Formation and Evolution of the Milky Way's Disk

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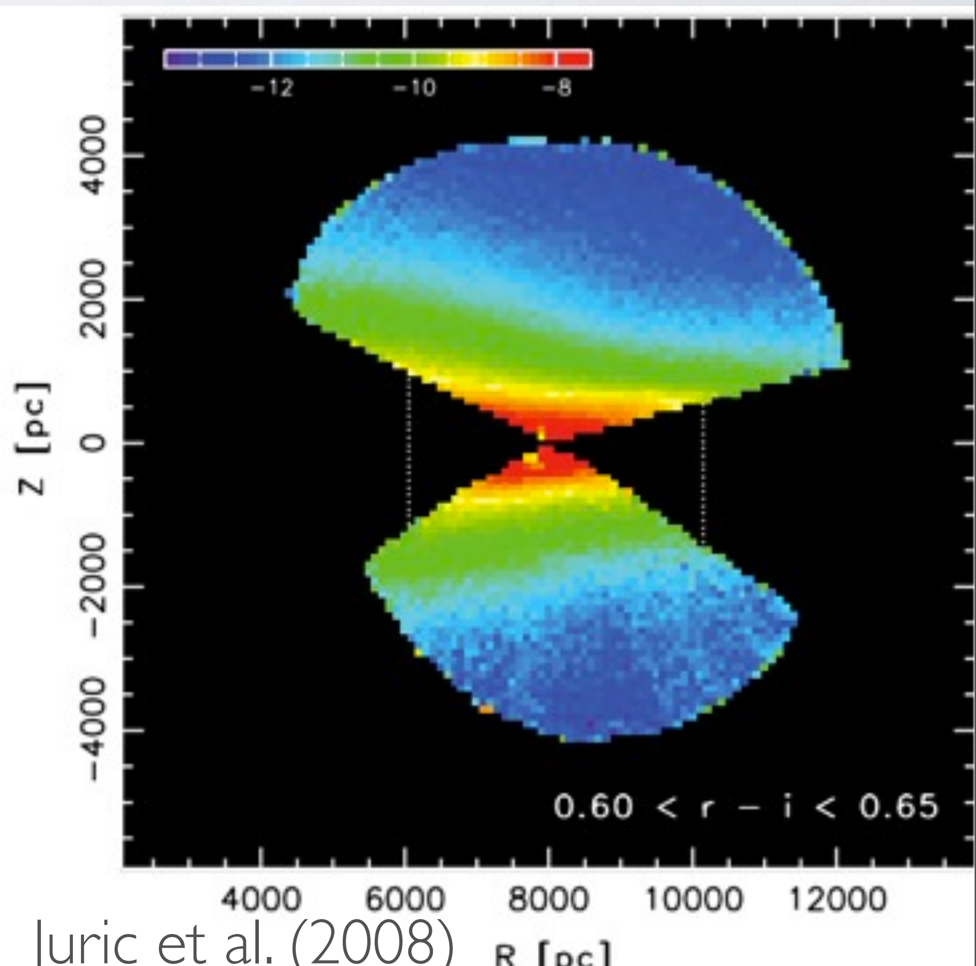
2MASS/J. Carpenter, T. H. Jarrett, & R. Hurt

DISK FORMATION AND EVOLUTION

- forming realistic disks *ab initio* remains difficult
- current structure: formation or evolution?
- internal and external evolution: what information about formation is retained?



Juric et al. (2008)

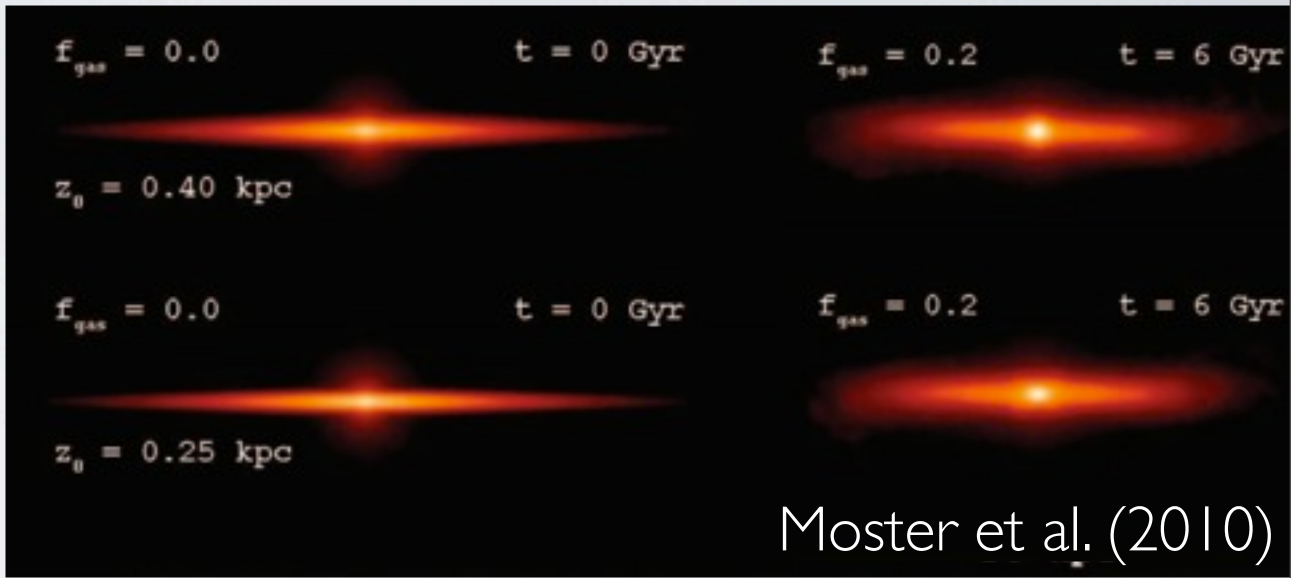
DISK EVOLUTION

- external: minor mergers can lead to *accretion* of satellite stars or *heating* of the existing disk

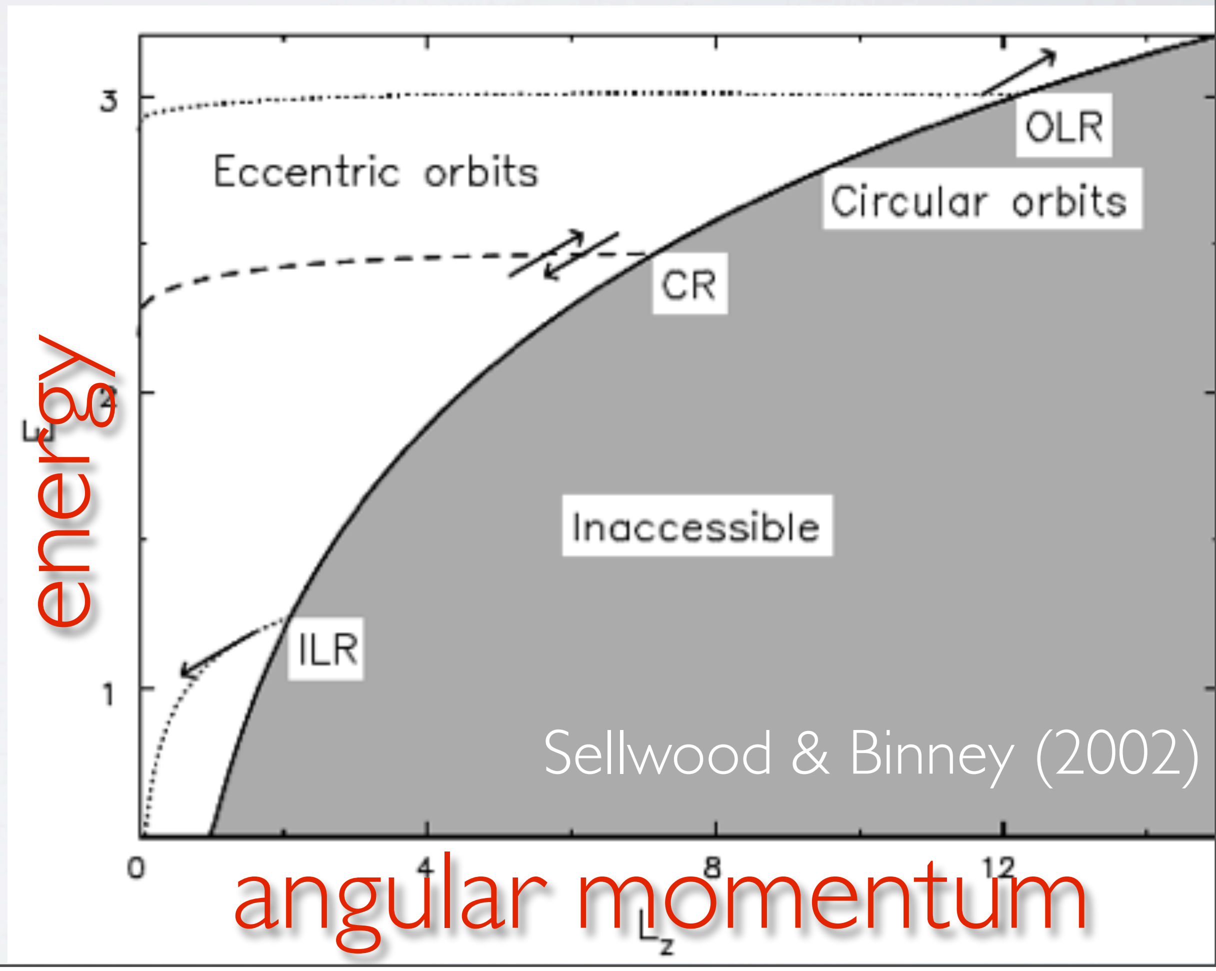
- internal: *wet merger* can induce rapid star formation, bar/spiral ams lead to *radial migration*

