USSP2019
Magnetic Fields Around Protostars

Student: Jason Huang 黃俊瑋
Advisor: Shi-Ping Lai 賴詩萍

Background image: https://science.sciencemag.org/content/353/6307/1492

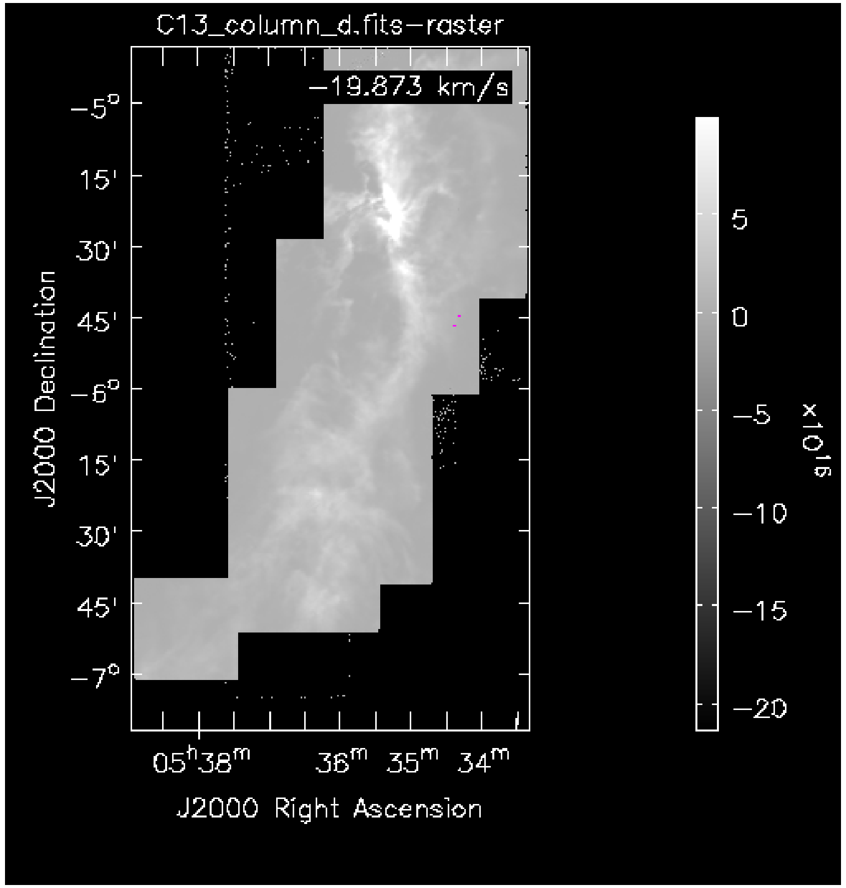
~~Magnetic Fields~~ How to do astronomical research

- Learn the methods of astronomy analyses
  1. Column density
  2. Radiative transfer
  3. CO, ^{13}CO, $C^{18}O$
  4. PV diagram

- Learn RADMC-3D modeling (HD163296)
  1. Study the manual
  2. Reproduce results from the papers

1-1. Column Density (N)

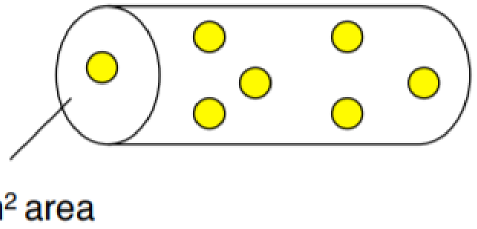
- Important in analyzing photos
- Determines how deep you're able to see



13CO column density
@ OrionA molecular cloud

N_{HI} = # of HI atoms per cm² in the line of sight.

Example:



$$N_{HI} = 7\,\mathrm{cm}^{-2}$$

$$N_{\mathrm{tot}}(\mathrm{C^{18}O}) = \frac{3\,h}{8\pi^3\mu^2 J_u R_i}\left(\frac{kT_{\mathrm{ex}}}{hB}+\frac{1}{3}\right)\exp\left(\frac{E_u}{kT_{\mathrm{ex}}}\right)\left[\exp\left(\frac{h\nu}{kT_{\mathrm{ex}}}\right)-1\right]^{-1}\int \tau_\nu dv.$$

Magnum (2016)

1-2. Radiative Transfer

- Describe the intensity (ie how many photons can go through medium and arrive to your eyes)

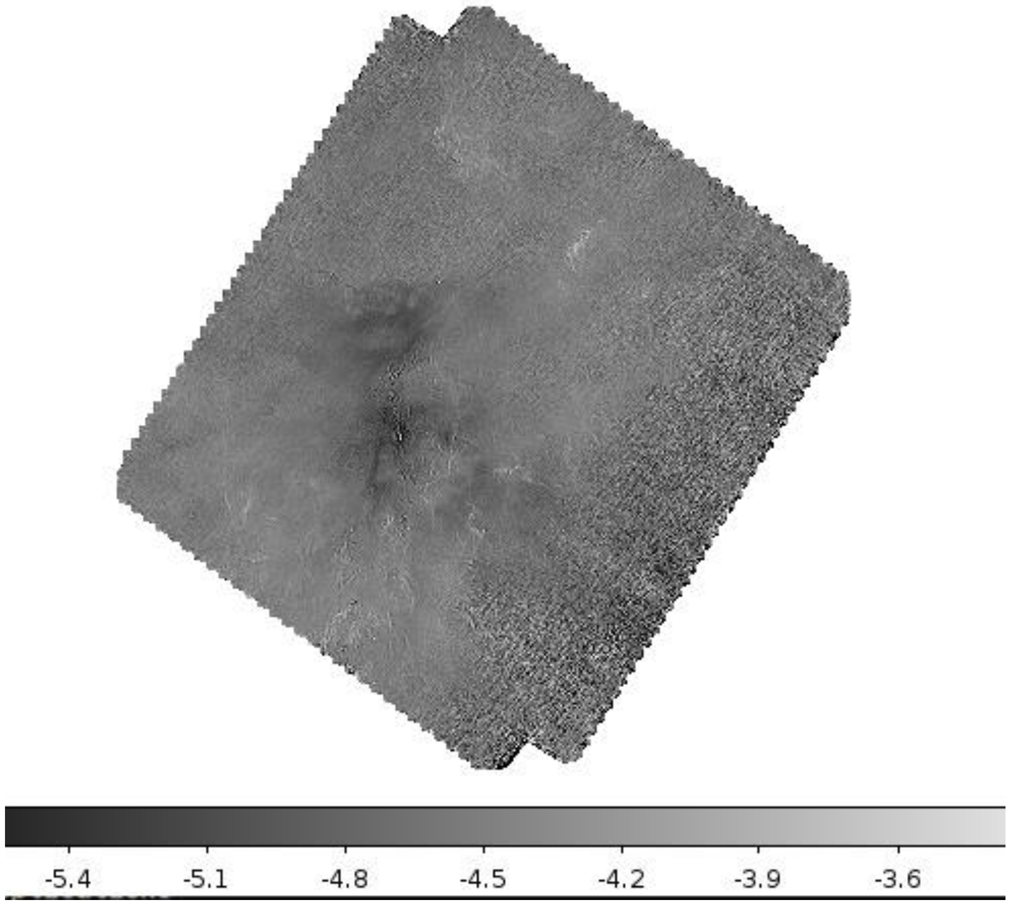
$$I_\nu = B_\nu(T)\left(1 - \mathrm{e}^{-\tau_\nu}\right)$$

