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A Face-on Accretion System in High Mass Star-Formation: Possible Dusty Infall Streams within 100 Astronomical Unit

(Motogi et al. 2017 submitted to ApJ)

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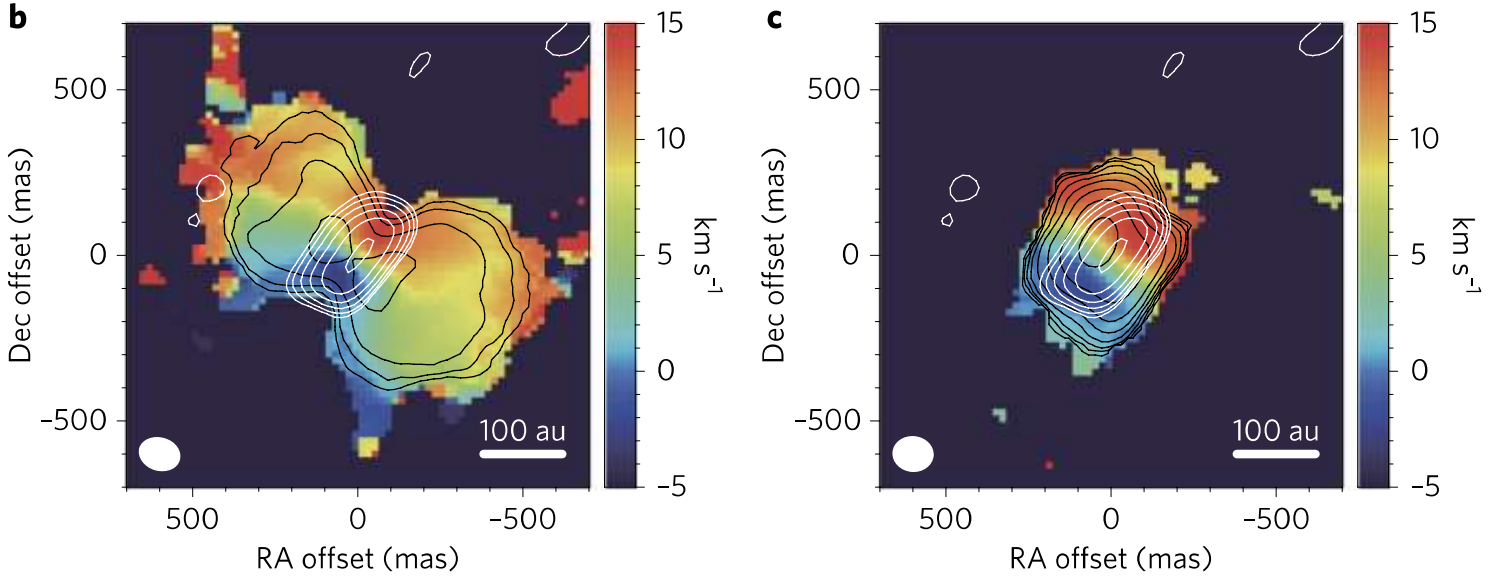
1. Introduction

High mass star-formation via accretion



Rotating outflow & disk in Orion source I (Hirota et al. 2017, Nature Astronomy)
→Basically consistent with previous expectations using maser kinematics
(e.g., Greehill et al. 2004b, Matthews et al. 2010)

- A lot of high mass accretion disk candidates has been found in this decade (e.g., Cesaroni et al. 2017).
- Universal process independent of stellar mass ?

My motivation

I hope to resolve

a “face-on” accretion system

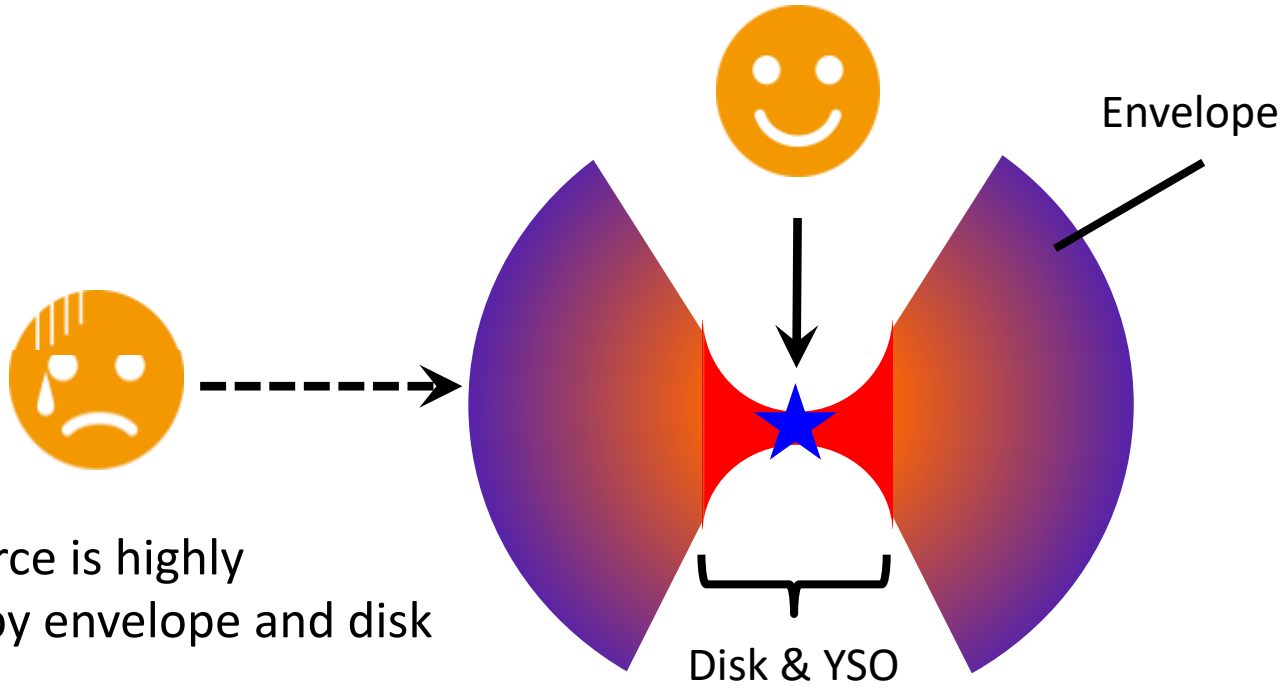
in high mass star-formation.

Why ?

Why “face-on” system ?

◯Avoiding self-shielding effect !!

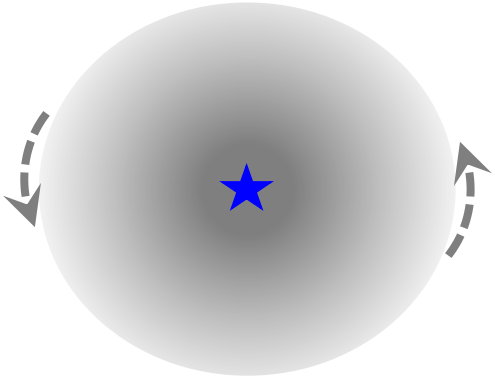
◯Total optical depth along the line-of-sight
is minimized in the face-on geometry !



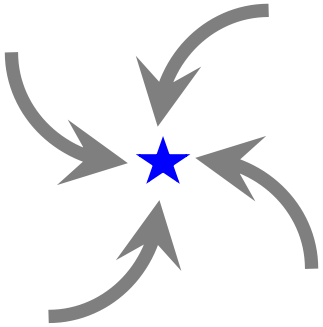
◯Edge-on source is highly
obscured by envelope and disk

“Bird’s-eye view” directly shows physics !!

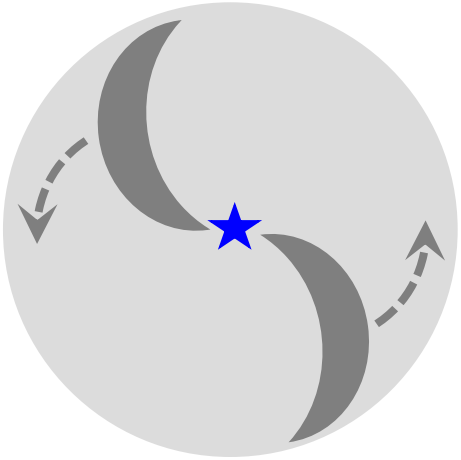
(1) Centrifugal disk ?



