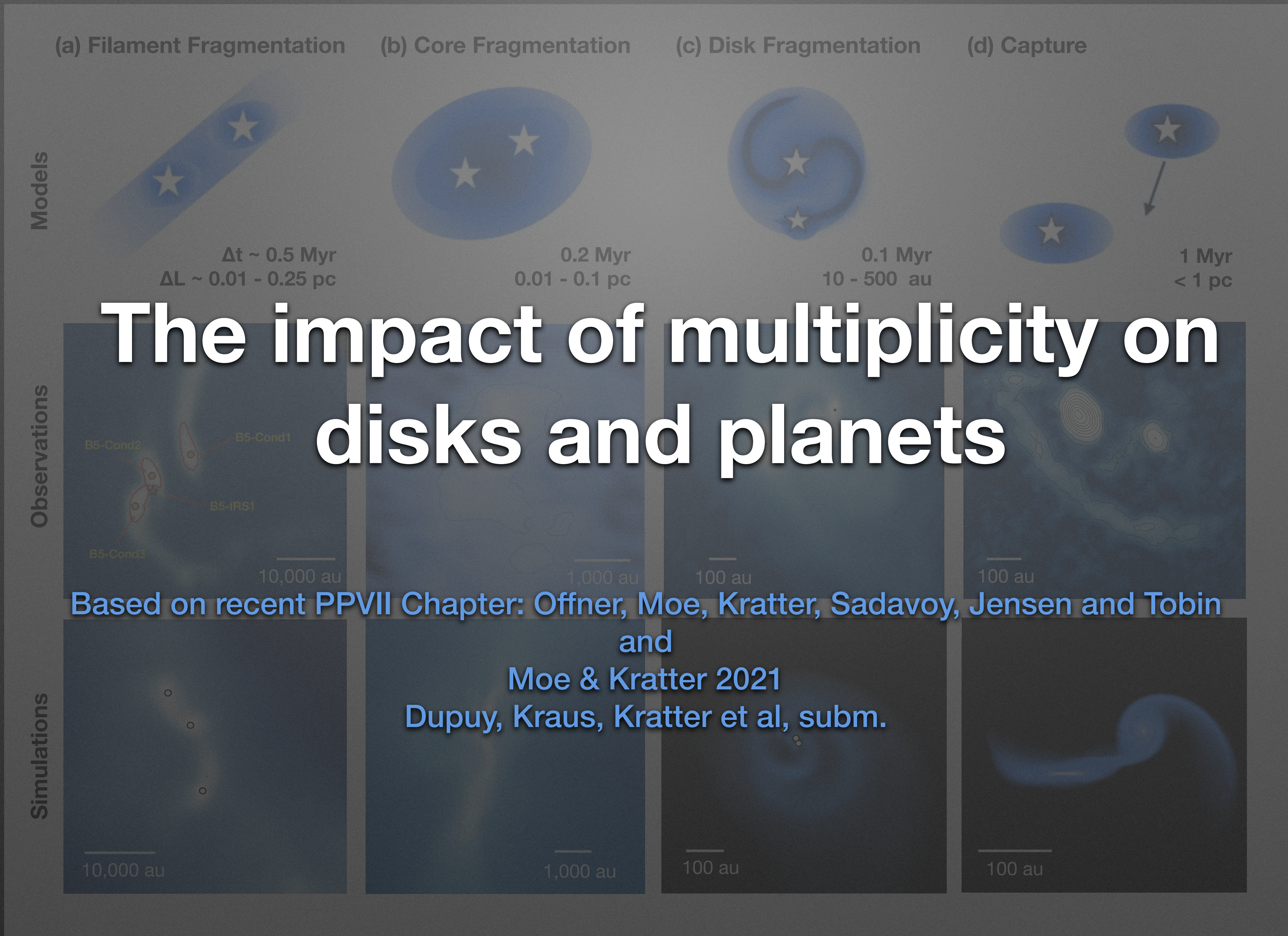
The impact of multiplicity on disks and planets



Based on recent PPVII Chapter: Offner, Moe, Kratter, Sadavoy, Jensen and Tobin

and

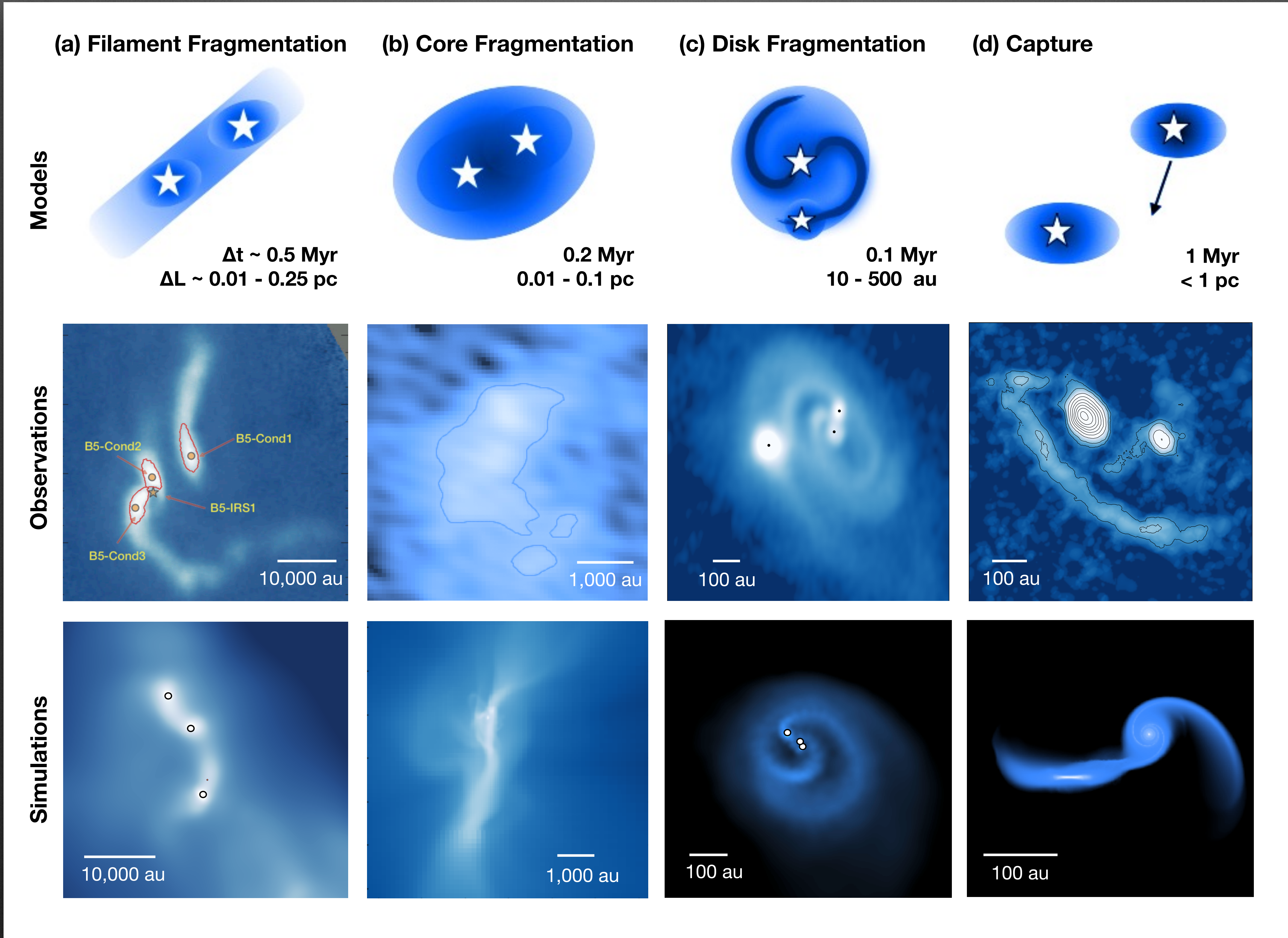
Moe & Kratter 2021

Dupuy, Kraus, Kratter et al, subm.

Outline

- Review of binary formation mechanisms
- Review of stellar multiplicity data
- Model and data comparison
- Impact on disk statistics and structure
- Impact on planet formation / occurrence rates

please jump in and interrupt me!



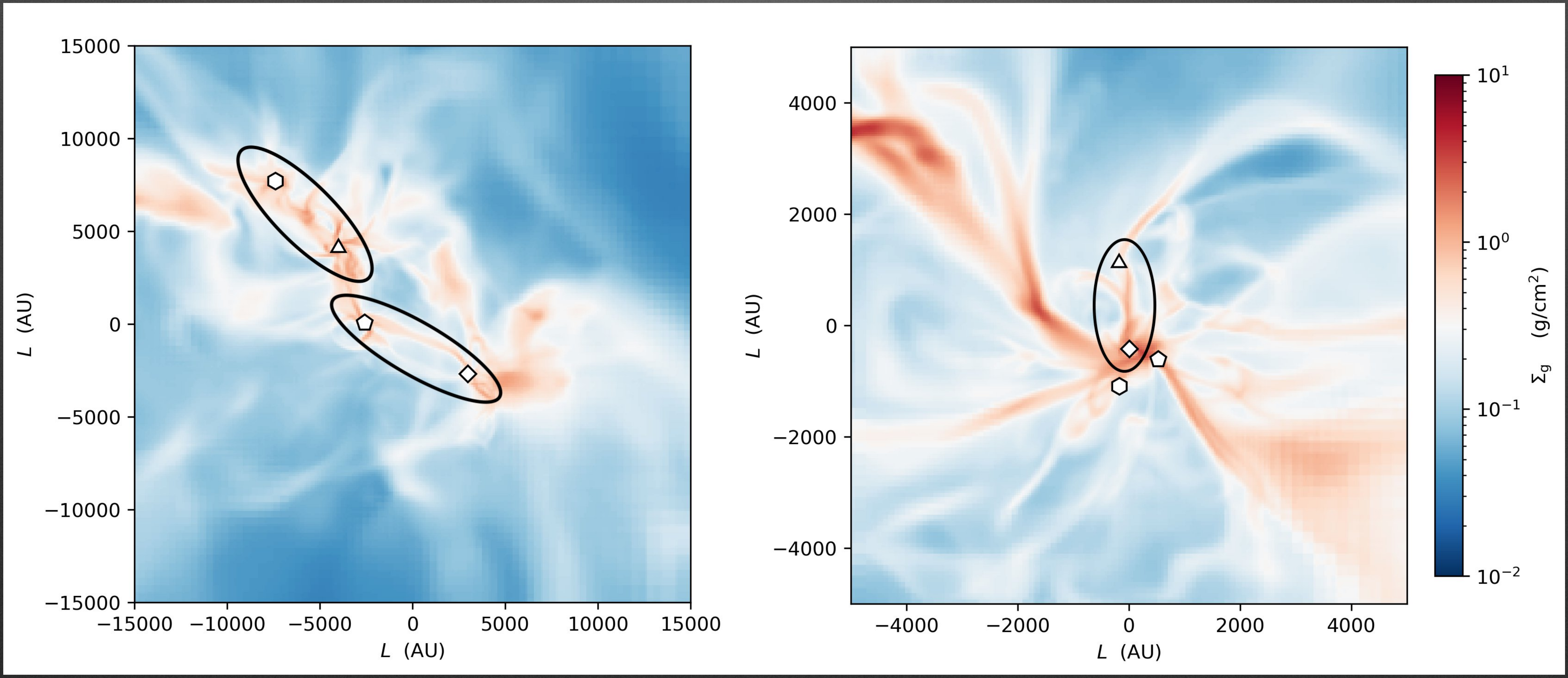
Binary Formation

Offner+ PPVII

Turbulent Fragmentation and "Capture"

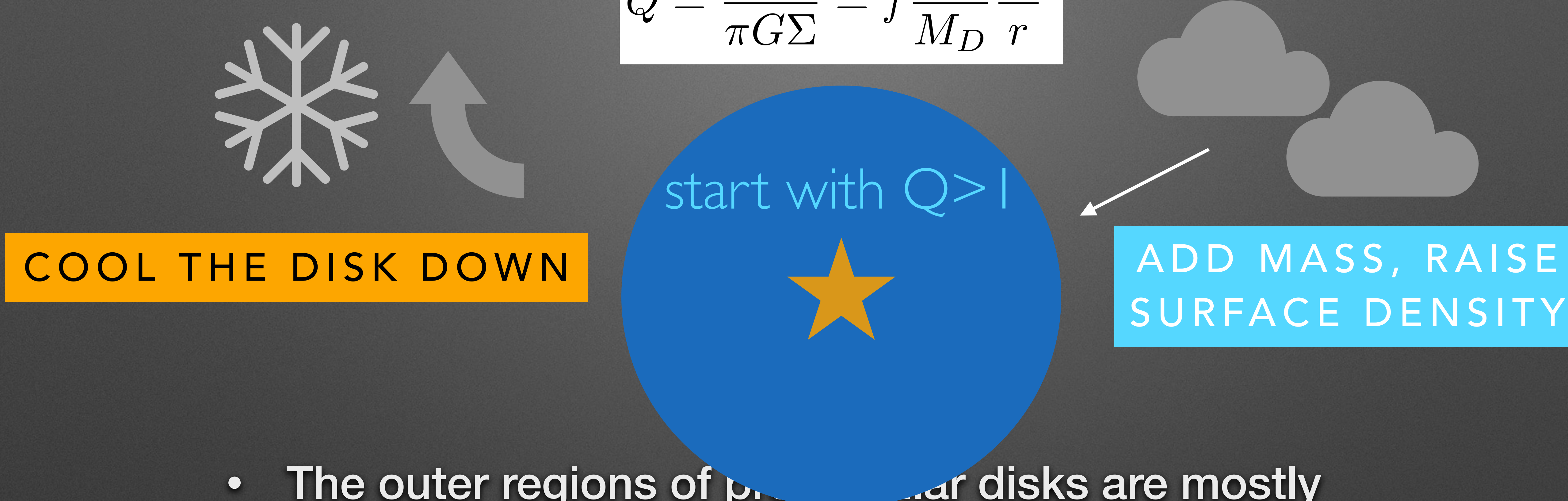
- Conditions for wide binary formation remain uncertain, but multiples tend to arise in cores that form from intersecting filamentary structures (Smullen,KMK+2020)

- Partner swapping is common early, and orbits evolve very quickly, but not traditional "capture" (Lee, Offner, KMK+2019)



How do disks become unstable? Typically by rapid accretion

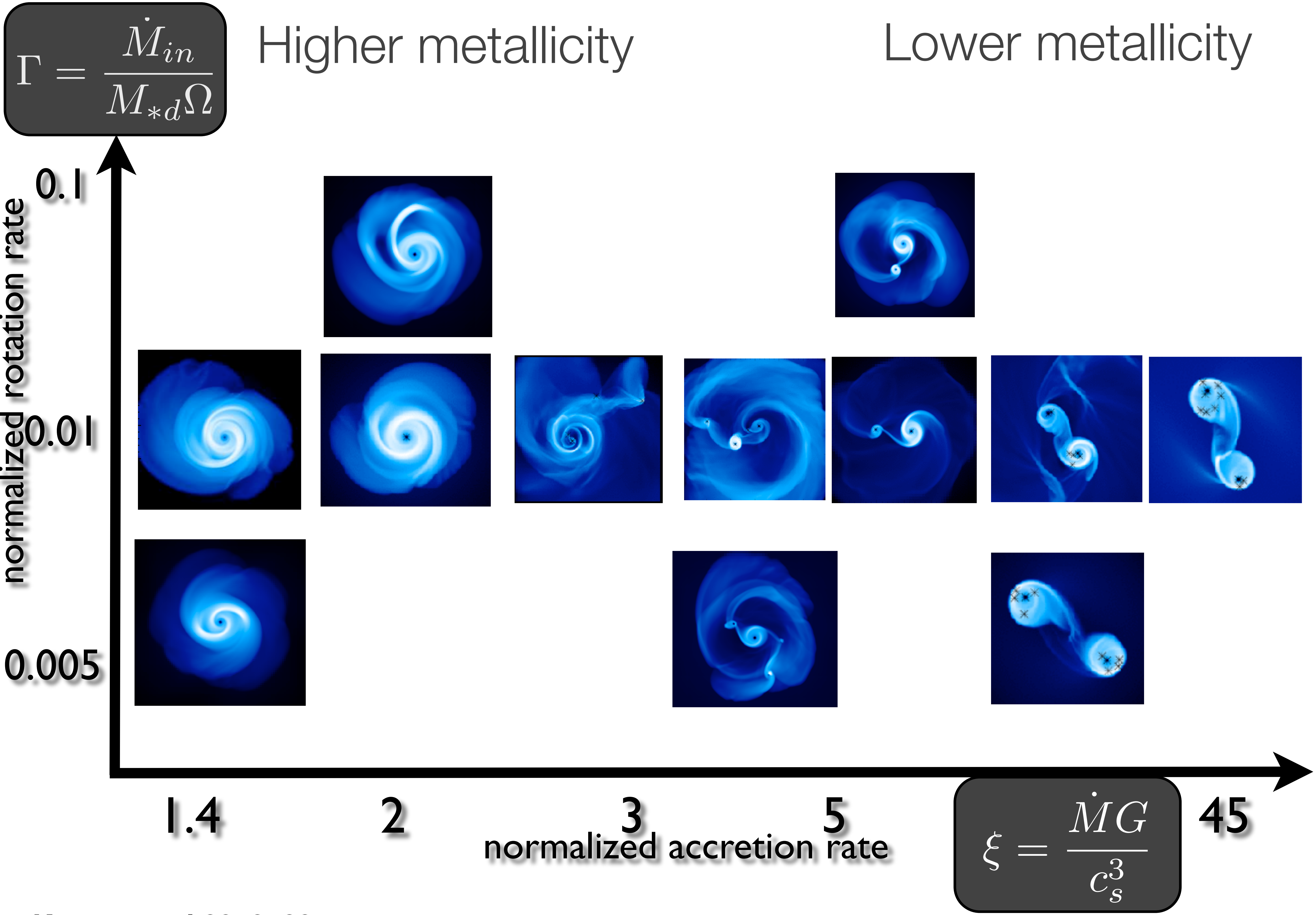
$$Q = \frac{c_s \Omega}{\pi G \Sigma} = f \frac{M_*}{M_D} \frac{H}{r}$$



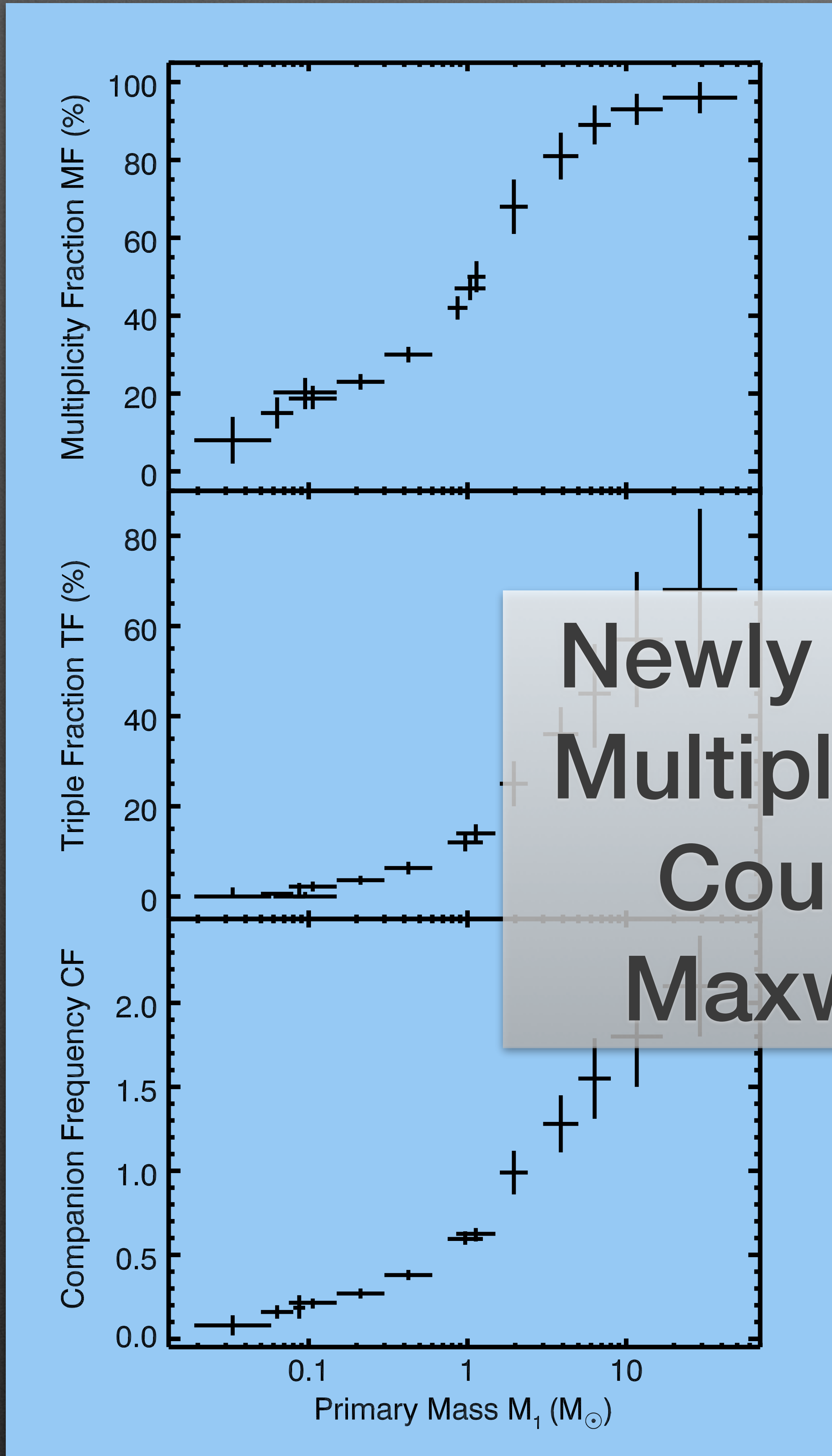
- The outer regions of pr... ...lar disks are mostly heated by stellar irradiation (not internal dissipation like many AGN), which fixes the temperature.

