APOGEE-1/2

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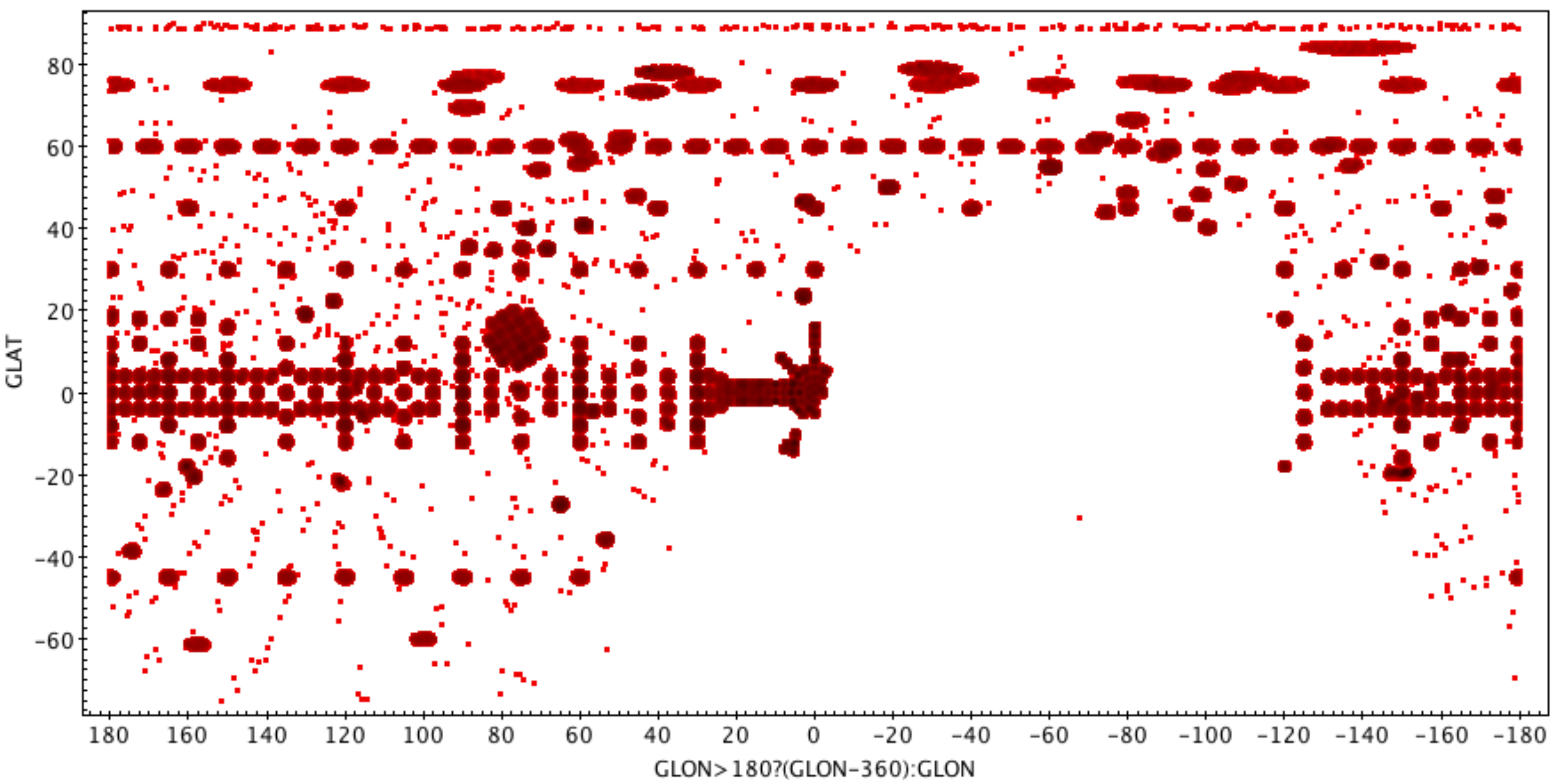
Outlines

- Introduction of the two surveys
- Some interesting works
  - Metallicity and evolution
  - dynamics
- What we are working on
  - Spatial distribution of the metallicity with RC
  - Cross-calibration with LAMOST
  - Dynamical modeling

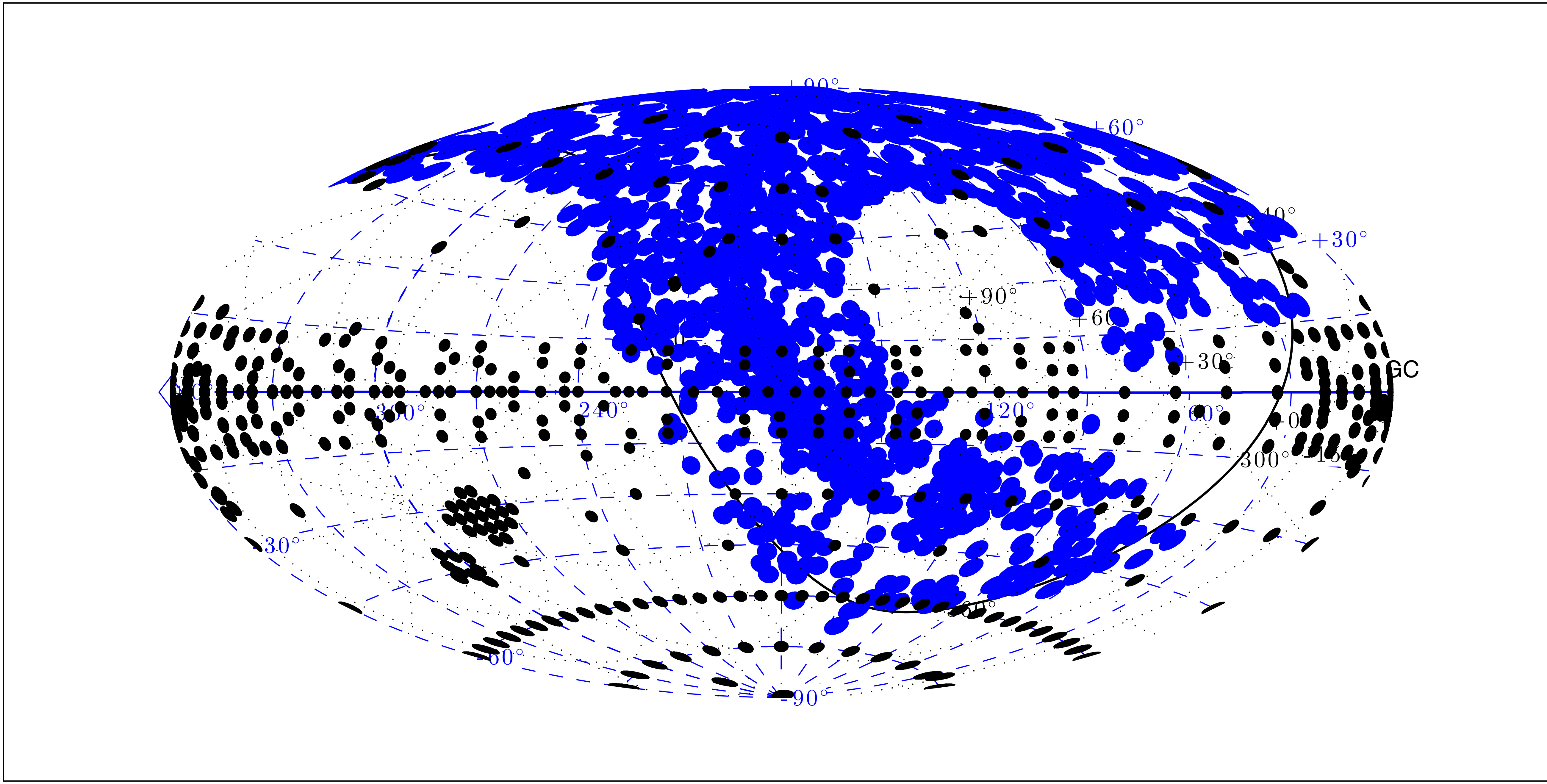
Introduction

DR12



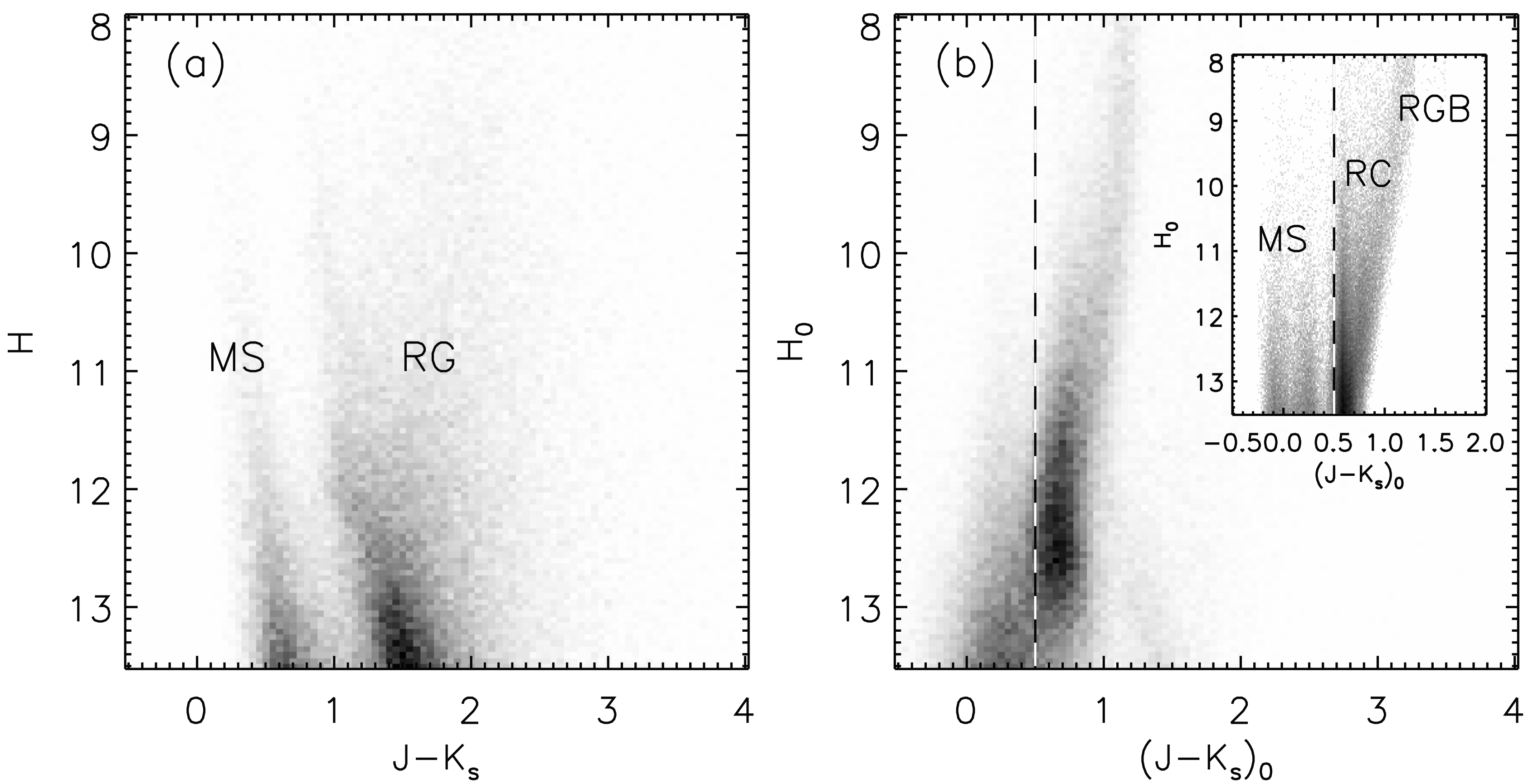
- Basics
  - H band (1.51-1.70mu)
  - R=22,500, 300 fibers
  - H_lim=12.2
  - t_expos=3hrs
  - S/N~100
  - sigma_v~0.1km/s
  - N=100,000
- DR12: N~163,278
- ASPCAP
  - RV, Teff, logg, [M/H],[alpha/M]
  - [C/M], [N/M]...

APOGEE-2 (S/N)



Targets selection

Disk targeting:



$A_K = 0.918(H-[4.5]-(H-[4.5])_0)$

$E(J-K) = 1.5A_K$

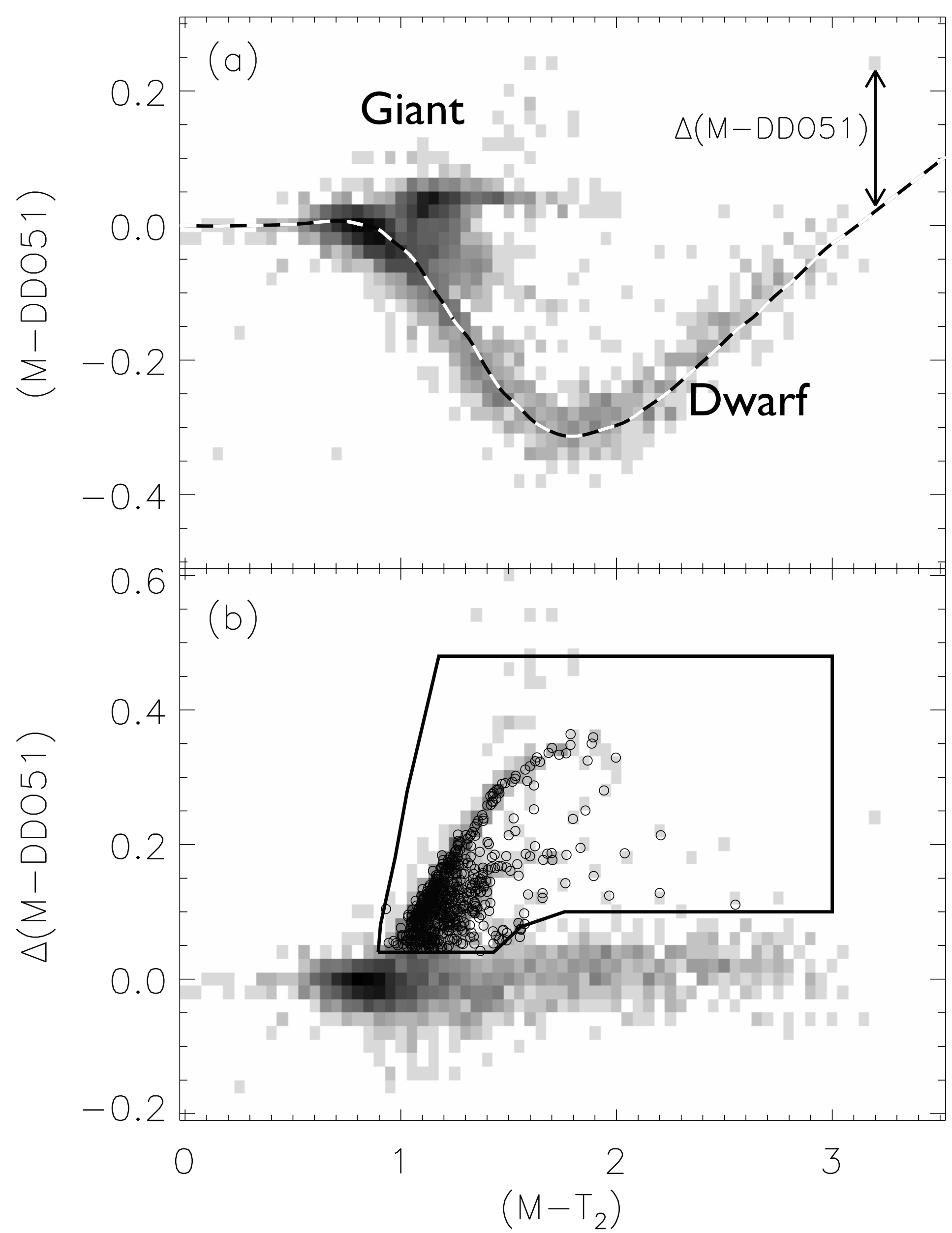
Majewski et al. 2011

Tagrets selection

Washington+DDO51
help to disentangle
the giant stars

Tagrets selection

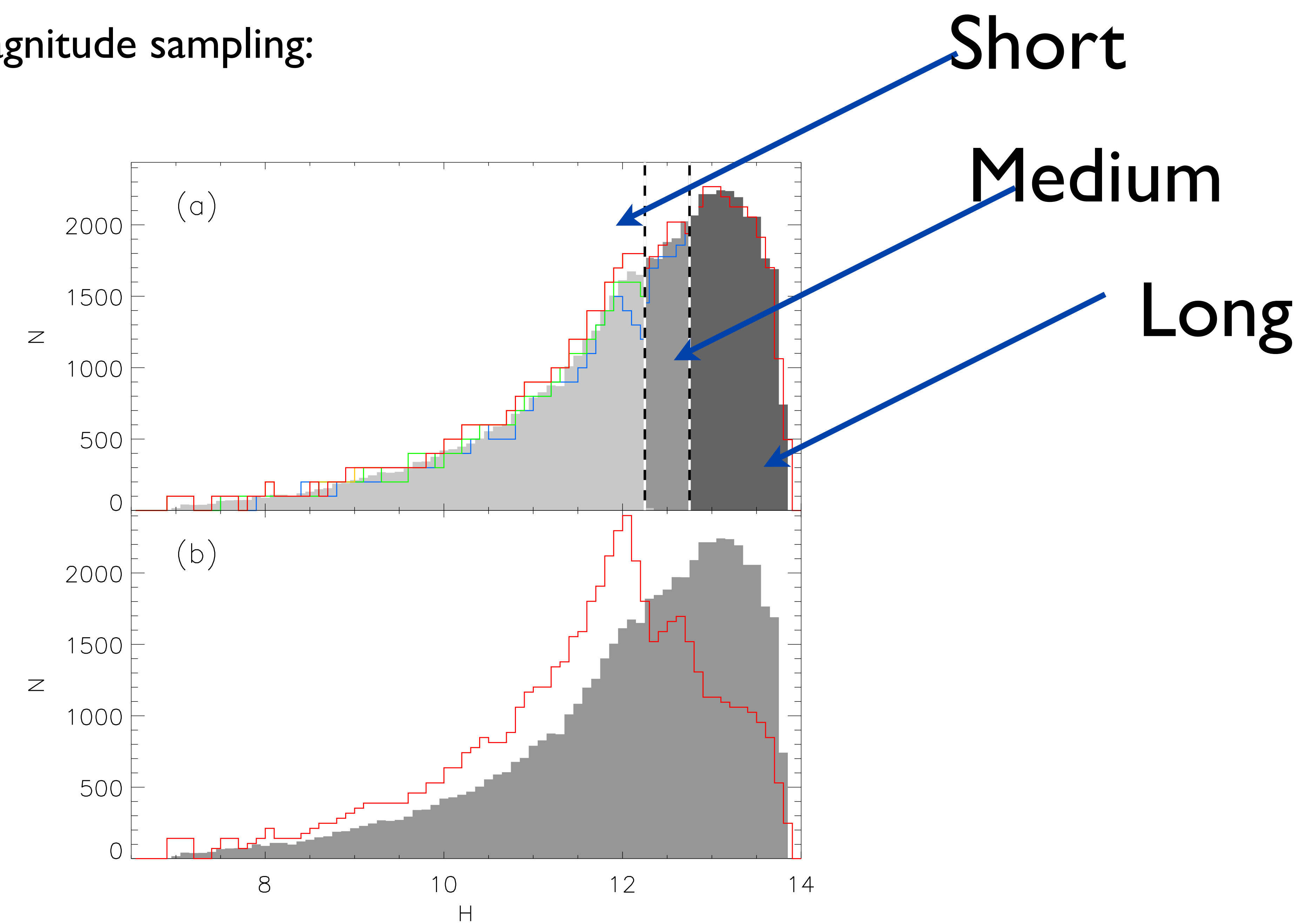
Halo targeting:

