ALMA Observations of the Class I Protostar L1489 IRS: Misaligned Disk Structure

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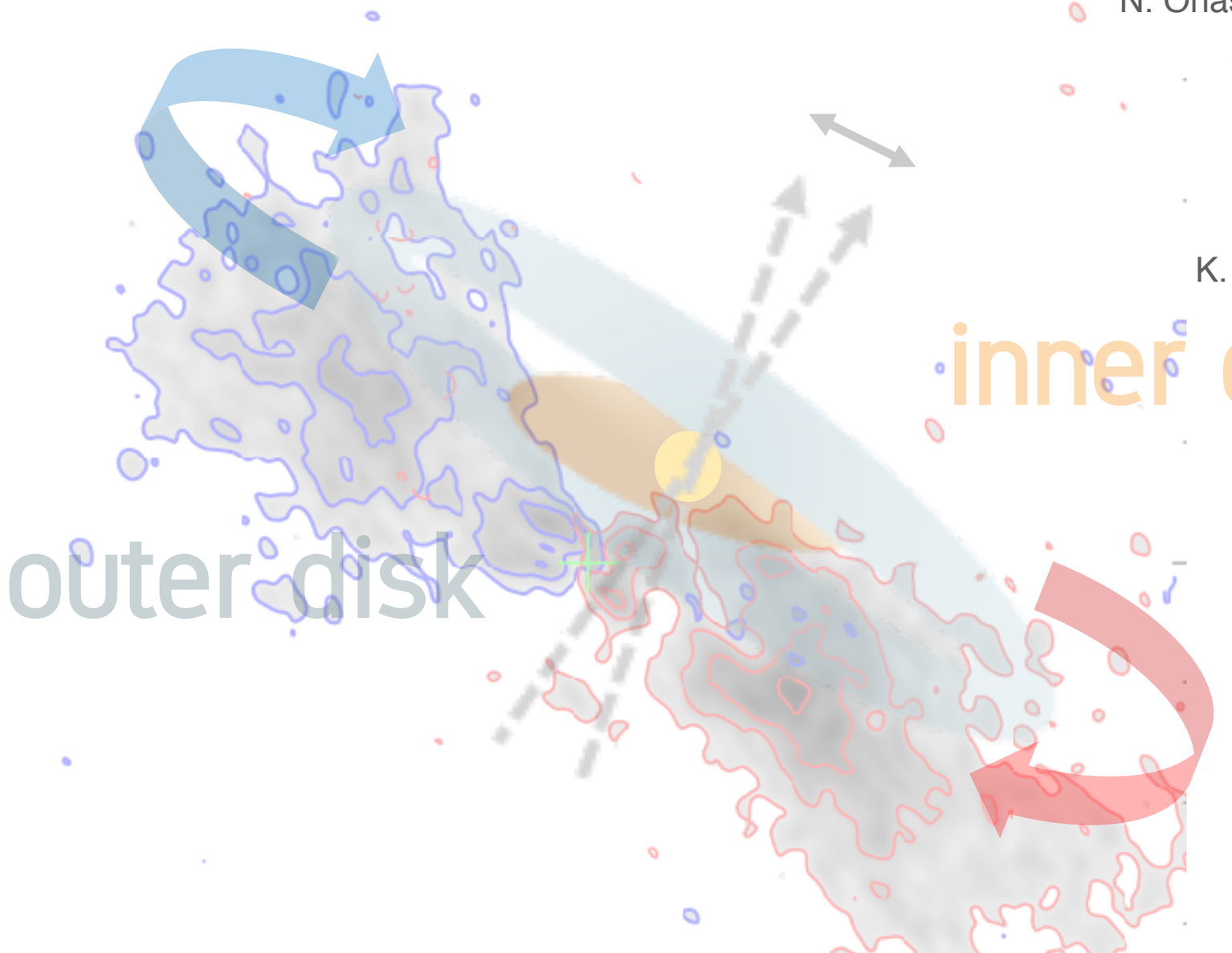
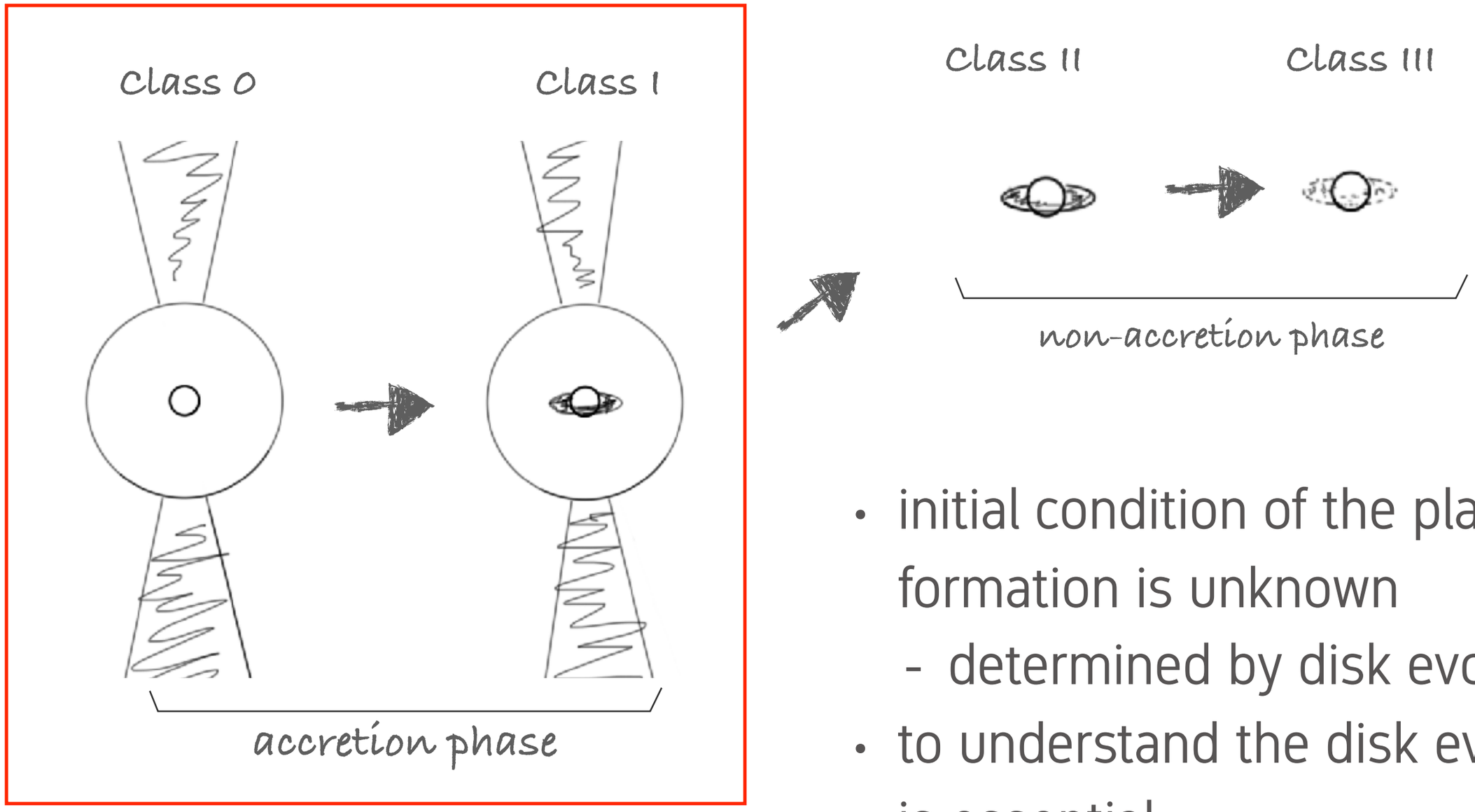


The Evolution of Circumstellar Disks



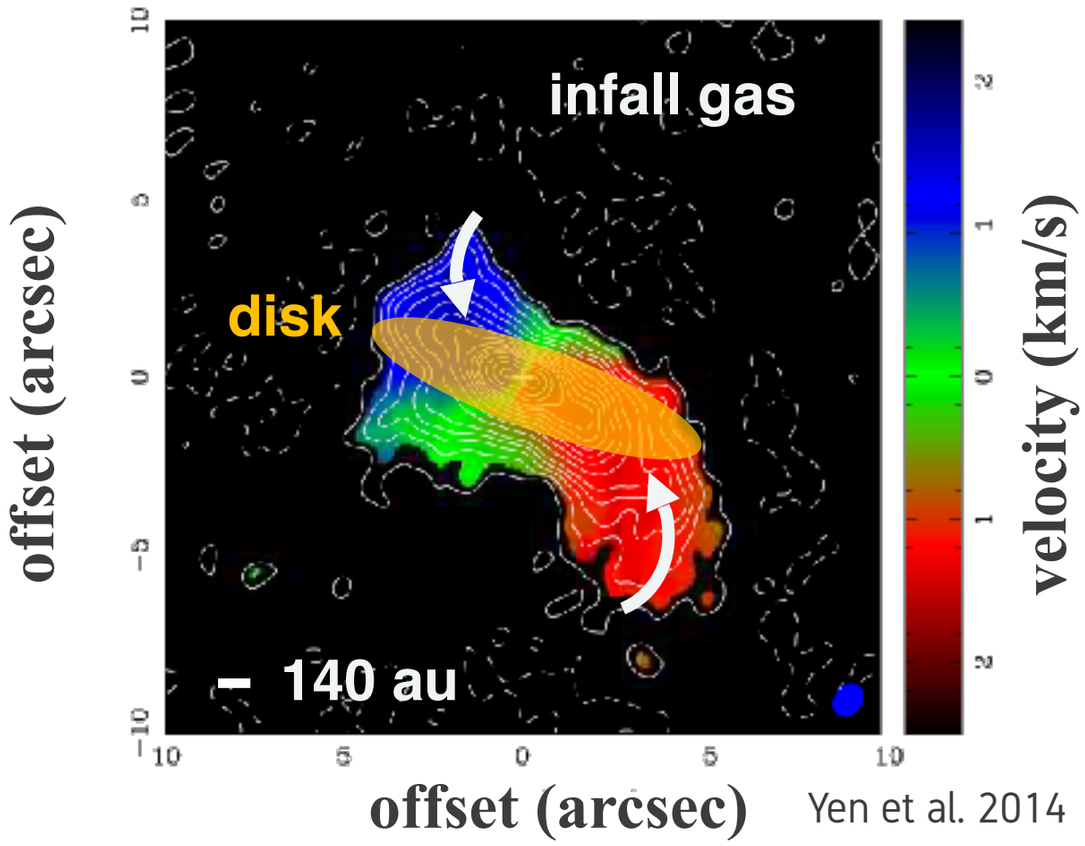
- initial condition of the planet formation is unknown
  - determined by disk evolution
- to understand the disk evolution is essential

It's needed to reveal disk kinematic structures

Class I Protostar L1489 IRS

- in Taurus molecular cloud (d =140 pc)
- M_{star} ~ 1.6±0.5 M_{sun}
- a large disk (r ~ 700 au) and an envelope
- two infall flows accreting at ~ 300 au on the disk
  - suggesting angular momentum is redistributed and it increase disk radius

$C^{18}O$ (2-1) image of Cycle 0 observations



Yen et al. 2014

Disk and infall gas are not spatially resolved

ALMA Cycle 2 Observations

Aim:

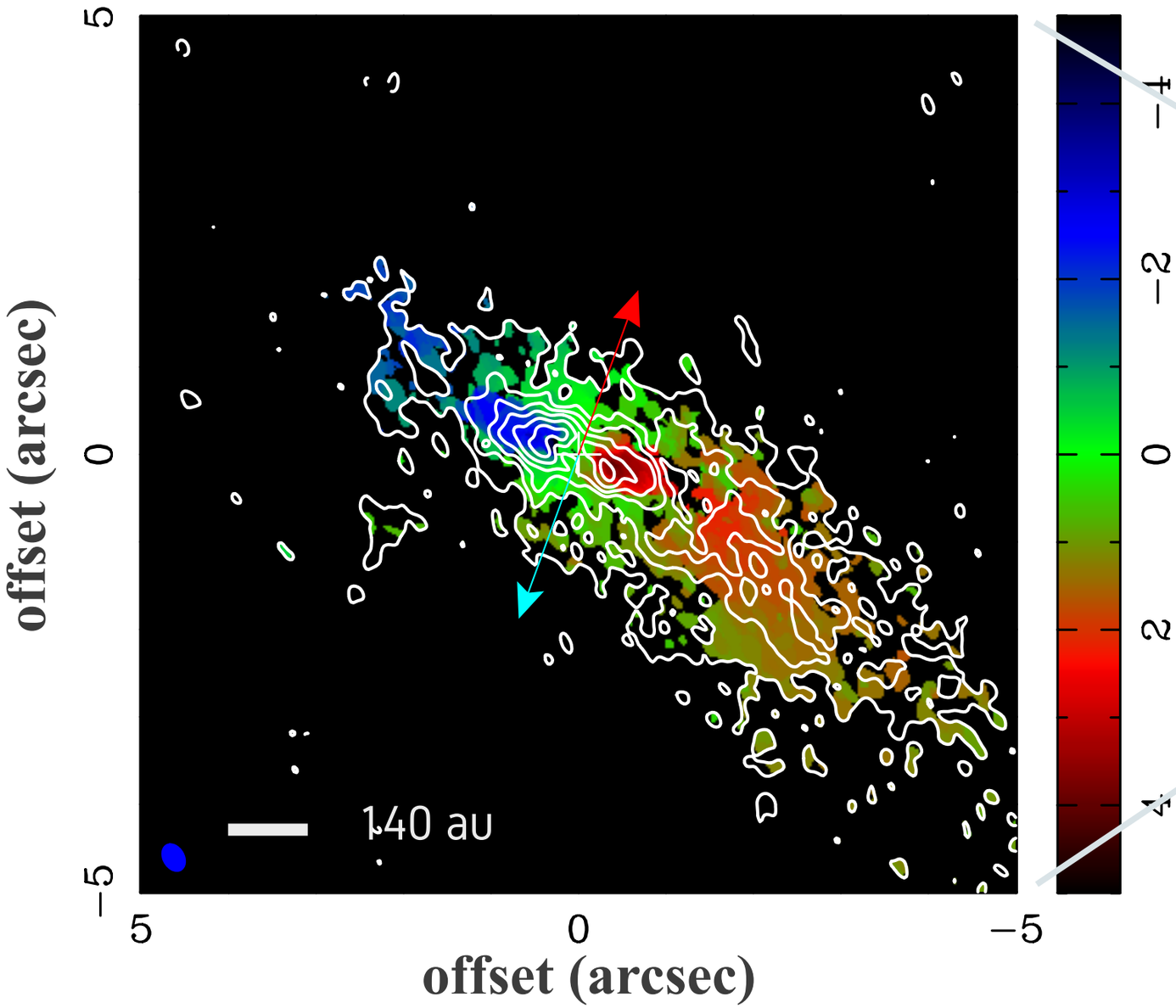
To resolve the Keplerian disk and the infalling gas in L1489 IRS to reveal the kinematic structure of the protostellar system

