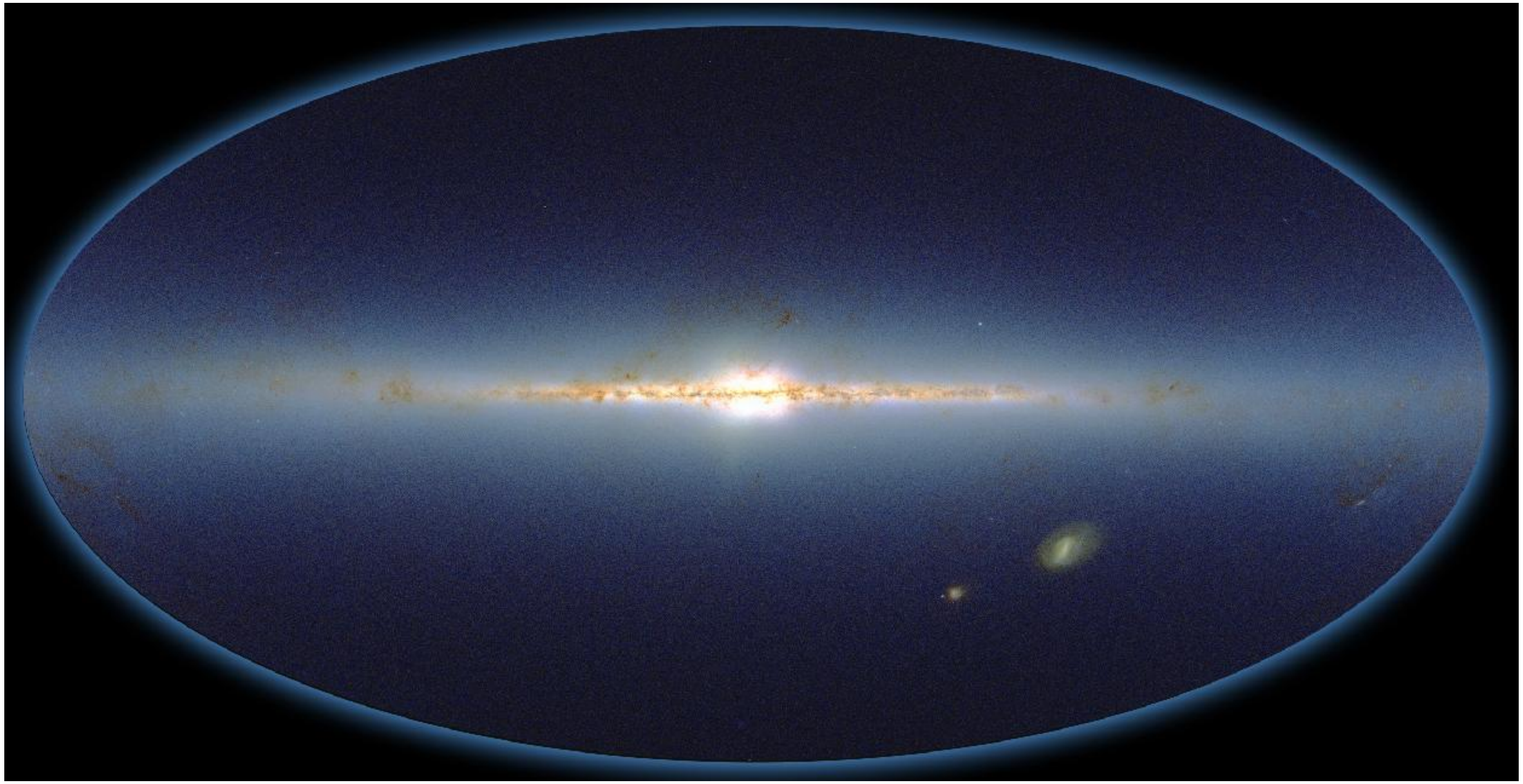
Dissecting and Assembling the Milky Way's (Stellar) Disk

H.-W. Rix (MPIA, Heidelberg)

Paris, Dec. 9 2011



In collaboration with:

J. Bovy @ IAS, Princeton

L. Zhang @ MPIA, C. Rockosi @ Santa Cruz & the SEGUE collaboration

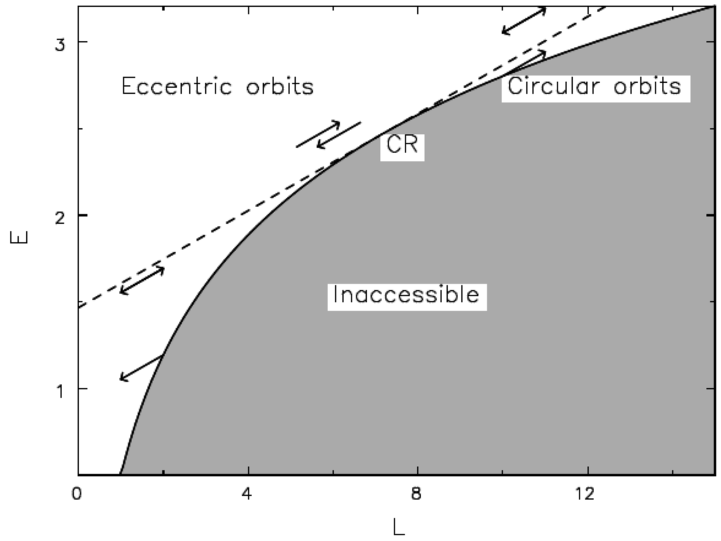
Bovy, Rix, et al 2011 ab (astro/ph)

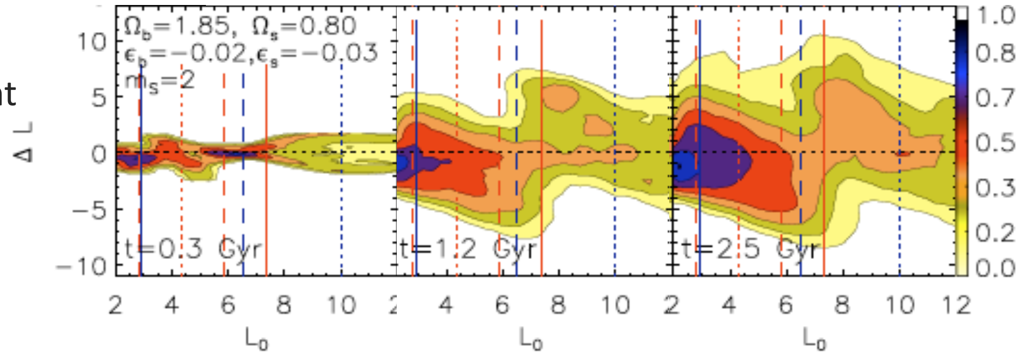
What makes the MW disk (cosmologically) interesting?

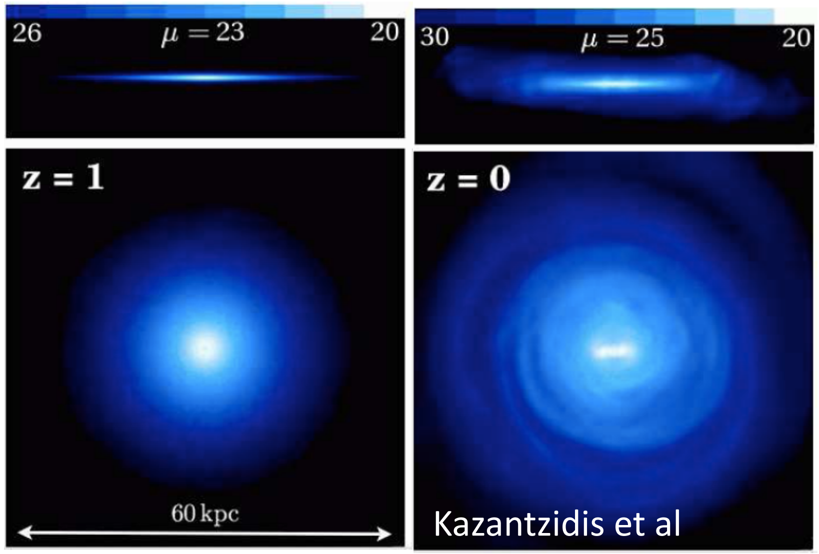
- Most MW stars are in the disk!
- Making 'realistic disks' in *ab initio* simulations remains formidable challenge
  - 'inside-out' grow seems generic feature
- What sets structure (e.g. radial/vertical profile) of stellar disks?
  - birth radius *vs.* present location
  - 'distinct' components a sensible description?
- What is the role of internal vs external drivers of disk evolution?
  - How much (dynamical) formation memory is erased?