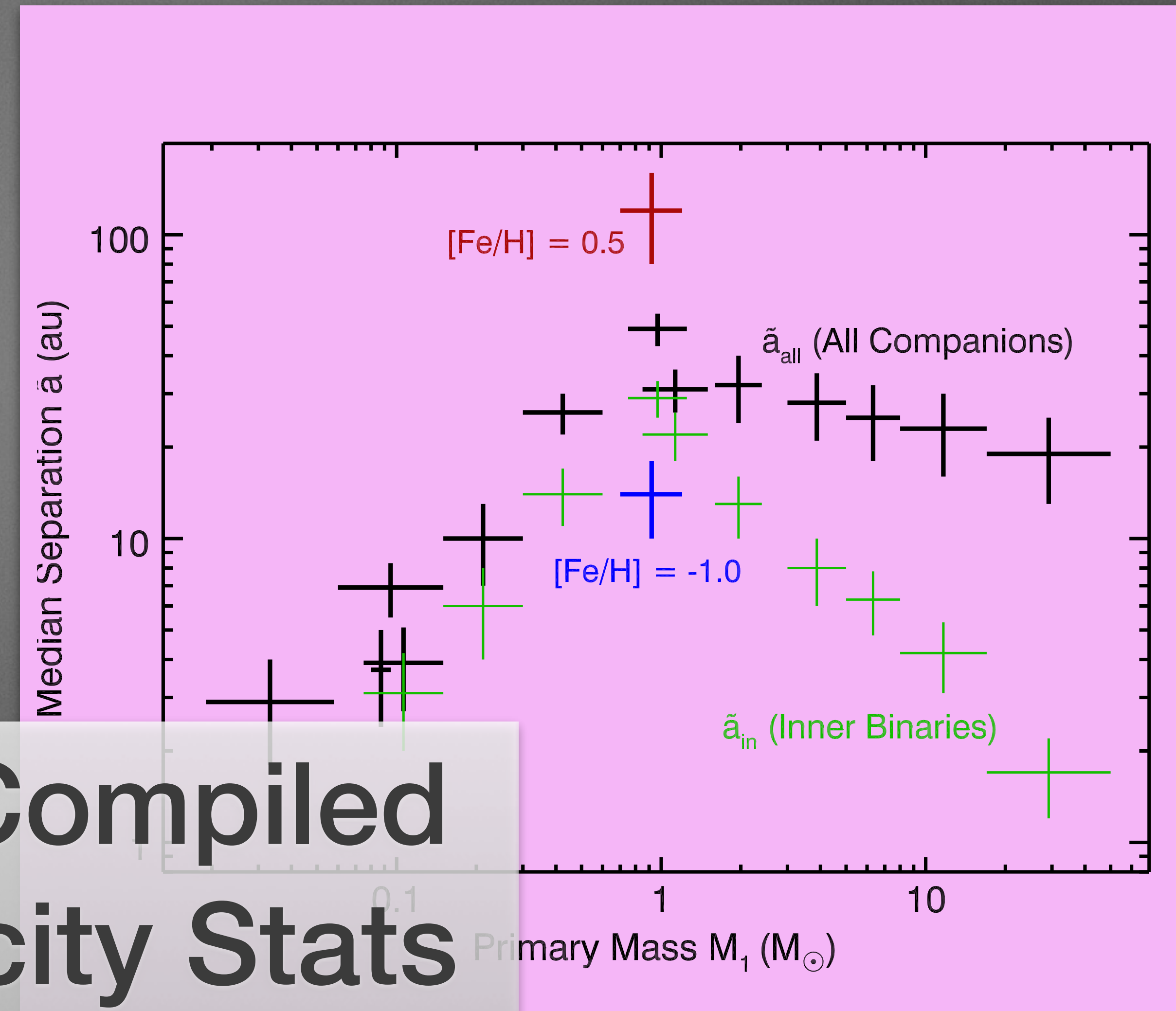
- Optical depth, cooling, set by dust and overall metallicity (keep this in mind)

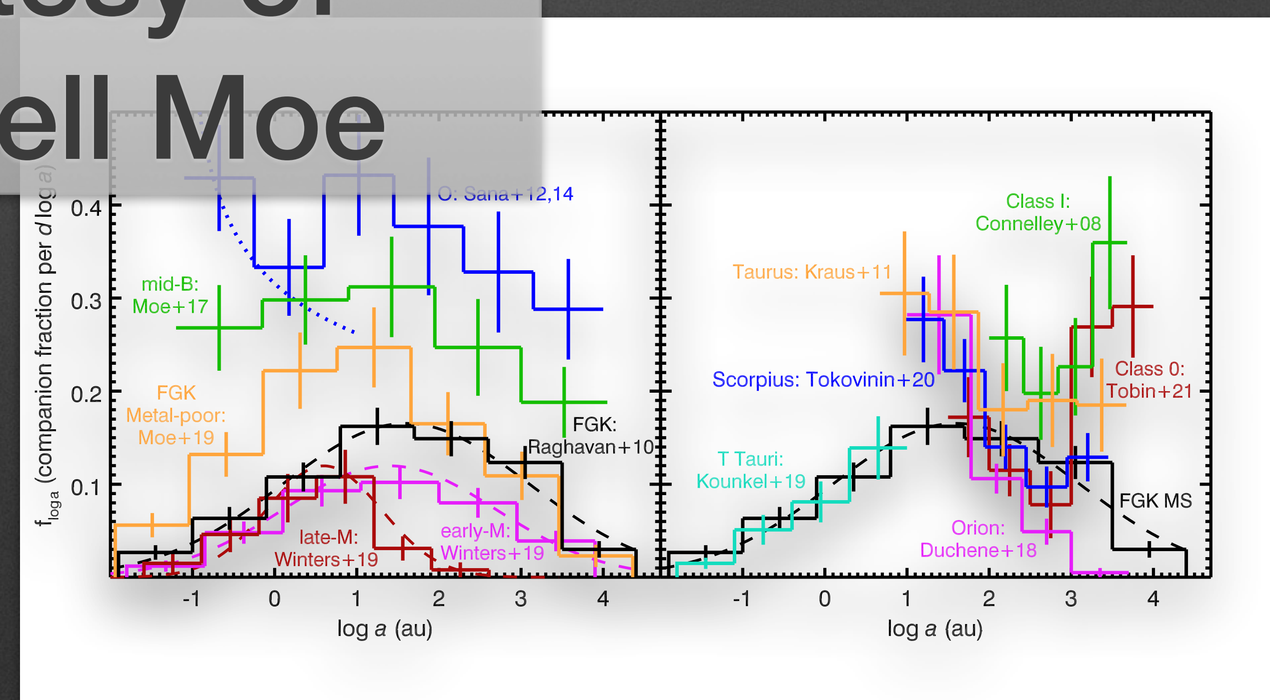
Accretion-driven instability makes binaries NOT planets!



Kratter et al 2010, 2011







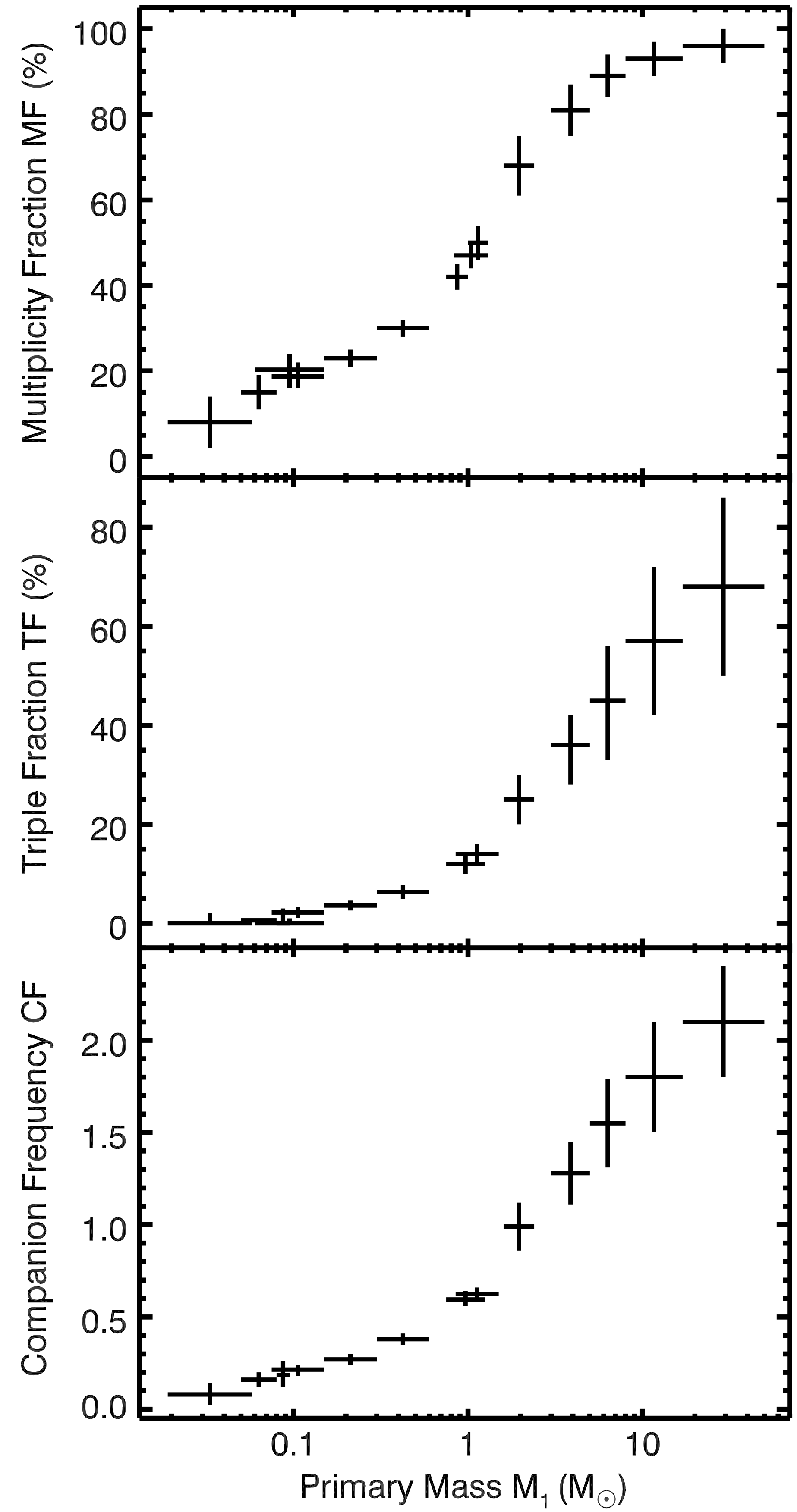
Newly Compiled Multiplicity Stats Courtesy of Maxwell Moe

Offner+ PPVII

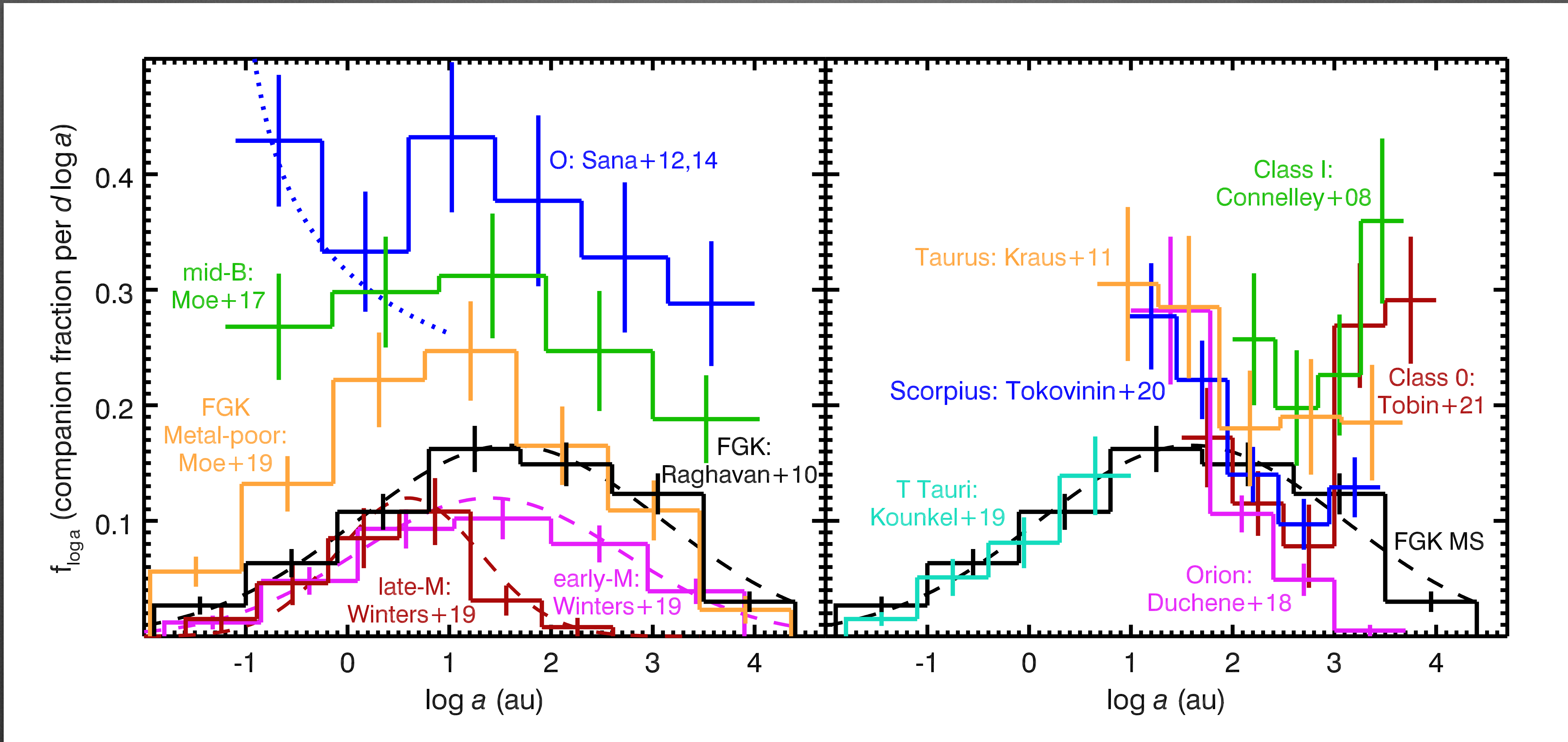
Comprehensive multiplicity stats

- Increasing MF (fraction of systems that are multis) with system mass
- Increasing TF (fraction that are triples)
- Increasing CF (average number of companions per system)

What's new?
Smaller error bars, compiled stats for M-dwarfs absent from other reviews

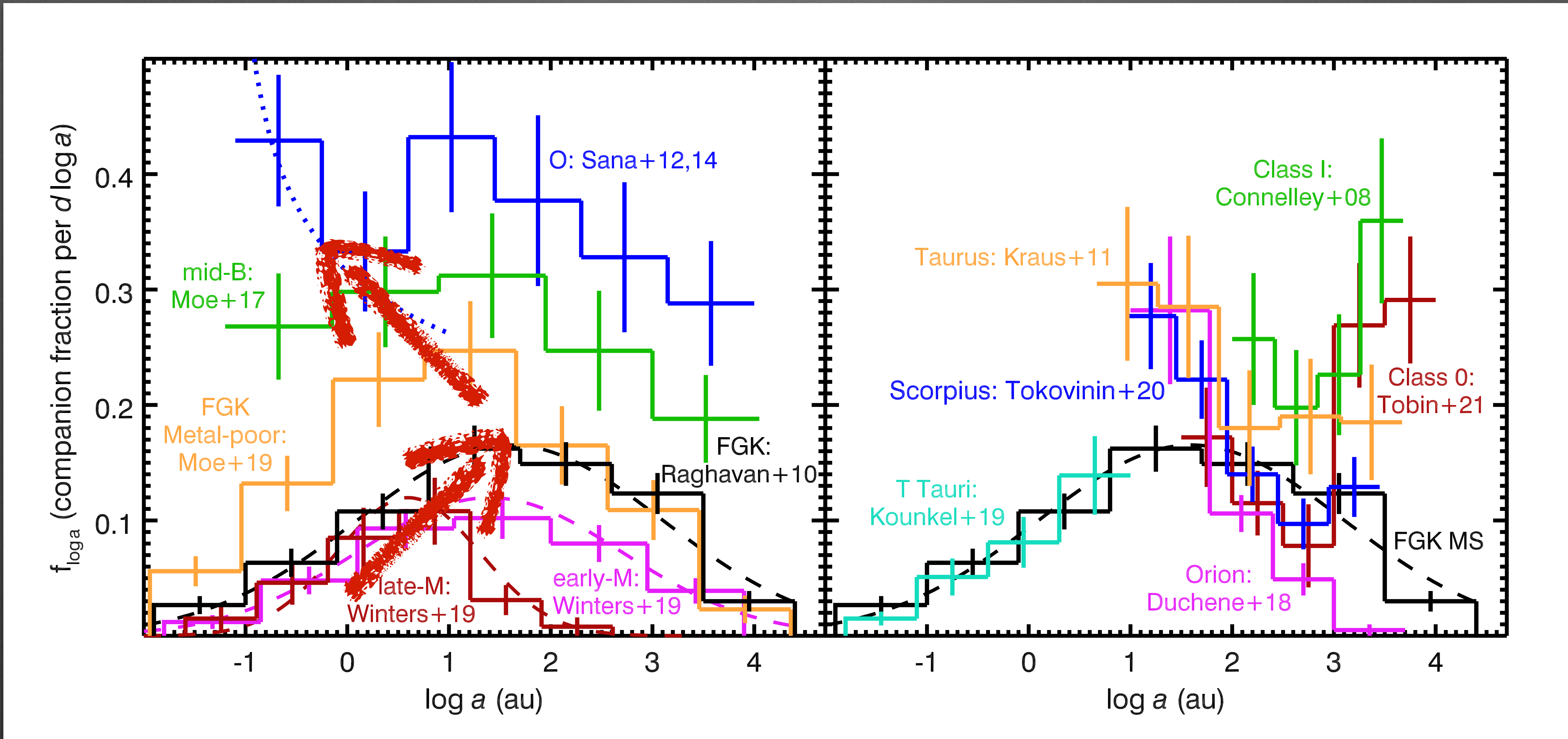


Offner+ PPVII



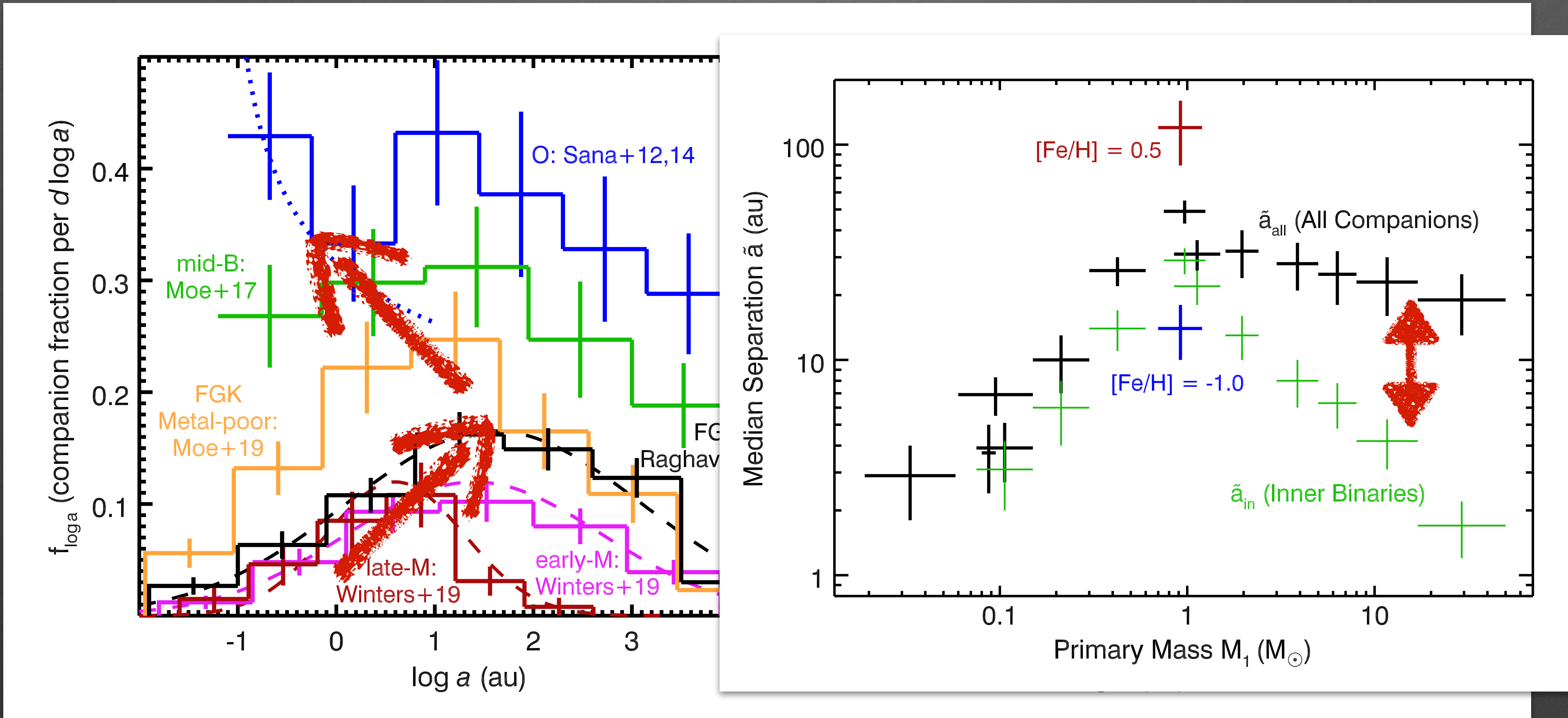
Separation distributions: protostars, PMS, and field as a function of mass

Offner+ PPVII



1. Peak separation moves out, then back in. Abundance of close massive binaries masked by triples

Offner+ PPVII



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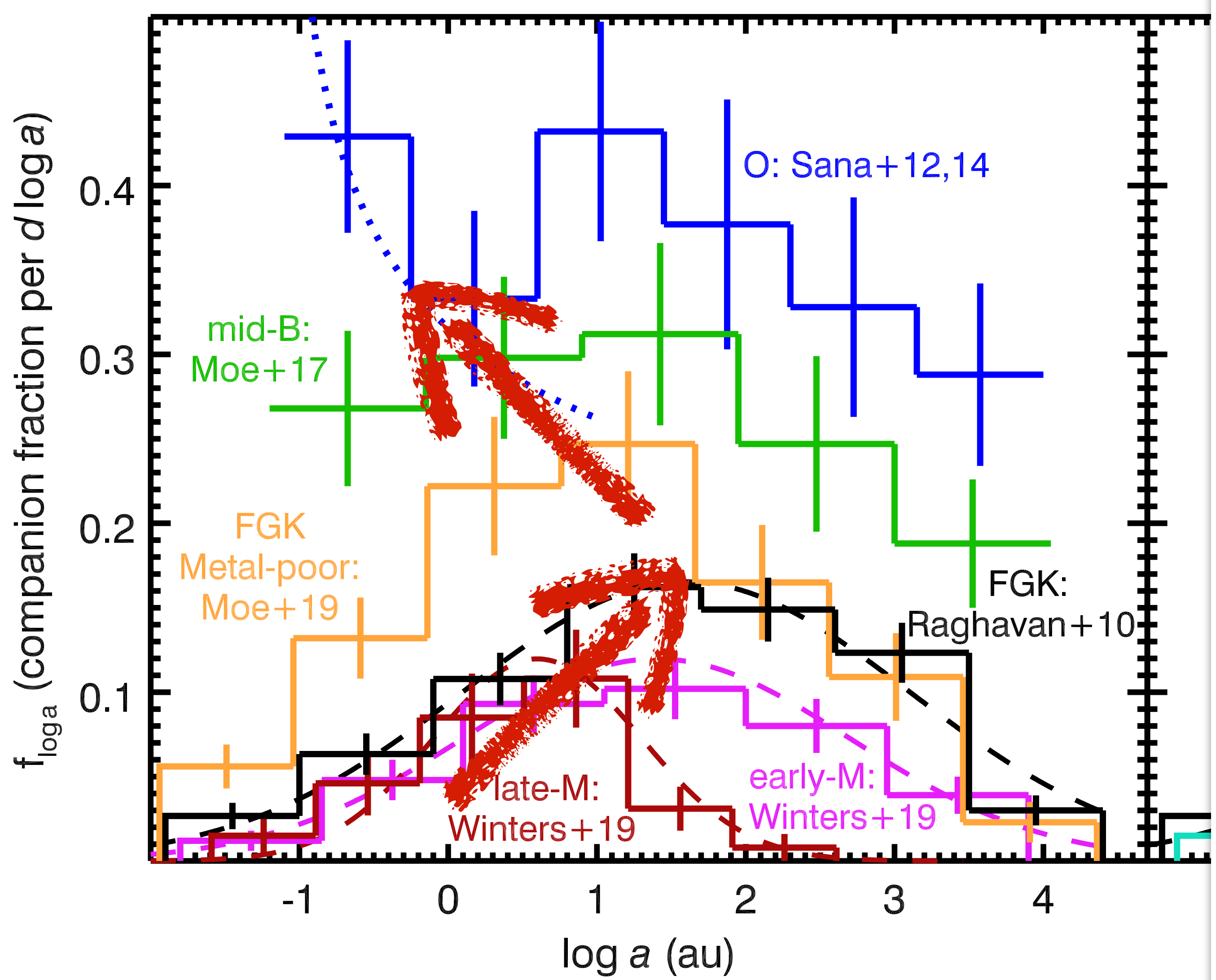

