Formation of a Keplerian Disk in the Protostellar System HH 111

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Picture: Derek Kubo

One of the Key questions

How a Keplerian disk can be formed around a central star inside an extended envelope?

Keplerian disk has been detected in Class II phase, some in Class I phase, and some yet to be confirmed in Class 0 phase. So, Class I source is the best choice for this study with the SMA (a few years back) in both continuum and lines.

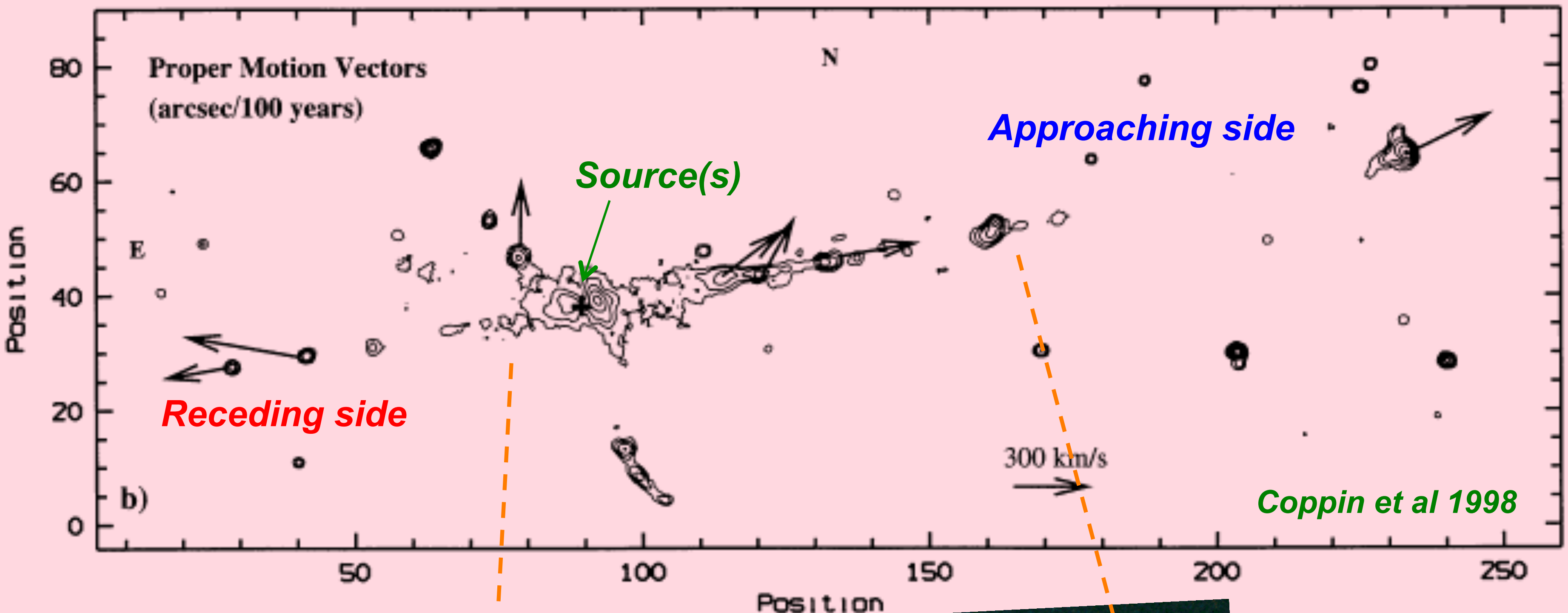
HH 111:

