ALMA observational evidence for the viscous evolution of a protoplanetary disk around HD 163296

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Abstract

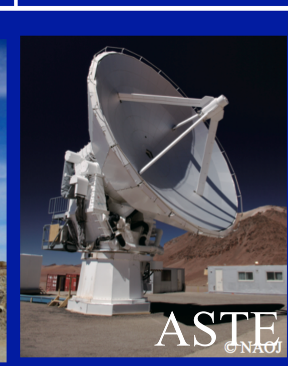
This presents a protoplanetary disk around a Herbig Ae star HD 163296 in ^{12}CO (J=2–1), ^{13}CO (J=2–1) and C^{18}O (J=2–1) lines obtained by ALMA observations and ^{12}CO (J=1–0), ^{13}CO (J=1–0), ^{12}CO (J=3–2), and ^{13}CO (J=3–2) lines obtained by the Nobeyama and ASTE single dish observations. Double-peaked emission profiles originated from the rotating circumstellar disk were detected in all of the lines. The radial surface density structures of the outer region of the disk were examined by comparing the similarity solution model with an exponential tapered edge in the standard accretion disk theory with the power-law disk model having a truncated outer edge represented by the minimum-mass solar nebula model. The exponential taper description in the similarity solution model effectively reproduces the observational data and the different velocity widths in each CO isotopologue line caused by the different Keplerian rotation velocity, indicating that the disk has diffuse gas in the outer region which tapers off gradually. Since the similarity solution model is based on the dynamical evolution of a viscous disk, it is likely that the disk around HD 163296 evolves by transferring angular momentum outwards via viscous diffusion. Although further quantitative studies are required in identifying what disk model is the best for describing physical disk structures, our results suggest that primordial disks with no complex structures, such as spiral arms or gap, likely have diffuse gas in the outer regions and the gas gradually fade out with increasing radial distance.

Introduction

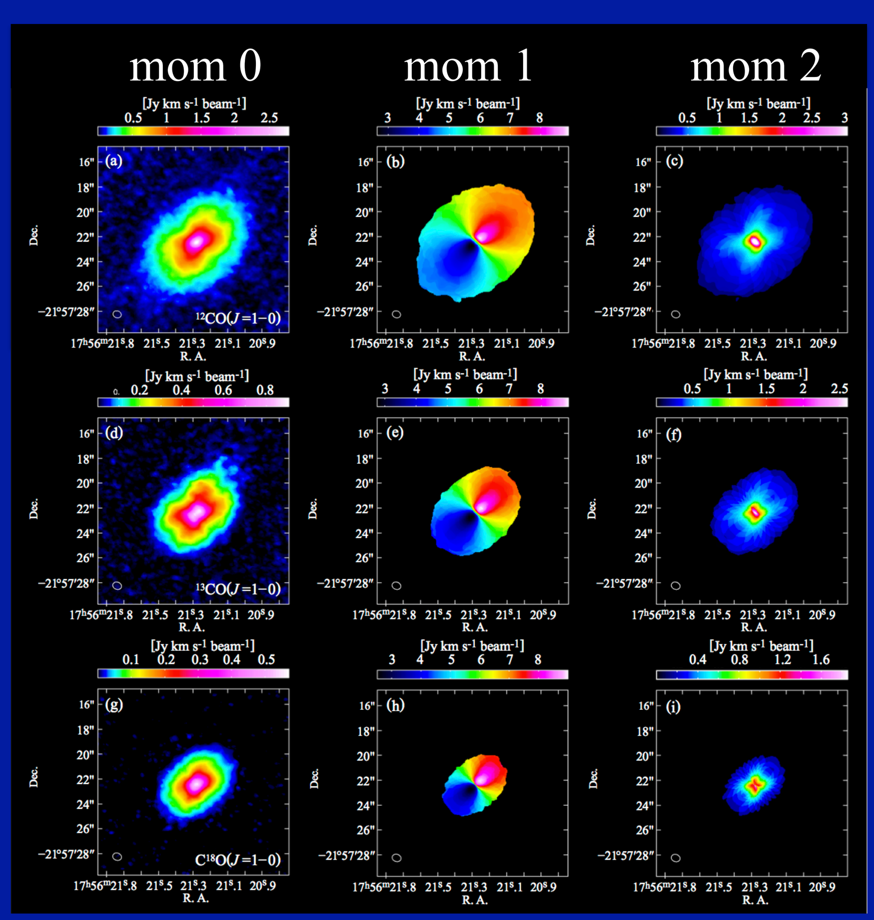
- HD 163296 is a very famous Herbig Ae star and has a uniformly distributed circumsteller disk, no complex structures such as a hole, a gap, and spiral arms.
  → Best for analyzing disk structure.
- It has been observed by many people and basic properties are already well known.
  → A lot of data are available from archive.
- Surface density structure have been mainly described by two models;
  ･power-law model was introduced in the minimum mass solar nebula (e.g. Kusaka et al. 1970, Hayashi et al. 1985).
  ･similarity solution model derived from viscous evolution (Lyndenbell & Pringle 1974, Hartmann et al. 1998)
- Discrepancy in disk size has emerged between the dust continuum and gas emission. Examples
  AB Aur (Pietu et al. 2005)
  Continuum (2.8, 1.4 mm): r_{disk} = 350±30 AU
  ^{12}CO(J=2-1) : r_{disk} = 1050±10 AU
  HD 163296 (Isella et al. 2007)
  Continuum (0.87 - 7 mm): r_{disk} = 200±15 AU
  ^{12}CO(J=2-1) : r_{disk} = 540±40 AU
- Similarity solution is better to reproduce both dust continuum and gas emission simultaneously than power-law model.
  →It is still under discussion (see Hughes et al. 2008 and de Gregorio-Monsalvo et al. 2013)

