Structures of the Protoplanetary Disk around HD163296

Chia-Ying Chung

Advisor : Vivien Chen

August 30th 2019

UCAT Summer Student Program

HD163296

Isolated, pre-main-sequence star

- Distance: 122 pc (van Leeuwen 2007)
- Age: 5 Myr
- M_* = 2.3 M_{sun} (Montesinos et al. 2009)

Disk properties

- Disk mass: 0.089 M_{sun} (~4% M_*)
- Outer radius: 550 AU in CO
- Inclination: 45° (Isella et al. 2007)

ALMA science verification data

Frequency band: Band 7 (345 GHz)

Dates: 9, 11, 22-Jun, 6-Jul-2012

Total integration time: 2.3 h (on source)

Antenna diameter: 12 m

Baselines length: 16 m (min), 400 m (max)

4 spectral windows:

Emission Line	Rest Frequency (GHz)
DCO^+ (5-4)	360.1697838
HCO^+ (4-3)	356.7342369
$H^{13}CO^+$ (4-3)	346.9983500
CO (3-2)	345.7959818

Data reduction and analysis

Calibration

- Bandpass
- Phase and Amplitude
- Flux

→ Apply Calibration →

Imaging the continuum

- Imaging
- 3 iterations of self-calibration

→ Continuum Subtraction →

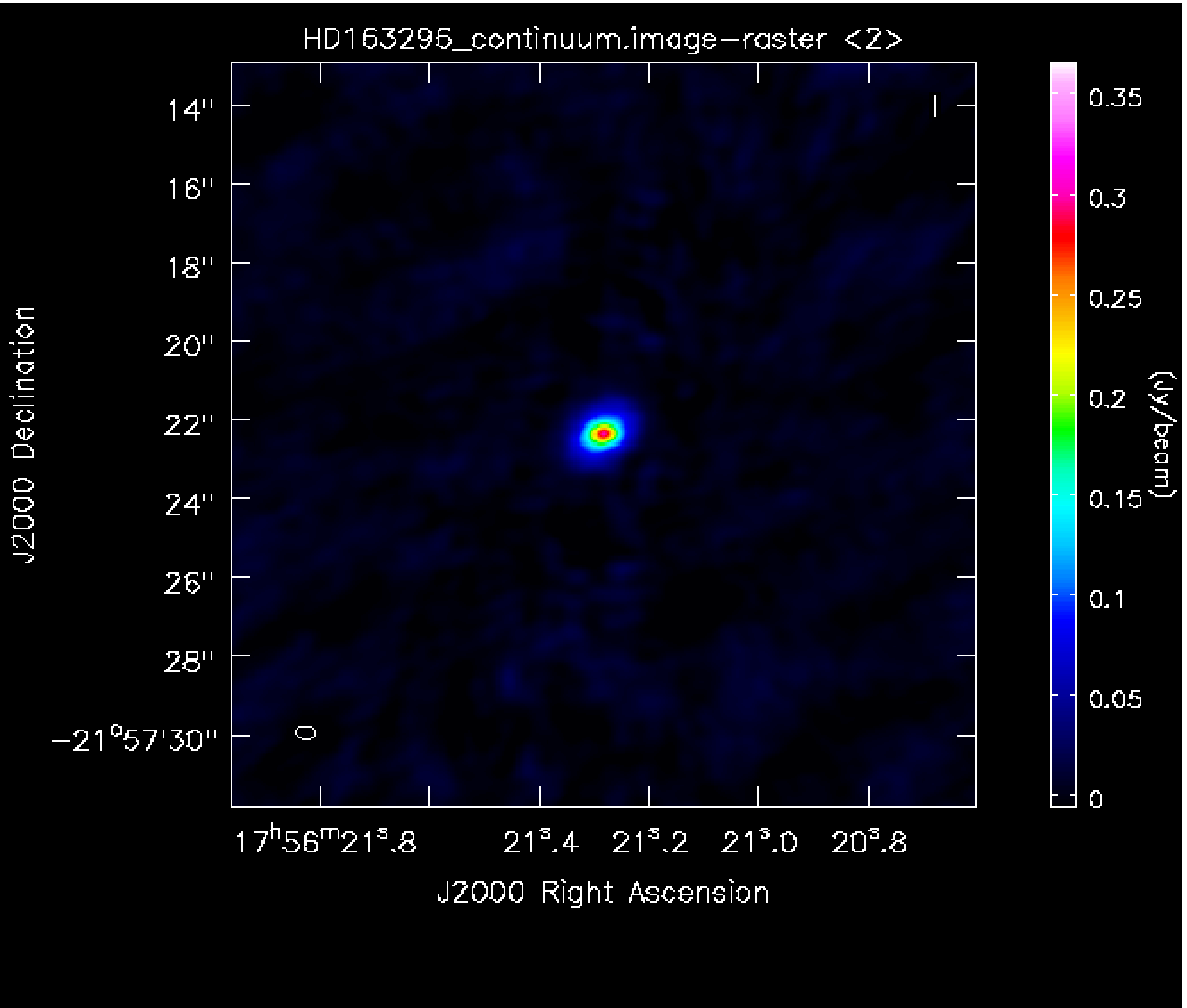
Spectral Line Imaging

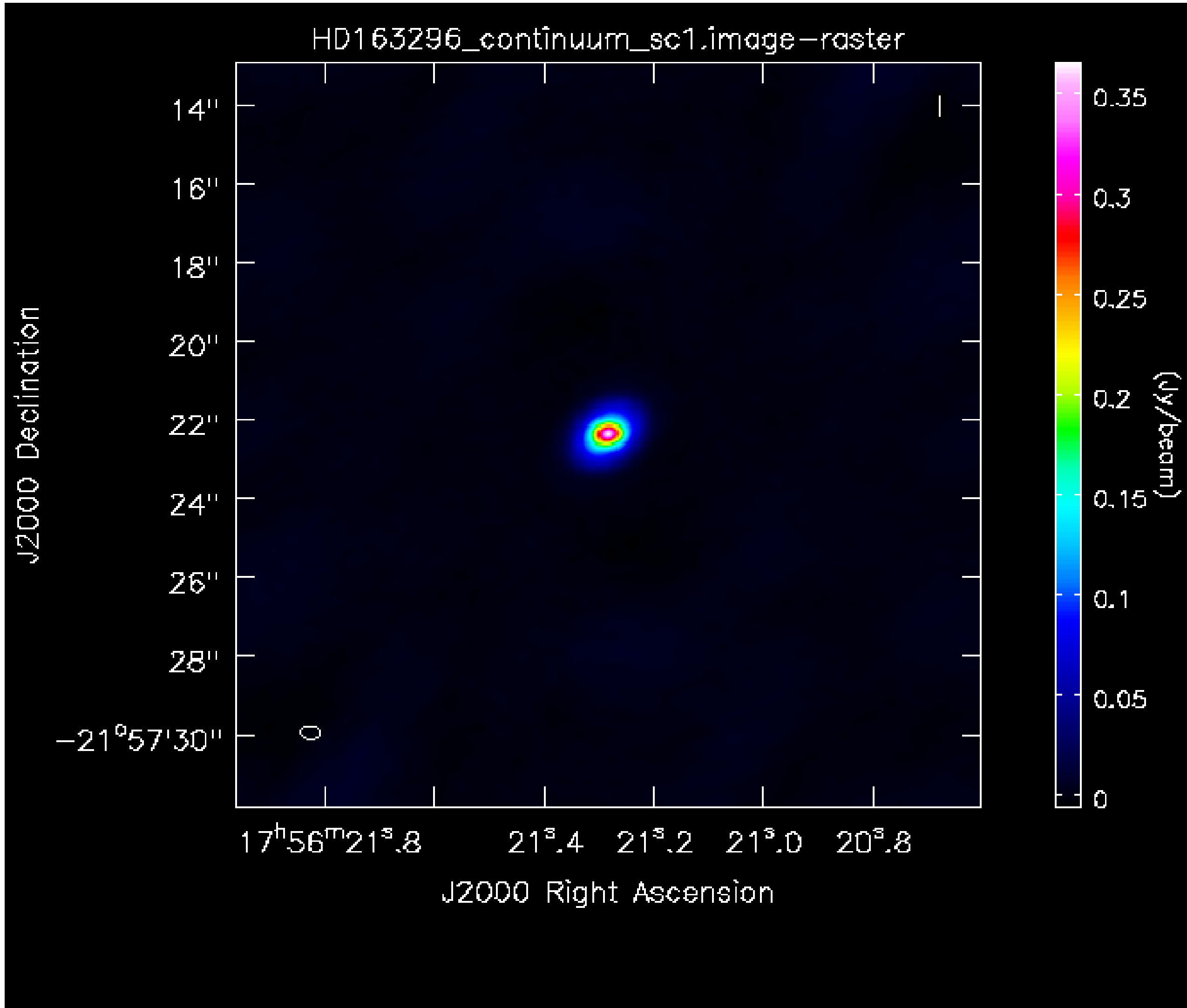
- Channel maps
- Mom0
- Mom1

quasar J1924-292
183GHz water
line /Neptune
quasar J1733-130

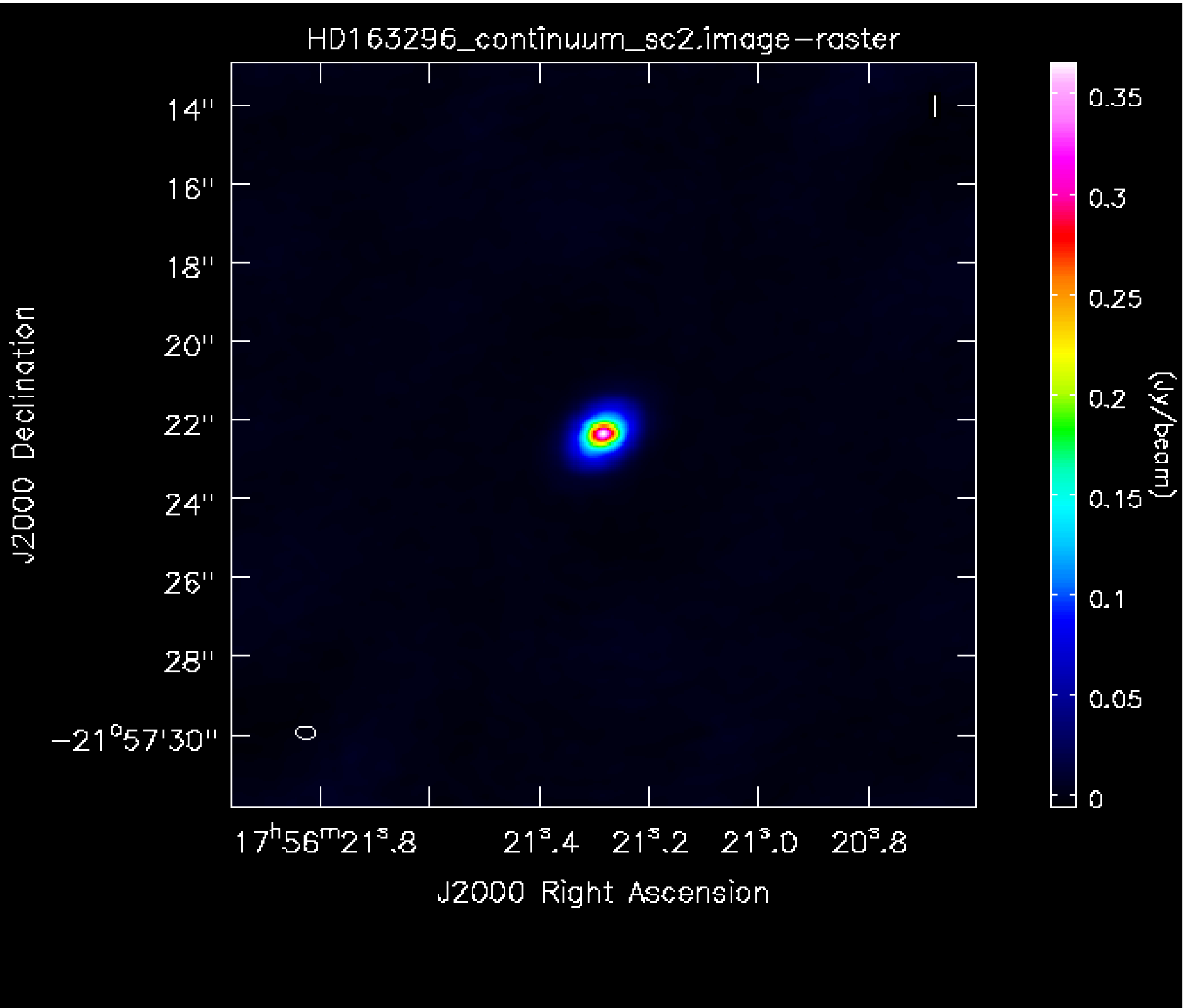
Continuum image

