UCL

Impacts of Radial Migration and flaring on the Galactic Thick and Thin Disks

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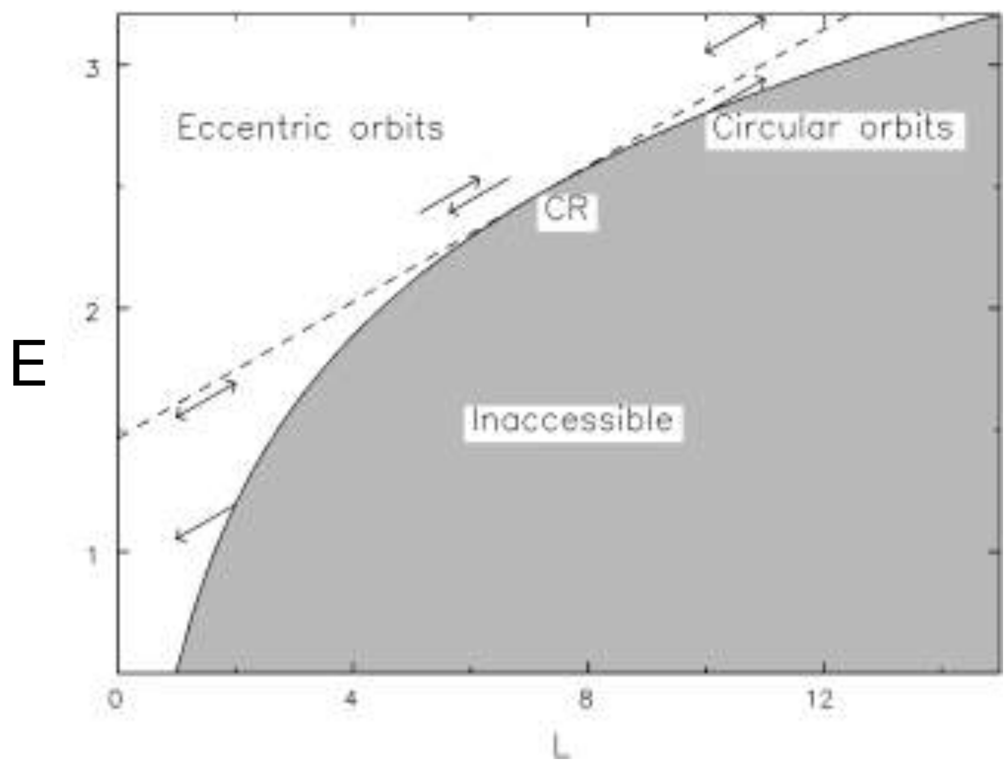
Radial migration (churning, changing Lz) due to transient spiral arms

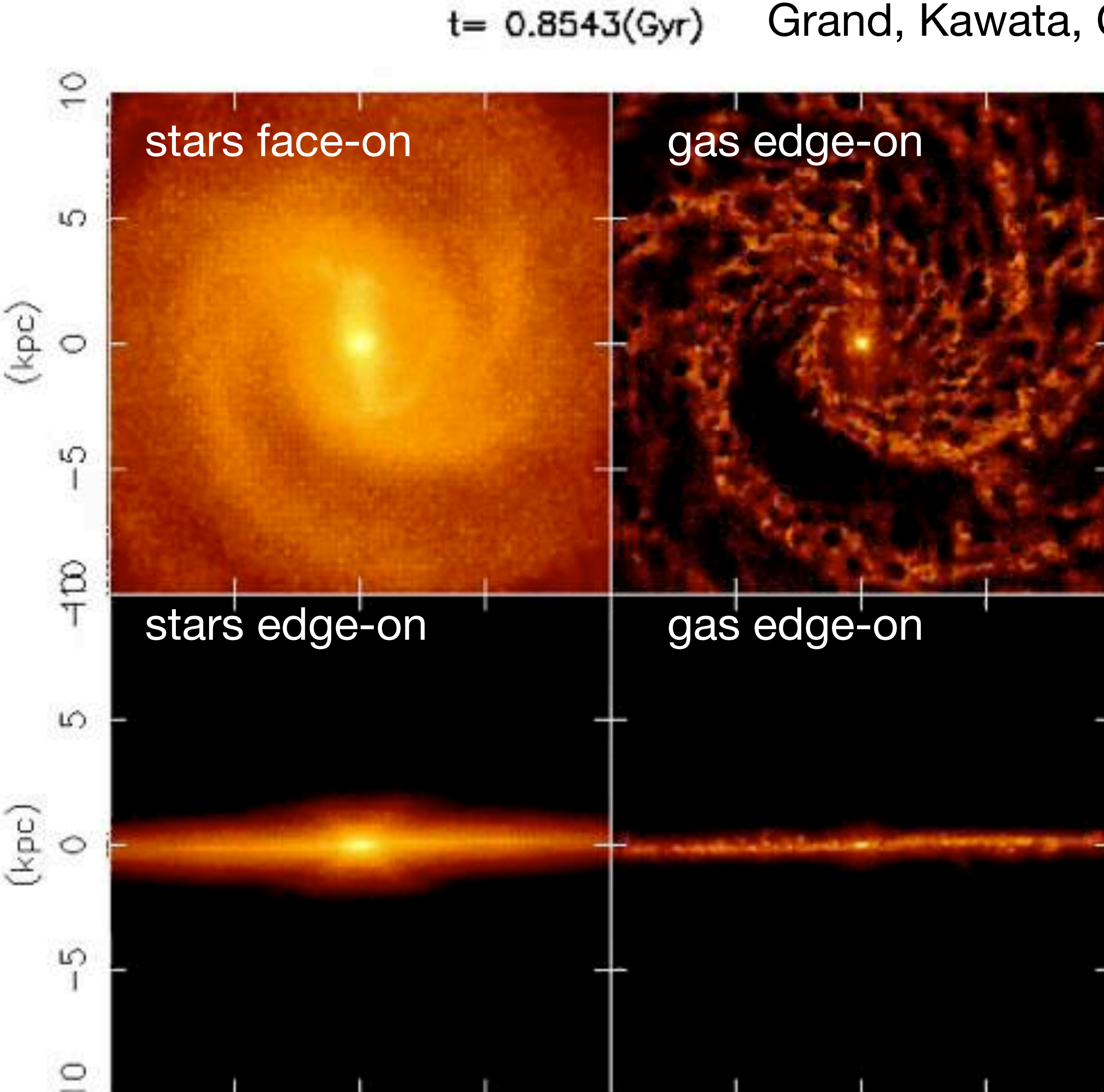
(e.g. Sellwood & Binney 2002; Roškar et al. 2008a,b; Sánchez-Blázquez et al. 2009; Minchev et al. 2010, Brunetti et al. 2011; Grand et al. 2012a,b, 2014; Kubryk et al. 2013, Vera-Circo et al. 2014, many more…)



Sellwood & Binney (2002)

Transient and co-rotating spiral arms commonly seen in N-body simulations

Grand, Kawata, Cropper (2012a,b,13,14)



spiral arm "features" transient winding and co-rotating!

Milky Way sized disk N-body/SPH simulation with GCD+ (my original code since 1998, e.g. Kawata et al. 2013)

N~2.4x10^6 disk gas and star particles, m_p=2.5x10^4 $M_\odot$ with a fixed NFW DM potential.

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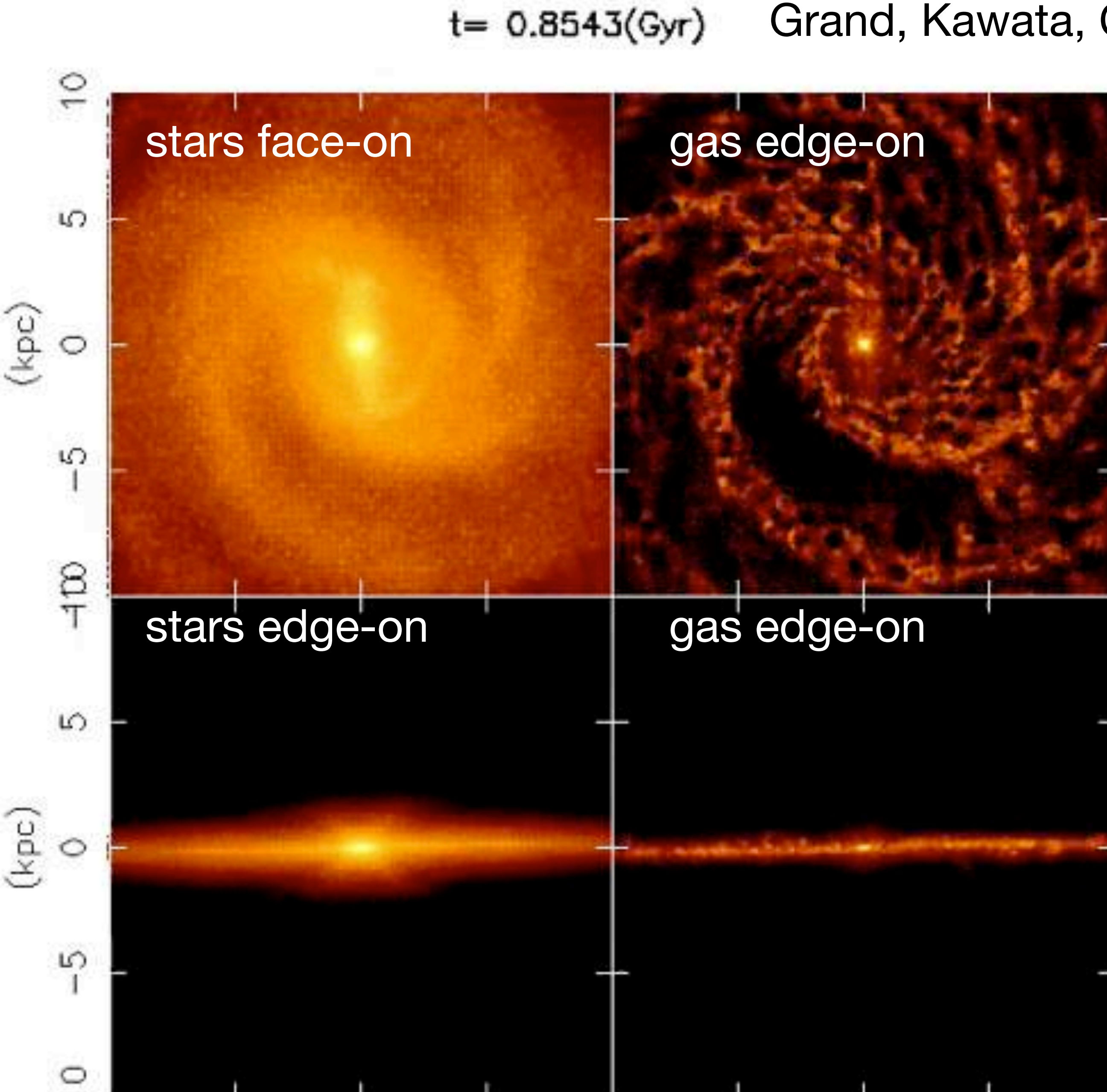

