Binary Star Populations

1. Evolved Binaries:

- A) POSYDON population synthesis (Meng Sun)
- B) Blue stragglers in triples (Nathan Leigh)
- C) HW Vir: post-CE binaries

2. Young Binaries

- A) Large-scale simulations (Rajika Kuruwita)
- B) $\dot{a}$ inferred from close solar-type binaries
- C) $\dot{a}$ inferred from close massive binaries

POSYDON: A Next Generation Binary Population Synthesis Code

The **POSYDON** collaboration: Jeff Andrews, Simone Bavera, Christopher Berry, Scotty Coughlin, Aaron Dotter, Tassos Fragos, Monica Gallegos, Jaime Roman Garza, Prabin Giri, Vicky Kalogera, Aggelos Katsaggelos, Konstantinos Kovlakas, Shamal Lalvani, Devina Misra, Juanga Perez, Philipp M. Srivastava, Ying Qin, Kyle Rocha, Petter Stahle, Meng Sun, Xu Teng, Pablo Ruiz, Nam Hai Tran, Goce Trajcevski, Manos Zapartas

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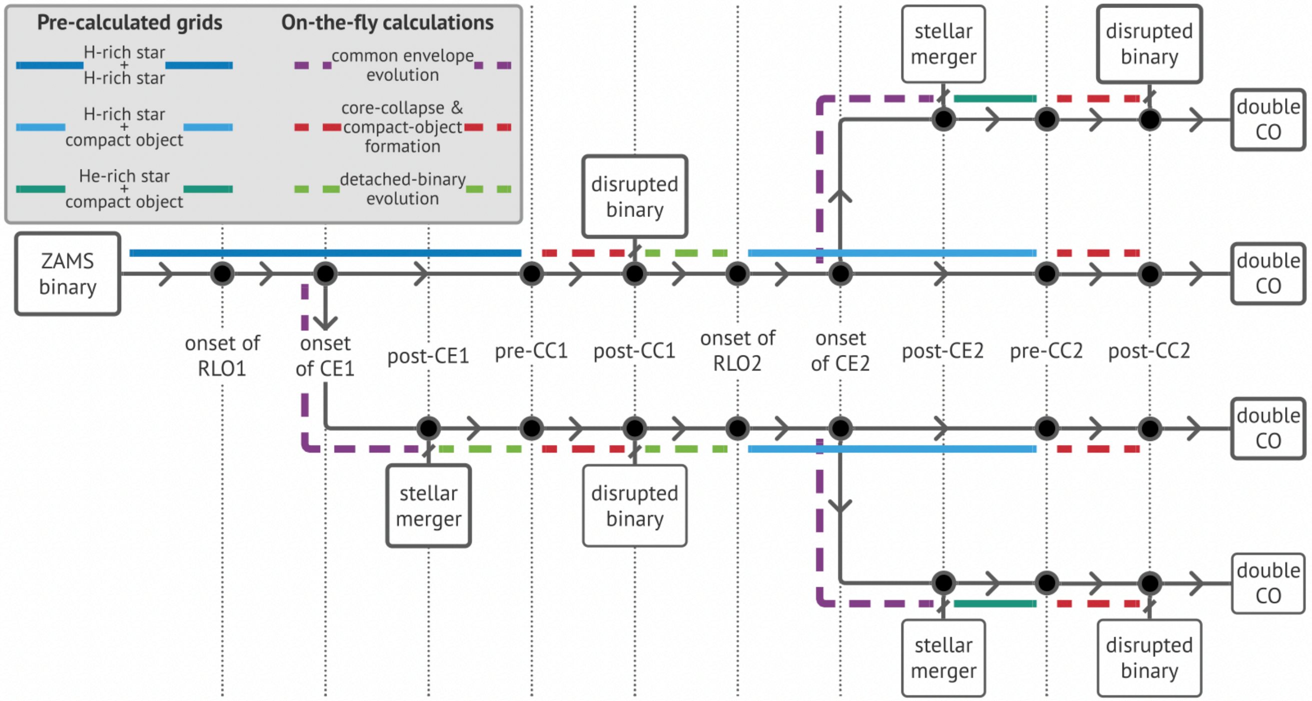
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

POSYDON: A New Population Synthesis Code with Detailed Binary-Evolution Simulations

- MESA based stellar and binary evolutionary tracks;
- Machine learning and active learning are used in classifying the grids, interpolating stellar and binary parameters in the final stage of the evolution and developing irregular grid for enhancing the computational efficiency;
- Mass-transfer history and stability analysis are from real 1-D stellar evolution simulations;
- The first version of the code focuses on neutron star and black hole progenitors at solar metallicity.



Fragos et al. 2022, submitted to ApJS

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Circumbinary Disk Accretion in Stellar Triples

Nathan W. C. Leigh
Universidad de Concepcion
American Museum of Natural History

Email: nleigh@amnh.org

SUPERMASSIVE BLACK HOLES
FORMATION & GROWTH
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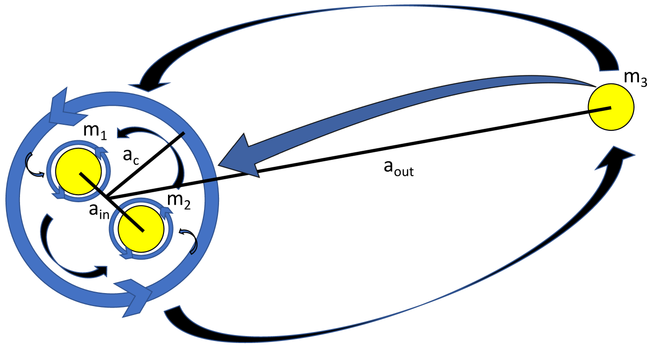
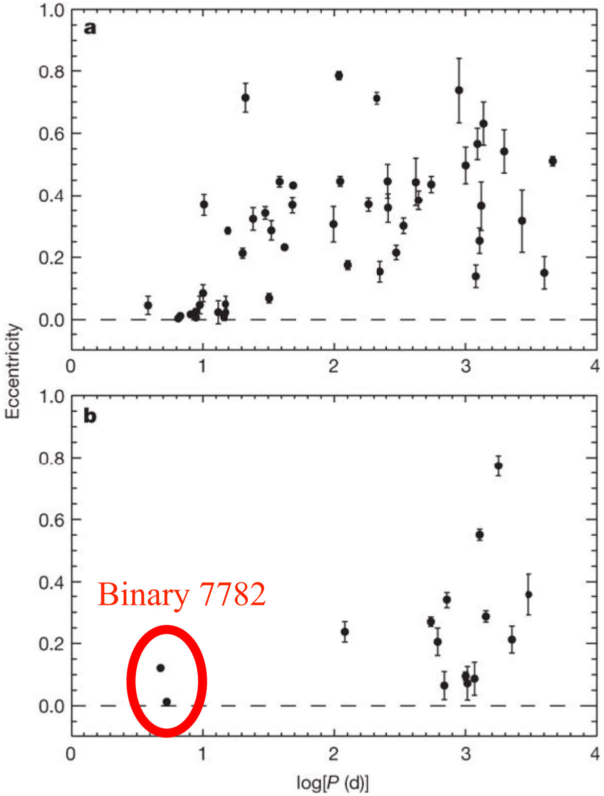
Other Ways to Merge Compact Objects via the Three-Body Problem???



