Stellar Parameters and the Close Binary Fraction in APOGEE

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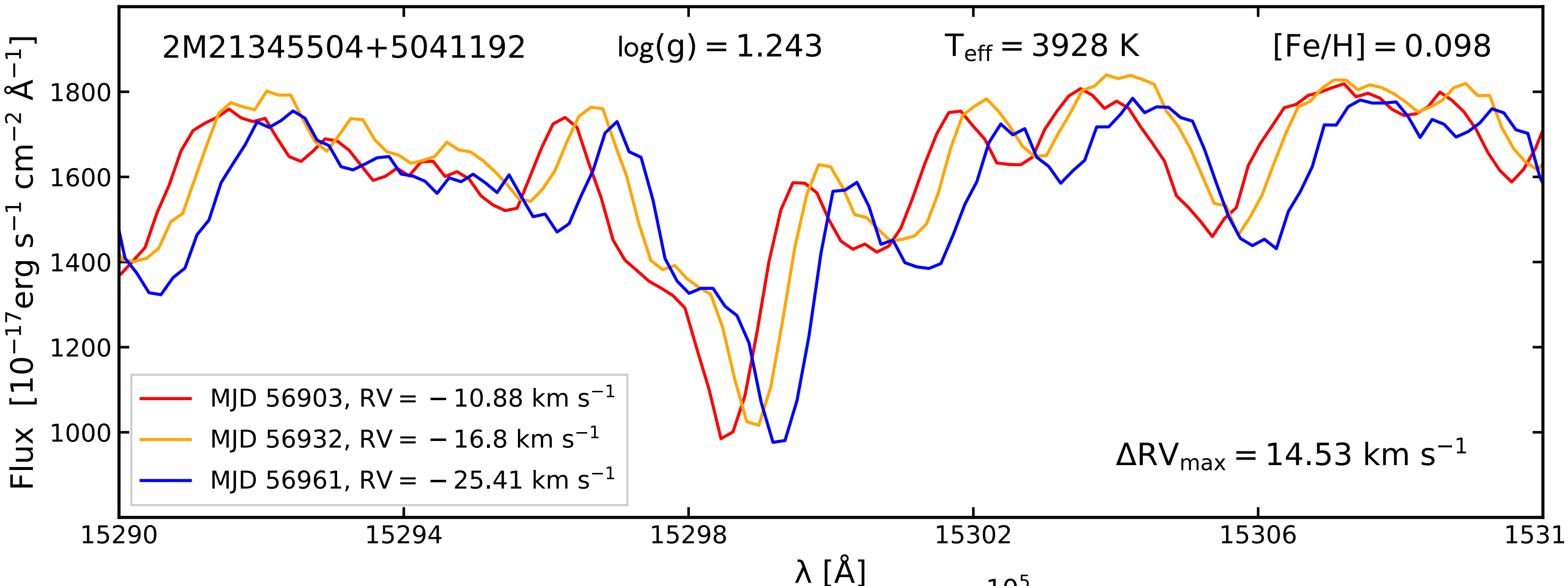
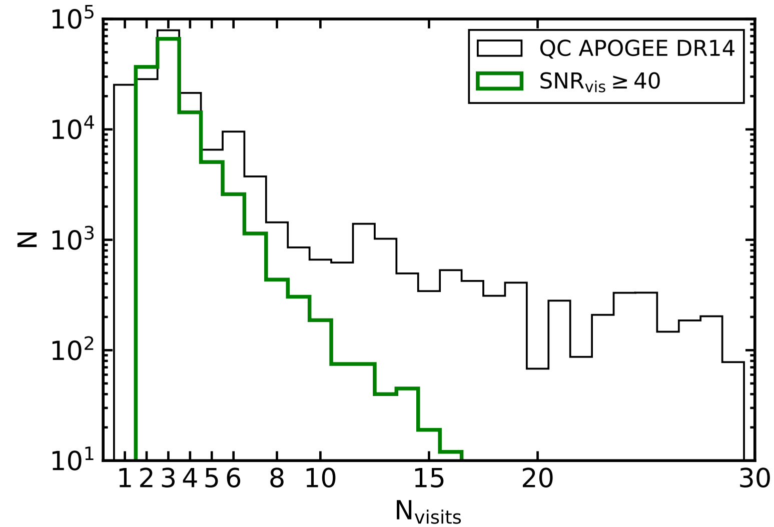
Stellar Multiplicity in APOGEE



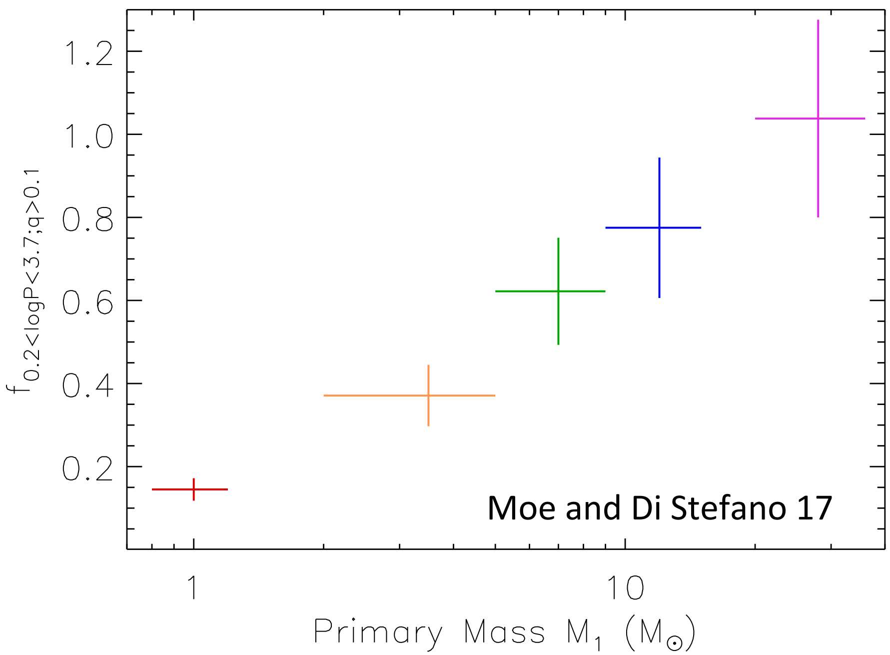
$$\Delta RV_{max} = |RV_{max} - RV_{min}|$$

Only requires that stars have $N_{visits} \geq 2$

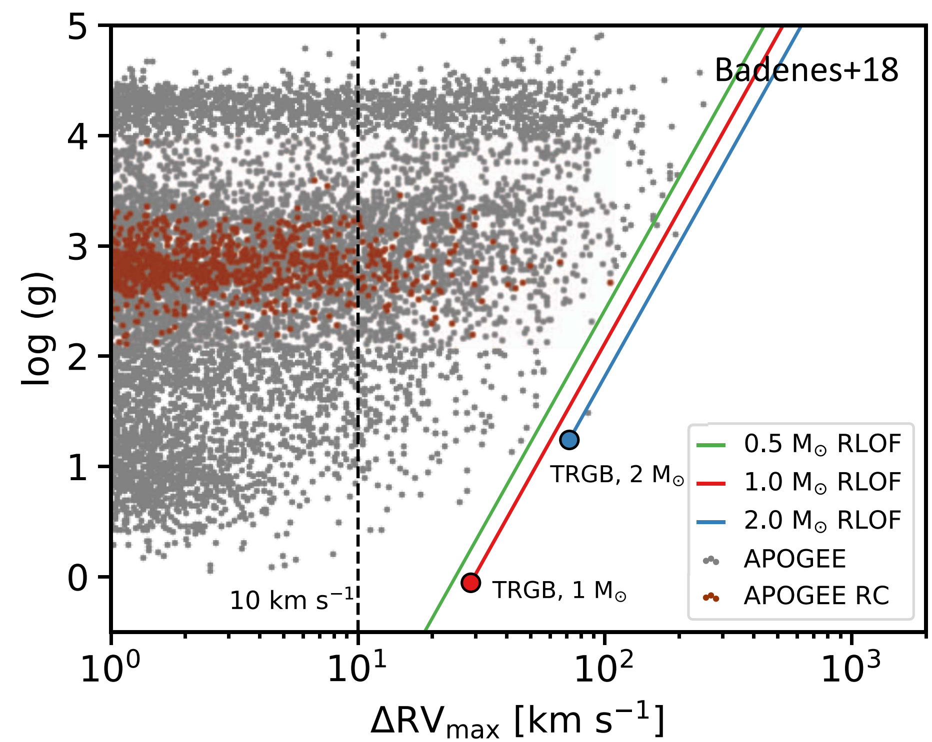
Can't derive orbital solutions, but can study their properties in large statistical samples!



Previously Known Correlations

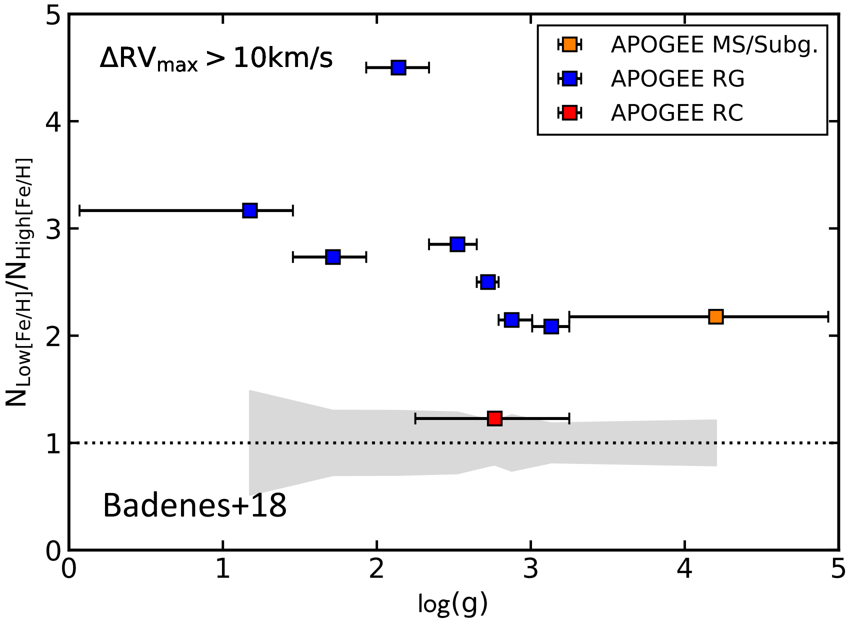


Primary mass is correlated with the close binary fraction, which has implications for **star formation theories**.



