Dissecting the Milky Way’s (Stellar) Disk

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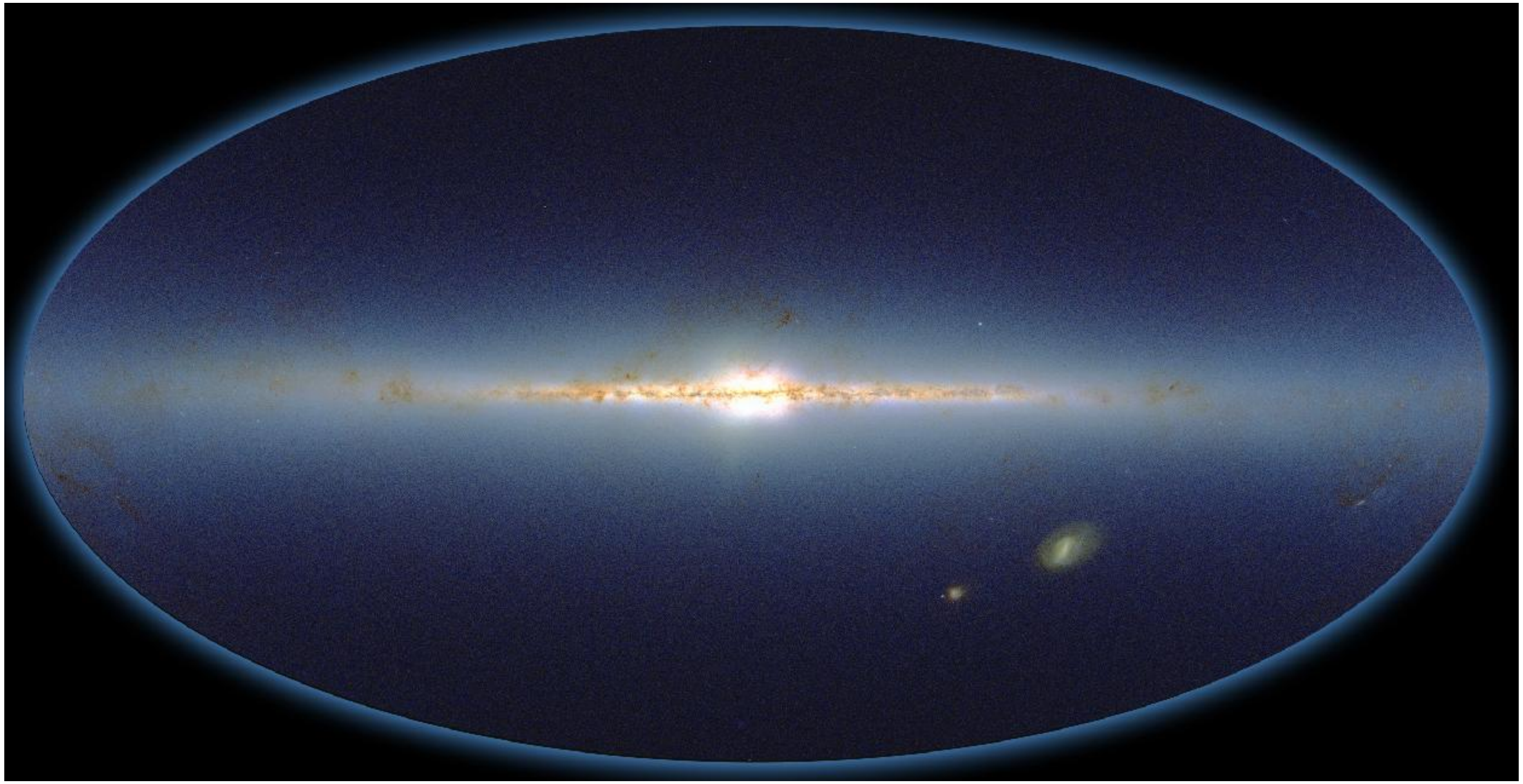


In collaboration with:

L. Zhang, C. Liu , G. van den Ven, A. Buedenbender @ MPIA

J. Bovy @ NYU

C. Rockosi @ Santa Cruz

& the SEGUE collaboration

(in particular: Lee, Schlesinger, An)

What makes the MW disk (cosmologically) interesting?

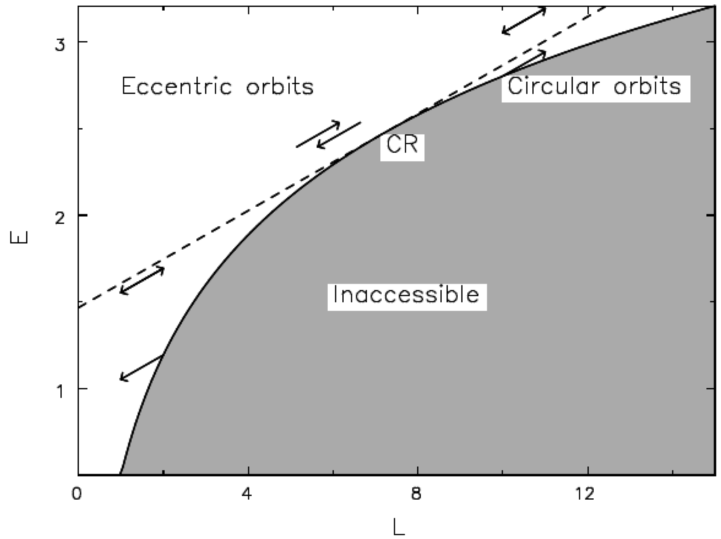
- Most MW stars are in the disk!
- Making 'realistic disks' in *ab initio* simulations remains formidable challenge
- What sets structure (e.g. radial/vertical profile) of stellar disks?
  - birth radius *vs.* present location
  - 'distinct' components a sensible description?
- What is the role of internal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