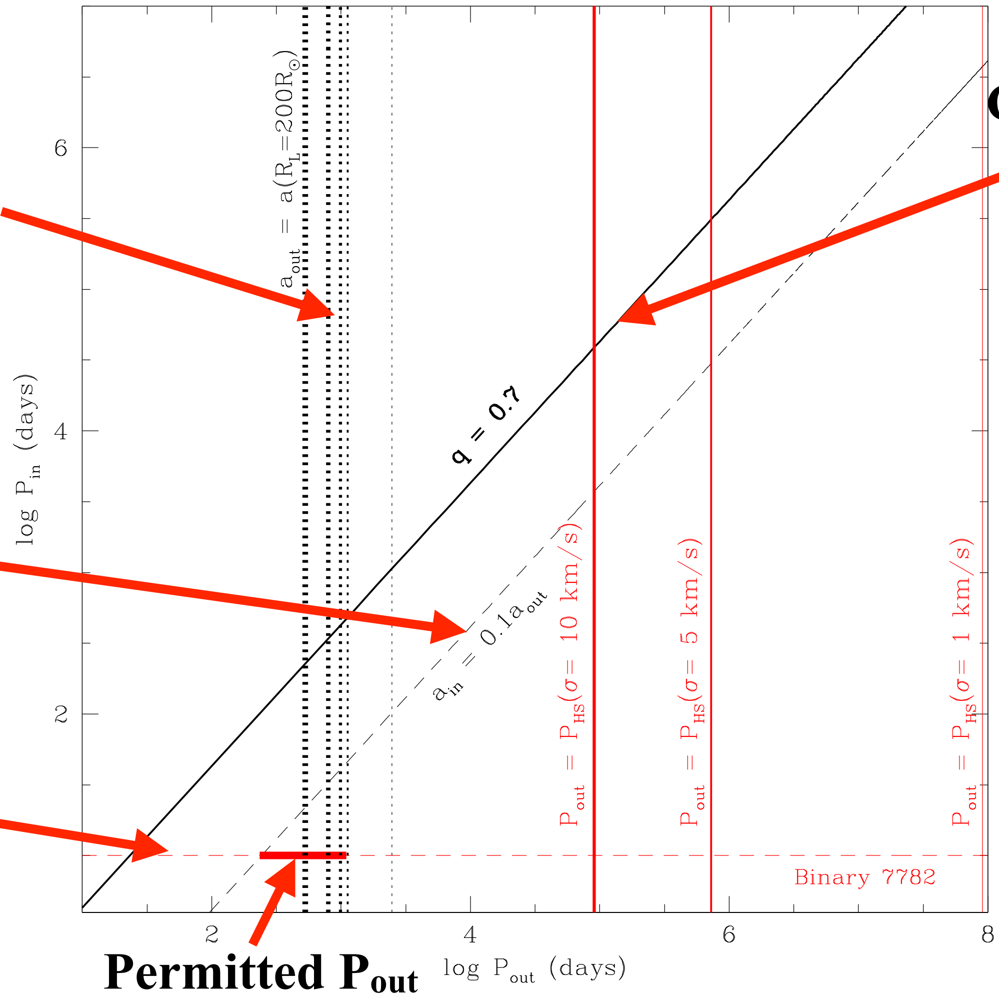
Portegies Zwart & **Leigh** (2019), ApJL, 876, 33

Figure 1. Cartoon depiction of our proposed scenario for the formation of Binary 7782, specifically mass transfer from an evolved outer tertiary companion on to a compact inner binary via a circumbinary disk. The outer tertiary component has mass m_3, whereas the inner binary components have masses m_1 and m_2. The inner and outer orbital separations are denoted by, respectively, a_{in} and a_{out}. The circularization radius of the accretion stream is denoted a_c, as calculated via Equation 2, and marks the mean separation of the circumbinary disk.

NGC188 orbital eccentricity/log period (*e*–log *P*) distributions.



RD Mathieu & AM Geller *Nature* **462**, 1032-1035 (2009) doi:10.1038/nature08568



Maximum period for outer tertiary to be Roche lobe-filling

Minimum period for outer orbit to remain dynamically stable

Observed period P_{in} of inner binary

Permitted P_{out}

Circularization radius

Initially, $m_1 = 1.1\ M_{Sun}$, $m_2 = 0.9\ M_{Sun}$ in the inner binary, and $q = 0.7$ for the outer tertiary m_3.

