Discs in multiple systems

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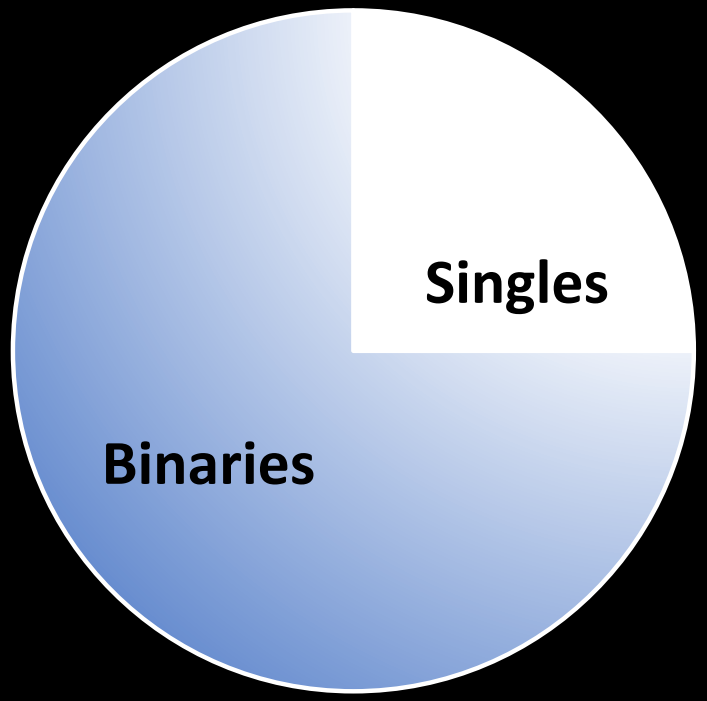
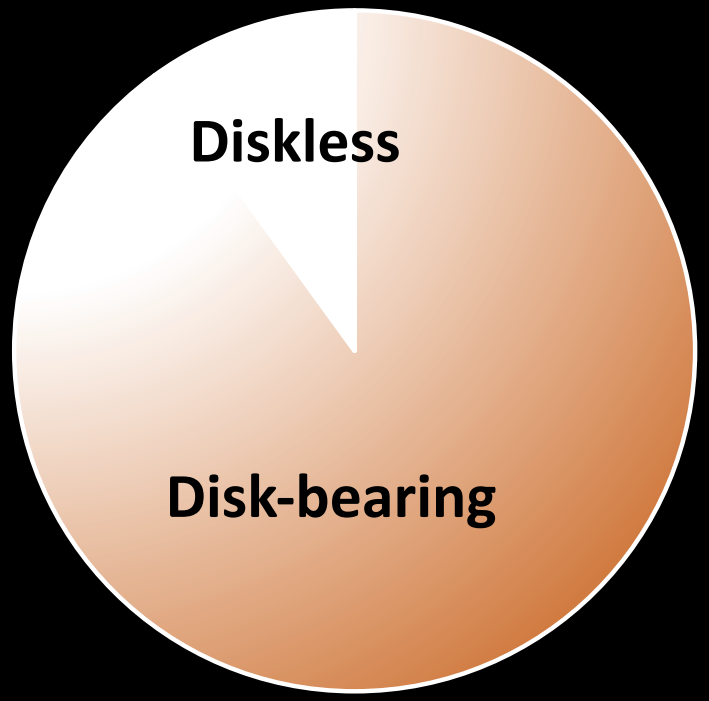
Binaries are the observer's equivalent of B field





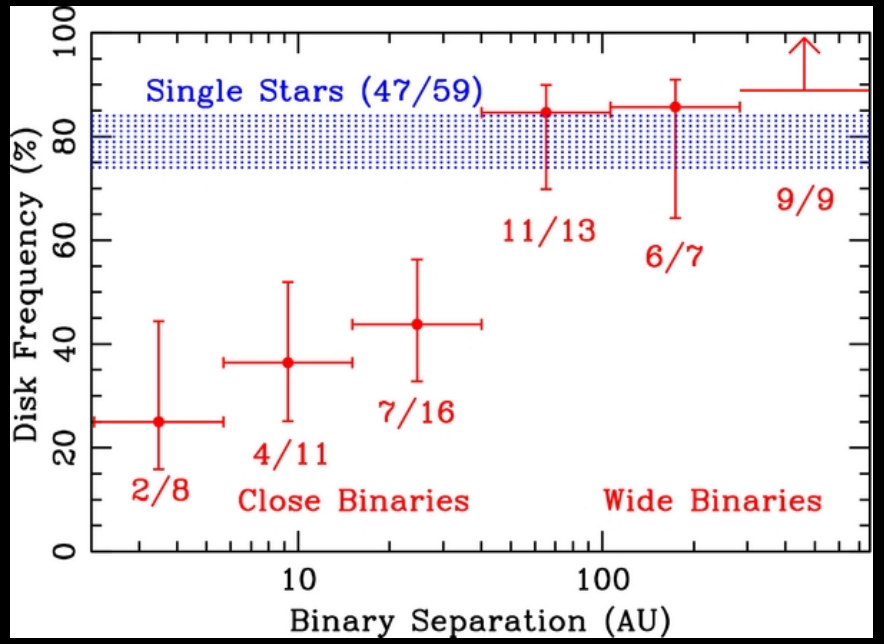
Occurrence rate of multiplicity in talks this week: 65 +/- 5 %

Disks in binaries: Key topics

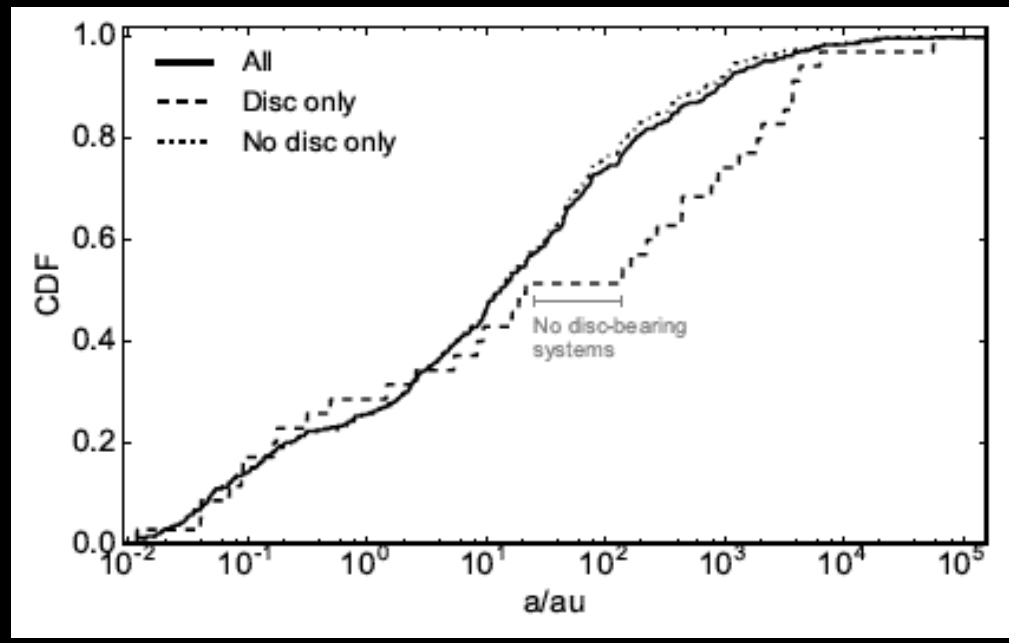
- Disks and planet occurrence rates in binaries
- Dynamical truncation/interactions by stellar companions
- Disk lifetime in binary systems
- Relative alignment of disks

Disks do not cohabit well with close binaries

- The closer the companion, the less common circumstellar disks are
  - Effective disruption / ineffective formation below 50 – 100 au?
  - More true for debris disks than for protoplanetary disks?



