# Grain size and dust scale height distributions in HD 163296 studied by ALMA polarization observation

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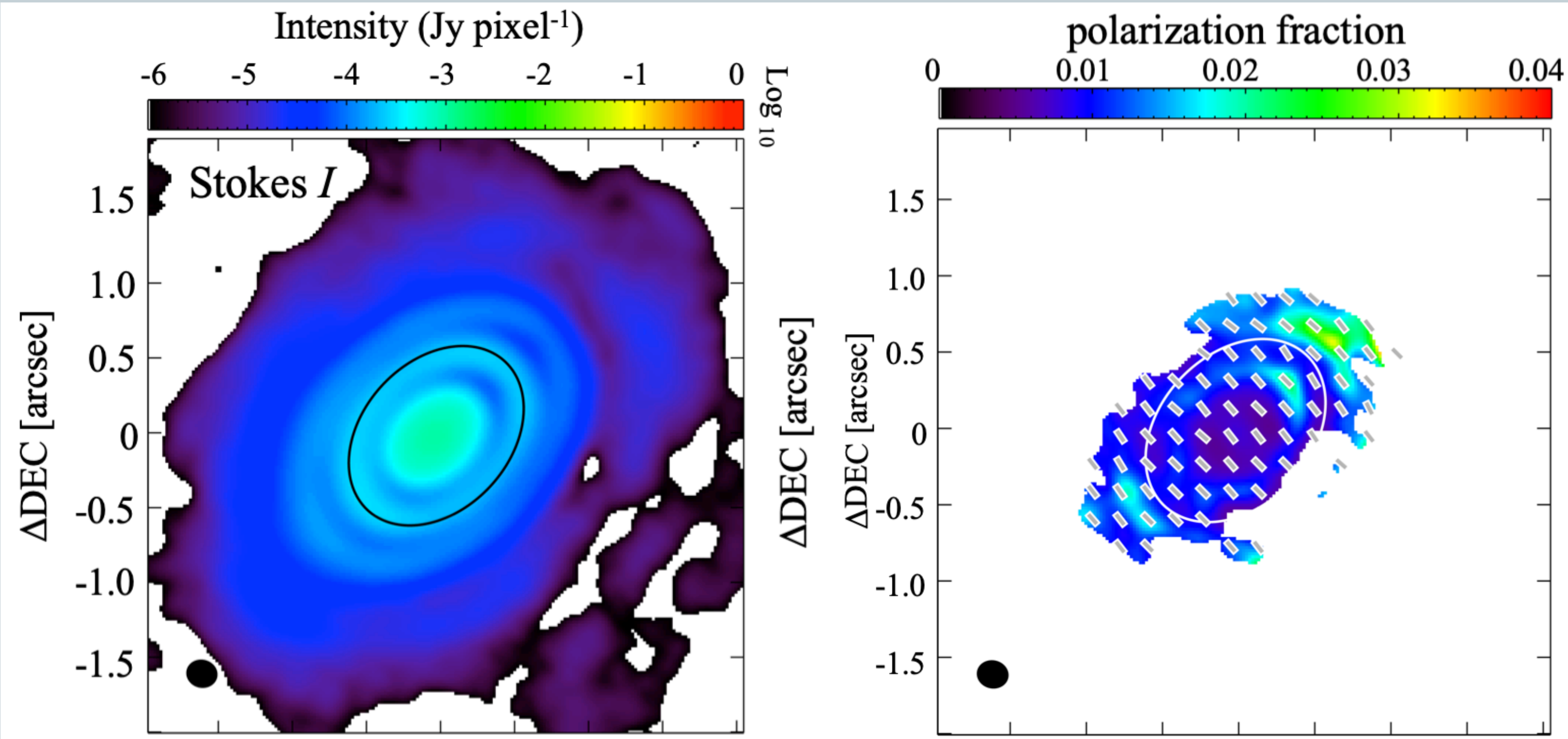
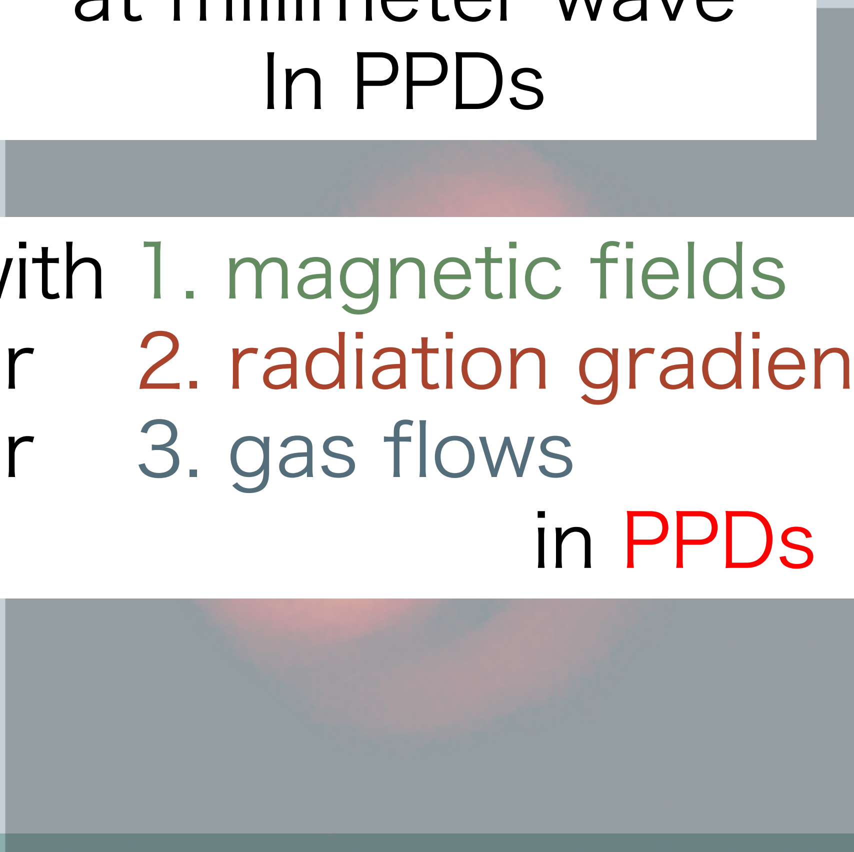
submitted to ApJ