Observations:

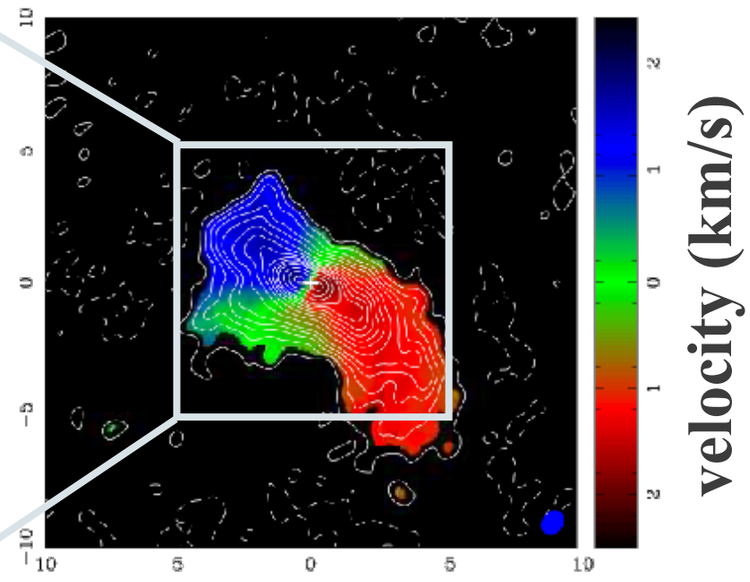
- project number: 2013.1.01086.S （PI: S. Koyamatsu）
- 1.3 mm continuum，^{12}CO, ^{13}CO, **C^{18}O (2-1)**, SO(6(5)-5(4))
- angular resolution: ~ 0”.34 x 0”.23
- velocity resolution: 0.17 km/s
- rms: 5.1 mJy/beam

$C^{18}O$ Moment 0/I Map

Cycle 2: beam size: 0.33” x 0.24”



Cycle 0
beam size: 0.96” x 0.75”



The inner disk is spatially resolved

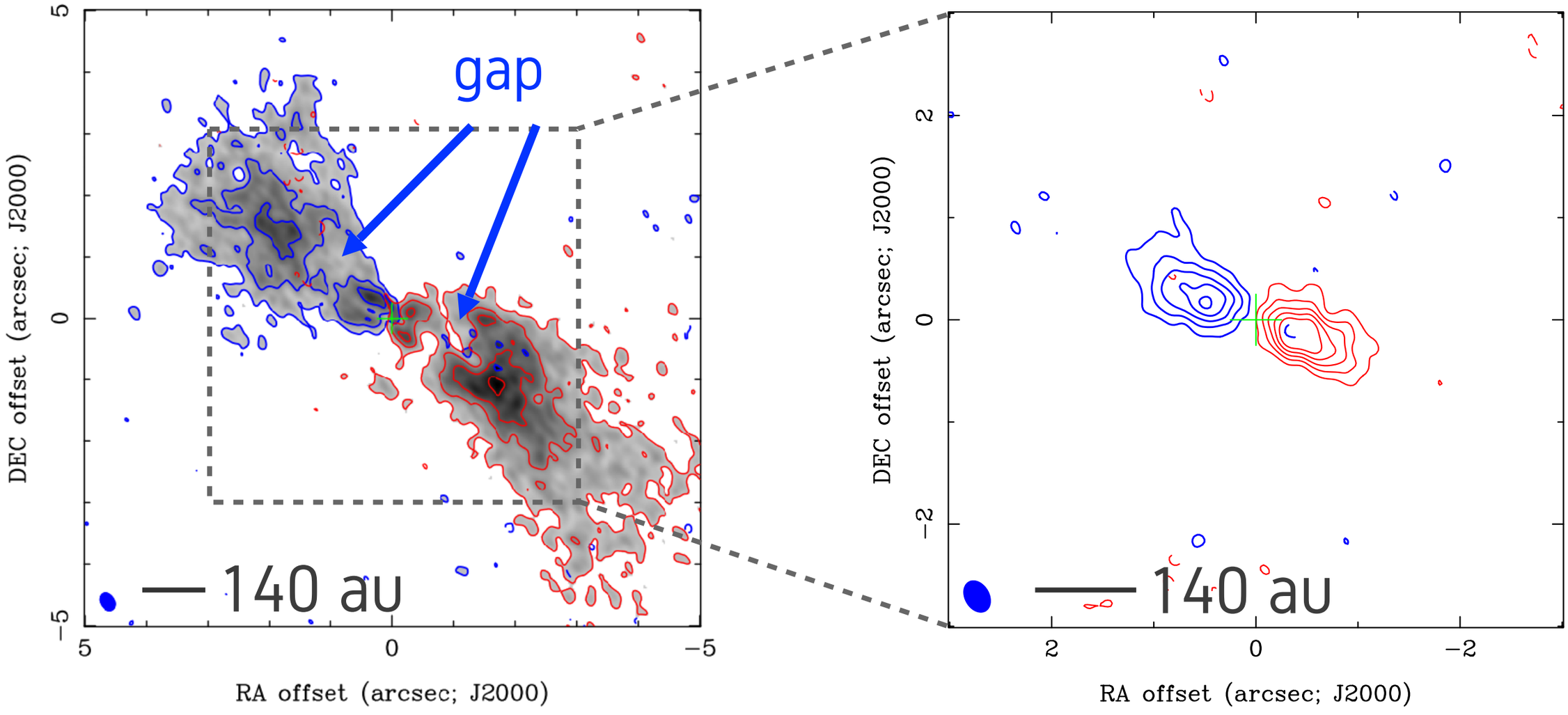
$C^{18}O$ 2-1 High/low Velocity Moment 0 Map

low velocity component

(velocity range: ± 1.19 ~ 2.21 km/s)

high velocity component

(velocity range: ± 2.55 ~ 4.59 km/s)



a gap structure separating the rotating gas into inner disk and outer part

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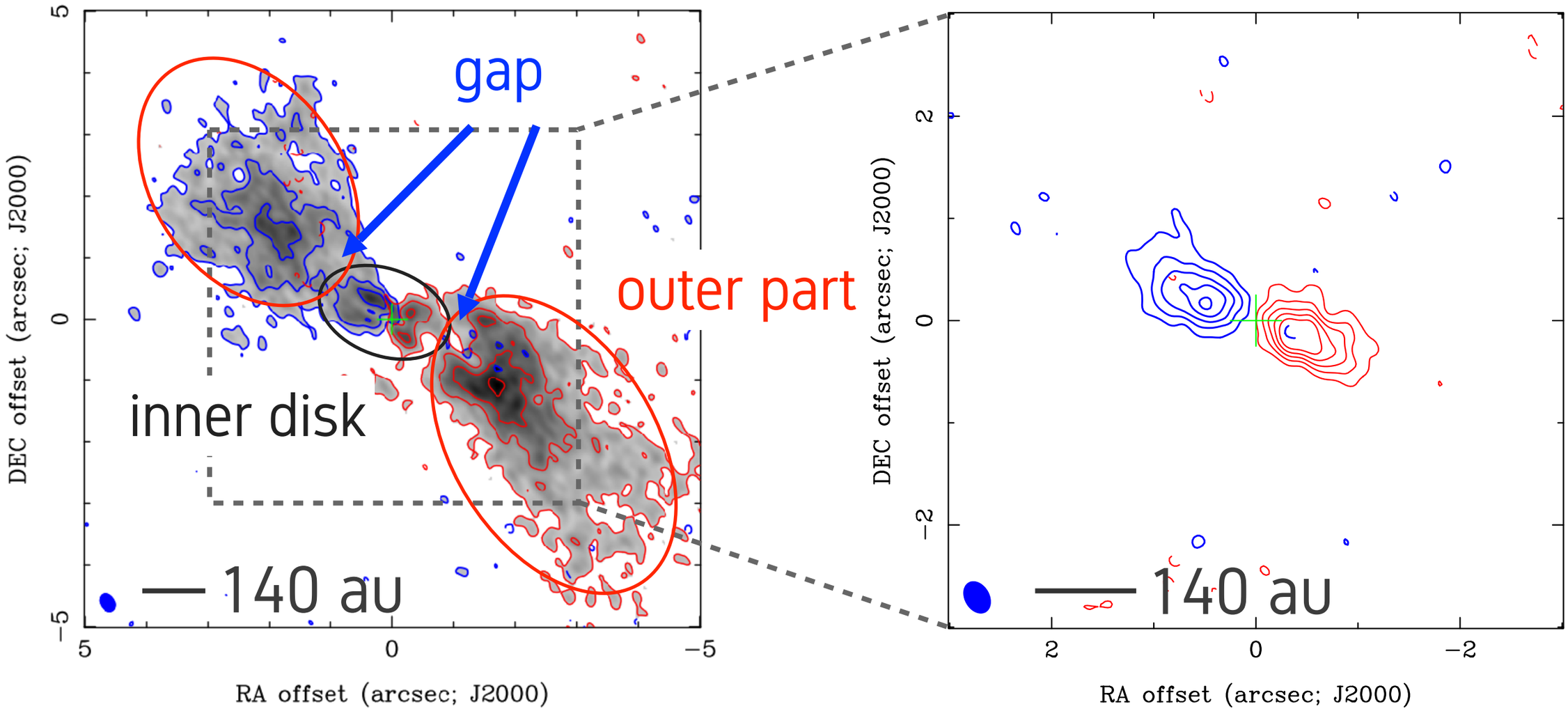

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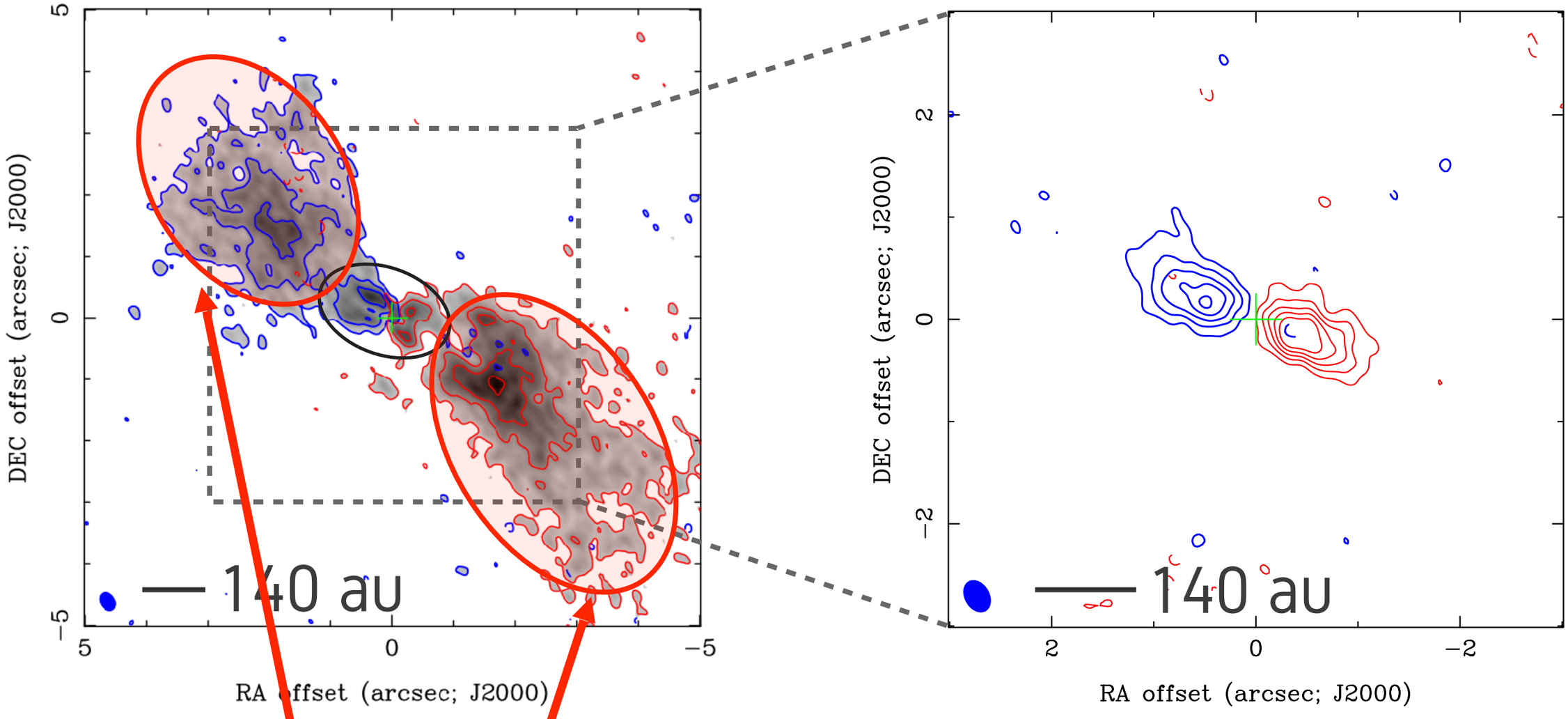
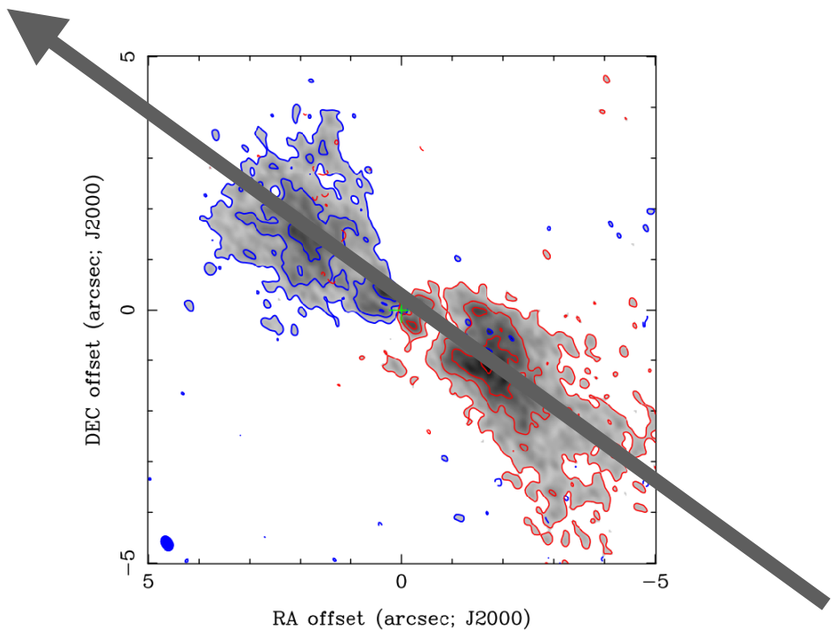
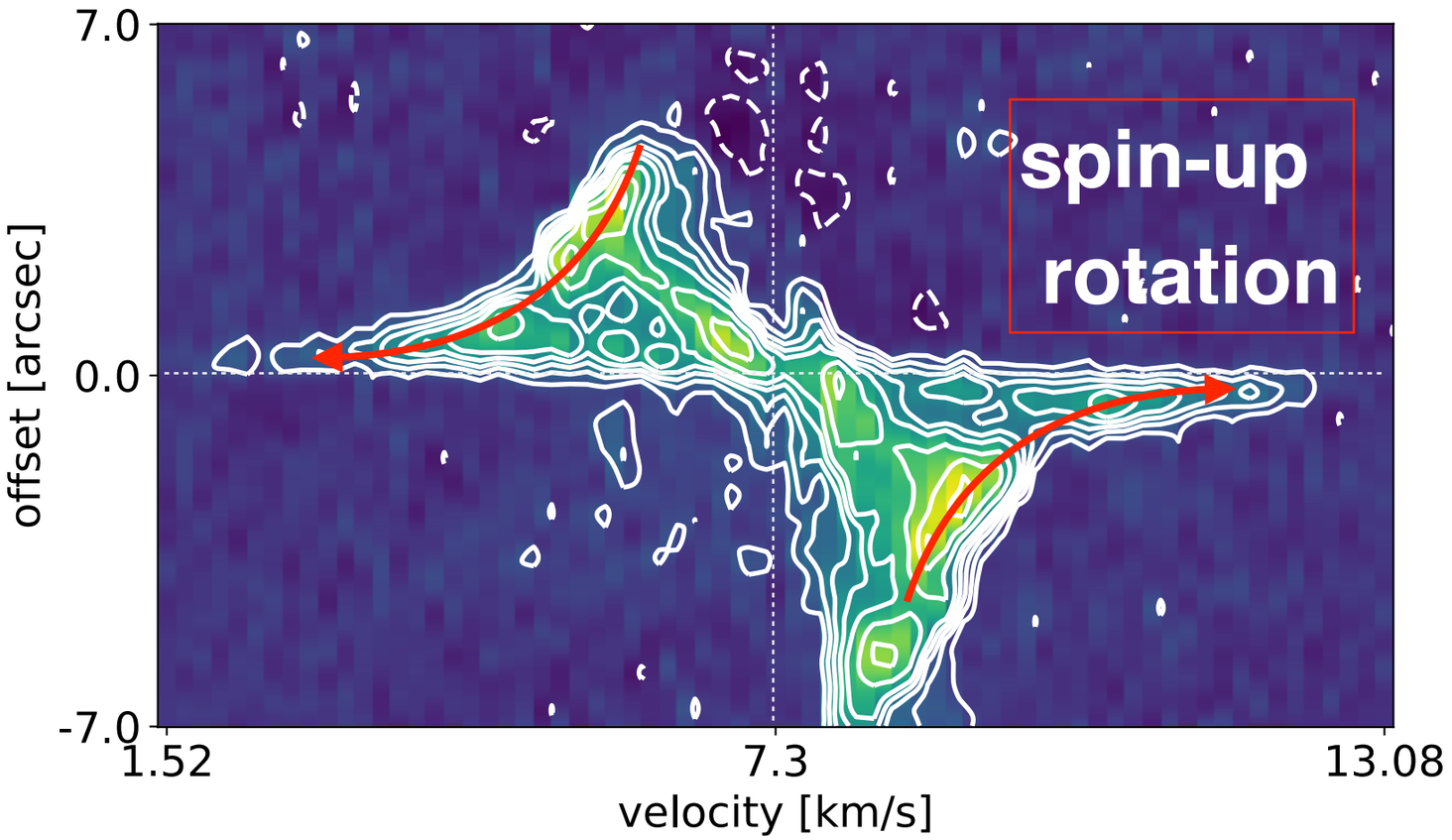


