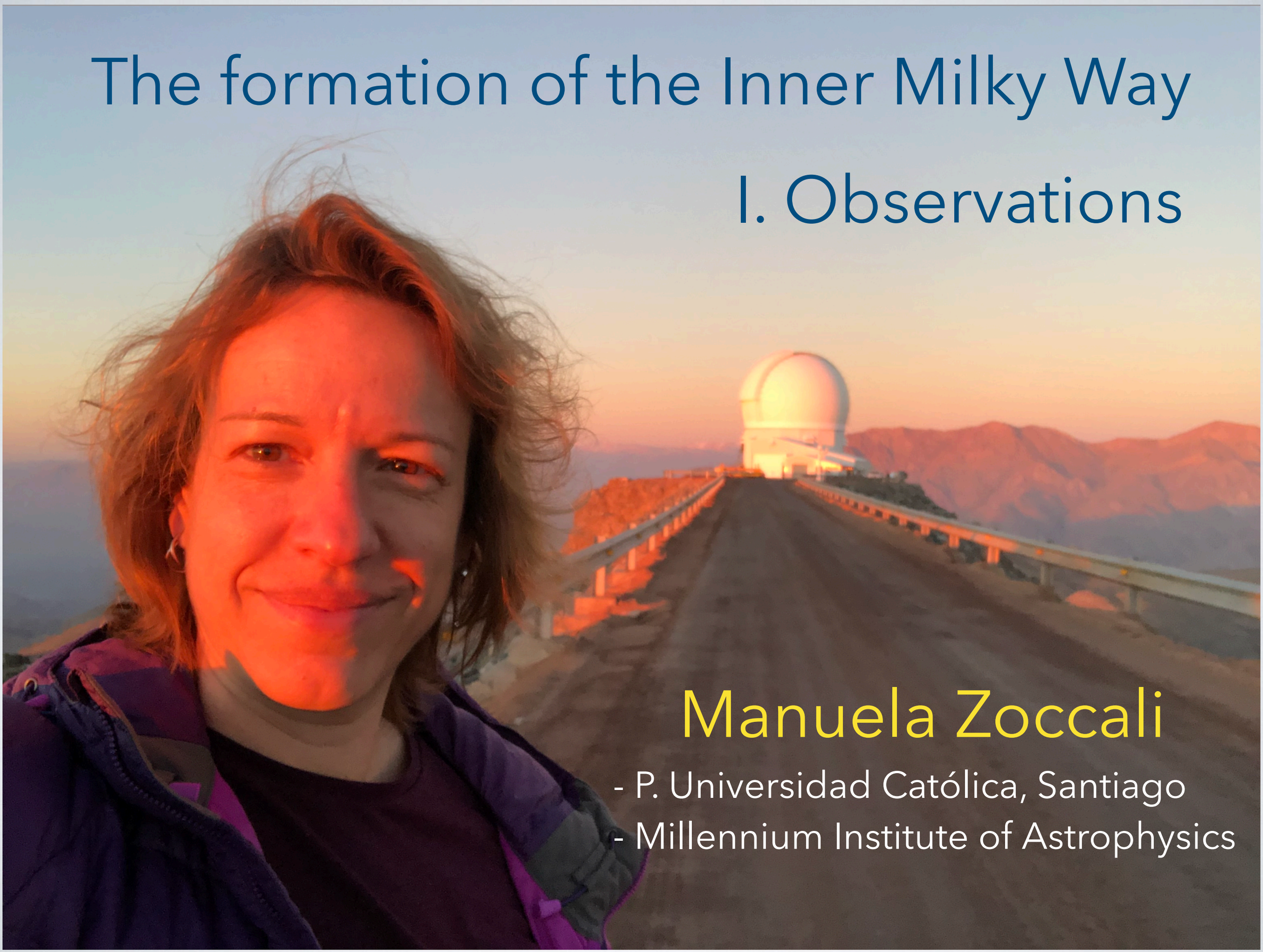
The formation of the Inner Milky Way

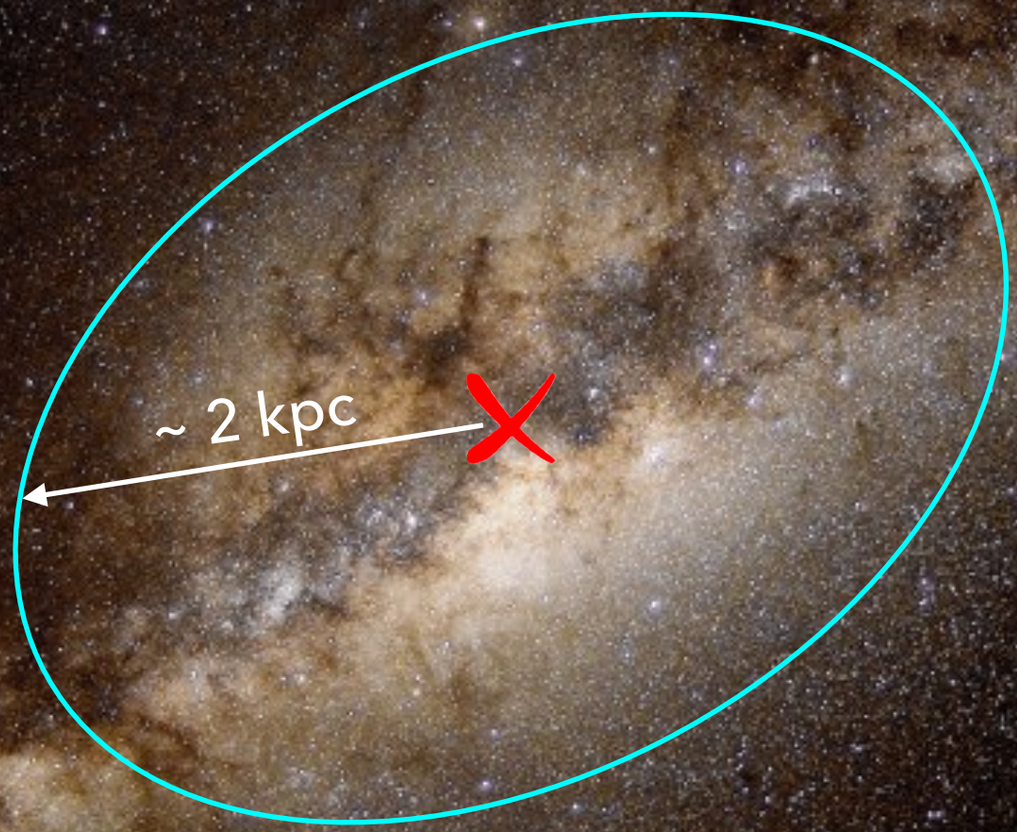
I. Observations



Manuela Zoccali

- P. Universidad Católica, Santiago
- Millennium Institute of Astrophysics

the Inner Milky Way (hereafter "bulge")



The G. bulge is massive (~1/3 the disk)

Bulge Stellar Mass

$M_B = 2 \times 10^{10}\ M_\odot$ Valenti & MZ (2016)

$M_B = 1.5 \times 10^{10}\ M_\odot$ Portail+2015

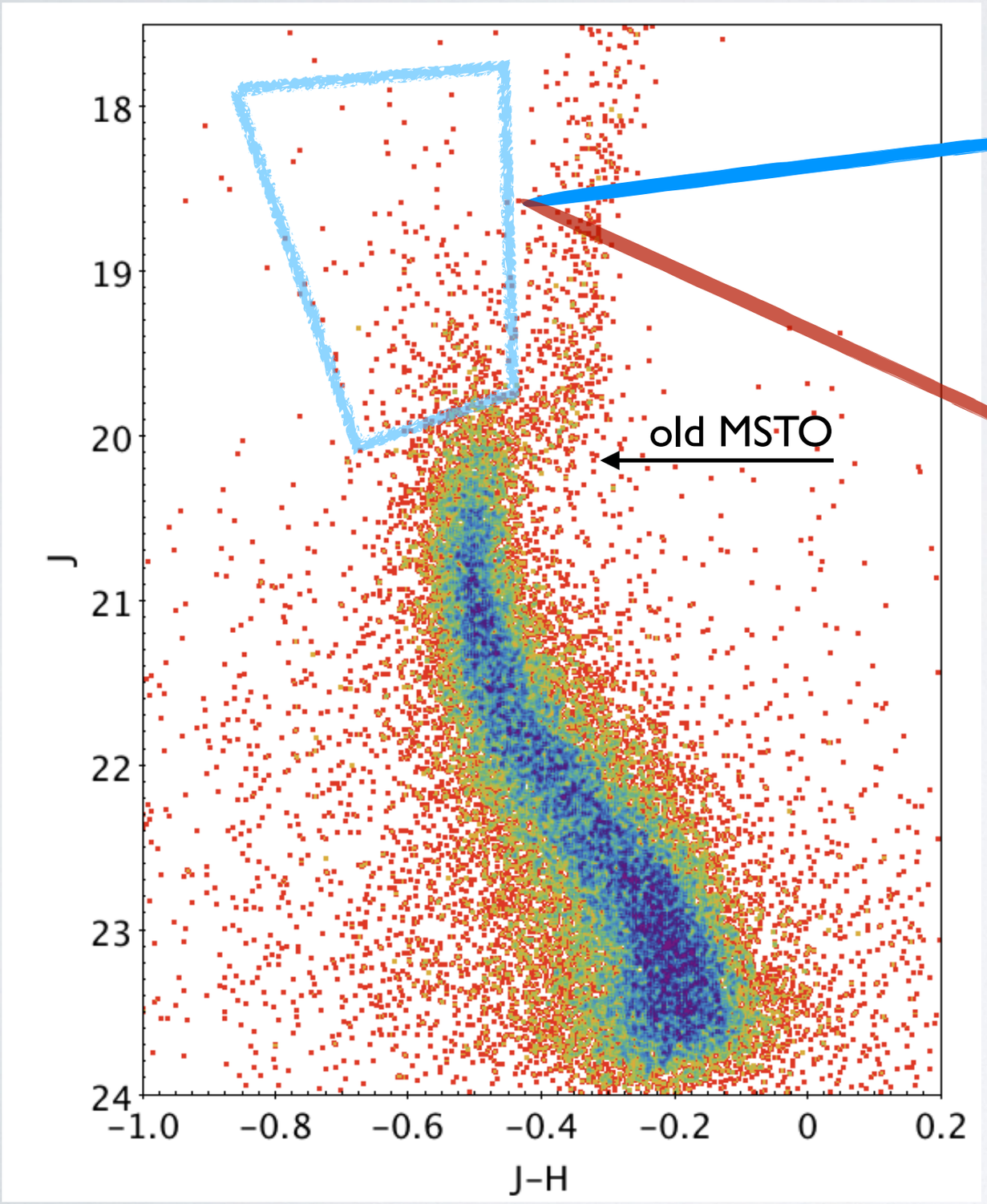
$M_B = 2.4 \times 10^{10}\ M_\odot$ Simion+2017

$M_B = 1.8 \times 10^{10}\ M_\odot$ Cao+2013

[…]

The G. bulge is *mainly* old (~10 Gyr)

adapted from Renzini+2018 HST-WFC3 data



Disk foreground and/or BSS:

e.g.: Clarkson+2008
Renzini+2018
Surot+2019

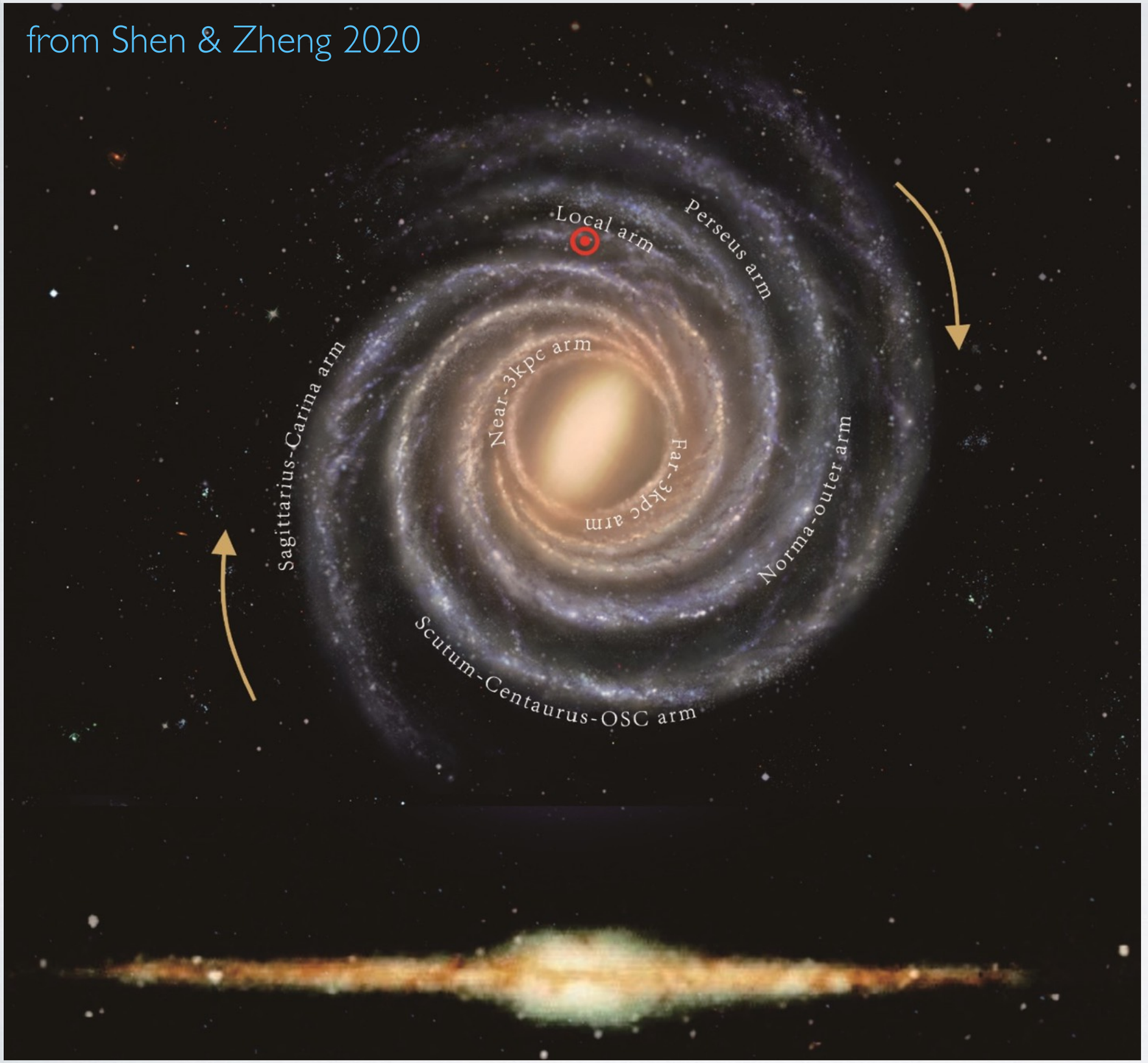
Young/Interm age stars

e.g.: Bensby+2017
Bernard+2018
Schultheis+2017
Haywood+2016

Bergh & Herbst (1974), Terndrup (1988), Ortolani+1995
Feltzing & Gilmore (2000), Kuijken & Rich (2002), MZ+2003,
Valenti+2013

Barbuy+2018 for a review

The inner Milky Way hosts a bar



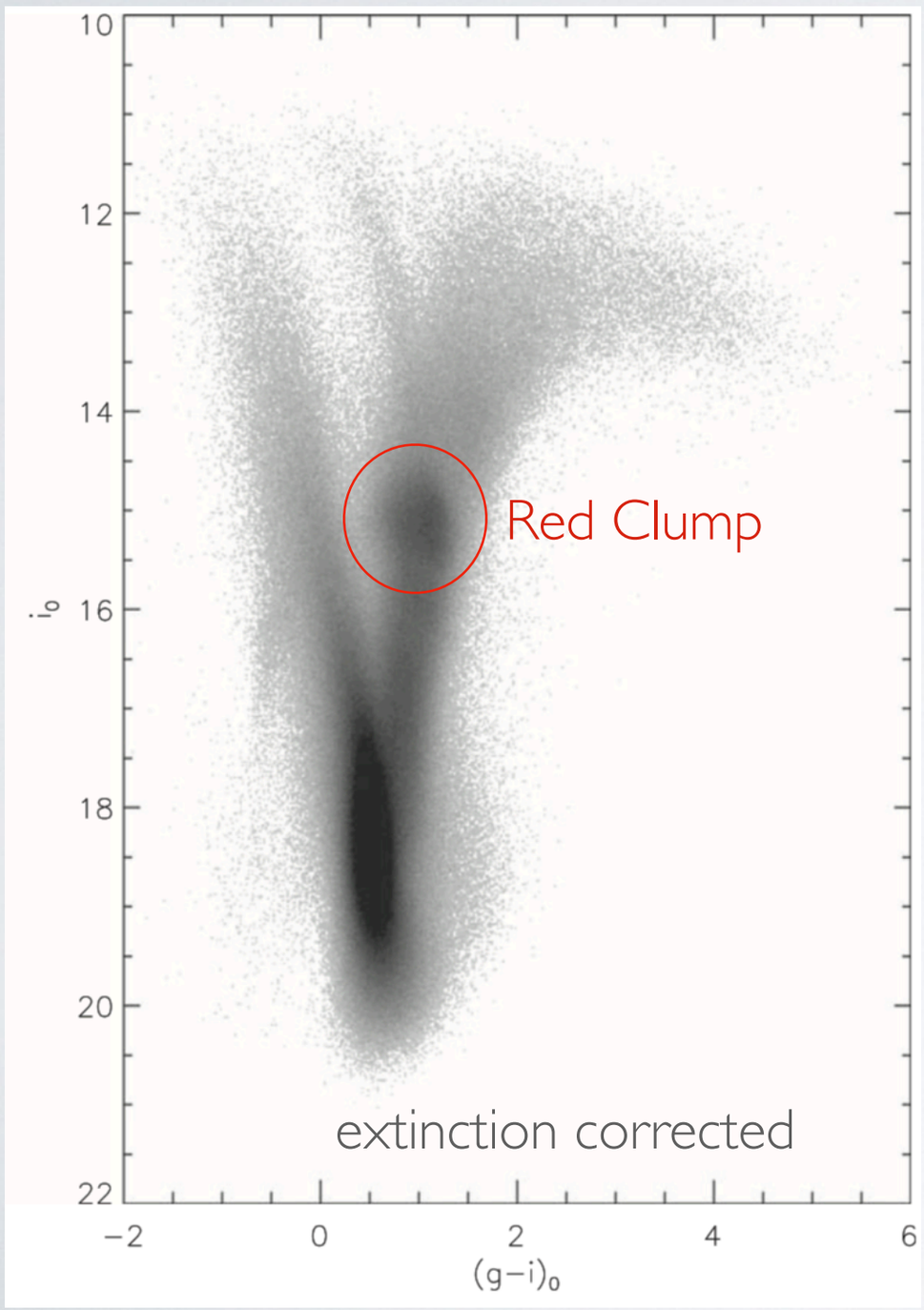
Credit: Xing-Wu Zheng & Mark Reid BeSSeL/NJU/CFA

known since
de Vaucouleurs (1964)

