Radial Migration in Spiral Galaxies

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University of Zürich

stars without borders

radial migration in spiral galaxies

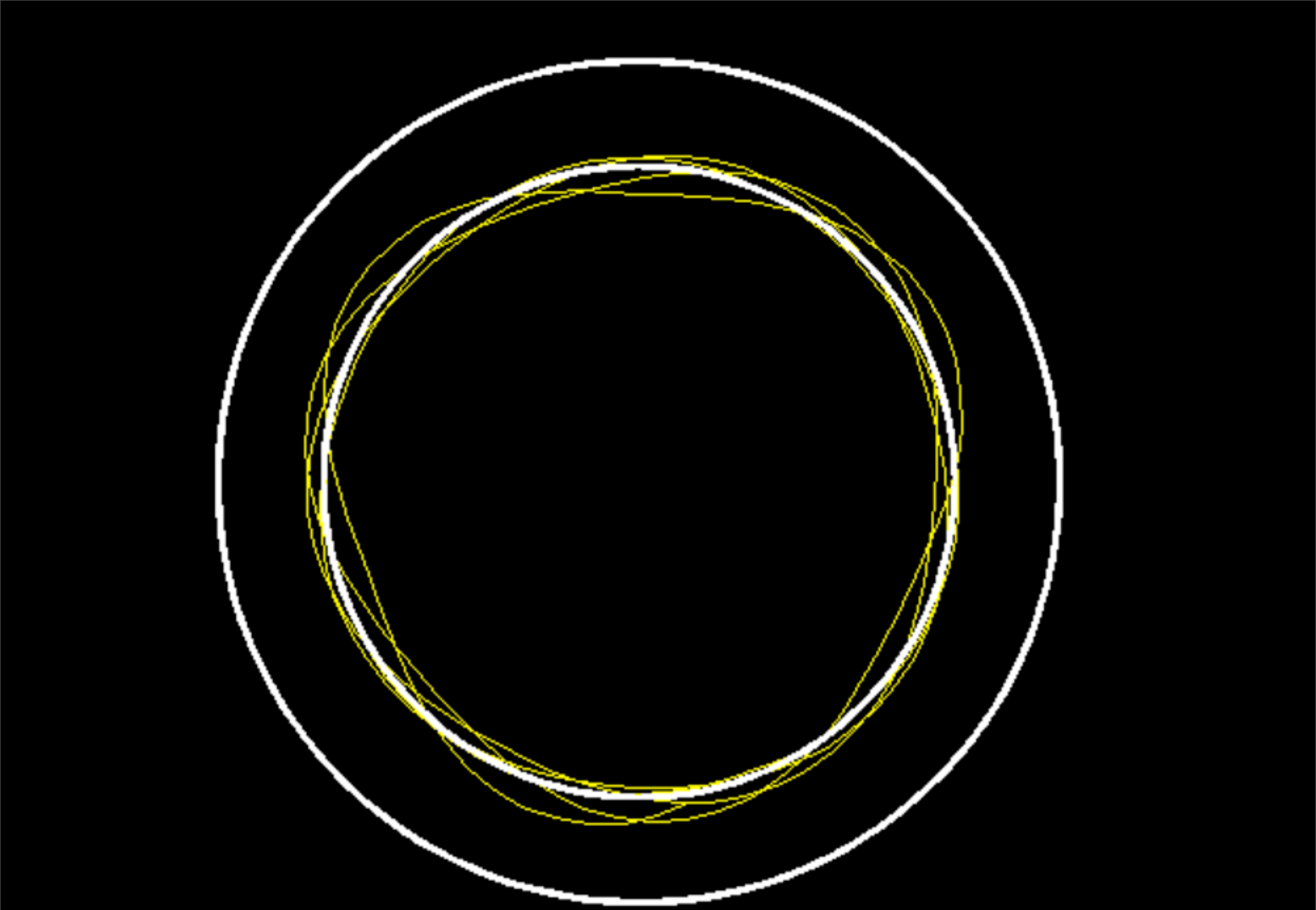
may 21-24, 2012

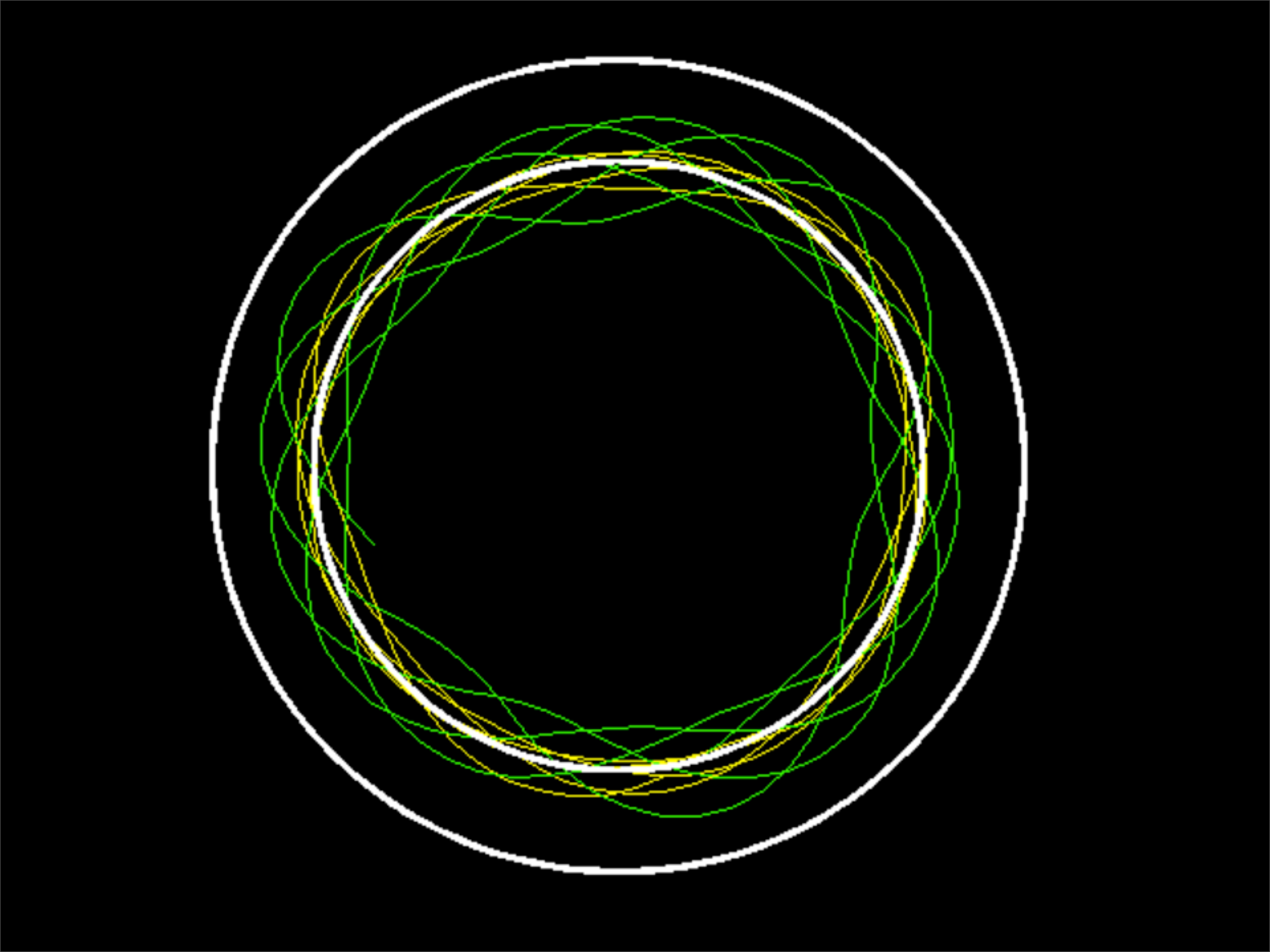
medana, slovenia

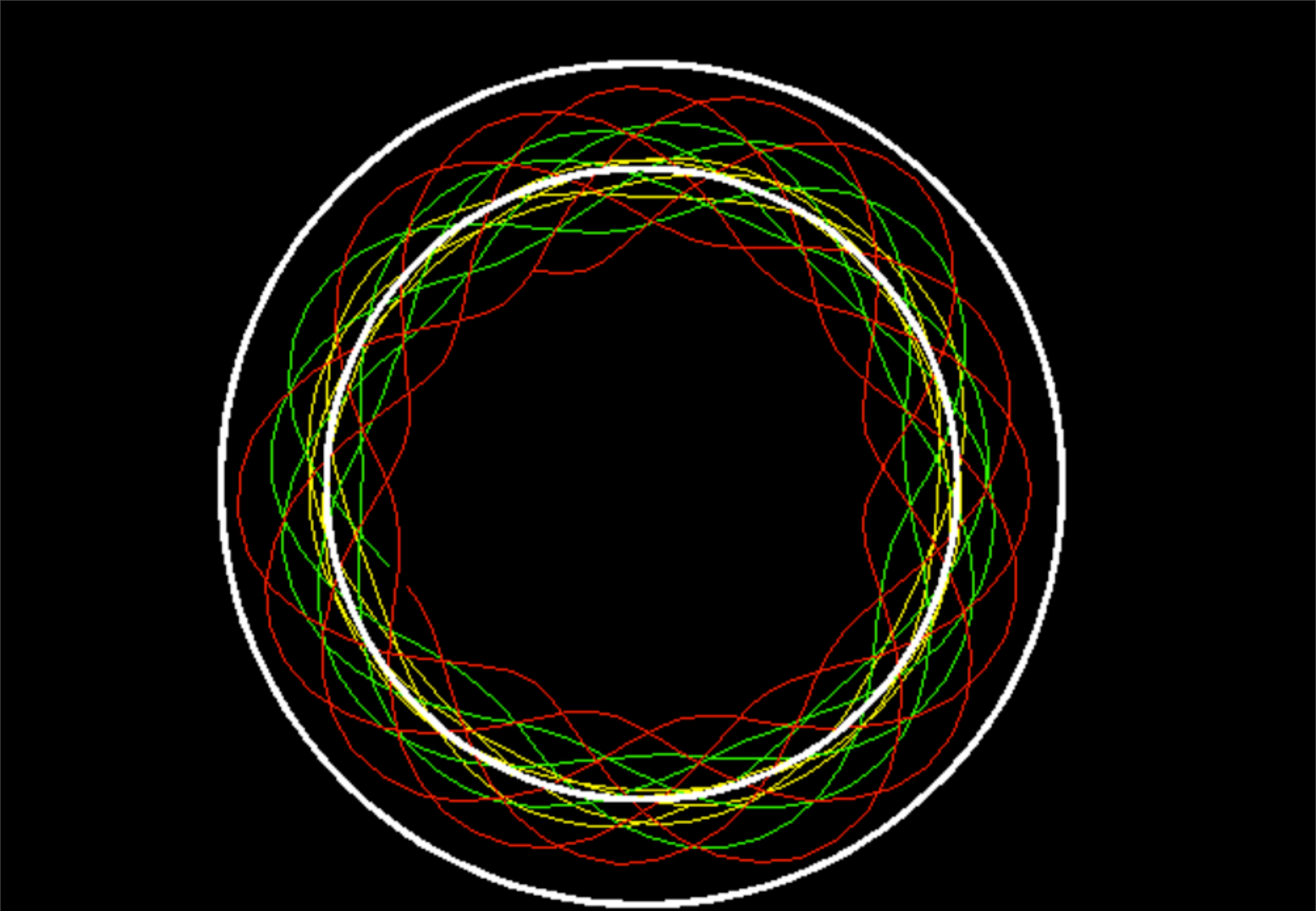
The workshop will take place in the picturesque Goriška Brda wine growing region of Slovenia. The main workshop venue will be at the Belica farm house in the quaint village of Šmartno and Kozana (page only in Slovene...)

We hope that the natural beauty of the surroundings, exceptional food and local hospitality will provide a stimulating atmosphere for the workshop. We will provide further information with regards to arrival, lodging, meals, and transportation in due course.