A Class I System at 400 pc in Orion with Extended envelope

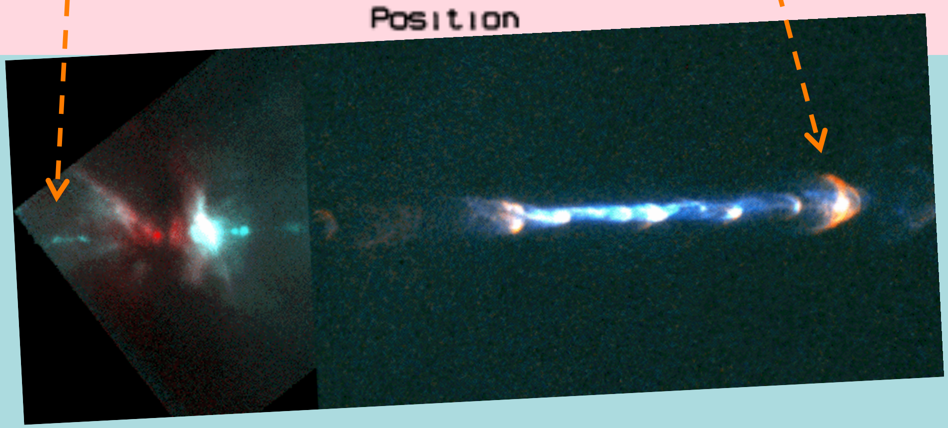
Powerful jet ➔ must have disk

T_{bol}~ 78 K. L_{bol}~ 20 L_{sun}

Powerful HH 111 Jet in shocked H_2 emission



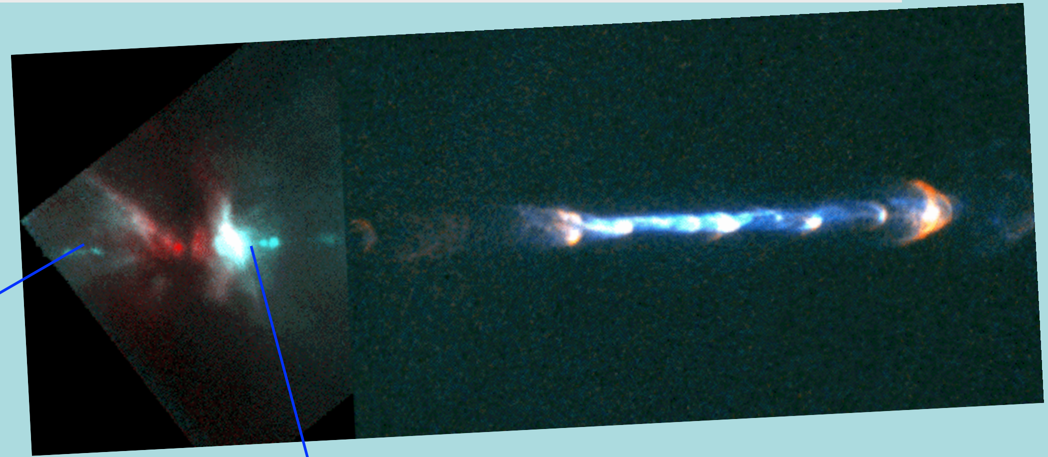
HST NICMOS image:
Red : H_2 2.12 um
Turquoise: [FeII] 1.64 um

