# Do Sun-like stars swallow their own planets?

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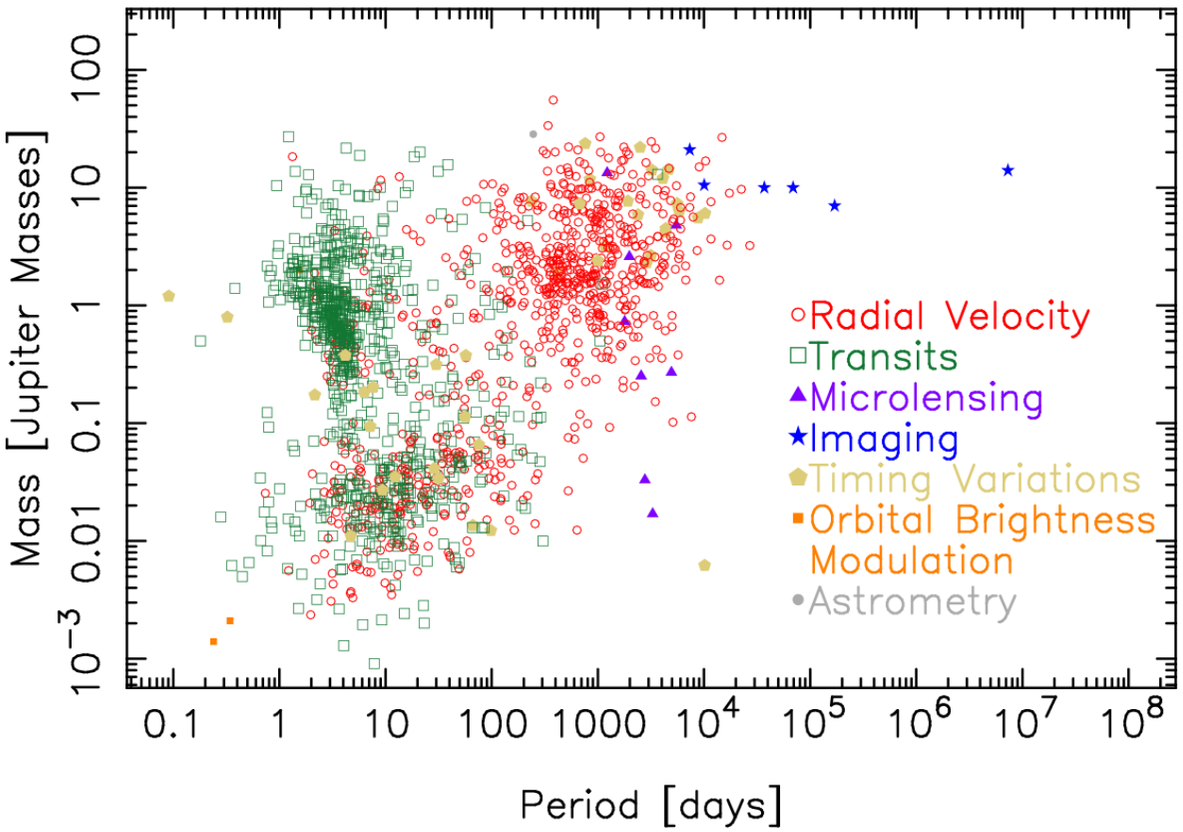
# Stars eating planets for dinner? Why should we care?




- Planetary systems are common in the Galaxy.
- Most of them are different from our Solar System.
- Diversity of exoplanetary systems is the result of severe dynamical processess and strong dependence on initial conditions.

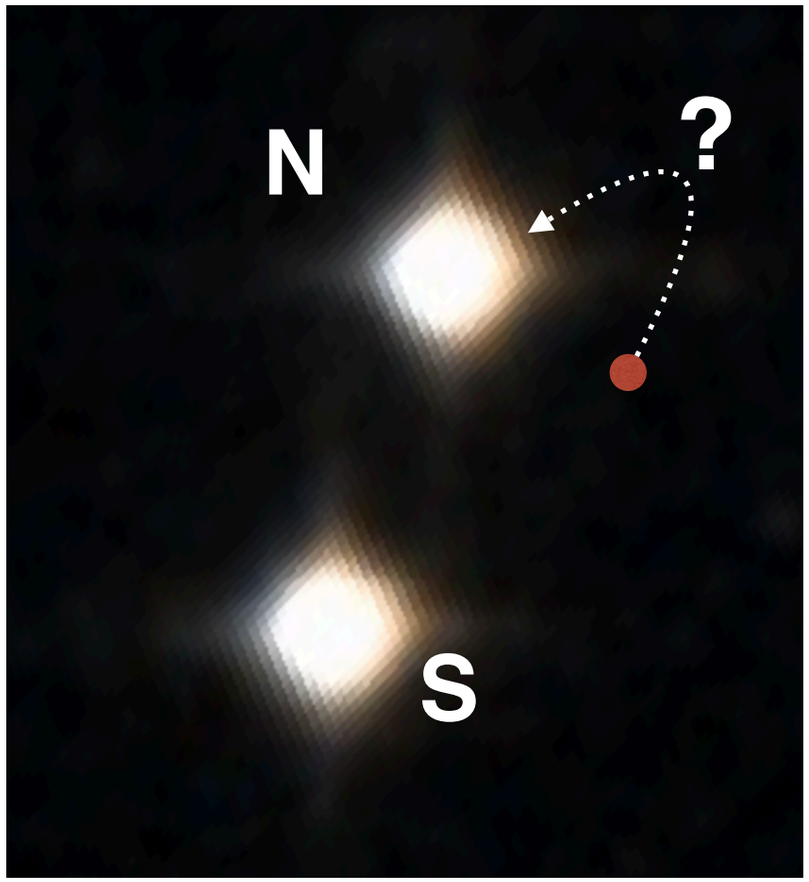
**Do Sun-like stars swallow their own planets?**
**On which frequency?**

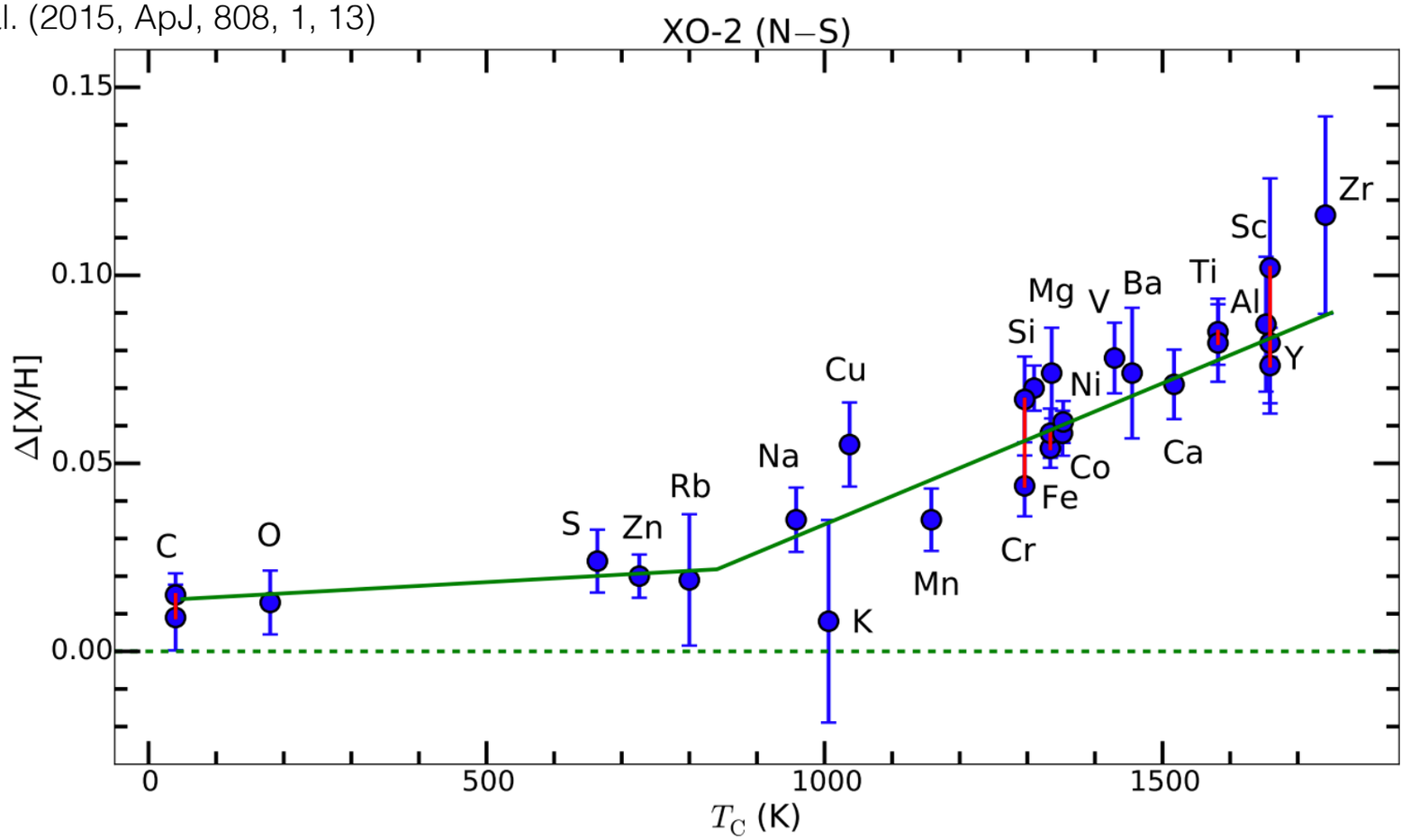
**Possible evolutionary paths of planetary systems.**

