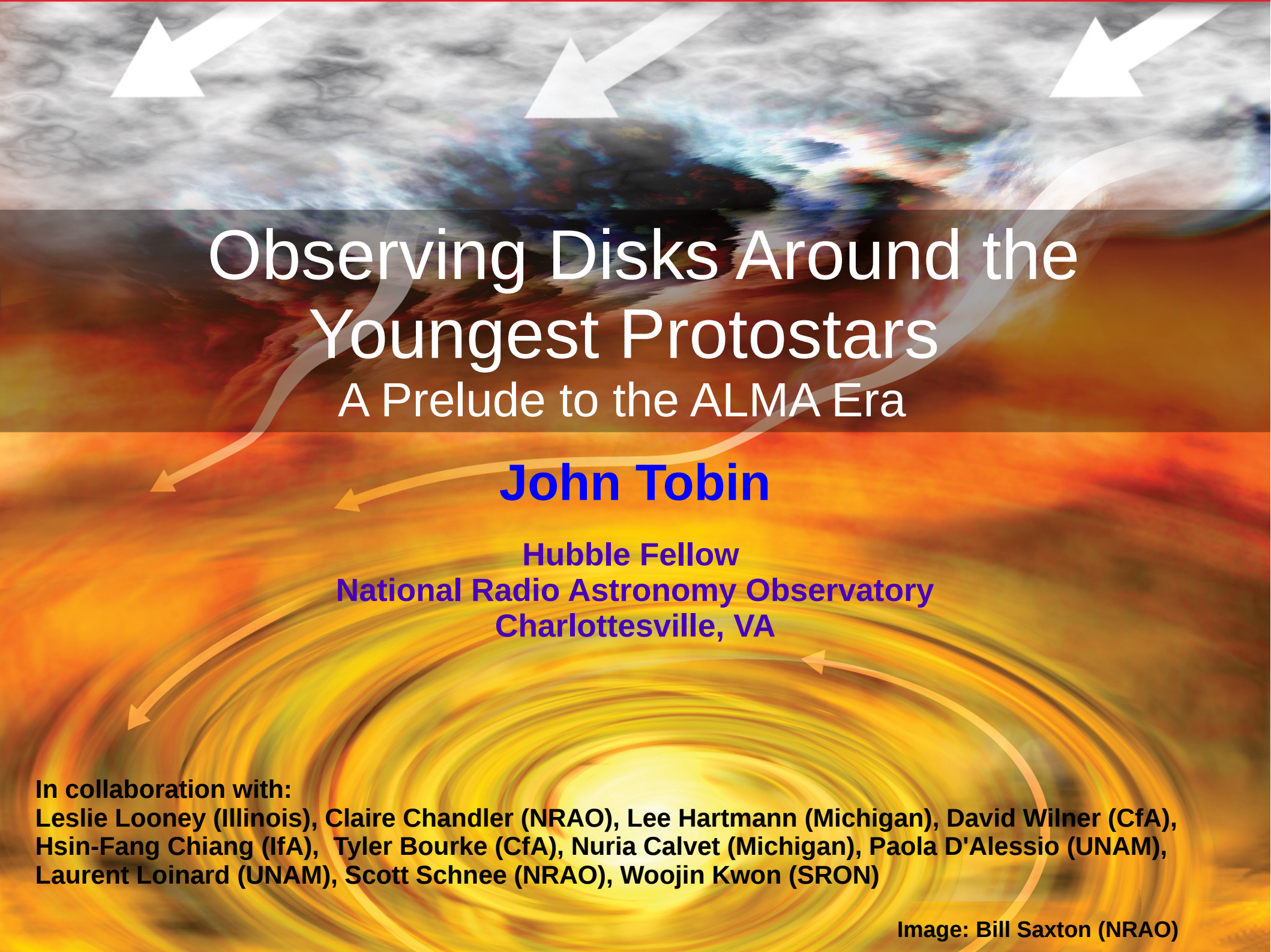

Observing Disks Around the Youngest Protostars

A Prelude to the ALMA Era

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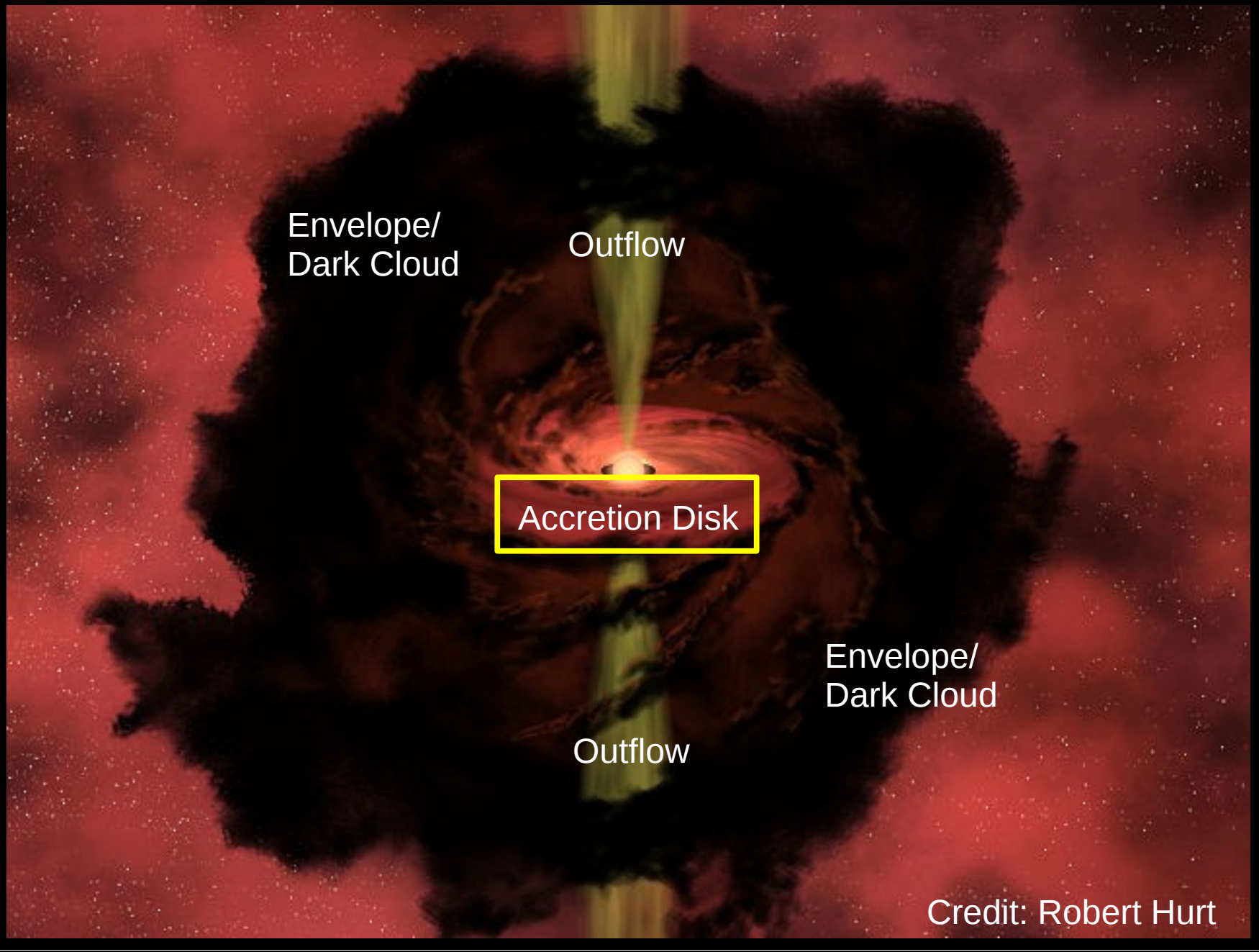
Image: Bill Saxton (NRAO)

