Transition from a Quiescent Core to an Infalling Envelope around the Class I Protostar L1489 IRS

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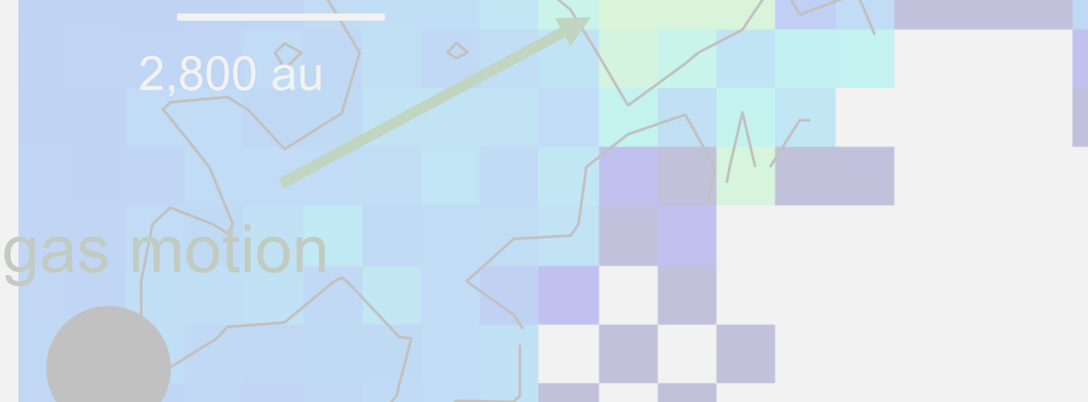
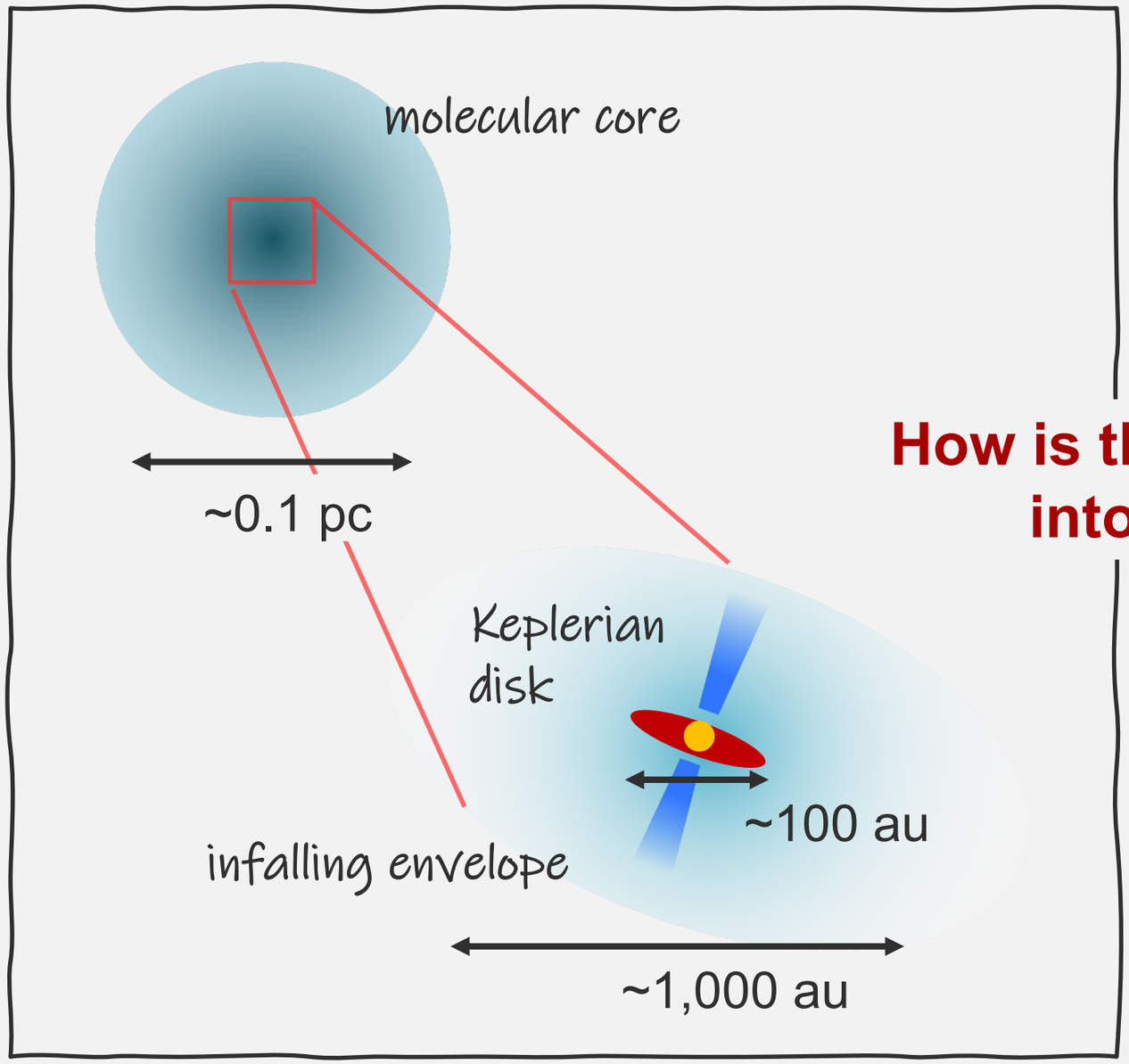
Large line width
indicating dynamical gas motion