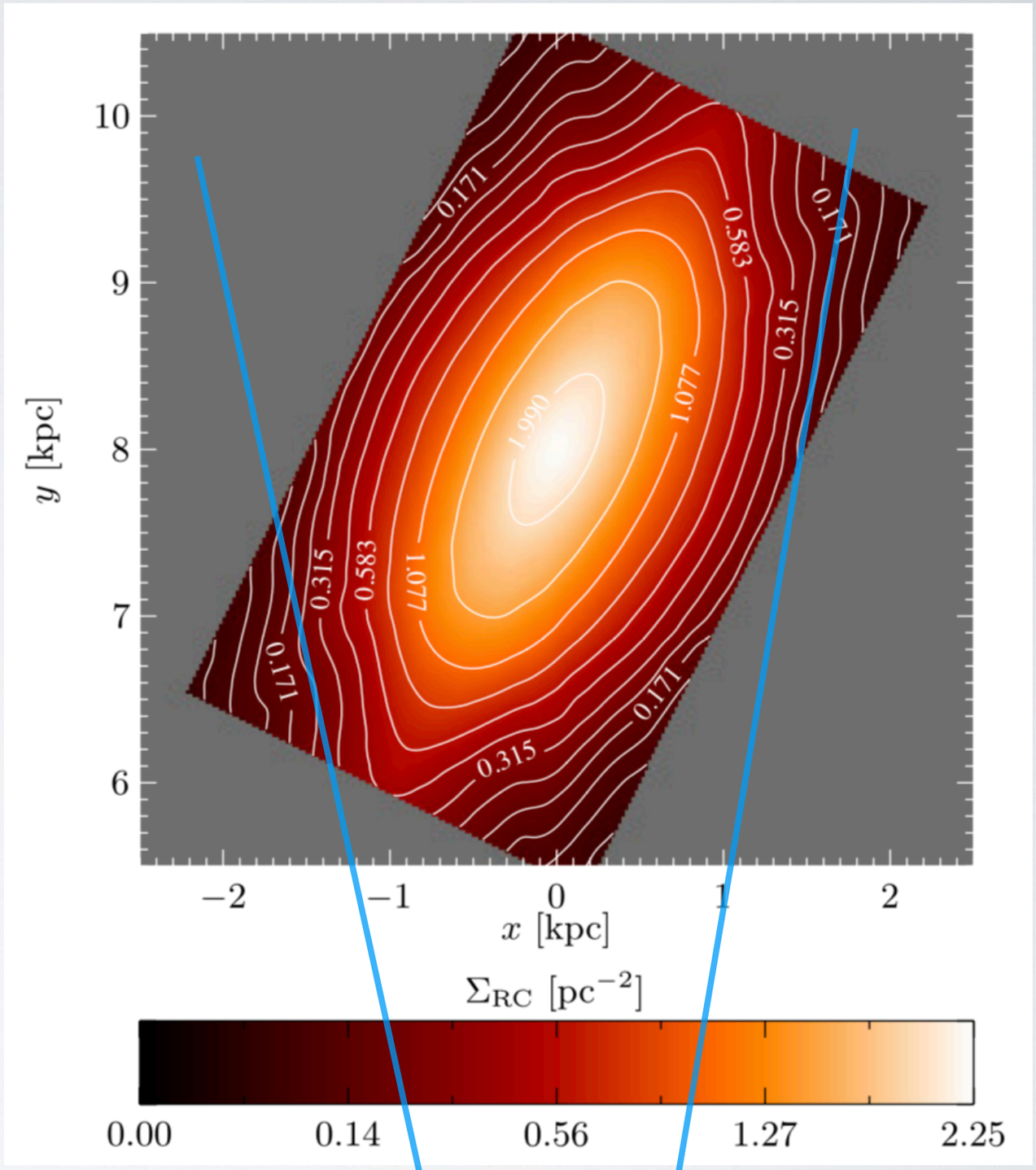
see also
Blitz & Spergel (1991)
Stanek +1994
Rattenbury+2007
…

The main Galactic bar

Saha+2019



Wegg & Gerhard (2013) VVV data



The main Galactic bar

axis ratio ≈ (1 : 0.45 : 0.30)

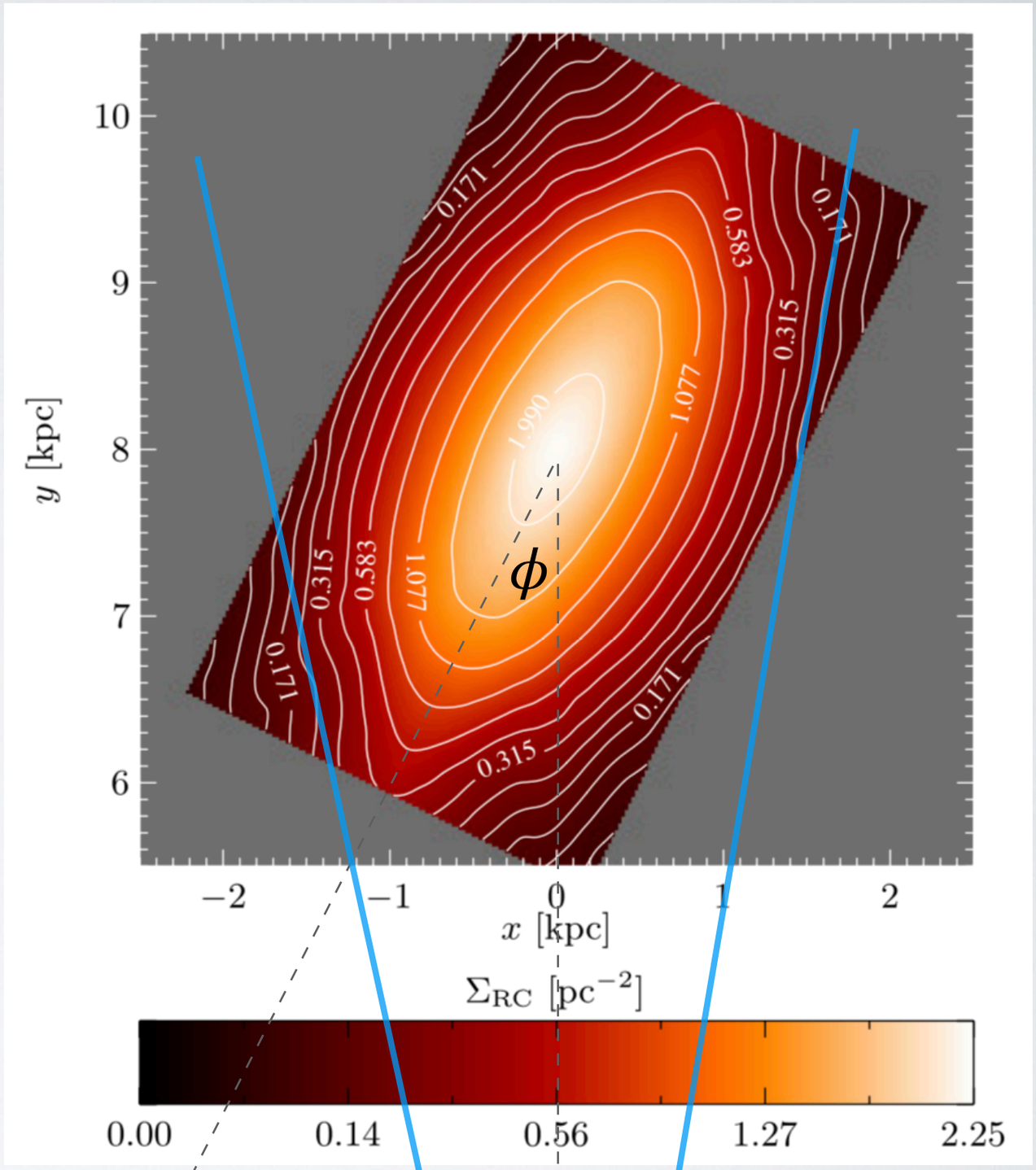
semi-major axis ≈ 0.7 kpc

angle ϕ= 20°-30°

see also:
Cao+2013
Simion+2017
Paterson+2020

MZ & Valenti (2016) for a review

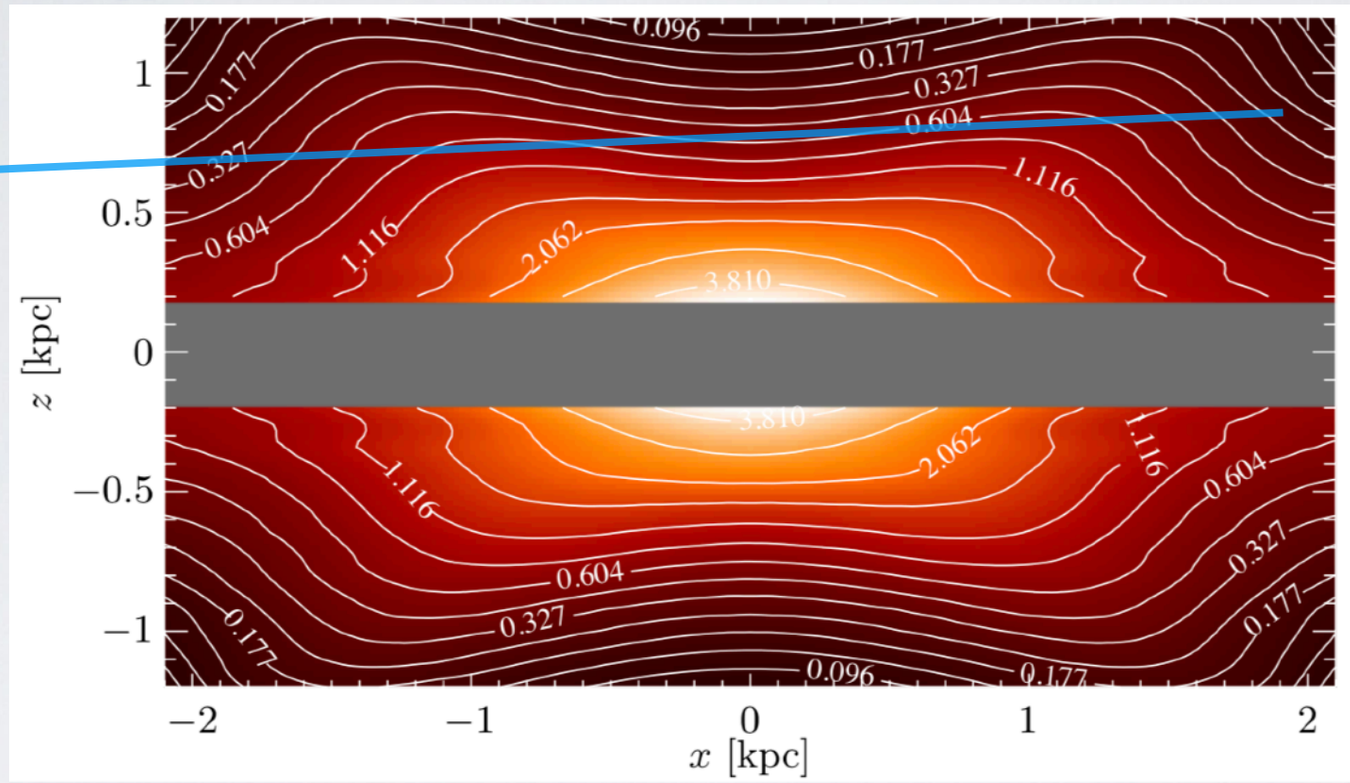
Wegg & Gerhard (2013) **VVV data**

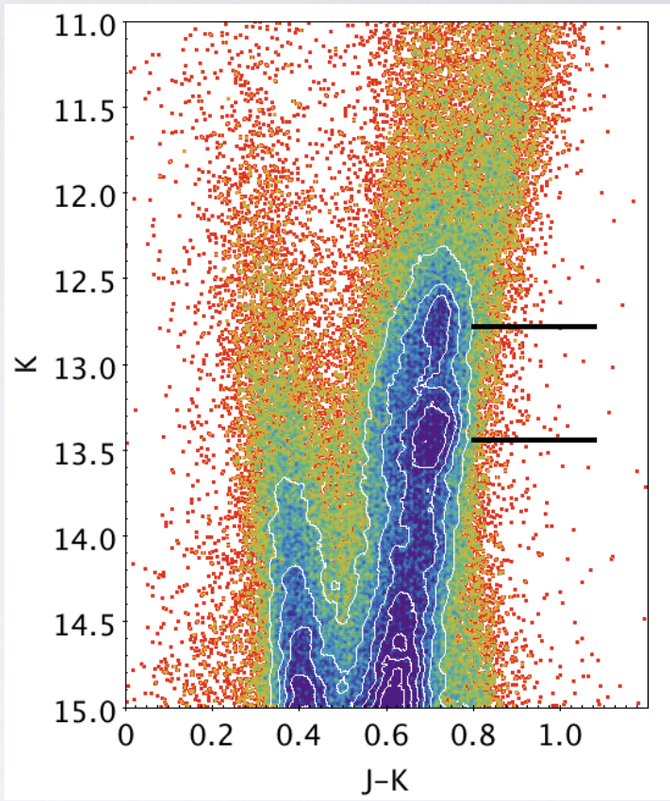


The B/P structure (X-shape)

Wegg & Gerhard (2013) VVV data

Sun



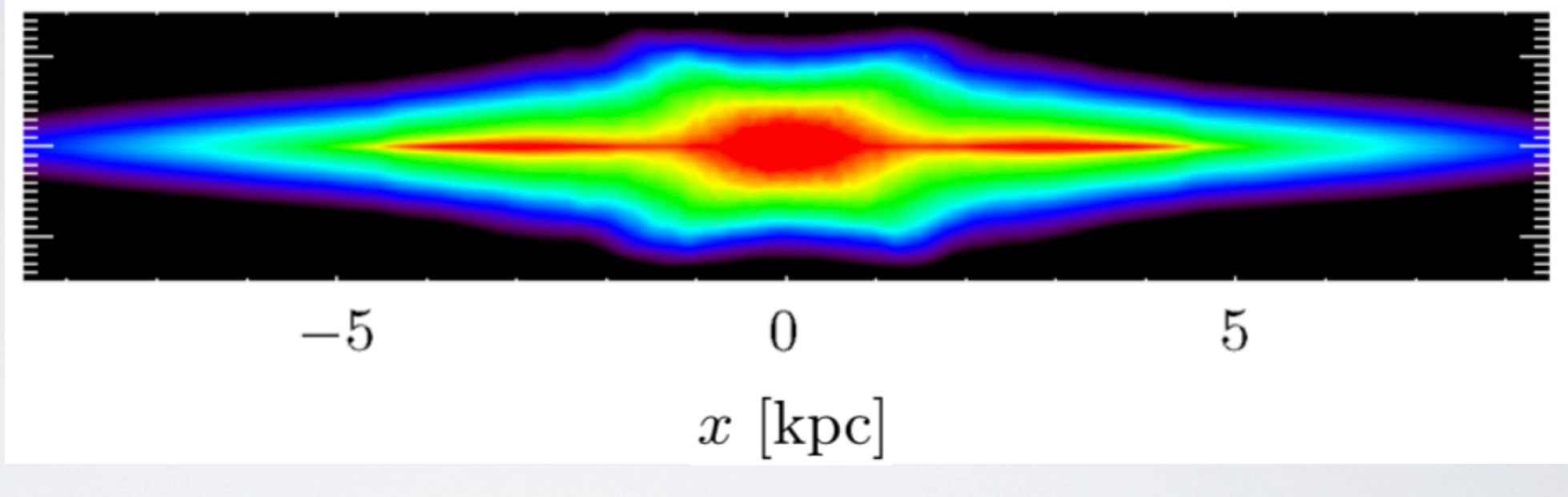


See also:
McWilliam & MZ (2010); Nataf+2010; Saito, MZ+2011; Cao+2013; Gonzalez, MZ+2015, Ness & Lang (2016); Simion+2017; Paterson+2020

The Thin Long Bar

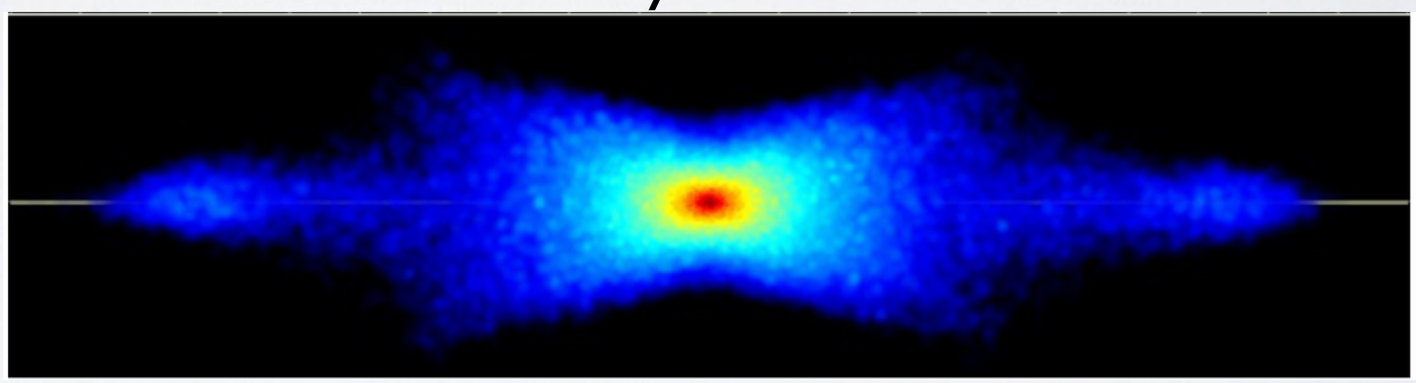
Wegg+2015

VVV data



Patsis+2002
Athanassoula (2005)

