Porous grains in protoplanetary disks

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1. Why porous grains?

Our study is motivated by observations and laboratory studies which indicate that dust particles in various astrophysical environments are porous. We focus on the specific case of protoplanetary disks where we investigate the impact of grain porosity on the **temperature distribution**, **spectral energy distributions**, and **spatially resolved intensity and polarization maps**. For this purpose we apply the radiative transfer software MC3D (Wolf et al. 1999, Wolf 2003) to compare the observational quantities resulting from disks consisting of compact spheres or porous dust grains.

2. Model setup

Disk model

Parameterized dust density distribution (Shakura & Sunyaev 1973): $\rho(r,z) \sim \left(\frac{r_0}{r}\right)^{\alpha} \exp\left(-\frac{1}{2}\left[\frac{z}{h_0}\left(\frac{r_0}{r}\right)^{\beta}\right]^2\right)$

α	β	h_0	r_0	$M_{\text{gas}}/M_{\text{dust}}$
2.625	1.125	10 AU	100 AU	100

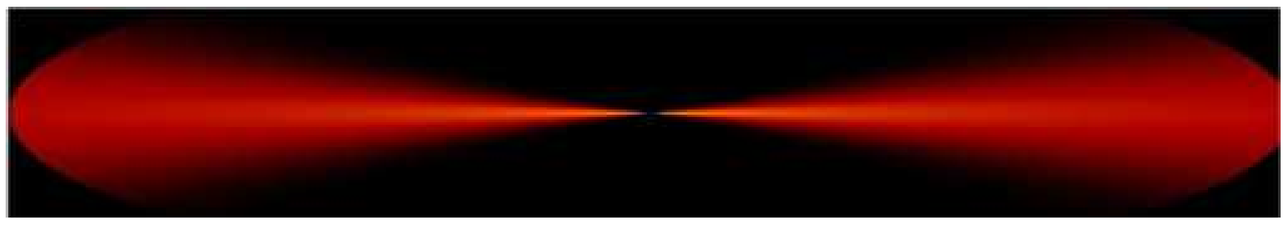
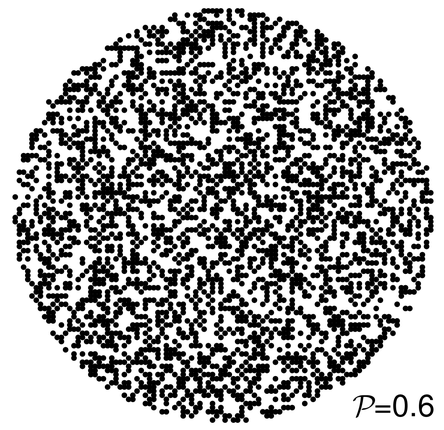


Figure 1: Density distribution of a flared disk, perpendicular to the disk midplane.

Dust model

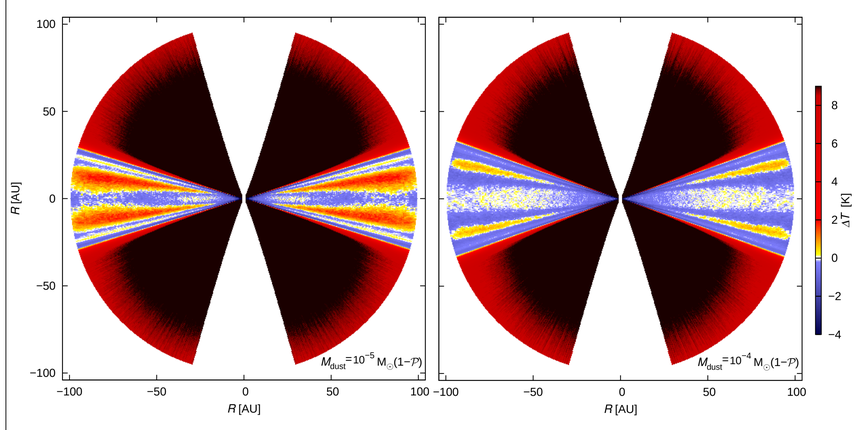


- Program DDSCAT (Draine & Flatau 1994, 2010) to calculate the scattering and absorption cross sections of irregular particles (discrete dipole approximation)
- Basic particle shape: Spherical (radius a); Porosity $\mathcal{P} = V_{\text{vacuum}}/V_{\text{total}}$
- Chemical composition: Astronomical silicate (Draine 2003a,b)

Figure 2: Slice through the midplane of a particle with porosity $\mathcal{P} = 0.6$ (Kirchschlager & Wolf 2013).

