Studying Exoplanet Population and Host Properties with LAMOST

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To Summarize Many Previous Talks,

Planets
Make Stars Great Again

For better planet statistics,

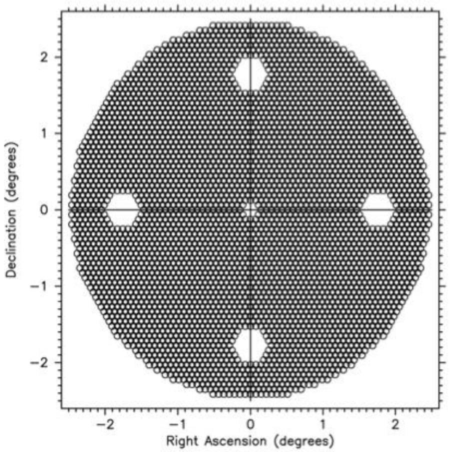
Stars First!

Ignore Planets (First)

$$f \propto \frac{N_{planet}}{N_{star}}$$

Any robust inference of planet-star connection
needs an un-biased (i.e., not planet-host biased!),
well-characterized, control (background) sample of target stars.

LAMOST = The Large Sky Area Multi-Object Fibre Spectroscopic Telescope



4m effective aperture

~4000 Fibers

5 degree diameter Field of View

R = 1800

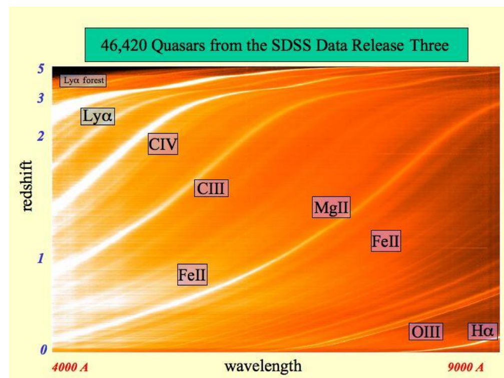
370-900nm

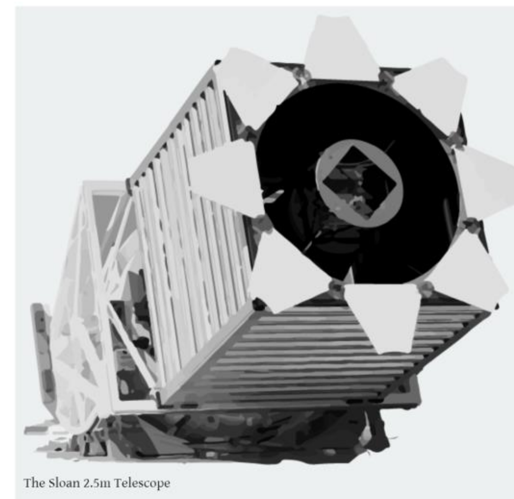
Cui et al., 2012, RAA, 12, 1197

LAMOST = The Large Sky Area Multi-Object Fibre Spectroscopic Telescope

Initial Science Objective:

Order of magnitude more quasars than SDSS

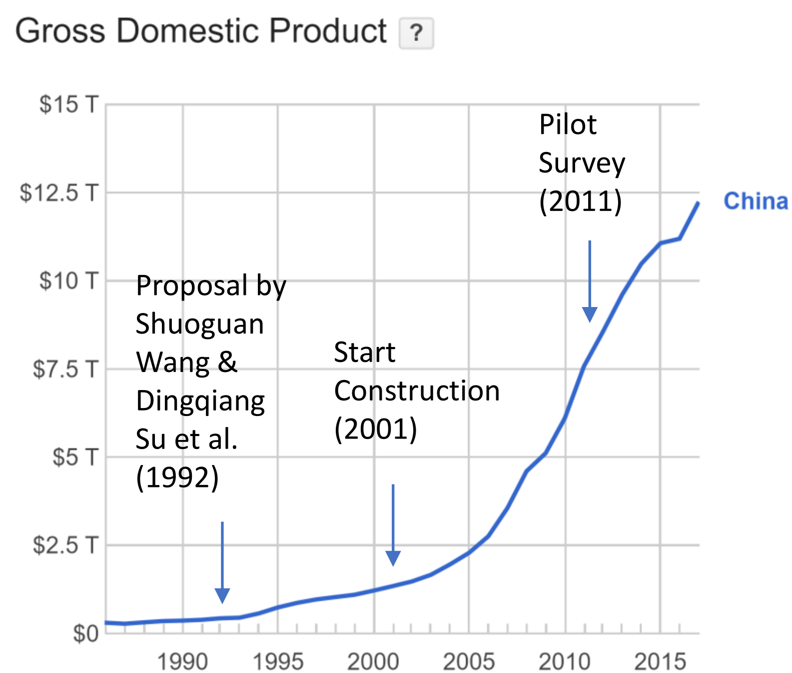




The Sloan 2.5m Telescope

LAMOST = The Large Sky Area Multi-Object Fibre Spectroscopic Telescope

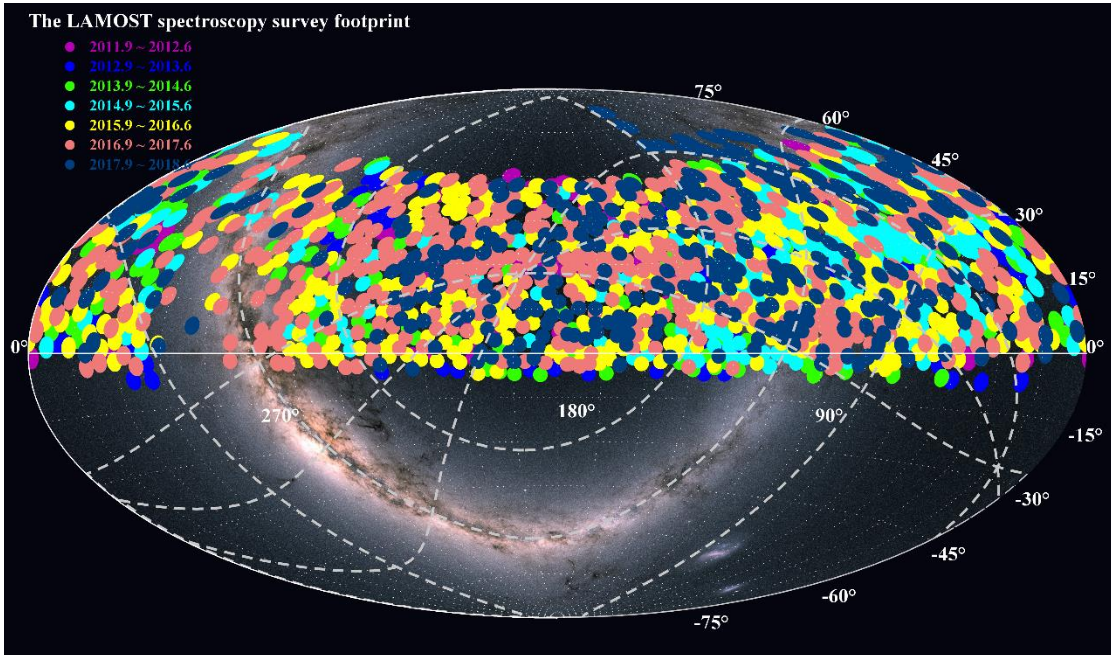
Initial Science Objective:
Order of magnitude more quasars than SDSS



