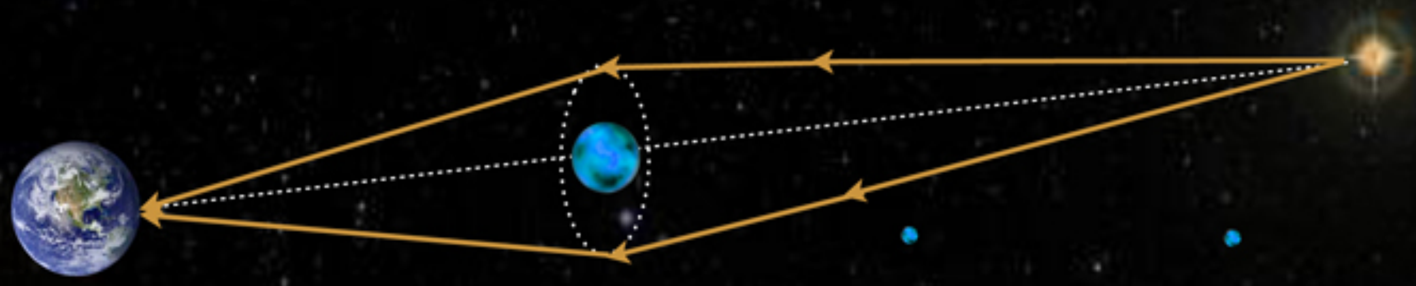
How can microlensing observations inform theories of planet formation?