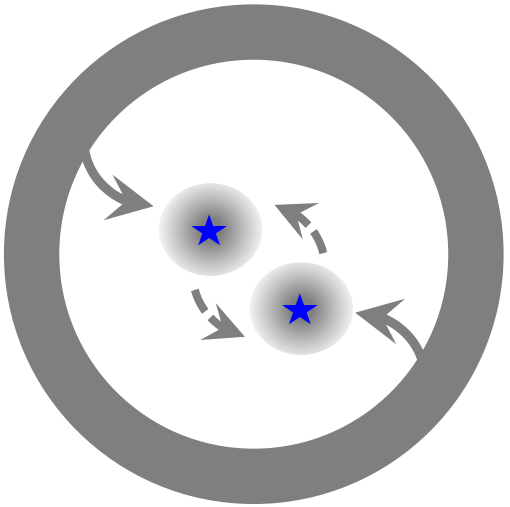
(3) Infall-dominated ?



How diverse ?



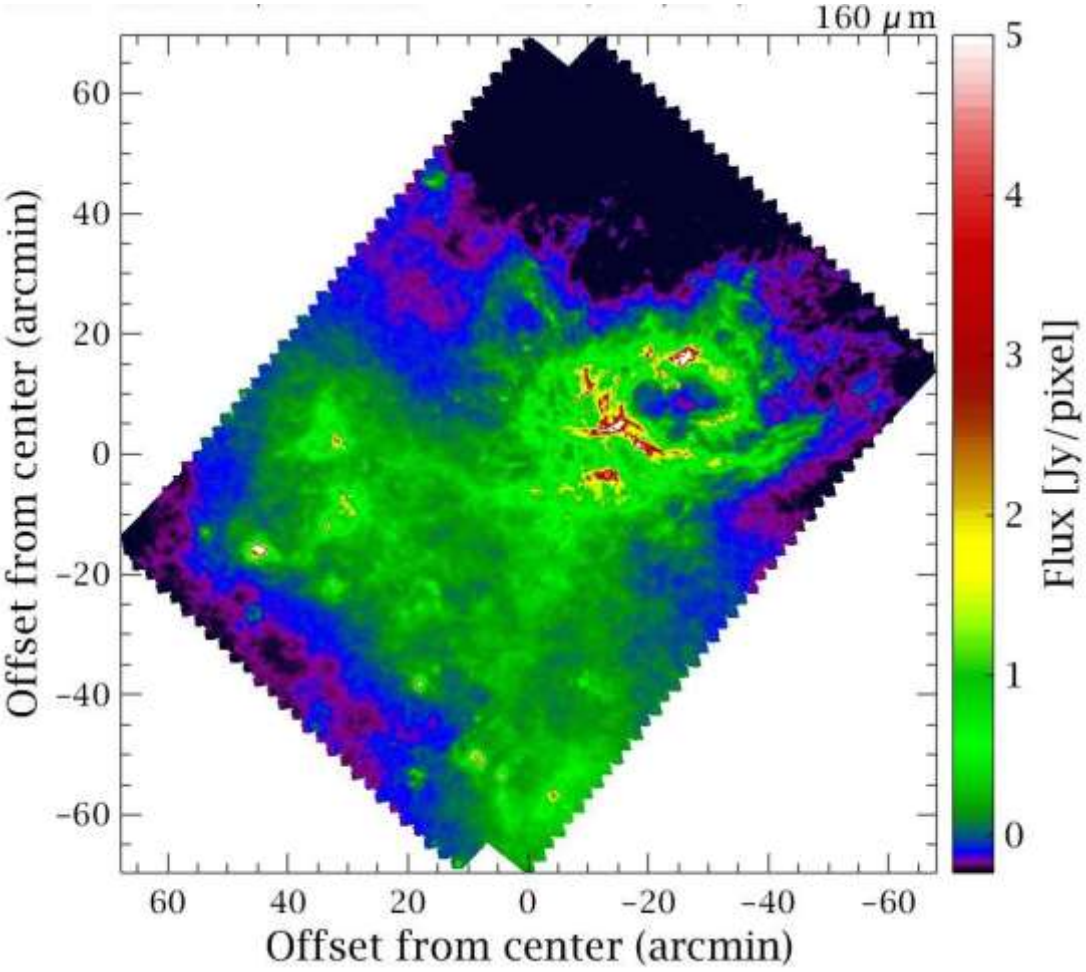
(2) self-gravitating disk
with spiral arms ?



(4) Nested binary system ?

2. Target

Target: G353.273+0.641



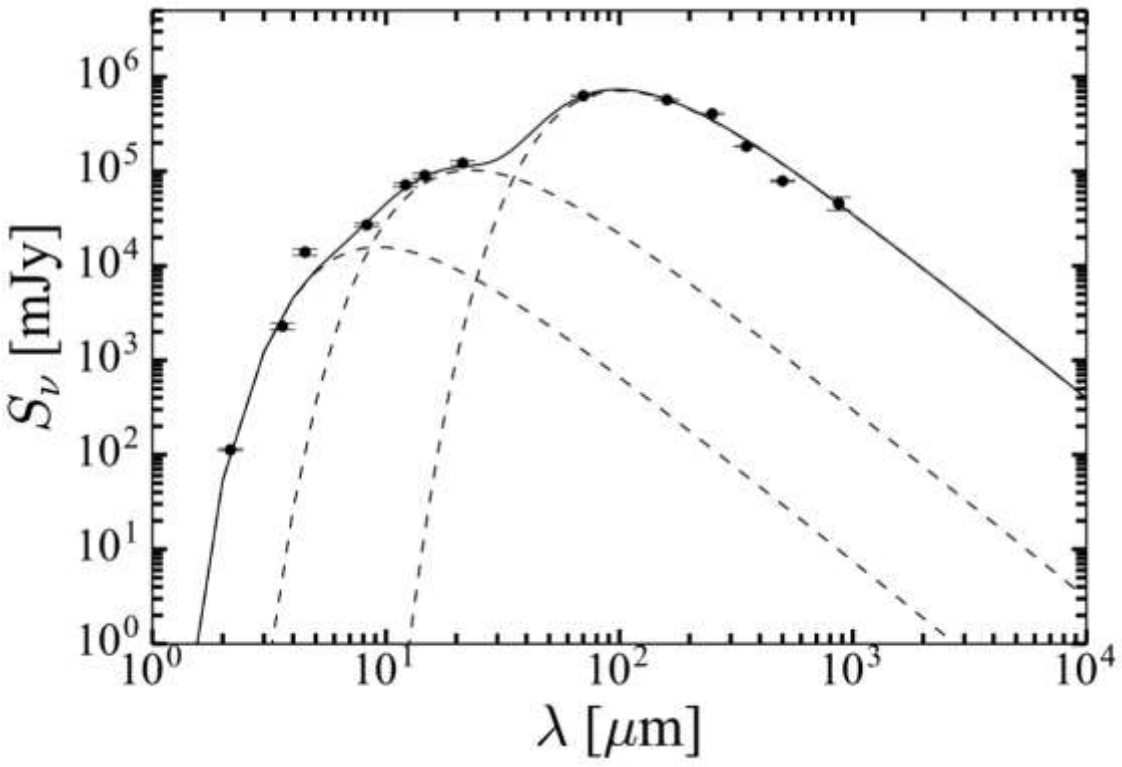
- High mass protostellar object in NGC6357 (Motogi et al. 2013)
- Southern Sky (Dec ～-34°)
- Relatively nearby

  Photometric distance
  1.74 ± 0.31kpc
  (Neckel 1978)

  Parallax
  1.70 ± 0.19 kpc
  (Motogi et al. 2016)