**Rate of orderly systems similar to our Solar System.**

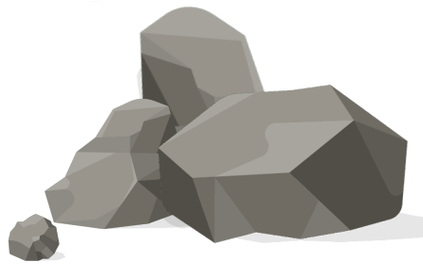
# Stars eating planets for dinner? Why should we care?

Biazzo et al. (2015, A&A, 583, A135) ; Ramirez et al. (2015, ApJ, 808, 1, 13)




**Volatile elements**



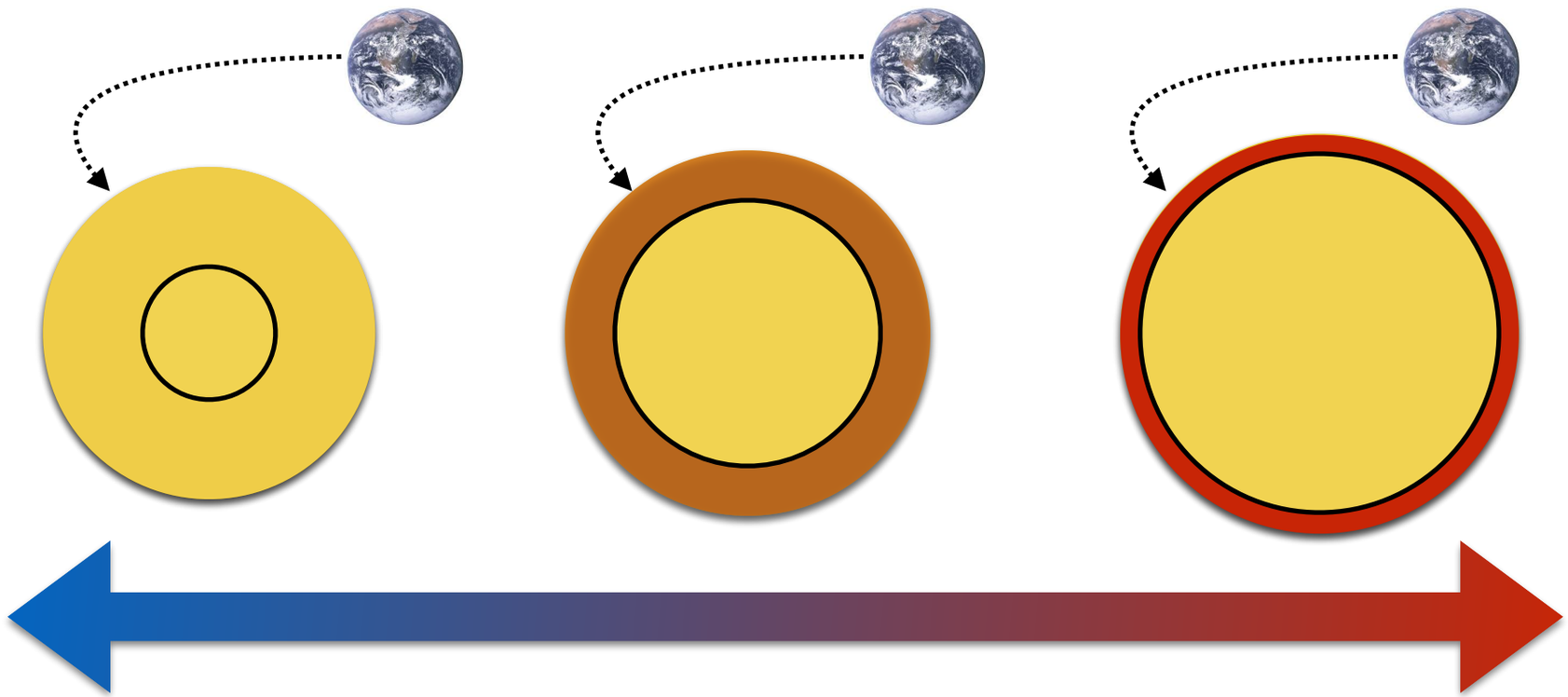
**Refractory elements**

**Observation**

**Theory**

**Planet engulfment event?**
**Protostellar cloud not well-mixed?**

# The experiment design




If the chemical anomalies are due to external pollution of rocky material, then the probability of finding anomalous stars should be function of the stellar temperature.

## Our sample

- 107 binary pairs composed by Sun-like stars (Spina et al., 2021; Nagar et al. 2020; Hawkings et al. 2020; and others...).
- Binary components have similar $T_{eff}$ and log g.
- Stars must have a convective external layer ($T_{eff}$ < 6500 K).

| **Chemically homogeneous** | | **Chemically anomalous** | |
|---|---|---|---|
| $\Delta Fe \leq 2\sigma_{\Delta Fe}$ | 74 pairs | $\Delta Fe > 2\sigma_{\Delta Fe}$ | 33 pairs |