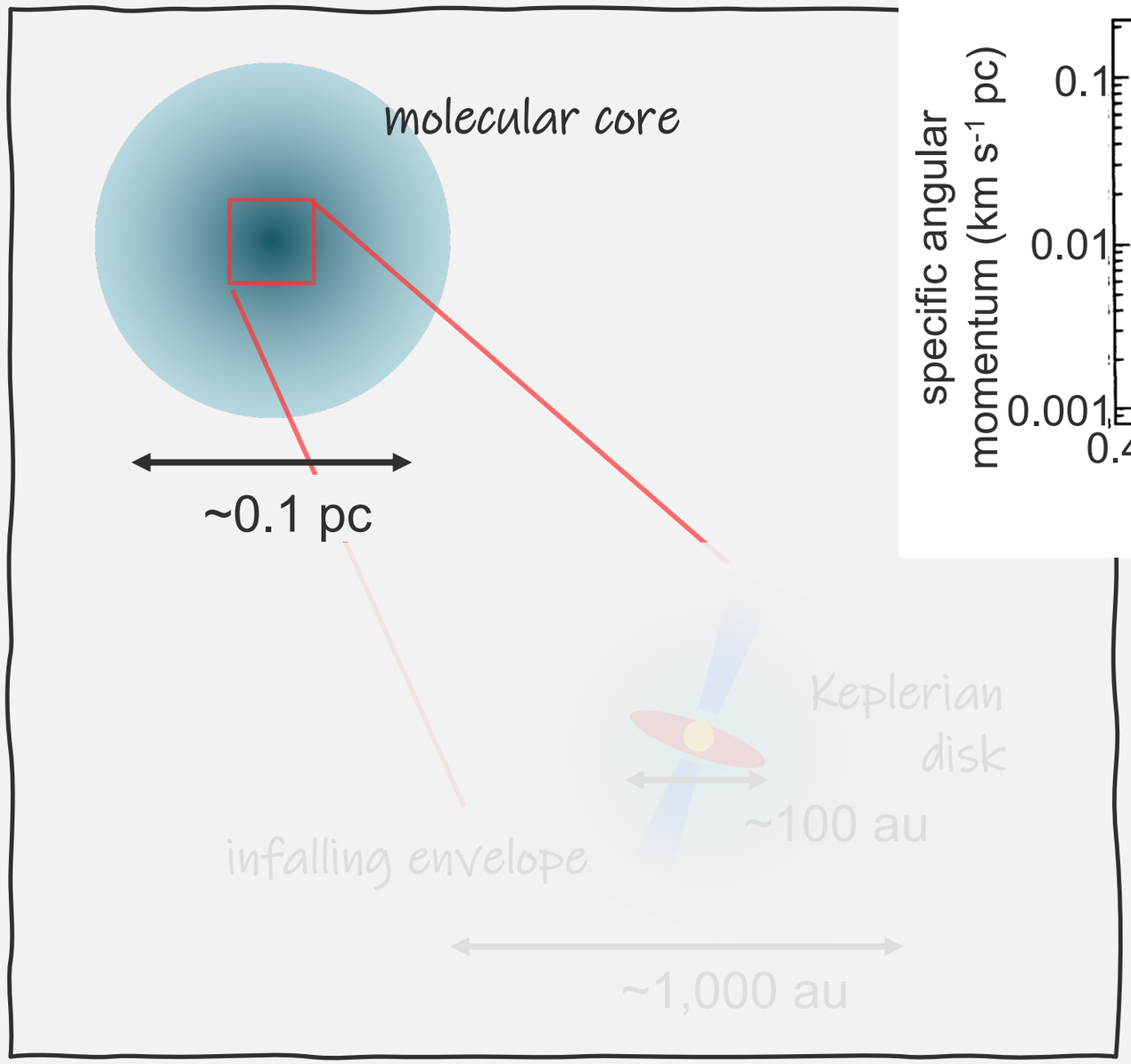


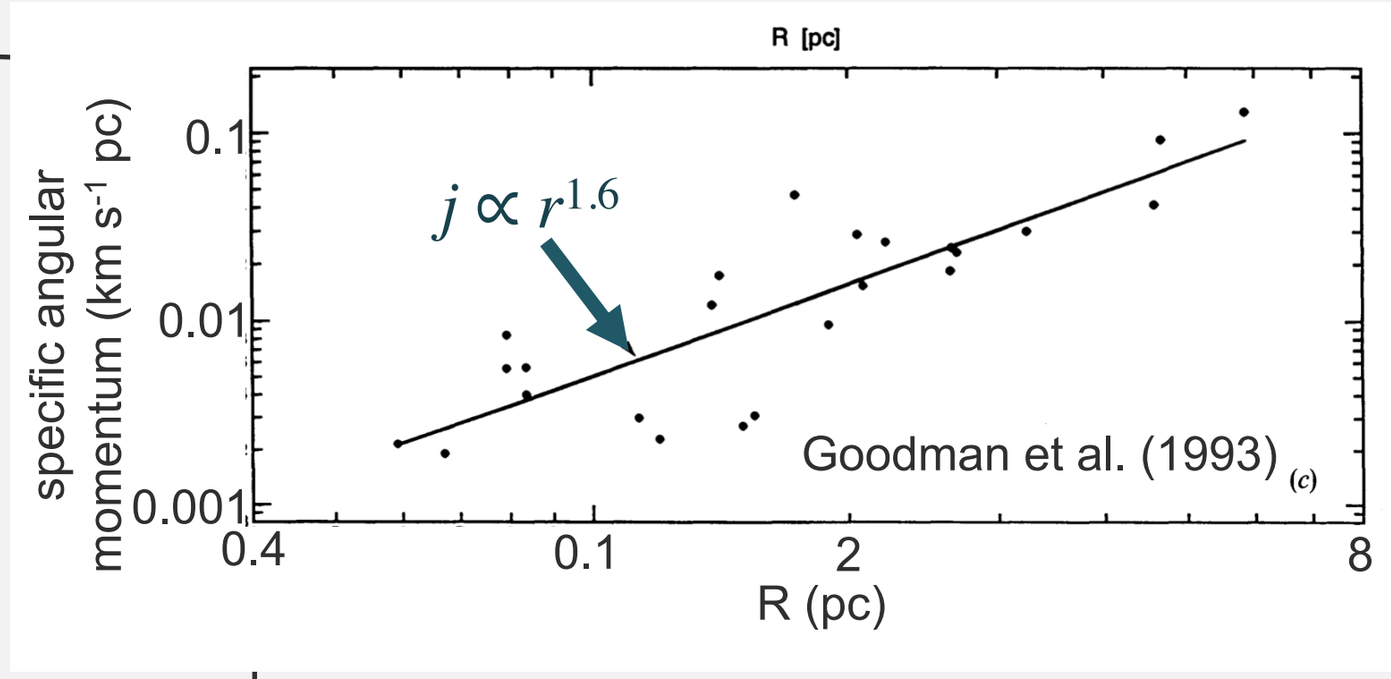
Star and Disk Formation



How is the angular momentum transferred into stars and disks from cores?

