Imprints of Formation on Exoplanets

The role of Stellar Mass and Metallicity

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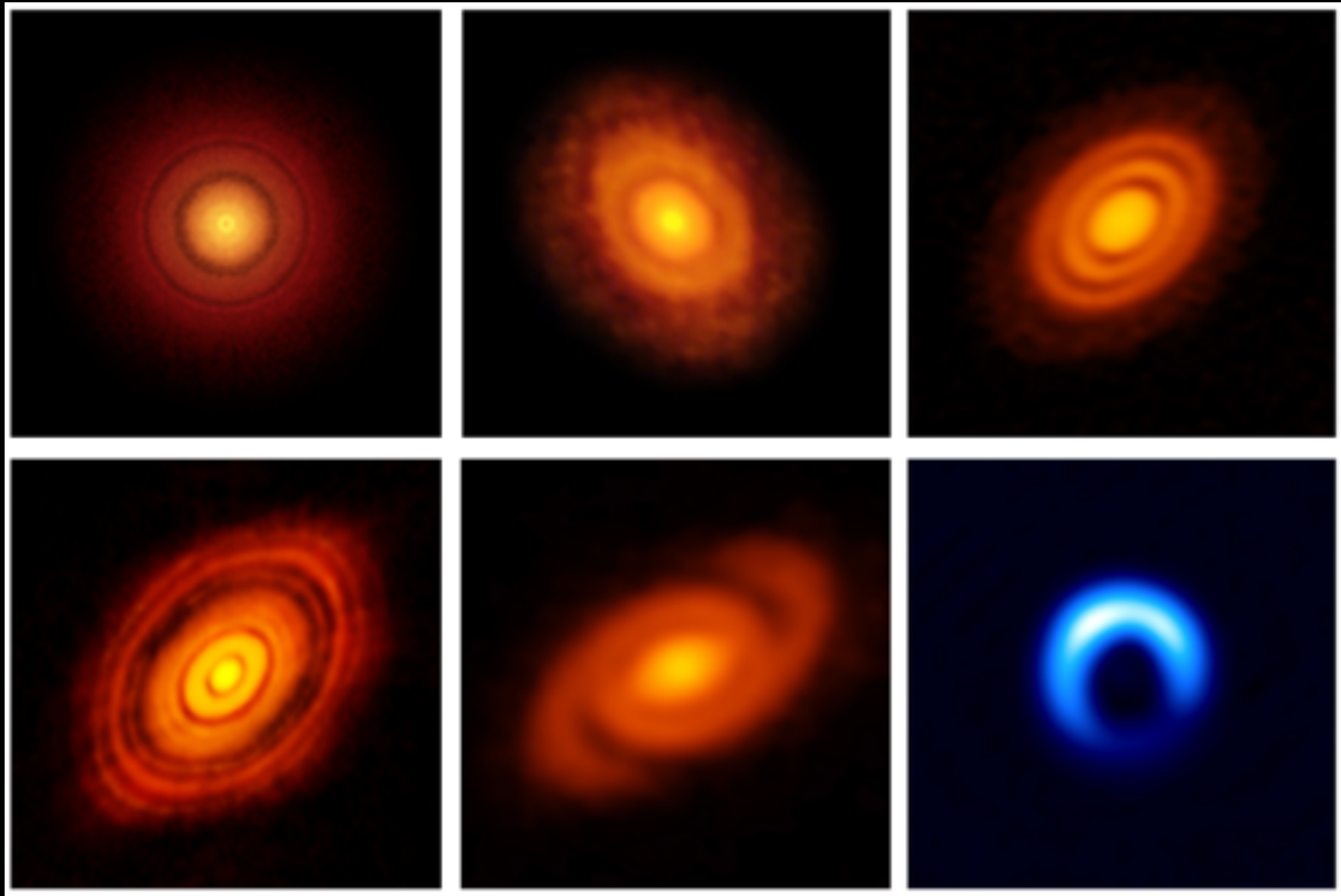
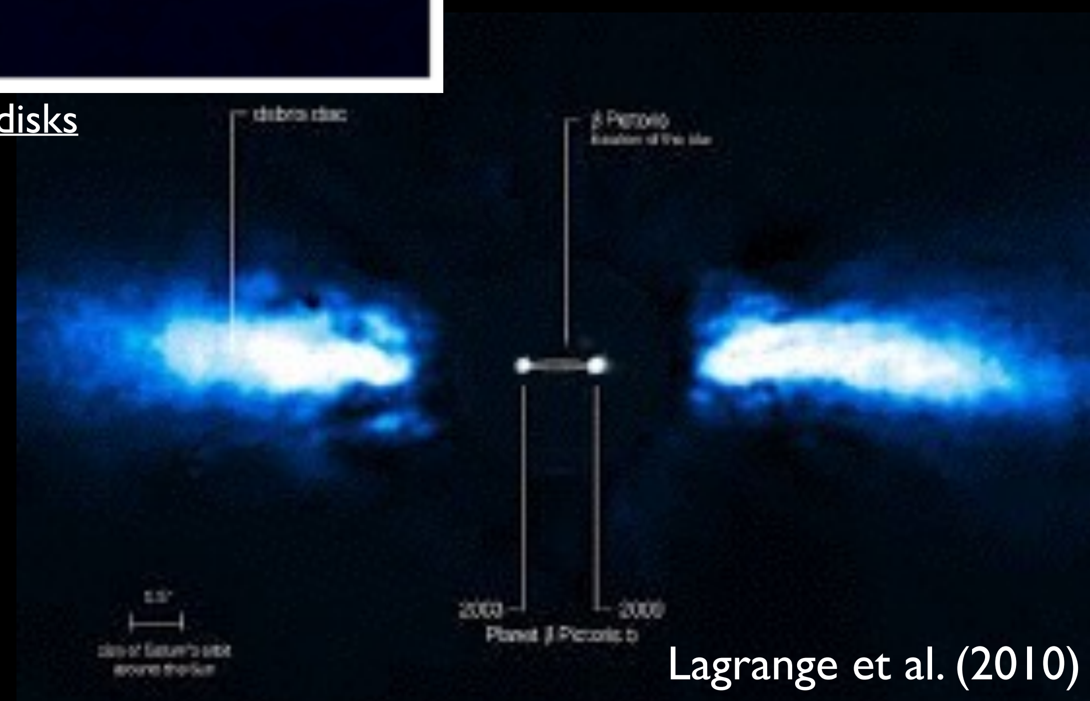
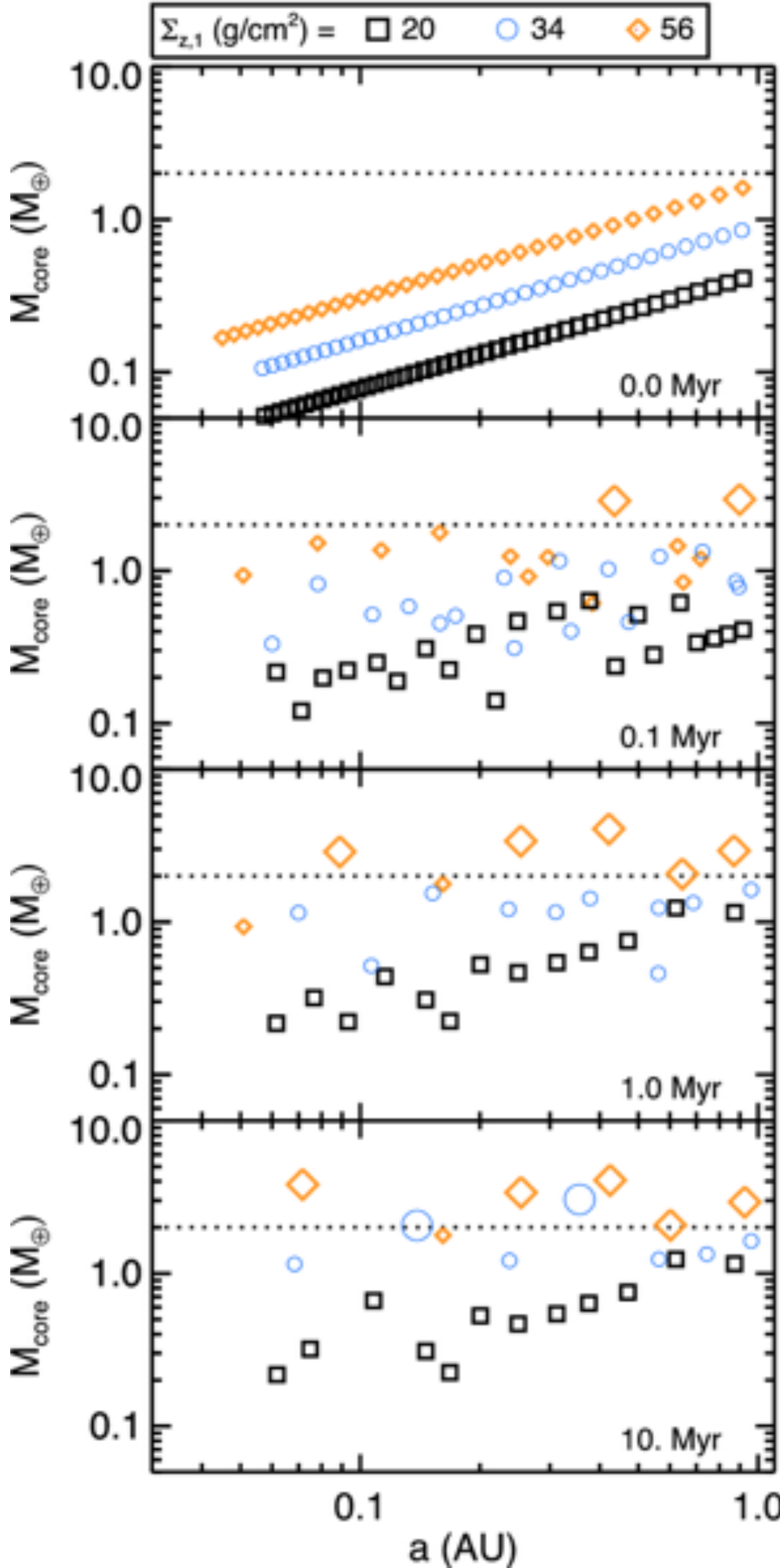


https://almascience.nrao.edu/alma-science/planet-forming-disks



Lagrange et al. (2010)

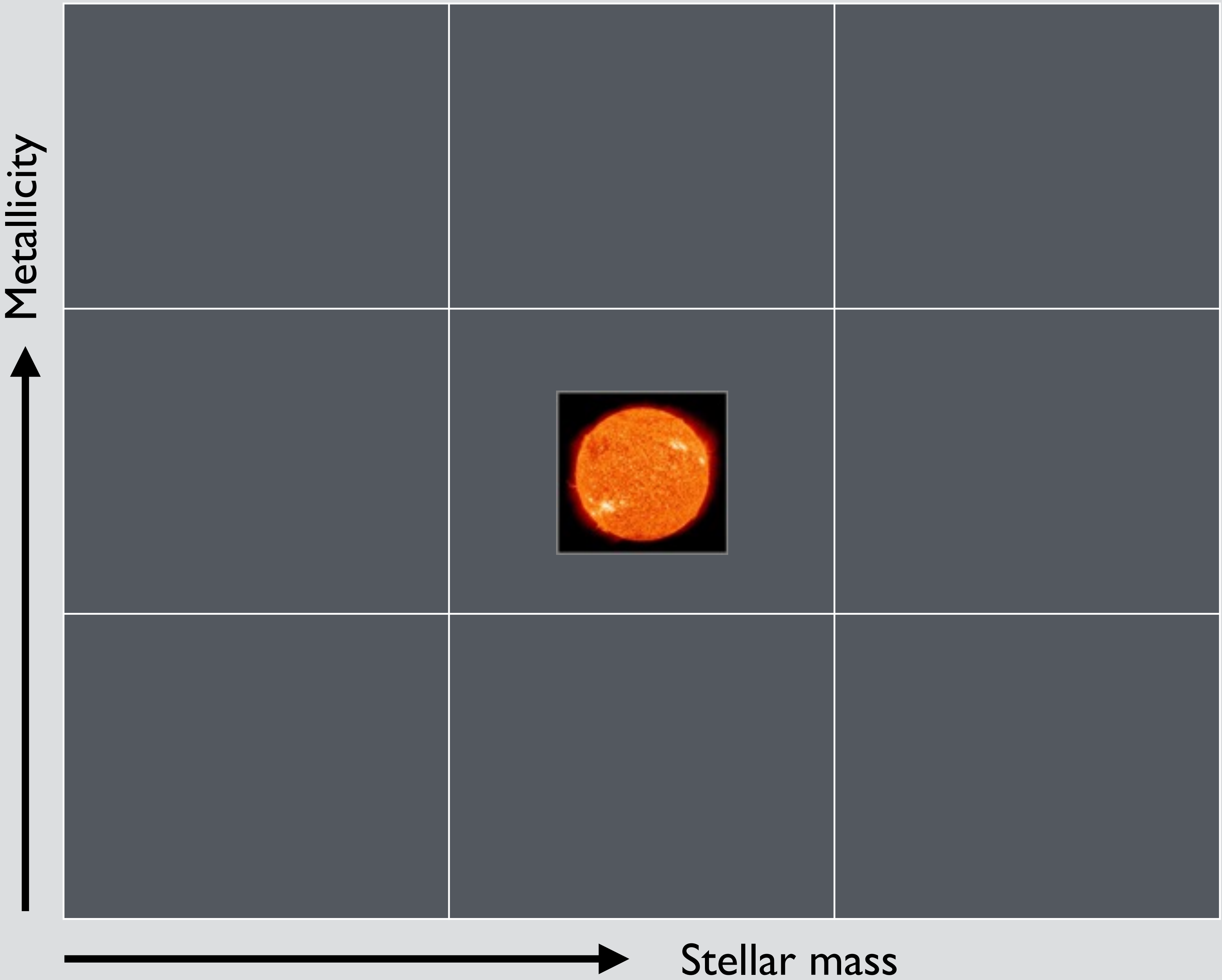


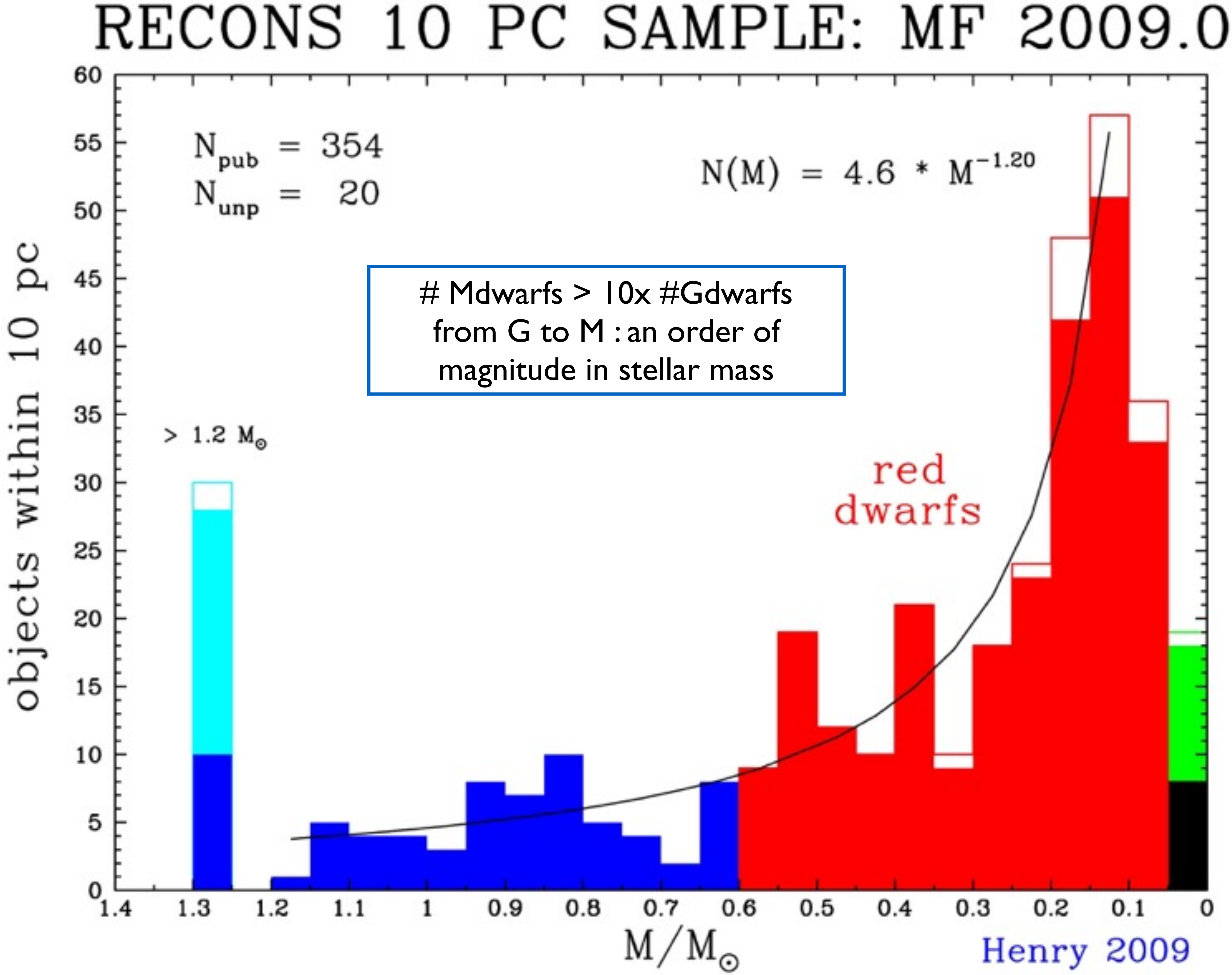
Dawson et al. (2015)

Stellar metallicity ~ Disk metallicity

Stellar mass and stellar metallicities → amount of solids in a disk to form planets

see also Ida & Lin (2004), Mordasini et al. (2012), Hansen & Murray (2013)