3. Results

Temperature distribution



Is there a difference in the temperature distribution perpendicular to the midplane for compact and porous dust grains (Fig. 3)? **Yes!**

Figure 3: Absolute temperature differences $T_{\mathcal{P}=0.0} - T_{\mathcal{P}=0.6}$

- $T_{\mathcal{P}=0.0} > T_{\mathcal{P}=0.6}$ in the optically thin, upper disk region and in selected regions close to the midplane;
- $T_{\mathcal{P}=0.0} < T_{\mathcal{P}=0.6}$ near the central star, at the optically thin/ thick transition region and around the midplane;
- Impact of different porosities on location of this transition region is low.

SED and scattering maps

What is the impact of porous grains on the observational appearance of circumstellar disks seen in nearly edge on orientation (Figs. 4, 5)?

Figure 4: SED of a disk with compact or porous dust grains

- Scattered flux at $\lambda \sim 1{-}10\,\mu\text{m}$ increased for disks with porous dust particles
- Silicate absorption feature is less pronounced

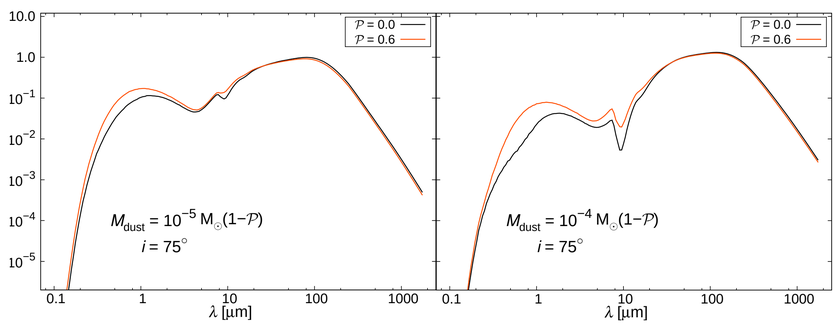
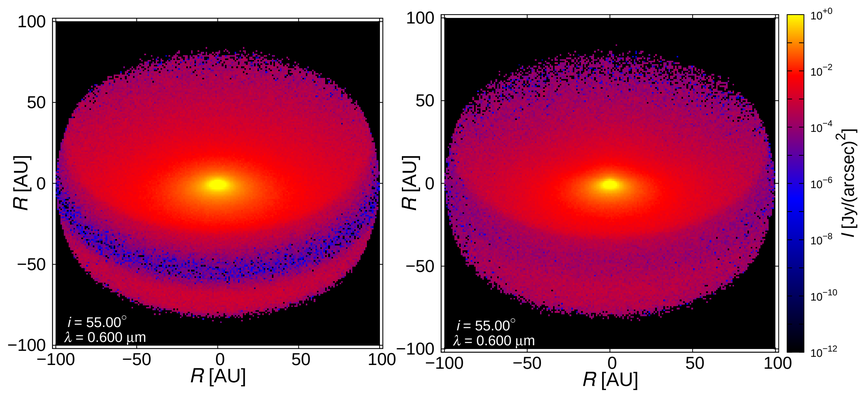


Figure 5: Significantly different scattered light images of a disk with compact (left) and porous ($\mathcal{P} = 0.6$, right) dust grains

