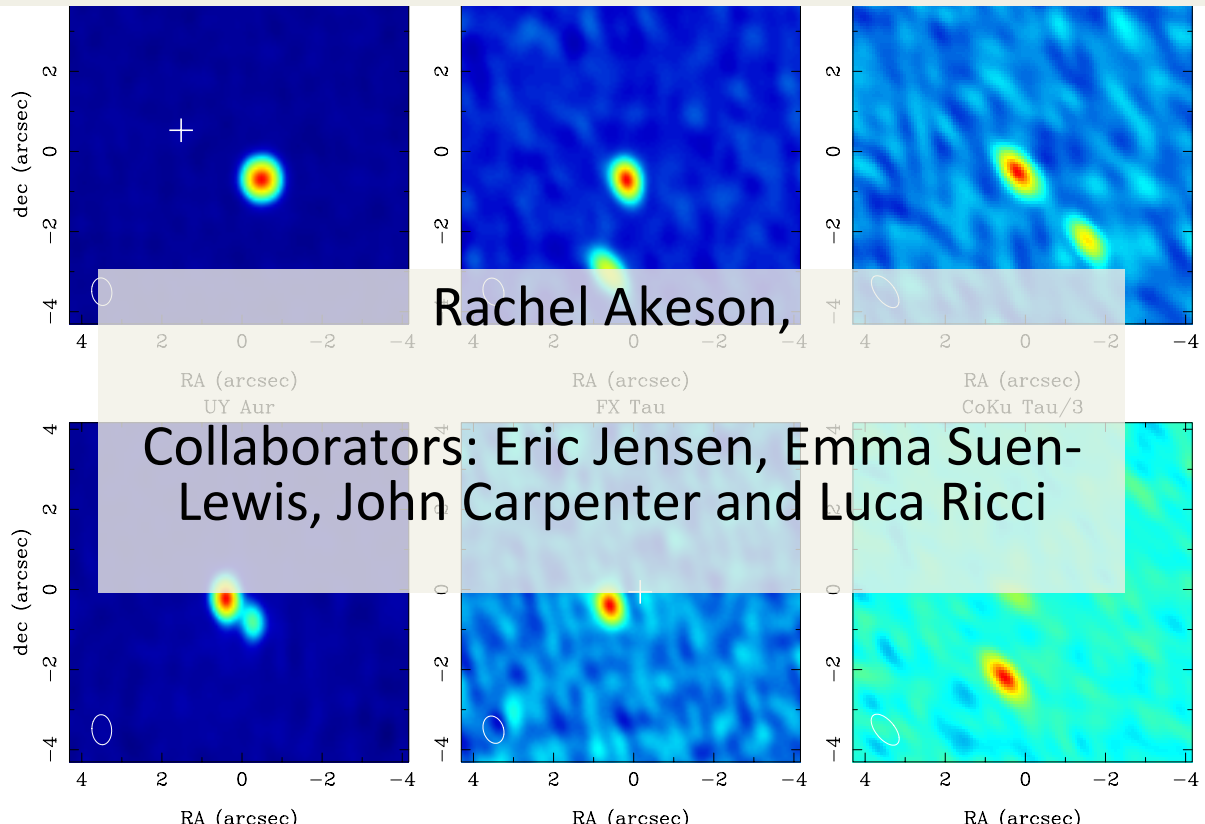
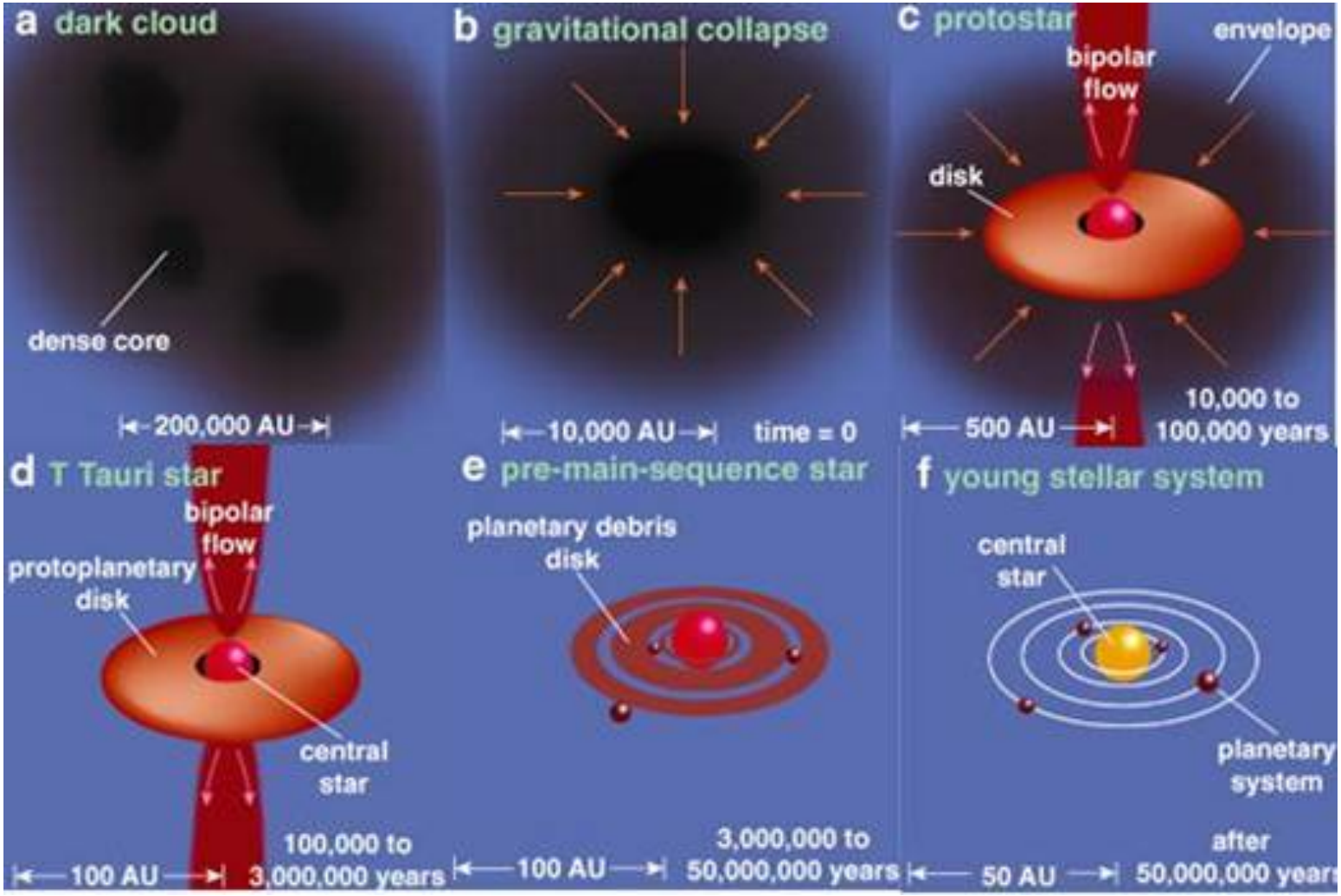
Environmental impacts on planet formation