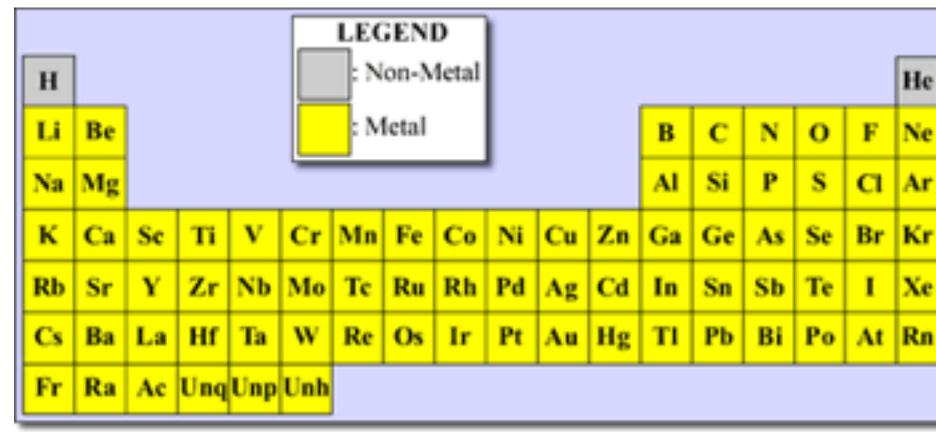

Metallicity
Stellar mass



RECONS 10 PC SAMPLE: MF 2009.0
N_pub = 354
N_unp = 20
N(M) = 4.6 * M^-1.20
Mdwarfs > 10x #Gdwarfs
from G to M : an order of
magnitude in stellar mass
> 1.2 M⊙
red
dwarfs
objects within 10 pc
M/M⊙
Henry 2009
0
5
10
15
20
25
30
35
40
45
50
55
60
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

Some definitions…

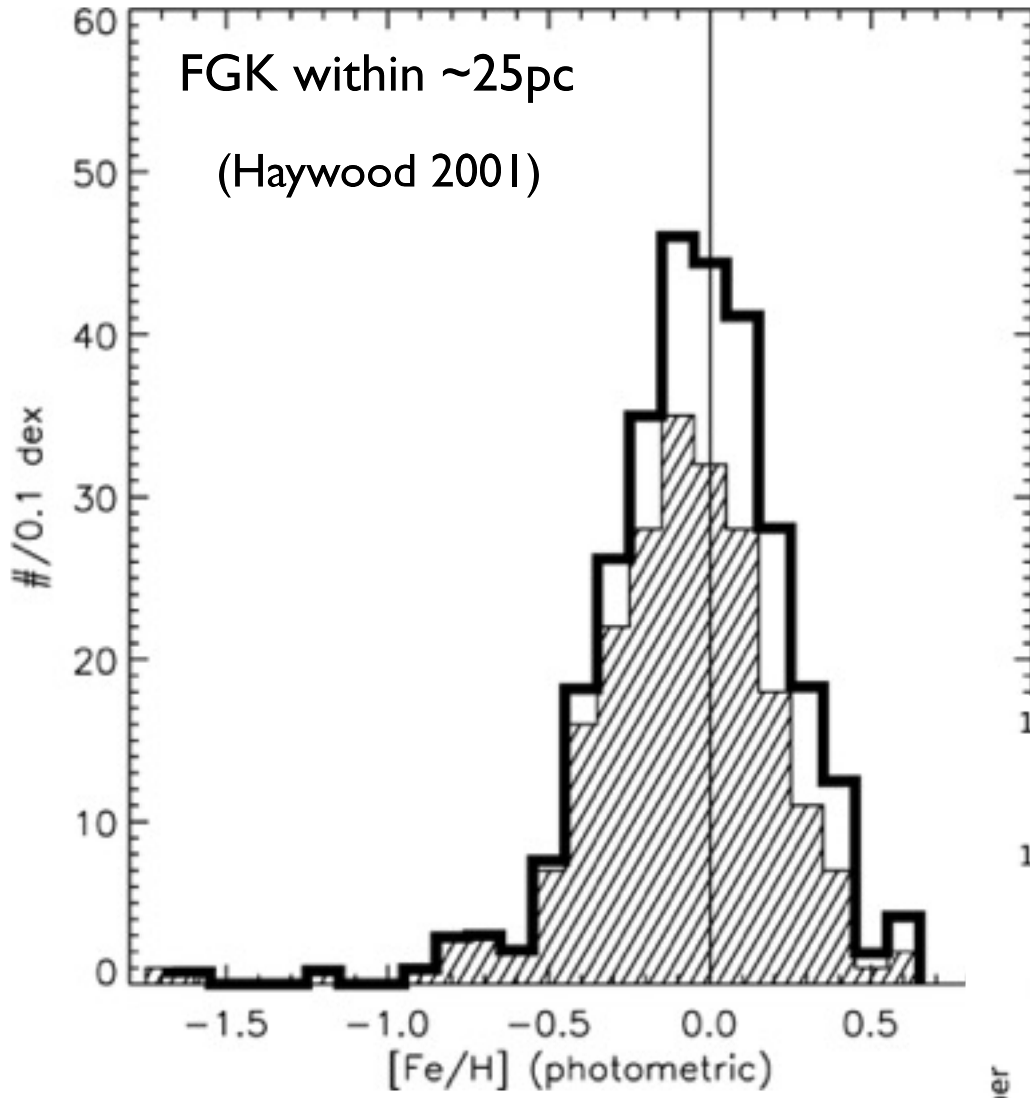
“Metals”: all elements heavier than He



“Metallicity”: Fe/H content with respect to solar

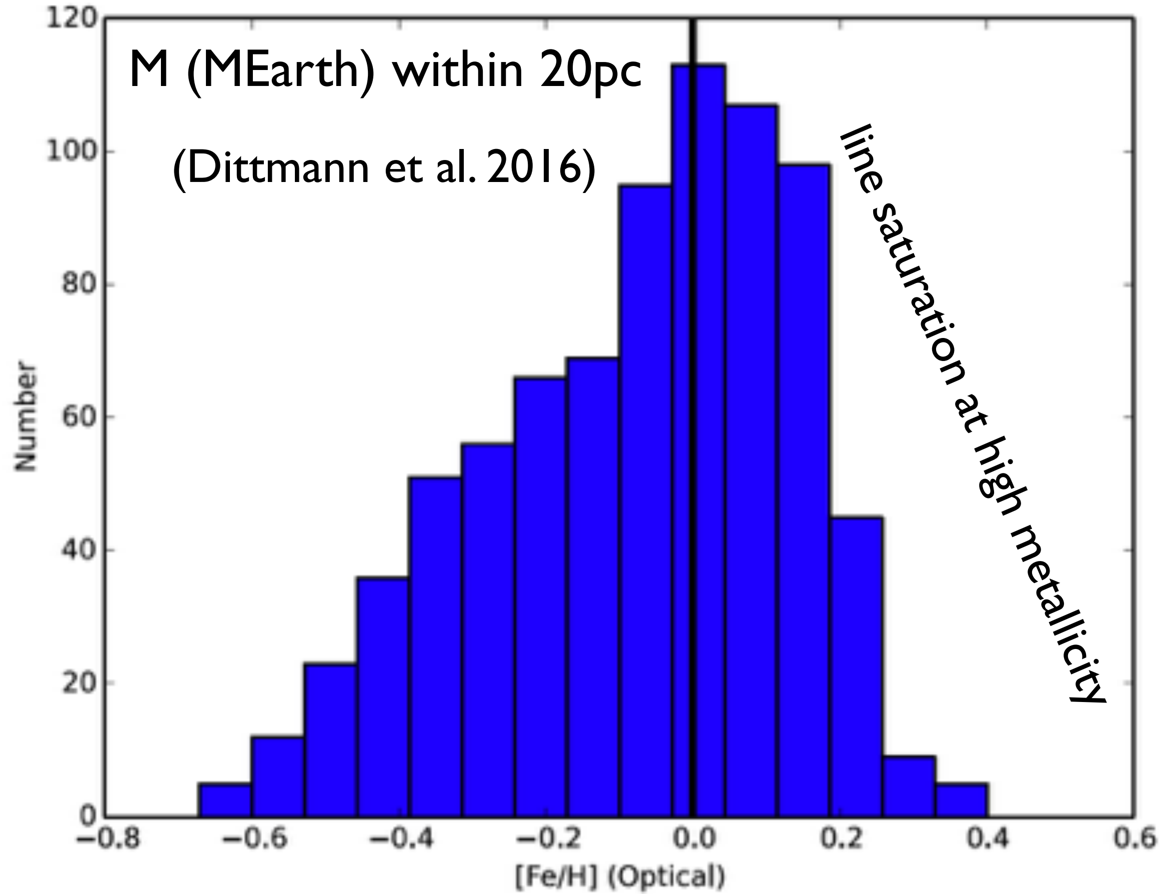
$$[Fe/H] = \log(Fe/H)_{Star} - \log(Fe/H)_{Sun}$$

[Fe/H] in the Solar Neighborhood

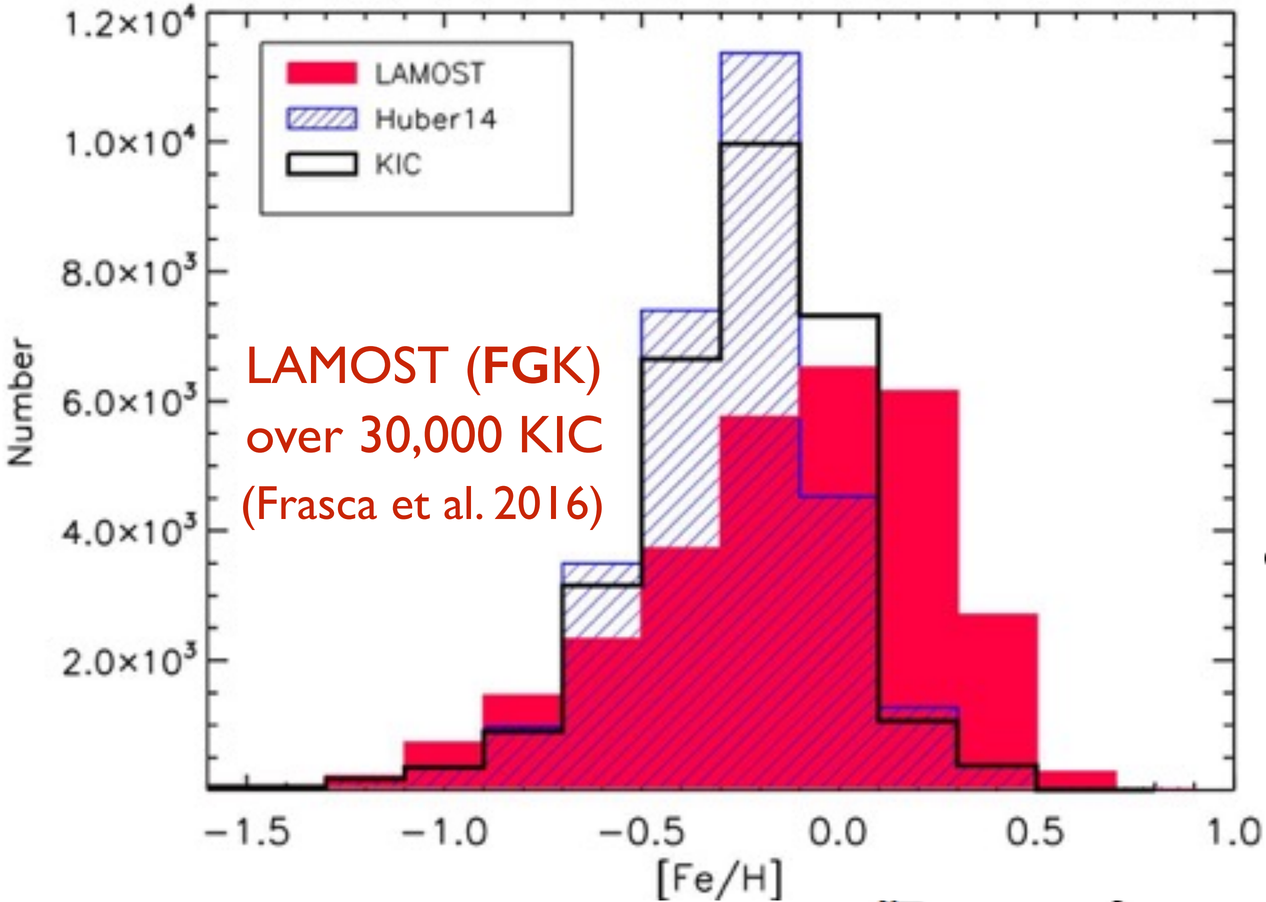


the sample spans an order of magnitude in metallicity

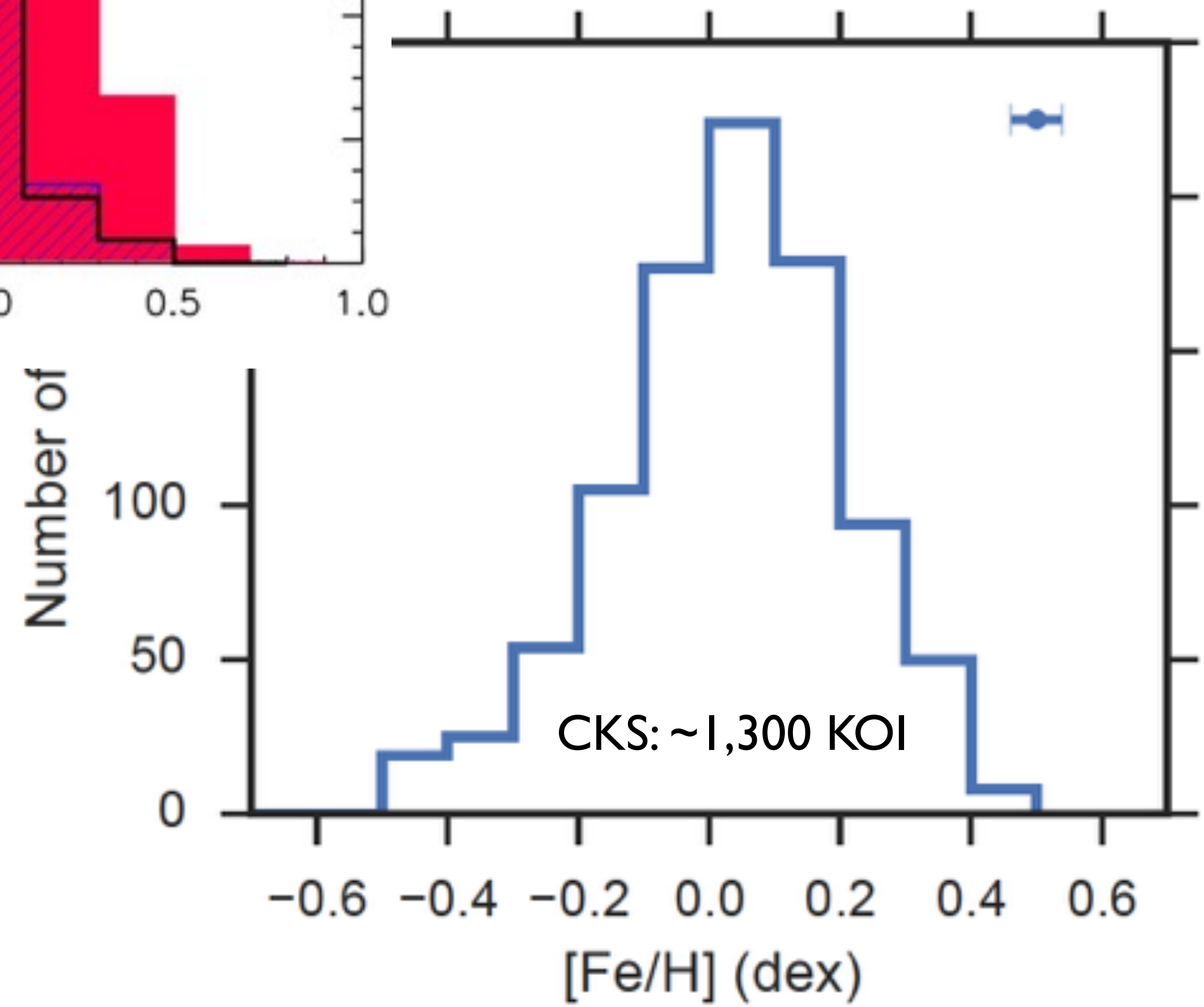
no evidence for a statistically different distribution of metallicities for G and M dwarfs



[Fe/H] in the *Kepler* field



Petigura et al. (2017)



See also Everett et al. (2013), Buchhave et al. 2014, De Cat et al. (2015), Endle & Cochran (2016)….

