Estimate on dust scale height from ALMA continuum image of the HD 163296 protoplanetary disk

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Abstract

The growth of dust in protoplanetary disks is the first step of planet formation. Therefore, revealing the distribution and physical state of the dust in protoplanetary disks is a key to reveal the planet formation process.

We constrain the dust scale height of HD 163296. This object is known to have two distinct ring structures at distances of 68 and 100 au from the central star (Isella et al. 2016), and in this study, we constrain the dust scale heights of these two rings. The results show that **h_d/h_g> 0.55 in the inner ring and h_d/h_g < 0.44 in the outer ring**, where h_g is the gas scale height and, h_d is the dust scale height. In other words, **the dust is flared in the inner ring, while it is settled in the outer ring**. When we take it together with the estimates of scale height at the dust gap based on polarization observations (Ohashi & Kataoka 2019), the picture of the dust scale height over the whole disk is represented as shown in Figure 2.

The dust scale height is modeled with the ratio of the gas turbulence α and the Stokes number St. Therefore, based on the dust scale height we constrain, we constrain the α/St. We find **α/St > 0.48 for the inner ring and α/St < 0.19** for the outer ring with 2σ error range.

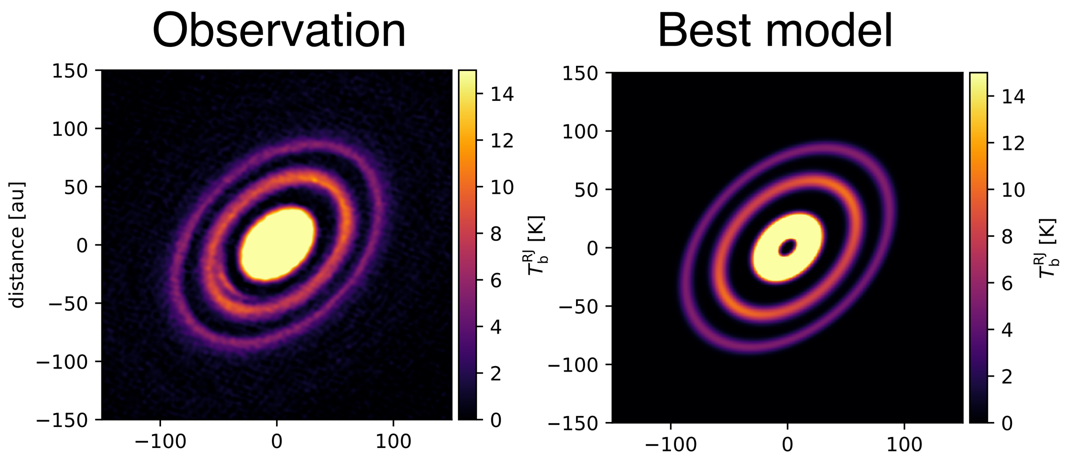


Fig. 1. Observation (left) and simulation of the best model (right)

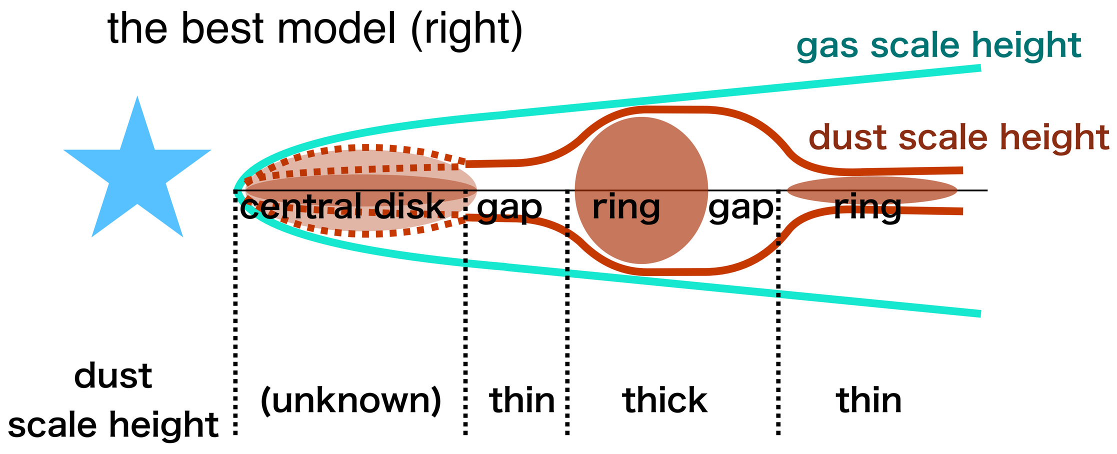


Fig. 2. Schematic view of the dust scale height.