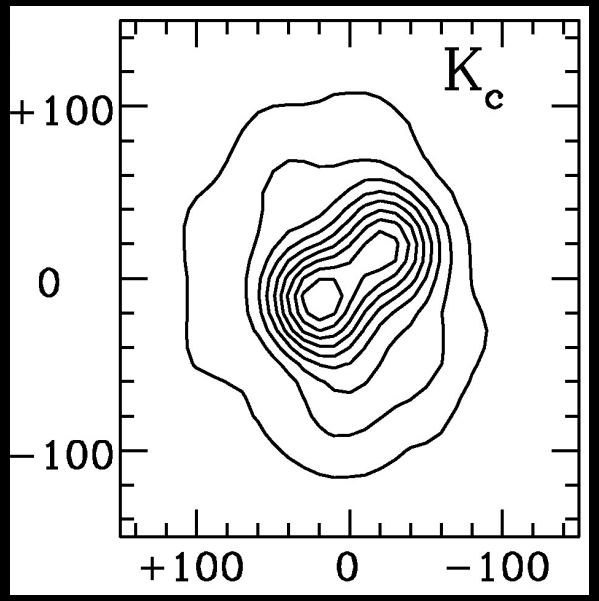
Kraus+ 2012



Yelverton+ 2019

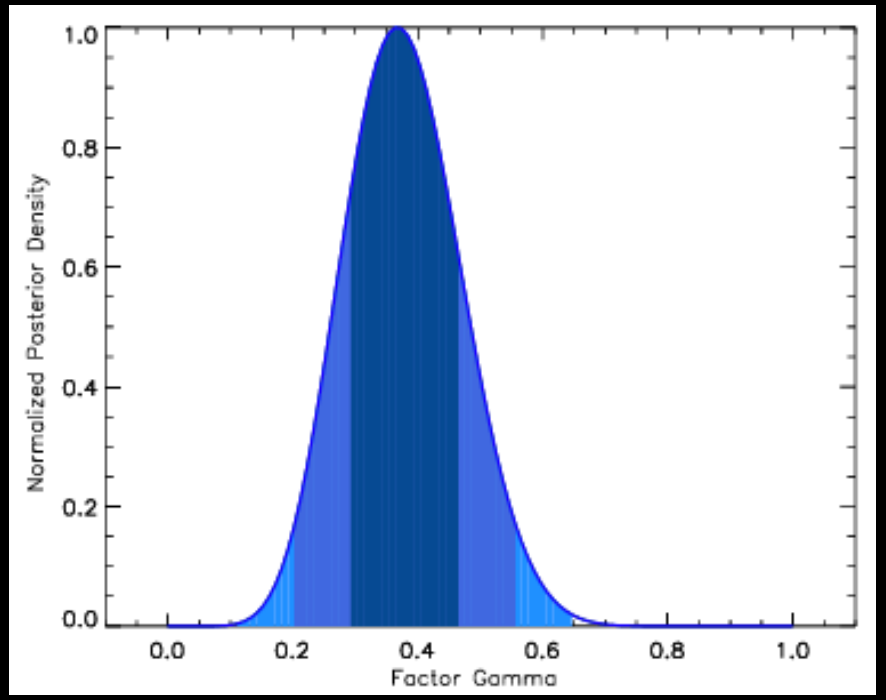
Transition disks: not (only) about binaries

- Binaries are always listed as a possible reason for the transition disk phenomenon
  - This is true sometimes (remember CoKu Tau 4!) but only in ~ 40% of the cases



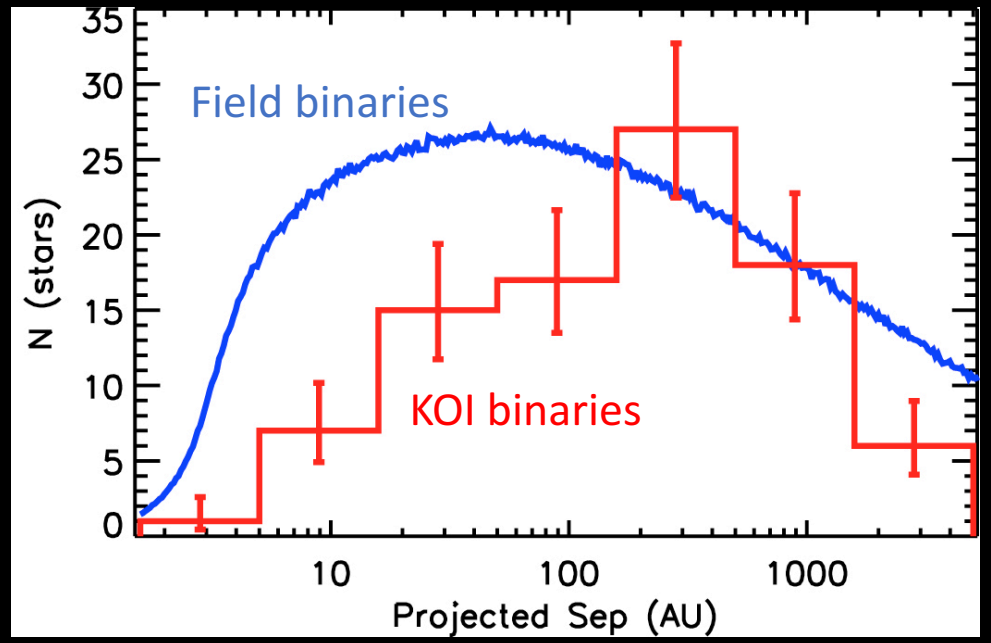
Ireland & Kraus 2008

Ruiz-Rodriguez+ 2016



"Close" vs "wide" binaries: planet occurrence

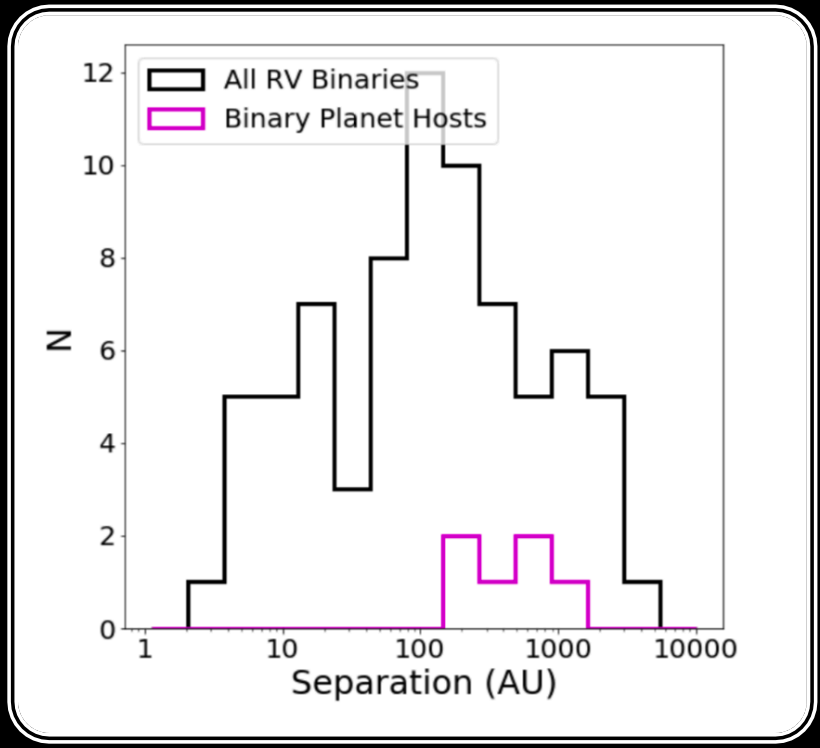
- Binaries in the 1 – 100 au range host less transit- and RV-detected planets than wider binaries and single stars



Earth-Neptune-size planets

Kraus+ 2016
(but see Matson+ 2018)

L. Hirsch+ (in prep)

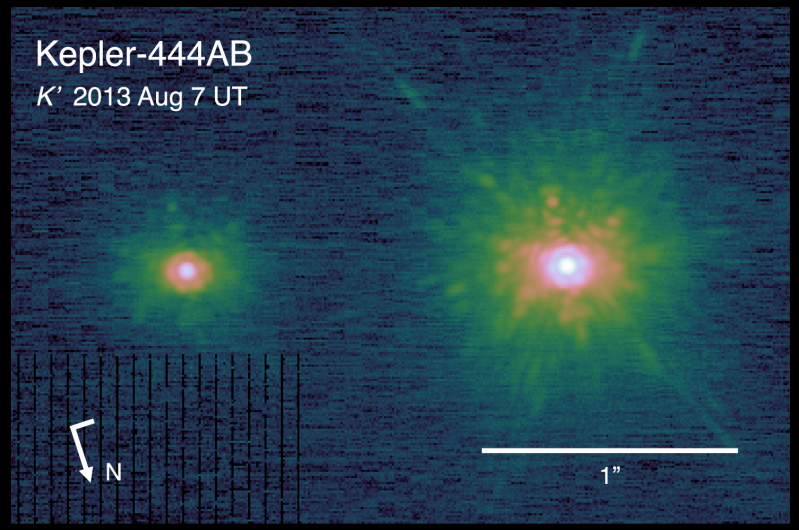


> Saturn-size planets

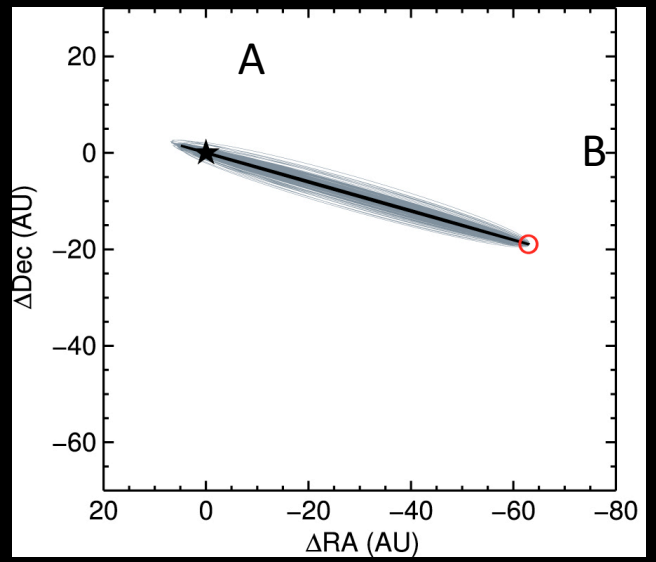
Close binaries are not "dead zones"

- γ Cep: a gas giant on a 2au orbit in a 20au binary
- Kepler 444, a packed 5-planet systems with a companion within 5 au

- Planets form even in the presence of a close outer companion!