- Dark lane is less pronounced



Polarization maps and reversal

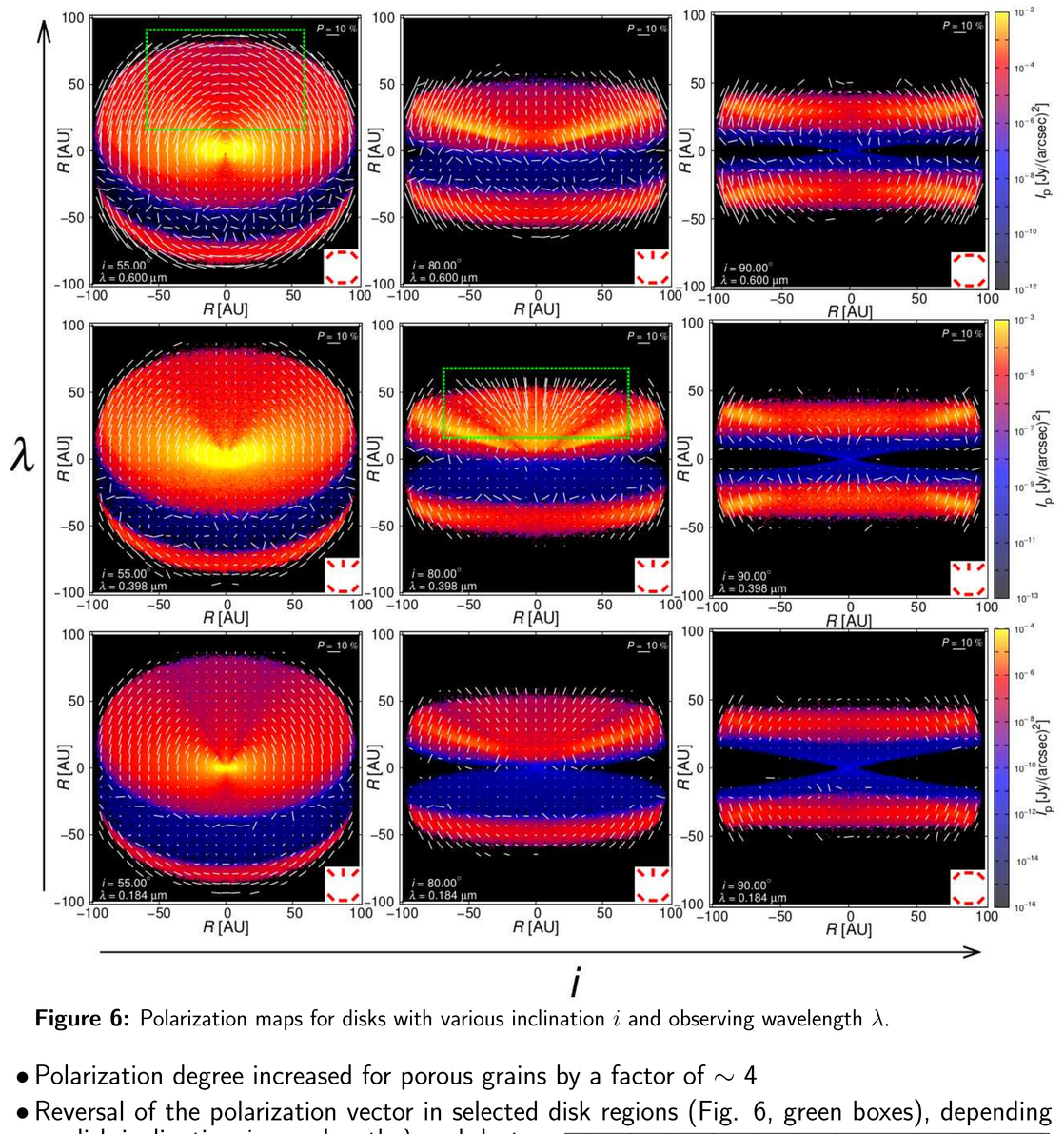
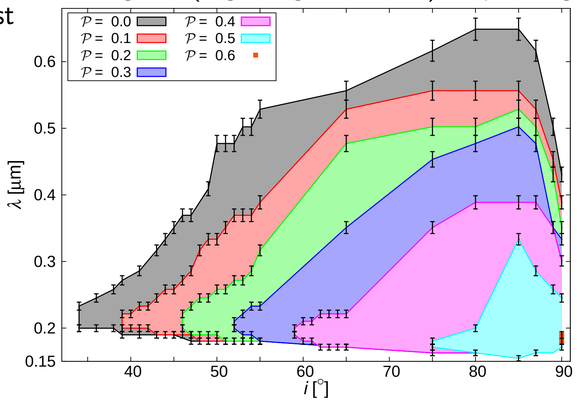


Figure 6: Polarization maps for disks with various inclination i and observing wavelength λ.

- Polarization degree increased for porous grains by a factor of ~ 4
- Reversal of the polarization vector in selected disk regions (Fig. 6, green boxes), depending on disk inclination i, wavelength λ and dust porosity $\mathcal{P}$ (Fig. 7)
- Polarization reversal may provide an observational test for porous dust grains in circumstellar disk

Figure 7: Wavelengths at which the polarization vector in selected disk regions is radially aligned. The effect depends on the disk inclination i and dust porosity $\mathcal{P}$. The effect occurs in the black colored area only for compact spheres, in the red colored area for grains with porosity $\mathcal{P} \leq 0.1$, etc..



References

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Please, see *Kirchschlager & Wolf, 2014 (accepted to A&A)* for further details.
The author of this poster is around and happy to answer any question!