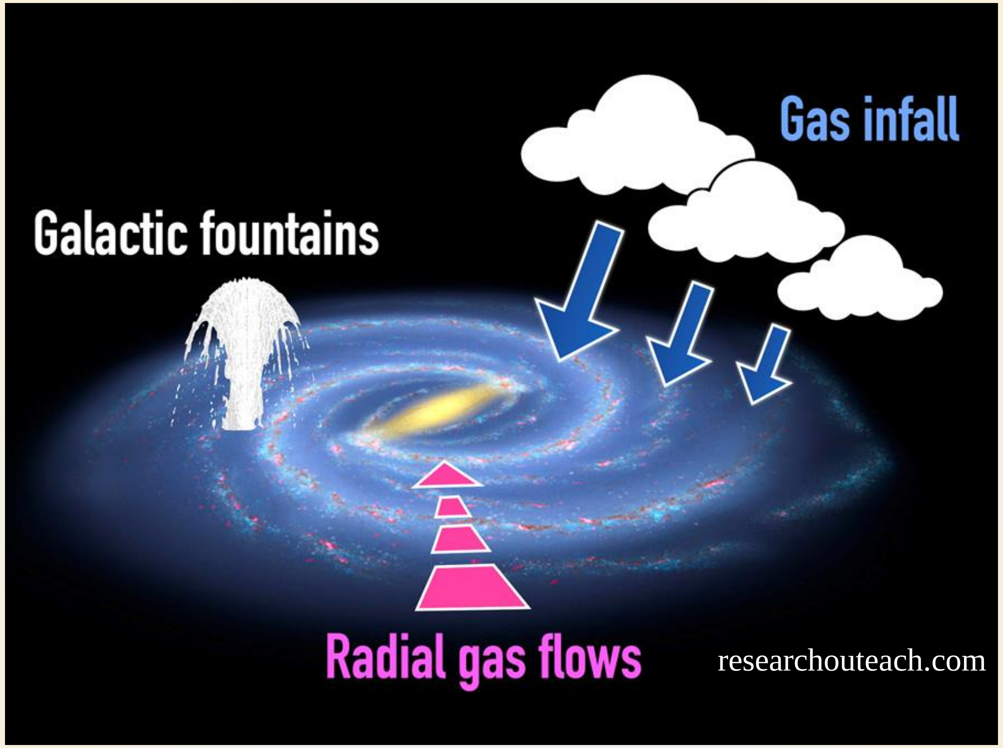
MODELLING THE CHEMICAL EVOLUTION OF THE MILKY WAY WITH OMEGA+



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I. RECENT OBSERVATIONS

- SDSS APOGEE & MWM
- GALAH
- Gaia-ESO

high resolution (R > 10 000) sky surveys exploring the chemical map of our Galaxy to date

a comparison between the three latest data releases of these surveys to investigate the accuracy, precision of derived parameters by placing the abundances on the absolute scale

main parameters: v_{rad}, T_{eff}, $log\ g$, [M/H], v_{micro} *+ commonly derived chemical abundances*

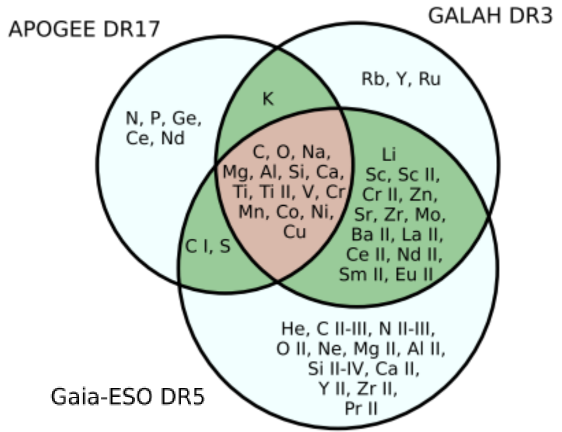
Hegedűs et al. 2023, A&A, 670, A107

High Resolution Spectroscopic Sky Surveys

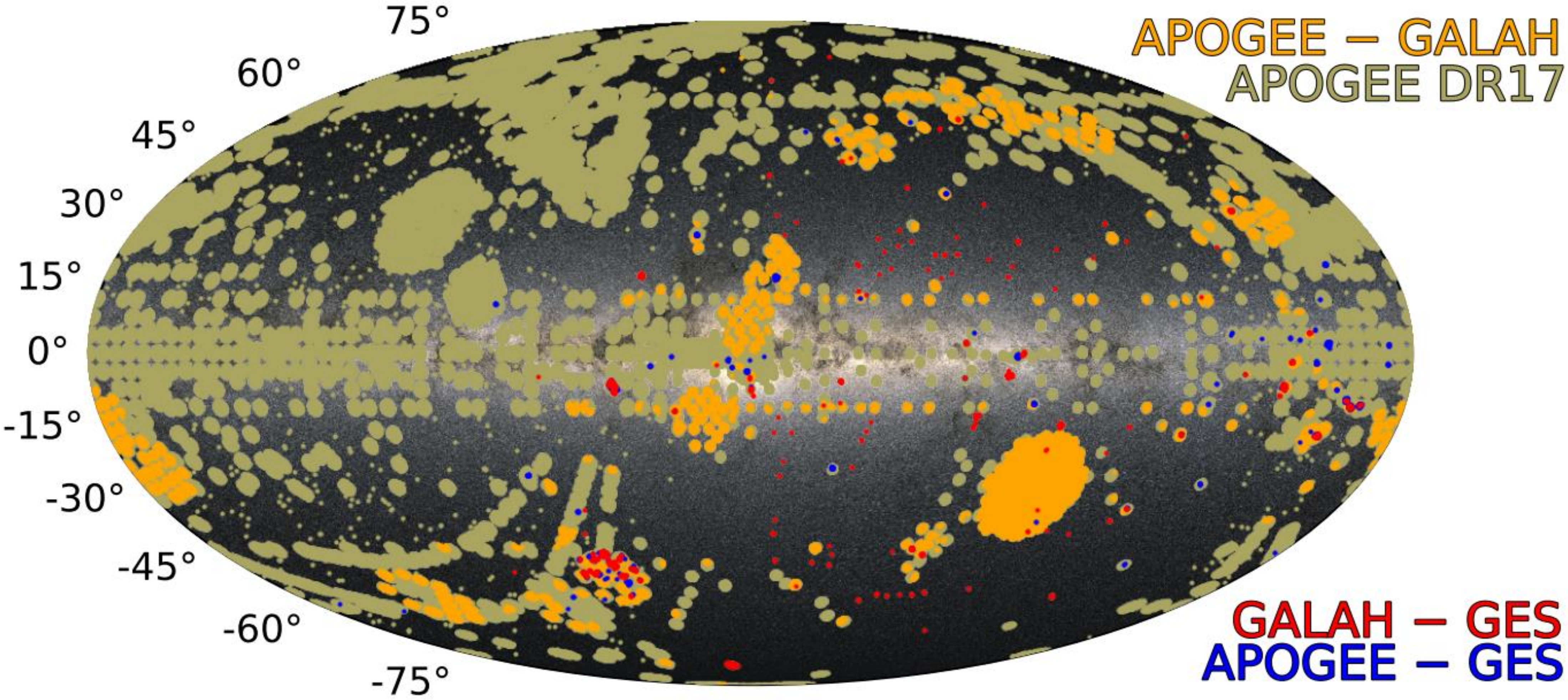
	APOGEE DR17	GALAH DR3	GES DR5
Date of data release	December 2021	November 2020	May 2017
Number of stars	733,901	588,571	114,324
Telescope	Sloan Foundation at APO, 2.5 m NMSU at APO, 1 m du Pont telescope at LCO, 2.5 m	Anglo-Australian Telescope at Siding Spring Observatory, 3.9 m	ESO Telescopes at the La Silla Paranal Observatory
Wavelength range	15 140—16 940 Å	4 optical bands: 4713—4903 Å, 5648—5873 Å 6478—6737 Å, 7585—7887 Å	multiple ranges from 4033 Å to 9001 Å
Resolution	$\sim$ 22 500	$\sim$ 28 000	$\sim$ 16 000 — 26 000, 47 000
Calibration	calibrated $T_{\rm eff}$, $\log g$, [M/H], [α/M], abundance parameters	calibrated abundance parameters	*Gaia* benchmark stars and calibrating clusters
Method of deriving parameters	ASPCAP (parameters and abundances)	Spectrum synthesis (SME and *The Cannon*)	equivalent widths, comparisons of observed spectra and a grid of templates (strategy: WGs)
Model atmospheres	Kurucz model (Cannon models), all-MARCS grid ($T_{\rm eff}$ <8000 K)	MARCS grid (plane parallel models for $\log g > 4$, spherical models for $\log g < 4$)	MARCS grid
1D/3D	spherical (Turbospectrum) or plane parallel (Synspec)	1D spherical	1D spherical
LTE/NLTE	LTE/NLTE	LTE/NLTE	
Spectral synthesis code	Turbospectrum (for the main spectral grids), Synspec	Spectroscopy Made Easy (SME)	e.g. Turbospectrum, SME, MOOG, COGs
1D/3D	Plane parallel and spherical	1D spherical	
LTE/NLTE	LTE/NLTE	LTE/NLTE	LTE
Solar reference table	Grevesse et al. (2007)	Buder et al. (2021)	Grevesse & Sauval (1998)

