The age structure of the Milky Way's thick disk

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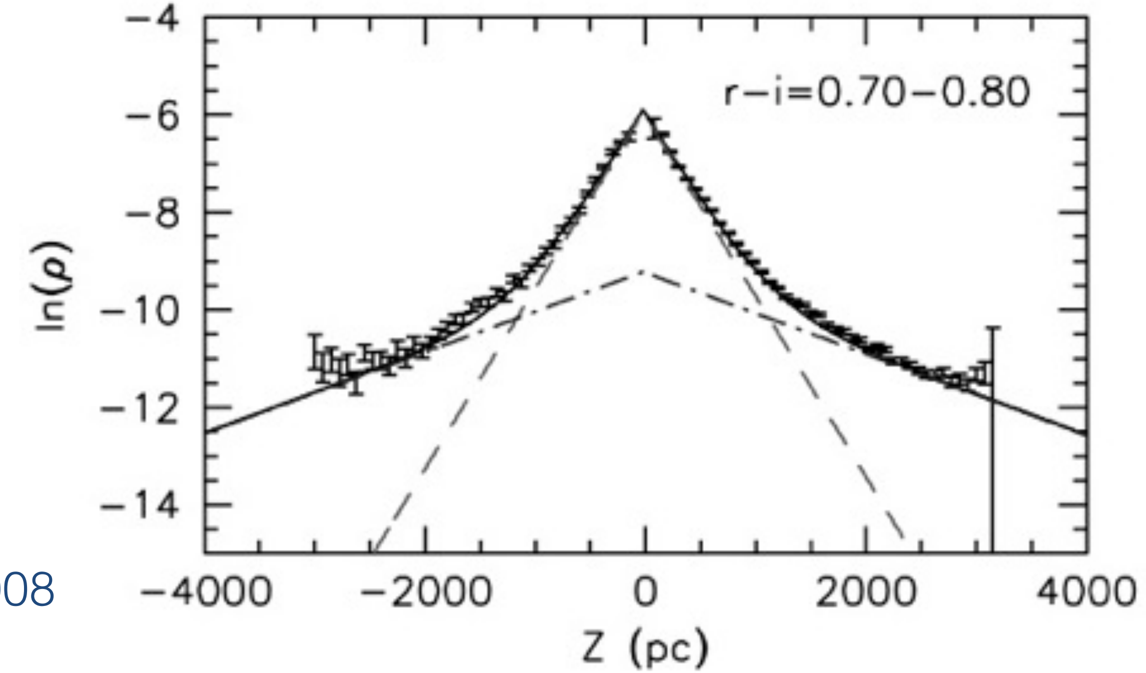
with Ivan Minchev, Morgan Fouesneau, Melissa Ness, Hans-Walter Rix

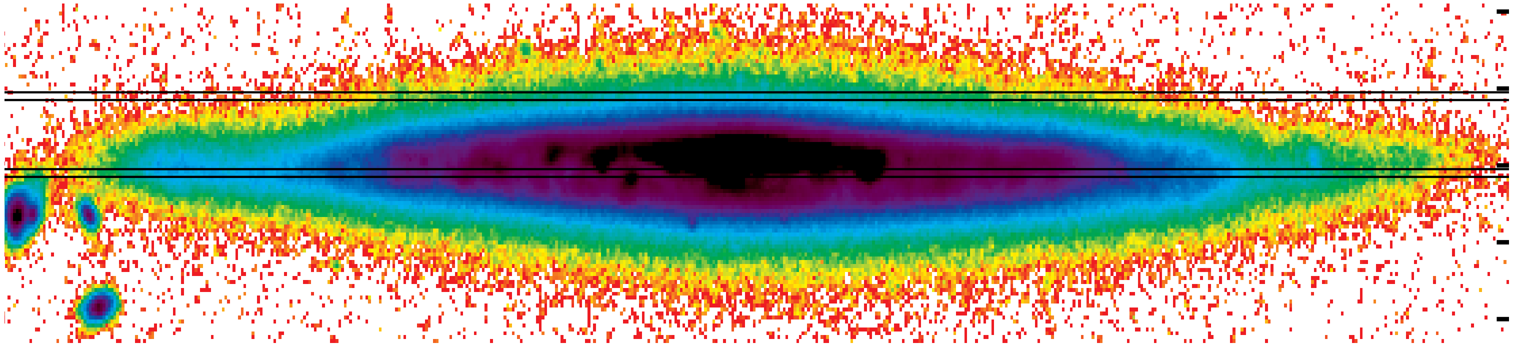
Thick disk definition based on...

- Morphology

(e.g., Gilmore & Reid 1983
Comerón et al. 2011)



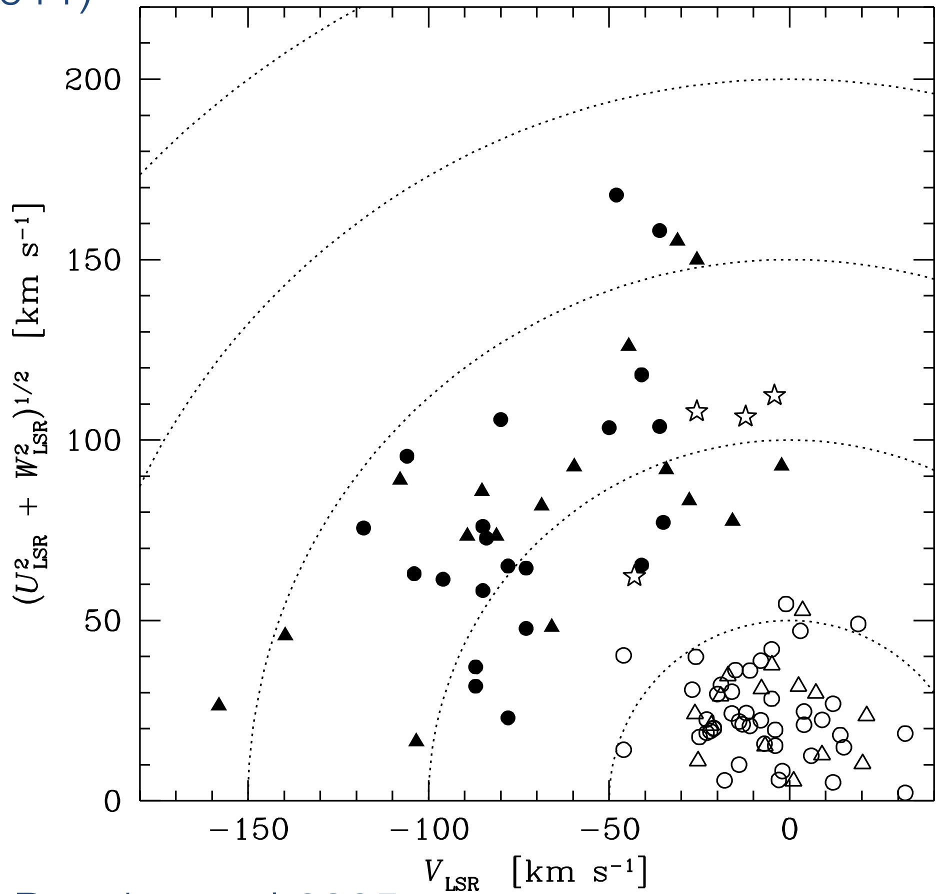
Juric et al. 2008



Yoachim & Dalcanton 2008

Thick disk definition based on...

- Morphology (Gilmore & Reid 1983, Yoachim & Dalcanton 2008, Juric et al. 2008, Comerón et al. 2011)
- Kinematics (Prochaska et al. 2000; Bensby et al. 2003; Reddy et al. 2003)



Bensby et al 2005

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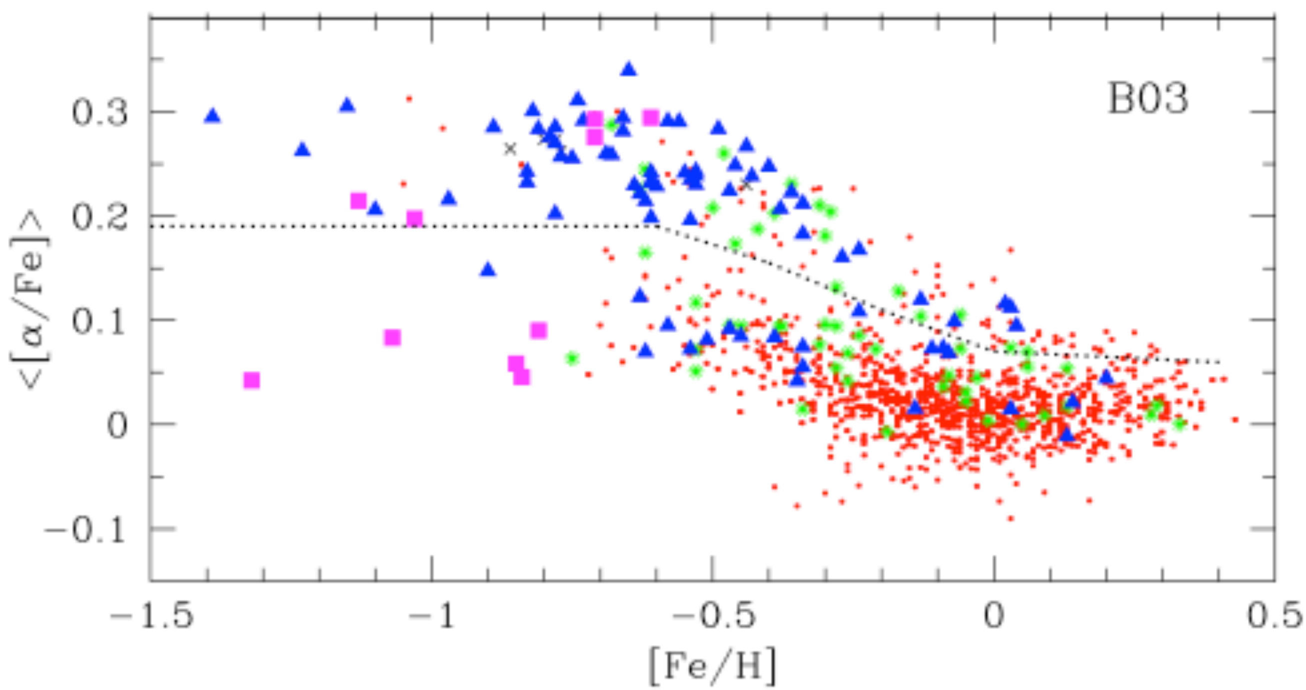
- Kinematics (Prochaska et al. 2000; Bensby et al. 2003; Reddy et al. 2003)
- Chemistry

(Fuhrmann 1998
Navarro et al. 2011
Adibekyan et al. 2012)



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- Kinematics (Prochaska et al. 2000; Bensby et al. 2003; Reddy et al. 2003)
- Chemistry (Fuhrmann 1998; Navarro et al. 2011; Adibekyan et al. 2012)
- Age (Bensby et al. 2014; Kubryk et al. 2015)

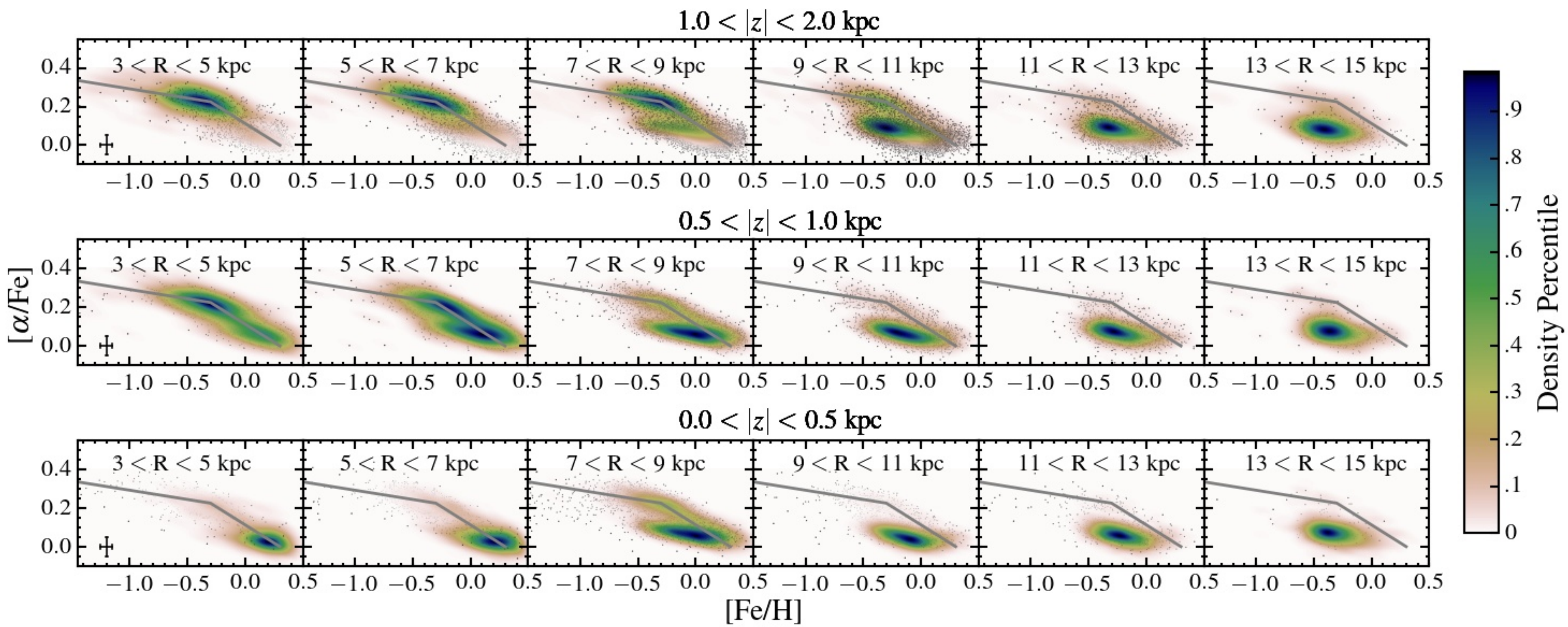
Thick disk definition based on...

