The Thick Thin Disk and the Thin Thick Disk: a New Paradigm from *Gaia*

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Observatoire de la Cote d'Azur

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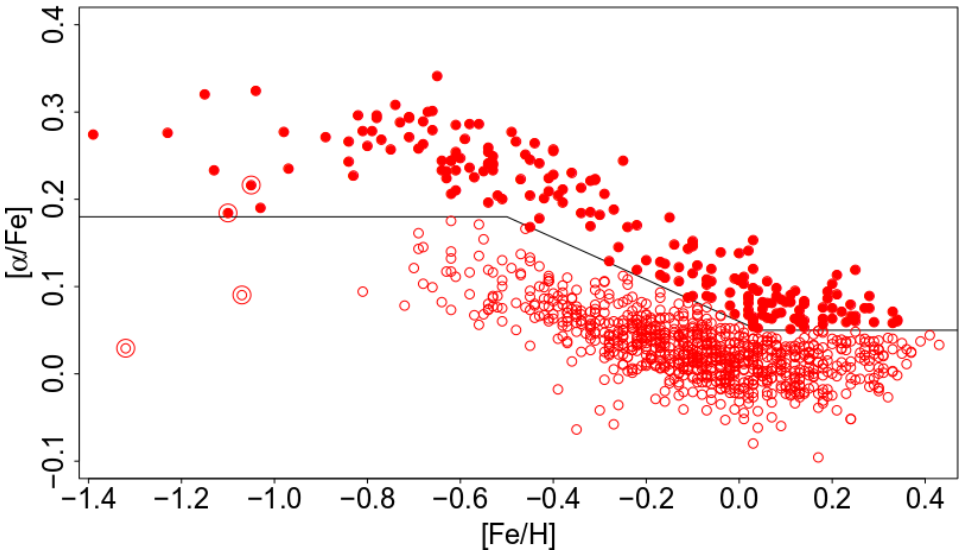
Overview

- The Structure of the Milky Way Disk
- The *Gaia* HARPs Sample
- Ages
- *Gaia* Kinematics

The Solar Neighborhood



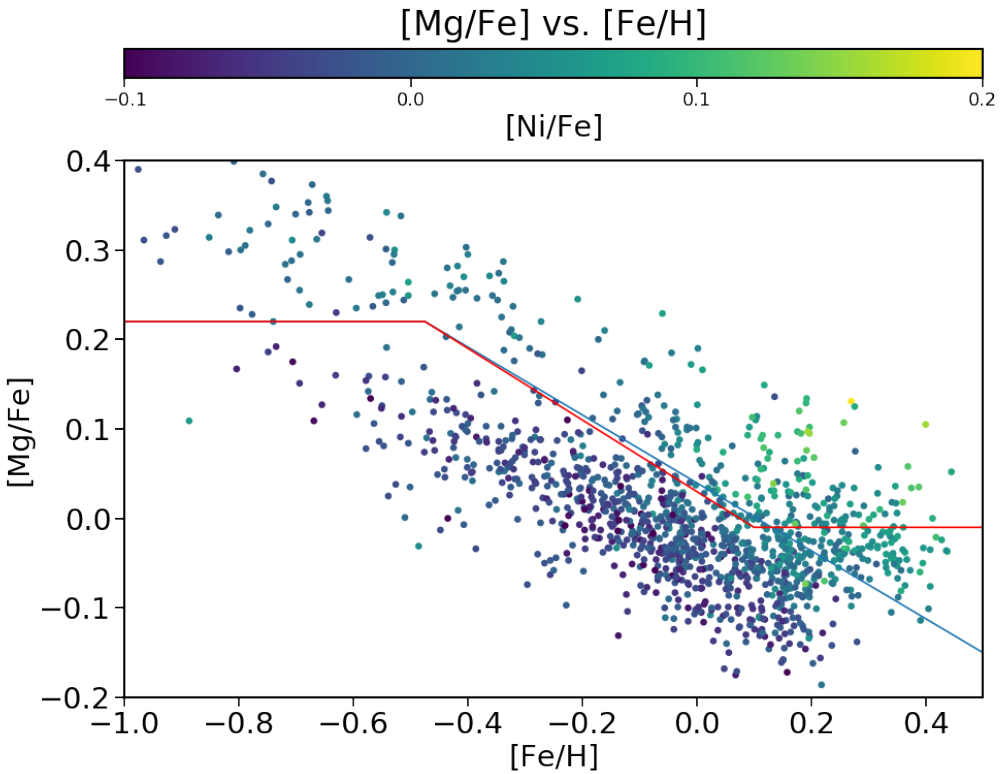
Adebekyan 2012+, Haywood 2013+

- High-α metal-poor stars identified as thick disk
- Solar-α stars: thinner disk
- Intermediate-α has two populations
- **Split disk into thin, thick based on α, metallicity**

AMBRE

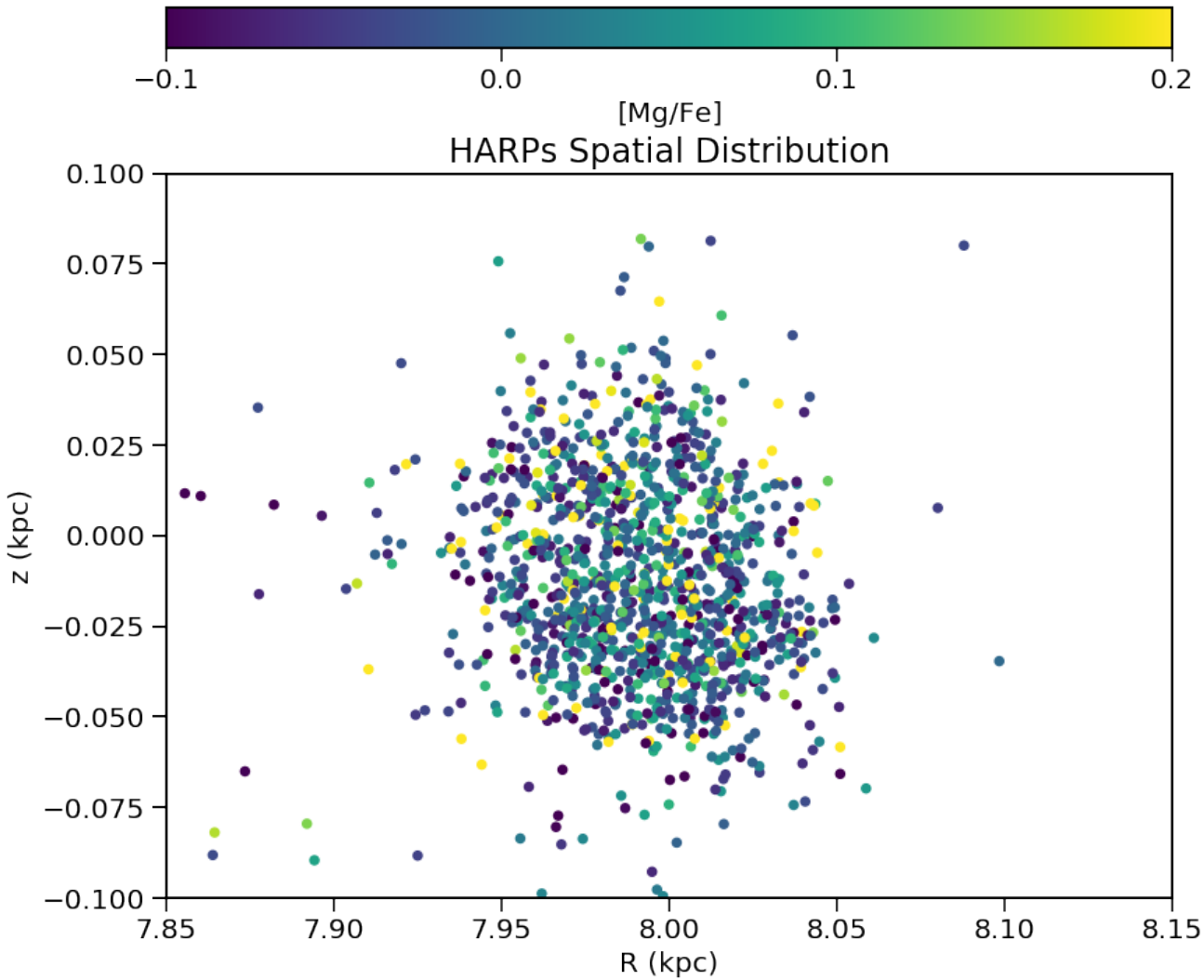
- Tens of thousands of high-res archival ESO spectra
- HARPs, UVES, Feros Instruments
- Uniform parameter determination from Matisse
- Individual abundances derived in Mikolaitis+2016
- Cross-match with *Gaia*: Not Trivial
- Many stars aren't in DR1: develop tools to use for future releases!