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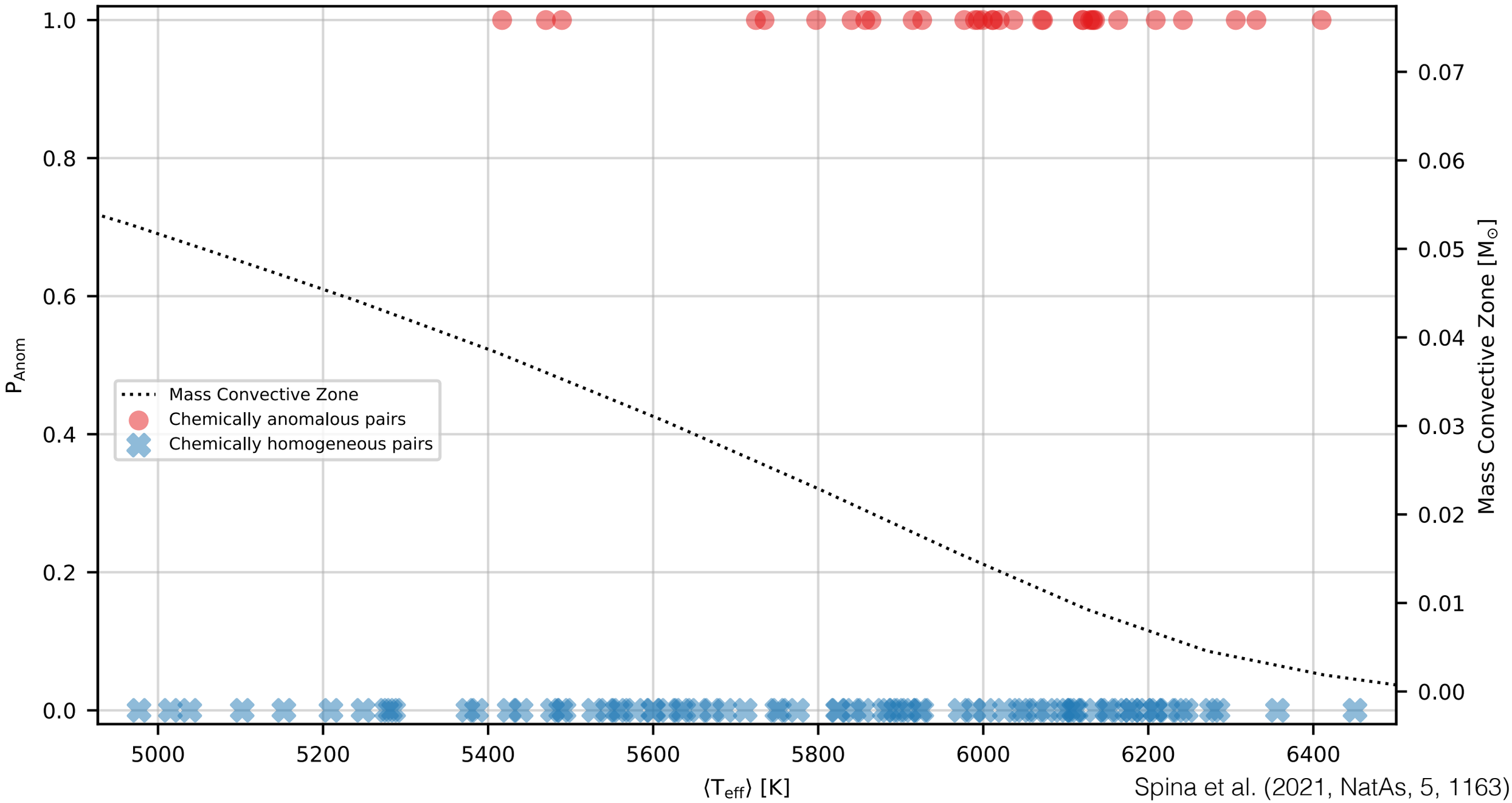
# The rate of chemically anomalous pairs




Spina et al. (2021, NatAs, 5, 1163)

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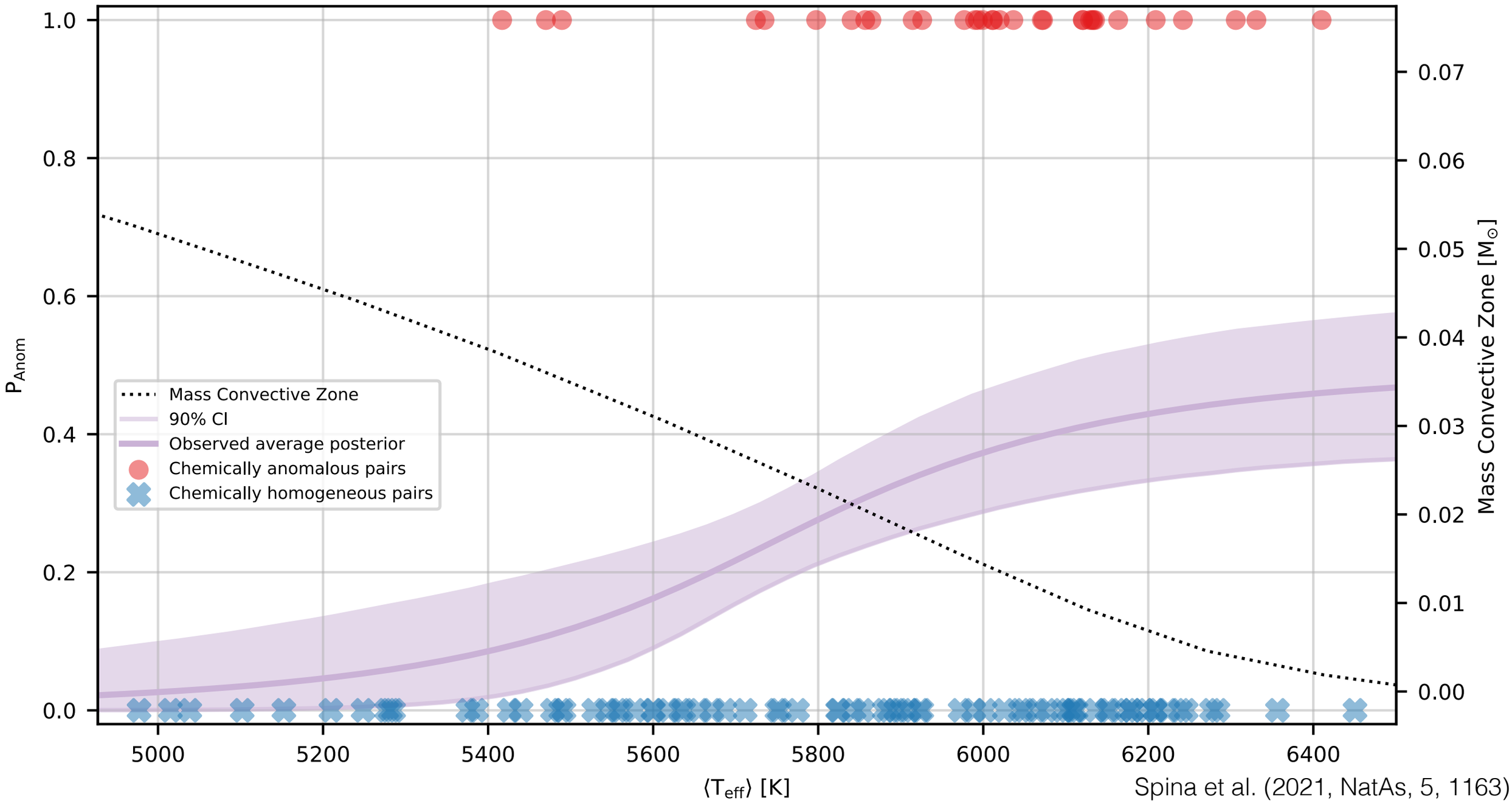


Spina et al. (2021, NatAs, 5, 1163)

## Sigmoid function

$$P_{anomaly} = \frac{\alpha}{1 + e^{-\beta(T_{eff} - k)}}$$

- The hottest stars change their composition at every planet engulfment event.
- At least 1 star in anomalous pairs has eaten a planet.