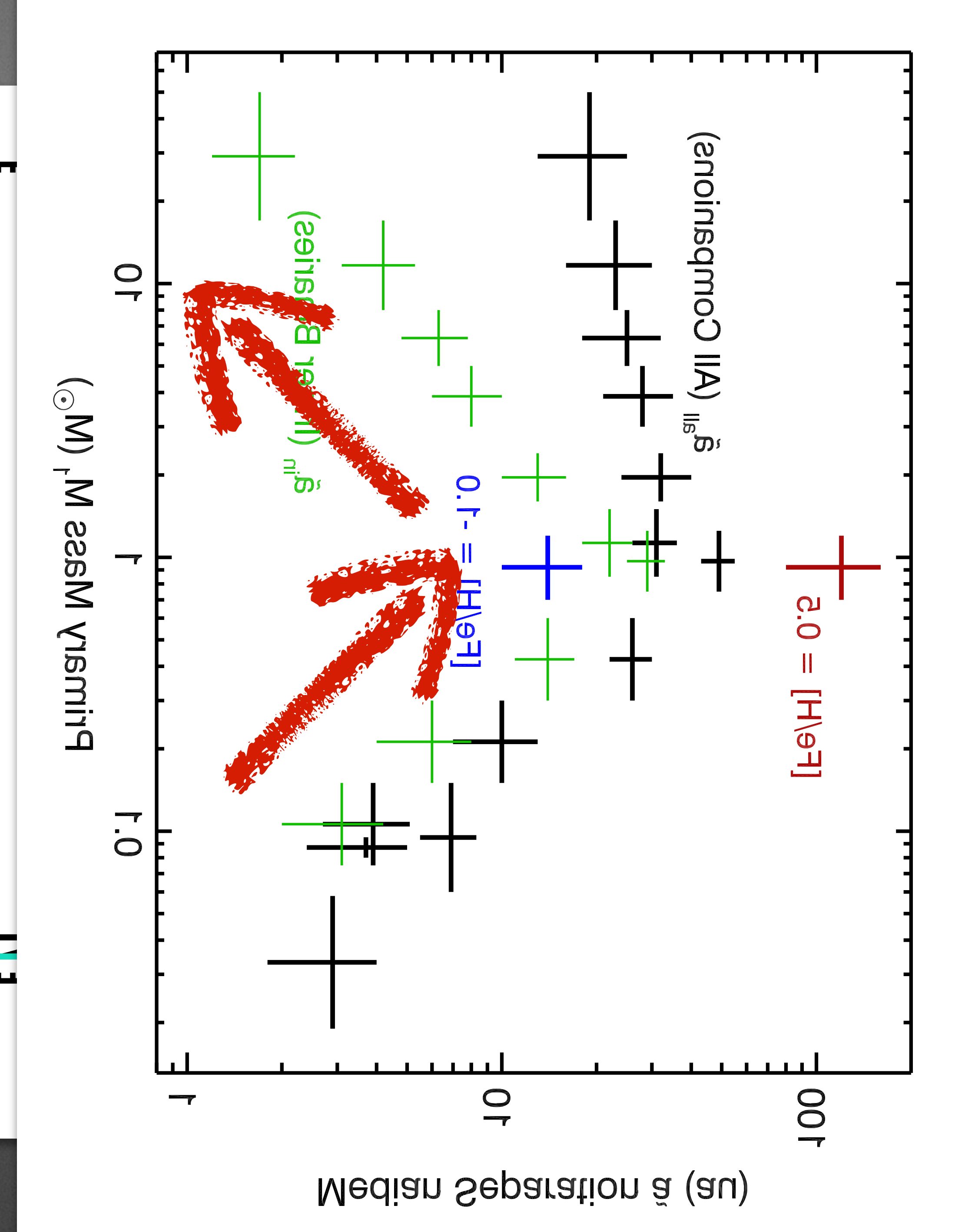

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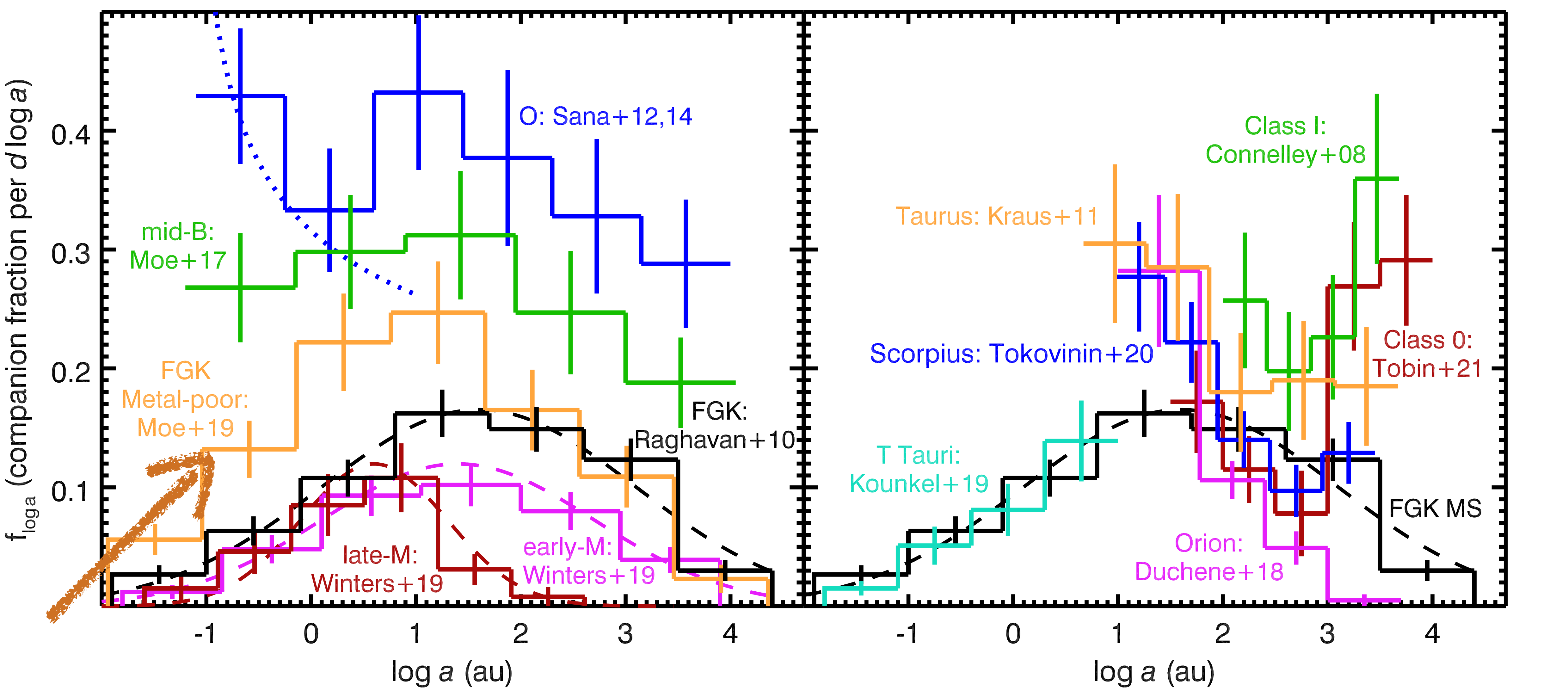
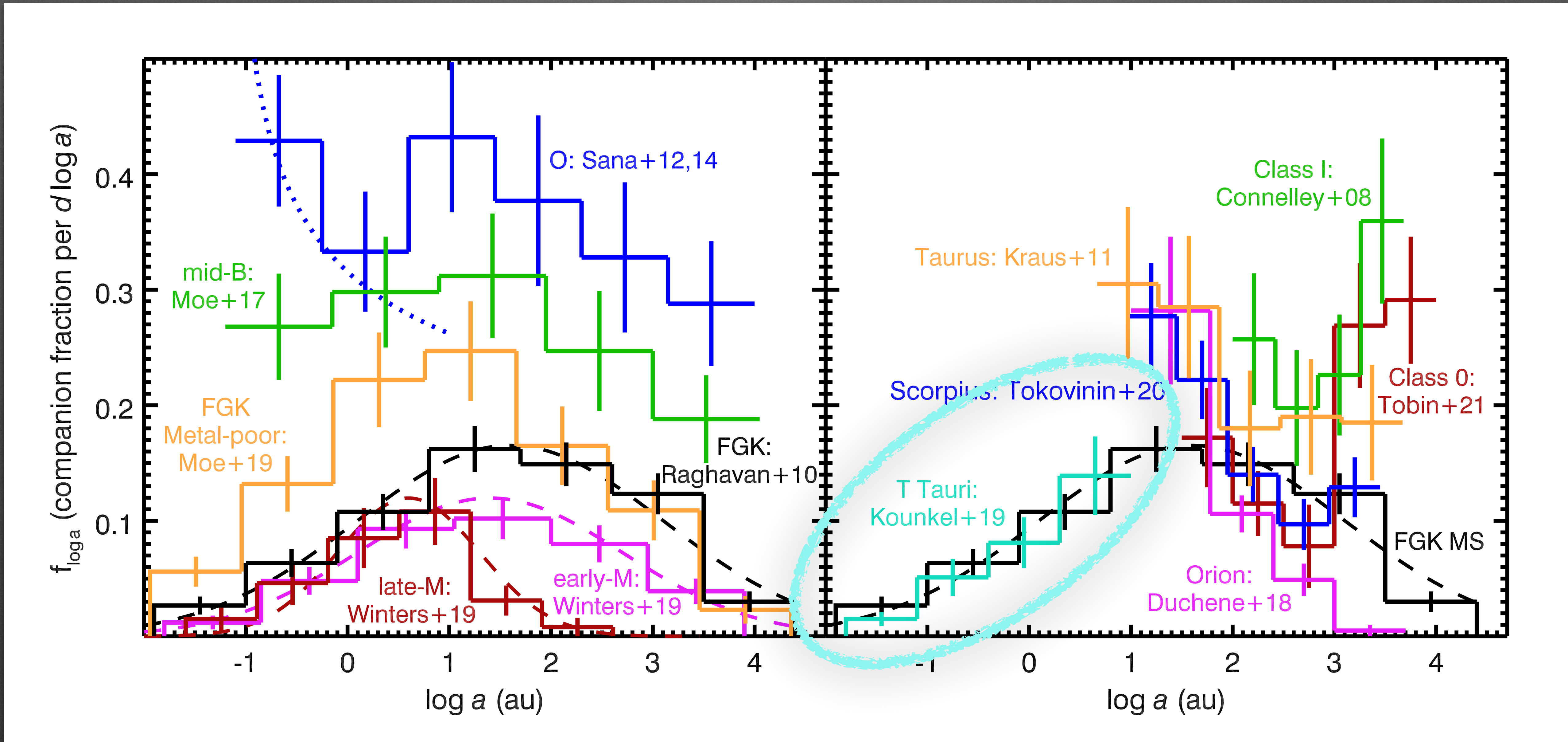
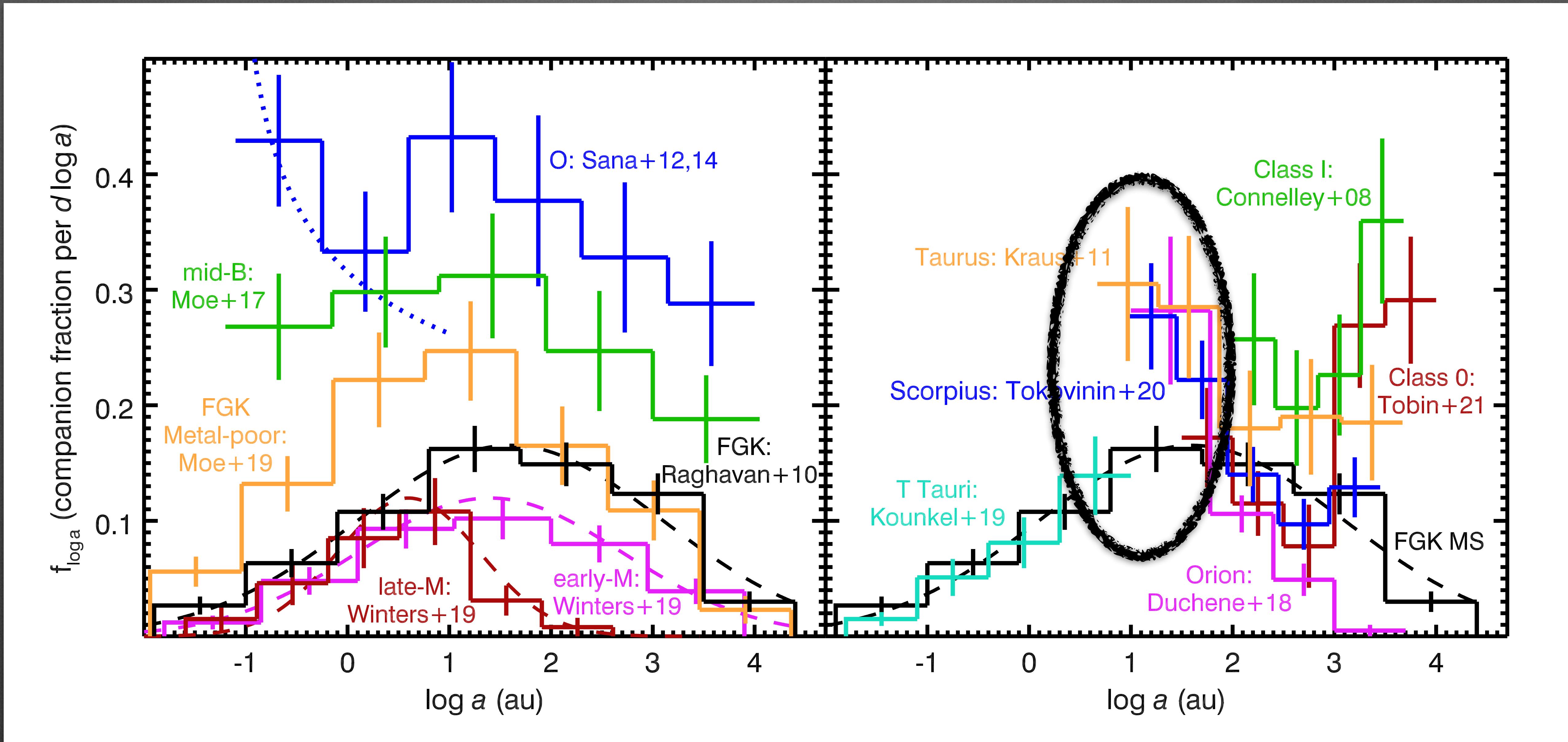


2. Metal poor solar type stars have enhanced close binary fraction like more massive stars

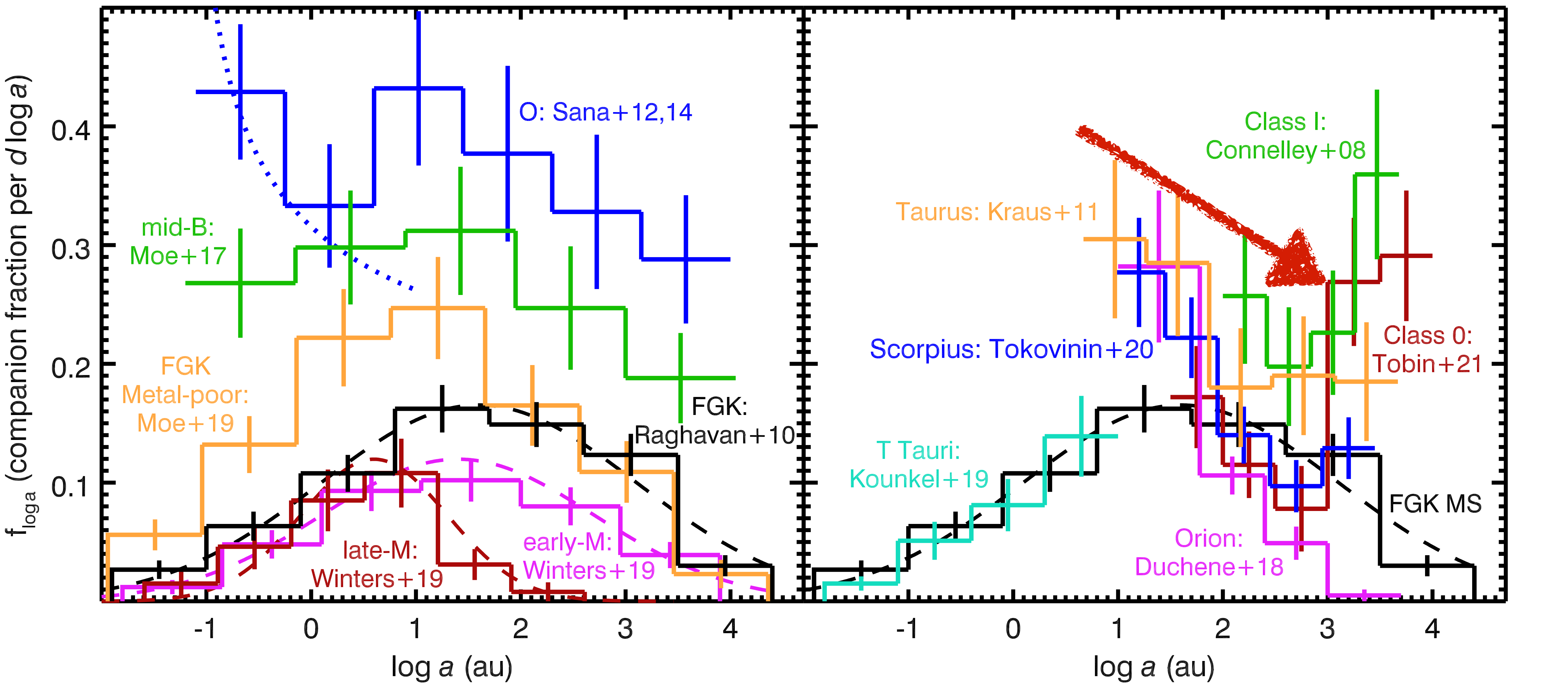
Offner+ PPVII



3. Field stars and PMS look very similar, especially close-in



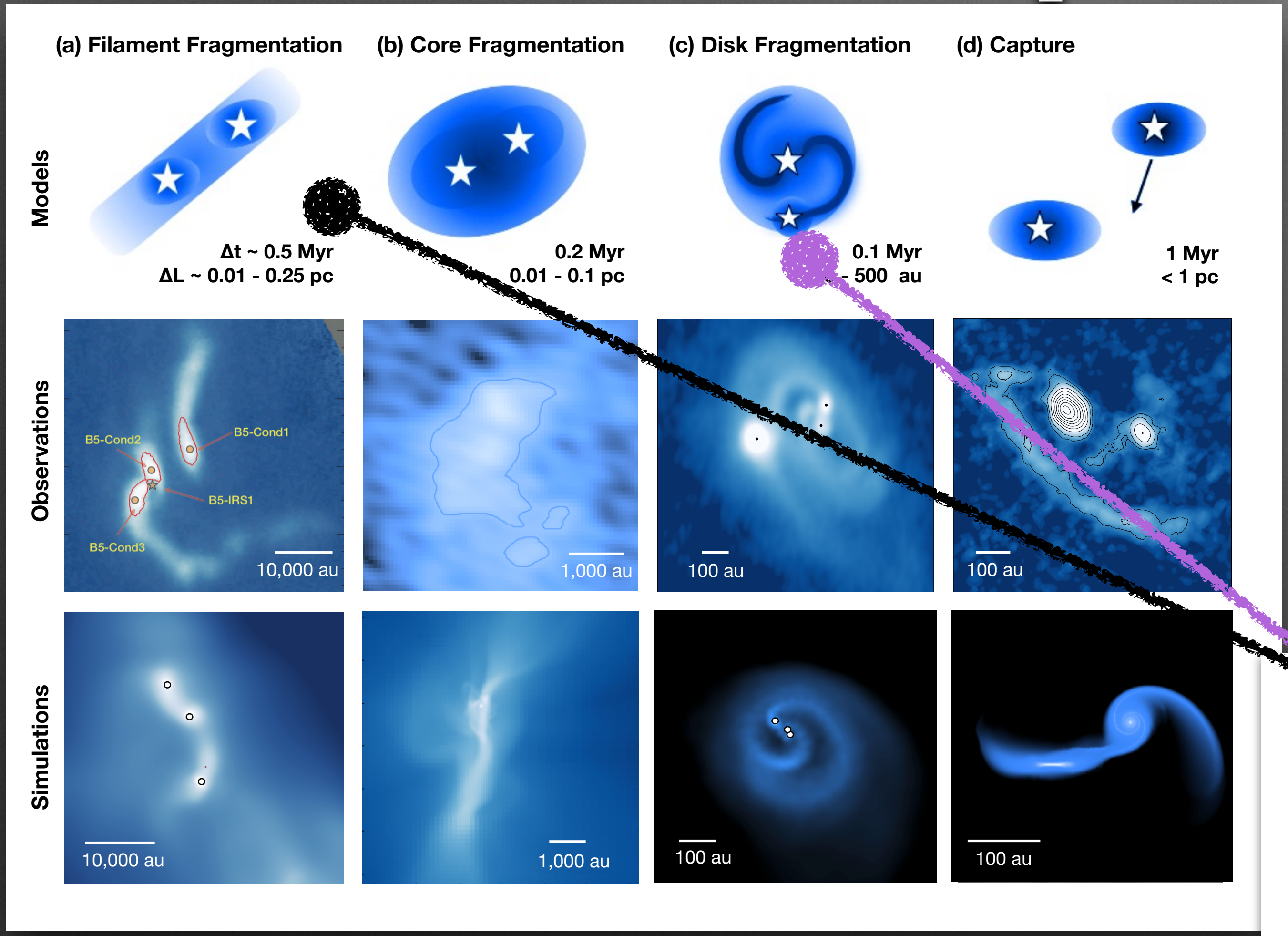
4. Something is "wonky" with AO samples of PMS binaries. Stay tuned, I trust the SB APOGEE sample.

