The California-Kepler Survey IV:
Metal-rich Stars Host a Greater Diversity of Planets

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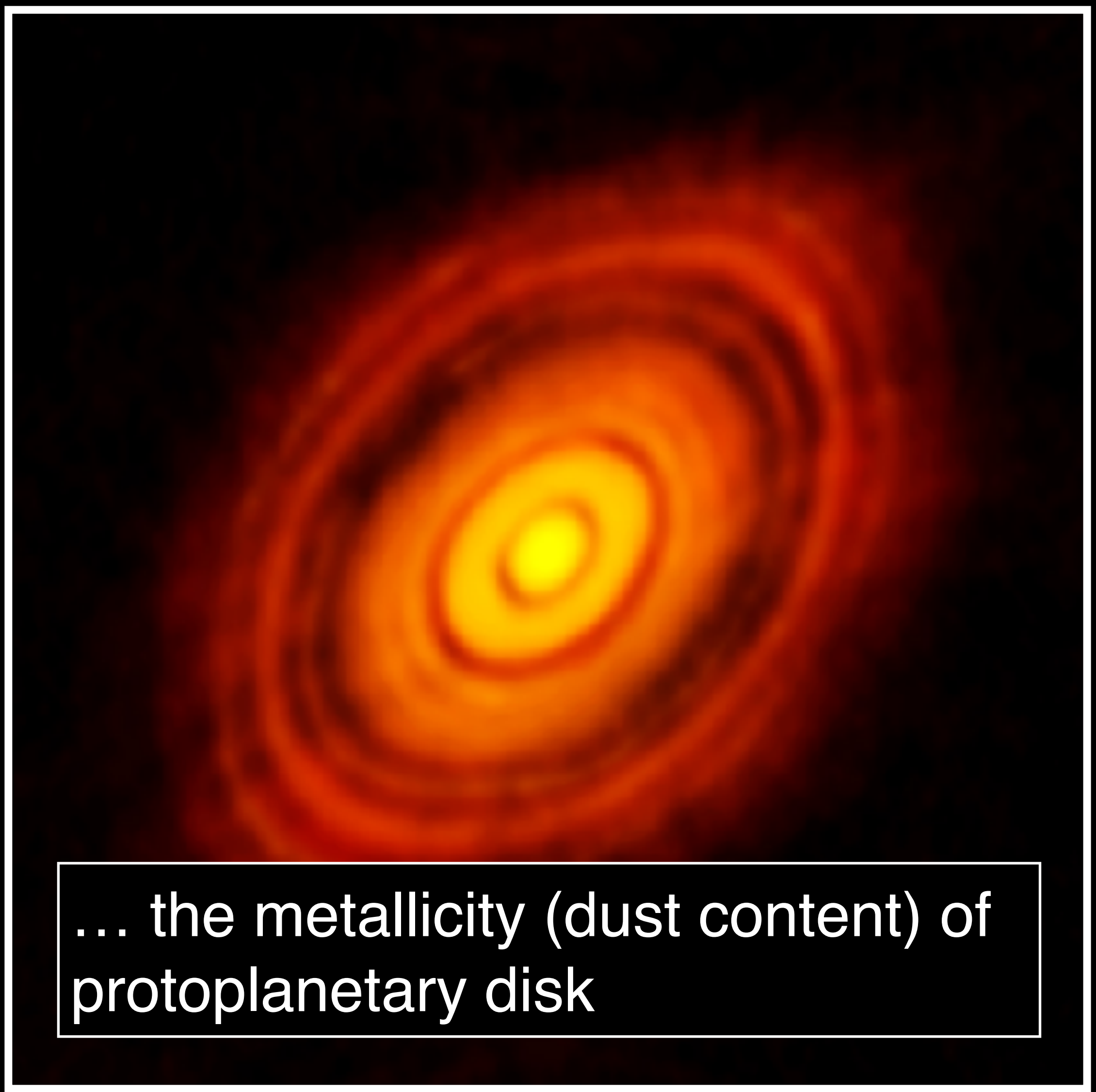
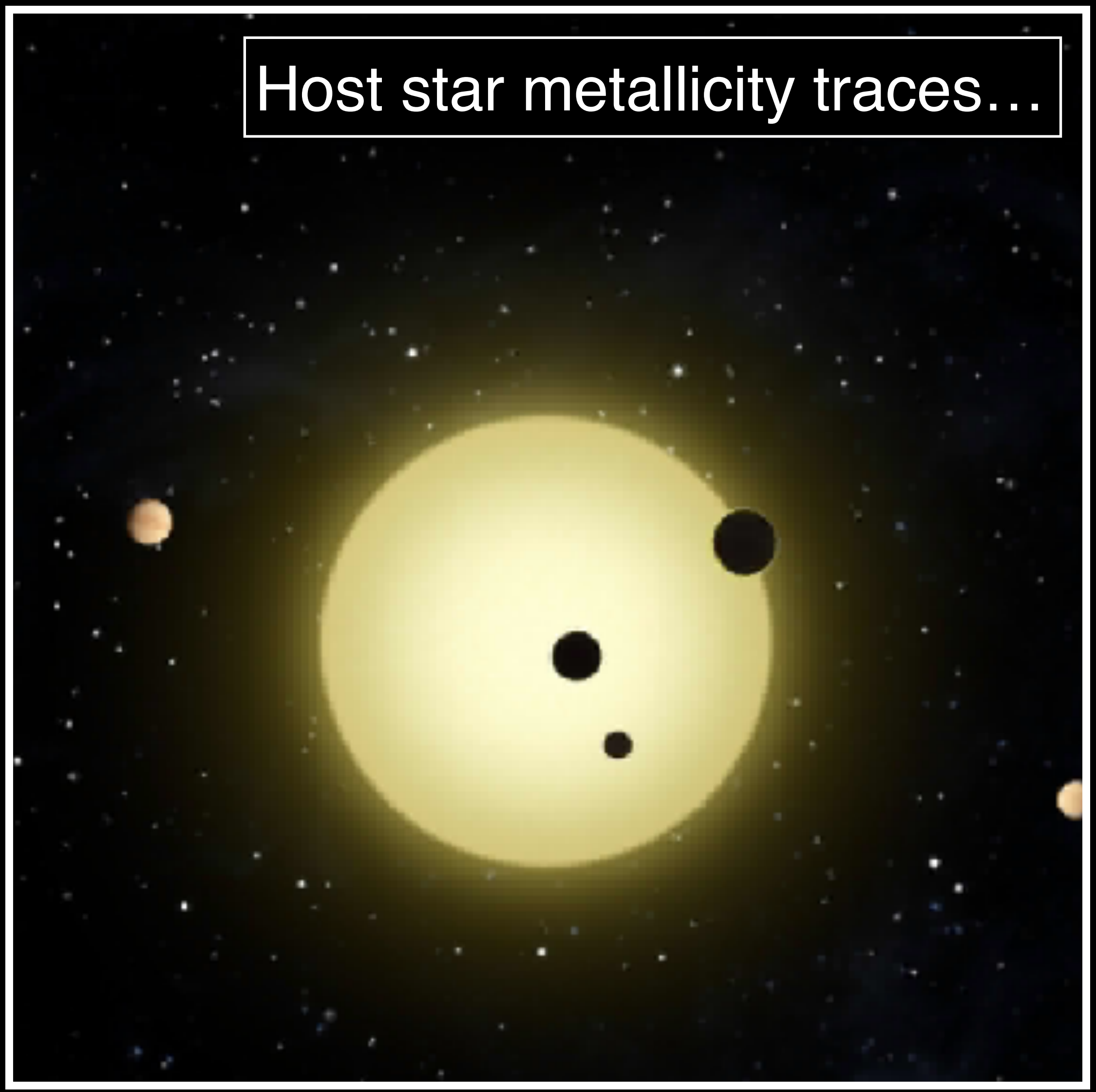
ExSoCal
September 18, 2018

Metallicity: Why Do We Care?



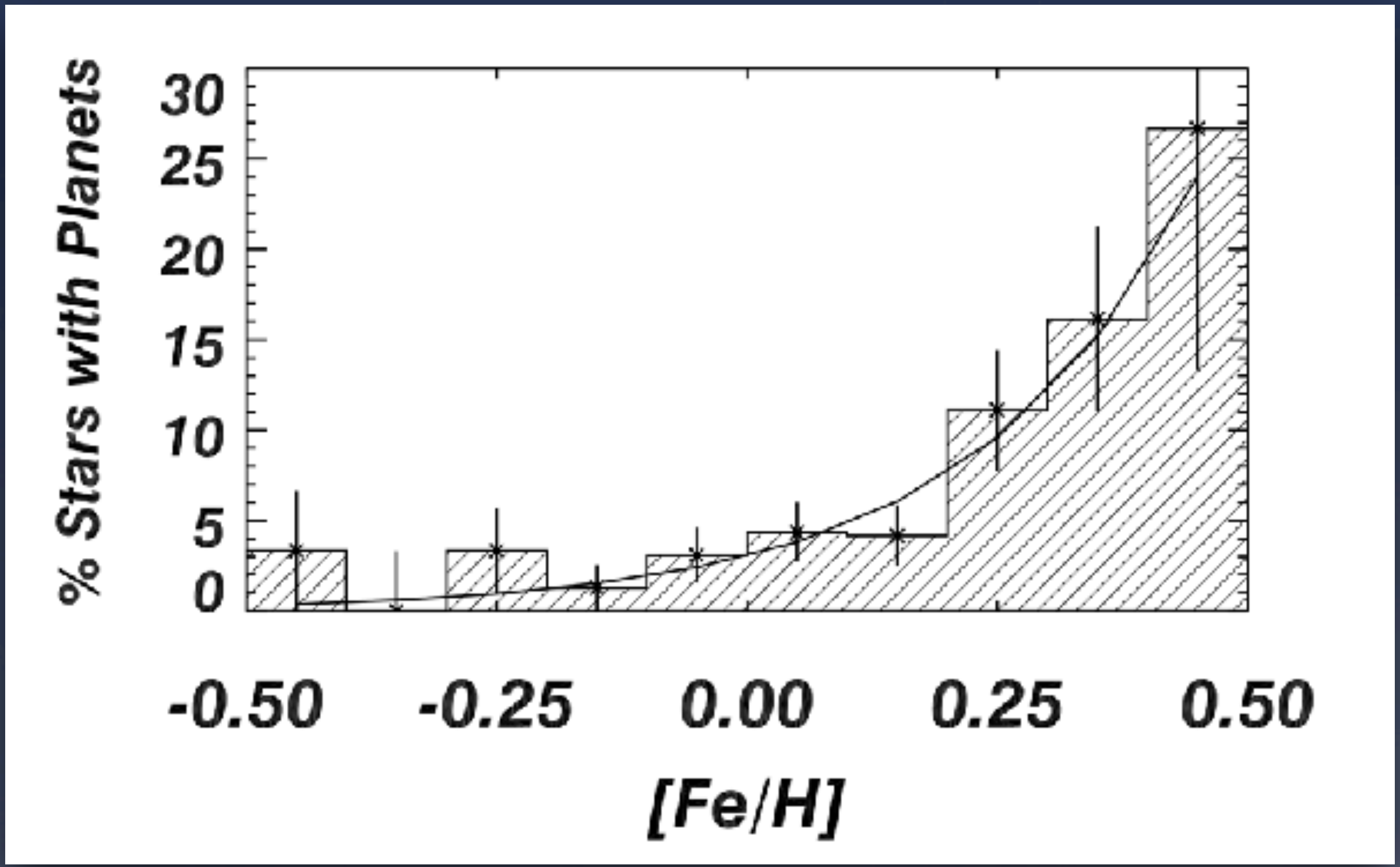
HL Tau / ALMA

?