$$P_{engulfment} = 0.27\ [0.20\text{-}0.35]_{90\%CI}$$

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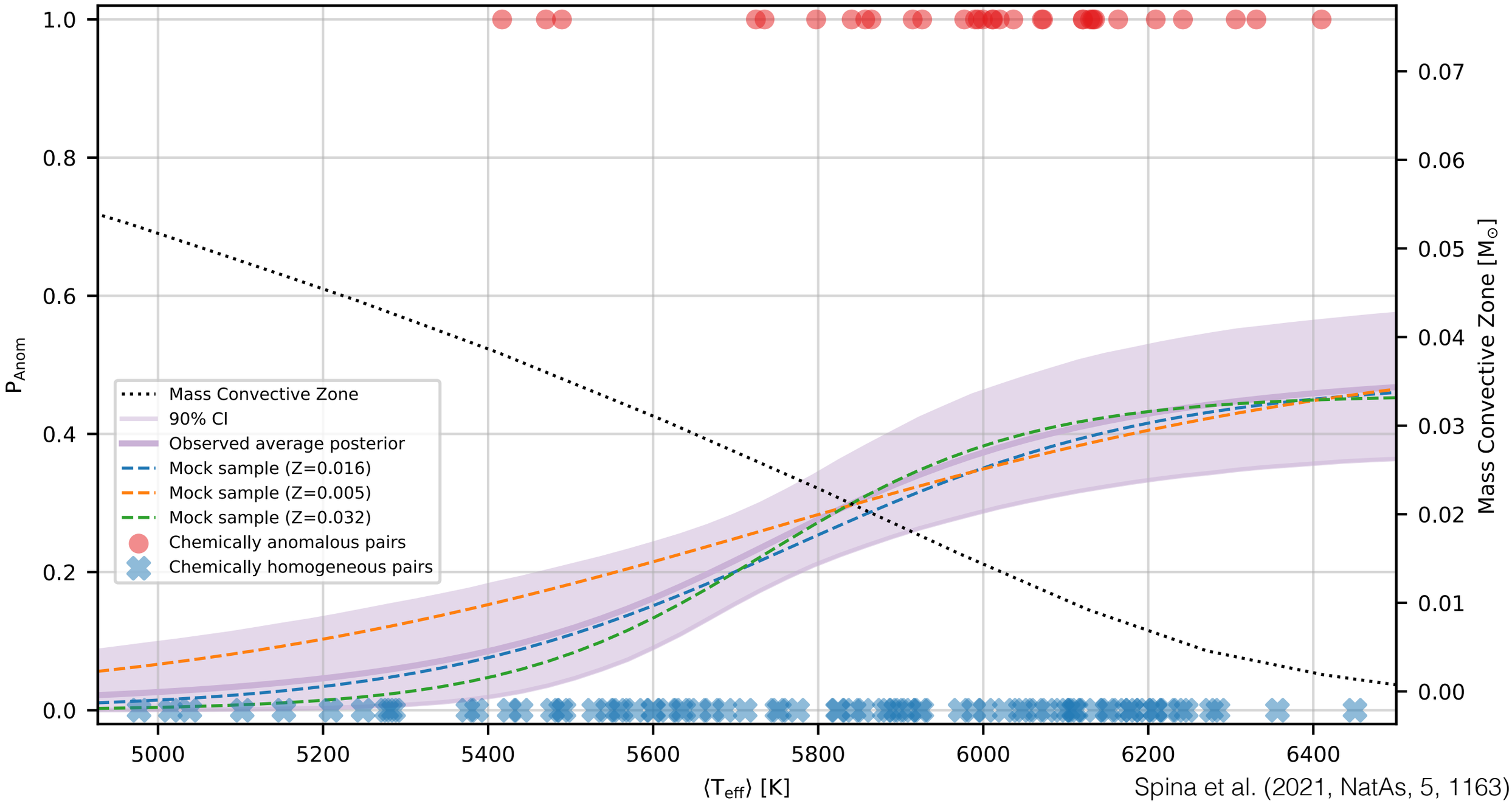
# The rate of chemically anomalous pairs




Spina et al. (2021, NatAs, 5, 1163)

- Mock dataset of 500 binary pairs with Yonsei Yale stellar models.
- We polluted 27% of these stars with planetary material.
- The amount of planetary material that pollutes the stellar atmospheres is randomly drawn from the Normal distribution N(2 $M_\oplus$, 1$M_\oplus$) limited between 0 and 10 $M_\oplus$.

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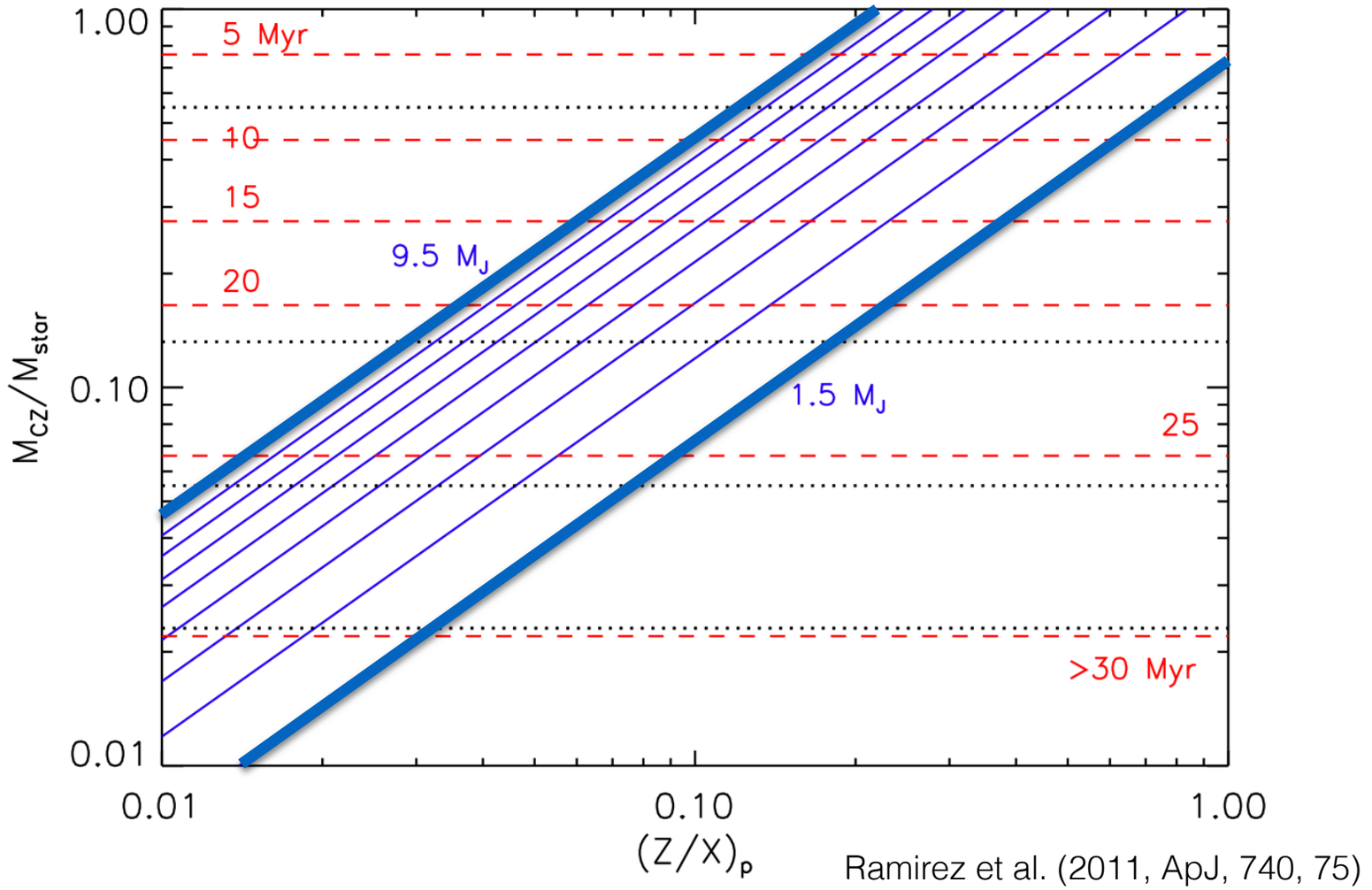
# When did planet engulfment happen?

It is normal a fall of material from the protoplanetary disk into the central star during the phase of planet formation.

Typically planets form within a few Myr and protoplanetary disks are completely dissipated before 10 Myr (e.g., Ribas et al. 2014, A&A, 561, A54).

