Observational tests of theory

Binary-Disk physics

Ian Czekala / Penn State / 3/16/22

A (highly subjective) list of hot CB disk-related issues

Binary

- Semi-major axis evolution: expansion or contraction?
- Binary eccentricity evolution
- Accretion by the binary components

Disk(s)

- CB disk structure, role of disk thermodynamics for everything
- Disk eccentricity structure and evolution
- Structure of and accretion through the mini-disks
- Misaligned disks, disk tearing

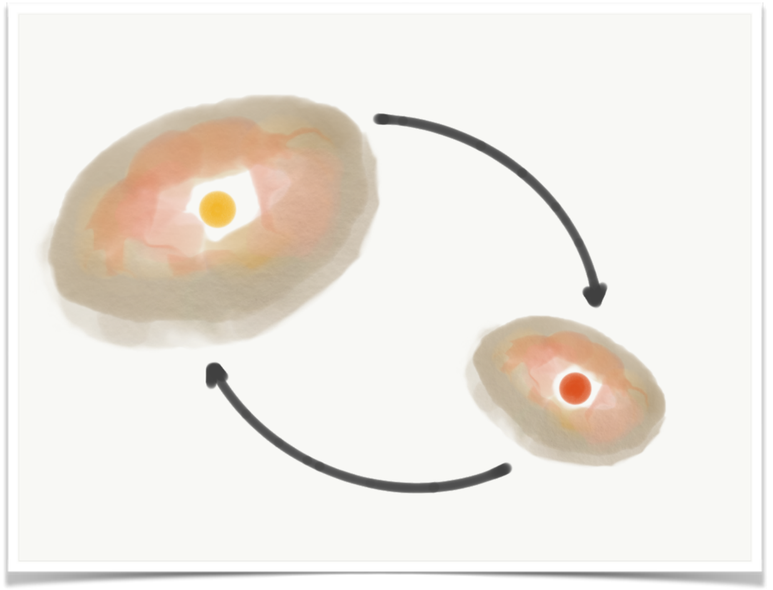
Roman Rafikov

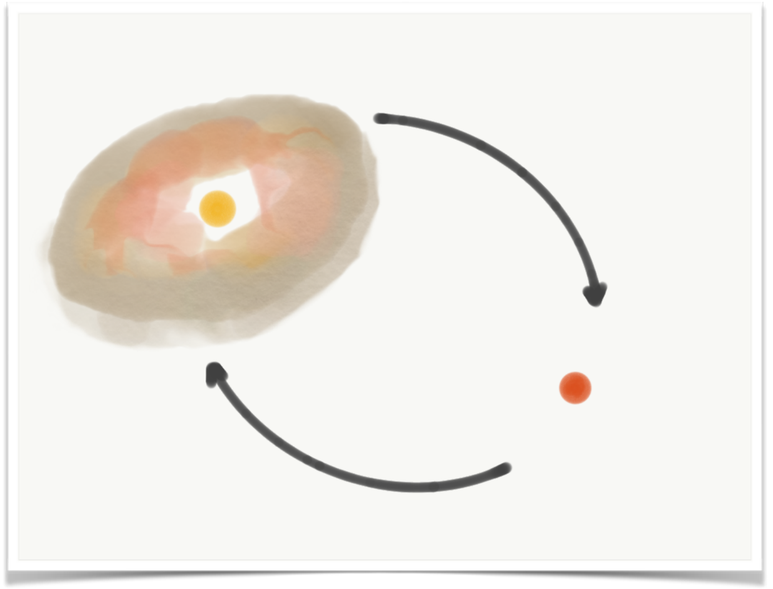
Topics

- Accretion: primary or secondary? pulsed at periastron? Winds? Impact on orbital inference?
- Varying scale: planetary systems as low-mass ratio binaries
- Alignment: binaries and circumbinary disks, binaries and circumbinary planets, circumstellar disks in binaries
- Eccentricity evolution
- Age evolution: tracking separations and orientations

