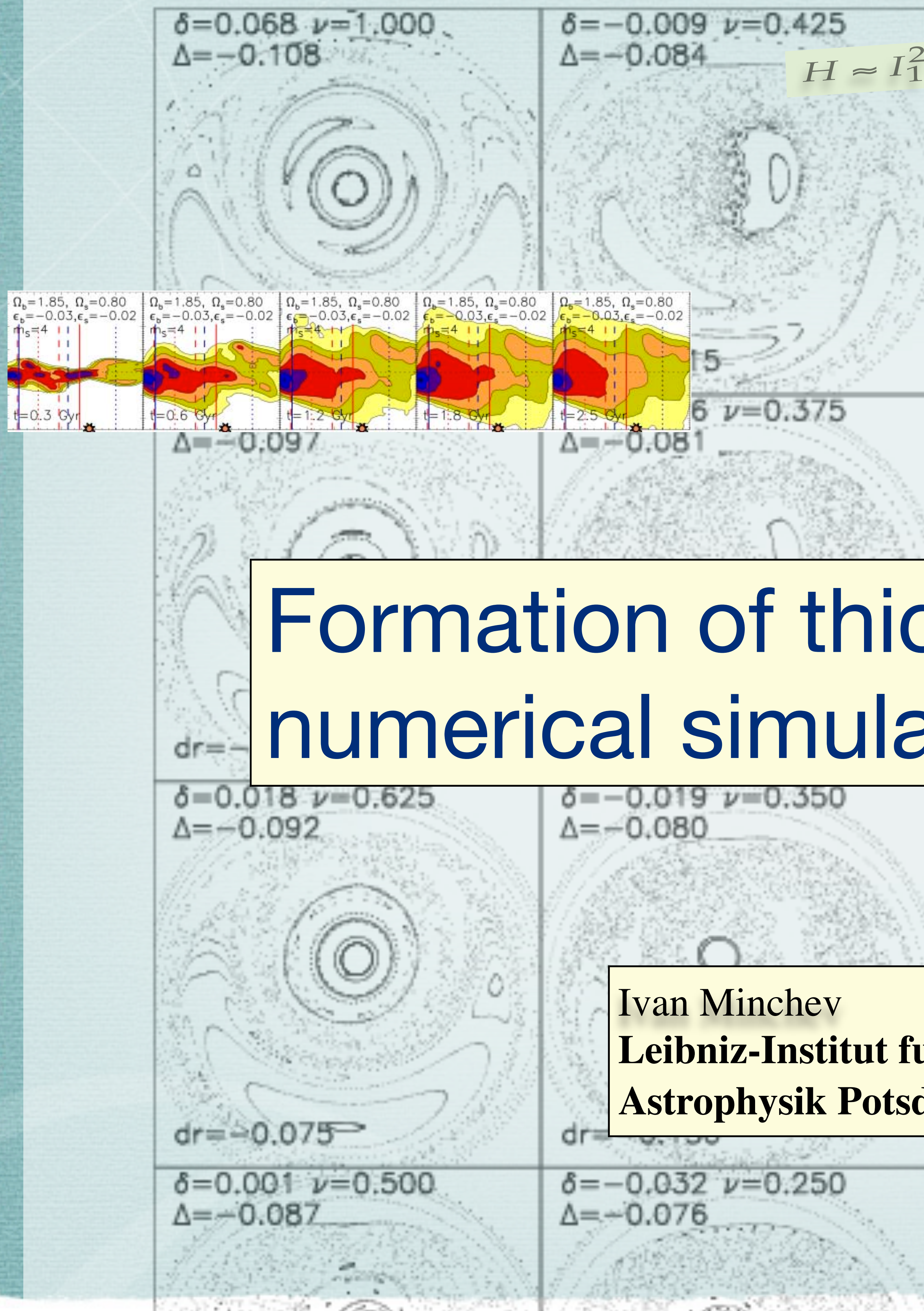

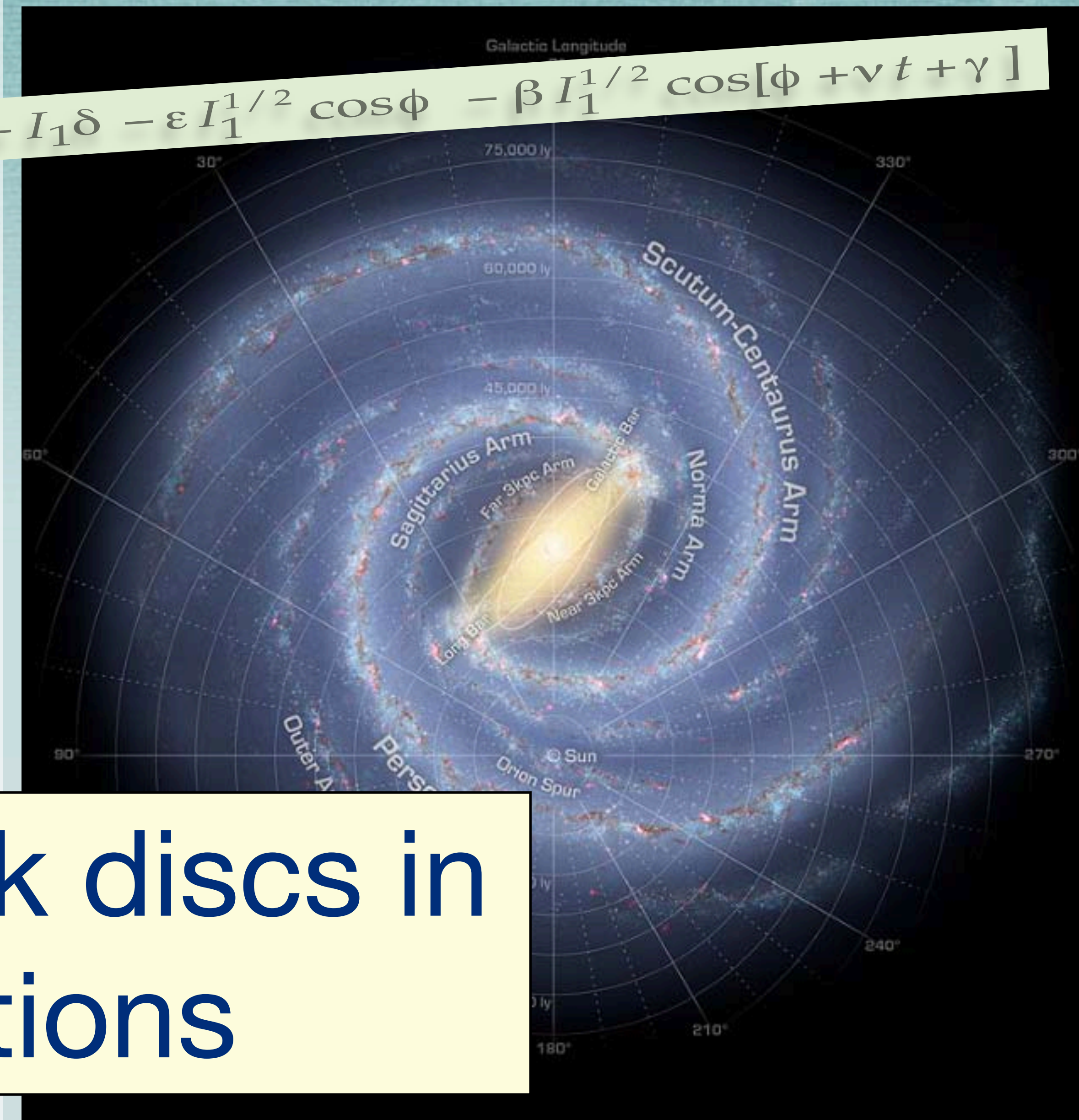

$$H \approx I_1^2 + I_1\delta - \varepsilon I_1^{1/2}\cos\phi \; - \beta I_1^{1/2}\cos[\phi + \nu t + \gamma]$$

Formation of thick discs in numerical simulations

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Thick disk formation

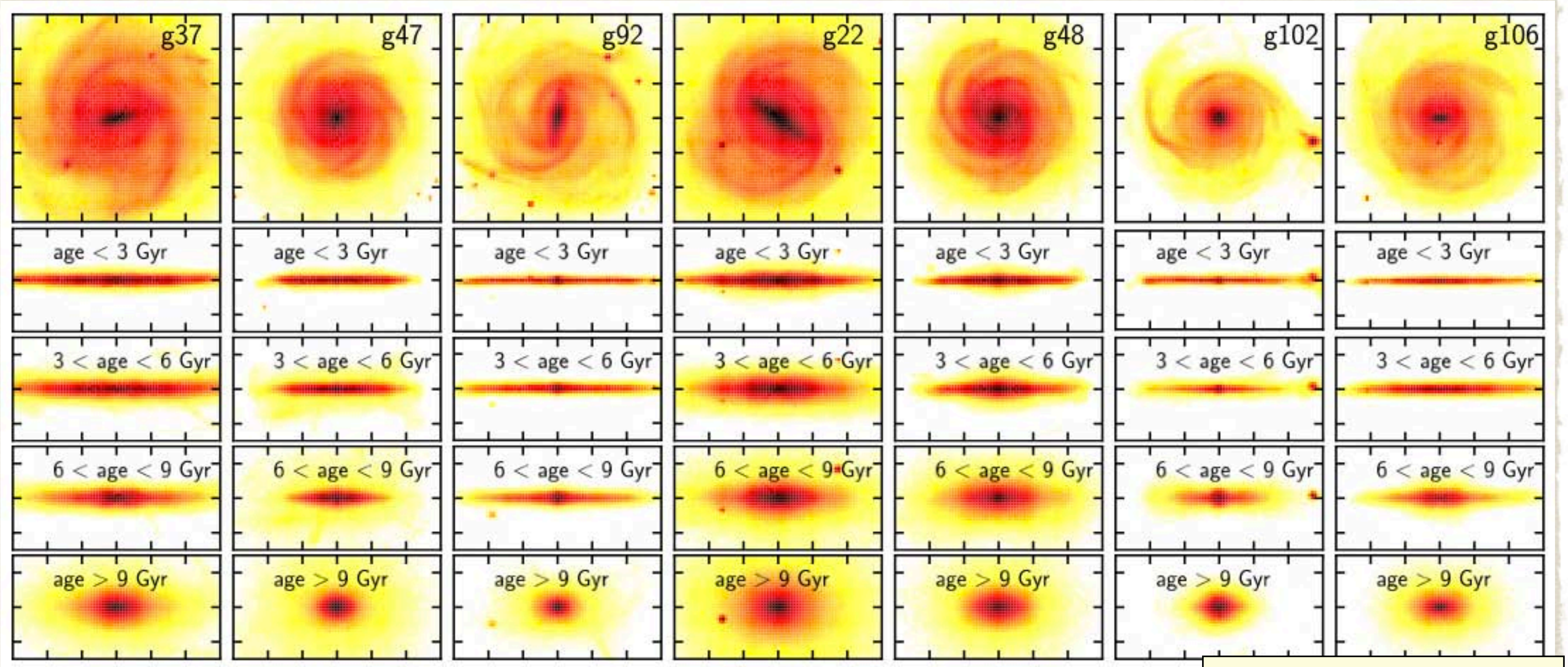
External mechanisms:

- Minor mergers heating a pre-existing thin disk (Quinn et al. 1993, Villalobos and Helmi 2008, Di Matteo 2011)
- Accretion of galaxy satellites (Abadi et al. 2003)
- Gas-rich mergers (Brook at al. 2005, 2012)
- Star born hot at high redshift (Forbes et al. 2012)

Internal mechanisms:

- Gas-rich, clumpy turbulent disks (Bournaud et al. 2009)
- Radial Migration (Schoenrich and Binney 2009, Loebman et al. 2010)