If optically thin

$$I_\nu \approx B_\nu(T)\,\tau_\nu$$

$$\tau_\nu = \int \kappa_\nu \varrho \,\mathrm{d}s\,,$$

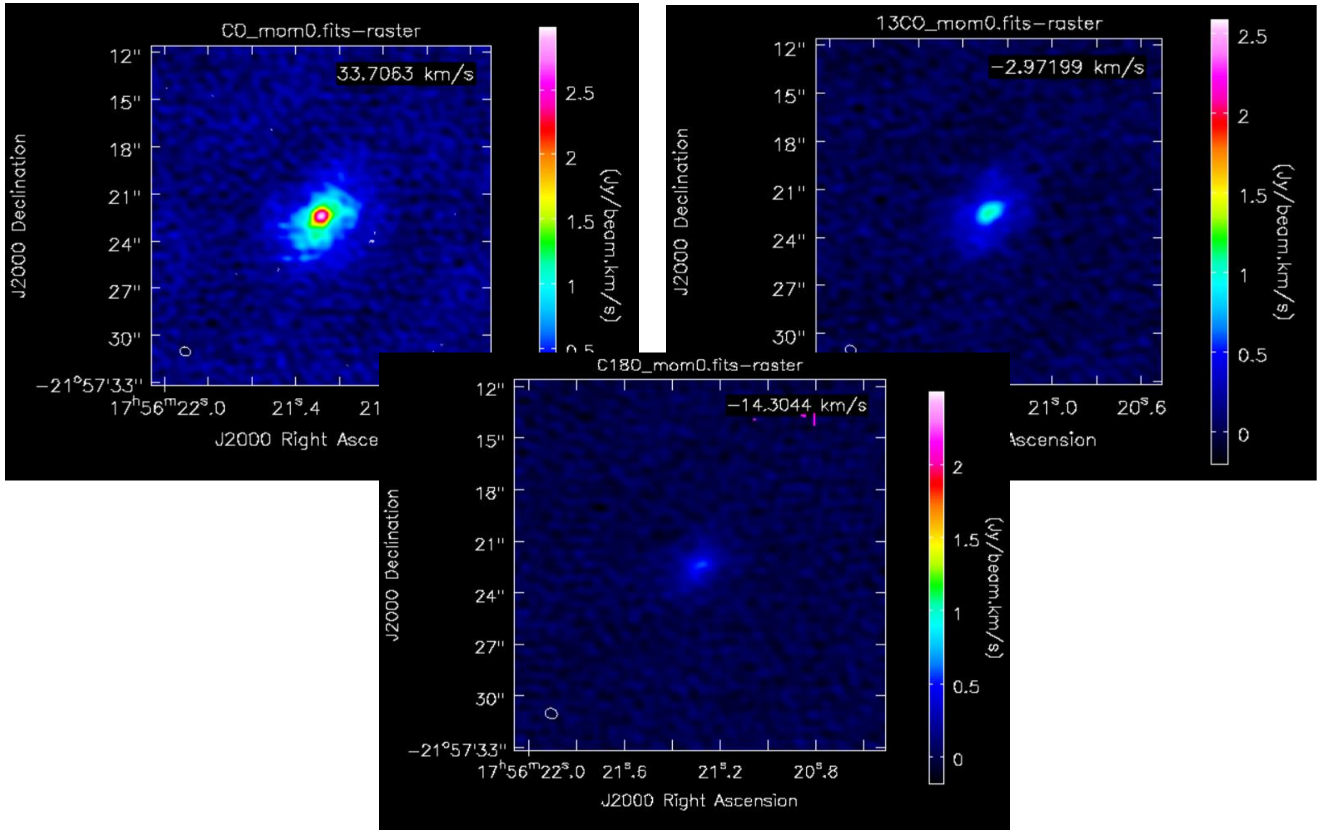
$$\kappa_\nu = \kappa_{230}\left(\frac{\nu}{230\mathrm{GHz}}\right)^{\beta}$$