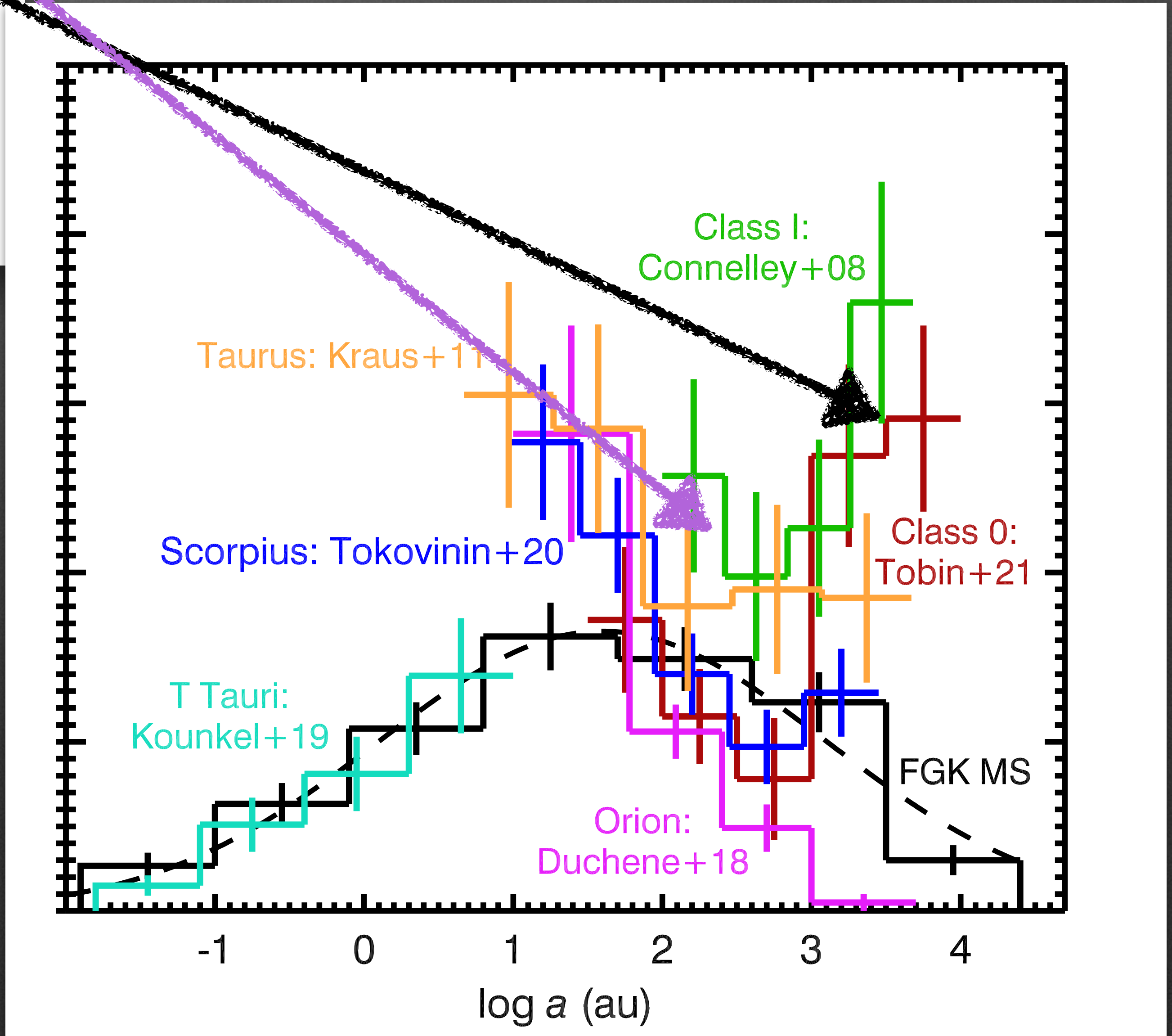


The youngest embedded binaries are much wider. Dearth below ~50 au is resolution dependent

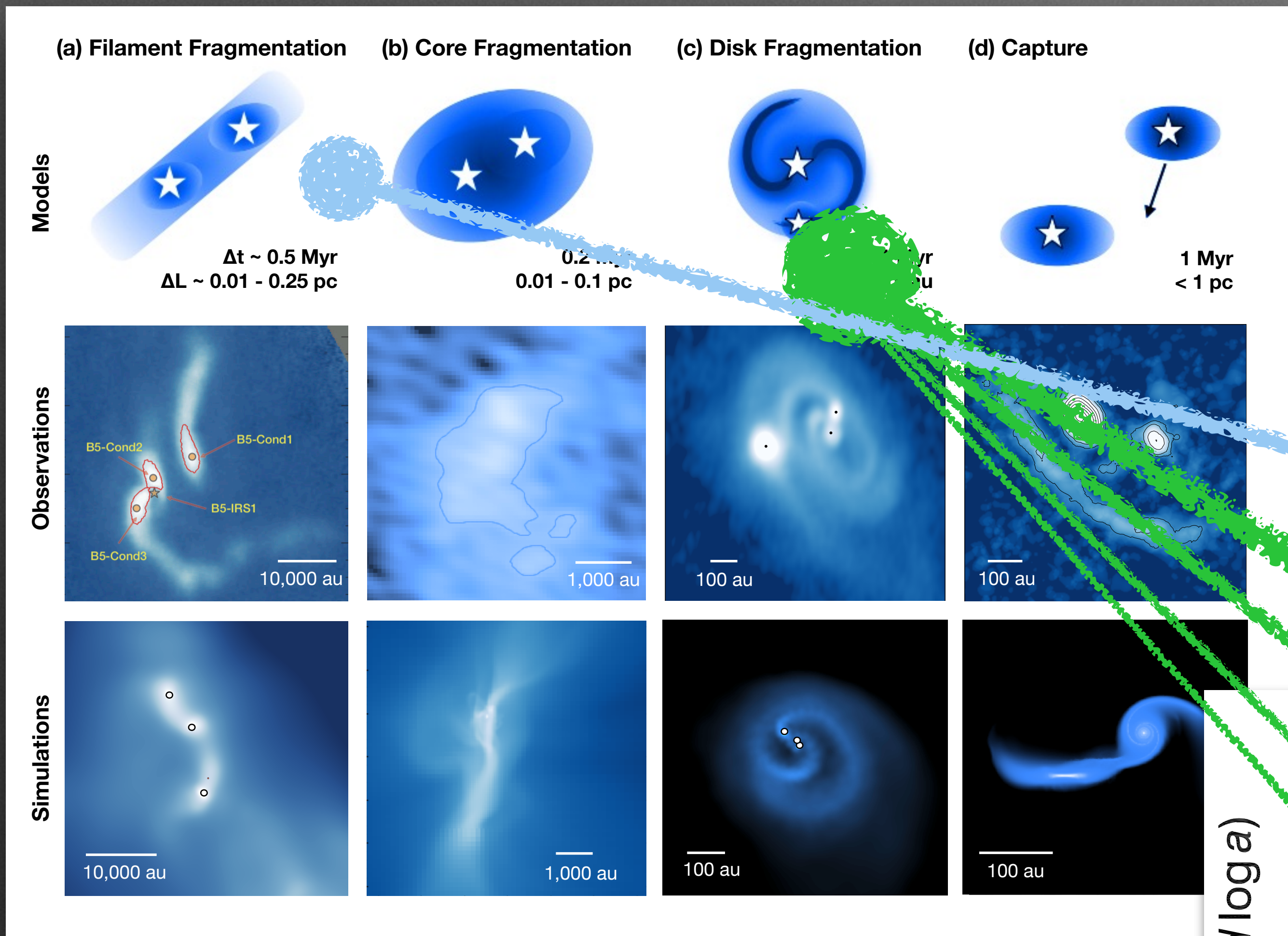
Offner+ PPVII

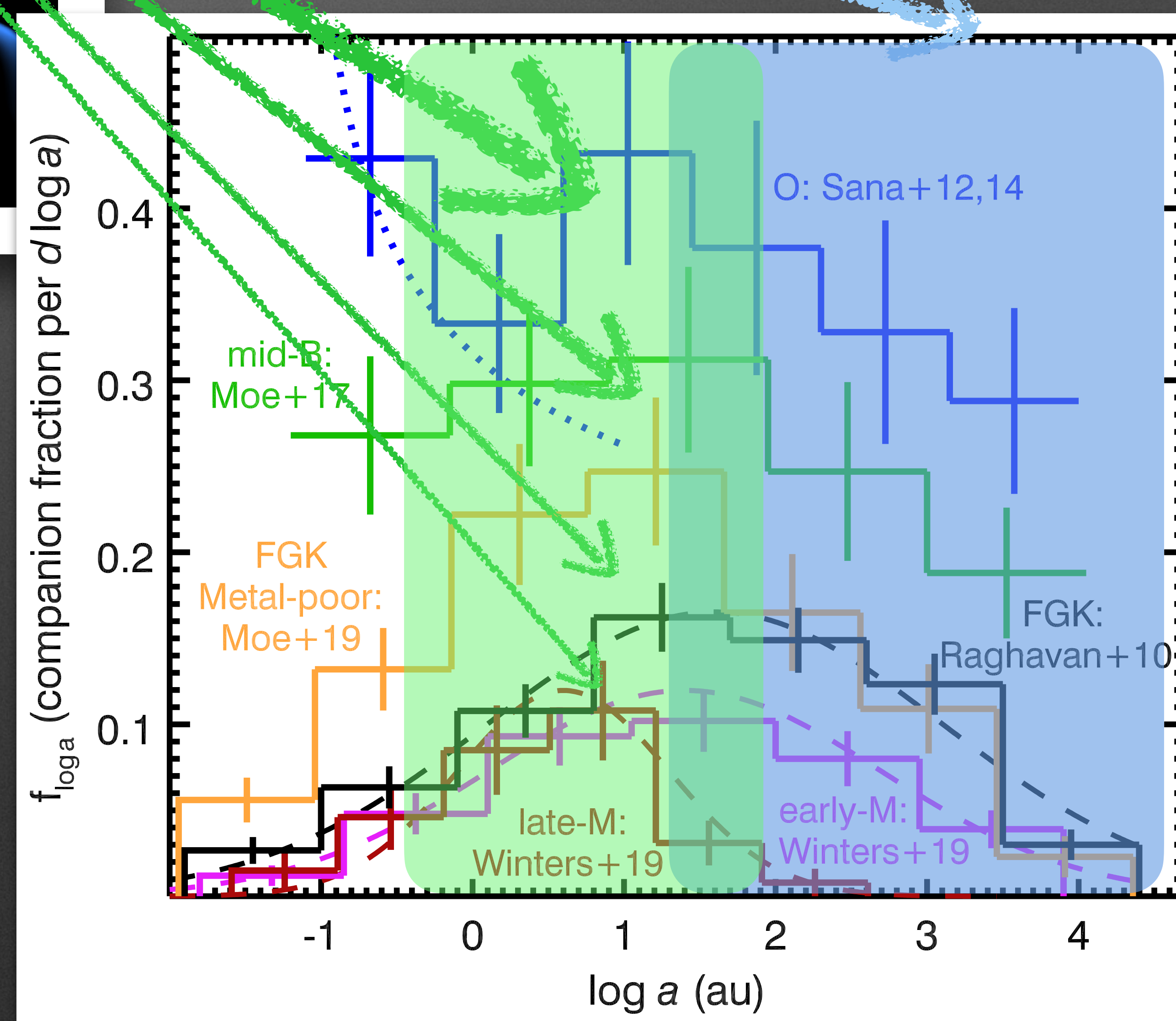
Once upon a time…





Once upon a time...

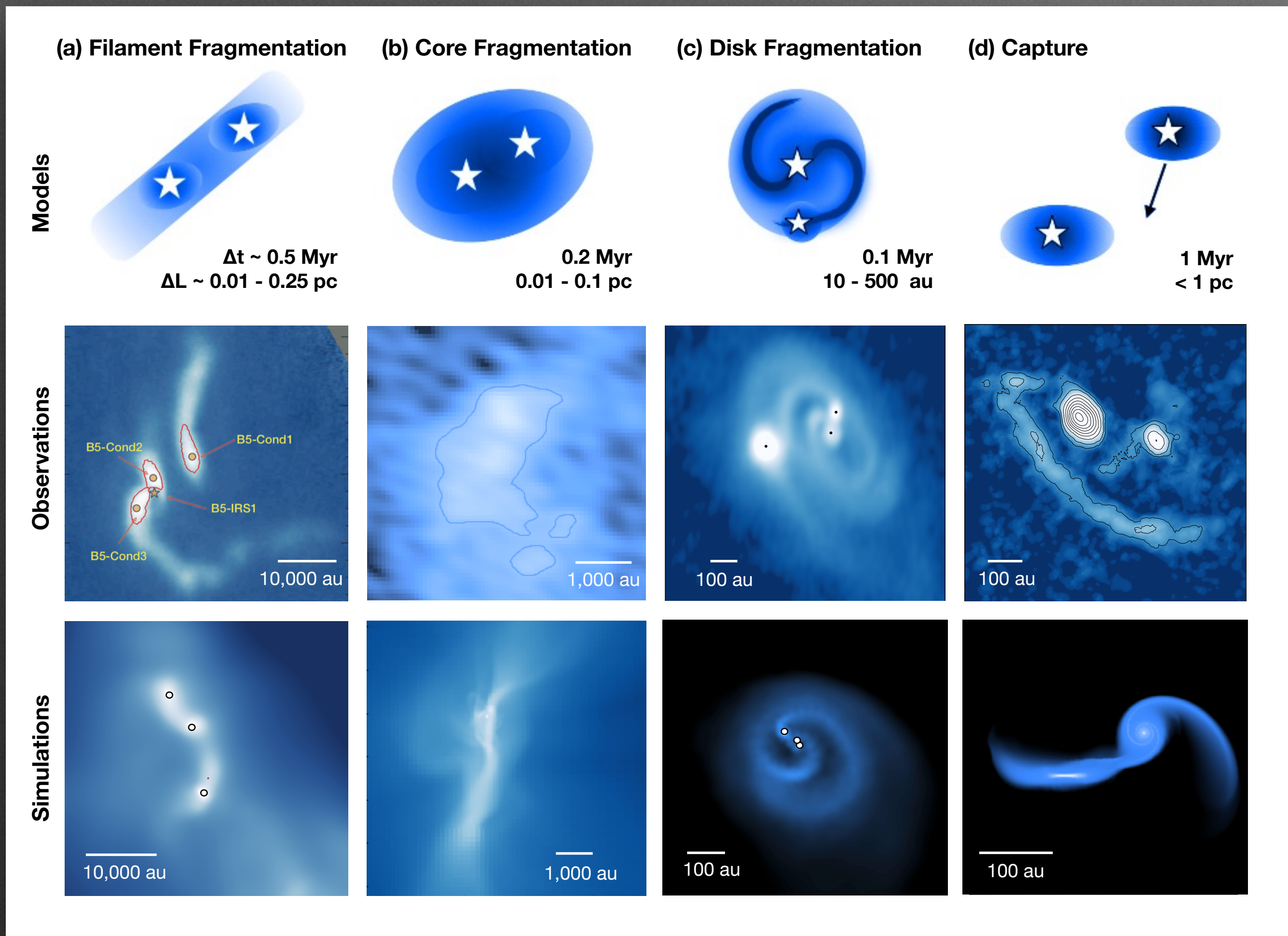




disk fragmentation more effective at high mass, low metallicity

-core fragmentation operates in mass independent fashion

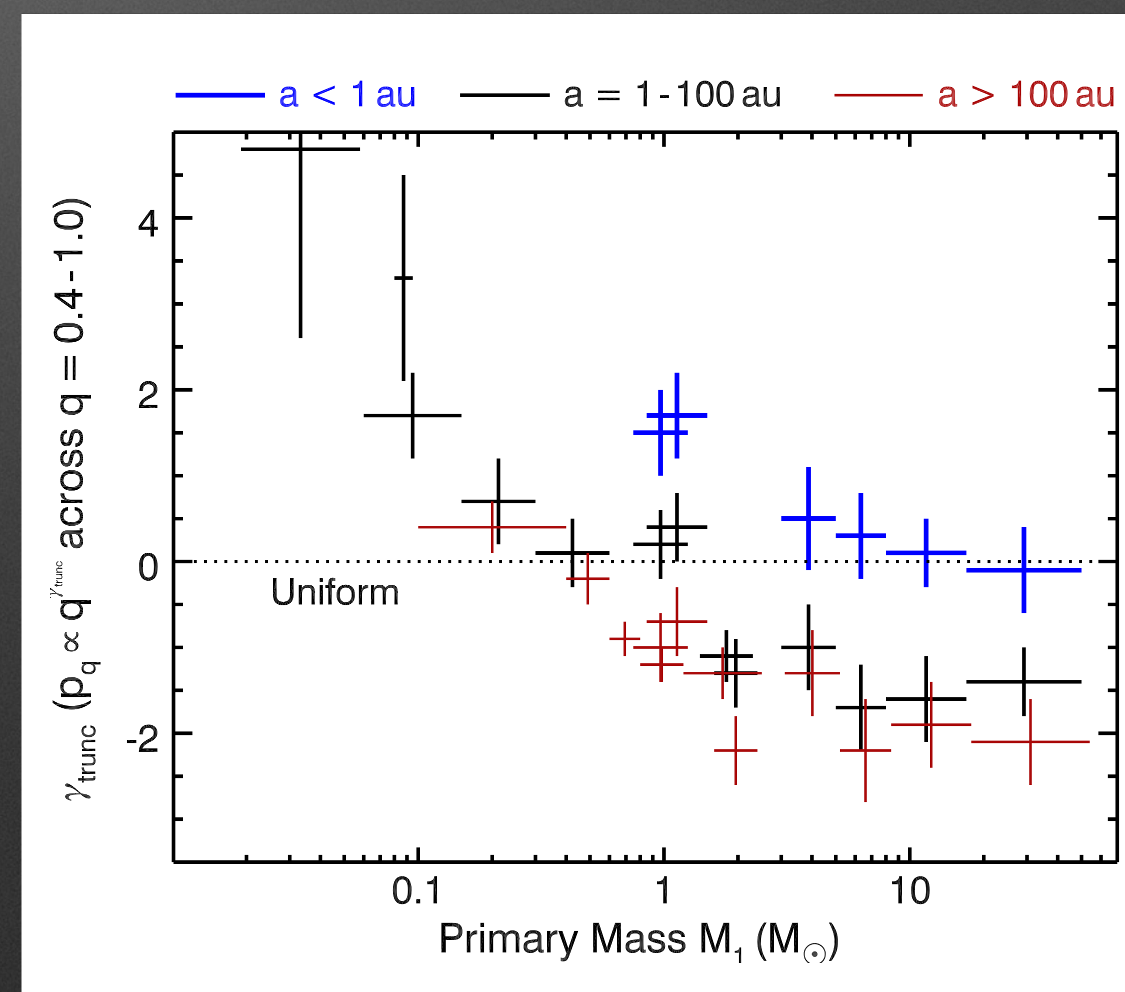
Once upon a time...



mass ratio distribution may reflect this division

disk fragmentation more effective at high mass, low metallicity

-core fragmentation operates in mass independent fashion



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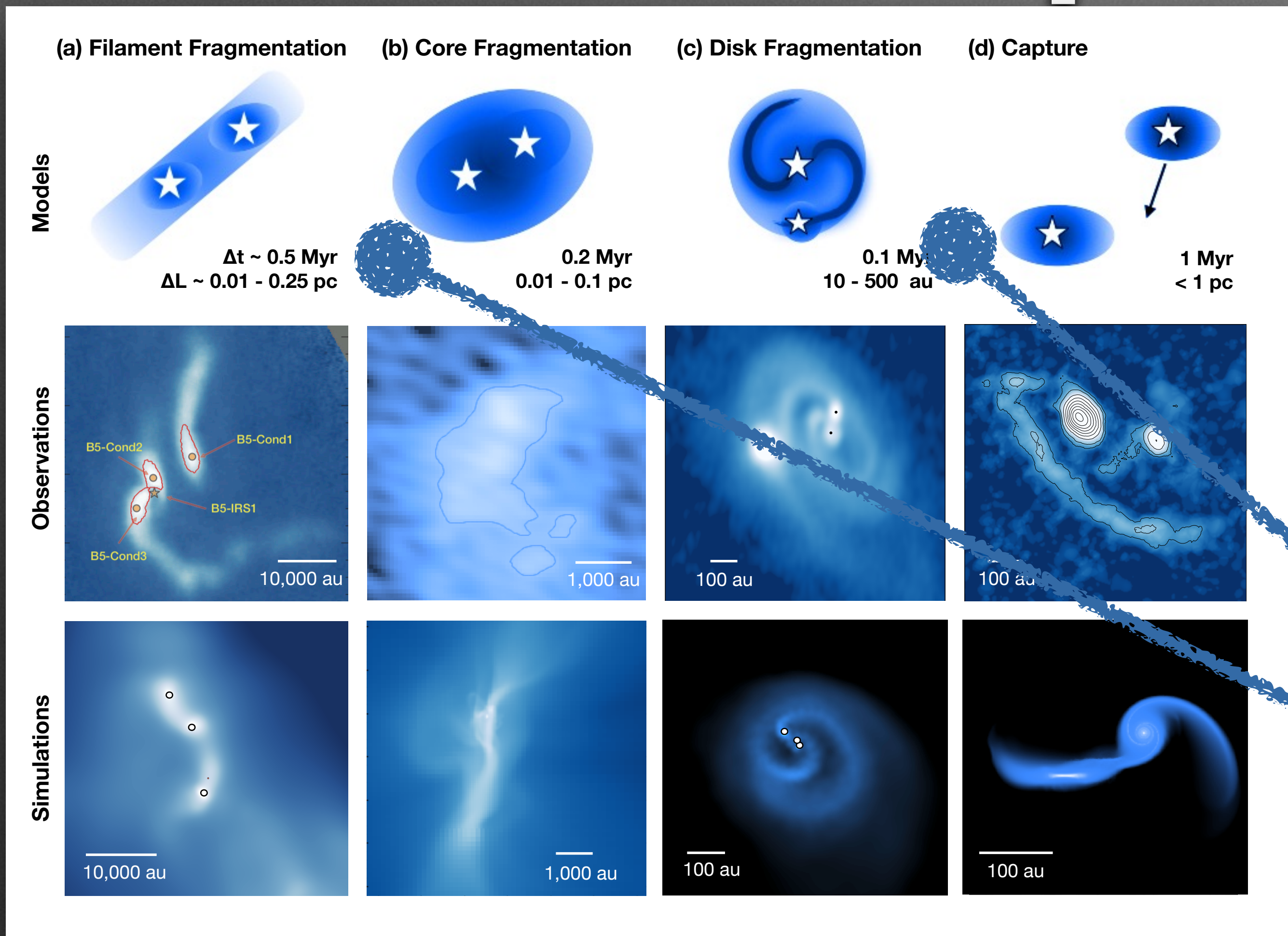
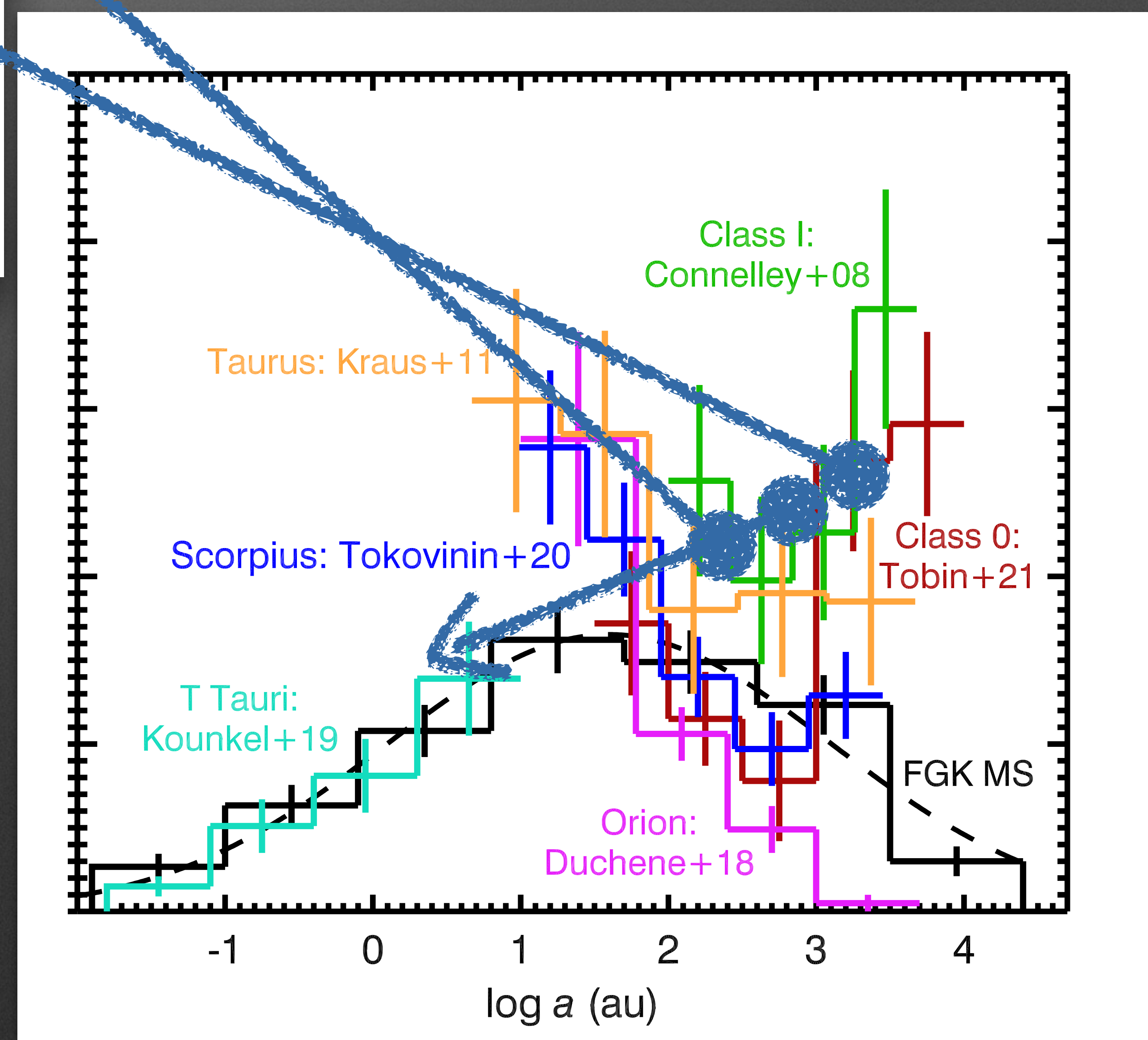
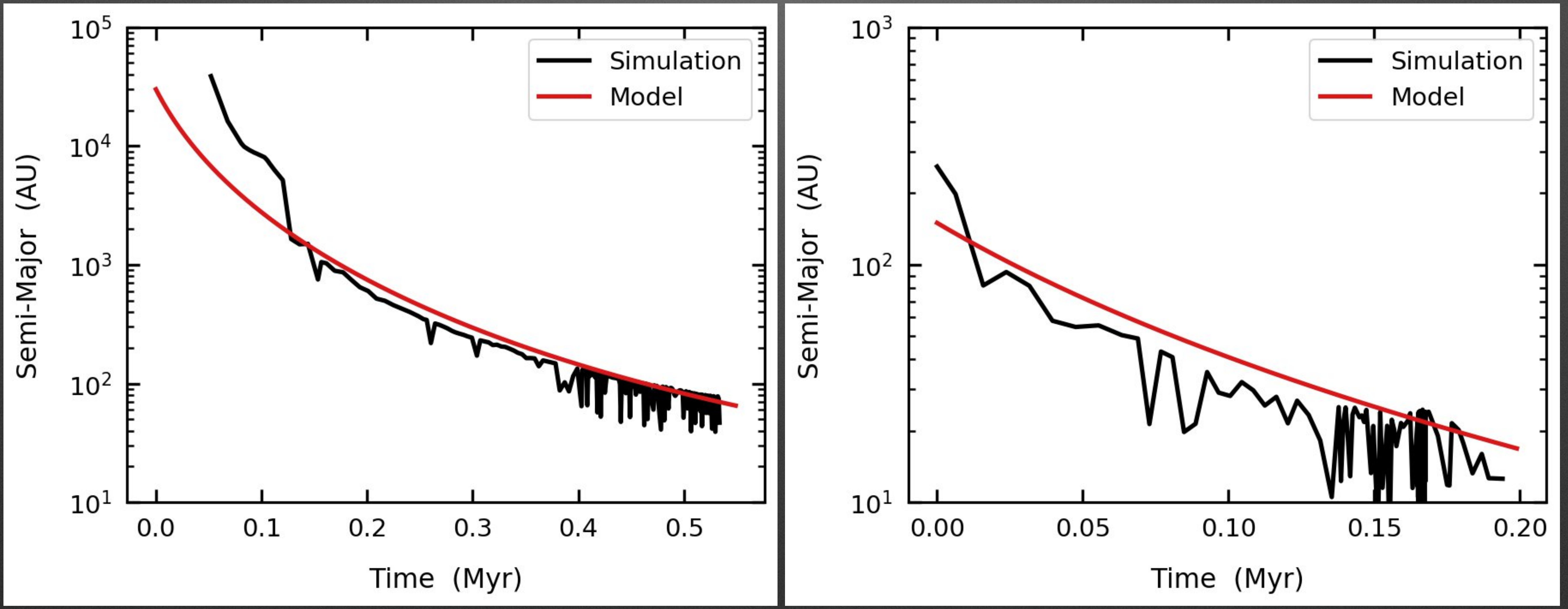