The HARPs Sample



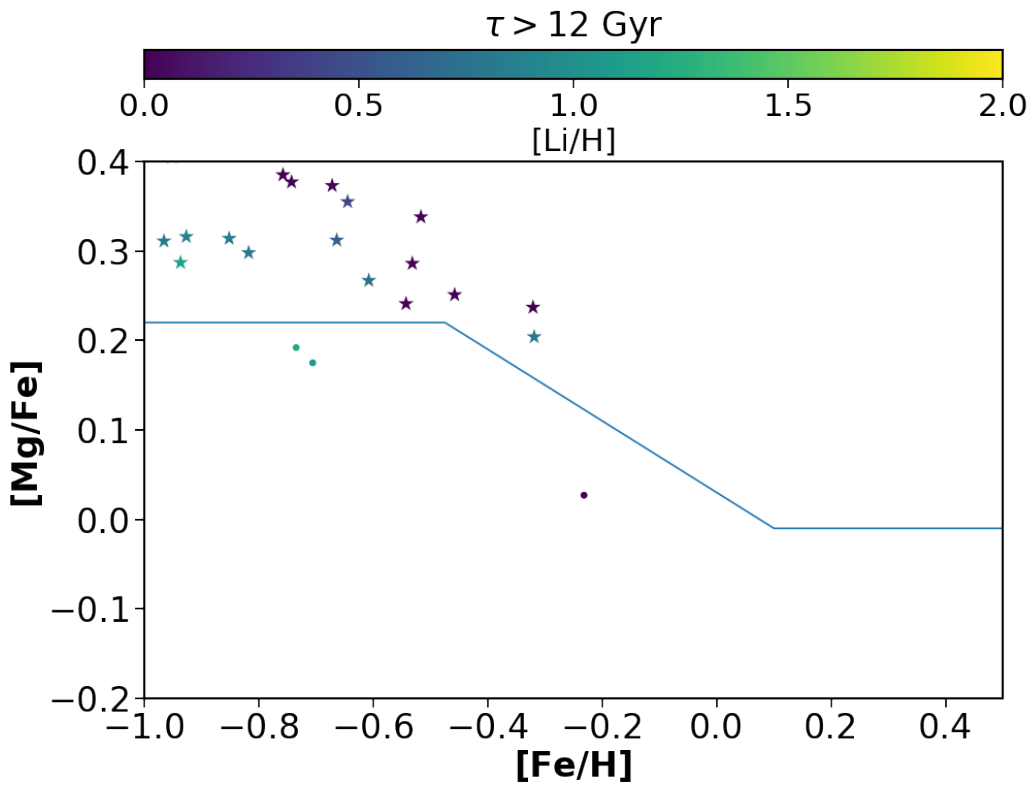
The HARPs *Gaia* Sample

- High-resolution spectra of $\sim 1,500$ stars with *Gaia* Overlap
- Local, within 200 pc
- Mainly G, F dwarfs & Subgiants
- Stellar Parameters from Matisse, Abundances from Mikolaitis+ 2016
- dispersion<0.05 dex in [Mg/Fe]
- **Split into thin, thick disk by eye based on red line**



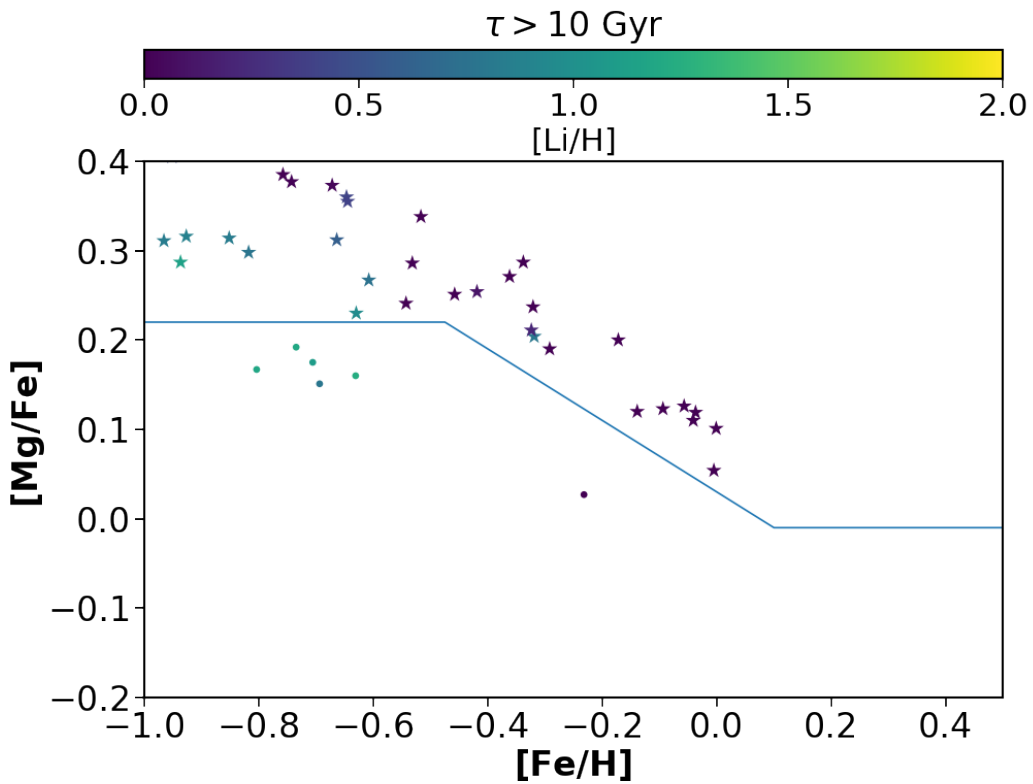
The HARPs *Gaia* Sample

[Mg/Fe] vs. [Fe/H] by Age



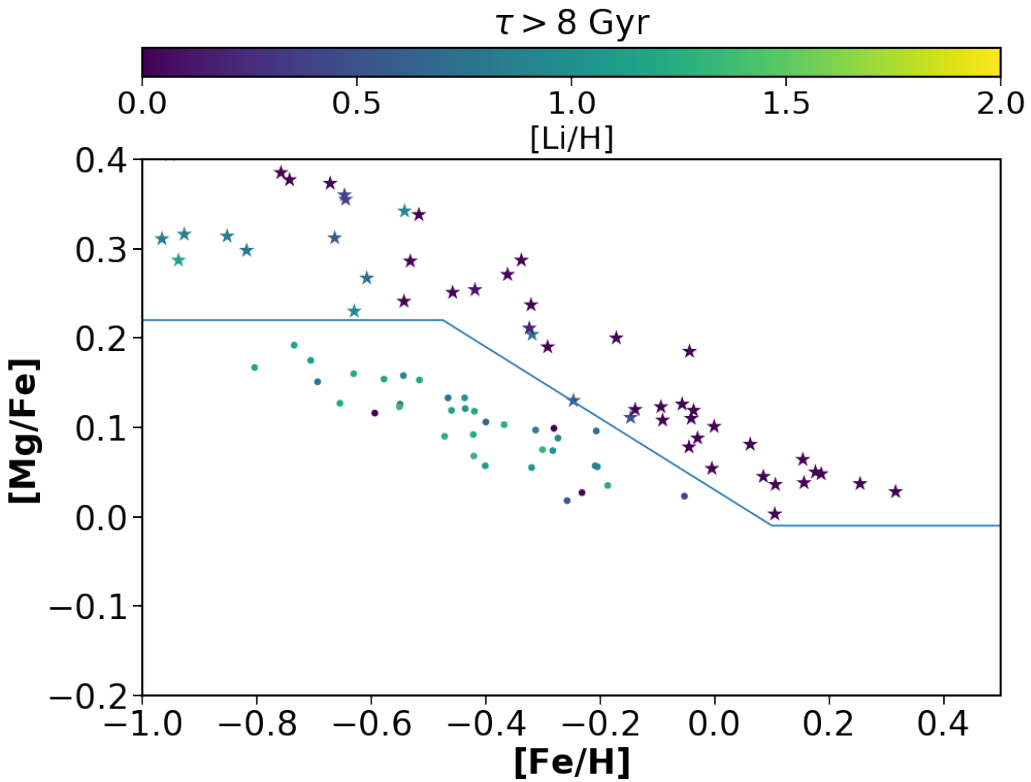
- From HARPs sample, select MSTO/Subgiant stars, $\sim$ 550 stars
- Ages reliable for these stars, primarily function of $T_{\rm eff}$
- Measure kinematic properties for all stars
- **Oldest stars are high-α, lower-metallicity**

[Mg/Fe] vs. [Fe/H] by Age



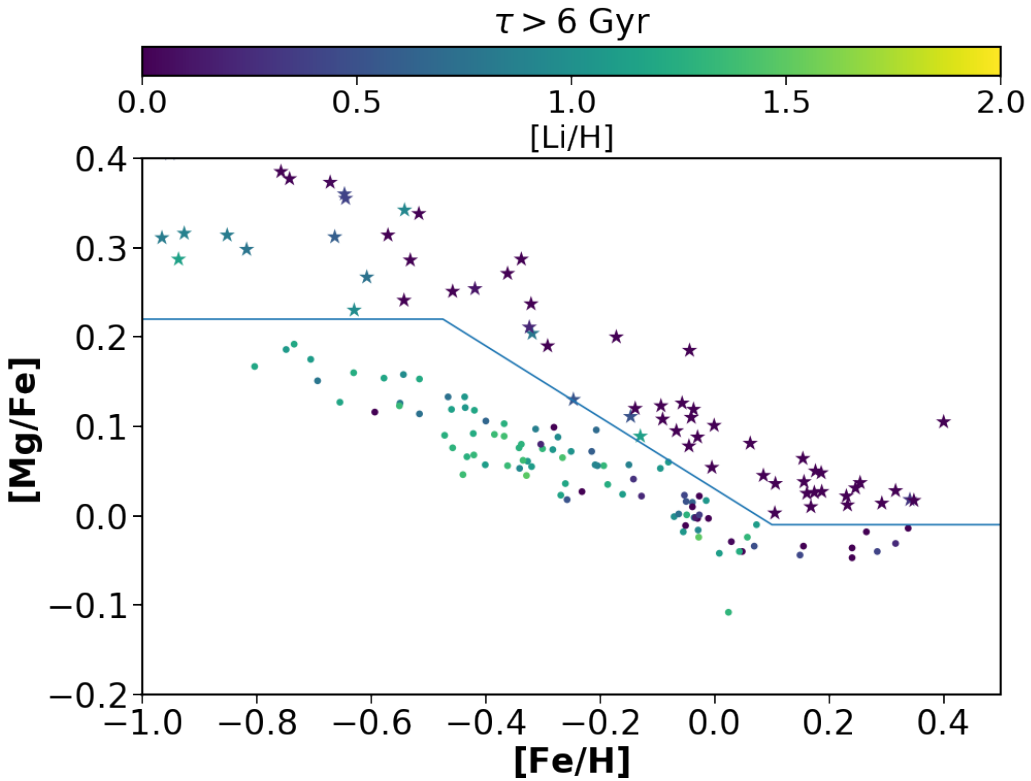
- Stars mostly high-α sequence
- The "thick disk" stars α has decreased ~ 0.2 dex, up to solar metallicity
- A few of the oldest "thin disk" stars appear