Rachel Akeson,

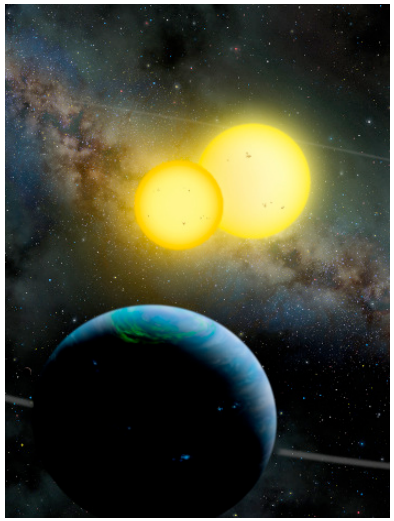
Collaborators: Eric Jensen, Emma Suen-Lewis, John Carpenter and Luca Ricci

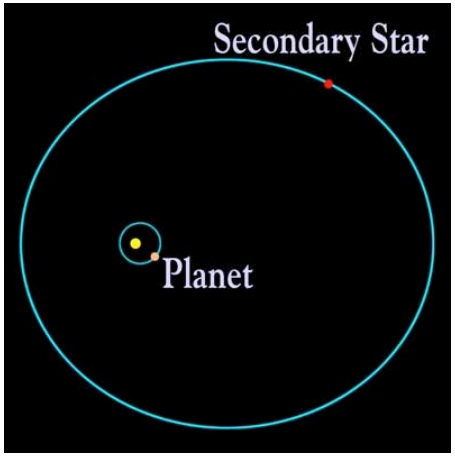
Where do planets come from?

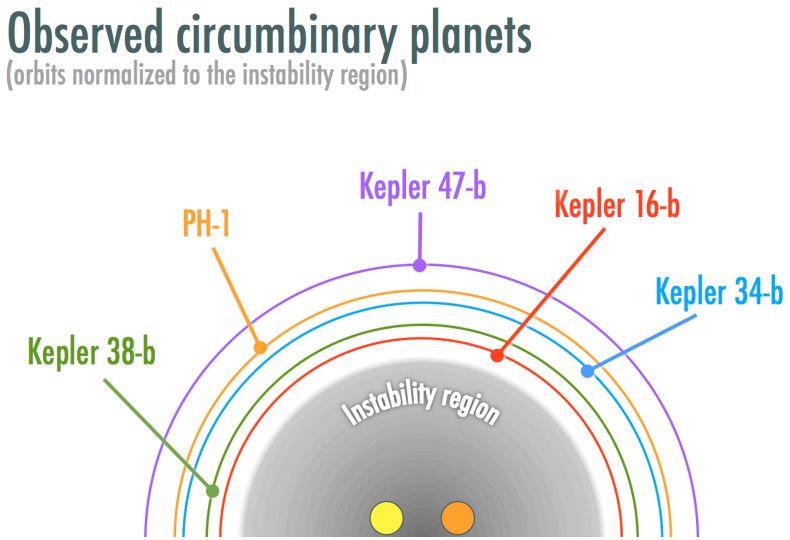


But stars aren't single

- In both the field and star formation regions, the majority of stars are in binary or higher-order multiple systems
- And we know that planets exist in binary systems
  - Both circumbinary planets and those around one stellar component