Anatomy of a Protostar

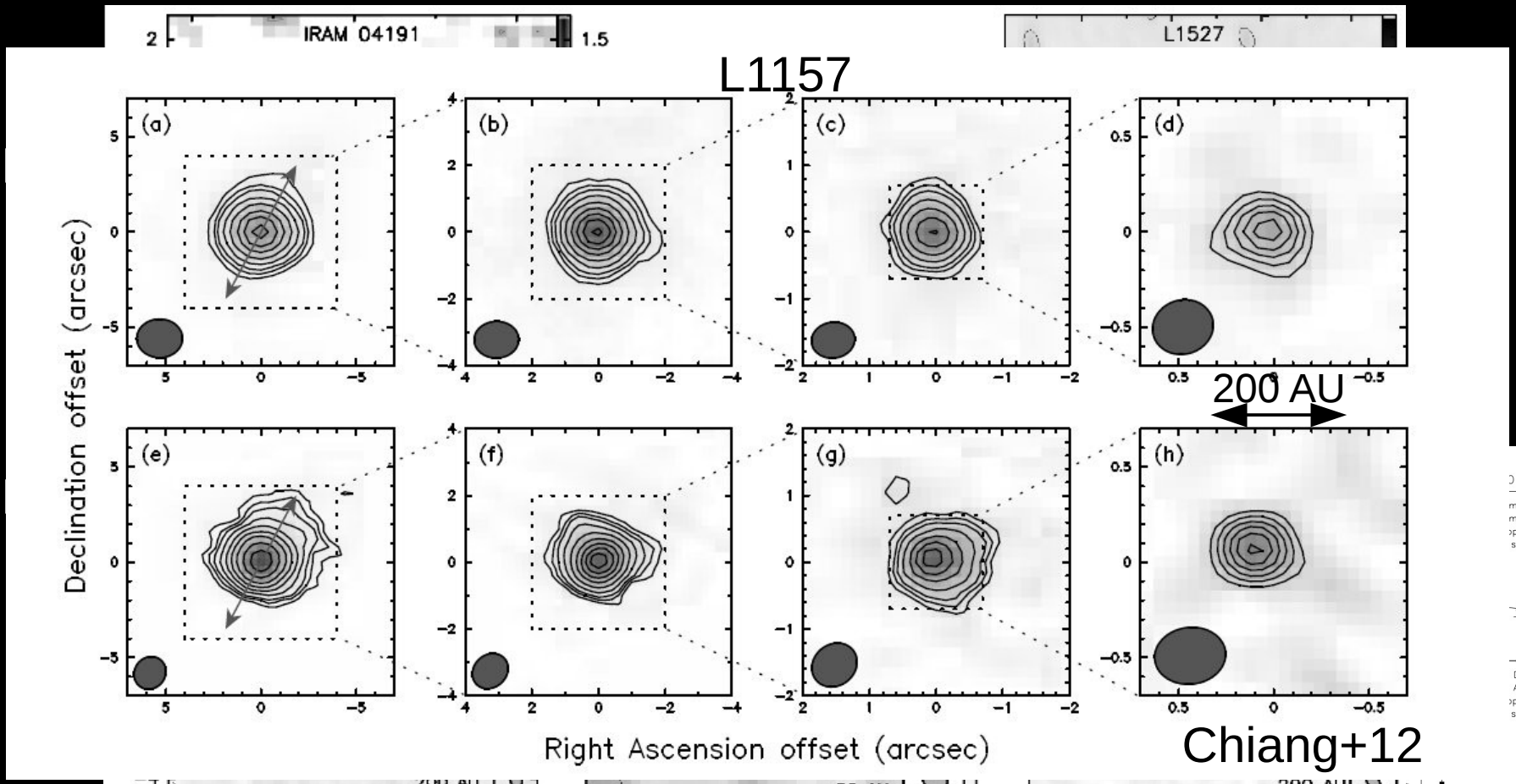


Class 0 Disks

- Important for disk evolution
  - Initial conditions/fragmentation potential
  - Size, mass, density profile
  - Grain growth
- Do large disks form in the Class 0 or I phase?
  - Magnetic braking problem
  - Non-ideal MHD, only small disks Dapp & Basu 11
  - Misaligned rotation/magnetic fields allow larger disks (Joos+12)
  - Important for close binary/giant planet formation