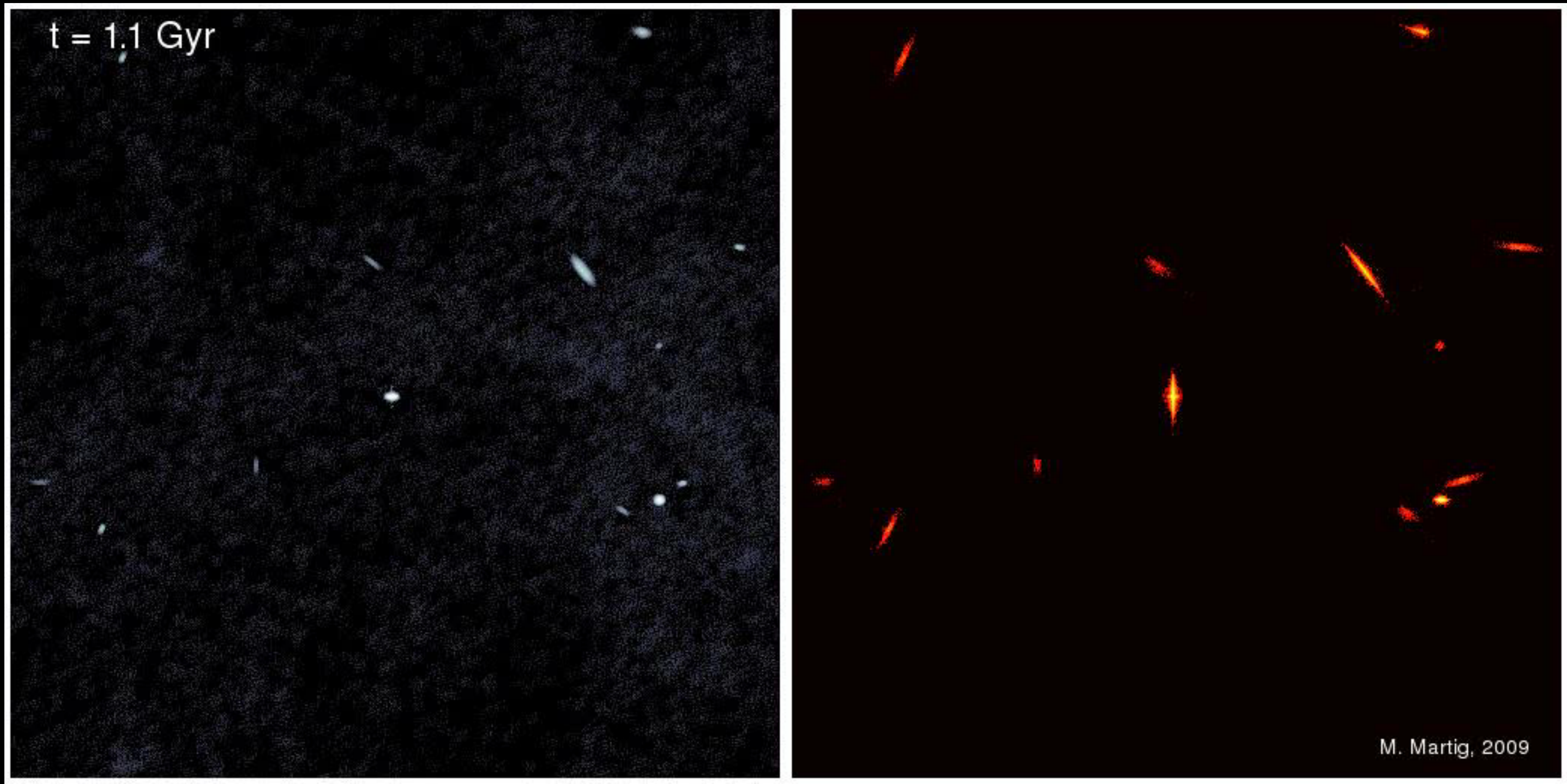
(Stellar) Disk Evolution Processes

- Gas Infall & Star Formation
- Radial Migration
  (Sellwood & Binney 2002, Minchev et al 2009)
  - Spiral arms, bars change orbits near co-rotation resonance
    - radius changes without eccentricity boost
    - bars/spirals arms are presumably transient → $R_{co\text{-}rot}$ wanders
  - Qualitatively inevitable whenever bars/spirals have been present
- Minor mergers
  - can heat the disk (e.g. Moster et al 2010)
  - can augment the disk (e.g. Abadi et al 2003)
  - Qualitatively inevitable









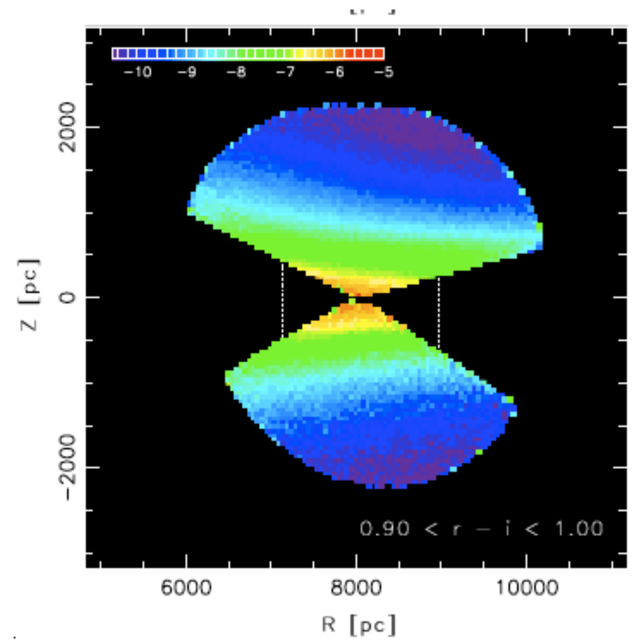
http://www.youtube.com/watch?v=tL4gTINR1Y8

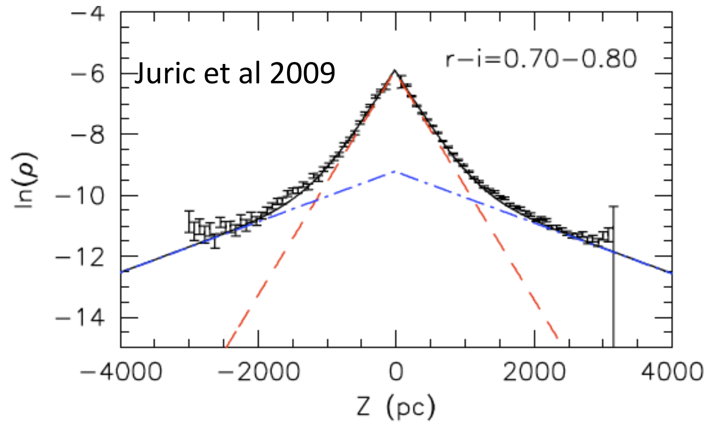
Characterizing the MW's Stellar Disks(s)

Geometry & Kinematics

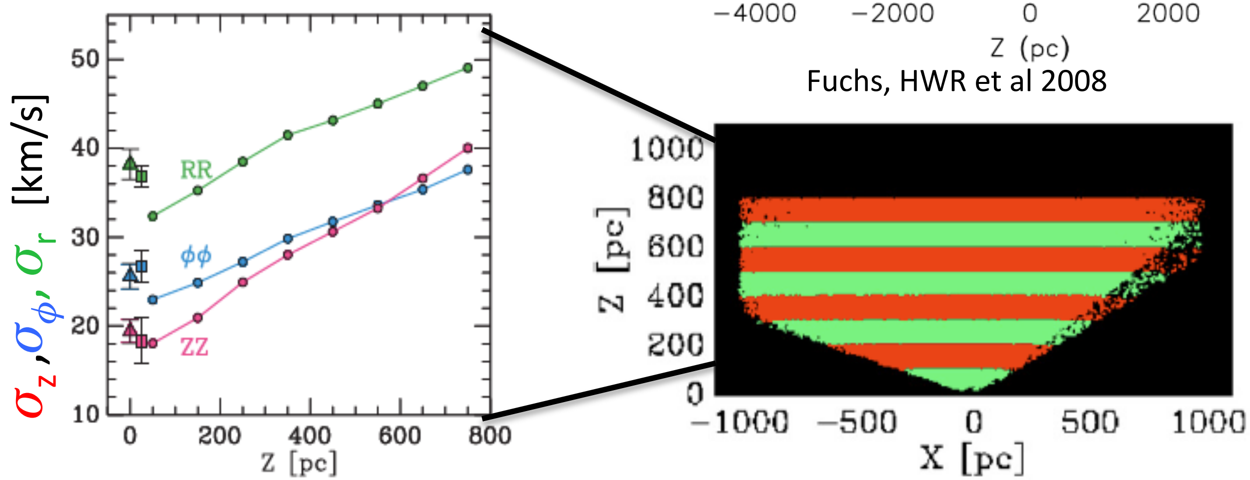
- Stellar Number Density
  - double exponential vertically (thick/thin disk)
  - exponential in radius: thick disk radially extended???
- Stellar kinematics
  - velocity dispersion increases with height
  - mean rotation velocity decreases accordingly
- Two component description sensible

  ..but the geom./kinem. data show no 'breaks'





