Constraining dust grain porosity via debris disk observations

Robert Brunngräber[1], Sebastian Wolf[1],
Florian Kirchschlager[1,2] & Steve Ertel[3]

[1]ITAP, Christian-Albrechts-Universität, Leibnizstraße 15, 24118 Kiel, Germany
[2]Department of Physics and Astronomy, University College London, UK
[3]Steward Observatory, University of Arizona, Tucson, USA

contact: rbrunngraeber@astrophysik.uni-kiel.de

Astrophysik Kiel

C A U
Christian-Albrechts-Universität zu Kiel
Mathematisch-Naturwissenschaftliche Fakultät

Introduction

In the analysis of debris disk observations dust grains are often considered as homogeneous, compact spheres, although it is expected that dust particles possess complex, irregular shapes and inclusions of various materials and voids. In addition, recent studies based on high-contrast, high-resolution imaging polarimetry show that the measured data cannot be reproduced by compact, spherical dust grains. Usually, only very weak constraints on the dust grain properties can be derived directly. Our goals:

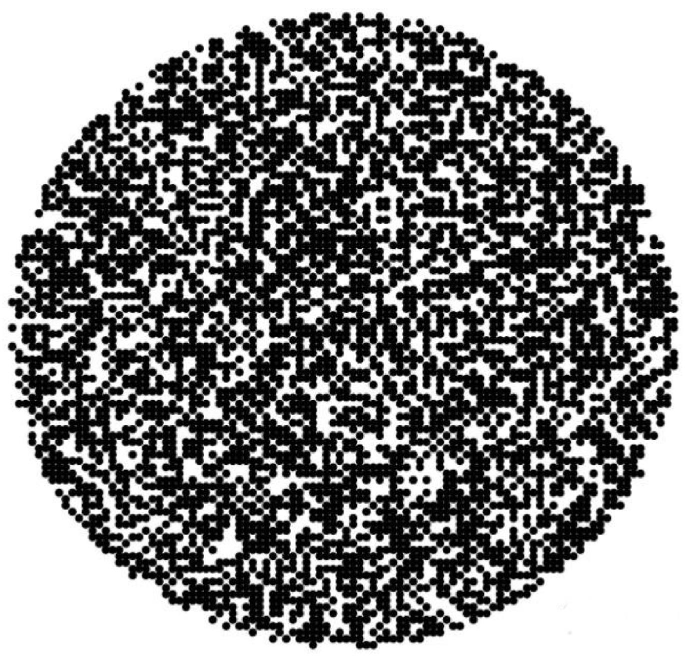
- **Calculation of the blowout size of porous grains**
- **Deriving an approximation function for the blowout size**
- **Investigation of the effect of porosity on disk modelling results**

Porous dust: Model

- Silicate dust grains with spherical shape and voids
- Porosity $\mathcal{P}$ defines volume fraction of vacuum
- Parameter space: $\mathcal{P} = 0.0$ .. 0.9 ($\Delta = 0.1$)
- Effective medium theory with Bruggeman mixing rule

$$(1-\mathcal{P})\frac{\varepsilon_{\text{astrosil}}-\varepsilon_{\text{eff}}}{\varepsilon_{\text{astrosil}}+2\varepsilon_{\text{eff}}}+\mathcal{P}\frac{\varepsilon_{\text{vacuum}}-\varepsilon_{\text{eff}}}{\varepsilon_{\text{vacuum}}+2\varepsilon_{\text{eff}}}=0$$

- Optical cross sections and asymmetry factor g calculated with MIEX (Wolf and Voshchinnikov, 2004)



Cut through dust grain with $\mathcal{P} = 0.4$; from Kirchschlager and Wolf (2013)