Credit: Robert Hurt

Protostellar Disks

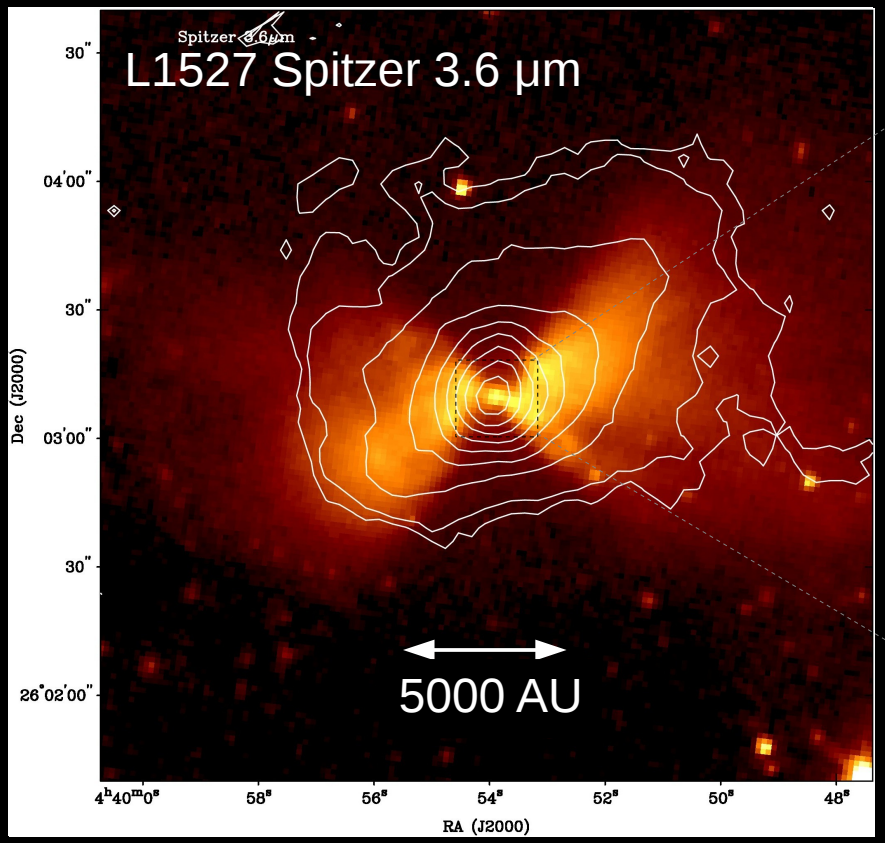


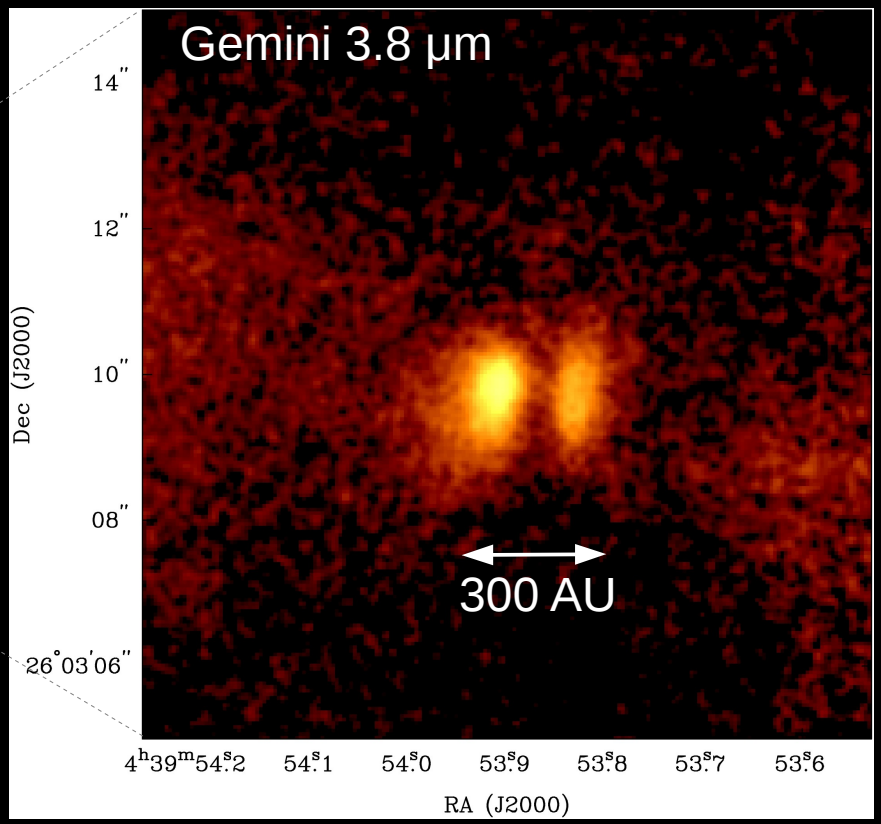
- Maury+2010 concludes that disks nor binaries (150 AU < R < 550 AU) are common in Class 0s

Harvey+2003

A New Hope for Class 0 Disks

- L1527-IRS in Taurus, D = 140 pc
  - Class 0 protostar, large envelope ~ 1 M_{sun}
  - 0.3” (42 AU) mid-IR imaging suggests a R ~ 200 AU disk

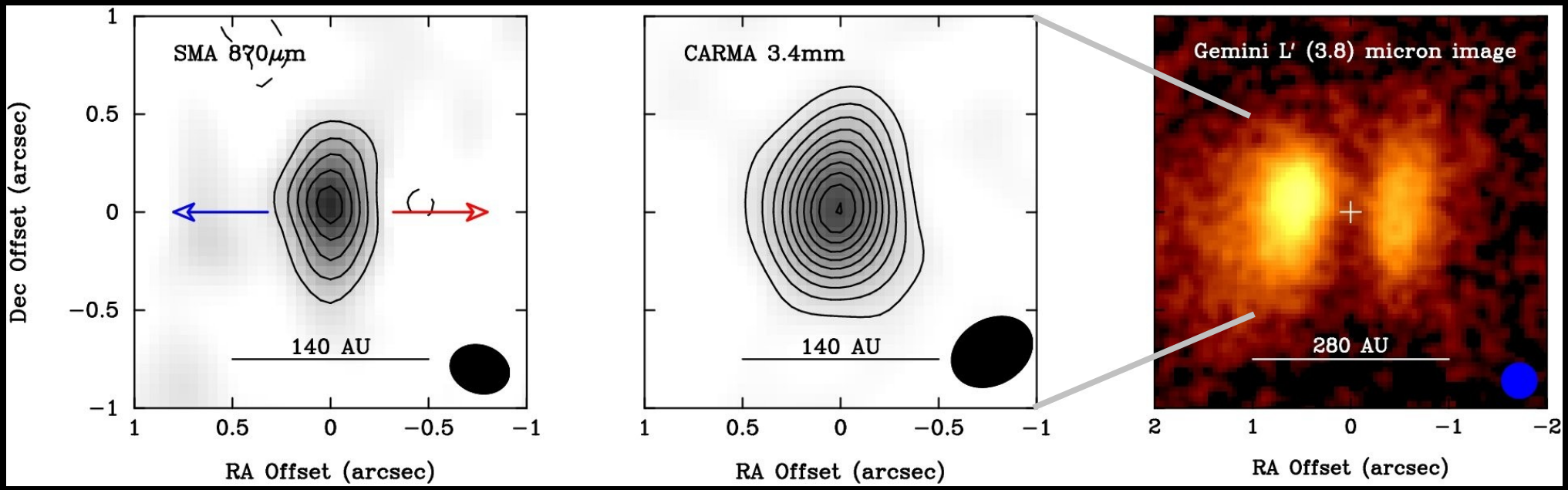




Tobin+2010

Sub/mm Imaging

870 μm 3.4 mm Gemini L'-band



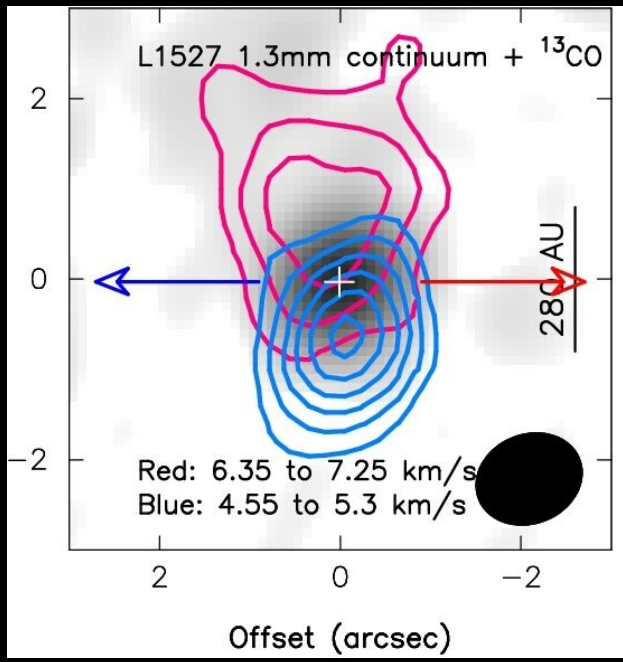
Tobin+12 Nature

- SMA (870 μm) and CARMA (3.4 mm) data
  - Dust emission to probe bulk of disk
  - 0.3” (870 μm) and 0.35” (3.4 mm)
    - A resolved disk! M_{disk} ~ 0.007 M_{sun}

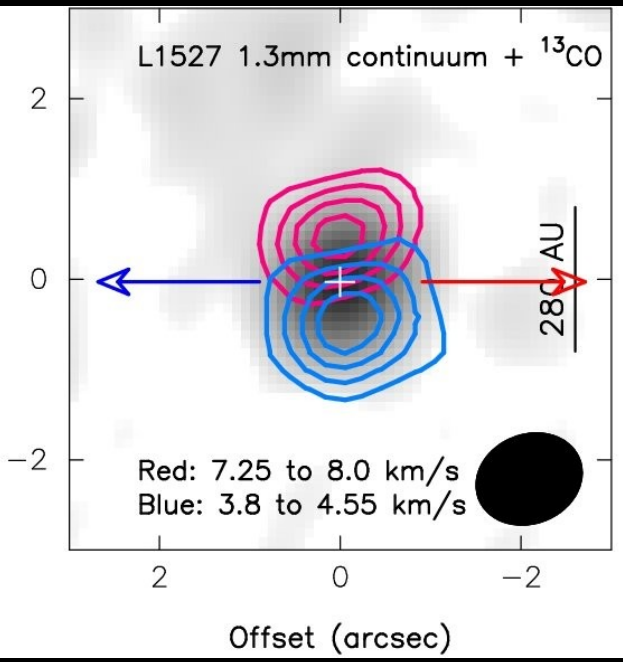
But..... need kinematics to confirm

Disk Kinematics

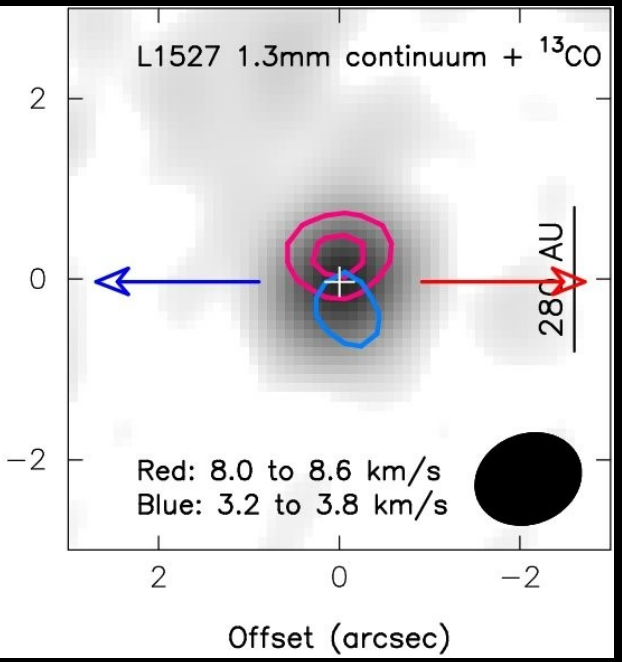
Low Velocity (0.6 – 1.4 km/s)



