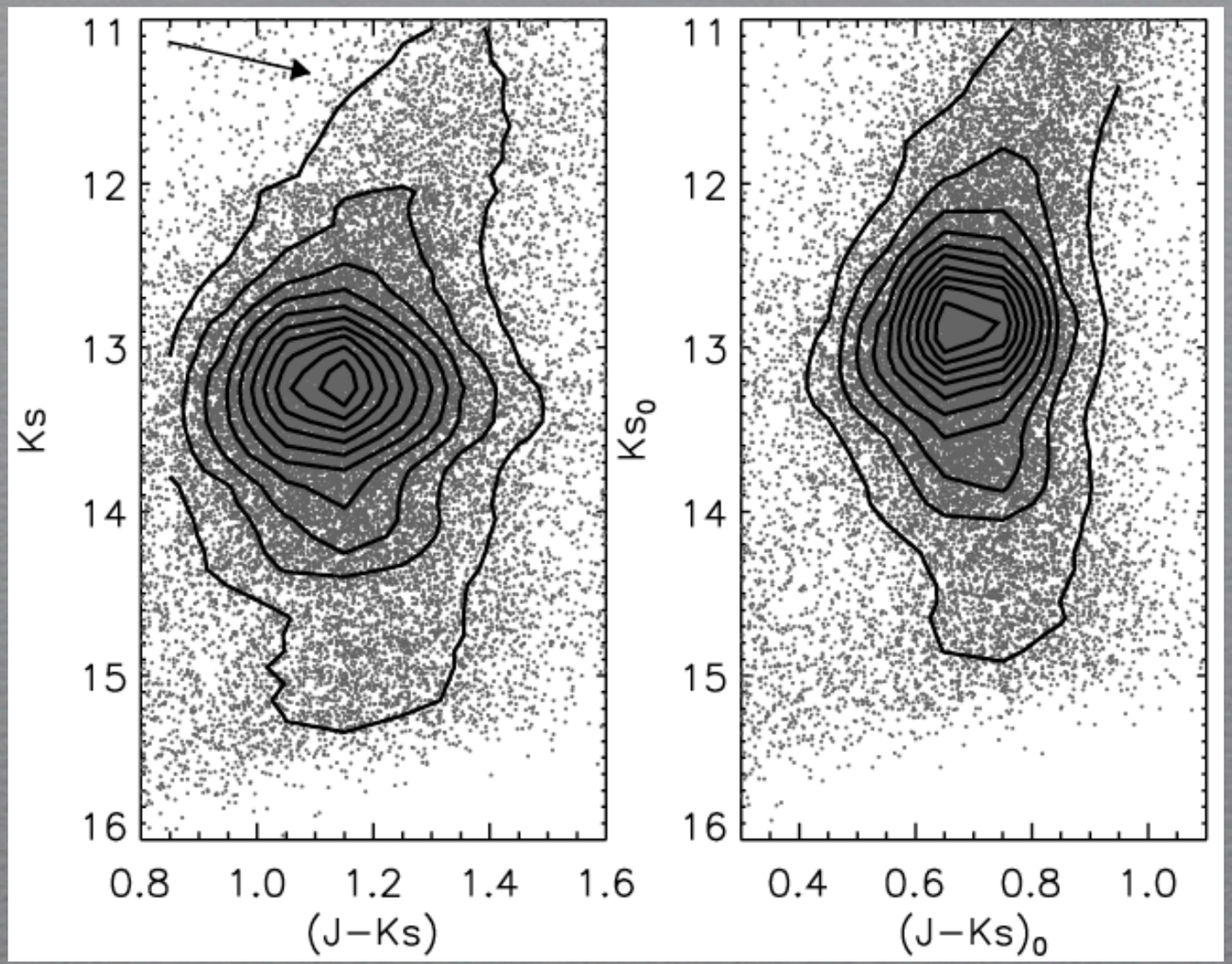
Bulge extinction map from VVV

Spatial Resolution 2’- 6’

Gonzalez et al. (2012)

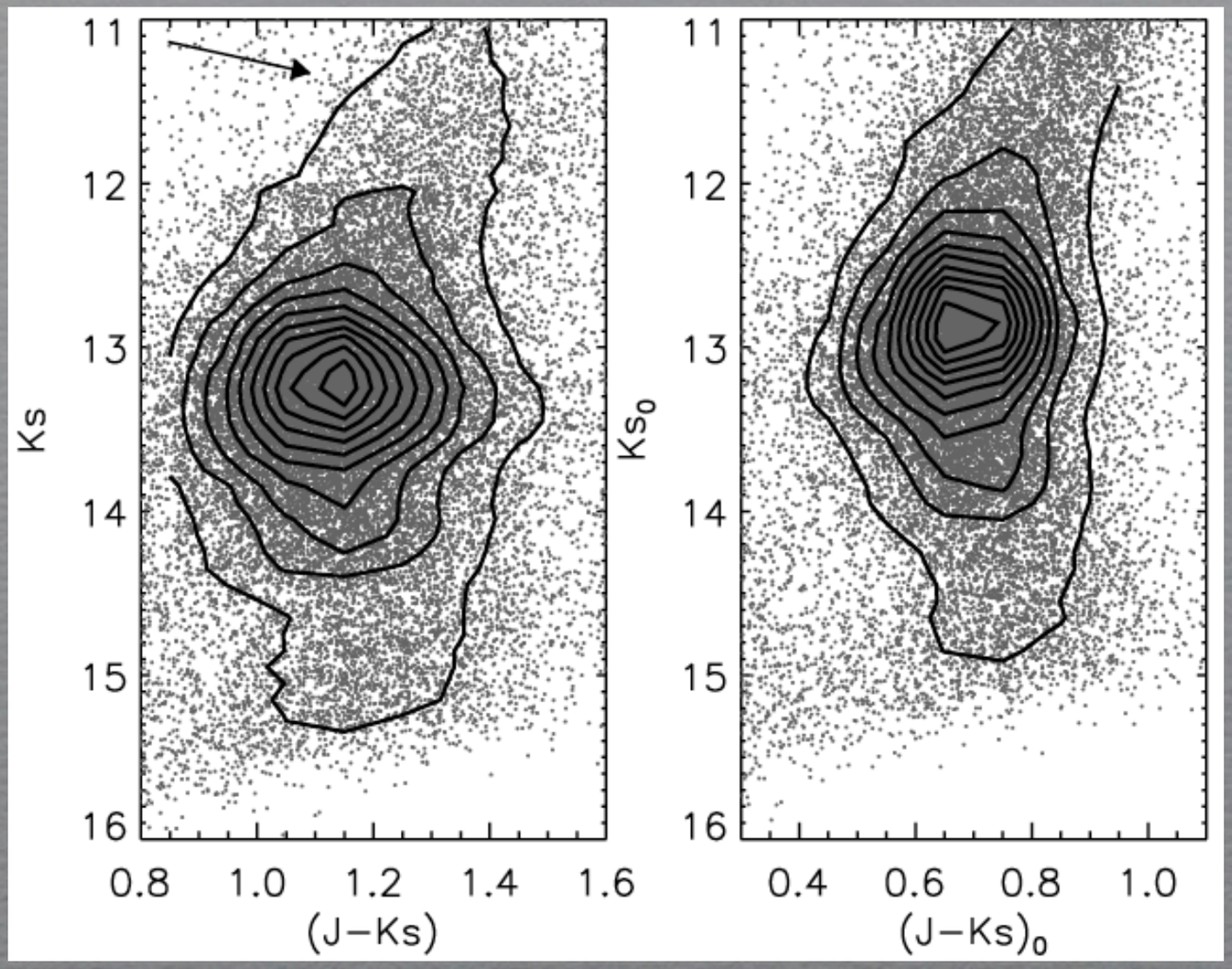


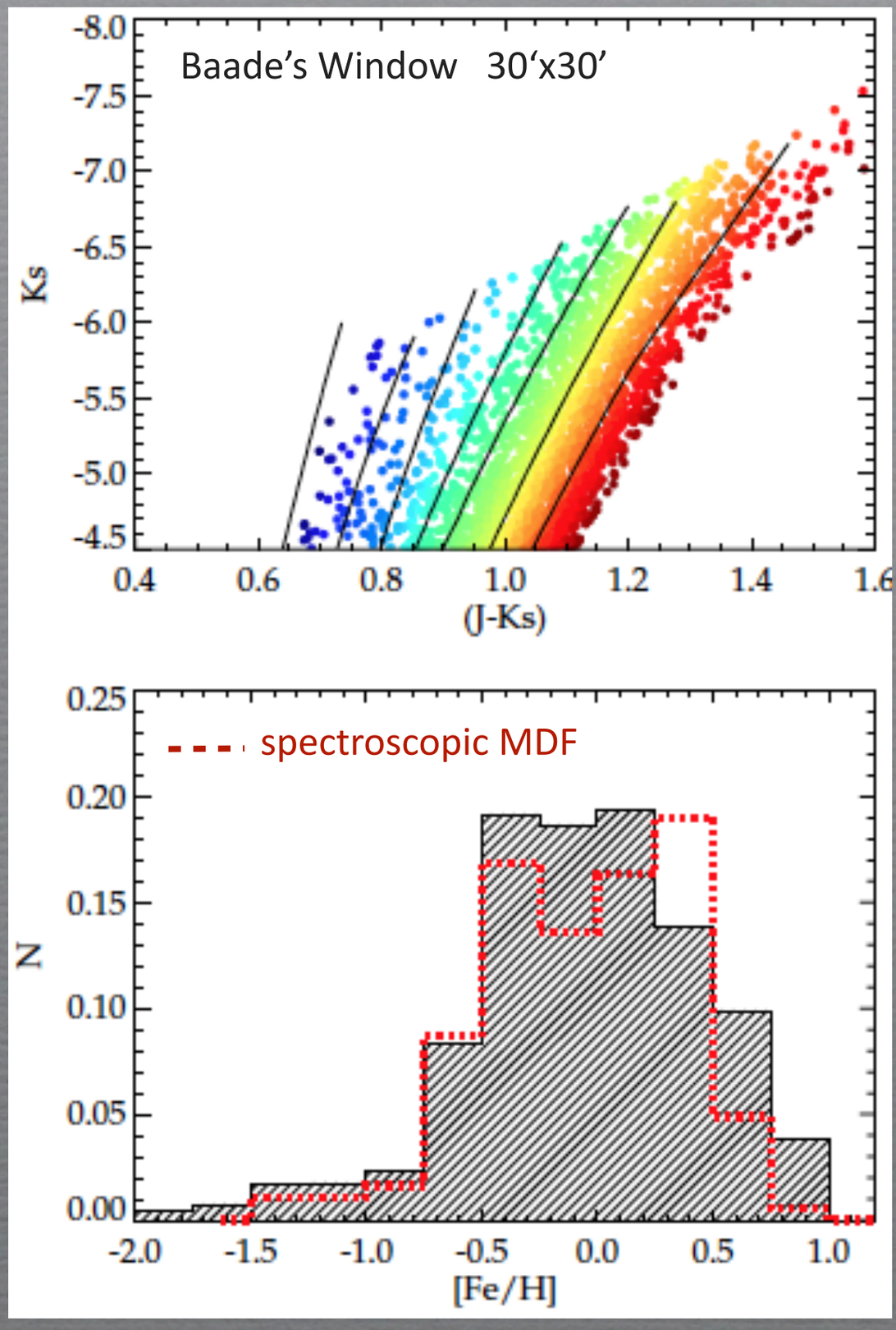
Correcting the bulge CMD for differential reddening.....



Correcting the bulge CMD for differential reddening.....

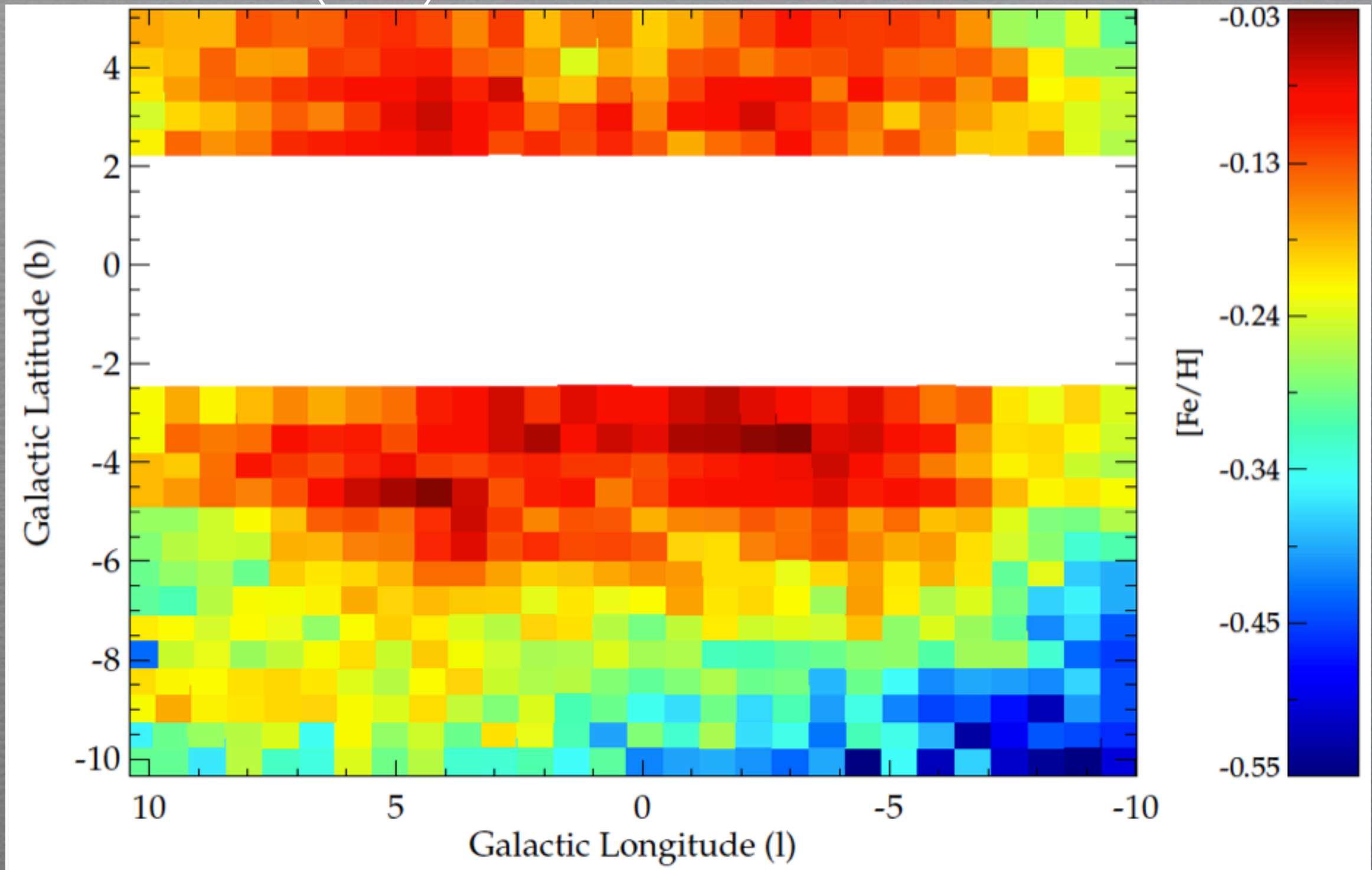
....and deriving the photometric MDF





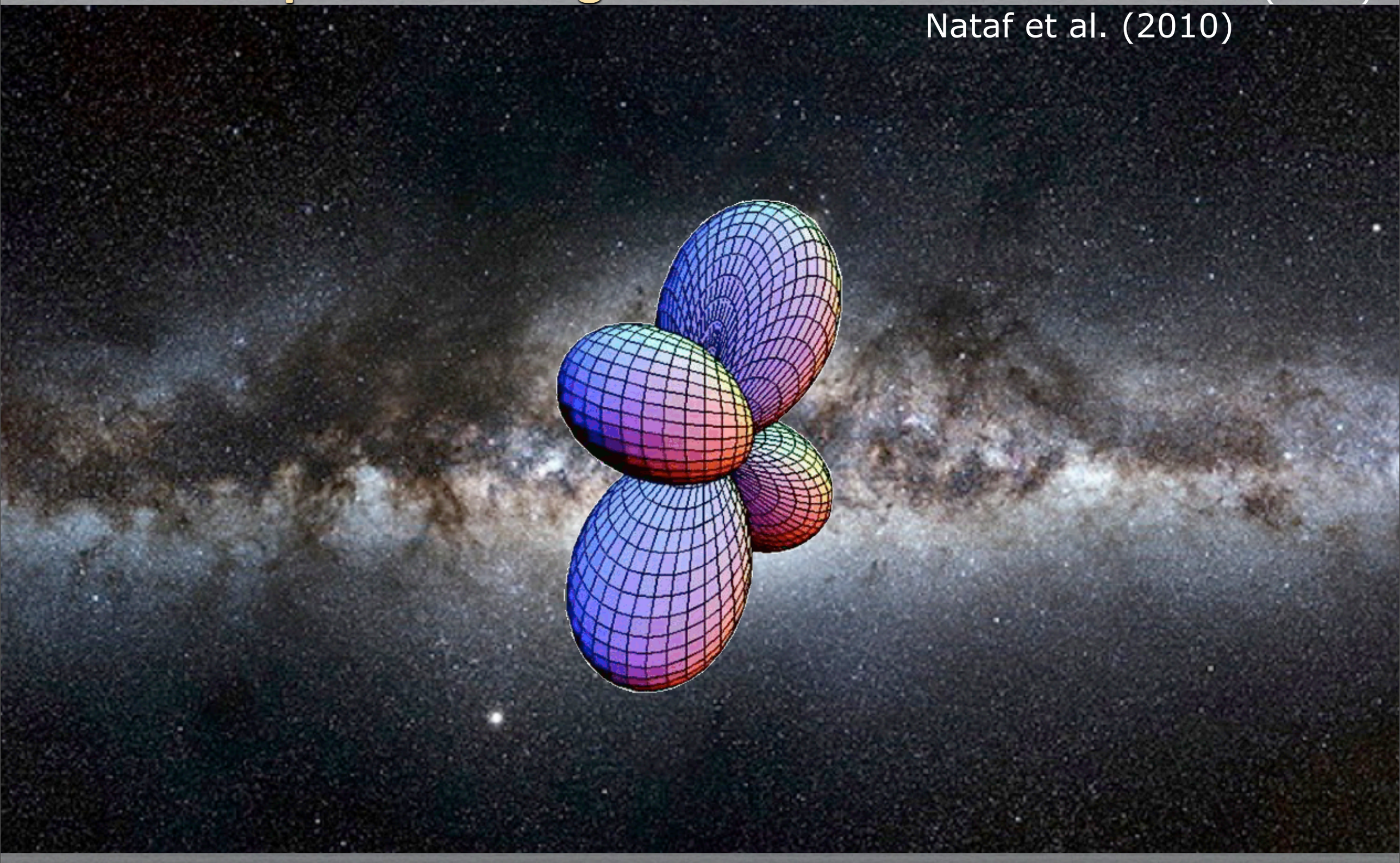
A complete (photometric) metallicity map of the bulge

