

The Galactic bulge

Manuela Zoccali



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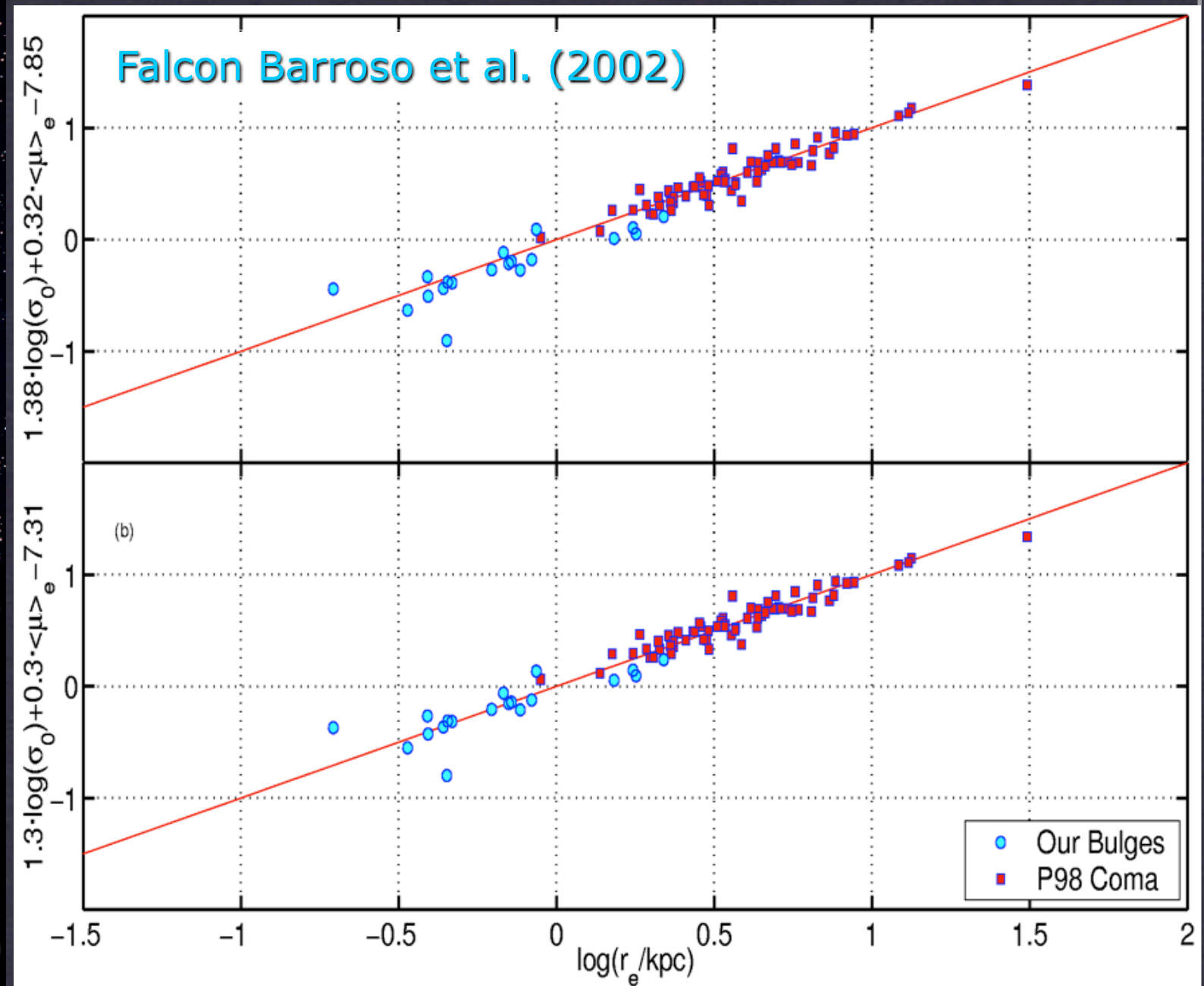
Why the bulge? To know how did the Milky Way form
To know how do galaxies form

On bulge formation

bulges & ellipticals = *spheroids*



The K-band Fundamental Plane



however....

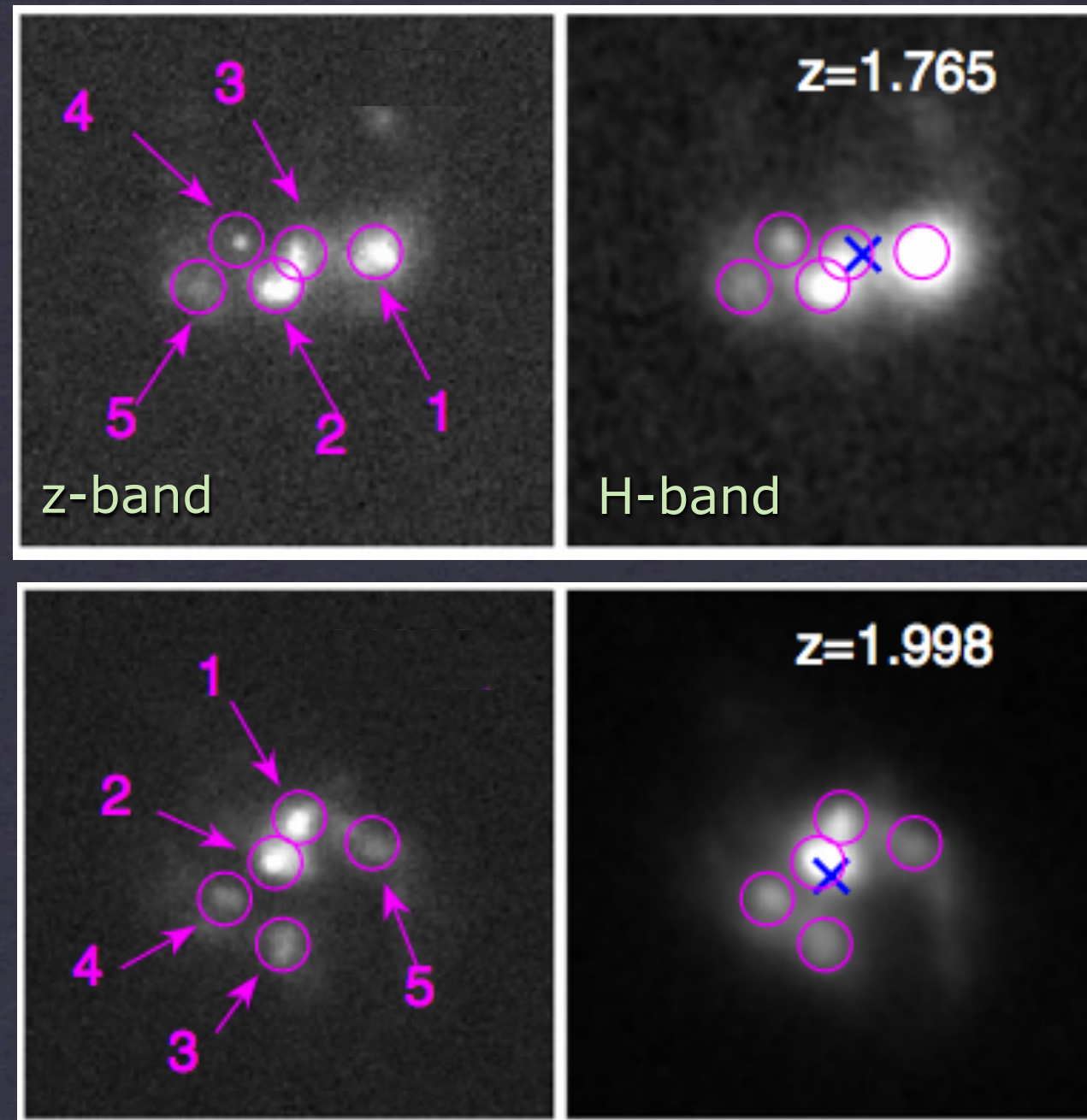
bulges = heated bars = ***the outcome of disk dynamical instability***



...and yet

star forming galaxies at $z \sim 2$ (10 Gyr ago) are gas rich and clumpy

bulge can form from the merging of gas clumps



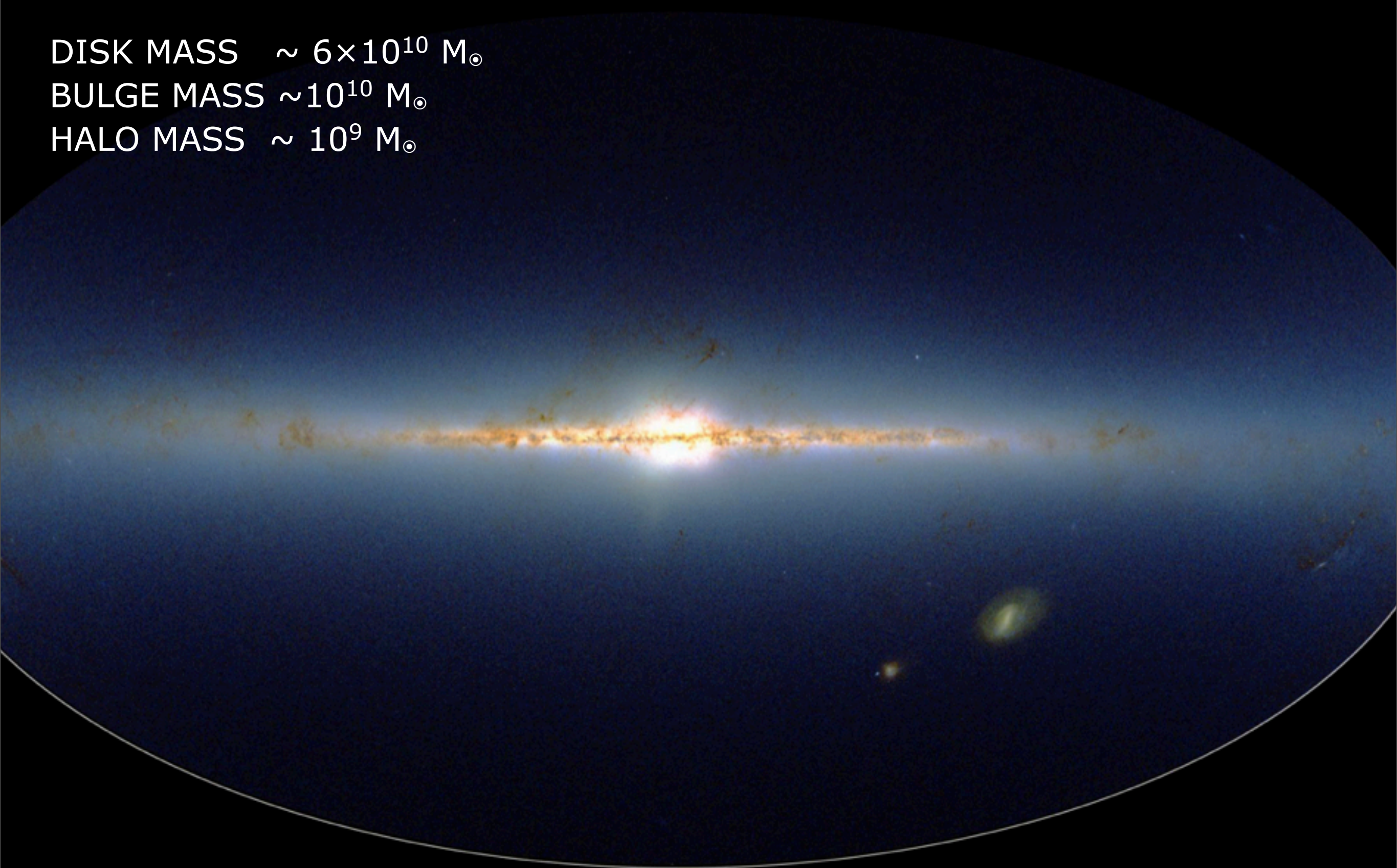
Why the Galactic bulge?

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

DISK MASS $\sim 6 \times 10^{10} M_{\odot}$

BULGE MASS $\sim 10^{10} M_{\odot}$

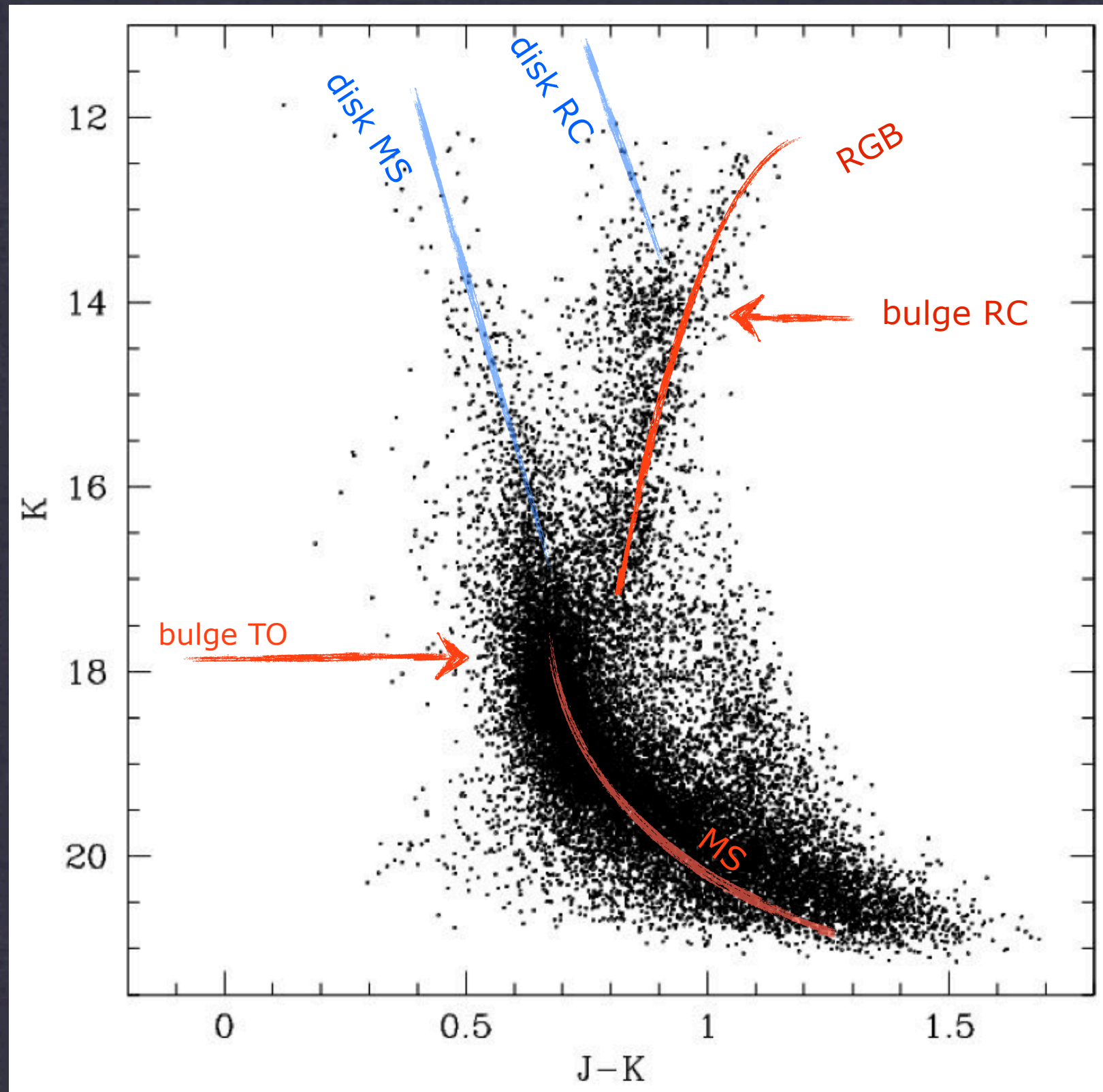
HALO MASS $\sim 10^9 M_{\odot}$



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



The bulge Color Magnitude Diagram in Baade's Window



The bulge is a bar

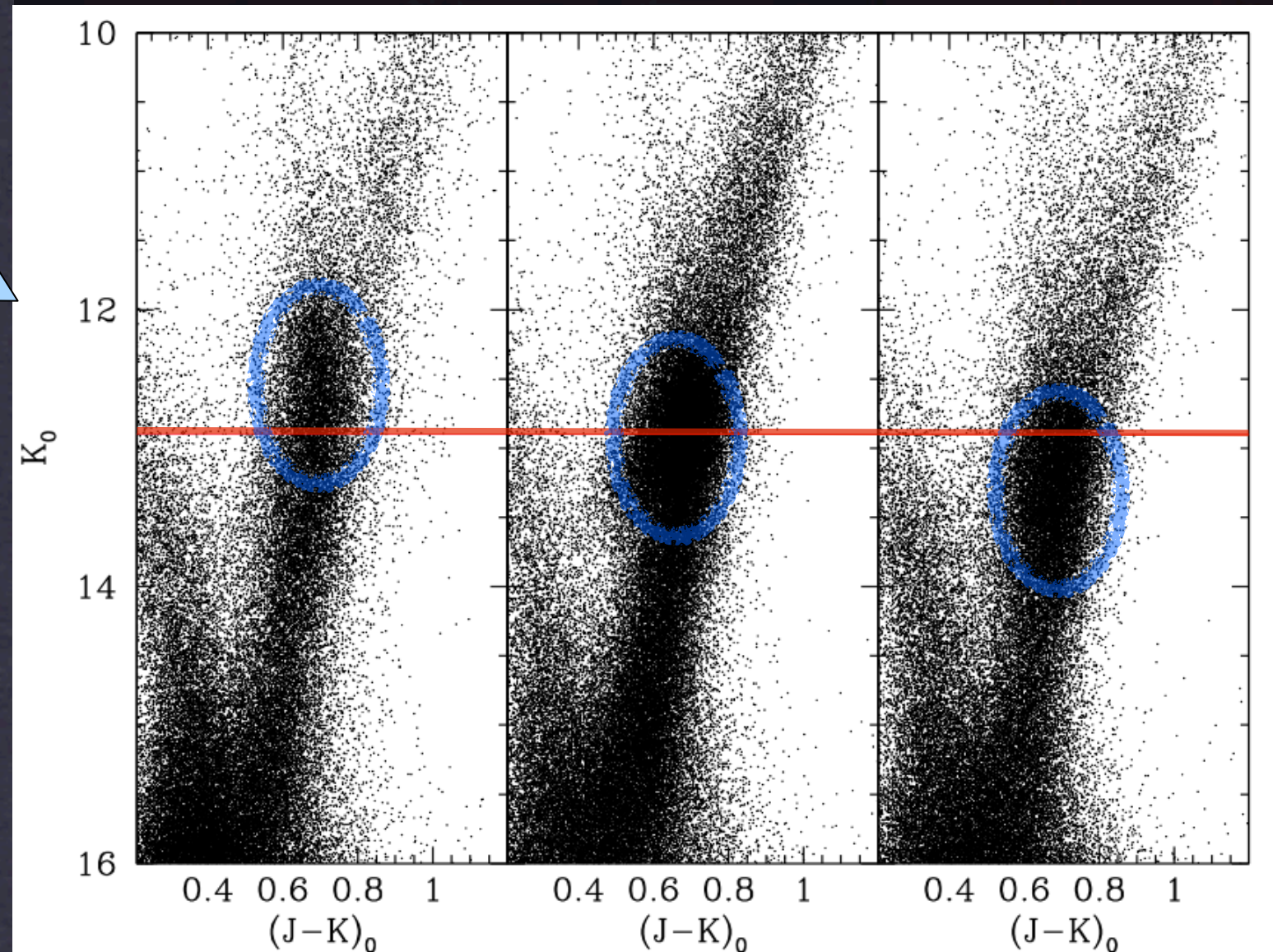
Observational evidence:
stars at positive longitudes
are brighter (closer) than
those at negative longitudes.

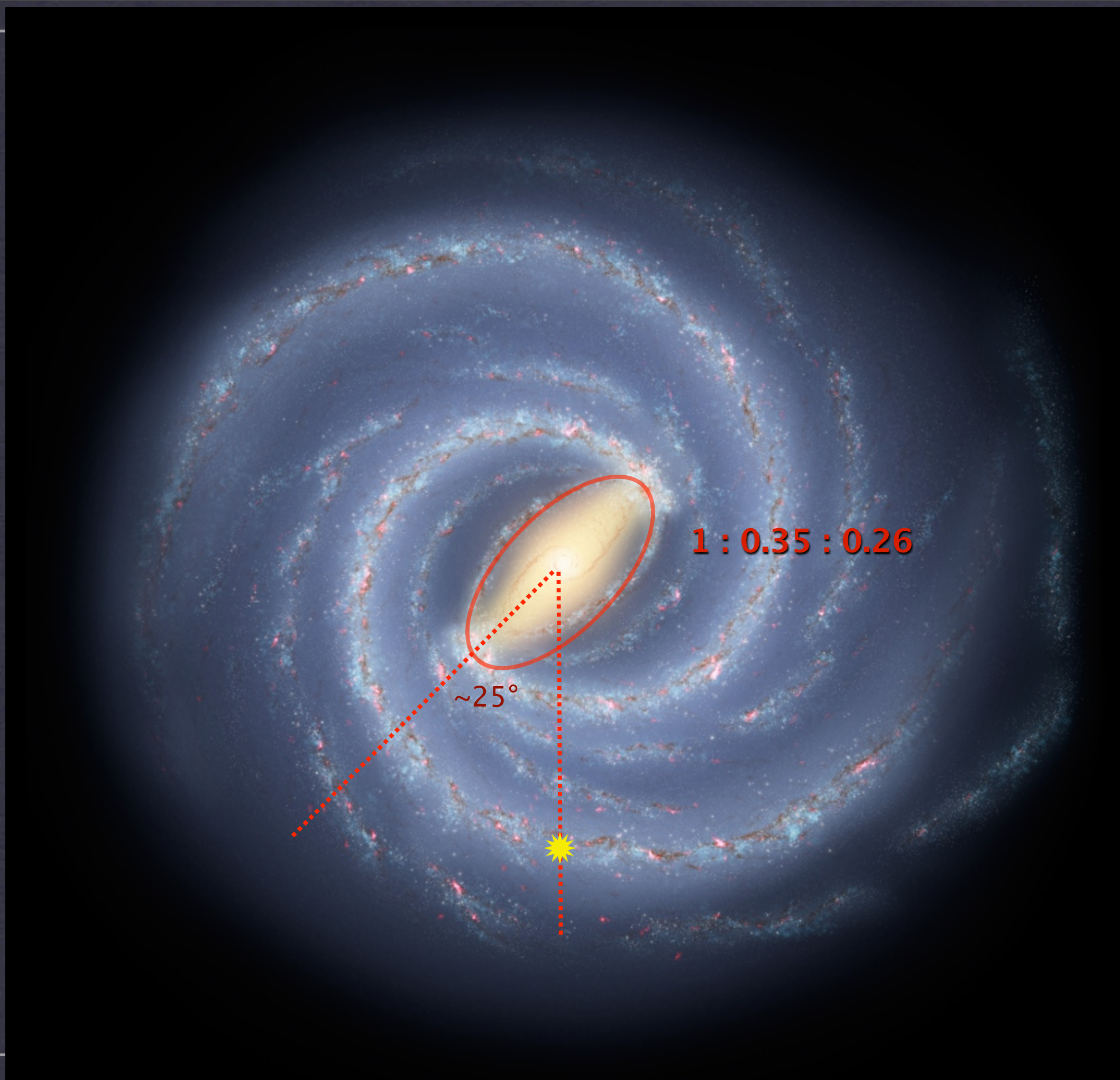
see also:
Bissantz & Gerhard (2002)
Babusiaux & Gilmore (2005)
Rattenbury et al. (2007)
Lopez Corredoira et al. (2007)
Cabrera Lavers et al. (2008)

...

brighter/closer

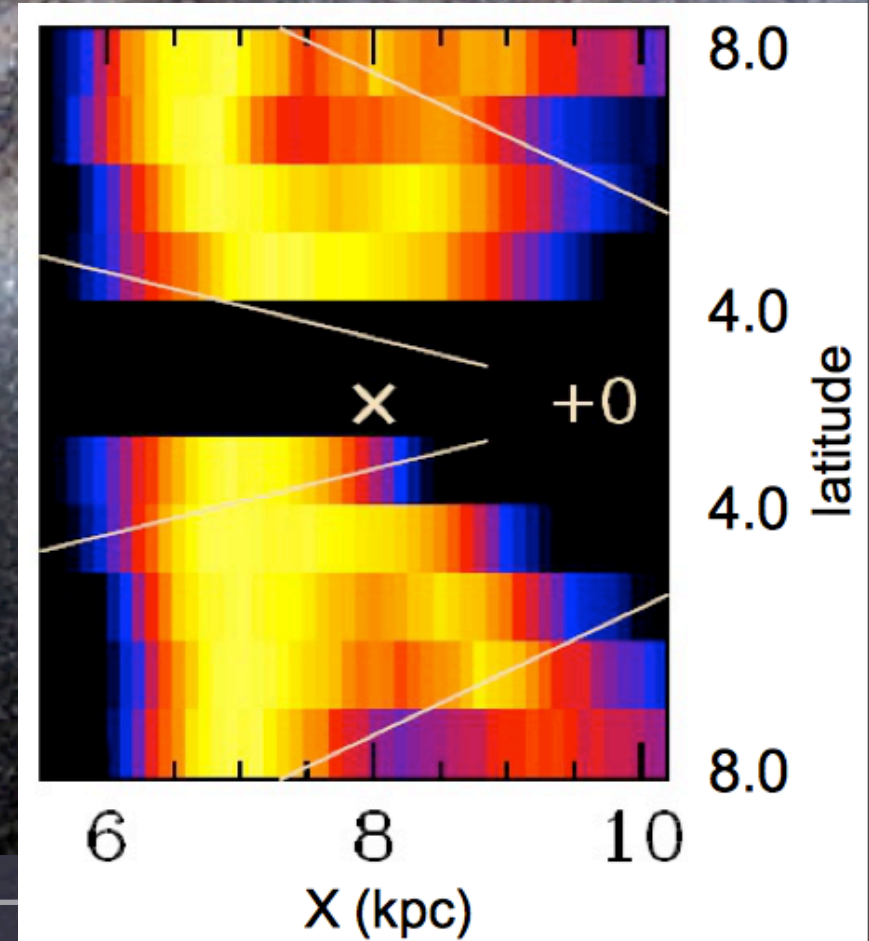
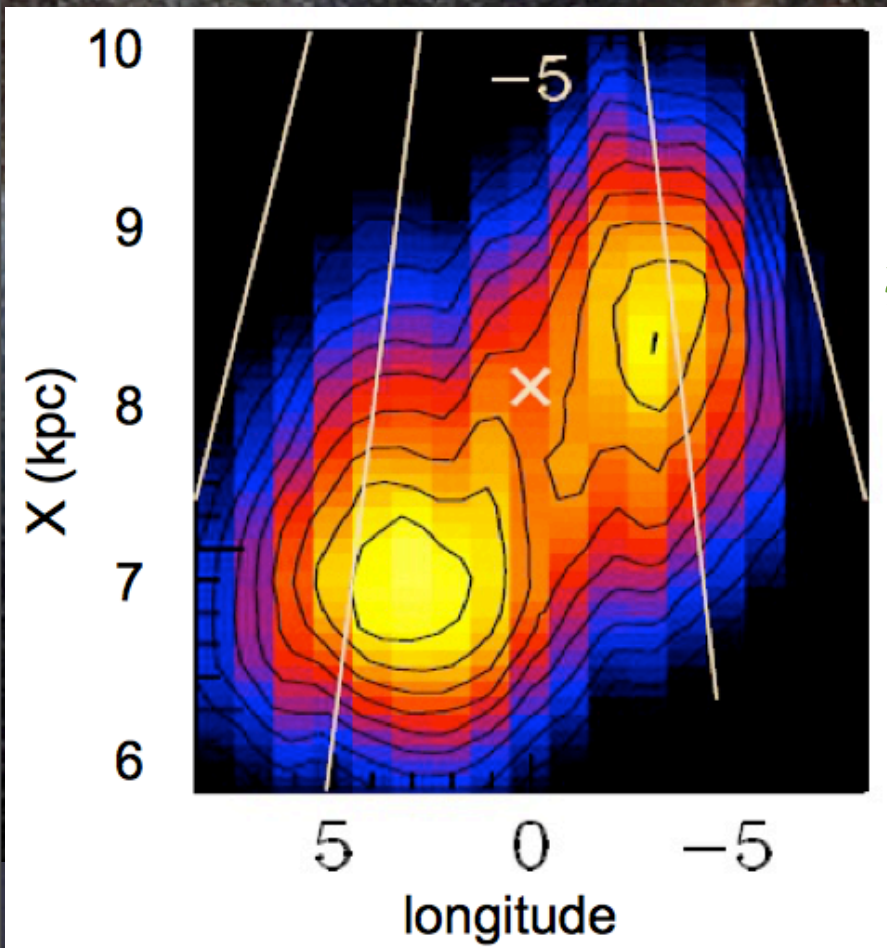
Stanek et al. (1994)