1st iteration

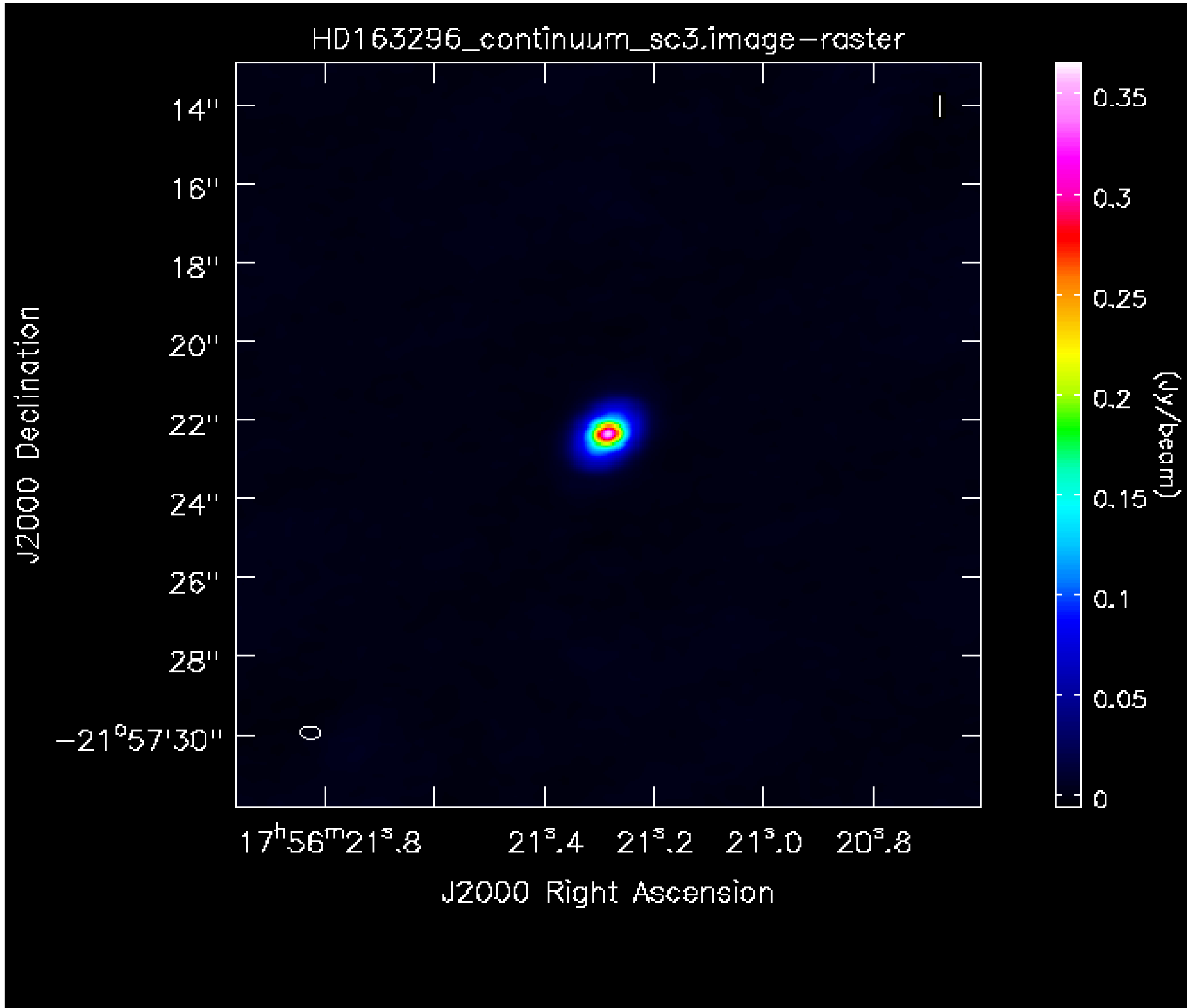




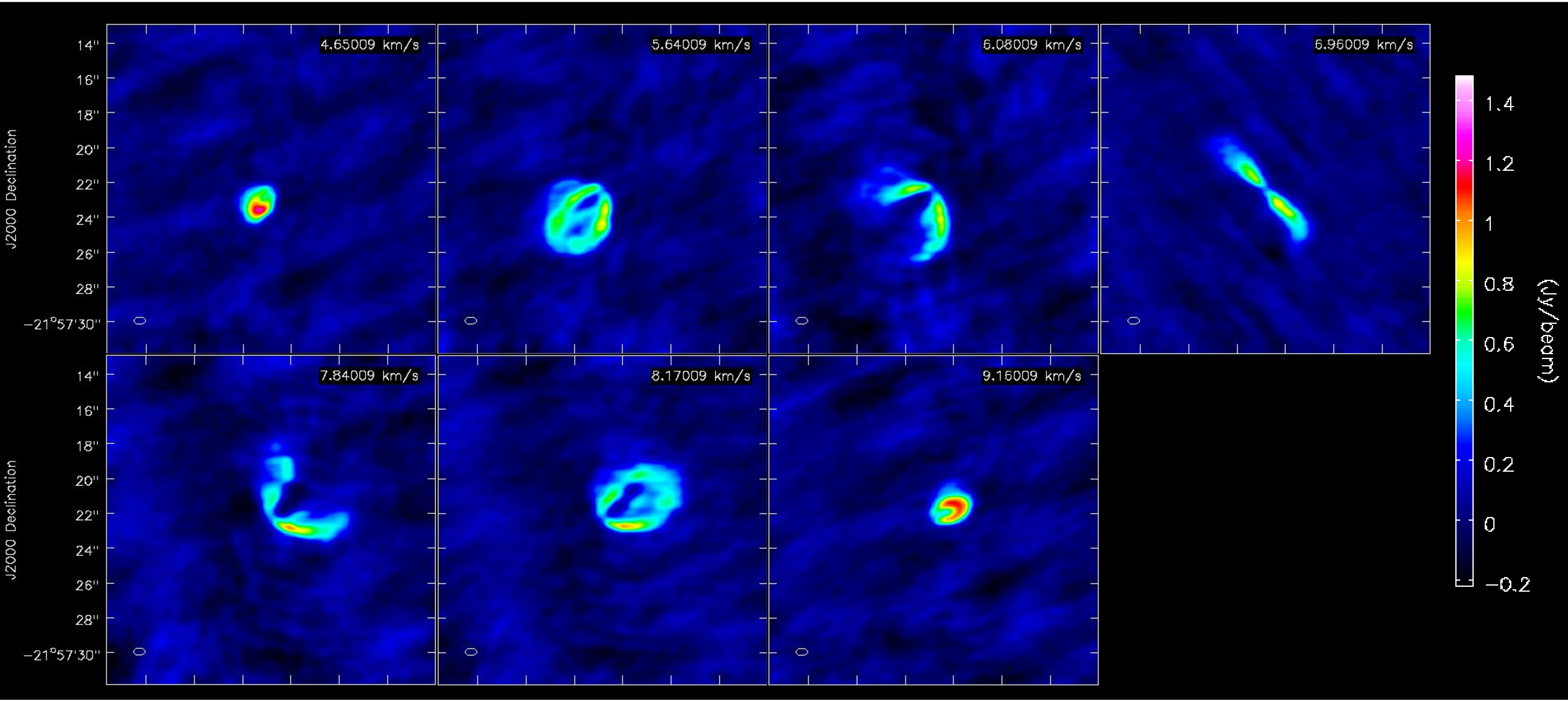
2nd iteration



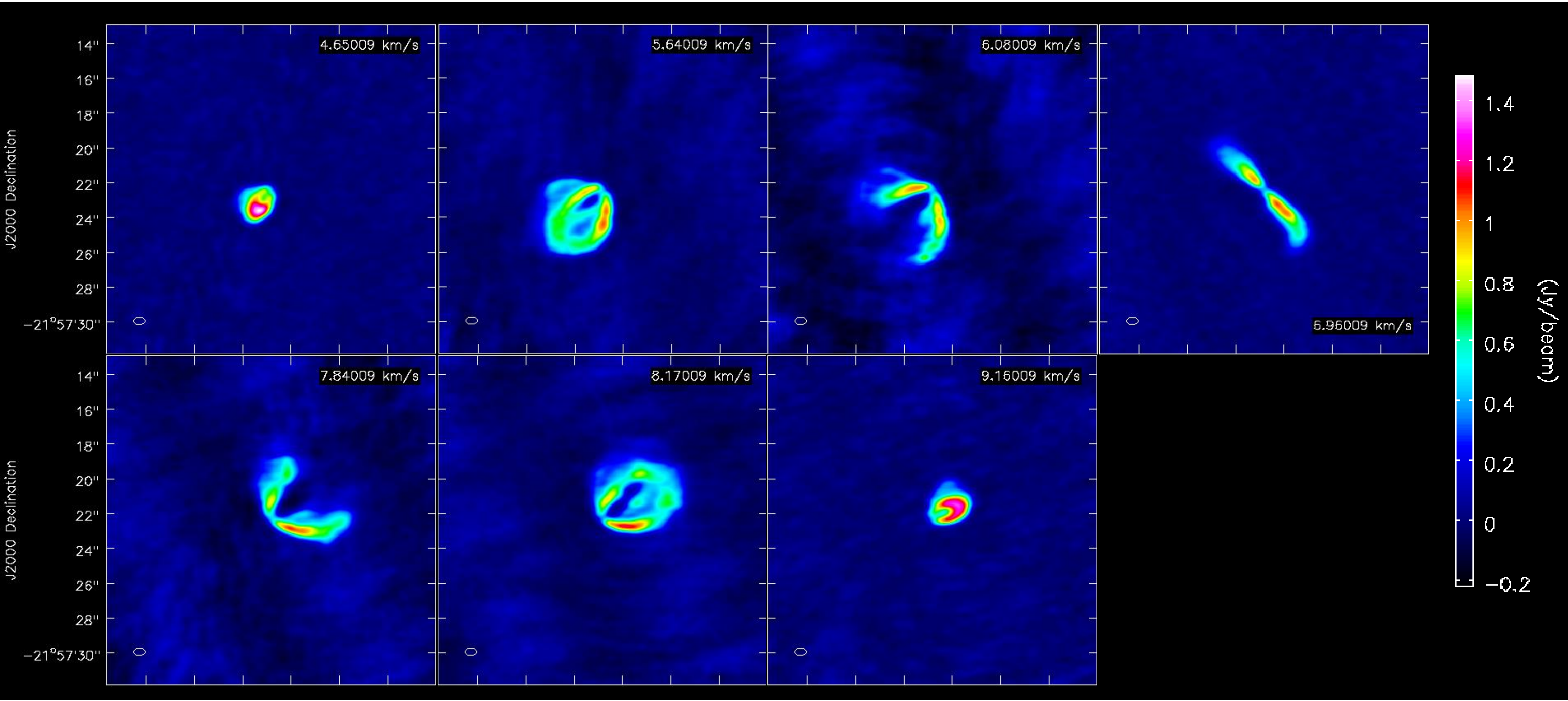
3rd iteration



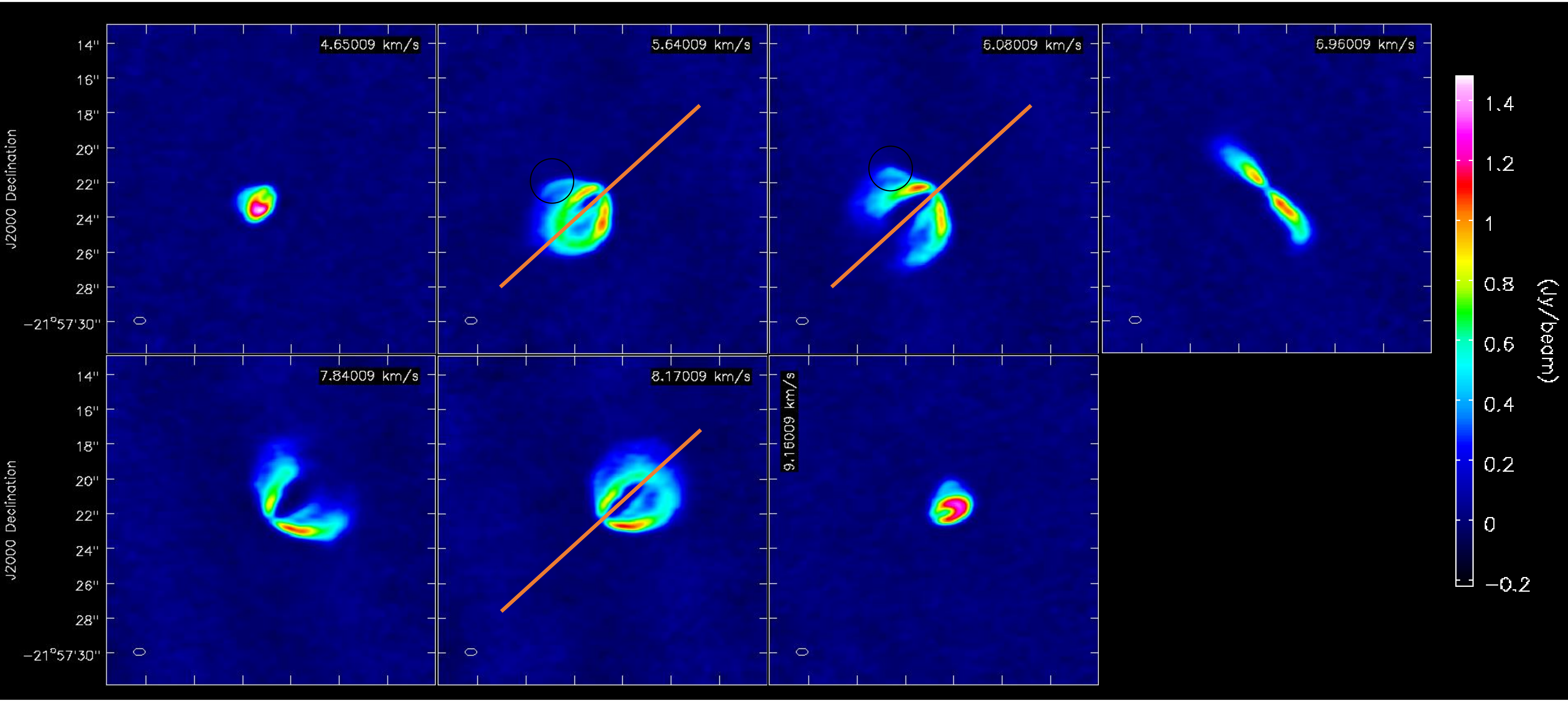
CO(3-2) channel map



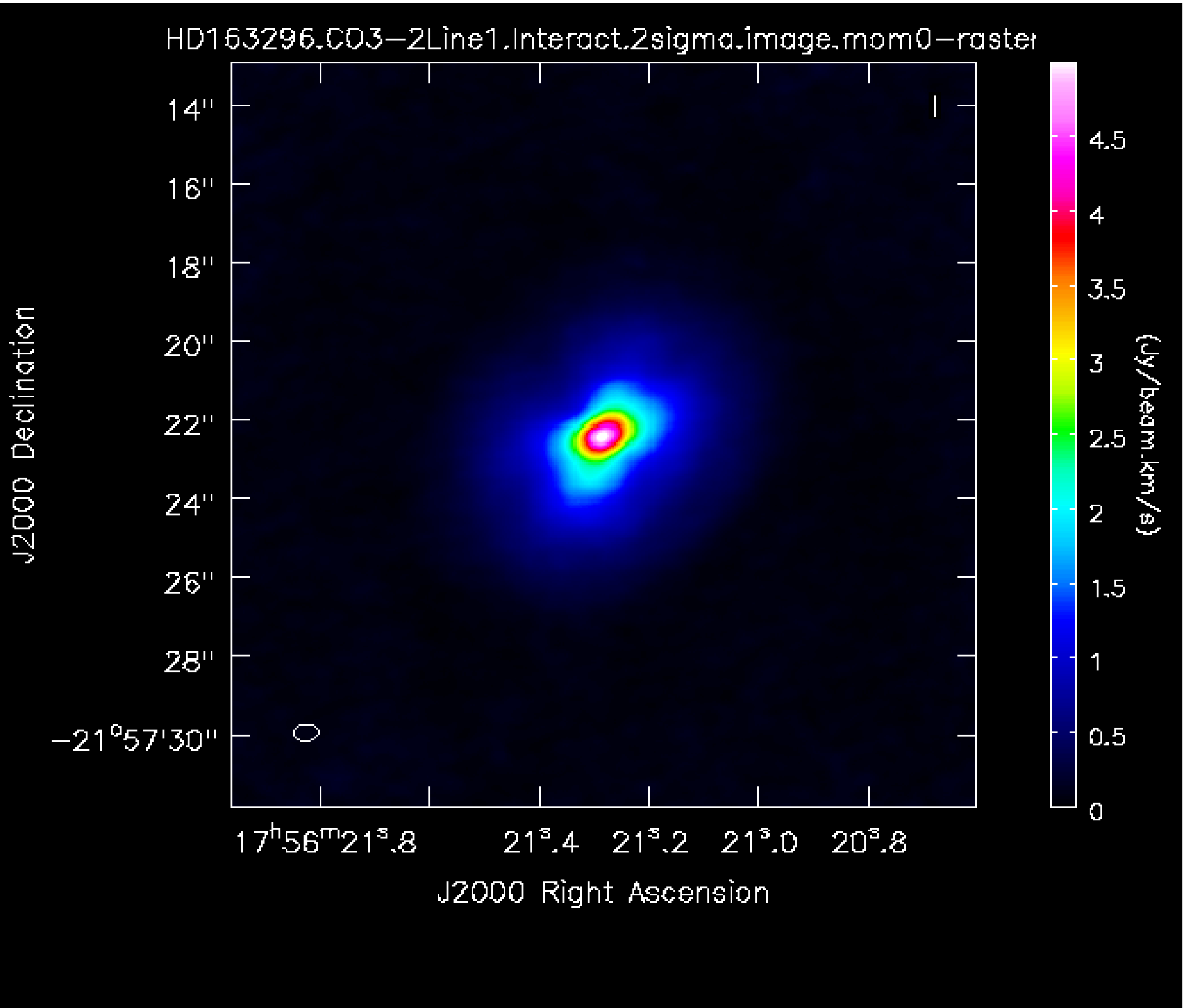
CO(3-2) channel map after self-calibration



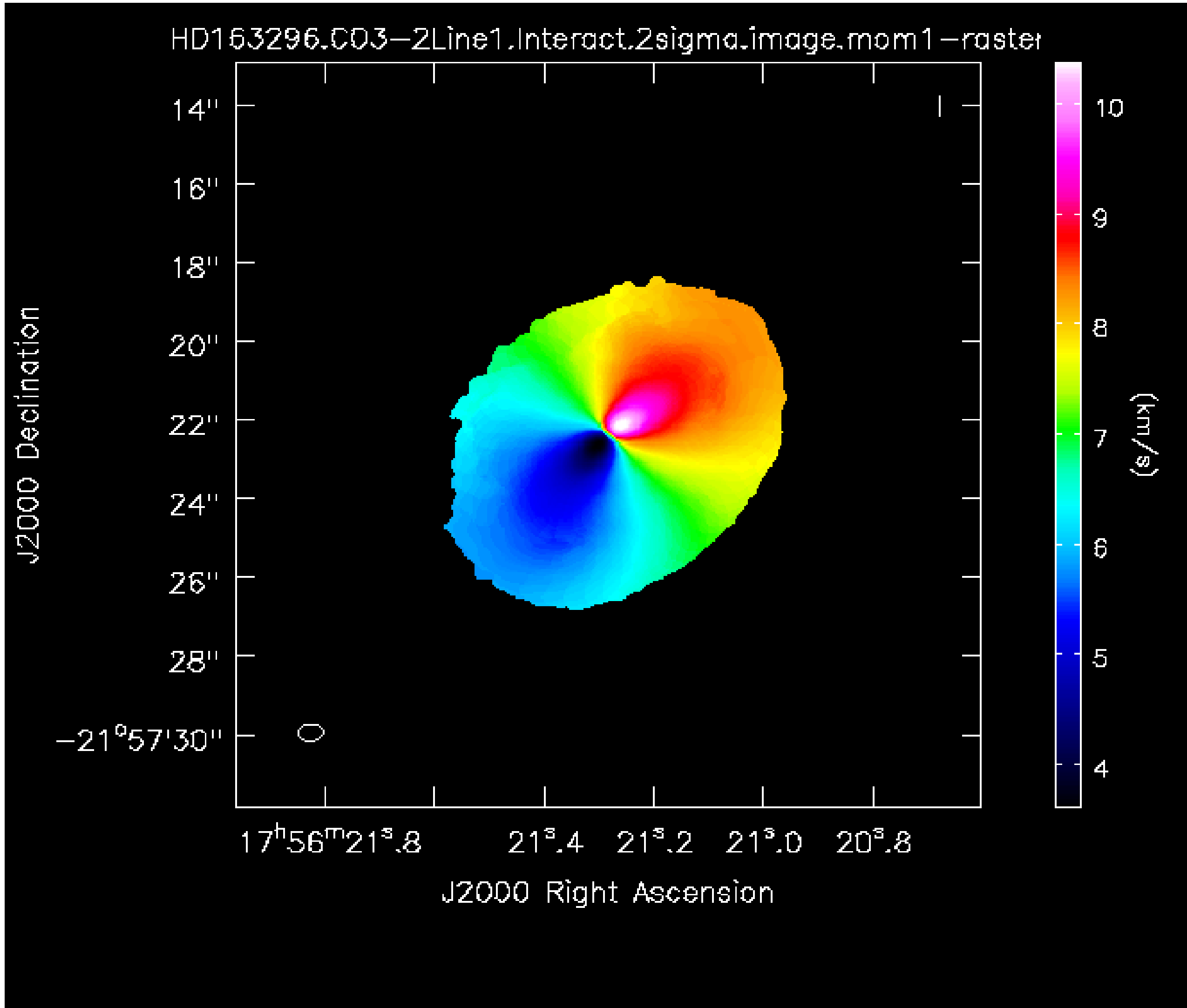
CO(3-2) channel map with interactive clean