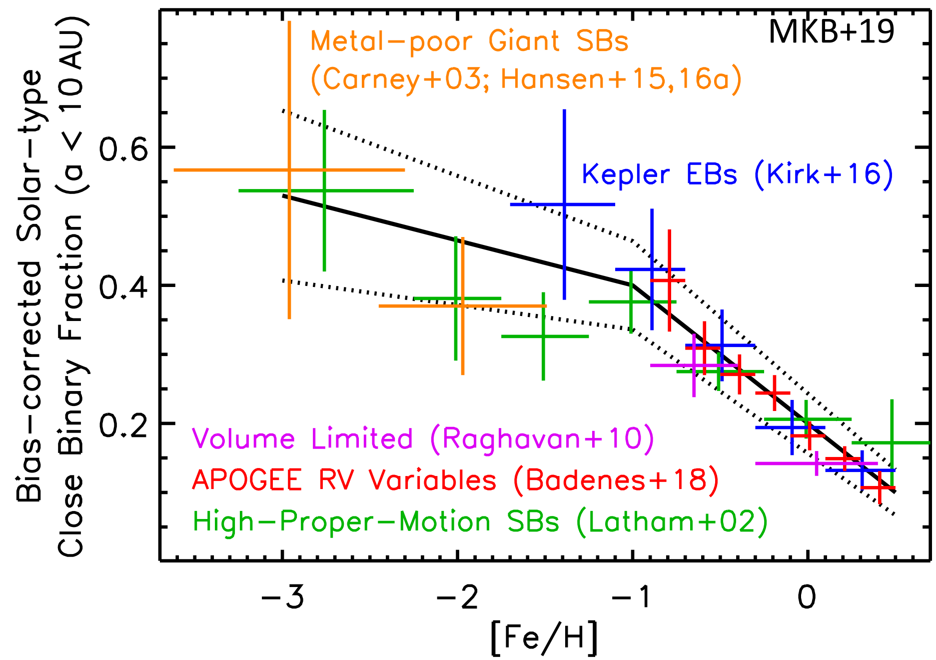
Whereas correlations with **surface gravity** yield insight into the frequency of RLOF events during both stars' lifetimes.

Previously Known Correlations



Badenes+2018 with APOGEE DR13 found an **anti-correlation** between **[Fe/H]** and **RV variability fractions**.

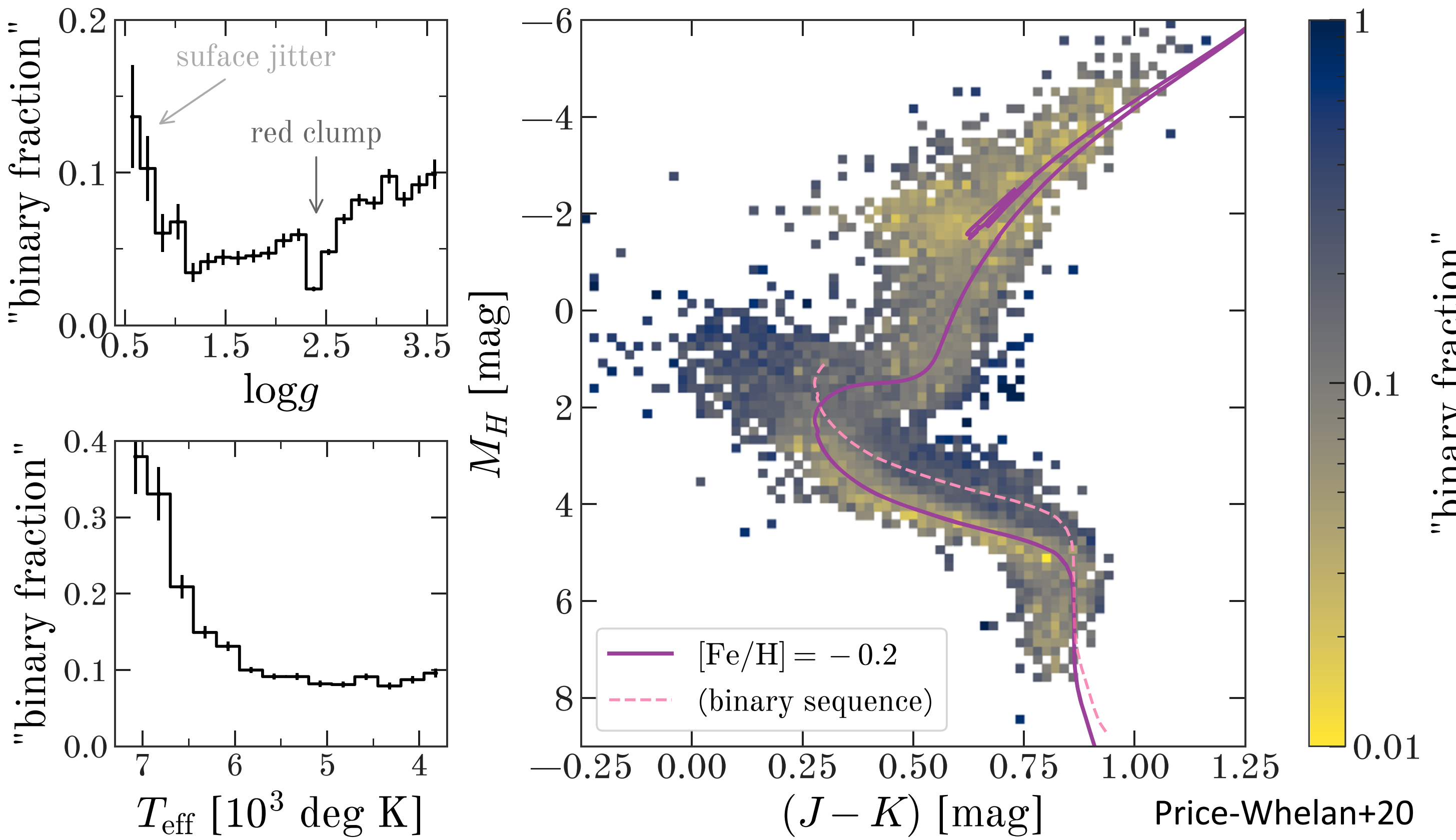
Previous studies were divided!



Moe, Kratter, and Badenes 2019 explained this divide: **uncorrected biases**.

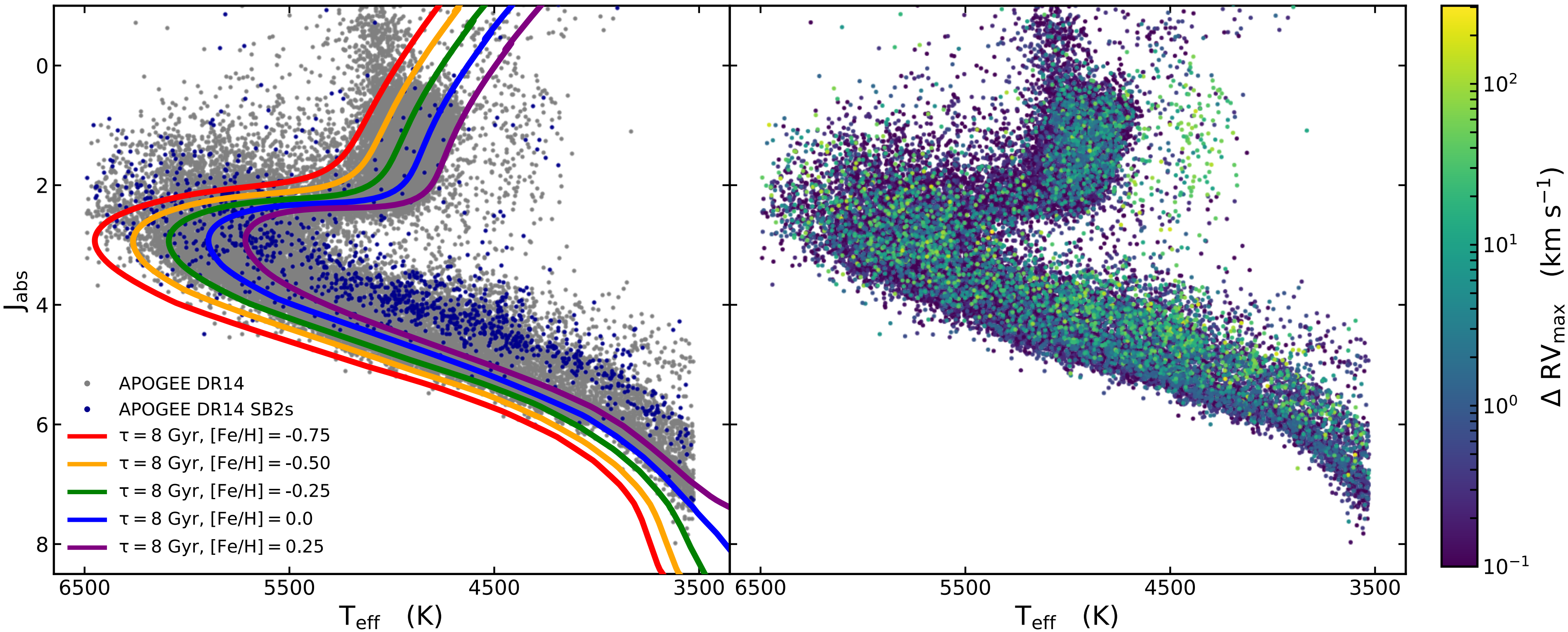
Previously Known Correlations

All three of these correlations were also found in a sample of binaries in APOGEE DR16, using T_{eff} as a proxy for stellar mass and bulk metallicity [M/H].



Price-Whelan+20

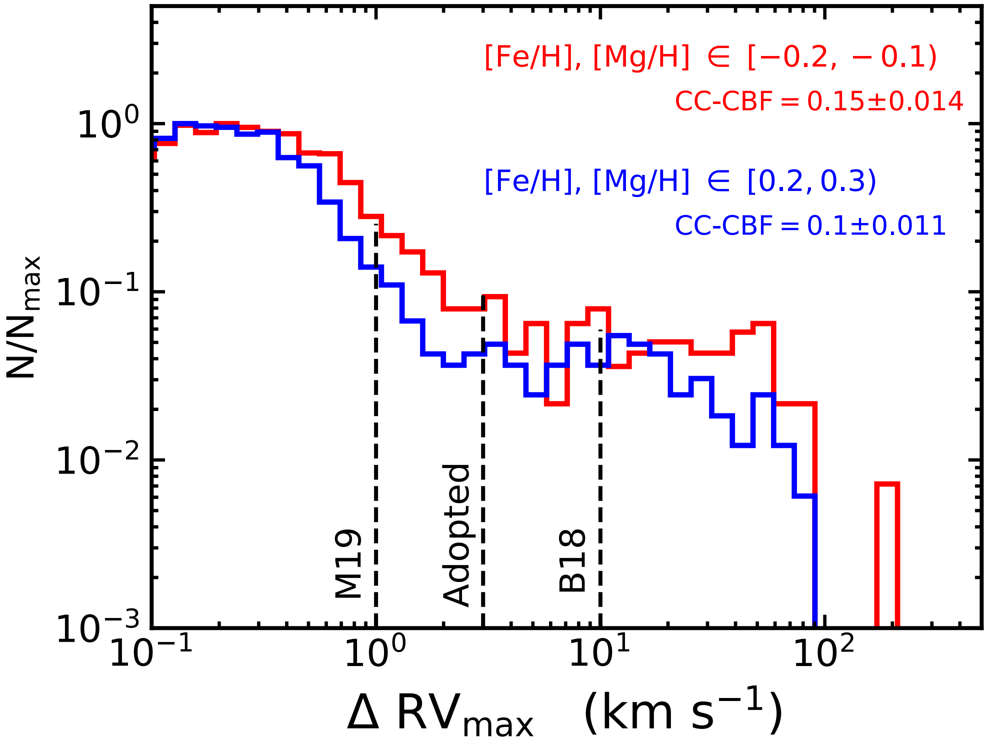
Our Data from APOGEE DR14



- Quality cuts on APOGEE bitmasks
- $N_{vis} \geq 2$, $SNR_{vis} \geq 40$
- SB2s: Kounkel+19 CCF methods
- log(g) ≥ 3.25, [Fe/H] ≥ -1

