The chemistry of the Milky Way disk

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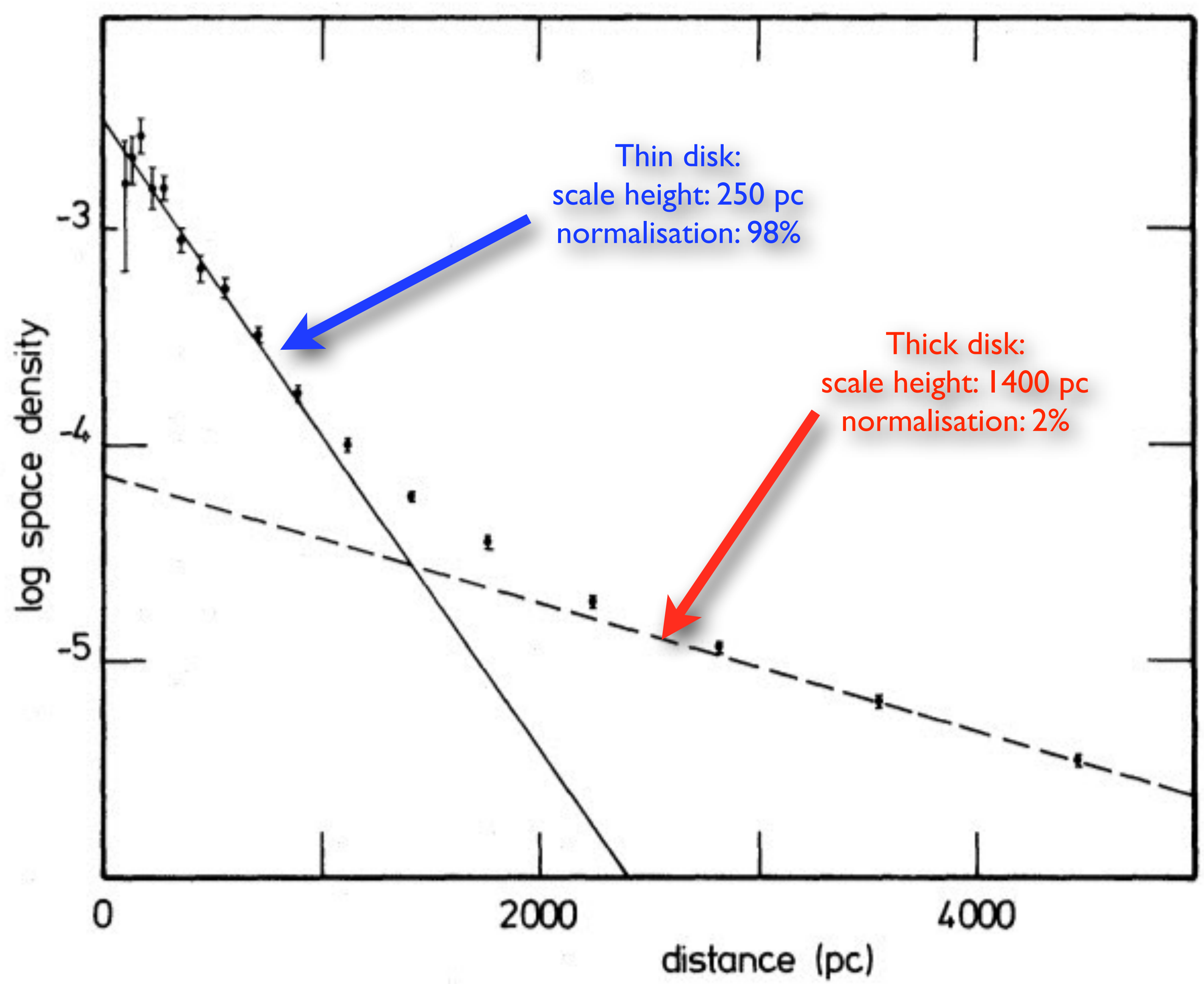
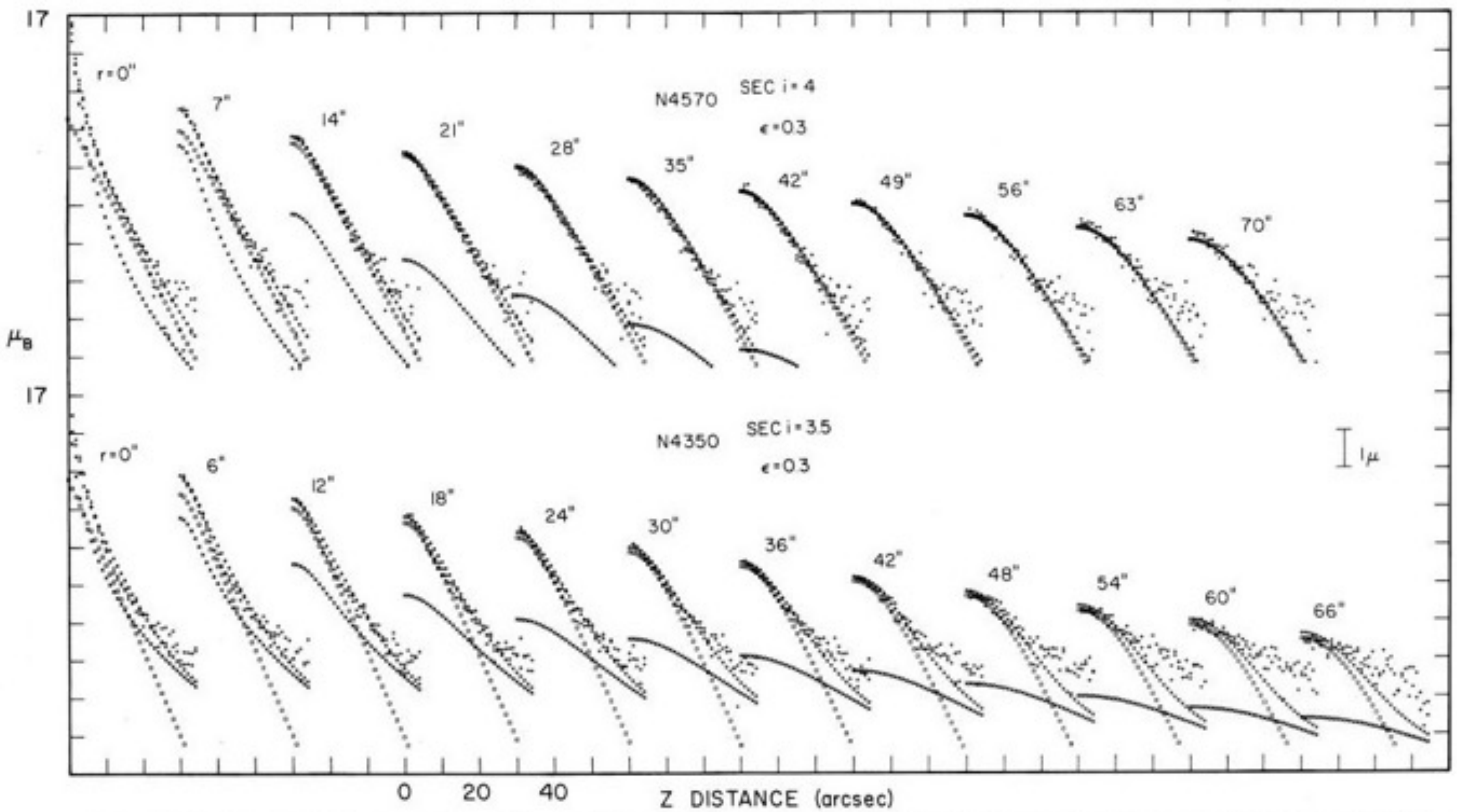
The Milky Way has two disk populations



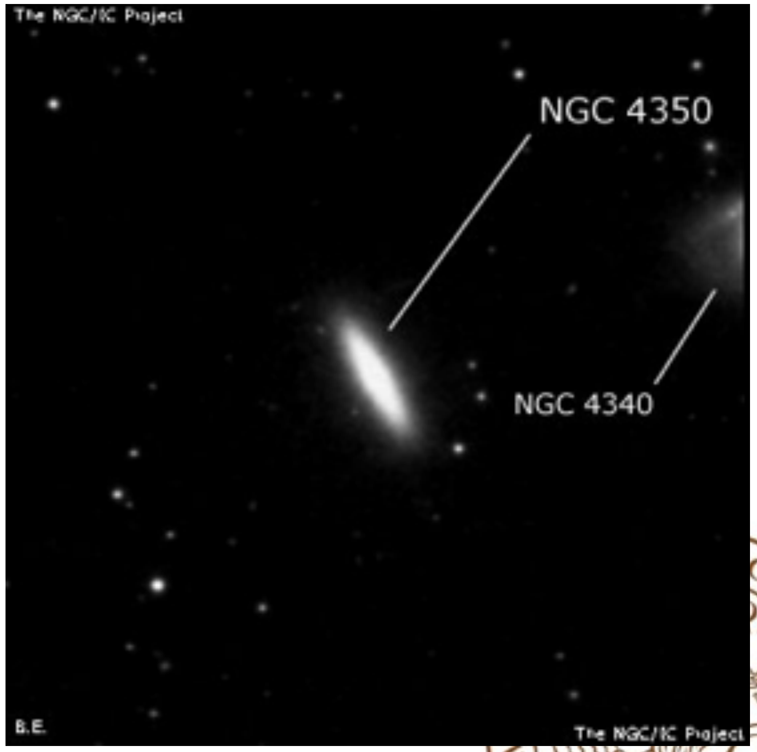
(Gilmore & Reid, 1983, MNRAS, 202, 102)

Thick disks in external galaxies

Burstein et al. (1979, ApJ, 234, 829)



Bulge and thin disk profiles shown, however a third diffuse component is needed to fit the luminosity distribution perpendicular to the plane, named the "Thick disk".