Binary Disk Configurations

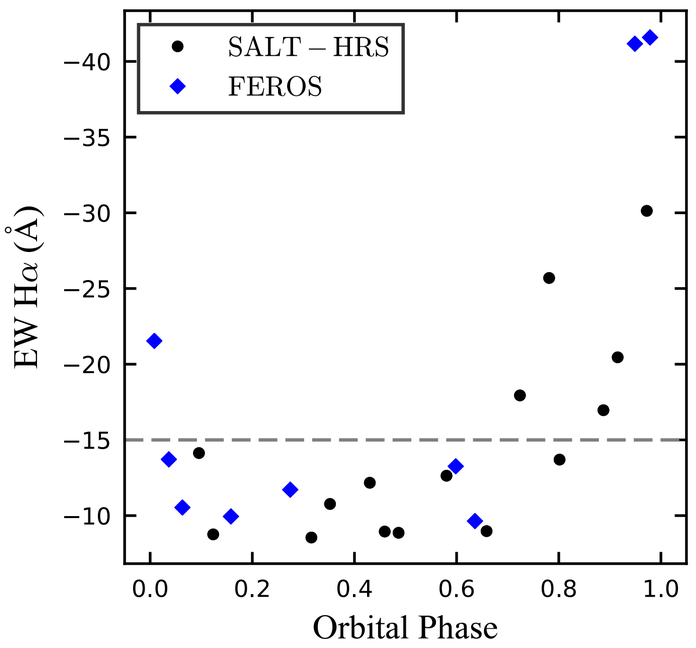
Circumbinary disk



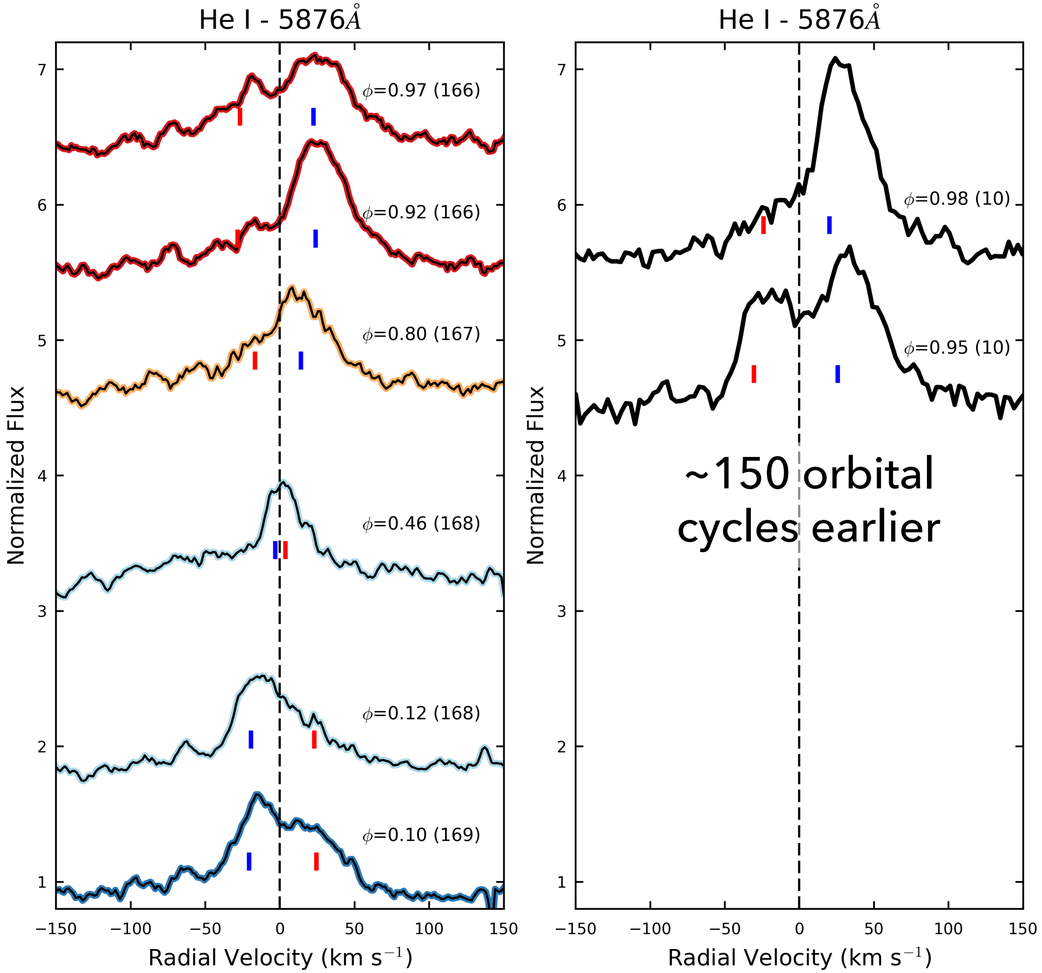


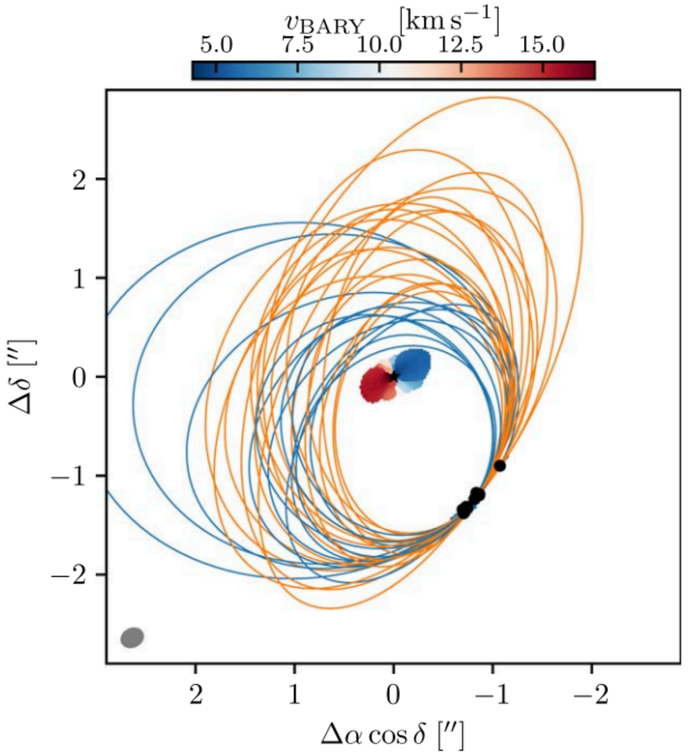
Circumstellar disk(s) in a binary system

TWA 3a



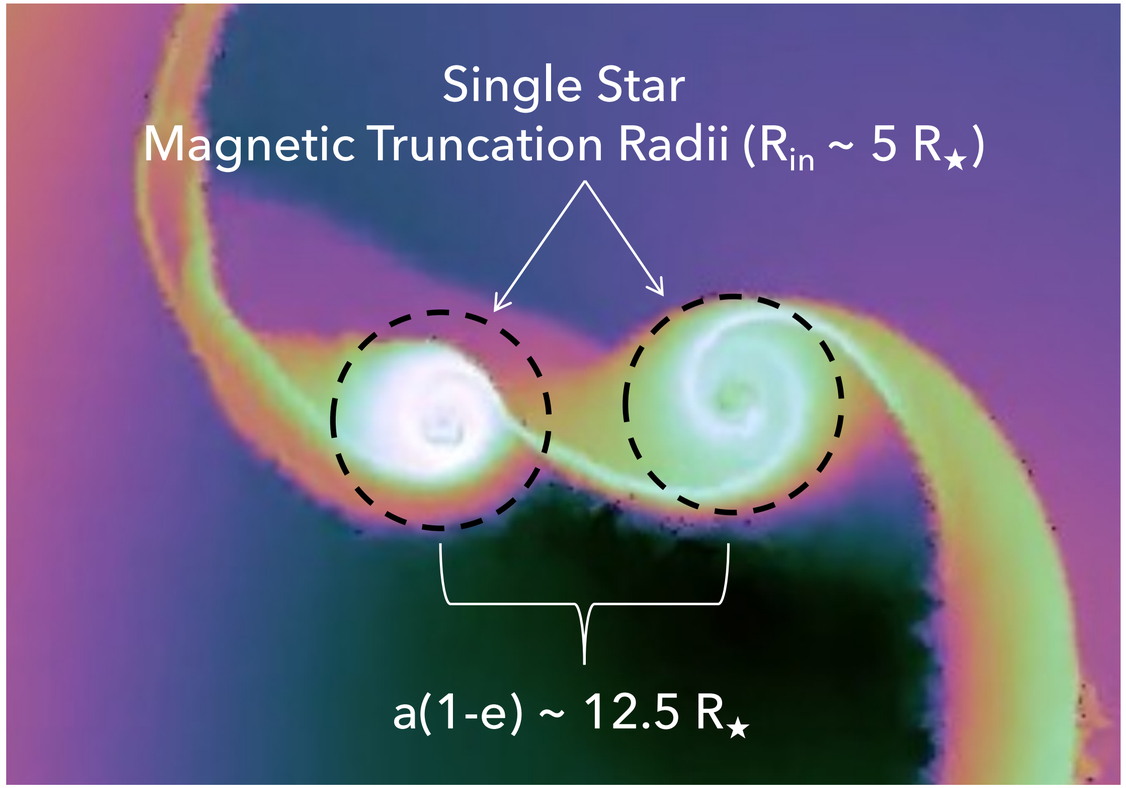
Tofflemire et al. 2019



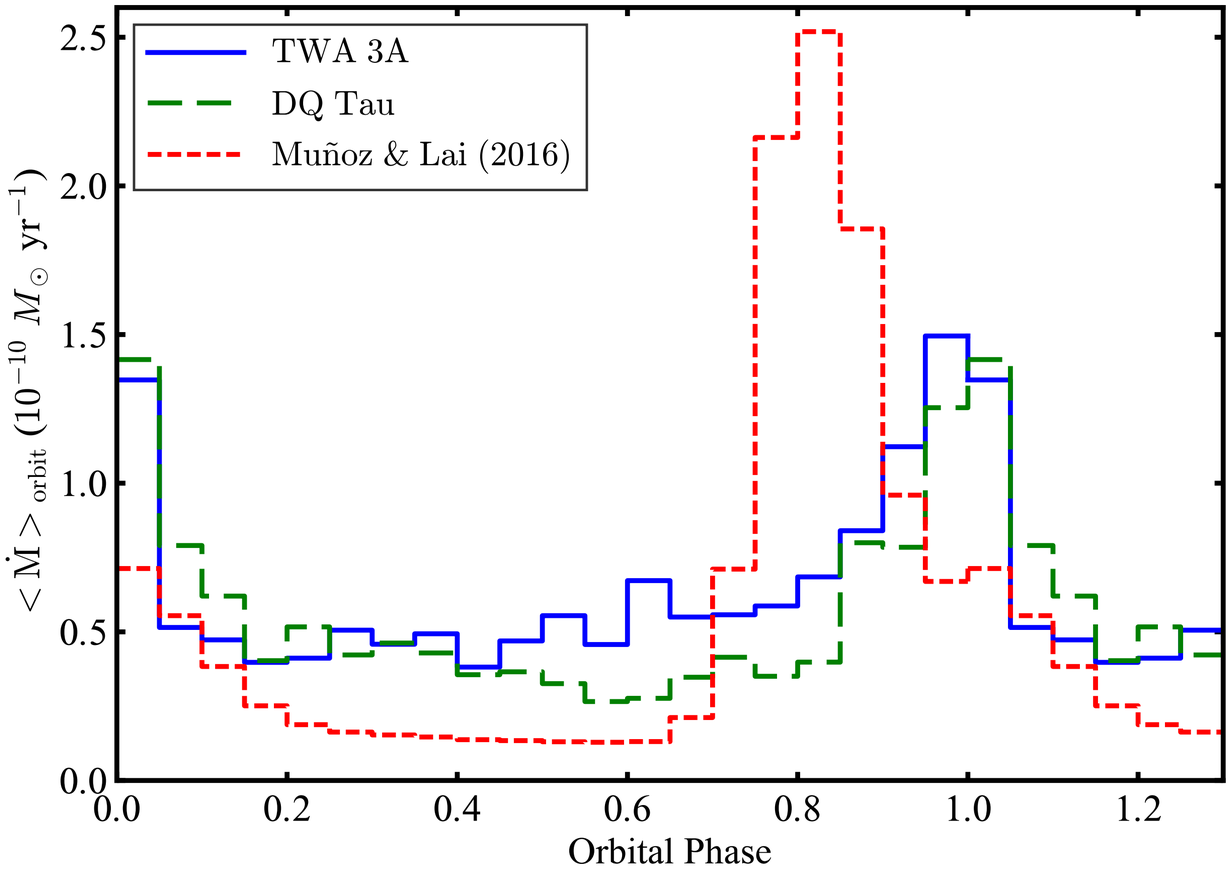


Tofflemire+19
Czekala+21a

Comparing Observations and Theory



Munoz & Lai 2016



Tofflemire et al. 2017b

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

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Classical Nova Carinae 2018: discovery of circumbinary iron and oxygen

Dominic McLoughlin [1]★ Katherine M. Blundell [1] and Steven Lee [2,3]

[1] *Physics Department, University of Oxford, Keble Rd, Oxford OX1 3RH, UK*
[2] *Research School of Astronomy and Astrophysics, Australian National University, Canberra, ACT 2611, Australia*
[3] *Anglo-Australian Telescope, Coonabarabran, NSW 2357, Australia*