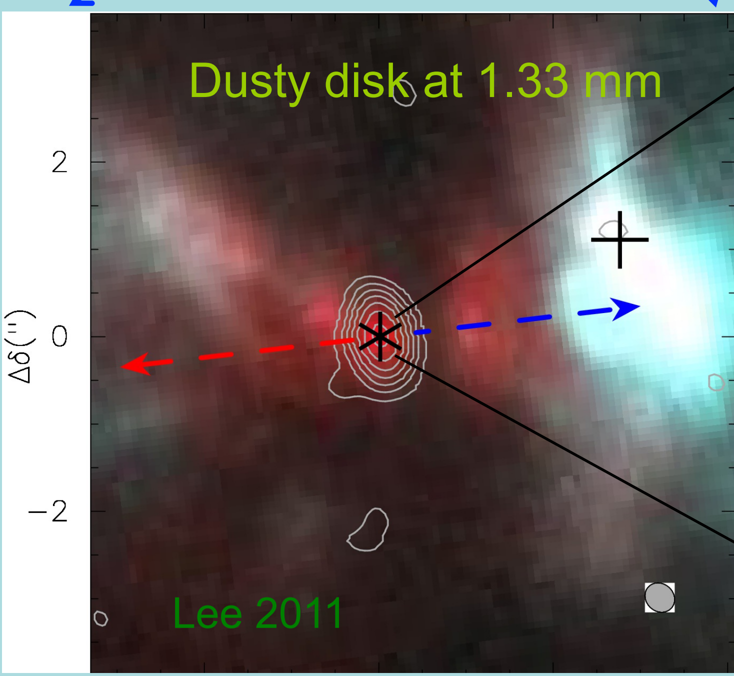


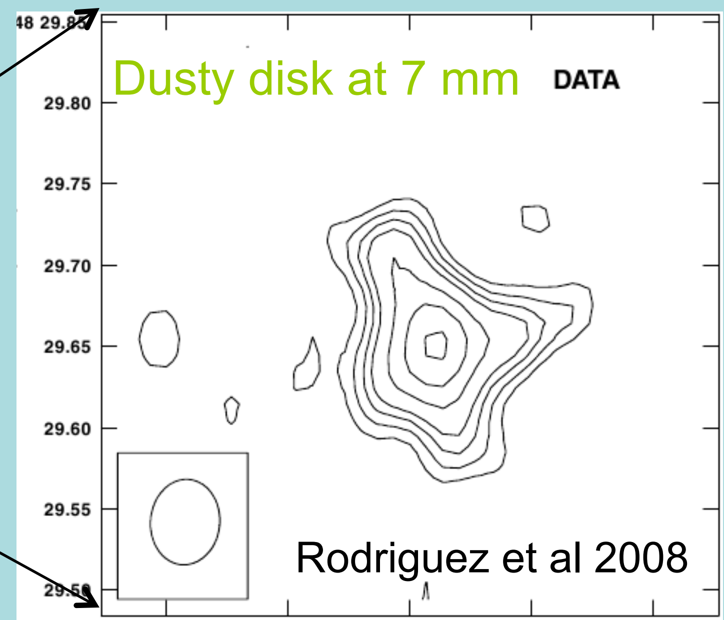
HST WFPC2 image:
Blue [SII]
Orange Ha

Reipurth et al 1999

A Resolved Dusty Disk around the central source at 1.3 mm