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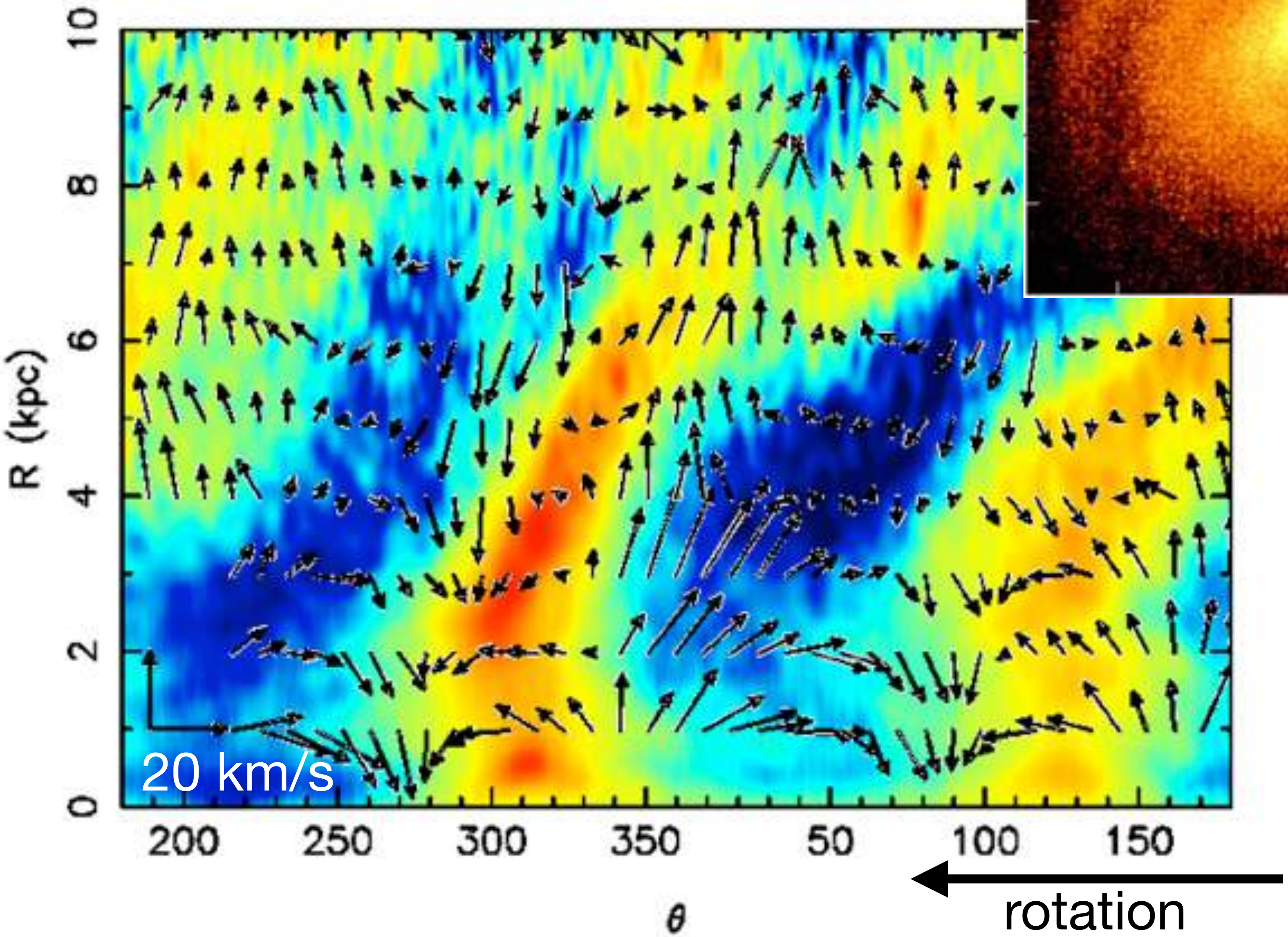
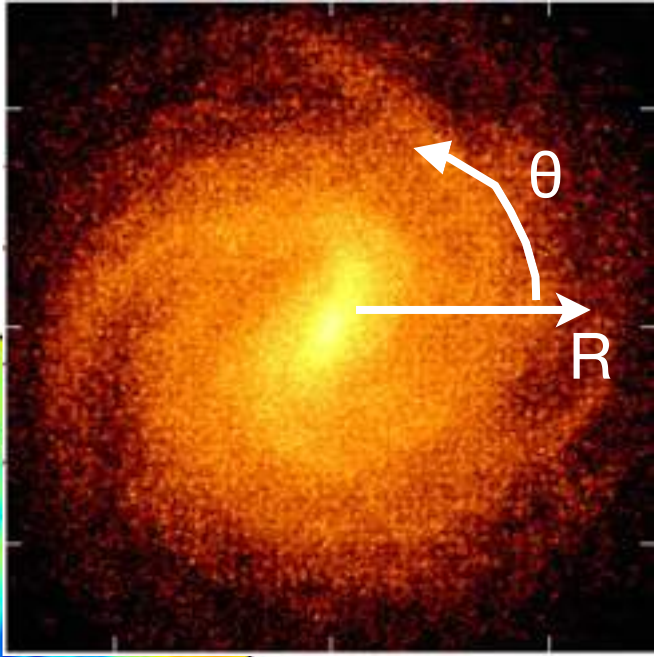
Trailing side migrating outward (low V), and leading side migrating inward (high V) (Grand, Kawata, Cropper 2012a,b; 2014)



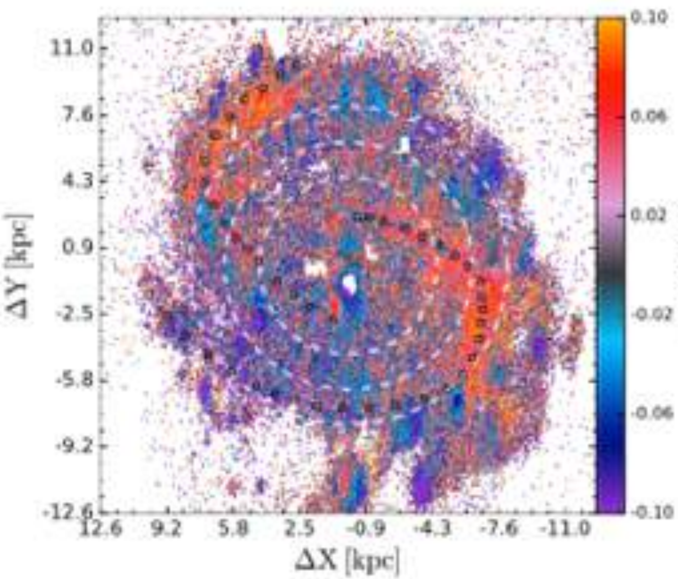


Evidences in the gas radial migration and metallicity distribution

(Sánchez-Menguiano, Sánchez, Kawata, … Grand, Minchev et al. submitted)

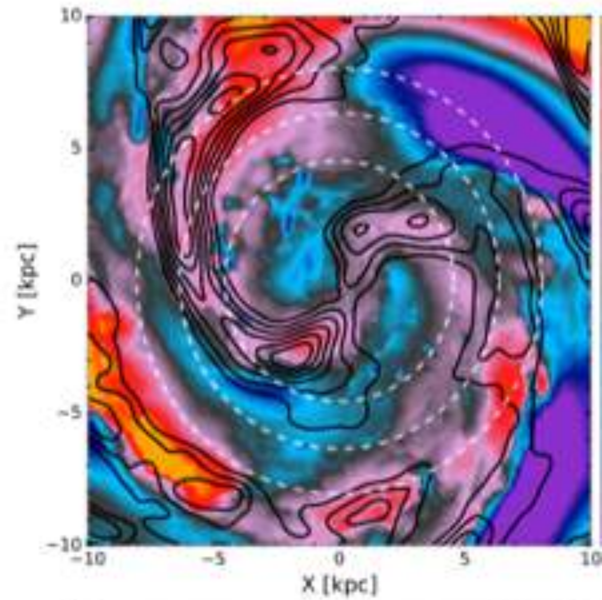
NGC6754 (MUSE)

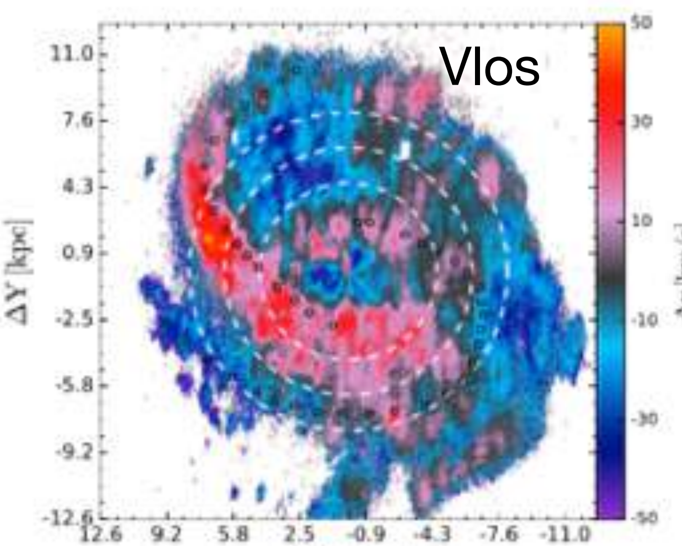
simulation



residual Z

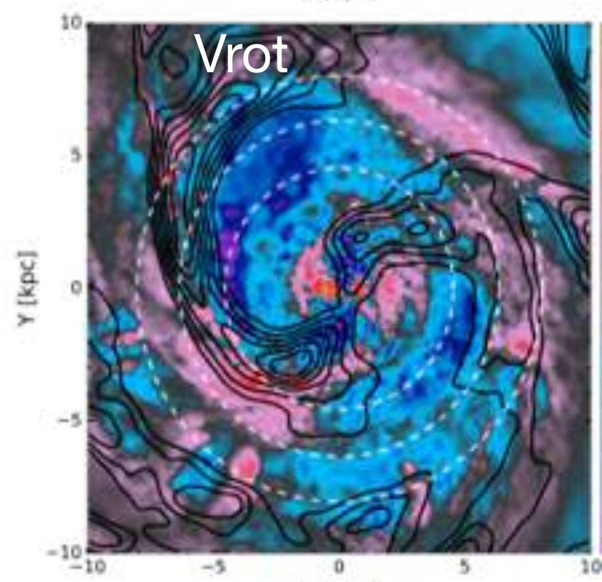
see model prediction
Grand et al. (2016)
for spiral
Di Matteo et al. (2013)
for bar





residual V

Behind the arm gas move outward and more metal rich and opposite trend at the front!

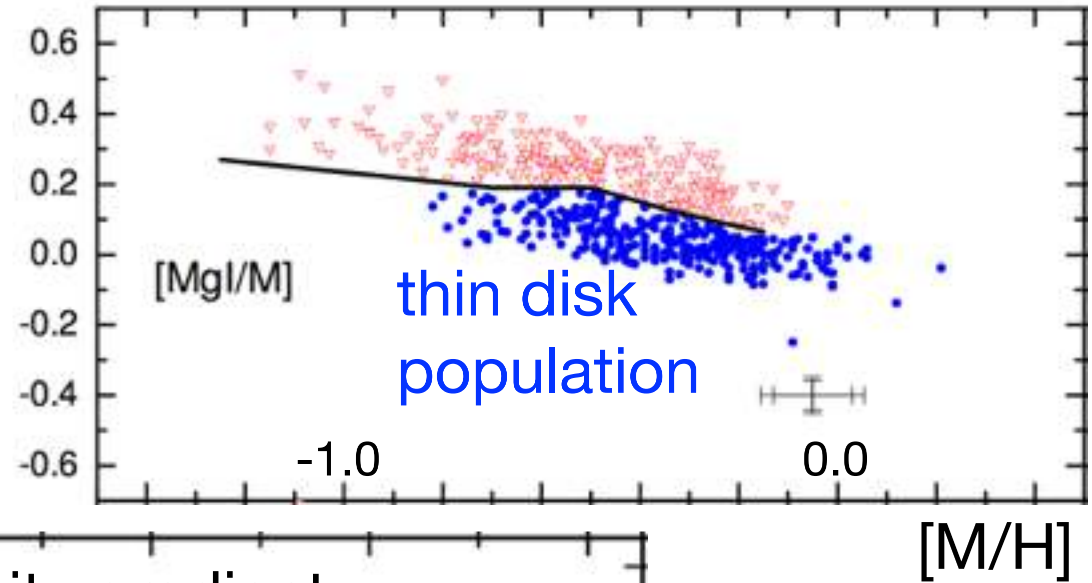


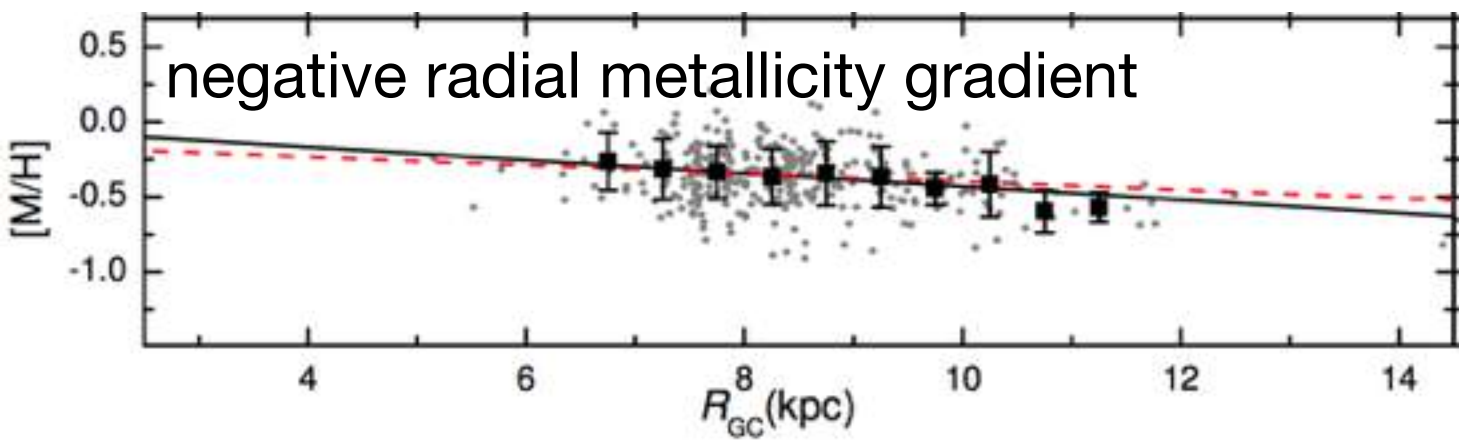
Radial migration is quite efficient in simulations.