- radial migration erases formation memory: metallicity gradients flatten

- radial migration retains radial structure, adiabatically changes vertical motion



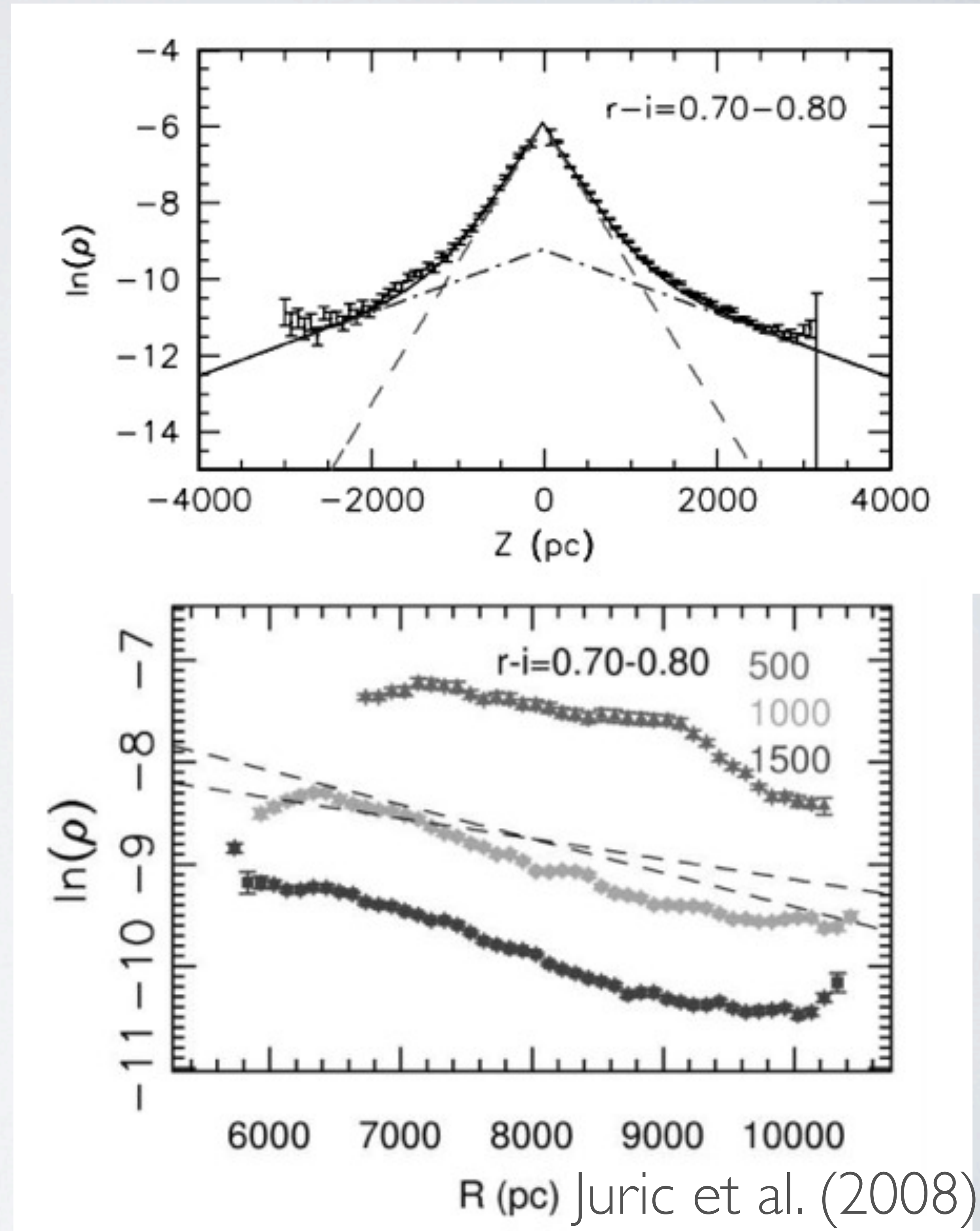
Moster et al. (2010)



Sellwood & Binney (2002)

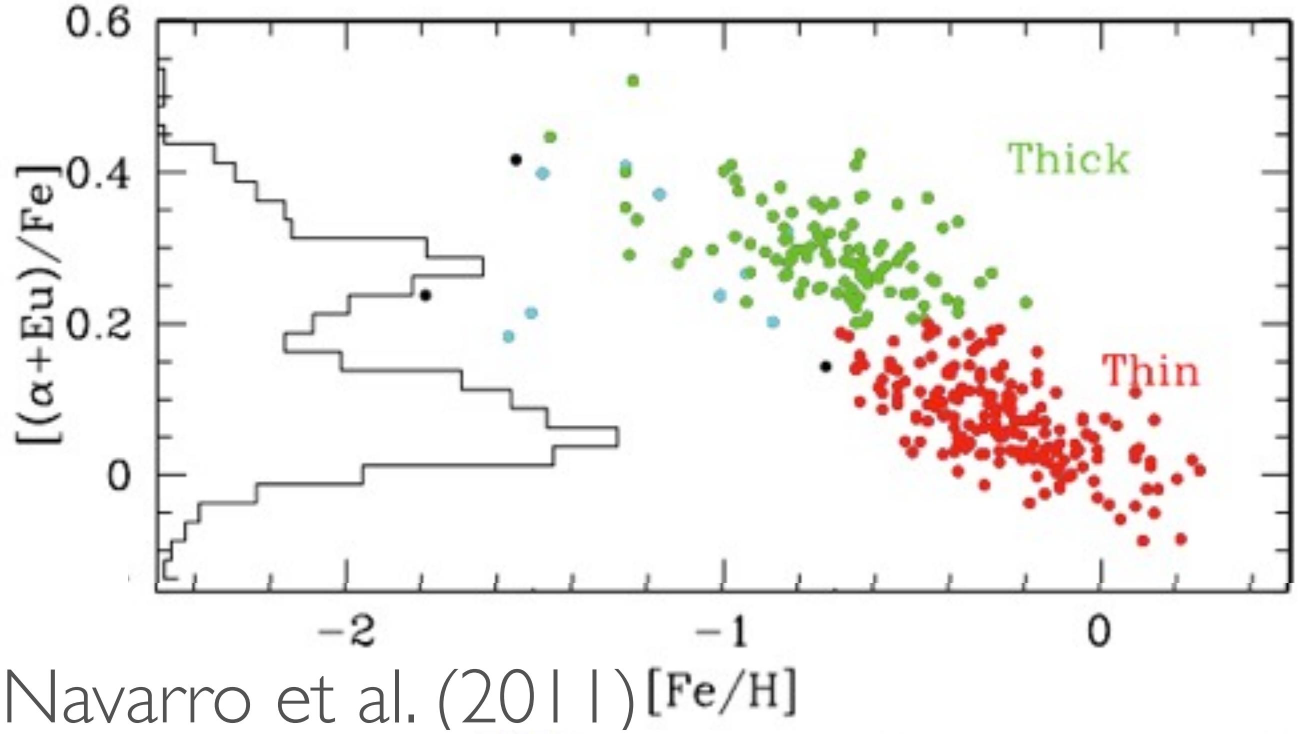
GEOMETRIC THICK–THIN DECOMPOSITIONS

- 2 component fits
- thin disk
  $h_Z \approx 300$ pc
  $h_R \approx 2.5$ kpc
- thick disk
  $h_Z \approx 900$ pc
  $h_R \approx 3.5$ kpc



