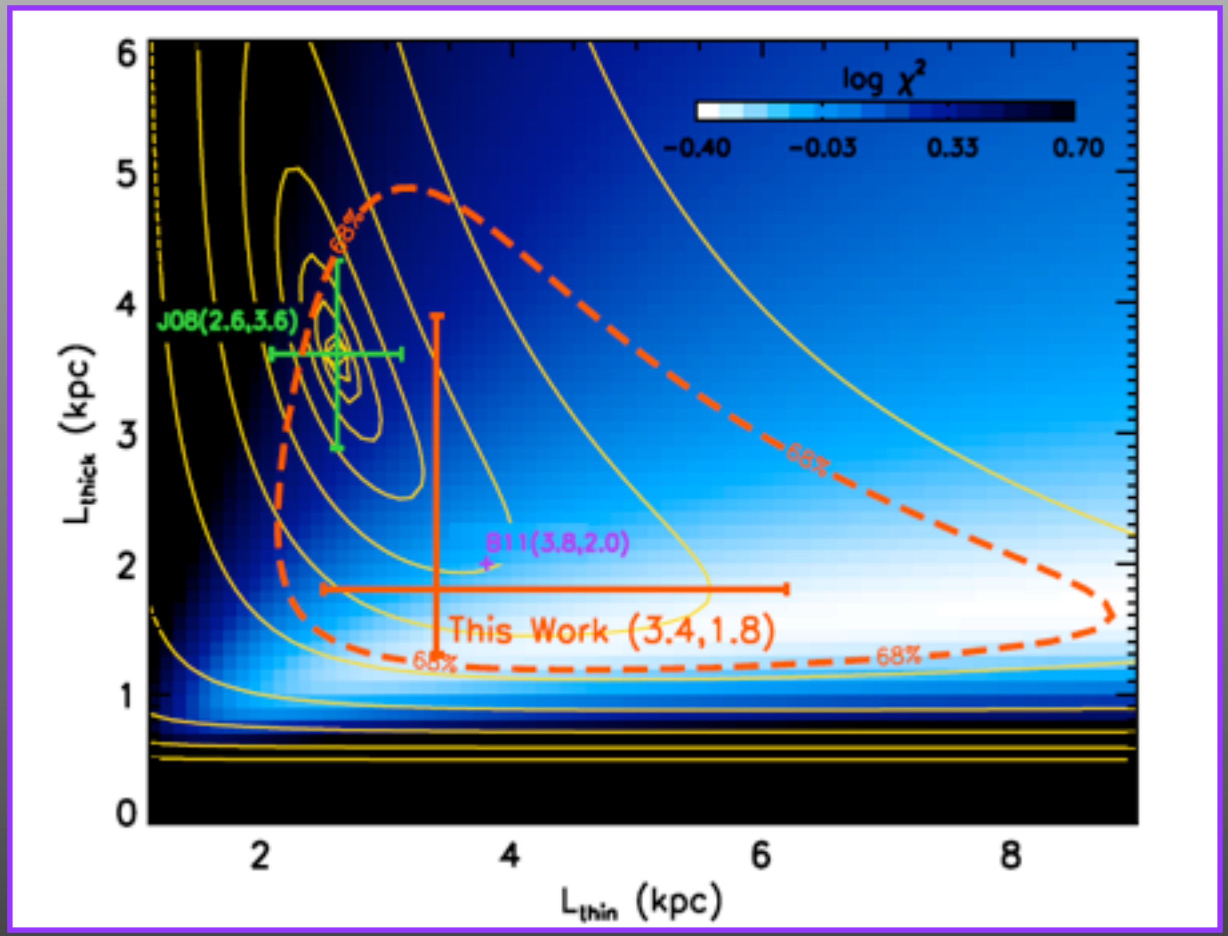
A REVIEW OF RECENT SDSS-SEGUE DETERMINATIONS OF METALLICITY AND ABUNDANCE TRENDS AS A FUNCTION OF STELLAR SAMPLE AND GALACTIC PARAMETERS



Jennifer Sobeck

May 31, 2012

CHENG et al. (2012 a,b): METALLICITY AND ALPHA-ELEMENT ABUNDANCE TRENDS AS A FUNCTION OF R AND |Z|

THE ASTROPHYSICAL JOURNAL, 746:149 (23pp), 2012 February 20 doi:10.1088/0004-637X/746/2/149

METALLICITY GRADIENTS IN THE MILKY WAY DISK AS OBSERVED BY THE SEGUE SURVEY

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ABSTRACT

The observed radial and vertical metallicity distribution of old stars in the Milky Way disk provides a powerful constraint on the chemical enrichment and dynamical history of the disk system. We present the radial metallicity gradient, $\Delta[Fe/H]/\Delta R$, as a function of height above the plane, $|Z|$, using 7010 main-sequence turnoff stars observed by the Sloan Extension for Galactic Understanding and Exploration survey. The sample consists of mostly old thin and thick disk stars, with a minimal contribution from the stellar halo, in the region $6\,kpc < R < 16\,kpc$, $0.15\,kpc < |Z| < 1.5\,kpc$. The data reveal that the radial metallicity gradient becomes flat at heights $|Z| > 1$ kpc. The median metallicity at large $|Z|$ is consistent with the metallicities seen in outer disk open clusters, which exhibit a flat radial gradient at $[Fe/H] \sim -0.5$. We note that the outer disk clusters are also located at large $|Z|$; because the flat gradient extends to small R for our sample, there is some ambiguity in whether the observed trends for clusters are due to a change in R or $|Z|$. We therefore stress the importance of considering both the radial and vertical directions when measuring spatial abundance trends in the disk. The flattening of the gradient at high $|Z|$ also has implications on thick disk formation scenarios, which predict different metallicity patterns in the thick disk. A flat gradient, such as we observe, is predicted by a turbulent disk at high redshift, but may also be consistent with radial migration, as long as mixing is strong. We test our analysis methods using a mock catalog based on the model of Schönrich & Binney, and we estimate our distance errors to be ~25%. We also show that we can properly correct for selection biases by assigning weights to our targets.

Key words: Galaxy: abundances – Galaxy: disk – Galaxy: evolution – Galaxy: formation

STELLAR SAMPLE CONSTRUCTION AND DETAILS:

- Main sequence turn-off stars (not restricted to the Solar Neighborhood)
- Locus of "bluer" stars featured in the CMD below
- No *absolute* cut in (g-r) (dependent upon the line of sight and Galactic extinction)
- 6 kpc < R < 16 kpc
- 0.15 kpc < |Z| < 1.5 kpc
- S/N > 20 (per pixel; ~ 1 Å
- 5771 members (with [α/Fe] measurement precision of 0.1 dex)

THE ASTROPHYSICAL JOURNAL, 752:51 (12pp), 2012 June 10 doi:10.1088/0004-637X/752/1/51