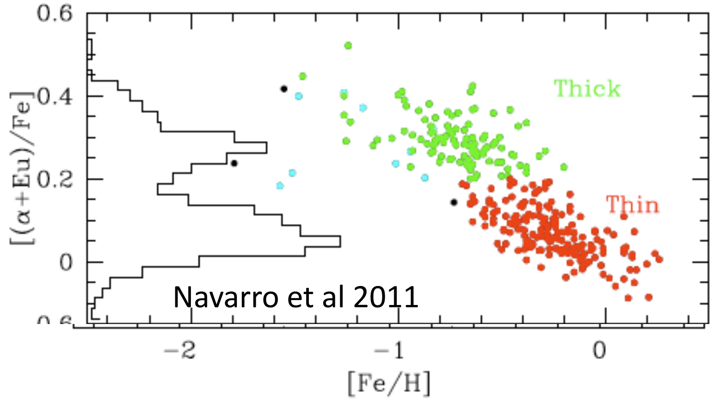
Fuchs, HWR et al 2008

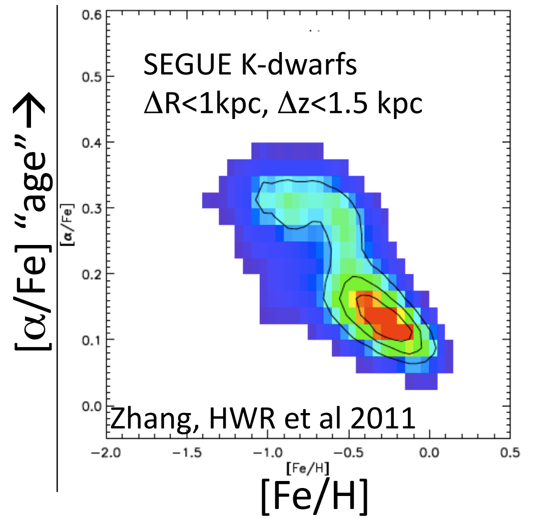


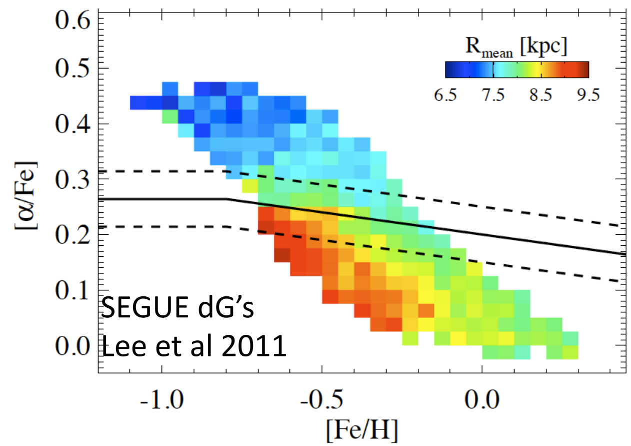
Characterizing the Stellar Disks(s)

Chemo-kinematic

- Bi-modal [α/Fe] distribution
  - Lee et al 2011, Navarro et al 2011
  - α–enhanced ← → rapid (early?) enrichment, best practical 'age tag'?
- Strong correlation between kinematics and abundances:
  - more metal-poor: kin. hotter
  - 'thick disk' is α-enhanced [α/Fe]>0.2
- α-enhanced stars come from inner galaxy
- Do the abundances argue for a "distinct thin-thick disk"?

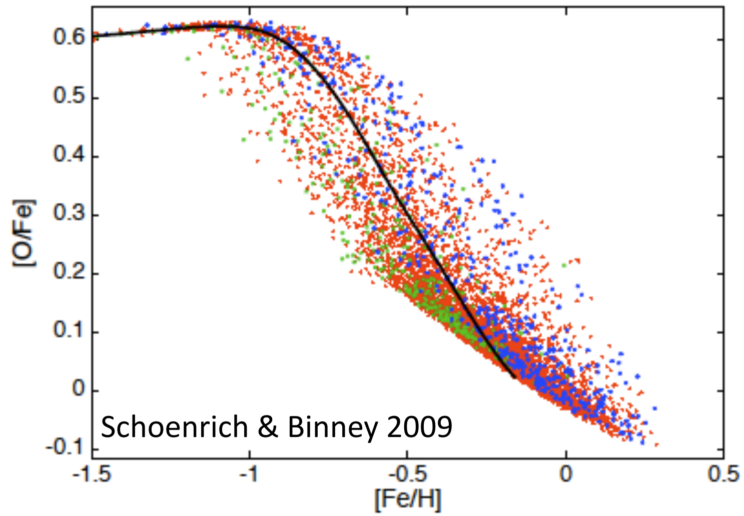






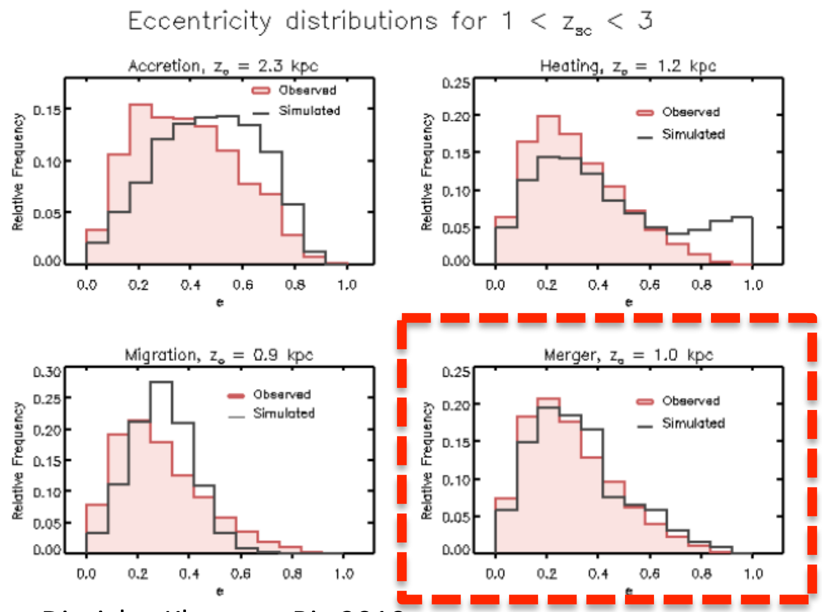
Testing Disk-Evolution Scenarios: data-model comparison around the Sun's position

- metallicity distribution of stars near the Sun as a consequence of radial migration
  (Schoenrich & Binney 2009)
  - [α/Fe] age proxy, [Fe/H] birth radius proxy
  - Does that model – tuned to R_o – get things right at other radii?



- What created the thick disk?
  - Satellite ingestion, satellite heating, 'wet' merger, or radial migration?
  - Excentricity distribution as a diagnostic?
  Sales et al 2009, Dierickx et al 2010, Wilson et al 2011

- Need non-local, spatially resolved data-model comparisons!



Dierickx, Klement, Rix 2010

Questions for this talk

Has the Milky Way disk grown inside out throughout its life?

Does it make sense to view distinct thin & thick disk components?

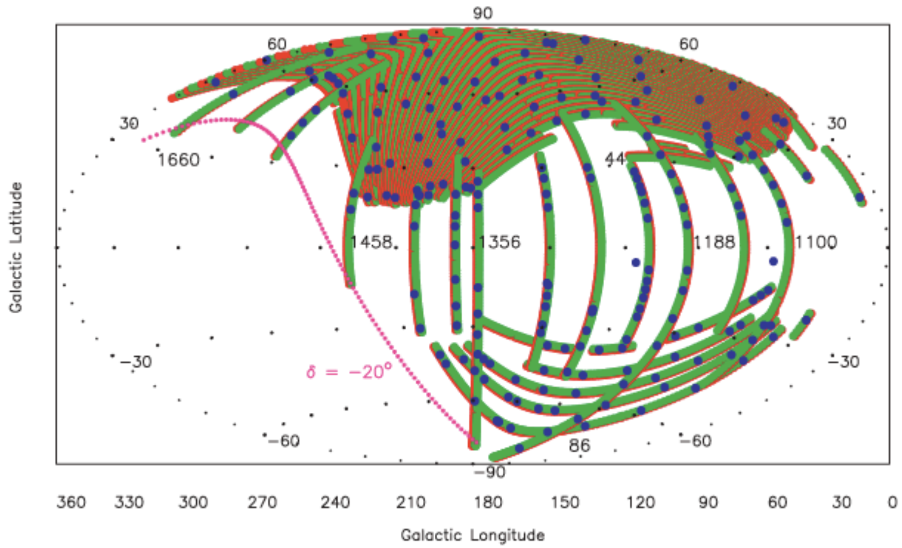
Differentiate disk heating mechanism from kinematic structure?