Host YSO

◯IR-SED of G353



IR data: 2MASS, GLIMPSE, MSX, Hi-GAL, ATLASGAL

- Bolometric luminosity

$\sim 5 \times 10^3 \, L_{\rm sun}$

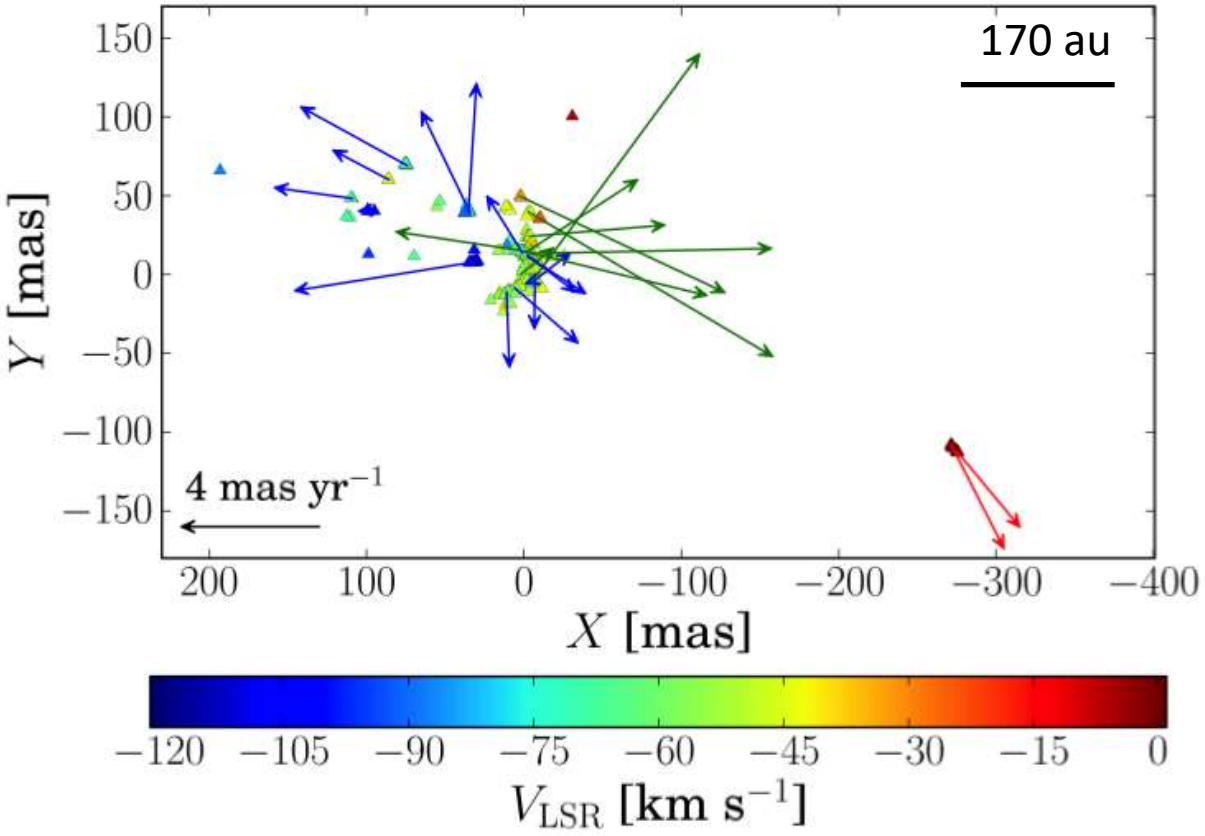
corresponding a host YSO mass of

$\sim 10 \, M_{\rm sun}$

- Flat SED shape at MIR is consistent with a face-on geometry (e.g., Zhang & Tan 2011)

H_2O maser jet (Motogi et al. 2016)

Internal proper motions of H_2O masers taken with VERA



Coordinate origin (RA,DEC) = (17h 26m 1s.59, -34° 15' 14".9)$_{J2000}$.

1 mas yr^{-1} = 32 km s^{-1} @ 1.7 kpc

- Blue-shift dominated (Caswell et al. 2008)
- Compact bipolar jet along E-W direction (～850 AU)
- Inclination ～ 8° from the LOS

→Nearly face-on object

3. VLA & ATCA observations of the face-on accretion system



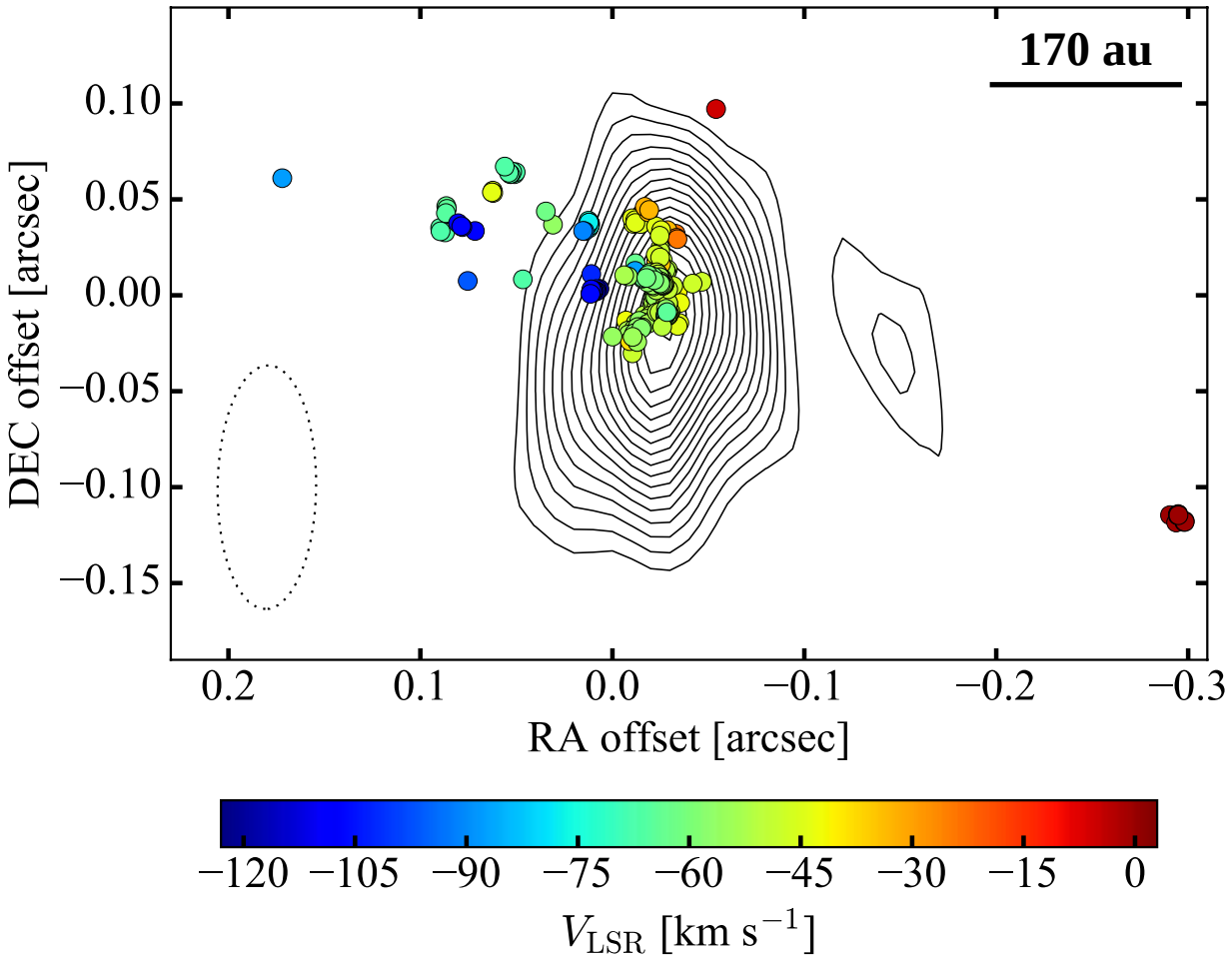
Observations

- SED measurements using J-VLA A configuration (Beam size: 0”.1 - 0”.2 at 20 – 45 GHz)

- 6.7 GHz CH_3OH maser mapping + C/X continuum imaging using ATCA (Beam size $\sim$ 2”.0)