Mid-Velocity (1.4 – 2.1 km/s)



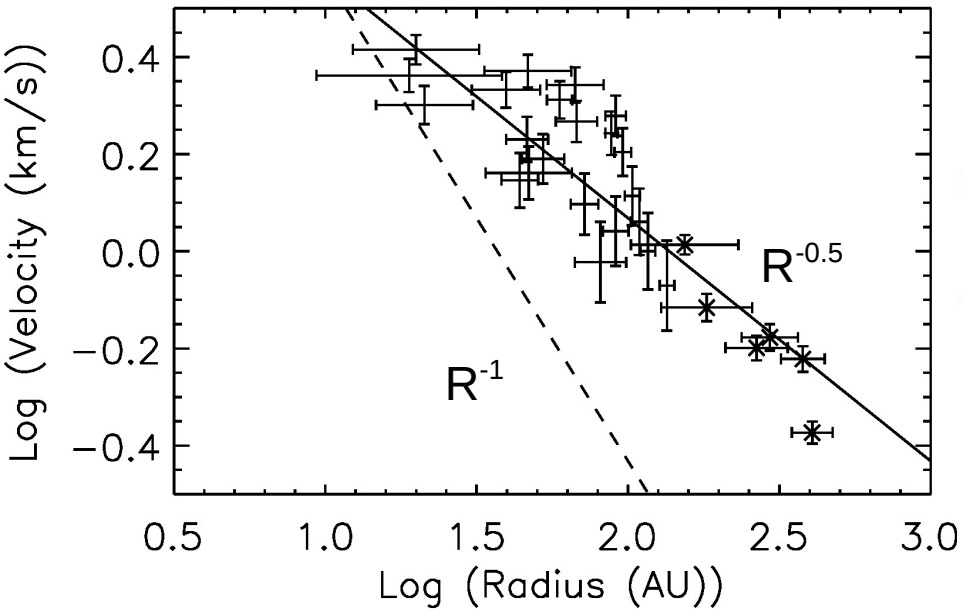
High Velocity (2.1 – 2.7 km/s)

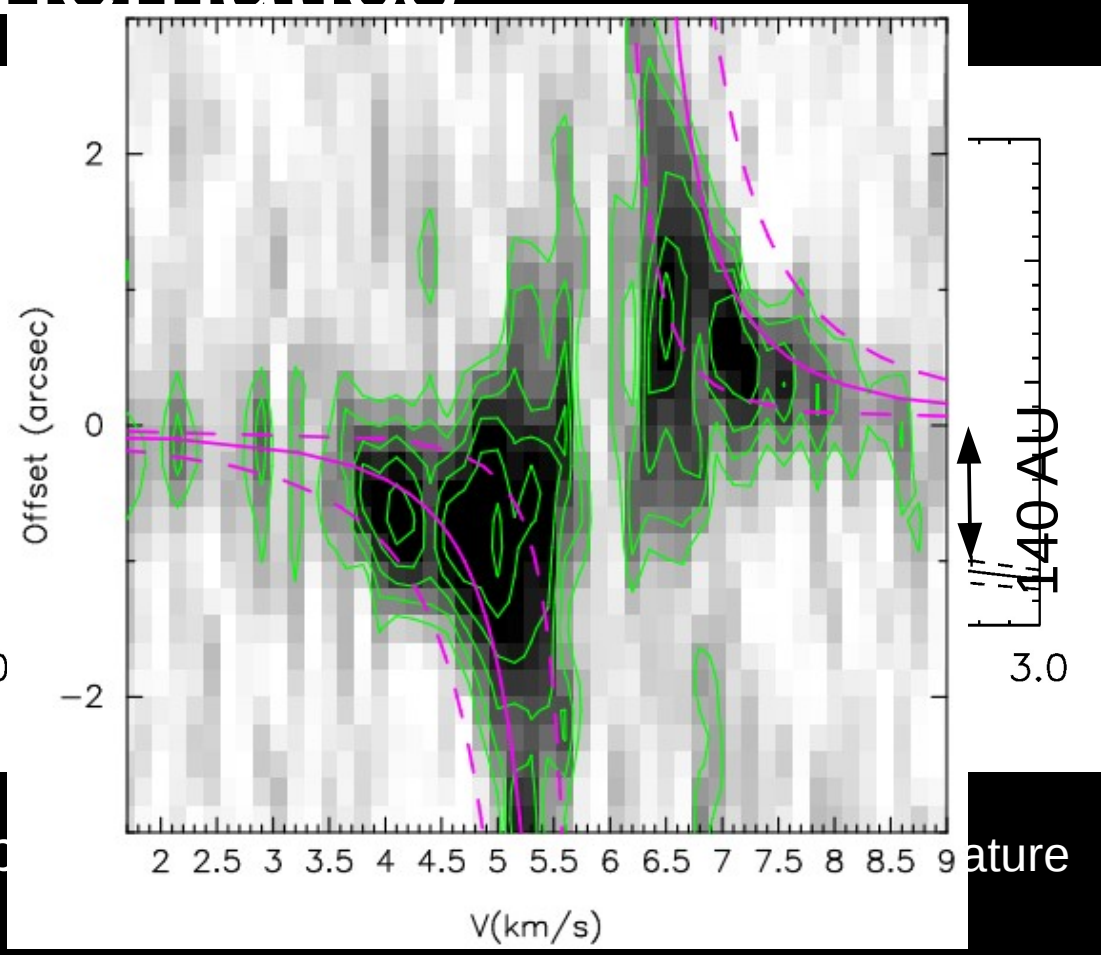


Tobin+12 Nature

- Obtained ^{13}CO (J=2-1) (1.3 mm) from CARMA in C-array
- ^{13}CO at velocities > 0.6 +/- V_{LSR} appears to trace rotation, not outflow
- Outflow at low velocities < 0.6 +/- V_{LSR} and resolved-out (Ohashi+97)