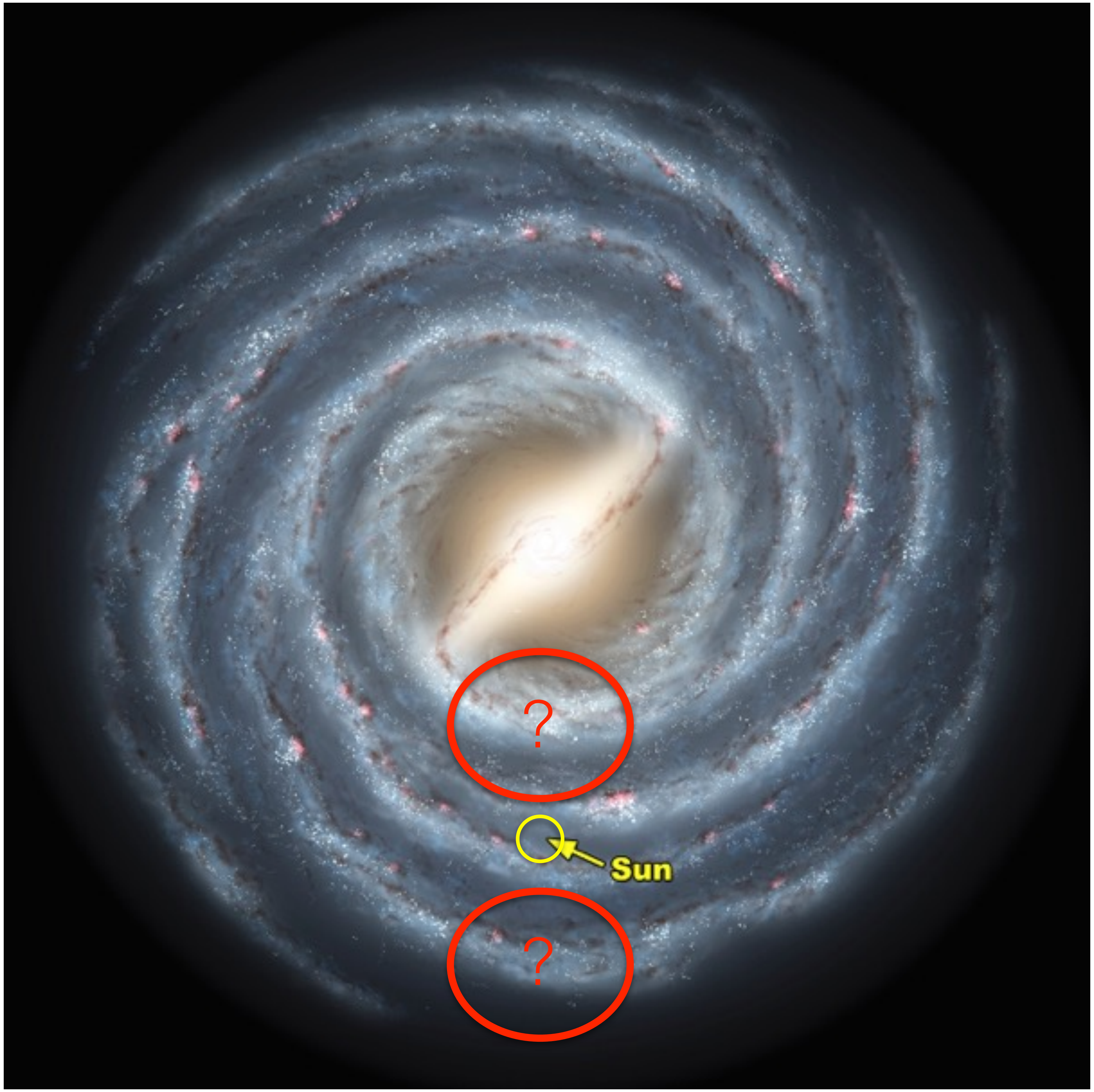


The Milky Way as a benchmark galaxy

Milky Way is the only galaxy that can be studied in great detail and a good understanding of its stellar populations is important for our understanding of galaxy formation in general

NGC 891

The Milky Way as a benchmark galaxy



Why does the Milky Way have two disk populations?

Need to characterize them in terms of

- velocities
- abundances
- ages

Not only in the solar neighbourhood, but throughout the Milky Way galaxy

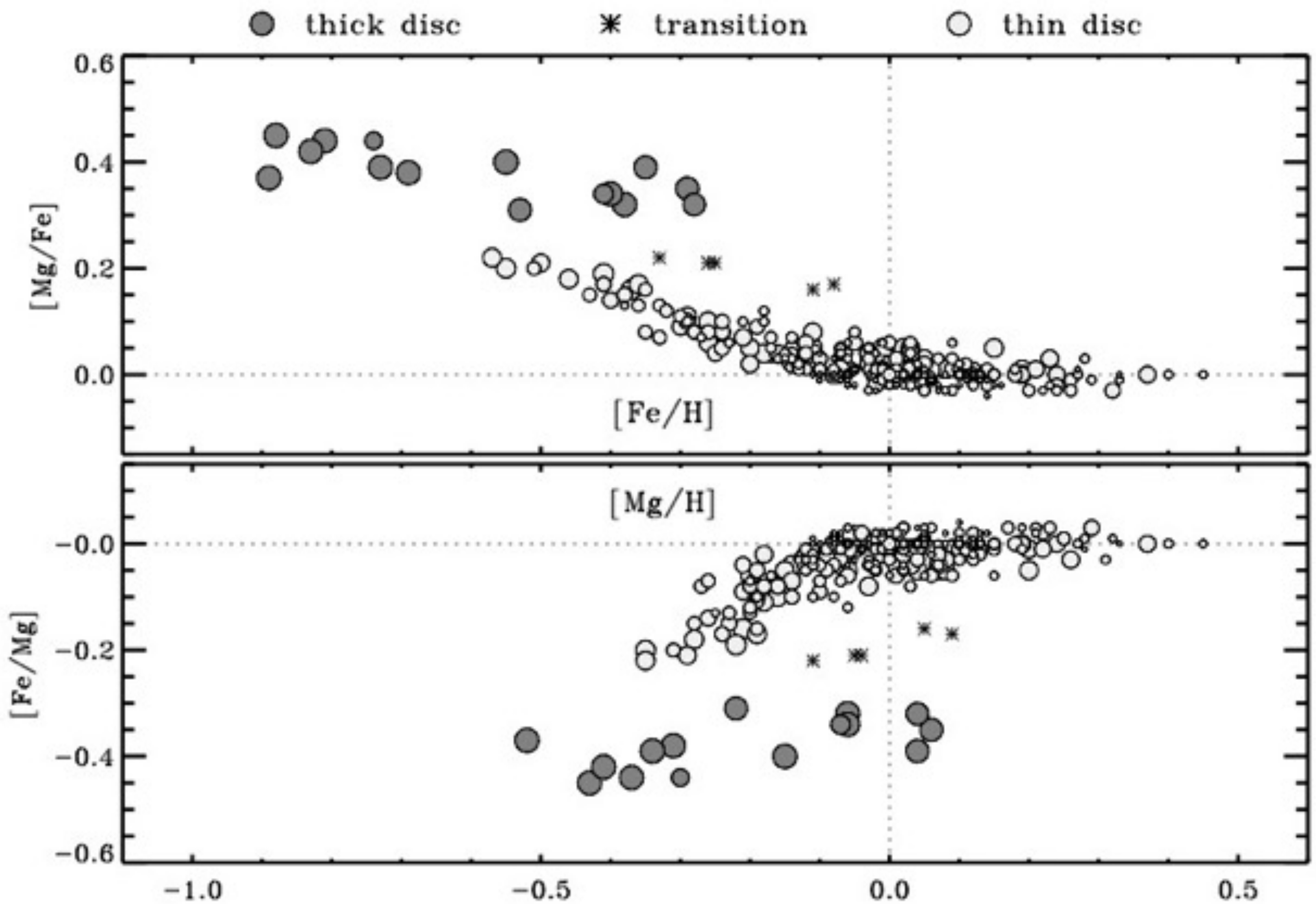
Nearby stars - no selection

- Fuhrmann's study is 85% volume complete for all mid-F type to early K-type stars down to Mv=6.0, north of dec=-15º, within a radius d<25pc from the Sun

- Two types of stars:

  1. Old stars with high [Mg/Fe] ratios

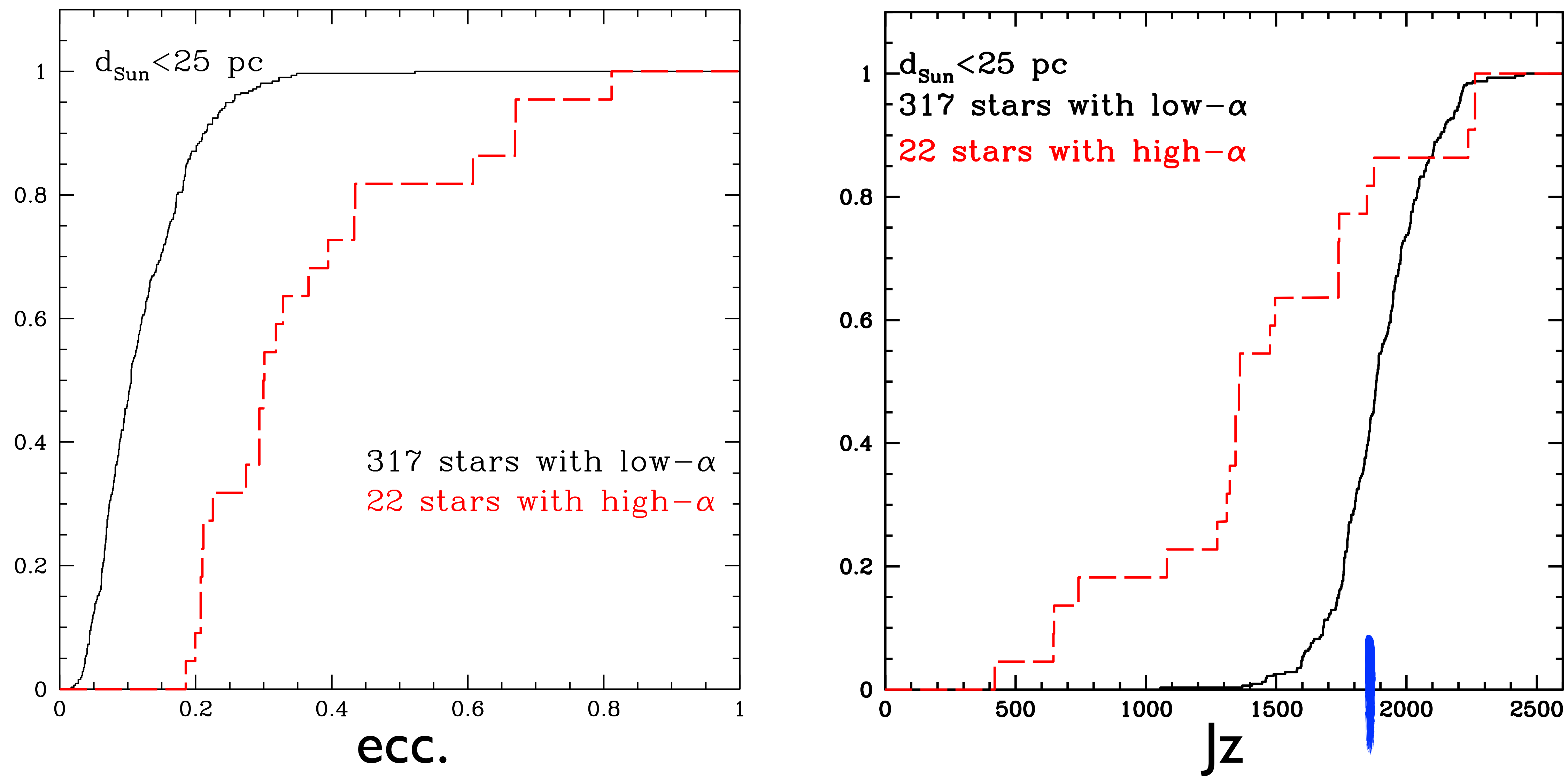
  2. Young stars with low [Mg/Fe] ratios