- Distance, mass, age, galactic dynamical properties taken from Sanders and Das 2018 catalog

Our Data: [Fe/H] and ΔRV_{max}



Core of RV measurement errors

Tail of RV variables

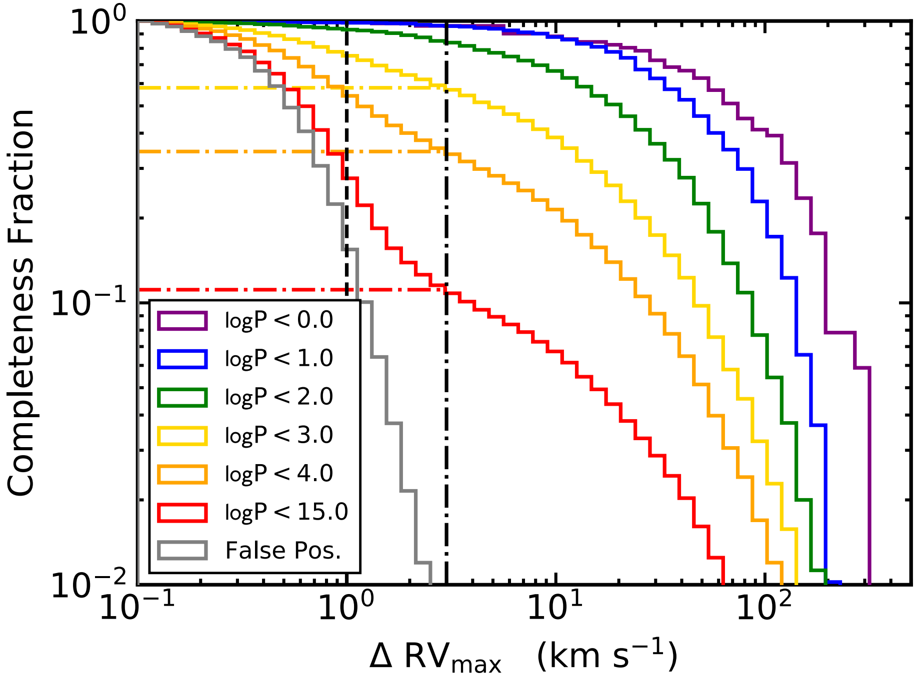
Two reasons cores can widen:

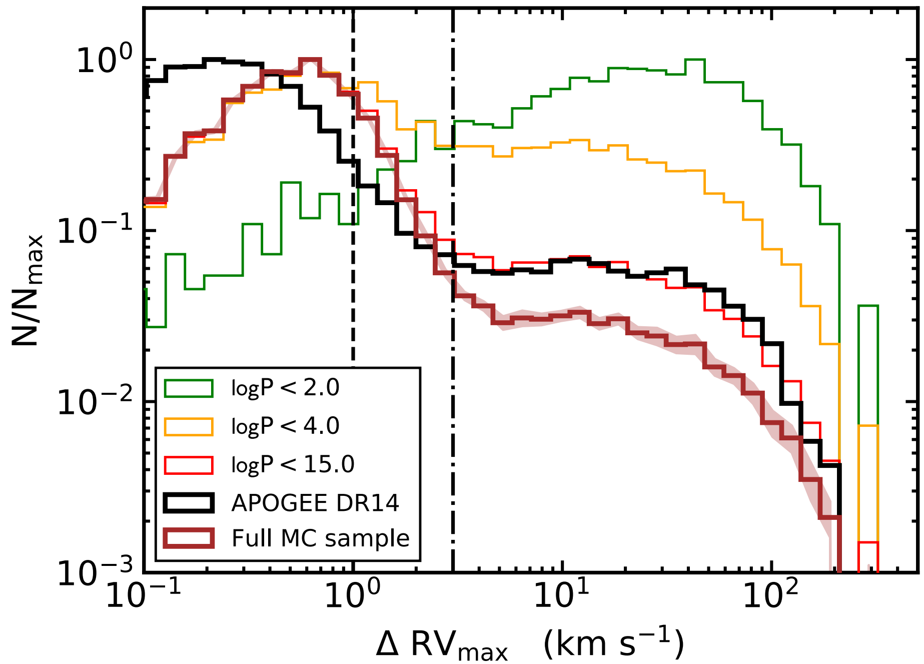
- lower log(g) (RV jitter)
- lower [Fe/H] (weaker lines)

Our threshold for RV variability:

$\mathbf{\Delta RV_{max} \geq 3\ km\ s^{-1}}$

MC: Estimating Completeness

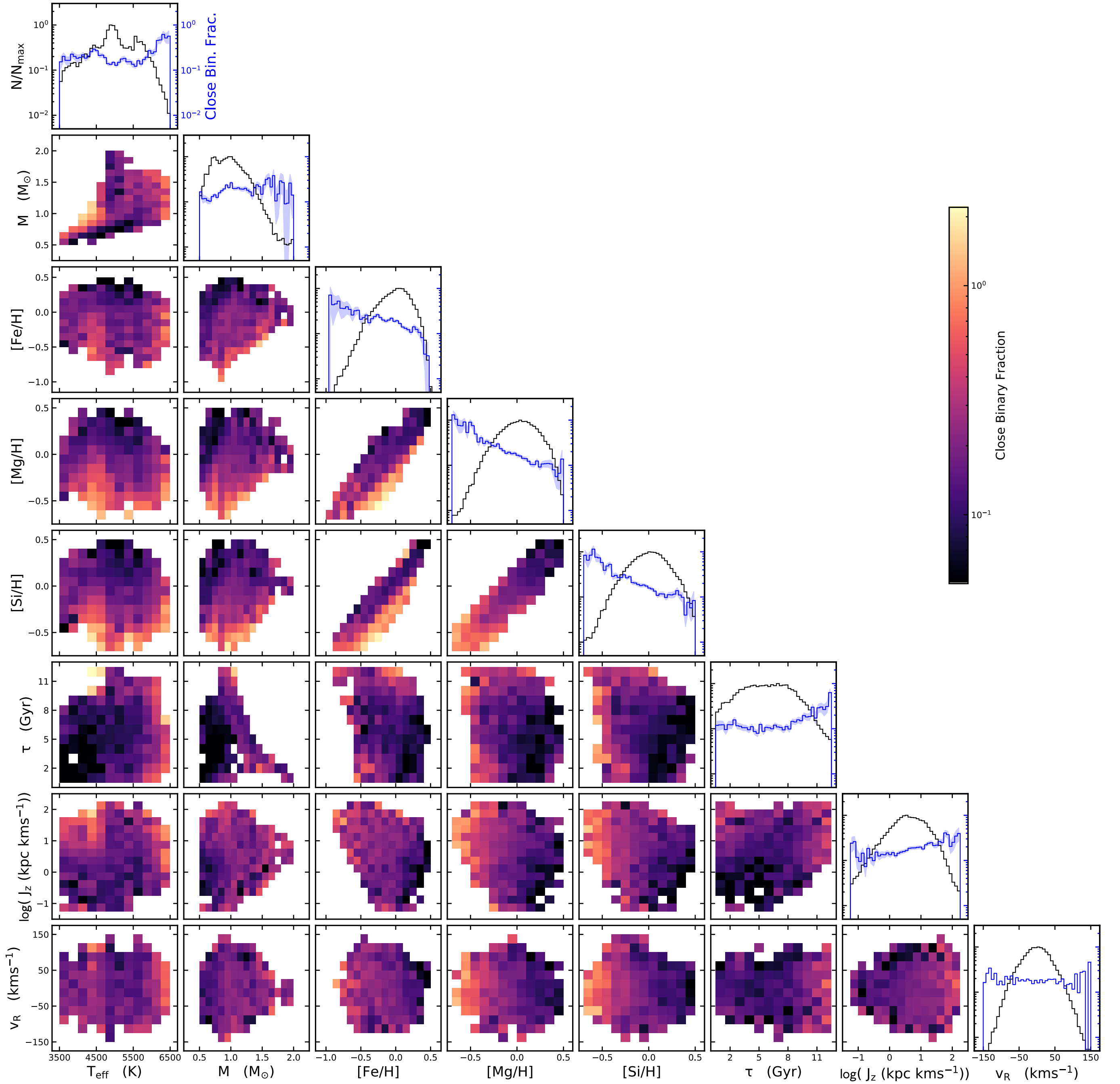




Simulated ***N* = 50,000** stars with ***f_m* = 0.5**

- **Period**: Raghavan+10 lognormal distribution
- **Mass ratios**: flat with 25% twin ($0.95 \leq q \leq 1.0$) excess fraction
- **RV error**: scipy.stats.t(*df* = 3.5, *loc* = 0.0, *scale* = 0.25)

Apply a 10% reduction to calculated CC-CBFs for Malmquist bias


N/N$_{max}$
Close Bin. Frac.
M (M$_\odot$)
[Fe/H]
[Mg/H]
[Si/H]
τ (Gyr)
log(J$_z$ (kpc kms^{-1}))
v$_R$ (kms^{-1})
T$_{eff}$ (K)
Close Binary Fraction

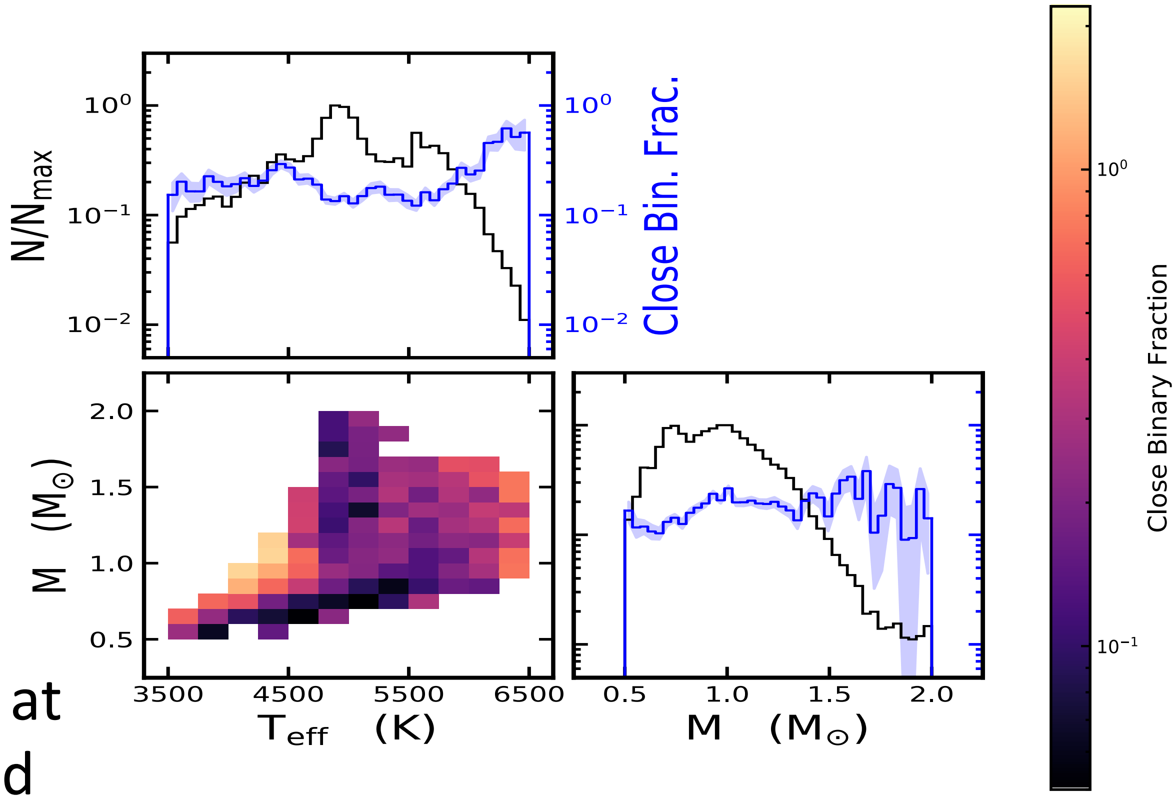
T_{eff} and M

Moe+17: CBF ~ $M^{0.5}$

Expect factor of ~2, we observe ~1.5, but

- Narrow mass range
- Large uncertainties, especially at high *M*

Apparent increase in CBF at $T_{eff} \geq 6000$ K, though could be due to mix of dwarfs and sub-giants at lower T_{eff}