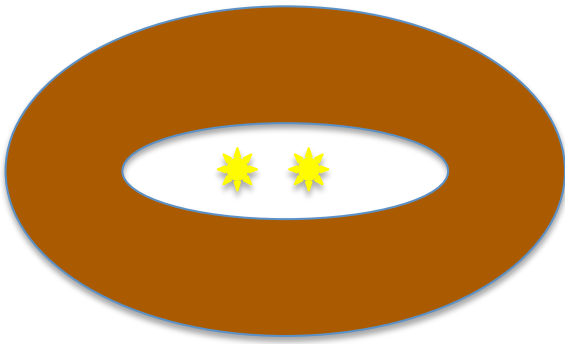


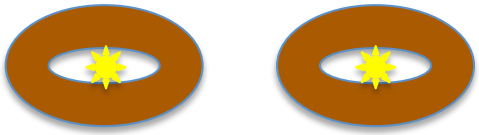


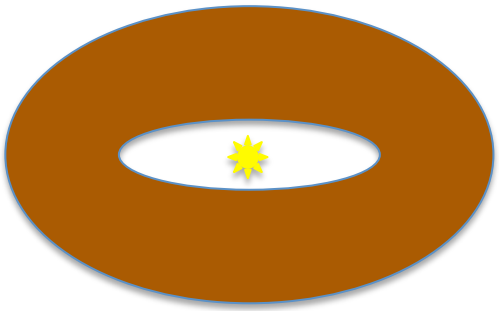


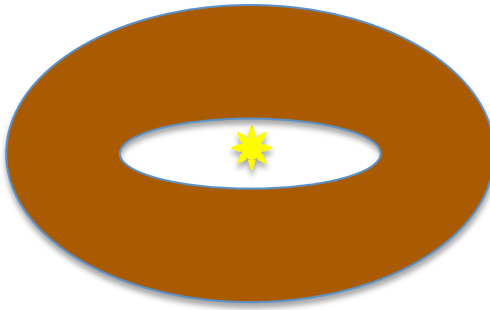
How do multiple stars impact the disk and planet formation?

- Can disks around stars in multiple systems support planet formation?
- Use millimeter and sub-mm observations trace the dust mass in the disk
- Early studies
  - Sub-mm single-dish flux lower for binaries with separations of 1 to 50-100 AU (Jensen et al, 1996)
  - Ascribed to dynamical truncation









But most stars are in multiple systems

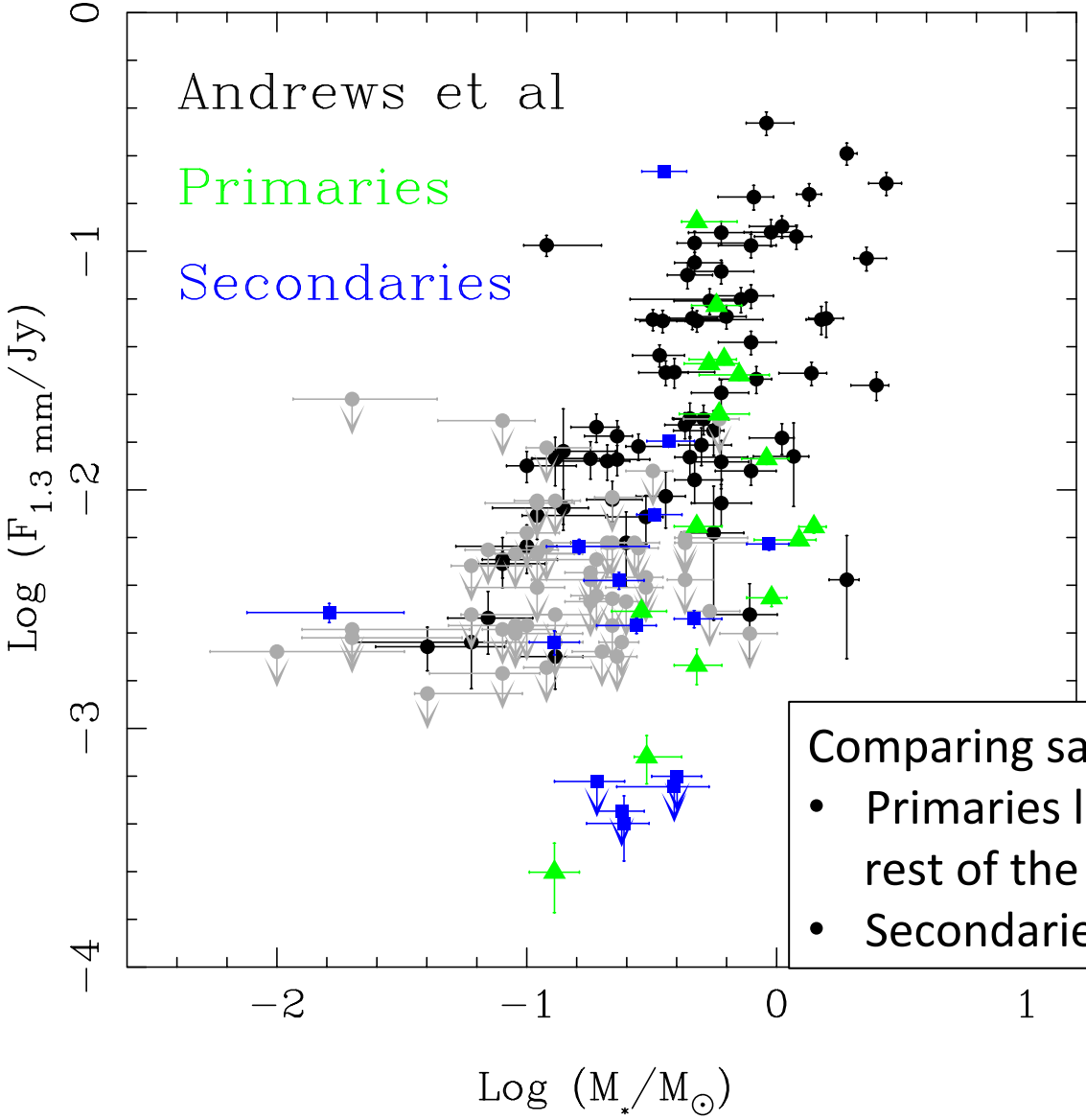
- Later studies with interferometry
  - Primary always brighter, secondary often not detected (Jensen & Akeson, 2003; Patience et al, 2008; Harris et al, 2014)
  - Expected from binary formation models
  - Not clear if secondary disks common

ALMA: Atacama Large Millimeter Array

- ALMA is a collaboration between NRAO, ESO and East Asia
  - 50 sub-mm antennas in the Atacama desert at 16,000 ft
- ALMA has the sensitivity and resolution to detect and resolve the individual disks
- Our Cycle 0 project: 17 wide binaries in Taurus star formation region known to have disks