Cosmological re-simulations

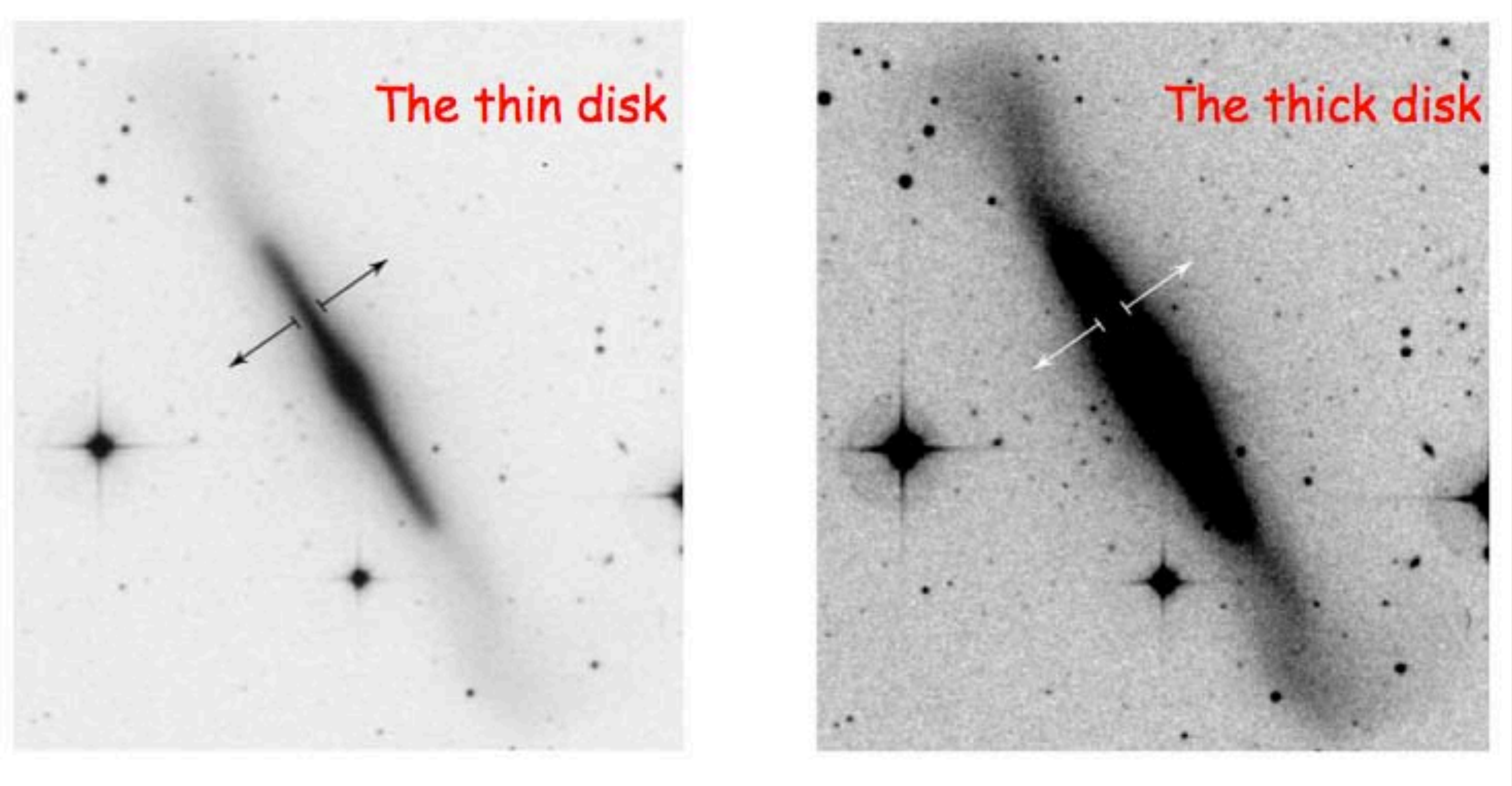


Martig, Minchev and Flynn, Submitted

Stars born hot at high redshift. In agreement with Brook et al. (2012), Stinson et al. (2013), Bird et al. (2013), ...

Thick disks are extended

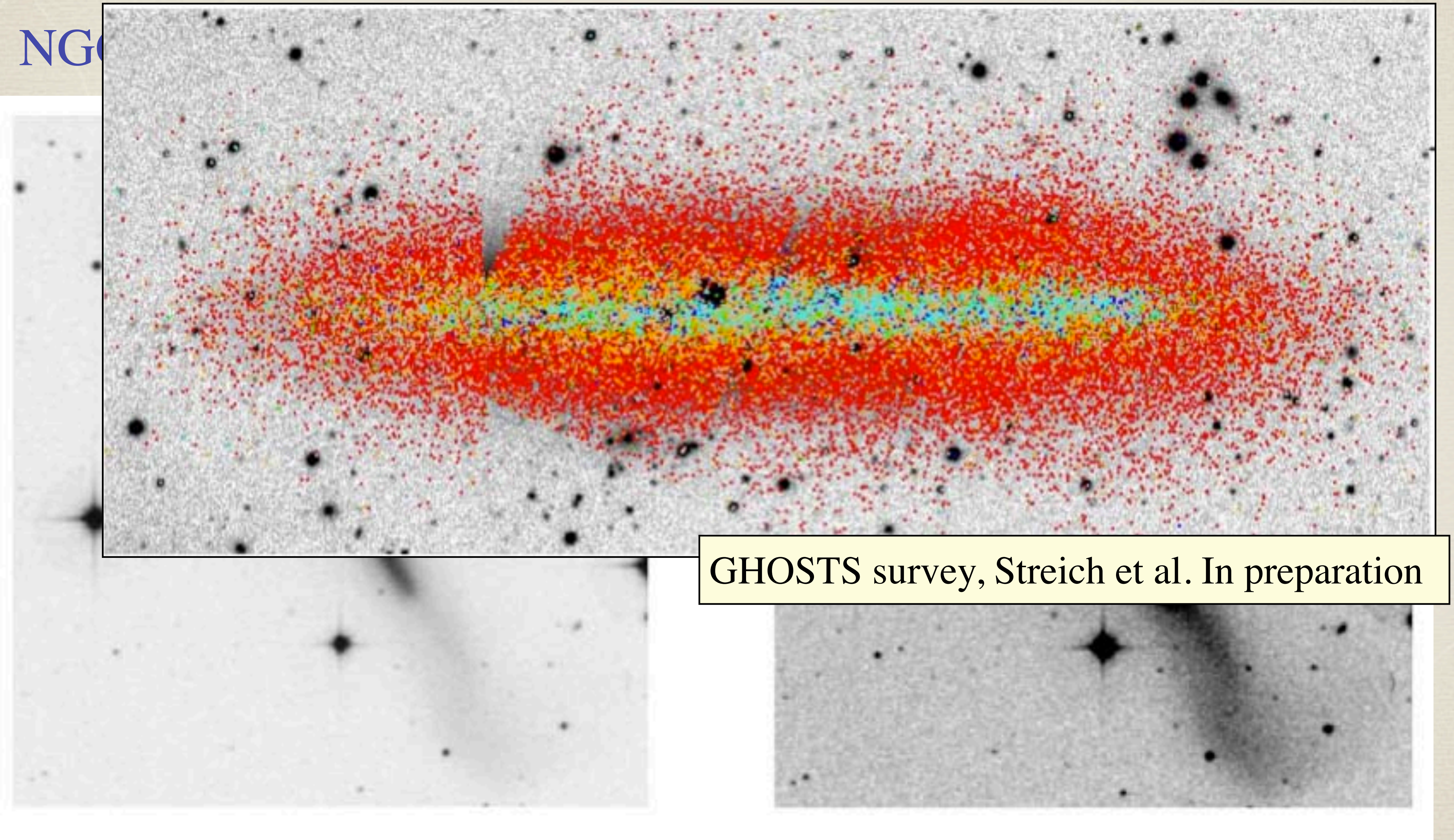
NGC 4762 - a disk galaxy with a bright thick disk (Tsikoudi 1980)



- Thick disks are ubiquitous in all size systems.

Thick disks are extended

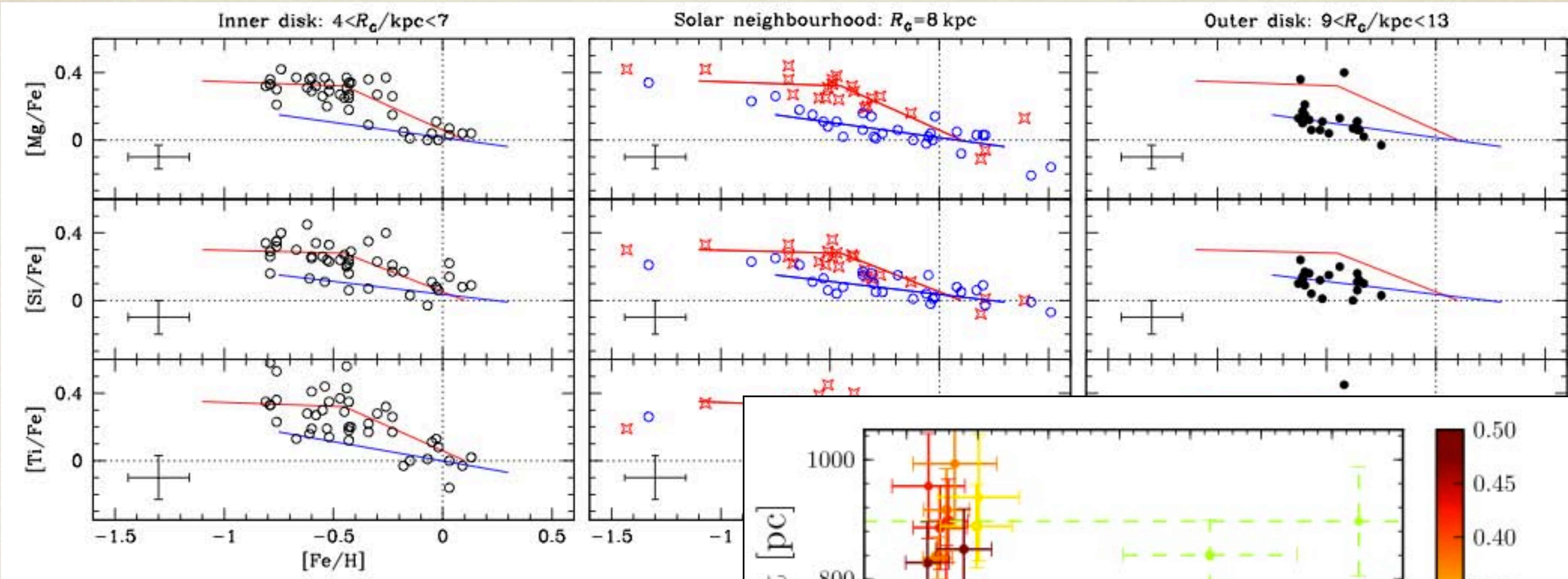
NG



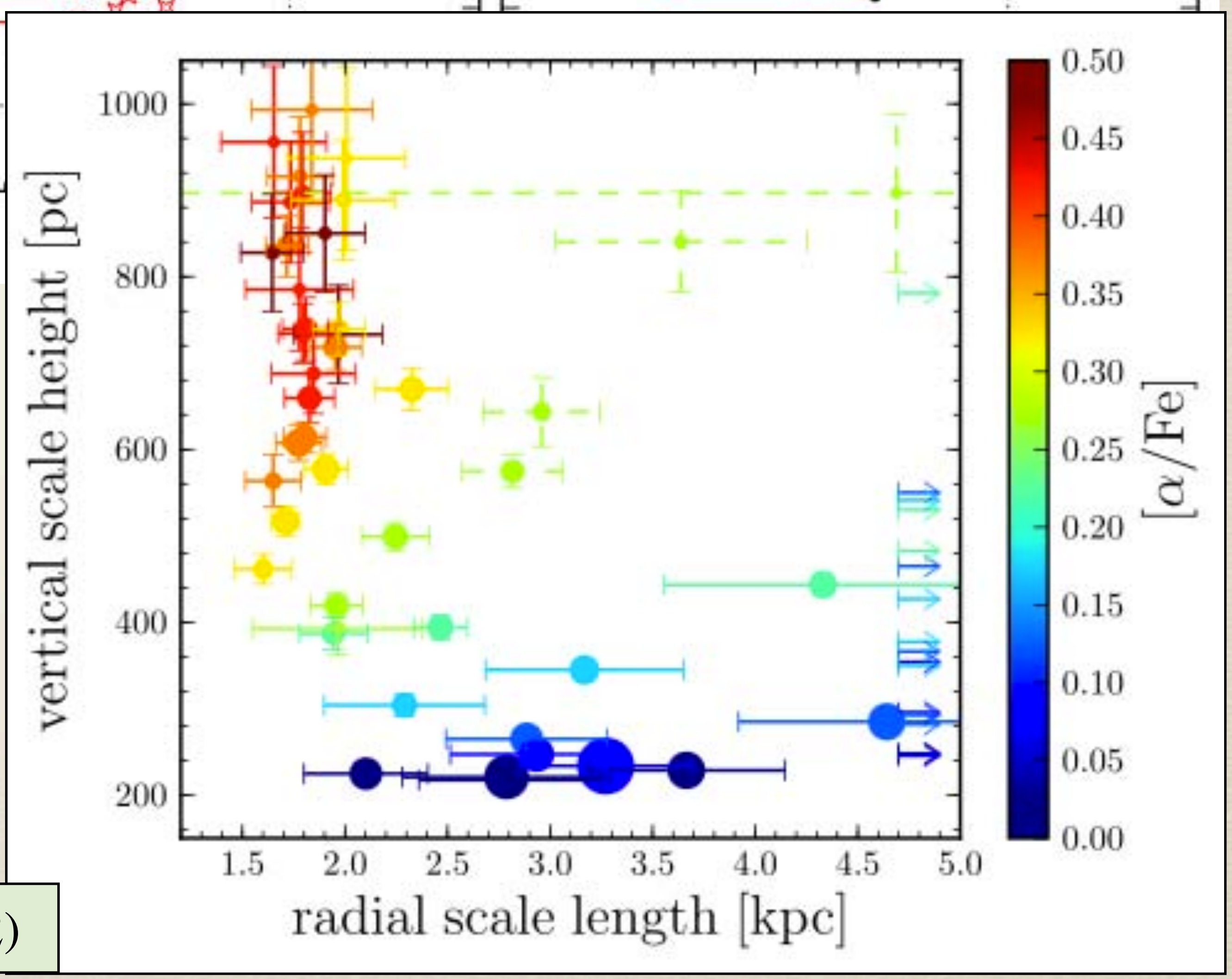
GHOSTS survey, Streich et al. In preparation