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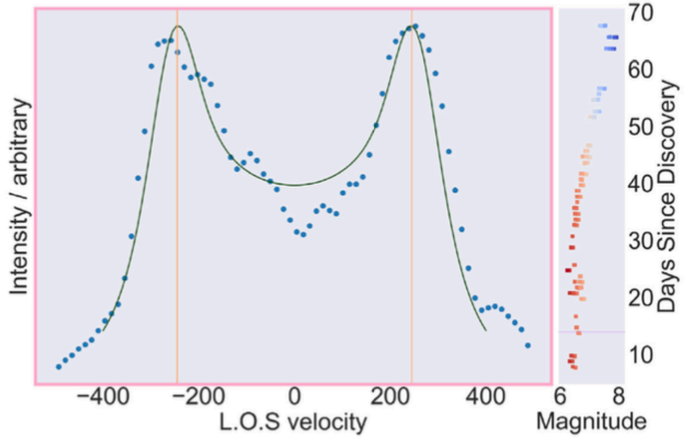
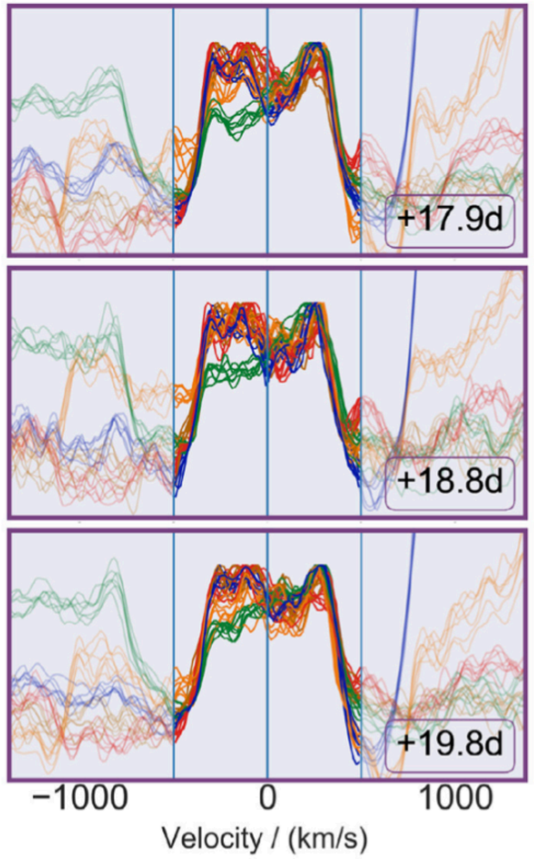




- Pre-existing circumbinary disc shock-heated by the nova detonation
- Line emission from it is only transient for ~2 weeks following the nova eruption

Radial velocity determinations in the *presence of a powerful wind* can *mis-lead!*

So we developed a model to account for the star's orbital motion AND the powerful wind

Uncovering the orbital dynamics of stars hidden inside their powerful winds: application to η Carinae and RMC 140

David Grant [1,★] Katherine Blundell[1] and James Matthews [1,2]

Application of this model refined the eccentricity of GG Carina from 0.3 to 0.5

GG Carinae: orbital parameters and accretion indicators from phase-resolved spectroscopy and photometry

Augustus Porter [1,★] David Grant [1] Katherine Blundell[1] and Steven Lee[2,3]

The circumbinary rings of GG Carinae: indications of disc eccentricity growth in the B[e] supergiant's atomic emission lines

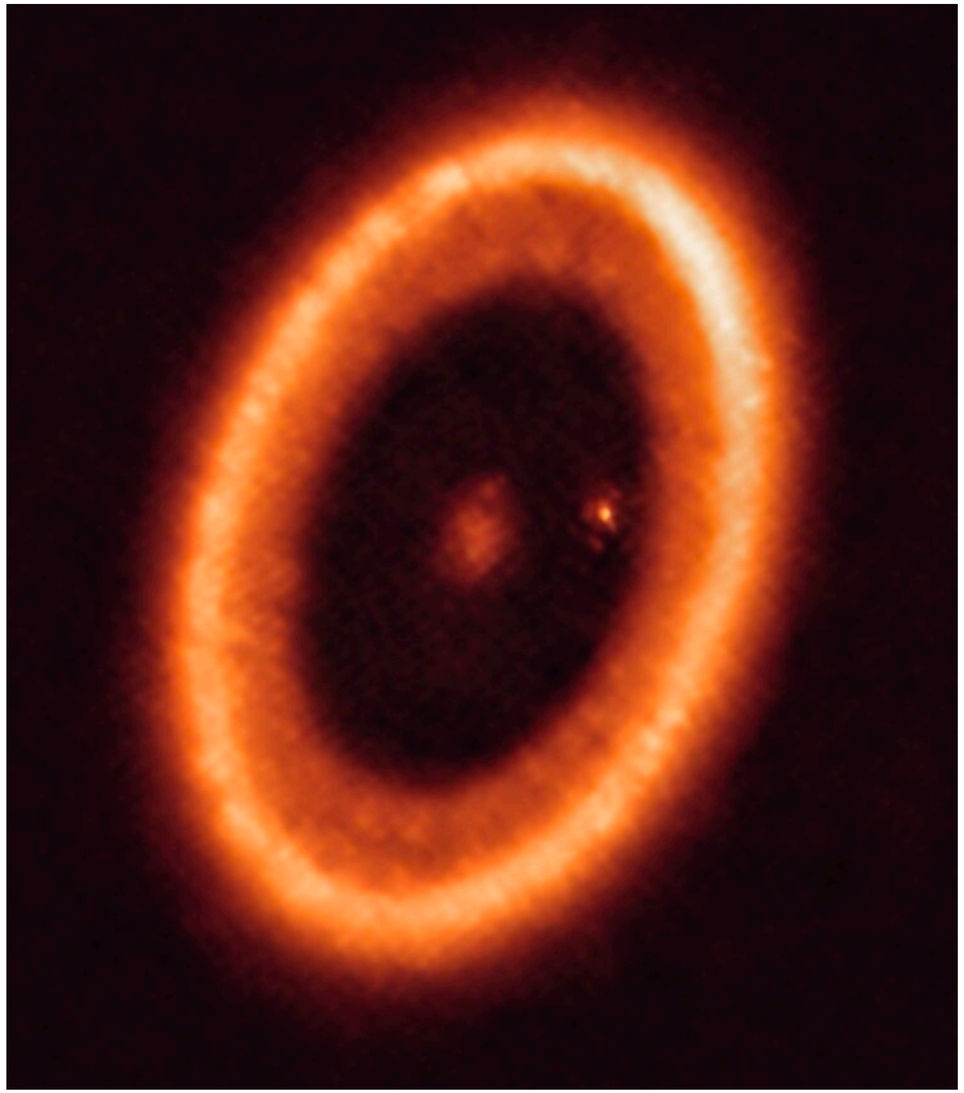
Augustus Porter [1,★] Katherine Blundell[1] and Steven Lee[2,3]

Orbital parameter algorithm challenge!

