Dust Evolution in the Late Stages of Planet Forming Disks

Joshua Garrett[1], Luca Ricci[1], Carey Weisberg[2], Andrea Isella [3]

[1]Department of Physics & Astronomy, California State University, Northridge, CA, [2] Department of Physics & Astronomy, California State LA, Los Angeles, CA, [3] Department of Physics & Astronomy, Rice Universtiy, Houston, TX

joshua.garrett.461@my.csun.edu

1. Introduction

Exoplanets are formed in protoplanetary disks that surround young stars. Fundamentally, planet formation is the product of small sub-μm sized particles collecting into large planetesimals in these protoplanetary disks. However, one of the main obstacles of planet formation in protoplanetary disk is the radial drift problem. Fast radial drift of particles occurs in regions with gas pressure strongly decreasing with distance from the star. As a consequence of the pressure force, the gas rotates slower than solids. Because of the gas drag, dust grains with sizes 1-10mm at radius of 100 AU move inward toward the protostar in less than 1 Myr. This is much less than the usual lifetime of a protoplanetary disk which is 1-10 Myr. The dust trapping mechanism is a potential solution to this problem. Dust trapping requires the presence of local pressure maxima where dust grains can concentrate and grow into bigger solids. These pressure maxima are evident in the structures found from new observations of protoplanetary disks with younger ages of 1-3 Myr. We want to investigate whether these local pressure maxima are still present in disks at the end of their lifetime. We focus on the Upper Scorpius region which houses disks that are 5-10 Myr old. Because of their age, these disks are very faint compared to the younger disks and finding evidence for structures from direct imaging is much more difficult. We instead investigate the presence of mm-sized grains in a sample of 24 disks in Upper Sco by analyzing their spectral index values at mm-wavelengths.

2. Method

For each disk, we measured their spectral index by combining the flux already measured at $\lambda = 0.88$mm by Barenfeld et al (2016)[1] with the flux at $\lambda = 2.87$mm from new ALMA observations. We utilize the spectral index for each object to characterize the grain size for each disk.