- Thick disks are ubiquitous in all size systems.

The Milky Way thick disk is concentrated



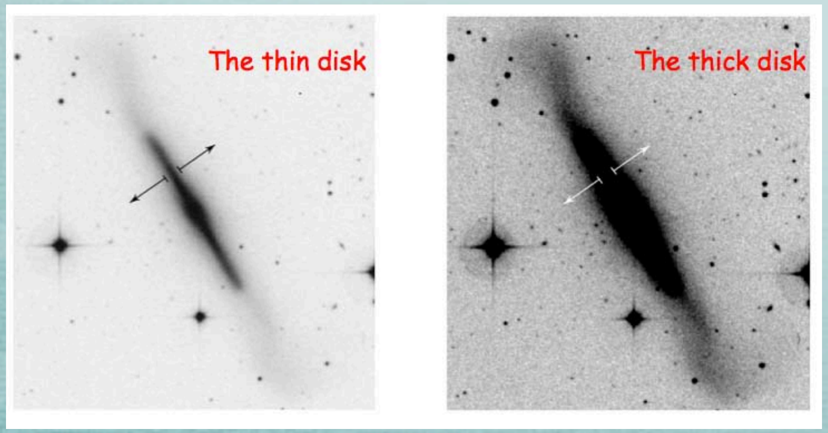
Bensby et al. (2011)

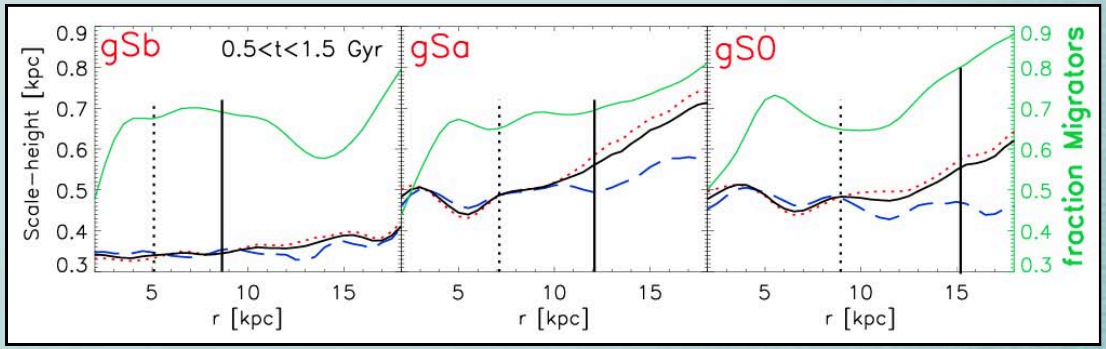


Bovy et al. (2012)

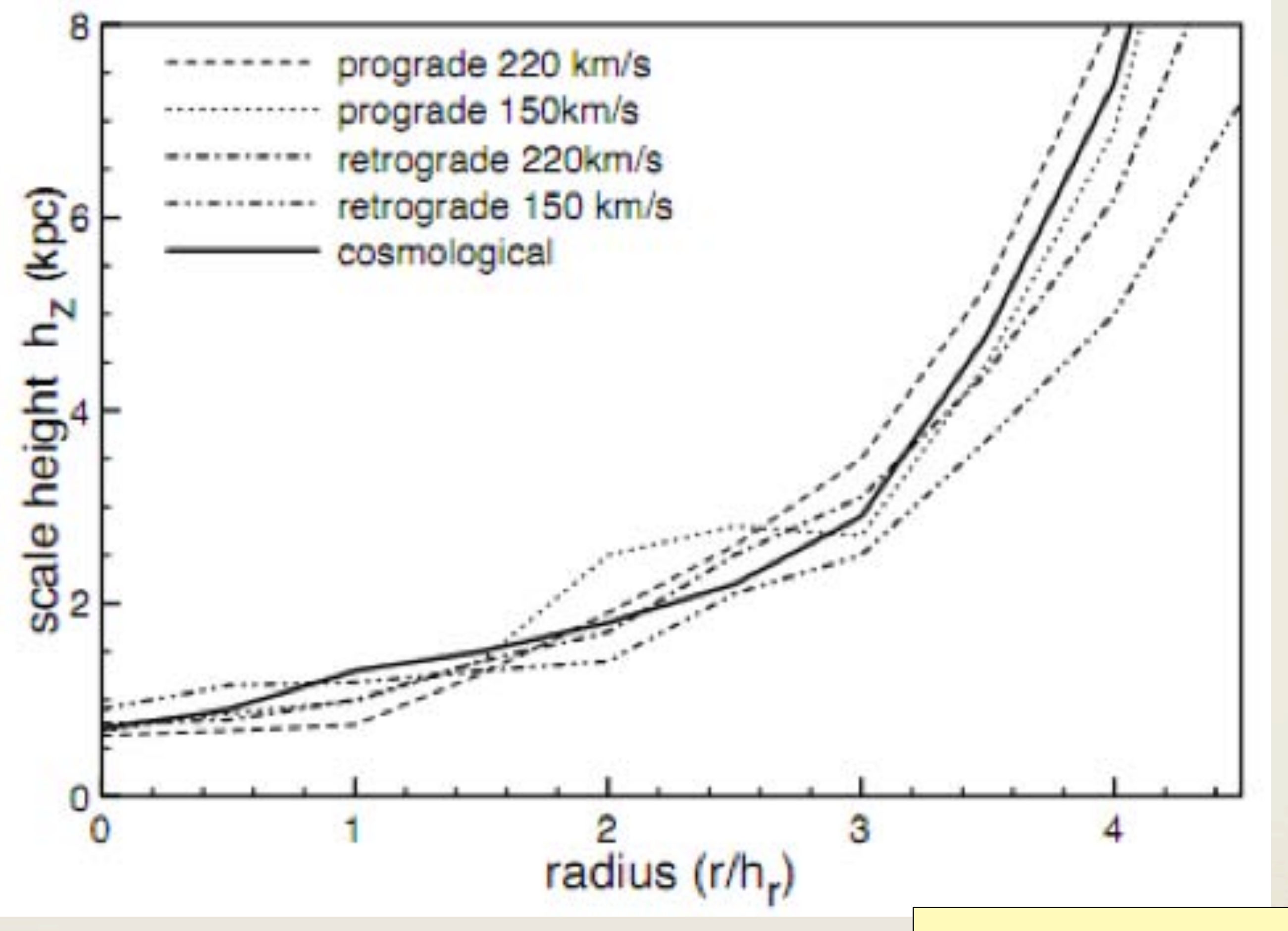
Milky Way thick disk appears centrally concentrated