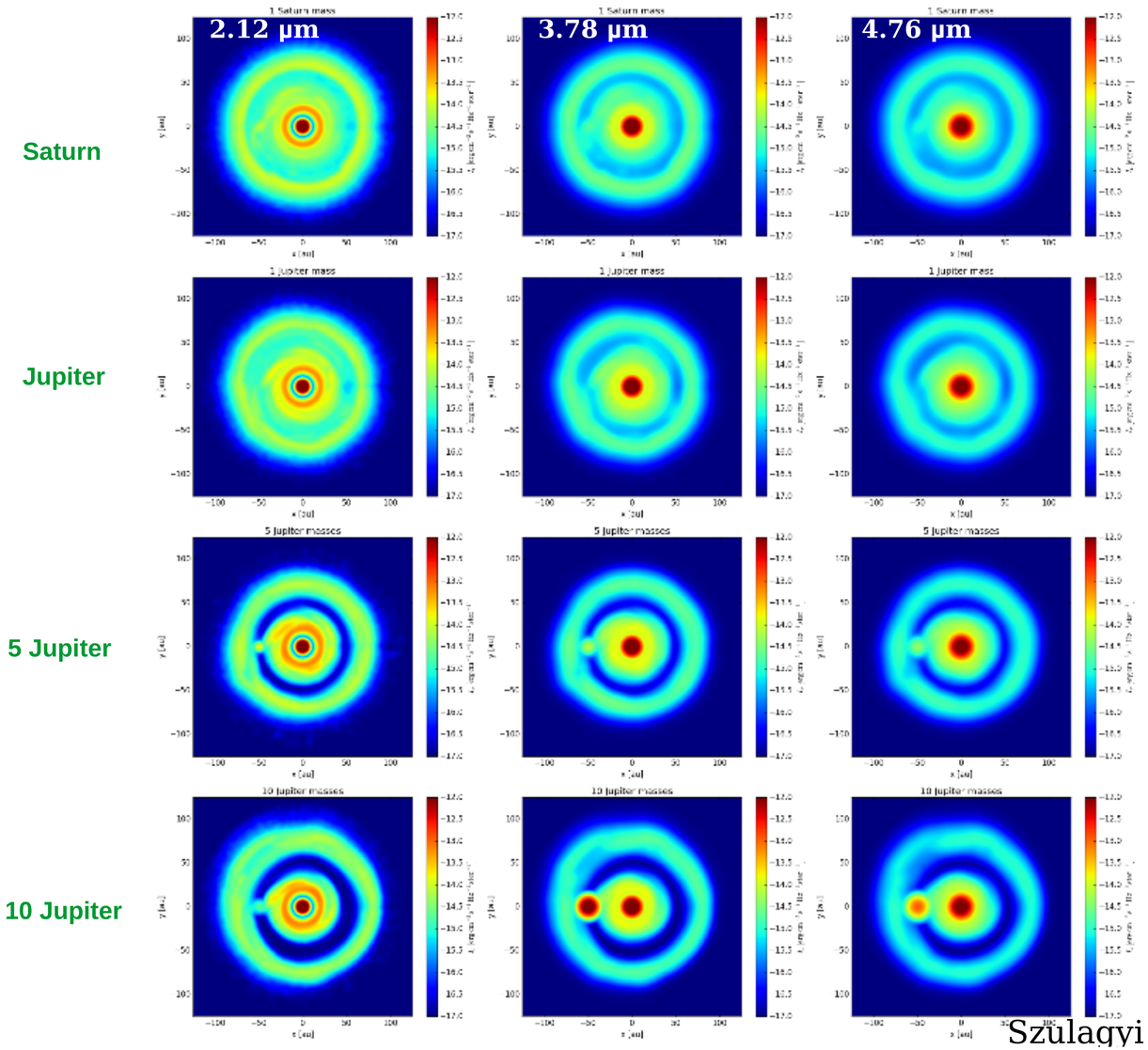
Probabilistic orbits and dynamical masses of emission-line binaries

David Grant [★] and Katherine Blundell
Department of Physics, University of Oxford, Keble Road, Oxford OX1 3RH, UK

Unambiguous detections of circumplanetary disks



Benisty+21, including Czekala

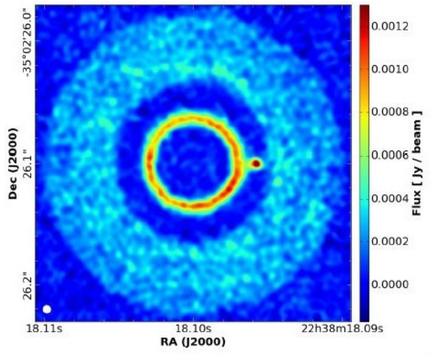


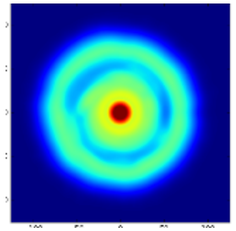
Szulagyi et al. 2019

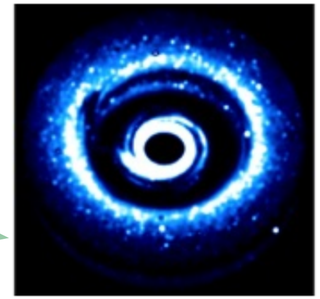
Summary of Observational Predictions

Wavelength/method/instrument

- ✔ – Sub-mm/radio
  - Szulagyi et al. 2018a
- ✘ – Near/mid IR
  - Szulagyi et al. 2019
- ✘ – Polarized Scattered Light
  - Szulagyi & Garufi subm. (on ArXiv)
- ✘ – Hydrogen Recombination Lines (H-alpha etc.)
  - Szulagyi & Ercolano subm. (on ArXiv)







✔: even Saturn-mass (potentially below that)

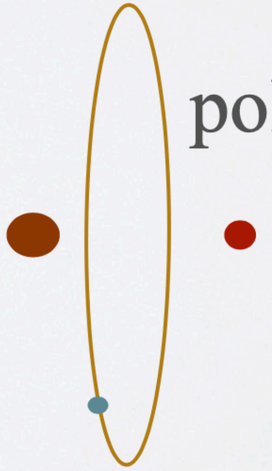
✘: only 10 Jupiter-mass planets or larger

POLAR CIRCUMBINARY PLANETS

CREDIT: STAR WARS IV

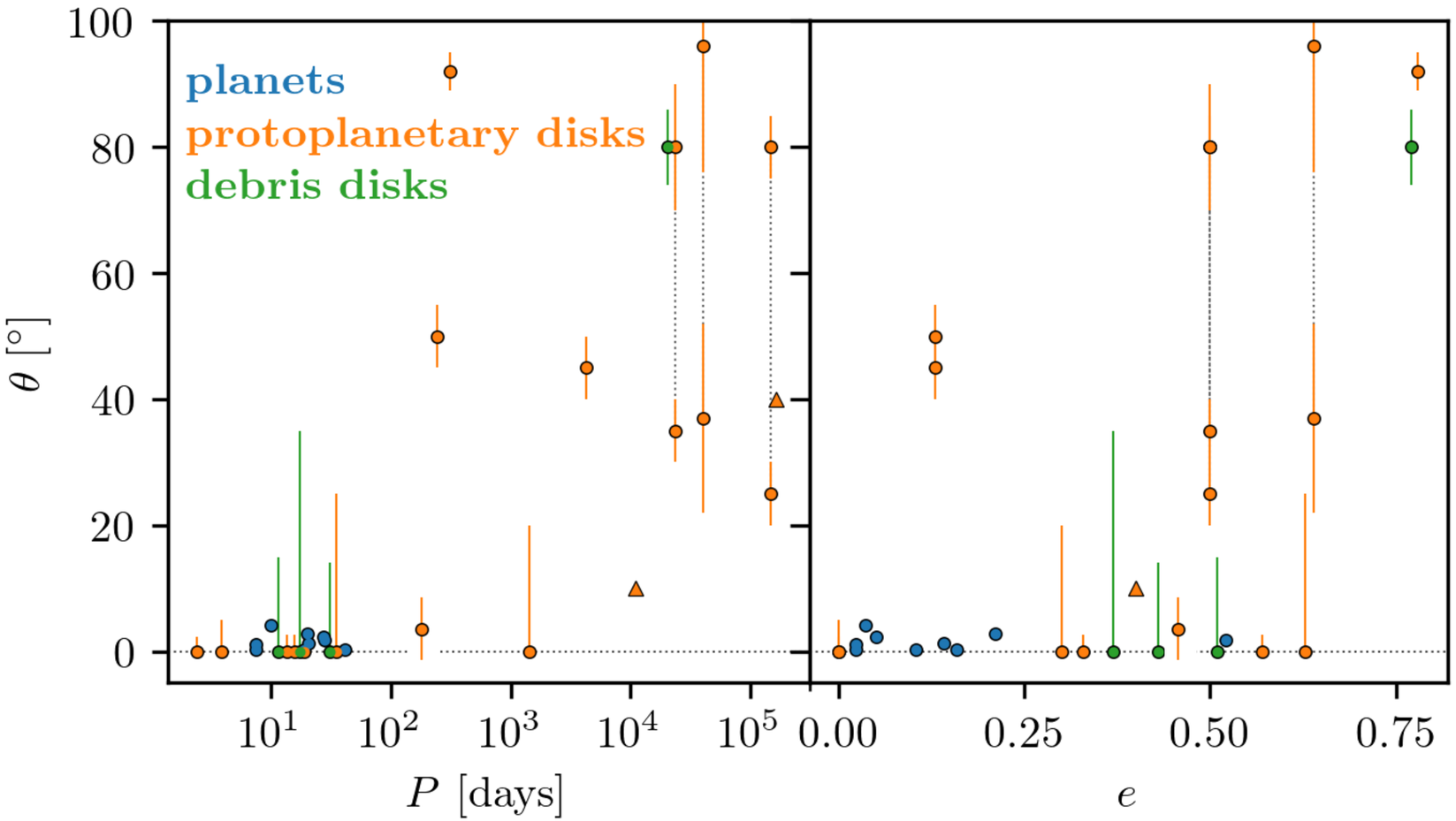
coplanar planet

polar planet?