[Mg/Fe] vs. [Fe/H] by Age



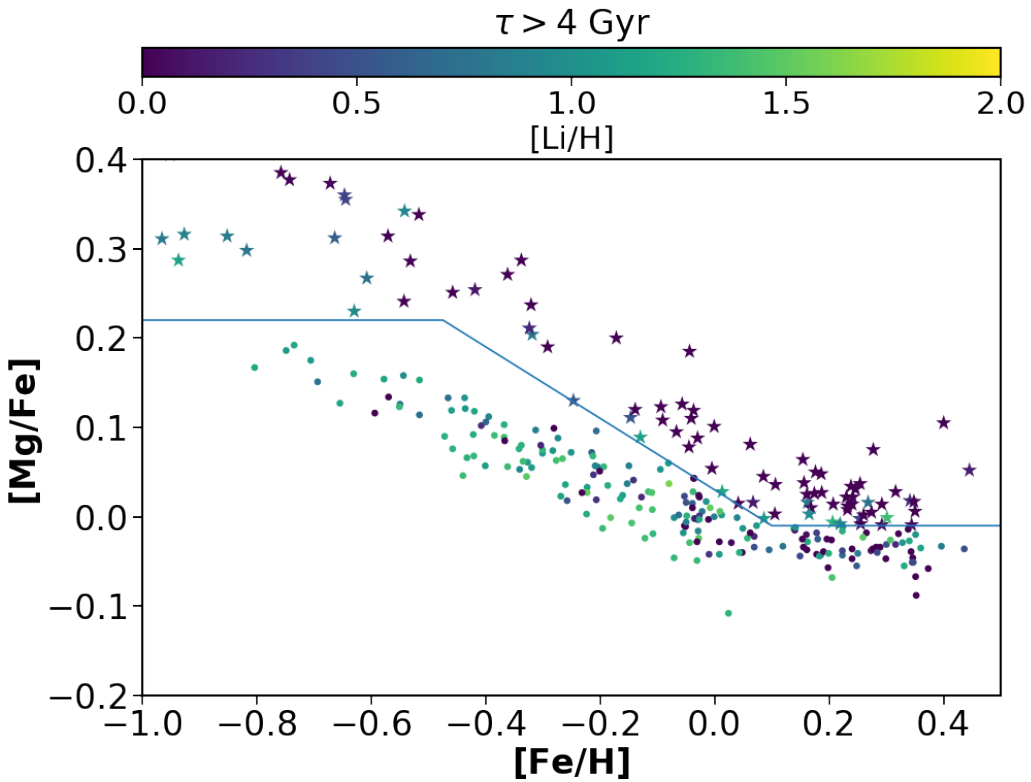
- **Thick-disk is at super-solar metallicities, clearly has extended star formation**
- **Thin, thick disk tracks have same age, same physical position, but metallicities different by more than 0.5 dex**
- **Need some form of radial mixing to explain observations**

[Mg/Fe] vs. [Fe/H] by Age



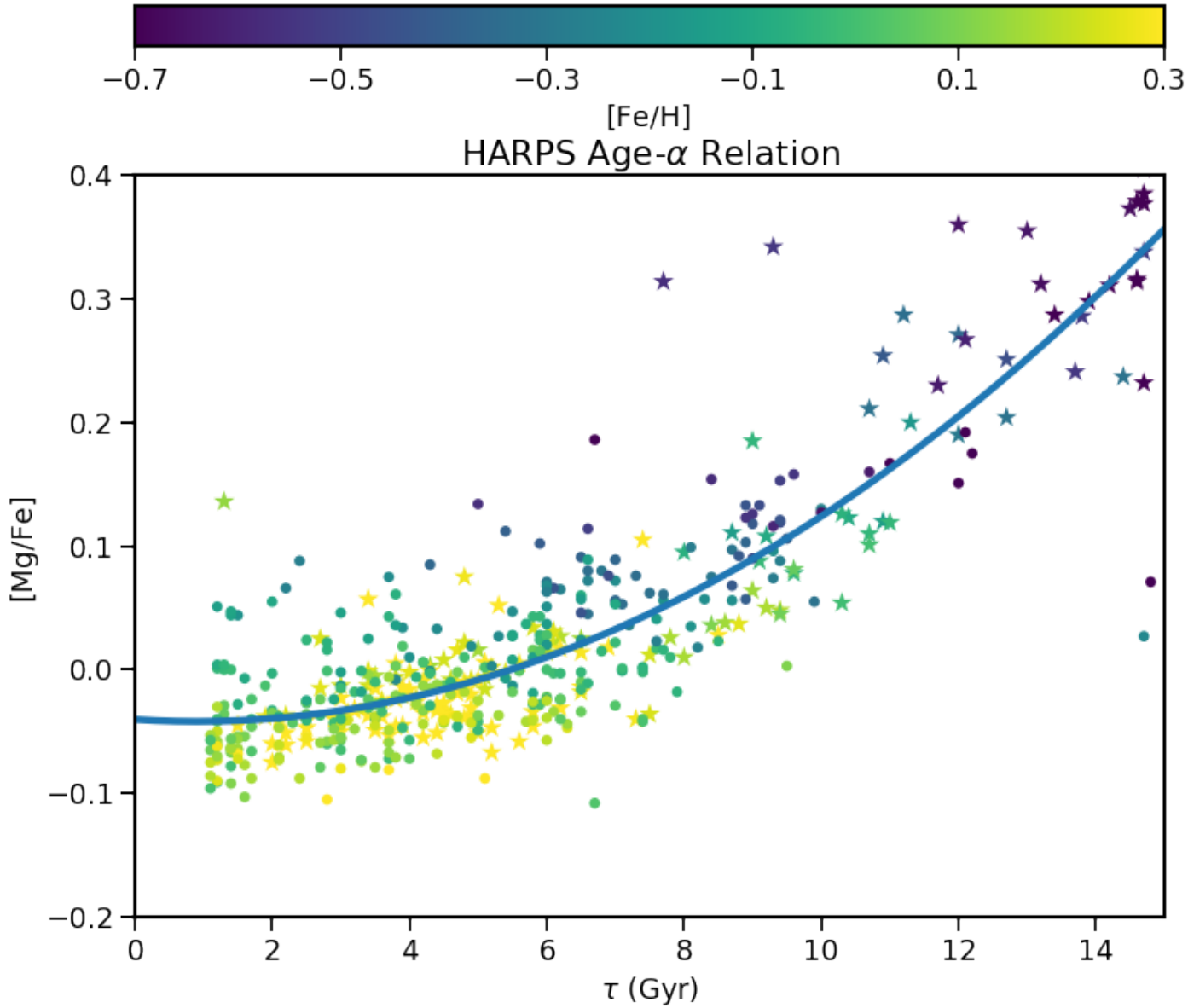
- More of "thin"-disk chemical track stars appear
- **Thick-disk track at solar-α, high-metallicity**

[Mg/Fe] vs. [Fe/H] by Age

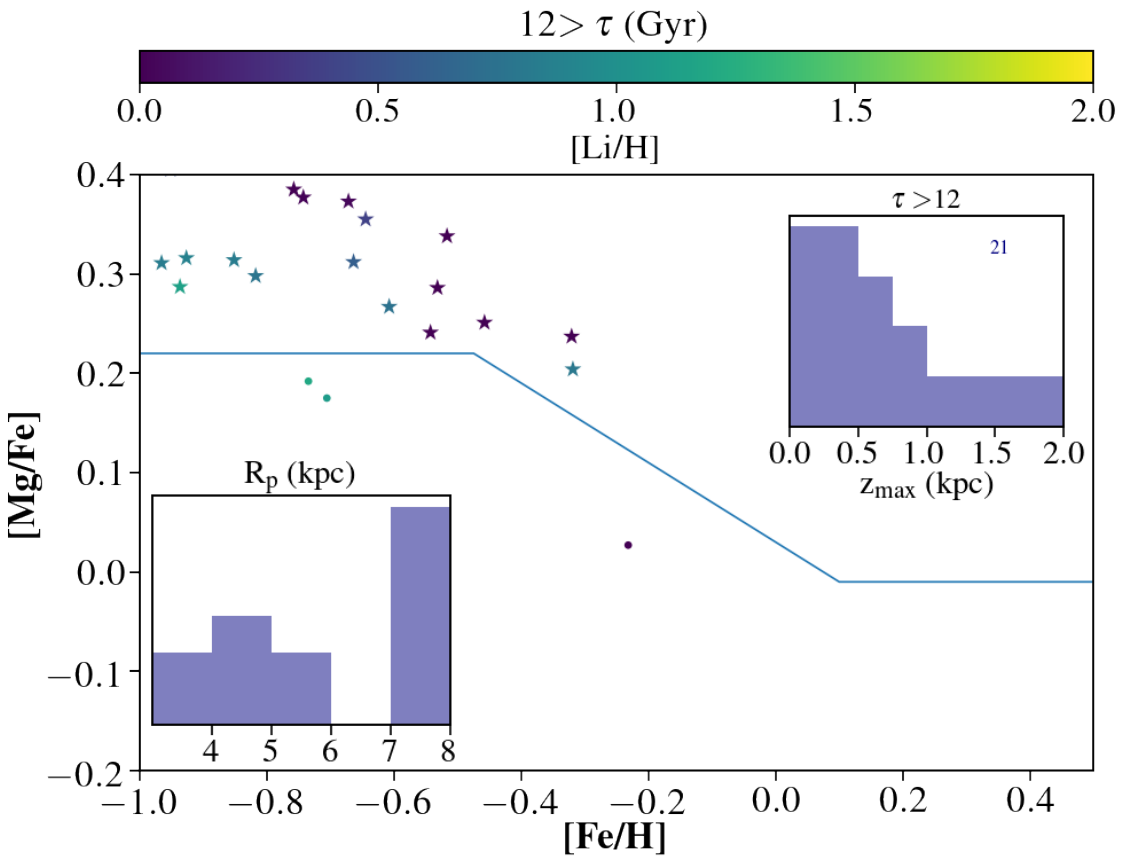


- **Unclear which track stars belong to at metal-rich end, could be "thin" or "thick" disk track**