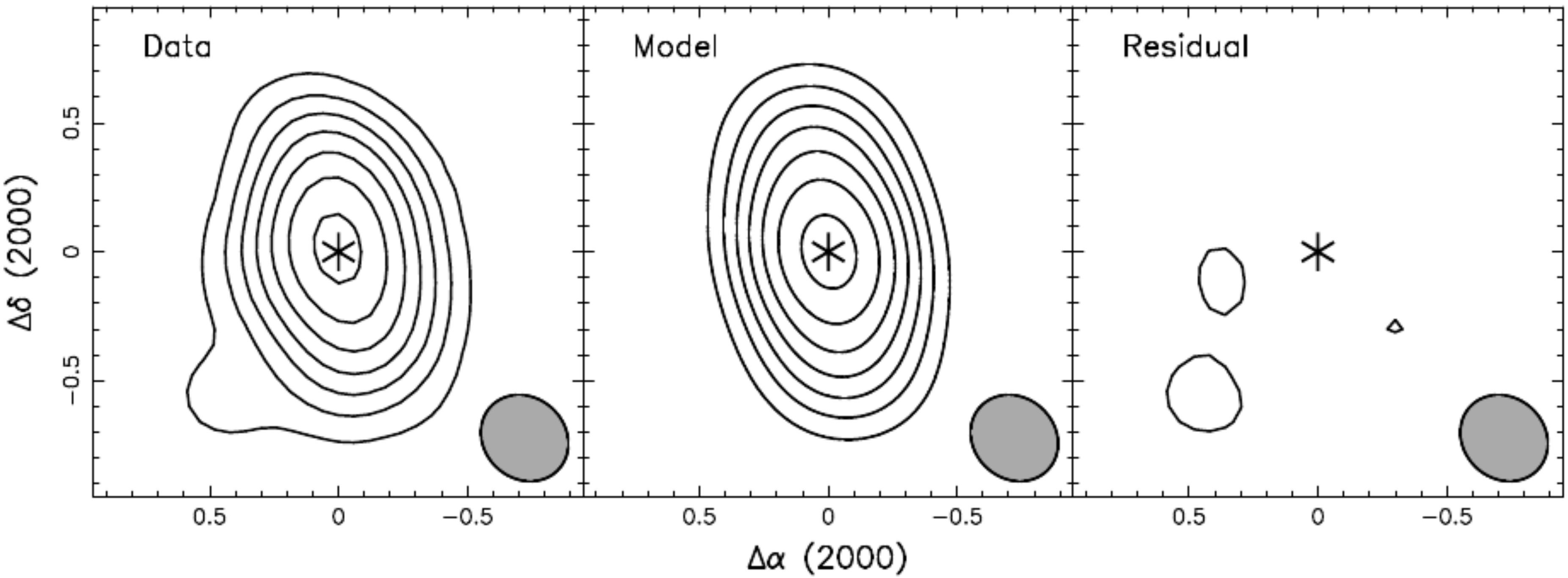




Deconvoled Size ~ 0.6" ~ 240 AU, M_{disk}=0.14 Ms

Size ~ 0.15" = 60 AU, M_{disk} < 0.1 Ms

Properties from 1.3mm cont



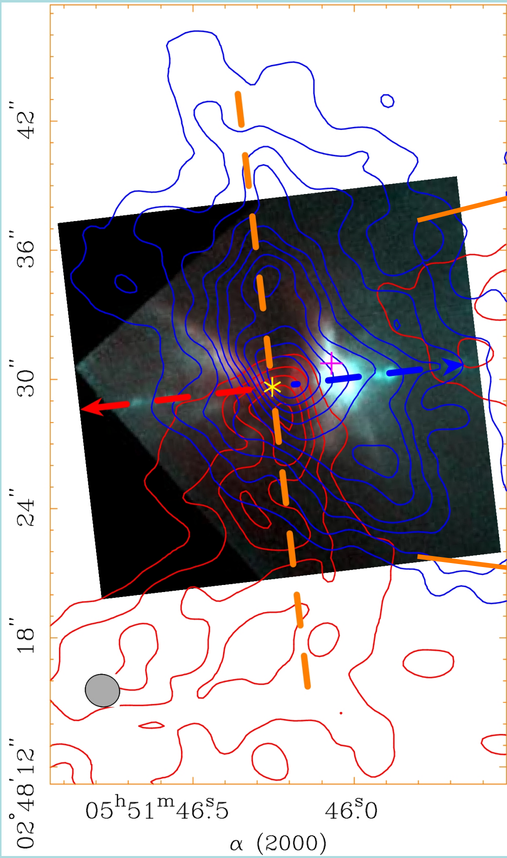
(Lee 2011)