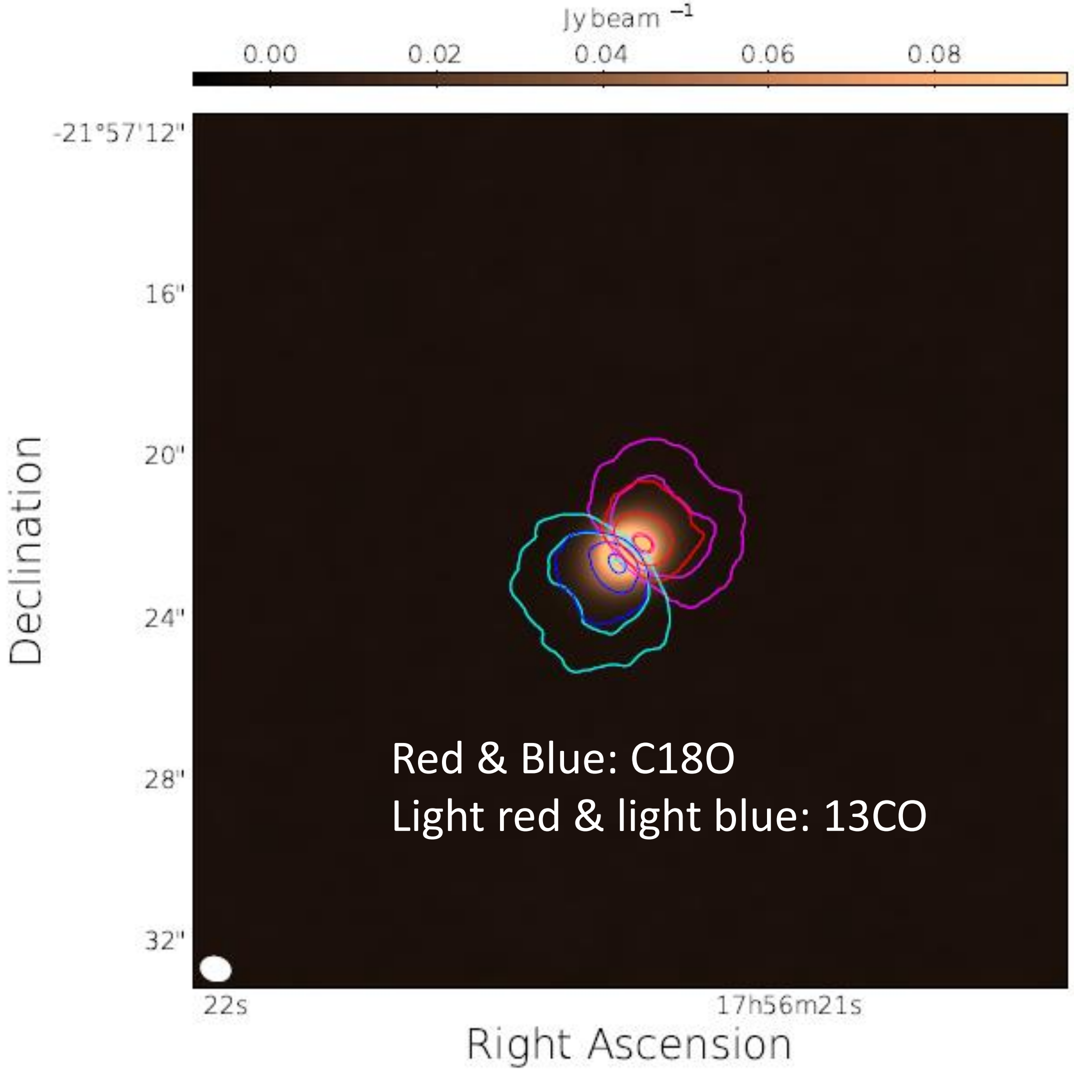


- Calculate beta, which is important to determine the star and dust properties

1-3. CO, ^{13}CO, $C^{18}O$

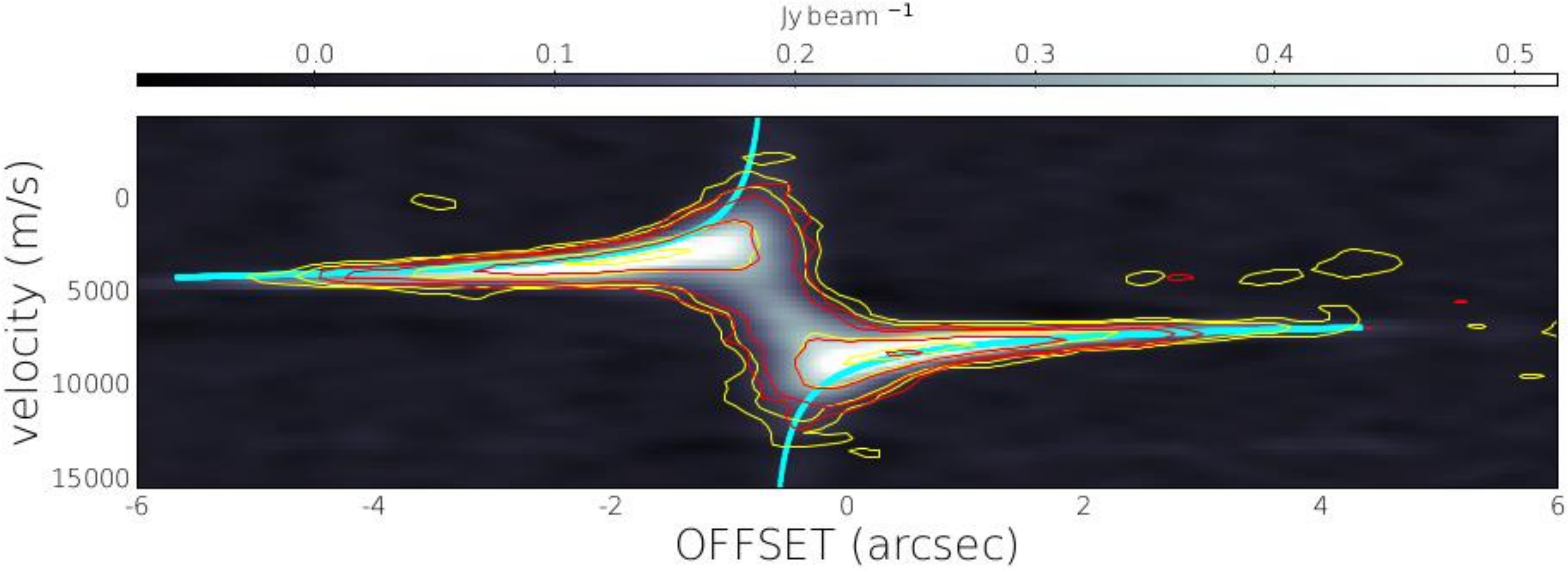
- Commonly used for spectrum analyses
- Avoid those which go optically thick





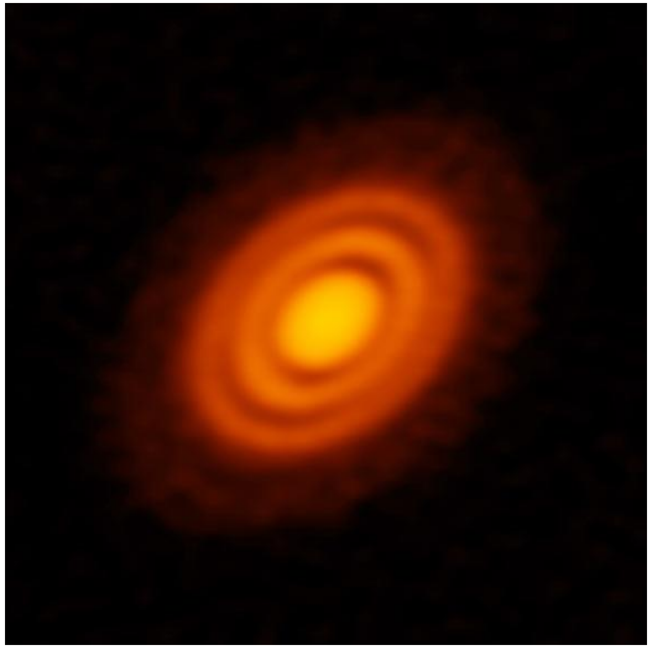
1-4. PV Diagram

- Identify which class the protostar is in
- Predict solar mass by Kepler's 3rd law



2. RADMC-3D Modeling

- Target: HD 163296
- Experimenting, not yet rigorous



http://cdn.sci-news.com/images/enlarge3/image_4448e-HD-163296.jpg

RADMC-3D

Input data files

amr_grid.inp
dust_density.inp
star.inp
Dustopac.inp

→

Intermediate data files

dust_temperature.dat

RADMC-3D

→

Output data files

.out (view by plotter)

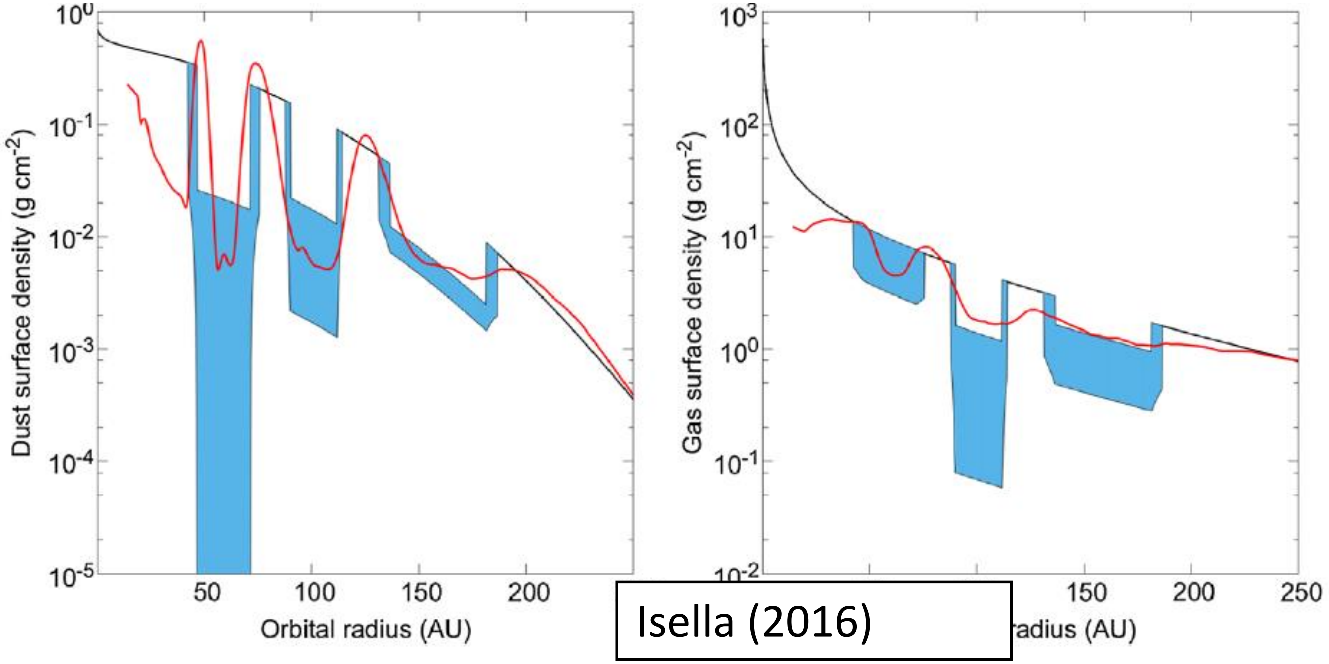
Isella (2016)