A SHORT SCALE LENGTH FOR THE α-ENHANCED THICK DISK OF THE MILKY WAY: EVIDENCE FROM LOW-LATITUDE SEGUE DATA

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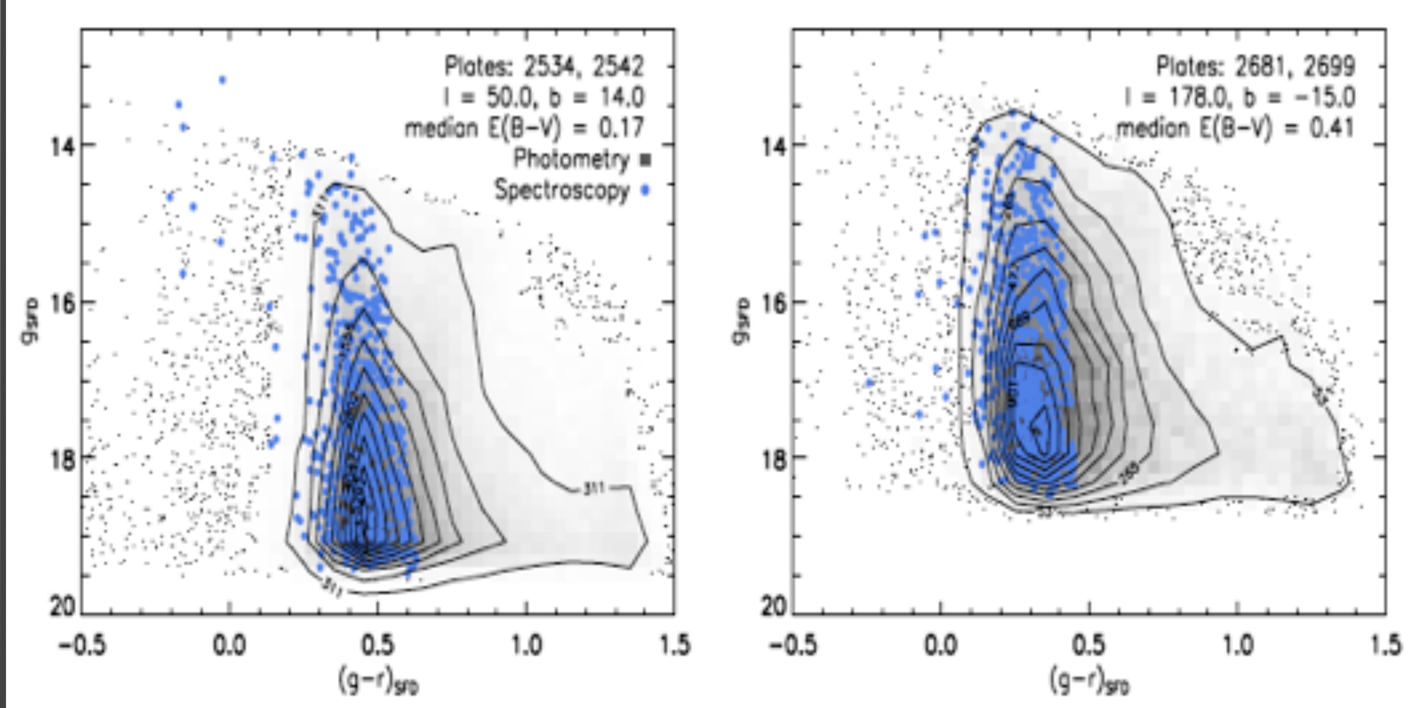
ABSTRACT

We examine the α-element abundance ratio, [α/Fe], of 5620 stars, observed by the Sloan Extension for Galactic Understanding and Exploration survey in the region $6\,kpc < R < 16\,kpc$, $0.15\,kpc < |Z| < 1.5\,kpc$, as a function of Galactocentric radius R and distance from the Galactic plane $|Z|$. Our results show that the high-α thick-disk population has a short scale length ($L_{thick} \sim 1.8$ kpc) compared to the low-α population, which is typically associated with the thin disk. We find that the fraction of high-α stars in the inner disk increases at large $|Z|$ and that high-α stars lag in rotation compared to low-α stars. In contrast, the fraction of high-α stars in the outer disk is low at all $|Z|$, and high- and low-α stars have similar rotational velocities up to 1.5 kpc from the plane. We interpret these results to indicate that different processes were responsible for the high-α populations in the inner and outer disk. The high-α population in the inner disk has a short scale length and large scale height, consistent with a scenario in which the thick disk forms during an early gas-rich accretion phase. Stars far from the plane in the outer disk may have reached their current locations through heating by minor mergers. The lack of high-α stars at large R and $|Z|$ also places strict constraints on the strength of radial migration via transient spiral structure.

Key words: Galaxy: abundances – Galaxy: disk – Galaxy: evolution – Galaxy: formation



CHENG et al. (2012 a,b): METALLICITY AND ALPHA-ELEMENT ABUNDANCE TRENDS AS A FUNCTION OF R AND |Z|

THE RADIAL METALLICITY GRADIENT BECOMES FLAT WITH INCREASING |Z|

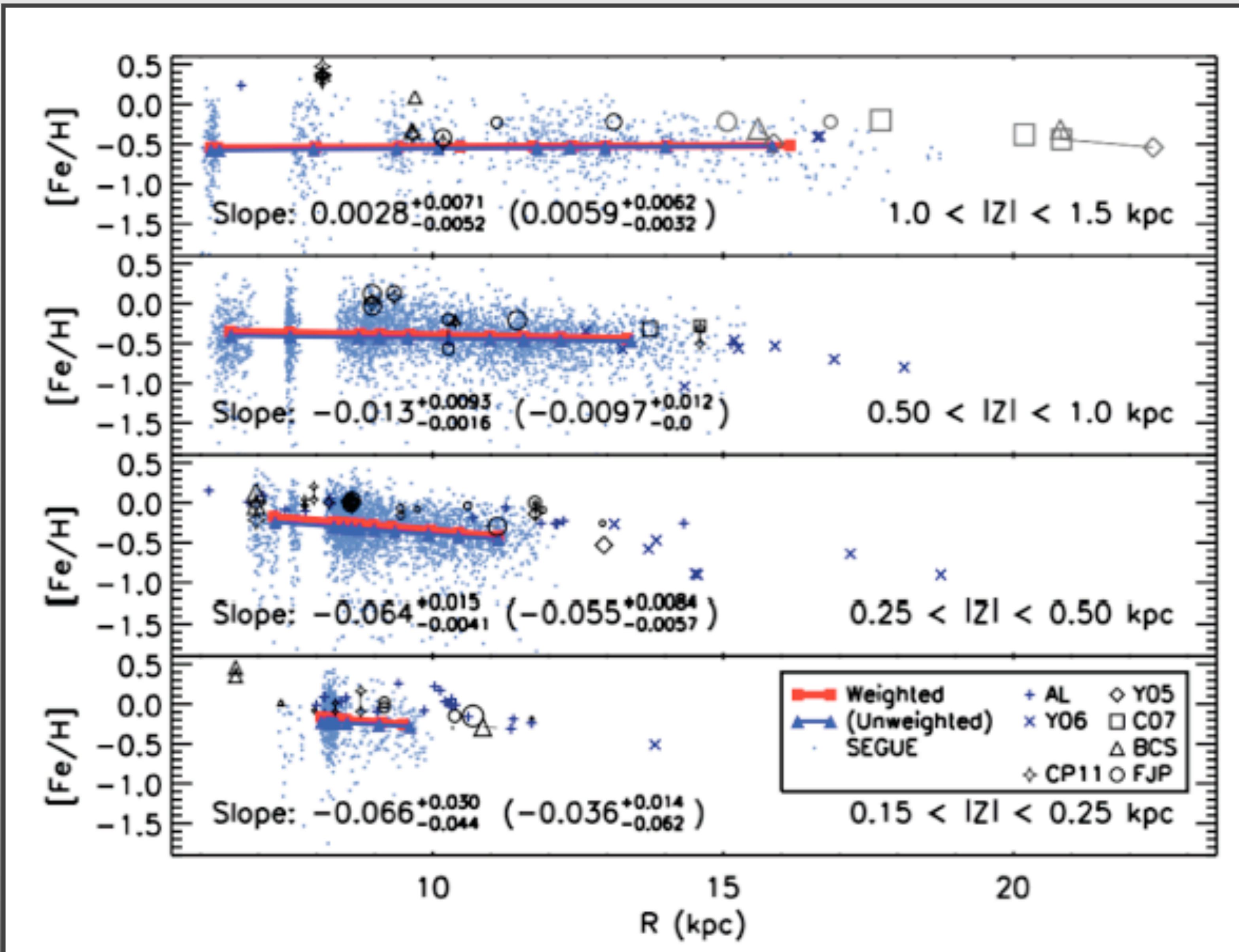


FIGURE: Metallicity [Fe/H] vs. Galactocentric radius R in four **|Z|** slices. Light blue points indicate the SEGUE data. The weighted median metallicity and the derived linear fit are shown as red squares, with the numerical values in the bottom left of each panel. The blue triangles and values in parentheses 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. The sizes of the open cluster symbols indicate their ages (smaller symbols for younger clusters).