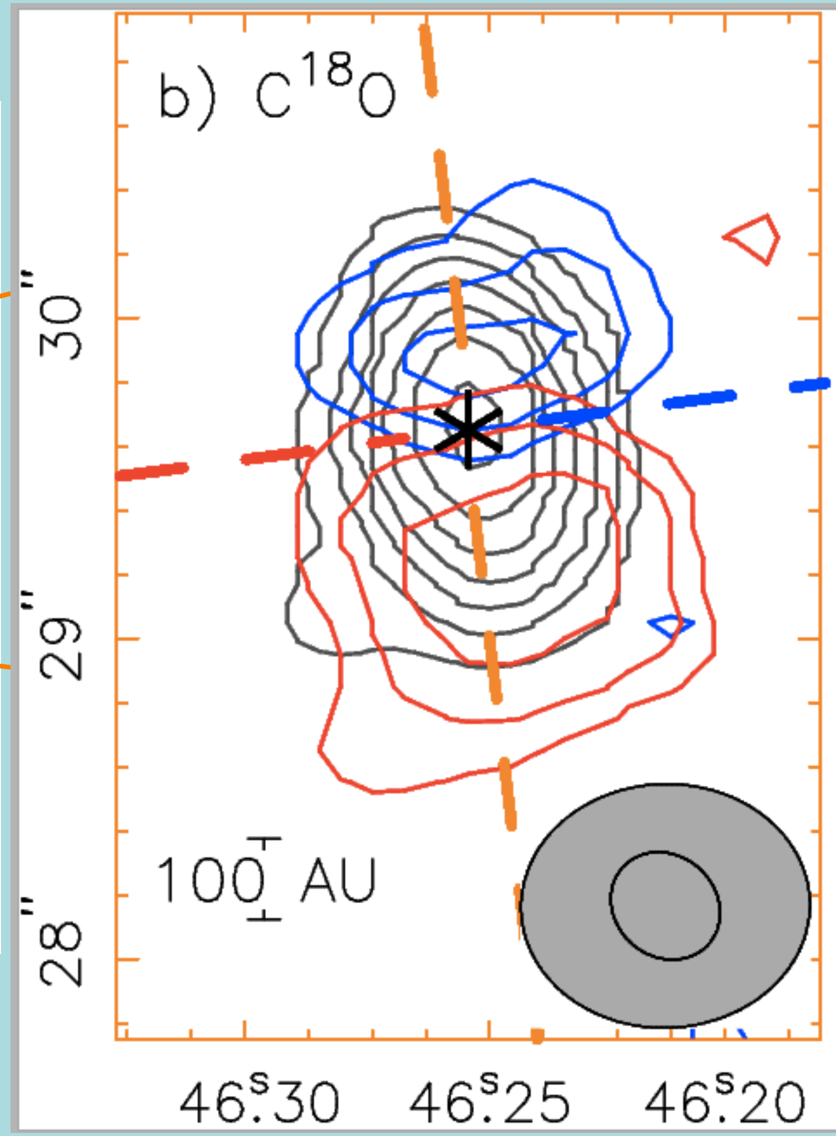
$$n = n_0(\frac{R}{R_0})^{-p}$$

$$T = T_0(\frac{R}{R_0})^{-q}$$

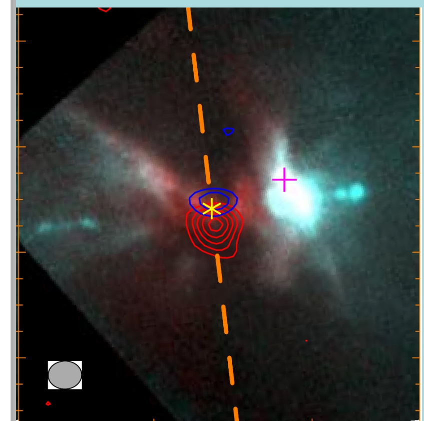
Ro = 120 AU, R_{out} = 240 AU (0.6”)
p = 1.0 (similar to that found in T Tauri disks) and no = 10^9 cm^{-3}
q = 0.5 (similar to that found in T-Tauri disks) and To=45 K

Surface density ~ 7.2 g cm^{-2} at 120 AU and 21.5 g cm^{-2} at 40 AU, similar to those found in the bright T-Tauri disks, e.g., GSS 39, in Ophiuchus ➔ young protoplanetary disk