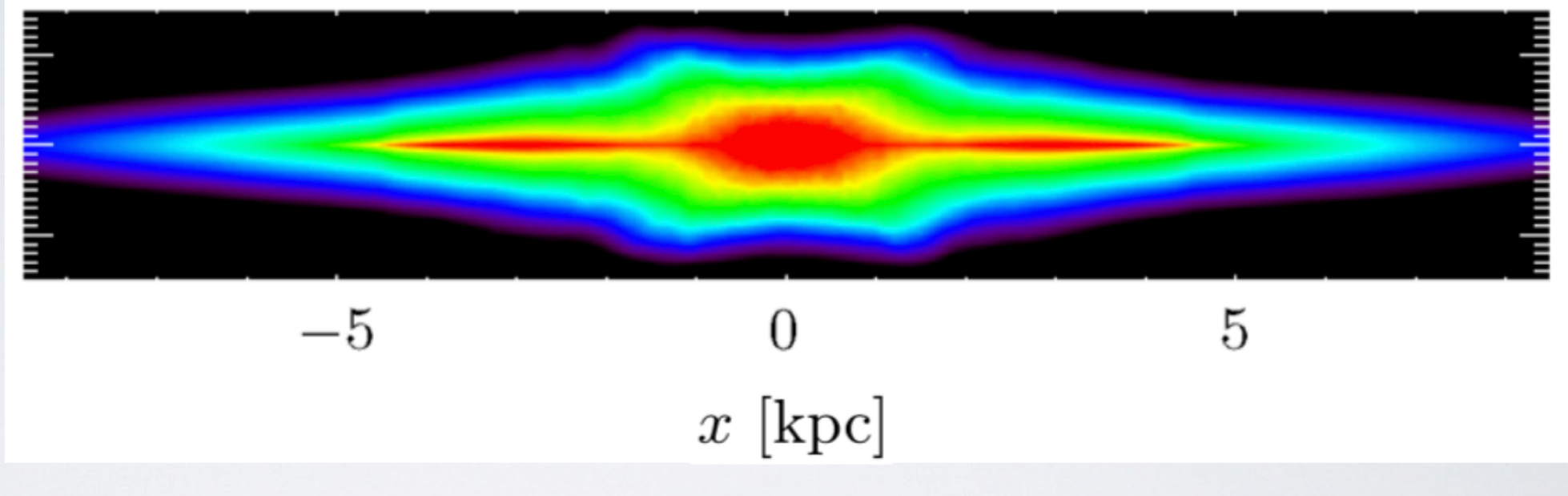
N-body simulations



The Thin Long Bar

Wegg+2015

VVV data



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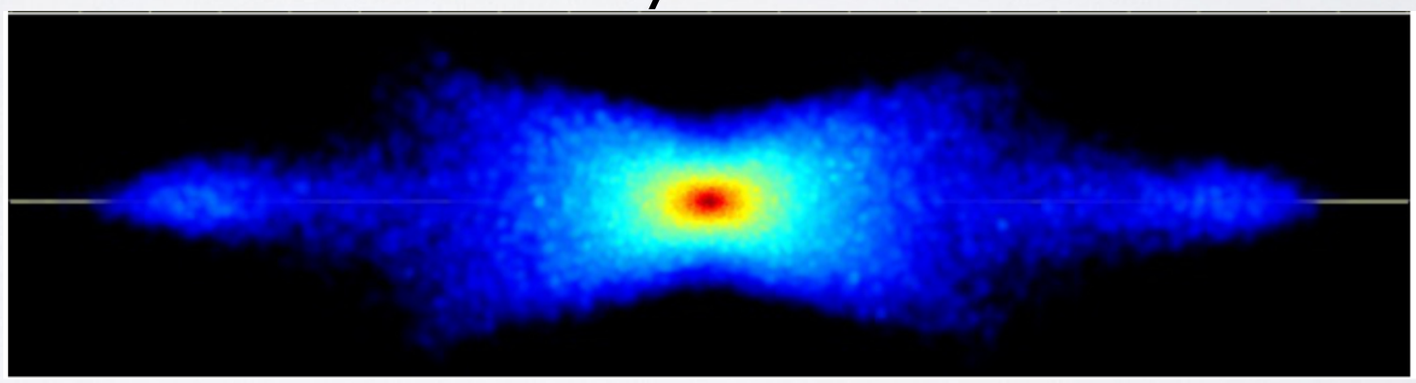
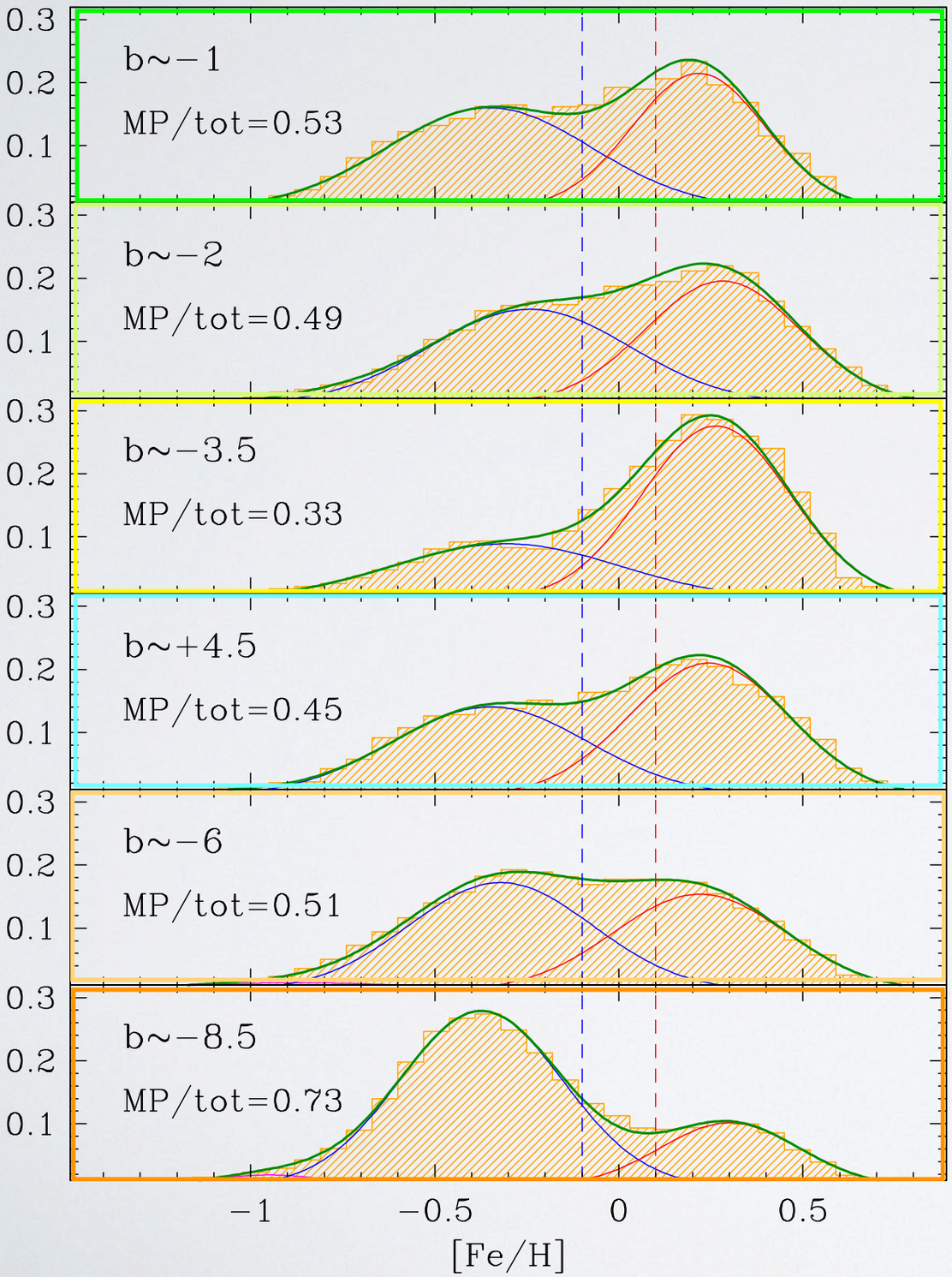


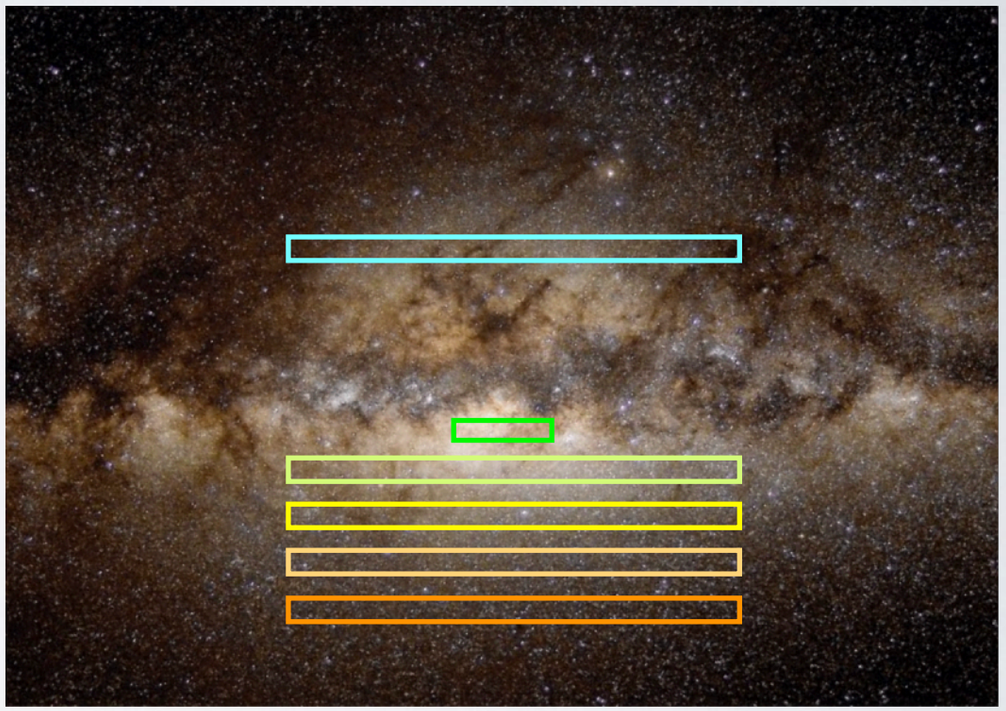
There are (at least) two components

MZ+2017 GIBS data



inner

outer

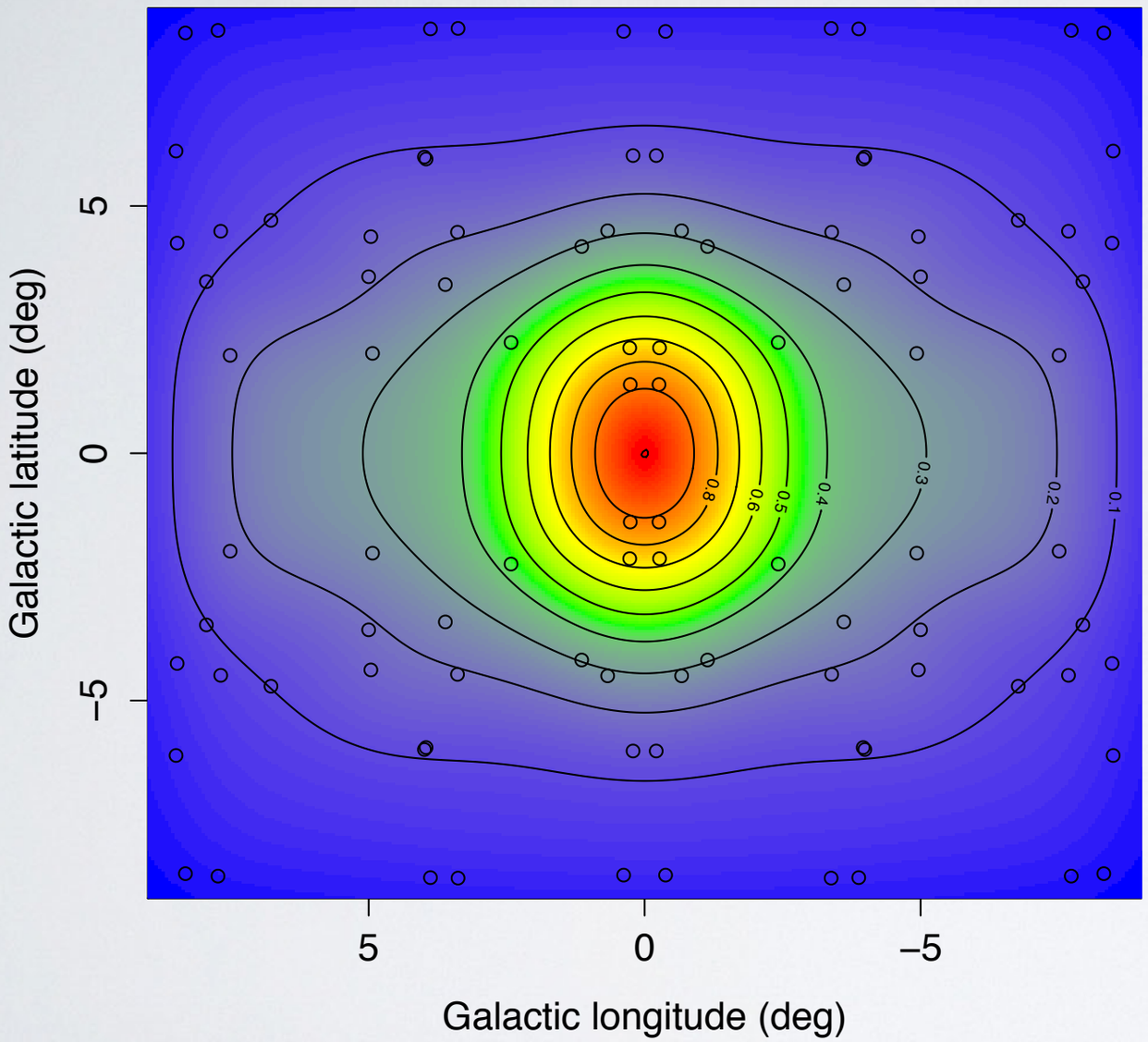


see also:
Hill+2011
Ness+2013 ARGOS
Rojas-Arriagada + 2017 GaiaESO
Rojas-Arriagada + 2020 APOGEE

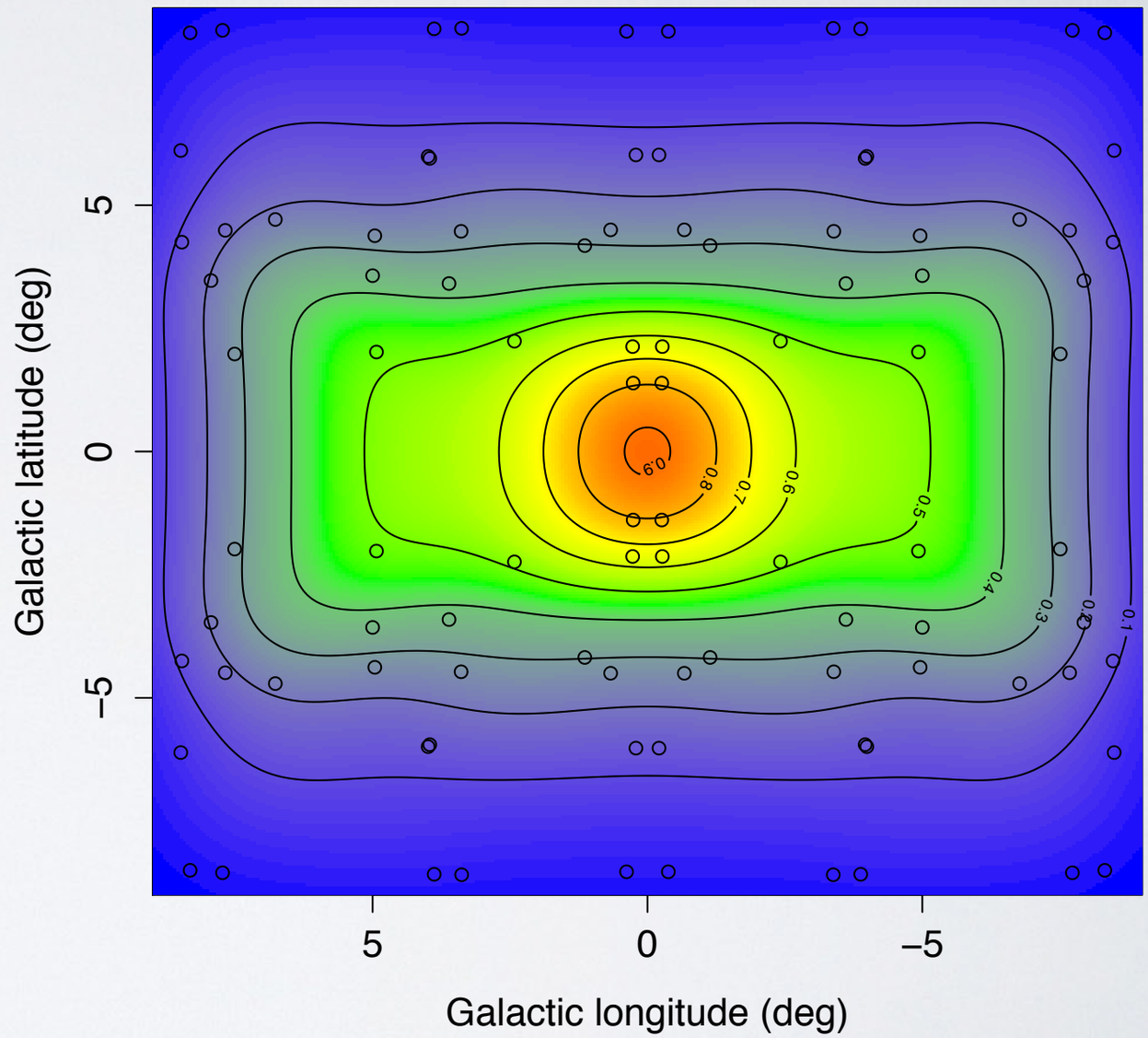
The two components have different spatial distribution

MZ + 2017, 2018

Metal poor stars (48%)

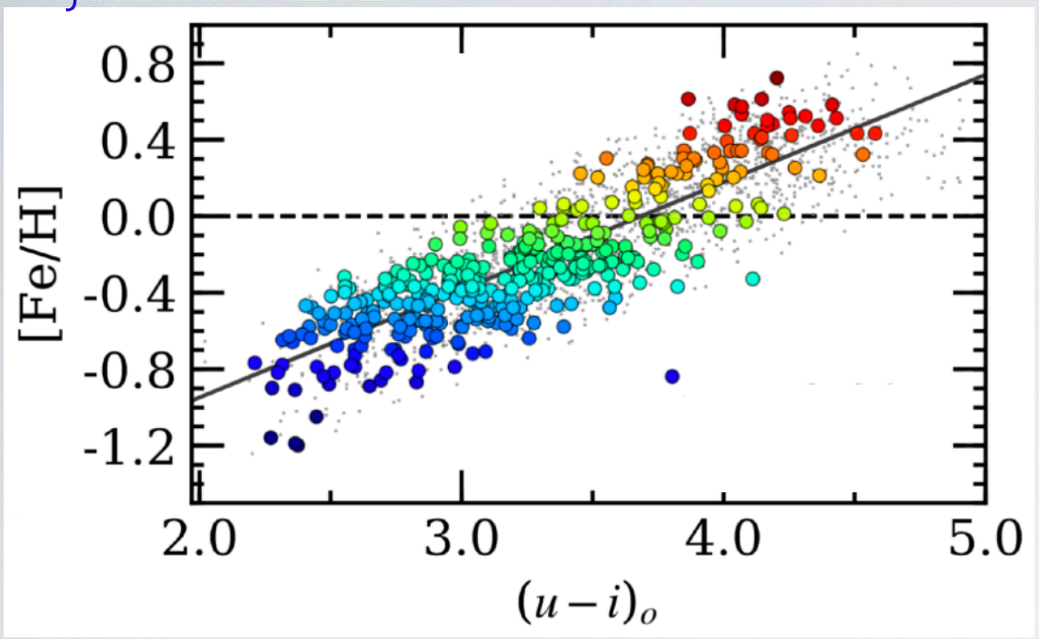


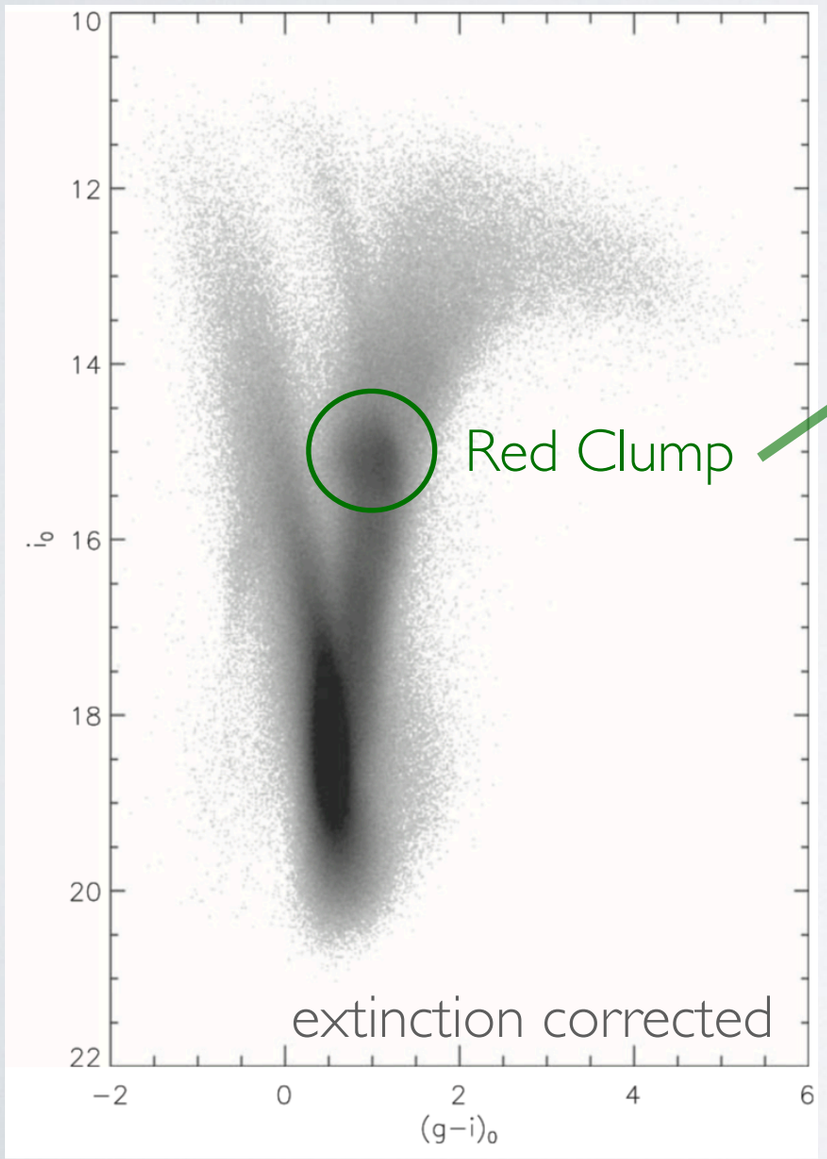
Metal rich stars (52%)