http://www.itp.uzh.ch/~roskar/migration_workshop/

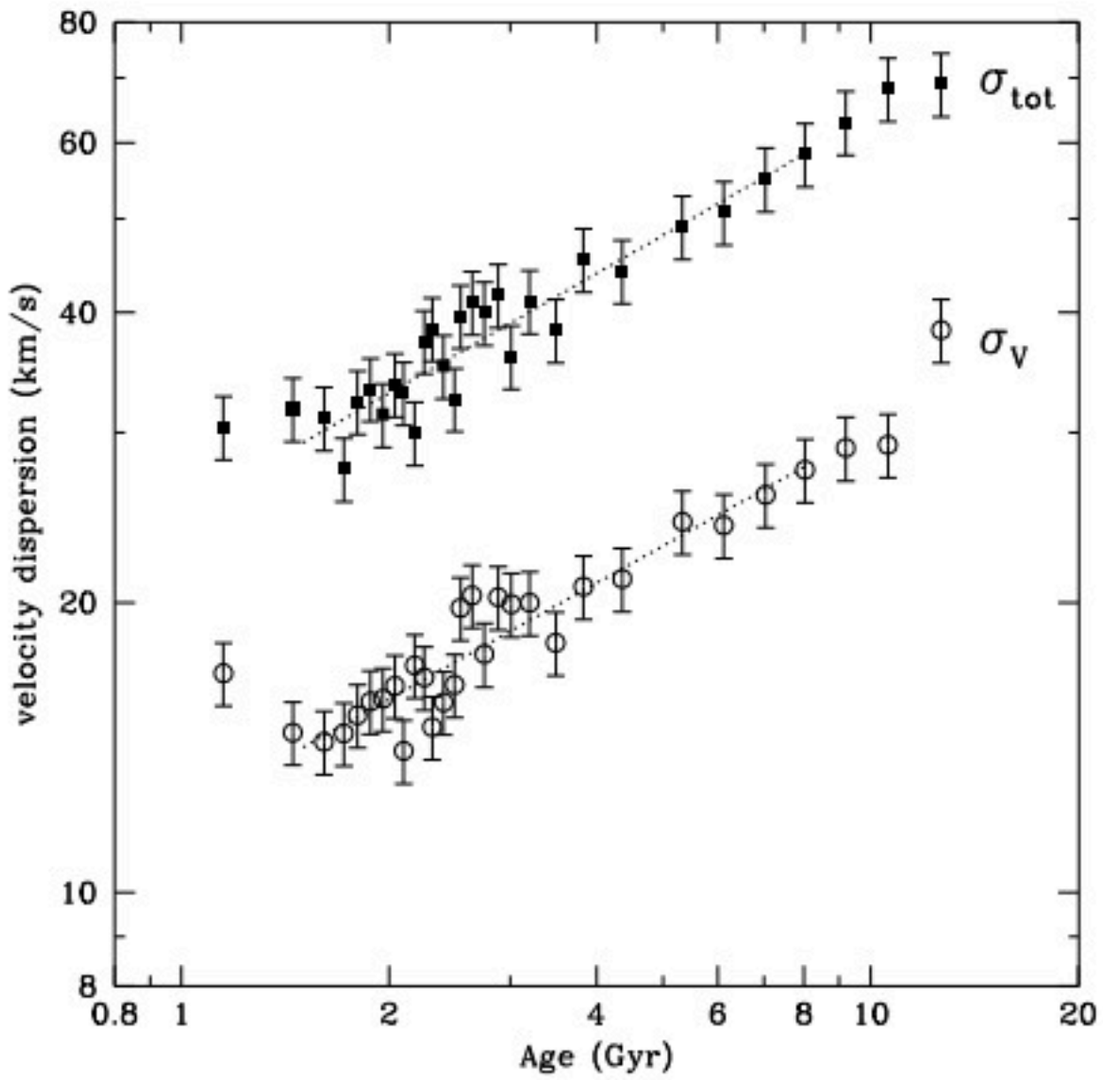


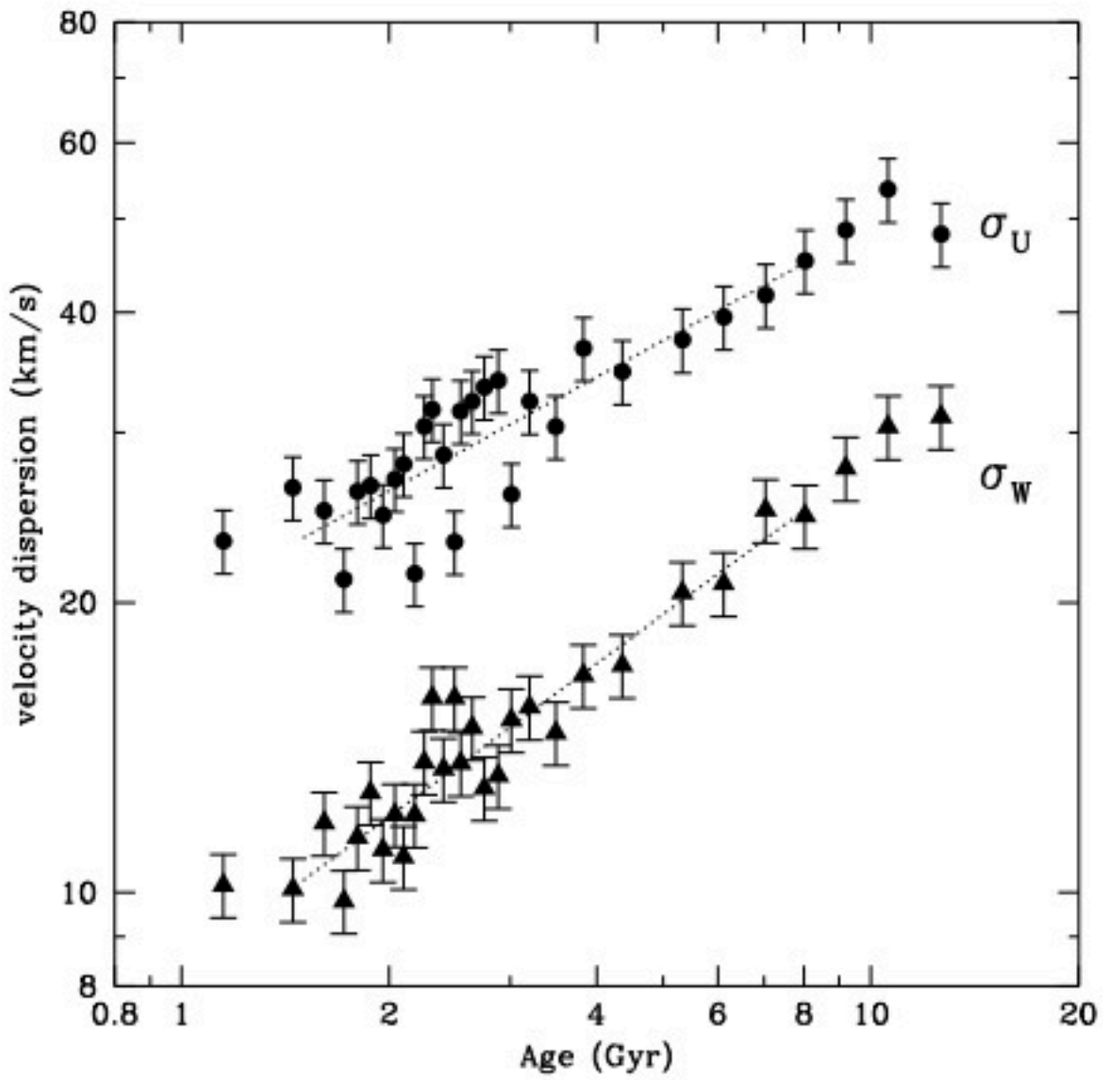




Radial Oscillations Limited by Observations of vel. Dispersion

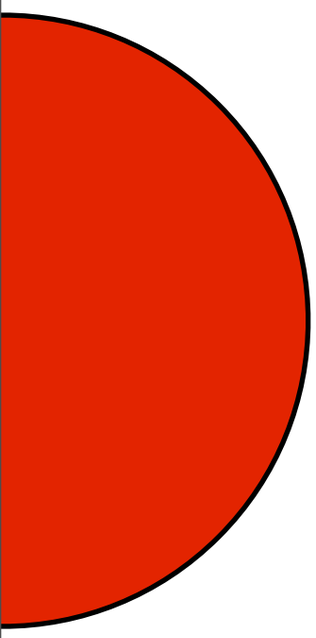
$$\Delta R \simeq \sqrt{2}\sigma_R/\kappa = 1.3 \text{ kpc}$$





GCS - Holmberg et al. 2009

Crucial assumption of the past several decades of disk modeling!



e.g. Tinsley 1975, Francois & Matteucci 1993, Chiappini+ 1997, Boissier & Prantzos 2001 etc.

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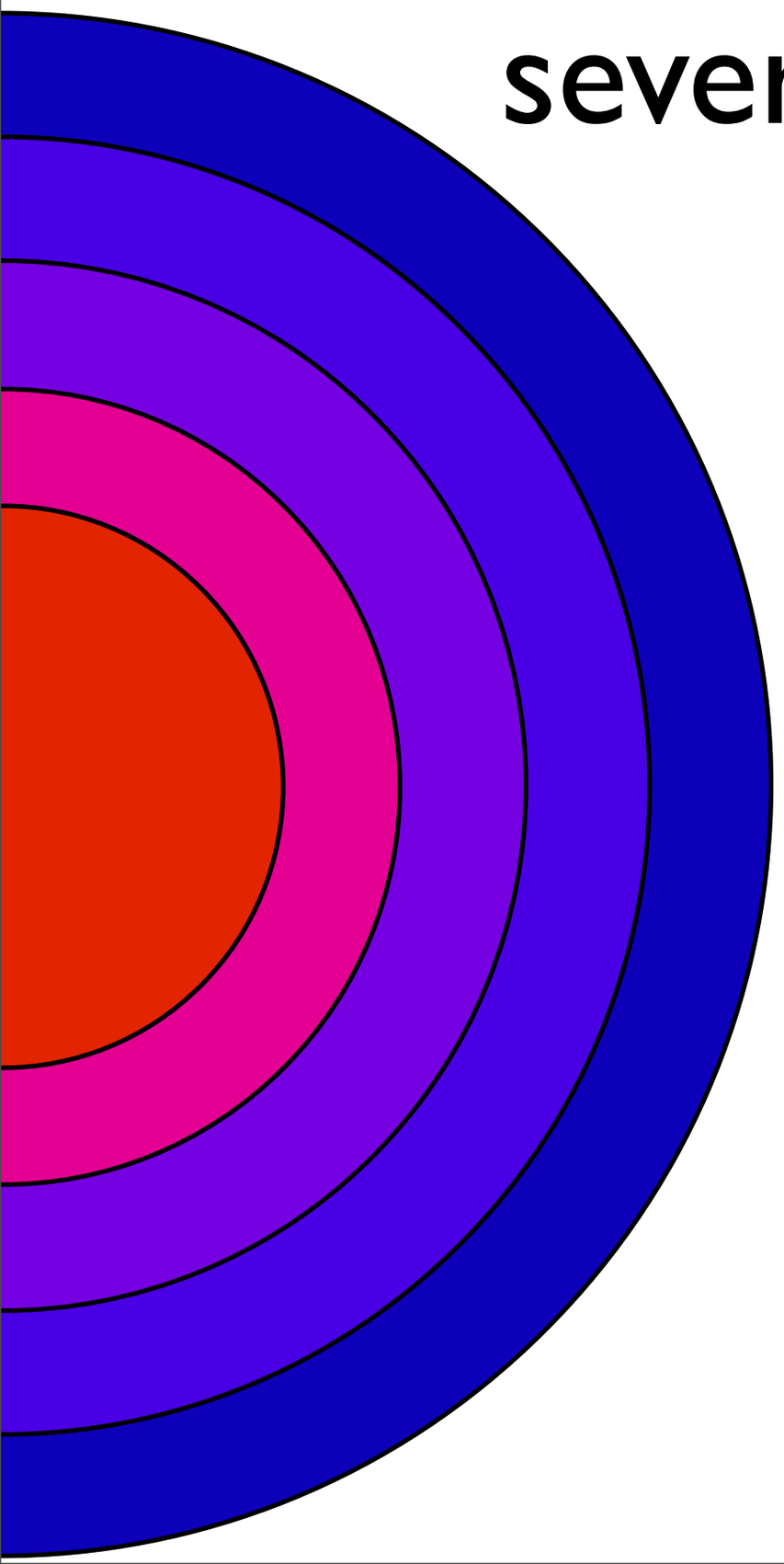

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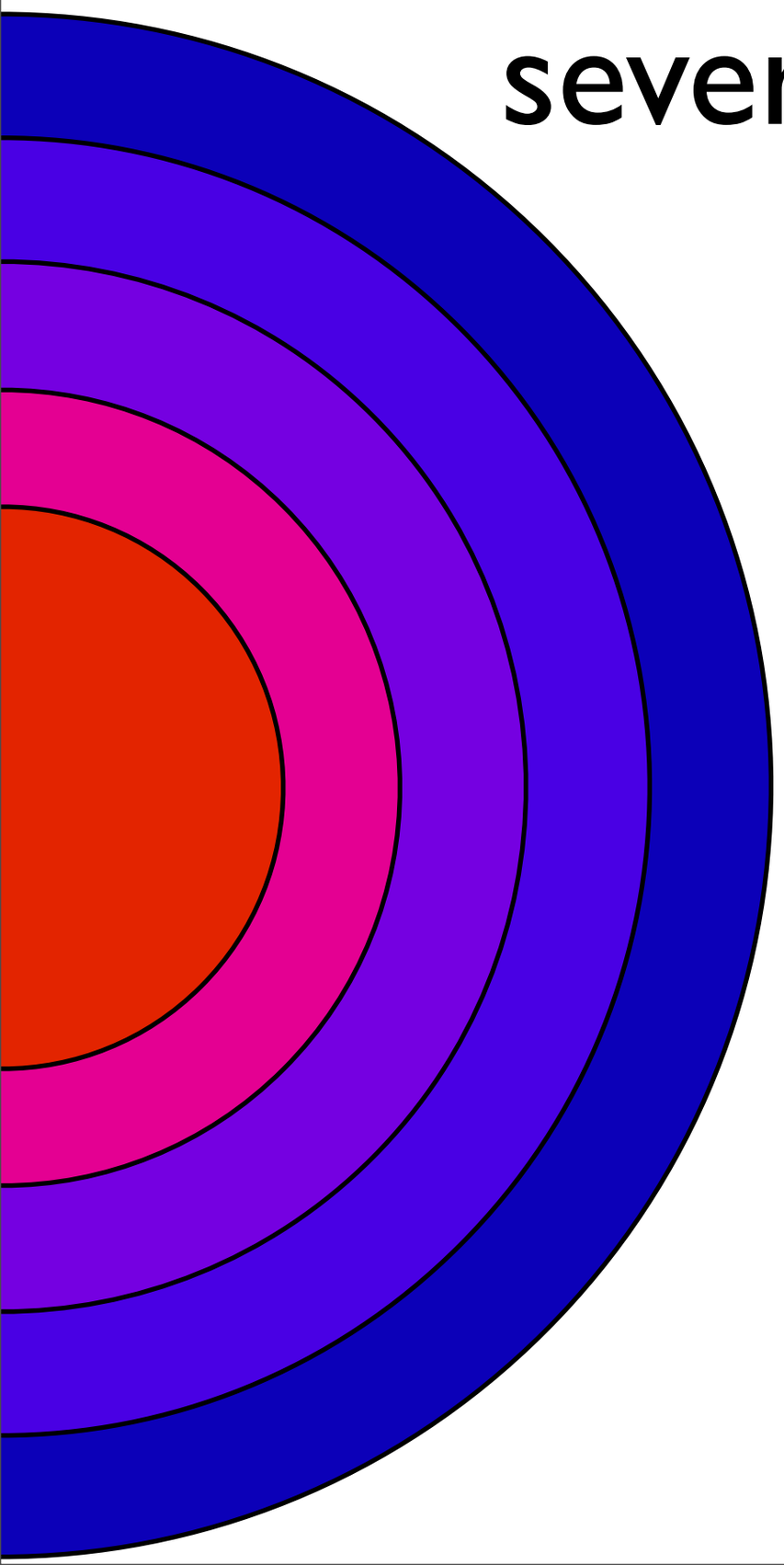