The Boxy/Peanut (X-shaped) Galactic bulge

McWilliam & MZ (2010)
Saito, MZ et al. (2011)



The VISTA Variables in the Vía Láctea survey (VVV)

PIs: Minniti, Lucas

DR2: <http://archive.eso.org/cms/eso-data/eso-data-products>



Y, Z, J, H, Ks filters
~100 epochs bulge in Ks
~90 epochs disk in Ks

The VISTA Variables in the Vía Láctea survey (VVV)

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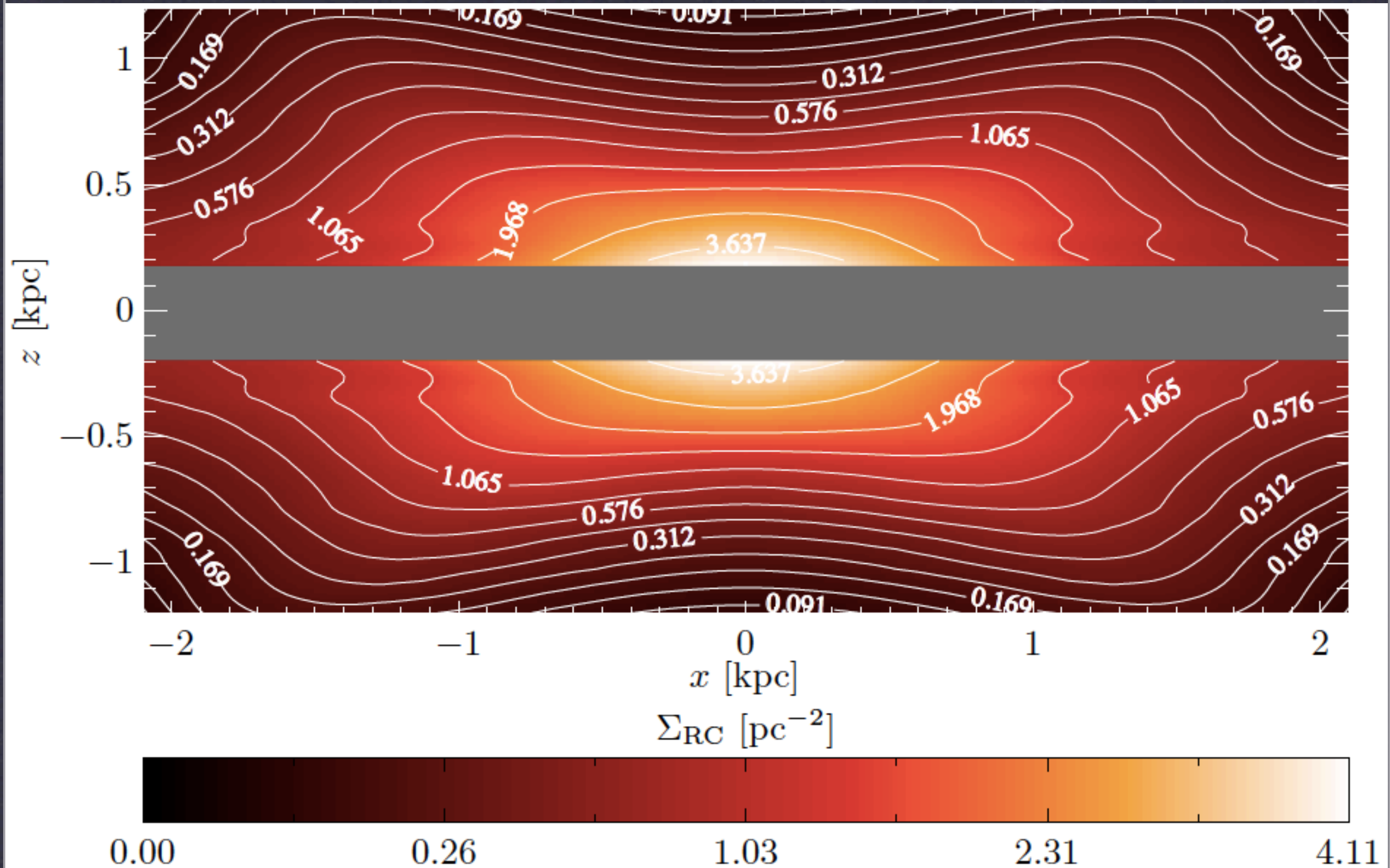
TALK BY JAVIER ALONSO

Y, Z, J, H, Ks filters
~100 epochs bulge in Ks
~90 epochs disk in Ks

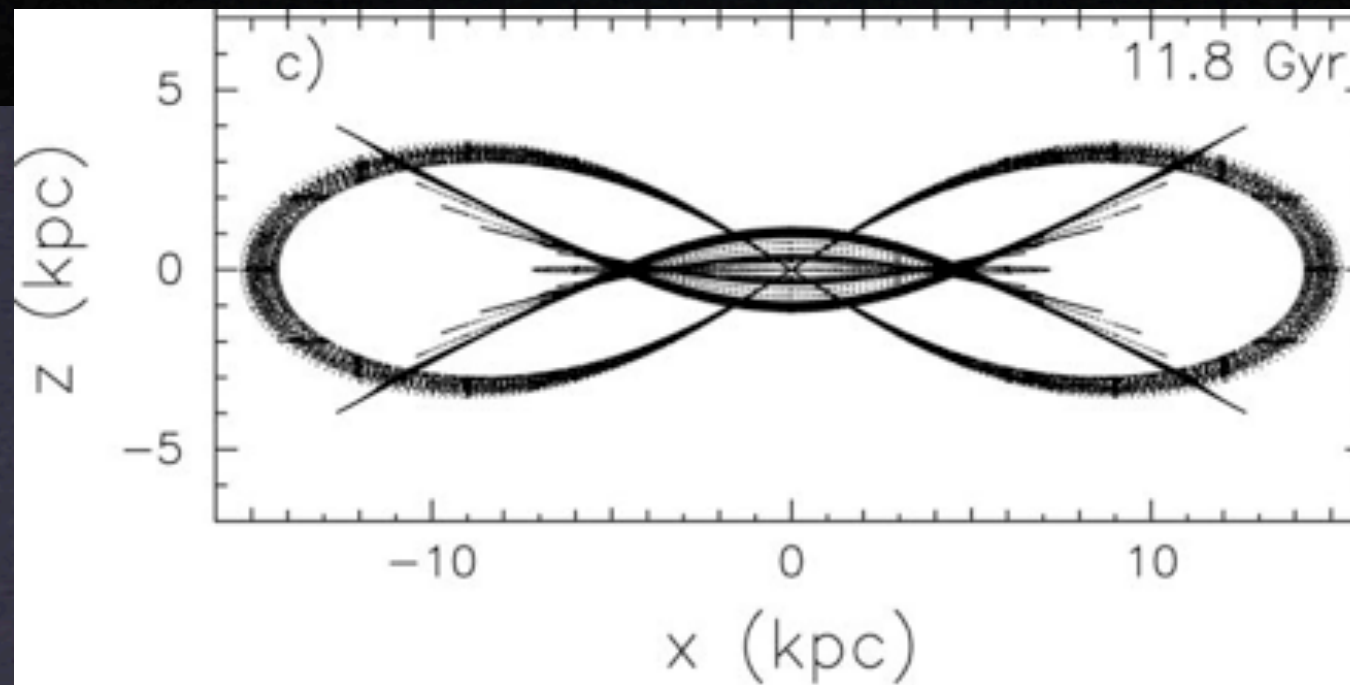
The X-shaped Galactic bulge

Wegg & Gerhard (2013)

using VVV Data Release 1

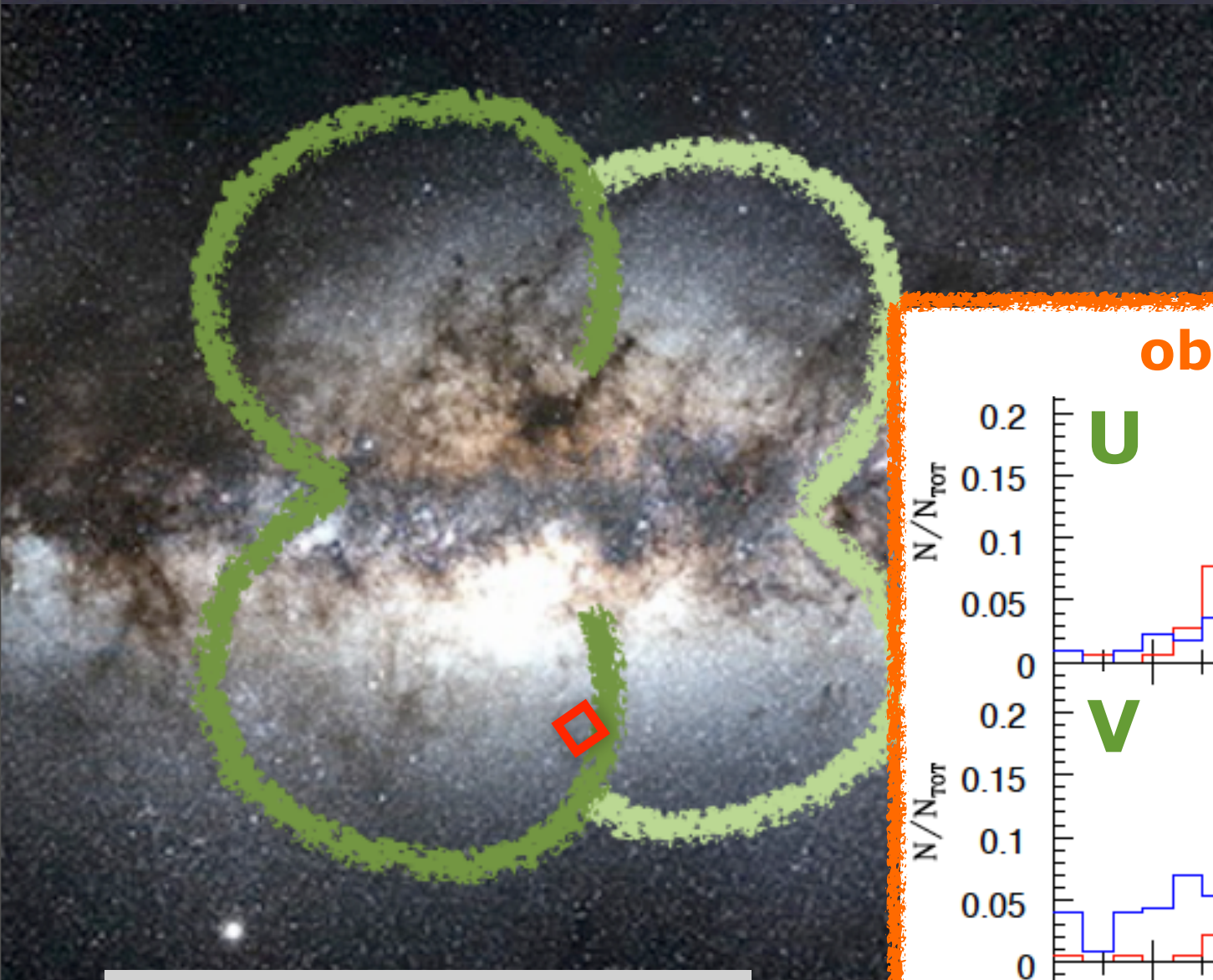


The X-shaped Galactic bulge



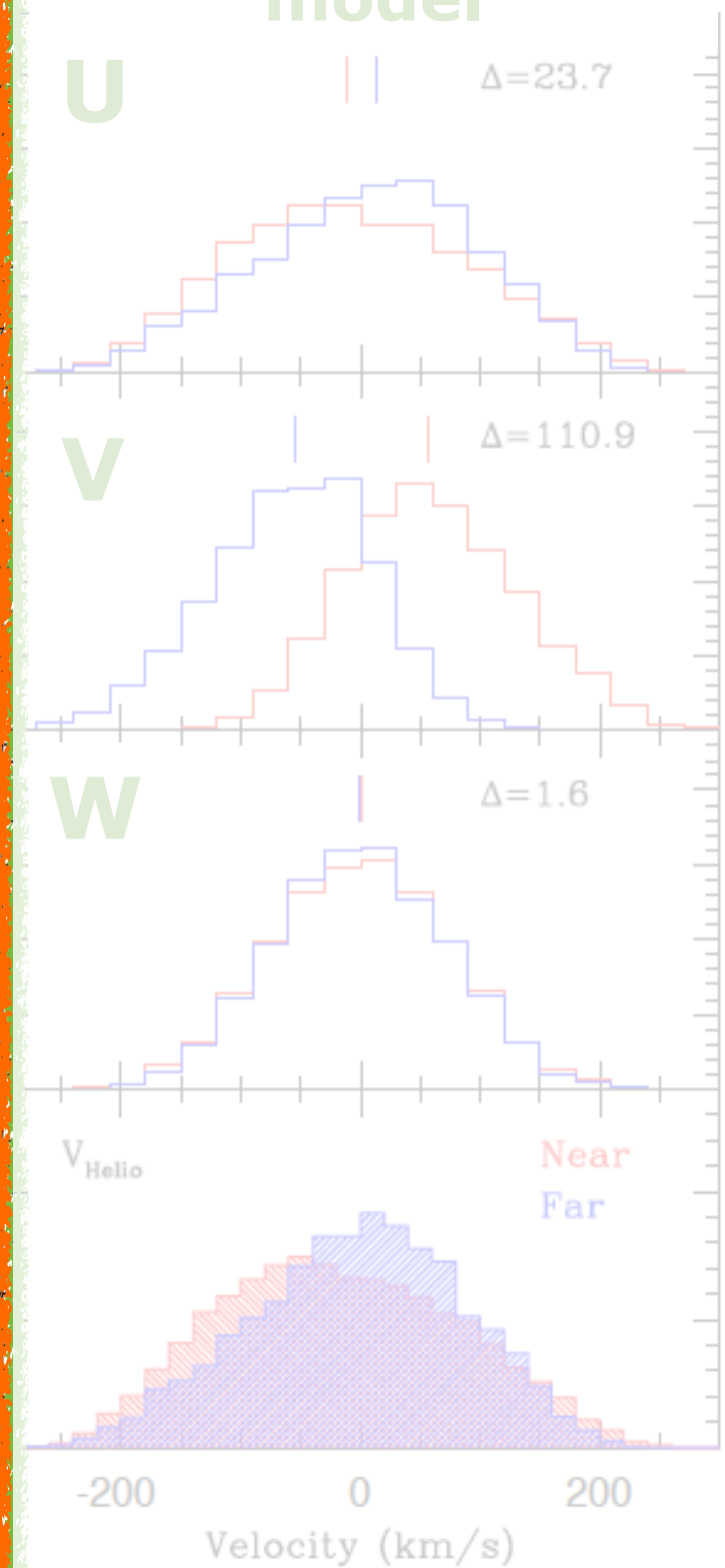
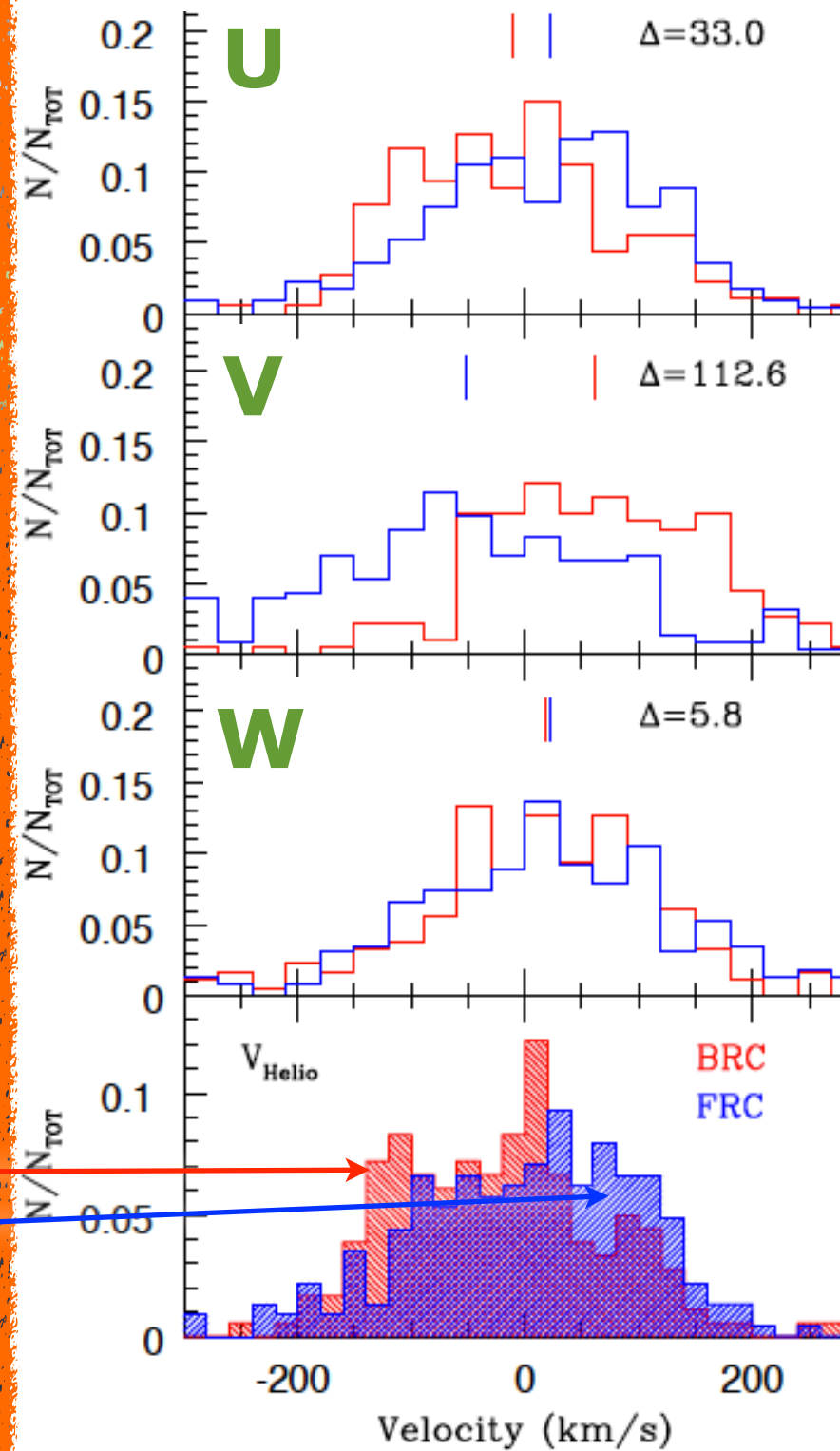
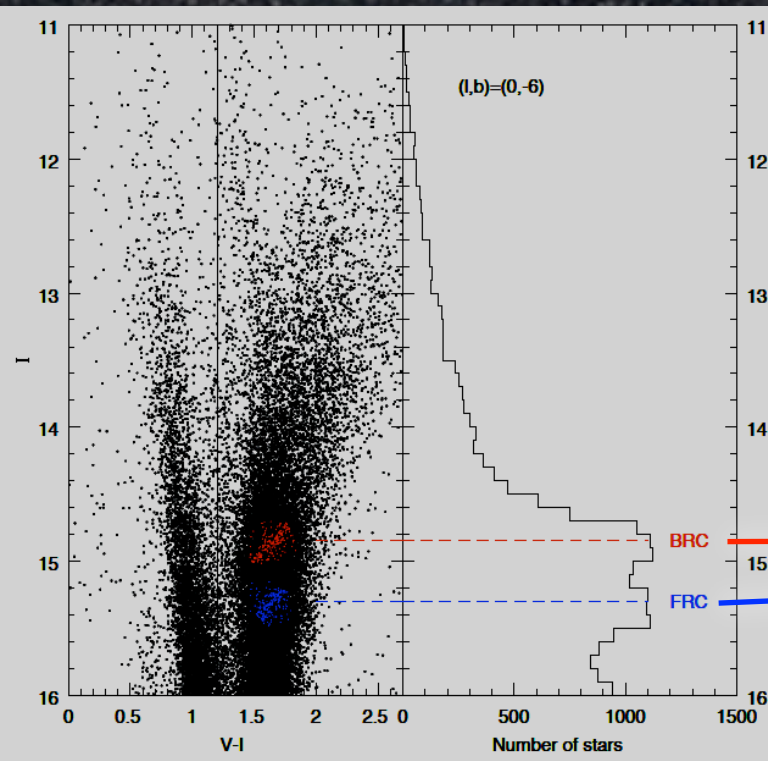
3D Kinematics

Vásquez, MZ et al. (2013)