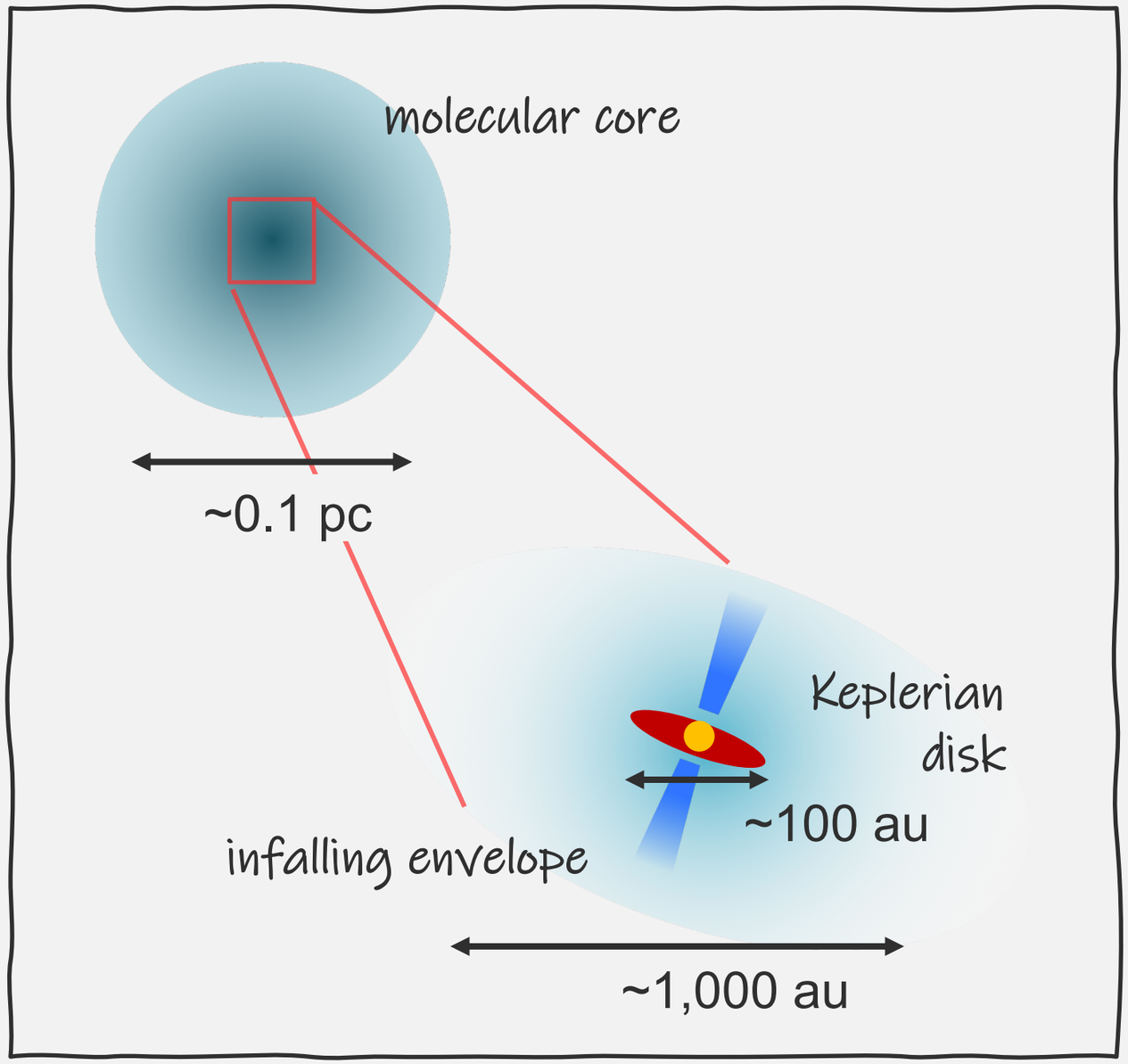
Star and Disk Formation

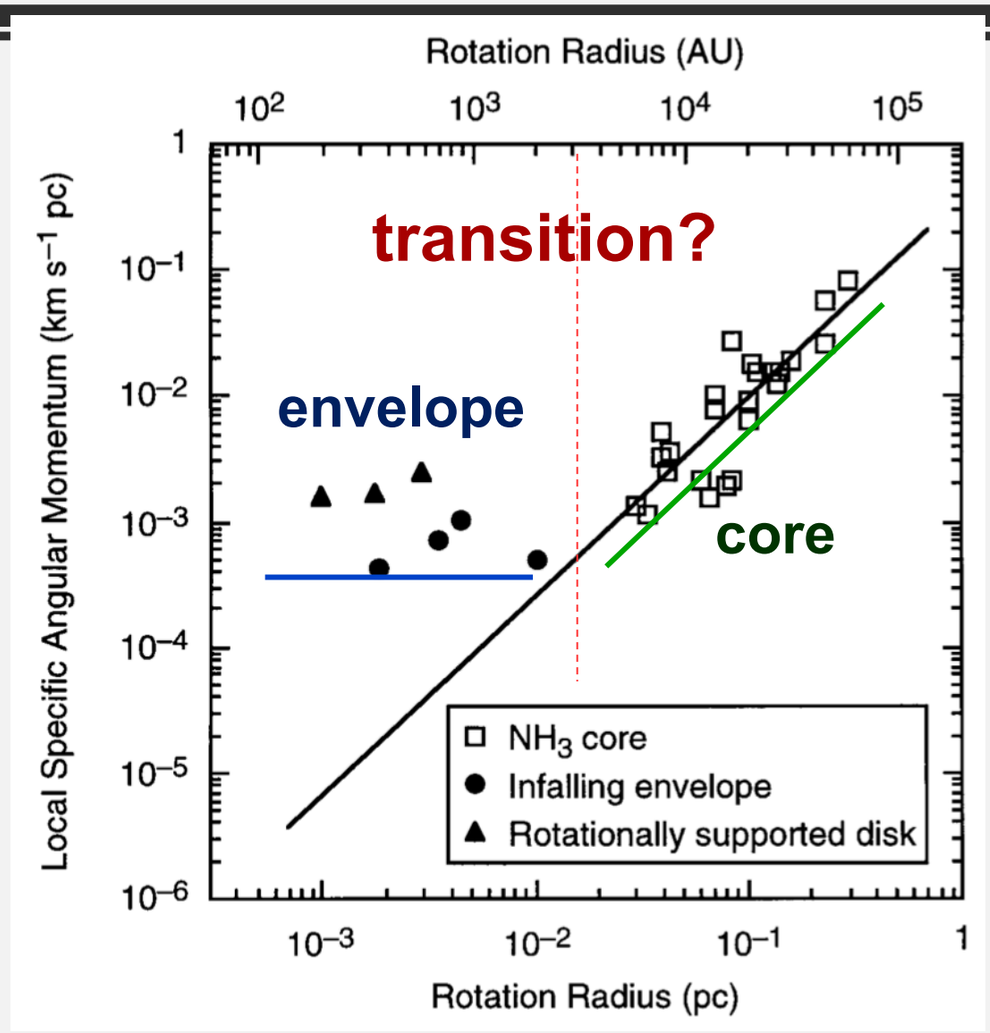




Cores rotate like a rigid-body

Star and Disk Formation

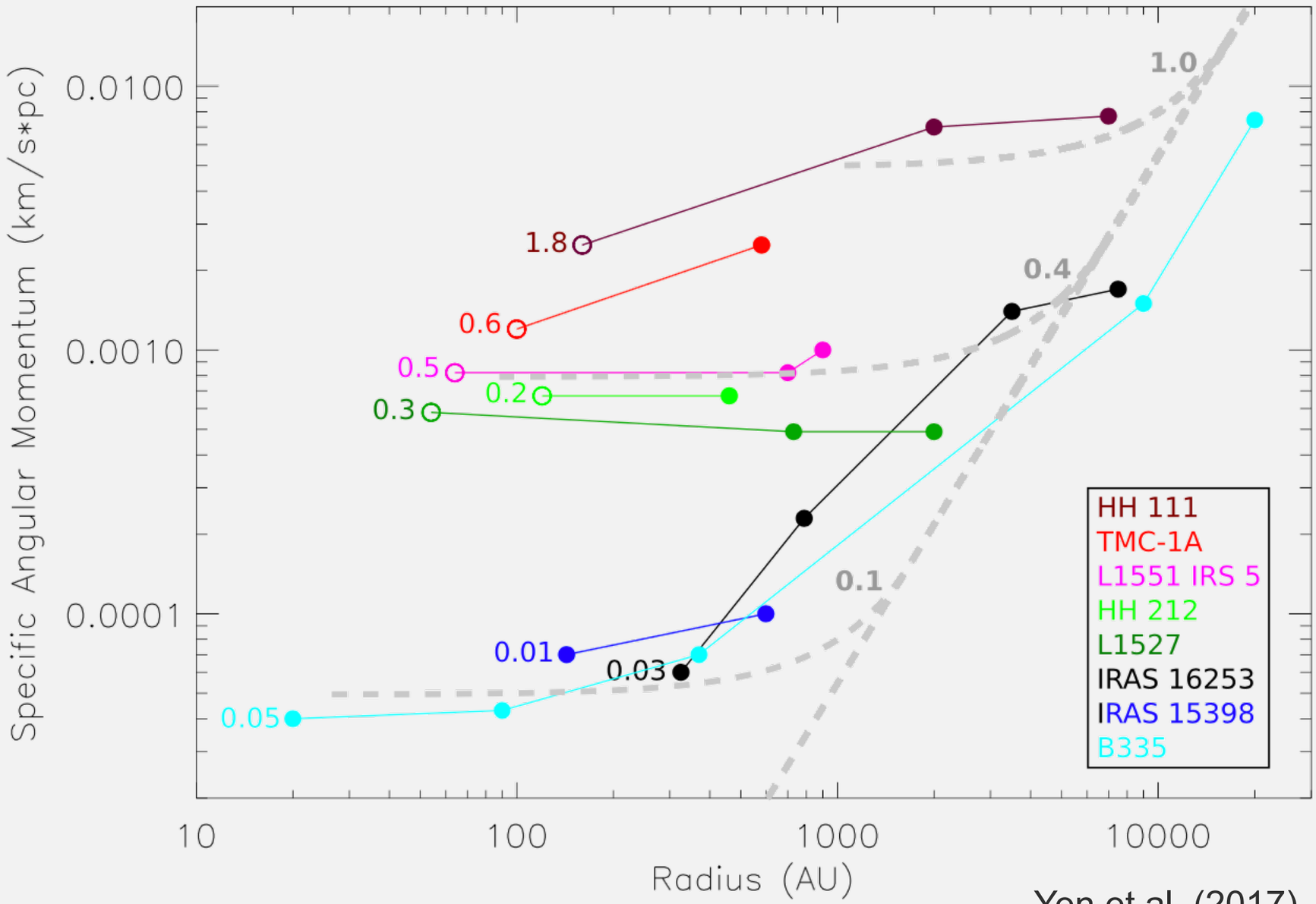




Ohashi et al. (1997)

Infalling envelopes rotate conserving angular momentum (j =constant)

Individual Protostars

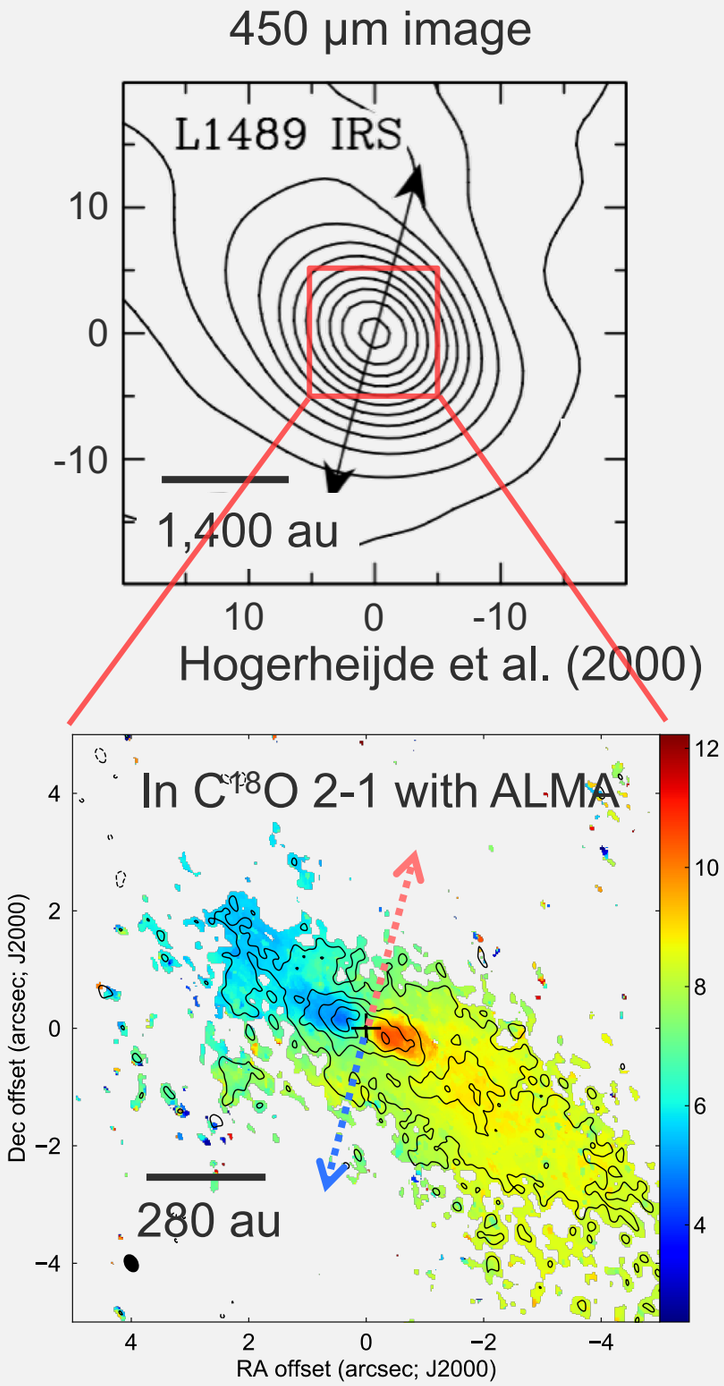


Yen et al. (2017)

