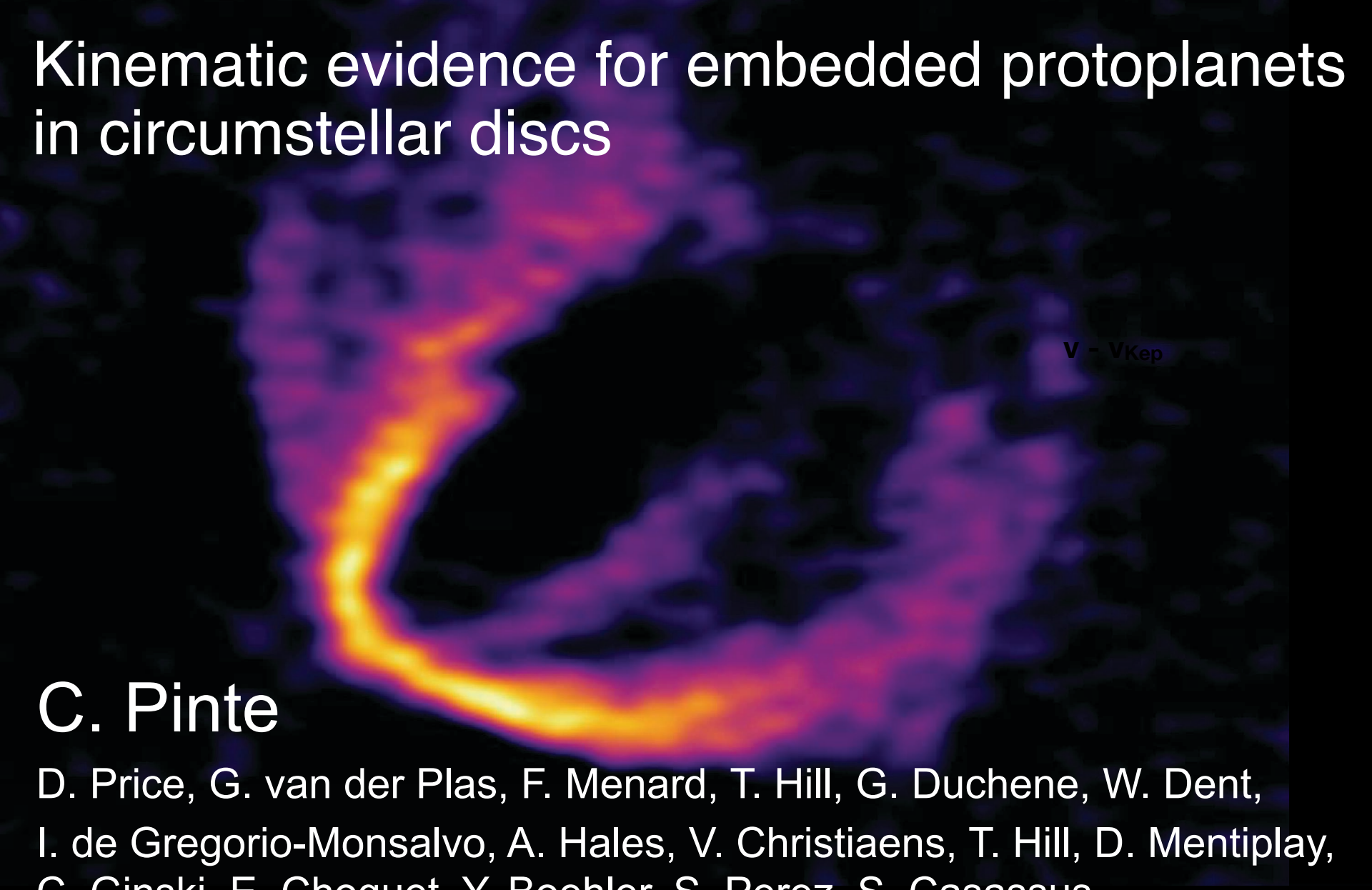
Kinematic evidence for embedded protoplanets in circumstellar discs



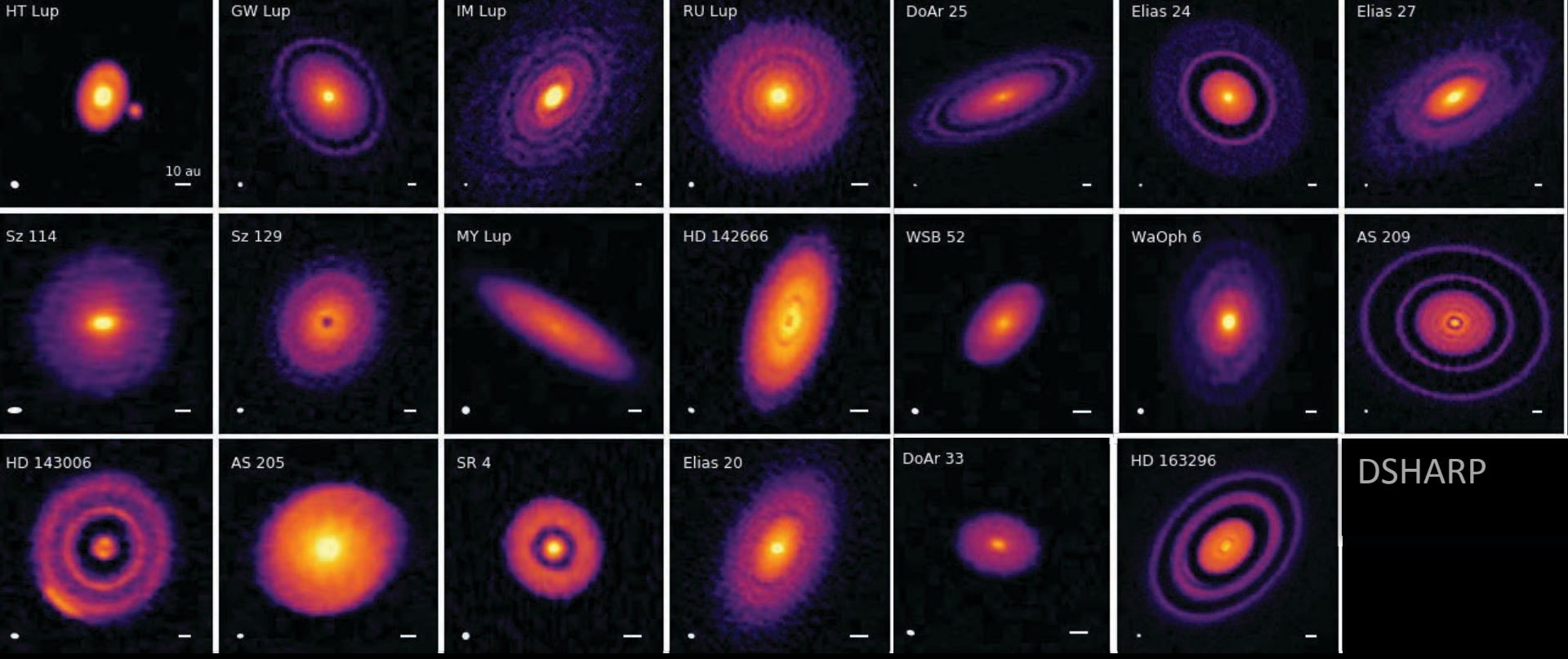
C. Pinte

D. Price, G. van der Plas, F. Menard, T. Hill, G. Duchene, W. Dent,
I. de Gregorio-Monsalvo, A. Hales, V. Christiaens, T. Hill, D. Mentiplay,
C. Ginski, E. Choquet, Y. Boehler, S. Perez, S. Casassus

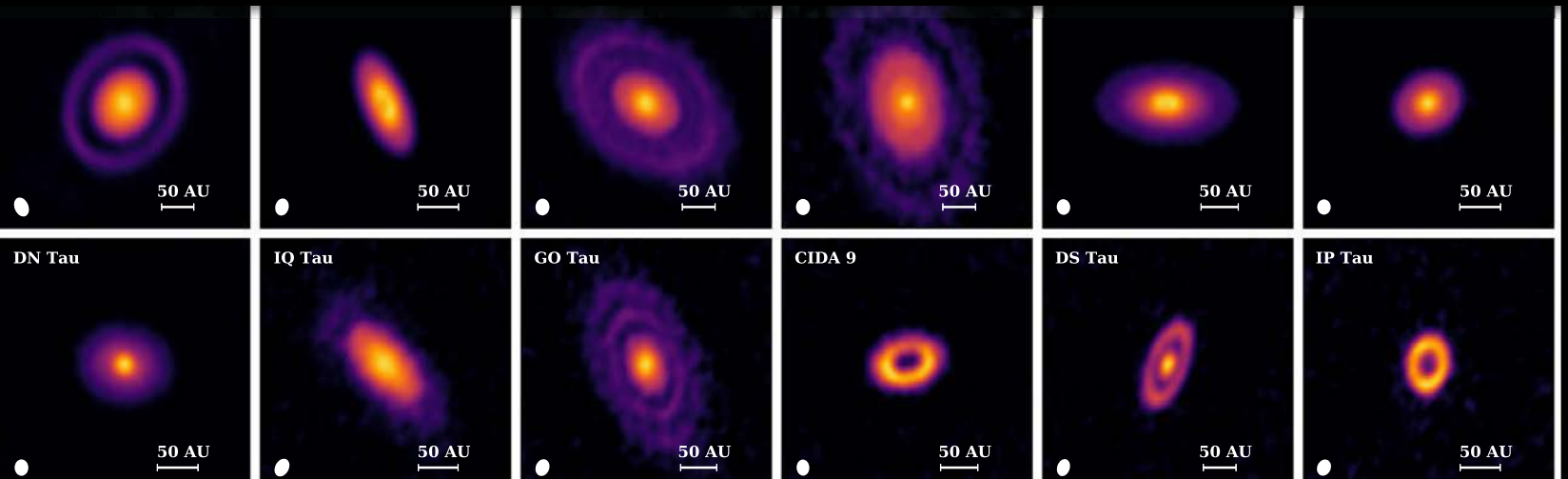
MONASH University

cnrs

IPAG Institut de Planétologie et d'Astrophysique de Grenoble



Are (some of) these gaps carved by planets ?