Fuhrmann (1998, 2000, 2004, 2008, 2011)

Two types of stars - high-alpha & low-alpha

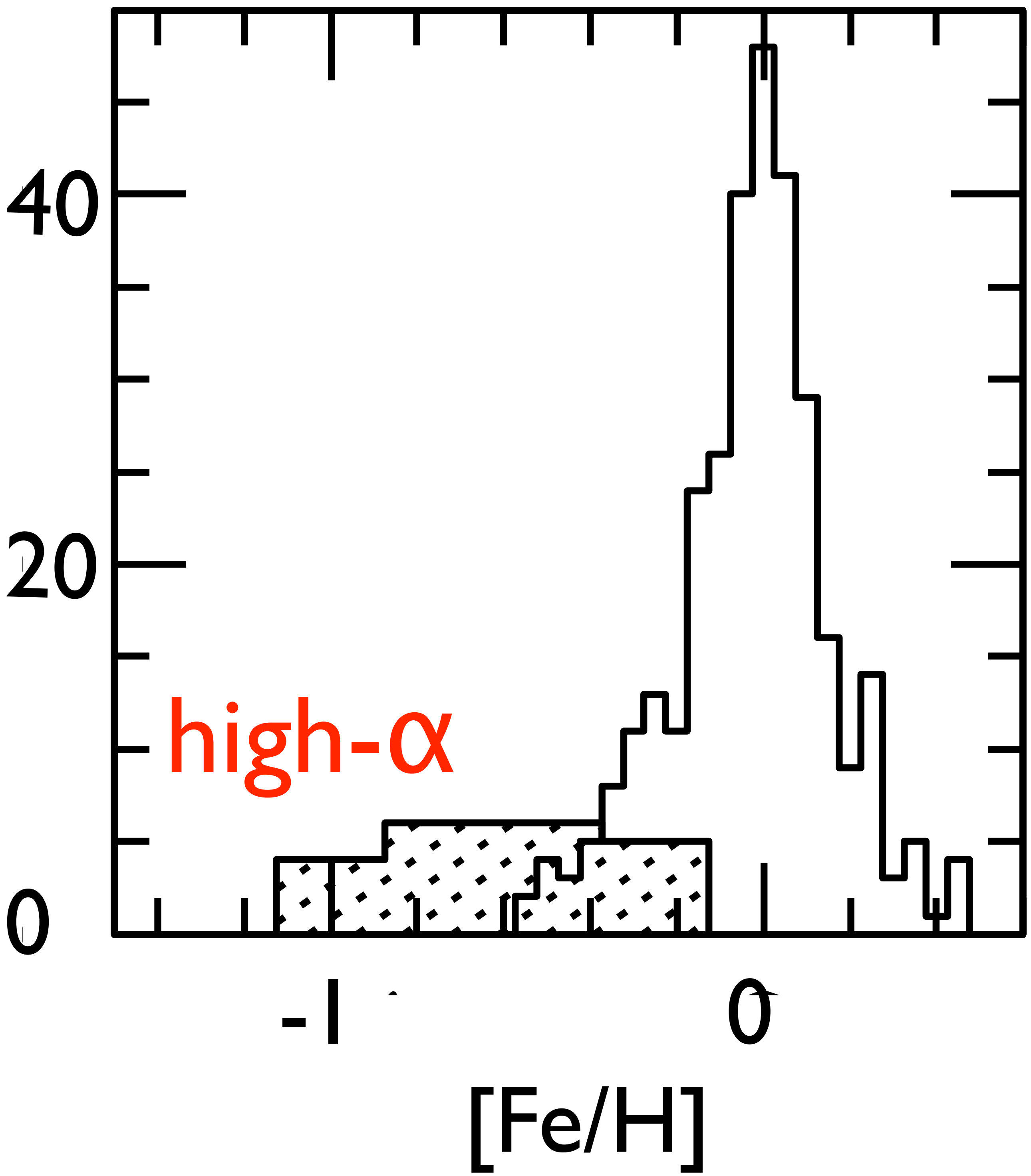
(data from Fuhrmann's papers)



Two very different distributions of eccentricity and Jz for low- and high-α stars

Metallicities

(data from Fuhrmann's papers)

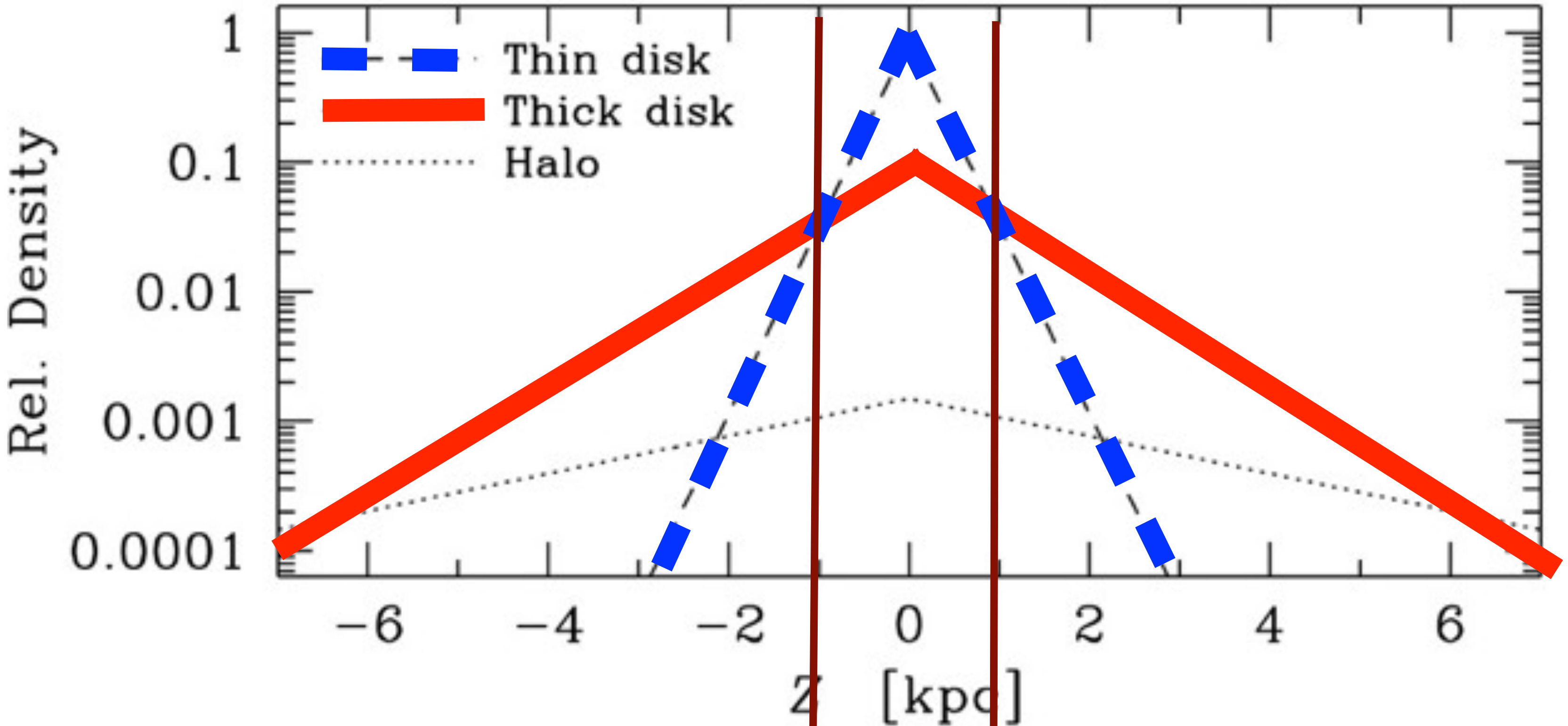


low-α stars

Thin disk:
<[Fe/H]> = 0
(see also, e.g., Nordtström et al., 2004, Casagrande et al. 2011)

Thick disk:
<[Fe/H]> = -0.6
(see also, e.g., Gilmore, Wyse, Jones, 1995; Carollo et al 2010)

Solar neighbourhood



Solar neighbourhood, in the plane:

~90 % thin disk
~10 % thick disk

scale-heights:
300 pc & 1000 pc, respectively

Thick disk dominates

Thin disk dominates

Thick disk dominates

To be sure to observe thick disk stars, you need to go at least 2 kpc above/below the plane

F and G dwarf stars usually too faint for high-resolution studies at those distances!!