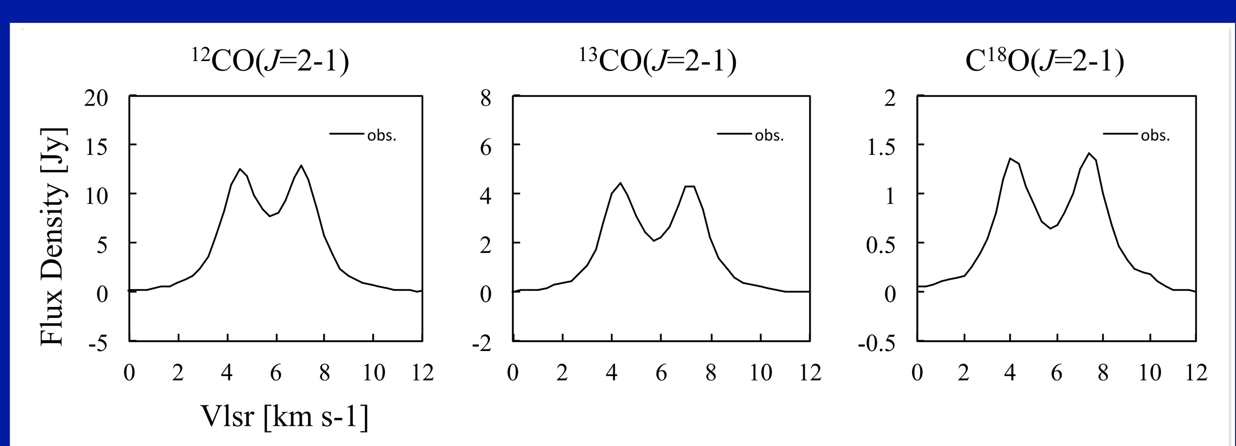
Observations

	mm obs.		sub-mm obs.
Telescopes	NRO 45 m	ALMA 12m 16 ~ 21 antennas	ASTE 10 m
HPBW	~ 15”	~ 0.6”	~ 23”
Line	^{12}CO(J=1-0) ^{13}CO(J=1-0) C^{18}O(J=1-0)	^{12}CO(J=2-1) ^{13}CO(J=2-1) C^{18}O(J=2-1)	^{12}CO(J=3-2) ^{13}CO(J=3-2)
Receivers	^{12}CO(J=1-0) : BEARS T100H/V ^{13}CO(J=1-0) : S80/S100 T100H/V C^{18}O(J=1-0) : T100H/V	band 6	CATS 345
Vel. resolution	^{12}CO(J=1-0) : 0.1km/s ^{13}CO, C^{18}O(J=1-0) : 0.05km/s	0.32 km s^{-1}	0.11 km s^{-1}