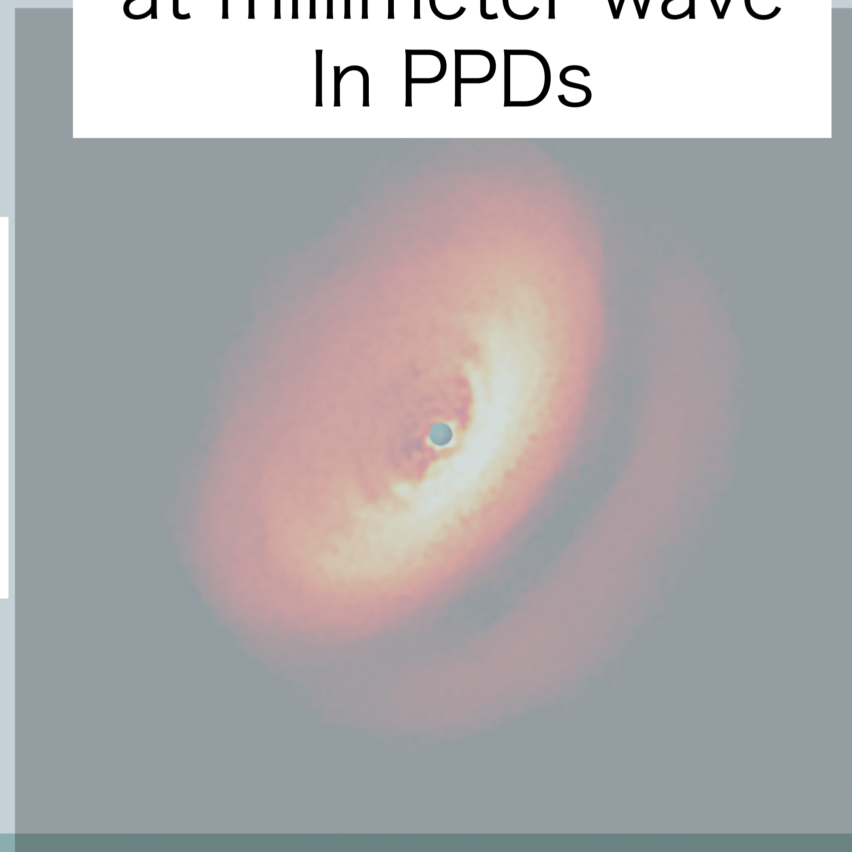


# Main mechanisms of dust polarization



Dust alignment
at millimeter wave
In PPDs

with 1. magnetic fields
or 2. radiation gradients
or 3. gas flows
in PPDs

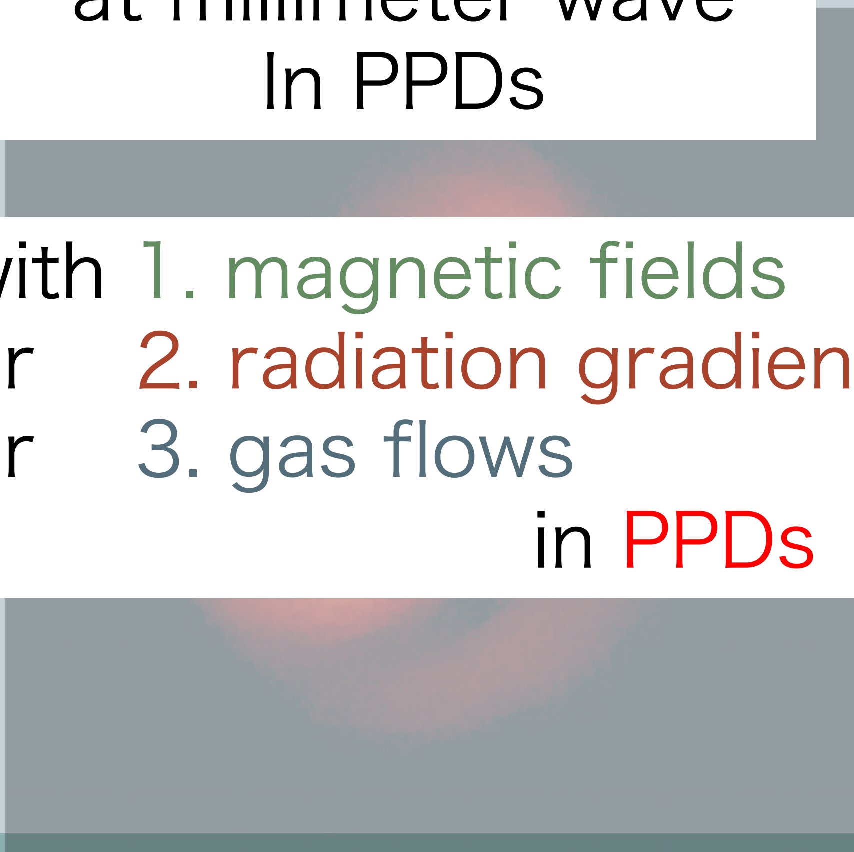


Scattering
at millimeter wave
In PPDs