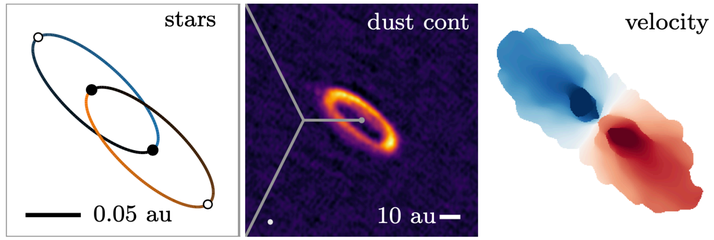
Lubow

Mutual inclinations



AK Sco

e = 0.6, P = 14 days
disk and binary *coplanar*



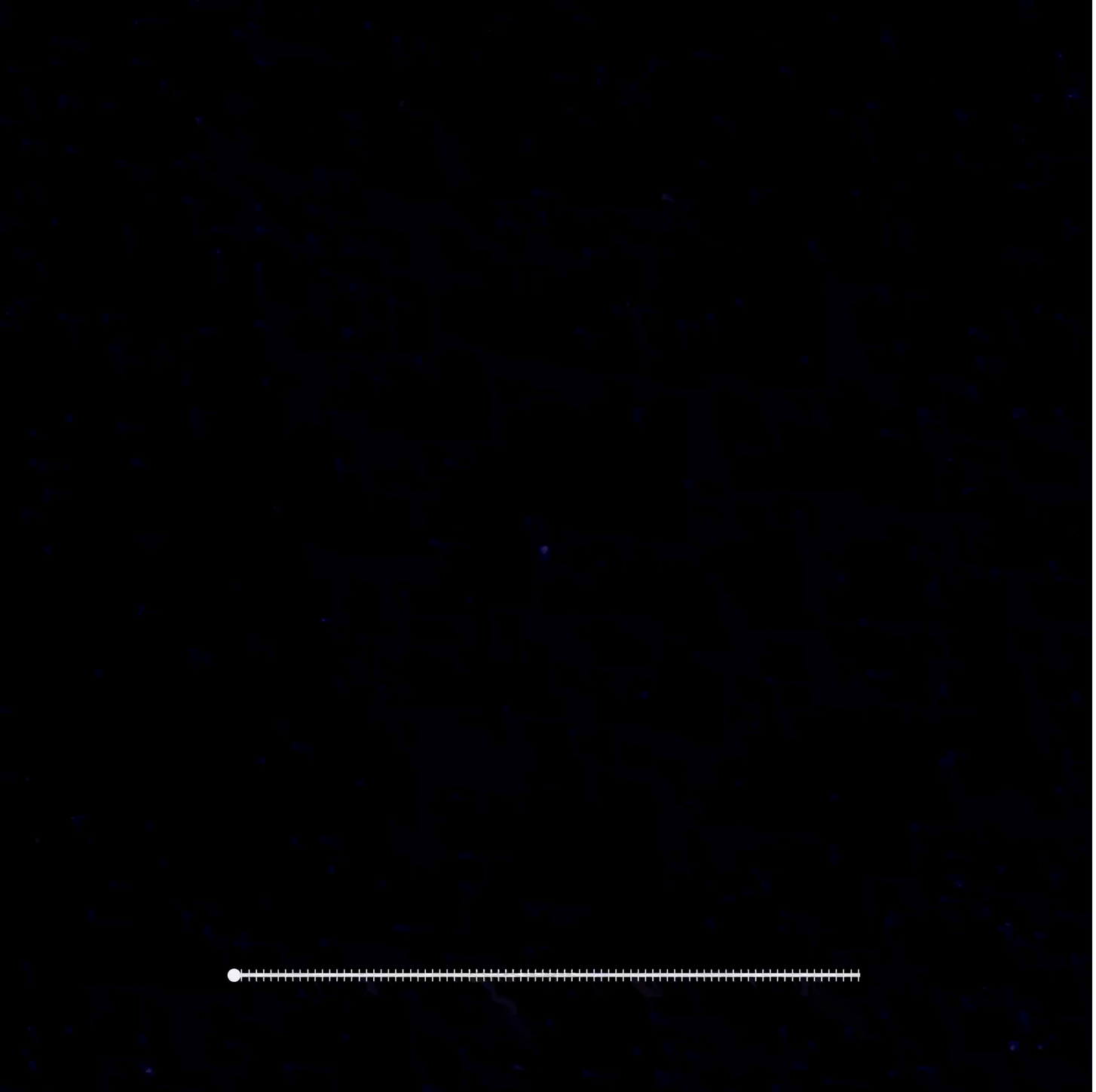
Czekala+19
Zawadzki, Czekala, in prep

Cristiano Longarini and Simone Ceppi:

- If we suppose that the initial distribution of disc inclination and stellar eccentricity is nearly random, why don’t we see a lot of disc in a polar configuration?

- How many young binaries that we observe with discs are actually multiple systems (> 2 stars)? -Many! 30%? HD 98800B, TWA 3, AS 205S, GG Tau, GW Ori, SR 24N, V4046 Sgr, UZ Tau E, HD 34700A, ROXs 42Ca, GV Tau S, …