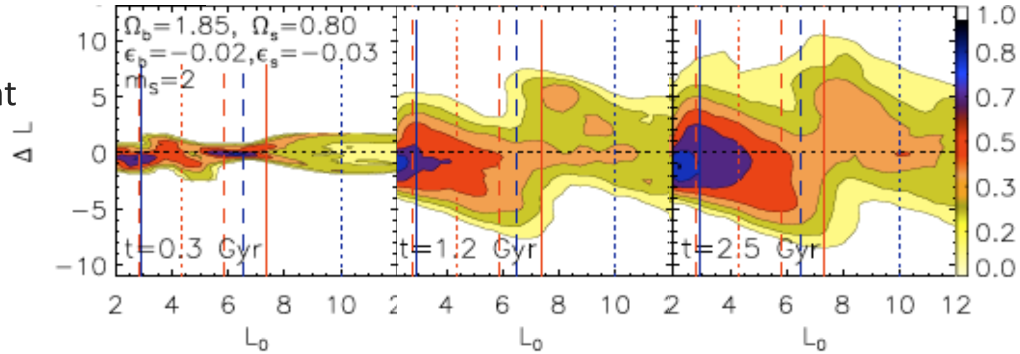
(Stellar) Disk Evolution Processes

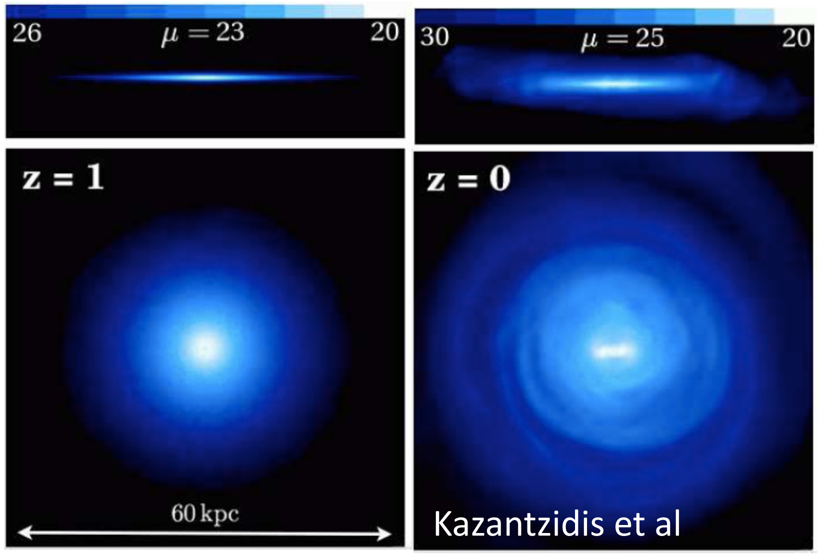
- Gas Infall & Star Formation

- 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



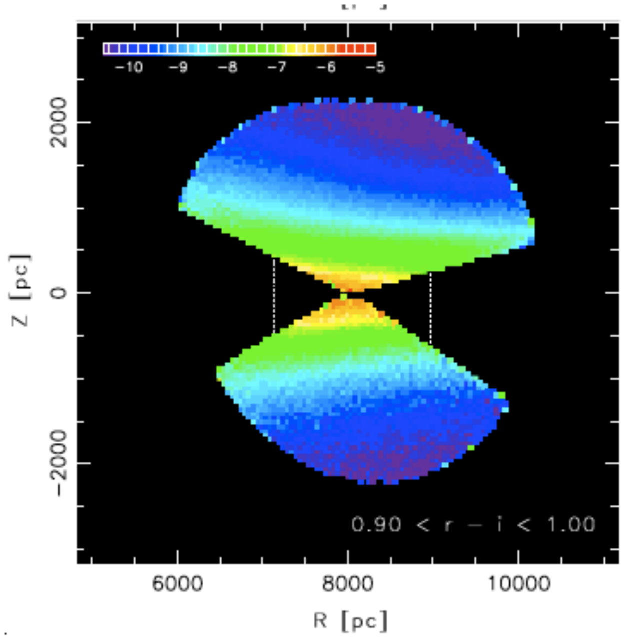


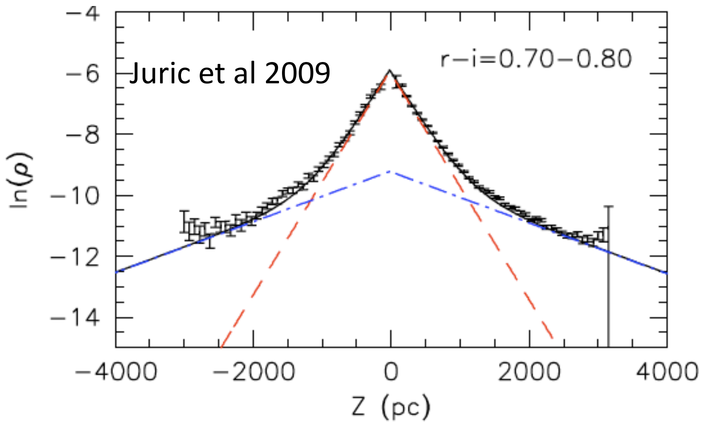


Characterizing the Stellar Disks(s)
Geometry & Kinematics

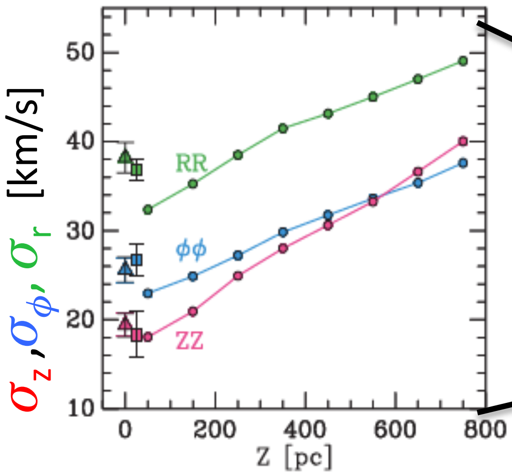
- Stellar Number Density
  - double exponential vertically (thick/thin disk)
  - exponential in radius
- Stellar kinematics
  - velocity dispersion increases with height