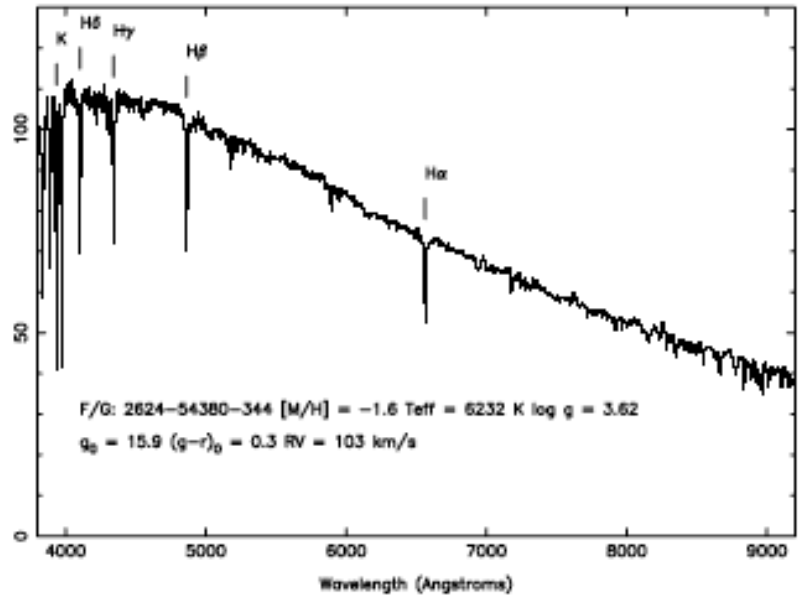
SEGUE

'SDSS spectroscopizes the Milky Way'

Yanny et al 2009; Rockosi: PI

- spectra for 240,000 stars
  - ~10 targeting categories
  - spectral res. R~1800
  - $14 < m_r < 20$
- yielding:
  - T_{eff}, log g
  - [Fe/H] (±0.2 dex), [α/Fe] (0.06dex) (Lee et al 09)
  - (MS) distances to ~7% (An et al 2010)
  - $\delta v \sim 7$ km/s ($\delta\mu \sim 2.5$mas/yr)
- good:
  - radial velocities 'good enough': ~8 km/s
  - distances 'good': ~5-10%
  - two abundance numbers: [Fe/H], [α/Fe]
  - giant/dwarf separation using log g
- less good:
  - mostly high latitude / optical spectra
  - D_{min} = 300-700 pc





The MW Disk Structure and Kinematics for Single-Abundance Sub-Populations

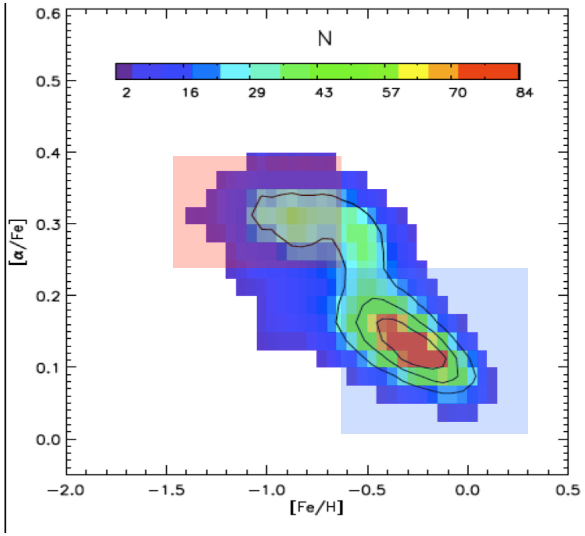
Bovy, Rix, et al 2011a

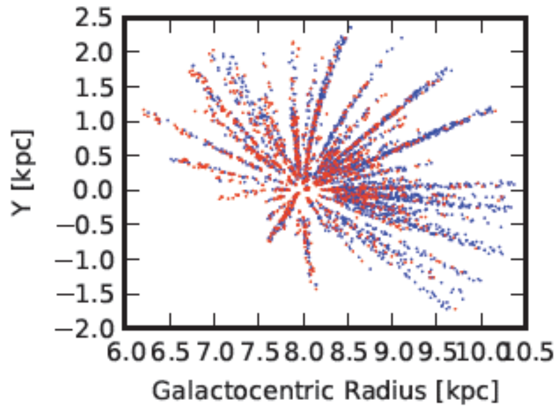
- Considering only a sub-population in [α/Fe] & [Fe/H] space …… what

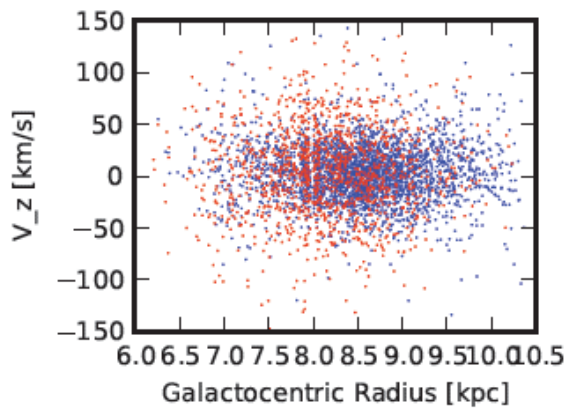
  is the ***spatial*** structure?
  - vertically, radially

  is the ***kinematic*** structure?
  - vertically, radially

- Data:
  - SEGUE K or G-dwarf sample
  - NB: complex selection function
    - Less important for kinematics
  - Velocities (and errors) distance dependent







Spatial distribution of [α/Fe]-components:
accounting for the sampling function

For given density model:

$$\nu_*(R,z \mid \vec{p}_*) = \left(\sum_i \nu_{0,i} \times e^{-\frac{|z|}{h_{z,i}(R)}} \right) \times e^{-\frac{(R-R_\bullet)}{R_{exp}}}$$

how best to determine the model parameters?

- Multiple scale heights?
- $h_z(R)$: flaring?

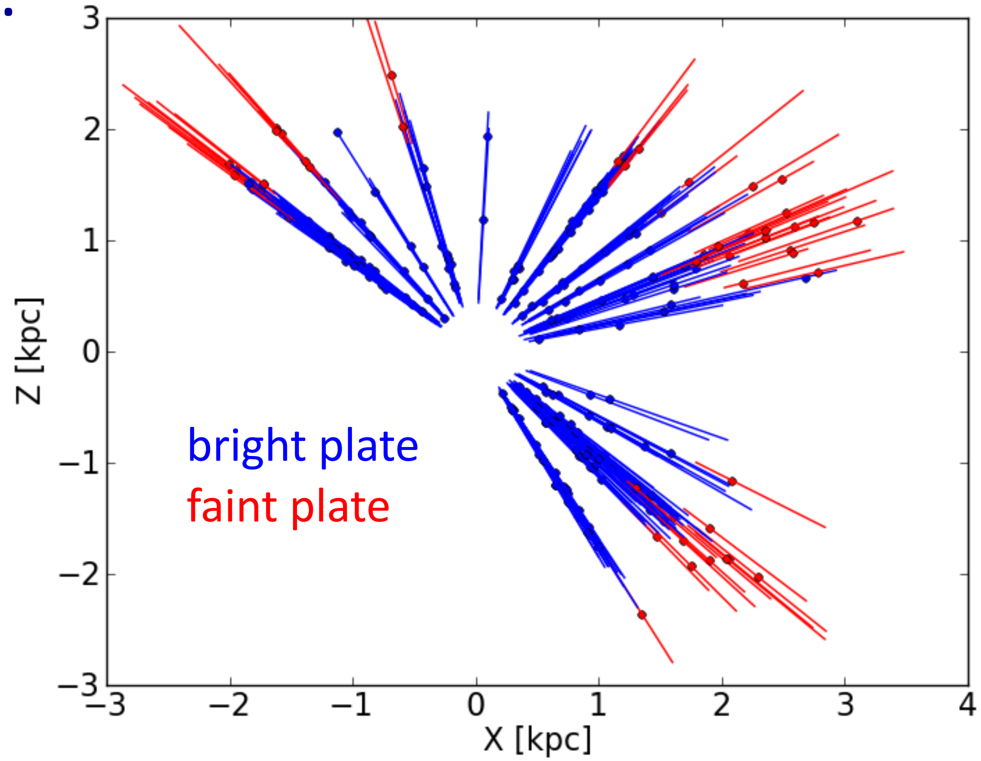
Sub-set of stars (65) targeted in m_r, g-r color-magnitude per (faint/bright) plate

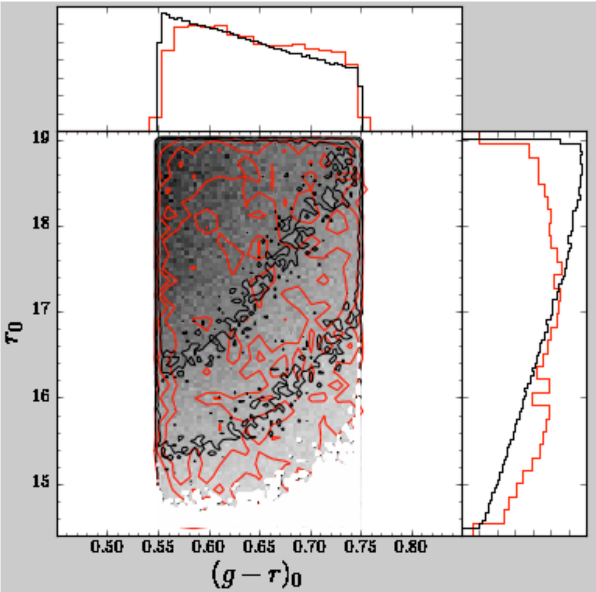
- S/N cut for [a/Fe] determination

Construct sampling function:

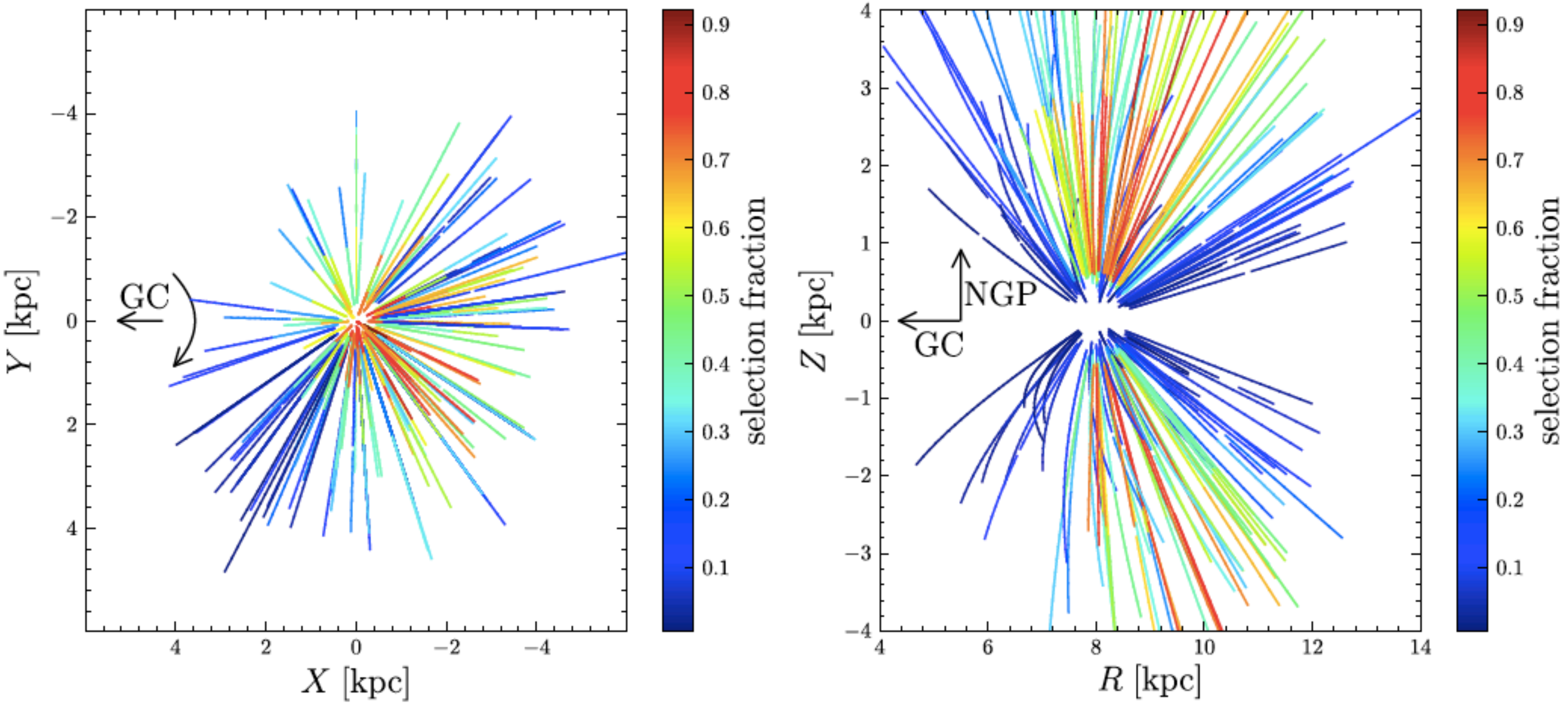
$$w_{spec}(R,z \mid (\mathrm{l,b}),\ \mathrm{m_r},\ \mathrm{g-r},\ [\mathrm{Fe/H}],\ \text{bright/faint})$$

Bovy, HWR et al 2011a

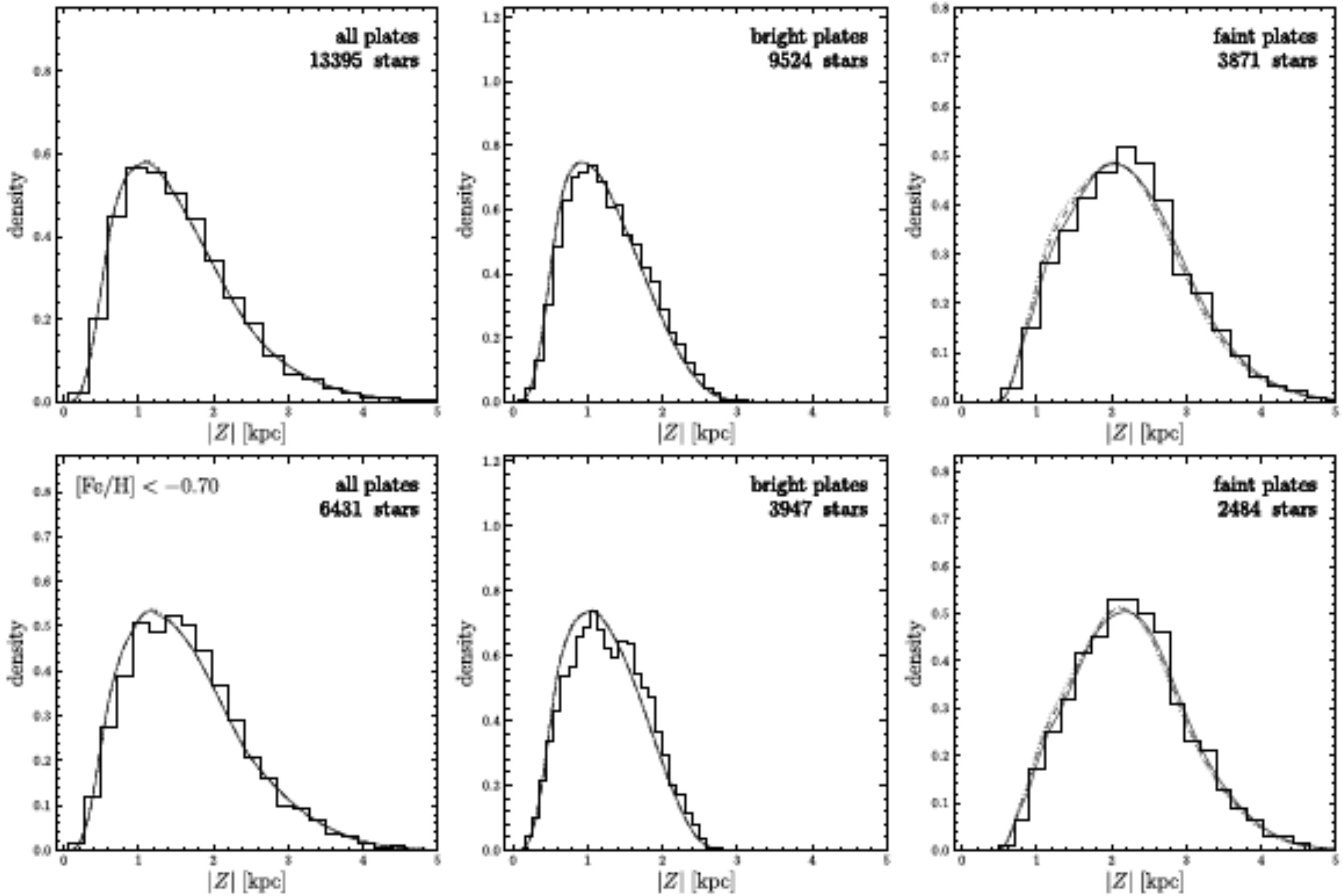




Which fraction of stars in a (m_r,g-r) bin get targetted by SEGUE?



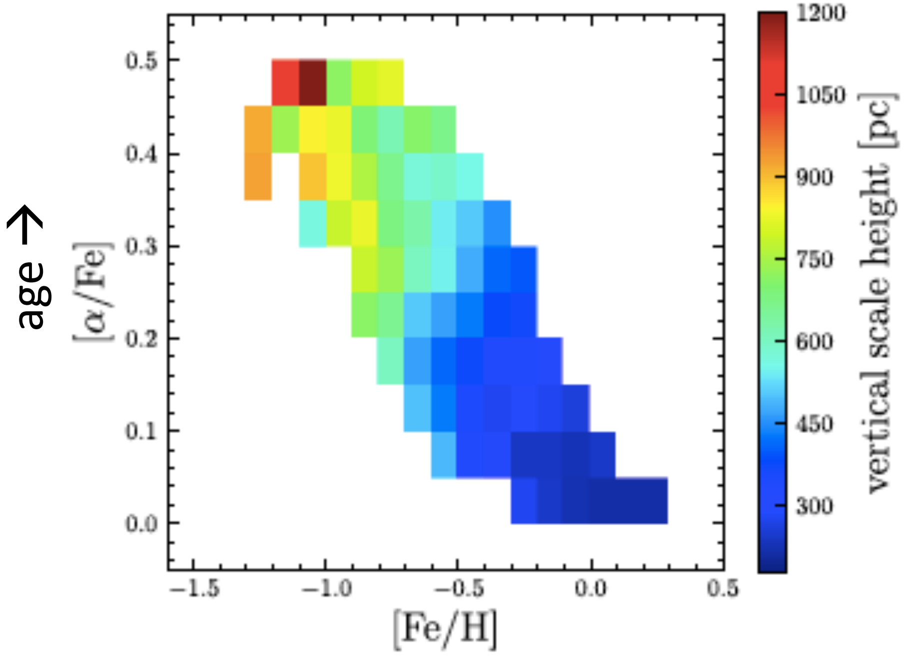
“Fitting”: how does a given (h_z,R_{exp}) - density models + selection function compare to the data?



