

The Marginal Importance of Distortions and Alignment in CASSI systems

–Supplementary material–

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This supplementary material provides:

- More comparisons between the PSFs estimated with our implementation and Zemax.
- Details on some characteristics of the considered systems, and acquisitions rendered with them.
- Further results on the reconstruction quality across the four considered systems with the different reconstruction algorithms.

I. POINT SPREAD FUNCTIONS COMPARISON WITH ZEMAX

Figures 8, 9, 10 and 11 show the PSF estimated with Zemax and with our implementation of dO [1], for the (SP), (mSP), (SP), (mSP) configurations respectively.

As stated in the main document, the (mSP) configuration is the one that yields the highest RMS differences between both implementations (up to $1.2\mu\text{m}$, well below the considered pixel size). The RMS differences are smaller in the three other configurations, especially for the Amici configurations (AP) and (mAP).

Each figure shows the two estimated PSF for the three wavelengths of interest: 450 nm, 520 nm, 650 nm, at four different positions in the field of view, denoted by the red dot on the bottom left of each figure. In the figures, the dotted black line represents the RMS radius centered on the centroid of the estimated PSFs. Note the pixel size scales are varying, because the size of the PSF depends on the considered configuration, wavelength and position in the field of view.

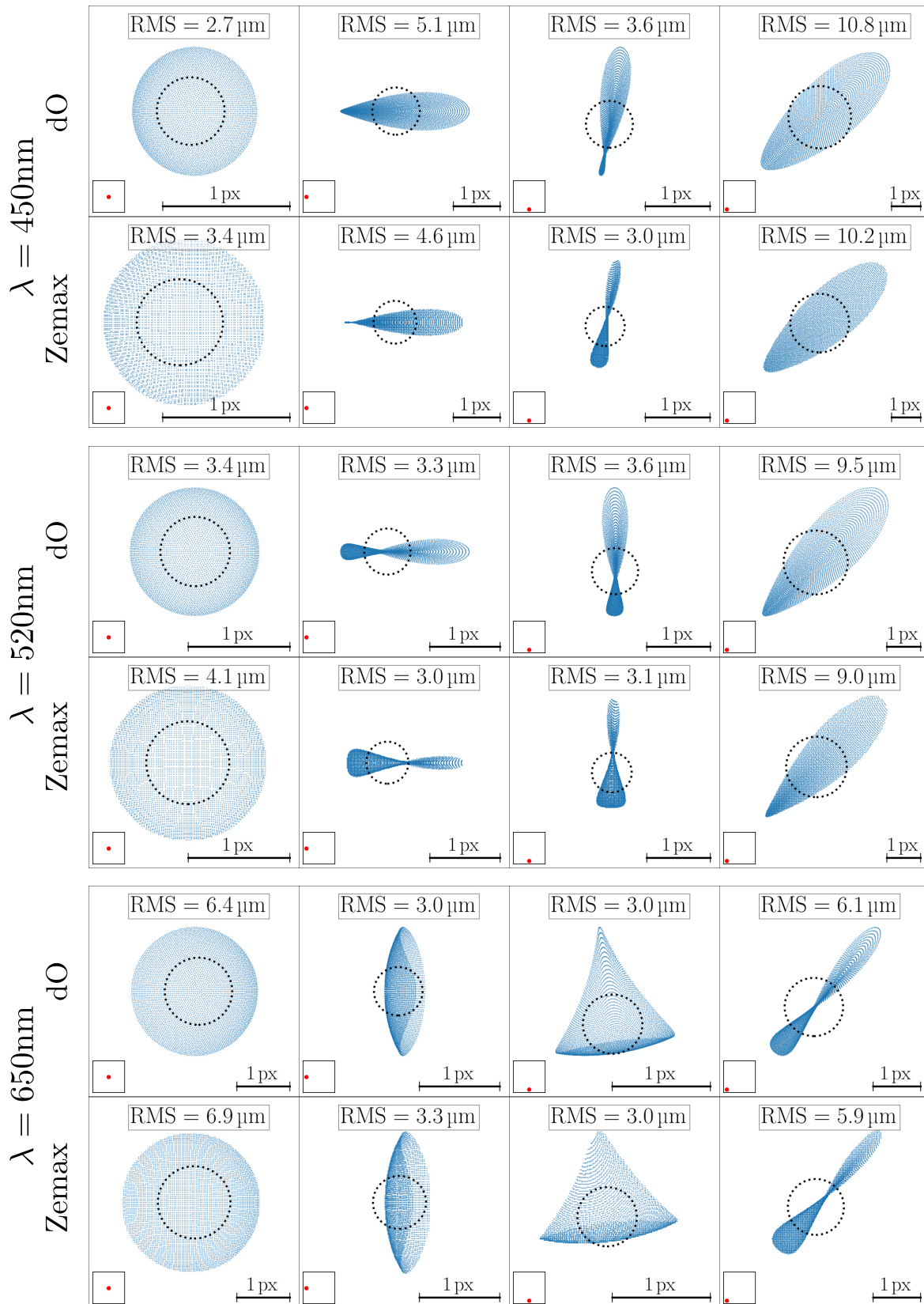


Fig. 8: PSFs obtained with the (SP) configuration at four positions in the field of view and for three wavelengths. Top rows show the PSFs obtained with dO, bottom rows show the PSFs obtained with Zemax.