What is this outer part?

Velocity Structure of the Outer Part





- Spin-up rotation implies
  - Keperian disk

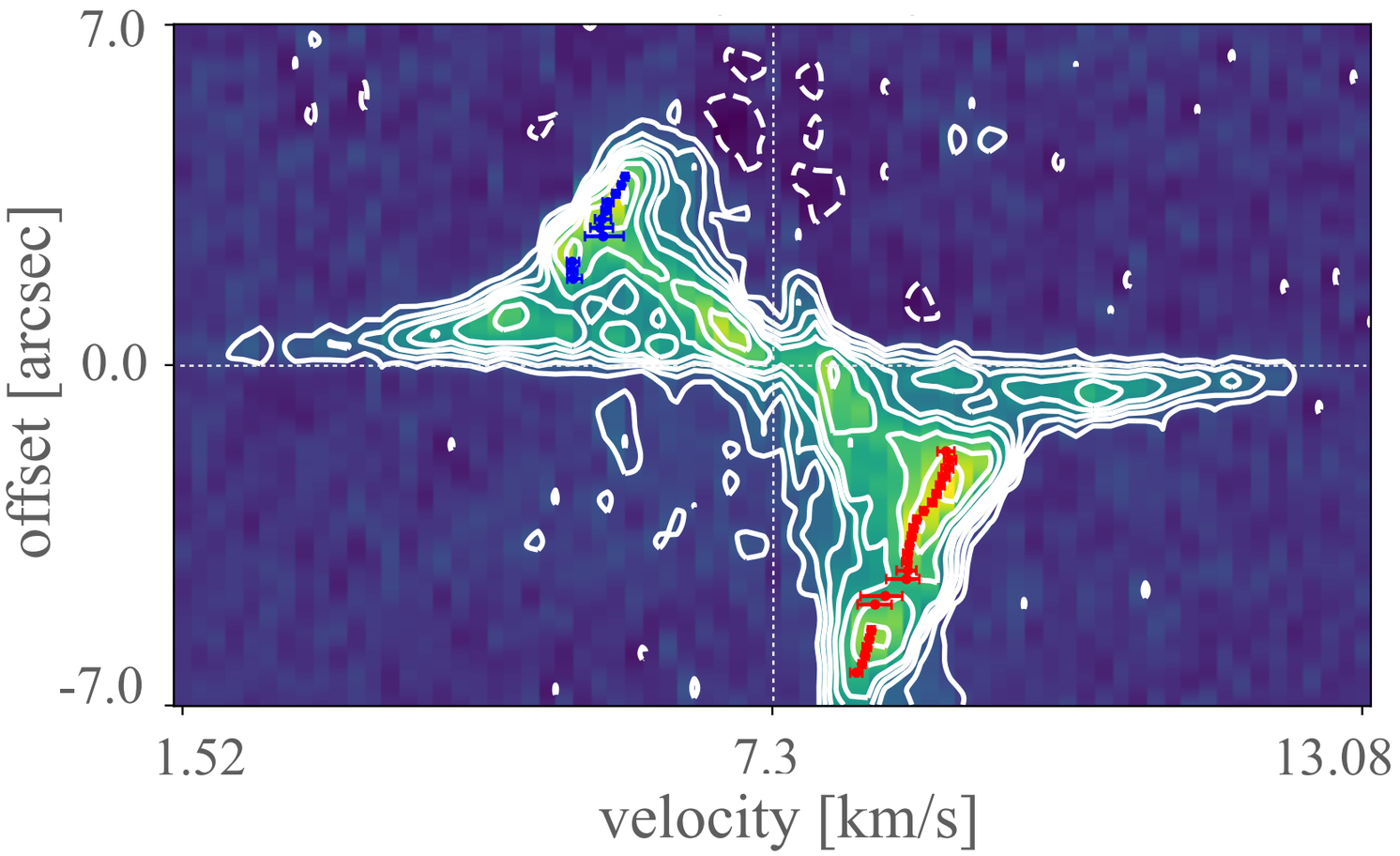
$$V_{\rm rot} = \sqrt{\frac{GM_*}{r}} \propto r^{-0.5}$$

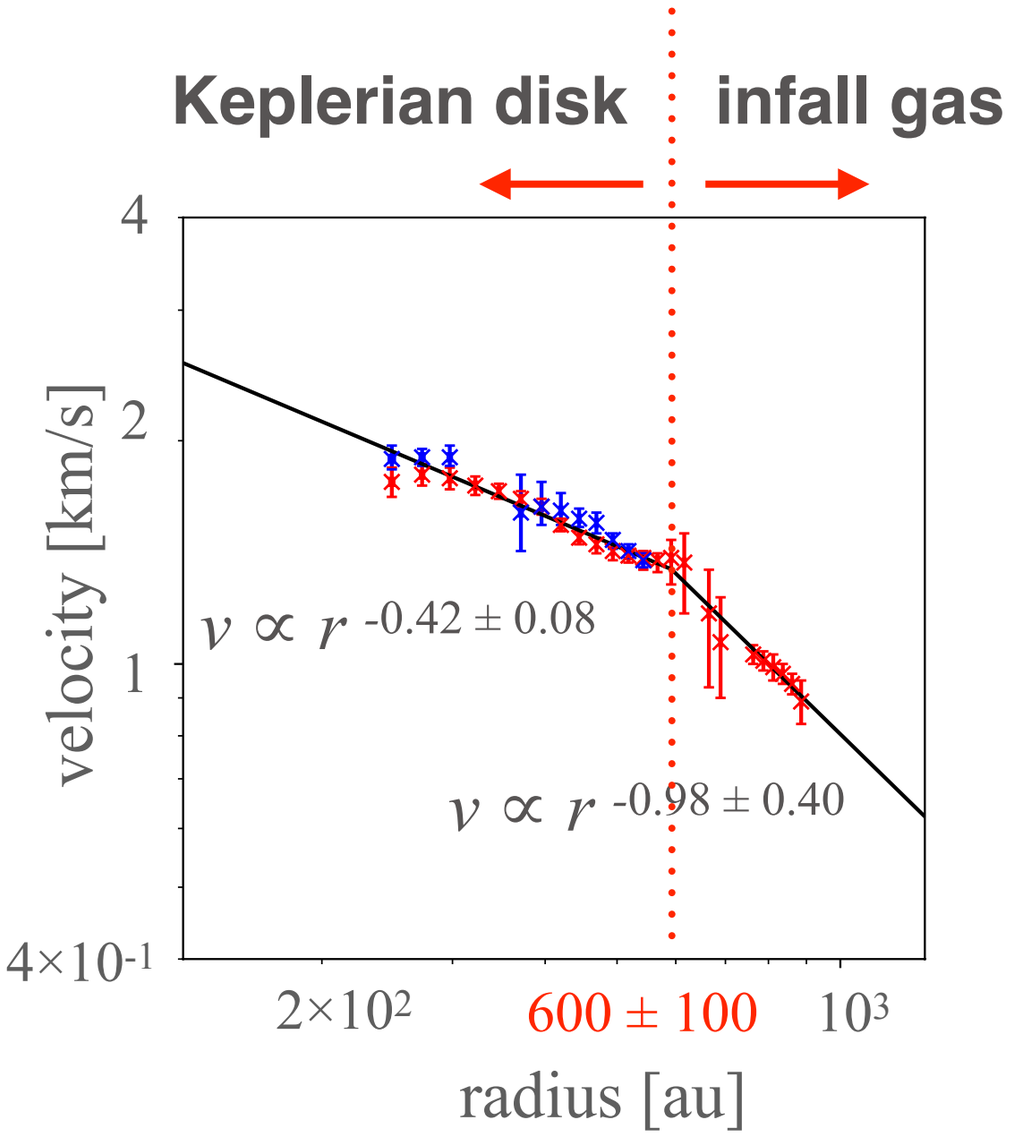
or

  - infall gas conserving angular momentum

$$V_{\rm rot} = \frac{j}{r} \propto r^{-1}$$

Keplerian Disk or Infall flows ?





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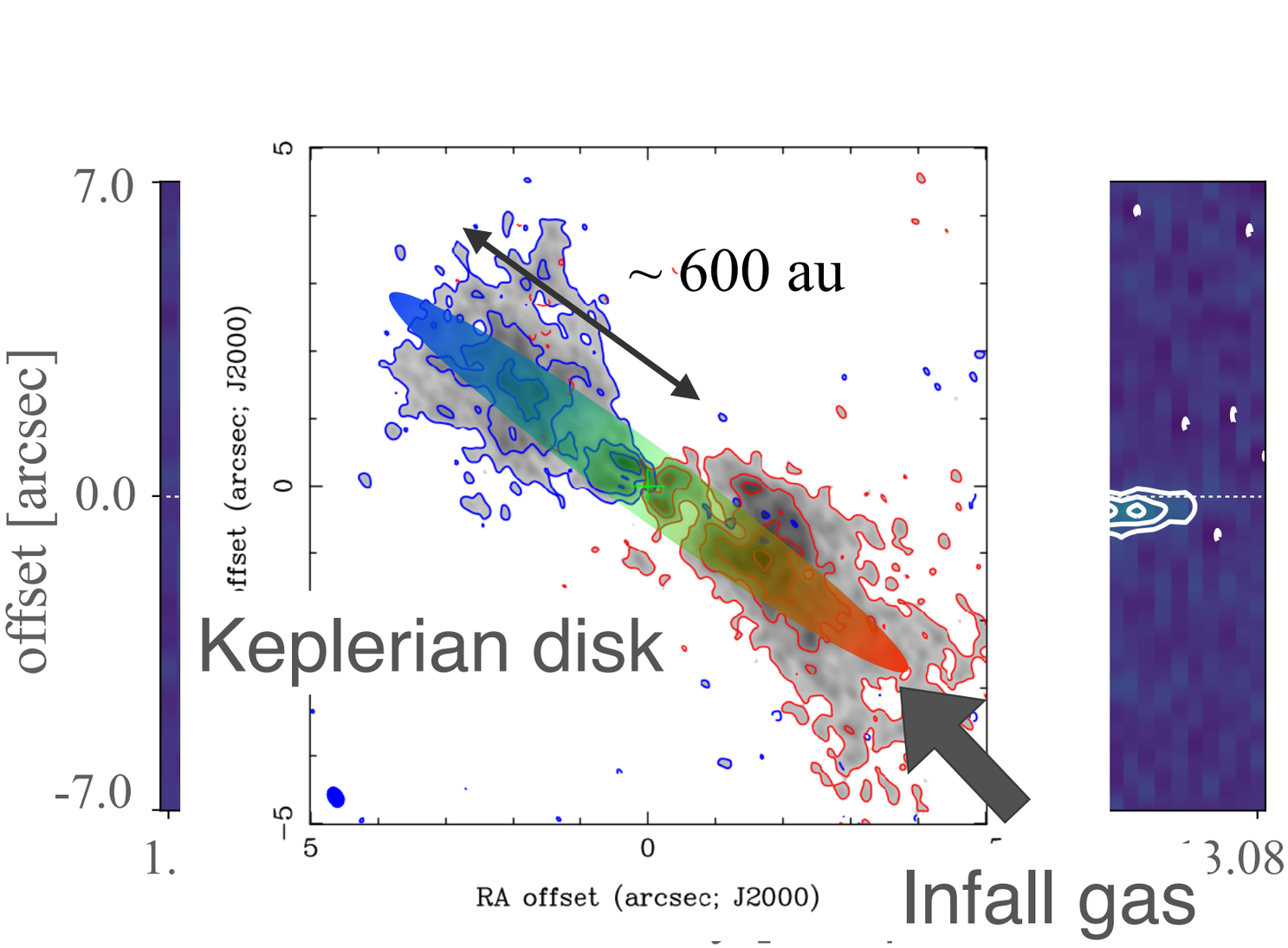
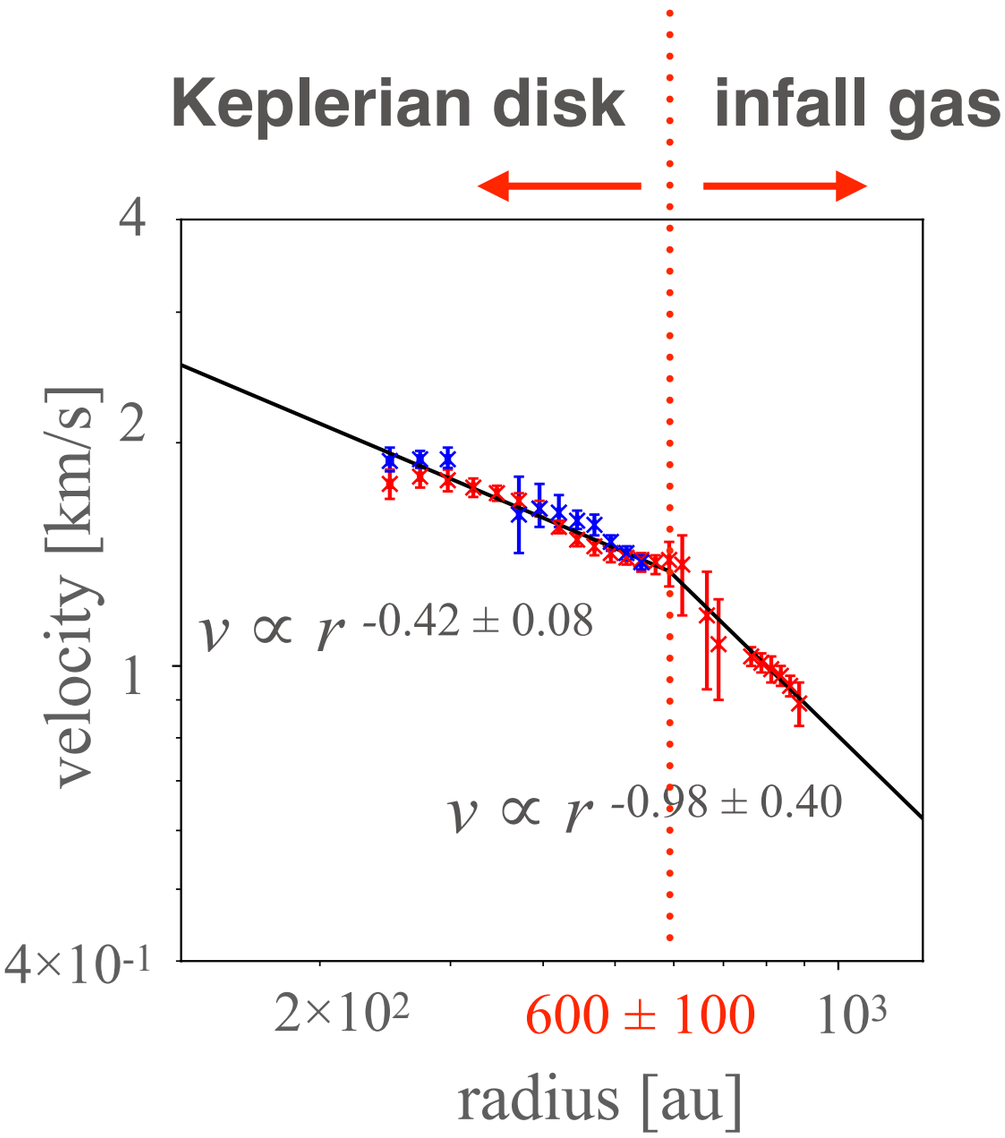