Disks flare in simulations





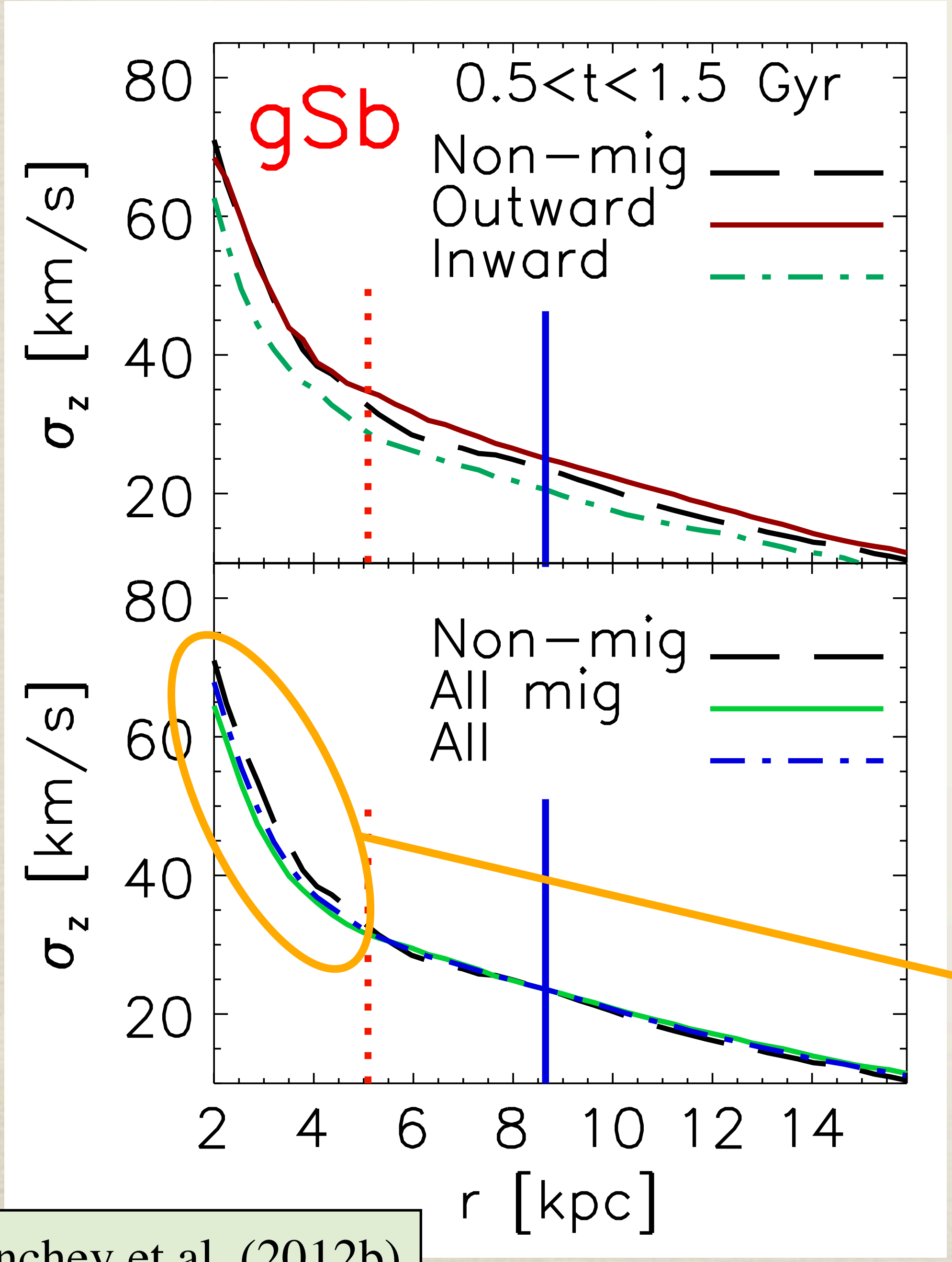
Disk flaring induced by mergers



Bournaud et al. 2009

Migration does not contribute much to disk heating

Vertical velocity dispersion



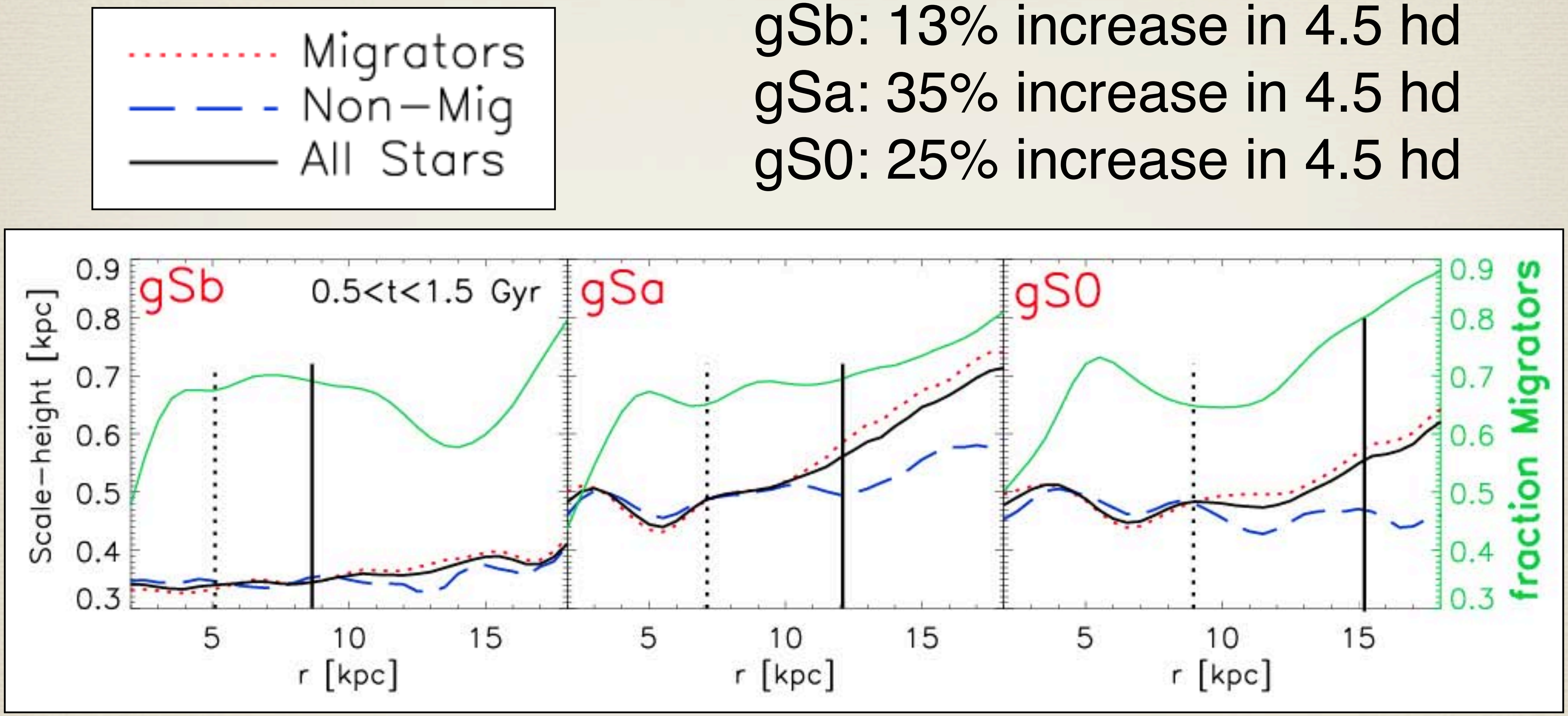
- Some increase in velocity dispersion from outward migrators.
- Some decrease in velocity dispersion resulting from inward migrators.
- Negligible overall effect.

Vertical disk cooling!

Minchev et al. (2012b)

Migration also flares disks

gSb: 13% increase in 4.5 hd
gSa: 35% increase in 4.5 hd
gS0: 25% increase in 4.5 hd

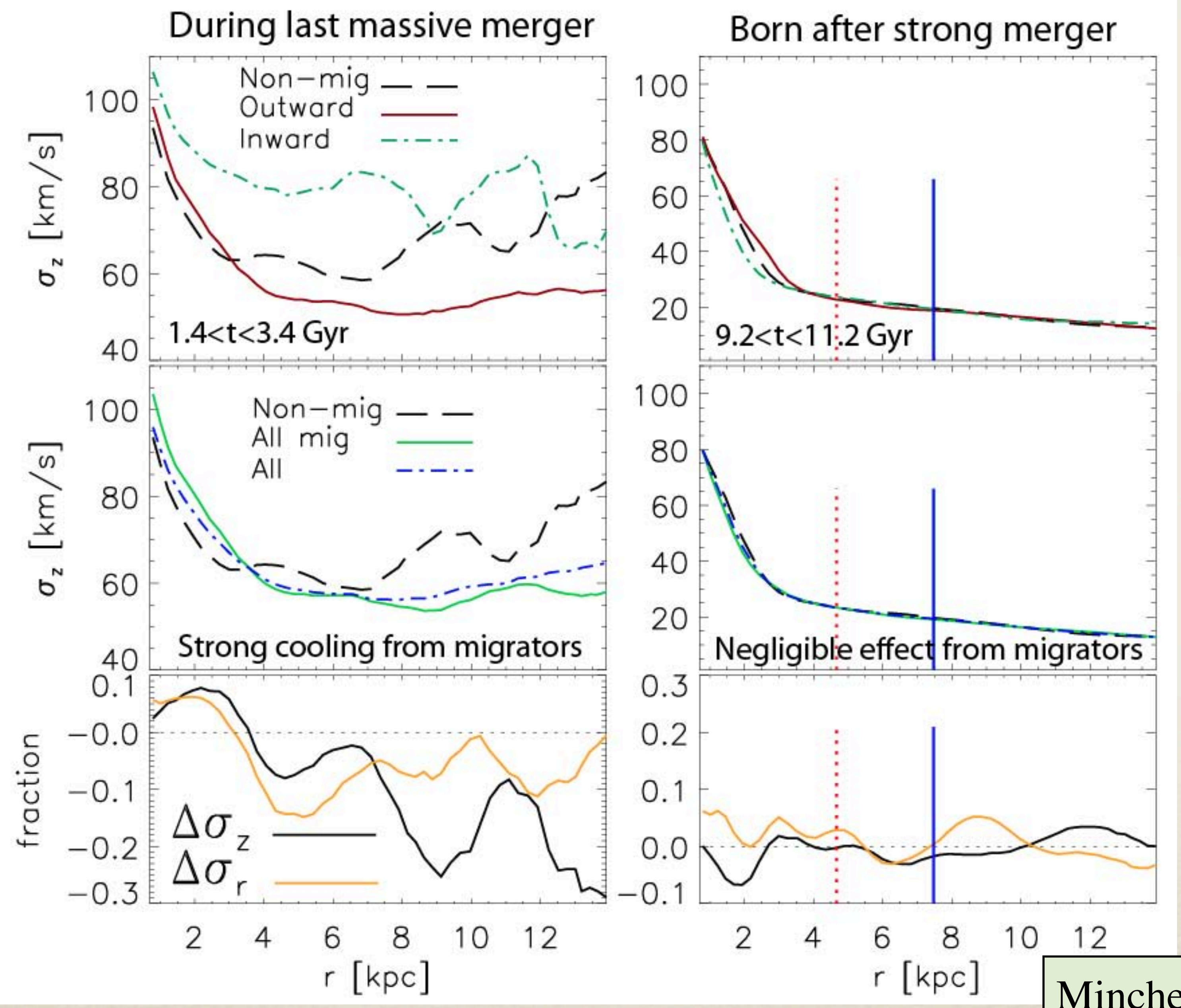


In the absence of mergers migration causes flaring in coeval stellar populations.

Migration cools the disk during mergers

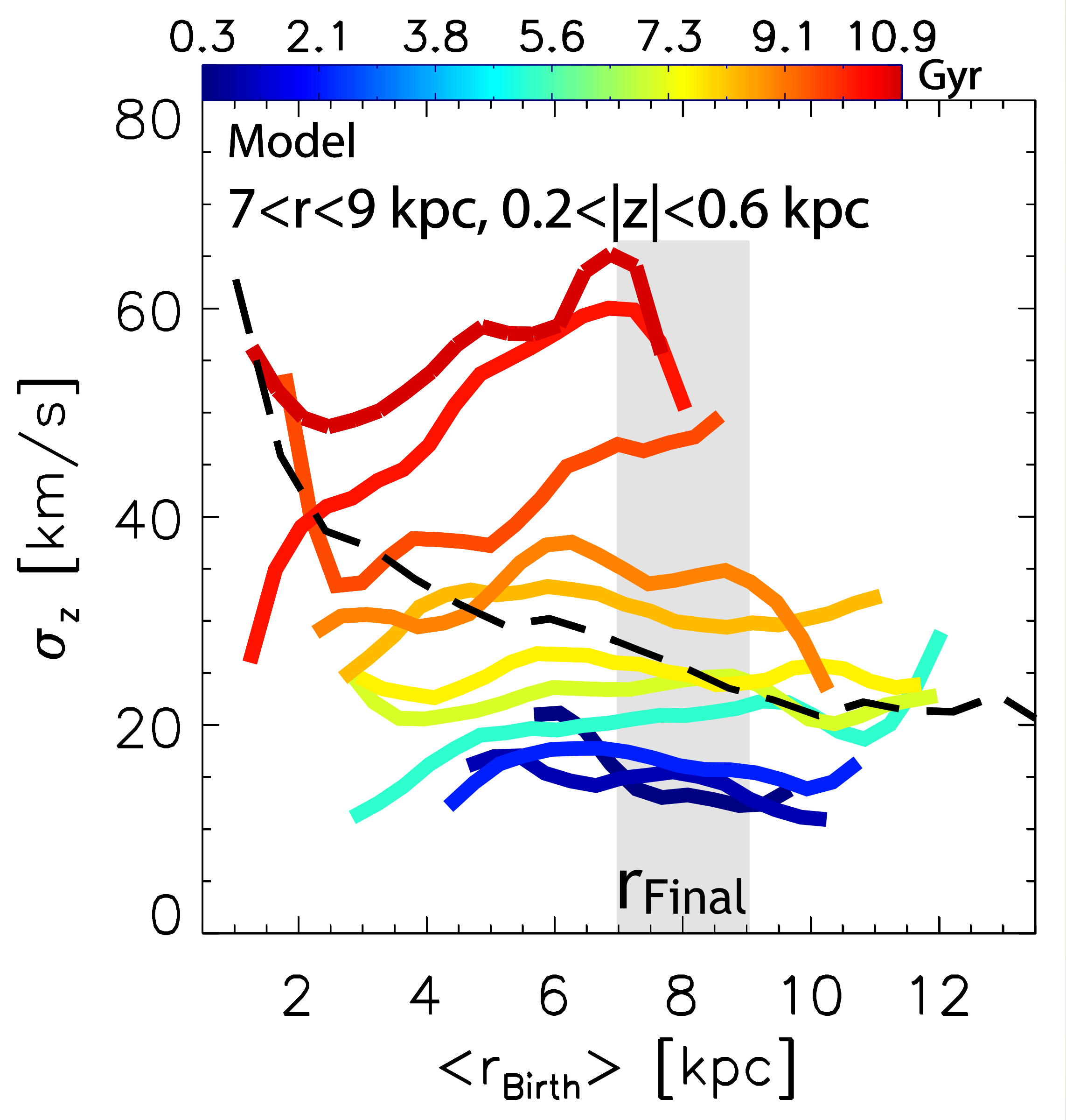
Migration works against disk flaring

No affect on the vertical velocity dispersion.



Minchev, Chiappini, and Martig (2013b), Submitted

Cool old stars can arrive from inner disk



Hot stars arrive from inner disk, but only because had more time for migration and heating.

