Porous dust grains in circumstellar disks

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1. Introduction

We investigate the impact of porous dust grains on the structure and observable appearance in circumstellar disks. Our study is motivated by observations and laboratory studies which indicate that particles in various astrophysical environments are porous. In addition, the modeling of the spatial structure and grain size distribution of debris disks reveals that under the assumption of spherical compact grains the resulting minimum grain size is often significantly larger than the blowout size, which might be a hint for porosity. Since the structure and observable appearance of the disks depend on the optical properties of the dust grains, we determine the scattering and absorption parameters of porous particles as a function of porosity, wavelength and grain size (radiative transfer: `MC3D`; Wolf et al. 1999, Wolf 2003).

2. Disk and dust grain 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	$M_\text{gas}/M_\text{dust}$	M_dust
2.625	1.125	10 AU	100 AU	100	$10^{-6}\,\mathrm{M}_\odot\,(1-\mathcal{P})$

- 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)

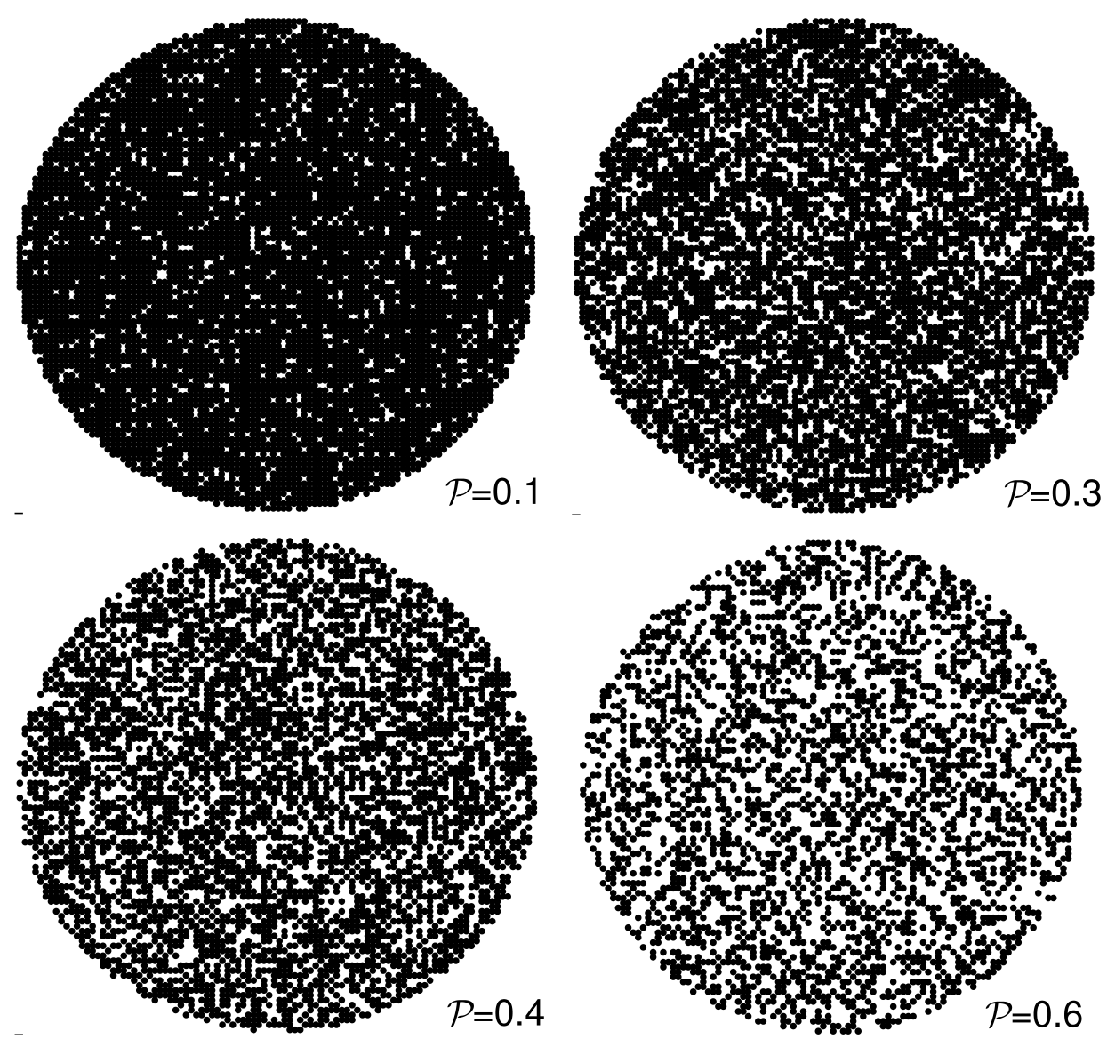

Figure 1: Slice through the midplane of particles with porosities $\mathcal{P} = 0.1$ to $\mathcal{P} = 0.6$ (*Kirchschlager & Wolf 2013*)

3. 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. 2, 3)?

