Modeling the Effects of Dust Scattering on the Sub-mm/mm fluxes in Protoplanetary Disks

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ABSTRACT

Studying the effects of dust scattering in protoplanetary disks is essential for understanding the evolution of dust grains into larger objects such as planets. While the scattering of stellar light at optical/IR wavelengths has been observed for decades, self-scattering of the dust's thermal emission at sub-mm/mm wavelengths has only recently been recognized as an important effect. We have created a fiducial protoplanetary disk model to test how different types of dust scattering affect the change in the measured sub-mm/mm fluxes of the disk. Since the optical depth is directly correlated to the emission flux, understanding our biases in its regard can provide insight into the chemical and physical properties of the dust grains. By systematically varying several disk parameters, we measure how the flux changes for different types of scattering.

CONTEXT

- Protoplanetary disks are disks of gas and dust surrounding a very young star
- Dust properties and the evolution of dust grains can be mapped using its interactions with light
- The measured flux scales with frequency as $F_\nu \propto \nu^\alpha$
- The disk's optical depth heavily impacts the measured flux
- Dust masses are derived from the flux assuming optically thin emission. High optical depth affects measured flux values, leading to underestimated dust masses [1]
- Dust scattering may be the driving mechanism behind the dust mass underestimation [2].

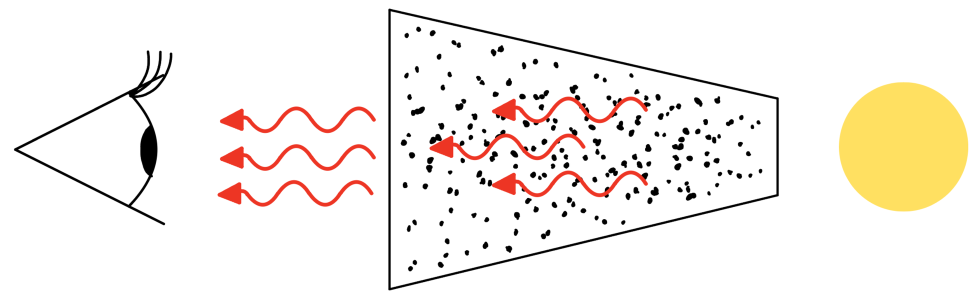

Figure 1: A schematic diagram of an optically thin disk. Thermal emission from the entire disk contributes to the measured flux.

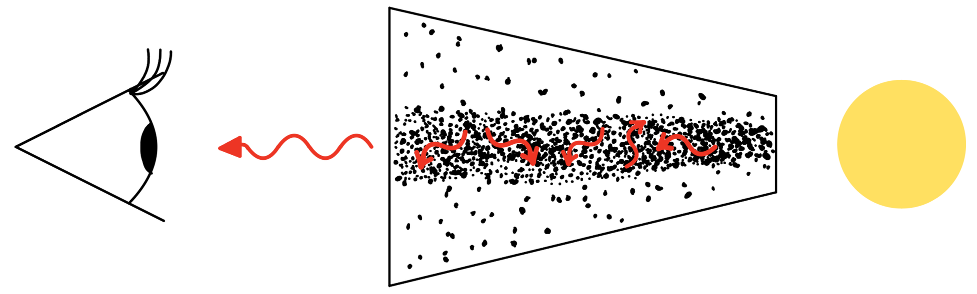

Figure 2: A schematic diagram of an optically thick disk. Thermal radiation is scattered and absorbed in the dusty regions of the disk, impacting the disk flux measurements.

METHODOLOGY

- Built a protoplanetary disk model based on the framework presented in Liu et. al (2022) [1] using an astronomical software called RADMC-3D [3], which makes radiative transfer calculations for the protoplanetary disk
- Main inputs: stellar properties ($T_\star$, $R_\star$, $M_\star$), dust density structure, dust chemical composition, dust grain size distribution, dust scattering mode
- Main outputs: dust temperature, spectral energy distribution, dust emission images
- Varied the dust mass and scattering mode to generate a family of 9 models
- Calculated the spectral index at the wavelengths: 0.89 – 1 mm, 1 – 1.3 mm, 2 – 3 mm, and 3 – 7 mm.