Disk Kinematics

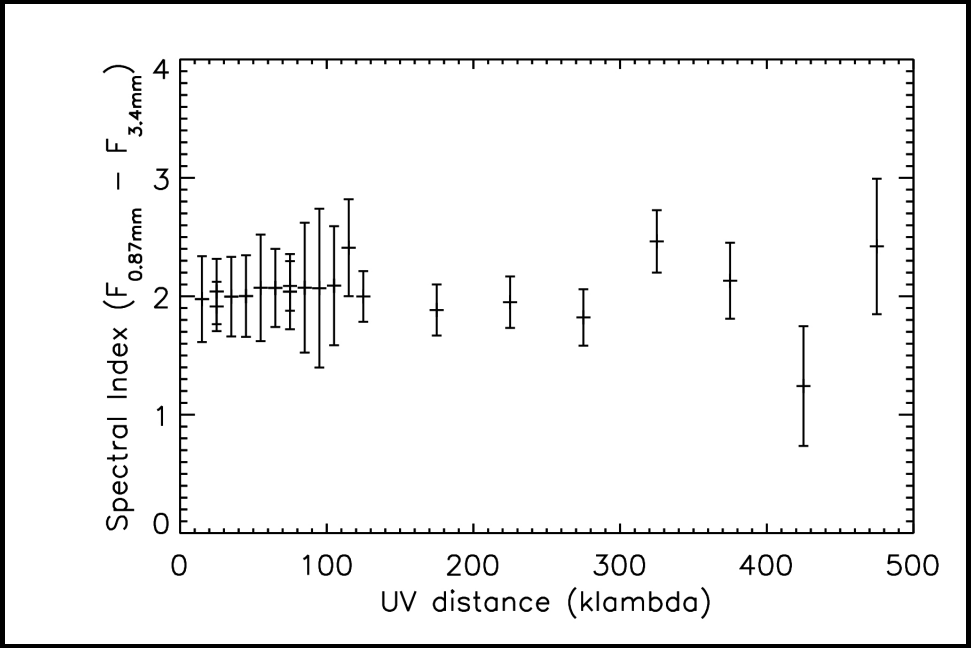




- Rotation curve consistent with Kep ature
- ^{13}CO position-velocity fit gives M_{ps} = 0.19 +/- 0.04 M_{sun}
- Youngest directly measured protostellar mass, ~20% of envelope mass
- In ALMA era, maybe can classify protostars with M_*/M_{env}
  - True spirit of Class 0 definition M_*/M_{env} < 1 (Andre+93)
  - How fast do protostars ‘grow-up’?

Dust Opacity Spectral index

- In R-J limit: $F_\lambda \sim \lambda^{-(2+\beta)}$
- Raw data consistent w/ $\beta \sim 0$
- Modeling gives $\beta \sim 0.25$

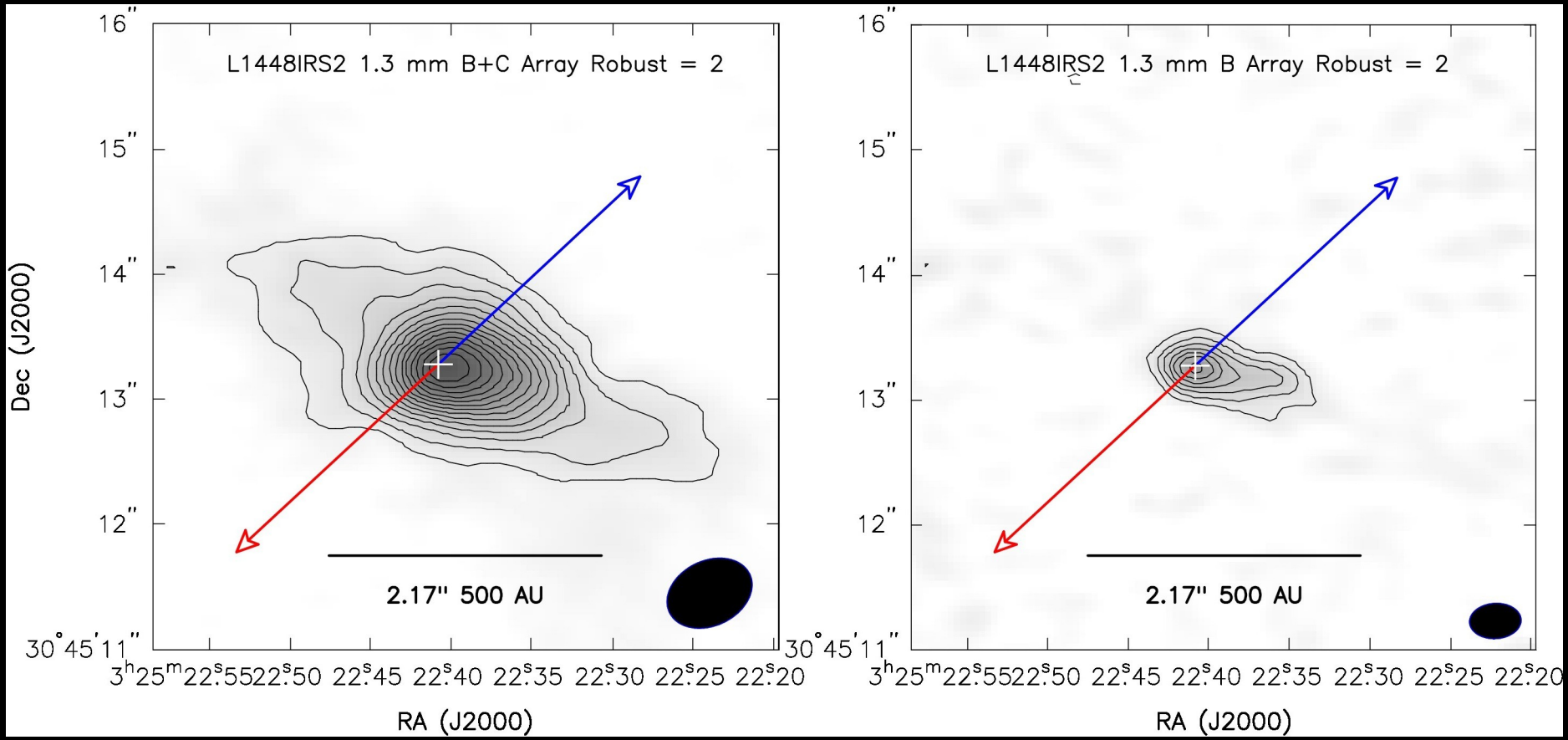


- Implies significant grain growth
- Scaife+12 suggests presence of cm-sized grains
- Models from Birnstiel+10 suggest such growth is possible