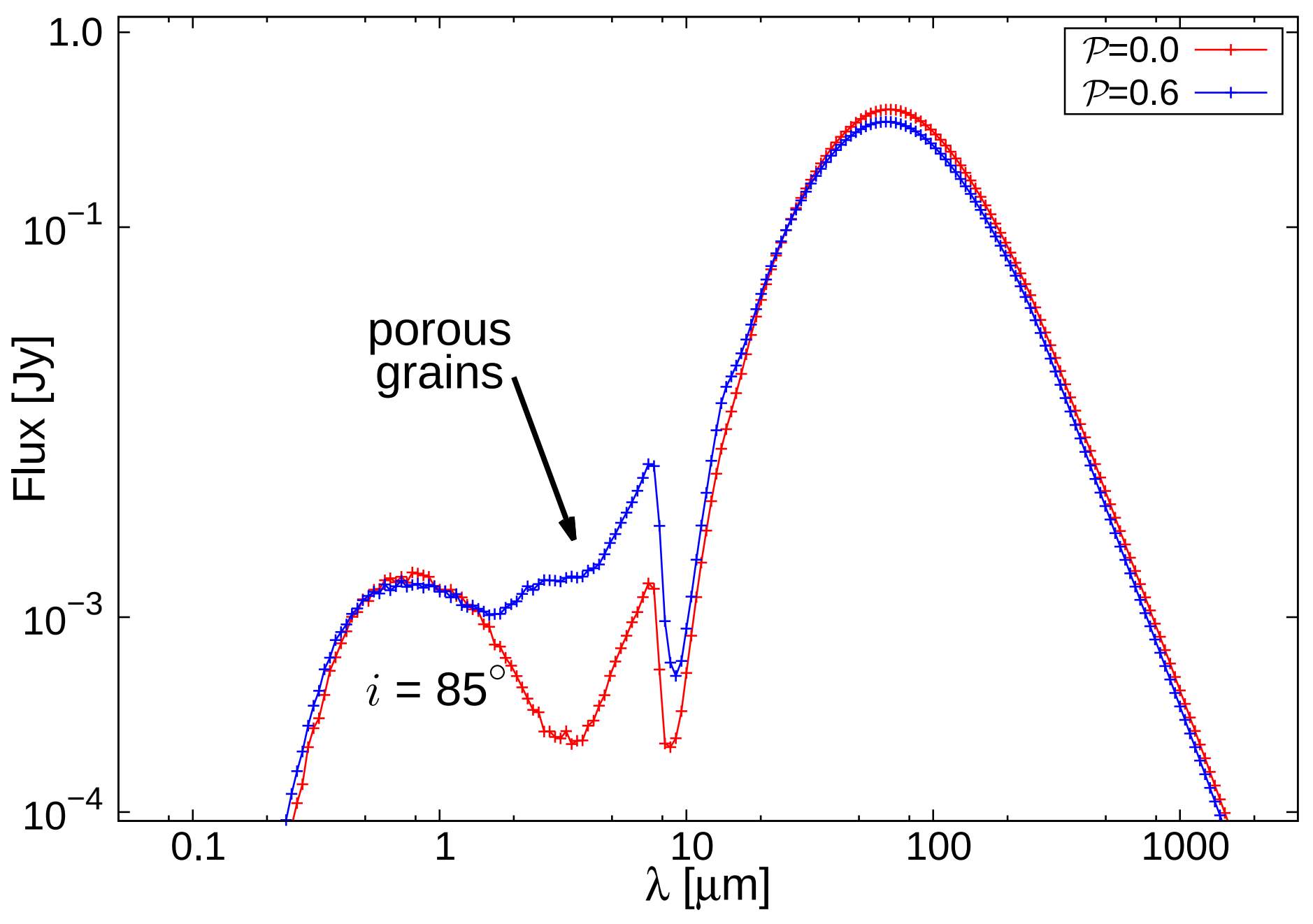

Figure 2: SED of a disk with compact ($\mathcal{P} = 0.0$) or porous ($\mathcal{P} = 0.6$) dust grains; Scattered flux at $\lambda \sim 1-10\,\mu$m increased for disks with porous dust particles; Silicate absorption feature is more pronounced