# Main mechanisms of dust polarization

This talk

Dust alignment
at millimeter wave
In PPDs



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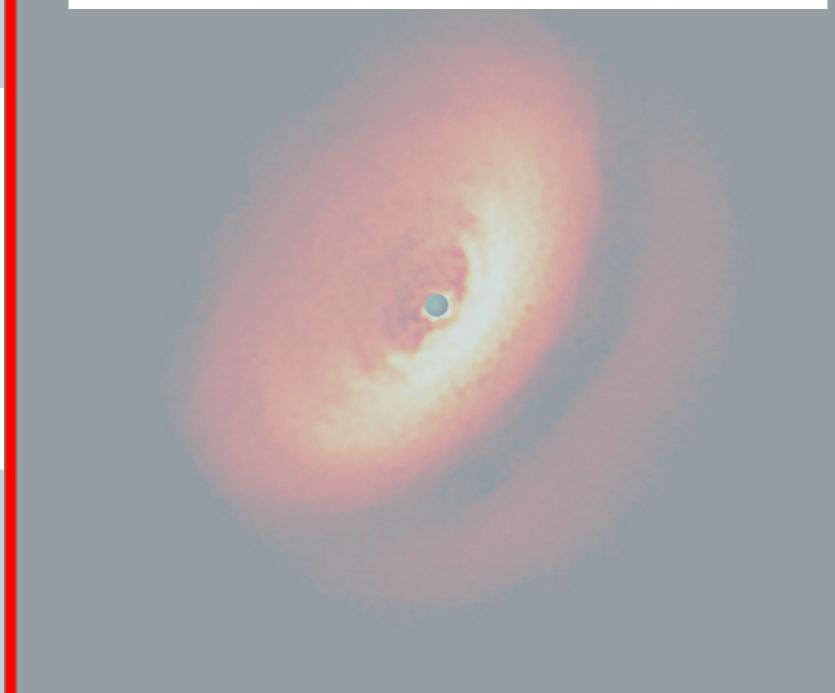
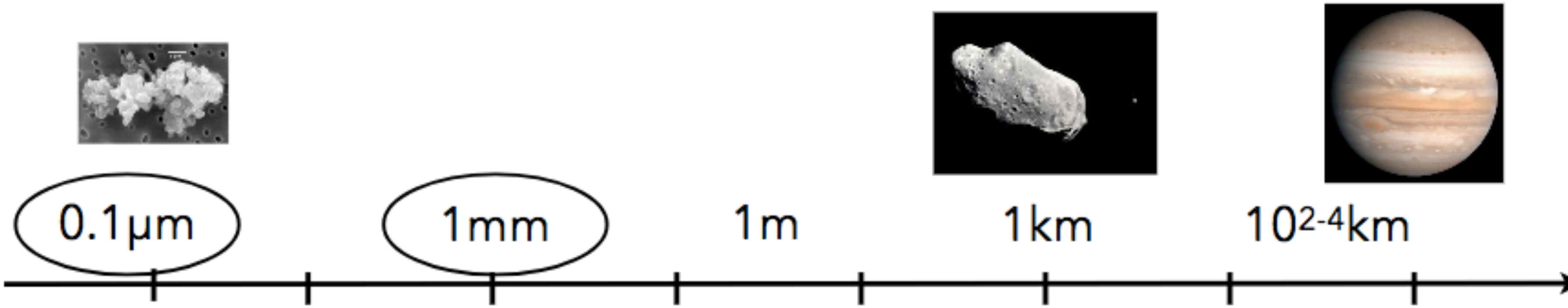
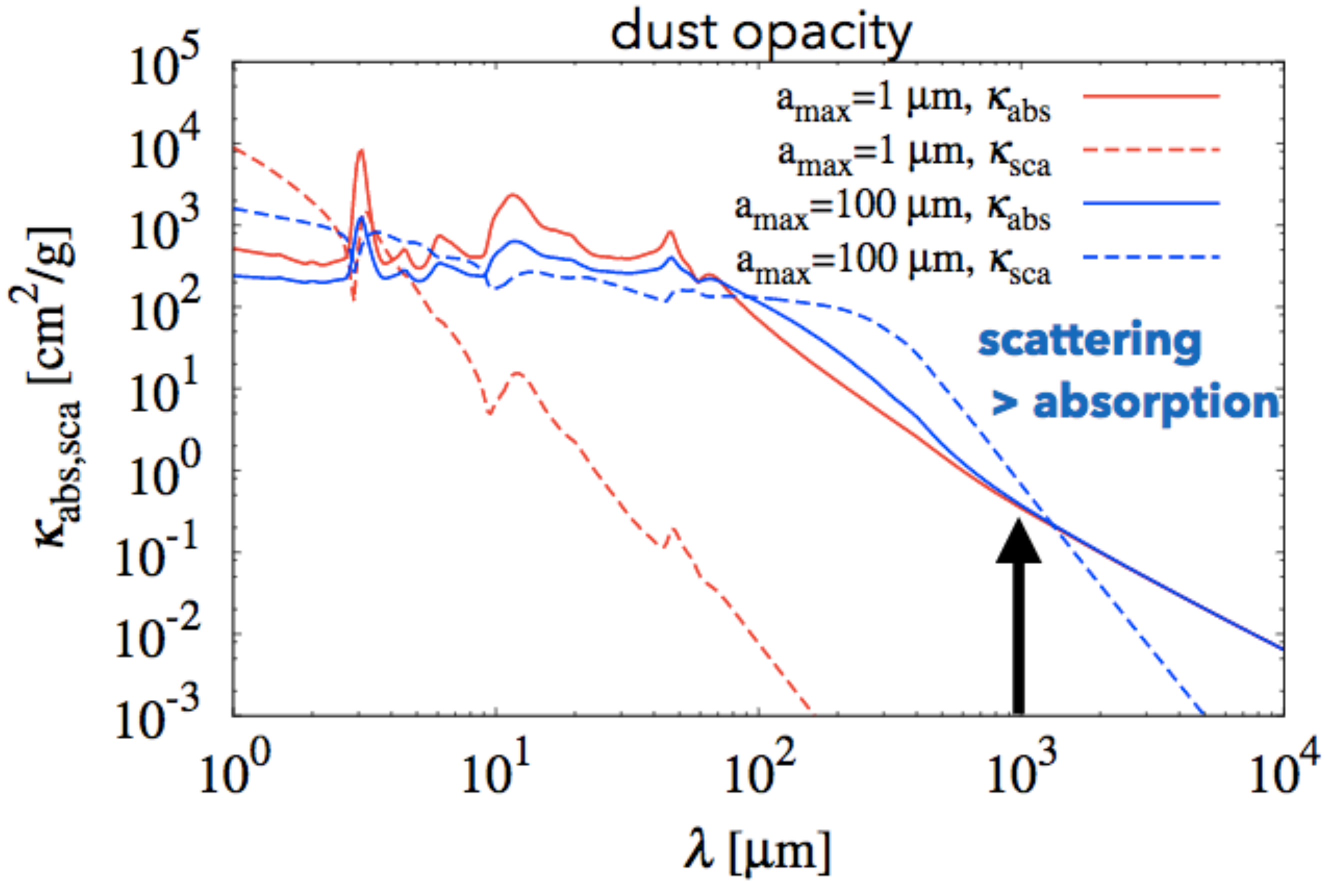
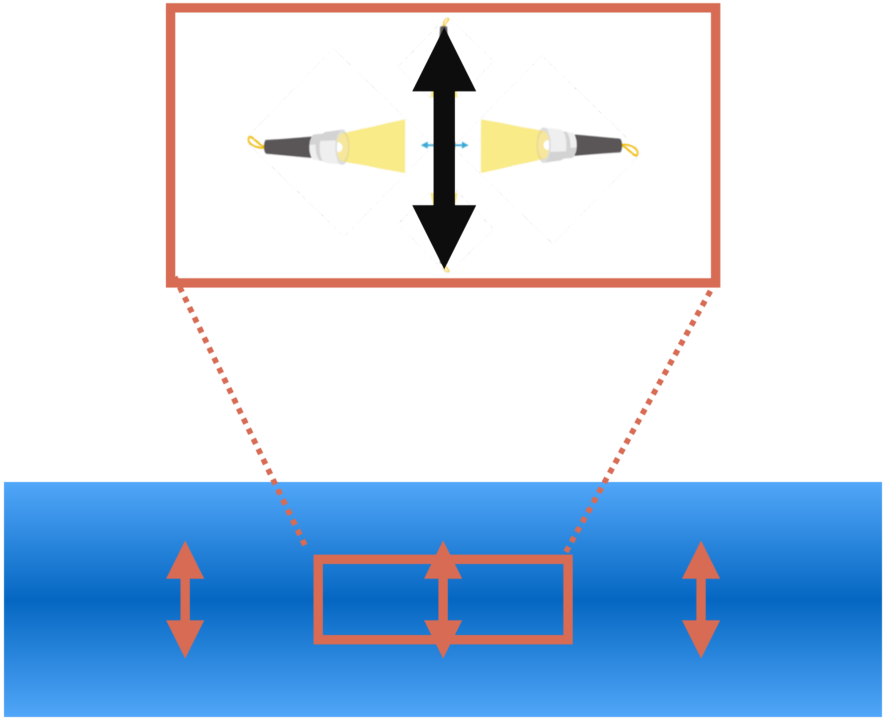