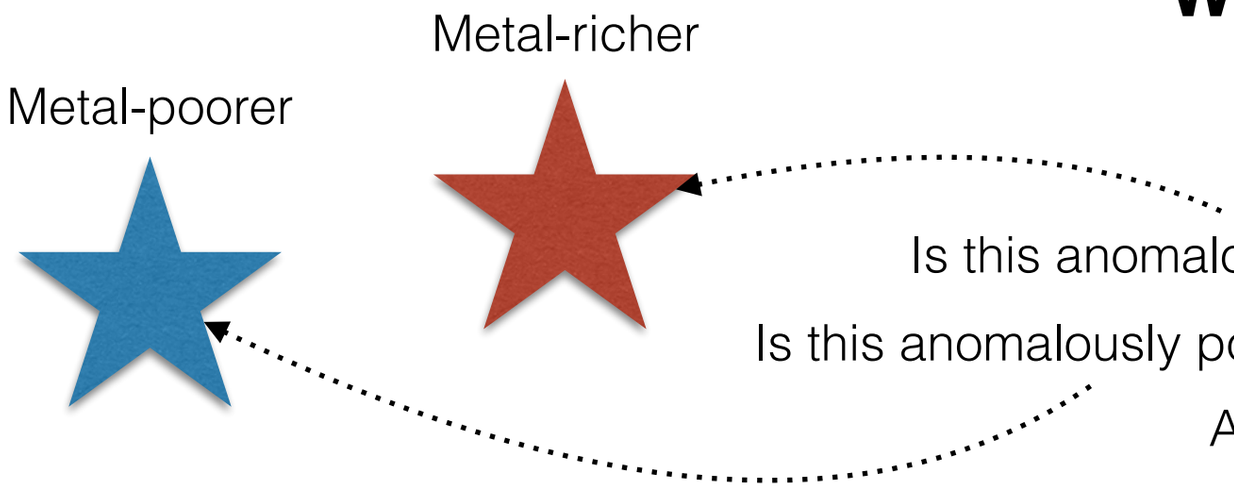
The chemical anomalies must have been imprinted by planet engulfment events occurred later in time (≥ 20 Myr), when planets are formed and disk dissipated.

The conditions to produce ΔFe~0.04 dex in a Sun-like star.




Ramirez et al. (2011, ApJ, 740, 75)

