Abundance distribution in the Galactic thick disk

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Discovery of thick disks

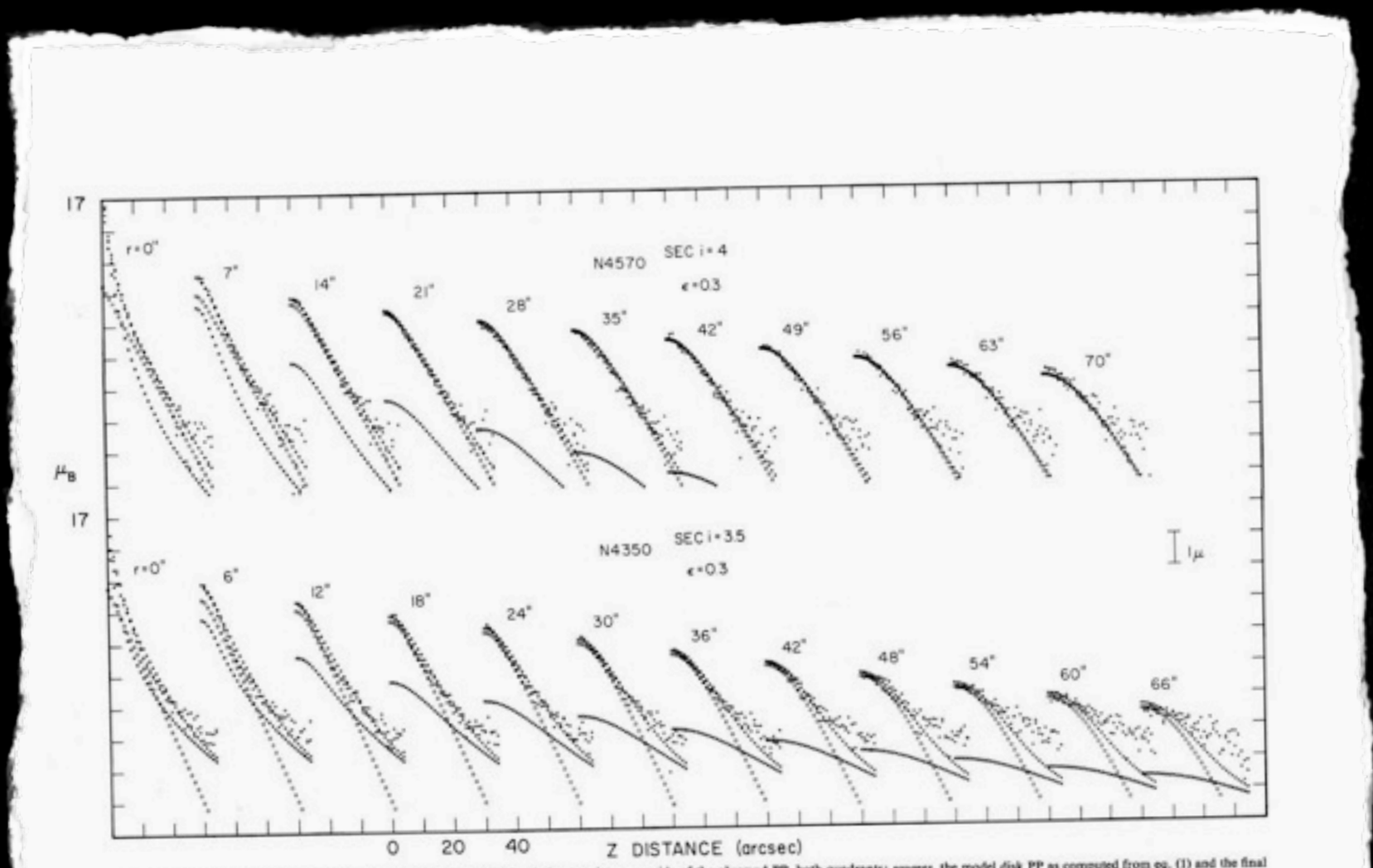
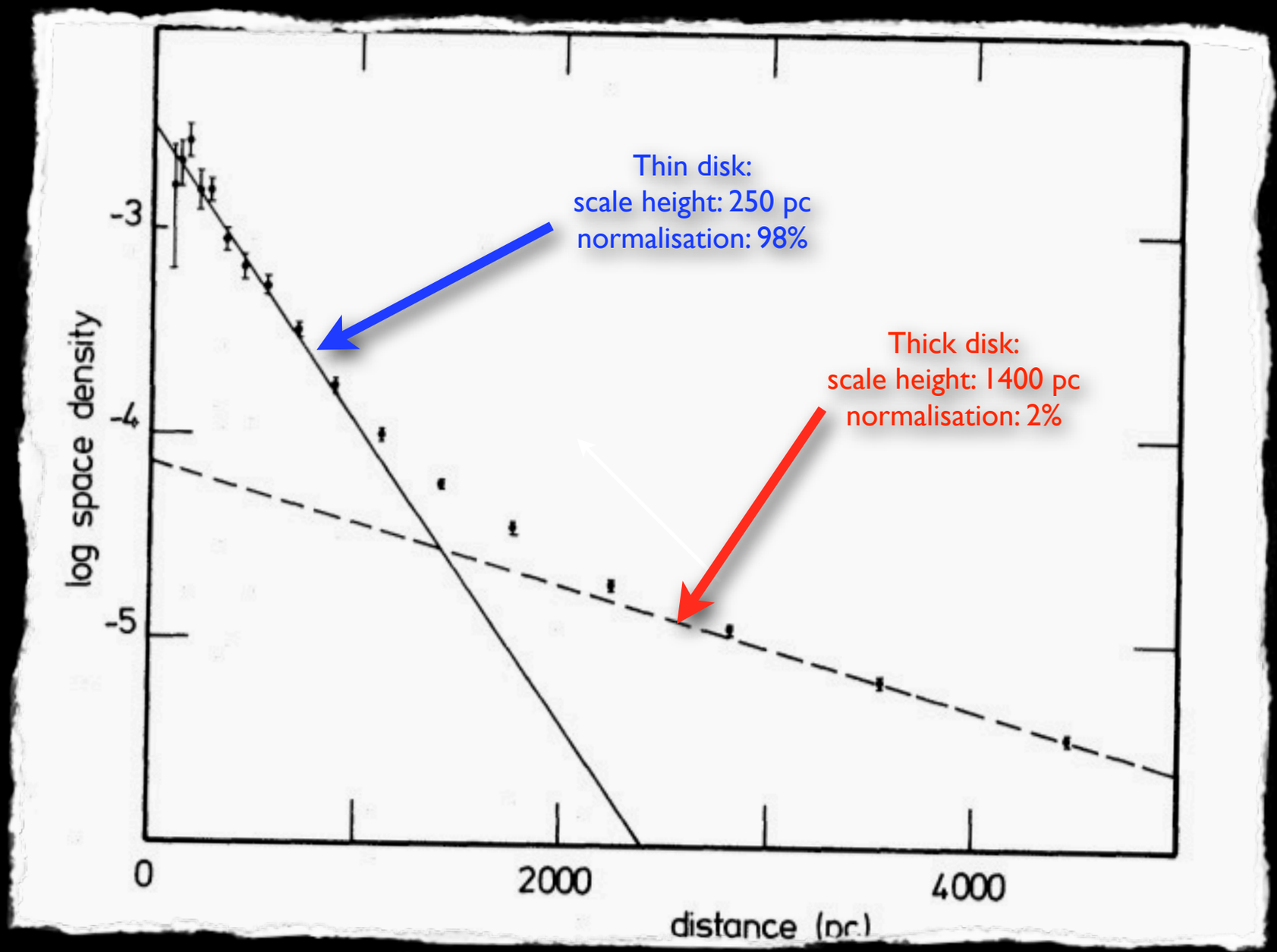


FIG. 3.—Model fits to the PP of Fig. 1*b* of NGC 4570 and 4350. Symbols are: *plusses*, one side of the observed PP, both quadrants; *squares*, the model disk PP as computed from eq. (1) and the final disk parameters in Table 1; *crosses*, the model bulge PP; *diamonds*, the model galaxy, disk plus bulge, PP. The inclination of NGC 4350 has sec $i = 3.5$ and the bulge is given as $\epsilon = 0.3$; NGC 4570 has sec $i = 4.0$ and $\epsilon = 0.3$.

(Burstein 1979, ApJ, 234, 829)