Class I Protostar L1489 IRS

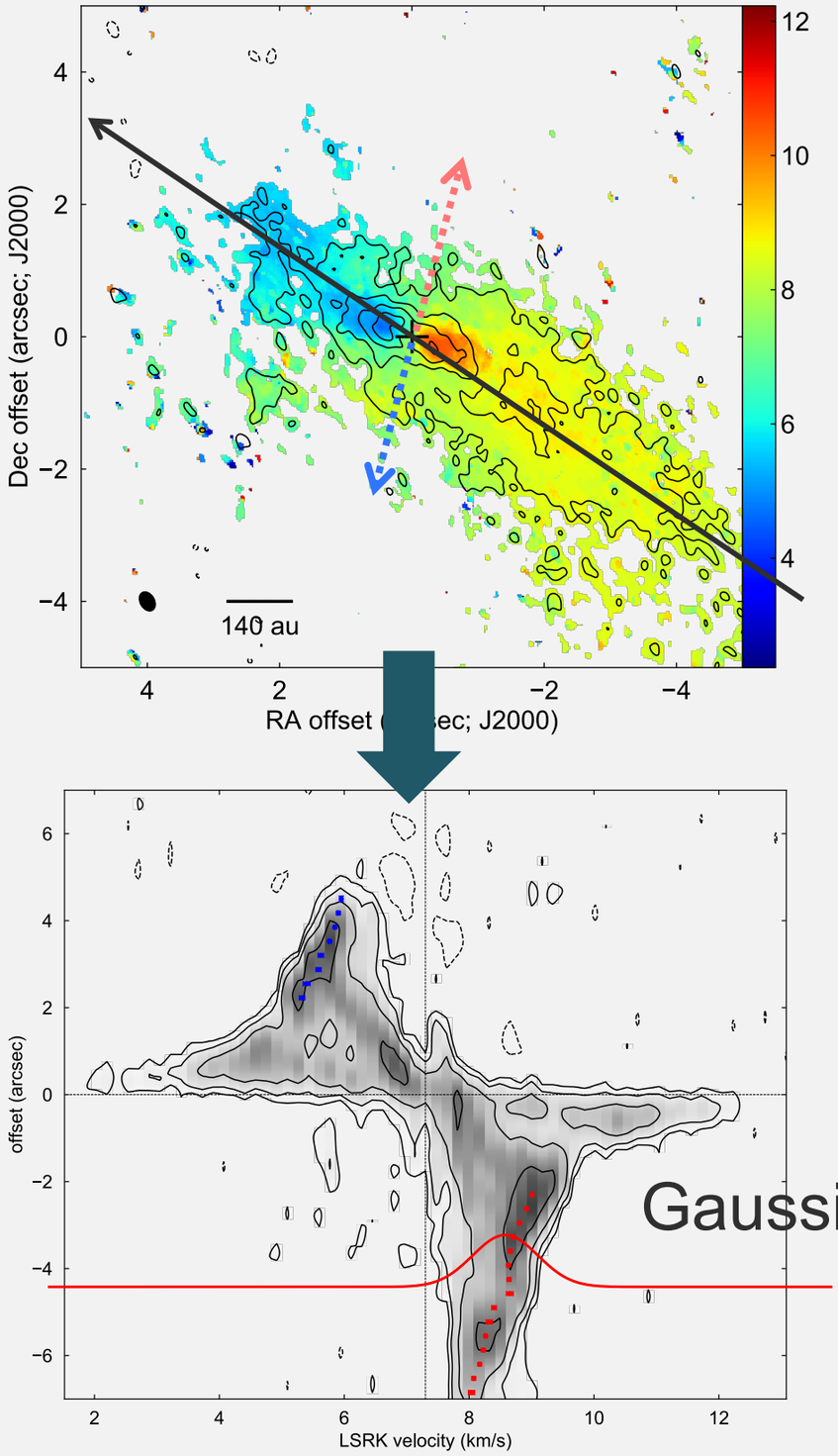
- Class I protostar in the Taurus Molecular Cloud (~140 pc)
- L_{bol}: 3.5 L_{sun}, T_{bol}: 226 K
- embedded in a relatively small gas condensation
- At the end of the Class I stage

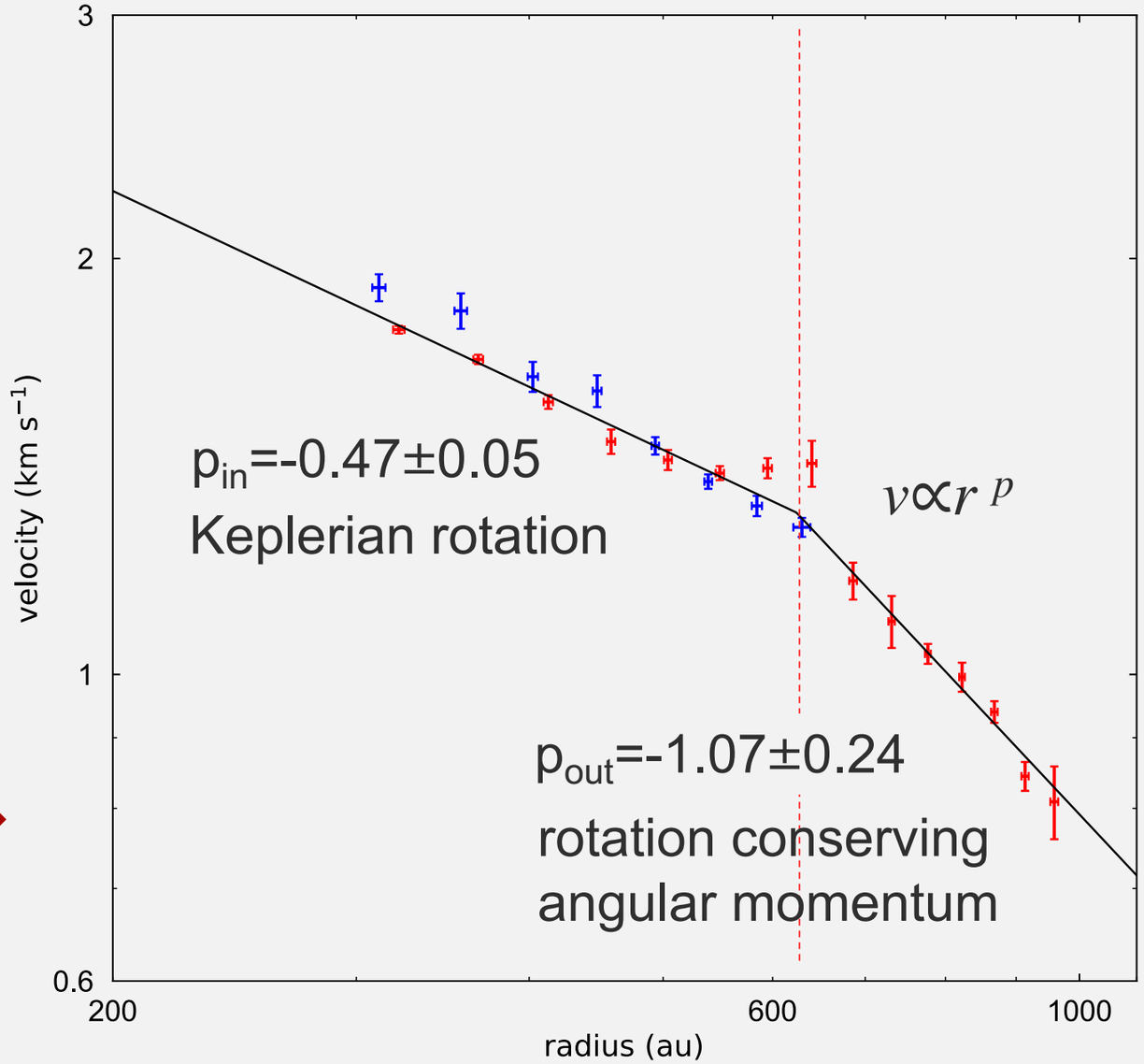
- We have observed this source with ALMA
  - Having a large Keplerian Disk with r~600 au
  - M_*: 1.6 M_{sun} (see also Yen+14)



Sai et al. (submitted)

Measurement of Rotation in the Previous Work





Sai et al. (submitted)

Single Dish Observations

- Mapping ~2’x2’ (~0.1 pc x 0.1 pc) region around L1489 IRS
- Telescope: IRAM-30m
- In **$C^{18}O$ J=2-1**, ^{13}CO J=2-1, N_2H^+ J=1-0, & 1.3mm continuum
- beam size: 11.8” (~1,700 au)
- Δv: 0.15 km/s
- rms: 70 mK

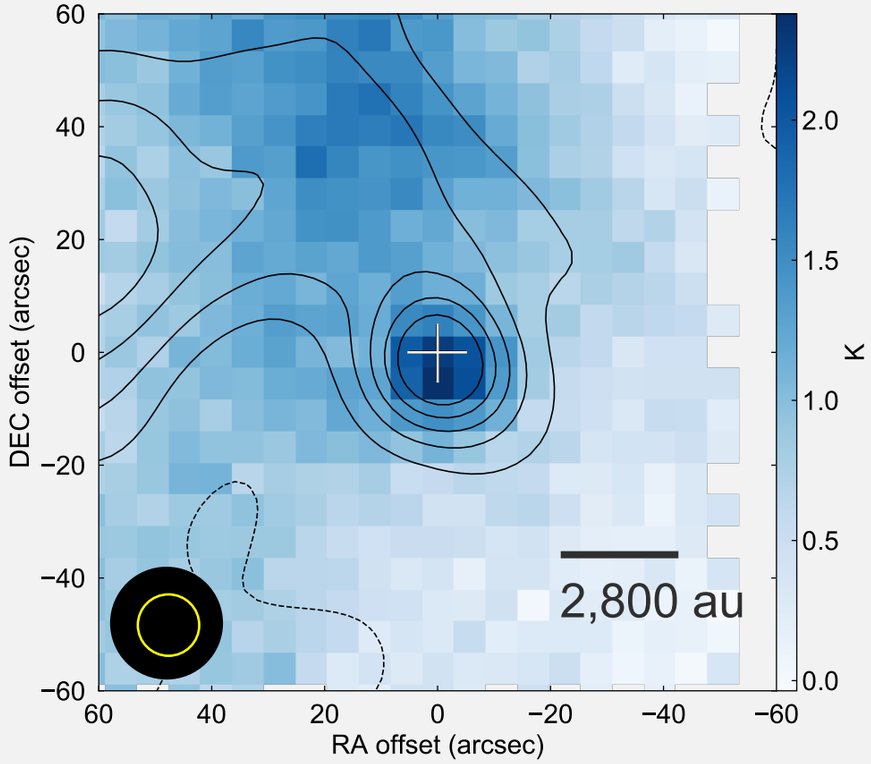
The purpose is to reveal the kinematics on ~1,000-1,0000 au scale and the transition from a core to an envelope