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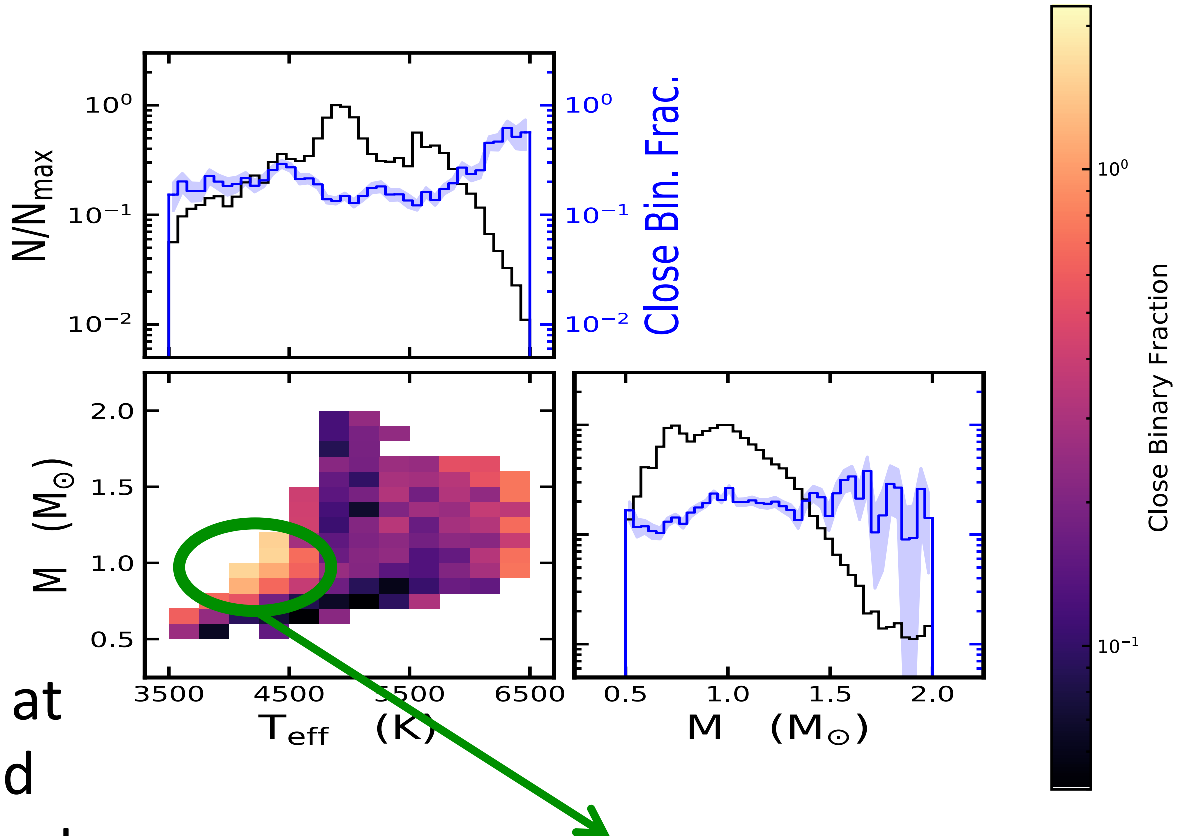
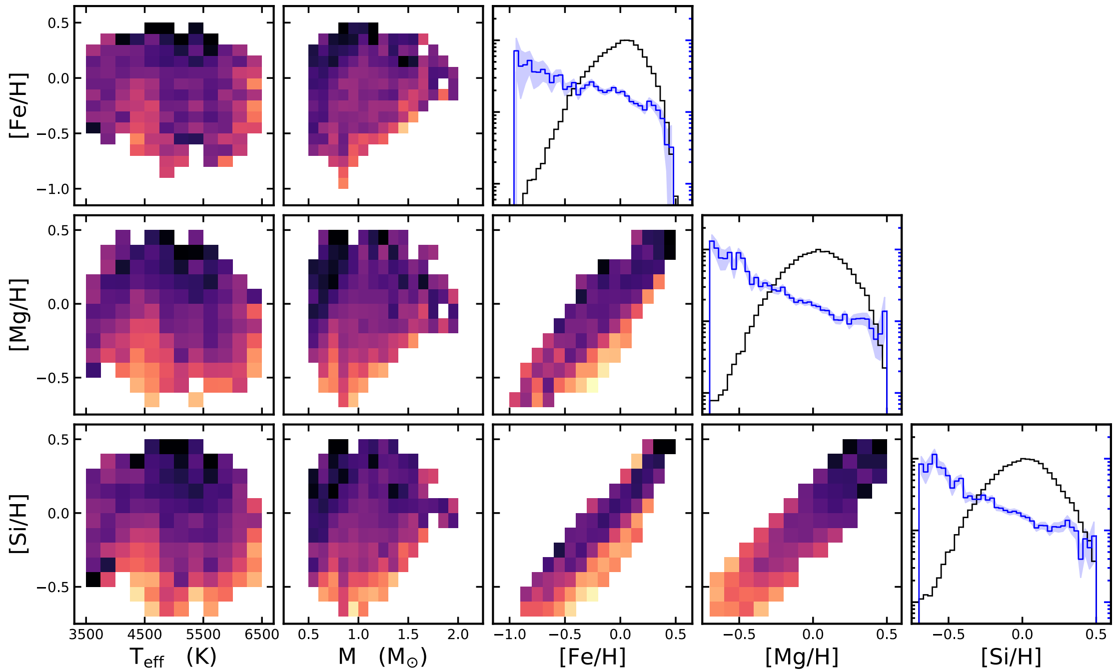
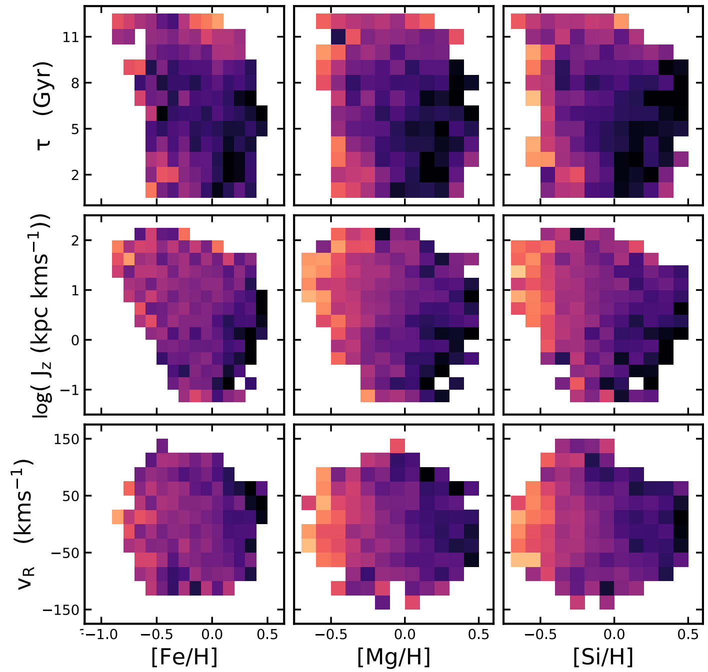


Probably bad mass estimates!

Metallicity and Chemistry



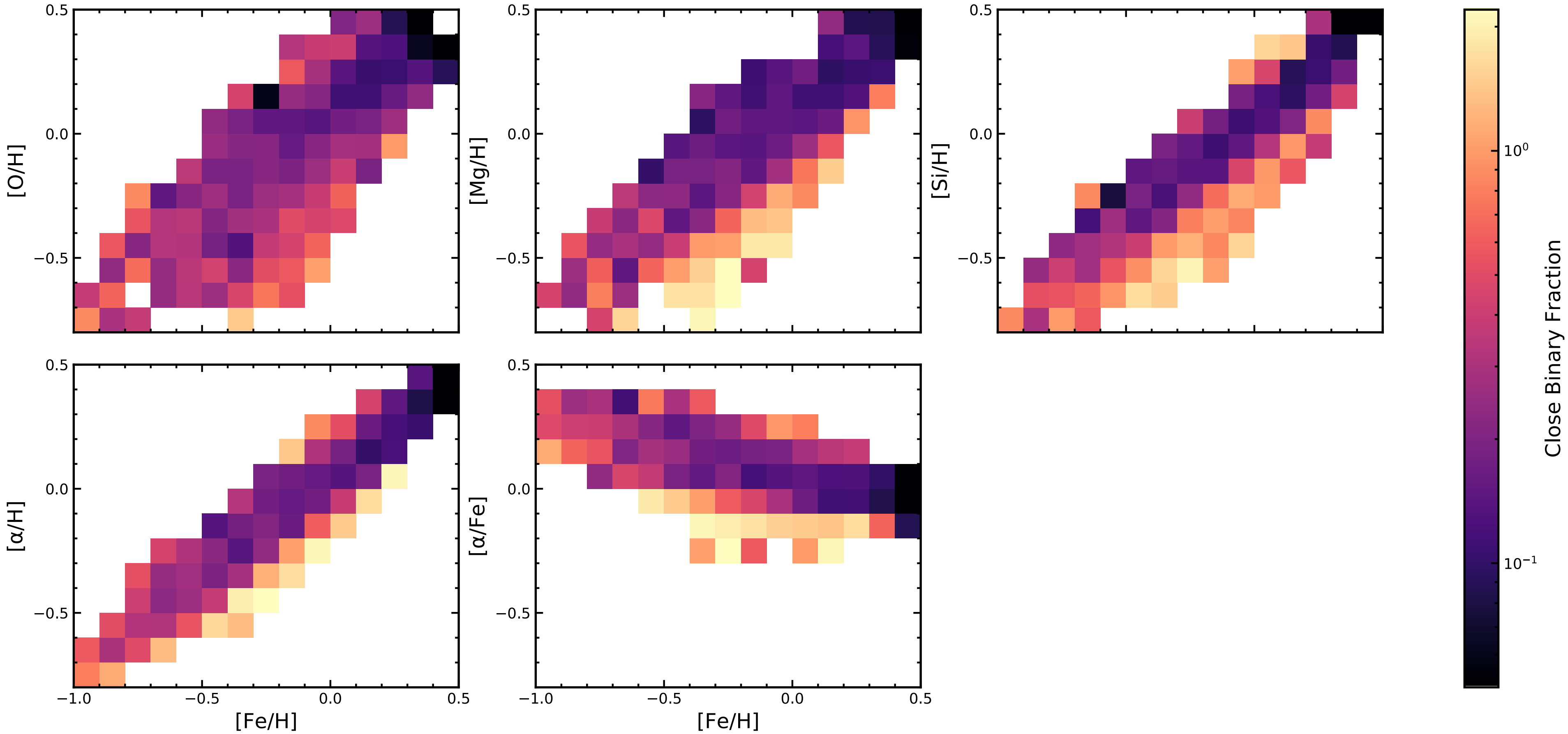


An anti-correlation between the CBF and [Fe/H] is again apparent.