Input: Column density

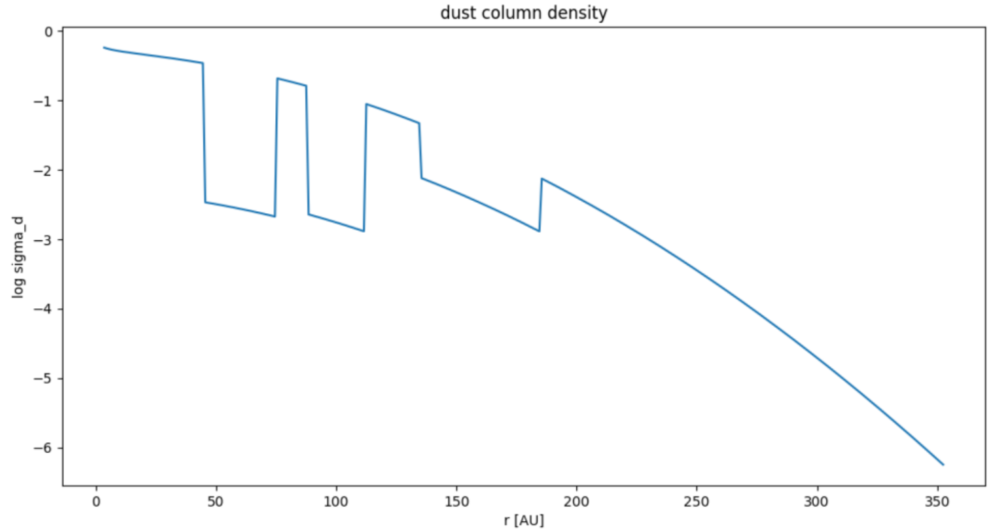
$$\Sigma(r) = \Sigma_c (r/r_c)^{-\gamma} \exp[-(r/r_c)^{2-\gamma}],$$

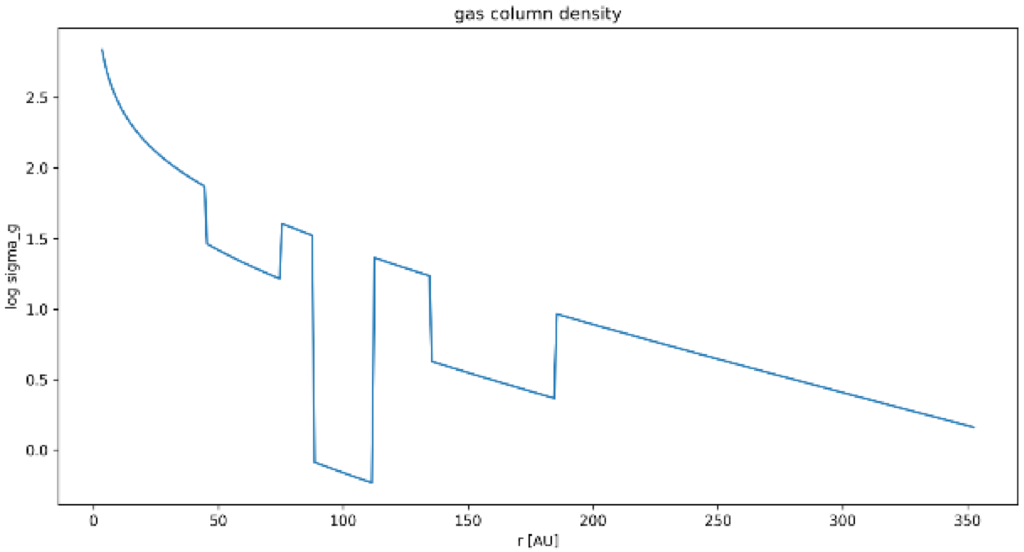
- Dust: $\gamma = 0.1,\ r_c = 90\ \mathrm{A.U.},\ \Sigma_c = 0.42\ \mathrm{g\ cm^{-2}}.$
- Gas (CO): $\gamma = 0.8,\ r_c = 165\ \mathrm{A.U.},$

$$\Sigma_c(^{12}\mathrm{CO}) = 1.6 \times 10^{-3}\ \mathrm{g\ cm^{-2}}$$



Isella (2016)





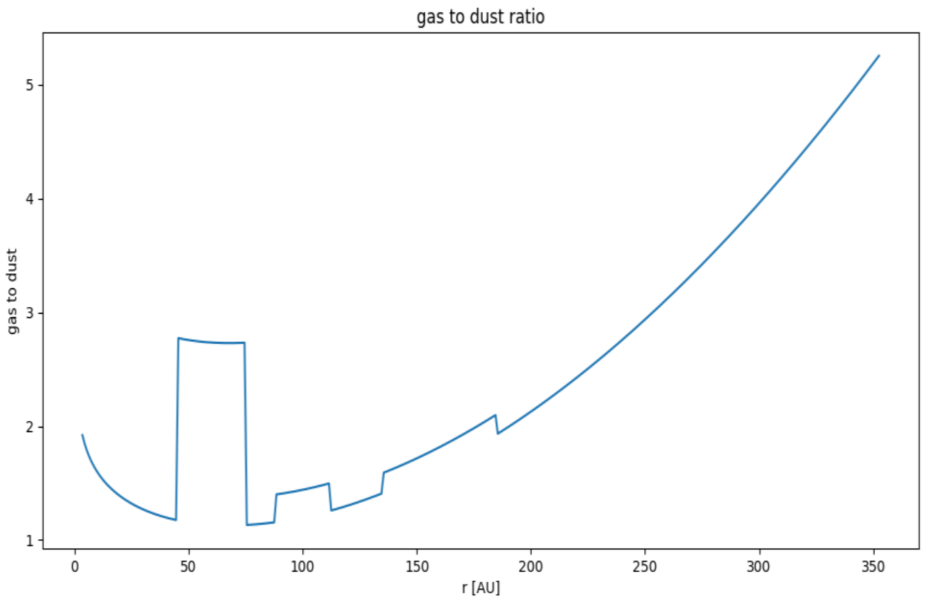
Gaps - Depletion factor

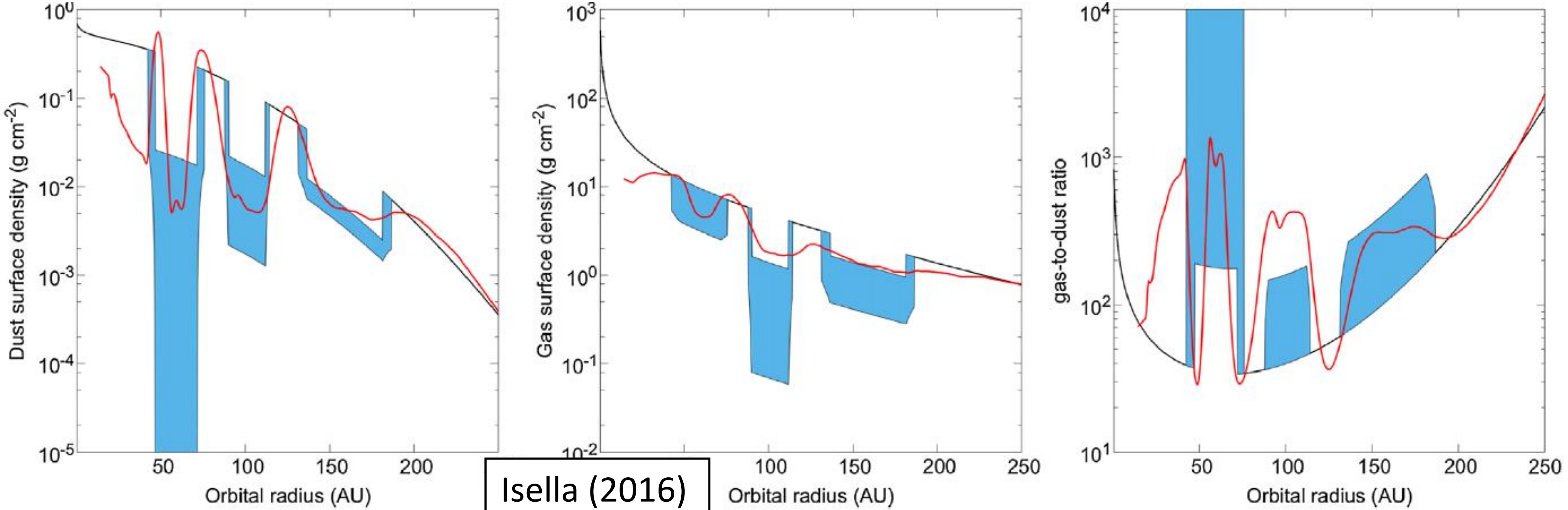
- Dust: max $\Delta_1 > 100, \Delta_2 = 70, \quad \Delta_3 = 6$

  min $\Delta_1 = 13, \Delta_2 = 7, \text{ and } \Delta_3 = 3.6.$
- Gas: max (2.5, 70, 6)

  min (0, 3.5, 1.8)

Big uncertainy !