Flat gradient at |Z| > 1.0 kpc

- At high **|Z|**, the constant [Fe/H] is consistent with the cluster metallicities reported by Yong et al. (2005) in the outer disk.
- Consistent with chemically homogenous thick disk

Negative gradient at |Z| < 0.5 kpc

- At low **|Z|** (<0.5 kpc), our derived gradient is consistent with published values.

CHENG et al. (2012 a,b): METALLICITY AND ALPHA-ELEMENT ABUNDANCE TRENDS AS A FUNCTION OF R AND |Z|

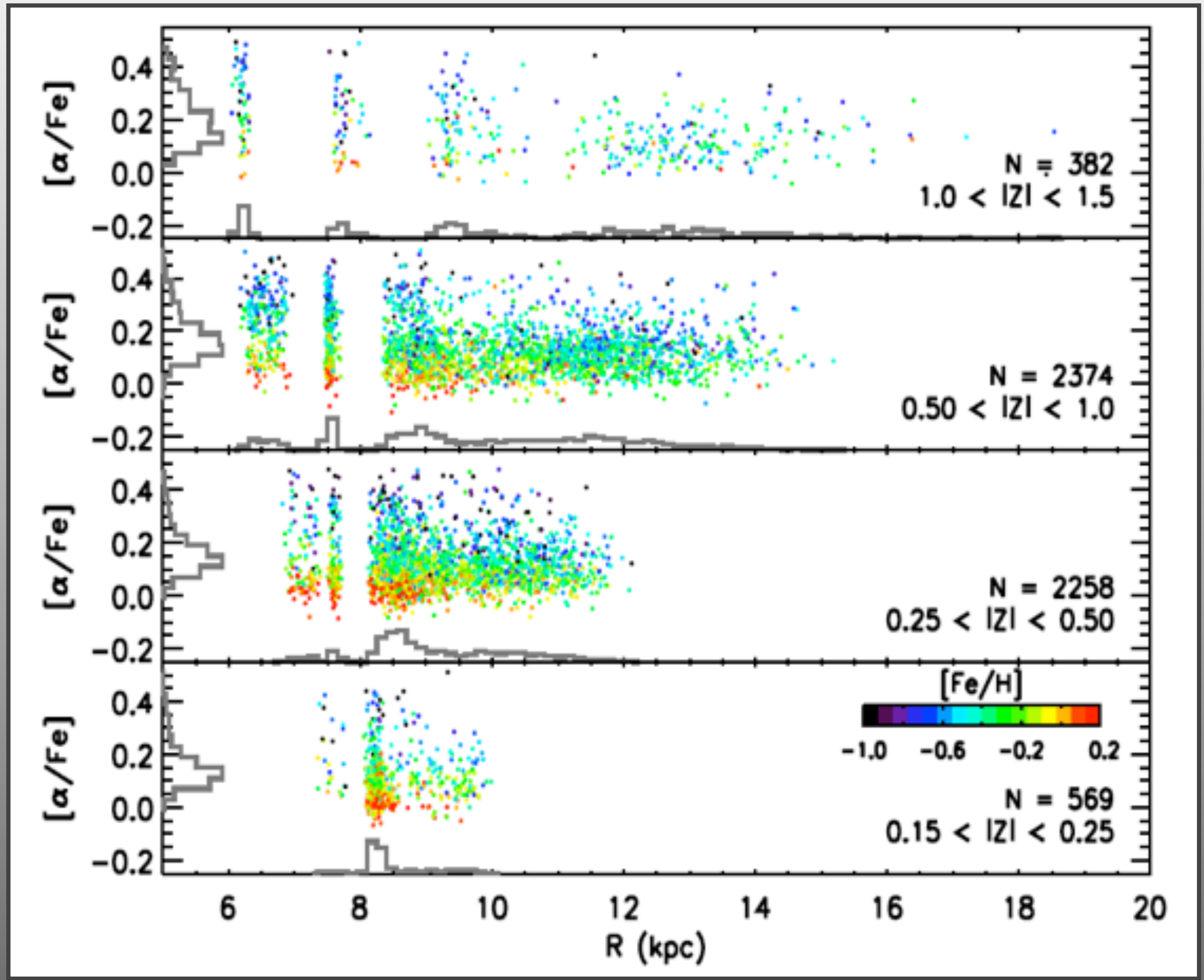


FIGURE: α-element abundance ratio [α/Fe] vs. Galactocentric radius R in four |Z| slices. The SEGUE data are shown as dots, colored coded by [Fe/H]. At all |Z|, the majority of the high-α stars are located at small R (<10 kpc).

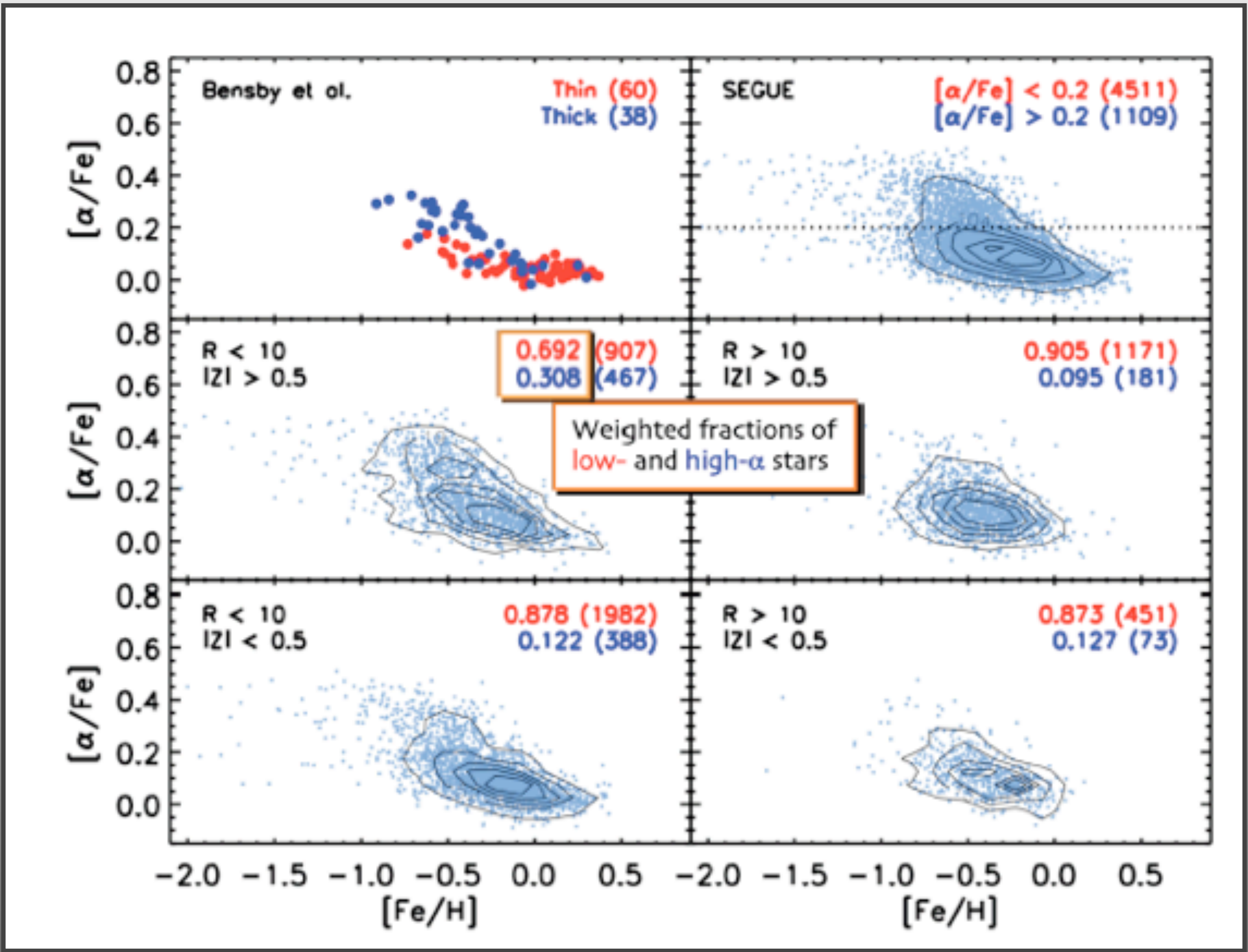
As shown in the above figure, the number of stars with [α/Fe] > +0.2 drops drastically at large R.

