Characterising Dust Properties in Protoplanetary Disks with Quantitative Polarimetry

J. MA [1], H. M. SCHMID [1] and C. TSCHUDI [1]

1ETH Zurich, Institute for Particle physics and Astrophysics, Zurich, Switzerland

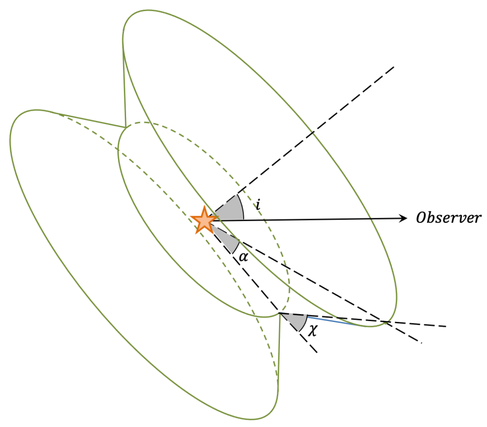
Contact: jma@phys.ethz.ch

Introduction & Aim

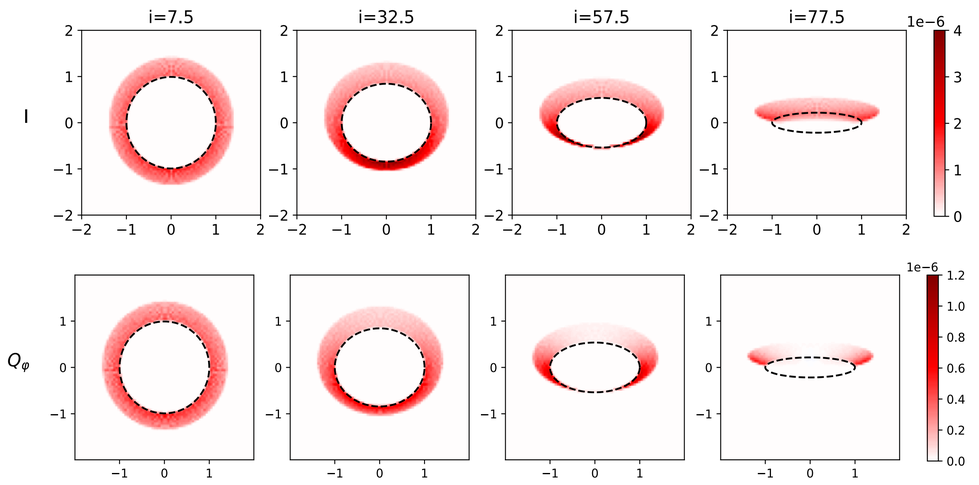
The dust in protoplanetary disks is an important ingredient in planet formation. The polarised scattered light images of circumstellar disks are essential to better understand the dust evolution and to constrain the composition of the forming planet. Many disks have been well-resolved with Polarimetric Differential Imaging (PDI) using AO instruments at large ground-based telescopes, e.g. VLT, Gemini and Subaru. Simulations reproduce well the various disk morphologies, however much fewer studies have been carried out on the characterisation of the dust properties based on quantitative measurements of the scattered light.

- We present a simplified disk model with 3 disk geometric parameters and 3 dust scattering parameters and investigate the diagnostic observational parameters to determine the dust scattering properties.
- The diagnostic parameters are then applied to RXJ1604 observations. Accurate quantitative measurements are performed to analyse the dust properties.
- Integrated polarised flux measurements were obtained for eleven selected circumstellar disks observed by SPHERE at multi-wavelength. The systematic study of disk colors and system parameters can constrain the dust evolution process.

Model Grid for the reflected light from transition disks[1]



Sketch of the inner wall of transition disk.



Examples of intensity I and polarisation Q_φ images for four inclinations i for the 0.5-reference model ($\omega = 0.5, g = 0.5, p_{max} = 0.5, \alpha = 10°, \chi = 32.5°$)

Geometric parameters:

- inclination i
- constant wall slope χ
- angular wall height α

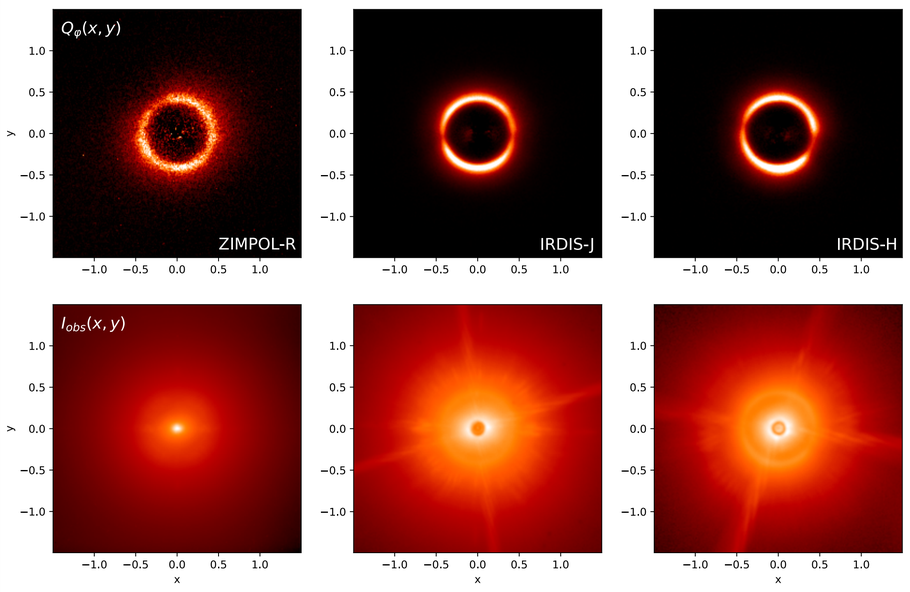
Dust scattering parameters:

- single scattering albedo ω
- scattering asymmetry g
- maximal polarisation p_{max}

We studied the dependencies of observable radiation on model parameters and find particularly strong constraints for the scattered radiation disk properties from certain diagnostic quantities:

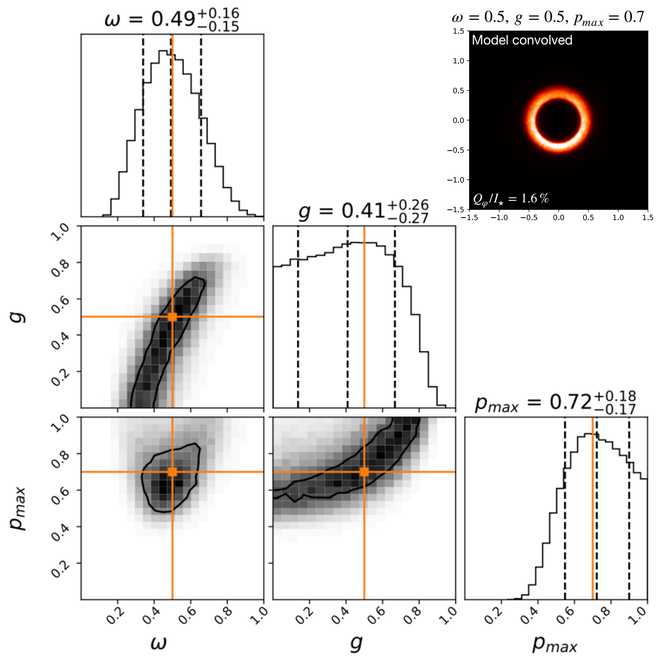
- The fractional polarisation depend predominantly on the dust scattering parameters ω and p_{max};
- For disks with well-defined inclination, the front-to-back brightness asymmetry depend mainly on the dust scattering asymmetry parameter g and the wall slope χ;
- Wavelength dependencies of integrated intensity and polarised intensity can mostly be attributed to the wavelength dependence of the dust scattering parameter $\omega(\lambda)$, $g(\lambda)$, and $p_{max}(\lambda)$

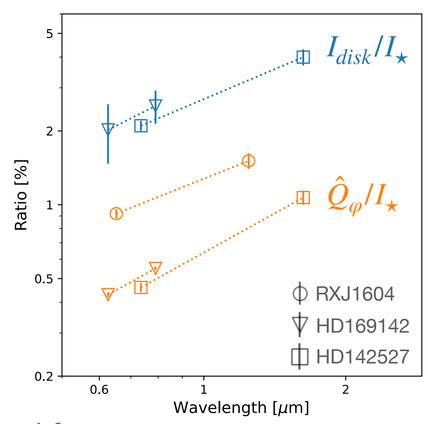
Quantitative polarimetry for RX J1604 transition disk[2]

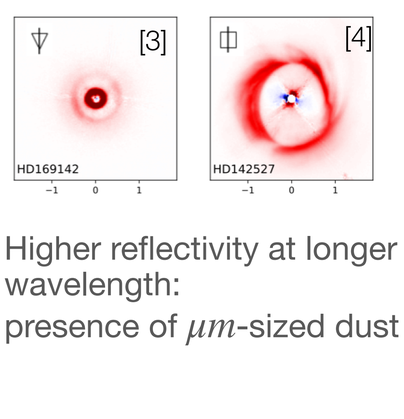


The bright axisymmetric disk of RX J1604 is well-suited as a benchmark object for accurate photo-polarimetric measurements.
We correct for the smearing effect and measure the integrated flux, polarised flux, and fractional polarisation for different wavelengths in the transition disk RX J1604.