Czekala+19, Tables 3,4,5

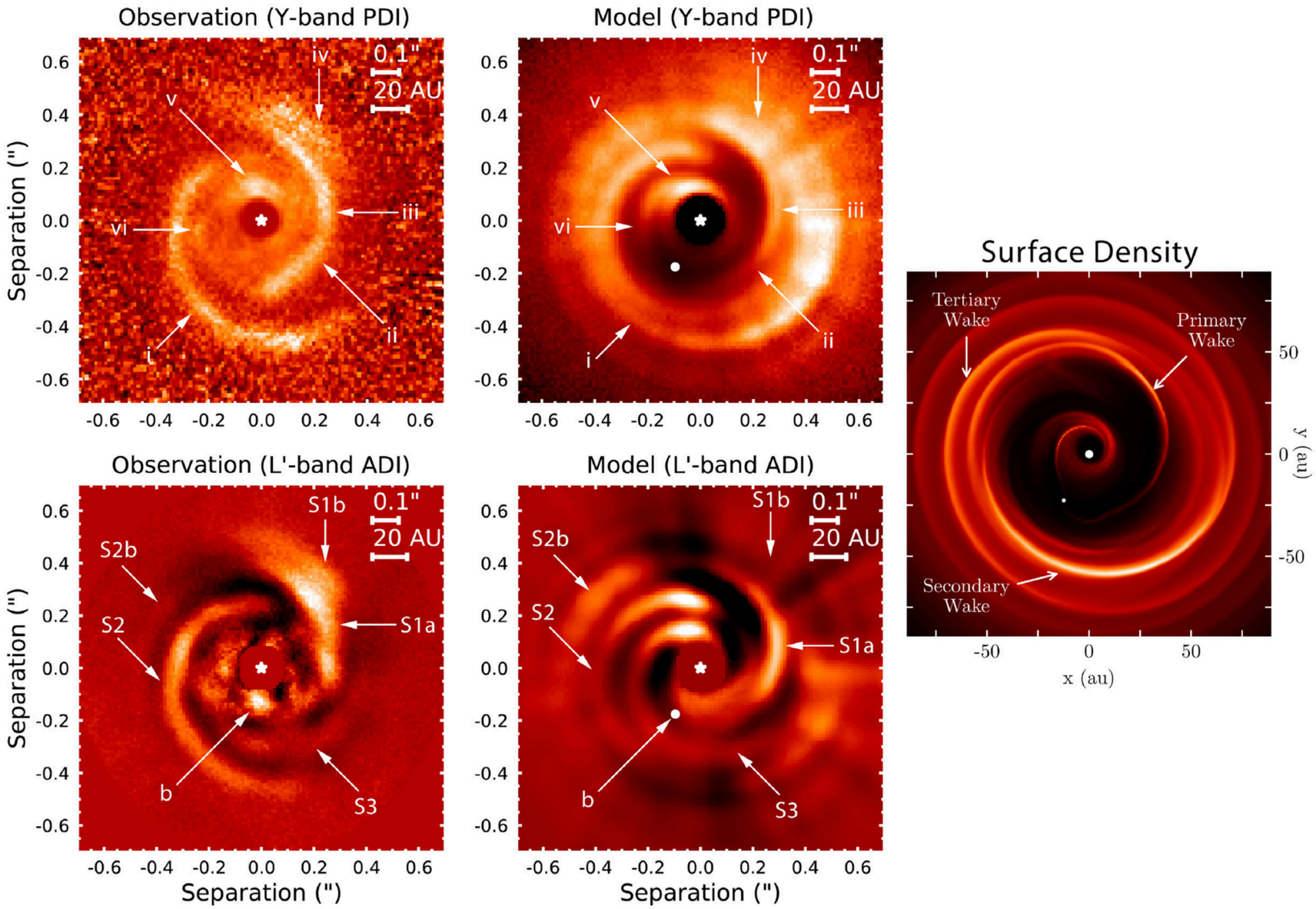


Mapping the protoplanetary velocity field

300 m/s velocity slices of a single disk

Warm molecular emission (carbon monoxide, CO) traces disk velocity field

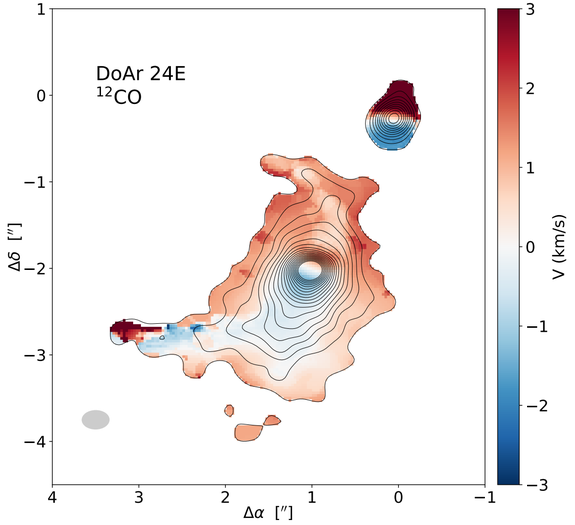
DSHARP Survey; Isella+18

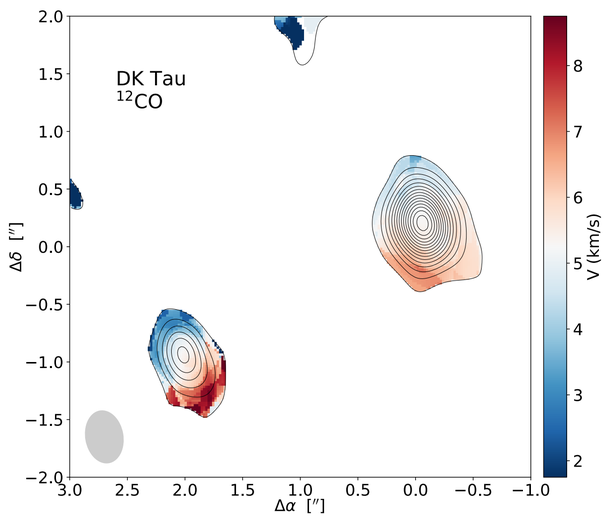


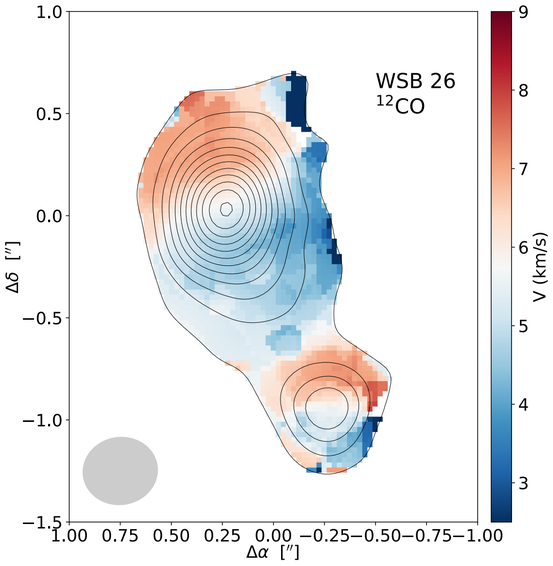
Calcino+2020

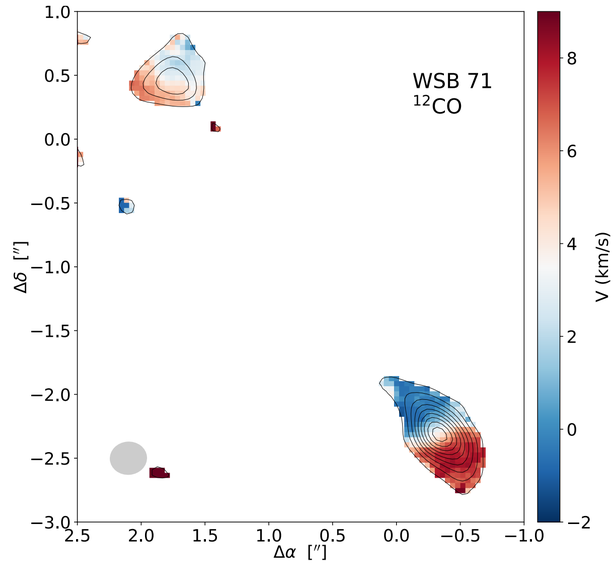
Are disks in young binaries aligned with each other?

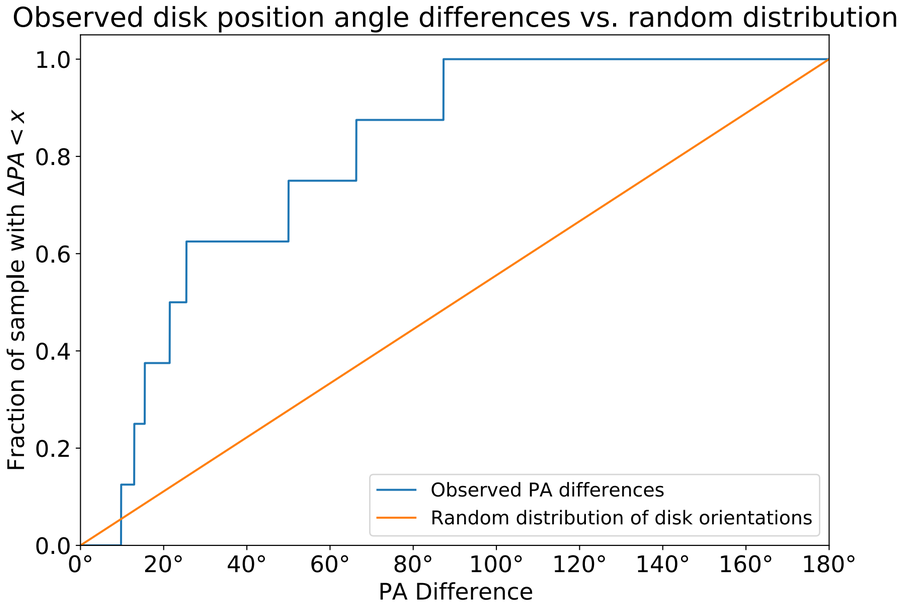
Eric Jensen, Swarthmore College; Rachel Akeson, Caltech/NExScI



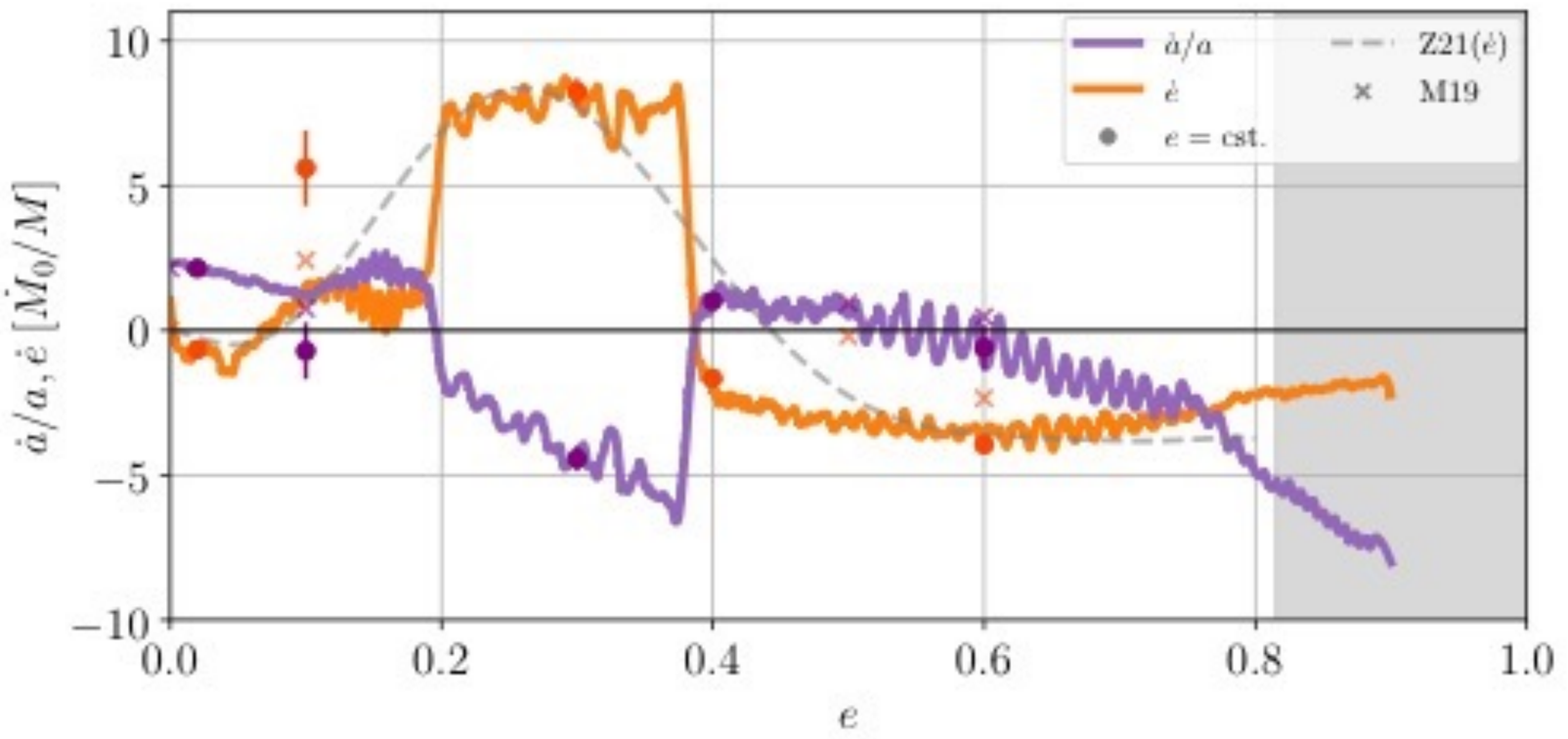








Predicted Eccentricity Evolution with Low-mass Circumbinary Disks



Results of 2D Simulations (D'Orazio & Duffell 2021; Zrake et al. 2021)

ė = 0 at e = 0.08, 0.18, and 0.38.