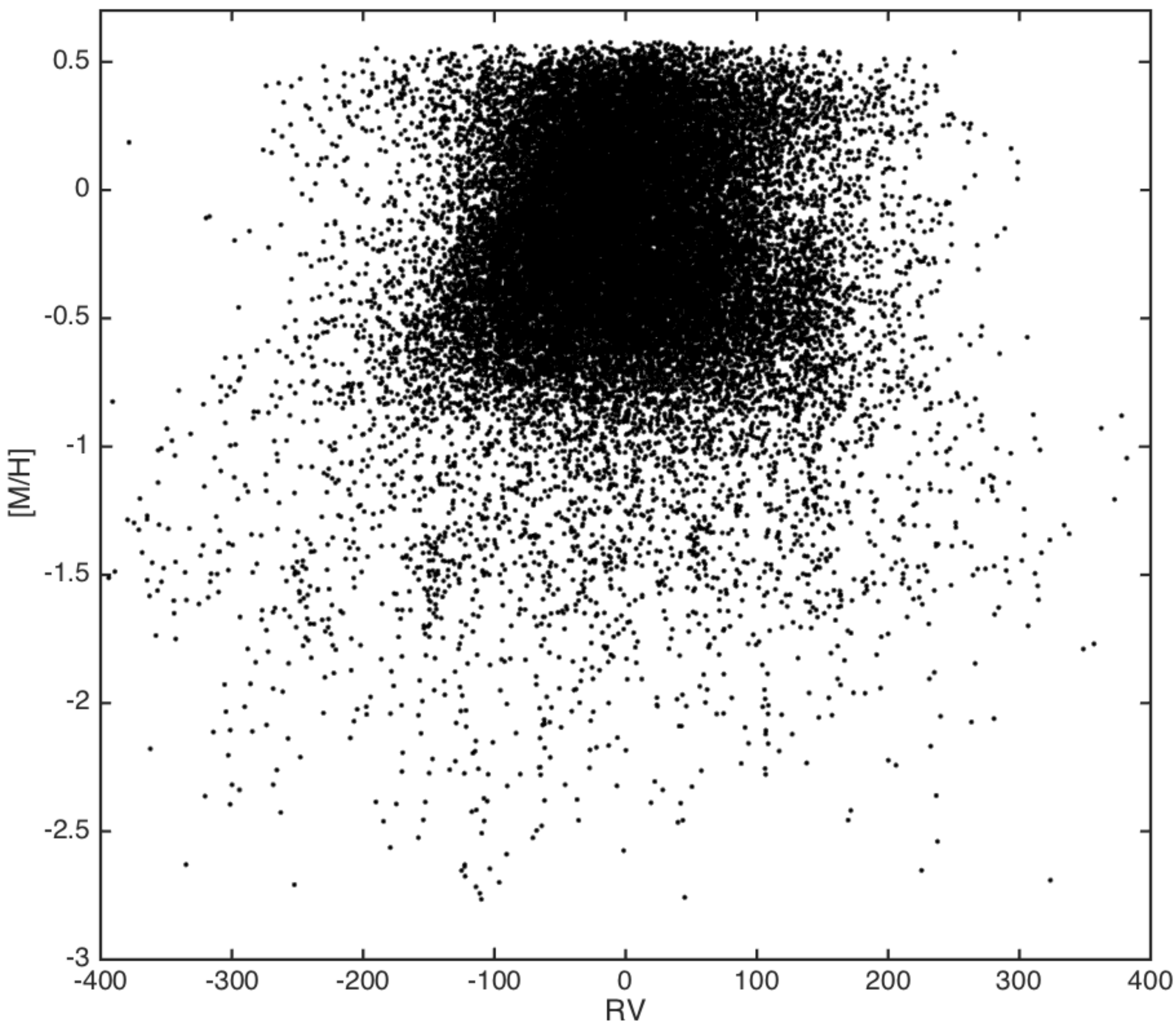


Washington+DDO51 help to disentangle the giant stars

Targets selection

magnitude sampling:

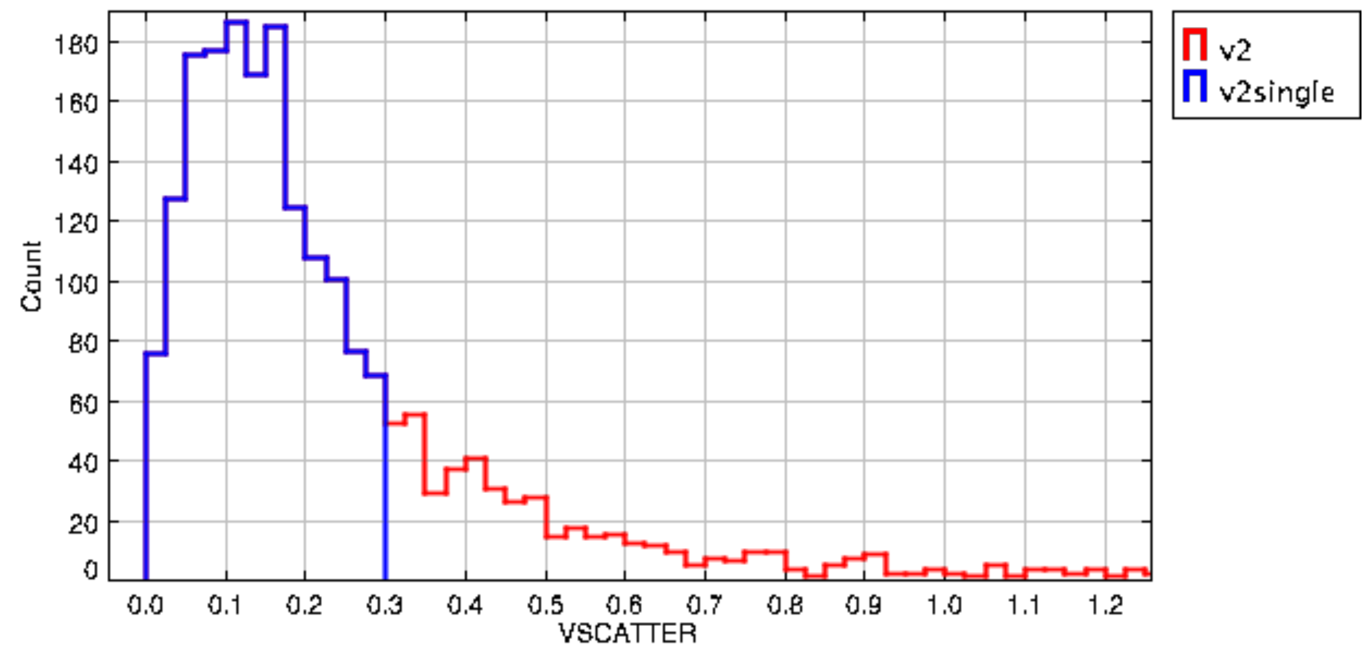


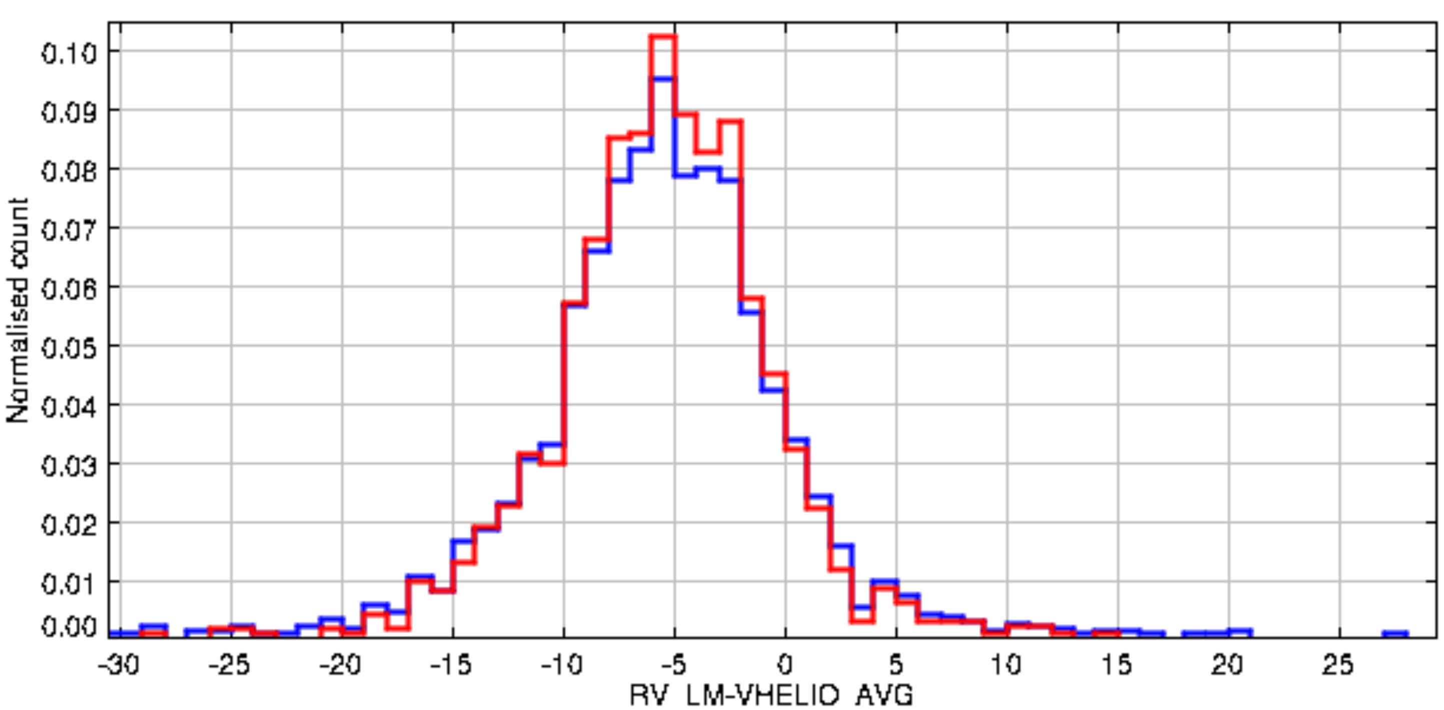


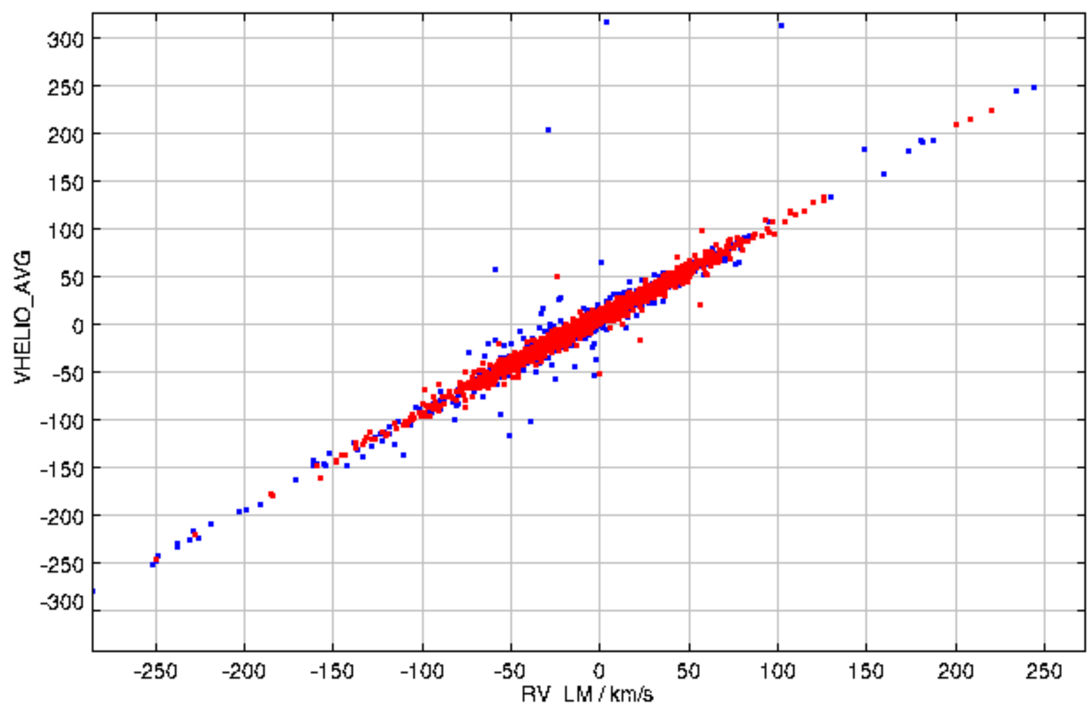
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
[M/H]
-400
-300
-200
-100
0
100
200
300
400
RV

- 2267 common objects given NVISITS>1, good apogee spectra (ASPCAPFLAG bit23 = 0)

- 1566 single stars







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15	☑	K_ERR	$14	Float				E
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19	☑	GLAT	$18	Double				D
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25	☑	SNR	$24	Float				E
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28	☑	ANDFLAG	$27	Integer				J
29	☑	ANDFLAGS	$28	String				59A
30	☑	VHELIO_AVG	$29	Float				E
31	☑	VSCATTER	$30	Float				E
32	☑	VERR	$31	Float				E
33	☑	VERR_MED	$32	Float				E
34	☑	SYNTHVHELIO_AVG	$33	Float				E
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39	☑	RV_LOGG	$38	Float				E
40	☑	RV_FEH	$39	Float				E
41	☑	RV_CCFWHM	$40	Float				E
42	☑	RV_AUTOFWHM	$41	Float				E
43	☑	SYNTHSCATTER	$42	Float				E
44	☑	STABLERV_CHI2	$43	float[]	2			2E
45	☑	STABLERV_RCHI2	$44	float[]	2			2E
46	☑	CHI2_THRESHOLD	$45	float[]	2			2E

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TOPCAT(1): Table Columns

Table Columns for 1: allStar-v603.fits

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52	☑	PARAM	$51	float[]	7			7E
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55	☑	FPARAM_COV	$54	float[]	49			49E
56	☑	ELEM	$55	float[]	15			15E
57	☑	FELEM	$56	float[]	15			15E
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73	☑	AL_H	$72	Float				E
74	☑	CA_H	$73	Float				E
75	☑	C_H	$74	Float				E
76	☑	FE_H	$75	Float				E
77	☑	K_H	$76	Float				E
78	☑	MG_H	$77	Float				E
79	☑	MN_H	$78	Float				E
80	☑	NA_H	$79	Float				E
81	☑	NI_H	$80	Float				E
82	☑	N_H	$81	Float				E
83	☑	O_H	$82	Float				E
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89	☑	CA_H_ERR	$88	Float				E

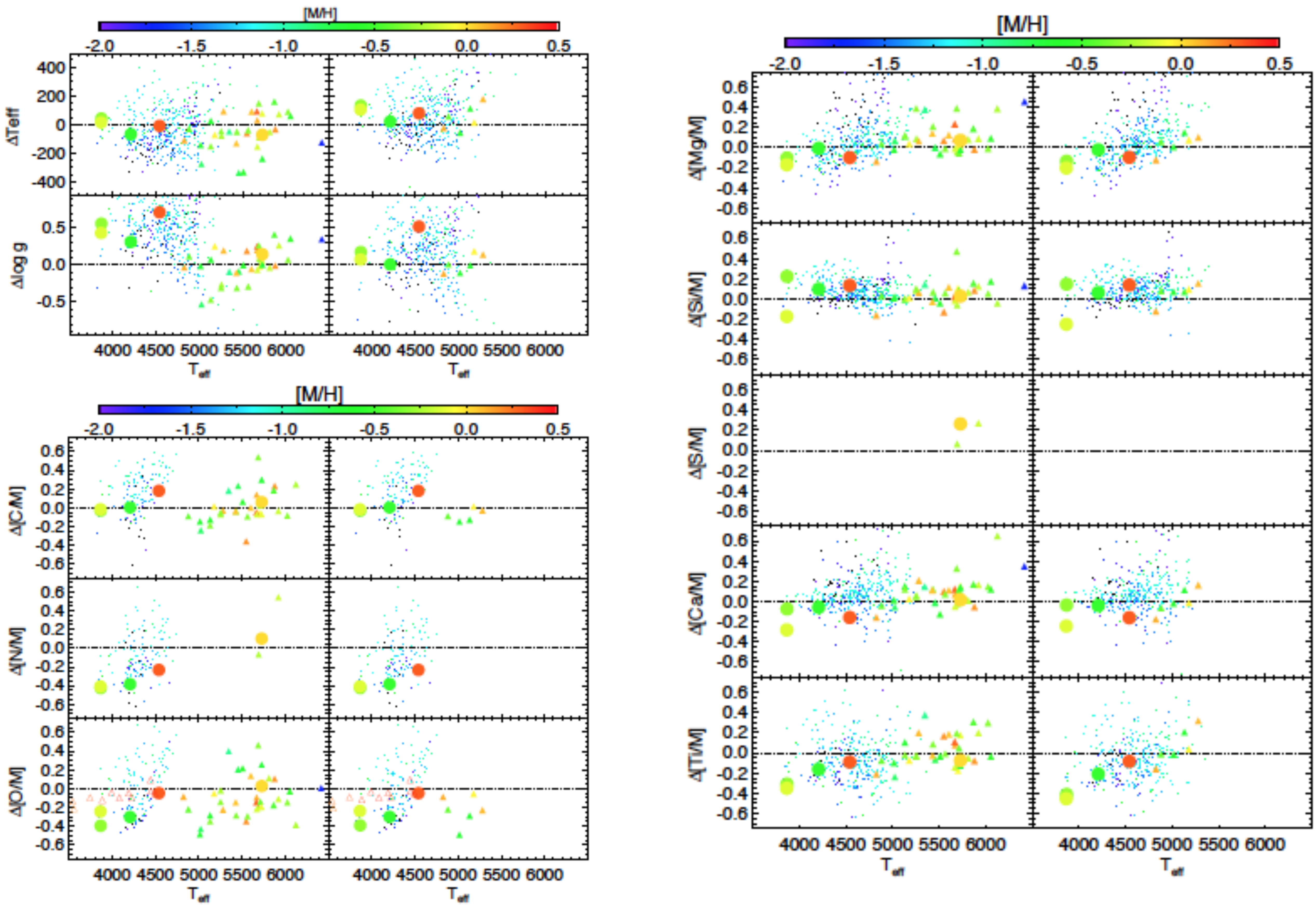
Current Working groups

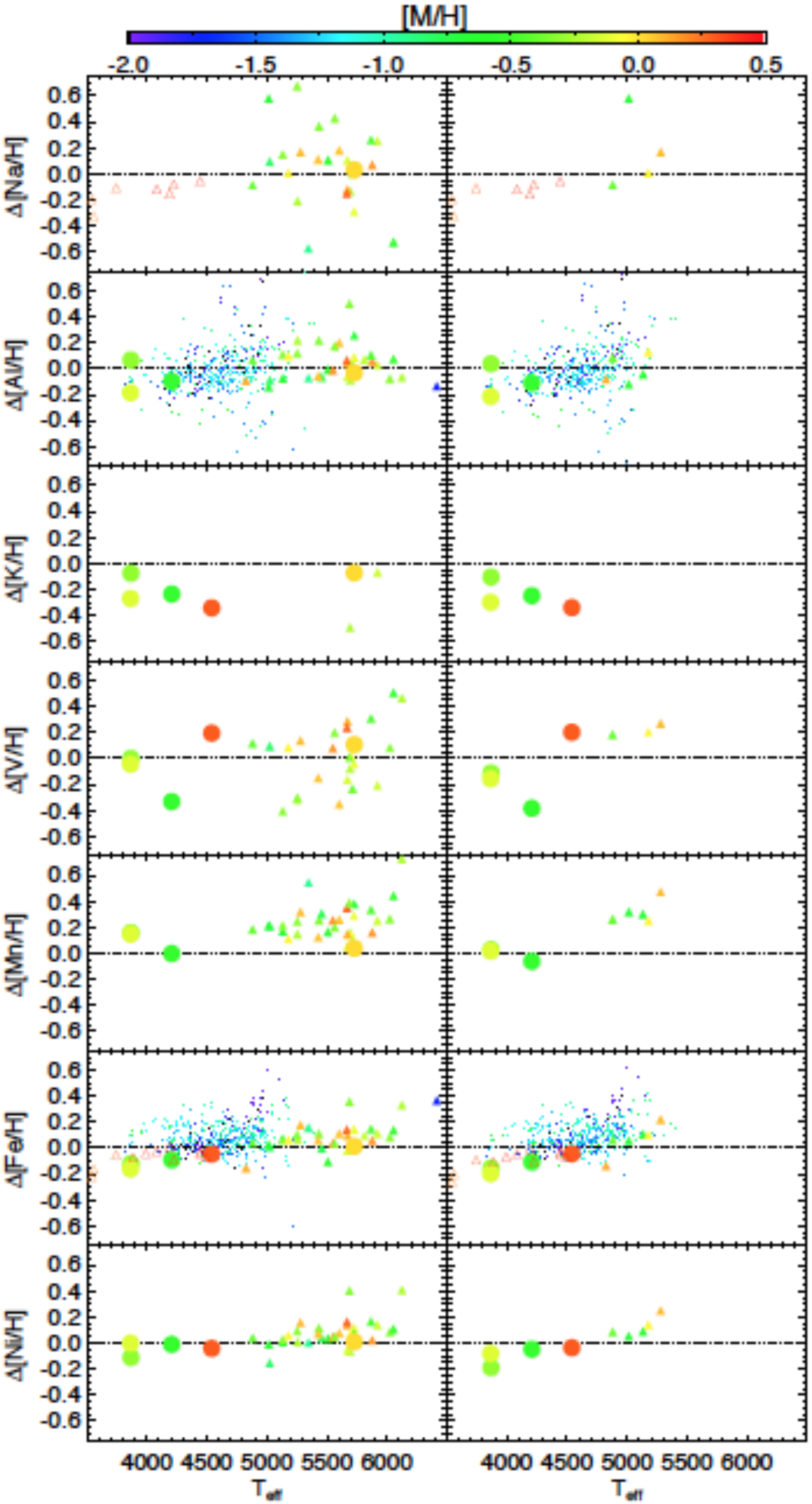
- Disk
- Bulge
- Halo
- Clusters
- AGB stars
- Be stars
- YSOs
- dwarf galaxies