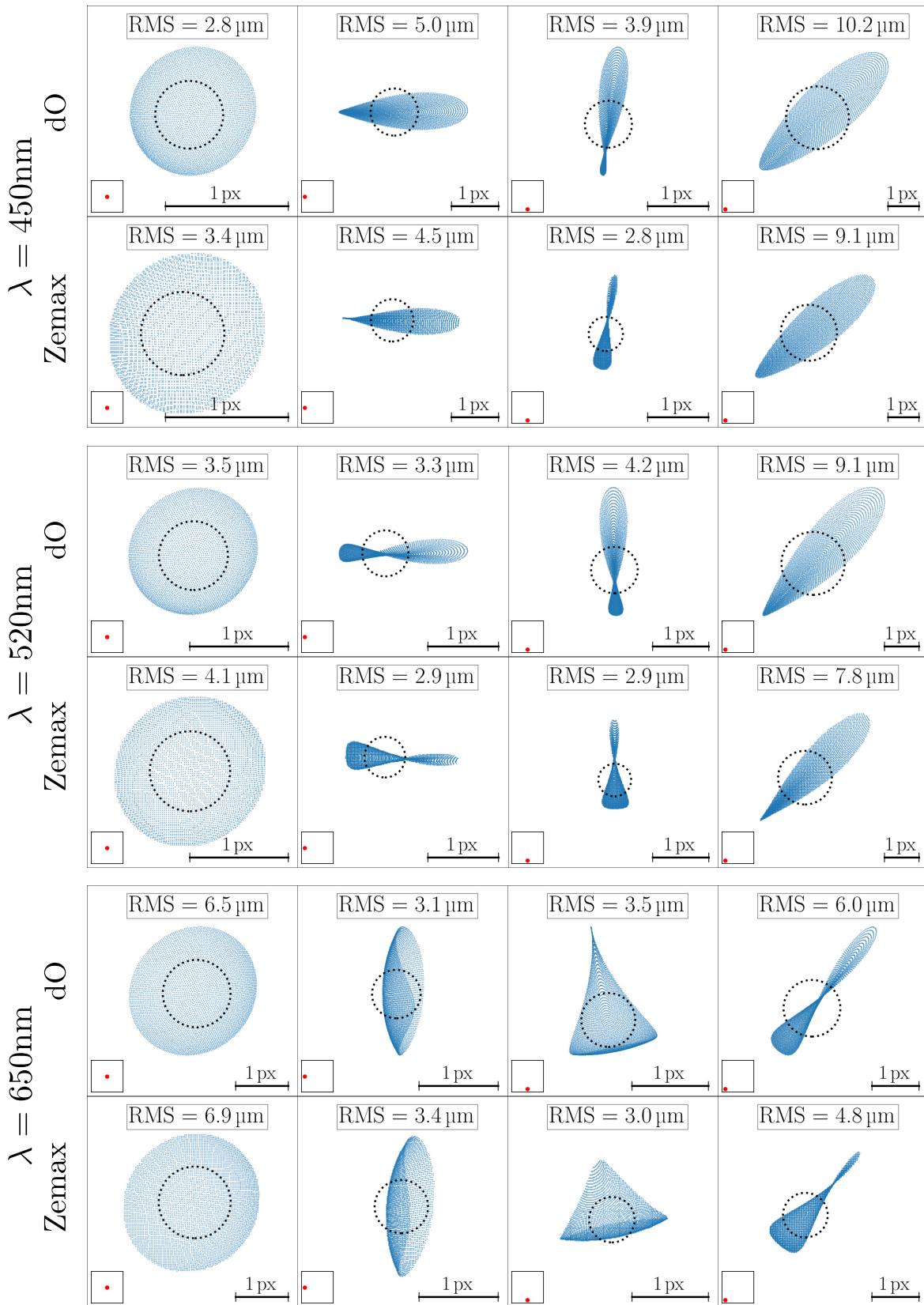


Fig. 9: PSFs obtained with the (mSP) configuration at four positions in the field of view and for three wavelengths. Top rows show the PSFs obtained with dO, bottom rows show the PSFs obtained with Zemax.

