The Imprints of Disk Evolution on the Vertical Structure of the Milky Way Disk

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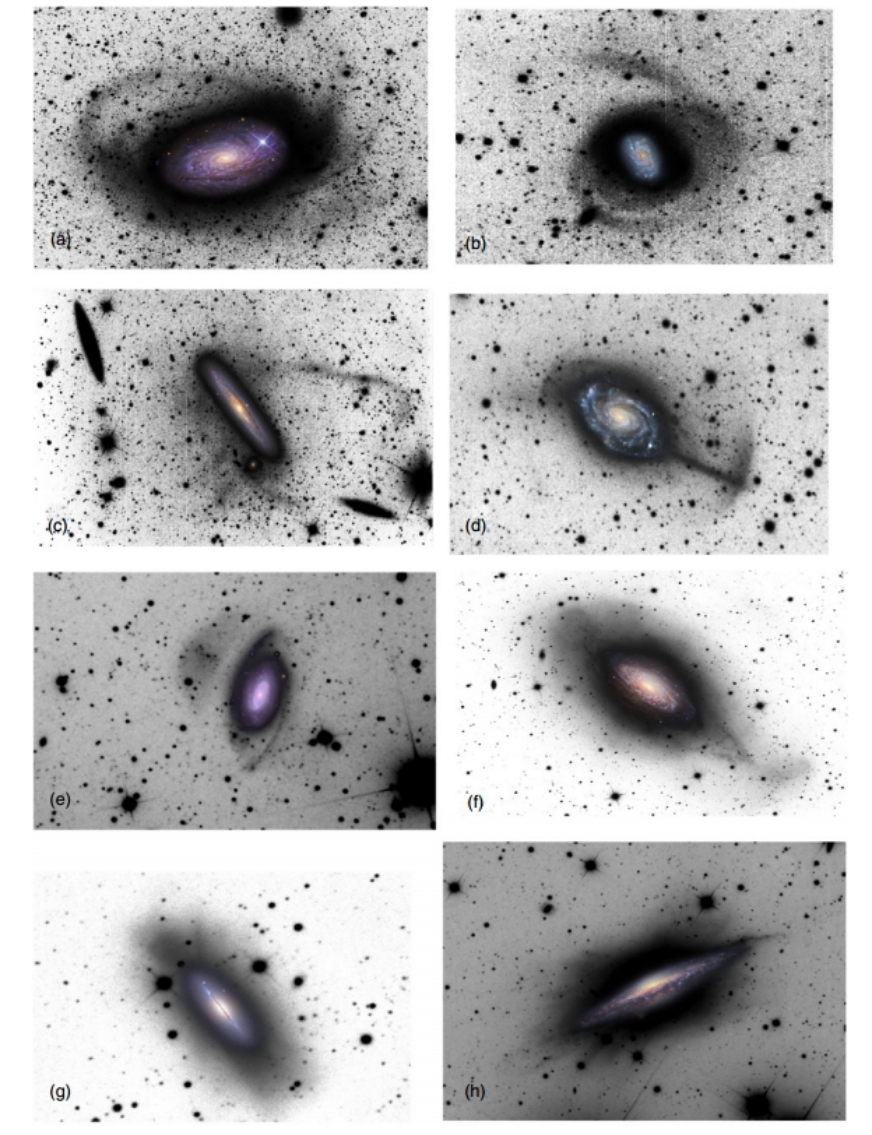
Chemical and Dynamical Evolution of the Milky Way and Local Group galaxies
Sexten Center for Astrophysics

The Milky Way Disk

- Formation processes?
- Radial migration?
- Merger rate?
- Distinct components?
- Similar for other galaxies?

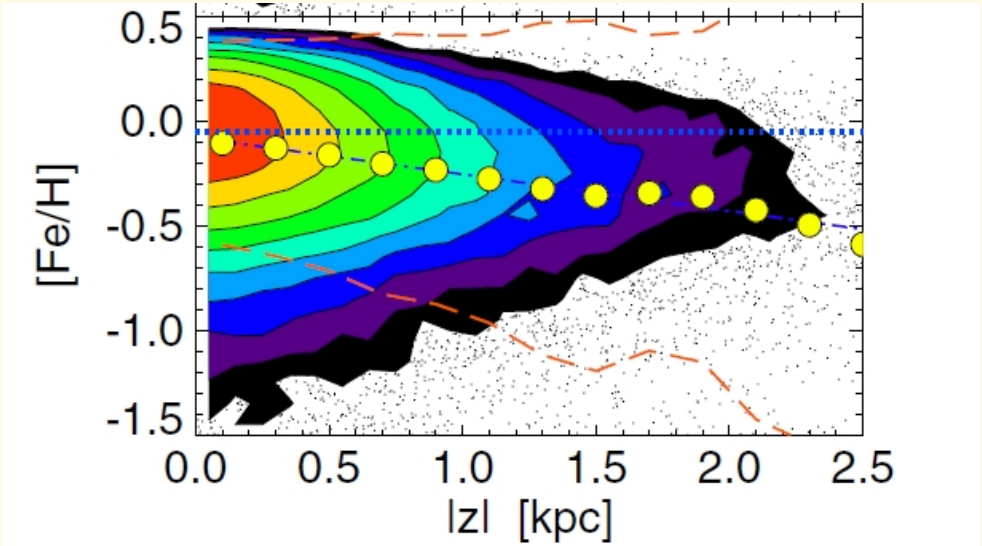


(Martinez-Delgado et al. 2010)

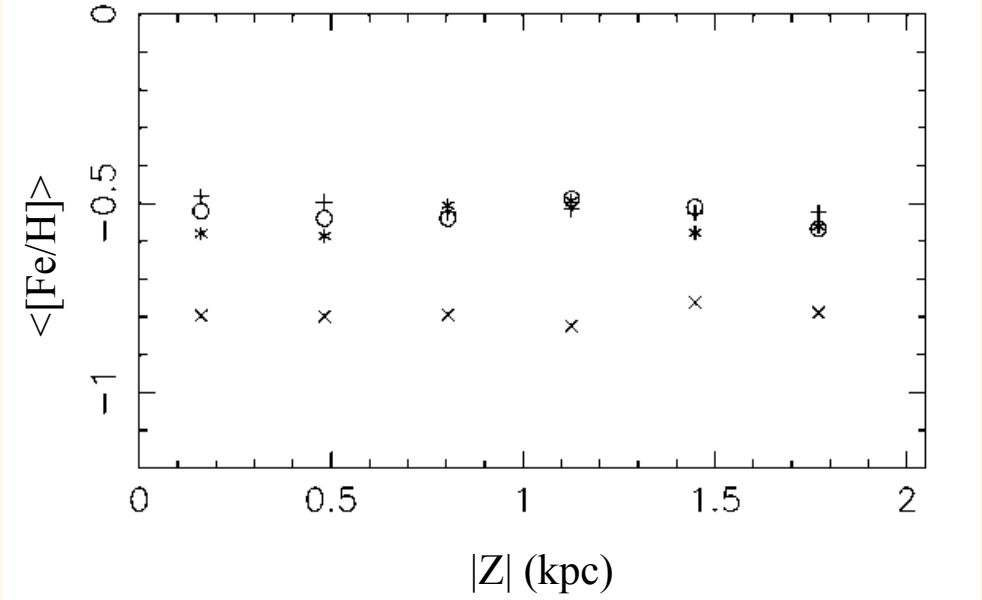
Vertical Structure

- Constraints for various disk formation models
  - Accretion of stars from satellites (Abadi et al. 2003)
  - Accretion of gas-rich material (Brook et al. 2004, 2005)
  - Vertical heating via mergers/close encounters (Kazantzidis et al. 2008, 2009, Bird et al. 2011)
  - Radial migration (Sellwood & Binney 2002, Roskar et al. 2008, Schönrich & Binney 2009, Minchev et al. 2010, 2011, Loebman et al. 2011)
- Thin/Thick disk separability
- Measure in external galaxies