Kinematical criteria to select nearby thick disk stars

$$P = X \cdot k \cdot \exp\left(-\frac{U_{\mathrm{LSR}}^2}{2\,\sigma_{\mathrm{U}}^2} - \frac{(V_{\mathrm{LSR}} - V_{\mathrm{asym}})^2}{2\,\sigma_{\mathrm{V}}^2} - \frac{W_{\mathrm{LSR}}^2}{2\,\sigma_{\mathrm{W}}^2}\right) \qquad k = \frac{1}{(2\pi)^{3/2}\,\sigma_U \sigma_V \sigma_W}$$

	σ_{U}	σ_{V}	σ_{W}	V_{asym}
	[km s^{-1}]			
Thin disk (*D*)	35	20	16	−15
Thick disk (*TD*)	67	38	35	−46
Halo (*H*)	160	90	90	−220

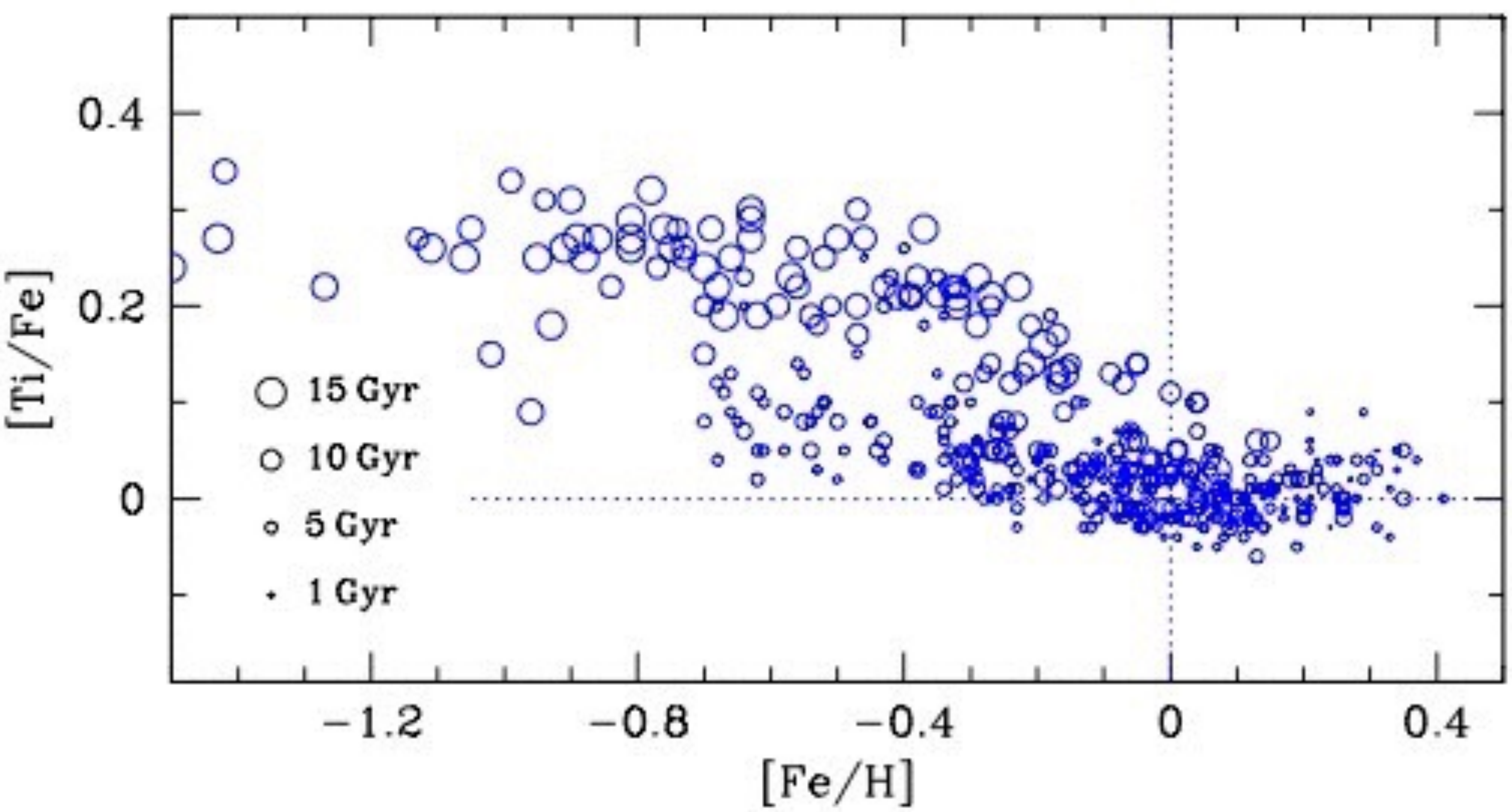
Gaussian velocity distributions, *X* is normalisation in solar neighbourhood (~90% thin, ~10% thick)

Probability ratios: *P*(TD/D)>1
is more likely to be a thick disk star

Chemistry of the Solar neighbourhood

Bensby et al. (2014, A&A, 562, A71)

712 F and G dwarf stars in the Solar neighbourhood



A clear dichotomy:

- **An old and alpha-enhanced population**
- **Less alpha-enhanced young population**

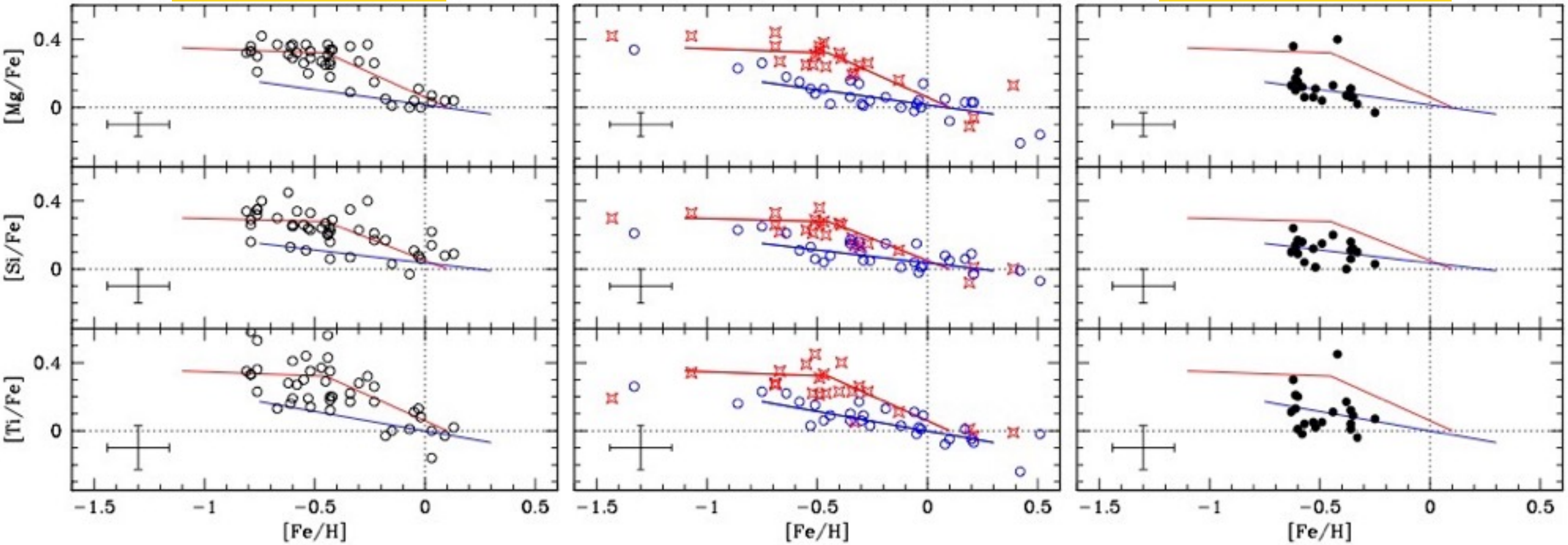
Similar dichotomy seen in many other Solar neighbourhood studies, e.g.,
Bensby+2003,2004,2005,2006,2007, Reddy+2003,2006,
Adibekyan+2012, Fuhrmann 1998,2001,2004,2008,2011, and others.....

A bit further away

Inner disk
4 < R_g < 7 kpc

Solar neighbourhood

Outer disk
9 < R_g < 13 kpc



Bensby, Alves-Brito, Oey, Yong, & Melendez, 2010, A&A, 516, L13

Alves-Brito et al. (2010)

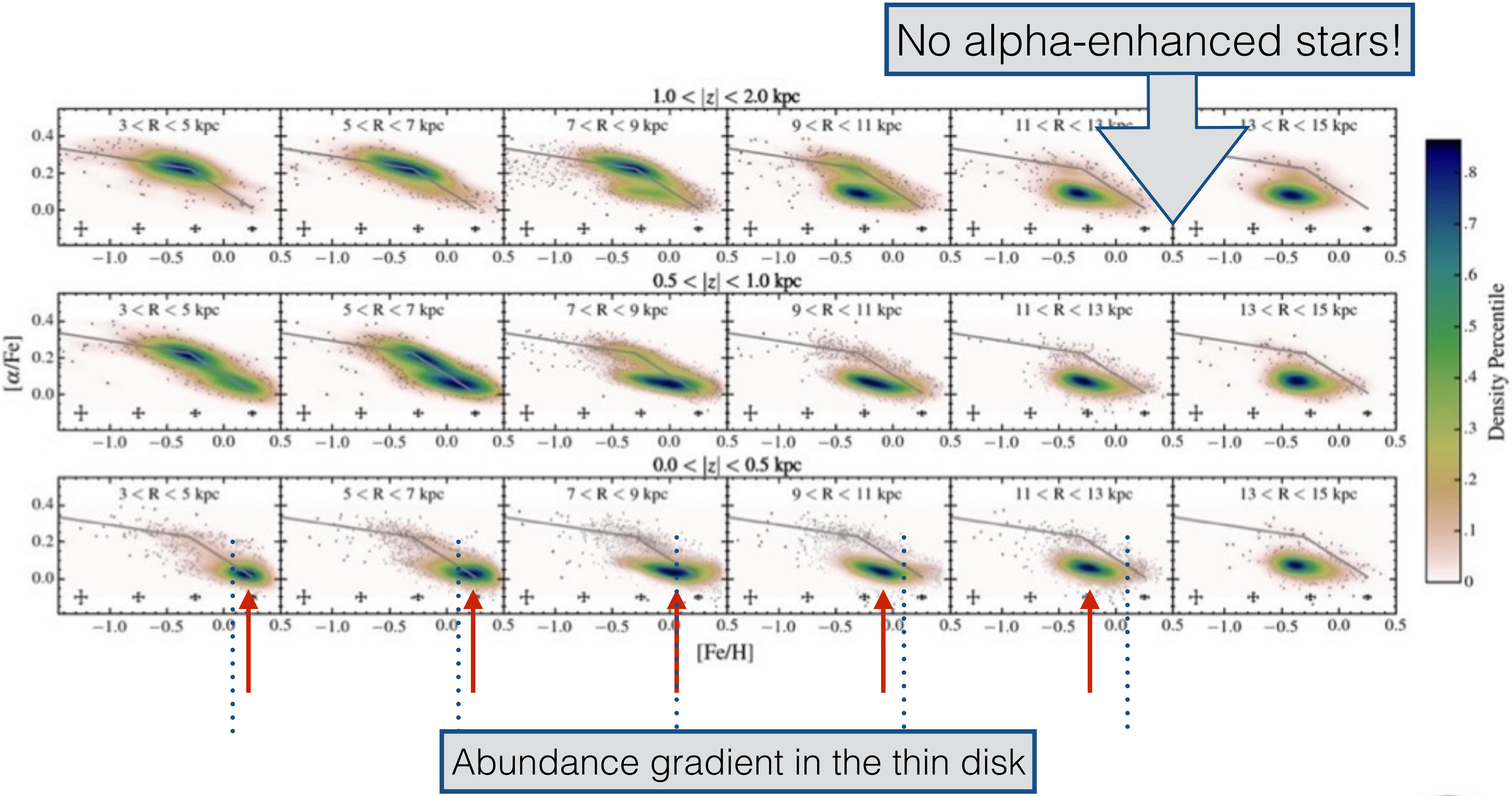
Bensby, Alves-Brito, Oey, Yong, & Melendez, 2011, ApJ, 735, L46

N<u>o</u> alpha-enhanced stars in the outer disk

=> Short scale-length for the thick disk !