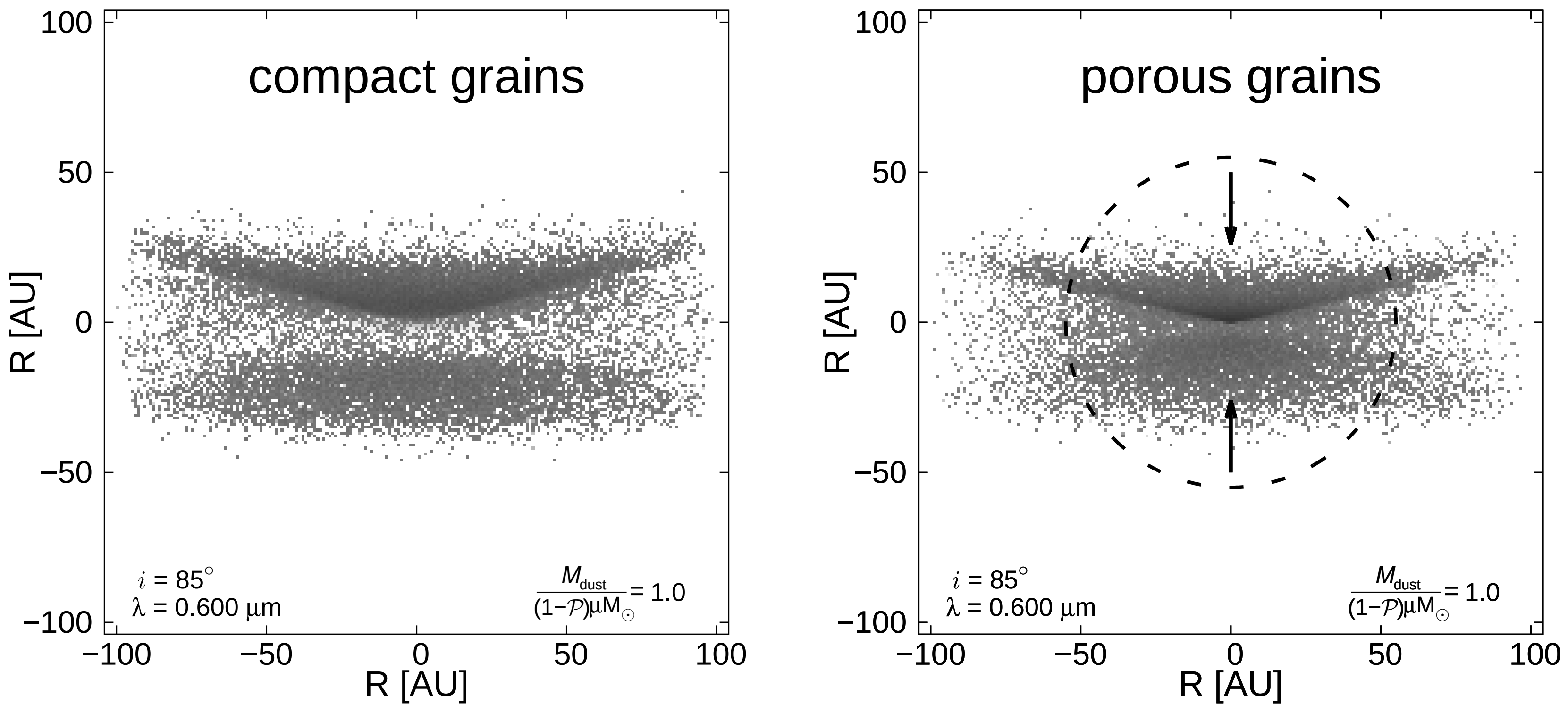

Figure 3: Significantly different scattered light images of a disk with compact (left) and porous ($\mathcal{P} = 0.6$, right) dust grains

4. Temperature distribution

Is there a difference in the temperature distribution perpendicular to the disk midplane for compact and porous dust grains (Fig. 4)?