Detected 8 new disks: 2 primaries and 6 secondaries

Compare to rest of Taurus

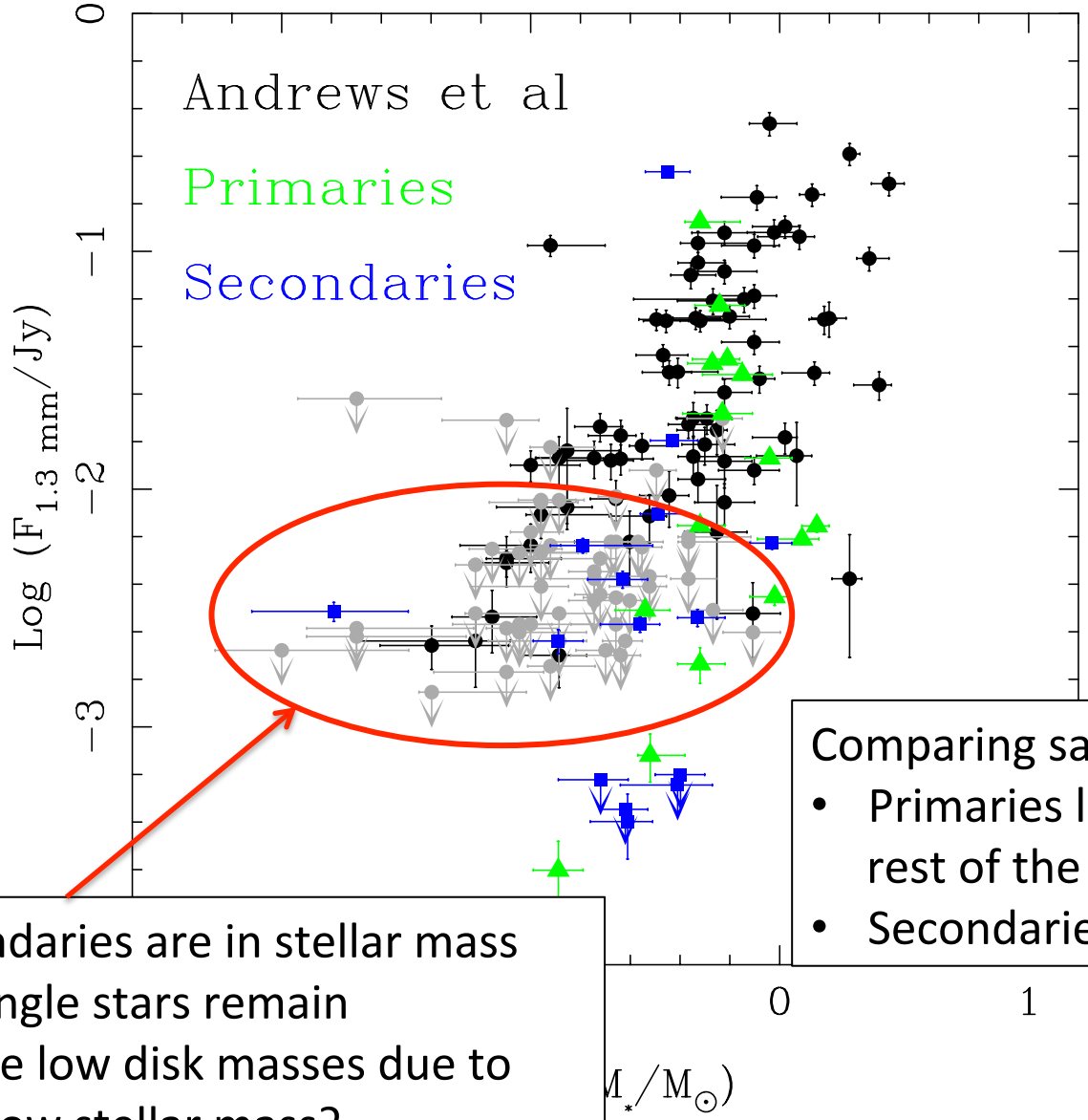


Akeson and Jensen (2014)

Comparing samples:

- Primaries look like the rest of the sample
- Secondaries do not

Compare to rest of Taurus



Akeson and Jensen (2014)