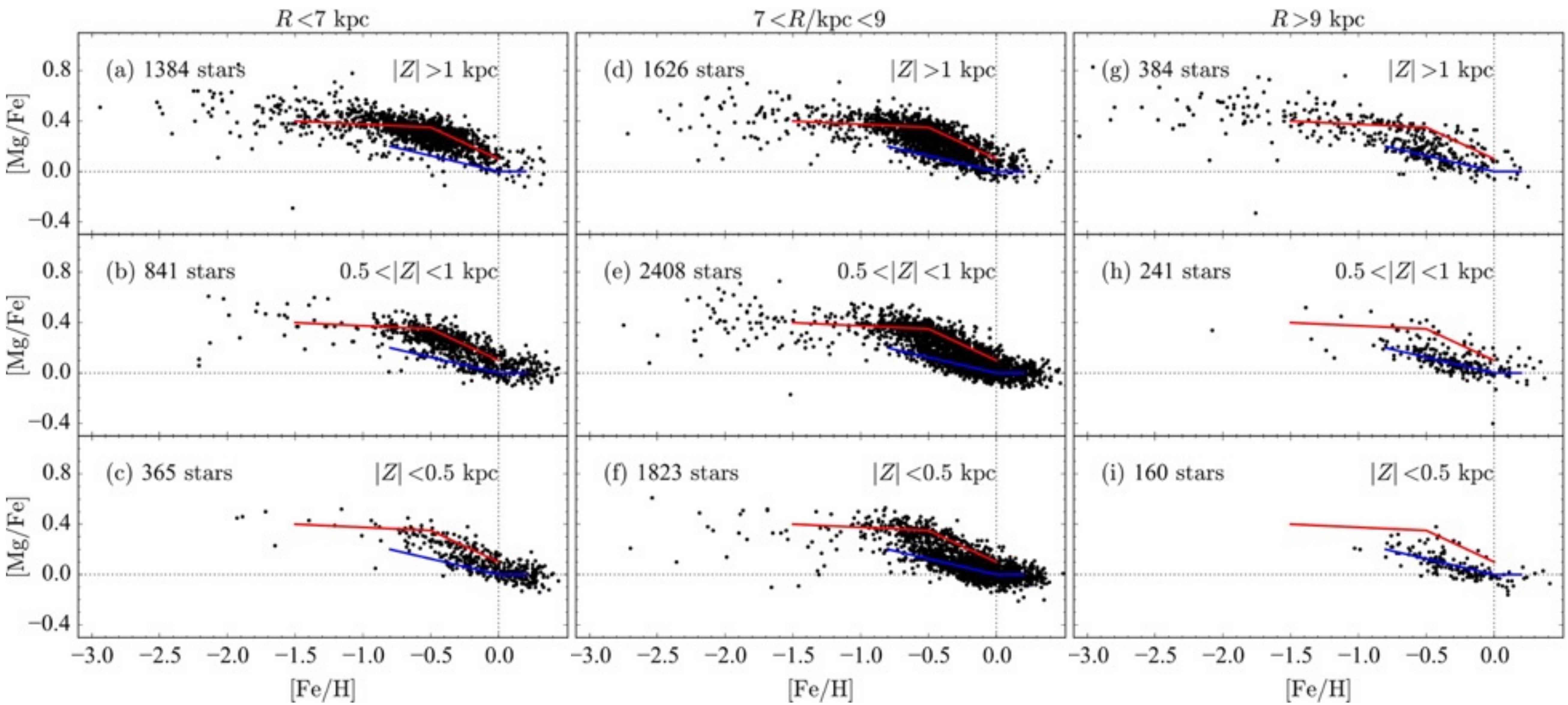
See also, e.g., Cheng et al. (2012), Bovy et al. (2012)

Further away and larger samples - APOGEE



- Hayden et al. (2015), based on red giants from APOGEE DR12

Further away and larger samples - Gaia-ESO

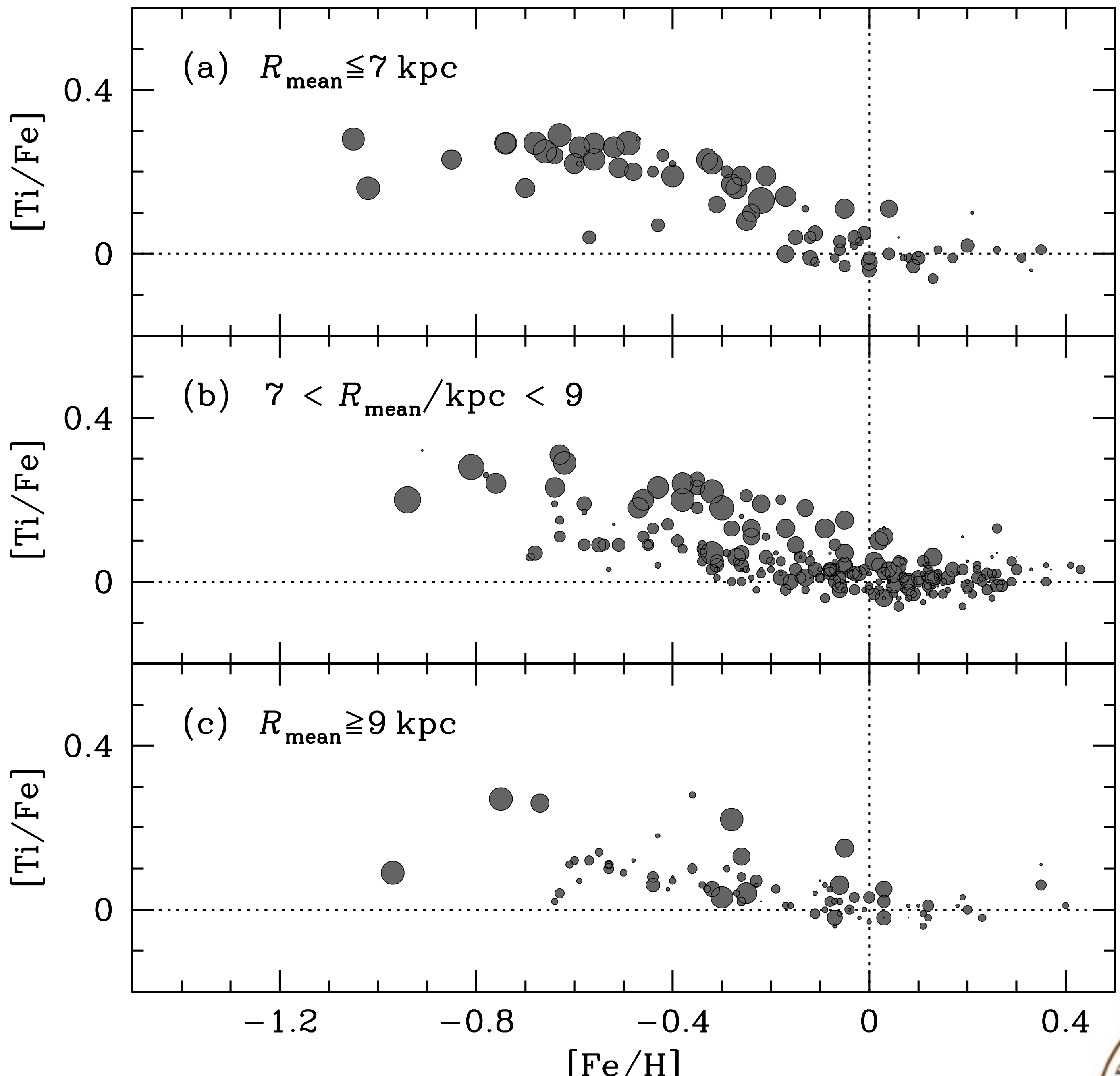


Lack of alpha-enhanced stars in the outer disk!