# Which one of the two stars is the chemically anomalous?

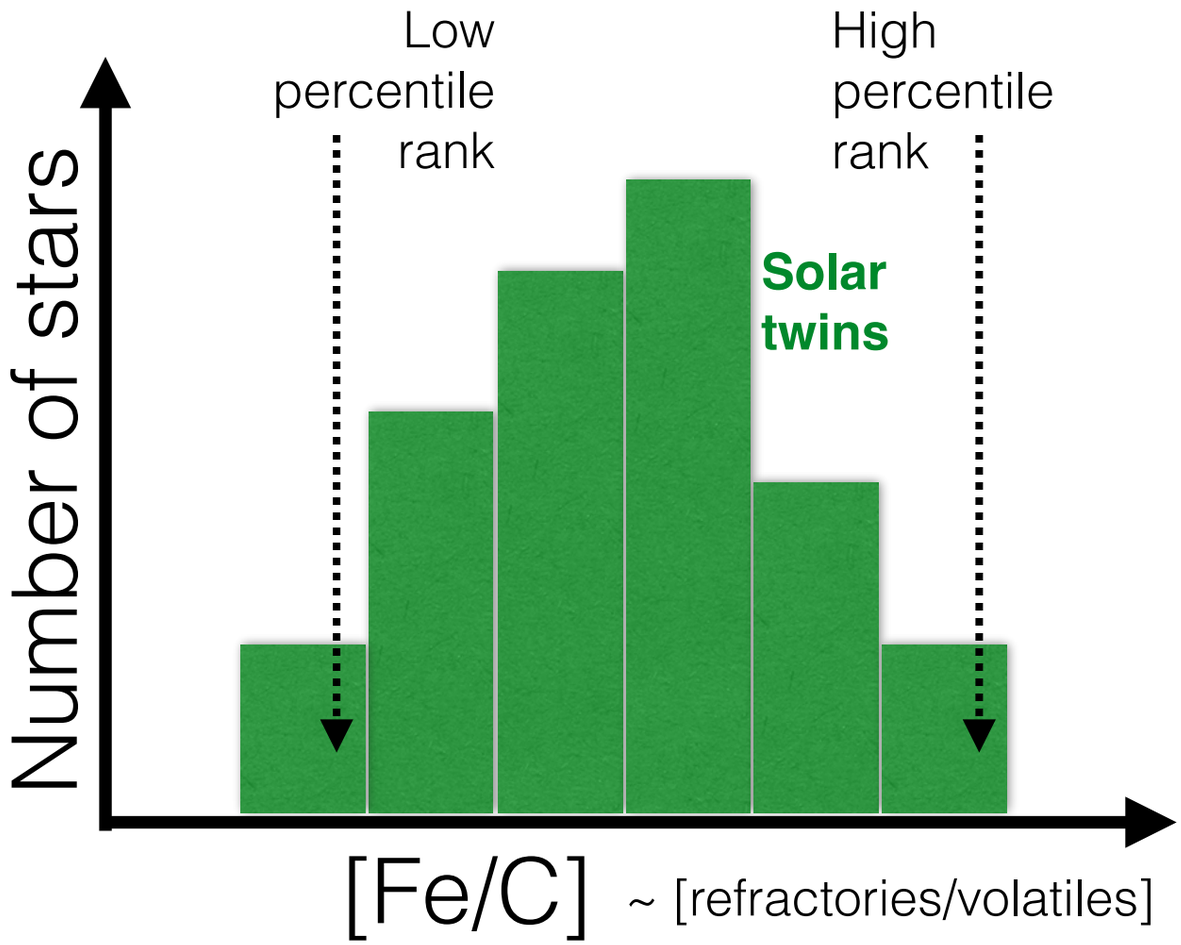


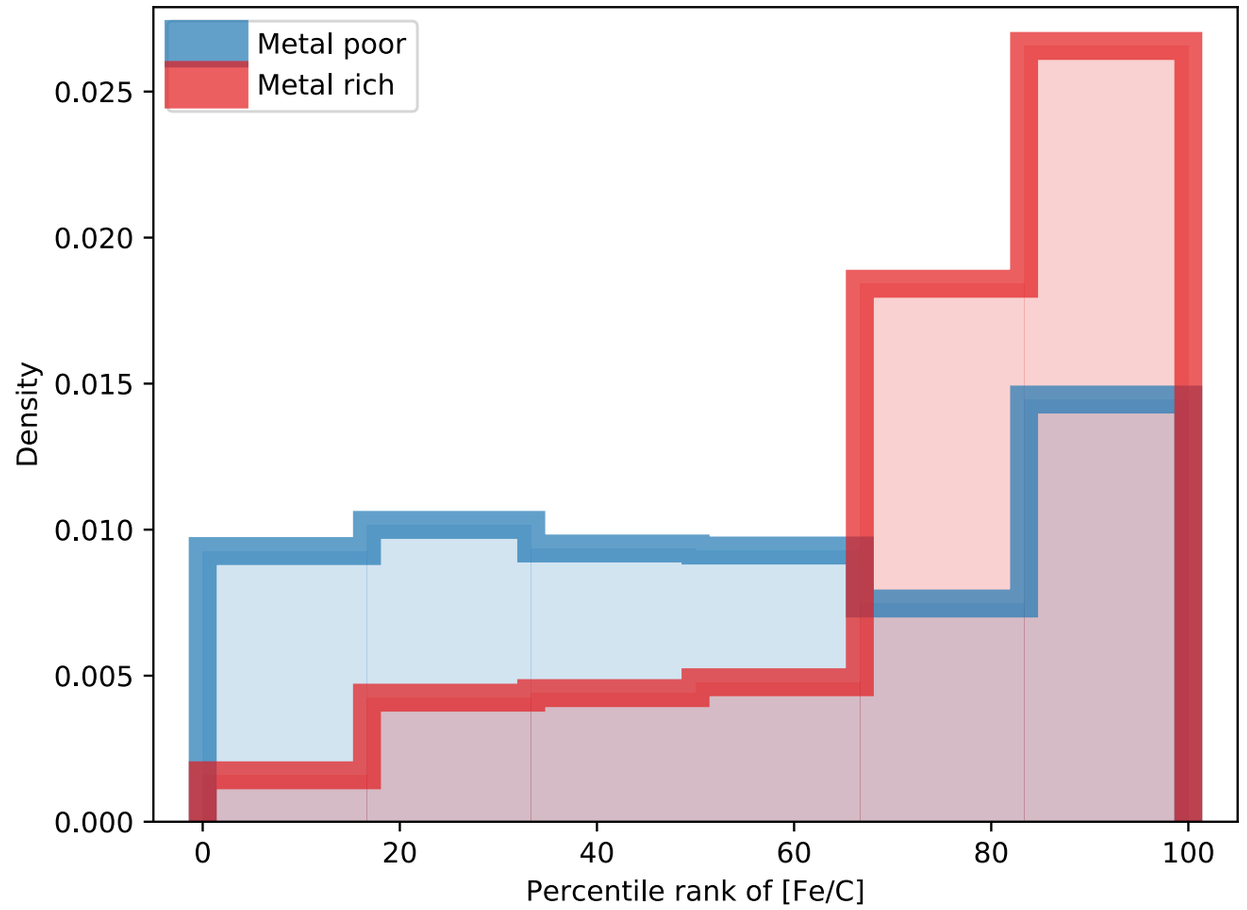

Is this anomalously rich of metals? ✓

Is this anomalously poor of metals? ✗

Are they both chemically anomalous? ✗

We compare the [Fe/C] abundance ratios of the metal poor/rich components of the anomalous pairs to the typical values observed in nearby solar twin stars (Casali et al. 2020).

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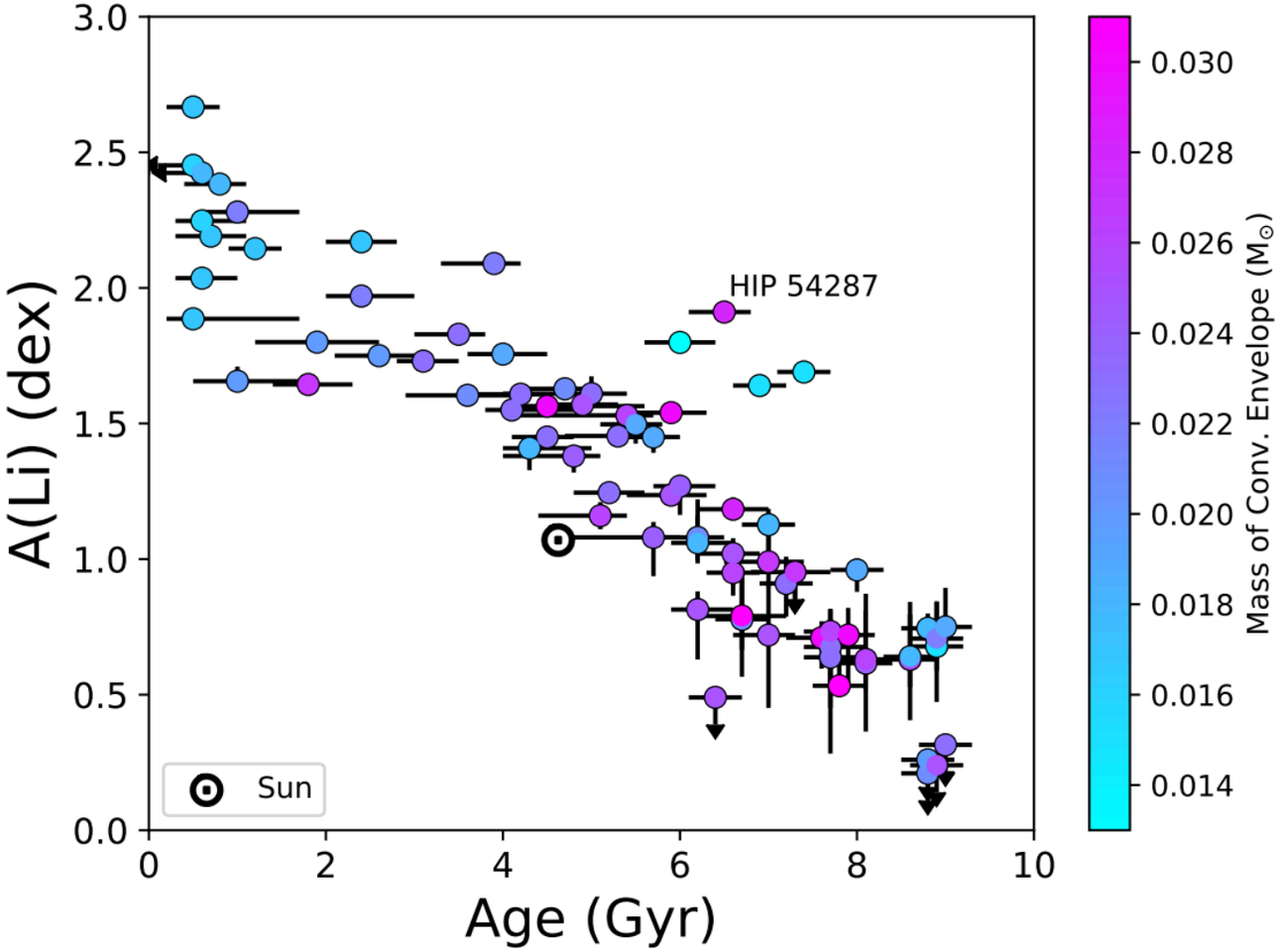
# The Lithium test

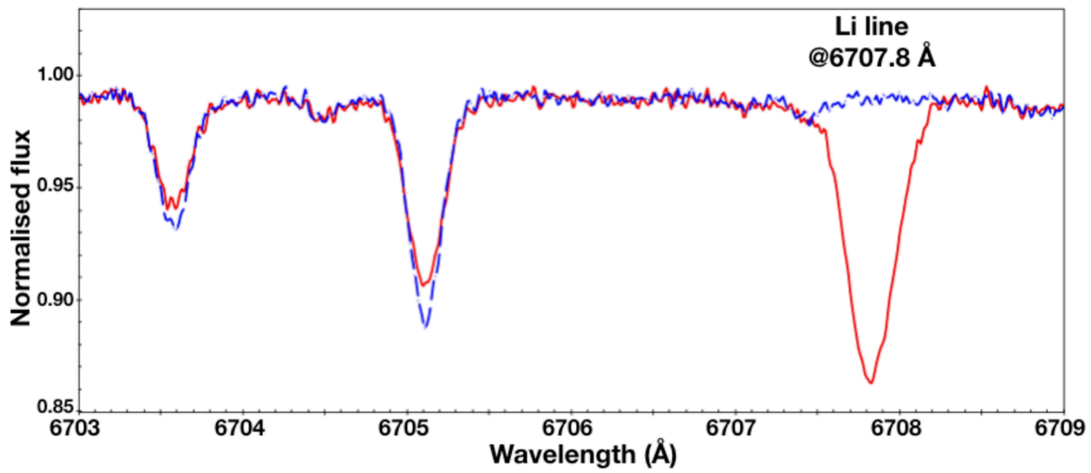



Carlos et al. (2018, MNRAS, 485, 3, 4052)

All stars and their planets are born with the same supply of Li in their atmospheres.

Lithium is depleted in sun-like stars at different rates depending on the stellar mass.