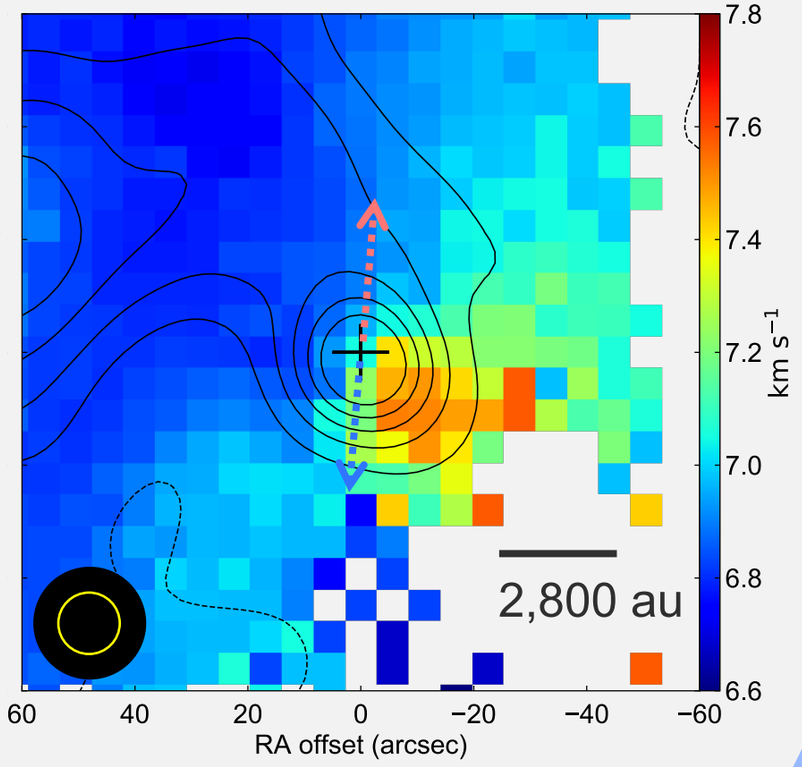
Observational Results in $C^{18}O$ 2-1

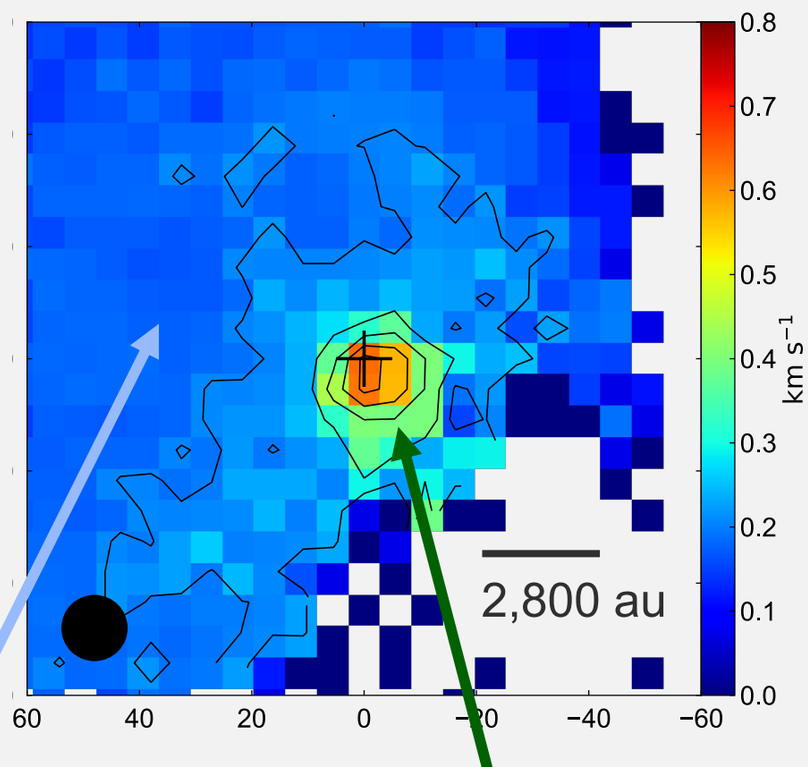
Moment 0/I maps

color: $C^{18}O$ 2-1
contour: 1.3 mm continuum

σ_v map





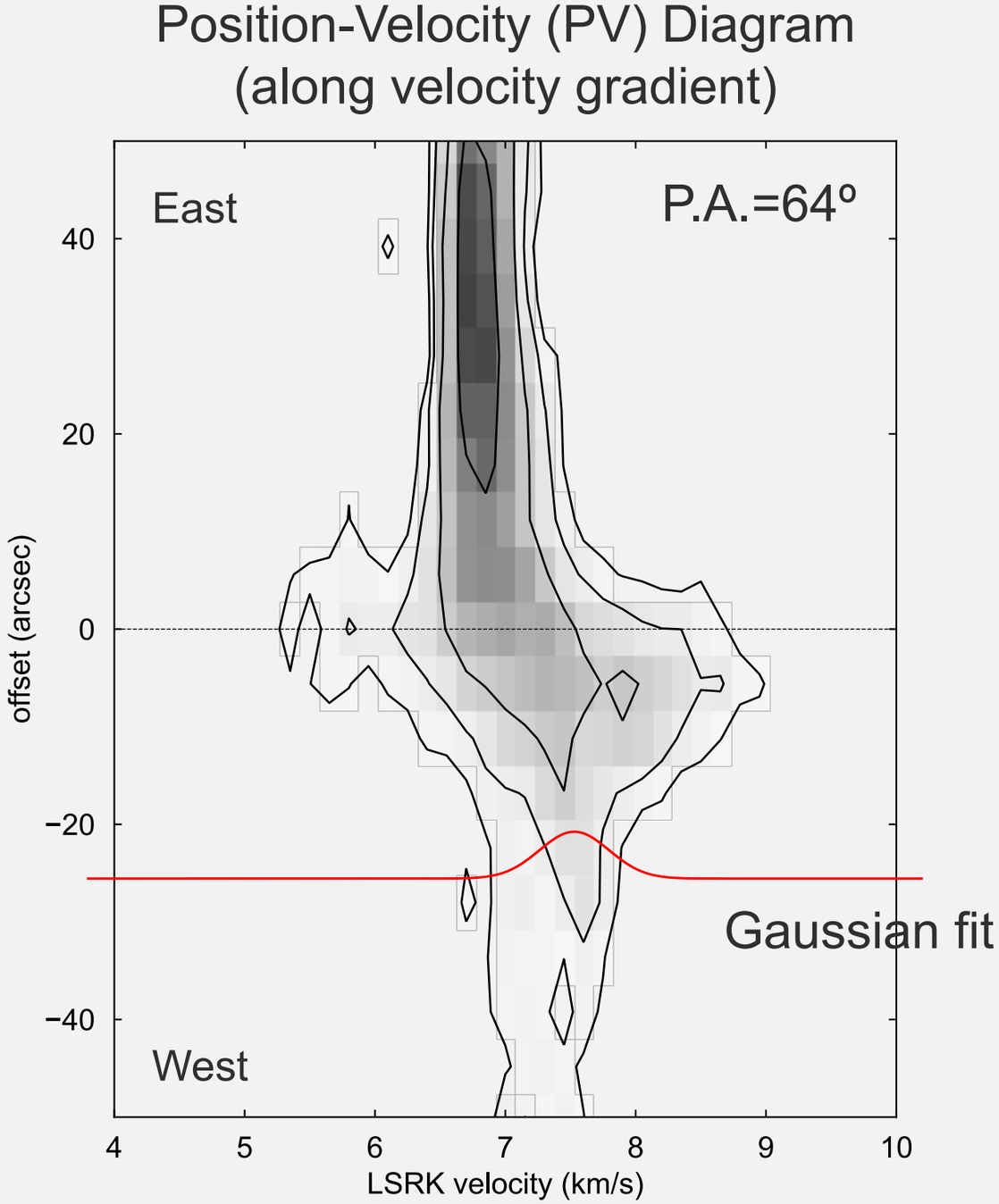


Narrow line width
indicating quiet state

Large line width
indicating dynamical
gas motion

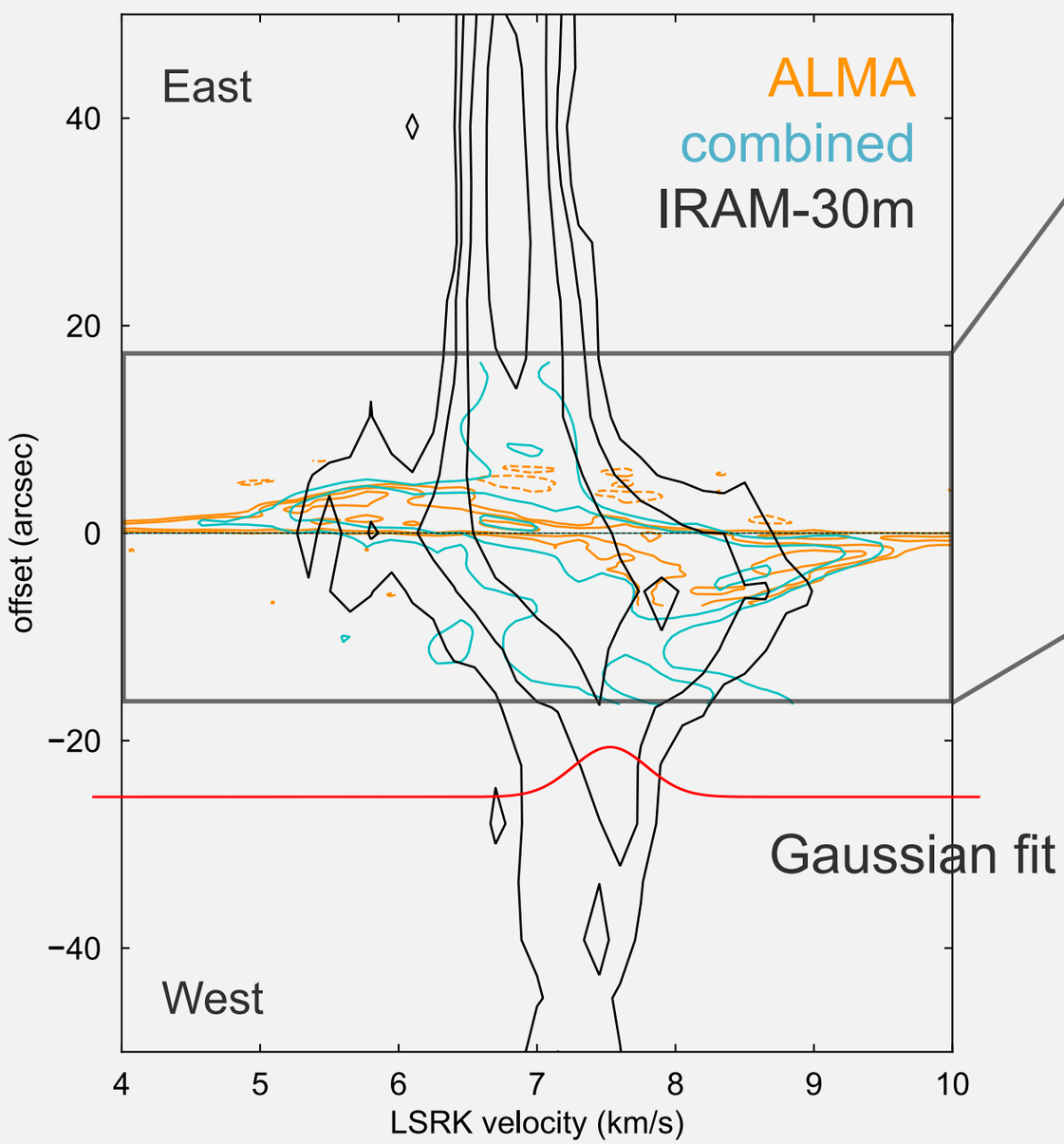
- **Compact structure with r~2,000 au with dynamical motion**