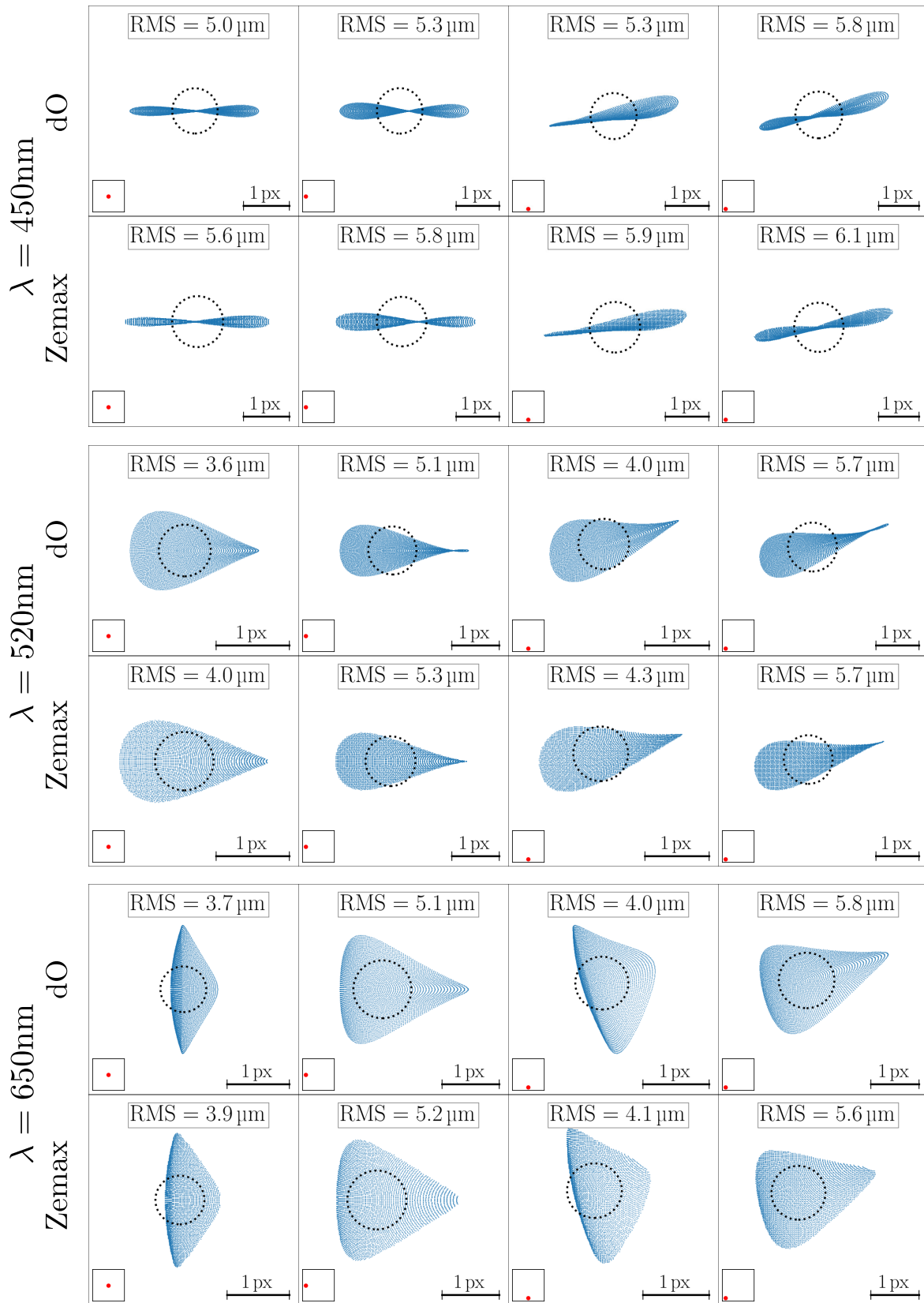


Fig. 10: PSFs obtained with the (AP) configuration at four positions in the field of view and for three wavelengths. Top rows show the PSFs obtained with dO, bottom rows show the PSFs obtained with Zemax.