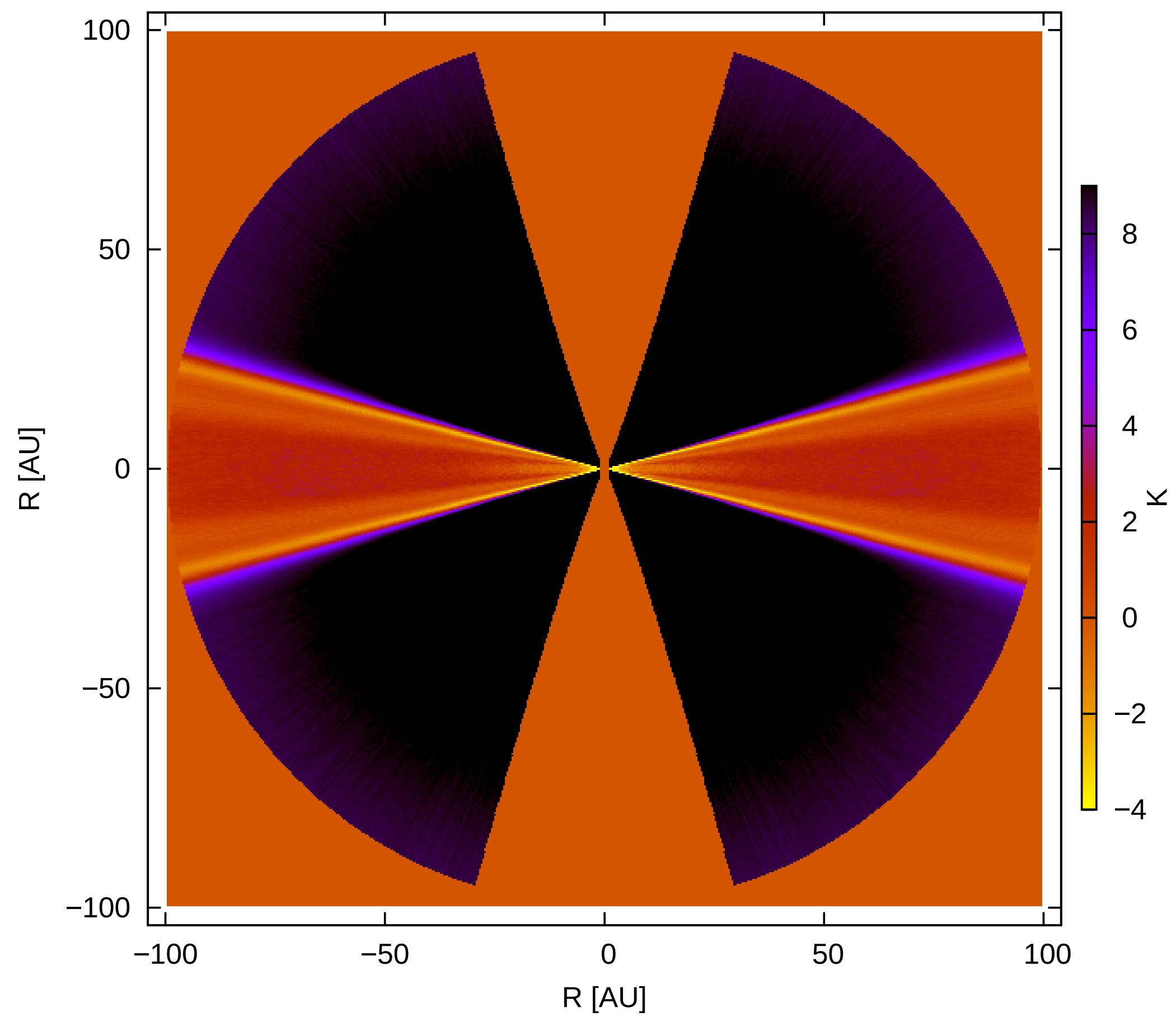

Figure 4: Absolute temperature differences $T_{\mathcal{P}=0.0} - T_{\mathcal{P}=0.6}$; $T_{\mathcal{P}=0.0} > T_{\mathcal{P}=0.6}$ in the optically thin disk region and in the optically thick, innermost regions; $T_{\mathcal{P}=0.0} < T_{\mathcal{P}=0.6}$ only in the region near the central star and at the optically thin/ thick transition region; Impact of different porosities on location of this transition region is low