  - mean rotation velocity decreases accordingly
- Two component description sensible

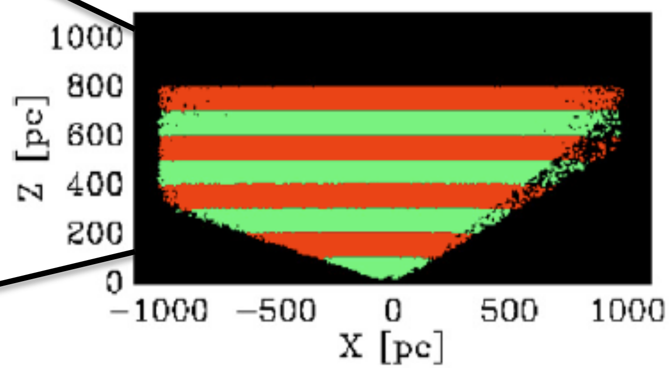
  ..but the geom./kinem. data show no ‘breaks’





Fuchs, HWR et al 2008



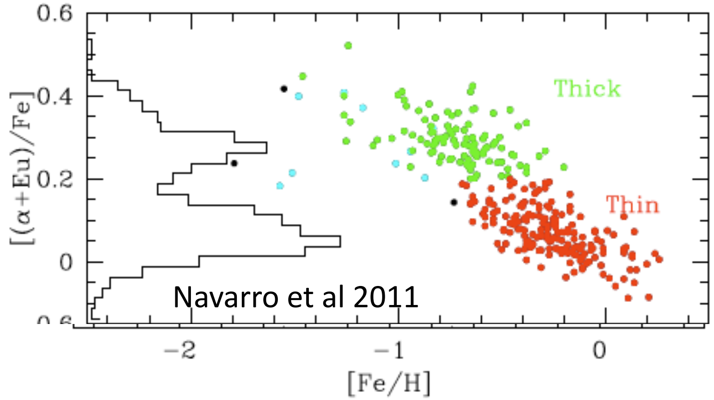


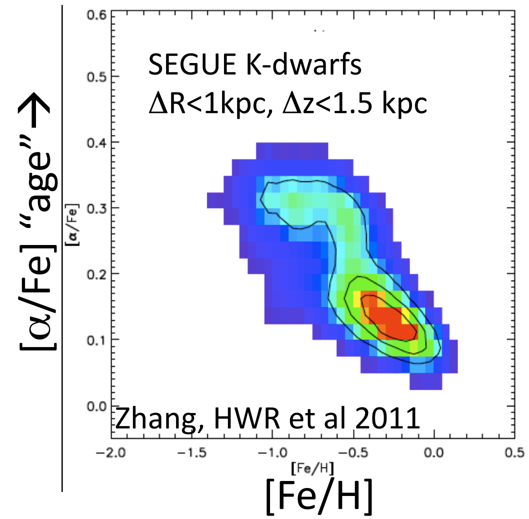
Characterizing the Stellar Disks(s)
Chemo-kinematic

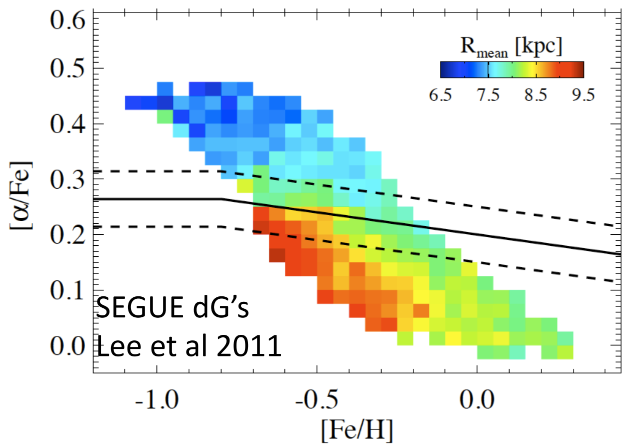
- Bi-modal [α/Fe] distribution
  - Lee et al 2011, Navarro et al 2011
  - α–enhanced ← → rapid (early?) enrichment, best practical 'age tag'?