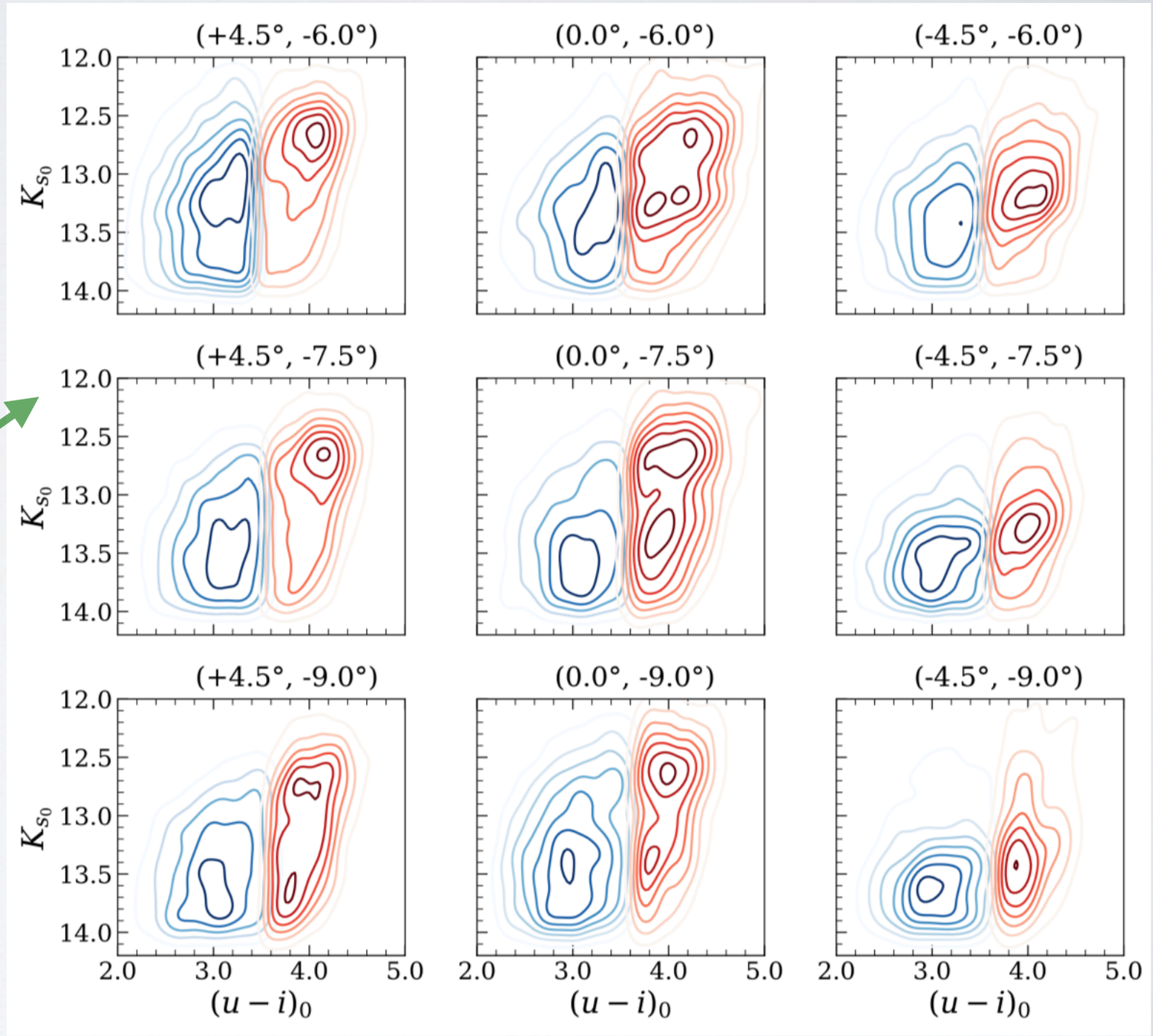
MP stars are **not in a bar** (nor a B/P)

Johnson+2020





Blanco DECam Bulge Survey Lim+2020



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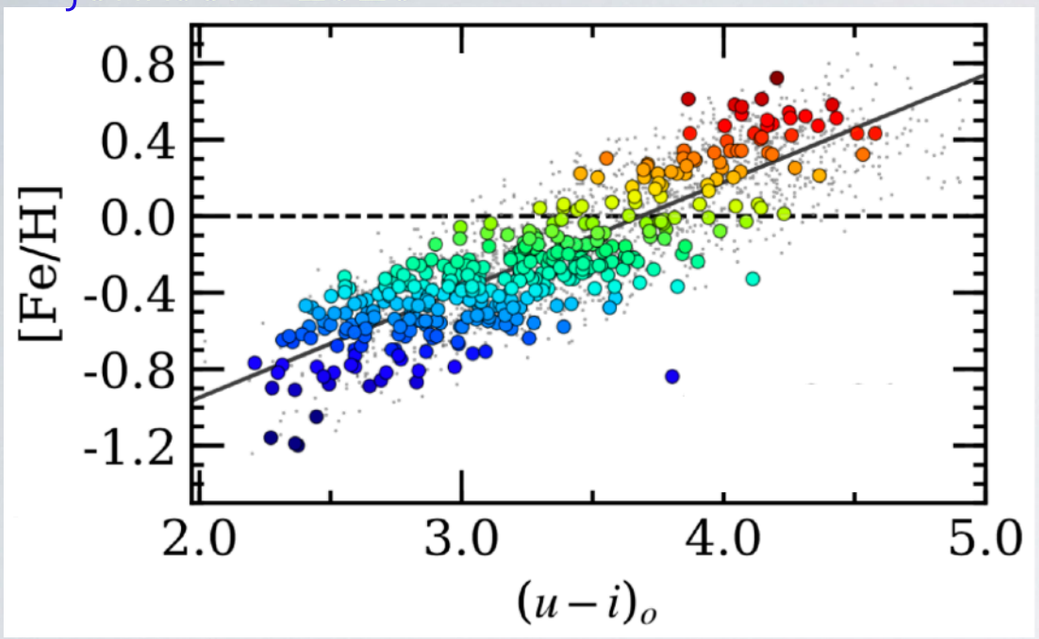

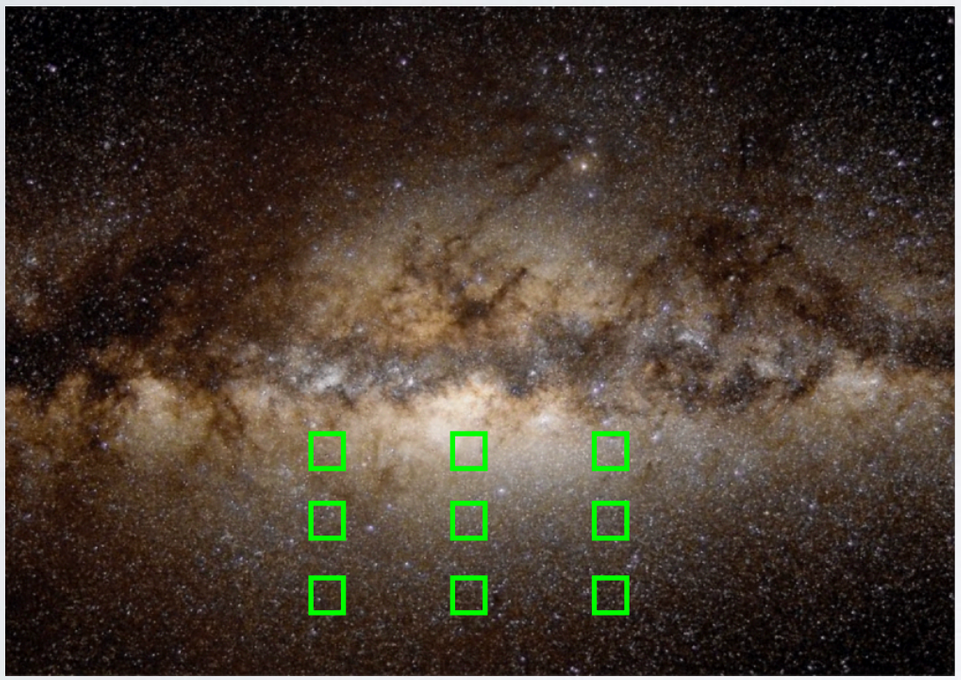

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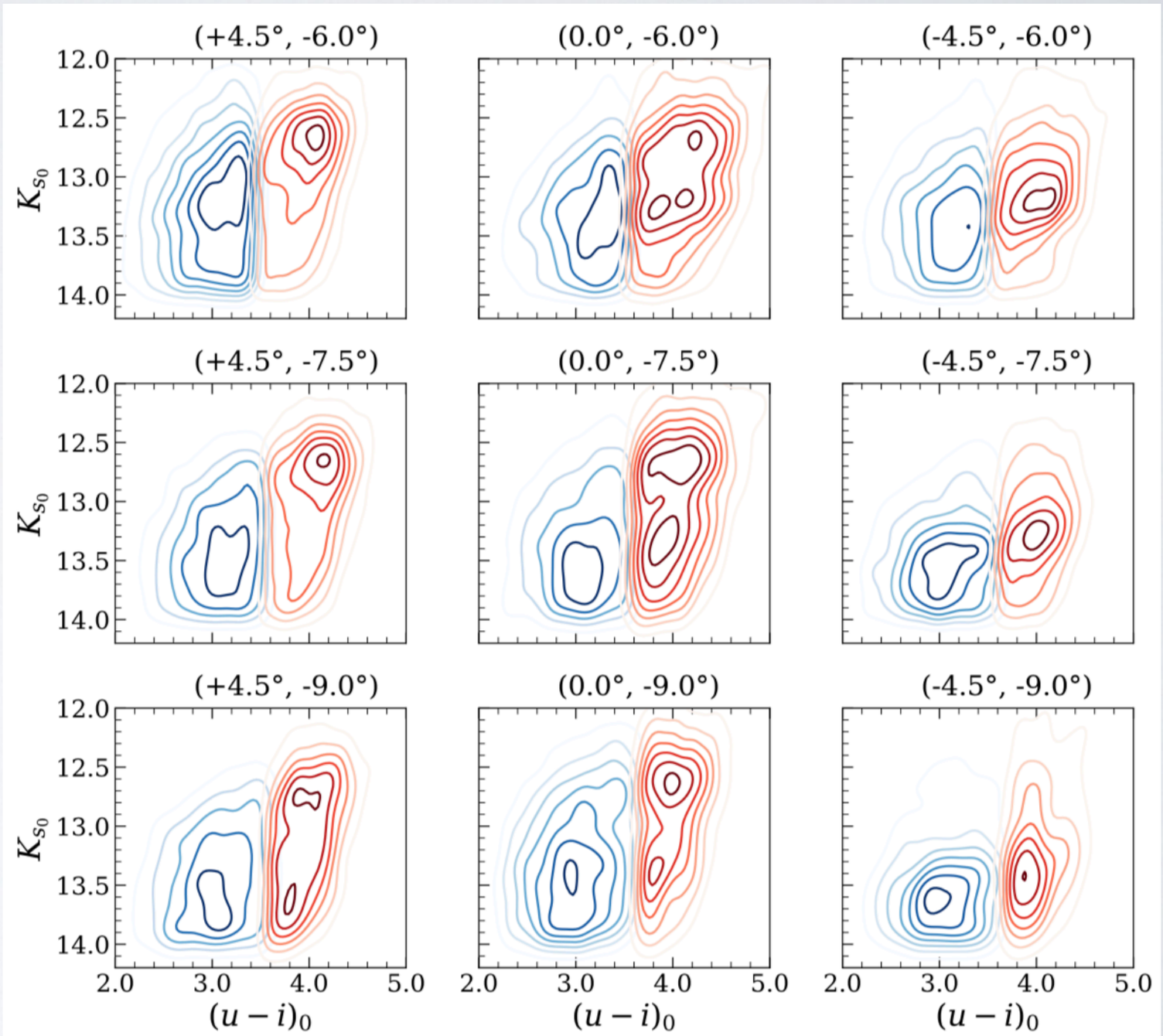

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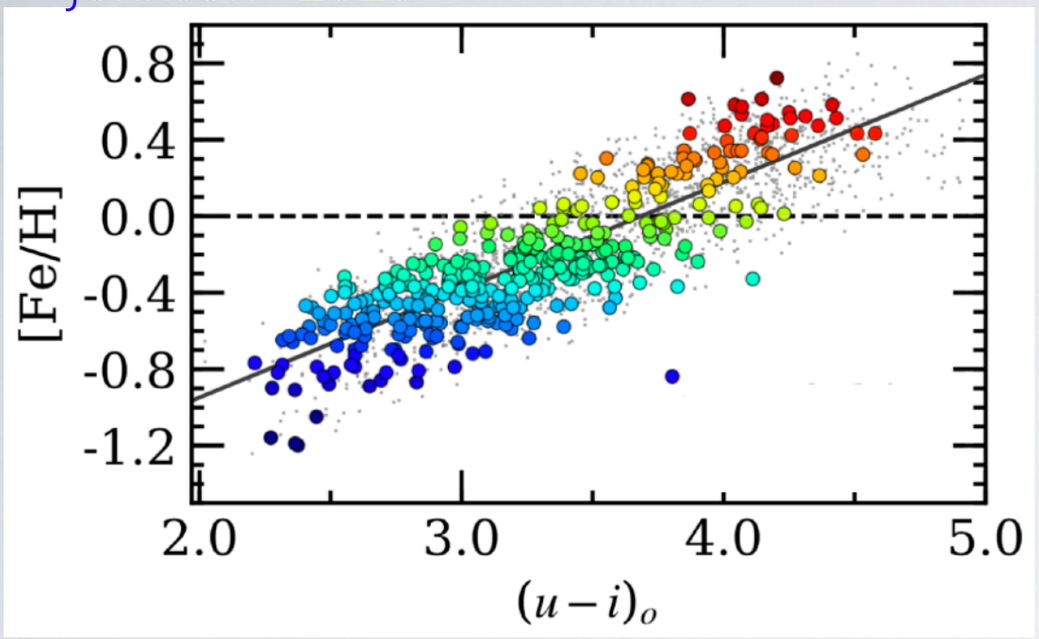
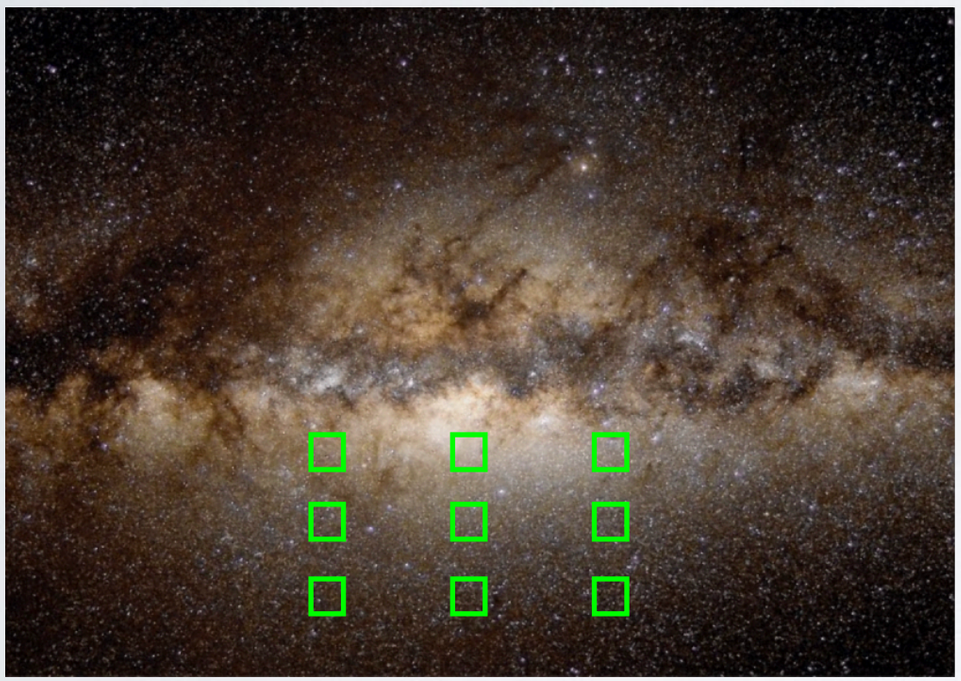
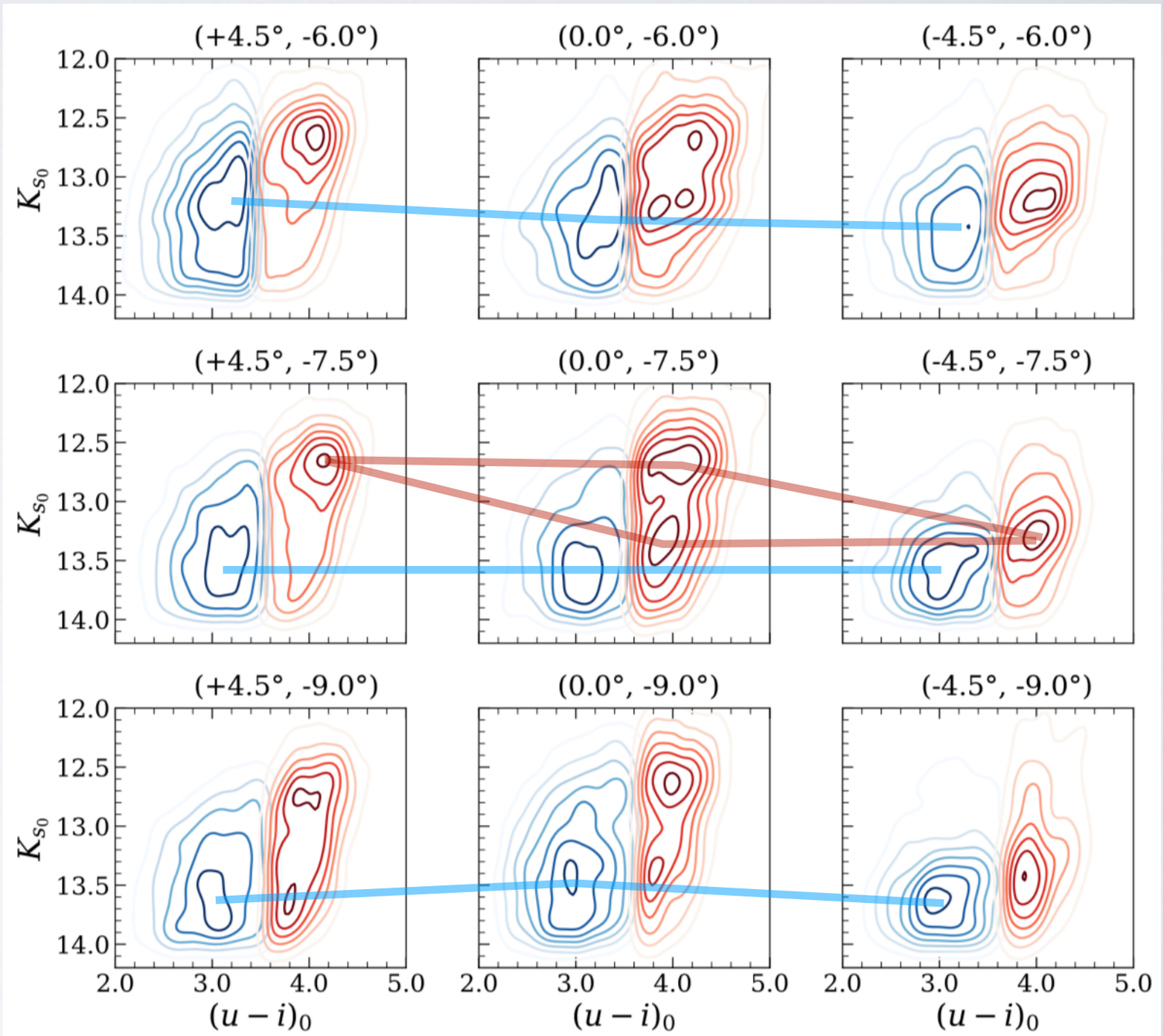


