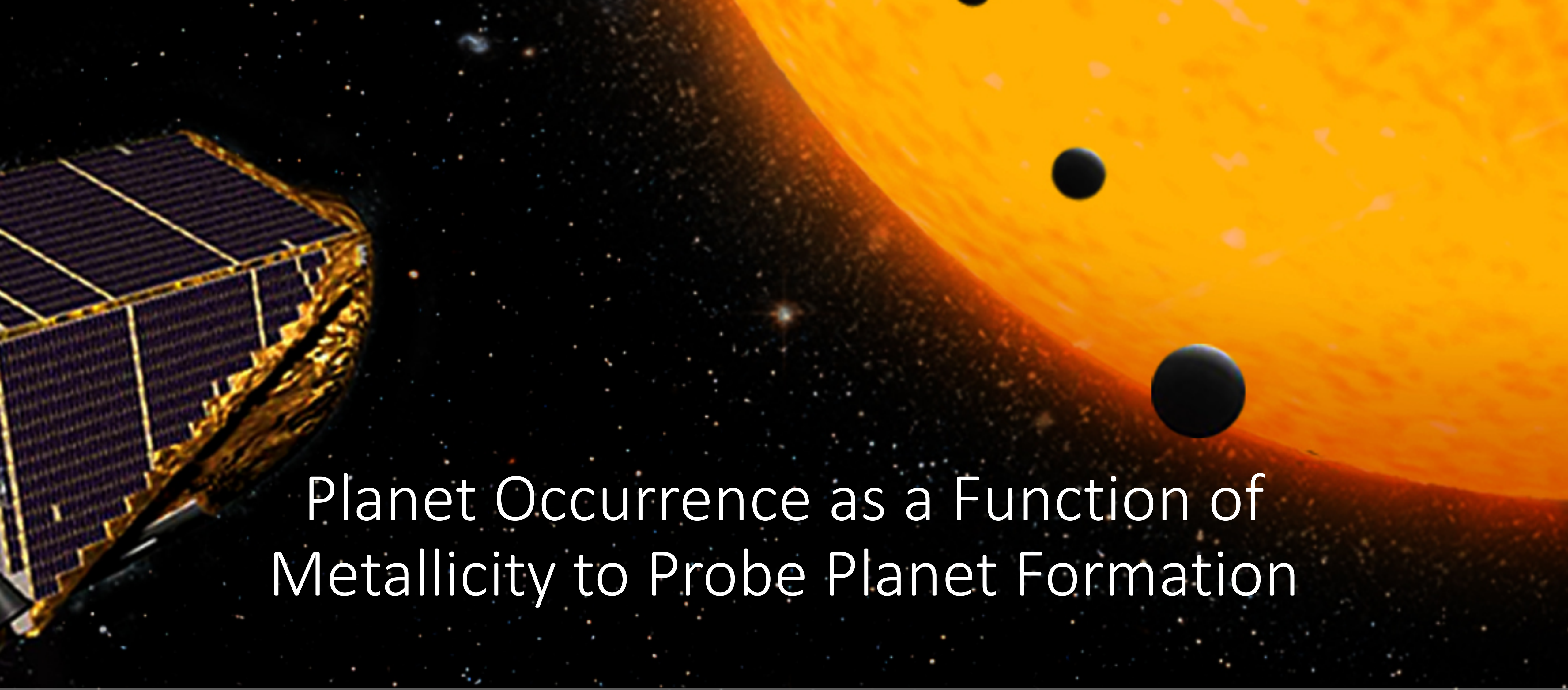
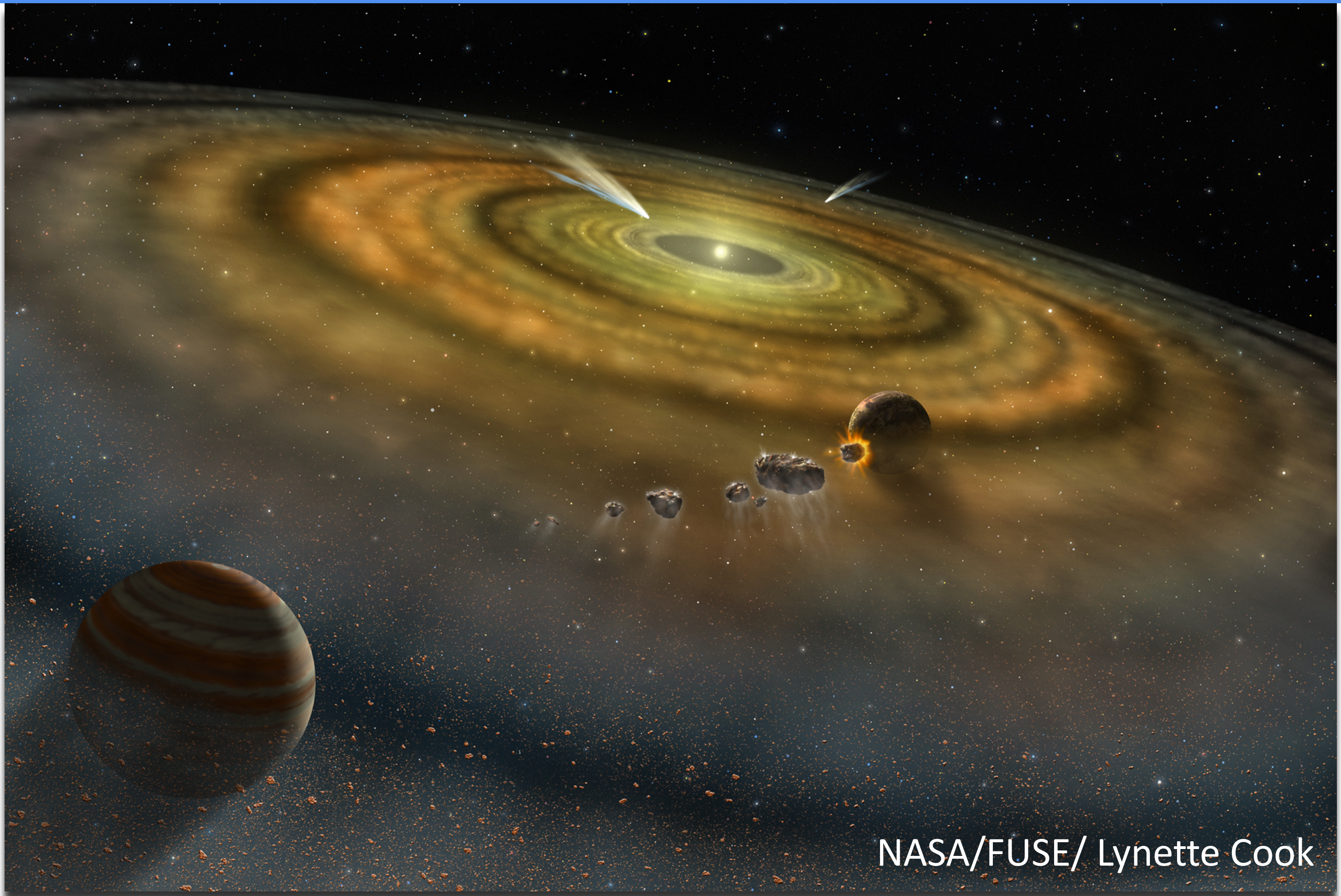