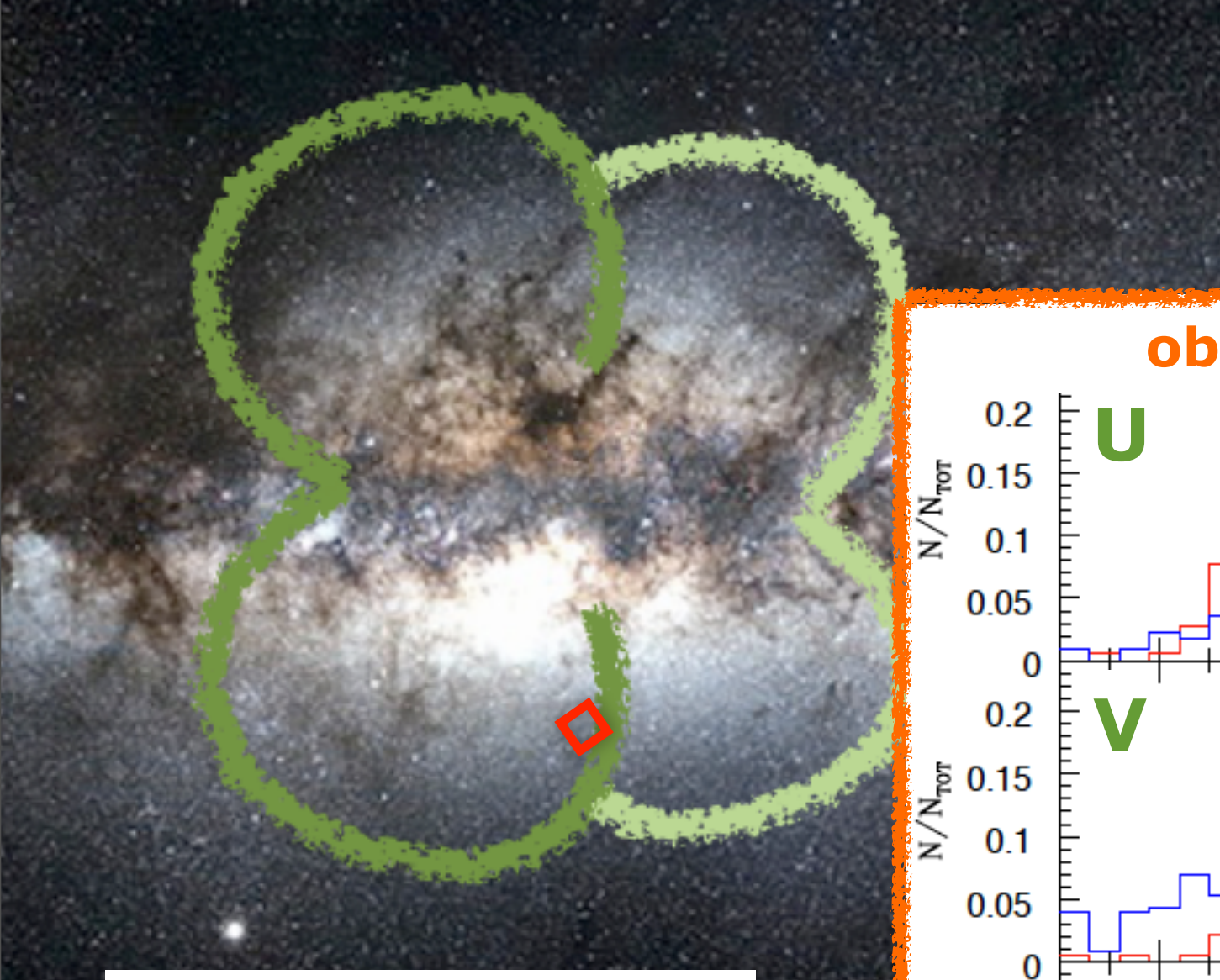
observations

model



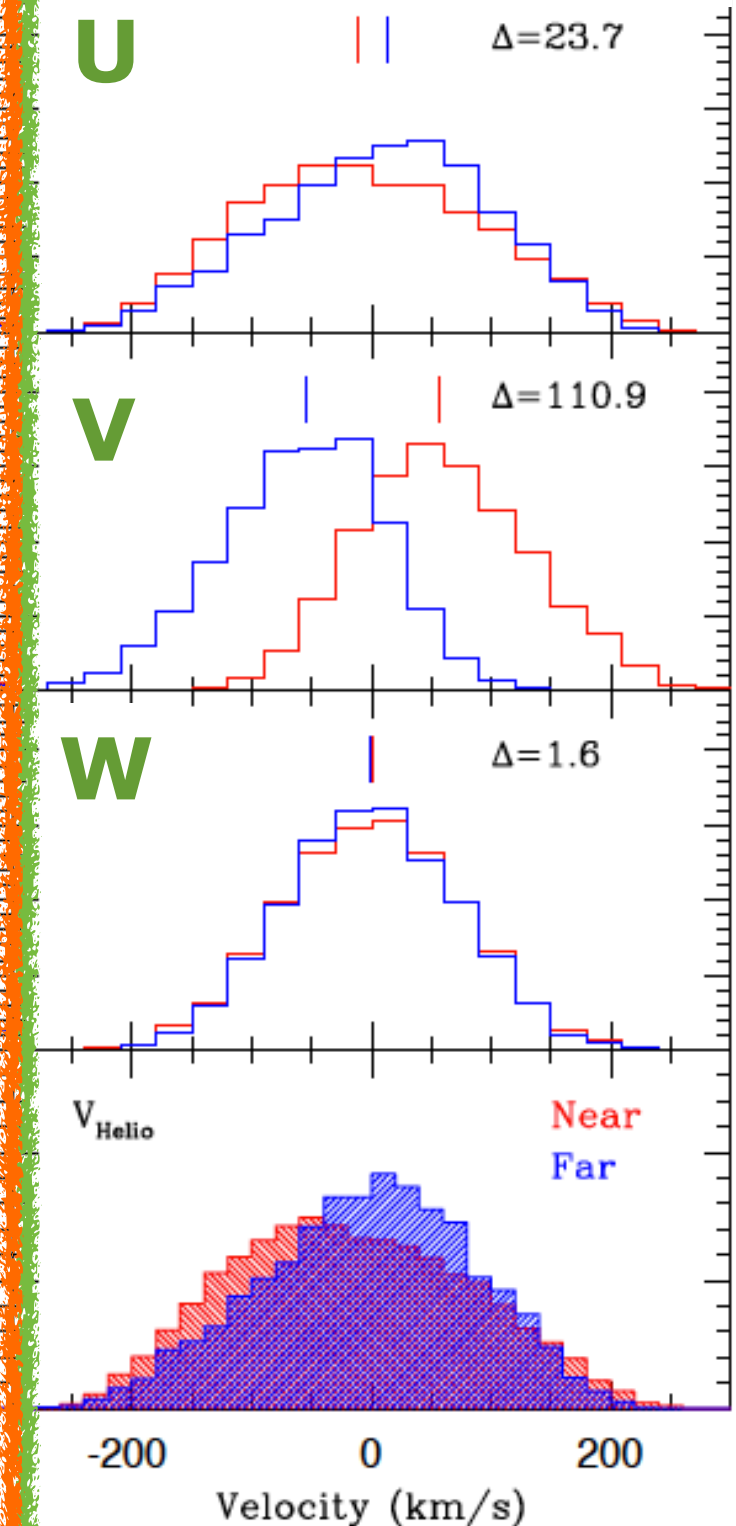
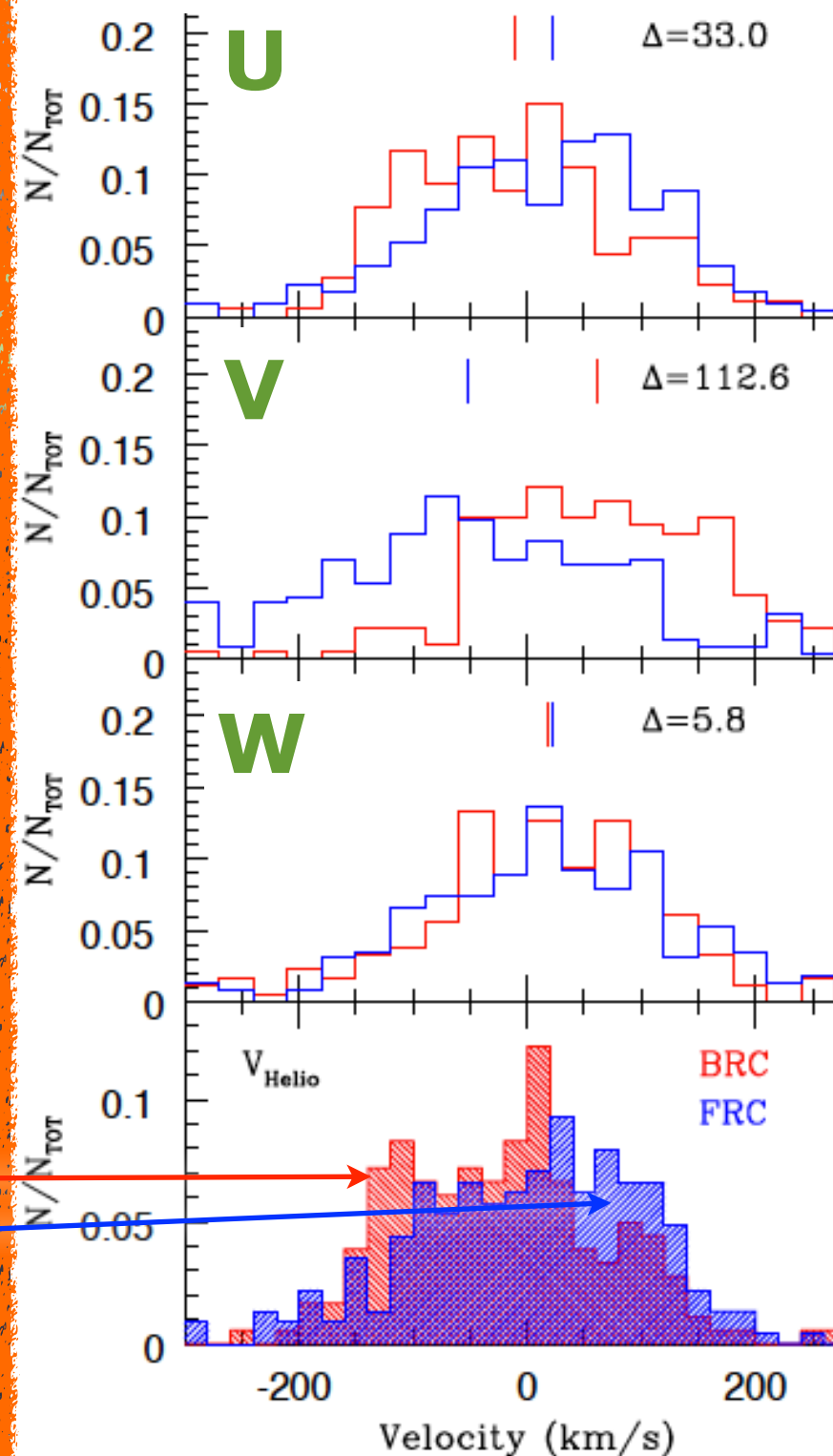
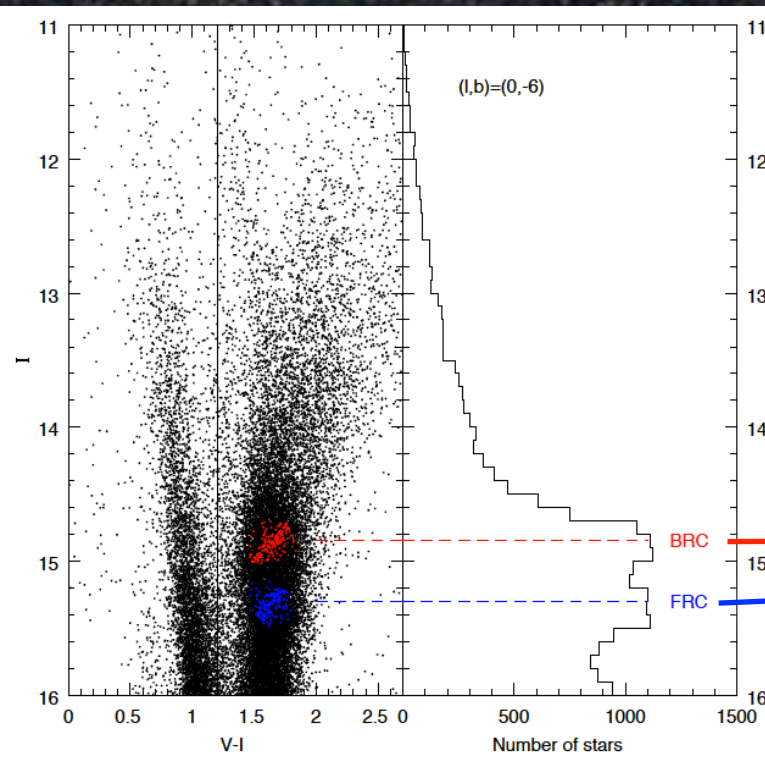
3D Kinematics

Vásquez, MZ et al. (2013)



observations

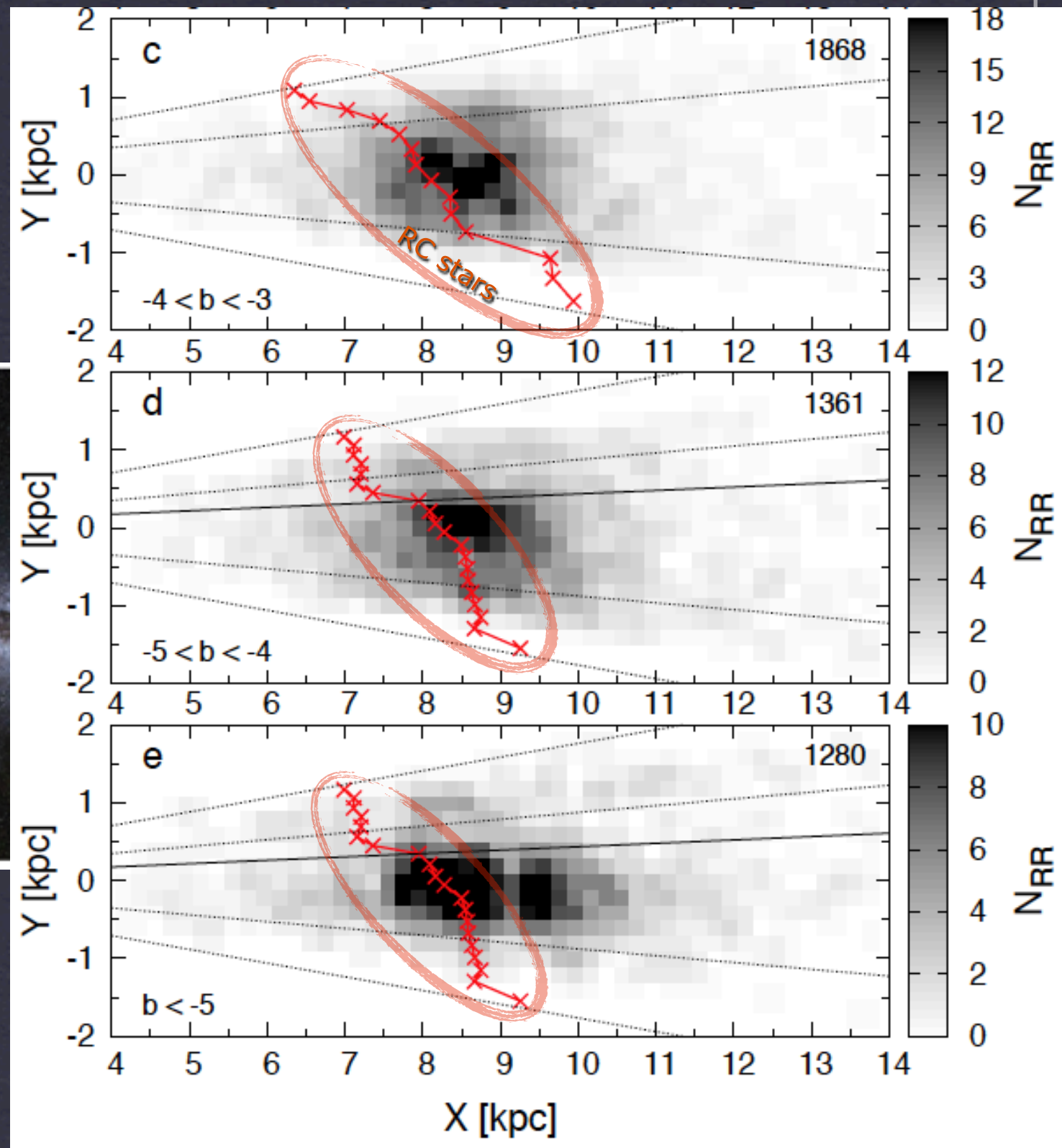
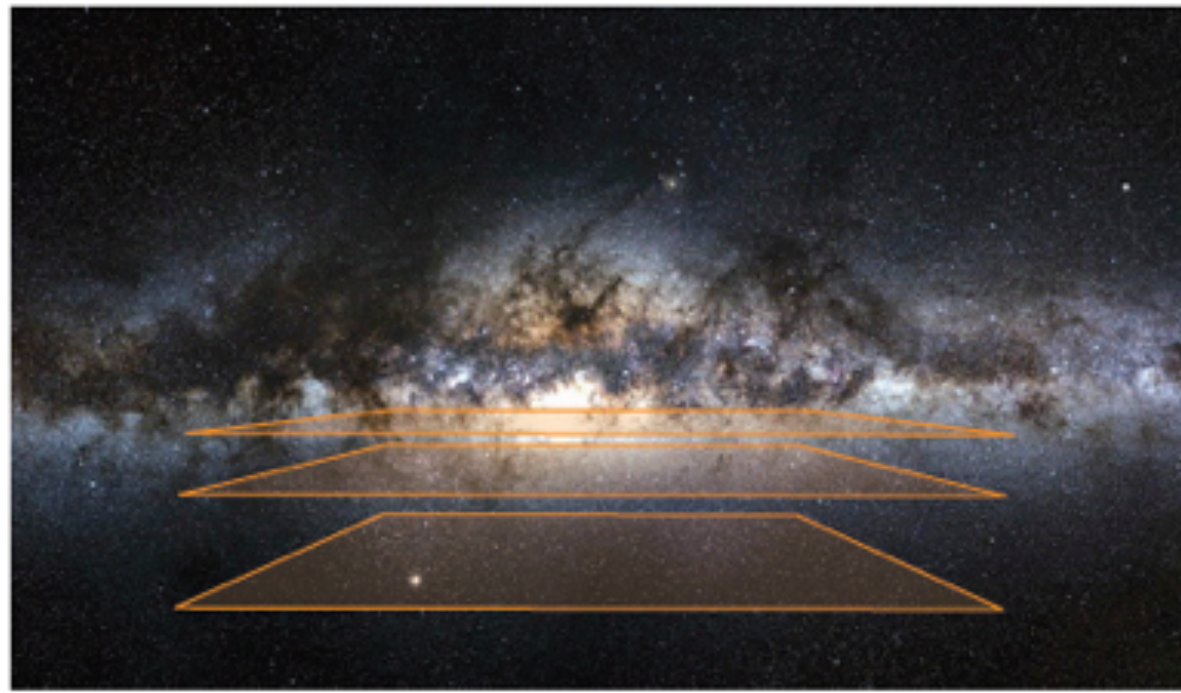
model of B/P bulge



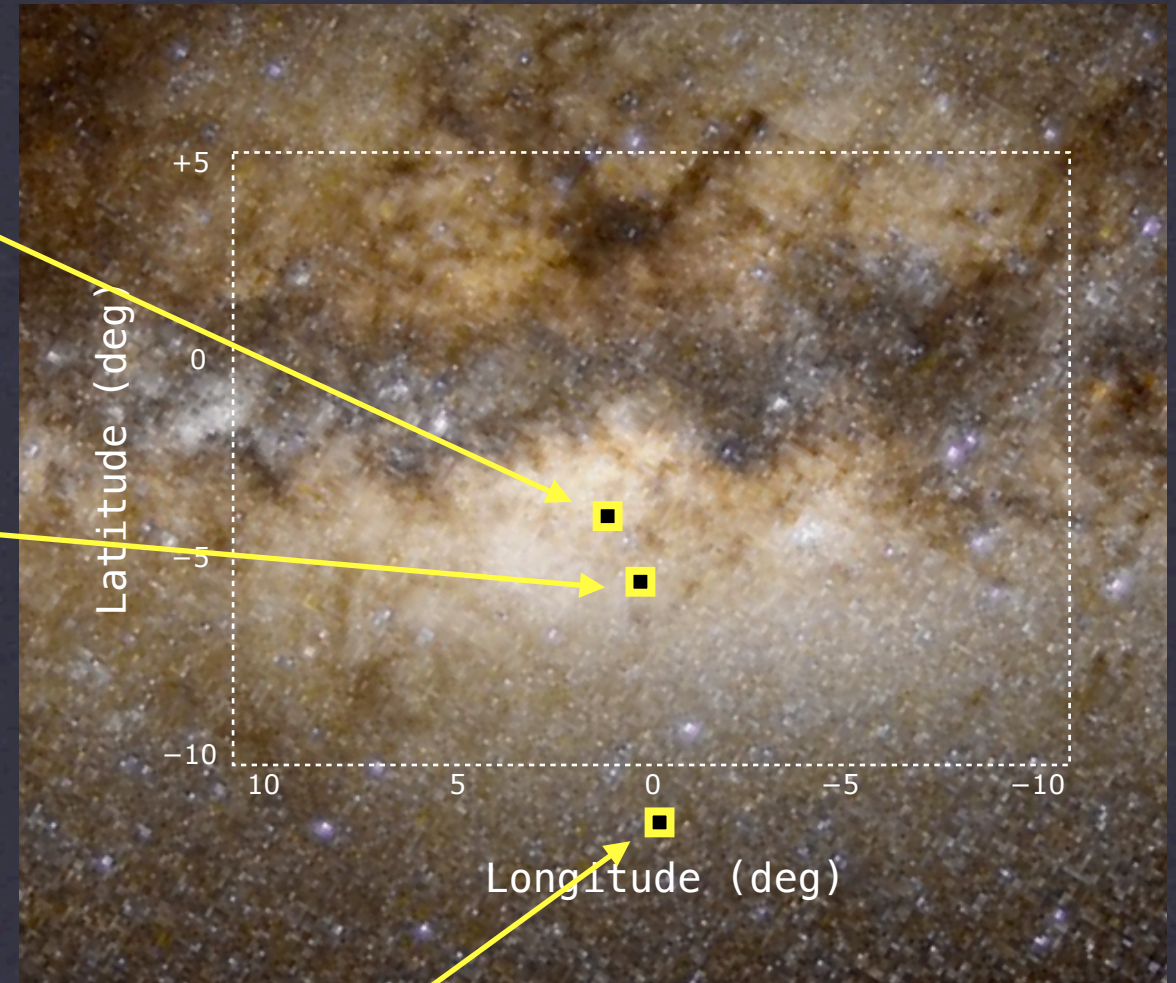
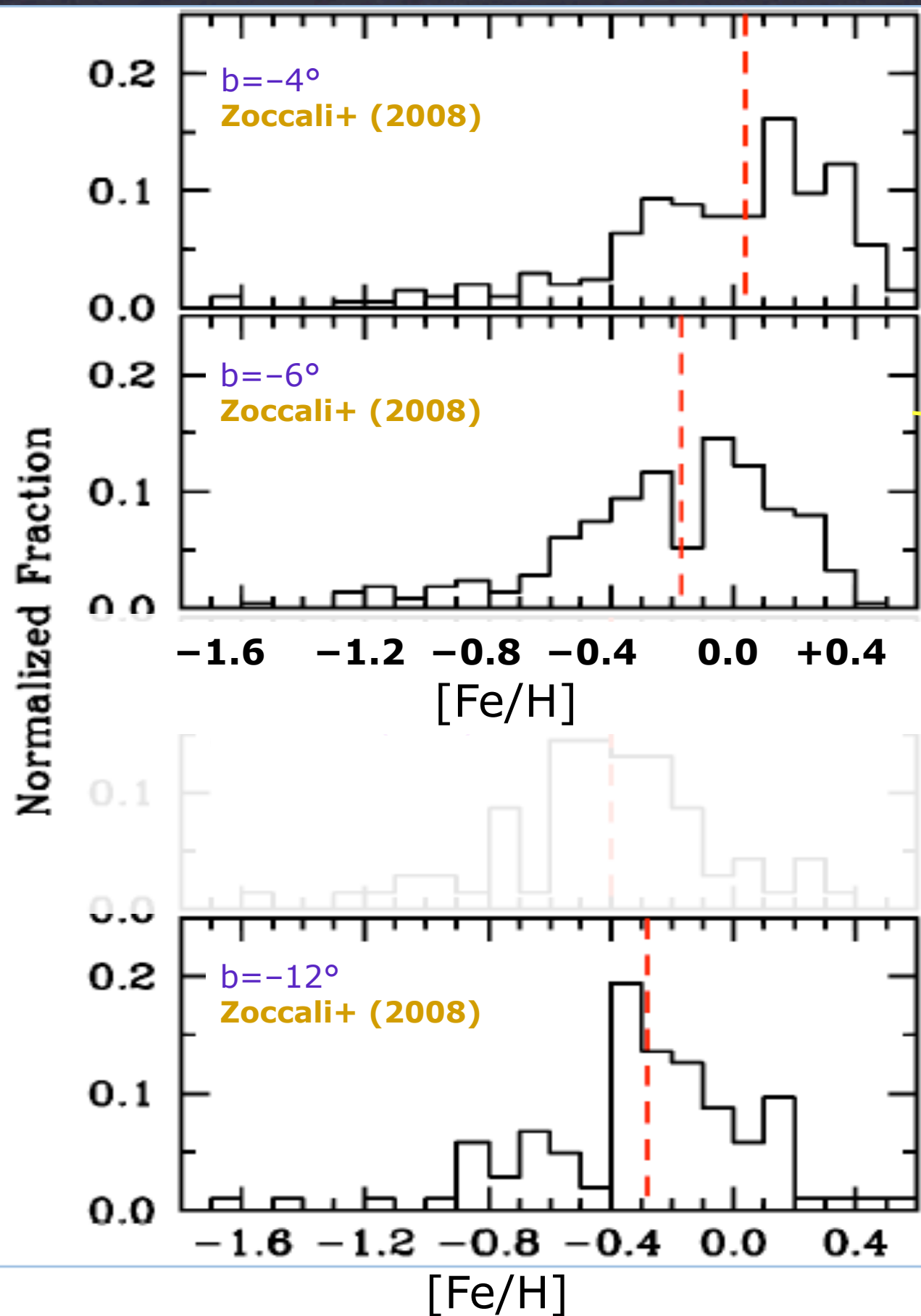
The 3D map from RR Lyrae a two-component bulge

Dékány et al. (2013)

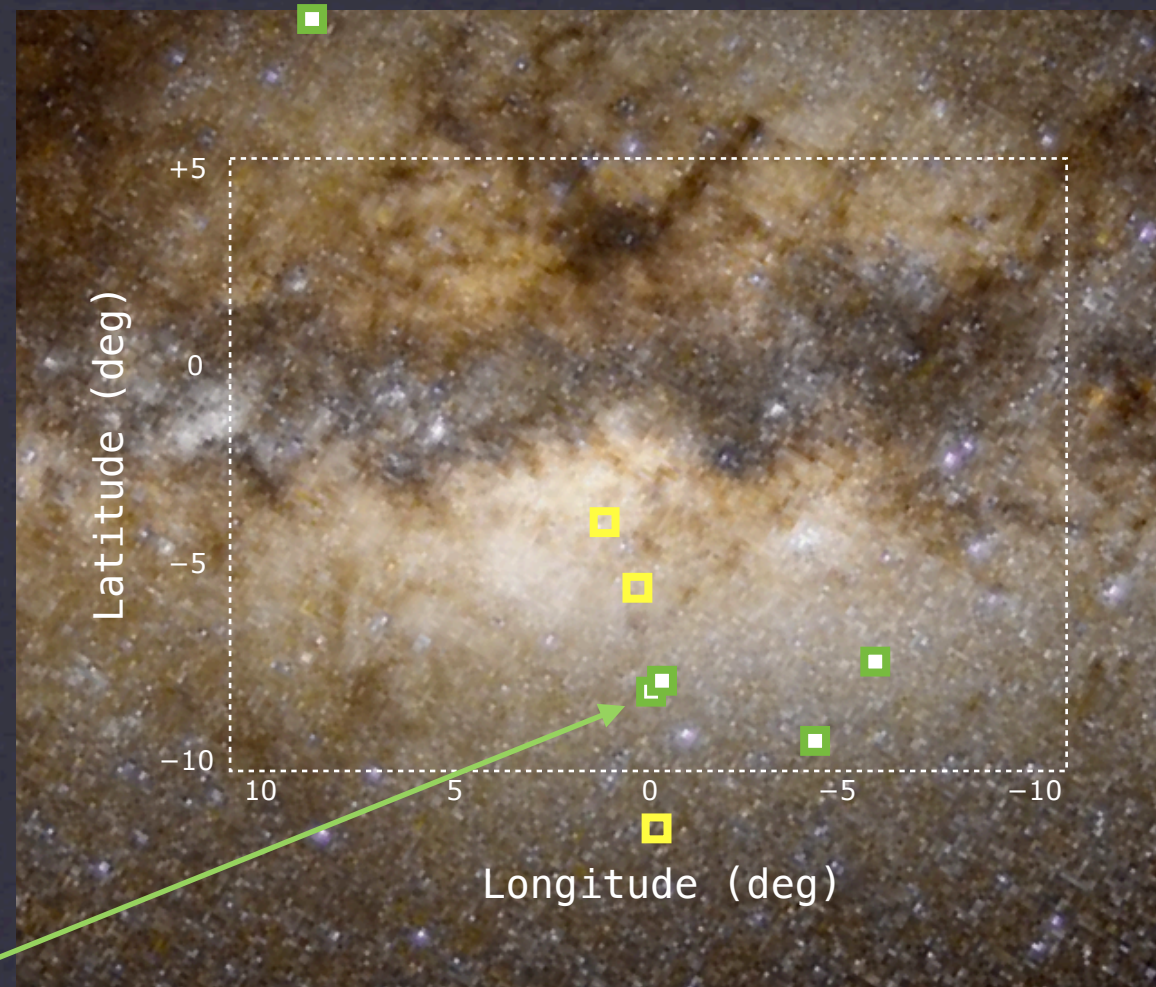
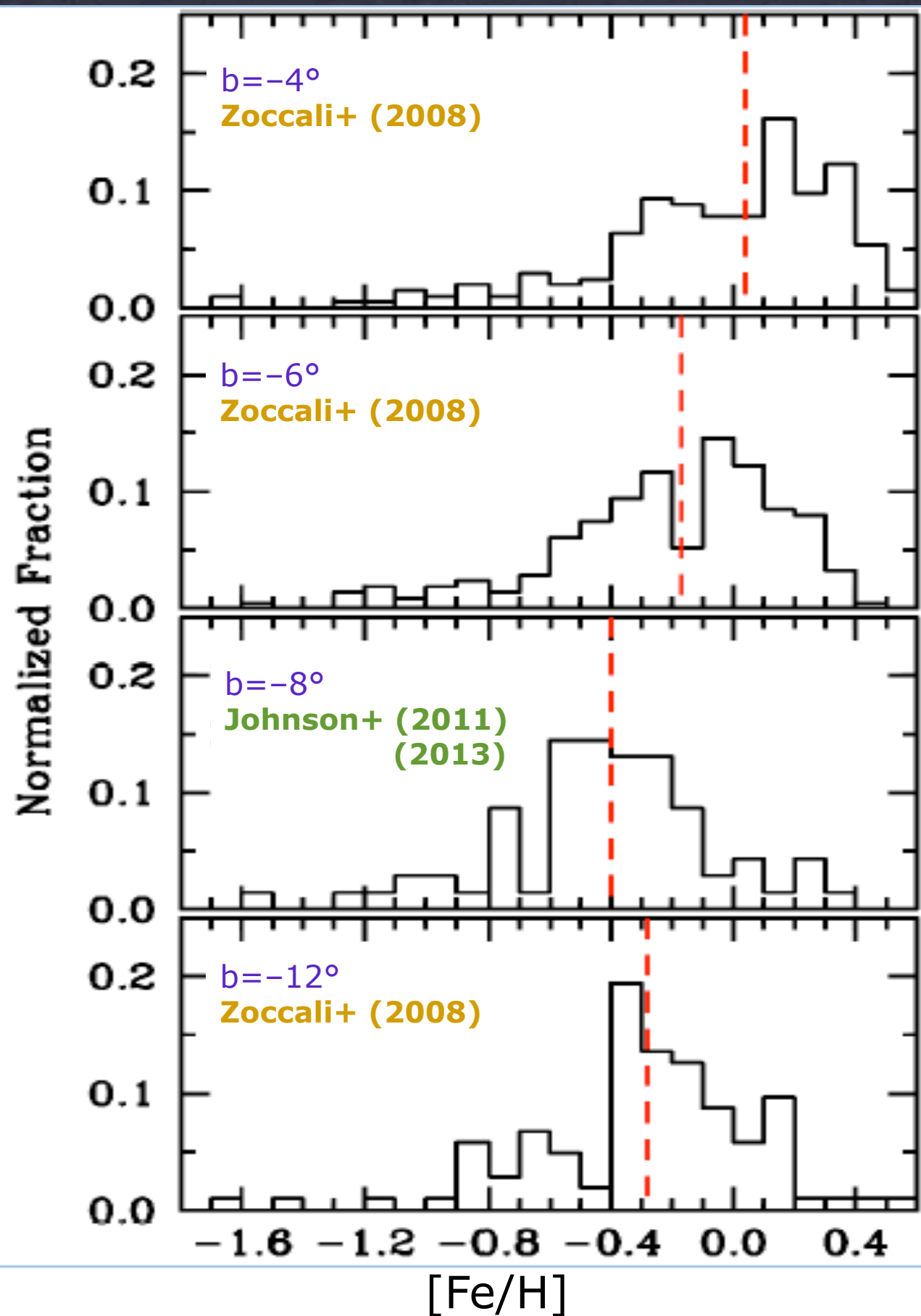
RR Lyrae stars do not show the bar (nor the boxy/peanut) traced by RC stars



Bulge Metallicity Distribution Function (MDF)