The outer part is almost a Keplerian disk

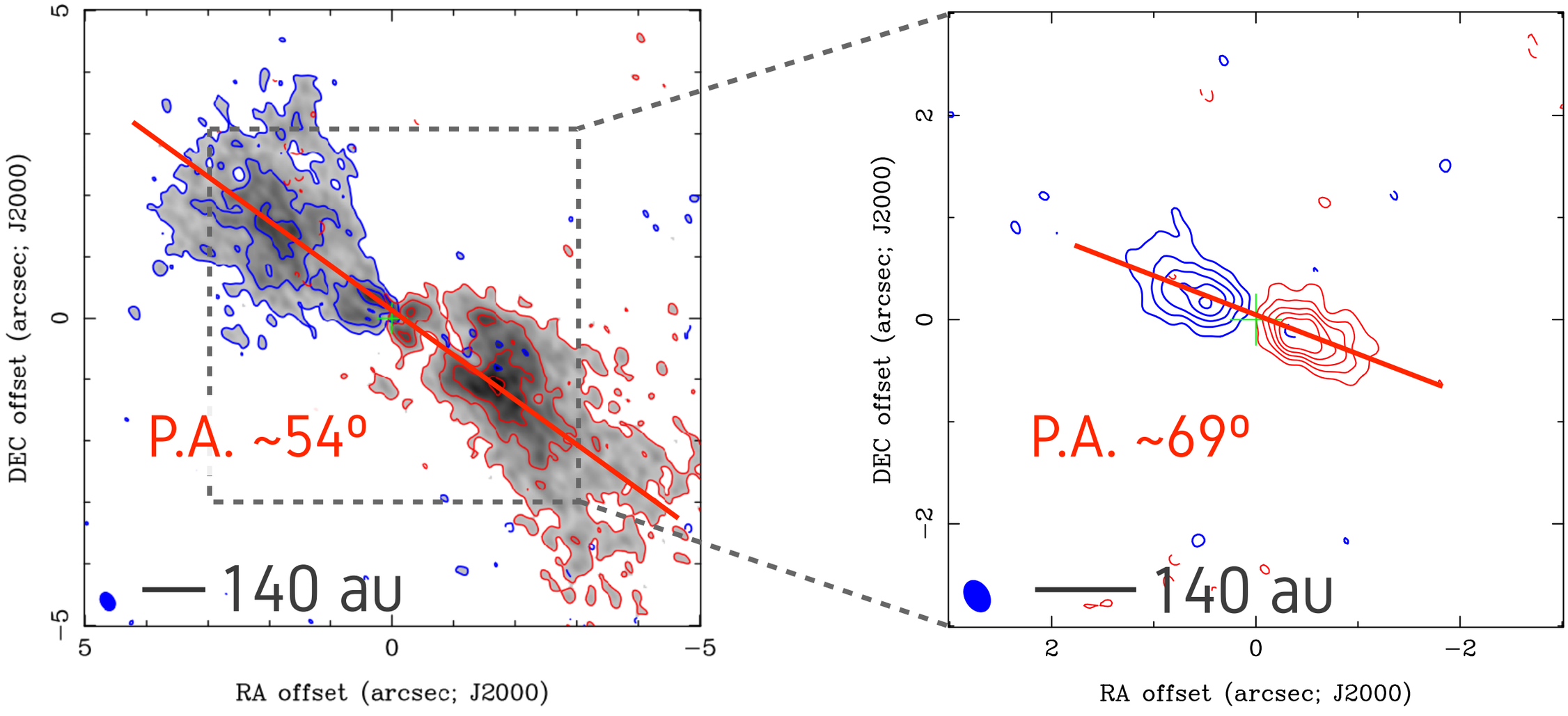
$C^{18}O$ 2-1 High/low Velocity Moment 0 Map

low velocity component

(velocity range: ± 1.19 ~ 2.21 km/s)

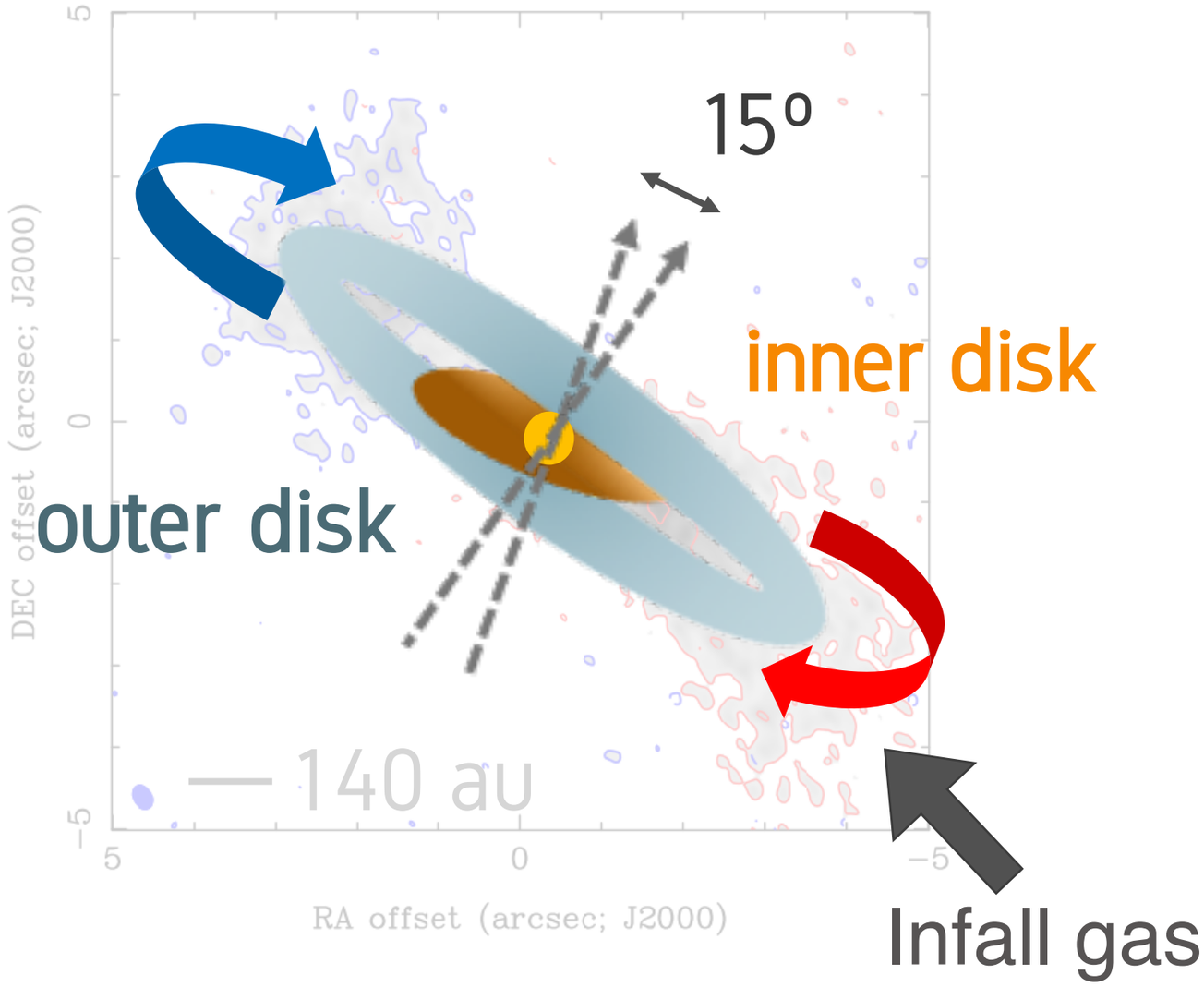
high velocity component

(velocity range: ± 2.55 ~ 4.59 km/s)