LAMOST = The Large Sky Area Multi-Object Fibre Spectroscopic Telescope

Farewell, (Faint) Quasars,

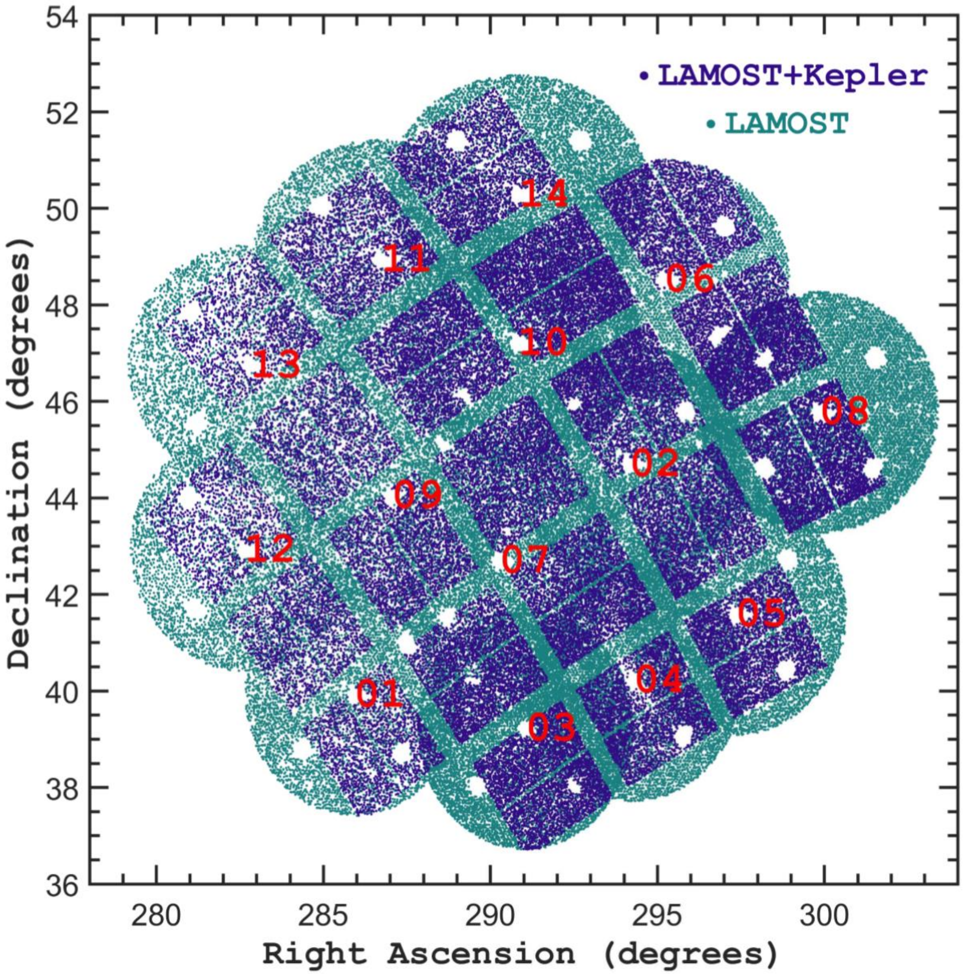
Hello, (Bright) Stars!



LAMOST DR6 (2018/06)

11 million spectra

6.4 million stars with stellar parameters



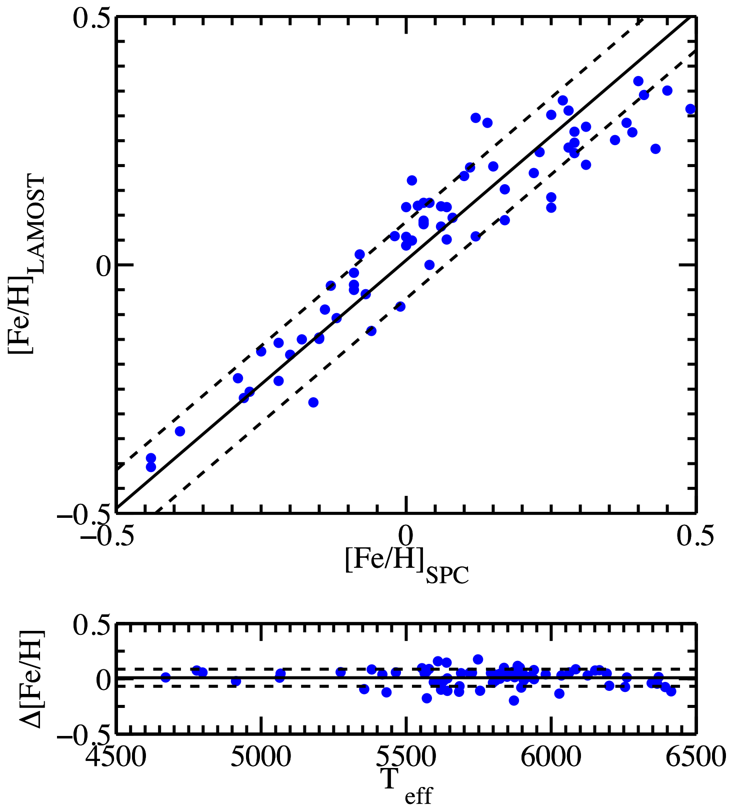
Initiated by Peter De Cat and Jianning Fu in 2011
Updated in 2015 for the full Kepler targets

~40% of
~2x10^5 Kepler target stars observed

No bias toward planet hosts

Zang et al. (2018)

LAMOST [Fe/H] vs. high-res spectroscopy (dwarfs)



Stellar Parameters from LAMOST Stellar Parameter Pipeline (LASP; Luo et al. 2015):

Compared with Buchhave et al. (2012)

$\sigma_{[Fe/H]}$ =0.1 dex

Dong, S. et al., (2014)

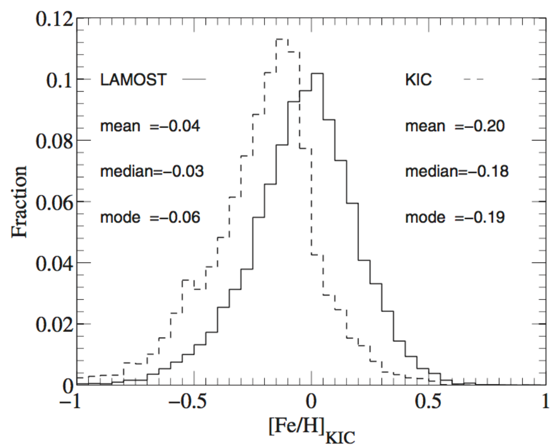
Dong, S. et al., (2014)

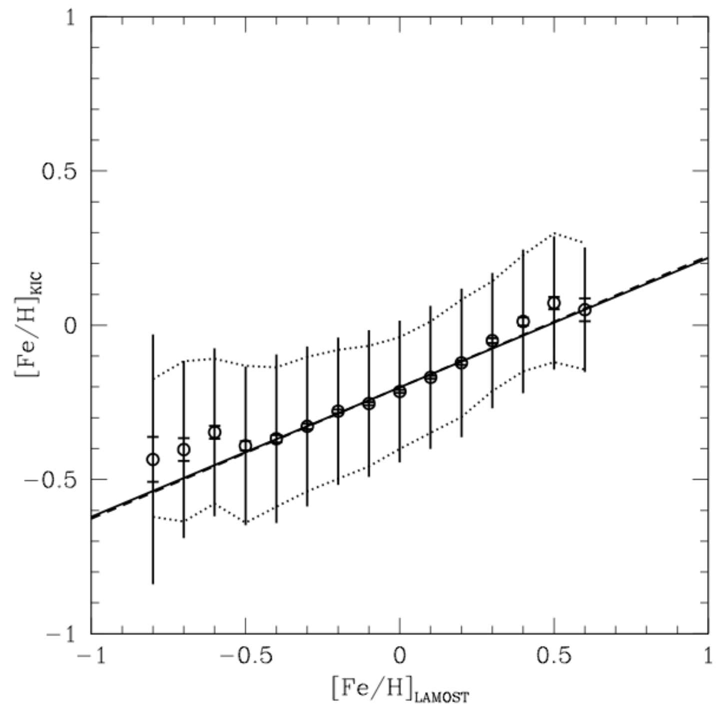
$$[\mathrm{Fe/H}]_{\mathrm{KIC}} = -0.20 + 0.43[\mathrm{Fe/H}]_{\mathrm{LAMOST}},$$