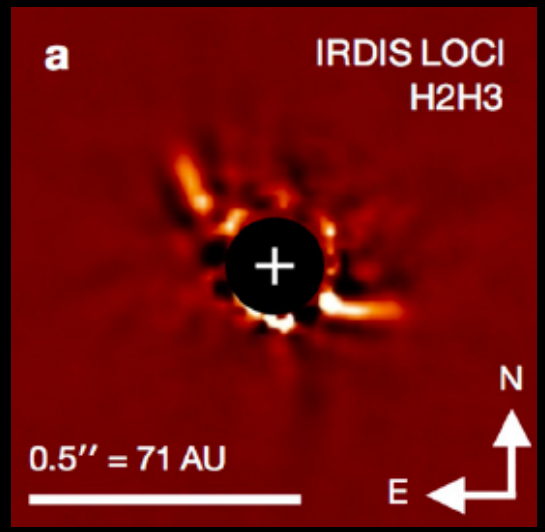
Dupuy+ 2016



The "new normal": circumbinary systems

- Spectroscopic binaries host protoplanetary and debris disks at (roughly) the same rate as single stars
  - E.g., Nguyen+ 2012, Kuruwita+ 2018
  - However, with surprisingly large inner cavity (e.g., AK Sco)

Janson+ 2016
(also Rosenfeld+ 2013)



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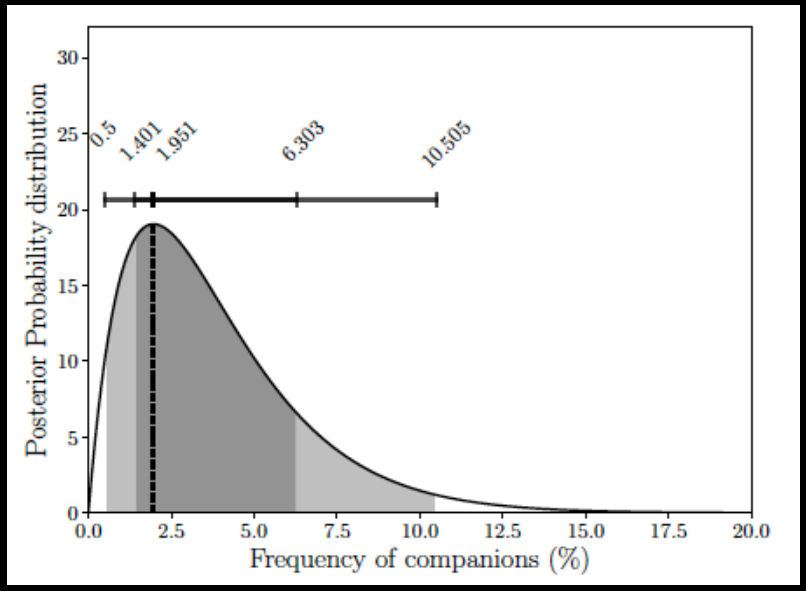
- Circumbinary planets also occur at "normal" rates
  - Short-period planets around SBs (Armstrong+ 2014)
  - Directly imaged planets (Asensio-Torres et al. 2018)



Asensio-Torres+ 2018

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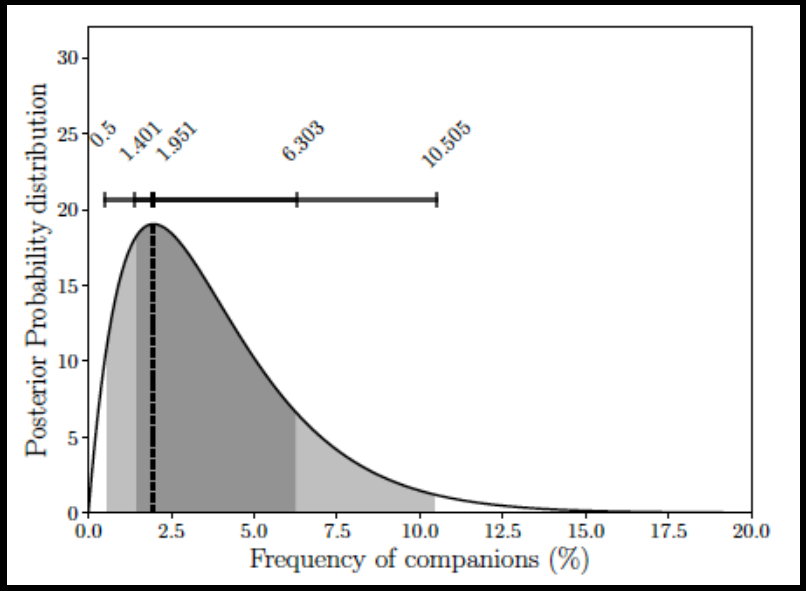
- Circumbinary planets also occur at "normal" rates
  - Short-period planets around SBs (Armstrong+ 2014)
  - Directly imaged planets (Asensio-Torres et al. 2018)
- Planets can form around the closest binaries!
  - But where and when does this happen?

Asensio-Torres+ 2018

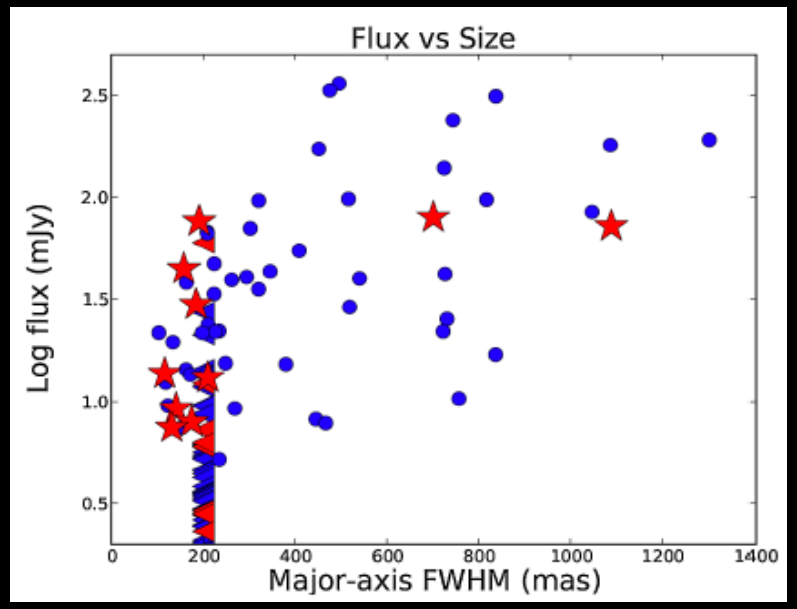


Disks in binaries: Key topics

- Disks and planet occurrence rates in binaries
- Dynamical truncation/interactions by stellar companions
- Disk lifetime in binary systems
- Relative alignment of disks

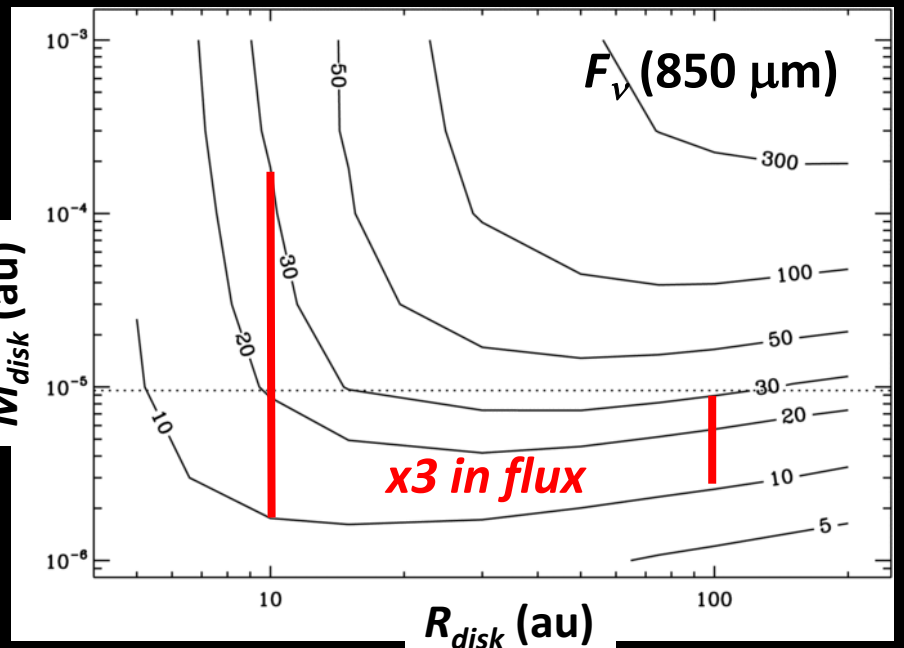
Close binaries: disk truncation (I)

- Binaries tighter than 100au have lower sub-mm total fluxes
  - e.g., Harris+ 2012, Akeson+ 2019
- This is also true for isolated, compact disks (the boring majority!)
- This is an optical depth (+ scattering) effect, not lower mass!