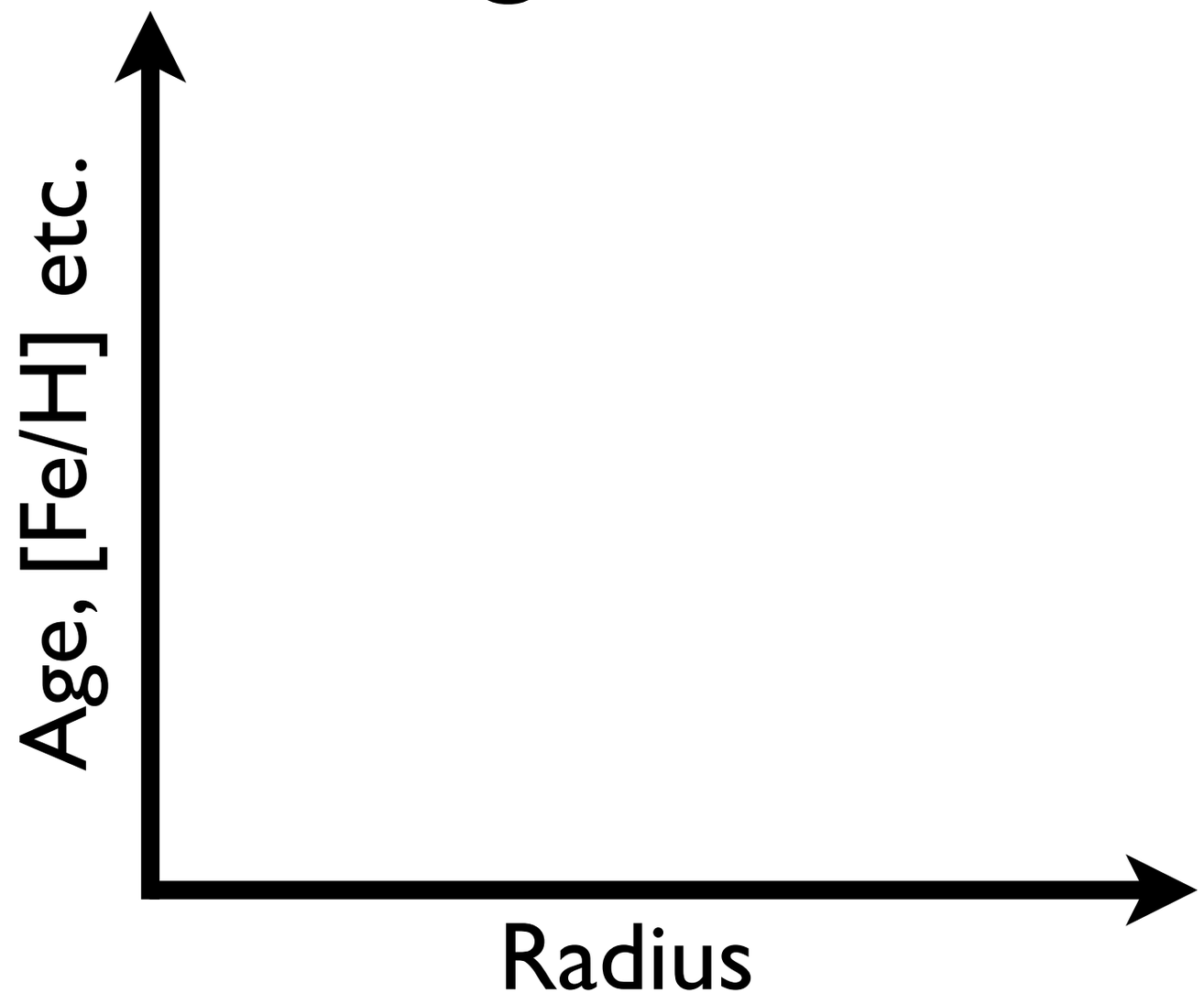

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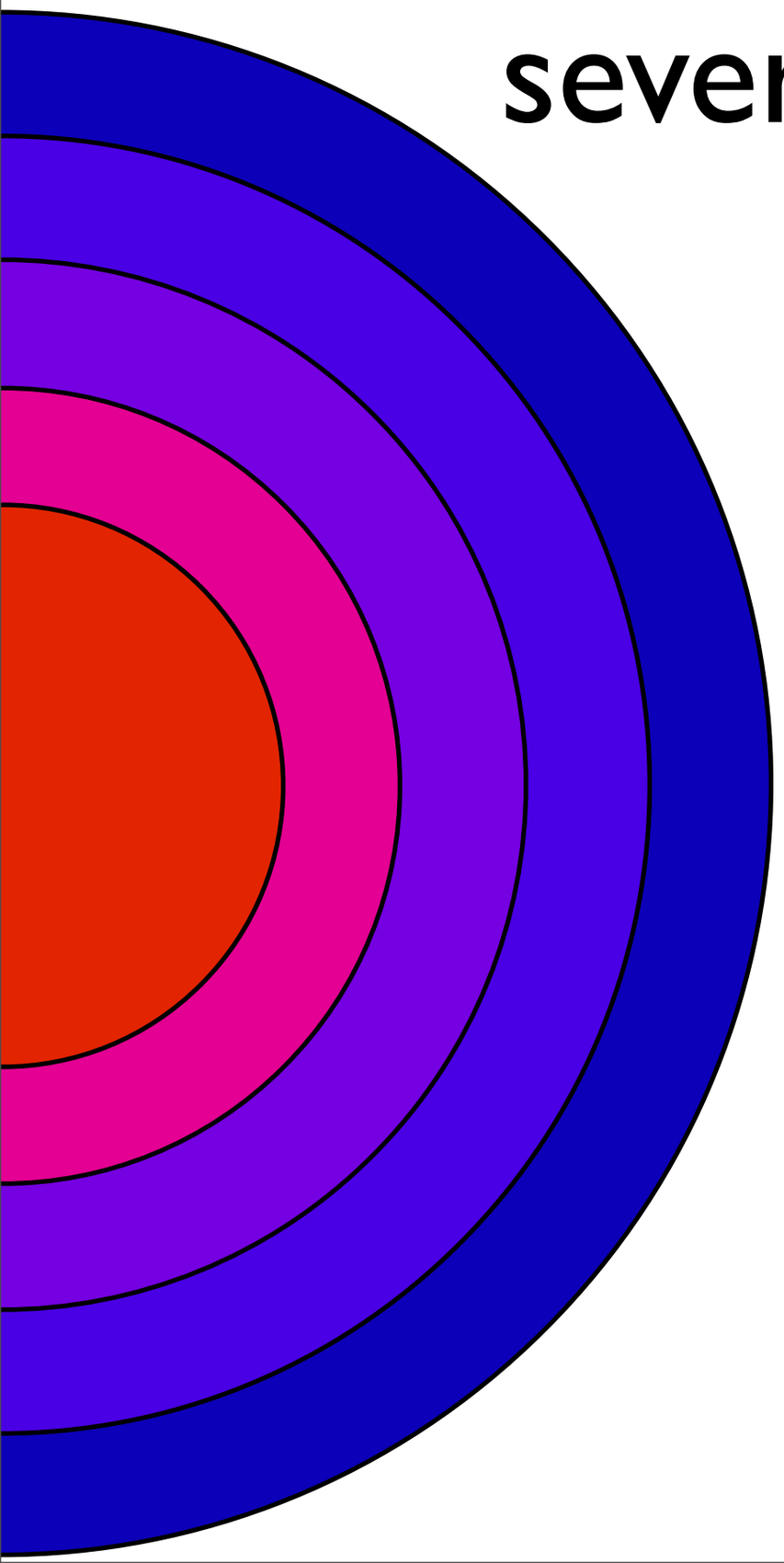
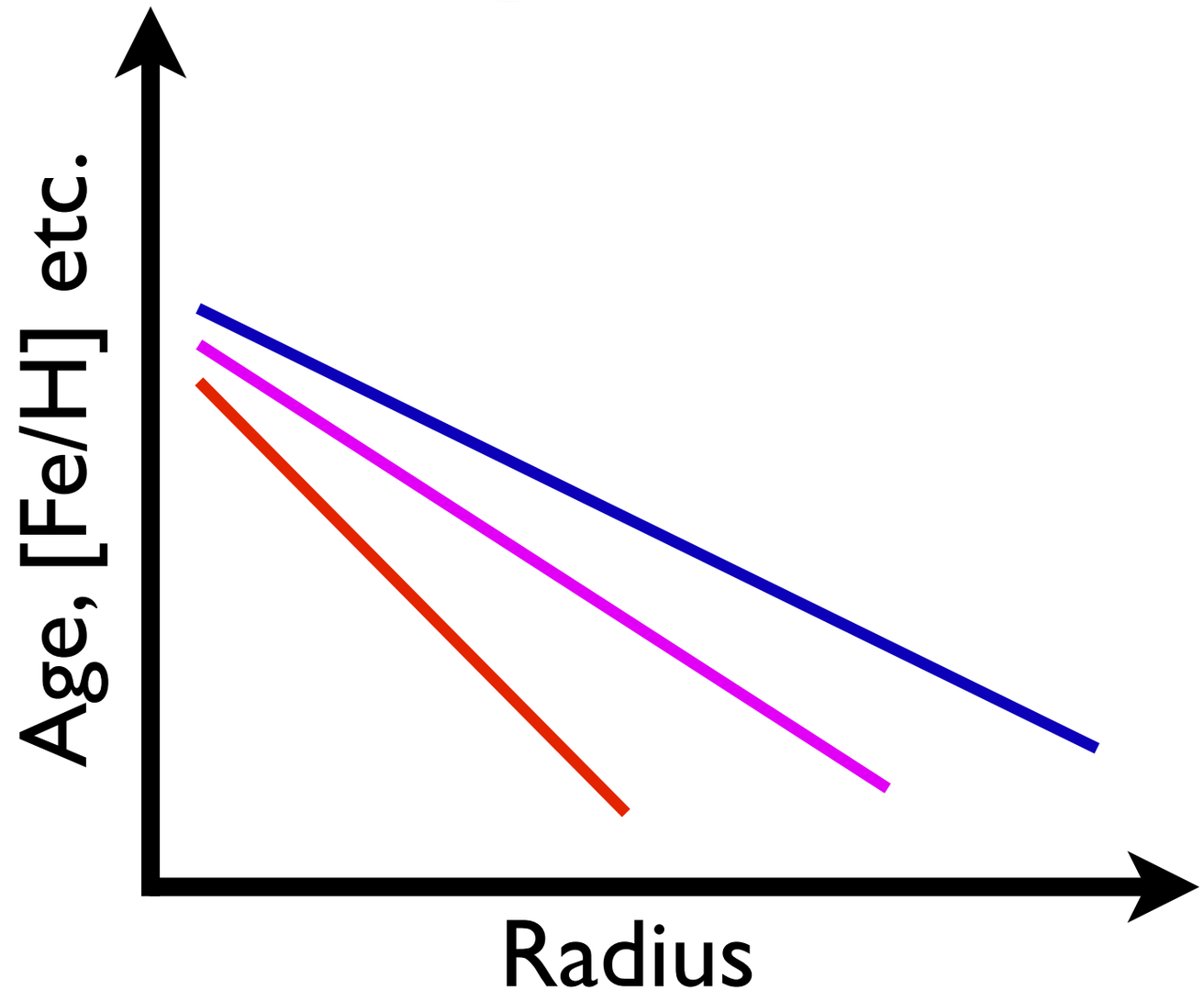
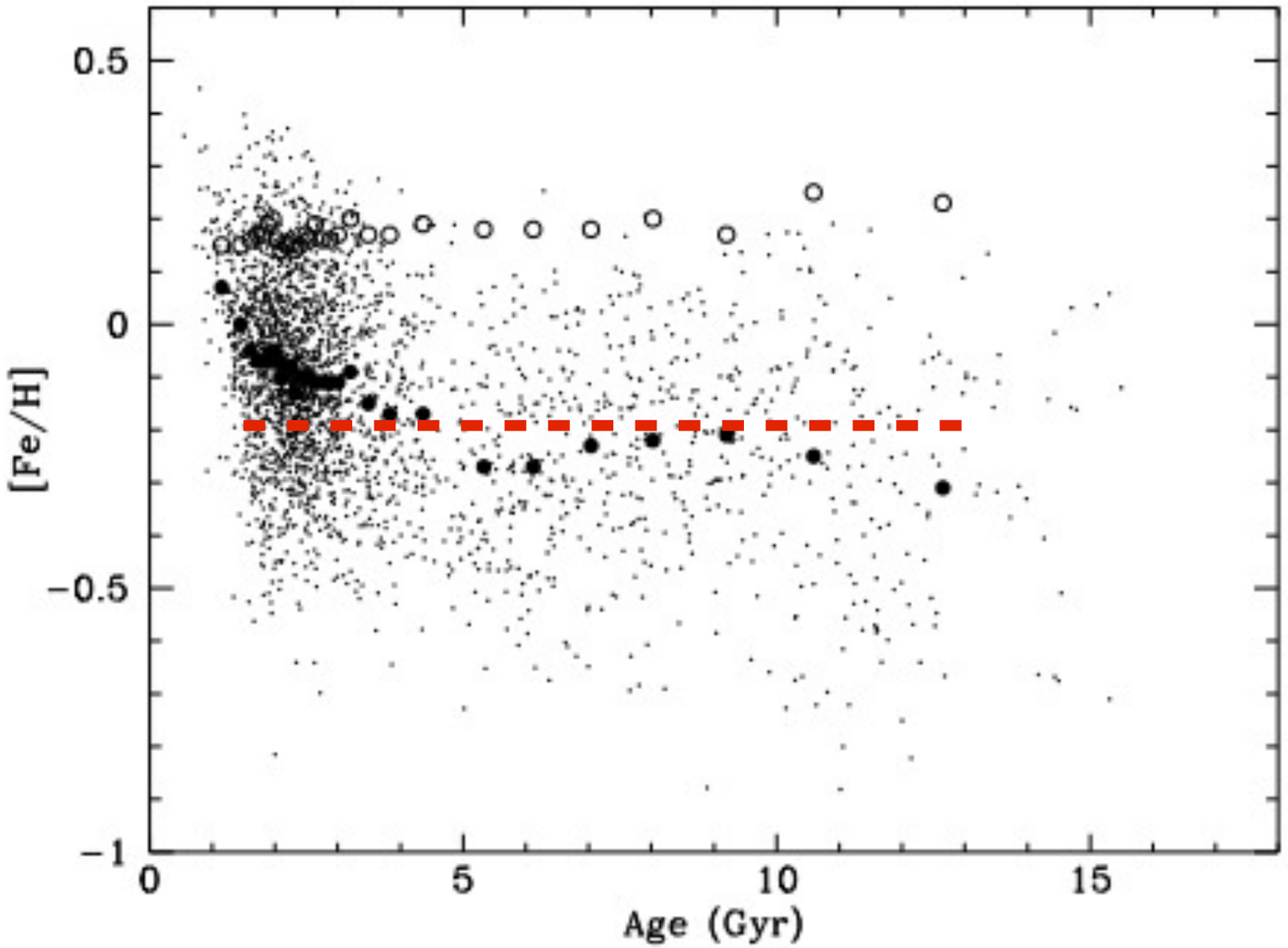




e.g. Tinsley 1975, Francois & Matteucci 1993, Chiappini+ 1997, Boissier & Prantzos 2001 etc.

Solar Neighborhood Incompatible with this Picture

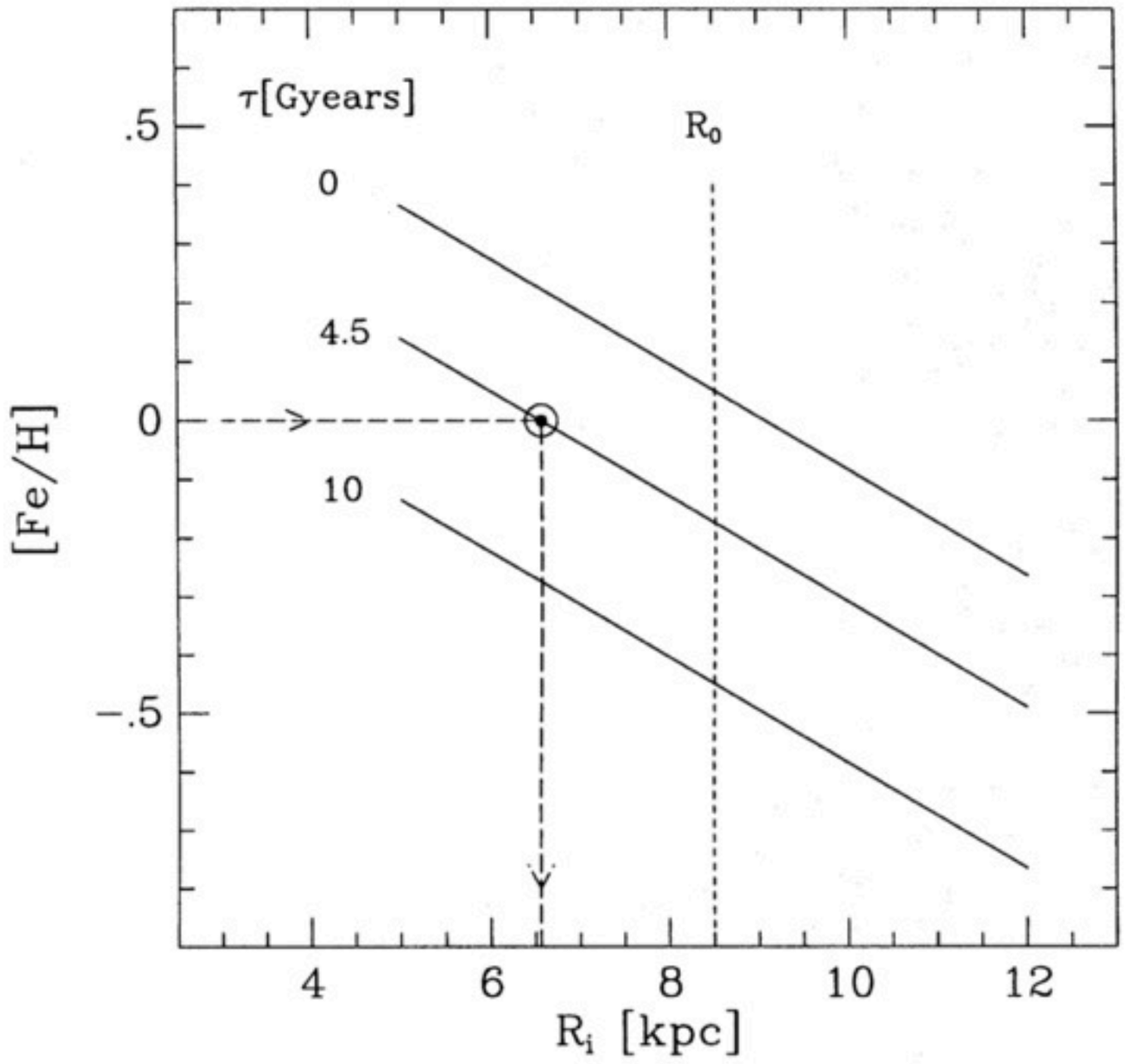


GCS - Holmberg et al. 2009

impossible to explain lack of age-metallicity relationship & high scatter

(confirmed by subsequent surveys and analyses e.g. Cassagrande et al. 2011)

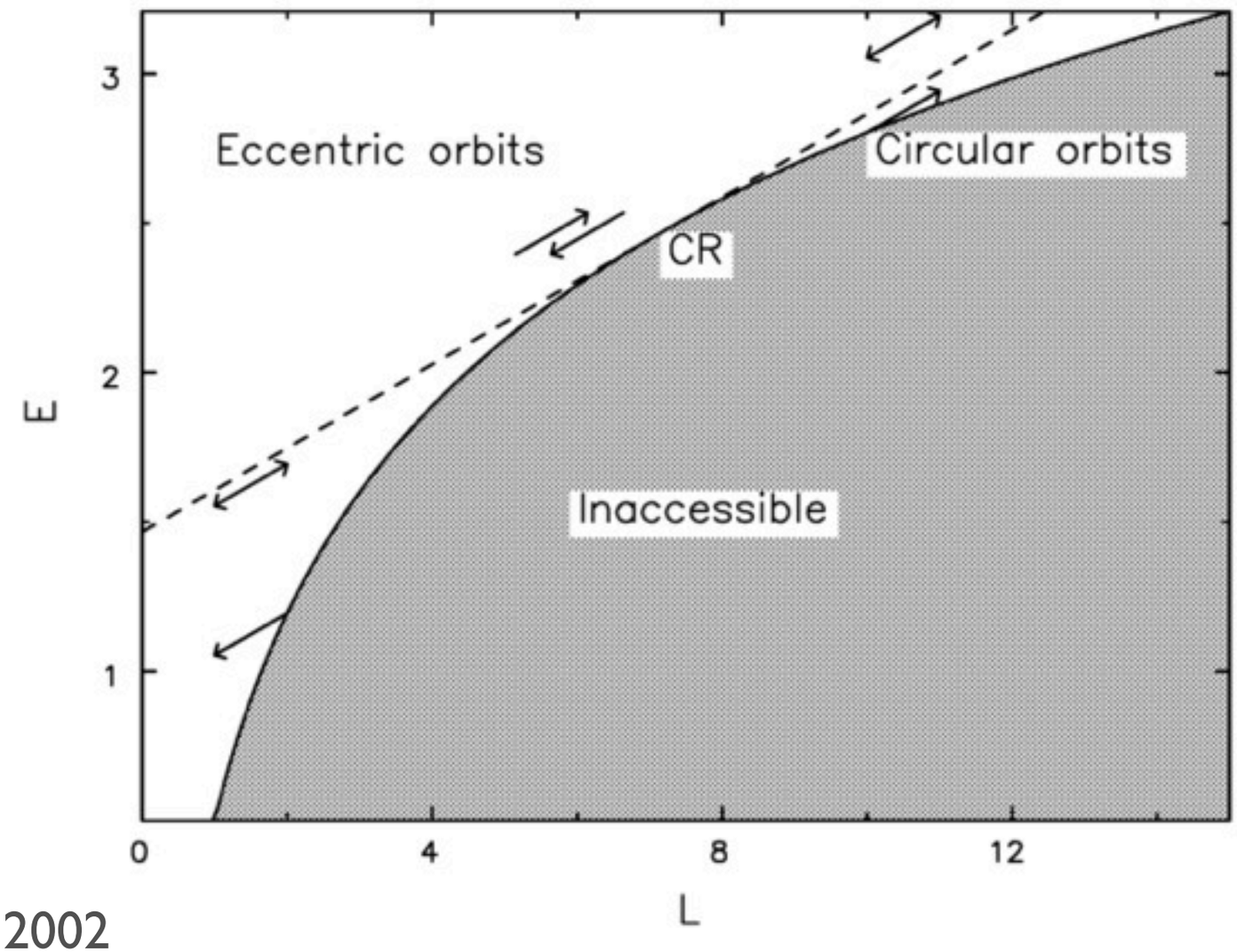
Solar Metallicity an Indication of Sun's Migration?