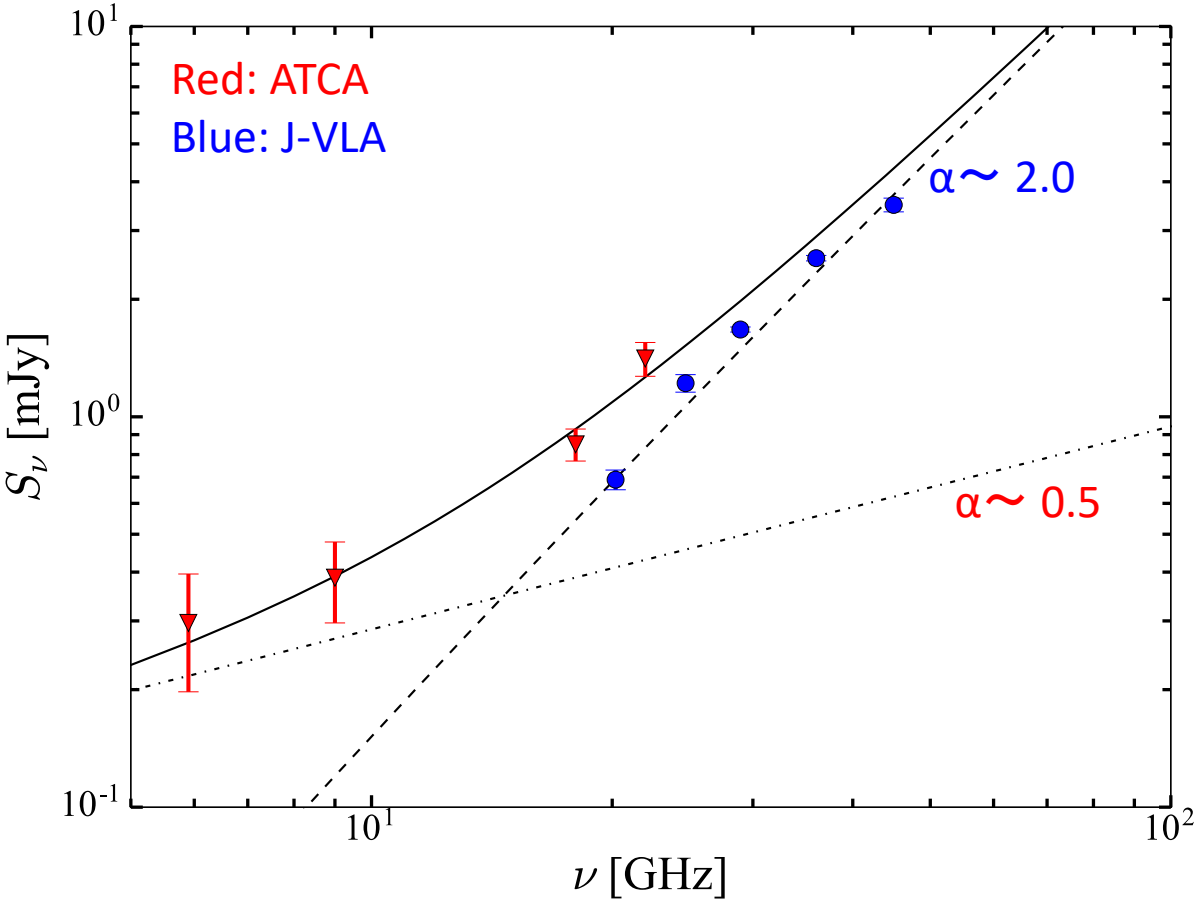


Highest-resolution J-VLA image @ 7-mm



- Compact source at the root of the maser jet
- Clearly resolved along E-W direction
- Total flux ∼ 3.5 mJy
  →brightness temperature ∼ 235 K

Centimeter SED



- Compact J-VLA source shows a optically thick SED slope (α∼ 2)
- Overall SED shape could be modeled by

  1. optically thick J-VLA source
     +
  2. extended radio jet (Motogi et al. 2013)

- Best-fit SED slope of the jet is ∼ 0.5 (e.g., Anglada 1996)

◯Low-resolution ATCA data contain extended emission that was resolved-out in J-VLA A-configuration data

Dust or Free-Free ?

- If J-VLA source is optically-thick HCHII region ($T_e = 10^4$ K), source size must be smaller than 15 mas at 7-mm

  →This is clearly inconsistent with the resolved image

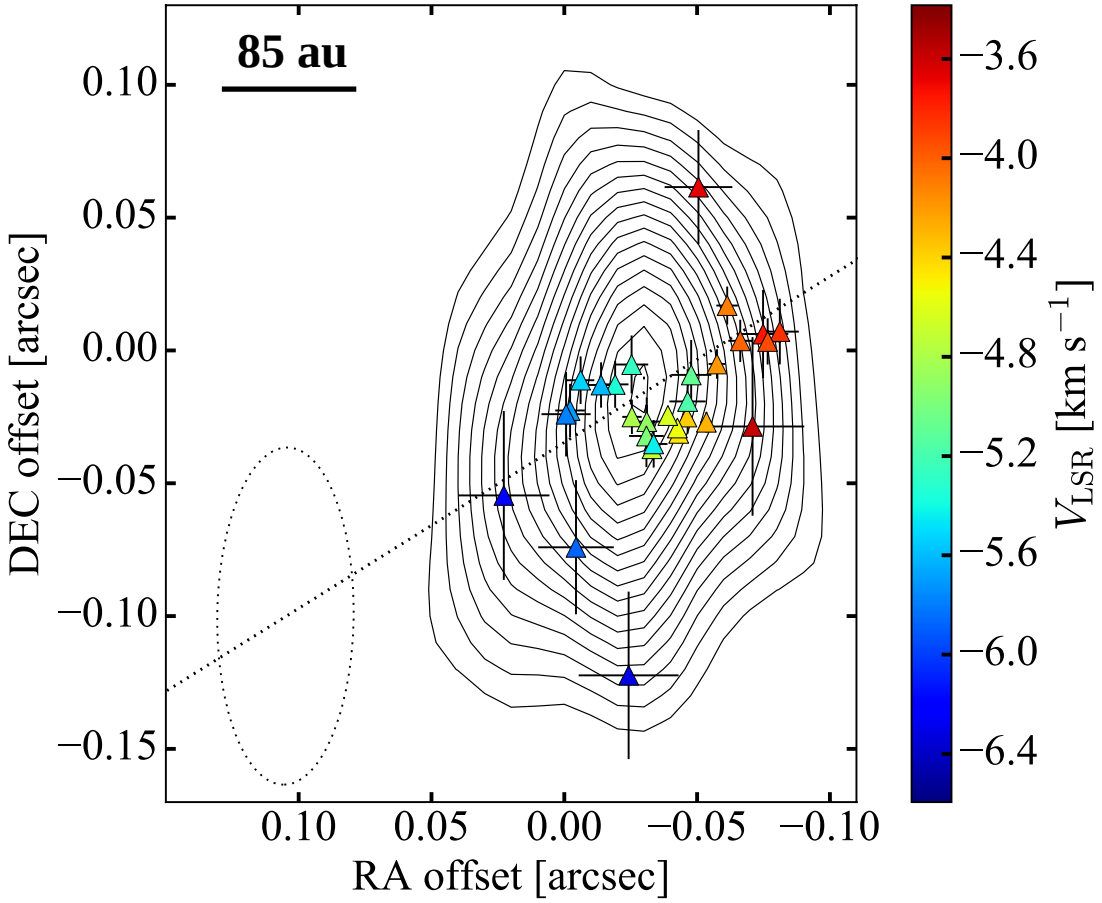
- Observed brightness temperature (235 K) is more consistent with "warm dust emission"

  →We suggest that the J-VLA source traces a dusty circumstellar system

- We cannot exclude any unresolved contamination from ionized gas near the central object.

  →Fully spatially-resolved study is still required to test it

6.7 GHz CH_3OH maser



- Spatial relation between masers and J-VLA source is still tentative, because of astrometric error in ATCA data (～400 mas).
- Spatial scale is comparable with that of J-VLA source