- Morphology   Milky Way and nearby galaxies
- Kinematics   Milky Way only
- Chemistry   Milky Way only
- Age   Milky Way only

→ different definitions make it difficult to compare the MW to nearby galaxies

The radial extent of thick disks

- In the MW, alpha-rich stars mostly in inner disk, with short scale-length (Bensby et al. 2011; Cheng et al. 2012; Bovy et al. 2012; Nidever et al. 2014; Hayden et al. 2015)



Hayden et al 2015

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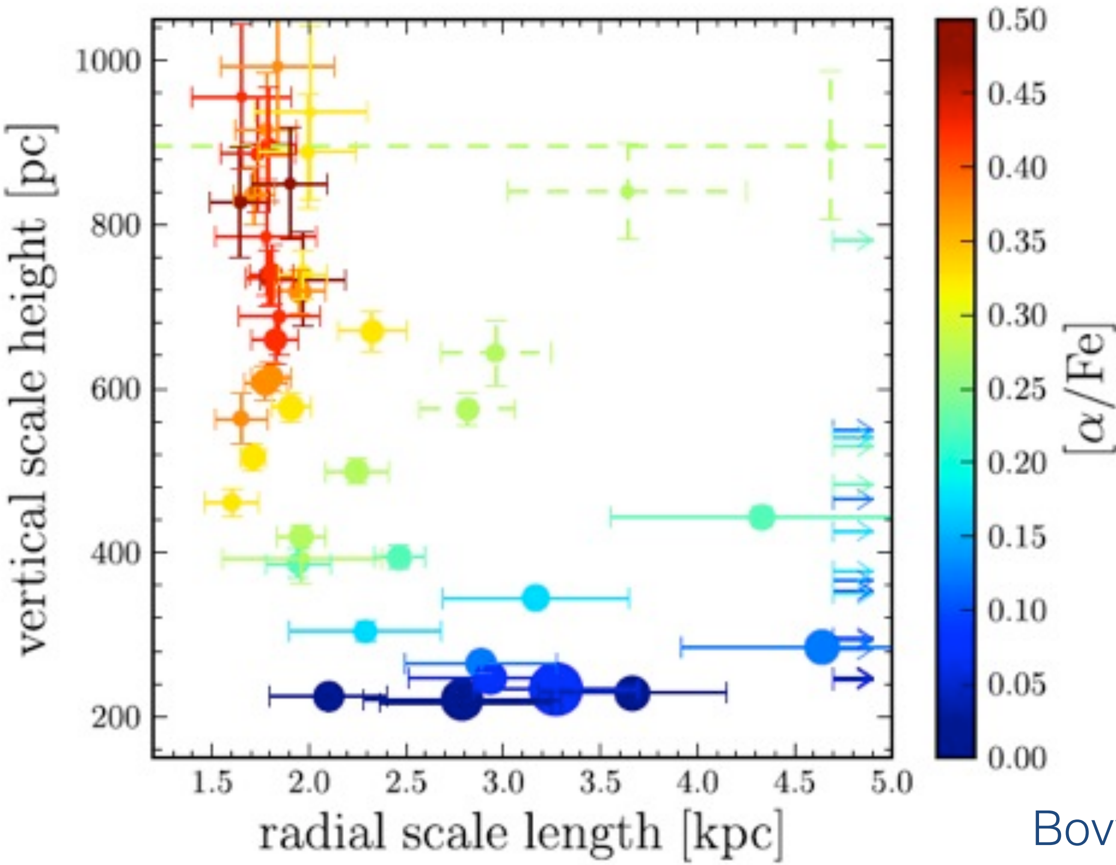

Bovy et al 2012

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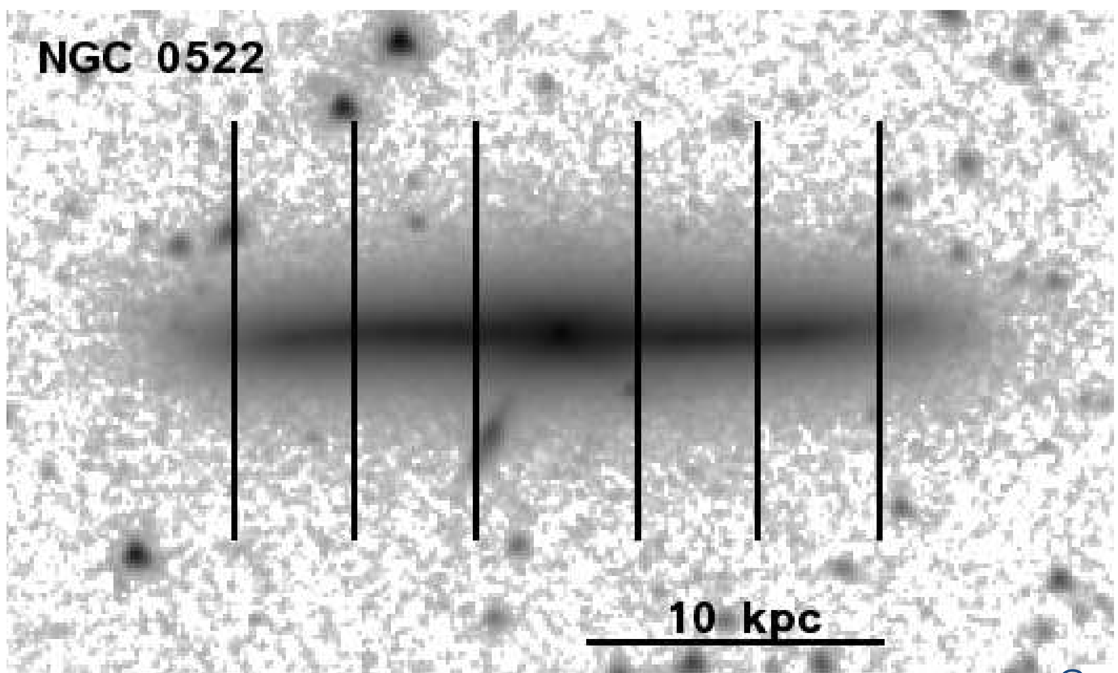

Comeron et al 2011

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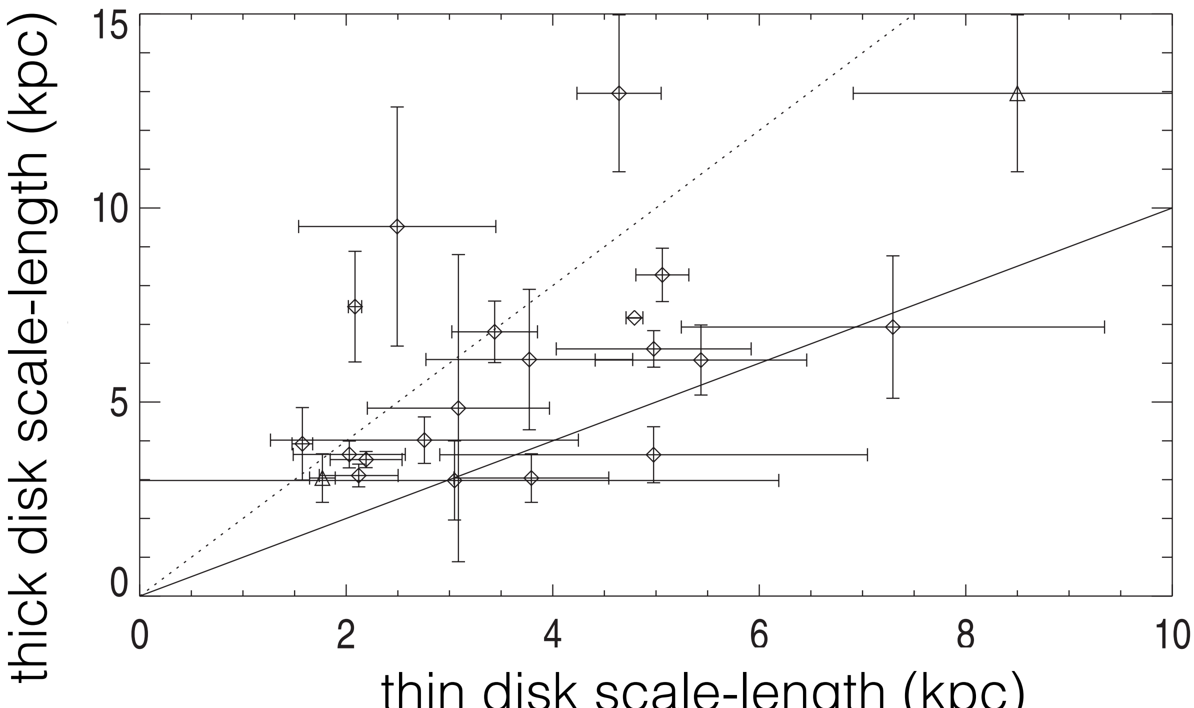

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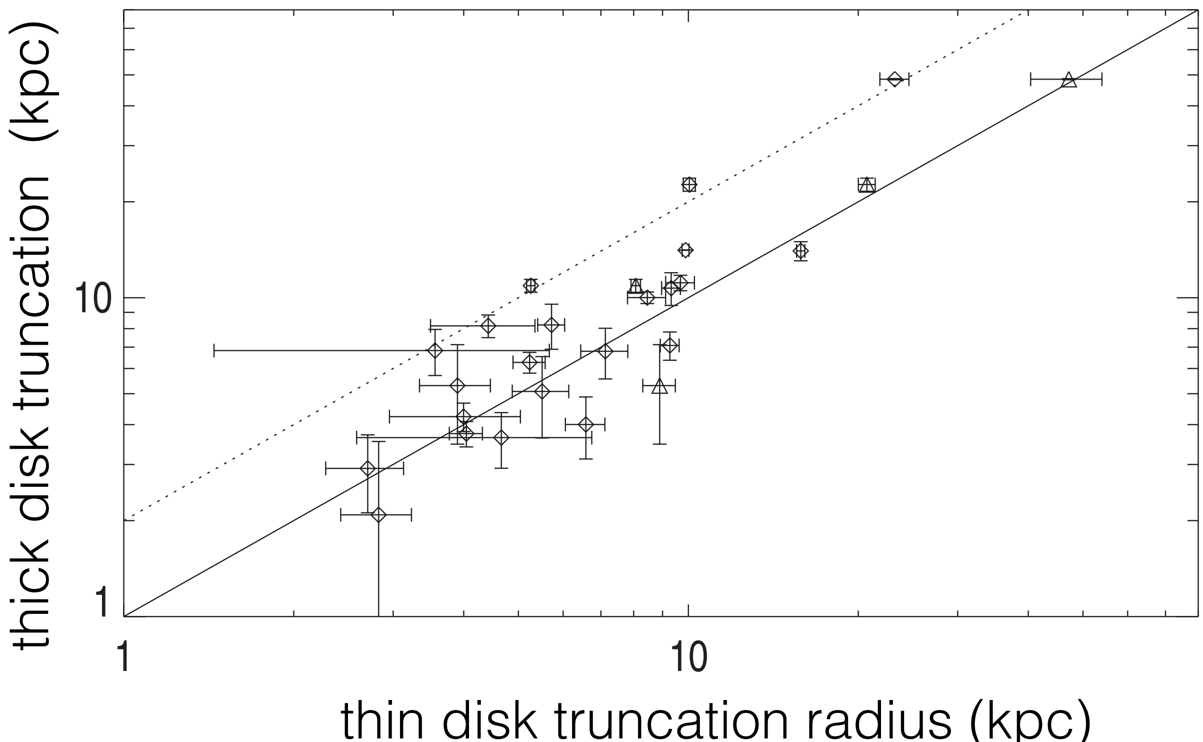

Comeron et al 2012

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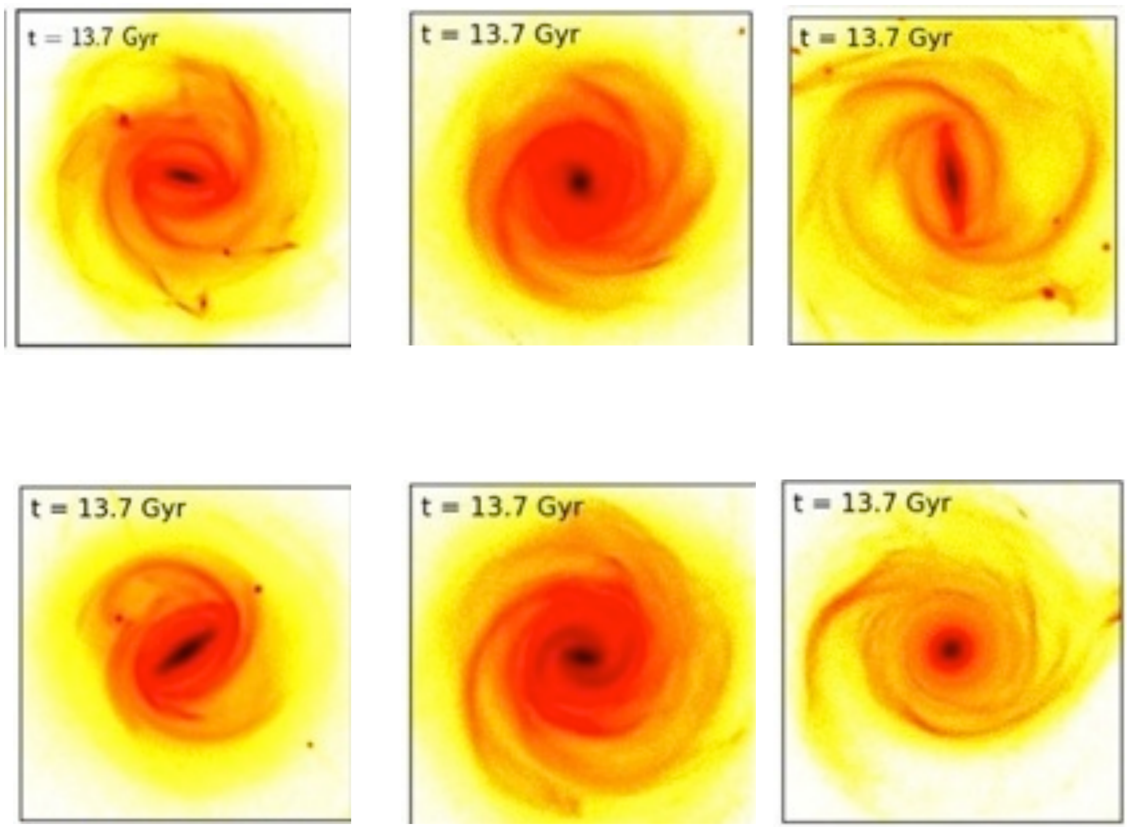
→ is the MW actually different, or is it just a matter of definition?