- 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

- α-enhancement better predictor of velocity dispersion than [Fe/H]

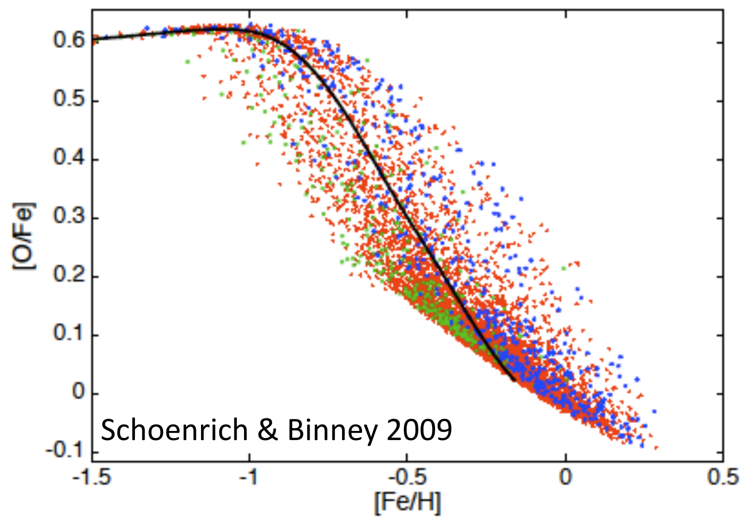






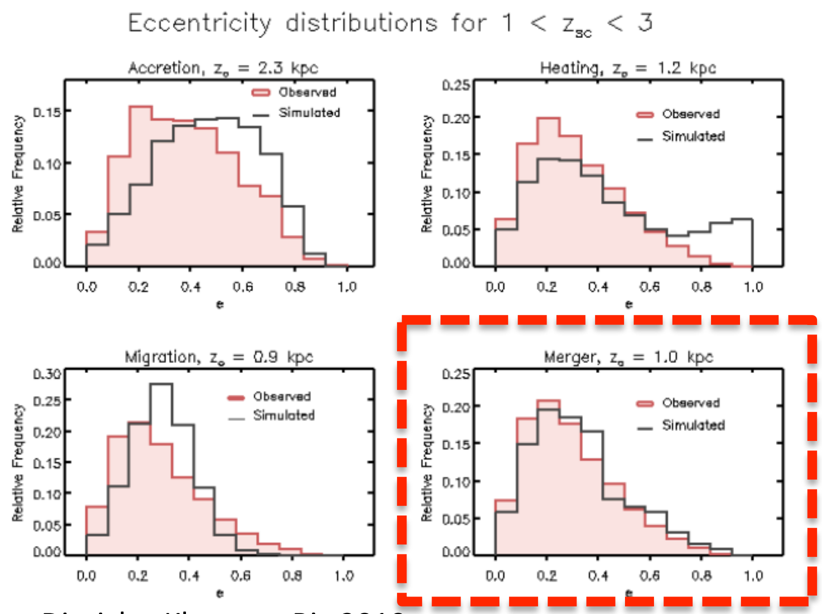
Testing Disk-Evolution Scenarios: data-model comparison around the Sun's position

- 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



Dierickx, Klement, Rix 2010

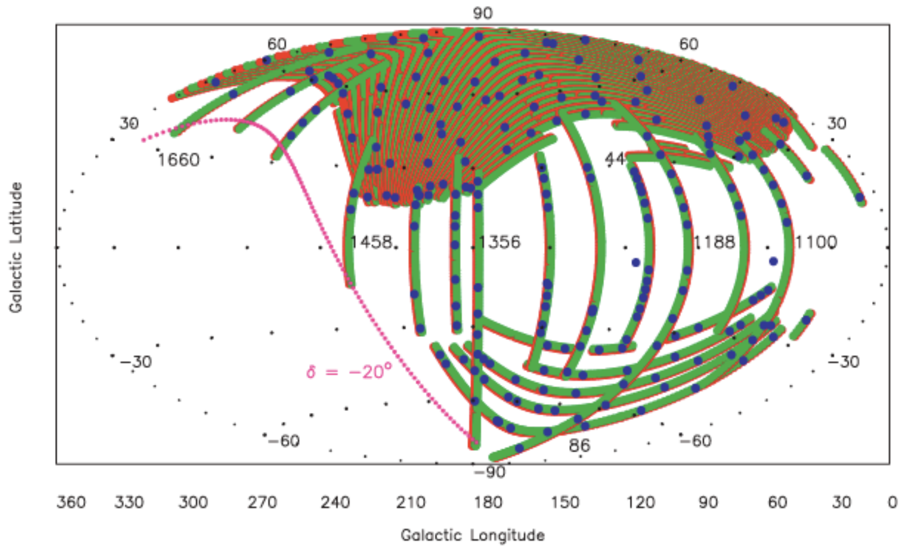
- Need non-local, spatially resolved data-model comparisons!