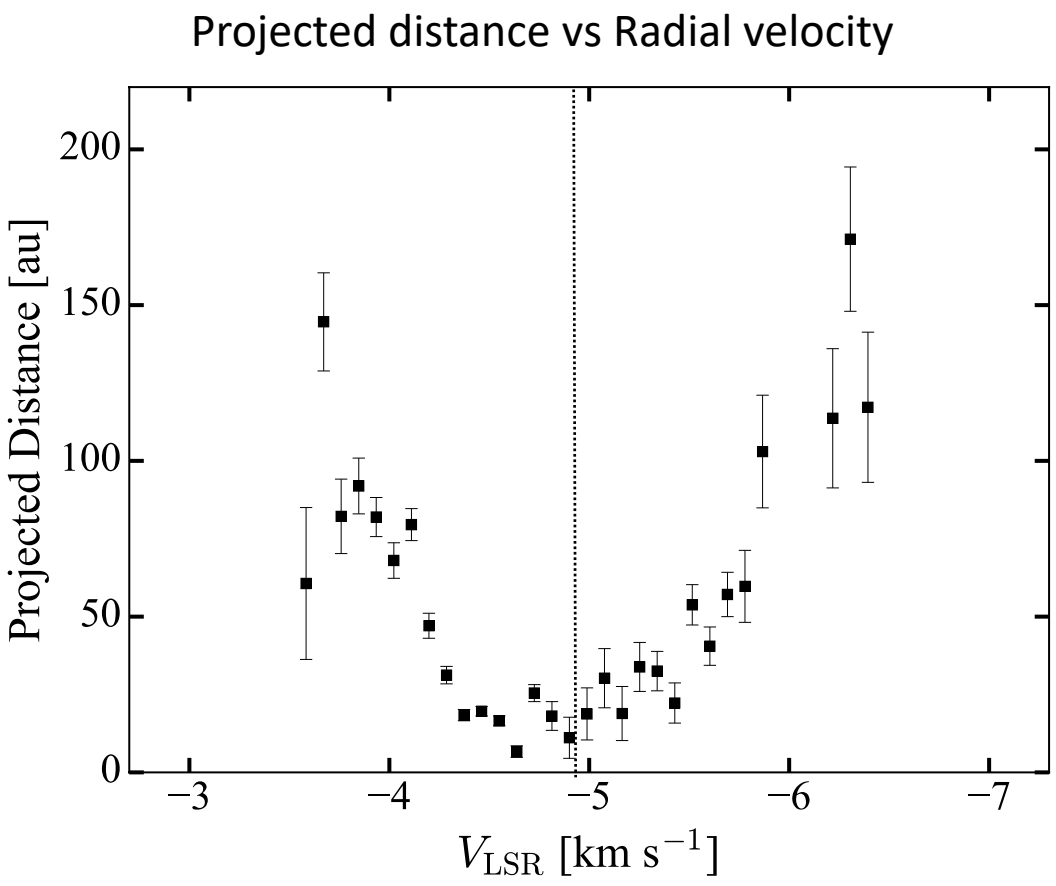
  →Maser excitation by warm dust ?
- Spiral-like distribution with a velocity gradient (± 1.5 km s^{-1} over 150 mas)
- Unlikely to be Keplerian rotation

  →Dynamical mass is only 0.3 M_{sun}

  →Clearly inconsistent with L_{bol}

* Masers are superposed on the 7-mm continuum assuming that the peak positions at 5-cm and 7-mm are identical

Distance-Velocity plot



- Radial velocity seems to be some parabolic function of projected distance from the averaged maser position.

- Two important features...

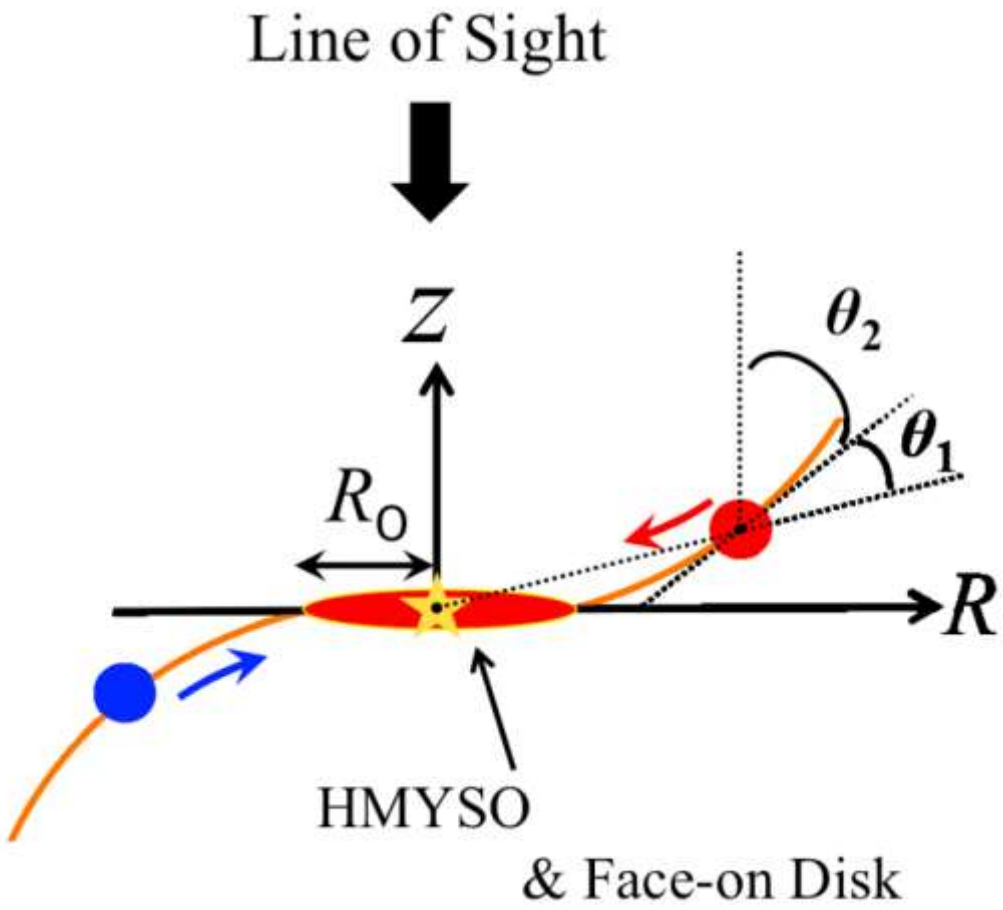
  1. $V_{\rm LSR}$ approaches the systemic velocity near the center

  2. $V_{\rm LSR}$ increases at the outer radius

→We tried to find-out proper kinematic model

4. Parabolic Infall Model

“Parabolic Infall Model”



◯Trajectory

$$Z = Z_0 \left(\frac{R - R_0}{R_0} \right)^p$$

◯Velocity field

$$V_{\rm mod} = V_{\rm sys} \pm \sqrt{\frac{2GM_*}{R^2 + Z^2}} \cos\theta_1 \cos\theta_2,$$

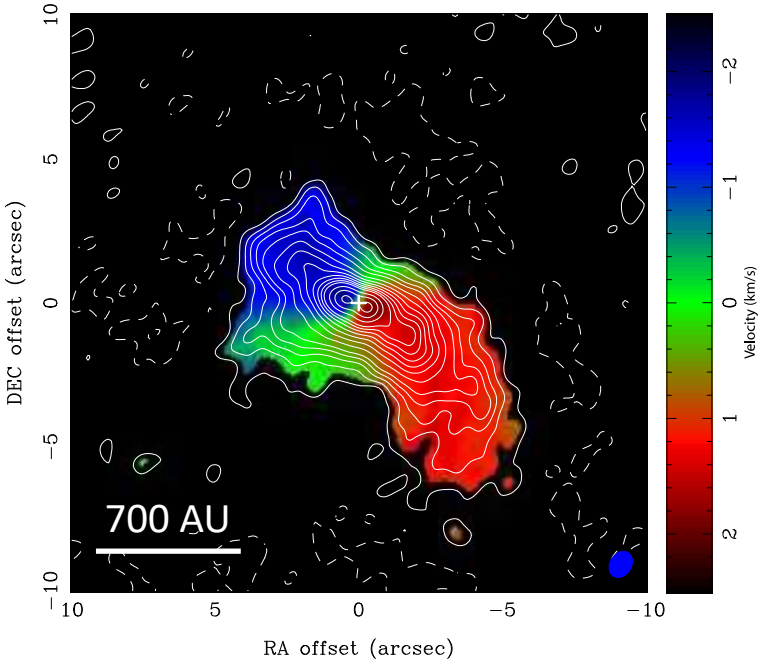
◯Parameters

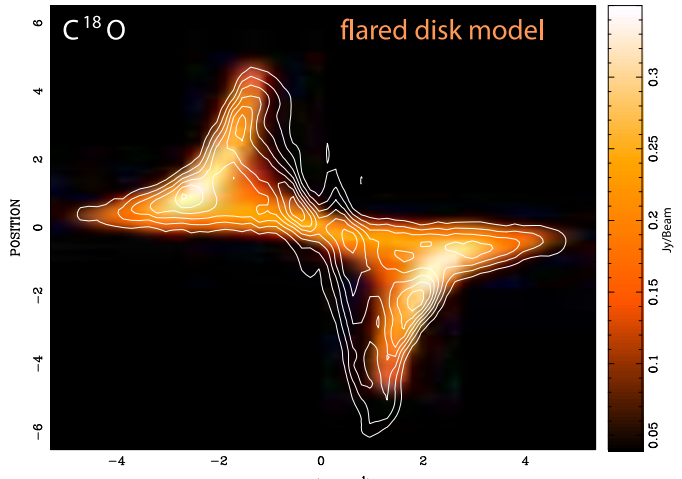
Trajectory (z_0, p)
Landing Radius (R_0)
Dynamical center (x_0, y_0)