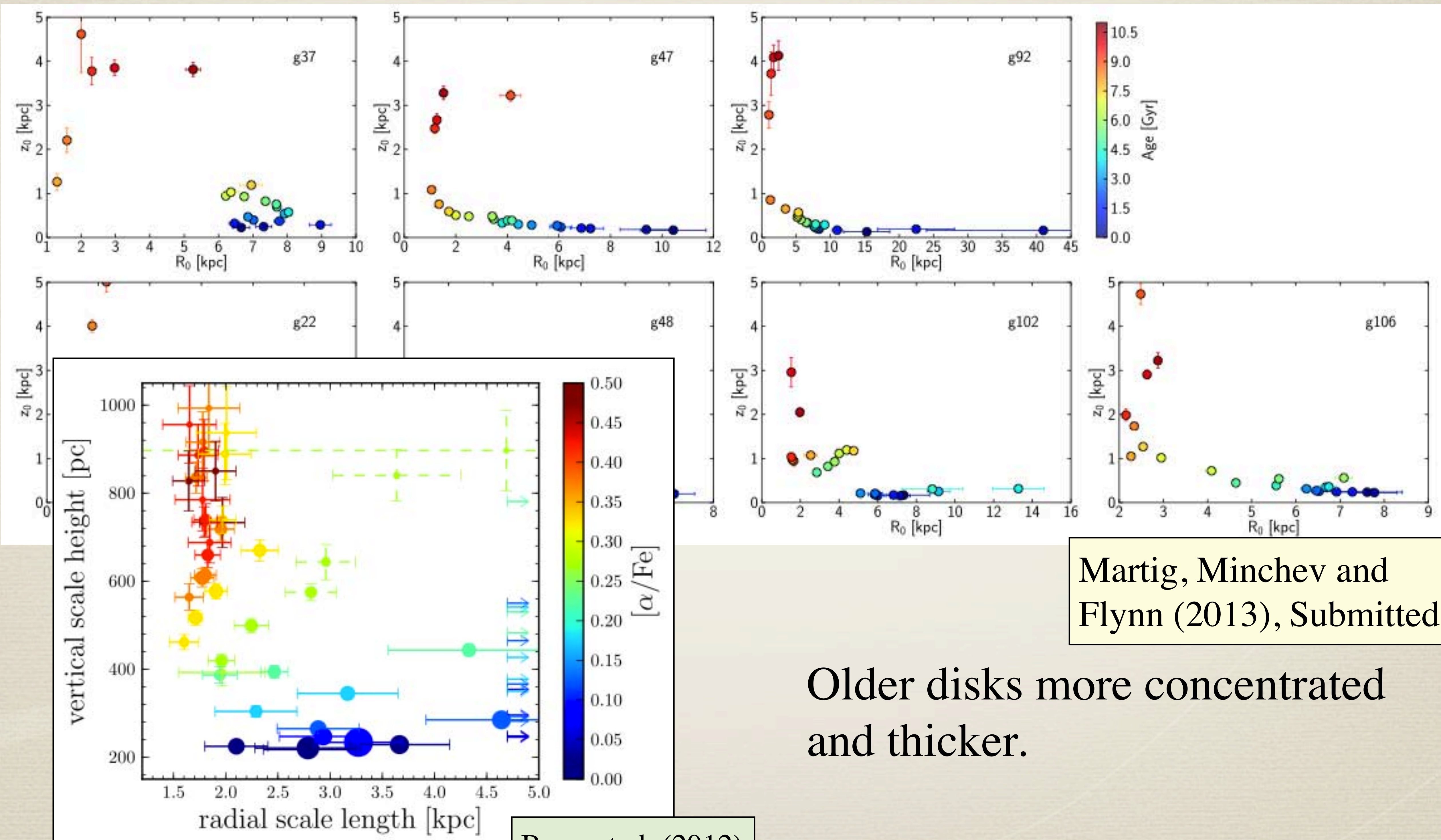
Old stars coming from the inner disk are cool: 30 km/s lower σz than in-situ born sample.

Slope becomes negative for the last several Gyr (no significant mergers).

Minchev + RAVE, 2013, arXiv:1310.5145

Explains inversion of vel. dispersion - [Mg/Fe] relation in RAVE and SEGUE G-dwarf data, see Minchev et al., 2013, arXiv:1310.5145

Scale-length vs scale-height

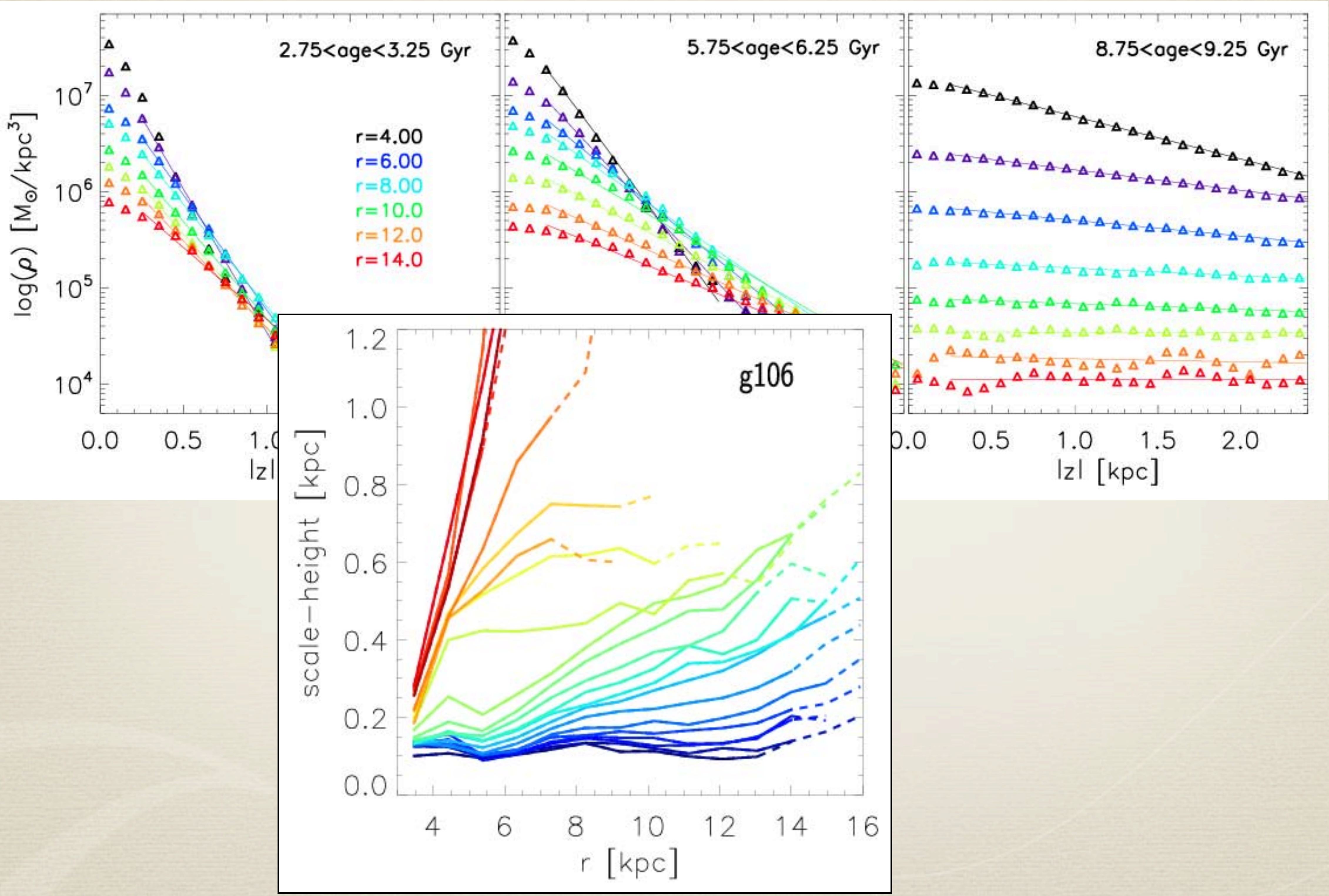


Martig, Minchev and Flynn (2013), Submitted

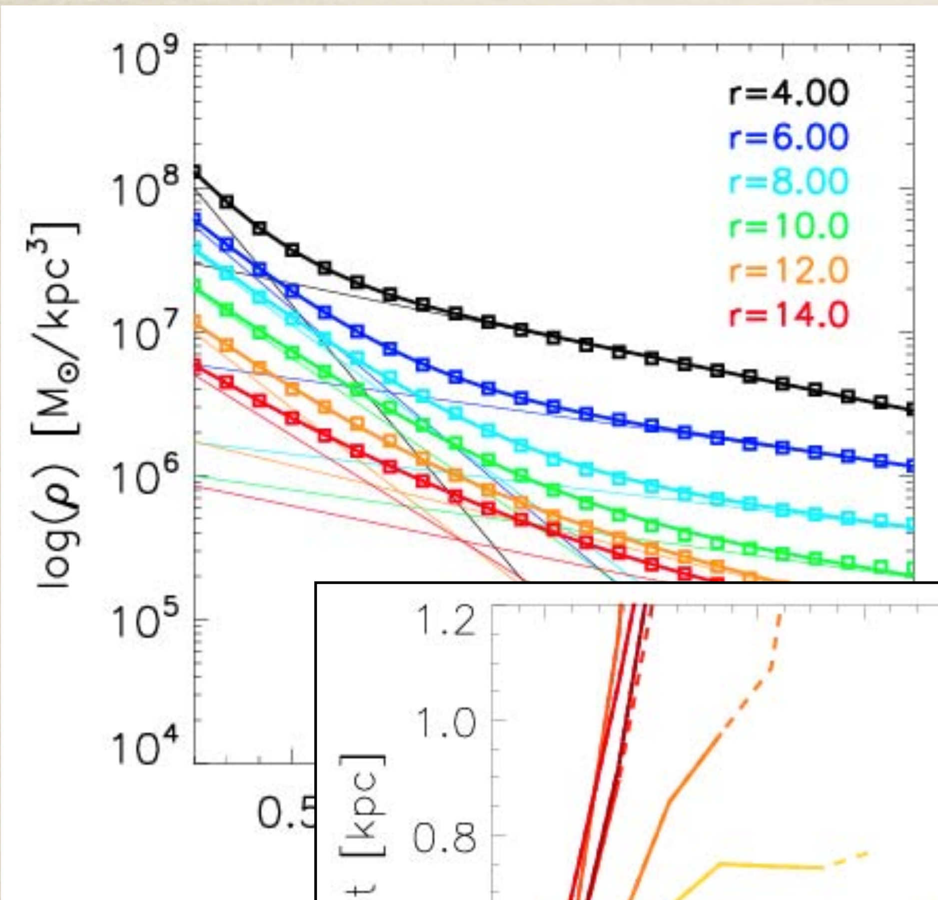
Bovy et al. (2012)

Older disks more concentrated and thicker.