Planet Occurrence as a Function of Metallicity to Probe Planet Formation

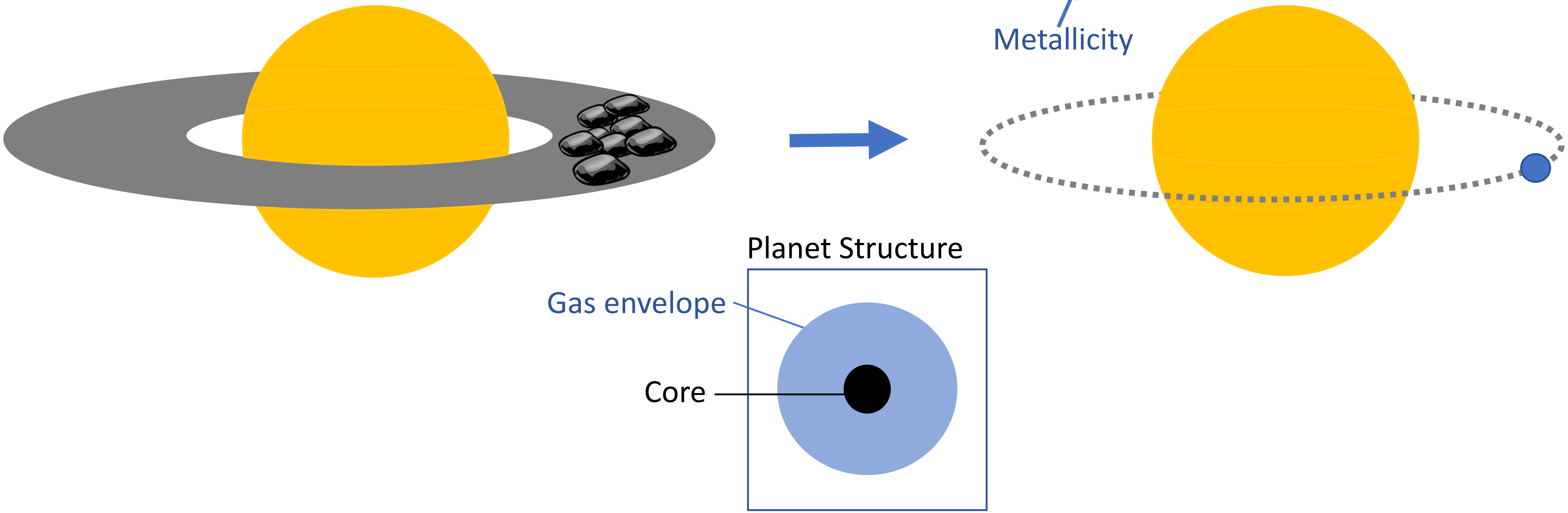
Cicero Lu, Kevin Schlaufman & Sihao Cheng (2020)
Johns Hopkins University