However, we also discover a **strong anti-correlation** with the CBF and both **Mg and Si**! This is the clearest trend among what we considered.

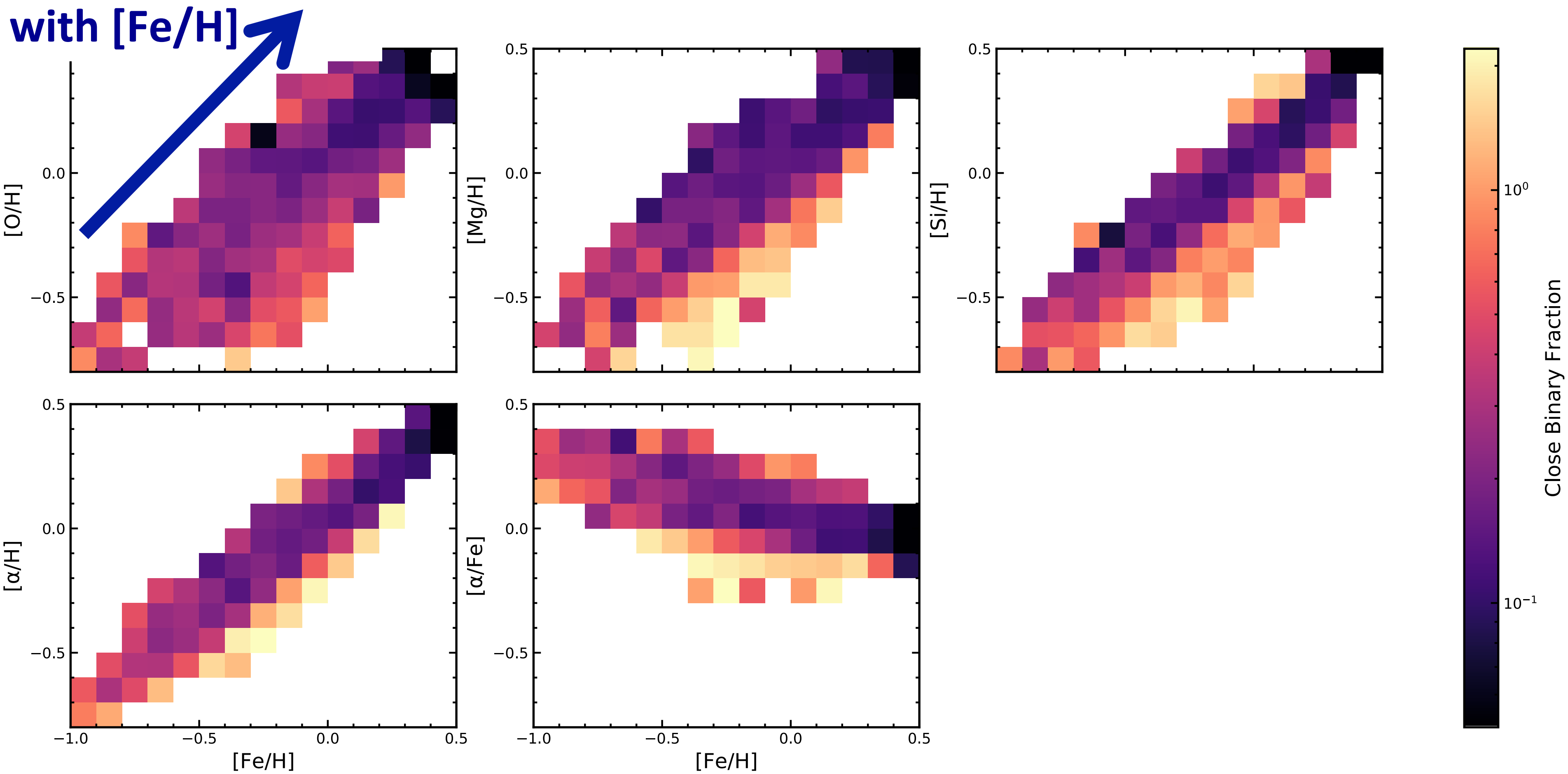
What about other α abundances?

Closer Look Into Chemistry

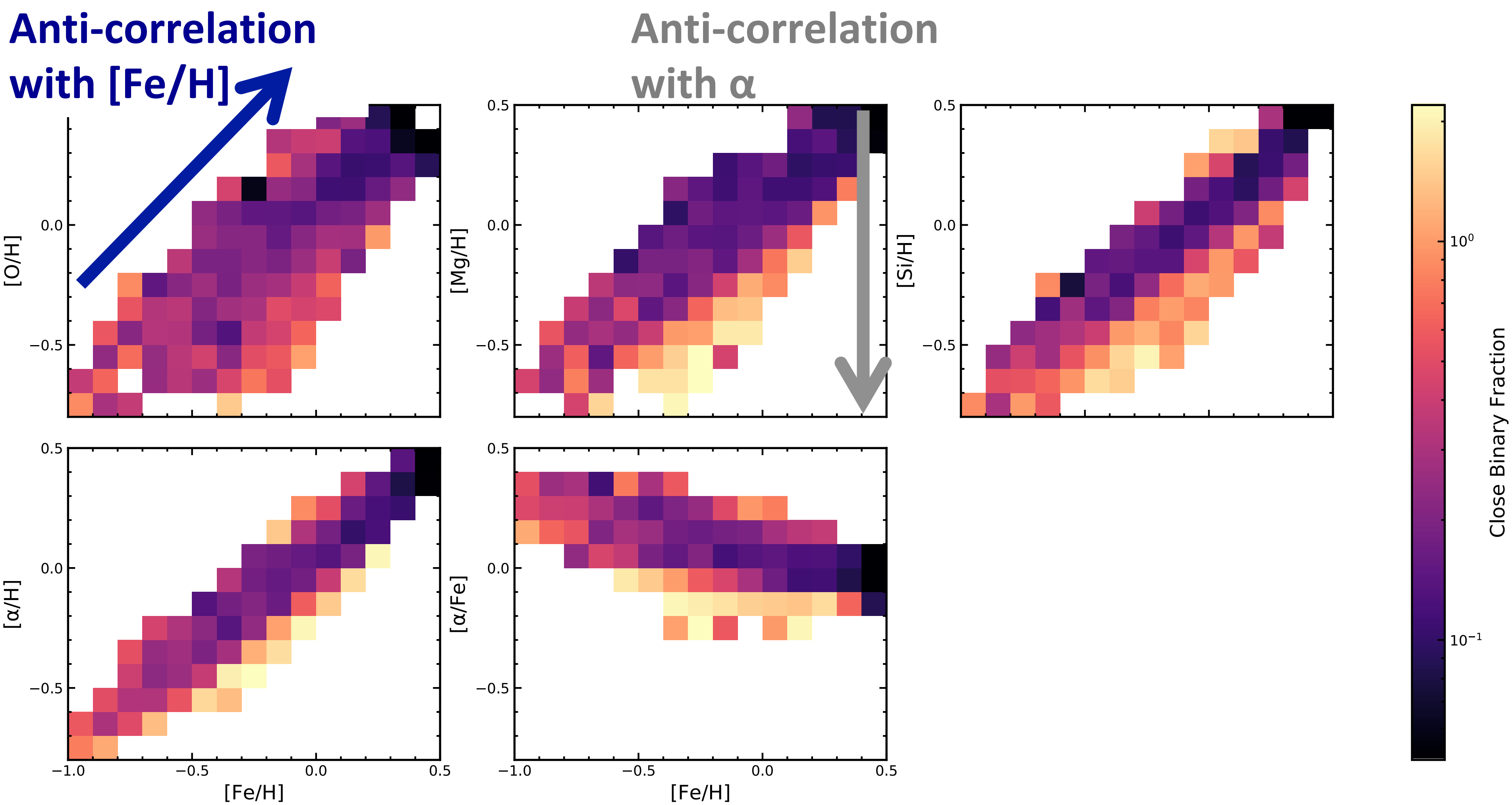


Closer Look Into Chemistry

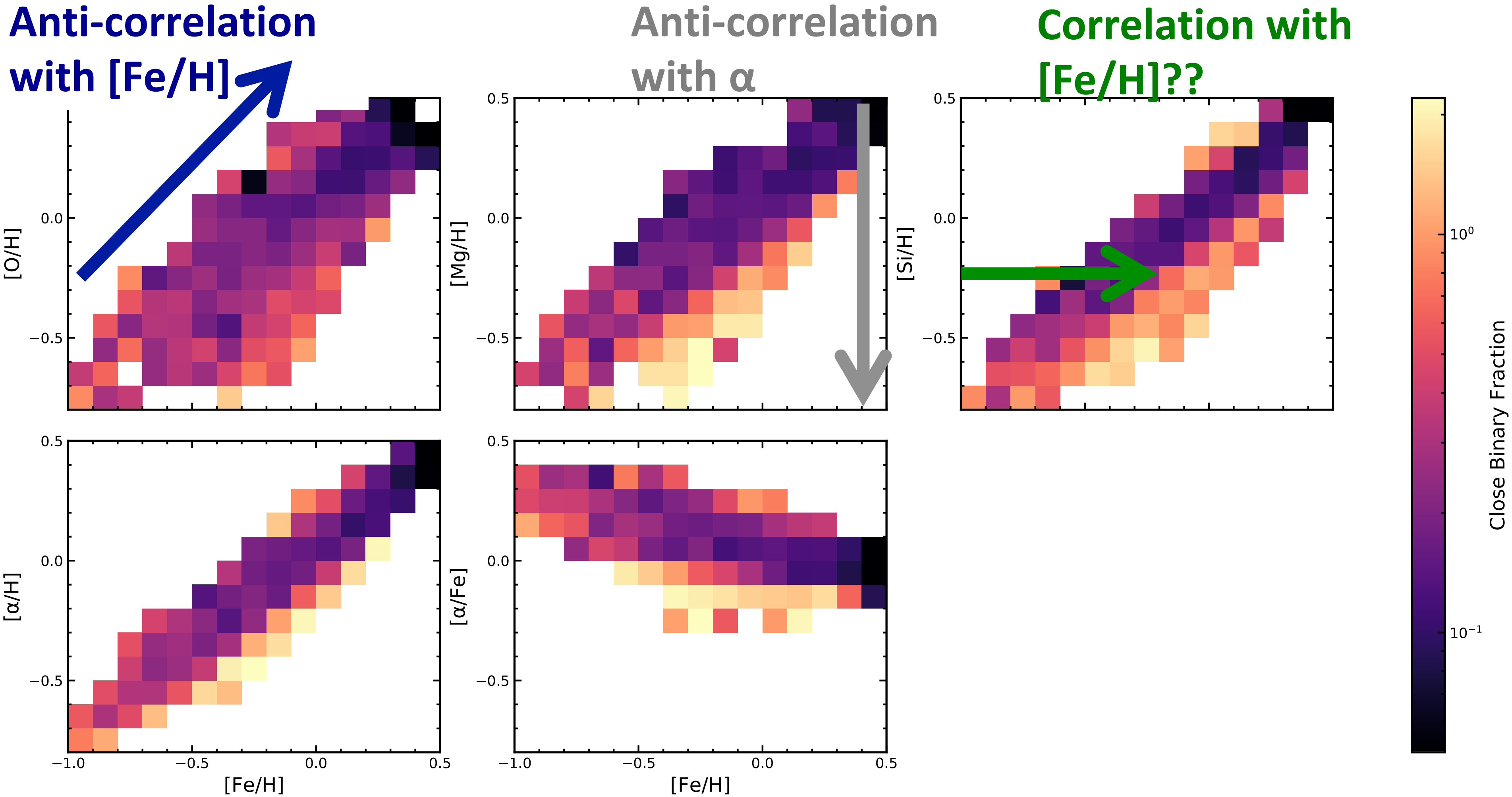
Anti-correlation with [Fe/H]