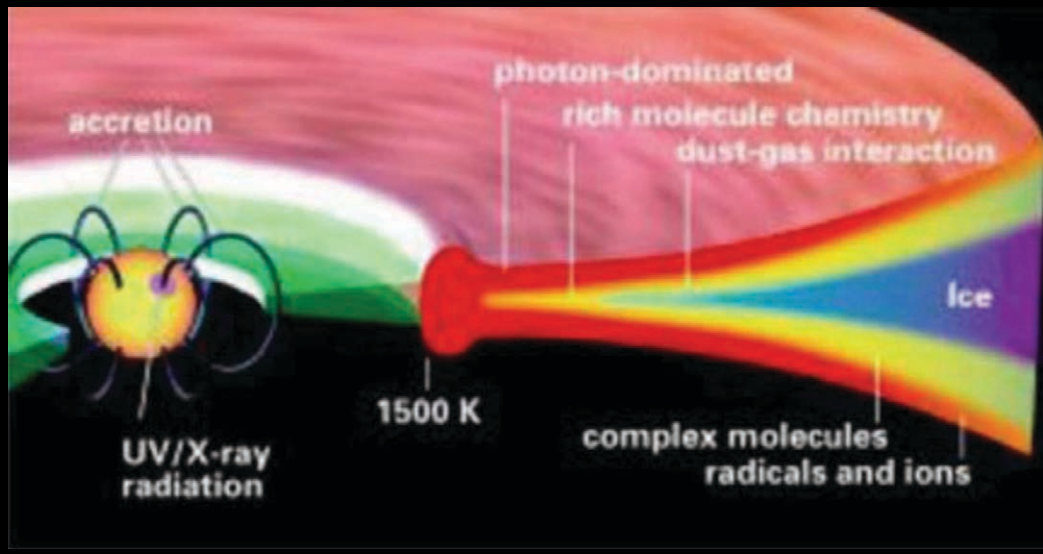


Taurus survey
Long et al 2018

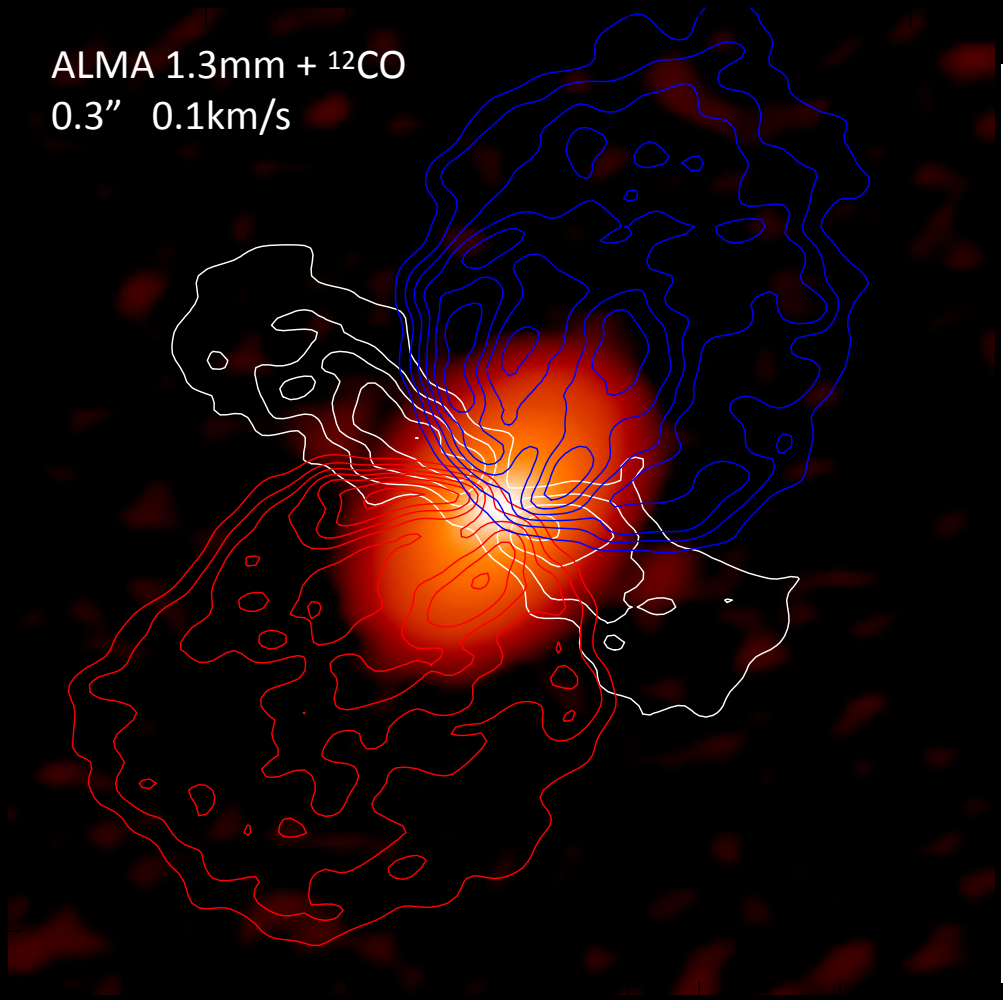
Chemical layers in a discs

Three layers of chemistry:

- Hot atomic layer (PDR)
- **Warm molecular layer**
  → probed by ALMA
- Cold icy mid plane
  → dust pebbles probed by ALMA

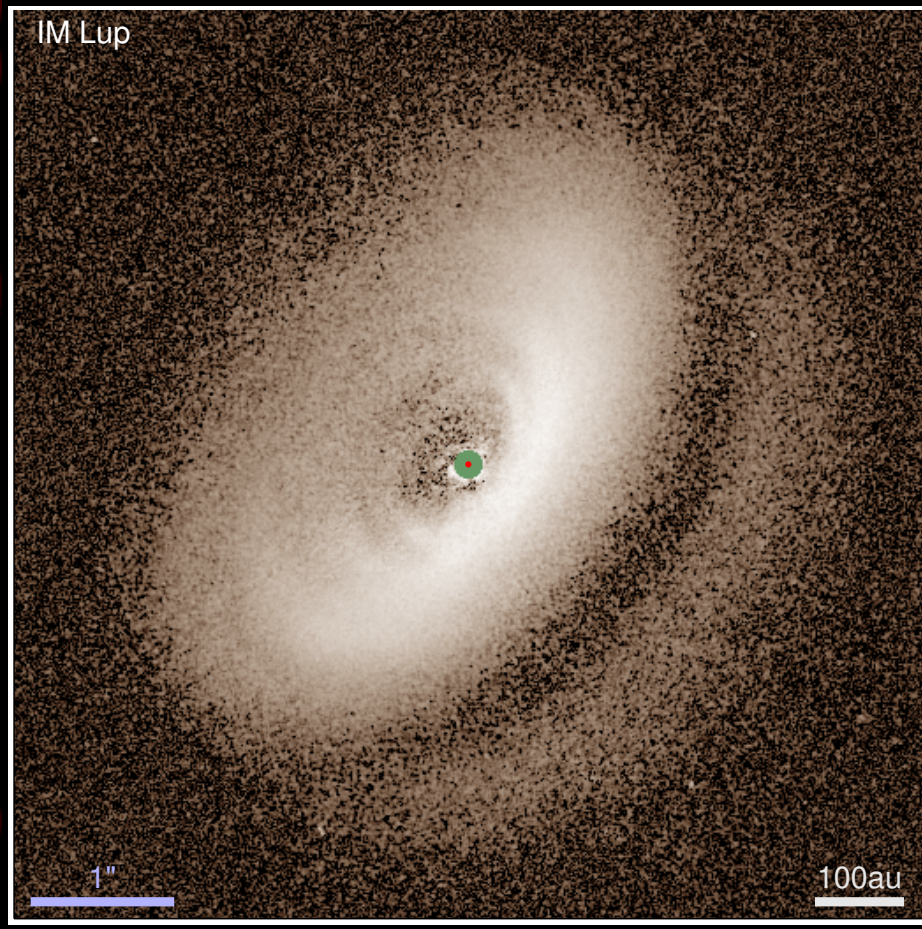


ALMA and SPHERE views of IM Lupi



Pinte et al. 2018

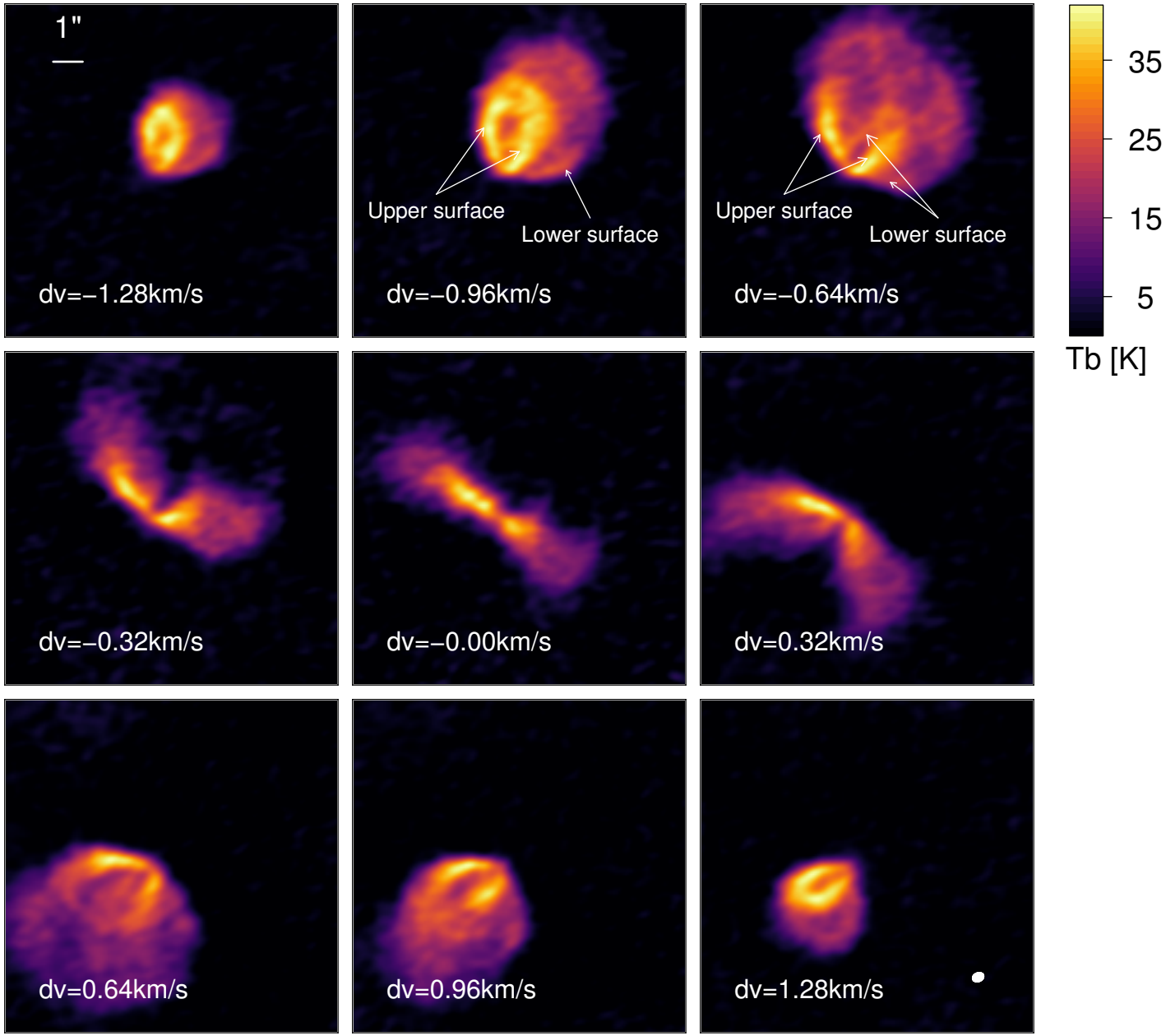
SPHERE H band DPI ~ 0.05”