Moment 0 map



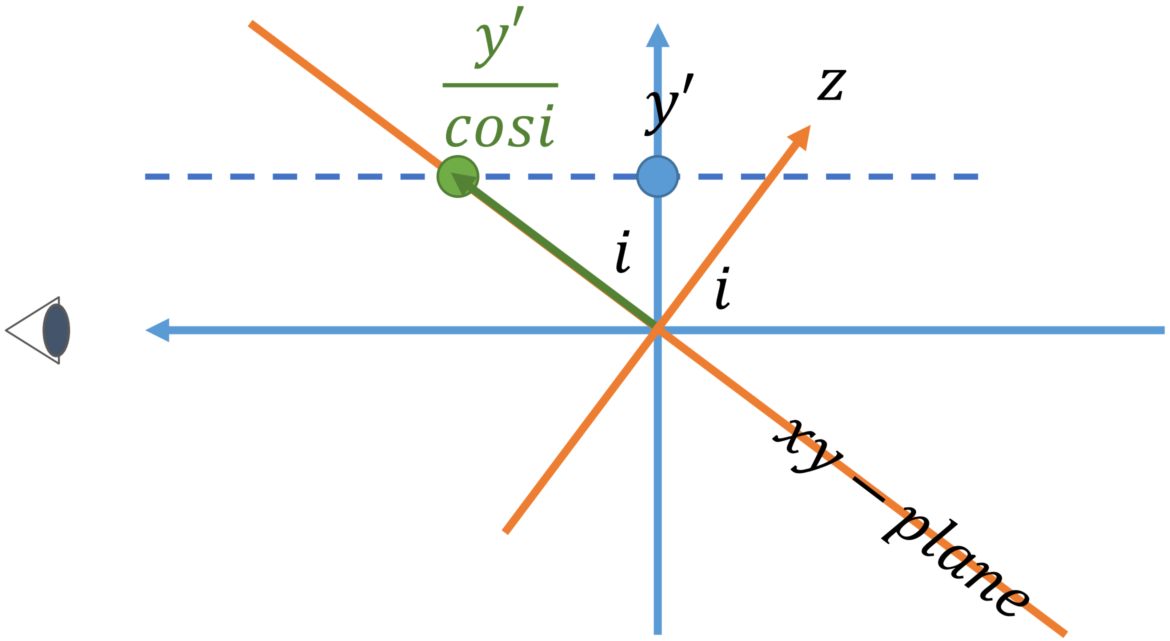
Moment 1 map

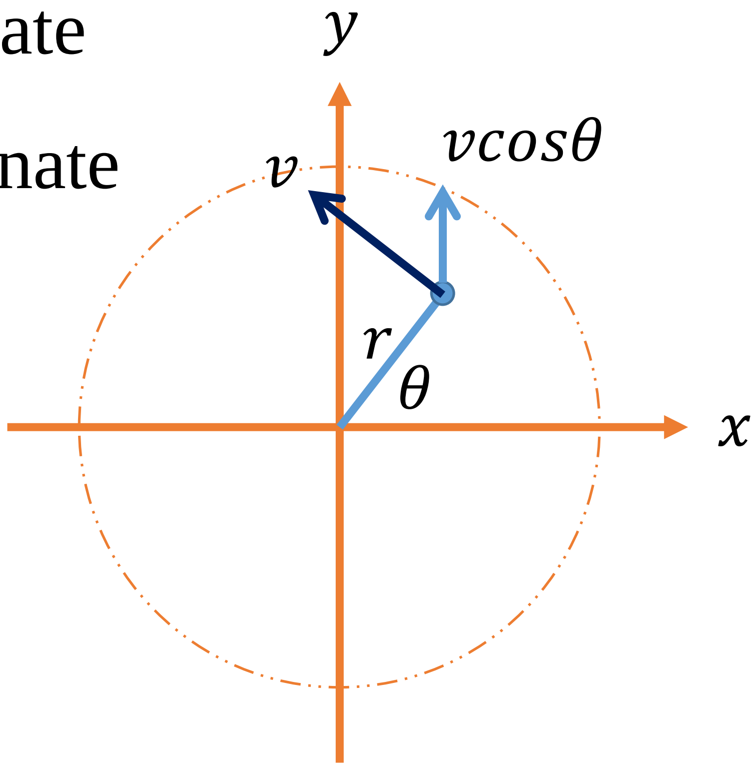


Flat disk model

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x' \\ y'/\cos i \\ 0 \end{pmatrix}$$

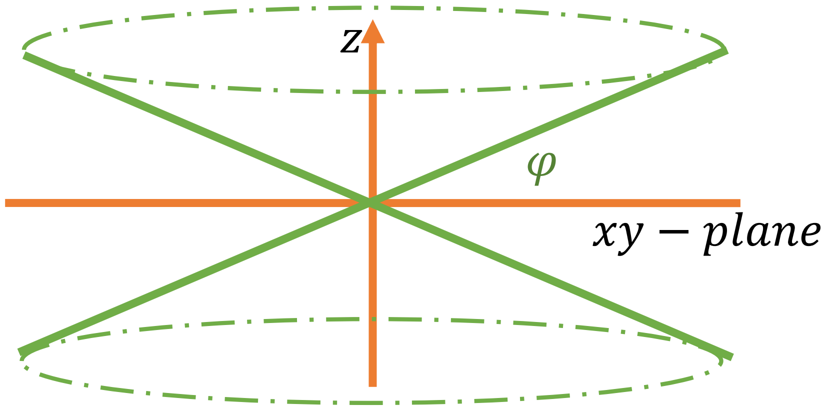
- (x, y, z = 0) : disk coordinate
- (x’, y’) : sky-plane coordinate
- i : inclination angle





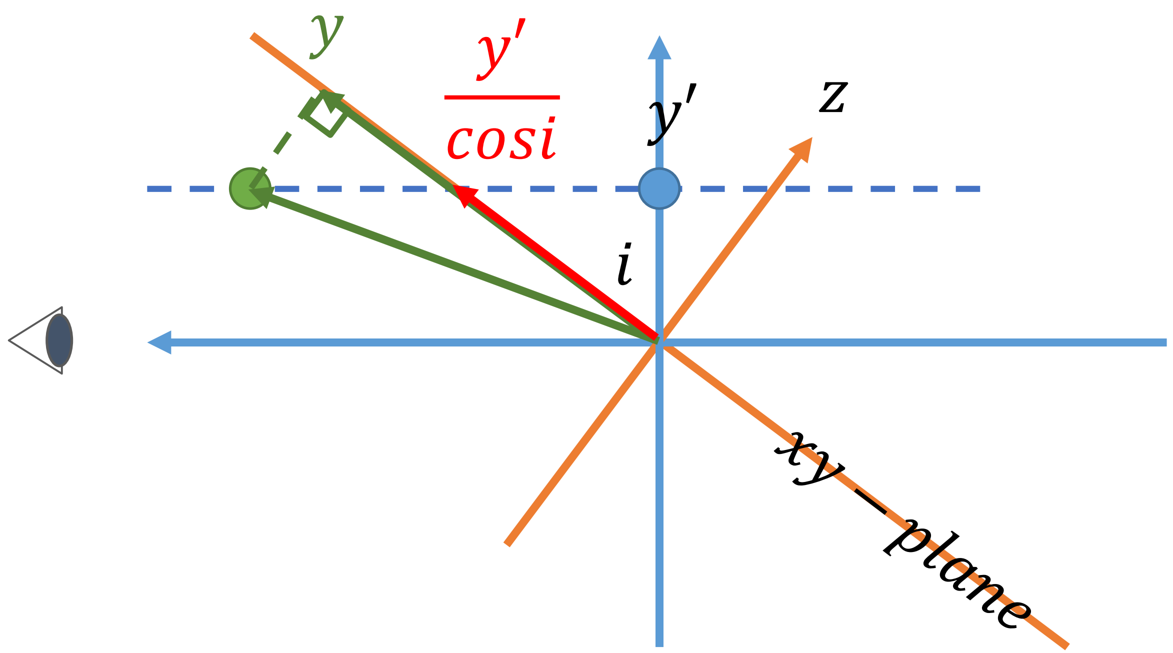
$$v_{obs}(x', y') = \sqrt{\frac{GM_*}{r}} \cos\theta \; \sin i$$