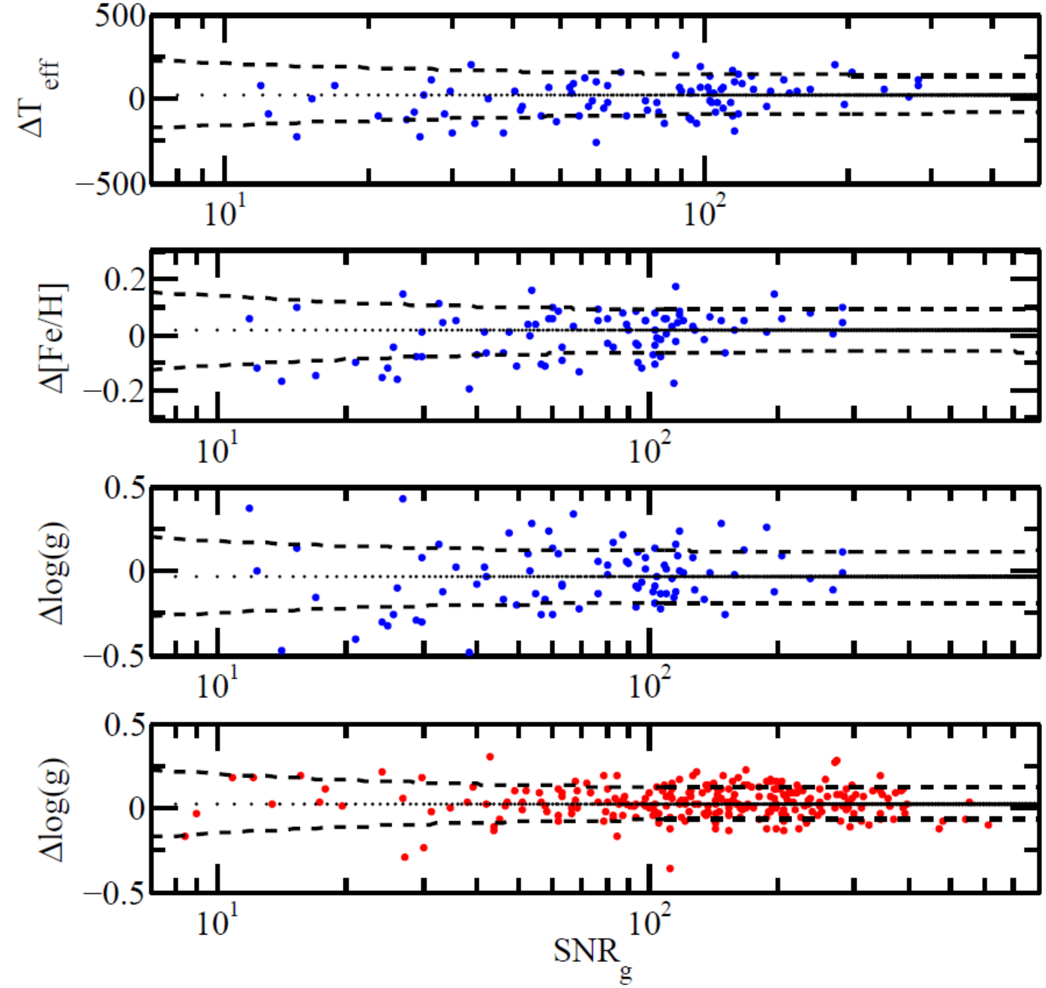
KIC -> Spectroscopic [Fe/H]:

0.6 dex scatter!

Kepler field is nearly solar metallicity







High-resolution spectra Comparison

$\sigma_{\text{Teff LAMOST}}$ = 100 K

$\sigma_{\text{[Fe/H]LAMOST}}$ = 0.1 dex

$\sigma_{\text{log(g)LAMOST}}$ = 0.15 dex

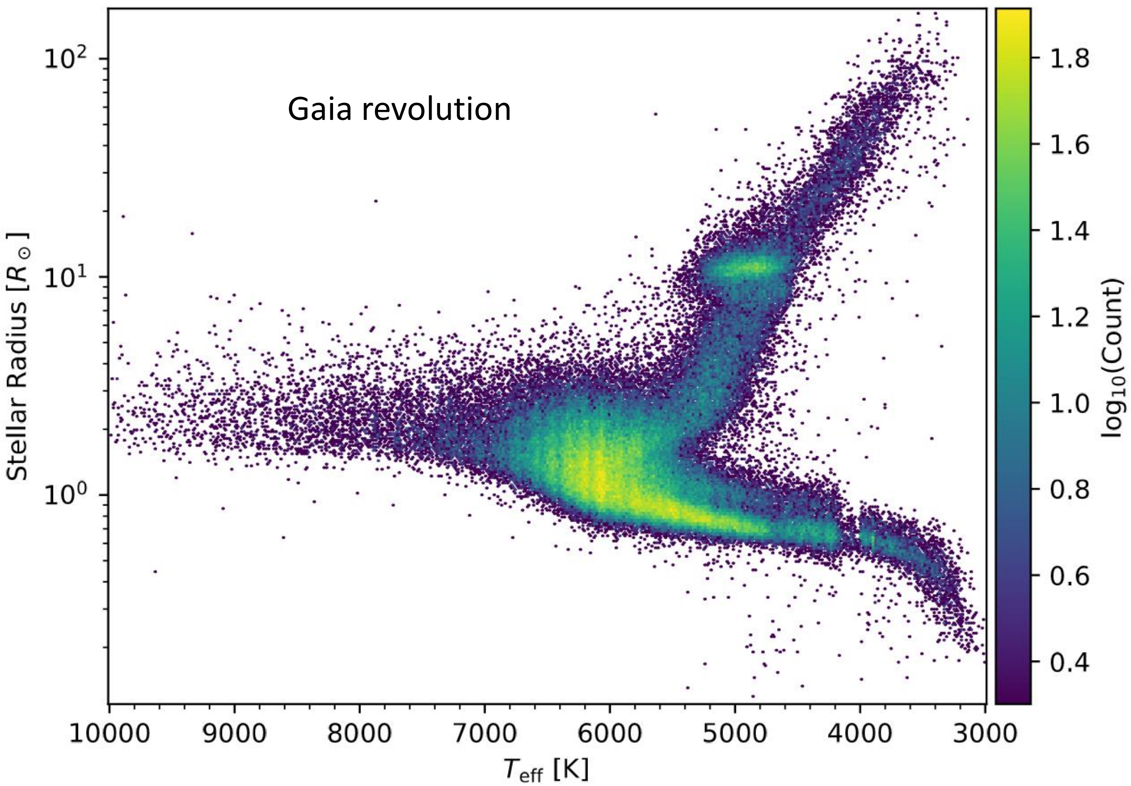
$\sigma_{\text{log(g)LAMOST}}$ = 0.1 dex

Asteroseismology (Almost Truth) Comparison
Chaplin et al. (2014)

Exoplanet results using LAMOST-Kepler data (an *incomplete* collection)