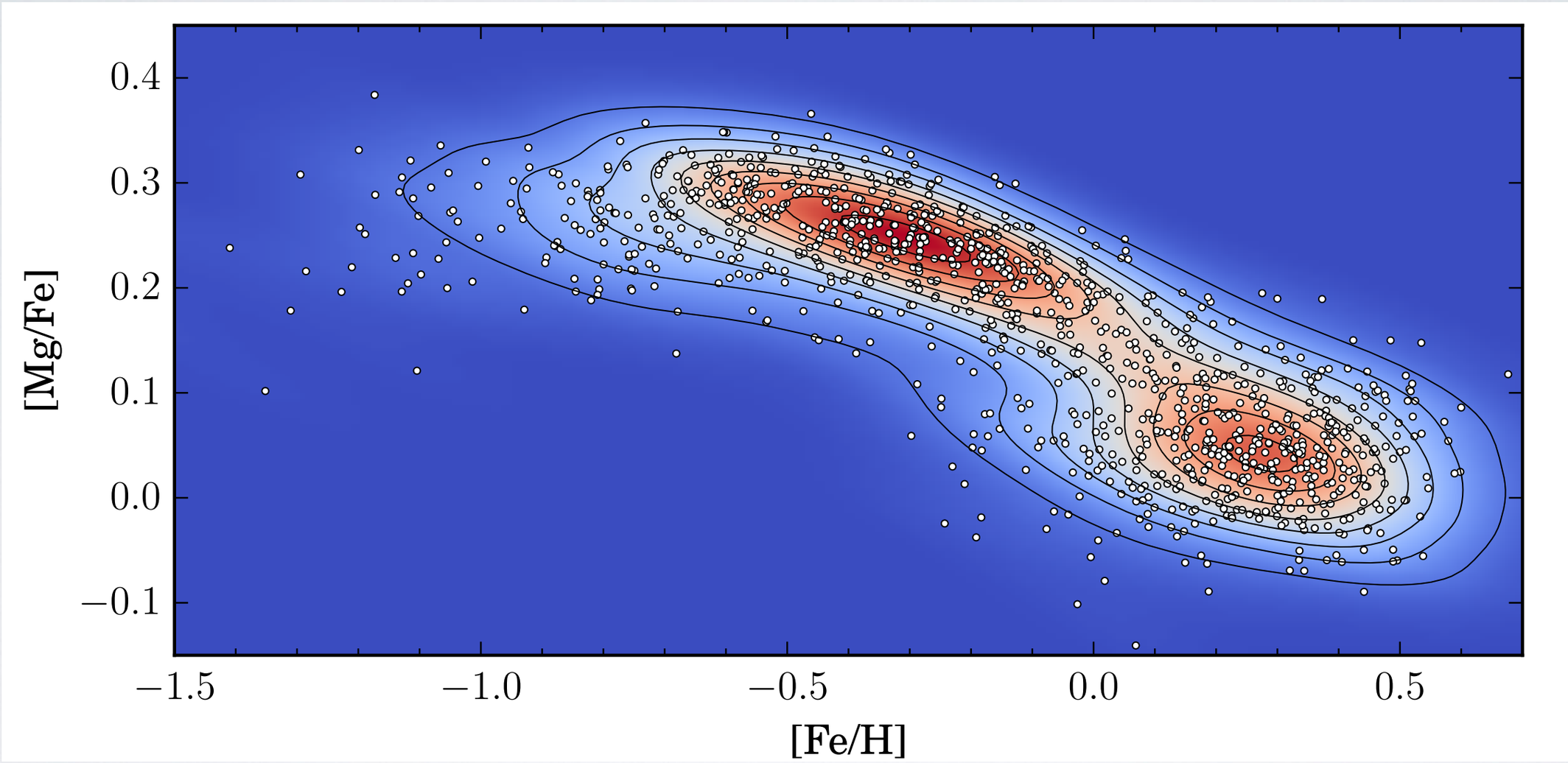


Blanco DECam Bulge Survey Lim+2020



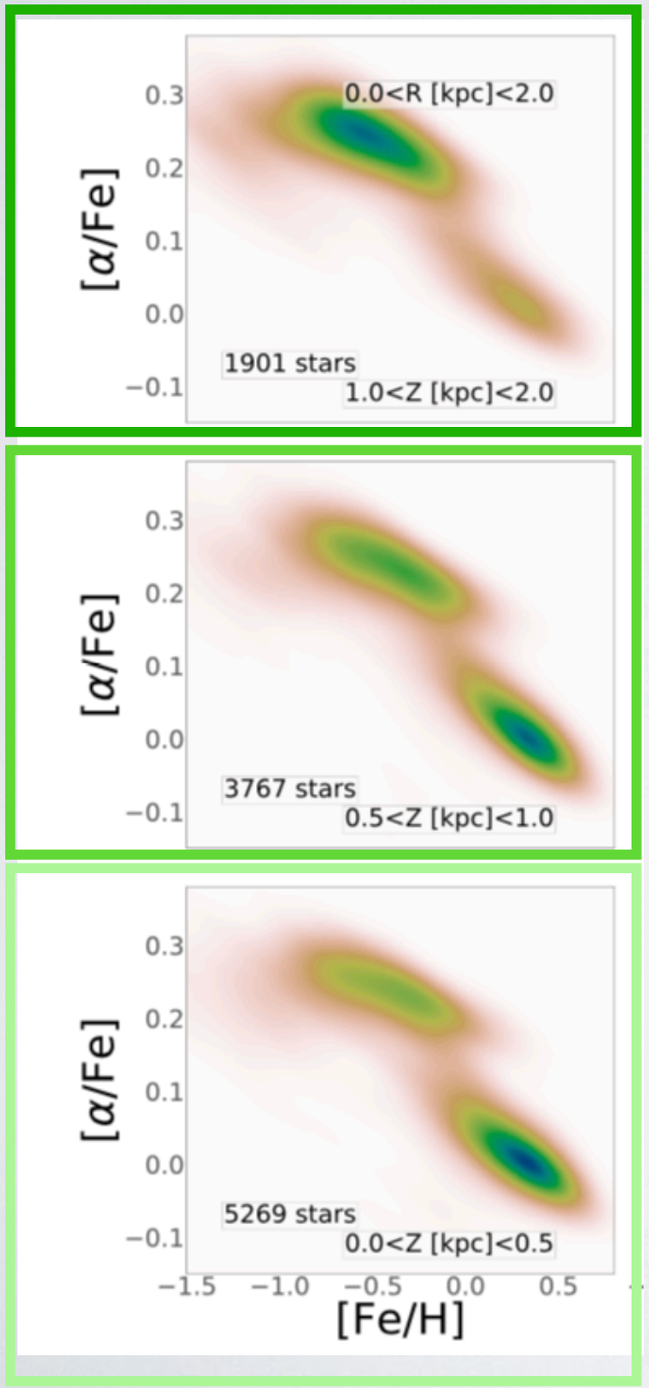
Two components also in [Mg/Fe] vs [Fe/H]