Zoom cosmological simulations
150 pc resolution, 15,000 Msun gas particles



Quiescent history in last 9 Gyr of evolution

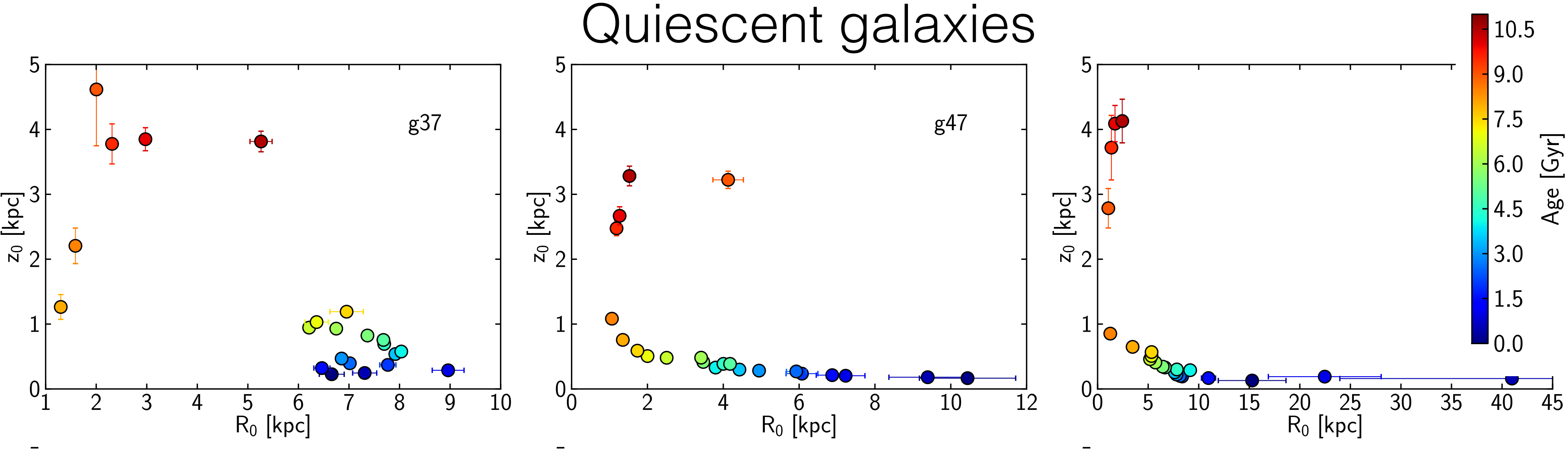
1:10, 1:4 and 1:15 mergers

→ select disk stars in 500 Myr age bins

Martig, Minchev & Flynn 2014a, b

Anticorrelation between scale-height and scale-length

Quiescent galaxies



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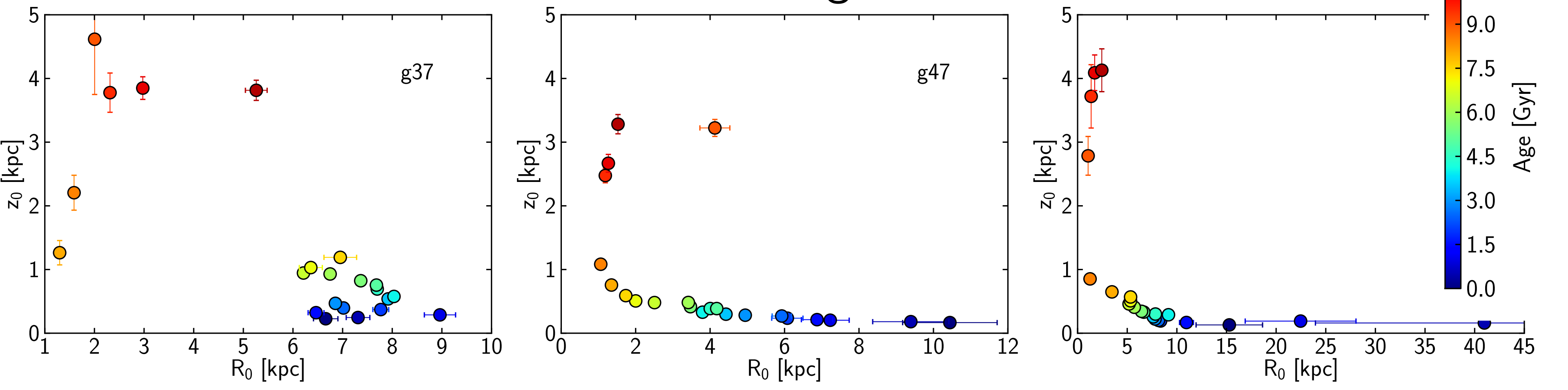
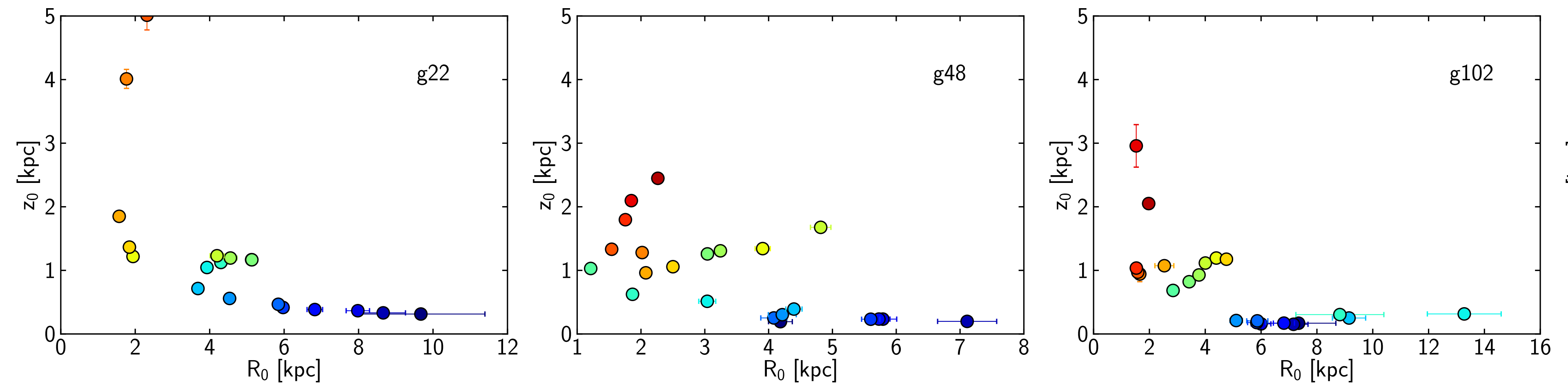
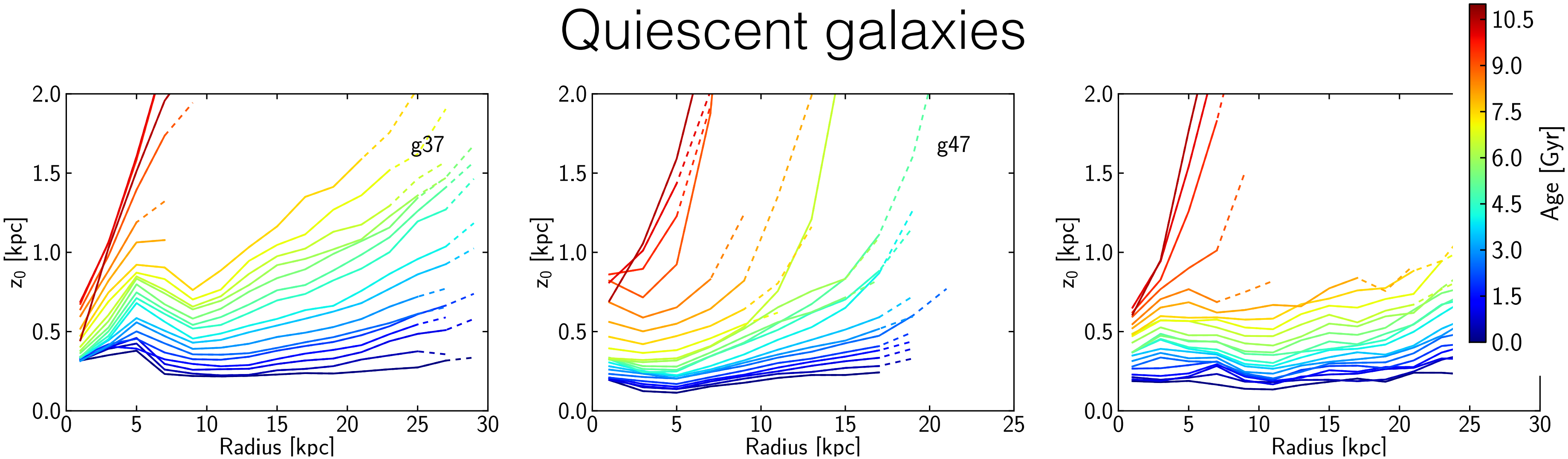


Galaxies with mergers



Mono-age populations are flared

Quiescent galaxies



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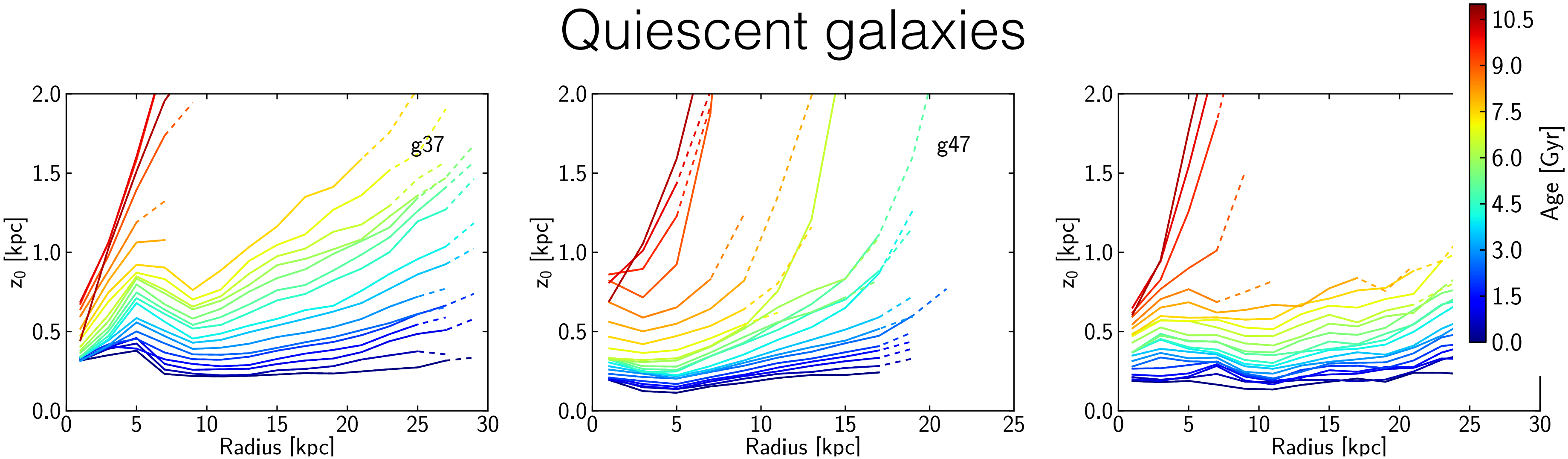