Kepler 11/NASA

Giant Planet Metallicity Correlation



Fischer & Valenti (2005)

- Occurrence of Doppler-detected giant planets is strong function of [Fe/H]
- Supports core accretion theory
- No sensitivity to small planets
- *N*(planets) ~ 100

- See also: Gonzalez+97, Santos+04, Sousa+08, Ghezzi+10, Dawson+13, Buchhave+14, Dong+14, Buchhave+15, Dawson+15, Schlaufman+15, Wang+15, Mulders+16, Guo+17,

Occurrence: Period-Radius

Given a sample of planets ***P***, drawn from a parent stellar population ***S*** the planet occurrence within a box spanning $[P_1, P_2]$ and $[R_{p1}, R_{p2}]$ is…

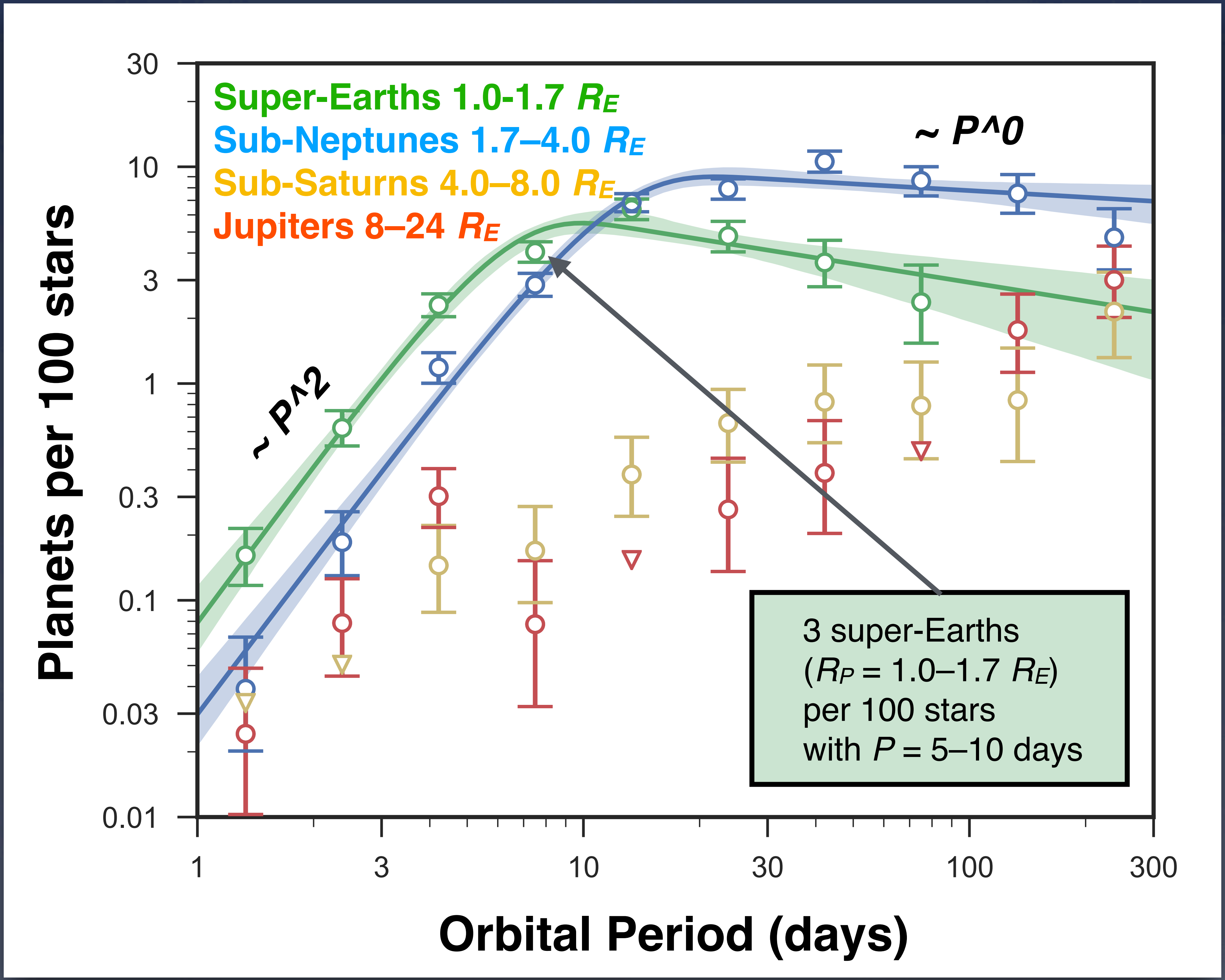
$$\boxed{f = \frac{\text{Num. planets in } \mathbf{P} \text{ within box*}}{\text{Num. stars in } \mathbf{S} \text{ within box}}}$$

**corrected for missed planets*

P **-** Q1-Q16 sample of *Kepler* planets (970) with CKS parameters

S **-** Magnitude limited sample of *Kepler* FGK dwarfs 36959 (18%)

Occurrence: Period-Radius



CKS-IV: Petigura et al. (2018b)

Occurrence: Period-Radius-Metallicity

Given a sample of planets ***P***, drawn from a parent stellar population ***S*** the planet occurrence within a box spanning $[P_1,P_2]$ and $[R_{p1},R_{p2}]$ and $[M_1,M_2]$

$$\boxed{f = \frac{\text{Num. planets in } \mathbf{P} \text{ within box*}}{\text{Num. stars in } \mathbf{S} \text{ within box}}}$$

**corrected for missed planets*

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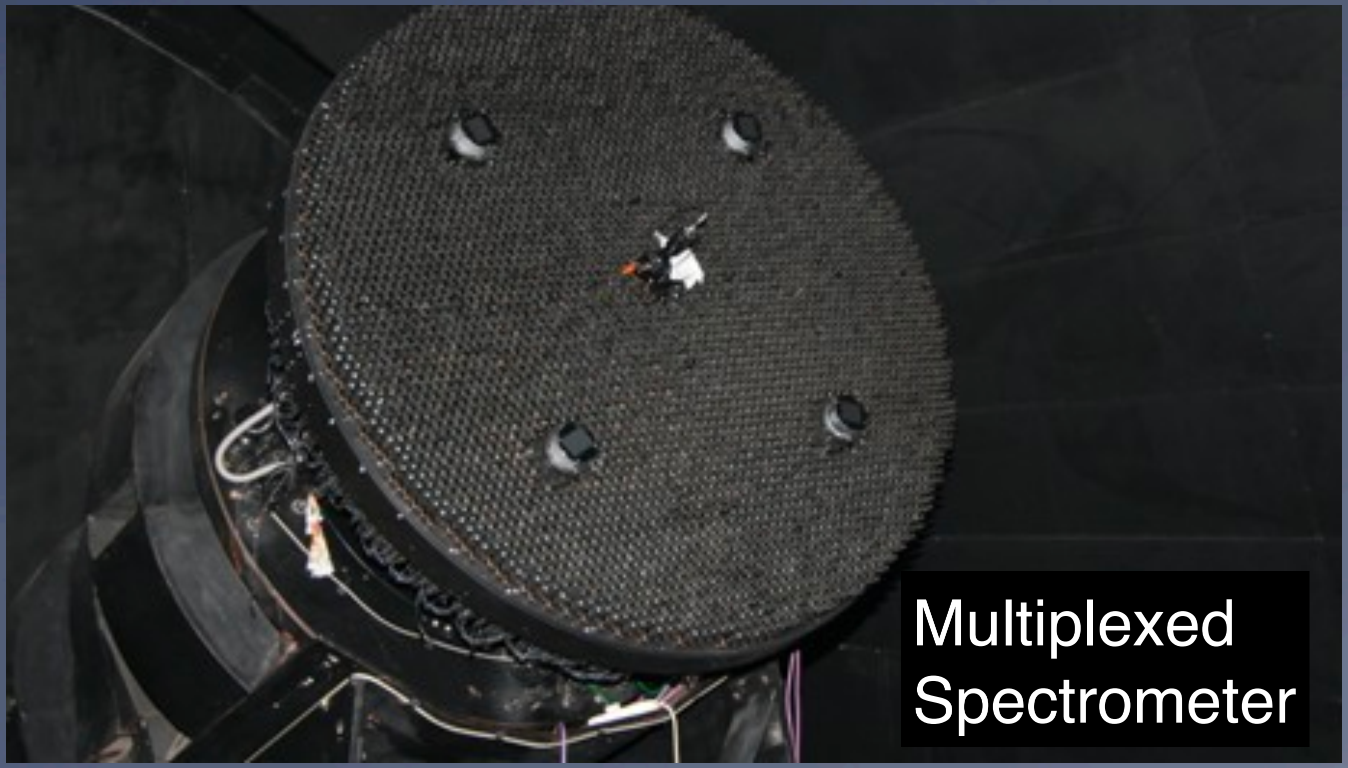
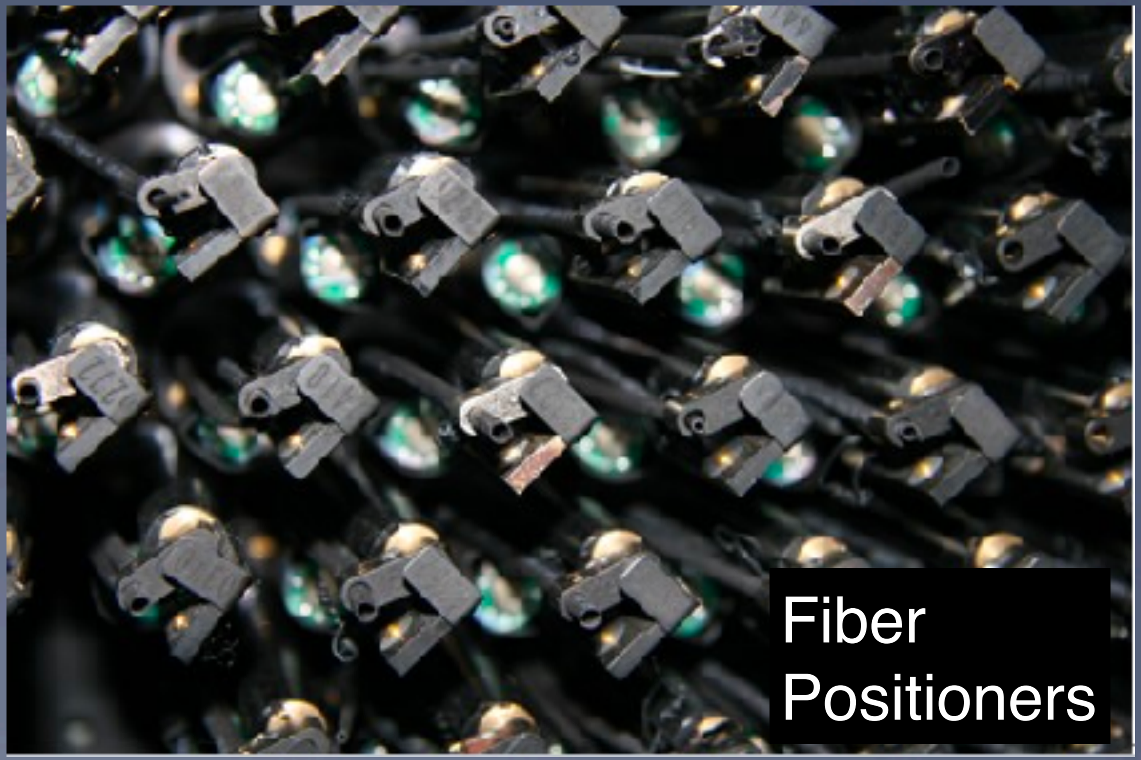
Key limitation: metallicity of Kepler field was unknown until c. 2015