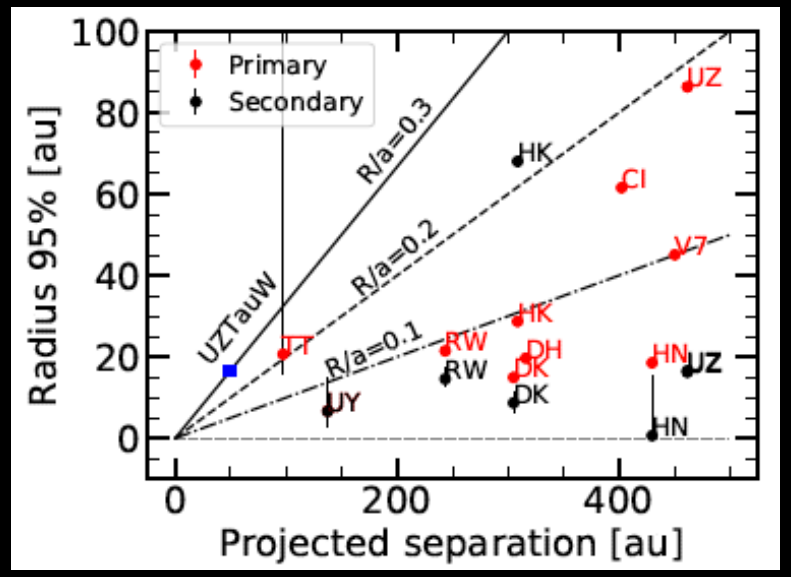
Cieza+ 2019

Duchene 2010



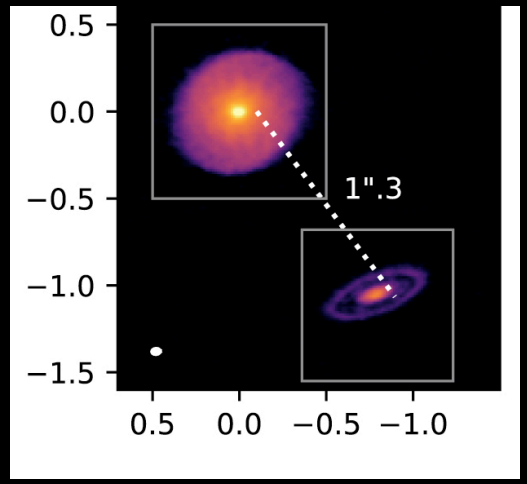
Close binaries: disk truncation (II)

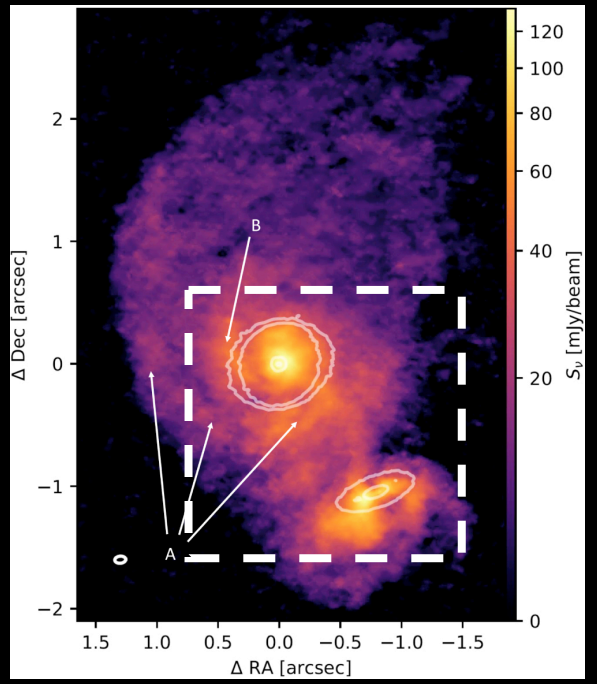
- Disks in binaries are truly smaller in size, and they have a sharper outer edge (in the mm continuum)
  - Indeed, disks are typically too small for “normal” truncation
    - We should not focus on the continuum, but on the gas component!
    - Disk edge can be extremely hard to define…



Manara+ 2019

Kurtovic+ 2018



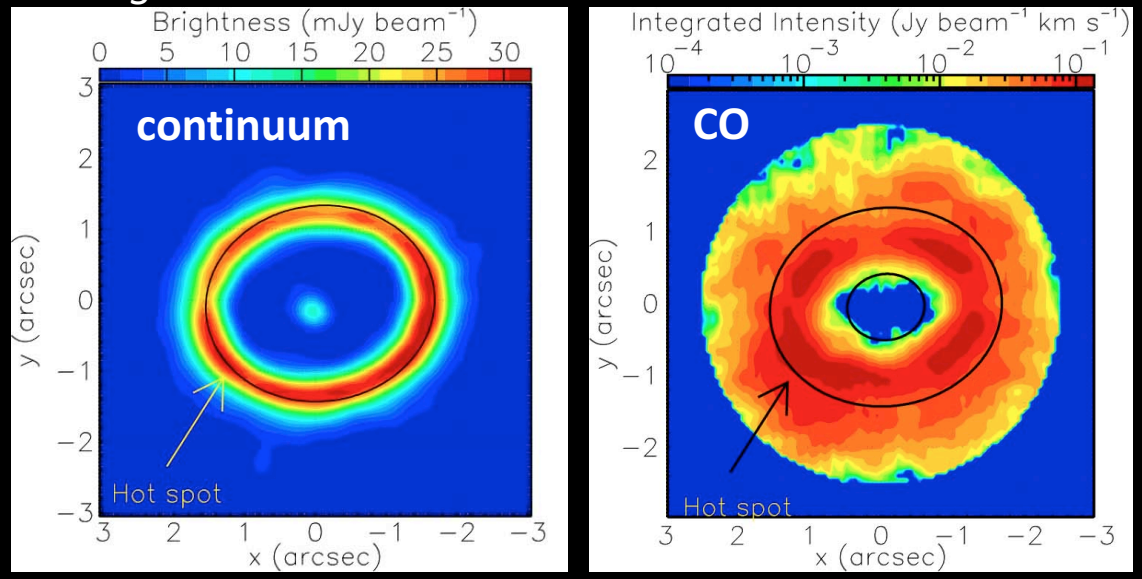


Differential dust/gas truncation

- Gaseous disks truncated by an inner binary have smaller cavities than the dust disks (dust trapping)
  - Could explain the “large” truncation radius (Cazzoletti+ 2017)