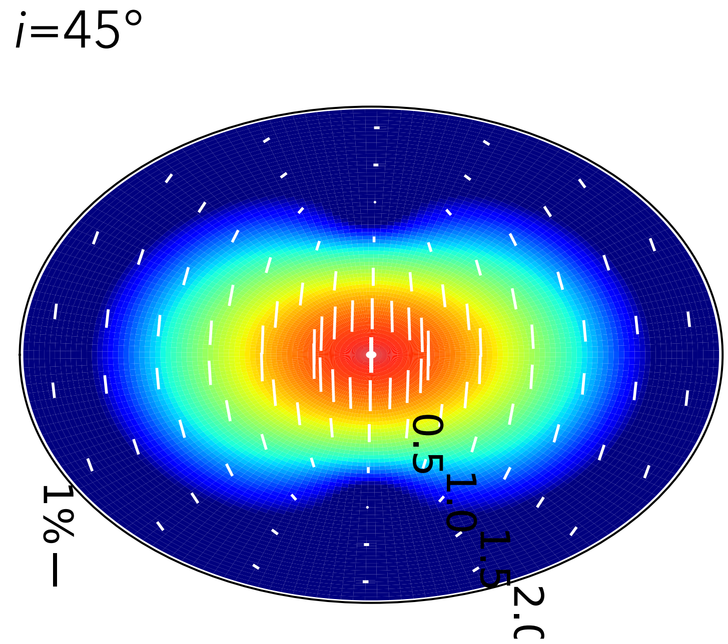
# Dust is big in disks



# Self-scattering in disks

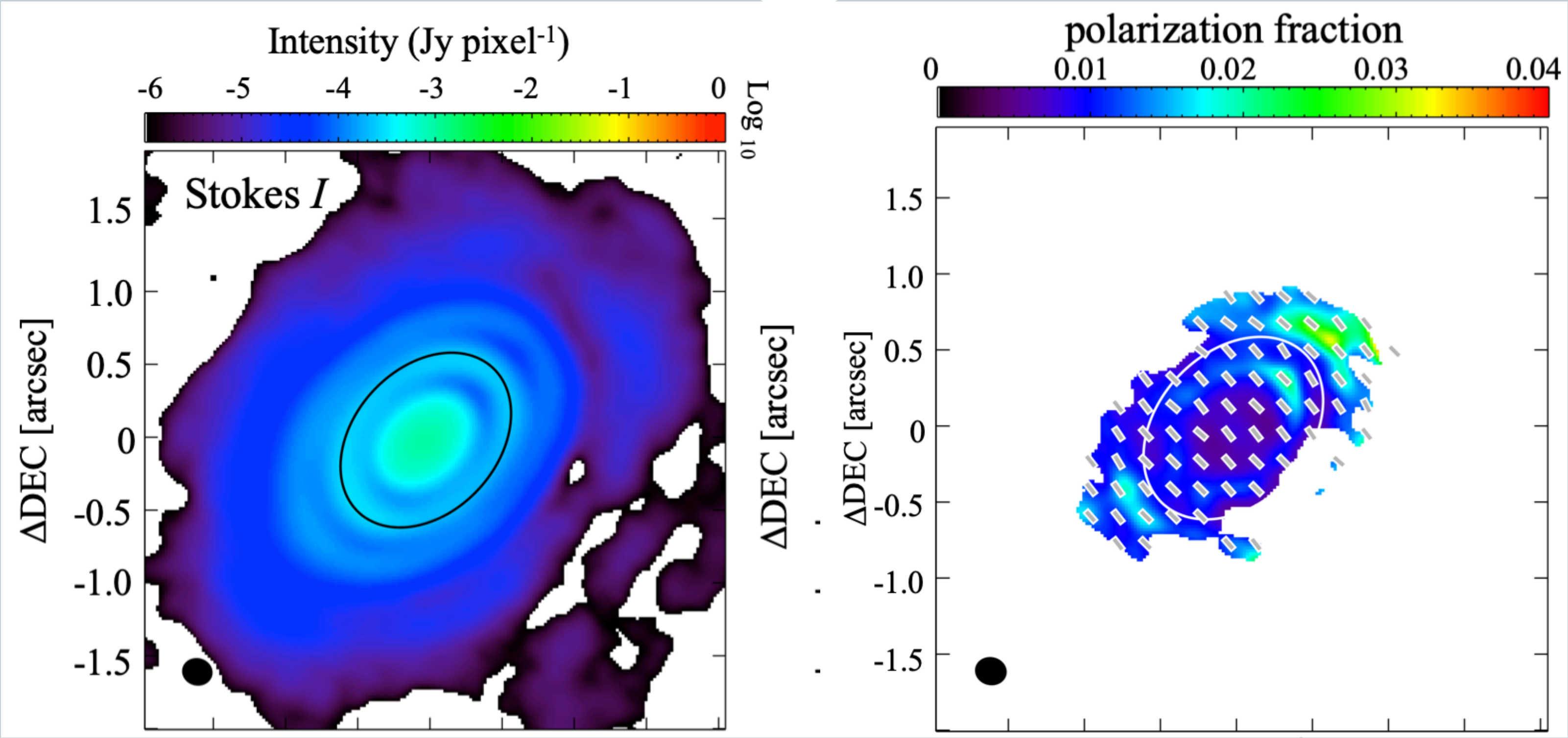



Yang, Li, et al. 2016

See also Kataoka et al. 2016a

# The ideal target of HD 163296 reported by Dent et al. 2019




Dent et al. (2019) have shown the polarization morphology within the disk

Can we model these observed features?

# Radiative transfer calculations (RADMC-3D)

- Dependence on grain size

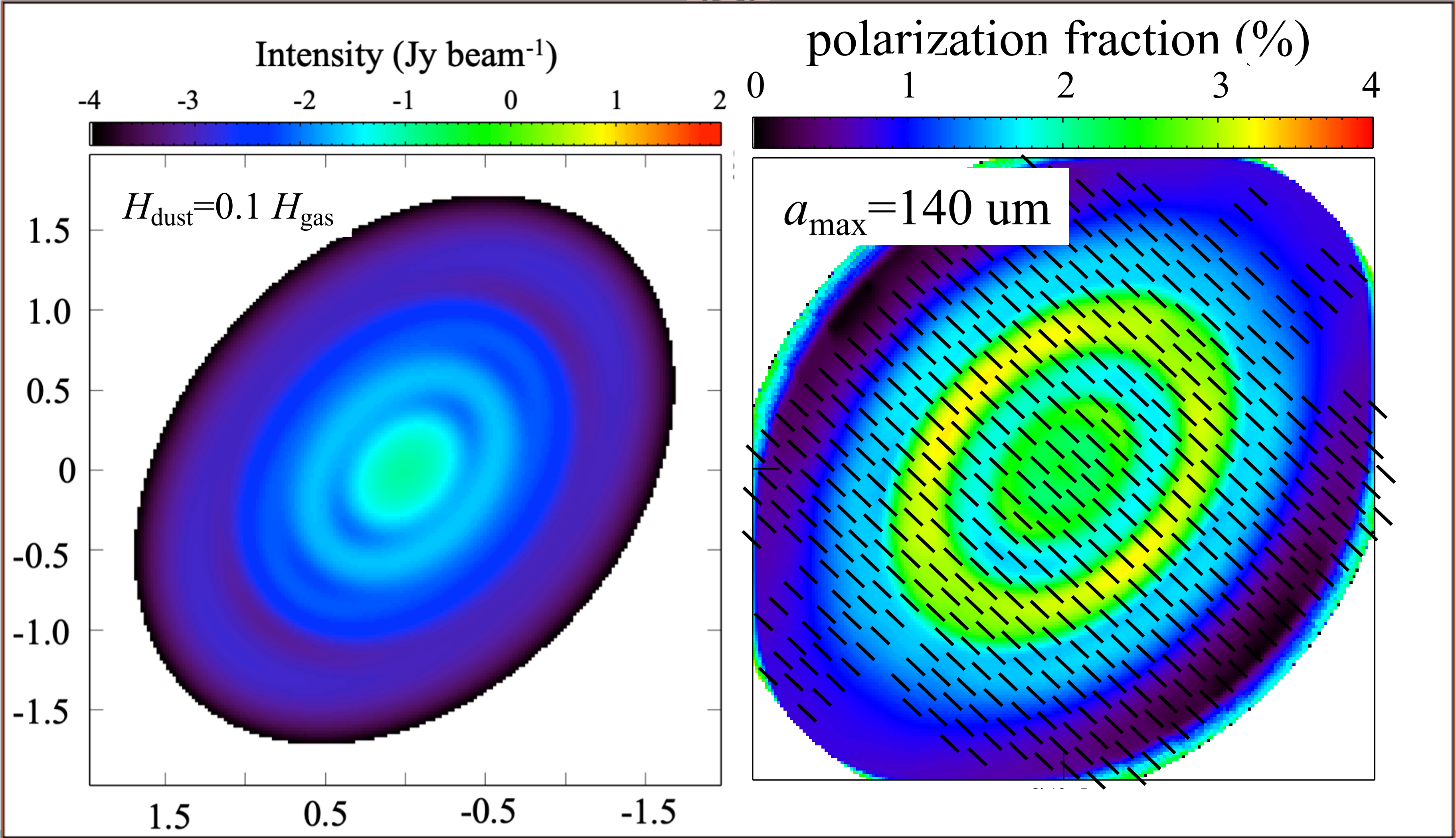
  *Polarization fraction depends on a size of grains, but polarization patterns are independent*