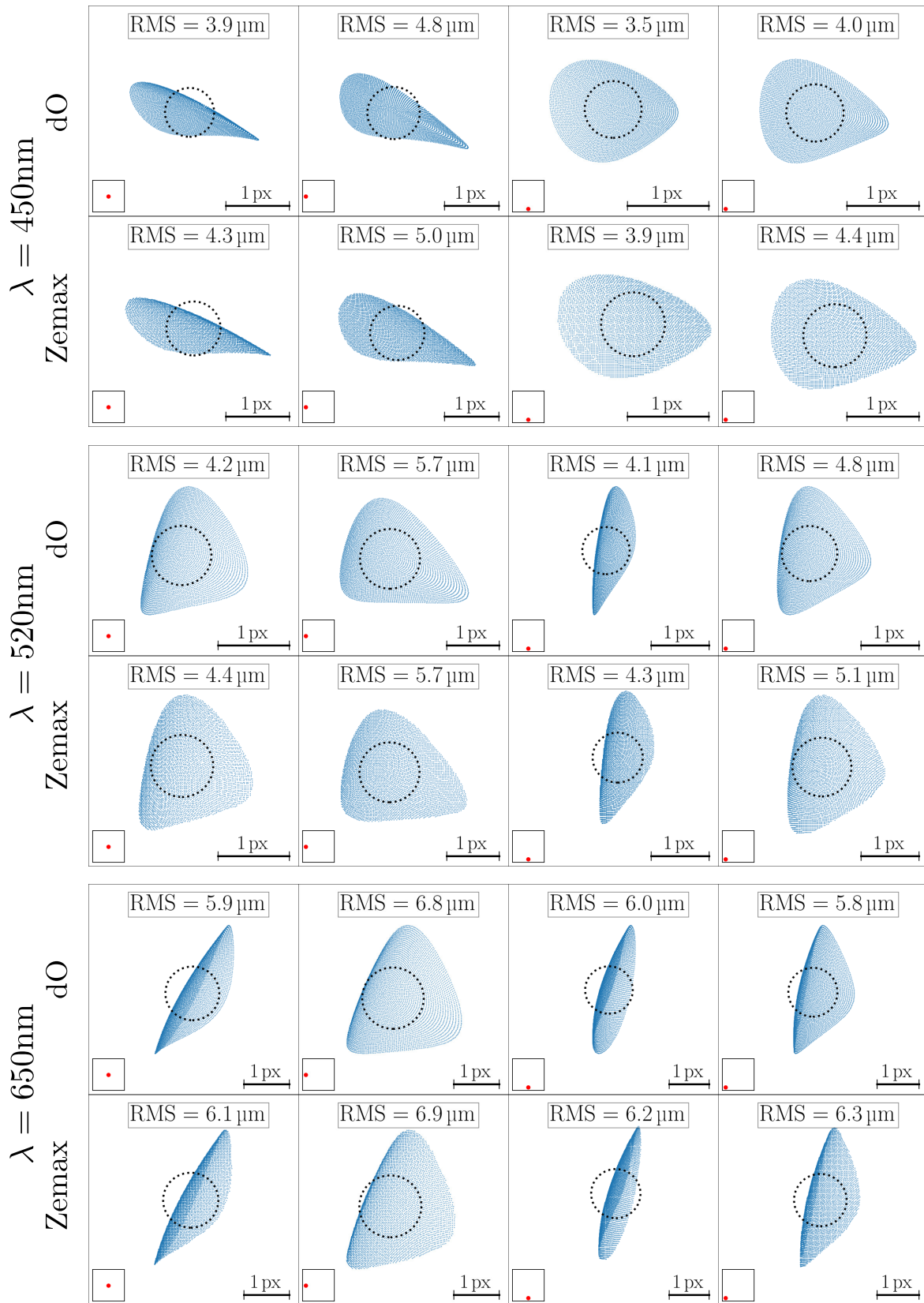


Fig. 11: PSFs obtained with the (mAP) configuration at four positions in the field of view and for three wavelengths. Top rows show the PSFs obtained with dO, bottom rows show the PSFs obtained with Zemax.

II. CONFIGURATIONS CHARACTERISTICS

A. Prisms Spreading

The spatio-spectral curves of (AP) and (SP) configurations are slightly different. We optimized the double-Amici assembly to achieve the same angular spectral dispersion as the single prism, and managed to reach the same overall spatio-spectral spreading extent, but there are slight mismatches with respect to the wavelength. This happens because the non-linearity of the spatio-spectral spreading is different for the considered prisms: these differences are shown in Figure 12.

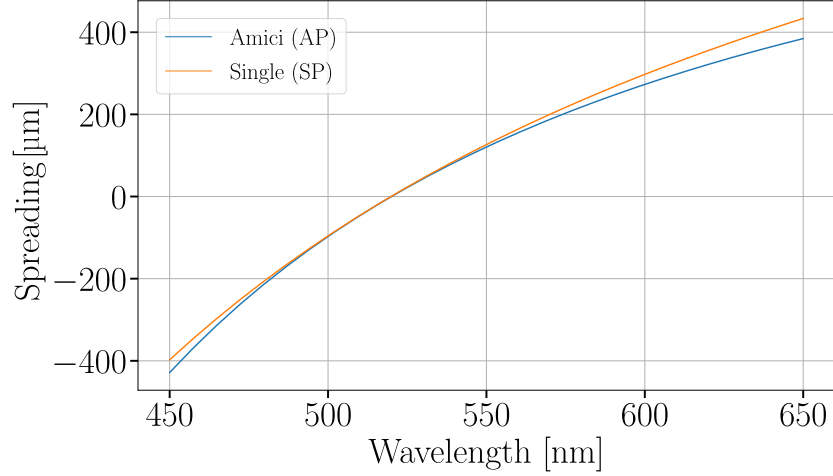


Fig. 12: Spatio-spectral spreading of the central point of the field of view for the (AP) and (SP) systems.

B. Distortions and Acquisitions

The distortion maps for the four configurations are illustrated in Figure 13. For perfectly aligned systems, the system with Amici prism assembly (AP) does not exhibit distortions whereas the system based on a single prism (SP) suffers from the so-called smile distortion: the vertical lines are imaged as arcs with a curvature that depends on both the wavelength and the position in the field of view. For the supposedly misaligned configurations The impact of misalignment is barely visible for the system with Amici prism assembly (mAP), with a magnification that slightly increases from left to right across the field of view. This impact of misalignment is much more important with a single prism (mSP), with important distortions along both the vertical and horizontal directions.