5. Polarization maps

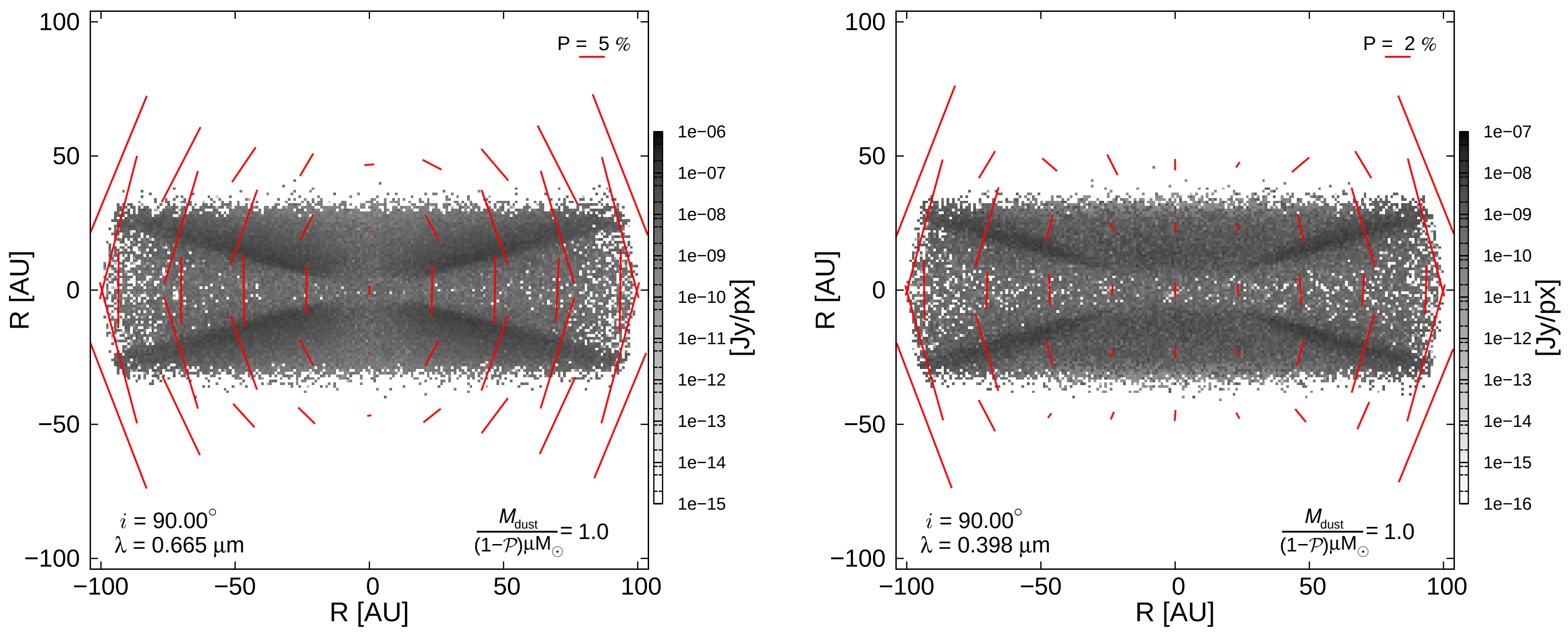

Figure 5: Wavelength-dependent polarization maps, Left: Polarization pattern rotationally symmetric as usual for large wavelengths ($\lambda > 0.6\,\mu$m), Right: Polarization vector rotated by 90° for decreasing λ

- Reversal of the polarization vector in selected disk regions detected (Fig. 5)
- Effect depends on disk inclination i and dust porosity $\mathcal{P}$ (Fig. 6)
- Polarization reversal may set an observational test for porous dust grains in circumstellar disks