- Dependence on scale height

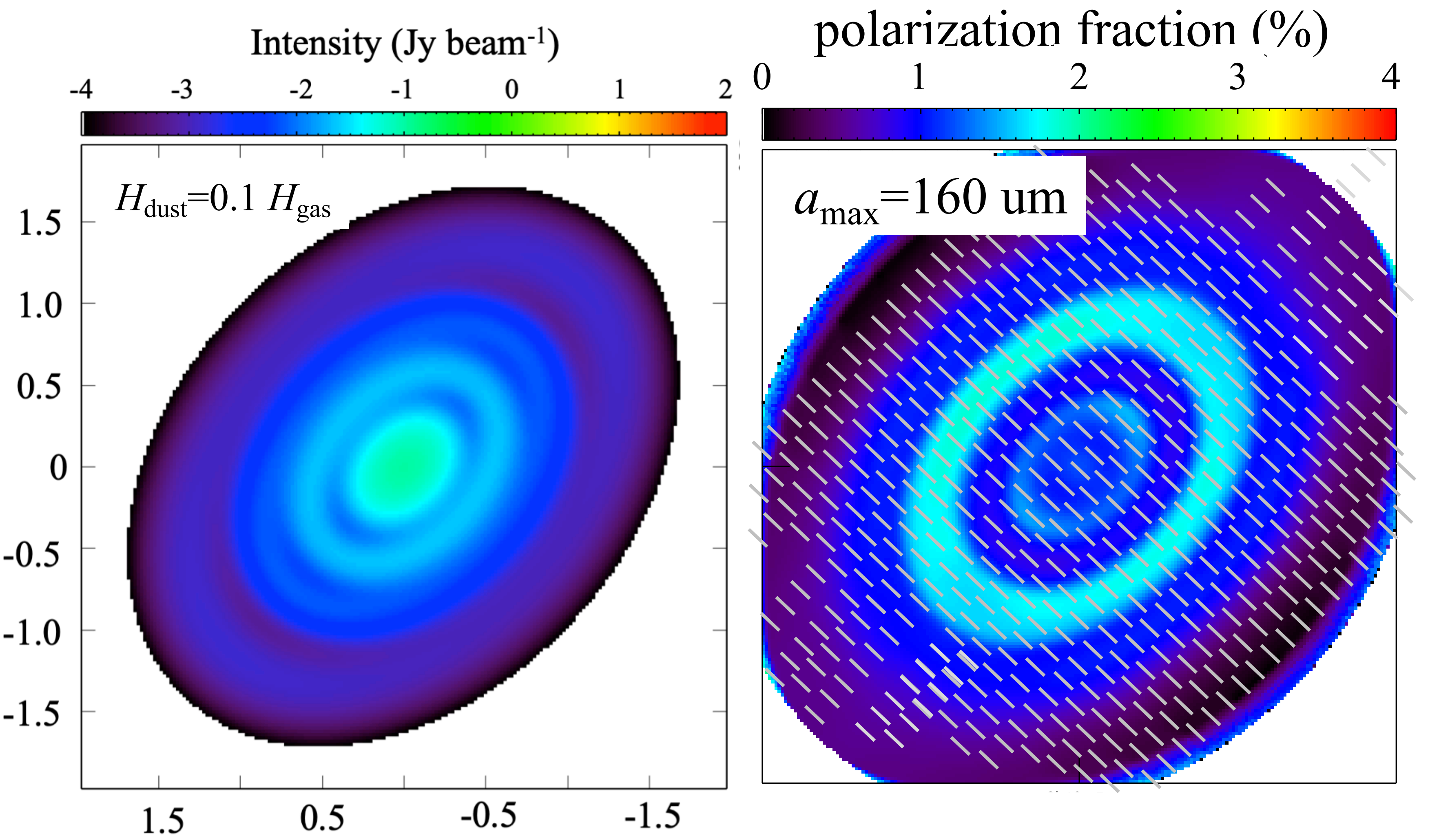
  *Azimuthal variation is enhanced by scale height*