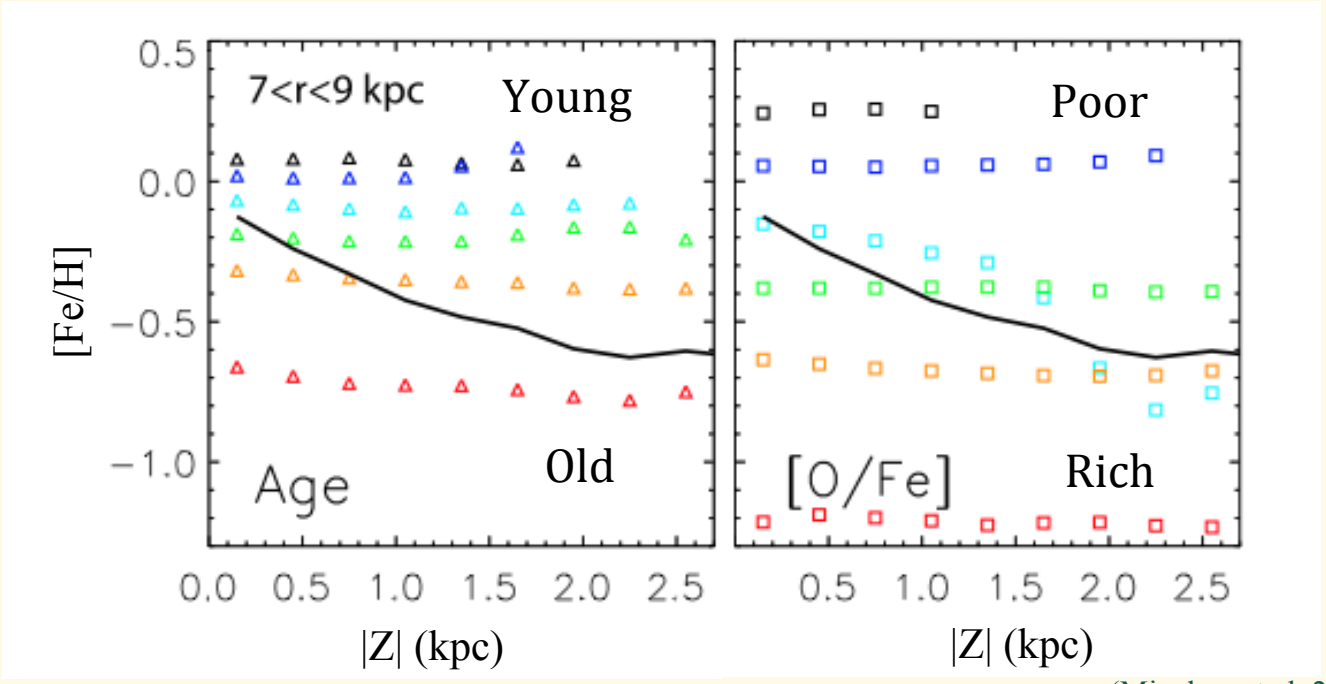
Abundance Trends



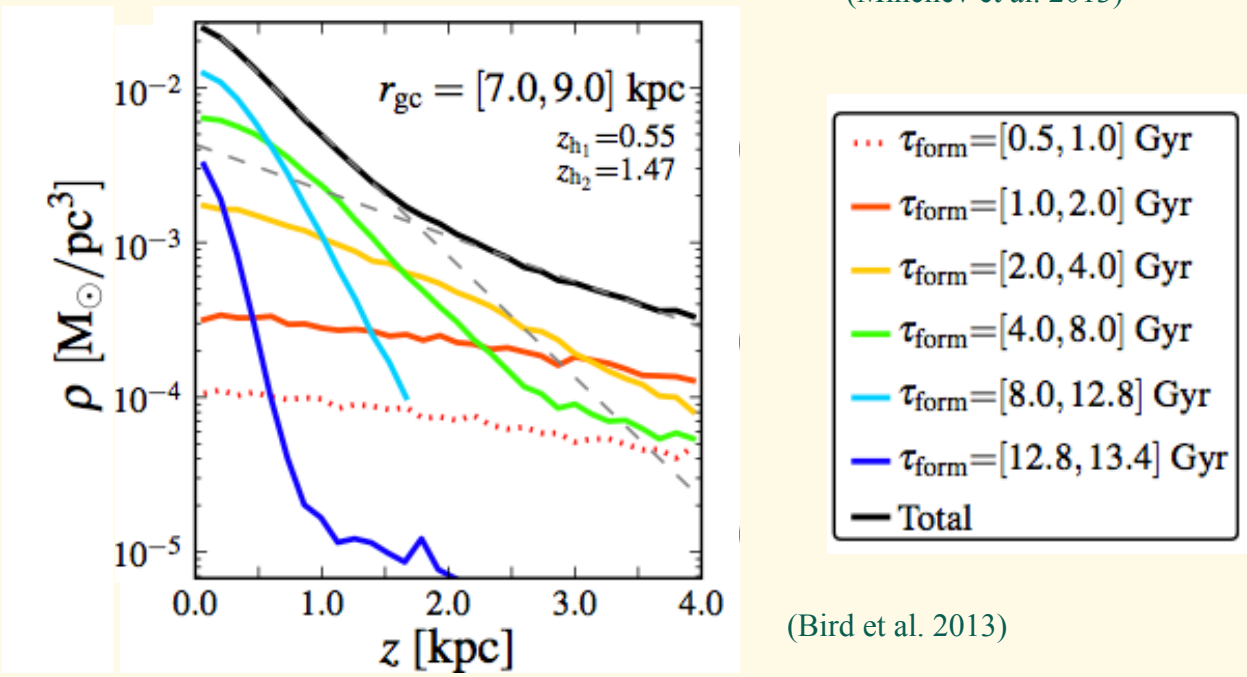
(Loebman et al. 2011)



(Brook et al. 2005)



(Minchev et al. 2013)



(Bird et al. 2013)

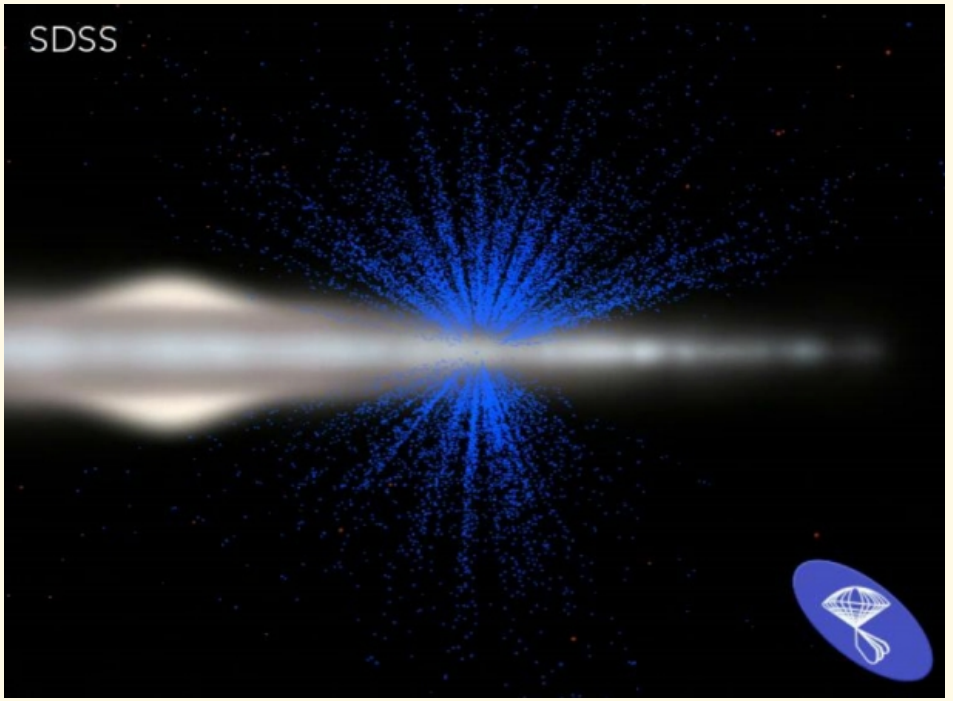
Previous Analyses

Work	Number of Stars	Metallicity	Distance Range	Spectral Types
Pagel & Patchett (1975)	133	Photometric	<25 pc	G
Wyse & Gilmore (1995)	127	Photometric	<30 pc	F/G
Rocha-Pinto & Maciel (1996)	287	Photometric	<25 pc	G
Flynn & Morell (1997)	179	Photometric	<25 pc	G/K
Favata et al. (1997)	91	Spectroscopic	<22 pc	G/K
Rocha-Pinto & Maciel (1998)	730	Photometric	<50 pc	F/G/K
Jørgensen (2000)	253	Photometric	<40 pc	F/G
Kotoneva et al. (2002)	431	Photometric	<25 pc	K