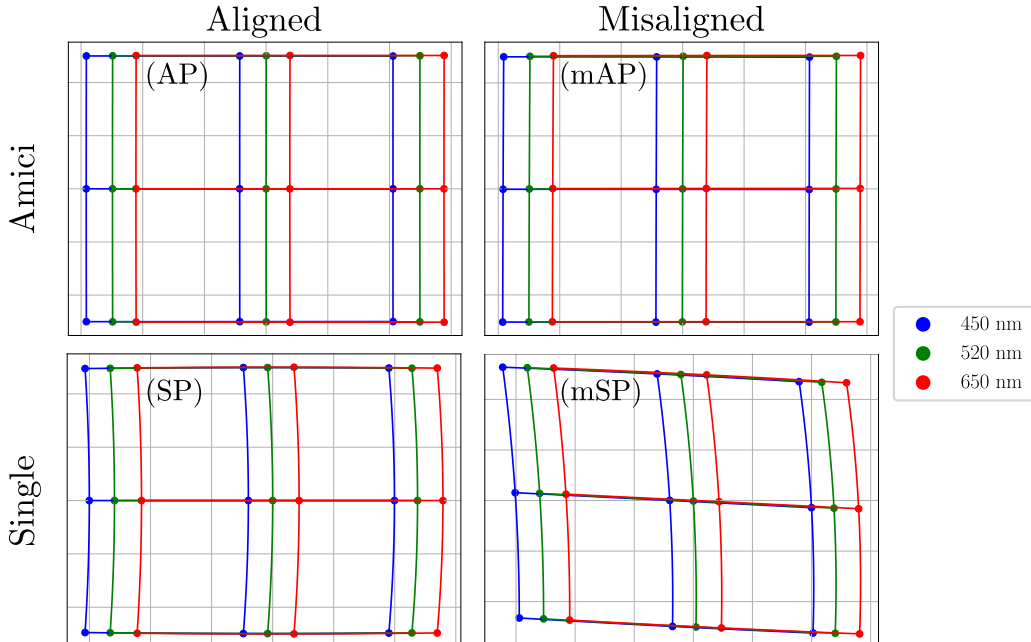


Fig. 13: Illustration of the distortions for the four CASSI configurations.

Figure 14 shows two typical acquisitions with the four configurations, for a given scene from both CAVE [2] and KAIST dataset [3] (see Figure 14). It illustrates the impact on the rendered images of the distortions and misalignment for each configuration.