O J=2-1



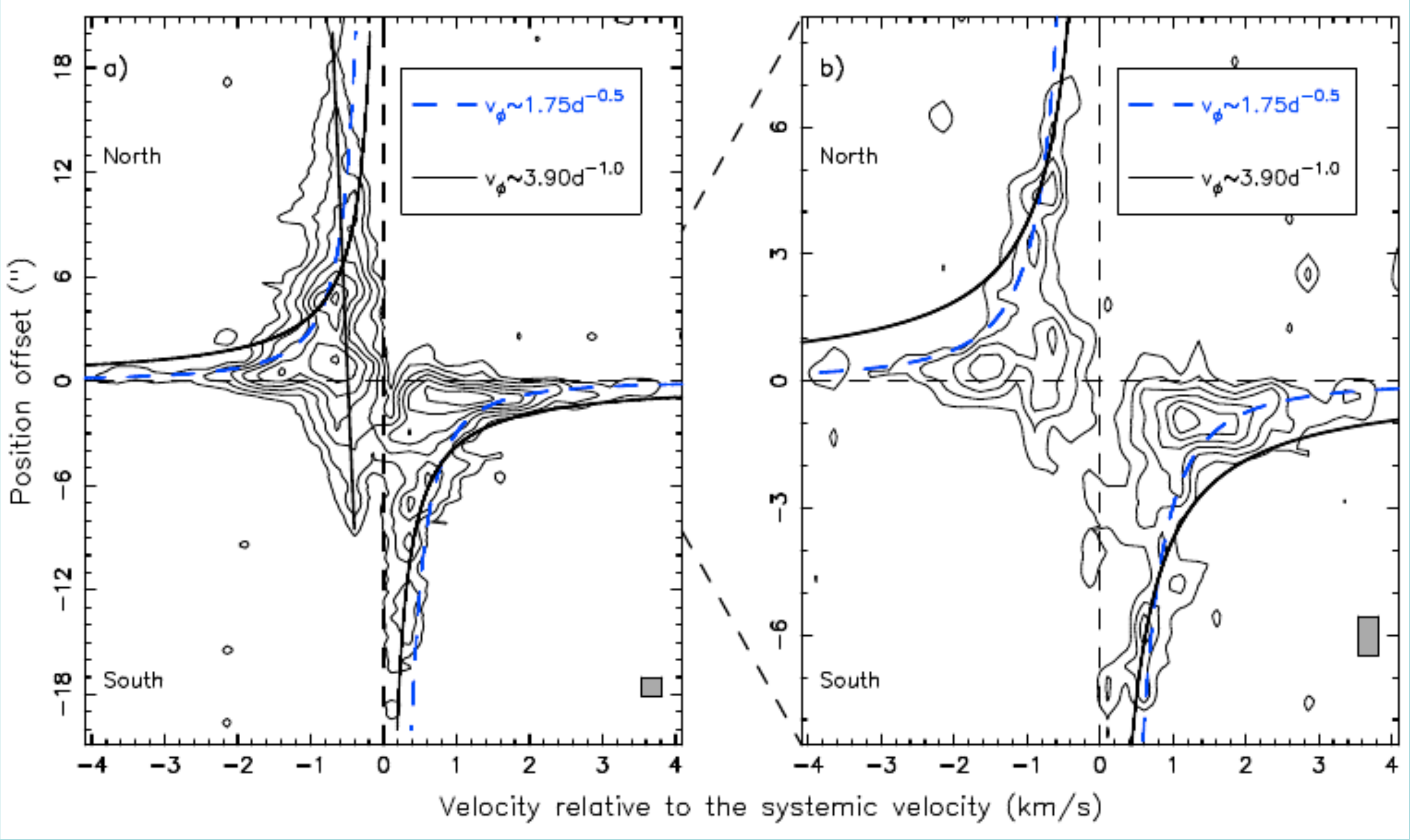
the jet

~ 0.035pc

the source

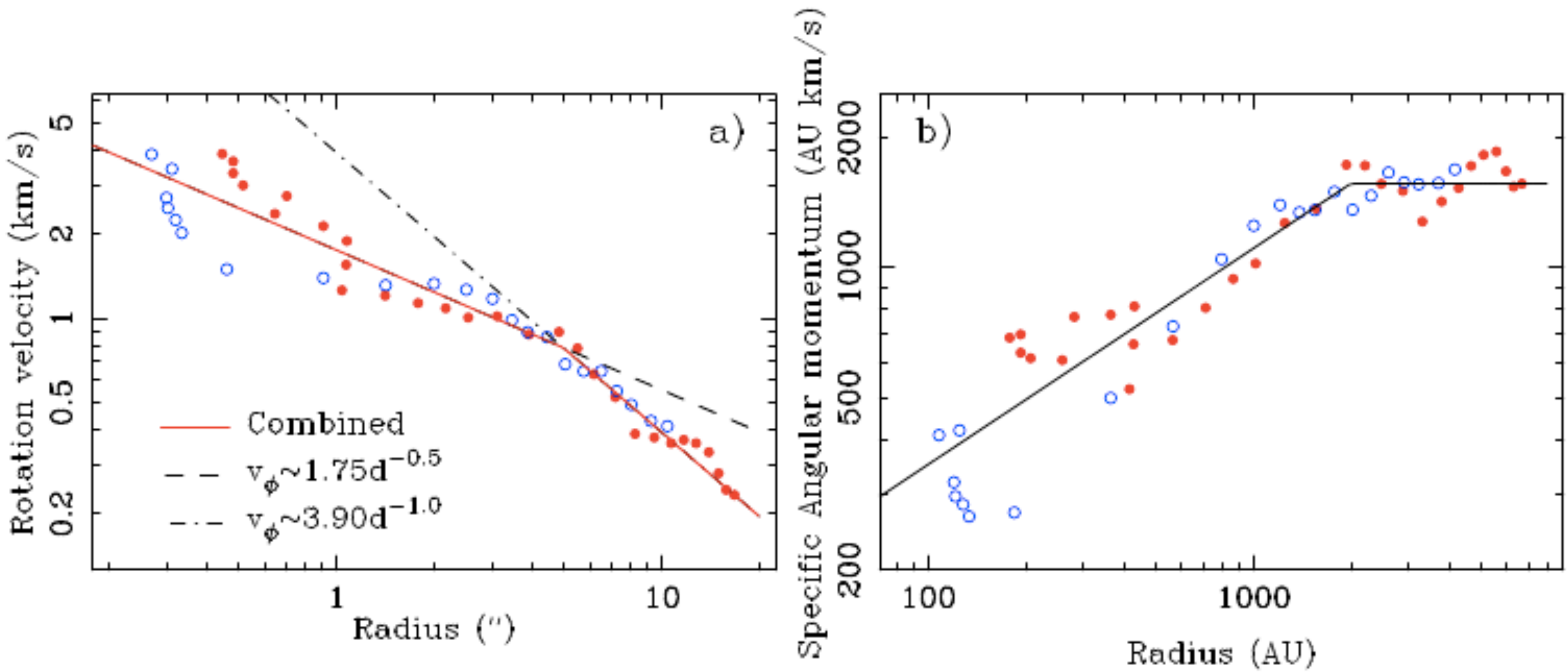
Envelope ➔ rotationally supported disk near the source! How?