Similar results seen in local data

Bensby et al. (2014, A&A, 562, A71)

- 714 F and G dwarfs in the solar neighbourhood (d<100 pc).
- Calculating stellar orbits to get $R_{mean} = (R_{min} + R_{max})/2$
- Almost no (old) high-alpha stars with R_{mean}>9kpc
- Almost no (young) low-alpha stars with R_{mean}<7kpc

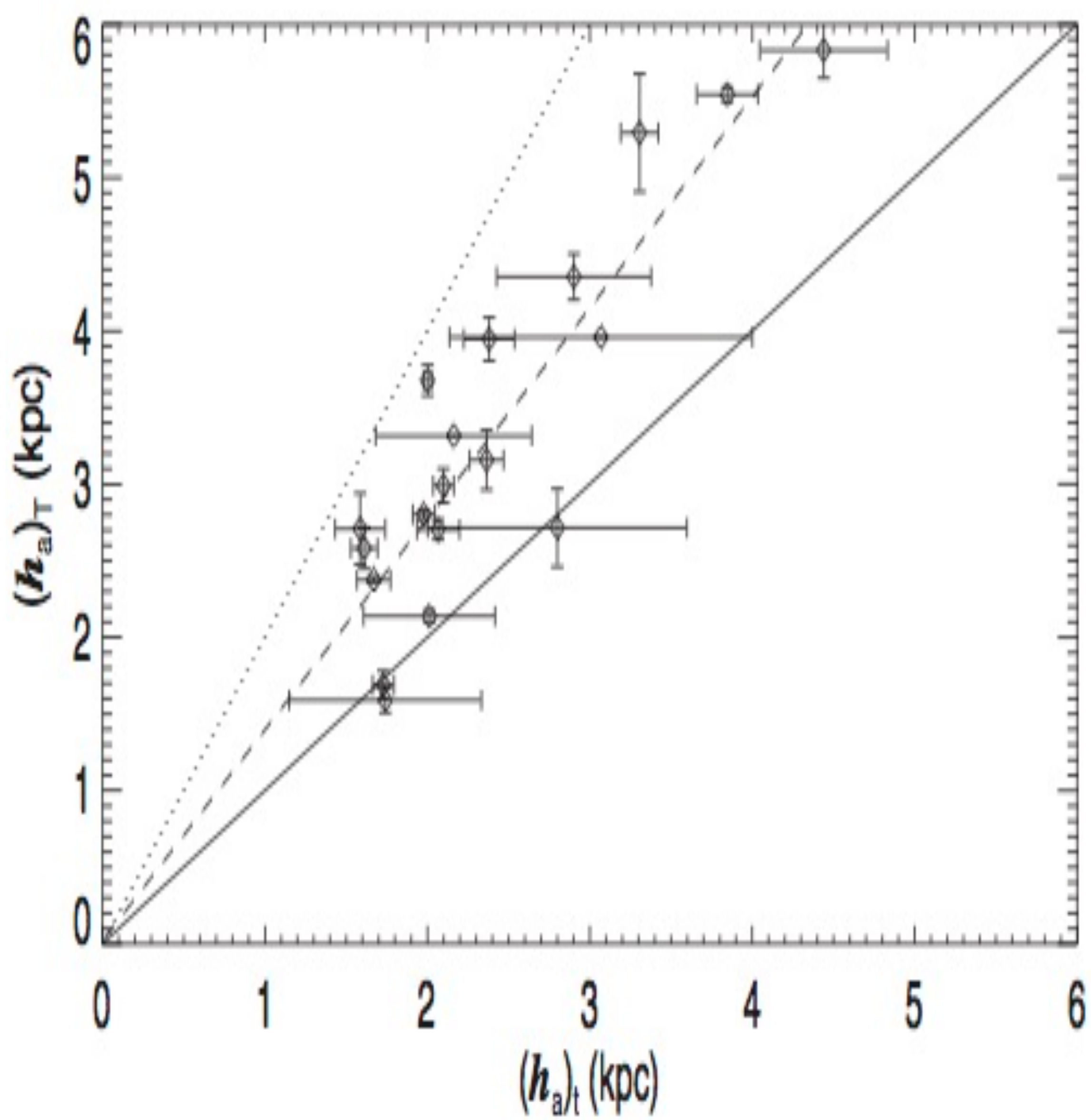


Sizes of circles prop. to age (larger = older)

Scale-lengths in external galaxies

Comeron et al. (2012, ApJ, 759, 98)
Luminosity profile fitting

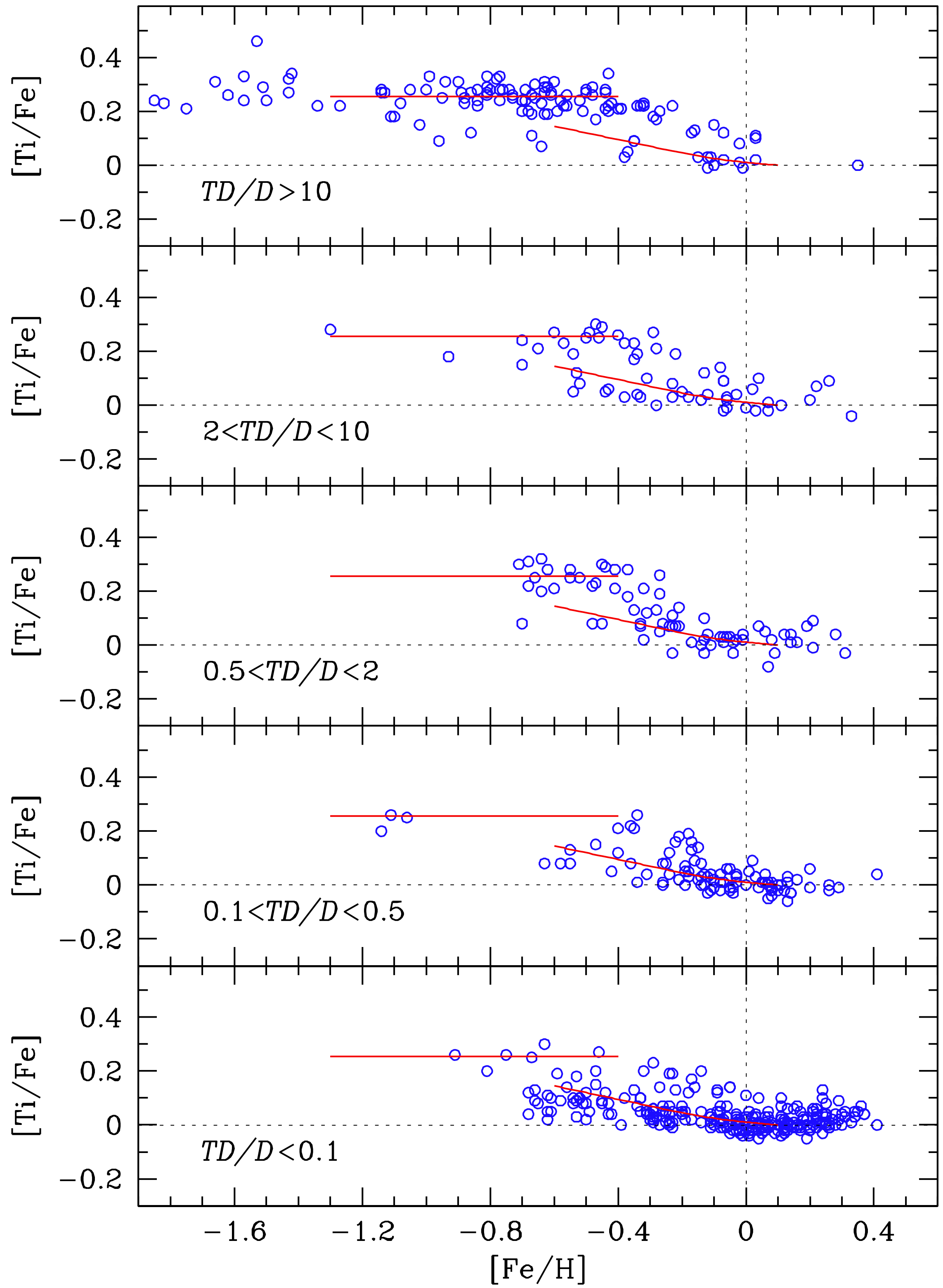
Thick disk scale-length



Thin disk scale-length

Thick disk scale-lengths are longer than thin disk scale-lengths!

Kinematics



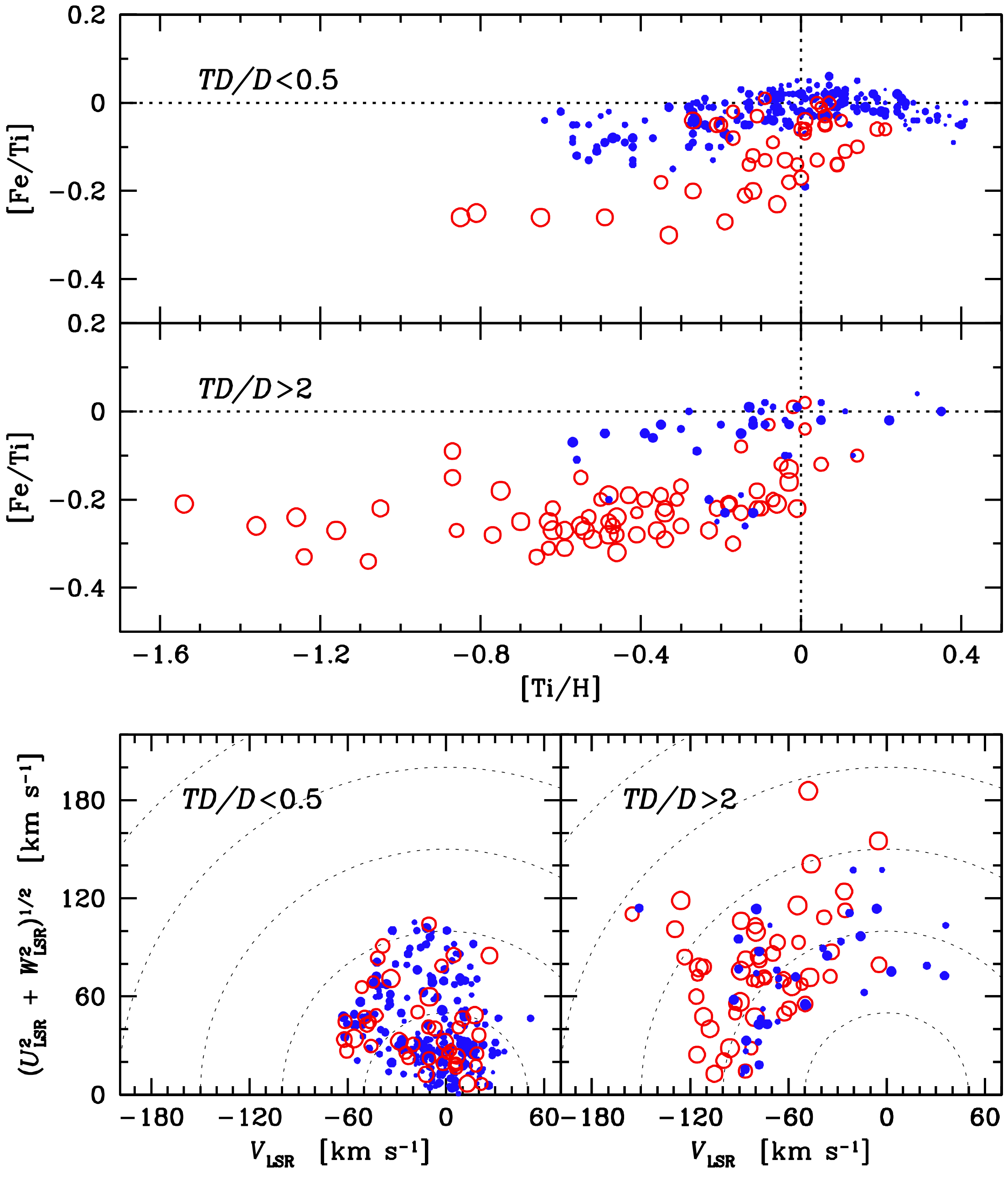
714 nearby dwarfs from Bensby et al, (2014)