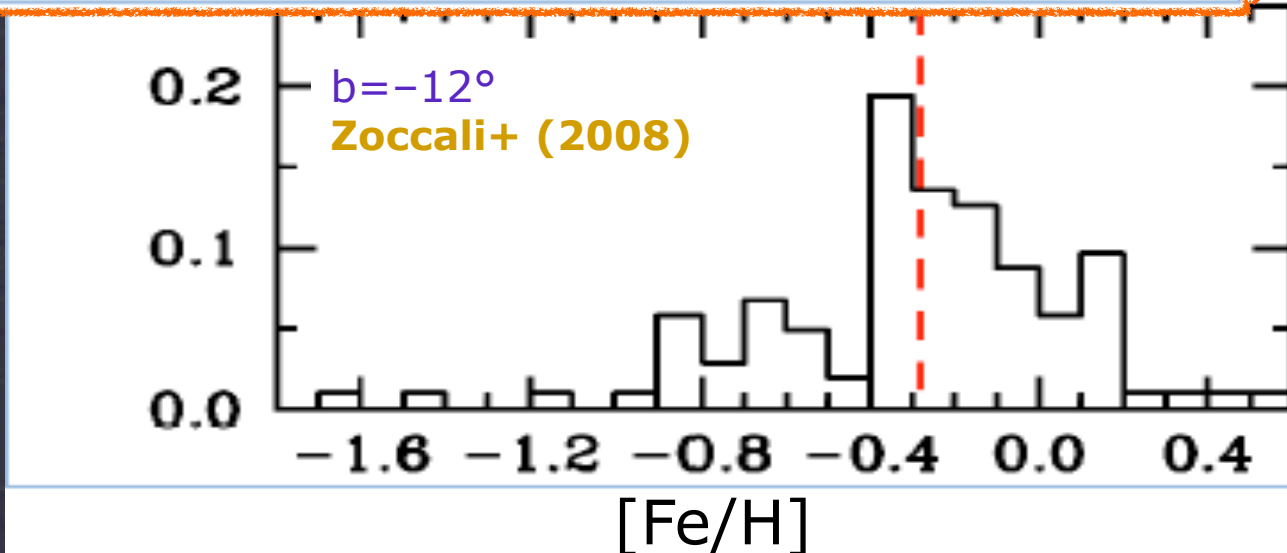
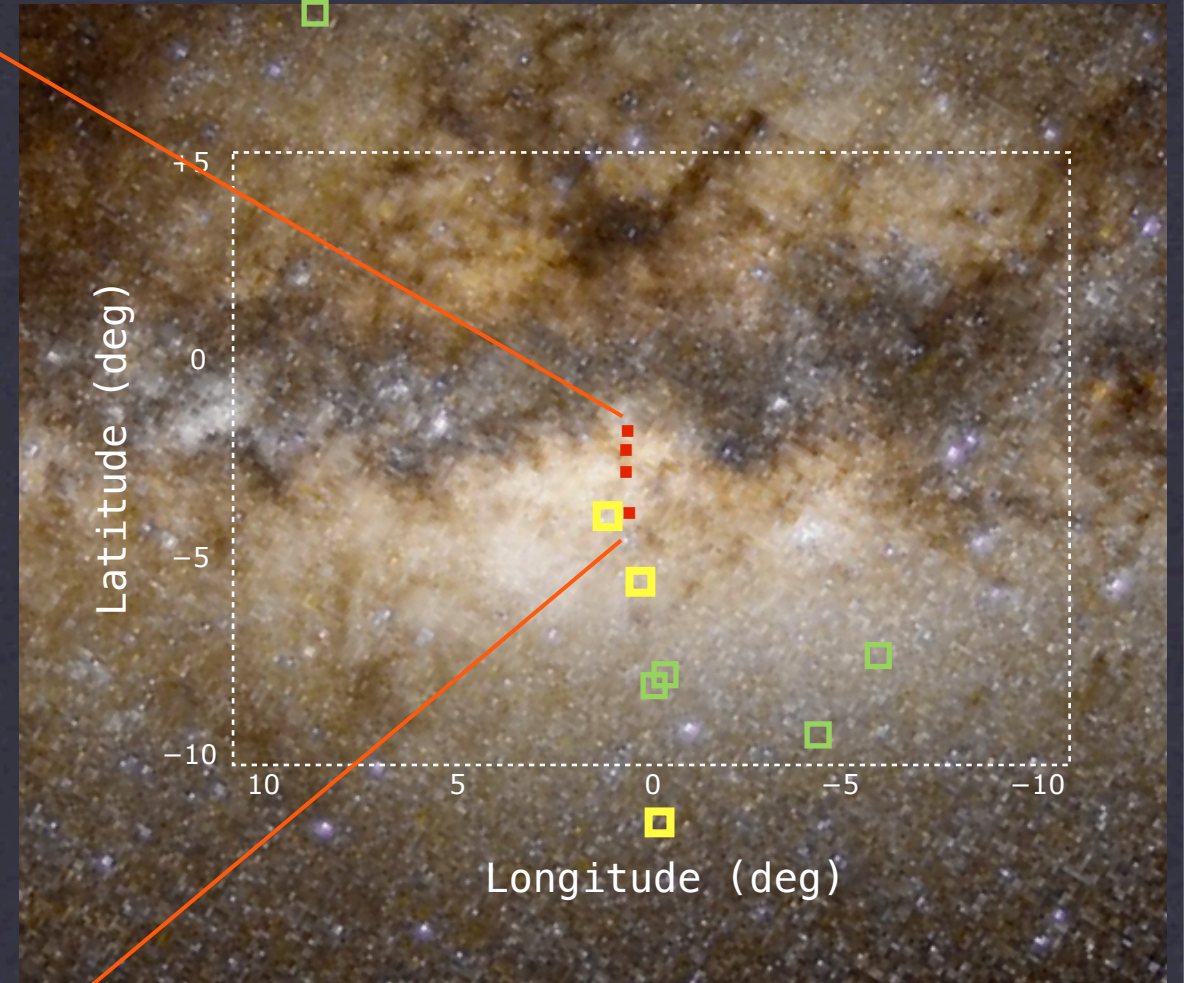
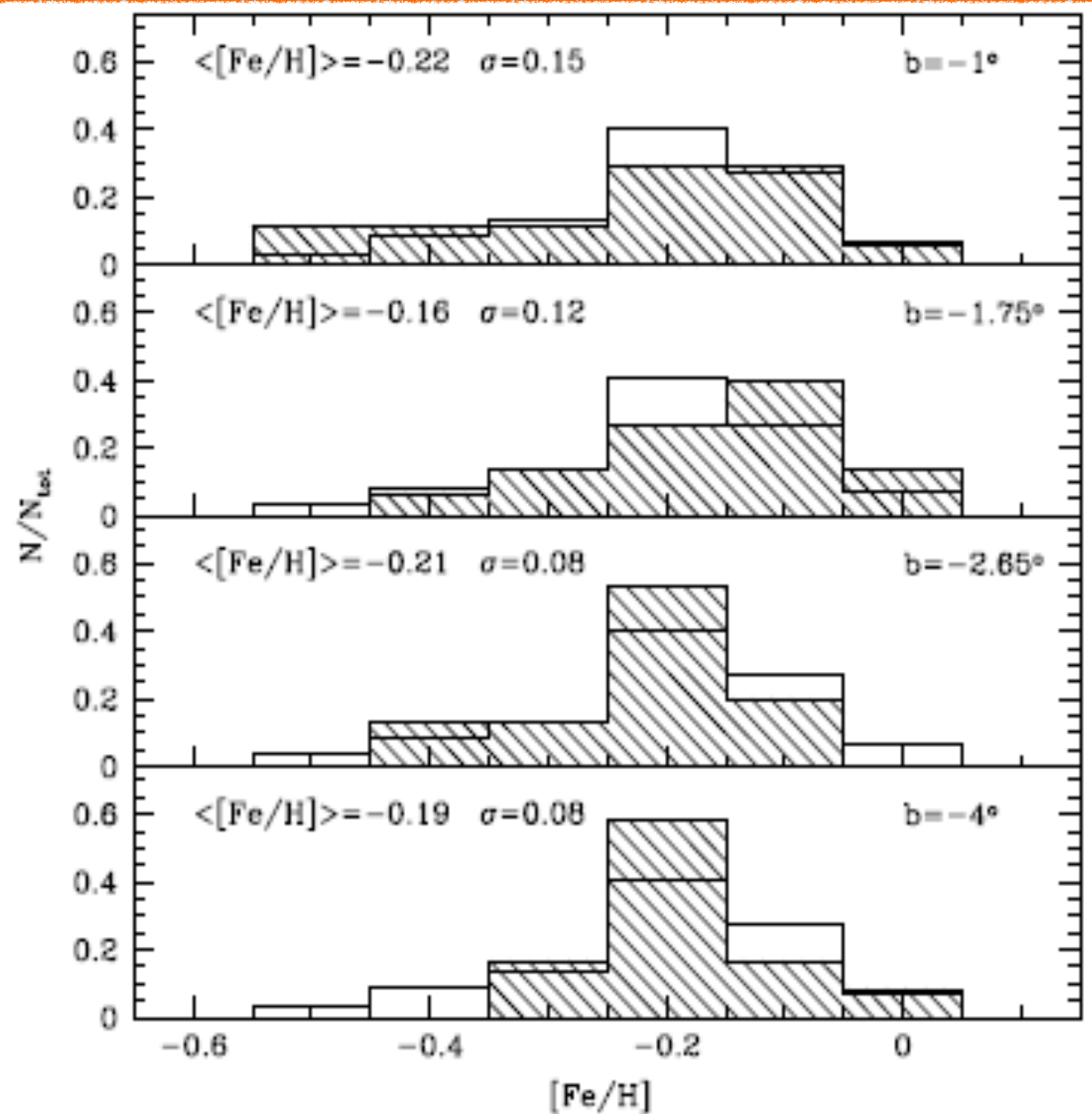


Bulge Metallicity Distribution Function (MDF)



Bulge MDF

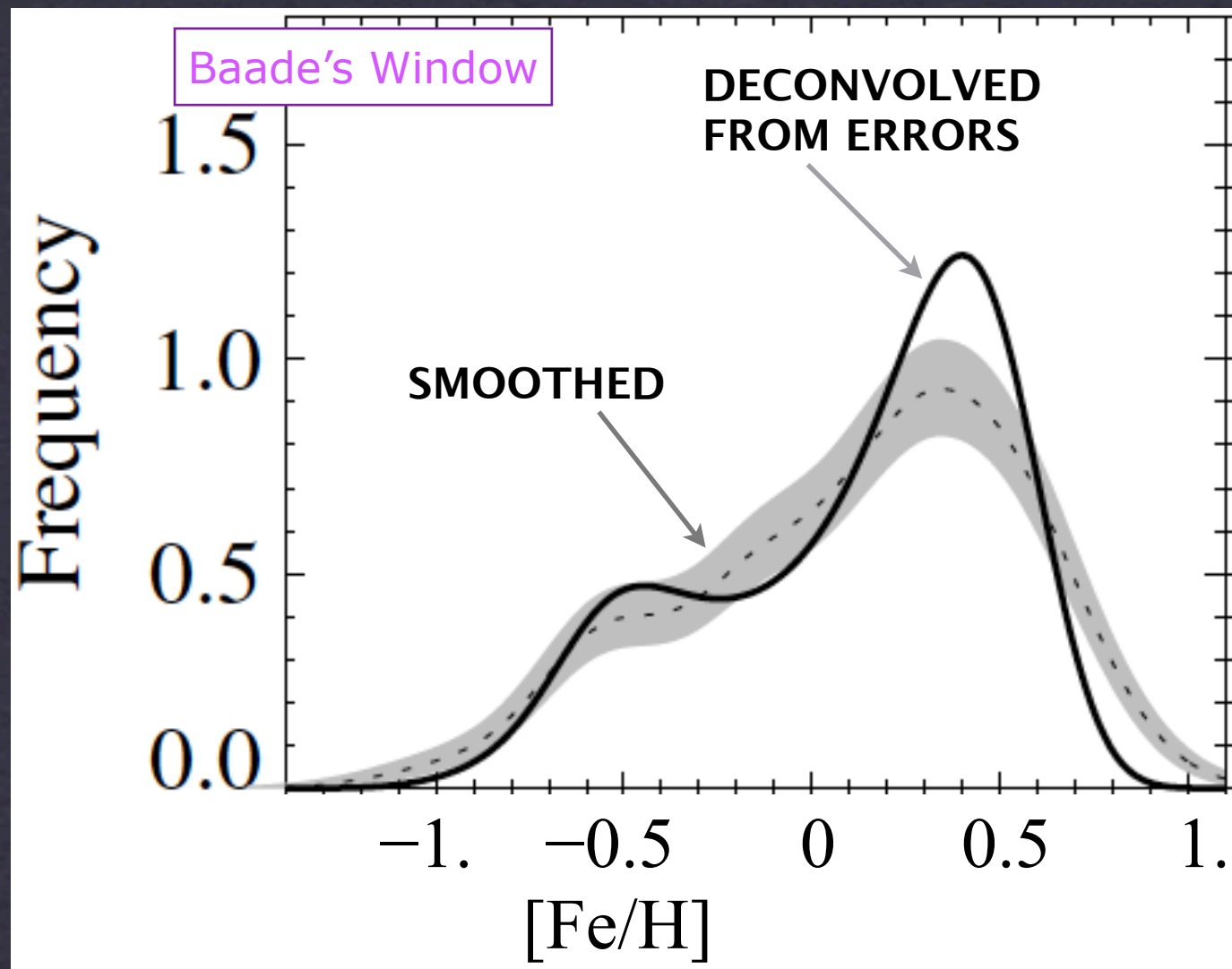
Rich, Origlia & Valenti (2007, 2011)



Coupling kinematics with metallicities

a two-component bulge?

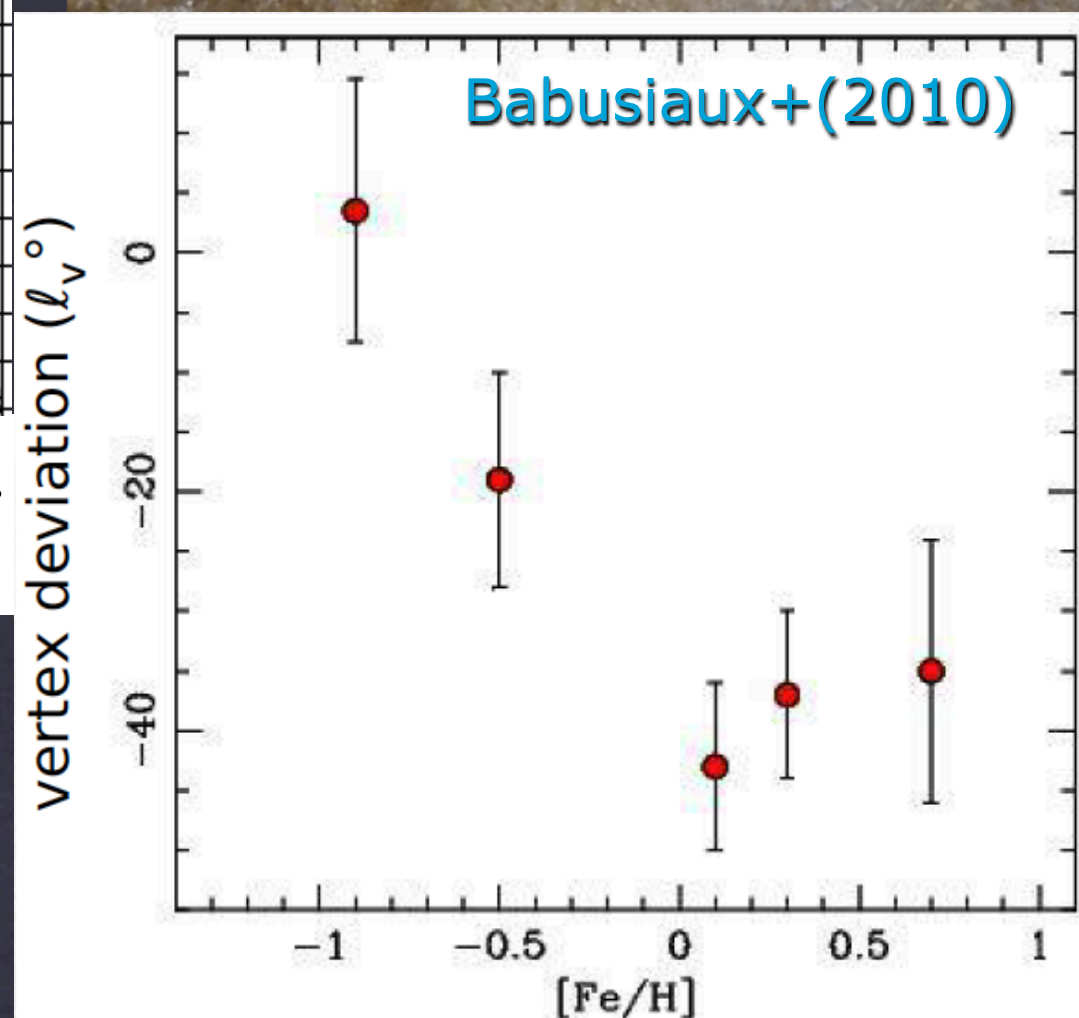
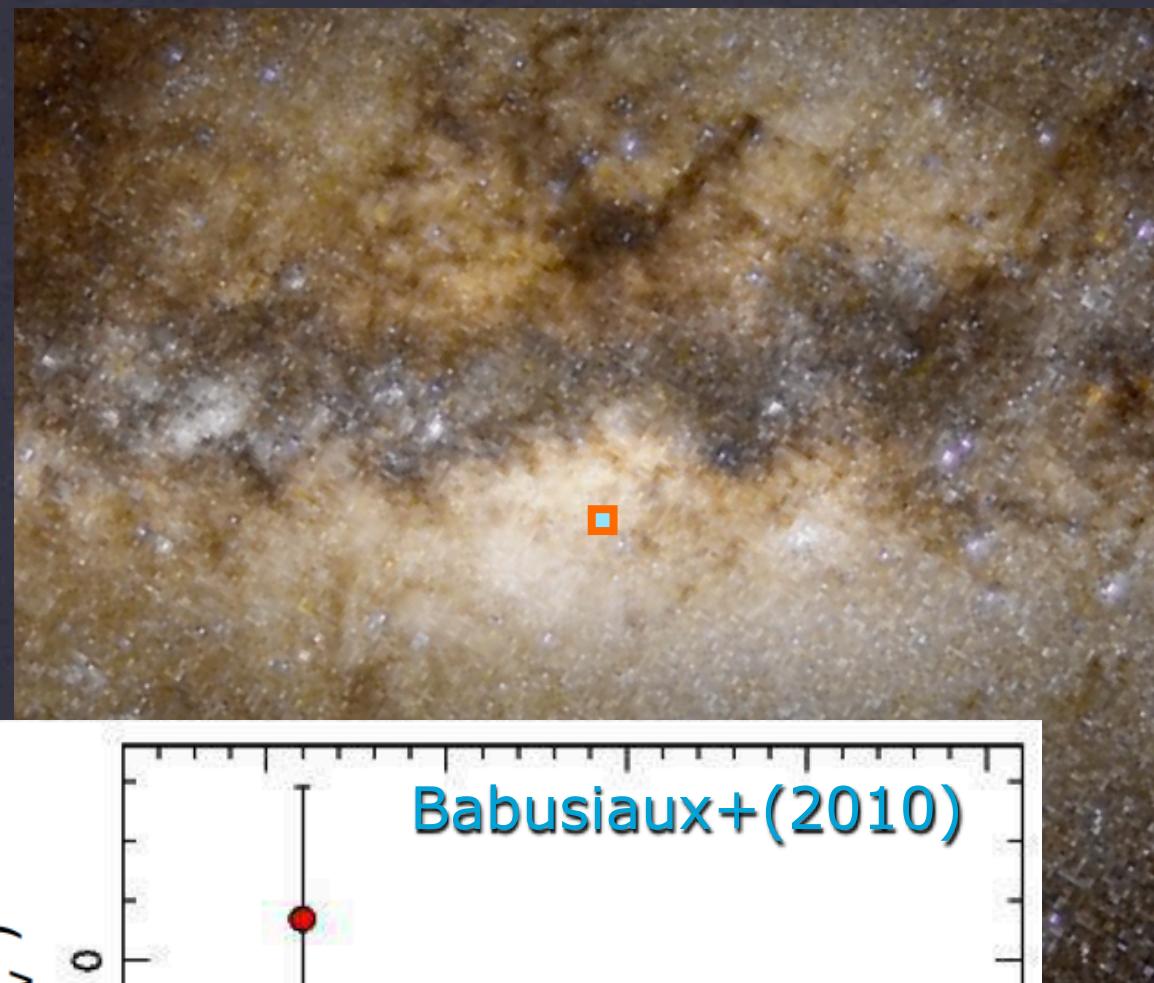
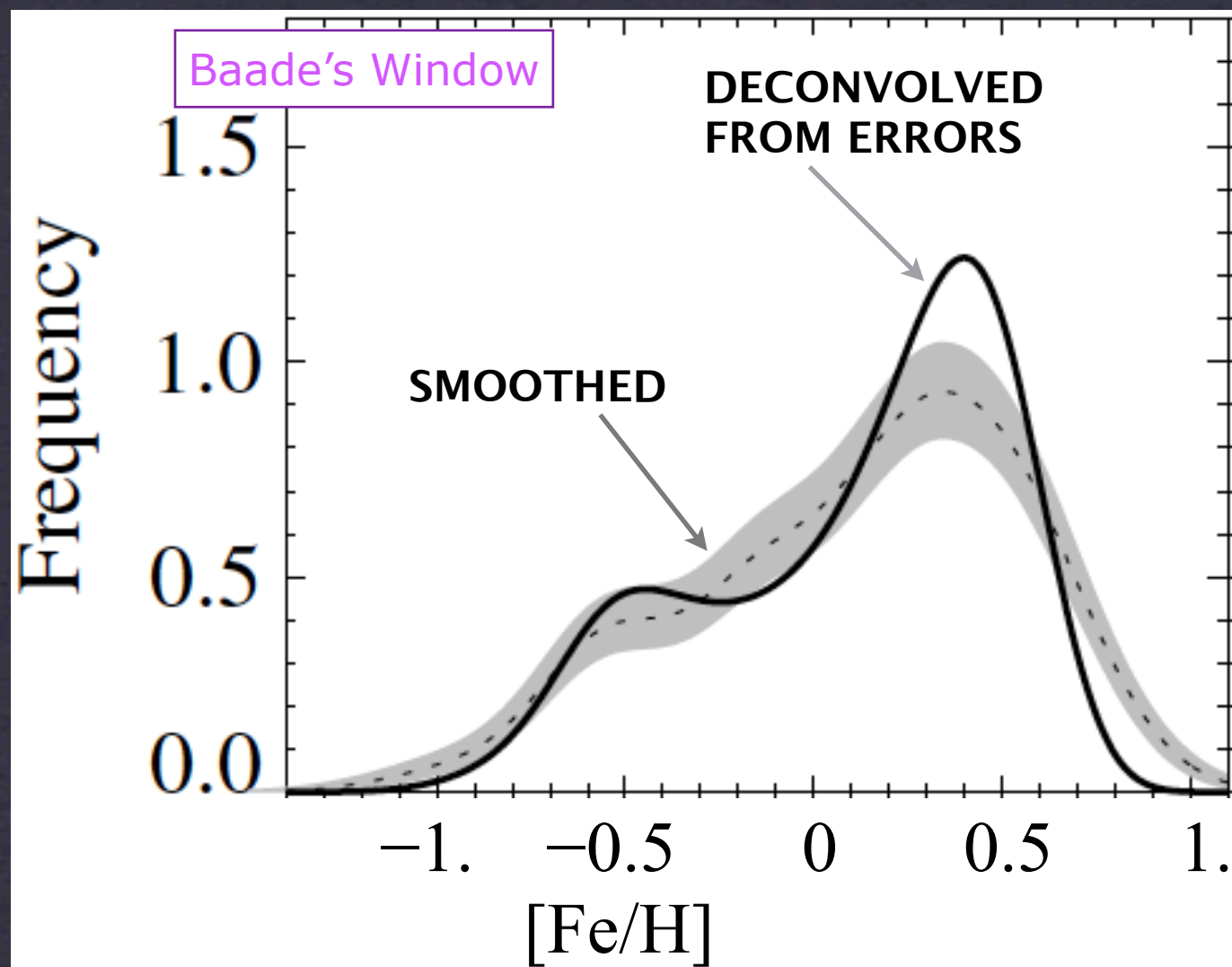
Hill et al. (2011)



Coupling kinematics with metallicities

a two-component bulge?

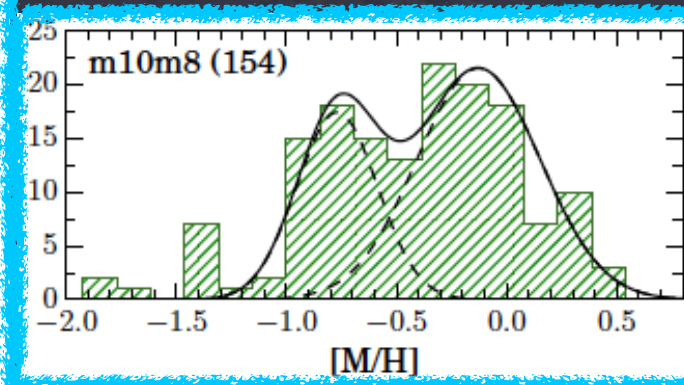
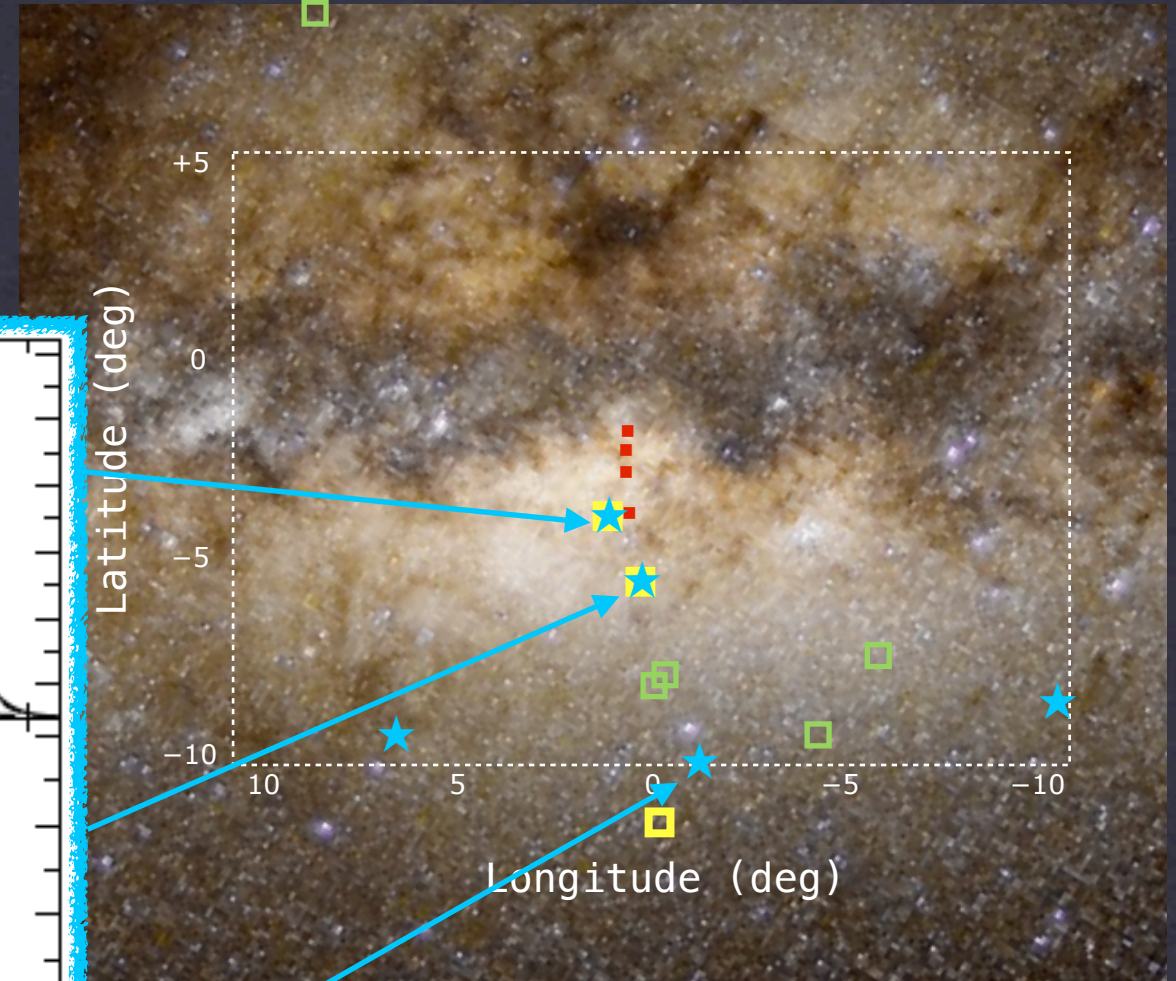
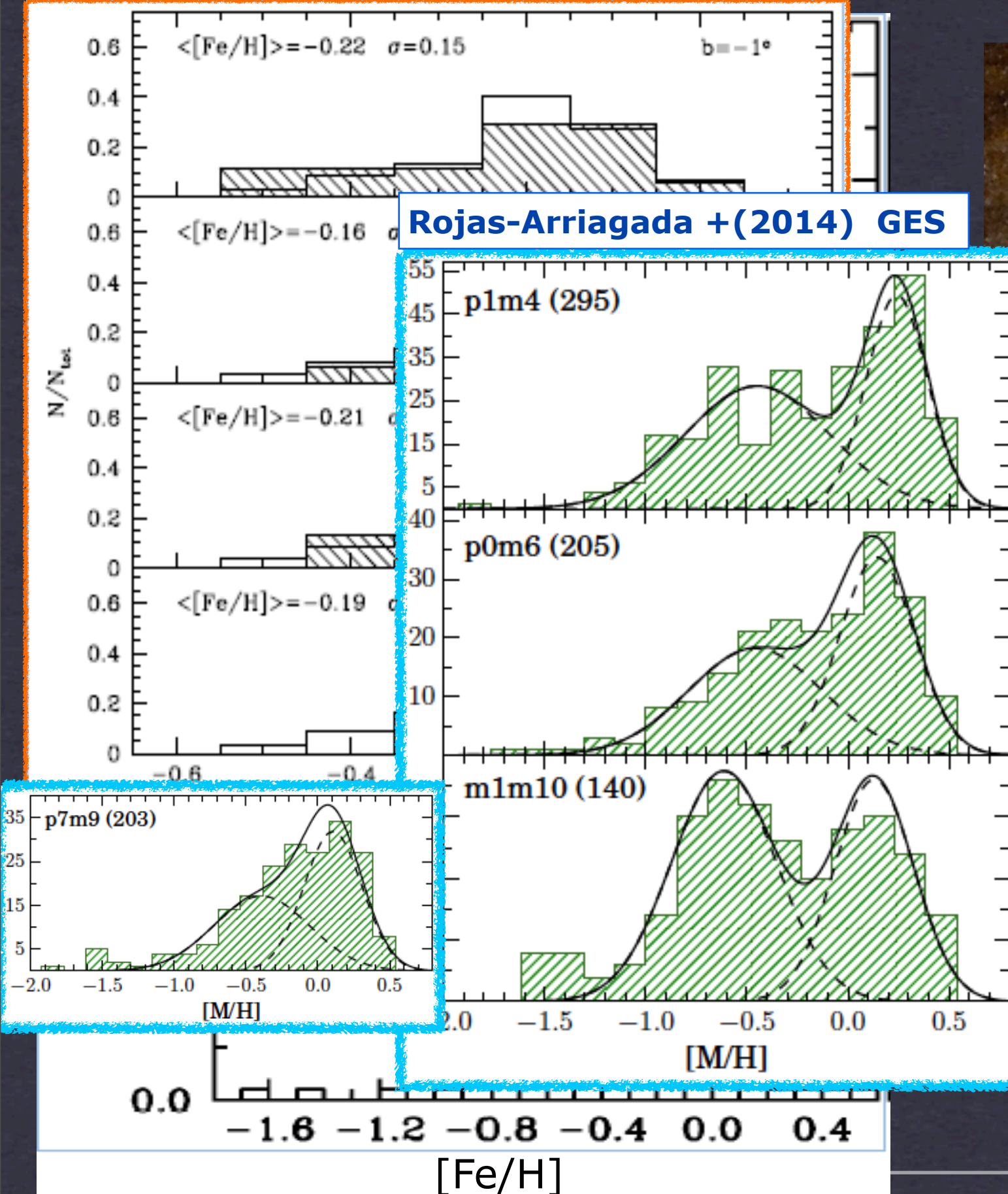
Hill et al. (2011)