Overlapping Statistics

	APOGEE-GALAH	APOGEE-GES	GALAH-GES
No. common stars[a]	37,770 (15,537)	2,502 (804)	1,510 (441)
Common parameters	$T_{\rm eff}$, $\log g$, $v_{\rm rad}$, [Fe/H], [α/Fe], $v_{\rm micro}$	$T_{\rm eff}$, $\log g$, $v_{\rm rad}$, [Fe/H], $v_{\rm micro}$	$T_{\rm eff}$, $\log g$, $v_{\rm rad}$, [Fe/H], $v_{\rm micro}$



The Commonly Observed Stars



- The common sample covers mostly thick disk, halo stars and Kepler K2 fields.
- The thin disk is not well sampled, but metal-rich stars are still abundant in the APOGEE-GALAH common sample.

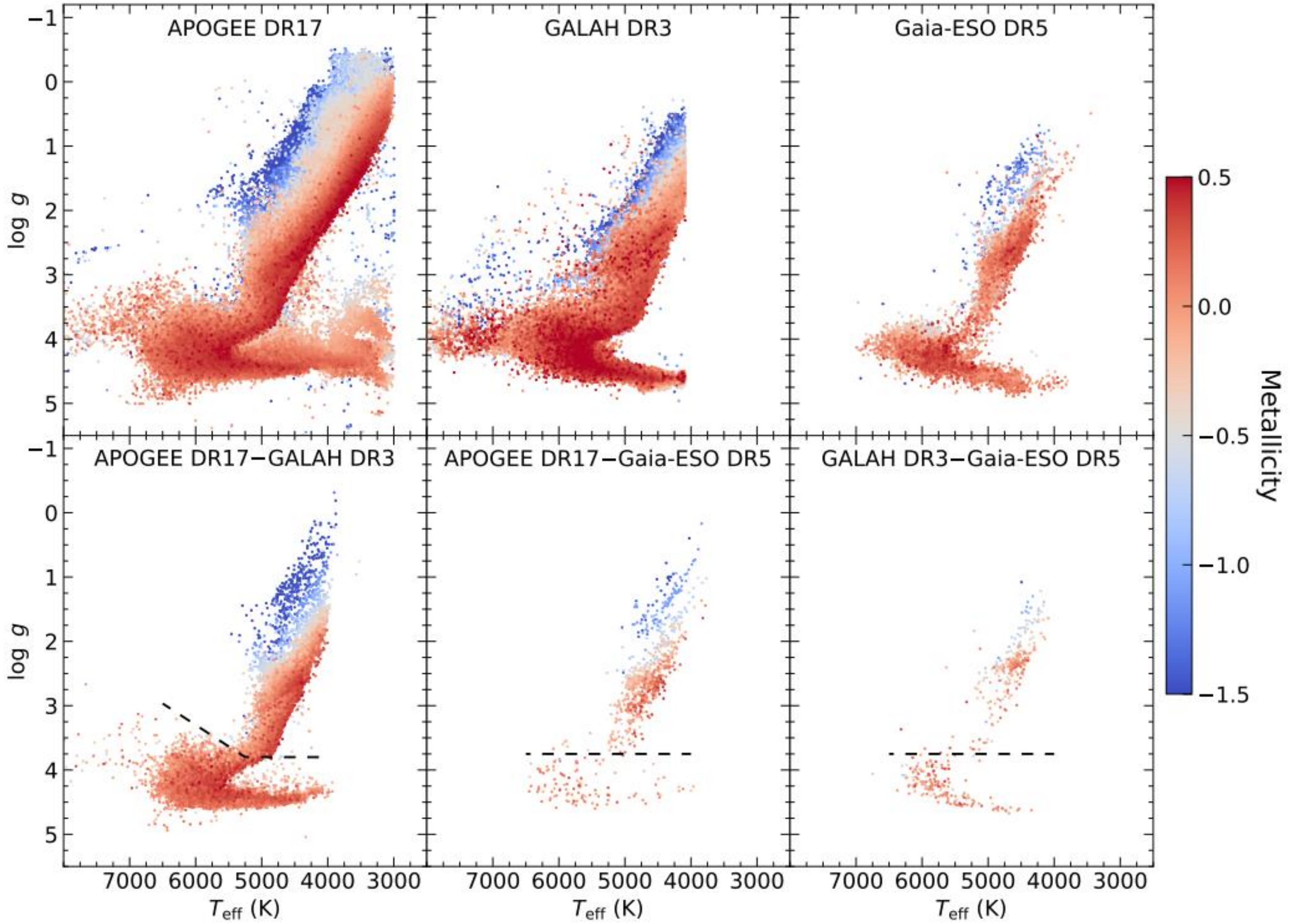
HRD of Commonly Observed Stars

- Top: each survey's latest DR
- Bottom: common sample
- investigate MS and RGB separately

- APOGEE-GALAH:

HRD is well sampled in a large $T_{\text{eff}}-\log g$ range.

- Average differences and their slope as function of parameters are discussed.



Overall Differences of Main Parameters

- We compare the strength of correlations with the average uncertainties in order to differentiate between the correlated errors and "true" correlations.
  - potential large discrepancies:

ΔT_{eff} with metallicity and log g (dwarfs only)

- v_{micro}-s are determined in a fundamentally different way
- but overall the differences lie within the reported uncertainties