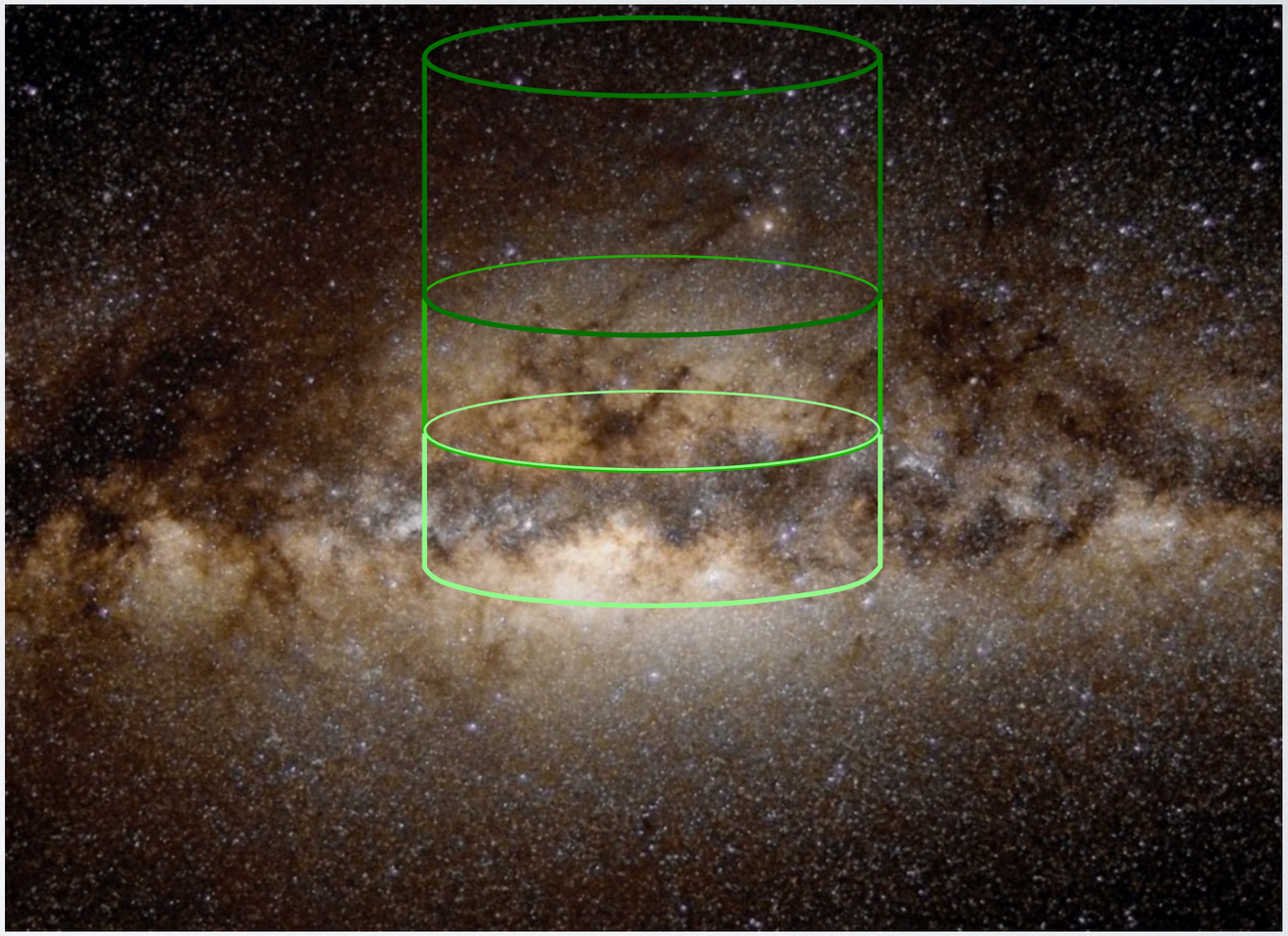
Rojas-Arriagada, MZ + 2019 APOGEE



The two components have different spatial distribution

Queiroz+2020 APOGEE+GaiaDR2 StarHorse





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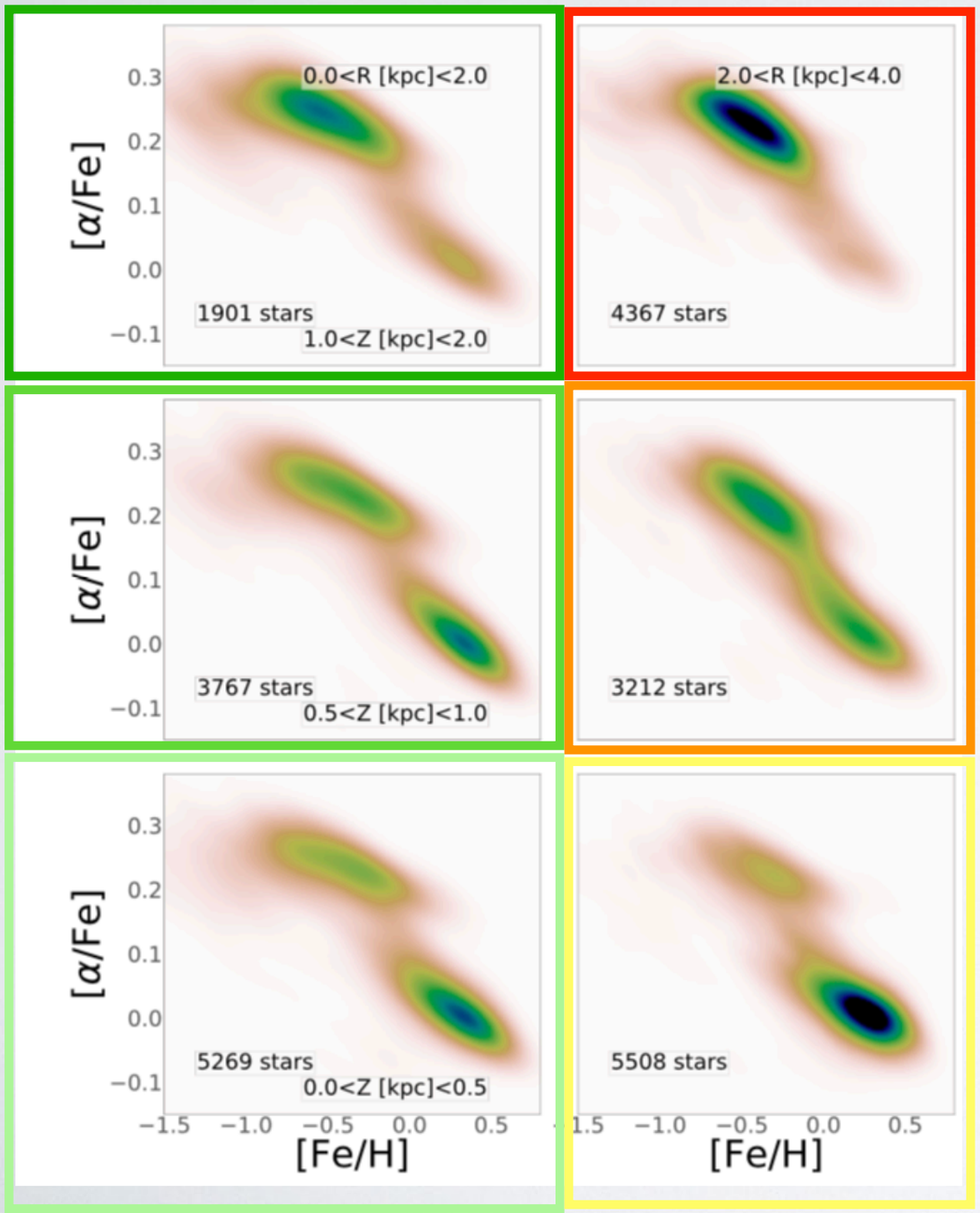
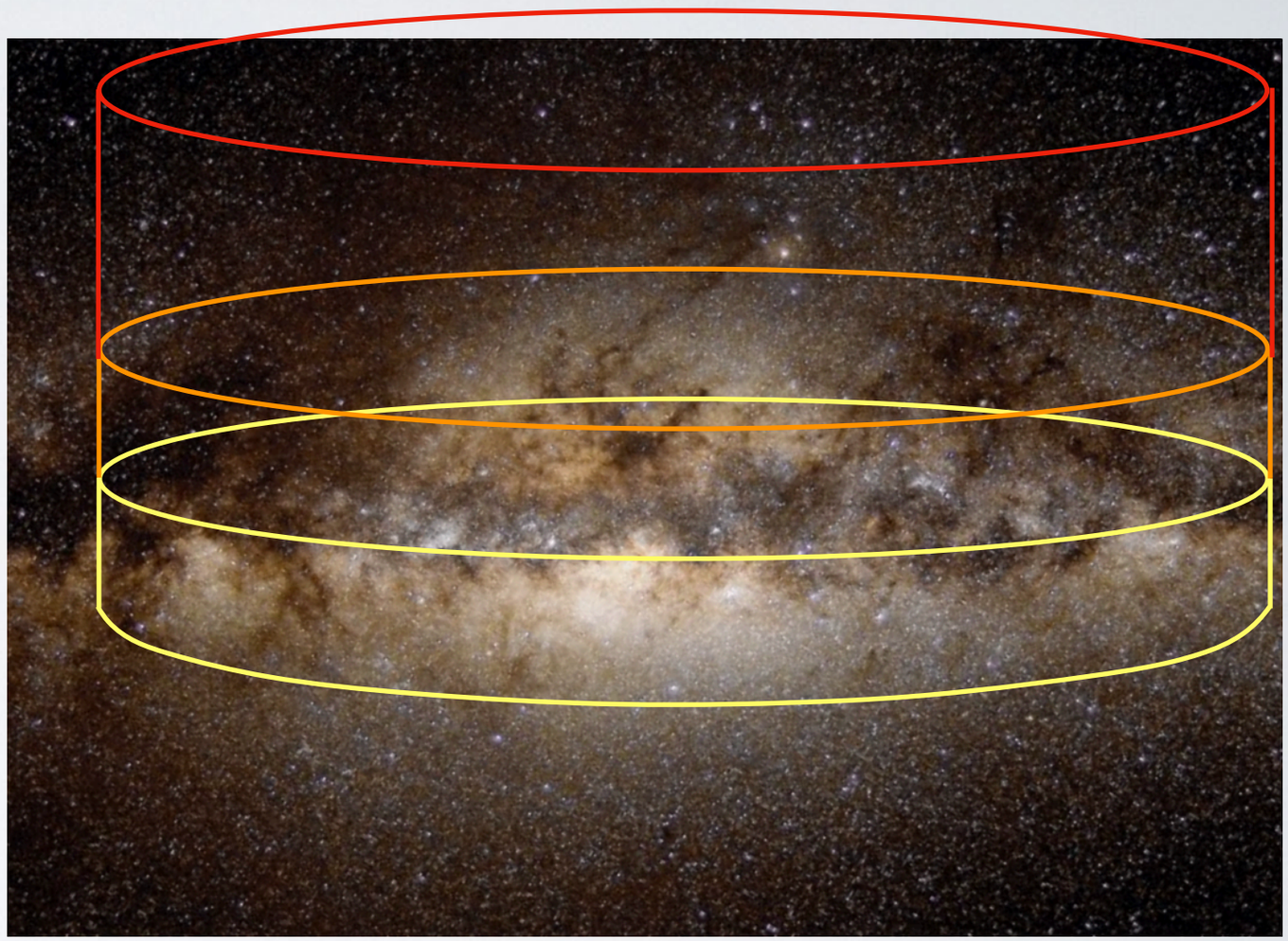
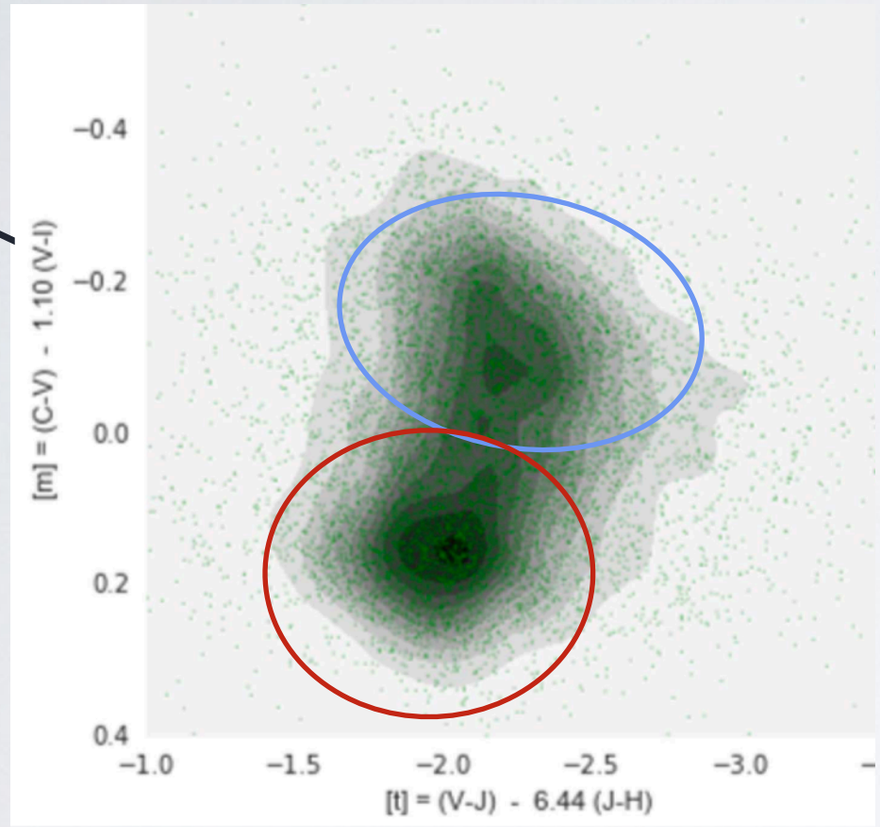
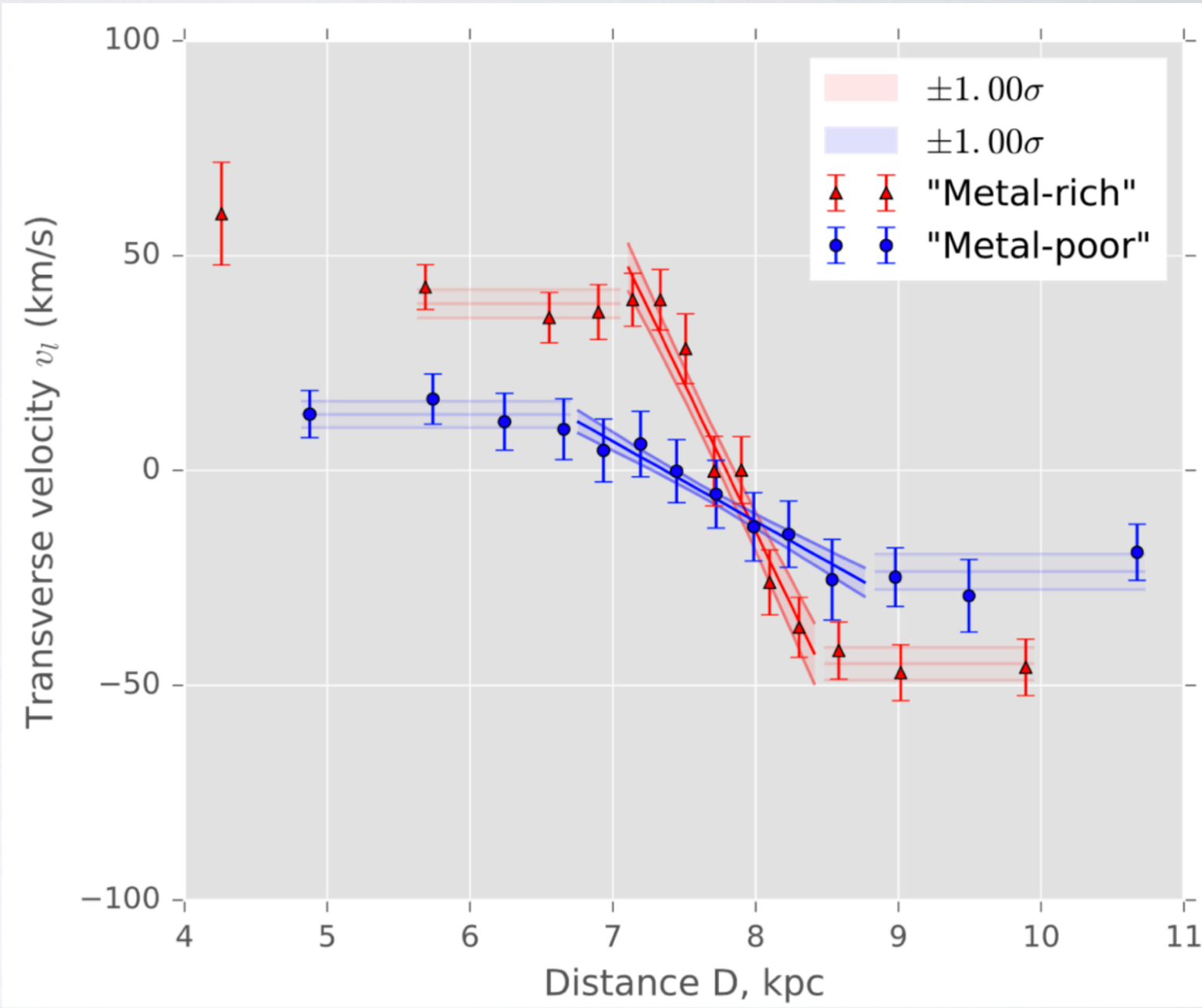




The two components have different kinematics

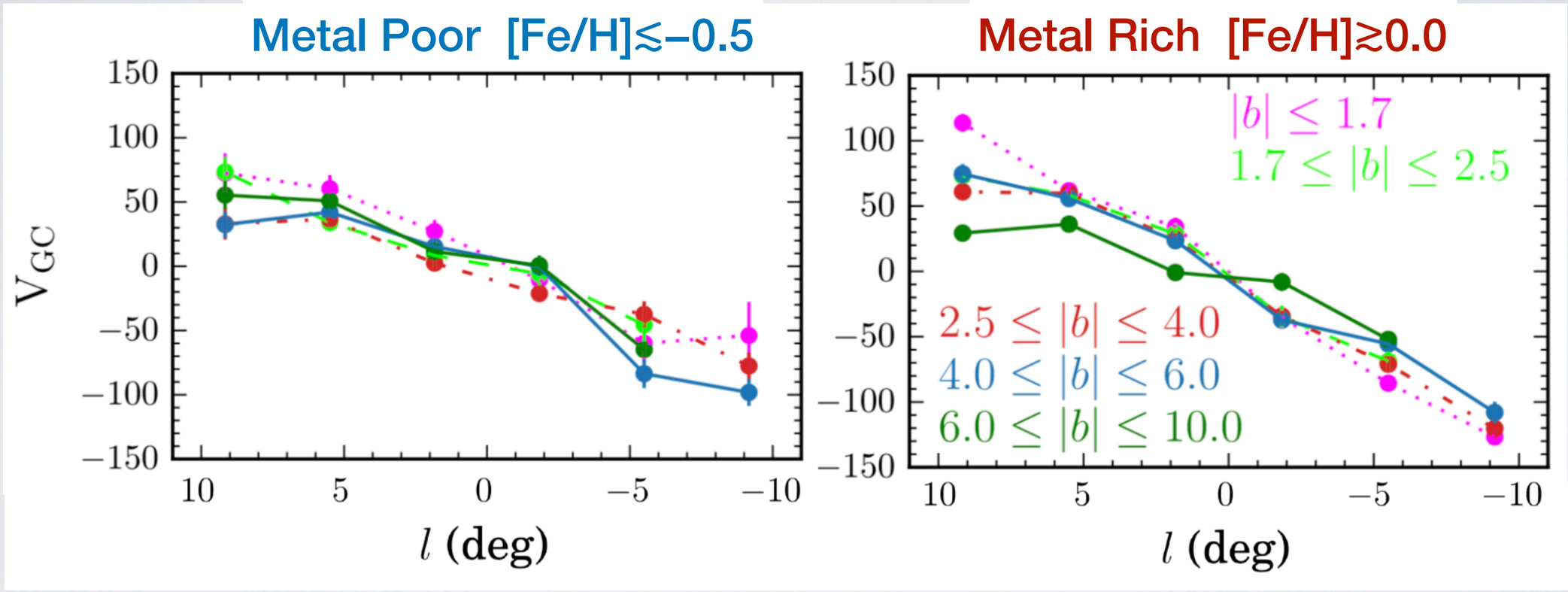


Clarkson+2018 HST Bulge Treasury



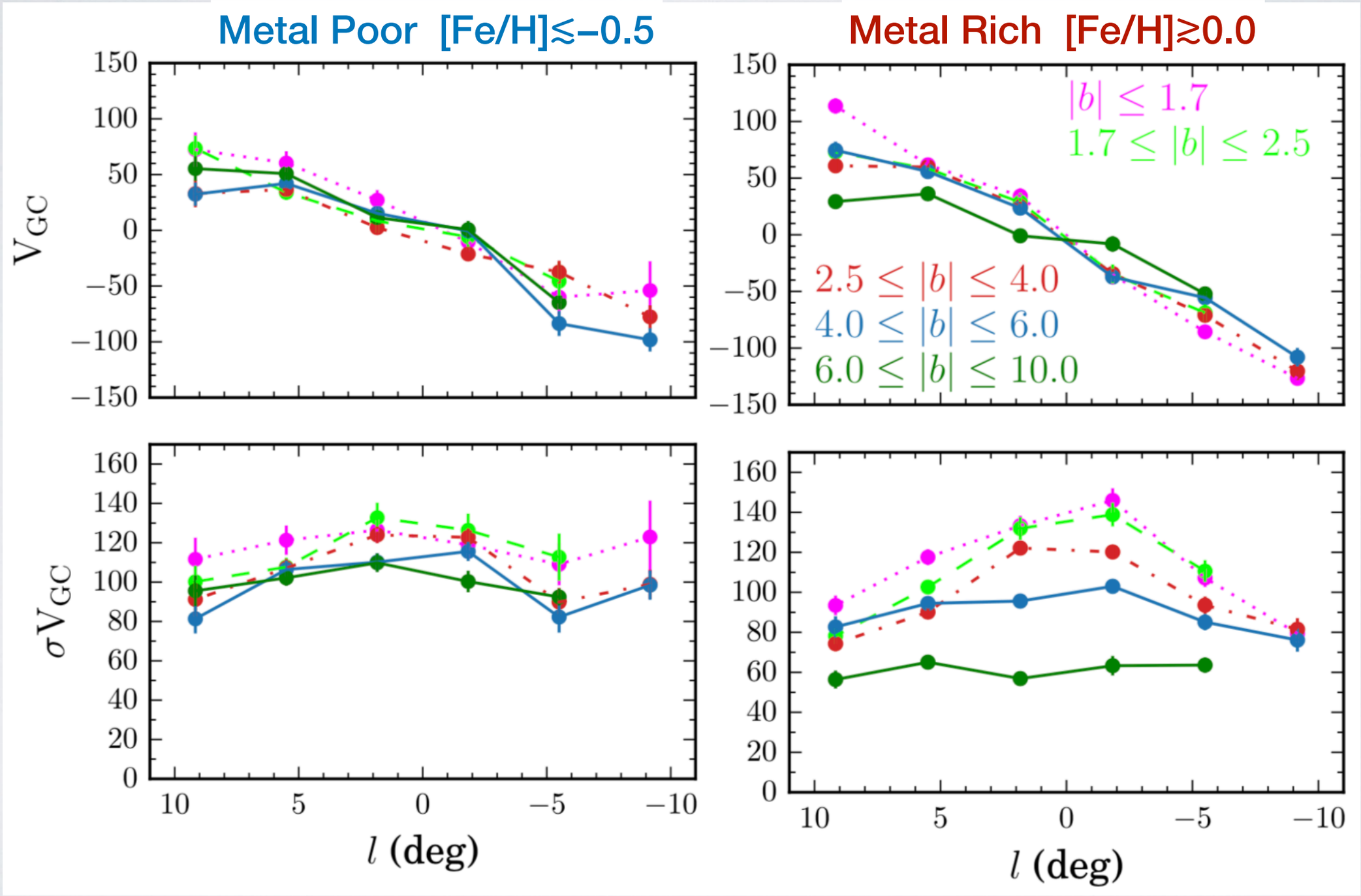
The two components have different kinematics

Rojas-Arriagada + 2020 APOGEE



The two components have different kinematics

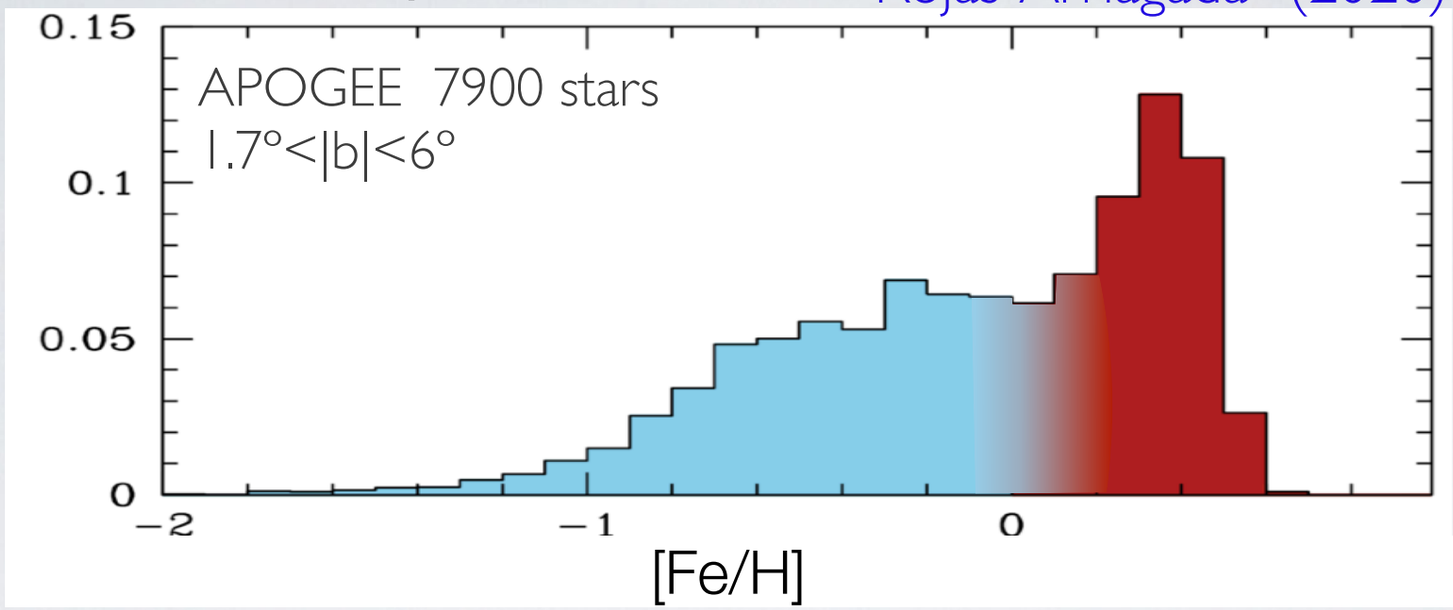
Rojas-Arriagada + 2020 APOGEE



see also MZ+2017, Ness+2013

(partial) Summary:

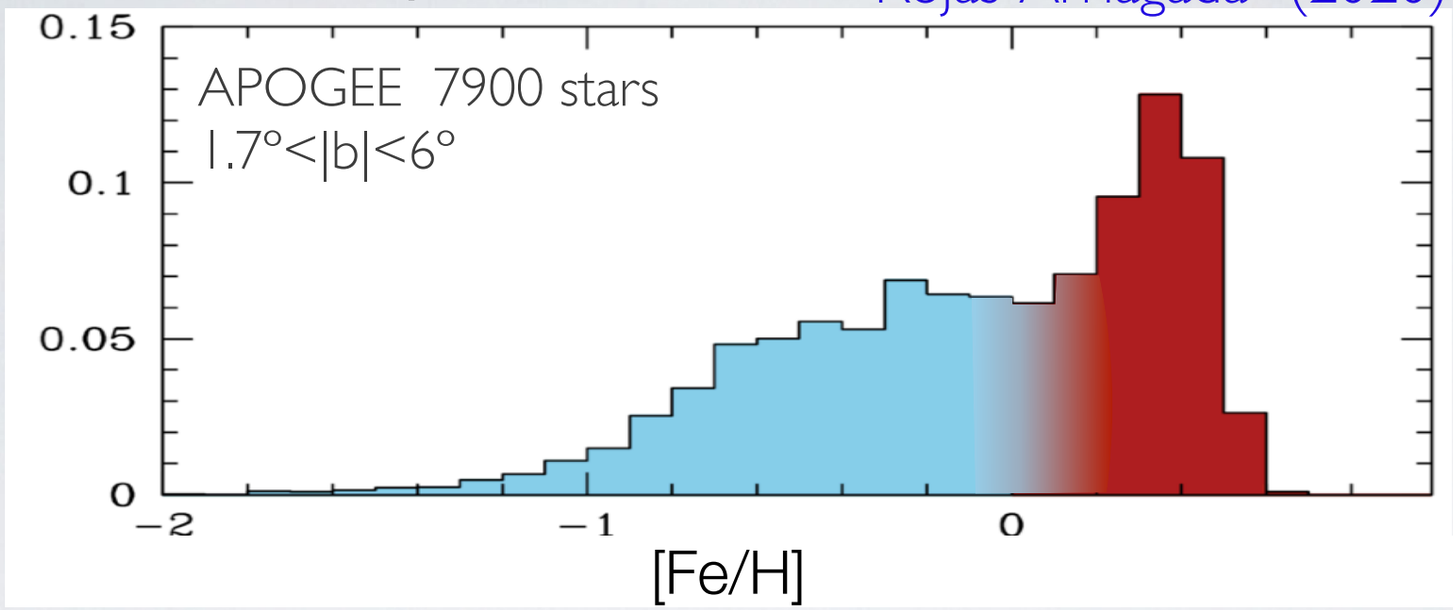
Rojas-Arriagada+(2020)



only old	old + ?
spheroidal	bar + B/P
high [α/Fe]	low [α/Fe]
rotates slower	rotates faster
constant σ_{RV}	gradient σ_{RV}

(partial) Summary:

Rojas-Arriagada+(2020)

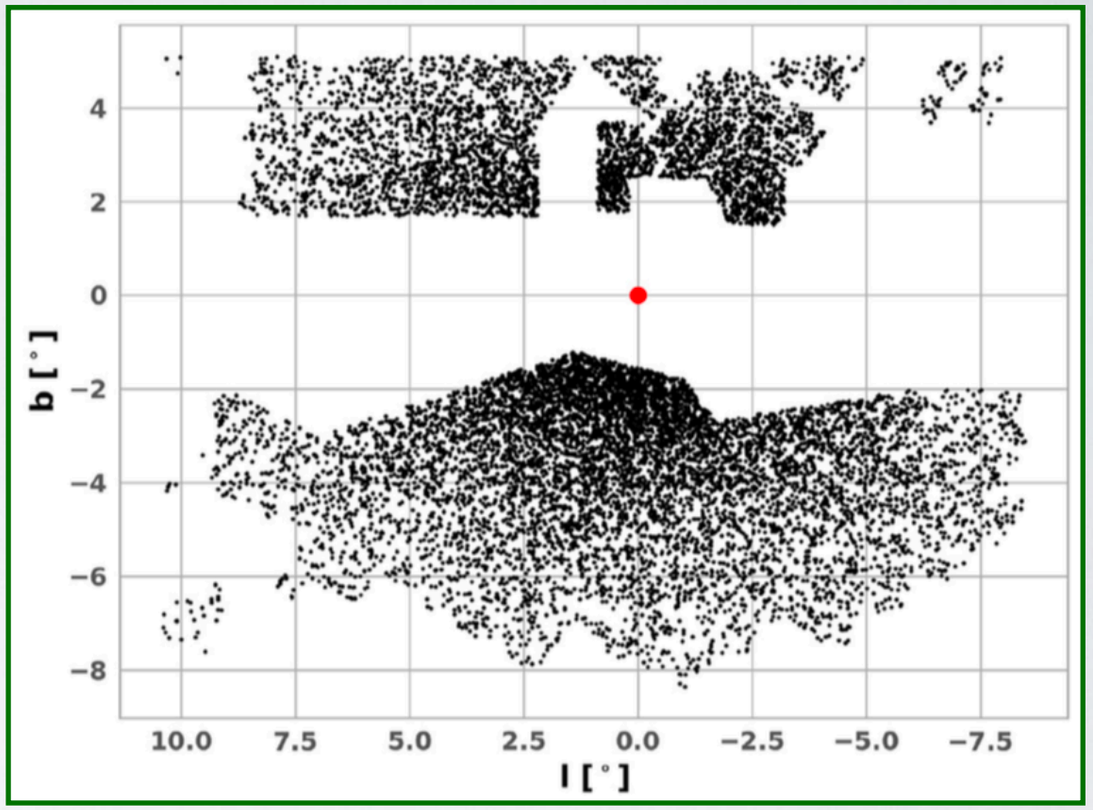


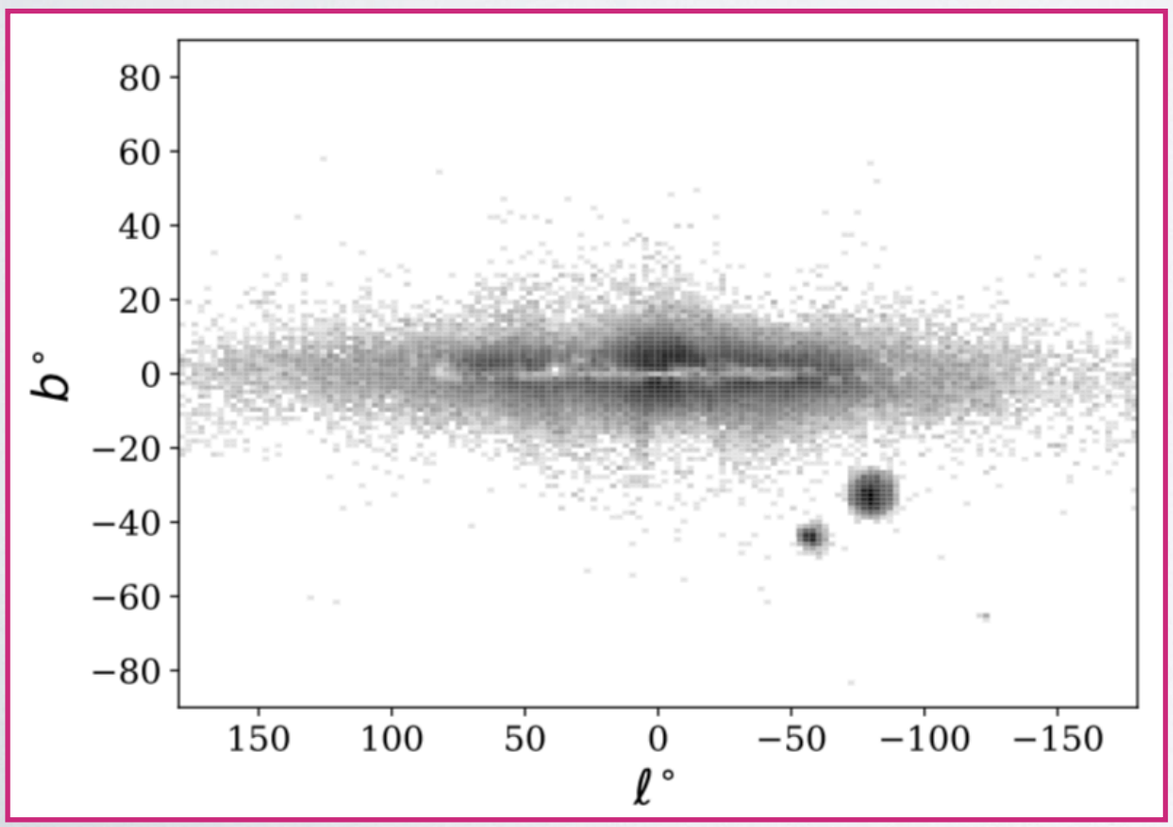
only old	old + ?
spheroidal	bar + B/P
high [α/Fe]	low [α/Fe]
rotates slower	rotates faster
constant σ_{RV}	gradient σ_{RV}

What can we learn from Variable Stars ?

RR Lyrae stars: certainly > 10 Gyr

Du+2020: ~12,300 "clean" RRL
in GaiaDR2 + OGLE



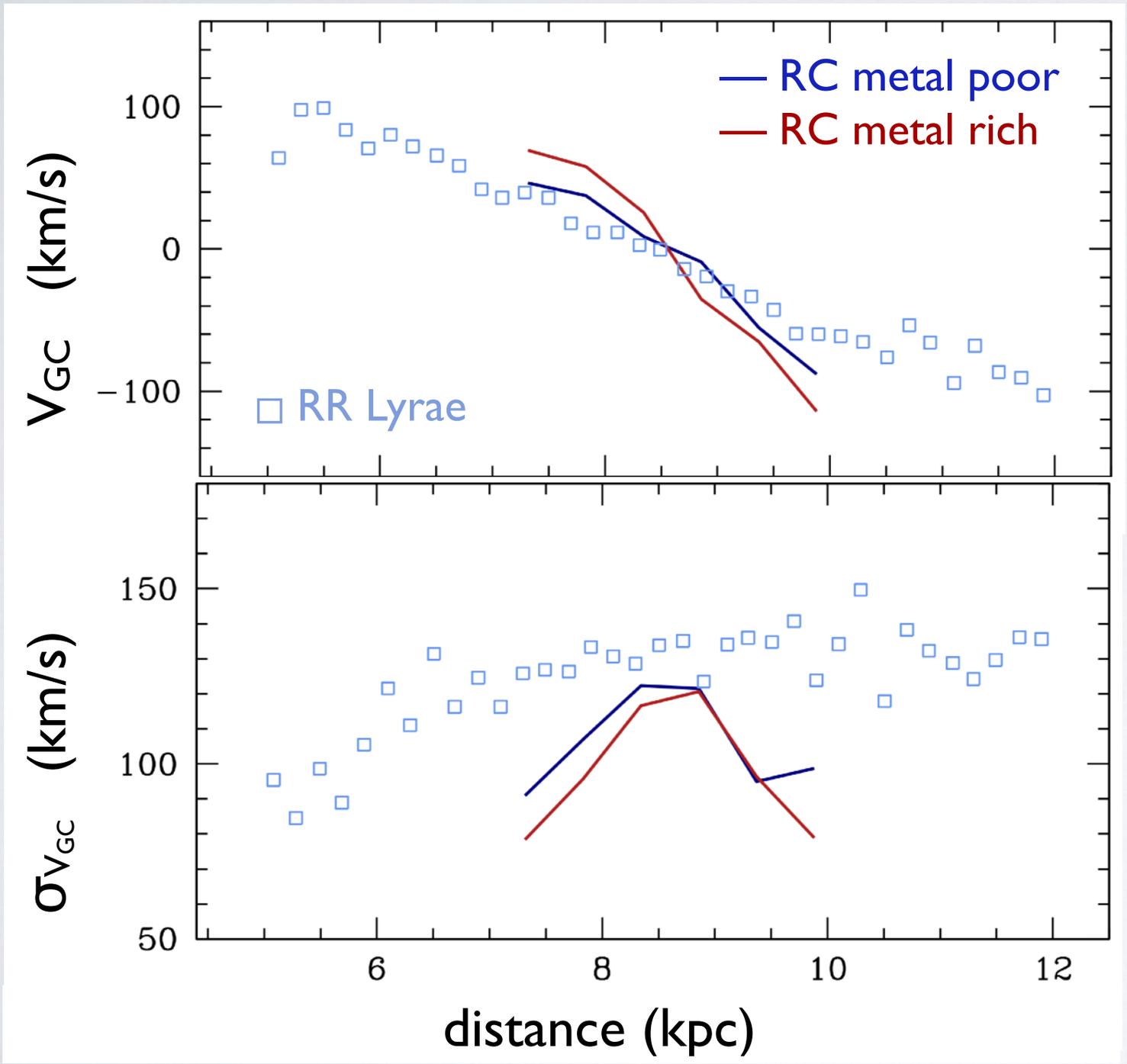


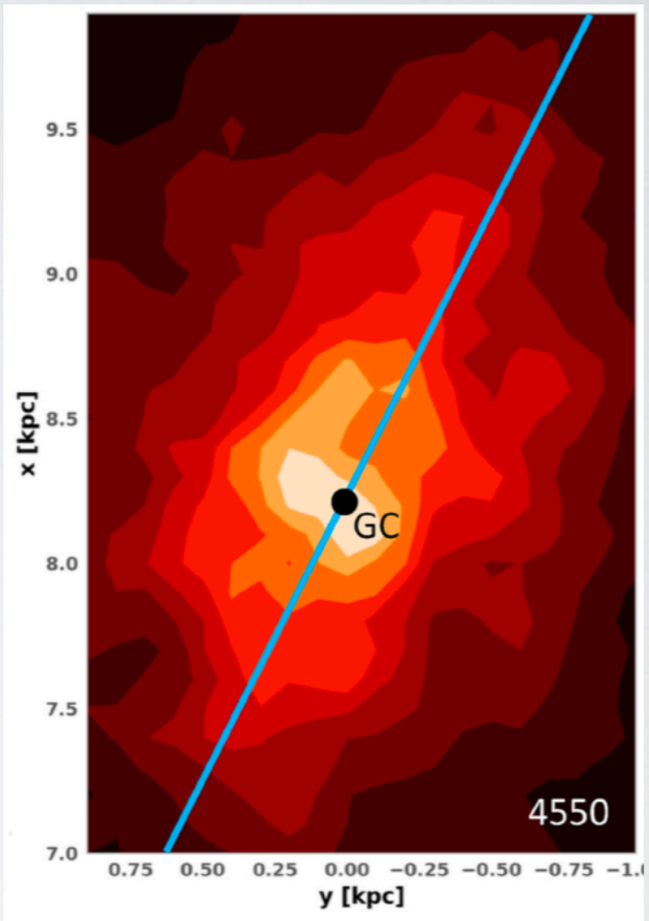
Mira variables: age / Period relation

Grady+2020 ~8,500 O-rich Miras
in GaiaDR2+OGLE+2MASS
with |b|>5°

RR Lyrae (a pure old population)

adapted from Du+2020 and Rojas-Arriagada + 2020

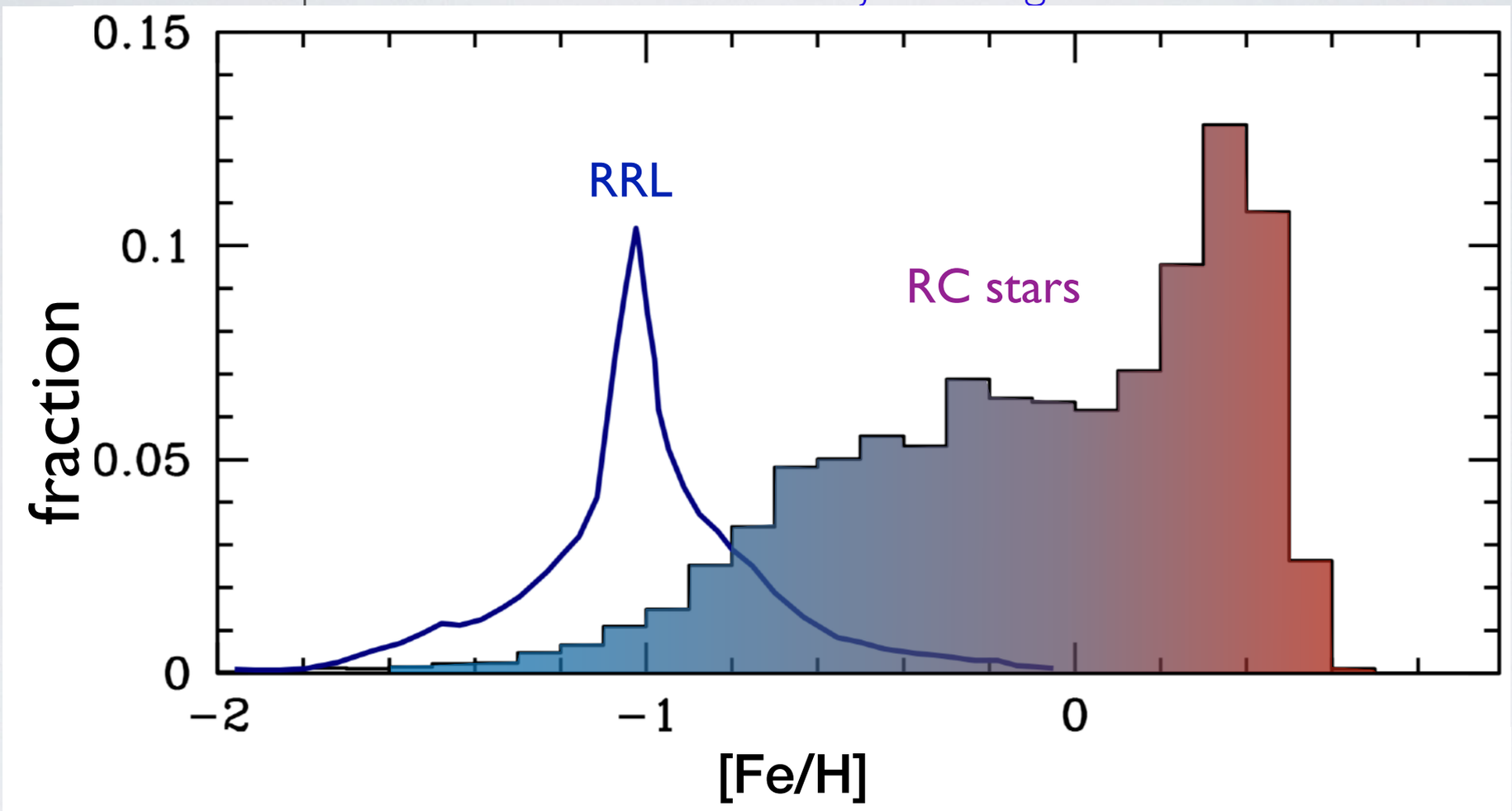




see also:
Kunder + 2015, 2020
Pietrukowicz+2015
Dékány+2013

Do RRL and metal-poor RC trace the same parent population?