- Dong, S. et al. 2014 (Kepler-field metallicity)
- Xie, J. et al, 2016 (Eccentricity dichotomy)
- Mulders, G. et al., 2016 (Super-solar metallicity for hot rocky planets)
- Dong, S. et al., 2018 (Hoptune – cousins of hot Jupiters)
- Petigura et al., 2018 (CKS: metal-rich more diverse; LAMOST = background)
- Zhu, W. et al., 2018 (Fraction of stars hosting Kepler-like systems ~ 30%)
- Zhu, W. 2019 (Metallicity influence on planet/planet system occurrence rate)

…

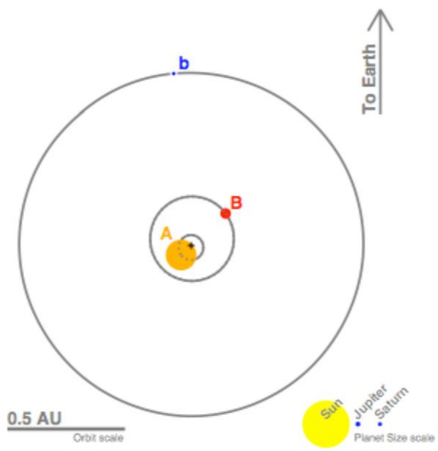


Berger et al. (2018)

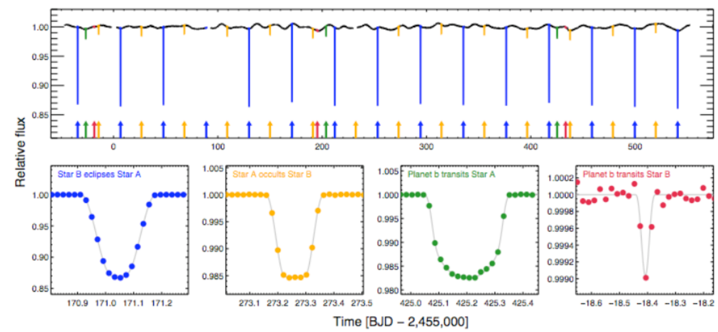
Preliminary Results from

Zhang, Zhanbo,
Dong, S., S. Albrecht, S. Faigler , T. Mazeh et al.,
in prep

Circumbinary Planets (CBPs) from Kepler



Doyle et al. (2011)



~10 around close eclipsing binaries

$R_p \approx$ 6-10 R_{earth} Inner binary: ~7.5 - 41 d

f~10% binaries hosting planet on nearly co-planar orbit (<5 deg) (see, e.g., Winn & Fabrycky 2015)

Are there mis-aligned circumbinary planets?

Observation:

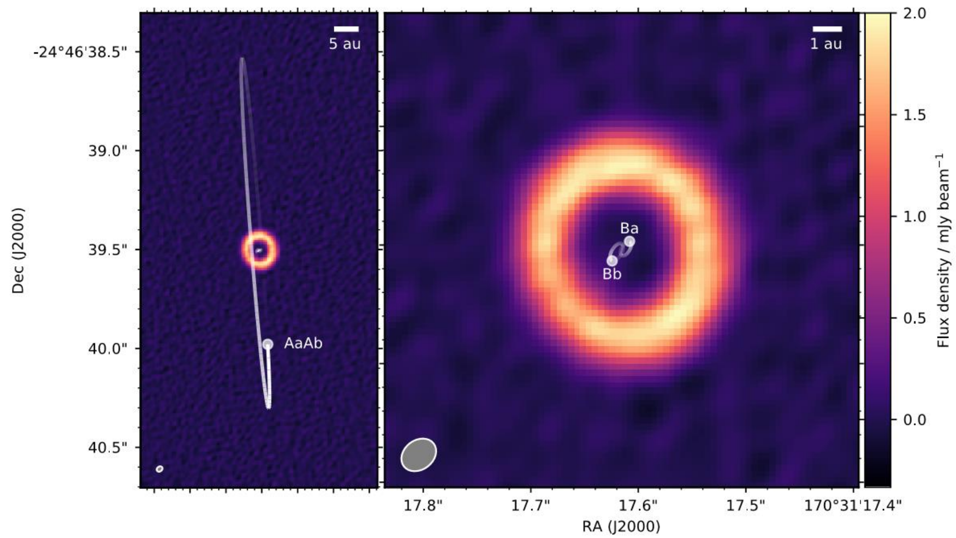
Existence of Misaligned/Polar Protoplanetary Disk

(e.g., Brinch et al. 2016; Jensen & Akeson 2014; Takakuwa et al. 2017, Kennedy et al. 2019)

Theory --

- Perturbation of eccentric binaries on disk

(see, e.g., Martin et al., 2014; Zanazzi & Lai; 2017; Martin & Lubow 2017)



Kennedy et al. (2019)

Are there mis-aligned circumbinary planets?

Observation:

All known coplanar CBPs are around binaries with period P_{bin} >7 days

(P_{bin} ~7.5 – 41 d)

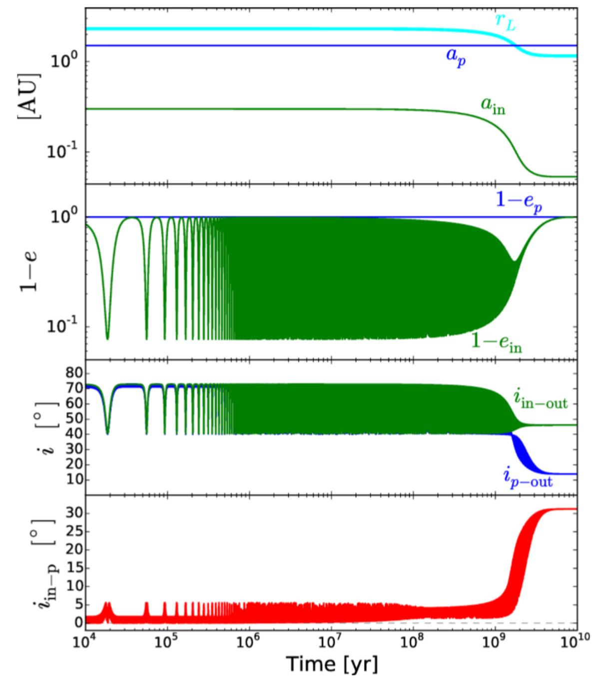
Theory --

- In Triples during Lidov-Kozai Tidal Friction shrinkage of binaries

-> Misaligned CBP at P_{bin}<~7 d

(Munoz & Lai 2015; Martin, Mazeh & Fabrycky 2015)

Can be found by transit over non-eclipsing binaries (Martin & Triaud 2014)



Munoz & Lai (2015)

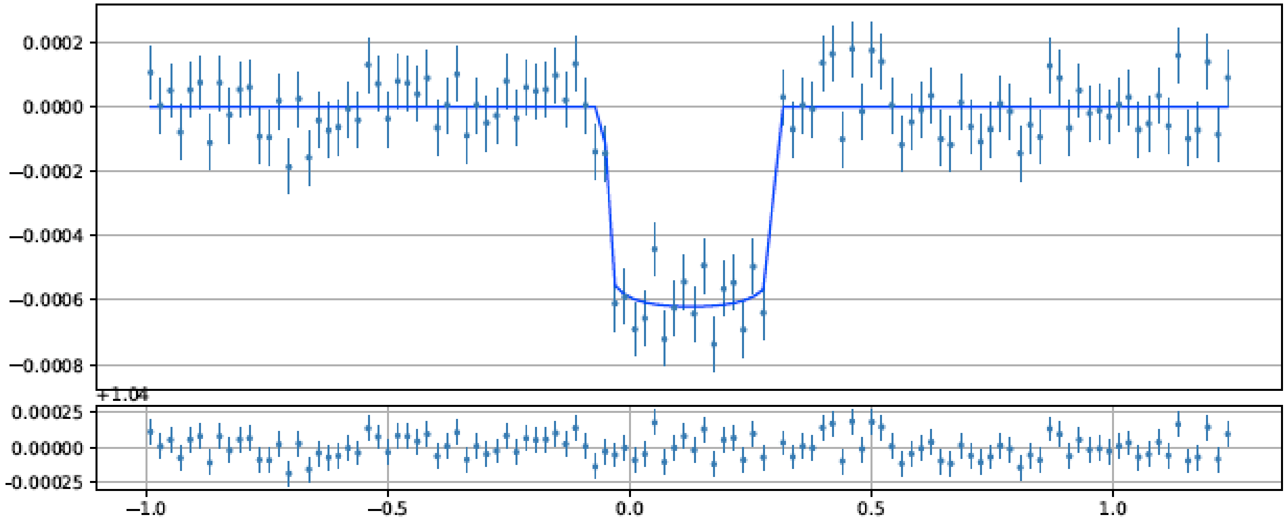
Search for misaligned CBPs with non-eclipsing binaries With LAMOST + *Kepler*