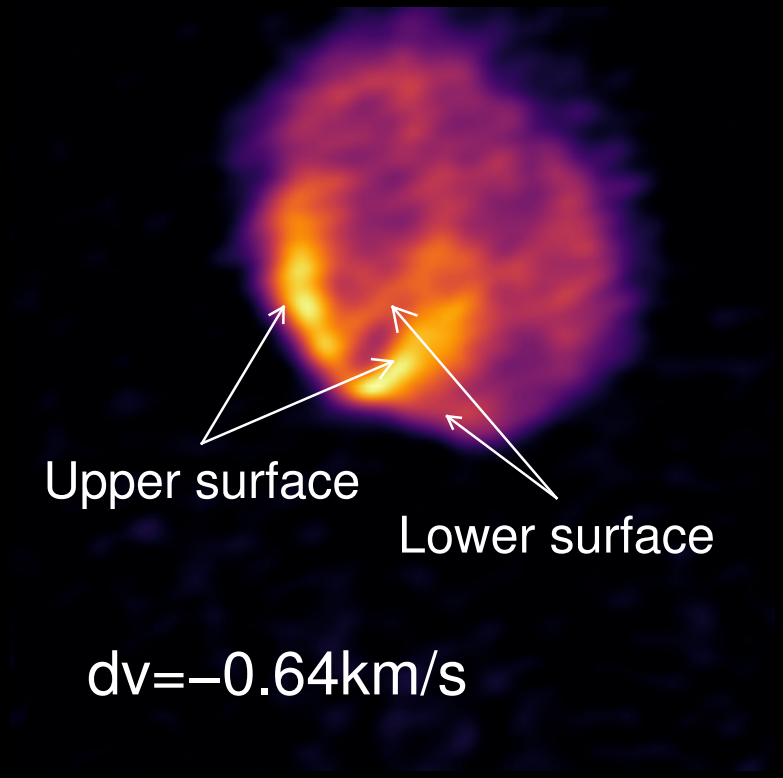
Avenhaus et al. 2018

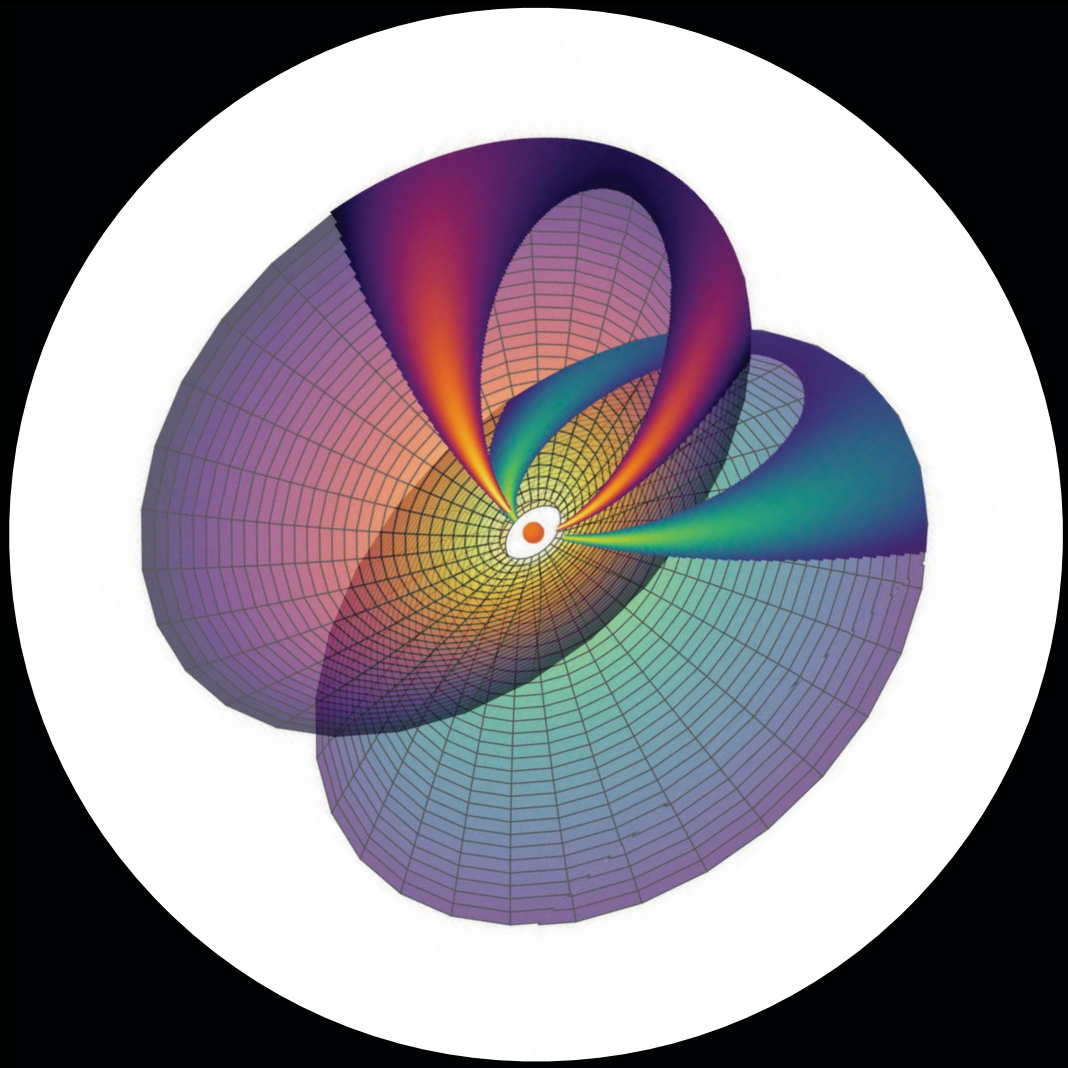
i = 50 deg

^{12}CO (2-1)

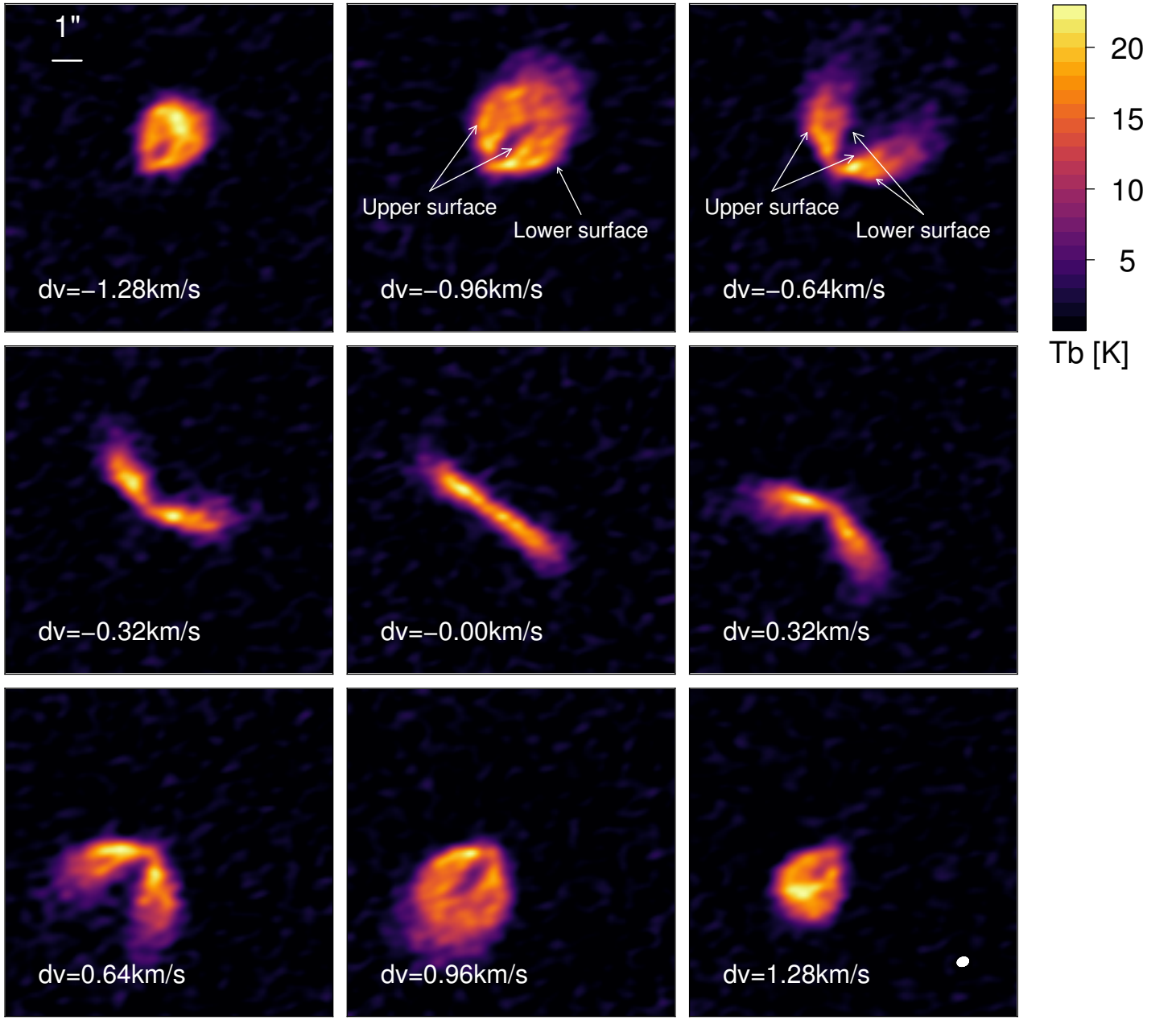

1"
dv=−1.28km/s
Upper surface
Lower surface
dv=−0.96km/s
Upper surface
Lower surface
dv=−0.64km/s
dv=−0.32km/s
dv=−0.00km/s
dv=0.32km/s
dv=0.64km/s
dv=0.96km/s
dv=1.28km/s
35
25
15
5
Tb [K]

^{12}CO (2-1)

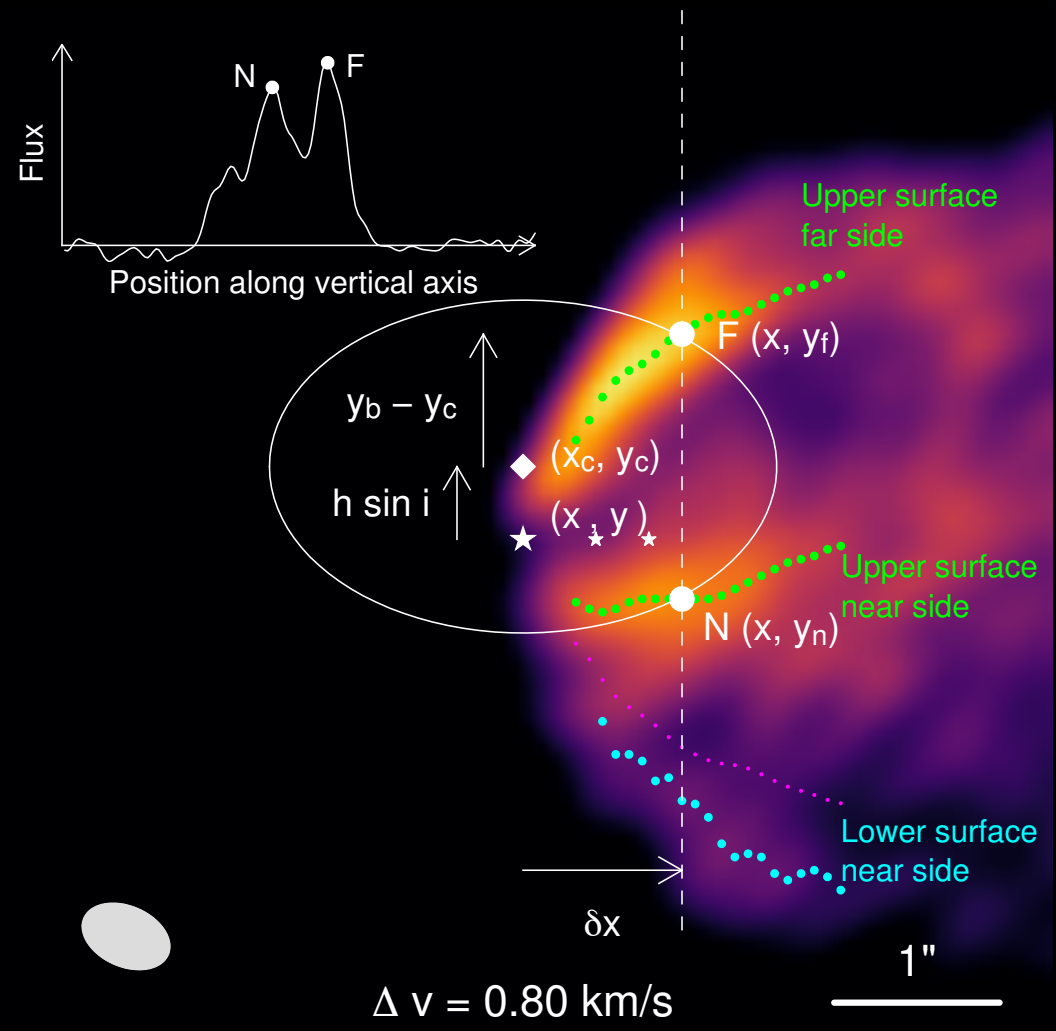




^{13}CO (2-1)


1"
Upper surface
Lower surface
Upper surface
Lower surface
dv=−1.28km/s
dv=−0.96km/s
dv=−0.64km/s
dv=−0.32km/s
dv=−0.00km/s
dv=0.32km/s
dv=0.64km/s
dv=0.96km/s
dv=1.28km/s
20
15
10
5
Tb [K]