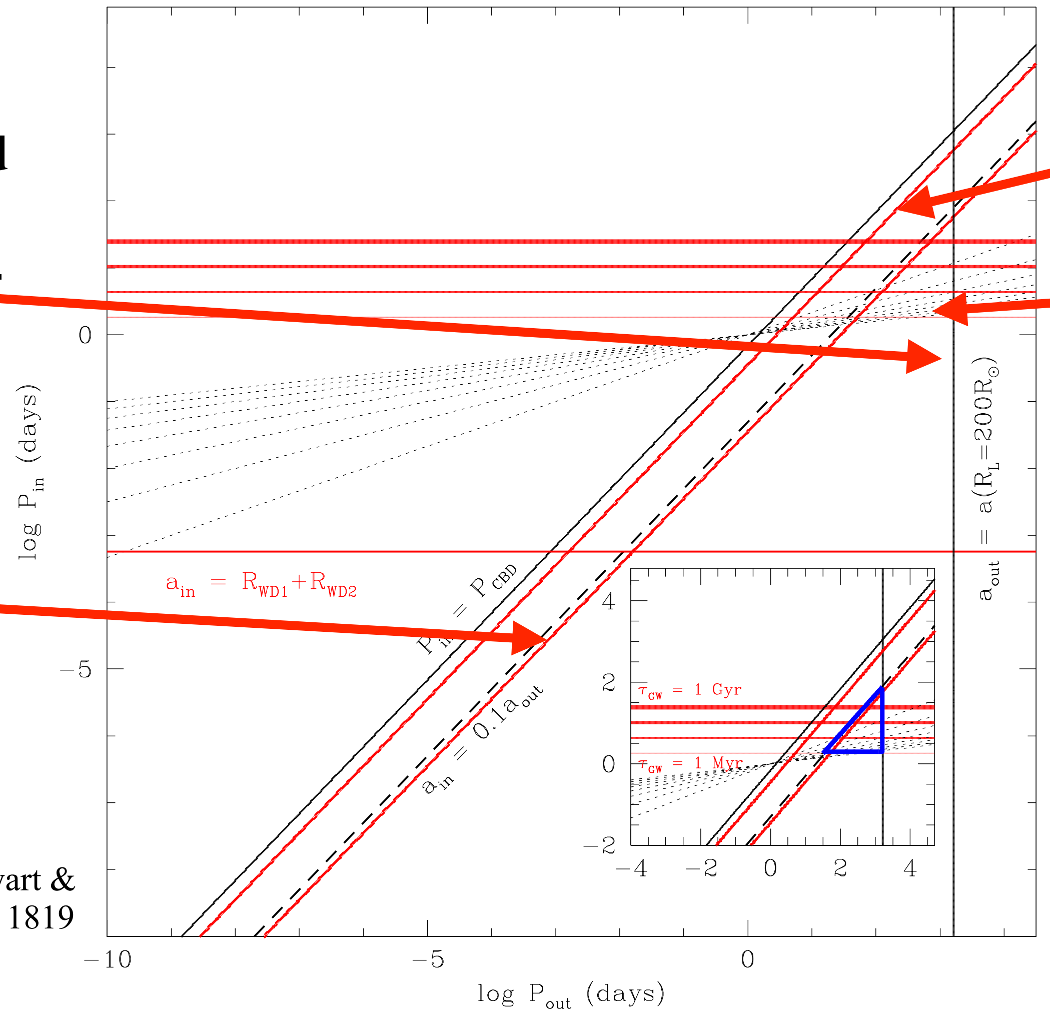
In the end, we assume $m_3 = 0.6\ M_{Sun}$ for the left-over WD tertiary, and the observed masses for the inner binary , or $m_1 = m_2 = 0.9\ M_{Sun}$.

Our results predict an outer white dwarf tertiary companion with an orbital period in the range $P_{out} \sim 200 - 1000$ days.

Parameter space in the P_{out}-P_{in}-plane allowed for the hypothetical outer tertiary orbit of Binary 7782 before Roche-lobe overflow.

Maximum period for outer tertiary to be Roche lobe-filling

Minimum period for outer orbit to remain dynamically stable



Circularization radius

τ_{GW} **= 1 Myr**

What if the inner binary is made up of compact objects instead of main-sequence stars?

Leigh, Toonen, Portegies Zwart & Perna (2020), MNRAS, 496, 1819

Parameter space in the P_{out}-P_{in}-plane allowed for the hypothetical outer tertiary orbit *before* Roche-lobe overflow.

What does the tertiary MT mechanism predict for the mergers of compact object binaries?

(see Leigh, Toonen, Portegies Zwart & Perna (2020), MNRAS, 496, 1819 for more details!)

Specific predictions for the masses of the companions?

- **Hypervelocity white dwarfs near the Chandrasekhar mass limit?**
- **Constraints on the maximum neutron star mass? Production of hypervelocity millisecond pulsars?**

What about the physics of mass transfer?

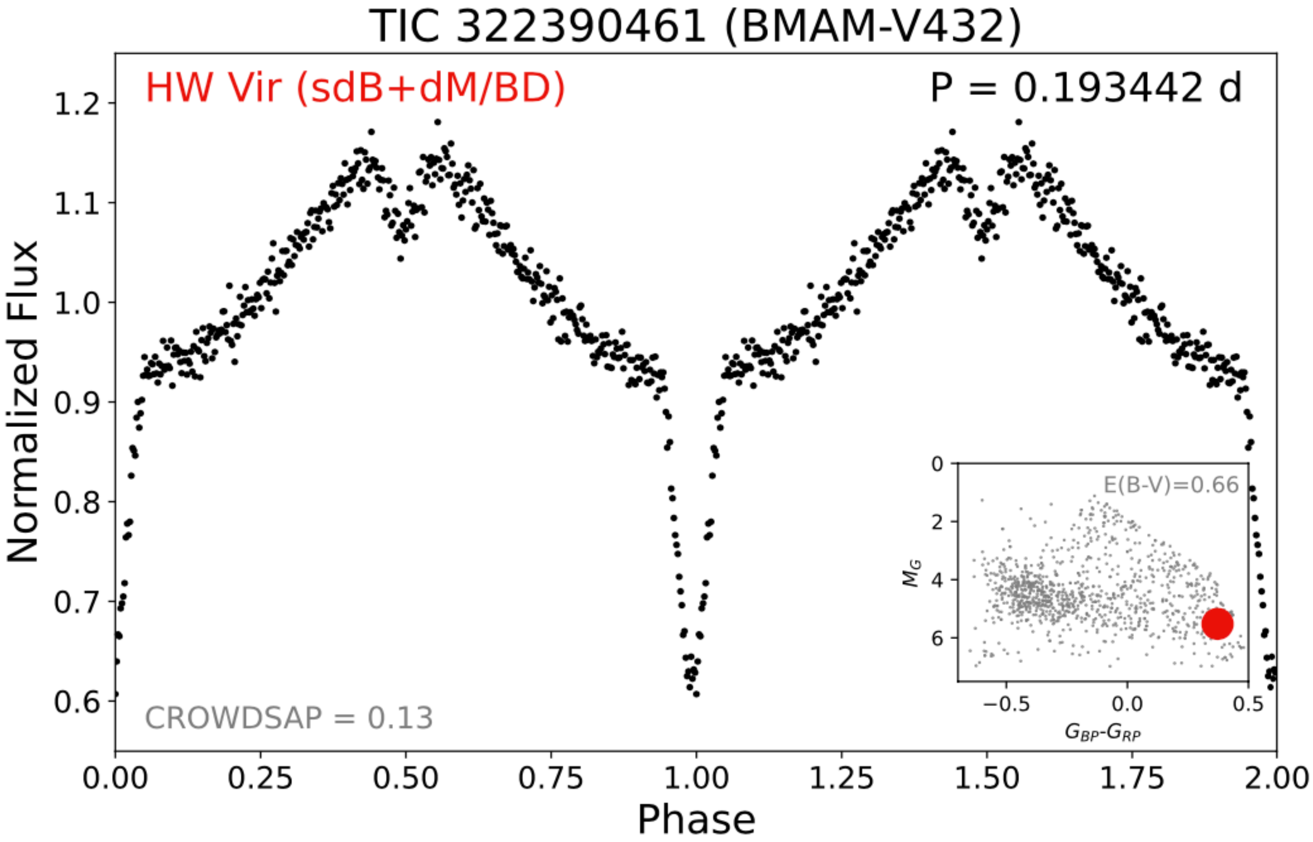
- **When is steady-state disk accretion achieved?**
- **Do we really believe the tendency to accrete toward a mass ratio of unity?**
- **When is a merger initiated?**
- **When is triple disruption initiated (i.e., by widening the inner orbit)?**