- gas driven migration (disks included)
- n-body dynamics

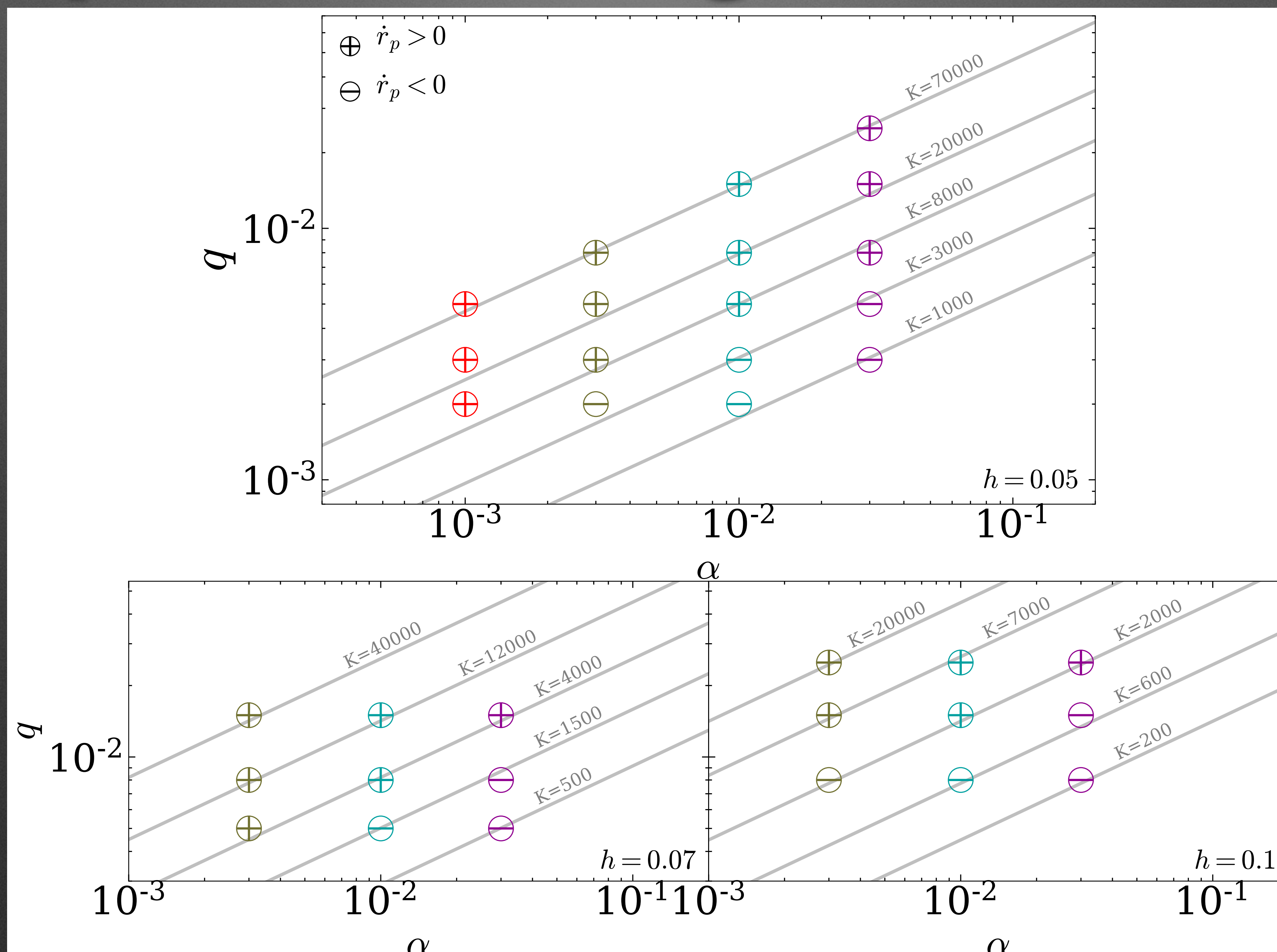
Wide binaries Migrate due to dynamical friction with the gas

They start their lives bound (typically), but can lose >90% of their energy and angular momentum to the dense gas



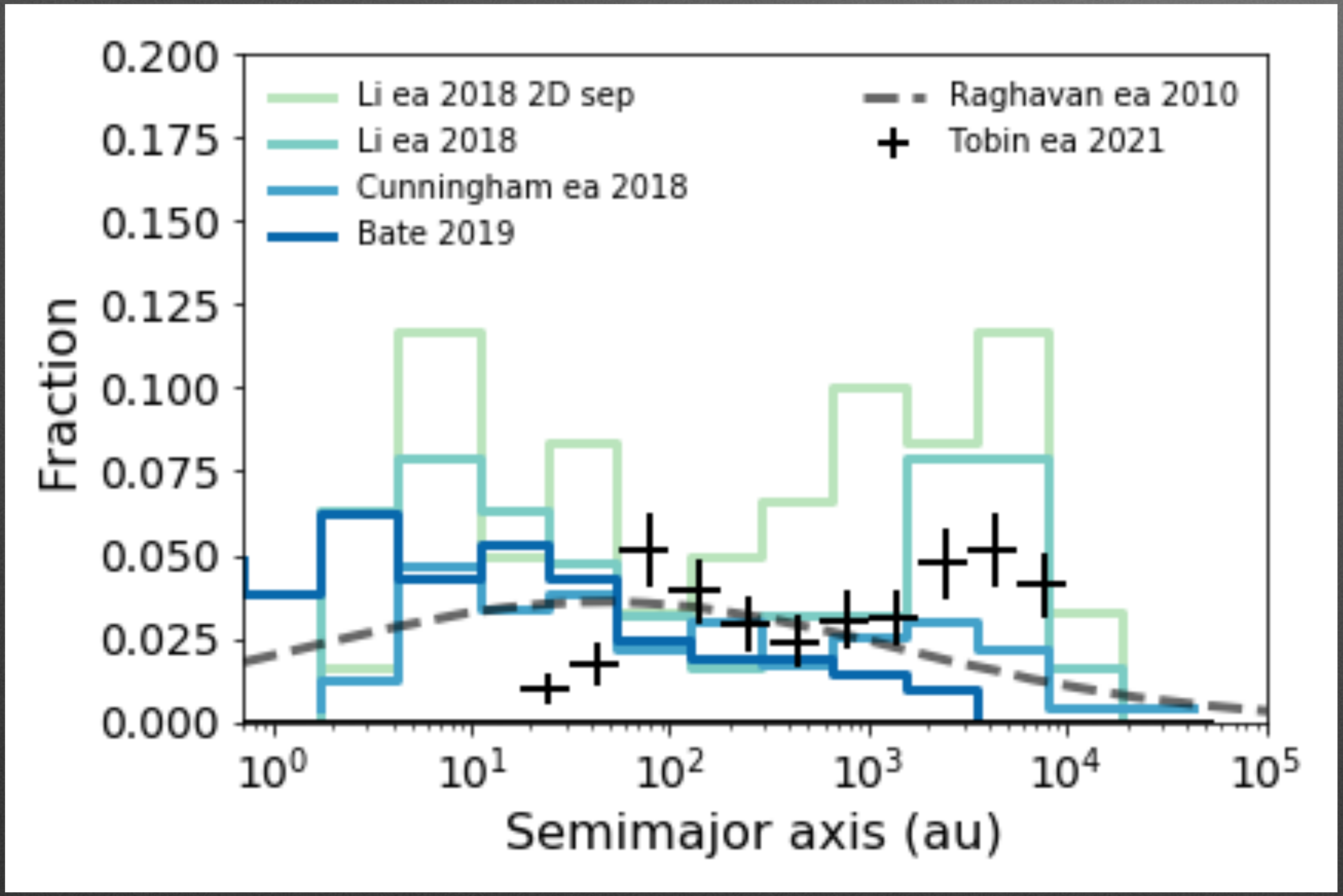
Lee, Offner, KMK,+2019

Disk migration is more complex: it can go both ways



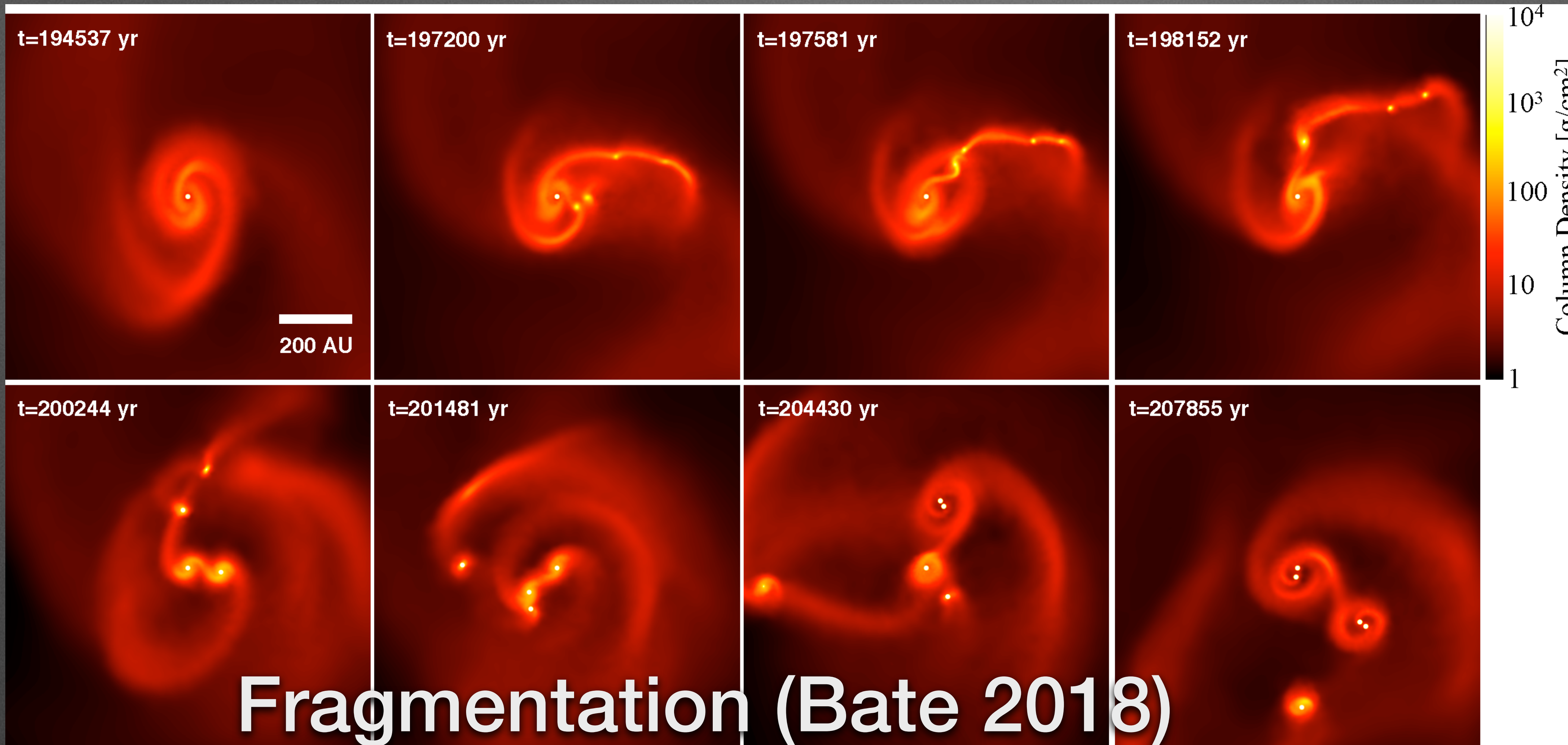
Dempsey+2021

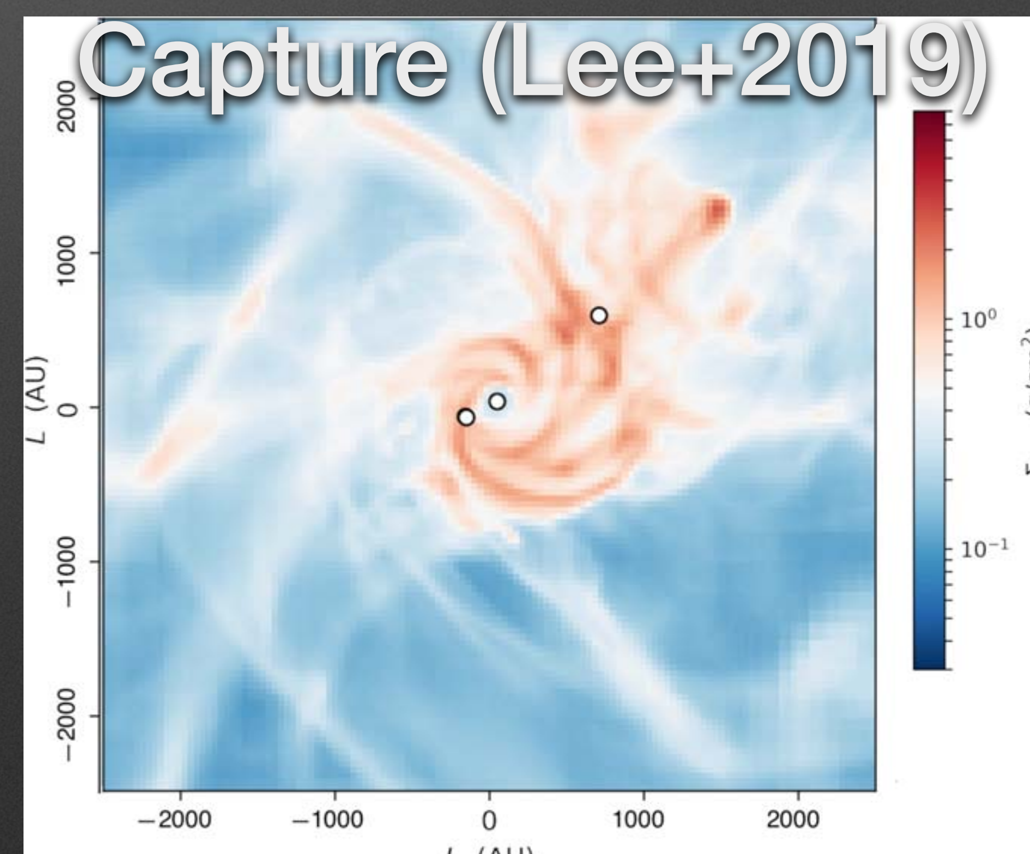
How well do cluster simulations do?



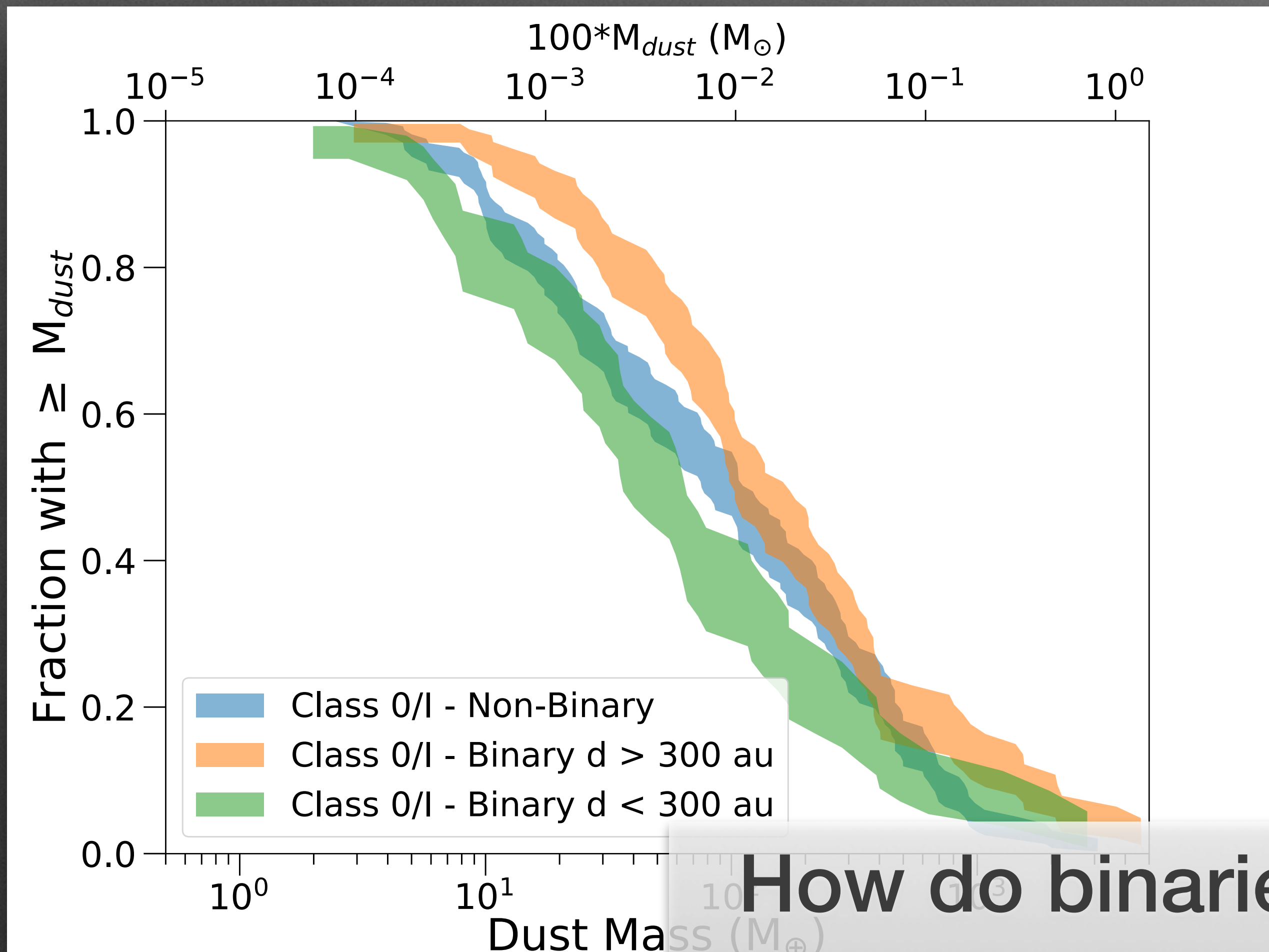
- Multiphysics simulations often get the "bulk" answer right (e.g. total fraction), but wrong on the details:
  - mass ratios
  - separation distributions