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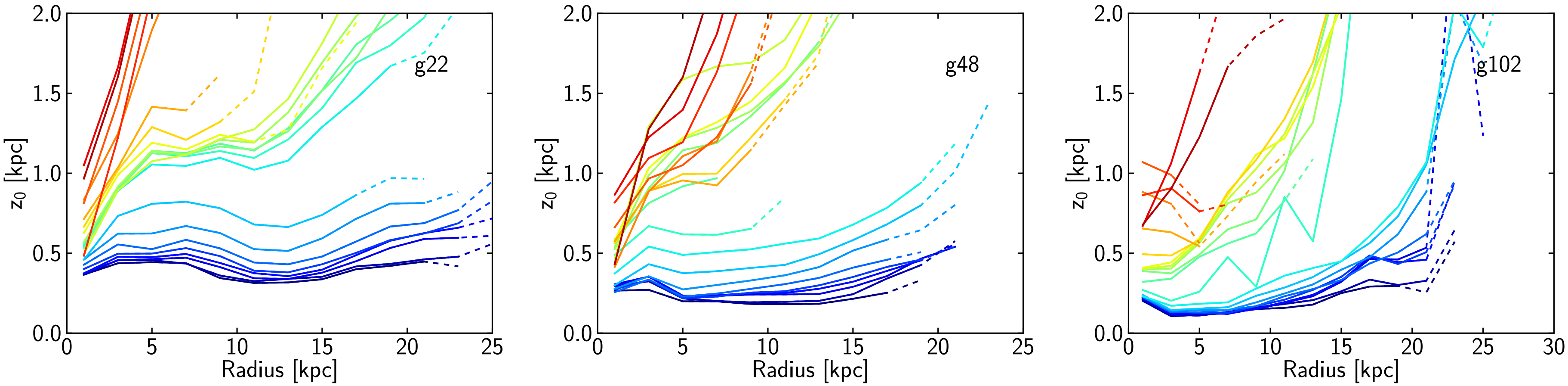
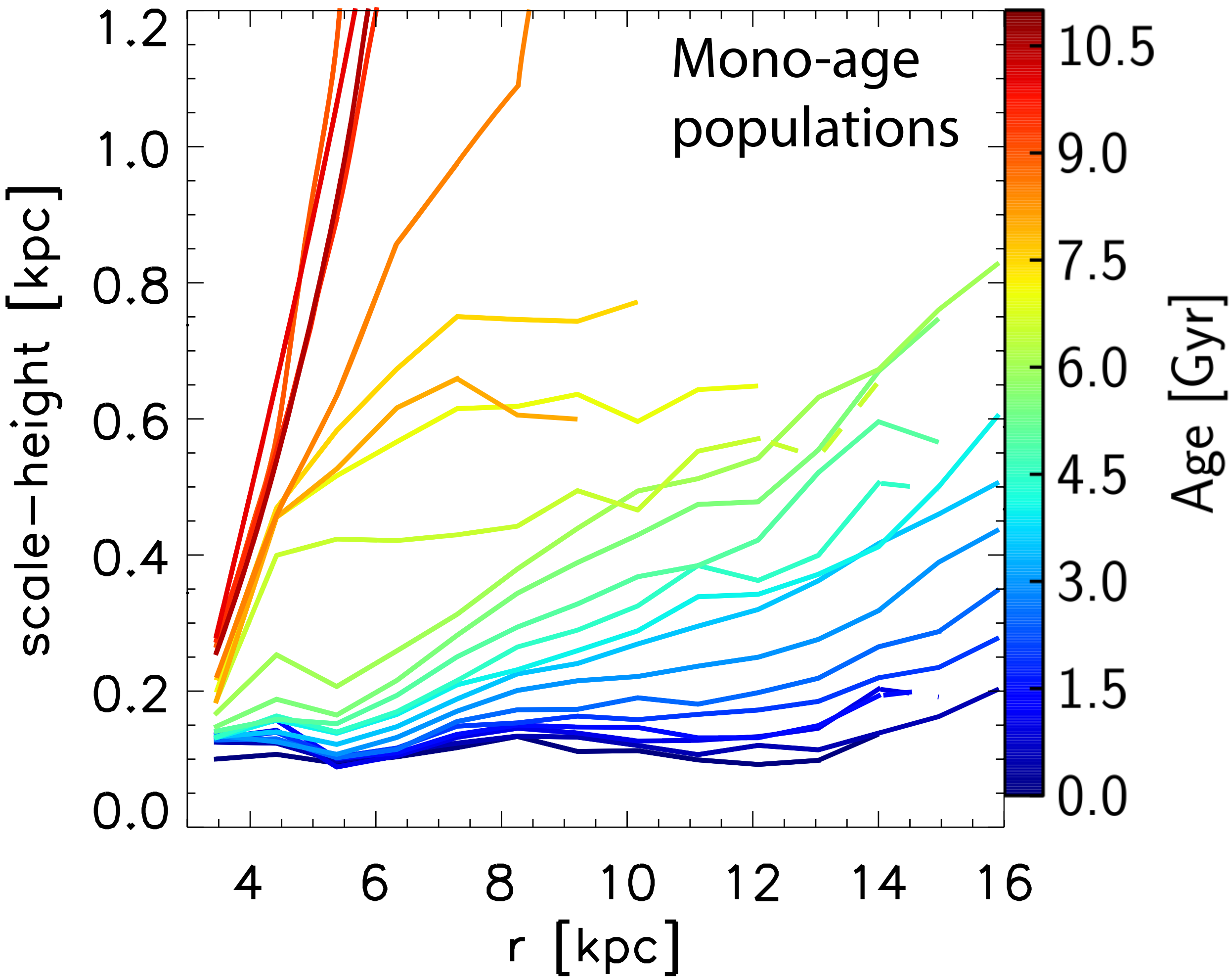
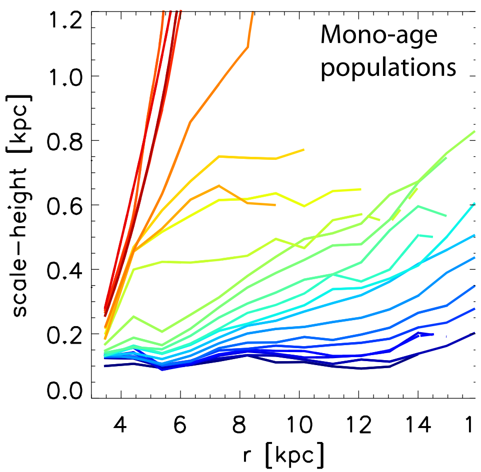
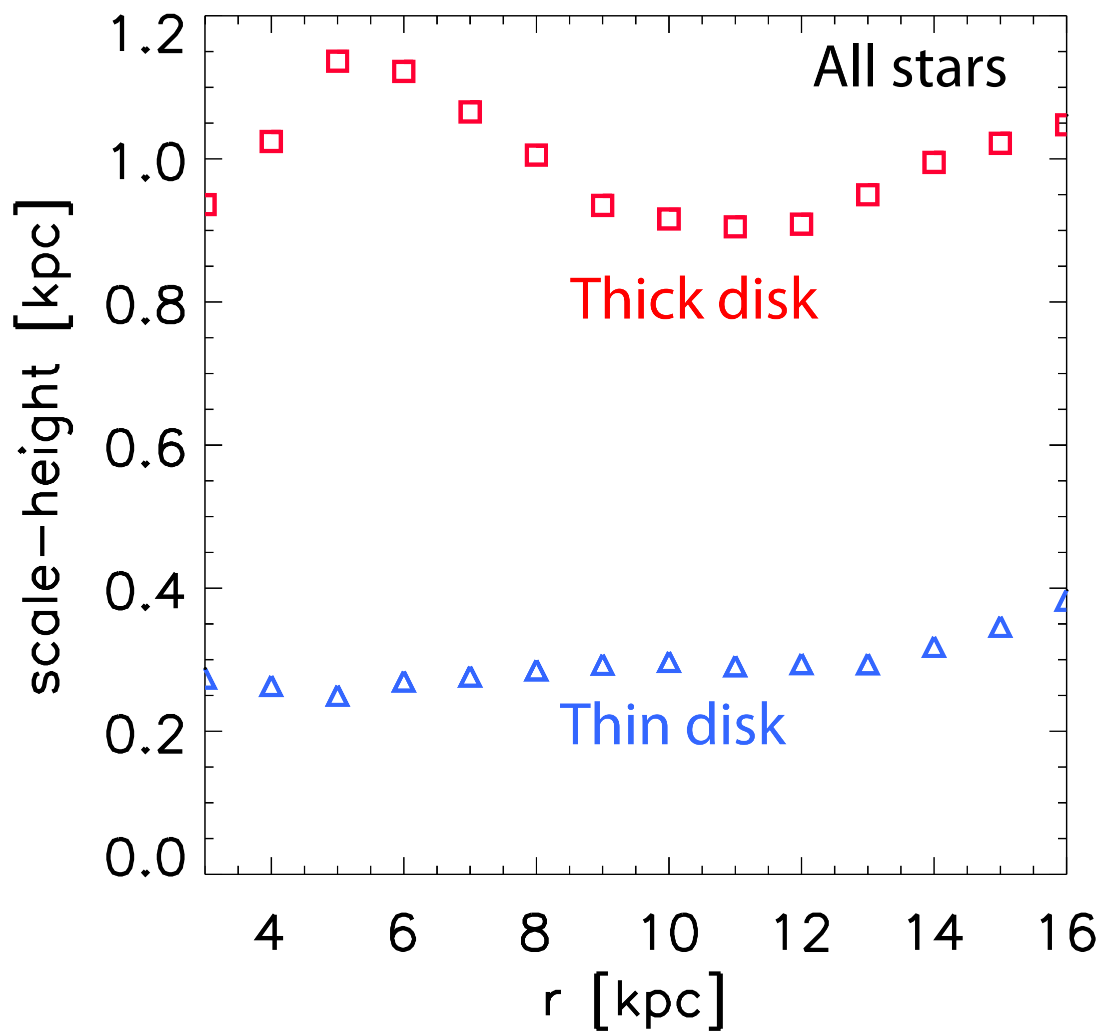


Mono-age populations are flared



But the global thick disk does not flare

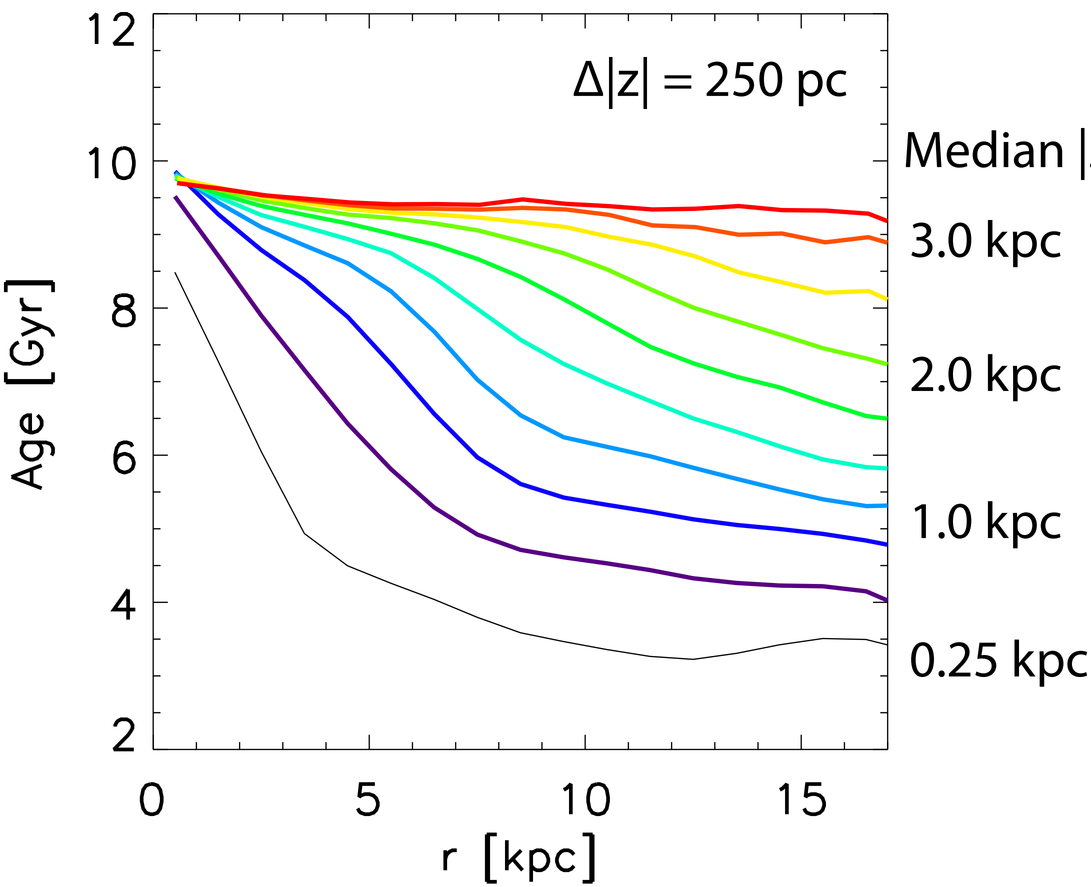




- a two-component decomposition is always possible
- Thick component extends to outer regions

Minchev, Martig et al 2015

The thick disk is made of all the "flared parts" of the mono-age populations



→thick disk is not a single component

→ there is a radial age gradient

Minchev, Martig et al 2015

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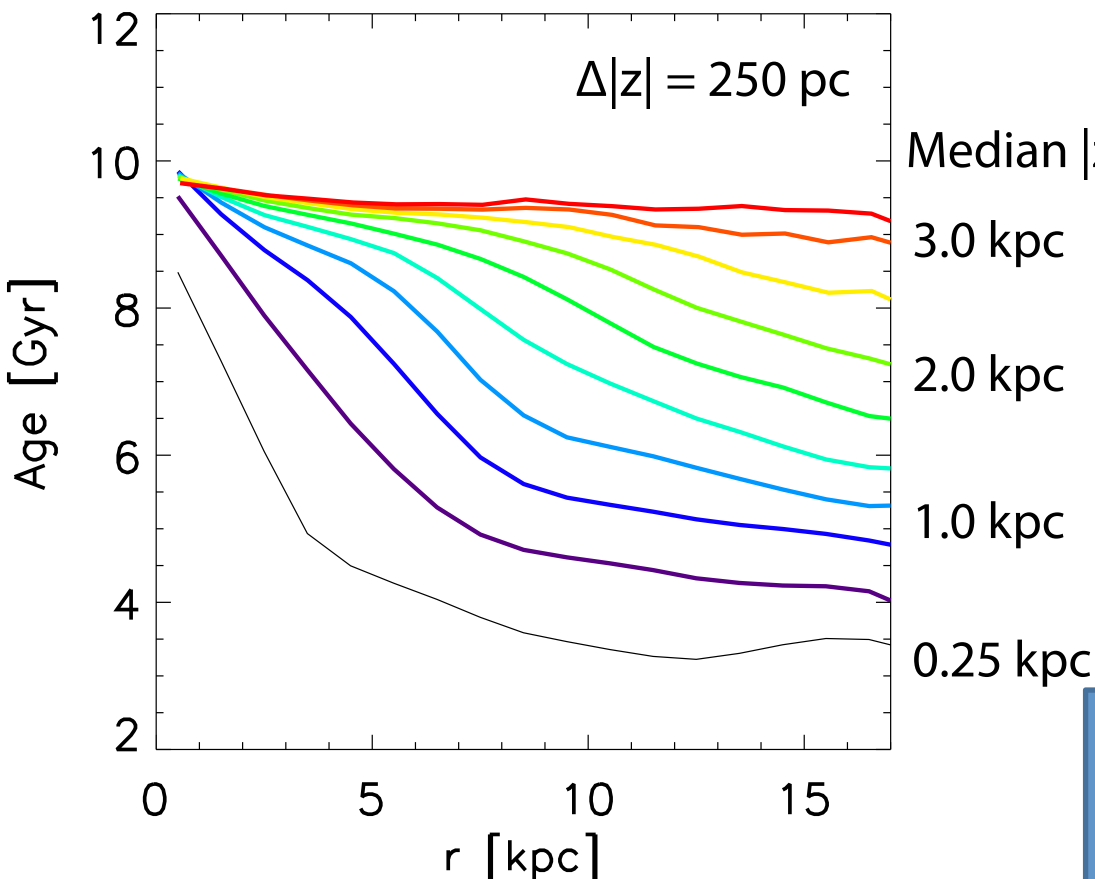