Would this mechanism predict anything observable?

- **It *does* seem to make strong predictions for the properties of the outer tertiary object and orbit.**
- **Faster rotation rates than expected for other mechanisms? Slower?**
- **Higher/lower magnetic fields? Is this observable (e.g.,** Halpha?**)**

Post Common Envelope Eclipsing Binaries

HW Vir: sdB + dM



TESS is discovering more HW Vir EBs (van Grootel et al. 2021)

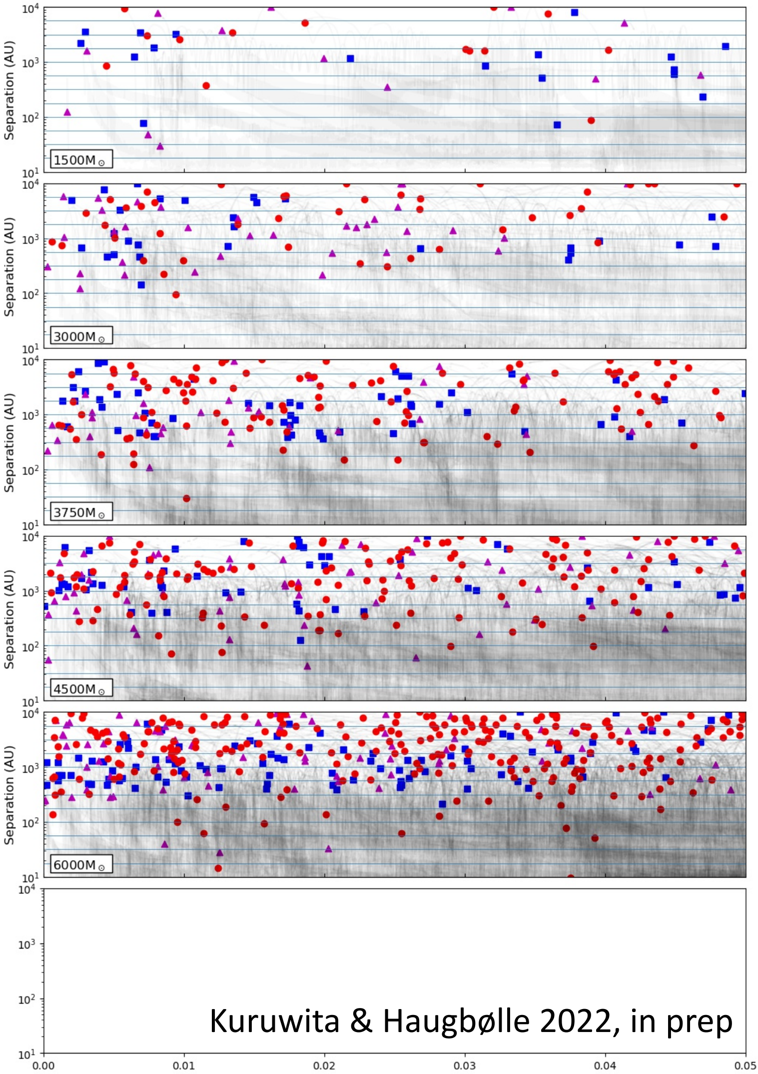
What do large populations of HW Vir EBs tell us about CE evolution?

Can we use them to benchmark simulations of circumbinary gas/disk-aided migration?

Binary Star Formation

Investigating formation pathways of multiple star systems in simulations of GMC with varying gas masses

- *Right:* shows the separations of all systems formed and markers colour code formation pathway.