LAMOST Metallicities of *Kepler* fields stars

- LAMOST Metallicities
  - R~1800 spectrometer
  - High multiplexing
  - High precision (~0.1 dex)
  - tens of thousands of Kepler stars

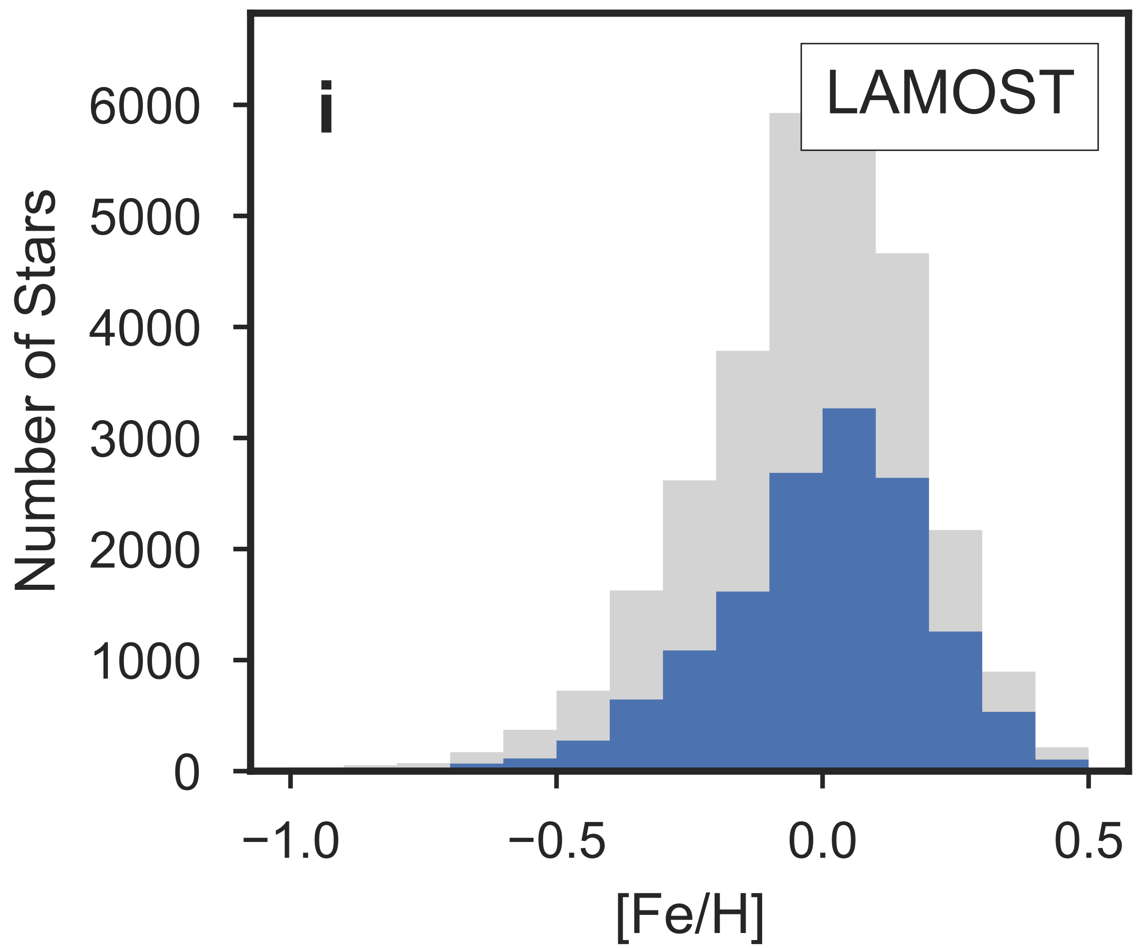




The *Kepler* Field is ***Not*** Metal-poor

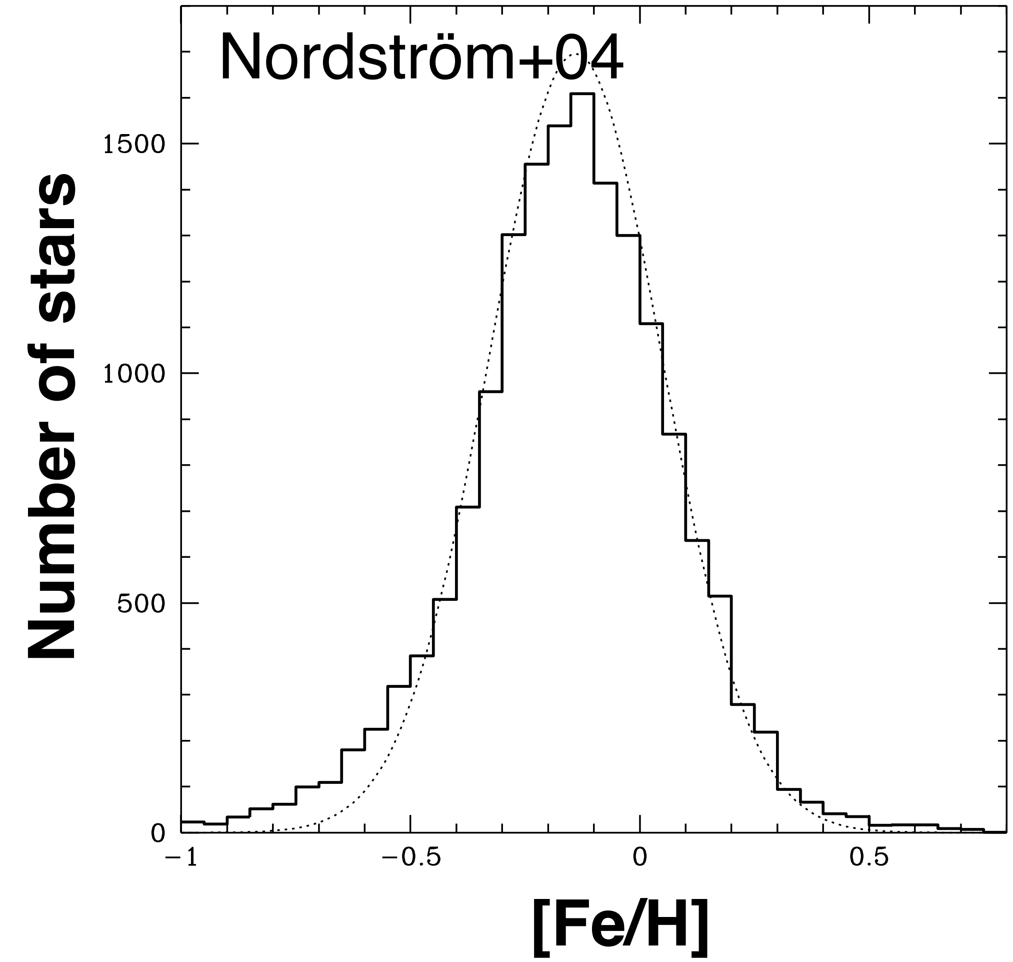
Kepler Field

- Mean([Fe/H]) = –0.005 ± 0.002



Solar Neighborhood

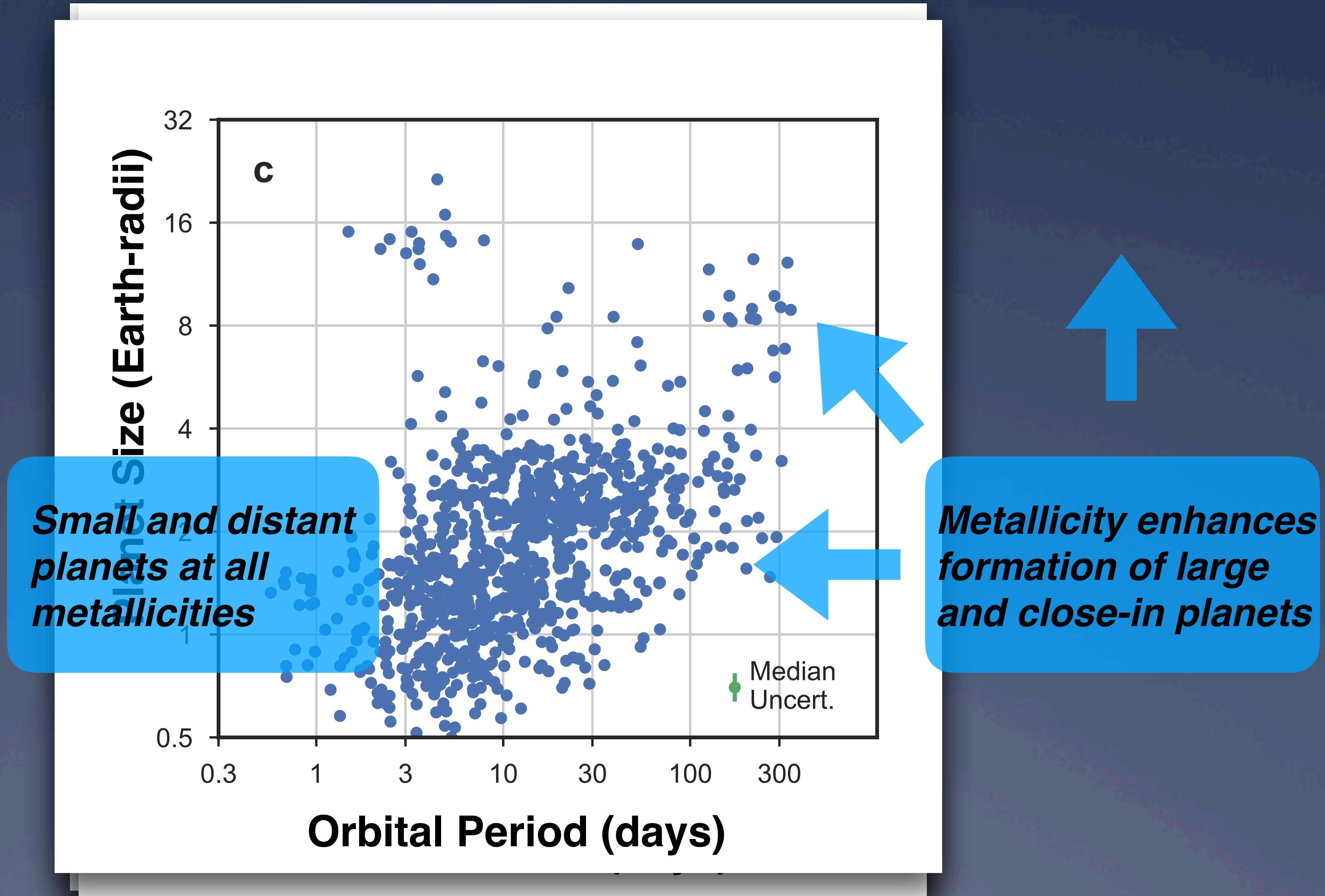
- Mean([Fe/H]) = –0.140 ± 0.001



"The occurrence of hot Jupiters in the Kepler field is only 40% that in the solar neighborhood. […] We are unable to explain this difference, although a paucity of metal-rich stars in the Kepler sample is one possible explanation."