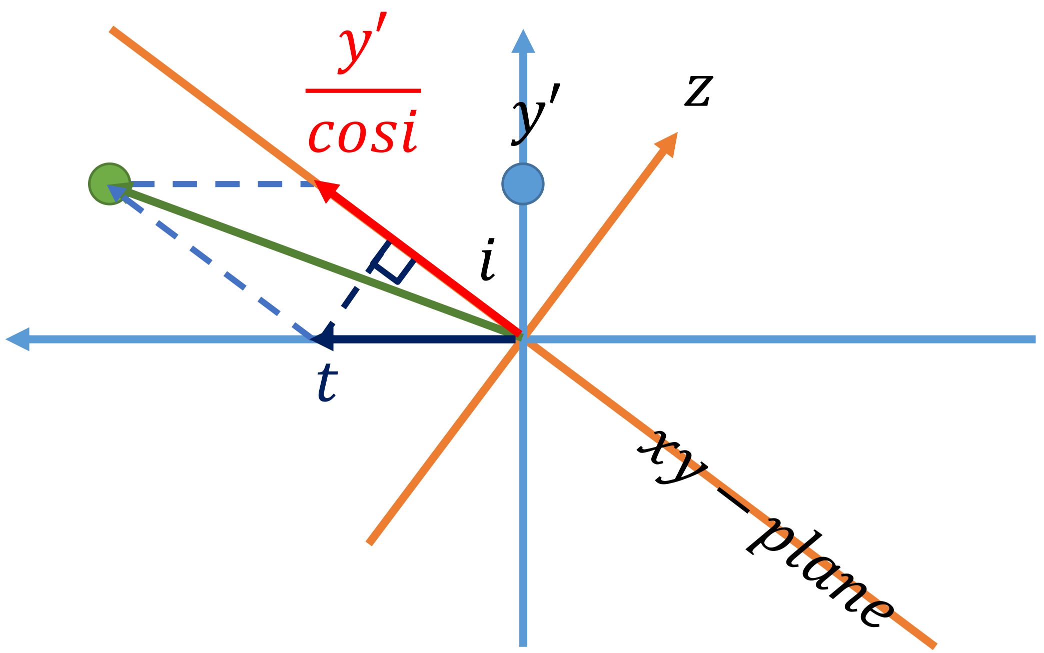
Double cone model



$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x' \\ y'/\cos i + t \sin i \\ t \cos i \end{pmatrix}$$

$$\Rightarrow \quad {v_\theta}^2 = \frac{GM}{\sqrt{x^2 + y^2}} = \frac{GM}{\sqrt{x'^2 + (y'/\cos i + t \sin i)^2}}$$





Isovelocity contour

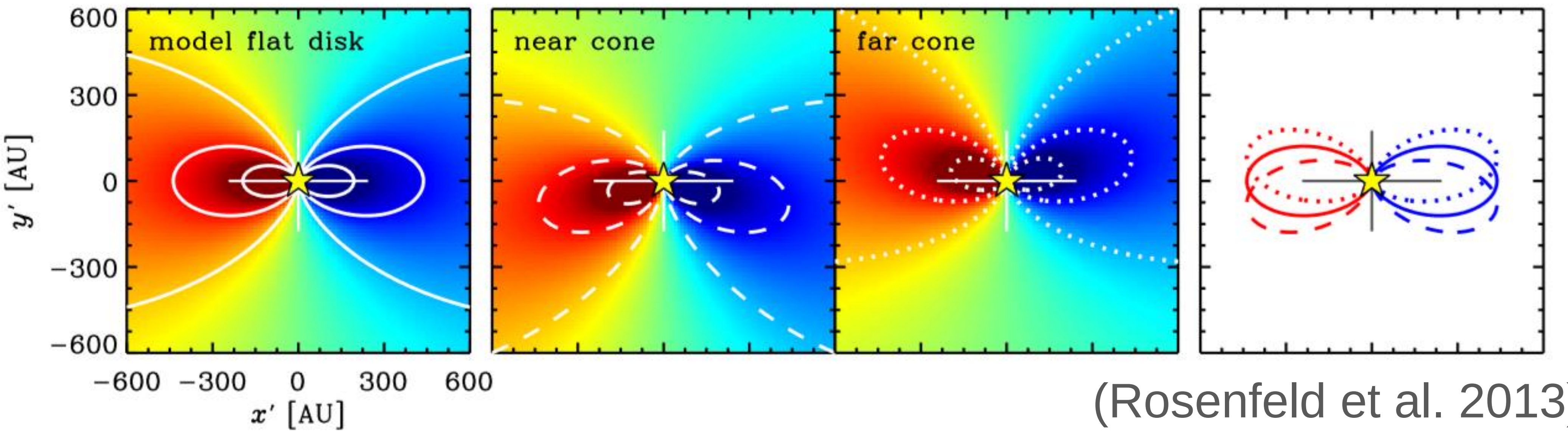
$$v_\theta{}^2 = \frac{GM}{\sqrt{x'^2 + (y'/\cos i + t\sin i)^2}}$$

- $t > 0$ $(near\ cone)$

  At same y', $v_\theta{}^2$ is smaller ➡ shift to smaller y'

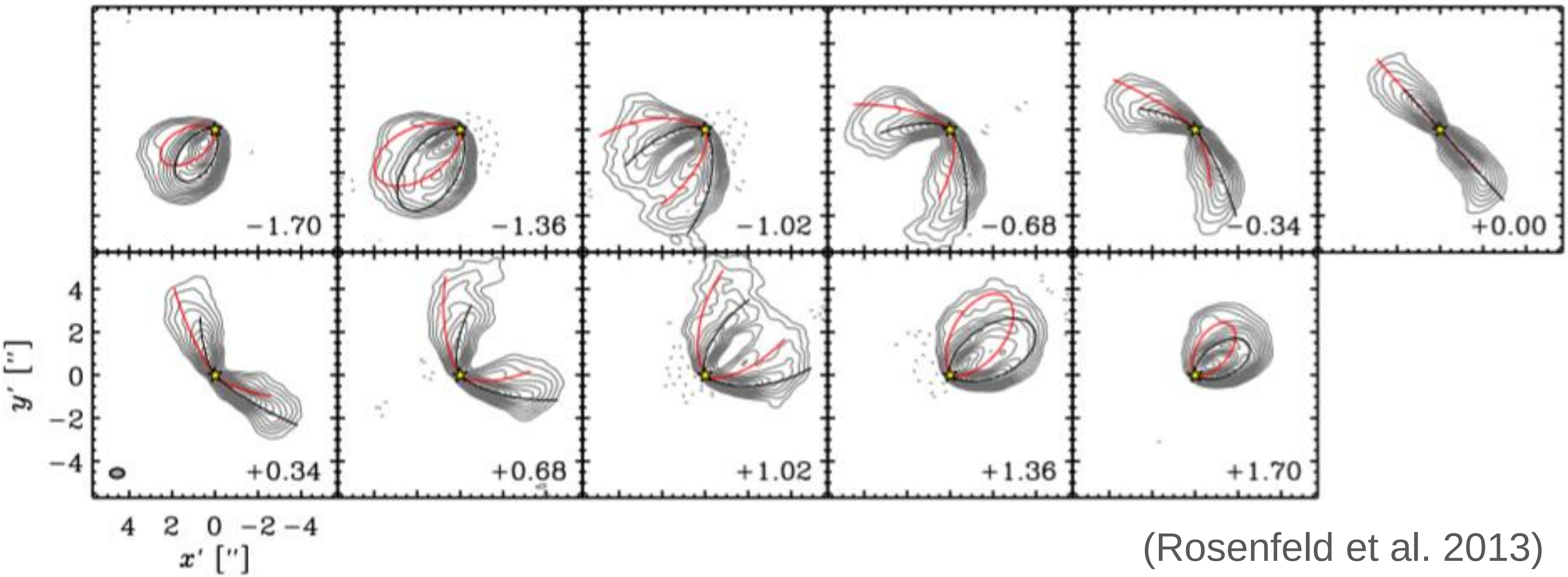
- $t < 0$ $(far\ cone)$

  At same y', $v_\theta{}^2$ is larger ➡ shift to larger y'



(Rosenfeld et al. 2013)

Contour shift in channel map



(Rosenfeld et al. 2013)

- CO emitting surface is like a double cone structure with $\varphi \sim 15°$

Literature review of Rosenfeld et al. 2013

- Line emission :

Calculate the molecular excitation state of the gas and integrate the radiative transfer equation