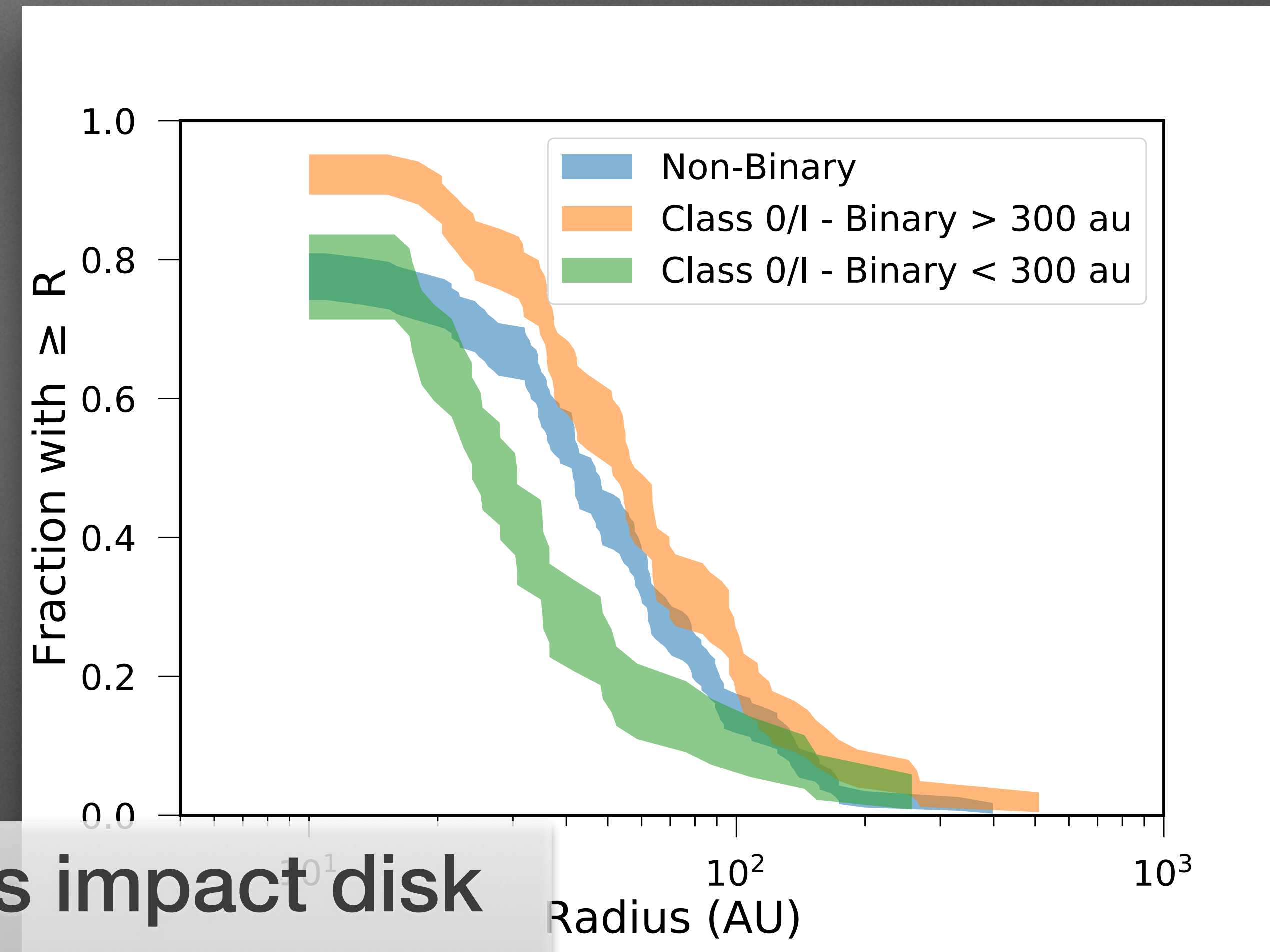
Offner+ PPVII



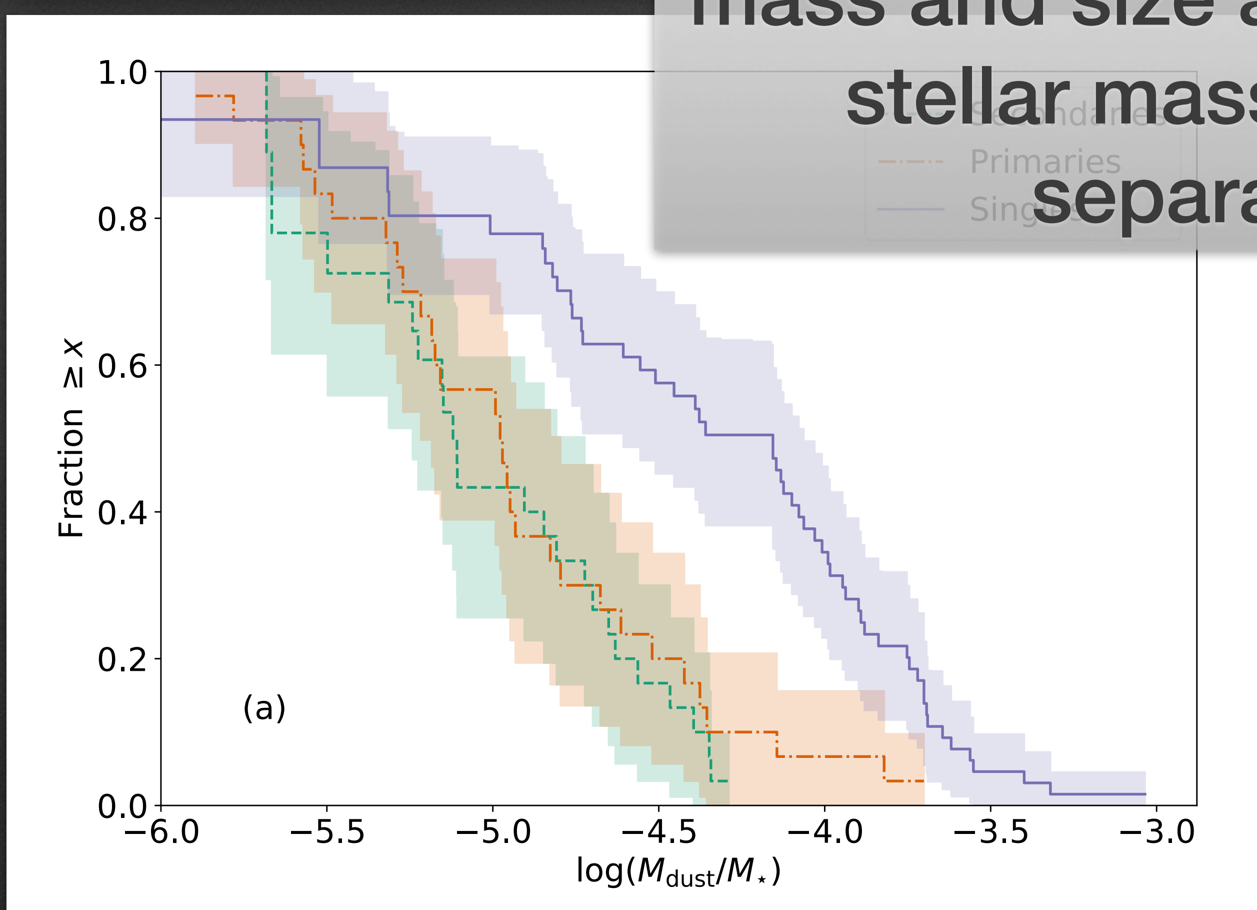


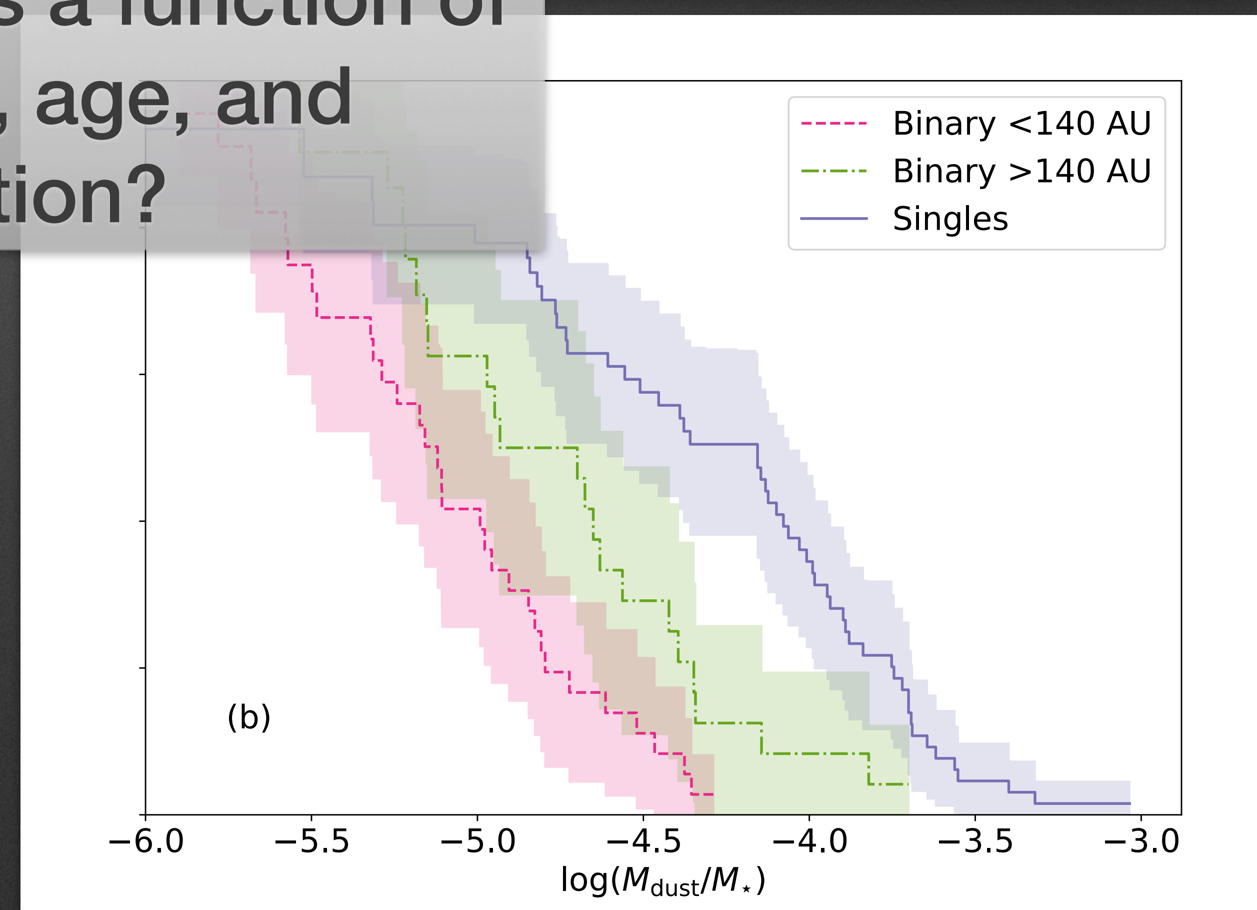
Morphology is not enough…



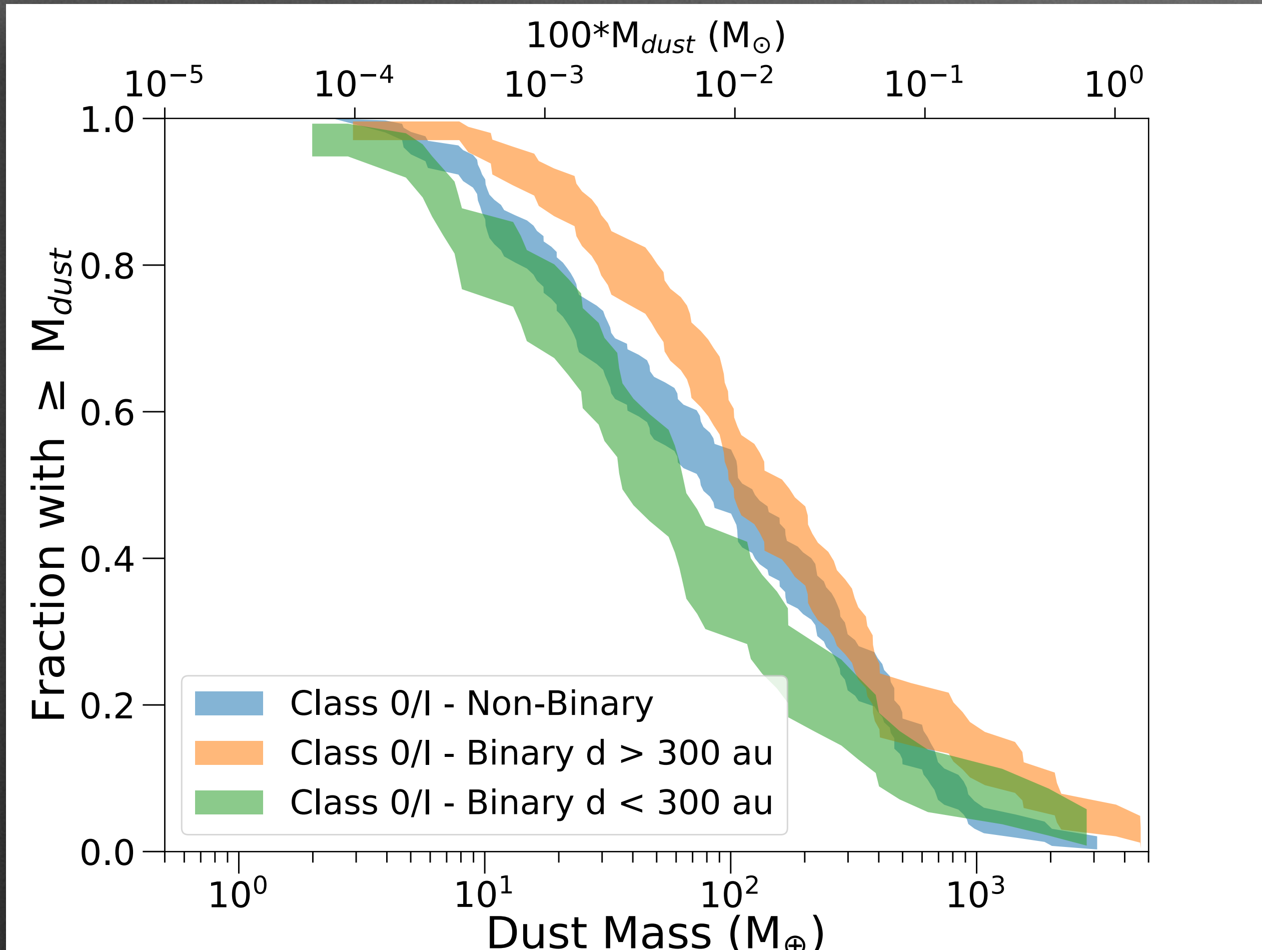


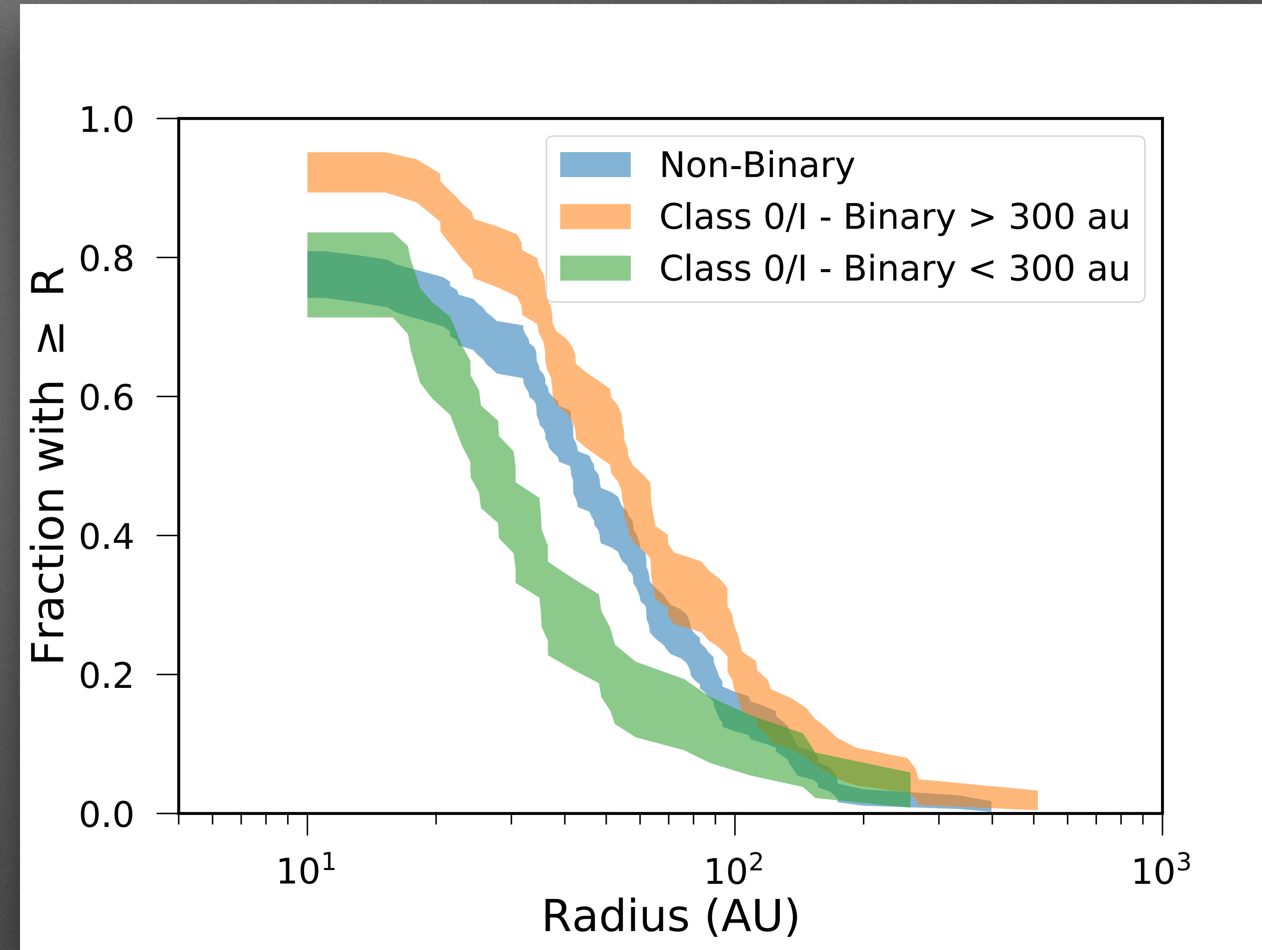
How do binaries impact disk mass and size as a function of stellar mass, age, and separation?





Offner+ PPVII

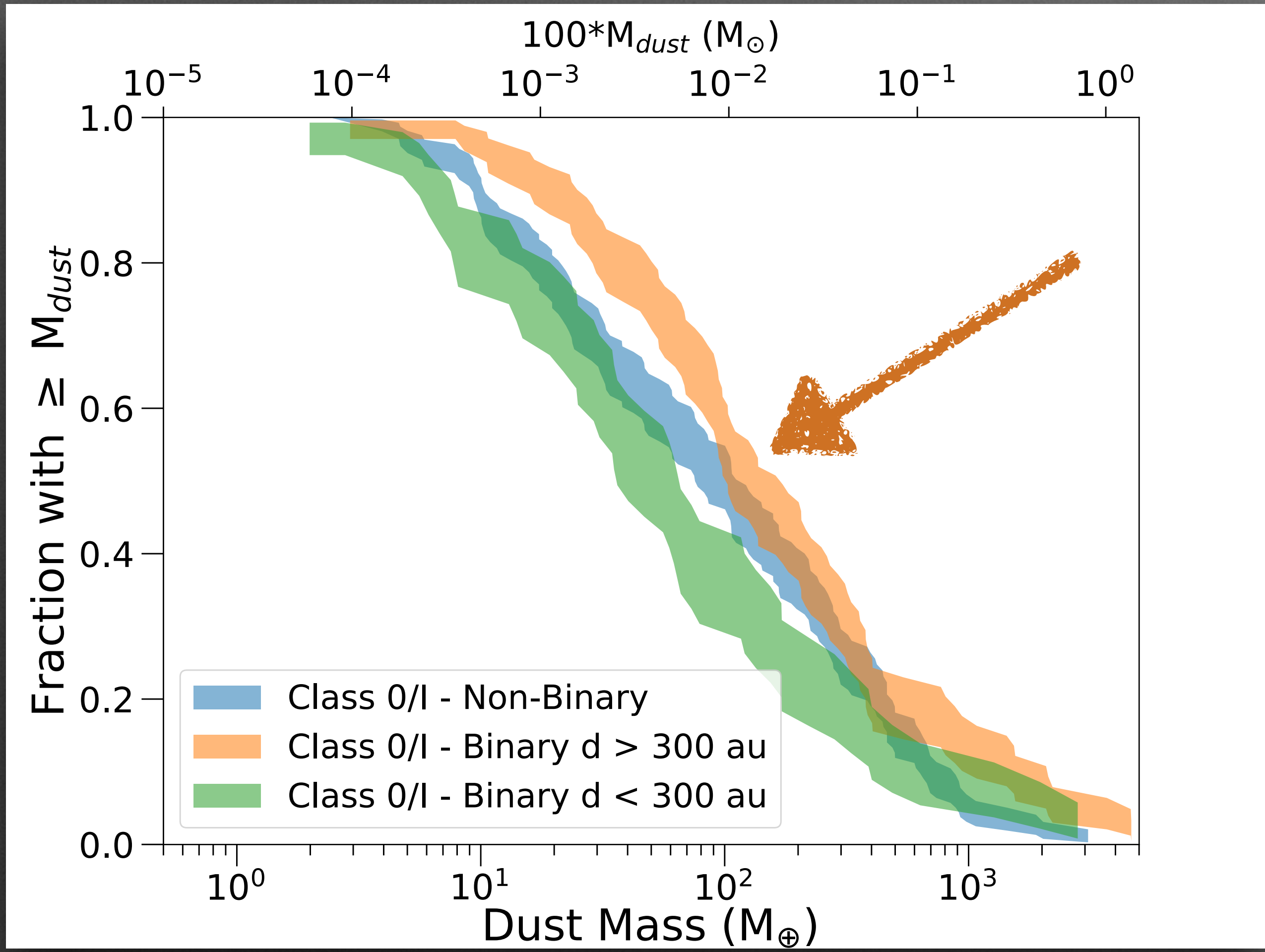


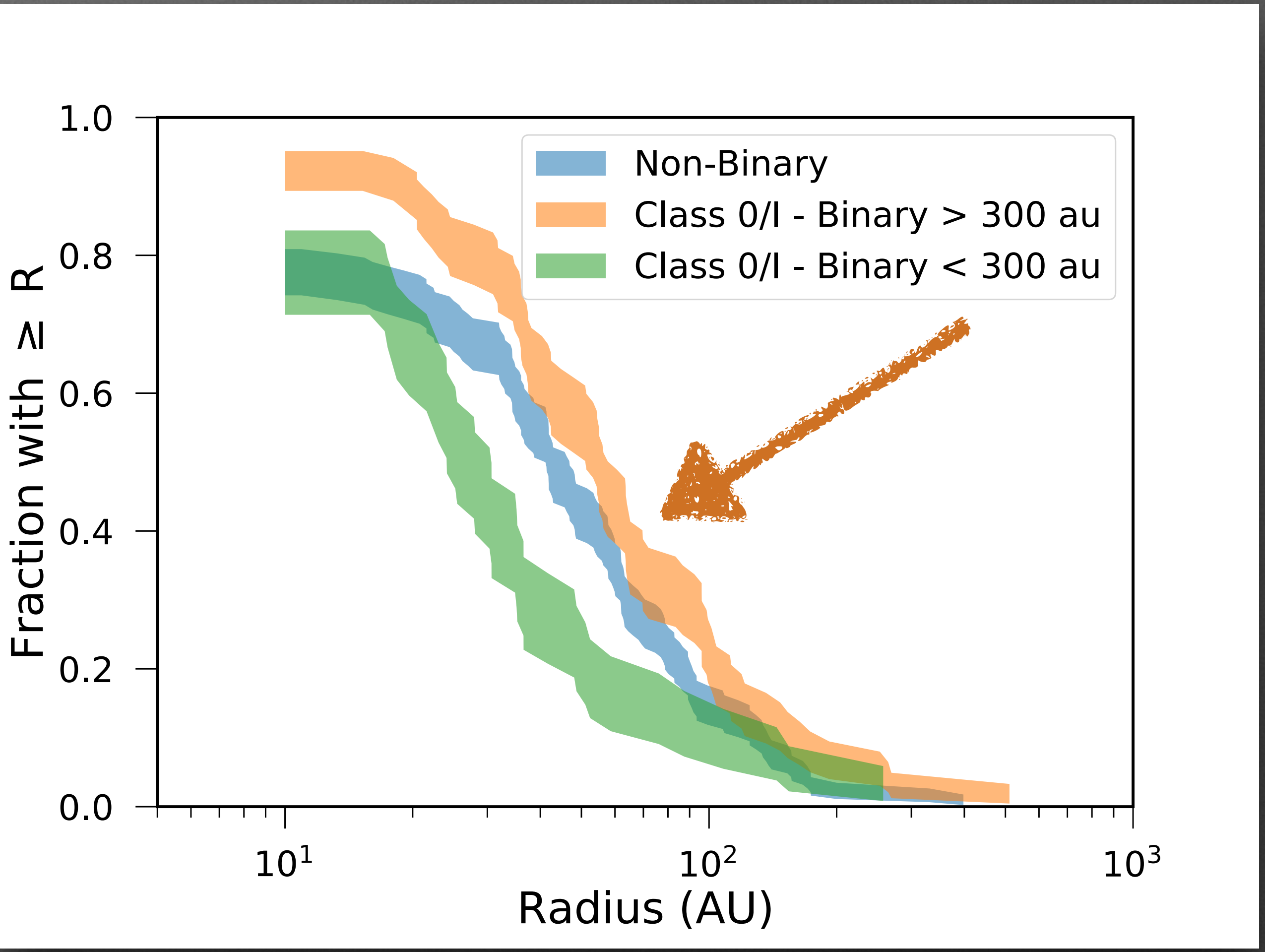


Data from Tobin+2020, division at 300 au chosen in part due to resolution. wide systems more consistent with semi-independent core/filament fragmentation.