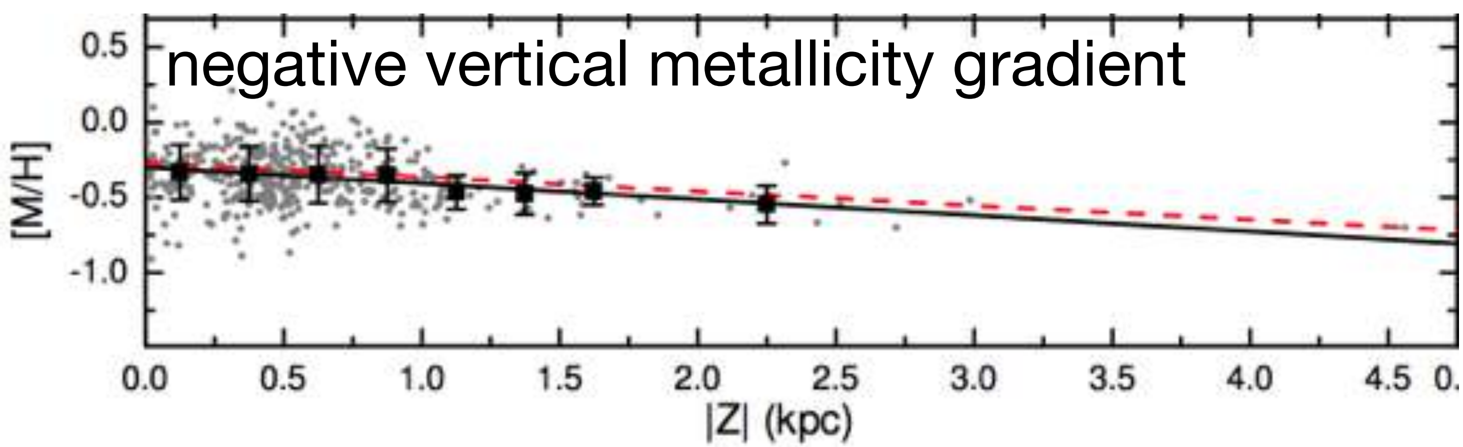
How radial migration impact
on the metallicity distribution of the thin disk population?

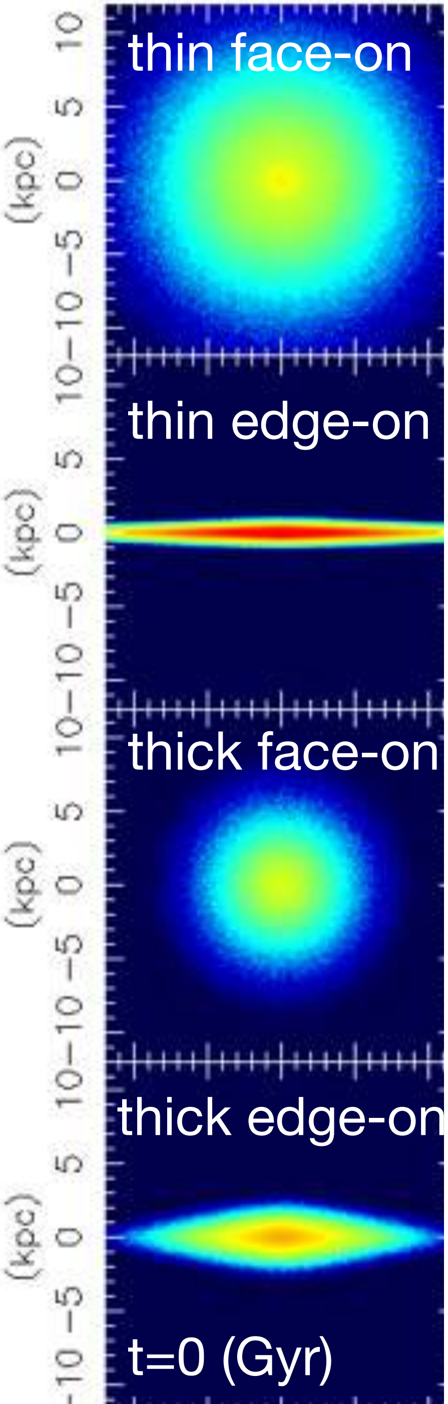
Mix (i.e. flatten) completely?

Mikolaitis et al. (2014)
Gaia-ESO survey
thin disk population
= low-α stars



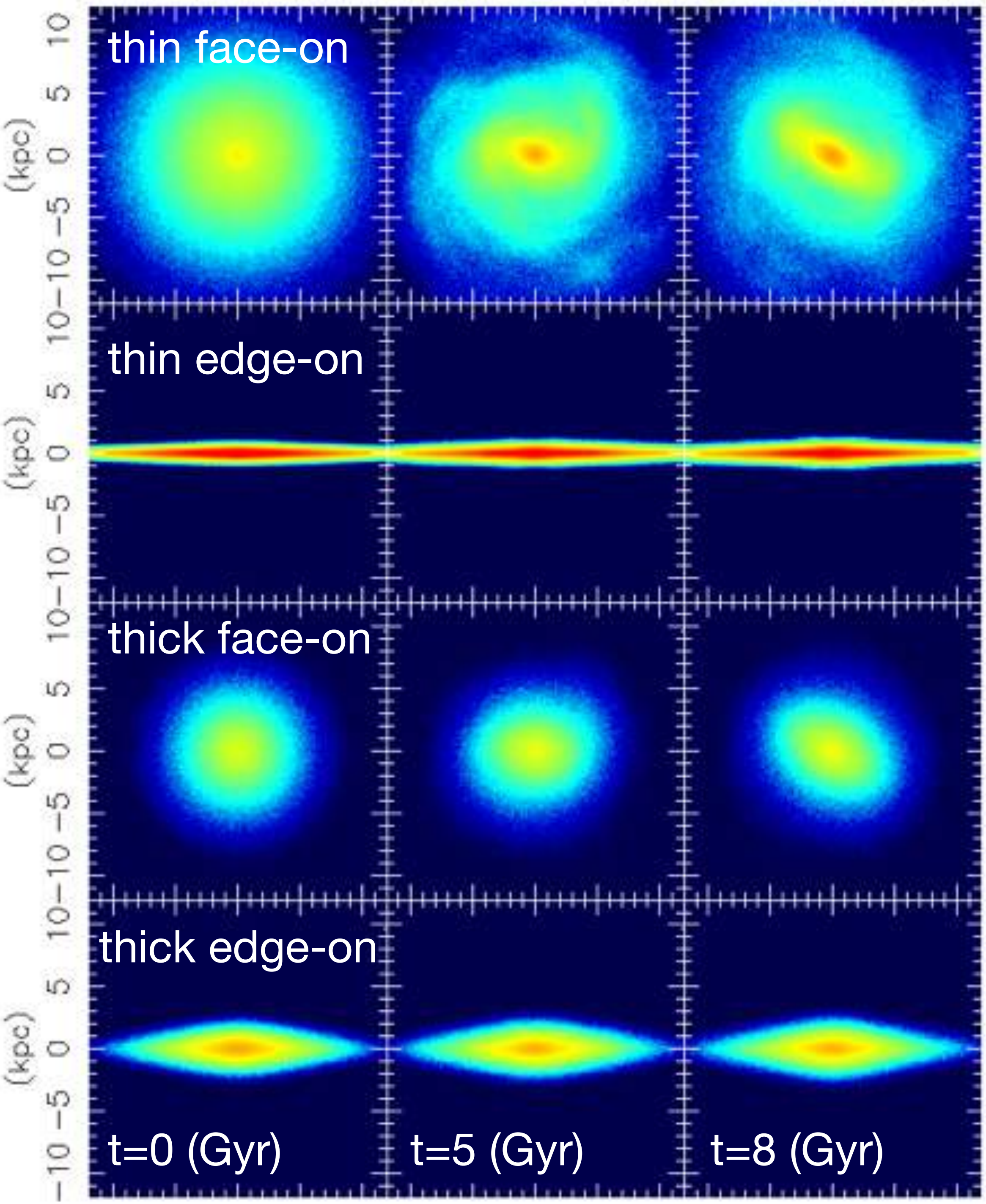






N-body Numerical Experiments

Kawata et al. (2016, MNRAS in press arXiv:160407412)



N-body Numerical Experiments

8 Gyr Evolution of
large thin disk
and
smaller thick disk

How radial mixing due to bar and spiral arms affects metallicity distribution of mono-age population of thin disk?

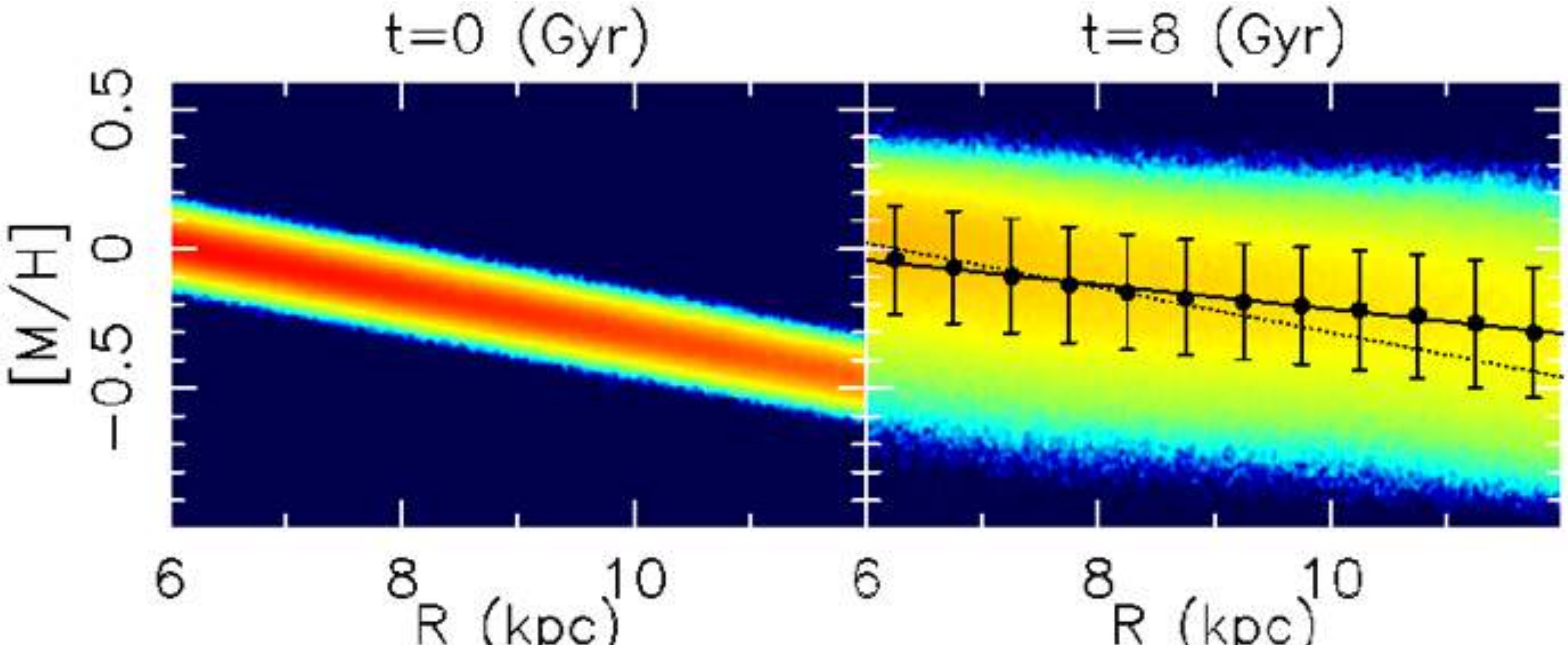
No flaring due to migration!