$$I_\nu = \int_0^\infty S_\nu(s) \exp[-\tau_\nu(s)] \, \alpha_\nu(s) ds$$

S_ν : source function, τ_ν : optical depth, α_ν : absorption coefficient

depend on the local temperature T_{gas} and density ρ_{gas}

Temperature structures

• Structure (a) : no vertical gradient

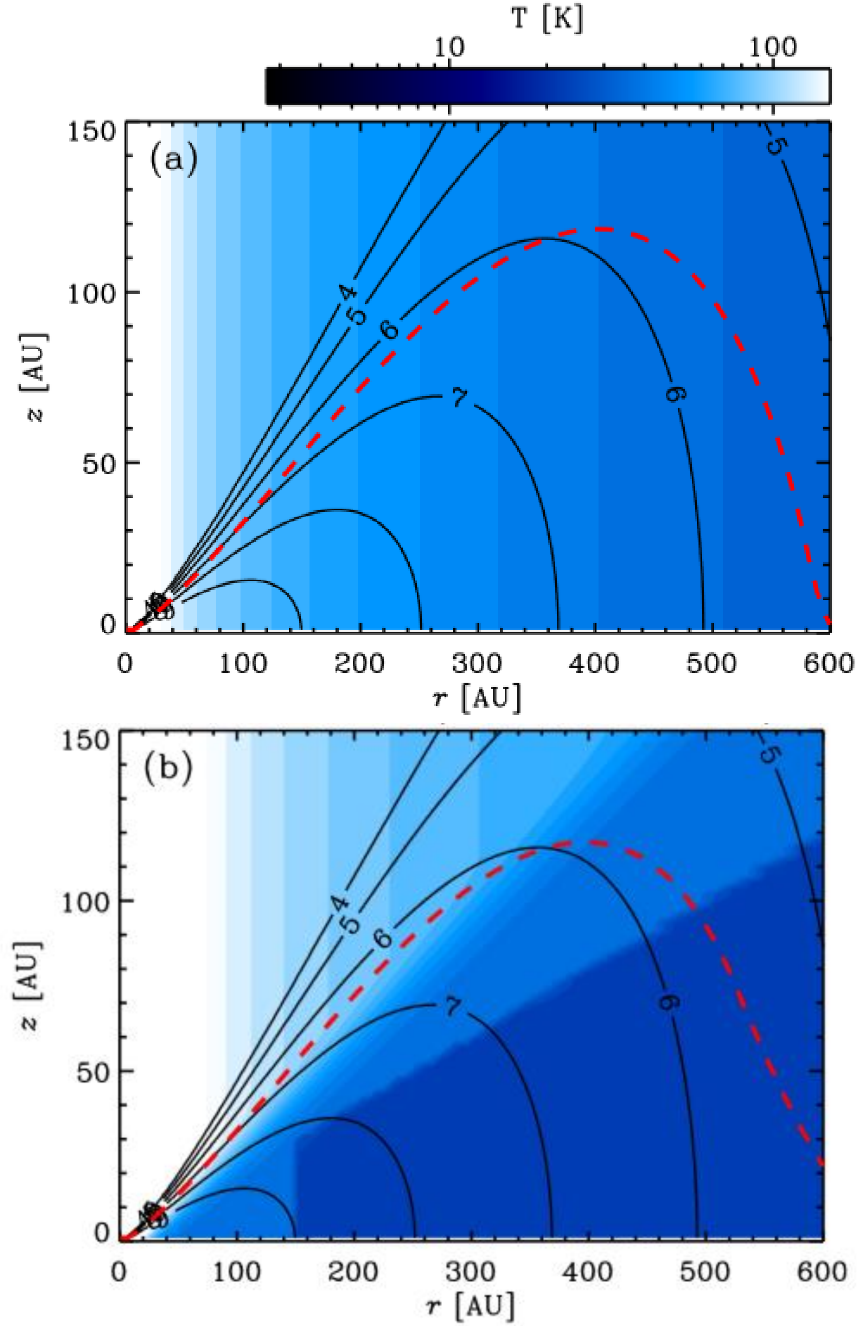
$$T_{gas}(r) = 65K(r/100AU)^{-0.5}$$

• Structure (b) : a warm molecular layer above a cold midplane

$$T_a = 30K \qquad z > 20(r/100AU)^{1.35}$$

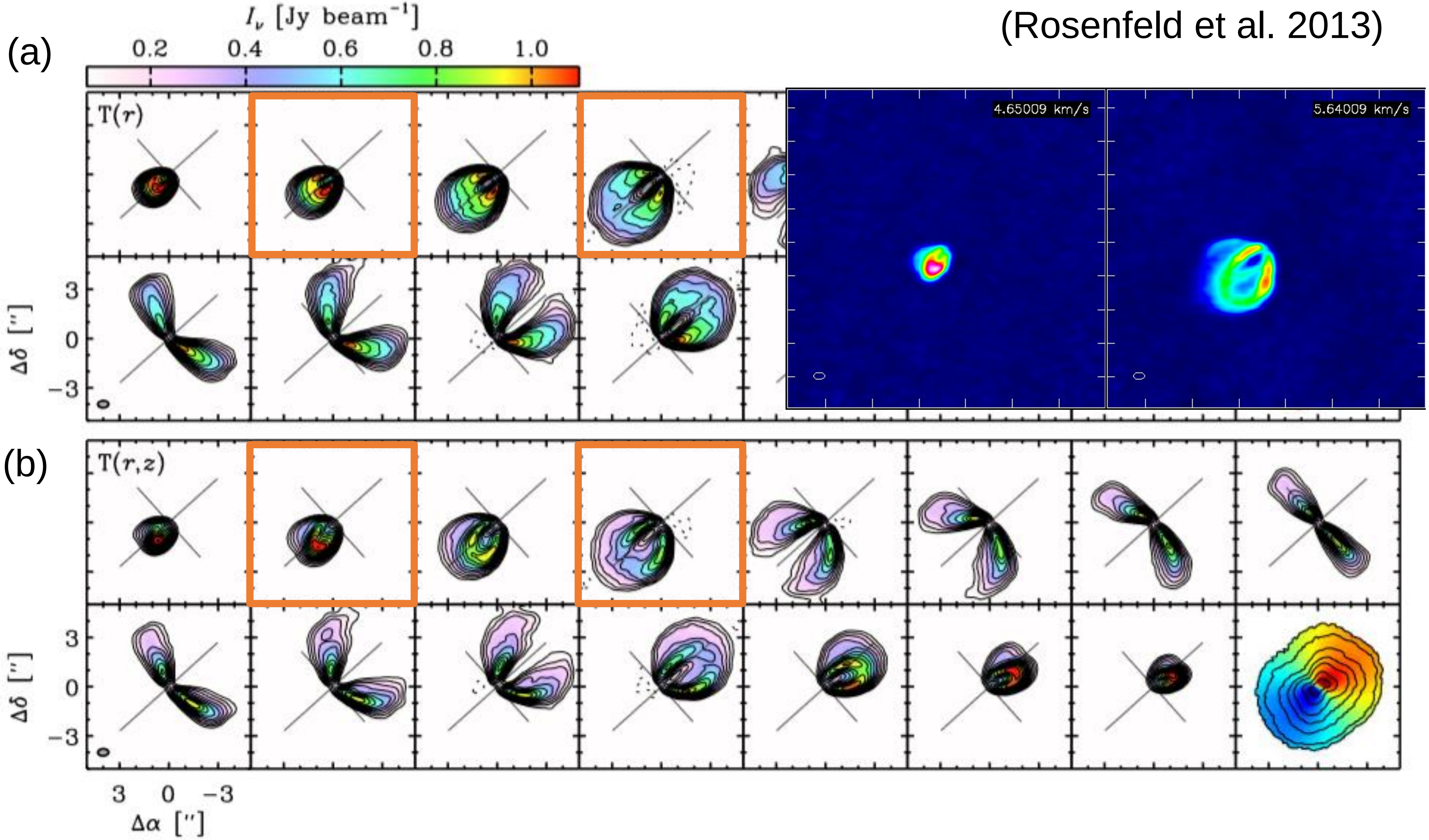
$$or \quad r < 150AU$$

$$T_m = 20K \qquad r > 150AU$$



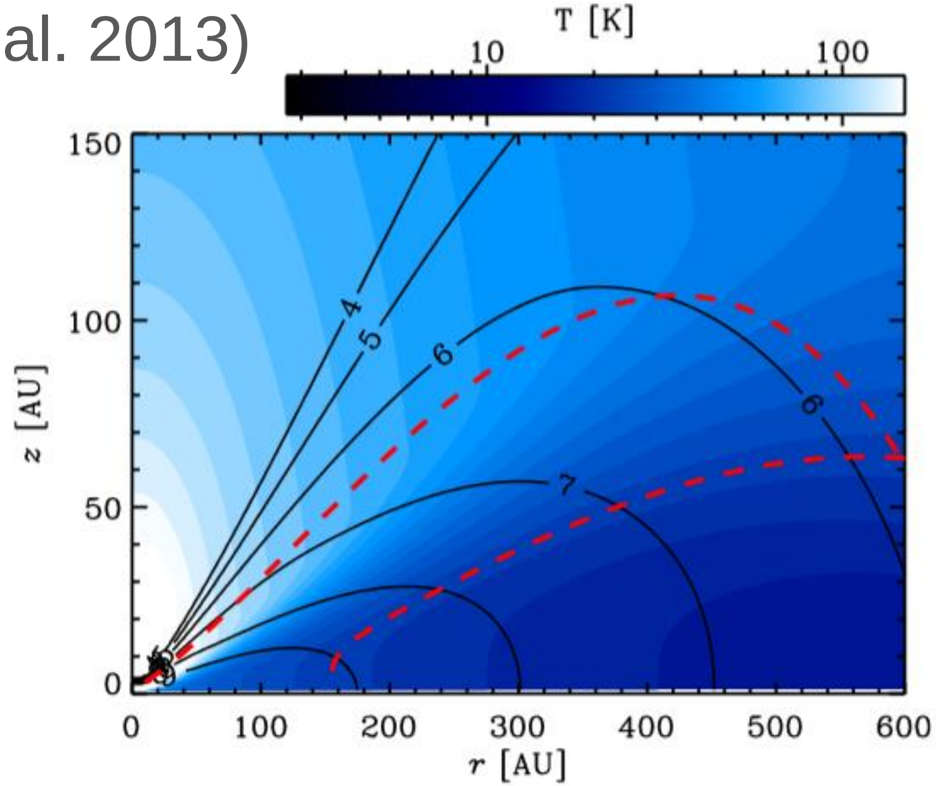
(Rosenfeld et al. 2013)