Bulge MDF

The GES Survey

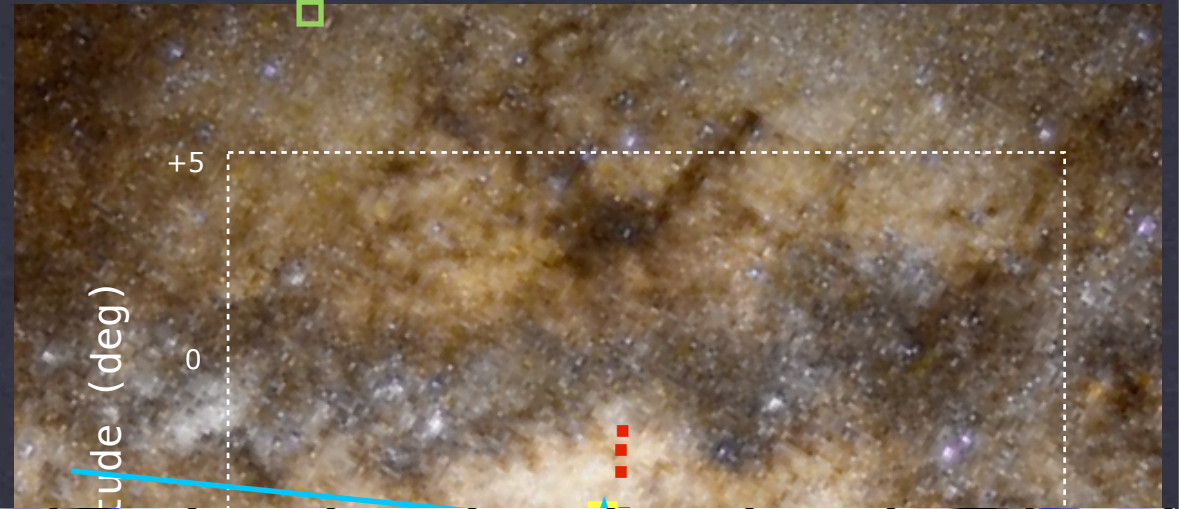
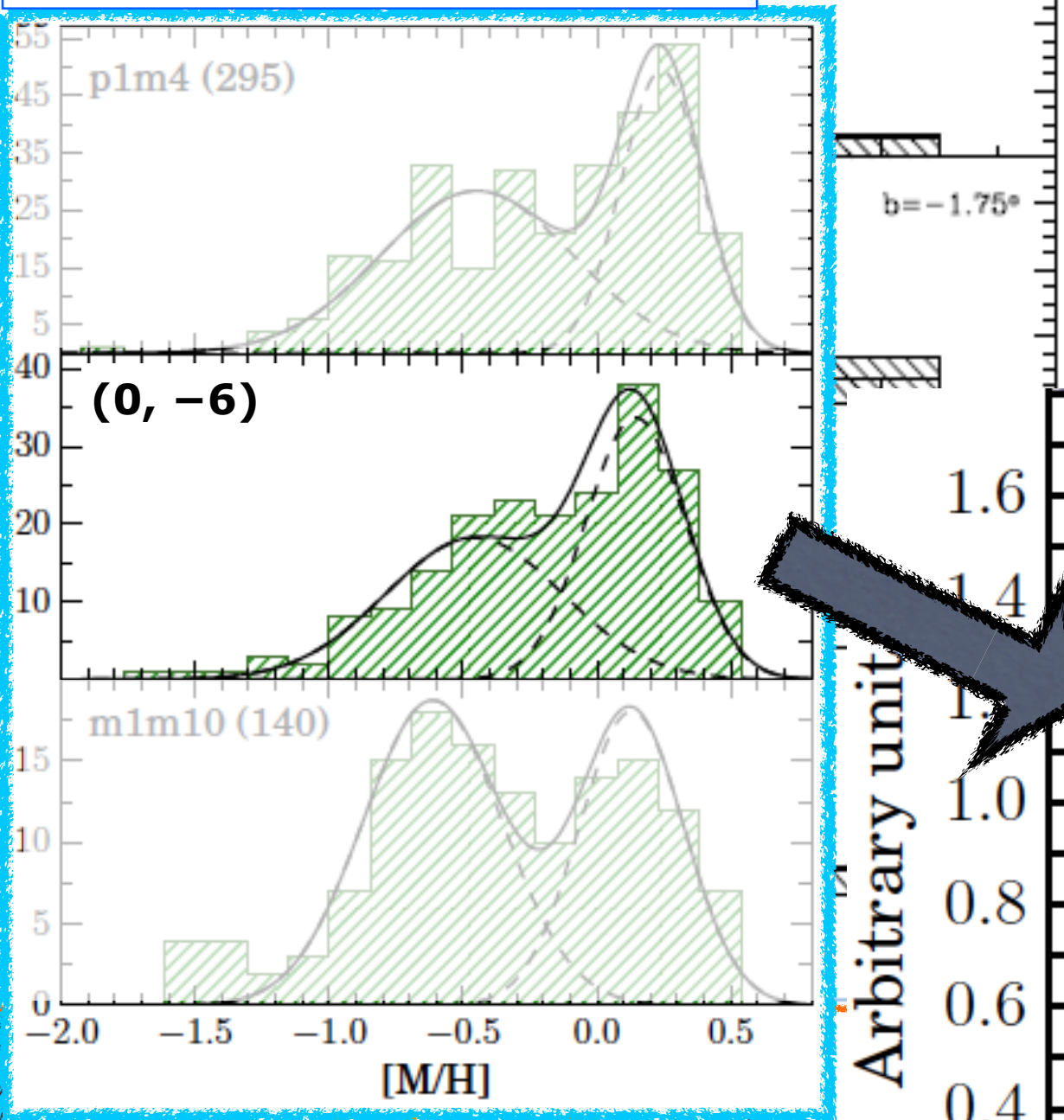
Rojas-Arriagada +(2014) GES



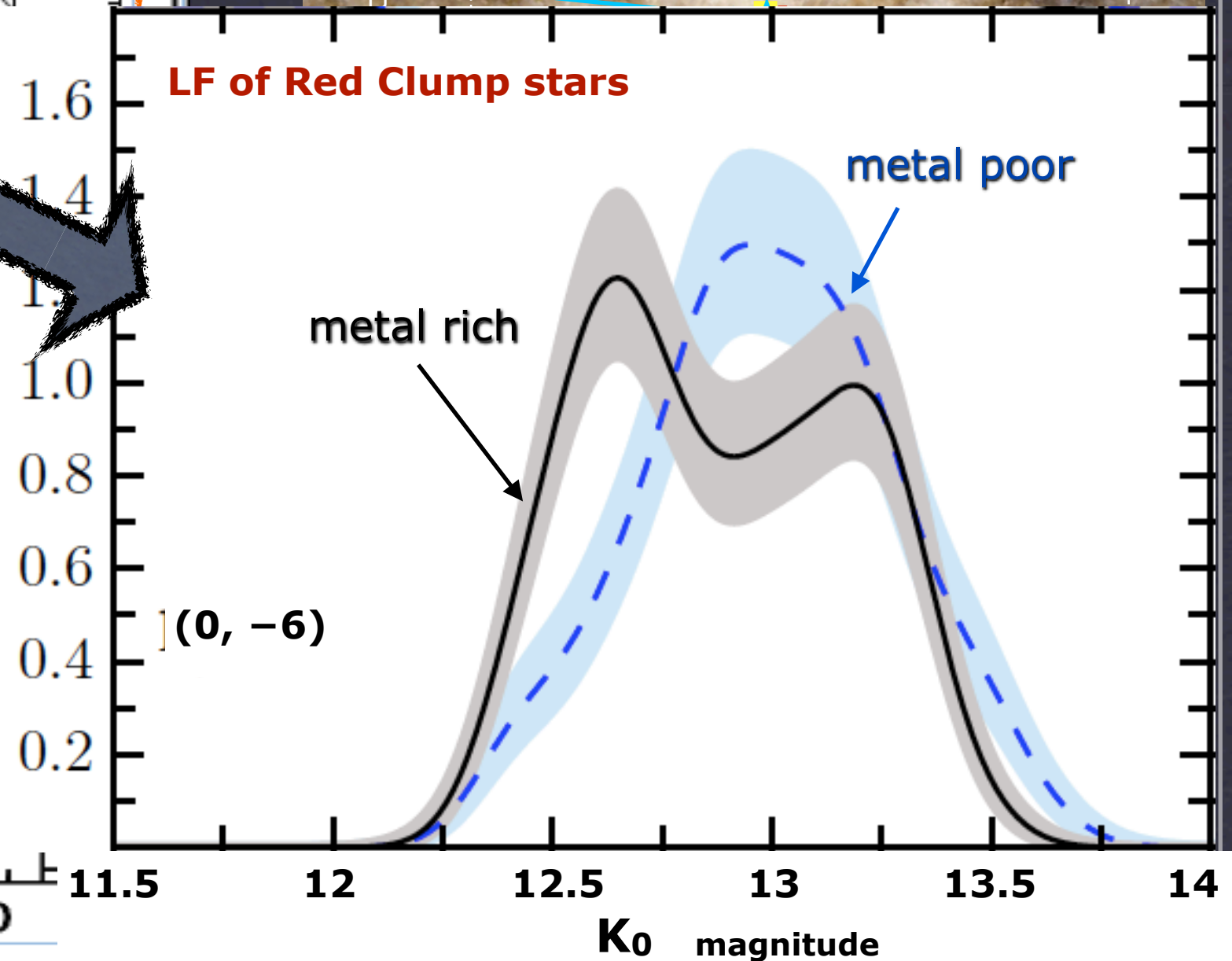
Bulge MDF

The GES Survey

Rojas-Arriagada +(2014) GES



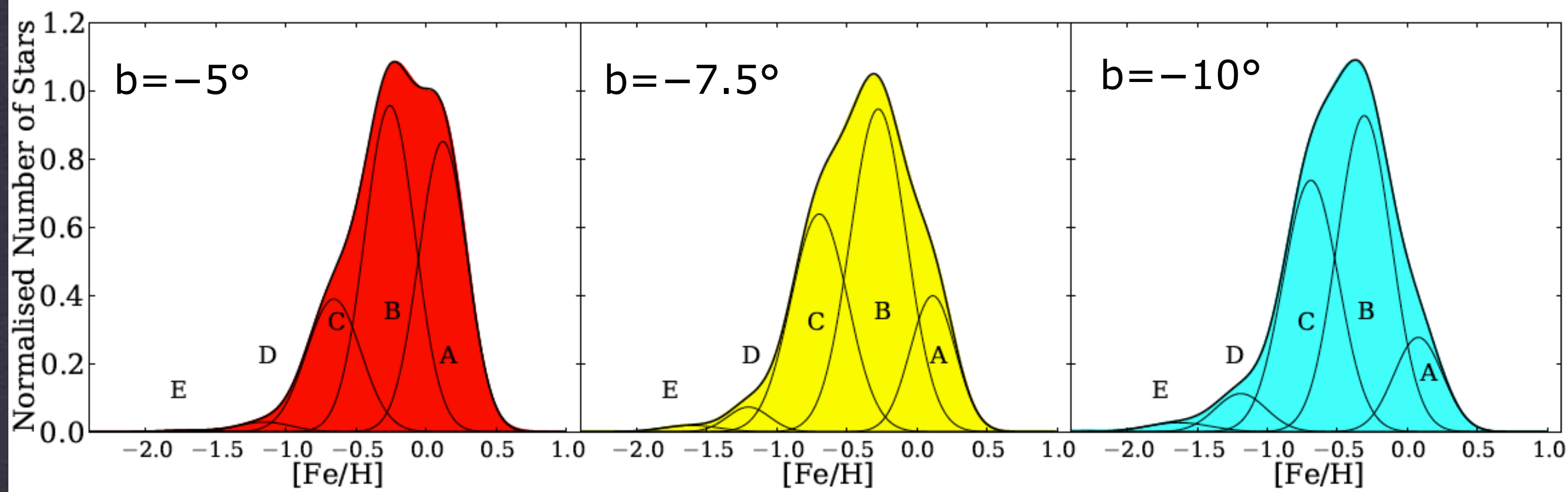
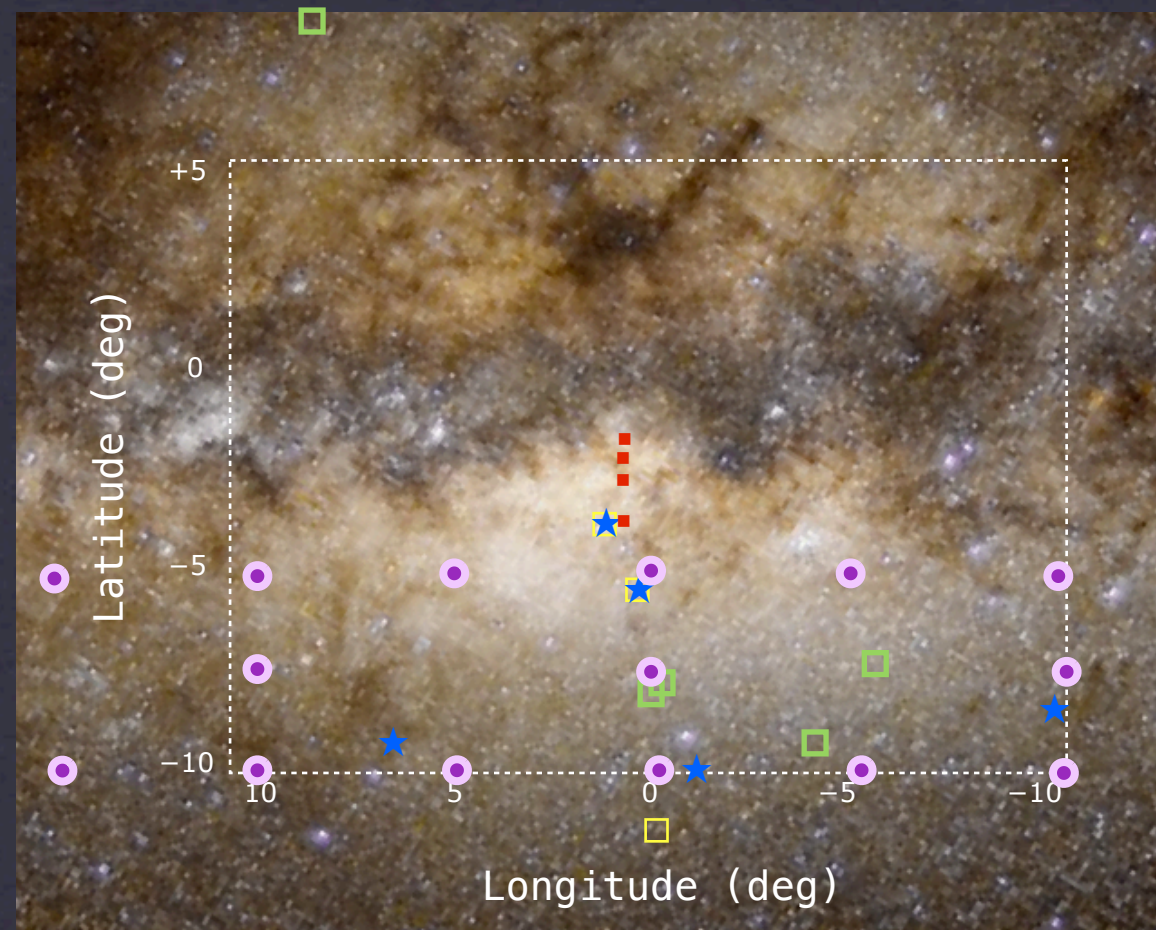
LF of Red Clump stars



Bulge MDF The ARGOS Survey

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

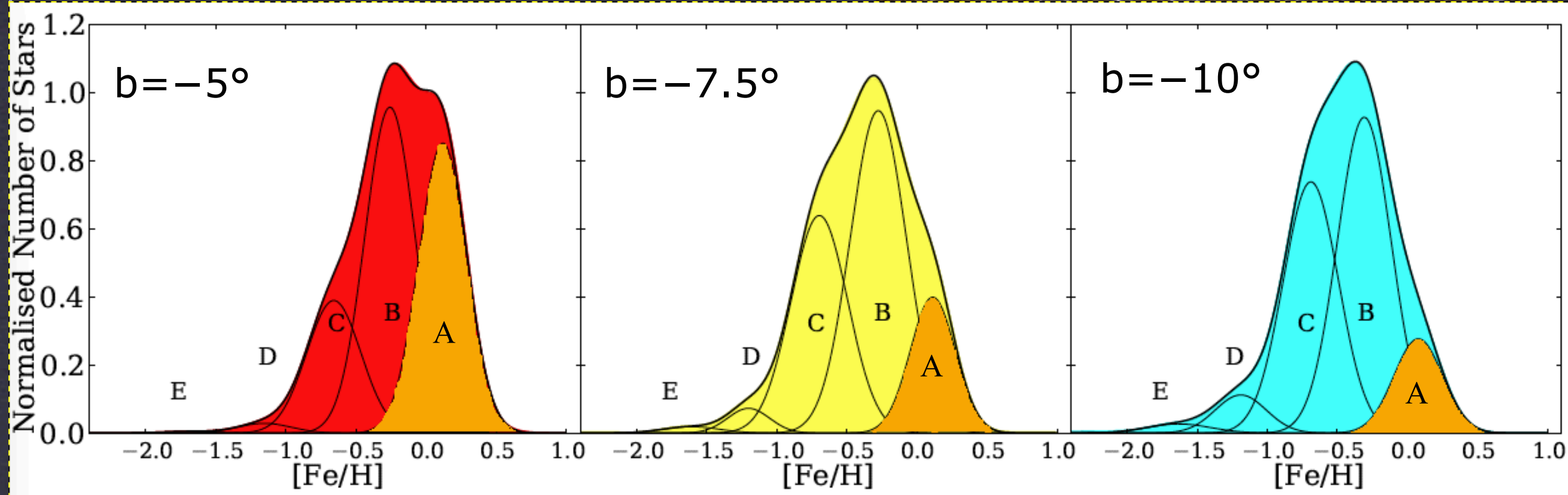
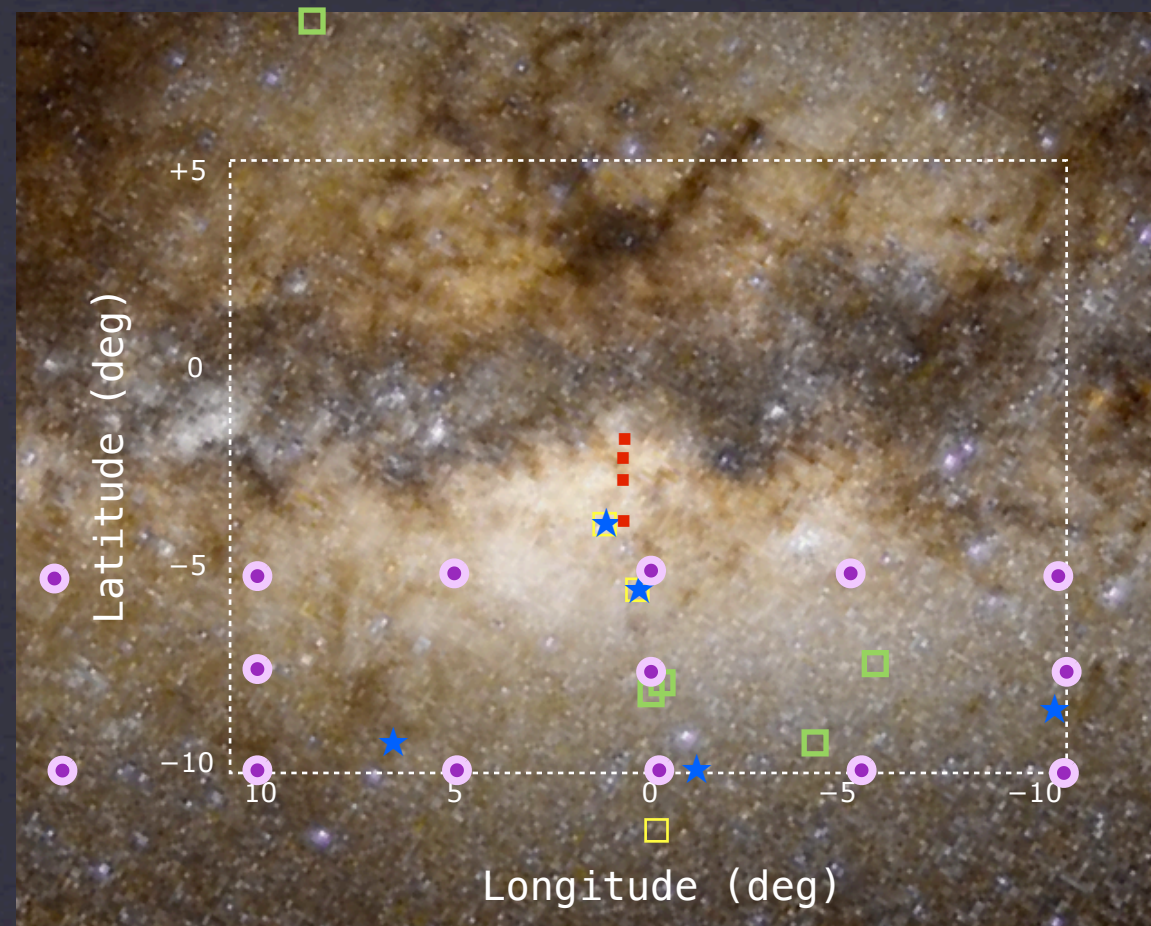
~ 1000 stars/field $R \sim 11,000$



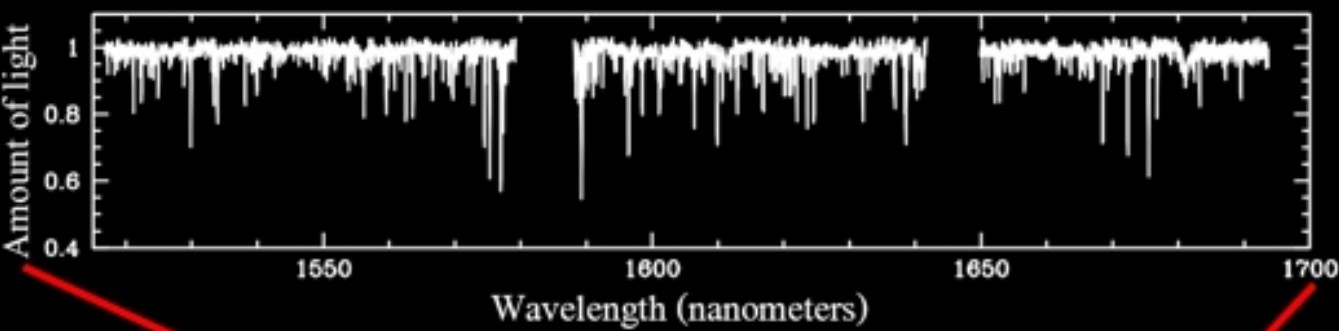
Bulge MDF The ARGOS Survey

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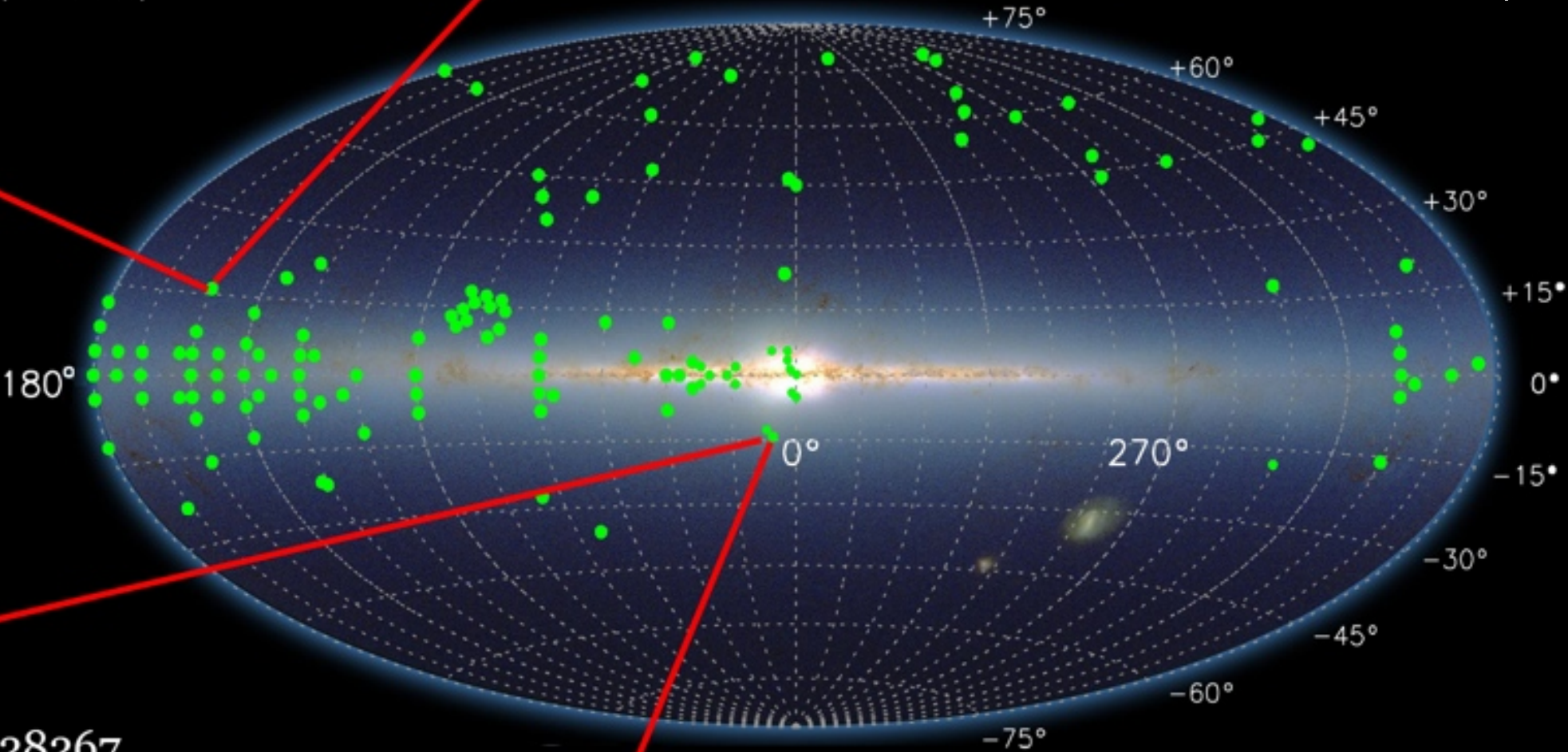