- Best model

# Effect of grain size



# Effect of grain size



# Conditions of dust grains for polarization

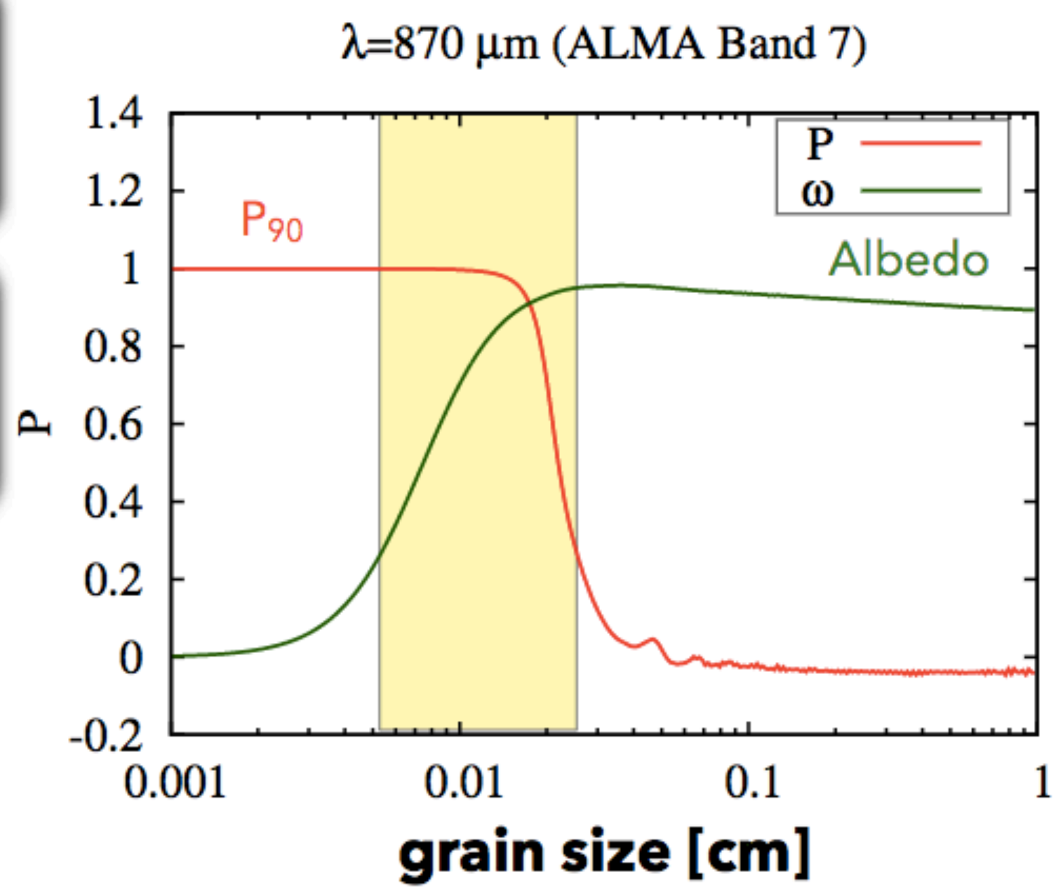
- For efficient scattering

  **(grain size) >~ λ**

- For efficient polarization

  **(grain size) <~ λ**

There is a grain size which contributes most to the polarized emission




**If (grain size) ~ λ/2π, the polarized emission due to dust scattering is the strongest**

# Radiative transfer calculations (RADMC-3)

- Dependence on grain size

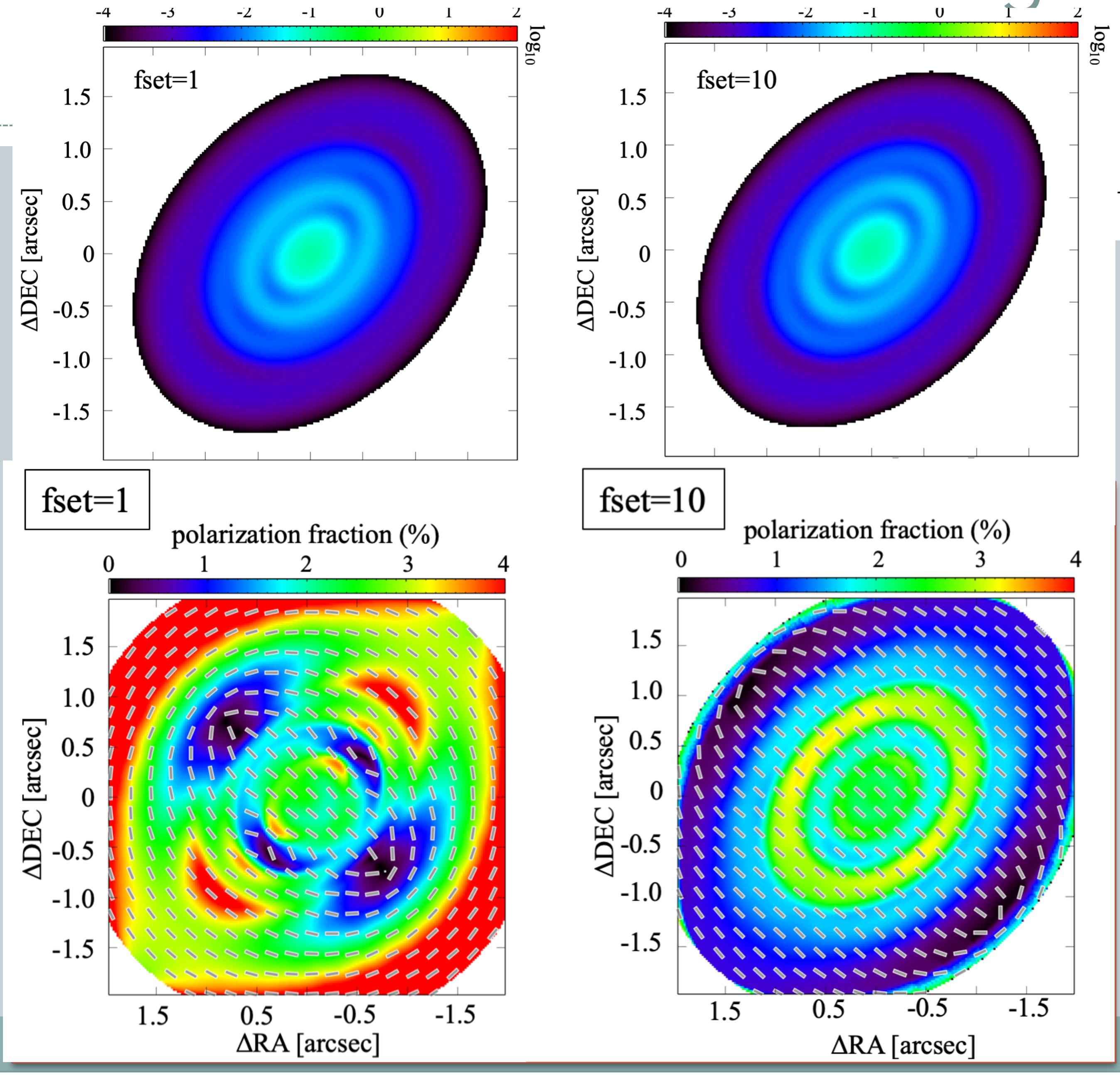
  *Polarization fraction depends on a size of grains, but polarization patterns are independent*