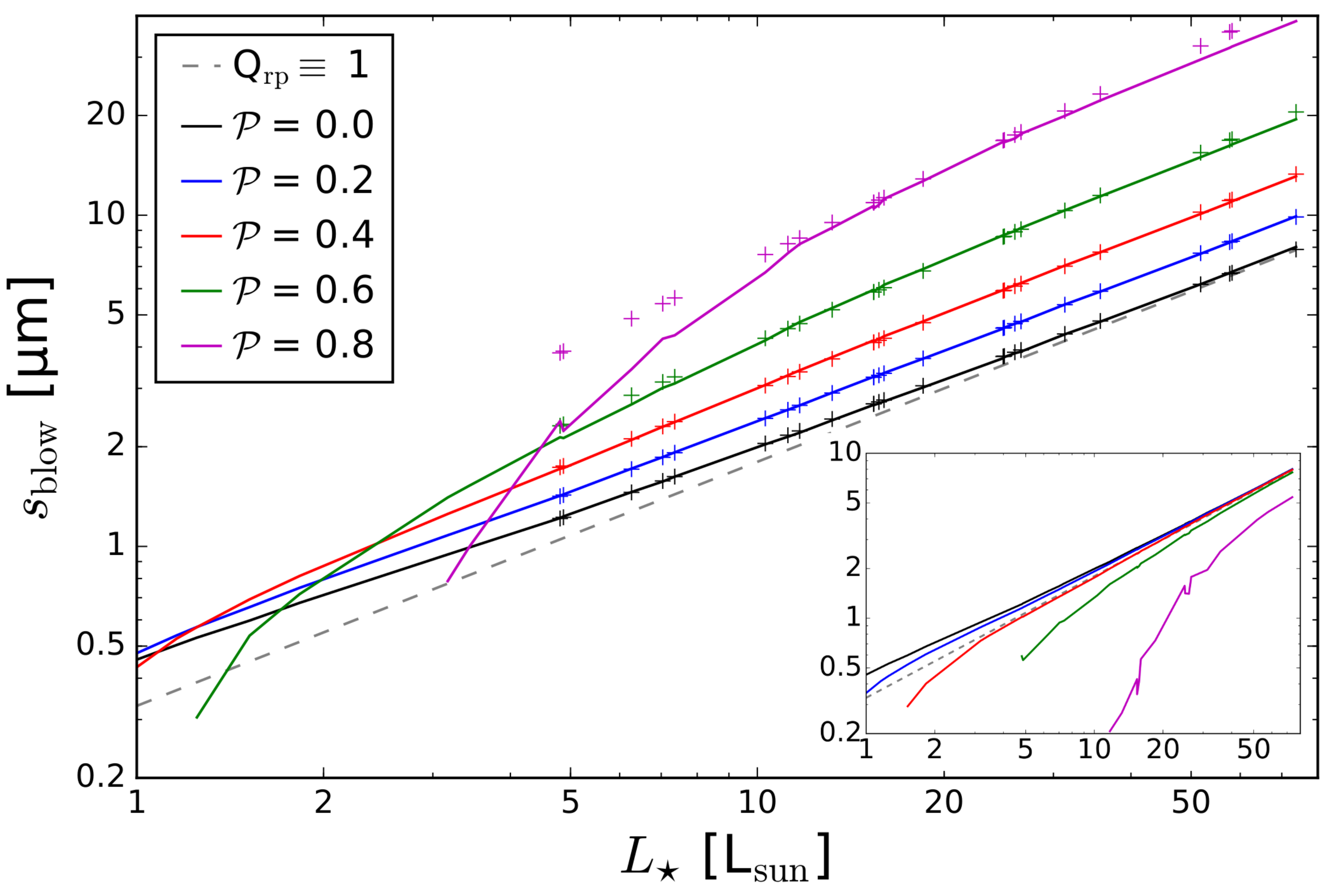
Blowout size

- Radiation pressure F_{rp} reduces gravitational attraction F_{grav}
- If $\frac{F_{\text{rp}}}{F_{\text{grav}}} = \beta \geq 0.5$: particles are removed by radiation pressure
- Blowout size s_{blow}: Grain radius radius for which $\beta = 0.5$

Analytical approximation function

$$\frac{s_{\text{blow}}}{1\,\mu\text{m}} = \left(\frac{3.5\,\text{g cm}^{-3}}{\varrho}\right) a_1 (1-\mathcal{P})^{b_1} \cdot \left(\frac{L_\star}{\text{L}_\odot}\right)^{a_2 (1-\mathcal{P})^{b_2}} \quad \text{with}$$

$a_1 = 0.414 \pm 0.004$
$b_1 = -0.508 \pm 0.025$
$a_2 = 0.685 \pm 0.002$
$b_2 = -0.168 \pm 0.008$



Blowout size s_{blow} as a function of stellar luminosity for different porosities $\mathcal{P}$. The crosses show results of the analytical approximation function.