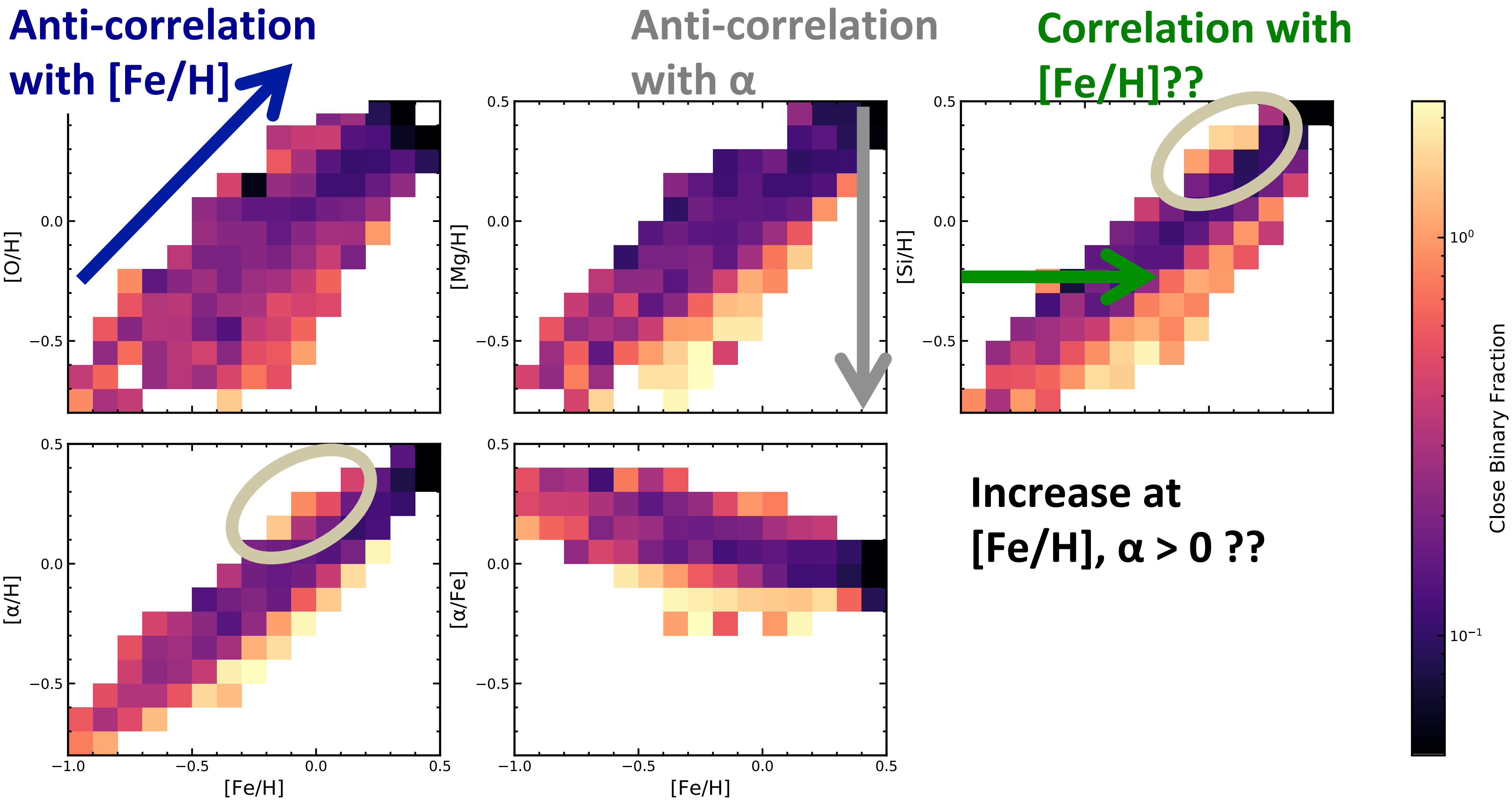
Closer Look Into Chemistry



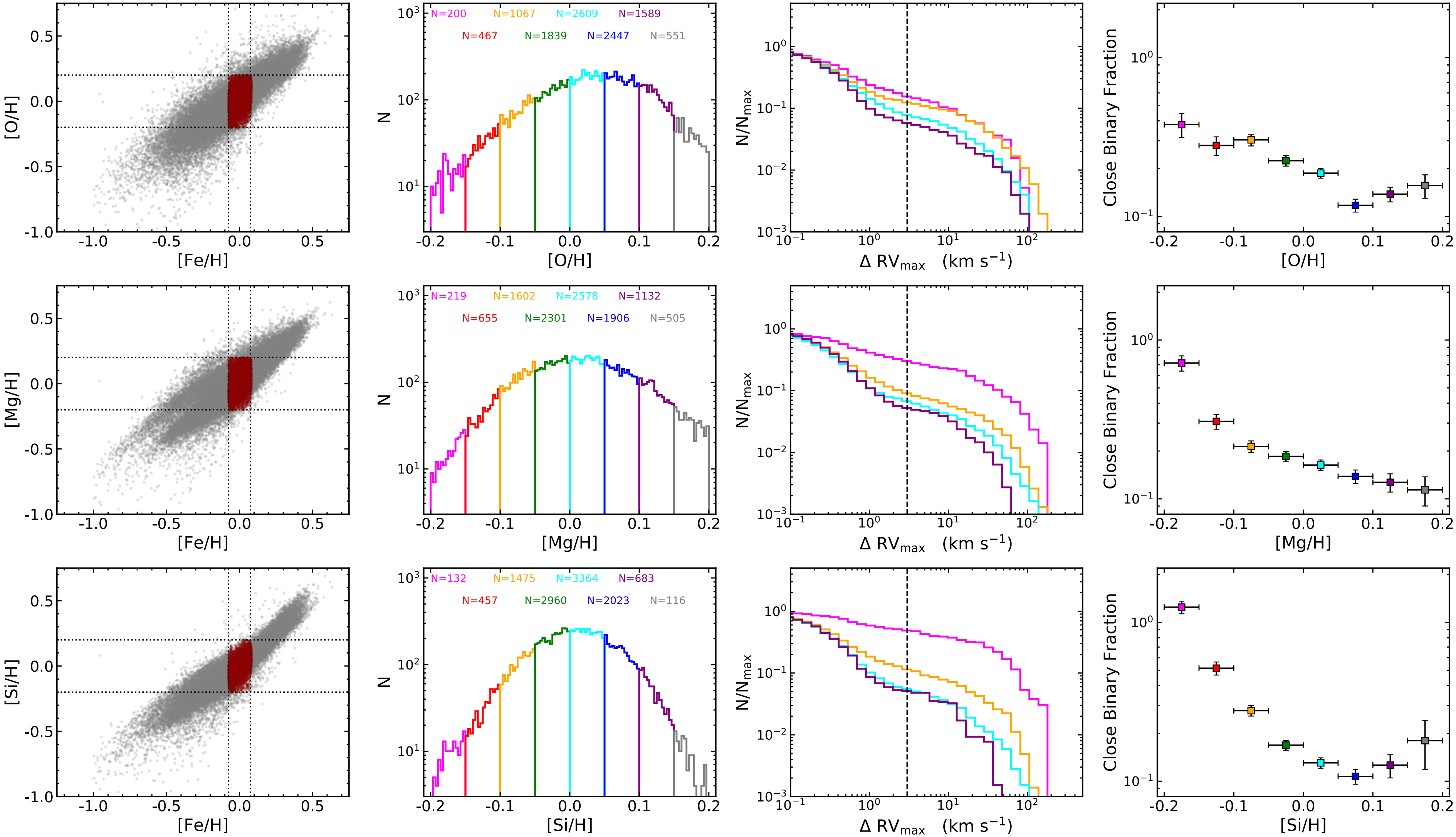
Closer Look Into Chemistry



Closer Look Into Chemistry



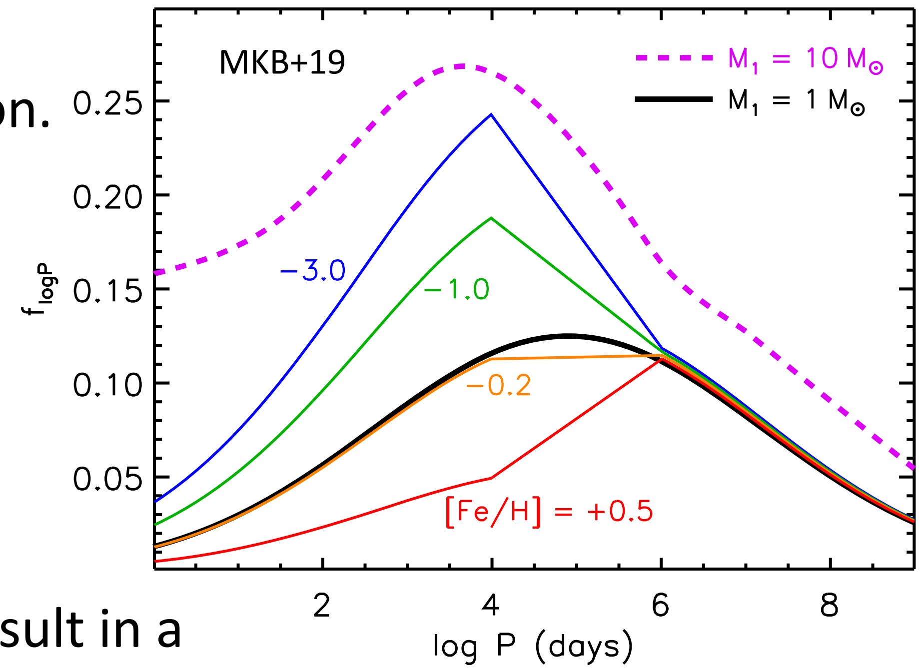
Closer Look: Constant [Fe/H]



Implications for Star Formation

Models predict an anti-correlation between [Fe/H] and disk fragmentation.