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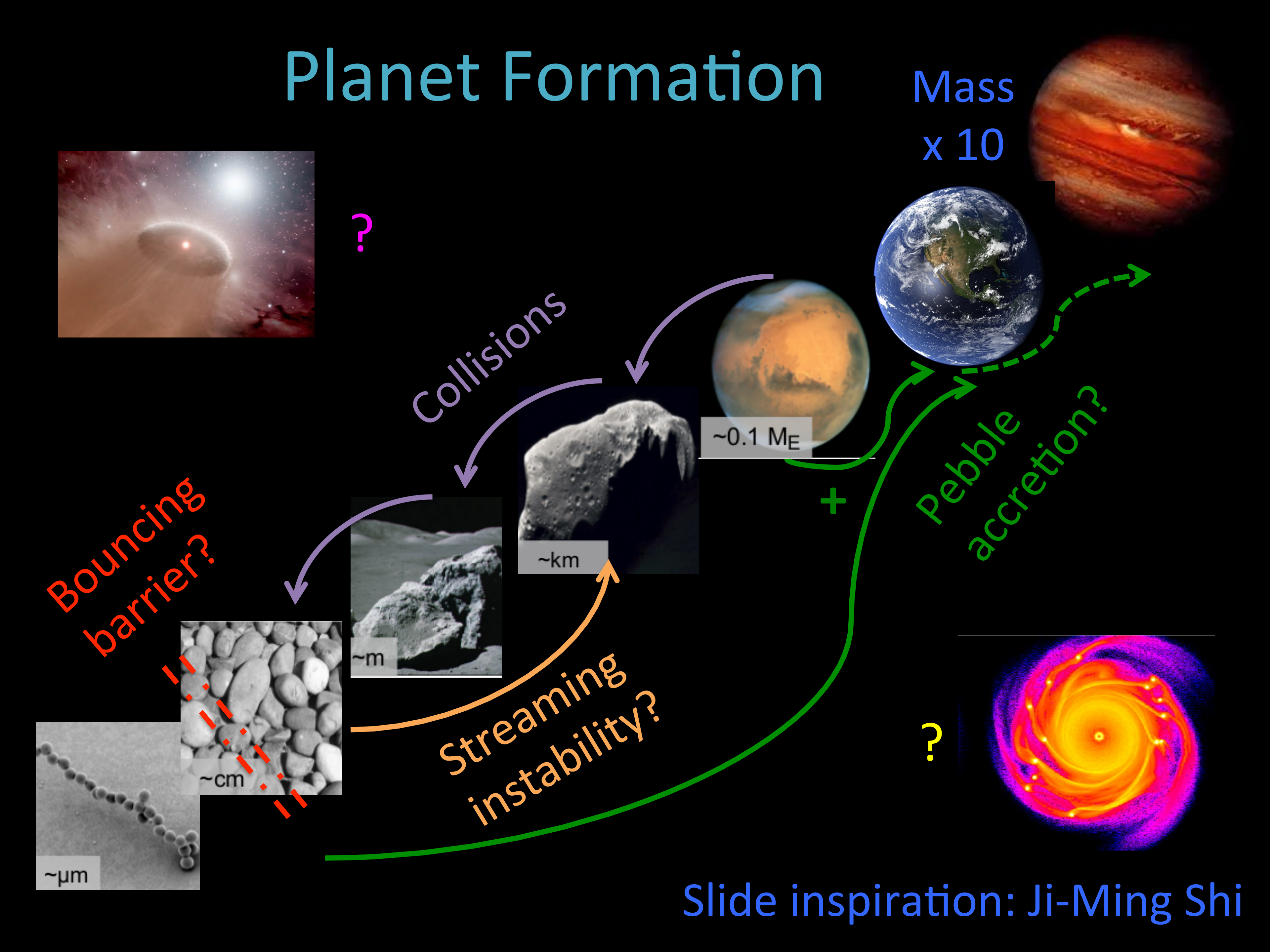
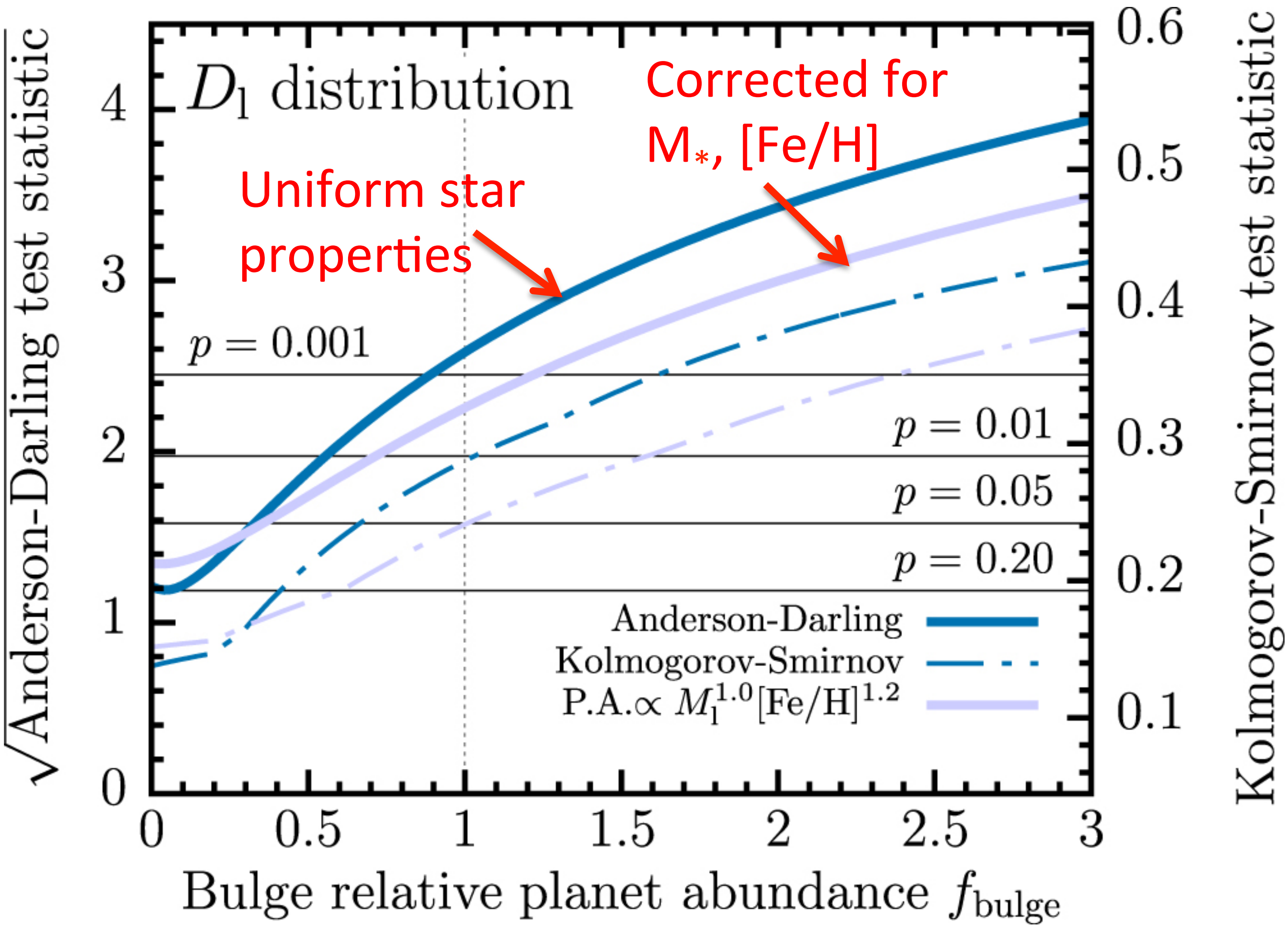
Outline

1. Introduction to planet formation
2. How does planet-forming efficiency depend on *cosmic time* and *Galactic environment*?
3. How much does *pebble accretion* contribute to Galaxy's giant planet inventory?
4. Is *disk instability* a viable planet, brown dwarf, or star-forming pathway?
5. Conclusions and future work