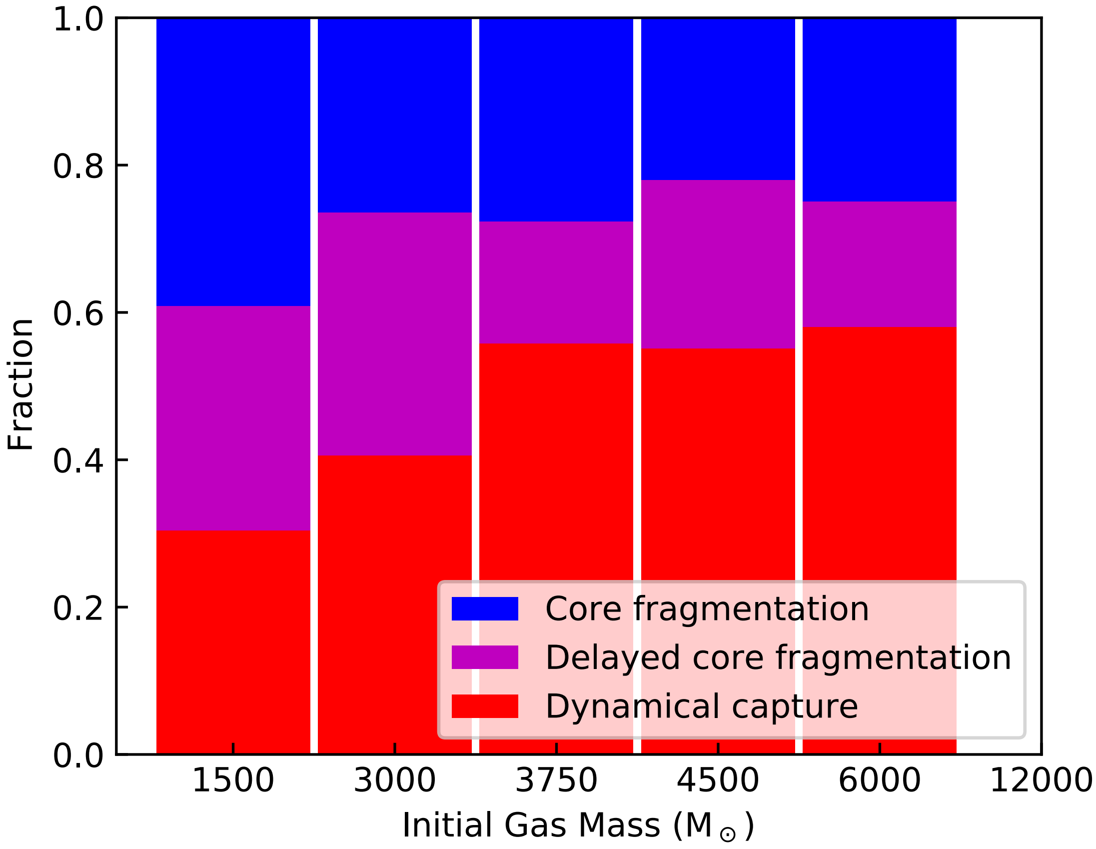
Kuruwita & Haugbølle 2022, in prep

Rajika Kuruwita, INTERACTIONS Fellow
KITP binary 22

Funded by European Union

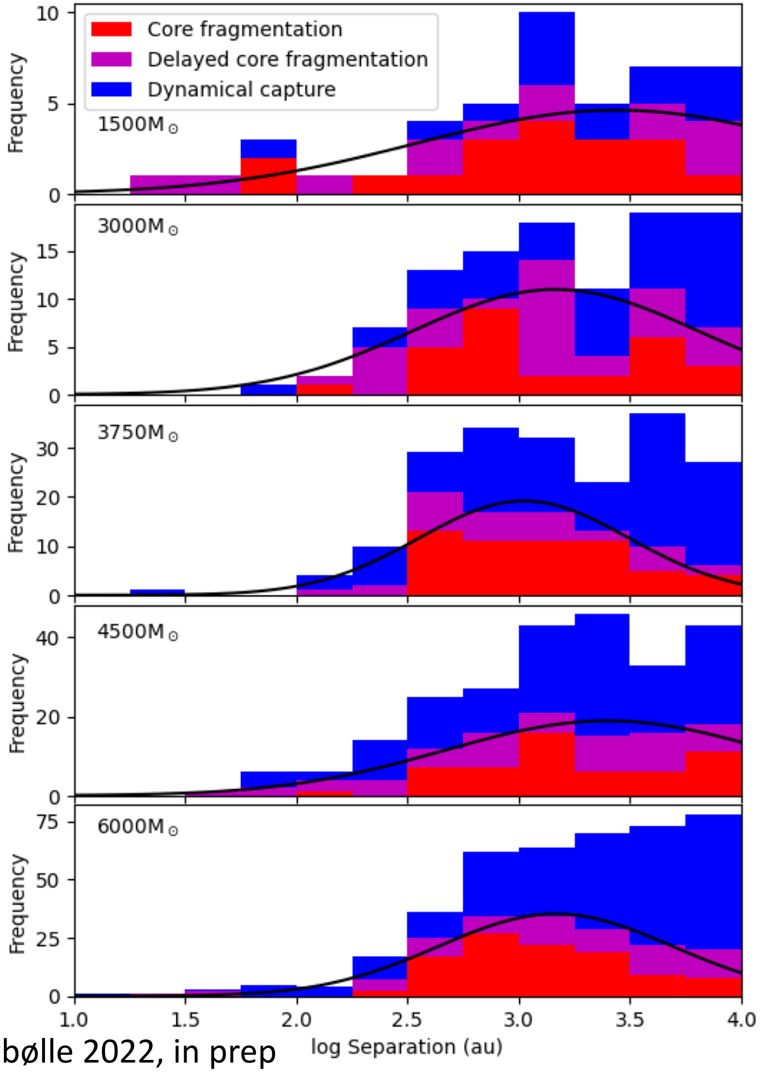
UNIVERSITY OF COPENHAGEN

- More systems form via core fragmentation in lower mass GMCs, probably due to a higher degree of clustering (measured with TPCFs).
- With higher mass GMCs, dynamical capture is marginally dominant