→thick disk is not a single component

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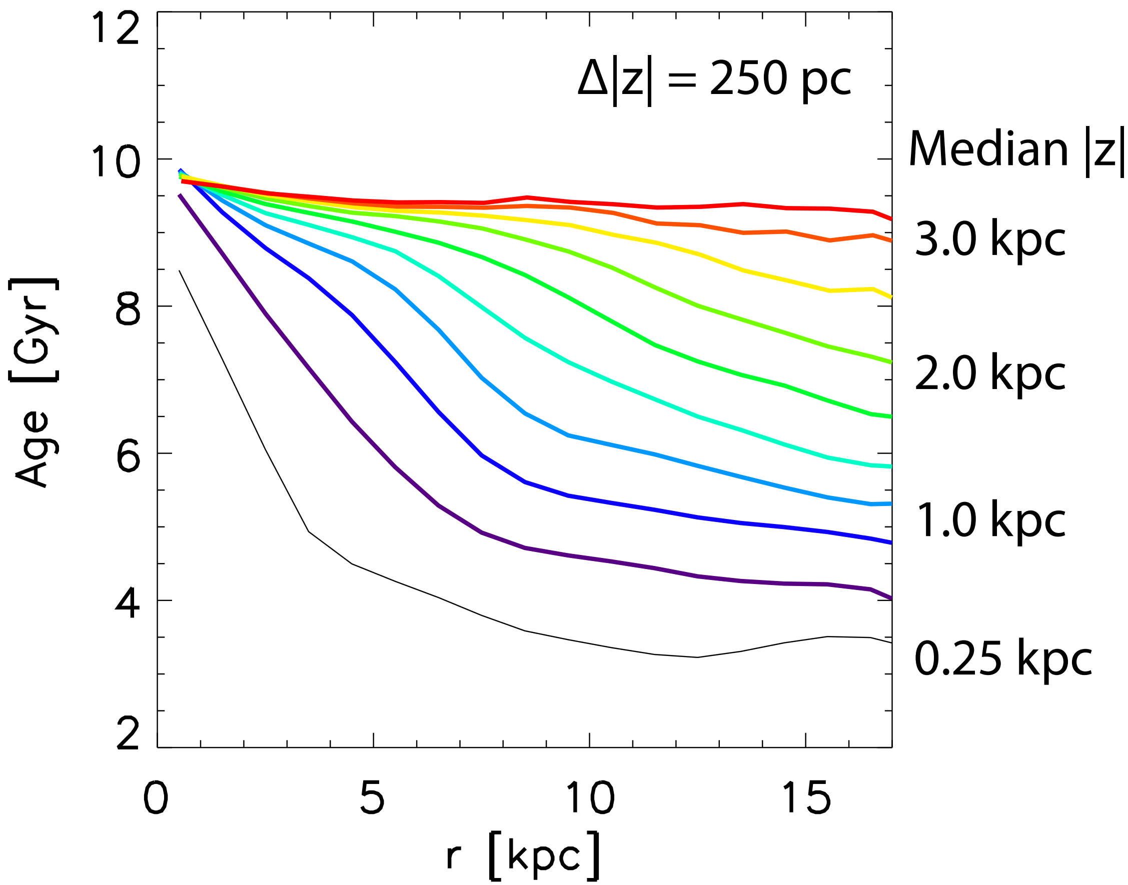
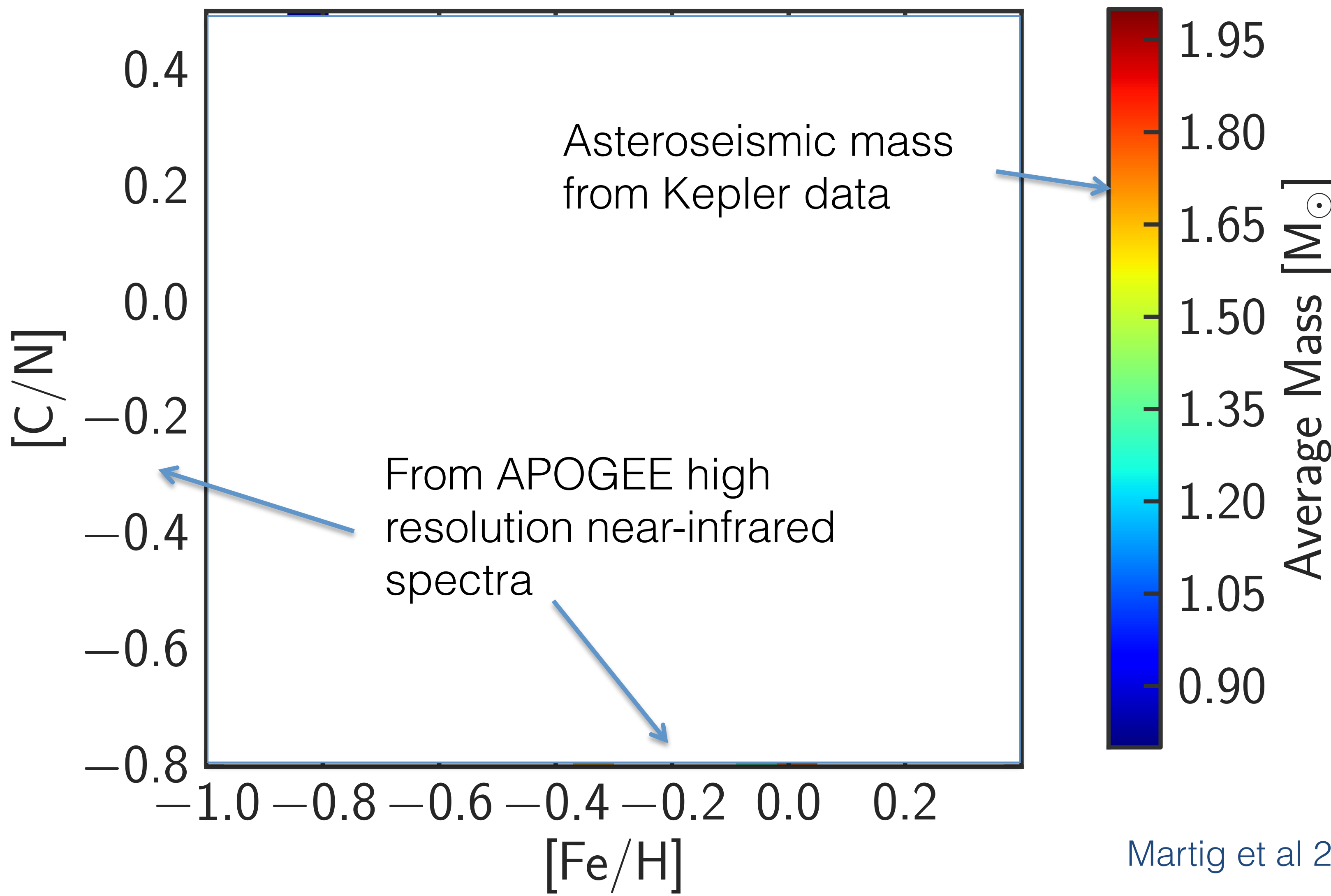
Minchev, Martig et al 2015

This would reconcile the MW with nearby galaxies

Could we directly test this in the Milky Way?



A new method to determine stellar masses



Martig et al 2016

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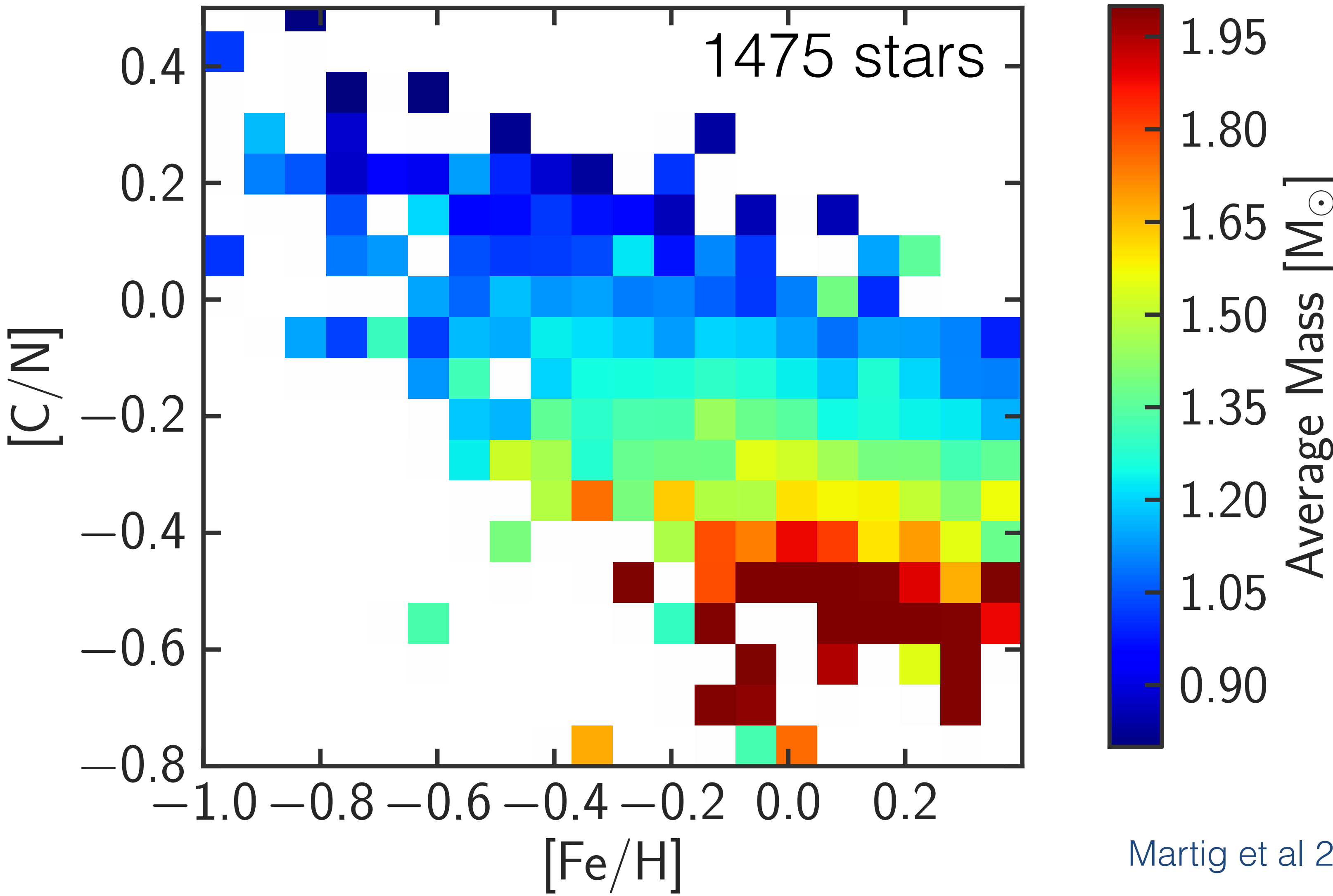
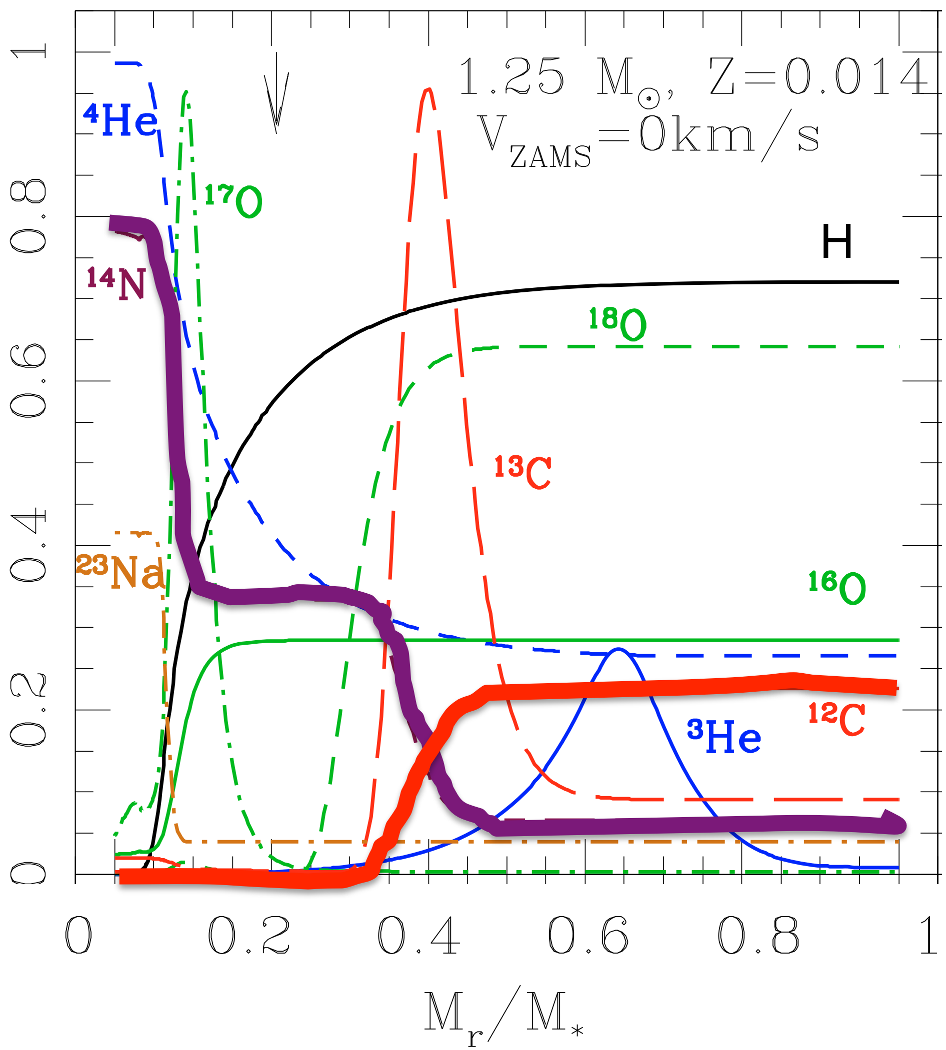