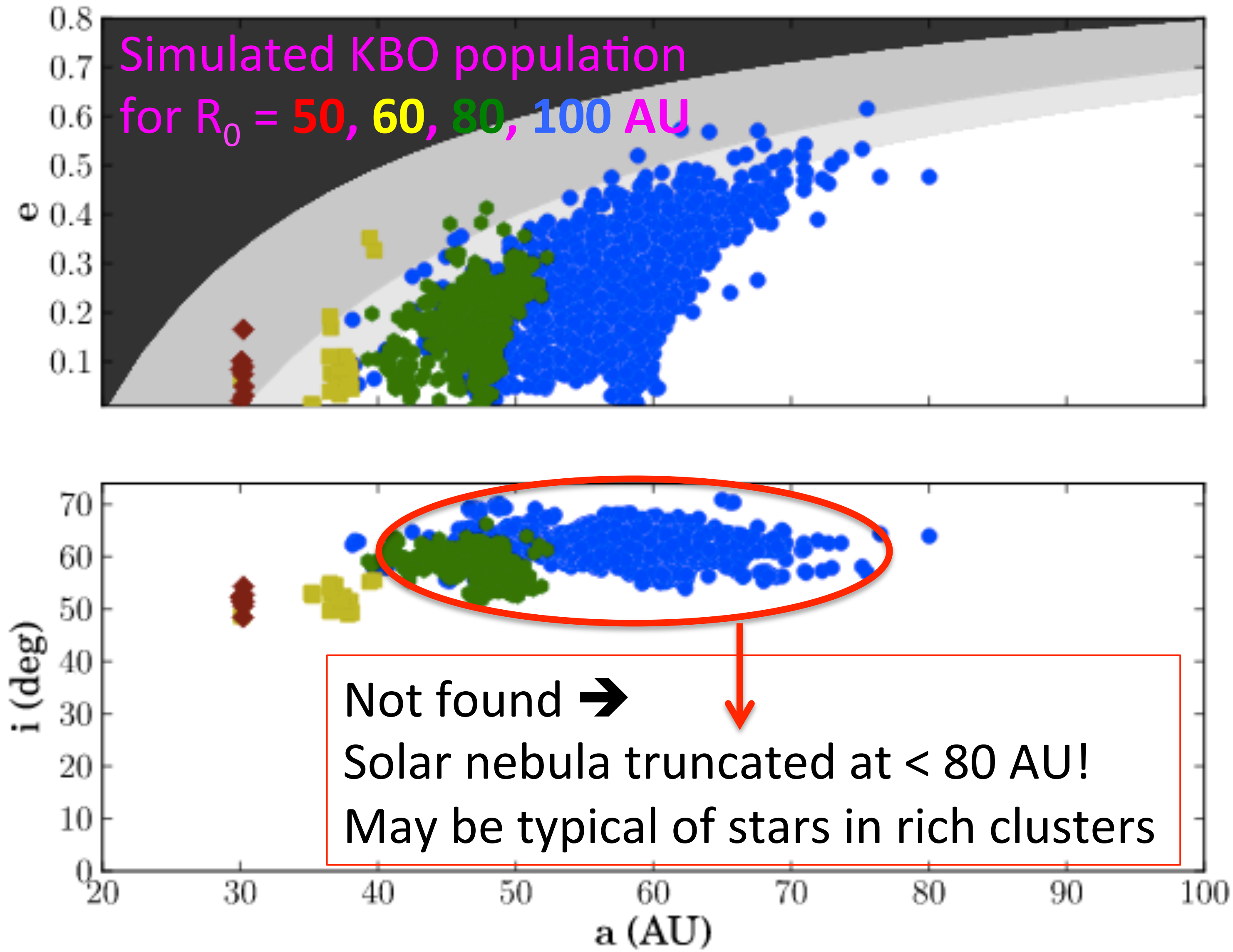

Planet Formation
Mass
x 10
?
Collisions
~0.1 M_E
~km
~m
~cm
~μm
Bouncing
barrier?
Streaming
instability?
+
Pebble
accretion?
?
Slide inspiration: Ji-Ming Shi