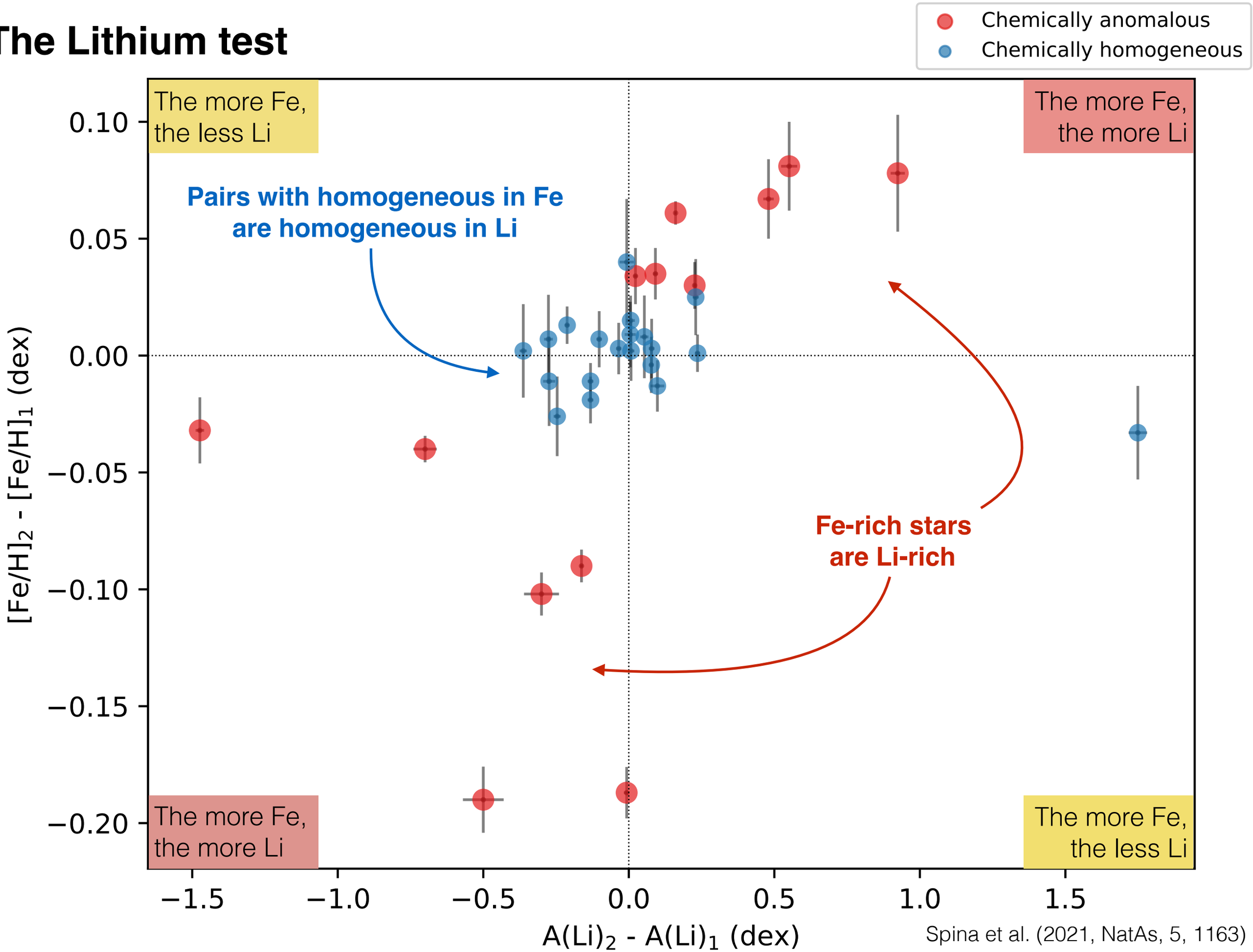
Planetary material retains the original supply of Lithium.




When "old" stars (i.e., stars with no Lithium) eat their planets, they should appear significantly Li-richer than their companion.

**Hypothesis** Some of the stars enriched in Fe because of planet engulfment should be richer in Li as well.

# The Lithium test

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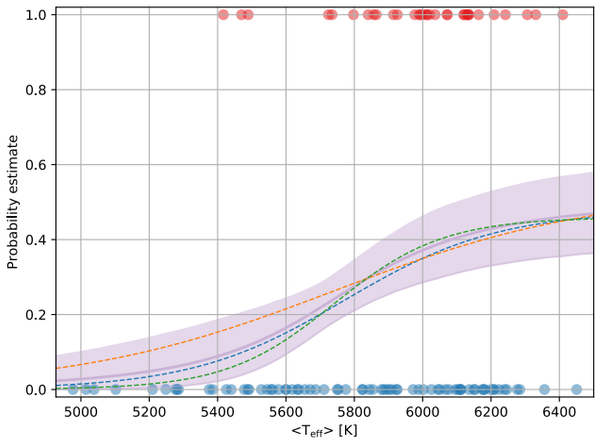
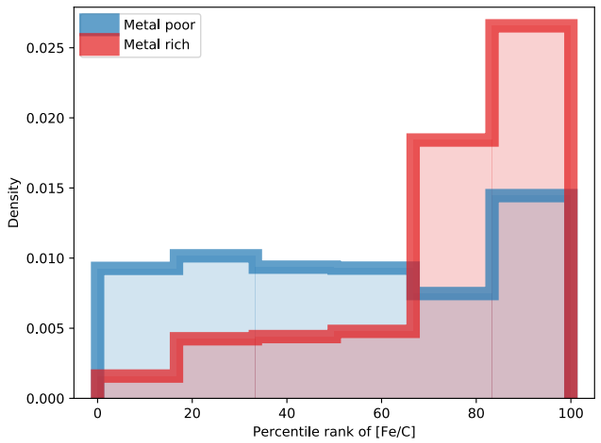
# The main results of our experiment

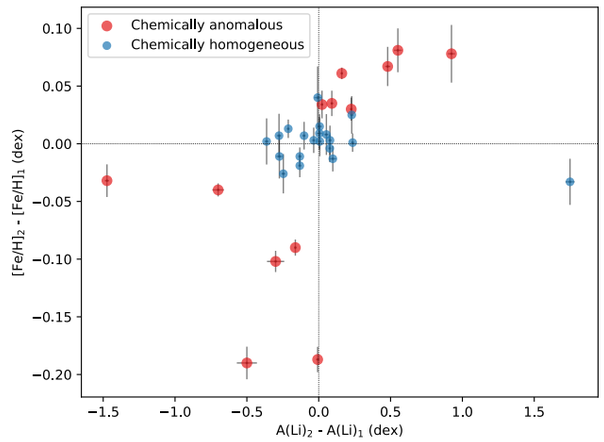
- Three pieces of evidence indicating that Sun-like stars swallow planets. Planet engulfment events produce an alteration of the stellar chemical pattern.