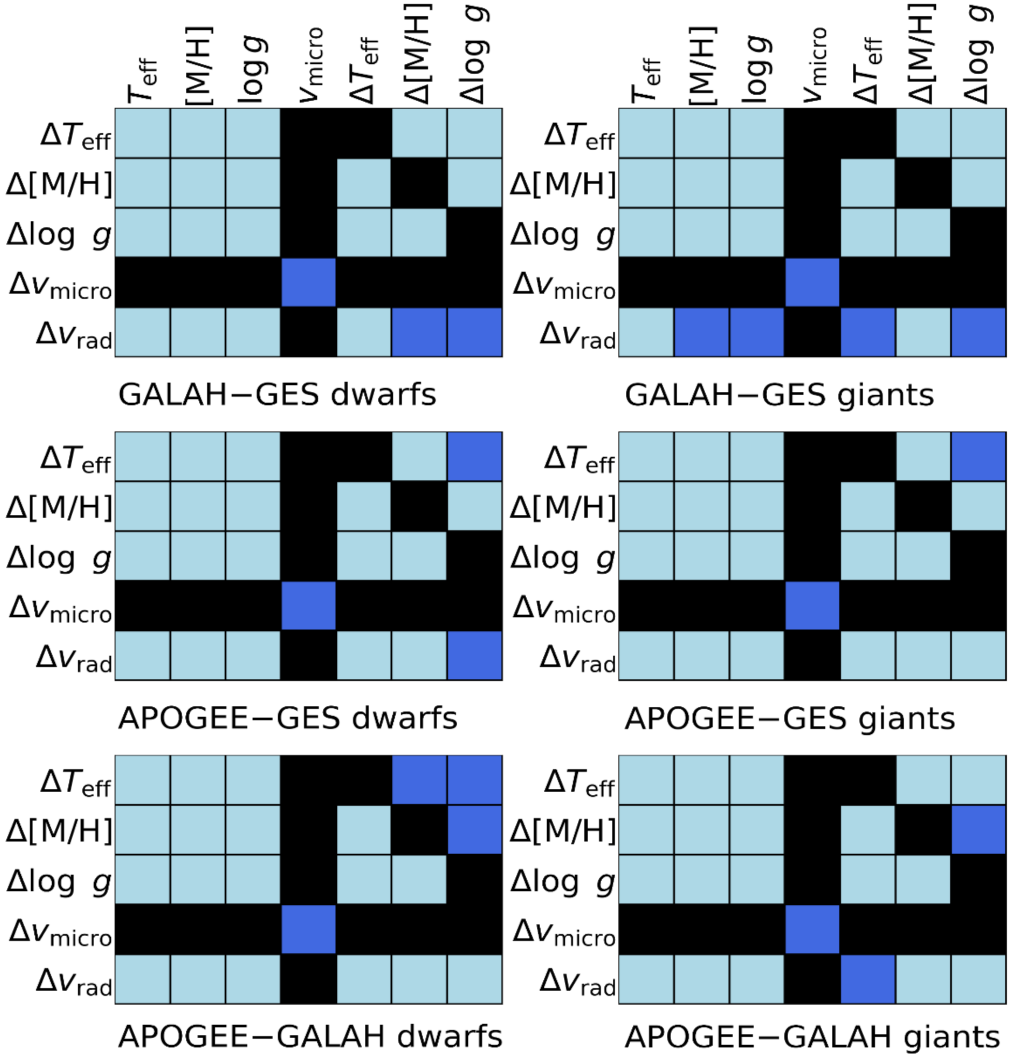
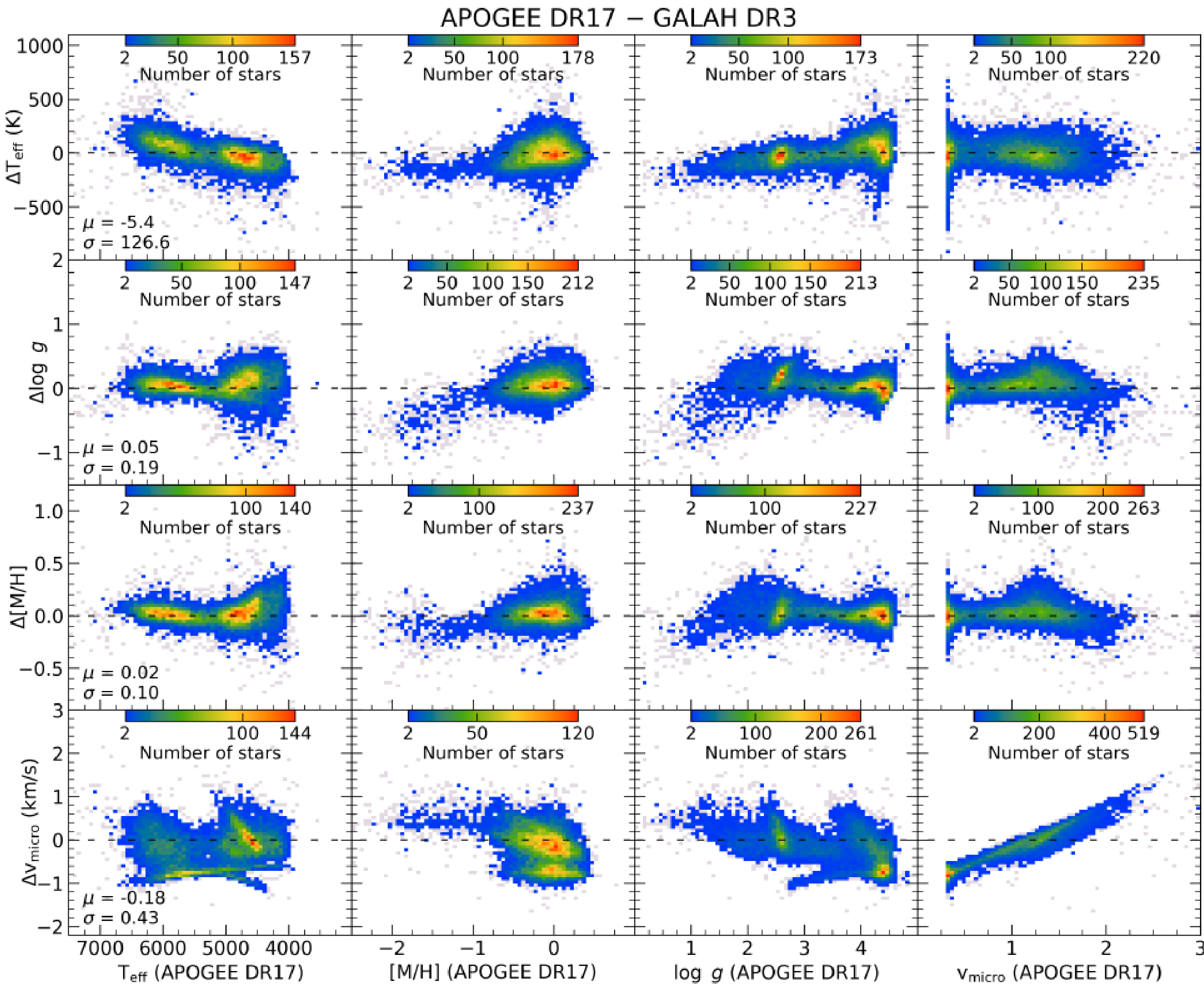


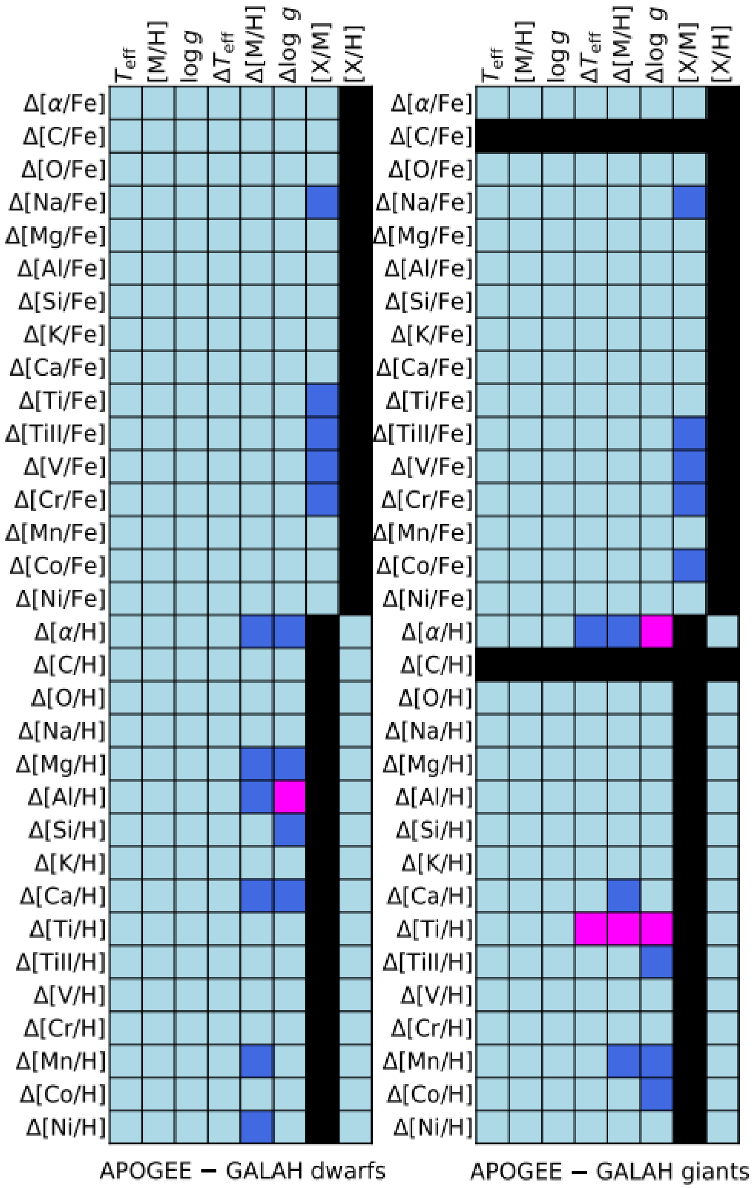
Fig. 5. The strength of the correlations between parameter pairs are indicated by colors. Light blue cells represent no significant correlations ($< 0.8\sigma$), while the dark blue ones mark weak correlations ($0.8\sigma - 1.5\sigma$). Black cells are not relevant due to the absence of reported uncertainties of v_{micro} or because connecting same quantities (e.g., ΔT_{eff} with ΔT_{eff}). The estimated strength of correlations are based on the comparison of the correlation slopes with the average of the reported individual uncertainties of stellar parameters and RVs. The stars have been separated into dwarfs (left column) and giants (right column).