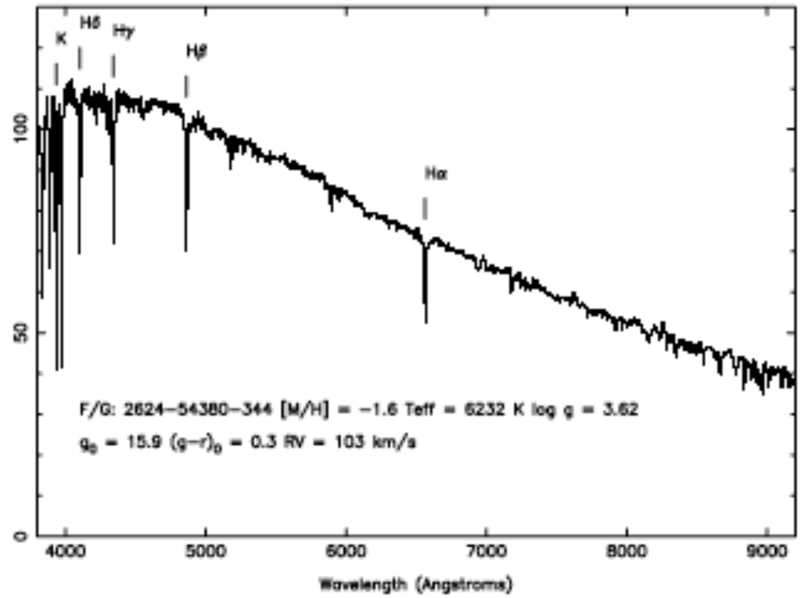
SEGUE

‘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)
  - δv ~ 7 km/s ($\delta\mu$ ~ 2.5mas/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

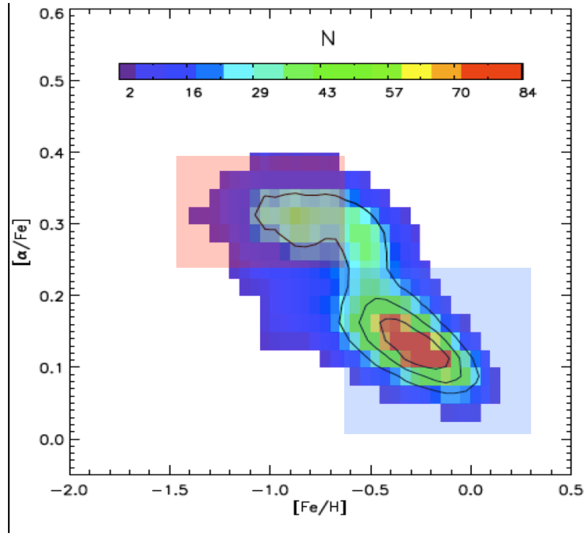
Bovy, Rix, Zhang, Liu (in prep.)

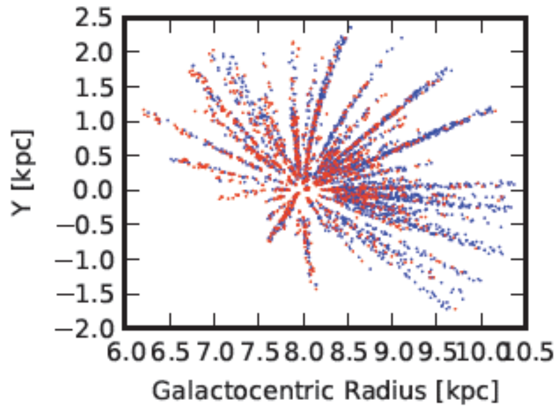
- Considering only a sub-population in [α/Fe] (& [Fe/H]) space …… what

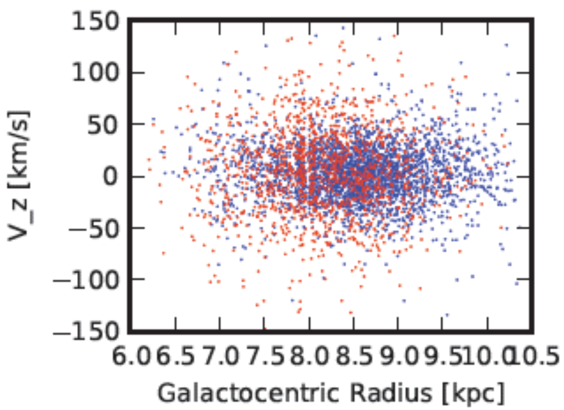
  is the ***spatial*** structure?
  - vertically, radially