$P_{anomaly}$ is function of $T_{eff}$




The metal rich components have unusual abundances

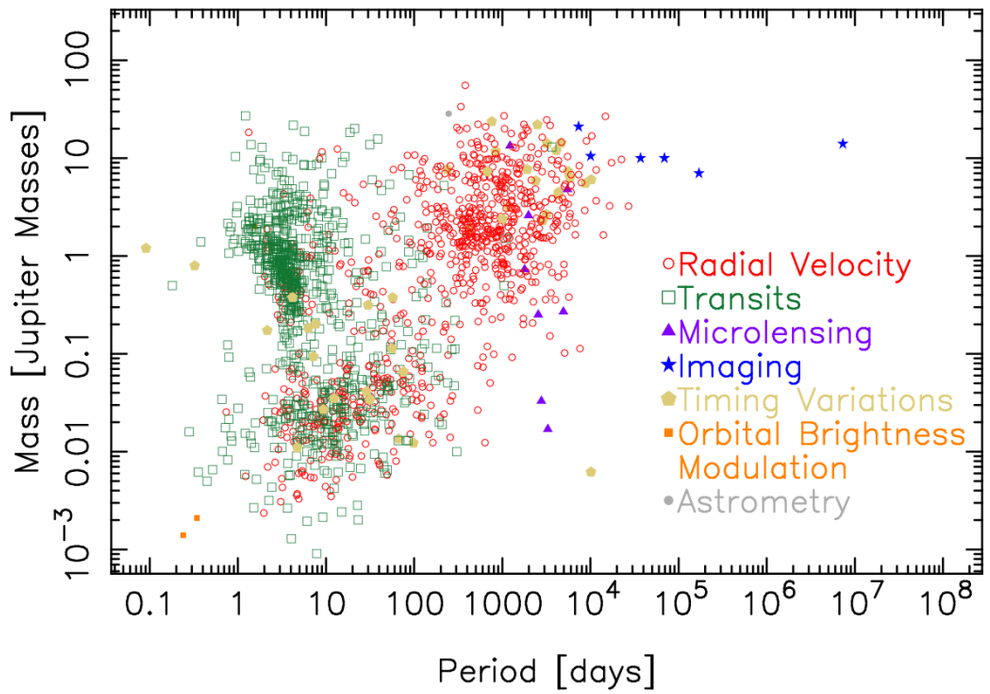



The more Fe, the more Li

- Planet engulfment events in Sun-like stars occur with a frequency of 0.27.

- A non-negligible fraction of planetary systems around Sun-like stars have experienced an extremely dynamical past, culminating with the fall of planetary material into the host star.

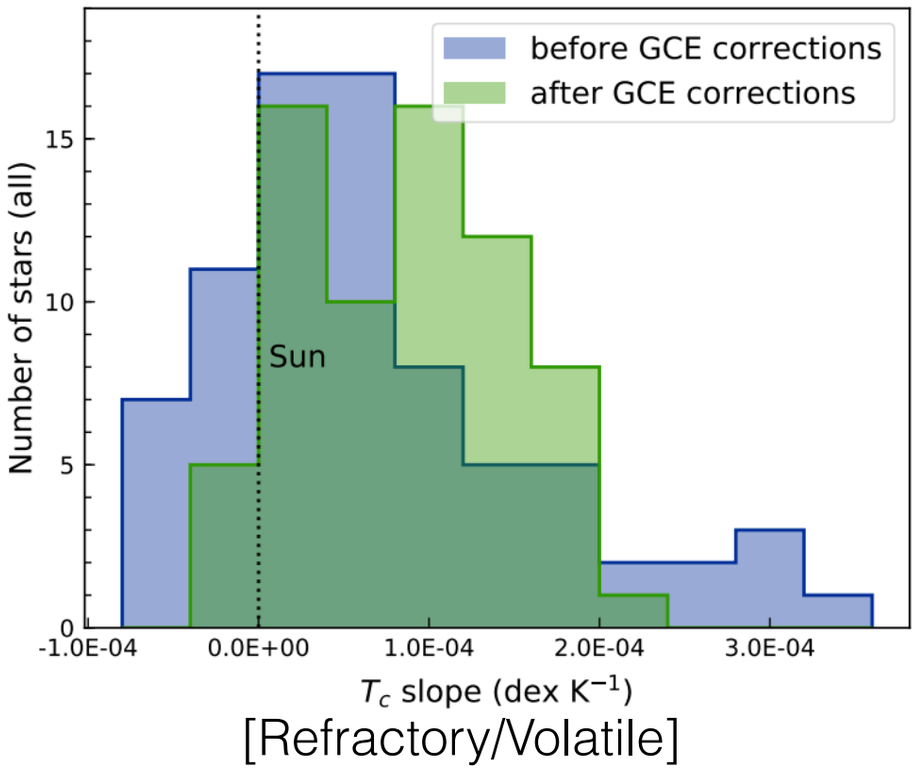
- Our research solely relies on a comprehensive description of stellar chemical patterns. It is completely independent from both exoplanet detection techniques, and n-body numerical simulations.



# Our Sun in the context of planet engulfment events

- The Sun has a low [refractory/volatile] and low Li if compared to nearby solar-twin stars.

Bedell et al. (2018, ApJ, 865, 68)

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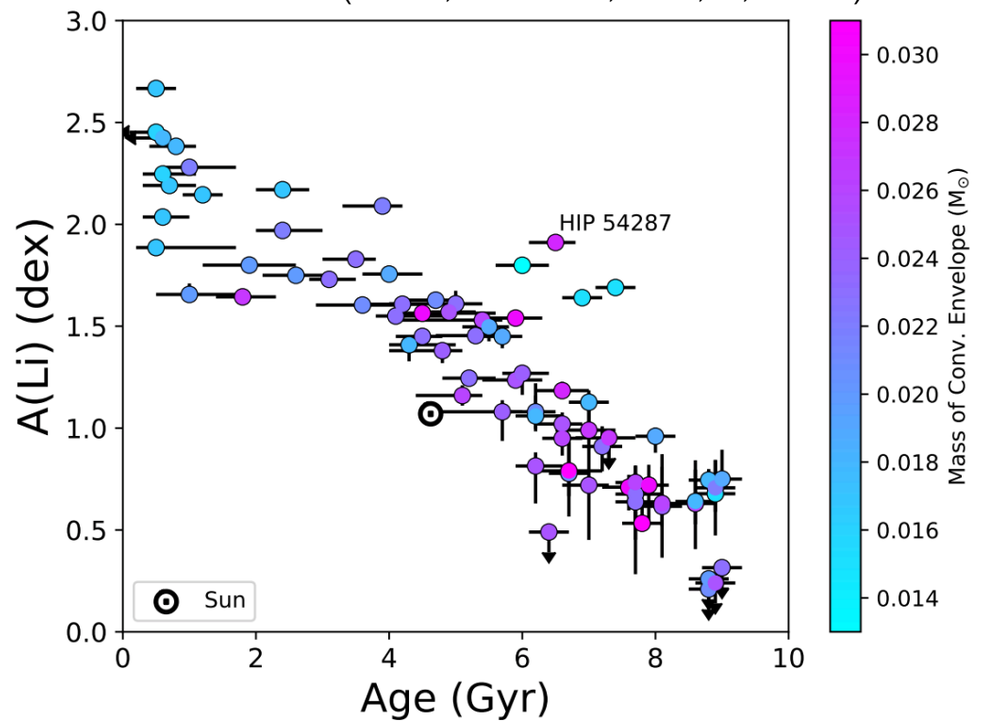
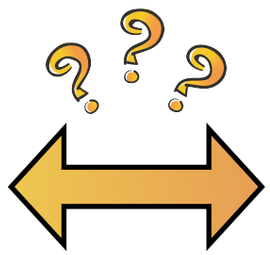
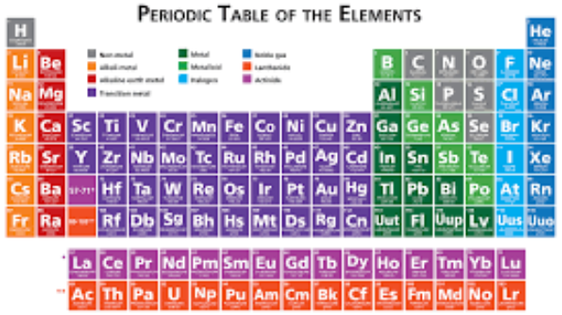



- Our Solar System has a very ordered and calm architecture: inner rocky planets, outer gaseous planets, nearly circular orbits. Perhaps the Sun has never engulfmed planetary material, while the other stars have done it.






- Can we use the chemical composition of stars to identify those with higher chances of hosting analogues of our Solar System?

- Stay tuned! Next-generation spectroscopic survyes (e.g., 4MOST, WEAVE) will dedicate significant fraction of observing time to stellar associations.

# Thank you!