Reconstructing the altitude, velocity and temperature of the CO emitting layers



$$r = \sqrt{(x - x_\star)^2 + \left(\frac{y_f - y_c}{\cos i}\right)^2}$$

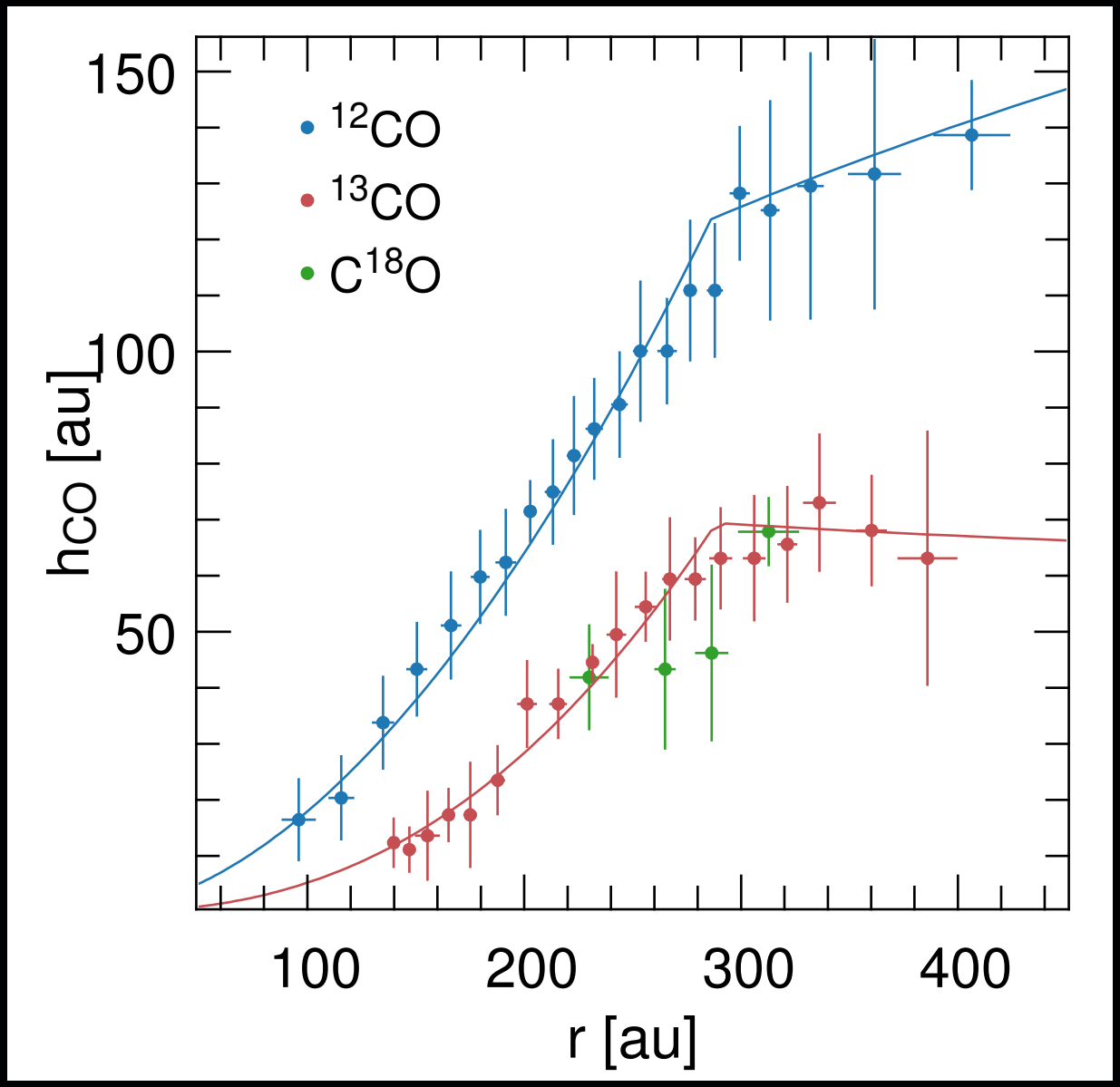
$$h = \frac{y_c - y_\star}{\sin i}$$

$$v = (v_{\rm obs} - v_{\rm syst})\,\frac{r}{(x - x_\star)\,\sin i}$$

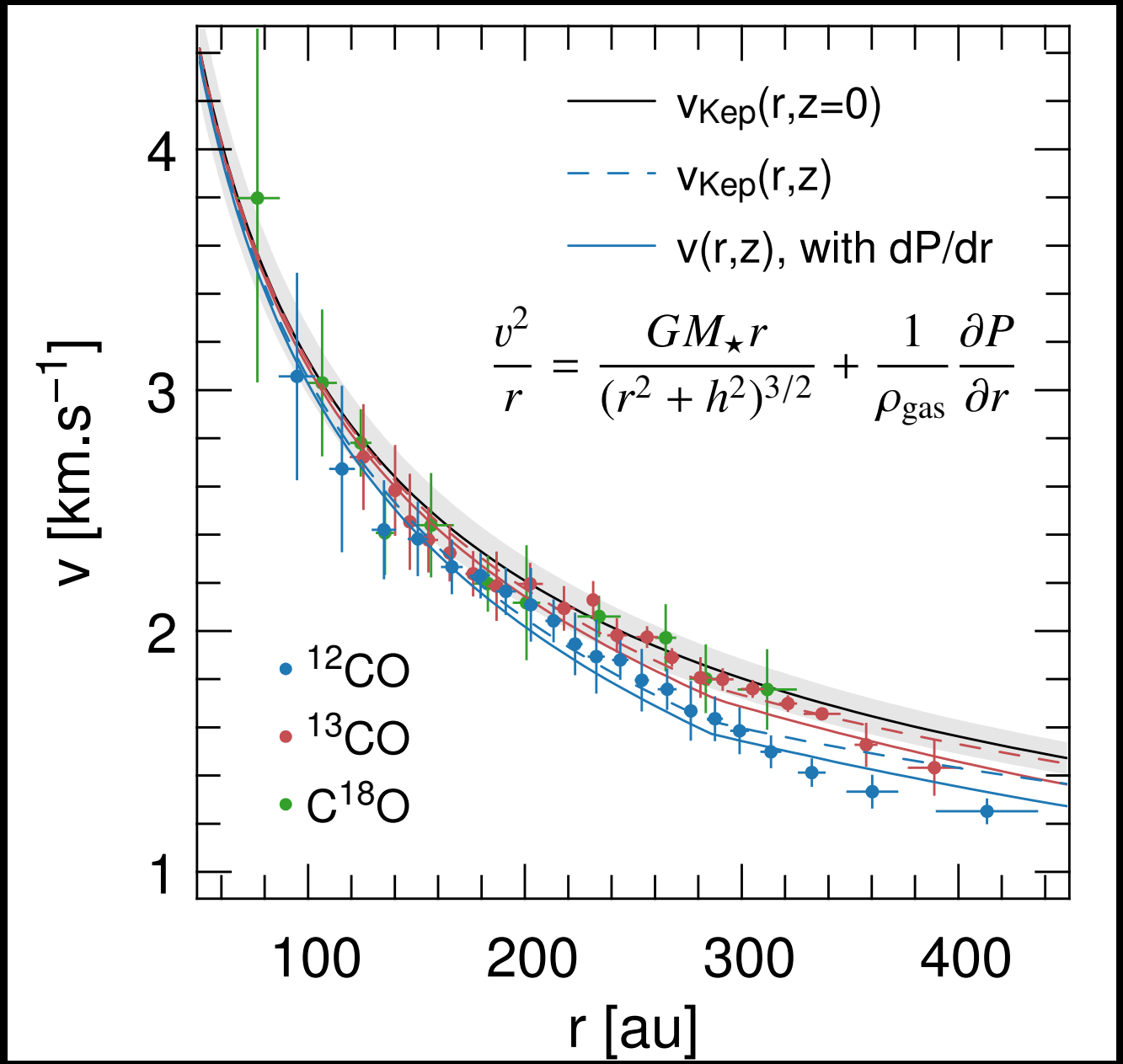
$$T_{\rm b} = T_{\rm ex}(1 - e^{-\tau})$$

Assuming Keplerian rotation and circular orbit

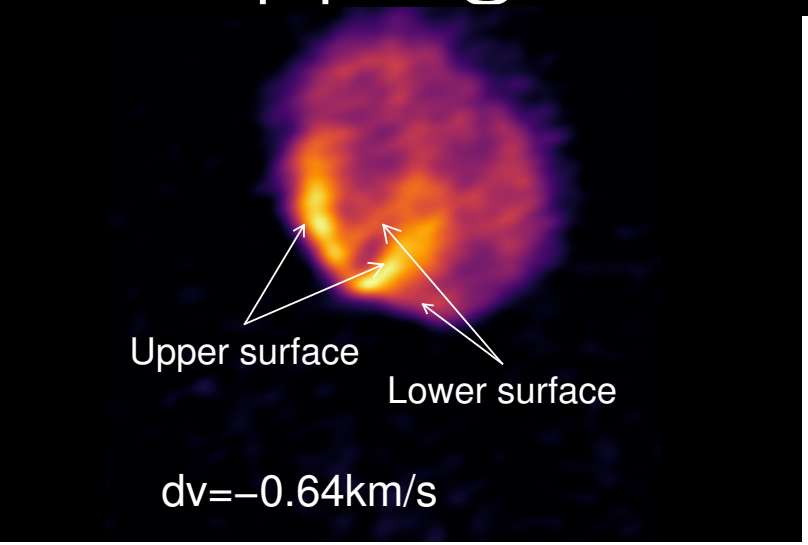
The CO layers

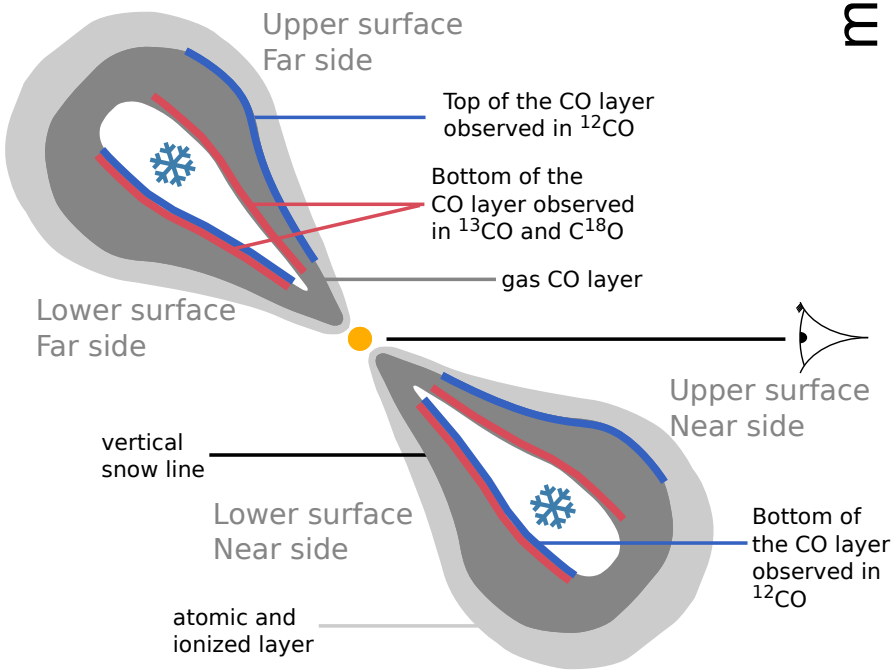


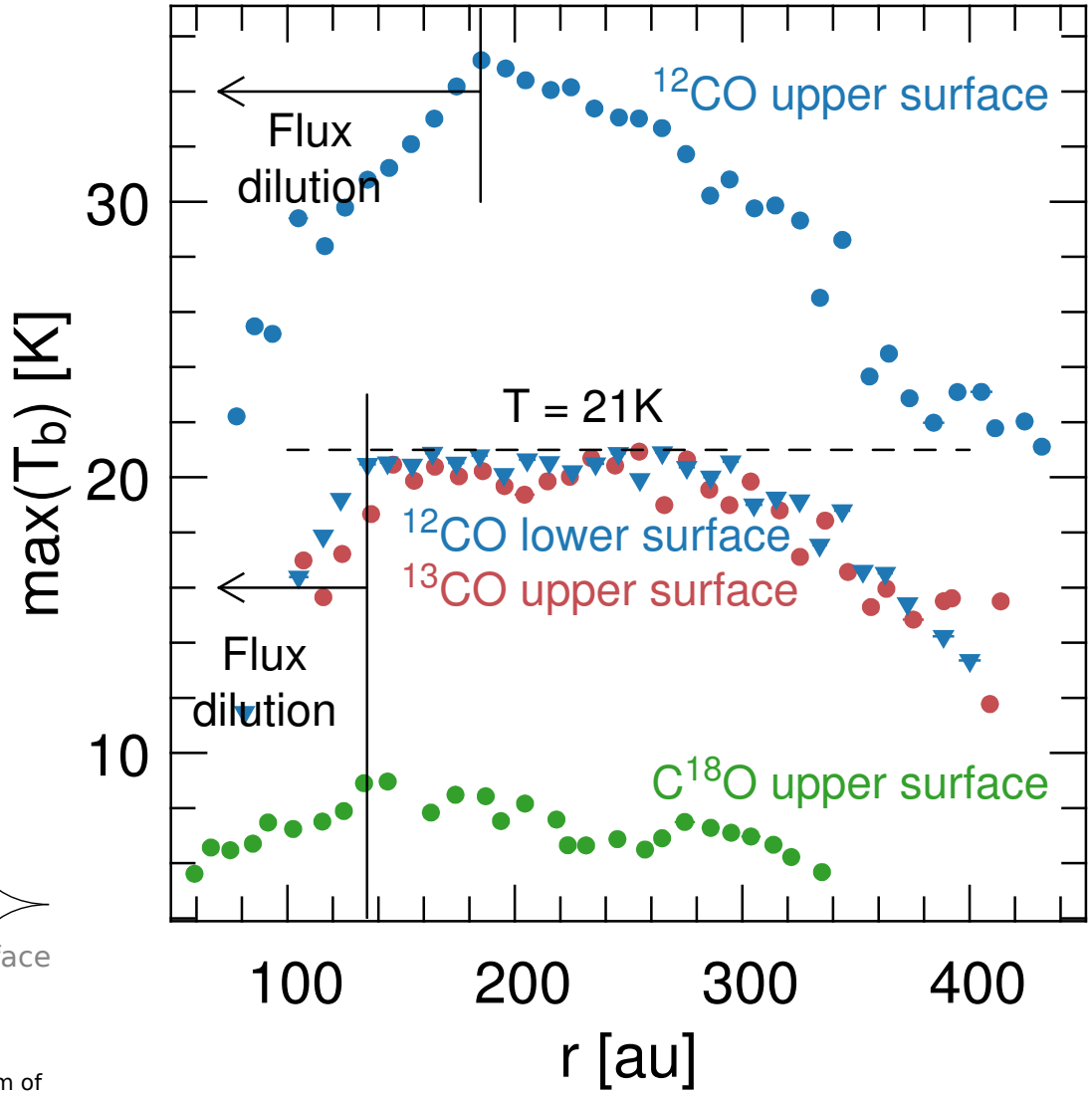
Vertical velocity gradient & sub-Keplerian rotation