(Rosenfeld et al. 2013)



(Rosenfeld et al. 2013)

Temperature structures



- Structure C : densities are coupled with the temperature

$$T_{gas}(r,z) = \begin{cases} T_a + (T_m - T_a)\, sin\left[\frac{\pi z}{2z_q}\right]^{2\delta(r)} \\ T_a \qquad \text{if } z \geq z_q \end{cases}$$

$$z_q = 63(r/200AU)^{1.3} \times \exp[-(r/800AU)^2]$$ (Dartois et al. 2003)

$$T_m(r, z=0) = 19K(r/155AU)^{-0.3}$$ (midplane)

$$T_a(r,z) = 55K(\sqrt{r^2+z^2}/200AU)^{-0.5}$$ (atmosphere)

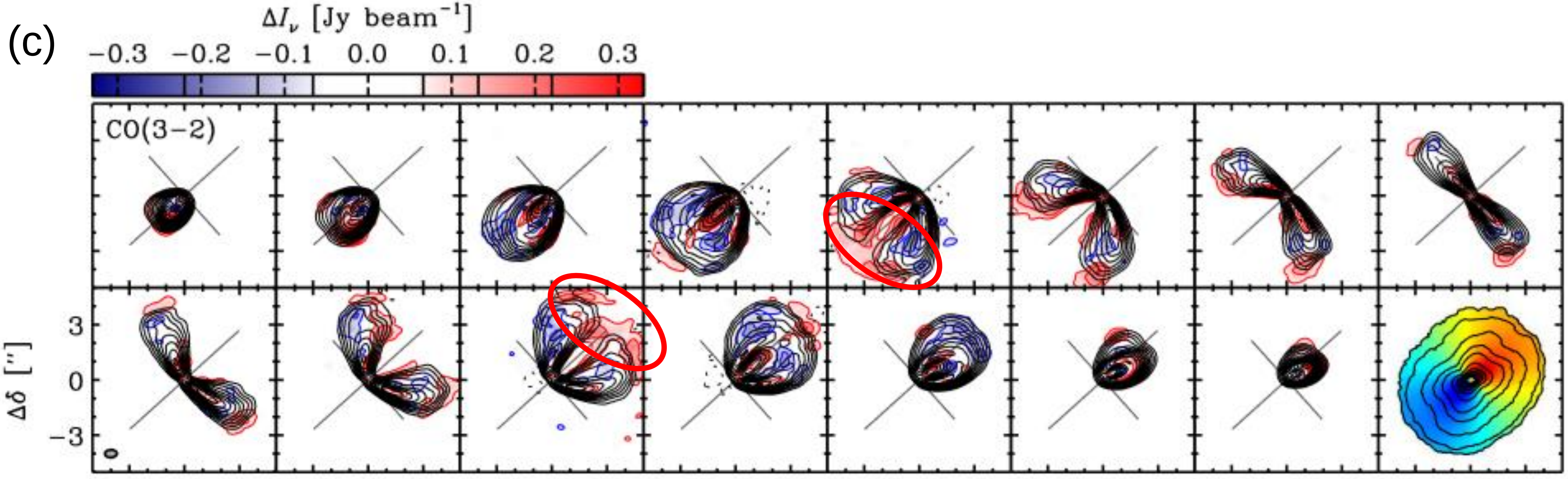
Model channel maps

There are systematic residuals at large radius at velocity $\approx 1\ km/s$

residual intensity $\Delta I_\nu = data - model$

(Rosenfeld et al. 2013)

(c)



Velocity deviation from Keplerian motions

- Assume the disk is rotating in vertical hydrostatic equilibrium
- Orbital velocity (assume circular orbits)

(III) Self-gravity

$$\frac{v^2}{r} = \boxed{\frac{r}{(r^2+z^2)^{1/2}}\left(\frac{GM_*}{r^2+z^2}\right)} + \boxed{\frac{1}{\rho_{gas}}\frac{\partial P_{gas}}{\partial r}} + \boxed{\frac{\partial \phi_{gas}}{\partial r}}$$

(I) Stellar gravity (II) Pressure gradient

Case I : vertical differential rotation

Case II : radial pressure gradient

Case III : disk's self-gravity

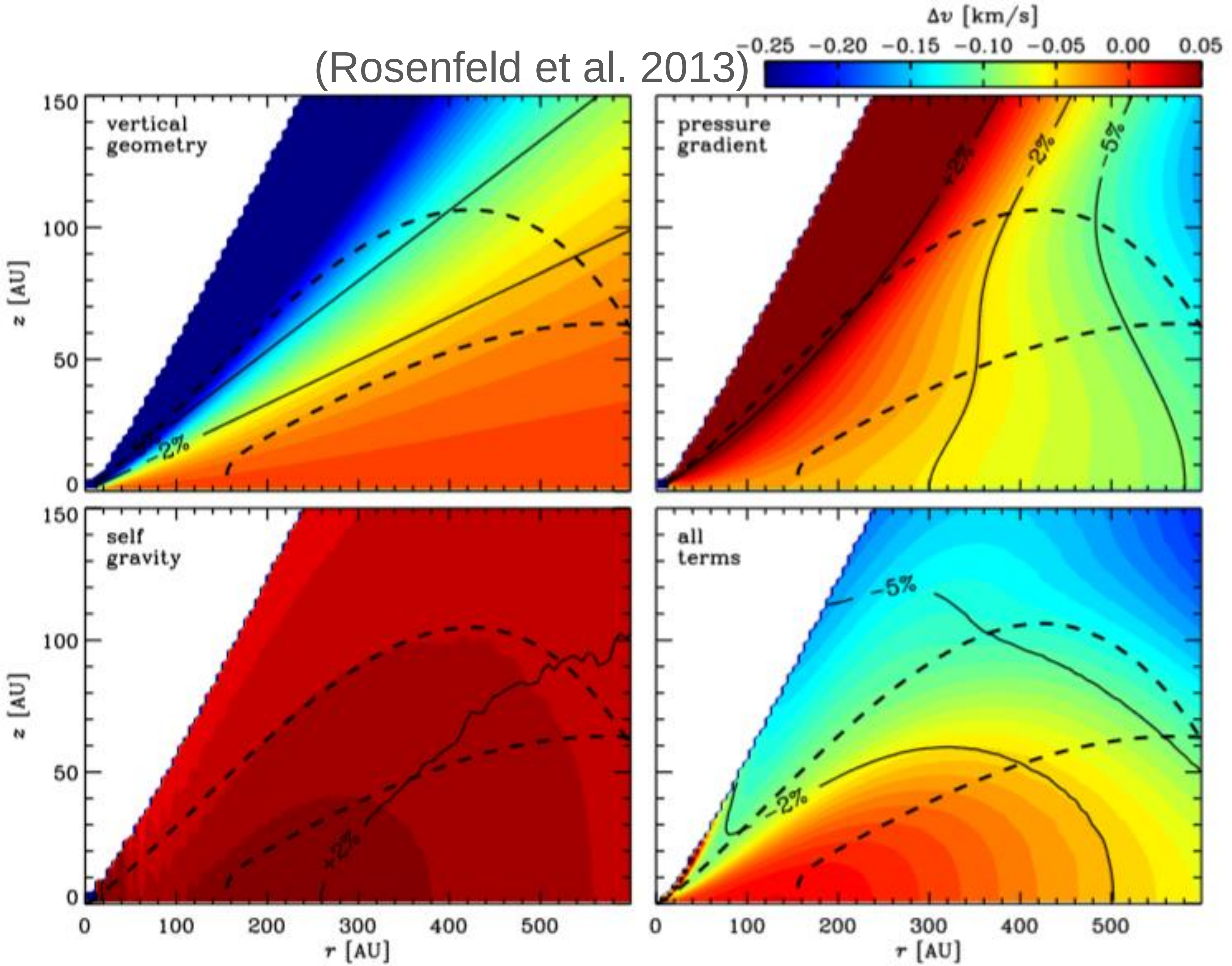
Case IV : all terms

Velocity difference compared to Keplerian velocity

I, II : slow down the gas high above and at large disk radius

III : speeds up the gas but has smaller effect

(Rosenfeld et al. 2013)



Summary

- Continuum image, CO(3-2) channel map, moment map have been done by CASA tasks
- Self-calibration improve the signal and sharpen the emission profile
- Asymmetry in the channel map shows the evidence of double cone structure
- Intensity distribution in channels reveals vertical temperature gradient in the disk structure
- Vertical geometry, pressure gradient and self gravity may cause the deviation of the velocity field from Keplerian velocity