1. Principle

1.1 Model

- Inclination angle: i
- Optically thin
- Ring like structure
  - The temperature is isothermal in the rings.
  - The distribution of the dust is Gaussian.

$$\rho(r,z)=\frac{\Sigma_0}{2\pi\sigma_z}\exp\left(-\frac{(r-r_0)^2}{2\sigma_r^2}-\frac{z^2}{2\sigma_z^2}\right).$$

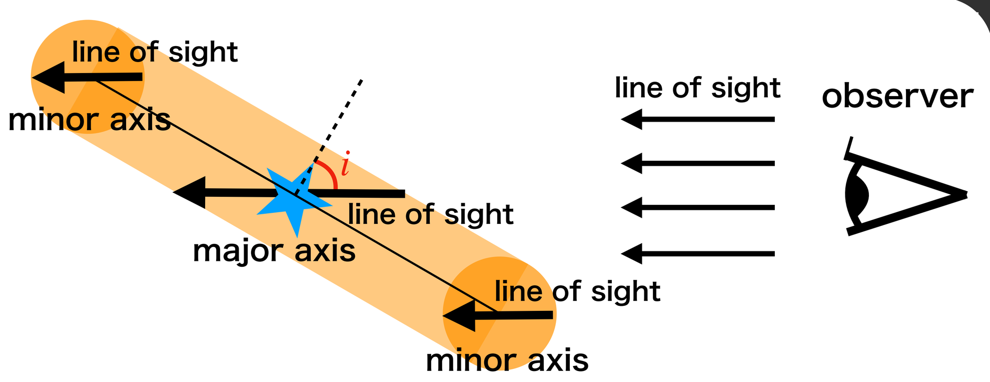


Fig. 3. Position of the disk and the observer.

1.2 The Azimuthal variation of the intensity

(along the peak of the ring)

$$I_\nu(r_0,\phi)=B_\nu(T)\frac{\kappa\Sigma_0}{\cos i}\frac{\sigma_r}{\sqrt{\sigma_r^2+\sigma_z^2\tan^2 i\sin^2\phi+\sigma_{beam}(\phi)^2}}.$$

σ_z : **dust scale height**
σ_r : **dust ring width**
σ_{beam} : **observation beam size**
$\phi=0,180^\circ$: **major axis**

☝ constrain this parameter!

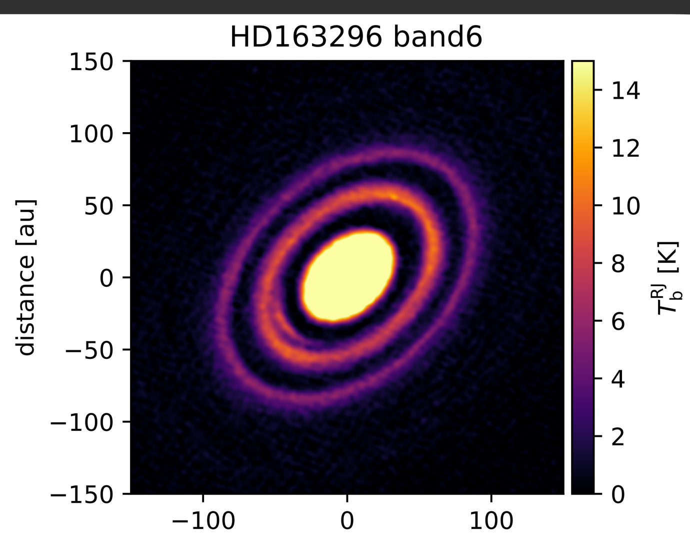
1.3 Summary

- **The intensity along the major axis does not depend on the dust scale height.**
- **The intensity along the ring** (except on the major axis) **depends on the dust scale height.**
  - **We can constrain the dust scale height from the azimuthal variation of the intensity.**

2. Data

Object: HD 163296
Distance: 101.5 pc (Gaia collaboration 2018)
Observation wavelength: ALMA Band 6 (1.25 mm)
Spatial resolution (FWHM)
: 0.038″ × 0.048″ = 3.8 × 4.8 au
Inclination: 46.7°
The ring parameters:

	width (FWHM)	distance
inner	9.4 au	67.9 au
outer	9.2 au	100.5 au



3. Method

We estimate the dust scale height by comparing the observation with radiative transfer simulation using RADMC-3D(Dullemond et al. 2012).