Mapping the vertical snow line

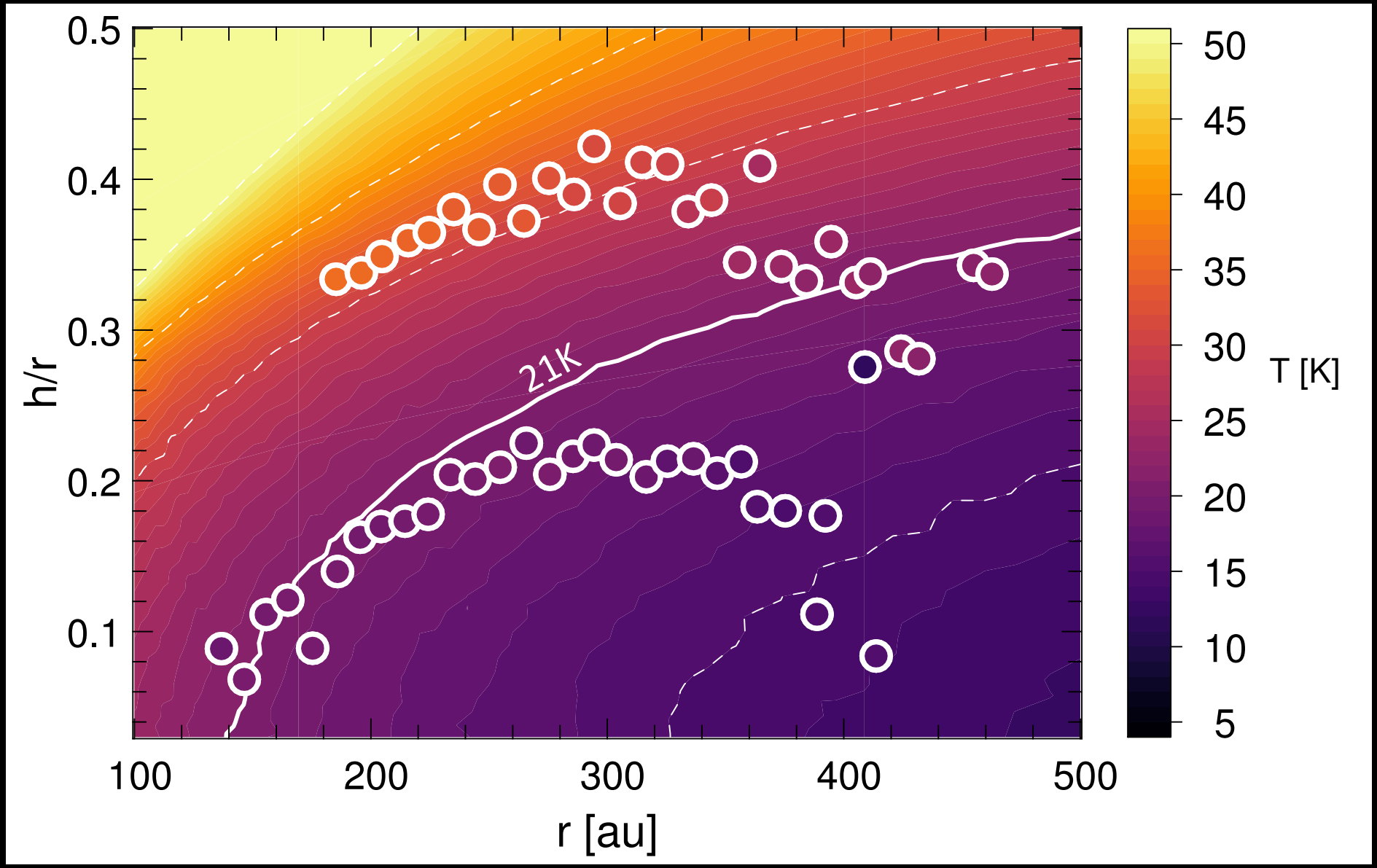




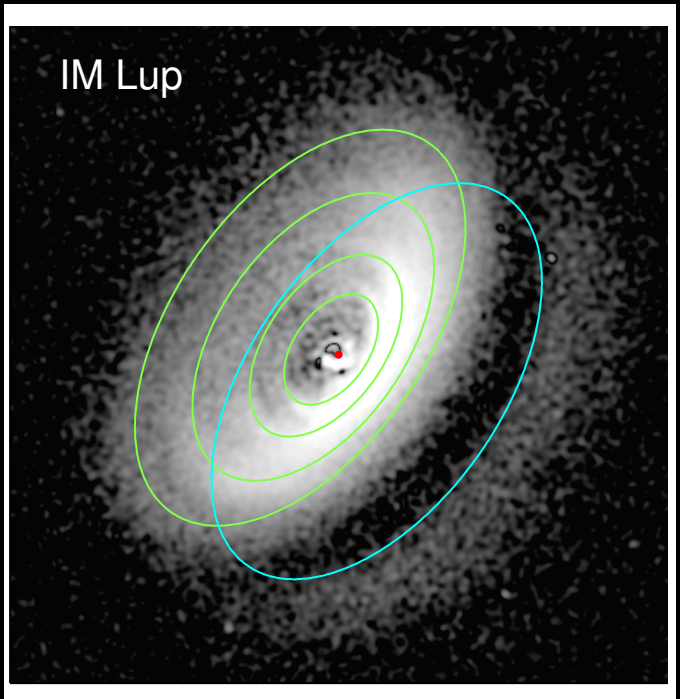


See also Schwarz et al. (2016)