Beyond L1527

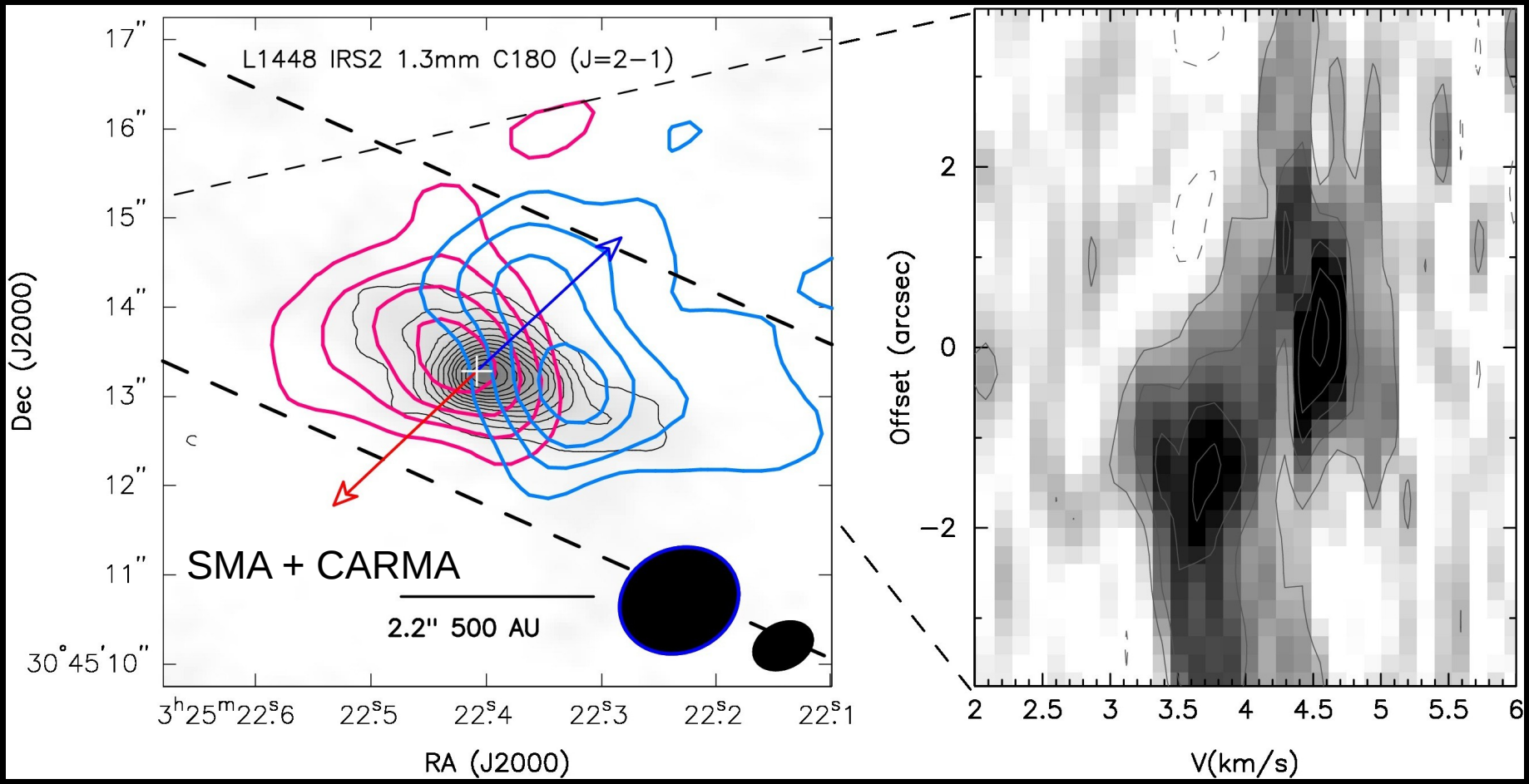
- L1527 an exciting, proof-of-concept discovery, but would like to achieve a more general characterization
- CARMA 1.3 mm survey of Perseus Class 0s at 0.35” (80 AU)
- JVLA pilot study of 3 Class 0/I systems

Perseus Survey



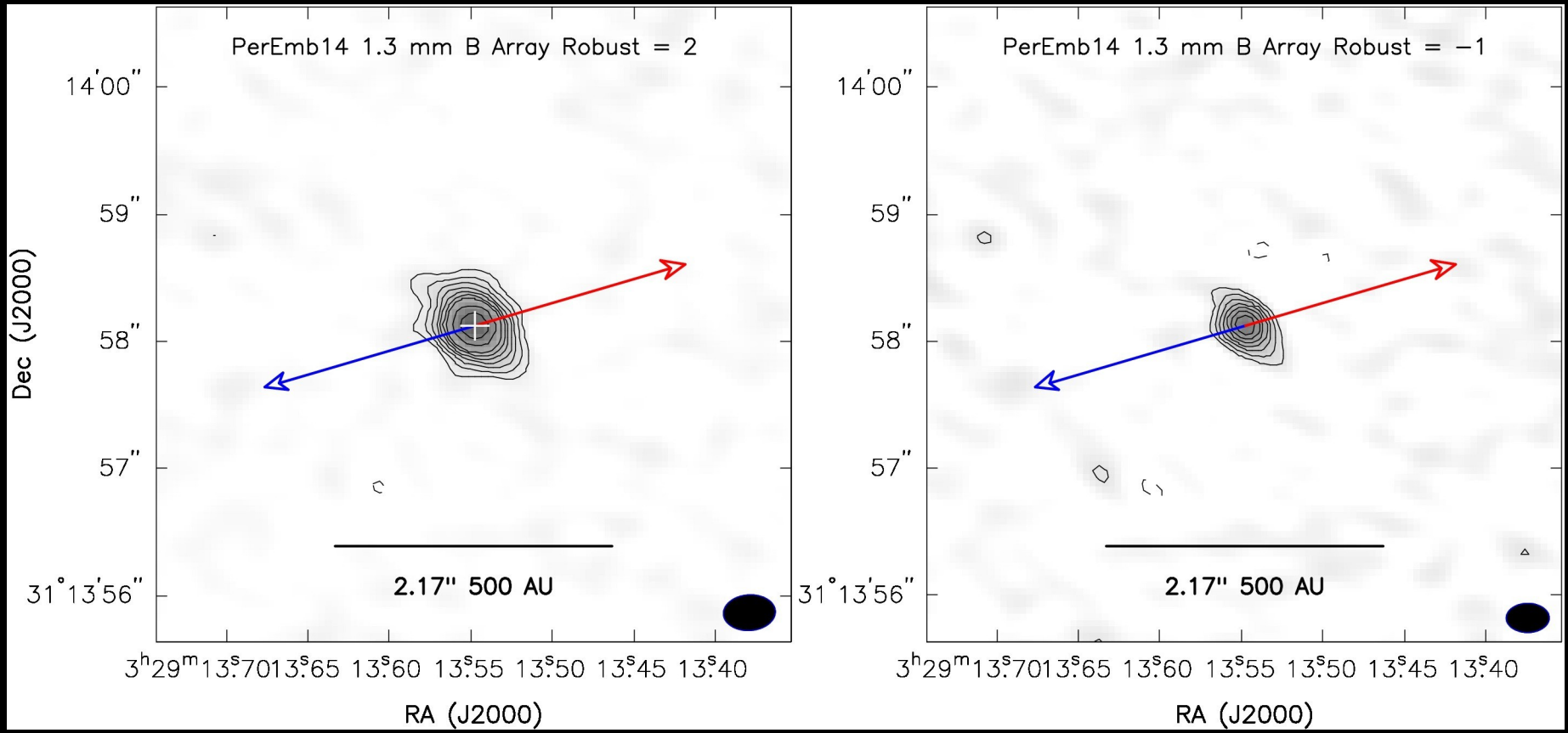
L1448 IRS2

L1448 IRS2



- Rotation evident in $C^{18}O$ emission, higher resolution/sensitivity need to determine if Keplerian