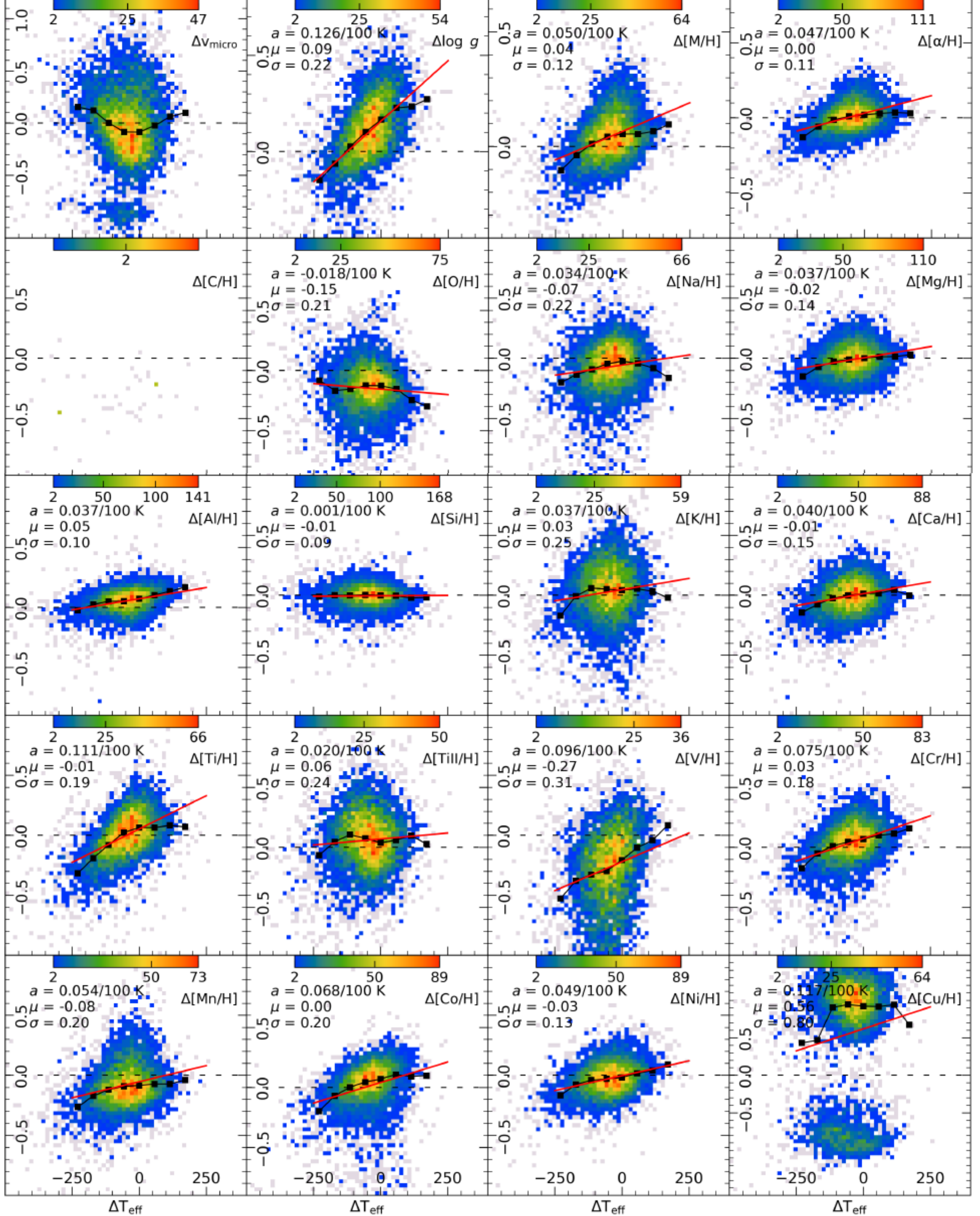
	APOGEE-GALAH	
No. common stars [(a)]	37 770 (15 537)	
Common parameters	$T_{\rm eff}$, $\log g$, $v_{\rm rad}$, [Fe/H], [α/Fe], $v_{\rm micro}$	
Common elements	C, O, Na, Mg, Al, Si, K, Ca, Ti, Ti II, V, Cr, Mn, Co, Ni, Cu	
S/N cut [(b)]	SNR > 100 & `snr_c3_iraf>30`	
Other quality cuts [(b)]	`vbroad<15` & `flag_sp==0` & `flag_fe_h == 0` & `VSCATTER<1` & `VSINI<15` & `VERR<1`, flags	
	$\mu \pm \sigma$ dwarfs	$\mu \pm \sigma$ giants
$\Delta T_{\rm eff}$(K)	43.6 ± 137.3	−54.3 ± 91.7
overall	−5.4 ± 126.6	
$\Delta \log g$(dex)	0.01 ± 0.13	0.09 ± 0.22
overall	0.05 ± 0.19	
Δ[M/H] [(c)]	0.006 ± 0.082	0.039 ± 0.121
overall	0.023 ± 0.105	
$\Delta[\alpha/{\rm H}]$(dex)	−0.014 ± 0.082	0.005 ± 0.107
overall	−0.005 ± 0.096	
$\Delta v_{\rm micro}$(km s^{-1})	−0.34 ± 0.42	−0.03 ± 0.36
overall	−0.18 ± 0.43	
$\Delta v_{\rm rad}$(km s^{-1})	−0.01 ± 4.10	−0.04 ± 2.81
overall	−0.02 ± 3.51	



Overall Differences of Abundances

- average differences for all cases and the strength of the correlation with main parameters and the differences of main parameters between APOGEE and GALAH
  - example plot: Δ[X/H] vs. ΔT_{eff} for giants
- strength of correlations in abundance pairs (linear fits)
- only few significant correlations are found between APOGEE and GALAH (Δ[Al/H] vs. $\Delta\log g$ dwarfs, Δ[α/H] vs. $\Delta\log g$ giants, Δ[Ti/H] vs. ΔT_{eff}, Δ[M/H], $\Delta\log g$ giants)