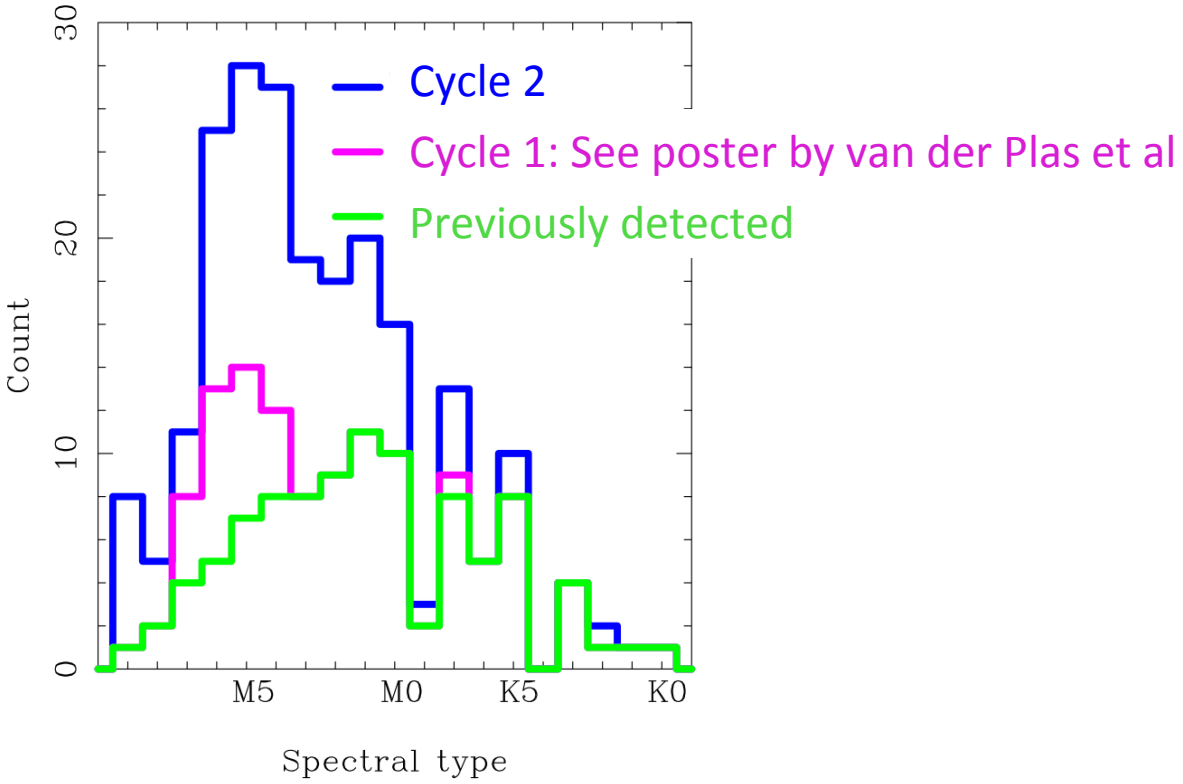
Comparing samples:

- Primaries look like the rest of the sample
- Secondaries do not

But most secondaries are in stellar mass range where single stars remain undetected: Are low disk masses due to multiplicity or low stellar mass?

Need complete survey of ALL Taurus disk sources

- Cycle 2 ALMA proposal
  - Target all Class II targets without mm-flux for all components down to spectral type of M9 and separations of ~15 AU
  - 69 systems with 94 resolvable disks, Band 6 continuum