Juric et al. (2008)

A CHEMICAL DEFINITION OF THE THICK DISK

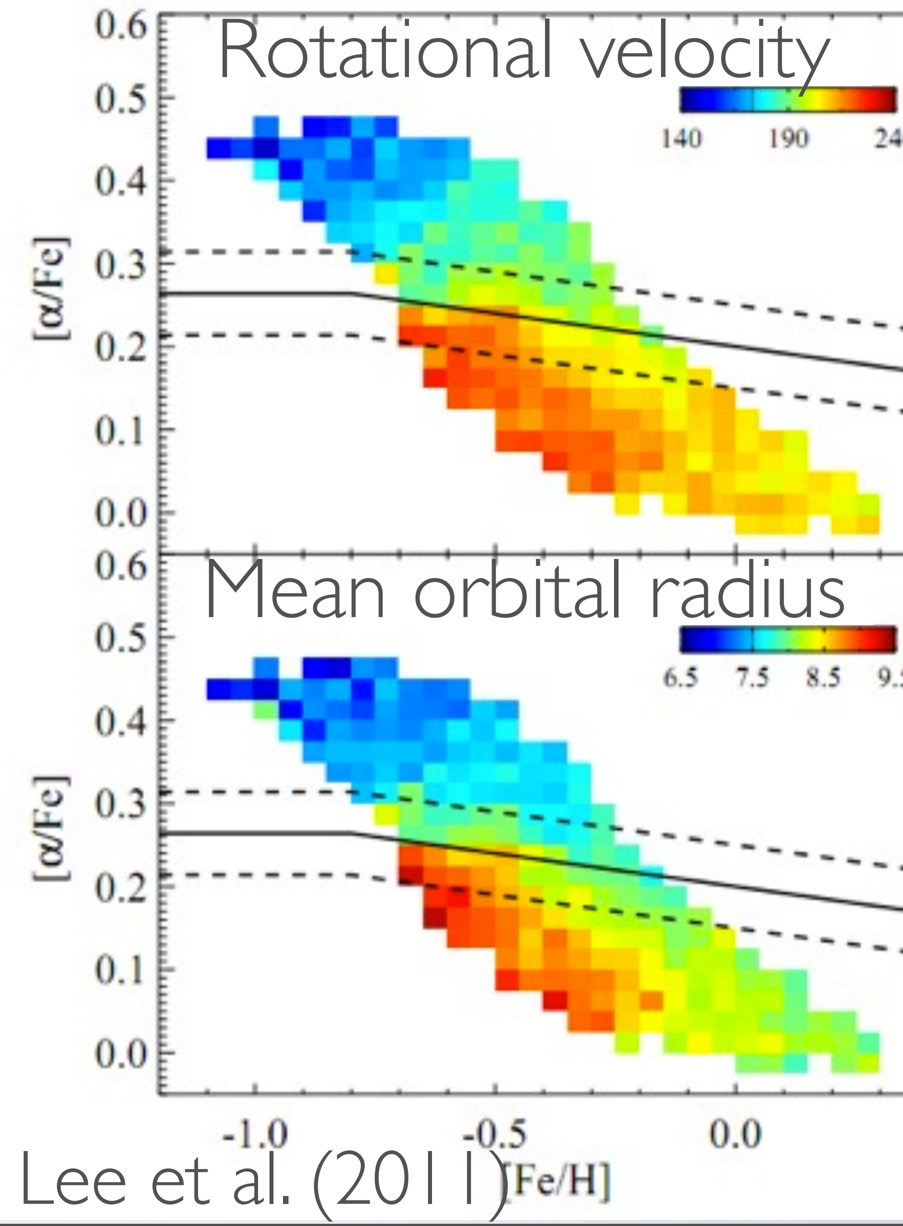


Navarro et al. (2011)

- traditionally thick disk stars are identified *kinematically*

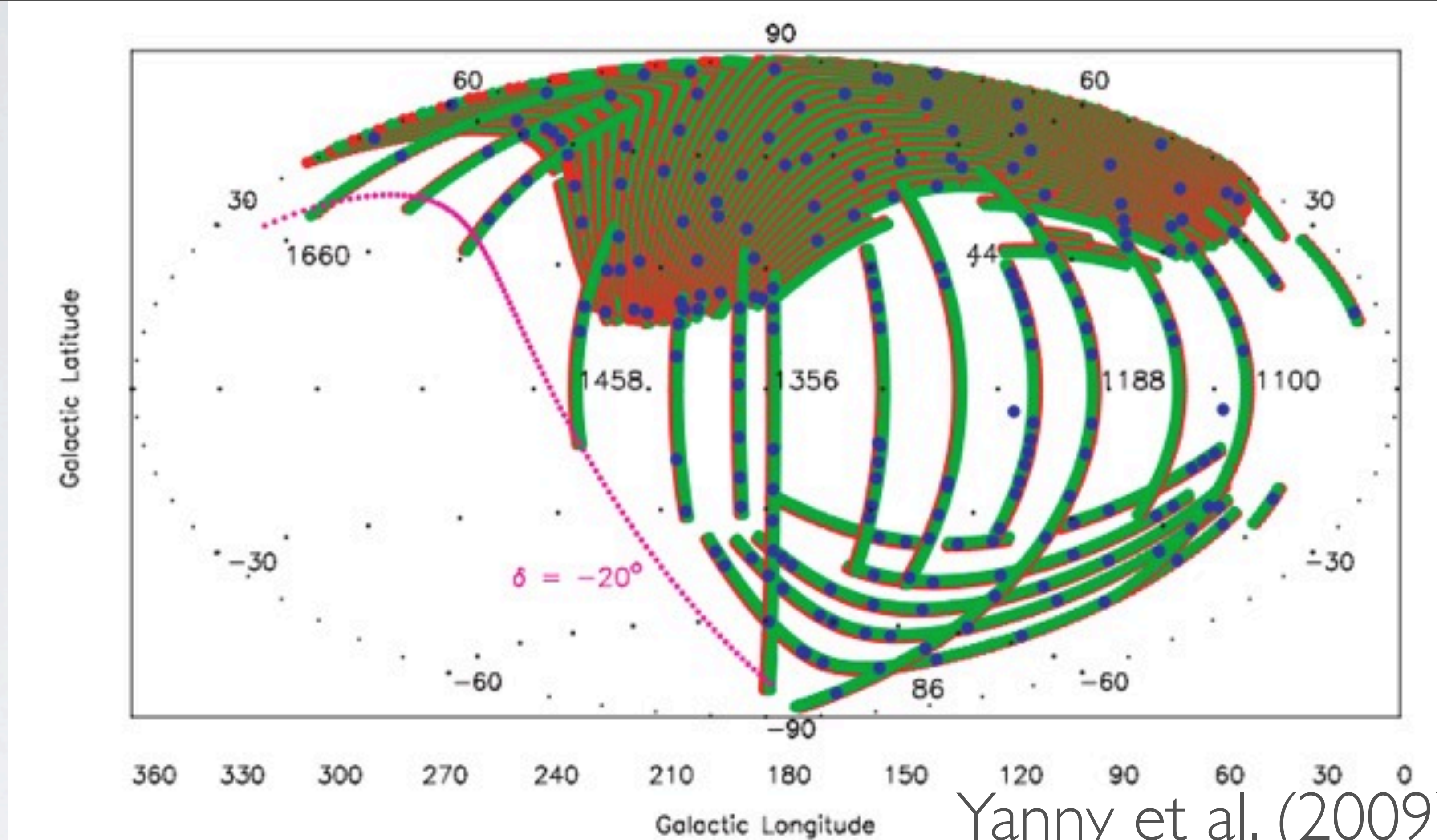
- thick disk is enhanced in alpha elements and metal poor

- cleaner than kinematic selection



Lee et al. (2011)