Wielen et al. 1997 argued that due to metallicity gradient evolution and the high solar metallicity, the sun must have come from the inner disk

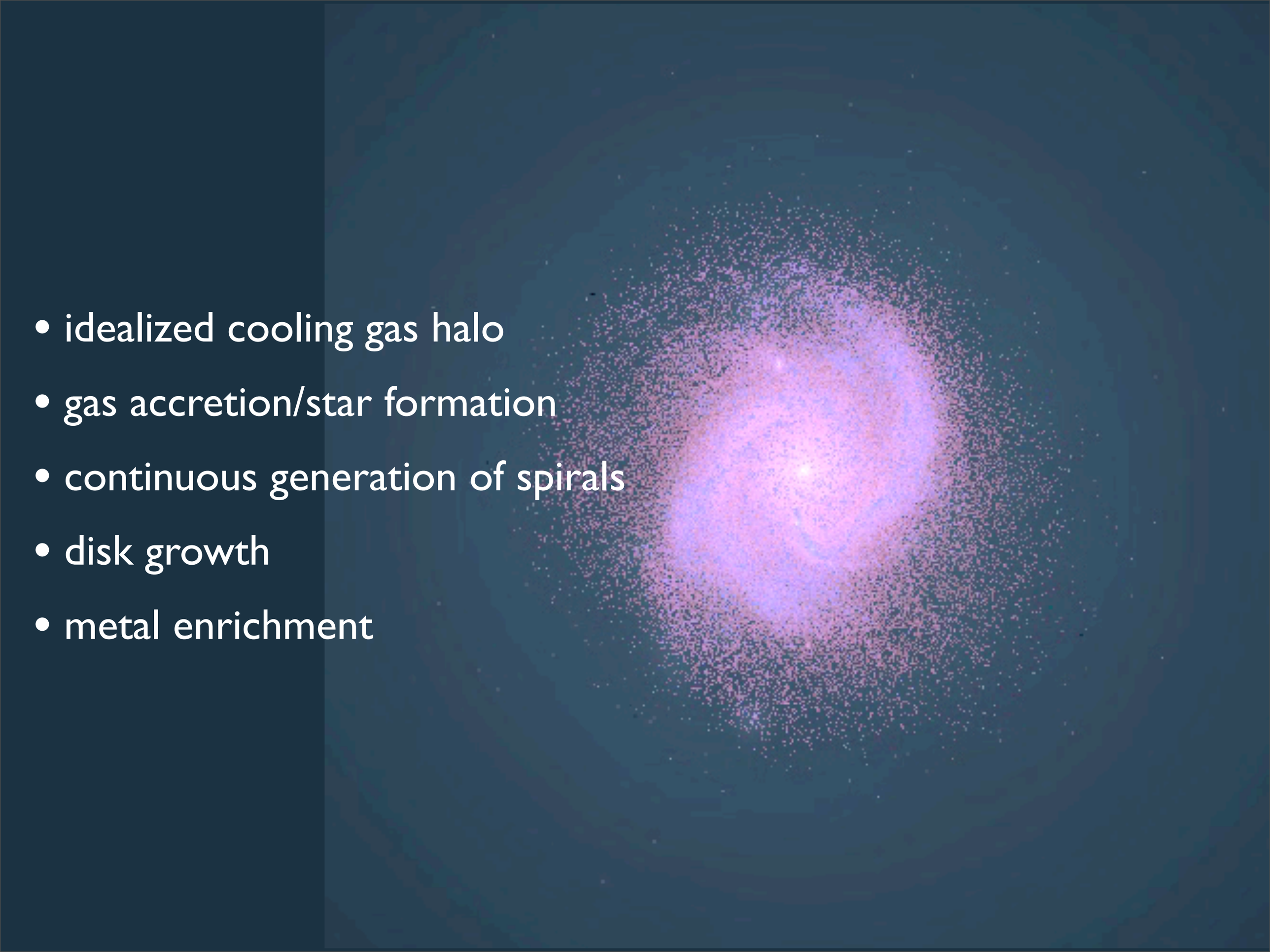
Efficient Radial Migration via Transient Spiral CR without Heating

Jacobi integral roughly conserved: $\Delta E \sim \Omega_p \Delta J$



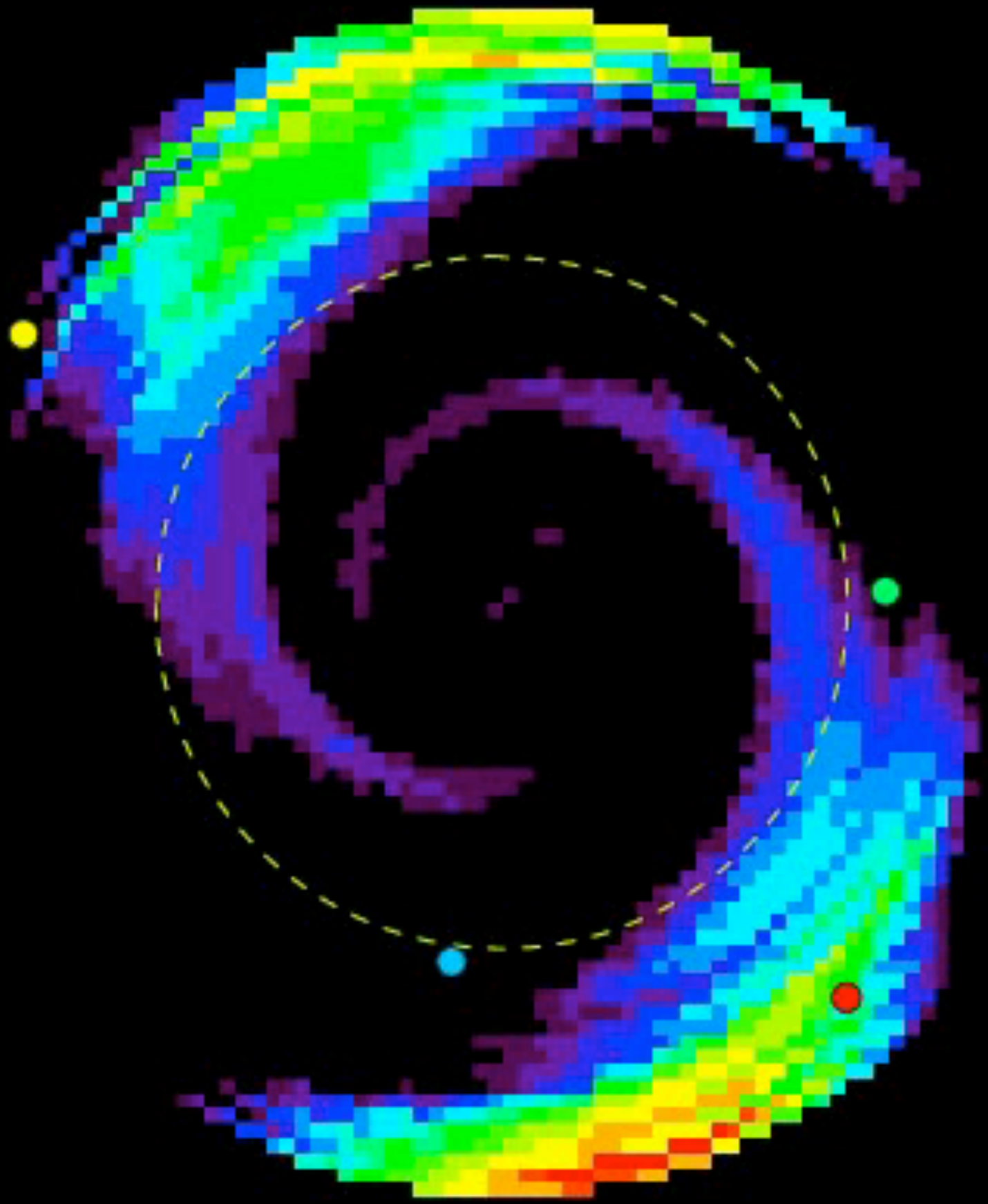
Sellwood & Binney 2002

- idealized cooling gas halo
- gas accretion/star formation
- continuous generation of spirals
- disk growth
- metal enrichment



Spirals Efficiently Move Particles

see Roškar et al. 2011 for more details on the process of mixing in our simulations



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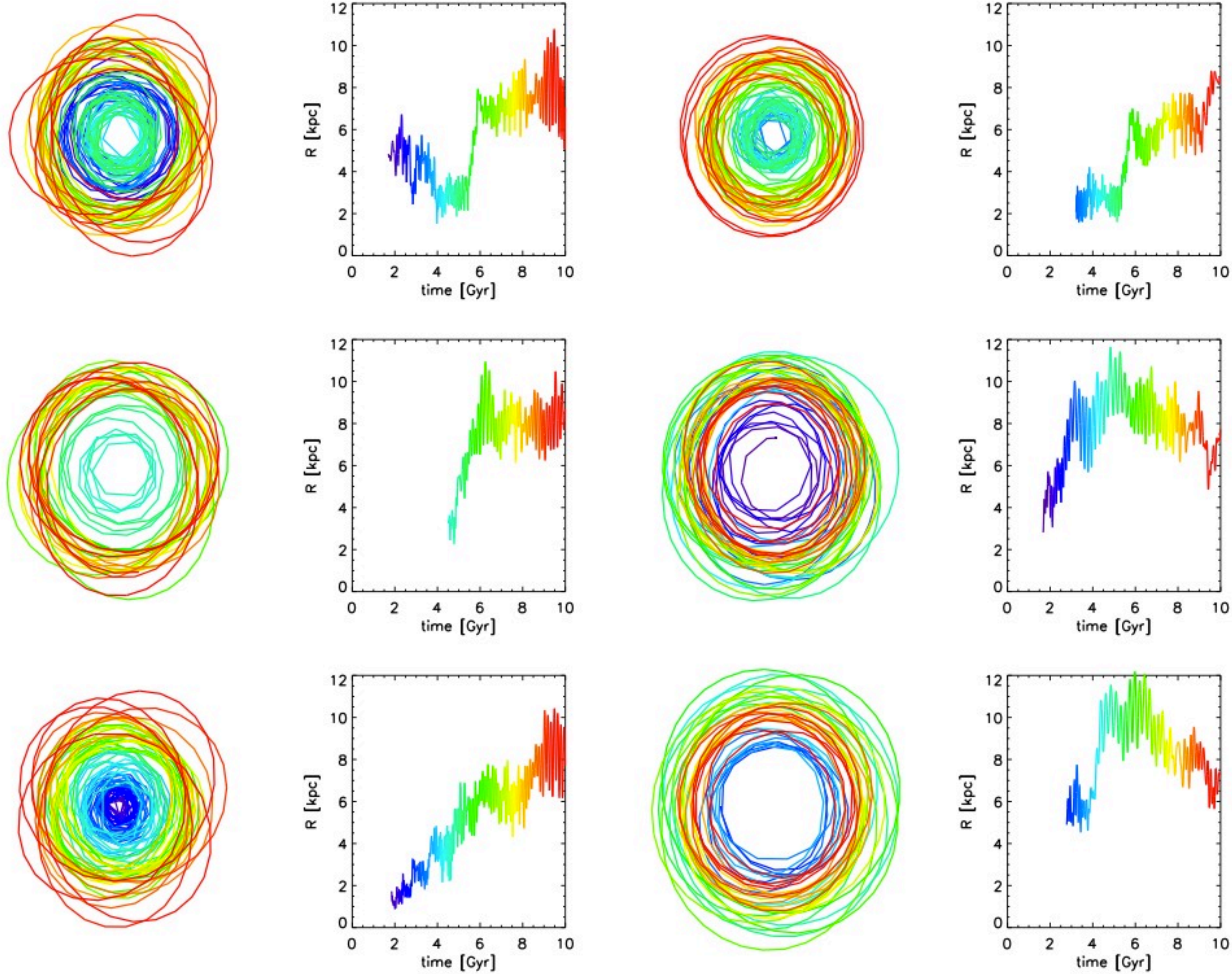
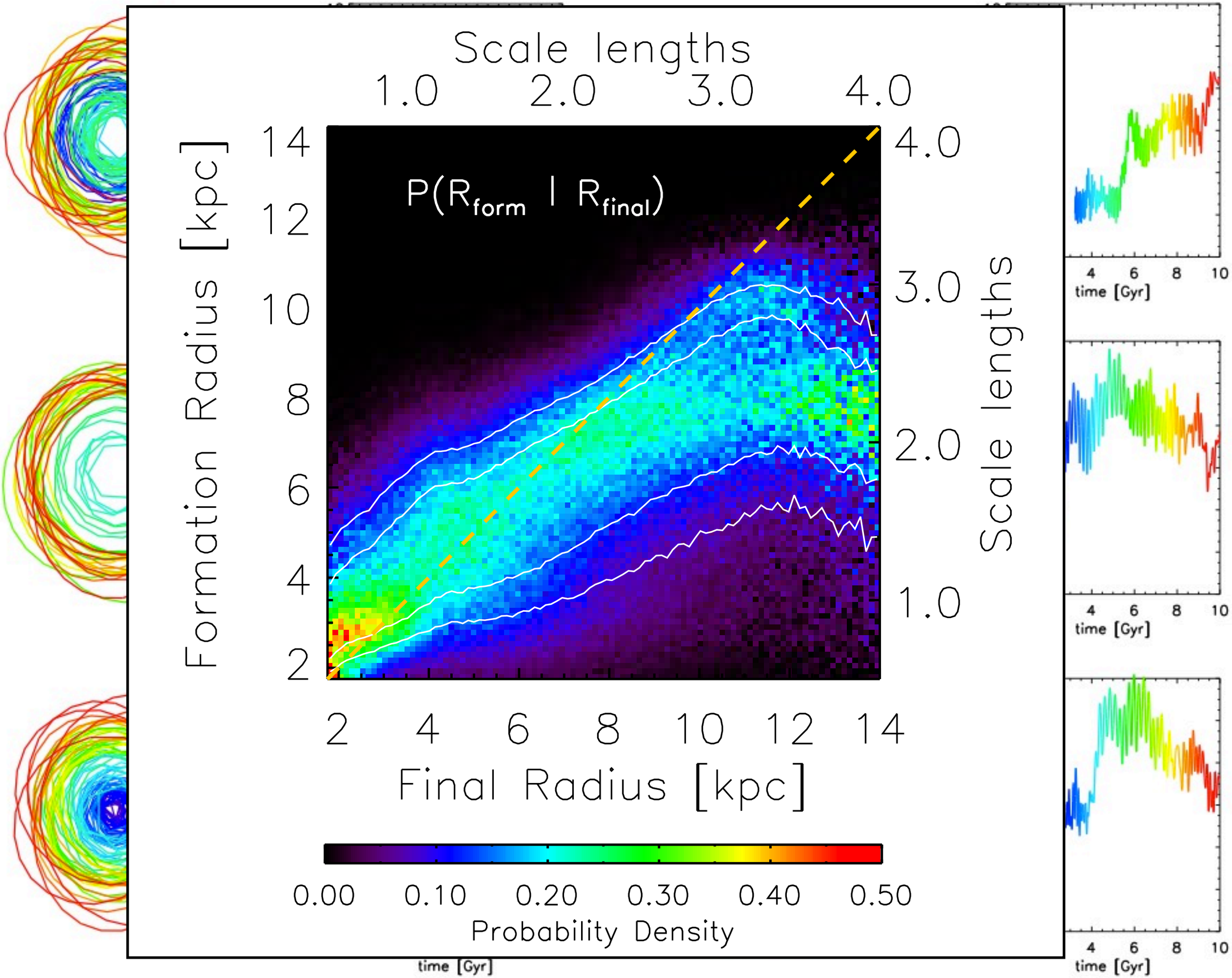
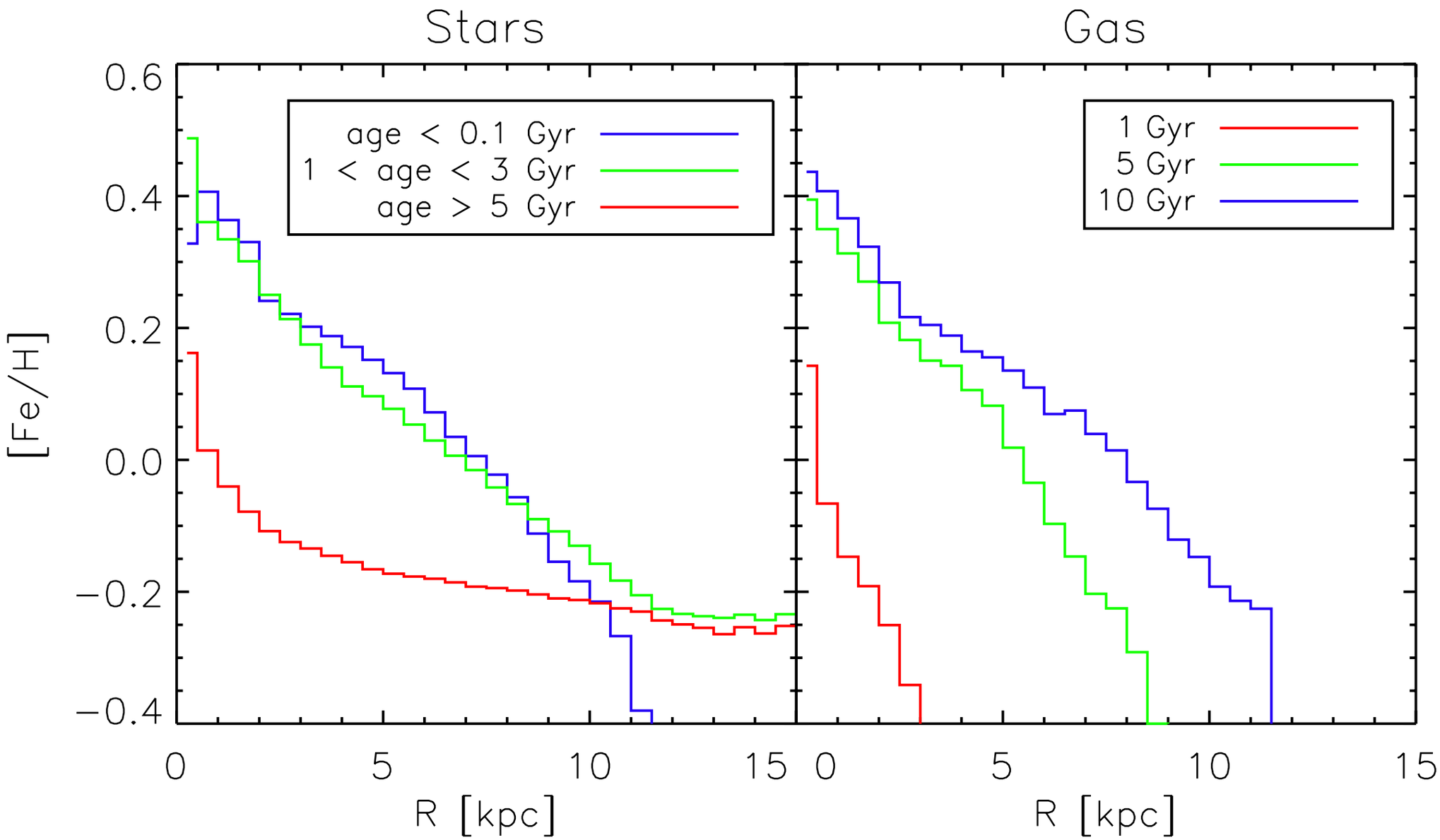