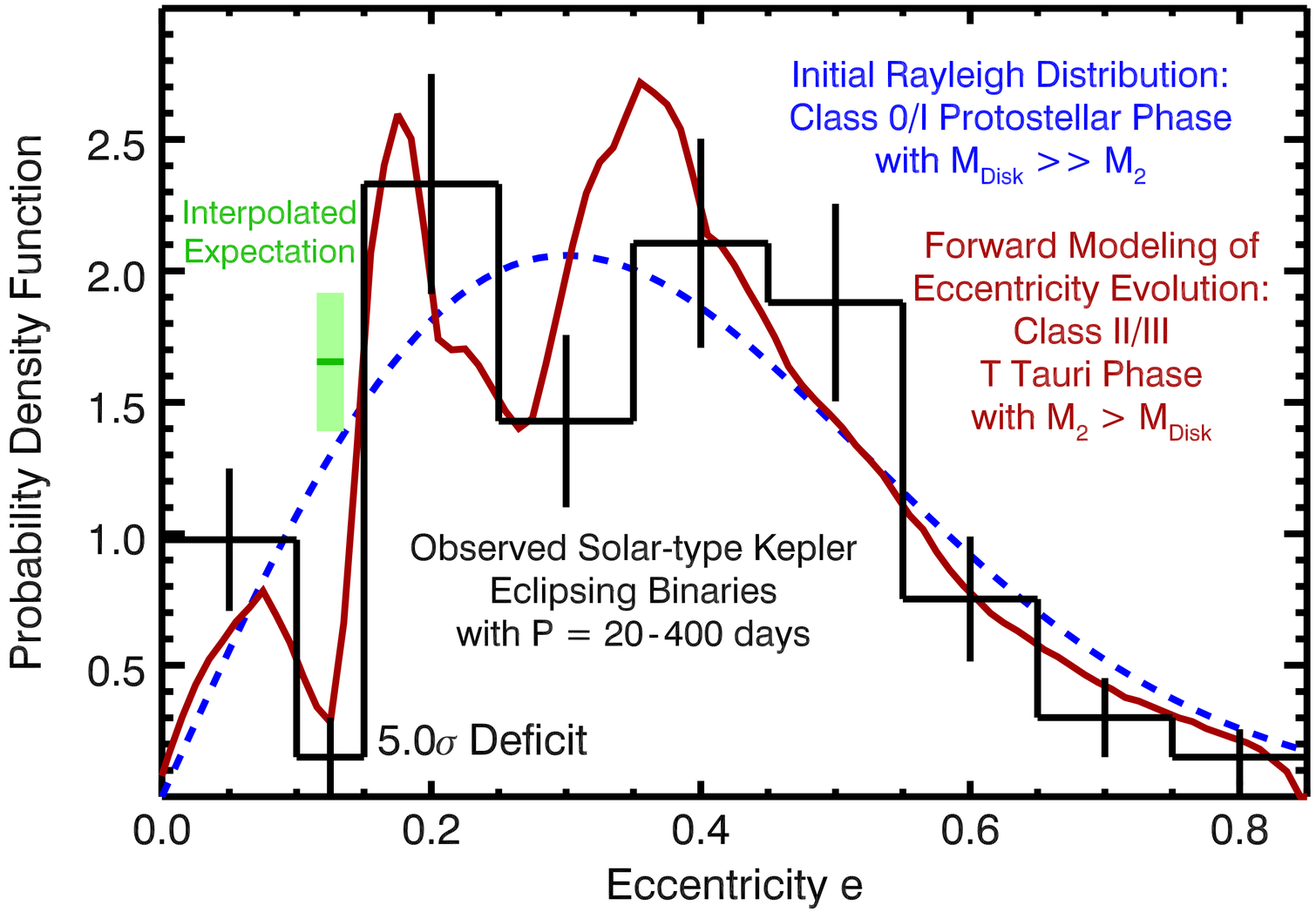
Prediction is a Tri-Modal Eccentricity Distribution

with Peaks at e = 0.04, 0.18 and 0.38 and

Deficits at e = 0.13 and 0.3

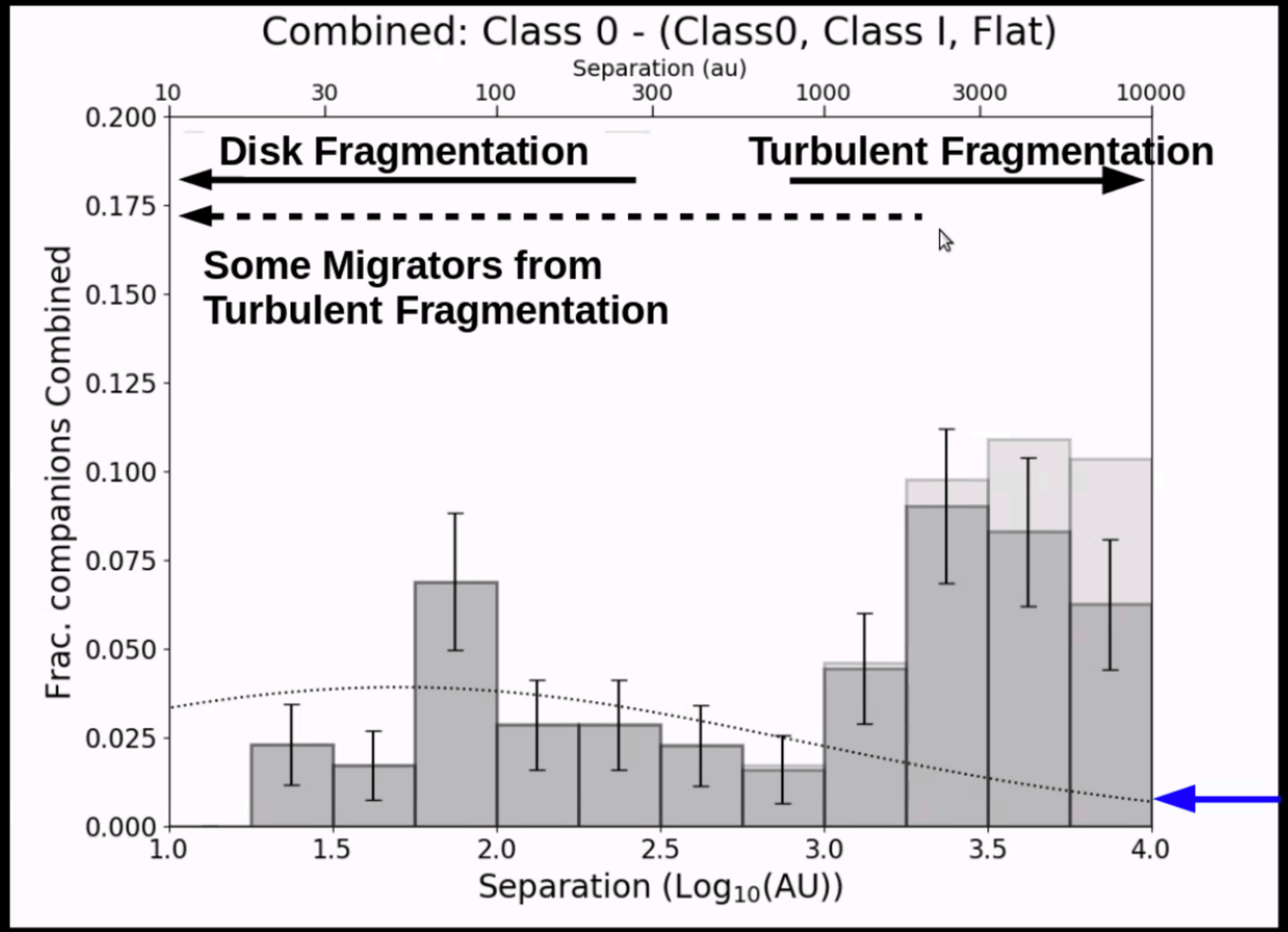
Moe

This Project Started 30 hours ago



Thank you organizers for bridging the gap between observers of stellar binaries (Moe) and theorists of binary black hole accretion (Duffell, D'Orazio, Haiman, Zrake, & Tiede)