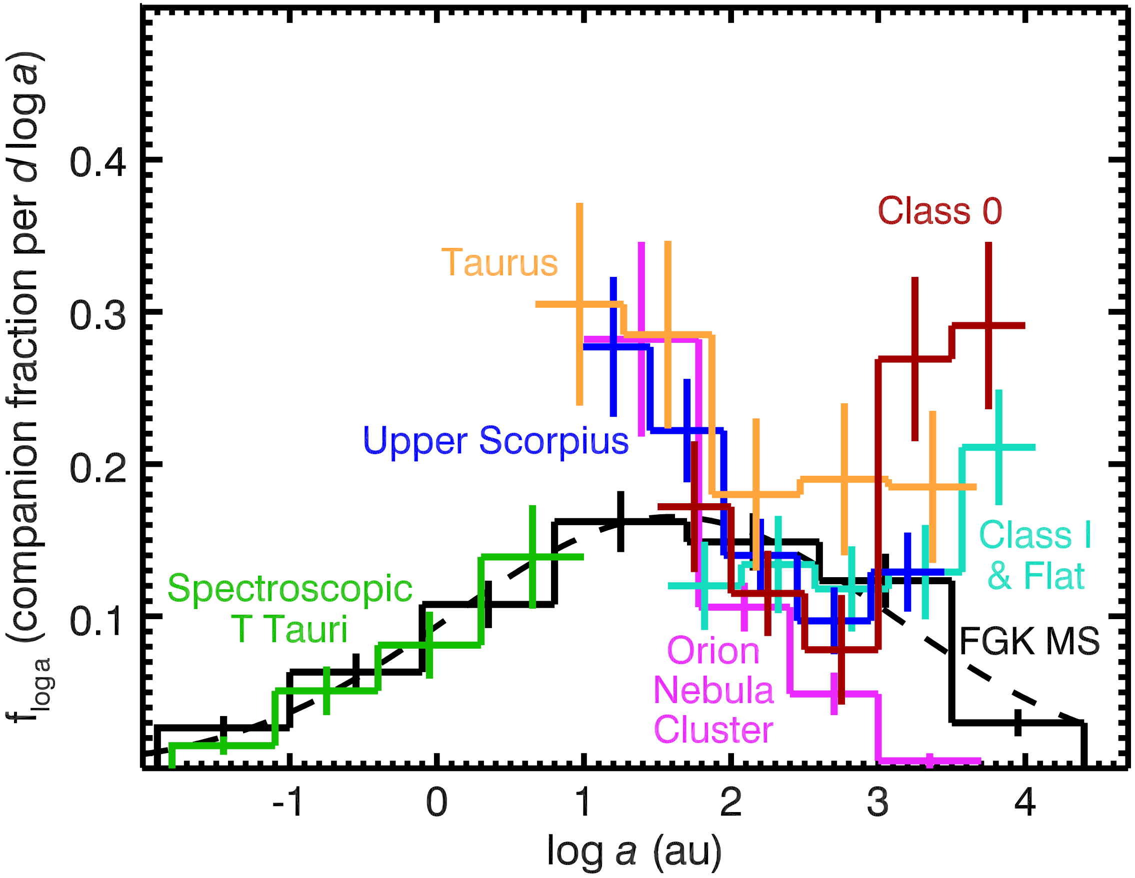
Kuruwita & Haugbølle 2022, in prep

- Trying to determine whether the core fragmentation scale varies with star forming environment
- It seems to shift around a little, but broadly peaks around a few thousand au
- Also in to determine if there is any significant orbital evolution between the formation pathways.



Kuruwita & Haugbølle 2022, in prep

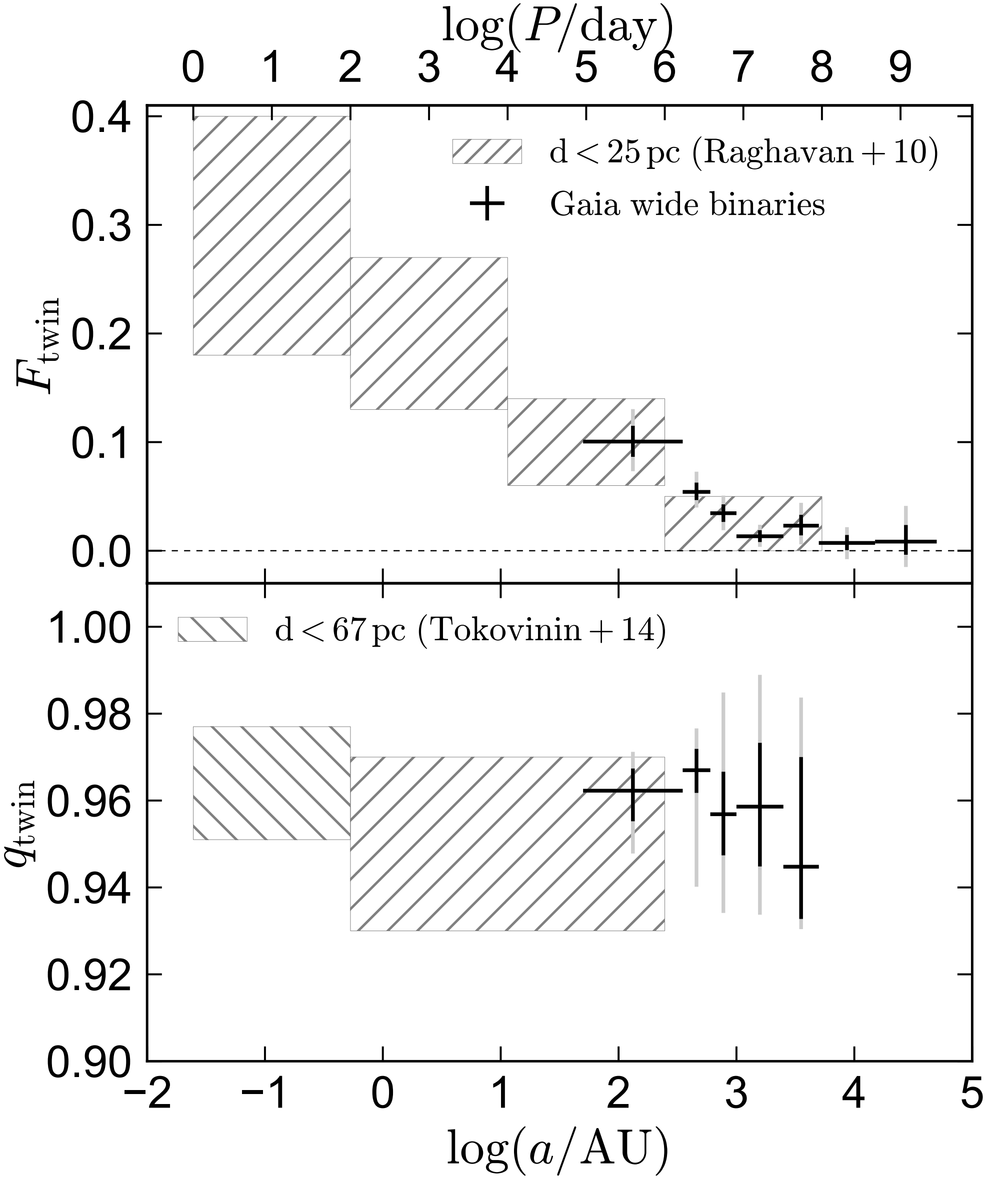
Close binaries (a < 10 AU) cannot form in situ (Boss 1986; Bate 1998, 2001), yet observed close binary fraction of Class II/III T Tauri stars (~3 Myr) matches field MS distribution (Mathieu 1994; Kounkel et al. 2019)



Offner, Moe, Kratter, et al.
(review chapter for
Protostars & Planets VII)

Close solar-type binaries originally migrated from a > 50 AU to a = 0.1 - 10 AU during embedded Class 0/I protostellar phase within τ < 2 Myr

Excess fraction of twin binaries with q > 0.95 decreases from 30% near 0.1 AU to 2% near 1,000 AU (Tokovinin 2000; Moe & Di Stefano 2017; El-Badry et al. 2019).