- Dependence on scale height

  *Azimuthal variation is enhanced by scale height*

- Best model

# Effect of dust settling




$$H_{\rm dust} = \frac{H_{\rm gas}}{\rm fset}$$

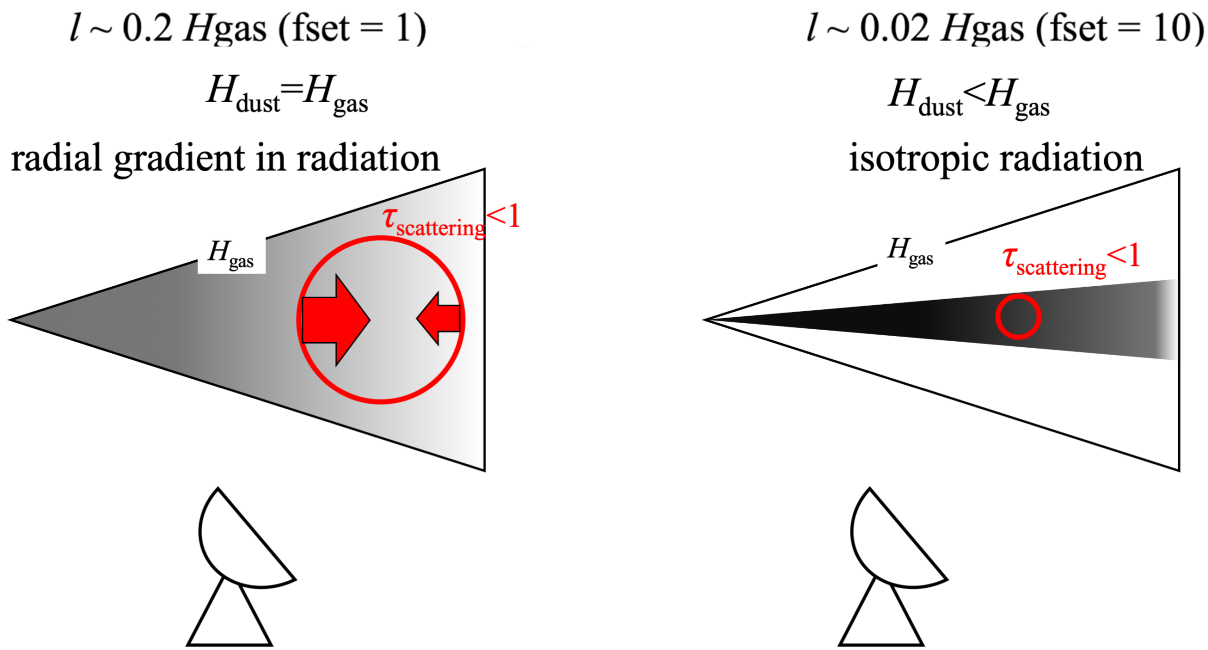
# Scale height is also important for scattering

Incoming flux along the radial direction increases with scale height
→ Azimuthal polarization is produced,

scale of photoshpere

$$l \sim \frac{H_{\rm dust}}{\kappa_{\rm scat}\Sigma_{\rm dust}} \sim \frac{H_{\rm dust}}{(6-7)\tau_{abs}} = \frac{H_{\rm gas}}{fset(6-7)\tau_{\rm abs}},$$

$$H_{\rm dust} = \frac{H_{\rm gas}}{\rm fset}$$



# Radiative transfer calculations (RADMC-3)

- Dependence on grain size

  *Polarization fraction depends on a size of grains, but polarization patterns are independent*

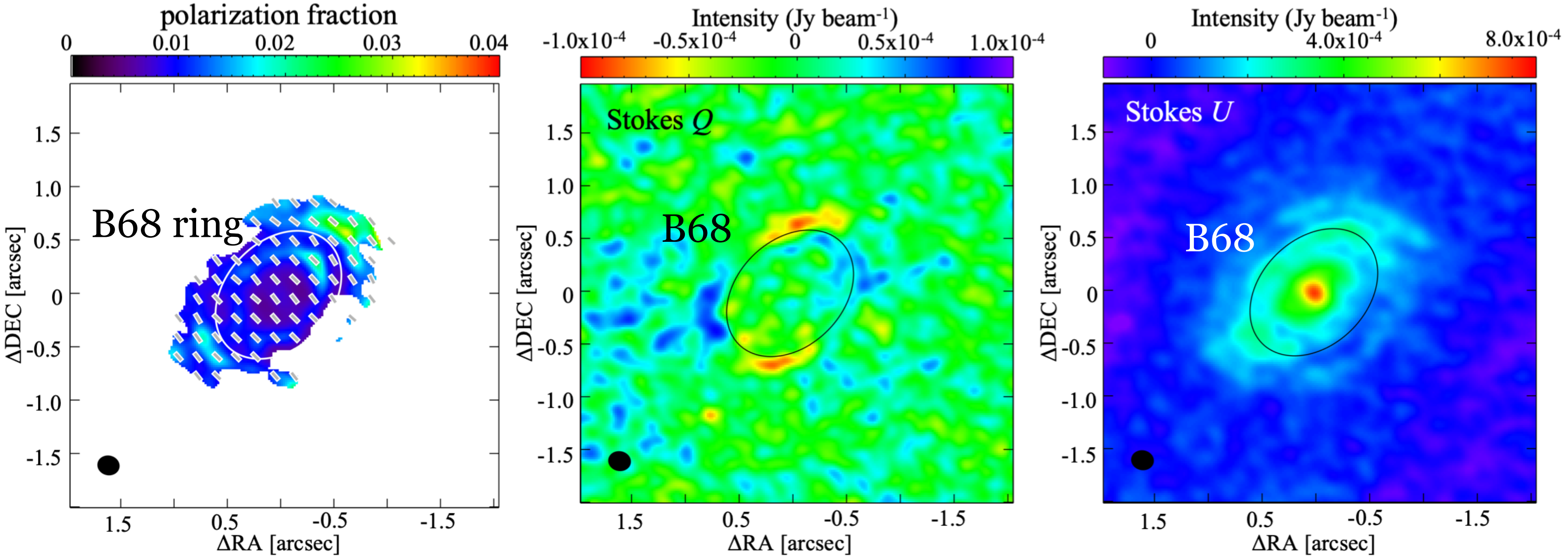
- Dependence on scale height

  *Azimuthal variation is enhanced by scale height*

- Best model

# Comparisons with observation

- polarization vectors may be difficult to compare between model and observation.
- We discuss Stokes *Q* and *U* images.