Core Accretion Model of Planet Formation



Core accretion

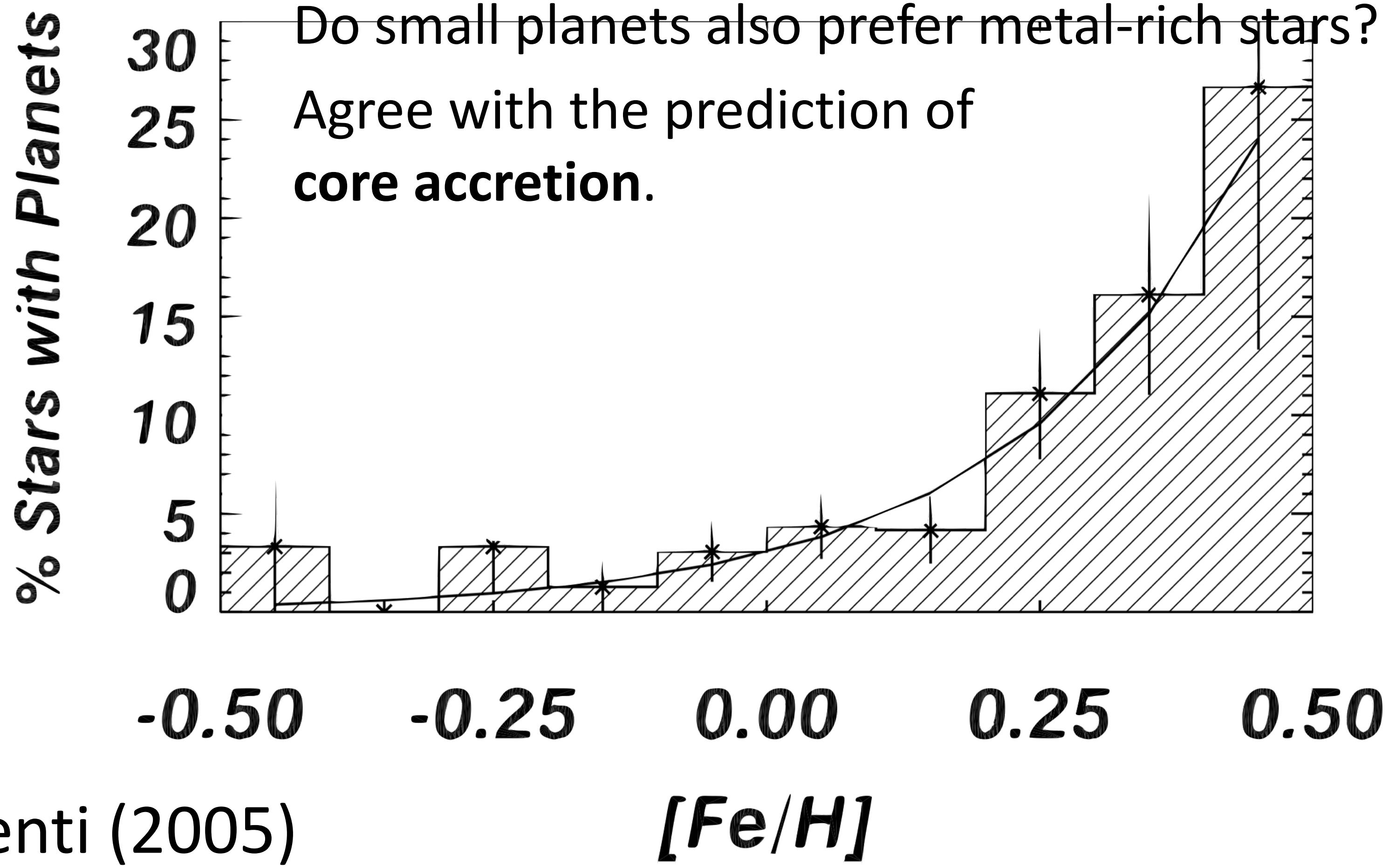
➢ $p(\text{planet}) \sim M_{\text{disk metal}} \propto Z_\star M_\star$



Giant planets prefer metal-rich stars.

Do small planets also prefer metal-rich stars?

Agree with the prediction of **core accretion**.

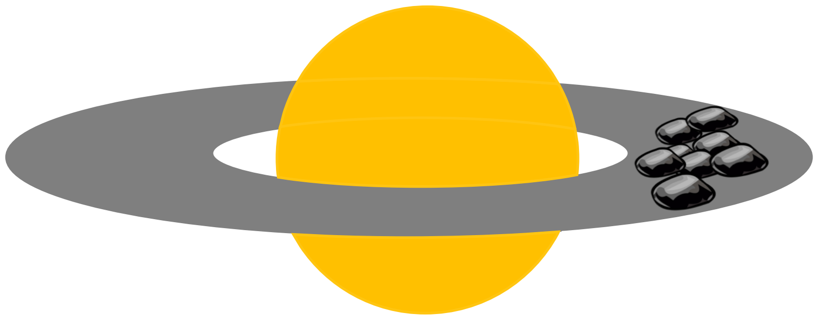


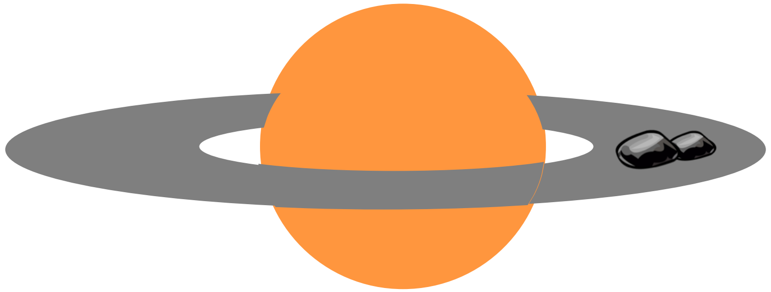
Fischer & Valenti (2005)

Do small planets also prefer metal-rich stars?