Kinematics:

Using Gaussian velocity ellipsoids to calculate probabilities that the stars belong to either the thin or the thick disks

TD/D = 1, equal probabilities
TD/D>1, more likely to be thick disk
TD/D<1, more likely to be thin disk

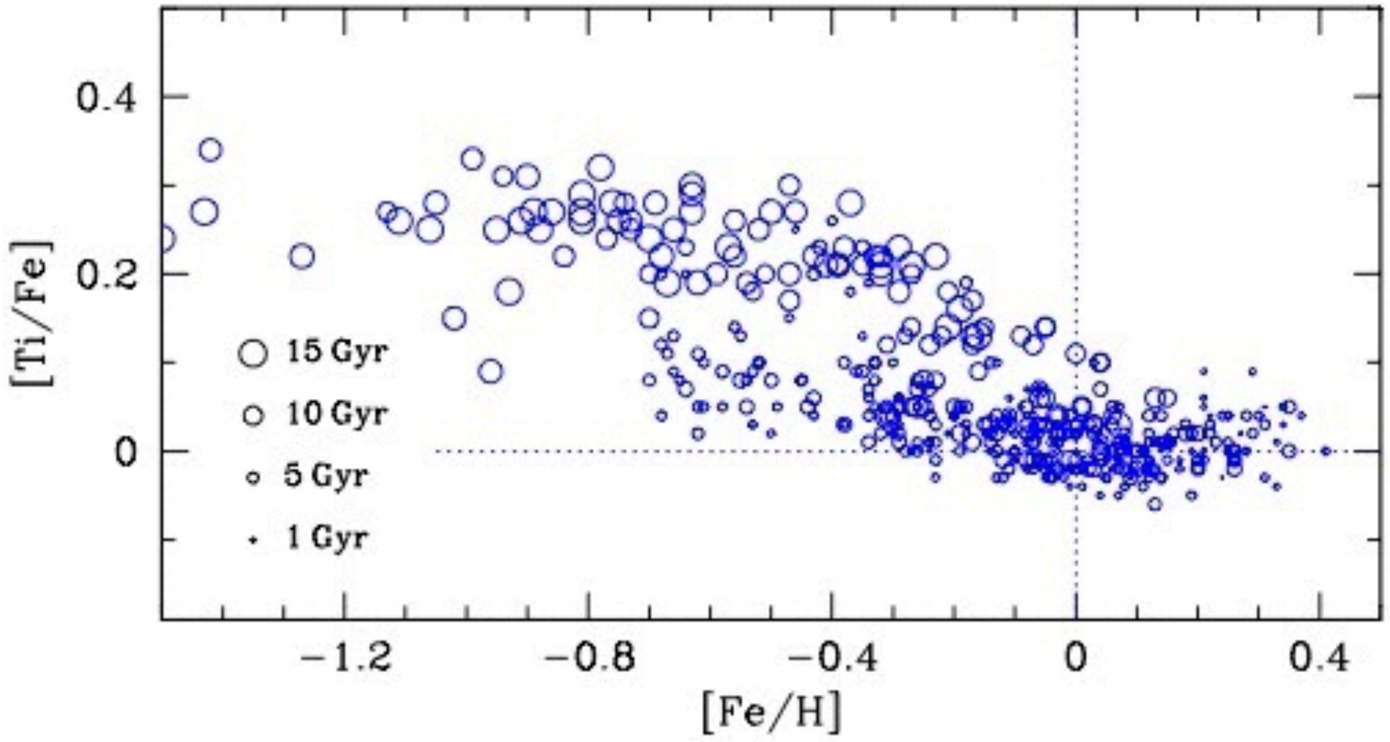
Kinematic confusion



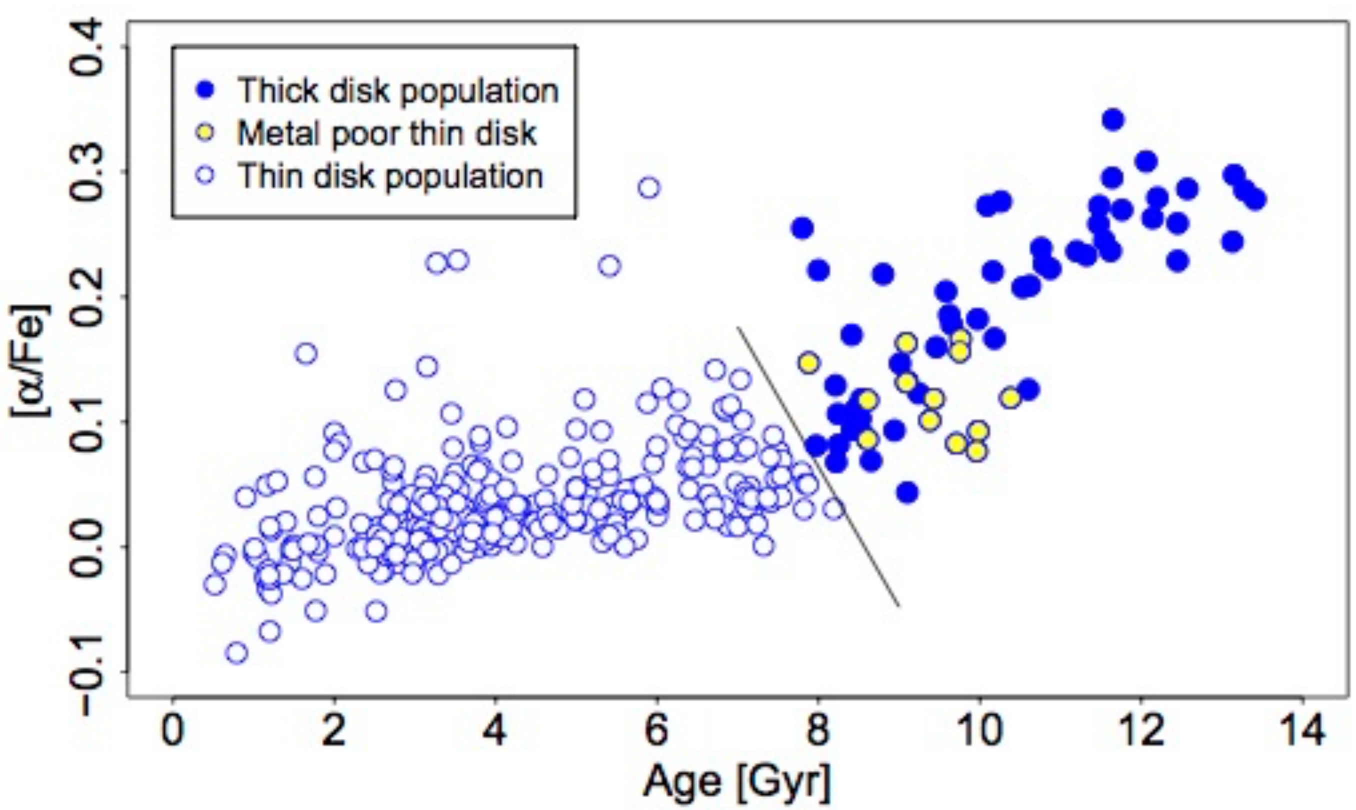
Two well-defined, but not perfectly clear trends

714 nearby dwarfs from Bensby et al, (2014)

Ages

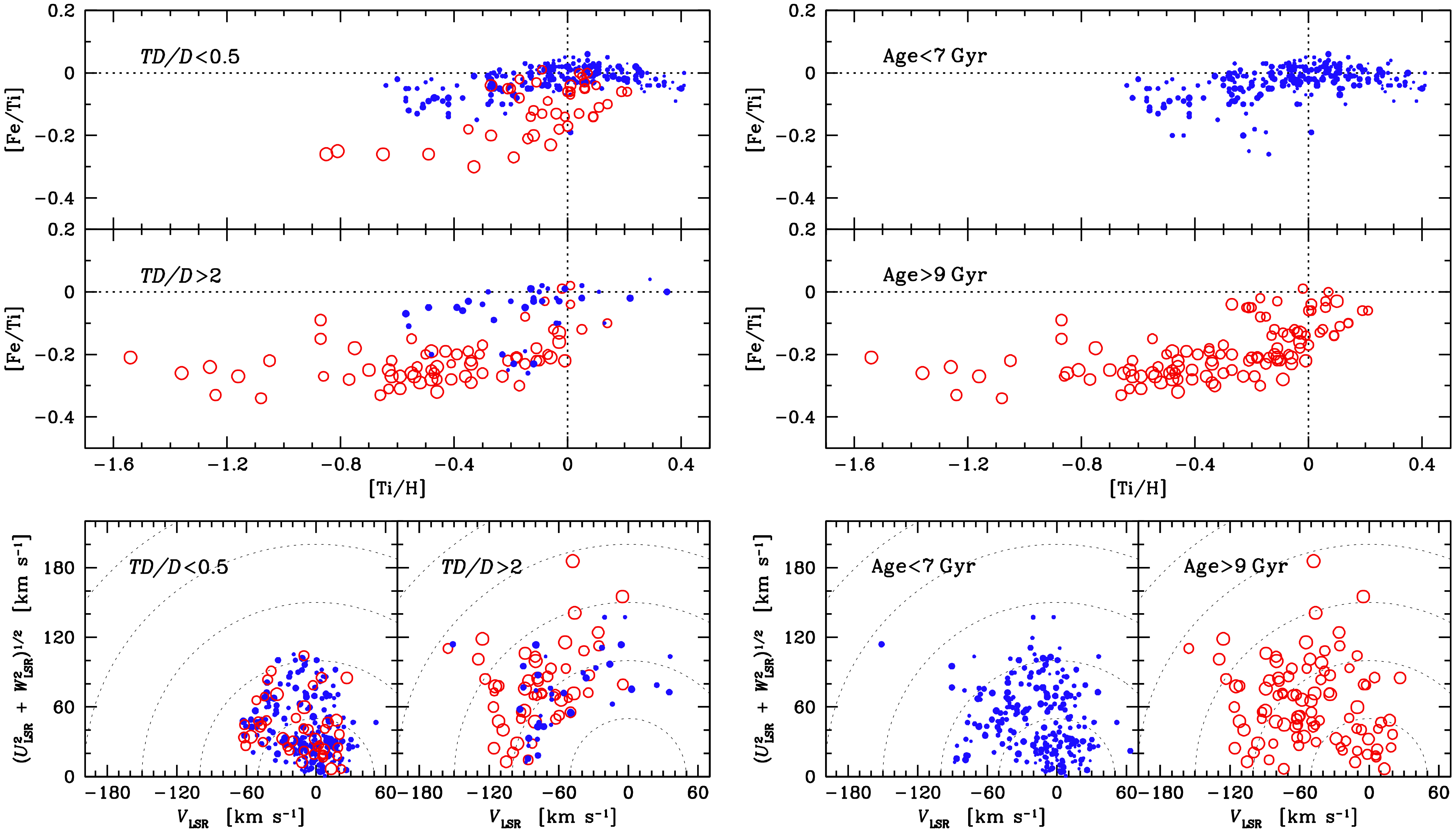


Bensby et al, (2014)