Survey	Number of Stars	Metallicity	Distance Range	Spectral Types
Geneva-Copenhagen Survey (GCS)	16,682	Photometric	<200 pc	F/G
RAdial Velocity Experiment (RAVE)	45,000	R~7,500	<1 kpc	
APOGEE	20,000	R~22,500 (IR)	0<R<15 kpc 0<Z<1.5 kpc	Giants
Gaia-ESO	$\geq 10^5$	R≤20,000	4<R<12 kpc 0<Z<3.5 kpc	
HARPS	1111	R~115,000	⊙ Nhood	F/G/K
Bensby et al.	714	R~40,-11,000	⊙ Nhood	F/G
SEGUE	240,000 (75,000 G/K)	R~2,000	6<R<11 kpc -2.5<Z<2.5 kpc	
SAGA	989	Photometric	7.6<R<8.6 kpc 0<Z<1.5 kpc	K Giants

SEGUE Survey

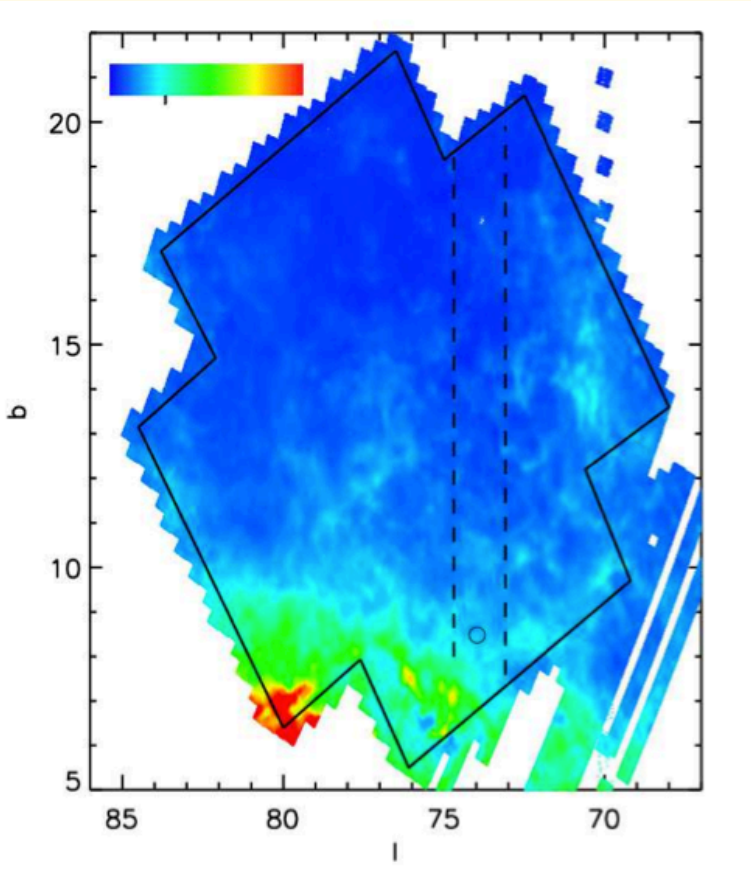
- *ugriz* photometry
  - $14 < g < 20.3$
- Large sky coverage
- Systematic target selection
- Low resolution optical spectra
- T_{eff}, log(g), [Fe/H], [α/Fe]
- Ca, Mg, (C, Si)
  (Fernández-Alvar et al., in prep)



Strömgren survey for Asteroseismology and Galactic Archaeology

(Casagrande et al. 2014)

- Strömgren photometry of giants and dwarfs in the *Kepler* field
- Over 29,000 sources as faint as $y \sim 18$
- 989 with seismic information



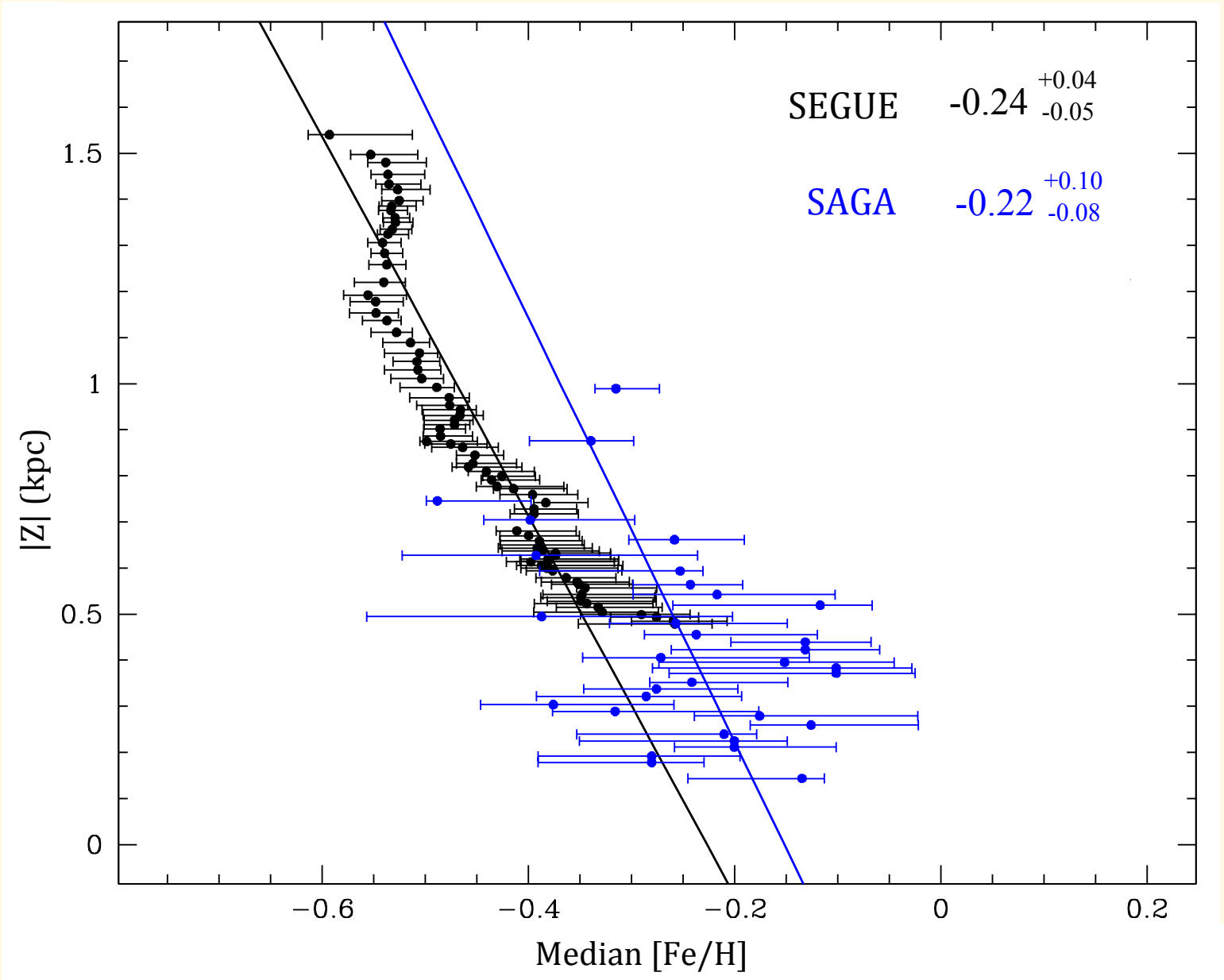
(Casagrande et al., 2014)