Questions? I am somewhere close by, **feel free to ask!**

Porosity influences modelling results

Procedure

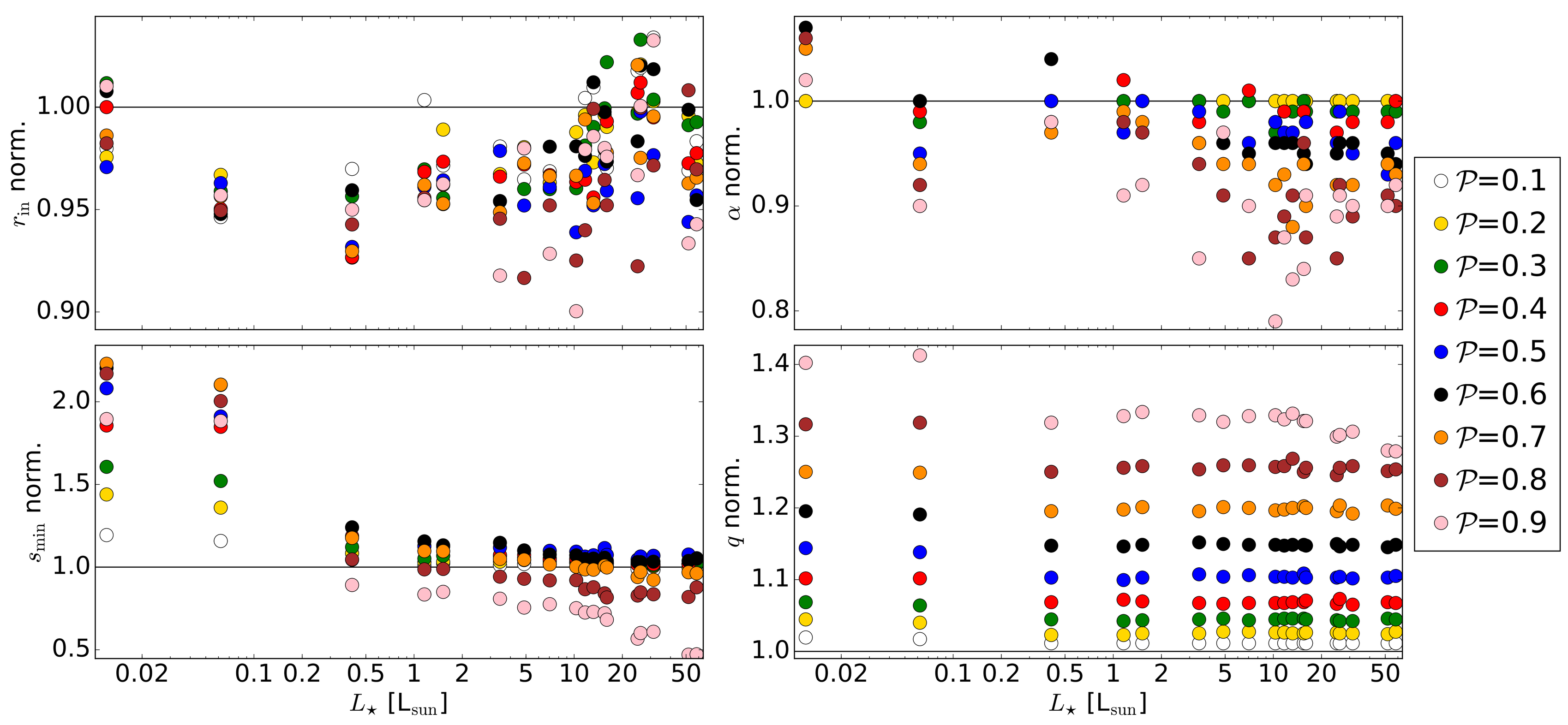
1. Calculation of the re-emission SED and images of an analytical dust distribution for different porosities $\mathcal{P}$,
2. Convolution of the images with a circular Gaussian to mimic a real observation; Extraction of radial profiles; Superposition of artificial uncertainties (noise),
3. Fitting of the SED and profiles with the debris disk fitting software `SAnD` (Ertel et al., 2012) assuming compact dust grains, i.e. $\mathcal{P} \equiv 0.0$,
4. Comparison of the fit results of the different porosities with the initial, i.e. correct values.

