The color of the reflecting dust in the circumstellar disk HD 142527

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INTRODUCTION

Protoplanetary disks are considered to be the places where planet formation occurs around young pre-main-sequence stars. The disks initially consist of a mixture of gas and submicron-sized dust particles. The analysis of the dust constituents and dust evolution mechanisms in young stellar environments is therefore vital for our understanding of planet formation. One way of constraining the dust properties is through the optical properties of the reflected light. A few studies in the past have used direct imaging of circumstellar disks to determine optical properties. Transition disks are well suited for scattered-light observations because they usually feature a dust-depleted inner cavity between the star and the inner disk wall. This results in a bright illuminated inner disk wall at a large enough distance from the star so that it can be observed in nearby star-forming regions. HD142527 has a very large inner cavity, its brightness and size make it exceptionally well suited for scattered-light observations.

AIM

We present high-precision photometry and polarimetry based on visual and near-infrared imaging data for the protoplanetary disk surrounding the Herbig Ae/Be star HD142527, with a strong focus on determining the light scattering parameters of the dust located at the surface of the large outer disk.

METHOD

We re-reduced existing polarimetric differential imaging data of HD142527 in the VBB (735 nm) and H-band (1625 nm) from the ZIMPOL and IRDIS subinstruments of SPHERE (Beuzit et al. 2019) at the VLT. With polarimetry and photometry based on reference star differential imaging (RDI), we were able to measure the linearly polarized intensity and the total intensity of the light scattered by the circumstellar disk with high precision. We used simple Monte Carlo simulations of multiple light scattering by the disk surface to derive constraints for three scattering parameters of the dust: the maximum polarization of the scattered light Pmax, the asymmetry parameter g, and the single-scattering albedo ω.

RESULTS

We measured the reflected light from the disk relative to the stellar flux and obtained $I_{\rm disk}/I_\star = 2.1\%$ and 4.0% for the VBB and H-band, respectively. We also find in the visual range a degree of polarization that varies between 28% on the far side of the disk and 17% on the near side. In the H-band, the degree of polarization is consistently higher by about a factor of 1.2. The disk also shows a red color for the scattered light intensity and the polarized intensity, which are about twice as high in the near-infrared when compared to the visual.

We determine with model calculations the scattering properties of the dust particles and find evidence for strong forward scattering (g ≈ 0.5 − 0.75), relatively low single-scattering albedo (ω ≈ 0.2 − 0.5), and high maximum polarization (Pmax ≈ 0.5 − 0.75) at the surface on the far side of the disk for both observed wavelengths.

The optical parameters indicate the presence of large aggregate dust particles, which are necessary to explain the high maximum polarization, the strong forward-scattering nature of the dust, and the observed red disk color.

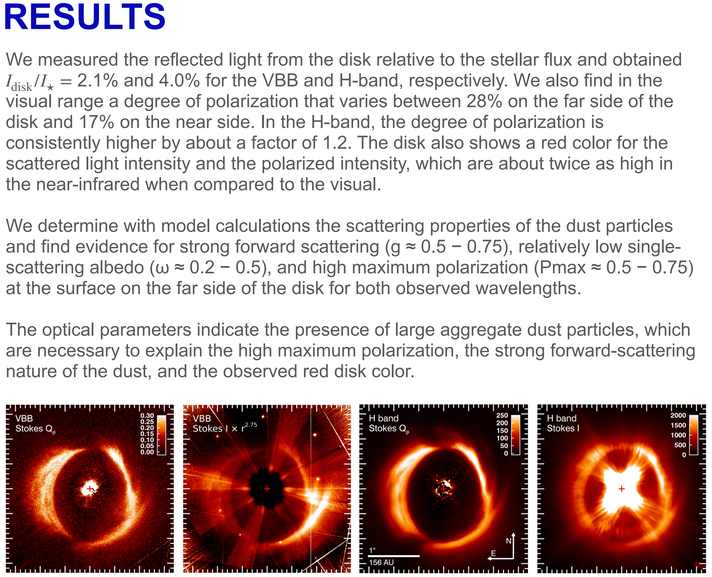

Fig. 1. Polarized intensity Q_ϕ and total intensity I signal of the disk around HD142527 for the non-coronagraphic VBB and the coronagraphic H-band observations.

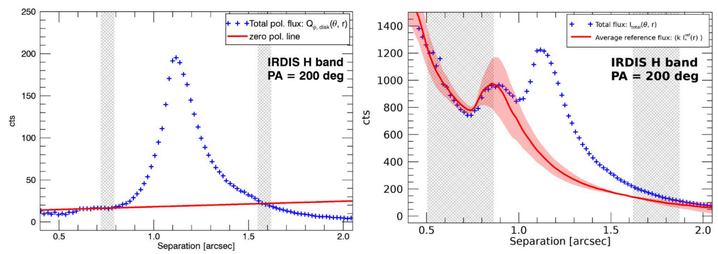

Fig. 2. Left: Measured radial polarized intensity profile from the HD142527 IRDIS data in H-band (blue crosses) at a position angle of 200◦. The solid red line was fit through the data points in the cross-hatched areas, considered as the zero line for the polarized surface brightness radial profiles. Right: Measured radial intensity profiles of HD142527 for the IRDIS H-band data (blue crosses) at a position angle of 200◦ compared to the mean of the best-fitting stellar PSF radial profiles derived from the reference data (solid red line).