Mono-age disks flare

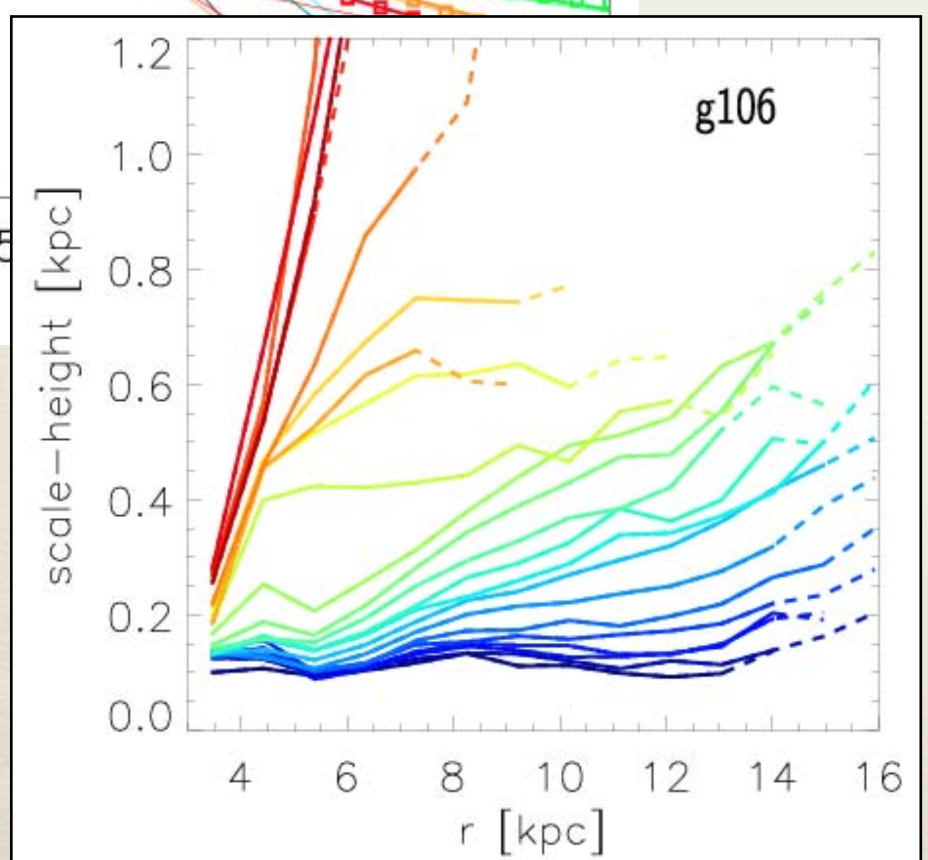


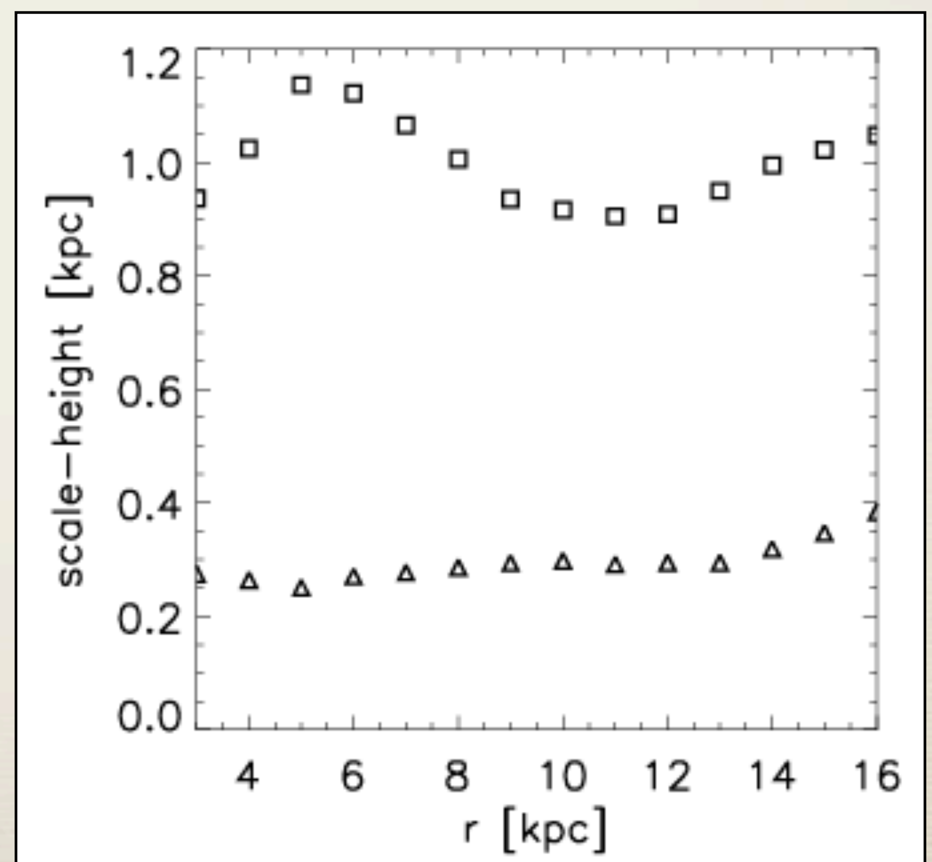
The total population does not flare



Thick disk formed by the flares of different populations.

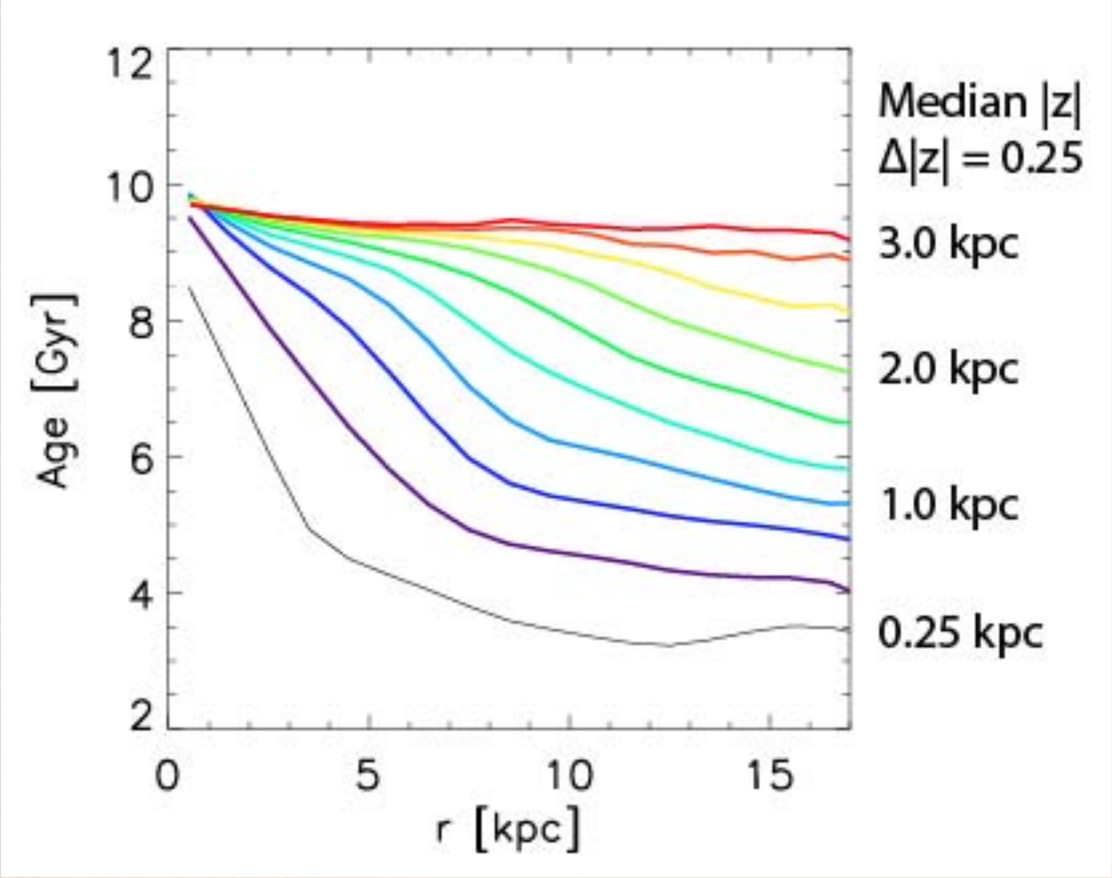
Related to the increase in scale-length of younger population, which flare at progressively larger radii.

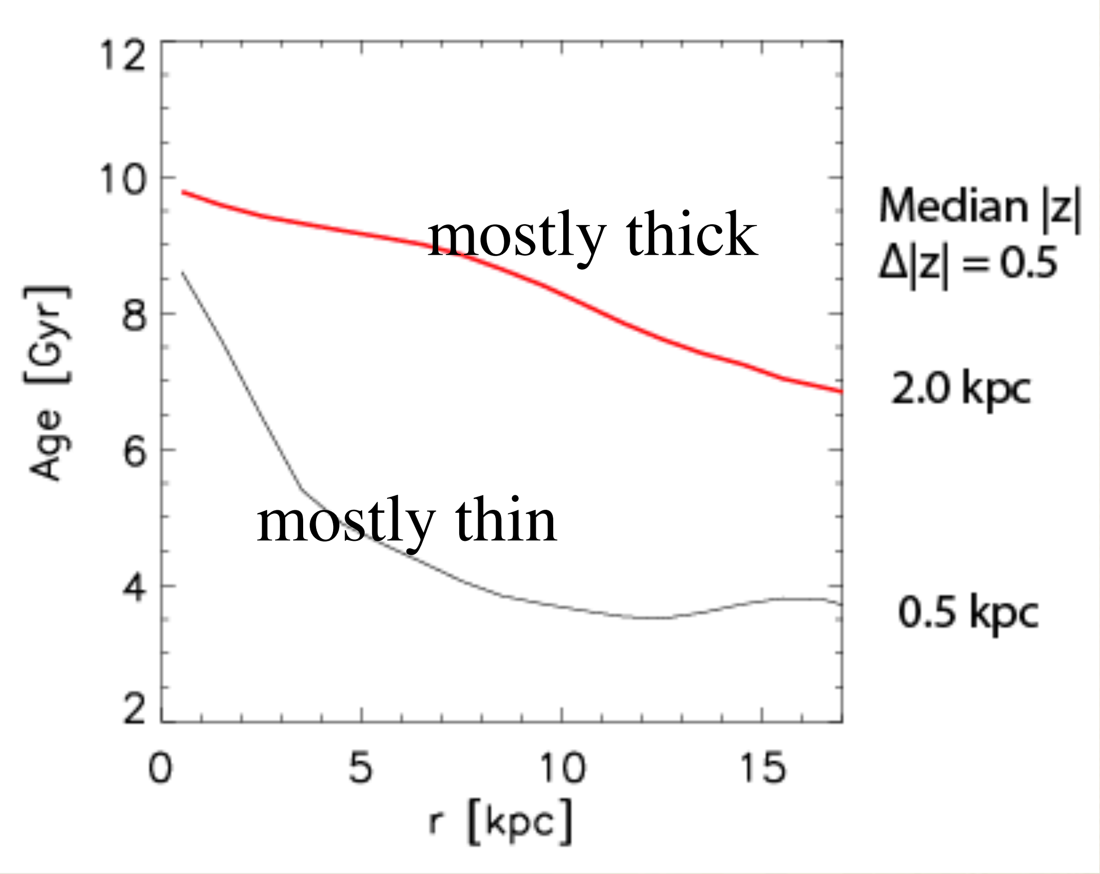




Decline in age in thick disk predicted at large radii

Age gradients at different height from disk midplane



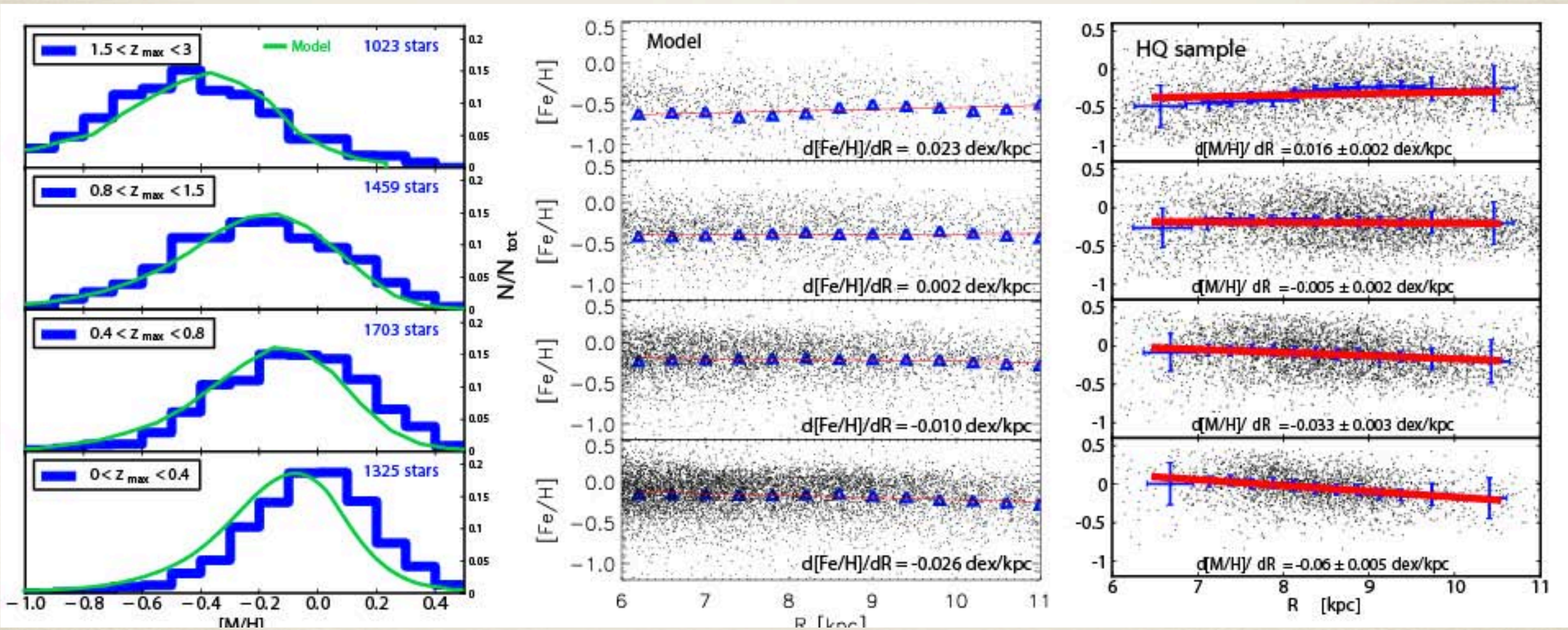


Discrepancy between concentrated thick disk in Milky Way and extended thick disks in external galaxies resolved if age gradient in thick disk allowed.