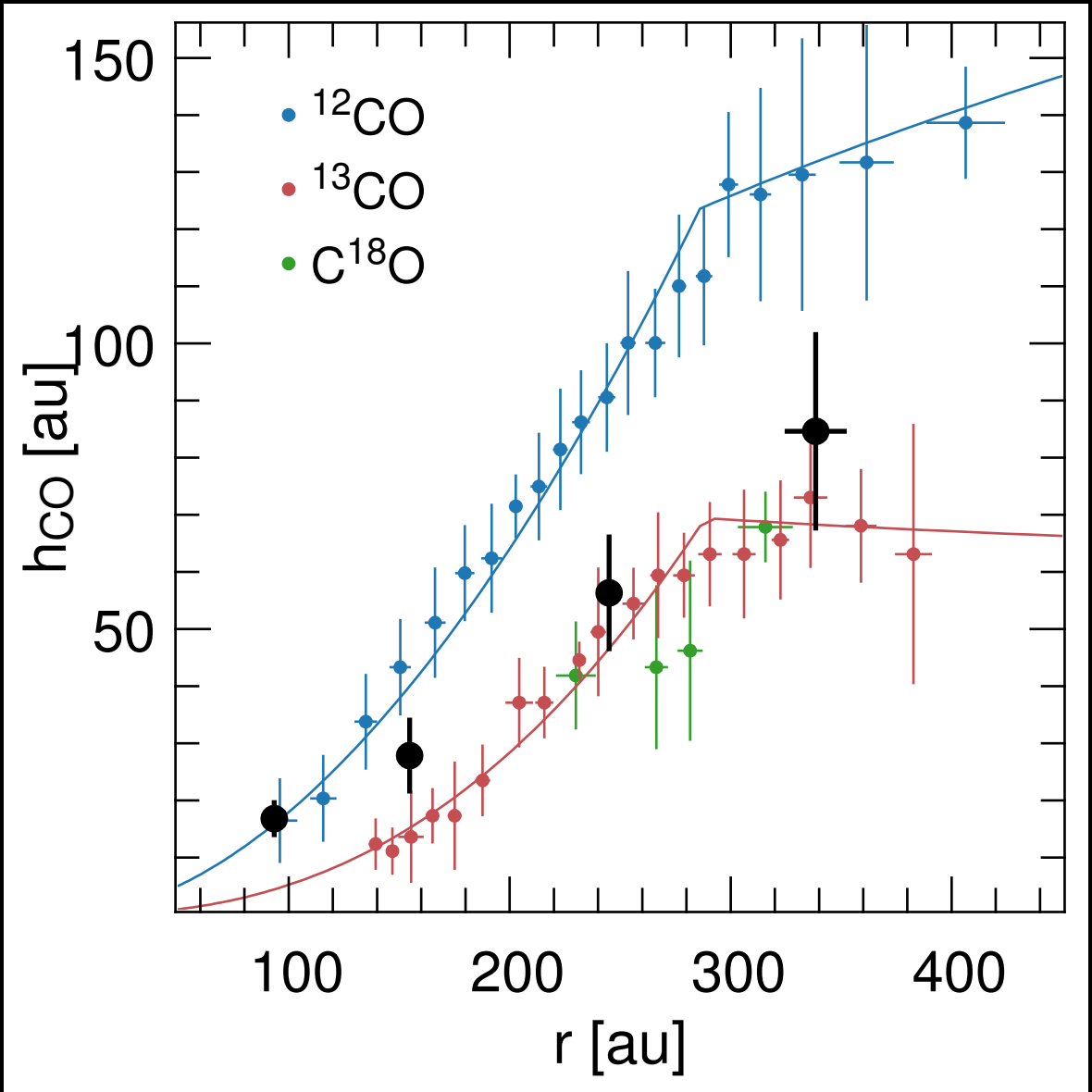
Comparison with models



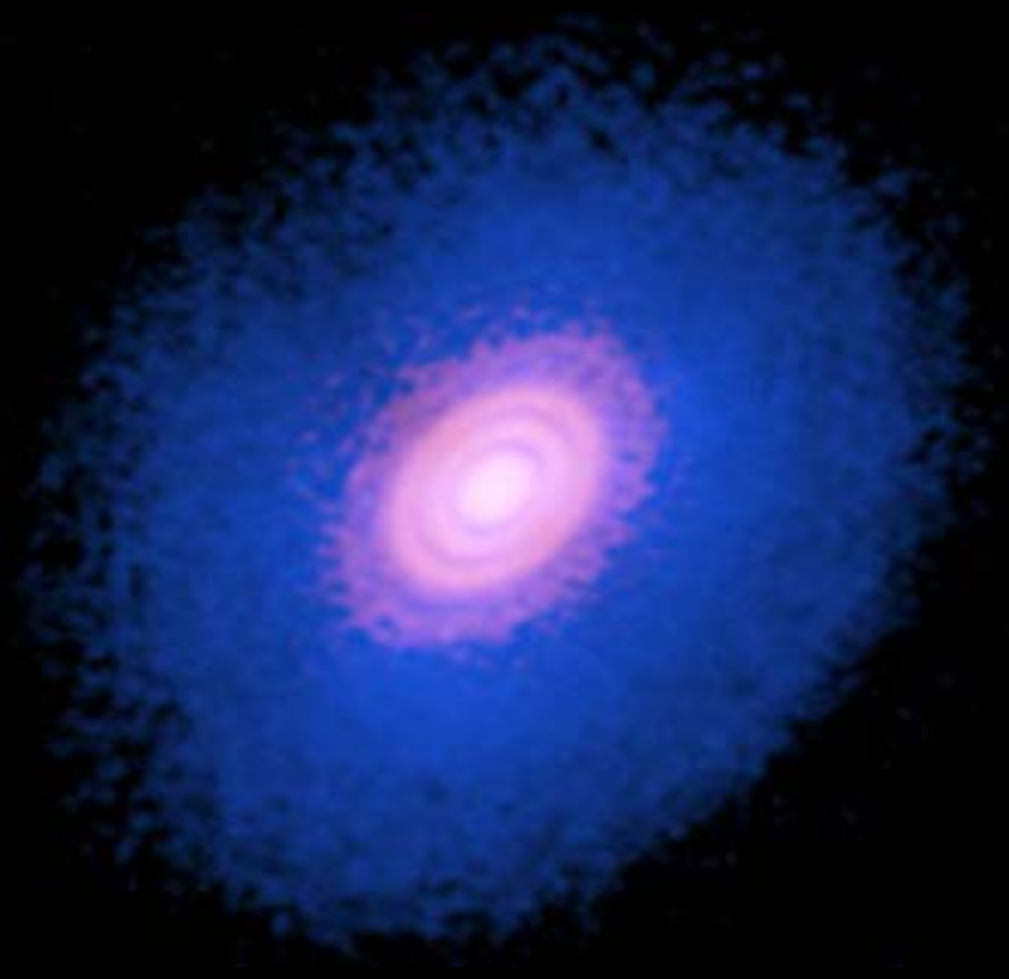
CO layers vs scattered light layer



Avenhaus et al, 2018

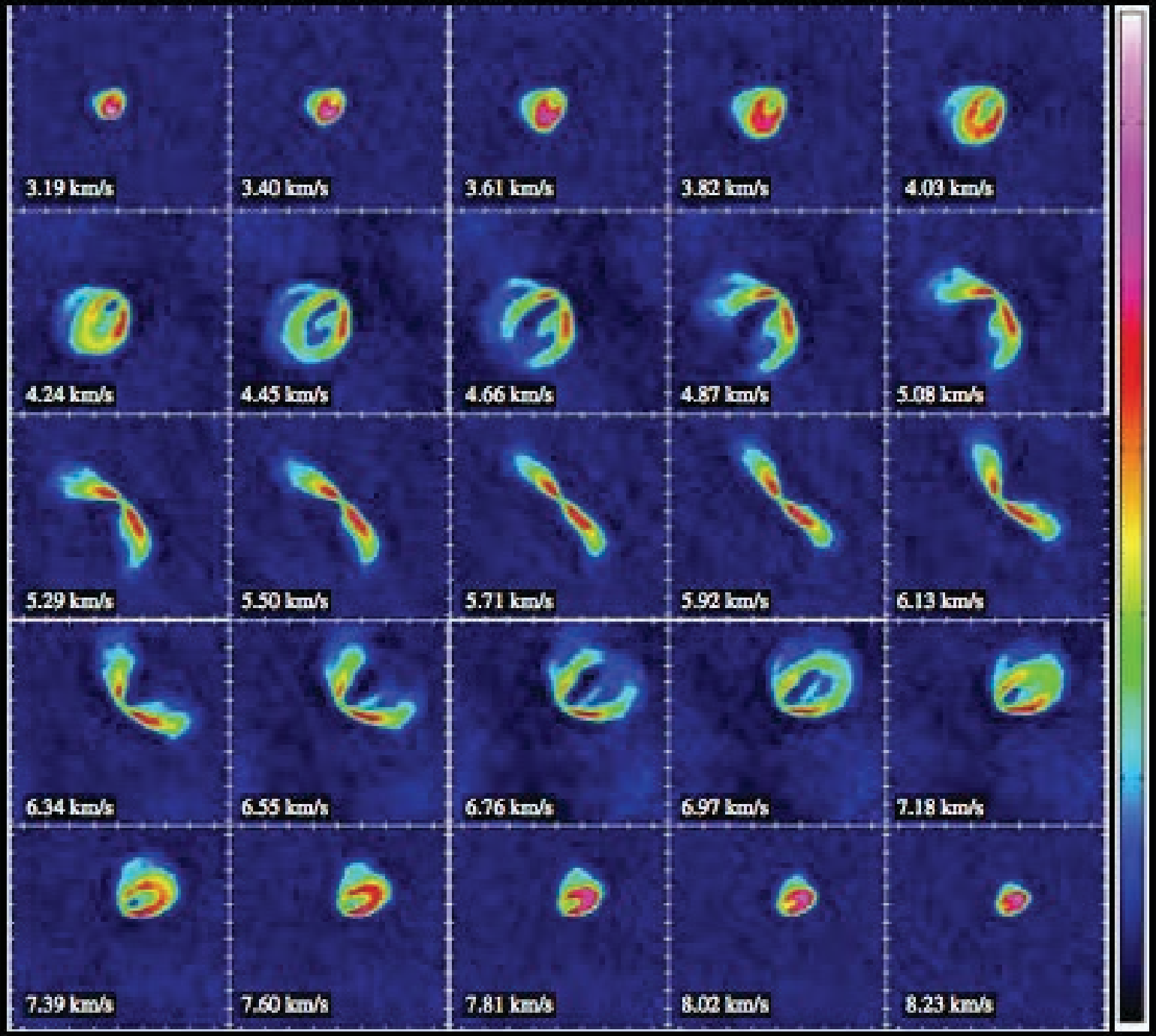


HD163296 in dust and gas

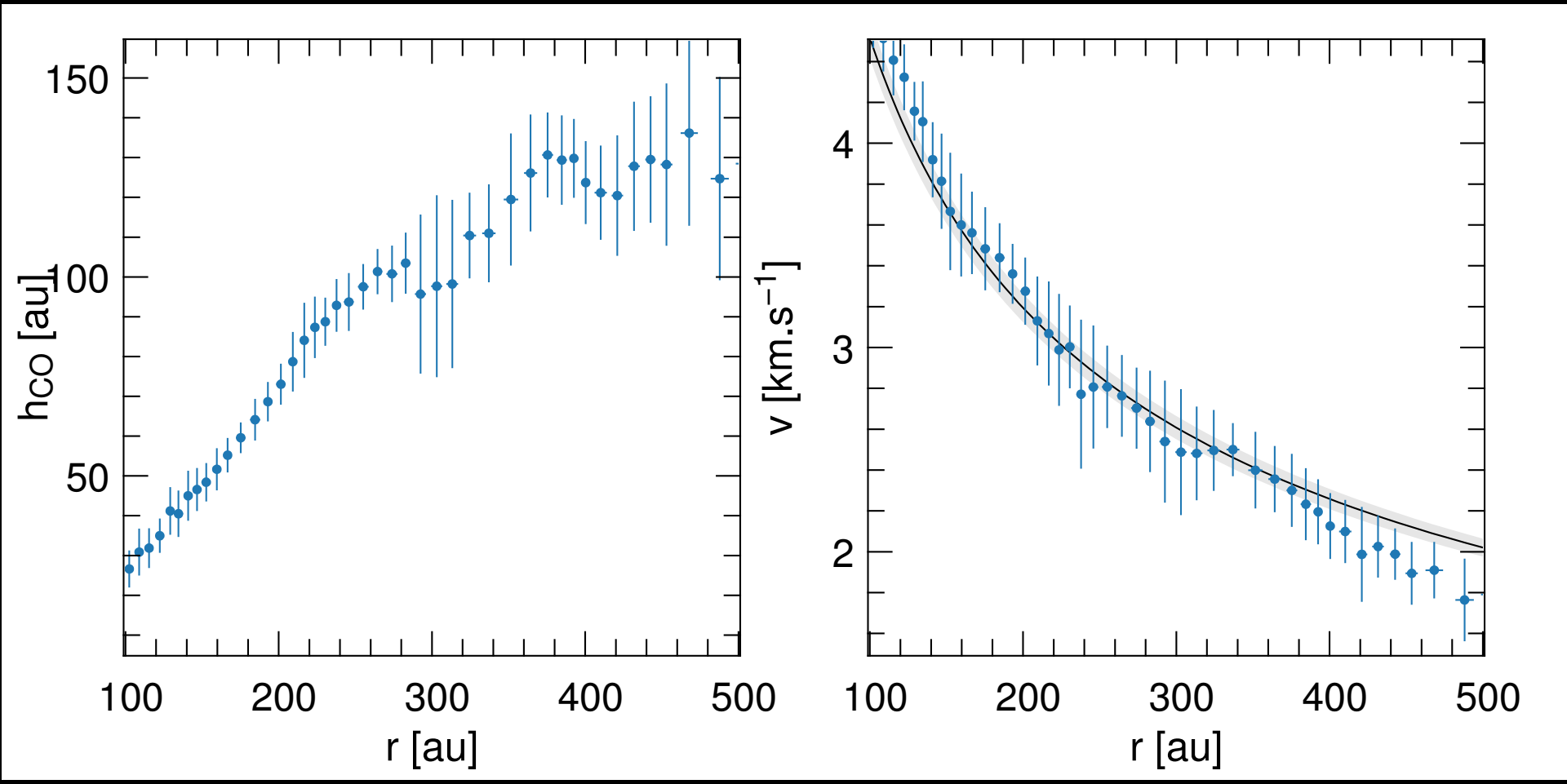


Gas=Blue, Dust=Red

Isella et al 2016

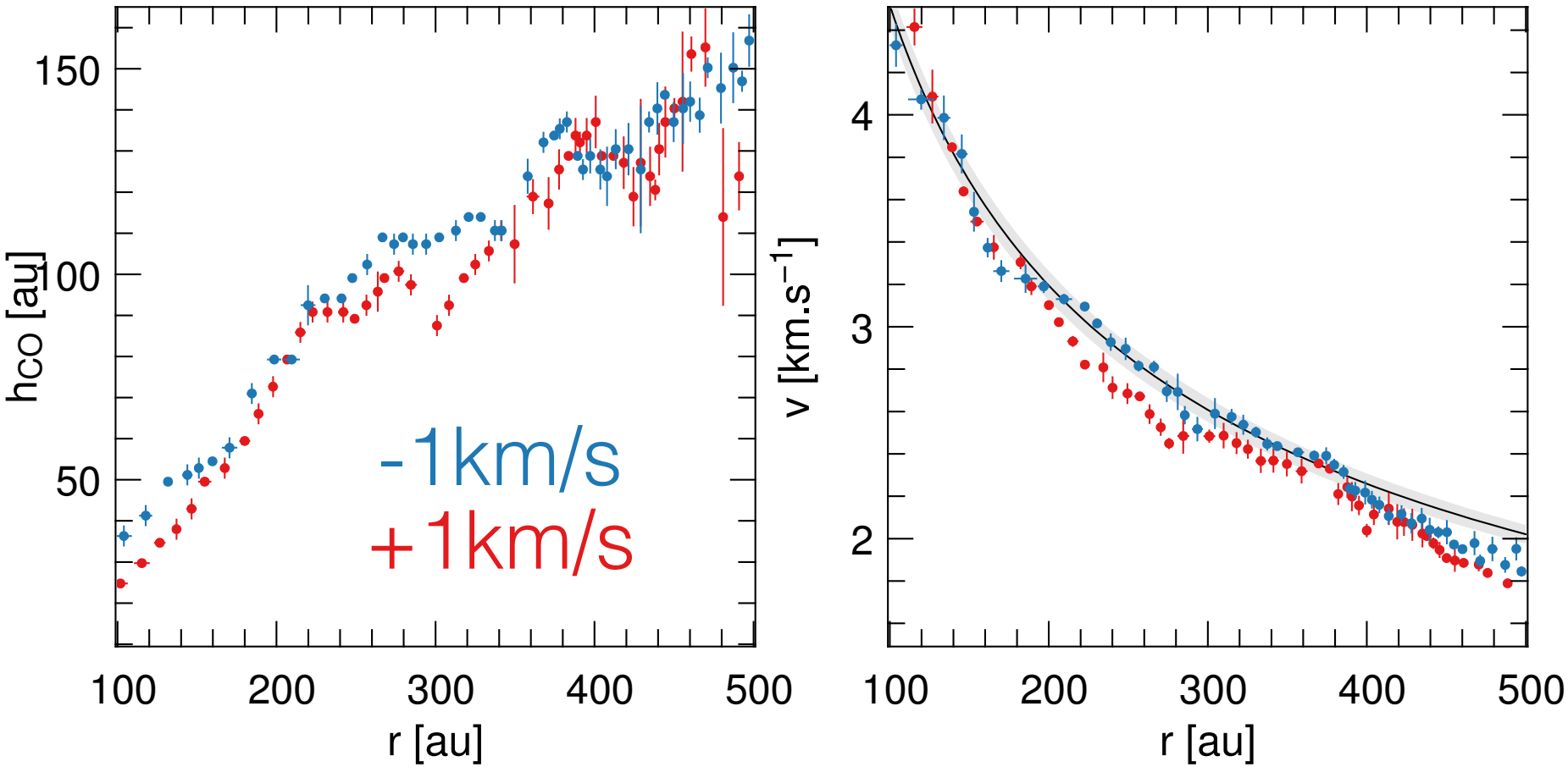

3.19 km/s
3.40 km/s
3.61 km/s
3.82 km/s
4.03 km/s
4.24 km/s
4.45 km/s
4.66 km/s
4.87 km/s
5.08 km/s
5.29 km/s
5.50 km/s
5.71 km/s
5.92 km/s
6.13 km/s
6.34 km/s
6.55 km/s
6.76 km/s
6.97 km/s
7.18 km/s
7.39 km/s
7.60 km/s
7.81 km/s
8.02 km/s
8.23 km/s