Galactic Environment: Bulge vs. Disk



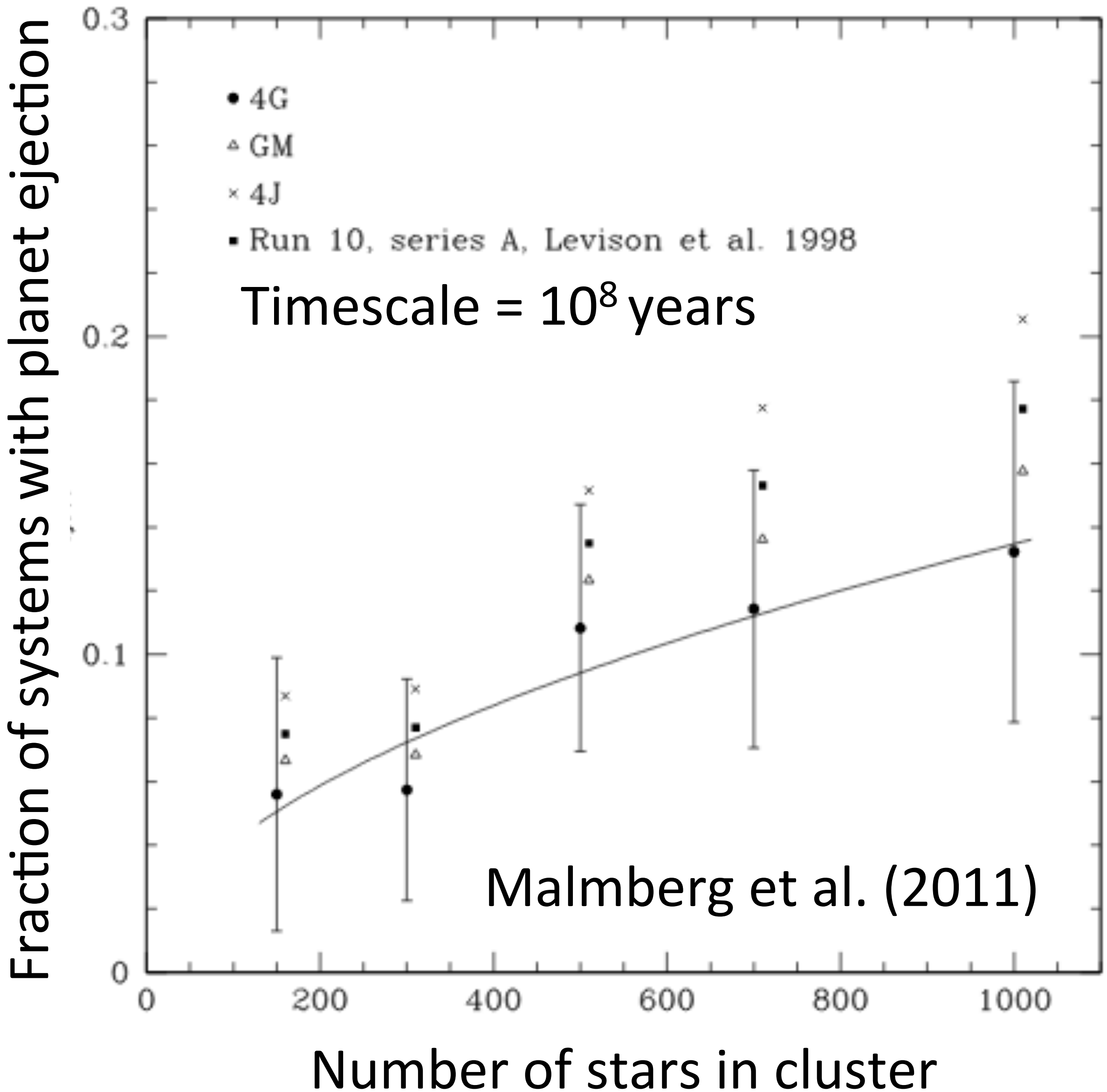
Penny, Henderson & Clanton 2016

Disk Truncation in Bulge?



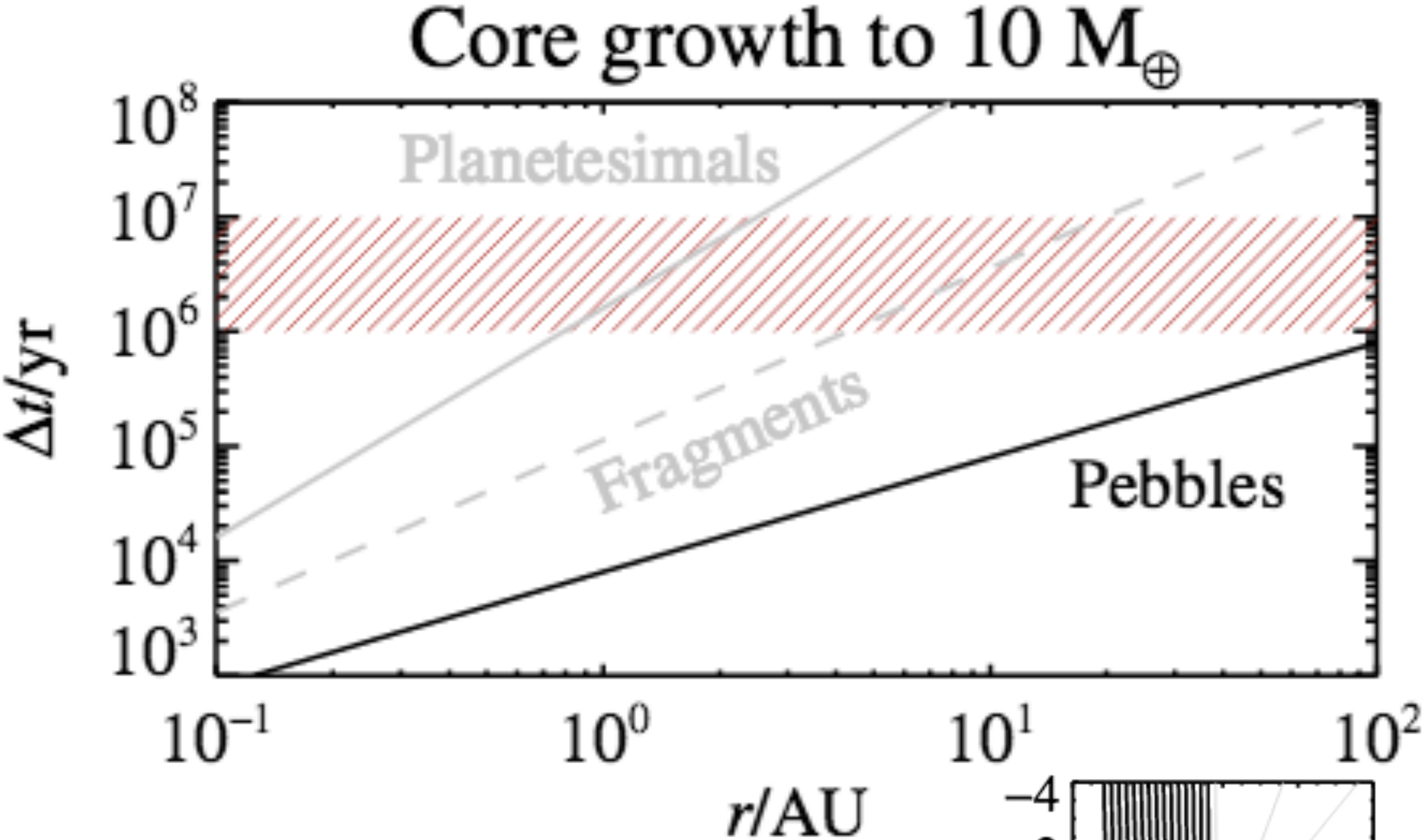
Kretke et al. (2012)