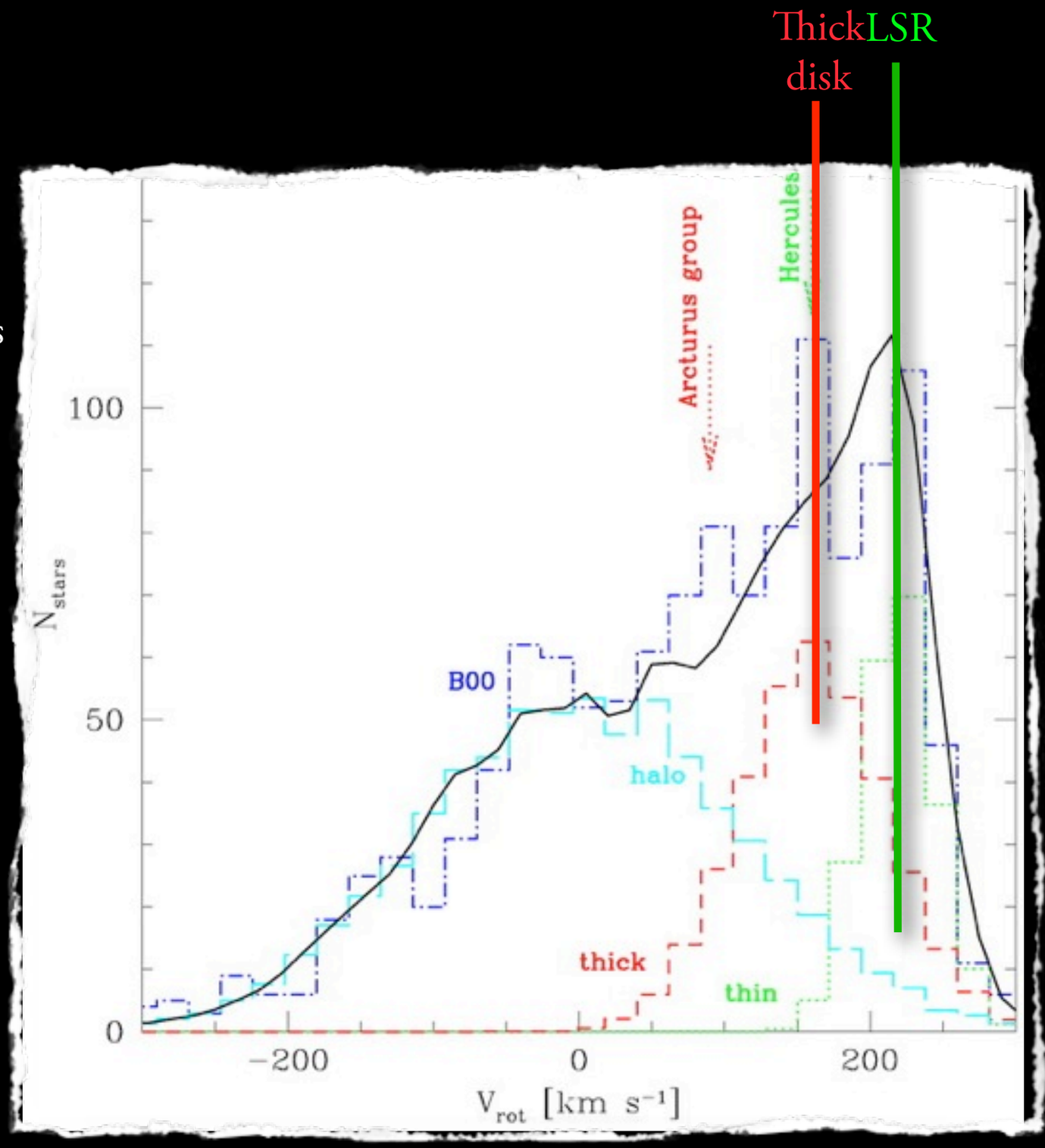
Discovery of the Galactic thick disk



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

The Galactic thick disk - rotation

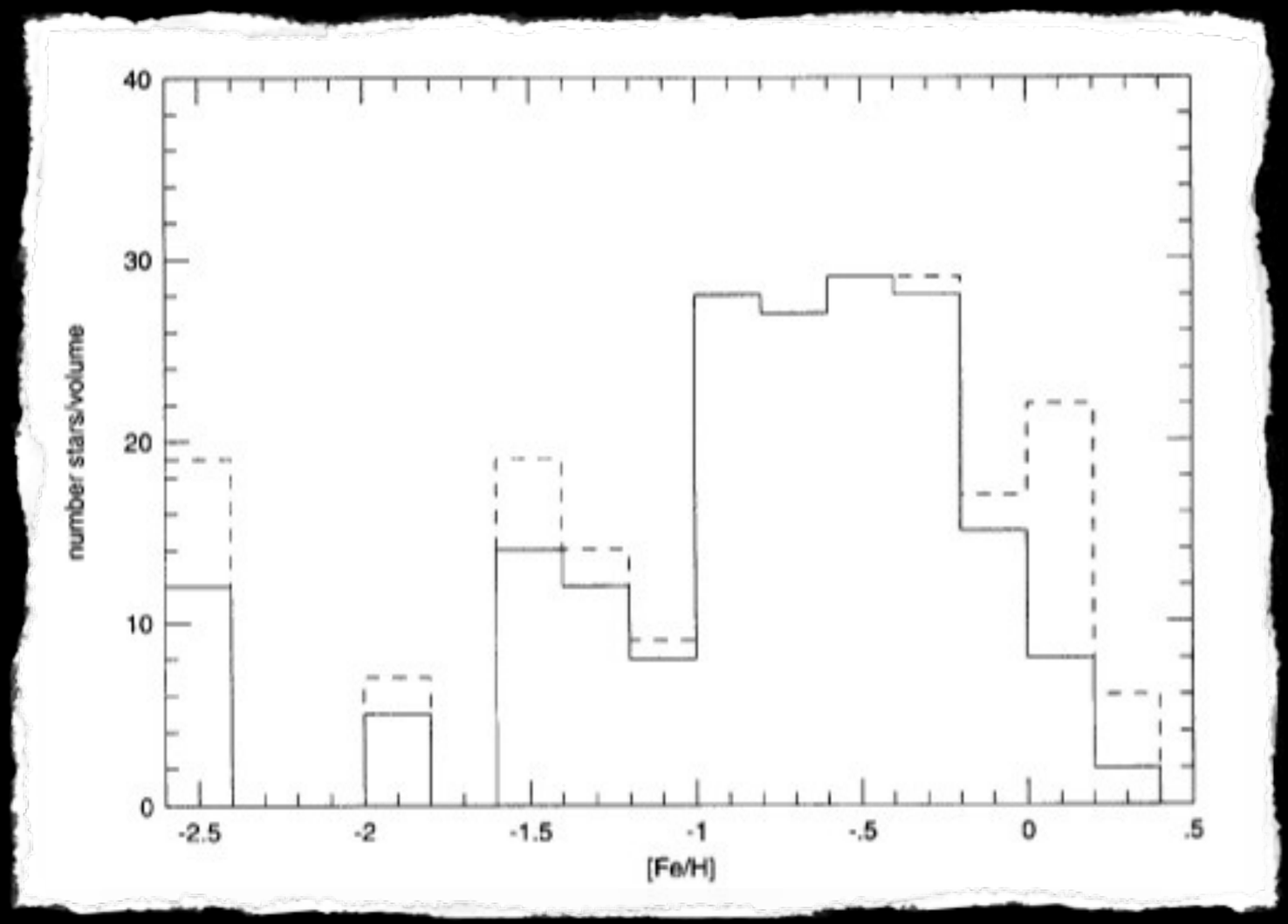
- Rotational lag and velocity dispersion
  - lags the LSR by ~40-50 km/s
  - higher velocity dispersions



(Navarro et al., 2004, ApJ, 641, L43)

The Galactic thick disk - metallicity

- Average metallicity: [Fe/H]=-0.6
- Intermediate to the thin disk and the halo



(Gilmore, Wyse & Jones, 1995, ApJ, 109,1095)

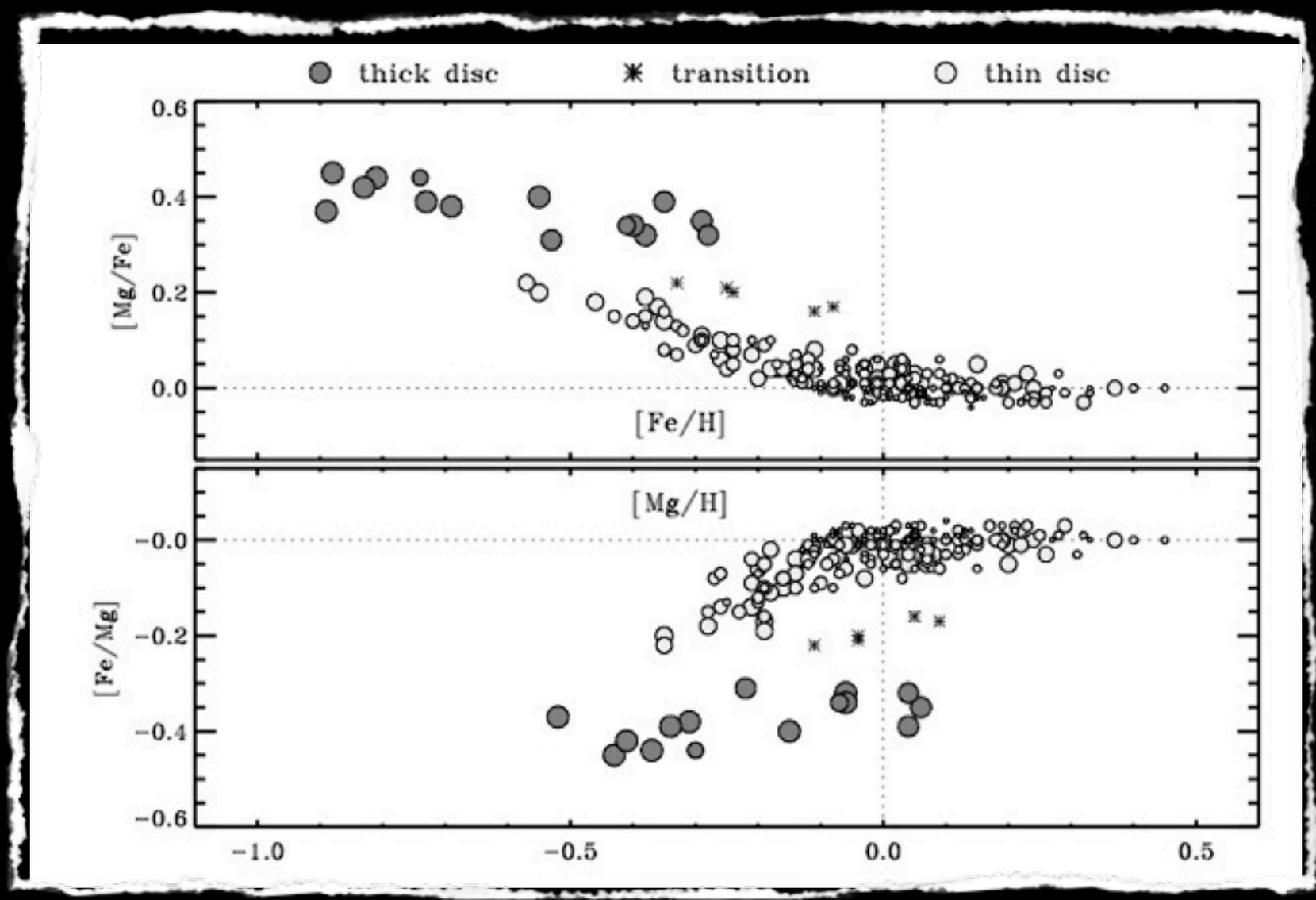
The Galactic thick disk - age and abundances

- 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=-15°, within a radius d<25pc from the Sun

  - Two types of stars:

    - Old stars with high [Mg/Fe] ratios

    - Young stars with low [Mg/Fe] ratios

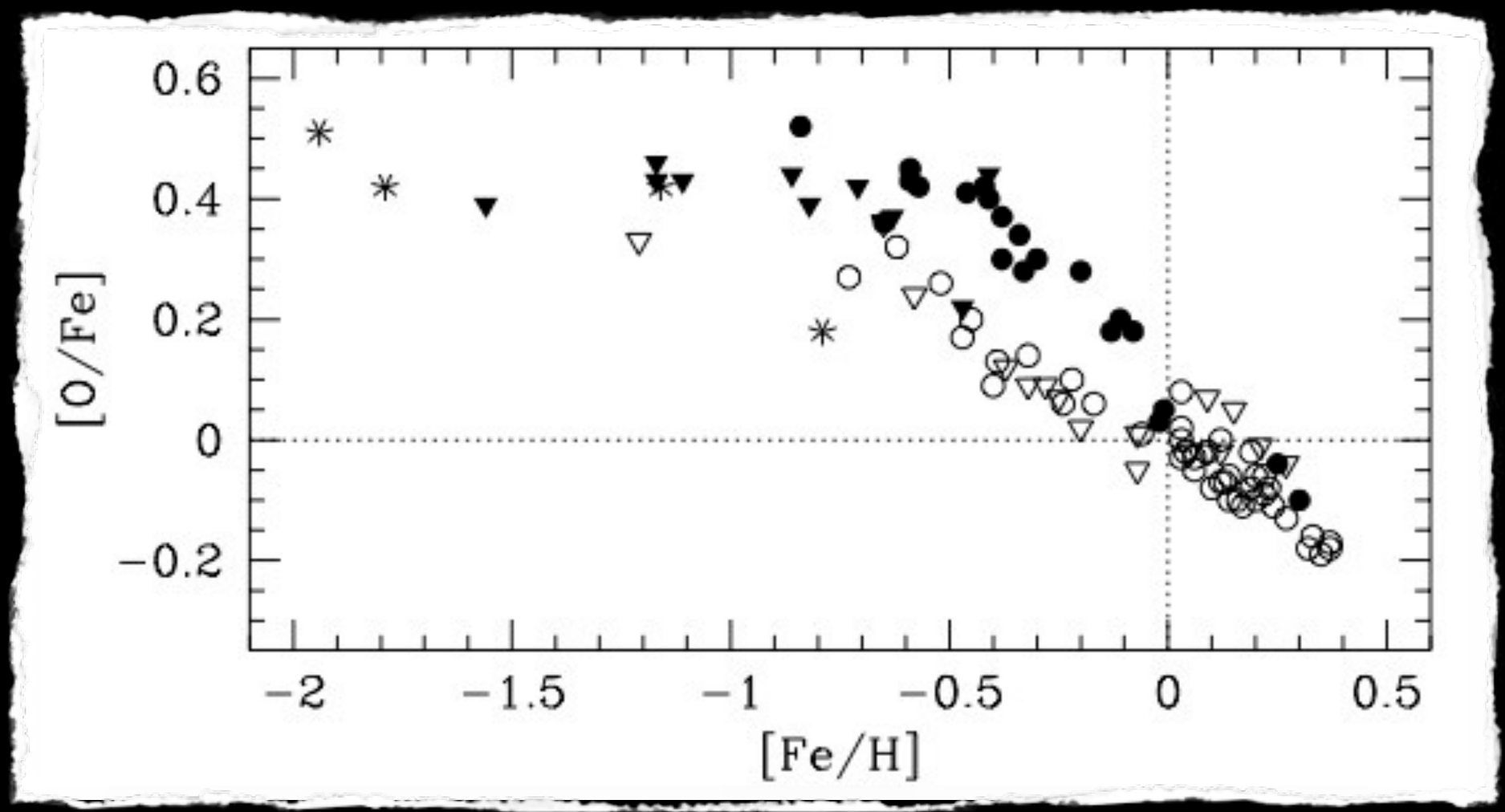


(Fuhrmann, 2008, MNRAS, 384, 173)

Sizes of circles scale with the ages of the stars

Kinematically selected samples

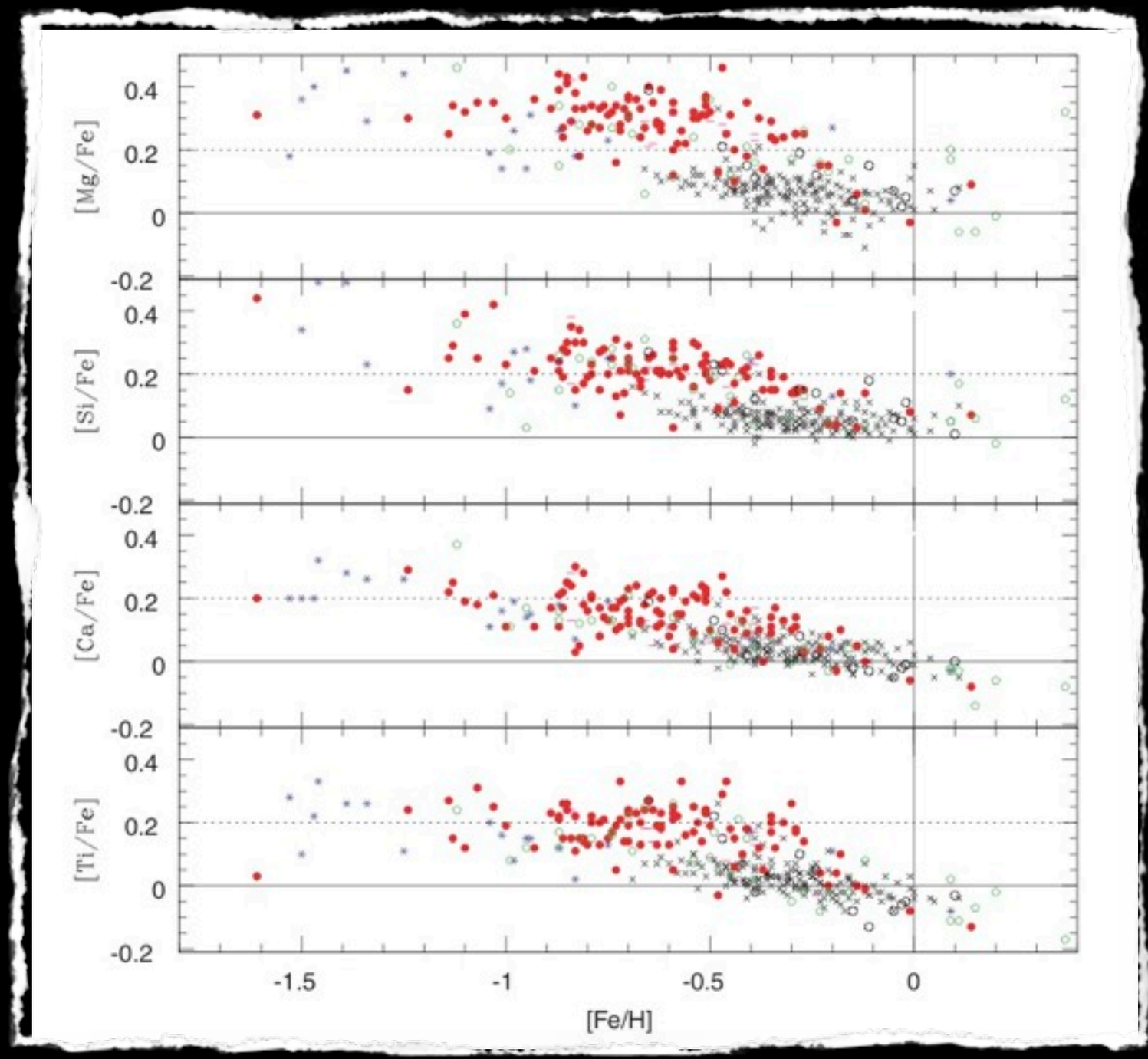
- Bensby et al. (2003, 2004, 2005)



(Bensby et al., 2004, A&A, 415, 155)

Kinematically selected samples

- Bensby et al. (2003, 2004, 2005)
- Reddy et al. (2003, 2006)



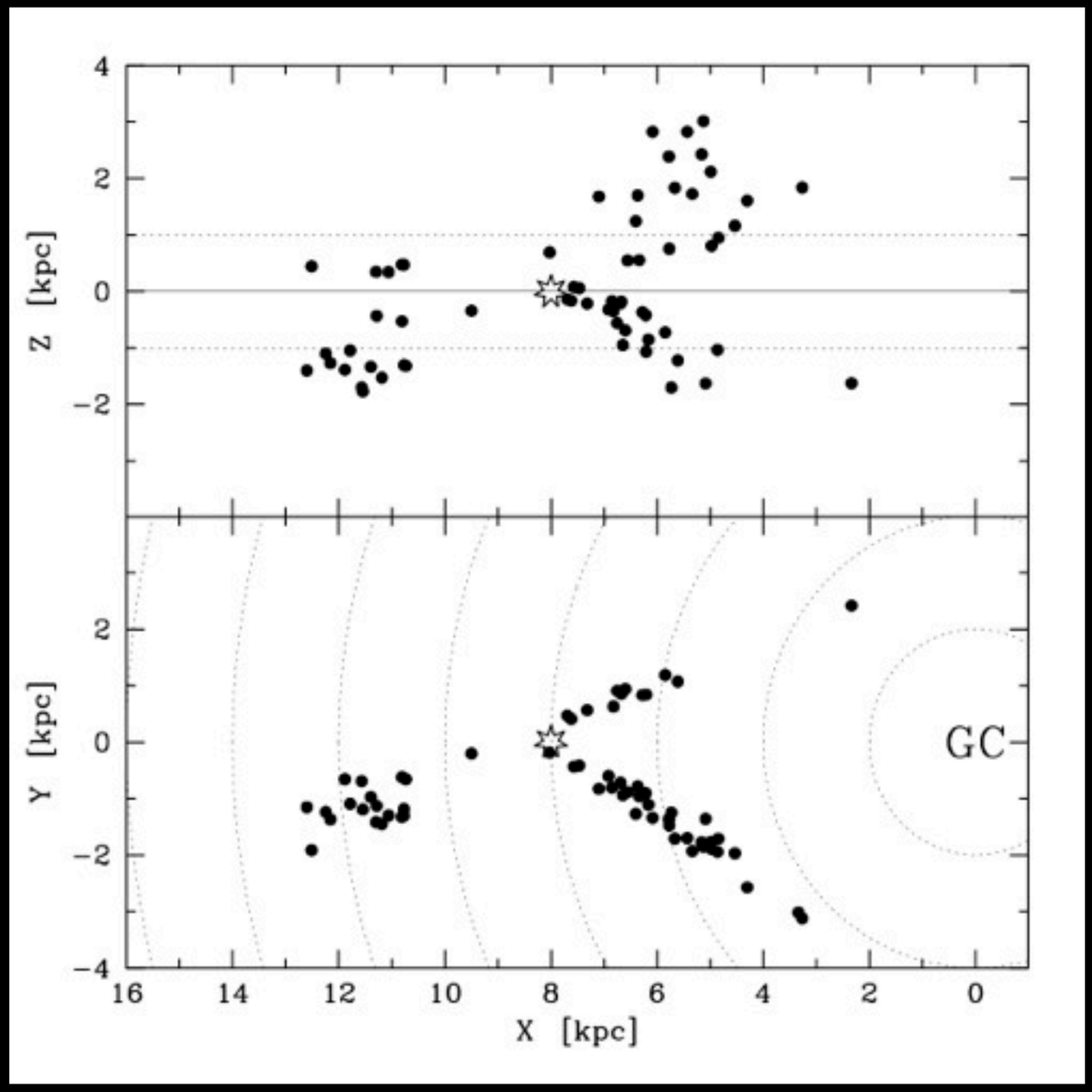
(Reddy et al., 2006, MNRAS, 367, 1629)

Properties of the (nearby) thick disk

Many more studies....., most agree that the thick disk is:

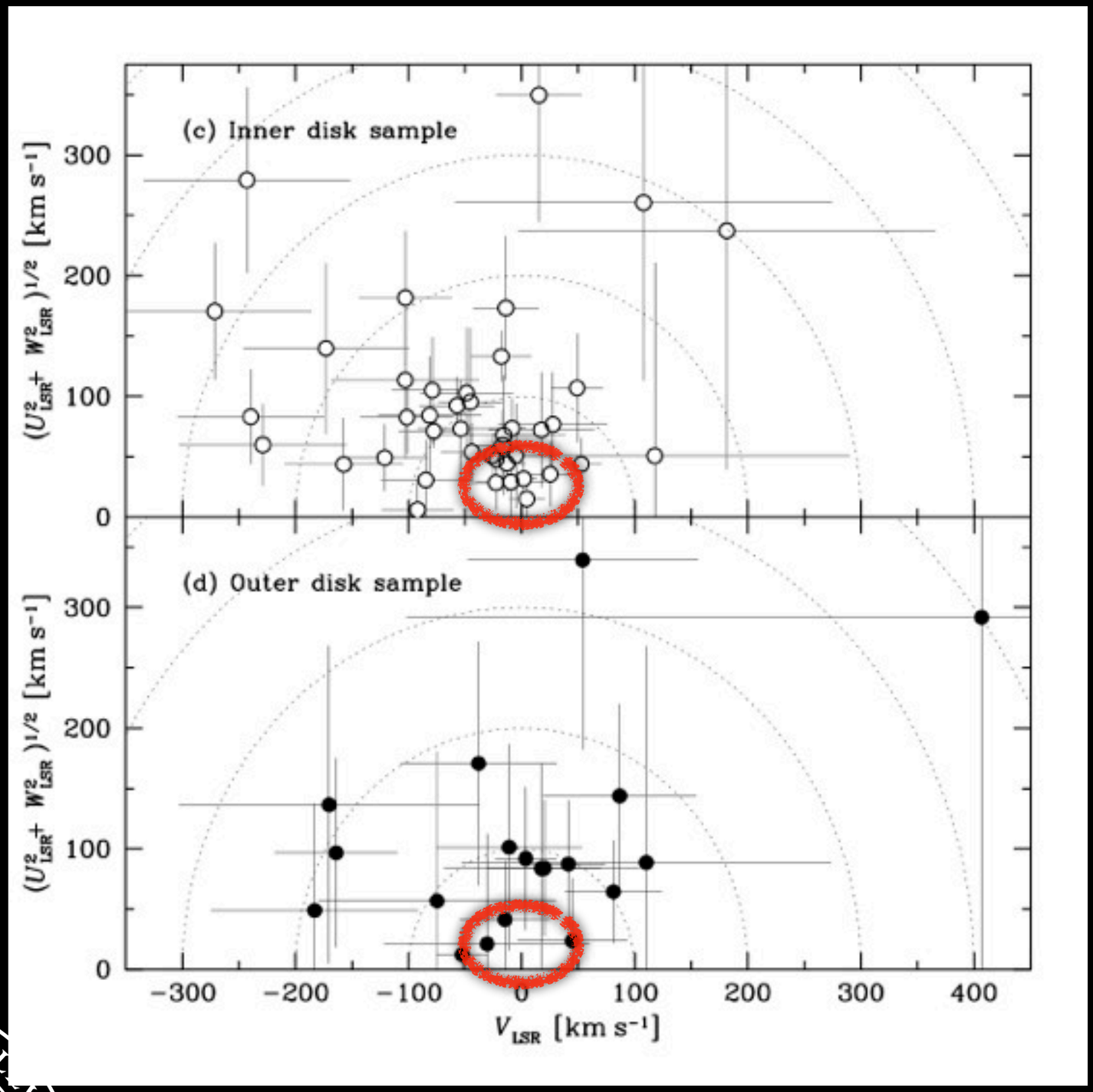
- kinematically hot
- old, ages > 8-9 Gyr
- relatively metal-poor
- alpha-enhanced
- approximately 10% of the stars in the Solar neighbourhood are thick disk stars

Red giants in the inner and outer disk



- 44 inner disk K giants
- 20 outer disk K giants
- Observed with MIKE@Magellan
  - R~55000
  - S/N>100
- Analysed in the same way (and by the same person!) as the disk and bulge giants in Alves-Brito et al. (2010)
- Truly diferential analysis between the bulge, the inner disk, the thin and thick disk in the SN, and the outer disk

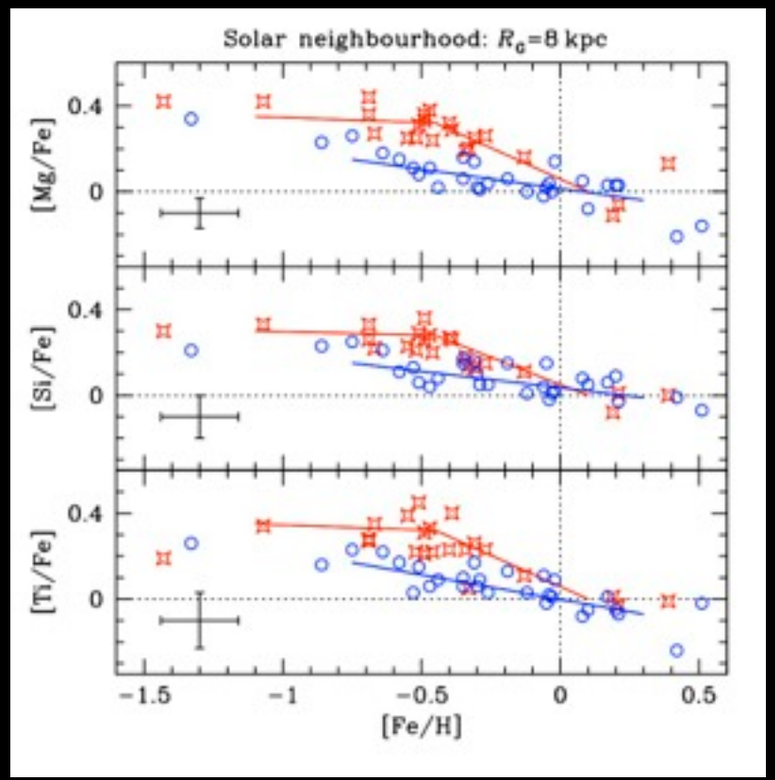
Kinematic properties



The red circles show typical values for the thin disk stars in the Solar neighbourhood

Both the inner and outer disk samples contain stars with cold and hot kinematics. If things are similar to what is seen in the solar neighbourhood we should have picked both thin and thick disk stars in the inner and the outer disk samples.

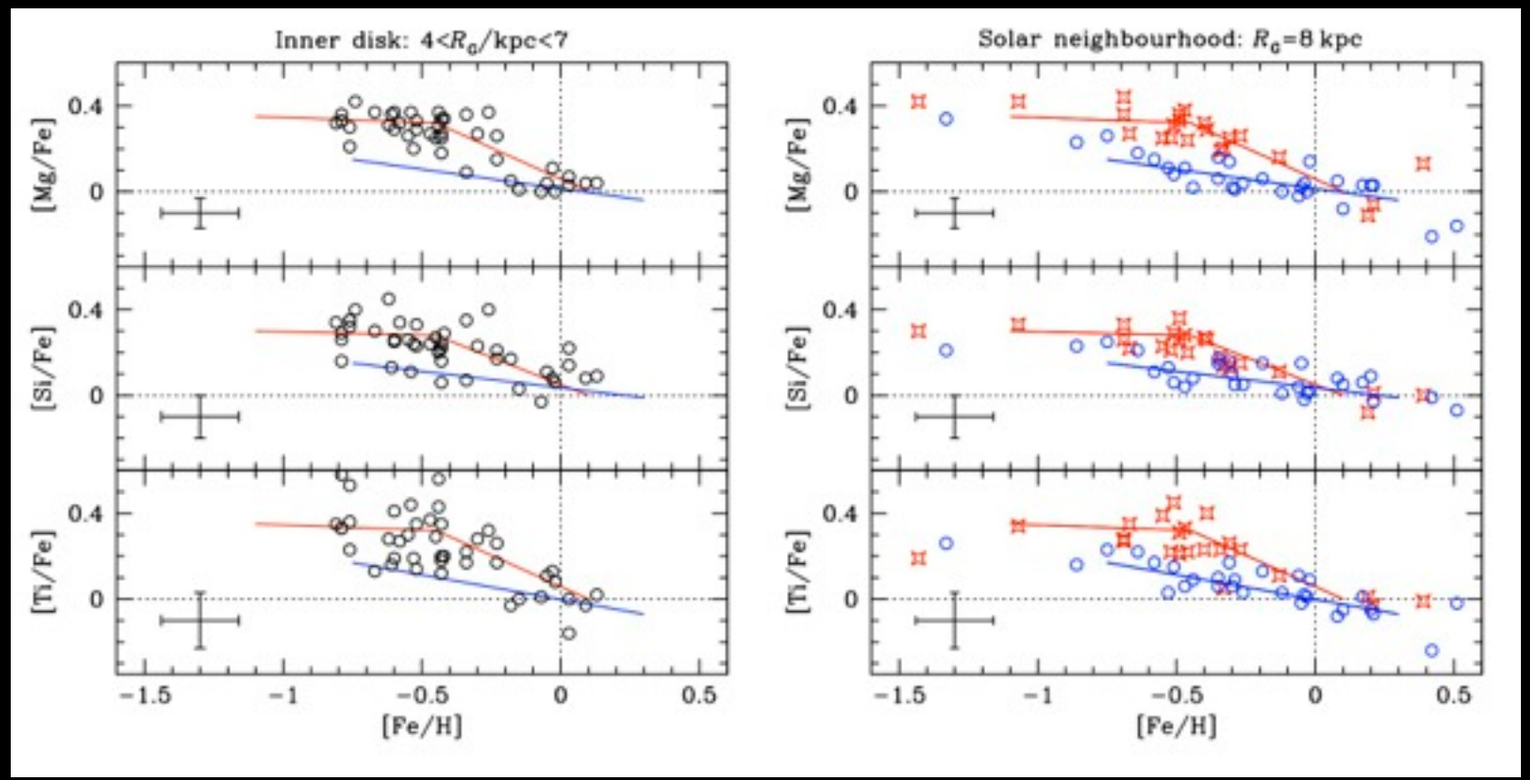
Abundances



Thin and thick disk red giants in the solar neighbourhood

Alves-Brito et al. (2010)

Abundances



Inner disk red giants

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

Thin and thick disk red giants in the solar neighbourhood

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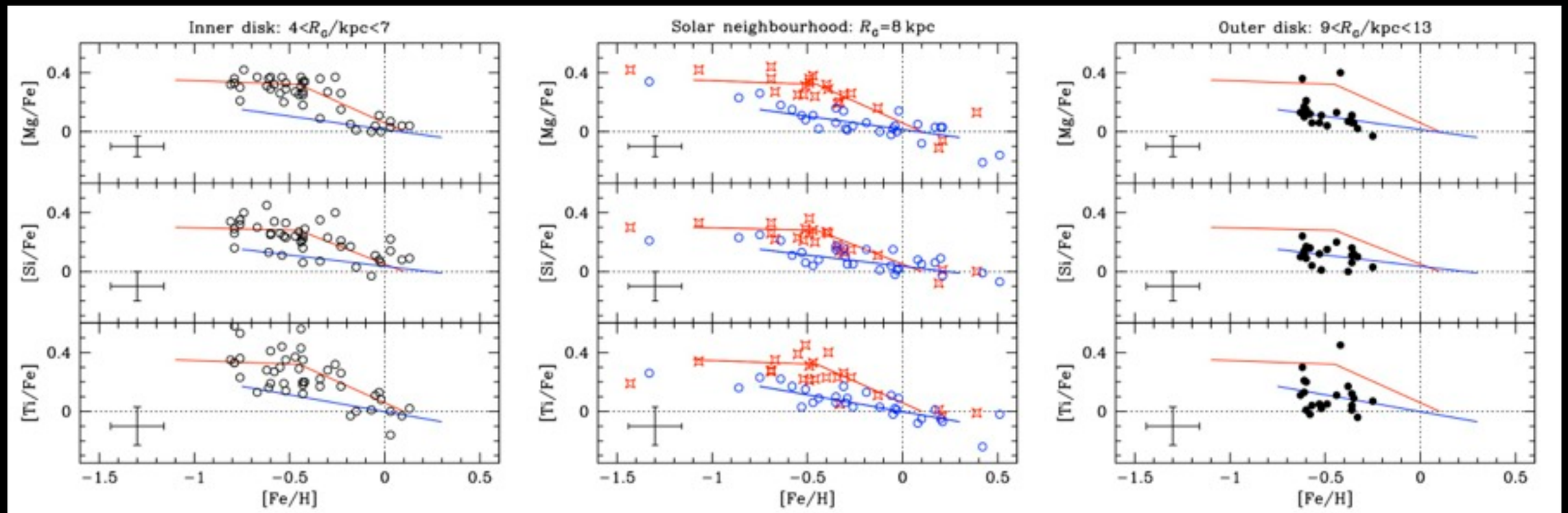
Abundances