SEGUE

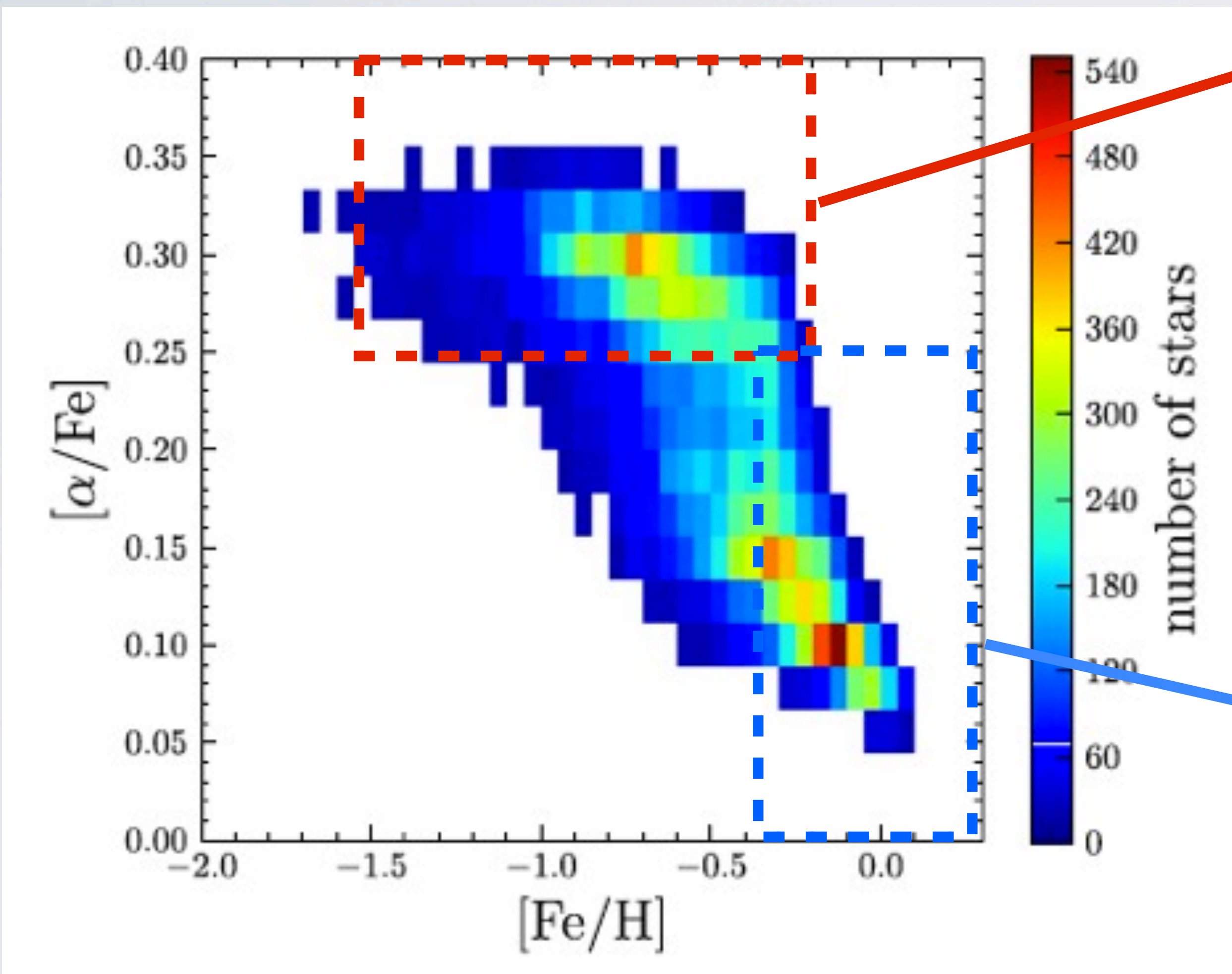


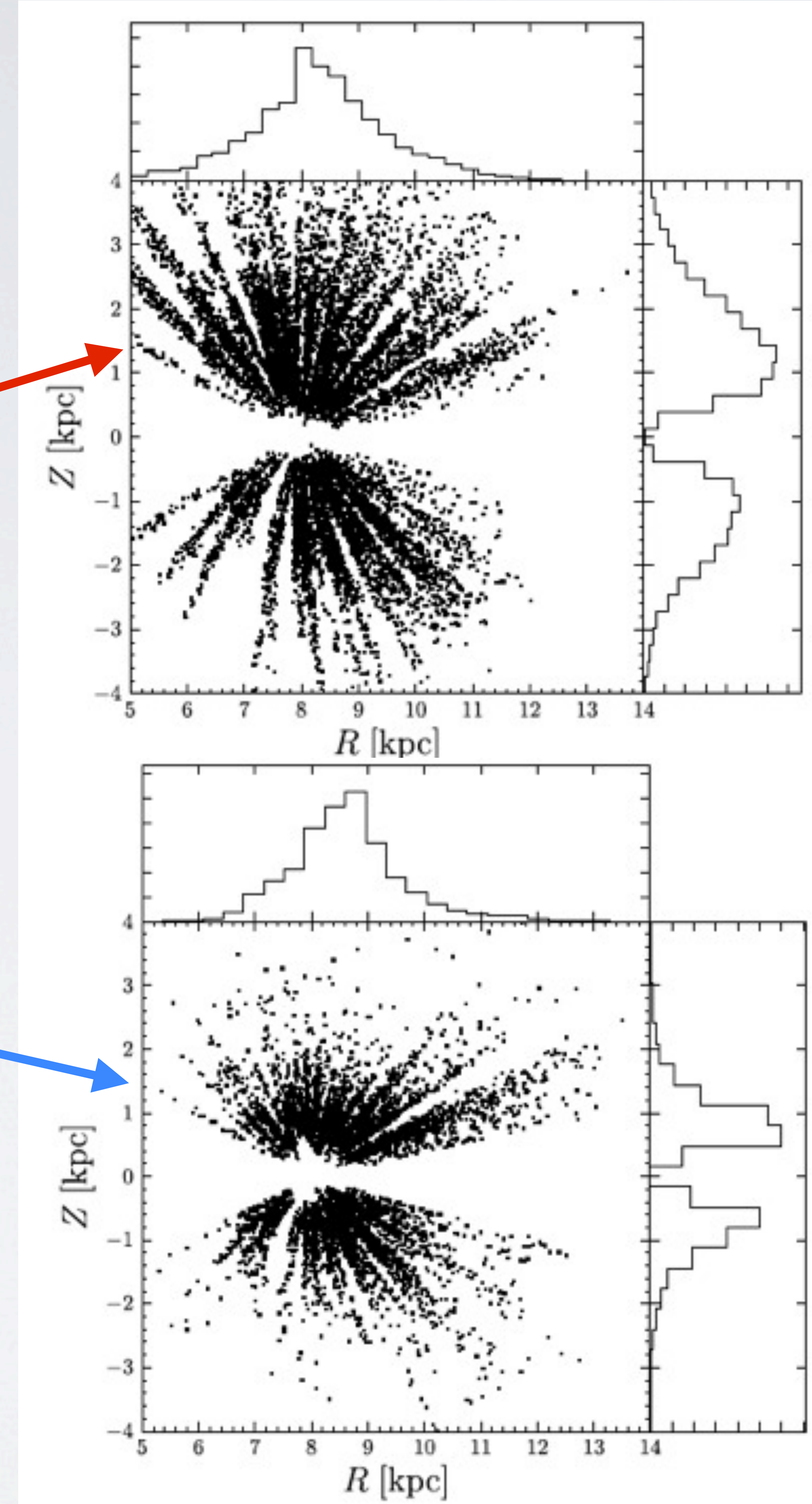
Yanny et al. (2009)

- spectra for 240,000 stars
- R ≈ 1800
- 14 < r < 20
- T_{eff}, log g, [Fe/H] (±0.2 dex), [α/Fe] (±0.1 dex)
- photometric distances ≈ 10%
- δv_{los} ≈ 7 km/s, **δμ** ≈ 2.5 mas/yr ≈ 12 km/s
- relatively simple selection

SEGUE G STARS

- G dwarf sample: 0.48 ≤ g-r ≤ 0.55, 14.5 ≤ r ≤ 20.2, log g > 3.75, SN > 15, —*30,000 stars*