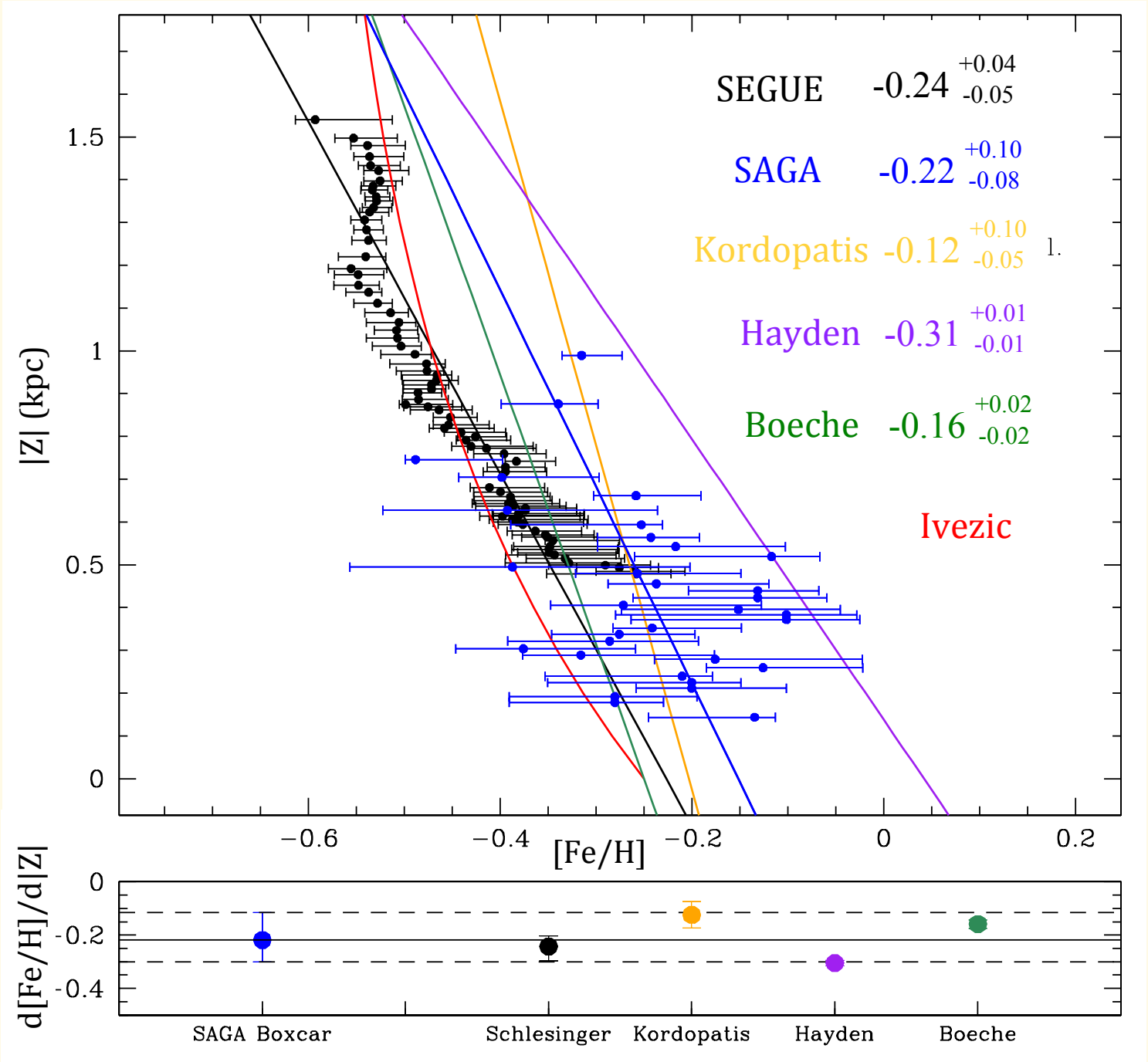
Strömgren survey for Asteroseismology and Galactic Archaeology

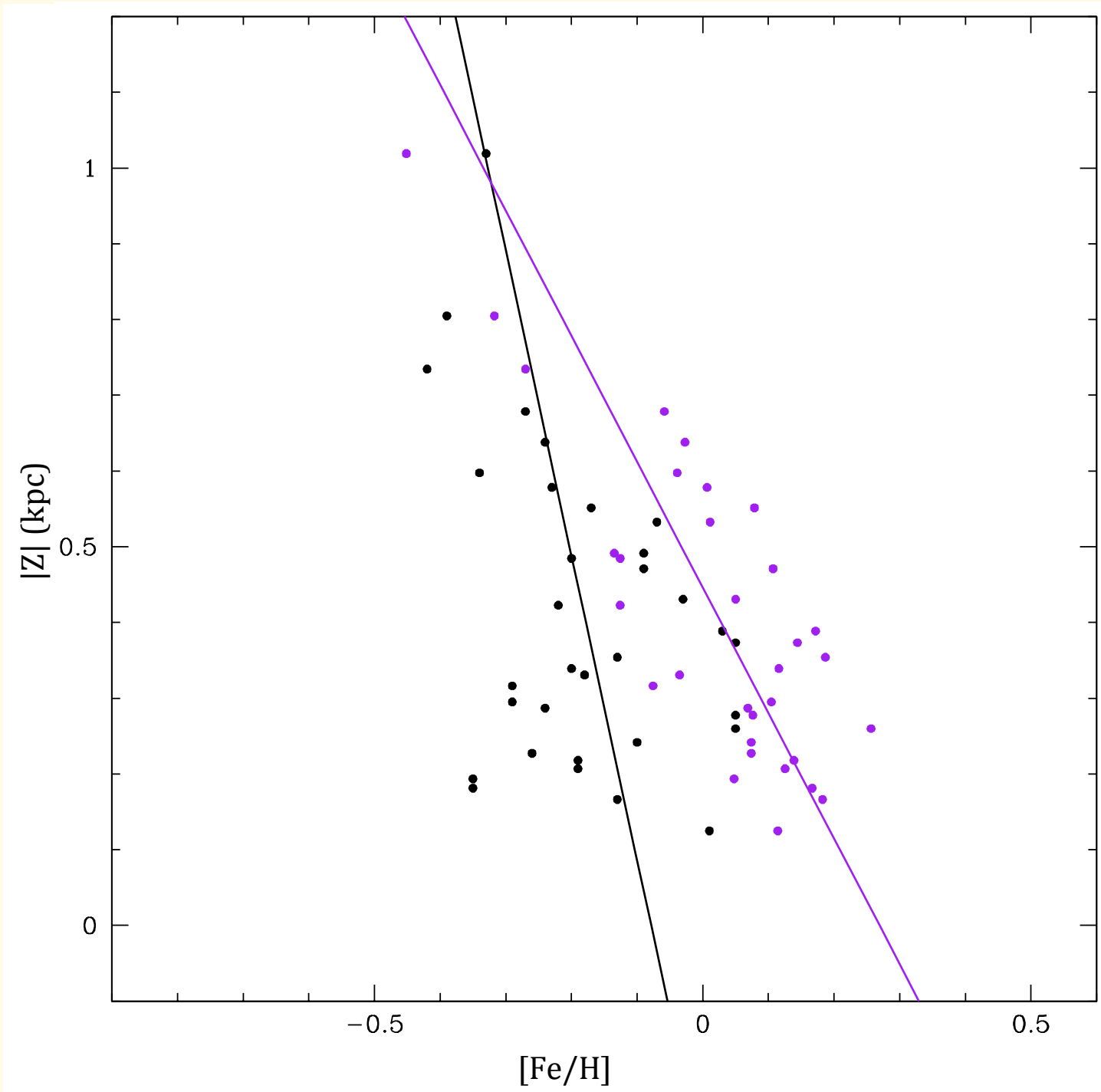
(Casagrande et al. 2014)