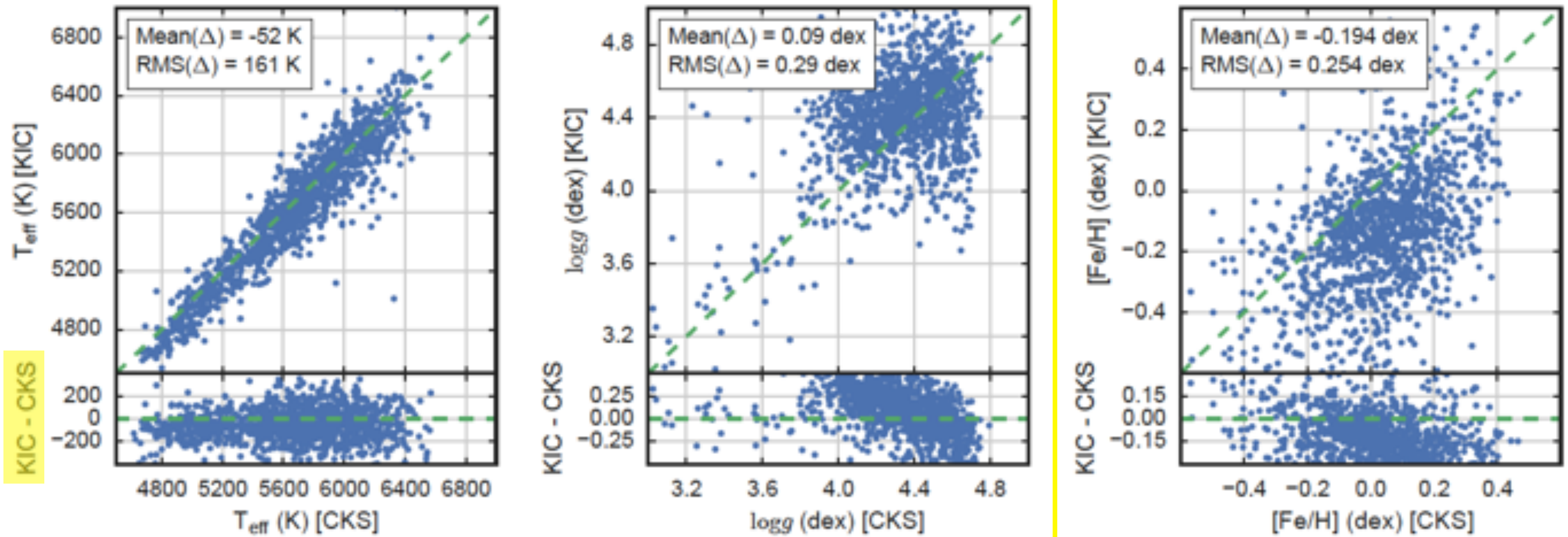


FIG. 13.— Comparison of $T_{\rm eff}$ (left), $\log g$ (middle), and [Fe/H] (right) values between CKS and Kepler Input Catalog (KIC; Brown et al. 2011) for 1215 stars in common. Annotations indicate the mean and RMS differences between the samples.

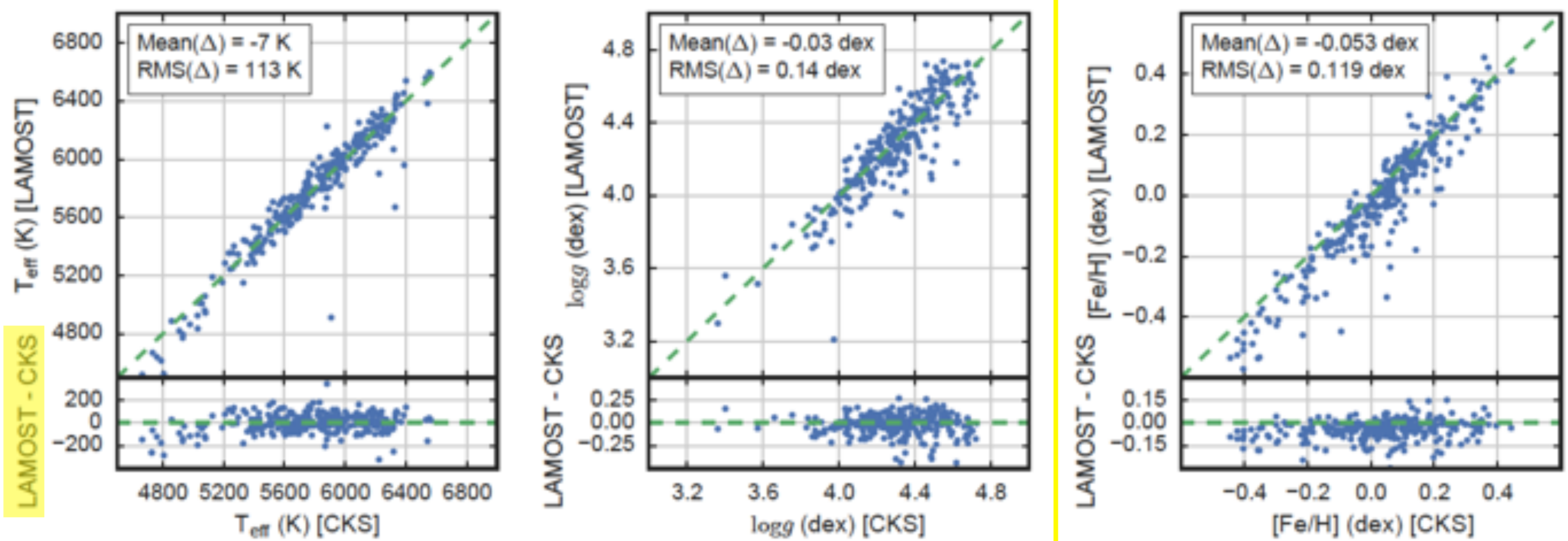
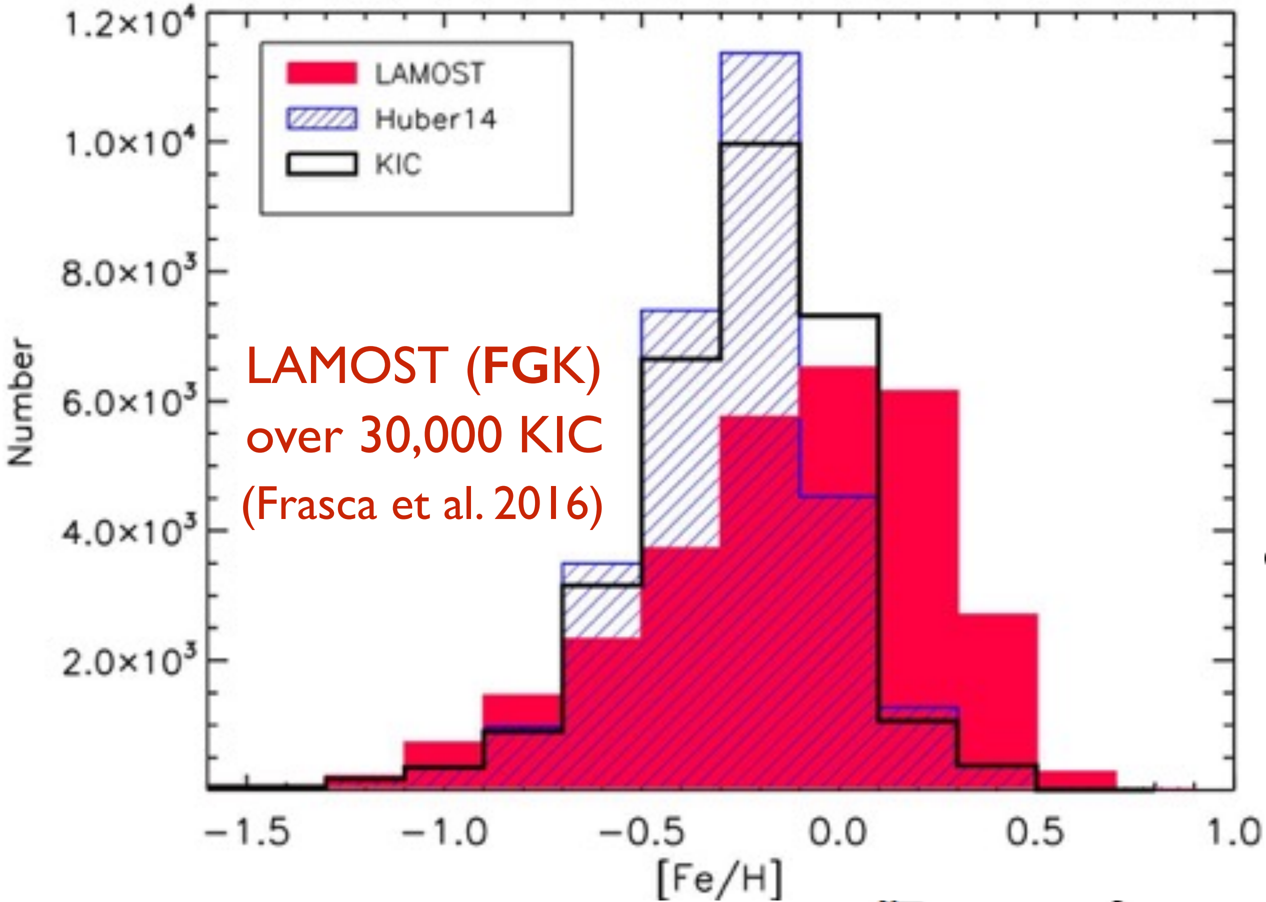


FIG. 15.— Comparison of $T_{\rm eff}$ (left), $\log g$ (middle), and [Fe/H] (right) values between CKS and the LAMOST survey (De Cat et al. 2015) for 283 stars in common. Annotations indicate the mean and RMS differences between the samples.

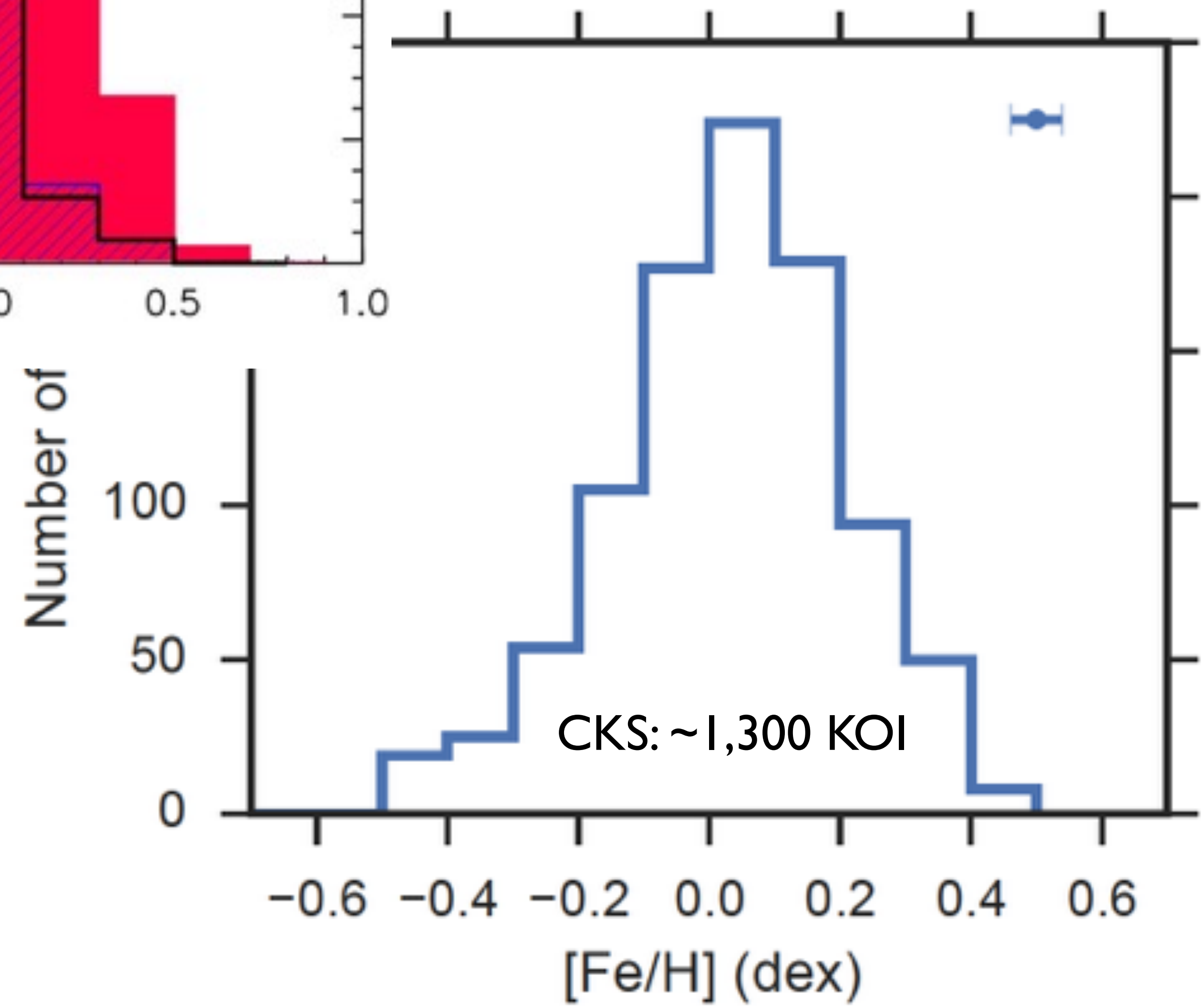
(talk by Teske on the challenges in deriving metallicities)

from Petigura et al. (2017)

[Fe/H] in the *Kepler* field

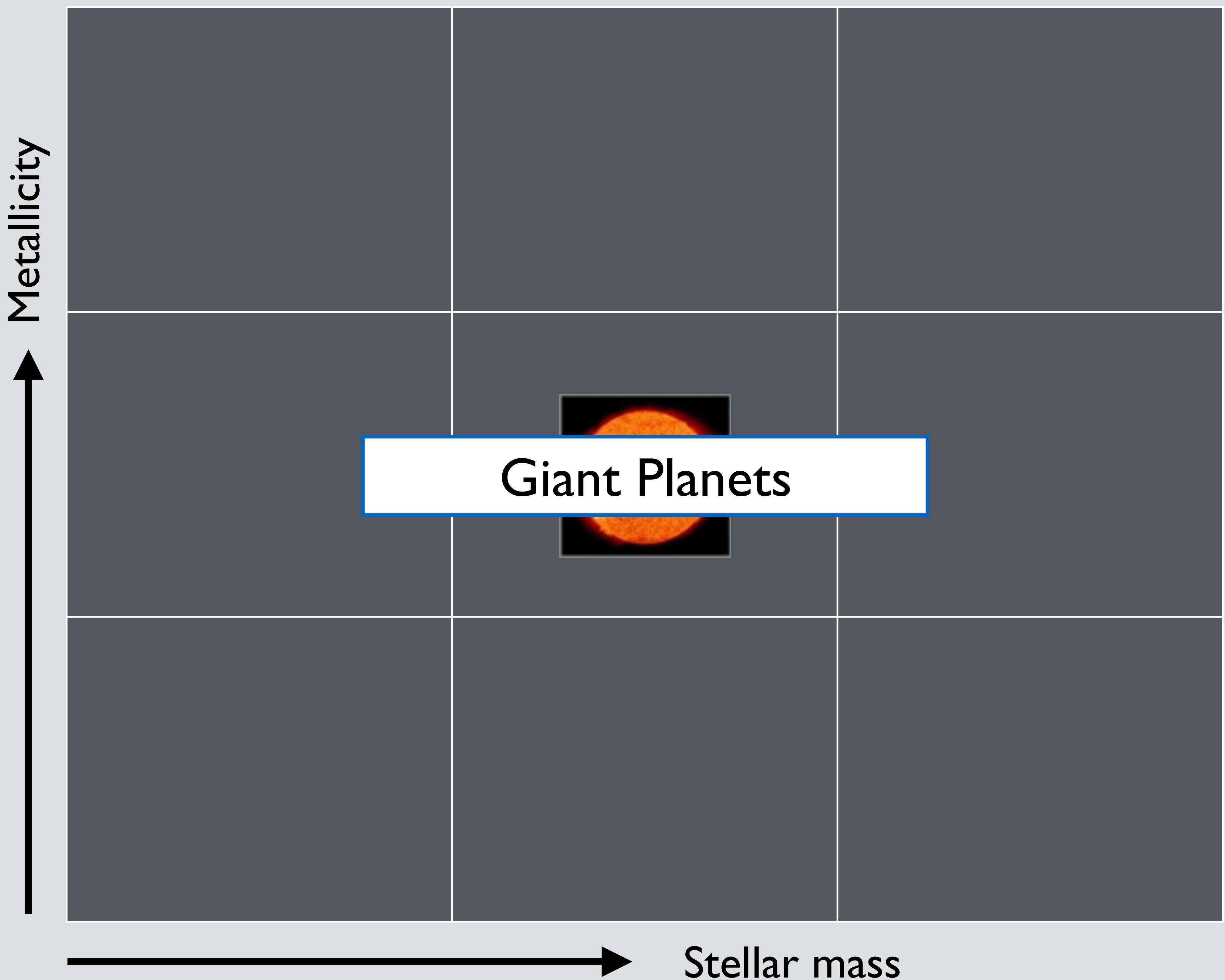


Petigura et al. (2017)



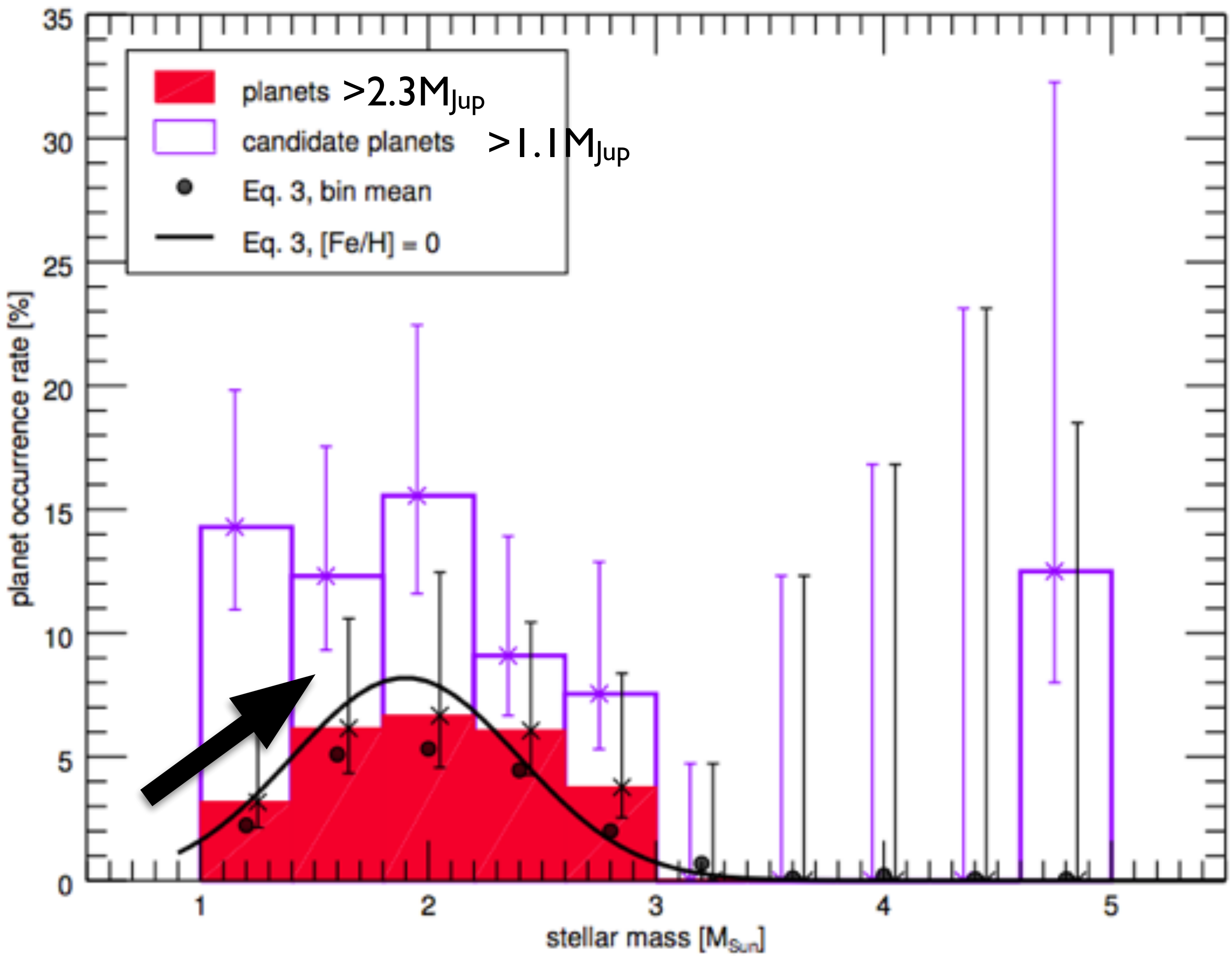
The mean of the KIC and KOI stars is **solar**