^{12}CO layer of HD163296

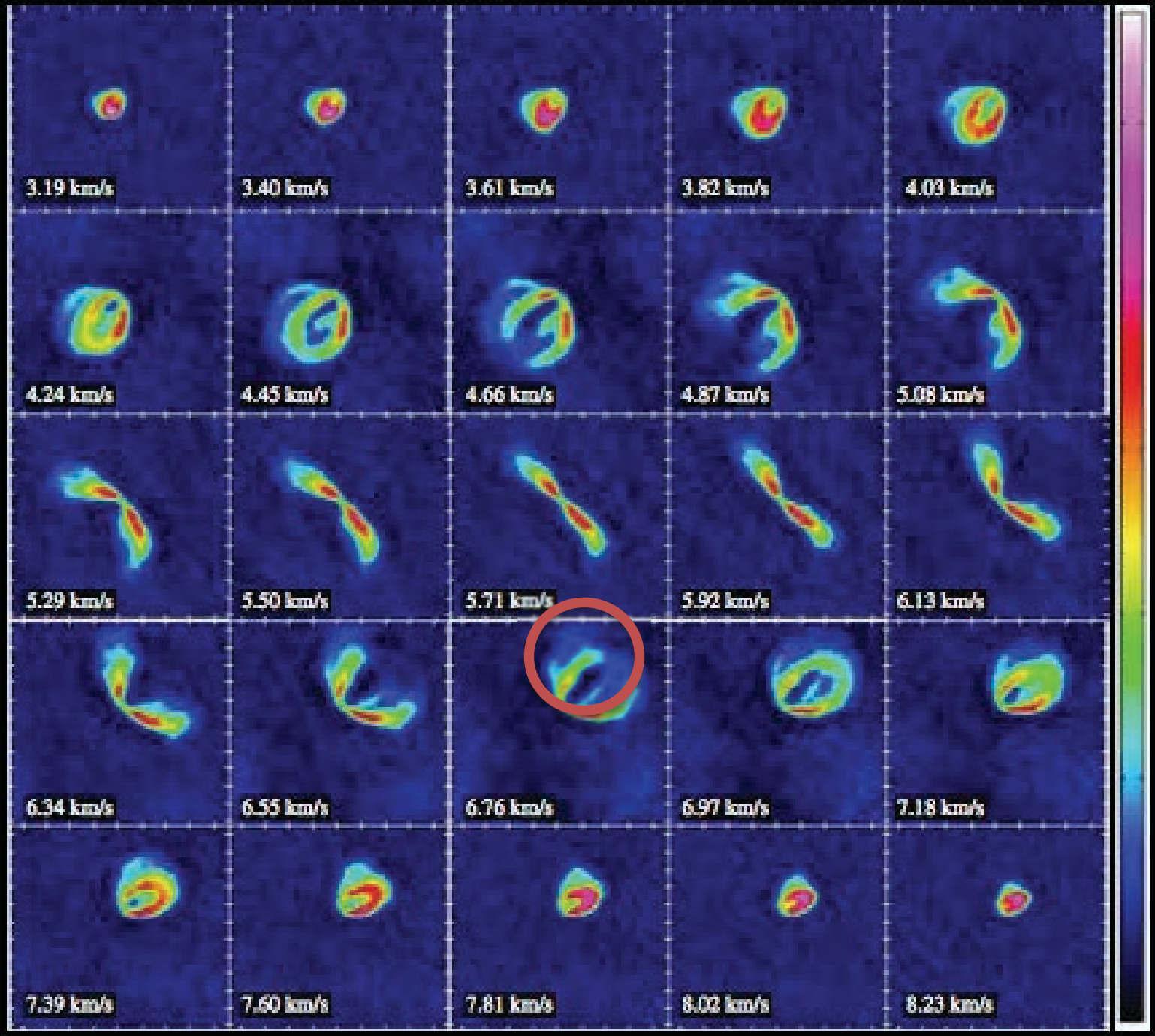


Circular orbits and/or Keplerian velocities assumption not valid anymore

^{12}CO layer of HD163296



Circular orbits and/or Keplerian velocities assumption not valid anymore


3.19 km/s
3.40 km/s
3.61 km/s
3.82 km/s
4.03 km/s
4.24 km/s
4.45 km/s
4.66 km/s
4.87 km/s
5.08 km/s
5.29 km/s
5.50 km/s
5.71 km/s
5.92 km/s
6.13 km/s
6.34 km/s
6.55 km/s
6.76 km/s
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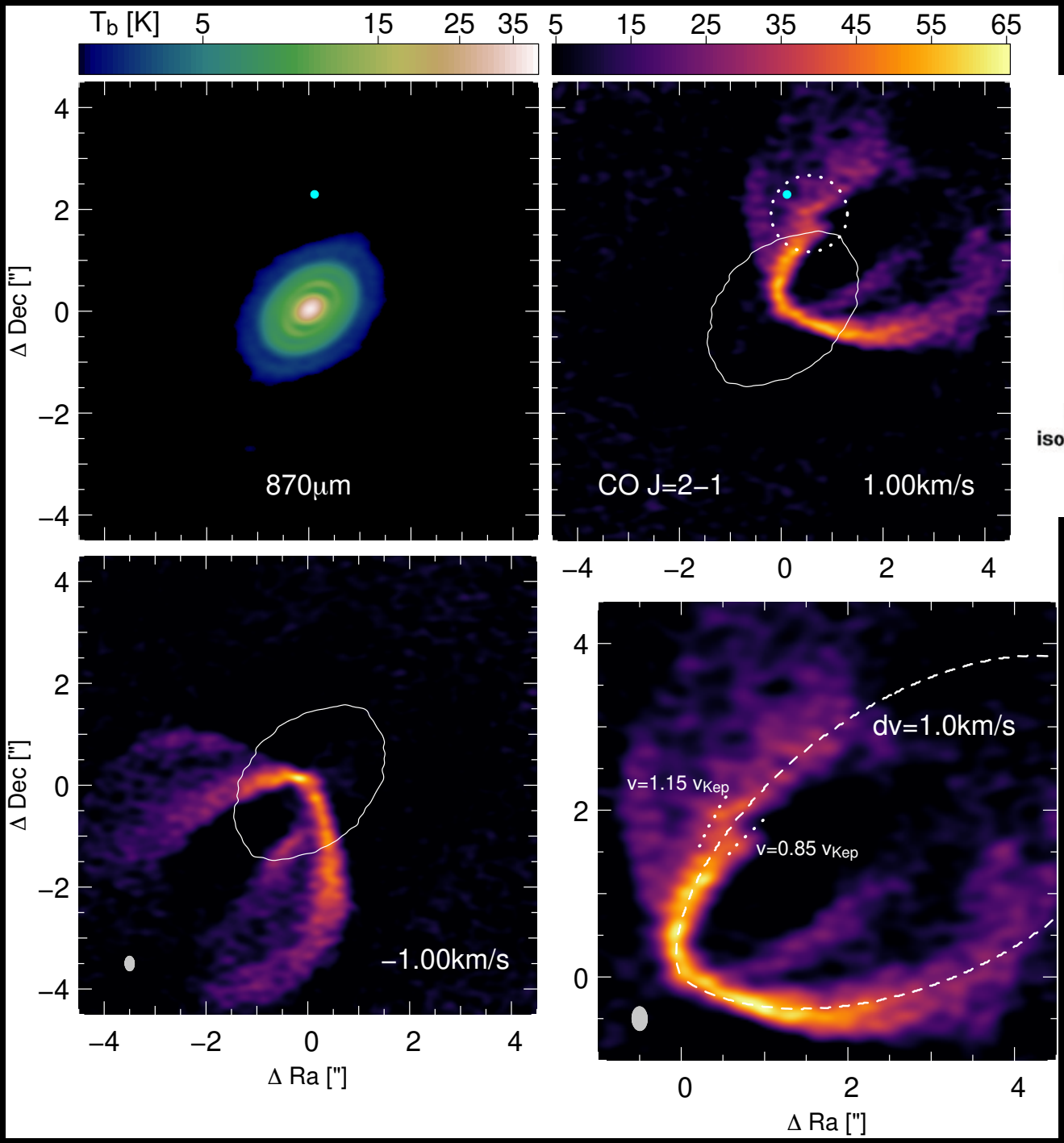
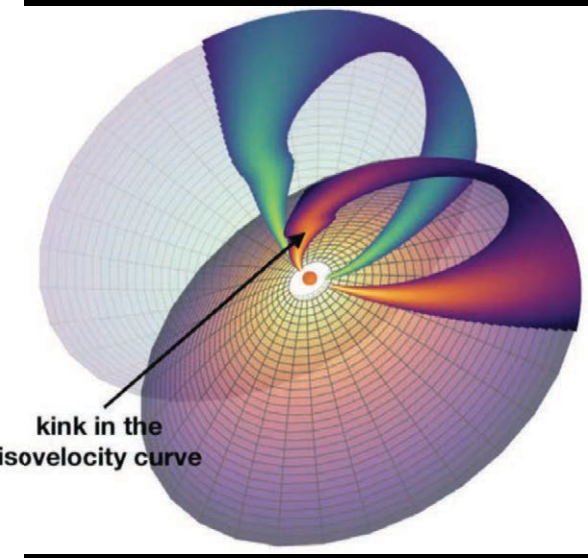
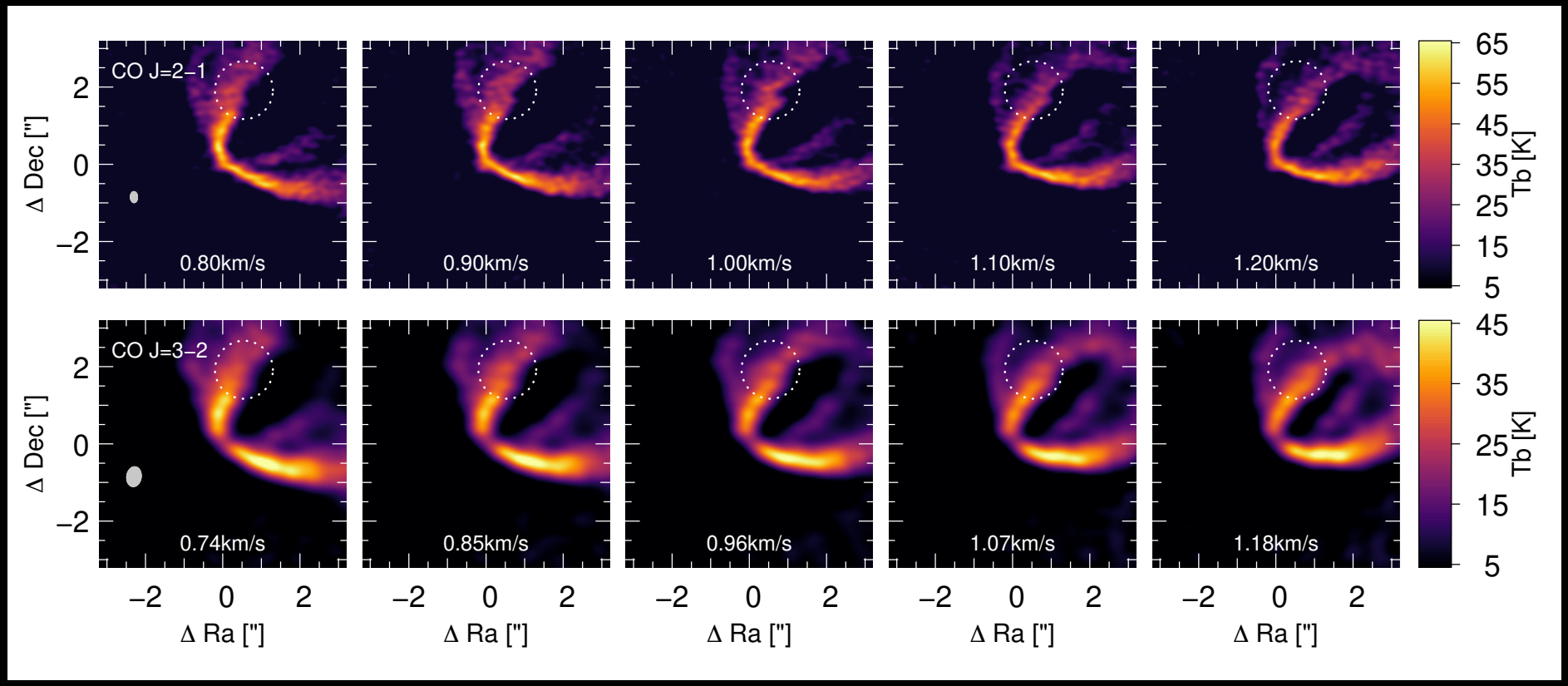
7.60 km/s
7.81 km/s
8.02 km/s
8.23 km/s