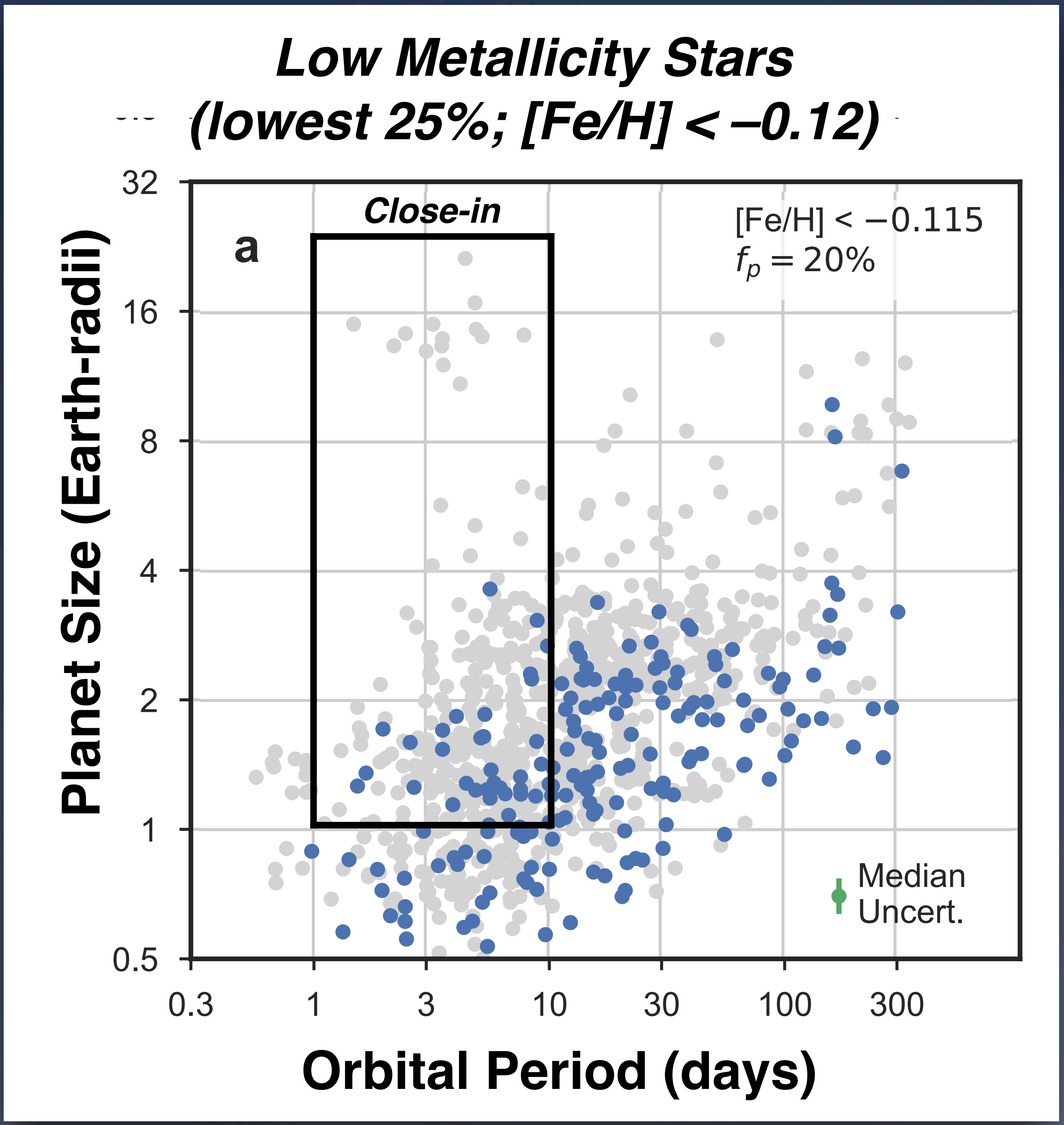
–Howard et al. (2012)

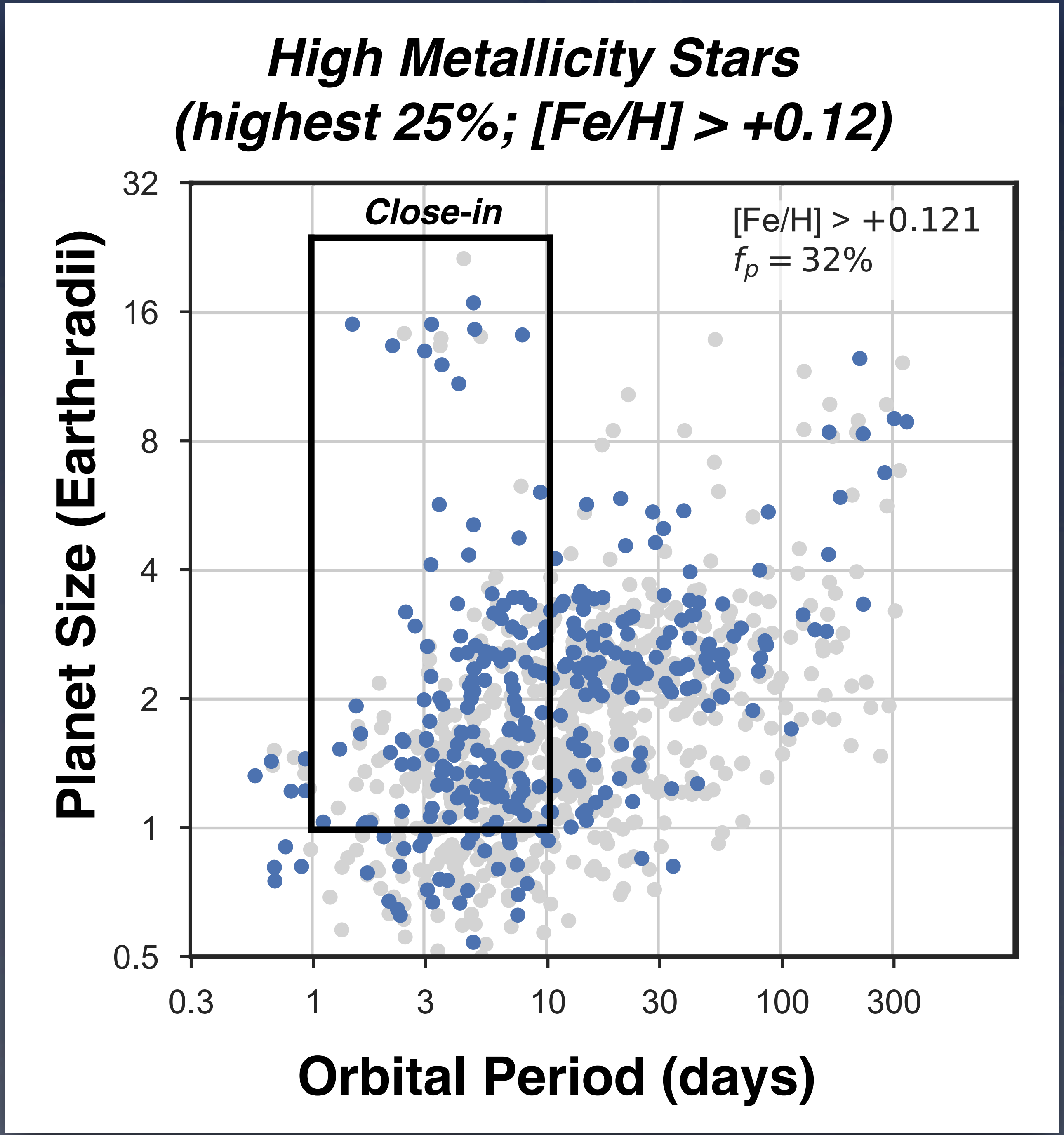
Metal-Rich Stars: Diverse Planets



CKS-IV: Petigura et al. (2018b)

Forming the Hottest Planets





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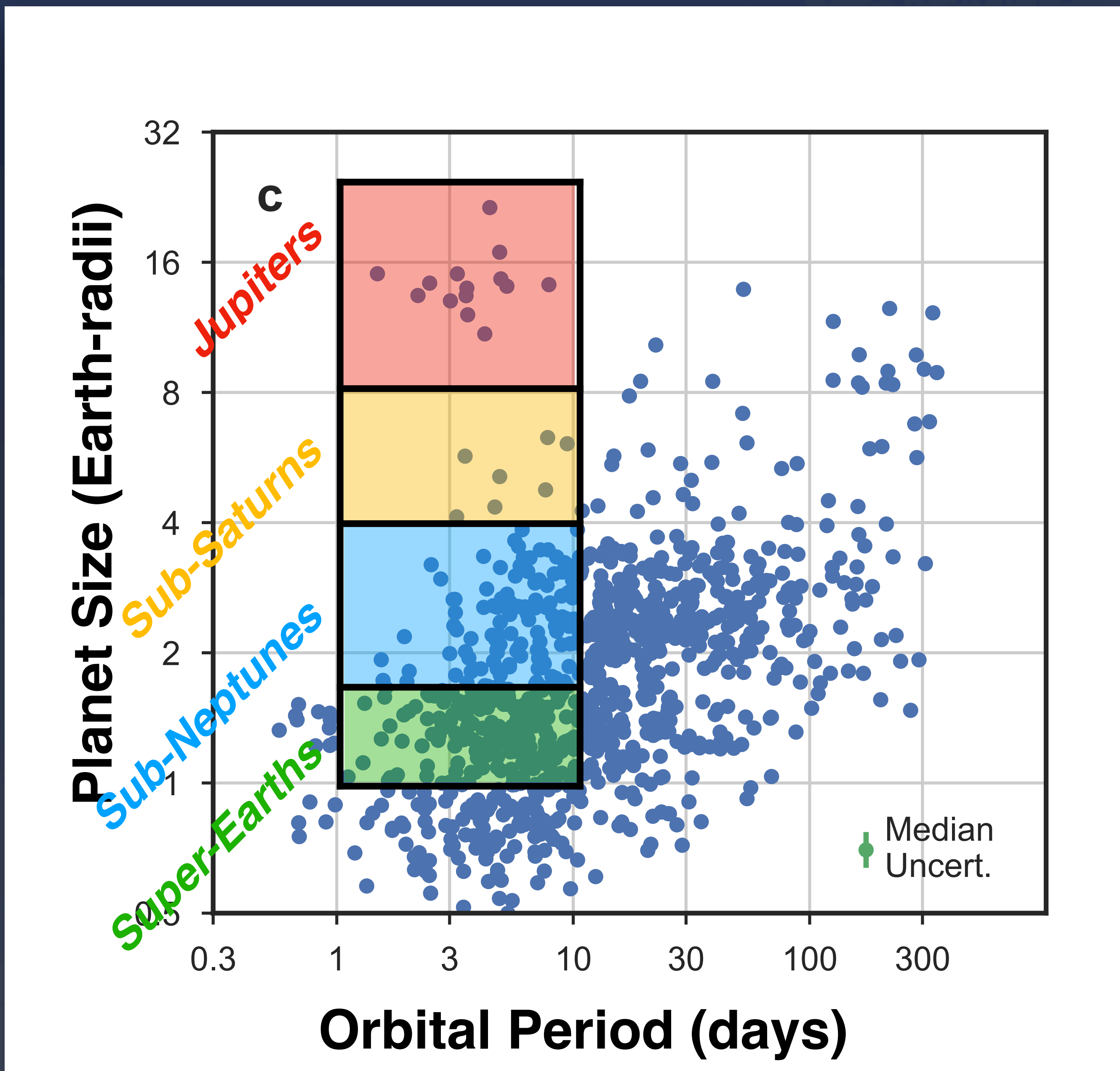