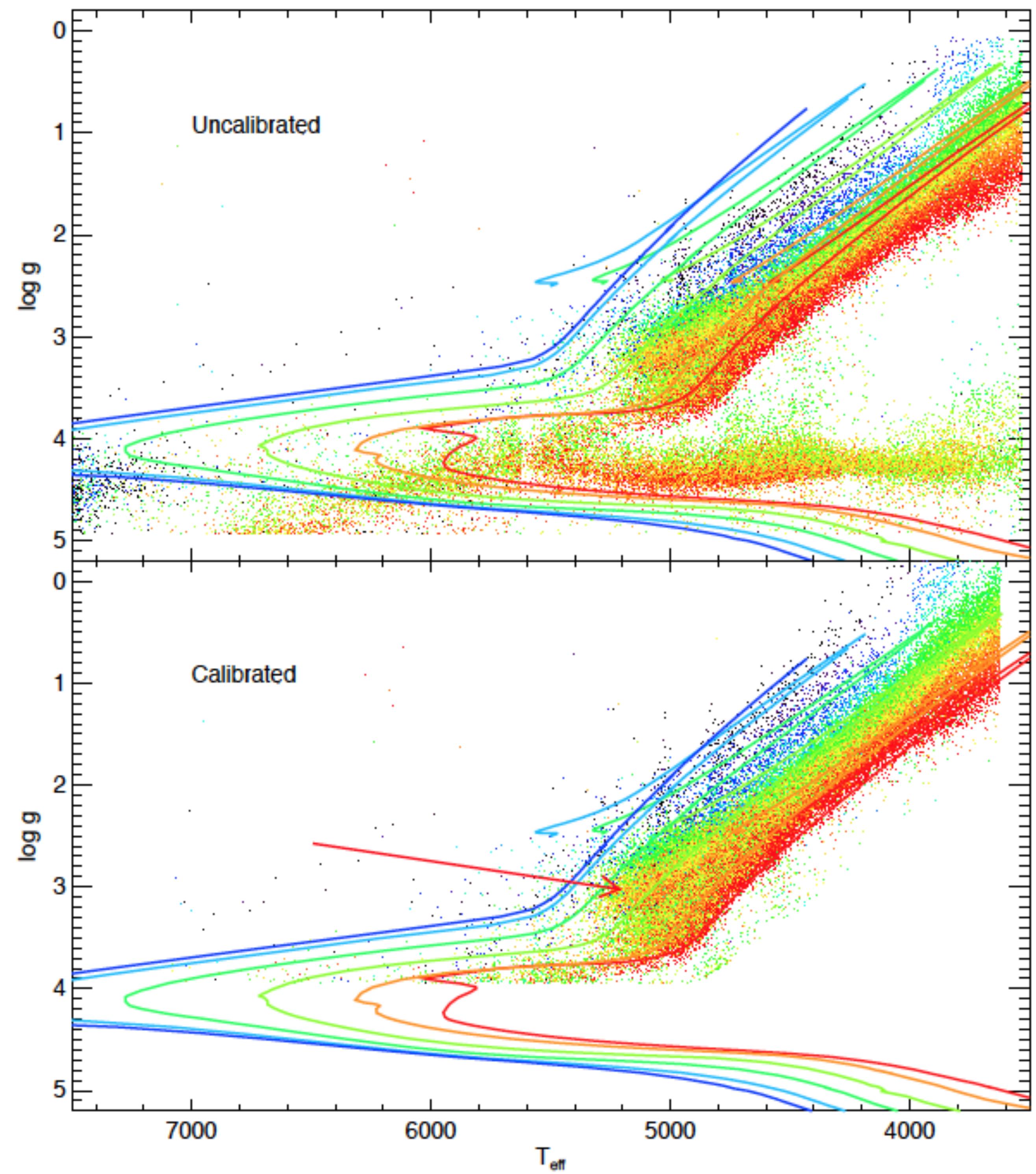
Some interesting works

- Stellar parameterization
  - Holtzman et al. 2015
  - Ness et al. 2015
- Metallicity
  - Anders et al. 2014
  - Bovy et al. 2014
  - Hayden et al. 2015
- Interstellar medium
  - Wang & Jiang 2015
  - Zasowski et al. 2015
- Evolution (APOKASC)
  - Pinsonneault et al. 2014
- Clusters
  - Frinchaboy et al. 2013
- Dynamics
  - Bovy et al. 2013

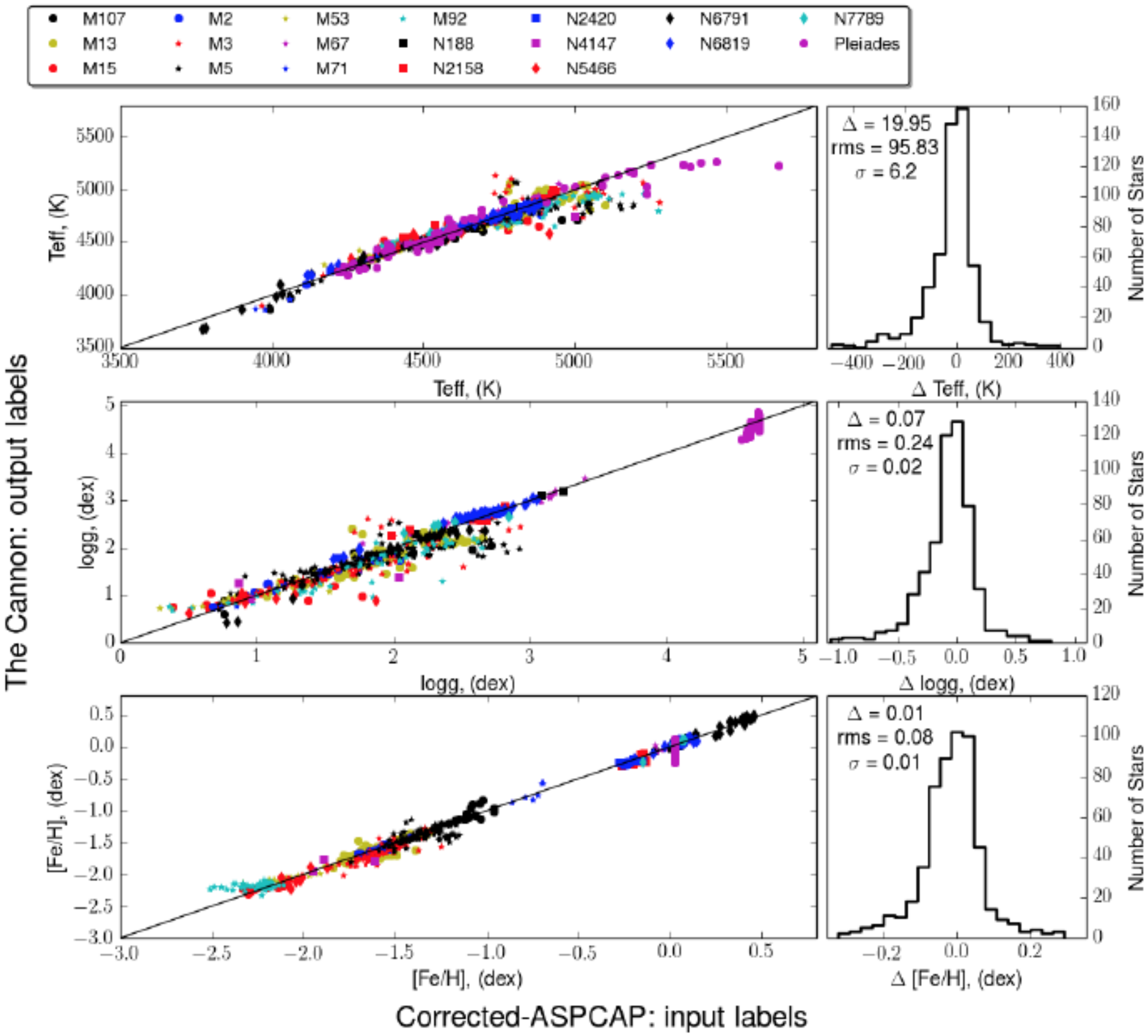
Holtzman et al. 2015
Garcia Perez et al. 2015 (ASPCAP)




[M/H]
-2.0
-1.5
-1.0
-0.5
0.0
0.5
Δ[Na/H]
Δ[Al/H]
Δ[K/H]
Δ[V/H]
Δ[Mn/H]
Δ[Fe/H]
Δ[Ni/H]
4000 4500 5000 5500 6000
T_{eff}


Uncalibrated
Calibrated
log g
7000
6000
5000
4000
T_{eff}

Ness et al. 2015



$$\ell_{nk} \ (\mathrm{T_{eff}}, \log \mathrm{g}, [\mathrm{Fe/H}], \cdots)$$

$$f_{n\lambda} \ = \ \boldsymbol{\theta}_\lambda^T \cdot \boldsymbol{\ell}_n + \mathrm{noise}$$

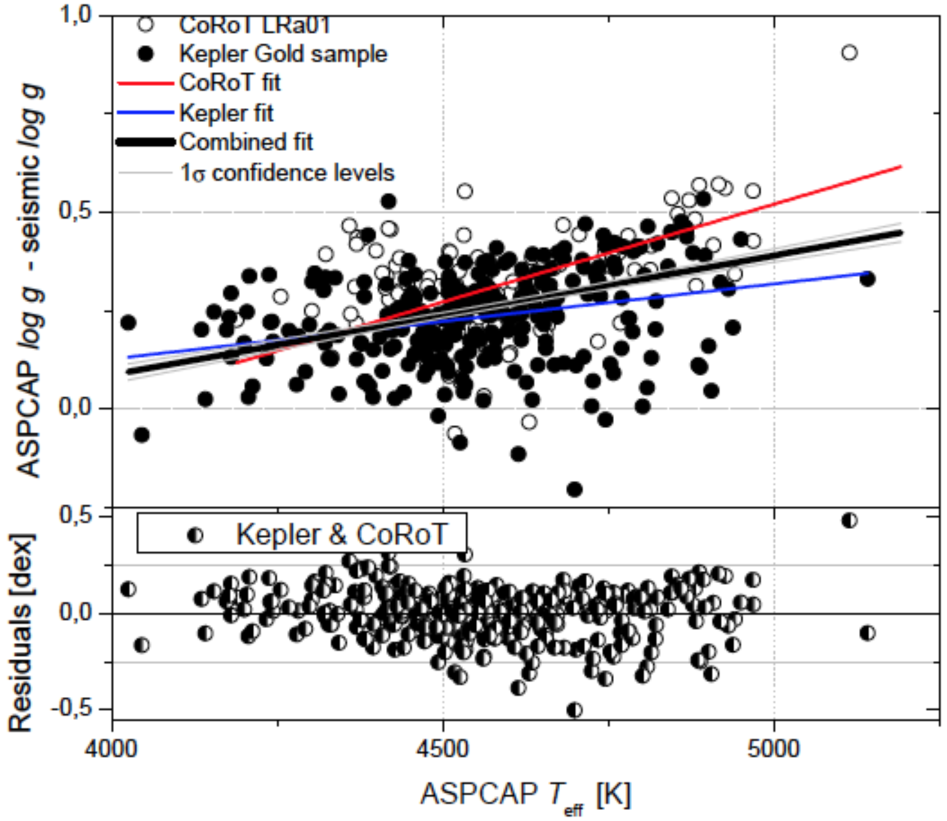
$$\boldsymbol{\ell}_n \ \equiv \ [1, \ell_{n1} - \overline{\ell_1}, \ell_{n2} - \overline{\ell_2}, \cdots, \ell_{nK} - \overline{\ell_K}]$$

$$\ln p(f_{n\lambda} \,|\, \boldsymbol{\theta}_\lambda^T, \boldsymbol{\ell}_n, s_\lambda^2) \ = \ -\frac{1}{2}\frac{[f_{n\lambda} - \boldsymbol{\theta}_\lambda^T \cdot \boldsymbol{\ell}_n]^2}{s_\lambda^2 + \sigma_{n\lambda}^2} - \frac{1}{2}\ln(s_\lambda^2 + \sigma_{n\lambda}^2)$$

Training

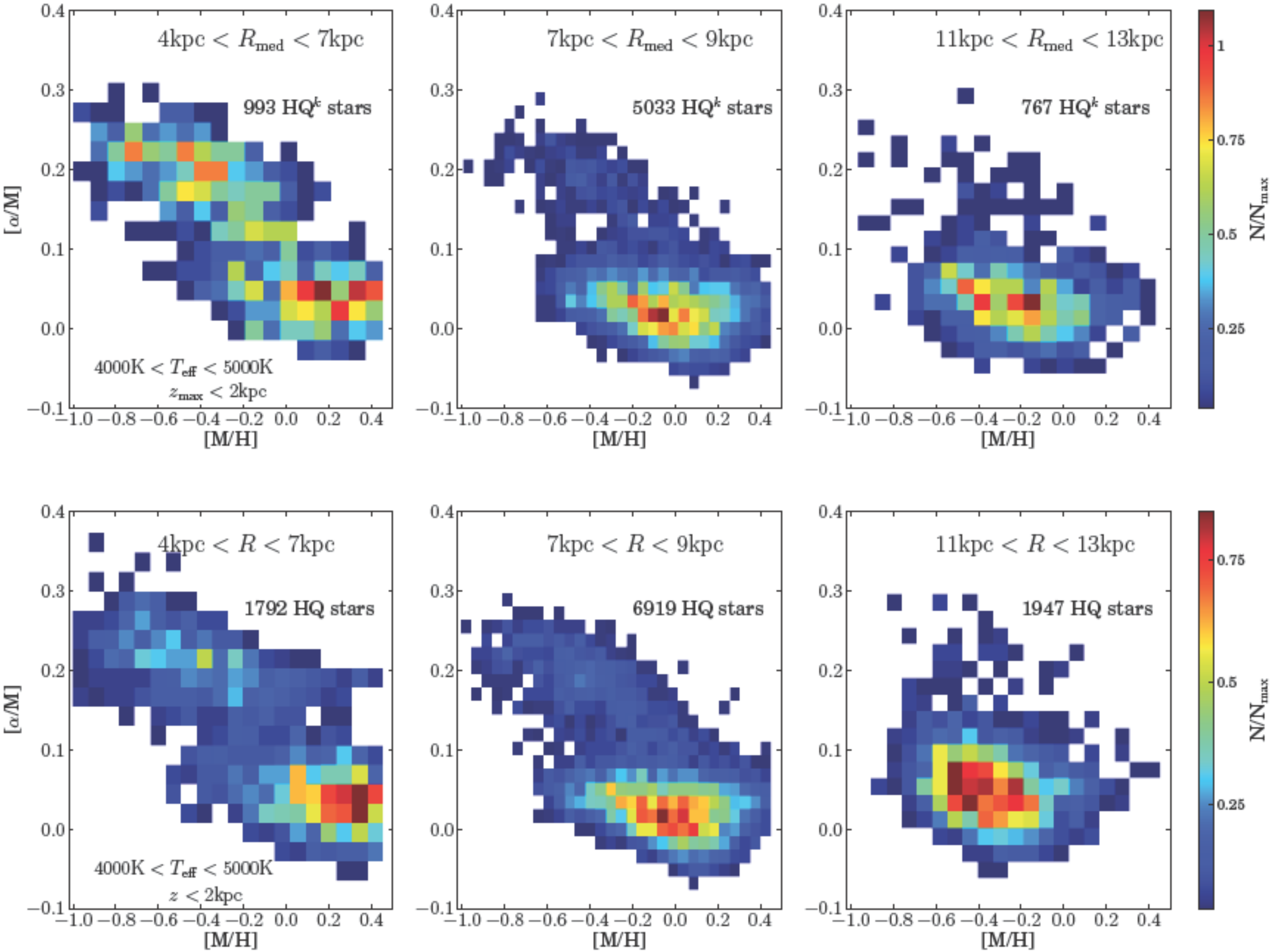
$$\boldsymbol{\theta}_\lambda, s_\lambda \leftarrow \underset{\boldsymbol{\theta}_\lambda, s_\lambda}{\mathrm{argmax}} \sum_{n=1}^{N} \ln p(f_{n\lambda} \,|\, \boldsymbol{\theta}_\lambda^T, \boldsymbol{\ell}_n, s_\lambda^2)$$

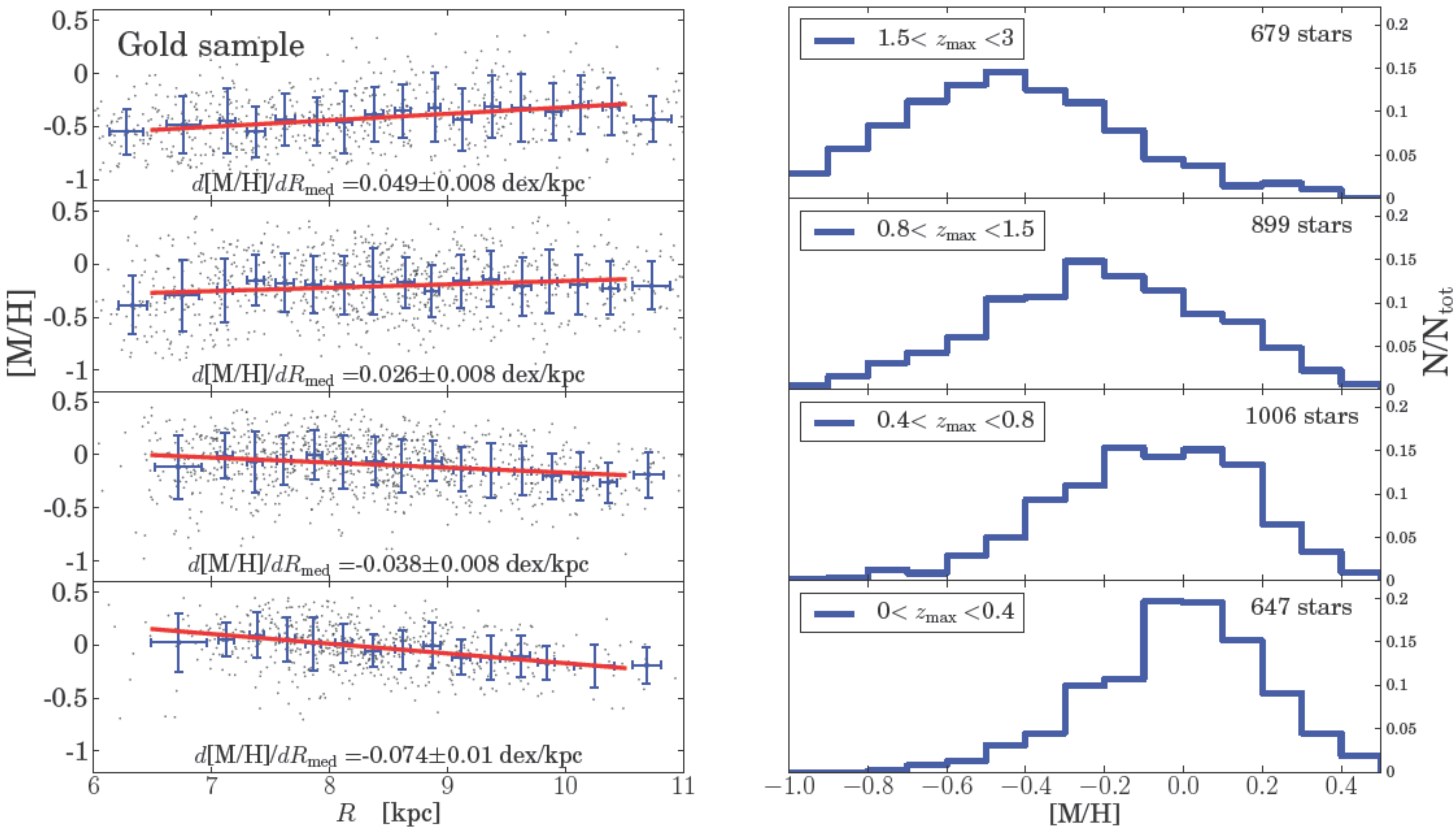
Anders et al. 2014



$$\Delta T_{\text{eff}} = (83.8 - 39.8 \cdot [\text{M/H}])\ \text{K}$$
$$\Delta \log g = 0.2\ \text{dex}$$
$$\Delta[\text{M/H}] = (0.055 - 0.036 \cdot [\text{M/H}])\ \text{dex}$$
$$\Delta[\alpha/\text{M}] = 0.08\ \text{dex}.$$