◯Assumption

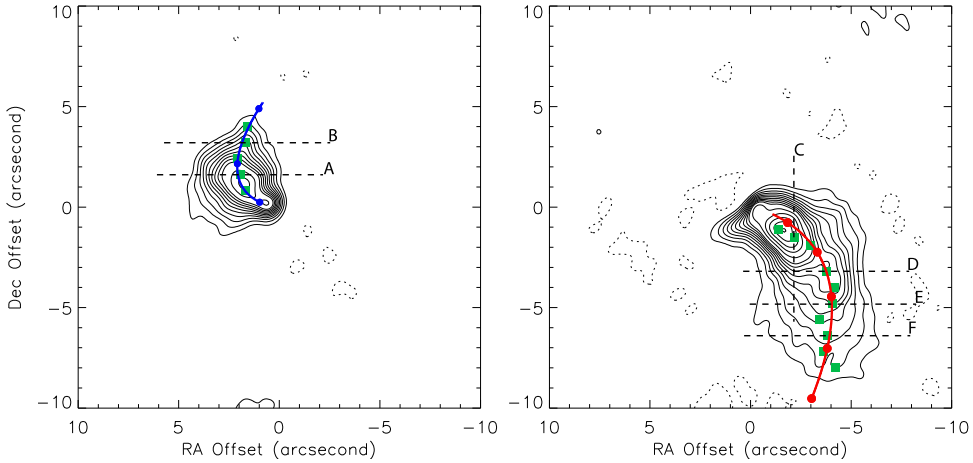
1. Completely face-on geometry
2. YSO Mass ～10 $M_{\rm sun}$

Low-mass example: L1489IRS (Yen + 2014)



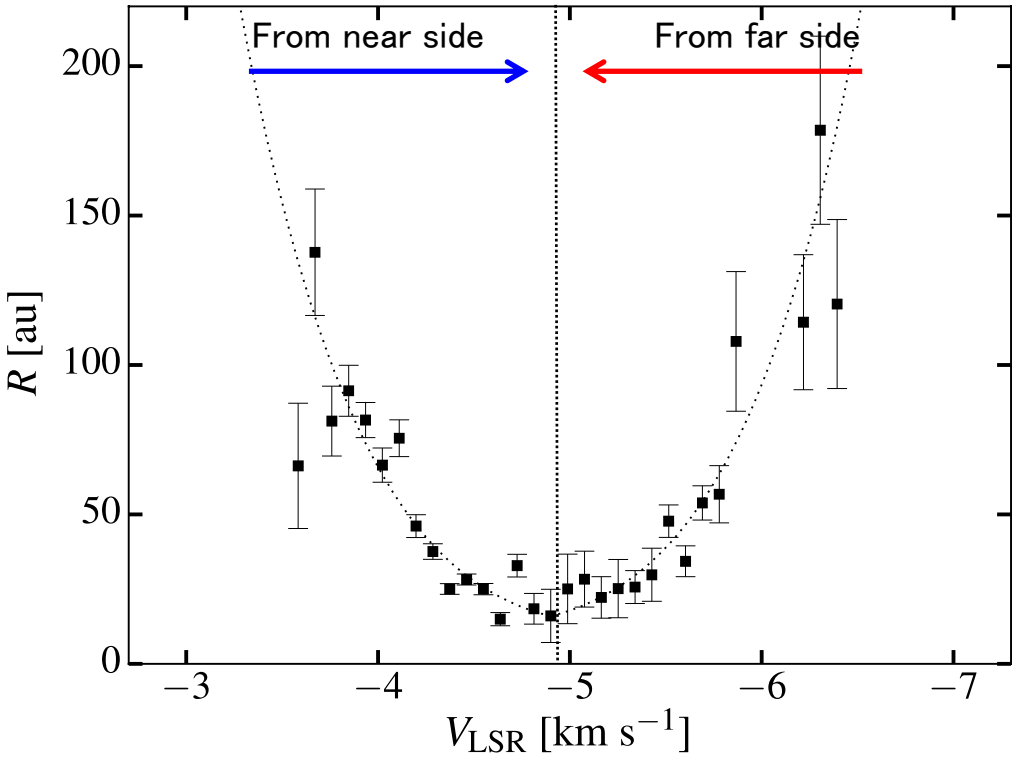


- Keplerian Disk
  (R～700 AU)
  + Spiral-like streams



Fitting Result

◯Modified distance-velocity plot



- The model can fit the data points very well (→Reduced $\chi^2 \sim 0.7$)
- Best fit parameters

  p = 1.9

  z_0 = 0.2

  R_0 = 16 AU

  (x_0, y_0) = (2.3 mas, 4.6 mas)

- The model suggests...

  Small angular momentum of initial collapsing core

  and/or

  6.7 GHz masers selectively trace inflow with small angular momentum

- If we consider a centrifugal barrier at 16 AU, specific angular momentum is,

$$8 \times 10^{20} \ (M_*/10 \ M_\odot)^{0.5} \ \mathrm{cm^2 \ s^{-1}}$$

What causes parabolic trajectory ?

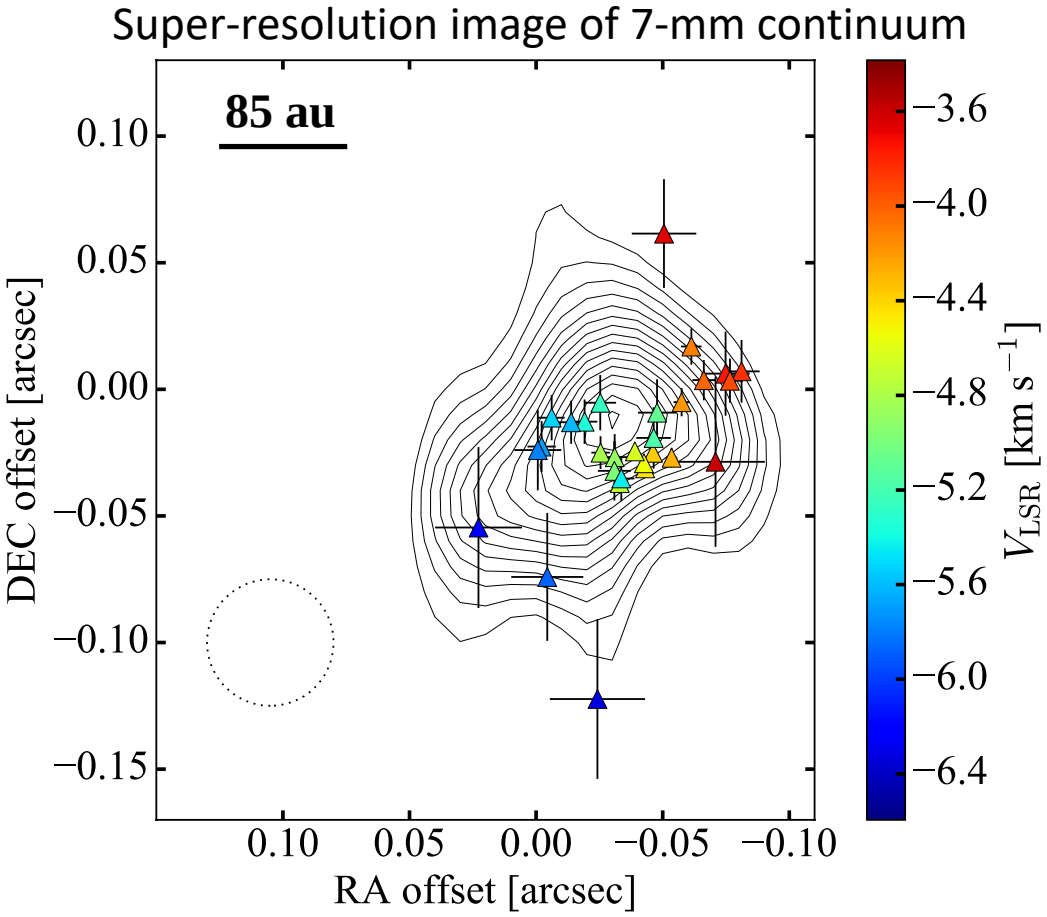
- Our infall model successfully explains observed velocity structure, however, the origin of such a specific structure is still an open question.