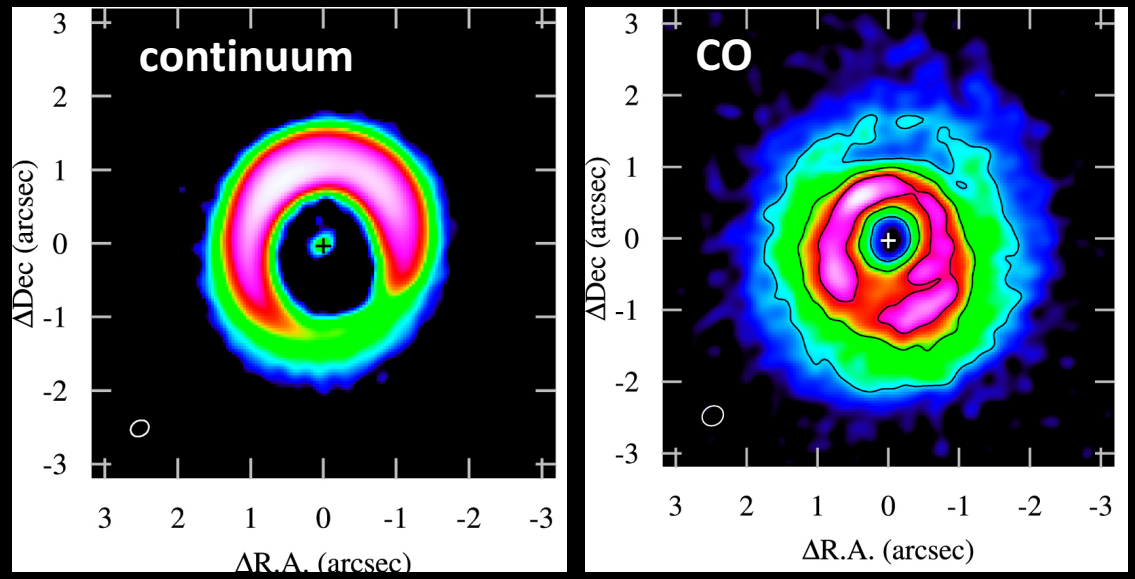
GG Tau

Phuong+ 2018



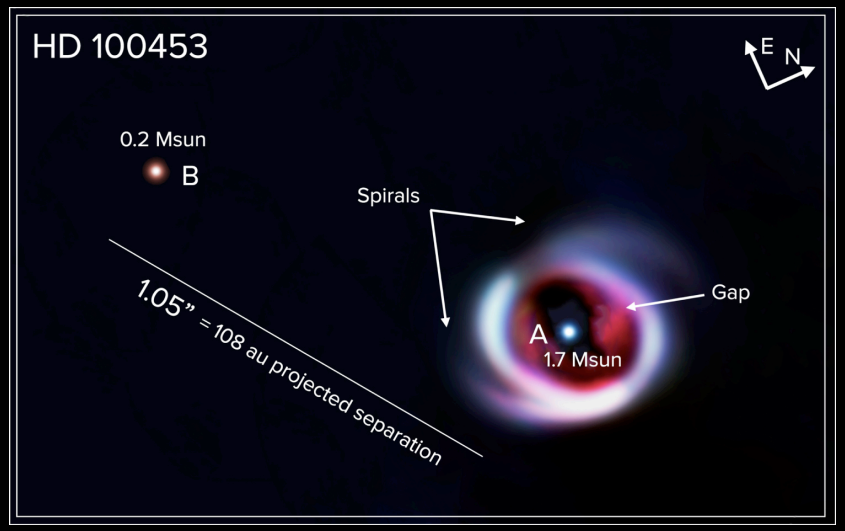
HD 142527

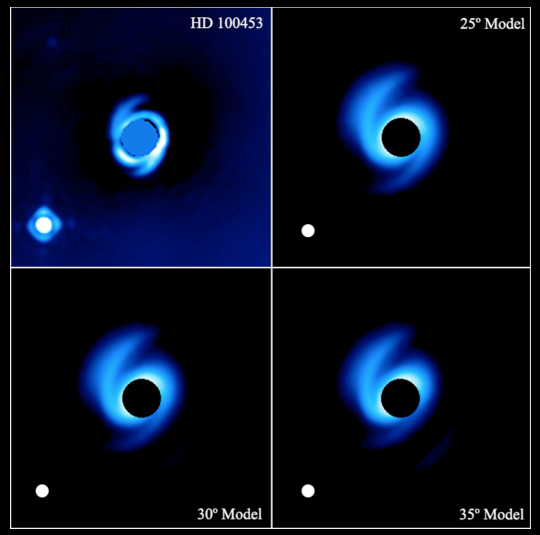
Boehler+ 2017



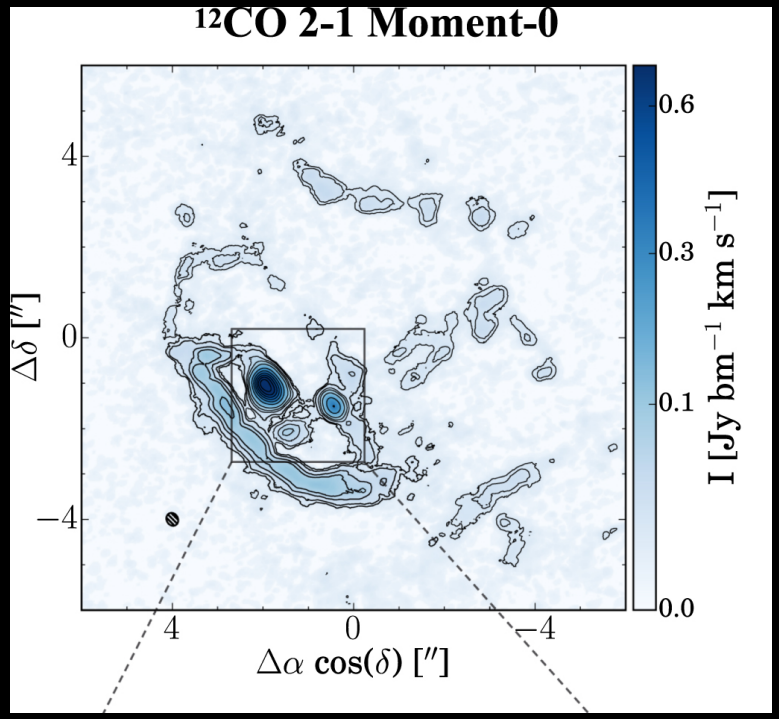
Disk substructures induced by companions

- Outer companions typically drive outer spirals in protoplanetary disks
  - Good tests to understand the dynamics of disks under the influence of a well-characterized external perturber





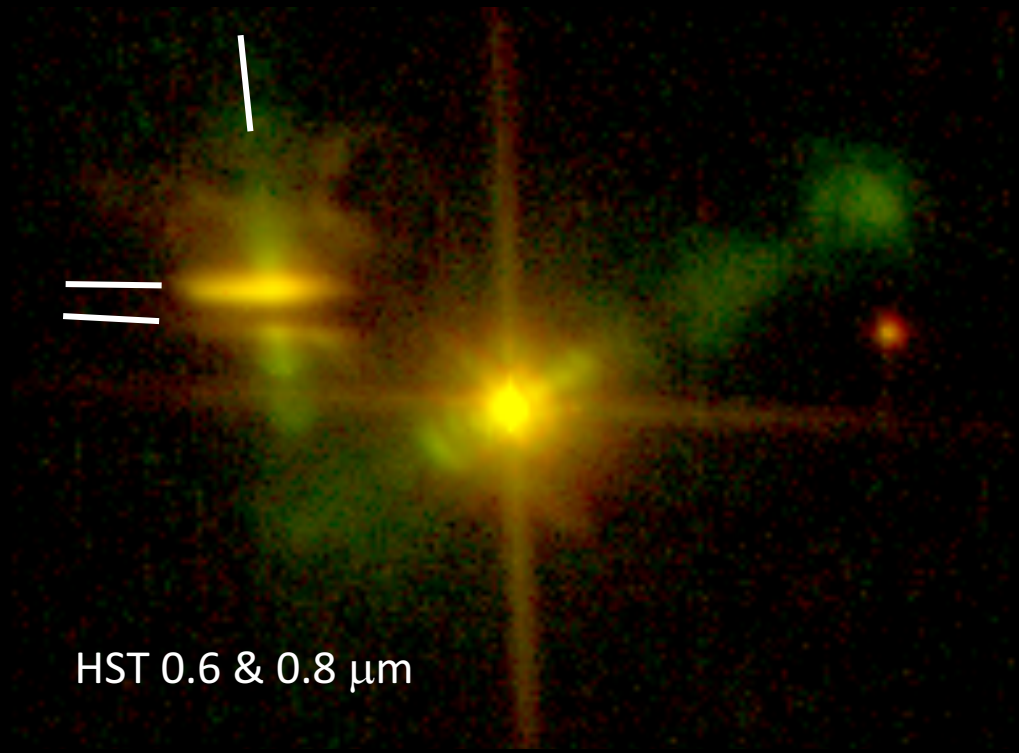
Wagner+ 2018



Rodriguez+ 2018

Disk substructures induced by companions

- Misaligned disks in binaries experience serious global perturbations!

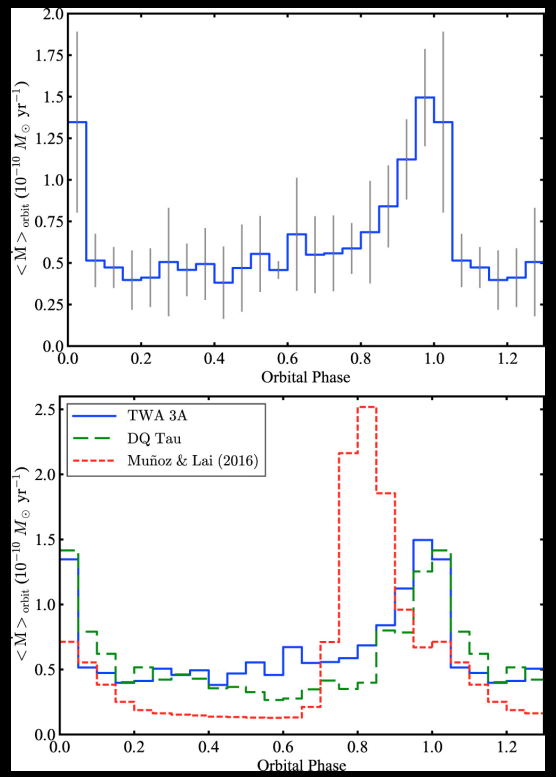


HST 0.6 & 0.8 μm

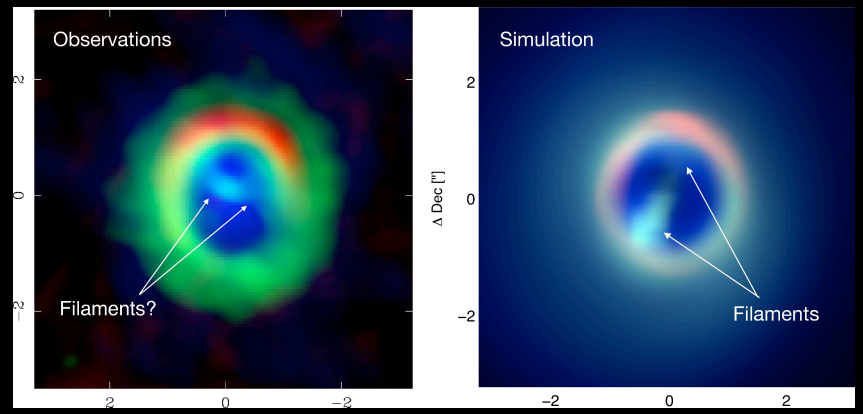
Stapelfeldt+ in prep.