$$\alpha = \frac{Ln(F_{\nu_1}/F_{\nu_2})}{Ln(\nu_1/\nu_2)}$$

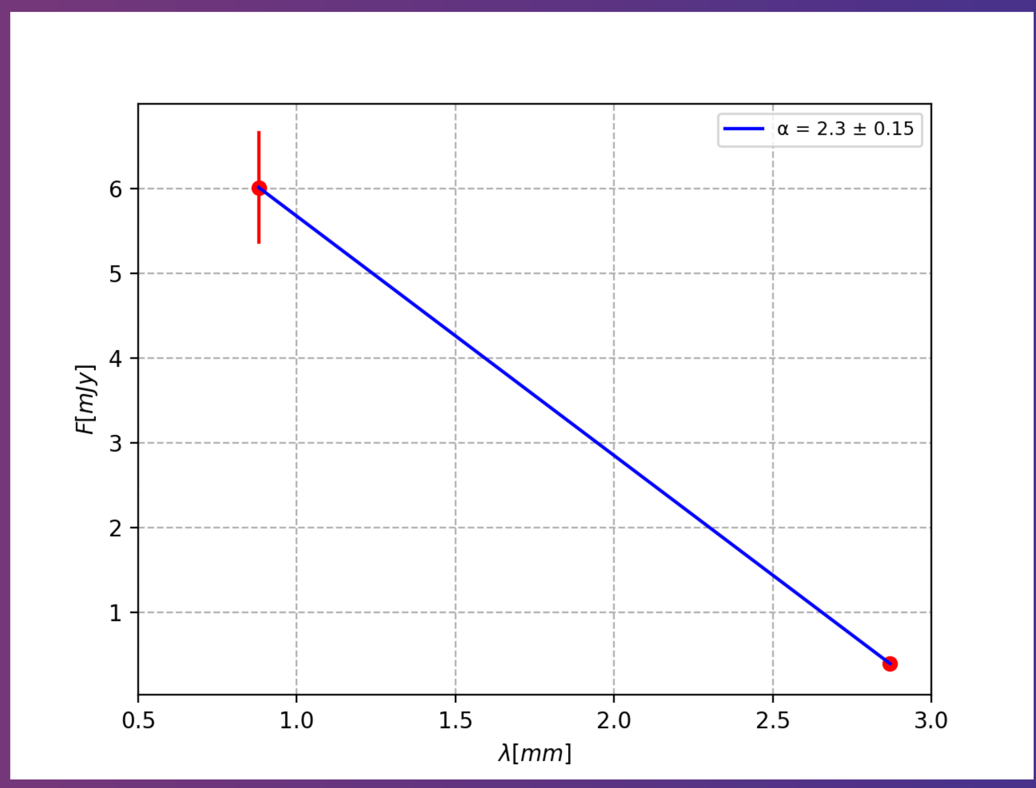

Figure 1: SED of J16123916 at mm wavelengths

3. Results

We measured alpha values between about 1.5 and 3.0. We can interpret the results and break up our 24-disks sample into two models. For $\alpha < 2$, we adopt disk models with optically thick emission, while for the cases with $\alpha > 2$ optically thin emission.

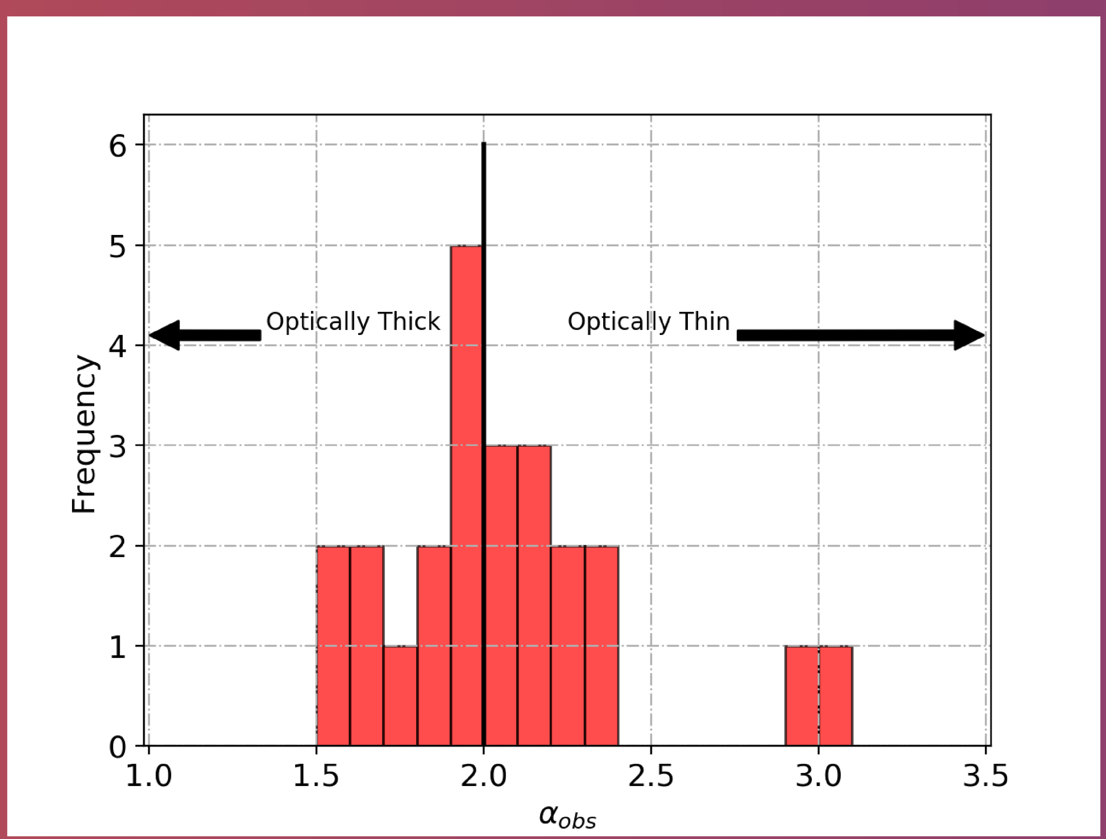

Figure 2: Histogram of measured spectral index values

4. Optically Thin

For the optically thin model, $\alpha = \alpha_{planck} + \beta$ where $\kappa_\nu \propto \nu^\beta$ and α_{planck} is the spectral index of the Planck function at the temperature of the emitting dust. We can assume the RJ-limit where $\alpha_{planck} = 2$. Hence, the disks with measured $\alpha < 2$ are explained with $0 < \beta < 1$. This implies that the grains as large as at least $a \sim 1$mm are present in the disk.