➢ $p(\text{planet}) \sim M_{\text{disk metal}} \propto Z_\star M_\star$

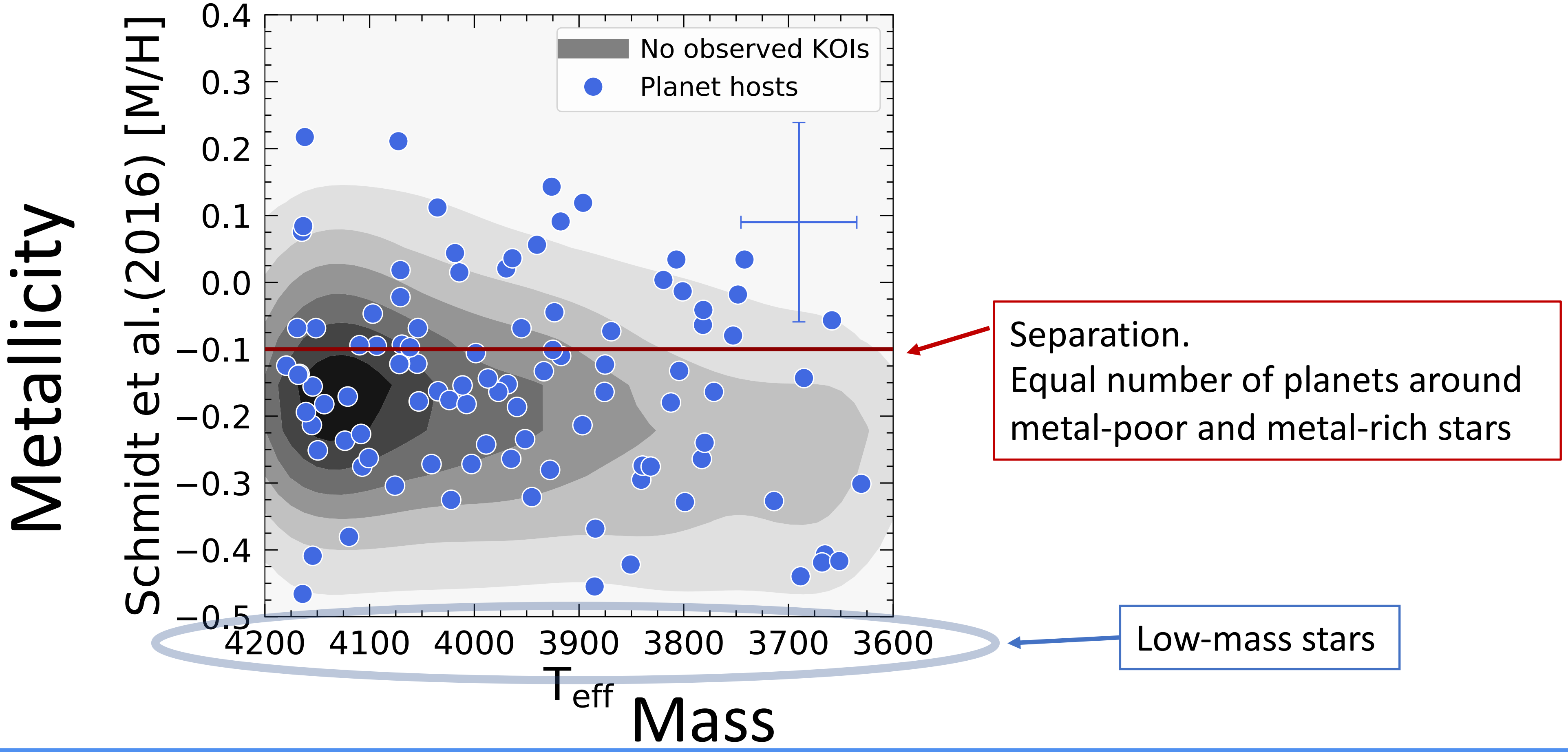
	Solar type	Metal-poor M dwarf
$Z_\star$	1	0.1
$M_\star$	1	0.5
$M_{\text{disk metal}}$	100 $M_\oplus$	5 $M_\oplus$





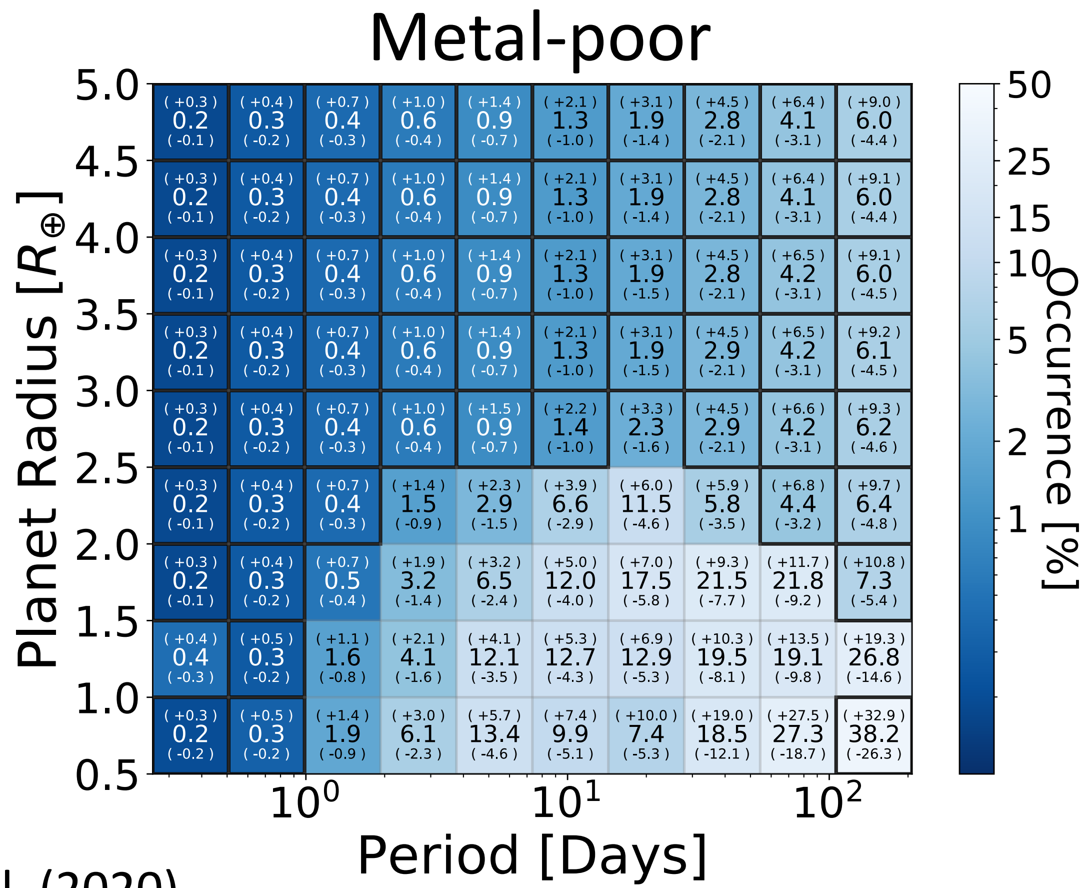
Scaling relations: Andrews et al. (2013, 2018); Gordon et al. (2003)