Perseus Survey



NGC1333 IRAS4C

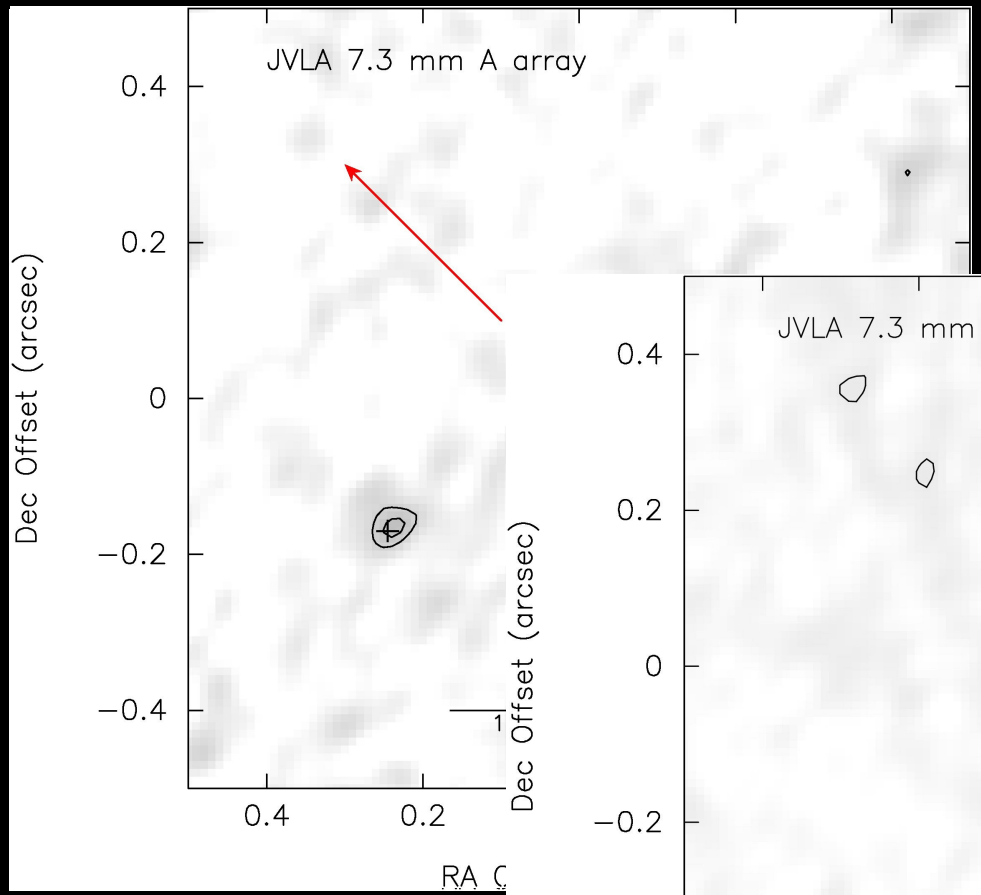
Initial Perseus Survey Results

- 2 strong disk candidates
- 4 potential candidates; elongated normal to outflow
- 4 with complex continuum structure/binary candidates
- 1 with compact unresolved structure

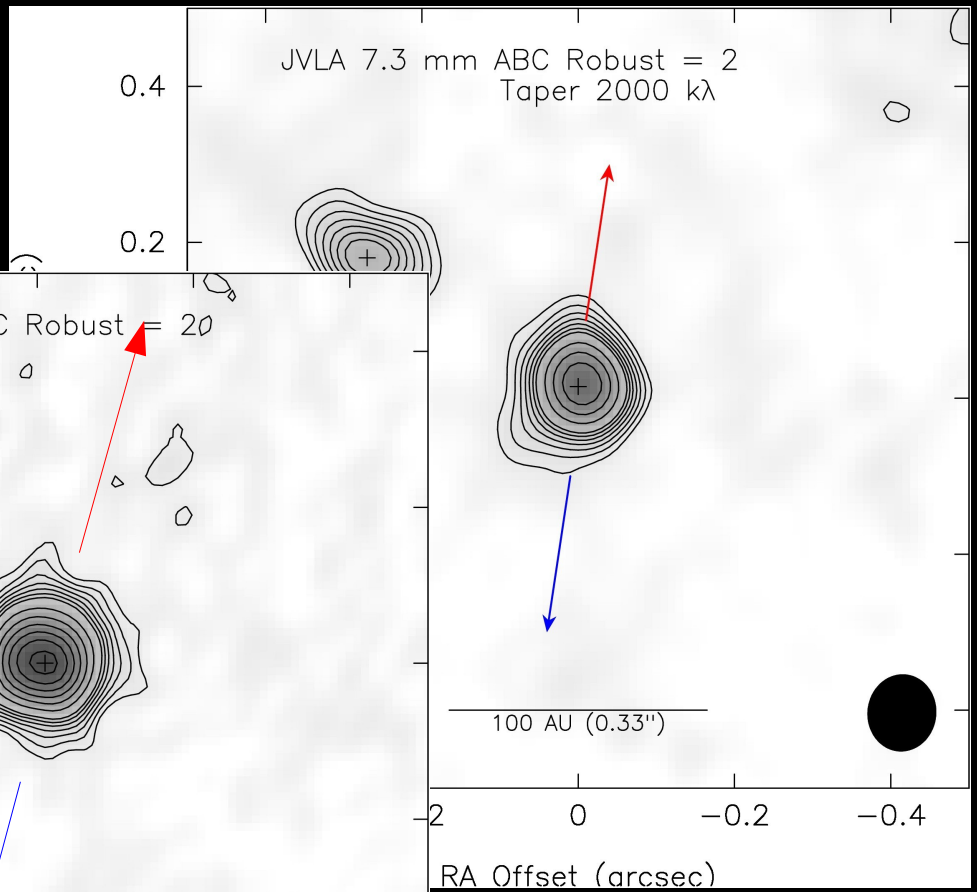
- Kinematic observations needed to confirm disk candidates

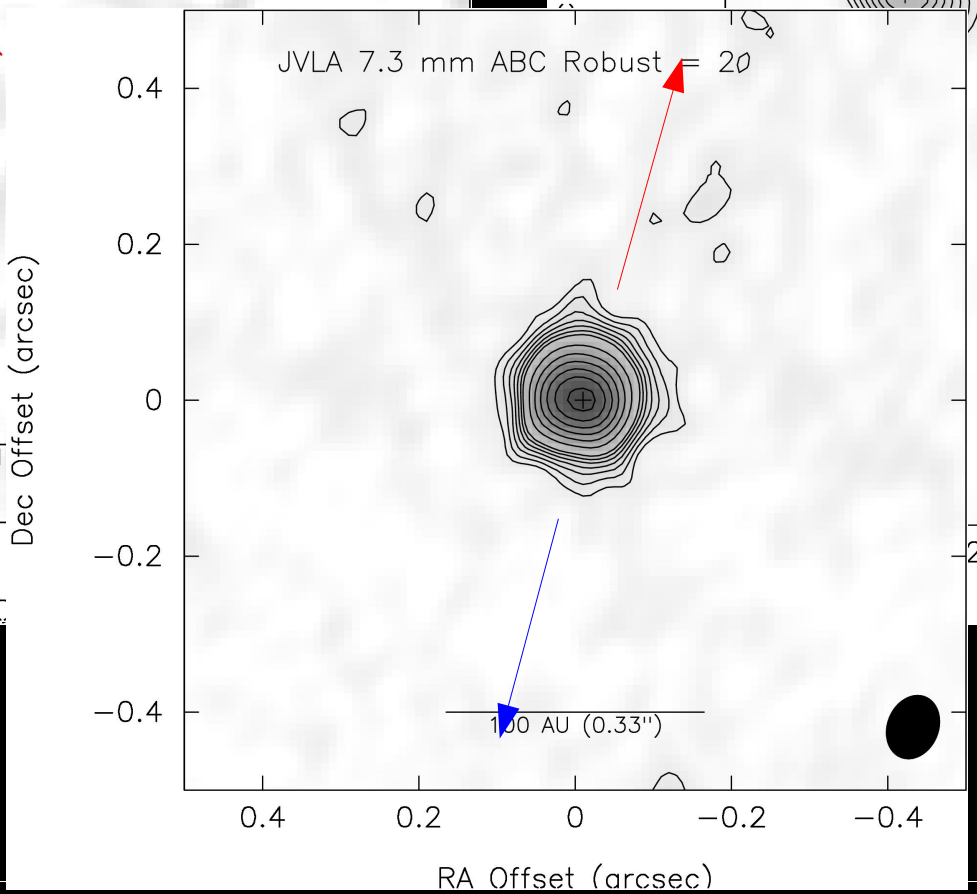
JVLA Survey

L1165 (Class 0/I)



CB230 (Class 0/I)