Inner disk red giants

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

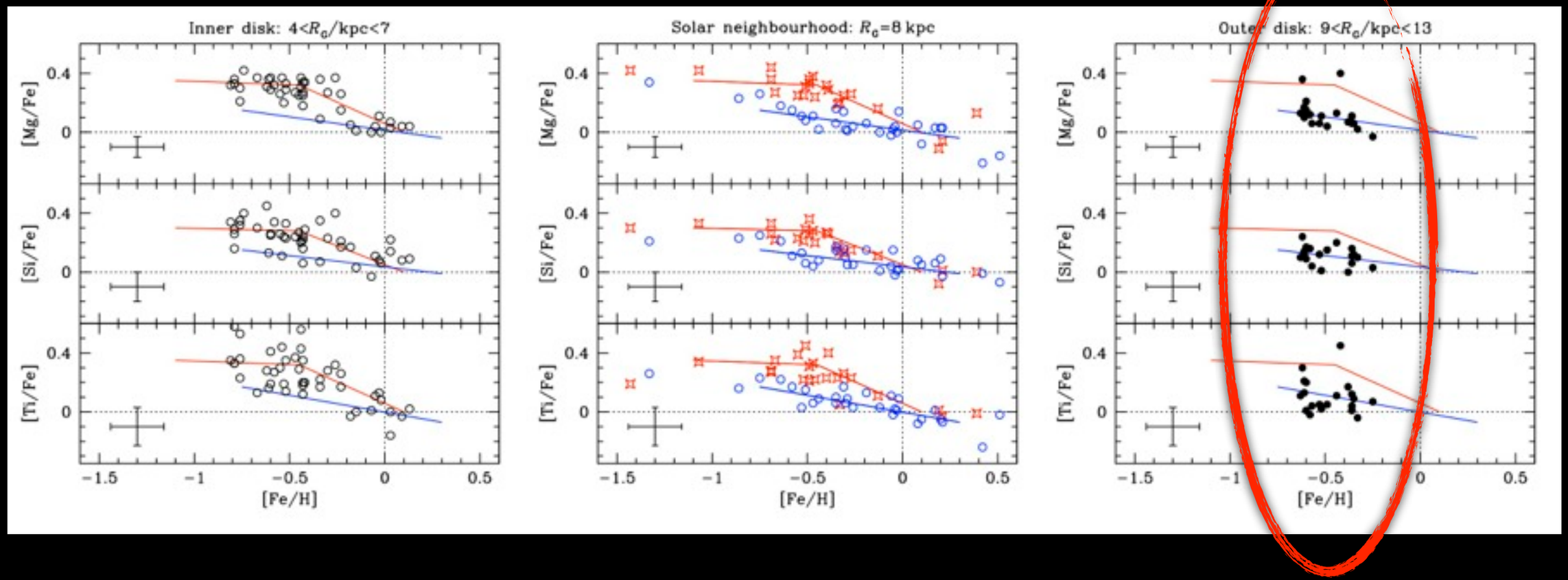
Thin and thick disk red giants in the solar neighbourhood

Alves-Brito et al. (2010)

Outer disk red giants

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

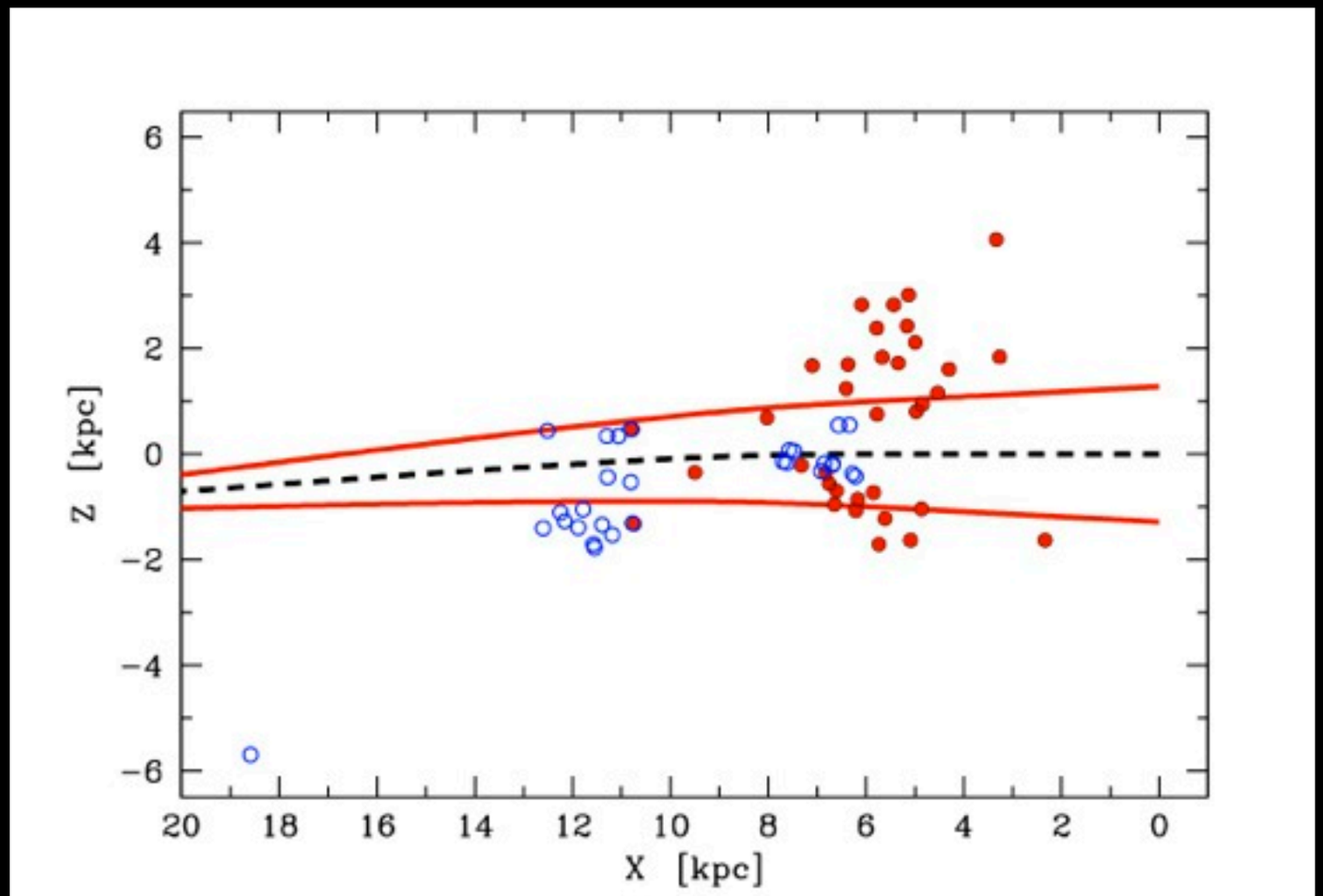
Abundances



Where is the α-enhanced outer thick disk?

(at majority of the stars are located at a distance from the galactic plane where the thick disk should be the dominating population)

Scale-lengths of the thin and thick disks



Red lines show the distance from the plane where the number densities of thin and thick disk stars are equal

L_{thick} = 3.6 kpc
L_{thin} = 2.6 kpc

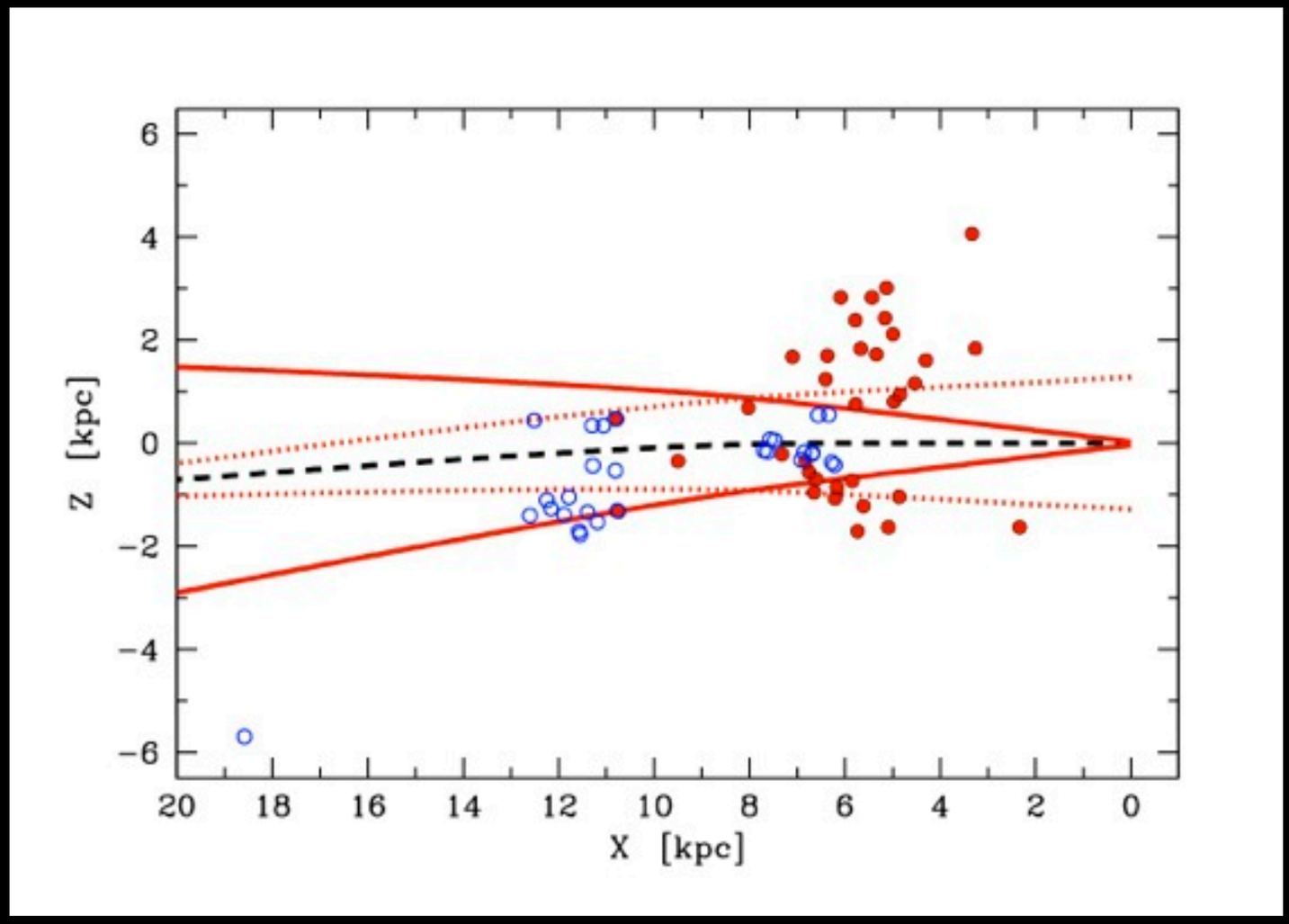
H_{thick} = 0.9 kpc
H_{thin} = 0.3 kpc

ρ_{thick} = 0.12
ρ_{thin} = 0.88

(Juric et al. 2008 SDSS data)