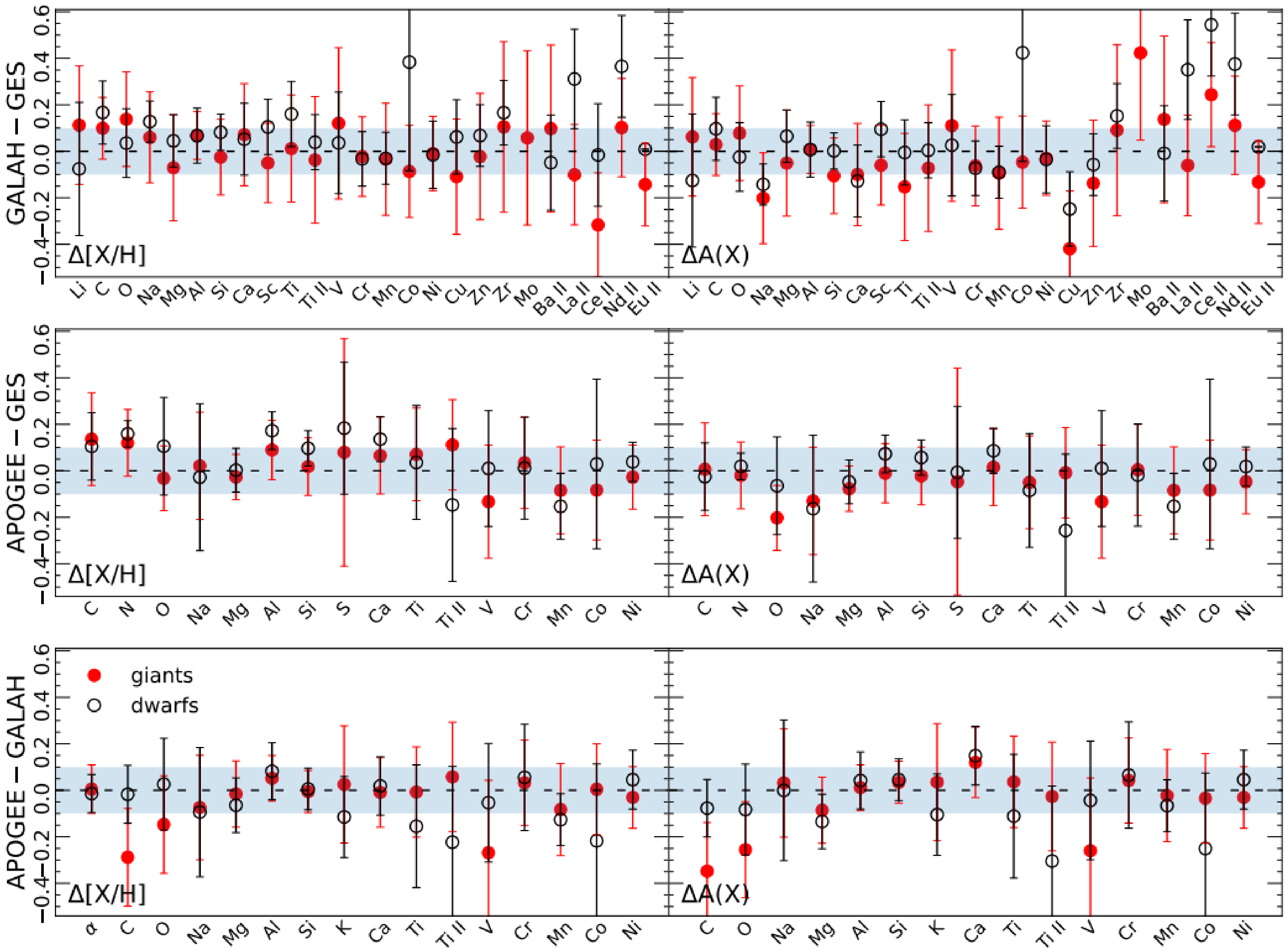


- average differences of [X/H] and A(X) in the whole sample for each element
- darker area indicates ± 0.1 dex
- correcting for the different Sun zeropoints slightly improves the agreement

Conclusions

- a remarkable job at replicating atmospheric and abundance parameters
- differences of the main APs agree within uncertainties, except ΔT_{eff} (M/H, log *g*) for dwarfs only
- significant correlation was found in Δv_{micro} (v_{micro}):

APOGEE fits the spectrum, while GALAH calculates it from T_{eff}



- significant correlations are found between APOGEE and GALAH for the following elements: Δ[Al/H] vs. Δlog *g* dwarfs; Δ[α/H] vs. Δlog *g* giants; Δ[Ti/H] vs. ΔT_{eff}, Δ[M/H], Δlog *g* giants

Effect on the MW chemical maps

- The GALAH and APOGEE median trends for Si and Ca are similar

sharper separations → both have a non-negligible contribution from SNIa

- Oxygen has a much stronger metallicity dependence in GALAH, while the APOGEE trends are nearly flat

The disagreements on the slopes of the [M/H] or [Mg/H] dependences could arise from the difficulty of deriving O abundances from both optical (GALAH) and near-IR (APOGEE) spectra.

APOGEE data agrees better with theoretical expectations, as the O and Mg enrichment have slight dependence on metallicity.

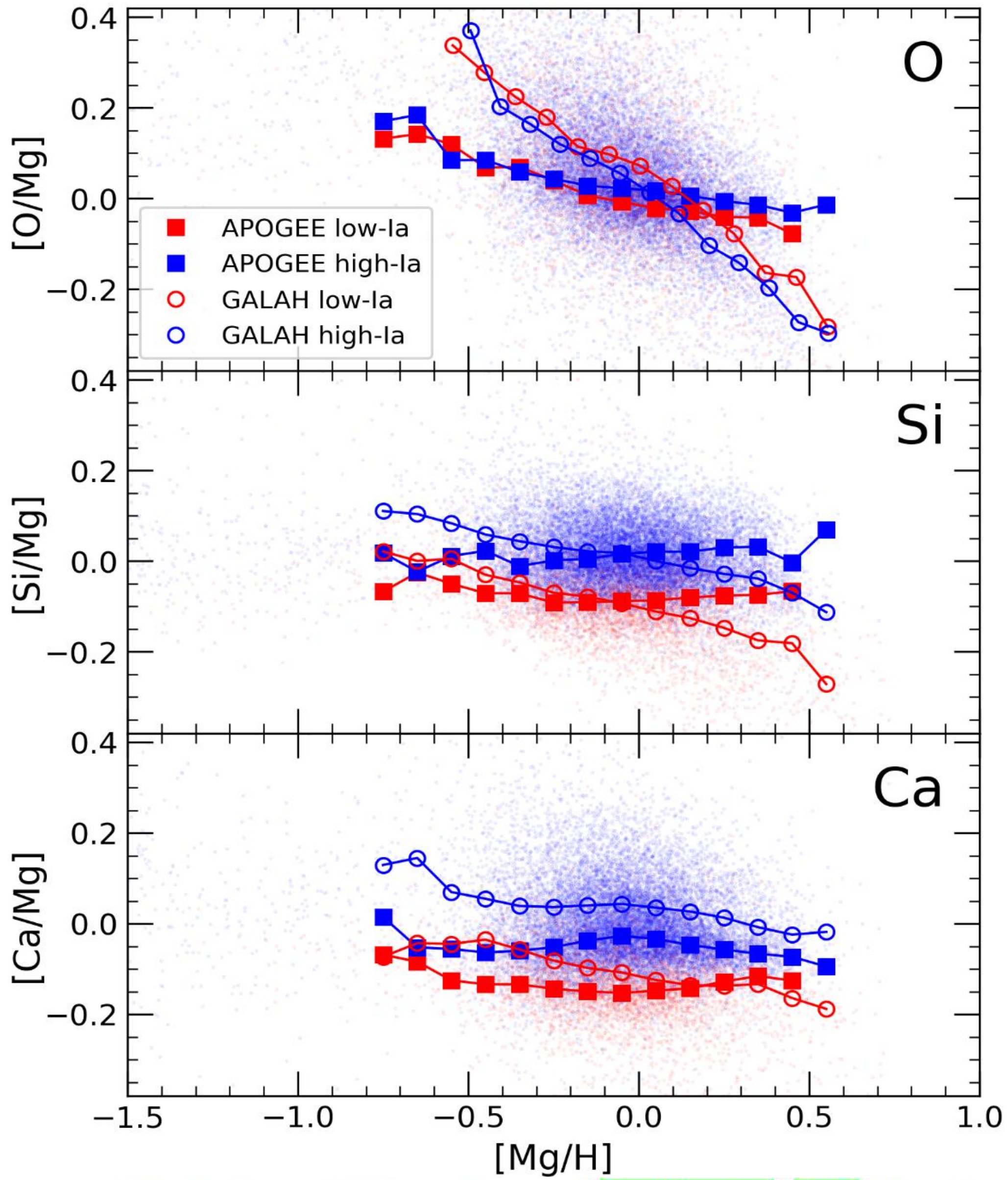
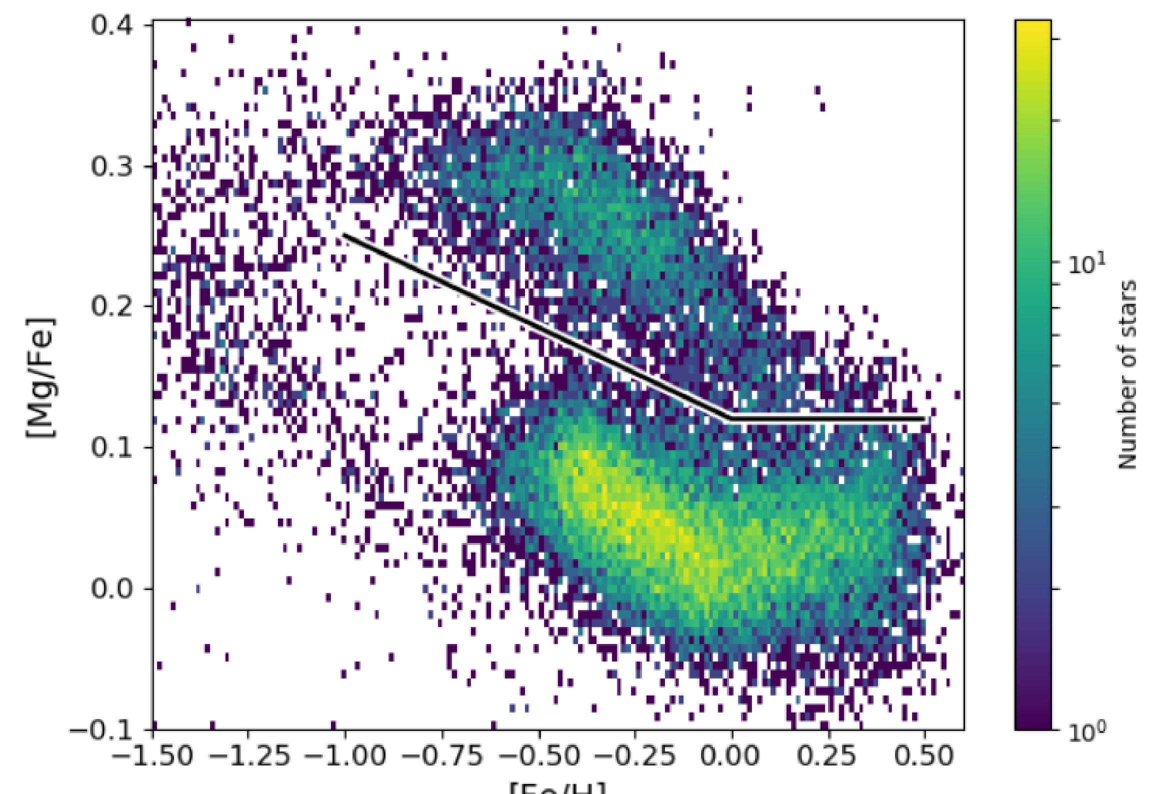