RESULTS

- The spectral index at 0.89, 1.3, and 3 mm for every model decreases with increasing dust mass; flux measurements from dusty disks with high optical depth may not necessarily be indicative of grain growth
- Dust scattering suppresses α[0.89 – 1 mm] from 2.1 to 1.87 for low mass (10^{-4} $M_\odot$) models
- α for no-scattering models are more sensitive to increasing dust mass
- At 3 – 7 mm, the disks are optically thin and α ≈ 4 for all models. This indicates that dust emission may be dominating the mm fluxes rather than scattering. Further analysis must be done to confirm this.

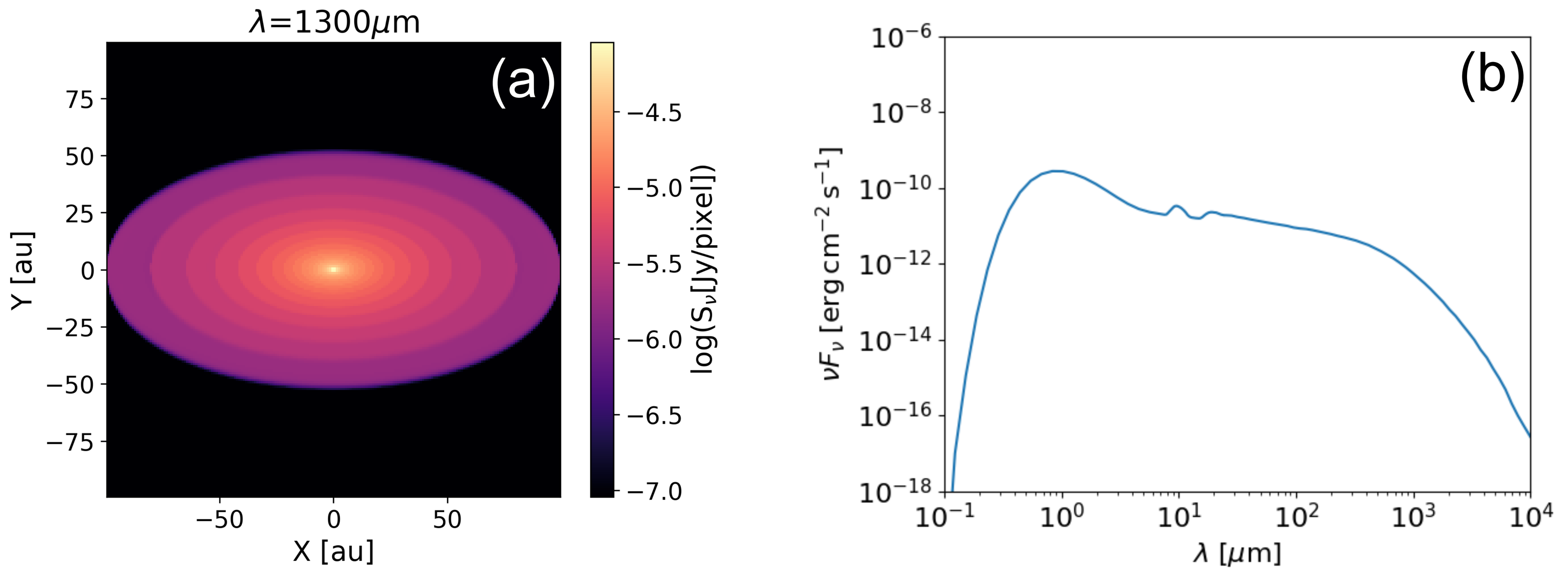

Figure 3: Panel (a) shows an image of the thermal emission of a disk model at 1.3 mm with M_{dust} = 3 × 10^{-4} $M_\odot$ and isotropic scattering. Panel (b) shows the entire spectrum of the same disk model.