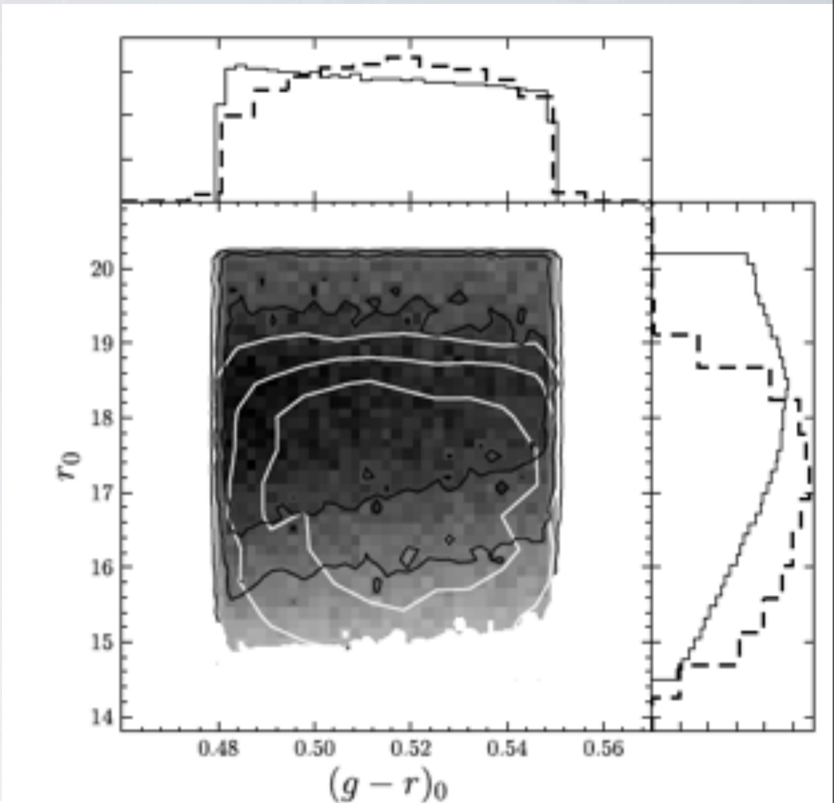


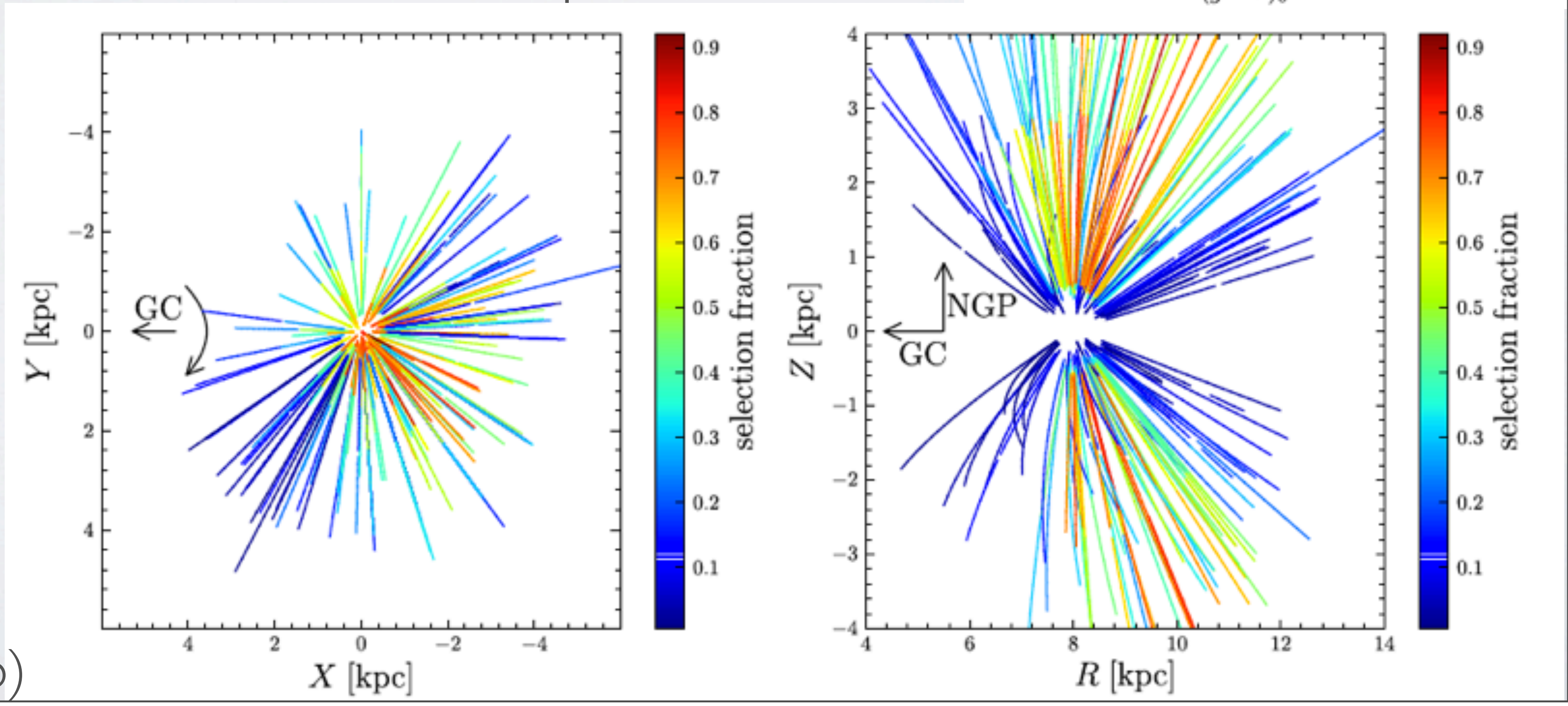


Bovy et al. (in prep)

SEGUE SELECTION FUNCTION

- SEGUE samples each line-of-sight uniformly down to r = 20.2 mag
- SN cut induces brighter cut-off
- for each plate we empirically determine the cut-off and the fraction of sampled stars





Bovy et al. (in prep)

LIKELIHOOD-BASED DENSITY FITS

- proper model is a *Poisson process*
- observed density of stars λ(l,b,d,r,g-r,[Fe/H]):

$$\lambda(l, b, d, r, g-r, [\mathrm{Fe/H}]) = \rho(r, g-r, [\mathrm{Fe/H}]|R, Z, \phi) \times \nu_*(R, Z, \phi) \times |J(R, Z, \phi; l, b, d)| \times S(\mathrm{plate}, r, g-r)$$

- log likelihood:

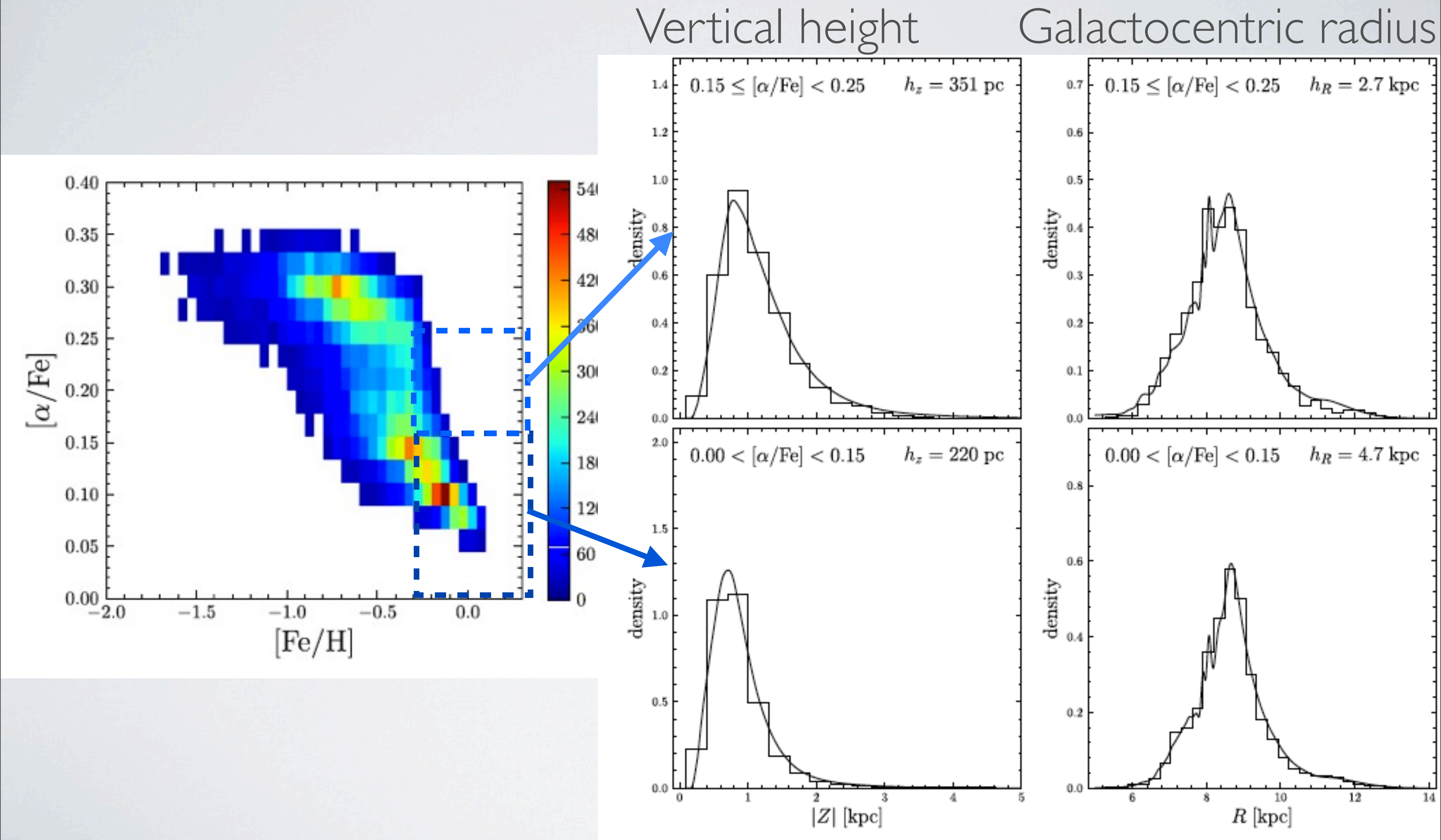
$$\ln \mathcal{L} = \sum_i \{\ln \lambda(\{l, b, d, r, g-r, [\mathrm{Fe/H}]\}_i|\theta)\} - \int \mathrm{d}l\, \mathrm{d}b\, \mathrm{d}d\, \mathrm{d}r\, \mathrm{d}(g-r)\, \mathrm{d}[\mathrm{Fe/H}]\, \lambda(l, b, d, r, g-r, [\mathrm{Fe/H}]|\theta)$$