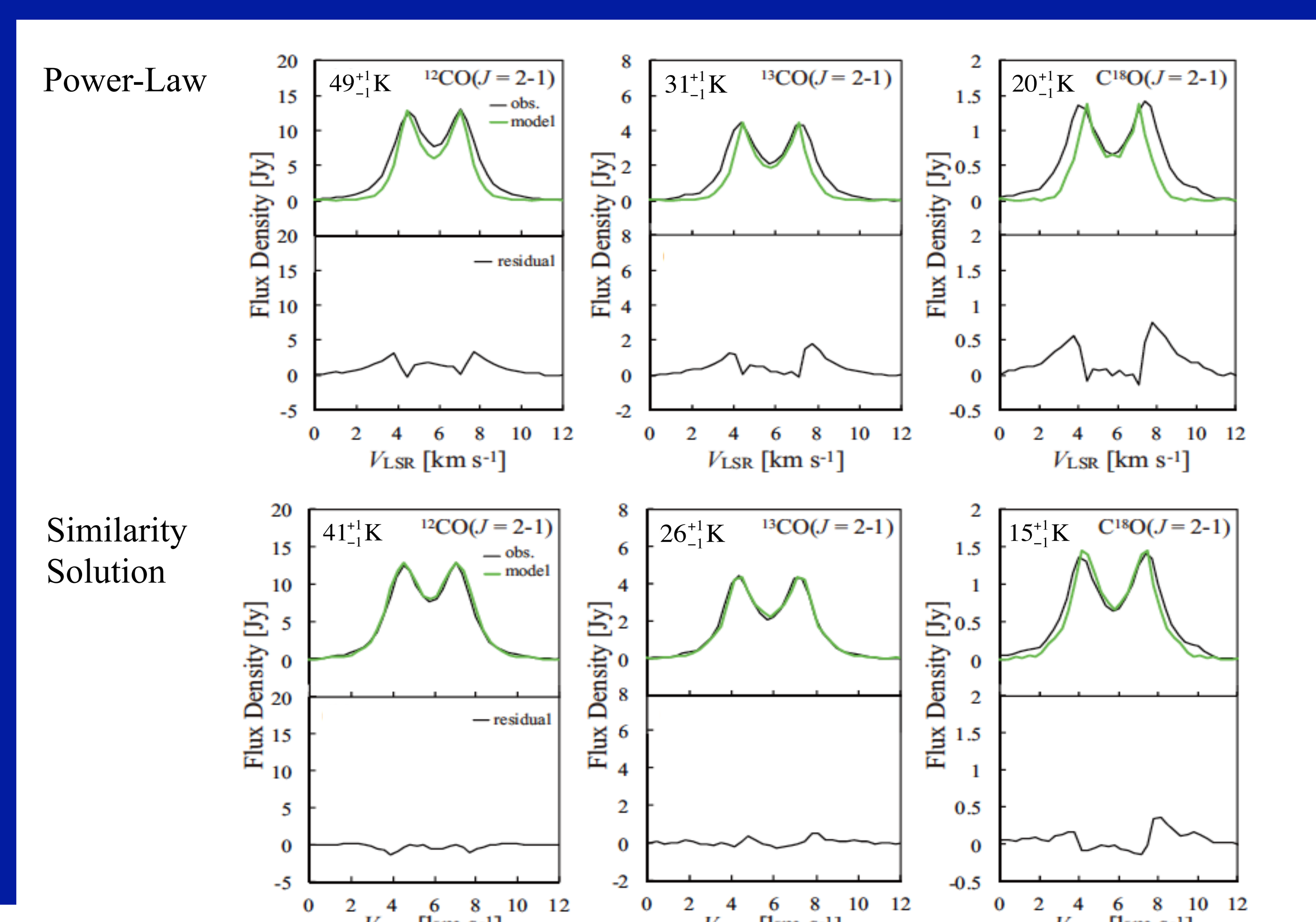


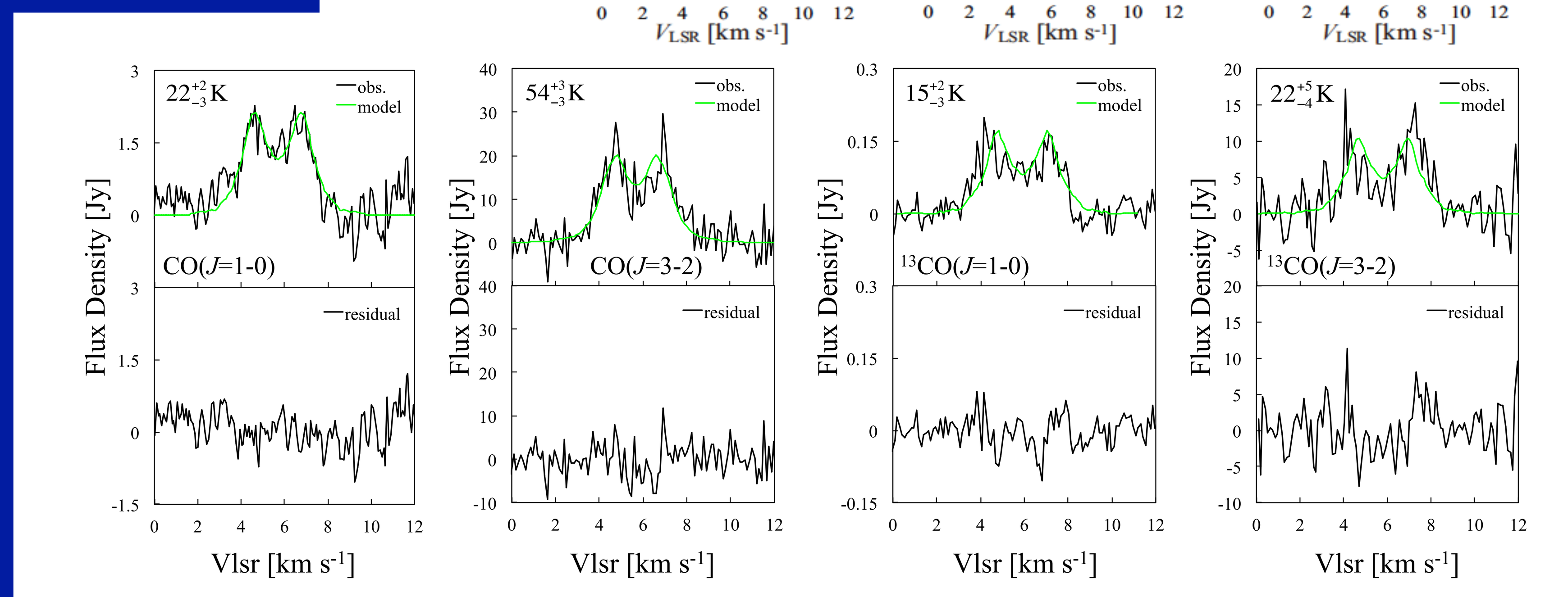
Result and Model Fitting





7 emission lines are obtained in total.
Moment 1 map shows the disk extends up to 5.5” (~ 700 AU).
No complex structures are seen.
The disk is in Keplerrian rotation.