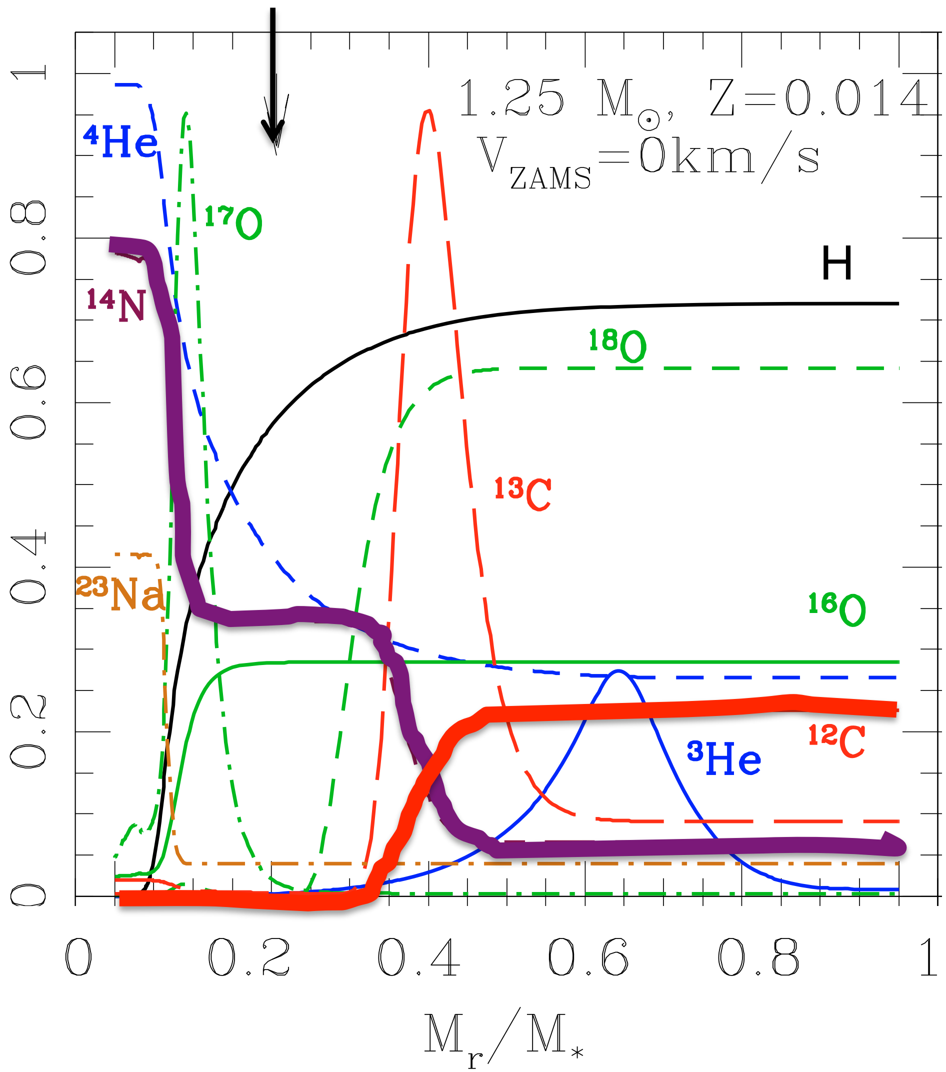
Martig et al 2016

Structure of star at MS turnoff



Structure of star at MS turnoff

depth reached by
convective envelope



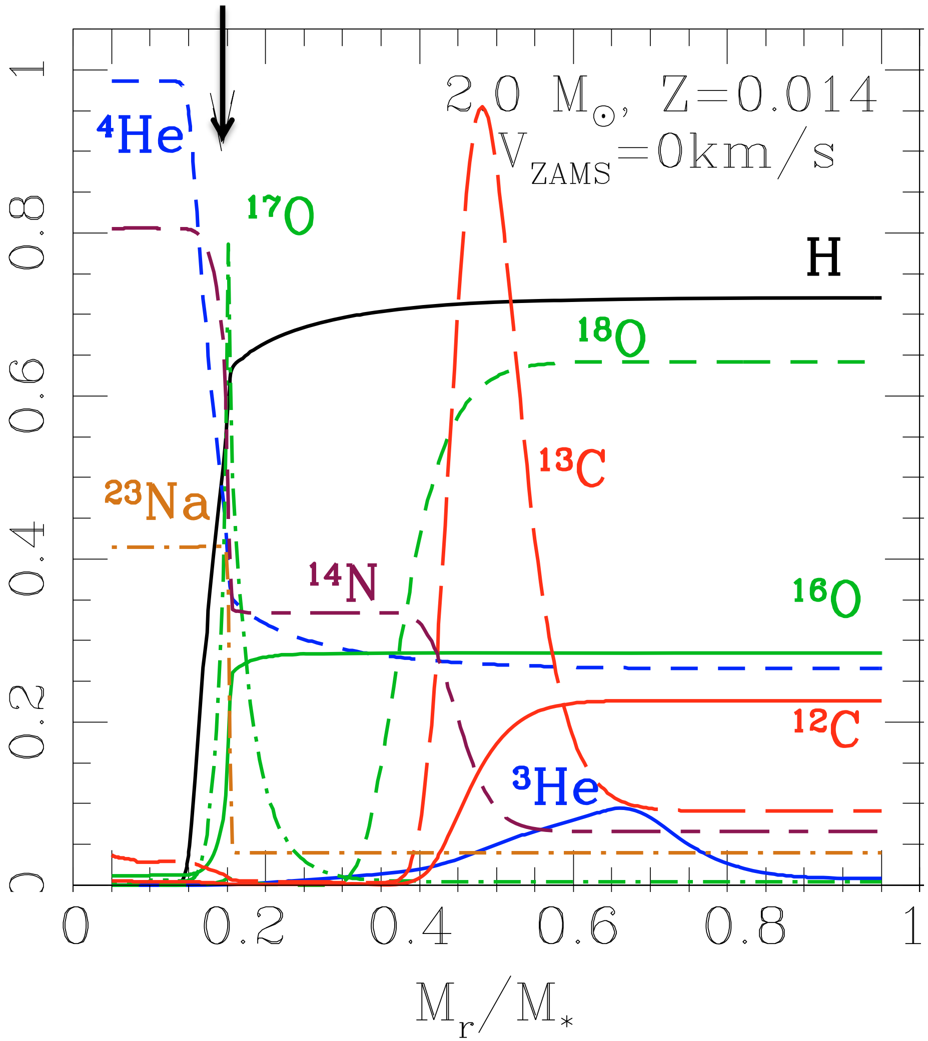
After the first dredge-up, the surface abundances change:

- Nitrogen increases
- Carbon decreases

→ [C/N] decreases

Surface [C/N] after the first dredge-up depends on stellar mass

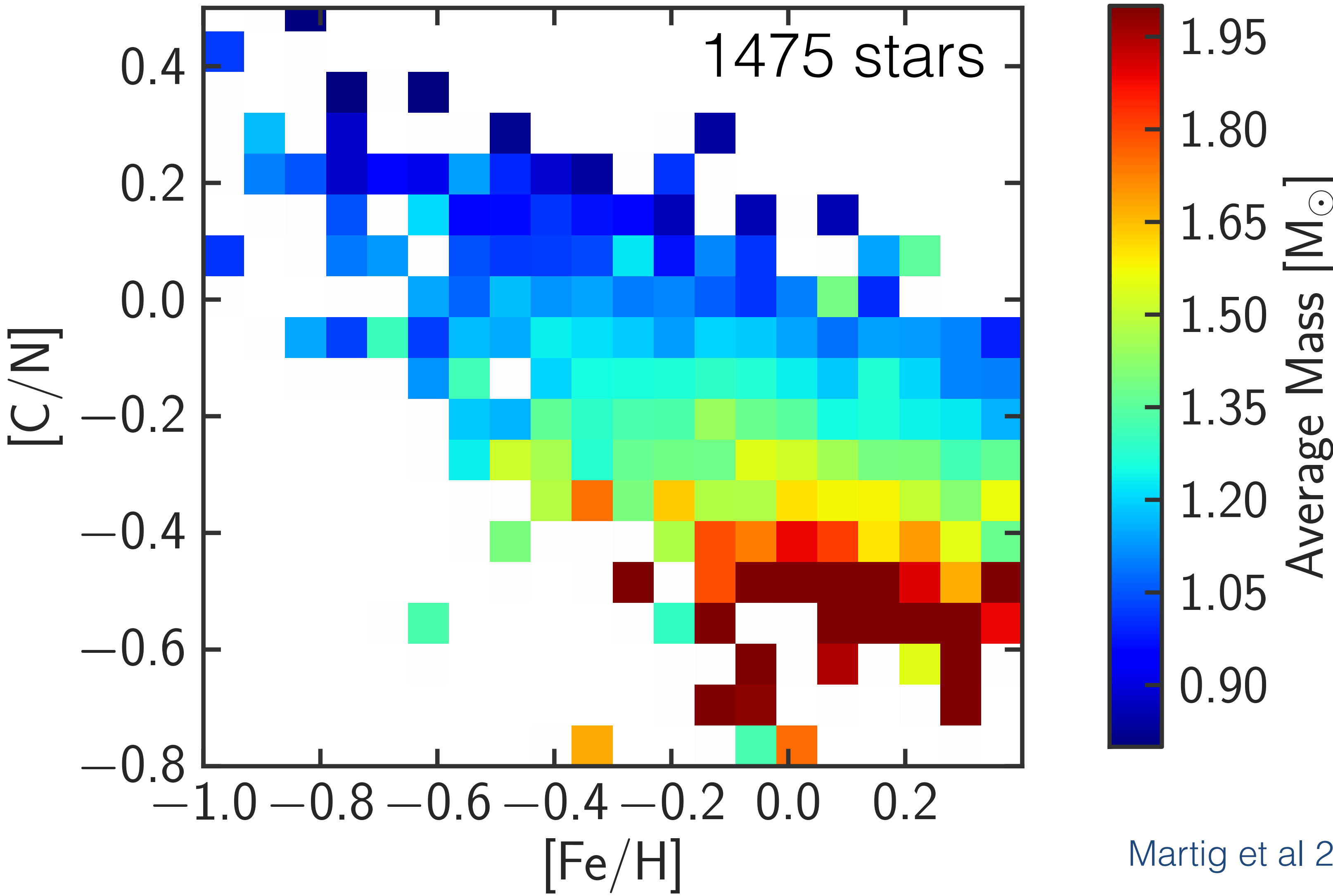
depth reached by convective envelope



Higher mass star:

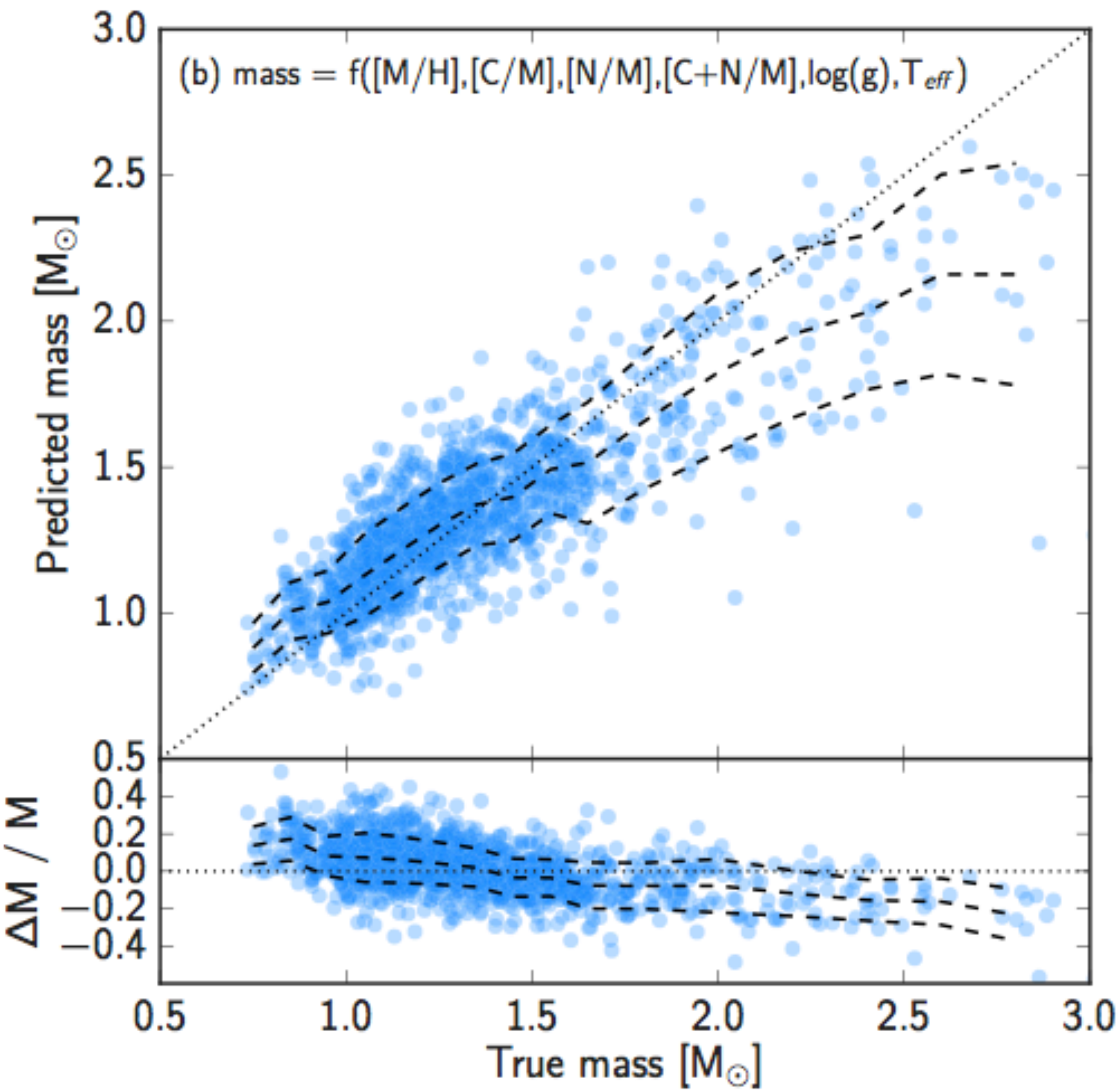
- larger zone where ^{12}C burned into ^{14}N
- convective envelope goes deeper during dredge-up