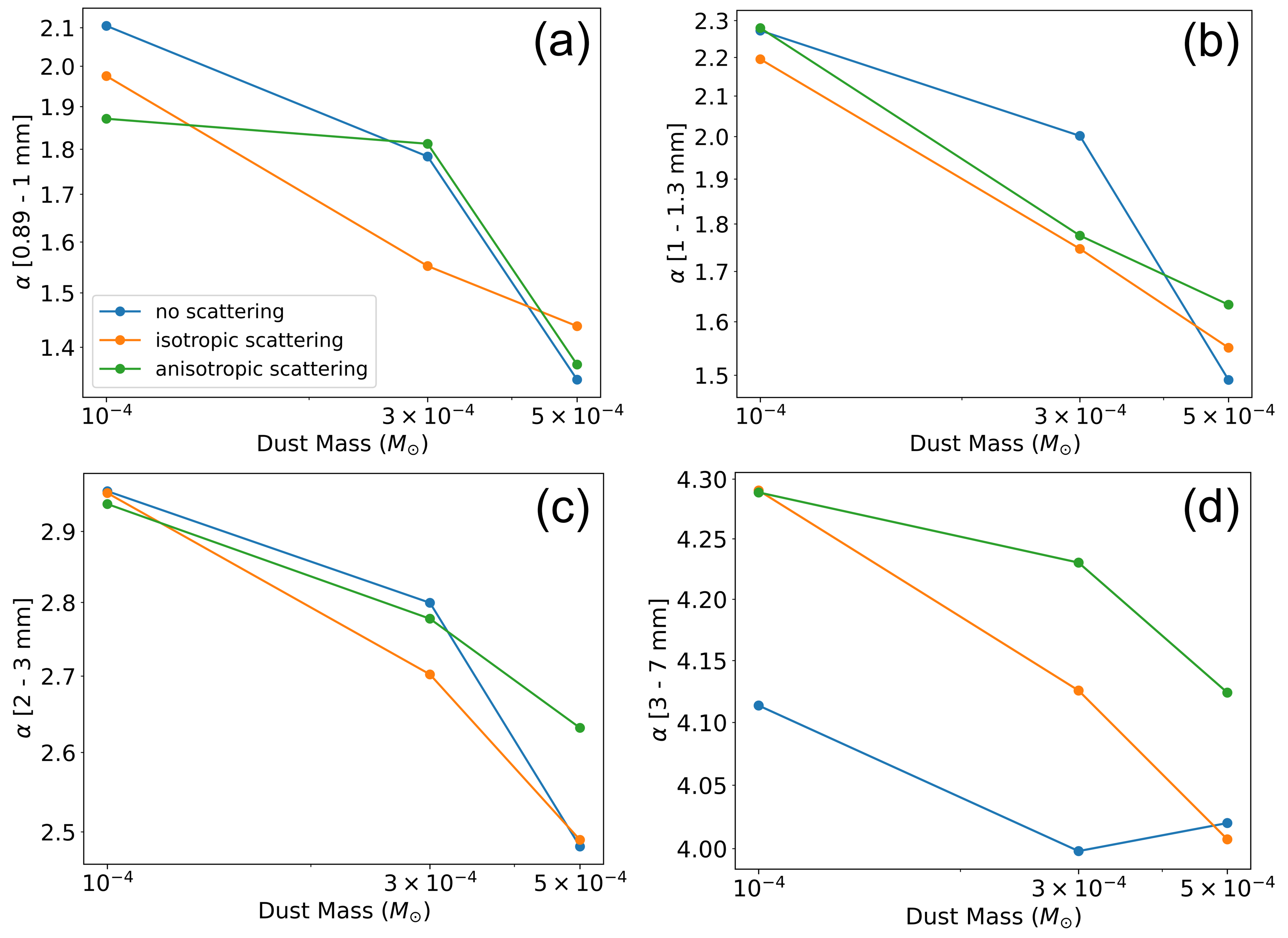

Figure 4: Spectral index for each model with varying dust masses and scattering modes at (a) 0.89 – 1 mm, (b) 1 – 1.3 mm, (c) 2 – 3 mm, and (d) 3 – 7 mm.

FUTURE WORK

- Vary other parameters such as the maximum grain size, disk size, & grain number density with the scattering mode
- Quantify the impact of scattering on the estimates of dust properties in protoplanetary disks

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