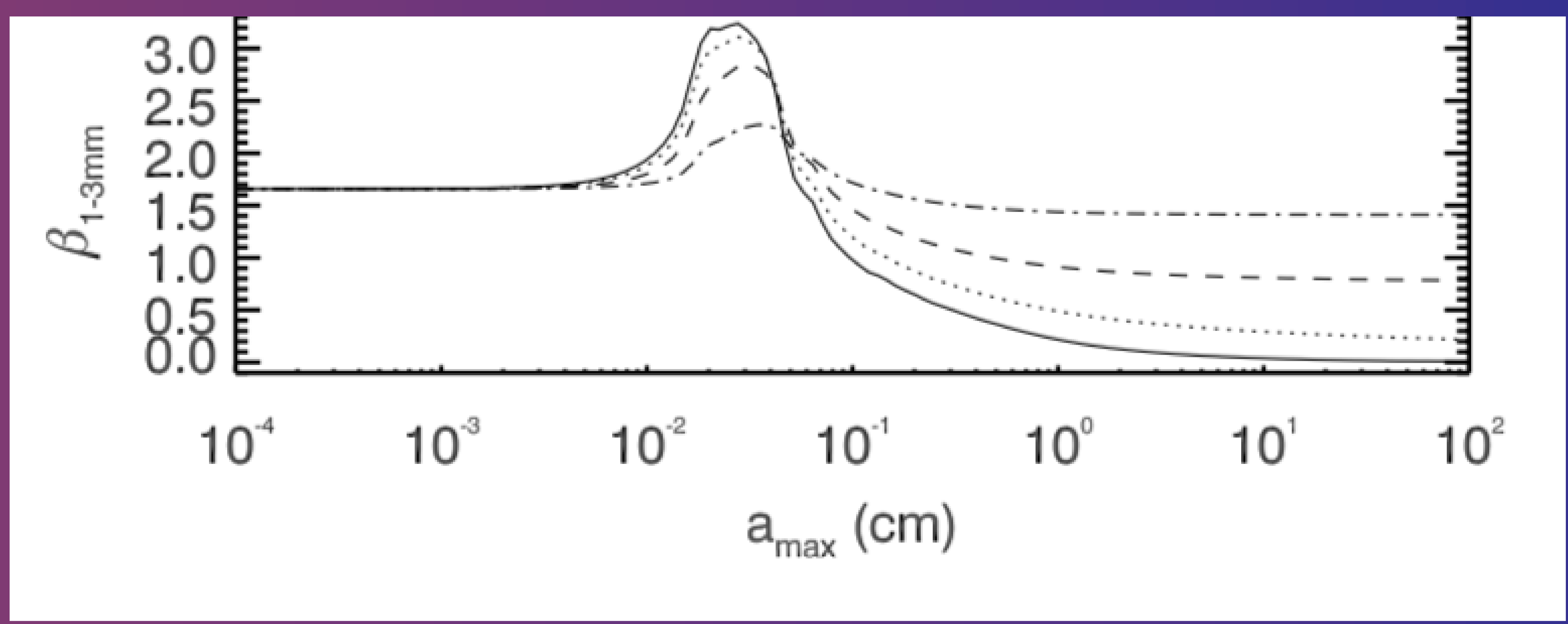

Figure 3: This plot shows the relationship of β and the largest grain size from Ricci et al 2010[2]. For our sample, the grain size is bigger than 1mm.

5. Optically Thick

For the optically thick model, $\alpha = \alpha_{planck}$ where in the RJ-limit $\alpha_{plack} = 2$. Recent investigations which account for dust scattering of mm-wavelength dust emission can explain $\alpha < 2$ from Zhu et al [3]. Preliminary results from models calculated with radmc-3d suggests that models with grains as large as $a \sim 10$cm are consistent with the data. .