R [kpc]
time [Gyr]
R [kpc]
time [Gyr]
R [kpc]
time [Gyr]
R [kpc]
time [Gyr]
R [kpc]
time [Gyr]
R [kpc]
time [Gyr]


Scale lengths
1.0
2.0
3.0
4.0
$P(R_{form} \mid R_{final})$
Formation Radius [kpc]
14
12
10
8
6
4
2
4.0
3.0
2.0
1.0
Scale lengths
2
4
6
8
10
12
14
Final Radius [kpc]
0.00
0.10
0.20
0.30
0.40
0.50
Probability Density
time [Gyr]
4
6
8
10
time [Gyr]
4
6
8
10
time [Gyr]
4
6
8
10
time [Gyr]

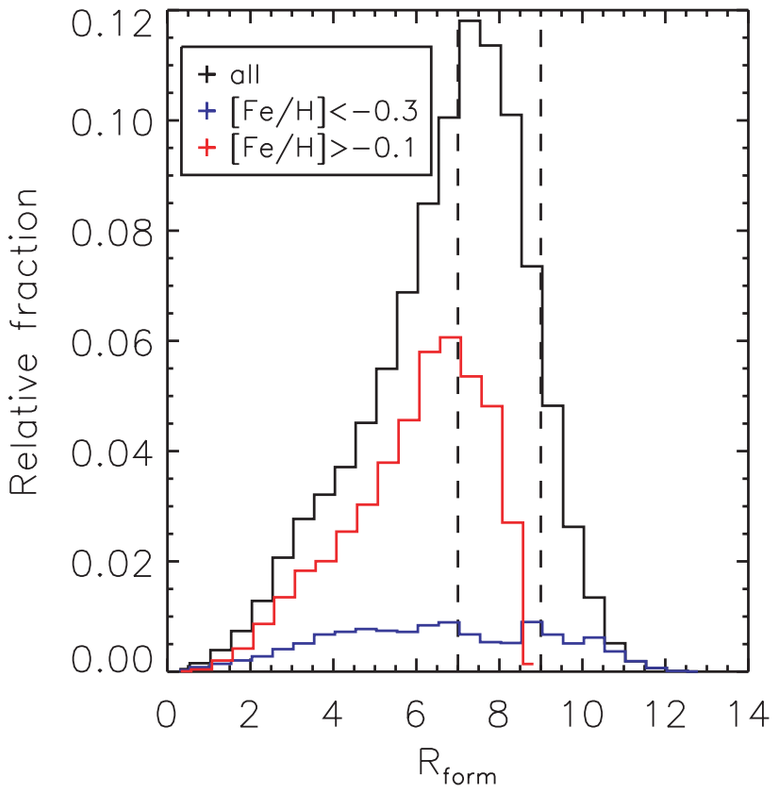
Effect on Metallicity Gradients

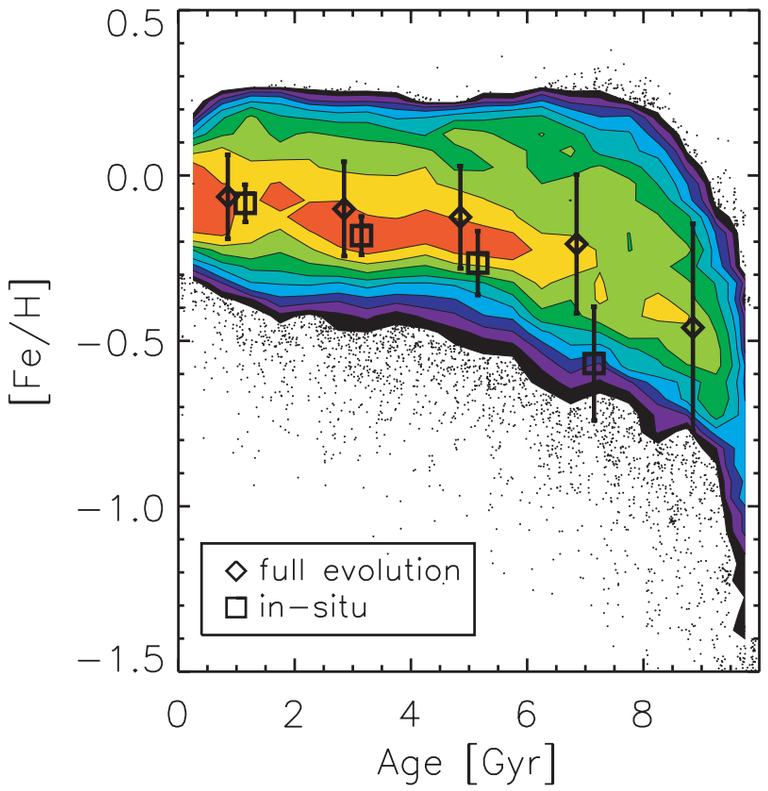


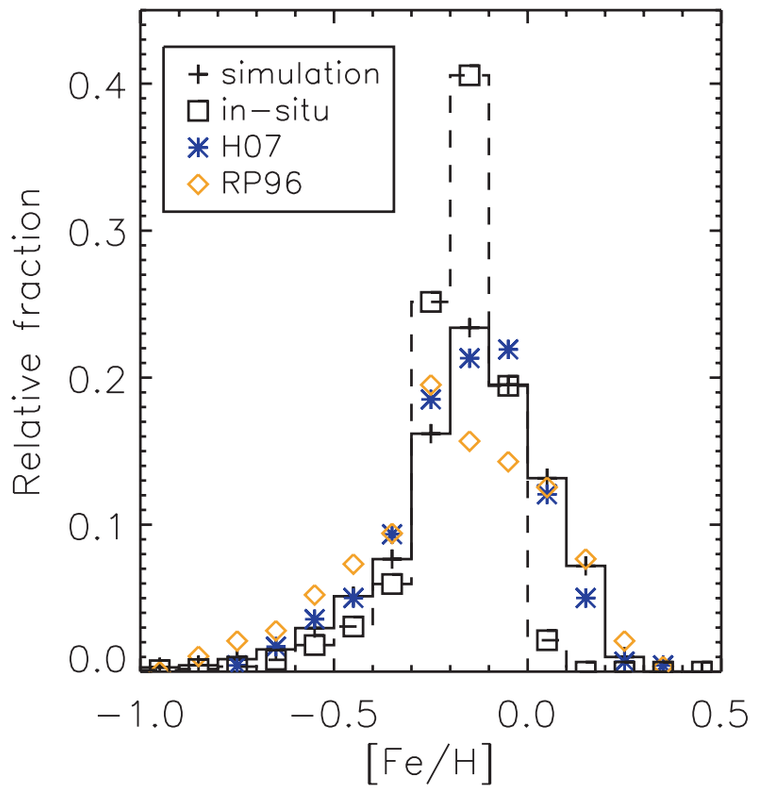
Tracers show flattening with time, but the gradient actually steepened!

Roškar et al. 2008b

Migration Dictates Solar Neighborhood Properties







1. migrant stars

2. flattened AMR

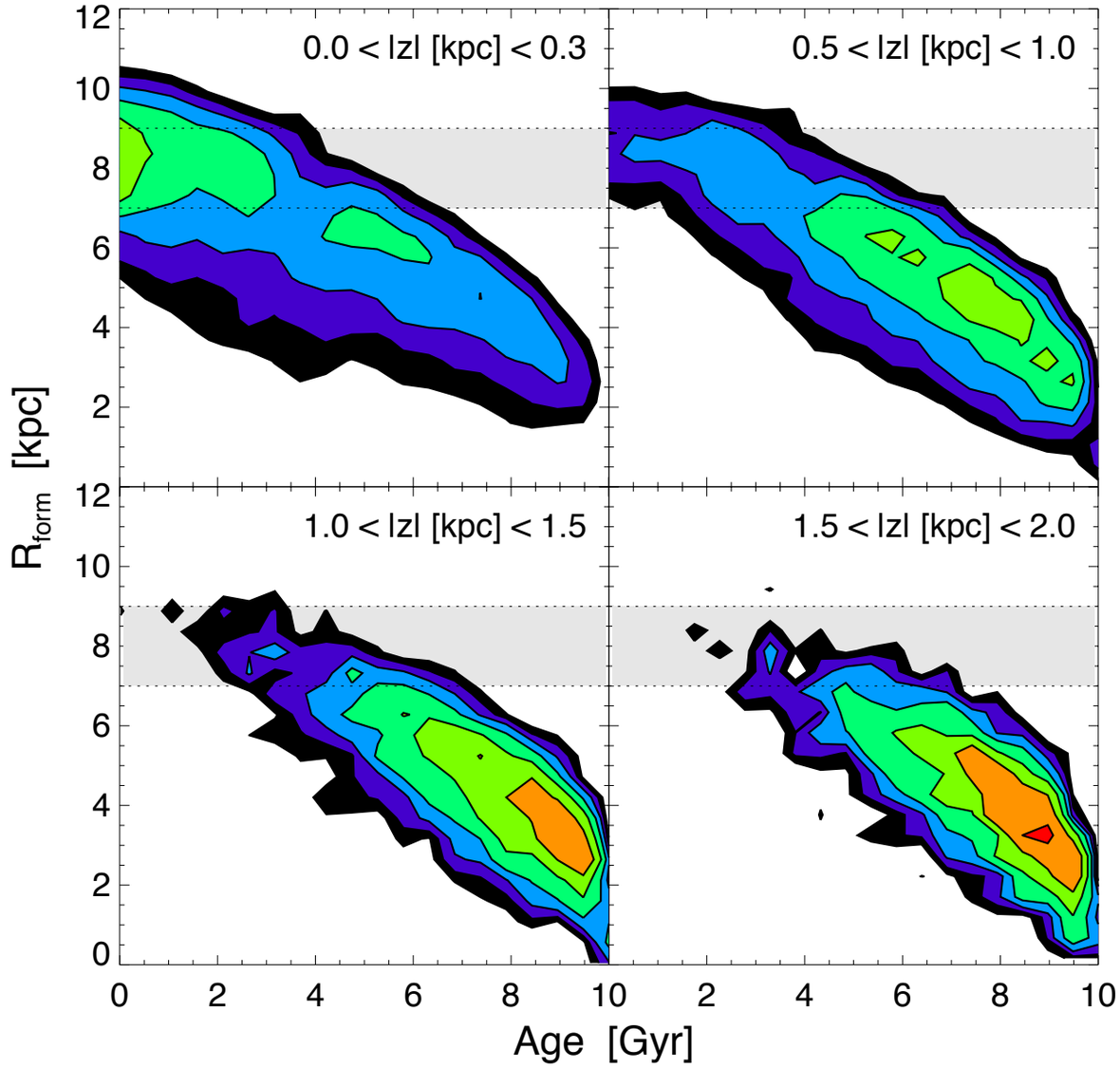
3. broadened MDF

Roškar et al. 2008b

(see also Sellwood & Binney 2002, Haywood 2008, Schönrich & Binney 2009a, Casagrande et al. 2011)

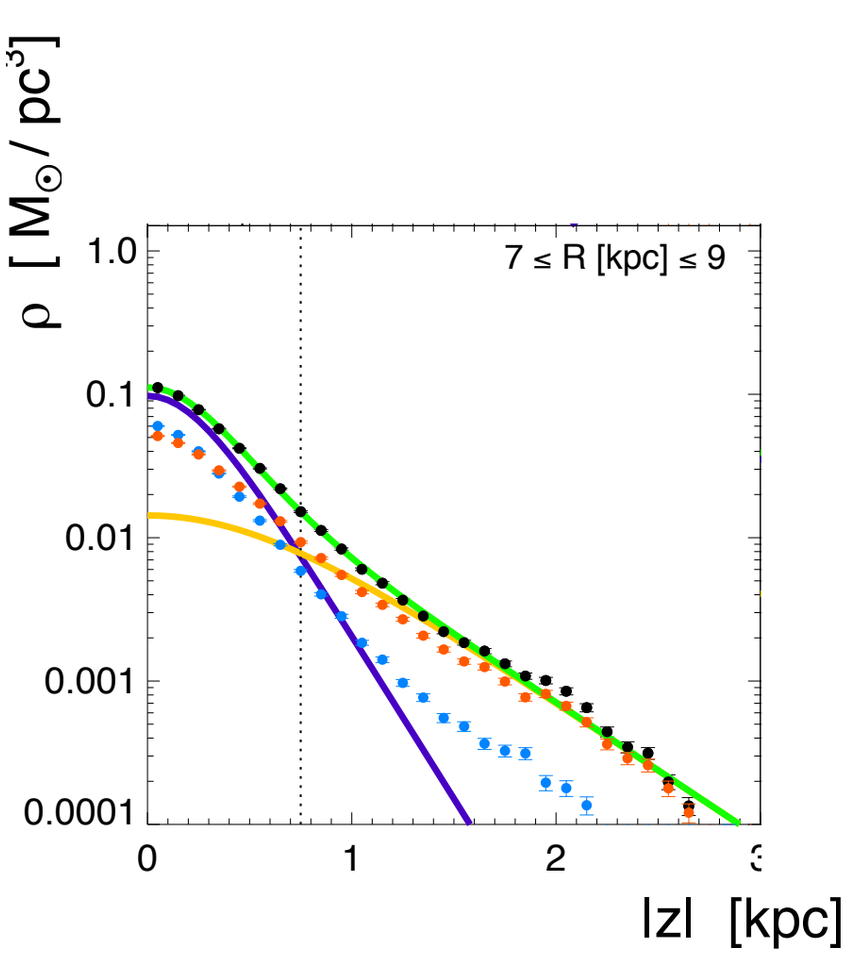
Migration Revealed in the Vertical Structure

- Further from the plane, stars are older
- Older stars were born in the interior
- at z > 1.0 old inner-disk migrants dominate



Loebman et al. 2011 (see also Schönrich & Binney 2009ab)