Star: 2M05344760+6309018
Heavy element content: 10% of the Sun

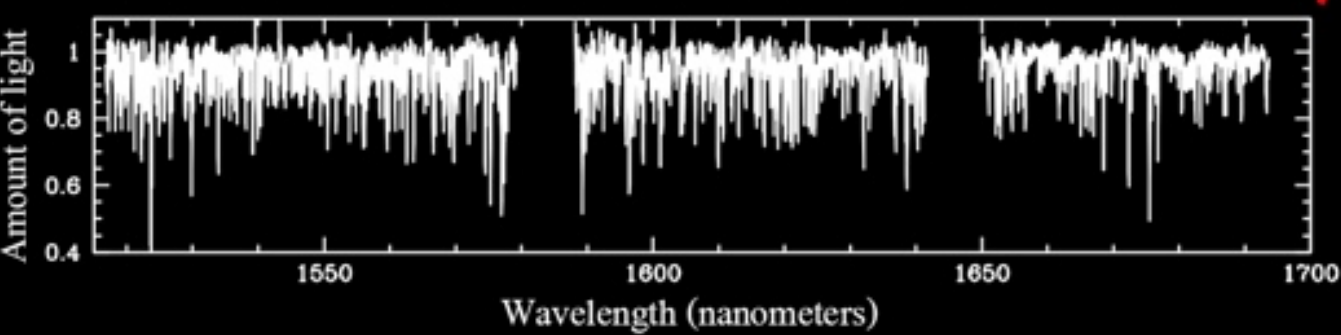


PI: Majewski

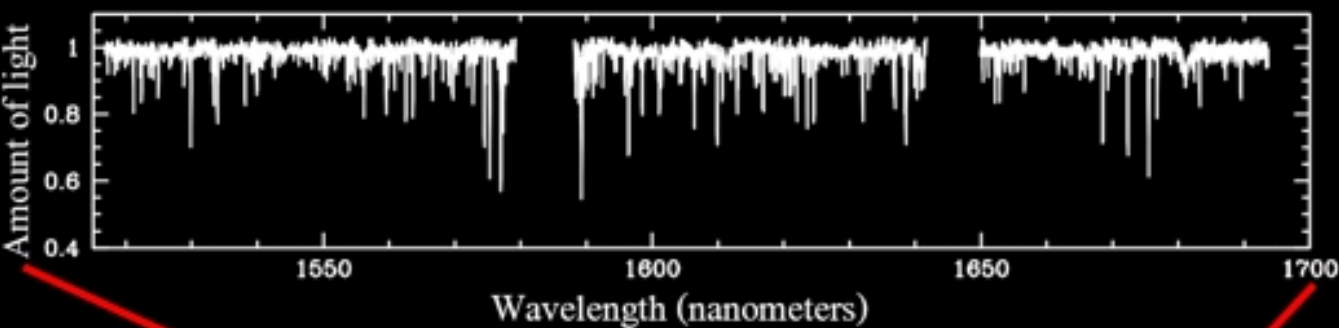
near-IR survey
100,000 stars
down to $H \sim 12.5$



Star: 2M18572662-3028267
Heavy element content: 150% of the Sun

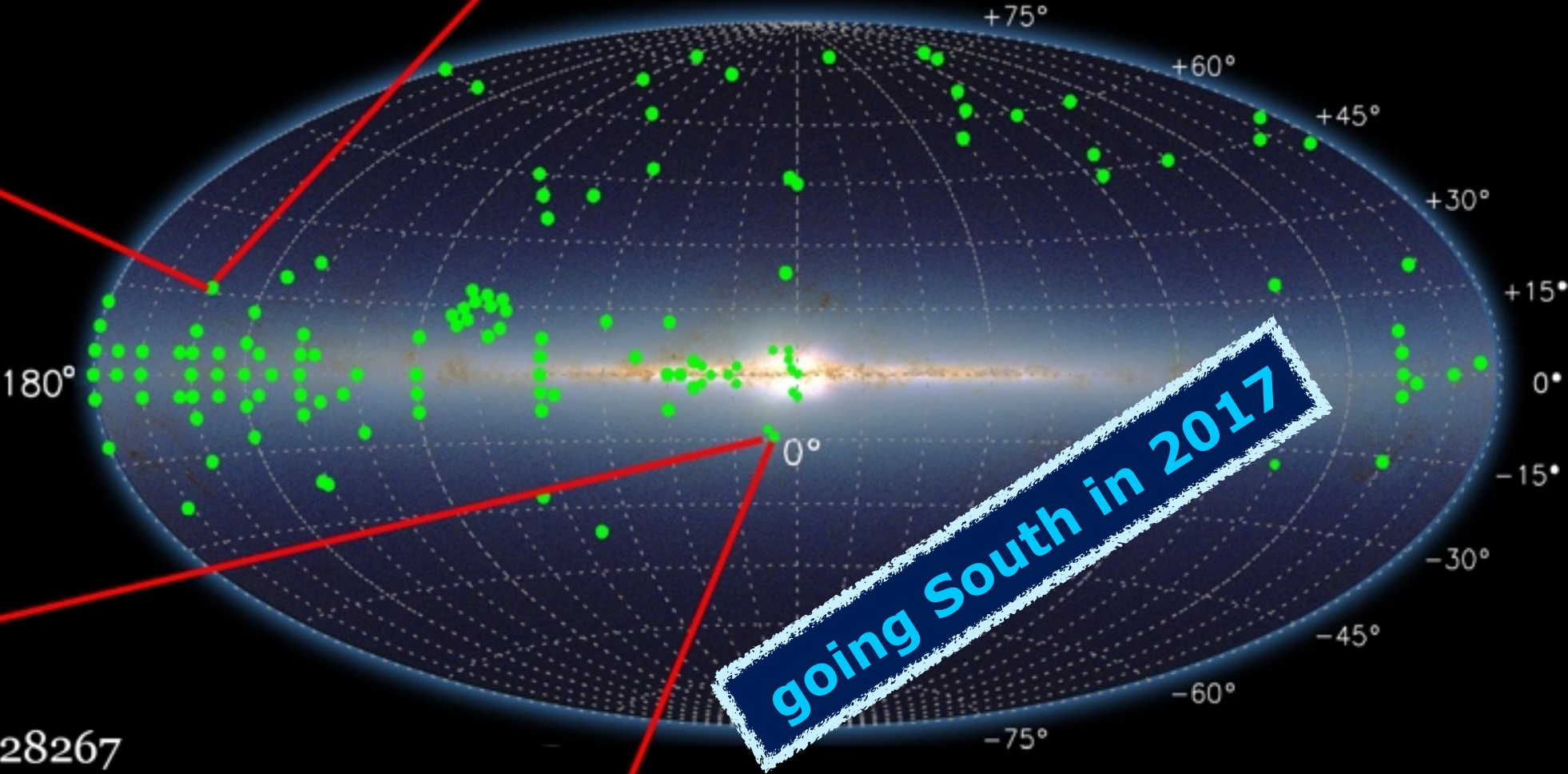


Star: 2M05344760+6309018
Heavy element content: 10% of the Sun

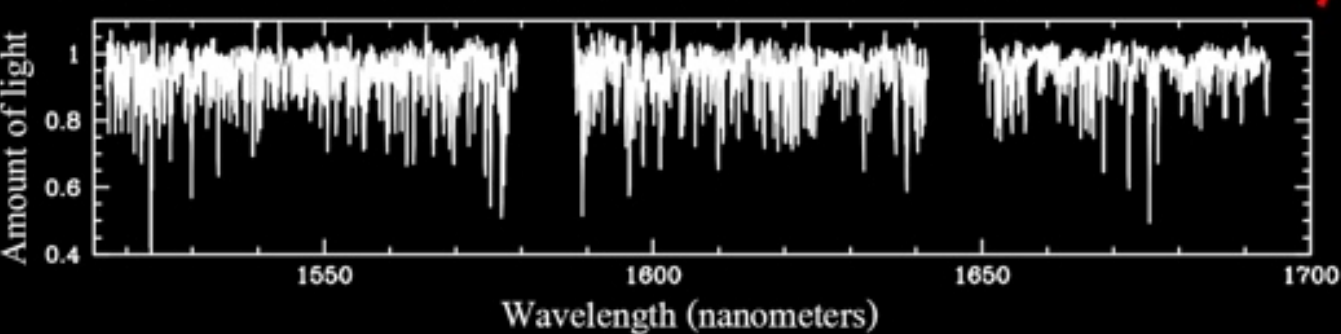


PI: Majewski

near-IR survey
100,000 stars
down to $H \sim 12.5$



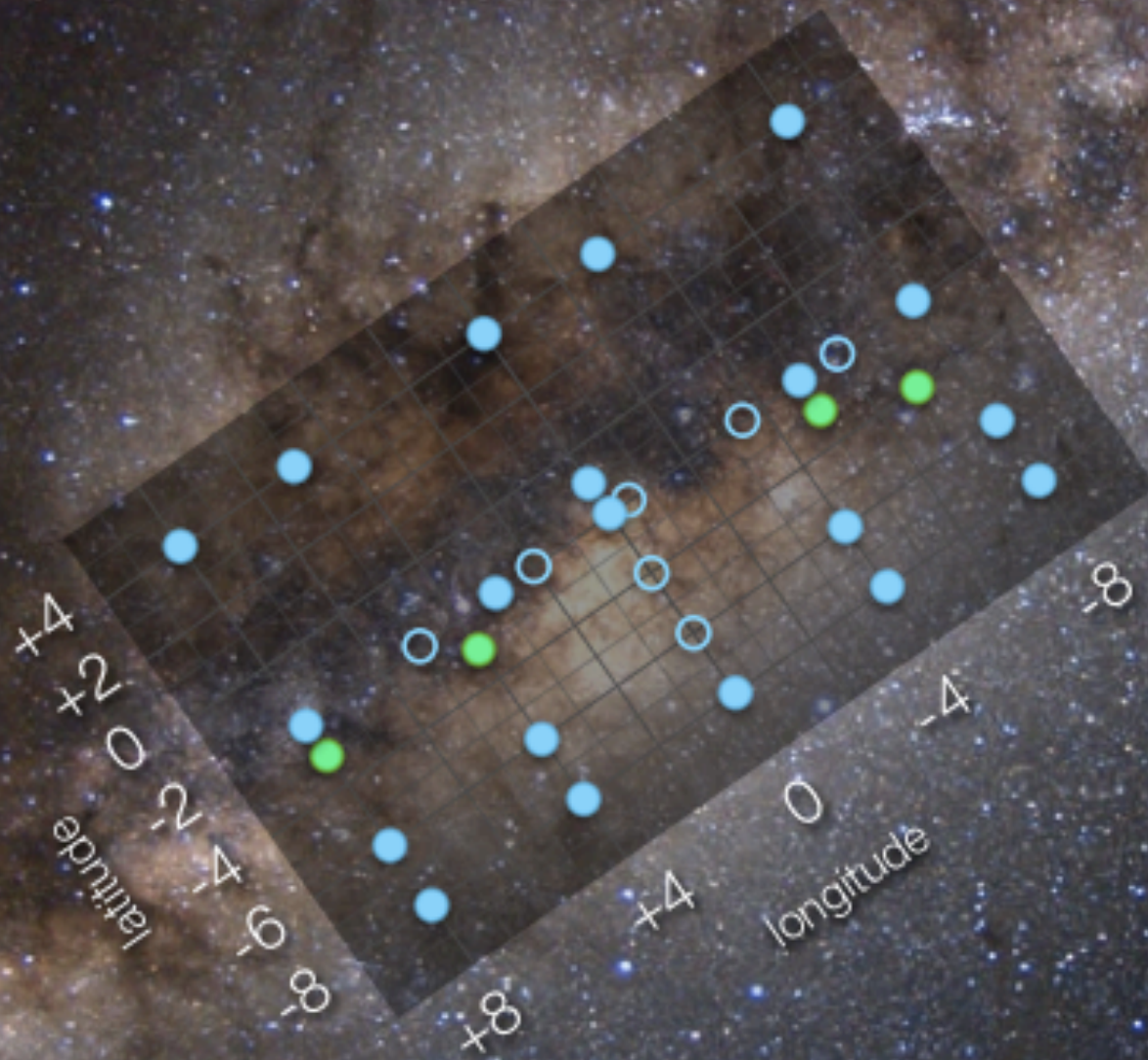
Star: 2M18572662-3028267
Heavy element content: 150% of the Sun



The Giraffe Inner Bulge Survey

PI: MZ

~ 6200 stars on CaT
~ 450 stars at $R \sim 22,000$



The Giraffe Inner Bulge Survey

PI: MZ

~ 6200 stars on CaT
~ 450 stars at $R \sim 22,000$

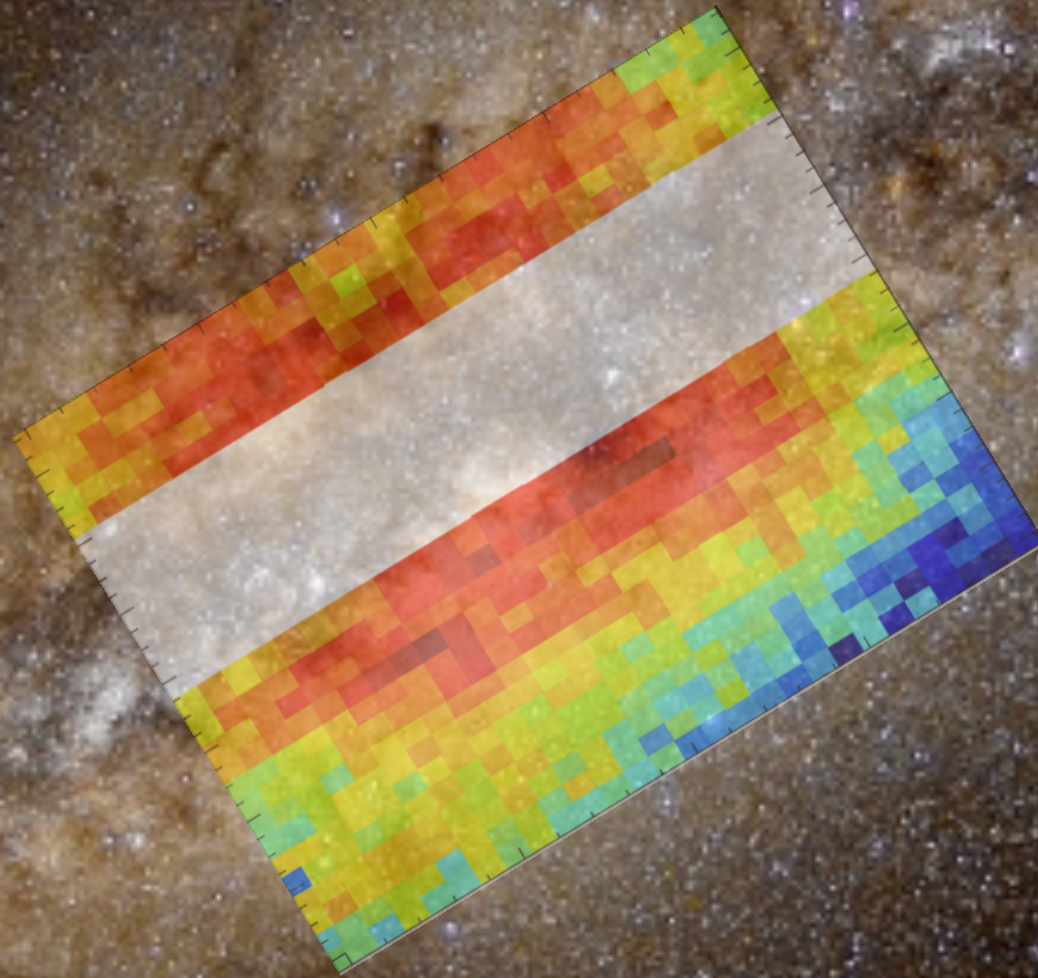


TALK BY ELENA VALENTI



The first global photometric metallicity map of the Galactic bulge

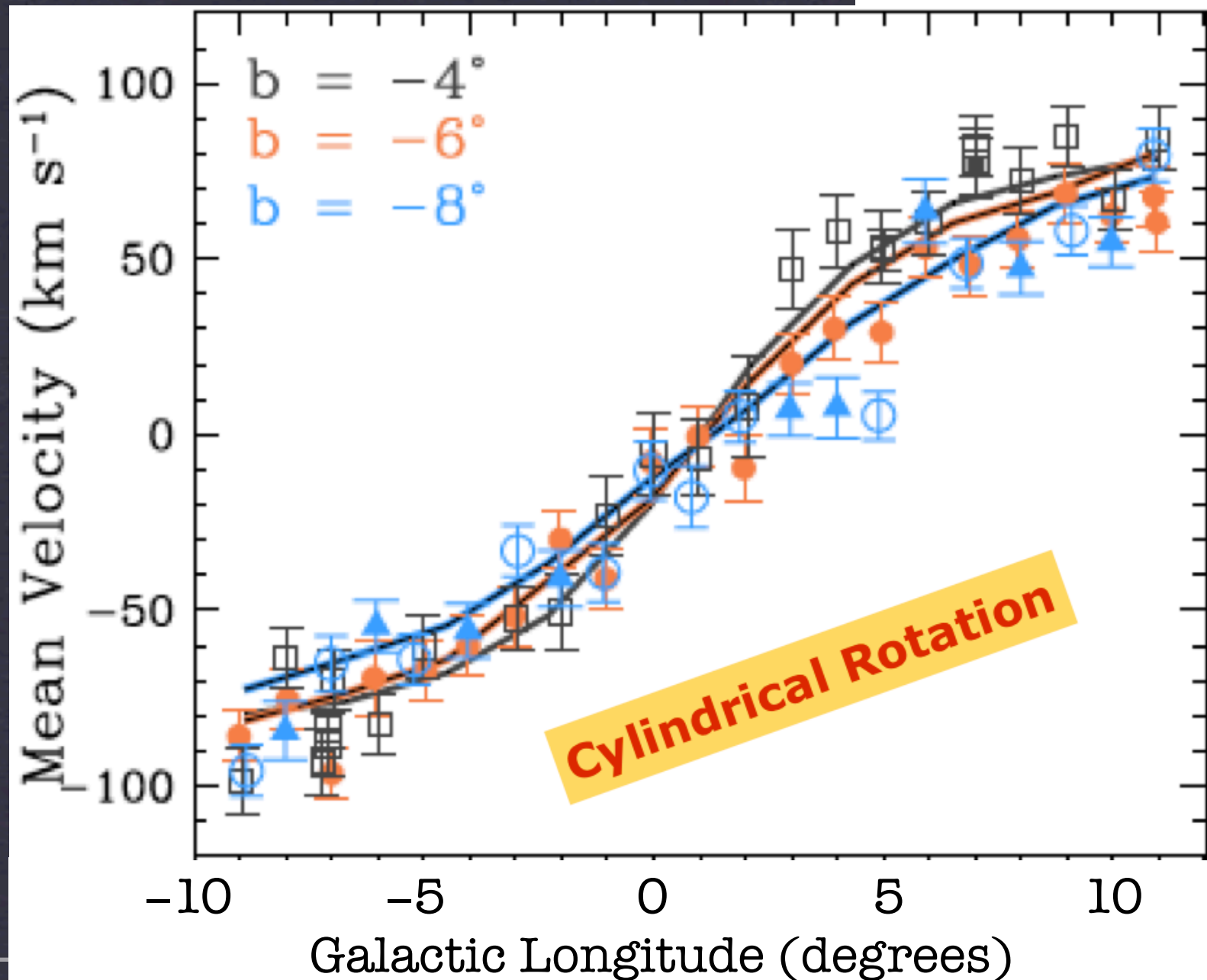
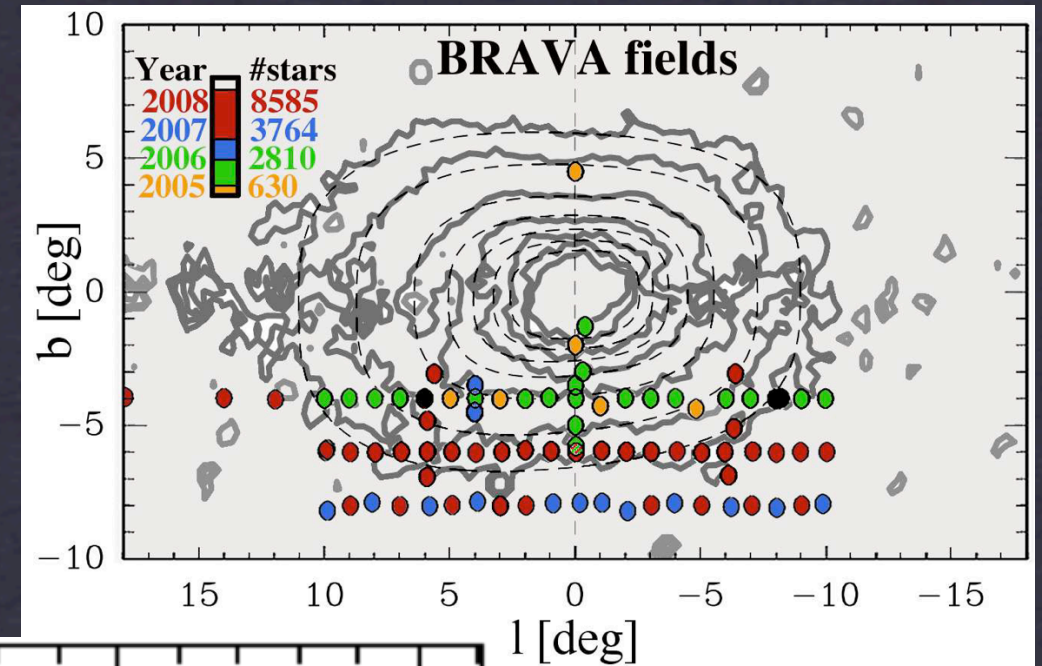
Gonzalez, Rejkuba, MZ (2013, A&A, 552, 110)



The BRAVA Survey

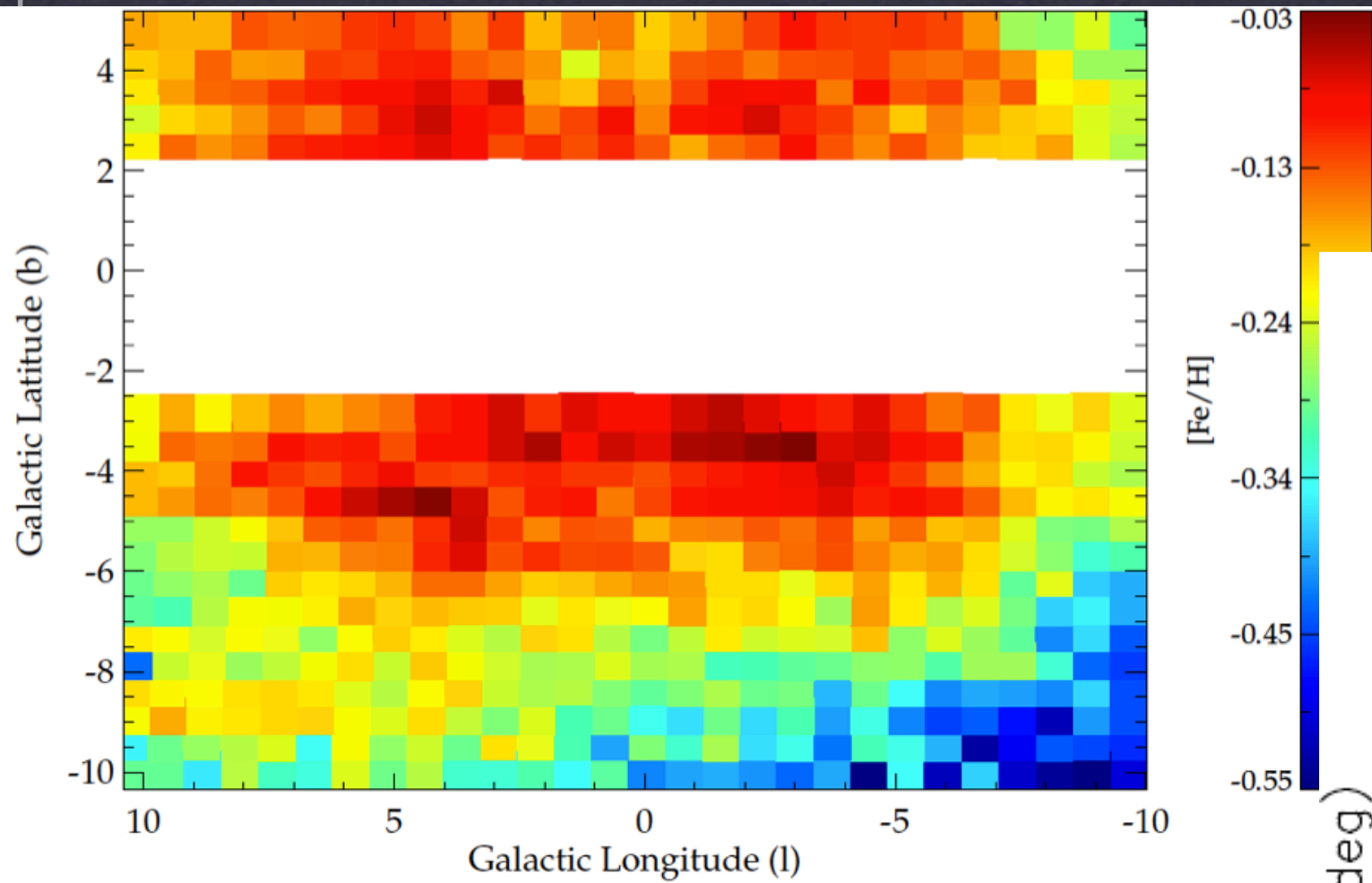
Rich et al. (2007)
Howard et al. (2009)
Shen et al. (2010)
Kunder et al. (2012)