[C/N] and stellar mass are correlated



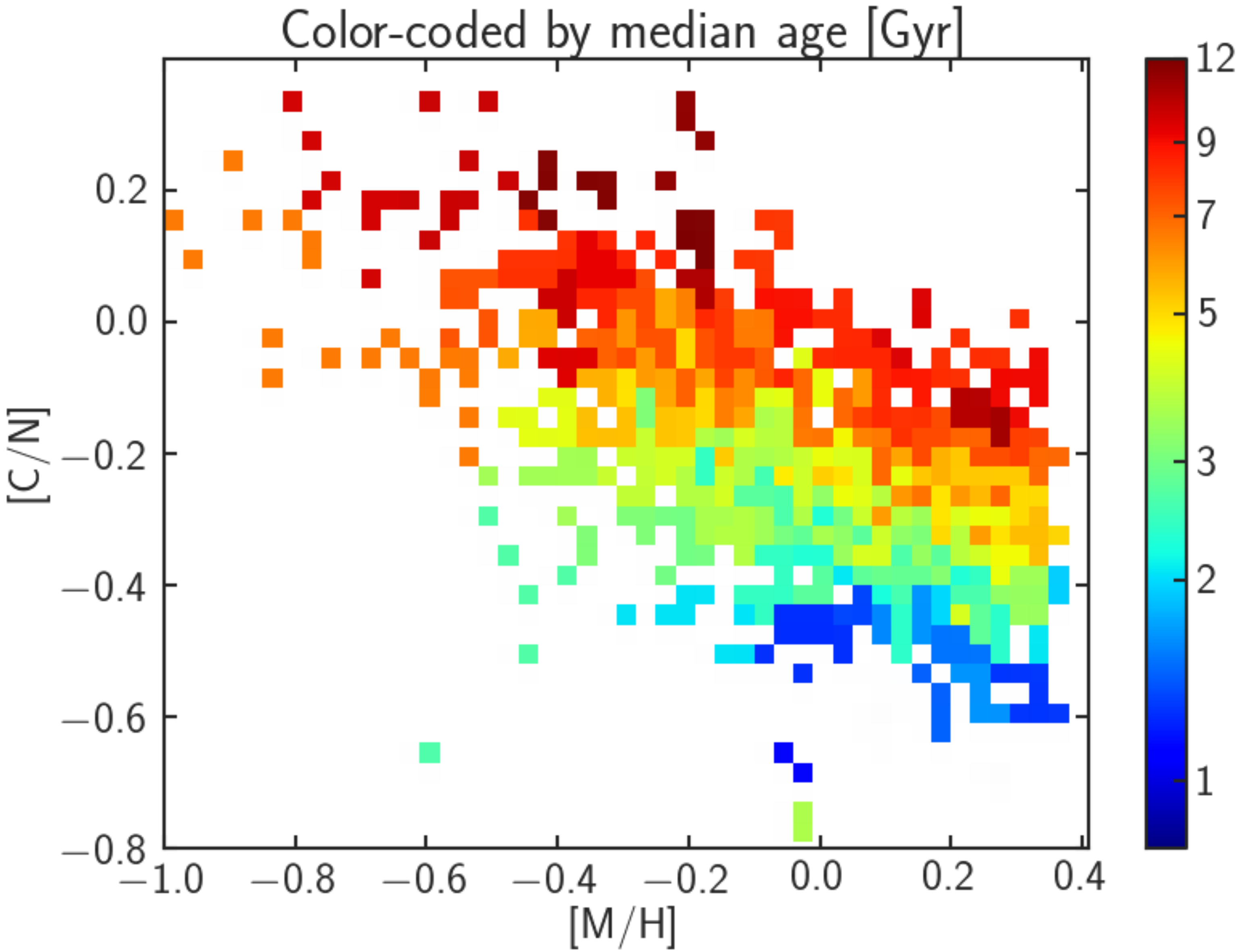
Martig et al 2016

A model for mass as a function of spectroscopic labels

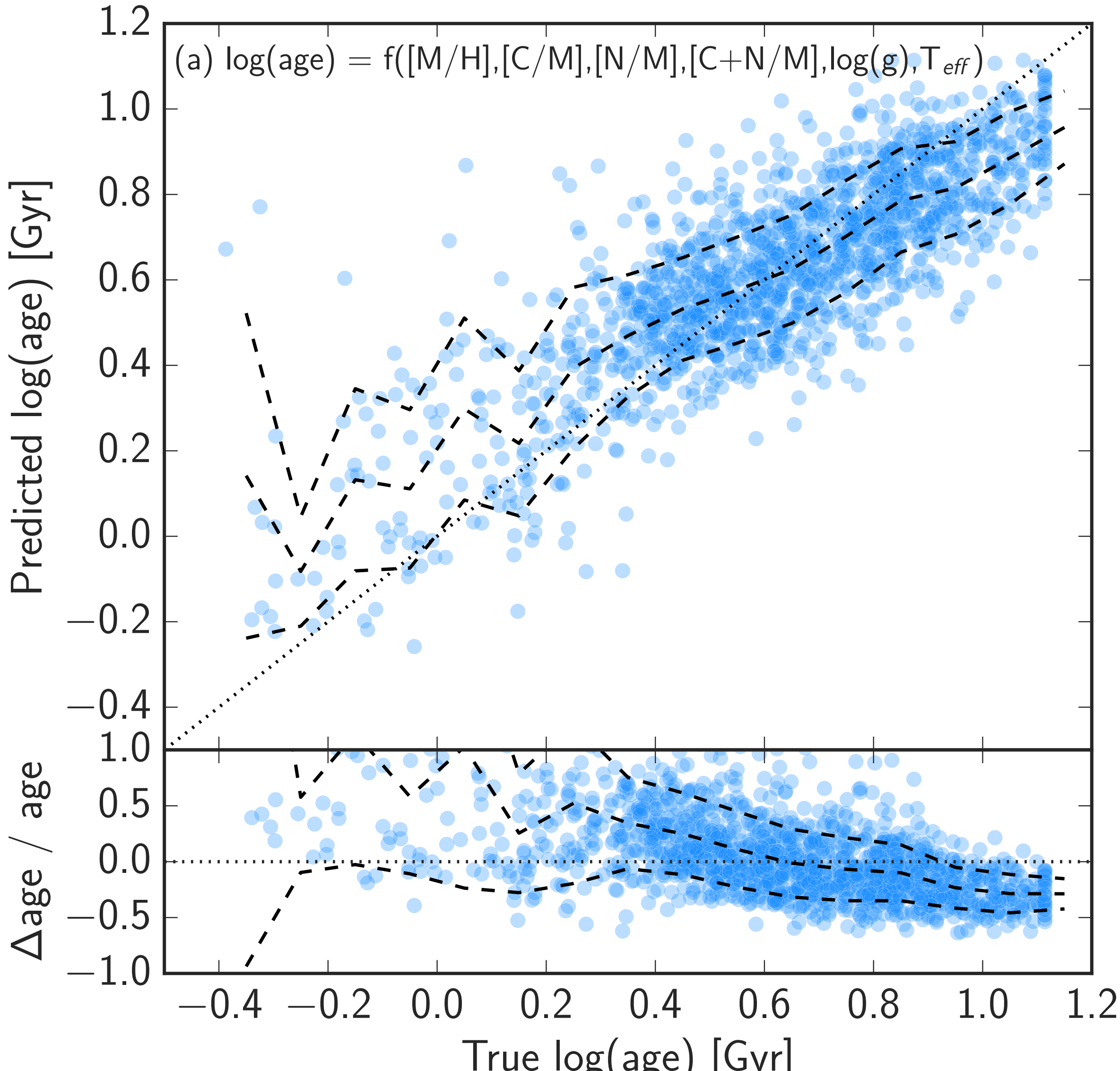


Training set: 1475 giants in APOKASC (APOGEE+Kepler)