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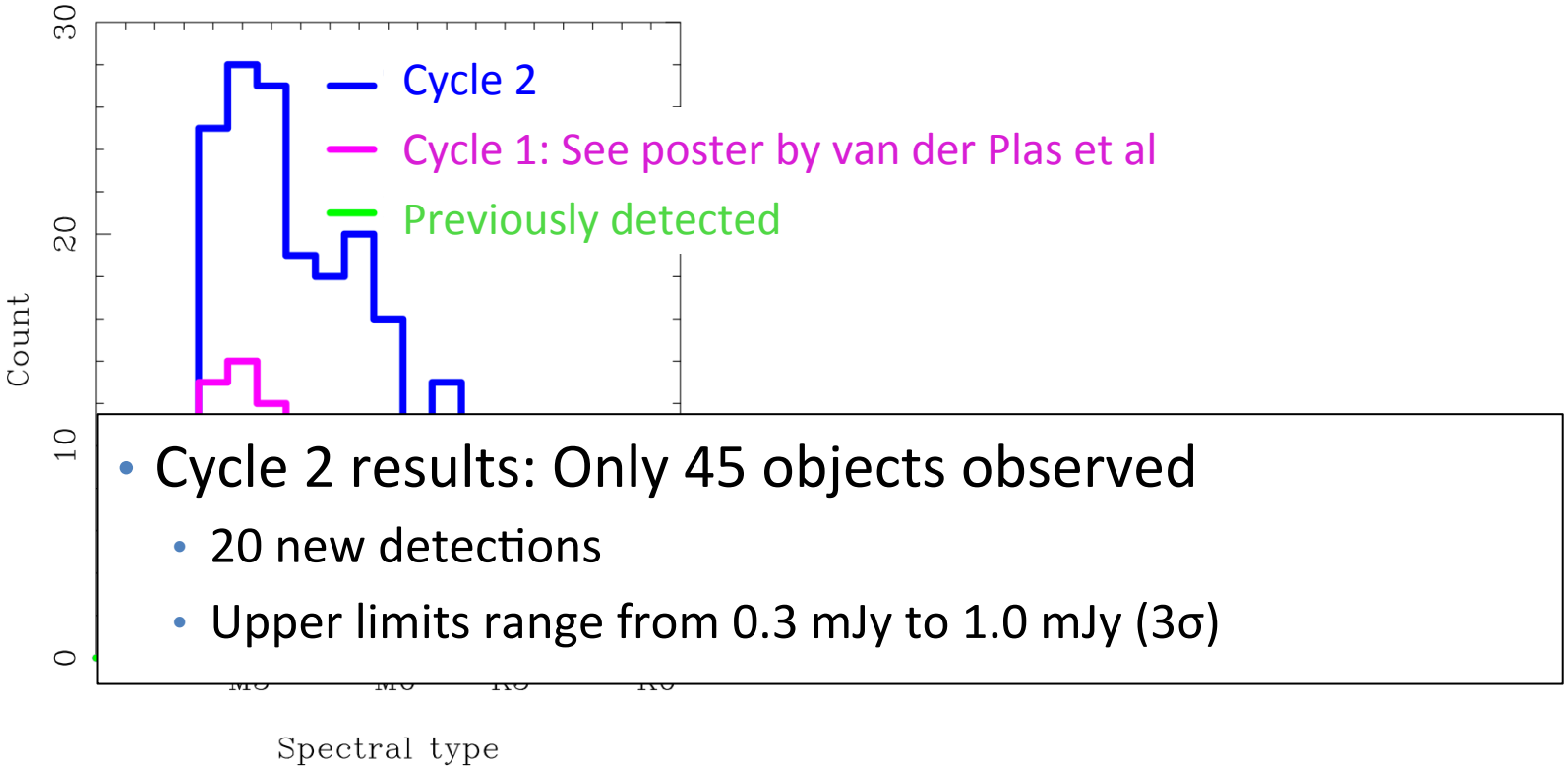
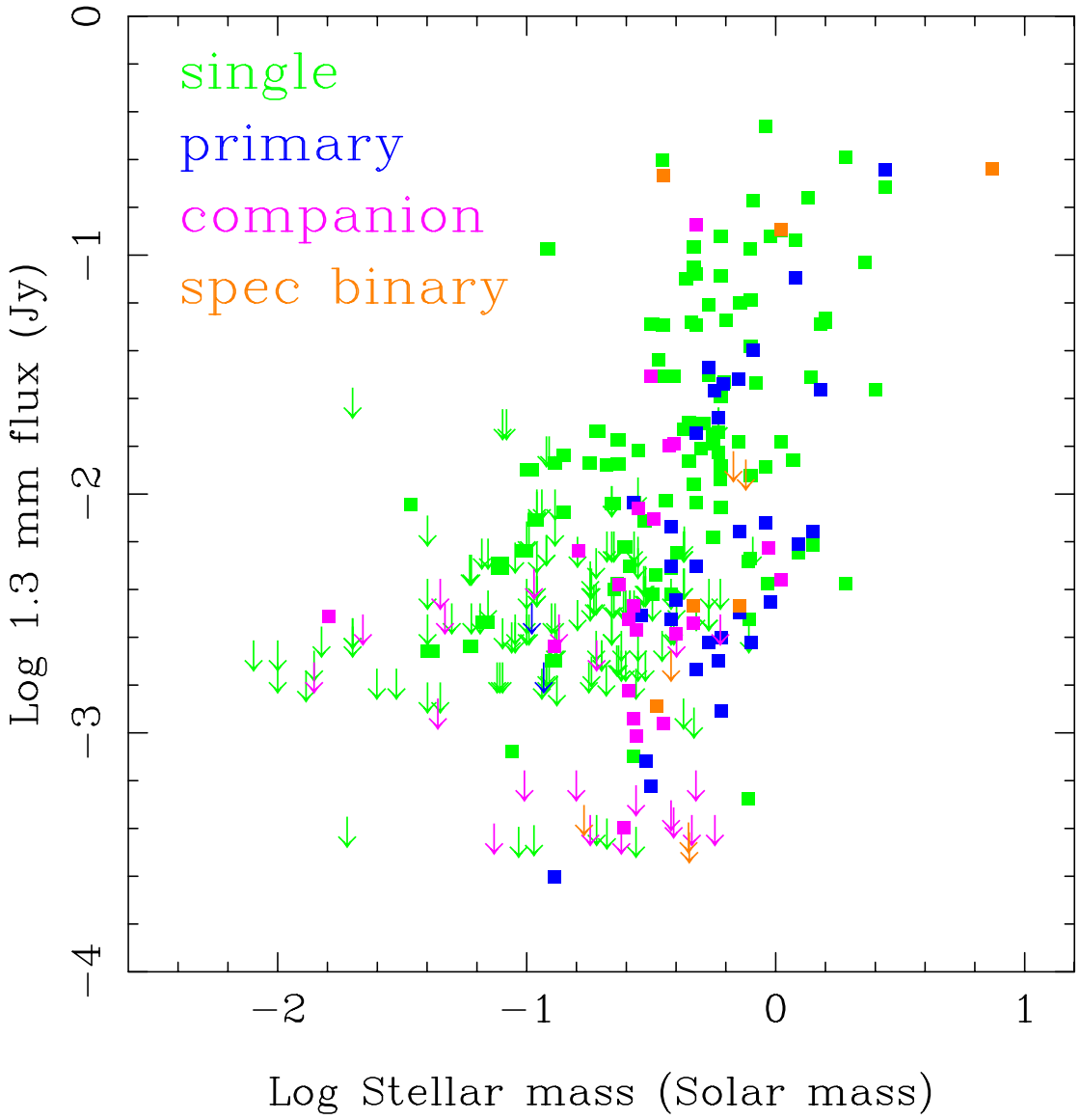
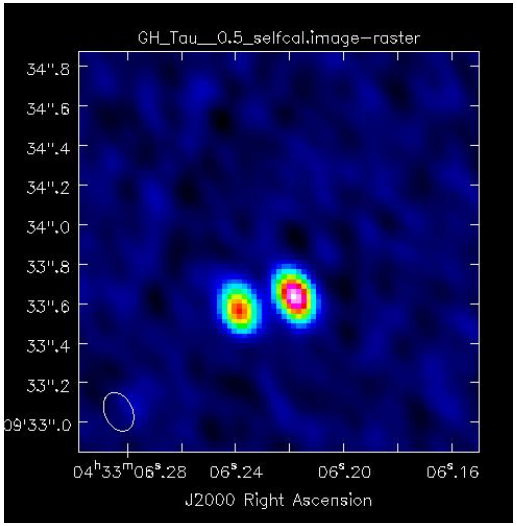


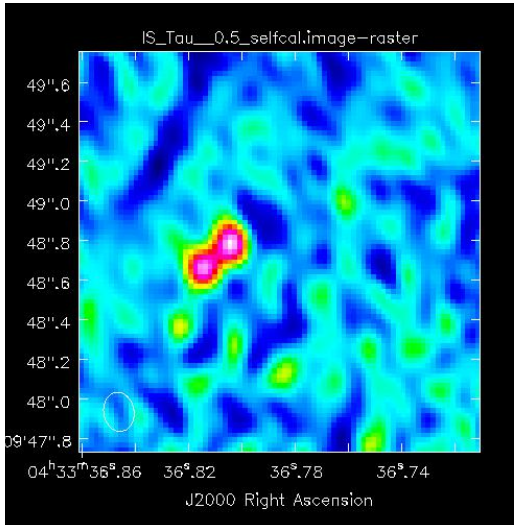
- Cycle 2 results: Only 45 objects observed
  - 20 new detections
  - Upper limits range from 0.3 mJy to 1.0 mJy (3σ)