- marginalize over amplitude:

$$\ln\mathcal{L} = \sum_i \left\{\ln \nu_*(R, z|\{l, b, d\}_i, \theta) - \ln \int \mathrm{d}l\, \mathrm{d}b\, \mathrm{d}d\, \mathrm{d}r\, \mathrm{d}(g-r)\, \mathrm{d}[\mathrm{Fe/H}]\, \lambda(l, b, d, r, g-r, [\mathrm{Fe/H}]|\theta)\right\}$$

Bovy et al. (in prep)

BROAD BINS IN ABUNDANCE



Bovy et al. (in prep)

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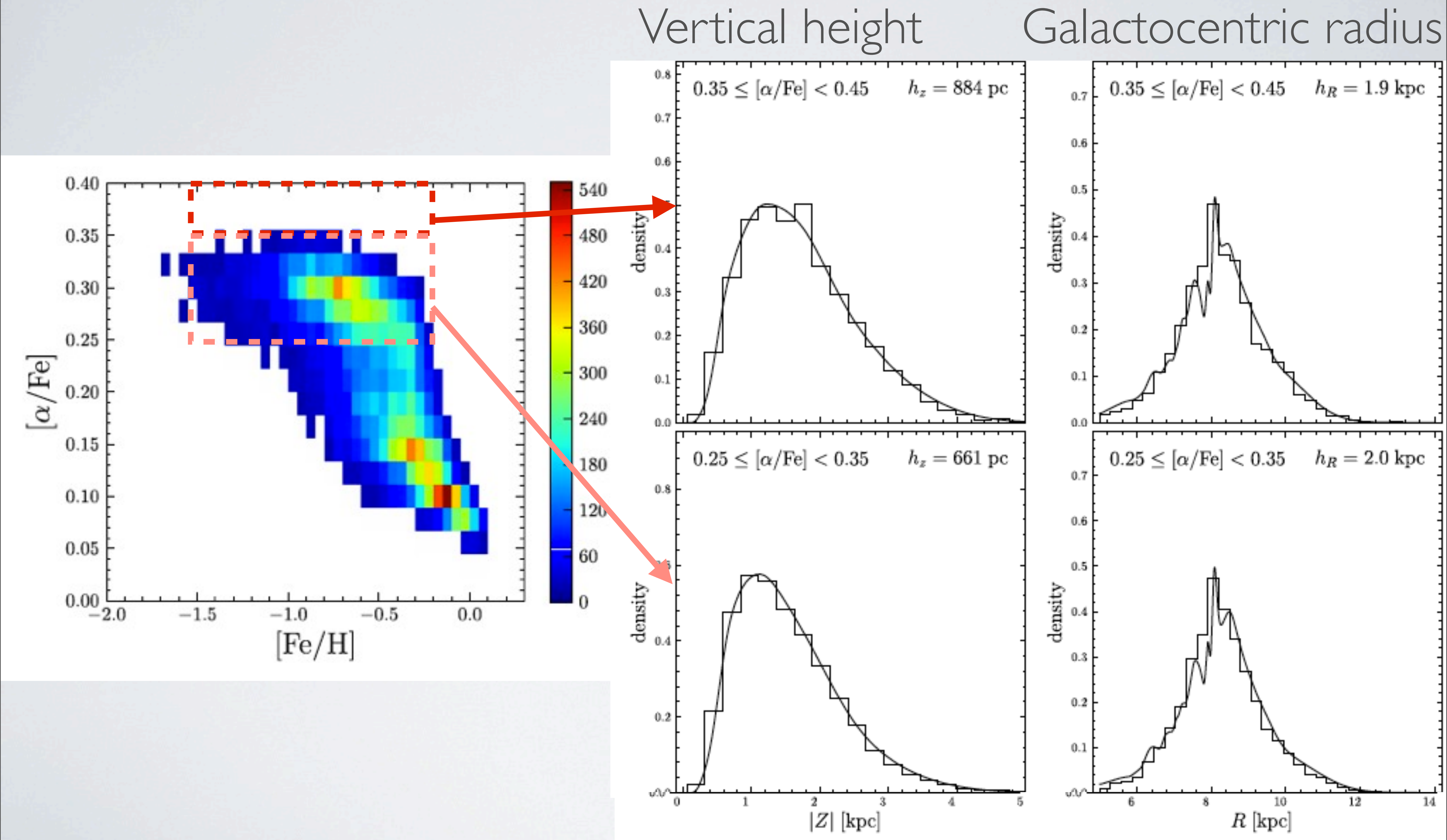
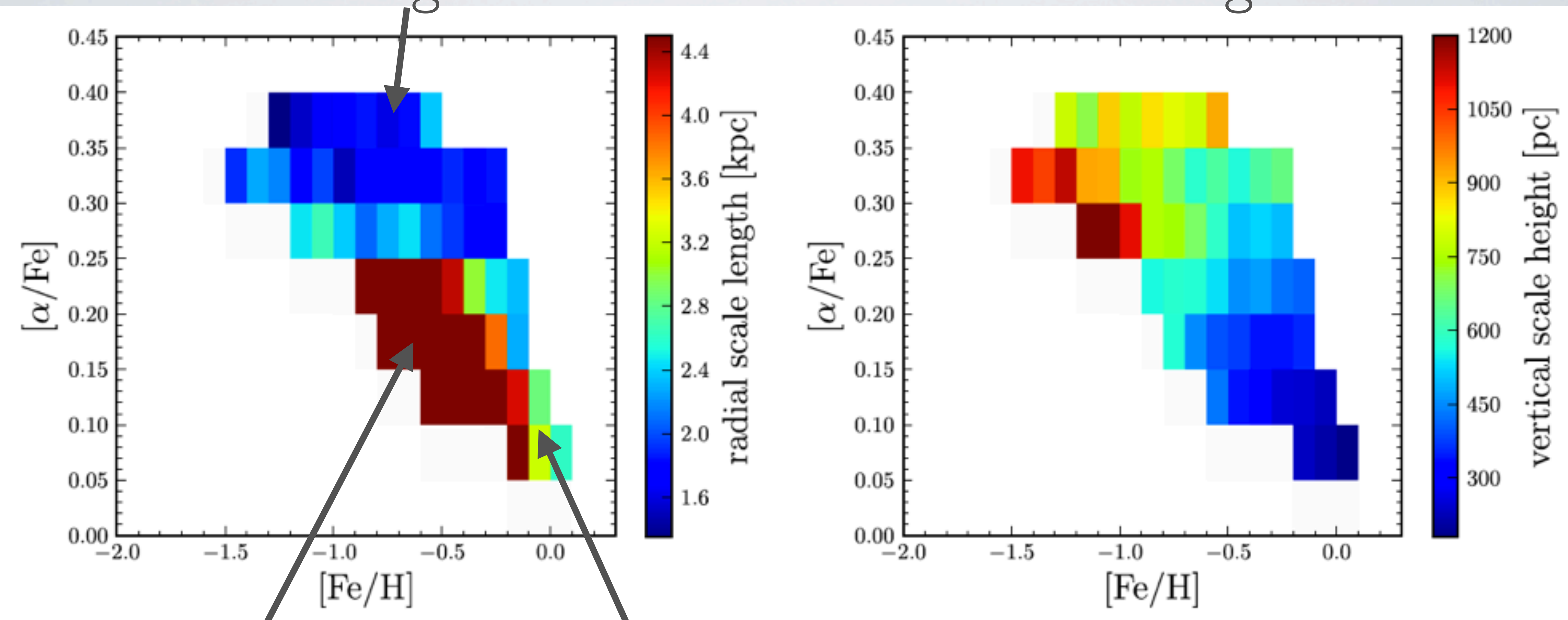