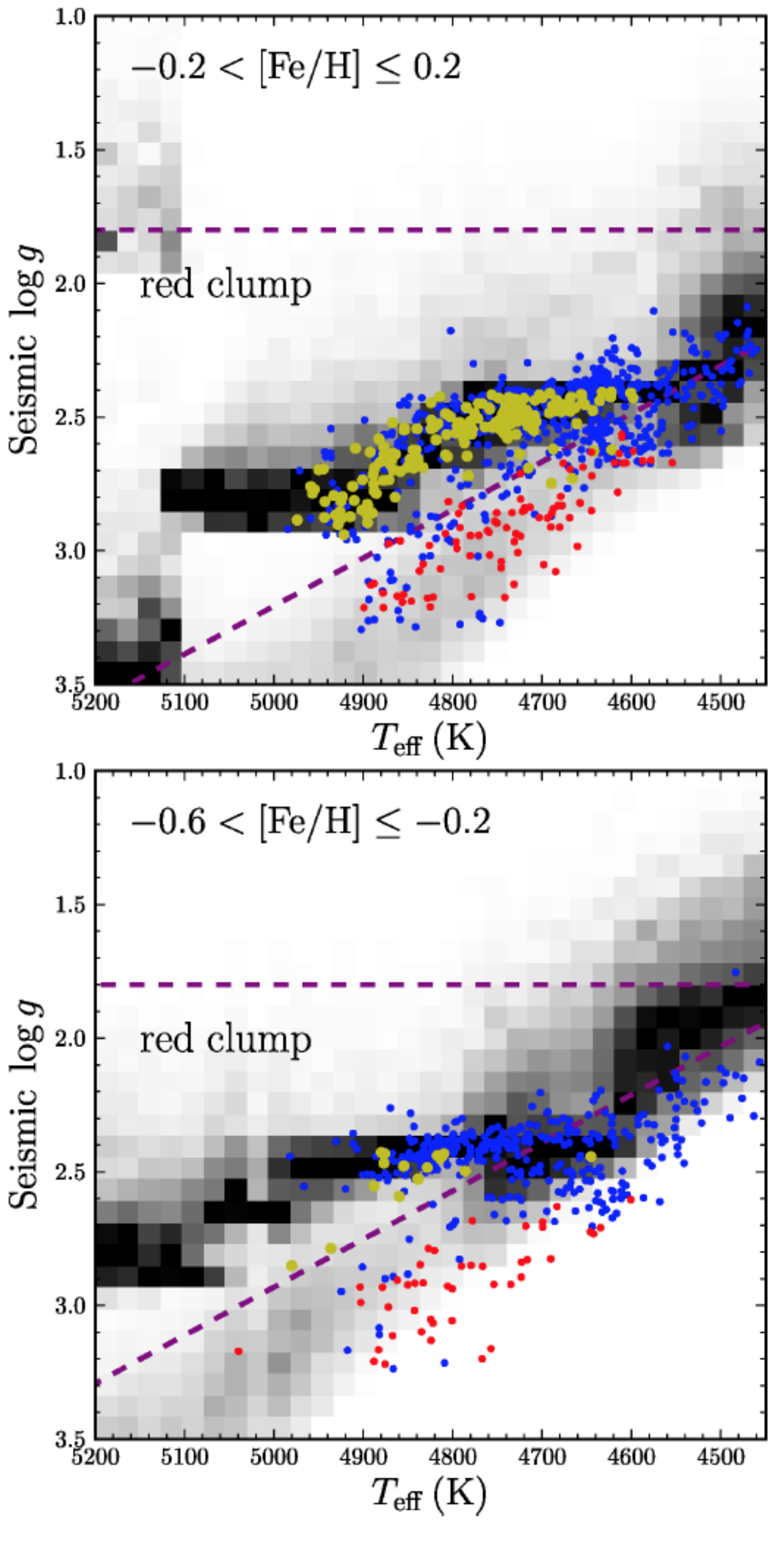
Name	Requirements	Number of stars
HQ sample	see Table 1	21 288
HQ sample with reliable α-element abundances	4000 K < T_{eff} < 5000 K	18 855
HQ sample with valid distance determination	distance code (Santiago et al. 2014) converges	21 105
HQ sample with (valid) UCAC-4 proper motions	PM criteria (see Sect. 3.2) are fulfilled	17 882
HQ^k sample	valid proper motions & distances	17 758
Local HQ sample	$d < 1$ kpc	1975
Local HQ^k sample	$d < 1$ kpc $\wedge$ HQ^k	1654
Gold sample	$\sigma(\mu) < 4.0$ mas/yr $\wedge$ $\sigma(d)/d < 20\%$	3984

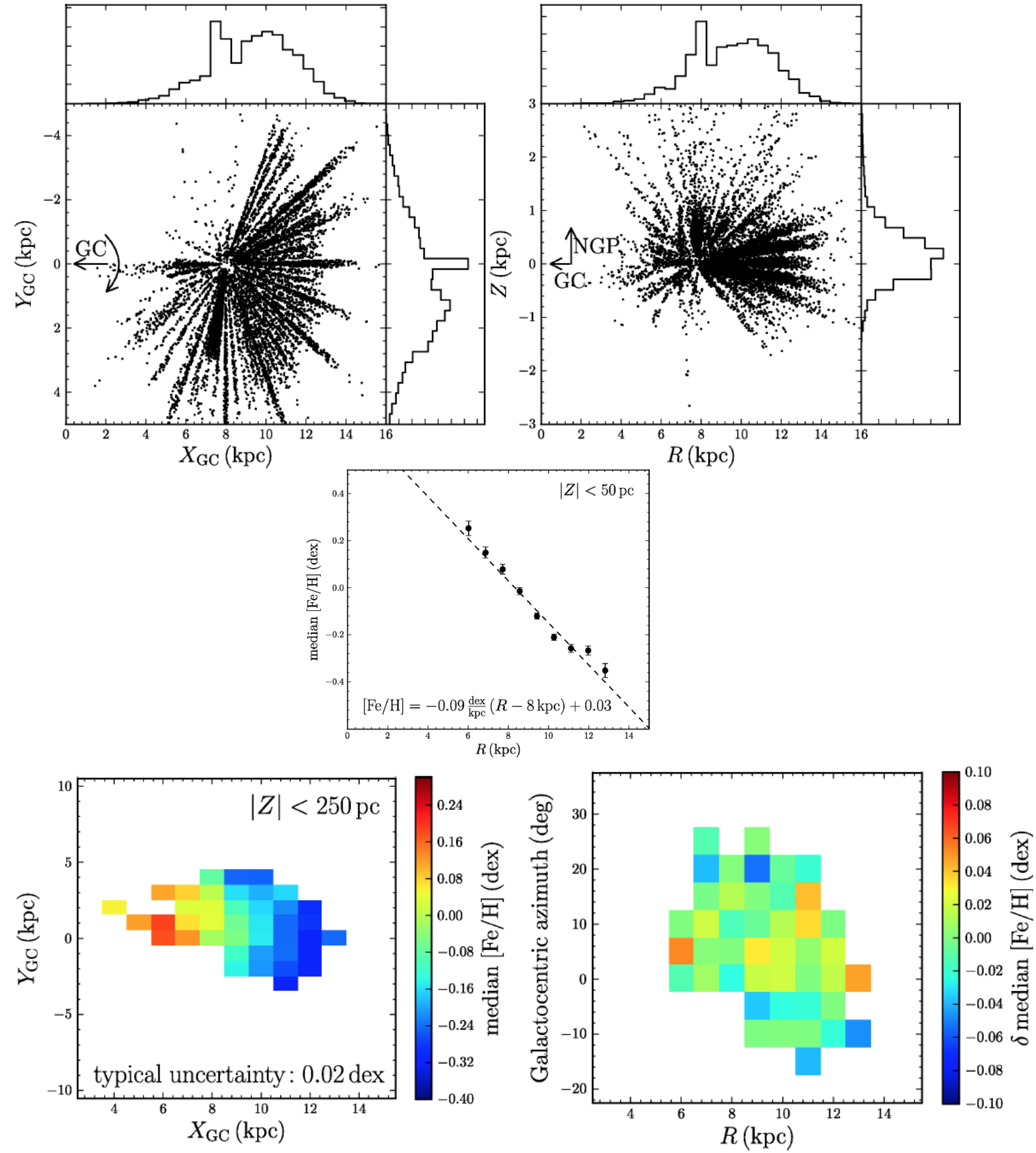

4kpc < R_{med} < 7kpc
993 HQ^k stars
4000K < T_{eff} < 5000K
z_{max} < 2kpc
7kpc < R_{med} < 9kpc
5033 HQ^k stars
11kpc < R_{med} < 13kpc
767 HQ^k stars
4kpc < R < 7kpc
1792 HQ stars
4000K < T_{eff} < 5000K
z < 2kpc
7kpc < R < 9kpc
6919 HQ stars
11kpc < R < 13kpc
1947 HQ stars
[α/M]
[M/H]
N/N_{max}



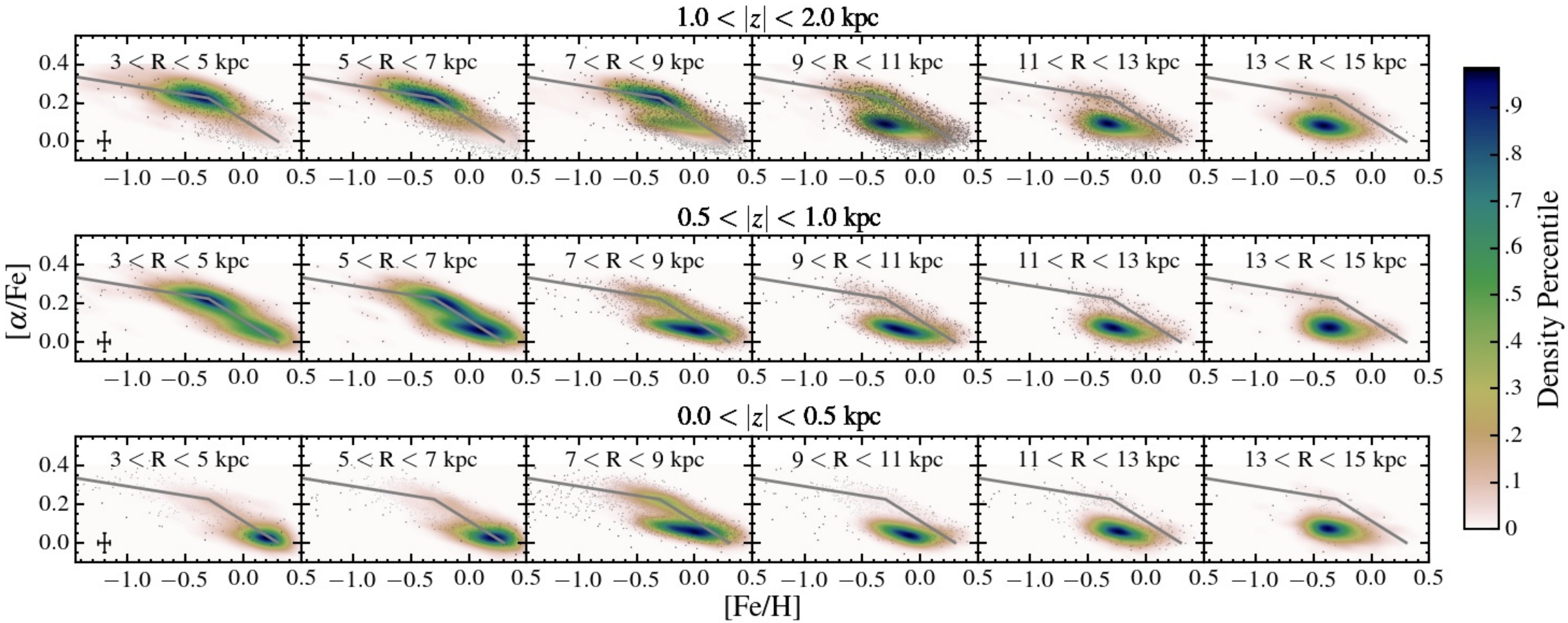
Gold sample
d[M/H]/dR_med =0.049±0.008 dex/kpc
d[M/H]/dR_med =0.026±0.008 dex/kpc
d[M/H]/dR_med =-0.038±0.008 dex/kpc
d[M/H]/dR_med =-0.074±0.01 dex/kpc
[M/H]
R [kpc]
1.5< z_max <3
679 stars
0.8< z_max <1.5
899 stars
0.4< z_max <0.8
1006 stars
0< z_max <0.4
647 stars
N/N_tot
[M/H]

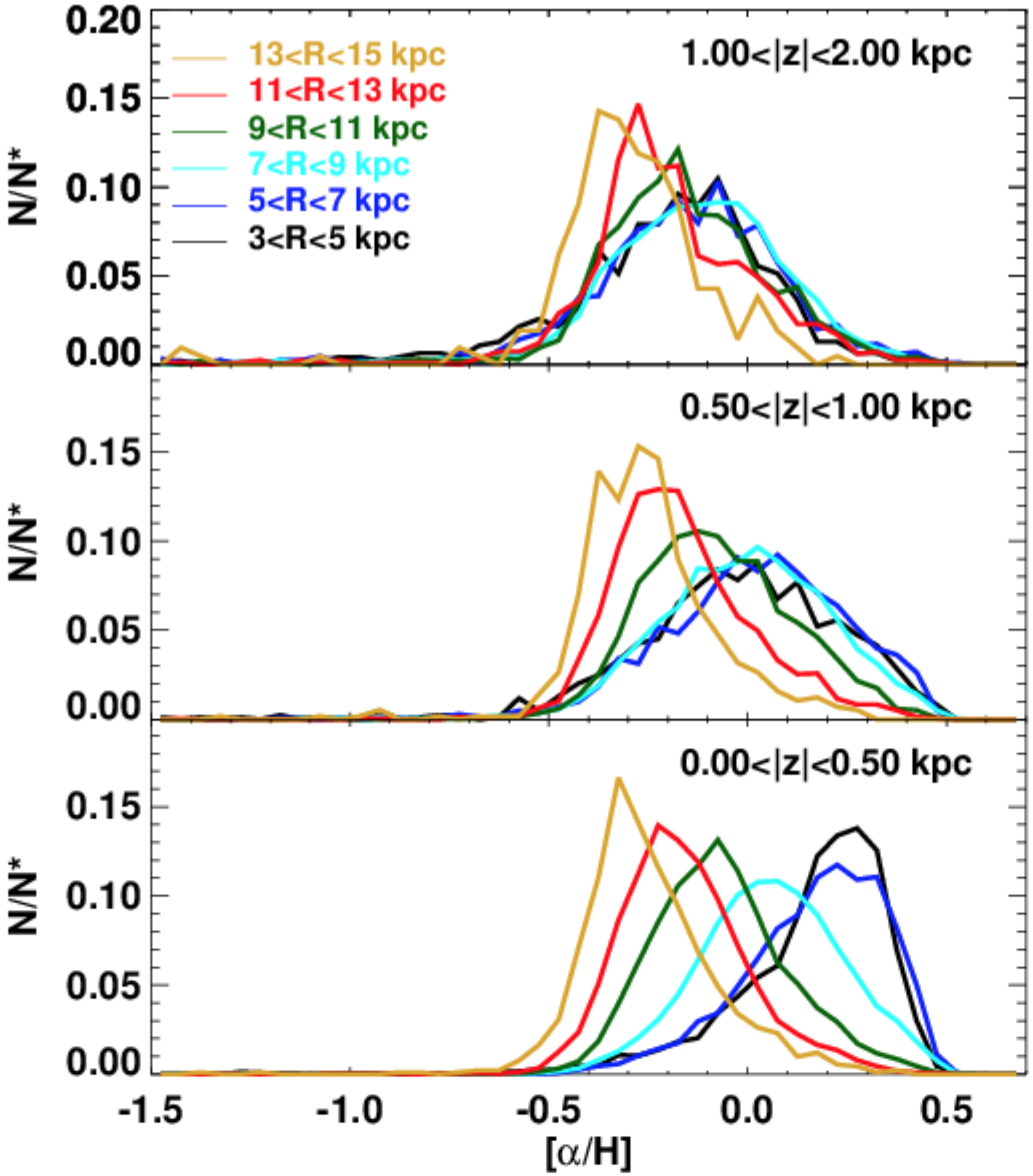
Bovy et al. (2014)

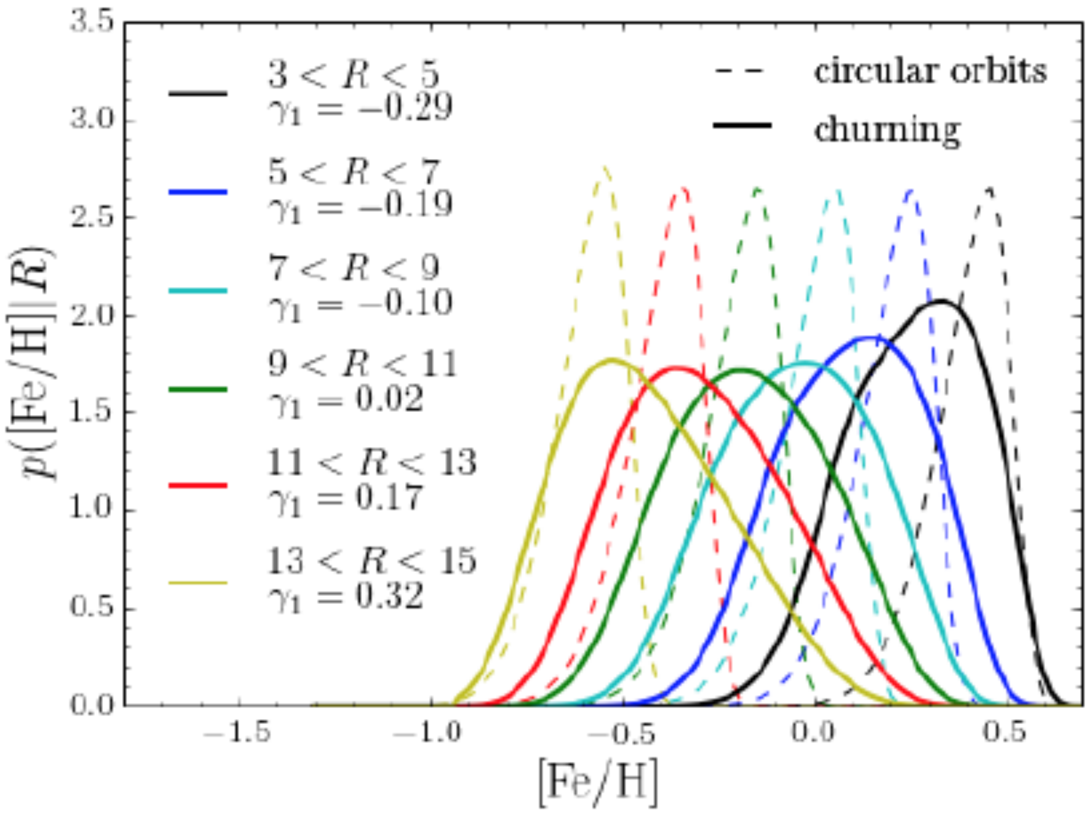




Hayden et al. 2015




13<R<15 kpc
11<R<13 kpc
9<R<11 kpc
7<R<9 kpc
5<R<7 kpc
3<R<5 kpc
1.00<|z|<2.00 kpc
0.50<|z|<1.00 kpc
0.00<|z|<0.50 kpc
N/N*
[α/H]