Similarity Solution Model: r_{out} = 700 AU, Σ_{100} = 0.01 g cm^{-2}, p = 1.0, q = 0.5
The fitting temperatures are provided in the upper left corner.
Akiyama et al. 2014 Submitted.

Similarity solution model reproduce the observation better than power-law model does.
→ It suggests viscous evolution.

Truncated Power – Law Model

- Power-law in radial temperature and surface density distribution (Hayashi et al. 1985, Beckwith et al. 1990).

$$T(r) = T_{100}\left(\frac{r}{100\mathrm{AU}}\right)^{-q} \quad \Sigma(r) = \Sigma_{100}\left(\frac{r}{100\mathrm{AU}}\right)^{-q}$$

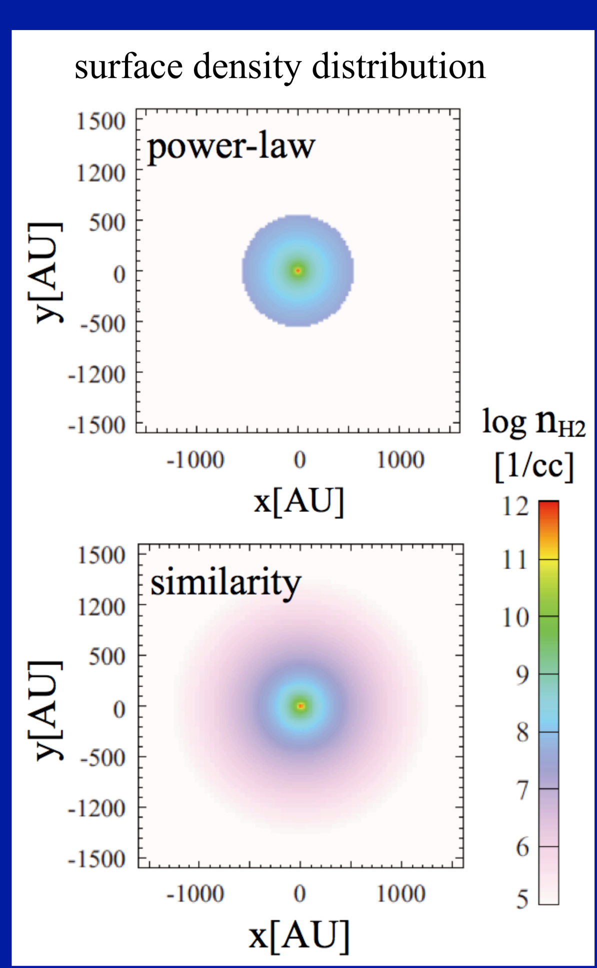
T_{100} : temperature at 100 AU from the central star
Σ_{100} : surface density at 100 AU from the central star

Similarity Solution Model

- Power-law with exponential taper in radial surface density distribution (Hughes et al. 2008, Qi et al. 2013).

$$\Sigma(r) = \frac{C_1}{r^p}\exp\left[-\left(\frac{r}{C_2}\right)^{2-p}\right]$$

C_1 : normalized surface density
C_2 : distance where $\Sigma(r)$ starts decreasing exponentially



- All parameters should be taken into account but 5 parameters, T_{100}, Σ_{100}, r_{out}, p, and q are treated as free parameters and the other parameters are applied by reference to other observations.

Reference

Beckwith et al. 1990, AJ, 99, 1059
de Gregorio-Monsalvo et al. 2013, A&A, 557, A133
Hartmann et al. 1998, ApJ, 495, 385
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Hughes et al. 2008, ApJ, 678, 11190
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Lyndenbell & Pringle 1974, MNRAS, 168, 603
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