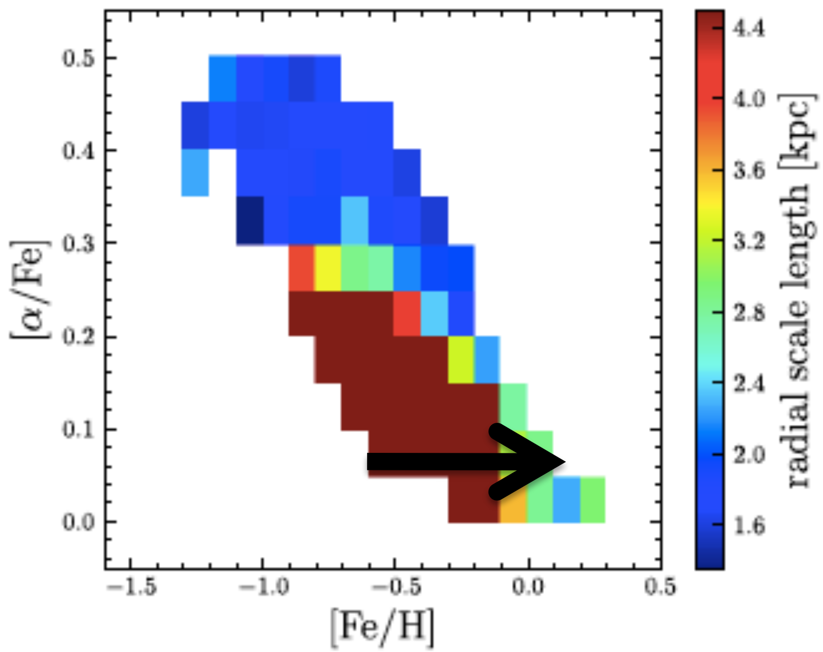
What does the Milky Way's disk look like in stars of a given [α/Fe]-'age'?

- for any given [α/Fe]-[Fe/H], disks are
  - single vertical exponentials (z)
  - single radial exponential (R)

→ mono-abundance components are simple



- [α/Fe]-old disk components are **thick**
- [α/Fe]-old disk components are **compact**
  - contrary to the geometric decompositions
- At a given [a/Fe]-age, more metal-poor components are more extended!
  - 'outward metallicity gradient'

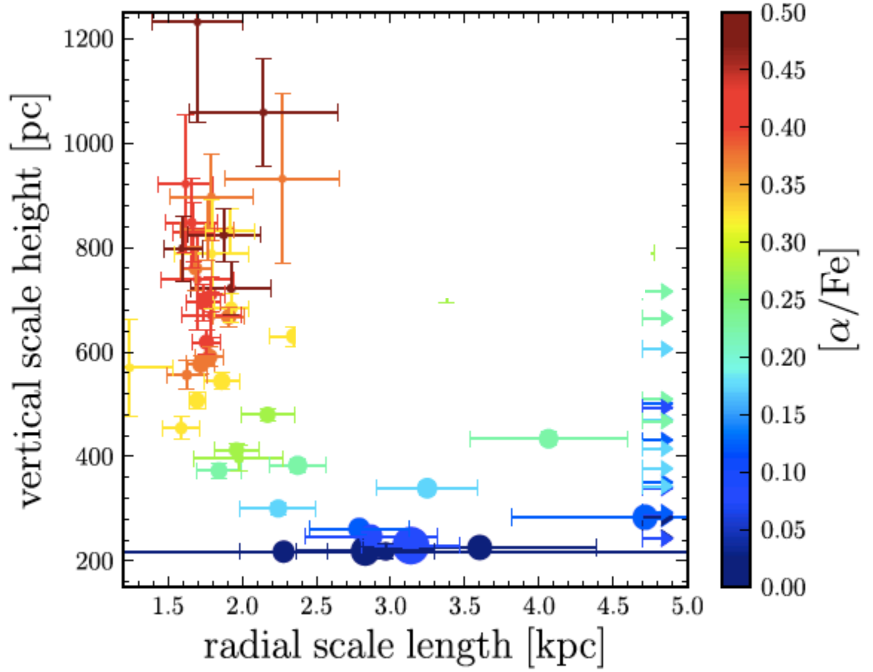


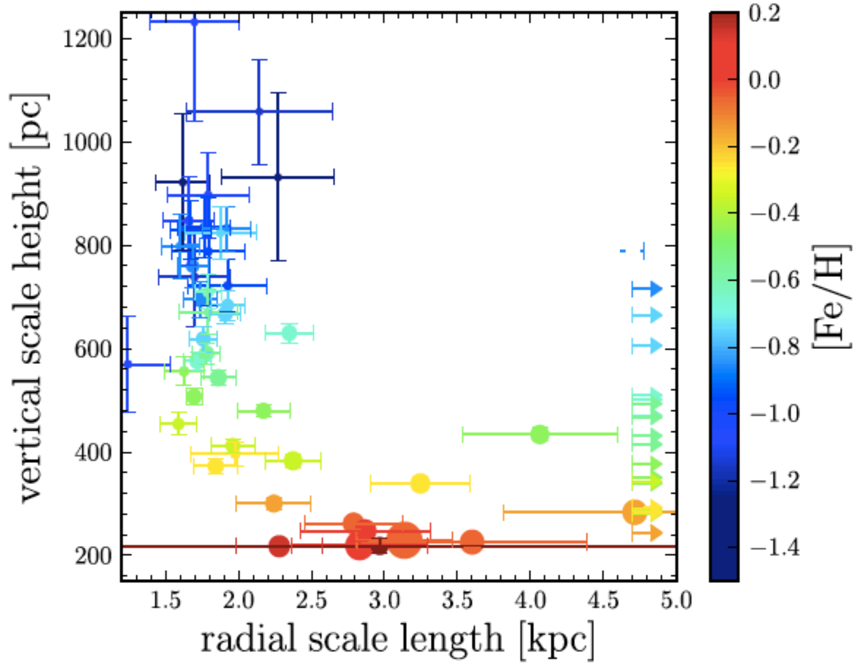
The Geometry of Mono-Abundance Sub-Populations

- thick = compact
  thin = radially extended

- NB: in a few bins error-induced abundance mixing is severe

- Some abundance bins have effectively flat radial profile at R_0



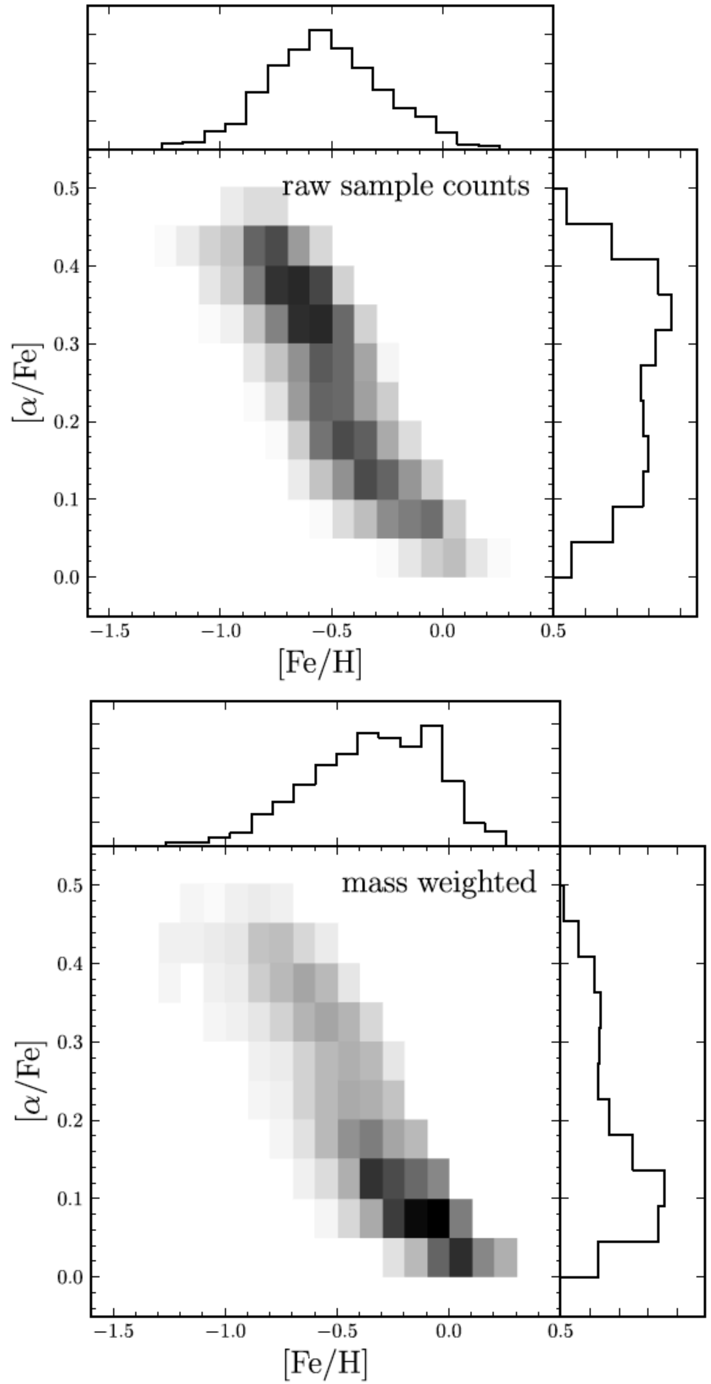


(Surface)-mass weighting of the abundance distribution in SDSS/SEGUE (at R_0)