High Planet Ejection Rate in Bulge?

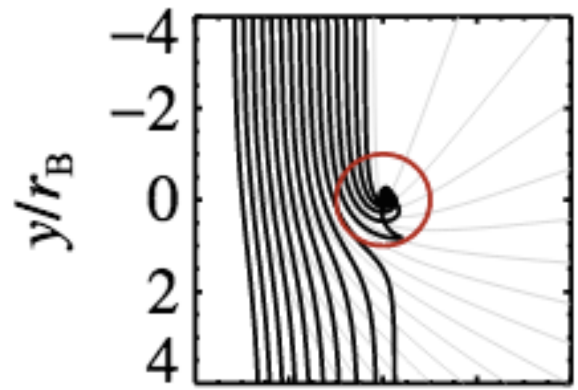


Penny et al. (2016) paper included only bound planets…
…could we distinguish between disk truncation and
planet ejection by measuring f_{bulge} for free-floaters?

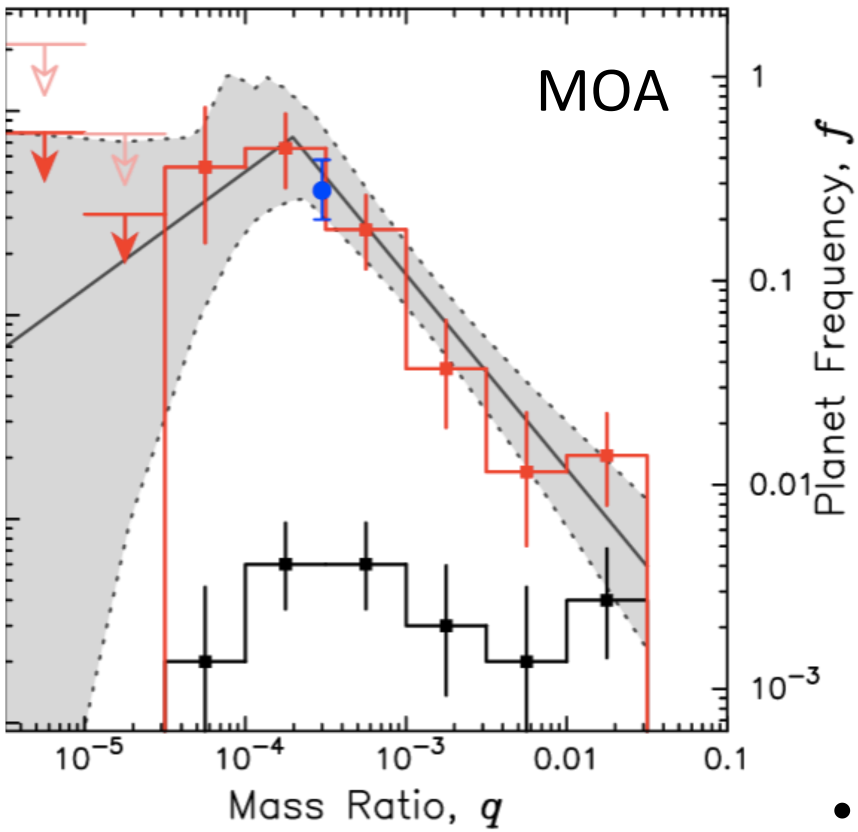
(Food for thought: Clanton & Gaudi [2017] find more free-floaters than wide-orbit planets from Sumi et al. survey)