Gonzalez et al. (2013)



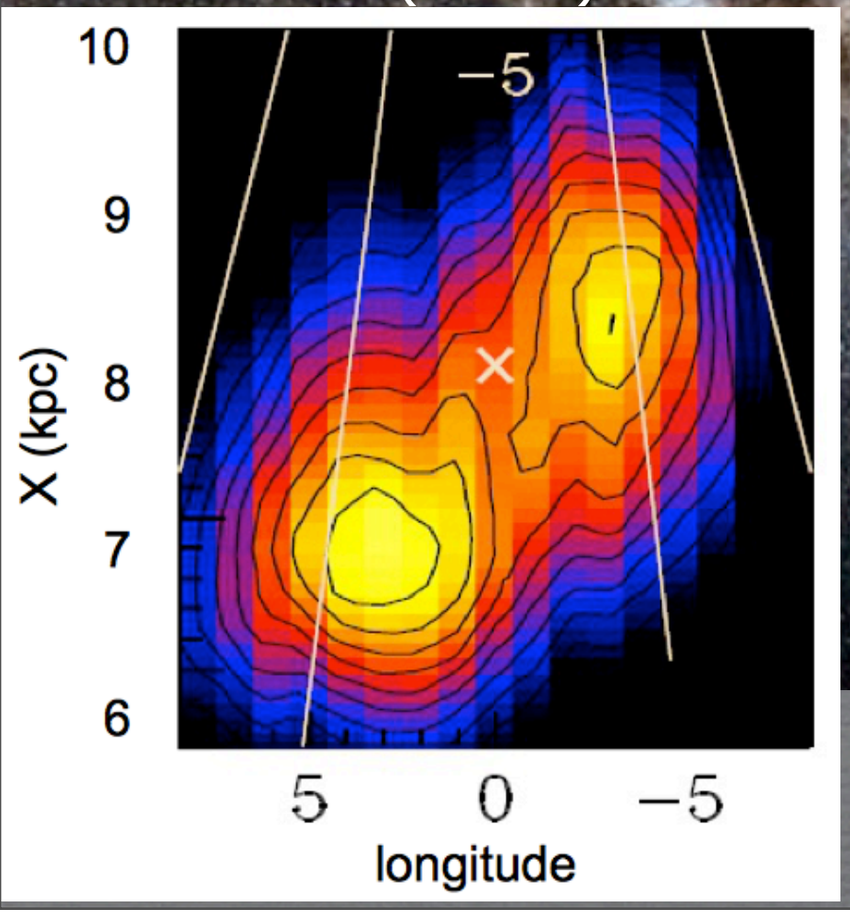
The X-shaped MW bulge

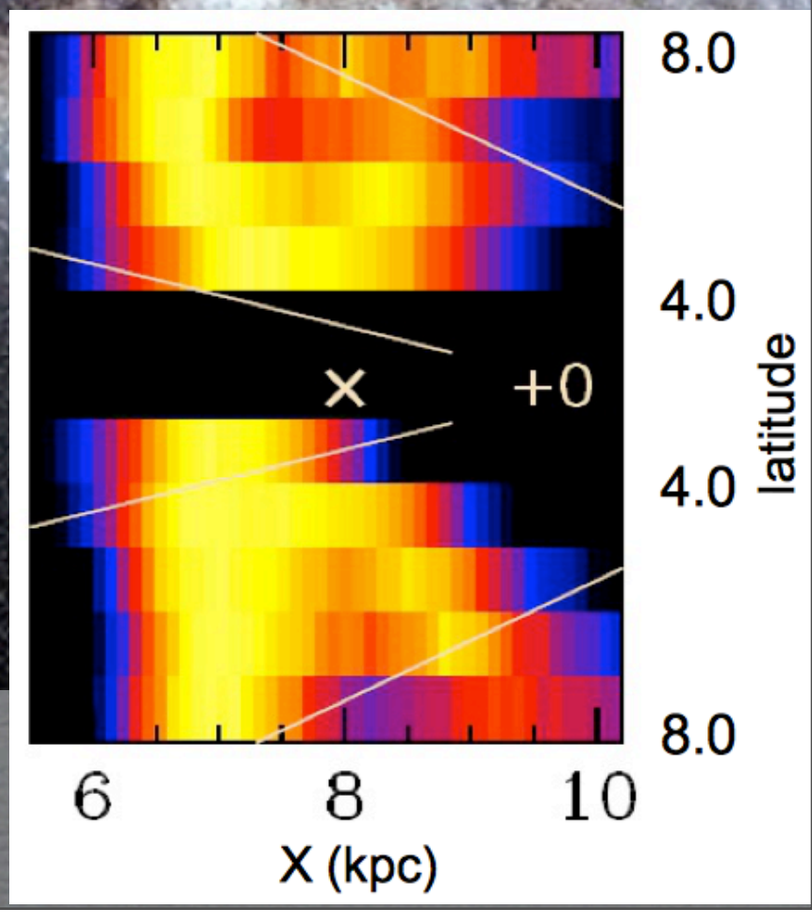
McWilliam & Zoccali (2010)
Nataf et al. (2010)



The X-shaped MW bulge

Saito et al. (2011)





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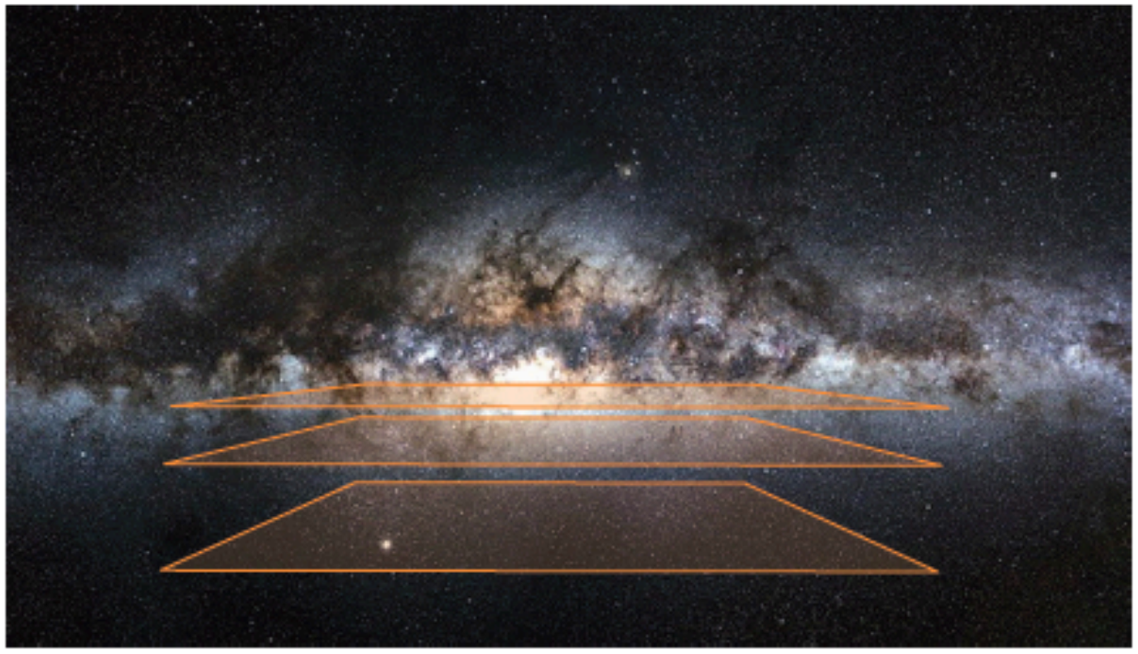

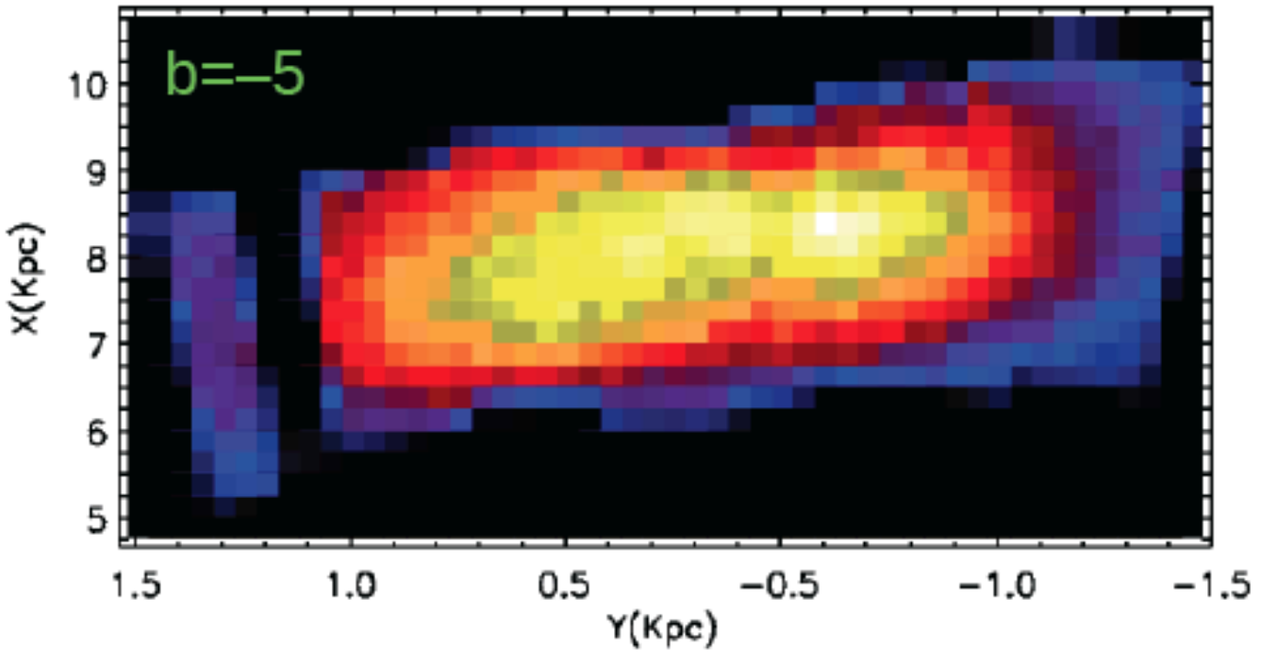

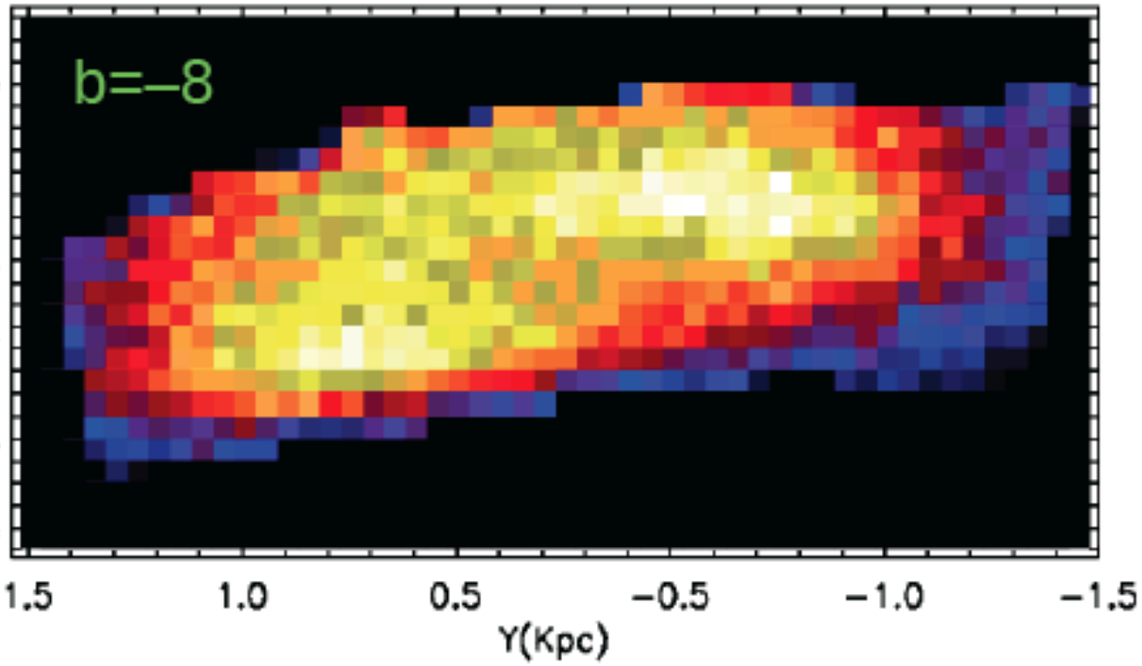

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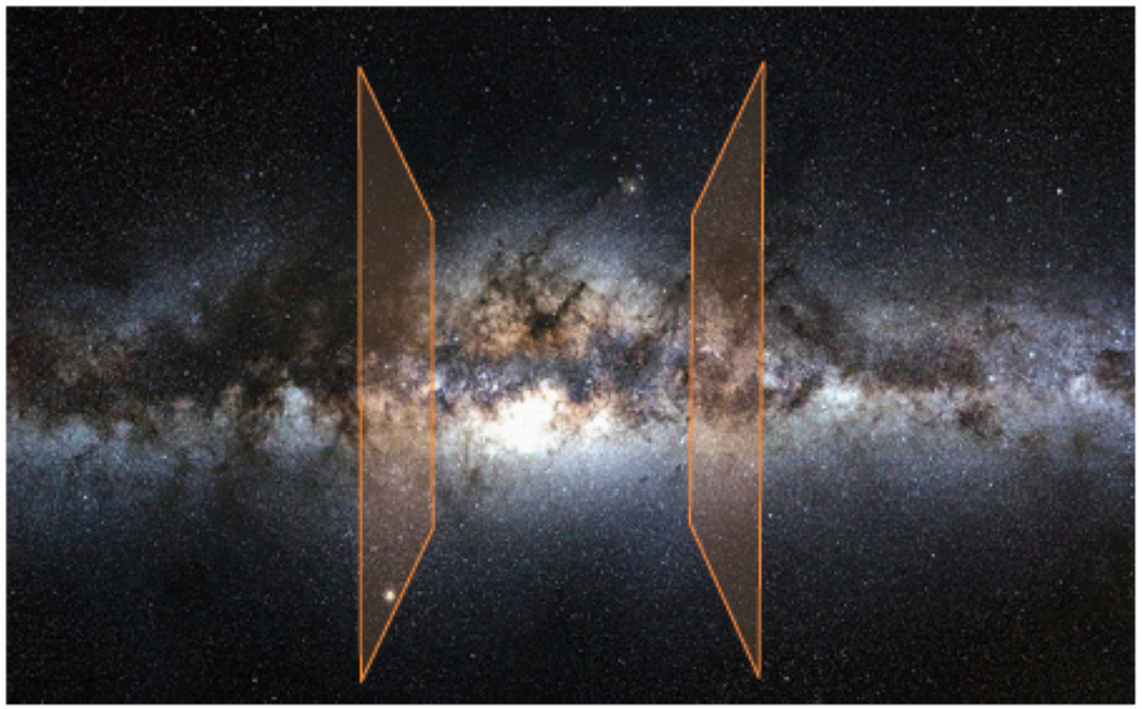
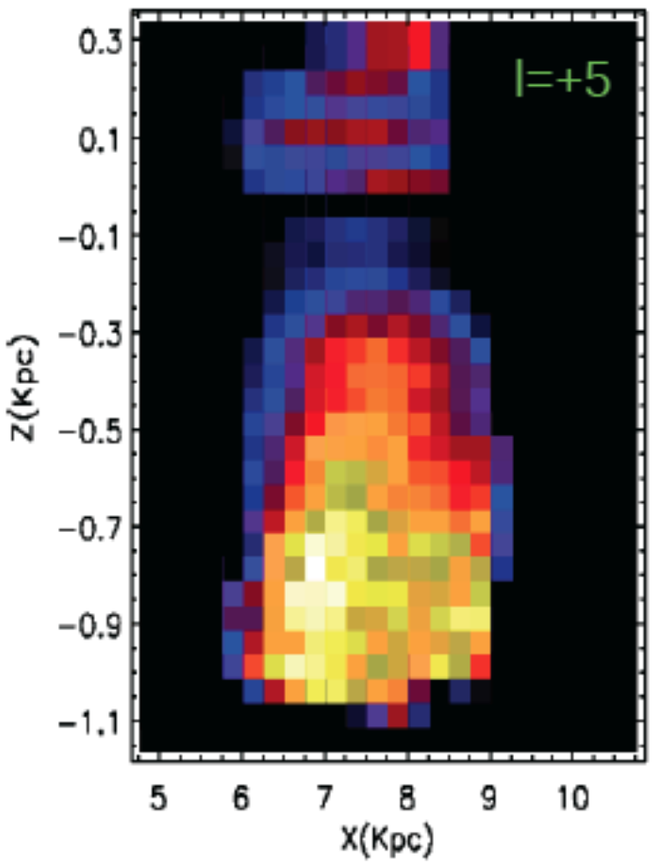
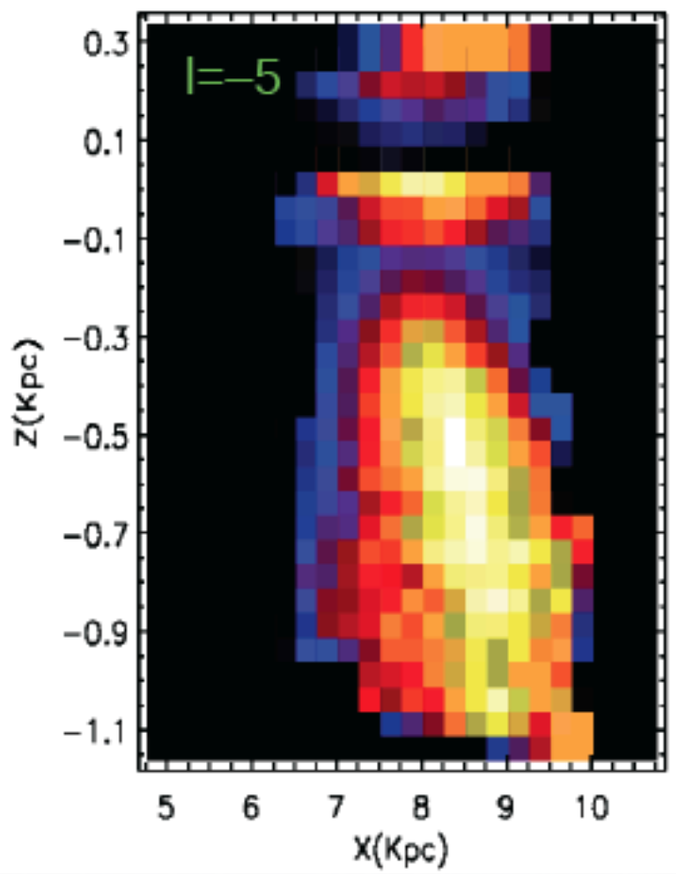
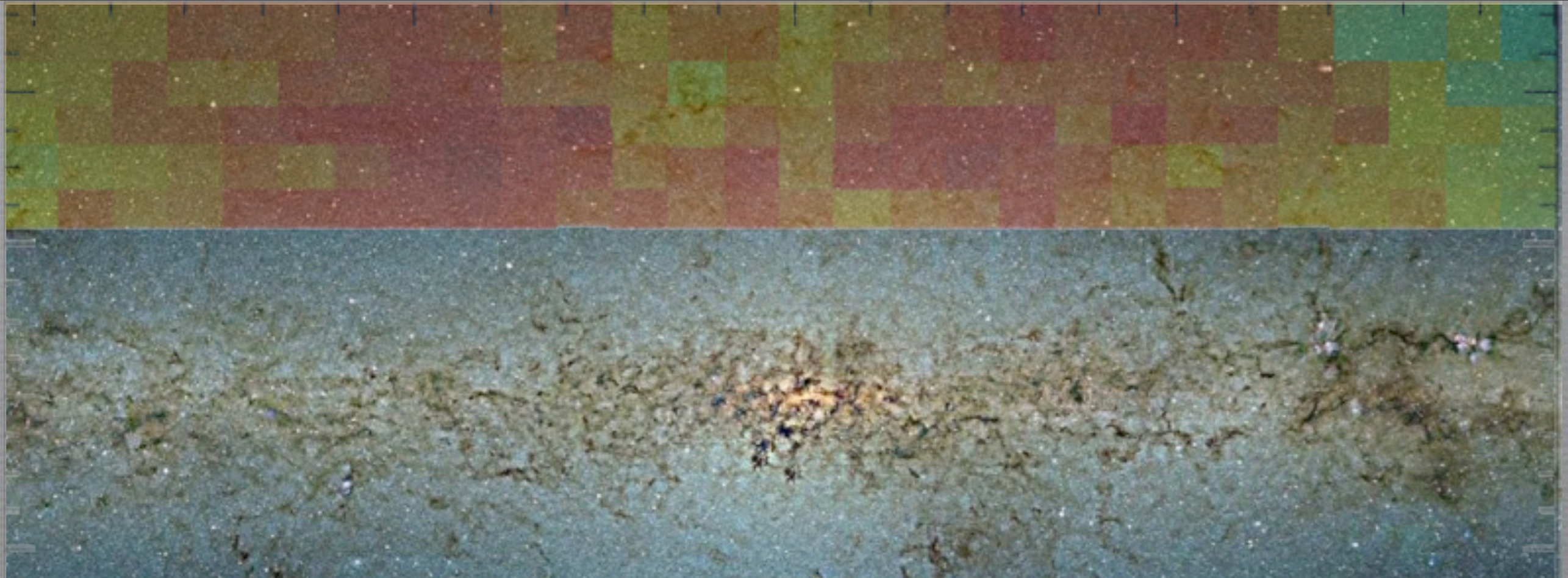