Age-α Relation

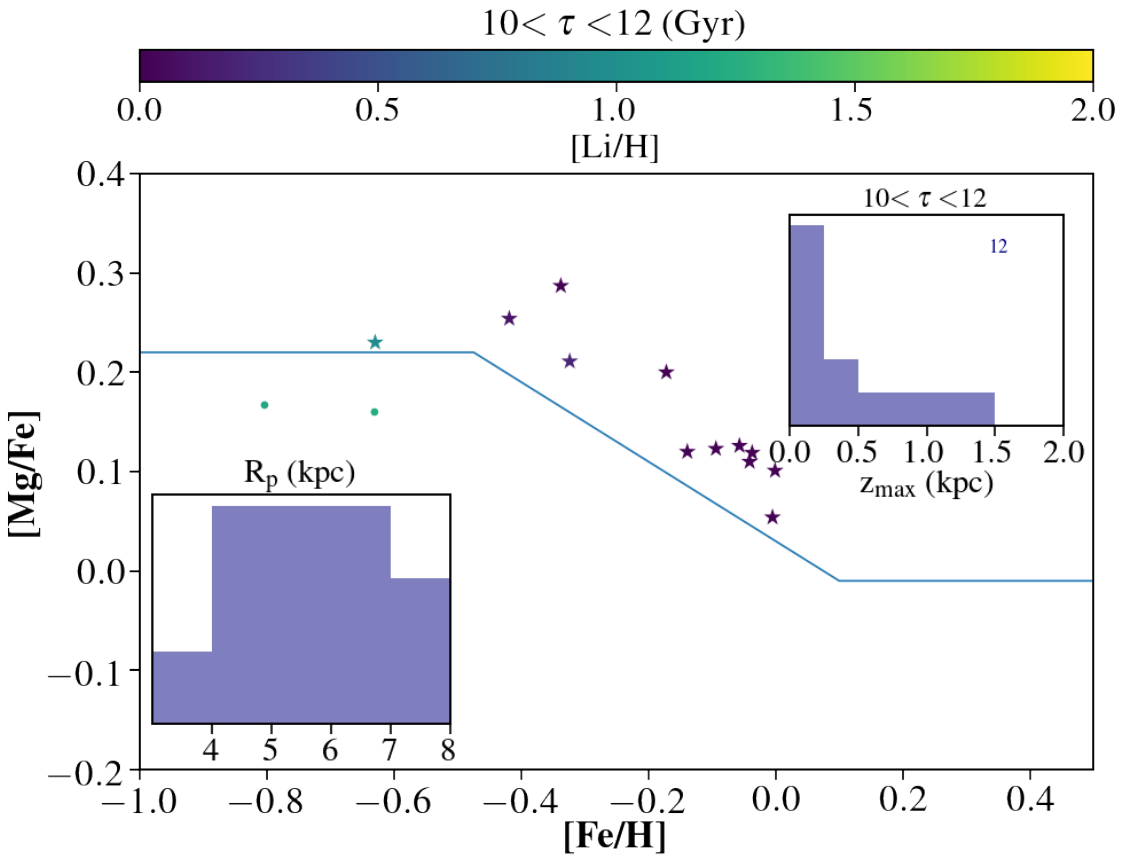


Thick Thin Disk, Thin Thick Disk



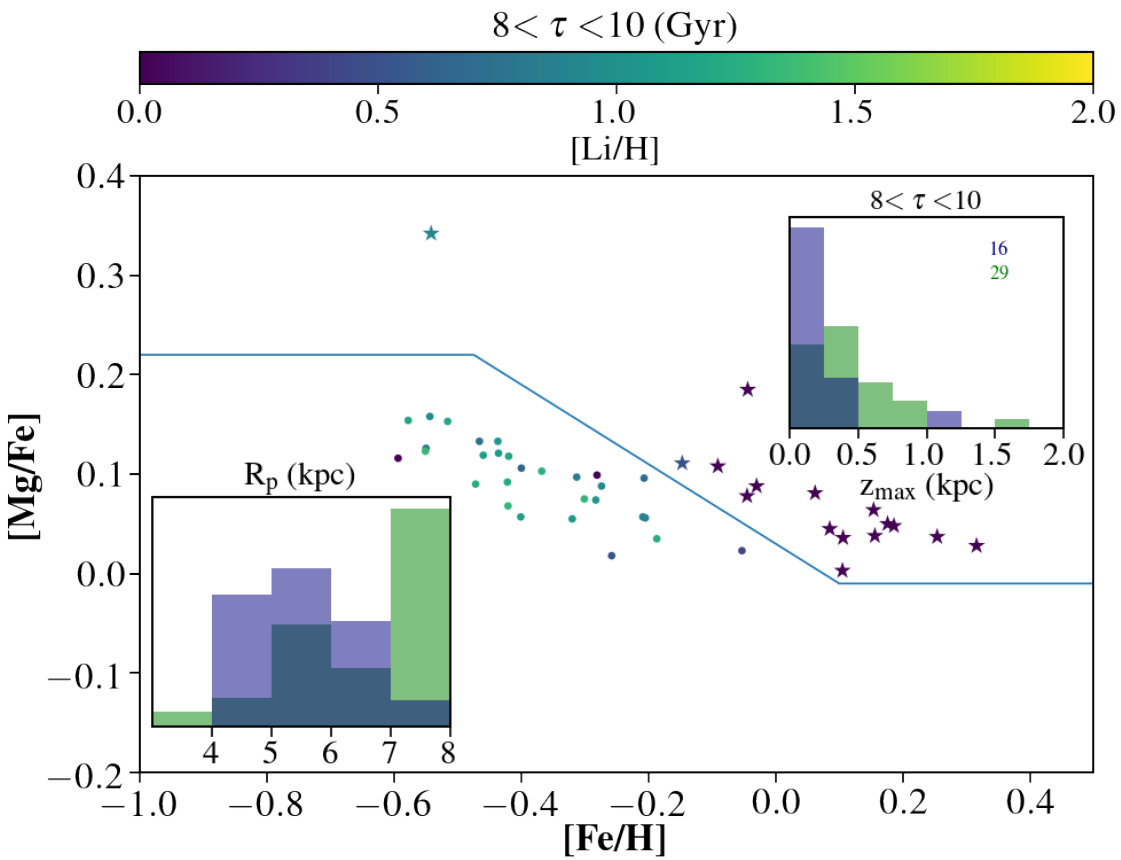
- Using *Gaia* proper motions, parallax compute kinematics, orbits
- Compare orbital properties for thin, thick disk track as function of age
- **Oldest stars have large scale-heights, come from inner Galaxy**

Thick Thin Disk, Thin Thick Disk



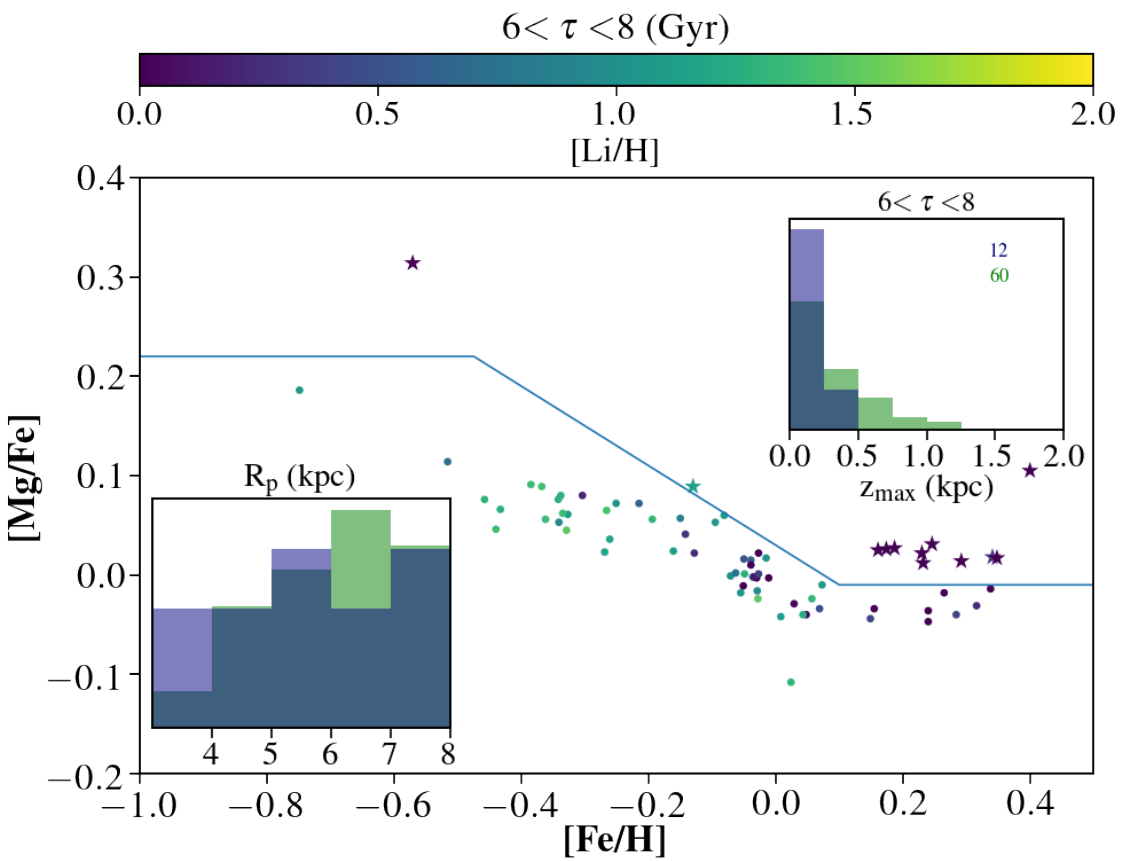
- **Still many thick disk stars with large z_{max}, but bulk of thick disk stars confined to the plane**
- Not many thin disk stars at these ages