3.1 The setup of radiative transfer simulation

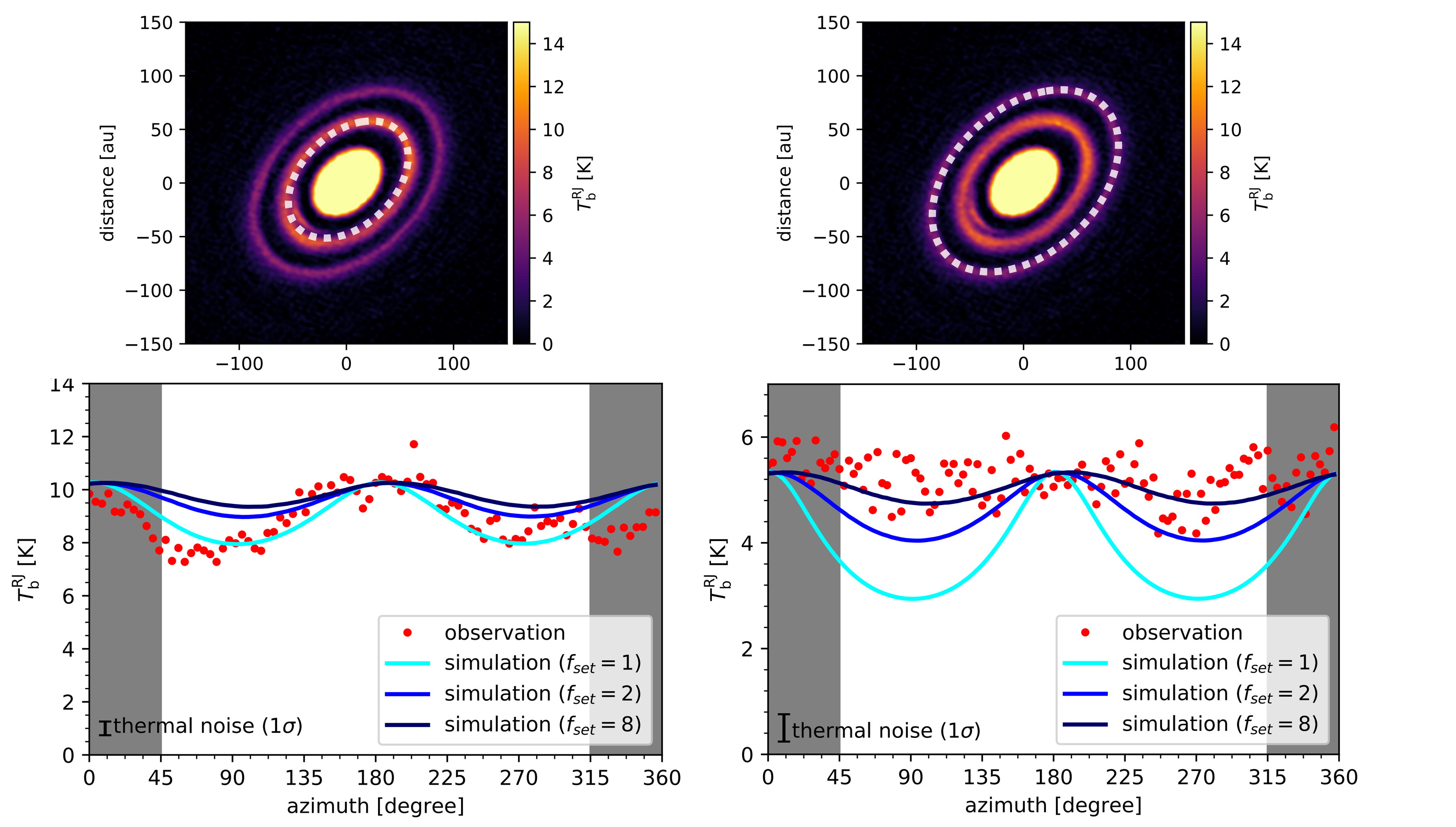
- The fixed parameters
  - The dust surface density: estimated from the intensity along the major axis
  - The dust opacity: from the DSHARP dust model(Birnstiel et al. 2018)
  - The dust temperature: from CO line observation(Dullemond et al. 2020)
- **The parameter we aim to estimate**
  - **The dust scale height**
    : f_{set}= the gas scale height/the dust scale height