[α/Fe] > 0.20: high-α stellar group (comparison to thick disk stars)

[α/Fe] < 0.20: low-α stellar group (comparison to thin disk stars)

CHENG et al. (2012 a,b): METALLICITY AND ALPHA-ELEMENT ABUNDANCE TRENDS AS A FUNCTION OF R AND |Z|

THE INNER AND OUTER DISKS SHOW DIFFERENT TRENDS WITH |Z| in [α/Fe] vs.[Fe/H]

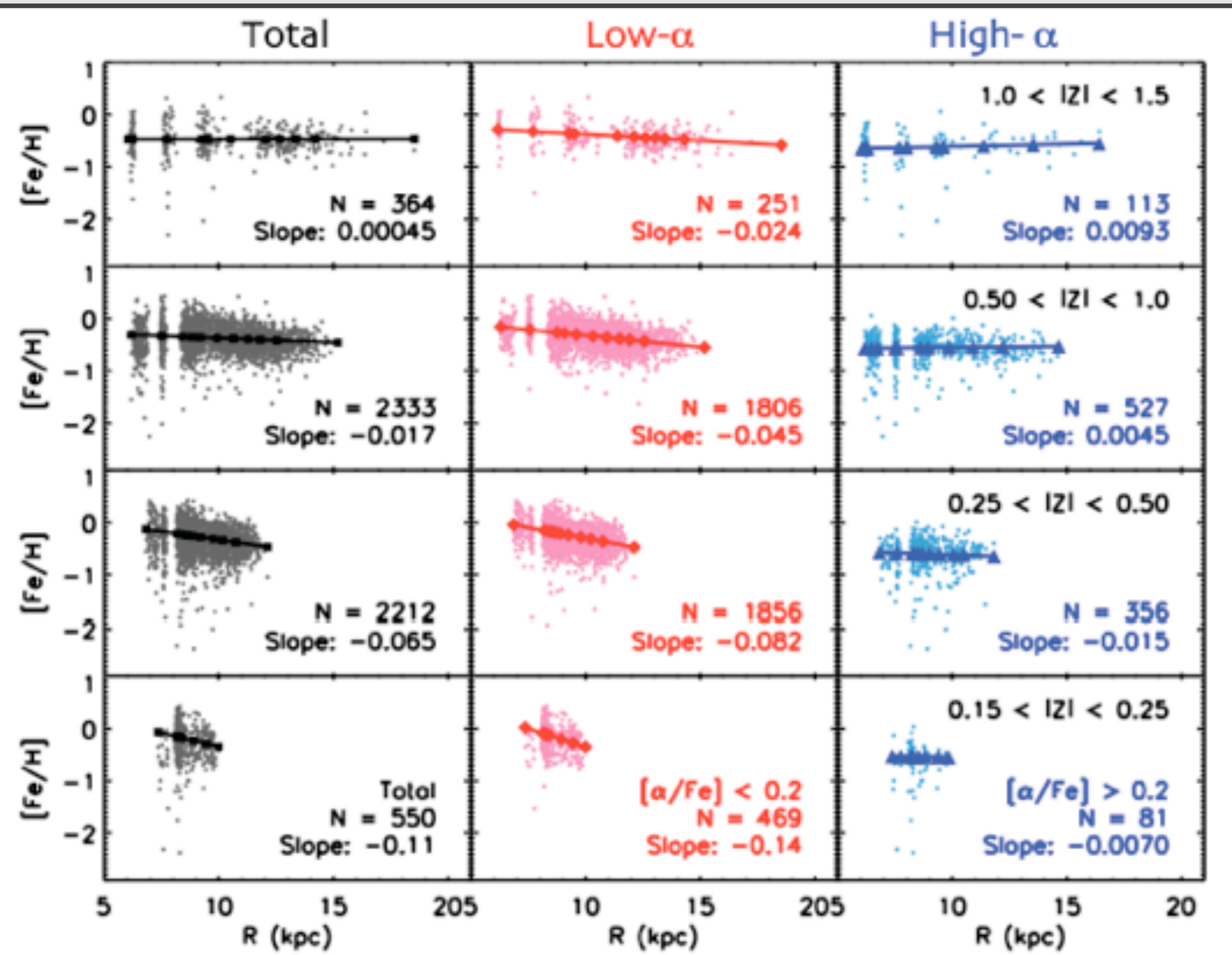


- At R > 10 kpc, the fraction of high-α stars is low at all |Z|.
- The abundance patterns at R < 10 kpc are similar to those seen for thin- and thick-disk stars in the solar neighborhood, with the fraction of high-α stars increasing at large |Z|.
- Accordingly, the fraction of high-a stars should increase as the thick disk becomes the dominant population at large |Z|.
- The above statement holds true at small R, but not large R.

TOP LEFT PANEL: the solar neighborhood sample of Bensby et al. (2003, 2005), with thin- and thick-disk stars (red and blue, respectively) assigned according to their kinematics.
TOP RIGHT PANEL: Total SEGUE sample. The horizontal dotted line indicates where we make the distinction between low- and high-α stars.
BOTTOM FOUR PANELS: the SEGUE sample, divided into four bins of R and |Z|. The labels on the contours indicate the number of objects in a box with dimensions of 0.15 dex in [Fe/H] and 0.05 dex in [α/Fe]. In each panel, the weighted fraction of high- and low-α stars (blue and red, respectively) is indicated, with the raw number of stars in each population in parentheses.