Kawata et al. (2016, MNRAS in press arXiv:160407412)

Radial metallicity gradient becomes shallower (still negative) and more scatter

(Grand, Kawata, Cropper 2014, 2015)

(Thin disk only)



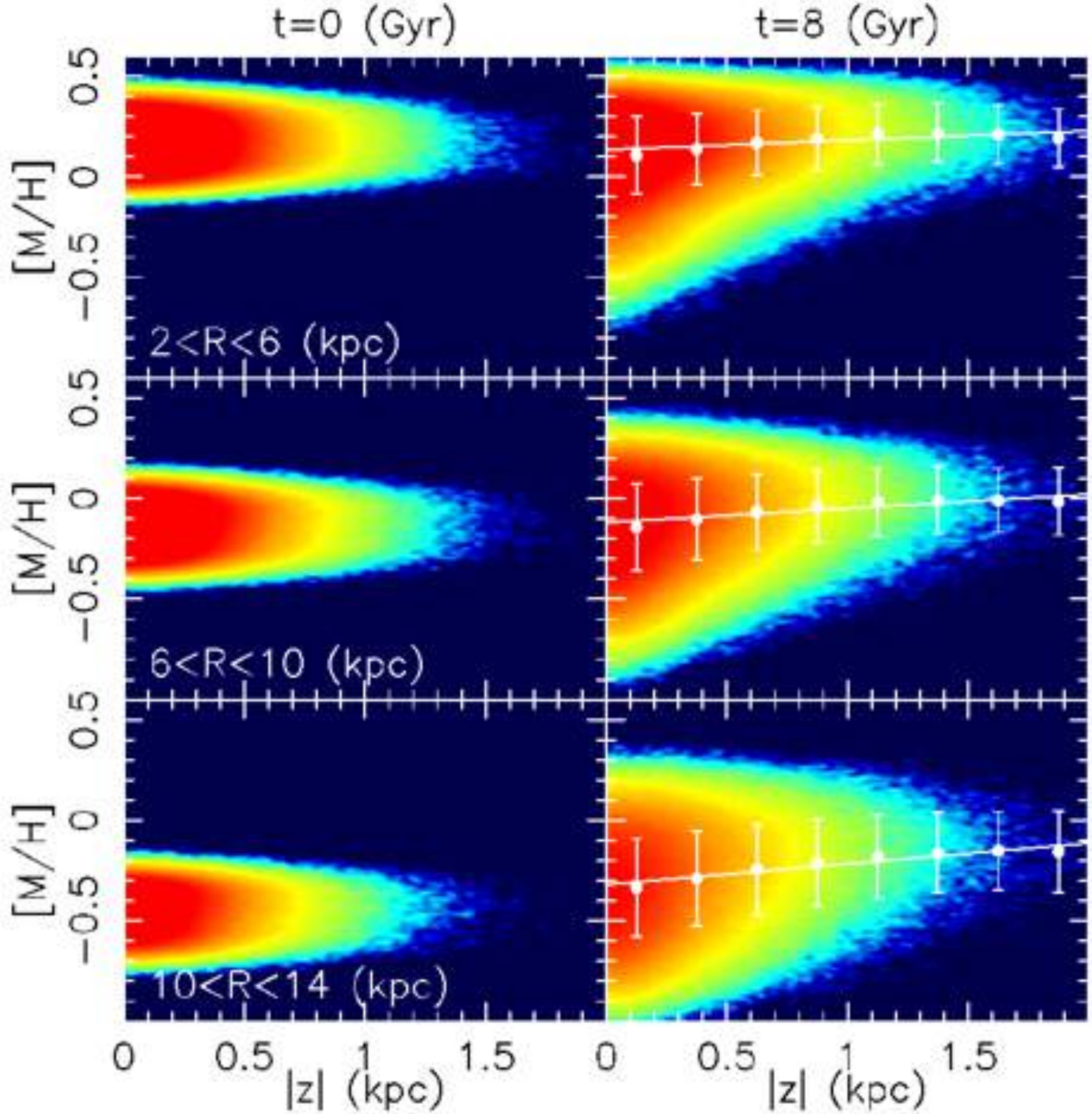
initially set
–0.08 dex/kpc
no vertical Z grad

–0.044 dex/kpc
not completely flat!

Kawata et al. (2016)

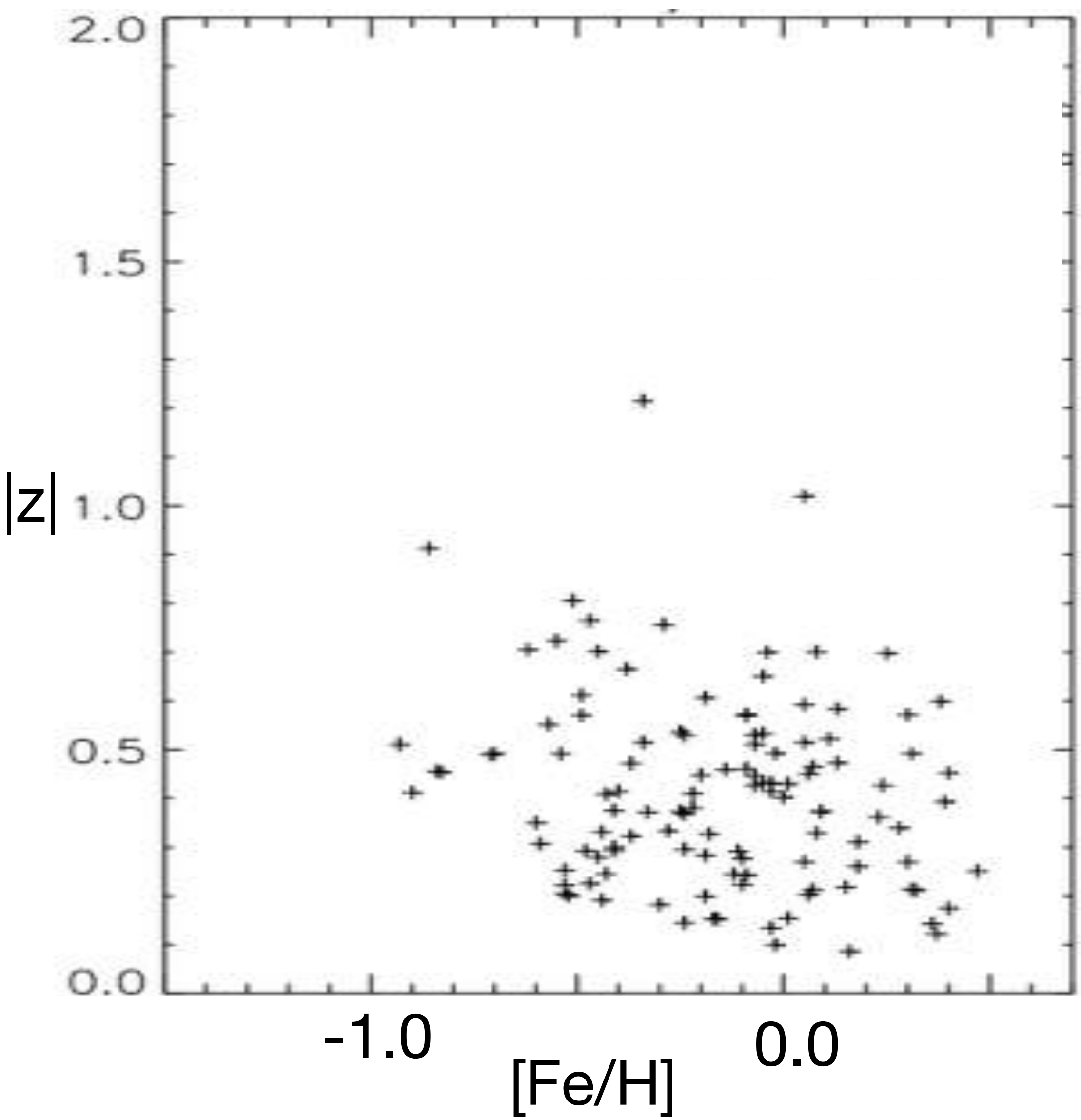
Radial migration drives a positive vertical metallicity gradient!

initially
no vertical
[M/H] gradient



Kawata et al. (2016)

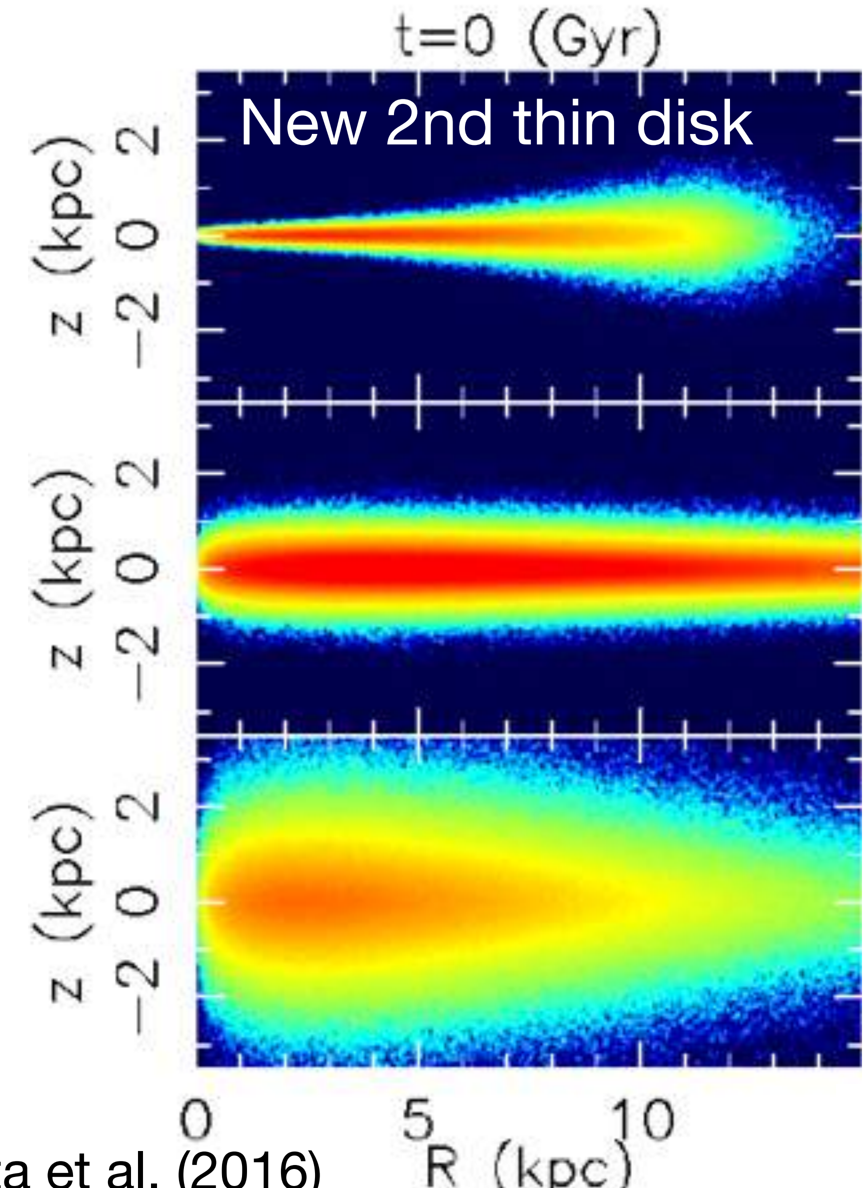
Vertical negative metallicity gradient
of mono-age population?
tough to study, need accurate age info.