- The power law index p of 1.9 is clearly larger than that for a scale height of typical standard disk ($p \sim 1$) and isothermal disk ($p \sim 1.5$)

- One possibility is that it is determined by 2D profile of temperature and density, that is closely related to the maser excitation

→Higher-resolution data of circumstellar structure is required

Dusty infall system ?



- We reconvolved all the clean components by a circular beam of 50 mas
- The continuum is elongated along the maser distribution

  →Both probably traces same dusty infall streams
- We require further spatially resolved study to verify exact relation of them

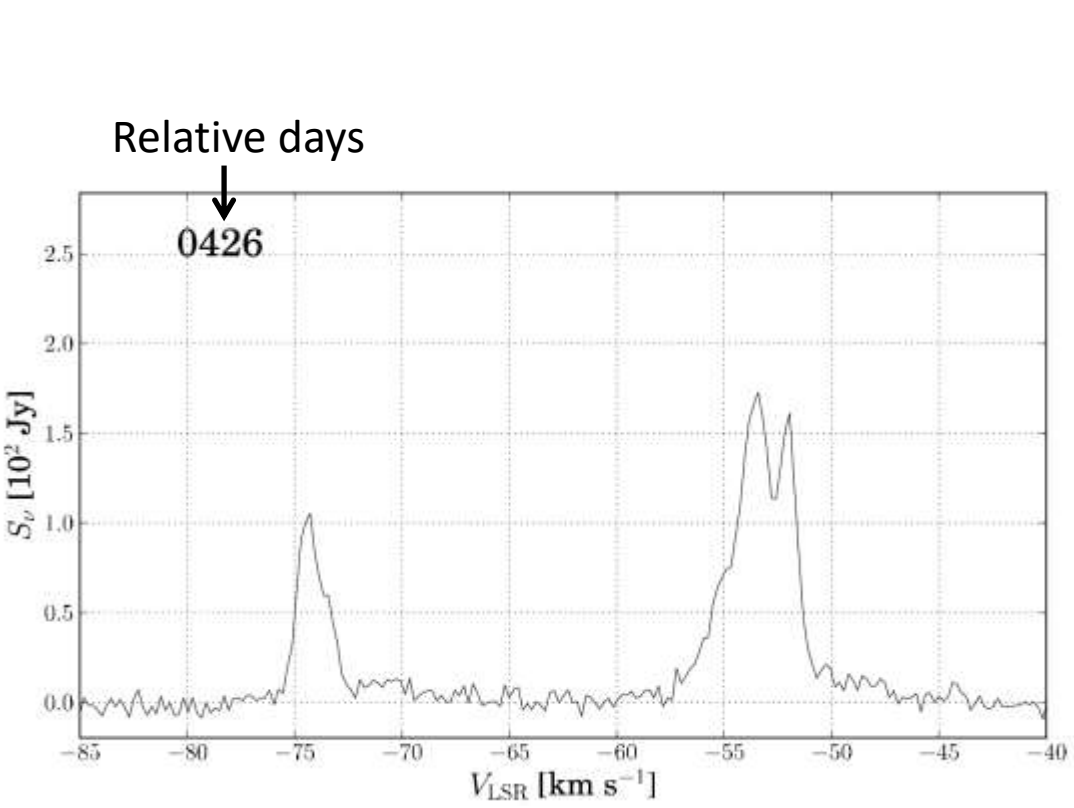
  →Now waiting for ALMA long baseline data in Cycle 4

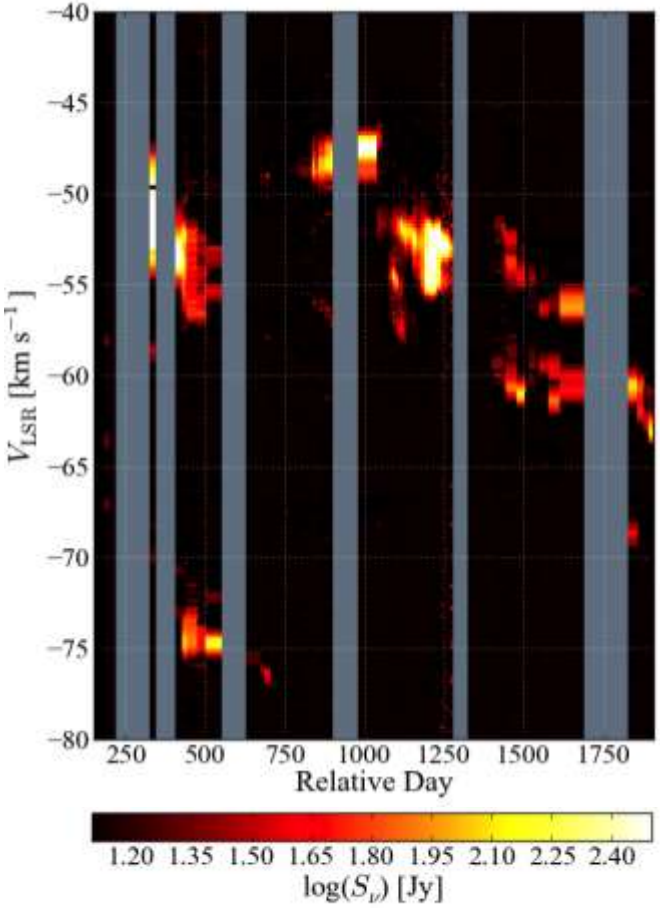
Summary

- We performed interferometric observations towards the face-on HMPO G353.273+0.641, searching for the innermost accretion system
- Optically thick compact continuum source was detected by the highest-resolution J-VLA observations
- The low brightness temperature and source size suggests that the continuum could be explained by warm dust emission, rather than HCHII region
- 6.7 GHz CH_3OH maser observed by ATCA shows the spiral-like distribution with a systematic velocity gradient.
- We found that the maser kinematics can be explained by “parabolic infall model”, suggesting that initial specific angular momentum in G353 is small, or the masers selectively trace inflow with small angular momentum.
- Both of the continuum and masers seem to trace same dusty infall streams, and we are now waiting follow-up ALMA long baseline data in cycle 4, in order to verify exact relation