Red circles: alpha-enhanced stars
Blue circles: no alpha-enhancements

A short thick disk scale-length



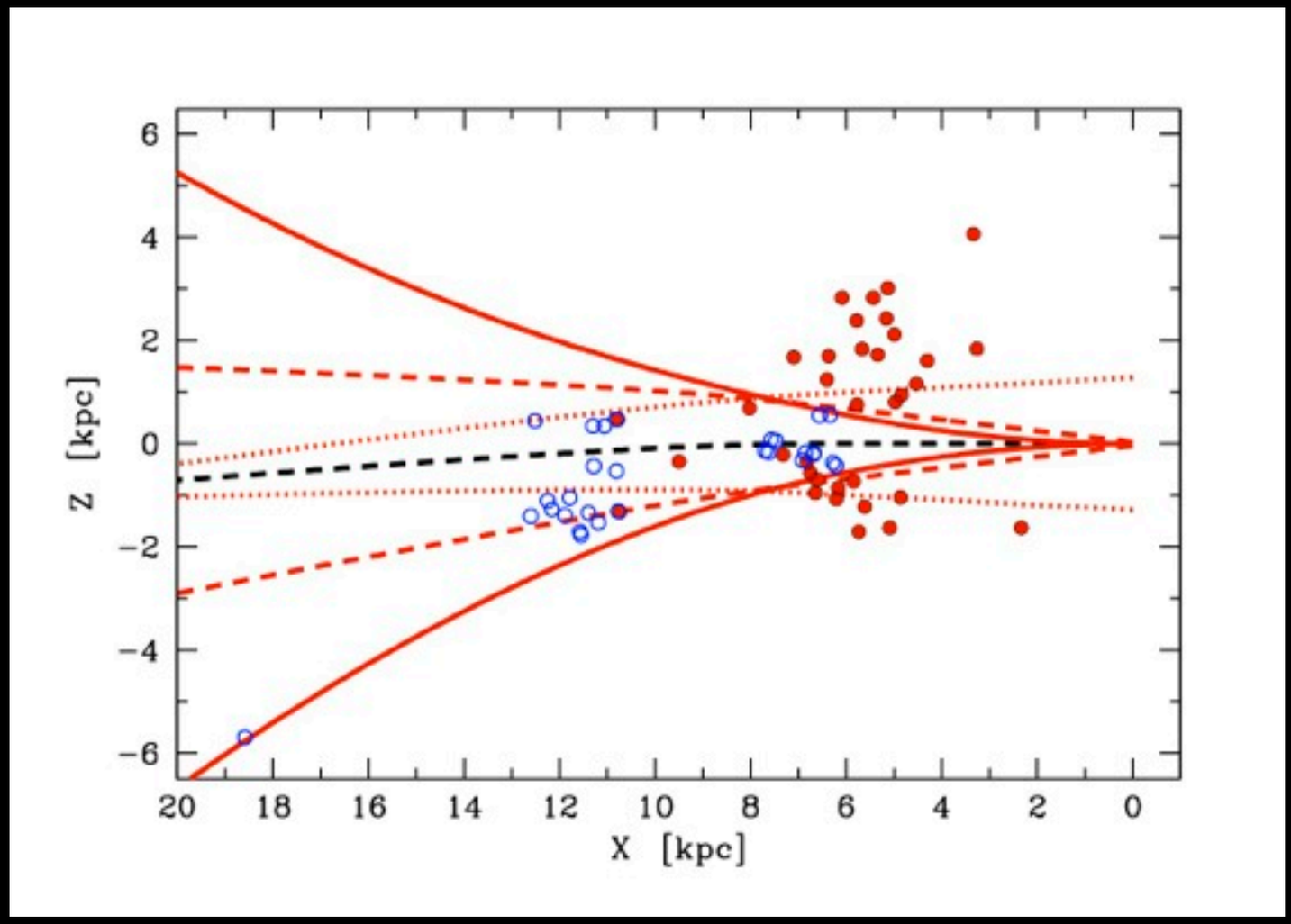
Red lines show the distance from the plane where the number densities of thin and thick disk stars are equal

L_{thick} = 2.0 kpc
L_{thin} = 3.6 kpc

H_{thick} = 0.9 kpc
H_{thin} = 0.3 kpc

Red circles: alpha-enhanced stars
Blue circles: no alpha-enhancements

A short thick disk scale-length with varying scale-height



Red lines show the distance from the plane where the number densities of thin and thick disk stars are equal

L_{thick} = 2.0 kpc
L_{thin} = 3.6 kpc

Scale-heights
H_{thick}, and H_{thin}
vary linearly with R_G/L

Red circles: alpha-enhanced stars
Blue circles: no alpha-enhancements

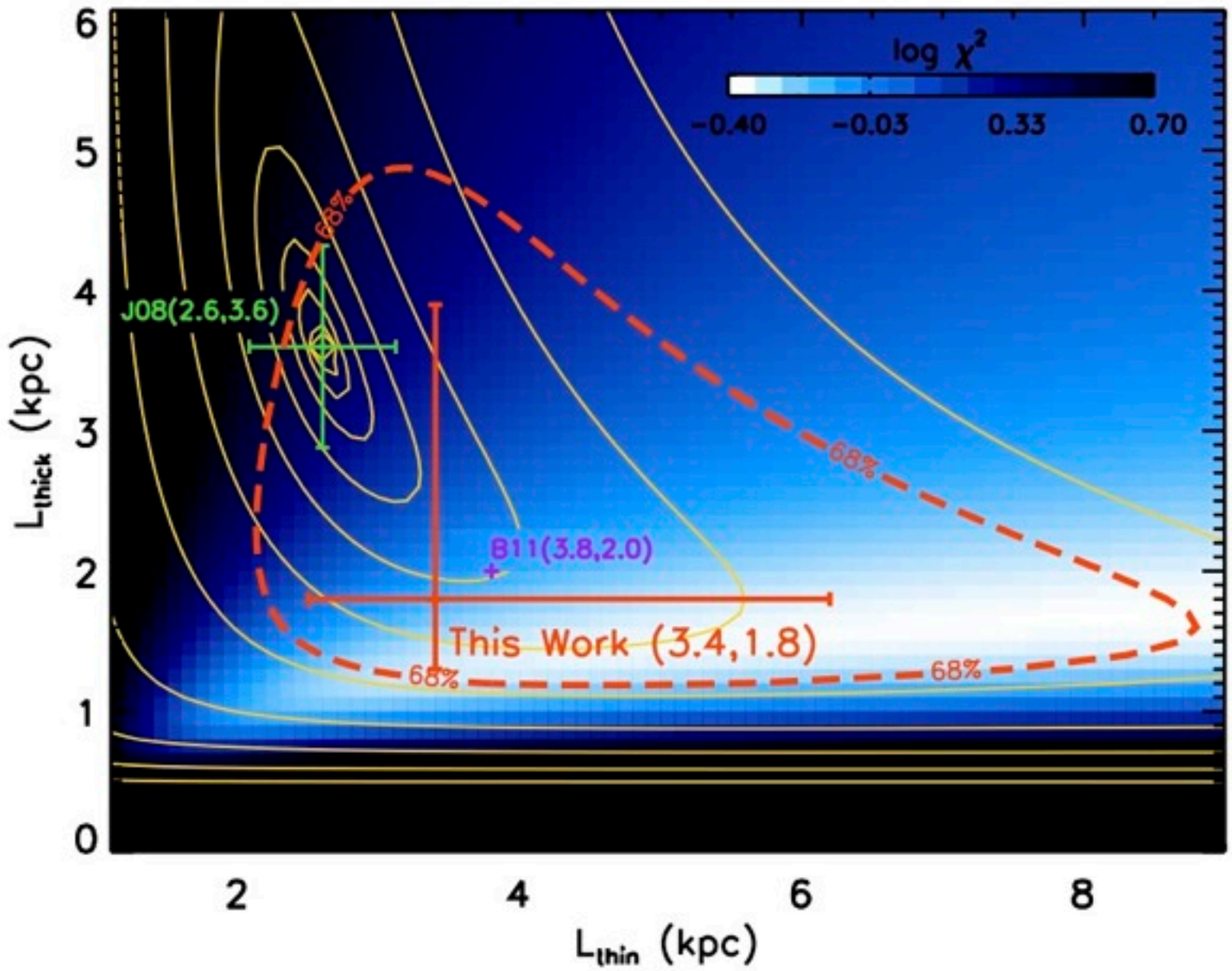
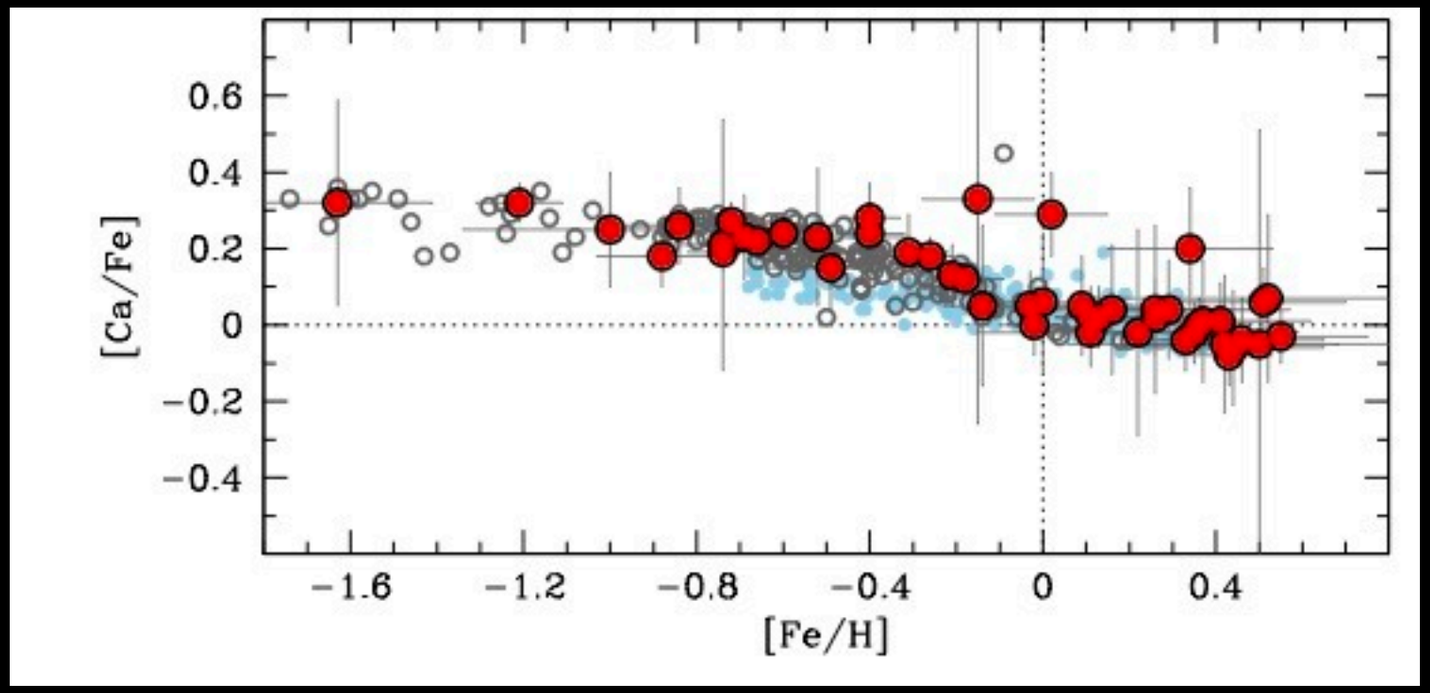
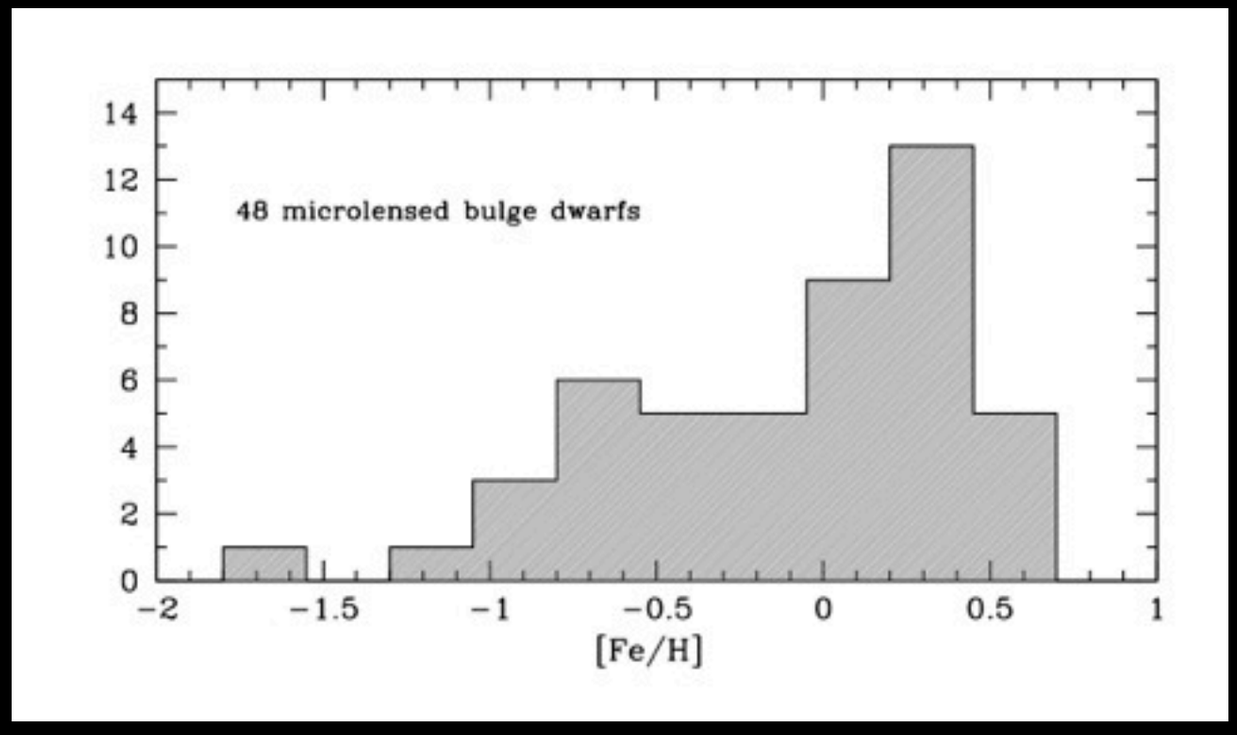