Position-Velocity Diagram along the Equatorial Plane



(Lee 2010)

Rotation Velocity and Angular Momentum Corrected for inclination angle



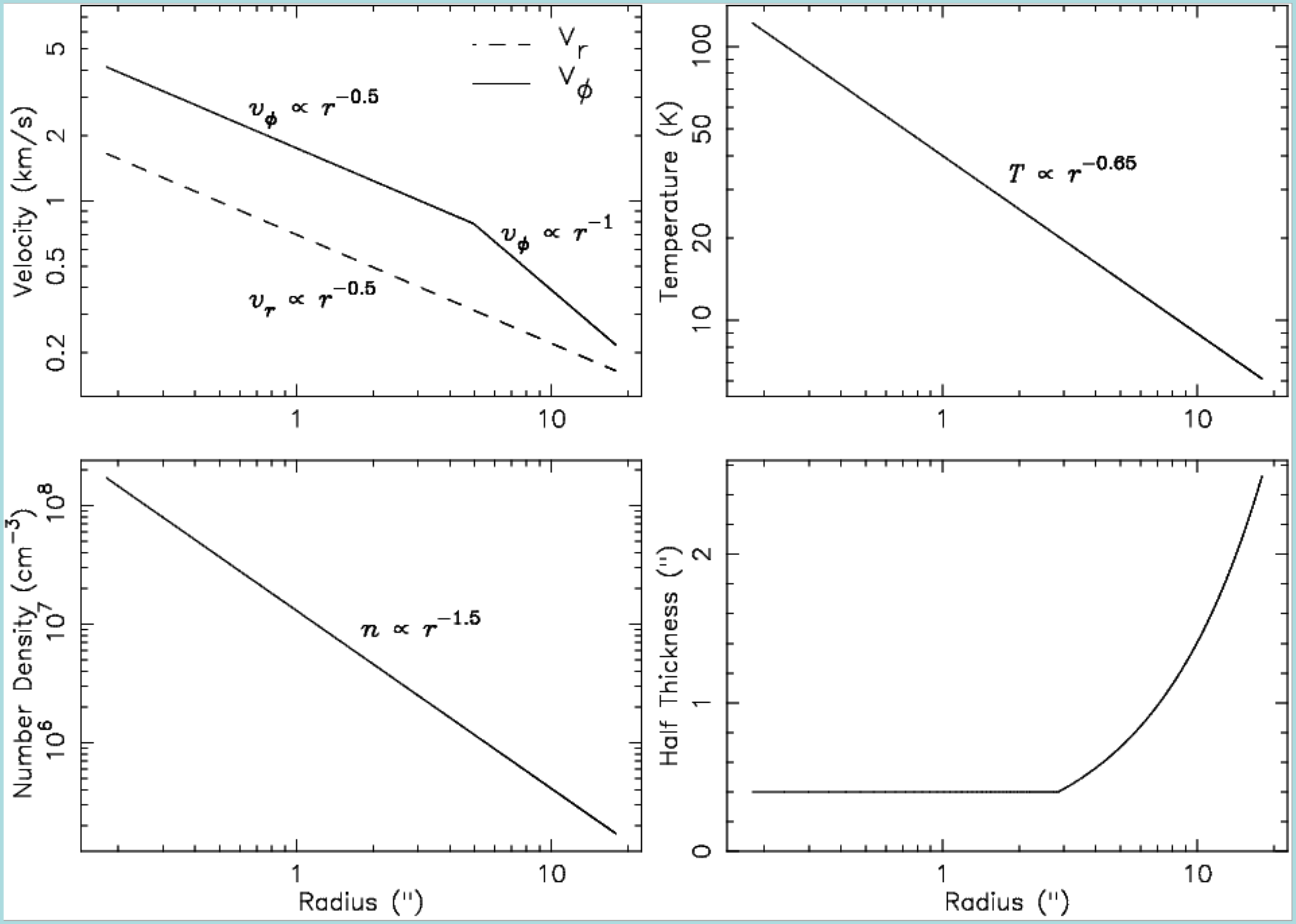
A Change of rotation profile at r~ 2000 AU (5") !!

➔ Decrease of angular momentum toward the center

(Lee 2010)

The data distribution is scattered but ALMA data to be obtained should improve it