3-5 Gyr populations
(Kepler asteroseismic age)
of Casagrande et al. (2016)

~−0.09 dex/kpc
preliminary analysis
by Luca Casagrande

A solution:
Flaring, increasing scale height, z_d, thin star forming disk



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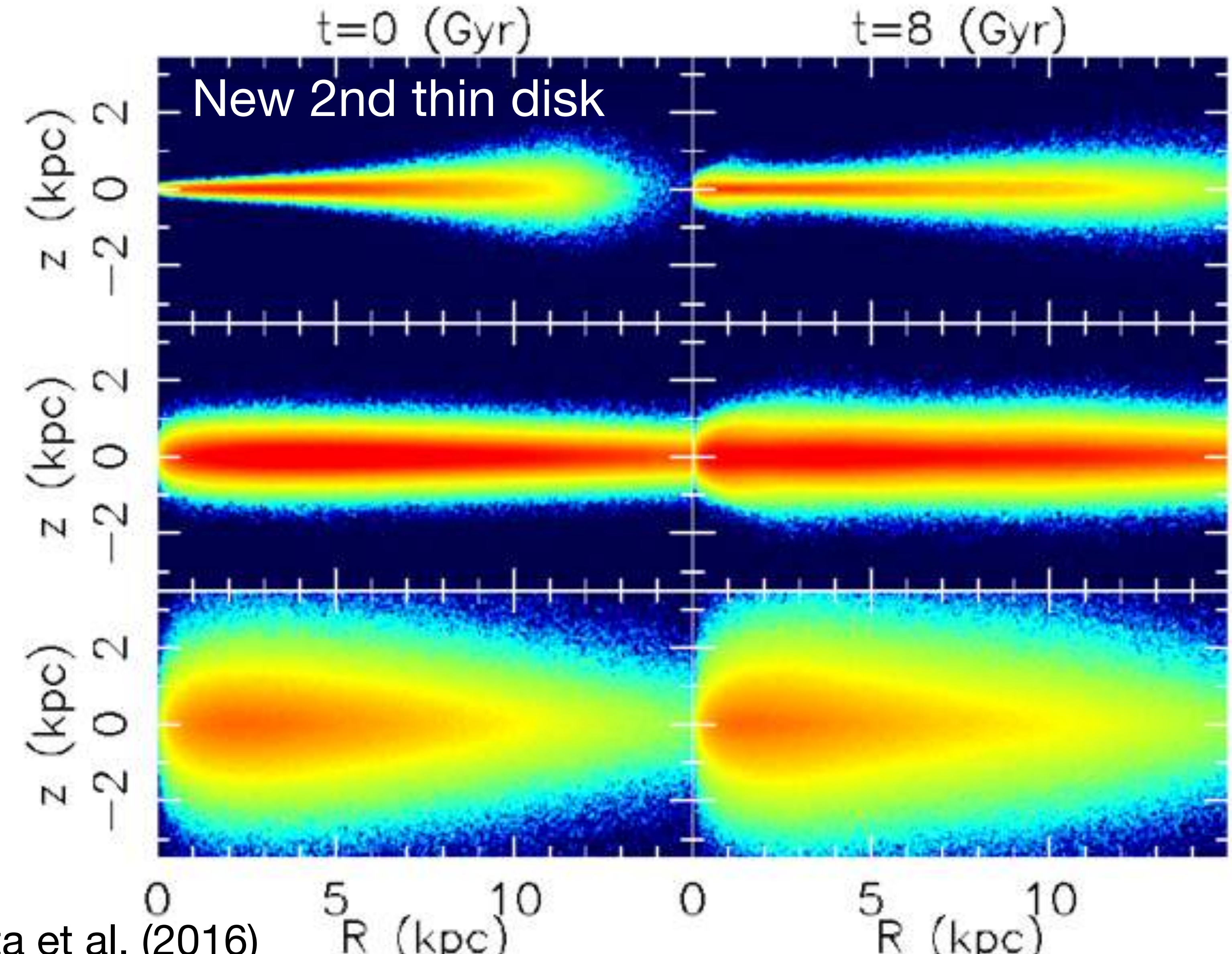
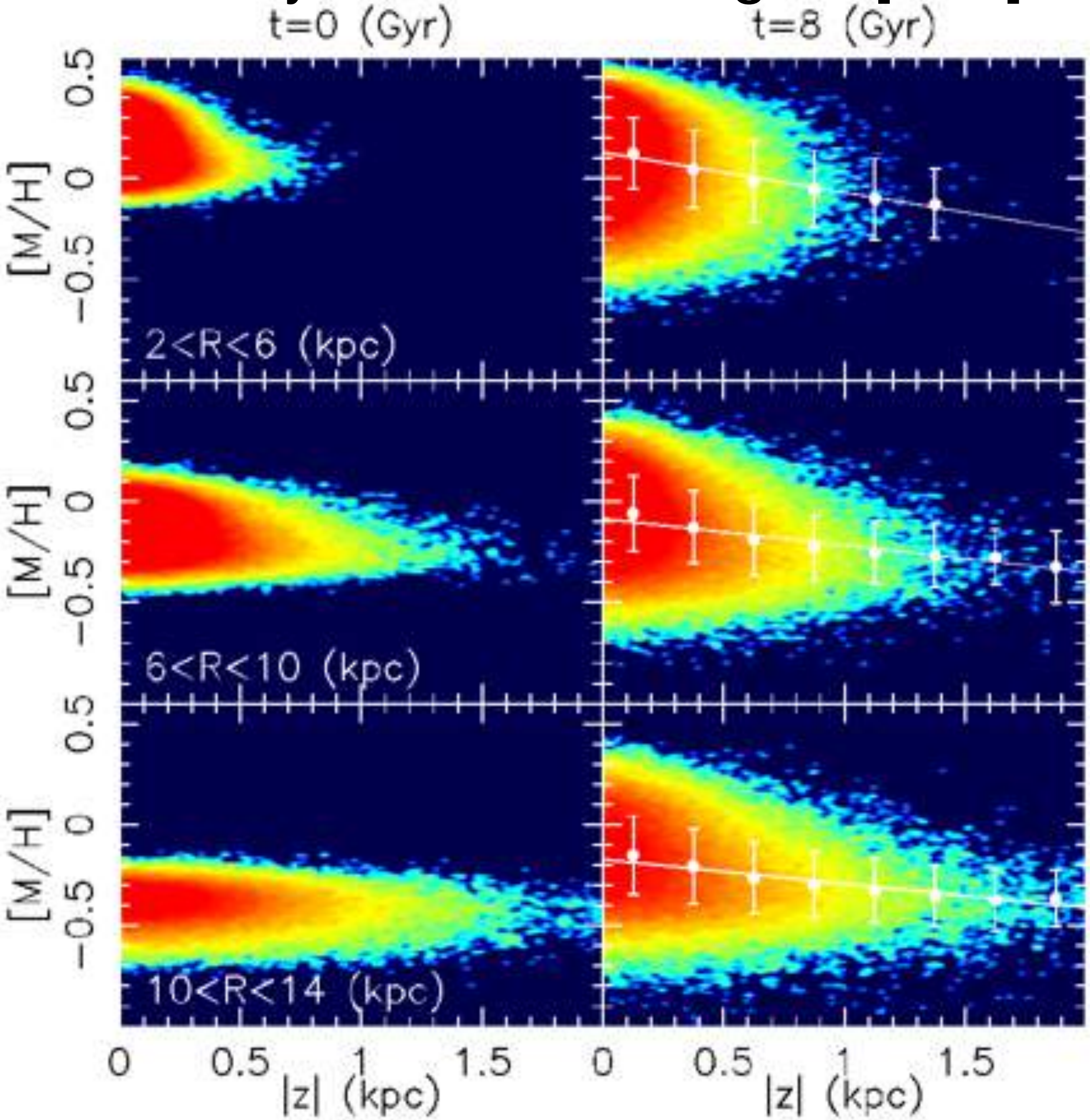


Kawata et al. (2016)

Negative vertical metallicity gradient for mono-age population!
(2nd flaring thin disk only)

initially set the same tight d[M/H]/dR=−0.08, d[M/H]/dz=0



vertical metallicity distribution of the flaring 2nd thin disk.

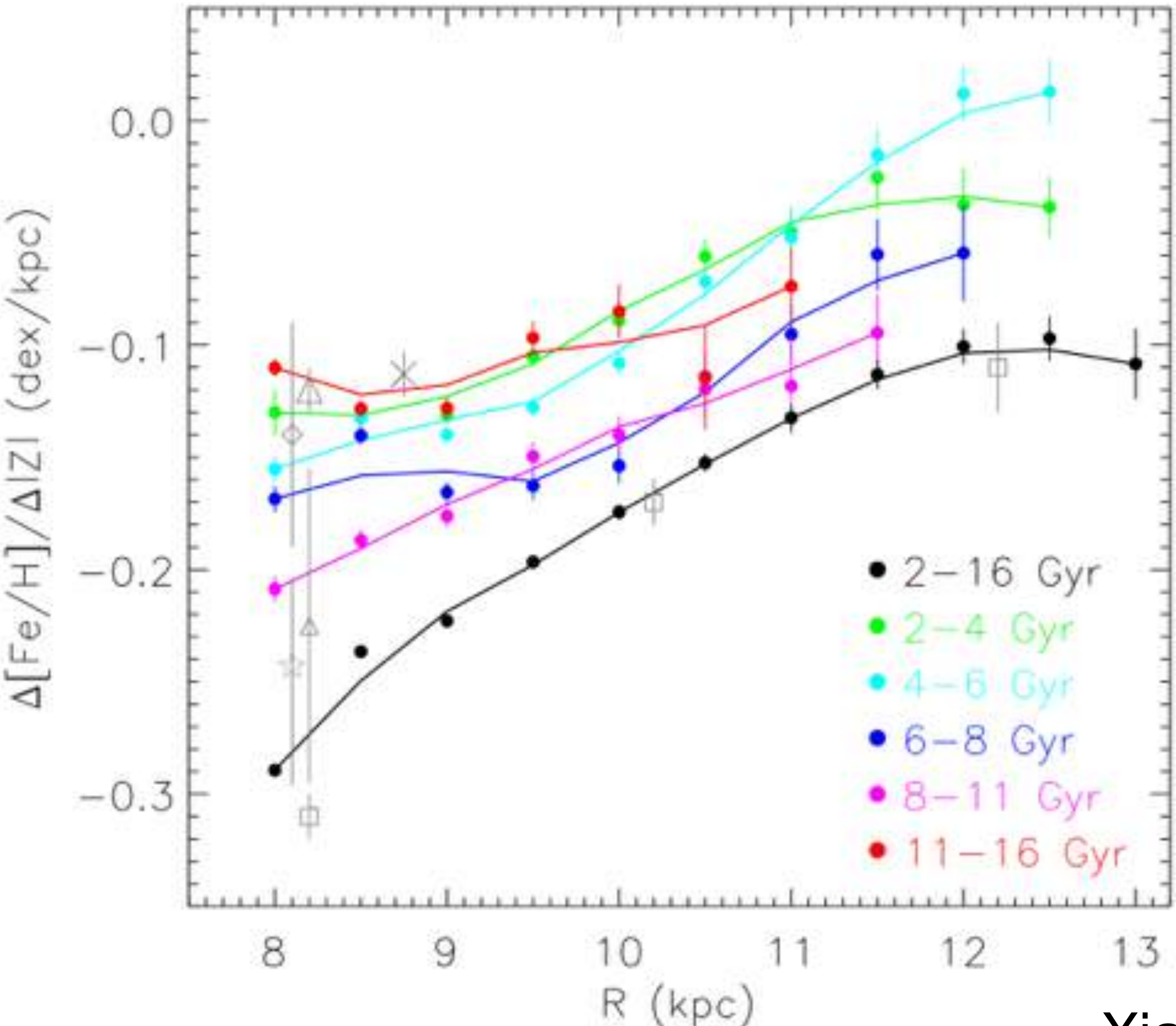
steeper vertical [M/H] gradient in the inner disk

⇧

Can be tested if we can sample mono-age population!