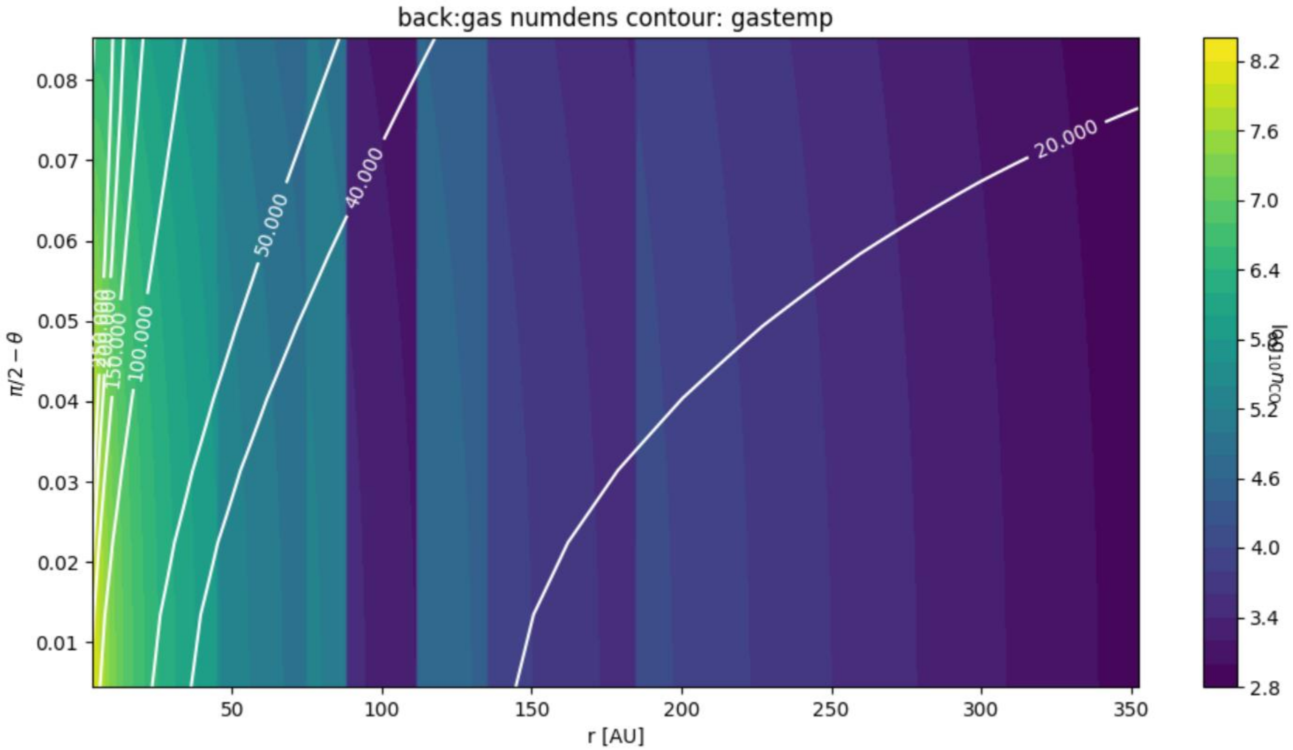
Isella (2016)

Input: Temperature

$$T(r,z) = \begin{cases} T_a(r,z) + [T_m(r) - T_a(r,z)]\left(\cos\frac{\pi z}{2z_q(r)}\right)^{2d(r)}, & \text{if } |z| < z_q(r) \\ T_a(r,z), & \text{otherwise.} \end{cases}$$

Isella (2016)

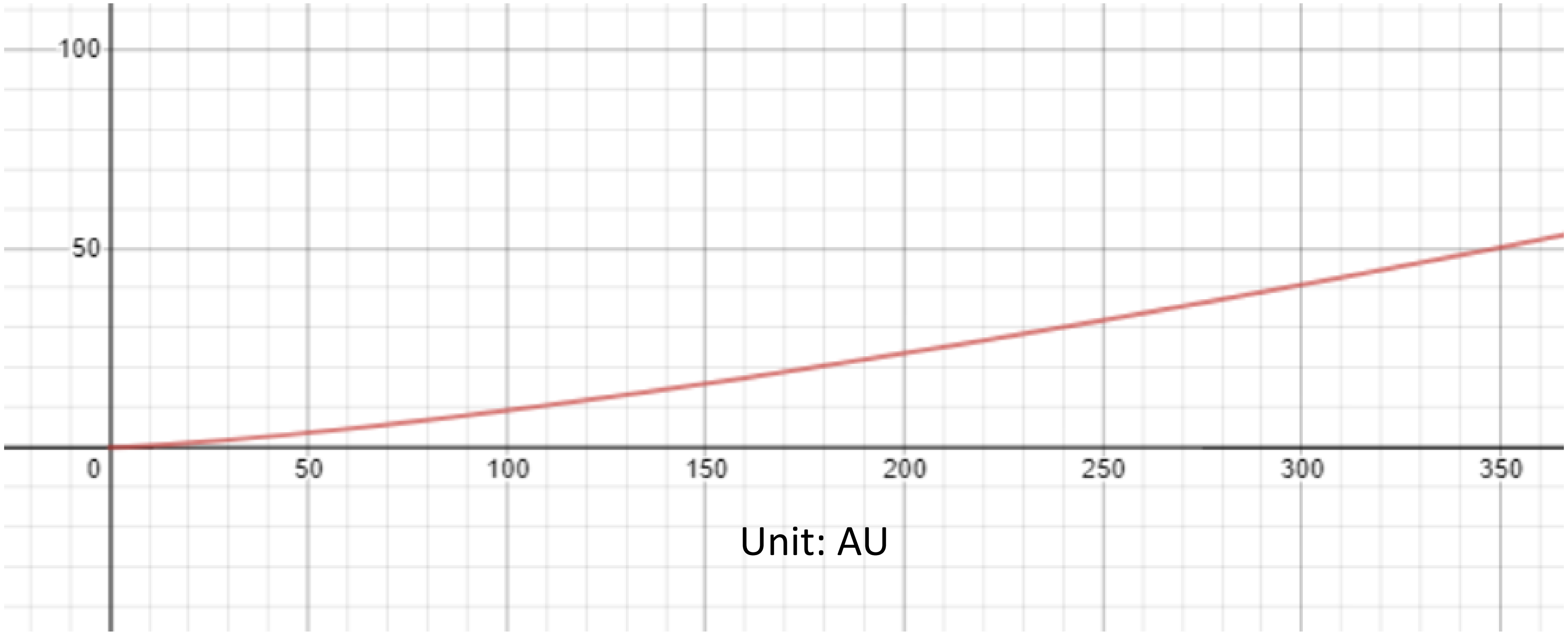
- Disk midplane $T_m(r) = 24\ \mathrm{K}(r/100\ \mathrm{A.U.})^{-0.5}$
- Disk surface temperature $T_a(r,z) = 68\mathrm{K}(\sqrt{r^2+z^2}/100\mathrm{au})^{-0.6}$