The inner disk and the outer disk are misaligned

Short Summary



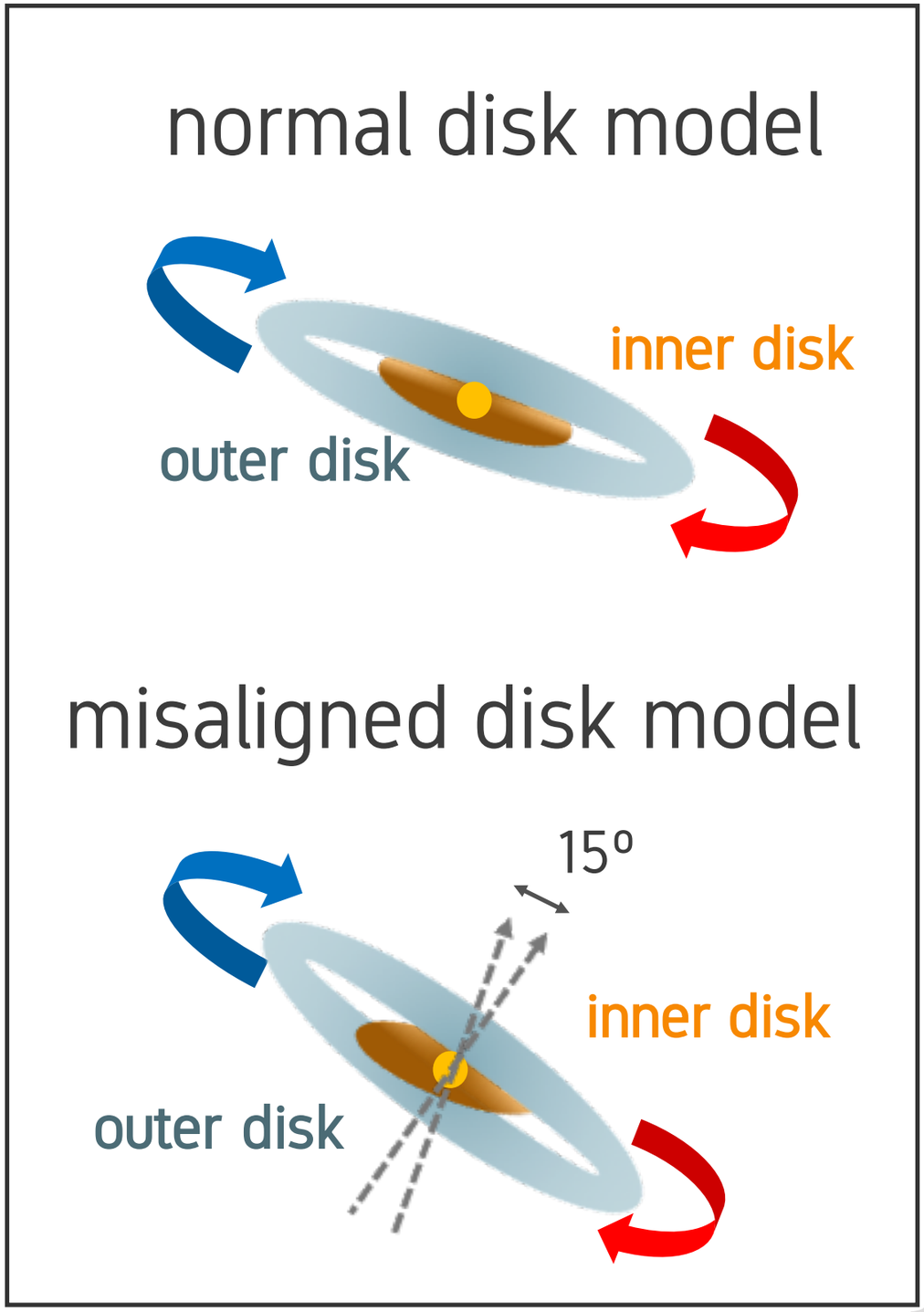
misaligned disks

+

an infall gas

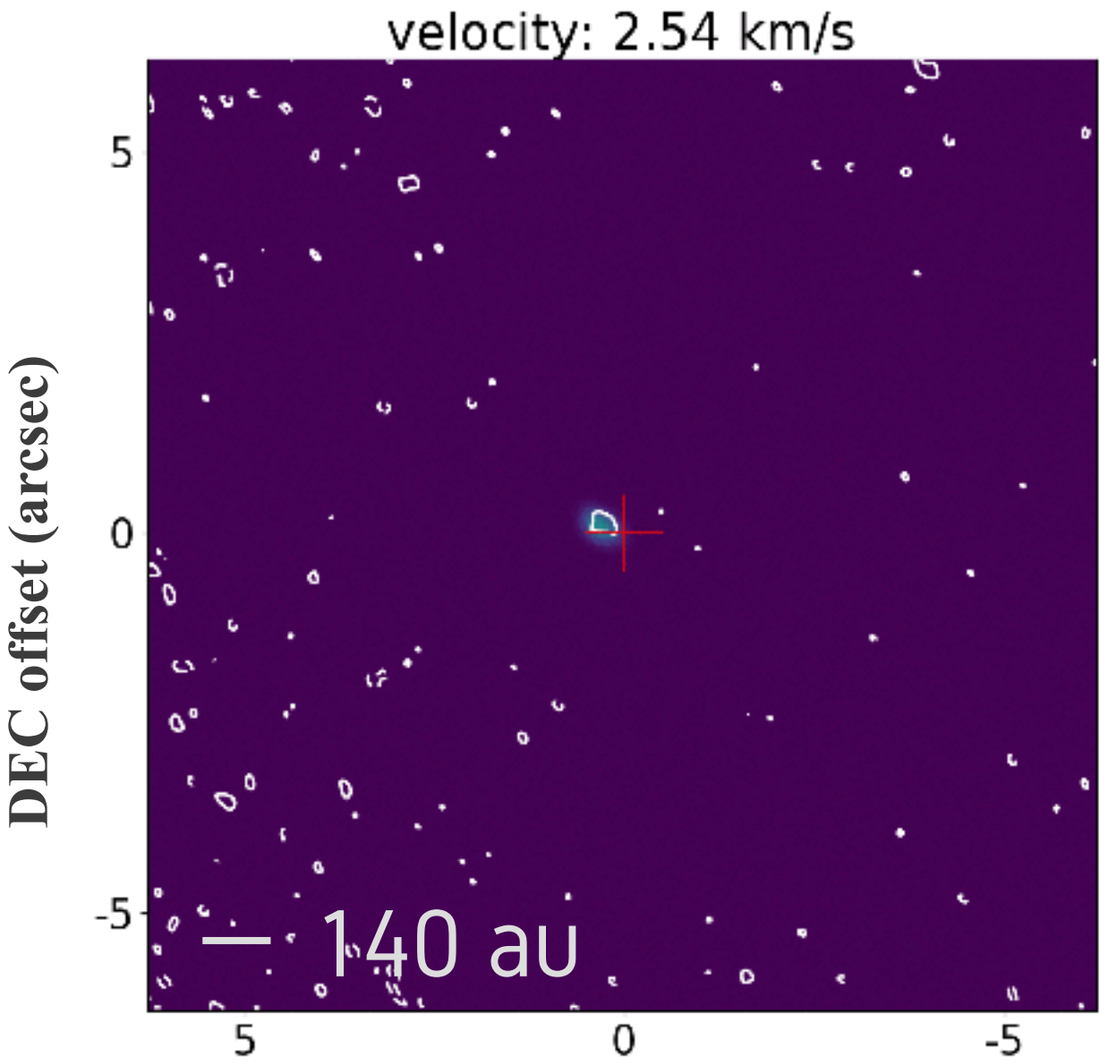
3D Simple Disk Model

- 3D Gap Disk Model
  - inner disk: 0.1 - 220 au
  - outer disk: 320 - 700 au
  - a gap at 220 - 320 au
- comparing 2-type models
  - parallel disks
  - misaligned disks
- solve radiative transfer and observe by CASA simulator

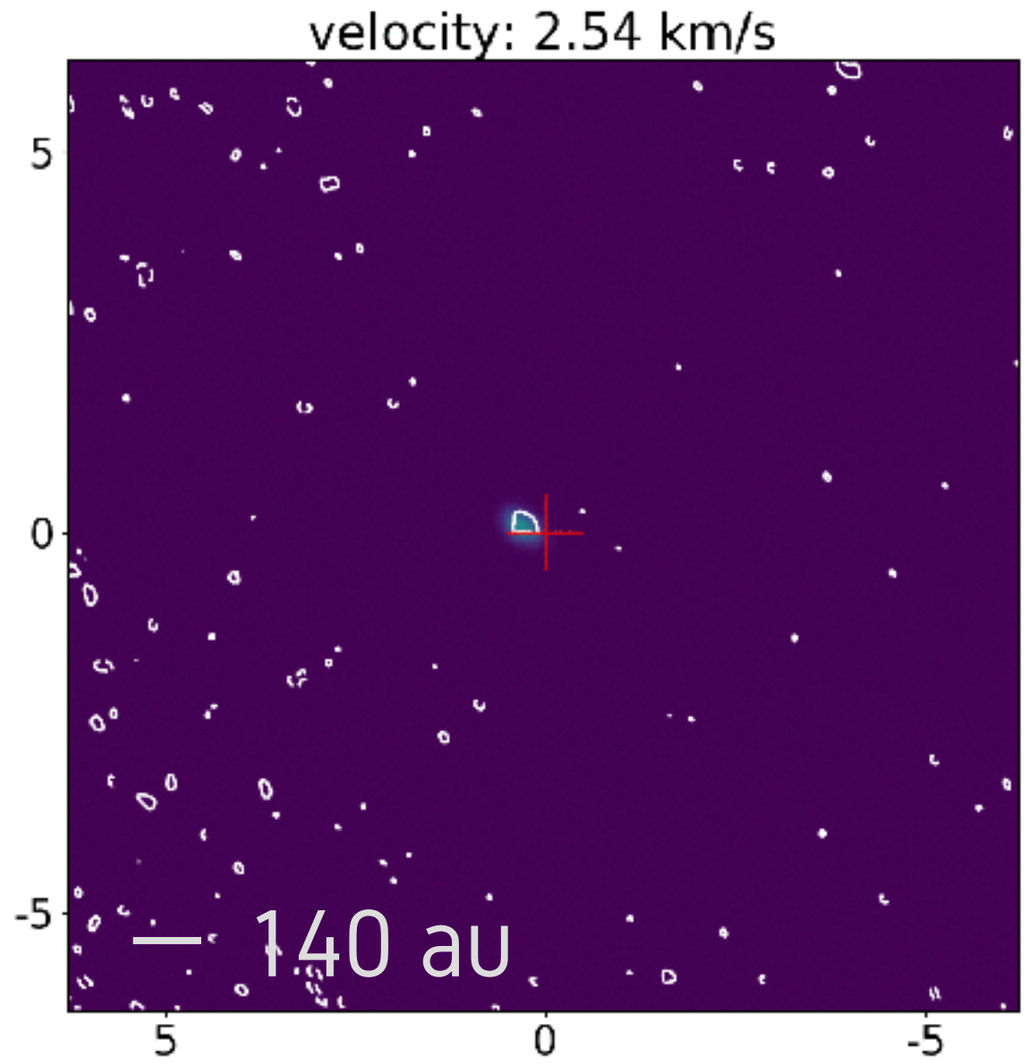


3D Model vs Observations

normal disk model



misaligned disk model (15º)



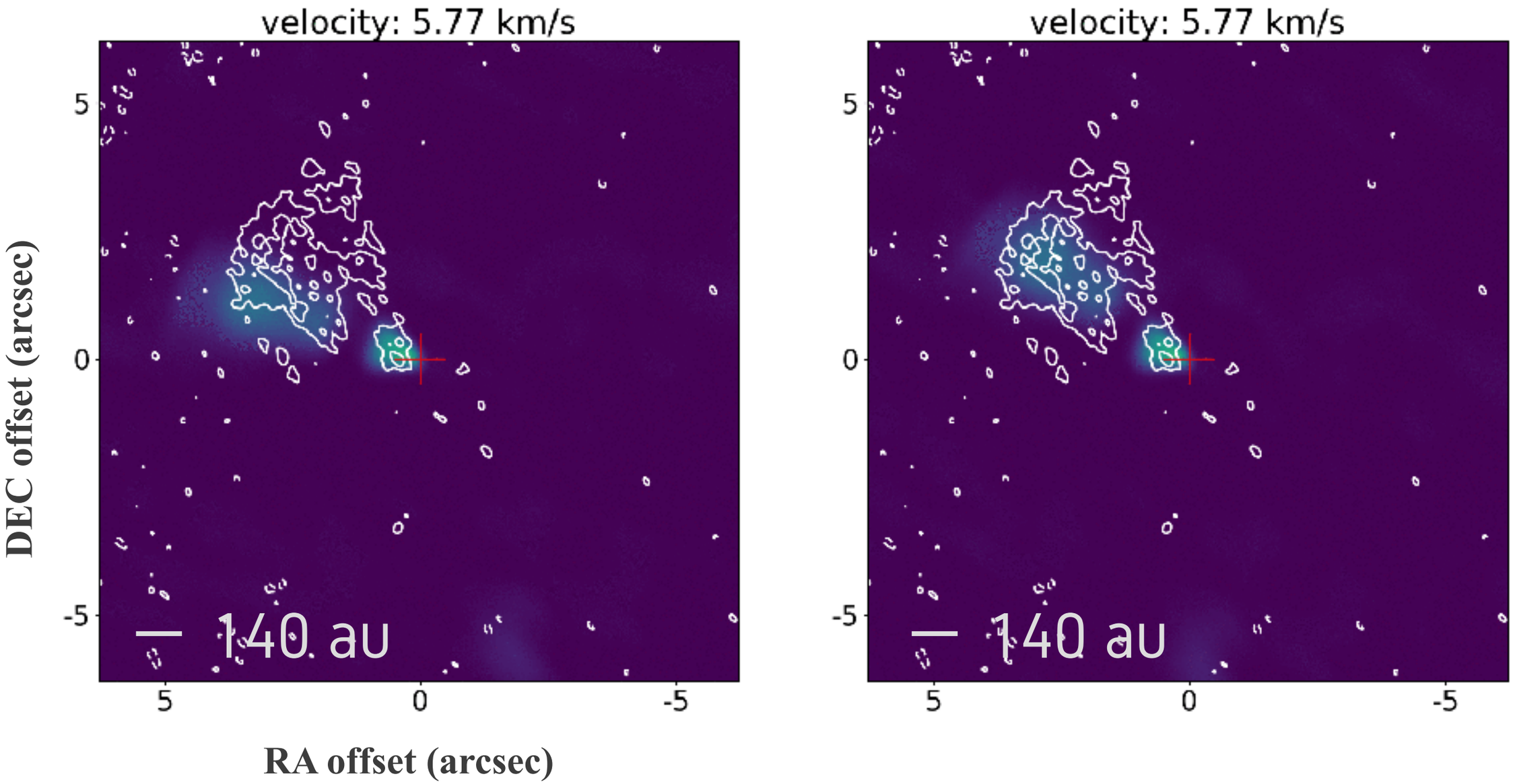
color: model

contour: observations

3D Model vs Observations

normal disk model

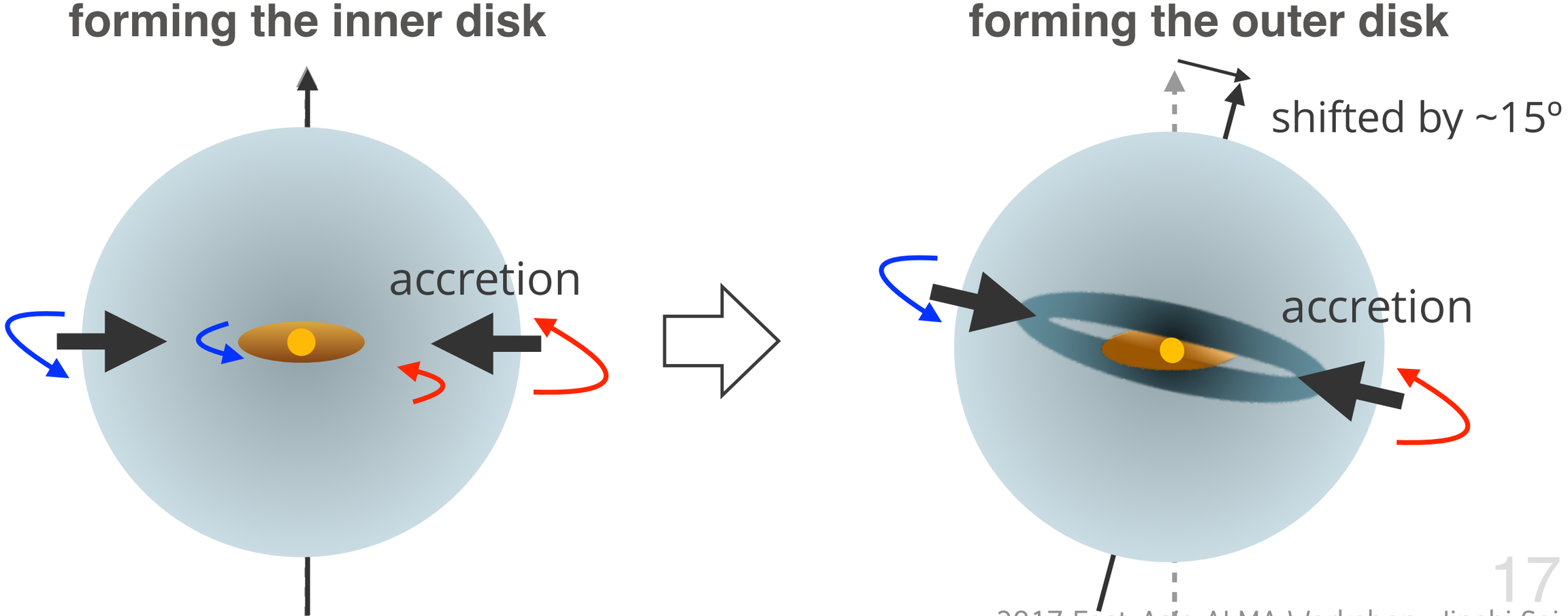
misaligned disk model (15º)



the Inner and outer disks are misaligned

How Are the Disks in L1489 IRS Formed?

- accretion from an envelope having different rotational axis from that of the inner disk
- Theoretical calculations suggest such envelope can be formed in a turbulent and magnetized core (Matsumoto et al. 2017)
- accretion from an envelope to a disk is not uniform?