We run multiple simulation changing only f_{set} and compare with the observation.

4. Result

4.1 Rough estimation

- The comparison with the intensity along the peak of the ring of the observation and the simulation (f_{set} =1, 2, 8)



inner ring: the dust is **flared up** **outer ring:** the dust is **settled**

4.2 Estimation using χ²

In 2σ error range
- **inner ring: f_{set} = $1.1^{+0.7}_{-0.1}$**
- **outer ring: f_{set} < 2.4**

5. Discussion

5.1 α/St

- The relation of the dust scale height and α/St

$$h_d=\left(1+\frac{St}{\alpha}\frac{1+2St}{1+St}\right)^{-1/2}h_g$$ (Youdin & Lithwick 2007)

- **inner ring: α/St > 0.48**
- **outer ring: α/St < 0.19**

5.2 The gas turbulence α, and the Stokes number (St∝the dust size)

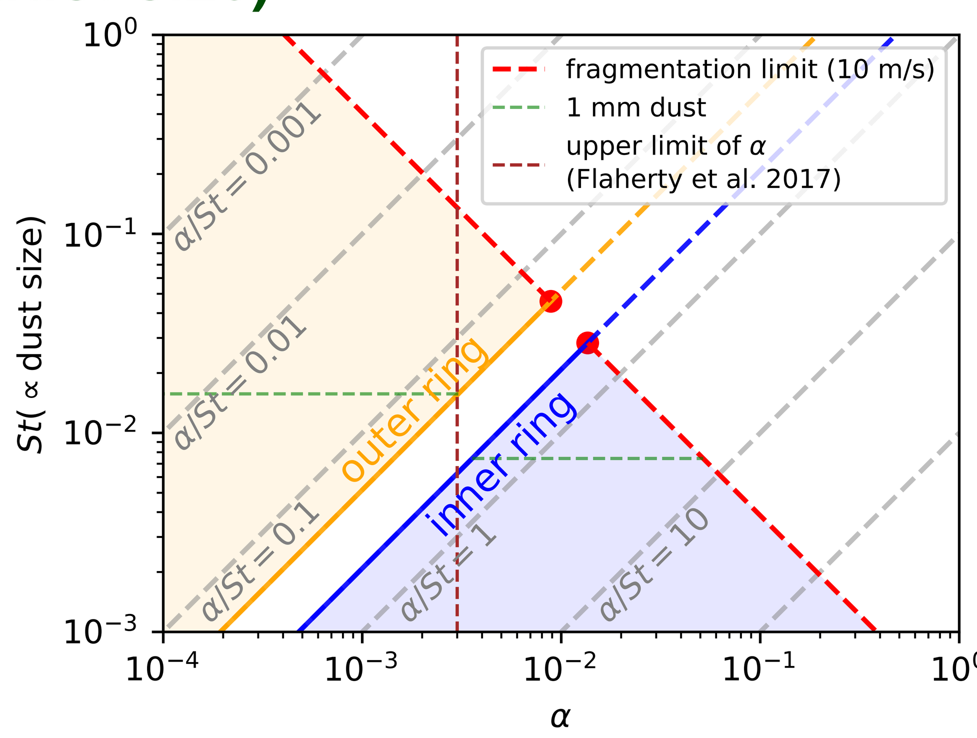


Fig 4. The possible range of turbulence (α) and Stokes number (St). The blue and orange areas represent the possible range of α and St for the inner and outer rings, respectively. The **red dashed** line represents the **fragmentation limit**, and the **blue** and **orange** lines represent the limit of **α/St**. The brown dashed line represents the upper limit of α from the observation of line broadening (Flaherty et al. 2017). The green dashed line represents the St when the dust size is 1 mm.