- Metal-poor cores are hotter, larger, and more gravitationally unstable.
- Metal-poor disks have lower optical depths, promoting cooling and fragmentation.



What about α abundances?

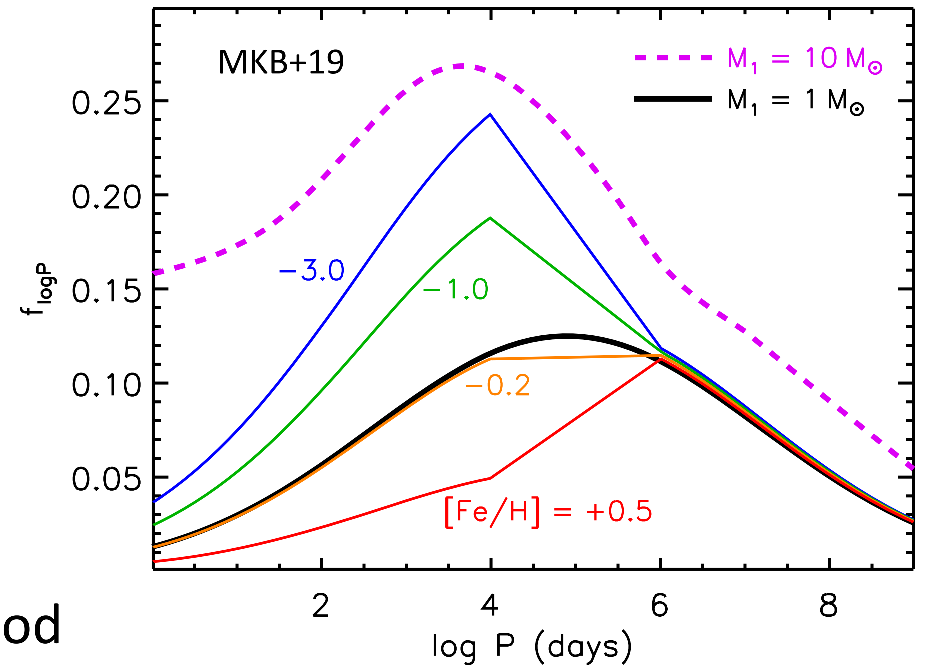
For [α/Fe] < 0.05, these two effects result in a stronger correlation with α abundance than with Fe.

For [α/Fe] > 0.05, a chemistry-independent floor of CBF ≈ 10% emerges.

- At least 10% of disks are massive or cool enough early on to fragment, regardless of chemistry?
- Metal-rich and/or low-M disks unsusceptible to fragmentation, thus all from cores that fragmented on larger scales and decayed into closer orbits?

Implications for Star Formation

Another consequence of these theories is that companions should be **skewed towards shorter periods**.



This would lead to an increase in high-ΔRV_{max} stars. Our ΔRV_{max} method cannot distinguish this shift from an increase in the CBF.

Our MC model assumes the same period distribution for the entire simulated sample, resulting in an overcorrection in our completeness estimate.

There is already some evidence for this in the latest release of the ASAS-SN Catalog of Variable Stars (Jayasinghe+2020), where their metal-poor eclipsing binaries are skewed towards shorter periods.

Conclusions

Many stellar parameters are correlated to the CBF and can be studied with large statistical RV samples.

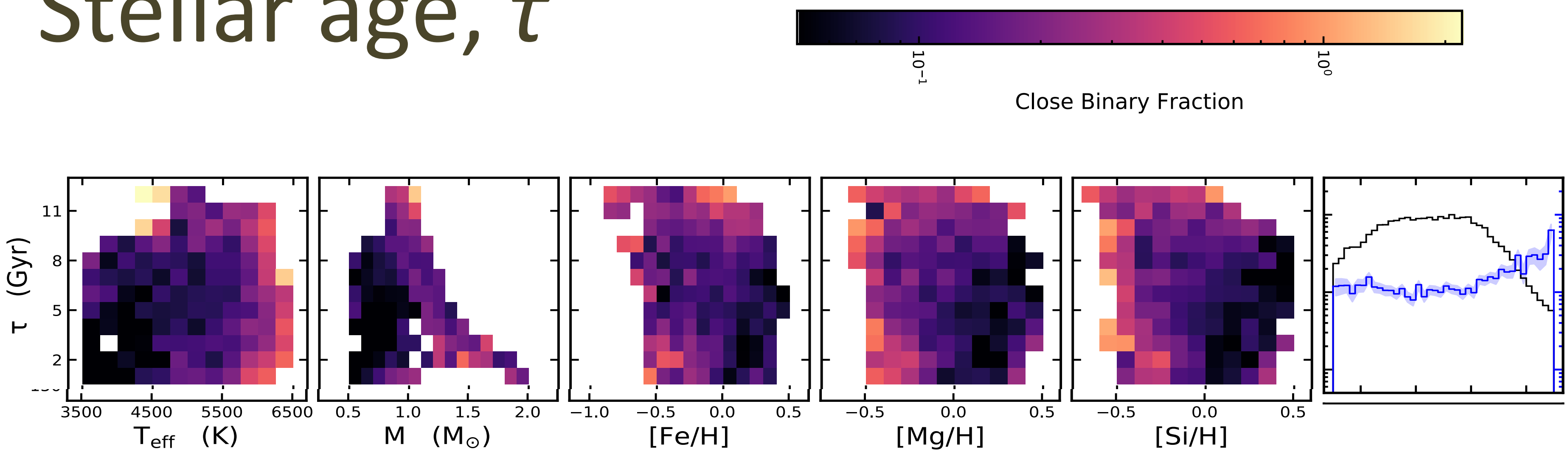
Interpreting these trends is tricky, as these parameters often have significant internal correlations.

Metallicity and chemistry are both strongly anti-correlated with the CBF in our APOGEE DR14 sample.

Despite being correlated with one another, we still find the effect with α abundance to be stronger than with Fe.

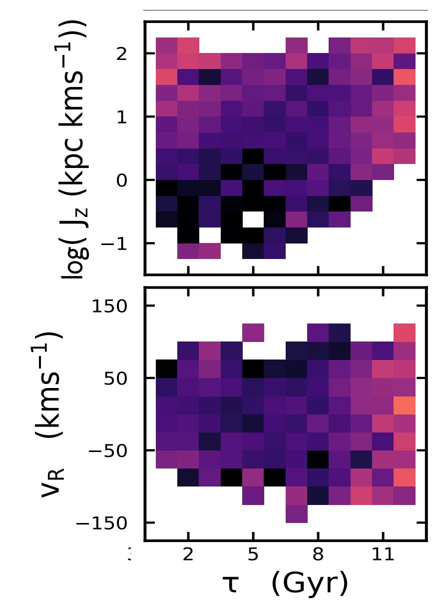
This matches with expectations from star formation theories, although some of our measured effect may also be due to shorter periods rather than a larger CBF.

Stellar age, τ

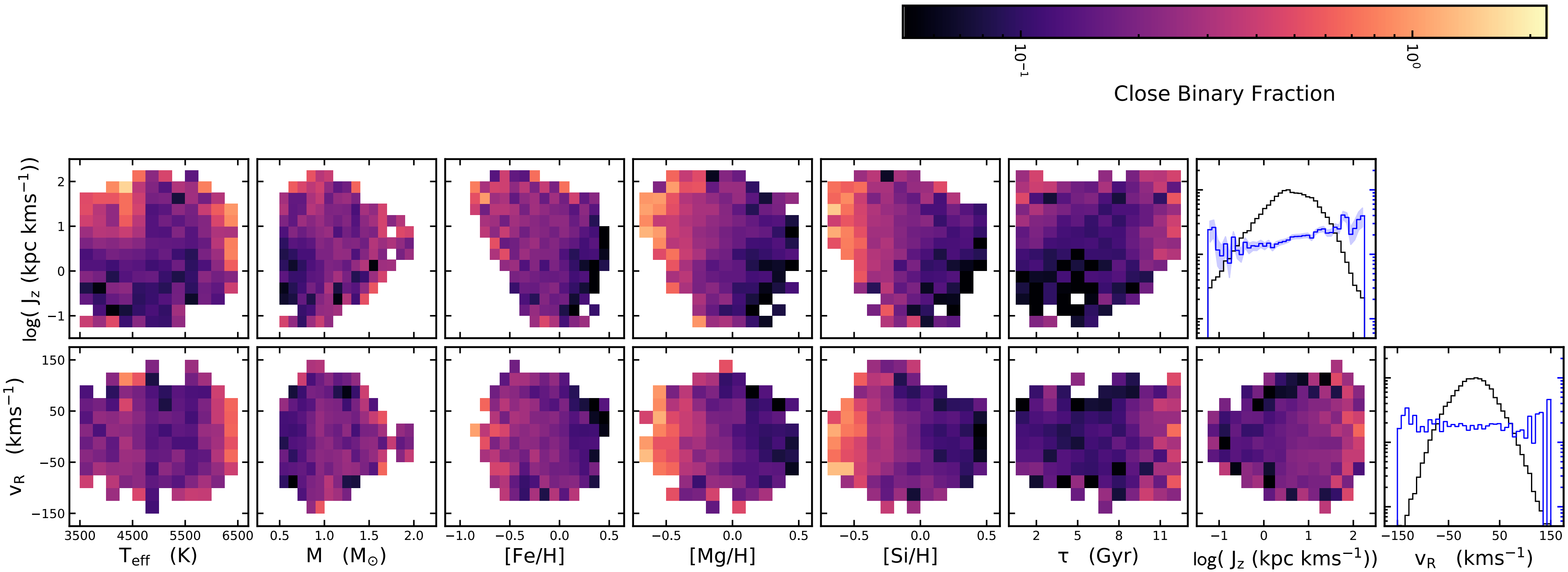


Modest upwards trend, though complicated

- Ages are correlated with [Fe/H] and [α/Fe]
- Age estimates are noisy
- SB2s often misclassified as 100s Myr or >10 Gyr
    - Increase at old end is probably just SB2s



Dynamics: J_z and v_R



Positive correlation with log(J_z)—but could it be due to a correlation with [Fe/H]?