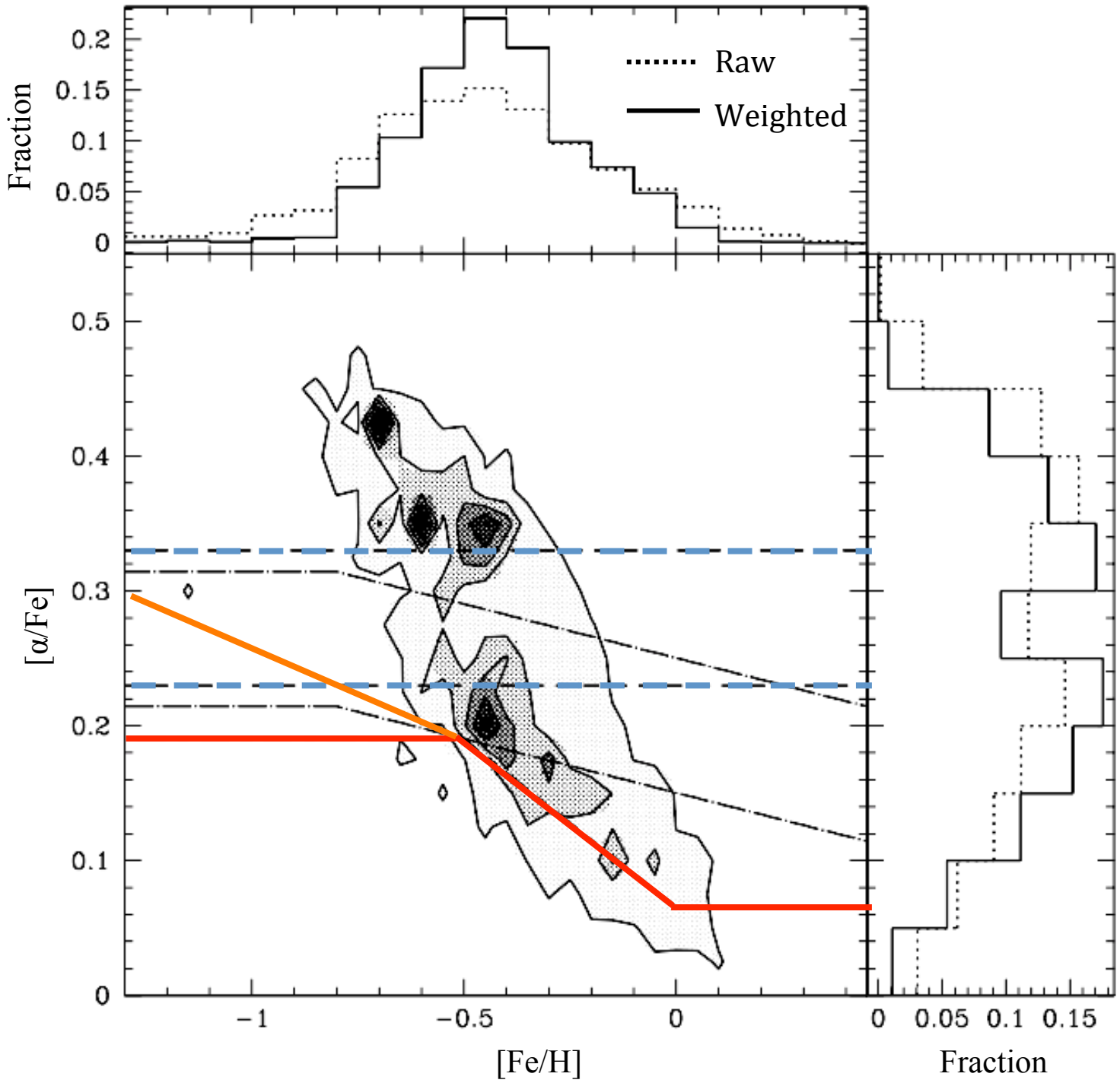
- IRFM to get T_{eff}, F_{bol}, θ, E(B-V)
- Color indices to get [Fe/H]
- *Kepler* Δν, ν_{max} to get M, log(g), Radii
- Mixed modes to determine evolutionary phase

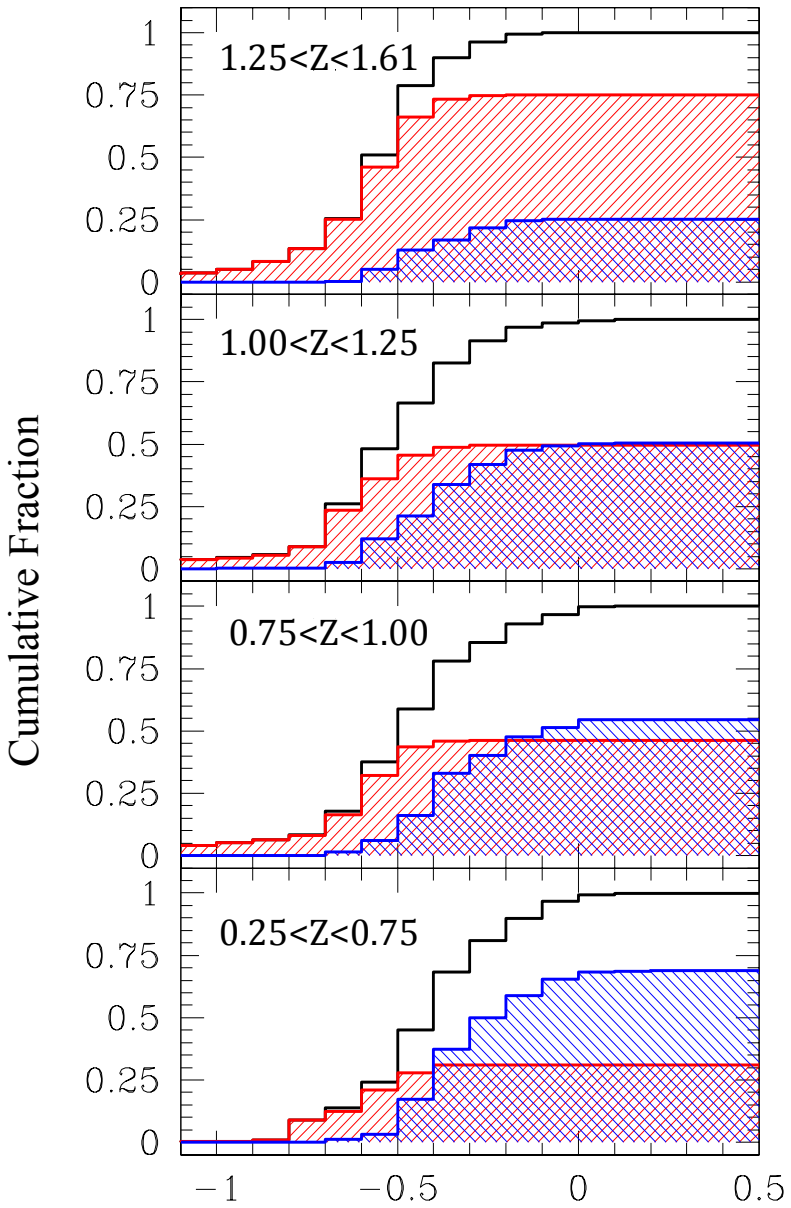
Parameter	Uncertainty
Temperature	82 K
[Fe/H]	0.17 dex
log(g)	0.006 dex
Distance	3.3%
Mass	6.0%
Age	10-30%