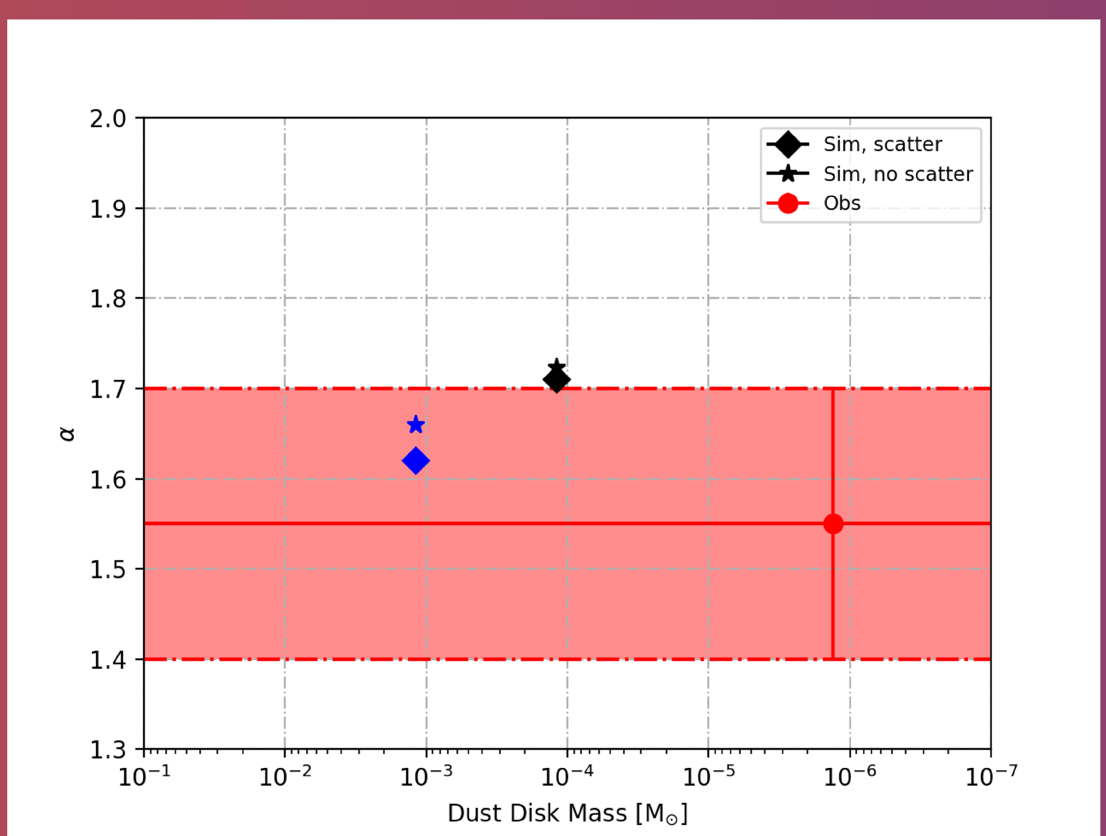

Figure 4: Disk J16062916 with a largest grain size of $a \sim 10$cm and grain size distribution q = 2.0. The red value is the observed spectral index and dust mass while blue and black come from calculations done with radmc-3d.

6. Conclusions

We obtained information on the grain size in 24 disks in the Upper Sco region (age $\sim$ 5-10 Myr). The results broke down into two models, the optically thin and thick case. From our analysis we learned that:

1. For disks with alpha > 2, the optically thin disk models can explain the observed fluxes with grain sizes of $a > 1mm$
2. For disks with $\alpha < 2$, optically thick disk models can explain the observed fluxes with largest grains of size of $a \sim 10cm$
3. As the optical depth of the disk increases, the spectral index decreases and the results differentiate between scattering models and non scattering models

The presence of grains as large as $a \sim 1$cm in these disk show that dust trapping is still efficient during the whole disk life-time. The presences of local dust traps imply that these disks have the potential to form new large solids, including possibly planets, until the end of their life.

7. References

[1] Barenfeld, S.A et al. 2016, ApJ, 827, 142

[2] Ricci, L. et al. 2010, A&A, 512, 15

[3] Zhu, Z. et al. 2019, ApJ, 877, 18