“standard” flux-dust conversions apply (tau <1, T=20K)

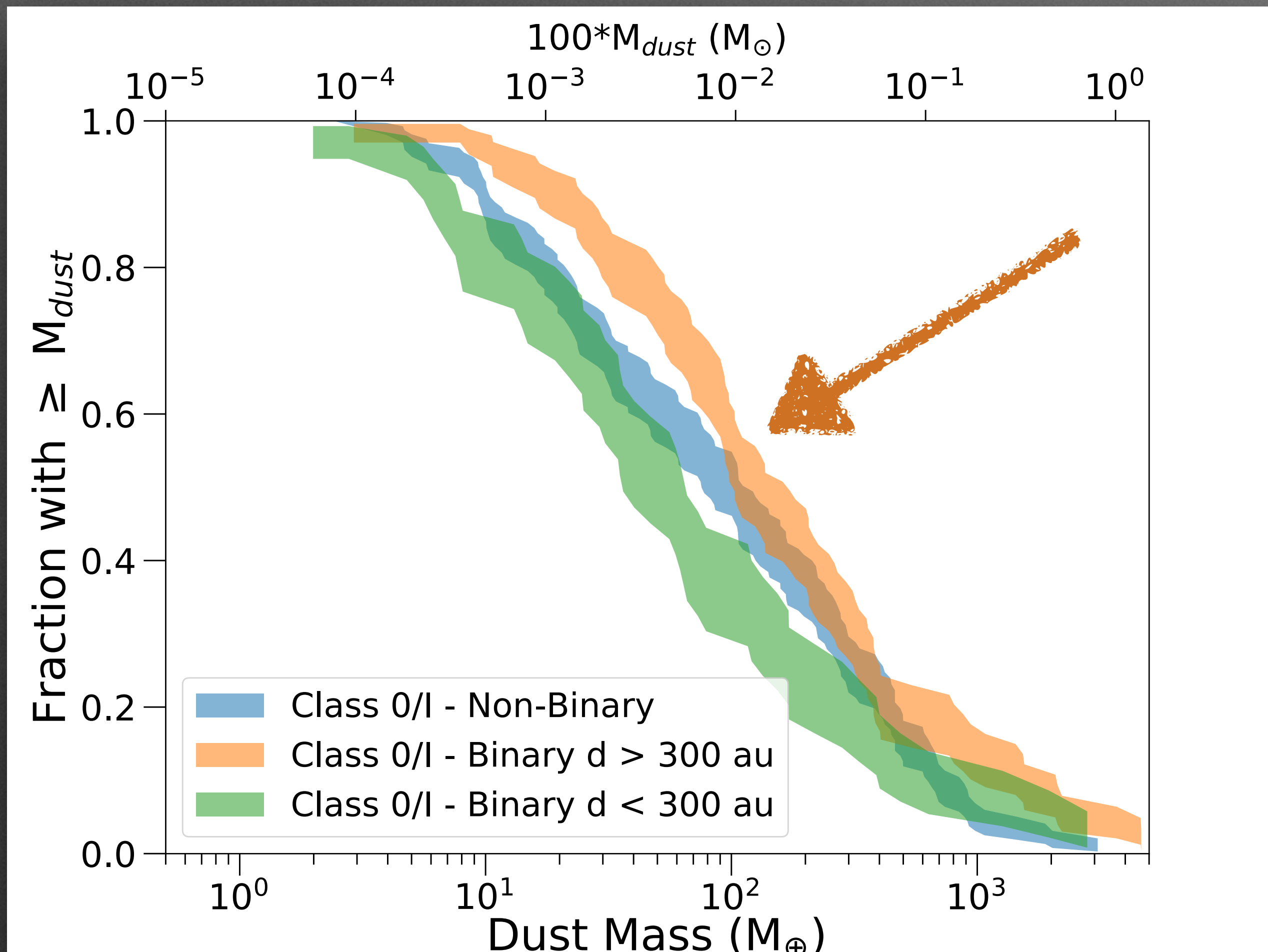
Offner+ PPVII

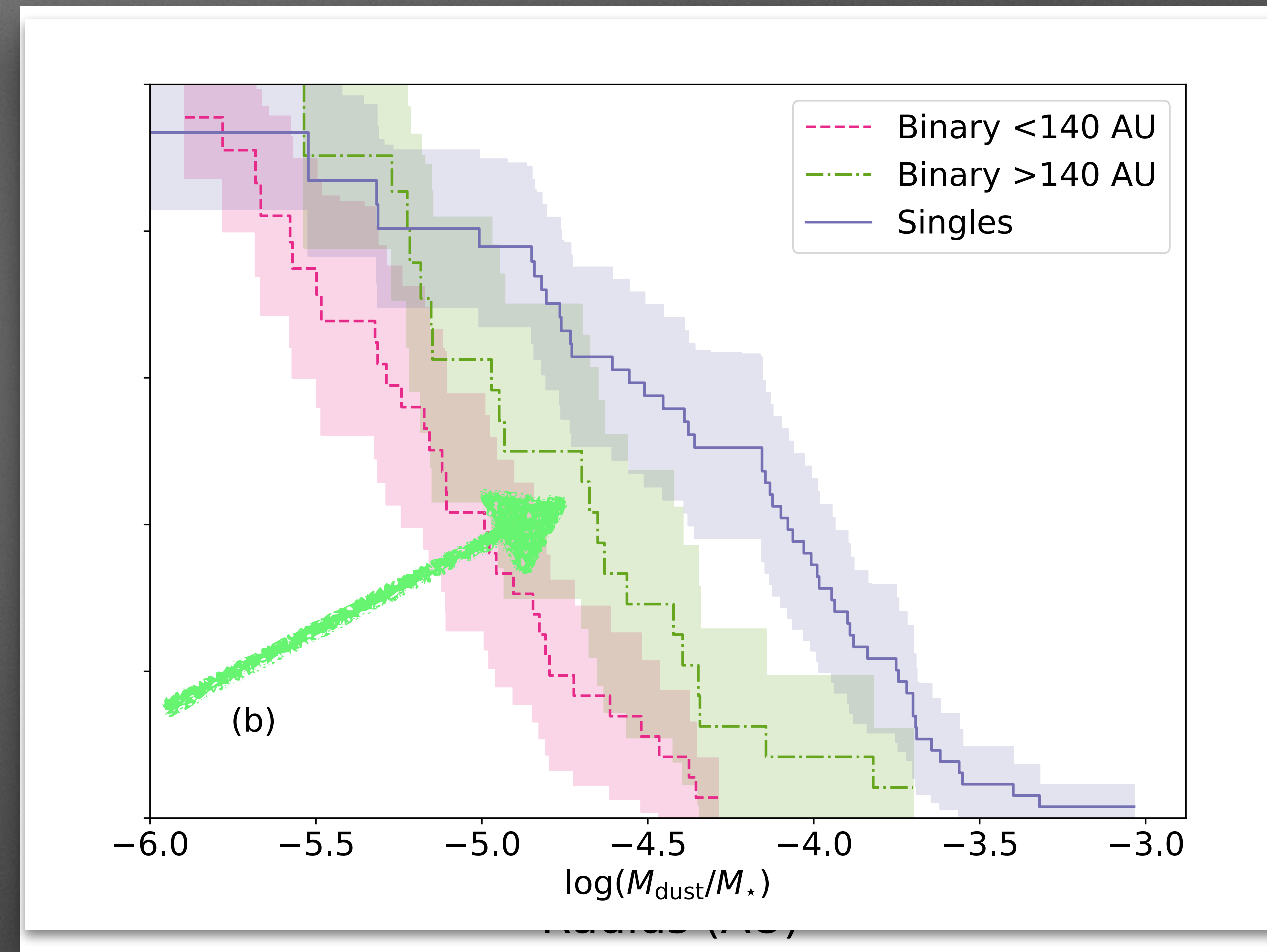




Yes, wide binaries have bigger and more massive disks at the Class 0/I phase. No, I don't know why

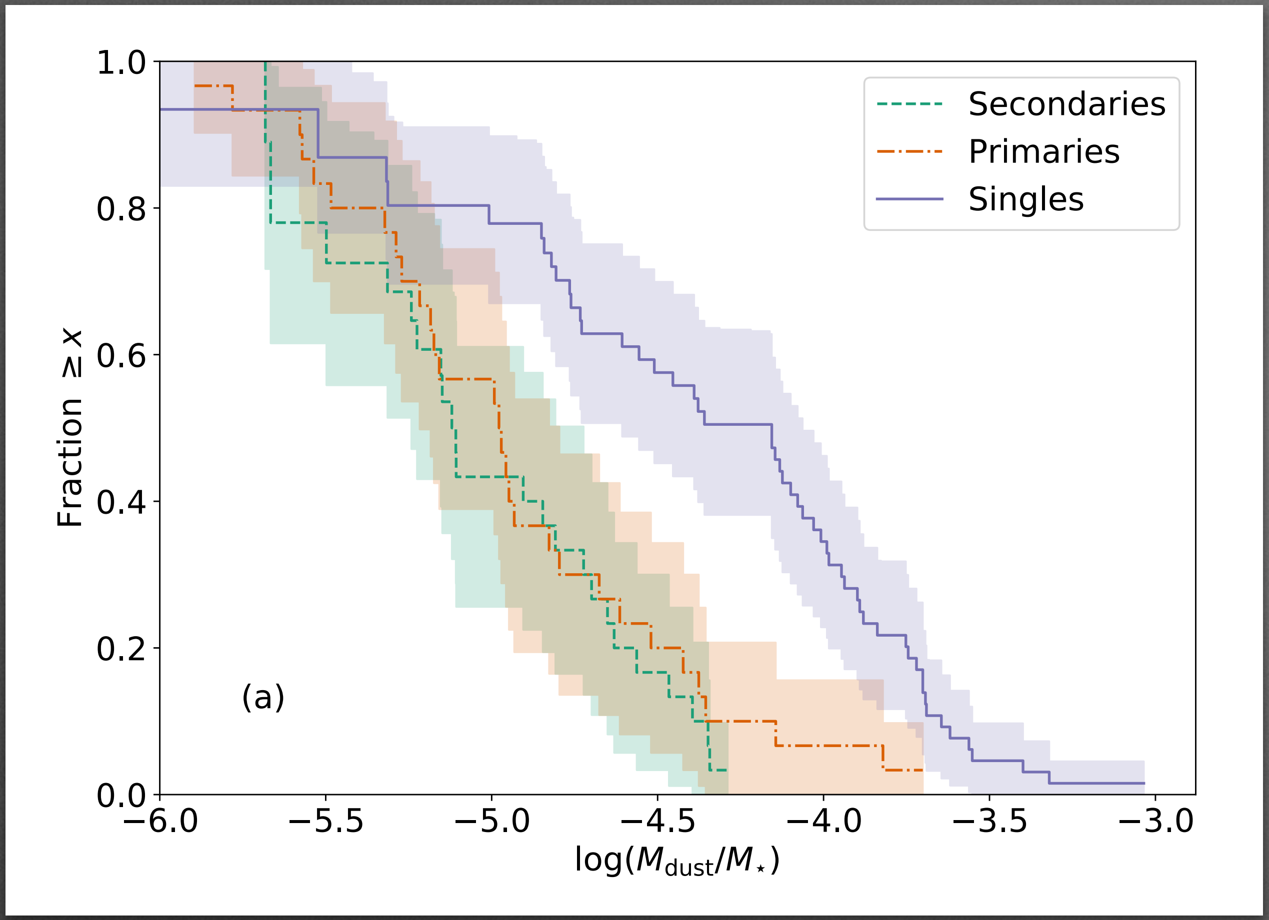
Offner+ PPVII

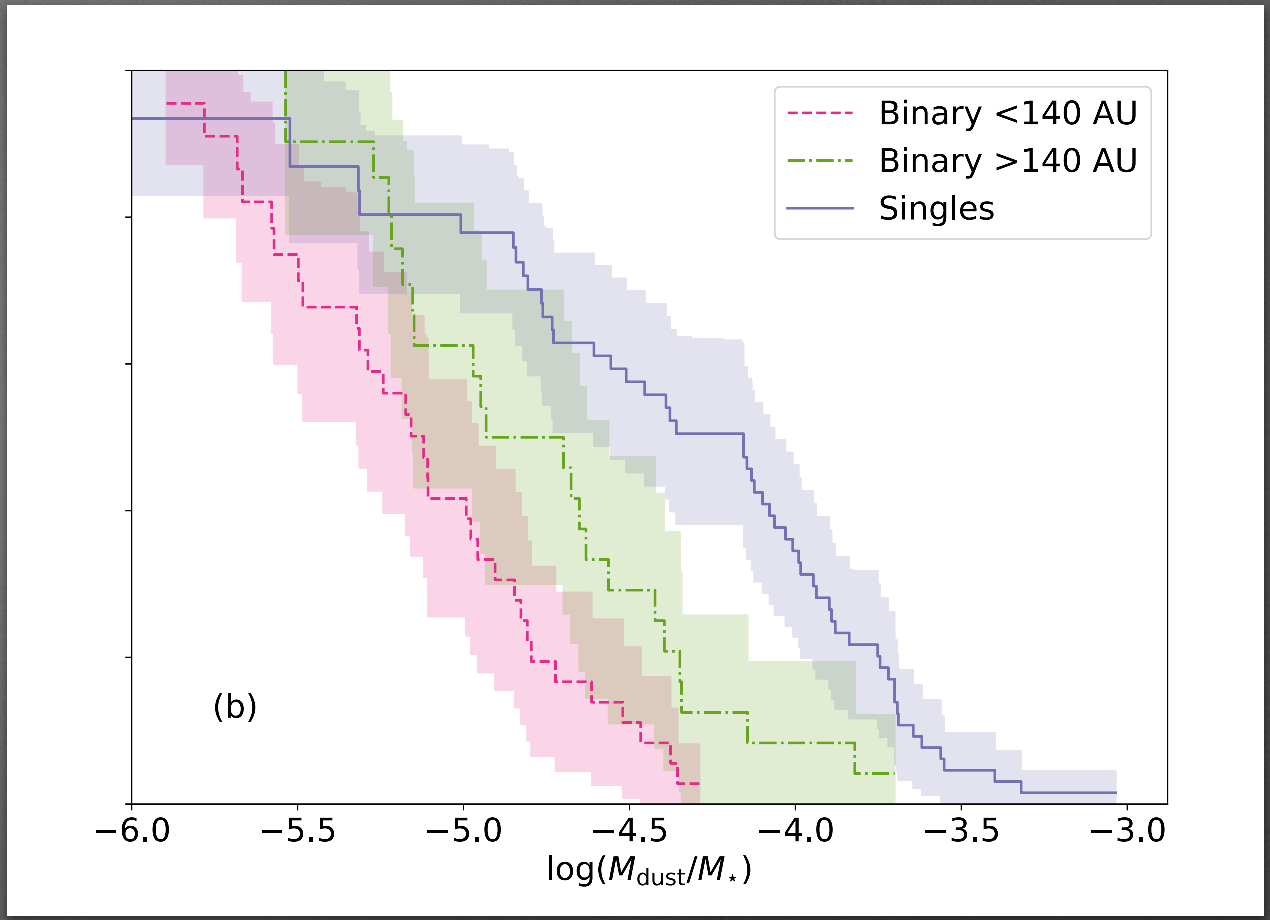




The trend disappears for T-Tauri sources, where single star disks are bigger.
A stellar mass effect could be lurking, but we don't know the masses of Class 0 sources

Offner+ PPVII

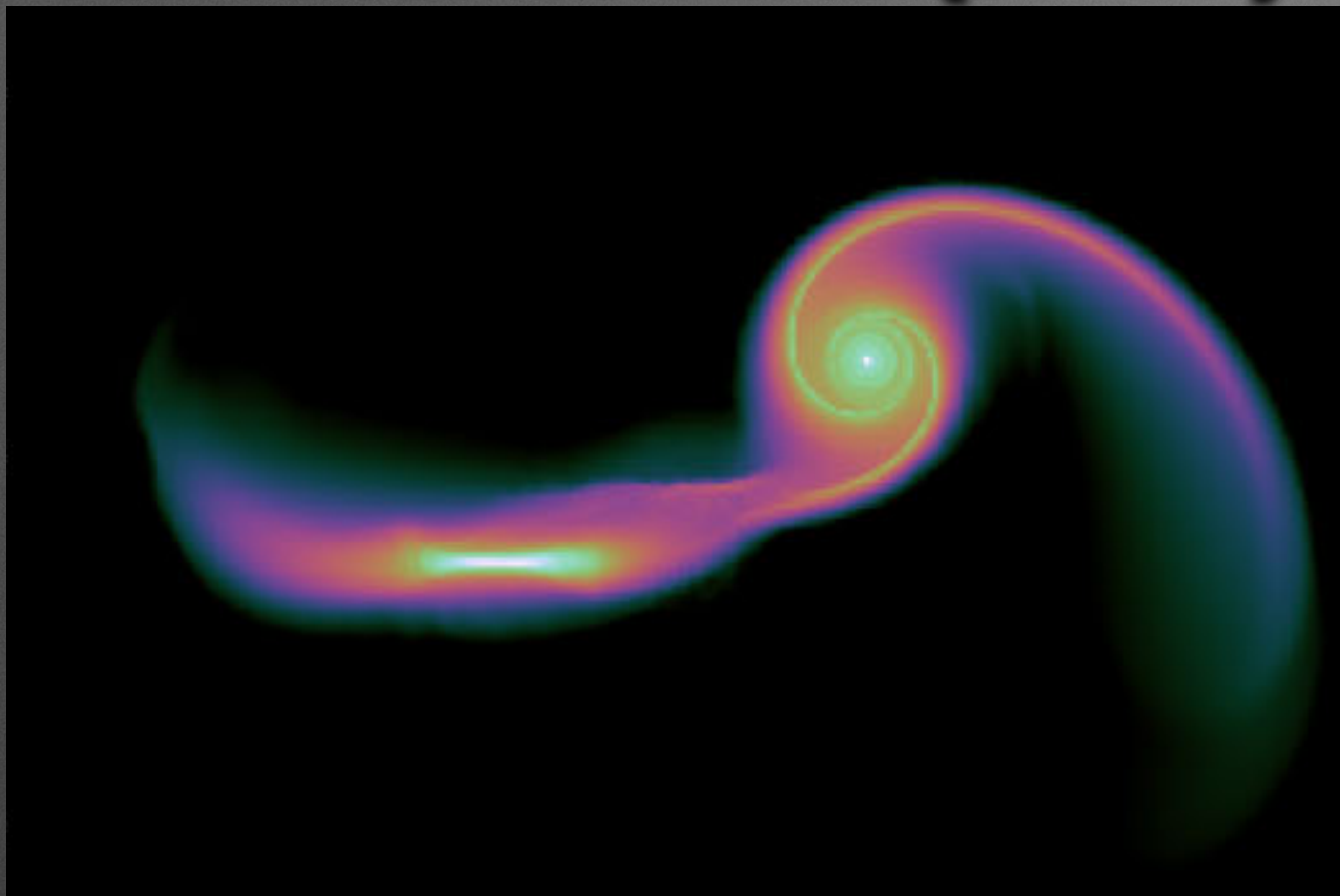




results for PMS stars in mm/submm Akeson+2019 mirror IR data that suggest all binaries, especially close ones, show dearth of disks compared to single star counterpart.