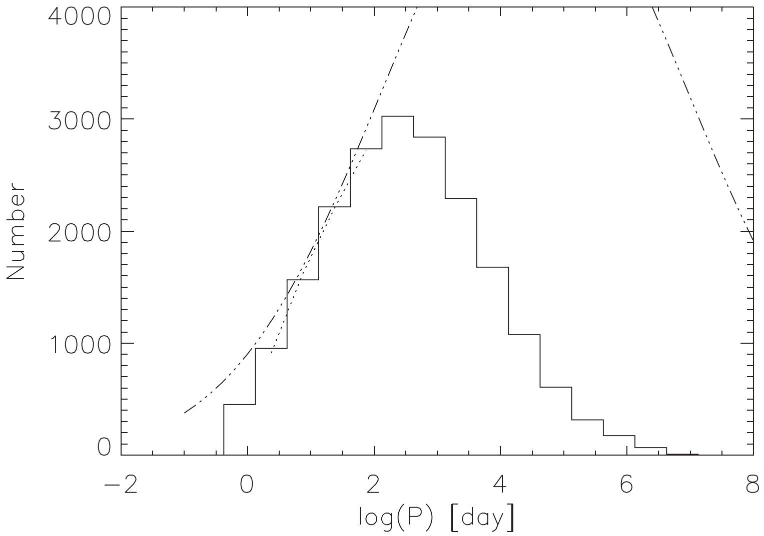


Evidence that protobinaries migrated inward as there was preferential accretion onto the secondary, driving q toward unity.

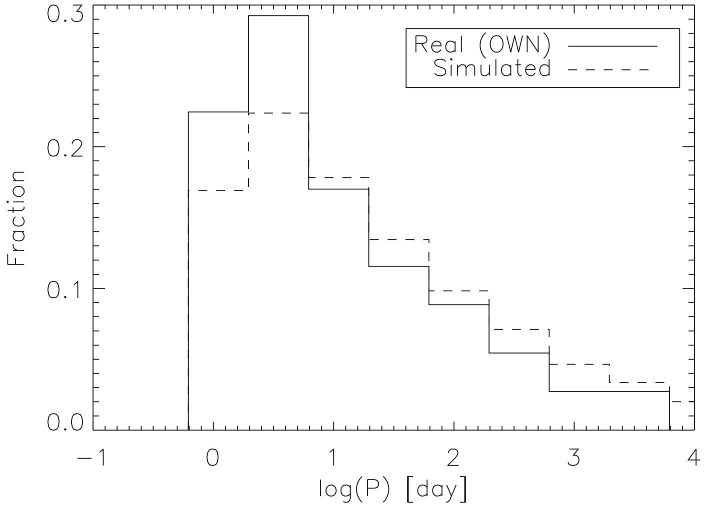
Toy Model of Disk Fragmentation, Accretion, & Migration (Tokovinin & Moe 2020)

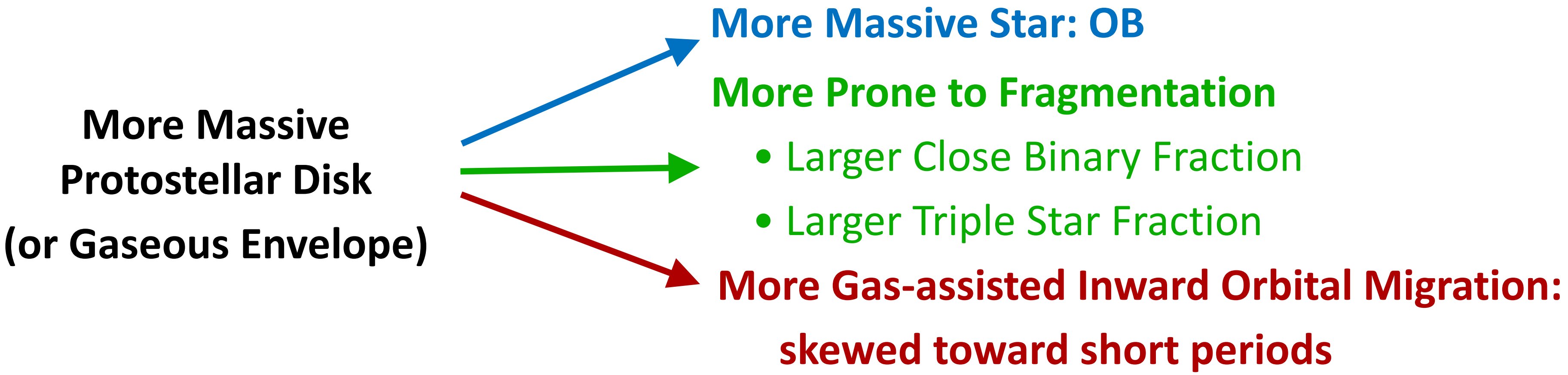
Simulated Period Distributions:

Solar-type Binaries -
skewed toward long periods



Massive Binaries -
skewed toward short periods





More Massive Protostellar Disk (or Gaseous Envelope)