Possible to Mimic Thick Disk by Migrated Population



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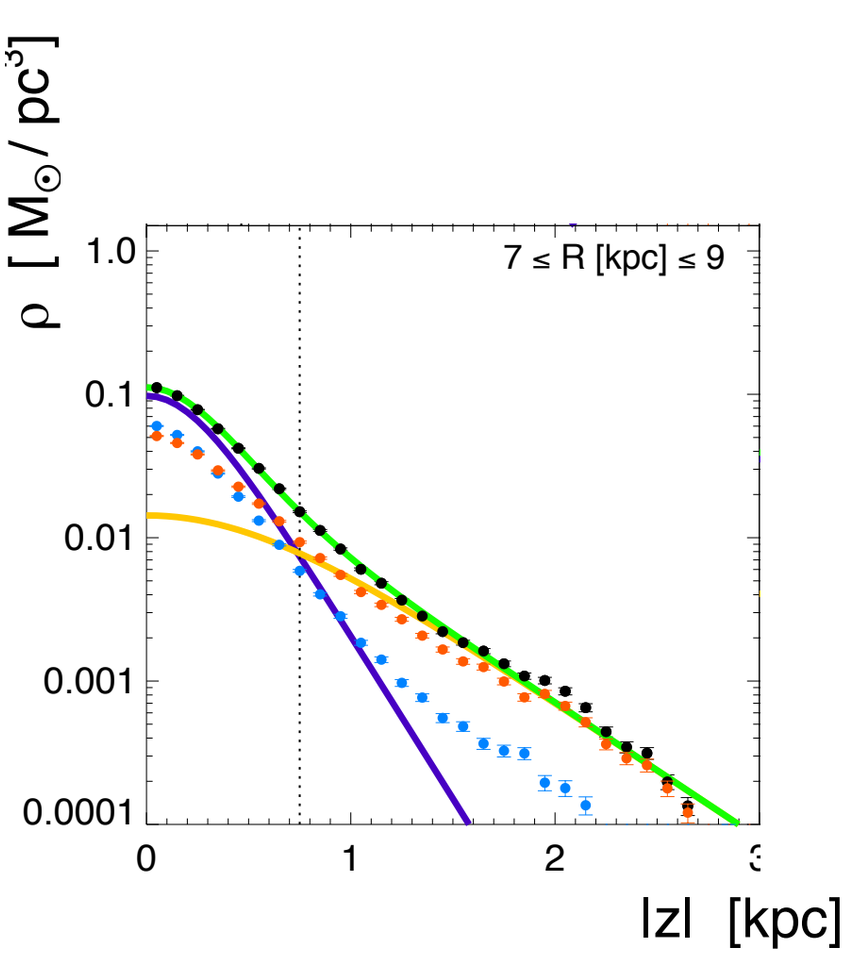
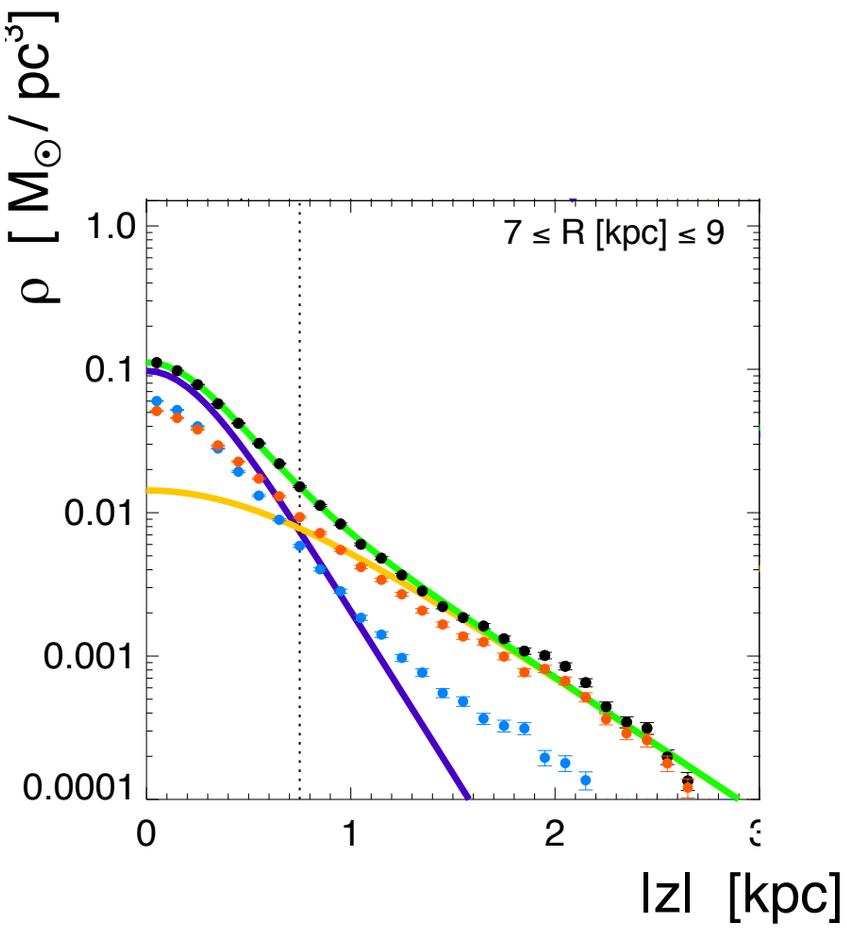


migrated population dominates away from the plane

Possible to Mimic Thick Disk by Migrated Population

younger, in-situ population dominates the midplane

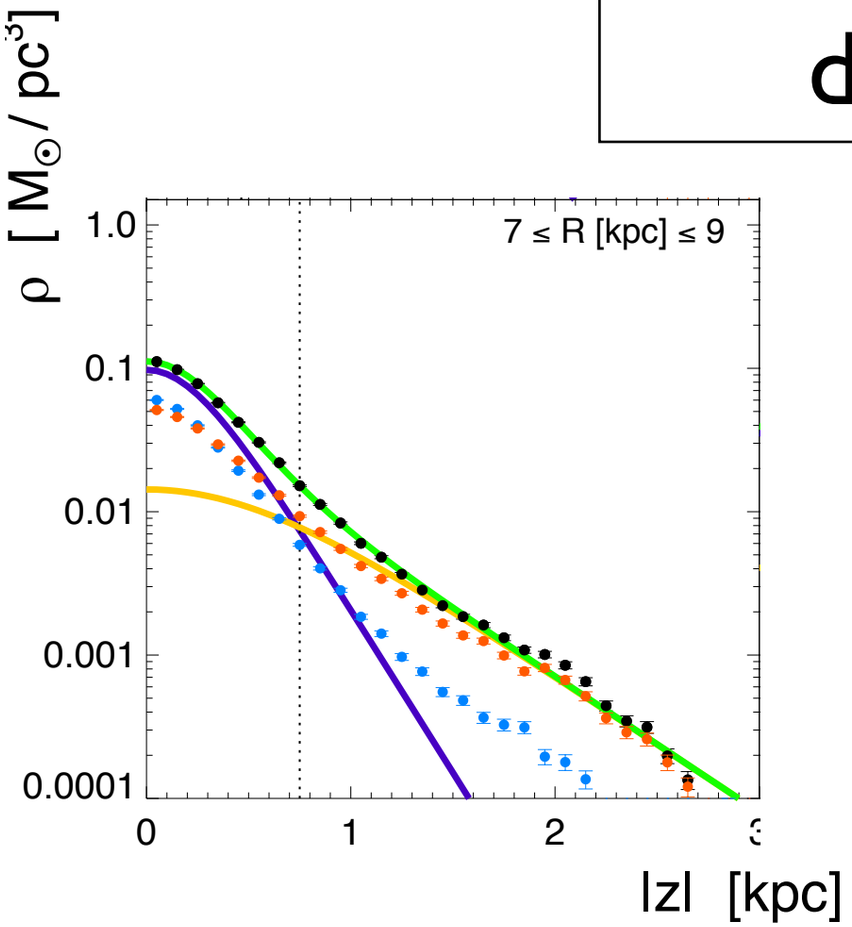


migrated population dominates away from the plane

Possible to Mimic Thick Disk by Migrated Population

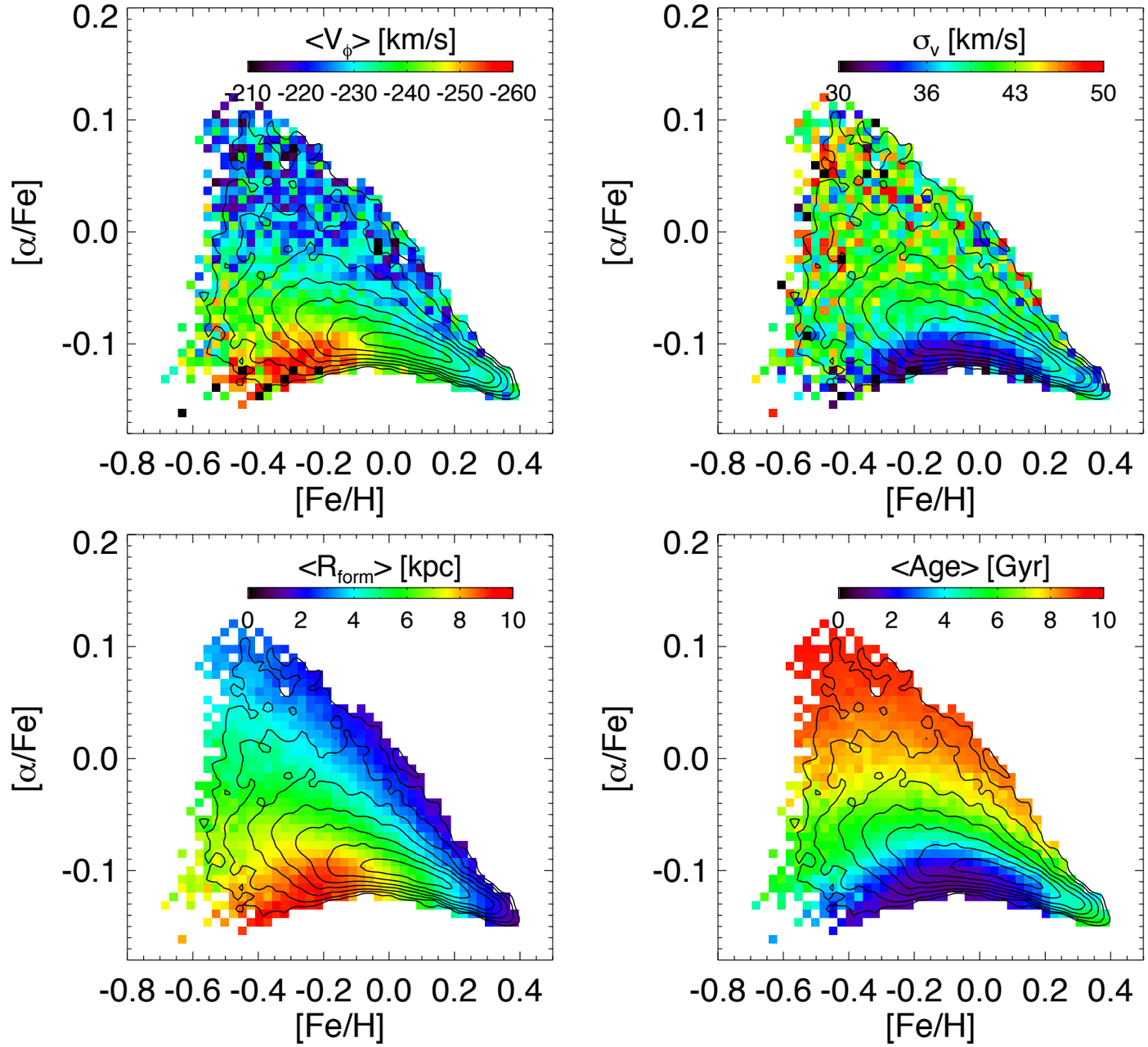
younger, in-situ population dominates the midplane

overall profile resembles the thin+thick disk vertical density distribution



migrated population dominates away from the plane

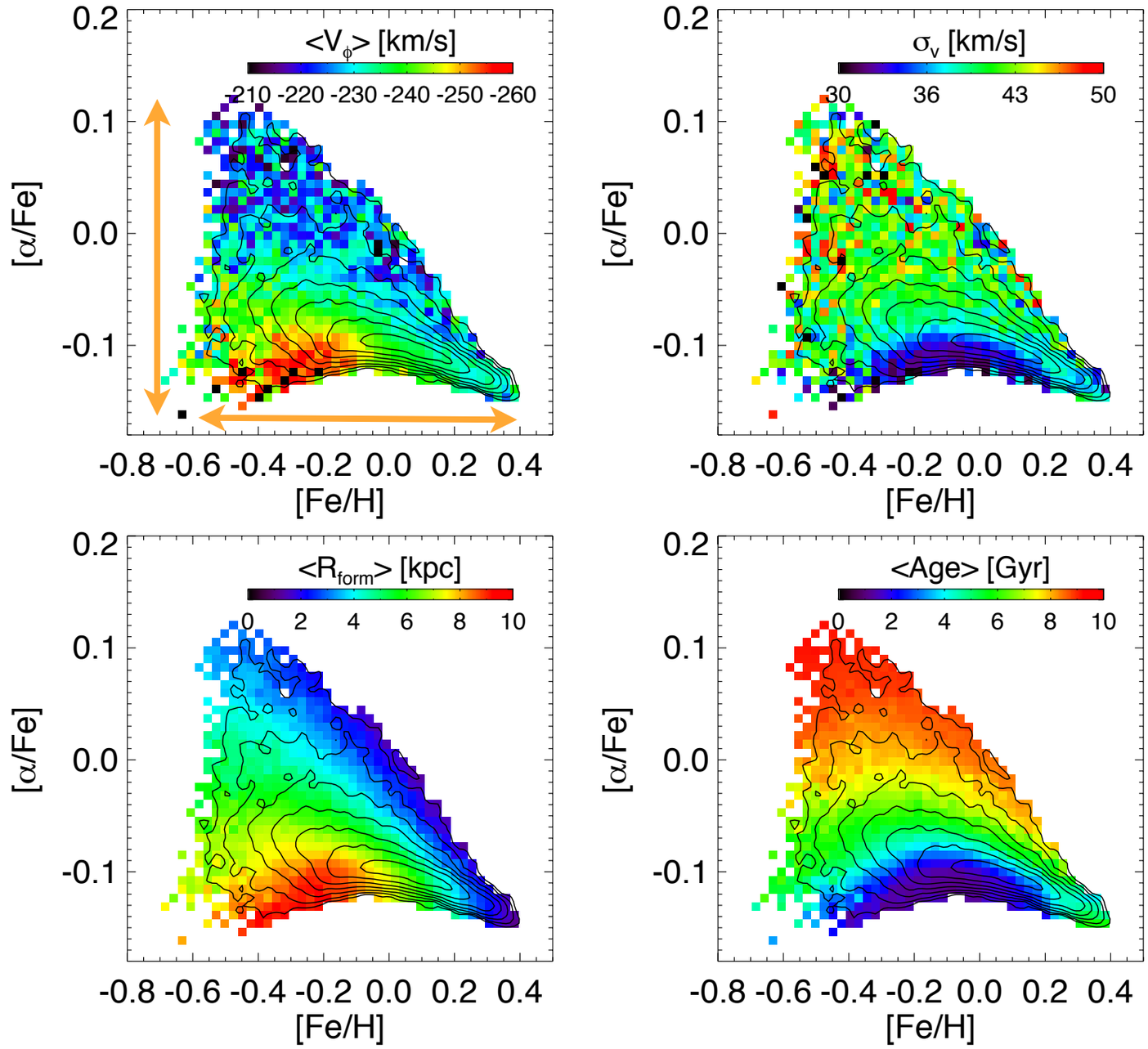
Properties of Stars in the Solar Neighborhood