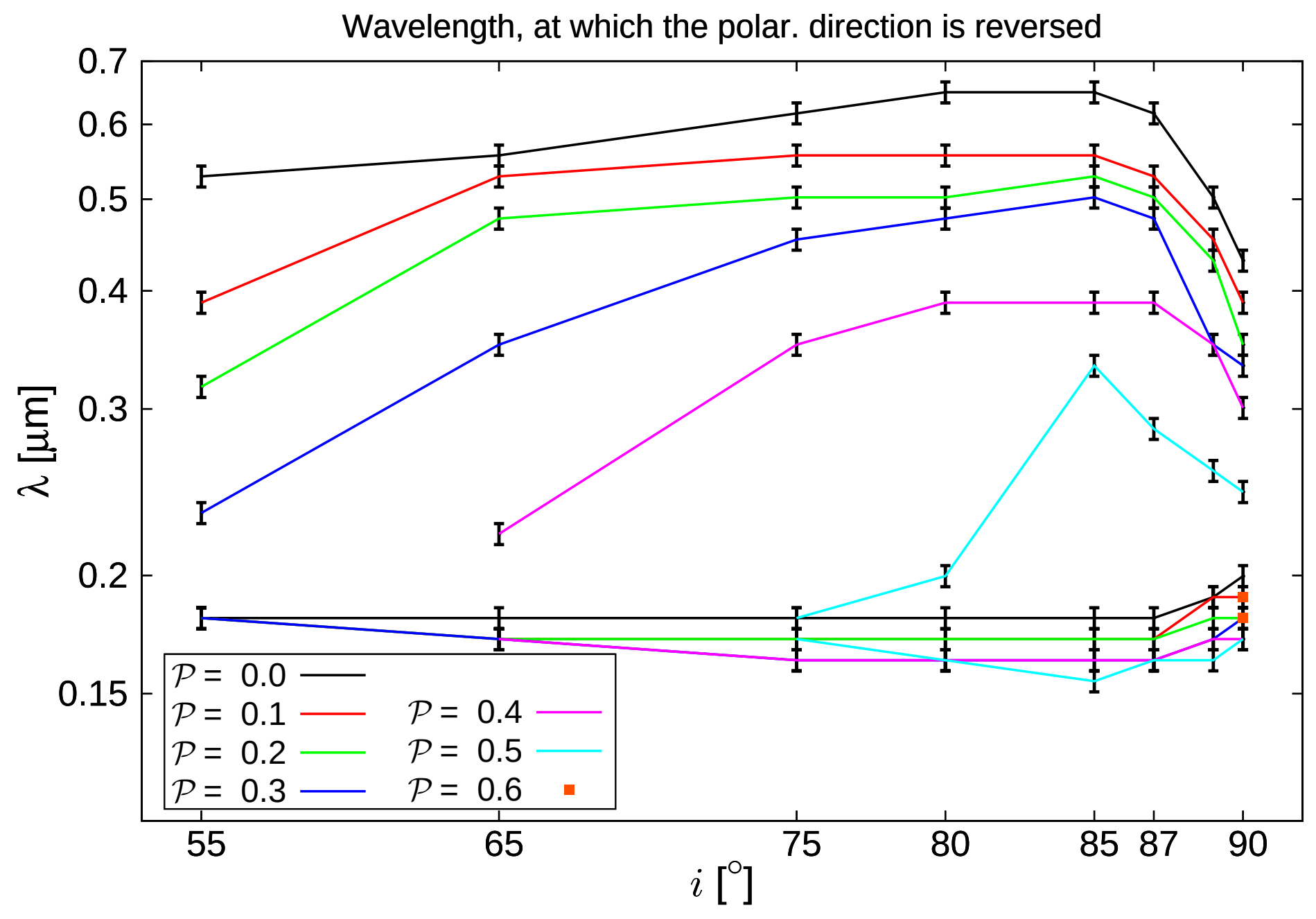

Figure 6: Polarization reversal as a function of disk inclination i and dust porosity $\mathcal{P}$; Polarization vector turns back again for lower wavelengths ($\lambda \sim 0.2\,\mu$m)

6. Blowout size as a function of porosity and stellar temperature

- Blowout size a_BO: Minimum grain radius in an optically thin disk (debris disk)
- Calculations performed for various numbers of dipoles N (see Fig. 7)
- Approximation equation to estimate the blowout size as a function of porosity and temperature can be derived:

$$a_\text{BO}(\mathcal{P},\,T_*) = (k_1\,T_* + k_2)\mathcal{P}^{\alpha} + (k_3\,T_* + k_4)\,,$$

$$k_1 = 5.07\cdot 10^{-3}\,\frac{\mu\text{m}}{K},\quad k_2 = -28.85\,\mu\text{m},$$

$$k_3 = 7.01\cdot 10^{-4}\,\frac{\mu\text{m}}{K},\quad k_4 = -3.65\,\mu\text{m},$$