Thick Thin Disk, Thin Thick Disk



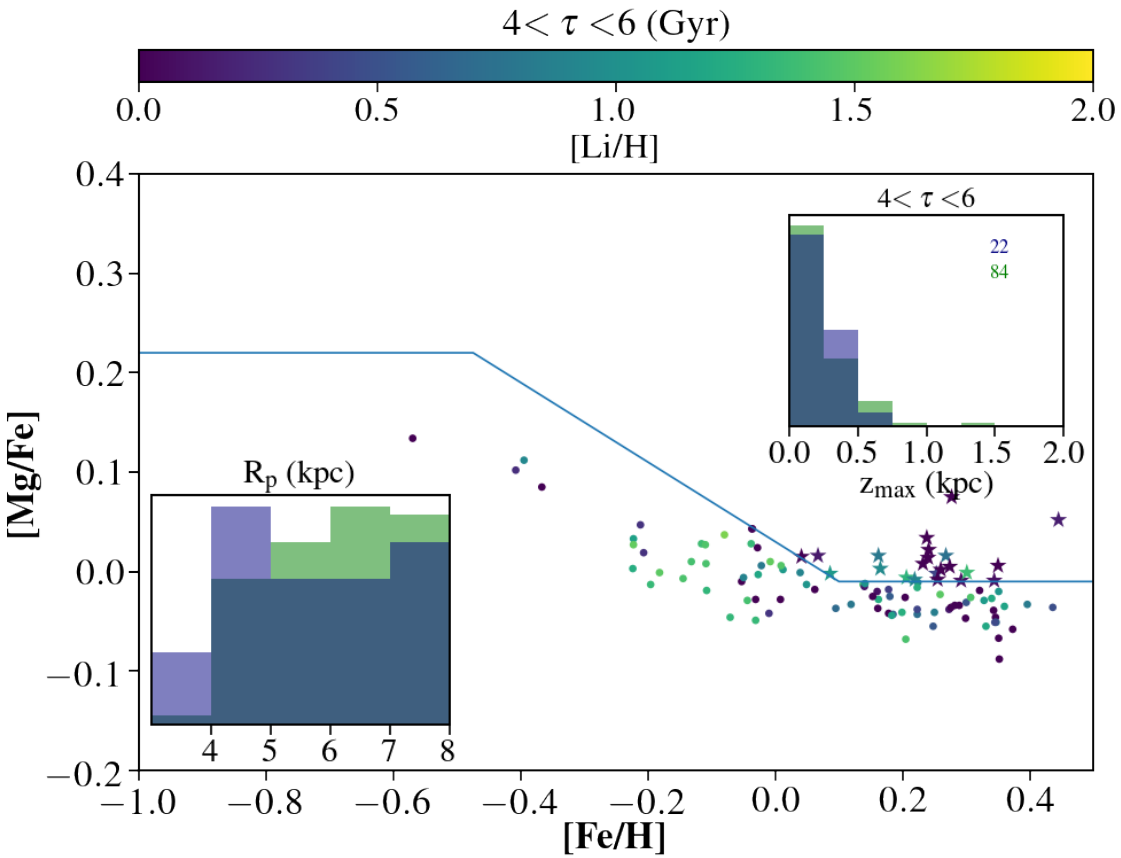
- Chemical thick disk predominately in plane, $z_{max}<0.5$ kpc for almost all stars
- "thin" disk has many stars at large maximum distances from plane
- **Chemical "thin" disk thicker than chemical "thick" disk for stars with** $8 < \tau < 10$ **Gyr**

Thick Thin Disk, Thin Thick Disk

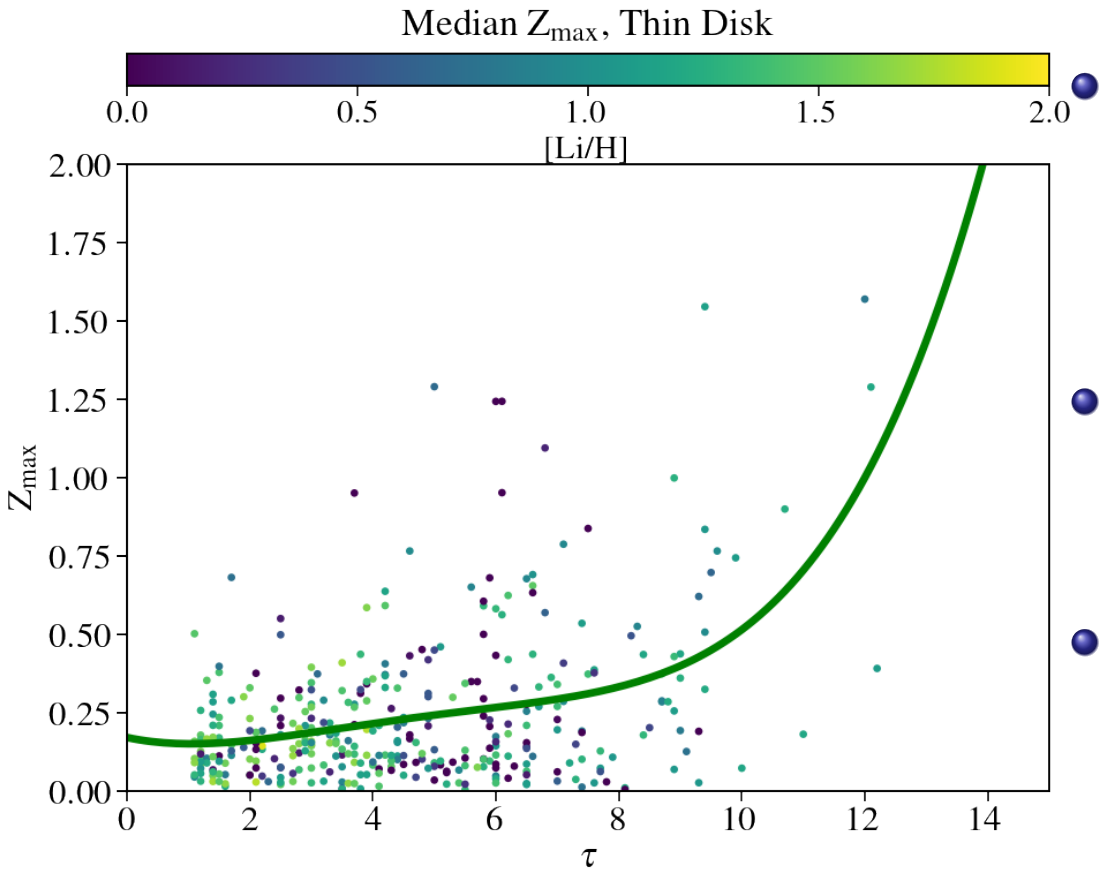


- Similar to previous age bracket, but bulk of both populations close to midplane
- **Chemical "thin" disk is again more vertically extended than chemical "thick" disk**