adapted from Du+2020 and Rojas-Arriagada +2020

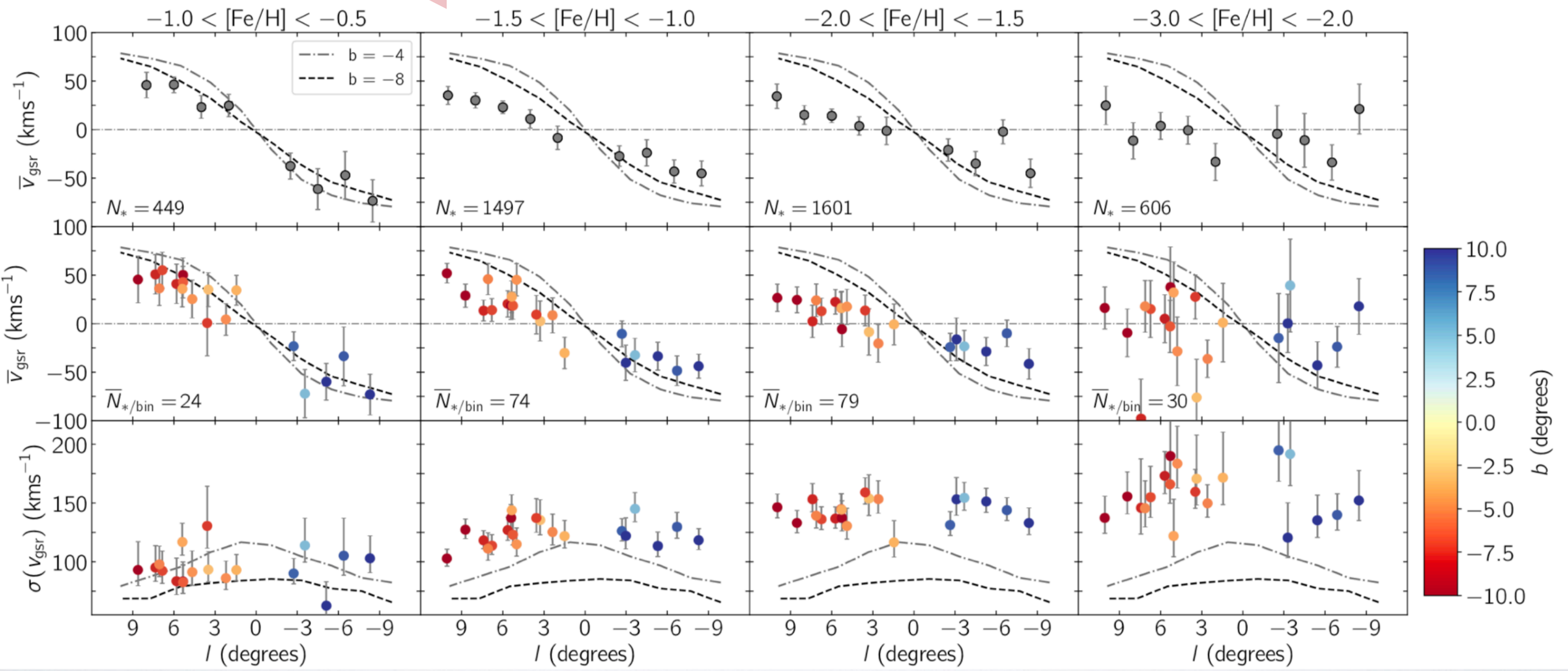


Probably yes.
However, RRL are contaminated by the halo especially at the metal-poor, outer end of their distribution (see Du+2020 and Kunder+2020)

The Bulge → Halo Transition

Arentsen+2020 PIGS

metallicity



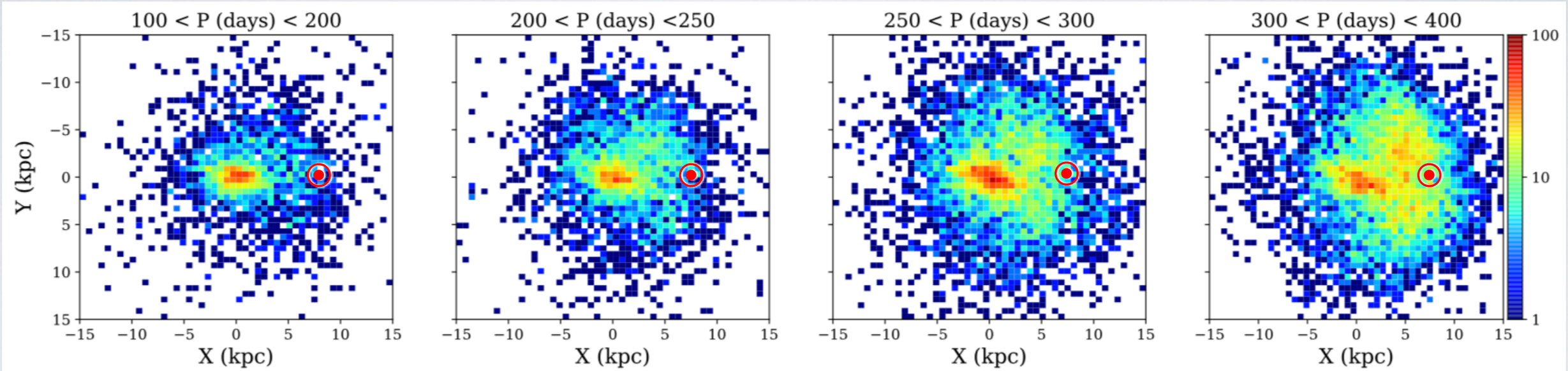
O-rich Miras: age slicing the inner MW

Grady+2020

old Miras (~10 Gyr)

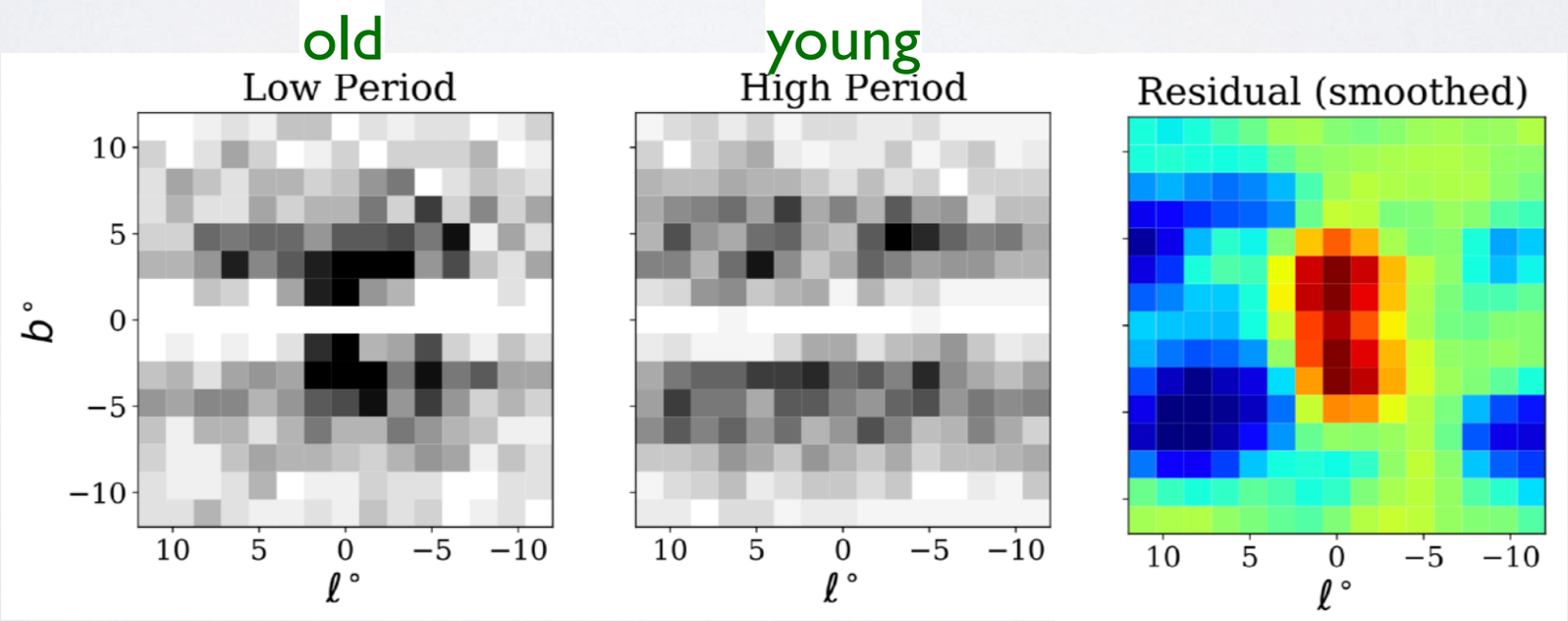
AGE

young Miras (5-7 Gyr)



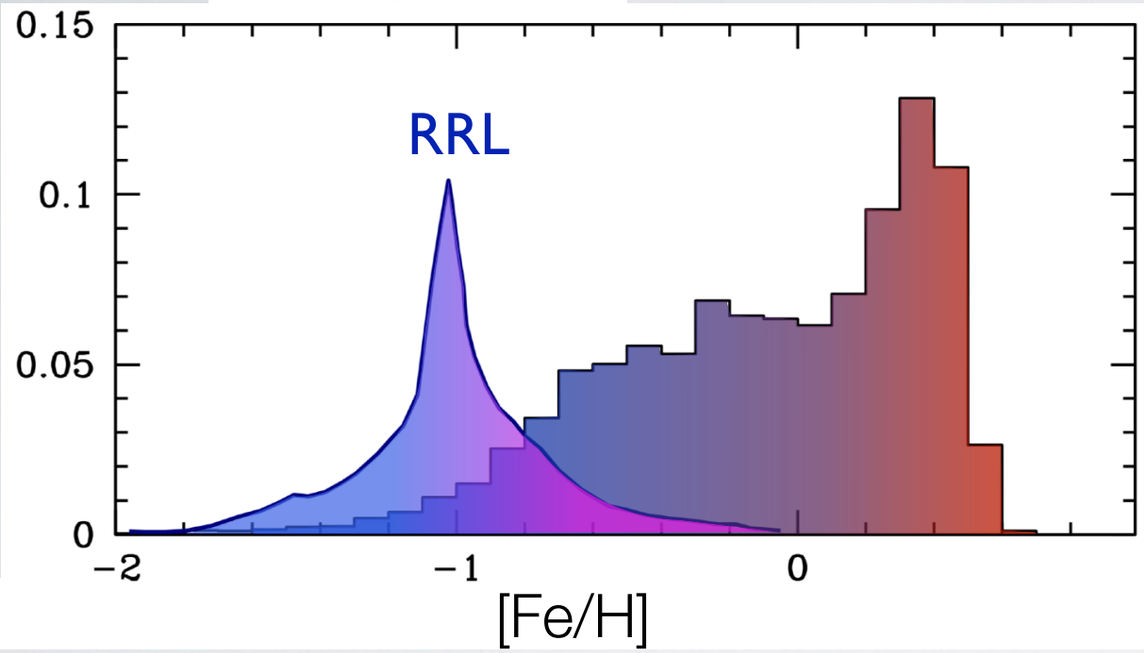
old

young

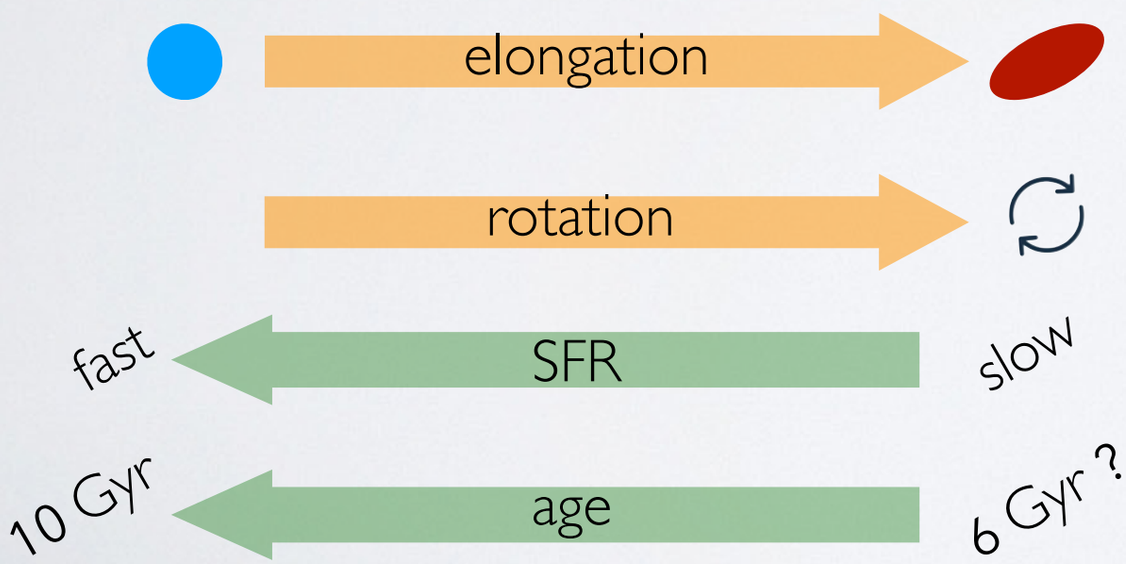


Summary

N components?

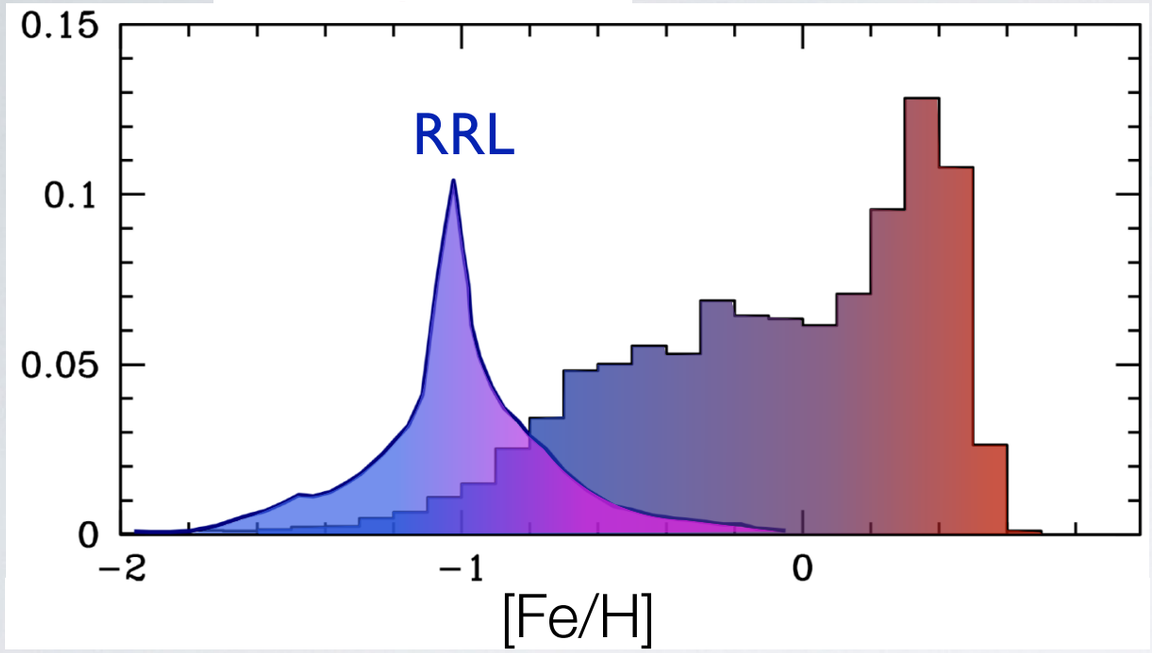


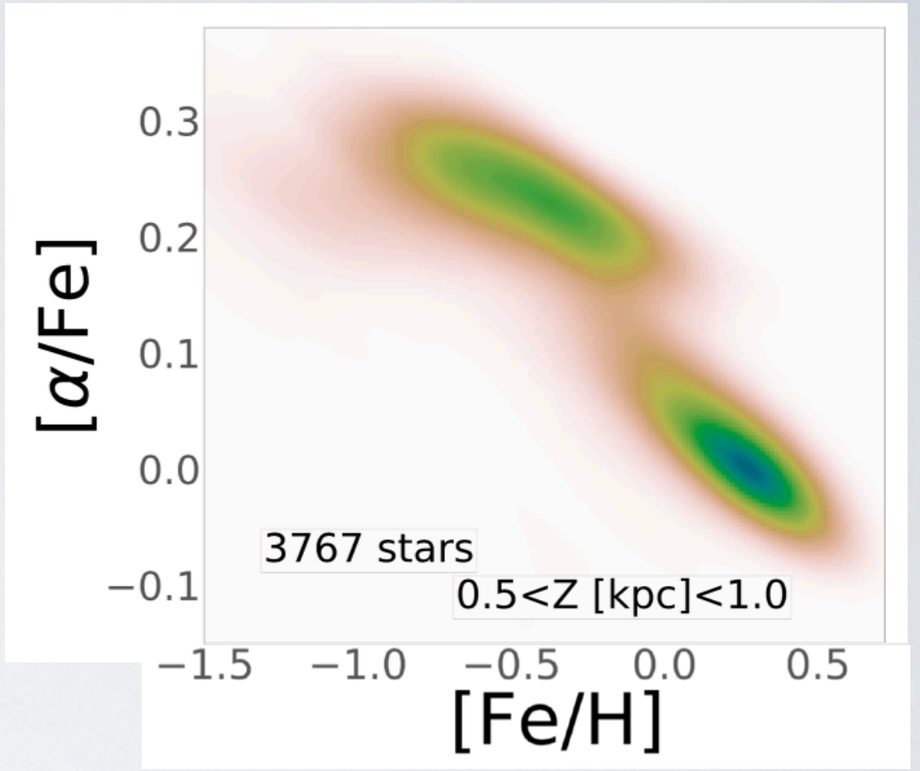
or perhaps a continuum?



Summary

N components?





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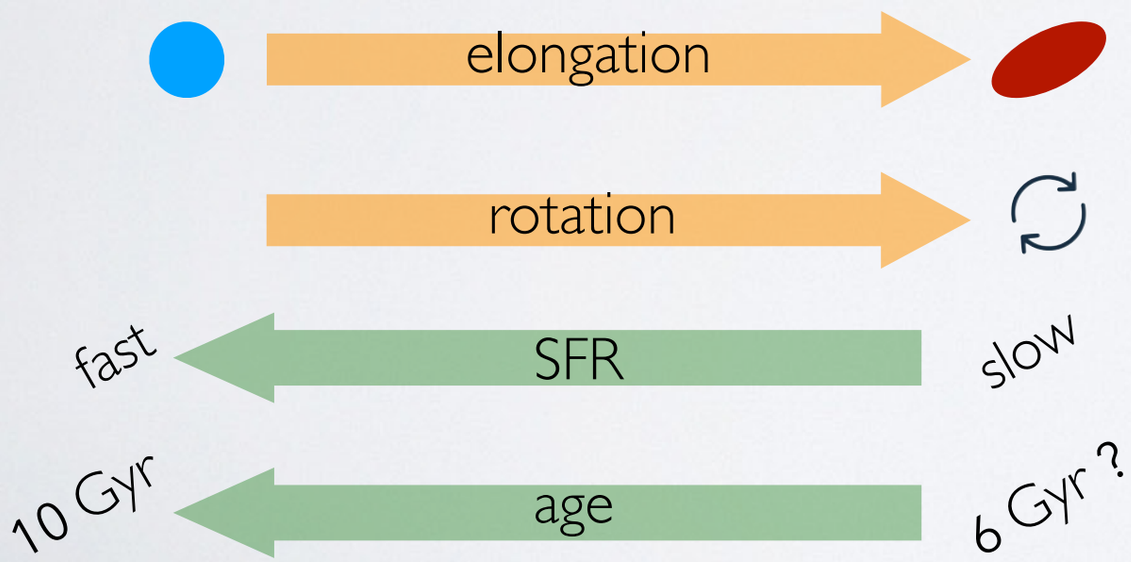

Red Clump Lim+2020