Bovy et al. (in prep)

ABUNDANCE-RESOLVED SPATIAL STRUCTURE

Short thick disk scale length

Smoothly increasing scale heights



Very long scale length

Longer thin disk scale length

Inside-out disk formation

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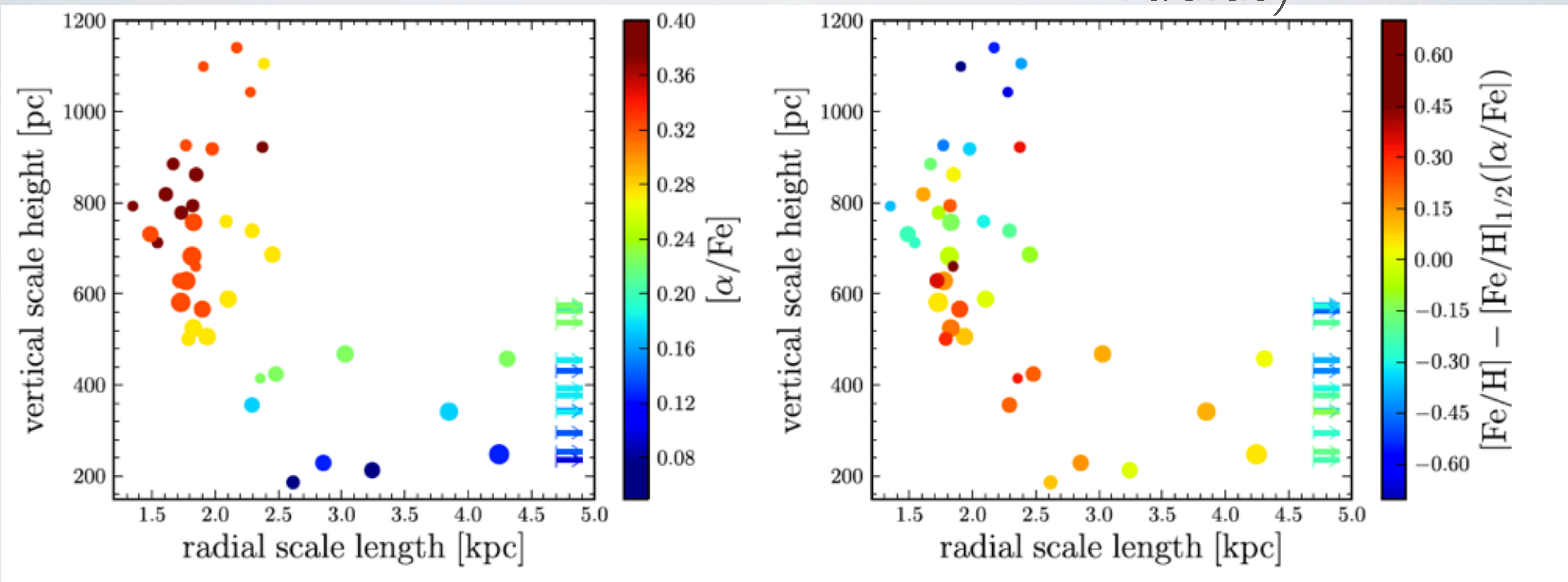
ABUNDANCE-RESOLVED SPATIAL STRUCTURE

Scale length and scale height are anti-correlated

Structure set both by [α/Fe] (~age) and [Fe/H] (~birth radius)



Smooth internal evolution / radial mixing

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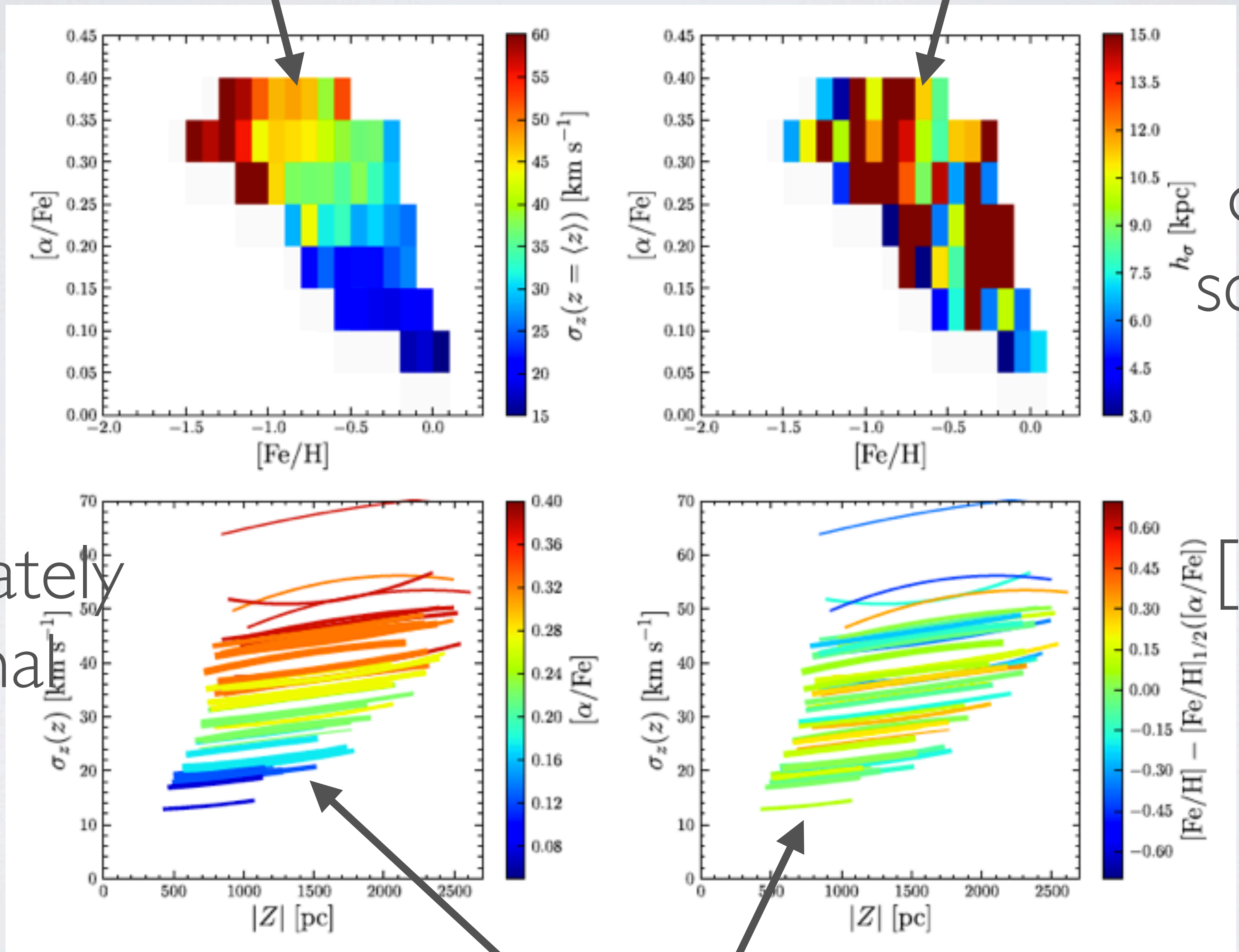
ABUNDANCE-RESOLVED VERTICAL KINEMATICS

Vertical dispersion

dispersion radial scale length

Smoothly increasing dispersion

Single dispersion scale length?



