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

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Metallicity: Why Do We Care?

Giant Planet Metallicity Correlation

Fischer & Valenti (2005)

- Occurrence of Dopplerdetected 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...

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

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 $[M_1, M_2]$

> *f Num. planets in P within box* Num. stars in S within box* **=**

**corrected for missed planets*

S - Magnitude limited sample of *Kepler* FGK dwarfs 36959 (18%) *P -* Q1-Q16 sample of *Kepler* planets (970) with CKS parameters *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]) = -0.140 ± 0.001 $-$ Mean([Fe/H]) = -0.005 ± 0.002 Nordström+04 **AMOST** 6000 1500 Number of stars **Number of stars** Number of Stars 5000 4000 1000 3000 2000 500 1000 $\overline{0}$ -1.0 -0.5 0.0 0.5 -0.5 $\overline{0}$ 0.5 -1 $[Fe/H]$ **[Fe/H]**

filter all filters in the contribution κ points in the κ LAMOST sample, respectively. Panels (d)–(f): distributions of host star *Kp*. Panels (g)–(i): distributions of host star metallicity from different catalogs. The sub-solar neighborhood. […] We are unable to explain this difference, although a paucity lish the calibrations. Open circles denote the cool (GK) stars, dots the he of hot . have used our new calibration to compute photometric metalich stars in the Kepler sample For the ∼600 stars in the interval 0.44 < *b* − y < 0.46, the new bution with mean of −0.14 and dispersion of 0.19 dex, covering the "The occurrence of hot Jupiters in the Kepler field is only 40% that in the solar The distribution of the photometric metallicities derived as of metal-rich stars in the Kepler sample is one possible explanation." mean of −0.14 and a dispersion of 0.19 dex) has been plotted

 t_{cluster} at al (20 This metallicity distribution for F- and G-type dwarfs is almost *–Howard et al. (2012)*

Fig. 9. Distribution of metallicities for the whole sample (full his-

Solar Neighborhood

Metal-Rich Stars and Planets Oan
H $\frac{1}{\sqrt{2}}$ $\overline{}$

0Hdian

0Hdian

0Hdian

Metallicity enhances formation of large and close-in planets

0.3 1 3 10 30 100 300

0.3 1 3 10 30 100 300

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

16. Orbital periods and radii of planets orbital periods and radii of planets orbital periods and radii of pl $\mathsf{D18h)}$ and radii of planets orbital periods and radii of planets orbital periods $\mathsf{D18h)}$ captures an equal fraction (25%) of the parent stellar sample *S* (see Table 3). In panel (a), blue points represent planets orbiting F_1 and radii of planets orbital periods and radii of planets orbital periods and radii of planets orbital F_2 captures an equal fraction (25%) of the parent stellar sample *S* (see Table 3). In panel (a), blue points represent planets orbiting captures an equal fraction (25%) of the parent stellar sample *S* (see Table 3). In panel (a), blue points represent planets orbiting

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B Forming the Hottest Planets

NH 773 8nFHUt.

0.5 *(lowest 25%; [Fe/H] < –0.12) Low Metallicity Stars*

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High Metallicity Stars *(highest 25%; [Fe/H] > +0.12)*

CKS-IV: Petigura et al. (2018b) and radii of planets orbital periods and radii of planets orbital periods orbital periods and radii of planets orbital periods of planets orbital periods of planets and radii orbital periods captures and particle stellar stellar stellar sample 3). In particle 3, in particle 3, in particle 3, in particle 3, $\frac{1}{2}$ S-IV: Petigura et al. (2018b). The energy of planets orbital periodic stars belonging to different metallicity bins. Each metallic captures an equal fraction (25%) of the parent stellar sample *S* (see Table 3). In panel (a), blue points represent planets orbiting

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 8 8 8 stellar metallicity (planets smaller than Neptune and $P > 10$ days) la
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- Metallicity traces some process that produces planets that are "misplaced" in the period-radius plane (larger than Neptune or $P < 10$ days)

CKS I. High-Resolution Spectroscopy of 1305 Stars Hosting *Kepler* Transiting Planets 15 CKS Precision: Metallicity

Spectroscopic Precision

-[Fe/H] ~ 0.04 dex (vs. \sim 0.3 dex phot.) *- R*★ ~ 10% (vs ~40% phot.)

Planet Detectability & Metallicity lower than the CKS values. *Right)* comparison of CKS and LAMOST metallicities after removing a linear systematic trend.

8 Planet Metallicity Correlation: Warm Planets

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

Planet Metallicity Correlation: Hot Planets

- Super-Earths: weak (significant) corr. 4 Source 51
- Sub-Neptunes: stronger corr.
- Sub-Saturns: strongest corr. 2
- Jupiters: strongest corr.
- Consistent with trends observed by Mulders+16, Dong+17, Wilson+17 1

The California-Kepler Survey