Ciao

Episodic nature of the maser



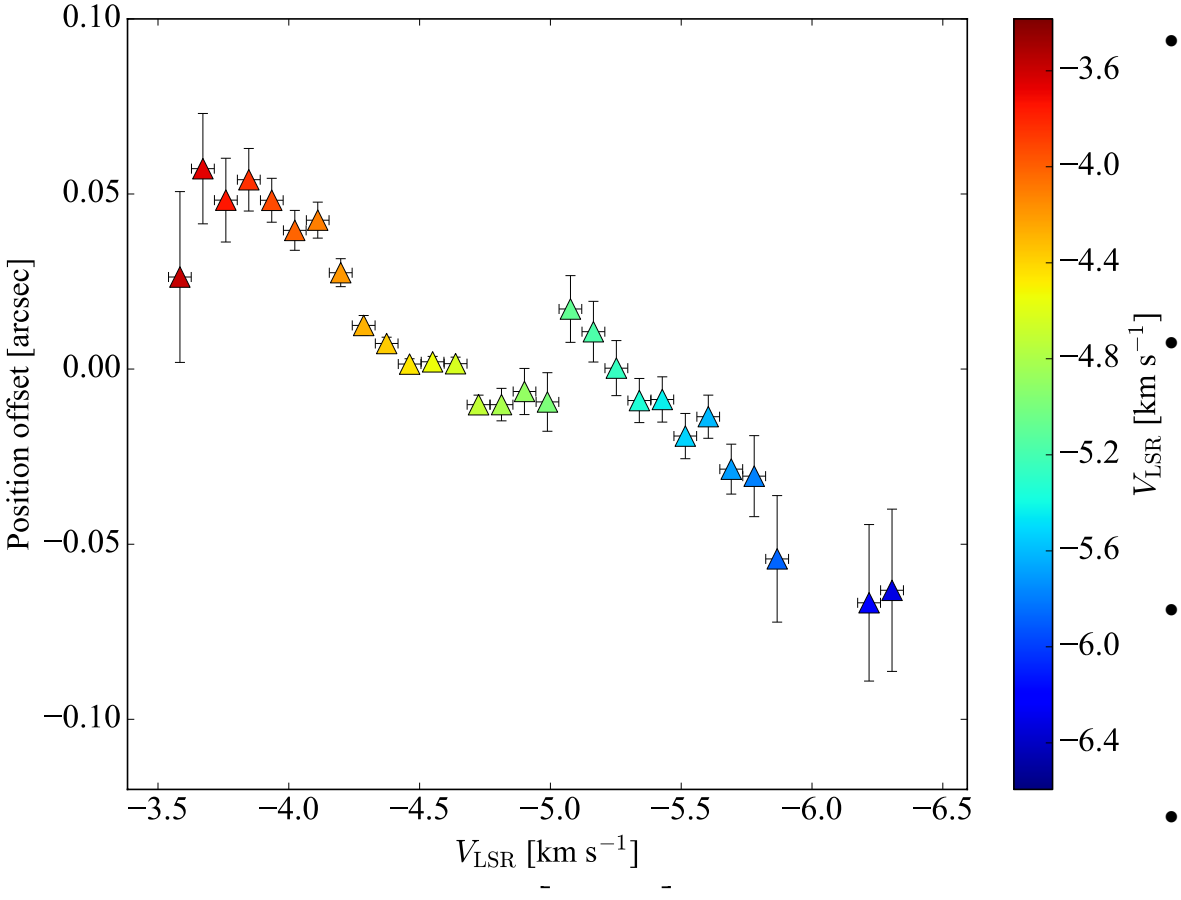


Intermittent Flare-up + Recurrent Acceleration

→Shock Propagation caused by episodic jet-launching

(Motogi et al. 2016)

6.7 GHz CH_3OH maser



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- Spiral-like distribution with a velocity gradient (± 1.5 km s^{-1} over 150 mas)

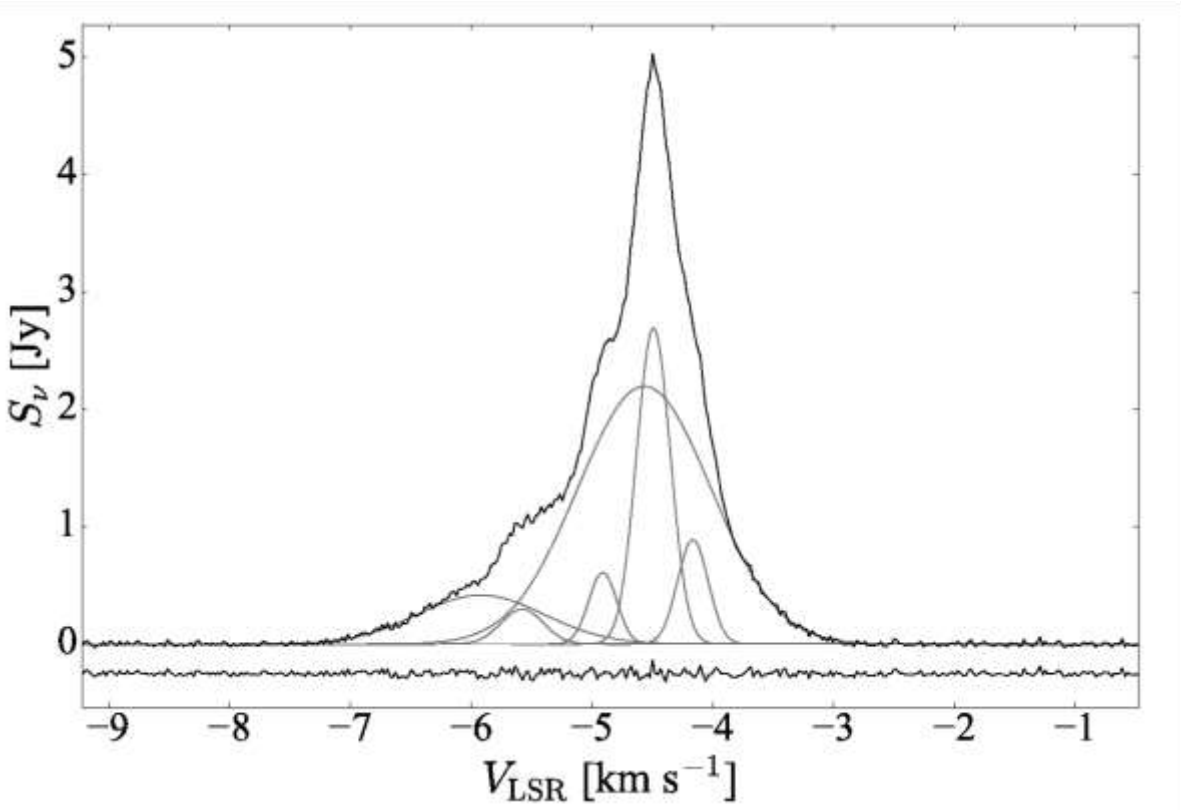
- Unlikely to be Keplerian rotation

  →Dynamical mass is only 0.3 $M_{\rm sun}$

  →Clearly inconsistent with $L_{\rm bol}$

* Masers are superposed on the 7-mm continuum assuming that the peak positions at 5-cm and 7-mm are identical

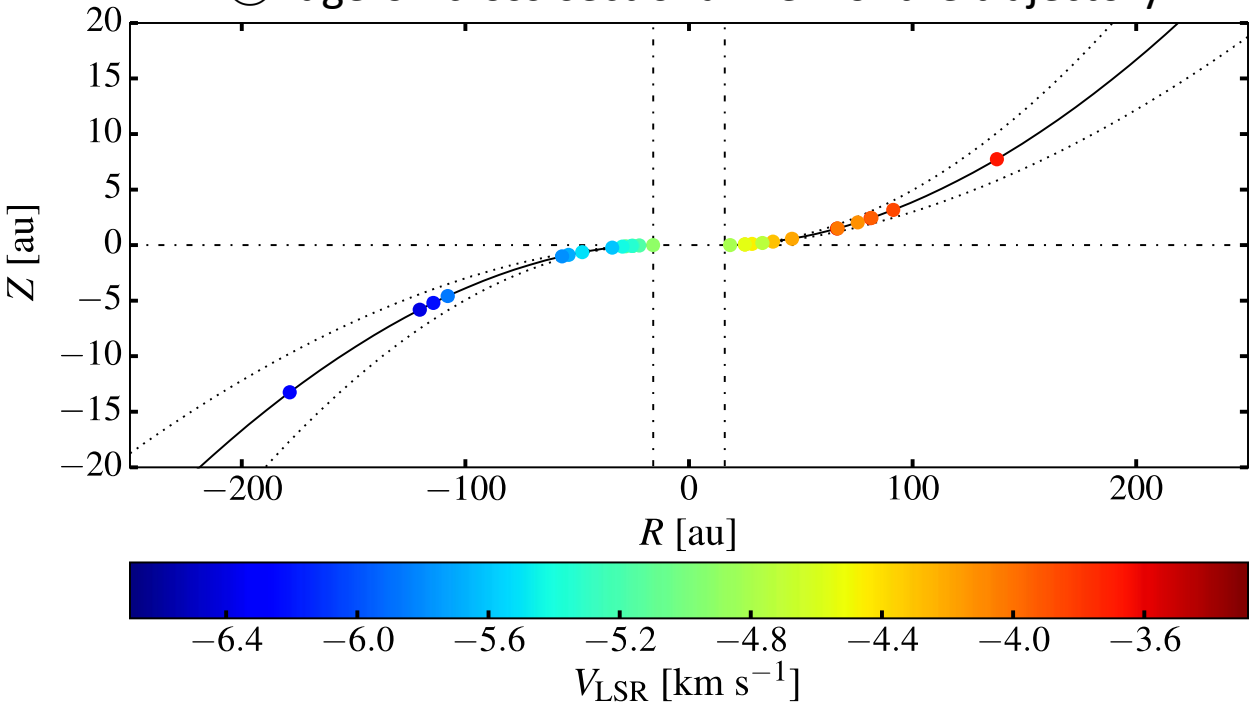
Maser Spectrum



- Multiple components

Edge-on view of the trajectory

◯Edge-on cross-sectional view of the trajectory



- The streamline is quasi-radial (Z/R < 0.1)

→Centrifugal force is basically negligible

!?