CHENG et al. (2012 a,b): METALLICITY AND ALPHA-ELEMENT ABUNDANCE TRENDS AS A FUNCTION OF R AND |Z|

THE RADIAL GRADIENT IS FLAT EVERYWHERE FOR HIGH-α STARS



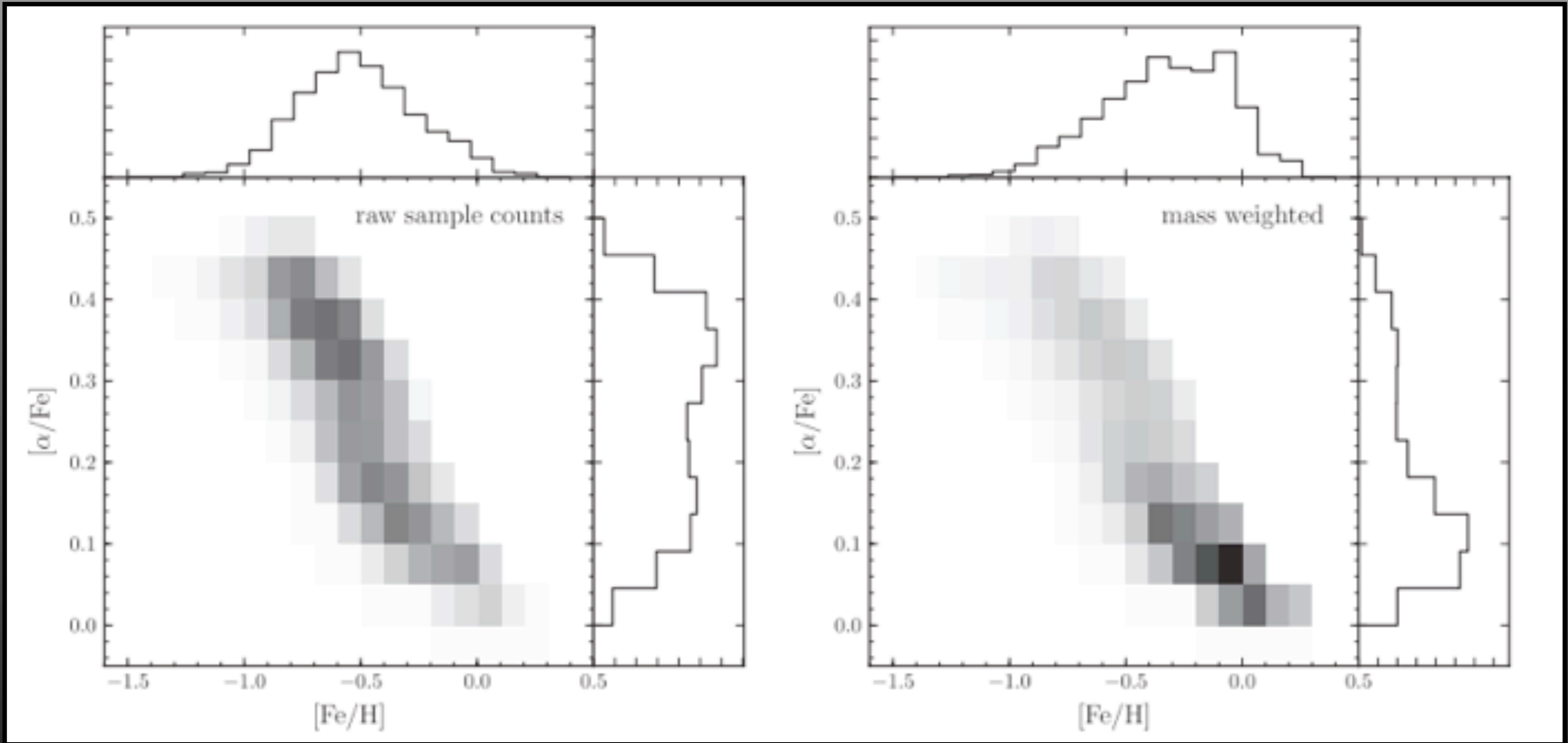
- The radial gradient in the total and low-α samples become flatter at large **|Z|**, while the radial metallicity gradient of the high-α sample is flat at all **|Z|**.
- The display of the flat radial gradient of high-α stars at all |Z| is consistent with the chemical homogeneity predicted by the clumpy disk scenario.
- The low-α stars exhibit a radial gradient that becomes flatter at large |Z|, which could possibly be due to radial mixing.

FIGURE: Galactocentric radius R vs. [Fe/H] in four **|Z|** slices for high- and low-**α** stars.
LEFT COLUMN: Total sample.
MiDDLE COLUMN: Low-**α** stars ([**α**/Fe] <+0.2).
RIGHT COLUMN: High-**α** stars ([**α**/Fe] > +0.2). In each panel, the raw number of stars and the measured slope are indicated in the bottom right corner. The lines show a linear fit to the data, with each star weighted to account for selection biases. The spacing of the symbols on the linear relation indicates the radial distribution of the stars.

COMPARISON OF THE ANALYSIS OF CHENG et al. (2012 a,b) TO THAT FROM BOVY et al. (2012)

COMMENTS WITH REGARD TO RECENT BOVY et al. PUBLICATIONS

- The observations of Chen et al. (2012) and Bovy et al. (2012) are in good agreement. Both analyses do find that the high-alpha/alpha-old populations have short scale lengths using two distinct samples from SEGUE.
- The Chen et al. samples does span a larger range in radius (see out to R ~ 16 kpc).
- Perhaps, it is a difference in language/terminology. Note though, that the Chen et al. data do not relay upon a disk model.
- Bovy et al. employs DR7 Parameters and quotes errors from the DR8 Release (incorporation of these errors is unclear).
- Bovy et al. perhaps utilize a variable G-dwarf definition



LEE et al. (2011): ALPHA-ELEMENT ABUNDANCE TRENDS OF THE G DWARF SAMPLE

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FORMATION AND EVOLUTION OF THE DISK SYSTEM OF THE MILKY WAY: [α/Fe] RATIOS AND KINEMATICS OF THE SEGUE G-DWARF SAMPLE

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ABSTRACT

We employ measurements of the [α/Fe] ratio derived from low-resolution ($R \sim 2000$) spectra of 17,277 G-type dwarfs from the SEGUE survey to separate them into likely thin- and thick-disk subsamples. Both subsamples exhibit strong gradients of orbital rotational velocity with metallicity, of opposite signs, −20 to −30 km s^{-1} dex^{-1} for the thin-disk and +40 to +50 km s^{-1} dex^{-1} for the thick-disk population. The rotational velocity is uncorrelated with Galactocentric distance for the thin-disk subsample and exhibits a small trend for the thick-disk subsample. The rotational velocity decreases with distance from the plane for both disk components, with similar slopes (−9.0 ± 1.0 km s^{-1} kpc^{-1}). Thick-disk stars exhibit a strong trend of orbital eccentricity with metallicity (about −0.2 dex^{-1}), while the eccentricity does not change with metallicity for the thin-disk subsample. The eccentricity is almost independent of Galactocentric radius for the thin-disk population, while a marginal gradient of the eccentricity with radius exists for the thick-disk population. Both subsamples possess similar positive gradients of eccentricity with distance from the Galactic plane. The shapes of the eccentricity distributions for the thin- and thick-disk populations are independent of distance from the plane, and include no significant numbers of stars with eccentricity above 0.6. Among several contemporary models of disk evolution that we consider, radial migration appears to have played an important role in the evolution of the thin-disk population, but possibly less so for the thick disk, relative to the gas-rich merger or disk heating scenarios. We emphasize that more physically realistic models and simulations need to be constructed in order to carry out the detailed quantitative comparisons that our new data enable.