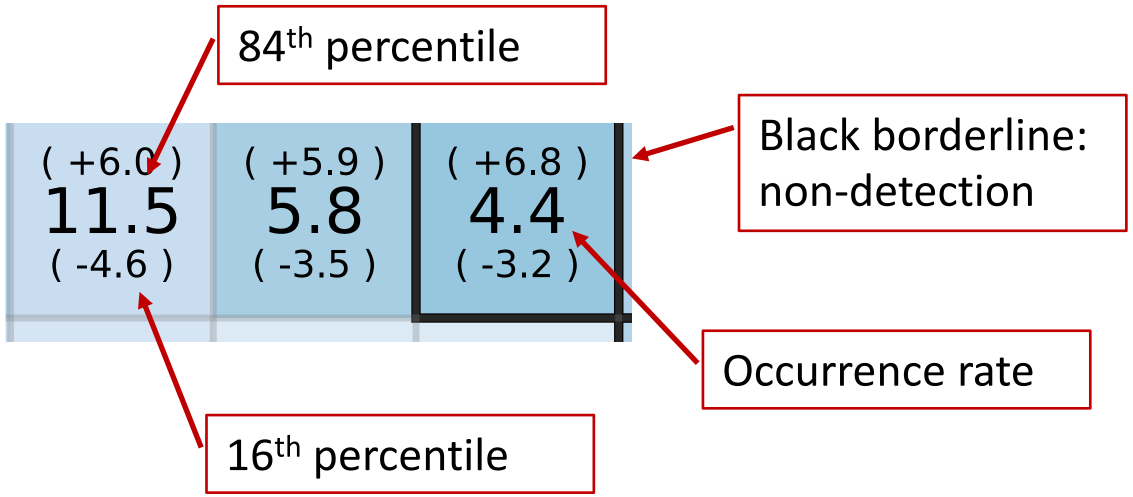
Separating metal-rich and metal-poor stars



Lu et al. (2020)

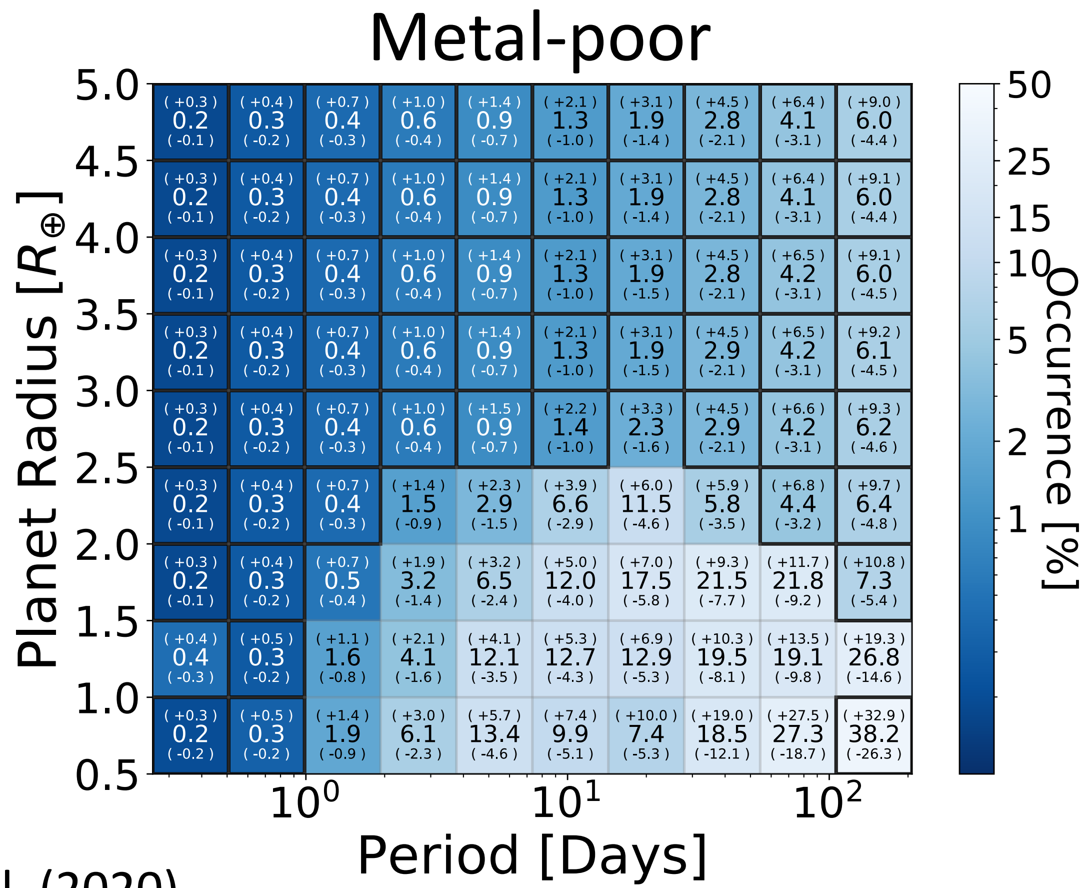
Small Planet Occurrence Increases with Host Star Metallicity