Input: Disk structure

- $H(r) = 16(r/150\ \mathrm{AU})^{1.35}$

Rosenfeld (2013)

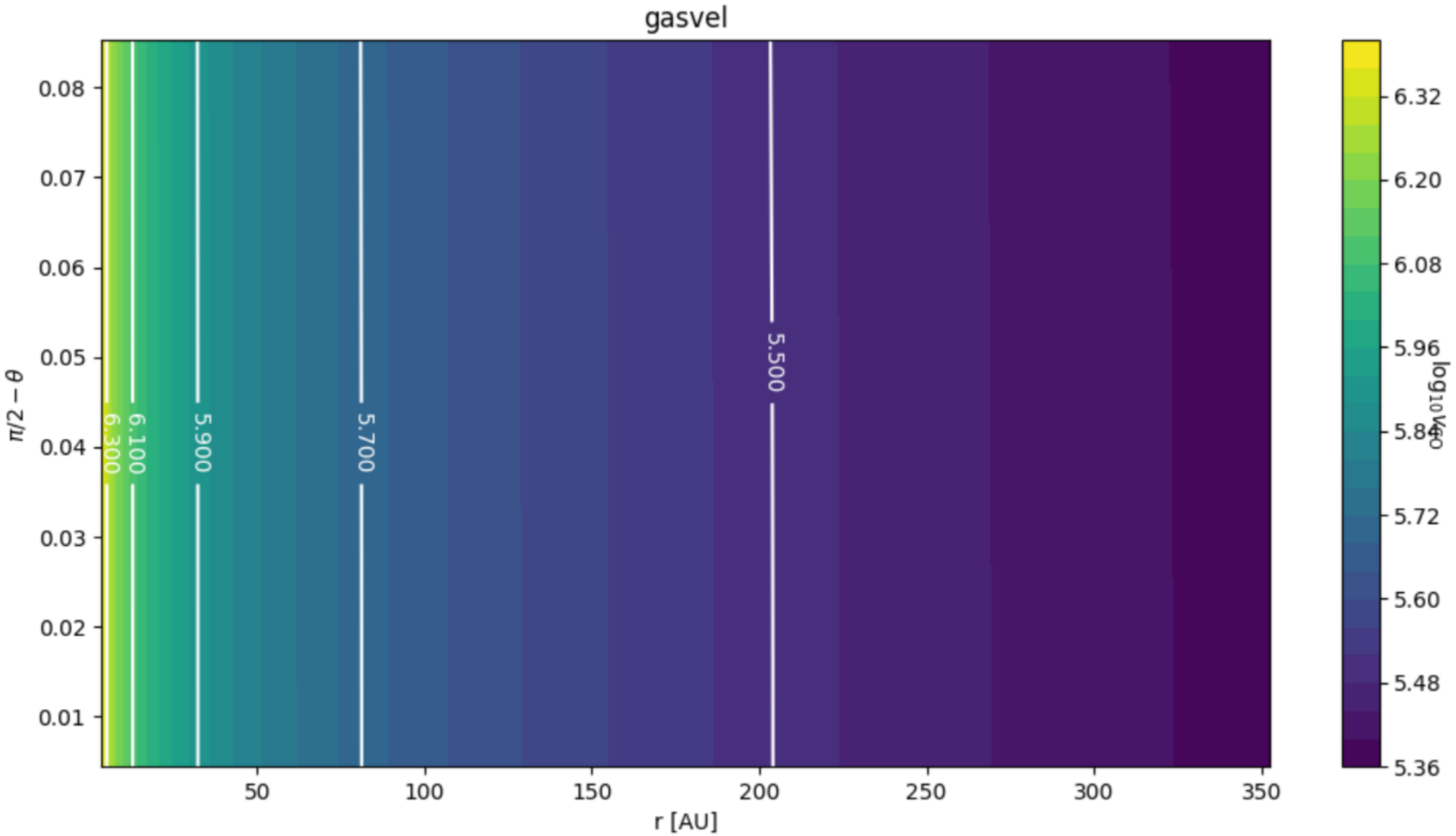


Unit: AU

Input: Gas velocity

Rosenfeld (2013)

- Assume Keplerian $$v_K{}^2 = \frac{GM_*}{r}.$$



RUN!

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==================================================================
     WELCOME TO RADMC-3D: A 3-D CONTINUUM AND LINE RT SOLVER

       This is the 3-D reincarnation of the 2-D RADMC code
               (c) 2010/2015 Cornelis Dullemond

************* NOTE: THIS IS STILL A BETA VERSION ***************
****** Some modes/capabilities are not yet ready/mature ********

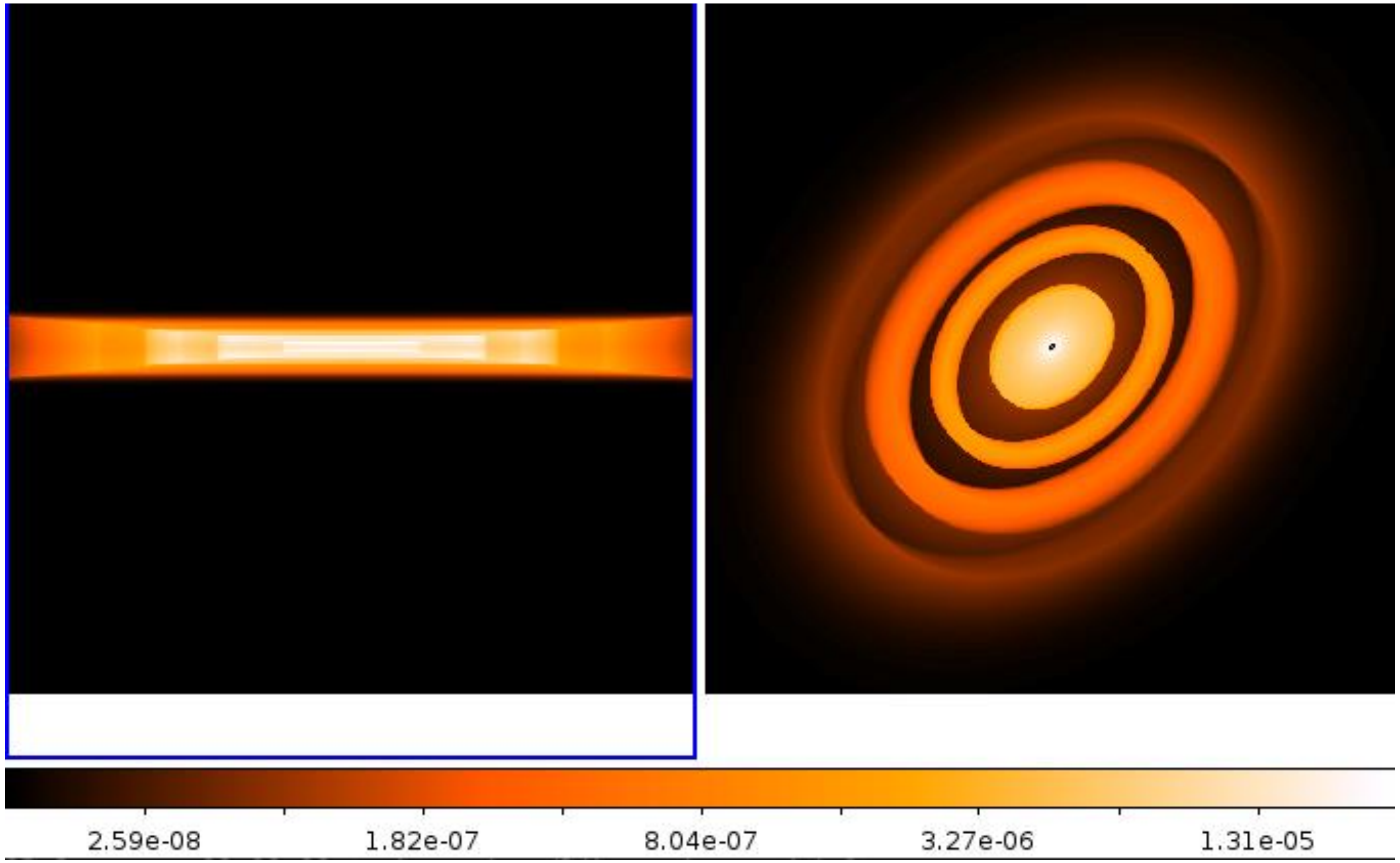
      Please feel free to ask questions. Also please report
       bugs and/or suspicious behavior without hestitation.
     The reliability of this code depends on your vigilance!