Inversion in metallicity gradients for APOGEE giants

Anders et al. (2013)

Flaring of mono-age disks results also in the inversion of metallicity gradient with increasing distance from disk midplane.

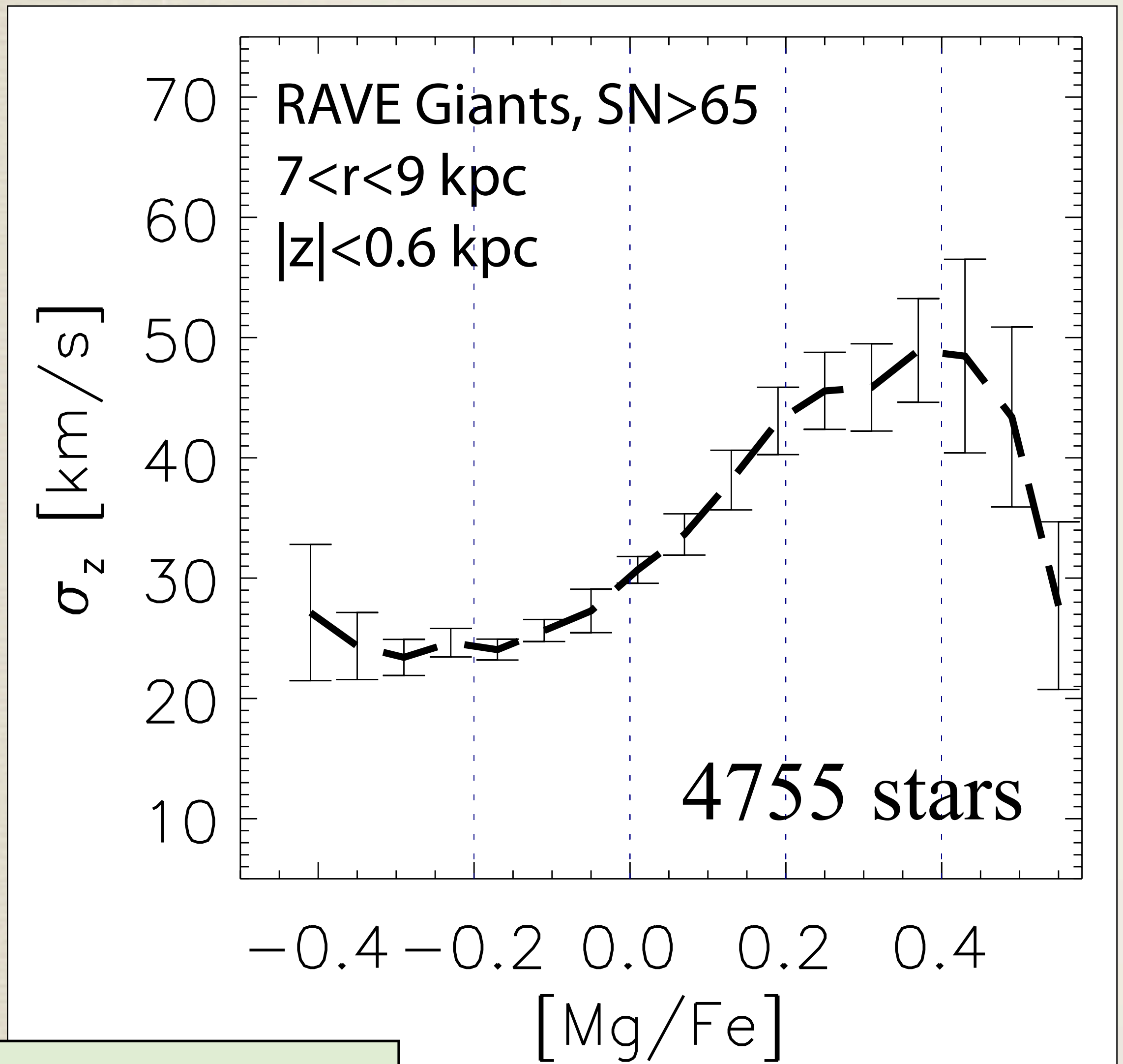


Model from Minchev, Chiappini and Martig (2013)

Summary

- Radial migration affects disk velocity dispersions only at disk boundaries in isolated disks - disk flaring induced.
- Radial migration cools the disc during mergers.
- In cosmological simulations mono-age populations should show disk flaring.
- Thick disks composed by the flares of different age populations, where younger disks are progressively more extended.
- No flaring for the total population (related to inside-out formation).
- Older populations still centrally concentrated.
- Discrepancy between concentrated thick disk in Milky Way and extended thick disks in external galaxies resolved if age gradient allowed.

Vertical velocity dispersion as a fn of [Mg/Fe] in RAVE: evidence of radial migration and merger history in the Milky Way

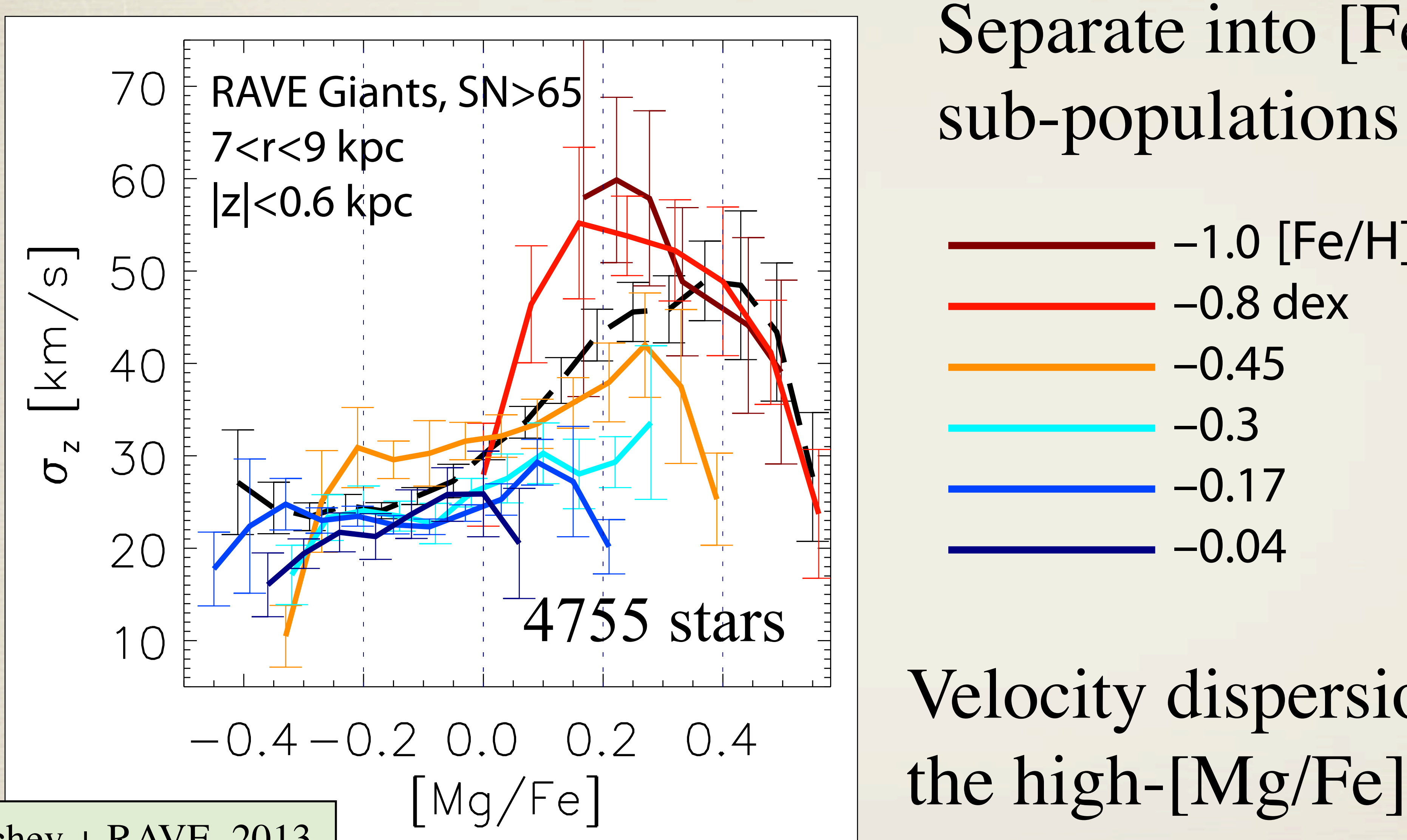


Minchev + RAVE, 2013, arXiv:1310.5145

Velocity dispersion drops at [Mg/Fe] > 0.4 dex

Related to cold old stars migrating from the innermost disk.

Vertical velocity dispersion as a fn of [Mg/Fe] in RAVE: evidence of radial migration and merger history in the Milky Way