- **Clear rotation motion**

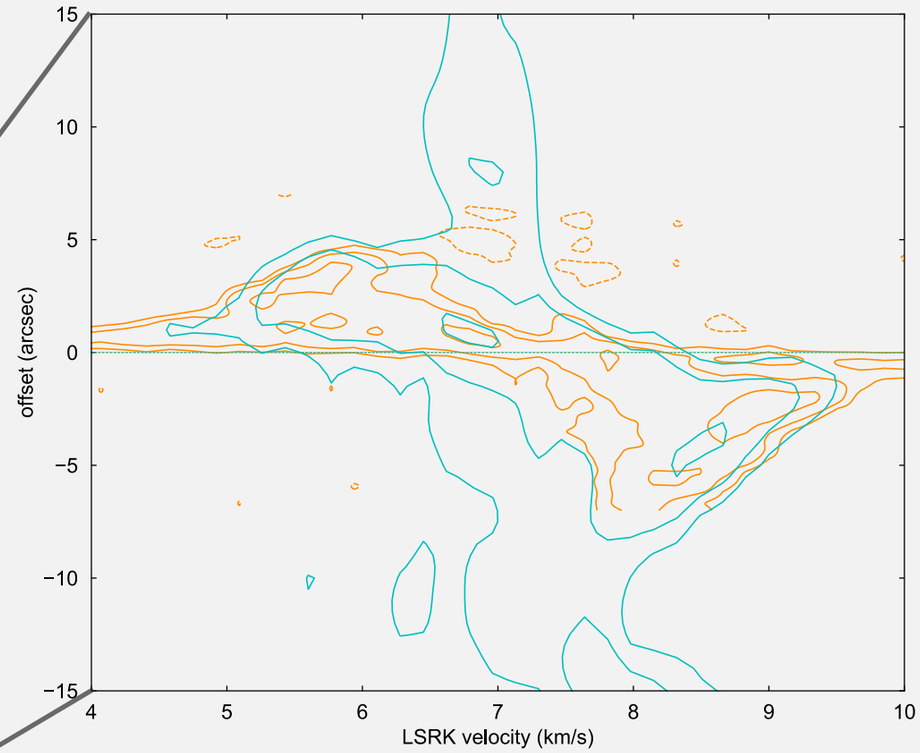
Measurement of Rotation



Measurement of Rotation

Position-Velocity (PV) Diagram
(along velocity gradient)

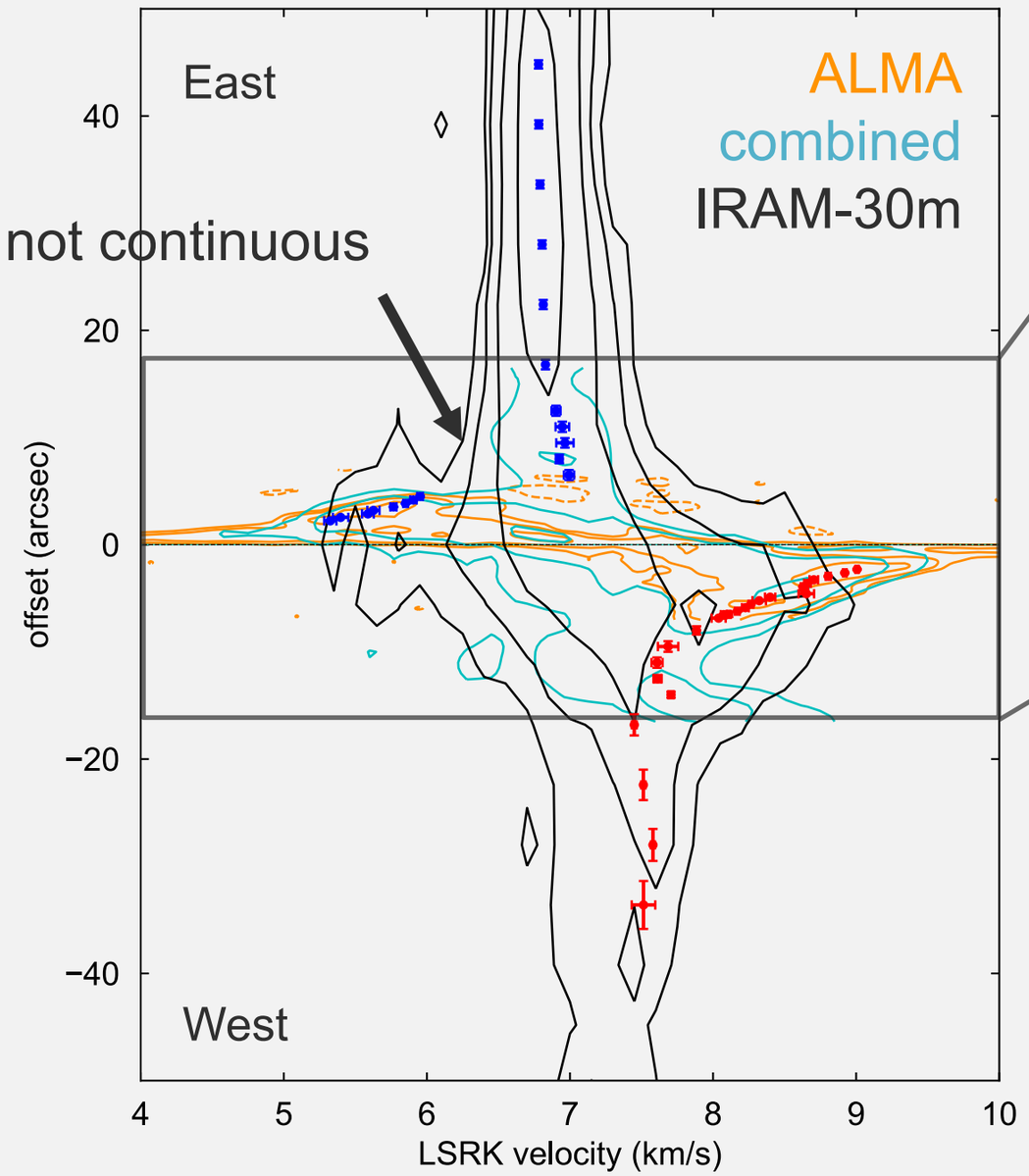


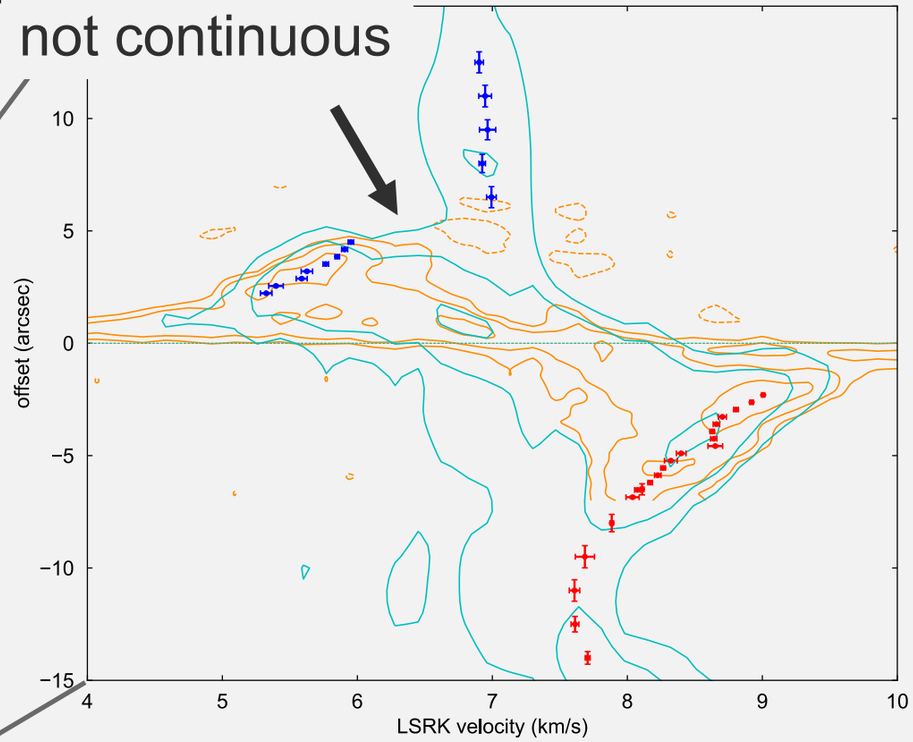


ALMA image	Combined image
θ: 0.33”x0.24”(30º)	θ: 2.6”x2.4”(-4.5º)
Δv: 0.17 km/s	Δv: 0.17 km/s
rms: 5.1 mJy/beam	rms: 0.084 Jy/beam
P.A.=54º	P.A.=54º