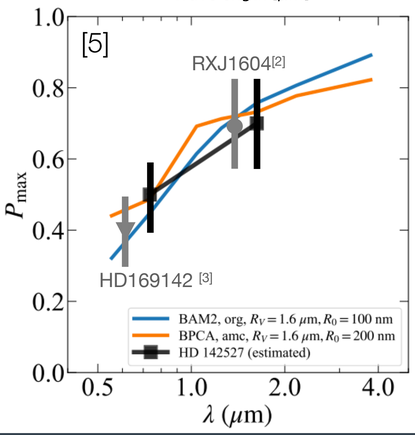
	$I_{disk}/I_\star$[%]	$Q_\varphi/I_\star$[%]	p_{disk}[%]
R (0.652μm)	-	0.92 ± 0.04	-
J (1.245μm)	3.9 ± 0.5	1.51 ± 0.11	38 ± 4
H (1.625μm)	3.8 ± 0.8	1.52 ± 0.45	42 ± 2

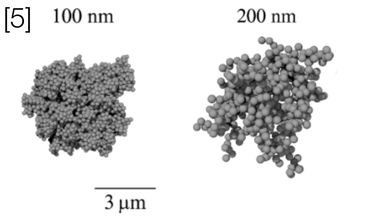






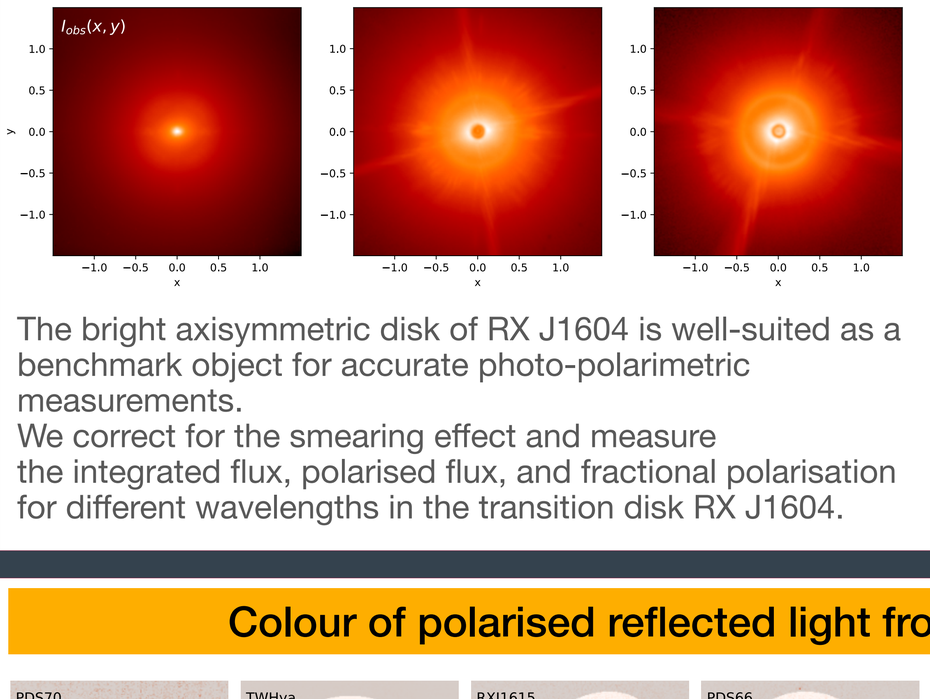
Higher reflectivity at longer wavelength:
presence of μm-sized dust





Degree of polarisation>20%: hints of porosity and monomer sizes

Colour of polarised reflected light from transition disks[6]



We selected eleven circumstellar disks that were observed with both the visual ZIMPOL and the near-IR IRDIS instruments to facilitate a multi-wavelength analysis.
We applied an approximate correction procedure for the PSF convolution effect in our measurement.

We measured seven disks with red colour and four disks with grey colour. The colour is correlated with stellar irradiation and system age, indicating the dust evolution processes in the disks.

Conclusions

- We demonstrate the potential of accurate photo-polarimetric measurements of protoplanetary disks for the determination of dust scattering parameters that constrain strongly the physical properties of the dust.
- The derived scattering parameters support the possible presence of micron-sized dust aggregates in agreement with dust coagulation.
- More such data for the dust in different types of disks need to be collected to test the existing dust aggregate models and better understand the dust evolution and the planet formation process.

Key references

[1] Ma, J., Schmid, H. M., 2022, A&A, 663, A110
[2] Ma, J., Schmid, H.M., Tschudi, C., 2023, submitted
[3] Hunziker, S., Schmid, H. M., Ma, J., et al. 2021, A&A, 648, A110
[4] Tschudi, C., Schmid, H. M. 2021, A&A, 655, A37
[5] Tazaki, R., Dominik, C. 2022, A&A, 663, A57
[6] Ma, J. et al., in prep

This work has been carried out within the frame of the National Centre for Competence in Research PlanetS supported by the Swiss National Science Foundation (SNSF). The data were taken with the VLT/SPHERE ZIMPOL and IRDIS of the European Southern Observatory (ESO) and retrieved from the ESO archive.