(sample spans an order of magnitude in metallicity)



Metallicity
Giant Planets
Stellar mass

The giant planet occurrence rate increases with stellar mass but drops for stars more massive than ~2.5M_{sun}

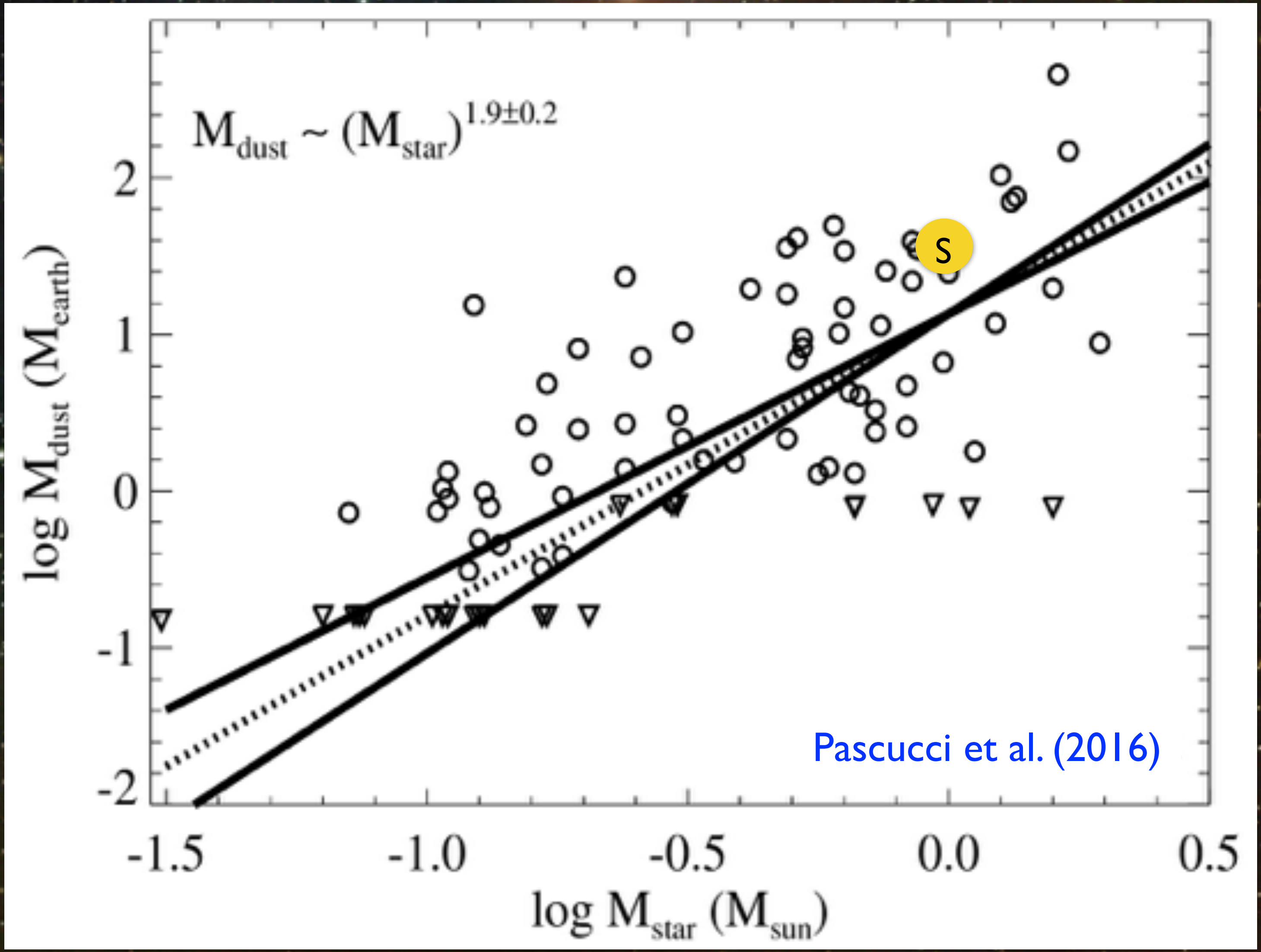


Reffert et al. (2015), based on RVs of giant stars

see also Johnson et al. (2010), Howard et al. (2012), Jones et al. (2016)

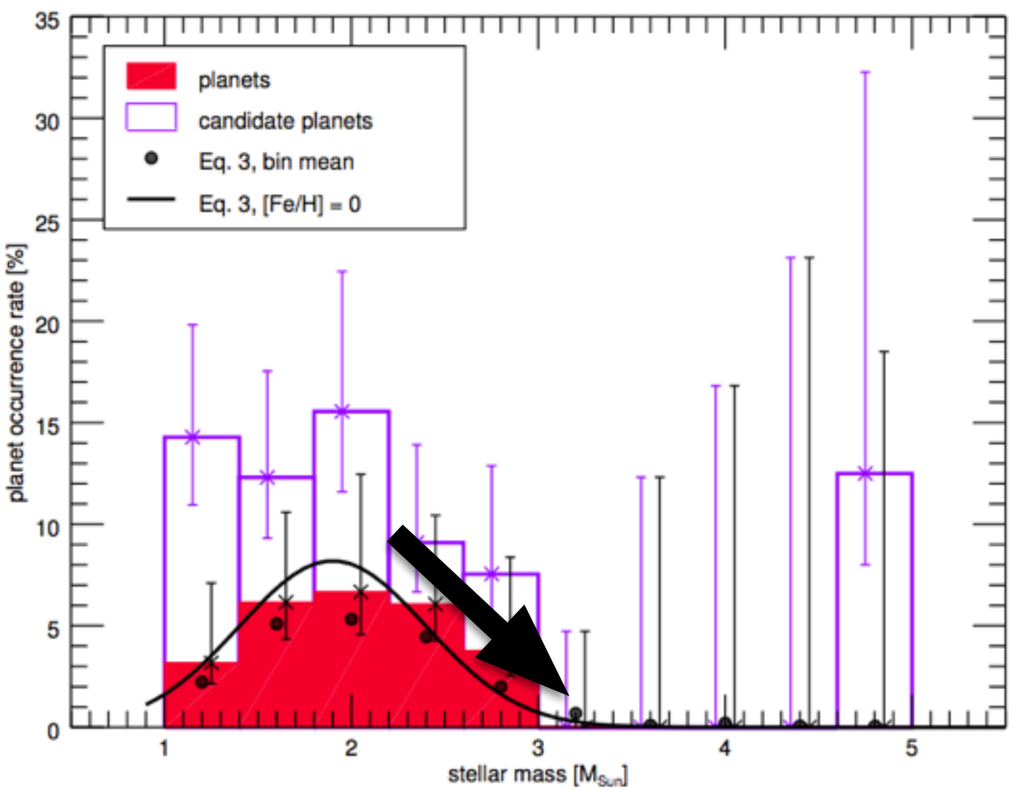
More solids available in disks around higher mass stars

(giant planet formation via core accretion)



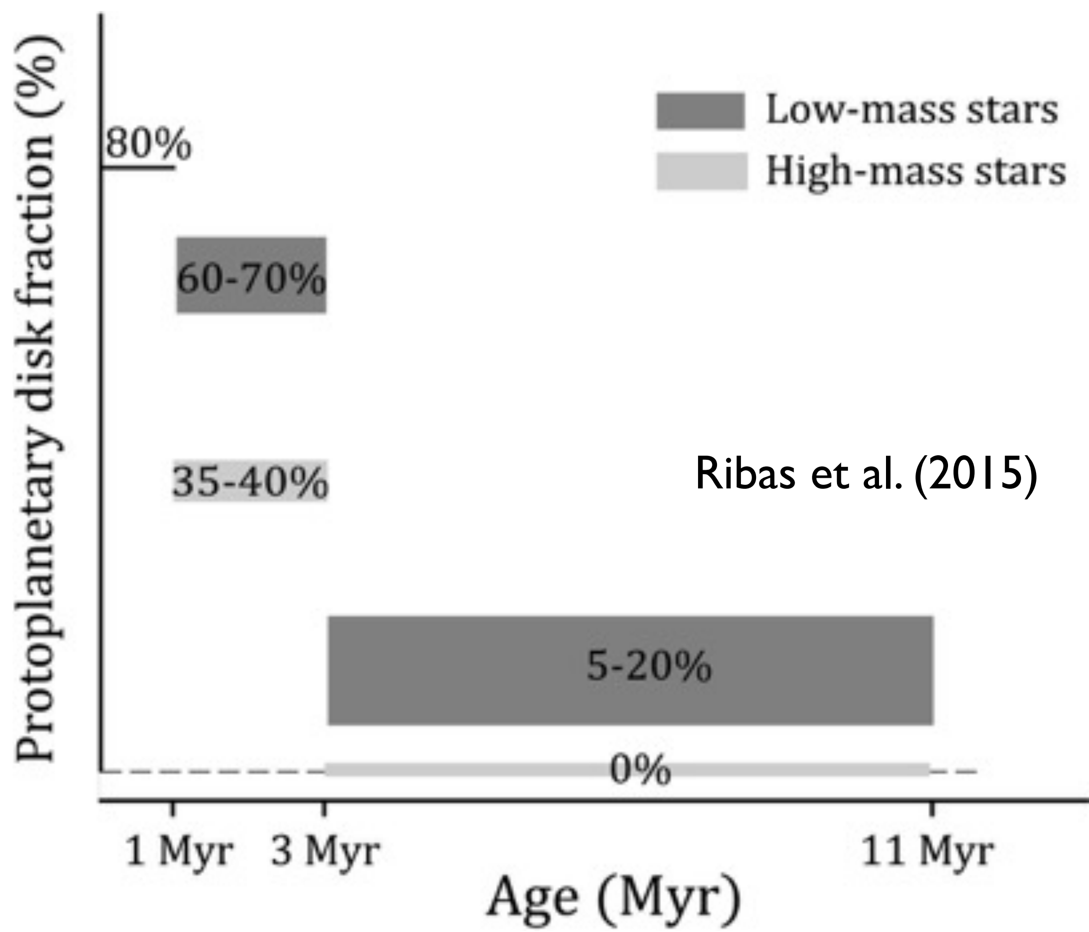
Solar System

see also Ansdell et al. (2016,207), Barenfeld et al. (2016)



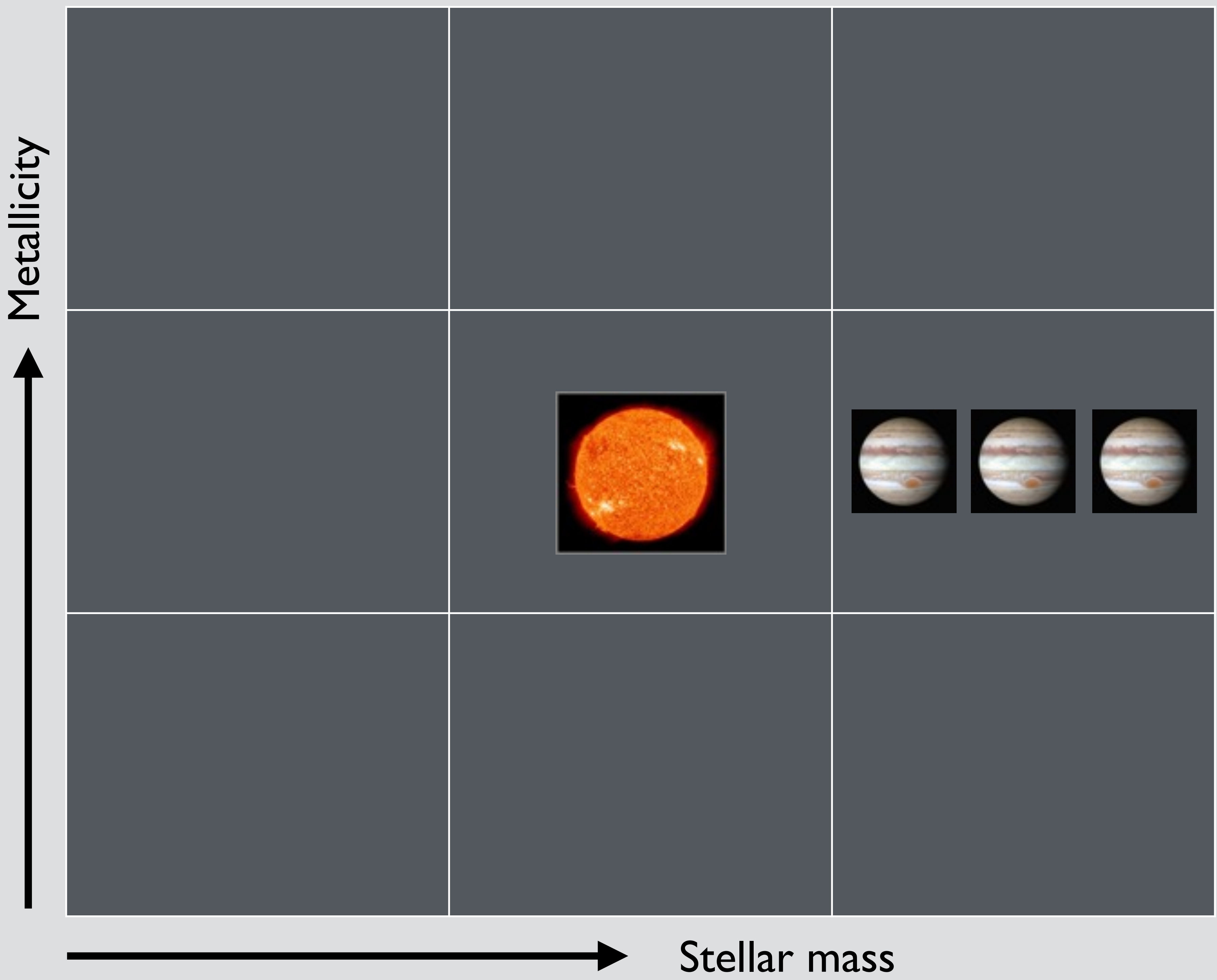
Reffert et al. (2015)

Disks around stars more massive than $2M_{sun}$ disperse faster



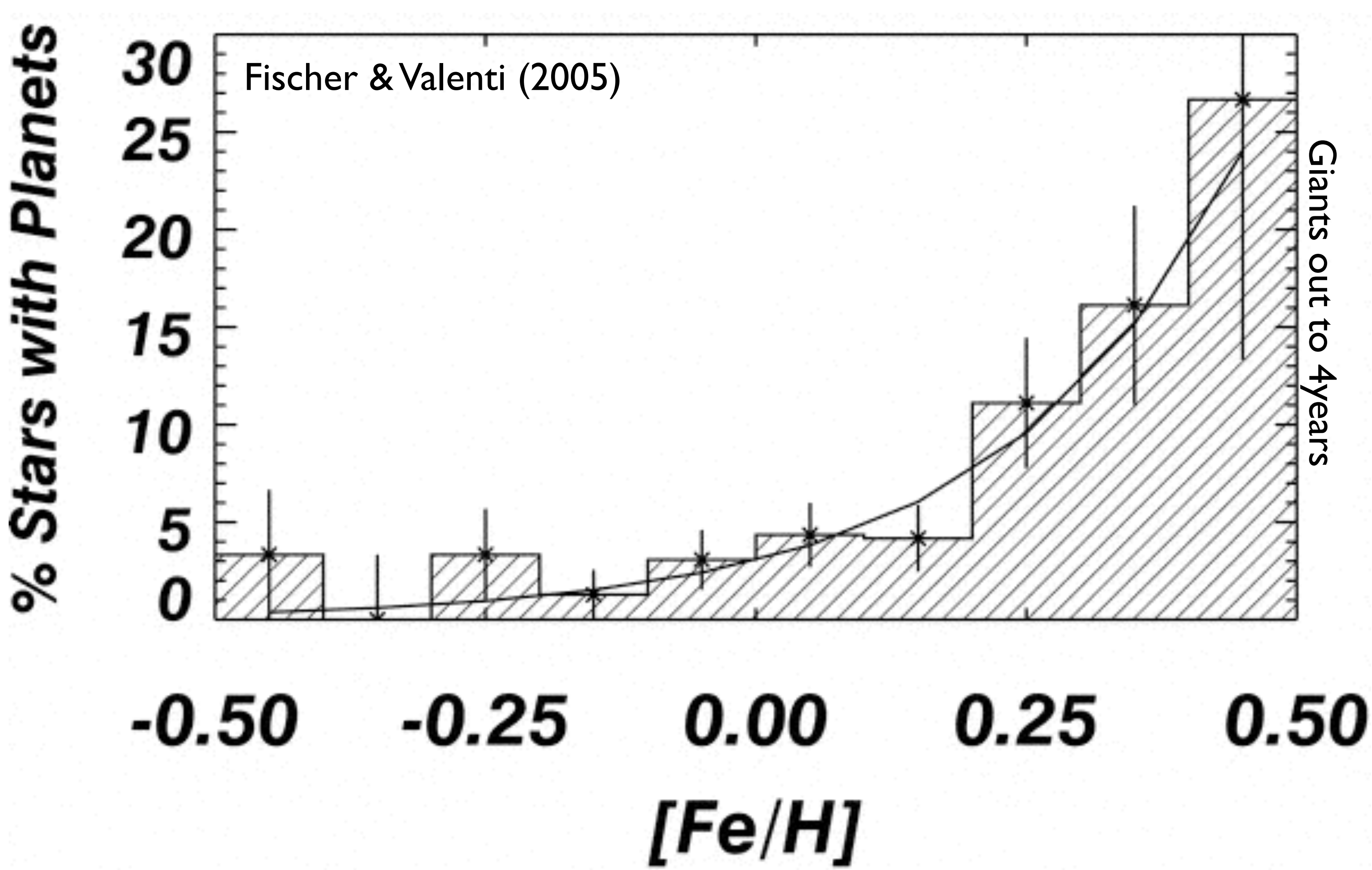
Ribas et al. (2015)

see also Carpenter et al. (2006), Dahm & Hillenbrand (2007), Currie et al. (2009)