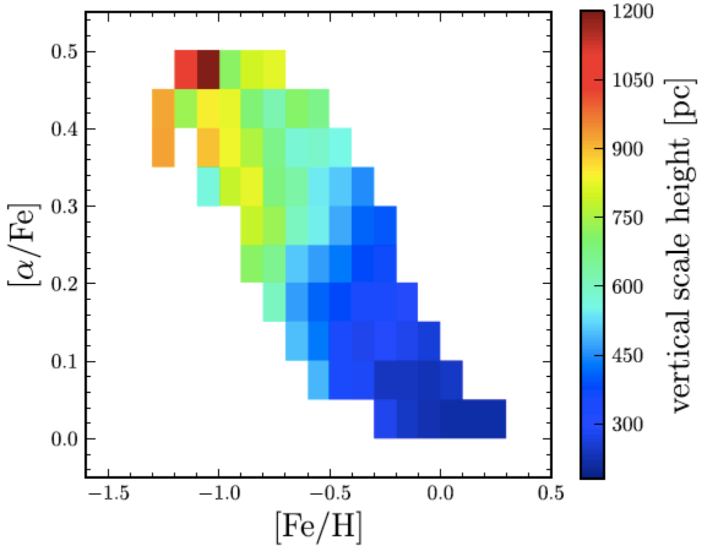
Bovy, Rix & Hogg 2011

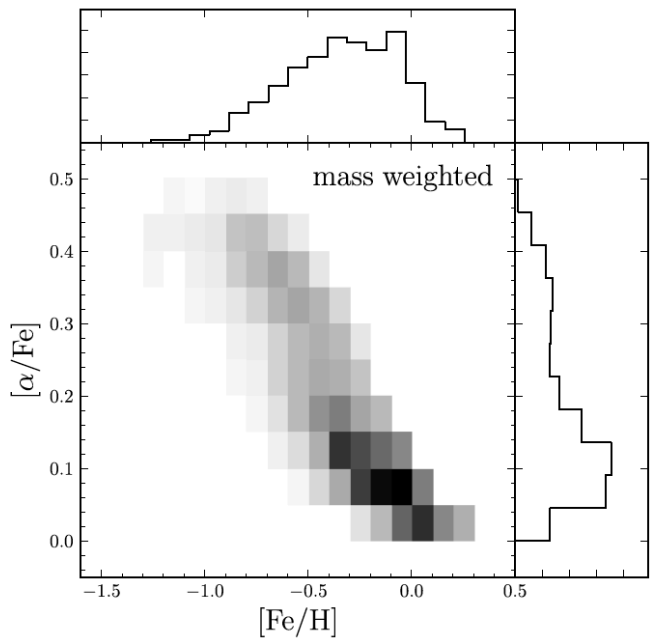
- So far, we have fitted number density models of G-dwarfs of given [α/Fe],[Fe/H]
- Which fraction of the stellar mass of a population with $p(t_{age}|[a/Fe],[Fe/H])$ is contained in 'color-selection box'?
- Assume e.g. Chabrier IMF, $p(t_{age})$ + isochrone and integrate over appropriate color range

  $n_{*(G\text{-dwarfs})} \rightarrow \rho_*$



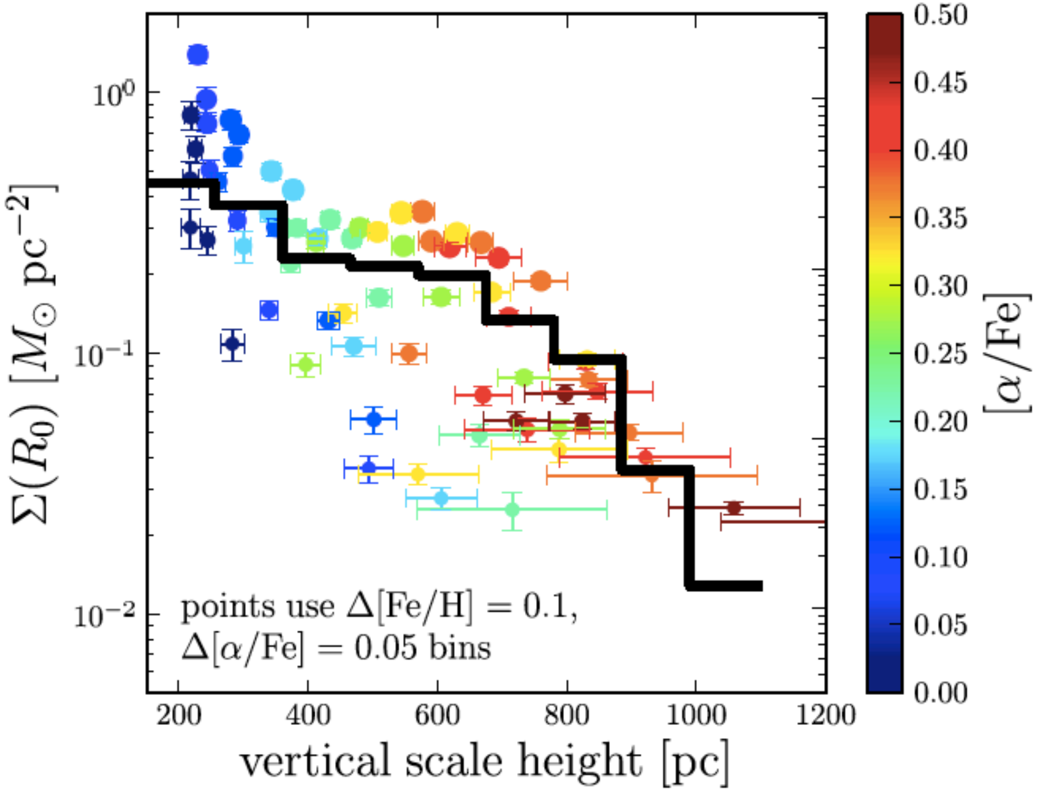
What is the scale-height distribution of stars in the Milky Way's disk?
or Is there a 'Distinct' Thick Disk





1) for each star: [α/Fe],[Fe/H] → h_z
2) for each [α/Fe],[Fe/H] bin → $\Sigma(R_0)$

→ scale height distribution $\Sigma(h_z)$ at R_0

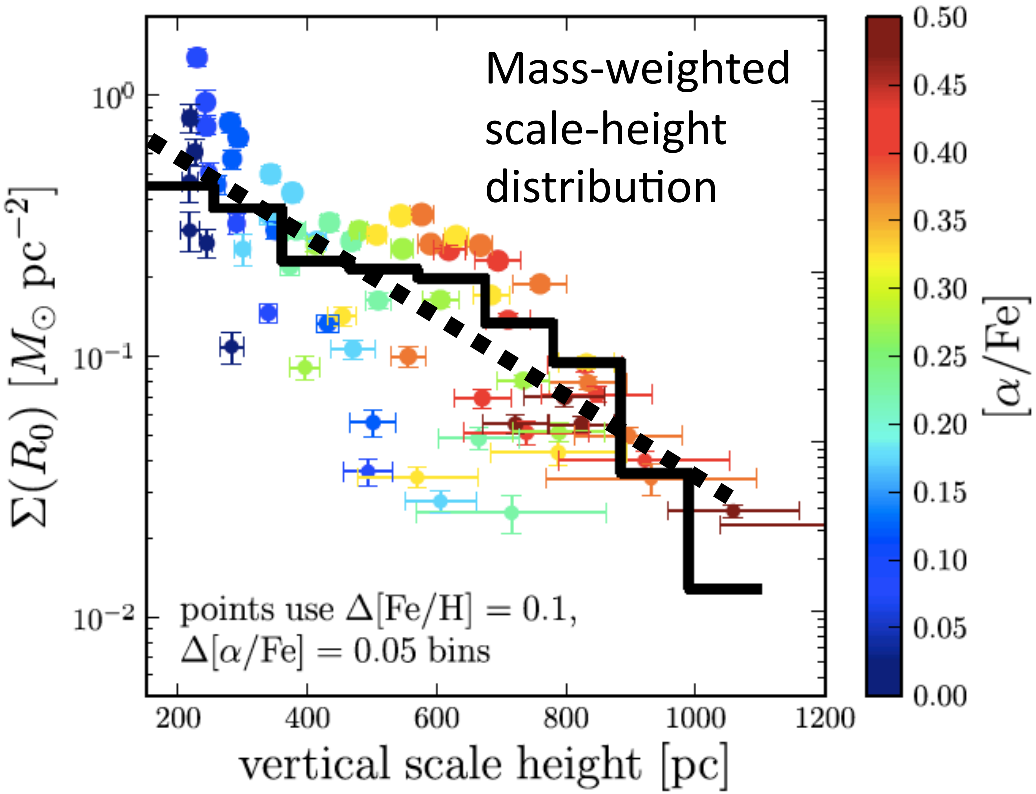


What is the scale-height distribution of stars in the Milky Way's disk?
or Is there a 'Distinct' Thick Disk

- $\Sigma_{R_0}(h_z)$ is NOT bi-modal!