   To keep up-to-date with bug-alarms and bugfixes, register to
     the RADMC-3D mailing list by sending an email to me:
                   dullemond@uni-heidelberg.de

             Please visit the RADMC-3D home page at
 http://www.ita.uni-heidelberg.de/~dullemond/software/radmc-3d/
==================================================================

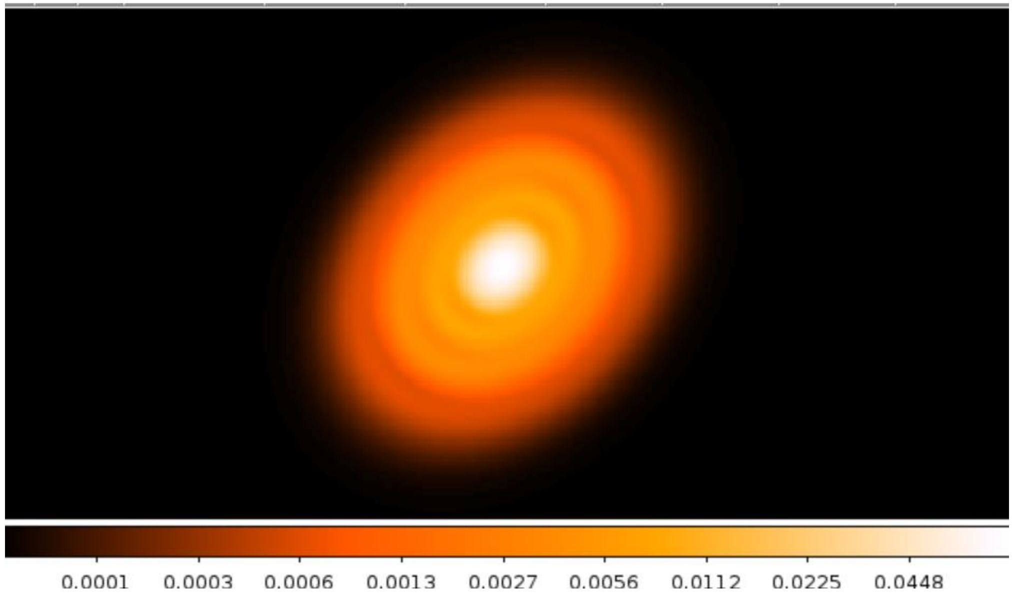
Number of processors:           40
Number of threads in use:            1
Reading global frequencies/wavelengths...
Reading grid file and prepare grid tree...
   Adjusting theta(ny+1) to exactly pi/2...
Reading star data...
Note: Please be aware that you treat the star(s) as
      point source(s) while using spherical coordinate mode.
      Since R_*<<R_in this is probably OK, but if you want
      to play safe, then set istar_sphere = 1 in radmc3d.inp.
Note: Star 1 is taken to be a blackbody star
      at a temperature T = 9330. Kelvin
Grid information (current status):
  We have 3500 branches, of which 3500 are actual grid cells.