Radial Velocities for 10,000 bulge M giants

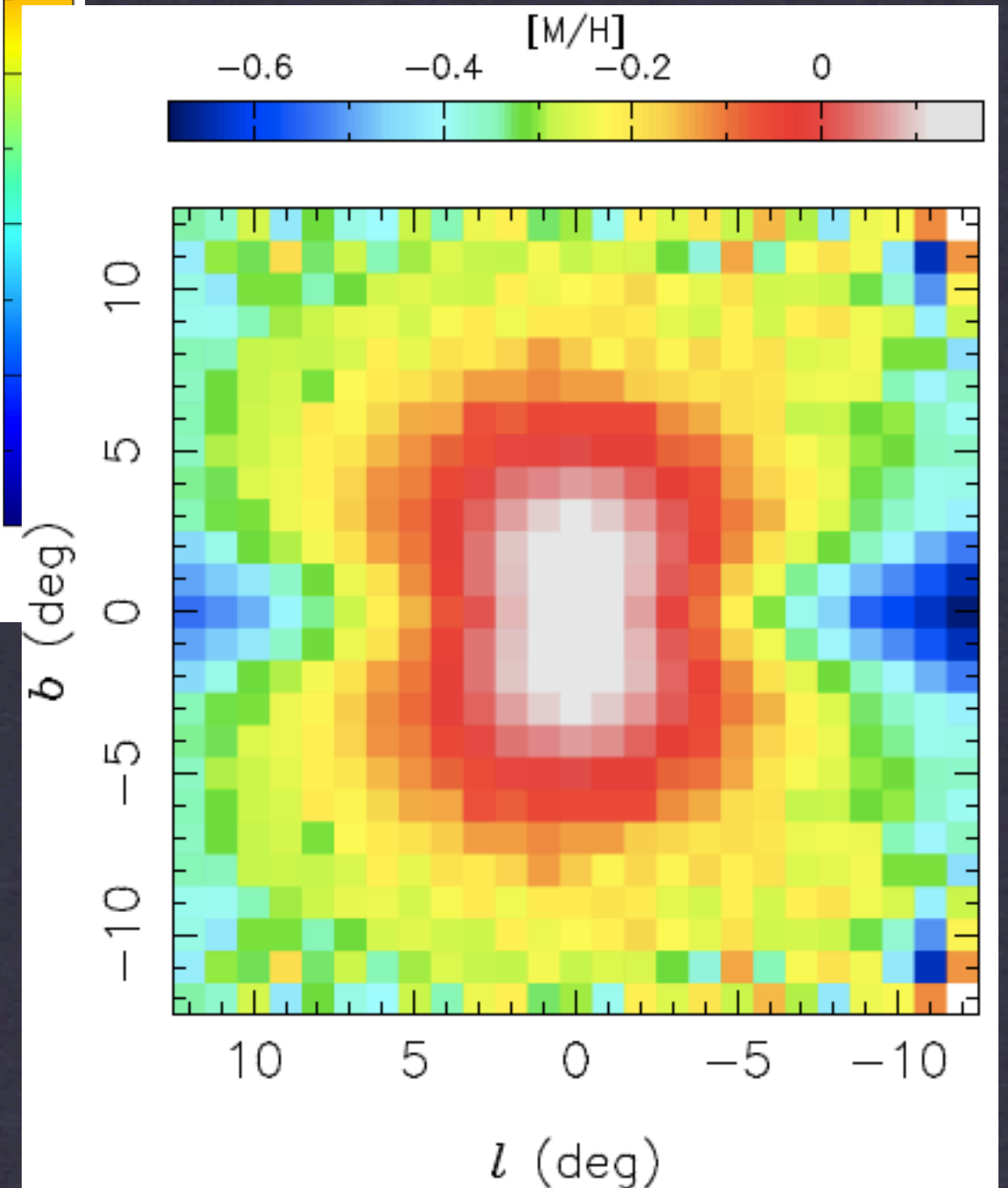


The radial metallicity gradient in the bulge

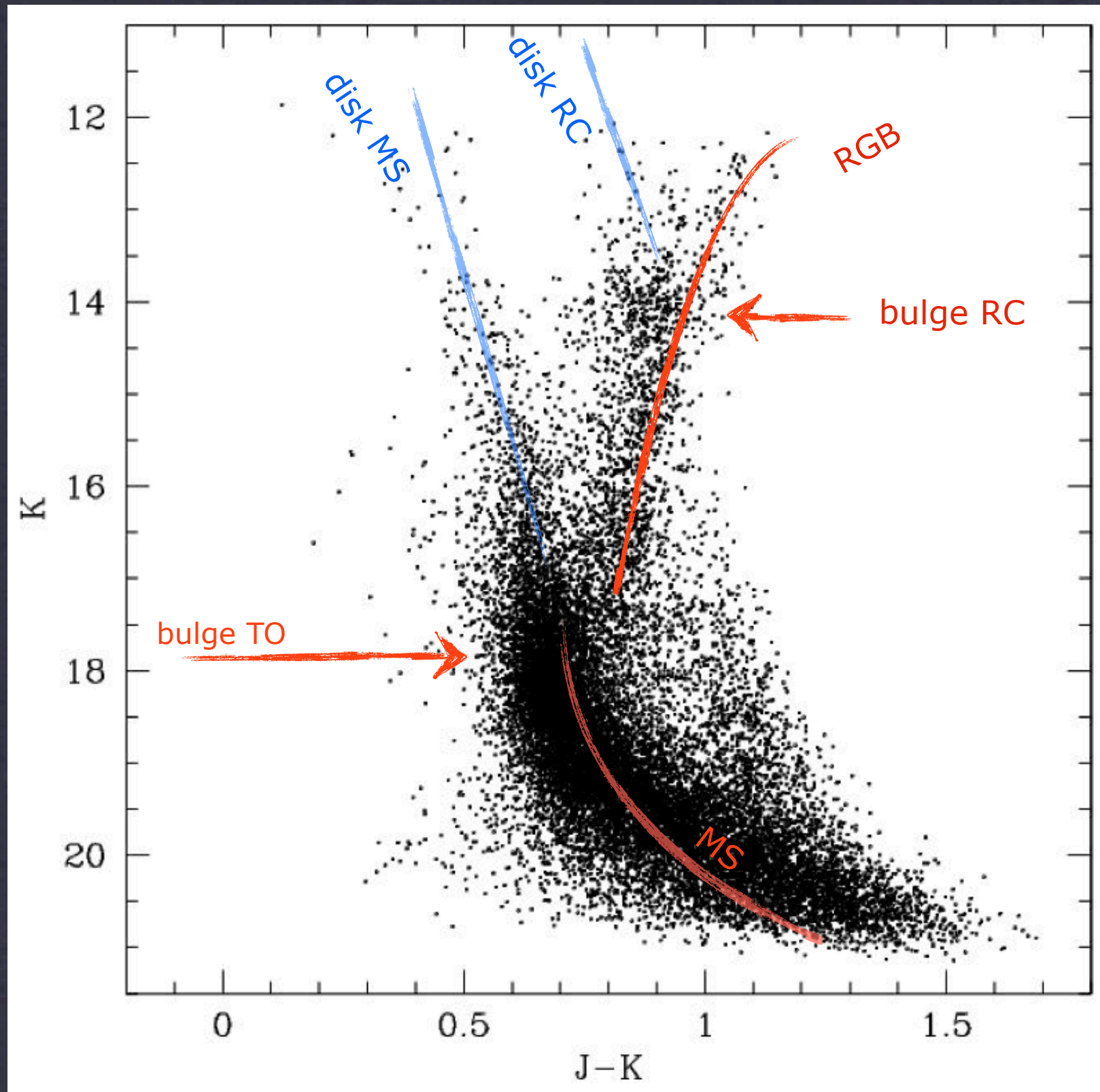
OBSERVED: Gonzalez et al. (2012)

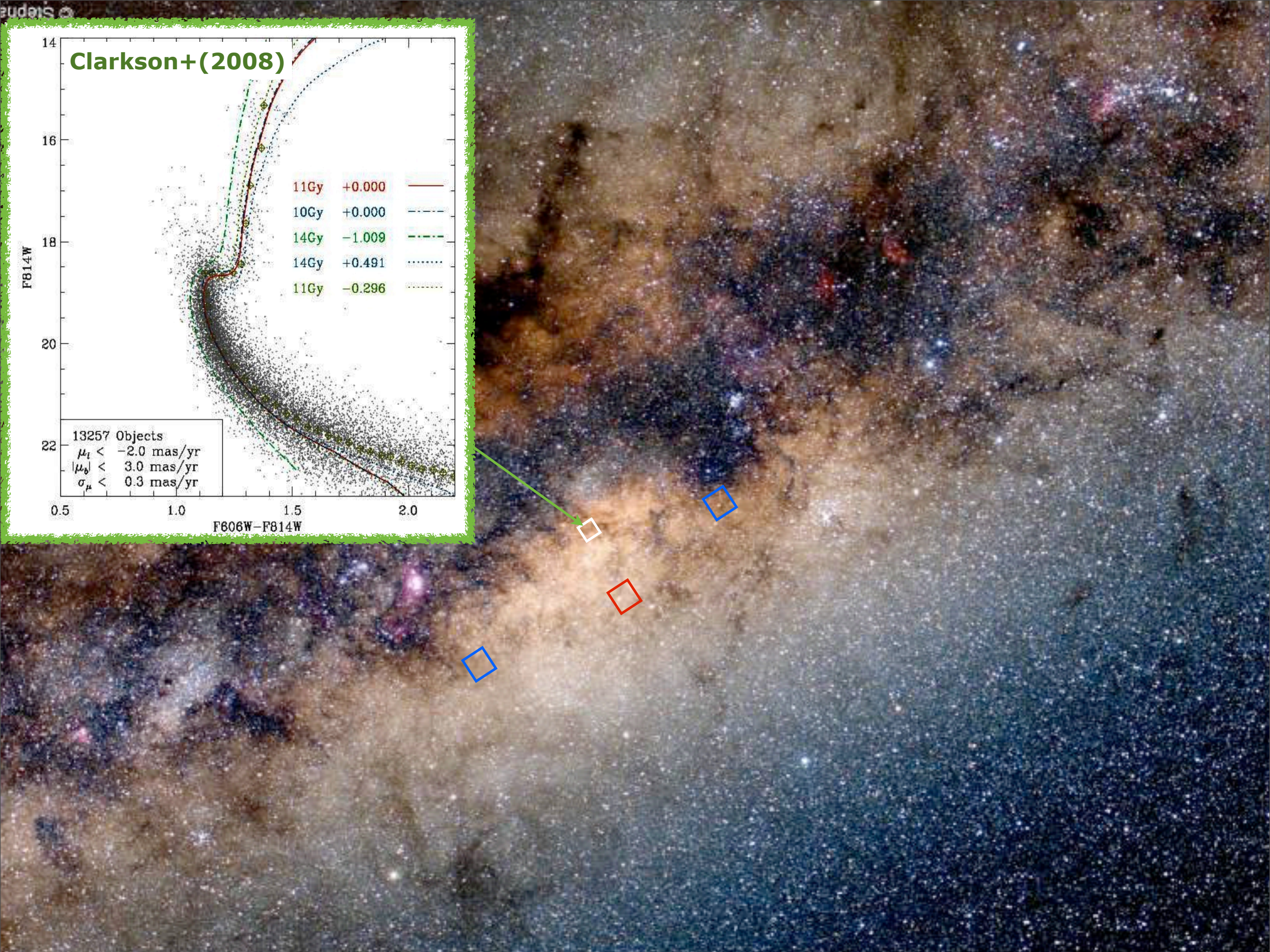
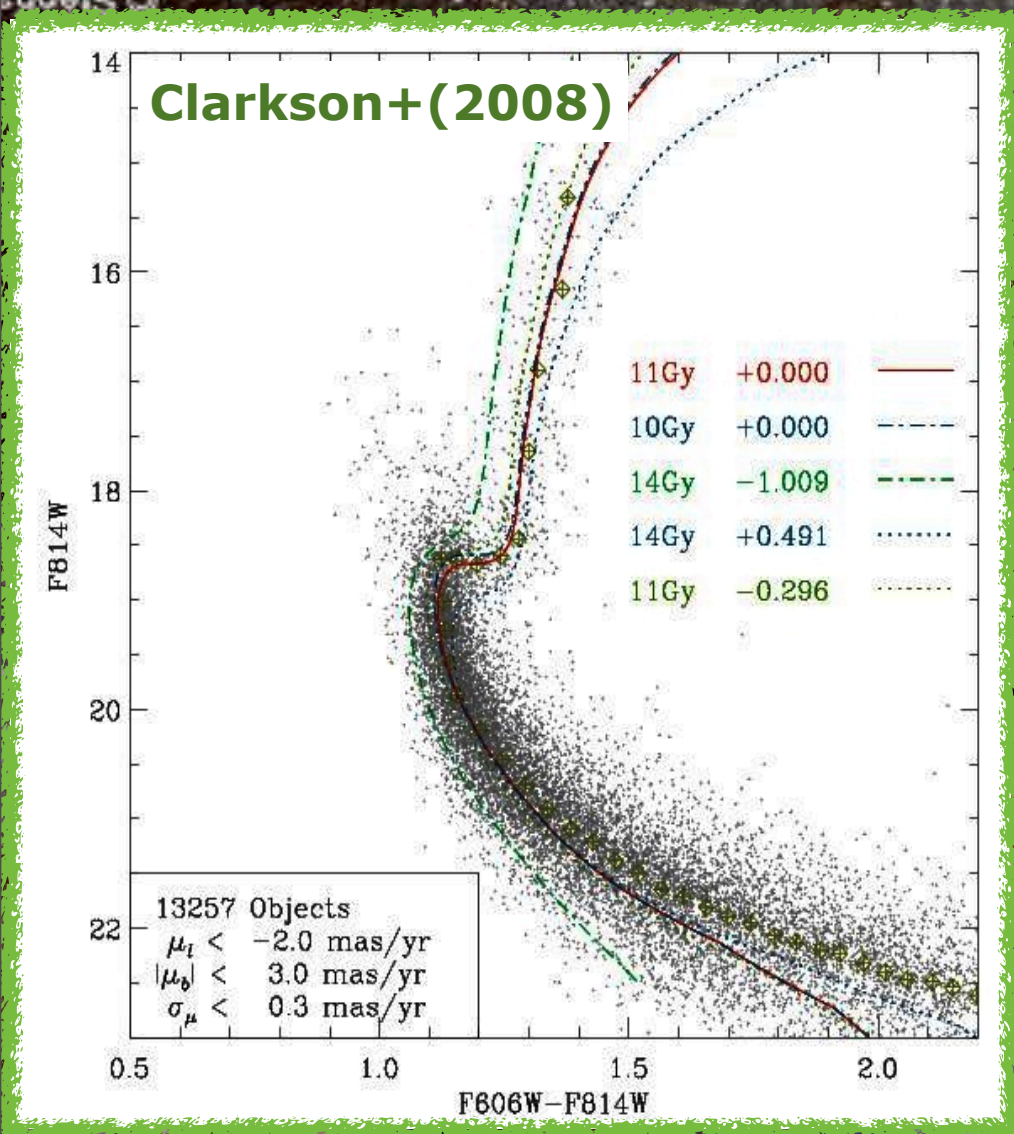


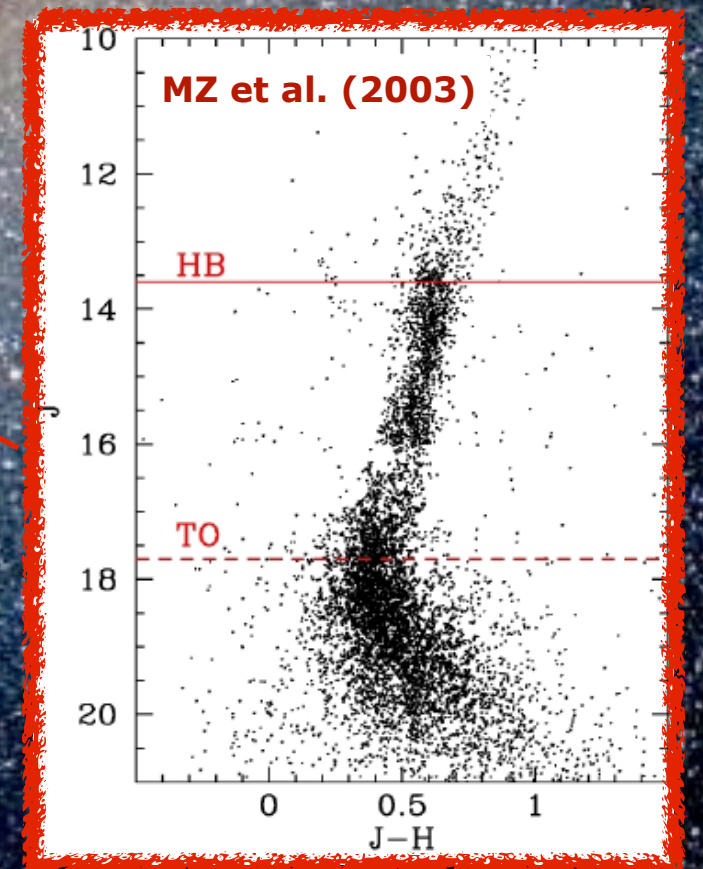
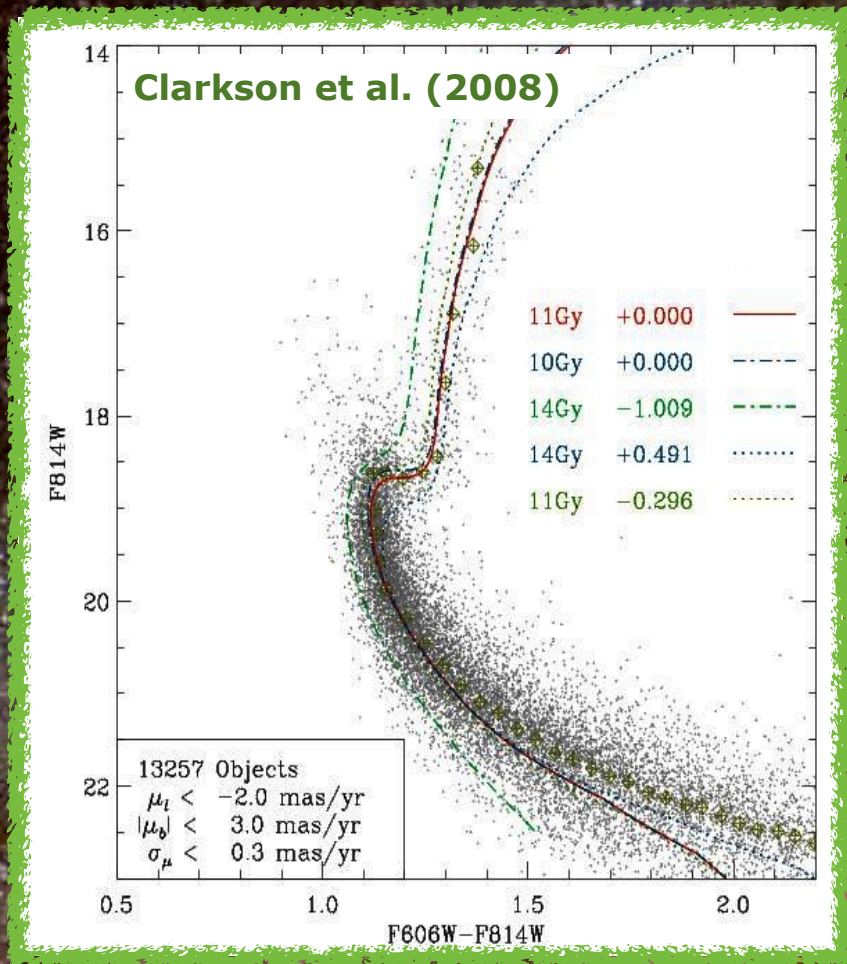
THEORETICAL:
Martinez-Valpuesta & Gerhard (2013)

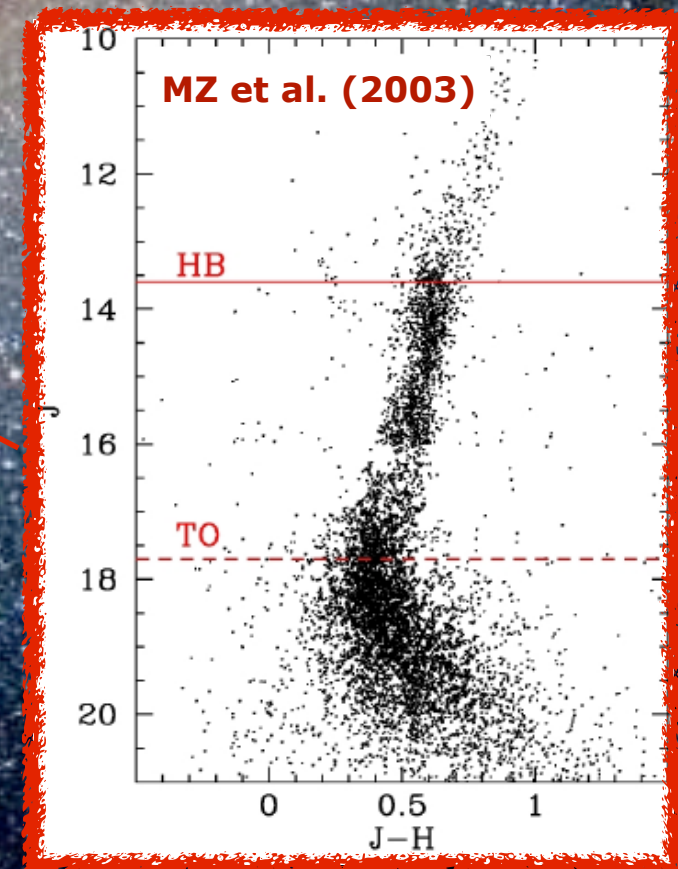
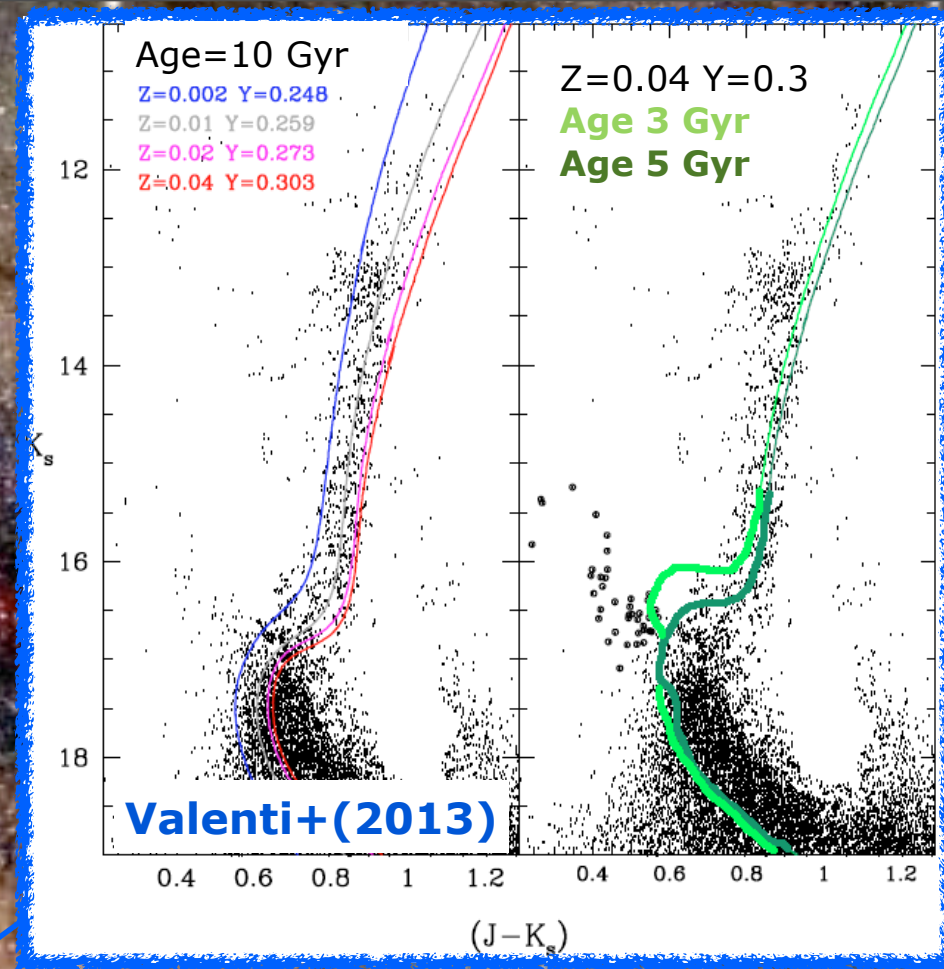
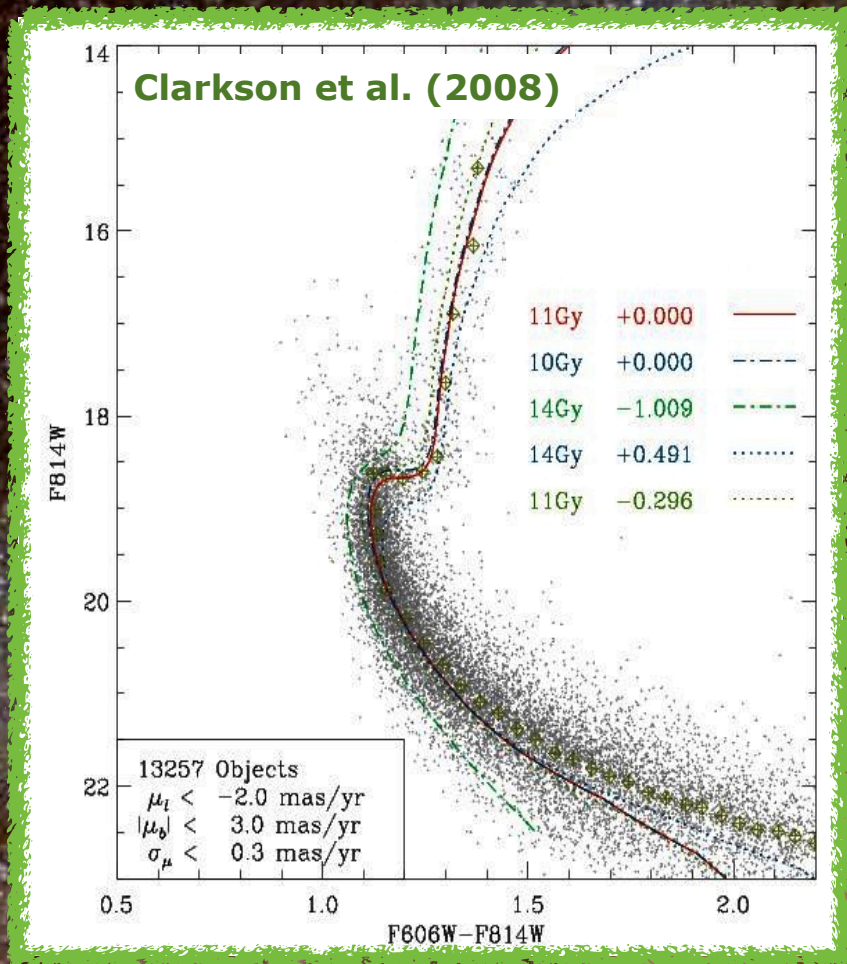


The Age of stars in the Galactic bulge







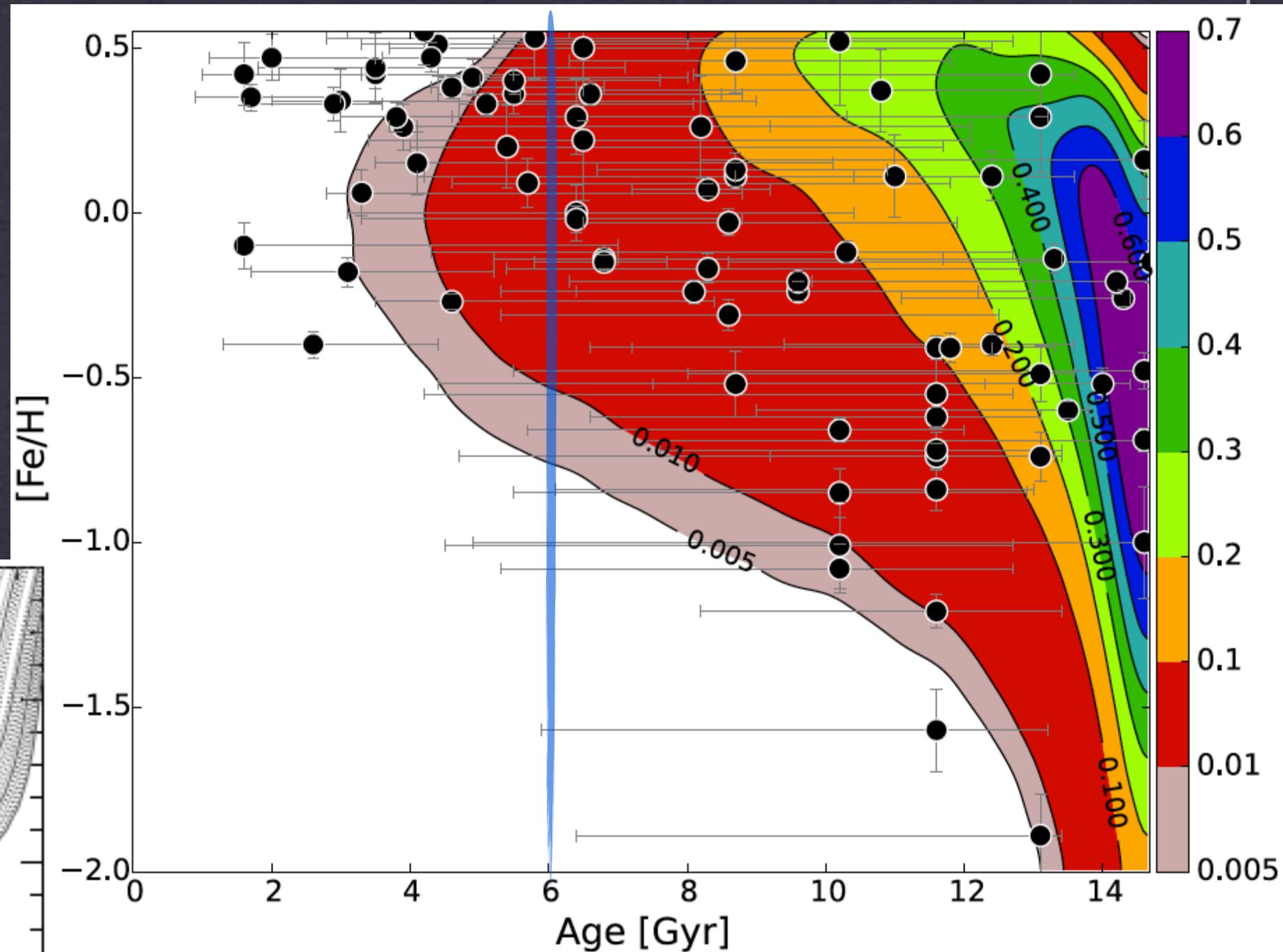
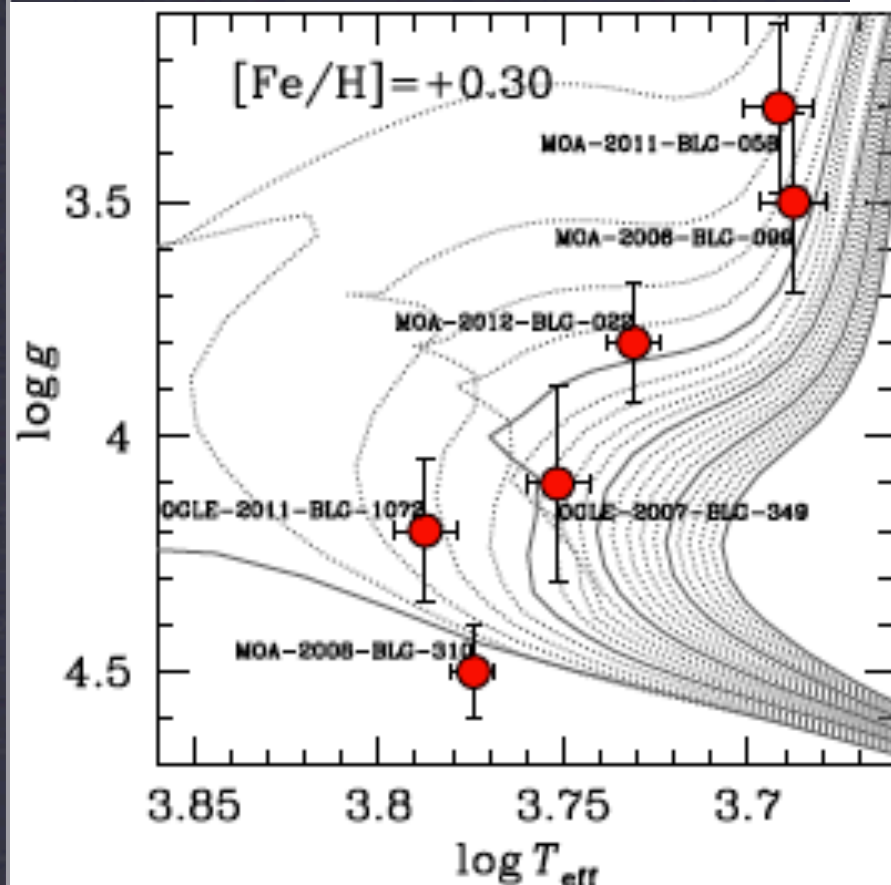