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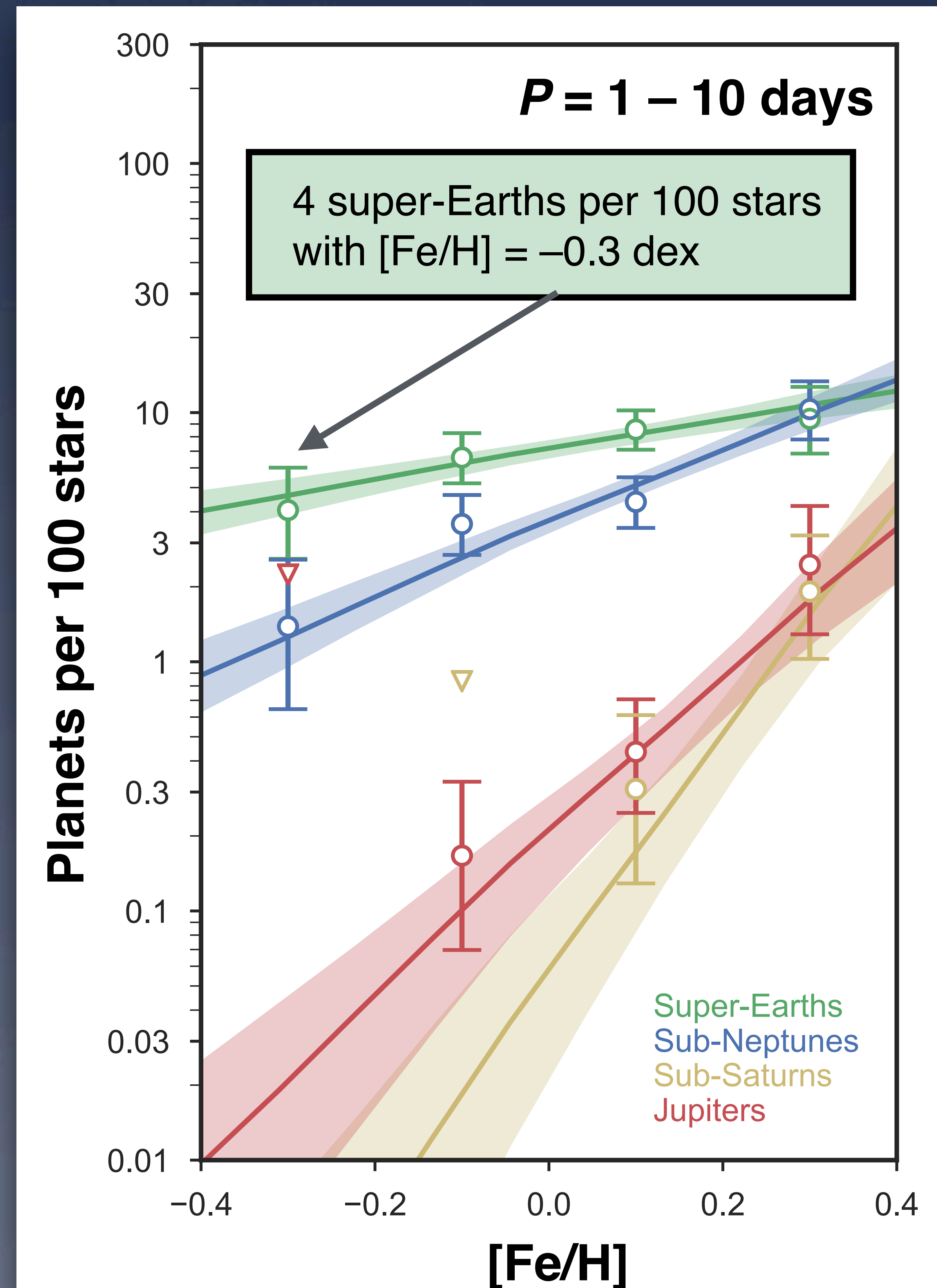
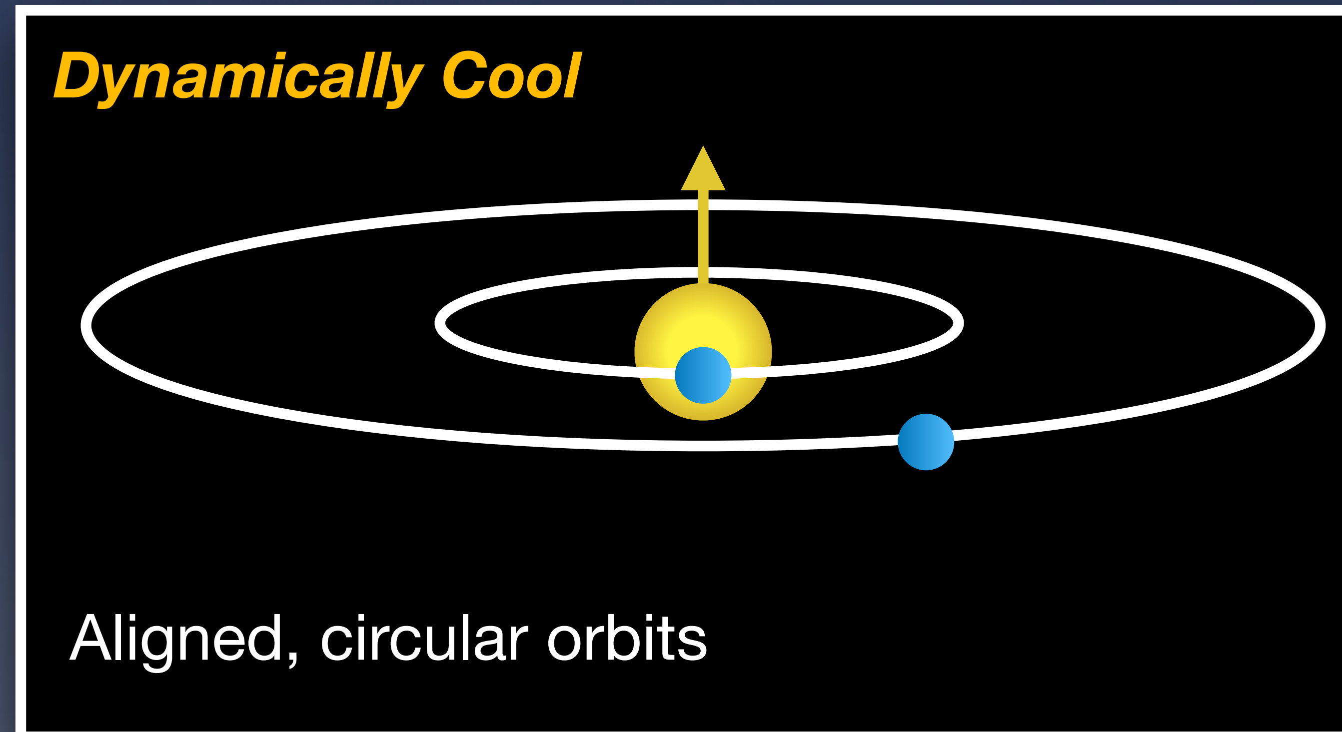


Forming the Hottest Planets

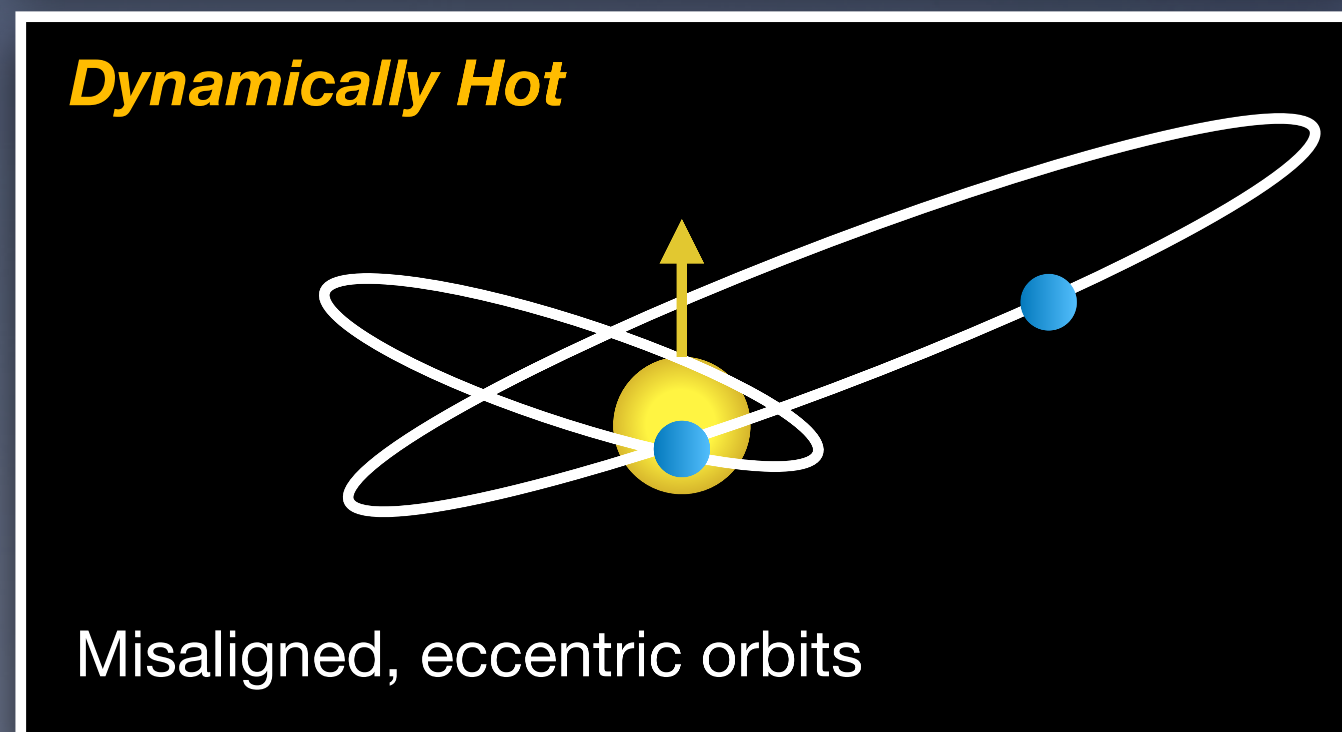
In situ models

- Planet-metallicity correlation possible if inner edge of disk is metallicity dependent
    - Stellar rotation (Lee+17)
    - Dust sublimation (Muzerolle+03)
- Predicts dynamically cool systems