Extremely flat with v_R, though with high errors at edges

Additional Information

	$\log f_m = b + aX$		$\log f_m = c + bX + aX^2$			
	b	a	c	b	a	$\chi^2_{\rm lin}/\chi^2_{\rm quad}$
$T_{\rm eff}$	-1.595	1.9e-7 2.7σ	3.318	-0.002 5.4σ	1.9e-7 5.8σ	2.7
M	-0.815	0.11 2.1σ	-1.329	0.993 3.1σ	-0.34 2.5σ	1.5
[Fe/H]	-0.787	-0.595 8.6σ	-0.782	-0.436 4.7σ	0.196 1.2σ	0.98
[Mg/H]	-0.806	-1.32 13.0σ	-0.752	-0.851 6.6σ	0.627 2.7σ	3.5
[Si/H]	-0.77	-1.15 9.1σ	-0.755	-1.011 3.6σ	0.187 0.5σ	1.3
τ	-1.355	0.077 2.8σ	-0.696	-0.127 3.5σ	0.013 4.4σ	4.7
$\log(J_z)$	-0.76	0.142 5.0σ	-0.783	0.045 1.1σ	0.062 2.7σ	1.4
v_R	-0.662	1.0e-5 0.1σ	-0.757	1.0e-4 0.4σ	1.0e-5 2.4σ	1.1

Additional Figures

Jayasinghe+2020

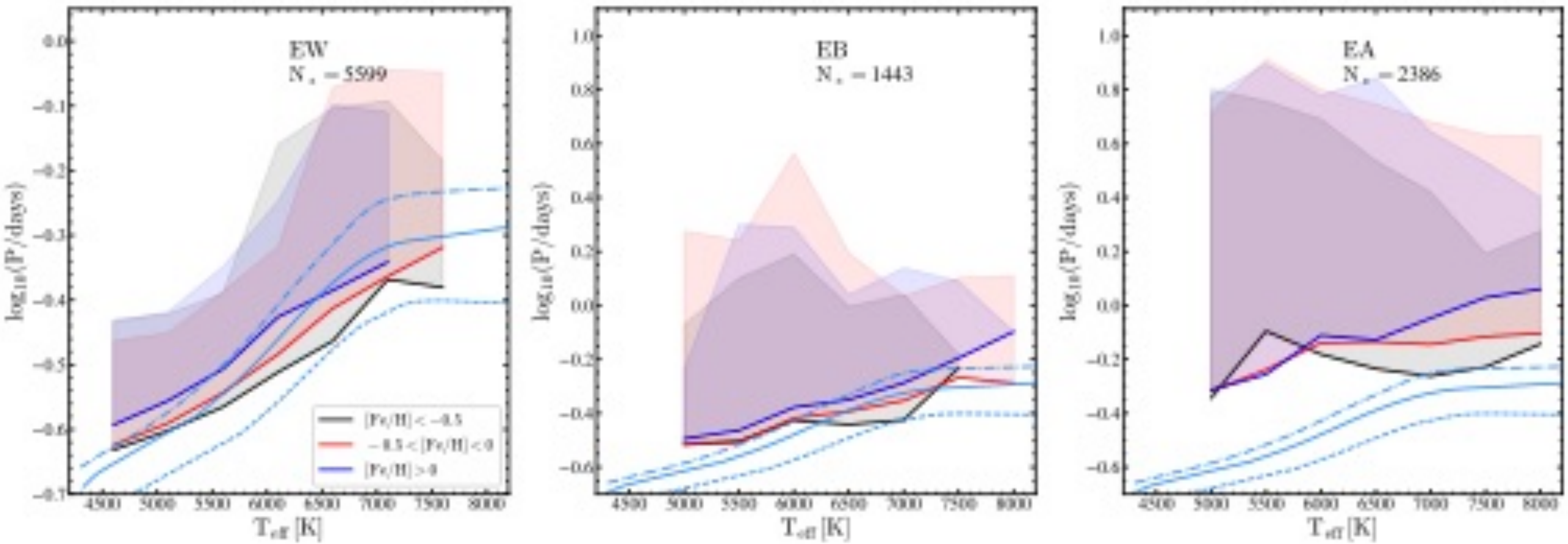


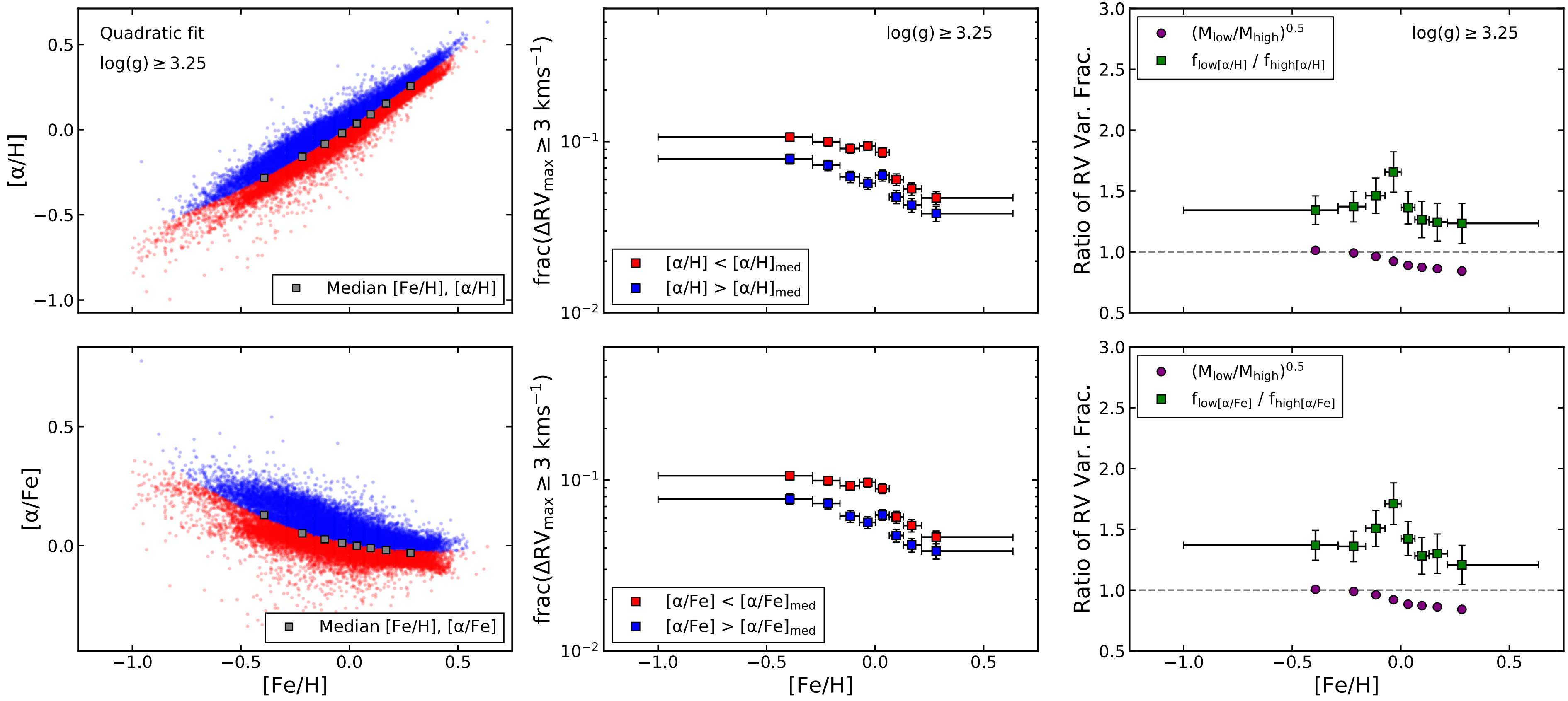
Figure 11. The distribution of the 5[th] percentile in log(P/d) vs T_{eff} for EW (left), EB (center) and EA (right) binaries in metallicity bins of [Fe/H] < −0.5 (black), −0.5 < [Fe/H] < 0 (red) and [Fe/H] > 0 (blue). The shaded regions correspond to the 5% to 95% ranges of the periods. The predicted period-temperature relationships (light blue) for equal mass MS binaries overflowing their Roche Lobes is derived using the MIST isochrones (Choi et al. 2016; Dotter 2016) and are shown for metallicities of [Fe/H] = −0.50 (dashed), [Fe/H] = 0 (straight) and [Fe/H] = 0.25 (dot dashed) for a 10^8 yr old stellar population.

EW: W Uma; contact binaries

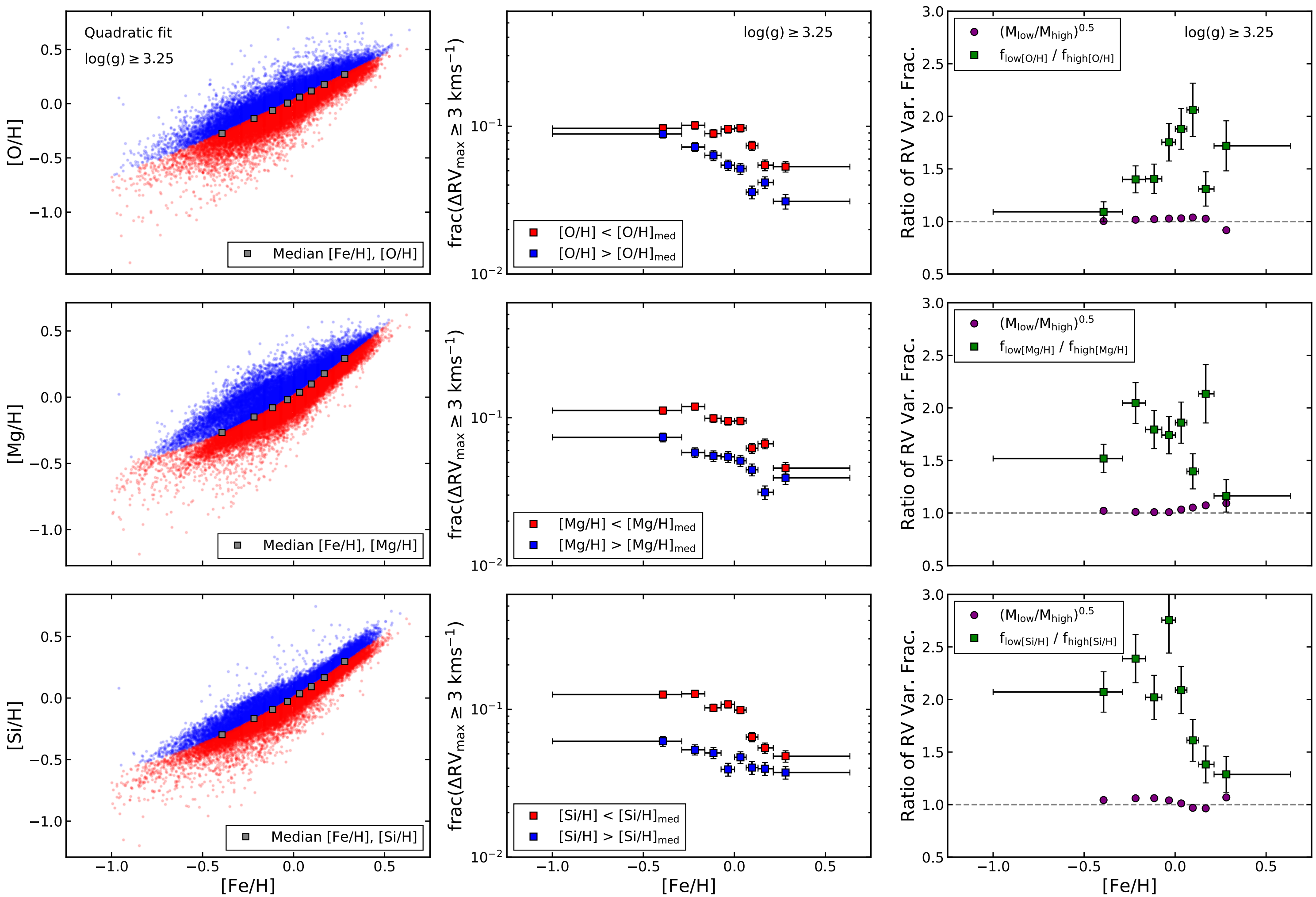
EB: β-Lyrae; contact and semi-detached

EA: Algol; detached

Additional Figures



Additional Figures



Additional Figures