Approximately isothermal

[α/Fe] (age) sets dispersion

Vertical dispersion profile

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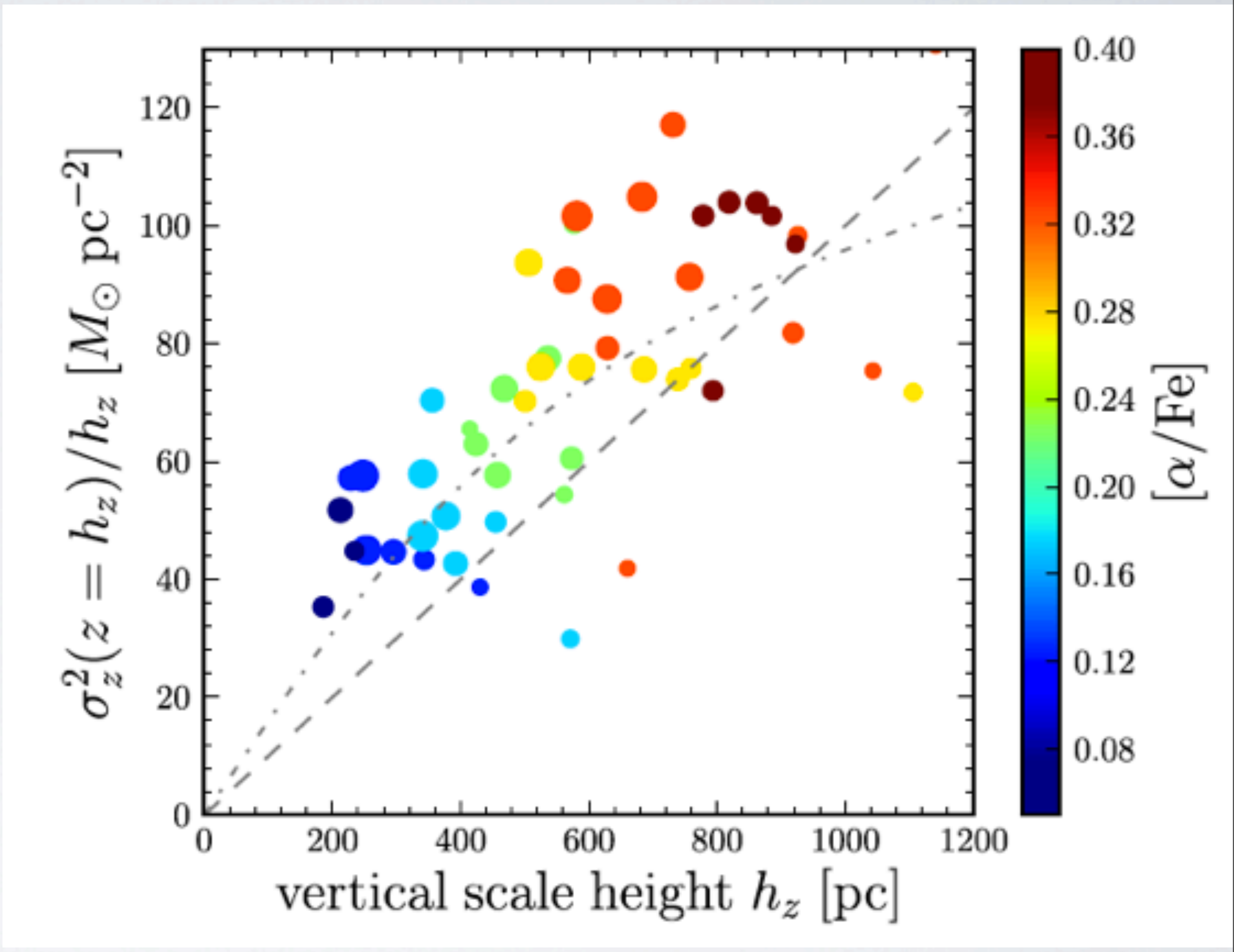
PROSPECTS FOR LOCAL DYNAMICS

- for isothermal population the surface-mass density $\Sigma(Z) \propto \sigma_Z^2 / h_Z$
- abundance resolved dynamics is simple and highly constraining
- stay tuned for $\Sigma(R,Z)$



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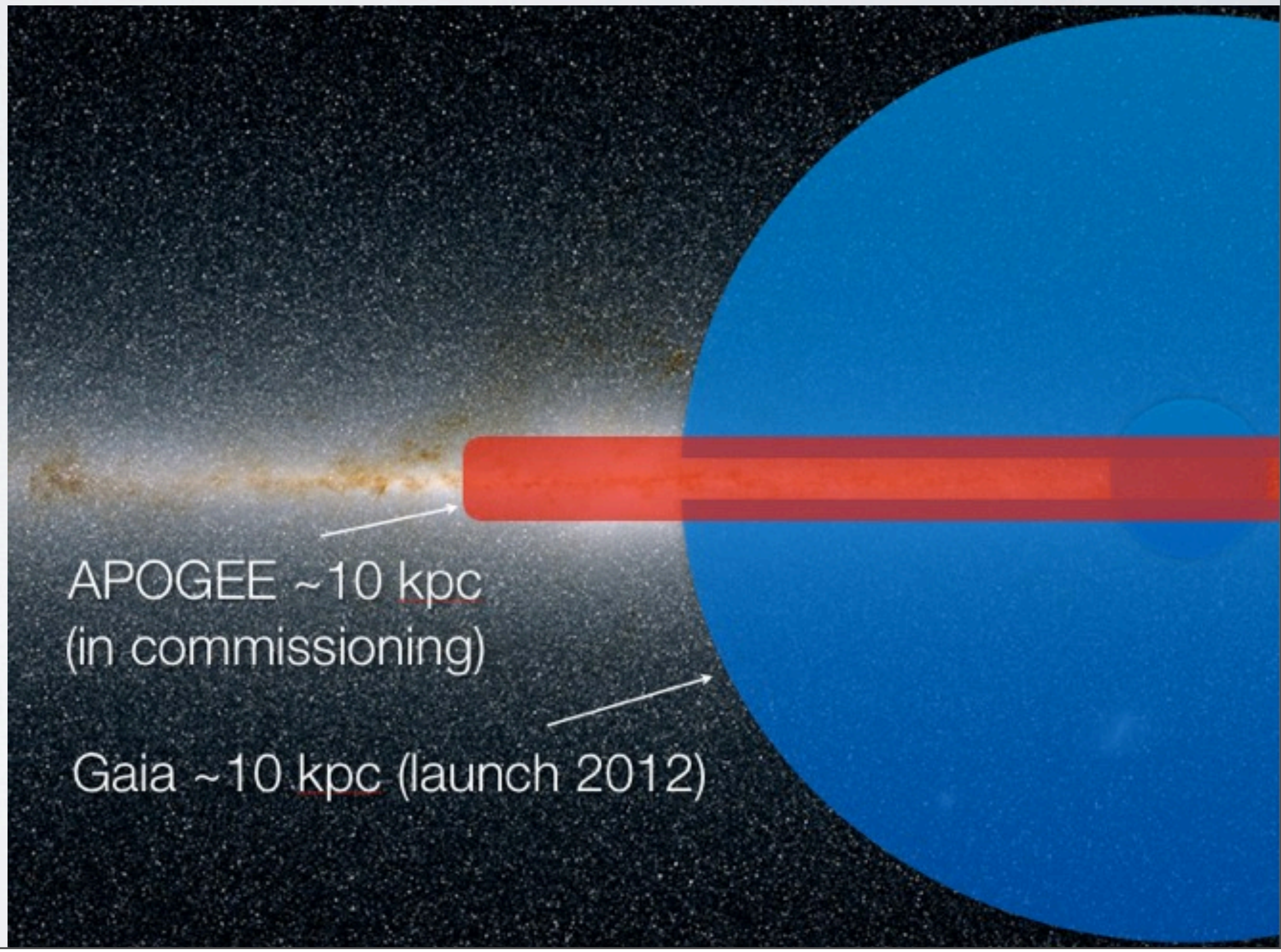
NEXT DECADE FOR THE MILKY WAY

- several large surveys approved, funded, or ongoing

- spectroscopic: SDSS-III APOGEE (commissioning started May '11), ESO-GAIA : spectroscopic view of large part of the disk; *100,000s of stars*

- GAIA: astrometric survey due for launch next year

- *1,000,000* stars, micro-as accuracy (up to 10 – 100 kpc)



CONCLUSIONS

- first real constraint on thick disk scale length shows that it is short ≈ 2 kpc
- scale length and scale height are anti-correlated, opposed to purely geometric thick–thin decompositions
- scale heights and vertical dispersion increases smoothly from thin to thick → no clear thick/thin disk break
- assuming that [α/Fe] is a proxy for age, our results show that old components are more centrally concentrated than young components → inside-out disk formation
- smooth increase in scale height and dispersion that is anti-correlated with scale length → radial migration played a large role in the evolution of the disk