credits: Ignacio Toledo
© ESO/VVV Consortium/Ignacio Toledo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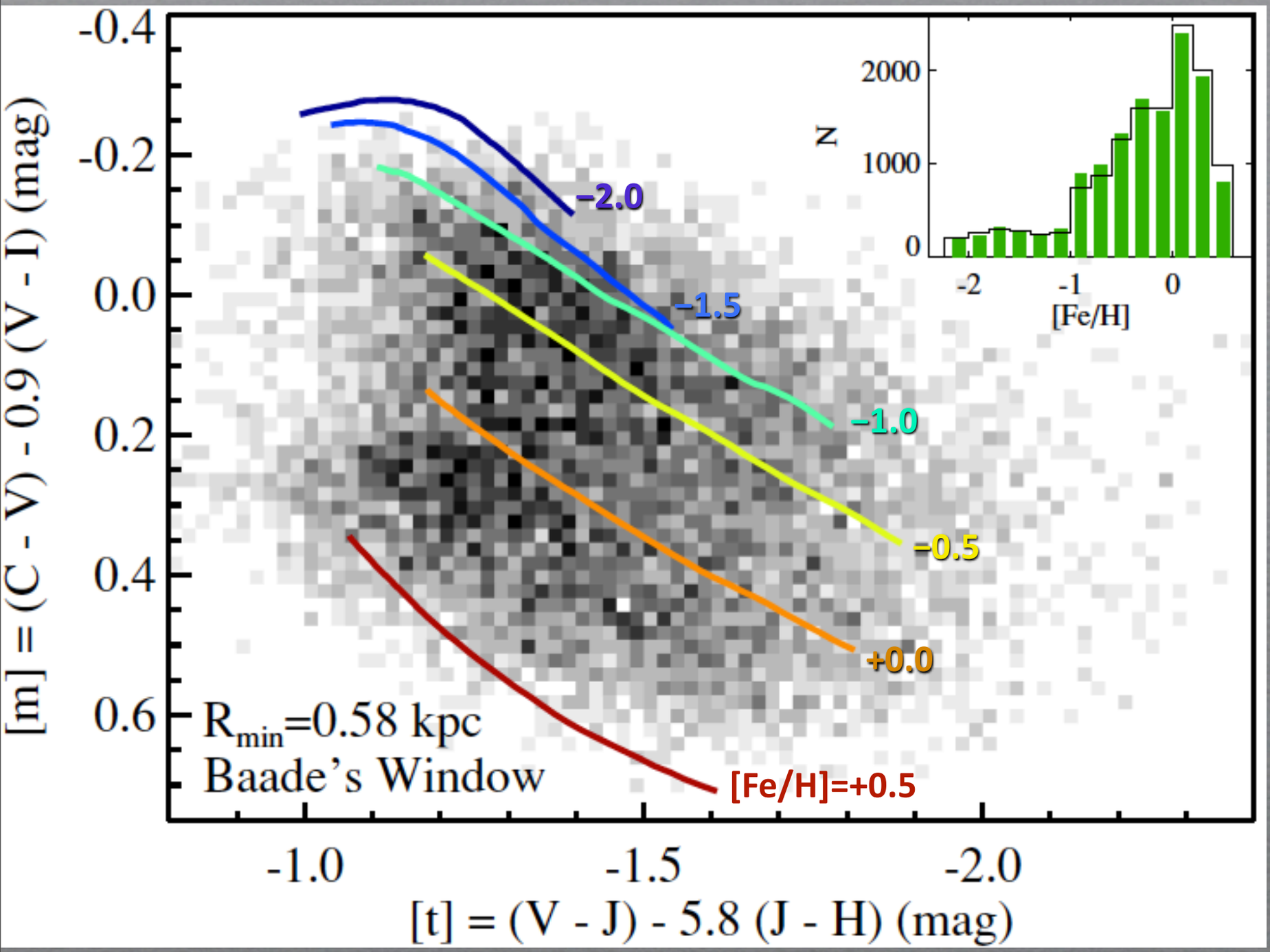
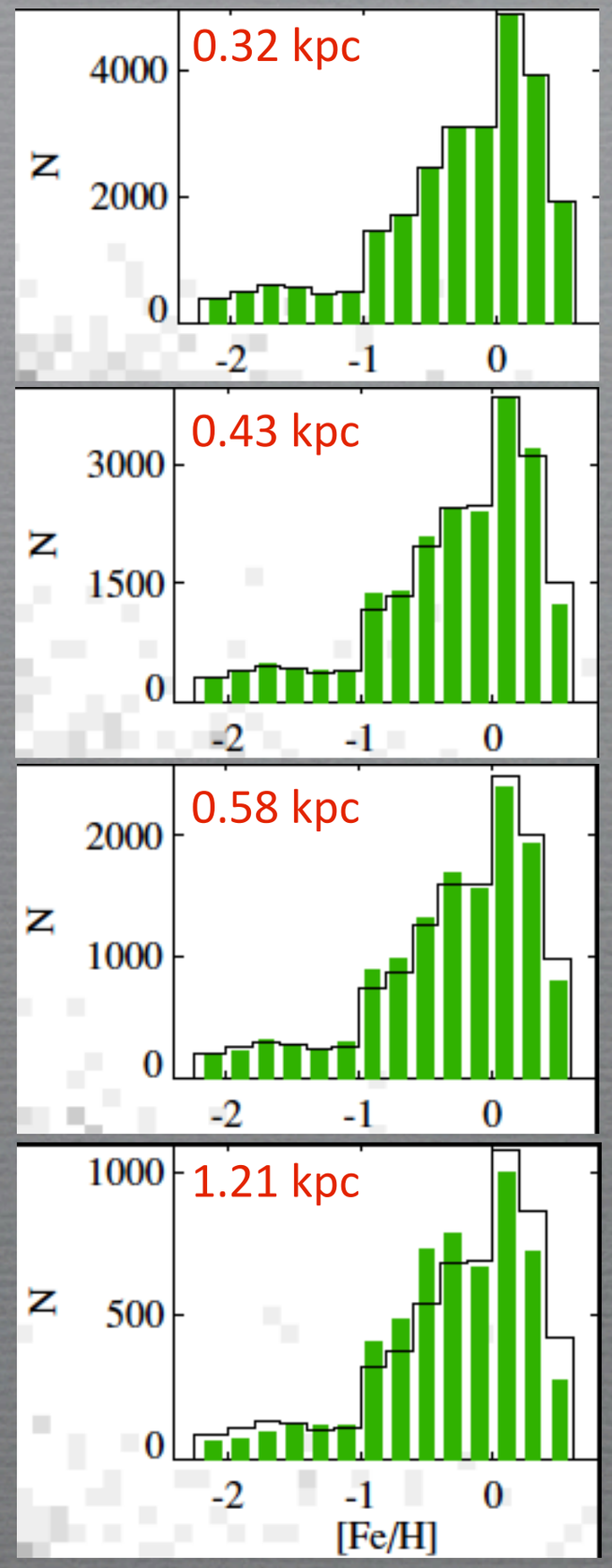
Bulge Treasury Programme with WFC3@HST

Brown et al. (2009, 2010)





Bulge Treasury Programme with WFC3@HST

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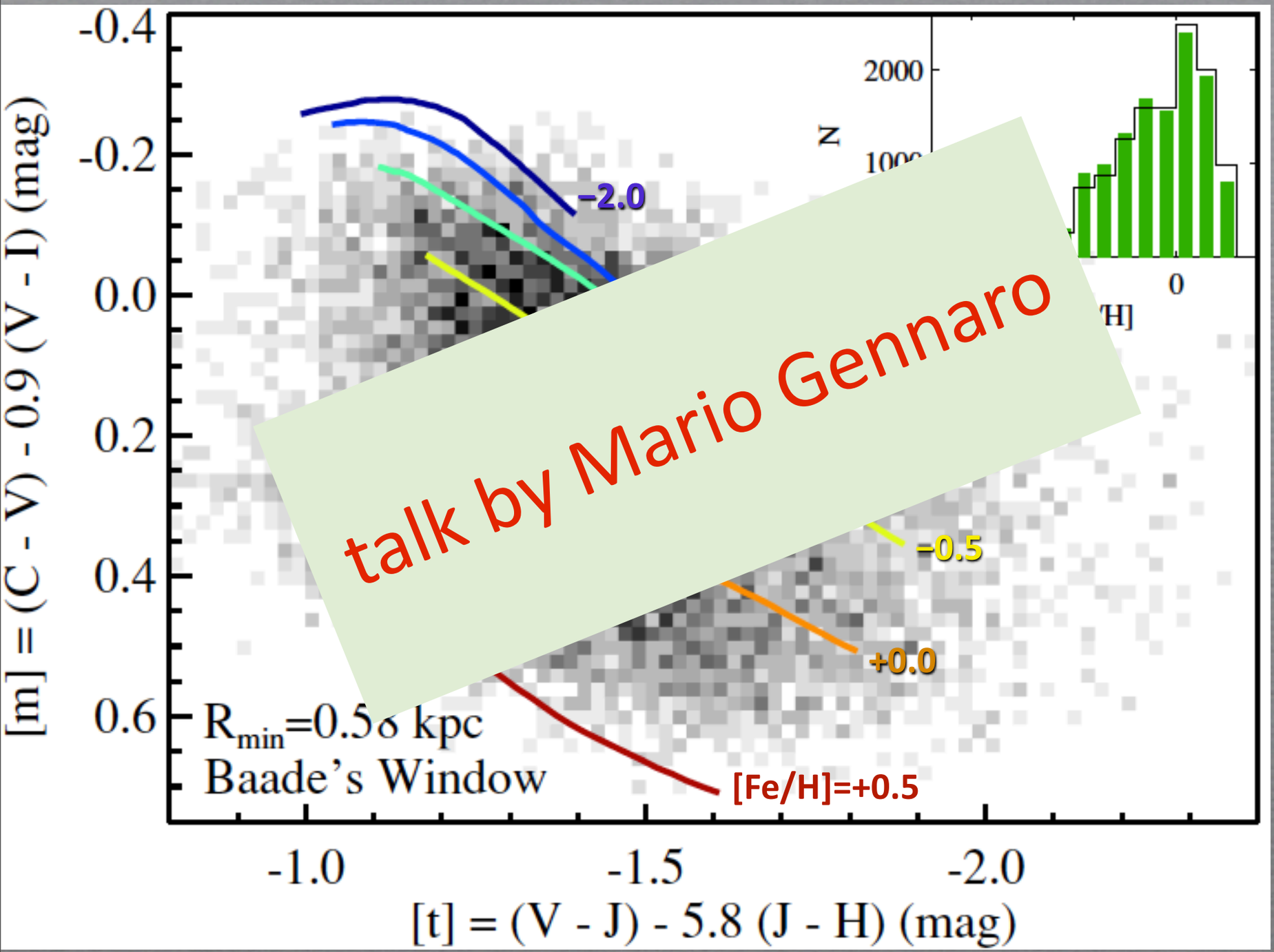
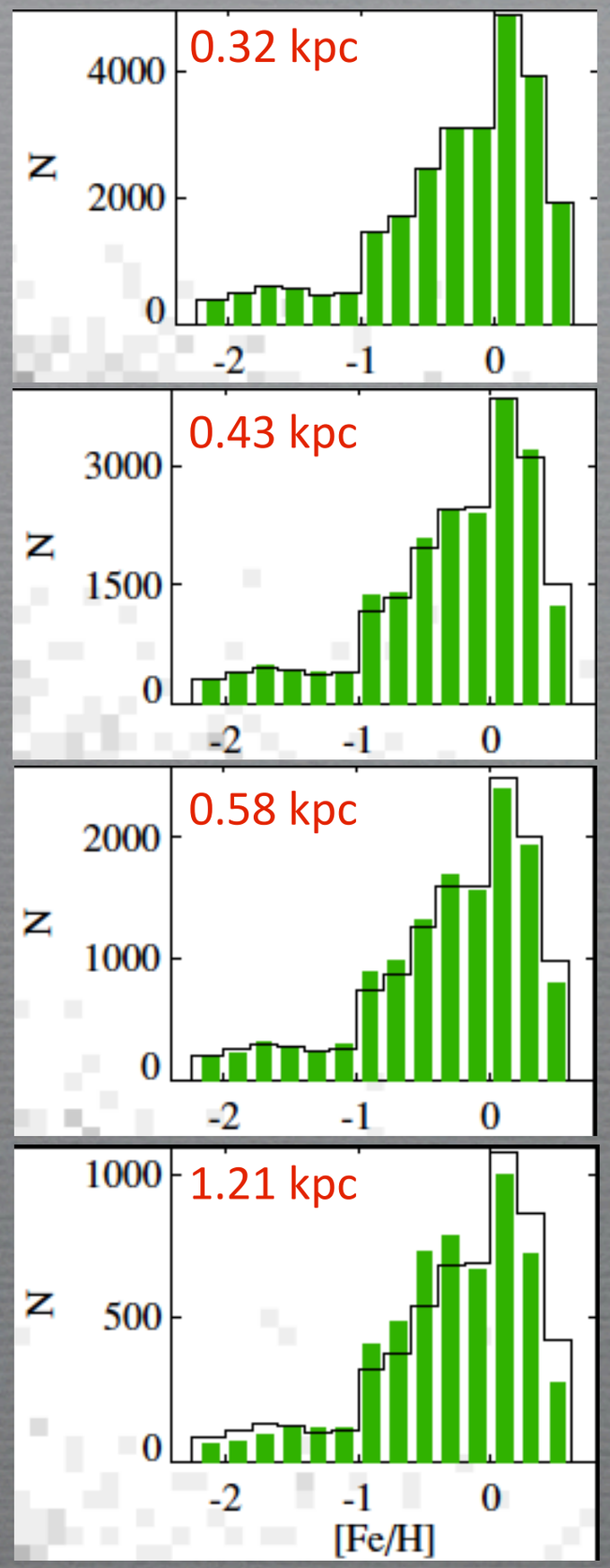
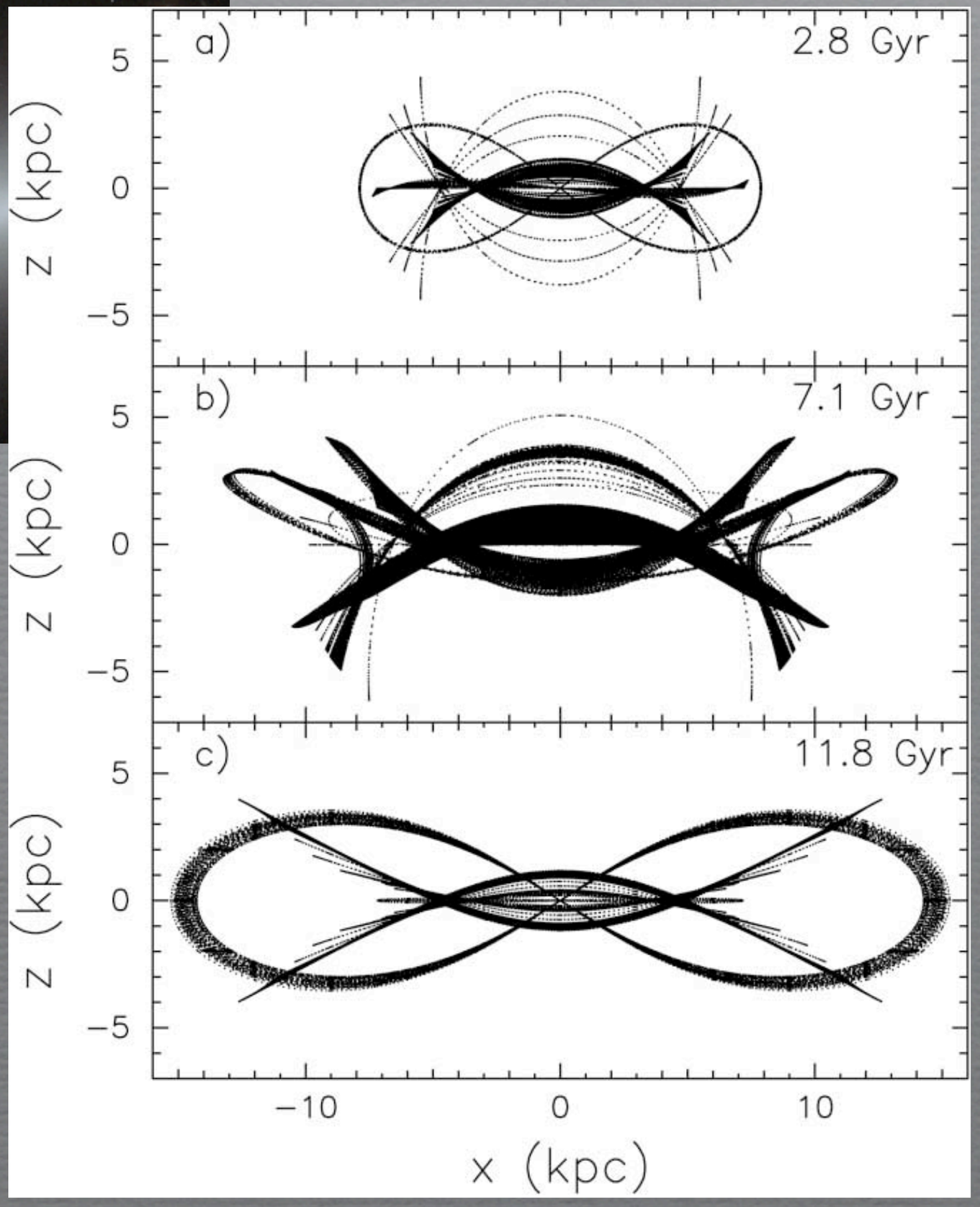