age $\sim 10 \pm 2$ Gyr

Age-Metallicity Relation from Microlensed Dwarfs

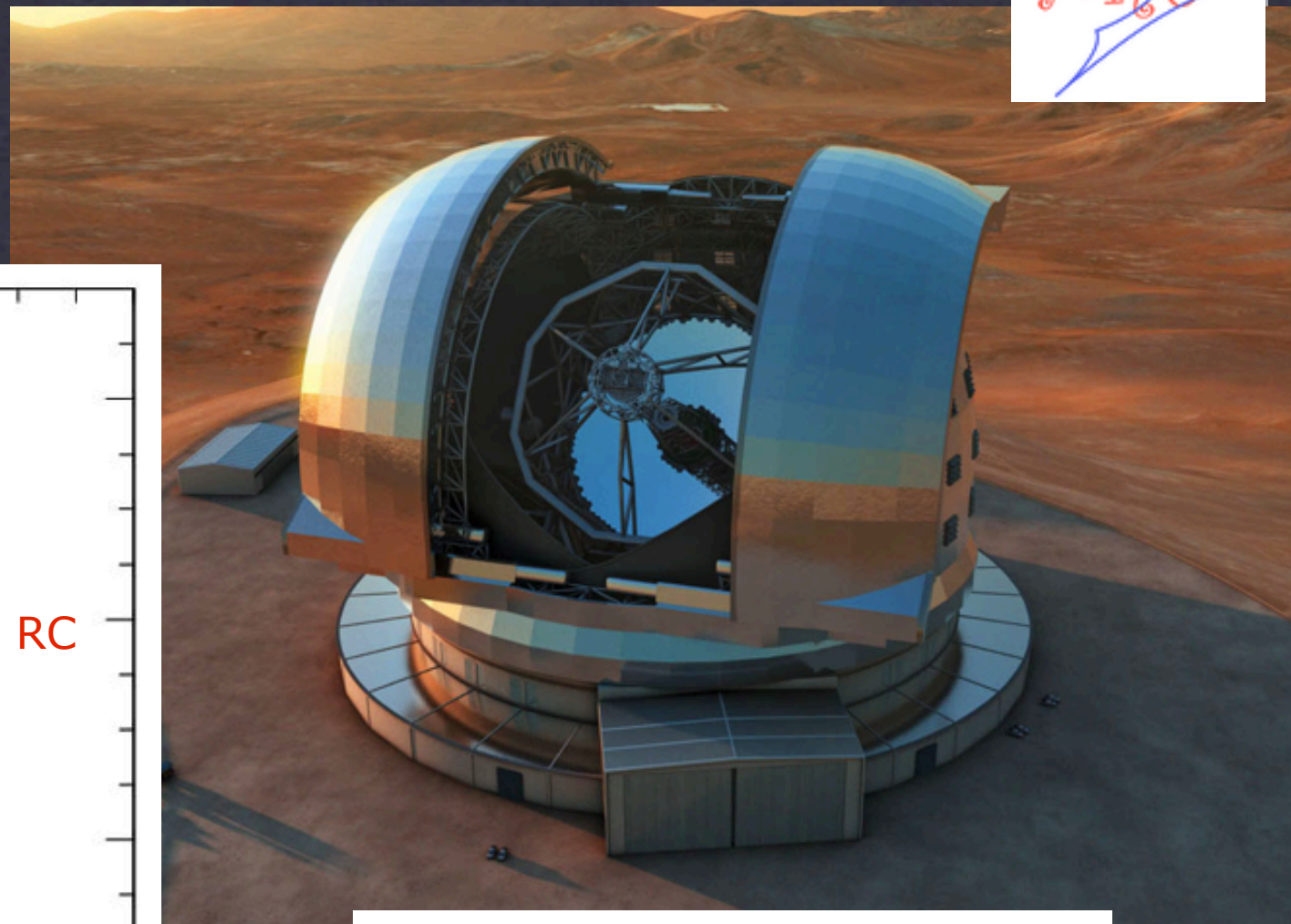
a two-component bulge?

Bensby et al. (2011)
Bensby et al. (2013)
Ness et al. (2014)

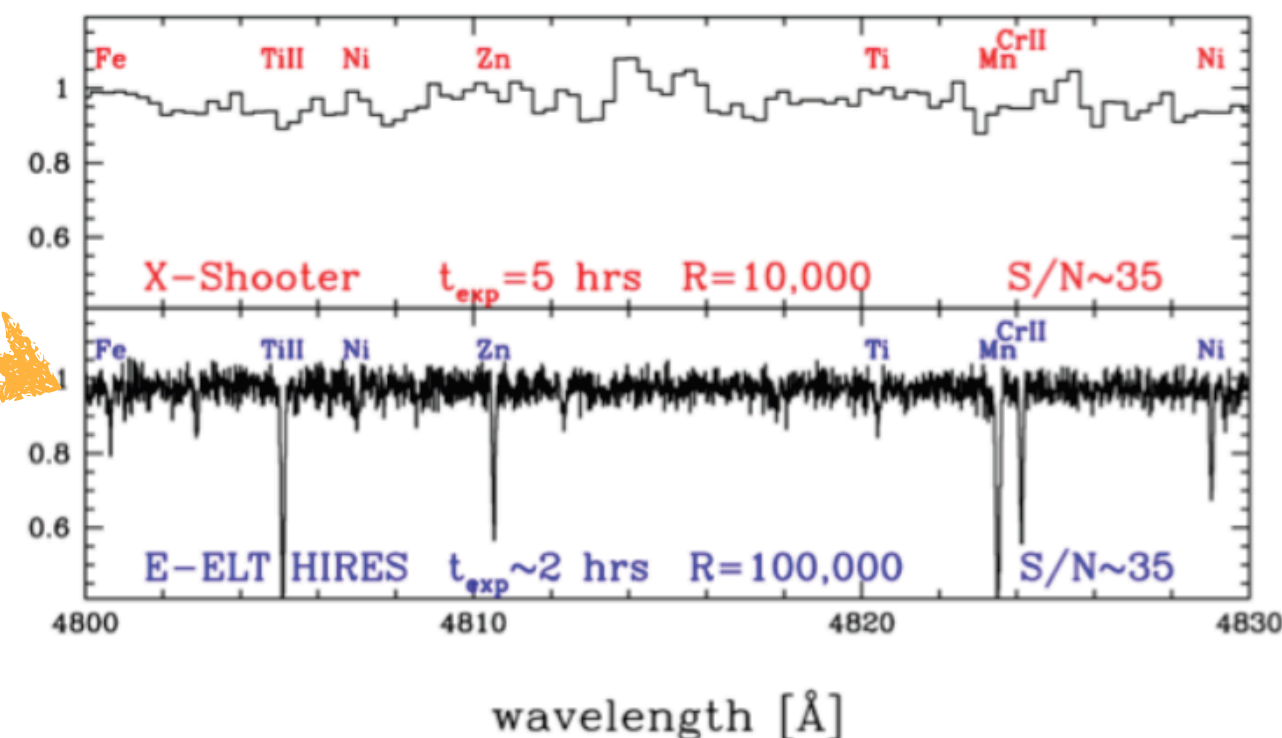
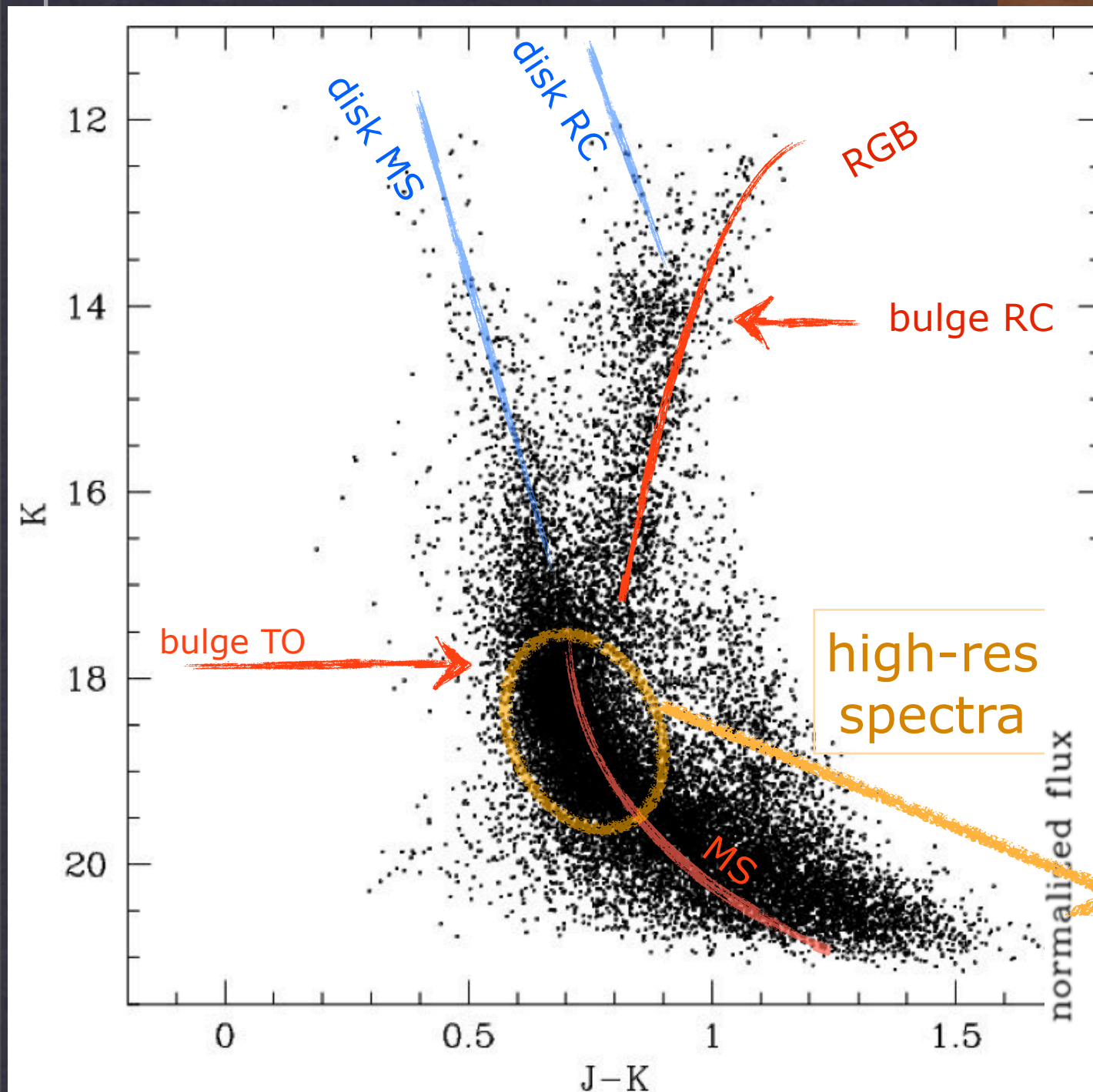


The Galactic bulge with the E-ELT

Abundances, temperatures and gravities for MS stars in the bulge.



MS stars in NGC2808 at 9.5 kpc



The Galactic bulge with MOONS @ VLT

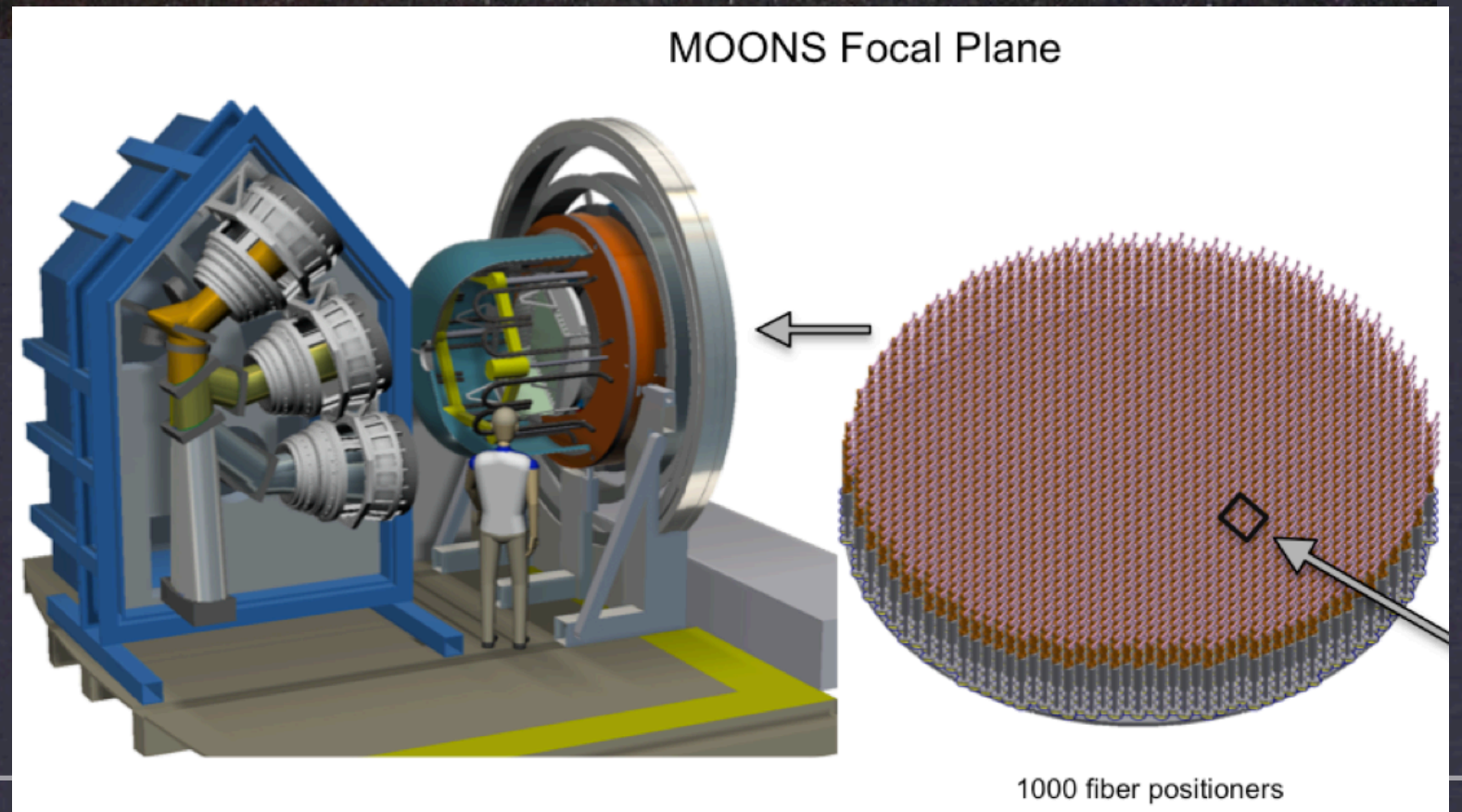
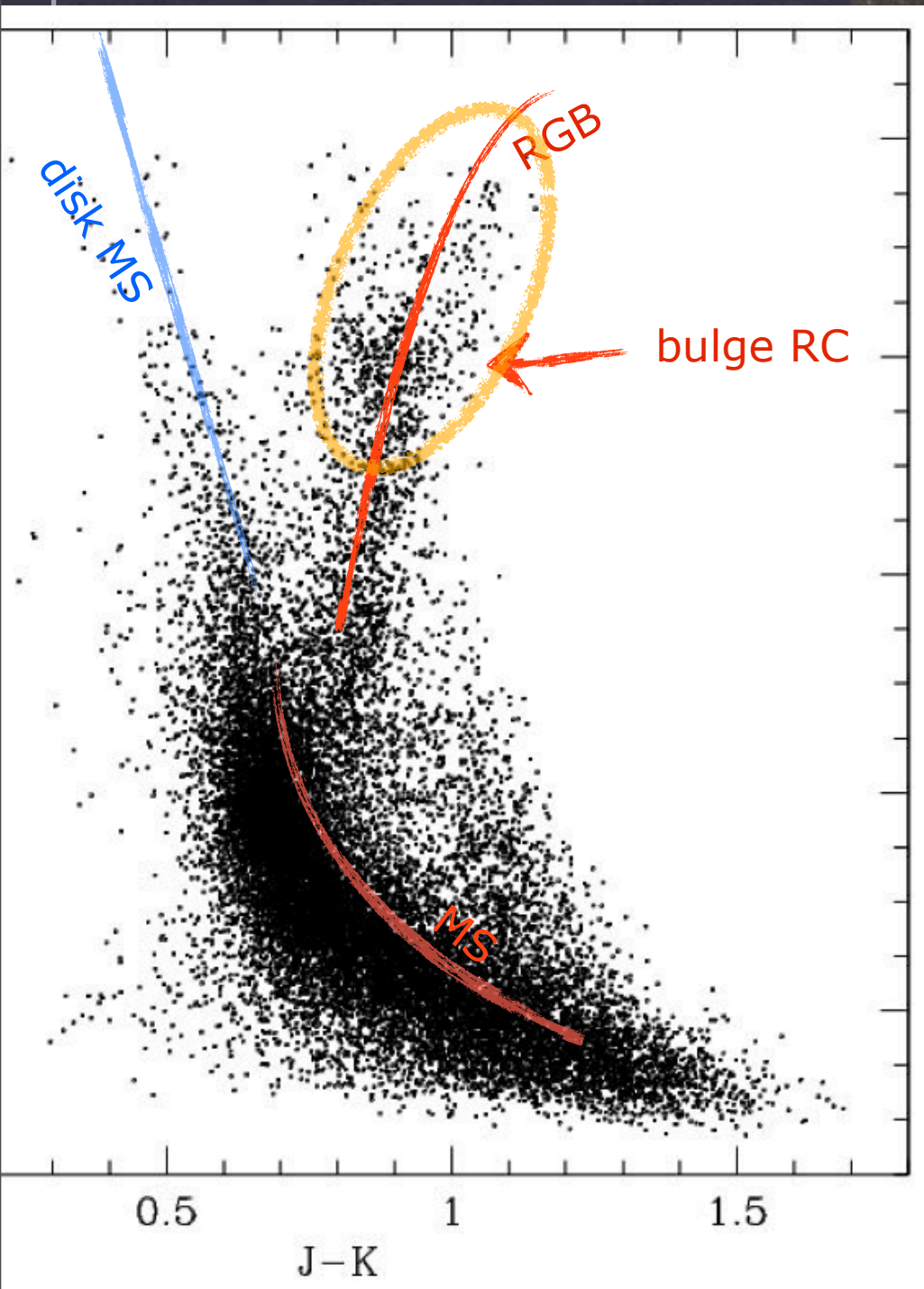
1000 objects in a single pointing
(e.g., 900 stars, 100 skies)

R=25,000 in H band

R=9,000 on CaT



© Xavier M. Jubier

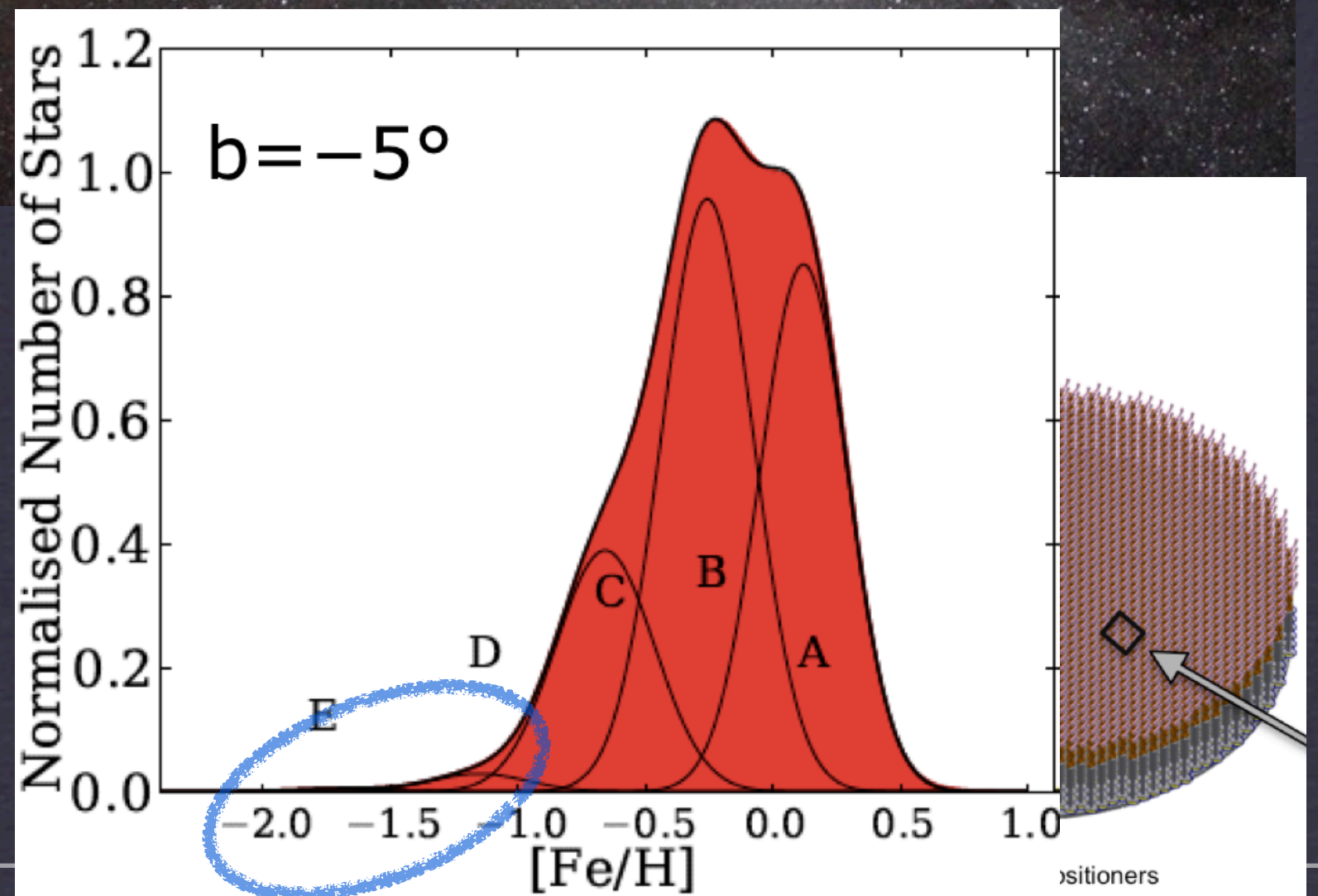
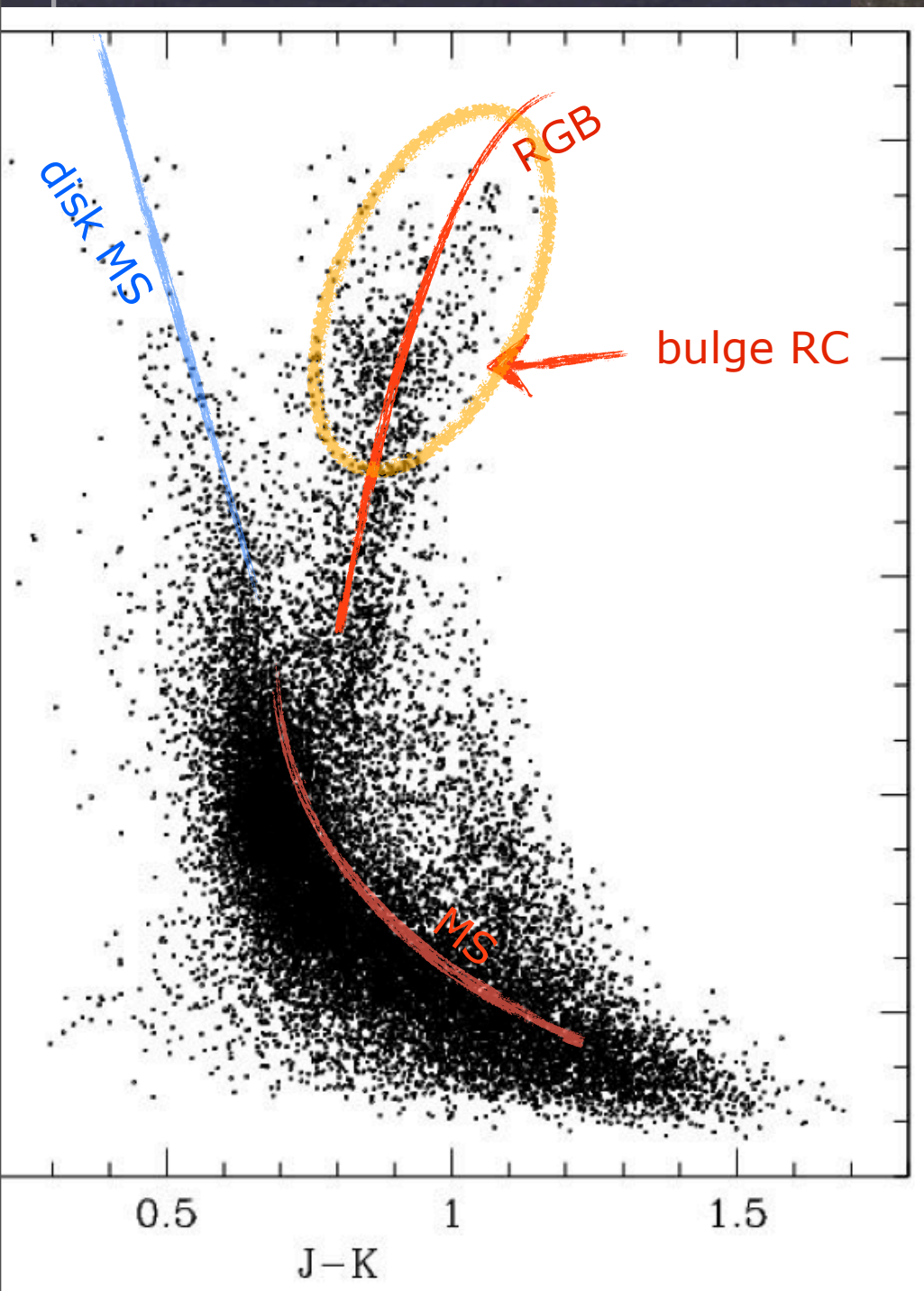


The Galactic bulge with MOONS @ VLT

1000 objects in a single pointing
(e.g., 900 stars, 100 skies)

R=25,000 in H band

R=9,000 on CaT



Summary

the Galactic bulge is very complex...

- Bulge red clump stars trace a boxy/peanut structure
- Several independent observations suggest the presence of two components
 - oldest (<10 Gyr) metal poor component is spheroidal traced by RR Lyrae
 - younger (8-12 Gyr) metal rich one is a boxy/peanut bar traced by RC stars
 - is there a younger (1-6 Gyr) component?
- A metallicity gradient, in the outer bulge, follows the boxy/peanut structure. No gradient seems to be present in the inner bulge.
challenge for dynamical models