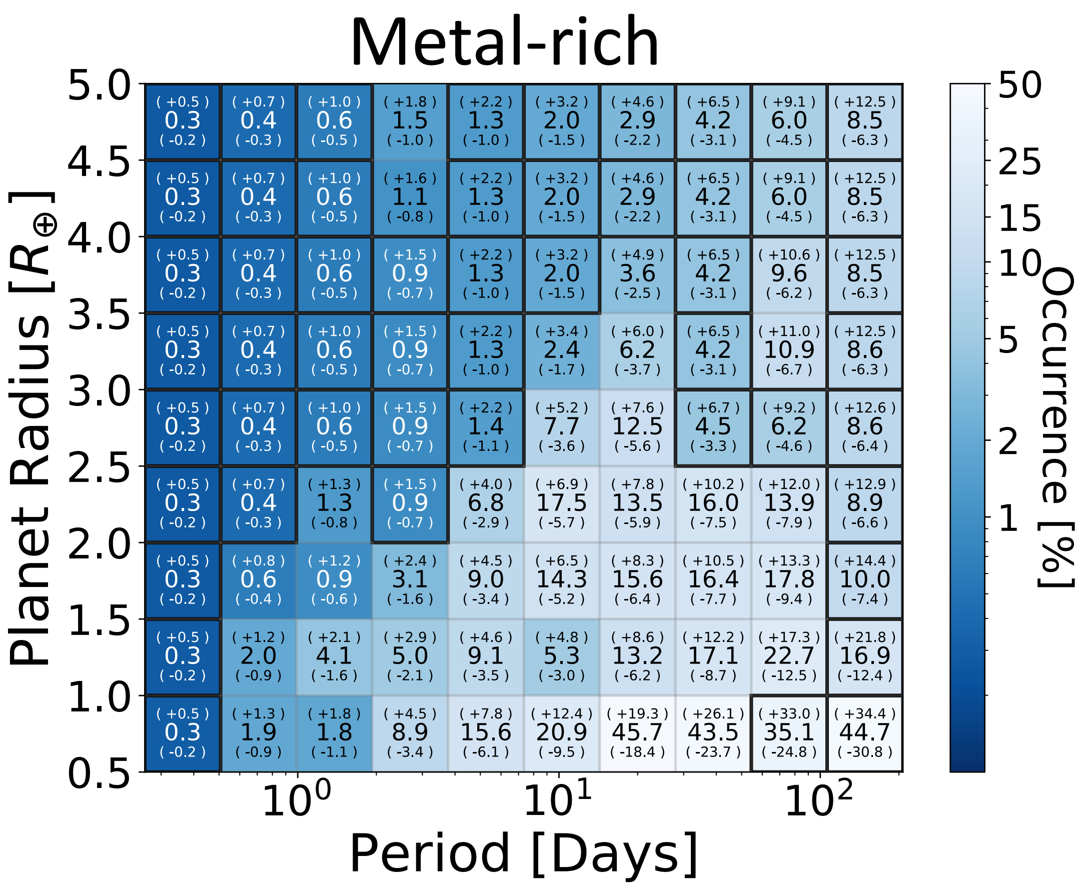




Lu et al. (2020)