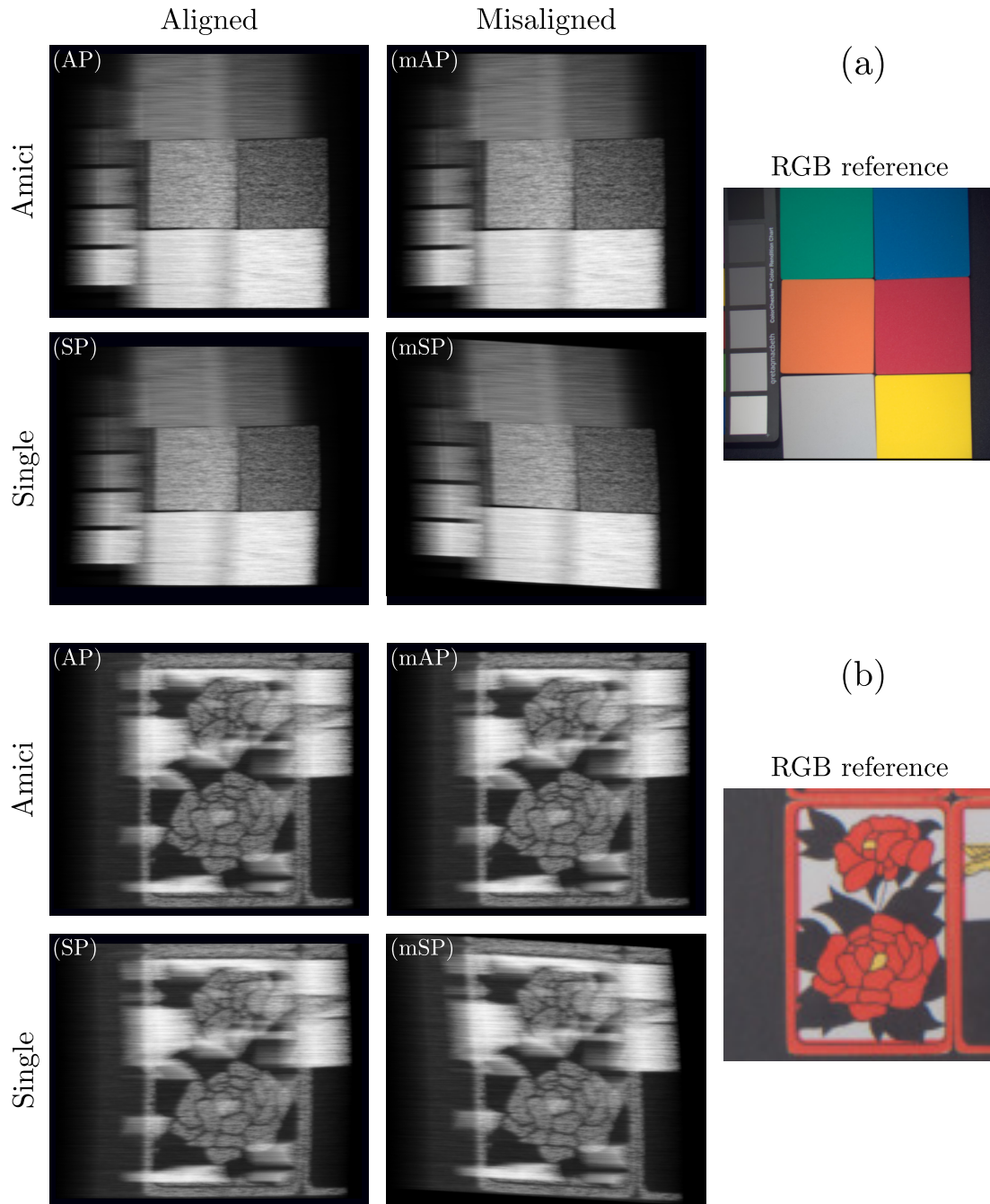


Fig. 14: Example coded acquisition for one hyperspectral scene from CAVE (a) and one from KAIST (b).

III. RECONSTRUCTION RESULTS

The following five tables Tables IV to VIII show the reconstruction results with the four configurations under study of the five state-of-the-art reconstruction algorithms. The results are detailed for each scene, the average and the standard deviation over the scenes are reported in the rightmost column. The four considered metrics are the same as the ones in the main document: Root Mean Square Error (RMSE), Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM), Spectral Angle Mapper (SAM). For the five algorithms and all scenes, all metrics are similar for the four considered configurations, confirming the results observed on the average over the scenes.

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Avg (\pm std)
RMSE \downarrow ($\times 10^{-3}$)	(AP)	30.7	32.1	34.1	16.8	46.3	33.3	42.8	41.8	46.4	42.9	36.7 \pm 8.7
	(SP)	32.1	36.4	37.6	18.8	51.3	35.6	44.8	43.7	48.2	42.4	39.1 \pm 8.8
	(mAP)	30.1	32.6	35.8	18.0	42.6	33.1	38.8	42.0	40.9	40.2	35.4 \pm 7.1
	(mSP)	31.6	37.6	36.0	18.8	46.3	36.0	45.0	46.5	66.3	43.4	40.7 \pm 11.7
PSNR \uparrow	(AP)	29.4	25.8	26.8	34.3	25.8	29.6	21.6	27.6	24.7	25.9	27.1 \pm 3.23
	(SP)	29.0	24.7	26.0	33.4	24.9	29.0	21.2	27.2	24.4	26.0	26.6 \pm 3.15
	(mAP)	29.6	25.7	26.4	33.8	26.5	29.6	22.4	27.5	25.8	26.5	27.4 \pm 2.88
	(mSP)	29.2	24.4	26.3	33.3	25.8	28.9	21.2	26.7	21.6	25.8	26.3 \pm 3.42
SSIM \uparrow [0 - 1]	(AP)	0.872	0.823	0.849	0.940	0.848	0.884	0.832	0.862	0.824	0.813	0.855 \pm 0.036
	(SP)	0.857	0.792	0.811	0.923	0.792	0.856	0.811	0.840	0.790	0.787	0.826 \pm 0.041
	(mAP)	0.853	0.803	0.794	0.930	0.792	0.863	0.802	0.854	0.807	0.790	0.829 \pm 0.043
	(mSP)	0.866	0.813	0.839	0.936	0.836	0.873	0.823	0.849	0.786	0.808	0.843 \pm 0.040
SAM \downarrow [0 - 1]	(AP)	0.067	0.082	0.069	0.065	0.064	0.082	0.063	0.099	0.077	0.072	0.074 \pm 0.010
	(SP)	0.075	0.104	0.081	0.082	0.091	0.109	0.071	0.118	0.085	0.100	0.092 \pm 0.015
	(mAP)	0.070	0.093	0.077	0.069	0.077	0.097	0.071	0.110	0.073	0.085	0.082 \pm 0.013
	(mSP)	0.070	0.092	0.076	0.068	0.080	0.092	0.072	0.108	0.092	0.078	0.083 \pm 0.012

TABLE IV: RMSE, PSNR (in dB), SSIM and SAM for DGSMP for each optical system.