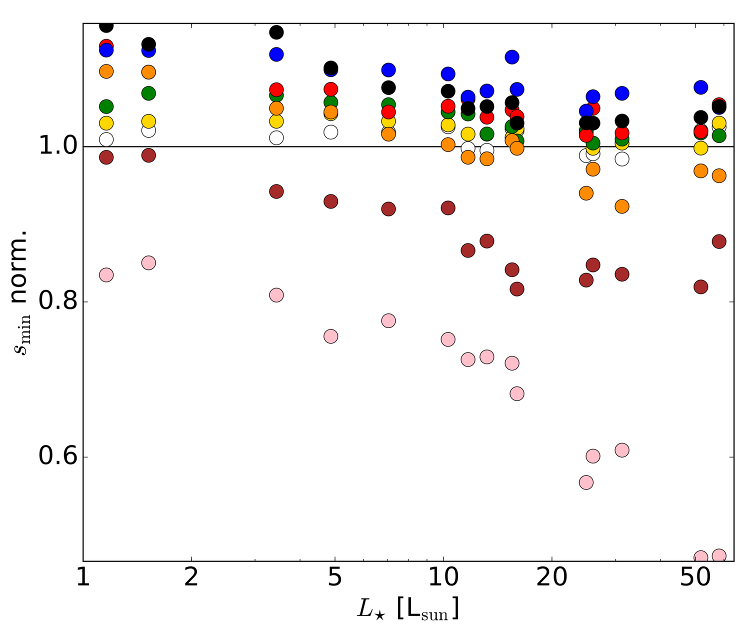
Density and size distribution

- $n(s) \propto s^{-q}$, where $n \cdot \mathrm{d}s$ is the number of particles in radius intervall $[s, s+\mathrm{d}s]$
- $r^{-\alpha}$, geometrically thin disk

Disk parameter	Sim. observation	FITTING Min.	Max.	n
M_{dust} [$\text{M}_\odot$]	10^{-6}	scaled to fit SED best		1
R_{in} [au]	40	5	60	2158
R_{out} [au]	200	100	500	1398
α	1	-1	3	80
s_{min} [µm]	3.73	0.1	10	403
s_{max} [µm]	1000	1000	1000	1
q	3.5	2	5	150
Inclination i [°]	0	0	0	1
Porosity $\mathcal{P}$	0.0 – 0.9	0.0	0.0	1

Results





- No porosity in fit process: Overestimation of slope q of the grain size distribution by up to 40 % and the minimum grain size s_{min} by up to 230 % for dim stars.
- Minimum grain size: smaller (50%) or larger (240%) than value derived from the analysis (luminosity and porosity dependent)

Conclusions

- Analytical expression for blowout size s_{blow} as function of stellar luminosity and porosity
- High porosities: Blowout size s_{blow} increases (factor 1.4 to 5, luminosity dependent)
- The higher the porosities, the lower $\beta = \frac{F_{\text{rp}}}{F_{\text{grav}}}$
- Grain size distribution and minimum grain size strongly depend on porosity

References

Brunngräber, R., S. Wolf, F. Kirchschlager, and S. Ertel (2017). **The influence of dust grain porosity on the analysis of debris disc observations**. In: *Monthly Notices of the Royal Astronomical Society* 464.

Ertel, S. et al. (2012). **A peculiar class of debris disks from Herschel/DUNES. A steep fall off in the far infrared**. In: *Astronomy and Astrophysics* 541.

Kirchschlager, F. and S. Wolf (2013). **Porous dust grains in debris disks**. In: *Astronomy and Astrophysics* 552.

Wolf, S. and N. V. Voshchinnikov (2004). **Mie scattering by ensembles of particles with very large size parameters**. In: *Computer Physics Communications* 162.

Acknowledgement: DFG grants WO 857/13-1 and WO 857/15-1