Accretion in binary systems

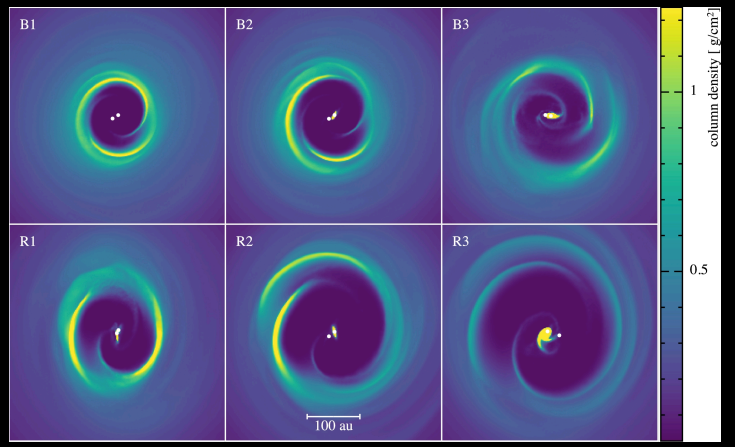
- Tight, eccentric, inclined binaries can drive accretion onto small, circumstellar disks or the stars themselves
  - ➢ *See D. Munoz' talk*



Tofflemire+ 2017
(see also poster by R. Kuruwita)



Price+ 2018



Disks in binaries: Key topics

- Disks and planet occurrence rates in binaries
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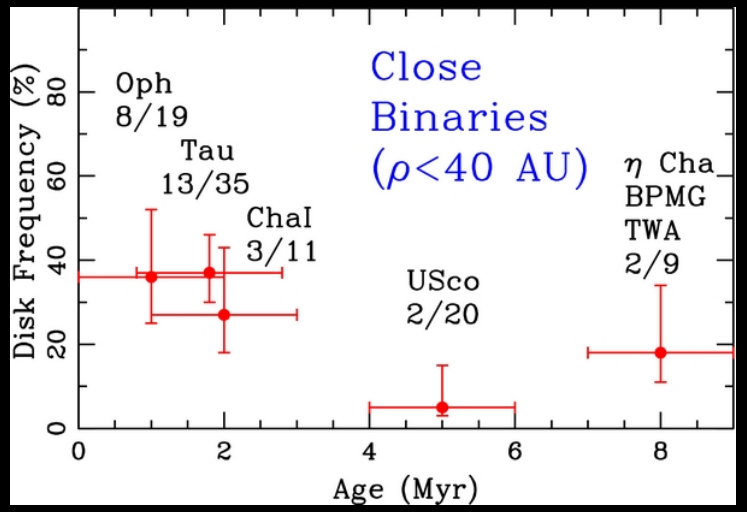
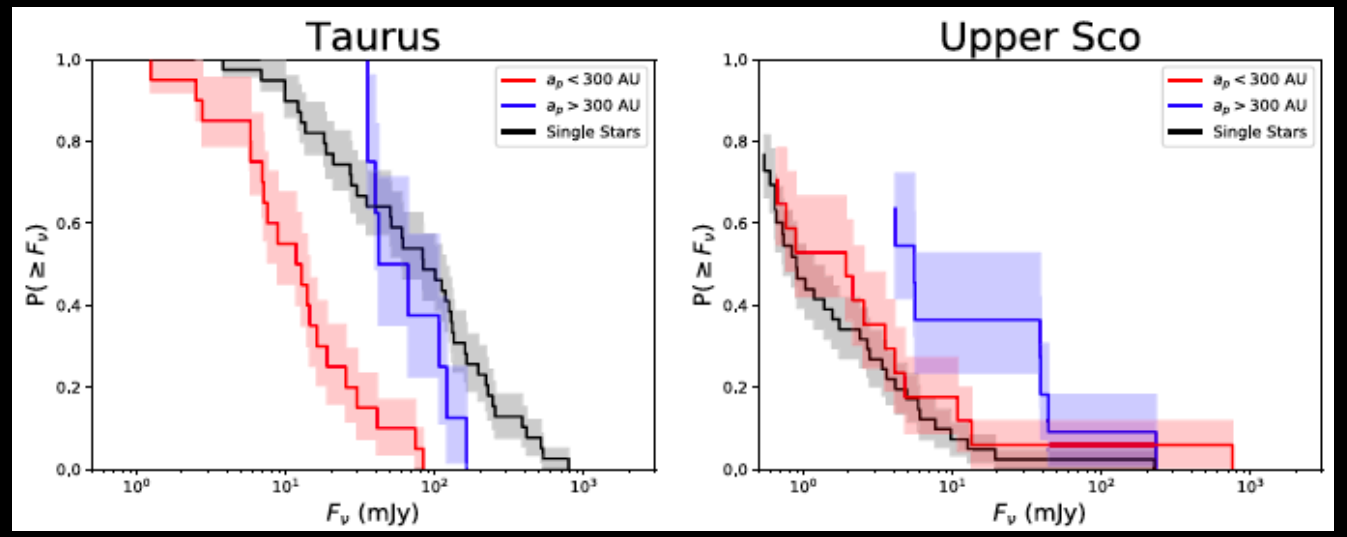
Disk survival timescales in binaries

- Disks in close binaries are not completely absent even at several Myr
  - Long-term disk survival not affected by a companion under some circumstances?
    - ➢ *See M. P. Ronco's talk*

Kraus+ 2012



Barenfeld+ 2019



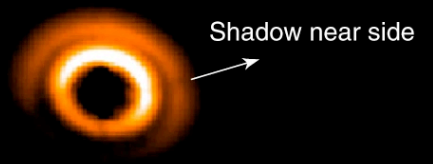
Disk survival timescales in binaries

- Disks in close binaries are not completely absent even at several Myr
  - Long-term disk survival not affected by a companion under some circumstances?
- This is particularly striking for circumbinary disks
  - HD 98800 is in the TW Hya association (~10 Myr)
  - V4046 Sgr are in the β Pic association (~23 Myr)
  - AK Sco is ~18 Myr-old
- Is planet formation delayed in circumbinary disks?

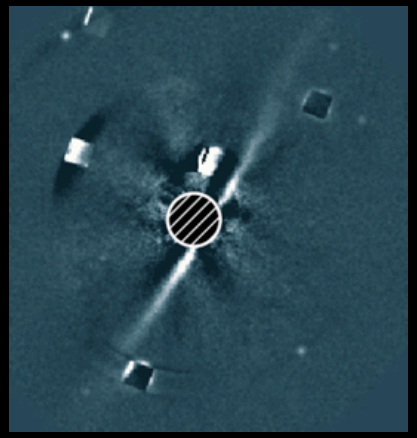
"Hybrid" binary/multiple systems

- We have now discovered a couple of multiple systems that host both a protoplanetary disk and a debris disk
  - Both in "old" populations, very wide systems, and with (scattered light) rings

V4046 Sgr (~12 kau, 23 Myr)

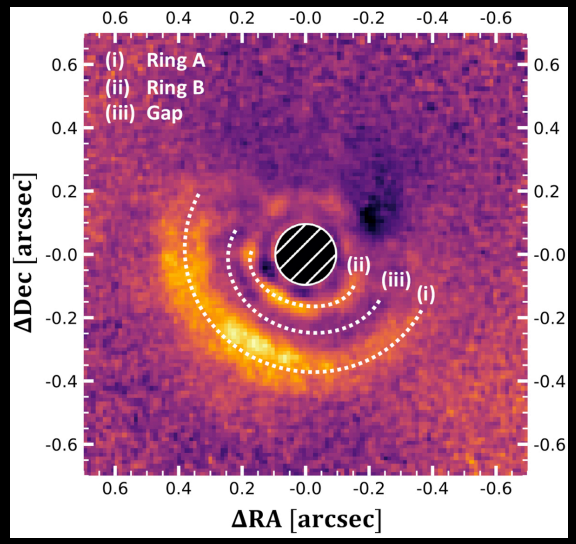


D'Orazi+ 2019



Sissa+ 2018

Wray 15-788 (~7 kau, 11 Myr)



Bohn+ 2019

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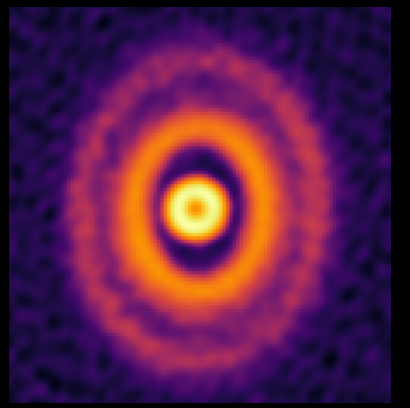
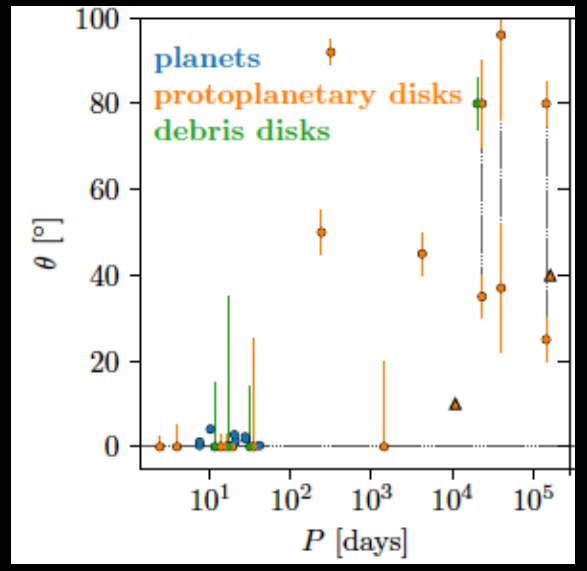
Disk alignment: Circumbinary disks