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Avg (\pm std)
RMSE \downarrow ($\times 10^{-3}$)	(AP)	24.6	25.2	24.2	12.7	32.0	26.0	32.3	33.4	30.9	32.6	27.4 \pm 6.0
	(SP)	23.8	24.5	22.0	11.9	32.1	25.7	31.4	31.8	30.0	32.5	26.6 \pm 6.1
	(mAP)	23.1	25.2	23.6	12.8	31.6	24.3	32.0	32.5	30.2	30.8	26.6 \pm 5.8
	(mSP)	24.3	25.9	25.9	13.2	32.9	27.3	33.3	35.2	32.4	34.1	28.5 \pm 6.3
PSNR \uparrow	(AP)	31.3	27.9	29.8	36.7	29.0	31.7	24.0	29.5	28.2	28.3	29.6 \pm 3.09
	(SP)	31.6	28.1	30.6	37.3	28.9	31.8	24.3	30.0	28.5	28.3	29.9 \pm 3.19
	(mAP)	31.9	27.9	30.0	36.6	29.1	32.3	24.1	29.8	28.4	28.8	29.9 \pm 3.11
	(mSP)	31.4	27.6	29.2	36.4	28.7	31.3	23.7	29.1	27.8	27.9	29.3 \pm 3.11
SSIM \uparrow [0 - 1]	(AP)	0.915	0.886	0.921	0.965	0.916	0.924	0.878	0.907	0.901	0.877	0.909 \pm 0.025
	(SP)	0.921	0.892	0.932	0.969	0.916	0.924	0.889	0.912	0.901	0.879	0.913 \pm 0.025
	(mAP)	0.921	0.888	0.922	0.958	0.914	0.926	0.881	0.910	0.898	0.883	0.910 \pm 0.022
	(mSP)	0.914	0.877	0.919	0.958	0.903	0.914	0.876	0.893	0.884	0.863	0.900 \pm 0.026
SAM \downarrow [0 - 1]	(AP)	0.054	0.062	0.047	0.070	0.045	0.061	0.049	0.074	0.052	0.058	0.057 \pm 0.009
	(SP)	0.050	0.060	0.044	0.058	0.041	0.057	0.047	0.068	0.049	0.056	0.053 \pm 0.008
	(mAP)	0.052	0.061	0.045	0.068	0.043	0.064	0.048	0.075	0.052	0.061	0.057 \pm 0.010
	(mSP)	0.050	0.062	0.048	0.064	0.047	0.061	0.054	0.074	0.056	0.064	0.058 \pm 0.008

TABLE V: RMSE, PSNR (in dB), SSIM and SAM for MST for each optical system.

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Avg (\pm std)
RMSE \downarrow ($\times 10^{-3}$)	(AP)	20.6	18.8	19.4	13.1	27.2	20.6	23.6	26.0	24.7	27.4	22.1 \pm 4.3
	(SP)	18.3	16.9	17.8	10.5	24.6	19.5	21.0	25.2	20.7	25.9	20.0 \pm 4.4
	(mAP)	19.2	17.5	18.5	11.1	25.9	19.1	20.9	24.5	21.0	25.6	20.3 \pm 4.2
	(mSP)	19.0	18.4	18.1	9.8	25.9	19.9	21.7	25.4	22.2	26.2	20.7 \pm 4.7
PSNR \uparrow	(AP)	32.9	30.4	31.7	36.4	30.4	33.7	26.7	31.7	30.2	29.8	31.4 \pm 2.47
	(SP)	33.9	31.3	32.5	38.3	31.3	34.2	27.8	32.0	31.7	30.3	32.3 \pm 2.64
	(mAP)	33.5	31.0	32.1	37.8	30.8	34.4	27.8	32.2	31.6	30.4	32.2 \pm 2.54
	(mSP)	33.6	30.6	32.3	39.0	30.8	34.0	27.5	31.9	31.1	30.2	32.1 \pm 2.88
SSIM \uparrow [0 - 1]	(AP)	0.932	0.929	0.933	0.966	0.931	0.945	0.923	0.932	0.928	0.907	0.933 \pm 0.014
	(SP)	0.943	0.933	0.948	0.974	0.944	0.949	0.936	0.938	0.944	0.920	0.943 \pm 0.013
	(mAP)	0.938	0.933	0.942	0.976	0.938	0.948	0.933	0.934	0.936	0.916	0.939 \pm 0.014
	(mSP)	0.940	0.924	0.944	0.972	0.938	0.943	0.928	0.933	0.938	0.912	0.937 \pm 0.015
SAM \downarrow [0 - 1]	(AP)	0.052	0.054	0.049	0.062	0.044	0.058	0.039	0.069	0.050	0.063	0.054 \pm 0.009
	(SP)	0.048	0.055	0.042	0.059	0.041	0.057	0.036	0.062	0.046	0.061	0.051 \pm 0.009
	(mAP)	0.047	0.053	0.041	0.059	0.043	0.059	0.036	0.069	0.046	0.059	0.051 \pm 0.010
	(mSP)	0.049	0.061	0.040	0.069	0.047	0.068	0.037	0.074	0.049	0.070	0.056 \pm 0.013

TABLE VI: RMSE, PSNR (in dB), SSIM and SAM for DAUHST for each optical system.