talk by Mario Gennaro

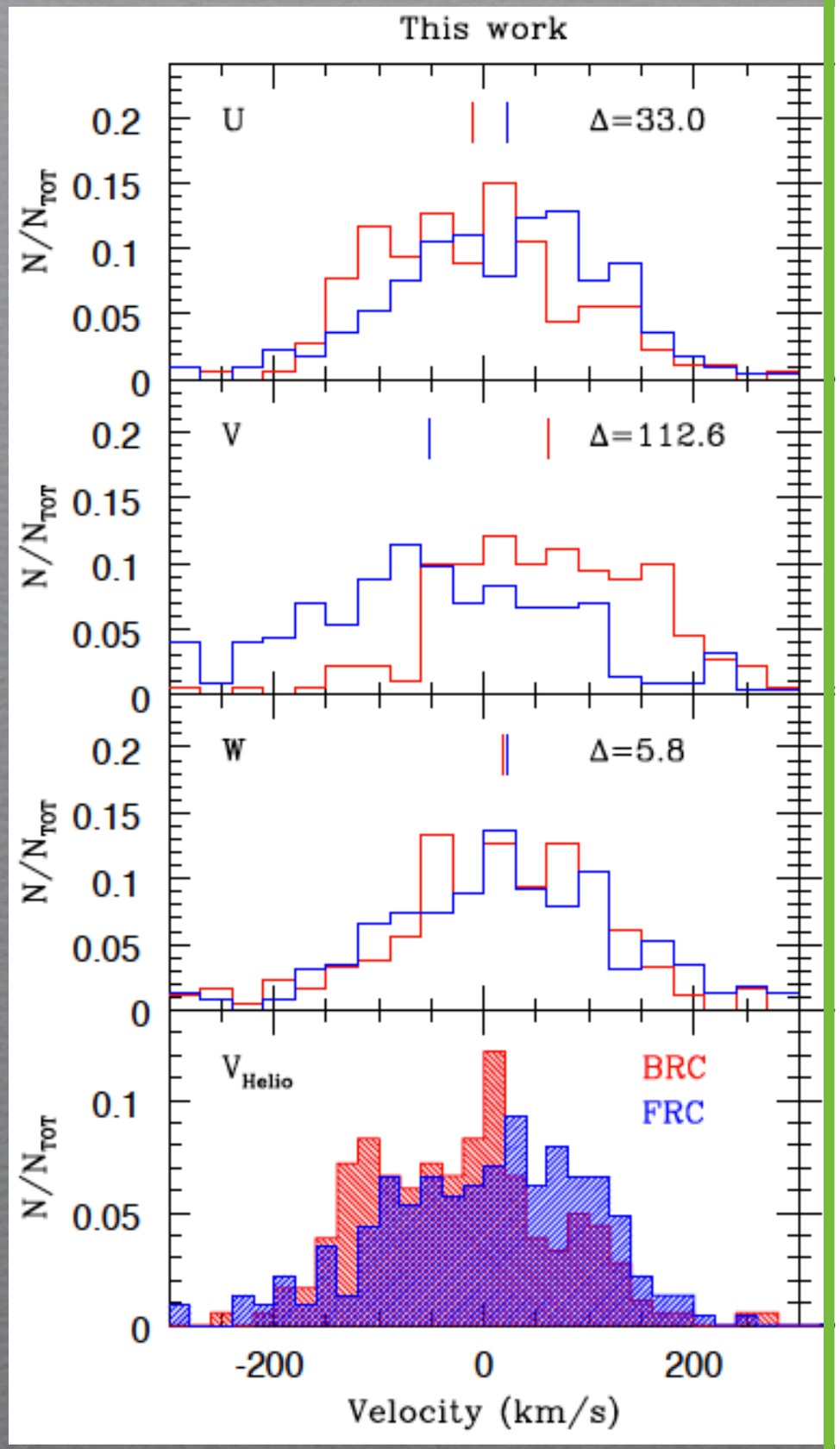


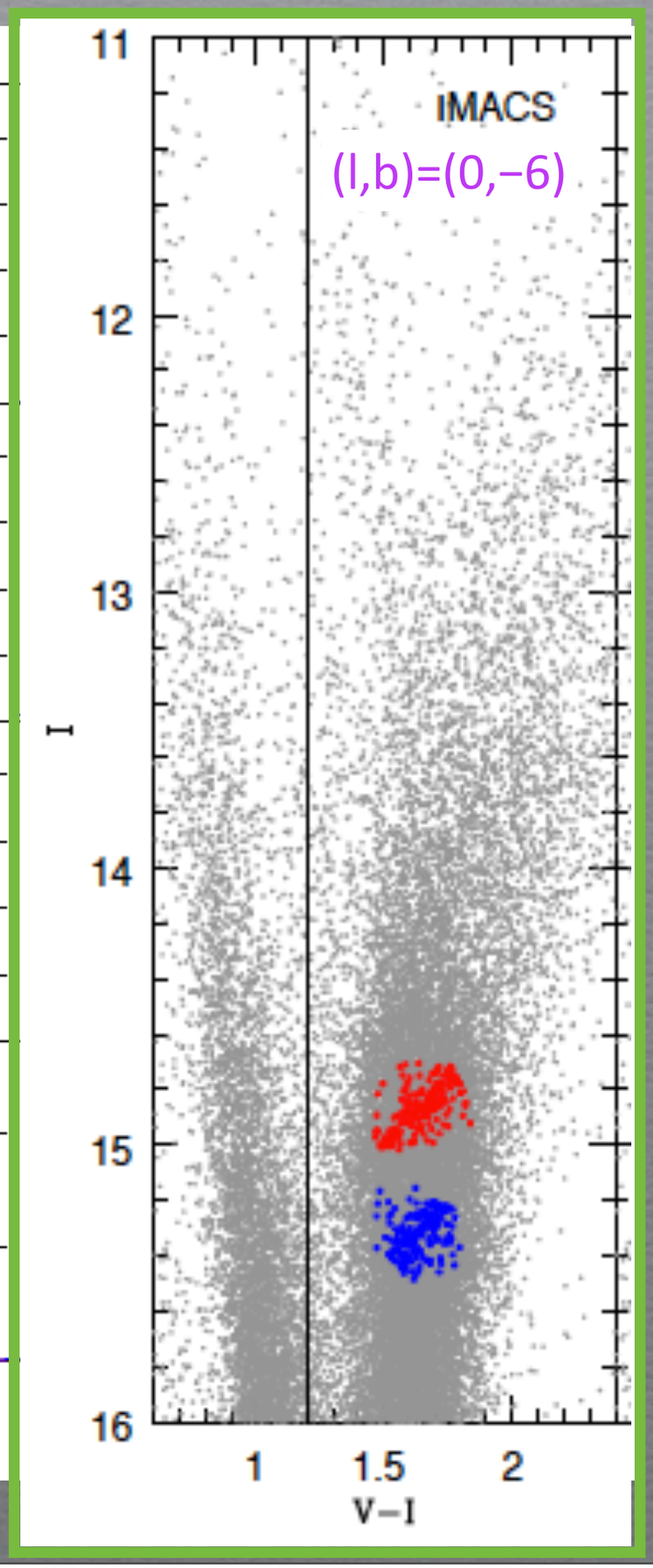
Kinematics in the X-shaped bulge



3D kinematics in the X-shaped bulge

Vásquez et al. (2013)

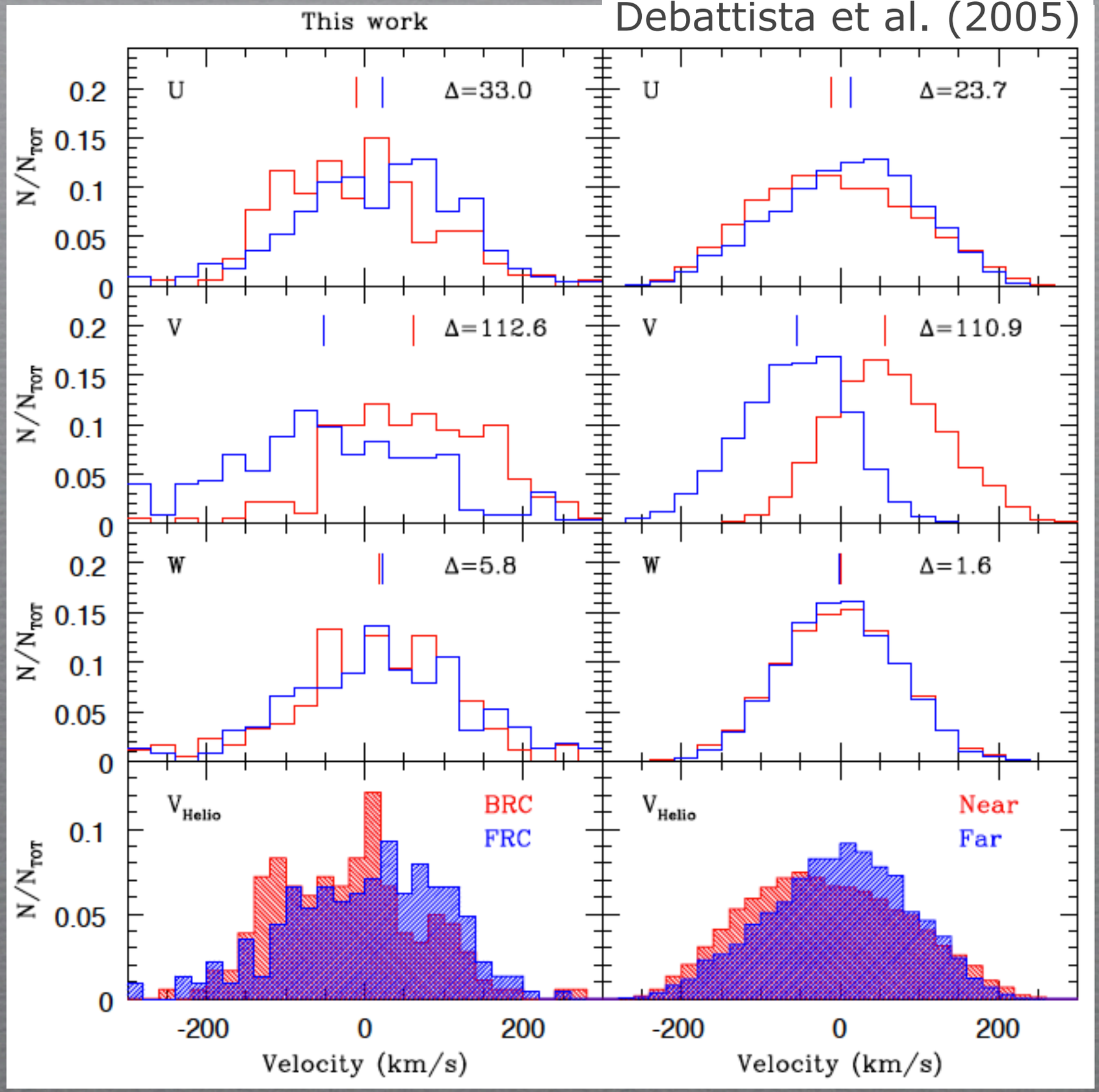




3D kinematics in the X-shaped bulge

Vásquez et al. (2013)

see also:
de Propris et al (2011)
Uttenthaler et al. (2012)
Ness et al. (2012)



Gaia ESO Spectroscopic Survey (GES)

PI: Gilmore, Randich

Targetting ~ 100,000 stars in the Milky Way

300 nights spread over 5 years 2012-2016

with GIRAFFE and UVES @ VLT

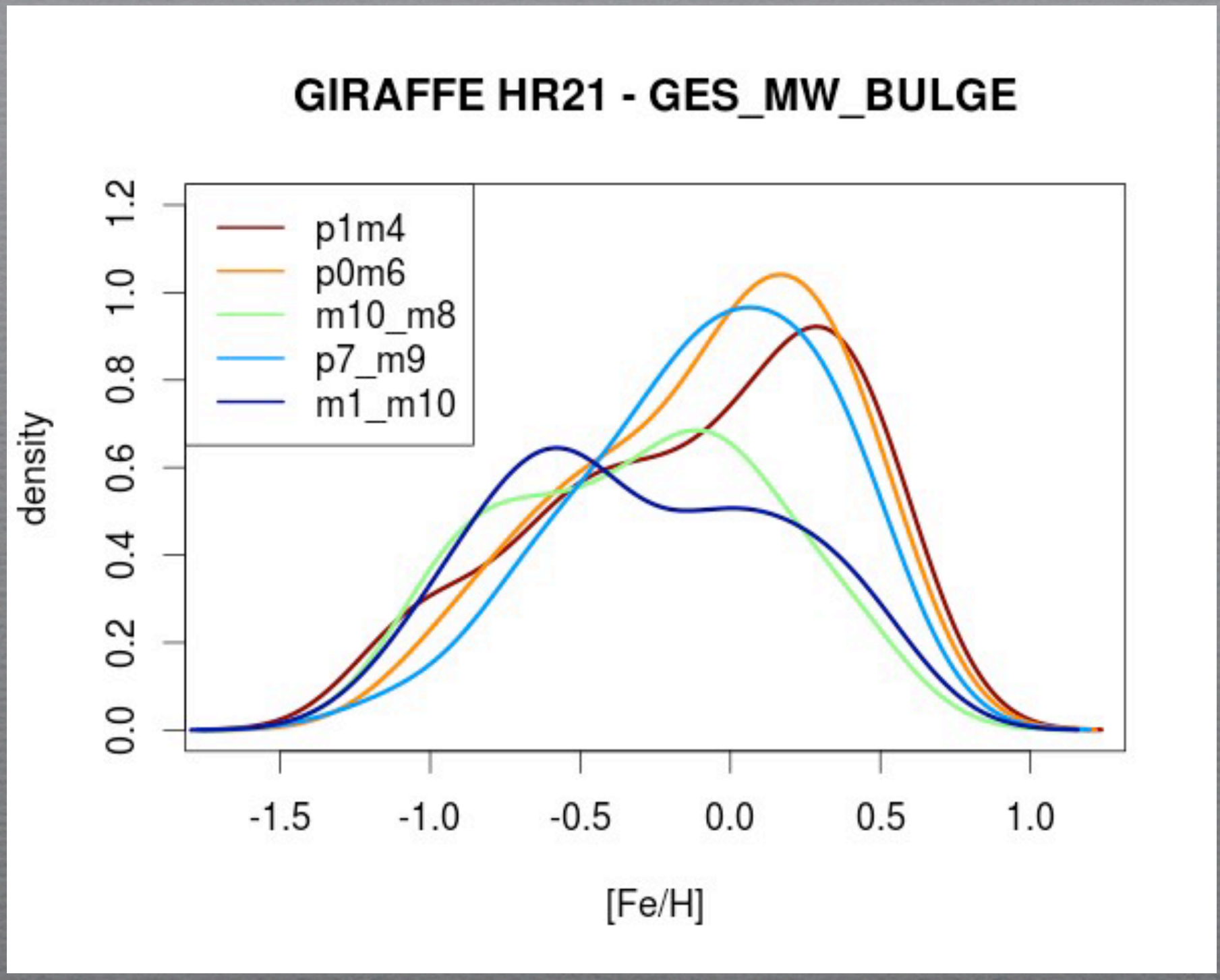
at R=25,000 ~8500Å S/N~100

in the bulge: ~30 nights ~10,000 Red Clump stars

Gaia ESO Spectroscopic Survey (GES)