Zhang et al. in prep

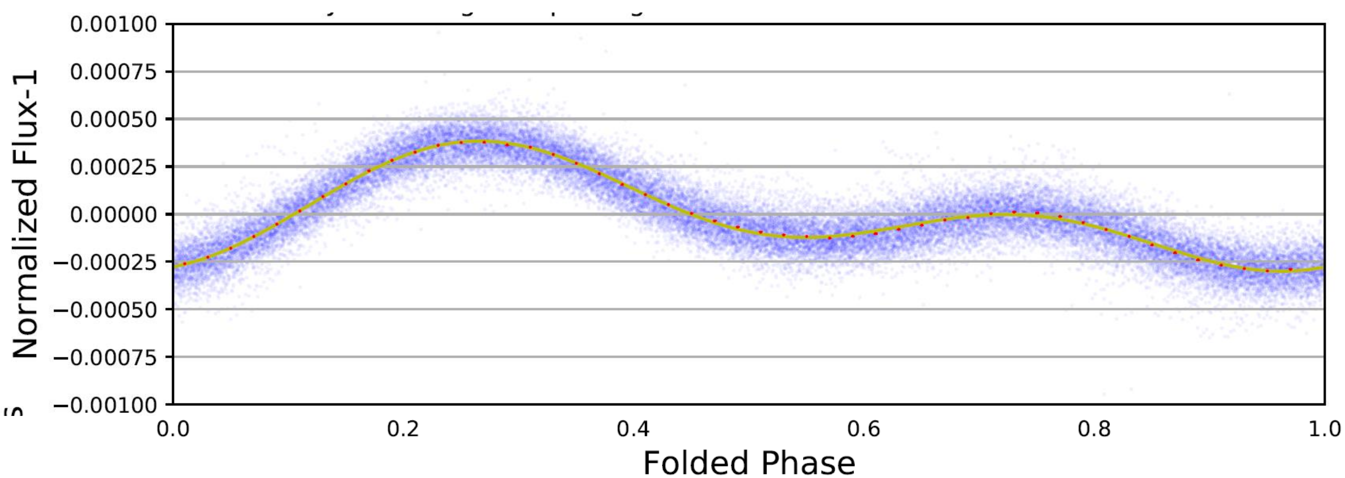
- ~15,000 Kepler targets with repeated LAMOST RV (σ_{RV} = 4-5 km/s) & log g>3.5 (DR4)
- ~300 objects with >5 sigma (secure) RV variations
- Search for (single) transits from *Kepler* light curves

(Boxcar + Visual Inspection)

Found one!



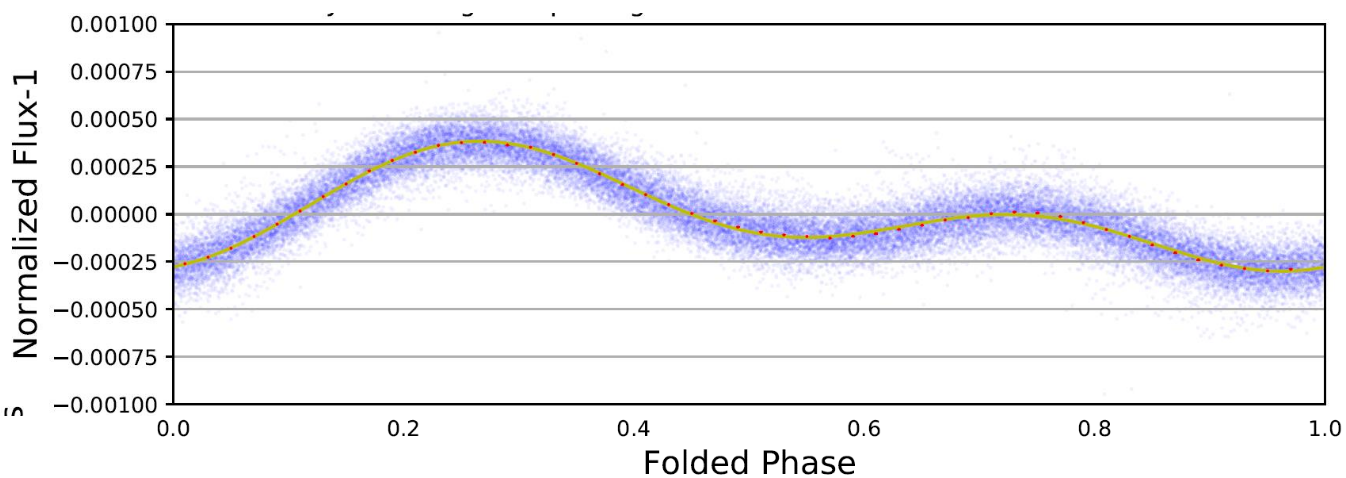
Transit Duration: 8.9 hr
Transit Depth: 0.0011



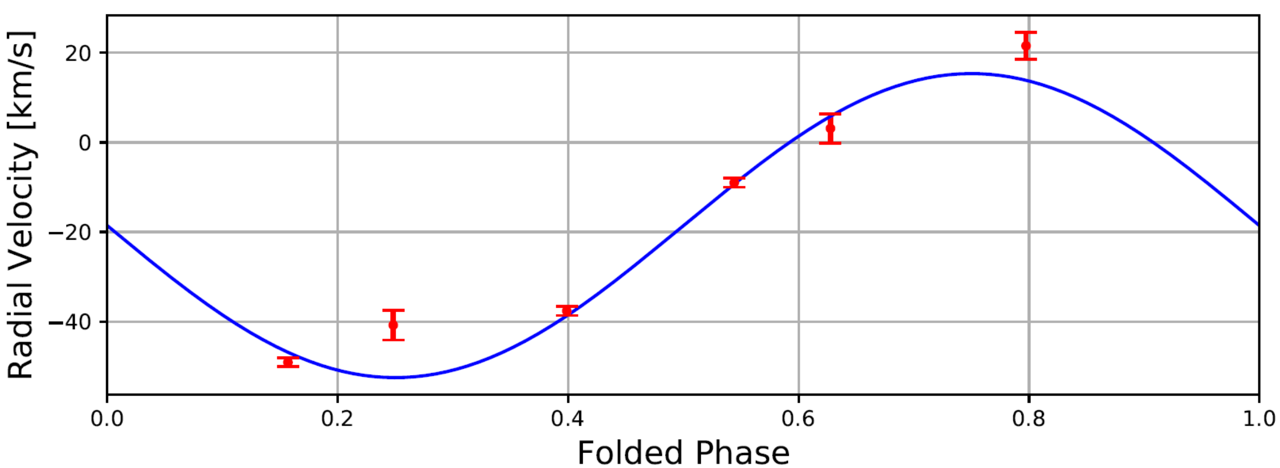
Period = 7.8d

BEER (BEaming, Ellipsoidal and the Reflection/heating periodic modulations) effects!