Loebman et al. 2011

Properties of Stars in the Solar Neighborhood

Large variation in chemistry

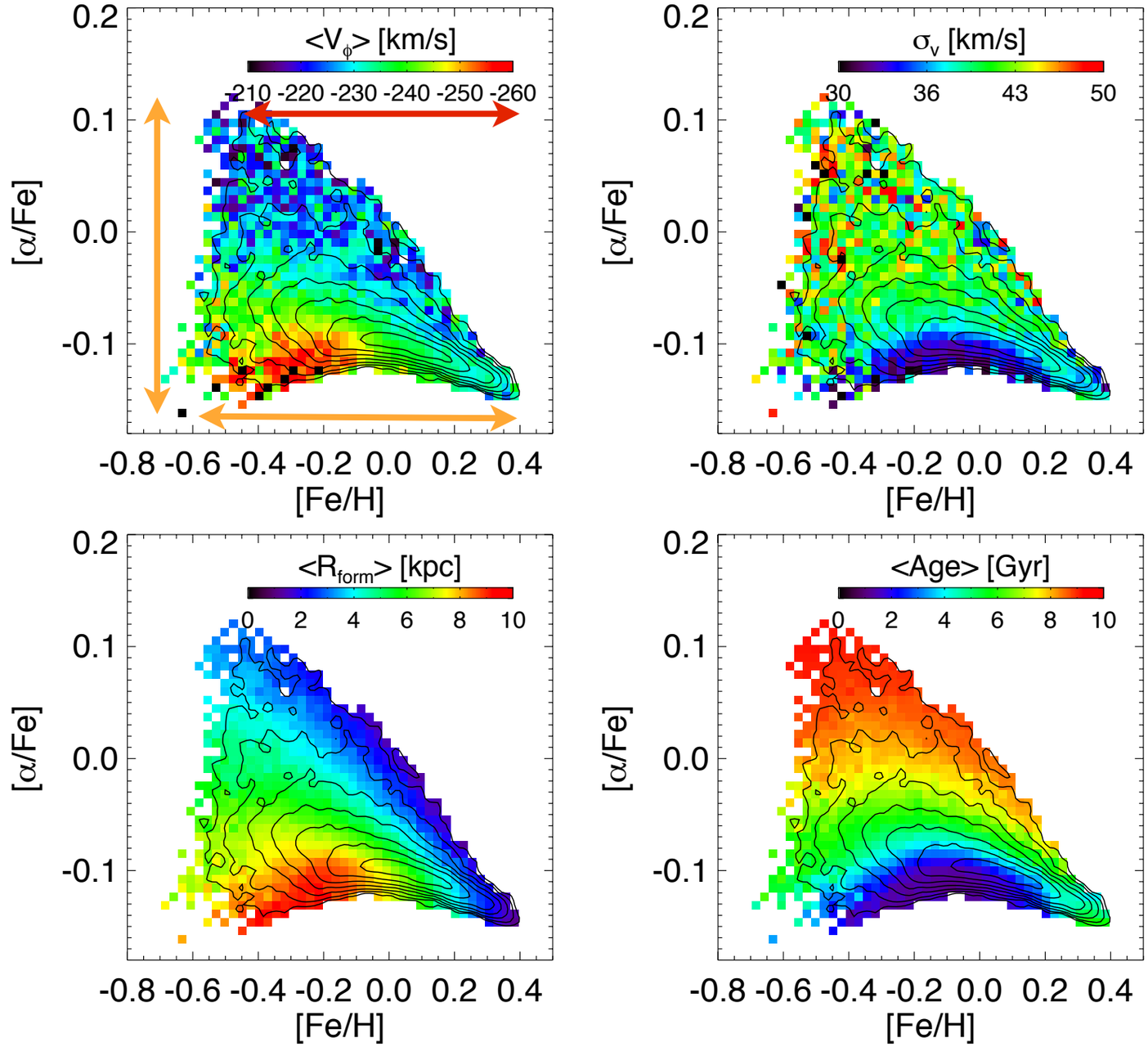


Loebman et al. 2011

Properties of Stars in the Solar Neighborhood

Large variation in chemistry

Small range in velocity



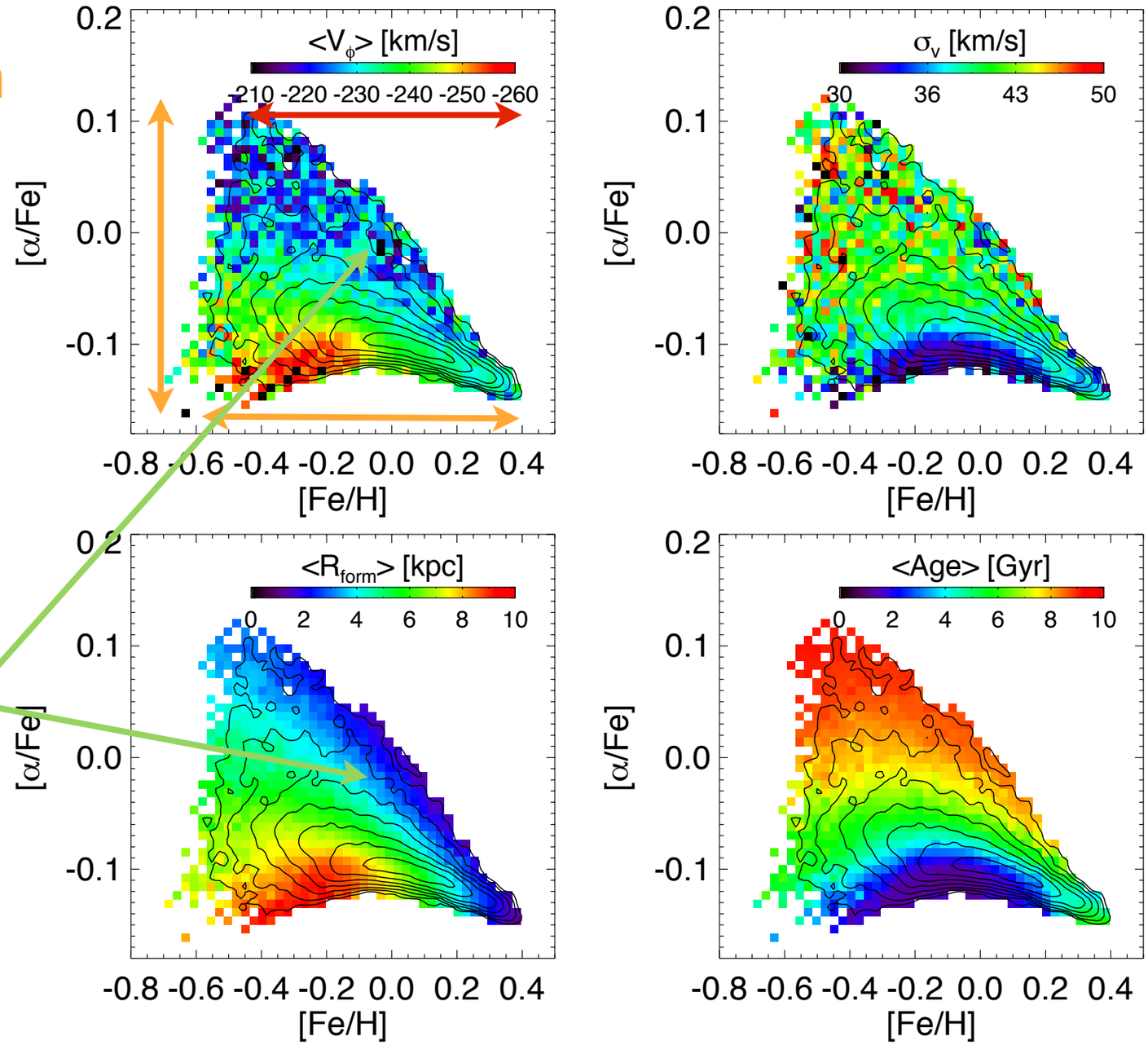
Loebman et al. 2011

Properties of Stars in the Solar Neighborhood

Large variation in chemistry

Small range in velocity

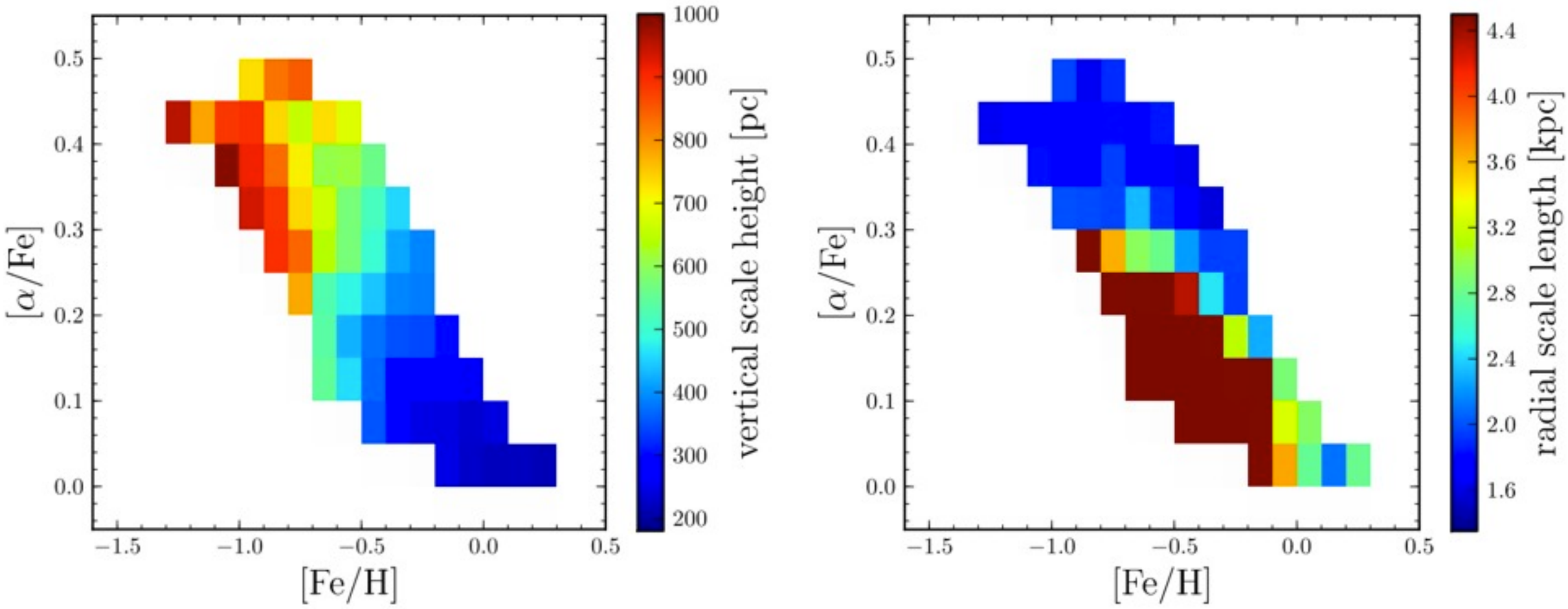
information of birth place not traced by kinematics



Loebman et al. 2011

Thick Disk: Preserving the Past?

SEGUE data shows smooth variation in structure with chemistry

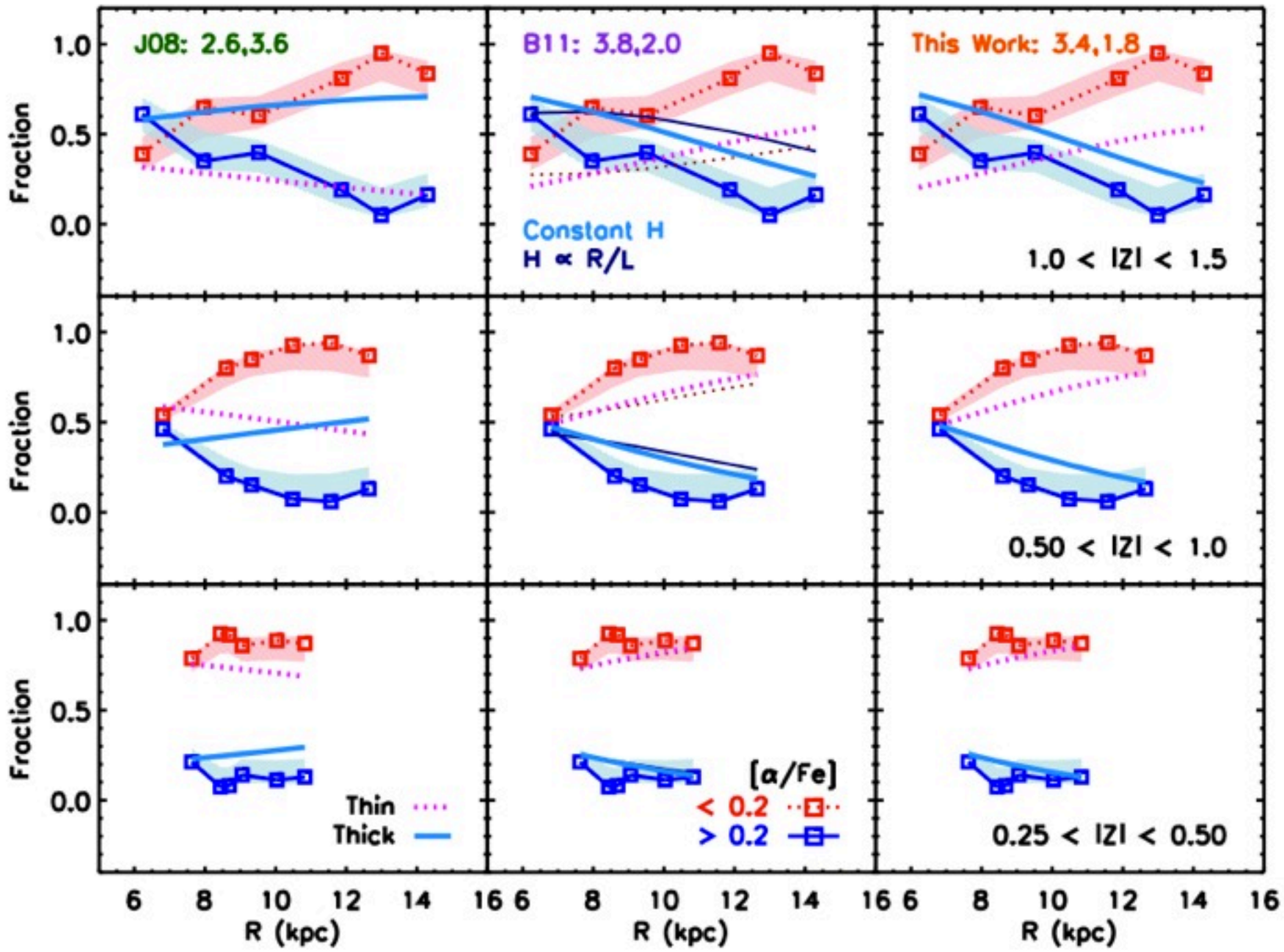


Bovy et al. 2012

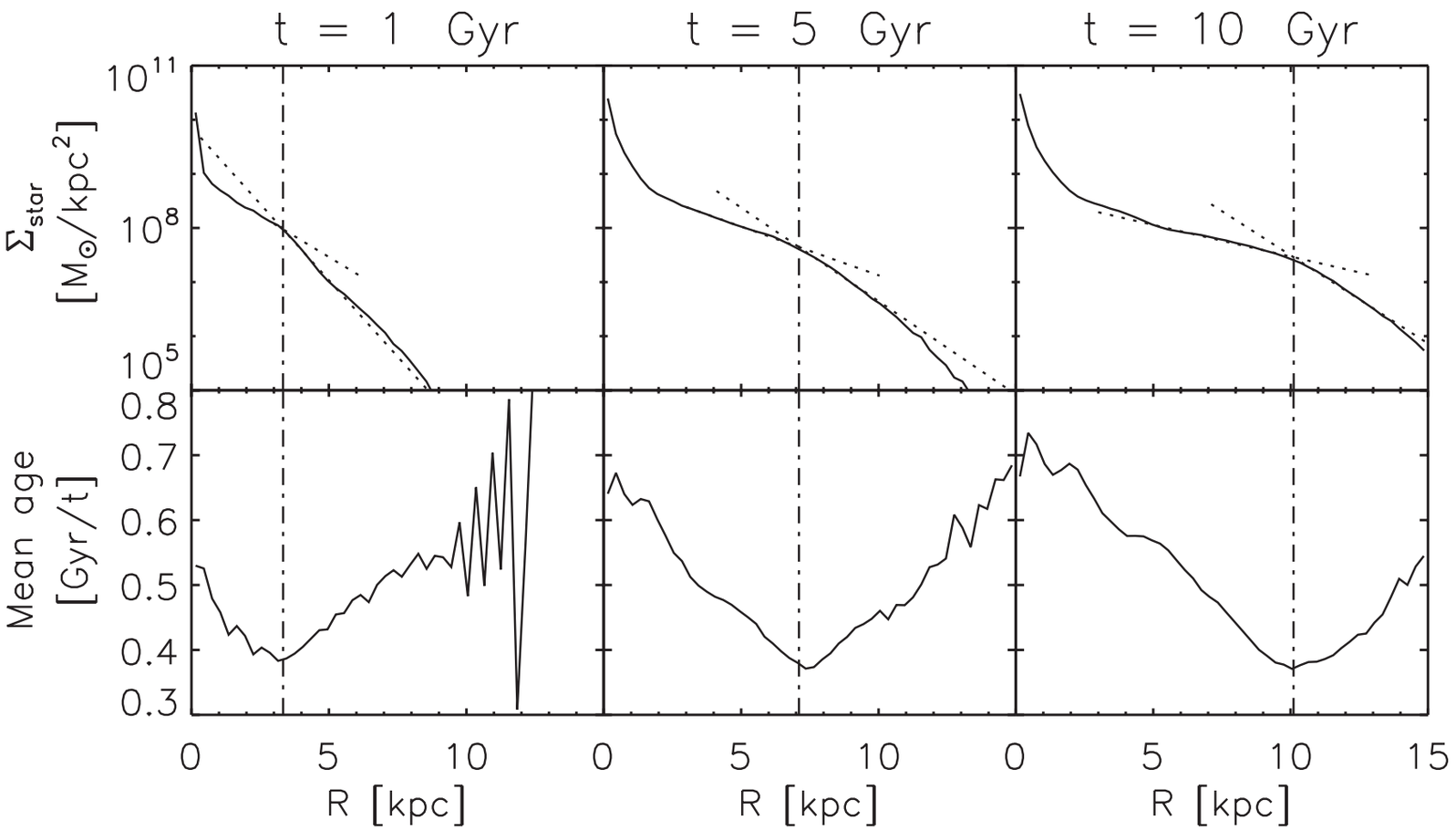
Natural outcome of migration -- but is it unique?