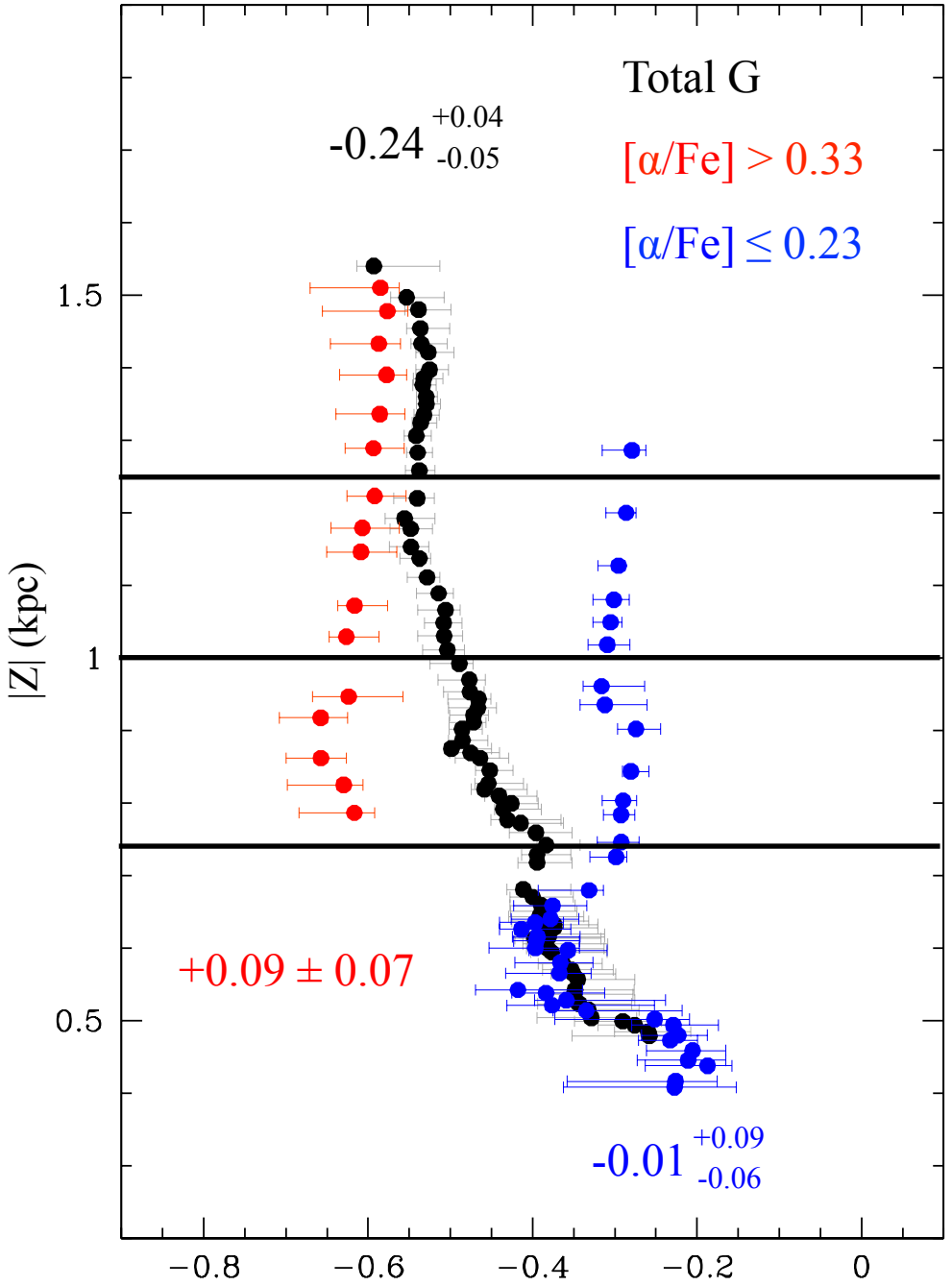

SEGUE -0.24 +0.04 -0.05
SAGA -0.22 +0.10 -0.08
|Z| (kpc)
1.5
1
0.5
0
−0.6
−0.4
−0.2
0
0.2
Median [Fe/H]

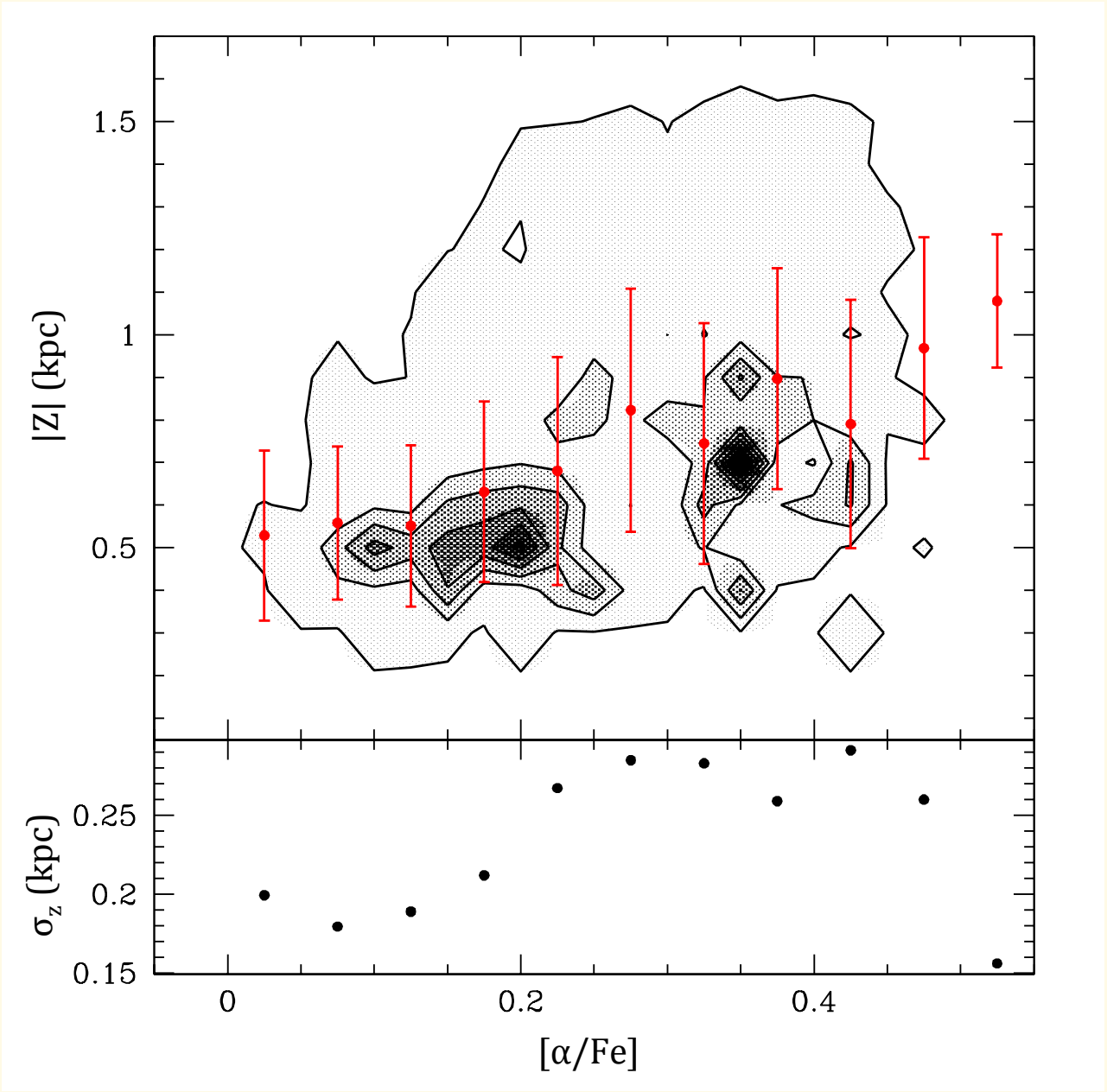

SEGUE -0.24 +0.04 -0.05
SAGA -0.22 +0.10 -0.08
Kordopatis -0.12 +0.10 -0.05
Hayden -0.31 +0.01 -0.01
Boeche -0.16 +0.02 -0.02
Ivezic
|Z| (kpc)
[Fe/H]
d[Fe/H]/d|Z|
SAGA Boxcar
Schlesinger
Kordopatis
Hayden
Boeche