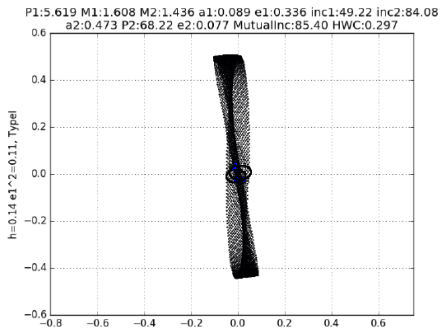
(Loeb & Gaudi 2003; Zucker, Mazeh &Alexander 2007; Faigler & Mazeh 2011)



Period = 7.8d M1 ≈1.9 M_{sun} M2 ≈0.6 M_{Sun}

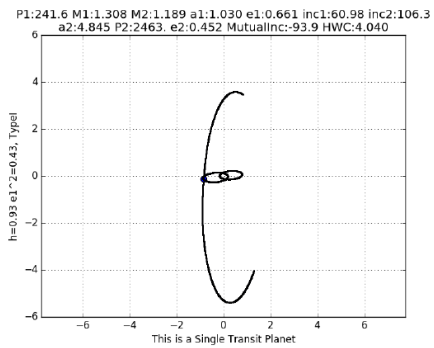


A likely misaligned CBP



Isotropic: f~12%

$R_p \approx 9\ R_{earth}$
Inner binary:7.8 d period

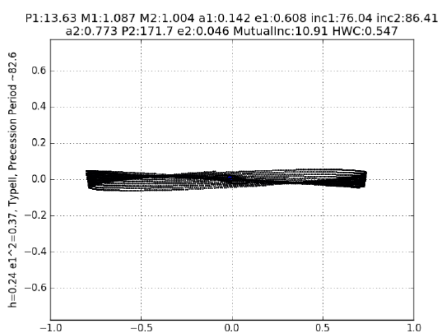


Polar: f~12%

The co-planar CBP population

$R_p \approx 6\text{-}10\ R_{earth}$ Inner binary: > 7 d

f~10% binaries hosting planet on nearly co-planar orbit (<5 deg)



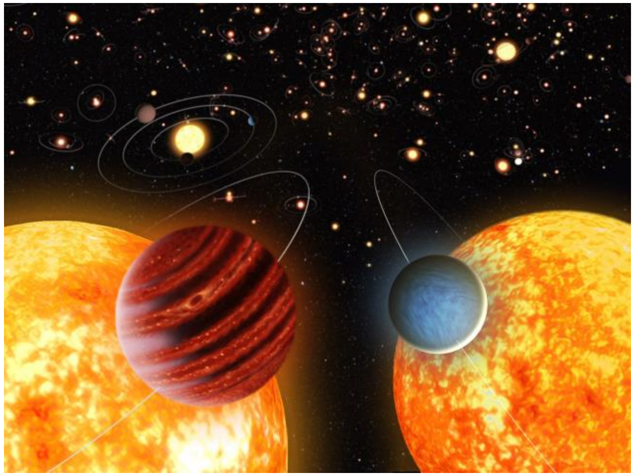
Coplanar: f~100%

(see, e.g., Winn & Fabrycky 2015)

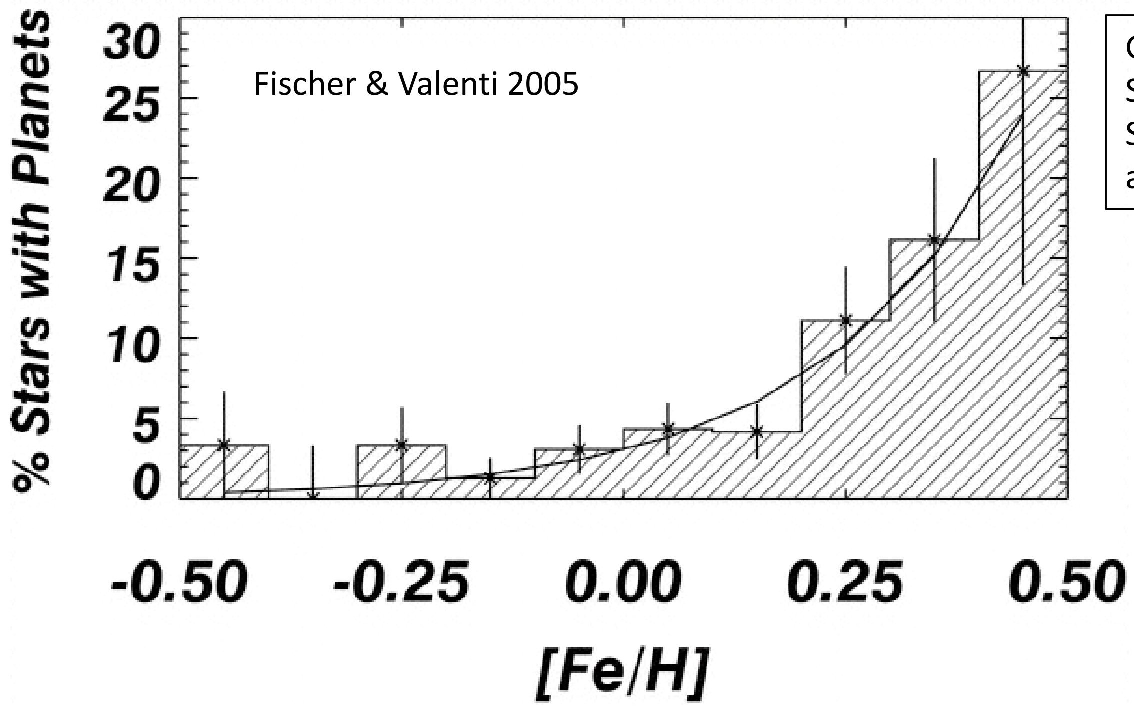
Finding “Relatives” of Hot Jupiters

- Orbiting ~1% of stars
- Unknown Formation Mechanism
- Hot Jupiters’ small Cousins found

Dong, Xie, Zhou et al. (2018)



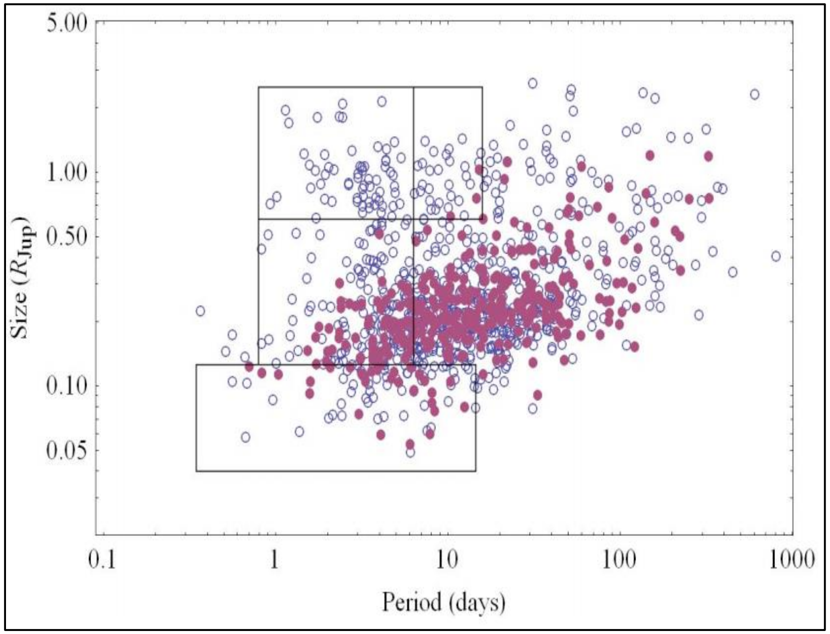
Clue 1: Short-period Jupiters, esp. hot Jupiters, are born in (metal-) “Rich” family