$$\alpha = 1.781 - \frac{61.72\,\text{K}}{T_* - 5670\,\text{K}}.$$

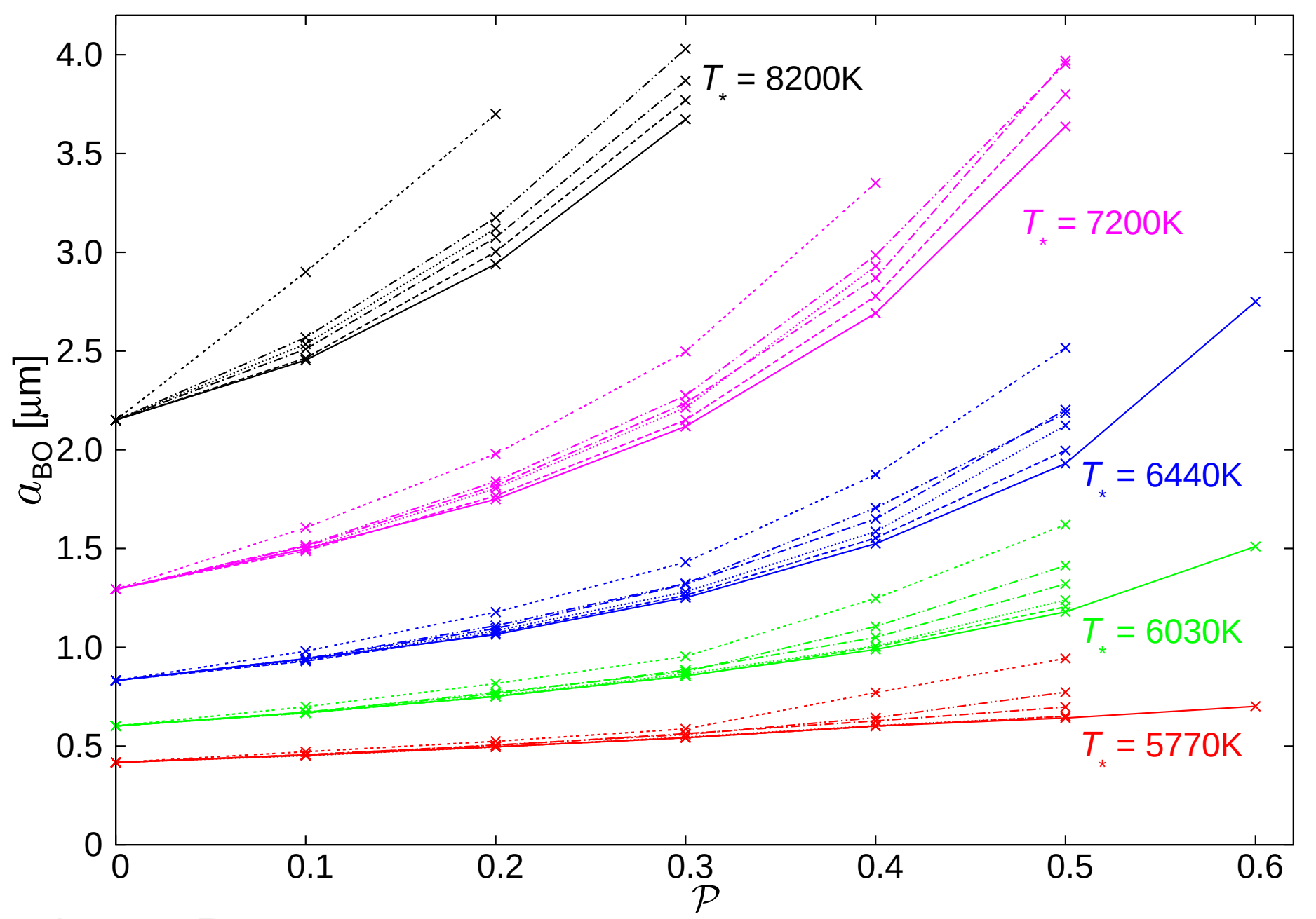

Figure 7: Blowout size a_BO increases both with porosity $\mathcal{P}$ and with stellar temperature T_* (*Kirchschlager & Wolf 2013*)

- Online tool for a_BO for porous grains available at *http://www1.astrophysik.uni-kiel.de/blowout/*

7. Equilibrium temperature of porous dust grains

What is the impact of porosity on the dust temperature in an optically thin disk, where grains are only heated by direct stellar radiation (Fig. 8)?