Metallicity
Stellar mass

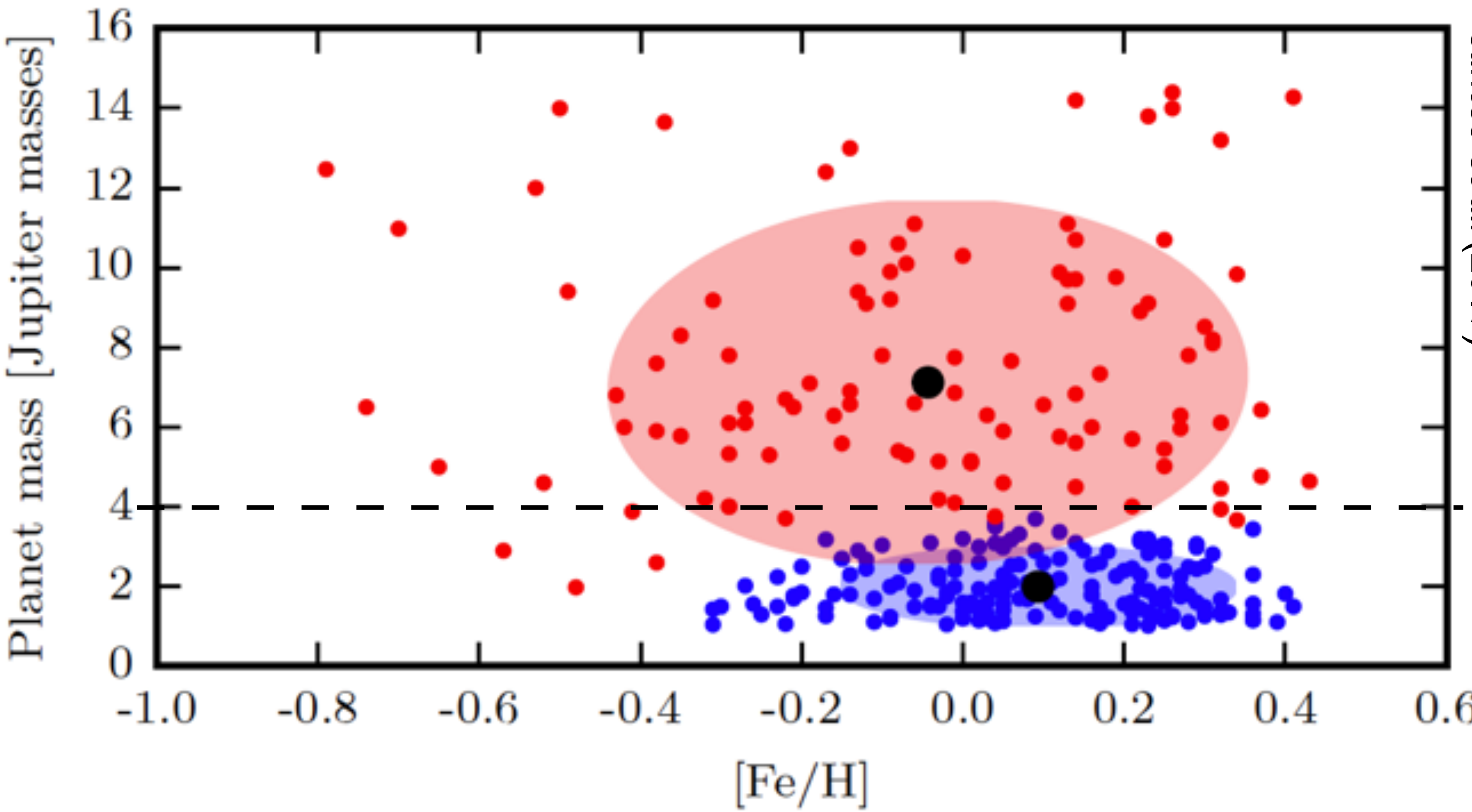
The giant planet occurrence rate increases with stellar metallicity

This finding supports giant planet formation via core accretion



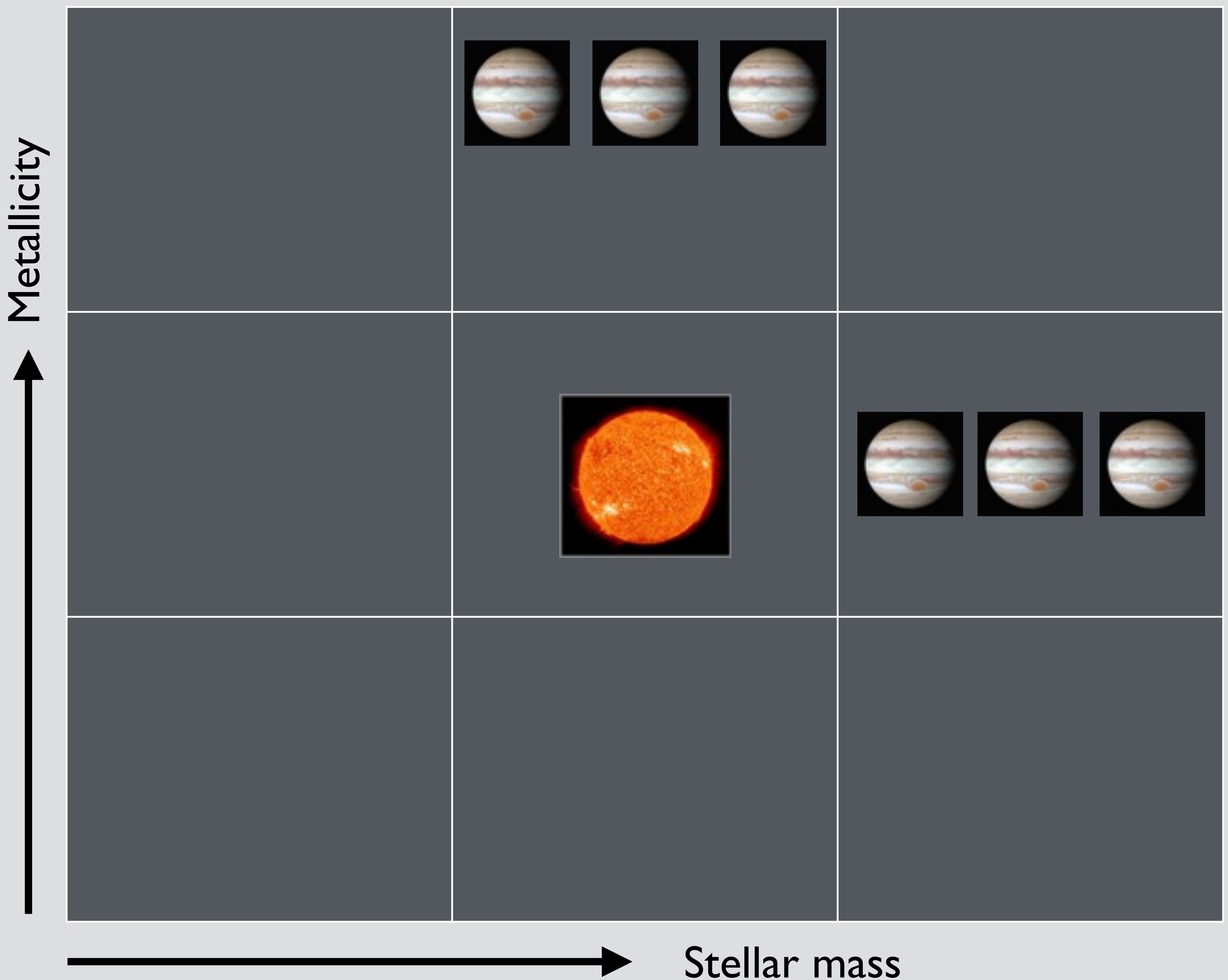
see also Udry & Santos (2007), Sousa et al. (2011), Mortier et al. (2013)

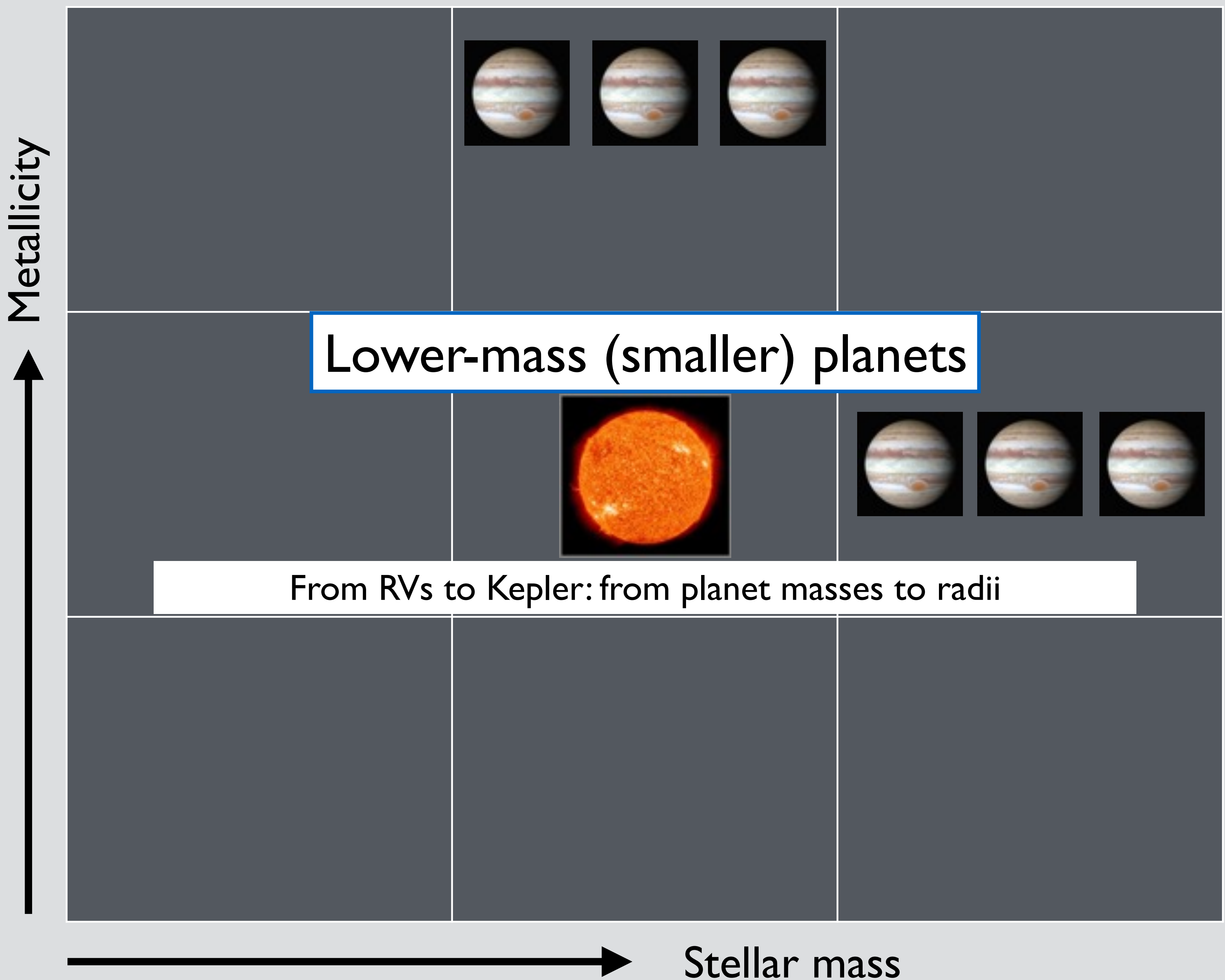
Two giant planet populations: two formation processes?



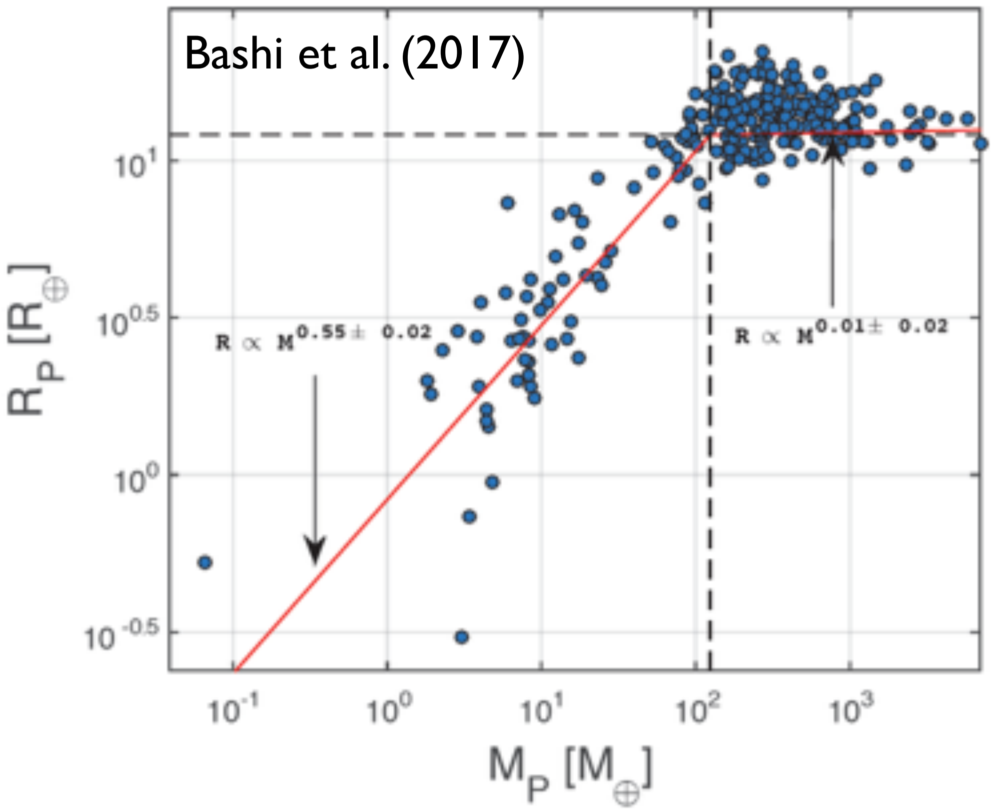
Santos et al. (2017)

(based on the exoplanet.eu and the SWEET-Cat catalogues)


Metallicity
Stellar mass

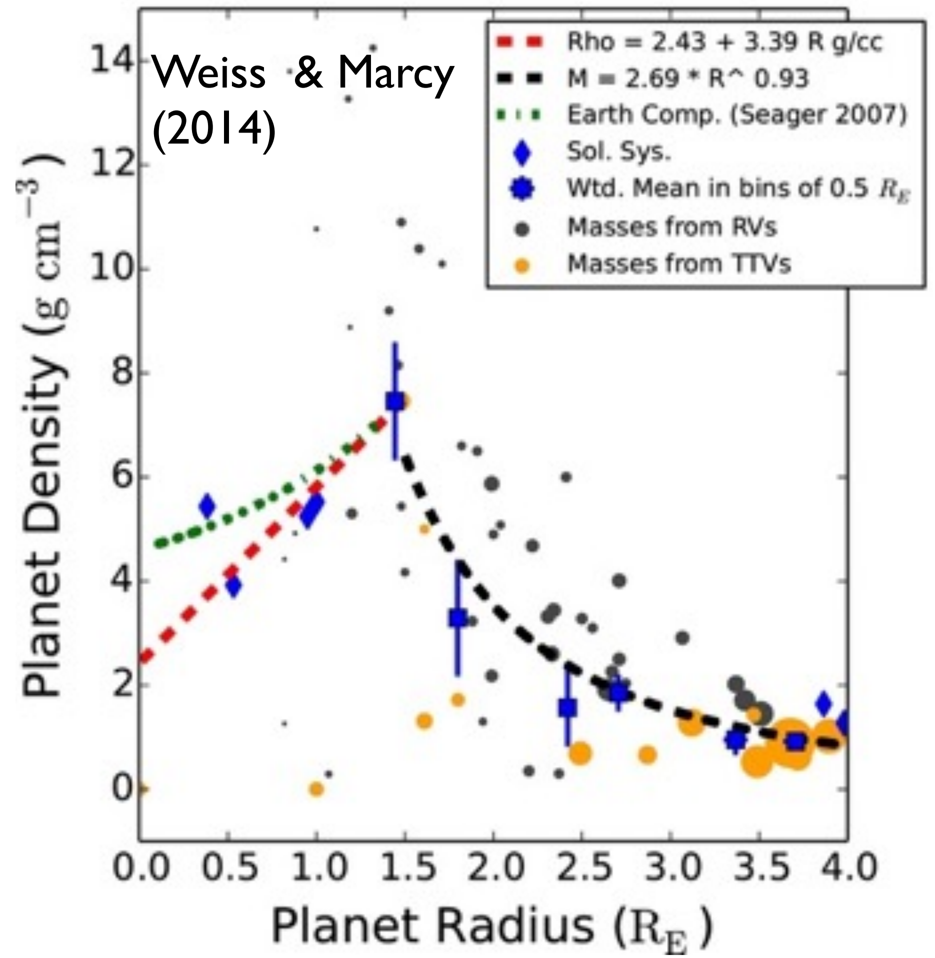

Metallicity
Lower-mass (smaller) planets
From RVs to Kepler: from planet masses to radii
Stellar mass