Haywood et al, (2011)

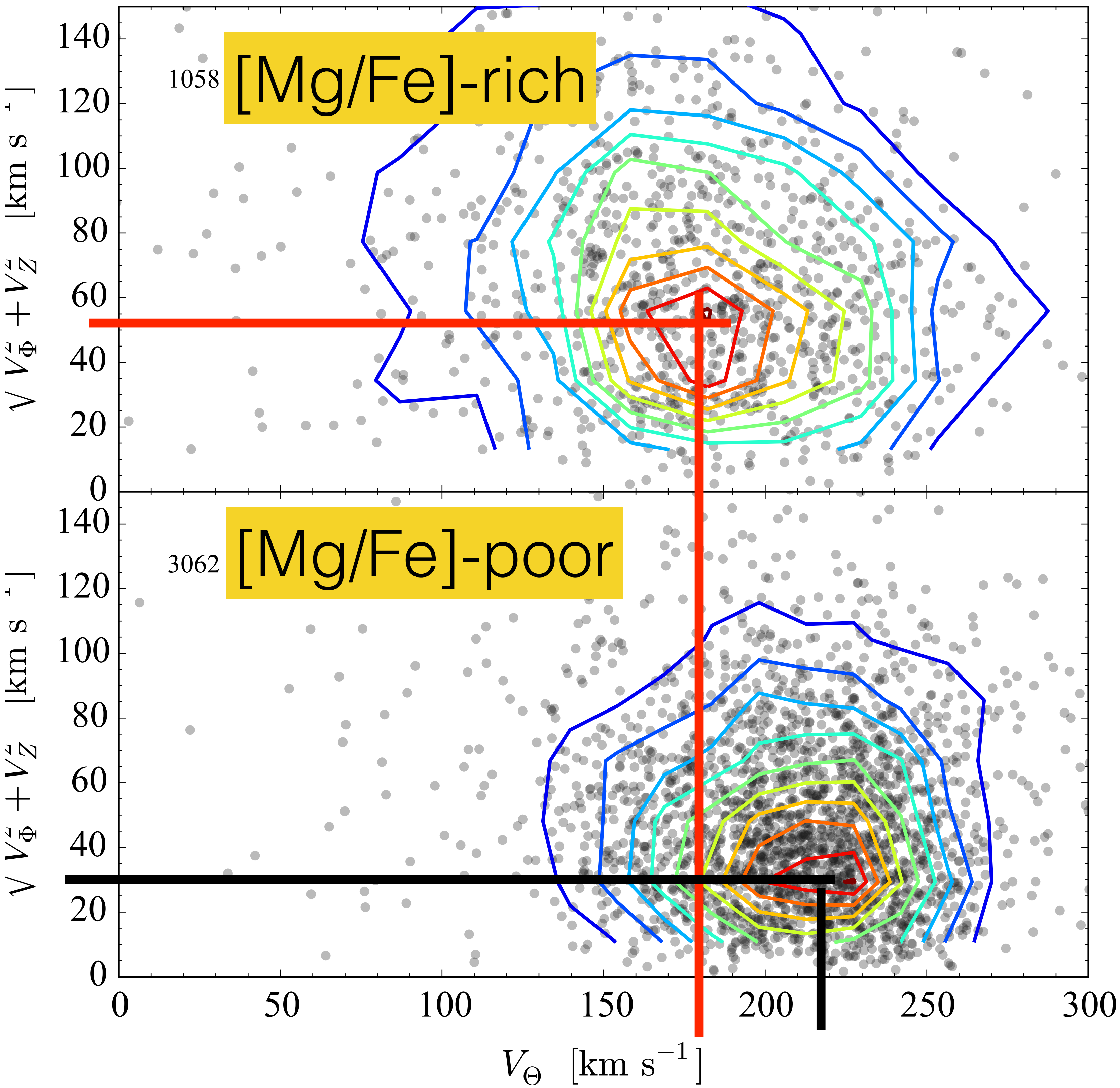
Kinematic confusion



Ages seem to better discriminator between thin and thick disk, but ages are rarely available and very difficult to determine

714 nearby dwarfs from Bensby et al, (2014)

Chemistry - GESiDr4, solar cylinder R=1 kpc

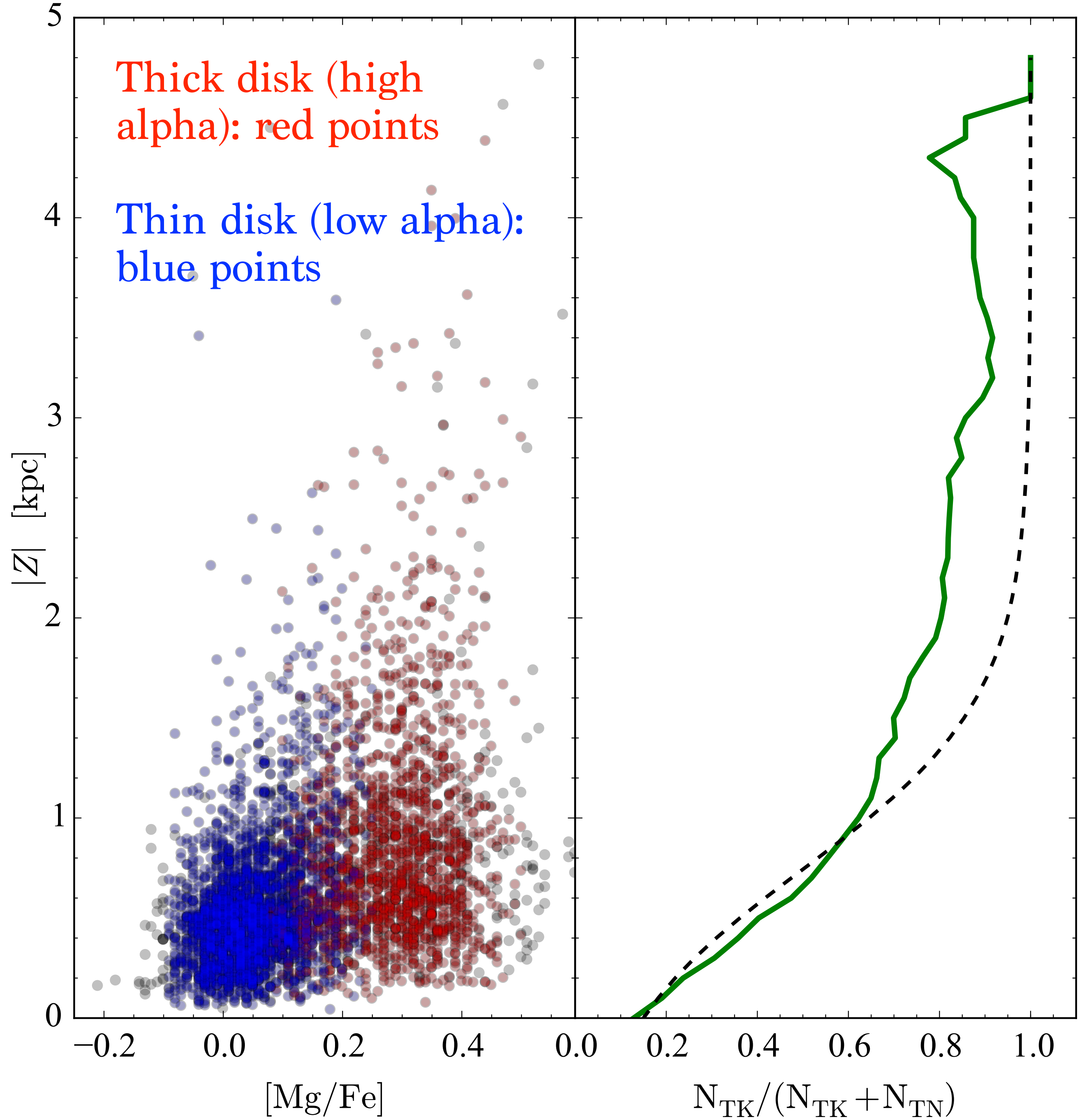


Toomre diagram:

Abundance criterion produces kinematical samples that are consistent with what we currently know about the thin and thick disks in the solar neighbourhood:

- alpha-rich disk lagging the alpha-poor disk by some ~40 km/s
- alpha-rich being kinematically hotter

Chemistry - GESiDr4, solar cylinder R=1 kpc



Dashed line:
Fraction of thick-to-thin disk stars using a 10% normalisation in the plane, and 300 pc and 1000 pc scale-heights for the thin and thick disks, respectively.

Green line:
The observed fraction of thick-to-thin disk stars, using alpha-enhancement as selection criterion

Summary

- Milky Way appears to have two distinct disk populations
- The thick disk has a short scale-length
- Galactic scale-length estimates based on chemistry (alpha-enhancement)
- Scale-lengths in external galaxies based on morphology, giving longer thick disk scale-lengths
- Gaia, in combination with results from the large spectroscopic surveys, will allow us to explore the thin and thick disks in terms of ages - kinematics - chemistry, throughout the Milky Way