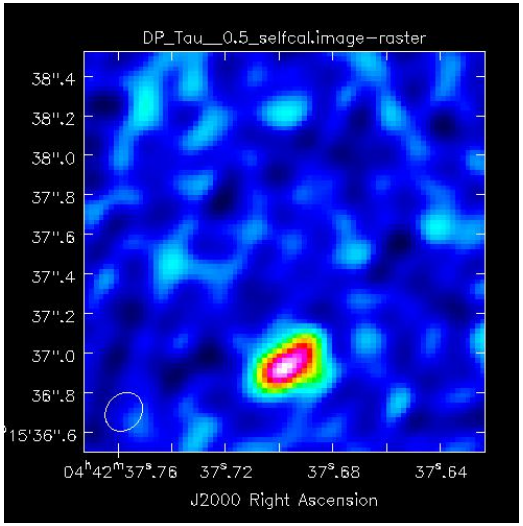
Sorted by multiplicity



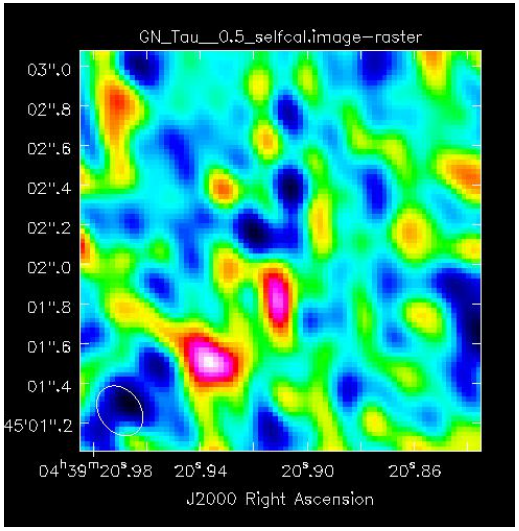
Binaries with separations of 15 to 100 AU: 10 of 13 have BOTH disks detected