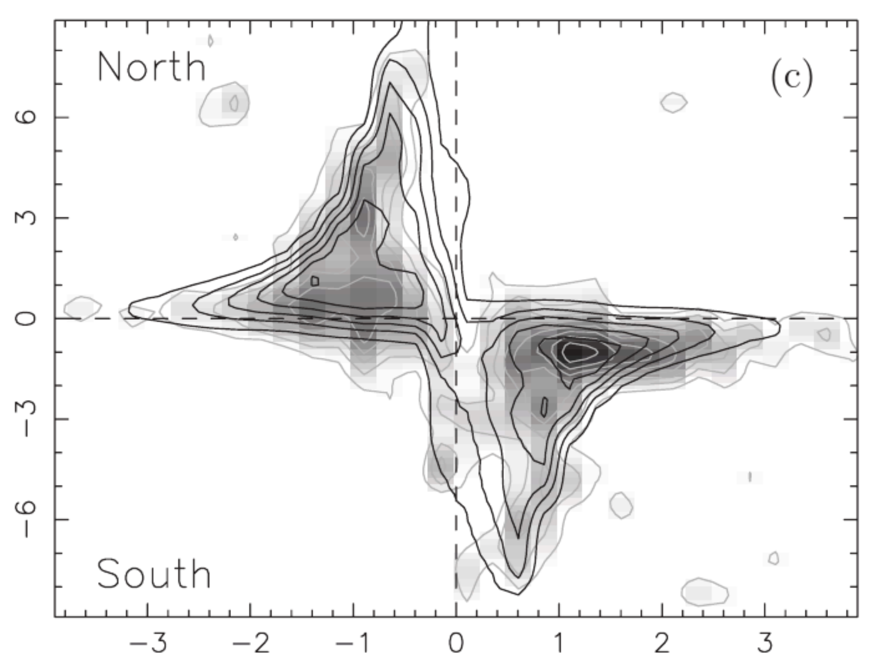
Modeling the envelope/disk(?) (Lee 2010)



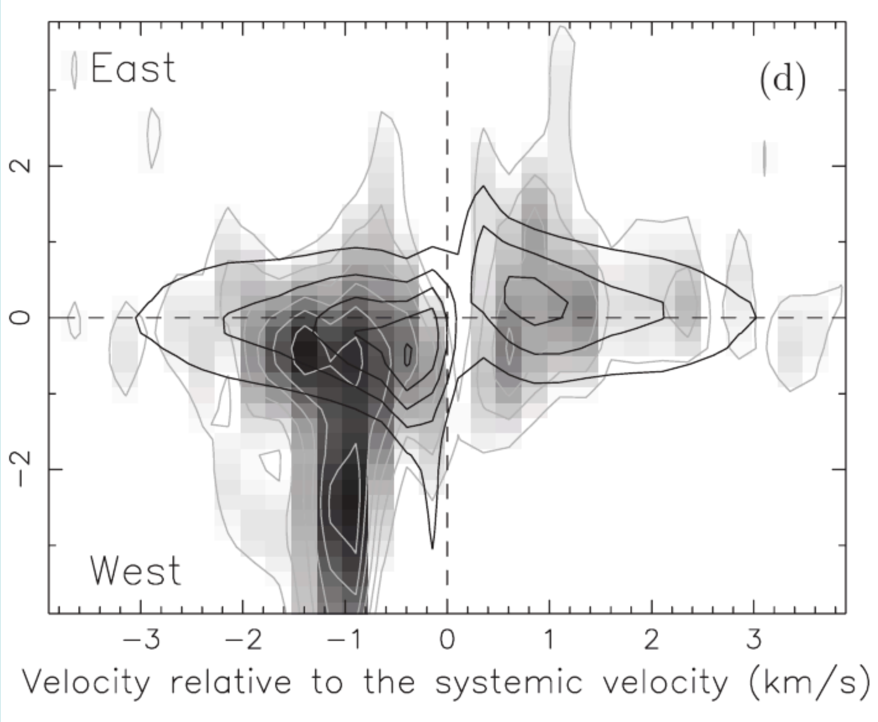
The infall velocity is roughly determined from the PV cut along the minor axis. v_r upto 0.7 v_Φ in the outer region and it decreases to v_r~ 0.4 v_Φ in the inner region.

Comparison betw. Model and obs (upto ~ 9")

PV cut along the major axis



PV cut along the minor axis



Lee 2010

Model Results and Implications

- Inner region: Keplerian rotation with small Infall motion
- From the Keplerian rotation ➔ The central star has a mass of 1.4 M_{sun} about 10 times the disk mass (derived from dust emission)➔ the disk is stable
- Outer region: rotation with conservation of angular momentum with some significant infall velocity

  ➔ material spiraling inward with an infall rate ~ 4.2x10^-6 Ms/yr (OK for Class I)
- Keplerian Radius ~ 5” ~ 2000 AU (large for low-mass protostars), crossing time ~ 30,000 yrs with c_s ~ 0.3 km/s (T~20 K)
- Why the Keplerian region is so big compared to the dusty disk? Is the Keplerian region only a transition region, i.e., a peusdo disk? Or Keplerian radius is overestimated due to not enough sensitivity and resolution?

Lee 2010