PI: Gilmore, Randich

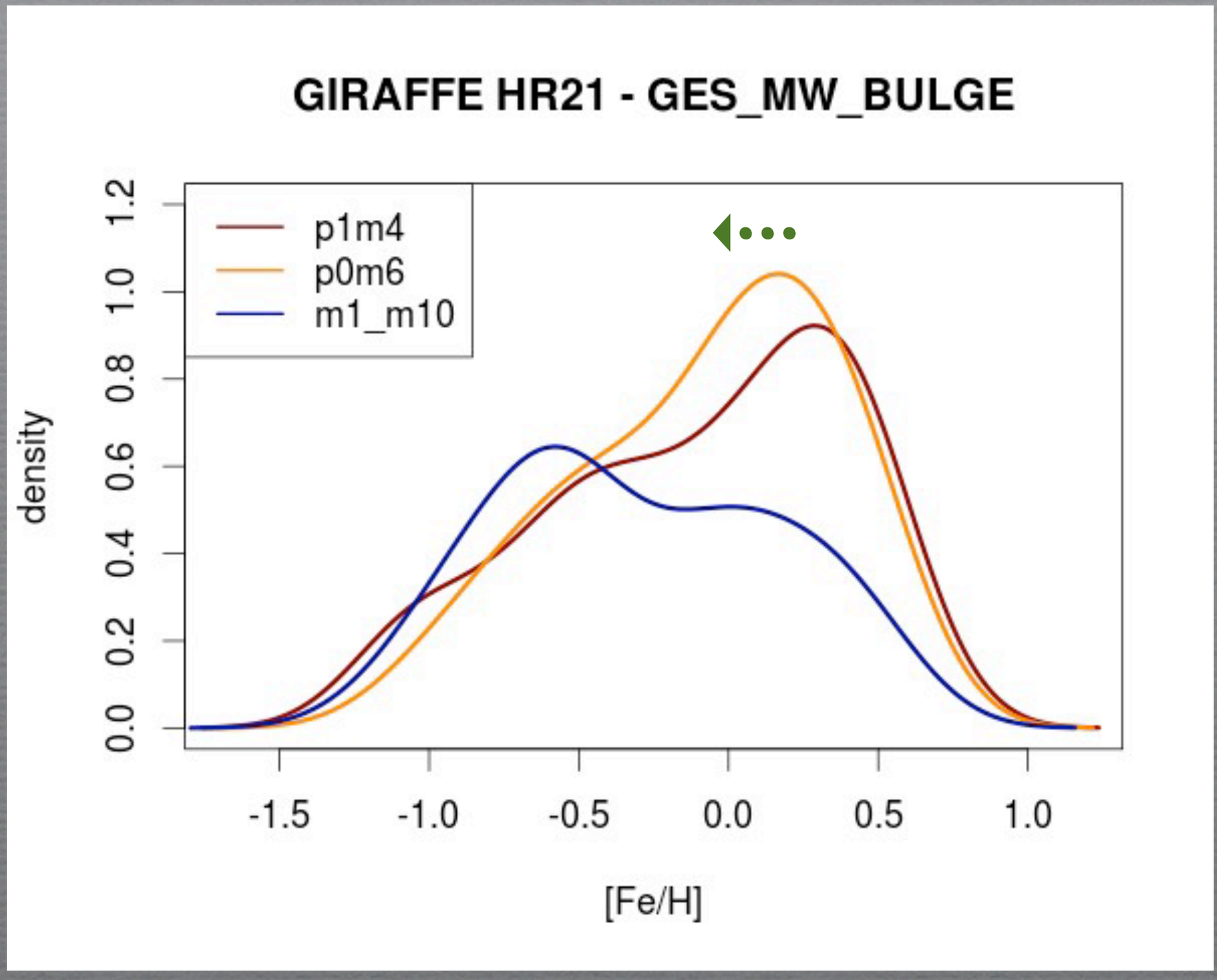
Field observed in 2012: preliminary results



Gaia ESO Spectroscopic Survey (GES)

PI: Gilmore, Randich

Field observed in 2012: preliminary results



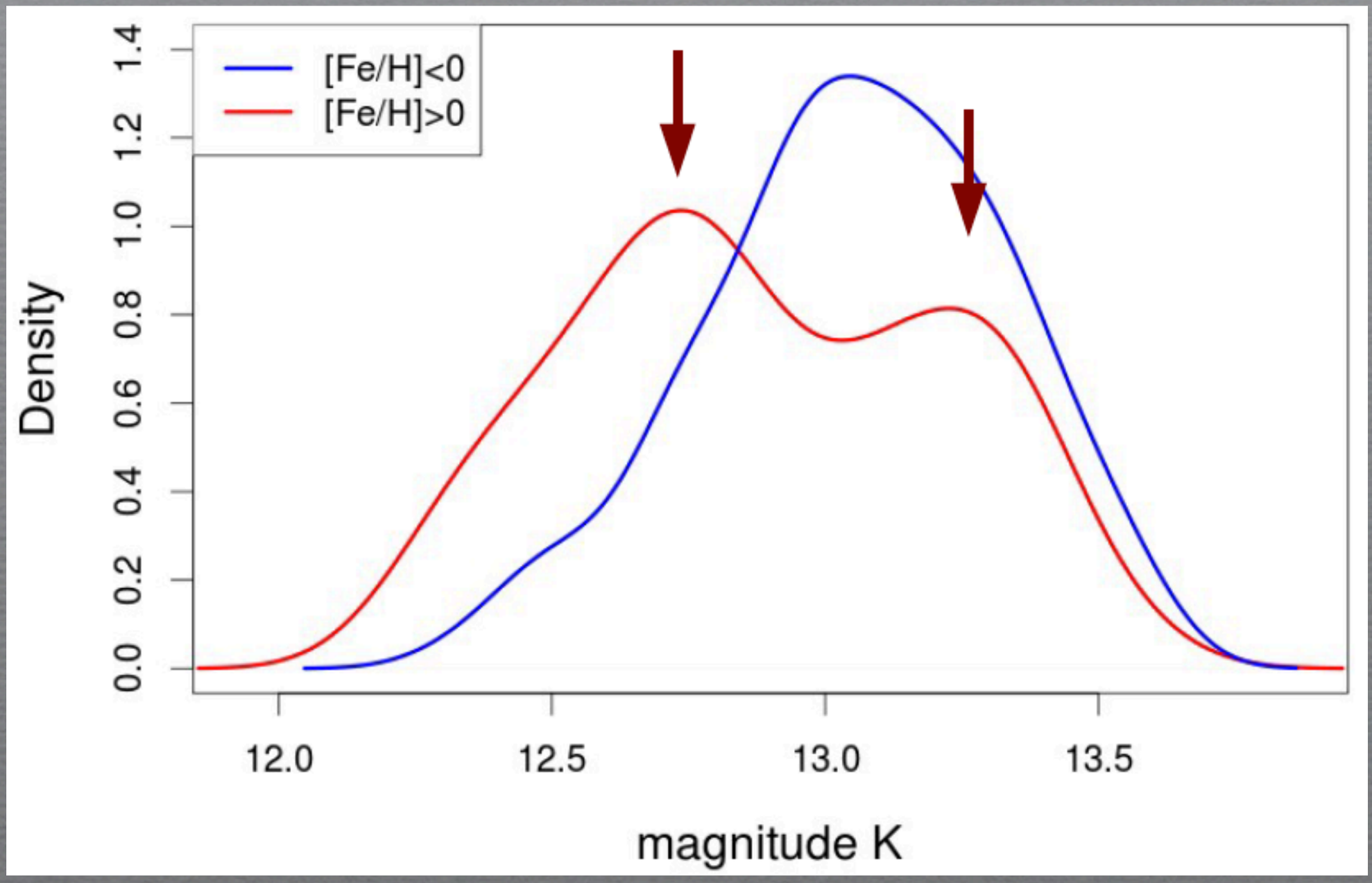
Gaia ESO Spectroscopic Survey (GES)

PI: Gilmore, Randich

Field observed in 2012: preliminary results

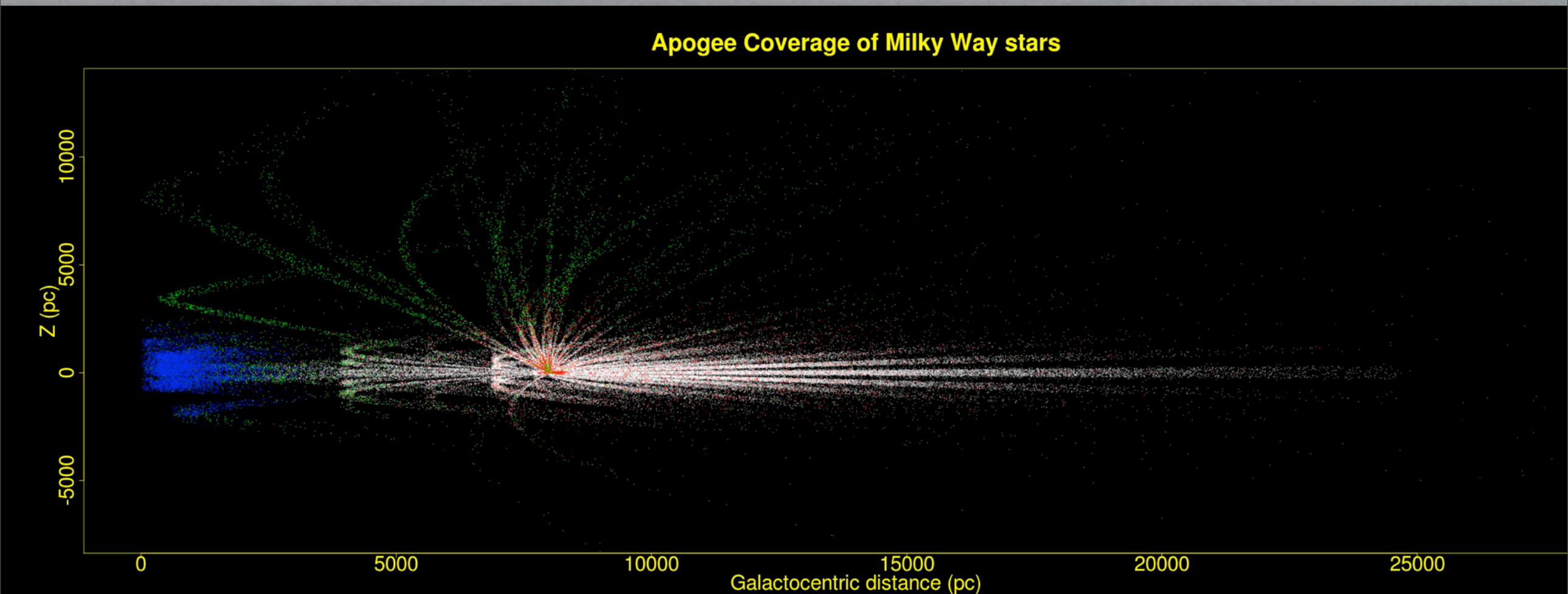
Metal rich population follows the x-shaped structure

e.g. Ness et al. (2013), Uttenthaler (2012)



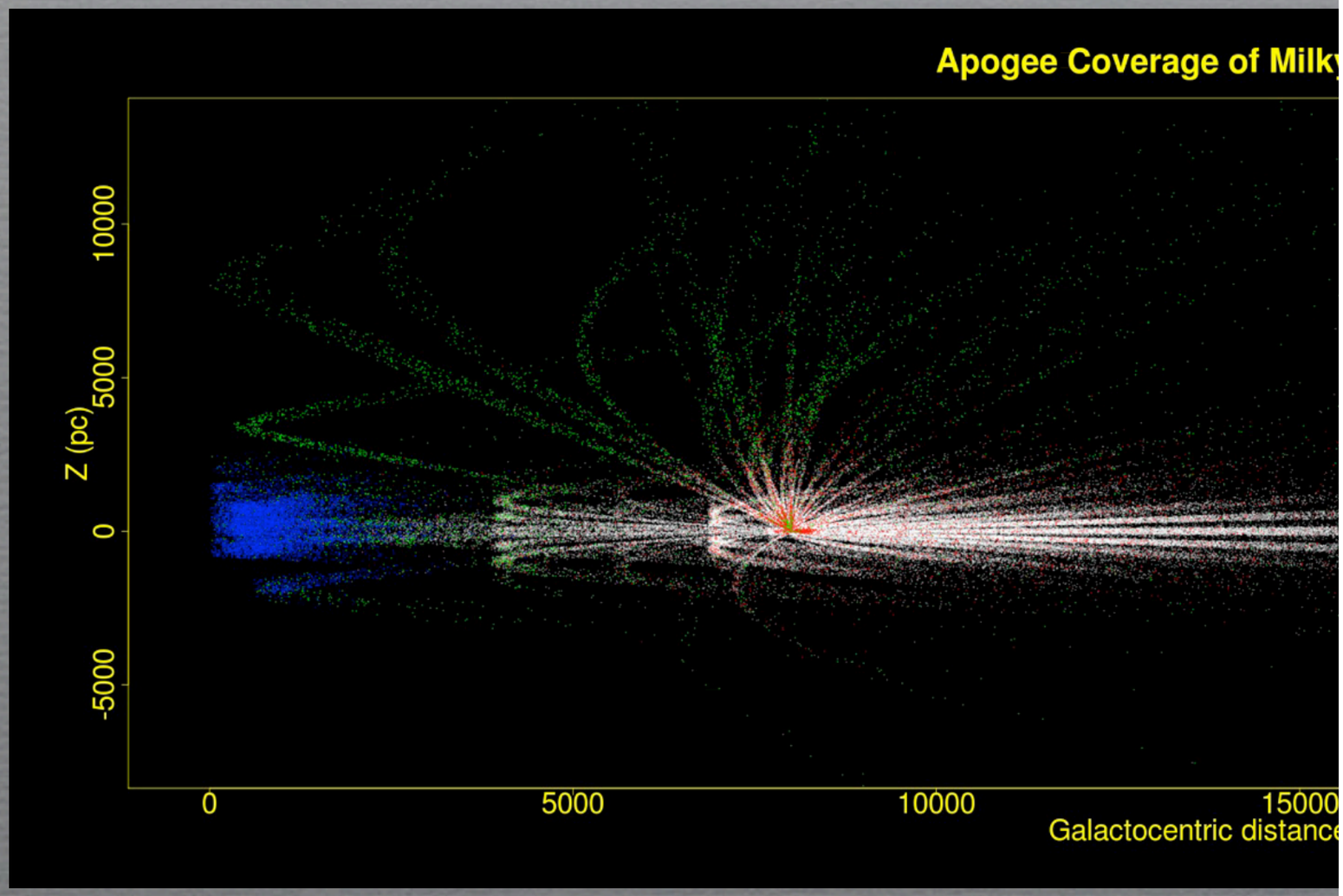
PI: Majewski

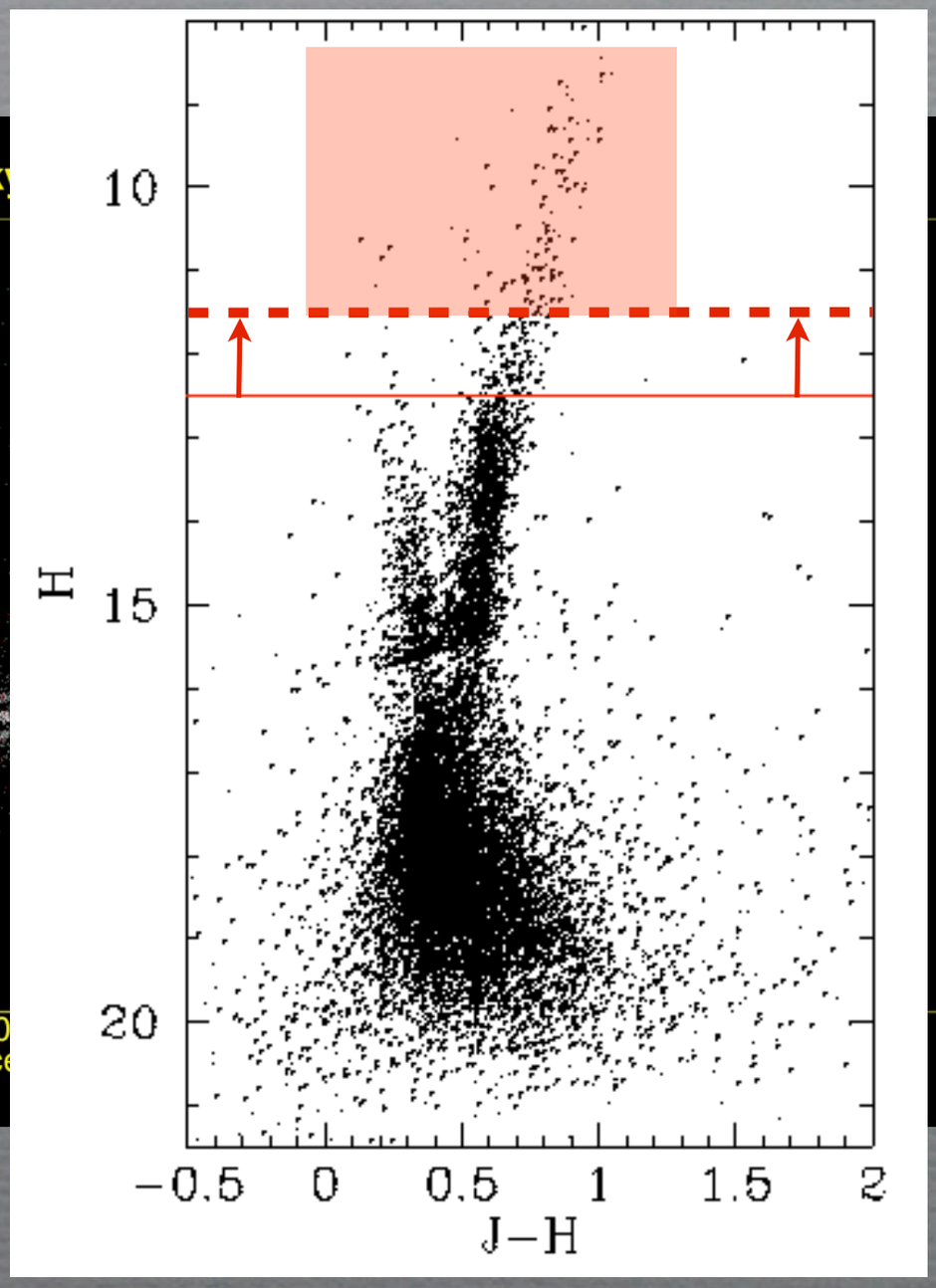
near-IR survey 100,000 stars down to H~12,5