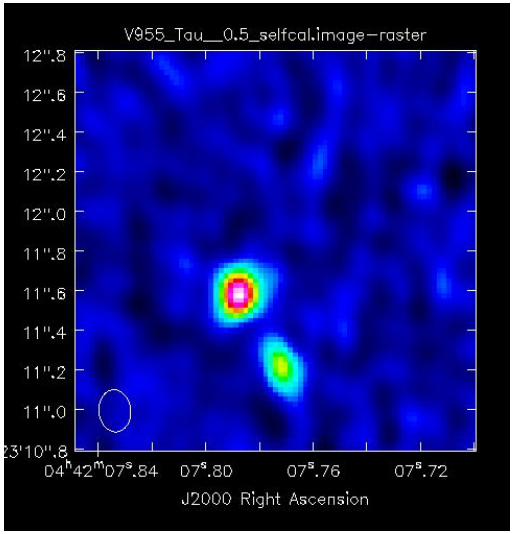


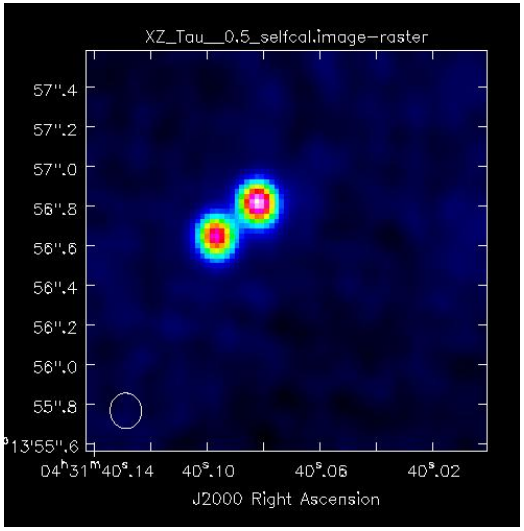




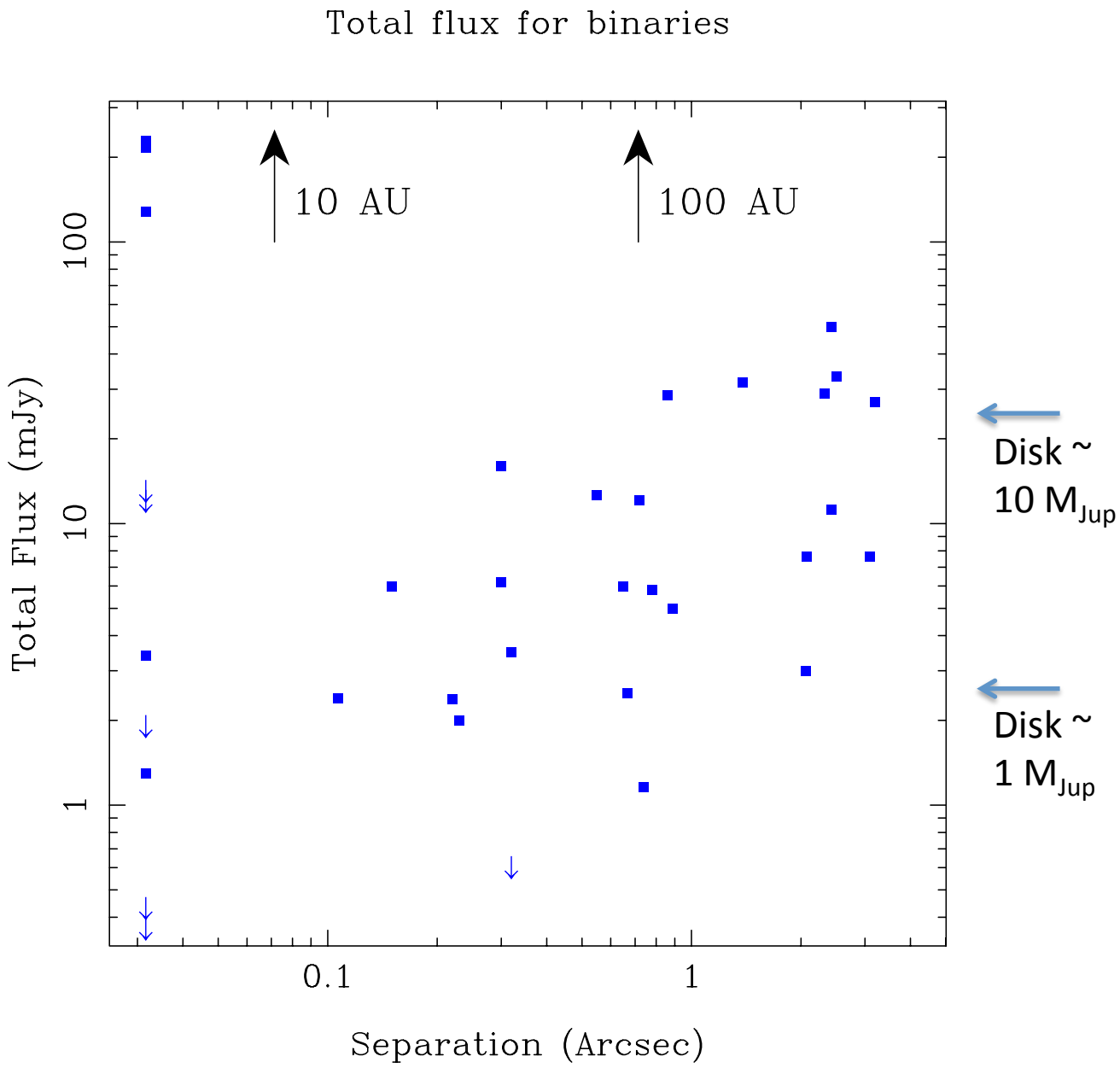
50 AU







Impact of binary separation



Disk ~ 10 M_{Jup}

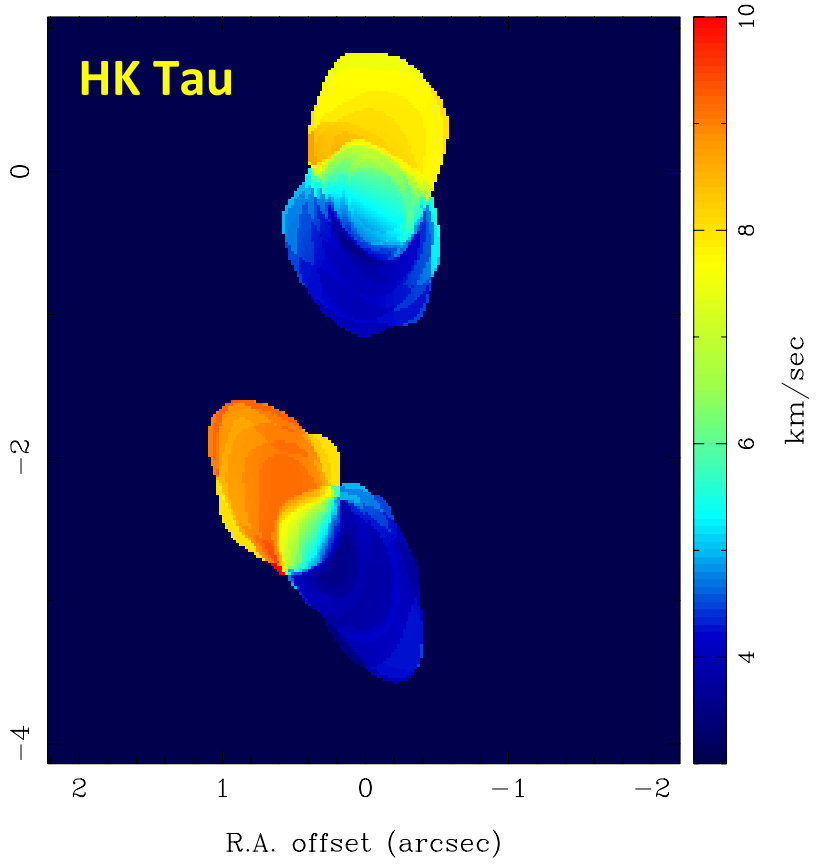
Disk ~ 1 M_{Jup}

Binaries with separations of 10 to 100 AU have lower flux: same as seen in Jensen et al (1996) and Harris et al (2014)

- But even close binaries have enough mass to make smaller planets

Use molecular lines to trace kinematics

Jensen and Akeson, Nature, 2014



Velocity-weighted CO emission

- Use CO emission to determine 3-dimension orientaiton
- Both disks can not be aligned with the binary orbit and at least one disk must be mis-aligned by at least 30°
  - Only 2% of all possible binary orbits are inclined to both disks by less than 39°
- Any planets formed in these disks would be subject to Kozai oscillations, one of the mechanisms invoked to explain high-eccentricity planets

Summary

- At a given stellar mass, companion stars have lower flux than single or primary stars
  - Stellar mass ratio does not determine disk mass ratio
  - Some secondary disks do have enough mass to support planet formation
- ALMA sensitivity also reveals structures