Key words: Galaxy: disk – Galaxy: formation – Galaxy: kinematics and dynamics – Galaxy: structure

STELLAR SAMPLE CONSTRUCTION AND DETAILS:

- Limited binary contamination
- S/N > 20 Å^{-1}
- log(g) ≥ 4.2
- 0.48 < (*g-r*) < 0.55 (narrow color cut)
- 17,277 Stars
- Likely Membership Determinations:

For stars with [Fe/ H] – 0. 8

(a) thin disk, if **[α/ Fe] < – 0. 08 * [Fe/ H] + 0. 15**

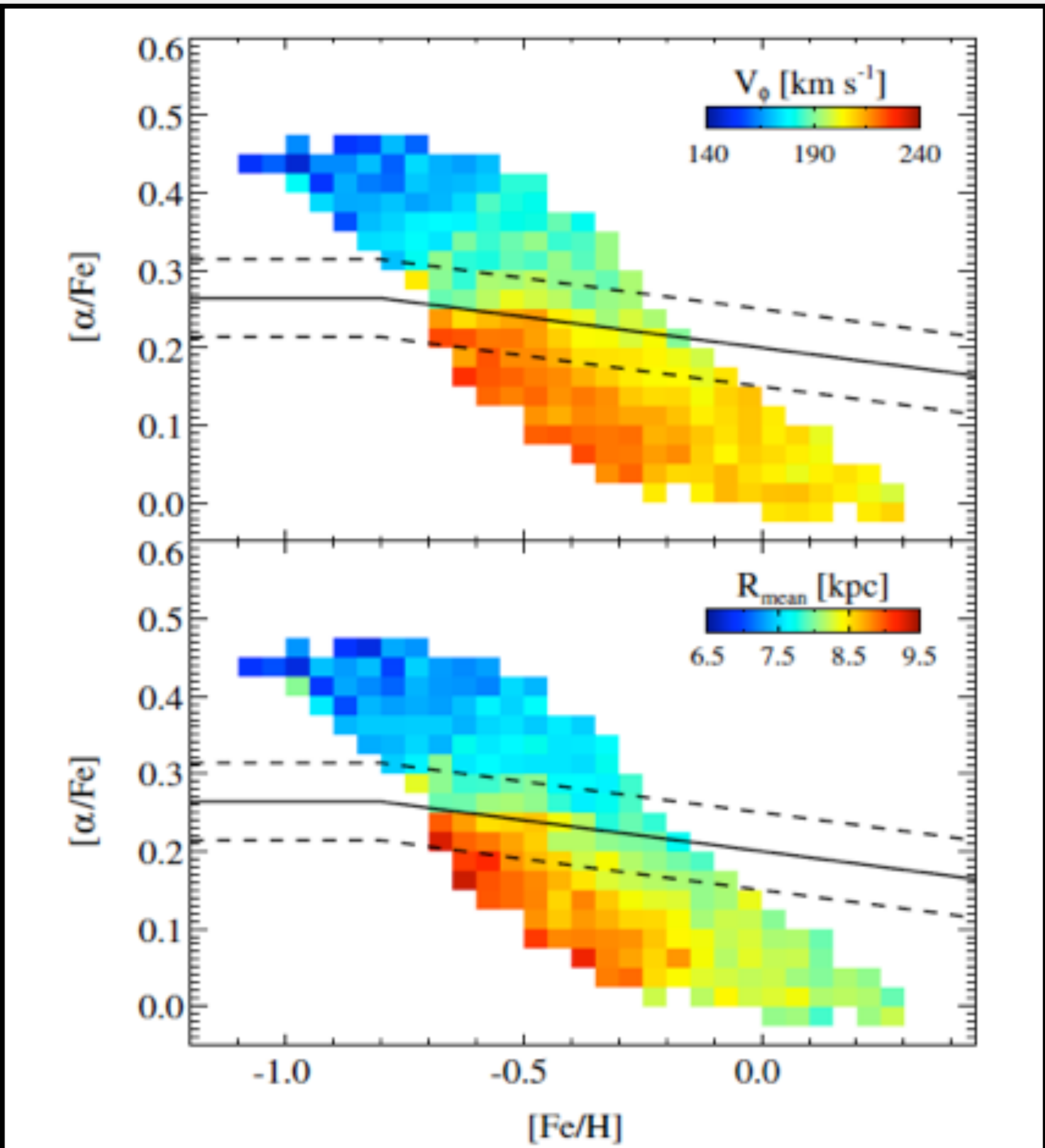
(b) thick disk, if **[α/ Fe] > – 0. 08 * [Fe/ H] + 0. 25**

For stars with [Fe/ H] **< – 0. 8**

(a) thin disk, if **[α/ Fe] <** +0. 214

(b) thick disk, if **[α/ Fe] >** +0. 314

LEE et al. (2011): ALPHA-ELEMENT ABUNDANCE TRENDS OF THE G DWARF SAMPLE



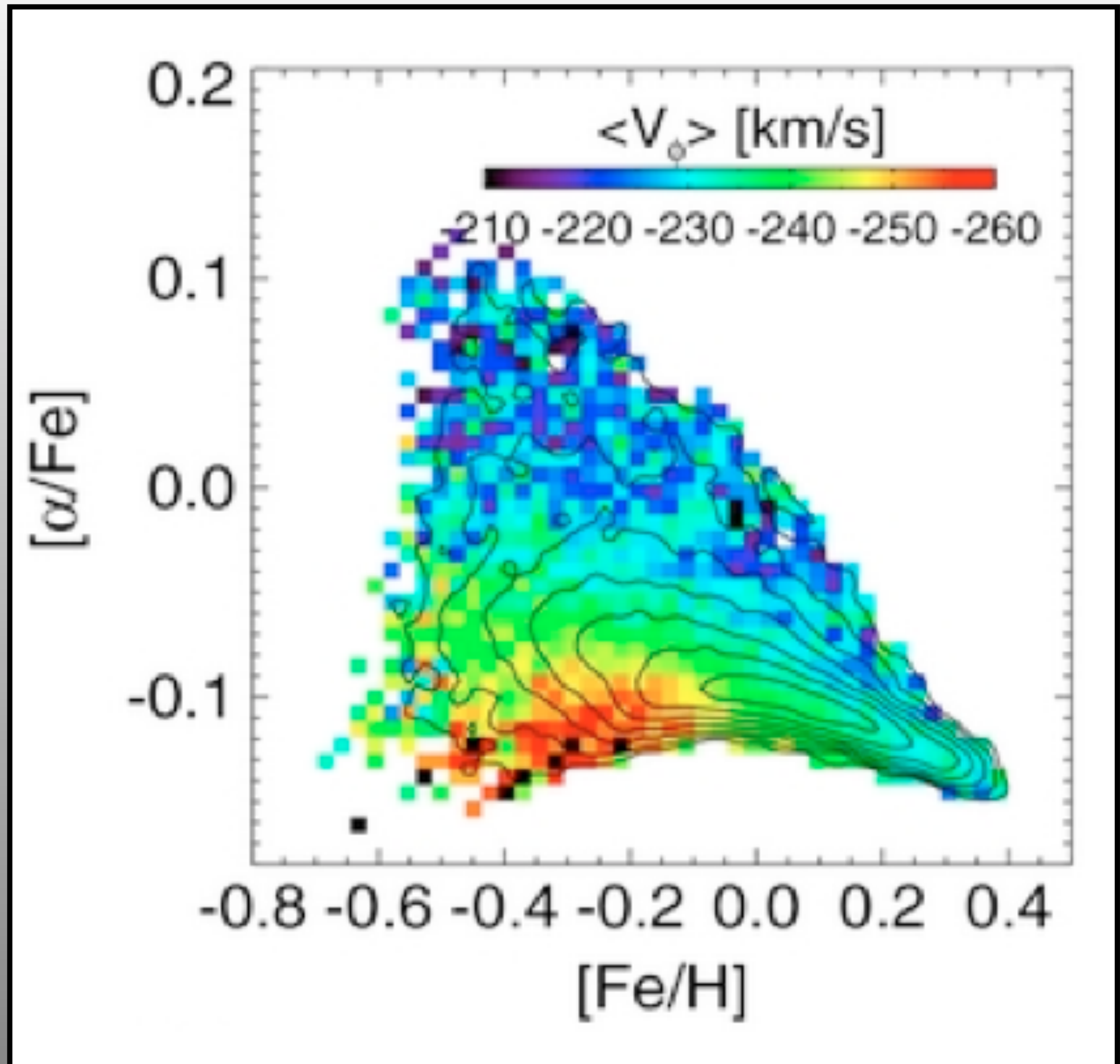


FIGURE: Data from Lobemann et al. (2011). The rotation velocity distribution is also featured.