Thick Thin Disk, Thin Thick Disk

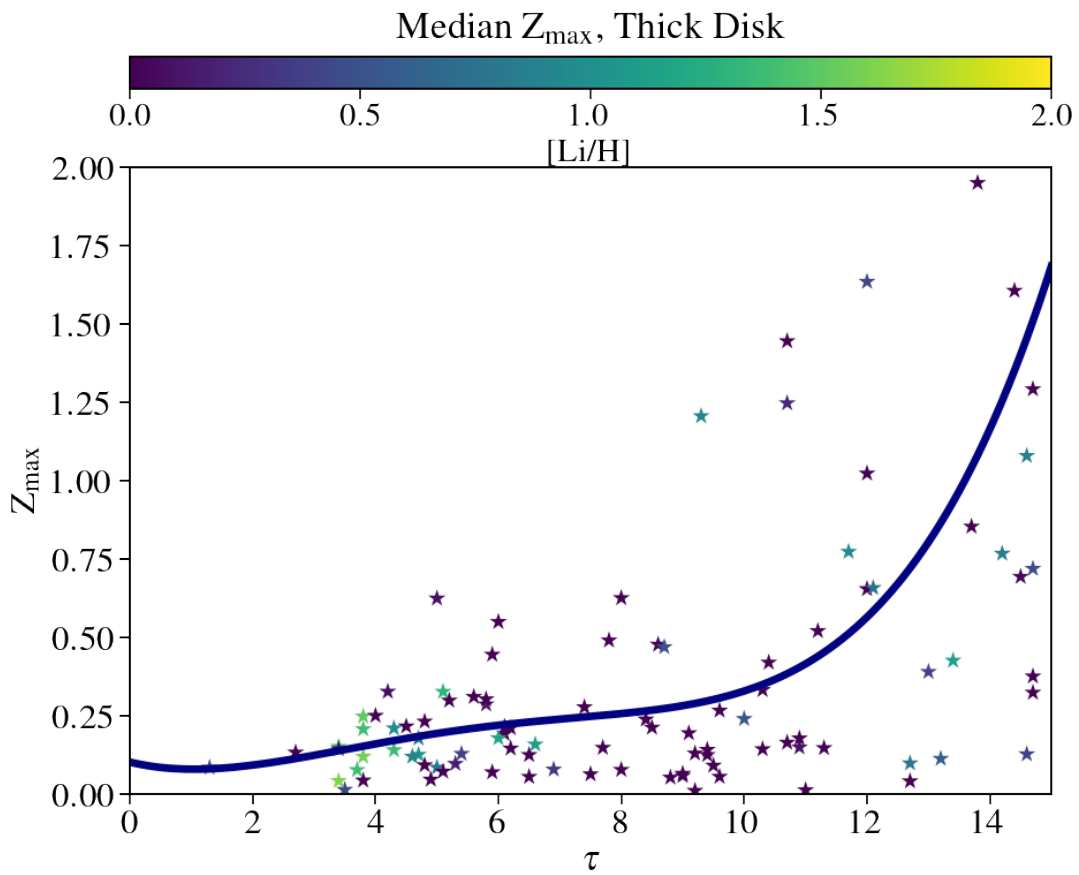


Thick Thin Disk, Thin Thick Disk



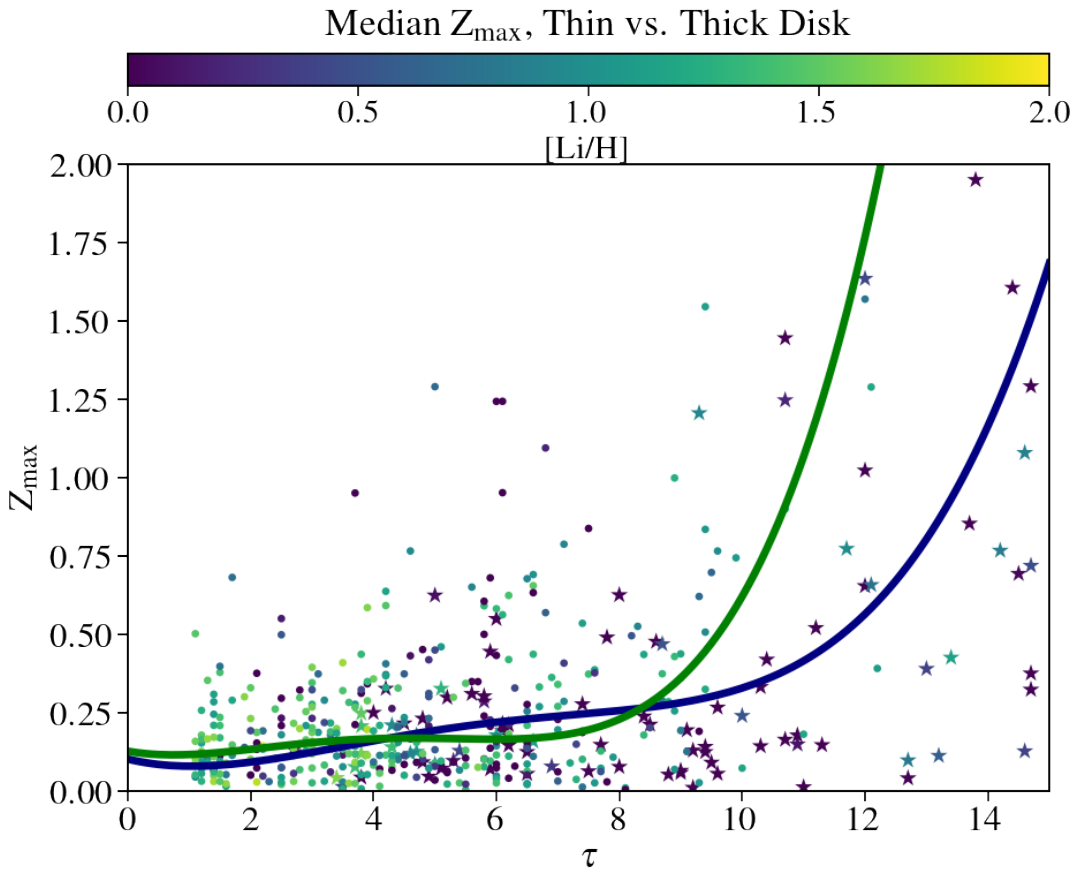
- Thin disk has median $z_{max} \sim 0.25$ kpc for stars younger than 6-8 Gyr
- z_{max} increases rapidly for stars older than 8 Gyr
- Significant scatter for $\tau > 4$ Gyr

Thick Thin Disk, Thin Thick Disk



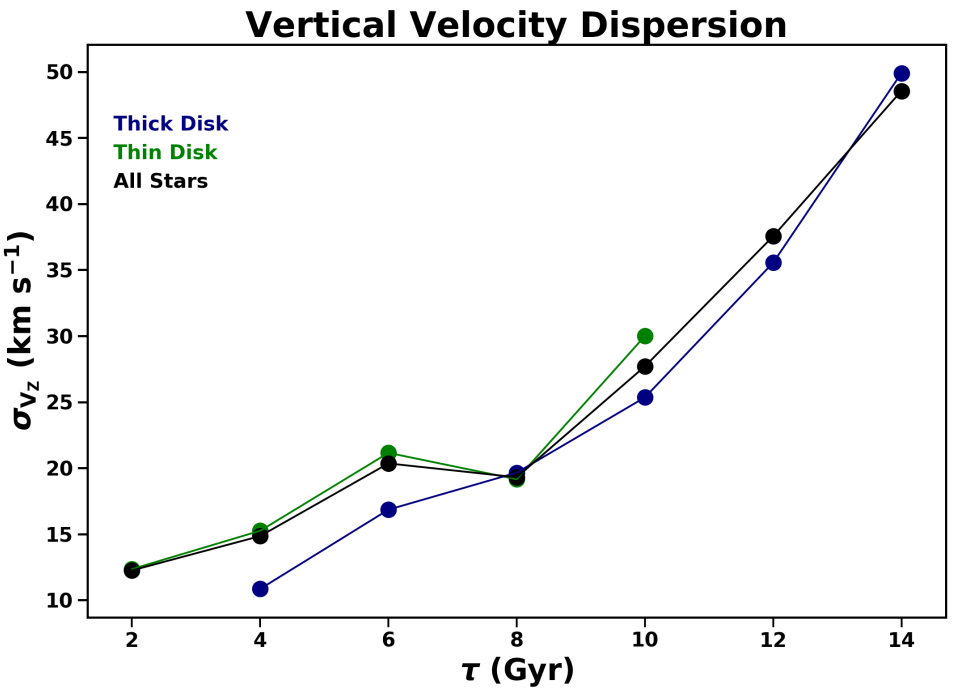
- Thick disk population in general older than thin disk
- Similar z_{max} distribution as thin disk, but shifted to slightly older τ for same z_{max}
- z_{max} increases rpaidly for stars older than 10 Gyr

Thick Thin Disk, Thin Thick Disk



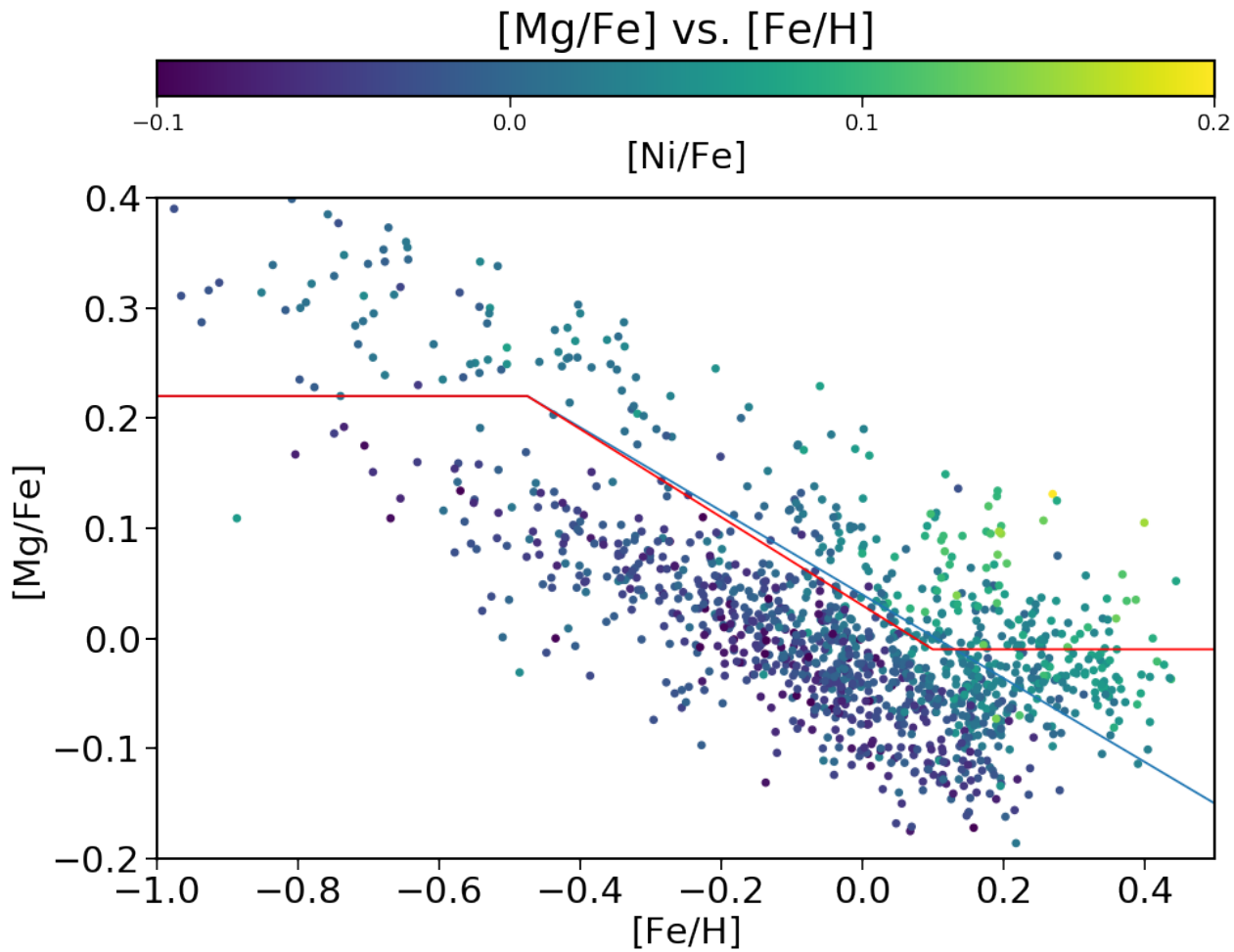
- Thick disk has, on average, similar $z_{\rm max}$ than thin disk at same age!
- **Chemical definition of thin, thick disk ambiguous, confusing!**