Multiplicity Origins and Evolution



Field solar-type stars Raghavan+10

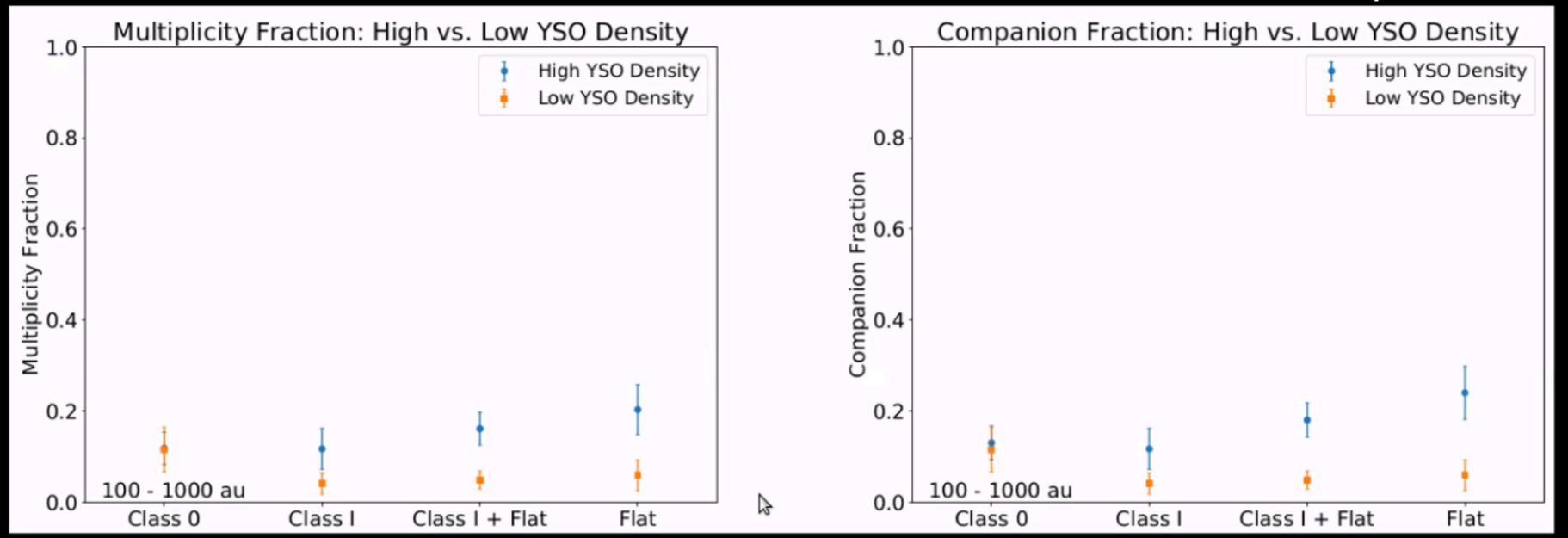
- Difficult to populate all small-scale multiples from migration (see Lee+2019)
- Evidence for disk fragmentation and migration?

Are circumbinary disks longer lived than single star disks?

Tobin+22

Evidence For Migration

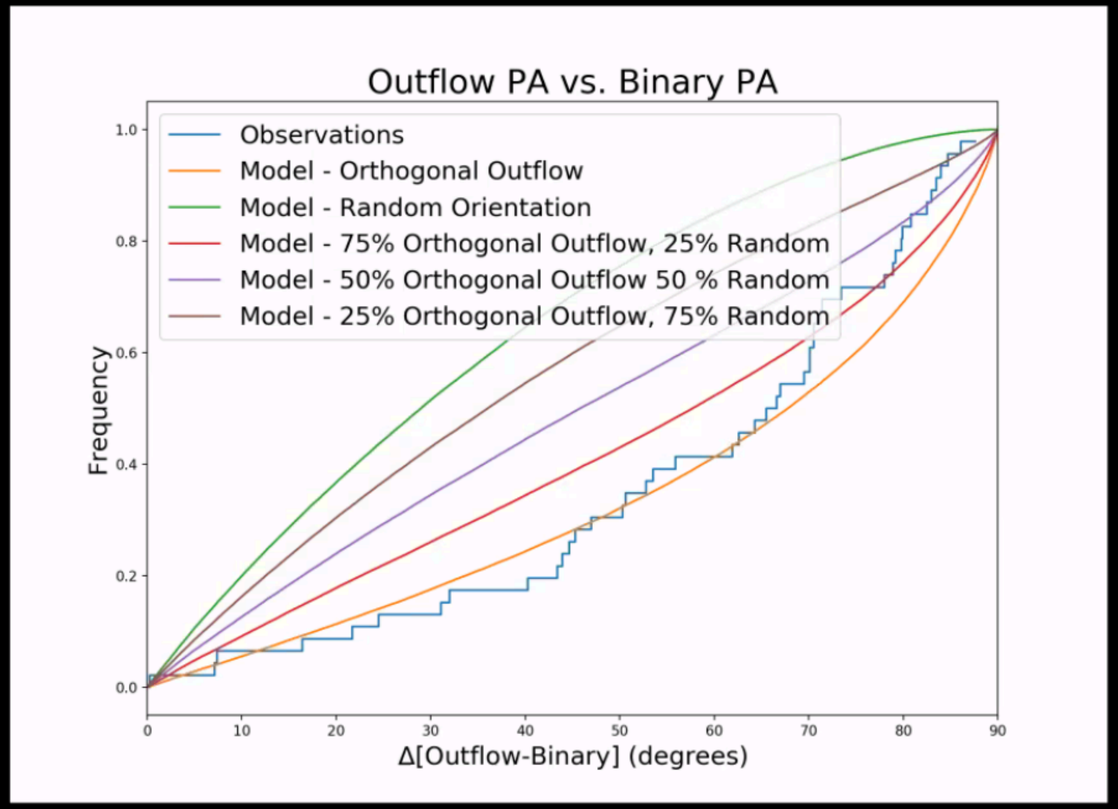
100 to 1000 au separations

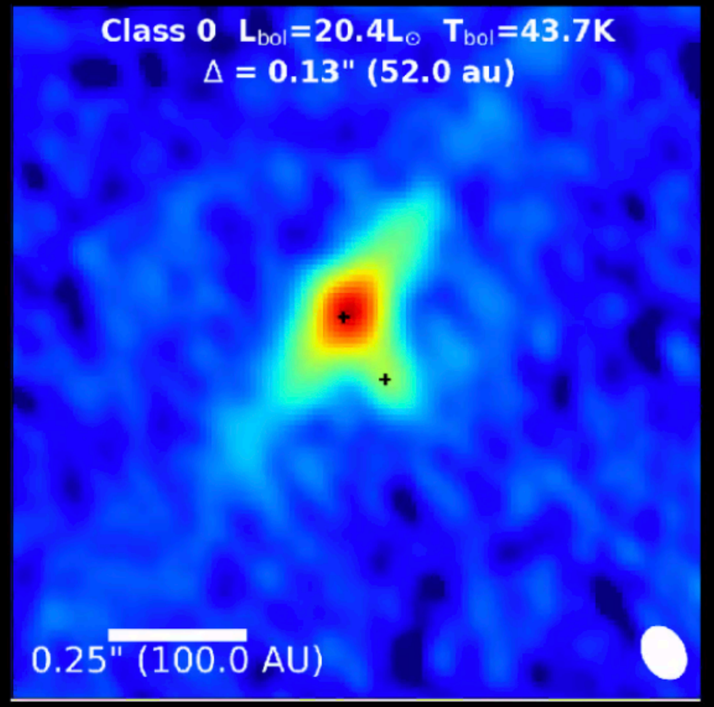


- 100 to 1000 au separation range is the ‘gulf’ that must be crossed to migrate from large to small separations
  - Ideal range to look for multiplicity evolution
- Class 0s constant between low vs. high – primoridal multiplicity
- Rising MF and CF for Class I+Flat and Flat – migration

Tobin+2021

Evidence for Disk Fragmentation





Tobin+ in prep.

- Circumbinary material not always easy to detect, look to outflows, assume orthogonal to disk, assume binary is in plane of CB disk
- Assume random circular orbits, random inclination
  - Examine distribution of binary PAs vs outflow PAs
  - Disk-related origin of binary should biased toward orthogonal vs parallel