High eccentricity migration

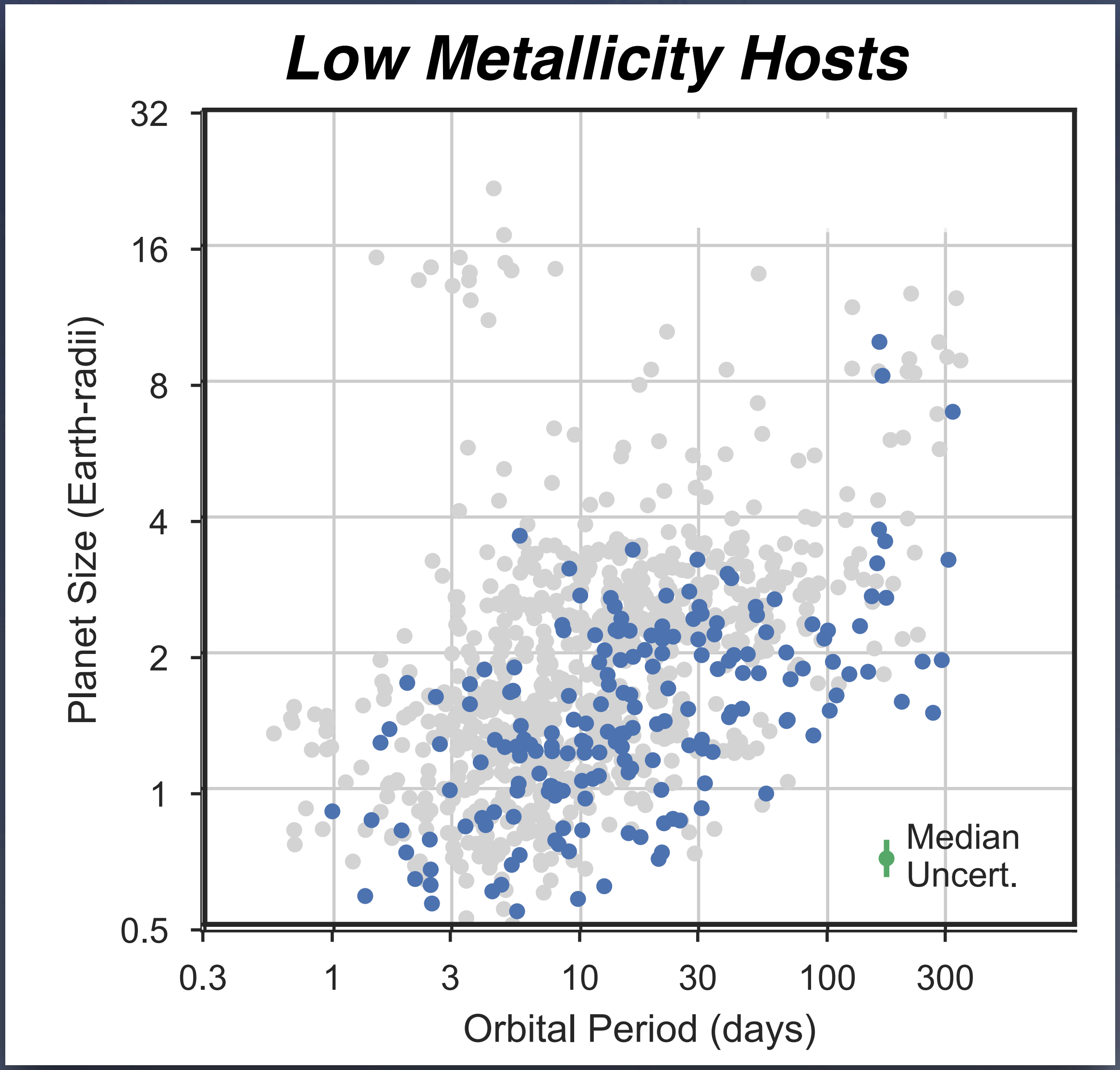
- Planet-metallicity correlation possible if migration efficiency is metallicity dependent
    - Planet-planet Kozai (Naoz+11)
    - Planet-planet scattering (Rasio+96)
    - Secular chaos (Wu+12)
- Predicts dynamically hot systems

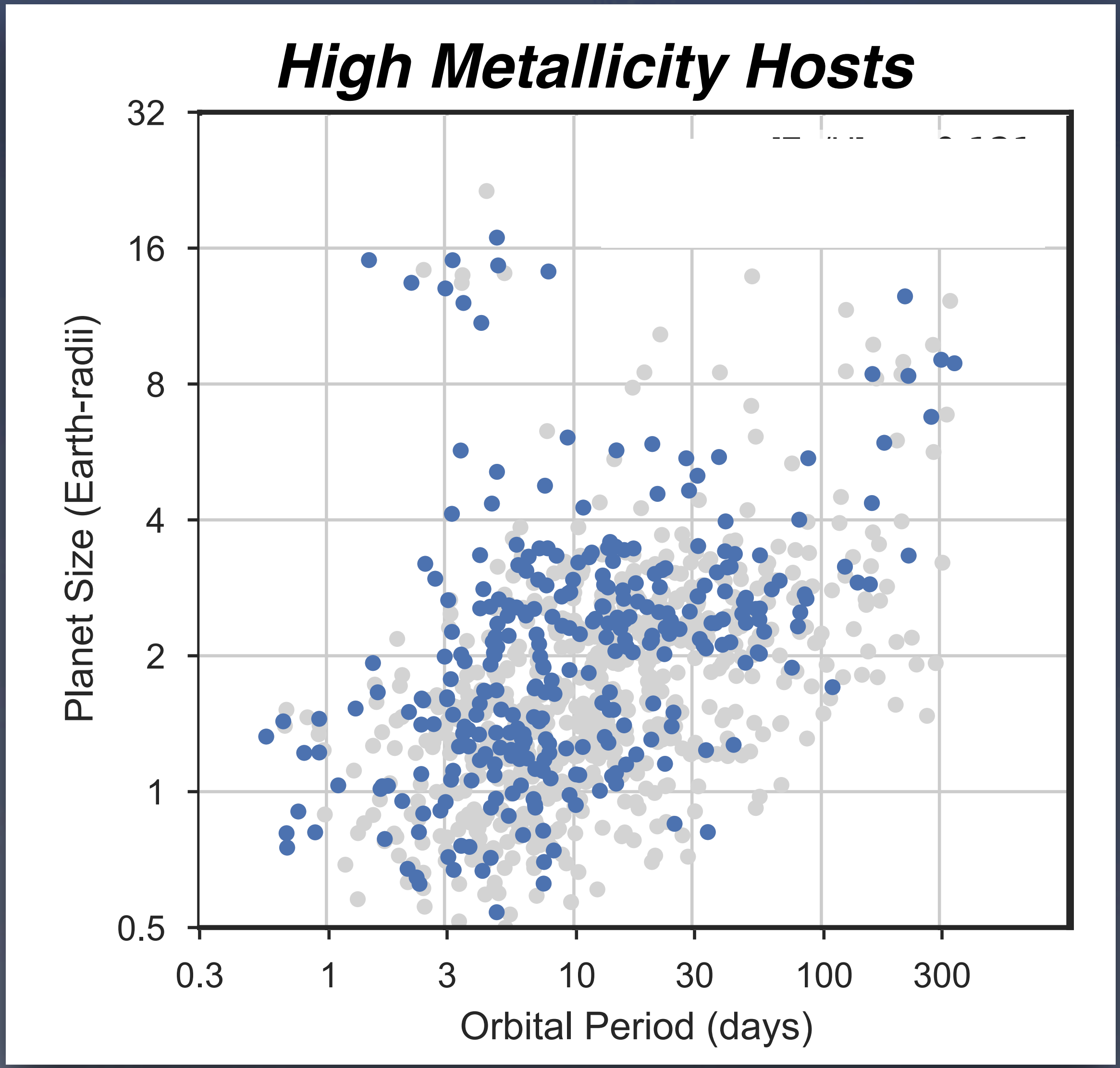


- The *Kepler* field is ***enriched*** in metals relative to solar neighborhood

- Nature produces some types of planets with high efficiency, regardless of stellar metallicity (planets smaller than Neptune and P > 10 days)

- Metallicity traces some process that produces planets that are “misplaced” in the period-radius plane (larger than Neptune or P < 10 days)