Jovians of mostly H and He for $R_p > 12R_{earth}$ ($M_p > 125M_{earth}$)

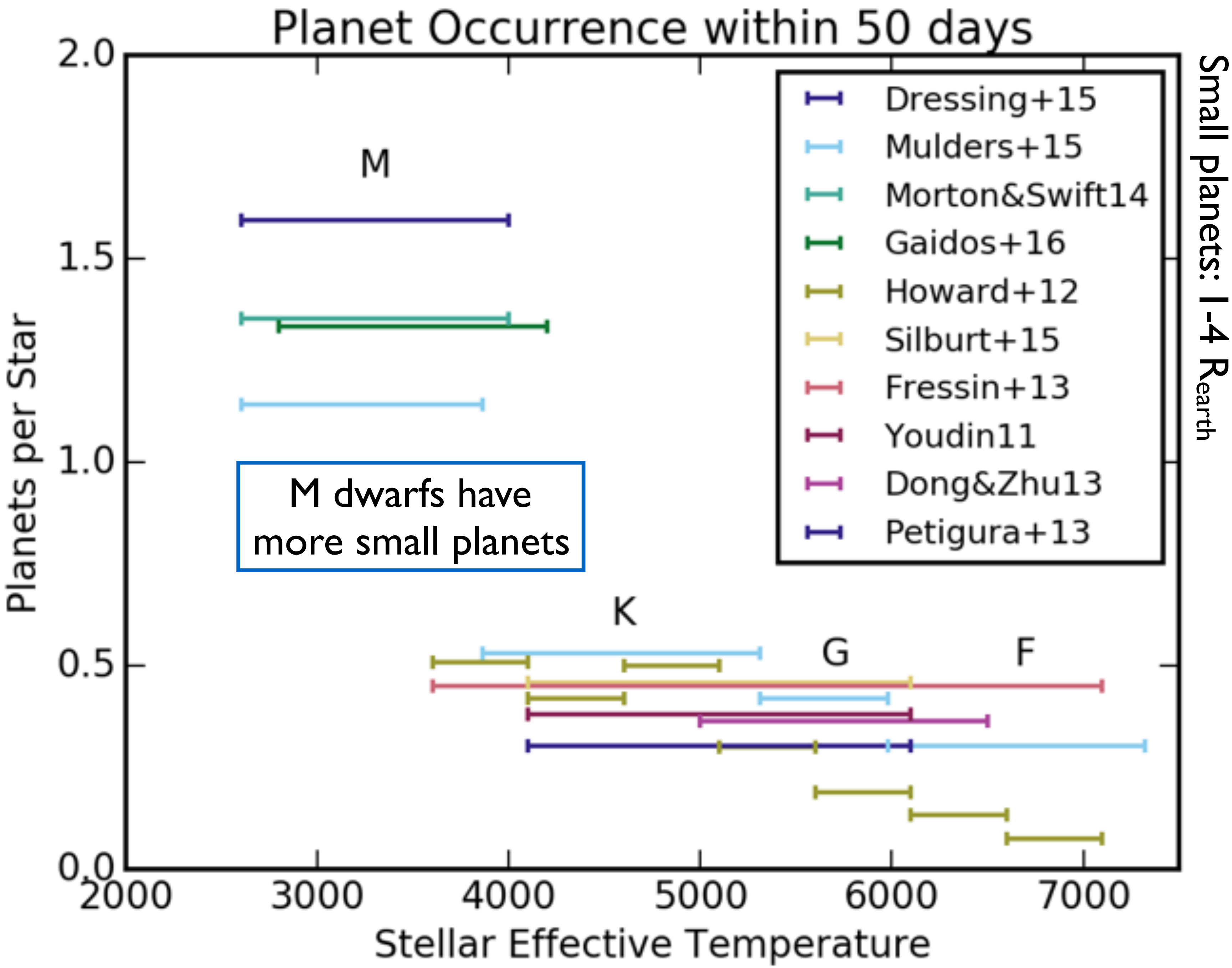


see also Weiss et al. (2013), Hatzes & Rauer (2015), Chen & Kipping (2017)

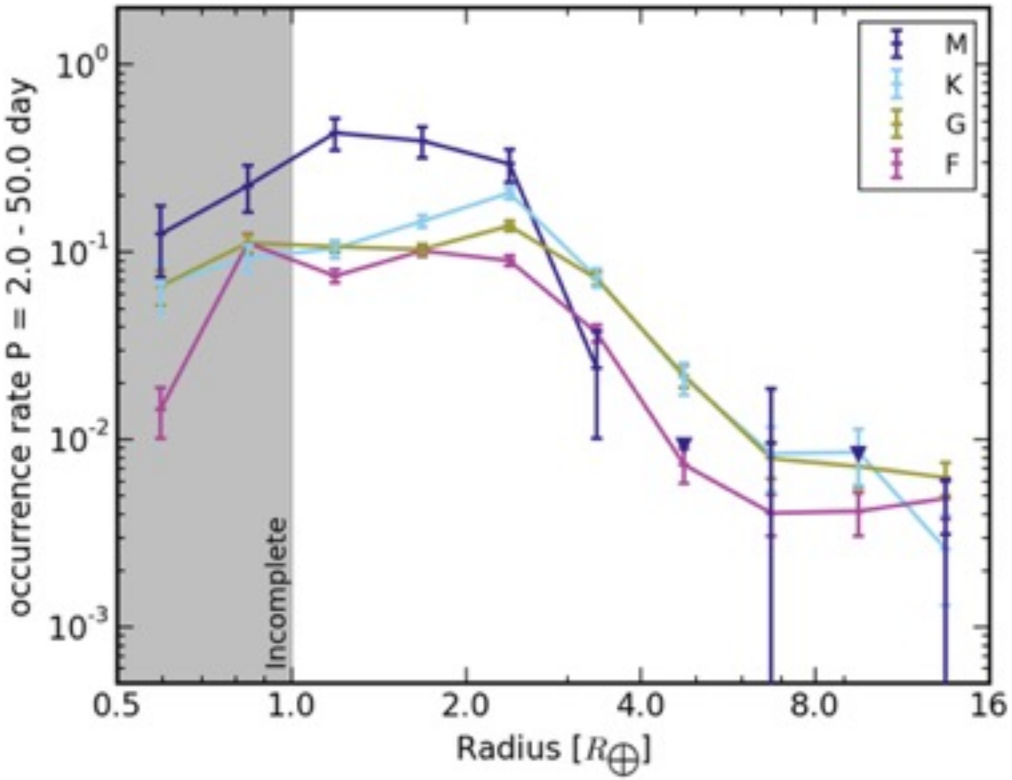
In the sub-Neptune regime ($<4R_{earth}$): Rocky planets for $R_p \lesssim 1.5R_{earth}$ ($M_p \lesssim 3M_{earth}$)



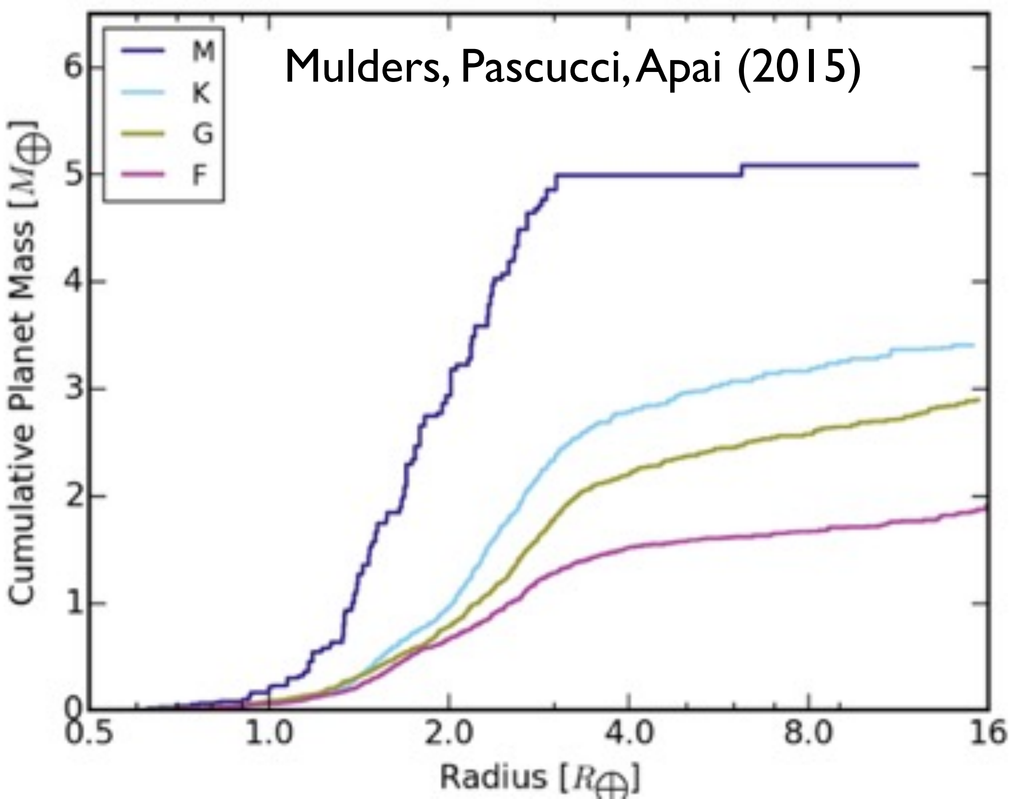
see also Rogers (2015), Wolfgang et al. (2016)



from G. Mulders (review chapter to appear in "Handbook of Exoplanets", eds. Dee & Belmonte)

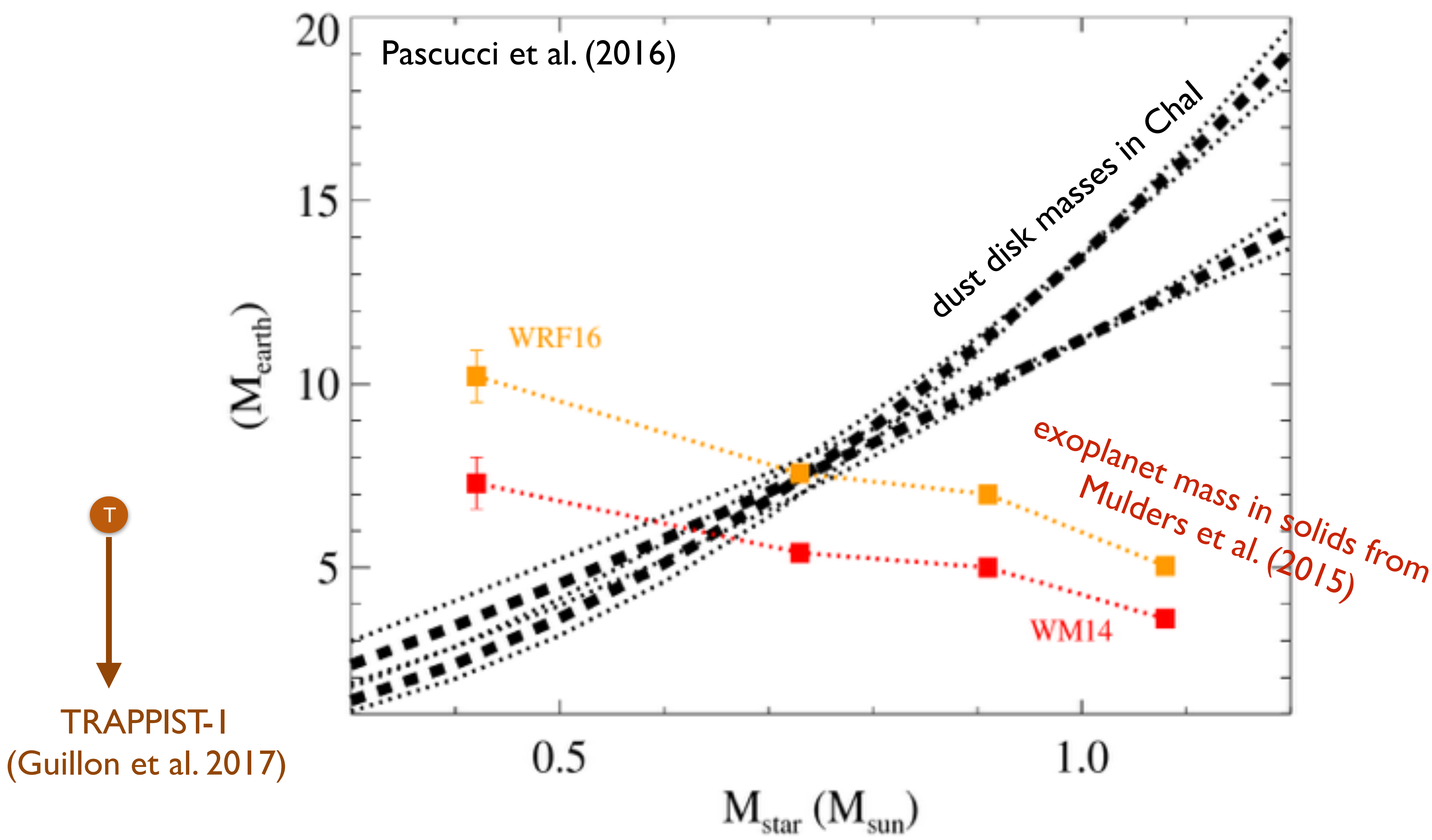


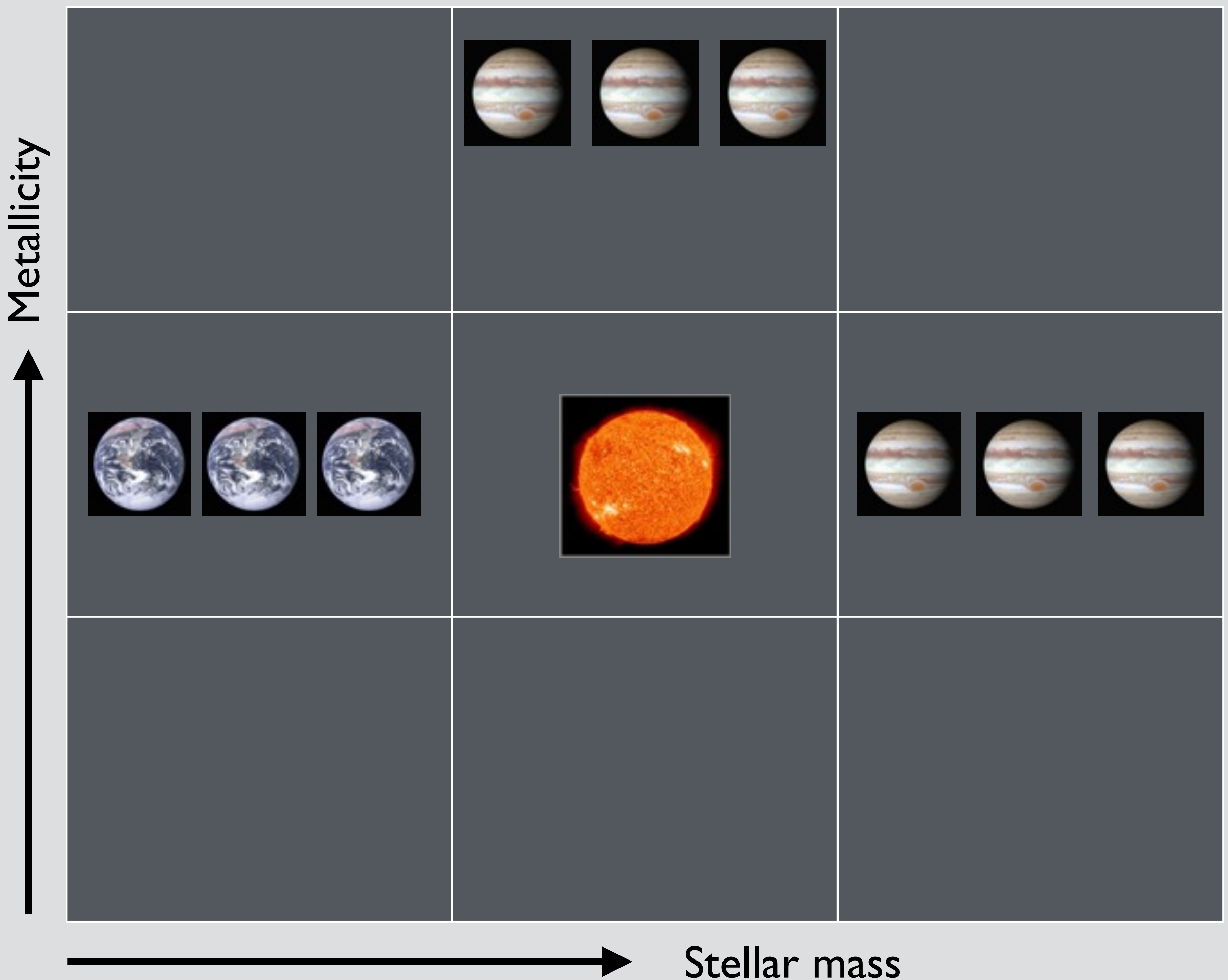
M dwarfs have ~3 times more 1-2.8R_{earth} planets than FGK stars (but two times less Neptune-size planets)