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Avg (\pm std)
RMSE \downarrow ($\times 10^{-3}$)	(AP)	20.5	19.7	20.2	12.6	28.8	22.3	24.9	29.3	23.3	28.3	23.0 \pm 4.9
	(SP)	23.2	21.9	22.5	14.5	32.0	23.3	28.4	29.4	27.0	31.2	25.3 \pm 5.0
	(mAP)	21.5	21.8	20.1	12.7	30.7	22.2	26.2	31.2	26.9	30.4	24.4 \pm 5.5
	(mSP)	22.9	21.8	23.0	13.0	31.0	24.1	29.0	31.9	26.8	30.6	25.4 \pm 5.4
PSNR \uparrow	(AP)	32.9	30.0	31.4	36.8	29.9	33.0	26.3	30.7	30.7	29.5	31.1 \pm 2.61
	(SP)	31.9	29.1	30.4	35.5	29.0	32.7	25.1	30.6	29.4	28.7	30.2 \pm 2.62
	(mAP)	32.5	29.1	31.4	36.7	29.3	33.1	25.9	30.1	29.5	28.9	30.6 \pm 2.80
	(mSP)	32.0	29.1	30.2	36.5	29.3	32.4	24.9	29.9	29.5	28.8	30.3 \pm 2.82
SSIM \uparrow [0 - 1]	(AP)	0.935	0.919	0.931	0.966	0.926	0.937	0.914	0.921	0.927	0.902	0.928 \pm 0.016
	(SP)	0.923	0.904	0.924	0.970	0.910	0.932	0.898	0.916	0.911	0.888	0.918 \pm 0.021
	(mAP)	0.930	0.906	0.929	0.965	0.919	0.937	0.908	0.914	0.912	0.895	0.921 \pm 0.019
	(mSP)	0.921	0.908	0.922	0.967	0.910	0.931	0.896	0.912	0.913	0.890	0.917 \pm 0.020
SAM \downarrow [0 - 1]	(AP)	0.047	0.058	0.042	0.058	0.047	0.059	0.040	0.075	0.051	0.060	0.054 \pm 0.010
	(SP)	0.053	0.061	0.046	0.055	0.050	0.061	0.046	0.075	0.052	0.061	0.056 \pm 0.008
	(mAP)	0.052	0.061	0.043	0.066	0.050	0.062	0.043	0.083	0.051	0.059	0.057 \pm 0.011
	(mSP)	0.053	0.061	0.044	0.056	0.048	0.062	0.046	0.076	0.049	0.058	0.055 \pm 0.009

TABLE VII: RMSE, PSNR (in dB), SSIM and SAM for DUF for each optical system.

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Avg (\pm std)
RMSE \downarrow ($\times 10^{-3}$)	(AP)	19.7	18.5	20.1	10.6	27.8	19.8	24.0	26.4	23.6	27.4	21.8 \pm 4.9
	(SP)	18.1	17.6	17.2	10.1	24.2	18.6	22.8	23.5	21.4	24.4	19.8 \pm 4.2
	(mAP)	20.4	19.1	20.7	12.6	27.6	21.4	24.3	28.0	25.3	26.8	22.6 \pm 4.5
	(mSP)	20.5	19.9	18.9	11.2	28.5	20.9	24.0	26.3	23.8	27.2	22.1 \pm 4.8
PSNR \uparrow	(AP)	33.3	30.6	31.4	38.3	30.2	34.1	26.6	31.6	30.6	29.8	31.6 \pm 2.92
	(SP)	34.0	31.0	32.8	38.6	31.4	34.6	27.0	32.6	31.4	30.8	32.4 \pm 2.86
	(mAP)	32.9	30.3	31.2	36.7	30.3	33.4	26.5	31.1	30.0	30.0	31.2 \pm 2.56
	(mSP)	32.9	29.9	31.9	37.8	30.0	33.6	26.6	31.6	30.5	29.8	31.5 \pm 2.81
SSIM \uparrow [0 - 1]	(AP)	0.940	0.928	0.937	0.966	0.933	0.947	0.917	0.932	0.924	0.913	0.934 \pm 0.015
	(SP)	0.944	0.932	0.948	0.971	0.943	0.950	0.924	0.941	0.938	0.925	0.942 \pm 0.013
	(mAP)	0.936	0.922	0.938	0.966	0.930	0.943	0.916	0.928	0.918	0.913	0.931 \pm 0.015
	(mSP)	0.936	0.921	0.943	0.965	0.931	0.943	0.921	0.929	0.929	0.910	0.933 \pm 0.014
SAM \downarrow [0 - 1]	(AP)	0.044	0.053	0.039	0.063	0.044	0.057	0.037	0.067	0.045	0.059	0.051 \pm 0.010
	(SP)	0.045	0.053	0.037	0.058	0.040	0.056	0.037	0.062	0.043	0.054	0.049 \pm 0.009
	(mAP)	0.046	0.057	0.040	0.062	0.044	0.060	0.039	0.071	0.049	0.058	0.053 \pm 0.010
	(mSP)	0.048	0.056	0.036	0.064	0.045	0.062	0.038	0.066	0.045	0.055	0.052 \pm 0.010

TABLE VIII: RMSE, PSNR (in dB), SSIM and SAM for PADUT for each optical system.

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