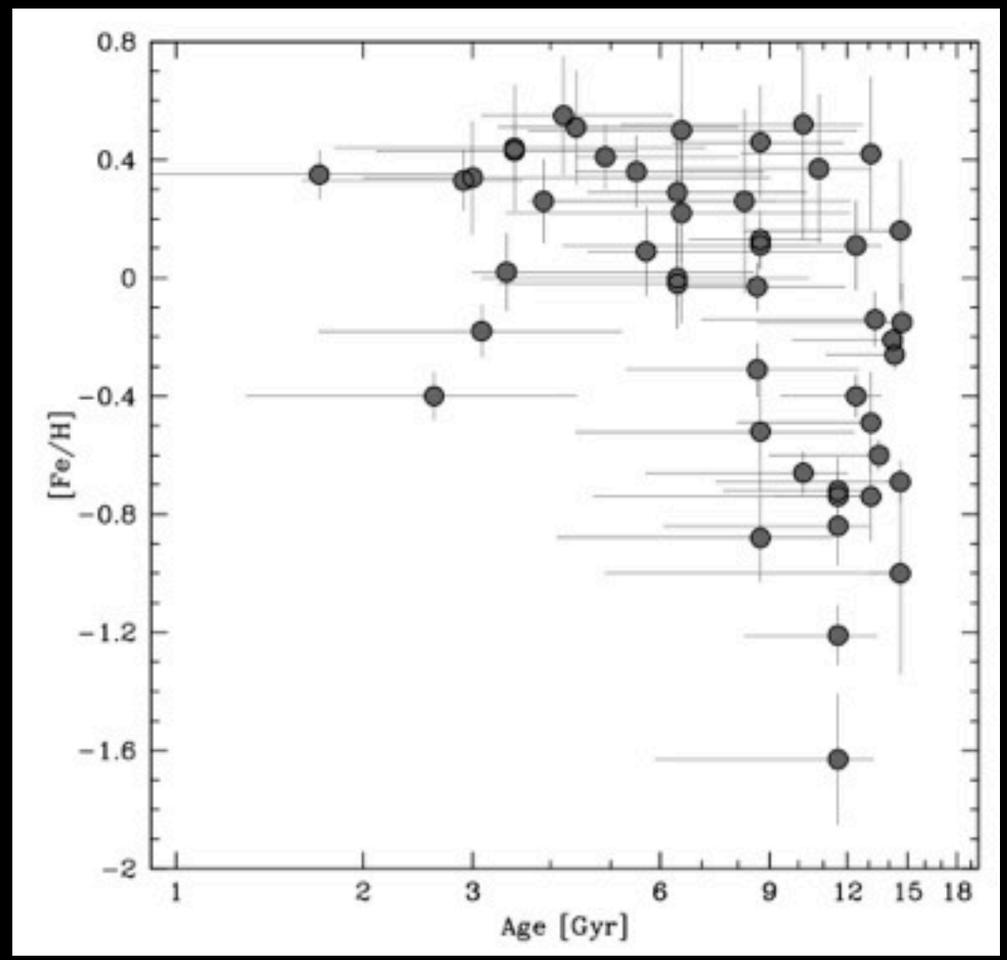
FIG. 6.— Best-fit thin and thick disk scale lengths. The blue shading shows the reduced χ^2 values using the fractions of high- and low-α stars as a function of R and $|Z|$ as a constraint. The thin yellow contours show the constraint of the total stellar density as determined by Jurić et al. (2008). Our best estimate of the thin and thick disk scale lengths using both constraints are $L_{\rm thin} = 3.4^{+2.8}_{-0.9}$ kpc and $L_{\rm thick} = 1.8^{+2.1}_{-0.5}$ kpc, marked by the large orange cross. The 68% contour for the combined constraint is shown as the thick dashed orange line. The published values of Jurić et al. (2008) and Bensby et al. (2011) are indicated in green and purple, respectively.

Cheng et al., 2012, ApJ, in press (arXiv:1204.5179)
5620 stars from SEGUE

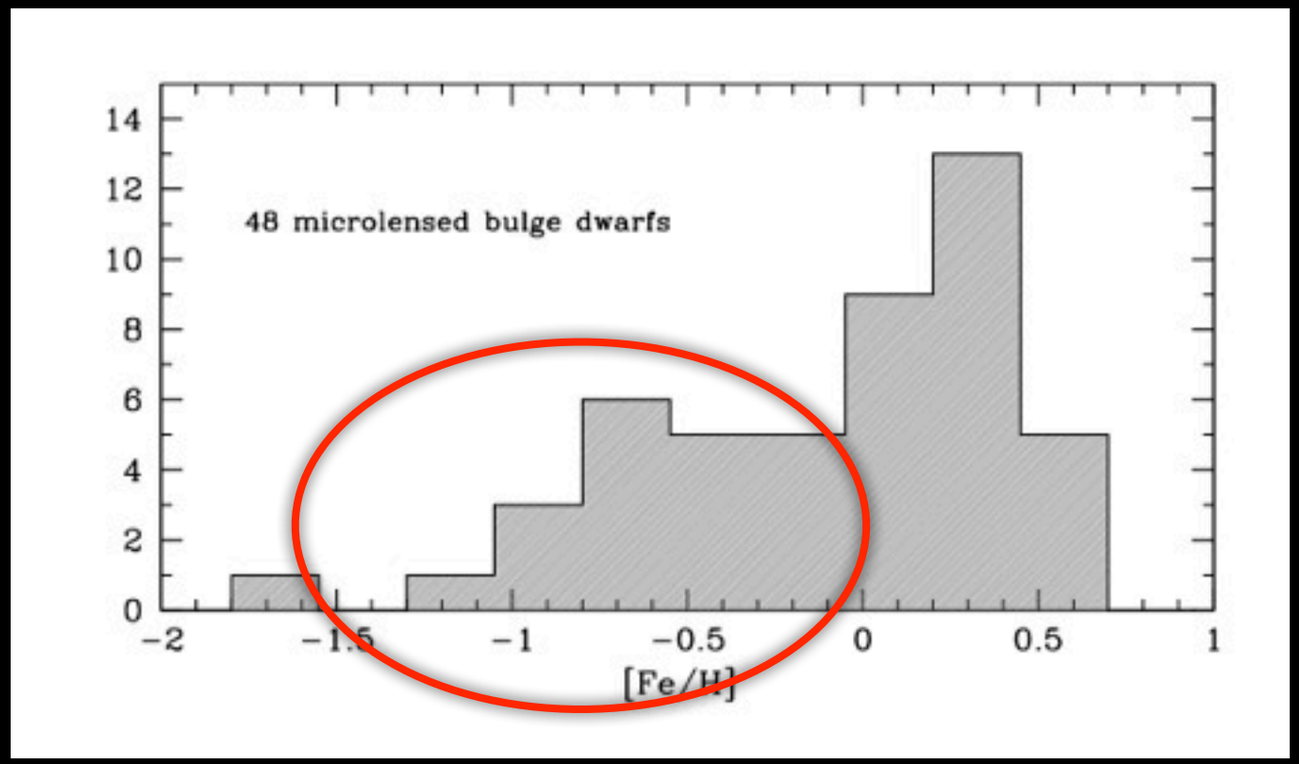
Microlensed bulge dwarfs







A bulge - thick disk connection?