Gonzalex 1998
Santos+2001
Santos+2004
and others

Clue 2 Hot Jupiter born in "one-child" Kepler families (predominantly single transiting planets)

Steffen+2012

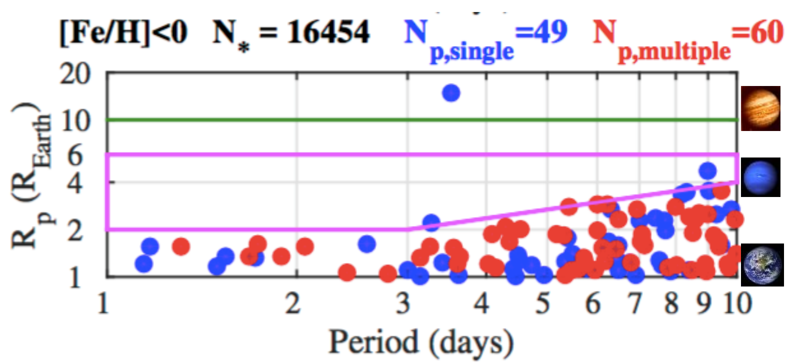


Huang+2016

group	total	N_{multi}	Inner	Outer
HJ	45	0	0	0
confirmed HJ	28	0	0	0
WJ	27	10	10	3
confirmed WJ	12	7	7	2

TABLE 1
SUMMARY OF TRANSITING COMPANIONS FOR *Kepler* GIANT PLANETS.

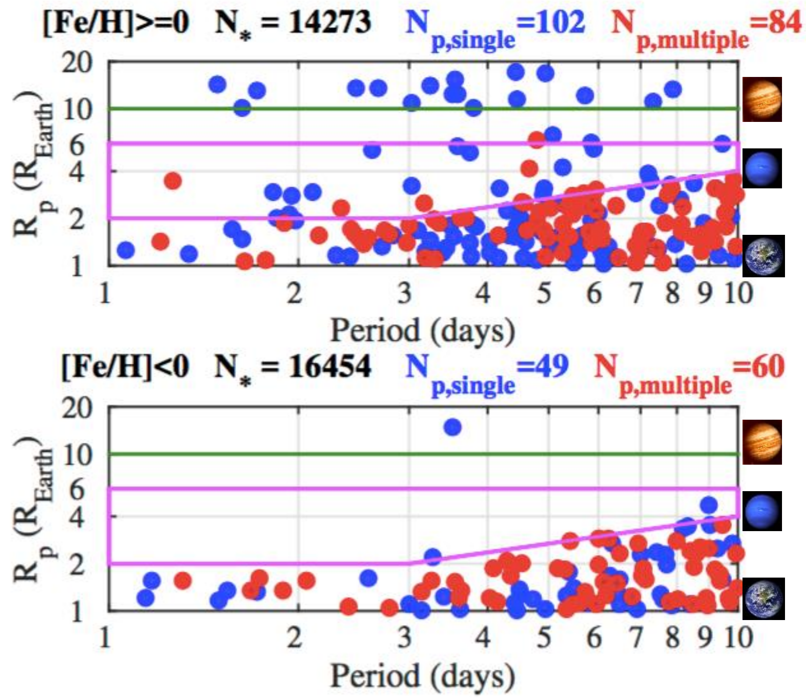
Dong, Xie, Zhou, Zheng, Luo, 2018, PNAS, 155, 266