PI: Majewski

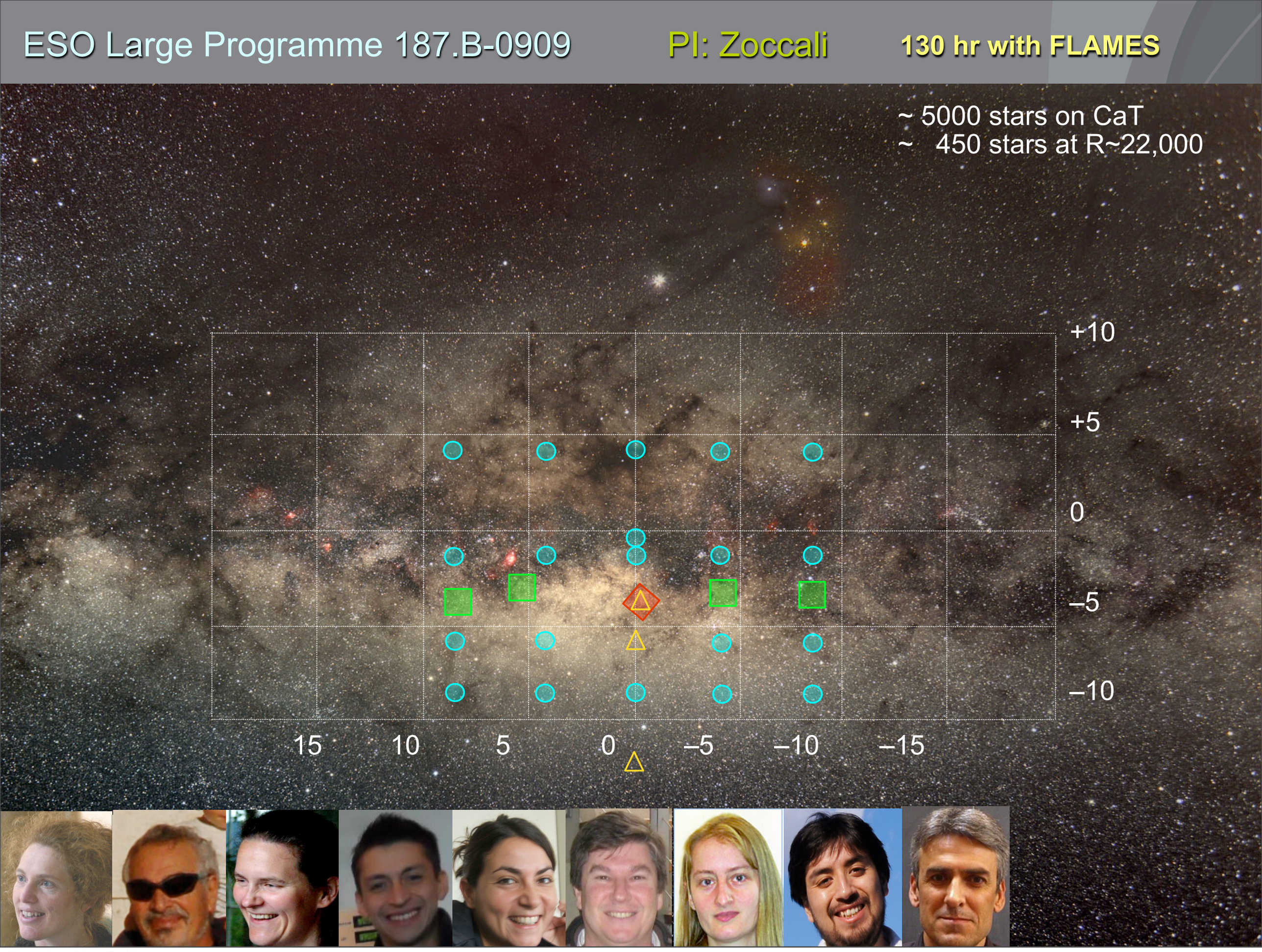
in the bulge ... down to H~11,5



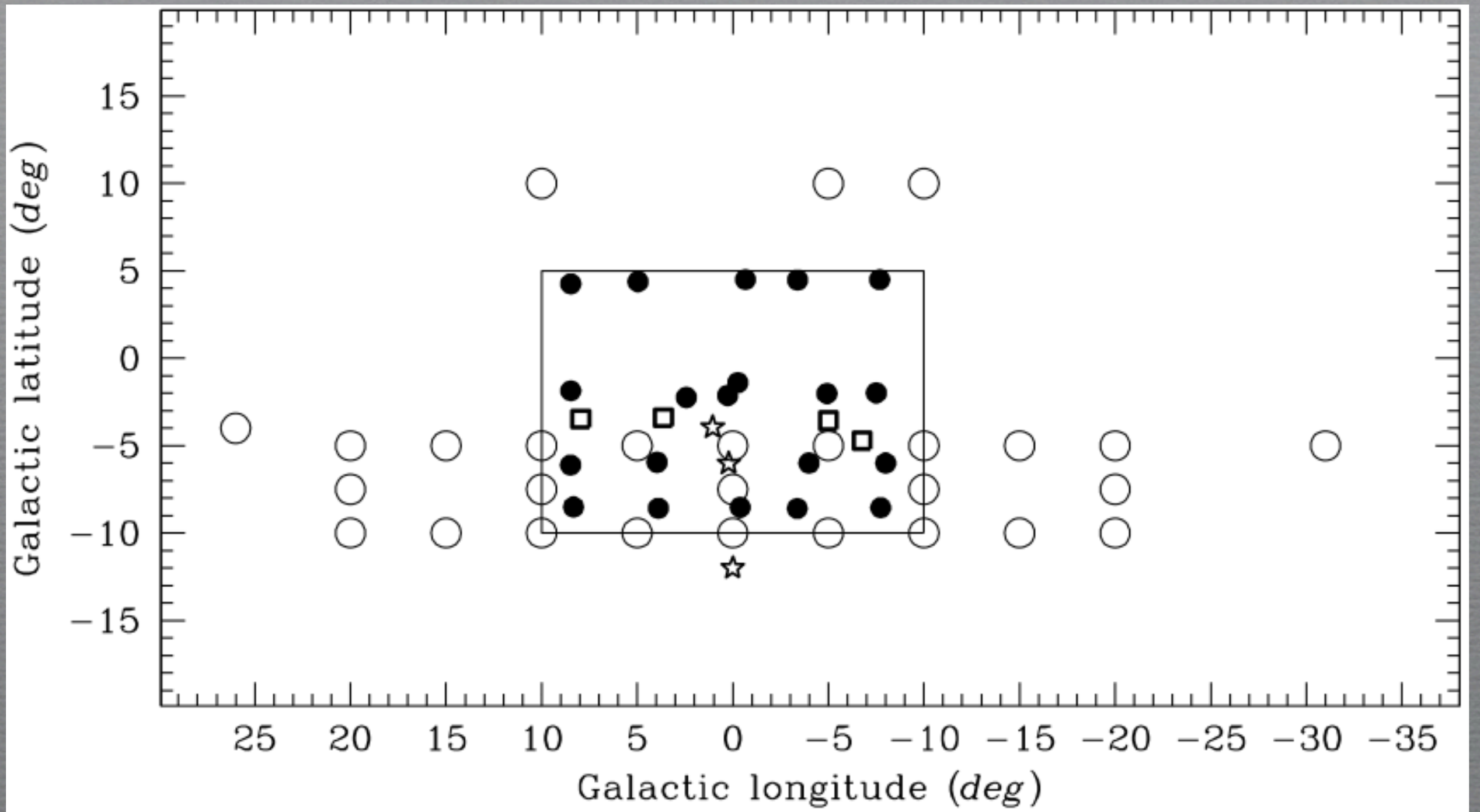


ESO Large Programme 187.B-0909 PI: Zoccali 130 hr with FLAMES

~ 5000 stars on CaT
~ 450 stars at R~22,000



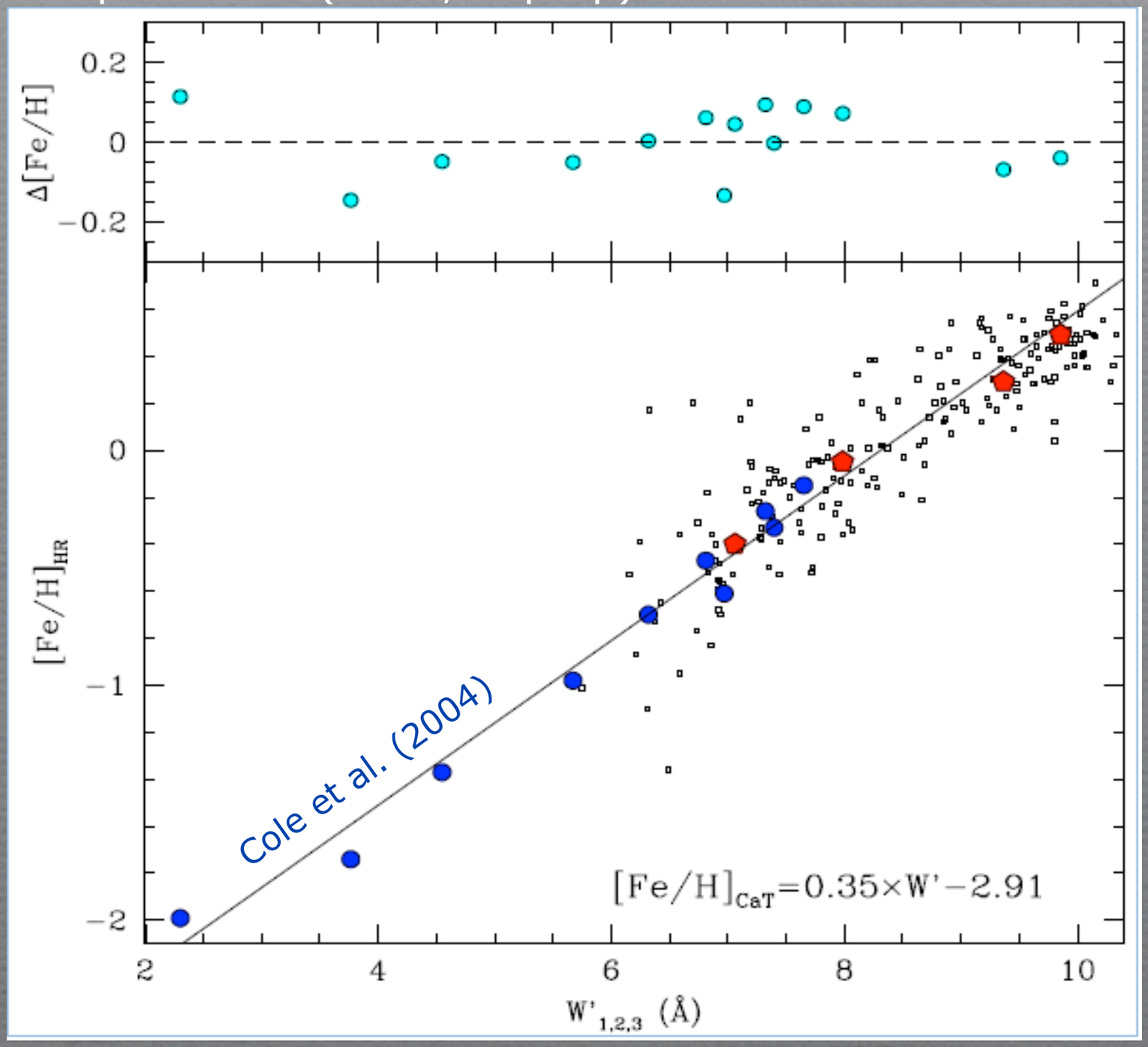
ESO Large Programme 187.B-0909 PI: Zoccali **130 hr with FLAMES**



A New Calibration of Calcium II Triplet EW versus [Fe/H]

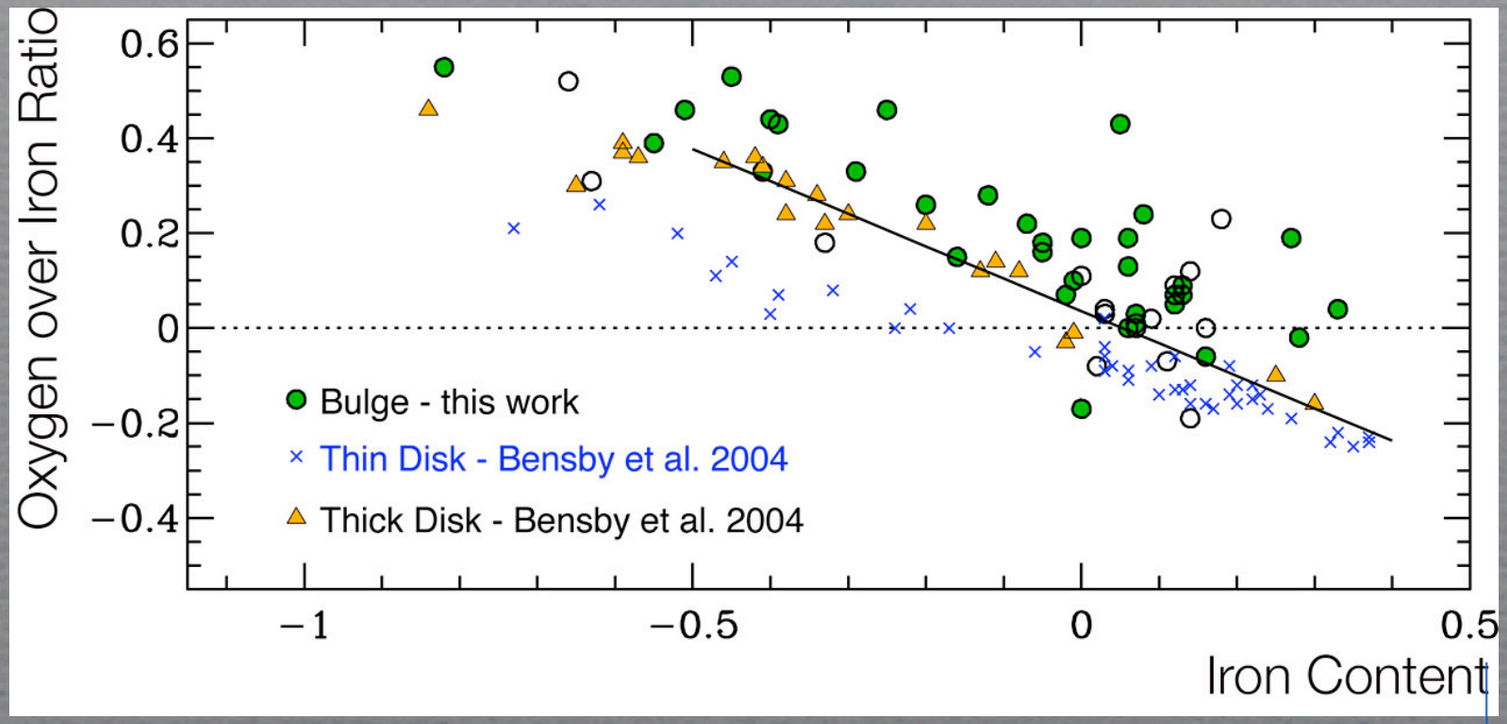
obtained for bulge K giants in Baade's Window

Vasquez et al. (2013, in prep)