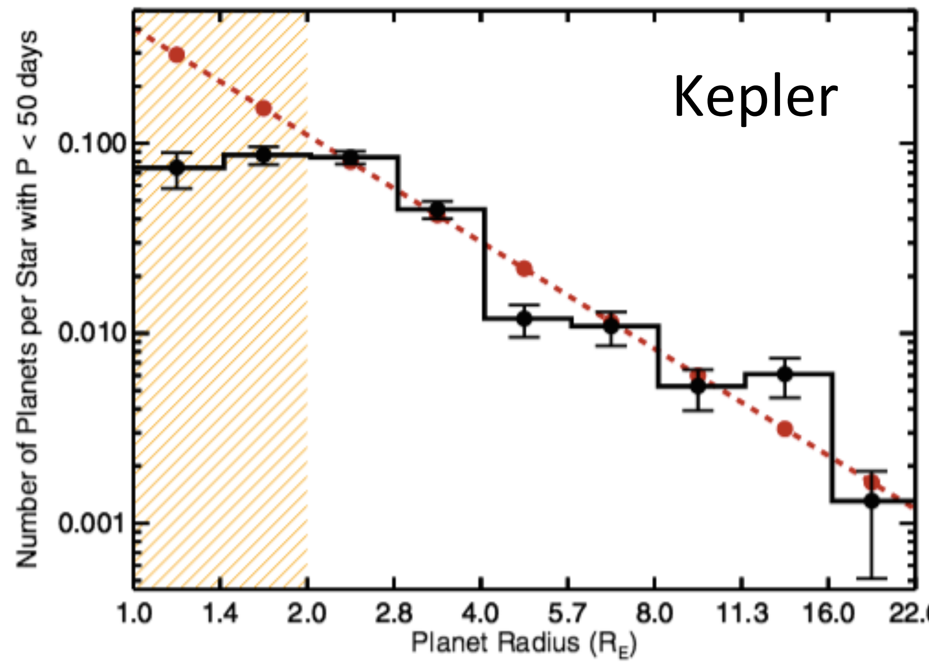
Lambrechts & Johansen (2012)



Planet Sizes



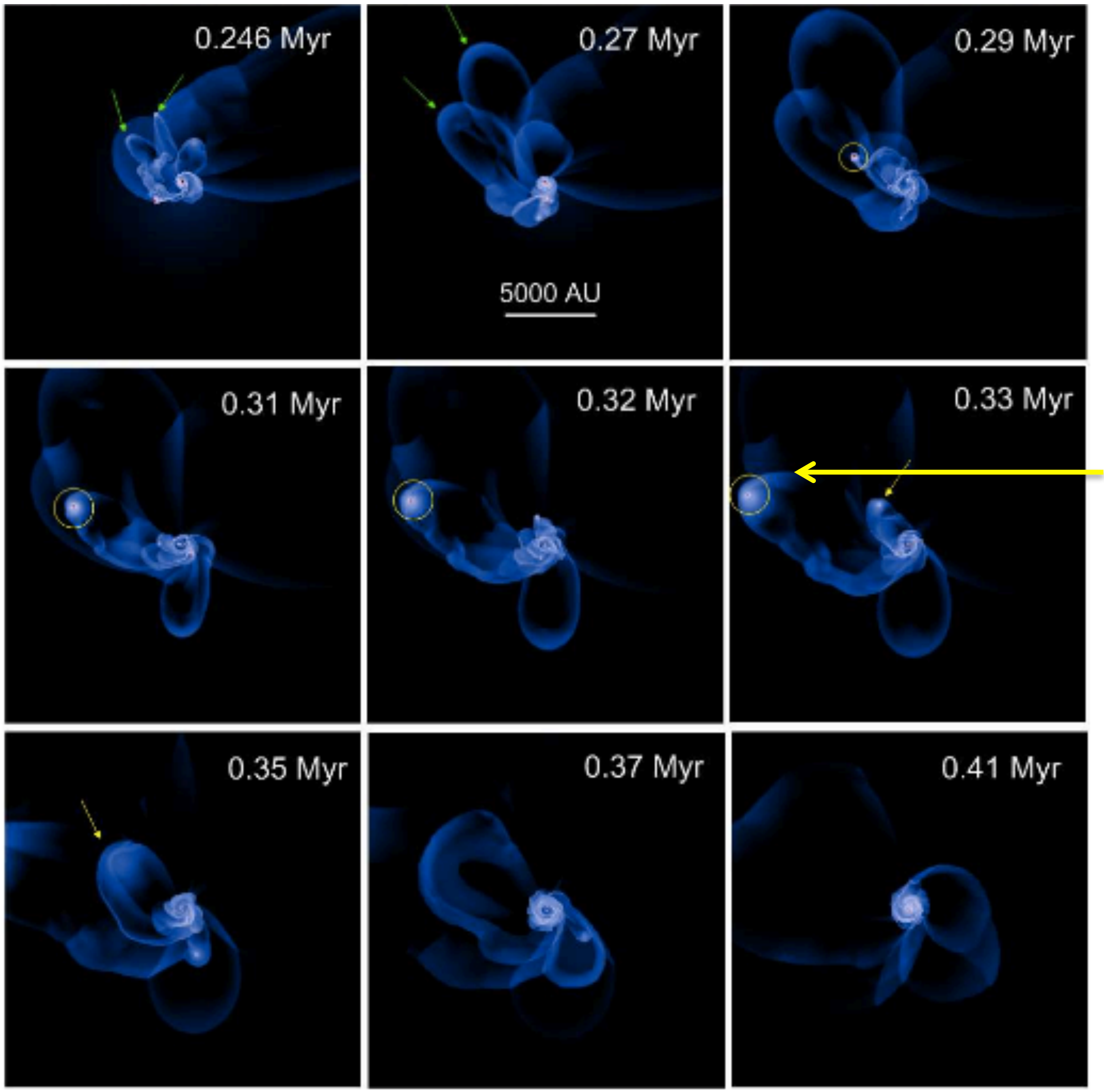
Suzuki et al. (2016)
Peak mass is Neptune for average $M_* = 0.6\ M_{sun}$