Thick Thin Disk, Thin Thick Disk

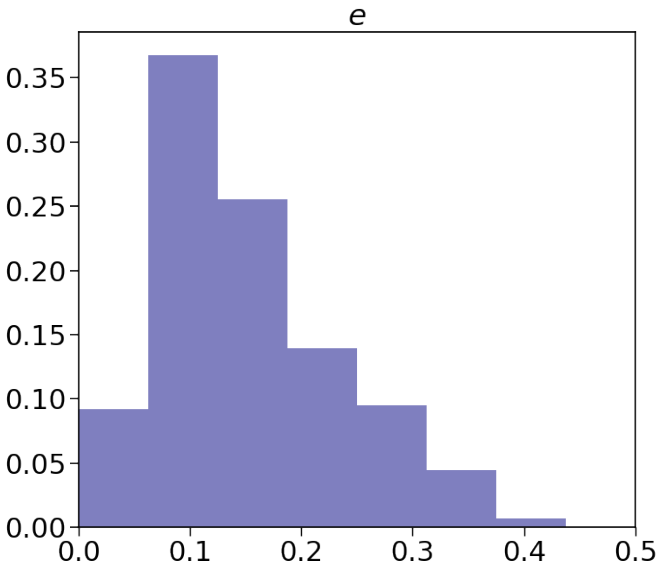


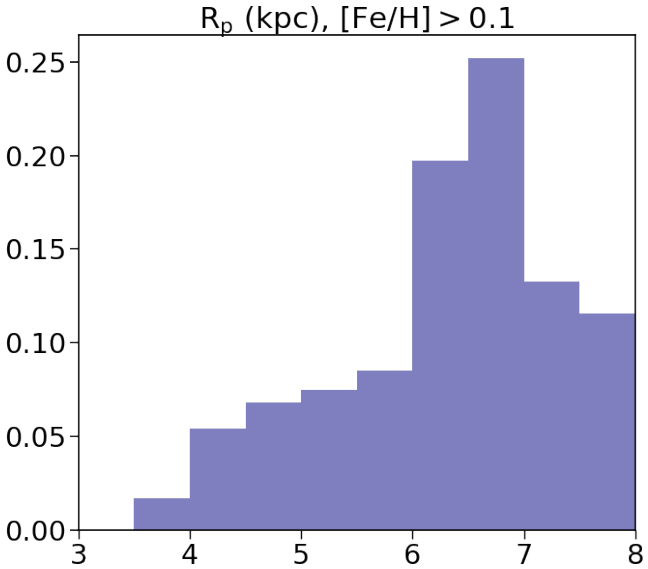
- σ_{V_z} lower for thick disk than thin disk at same age
- Chemical definition of thin, thick disk ambiguous, confusing
- **Thin, thick disk terms should be reserved for geometric disk**
- Clearly two primary chemical evolution sequences
- **New definition: Inner Galaxy, Outer Galaxy**

Metal-rich Populations: Migration



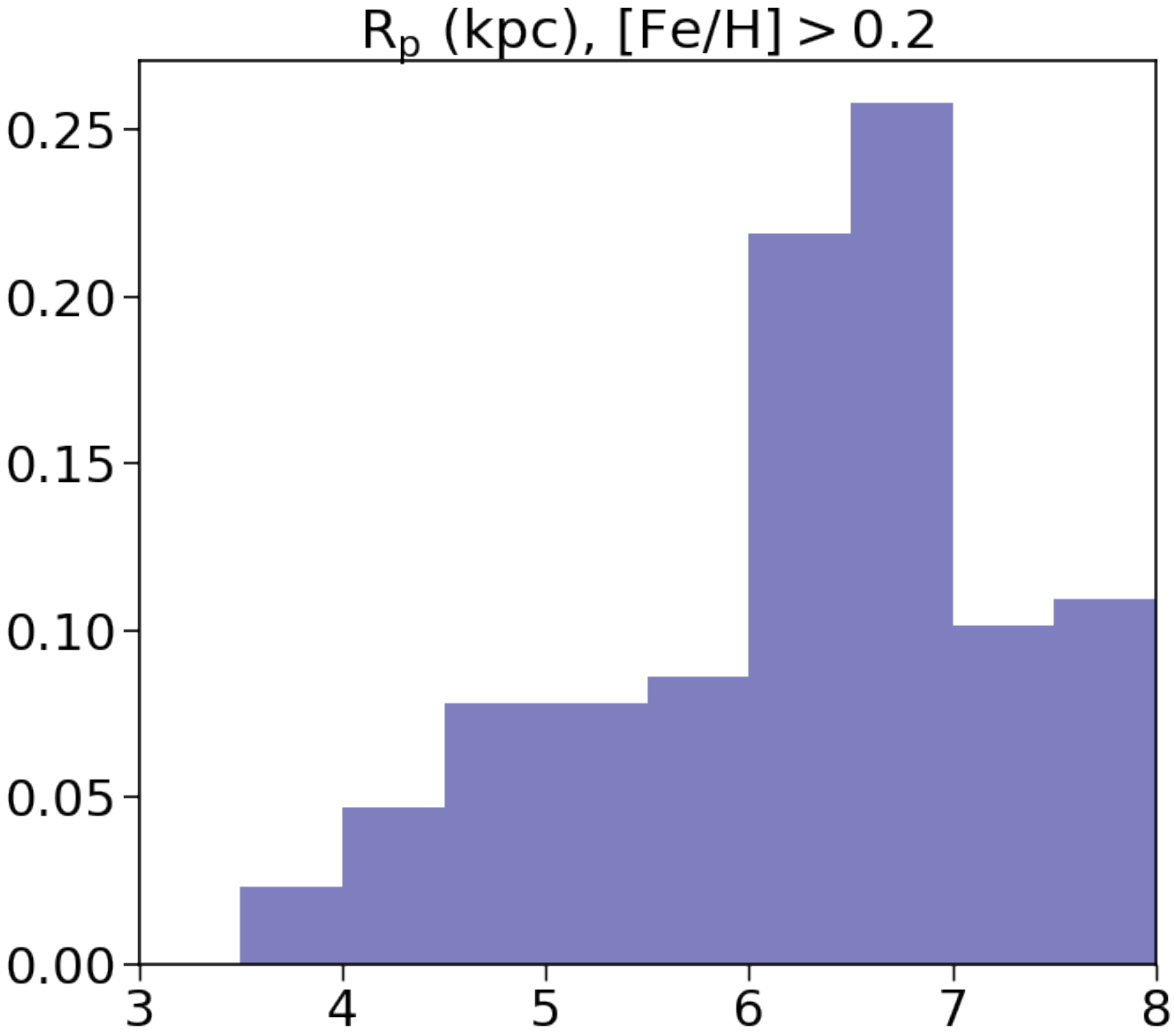
Metal-rich Populations: Migration





- Select stars with [Fe/H]$>$ 0.1 (i.e. those that didn't form in solar neighborhood!)
- More than half of metal-rich stars have eccentricities < 0.2, $R_P > 6$ kpc – likely migrated!
- $>1/4$ of metal-rich stars have perigalacticons$>$ 7 kpc
- R_P distribution similar no matter the definition of "metal-rich"