FIGURE: Distribution of rotational velocities (**Vφ**, top panel) and the average orbital radii (**R**mean, bottom panel) for our G-dwarf sample in the [**α**/Fe] vs. [Fe/H] plane. The dividing lines for the thin- and thick-disk subsamples are shown. Each bin has a size of 0.025 dex in [**α**/Fe] by 0.05 dex in [Fe/H] and is occupied by a minimum of 20 stars. The median occupancy is 70 stars. Each bin represents a 3**σ** clipped mean of **Vφ** so that outliers in each bin do not significantly affect the average behavior.

As shown, Vphi increases as [Fe/H] decrease for low alpha thin disk stars as predicted by radial migration model by Loebman et al (the thick disk stars are the ones above the dashed line and thin disk stars below the dashed line).

LEE et al. (2011): ALPHA-ELEMENT ABUNDANCE TRENDS OF THE G DWARF SAMPLE

Velocity distribution in vertical distance vs. [Fe/H]

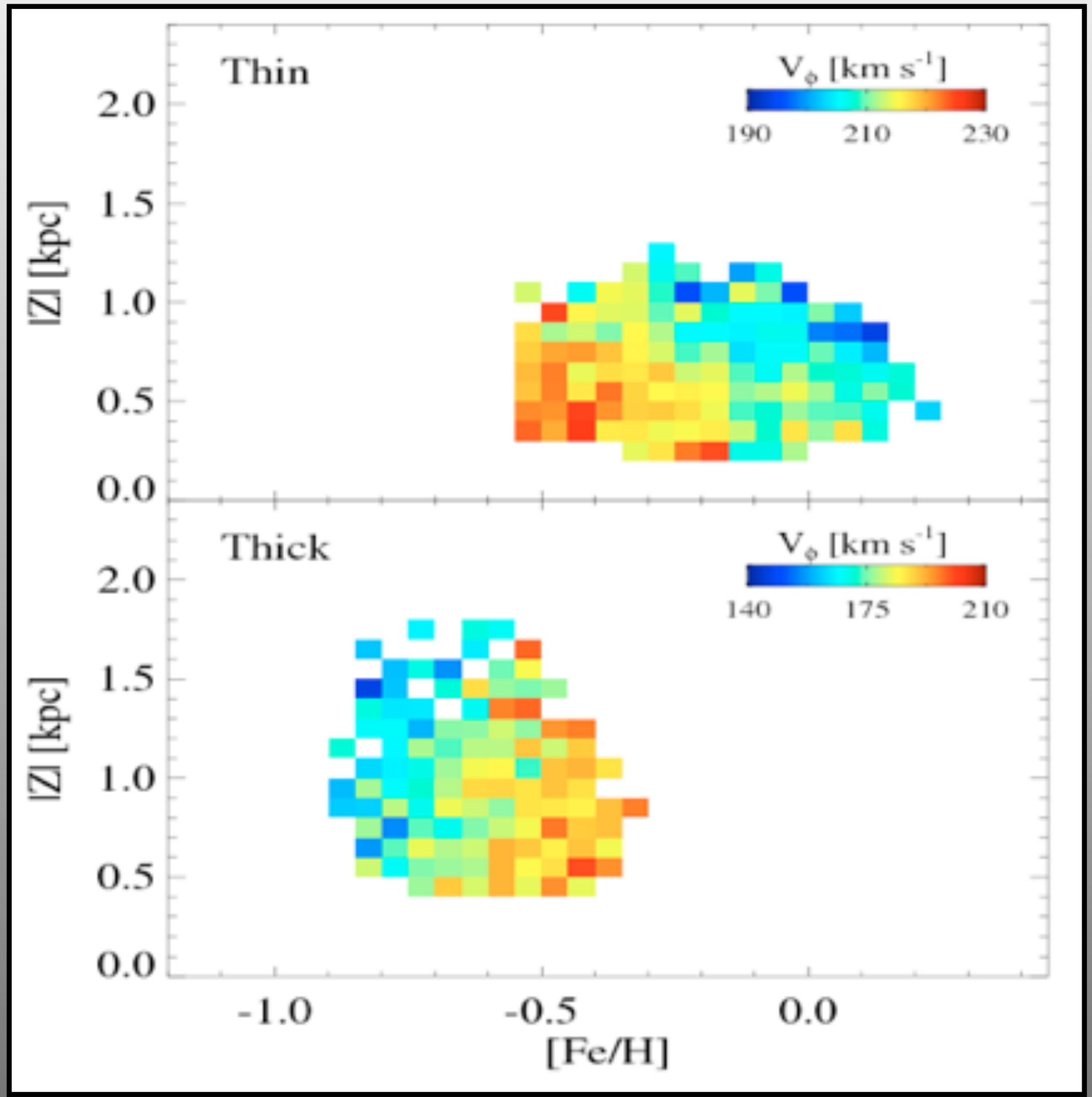


FIGURE: Distribution of rotational velocities for the low-**α**, thin-disk subsample (top panel) and the high-**α**, thick-disk subsample (bottom panel) in the **|Z|** vs. [Fe/H] plane. Each bin has a size of 0.025 dex in [**α**/Fe] by 0.05 dex in [Fe/H] and is occupied by a minimum of 20 stars. The median occupancy is 47 stars. Each bin represents a 3**σ** clipped mean of **Vφ** so that outliers in each bin do not significantly affect the average behavior.