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

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

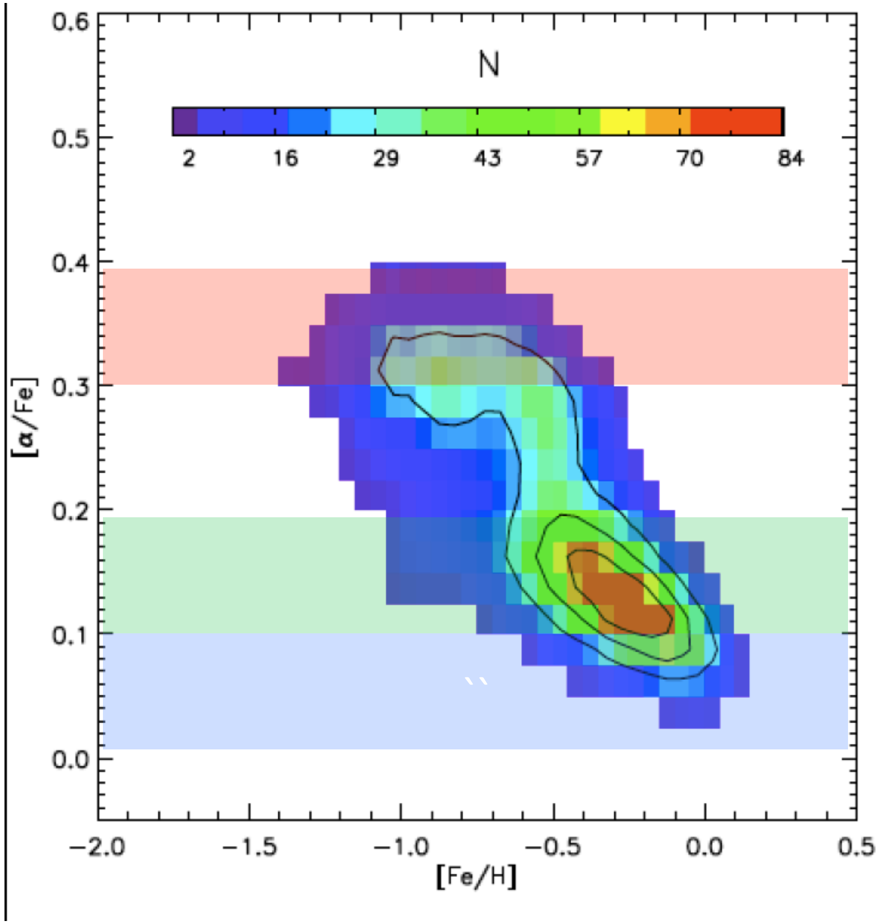






Abundance Dissection of the MW Disk

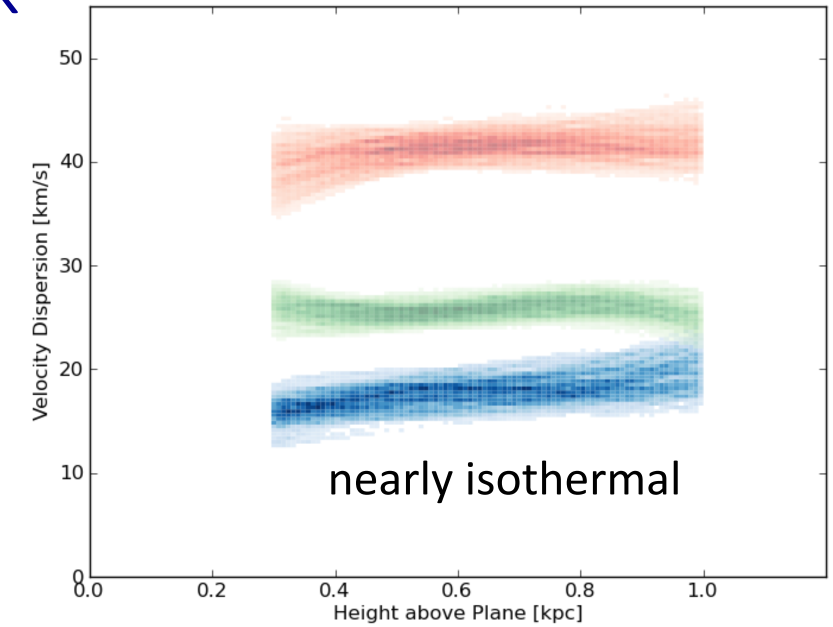
Zheng, Bovy, Rix (in prep.)