$$\Sigma_{R_0}(h_z) \sim e^{-h_z}$$

$$\Sigma_{R_0}(h_z) \sim e^{-\sigma_z^2} \sim e^{-kT}$$

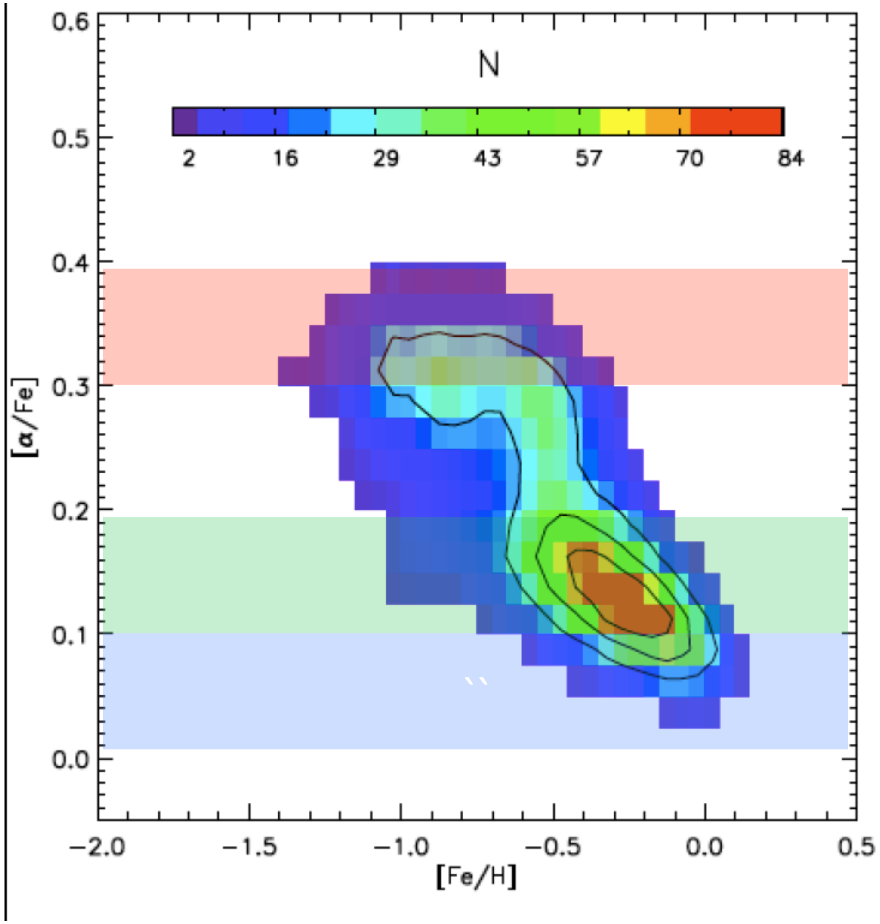


→ thick disk portions appear as 'thermal tail' of a vertical height/temperature distribution

Picture of distinct thin/thick disk not supported by data!

Abundance-dependent kinematics of the MW Disk

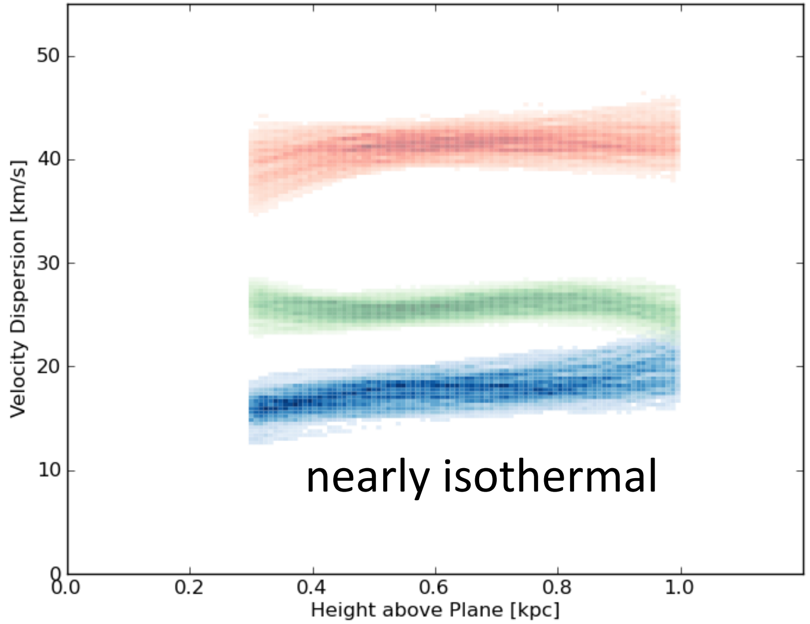
Zheng, Bovy, Rix (in prep.)

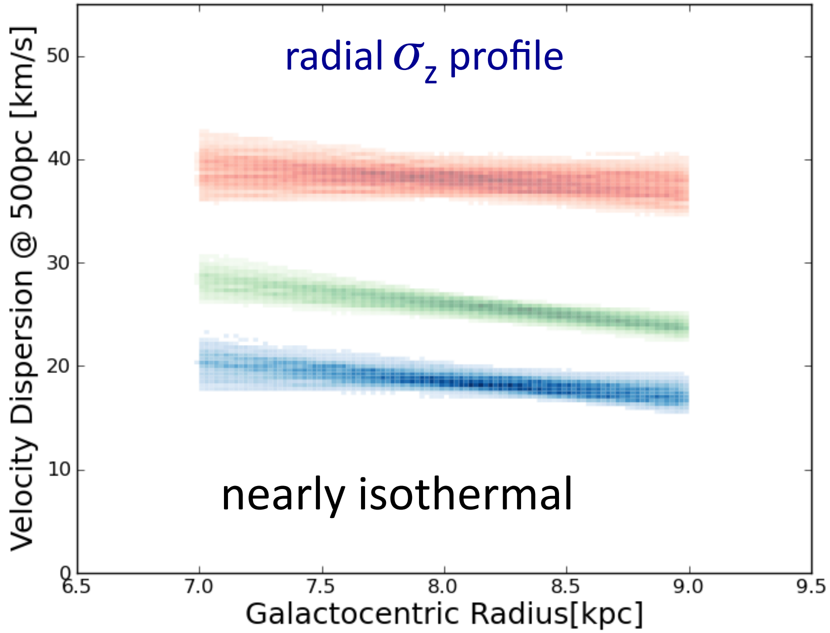


Make – and fit – model for velocity dispersion

$$\sigma_z(R, z; \theta) = (p_1 + p_2|z| + p_3|z|^2)\ \exp\left(-\frac{R - R_\odot}{R_\sigma}\right)$$

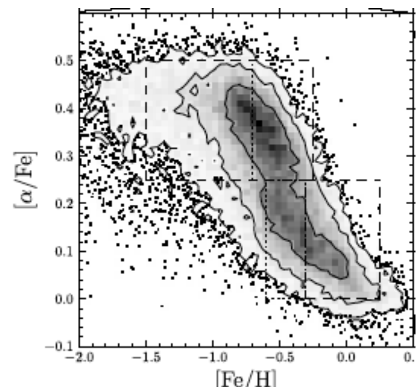
vertical σ_z dispersion profile



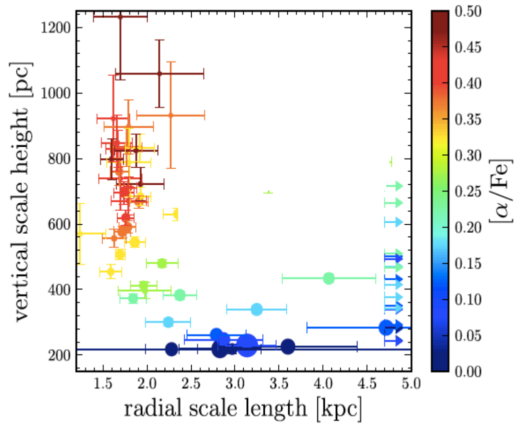


Conclusions

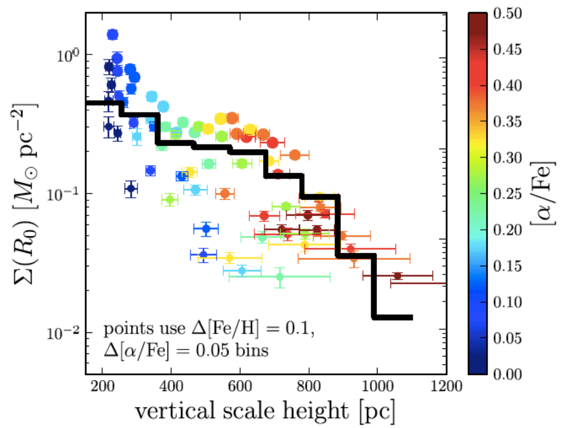
- Looking at the Milky Way in α-age,[Fe/H]-bins slices the stellar disk into 'simple components'



- α-old stars are thickest ***and*** centrally concentrated
  - inside out growth of the Milky Way disk over ~10Gyrs



- $\Sigma(h_z) \sim e^{-hz}$: data do not support *distinct* thick disk
  - no inconsistencies with previous claimed 'dichotomies'



→ continuous or many-episode disk heating
  - radial migration explains many aspects