LEE et al. (2011): ALPHA-ELEMENT ABUNDANCE TRENDS OF THE G DWARF SAMPLE

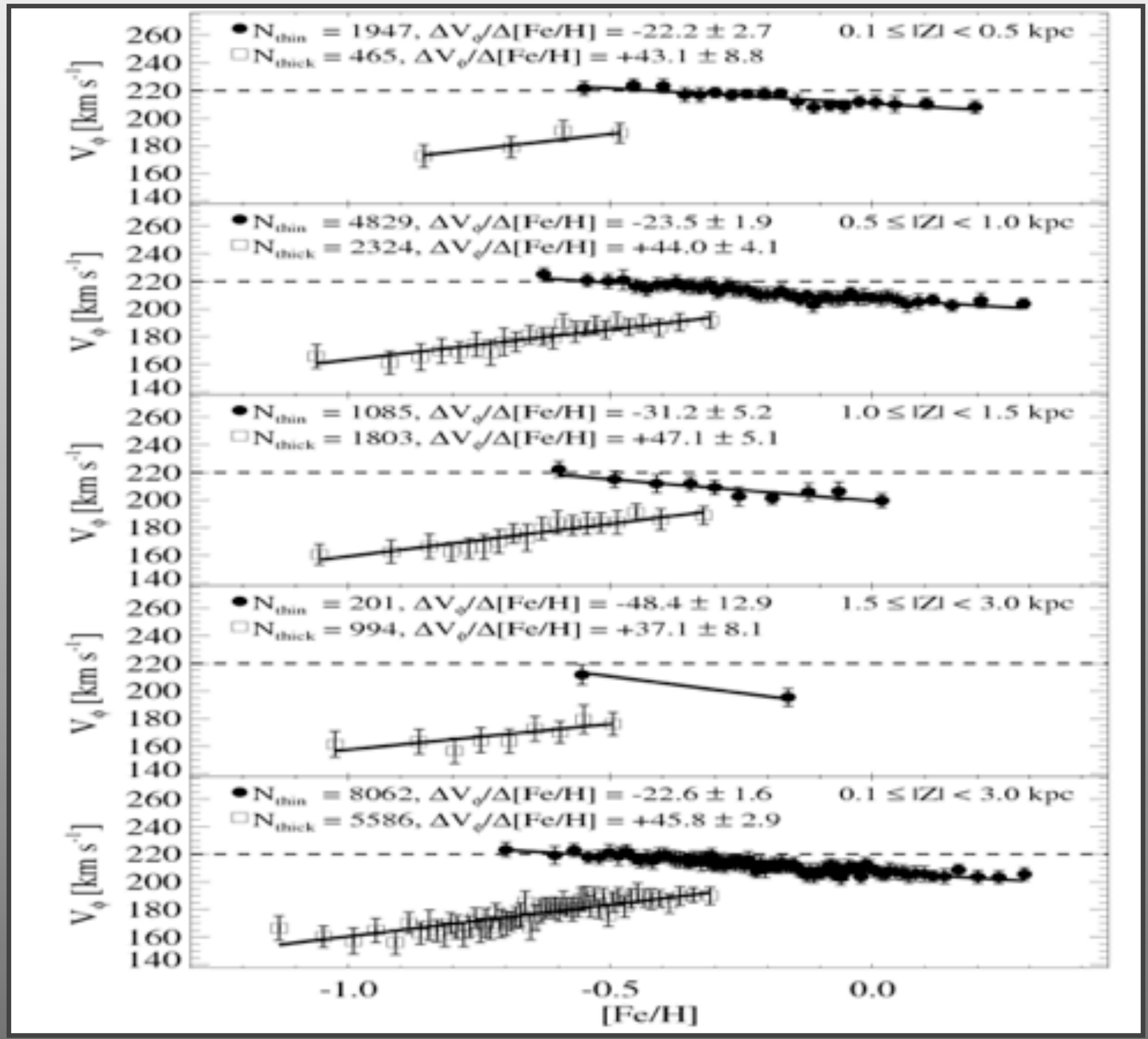


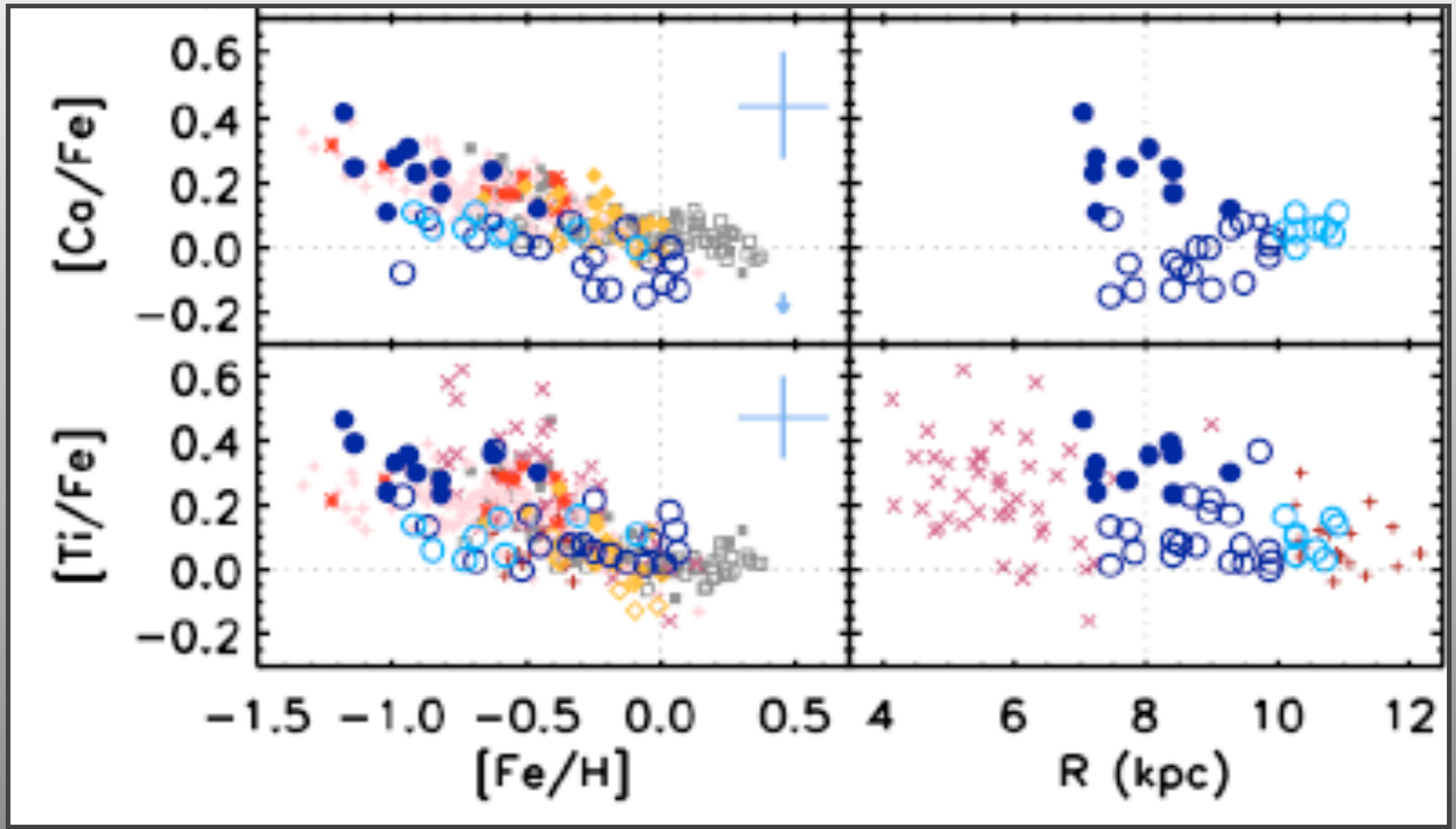
FIGURE: Rotational velocity gradients with metallicity for different slices in distance from the Galactic plane, for stars assigned to the thin-disk (black dots) and thick-disk (open squares) populations. Each dot represents a 3σ clipped average of 100 stars. Note that the 1σ error bars associated with each point are very small (on the order of 3–5 km s^{-1}), so for visualization purposes 2σ error bars are plotted instead. The error bars are calculated by resampling the 100 stars in each population (with replacement) 1000 times. The bottom panel shows the results for the full samples of stars considered. Note that although binned data are shown for clarity, estimates of the slopes and their errors are obtained for the full unbinned data.

LEE et al. (2011): ALPHA-ELEMENT ABUNDANCE TRENDS OF THE G DWARF SAMPLE

RECENT CHANGES AND POSSIBLE FUTURE IMPROVEMENTS

- DR9 alpha value is on average a bit higher by 0.05 dex for mostly metal-rich stars([Fe/H] < -0.5 or so) than the DR8 value.
- Reasons for the shift: utilization of a lower gravity estimate and higher temperature estimate as well as employment of a new grid of synthetic spectra
- New log g calibration with recent results from high resolution analysis (lower log g value than Allende Prieto et al. 2008)
- Higher Teff value results from the adoption of an IRFM temperature scale
- DR8 use a different value for the microturbulence as opposed to DR9
- High resolution calibration of [α/Fe] perhaps will also be employed

LEE et al. (2011): ALPHA-ELEMENT ABUNDANCE TRENDS OF THE G DWARF SAMPLE



Two high resolution efforts underway