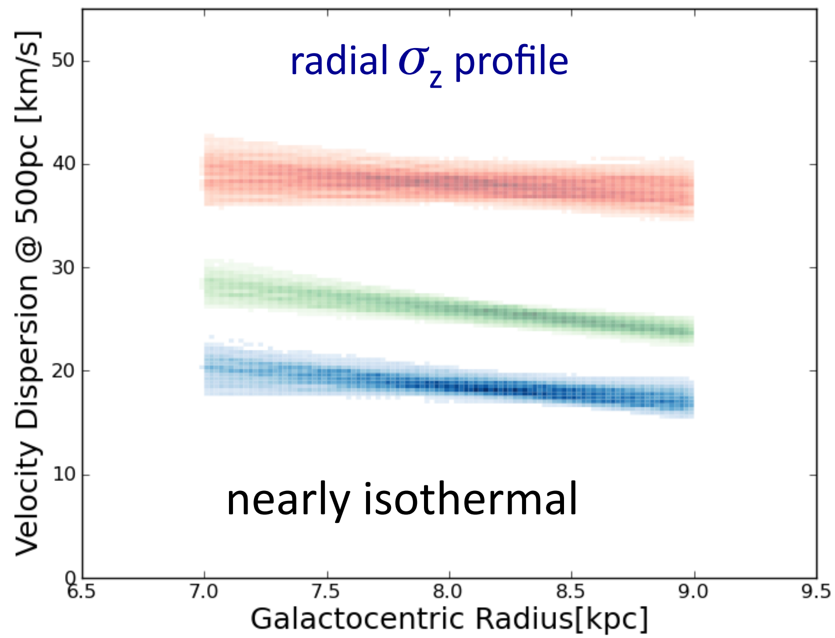


Make – and fit – model for velocity dispersion

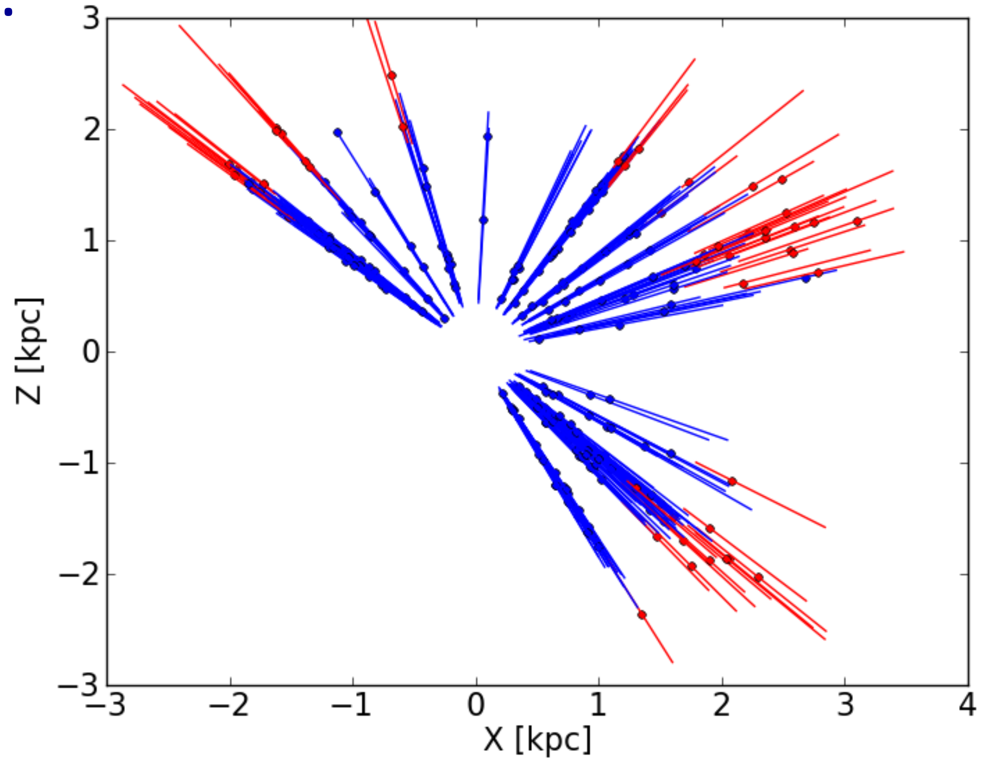
$$\sigma_z(R, z; \theta) = (p_1 + p_2|z| + p_3|z|^2)\ \exp\left(-\frac{R - R_\odot}{R_\sigma}\right)$$

vertical σ_z dispersion profile





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?

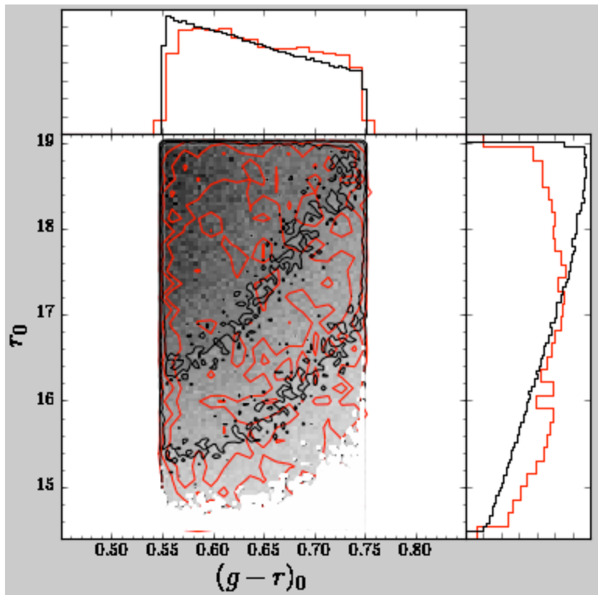
- Multiple scale heights?
- $h_z(R)$: flaring?

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:

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



Schlesinger et al, Bovy, HWR et al (in prep.)

First result on fitting spatial distribution of [a/Fe]-selected sub-populations

Determine models:

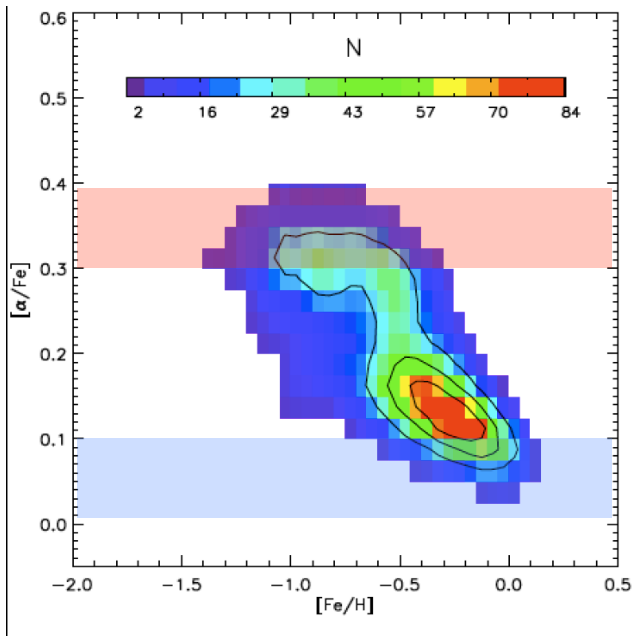
$$\nu_*(R,z \mid \vec{p}_*) = \left(\sum_i \nu_{0,i} \times e^{-\frac{|z|}{h_{z,i}(R)}} \right) \times e^{-\frac{(R-R_\bullet)}{R_{\exp}}}$$