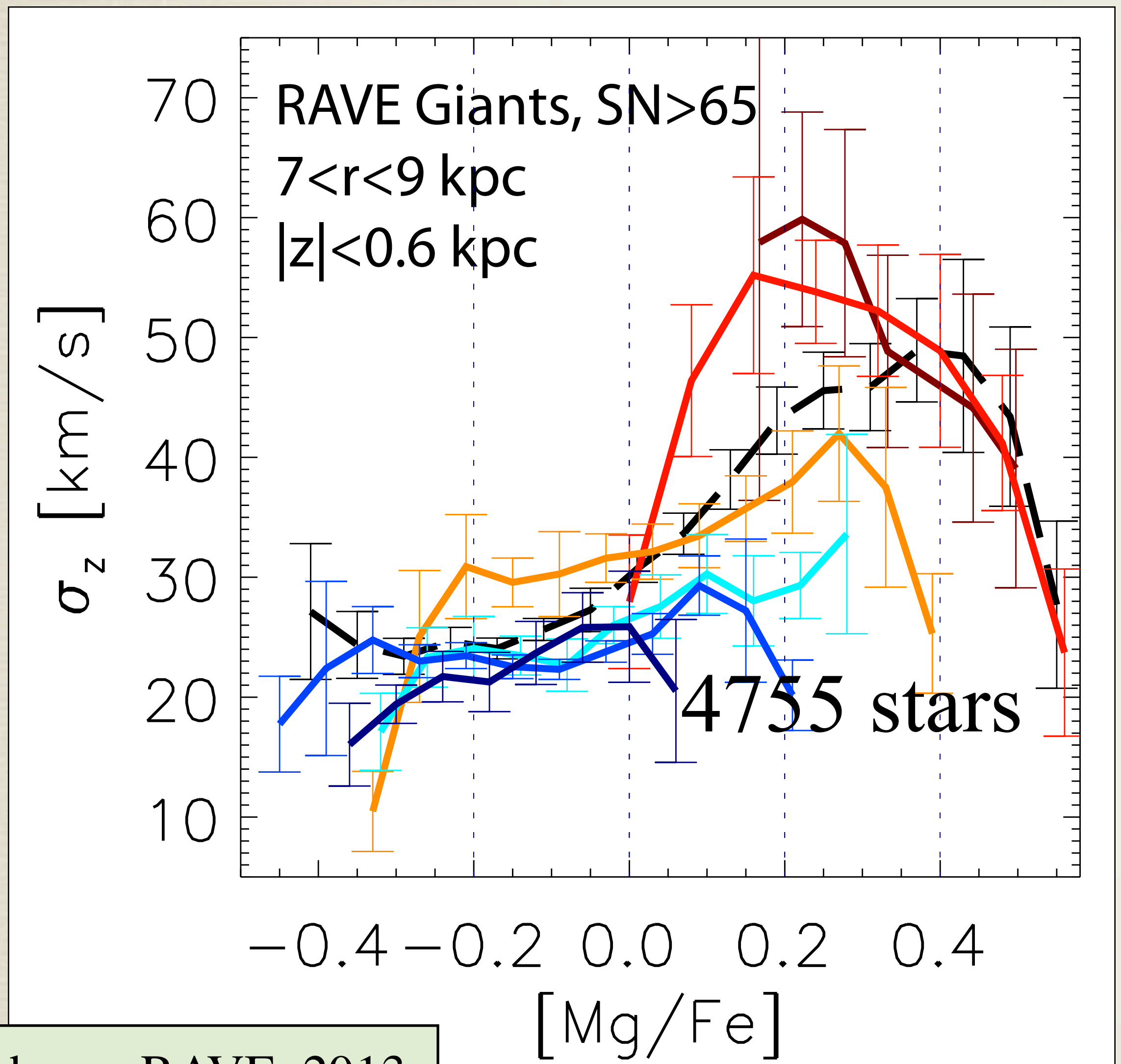
Minchev + RAVE, 2013, arXiv:1310.5145

Separate into [Fe/H] sub-populations

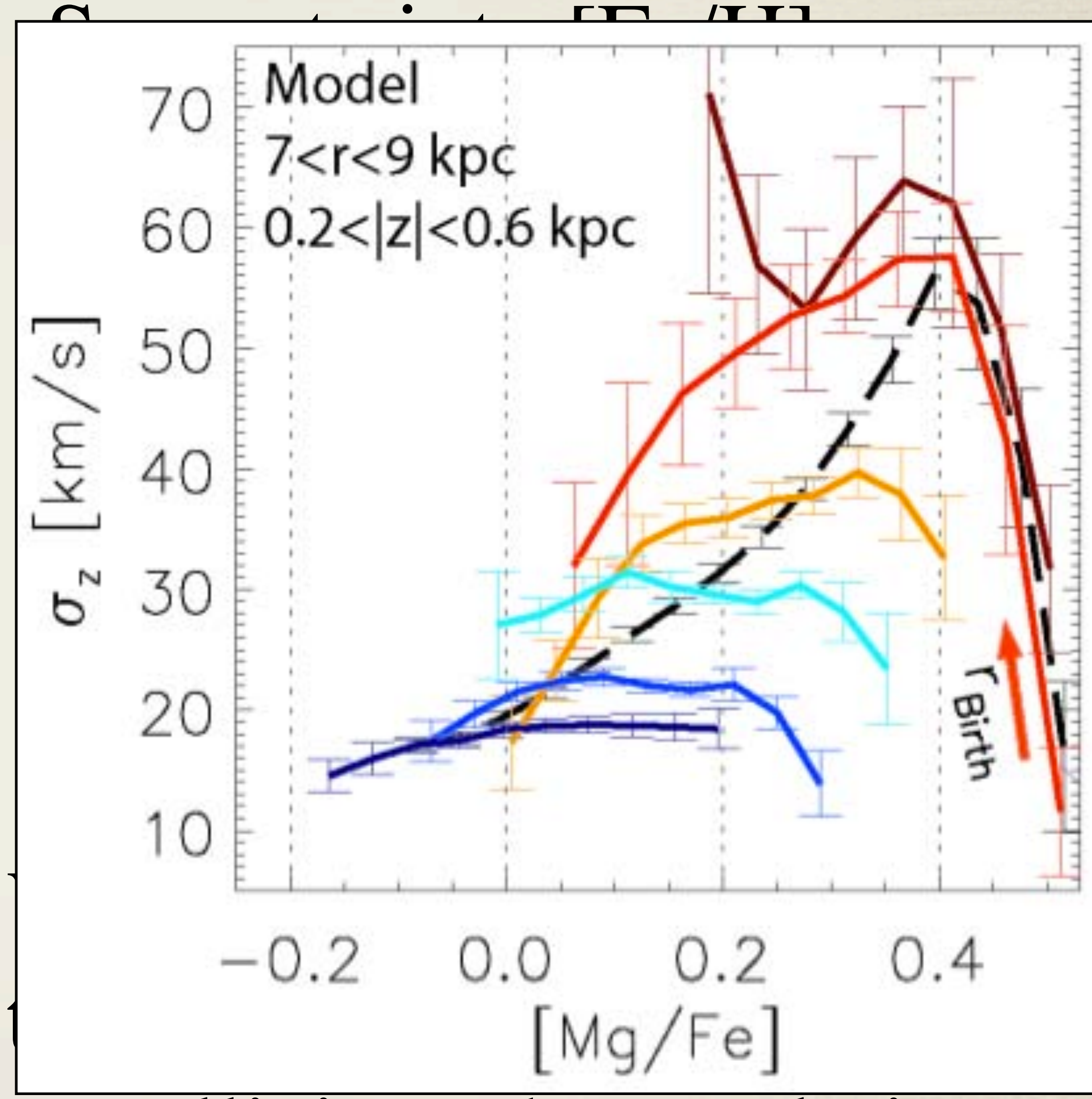
Velocity dispersion drops at the high-[Mg/Fe] end for each metallicity sub-population

Related to cold old stars migrating from the innermost disk.

Vertical velocity dispersion as a fn of [Mg/Fe] in RAVE: evidence of radial migration and merger history in the Milky Way



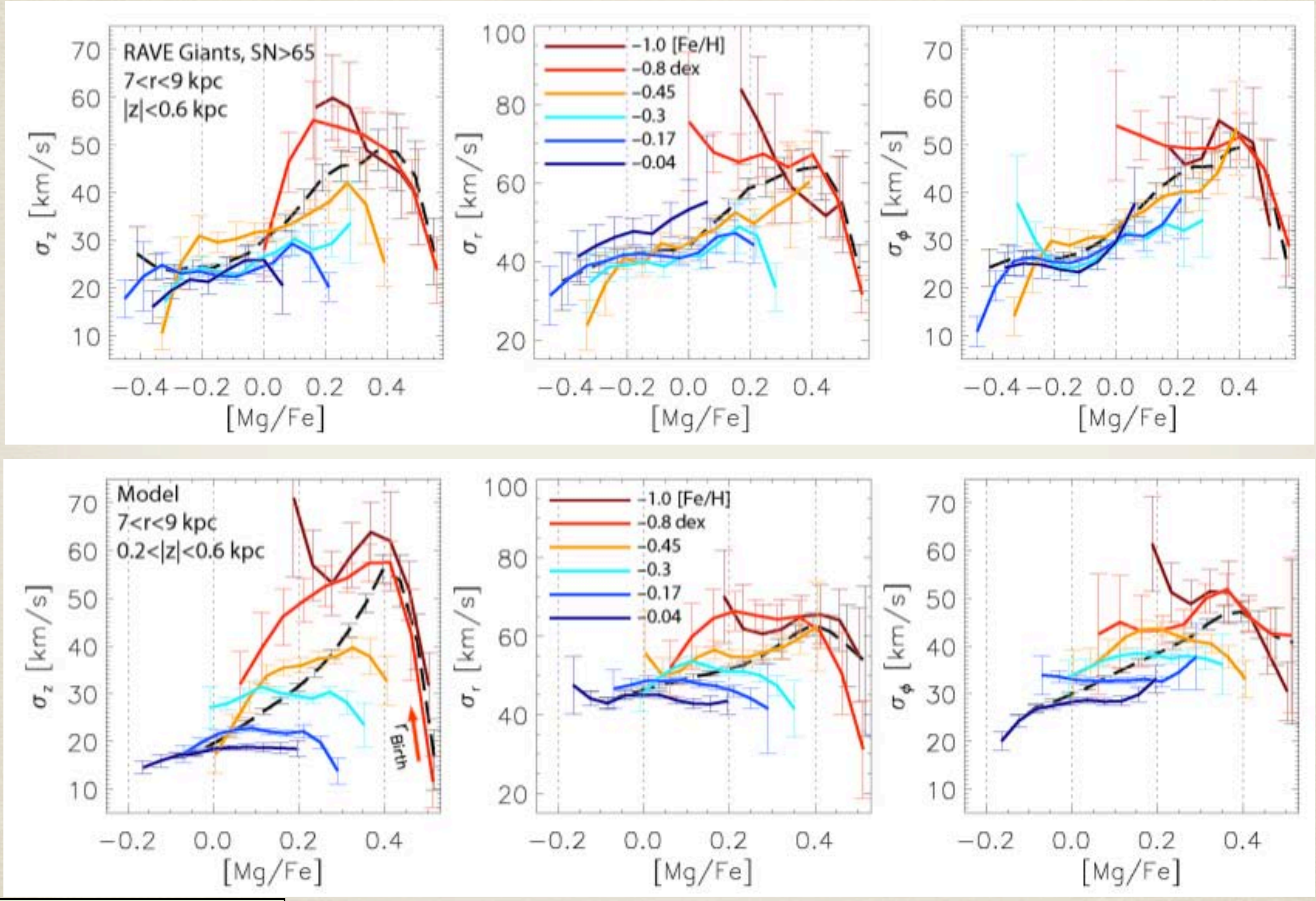
Minchev + RAVE, 2013, arXiv:1310.5145



metallicity sub-population

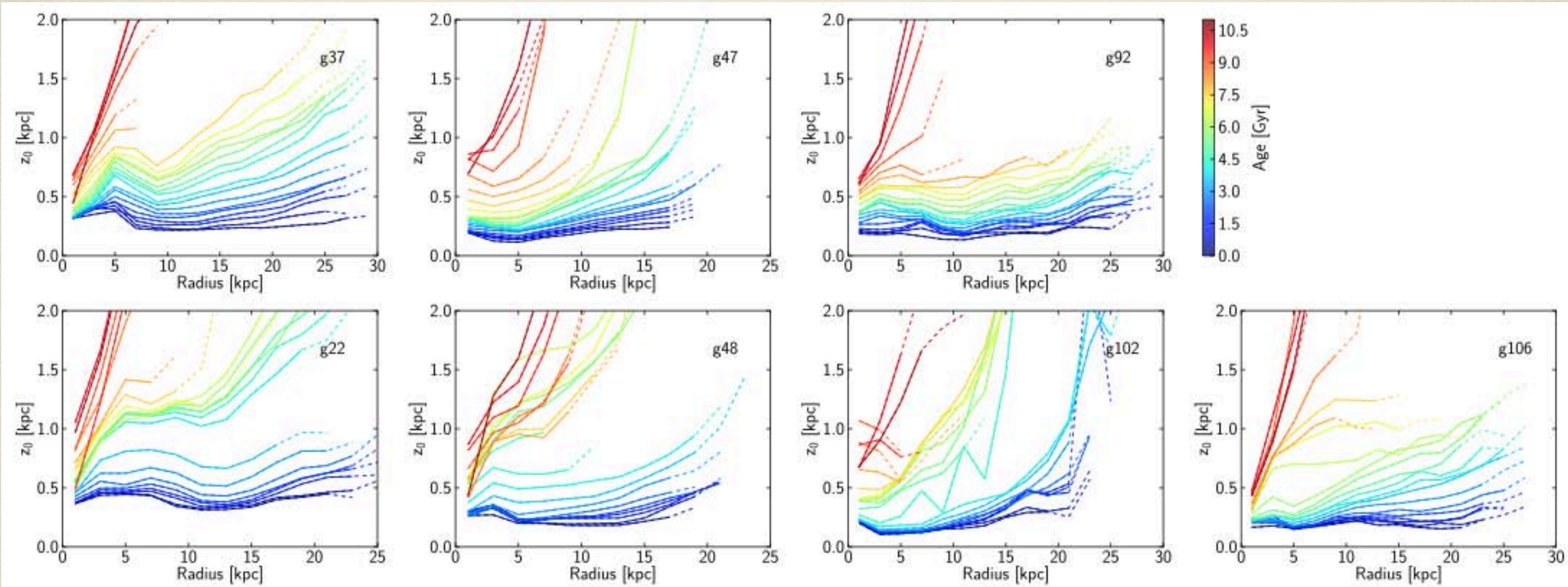
Related to cold old stars migrating from the innermost disk.

Inversion in velocity dispersion-[Mg/Fe] relation in the solar neighborhood



Minchev + RAVE, 2013, arXiv:1310.5145

Scale-height variation with radius



Martig, Minchev and Flynn (2013), Submitted

Mono-age disks always flare because of the effect of orbiting satellites and/or radial migration.