Most of the solid mass is in 1-3R_{earth} planets

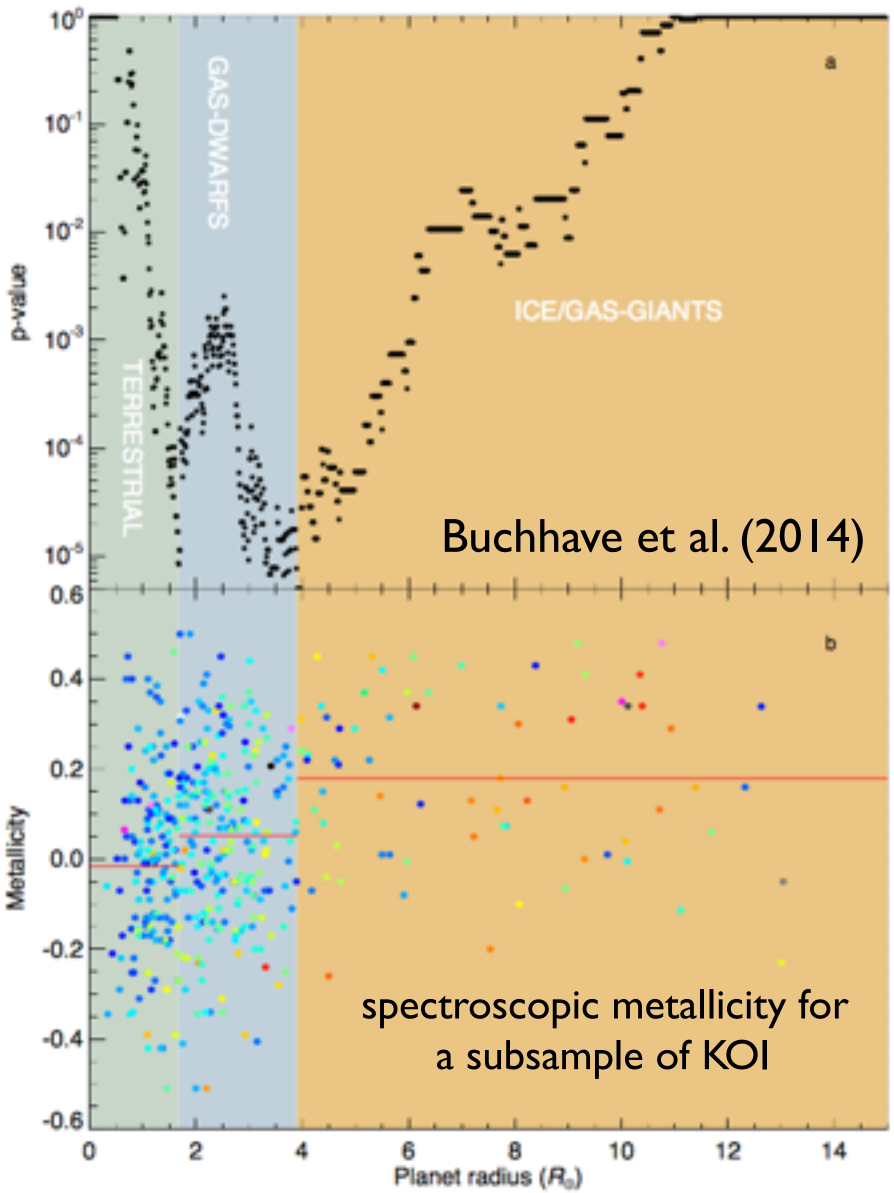
Paucity of pebbles in ~2Myr-old disks around low-mass stars: faster inward migration (link to giants?) and/or planetesimal formation



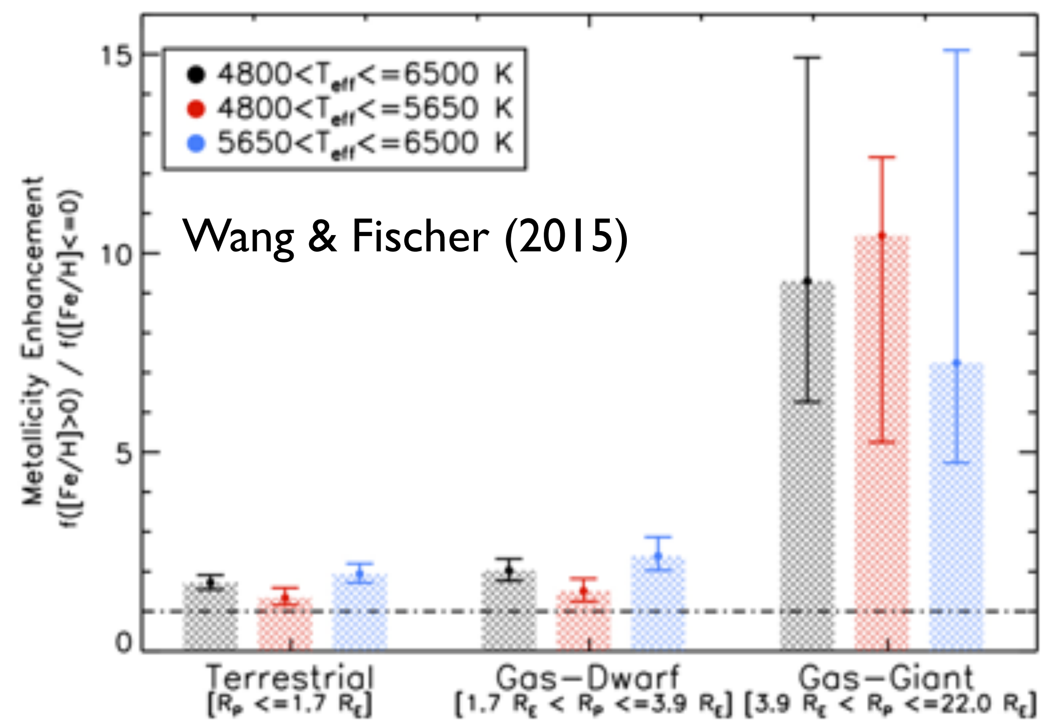

Metallicity
Stellar mass

Are all types of planets more frequent around metal-rich stars?

NO



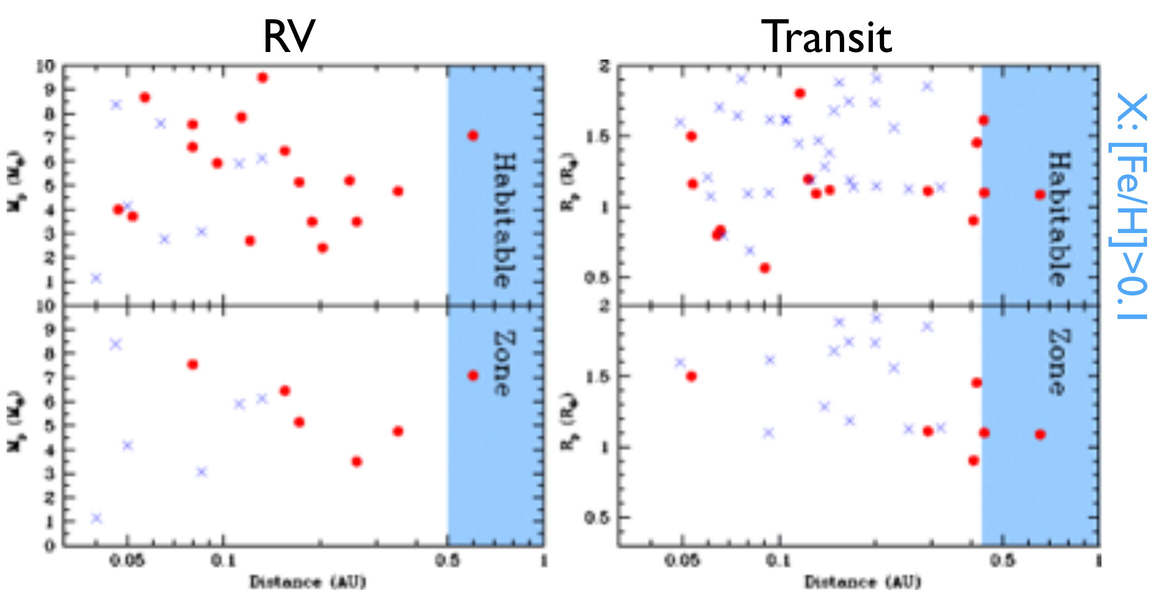
YES



photometric KIC metallicities

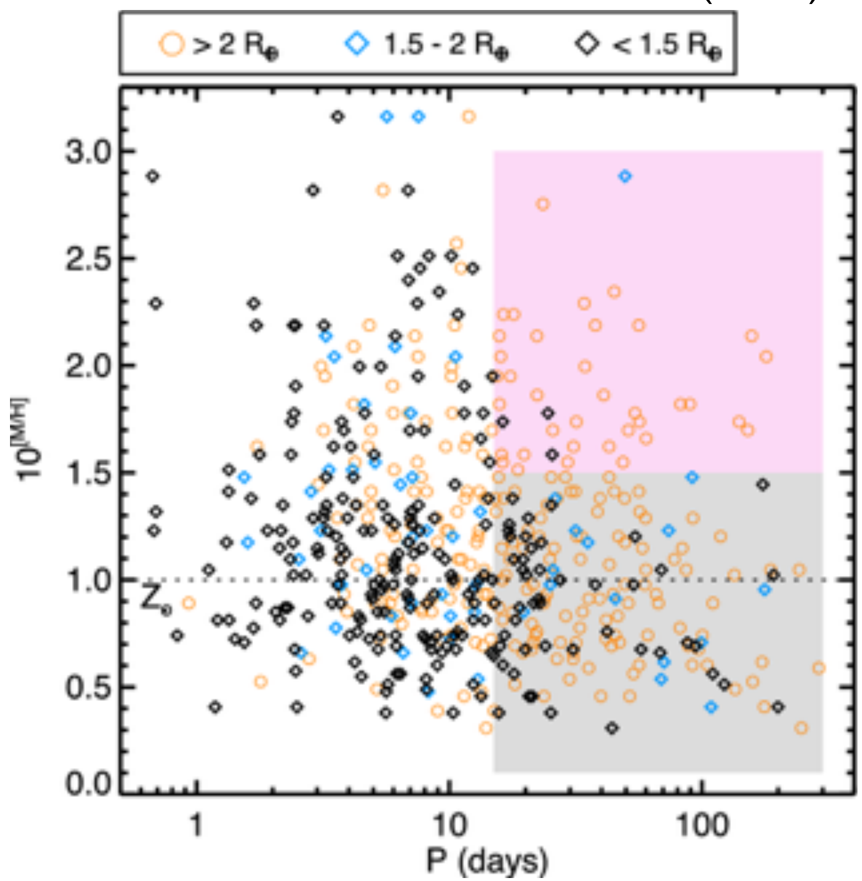
but see also Schlaufman (2015)

Metallicity–Orbital Period dependence

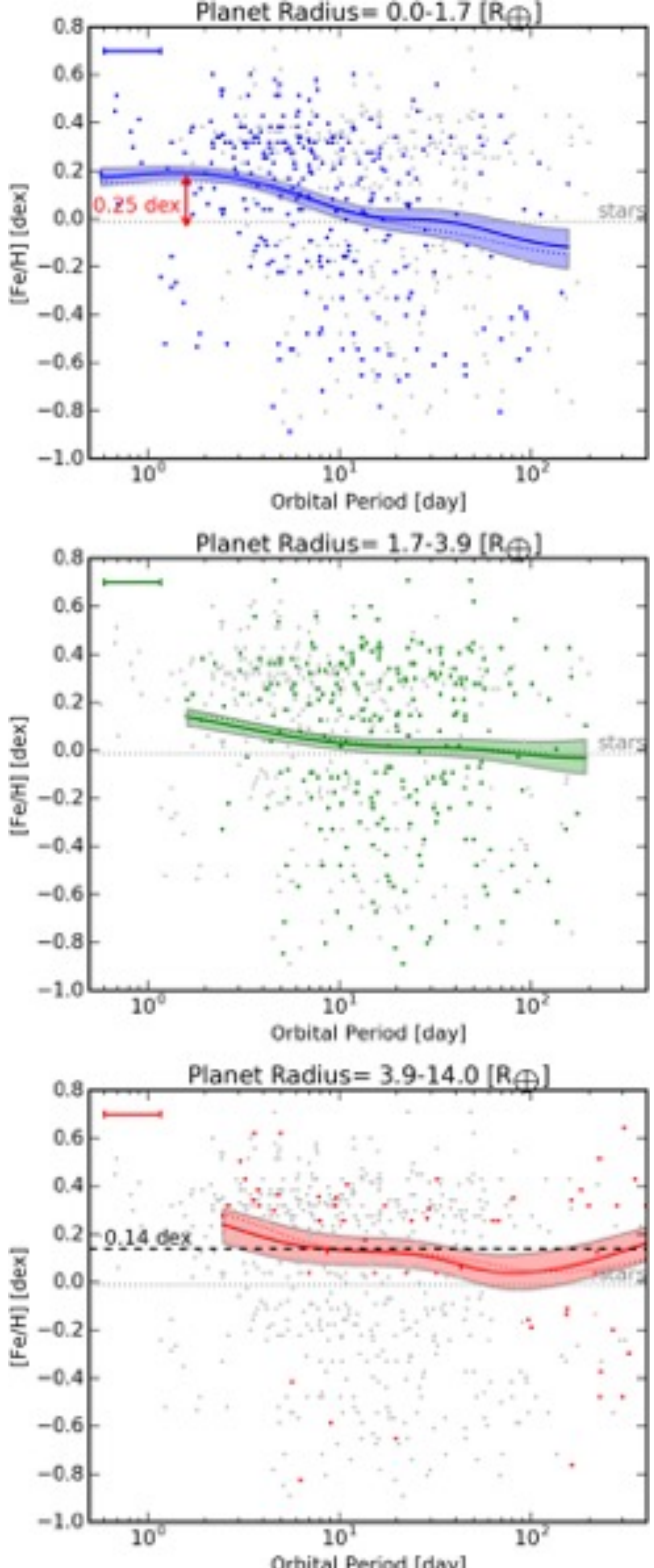


Adibekyan et al. (2016)

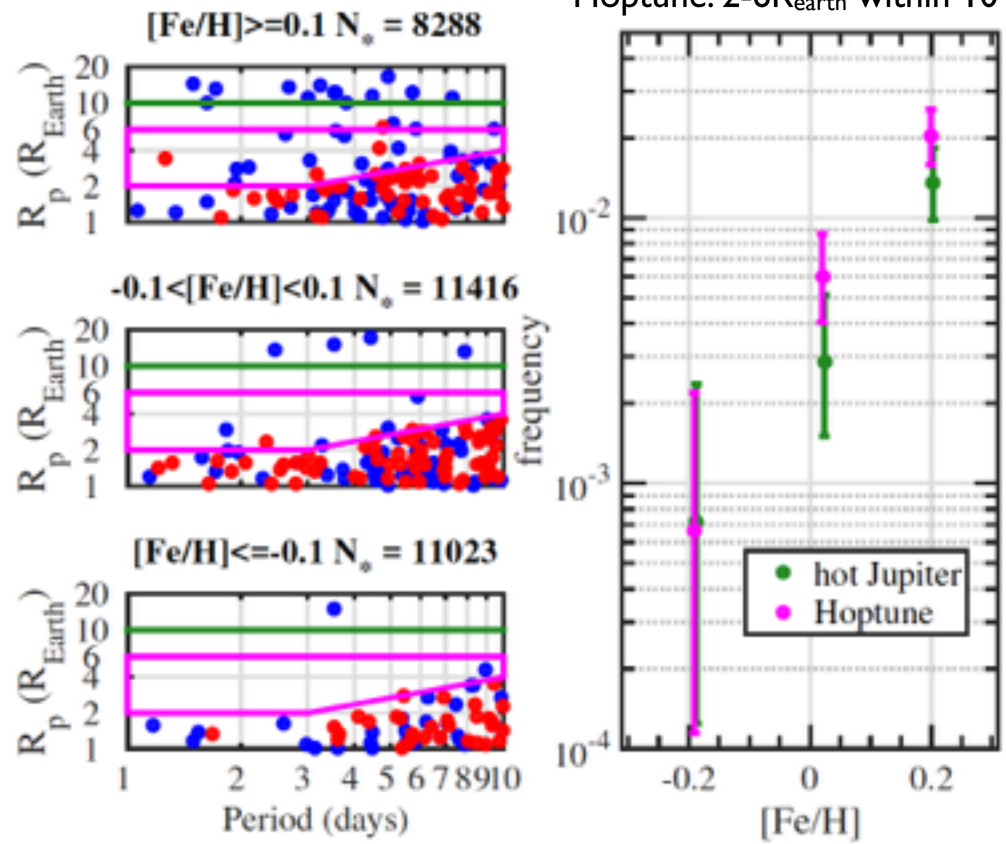
Dawson et al. (2015)



see also Beaugé & Nesvorný (2013), Dawson & Murray-Clay (2013), Adibekyan et al. (2013)