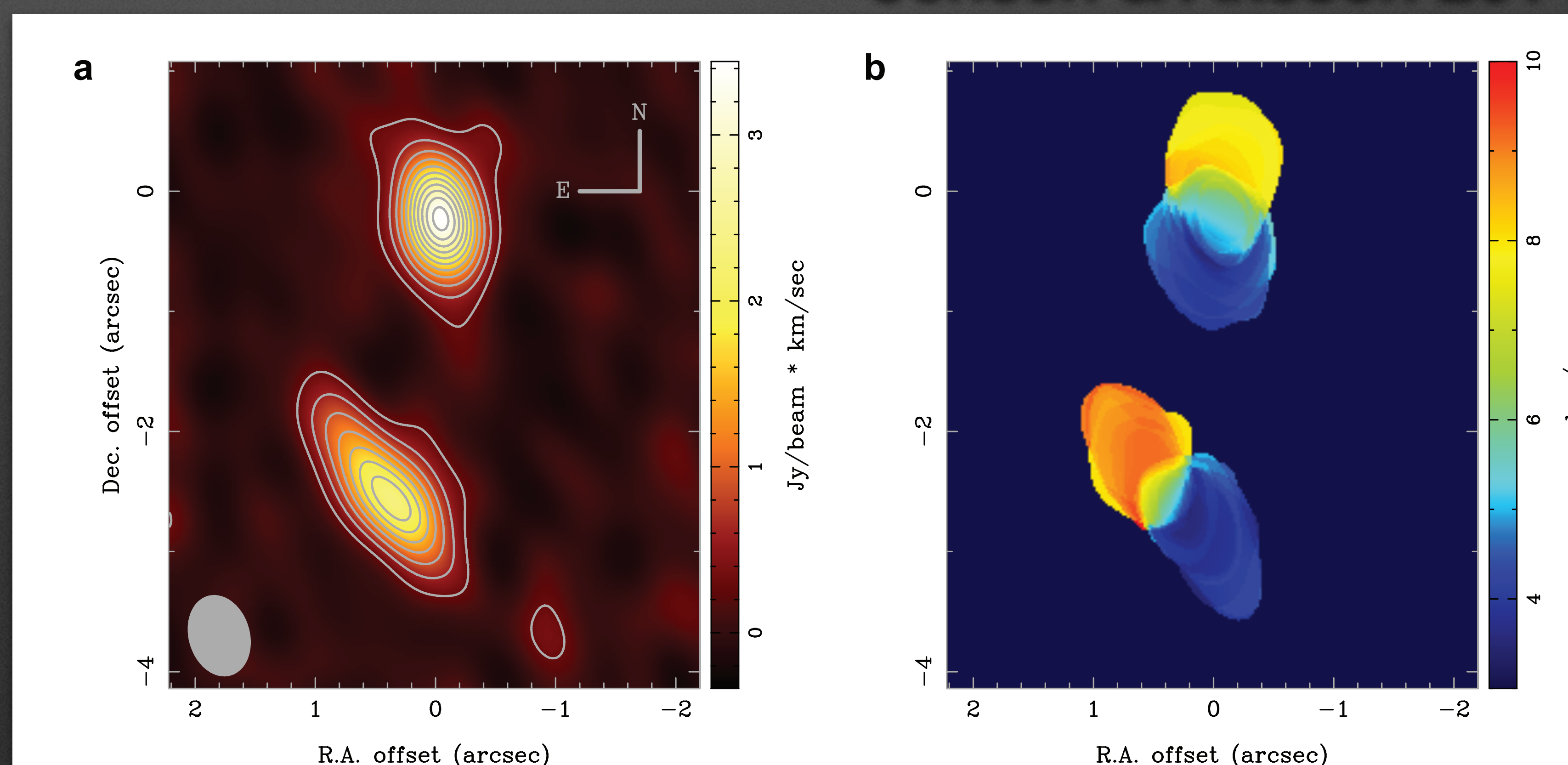
Offner+ PPVII

Disk (mis)alignment



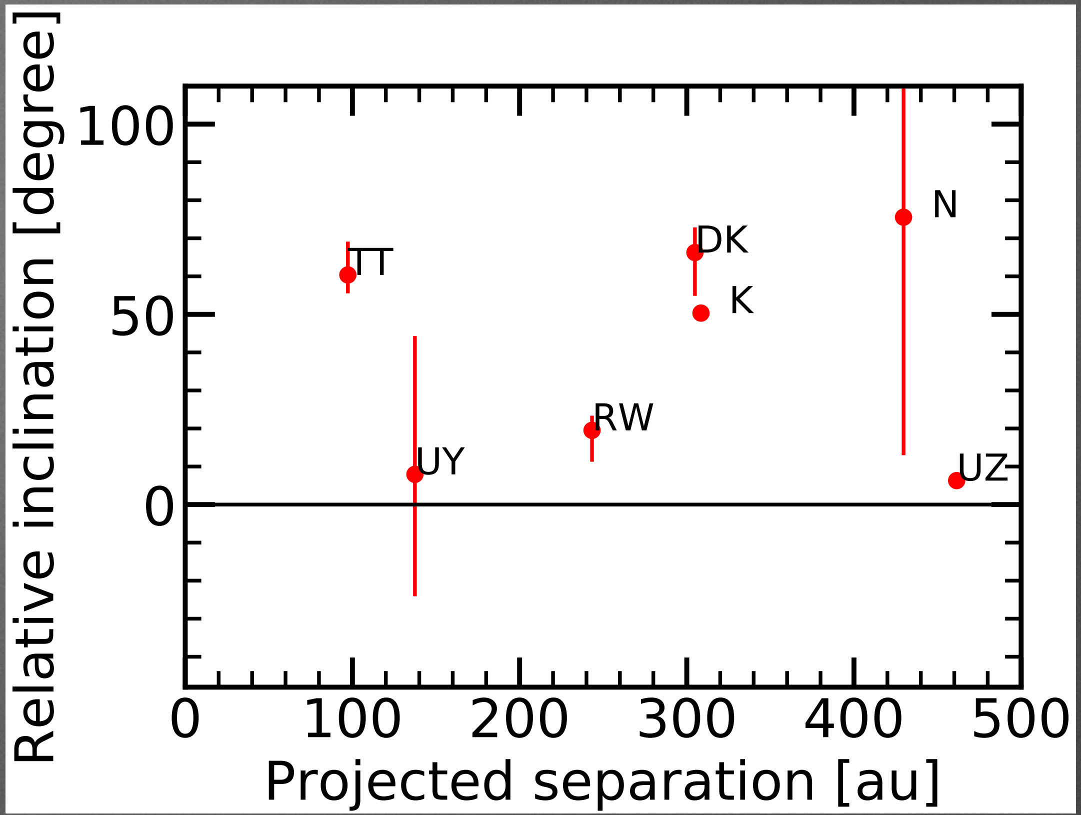
Munoz+2015

Jensen & Akeson 2014

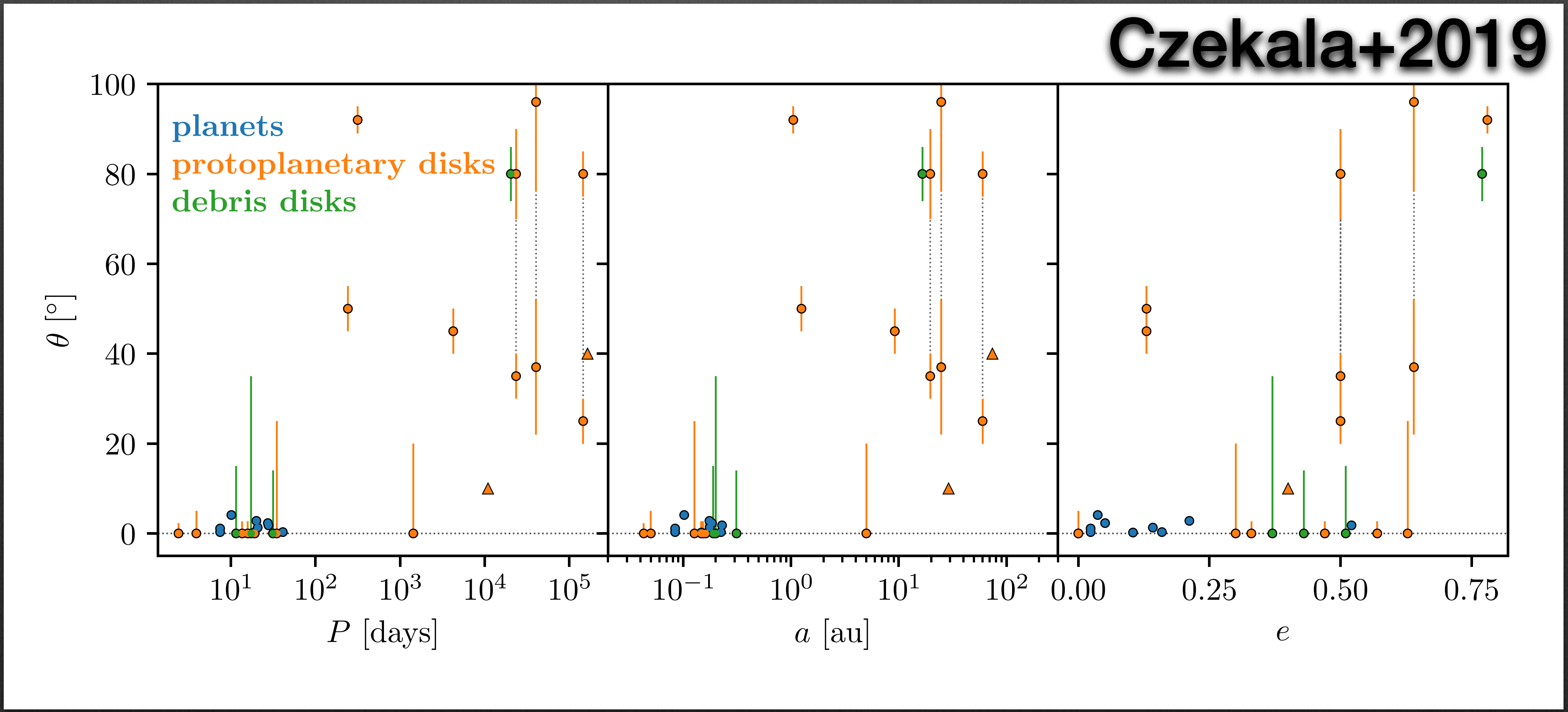


Disk Alignment

Manara+2019

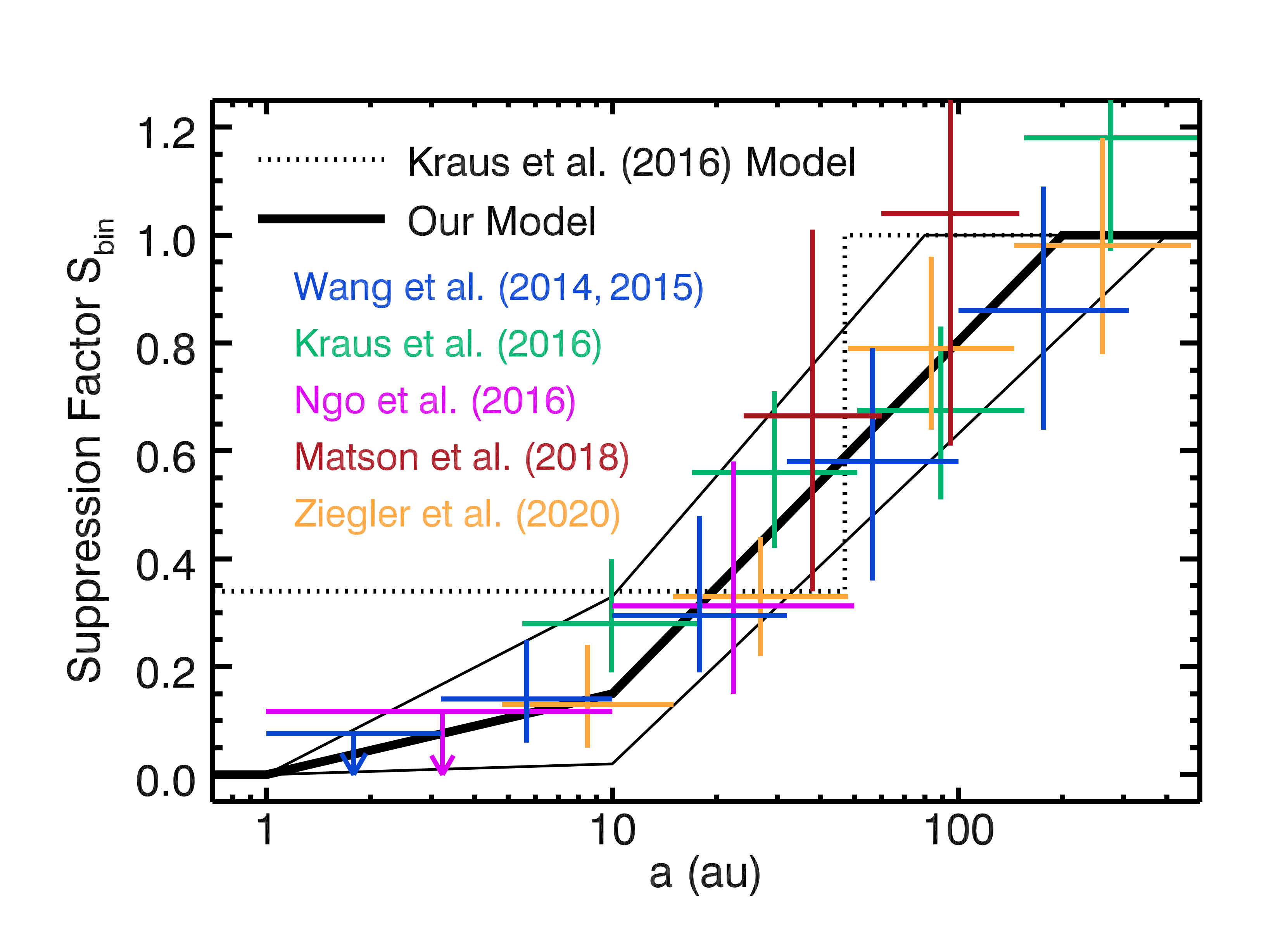


- At intermediate - wide separations, binaries with two resolved disks do not show preferential alignment
- Circumbinary disk DO show preferential alignment
- What about close separation binaries?



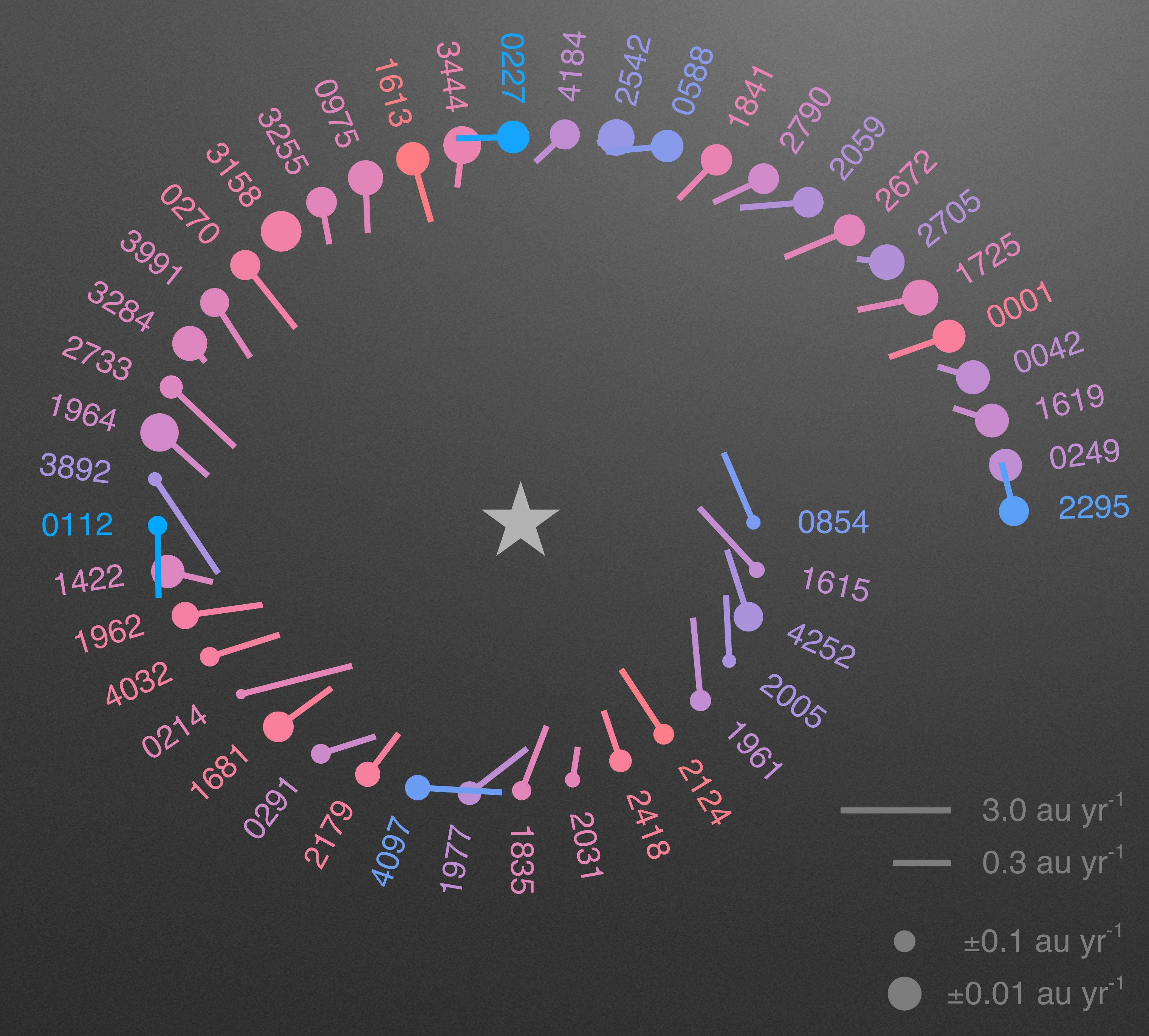
Planet Occurrence Rates

- The T Tauri disk result aligns well with planet occurrence rates: binaries <50 au strongly supress planet formation
- Recall that the truncation radius for the disk is ~1/3 the separation (modulo eccentricity).



Moe & Kratter 2021

Measuring Planet-Binary Alignment

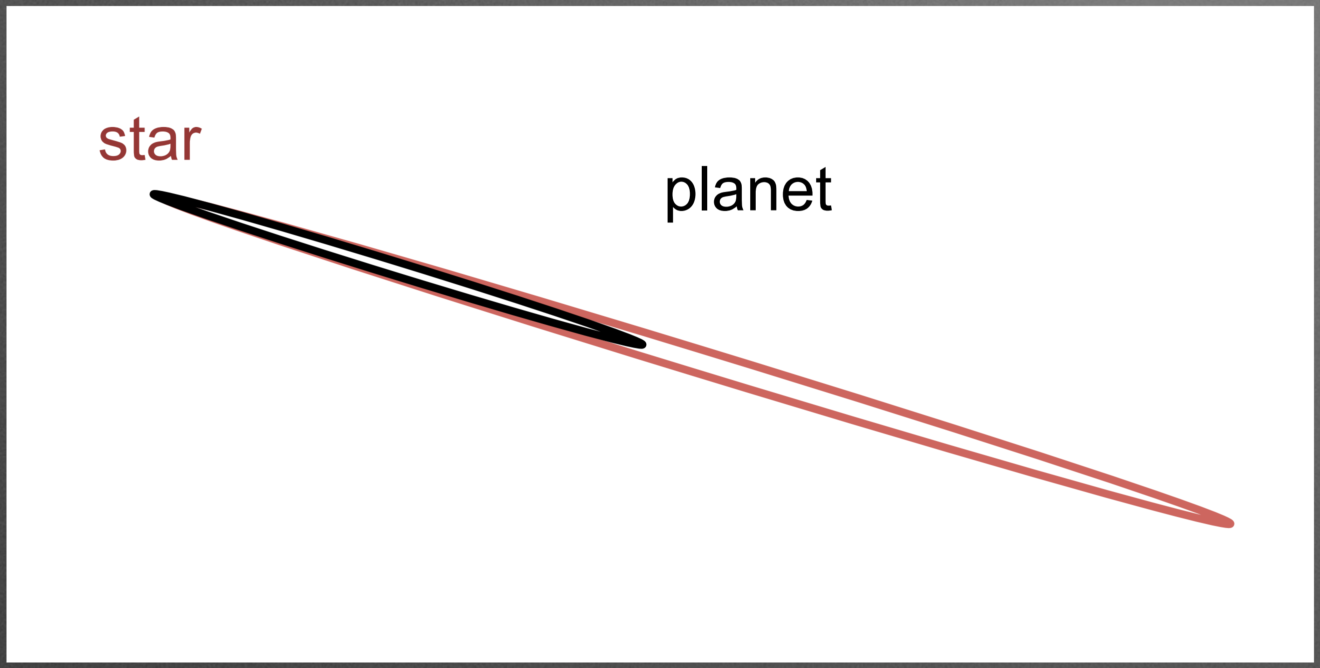


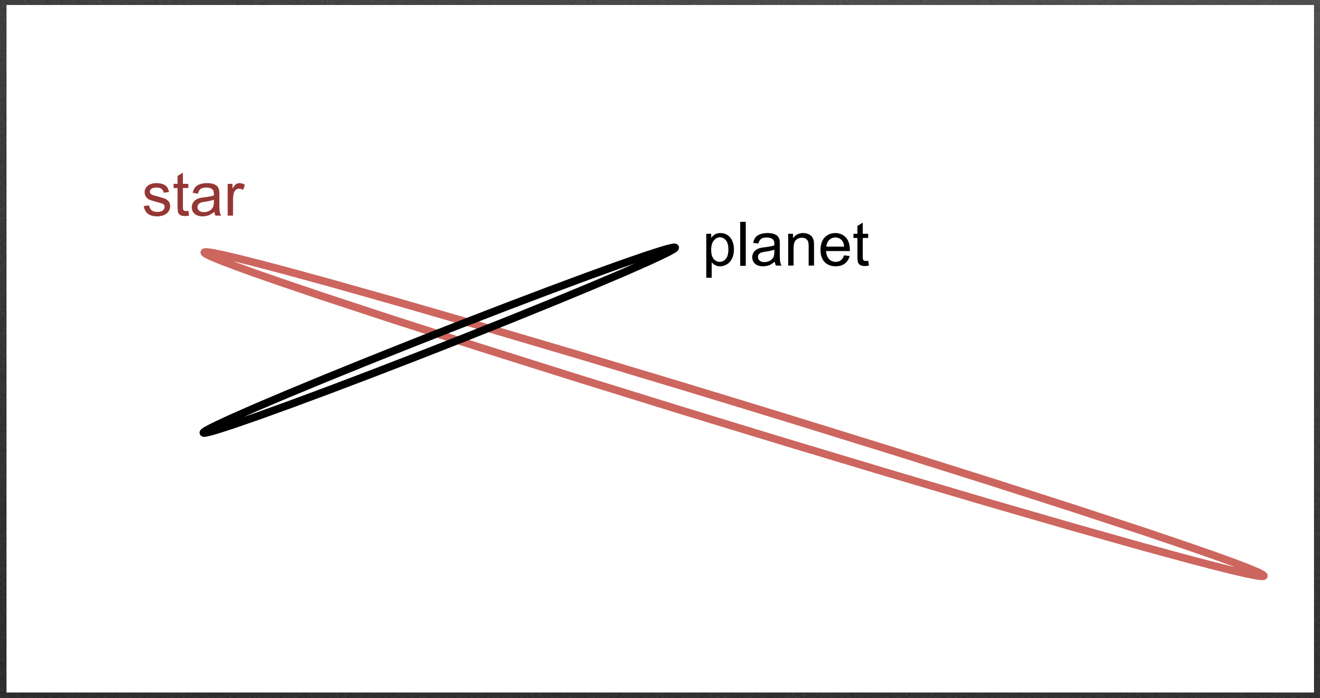
Quantify degree to which astrometric binaries are aligned based on orbital motion in PA vs separation

Planets are all transiting

Dupuy+subm

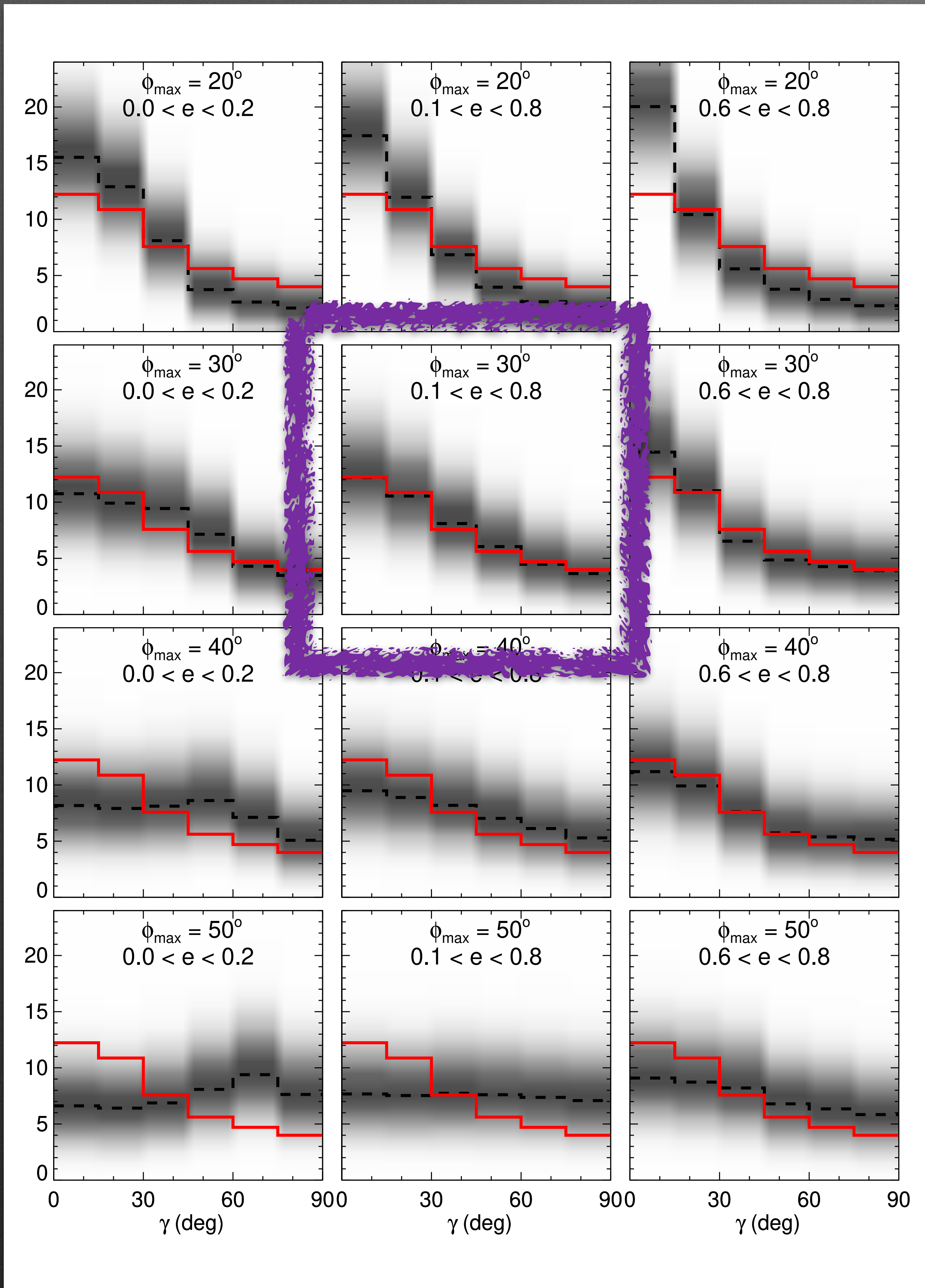
Alignment is statistical





Probability that we observe two edge-on orbits that are misaligned is low, but…

Planet Alignment



- Strong evidence for preferential alignment (<30 deg) for Kepler planets and binary companions with a~<100 au.
- Note that 30 !=0. Fits with two components are also possible

Dupuy+, sub

Open Questions

- What is the fractional contribution of core vs disk fragmentation? Do these lead to different disk and planet formation outcomes?
- What drives observed differences in disks in singles vs multis: age, mass, detection biases are hard to address!!
- At what stage are planetary system properties “frozen in” especially e.g. inclination