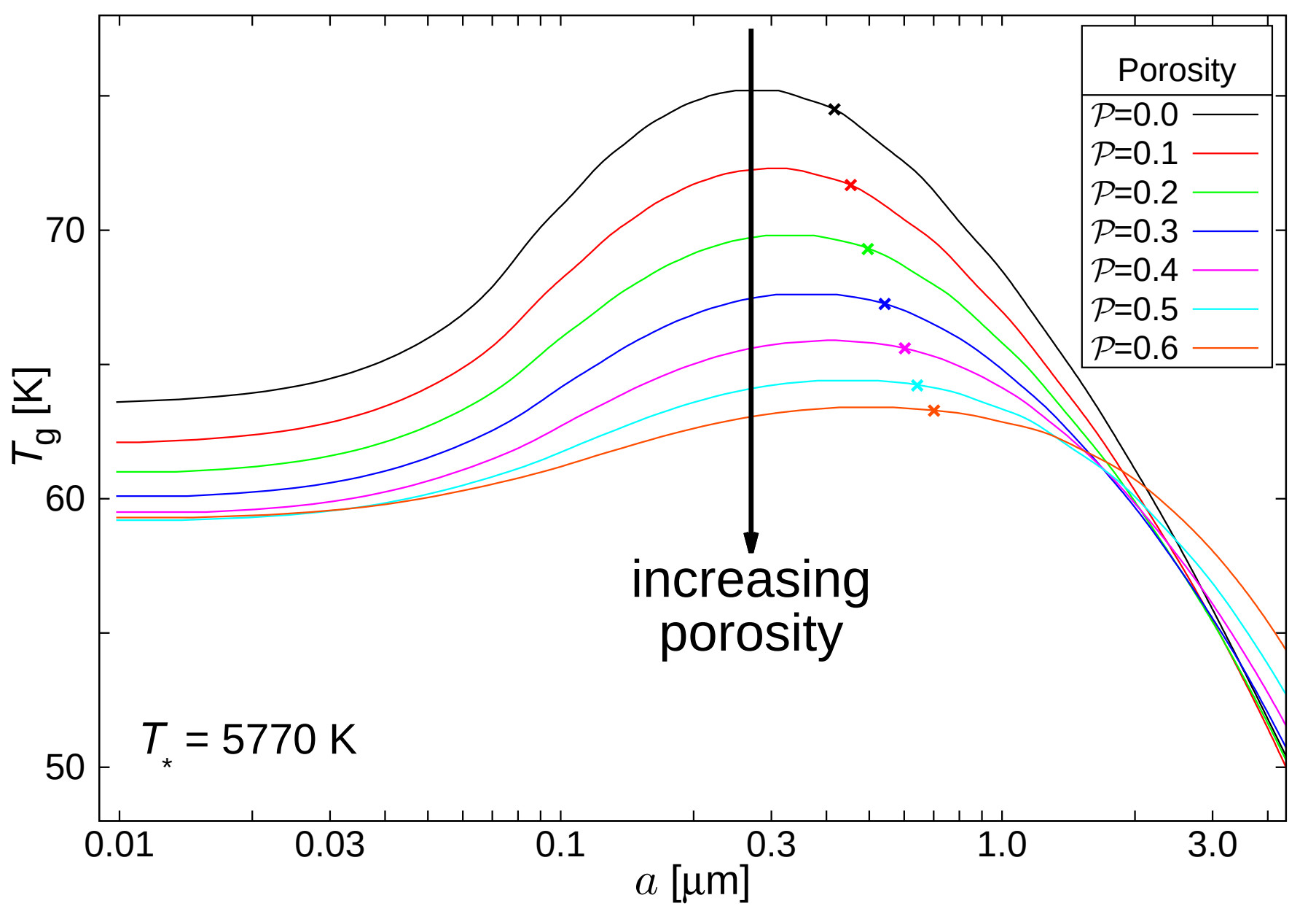

Figure 8: Dust equilibrium temperature T_g at the distance of 50 AU from a star with effective temperature $T_* = 5770\,$K, depending on grain radius a and porosity $\mathcal{P}$; Blowout sizes marked as crosses; Dust temperatures of porous particles are lower than for compact particles; Maximum temperature shifts with increasing porosity to larger radii *(Kirchschlager & Wolf 2013)*

References

Draine, B. T. 2003a, APJ, 598, 1017; Draine, B. T. 2003b, APJ, 598, 1026; Draine, B. T. & Flatau, P. J. 1994, JOSA A, 11, 1491; Draine, B. T. & Flatau, P. J. 2010, ArXiv; Shakura, N. I. & Sunyaev, R. A. 1973, A&A, 11, 1491; Wolf, S. and Henning, T. and Stecklum, B. 1999, A&A, 24, 337; Wolf, S. 2003, CPC, 150, 99

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Please, see *Kirchschlager & Wolf 2013, A&A, 552, A54* for further details.
The author of this poster is around and happy to answer any question!