Measurement of Rotation

Position-Velocity (PV) Diagram
(along velocity gradient)





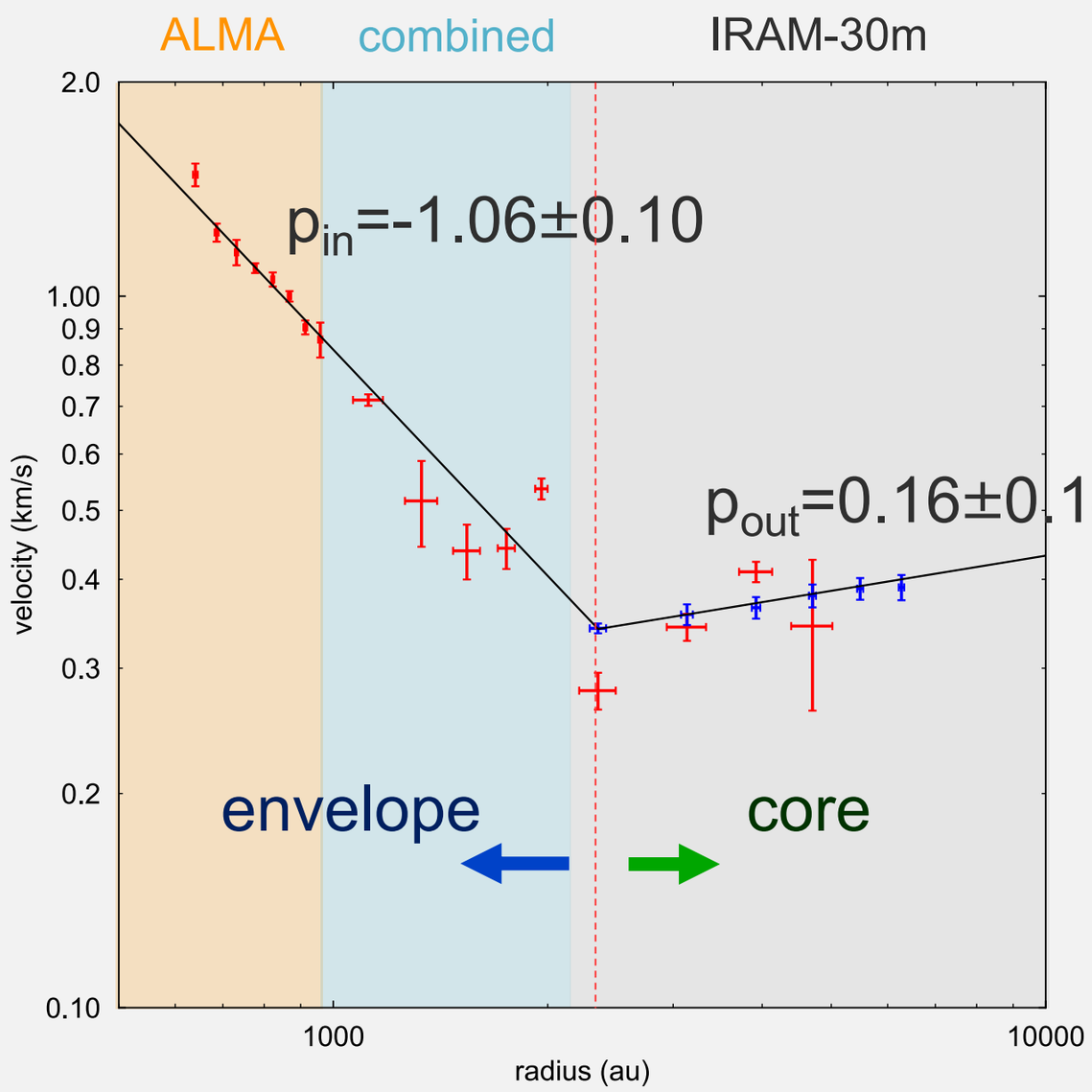
ALMA: -1,000 au (-7”)
combined: 1,000 au-2,100 au (7”-15”)
IRAM-30m: 2,100 au-7,000 au (15”-50”)

Rotation Diagram

Position-Velocity (PV) Diagram
(along velocity gradient)

fitted double power-law function

$$V_{\rm rot} = \begin{cases} V_{\rm break}\left(\dfrac{r}{R_{\rm break}}\right)^{p_{\rm in}} & (r \leq R_{\rm break}) \\ V_{\rm break}\left(\dfrac{r}{R_{\rm break}}\right)^{p_{\rm out}} & (r > R_{\rm break}) \end{cases}$$



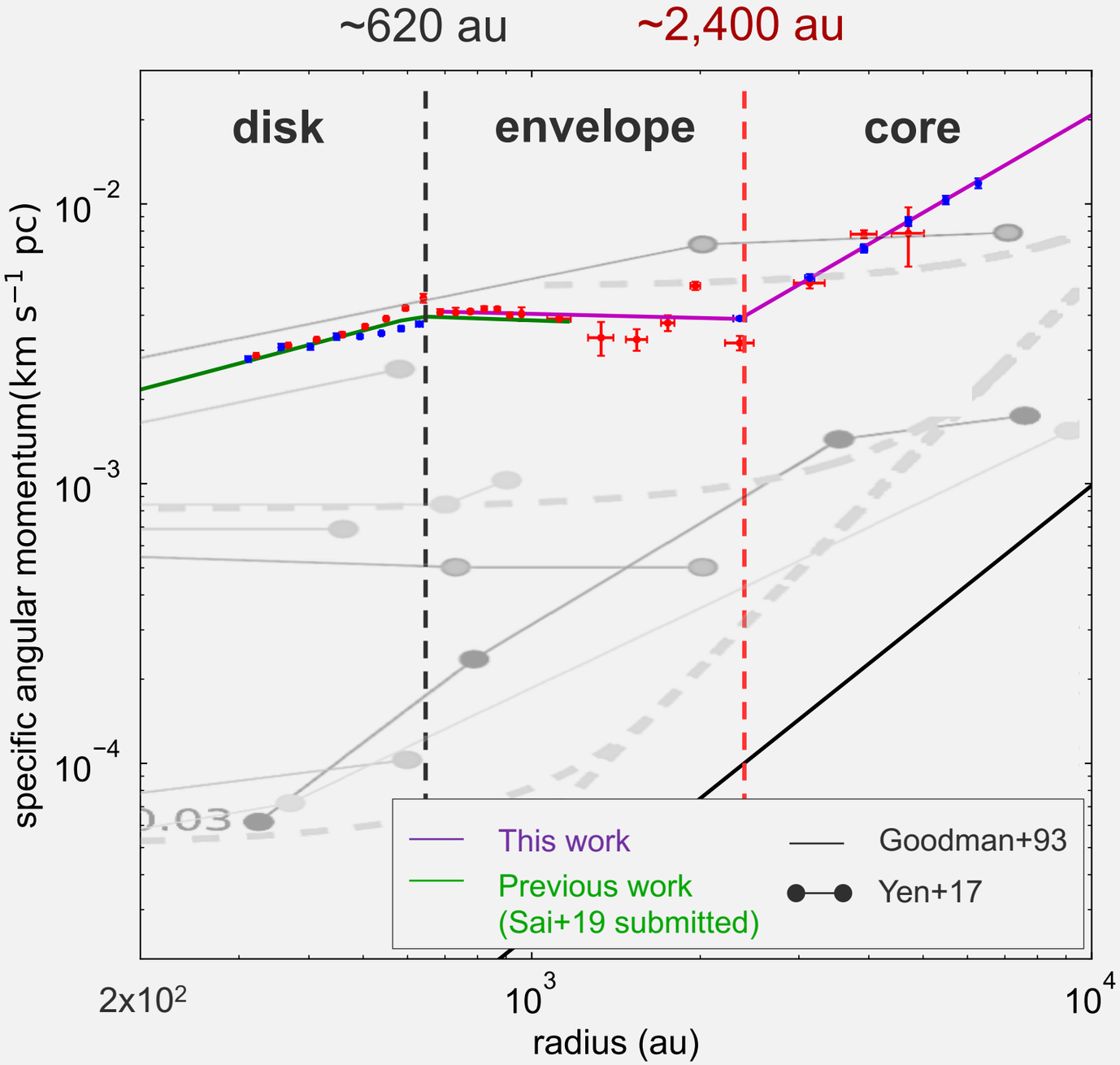
Good agreement with the compact structure in the observed maps