  ---> 100.000% mem use for branches, and 100.000% mem use for actual cells.
  No grid refinement is active. The AMR tree is not allocated (this saves memory).
Reading the heat source spatial distribution...
ALWAYS SELF-CHECK FOR NOW...
Using mirror symmetry in equatorial plane, because max(theta)==pi/2.
Starting procedure for rendering image...
      No dust included...
  --> Including lines
      No gas continuum included...
Using Gaussian line profile
Reading line data...
NOTE: In lines.inp for molecule 1 no collision partners specified, therefore no no
Reading line data of molecule co ...
```

Result – Continuum Model



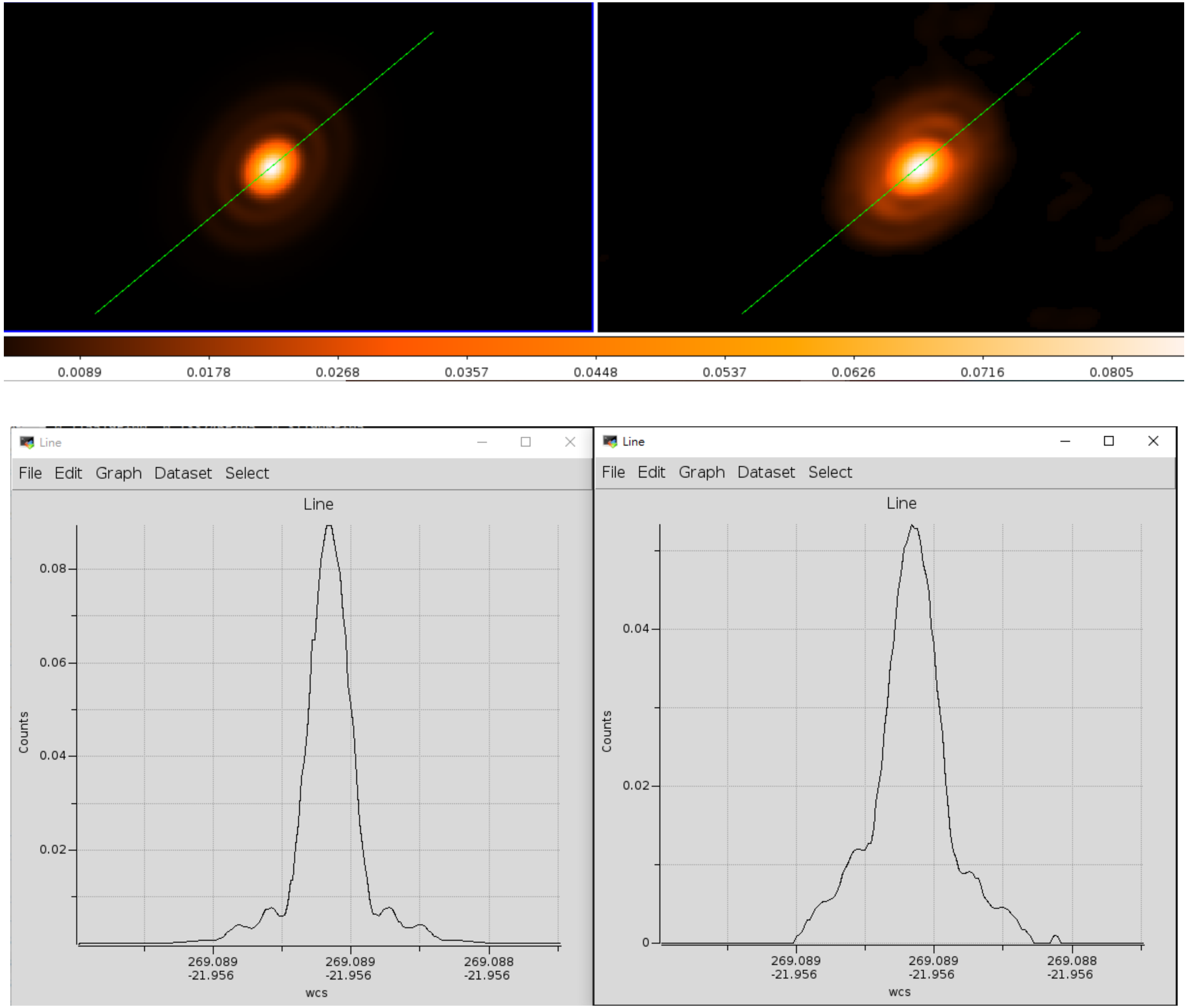
- Convolve

(astropy: Gaussian2DKernel())

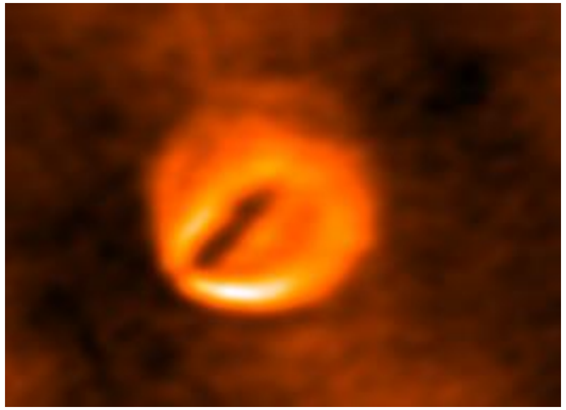


My model

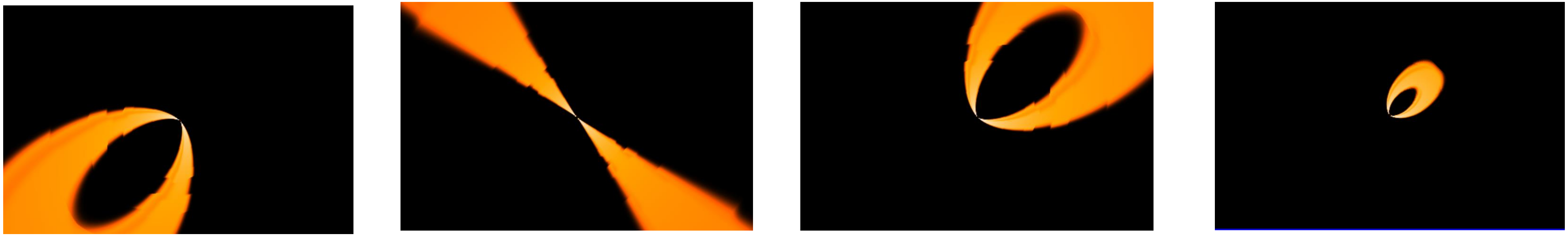
ALMA



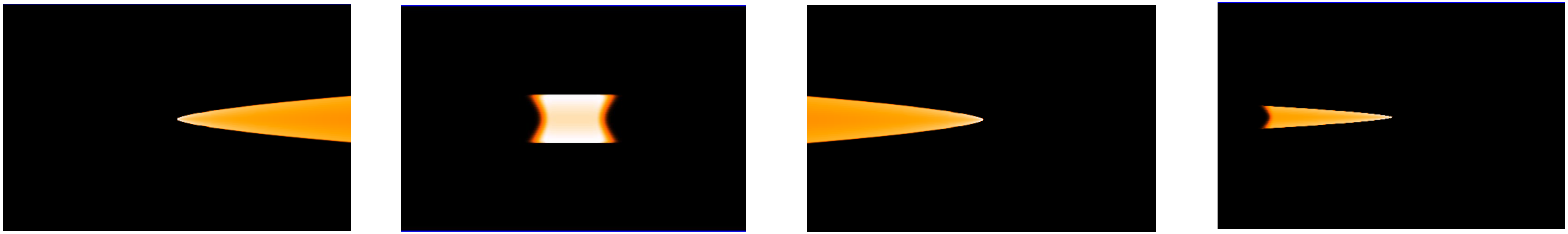
Line Model (CO 3-2)



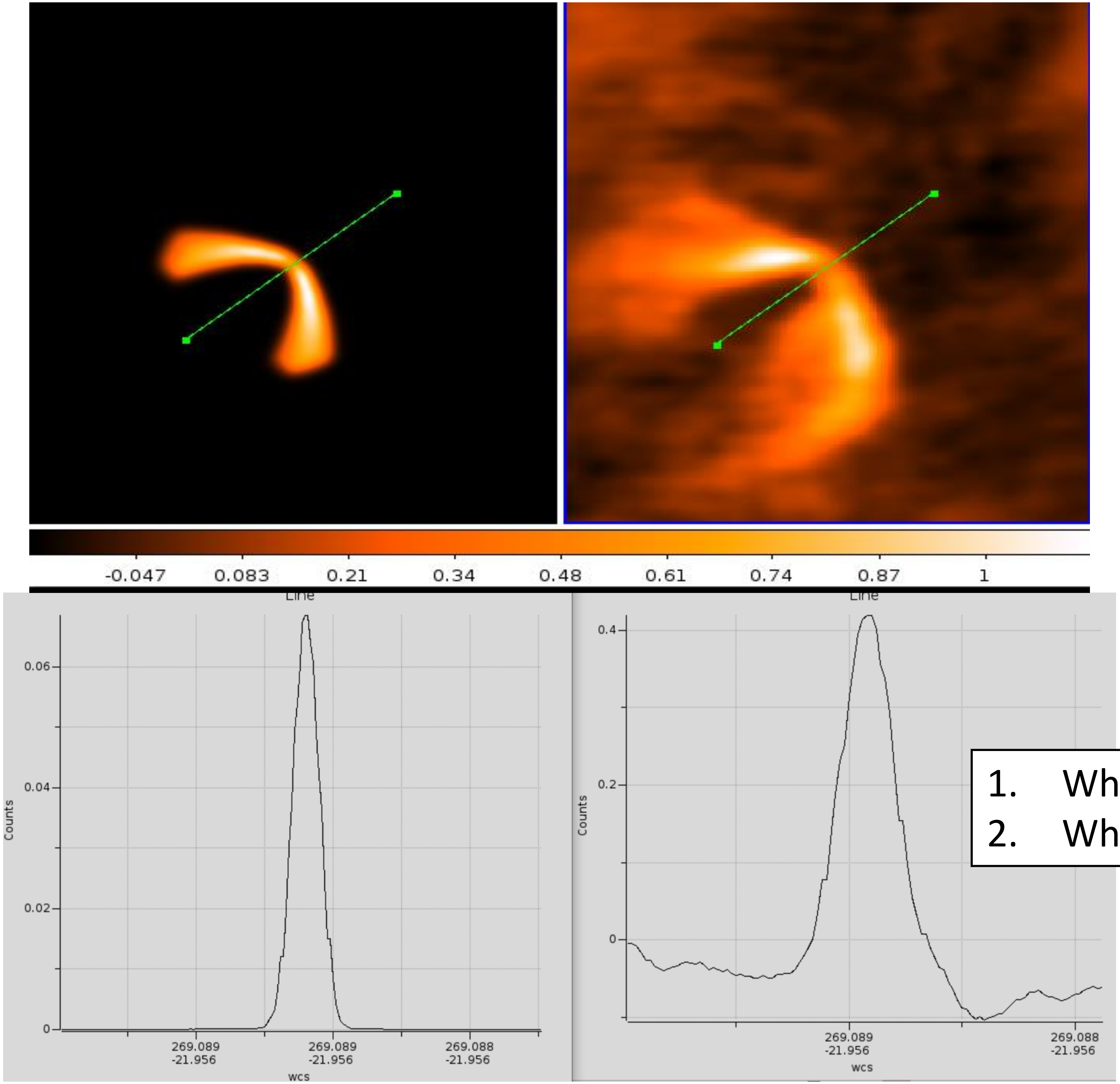
Incline = 45 degrees, position angle = 135 degrees



Edge-on



My model



ALMA

1. Why the discrepency?
2. Where is the double cone?

Thank you!

Q&A