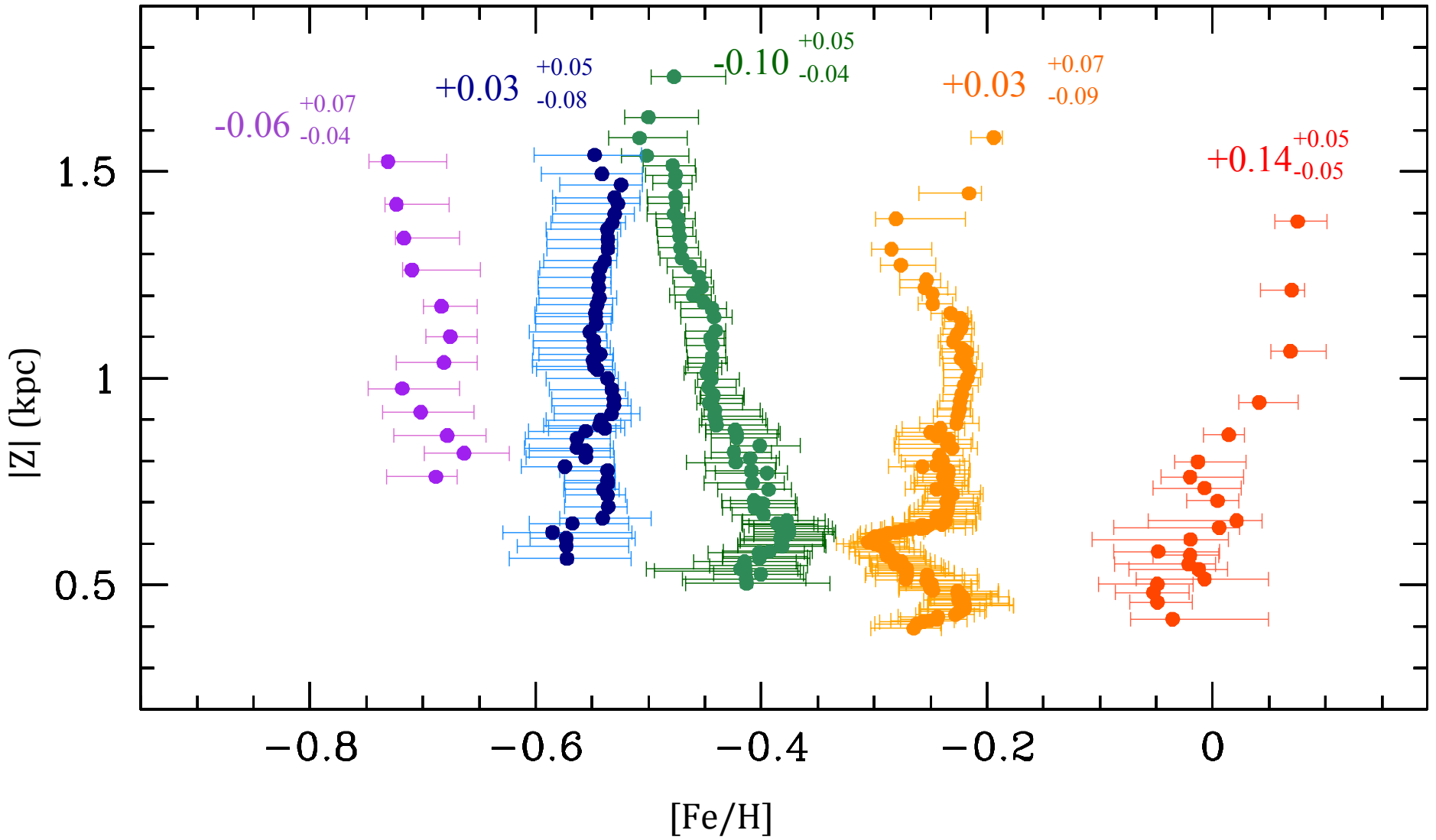

1
0.5
0
|Z| (kpc)
−0.5
0
0.5
[Fe/H]

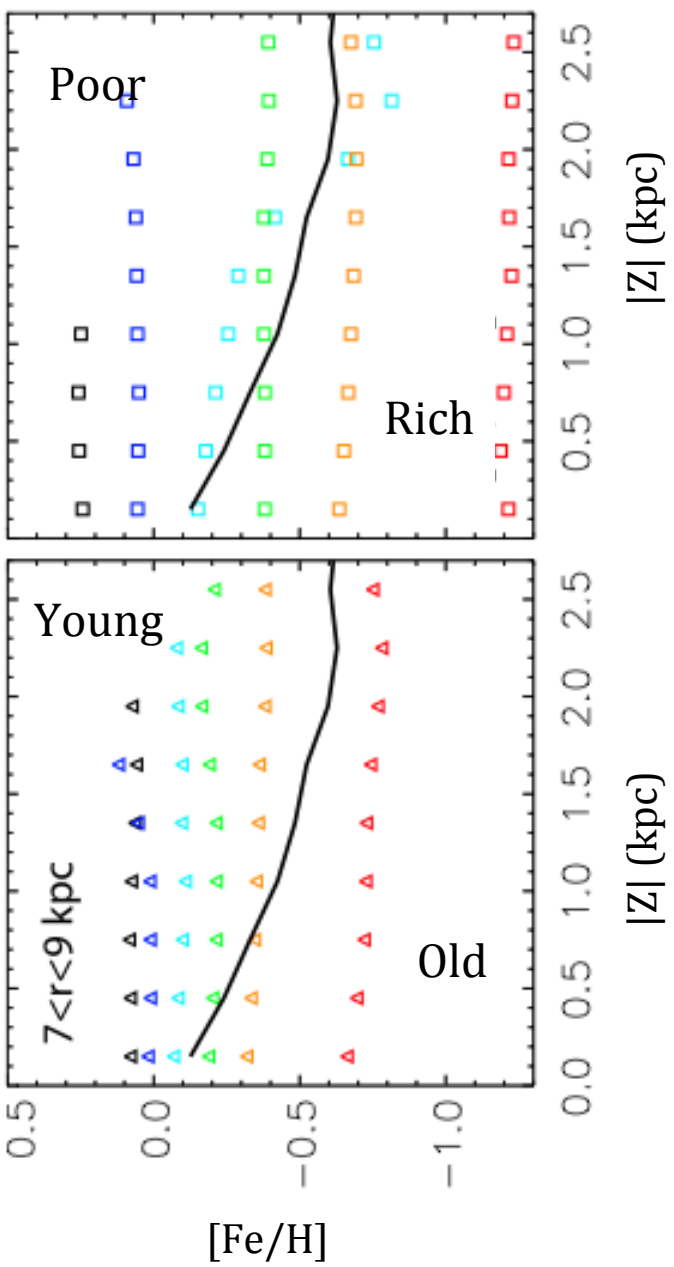

Raw
Weighted
Fraction
0.2
0.15
0.1
0.05
0
0.5
0.4
0.3
0.2
0.1
0
[α/Fe]
−1
−0.5
0
[Fe/H]
0
0.05
0.1
0.15
Fraction


Cumulative Fraction
1.25<Z<1.61
1.00<Z<1.25
0.75<Z<1.00
0.25<Z<0.75
1
0.75
0.5
0.25
0
−1
−0.5
0
0.5