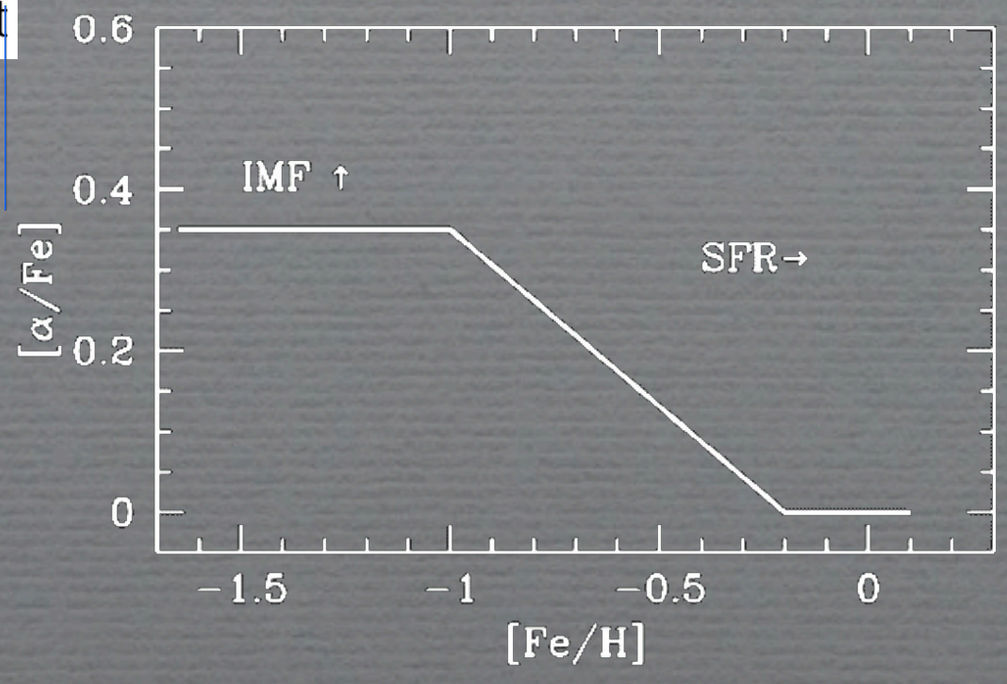


Alpha element ratios in the Galactic bulge

Rich & Origlia (2005-2007)
Zoccali et al. (2006)
Cunha & Smith (2006)
Fulbright et al. (2007)
Lecureur et al. (2007)



bulge must have formed faster than both thick and thin disk



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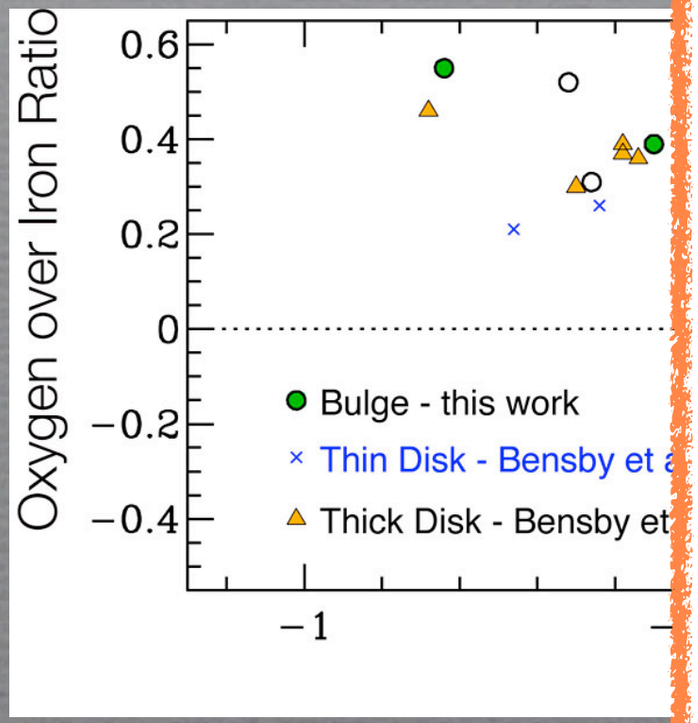
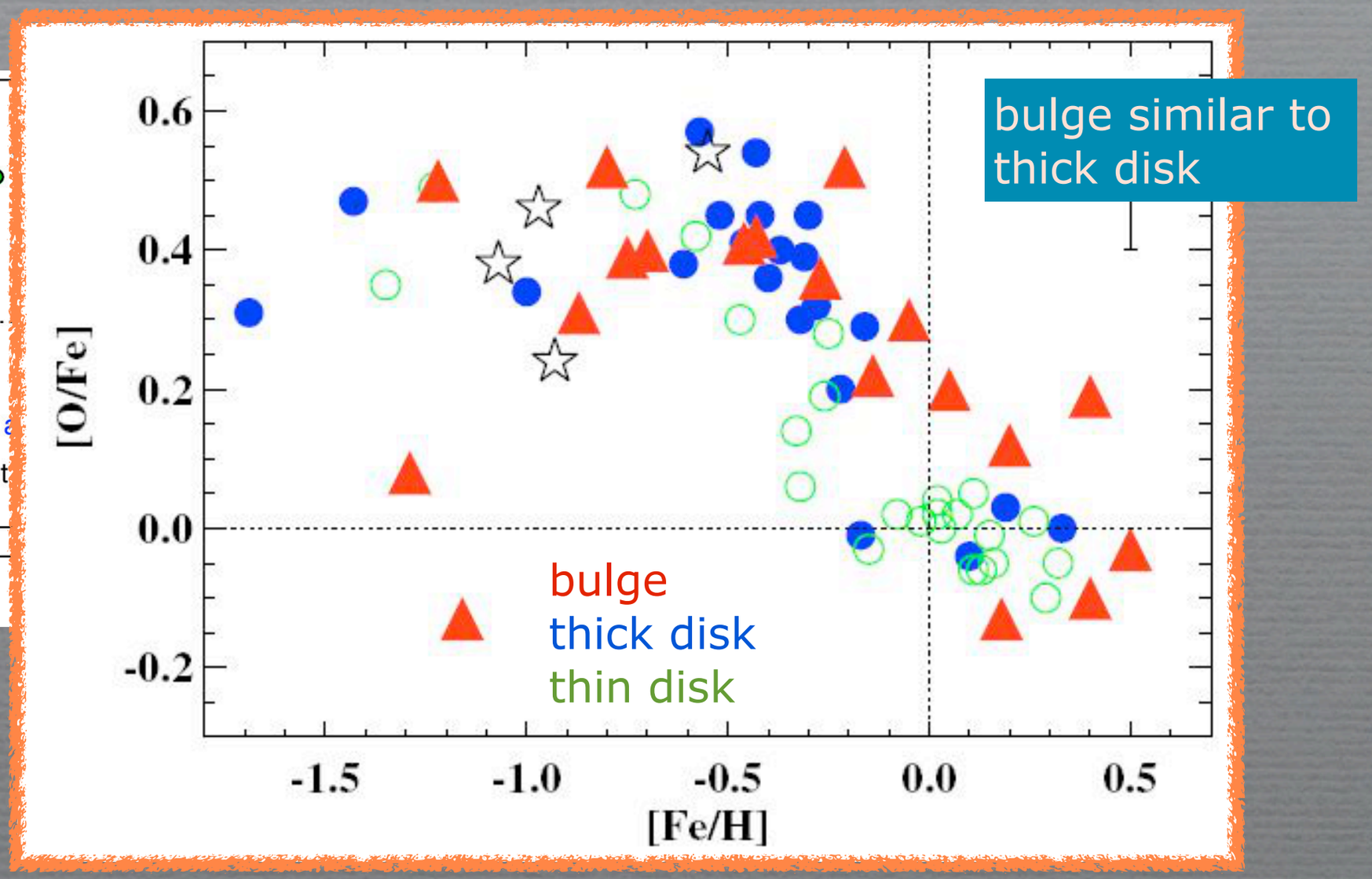


Meléndez et al. (2008)



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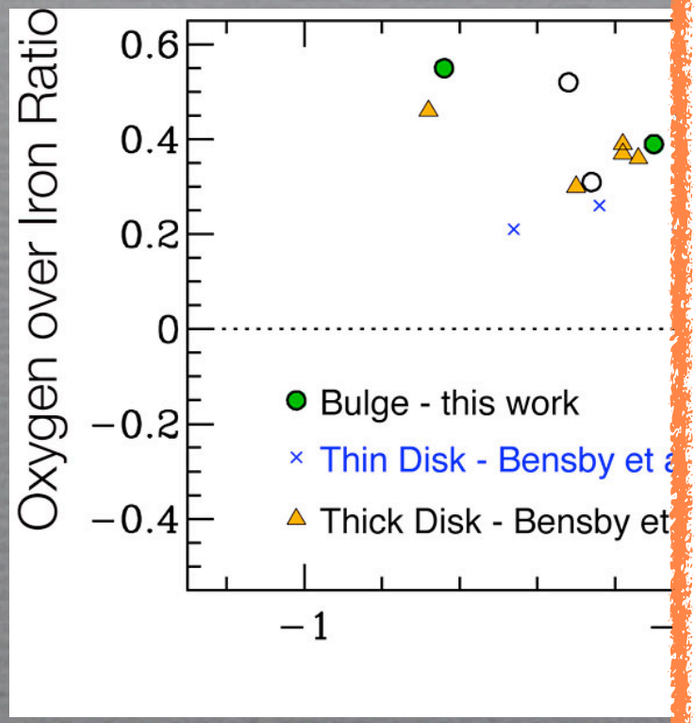
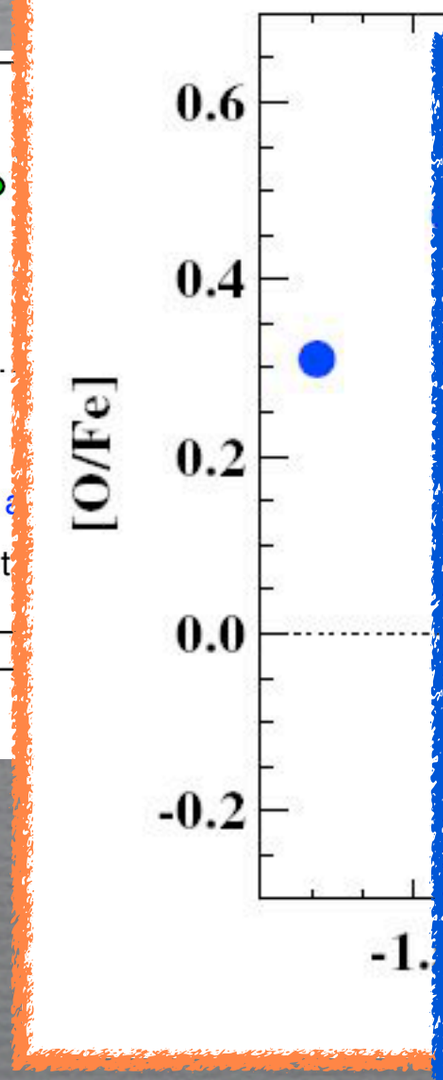
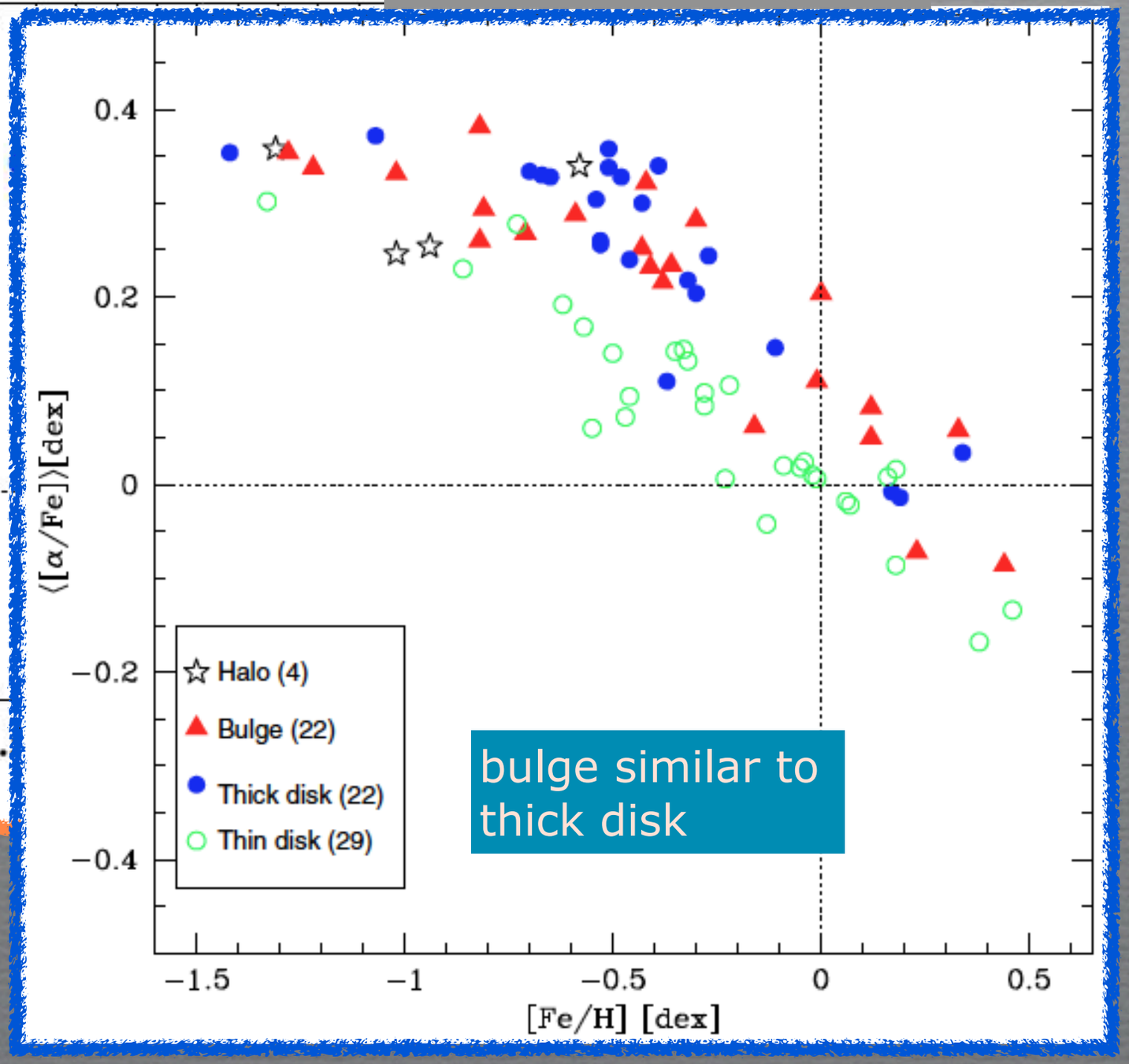


Meléndez et al. (2008)



Alves Brito et al. (2010)

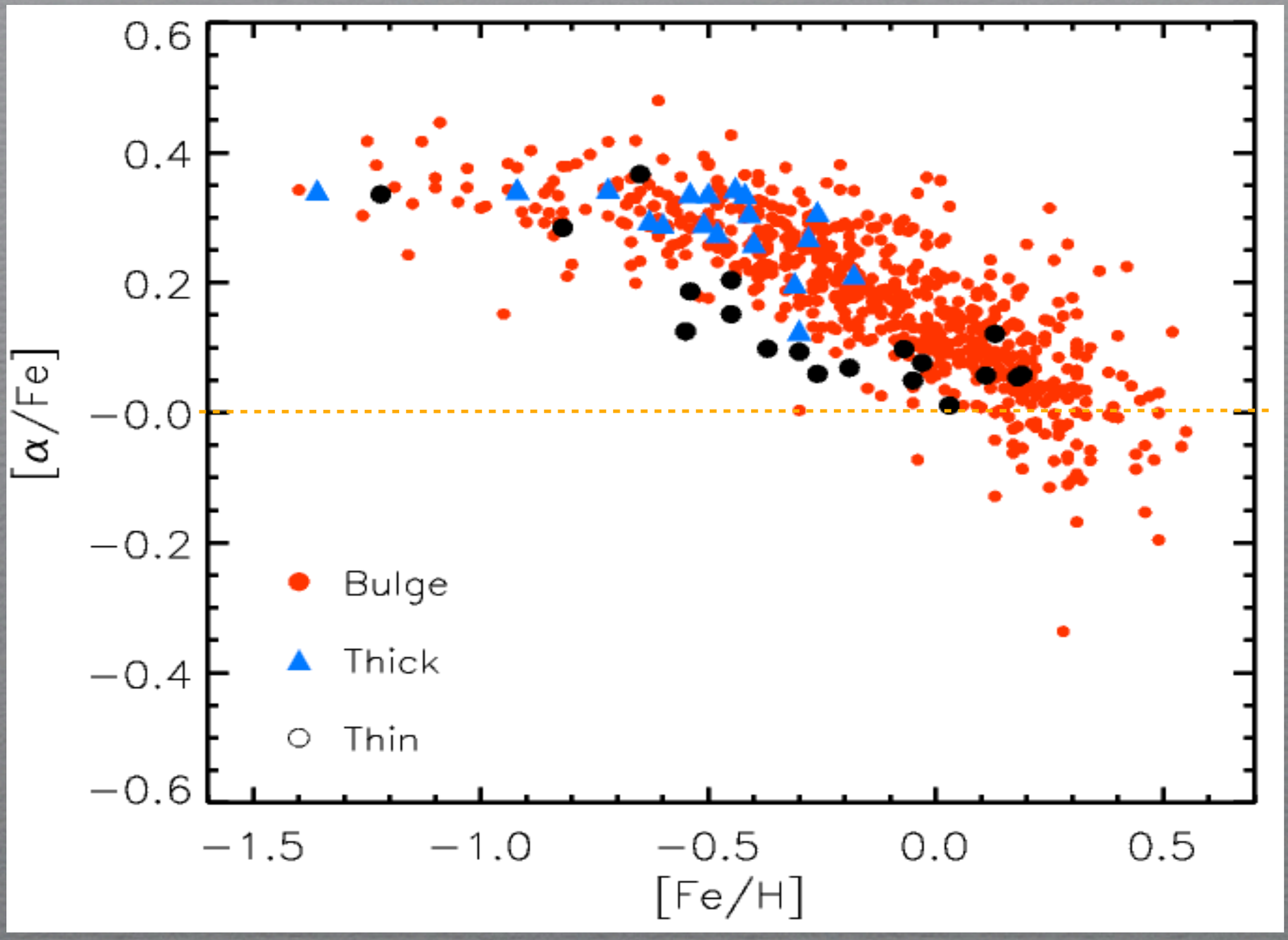


Alpha element ratios in the Galactic bulge

Gonzalez et al. (2011)