R_{break}=2,350±270au

Specific Angular Momentum Distribution around L1489 IRS

- The core has larger angular momentum than that measured in Goodman et al. (1993)

- Larger angular momentum in the envelope compared with the other sources
  - Large angular momentum was already transferred

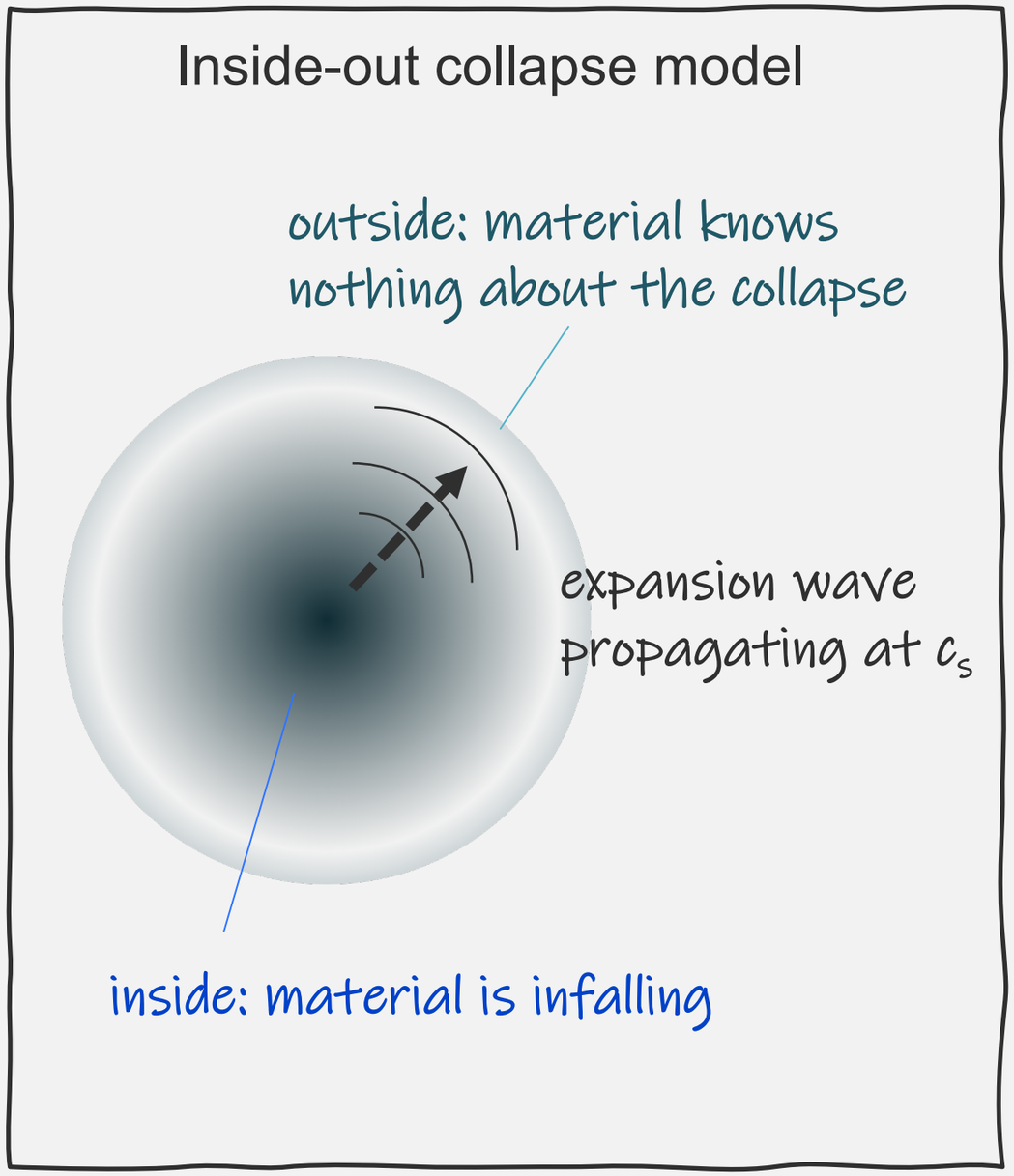


Comparison with the Theoretical Prediction

- Infalling region expands via the expansion wave in the Inside-out collapse model

- The front of expansion wave (=c_s x t_{age})
  - R_{front}~4,200 au assuming c_s=0.2 km s^{-1} and $t_{age}=10^5$ yr
  - much larger than the suggested transitional radius of ~2,400 au

- Protostellar mass of 1.6 M_{sun} was contained within r~2,400 au?
  - Heavy but small initial core!
  - Strong turbulence or magnetic field?



Summary

We have conducted **single-dish observations mapping ~2'x2' region around L1489 IRS to investigate the kinematics on 1,000 au-10,000 au scale**

In $C^{18}O$ 2-1

- **A compact structure with r~2,000 au with dynamical motion** is found at the protostellar position
- Rotational velocities are measured at radii from 700 au to 7,000 au
    - The rotation diagram suggests that **the rotation nature changes at r~2,400 au**, i.e., **transition from an infalling envelope (p~-1) to a core (p~0.16)**
    - The suggested transitional radius is consistent with the radius of the observed compact structure at the protostellar position
- The **transitional radius is much smaller than the theoretical prediction** in the Inside-out collapse model
    - The protostellar mass of ~1.6 M_{sun} was contained within r~2,400 au?

Prospect

- What causes such a small transitional radius even in the well evolved Class I source?
- What is the initial condition of L1489 IRS? Turbulent or Strong B-field?

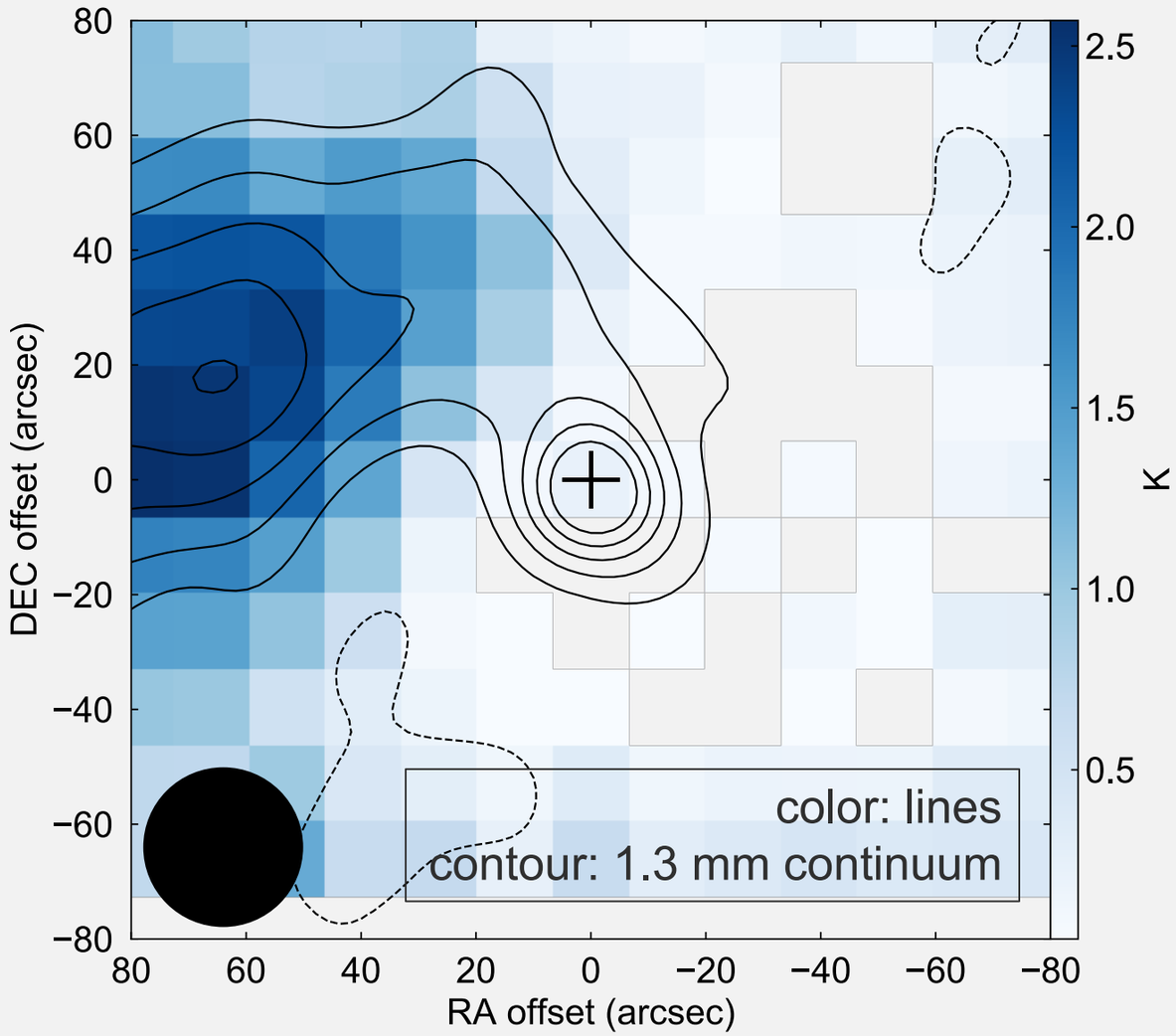
With JCMT!

- **$C^{18}O$ 3-2 mapping** to analyze multi transitions and probe the difference of physical condition between the envelope and the core
- **Polarization observations** to investigate the morphology of B-field

Backup

N_2H^+ J=1-0

N_2H^+



$C^{18}O$