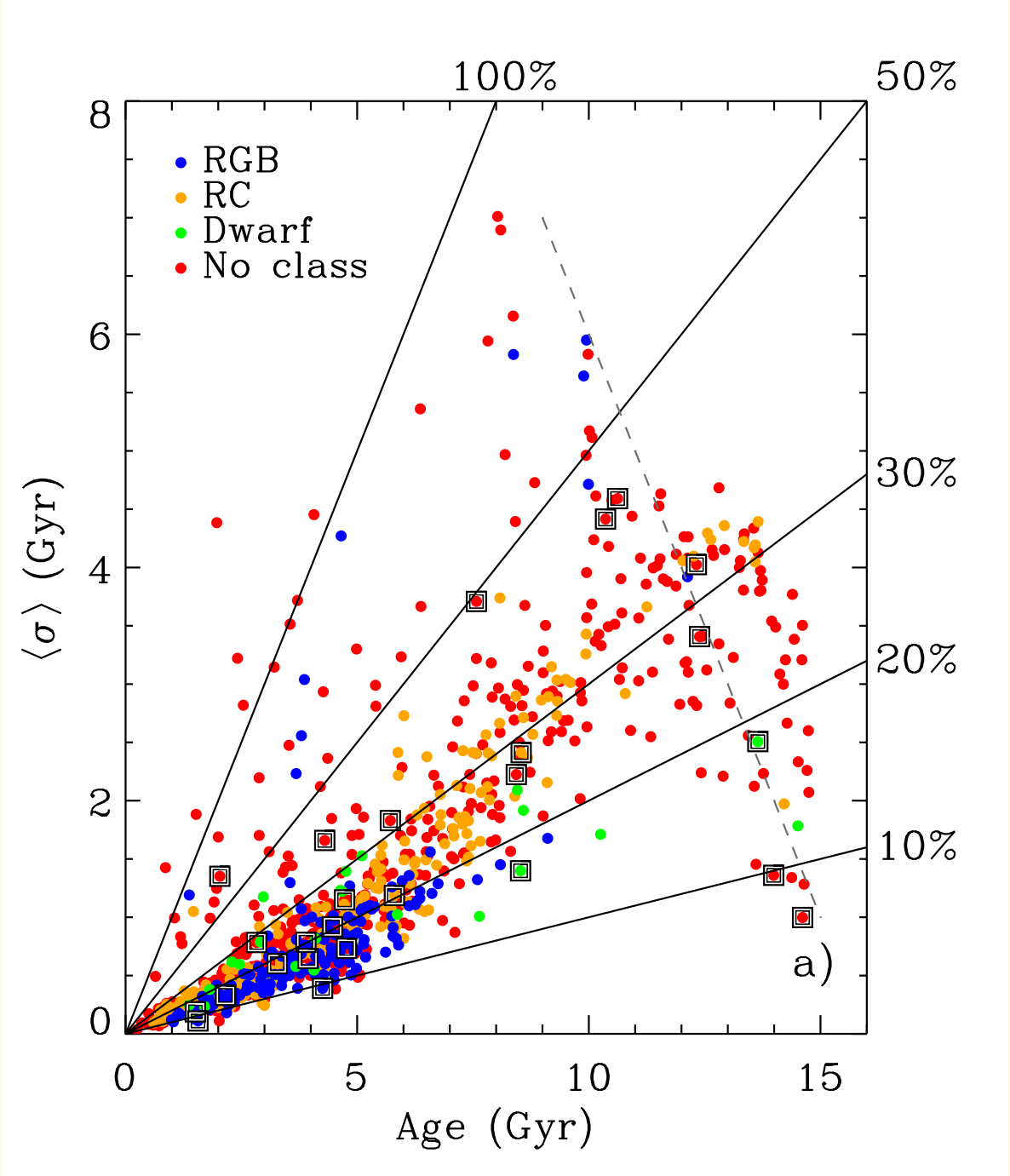

Total G
-0.24 +0.04 -0.05
[α/Fe] > 0.33
[α/Fe] ≤ 0.23
+0.09 ± 0.07
-0.01 +0.09 -0.06
|Z| (kpc)
1.5
1
0.5
−0.8
−0.6
−0.4
−0.2
0

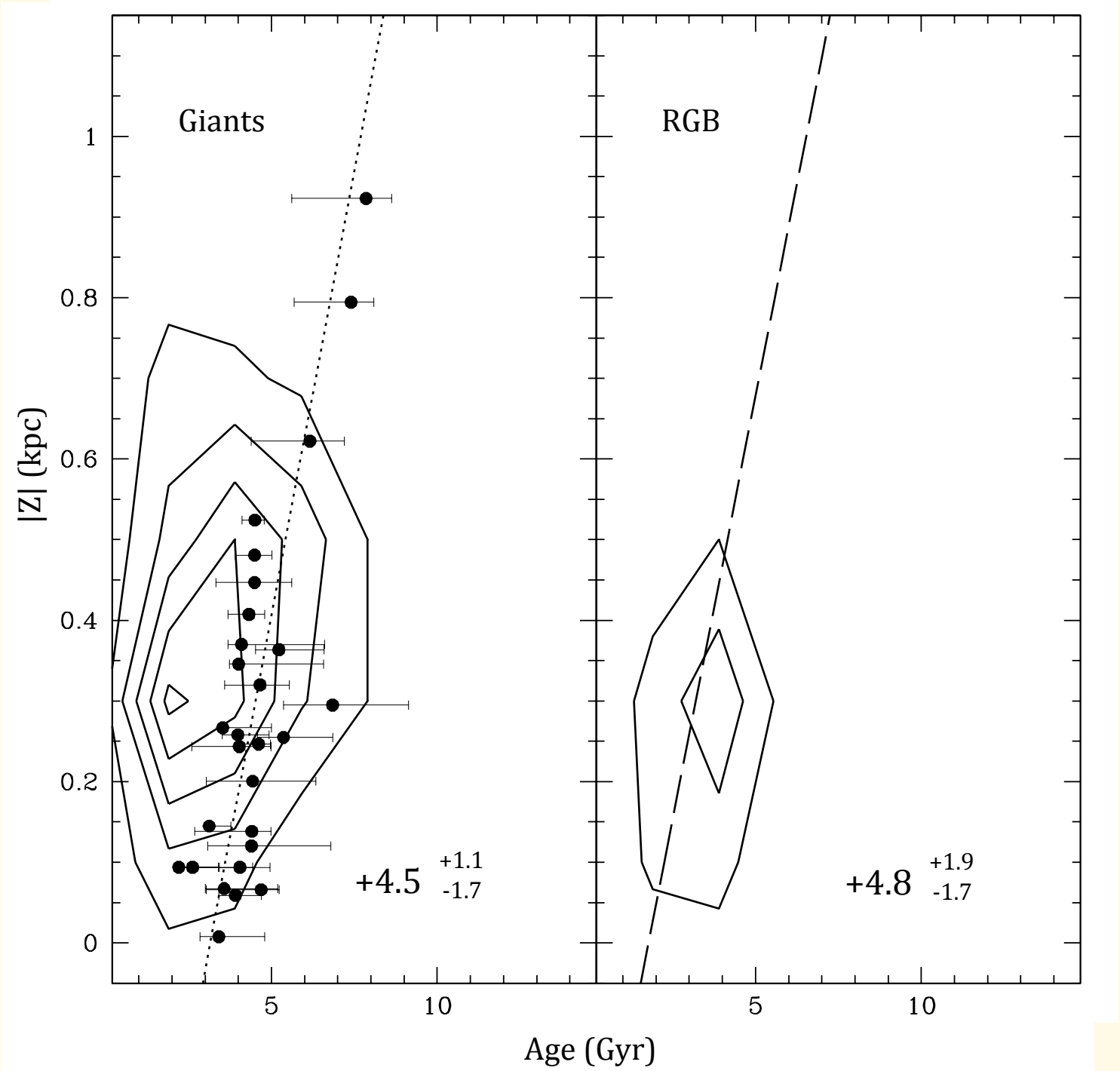

1.5
1
0.5
|Z| (kpc)
0.25
0.2
0.15
σz (kpc)
0
0.2
0.4
[α/Fe]


-0.06 +0.07 -0.04
+0.03 +0.05 -0.08
-0.10 +0.05 -0.04
+0.03 +0.07 -0.09
+0.14 +0.05 -0.05
1.5
1
0.5
|Z| (kpc)
−0.8
−0.6
−0.4
−0.2
0
[Fe/H]



(Minchev et al. 2013)


100%
50%
30%
20%
10%
RGB
RC
Dwarf
No class
a)
⟨σ⟩ (Gyr)
Age (Gyr)
0
2
4
6
8
0
5
10
15


Giants
RGB
|Z| (kpc)
Age (Gyr)
0
0.2
0.4
0.6
0.8
1
5
10
5
10
+4.5 +1.1 -1.7
+4.8 +1.9 -1.7

Summary

- Negative gradient (-0.23 dex/kpc) over disk reflects transition between [α/Fe] populations with respect to height
- See chemical gap in SEGUE but different than that of other surveys
- Individual [α/Fe] subsamples show negligible change with height
  - Consistent behavior from $0.1<[\alpha/Fe]<0.6$
  - Similar to various chemodynamical simulations (e.g., Bird et al. 2013, Minchev et al. 2014)
- See an age gradient of ~4.5 Gyr/kpc

Future Work

- SAGA gradients in age bins
- Age-Metallicity relation
- SAGA in conjunction with ESI and APOGEE chemical information
- Kinematic analysis of SAGA members

- High-resolution survey of a million stars in the Southern sky
- Survey well under way, with 100,000 targets observed

http://www.mso.anu.edu.au/galah/home.html

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