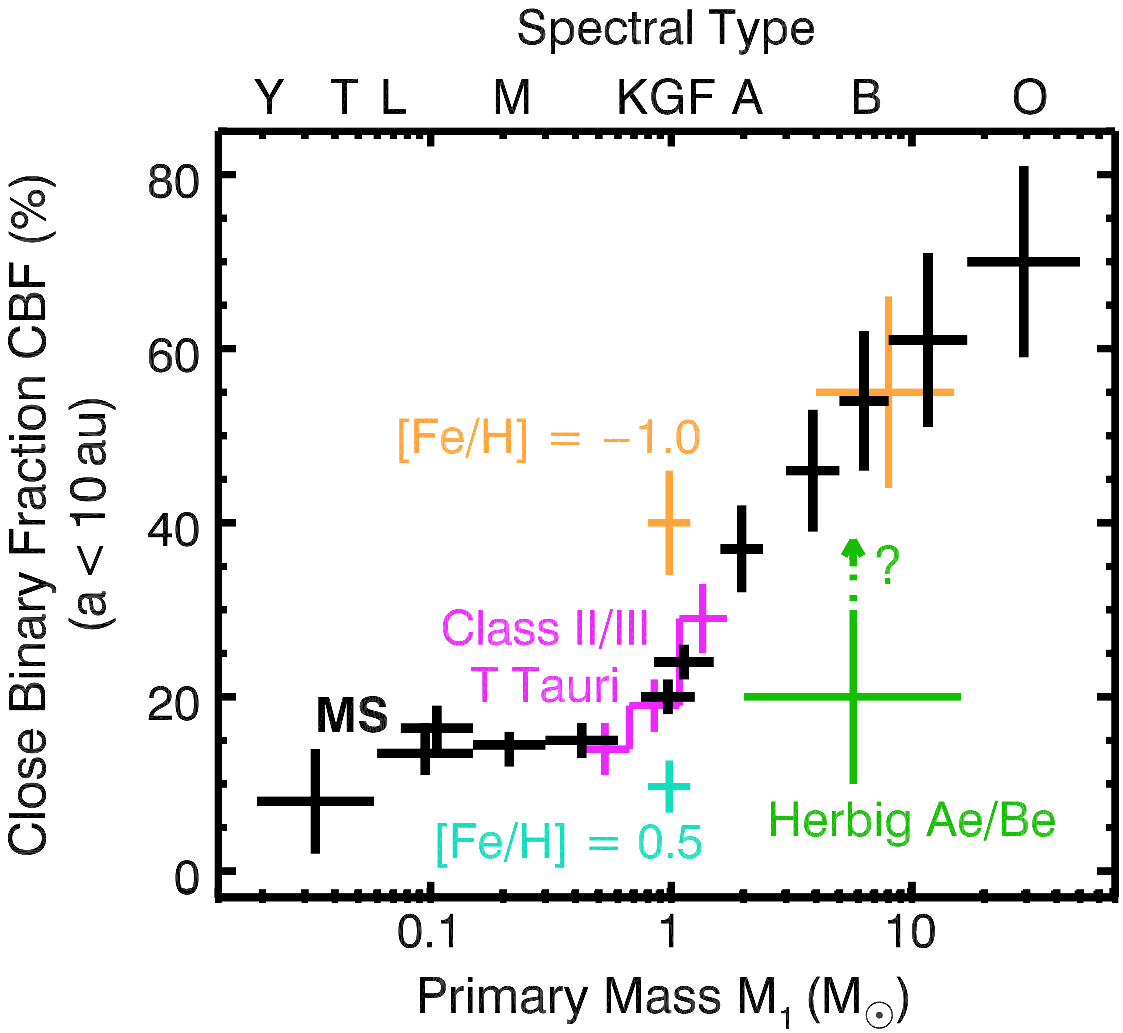
More Massive Star: OB

More Prone to Fragmentation

- Larger Close Binary Fraction
- Larger Triple Star Fraction

More Gas-assisted Inward Orbital Migration: skewed toward short periods

Close Massive Binaries



Offner, Moe, Kratter, et al.

(review chapter for Protostars & Planets VII)

Measured close binary fraction of Herbig Ae/Be pre-MS stars is *smaller* than their A/B MS counterparts

(Corporon & Lagrange 1999; Apai et al. 2007; Sana et al. 2017; Ramírez-Tannus et al. 2021)

Close Massive Binaries

In M17 (Swan Nebula; τ ≈ 1 Myr),
there are ≈60 early-B stars.

Only 11 are YSOs / Herbig Be stars
with signs of active disk accretion.

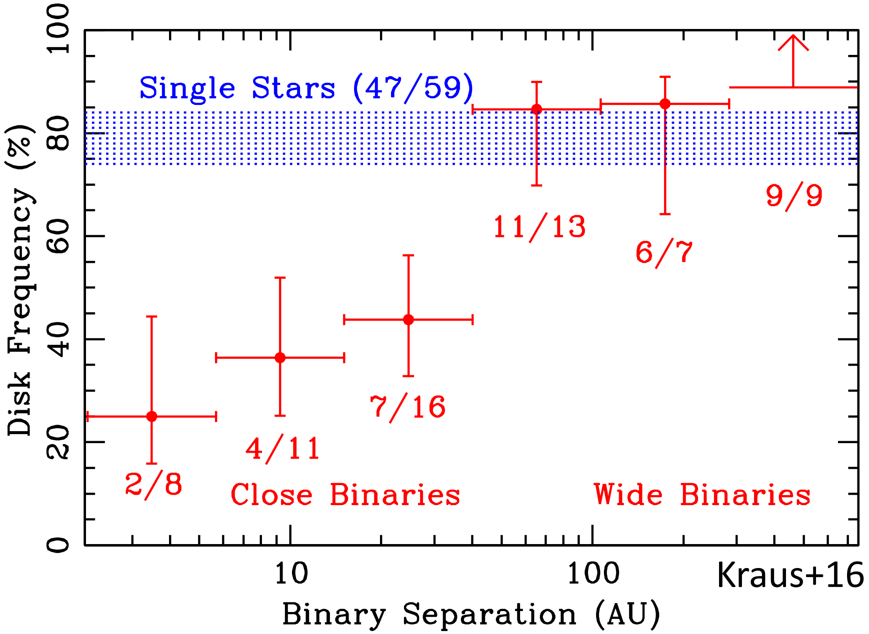
None of these 11 have
close companions (Sana et al. 2017).

But O/early-B stars in slightly
older clusters (τ ≈ 3 Myr)
have large close binary fraction.


(ESO)

Interpretation #1: Close companions to OB stars migrate inward between τ ≈ 1 Myr and 3 Myr *after most of the gas/disk has dissipated.*
No theoretical explanation yet – any ideas?!?!

Interpretation #2: Selection Effect – subset of OB stars with disks are biased against close binaries because close binaries shorten disk lifetimes (similar to T Tauri sample).



Kraus+16