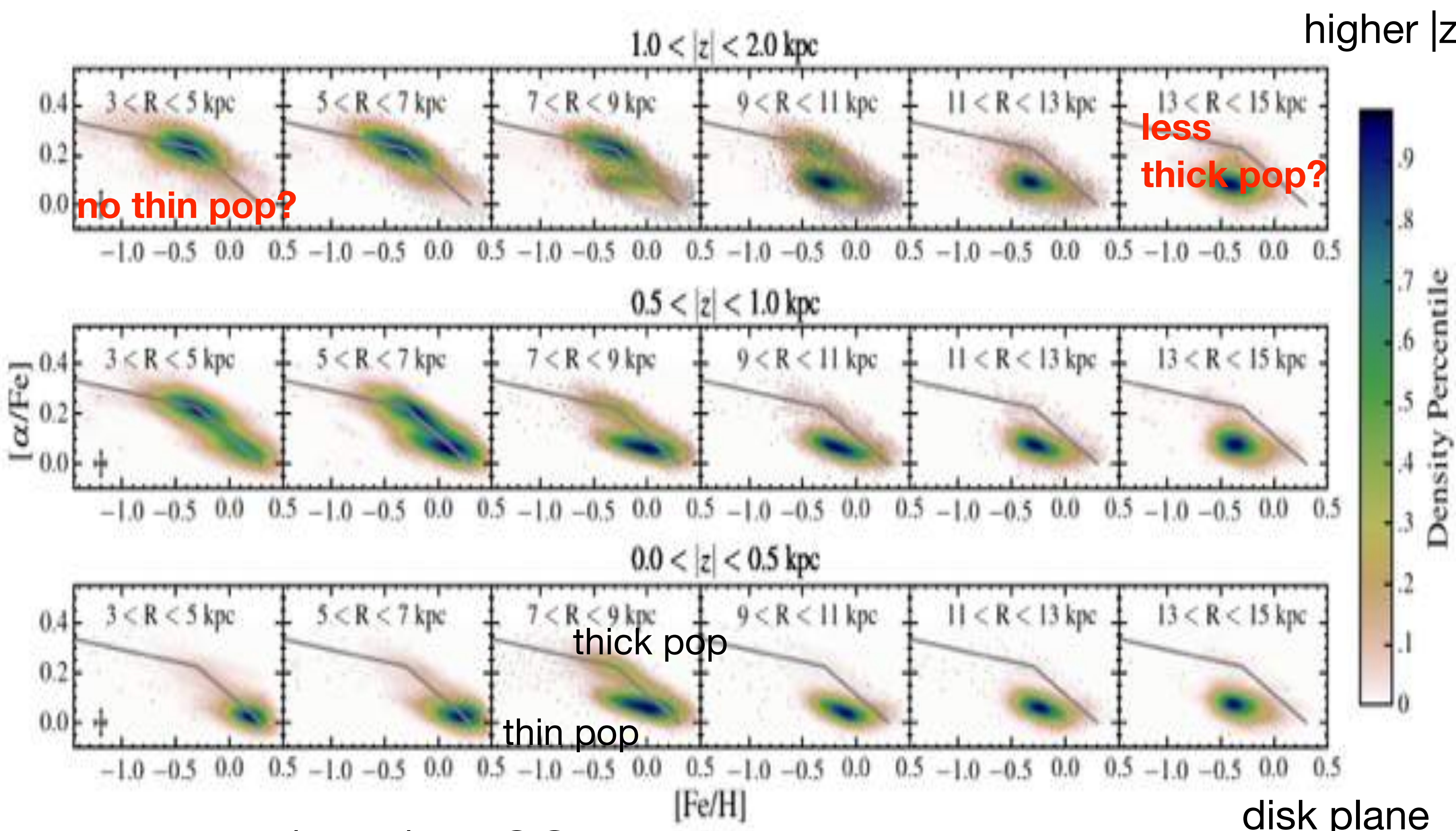
Kawata et al. (2016)

steeper vertical [M/H] gradient in the inner disk
for mono-age populations
seen in LAMOST turn-off stars!



Xiang et al. (2015)

Contact thick disk and larger flaring thin disk



Hayden et al. (2015) APOGEE

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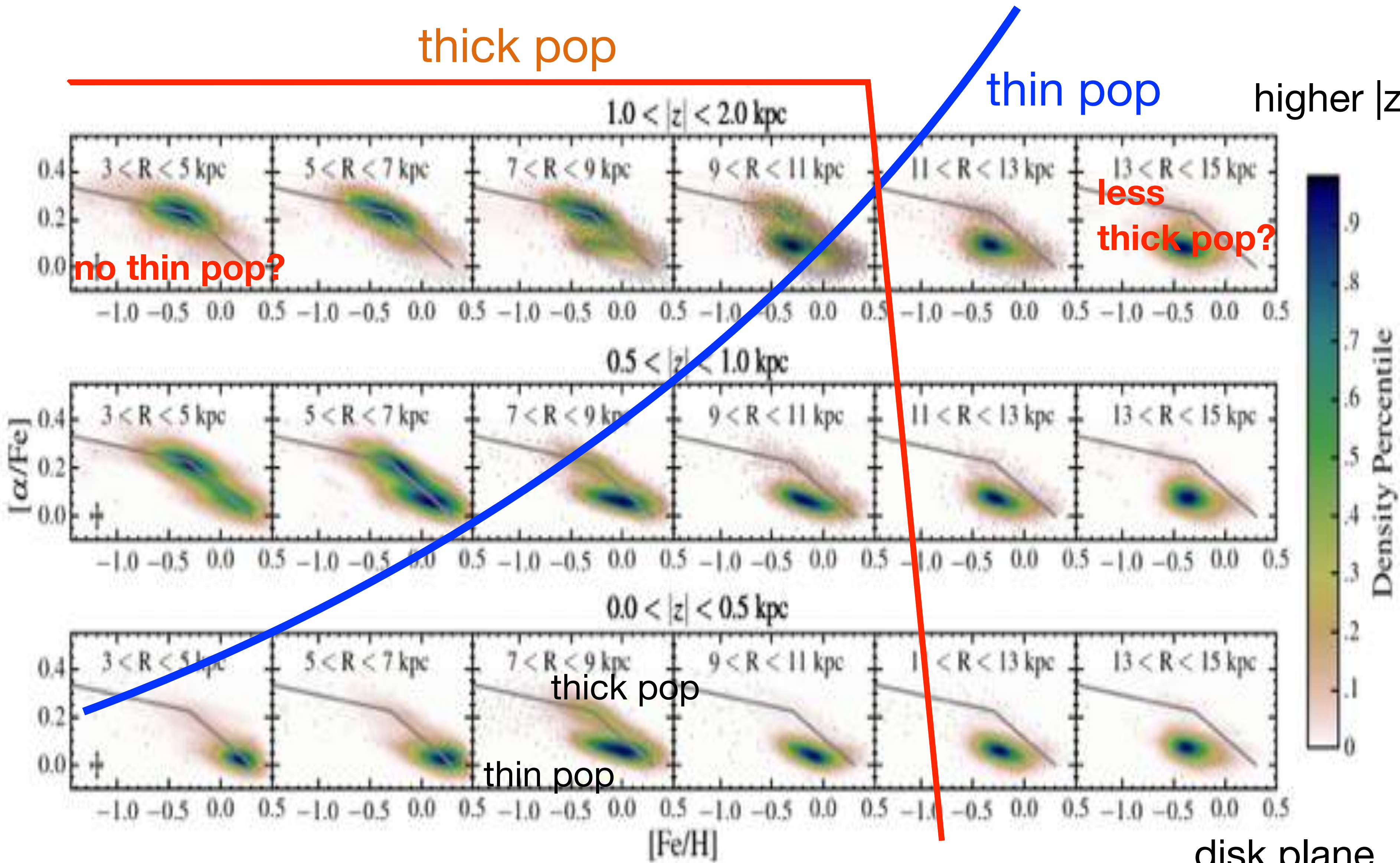
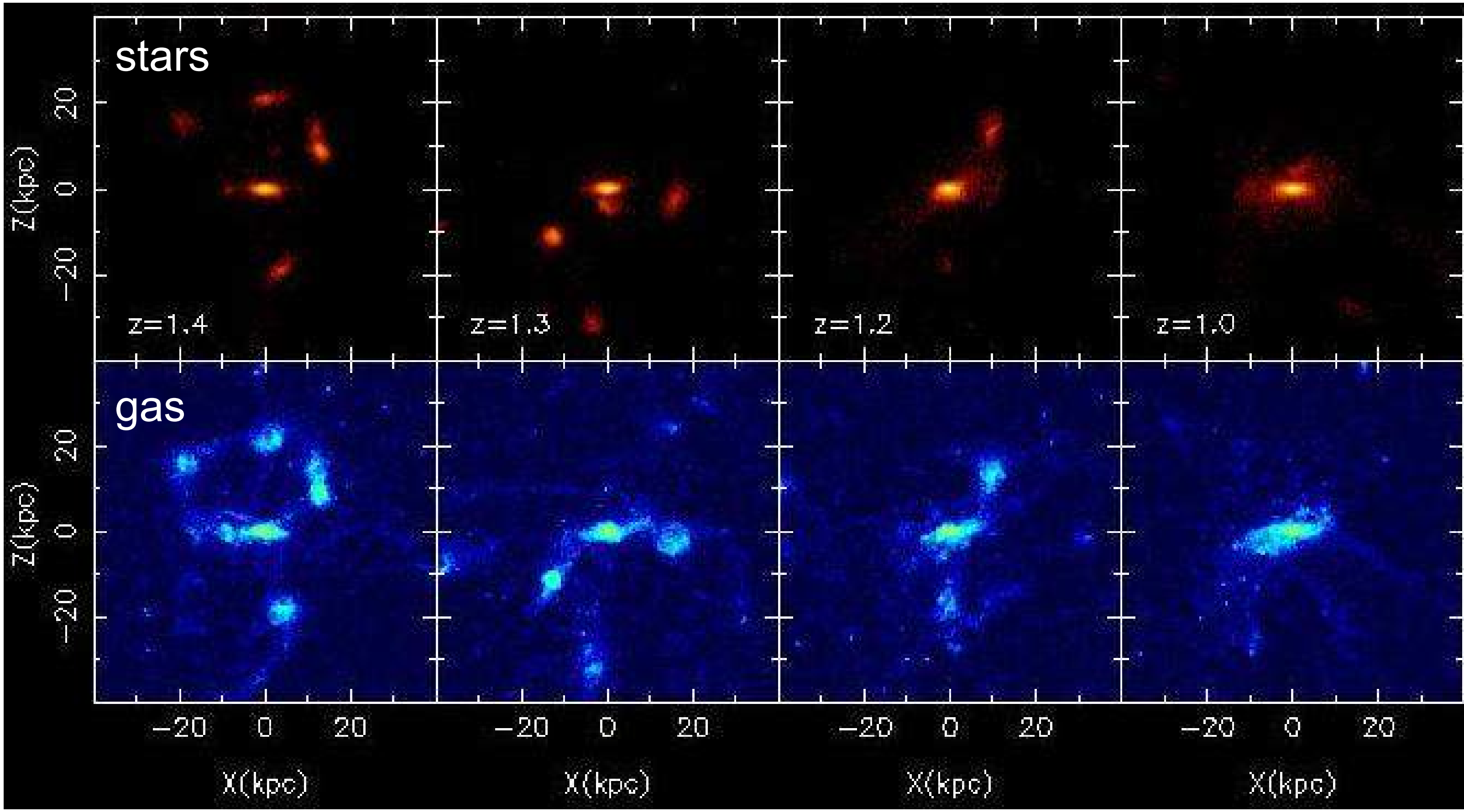


Hayden et al. (2015) APOGEE

Compact older thick disk and younger flaring larger thin disk

consistent with Book et al. (2004) thick and thin disk formation scenario!