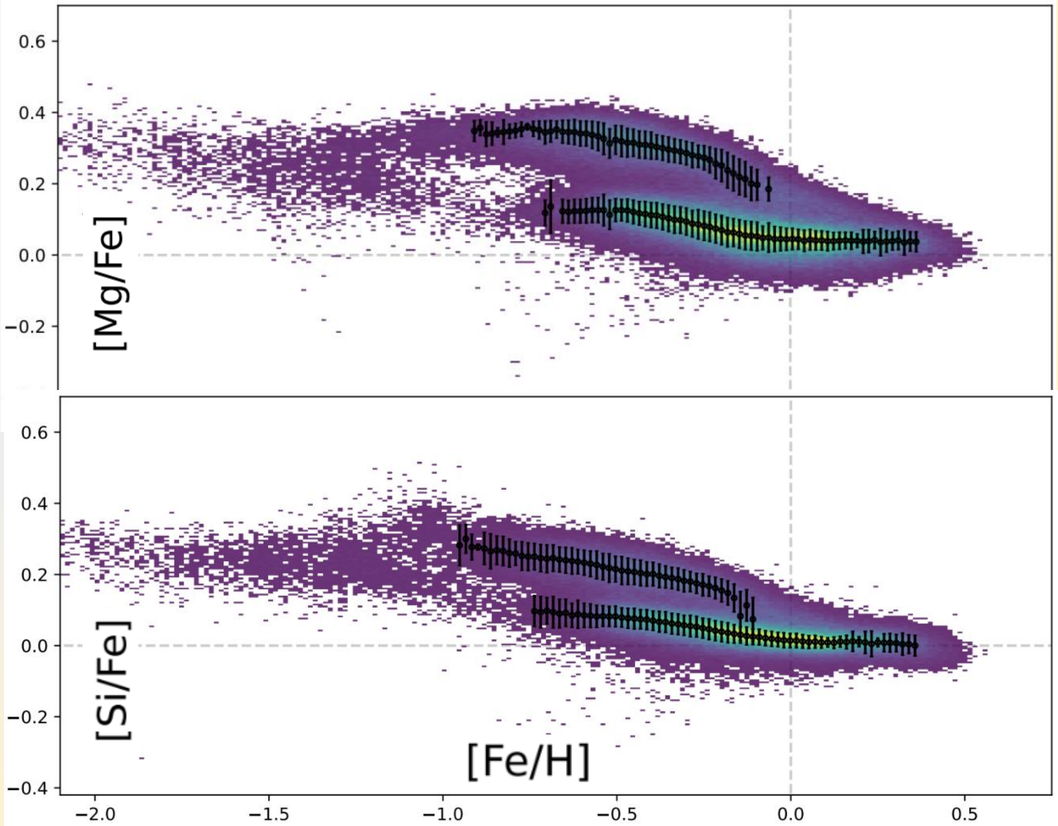
Fig. 12. Reproduction of Figure 3, Griffith et al. (2019), based on the most current versions of the databases. GALAH DR3 α-element median abundances of the high-Ia supernovae (empty blue circles) and low-Ia supernovae (empty red circles) populations. Data are binned by 0.1 dex in [Mg/H]. APOGEE DR17 median abundances are also included (squares).

I. CHEMICAL EVOLUTION OF THE MW

- SDSS APOGEE & MWM private data (Kollmeier et al. 2017)
- OMEGA (Côté et al. 2017)
- OMEGA+ (Côté et al. 2018)



Weinberg et al. 2019

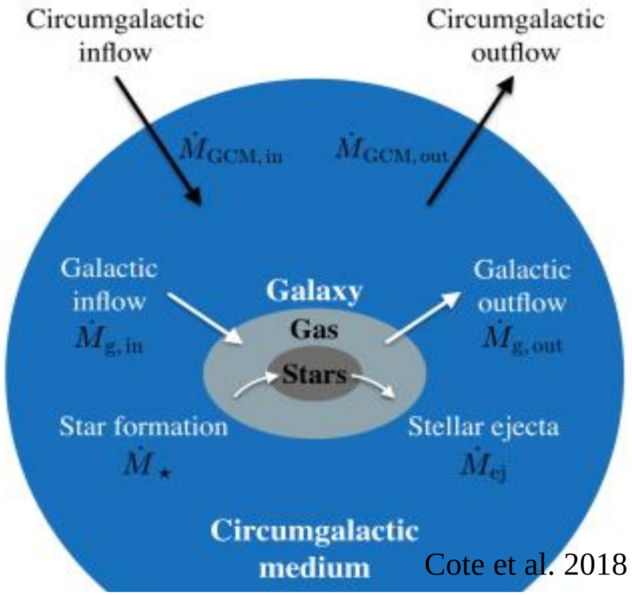


Building up the Galactic formation

- Main equation:

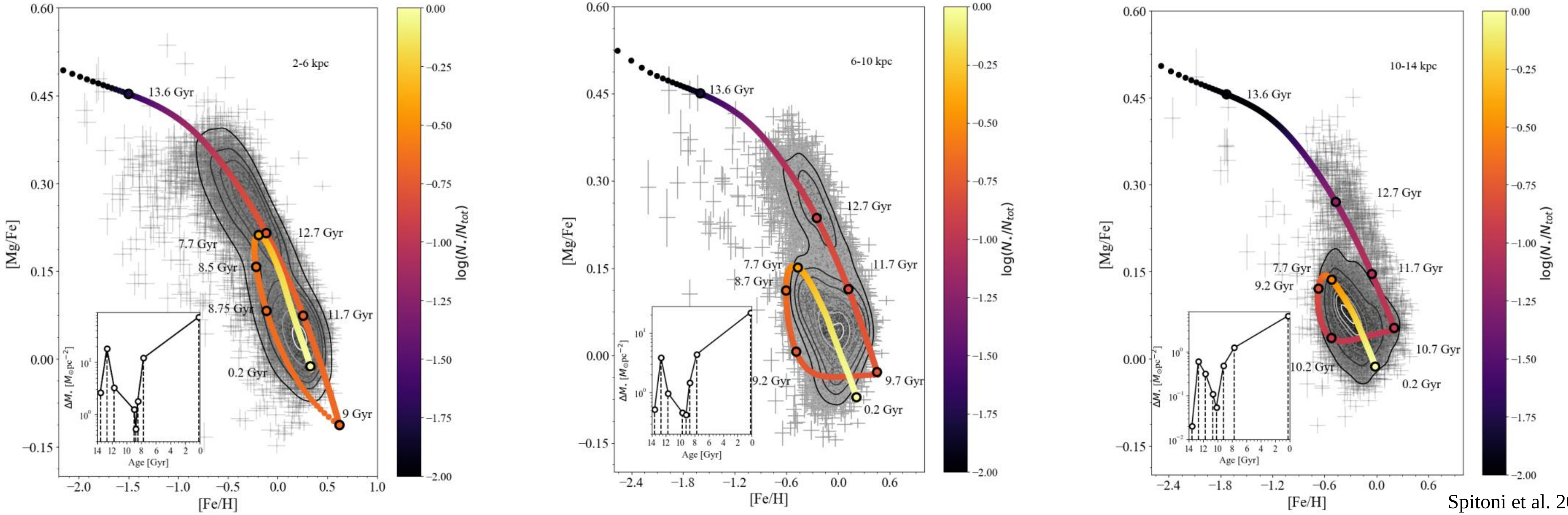
$$M_{\rm gas}(t+\Delta t) = M_{\rm gas}(t) + \left[\dot{M}_{\rm in}(t) + \dot{M}_{\rm ej}(t) - \dot{M}_{\star}(t) - \dot{M}_{\rm out}(t)\right]\Delta t$$

- Parameters in MW models:
  - star formation history, mass-loading (η), surface mass densities ($\sigma_{1,2}$), IMF-type, time of each infall ($t_{max1,2}$), inflow-rate, SNIa and SNII rates as function of Galactic age
  - stellar yields for individual elements → tables



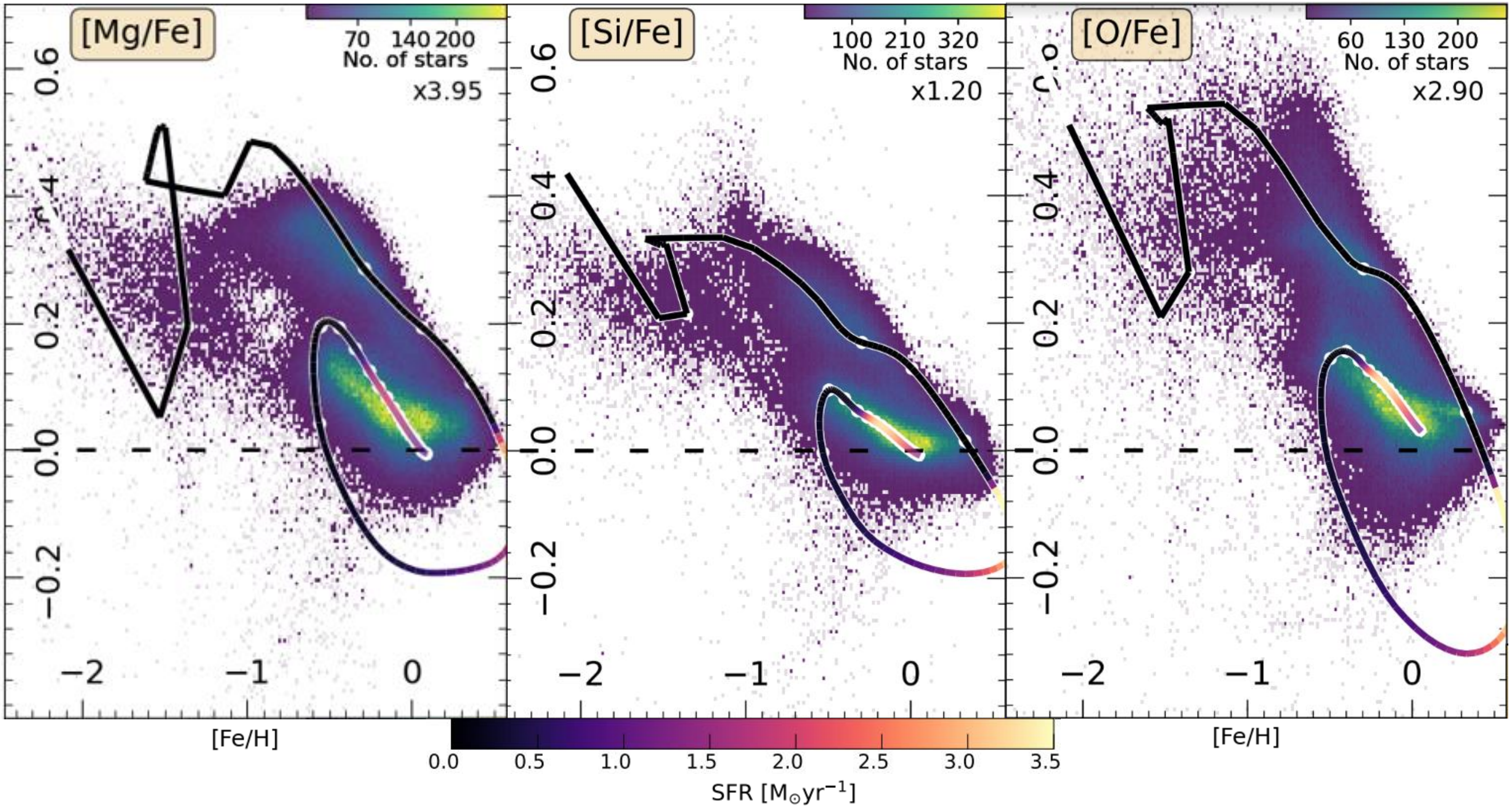
Cote et al. 2018

- Recent results on two-infall formation models:



Spitoni et al. 2021

- **Meeting observations:**



Outlook

Stellar migration?