Summary

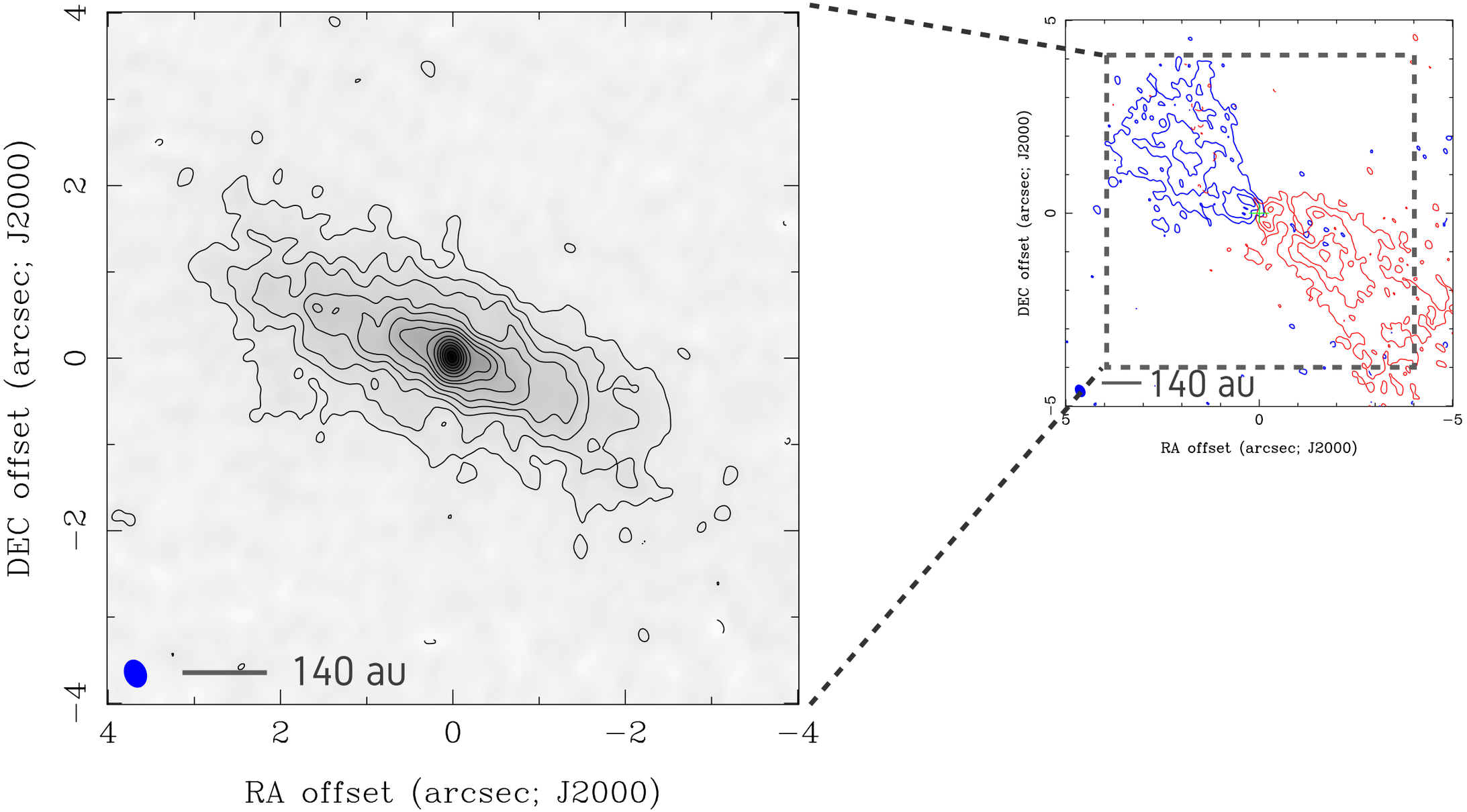
We observed the Class I protostar L1489 IRS at high spatial resolution (~ 0.34”) with ALMA

We revealed that

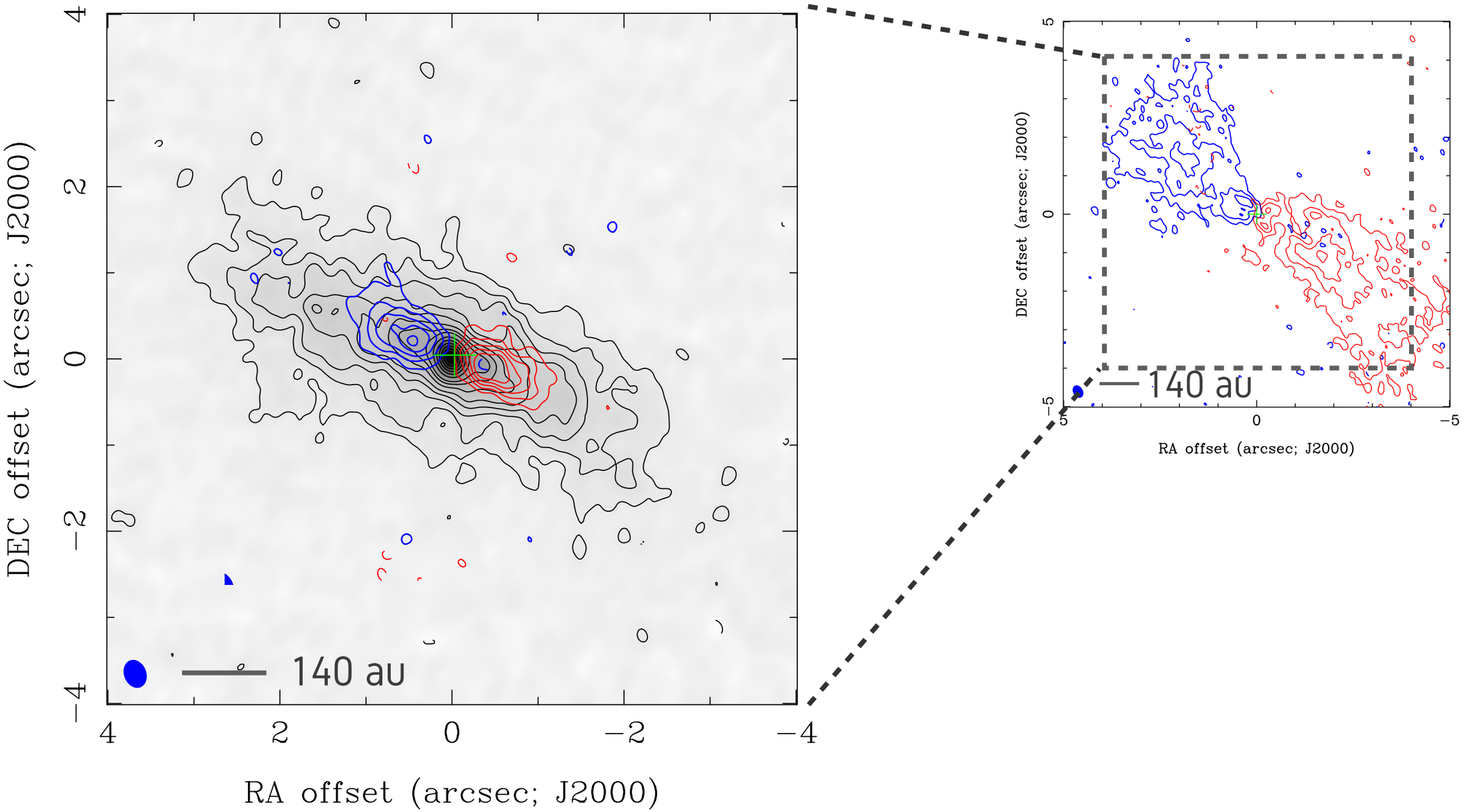
- a gap structure separates Keplerian disks
- Keplerian disks consist of the inner and outer disks
- the outer disk radius is ~ 600 au
- the inner disk and the outer disk are misaligned
  - formed by accretion flows having different rotational axis from disks ?
  - suggesting that accretion flows from an envelope onto a disk during accretion phase are not uniform

Back Up

1.3 mm Continuum



1.3 mm Continuum vs $C^{18}O$ 2-1



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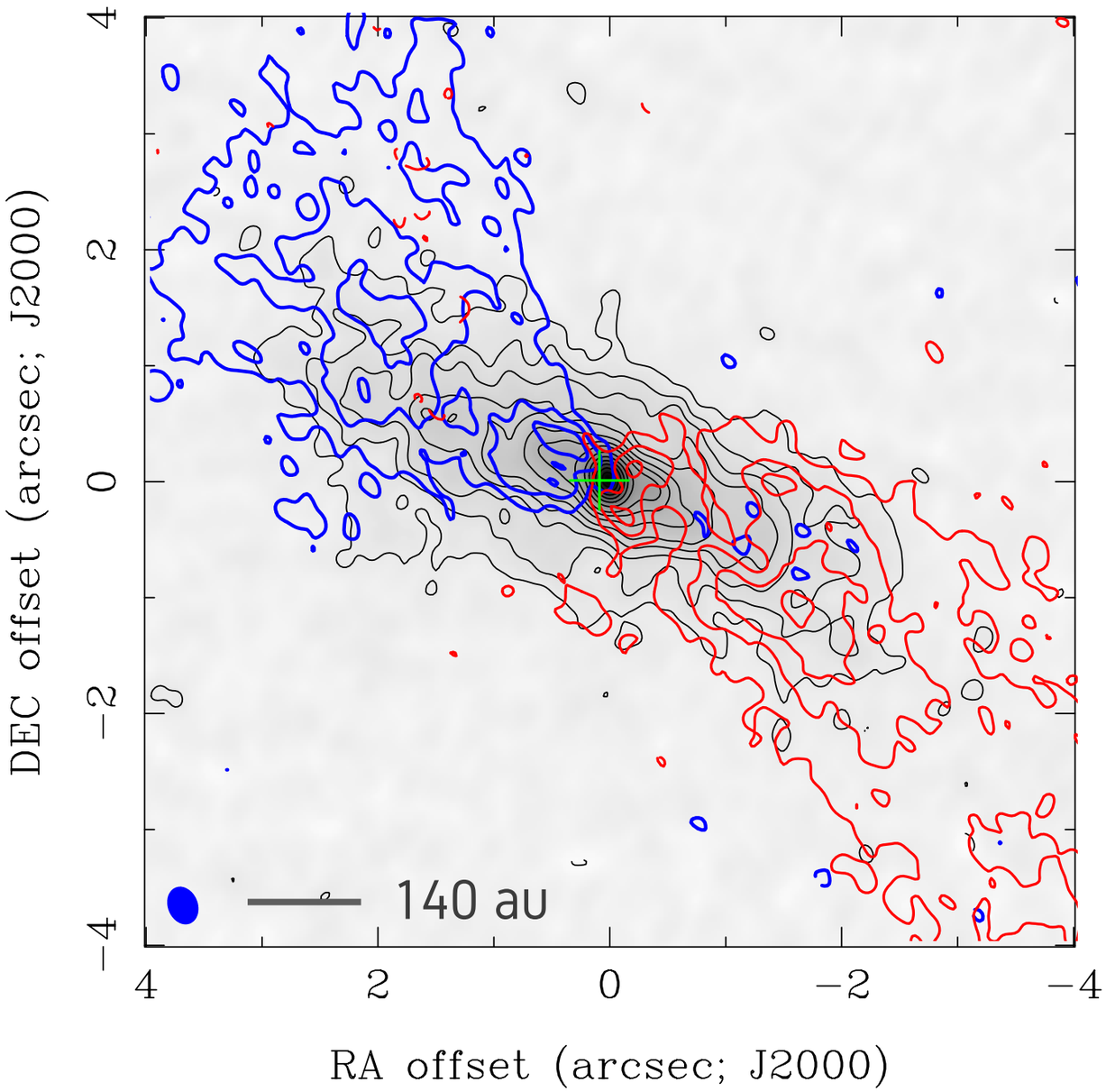
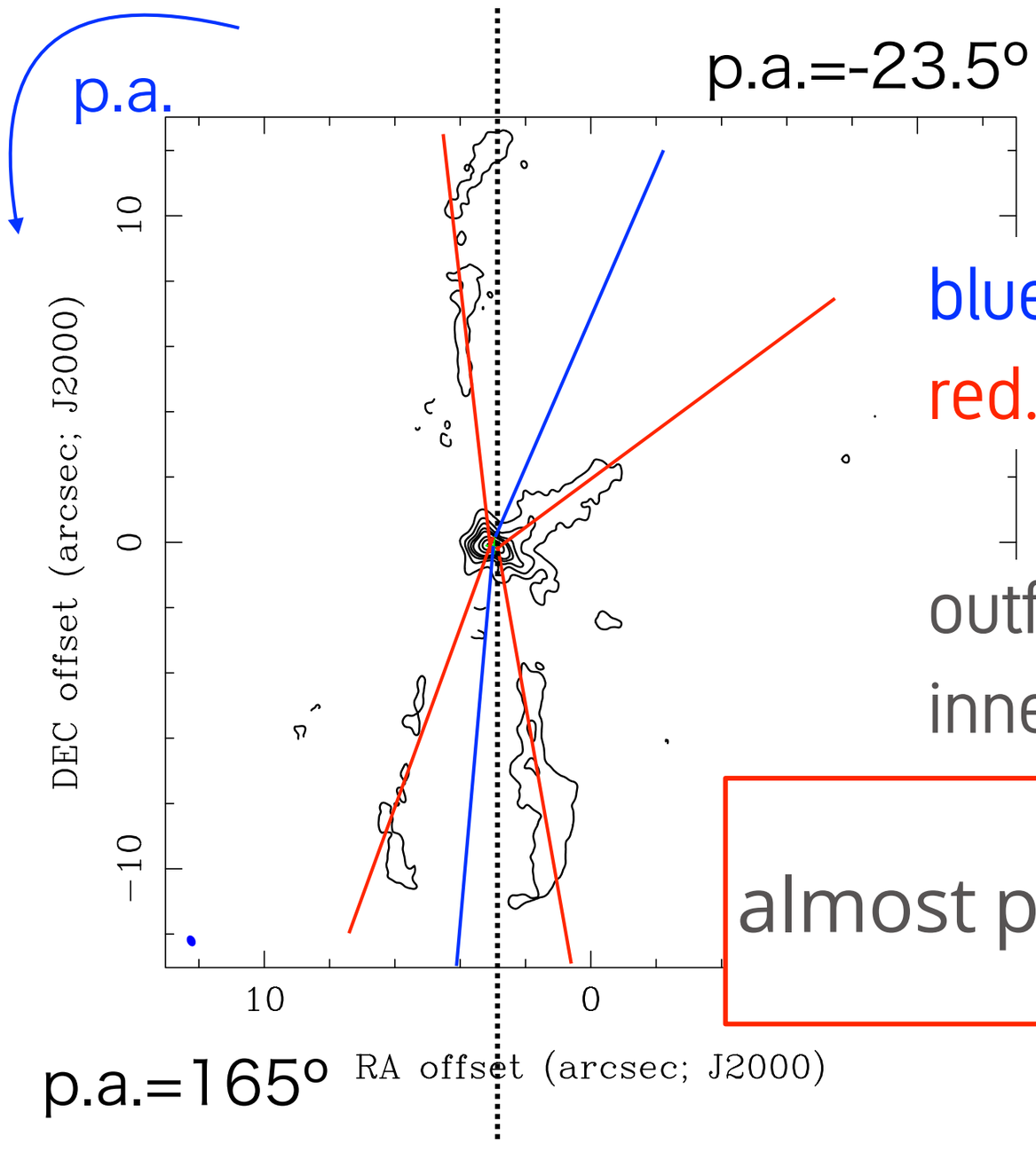