Howard et al. (2012)

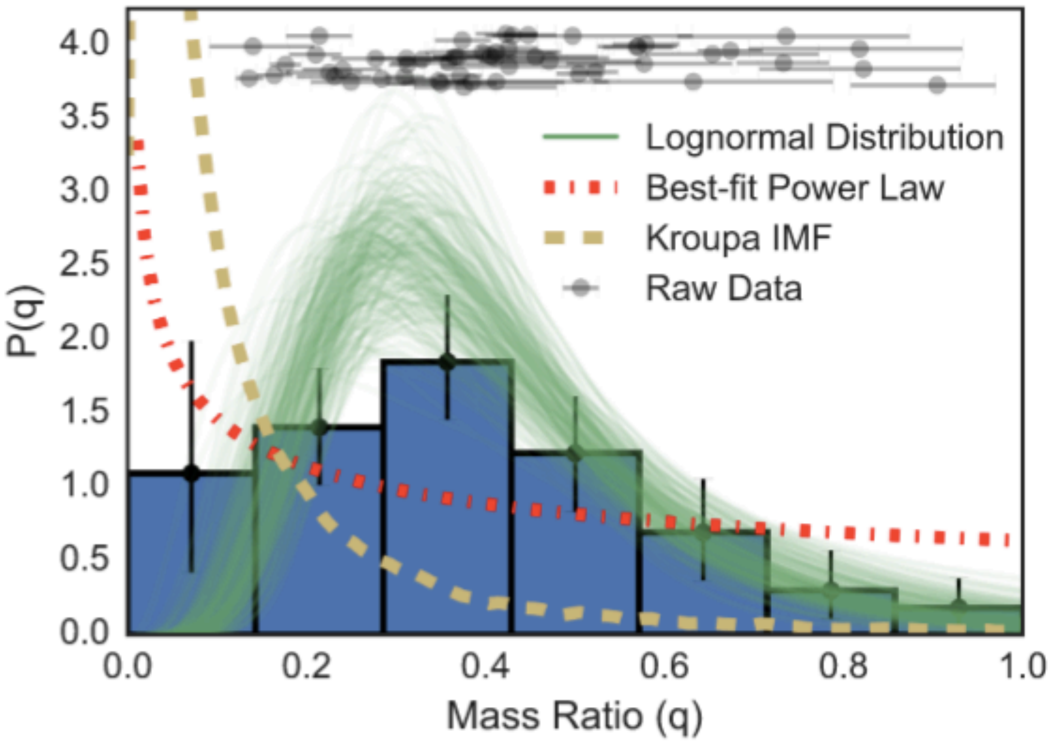
- Planets on wide orbits may be more massive than short-period ones, even with migration
- Suggests either long-lived disks, or efficient formation: pebbles?

Disk Instability → Free Floater?

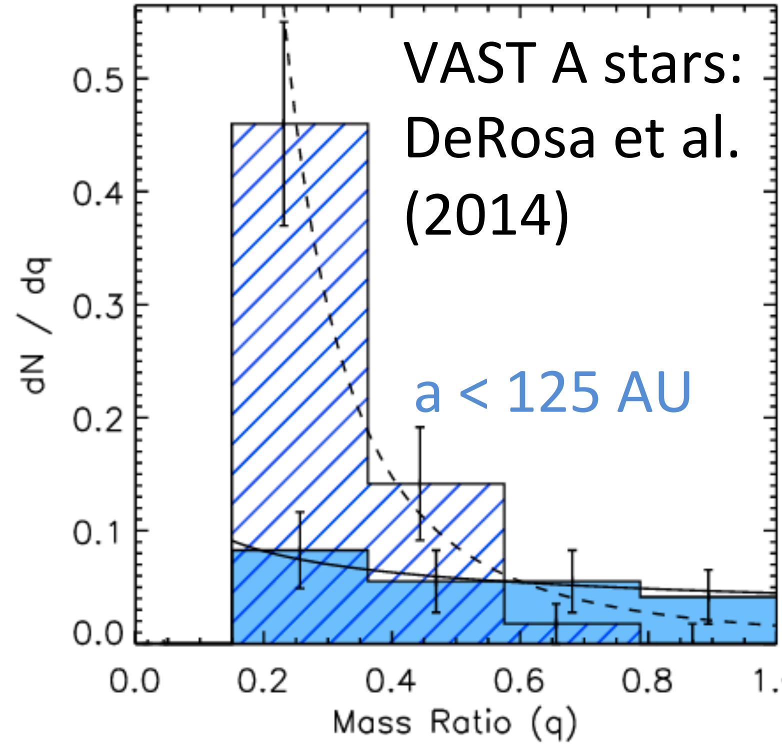


Vorobyov (2016): Clump survives ejection, becomes free-floater

Disk Instability ➔ Bound System?