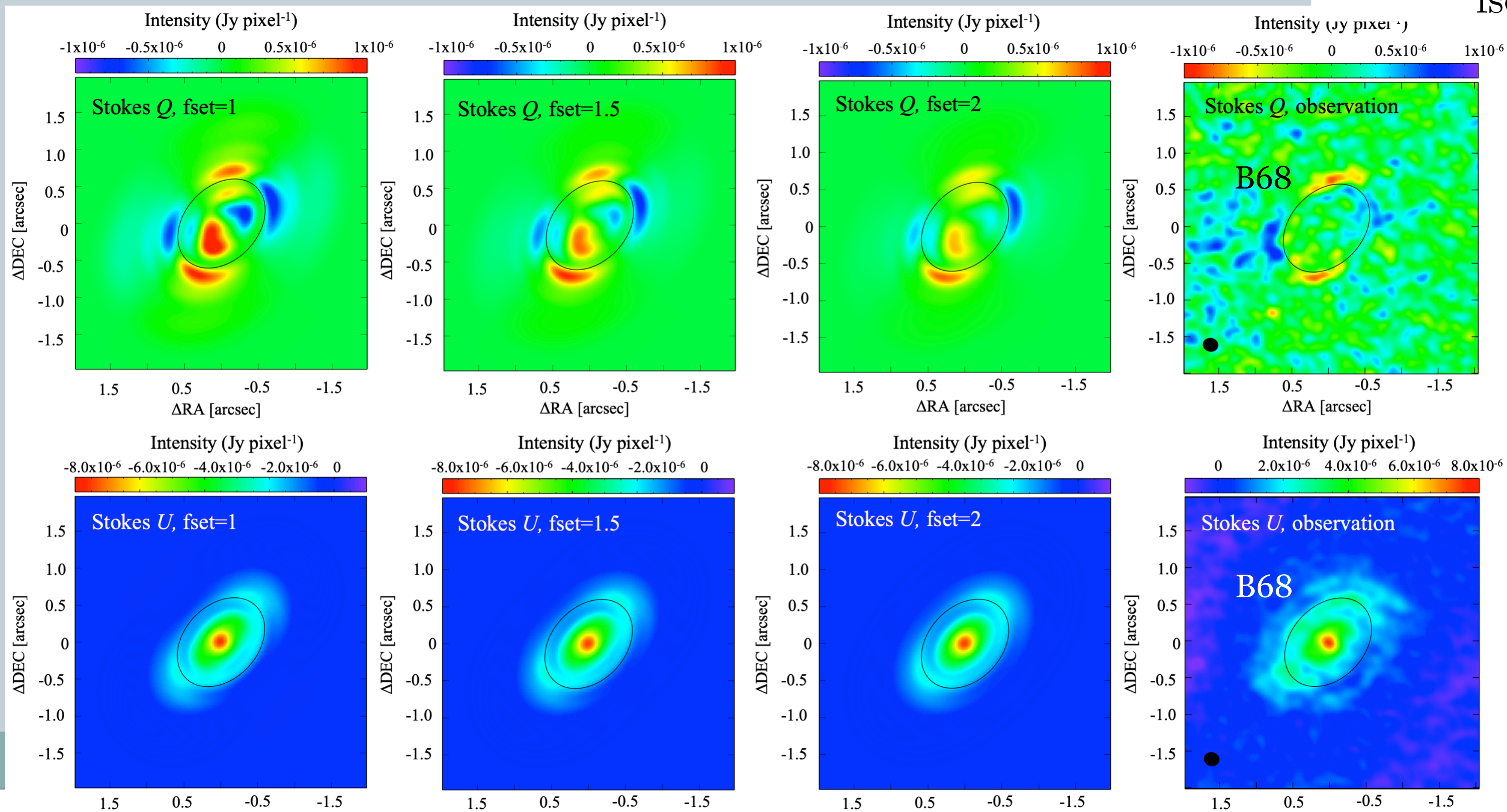



*Note: grain sizes set to be 1 mm at the rings and 140 micron at the gaps to match the observed polarization*

# Radial variations of scale height

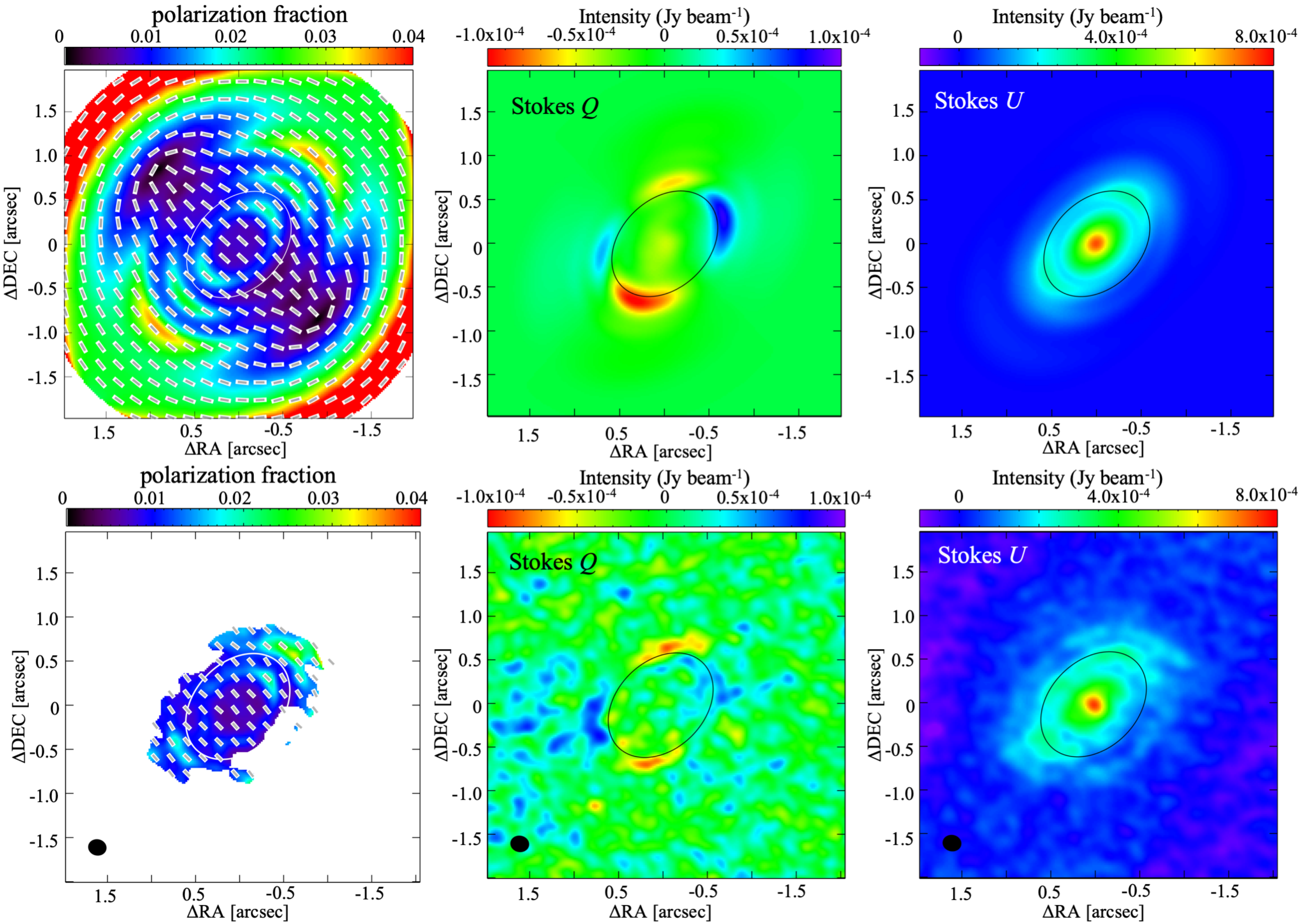
Stokes $Q$ is increased by increasing scale height
The observation shows no Stoke $Q$ emission $r < 70$ au,
indicating the scale height is low $r < 70$ au and high $r > 70$ au

$$H_{\mathrm{dust}} = \frac{H_{\mathrm{gas}}}{\mathrm{fset}}$$



# Best model

140um and 1mm model: scale height $H_d$=0.1 $H_{gas}$ ($r$ < 68 au) and 0.7 $H_{gas}$ ($r$ > 68 au)



# Radial variations of grains and scale height

Dust scale height

$$H_{\mathrm{dust}} \sim \sqrt{\frac{\alpha}{\mathrm{St}}} H_{\mathrm{gas}}$$

$$\mathrm{St} = \frac{\pi \rho a}{2\Sigma_{\mathrm{gas}}}$$

turbulence $\alpha$ will be different between 50 and 90 au

$\alpha \lesssim 1.5 \times 10^{-3}$ at 50 au

$\alpha \sim 0.015 - 0.3$ at 90 au

*Scattering allow us to investigate not only grain size but also dust scale height*