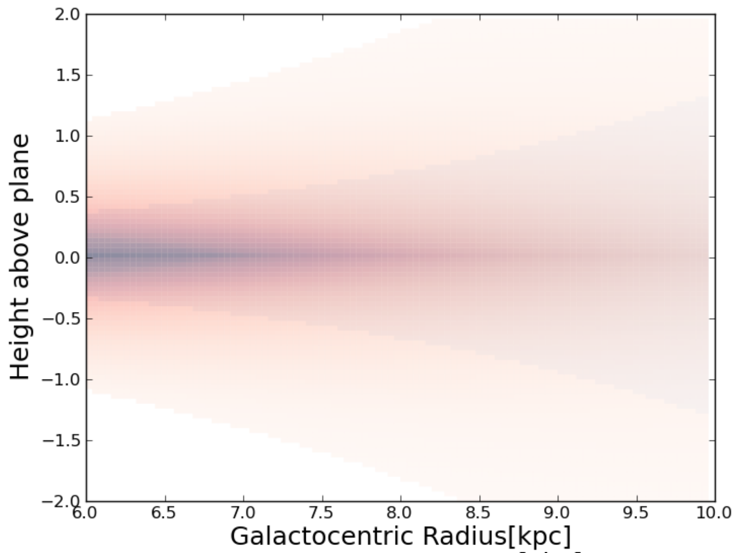
maximize $\mathcal{L}(\vec{D}_i \mid \vec{\mathrm{p}}_*, w_{spec})$ with $\vec{\mathrm{D}}_{\mathrm{i=1,N_{sub\text{-}sample}}}$

For a given [a/Fe]-subpopulation:

- single vertical exponential
- $h_z(R_o)$~ 280pc – 900 pc (→ α-enhanced)
- R_{exp}~ 3 – 2 kpc (→ α-enhanced)
- Sub-disks flare ~3 kpc scale

This does not mean that the overall (luminosity-weighted) disk flares or is radially isothermal!





Conclusions

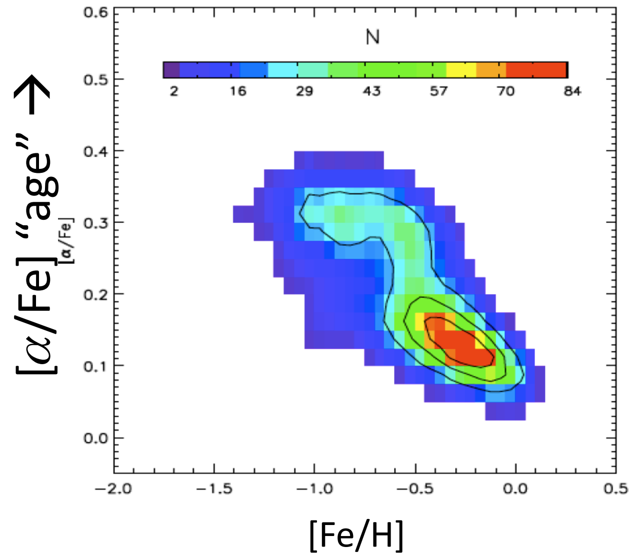
- Data now enable 'non-local' analysis of ***abundance-selected*** sub-samples
  - selection function modeling is crucial for spectroscopic surveys a la SEGUE
  - $[\alpha/Fe]$ is proxy for age
  - determines scale height/ kinematics more than [Fe/H]

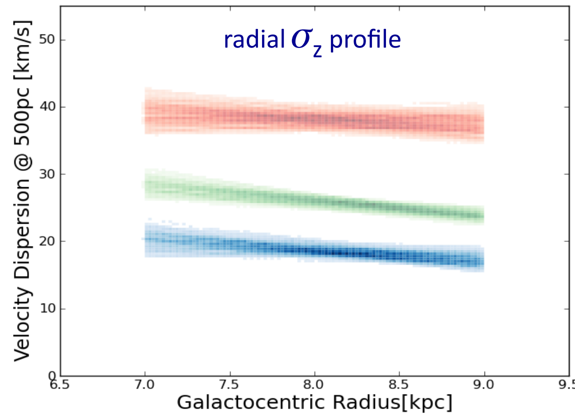
- **$[\alpha/Fe]$-sub-samples appear simple disk building blocks:**
  - σ_z near-isothermal in z and R
  - near-(single) exponential in z and R, *flaring!*
  - no evidence for dynamical dichotomy?

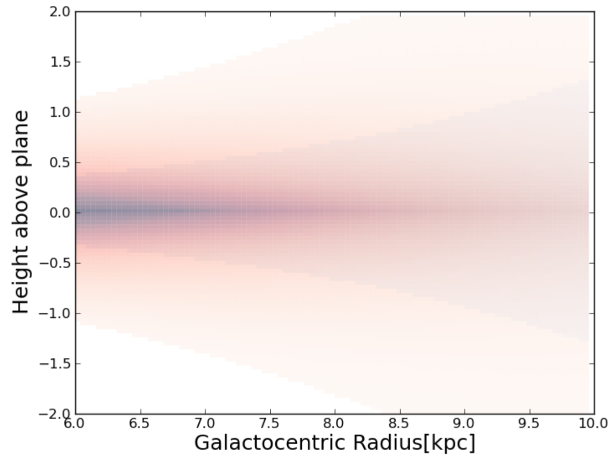
- **Radial migration explains many of these aspects naturally:**

  as stars migrate out they do not cool vertically
  → isothermal(?) & flaring

- 'Oort-limit' = $\Sigma_{disk}(z)$ imminent







SEGUE: K. Schlesinger , C. Rockosi (selection function)
D. An (distances), Y. Lee ([a/Fe])