Outflow Directions

^{12}CO 2-1 moment 0 map



blue...outflow direction

red...opening angle

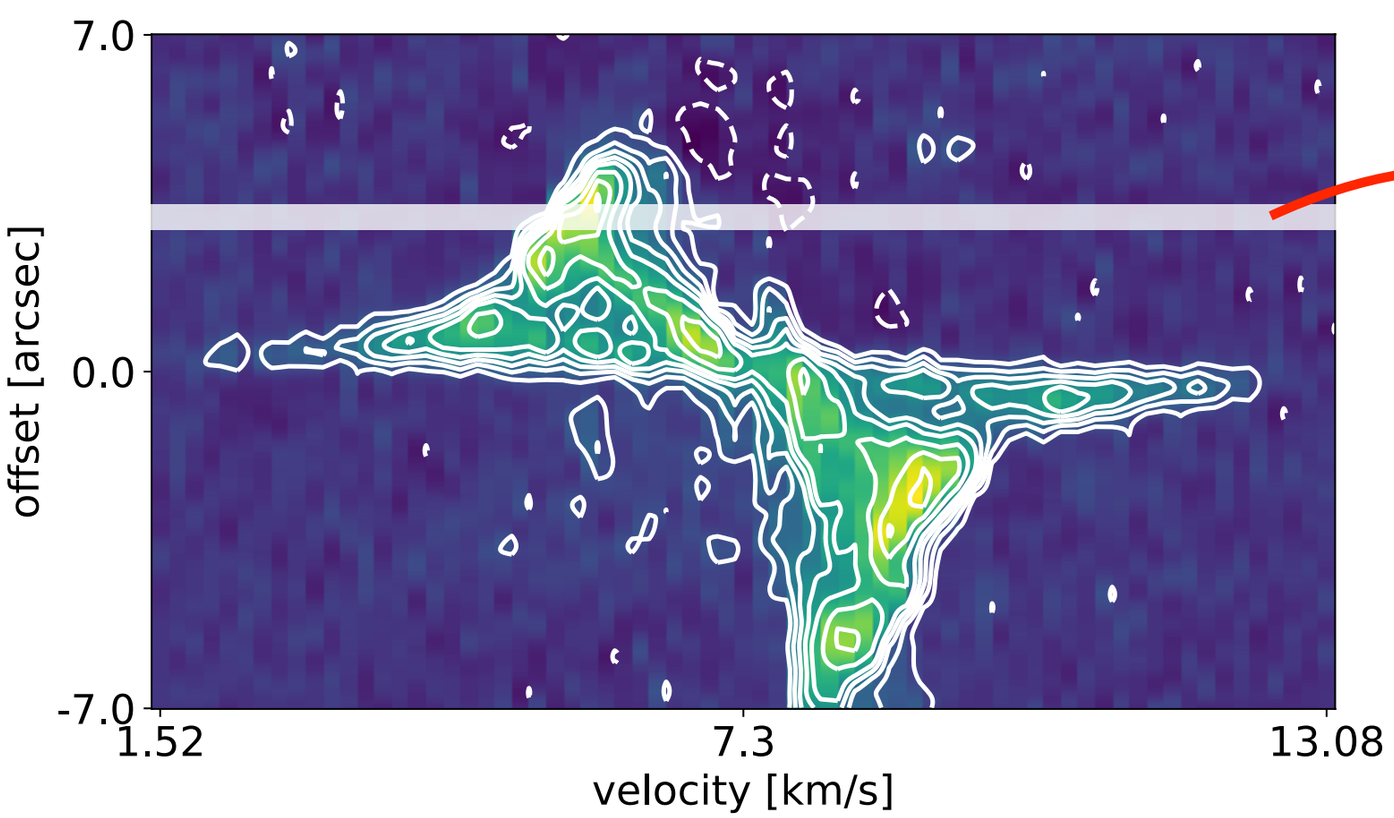
outflow direction: - 23.5º / 165º

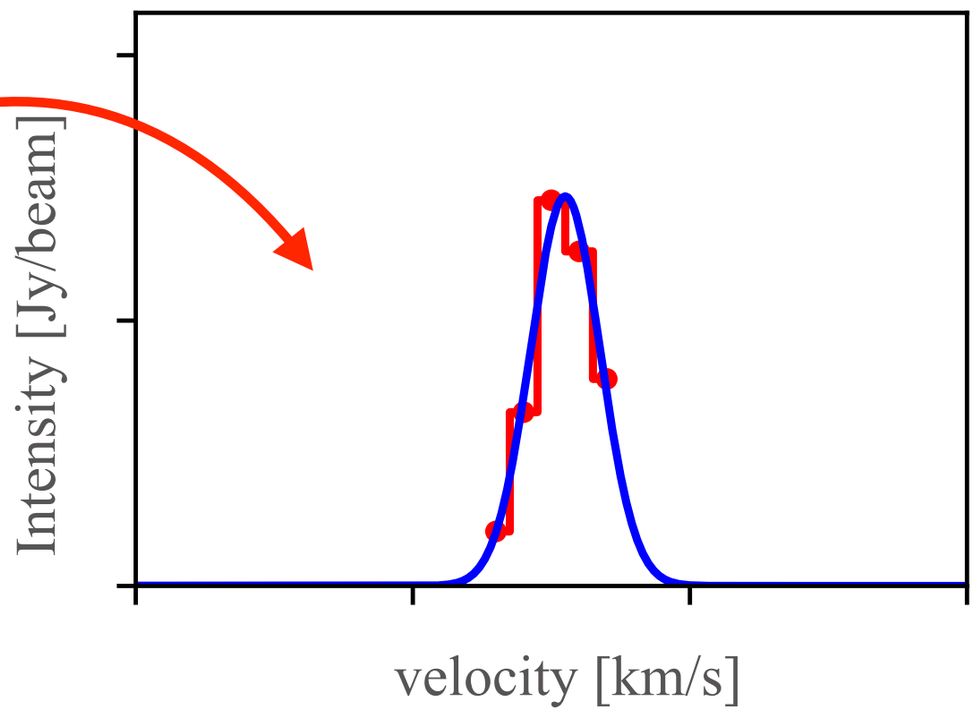
inner disk minor axis: -21º / 159º

almost perpendicular to the inner disk

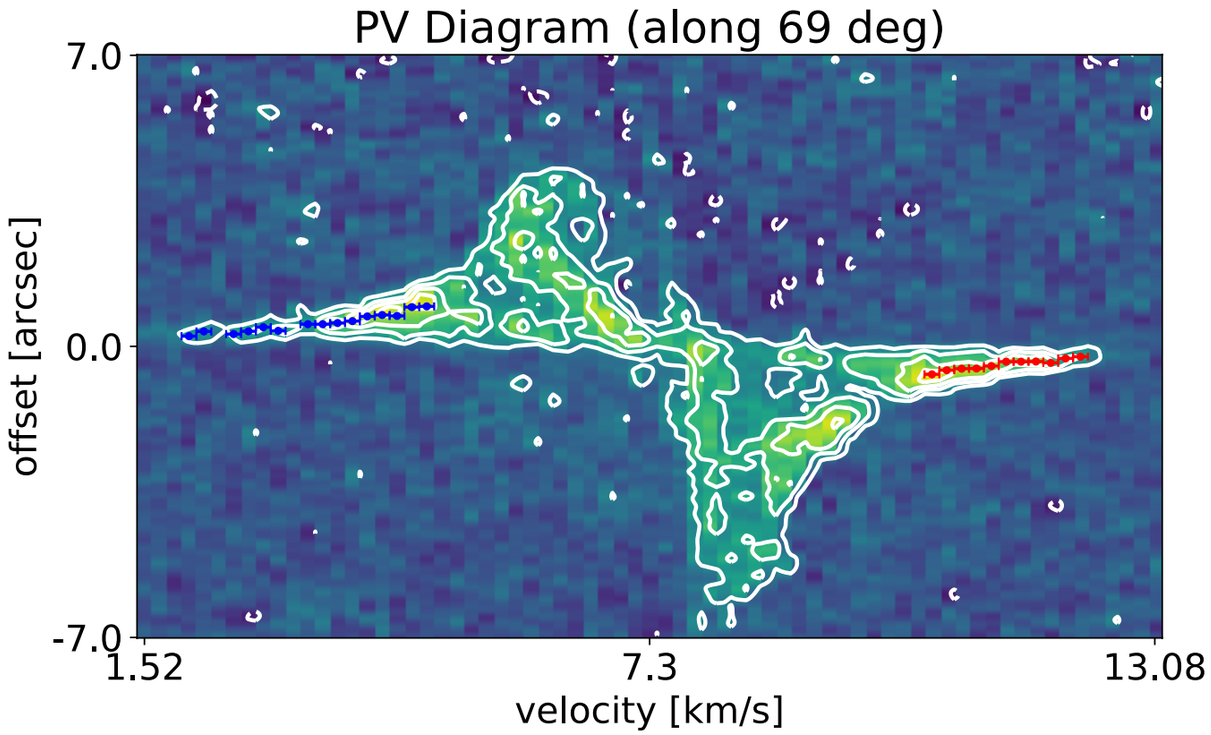
Representative Points on P-V Diagram

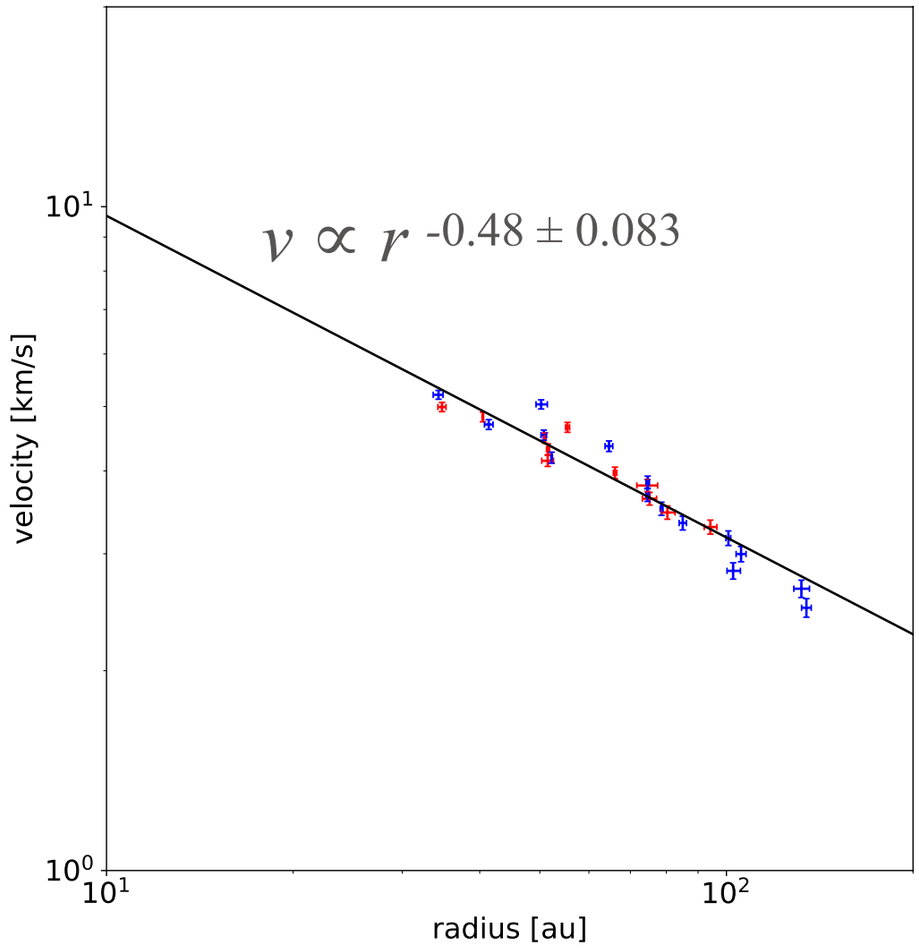
- determine representative velocity at each position
  - to cut p-v diagram at one position
  - to fit Gaussian function toward the data points (> 3σ)
  - fitted Gaussian peak position is the representative velocity
  - using tapered image (beamsize ~ 0.71”x 0.64”)





Power-Law Index of the High Velocity Component



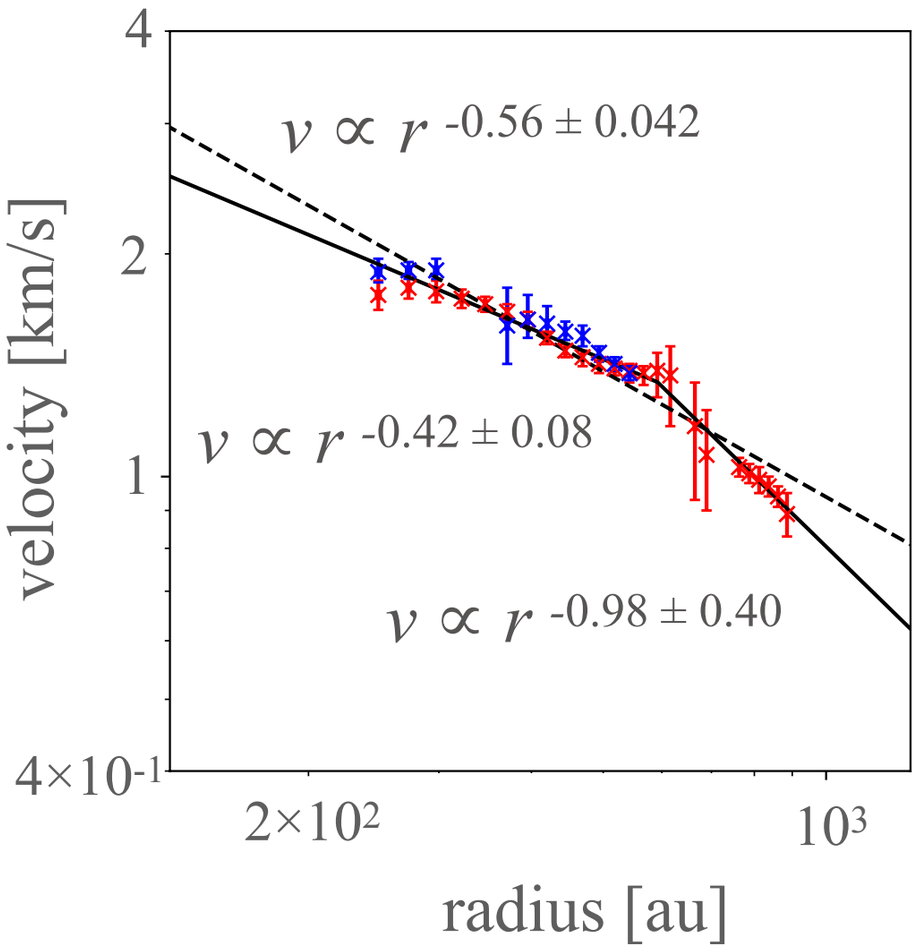


The inner part is a Keplerian disk

Keplerian Disk or Infall flows ?