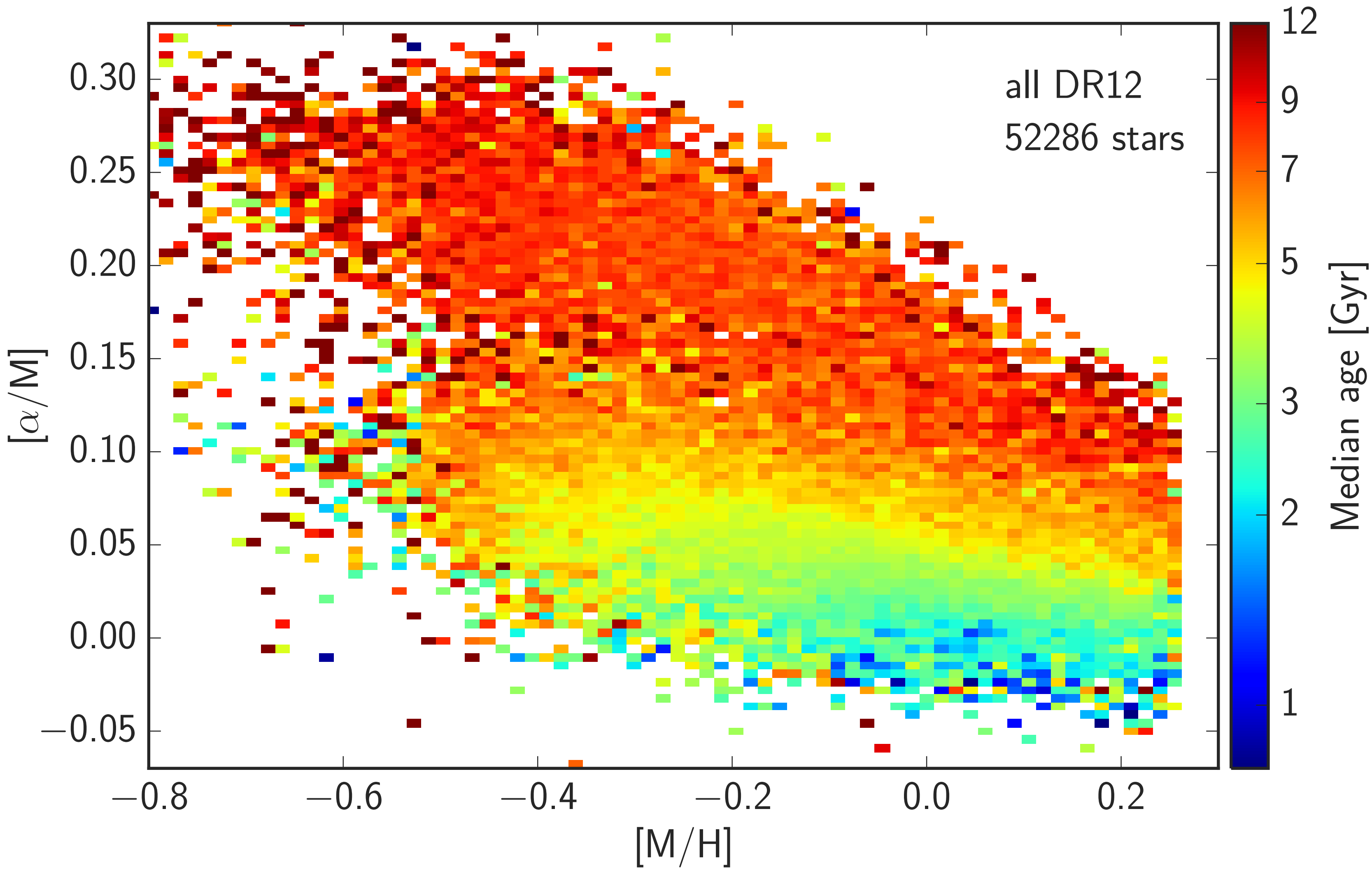
Mass and age are correlated



We also build a model for age

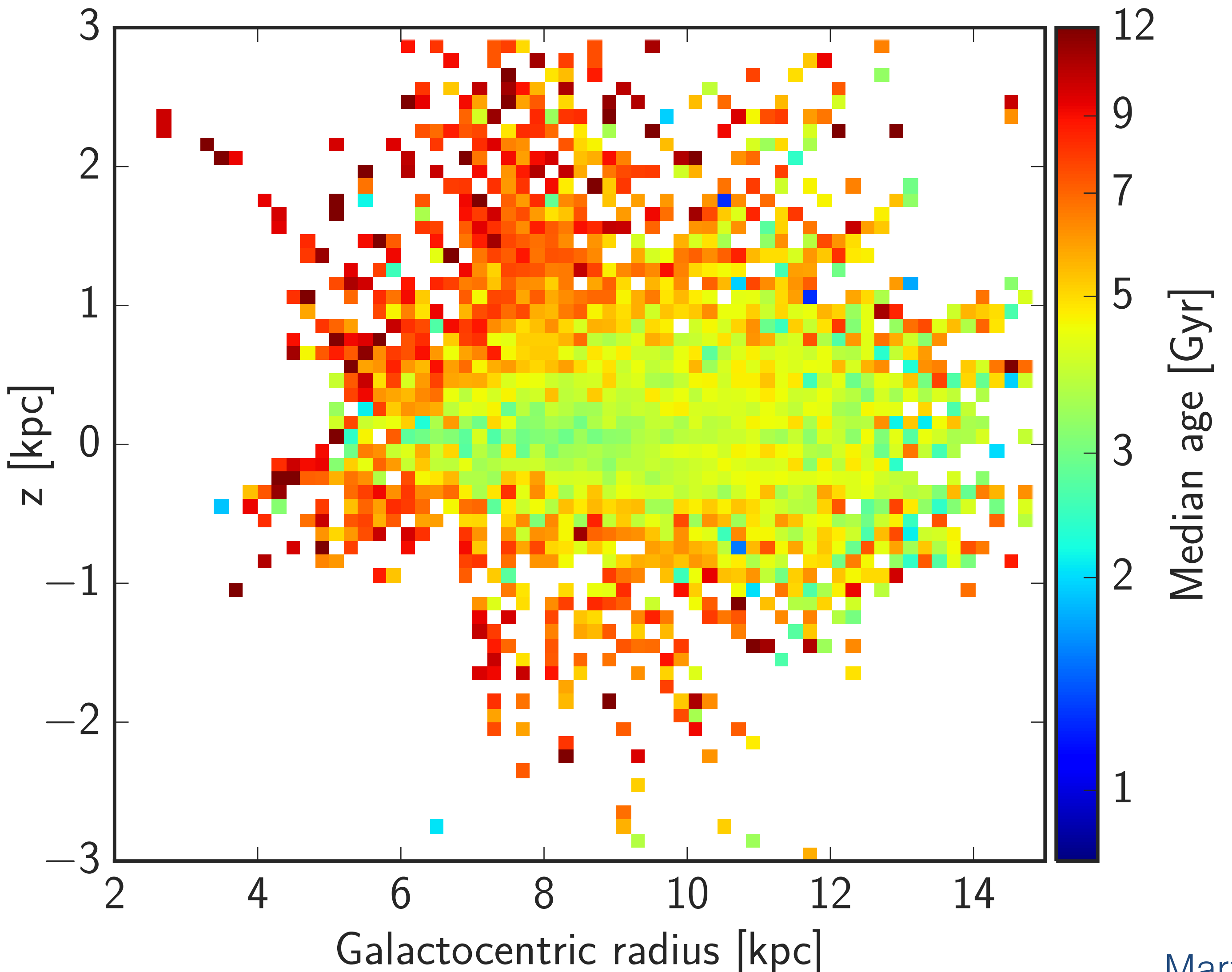


Mass/age labels transferred to APOGEE DR12 stars



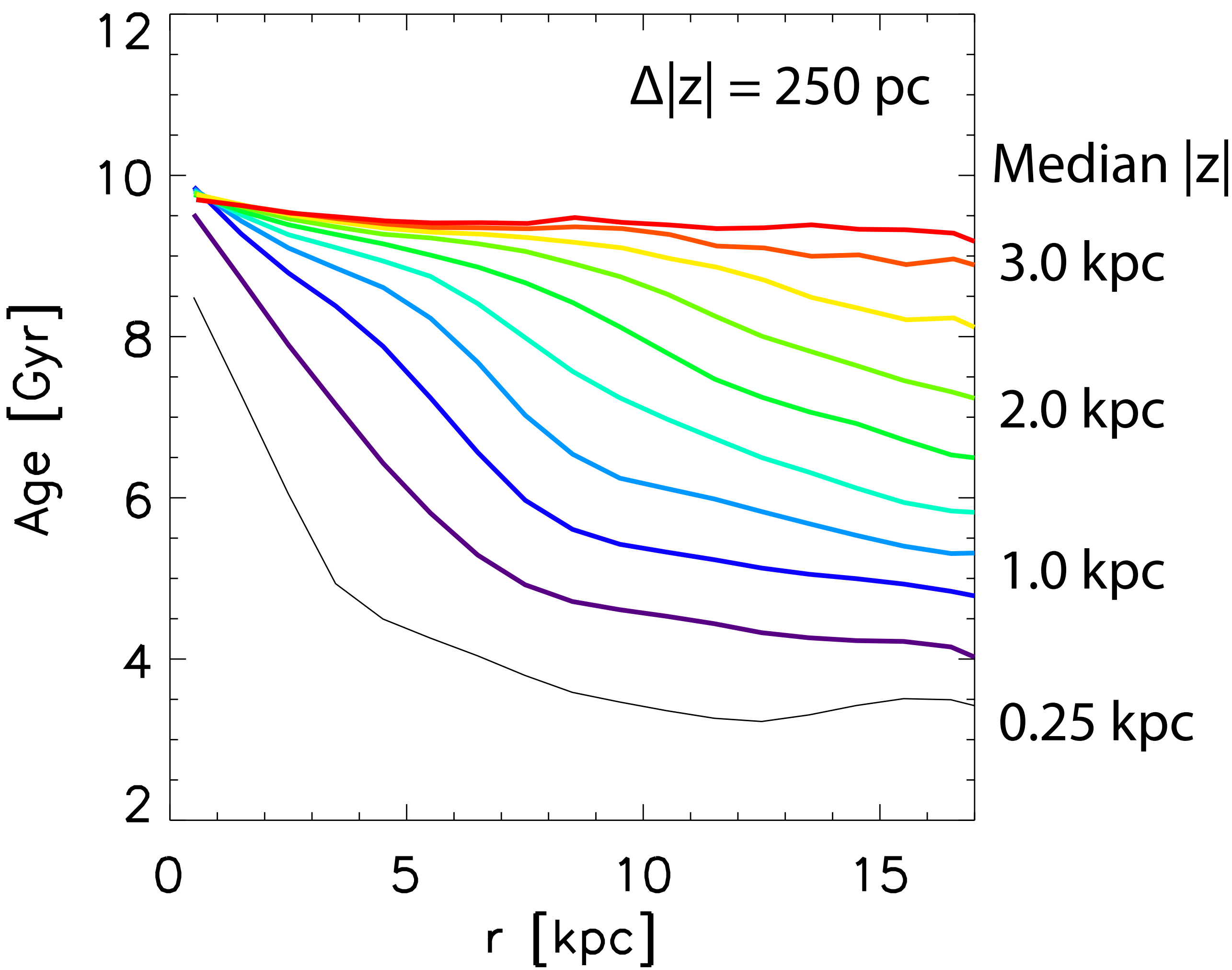
Martig et al 2016

Ages for red clump stars



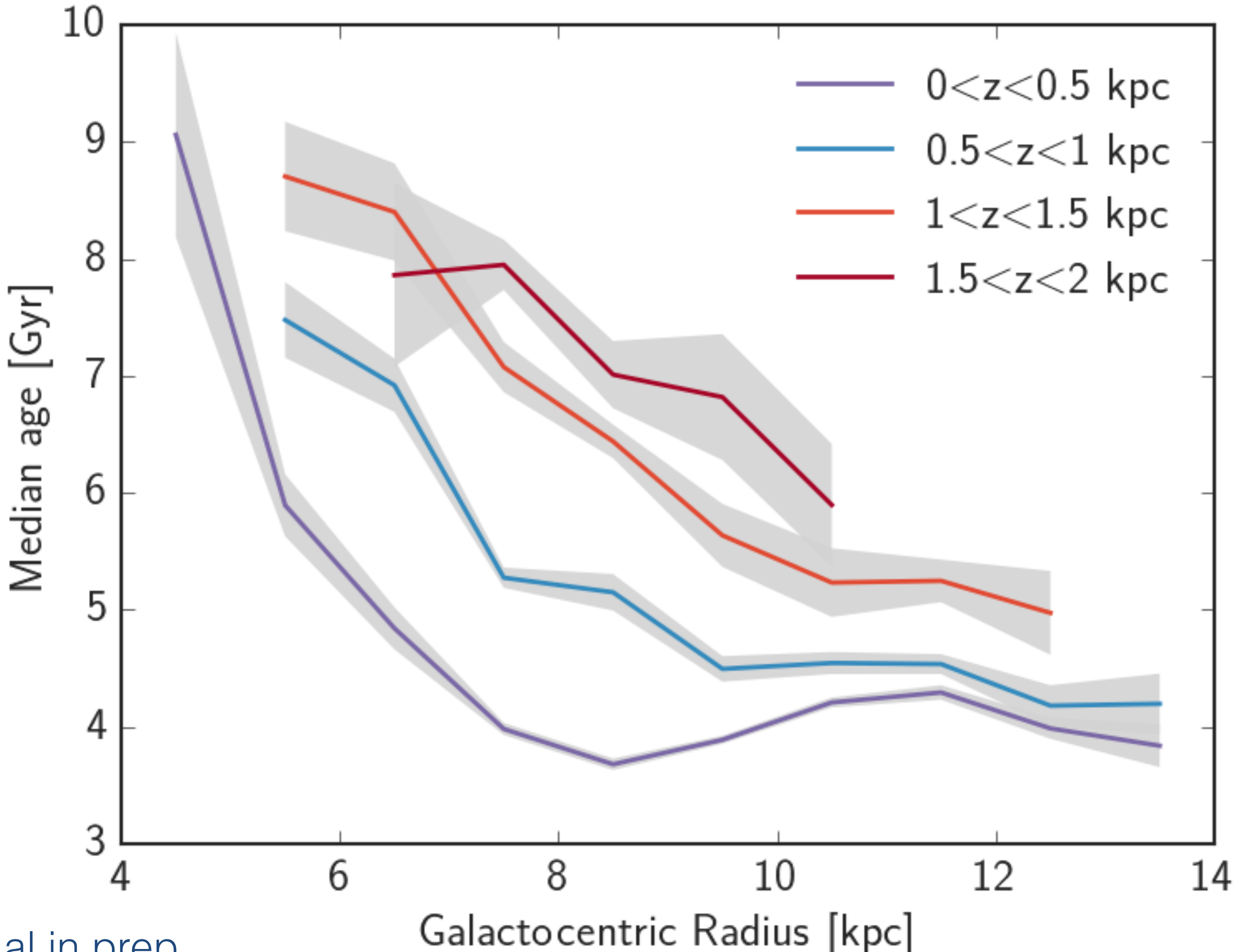
Martig et al 2016

Simulations predicted radial age gradients



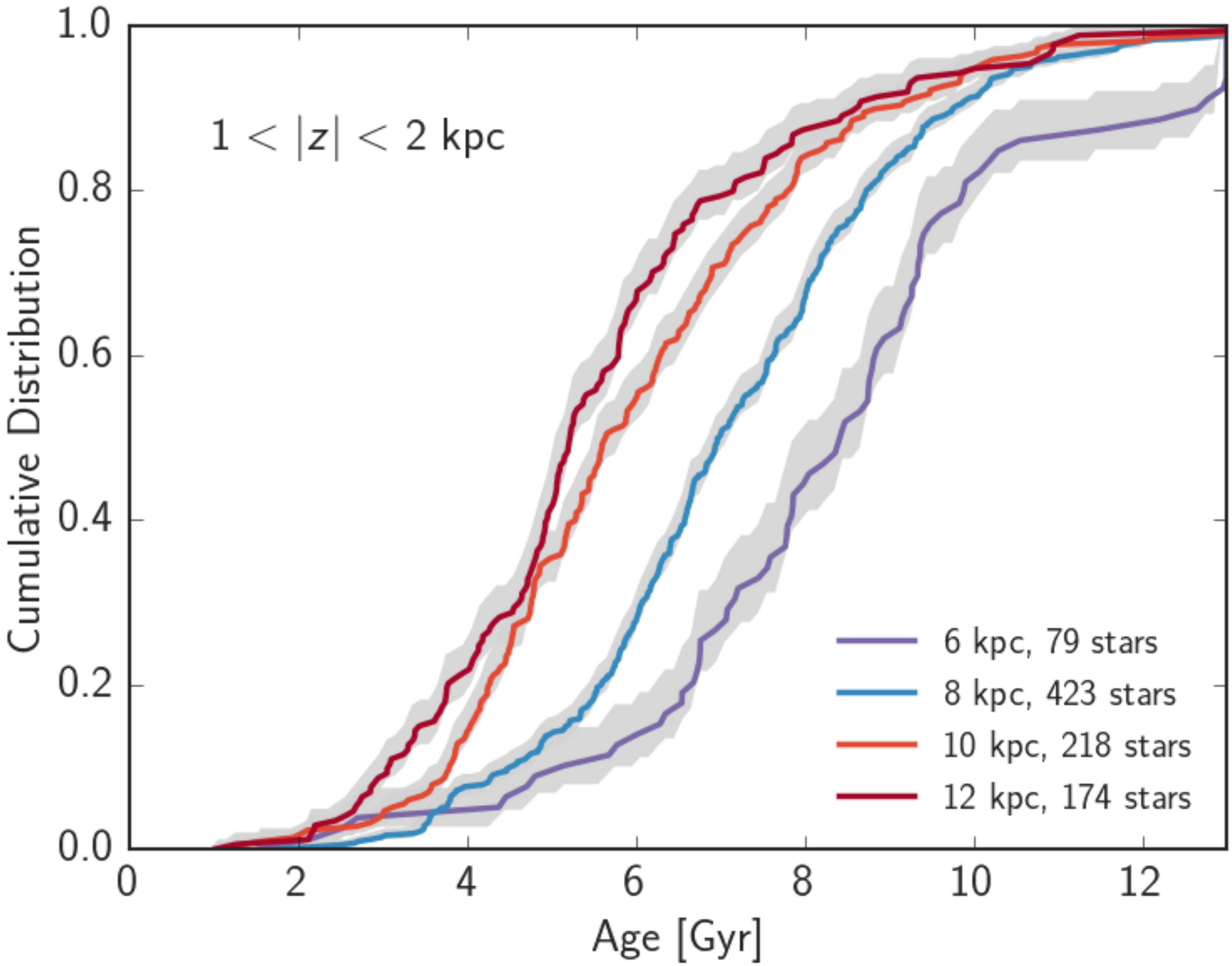
Minchev, Martig et al 2015

Radial age gradients for APOGEE RC stars



Martig et al in prep

Radial age gradients for APOGEE red clump stars



Summary

- Thick disks: short scale-length in MW / extended in external galaxies
- "Morphologically-defined" thick disk are NOT a distinct, uniformly old components
- Age gradient present in APOGEE data