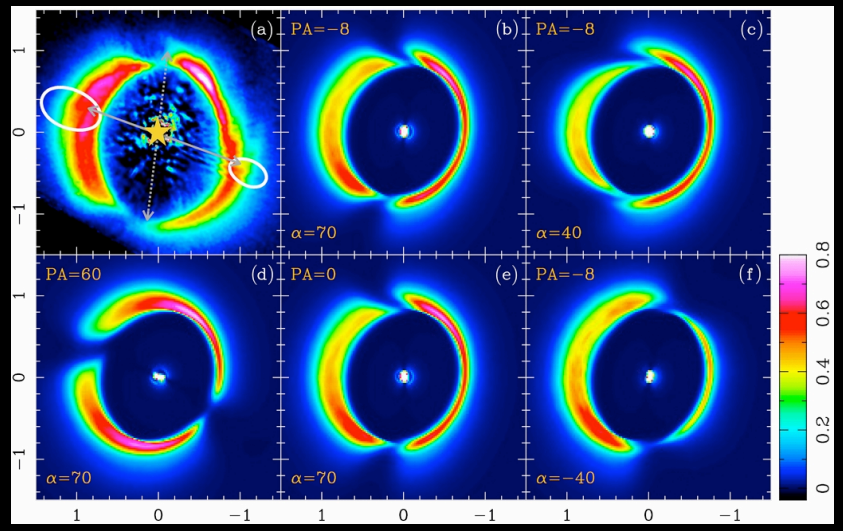


Dong+

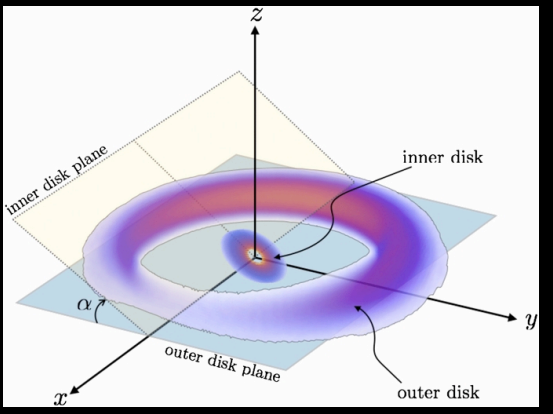
- CB disks are aligned for < 1au orbits, not for wider orbits
- Effect of misalignment on outer disks can be important
  - Scattered light shadows
  - Thermal emission shadows, spiral launching, …



Czekala+ 2019



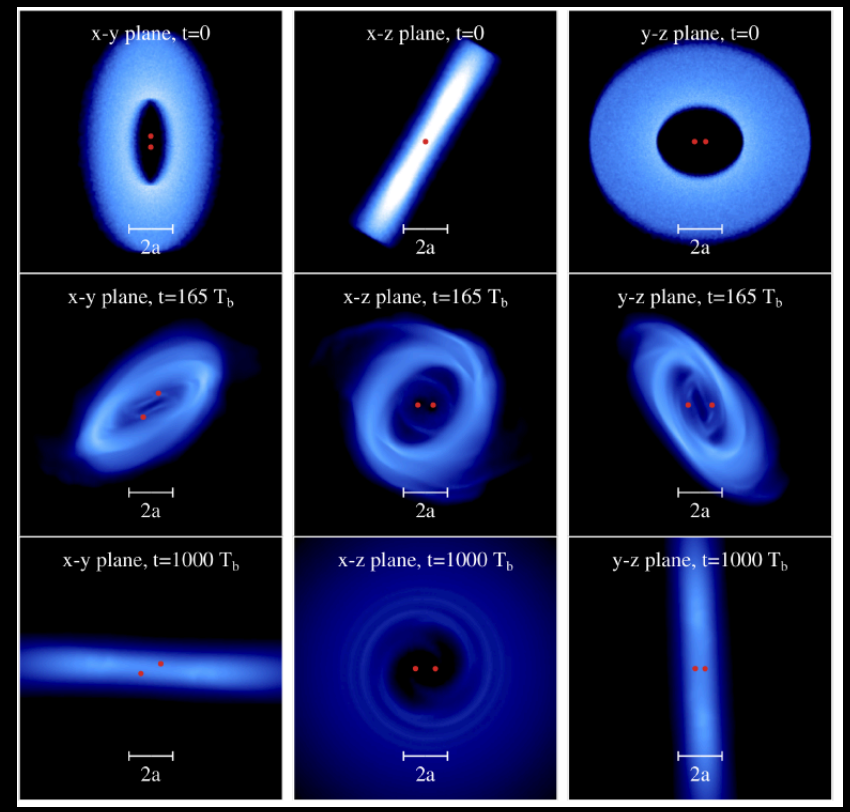
Marino+ 2015



See poster by K. Hirsch

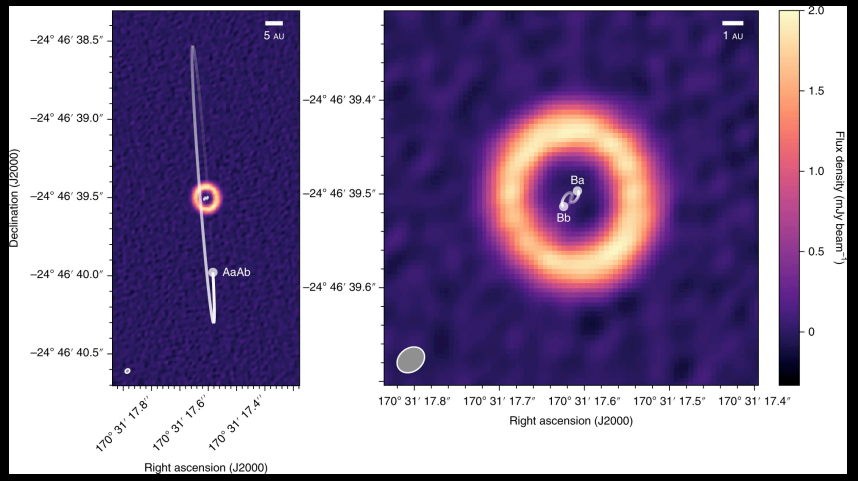
A new configuration: Polar orbits

- If inner binary is eccentric, disks and planetary orbits can be stabilized into a polar orientation
- Not just an abstract theory!
  - 99 Her (Kennedy+ 2012): debris disk
  - HD 98800 B: protoplanetary disk
    - ➢ *See G. Kennedy's talk*



Cuello & Giuppone 2019

Kennedy+ 2019



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- Not just an abstract theory!
  - 99 Her (Kennedy+ 2012): debris disk
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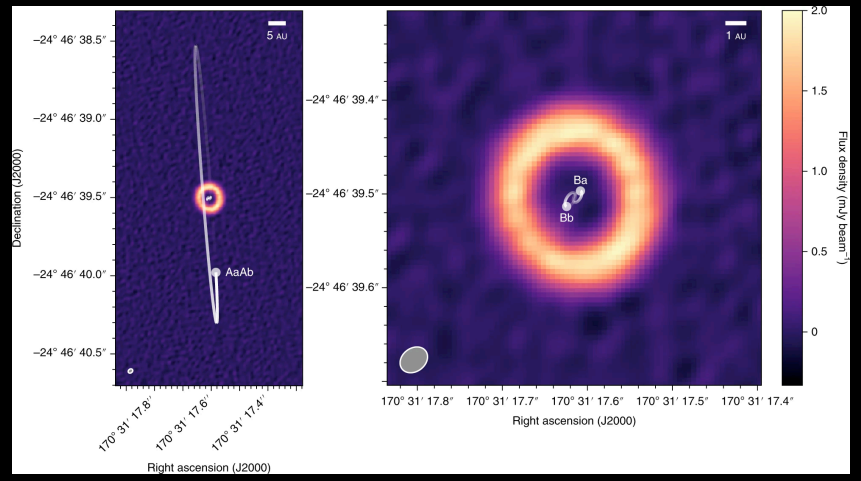
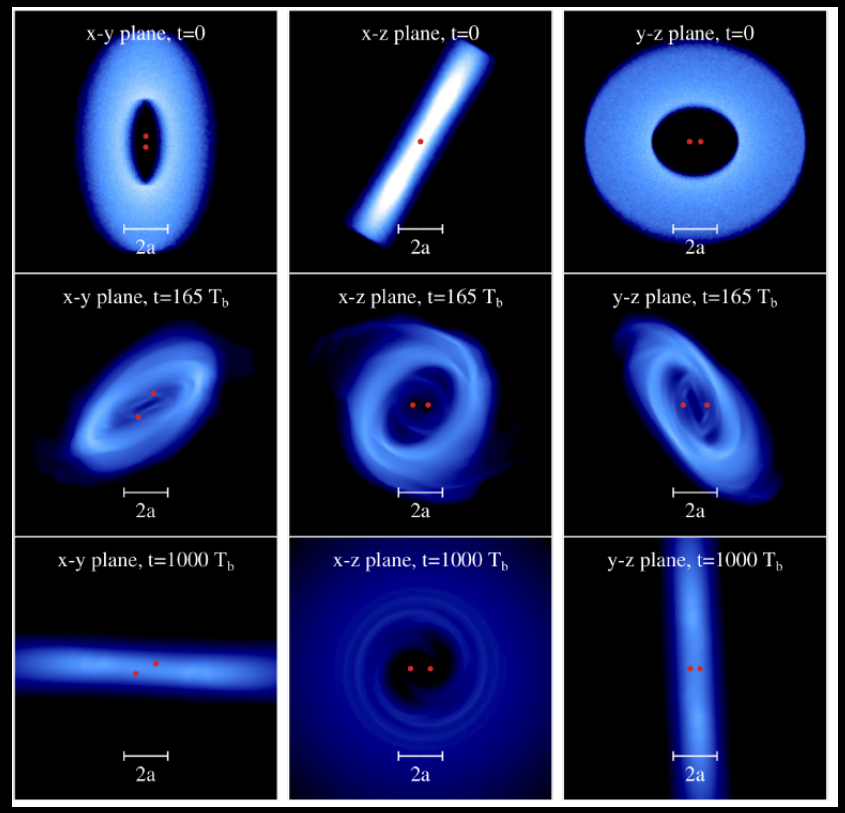
- Can we find the resulting planets?