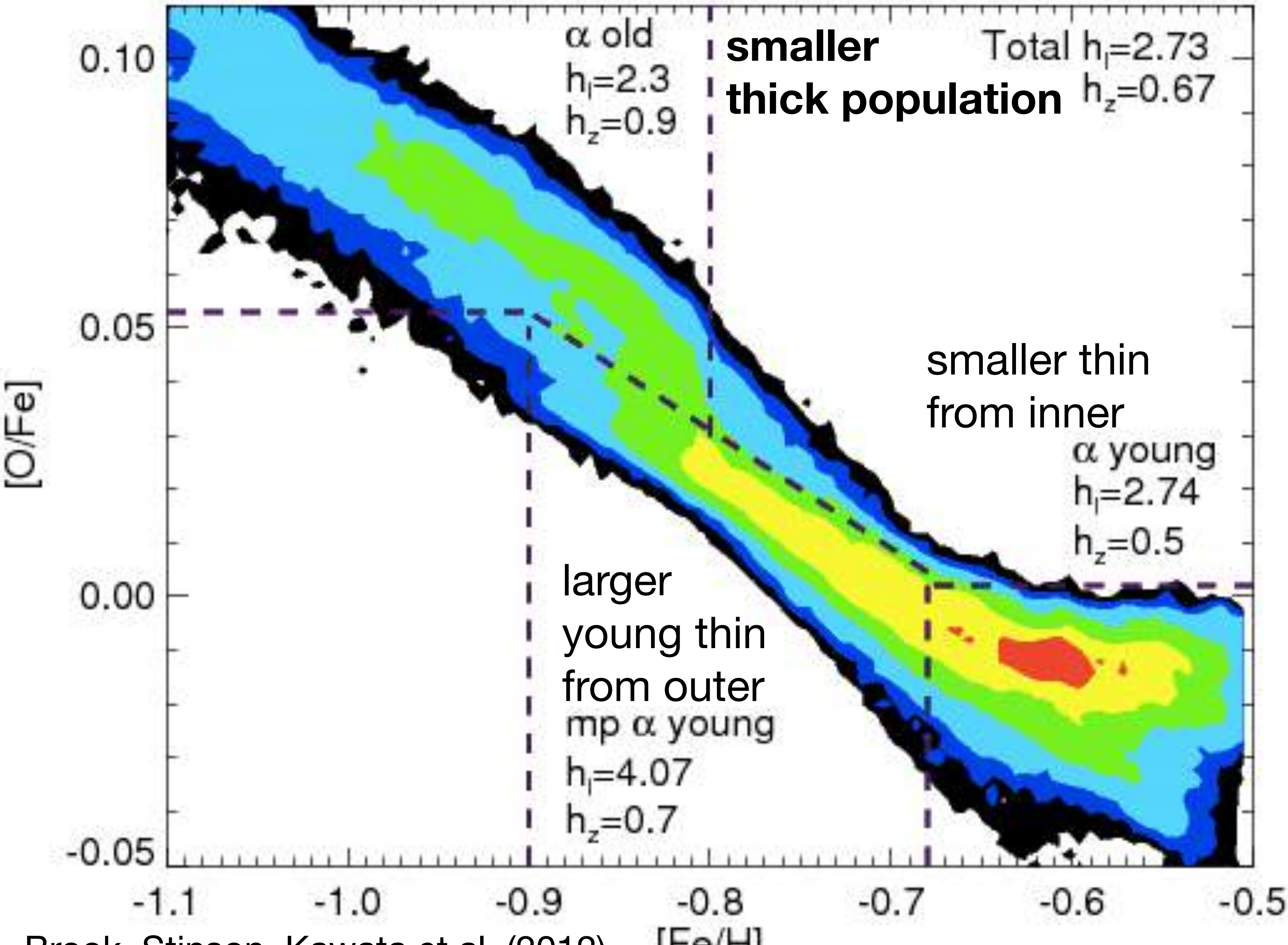
In-situ high-z thick disk formation in CDM Universe
(Brook, Kawata, Gibson, Freeman 2004)



thick disk←kinematically hot gas disk
during multiple gas rich mergers of building blocks at z>1
before the formation of the thin disk.

Smaller and older thick disk (Brook, Kawata et al. 2006)

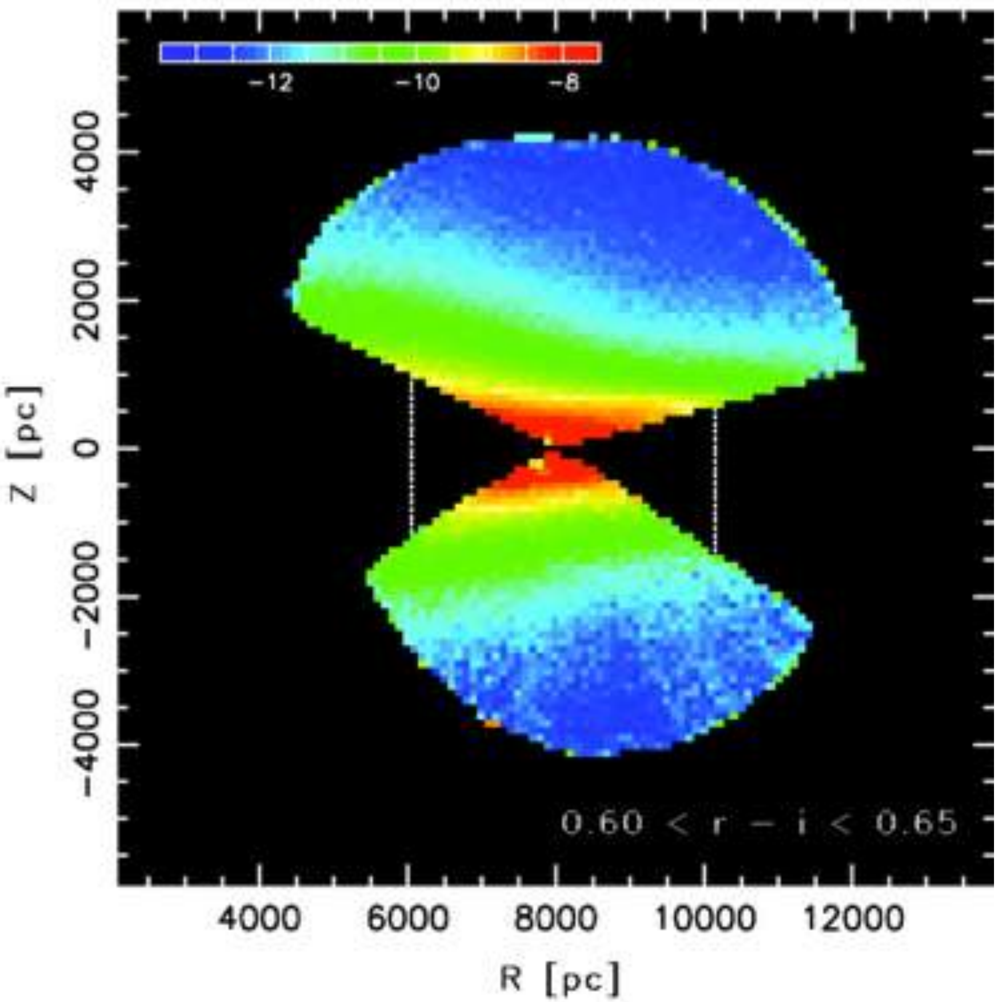
Consistent with more recent works (Bird, Stinson, Minchev…)



Brook, Stinson, Kawata et al. (2012)

“Geometrically” thick disk bigger than thin disk?

(Juric et al. 2008, SDSS Milky Way Tomography)

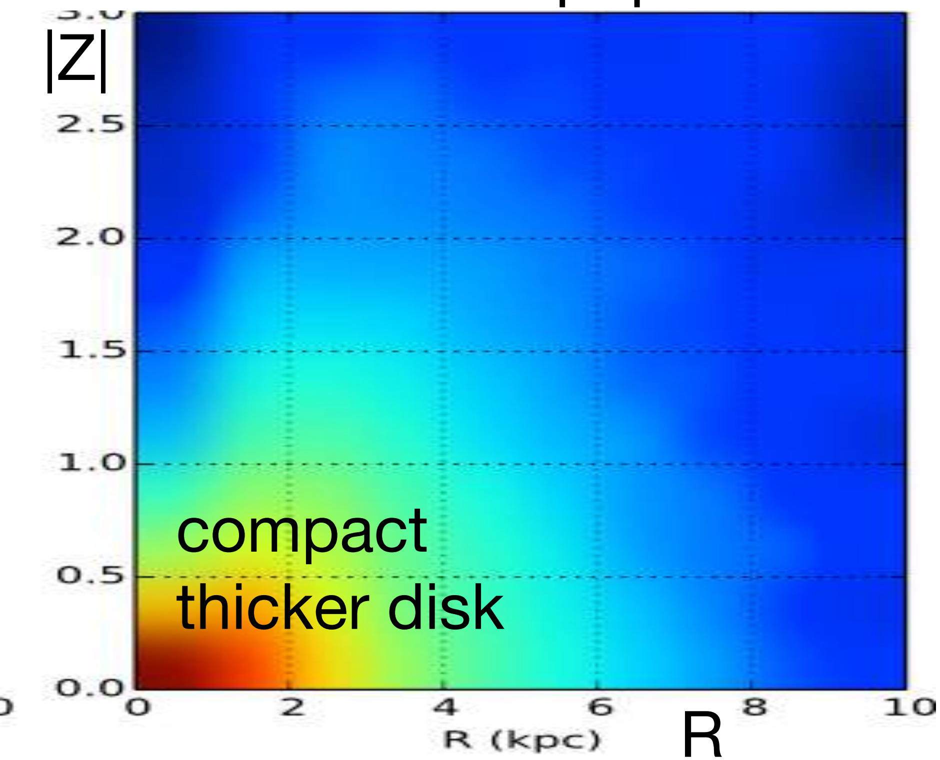


	Scale Length	Scale hight
thick	3.6 kpc	0.9 kpc
thin	2.6 kpc	0.3 kpc

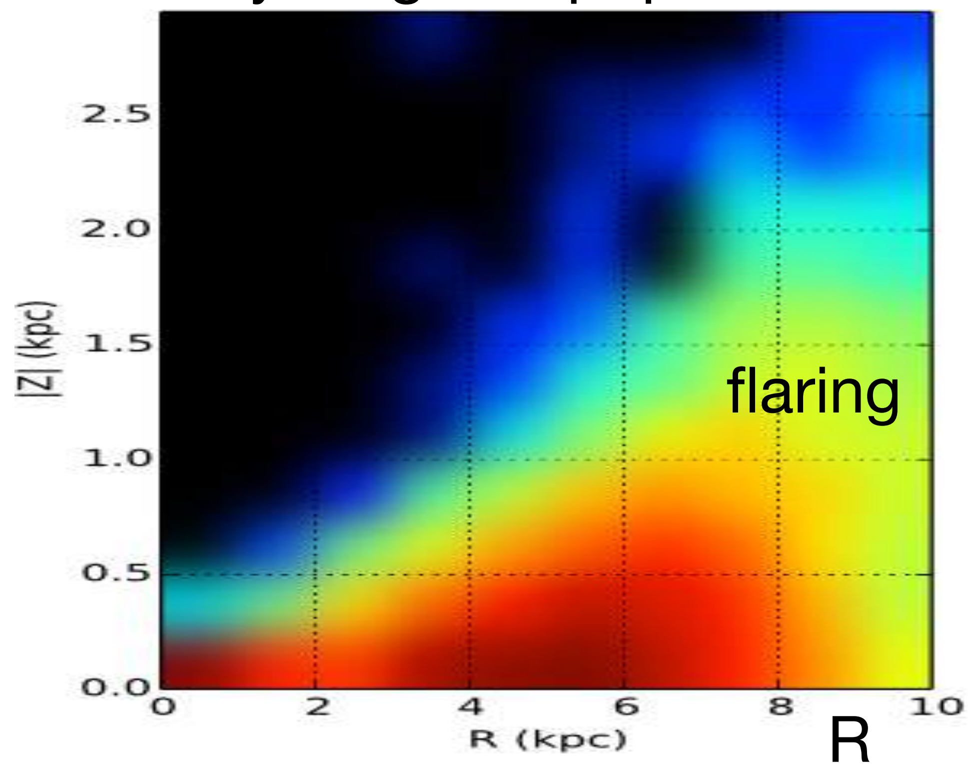
Focus on geometric structure of all the population.
Not considering chemical properties.