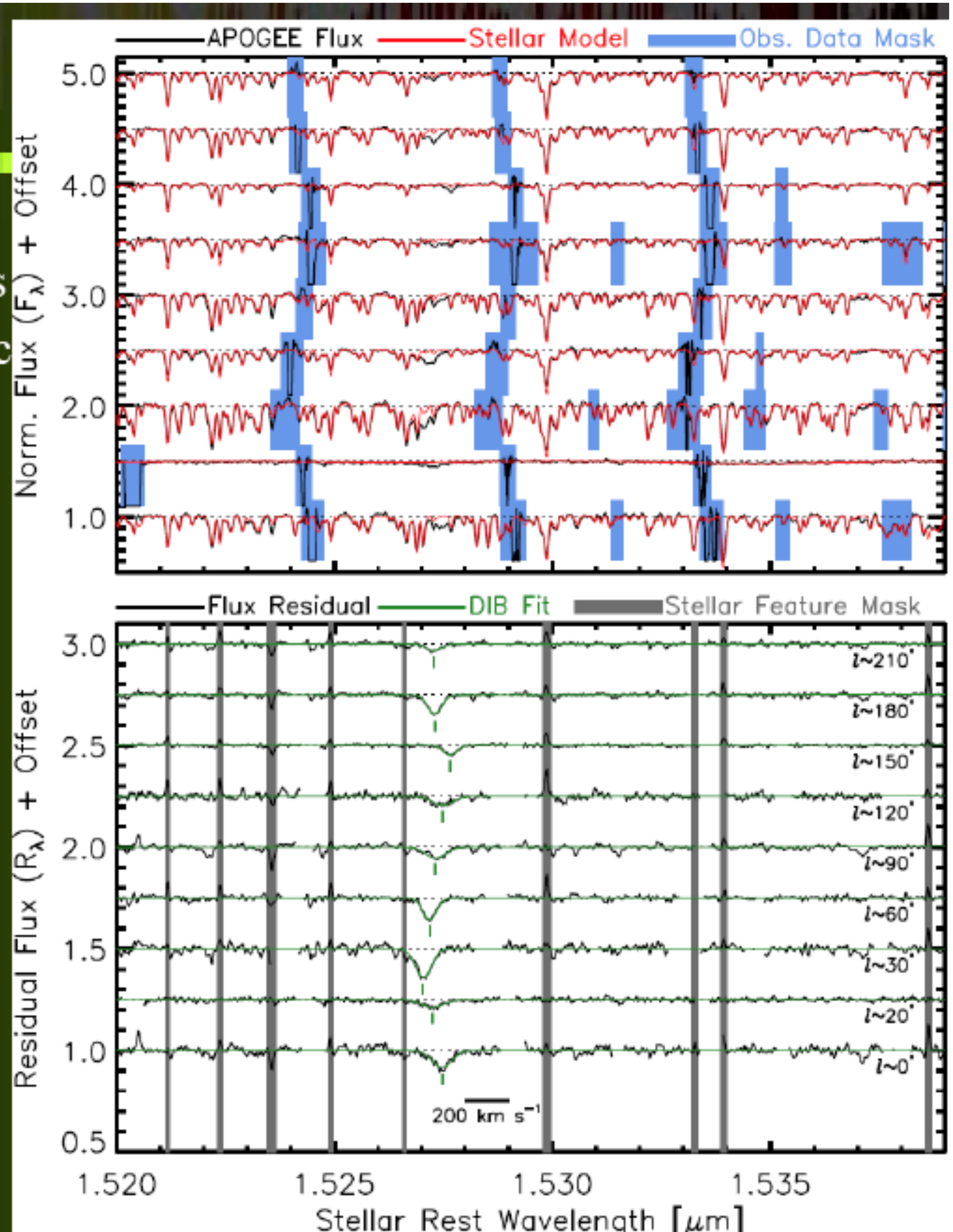

3 < R < 5 γ1 = −0.29
5 < R < 7 γ1 = −0.19
7 < R < 9 γ1 = −0.10
9 < R < 11 γ1 = 0.02
11 < R < 13 γ1 = 0.17
13 < R < 15 γ1 = 0.32
circular orbits
churning
p([Fe/H]| R)
[Fe/H]

Zasowski

Method

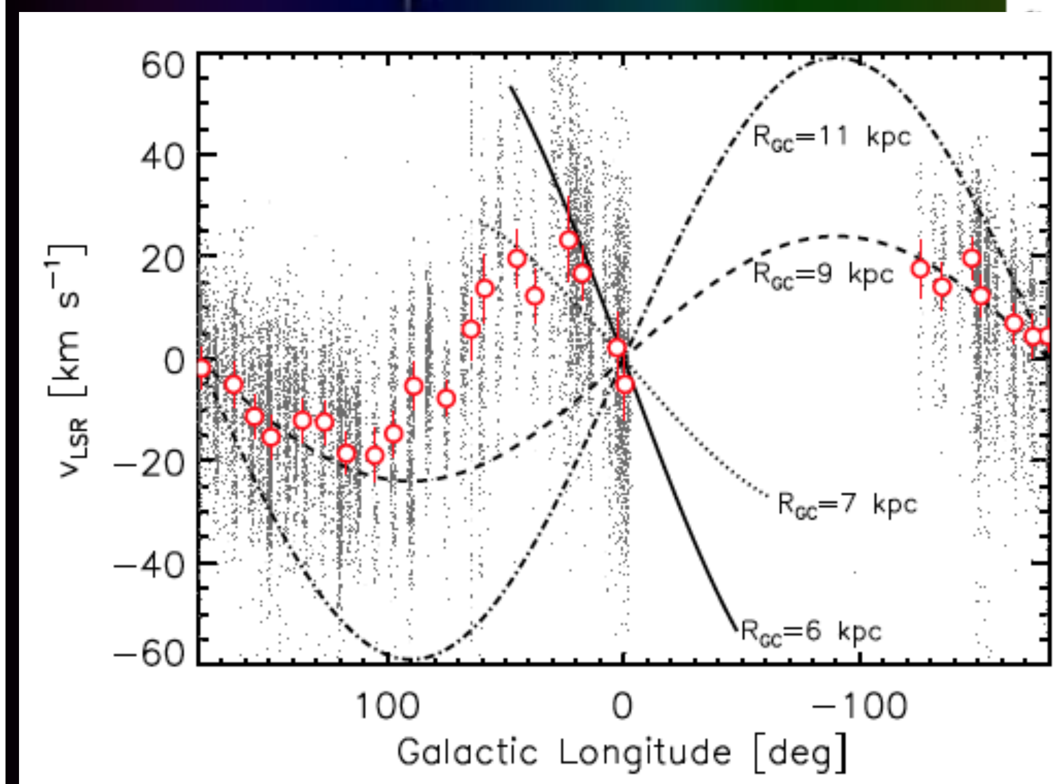
- Targets: K and M dwarfs (cool)
- Dominated by absorption features
- ASPCAP –provide F' best fit spec
- Multi-D χ^2-minimization
- Residuals: $R = F/F'$
- Stellar rest frame

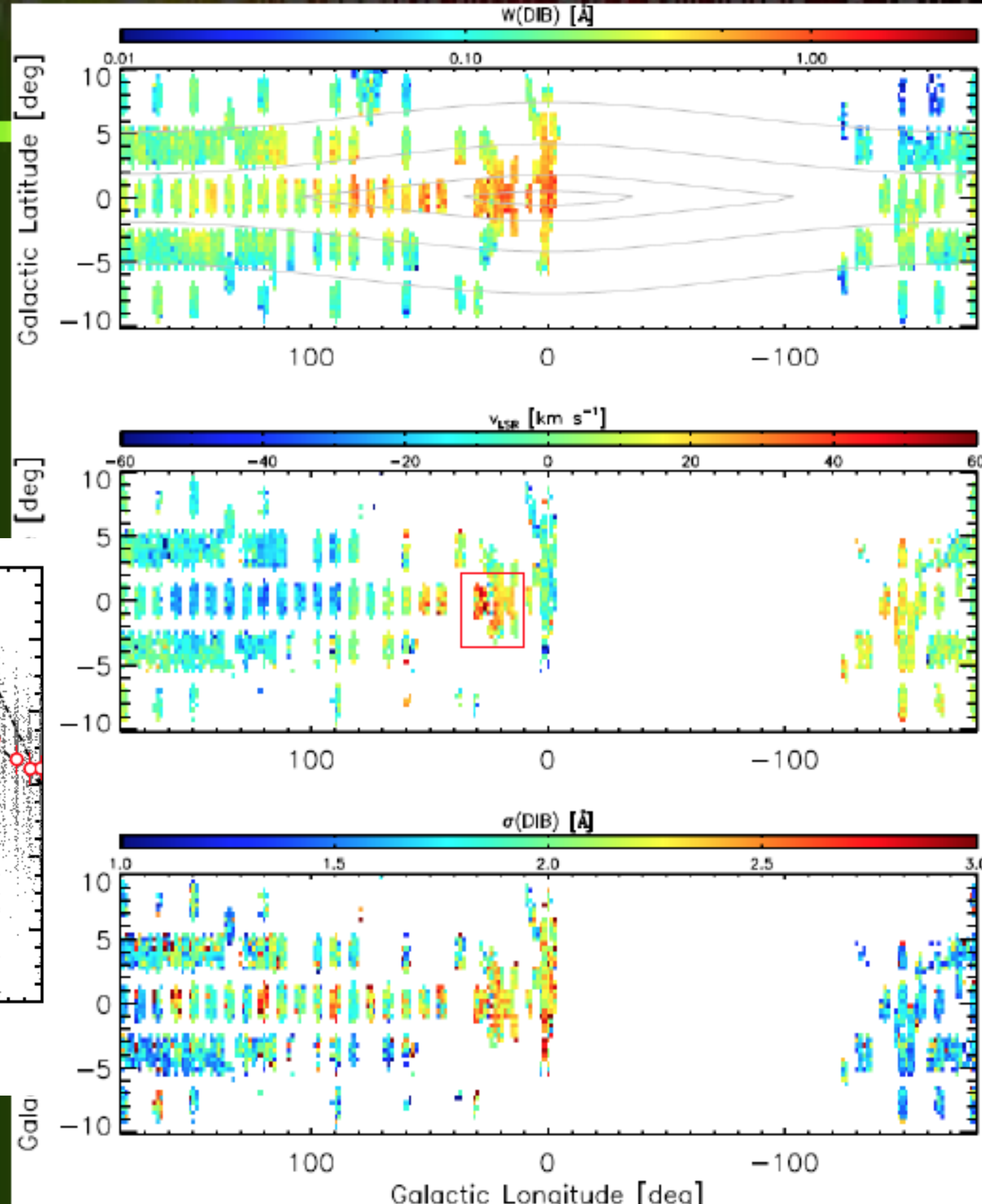
- Clean samples: 58605 / 96938
- Locally good ASPCAP fit:
  - $\sigma(R_\lambda)/\sigma(F_\lambda) \leq 0.55$
- Smooth residual
  - $\sigma(R_\lambda) \leq 5\%$
- Well measured stellar RV
  - $VSCATTER \leq 1\ km\ s^{-1}$
- Gaussian fit $$W = \int_{\lambda_1}^{\lambda_2} (1 - R_\lambda)\, d\lambda = \sqrt{2\pi}\, A\, \sigma.$$