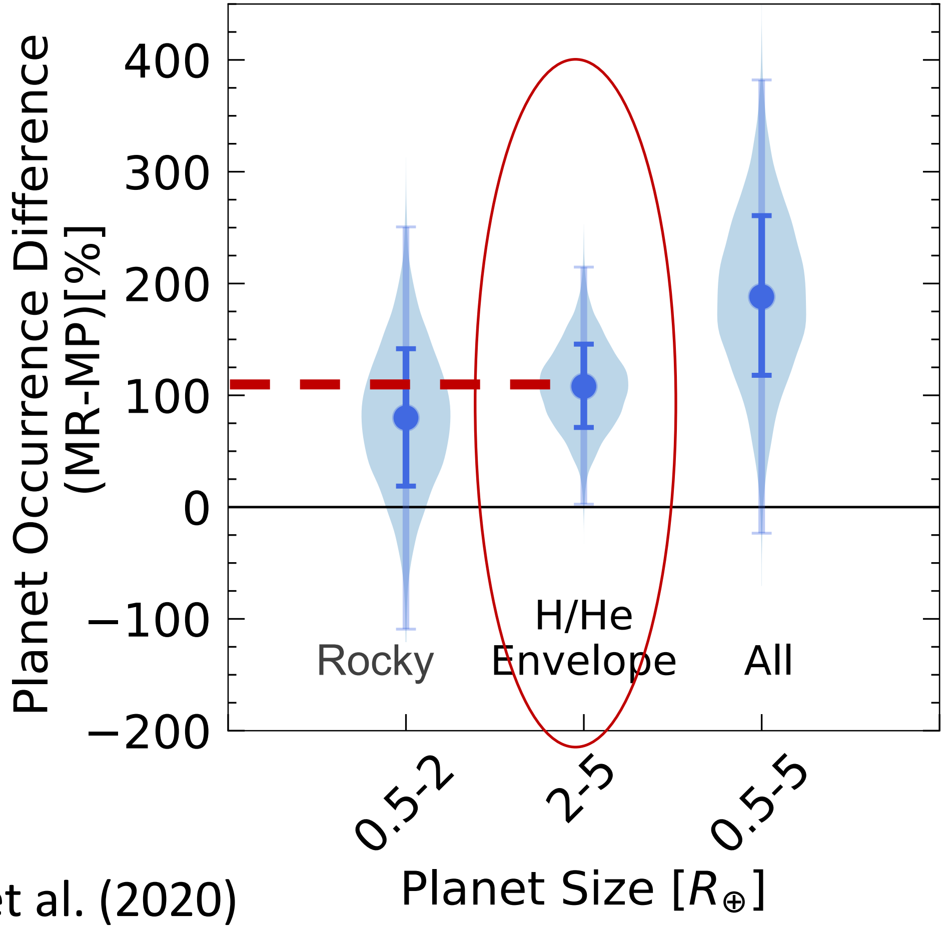
Small Planet Occurrence Increases with Host Star Metallicity

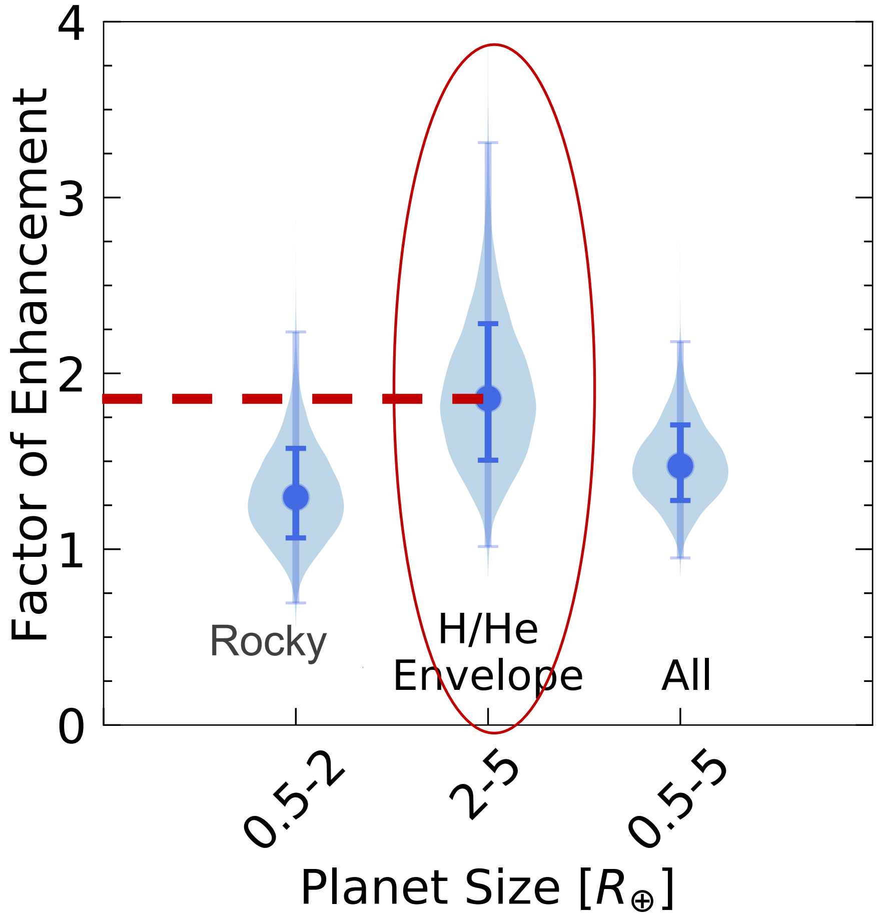




Lu et al. (2020)

Small planet occurrence rises linearly with metallicity





Lu et al. (2020)

Using planet occurrence to distinguish models of planet formation

Planetesimal accretion:

- slow
- uses ~30% of all solids

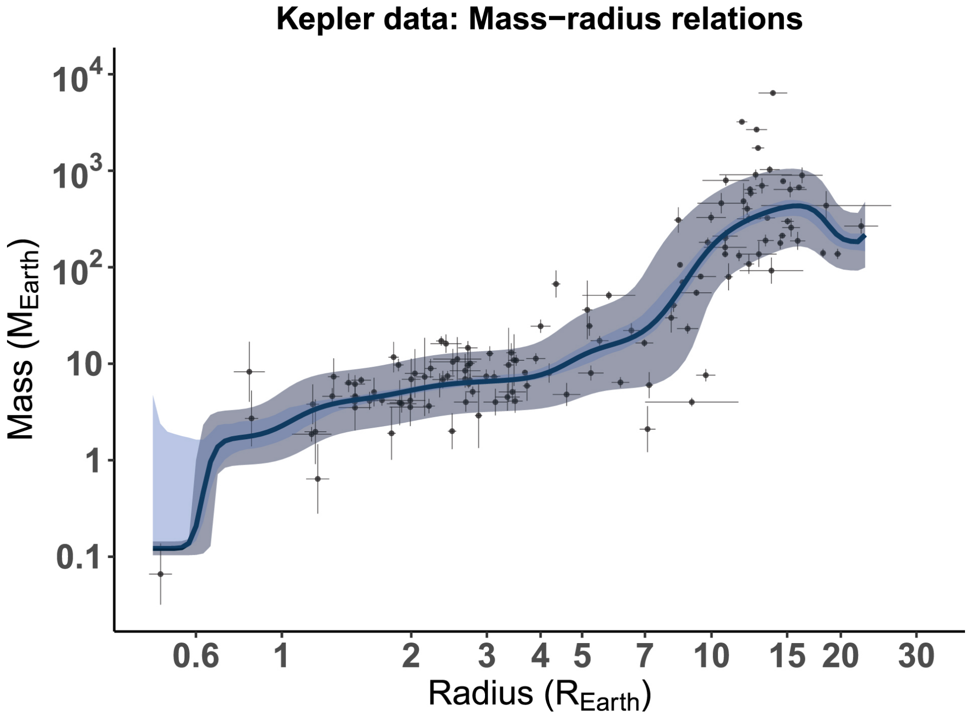
Pebble accretion:

- Fast but wasteful
- uses ~10% of all solids

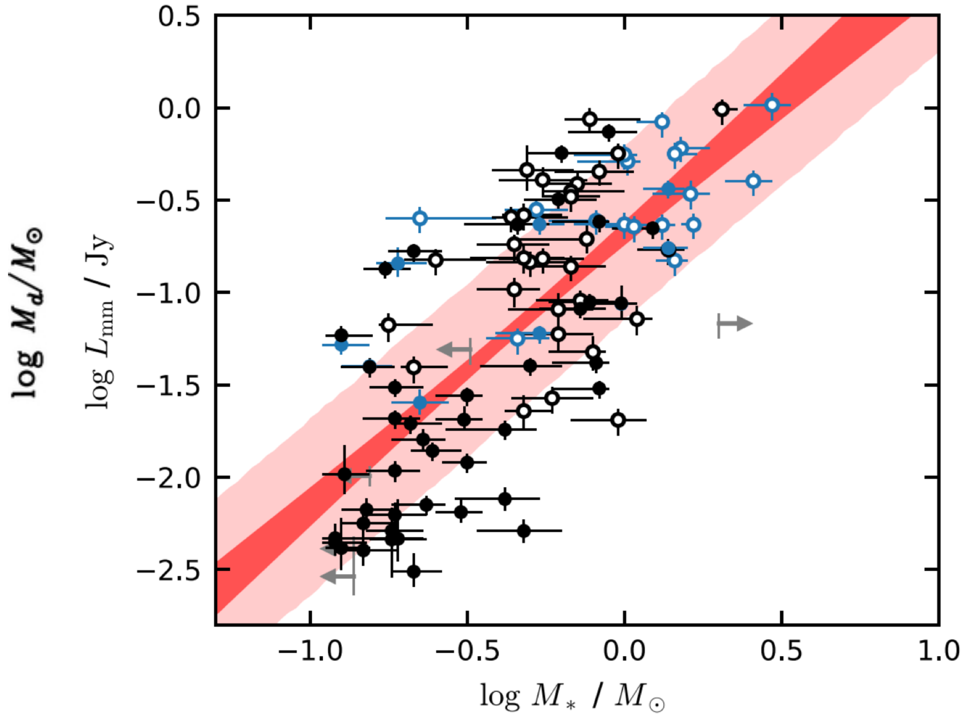
(Lin et al. 2019)

Estimate planet formation efficiency from Kepler data

Planet formation efficiency = Mass in planets/ Solids mass in the Disk



We convert sizes of planets into masses using Mass-radius relation (Ning et al. 2018 ; Kanodia et al. 2019) with *MRExo*.



Andrews et al. (2013, 2018) shows that the disk mass to is linear, with a typical disk-to-star mass ratio of ~0.5%, with which we obtain the disk mass from. We estimate the mass of solids in the disk with stellar metallicity, because metallicity is a proxy of fraction of solids in the disk.

The small planets in the Kepler field favor the planetesimal accretion model.

Sample	Expected Mass in Planets ($M_\oplus$)	Expected Mass in Disks ($M_\oplus$)
Metal-poor	$16.5^{+0.6}_{-1.8}$	14
Metal-rich	$24.5^{+0.9}_{-2.5}$	28
Complete	$13.9^{+0.5}_{-1.2}$	20

Our results shows that planet formation efficiency exceeds 50%. Therefore, we favor planetesimal accretion model.

Alternatively, the disks in the Kepler field can be more massive than that of the solar neighborhood.

Caveats:
Kepler data is limited to planets with periods less than 200 days.
If more long-period planets exist, then the planet formation efficiency can change.

Summary

- We found that for small planets with radii between 2 to 5 Earth radii, their occurrence increases linearly with stellar metallicity.
- We investigated the planet formation efficiency to constrain planet formation model. We found that the small planets in the Kepler field favors the planetesimal accretion.