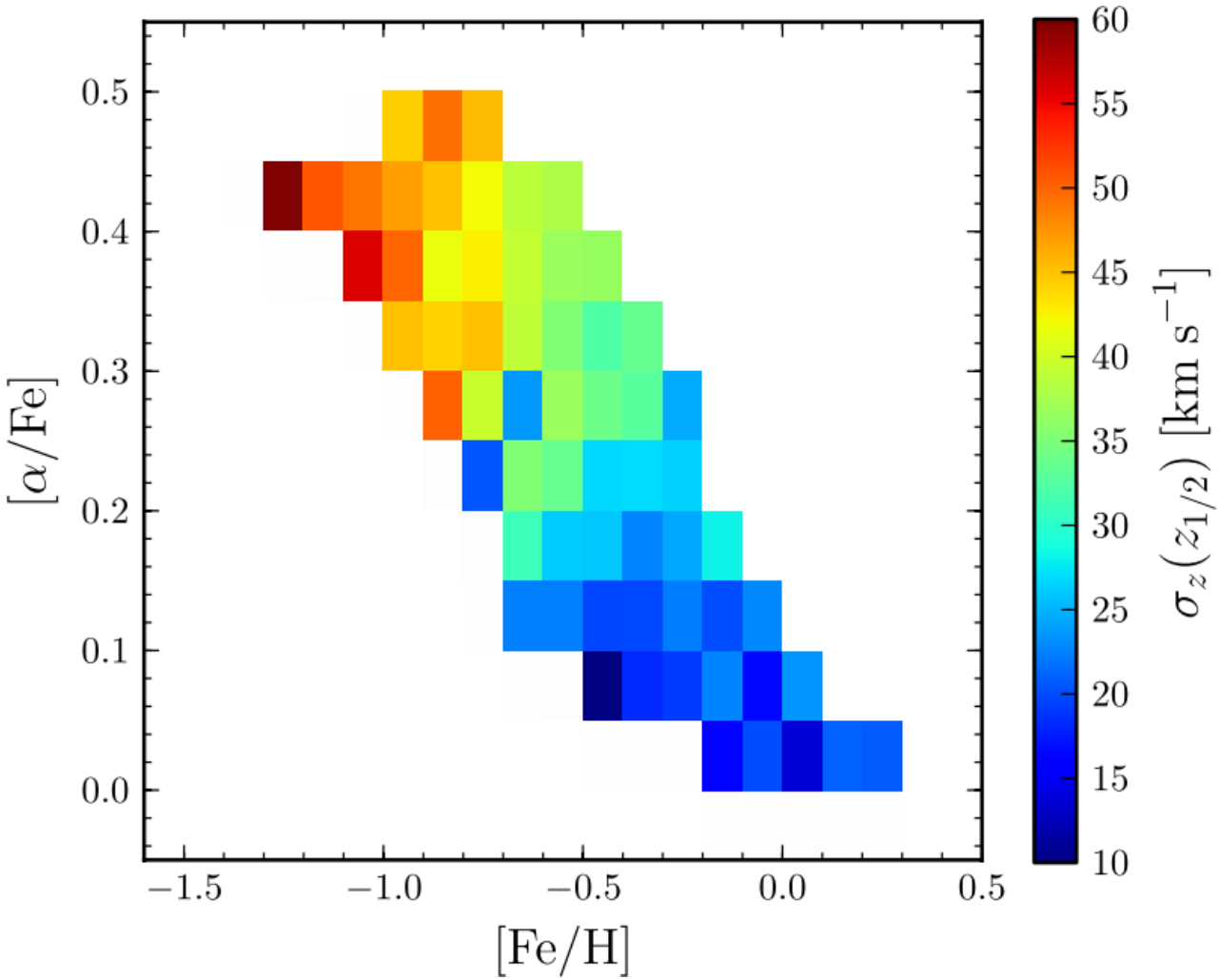
Migration



Summary

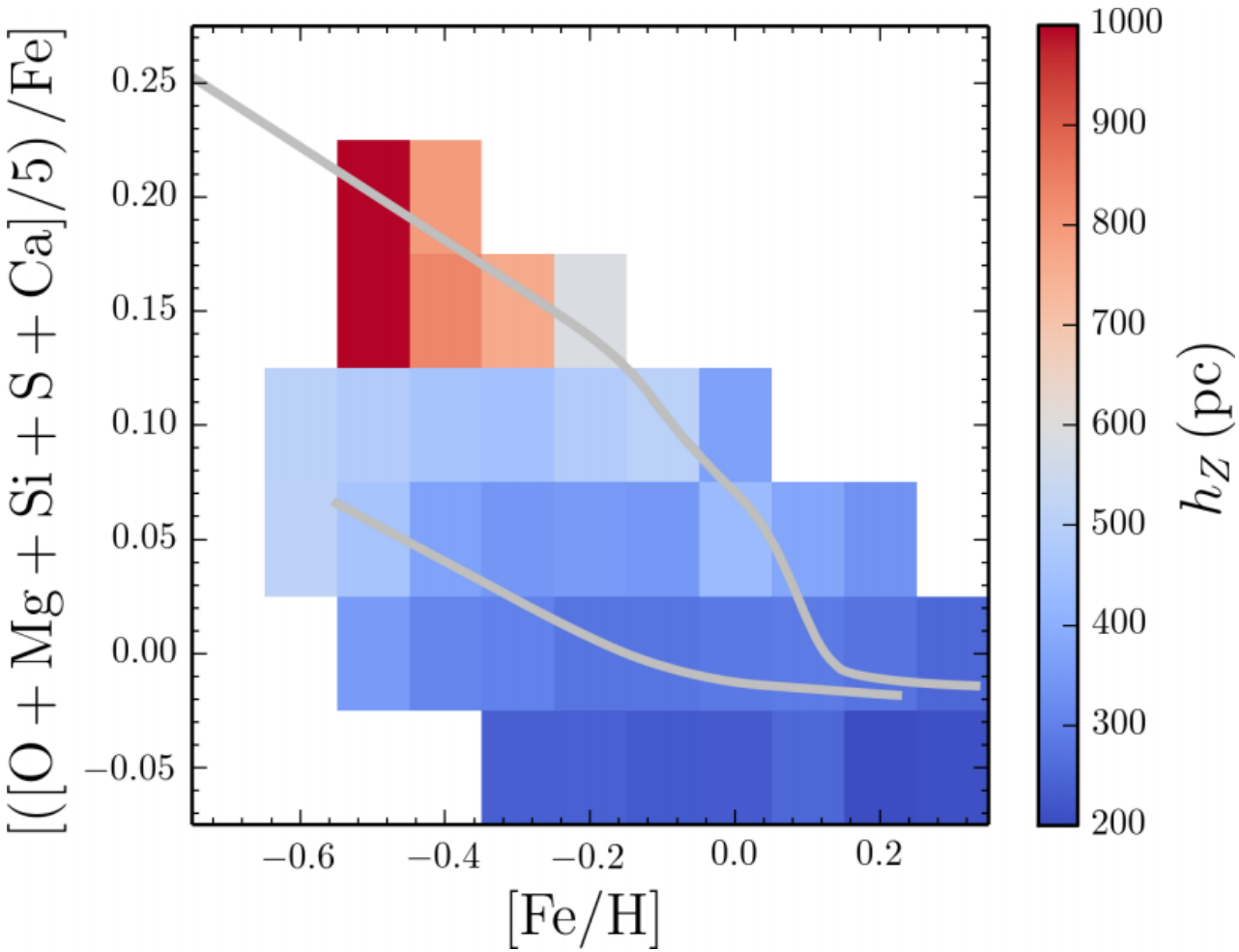
- Derived ages, kinematics for sample of HARPs stars, can be applied to larger data sets!
- Chemical thick disk has extended star formation history, potentially up to present day
- The chemically defined thick disk has a similar scale height than chemically defined thin disk for same age
- Chemical separation of thin-thick disk misleading: need new definition
- Inner Galaxy vs. Outer Galaxy
- Radial Mixing: more than half of metal-rich stars on circular orbits+large perigalictons, migration important for these populations

Thick Thin Disk, Thin Thick Disk



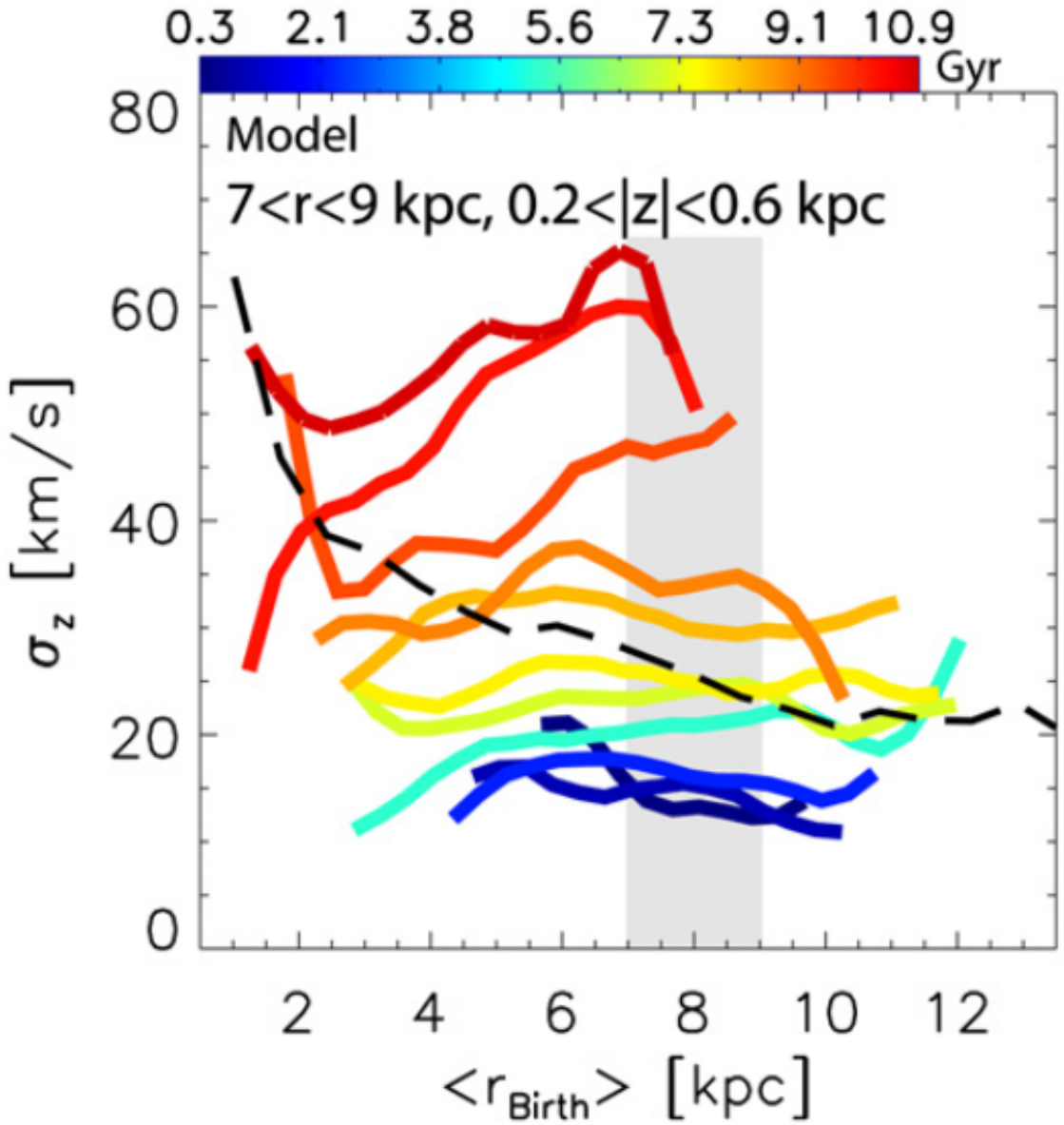
Bovy+2012

Thick Thin Disk, Thin Thick Disk



Bovy+2016

Thick Thin Disk, Thin Thick Disk



Minchev+2014