Compact thick + thin populations flaring at the outer radius
= large geometric thick disk

old thick population



young thin population



Numerical simulation in Rahimi, Carrell, Kawata (2014)
positive d[Fe/H]/dR and **negative d[α/Fe]/dR** at high |z|
(see also Bensby et al. 2011, Minchev et al. 2015)

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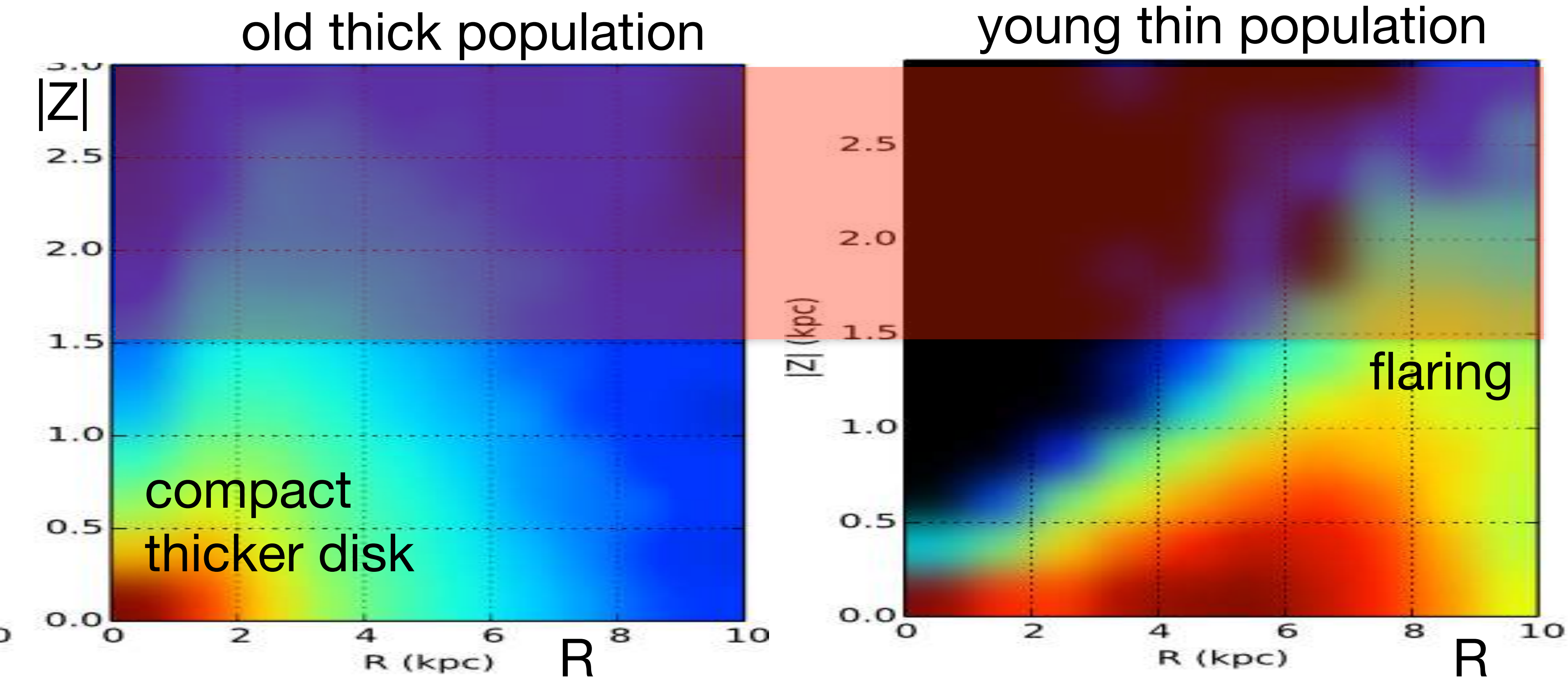

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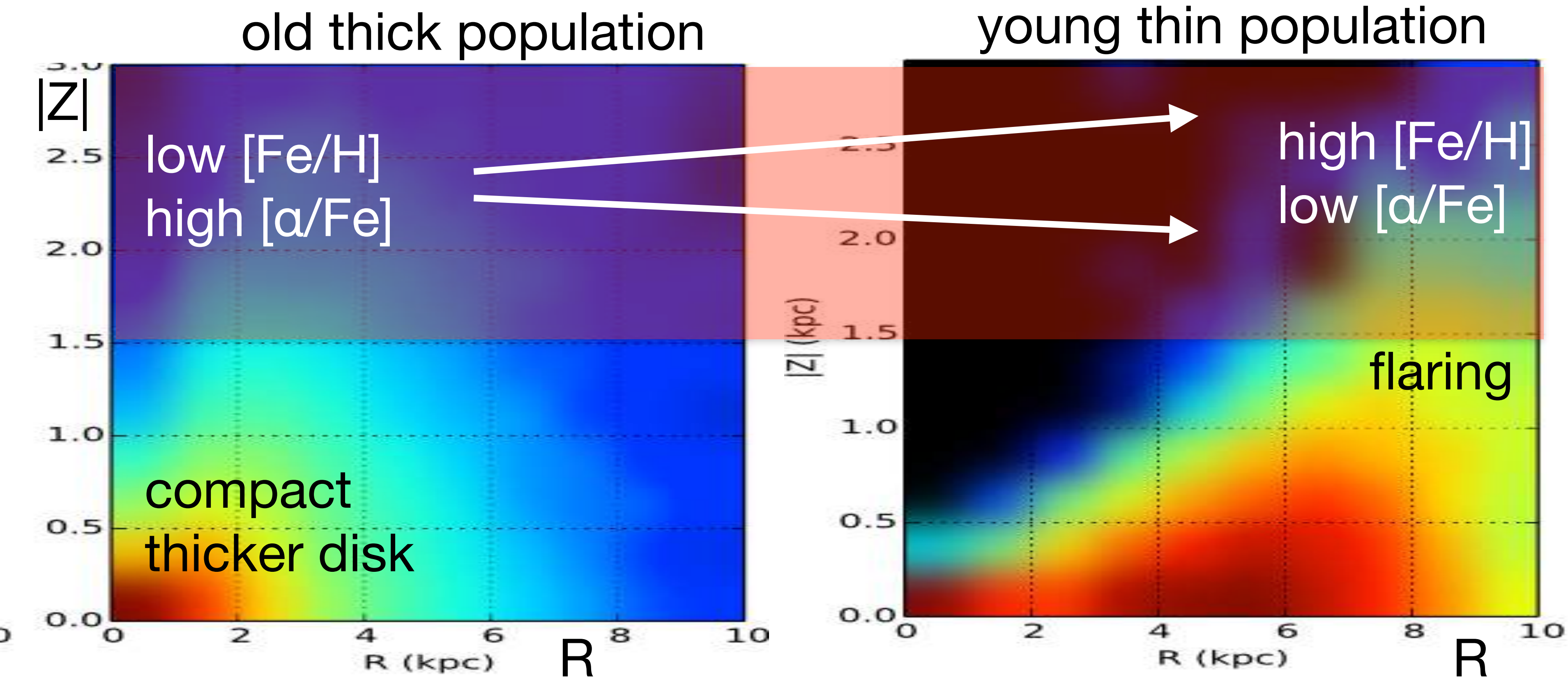

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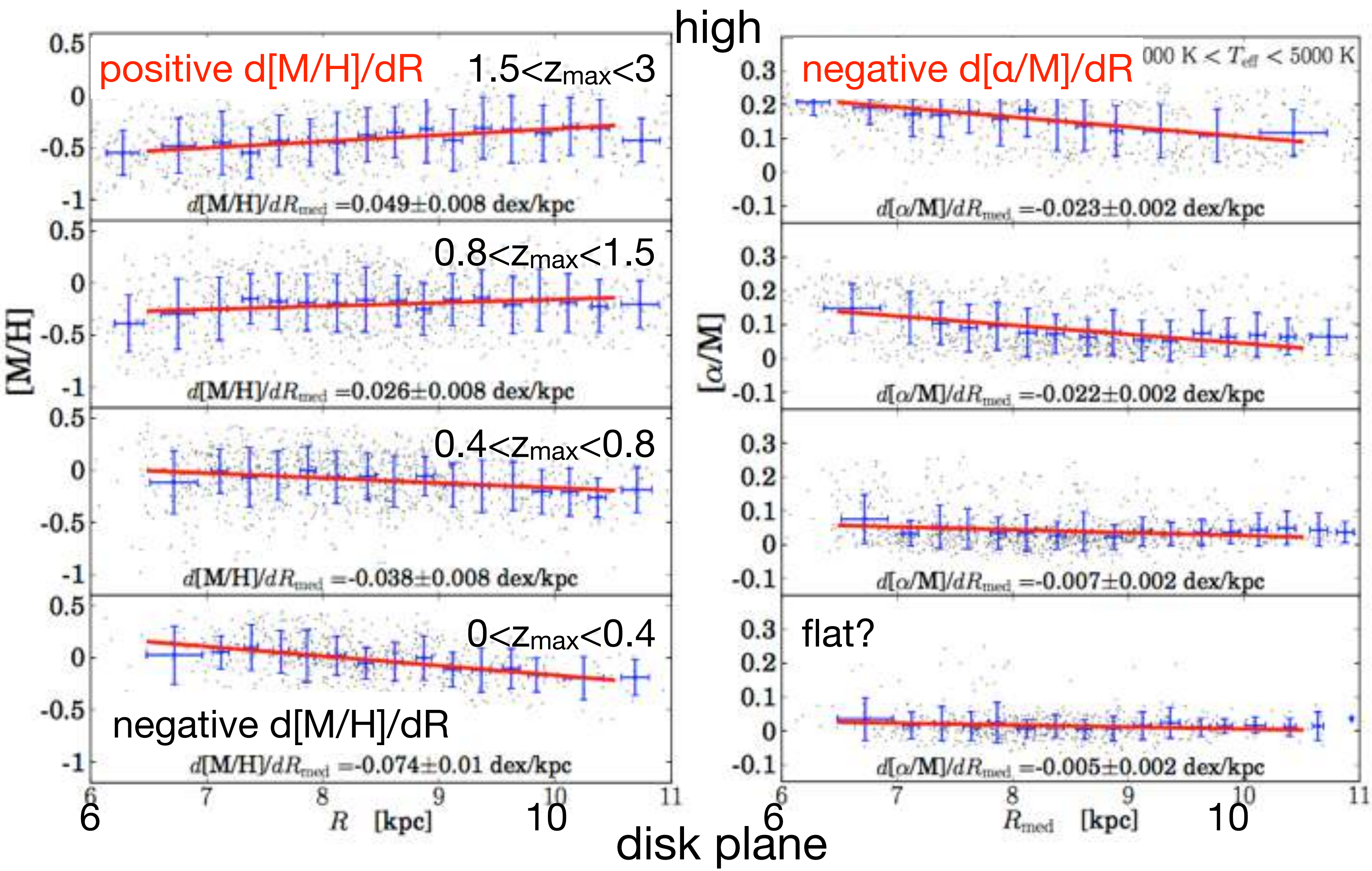
e.g. Anders et al. (2014): APOGEE



Summary

- If the scale height is constant, radial migration drives a positive vertical metallicity gradient.
- Flaring star forming region is a possible explanation of negative vertical metallicity gradient of the mono-age population.
- Flaring thin disk population can explain larger geometrically thick disk and positive (negative) radial [M/H] ([α/Fe]) gradient at high vertical height with Brook et al. (2004) disk formation scenario

Structure (Gaia) and metallicity (spectroscopy) distribution of the mono-age (asteroseismology) population of the disk will be a crucial information for disk formation scenario!

Gaia + spectroscopic surveys + K2 and future Plato!