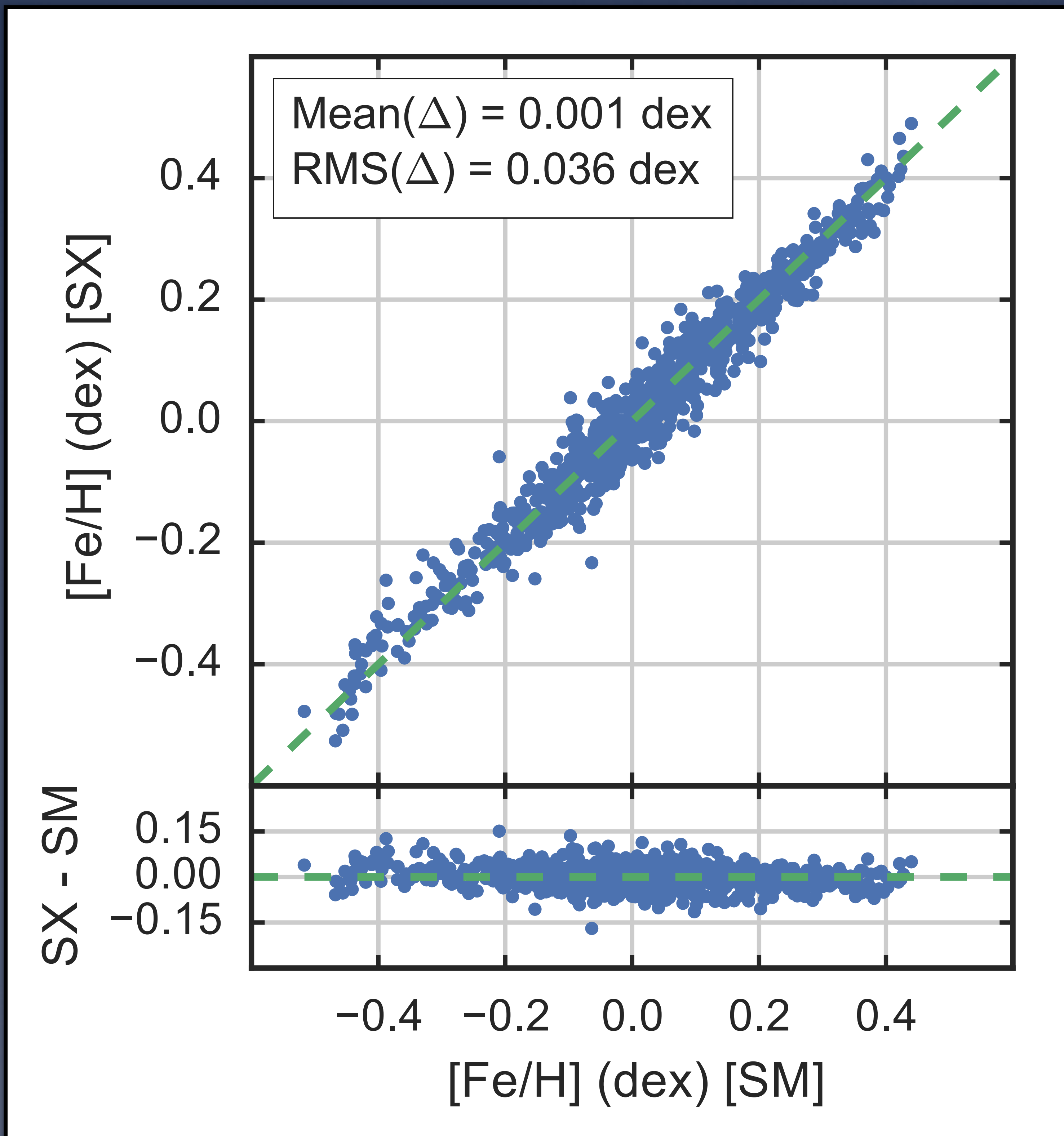




CKS-IV: Petigura et al. (2017)

Backup

CKS Precision: Metallicity

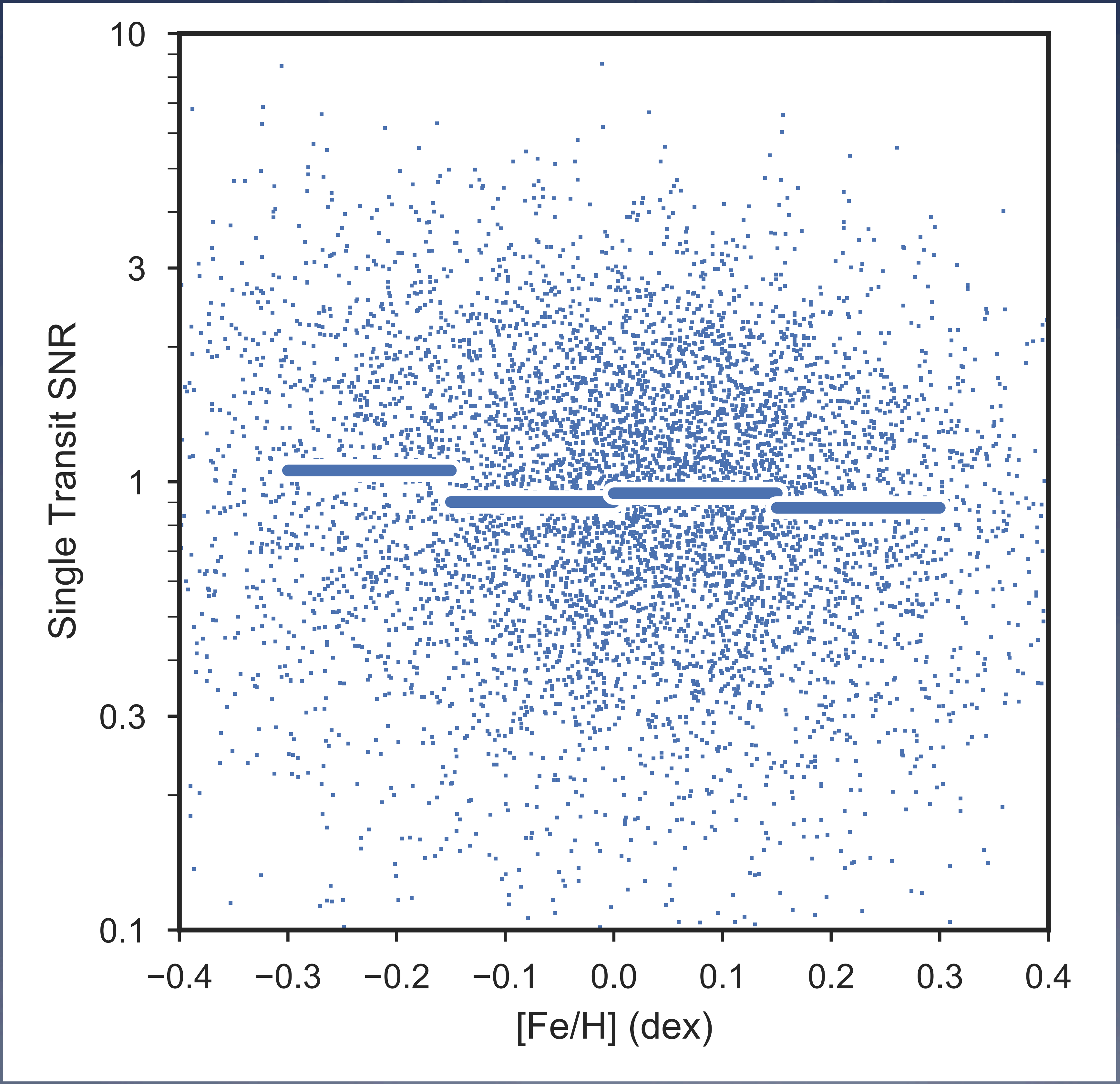


CKS-I: Petigura, Howard et al. (2017)

Spectroscopic Precision

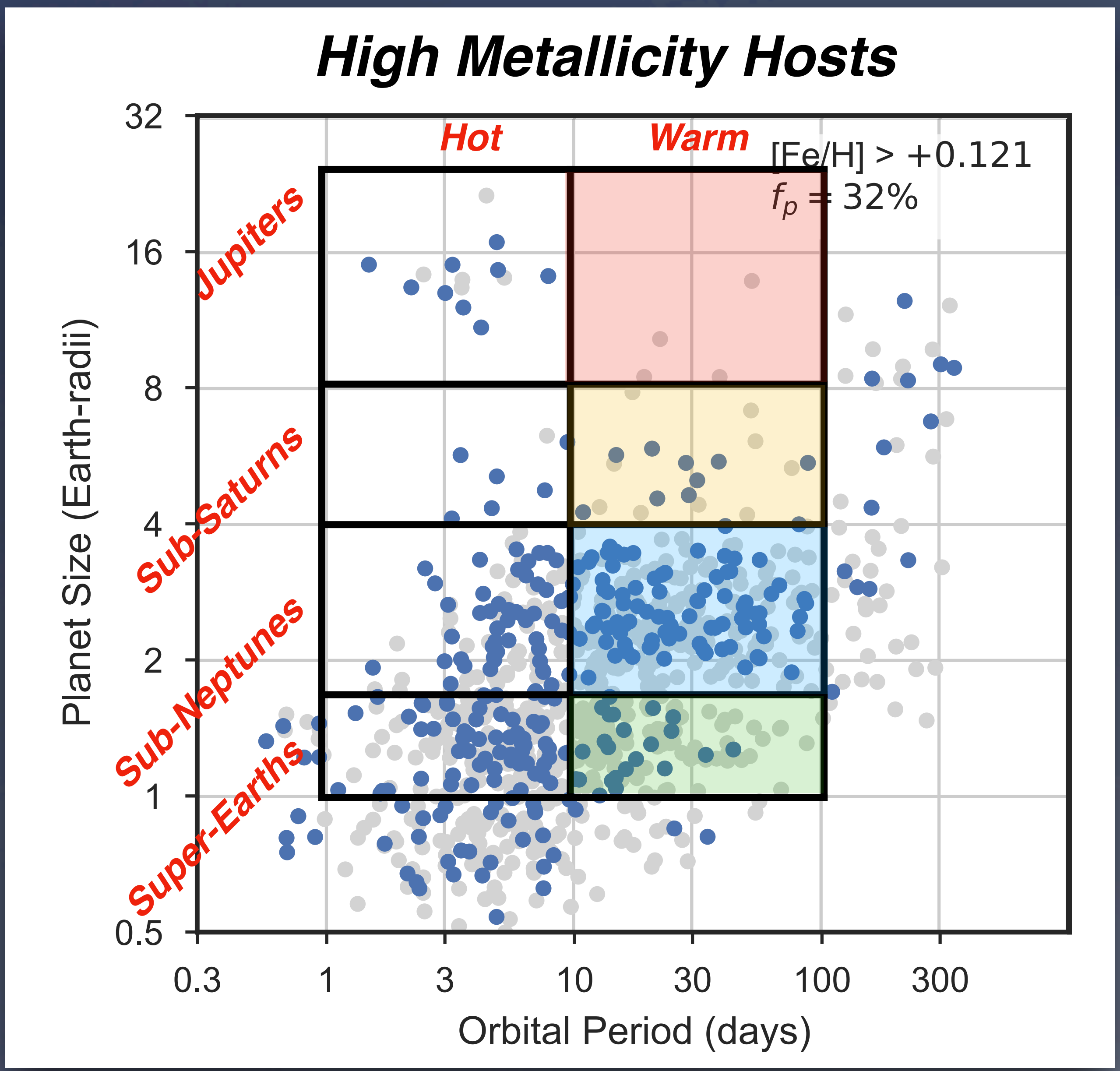
- [Fe/H] ~ 0.04 dex
  (vs. ~0.3 dex phot.)
- $R_\star$ ~ 10%
  (vs ~40% phot.)