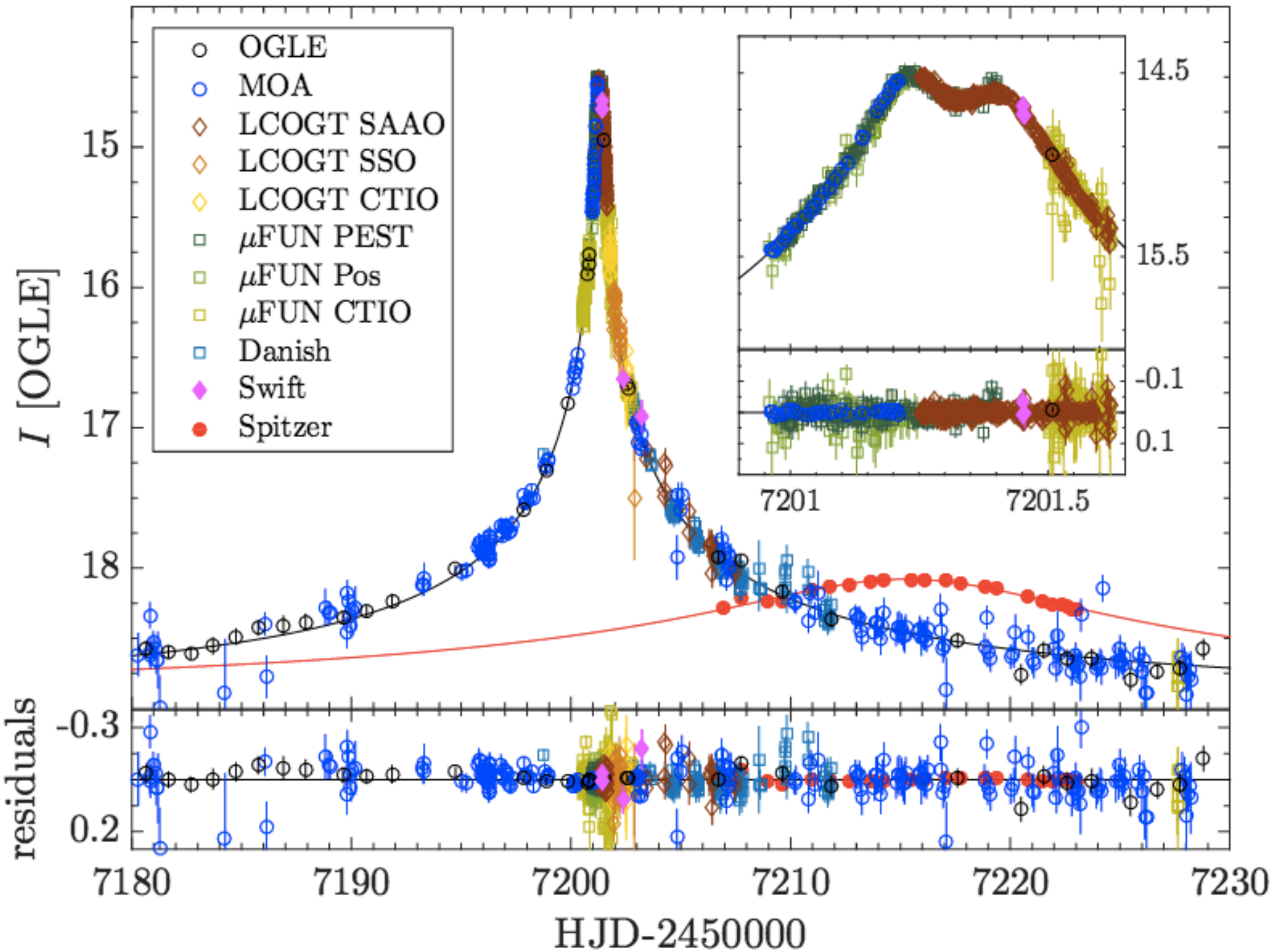


Gullikson, Kraus, D-R 2016



- Preferred mass ratio suggests disk instability (Clarke et al. [2001])
- Why use A stars? Because *secondary at preferred mass ratio is a star*! Much easier than brown dwarf

Brown Dwarfs and Binaries



Shvartzvald et al. (2016)

BD / star mass ratio: q = 0.04-0.13

We care about brown dwarfs (orbiting and free-floating) AND binaries!

Please publish statistics!

…companions may have “downsized” through cosmic time as primaries get less massive and gas gets more metal-rich. Do the bulge and disk have the same brown dwarf/binary occurrence rates?

Conclusions

Microlensing can help us figure out:

- How was the planet-forming environment different in the disk vs. the bulge?
- How chaotic is a planet's progress up the size scale? (Traditional core accretion is mostly steadily upward, while pebble accretion requires intermediate breakdown / backfill)
- How many companion formation mechanisms are there? (Star, planet, disk instability?)

Yes binary stars and brown dwarfs!