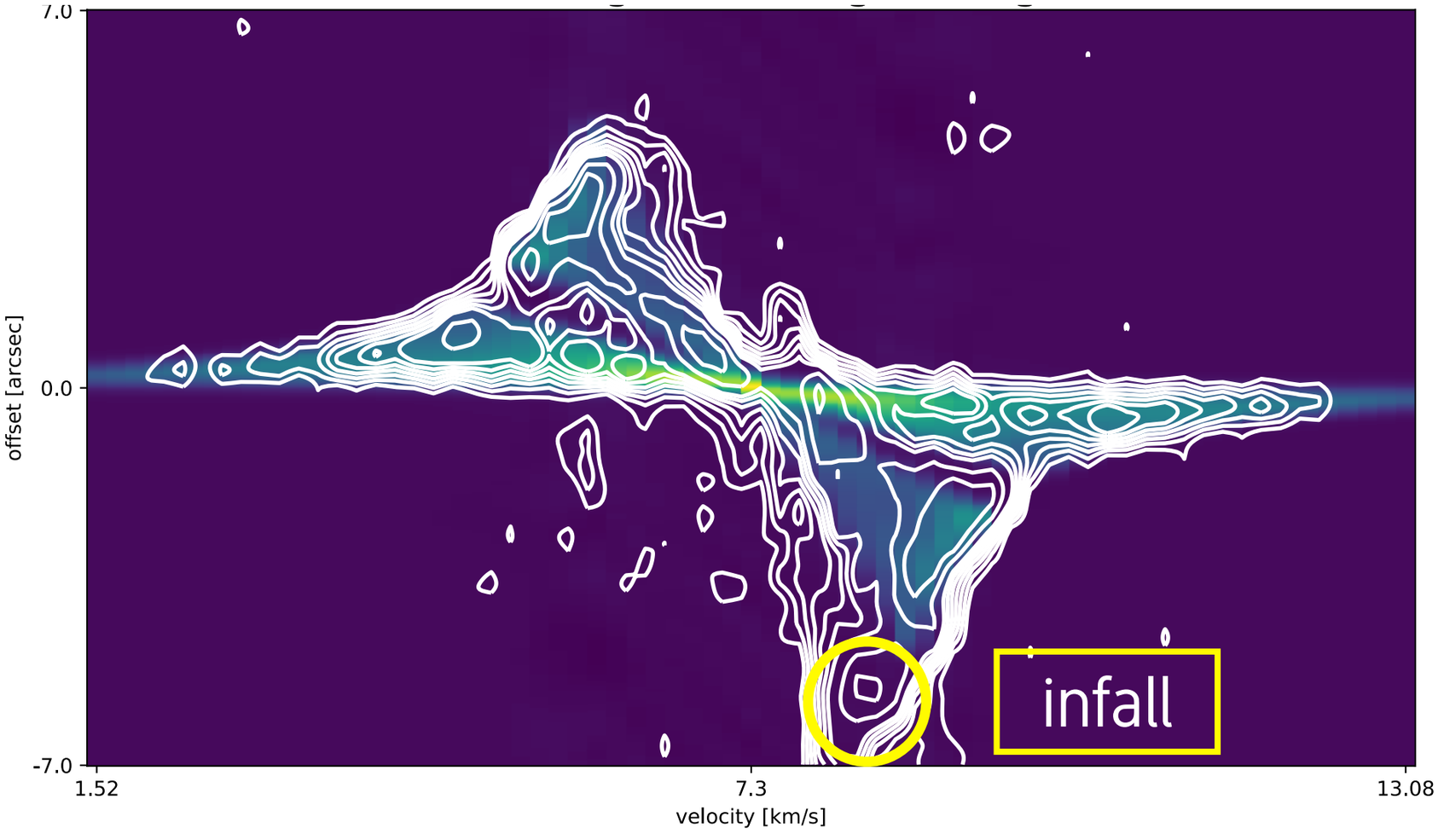
test two type power-law fit

- single power-law
  - χ^2 = 2.1
- double power-law
  - χ^2 = 0.35



double power-law is more appropriate

Model vs Observation on P-V Diagram

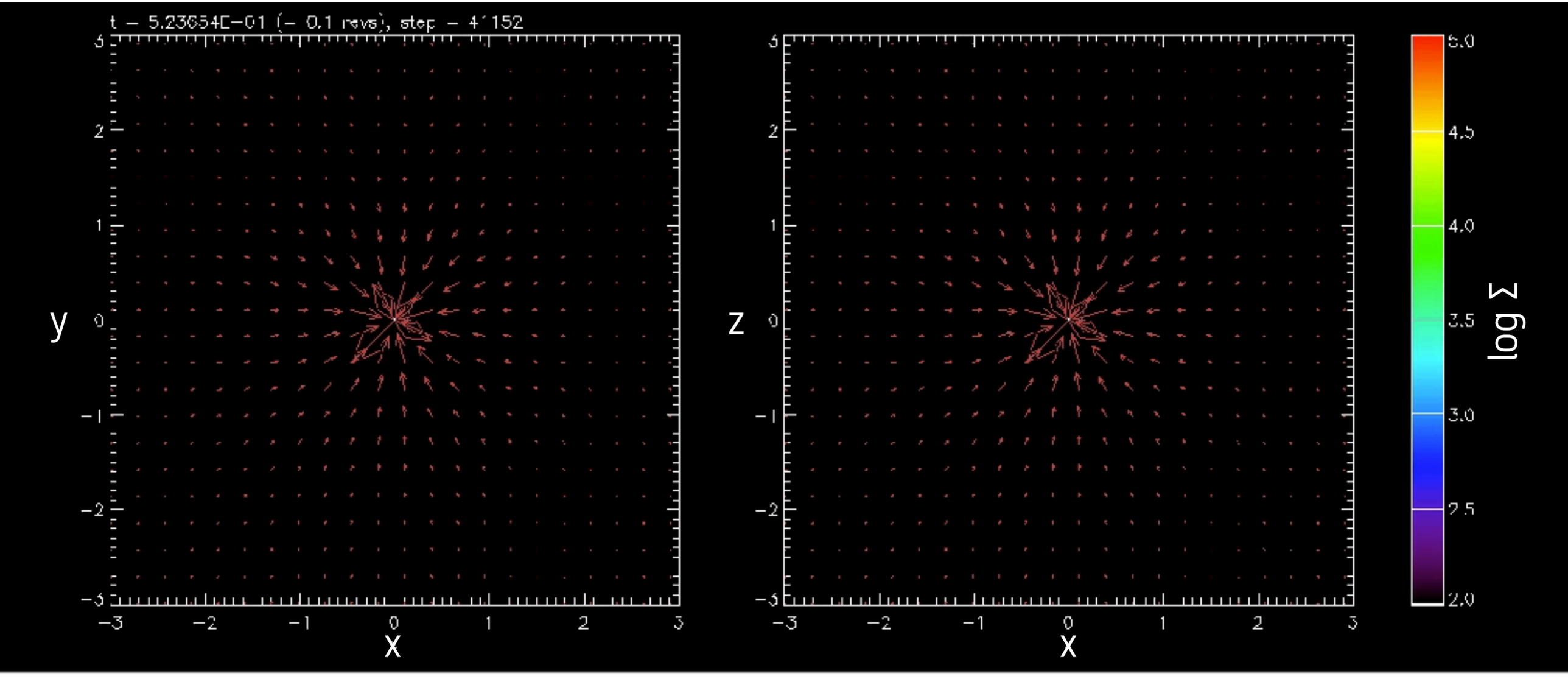


color: model

contour: observation

almost reproduced by gap disks model

How Are the Disks in L1489 IRS Formed?



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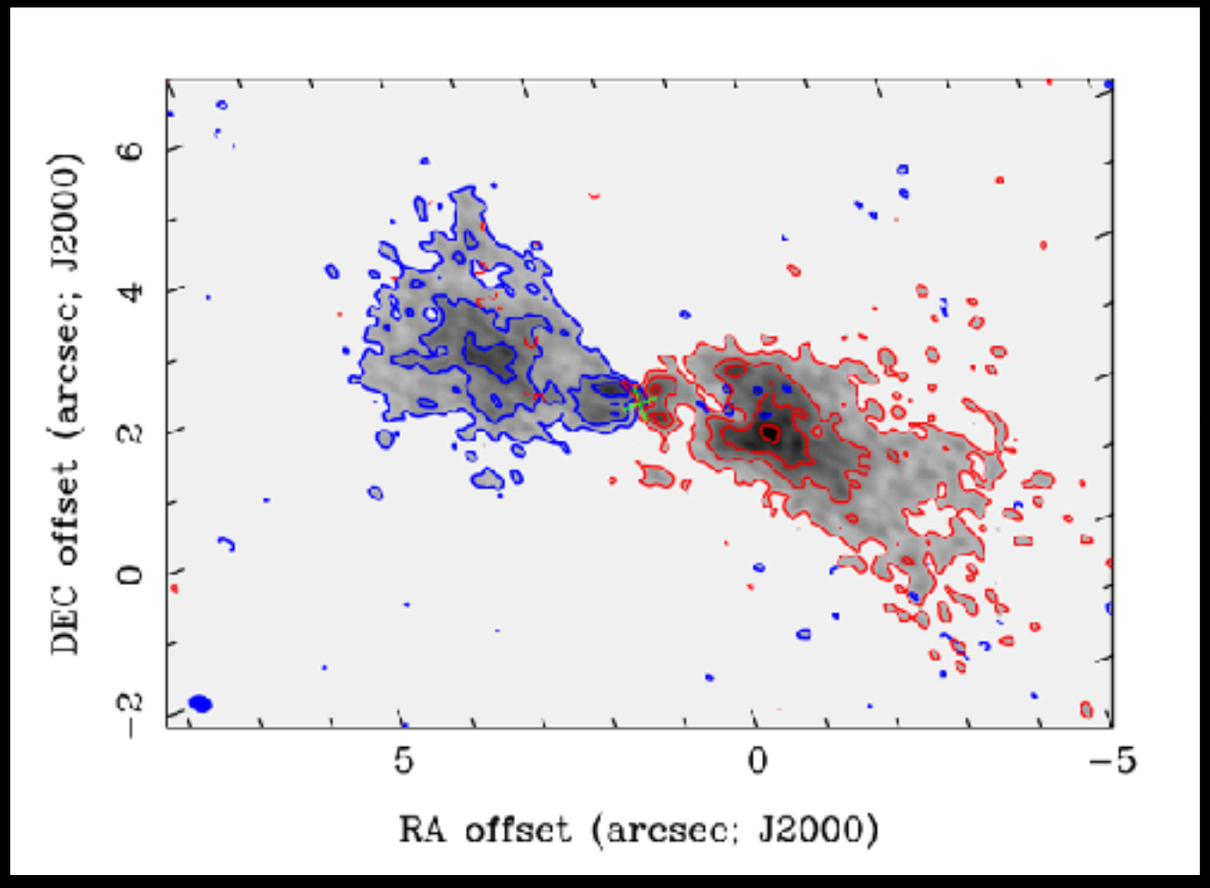

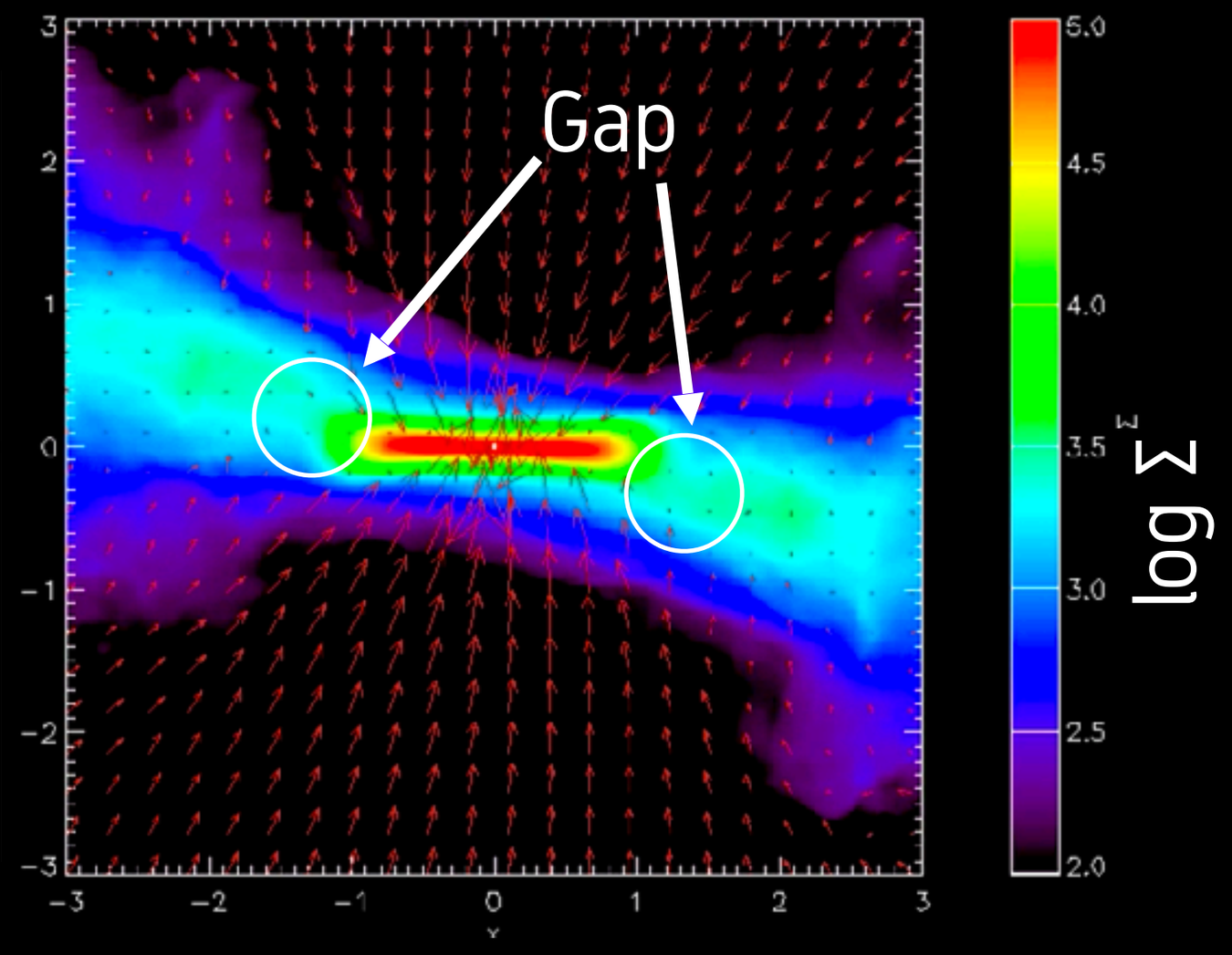

The observational features is reproduced by simulations