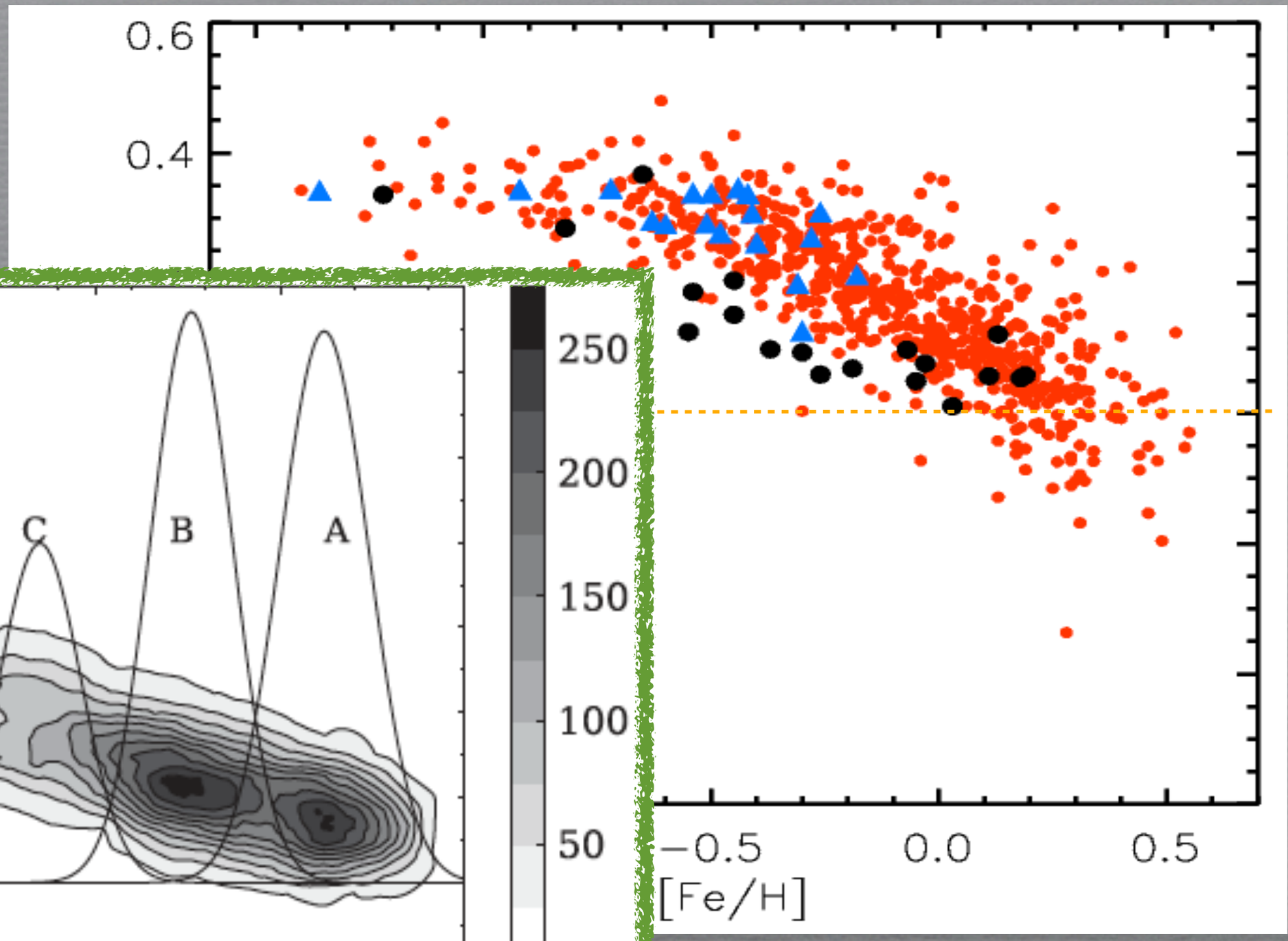
Bulge had short formation timescale. Similar to thick disk.

Shorter than thin disk

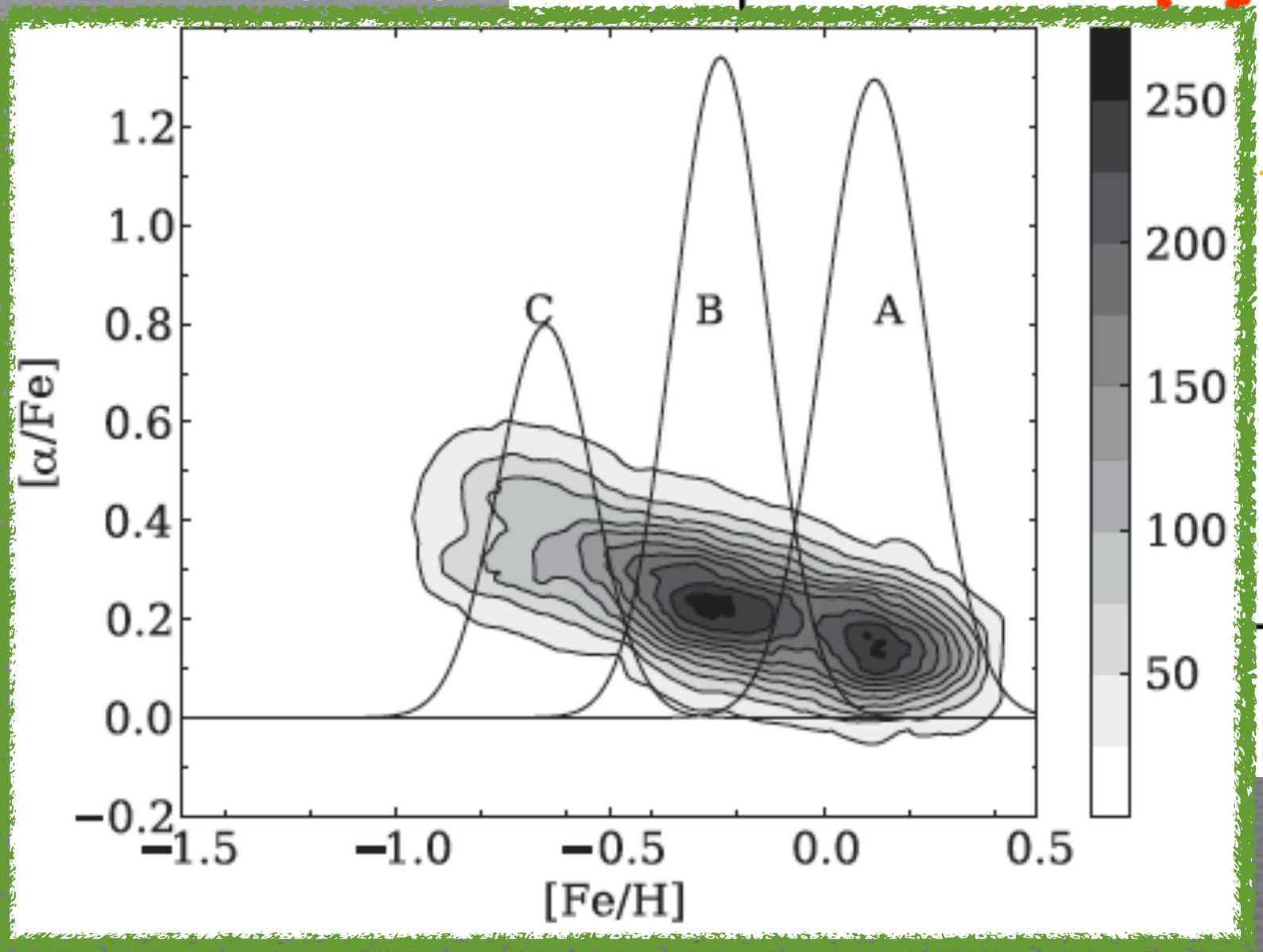


Alpha element ratios in the Galactic bulge

Gonzalez et al. (2011)



Ness et al. (2013)

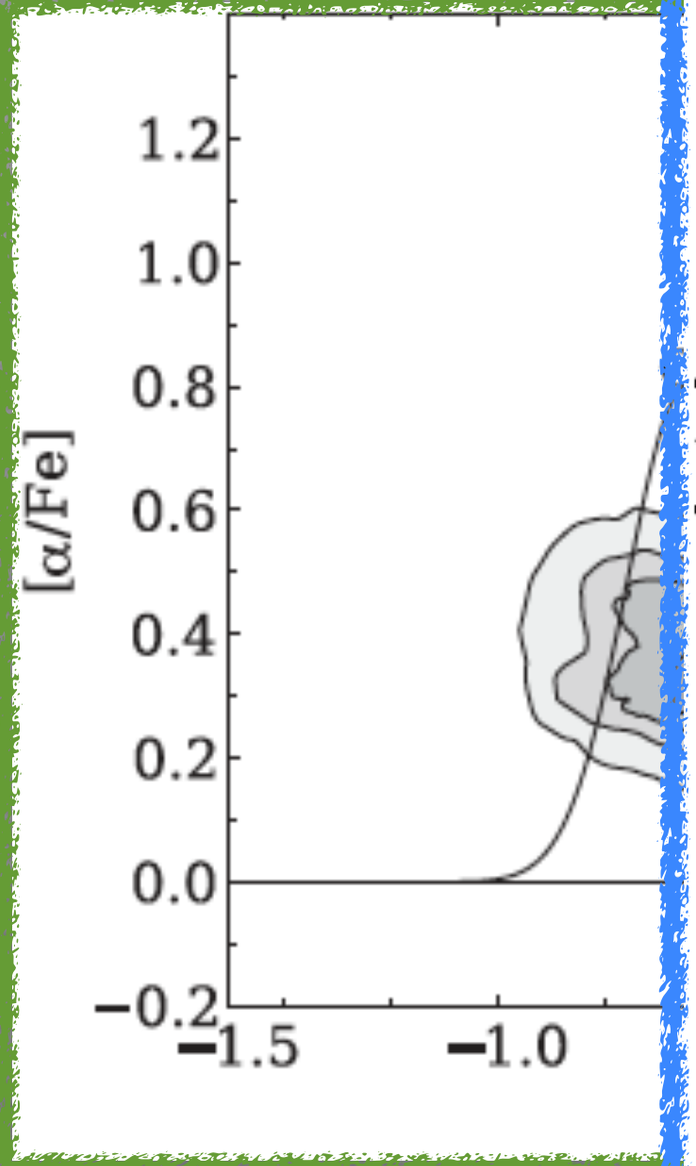


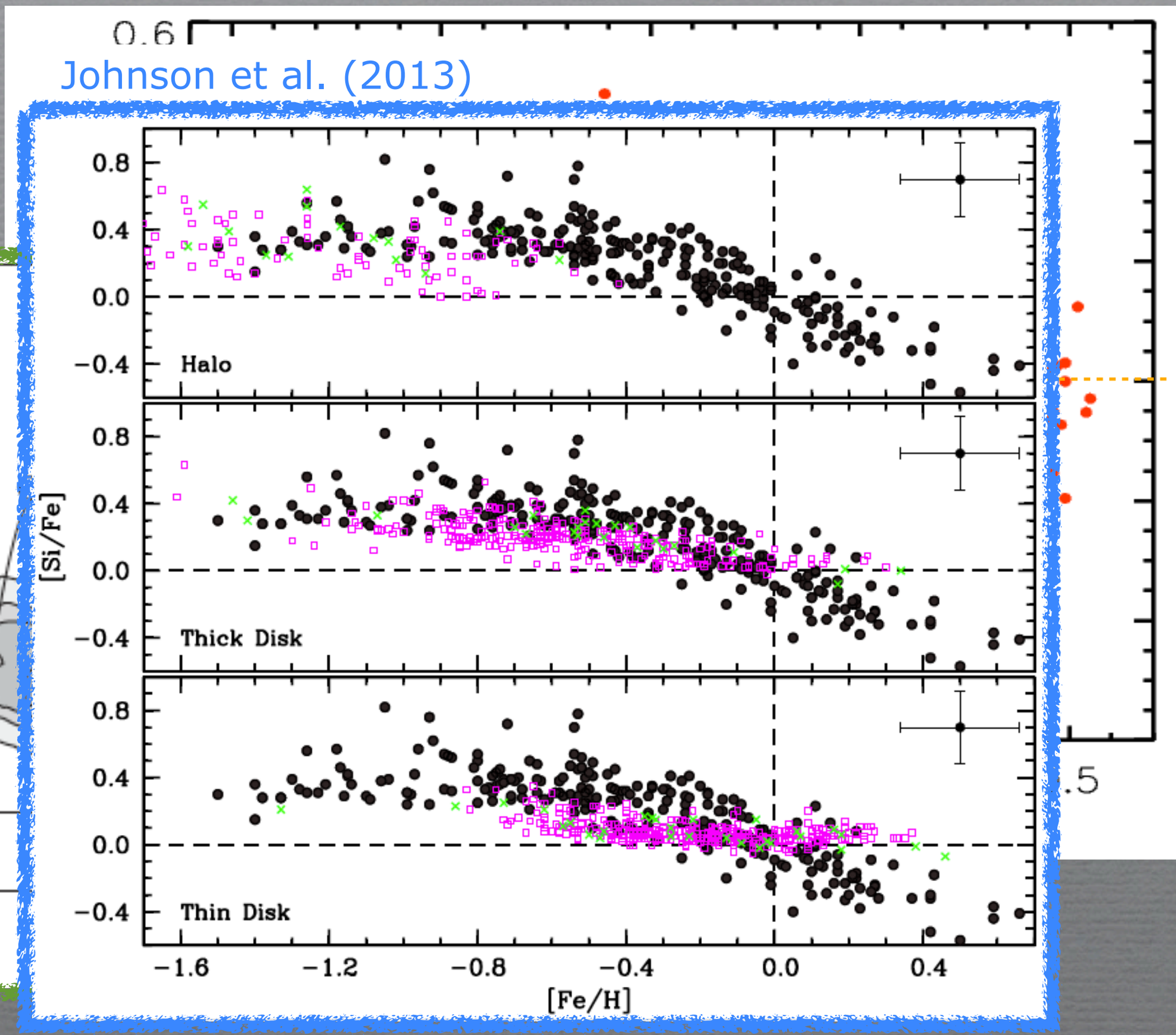
Alpha element ratios in the Galactic bulge

Gonzalez et al. (2011)

Johnson et al. (2013)

Ness et al. (2013)



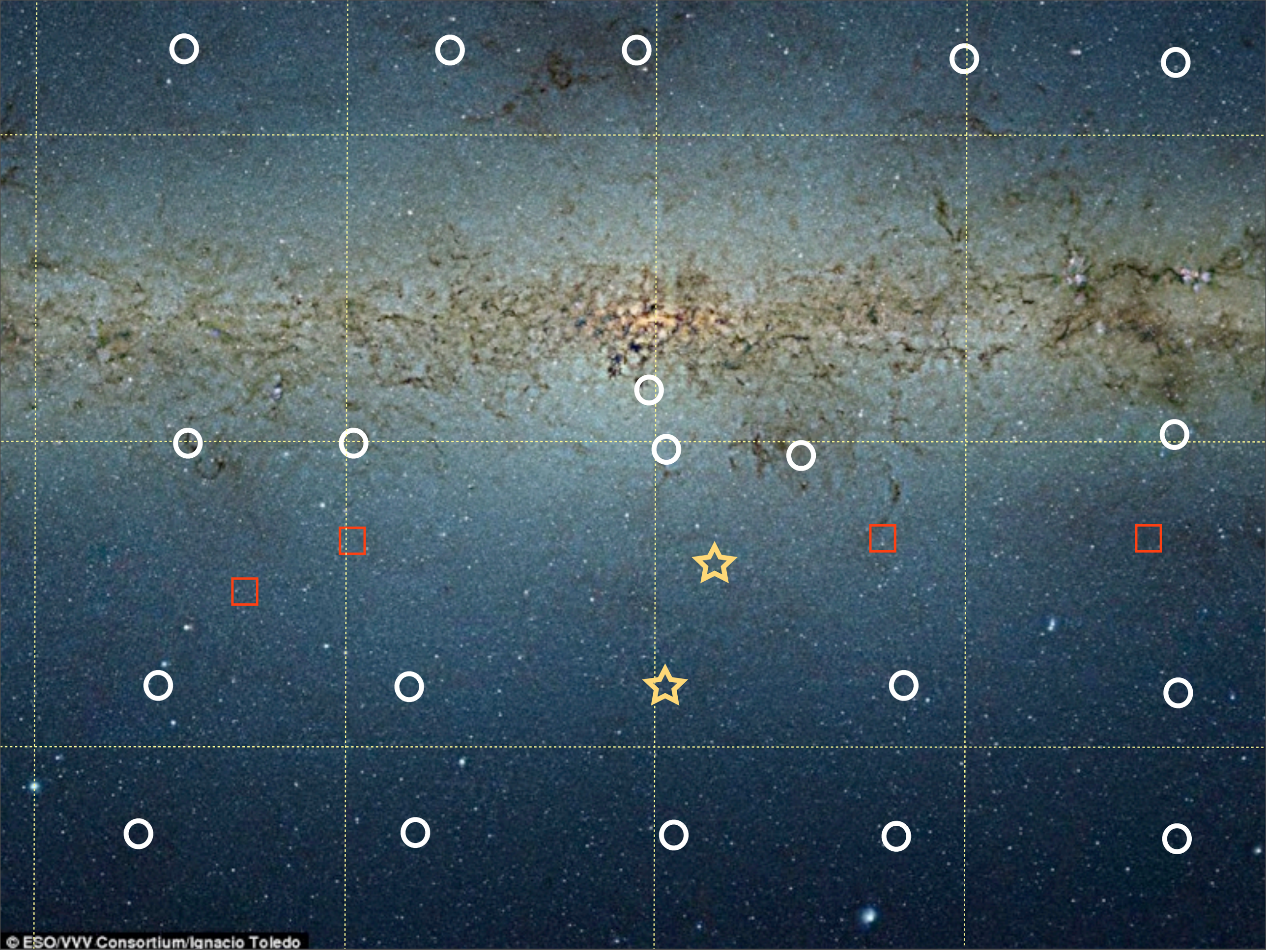


Summary

- The Galactic bulge hosts a boxy/peanut structure
  - most likely this originated from dynamical instability of the disk
- A metallicity gradient, in the outer bulge, follows the boxy/peanut structure
  - dynamical models need to account for this
  - perhaps this indicates the presence of more than one component
- Bulge stars are old and metal rich, with high [α/Fe] ratio
  - rapid star formation occurred, some 10 Gyr ago. ~~Secular evolution~~

Large scale surveys are providing a great deal of information, both on the chemical abundances and kinematics of bulge stars.

Models optimized for the Milky Way, including gas and chemical evolution are badly needed to interpret the observational results.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Fulbright et al. (2007)