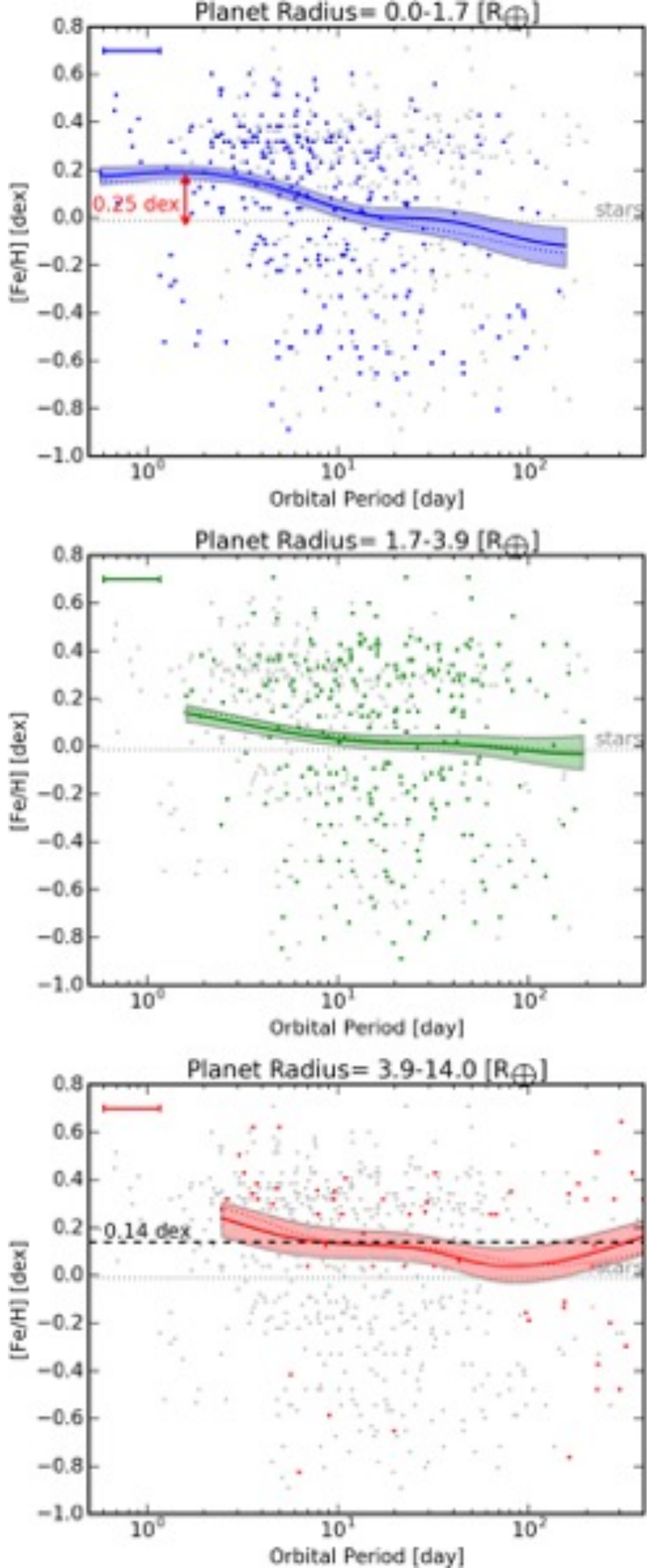
Hoptune: 2-6R_{earth} within 10 days

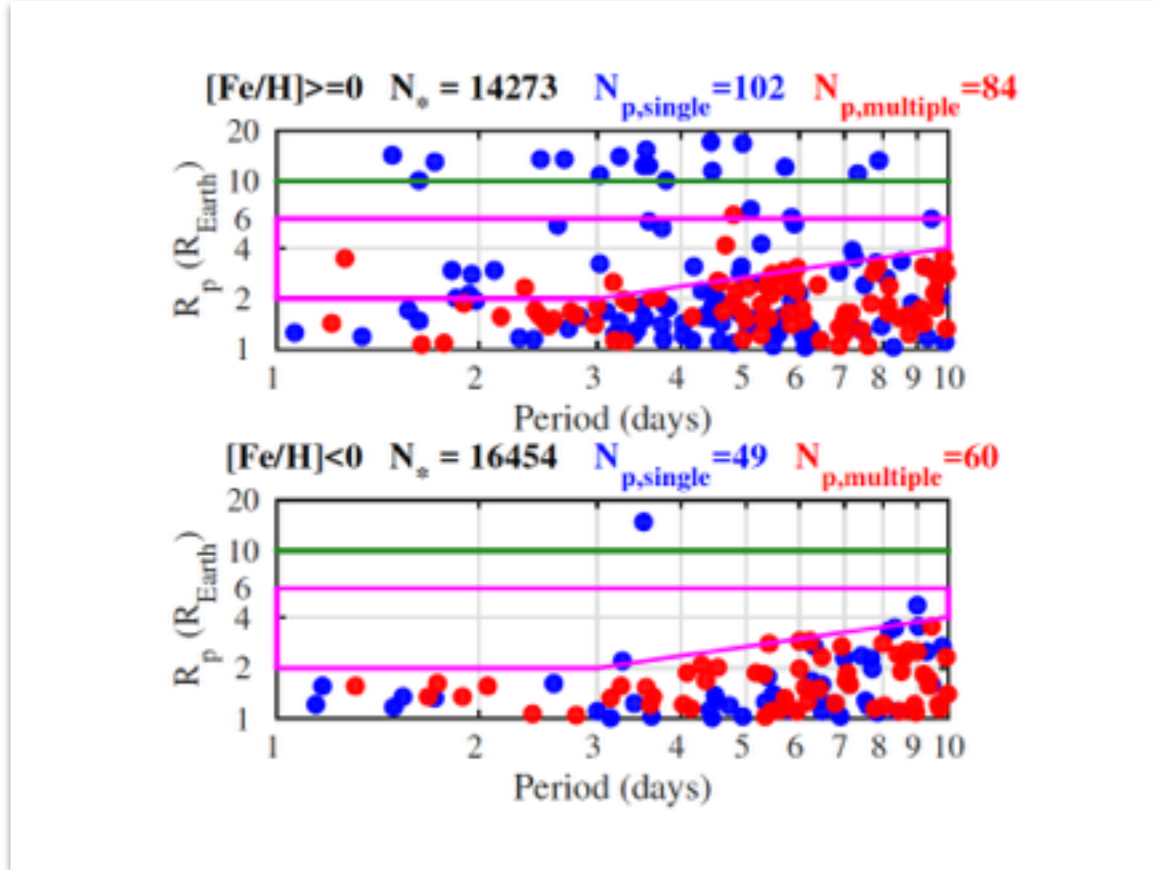


Dong et al. (2017) with LAMOST metallicities from De Cat et al. (2015)

Exoplanets with orbital periods less than 10 days are preferentially found around metal-rich stars

Mulders, Pascucci et al. (2016) with LAMOST metallicities from Frasca et al. (2016)

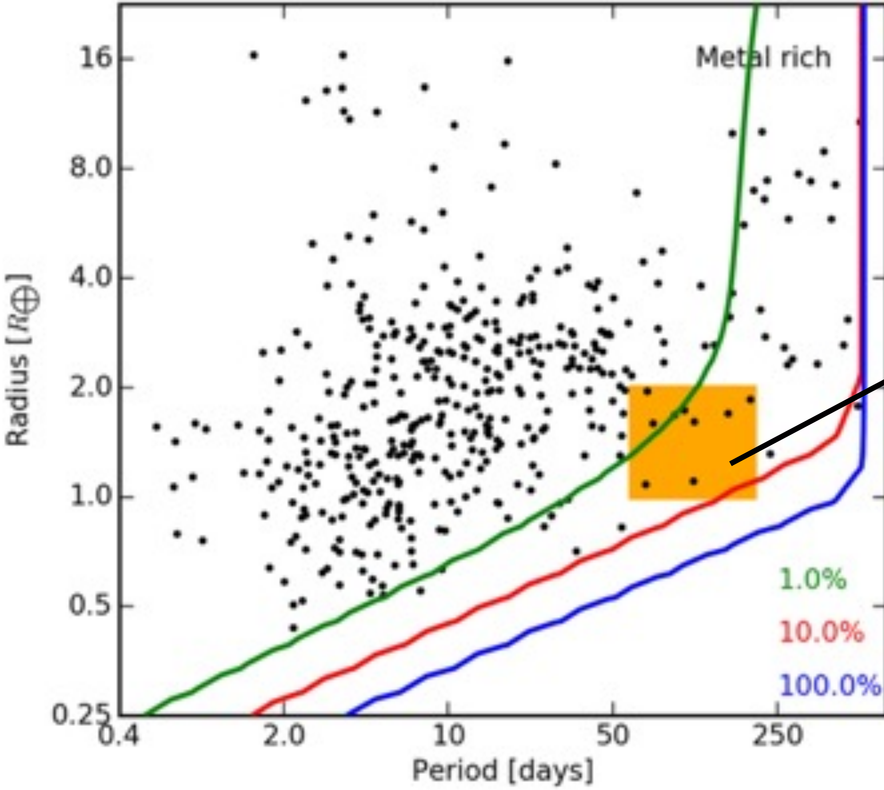




Dong et al. (2017) with LAMOST metallicities from De Cat et al. (2015)

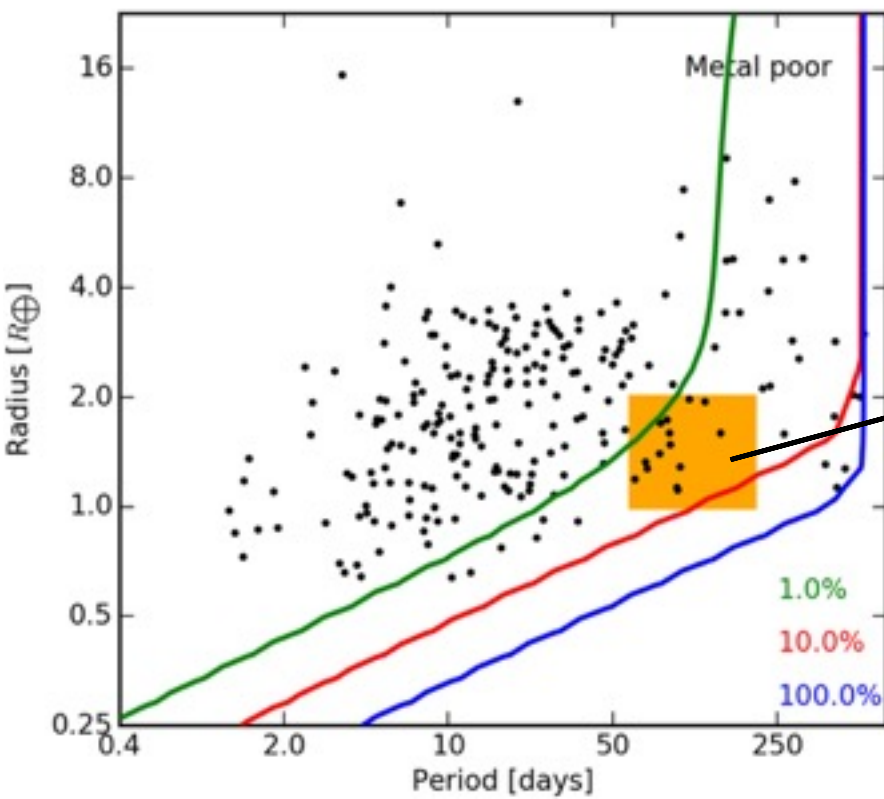
Hot Jupiters and hot Neptunes are mostly in single systems

Mulders, Pascucci et al. (2016) with LAMOST metallicities from Frasca et al. (2016)



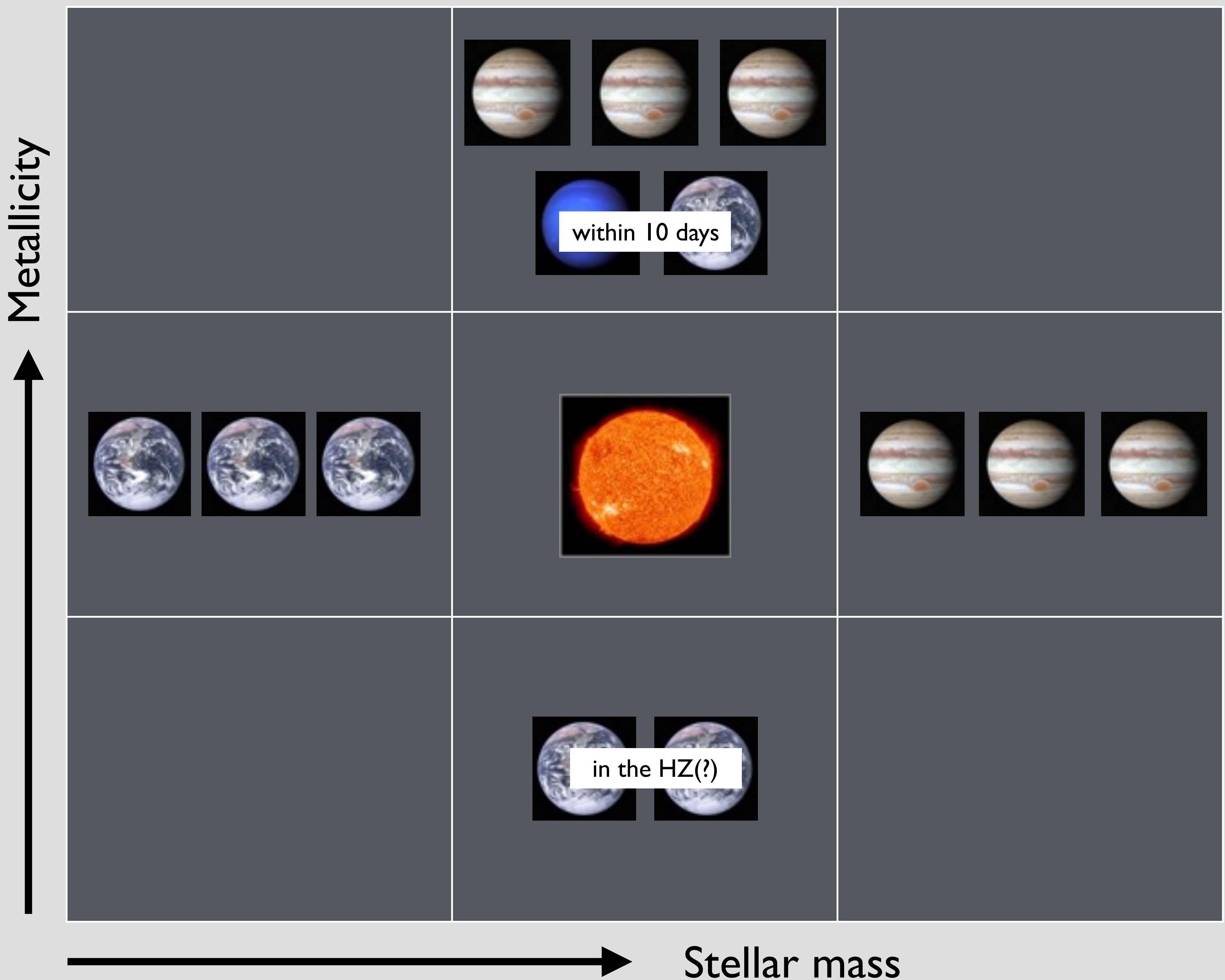
Occurrence rate = 14+/-5%

The occurrence rate of 1-2 R_{earth} planets with a period 70-200 days is higher around metal poor stars (but the difference is not statistically significant)

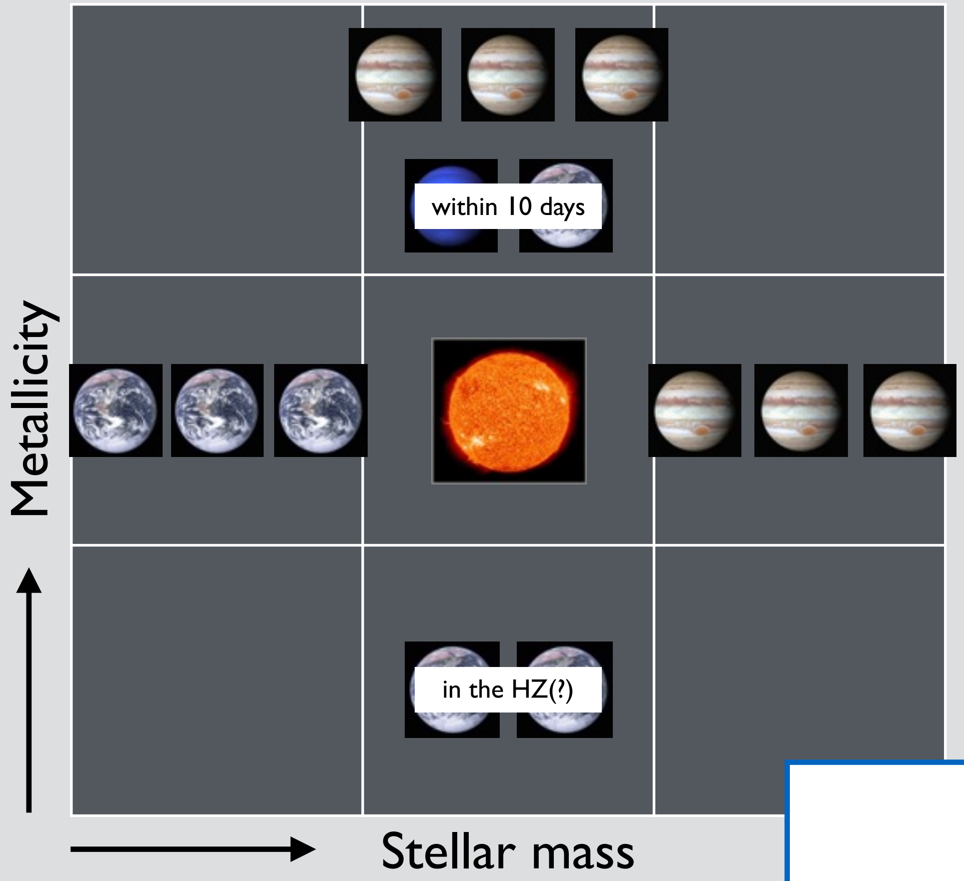


Occurrence rate = 27+7%

Mulders, Pascucci et al. (2016)



Metallicity
within 10 days
in the HZ(?)
Stellar mass



Take home messages:

– The amount of solids in a disk impacts the type of planets that can form (higher stellar mass and/or higher metallicity → higher occurrence rate of giant planets)

– Giant planets affect the formation of rocky planets (e.g. single hot Jupiters and Neptunes, lack of giants → more pebbles in the planet-forming zone)