"Metal Poor"
[Fe/H]<0

30727 Stars: 4700K < T_{eff} < 6500K and log g > 4.0
295 planets with 1d<P<10d, $1R_{\oplus}$ < $Rp < 20R_{\oplus}$

Dong, Xie, Zhou, Zheng, Luo, 2018, PNAS, 155, 266



”Metal Rich”
[Fe/H]>0

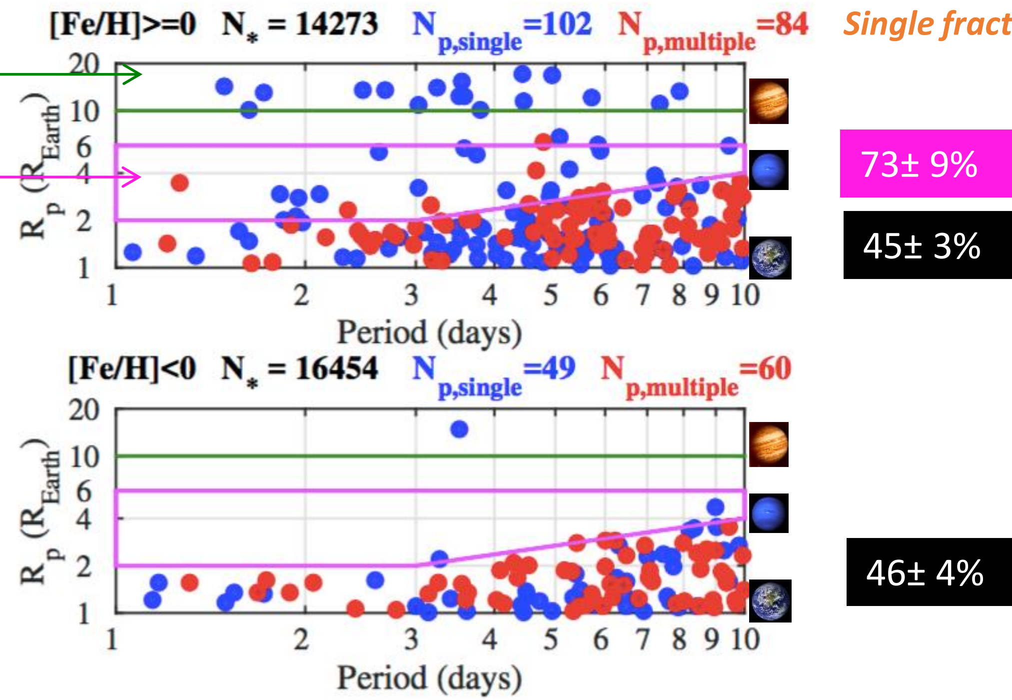
”Metal Poor”
[Fe/H]<0

30727 Stars: 4700K < T_{eff} < 6500K and log g > 4.0
295 planets with 1d<P<10d, $1R_\oplus$ < Rp < $20R_\oplus$

Dong, Xie, Zhou, Zheng, Luo, 2018, PNAS, 155, 266

Hot Jupiter

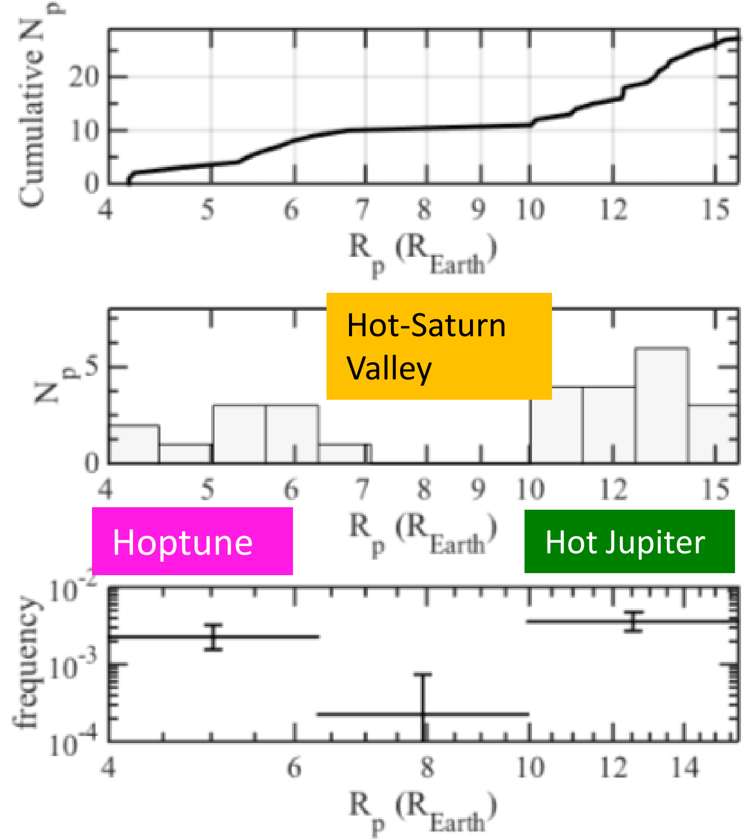
Hoptune



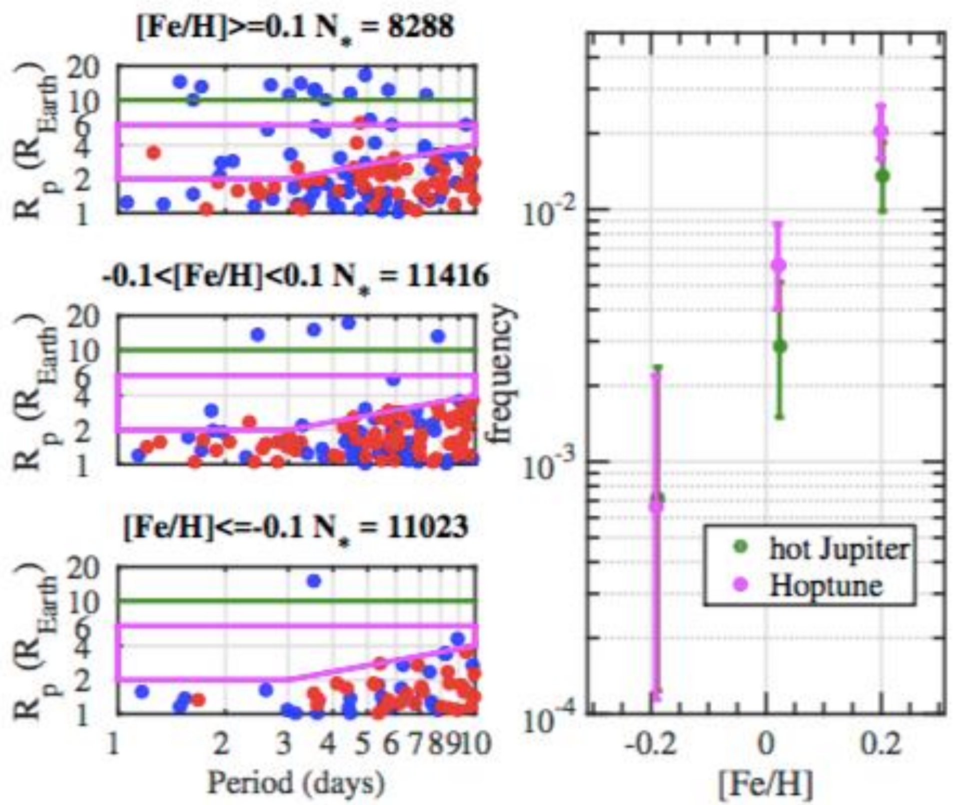
- Hoptune ($2R_{Earth}<R_p<6R_{Earth}$), like hot Jupiters, prefer to be in ***metal-rich*** and ***single-child*** Kepler systems!

** We do not know if all hoptunes are hot Neptunes!*

Dong, Xie, Zhou, Zheng, Luo, 2018, PNAS, 155, 266



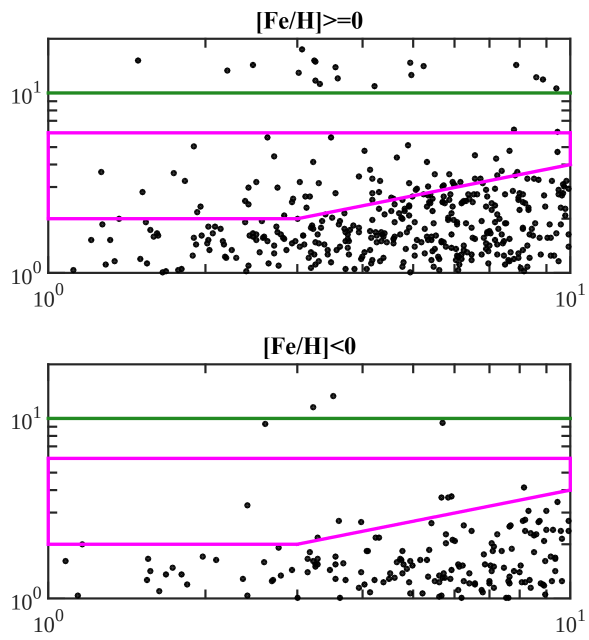
Dong, Xie, Zhou, Zheng, Luo, 2018, PNAS, 155, 266



- Hoptunes are similarly frequent (1%) as hot Jupiters
- Similar preference with metal-rich hosts
- Similar preference in single-transiting Kepler systems, while hot Jupiters have higher single fractions than Hoptunes
- Similar formation mechanisms? Though producing more “Cains” than “Abels” for hot Jupiters

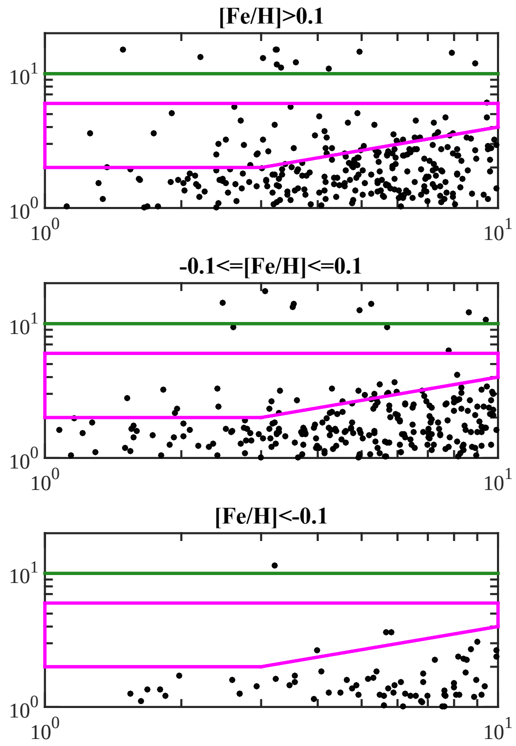
Main features confirmed by the Keck data from the CKS sample (Petigura et al. 2017)

Dong et al., in prep



The Hoptune radius vs. [Fe/H] evolution seems clear using CKS data

Dong et al., in prep



LAMOST/MRS-Exoplanet

- LAMOST has upgraded to medium resolution spectrograph (MRS) (Liu et al. in prep):
  - R ~7500
  - RV precision ~ 1 km s; v sini ~ 10 km/s
  - ~20 elemental abundance, including C, Na, Mg, Ca, Ti, Si, Sc, Cr, Fe, V, Mn, Co, Ni, Cu, Ba, Y, Sm, Nd, and Li …
- LAMOST/MRS-TESS synergy (Oct 2018 +)
  - 10^5 stars over ~5 years
  - 40 plates: Northern ecliptic pole CVZ + covering a large range of Galactic latitude
  - Logarithm cadence: ~day, ~week, ~month, ~year, ~several years + Gaia RVs
  - + add-on targets all sky (<12 mag) for spare fibres of other programs