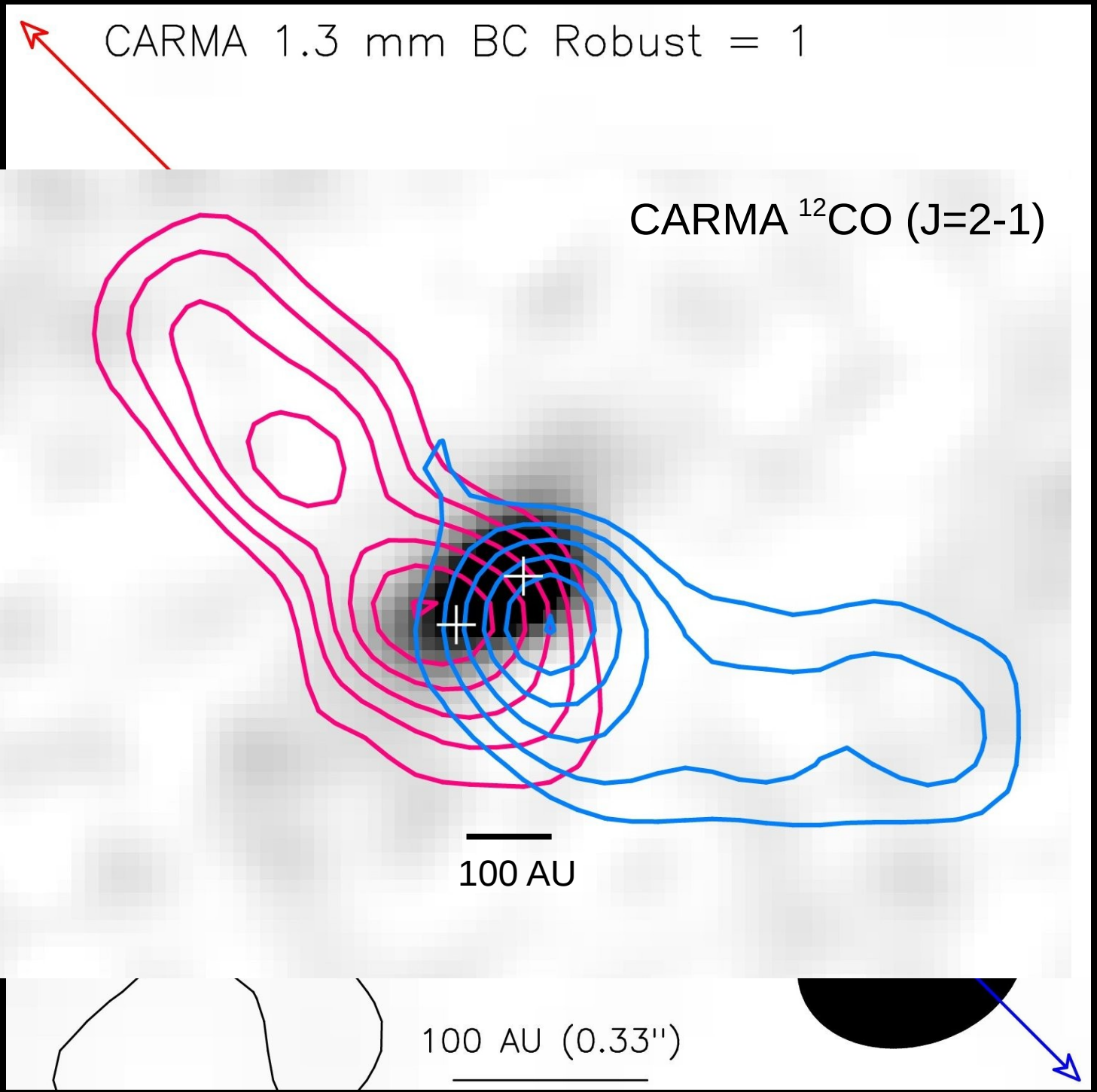




Tobin+ in prep.

7.3 mm

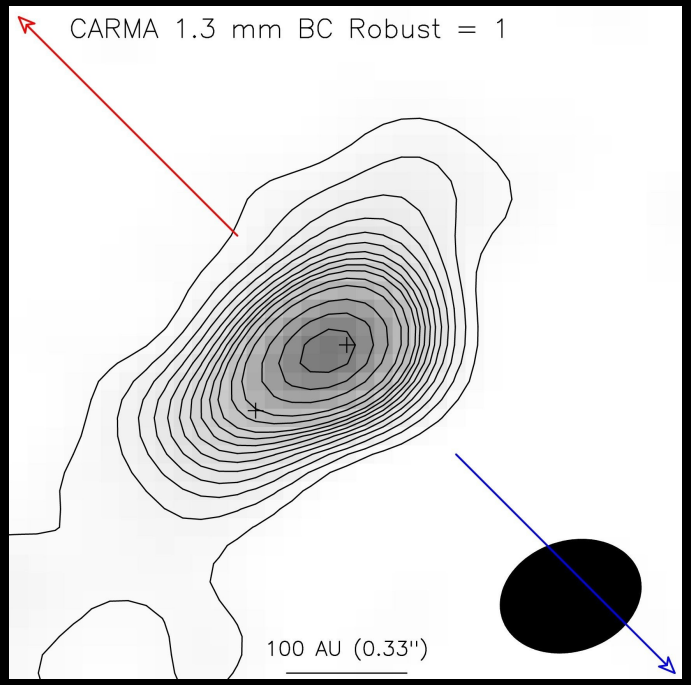
L1157 (Class 0)

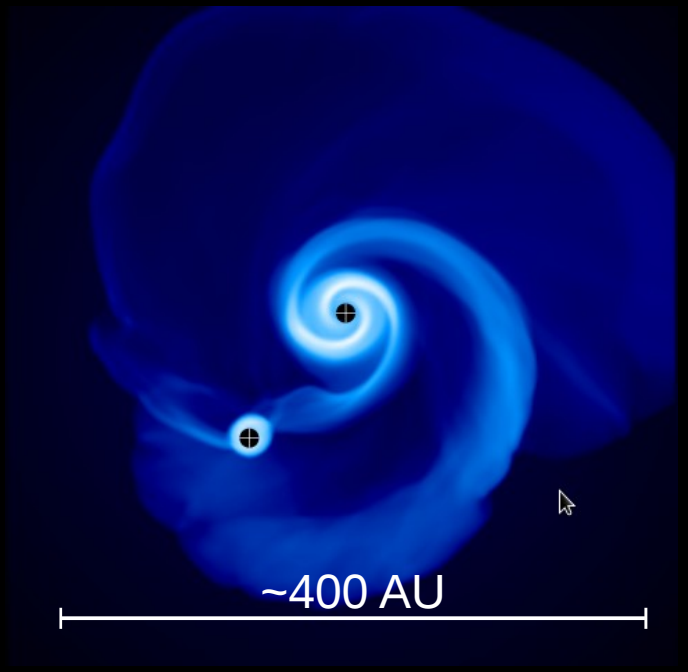


JVLA
7.3 mm

CARMA
1.3 mm

Disk Fragmentation?





Kratter+10

- L1165 has apparent circumbinary disk
- Companions located near expected disk plane
  - Possible parallel outflows from L1165 A and B
- Are large disks prevalent enough in Class 0 phase to produce close binaries in-place?

Disks in Class 0 Phase

- ~18 Class 0 protostars observed with resolution to detect disks (<= 80 AU) (e.g. Maury+10, Lee+09, Chiang+12, Murillo+13, ...)
  - L1527, Per-emb14, L1448 IRS2, L1165, HH211, VLA1623A; have evidence of large disks
  - L1527 confirmed rotational support
    - HH211, L1448 IRS2, VLA1623A, L1165 have rotation, Keplerian not yet confirmed
- Large rotationally supported disk fraction could be 6/18

  ~33%
- Points to a variety of disk properties, likely linked to initial conditions – ALMA can check!

Summary

- R ~125 AU disk discovered around Class 0 protostar L1527
- Kinematics w/^{13}CO confirm rotational support and yield first Class 0 protostellar mass!
  - 0.2 M_{sun} protostar; Envelope 5x more massive
- Disk candidates detected toward Perseus protostars
- 2/3 JVLA sources binary harbor 100 AU binaries and possible circum-binary disk in L1165
- Large (>100 AU) rotationally supported disk fraction could be ~33%
- JVLA Large Program -proposed- to observe all Perseus Protostars – Characterization of binaries and disks