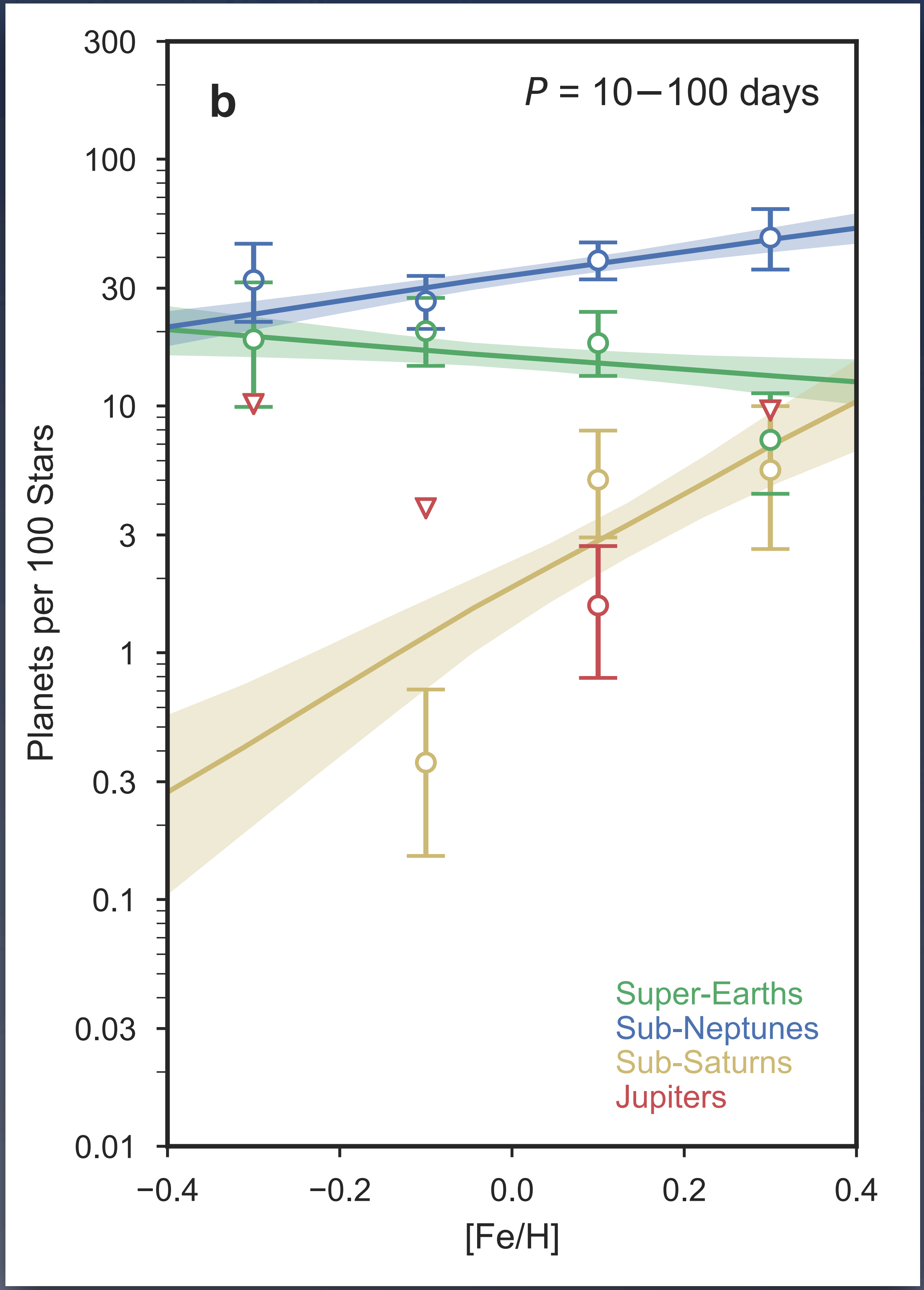
Planet Detectability & Metallicity



Planet Metallicity Correlation: Warm Planets

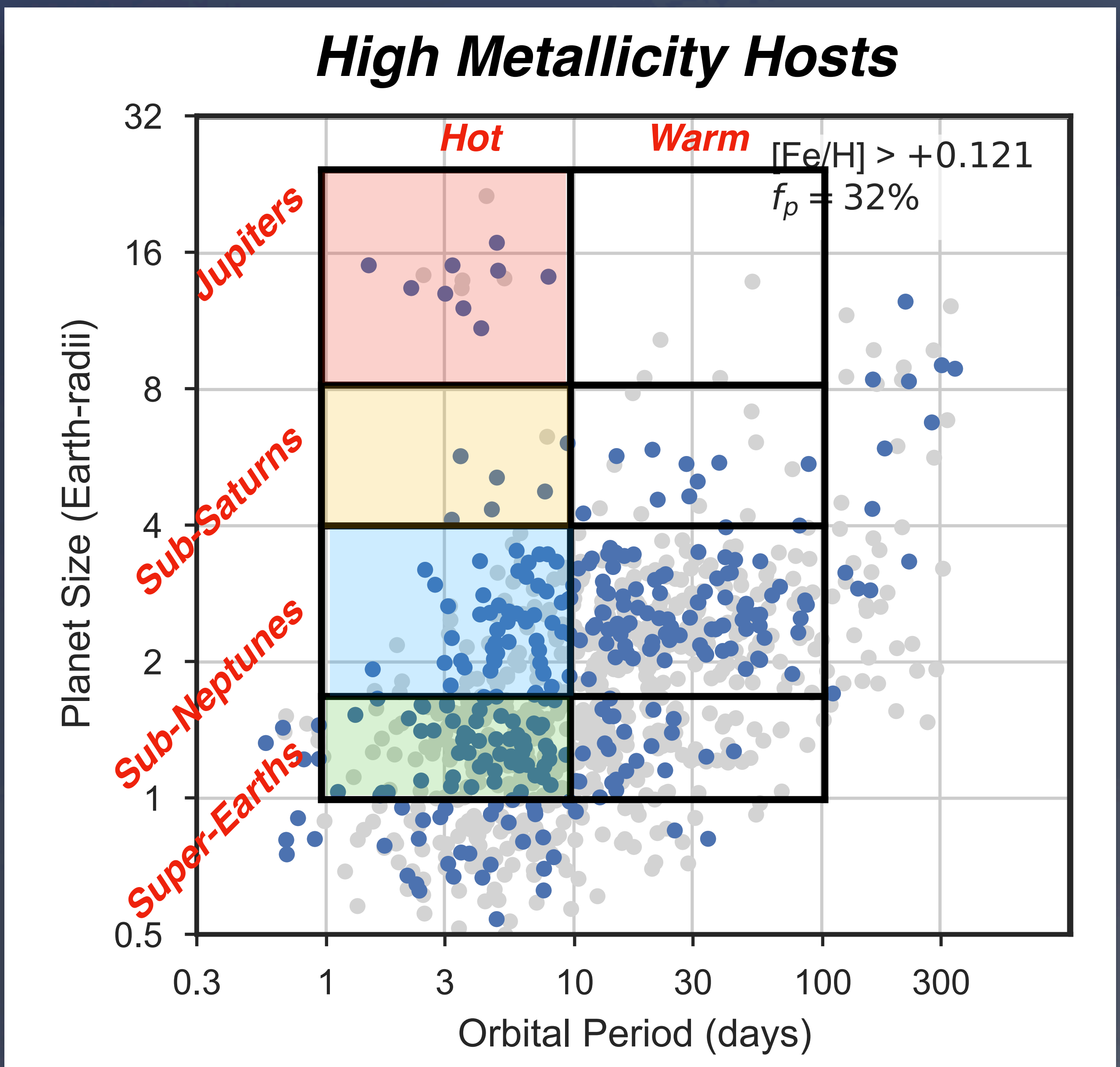
- Super-Earths: no corr.
- Sub-Neptunes: weak (but significant) corr.
- Sub-Saturns: strong corr.
- Jupiters: not clear (small sample size)

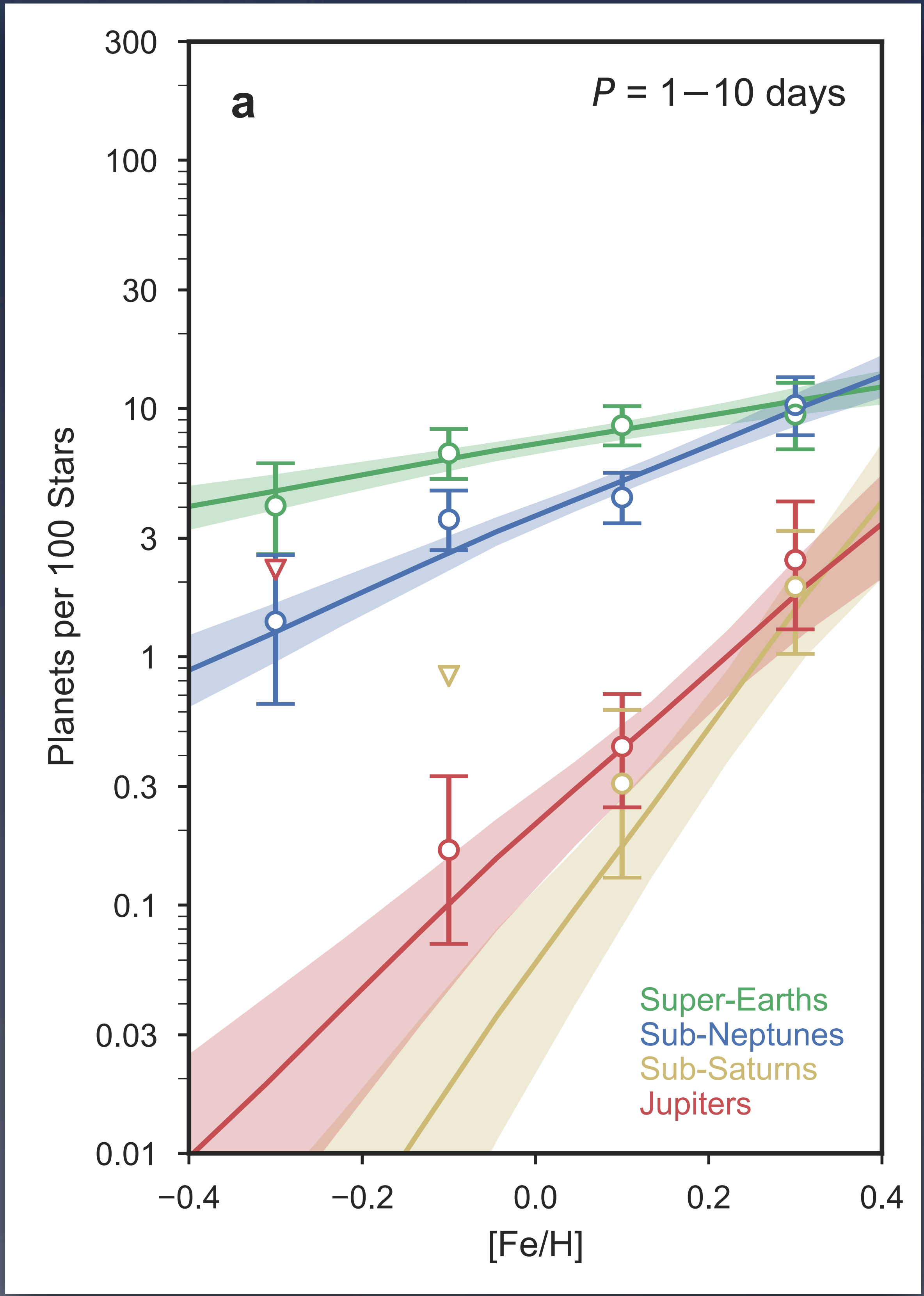




Planet Metallicity Correlation: Hot Planets

- Super-Earths: weak (significant) corr.
- Sub-Neptunes: stronger corr.
- Sub-Saturns: strongest corr.
- Jupiters: strongest corr.
- Consistent with trends observed by Mulders+16, Dong+17, Wilson+17





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