Fix certain parameters

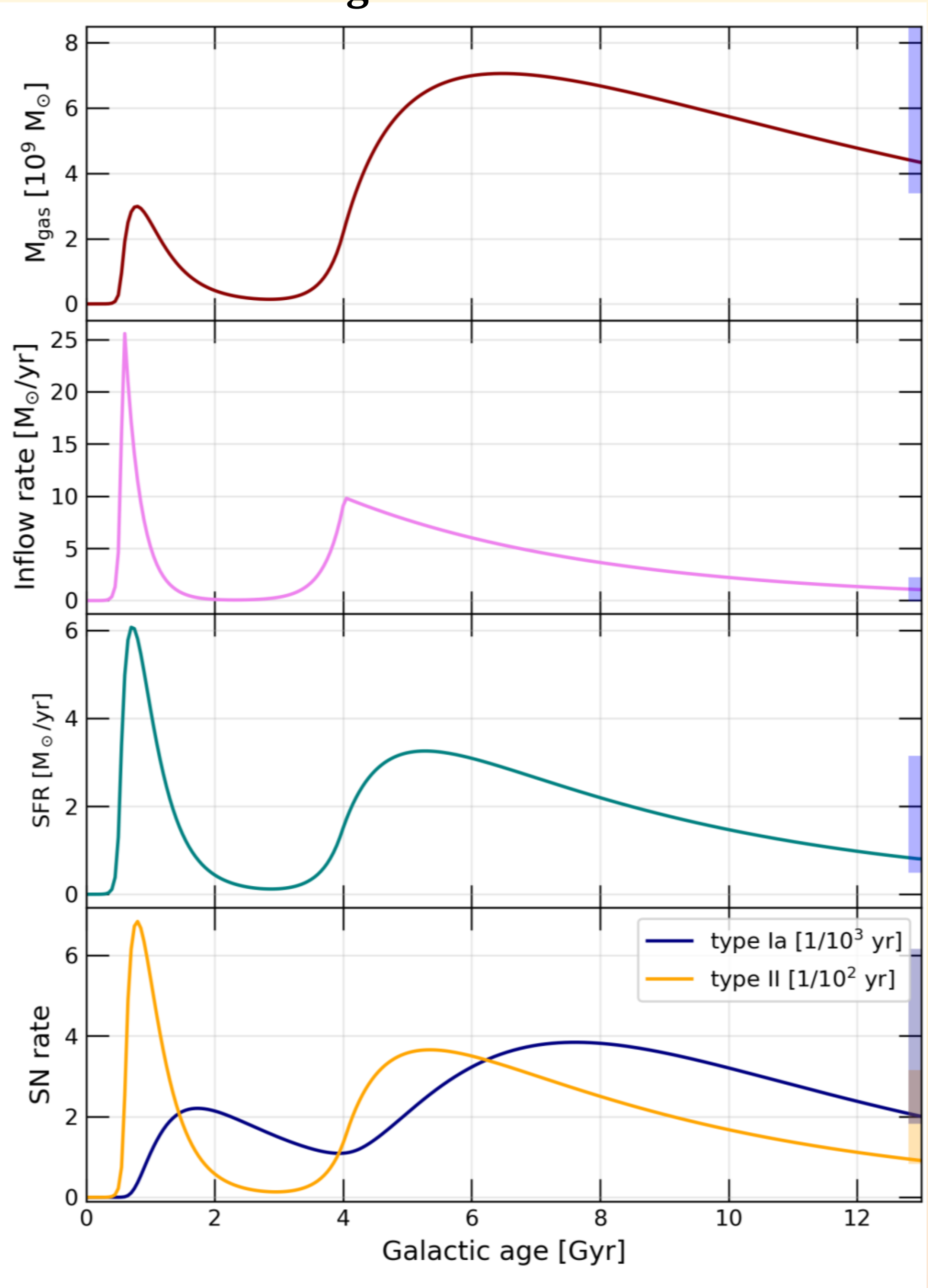
Fit on the latest results of MWM

Vary the yield tables

Fit models for the alpha and also for the odd-Z elements

Thank you for your attention

- **Meeting observations:**



Effective Temperature

- T_{eff} differences are shown in the top row as a function of T_{eff}, [M/H], log g, v_{micro}
  - Overall statistics (K):

APO-GALAH: -5.4 ± 126.6

APO-GES: -35.0 ± 79.0

GALAH-GES: 15.7 ± 125.2

- overall differences: within the error budget
  - a discrepancy between giants and dwarfs as a function of T_{eff} (top left panel)

Surface Gravity

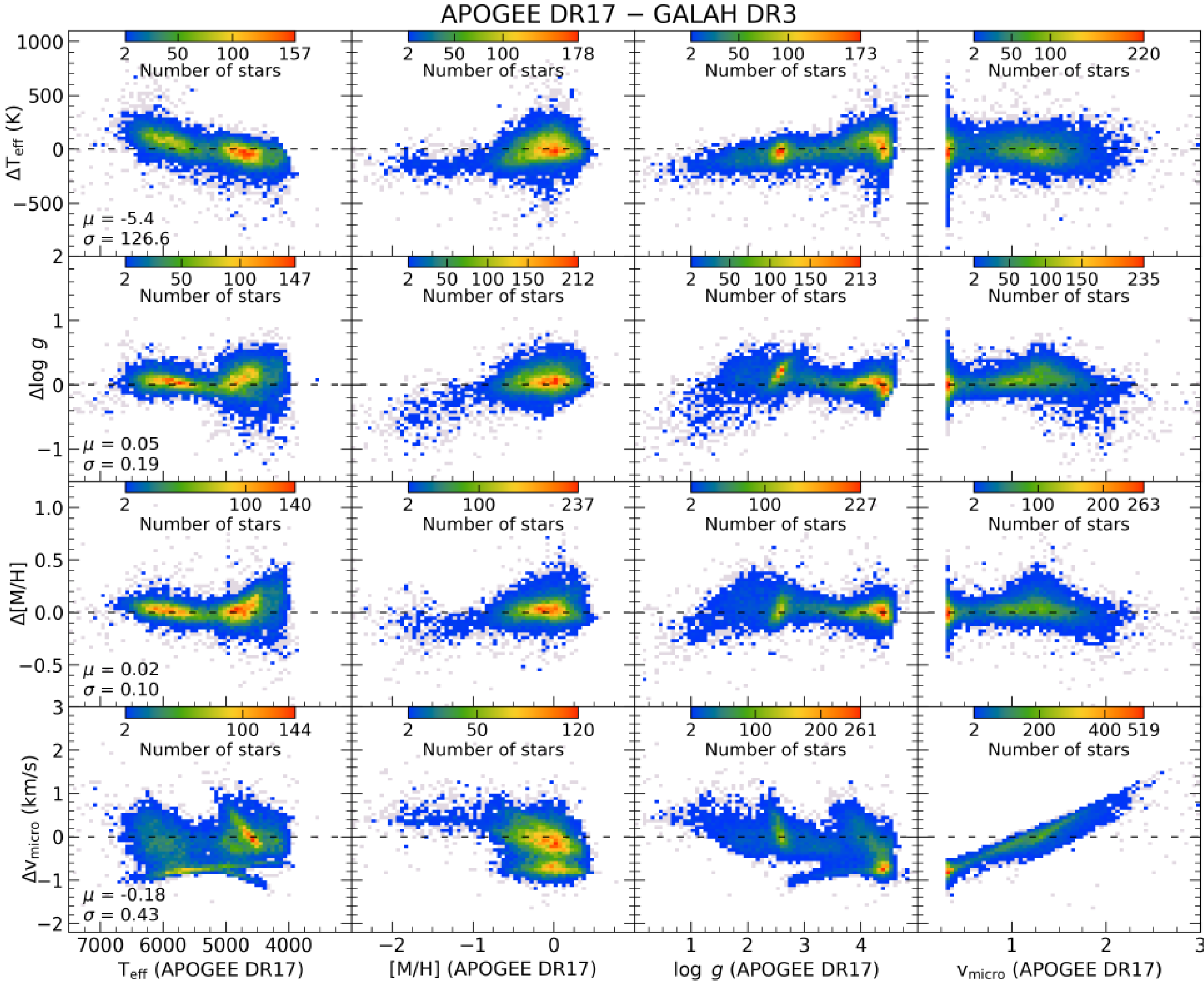
- log g differences are shown in the second row from the top
  - Overall statistics:

APO-GALAH: 0.05 ± 0.19

APO-GES: 0.07 ± 0.17

GALAH-GES: -0.10 ± 0.19

- Note that APOGEE consistently measures higher surface gravities than asteroseismic log g-s



Metallicity

- second row from the bottom
  - Overall statistics:

APO-GALAH: 0.02 ± 0.10

APO-GES: −0.01 ± 0.07

GALAH-GES: −0.16 ± 0.23

- Overall differences are within the error budget, but note the discrepancy as a function of low T_{eff} -s (APOGEE-GALAH)

Microturbulent Velocity

- bottom row
  - Overall statistics:

APO-GALAH: −0.18 ± 0.43

APO-GES: 0.0 ± 0.34

GALAH-GES: −0.15 ± 0.20

- Significant correlation found as a function of v_{micro}: APOGEE fits the spectrum, while GALAH calculates it from T_{eff}