	VBB (0.735 μm)			H (1.625 μm)		
	total	near	far	total	near	far
$Q_{\phi,\rm disk}/I_{\rm total}$ [%]	0.46 ± 0.02	0.23 ± 0.01	0.23 ± 0.01	1.07 ± 0.07	0.51 ± 0.04	0.56 ± 0.05
$p_{\rm disk}$ [%]	21.8 ± 0.4	17.1 ± 0.4	28.0 ± 0.9	26.7 ± 0.4	20.2 ± 0.6	35.1 ± 2.1
$I_{\rm disk}/I_{\rm total}$ [%] [a]	2.1 ± 0.1	1.3 ± 0.1	0.82 ± 0.06	4.0 ± 0.3	2.5 ± 0.3	1.6 ± 0.2

Tab. 1. Relative photopolarimetric measurements for HD142527 from this work

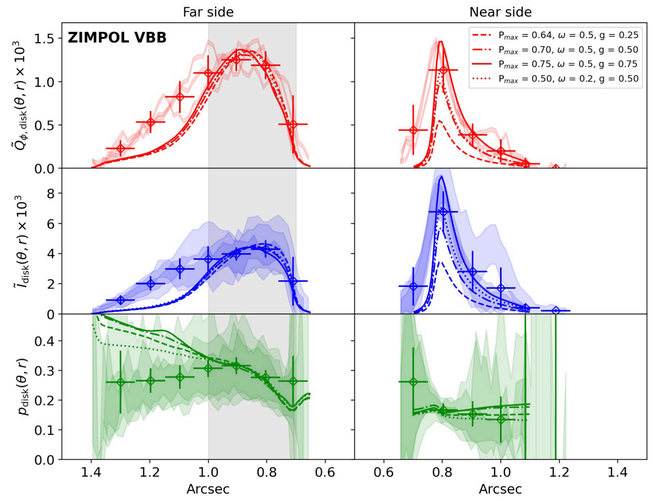

Fig. 3. Comparison of PSF-convolved model calculation for the radial profiles of $\tilde{Q}_{\phi,disk}$, $\tilde{I}_{disk}$, and p_{disk} with measured profiles along the minor axis of HD142527. The lines show simulation results for different dust-scattering parameter combinations for the geometry adapted from Marino et al. (2015). The shaded bands show a selection of three measured radial profiles close to the semi-minor axes of the disk on the far and near side of the disk at position angles of 70◦, 80◦, and 90◦ and 270◦, 285◦, and 290◦, respectively, in units of surface brightness relative to the total flux of the system, i.e., $[I_{total}/arcsec^2]$, and the diamonds show the average and the spread of all data points for all radial profiles combined. The model profiles are normalized and fitted to the measurements between 0.7" and 1" on the far side (shaded gray regions), where the plane-parallel surface approximation applies best.

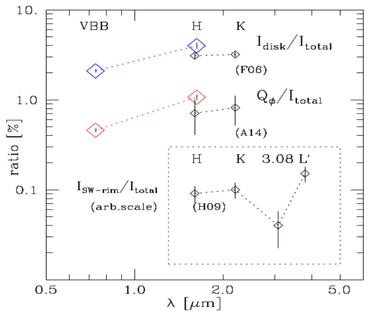

Fig. 4. Wavelength dependence of the measured relative intensities I_{disk}/I_{total} and polarized intensities $Q_{\phi,disk}/I_{total}$ for the scattered light from the disk in HD142527. The colored symbols are from Table 3, the values marked with (F06) from Fukagawa et al. (2006) and (A14) from Avenhaus et al. (2014). The values (H09) from Honda et al. (2009) are given in an inset with an arbitrary scale factor to offset them from the other data because these are relative measurements for an area at the southwest rim of the disk.

CONCLUSIONS

We presented high-precision measurements of the polarized intensity, the intensity, the degree of polarization, and the surface brightness for the scattered light from the extended disk around HD142527 for the two wavelengths 735 nm and 1.625 μm based on SPHERE/VLT data. The accuracy we achieved is unprecedented for the visual to near-IR color of the polarized flux and degree of polarization for a protoplanetary disk. Measurements of the wavelength dependence for the scattered light provide a key for determining the scattering properties of the dust because additional ambiguities in the interpretation of the measurements can be lifted.

We compared our measurements with a simple scattering model analysis for the wall on the far side of the disk, taking the near side into account as well. Our analysis yields some rough estimates for the single-scattering albedos (ω ≈ 0.2 − 0.5) and the maximum polarization introduced in the scattering (Pmax ≈ 0.5 − 0.75) and confirms the presence of forward-scattering dust particles (g ≈ 0.5−0.75), as has been suggested by previous studies. Systematic model calculations applied to our measurements or future high-precision measurements of other protoplanetary disks should provide much better determinations, including the wavelength dependence of these dust scattering parameters.

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