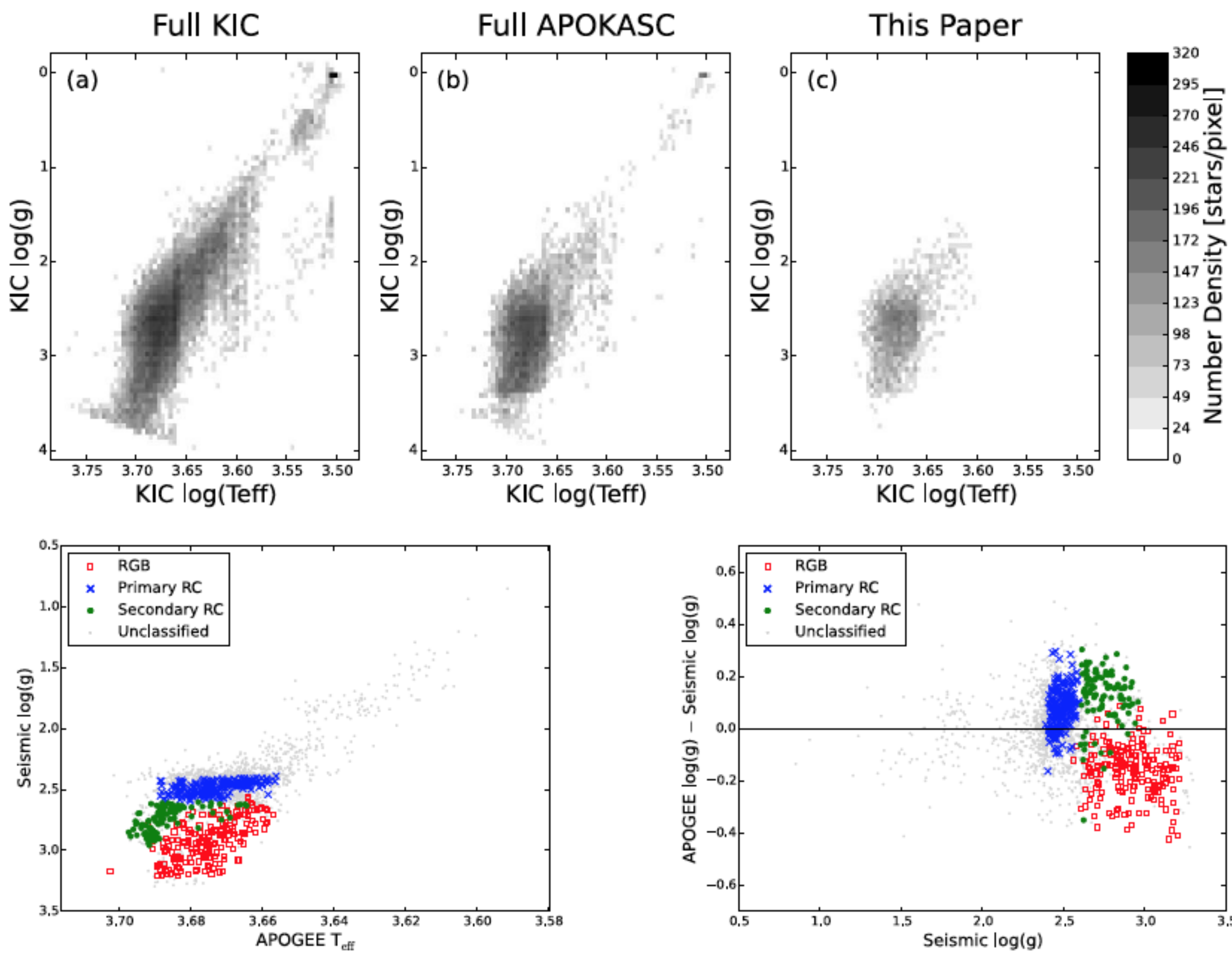
Mean Properties

- EW_{DIB} vs A_V
  - RJCE

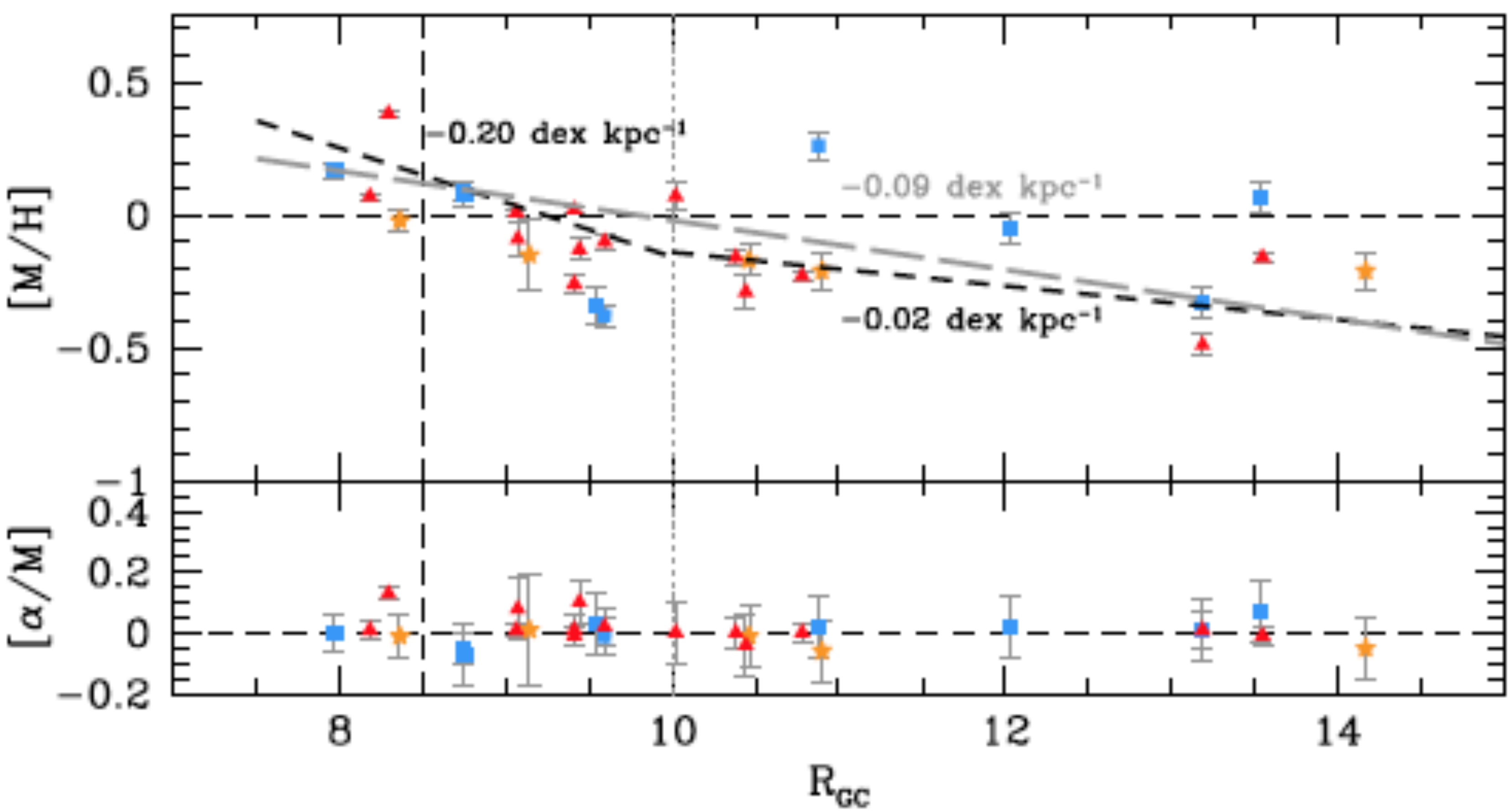


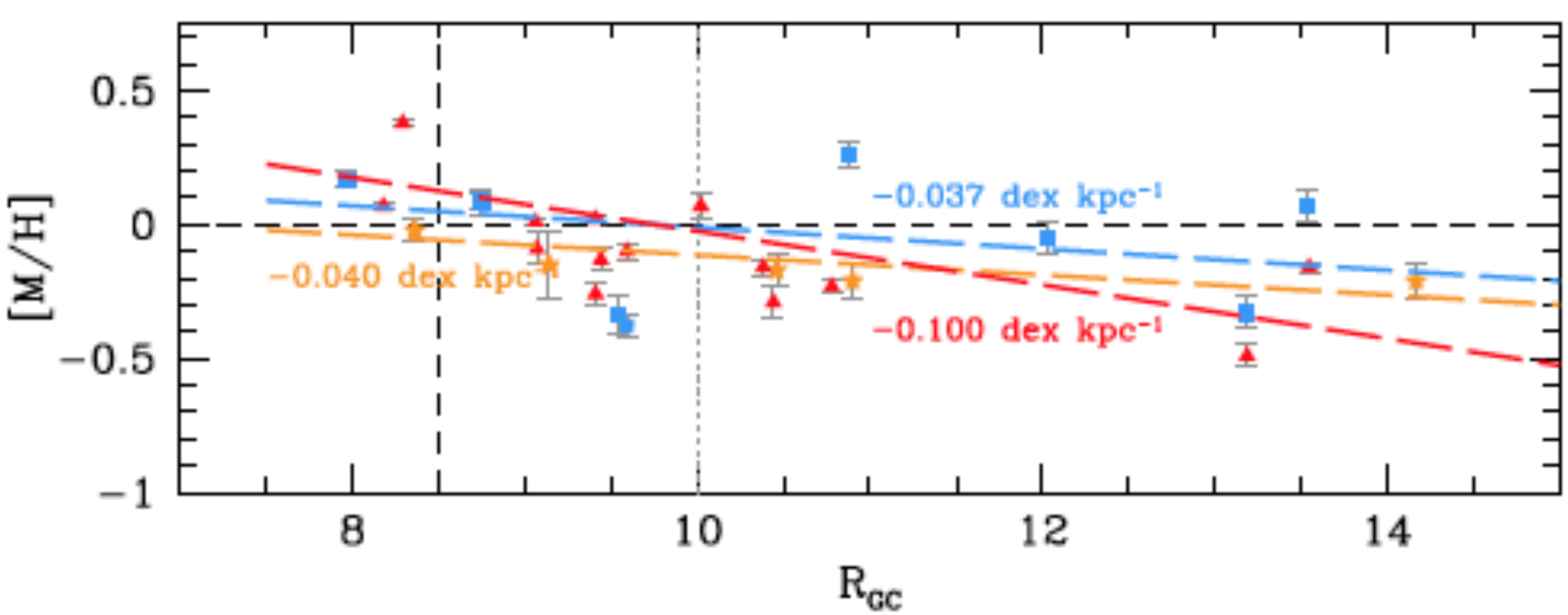


Pinsonnault et al. 2014 (APOKASC) APOGEE+Kepler

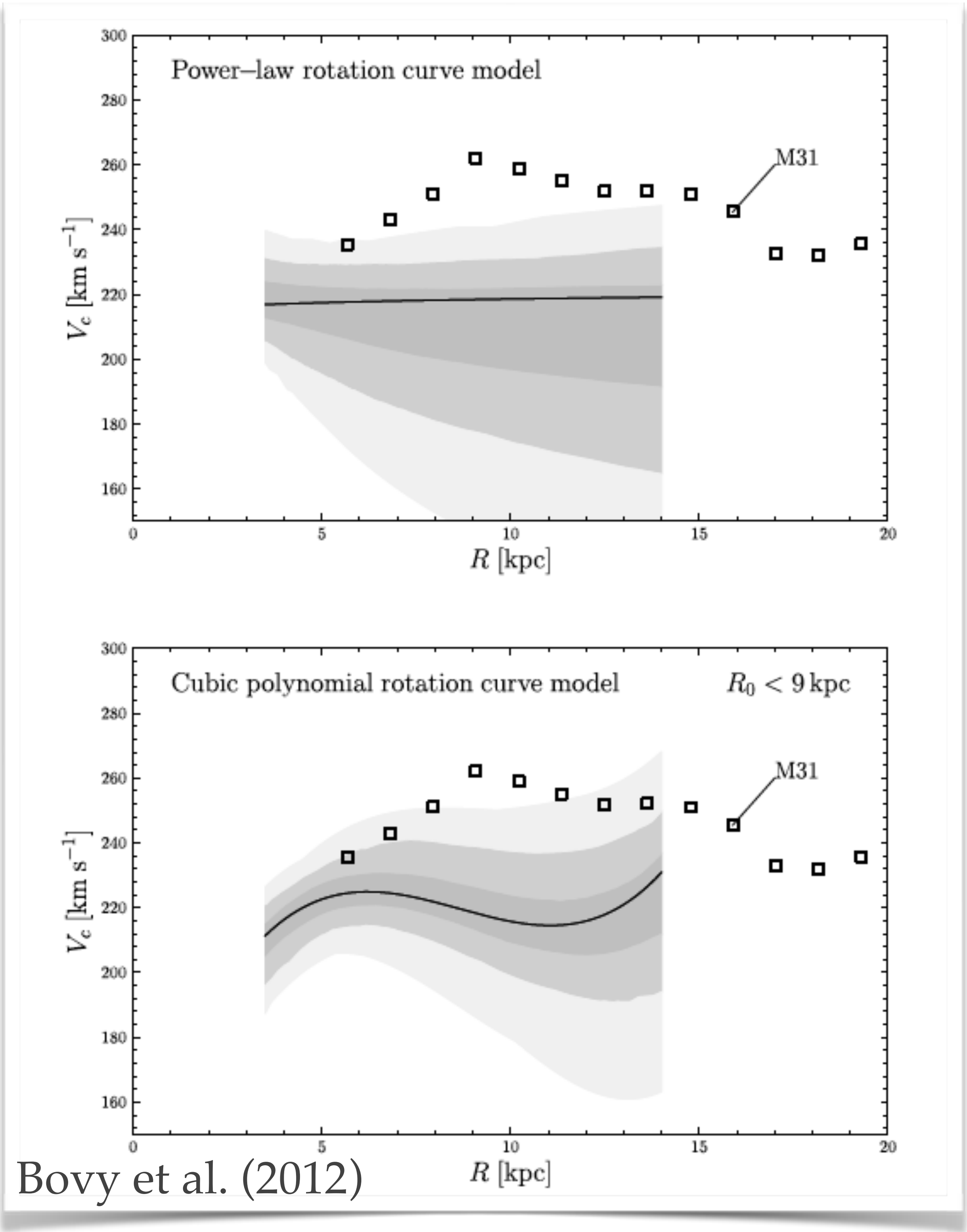


Frinchaboy et al. 2013   28 OCs





APOGEE data



Bovy et al. (2012)

vc=218 km/s M_{halo}=0.8x10^{12} $M_\odot$

$$V_c = V_\phi - V_a$$

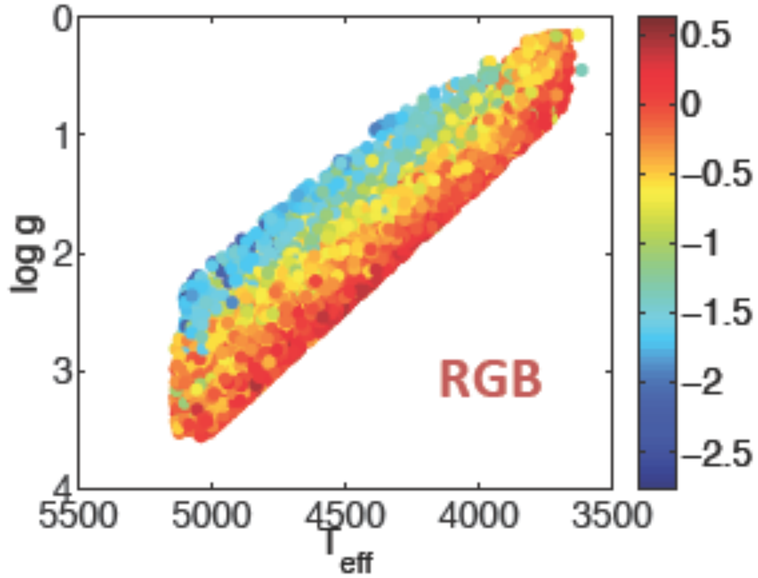
$$\frac{V_c(R)V_a(R)}{\sigma_R^2(R)} = \frac{1}{2}\left[X^2 - 1 + R\left(\frac{1}{h_R} + \frac{2}{h_\sigma}\right)\right]$$

$$f_{\rm Dehnen}(E, L) \propto \frac{\nu_*(R_e)}{\sigma_R^2(R_e)} \exp\left[\frac{\Omega(R_e)\left[L - L_c(E)\right]}{\sigma_R^2(R_e)}\right]$$

Our ongoing works

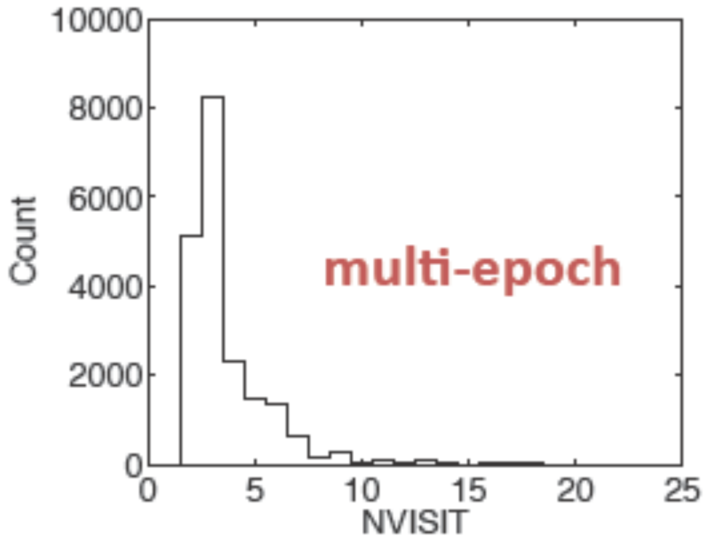
- Spatial variation in metallicity
    - Wan et al.
- Cross-calibration
    - Chen et al.
    - Ho et al.
- Dynamical modeling
    - Liu et al.

Project #1



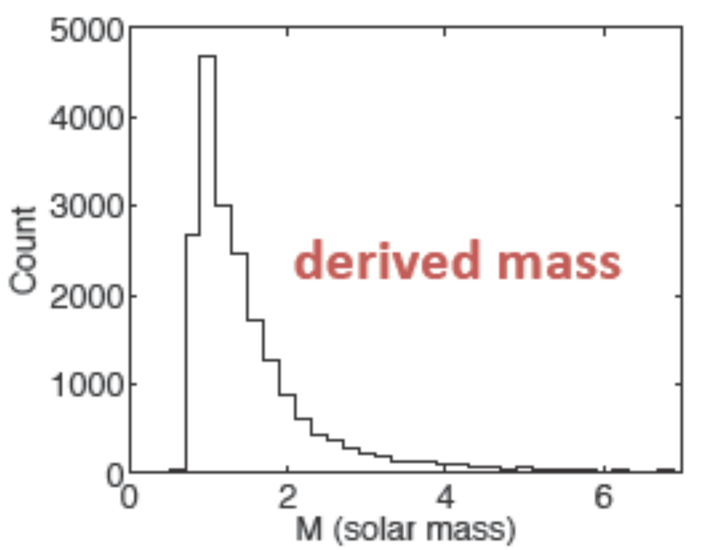
- Gao et al. (2014) found f_B is a function of *Teff* (*SpT*) and [Fe/H] (age).
- The method is based on spectral differential *RV* and detection power of Period is limited under *1000 days*.
- It implies **that orbital parameters evolve with age and SpT.**

Constrains of (RGB) binary orbital parameters



- Each target of APOGEE is observed **twice to twenty** times.
- RV dispersion *VSCATTER* shows long-tailed form
- Orbital parameters (P, q, e) are implicit in RV dispersion, which can be revealed by MCMC algorithm.

$$v_i = q[\frac{2\pi G M_1}{P(1+q)^2}]^{1/3} \frac{1}{\sqrt{1-e^2}} \sin i \cos(\frac{2\pi t_i}{P} - \phi_0)$$

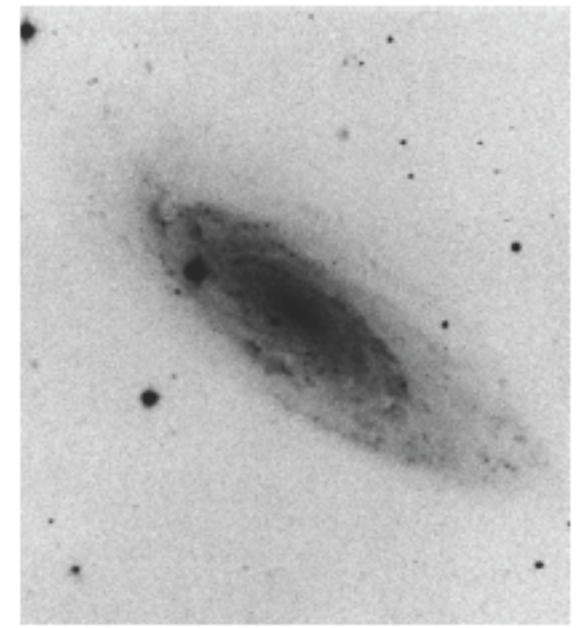


- Stellar mass M_1 is derived from isochrones
- We apply parameterization of 3 orbital para. (P, q, e) to describe their distributions.
- Each para. is separated into *N* evenly-spaced ranges, that are weighted by *N* weights.

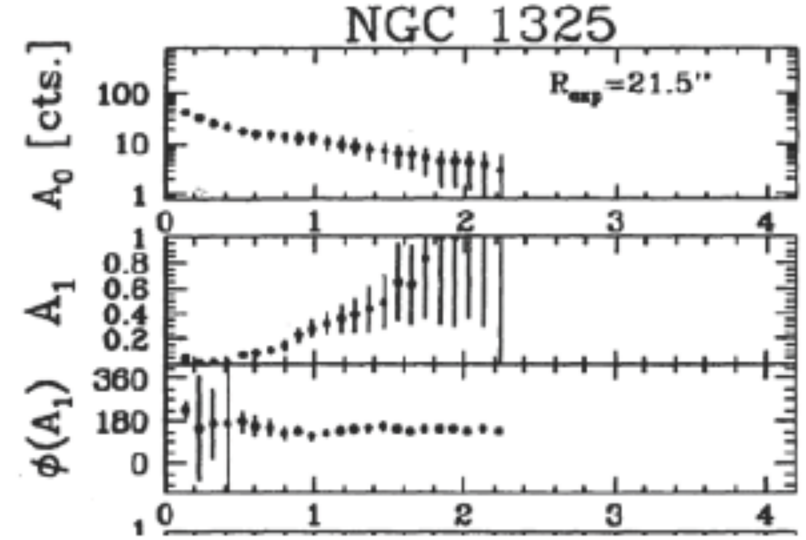
Project #2

Non-axisymmetry of the Galactic stellar disk

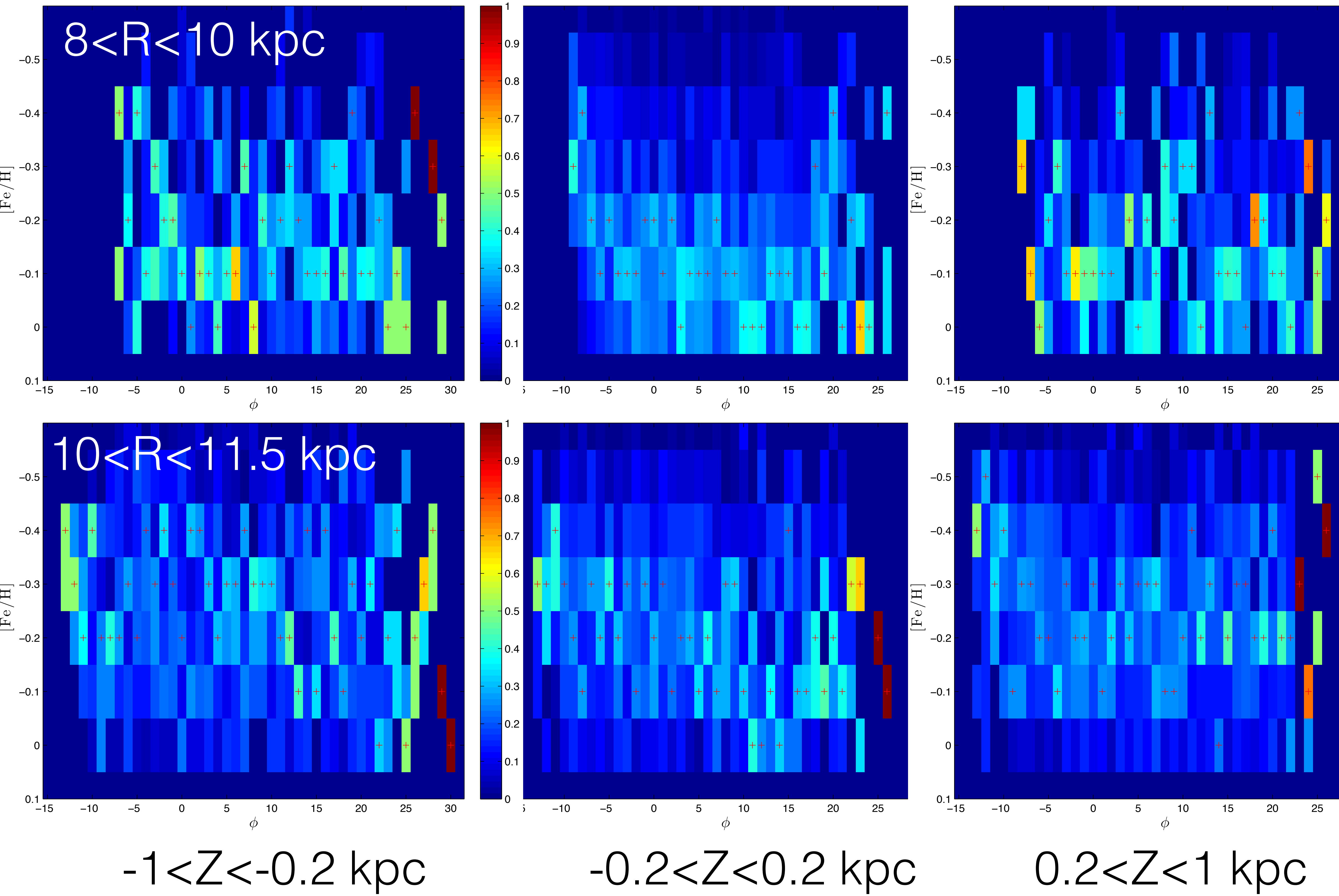
- Goal: looking for the evidence of lopsidedness or ellipticity of the Galactic disk
    - 1/3 disk galaxies are lopsided (Rix & Zaritsky 1995)
    - Kuijken & Tremaine (1994) tested the elliptically of the Galactic disk
    - Nature of the lopsidedness:
        - interaction with a passing-by galaxy
        - minor merger
        - asymmetric gas accretion
        - secular evolution with a triaxial halo etc.
    - help to constrain the evolution of the Galactic disk
- Method: Find the difference in <v_R(R)> or <v_phi(R)> between QII and QIII disk with red clump/RGB stars