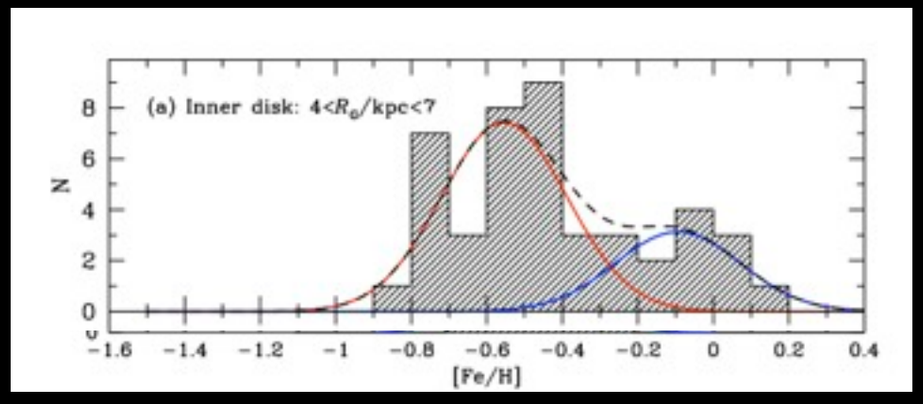


Metal-poor bulge dwarfs have average metallicity of [Fe/H]~ -0.6

....and they are all old

and

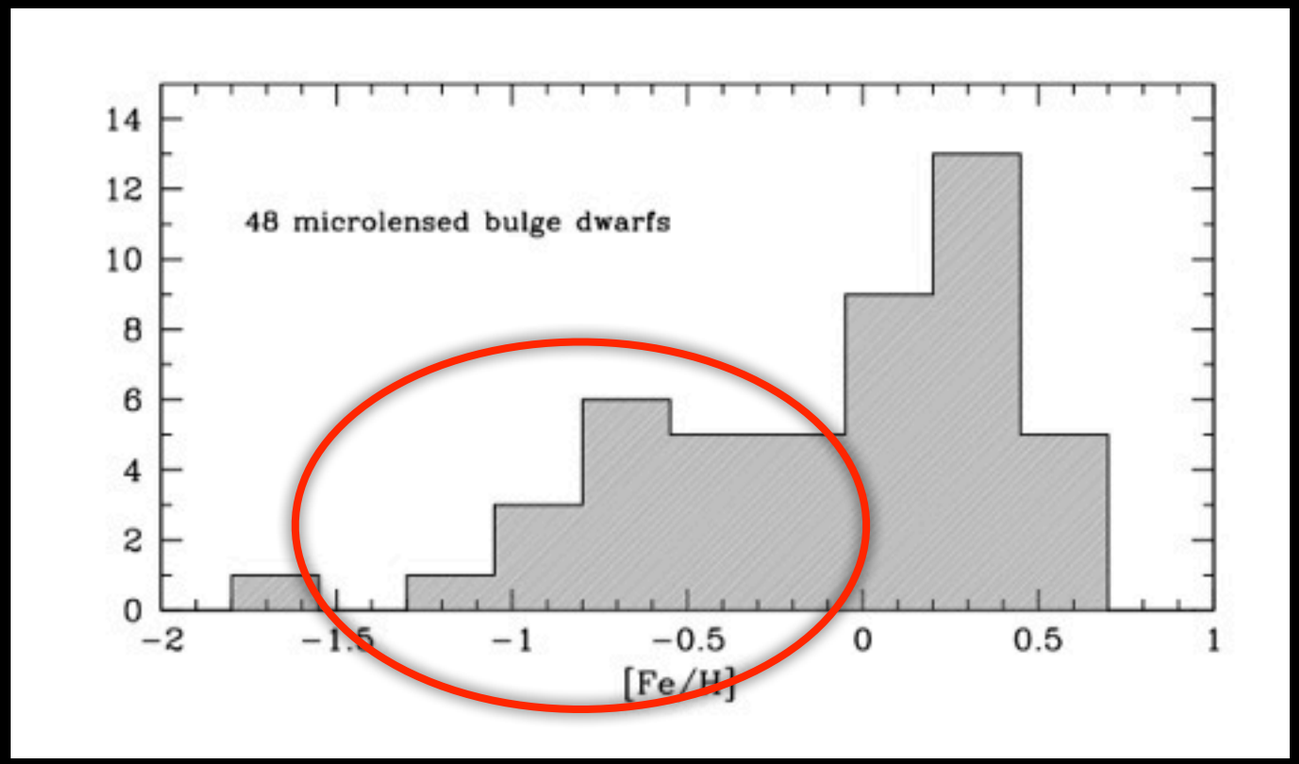
alpha-enhanced as the thick disk in the Solar neighbourhood



α-enhanced red giants in the inner disk has average metallicity of [Fe/H]=-0.6

Average metallicity of the thick disk in the Solar neighbourhood is [Fe/H]=-0.6 (e.g. Carollo et al. 2010)

A bulge - thick disk connection?



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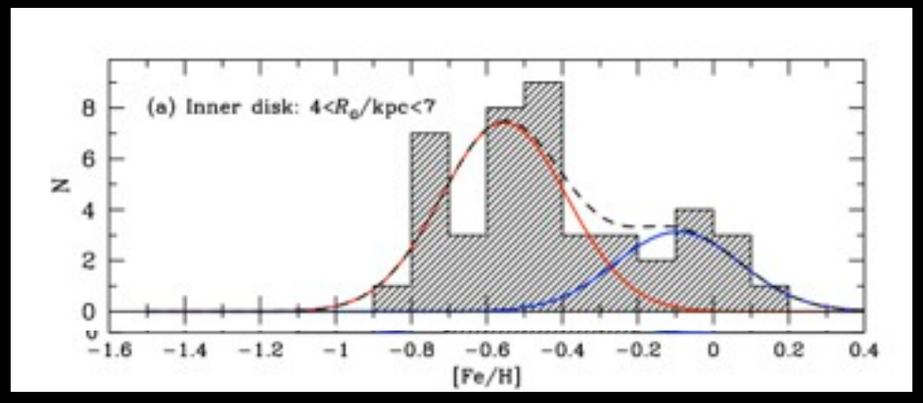

α-enhanced red giants in the inner disk has average metallicity of [Fe/H]=-0.6

No metallicity gradient in the thick disk!

No metallicity gradient.....

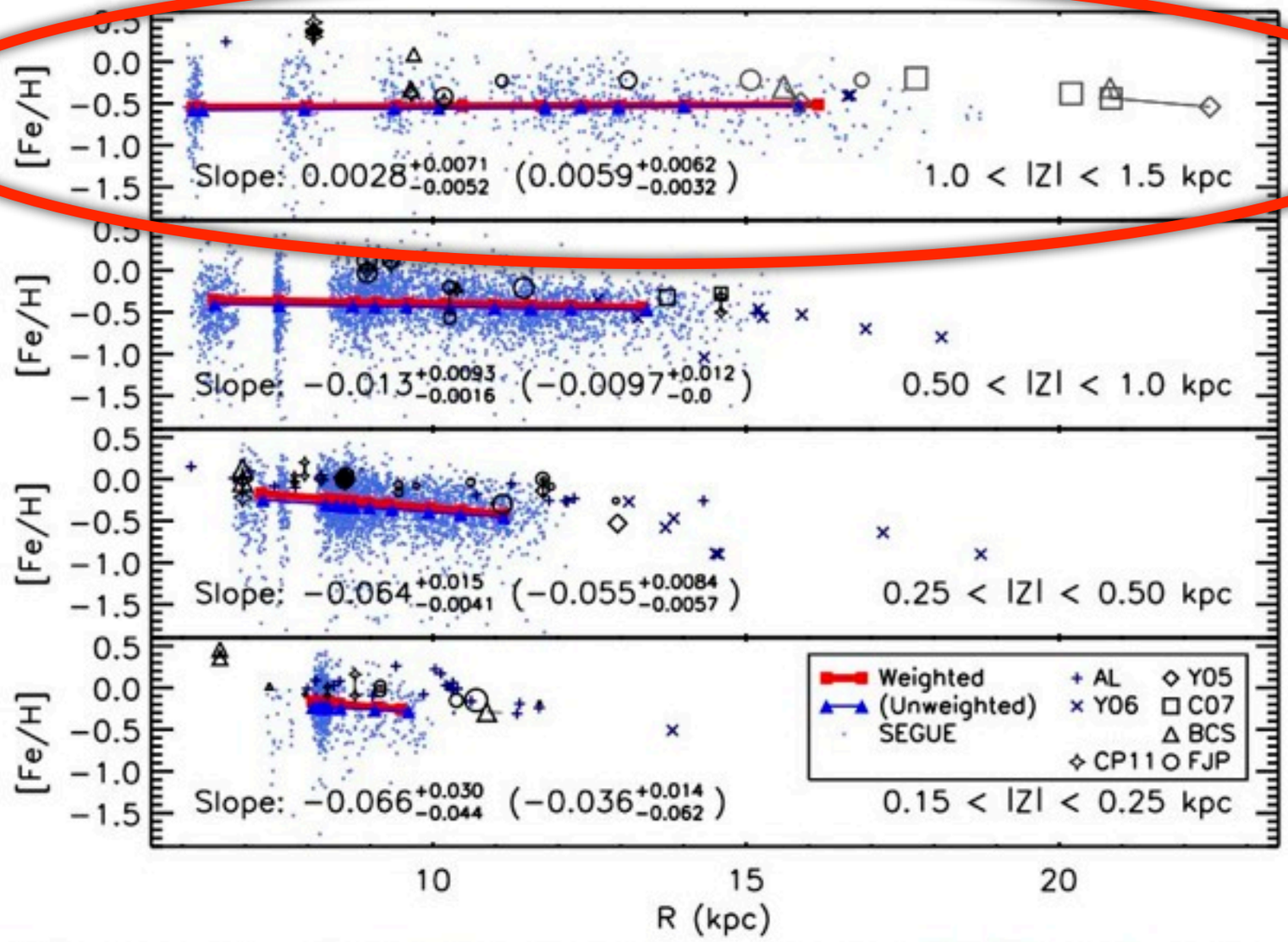

Figure 7. Metallicity [Fe/H] vs. Galactocentric radius R in four $|Z|$ slices. Light blue points indicate the SEGUE data. The weighted median metallicity and the derived linear fit are shown as red squares, with the numerical values in the bottom left of each panel. The blue triangles and values in parentheses show the results we would have obtained if no corrections for known selection effects had been applied. The spacing of the symbols indicates the radial distribution of the targets. Open symbols and pluses/crosses are open clusters and Cepheids from the literature (see Section 7.2 for details). The sizes of the open cluster symbols indicate their ages (smaller symbols for younger clusters). At low $|Z|$ (< 0.5 kpc), our derived gradient is consistent with published values. At high $|Z|$ (> 0.5 kpc), the constant [Fe/H] is consistent with the cluster metallicities reported by Yong et al. (2005) in the outer disk.

Cheng et al., 2012, ApJ, 746:149

Challenges.....

- The Milky Way has no distinct thick disk (Bovy et al. 2012).....
  - .....but J. Cheng (2012) used essentially the same data set and found two distinct populations and that the thick disk has a short scale length...
  - .... and Veltz et al (2008) using ~22000 RAVE stars and finds two distinct populations associated with the thin and thick disks
  - .... and .....?

- To what degree is radial migration important ?
  (Rok Roskar)
  - is radial migration responsible for the lack of a radial metallicity gradient in the thick disk?