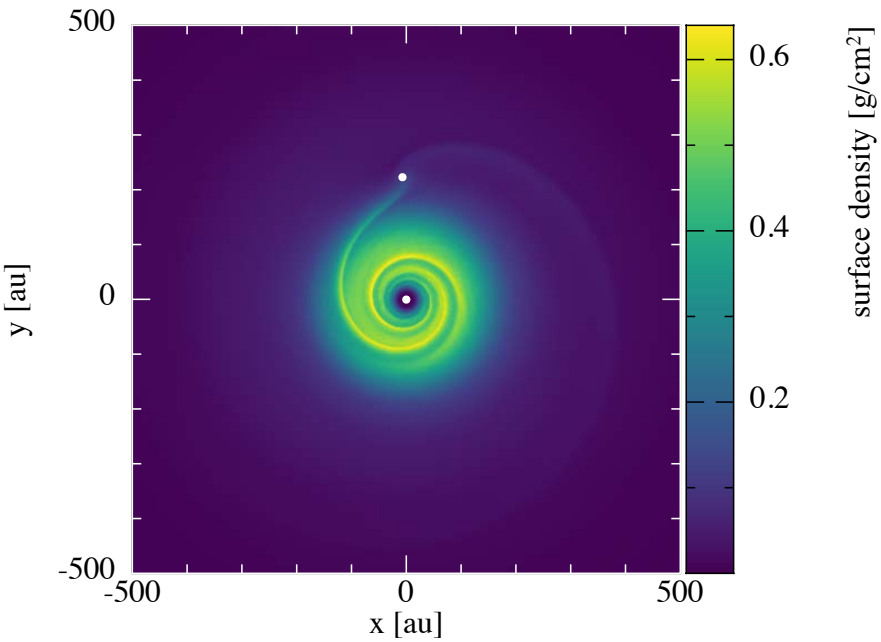


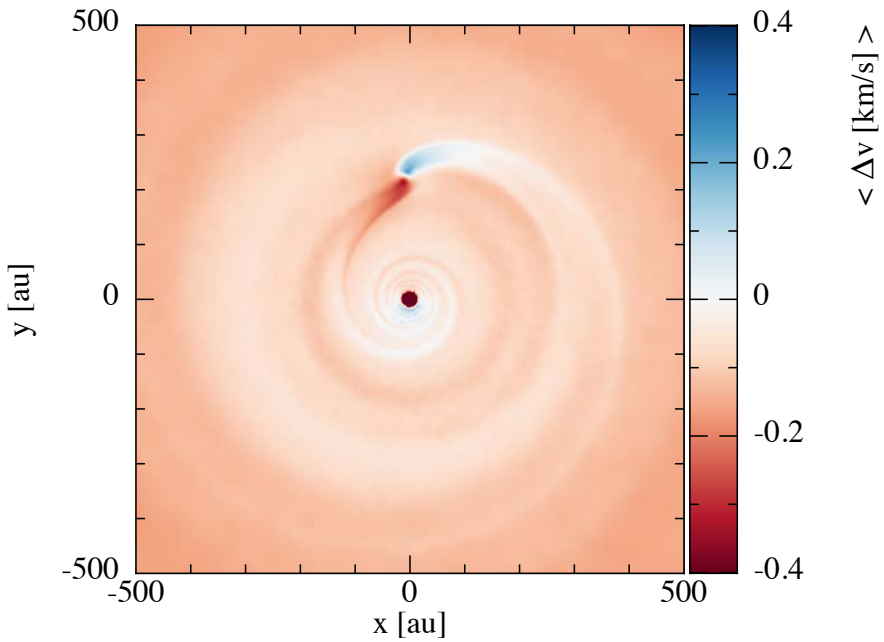
Pinte et al. 2018b

Velocity deviation is localised spatially and in velocity



Phantom model

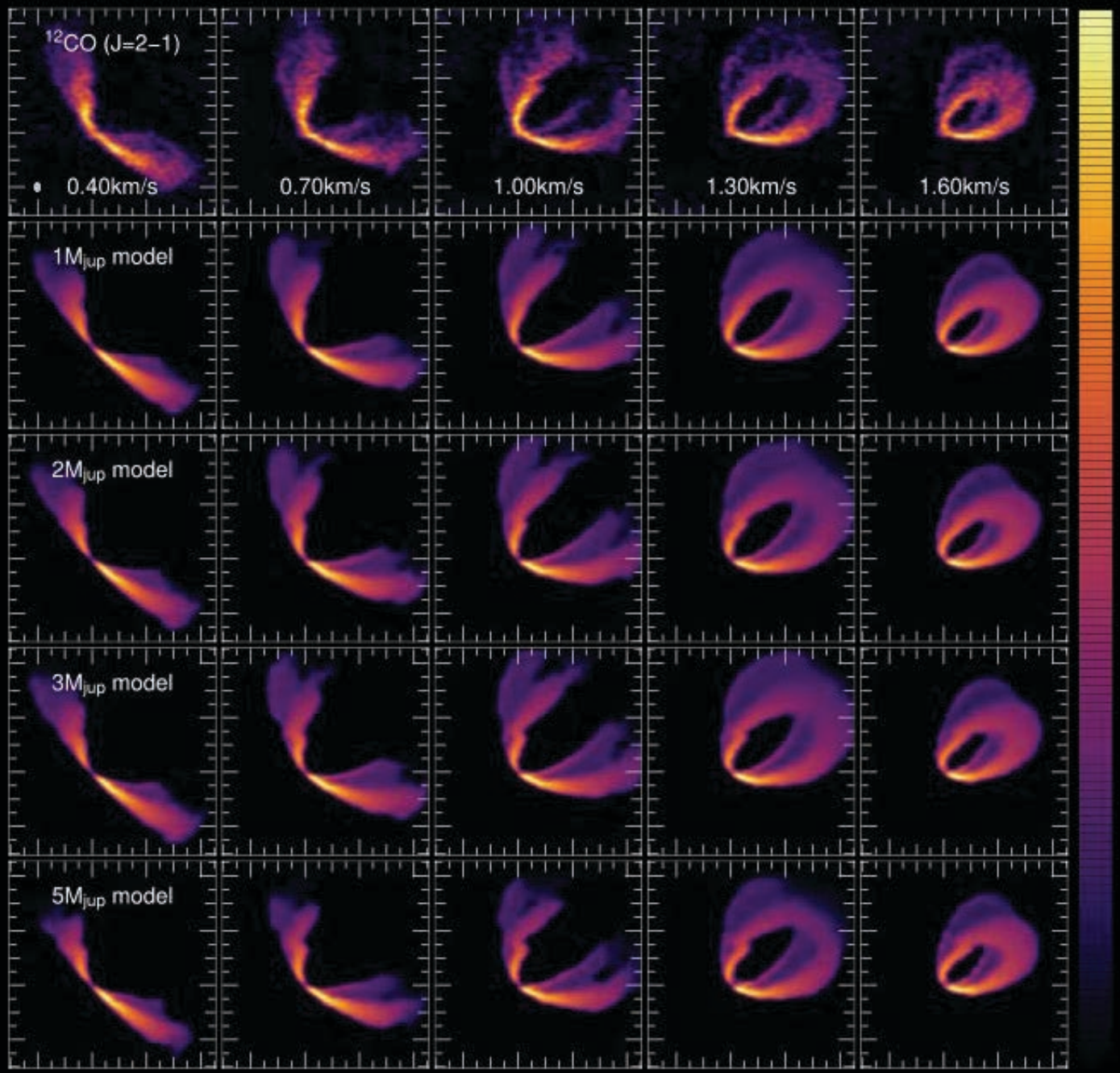


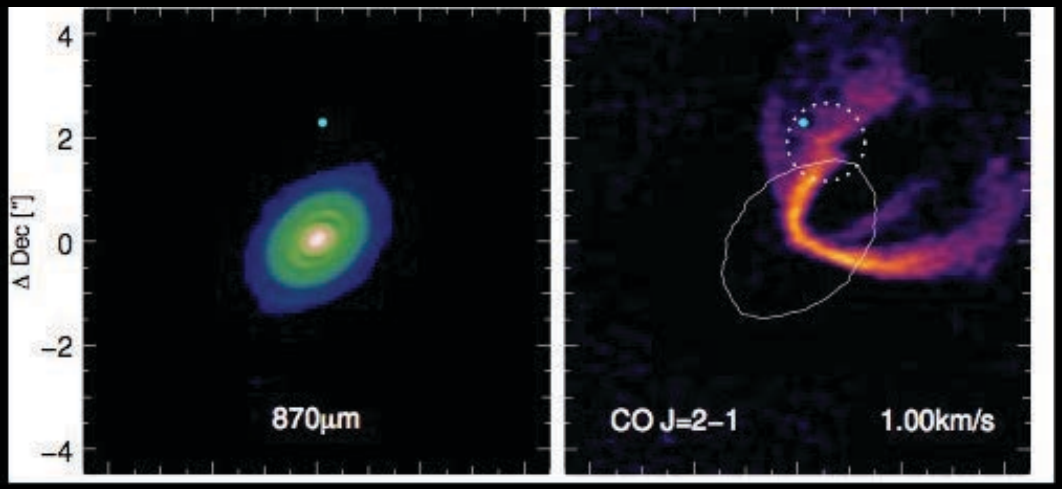


Gas density

Deviation from Keplerian velocity

Observations vs MCFOST + Phantom models





THE ASTROPHYSICAL JOURNAL, 544:895–902, 2000 December 1

STIS CORONAGRAPHIC IMAGING OF THE HERBIG Ae STAR: HD 163296

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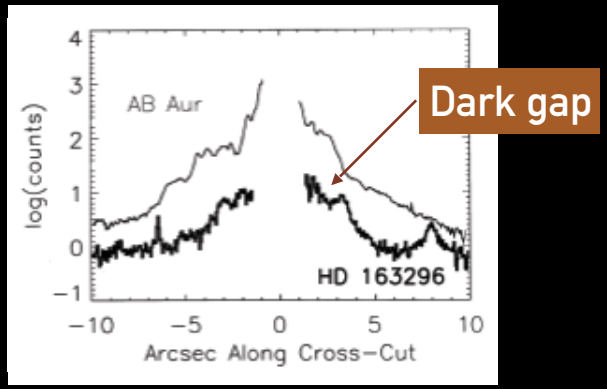
Received 1999 November 11; accepted 2000 June 9

ABSTRACT

Coronagraphic imaging with the Space Telescope Imaging Spectrograph on board the *Hubble Space Telescope* reveals a ~450 AU radius circumstellar disk around the Herbig Ae star HD 163296. A broadband (0.2–1.0 μm) reflected light image shows the disk oriented at a position angle of 140° ± 5° and inclined to our line of sight by ~60° ± 5°. The disk includes an annulus of reduced scattering at 325 AU and exhibits a flat trend of surface brightness in to 180–122 AU (1″.5–1″), consistent with a cleared central zone. For $r \geq 370$ AU the disk surface brightness drops as r to the approximately −3.5 power. The disk cannot be traced beyond 450 AU in our data. The disk is accompanied by a chain of nebulosities at P.A. = 42°.5 ± 3°.5, compatible with detection of a Herbig-Haro flow. The HD 163296 disk most closely resembles the disk of HD 141569. As in the HD 141569 system, the dynamical effects of a planet may be necessary to explain the structure in the outer disk.

Subject headings: circumstellar matter — planetary systems — stars: individual (HD 163296) — stars: pre–main-sequence



INFERRED 18 YEARS AGO!

Concluding remarks

- Measure T(r,z), v(r,z) and map CO surfaces : pressure gradients, snow line

- With high spatial and high spectral resolution, we can detect the kinematic signature of a planet.
→ planet mass, complementary to direct imaging

- So far, planets detected by kinematic method are located inside gaps.
At least some of the gaps are carved by planets.

- Massive planets far out : a few M_{jup} at 100-300au
How do they form ?

- We can estimate Stokes number if planet mass is known