NGC 1325

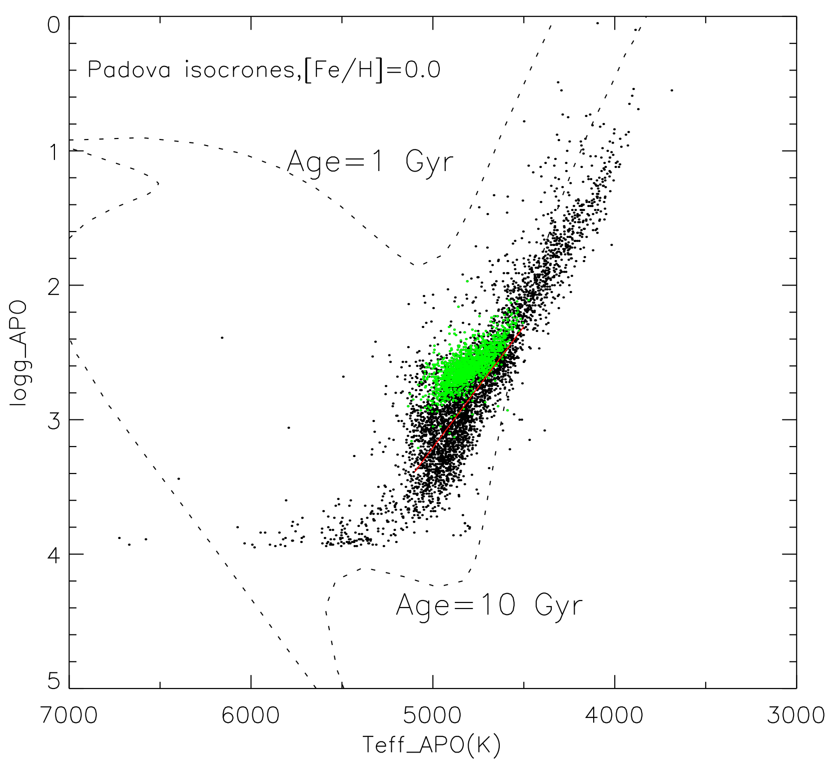


$$\langle v_R \rangle = 7.4 \text{ km s}^{-1} \left(\frac{v_c}{200 \text{ km s}^{-1}}\right)\left(\frac{\tilde{A}_1}{0.11}\right)\left(\frac{2.5R_{exp}}{R}\right).$$

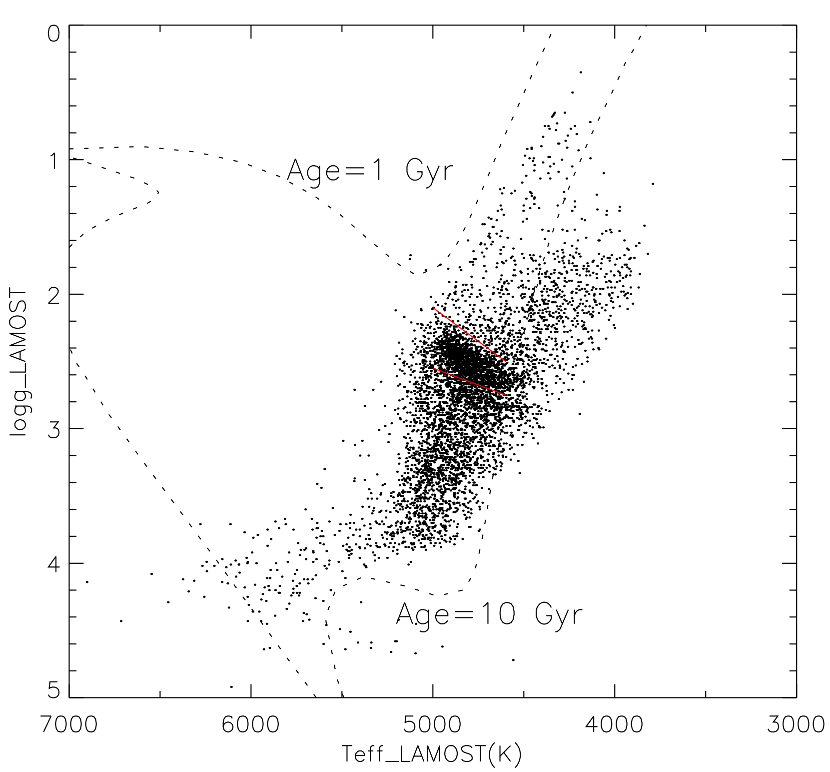


Wan et al.

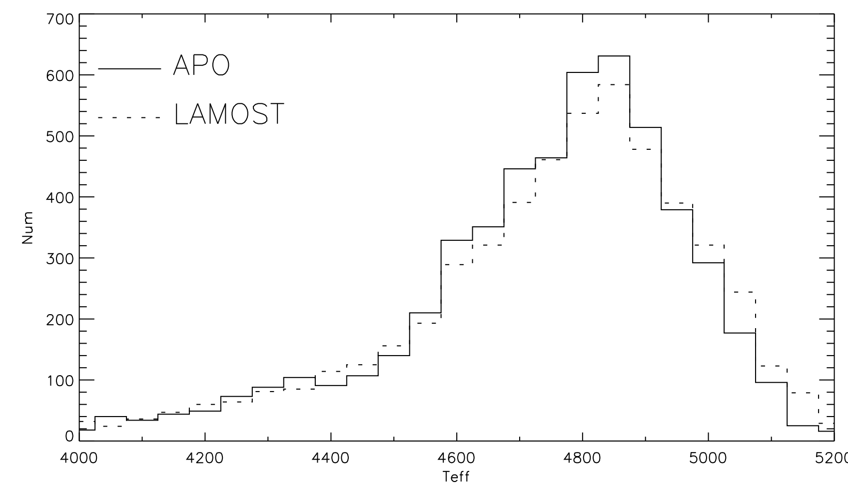
Chen et al.



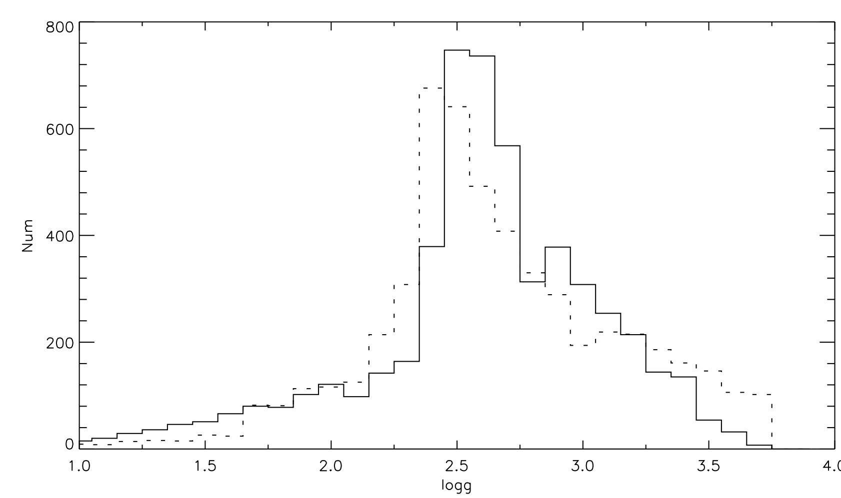
Padova isocrones,[Fe/H]=0.0
Age=1 Gyr
Age=10 Gyr
logg_APO
Teff_APO(K)
0
1
2
3
4
5
7000
6000
5000
4000
3000



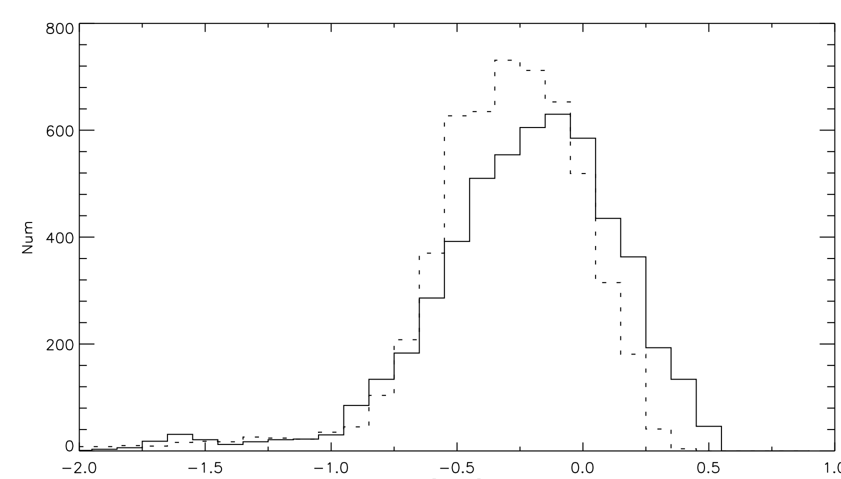
Age=1 Gyr
Age=10 Gyr
logg_LAMOST
Teff_LAMOST(K)
0
1
2
3
4
5
7000
6000
5000
4000
3000



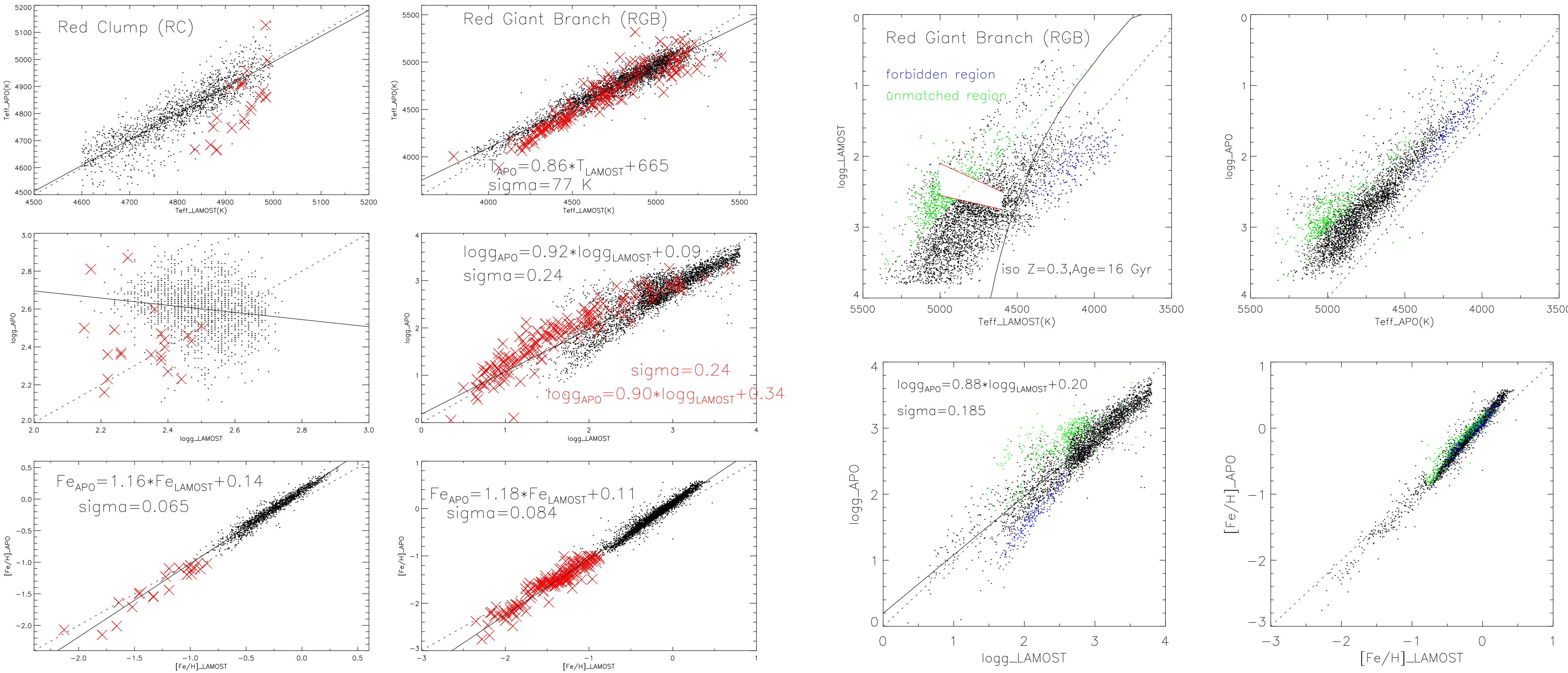
APO
LAMOST
Num
Teff
0
100
200
300
400
500
600
700
4000
4200
4400
4600
4800
5000
5200



Num
logg
0
200
400
600
800
1.0
1.5
2.0
2.5
3.0
3.5
4.0



Num
[Fe/H]
0
200
400
600
800
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0

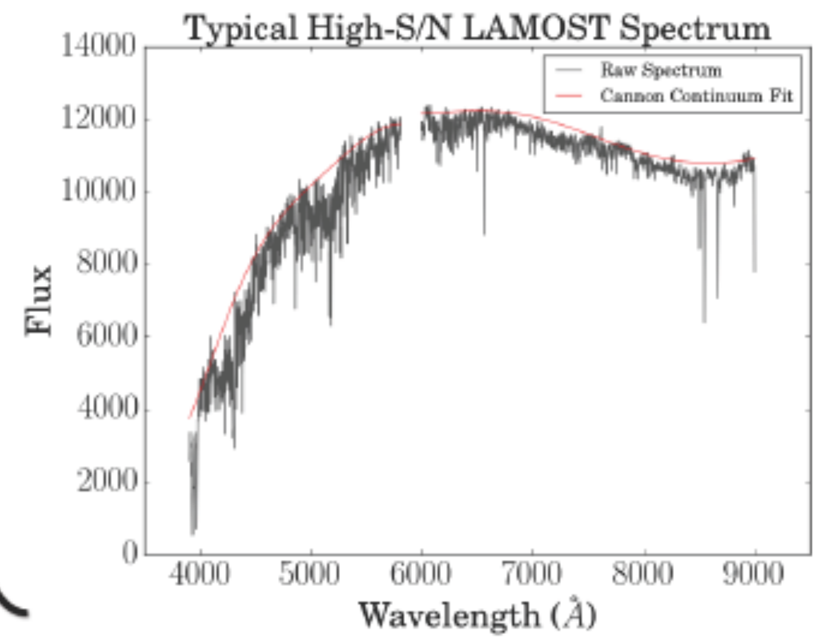


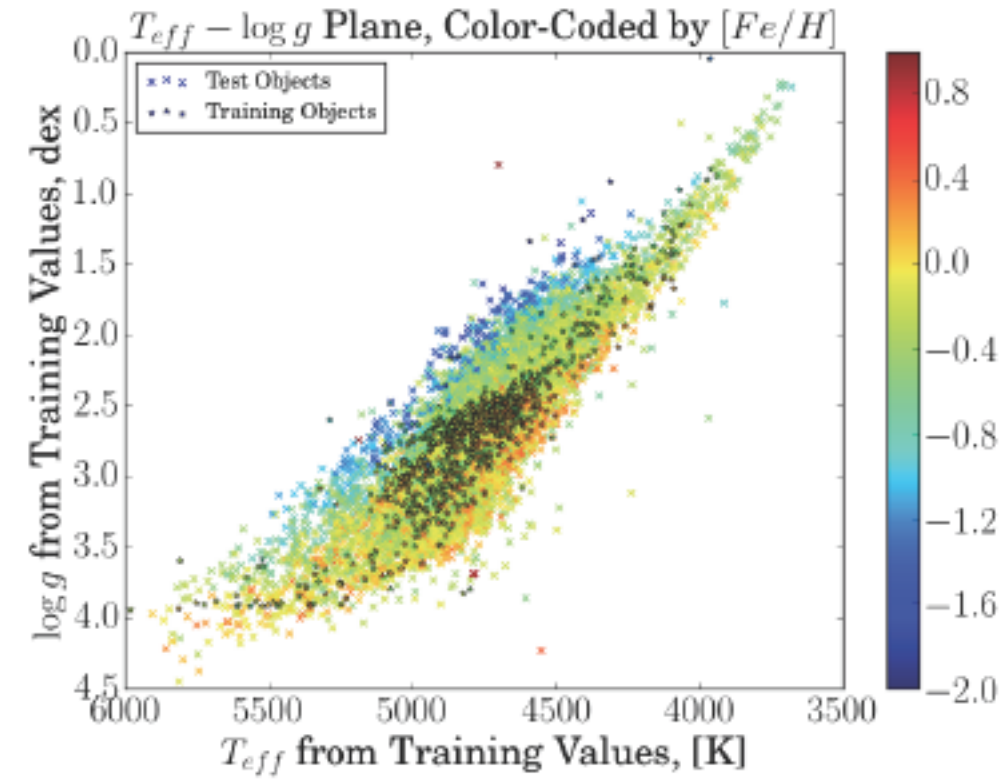
Red Clump (RC)
Teff_APO(K)
Teff_LAMOST(K)
Red Giant Branch (RGB)
$T_{APO}=0.86*T_{LAMOST}+665$
sigma=77 K
logg_APO
logg_LAMOST
$logg_{APO}=0.92*logg_{LAMOST}+0.09$
sigma=0.24
sigma=0.24
$logg_{APO}=0.90*logg_{LAMOST}+0.34$
$Fe_{APO}=1.16*Fe_{LAMOST}+0.14$
sigma=0.065
$Fe_{APO}=1.18*Fe_{LAMOST}+0.11$
sigma=0.084
[Fe/H]_APO
[Fe/H]_LAMOST
Red Giant Branch (RGB)
forbidden region
unmatched region
iso Z=0.3,Age=16 Gyr
logg_LAMOST
Teff_LAMOST(K)
logg_APO
Teff_APO(K)
$logg_{APO}=0.88*logg_{LAMOST}+0.20$
sigma=0.185

Sample Reference Object Spectrum (with continuum fit from *The Cannon*)

Reference objects:

- Subset of spectra with high-fidelity labels (ex. calibration objects)
- We use **803 high-S/N LAMOST spectra** and corresponding APOGEE labels

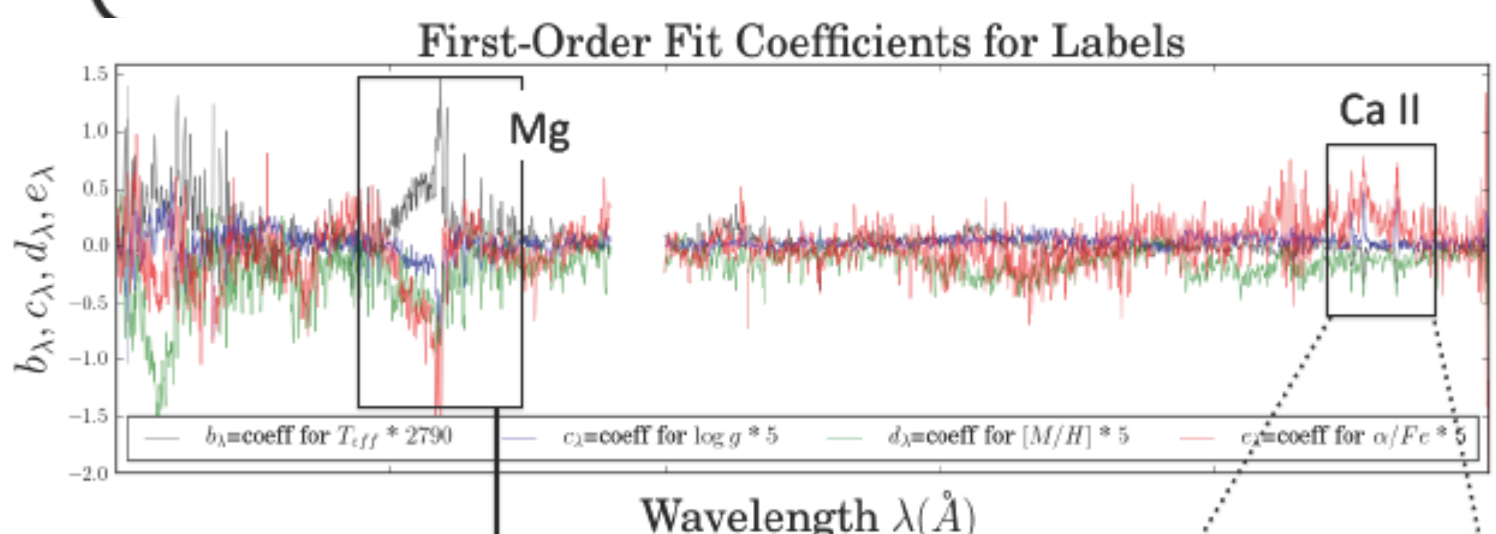




Spectral model:

- Flux for object n at wavelength λ is a function of the labels
- We use a model that is quadratic in the labels, but we show it as linear for brevity
- The training step consists of solving for the coefficients highlighted in blue

$$f_{n\lambda} = a_\lambda + b_\lambda(T_{\rm eff})_n + c_\lambda(\log g)_n + d_\lambda([Fe/H])_n + e_\lambda([\alpha/Fe])_n + \text{scatter}_\lambda$$



Teff

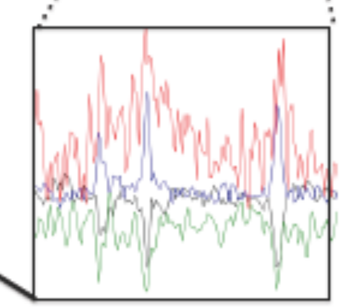
logg

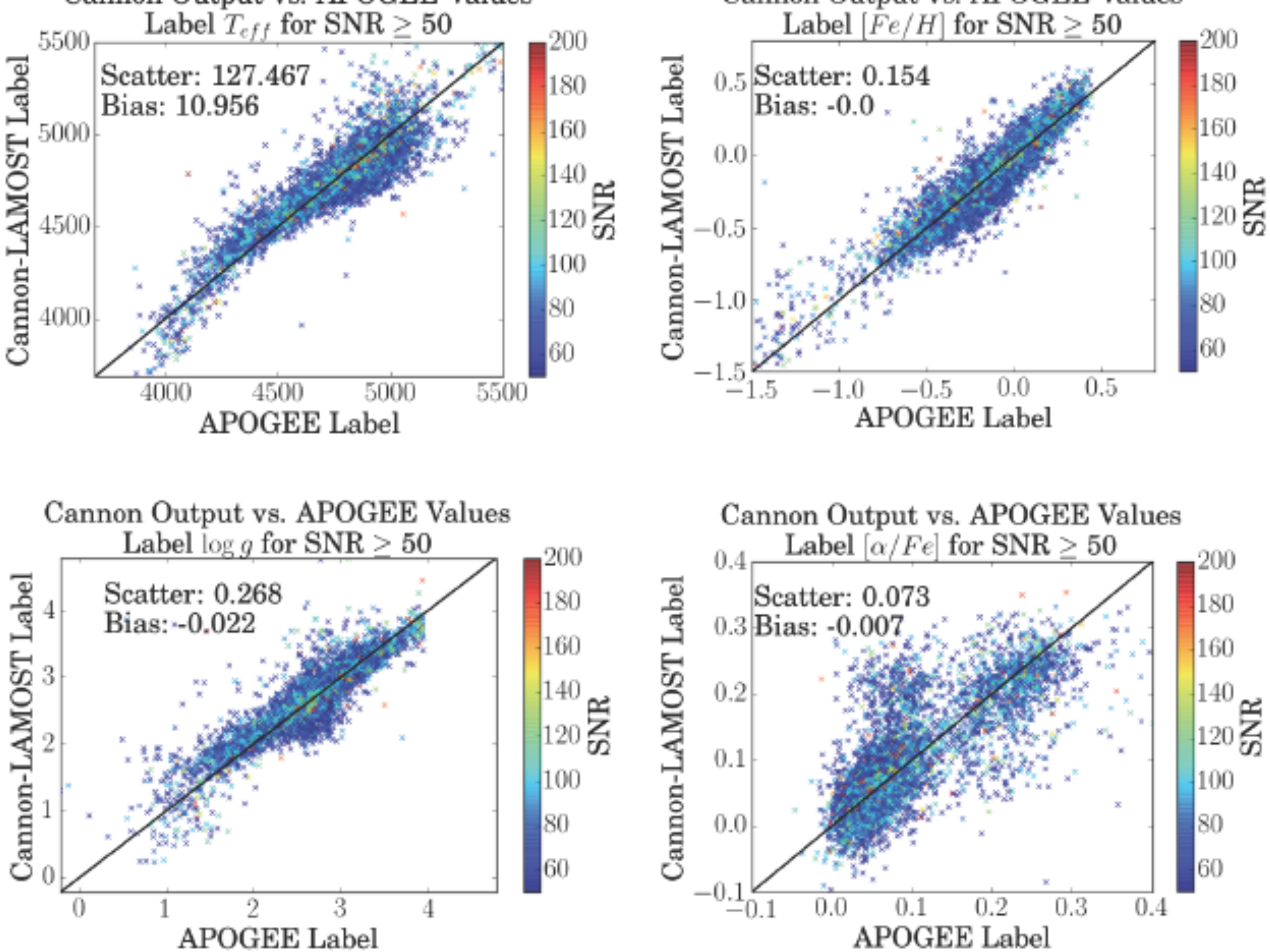
[M/H]

a/Fe

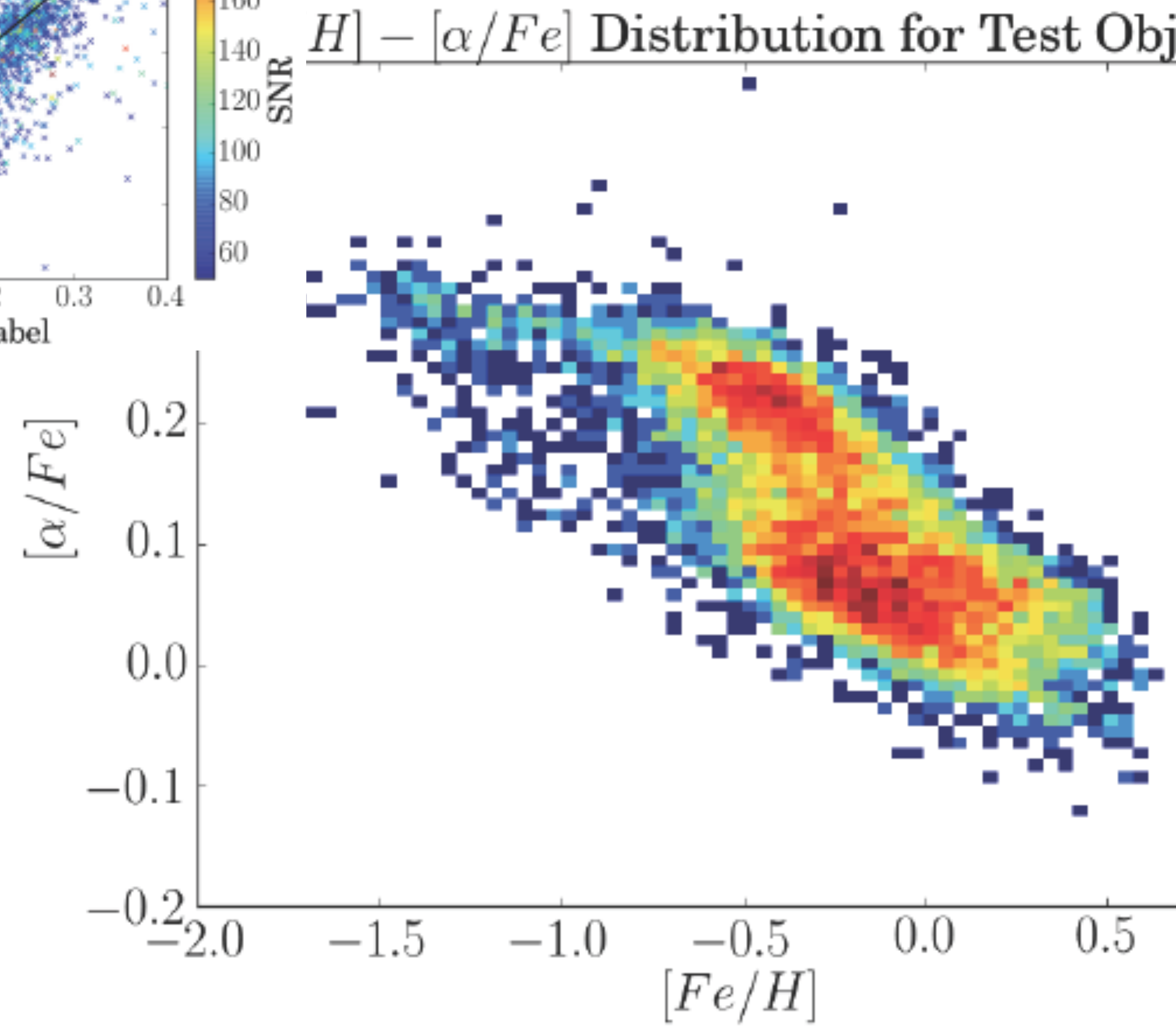
The Cannon
MPIA group
Ho et al.

- The coefficients of the spectral model indicate how sensitive each pixel in the spectrum is to each of the labels
- "Sensitive" regions – peaks in the coefficients - correspond to known spectral lines





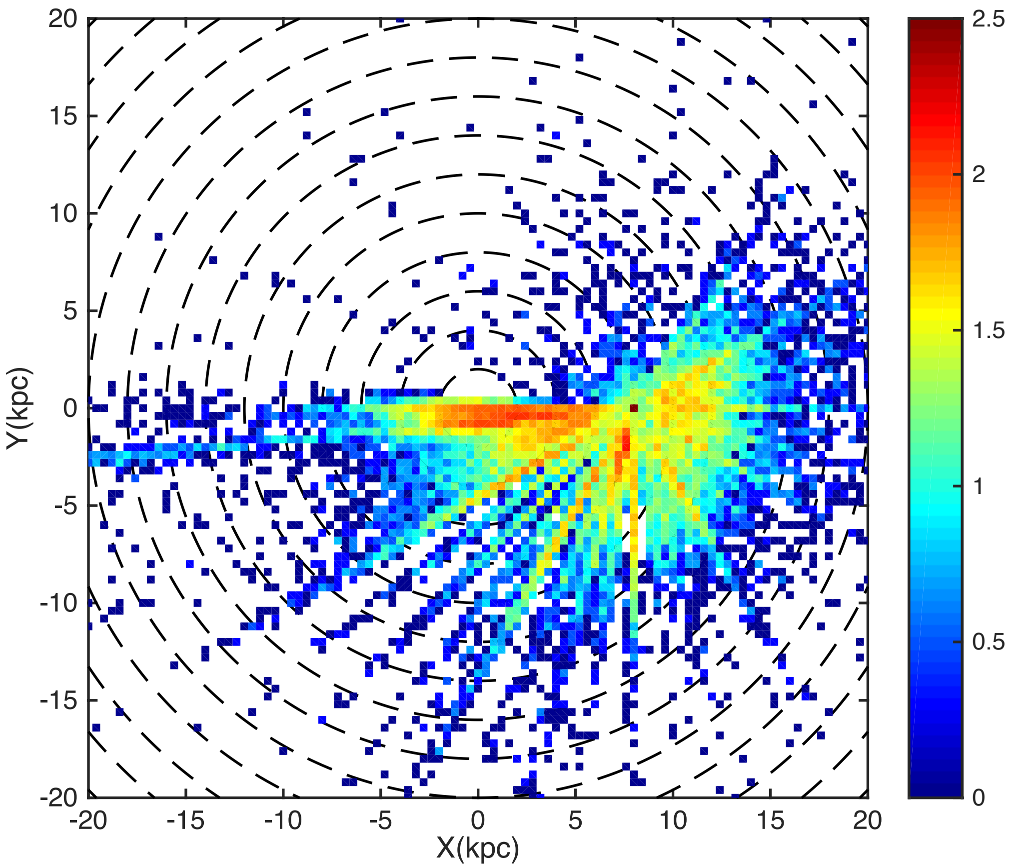
Label T_{eff} for SNR ≥ 50
Scatter: 127.467
Bias: 10.956
Cannon-LAMOST Label
APOGEE Label
SNR
Label $[Fe/H]$ for SNR ≥ 50
Scatter: 0.154
Bias: -0.0
Cannon-LAMOST Label
APOGEE Label
SNR
Cannon Output vs. APOGEE Values
Label $\log g$ for SNR ≥ 50
Scatter: 0.268
Bias: -0.022
Cannon-LAMOST Label
APOGEE Label
SNR
Cannon Output vs. APOGEE Values
Label $[\alpha/Fe]$ for SNR ≥ 50
Scatter: 0.073
Bias: -0.007
Cannon-LAMOST Label
APOGEE Label
SNR

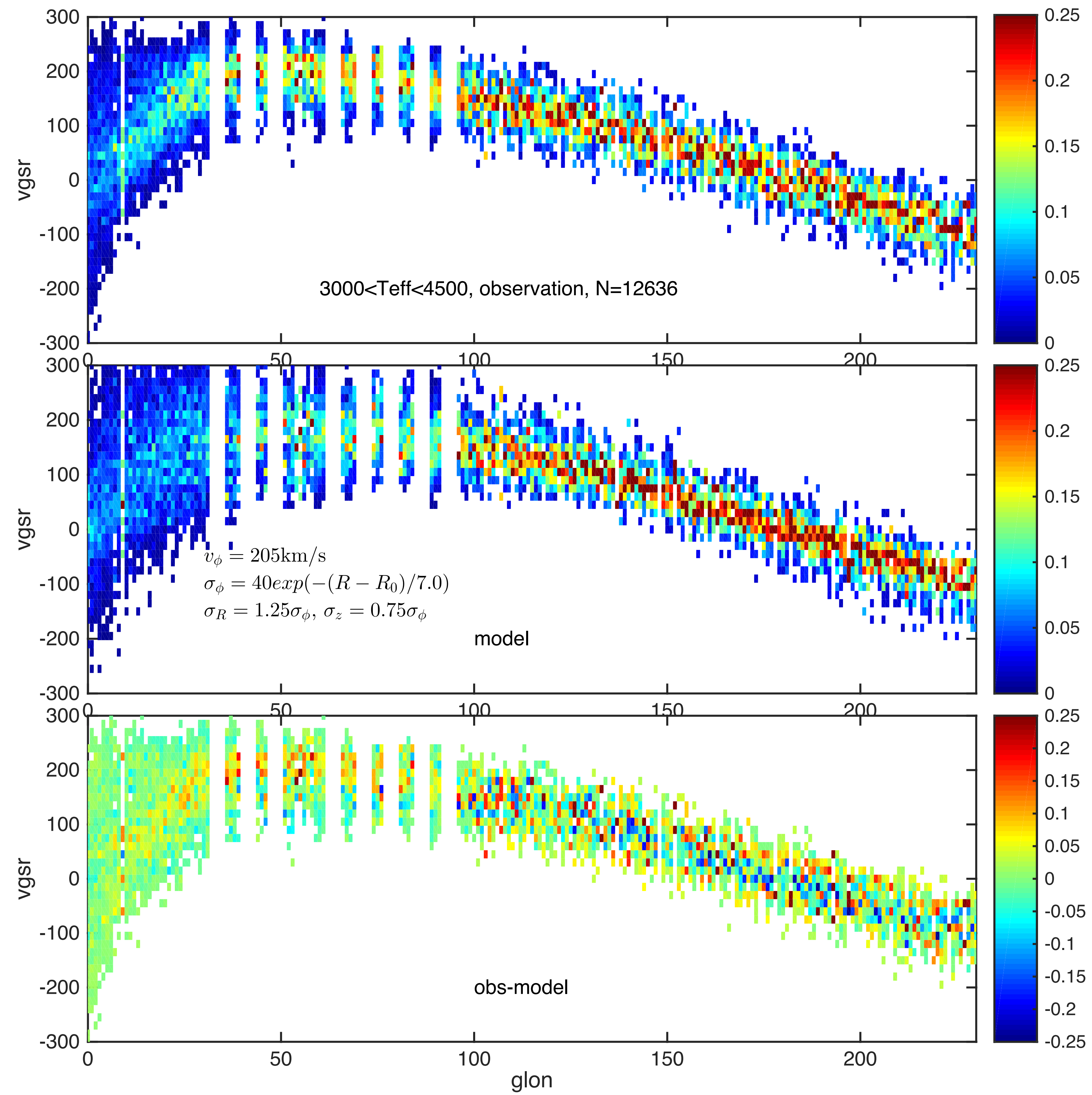


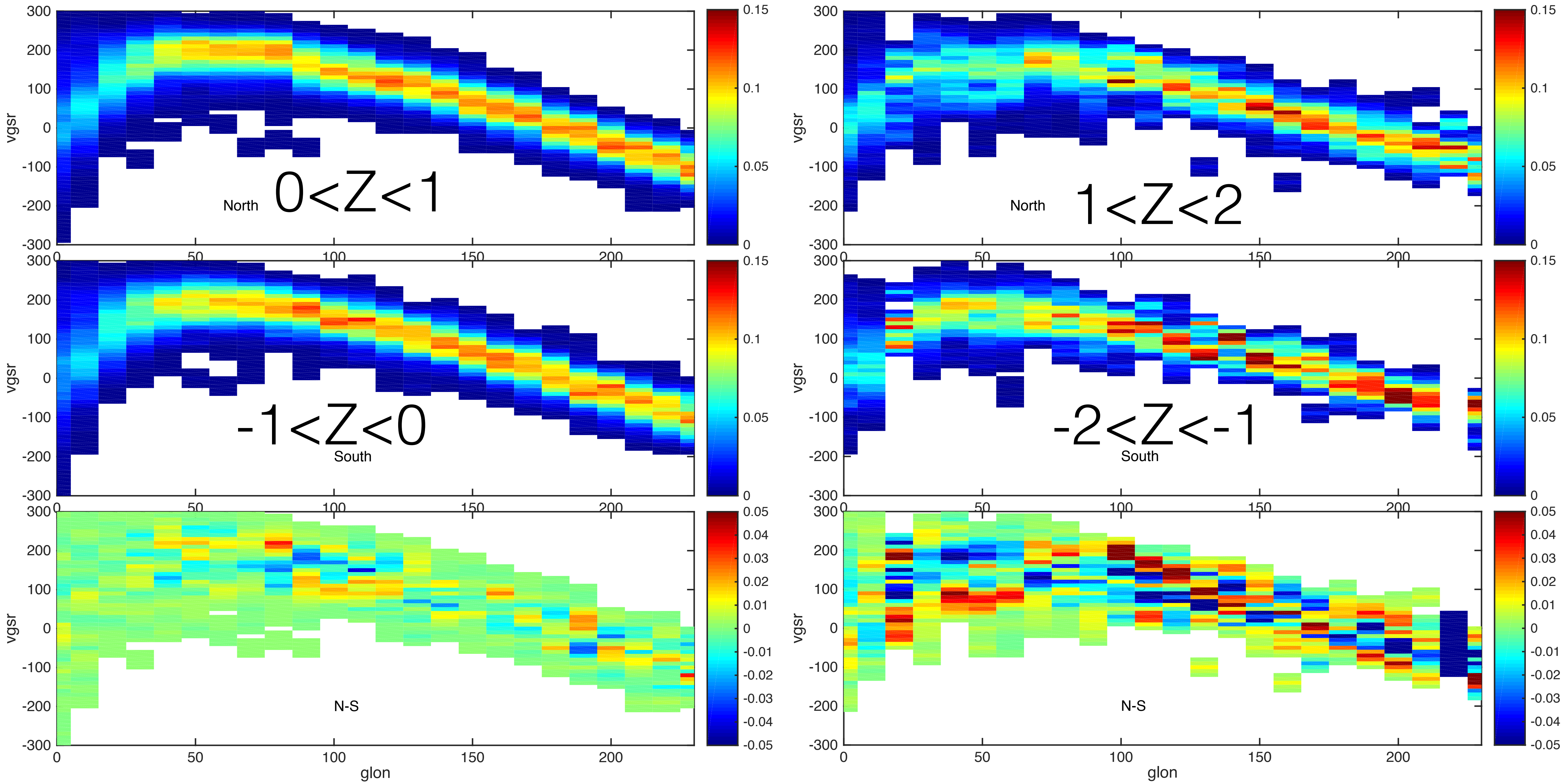
$H] - [\alpha/Fe]$ Distribution for Test Obj
$[\alpha/Fe]$
$[Fe/H]$

Liu, Wan et al.

Dynamical modeling






North
0<Z<1
North
1<Z<2
-1<Z<0
South
-2<Z<-1
South
N-S
N-S
vgsr
glon
0.15
0.1
0.05
0
0.05
0.04
0.03
0.02
0.01
-0.01
-0.02
-0.03
-0.04
-0.05