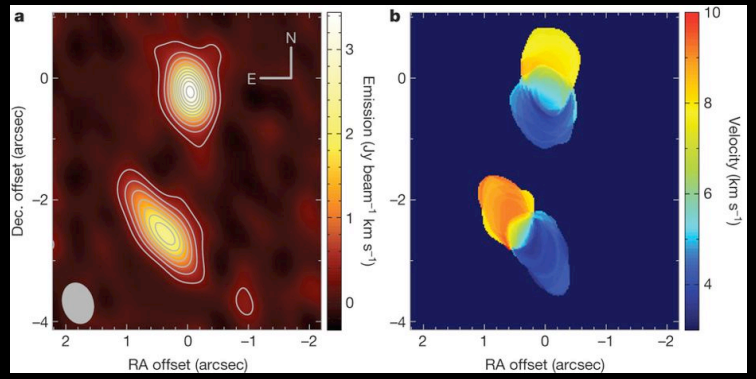
Kennedy+ 2019



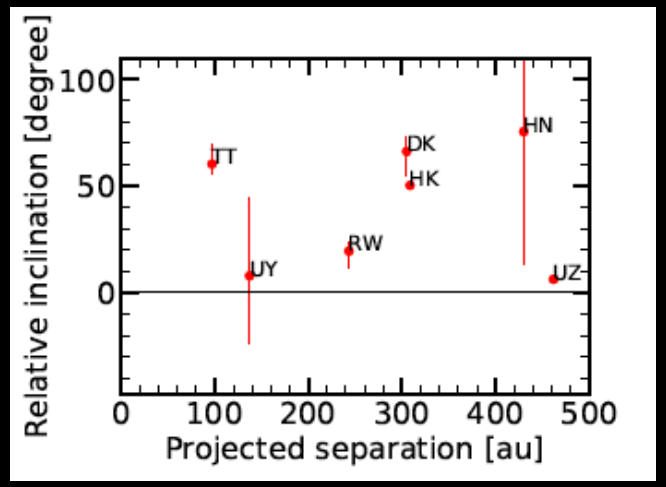
Cuello & Giuppone 2019

Disk alignment: Circumstellar disks

- Misalignment in wide binaries has long been known to be common
  - Or maybe not so much after all?

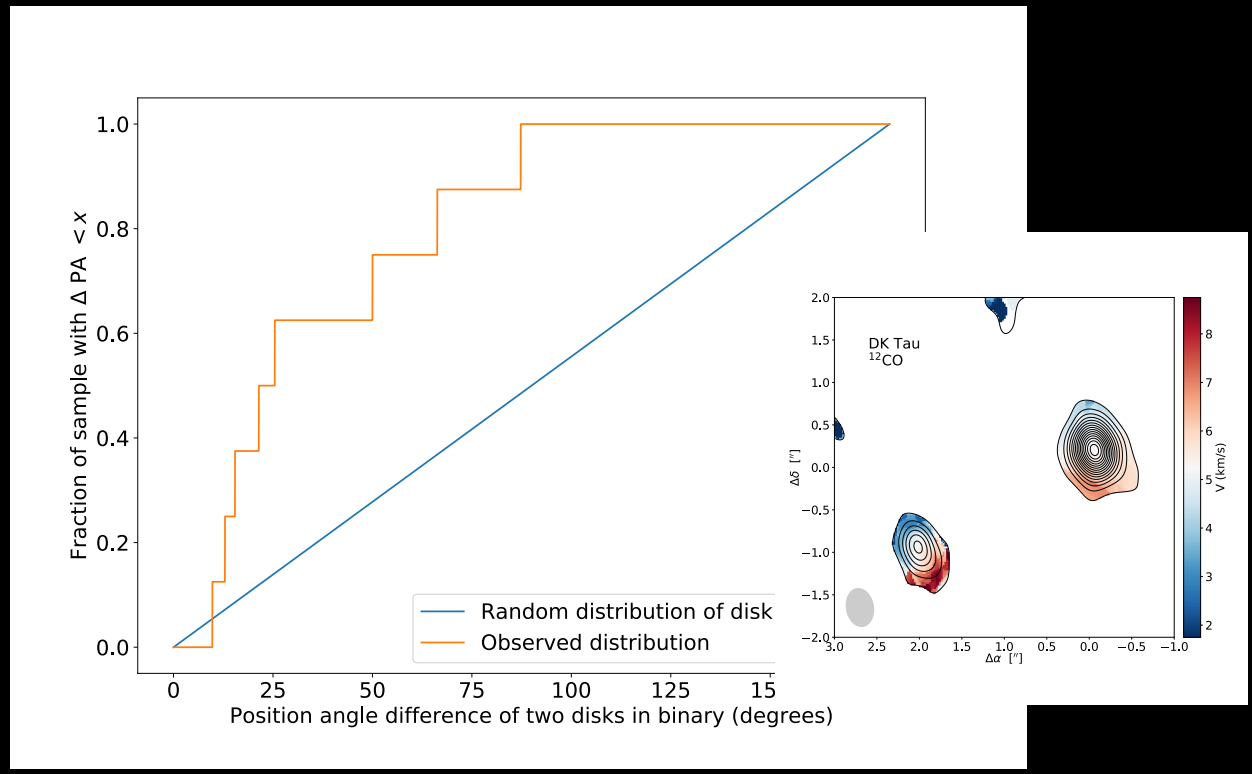


Jensen & Akeson 2014



Manara+ 2019

Jensen, Akenson+ in prep



Disk alignment: Circumstellar disks

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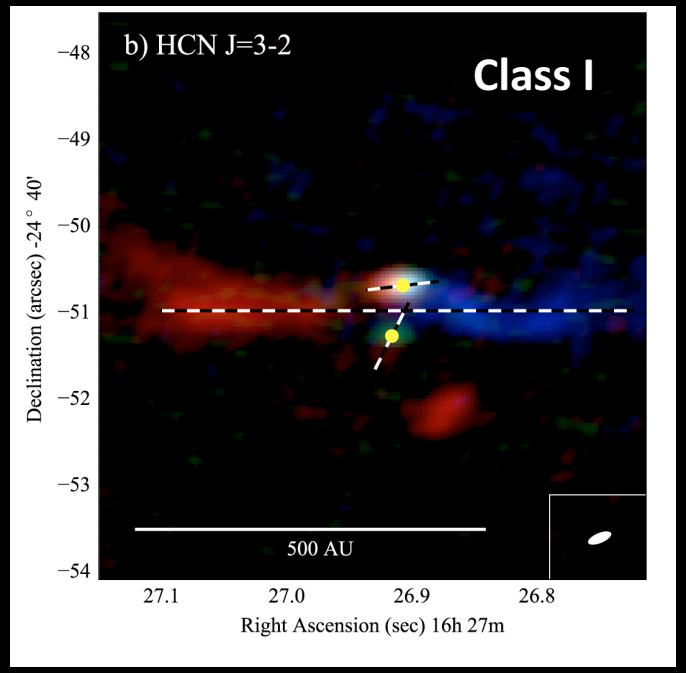
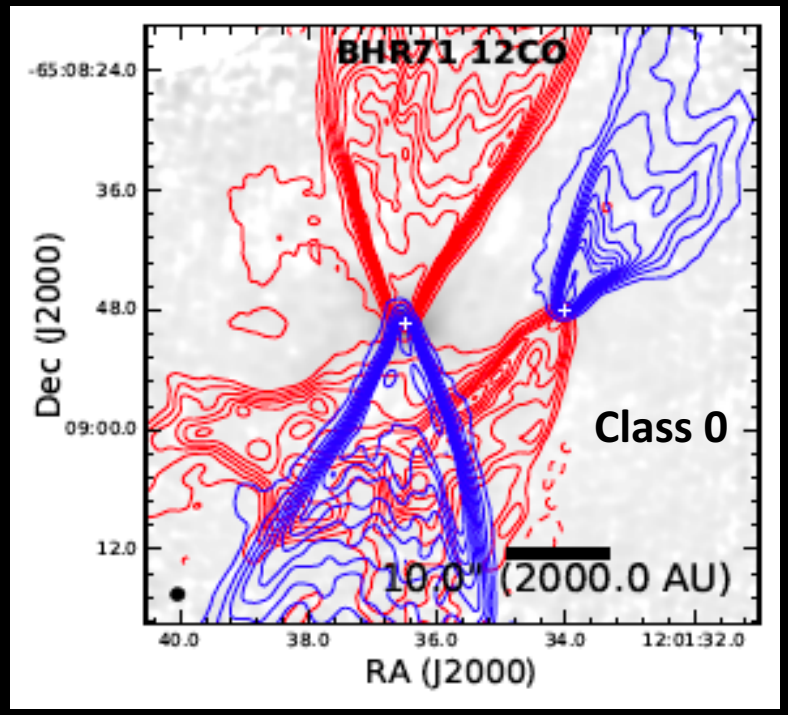
  - Or maybe not so much after all?
- At least in some cases, misalignment is established very early on



Brinch+ 2016

Tobin+ 2019



Final thoughts

- Disks and multiple systems are not at all mutually exclusive
- Planet formation succeeds in all types of binaries
- It is harder when the binary is less than 50 – 100 au, though
  - Does this say anything about “boring” disks?
- Dynamics are more complicated and diverse than anticipated
  - Especially in the chaotic early phases when most mass is still to be accreted