Thick Disk: no Migrated Stars

Cheng+2012 argue that dearth of high-alpha stars at large R implies distinct populations



Searching for Migration Elsewhere: Outer Disks Dominated by Migrated Stars



Roškar et al. 2008a

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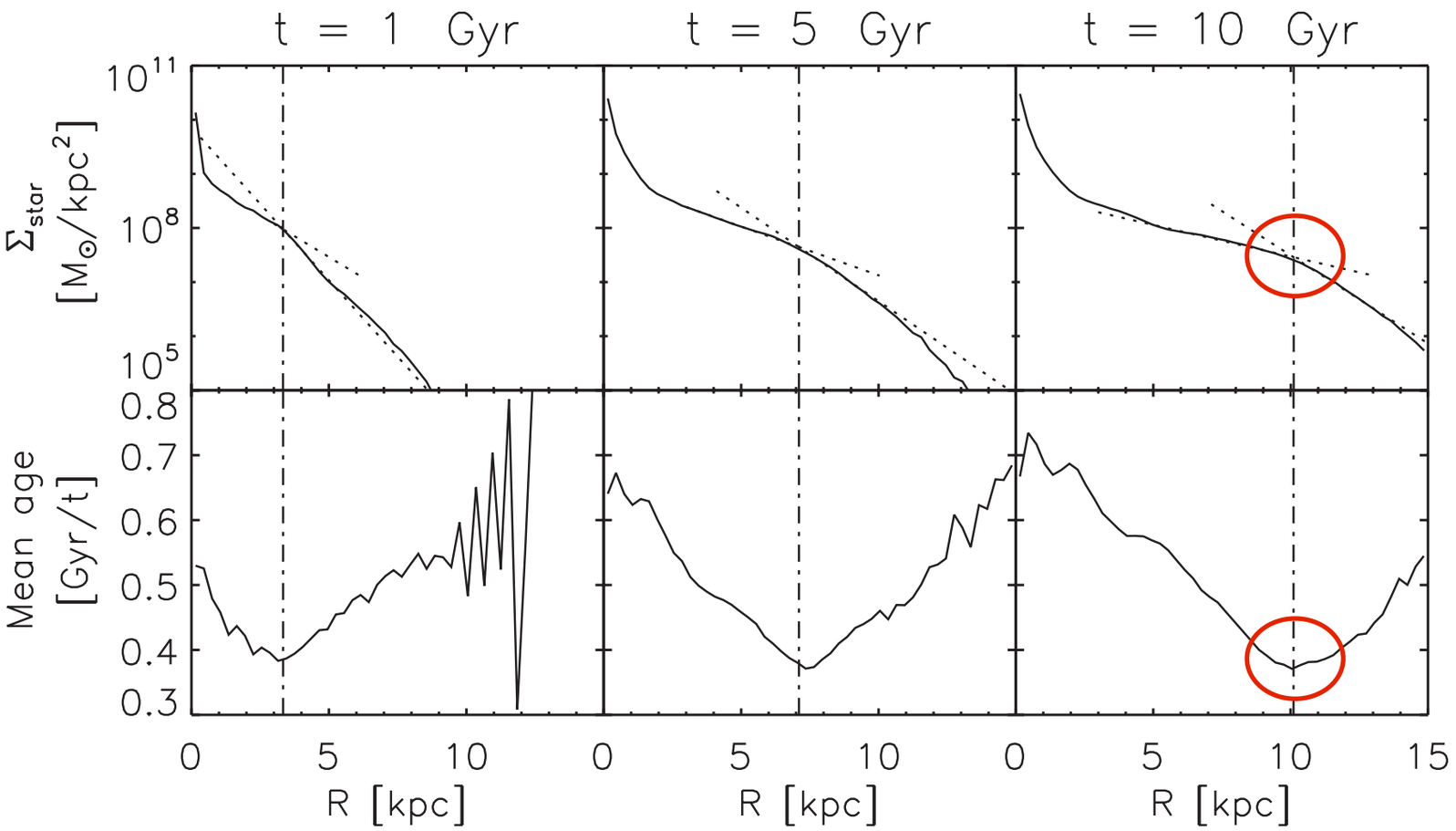

Mean age trend change at the break radius

Roškar et al. 2008a

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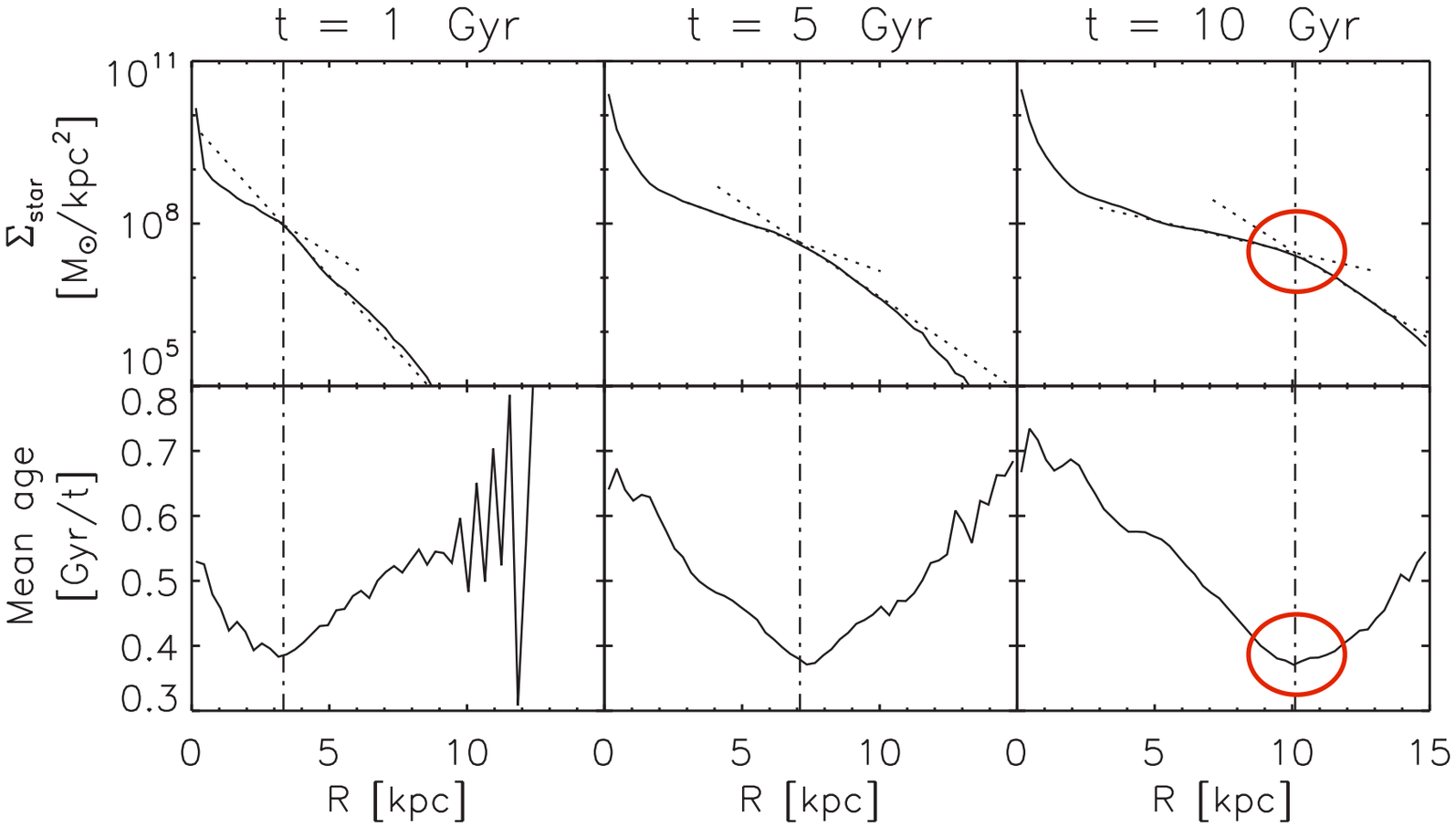
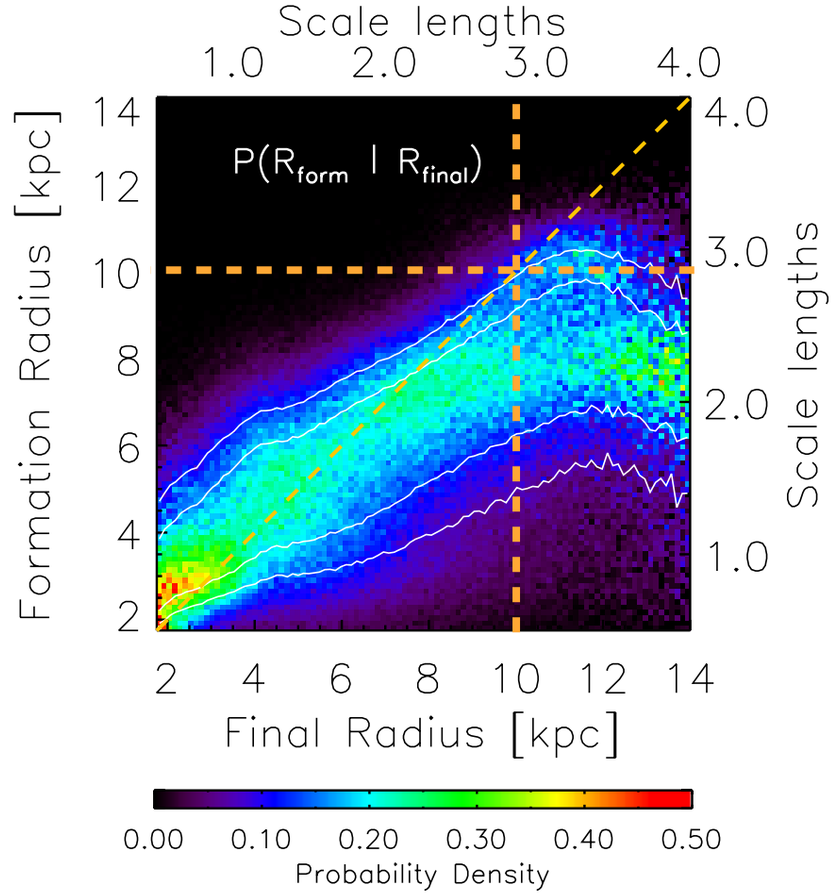
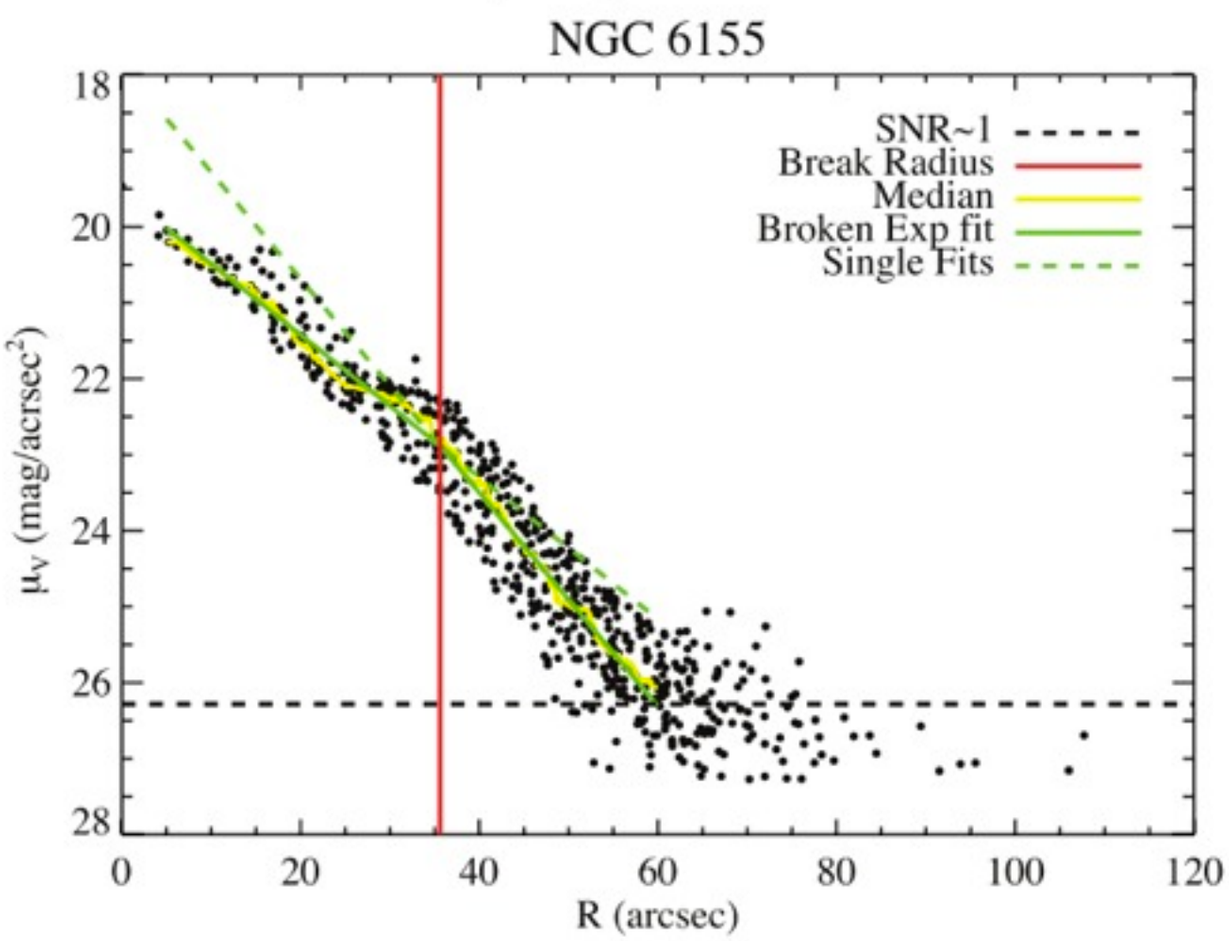


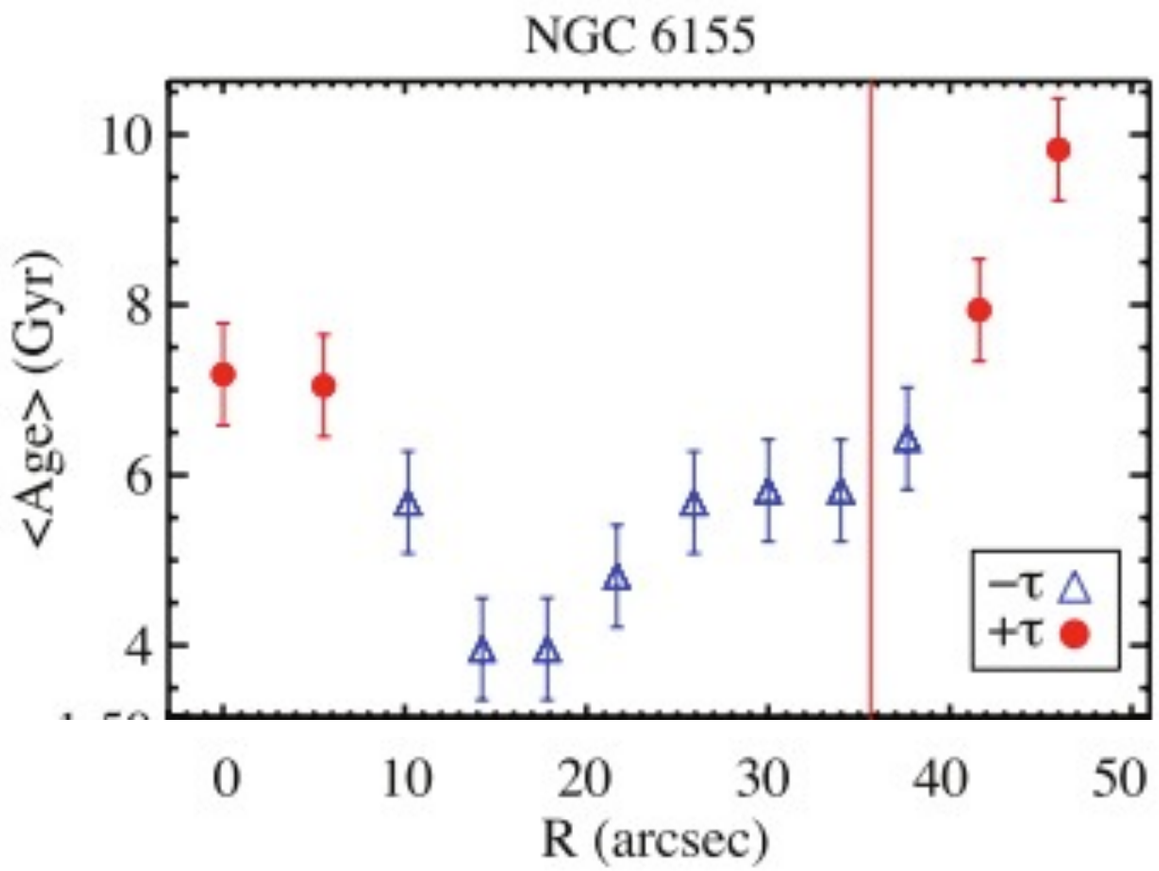


Mean age trend change at the break radius

Roškar et al. 2008a

Observational Evidence?
IFU Stellar Population Modeling





Yoachim, Roškar & Debattista 2010, 2012
(also see Bakos et al. 2008, Azzollini et al. 2008)

Summary

- spiral structure drives efficient radial mixing of stars
  (see also works by Bird et al., Minchev et al., and Solway et al.)
- chemical diversity of stellar populations is greatly enhanced by mixing processes
- radial migration by corotation resonance masks itself because it does not cause heating
- the Milky Way thick disk may have been influenced by radial mixing
- properties as a fxn of radius should give us more leverage on model predictions