Simulating Patterned (Photovoltaic) Glass with Data-Driven Variable-Resolution BRDFs
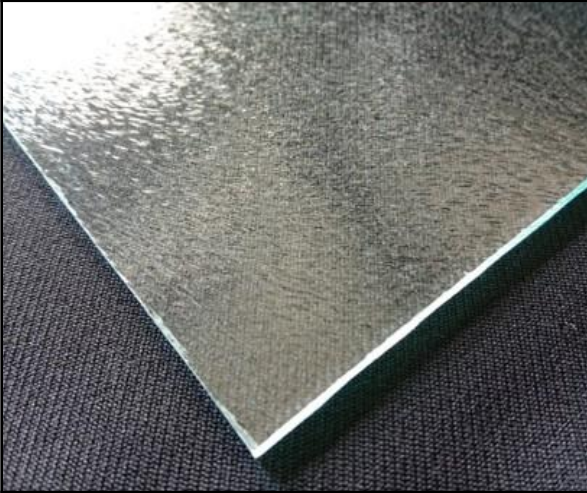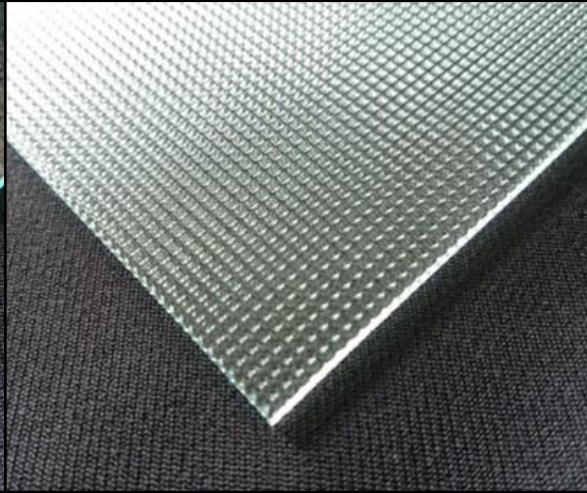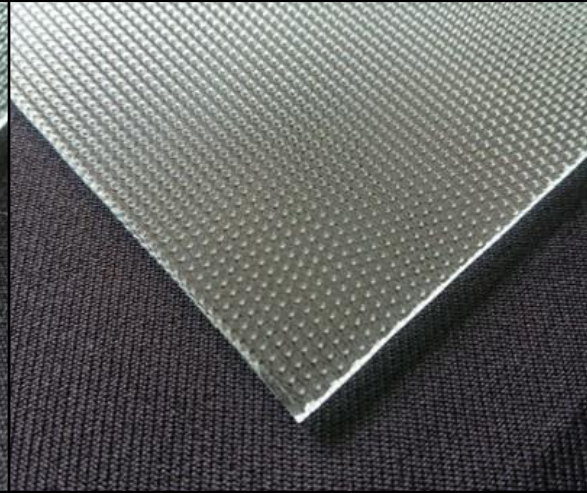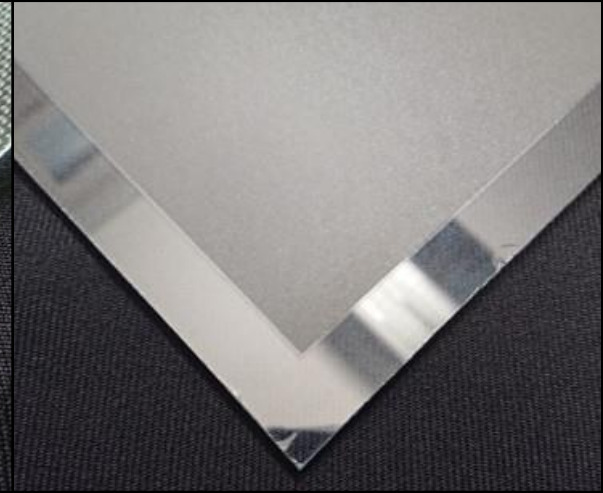
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Radiance Workshop 2023
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www.ise.fraunhofer.de

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Motivation

Problem	Solar reflection on photovoltaic (PV) modules can be the cause of glare
Aim	Glare analysis of PV modules with textured glass based on the evaluation of luminance images
Question	How accurate are simulations with tensor tree BRDFs in this context?
Method	Compare measured and tensor tree BRDFs as well as measured and simulated luminance images of different samples

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Sample selection and preparation

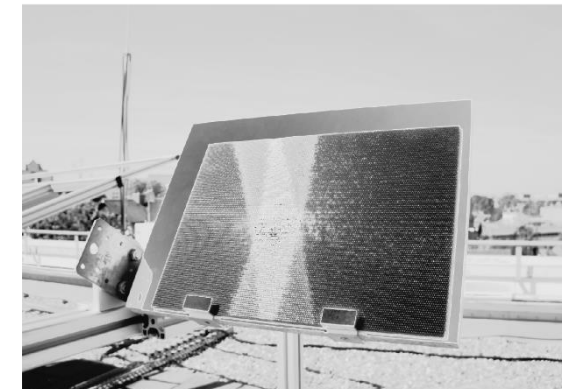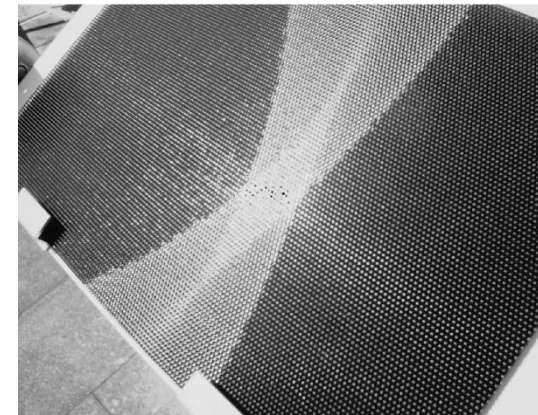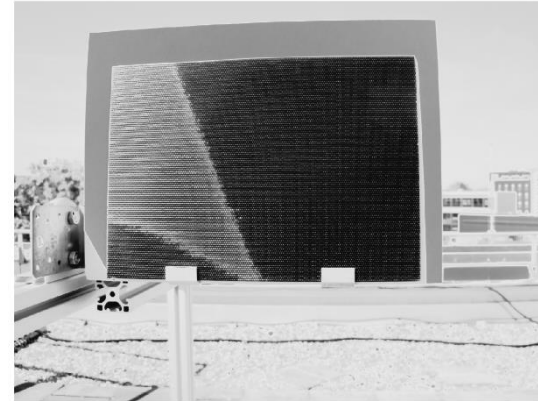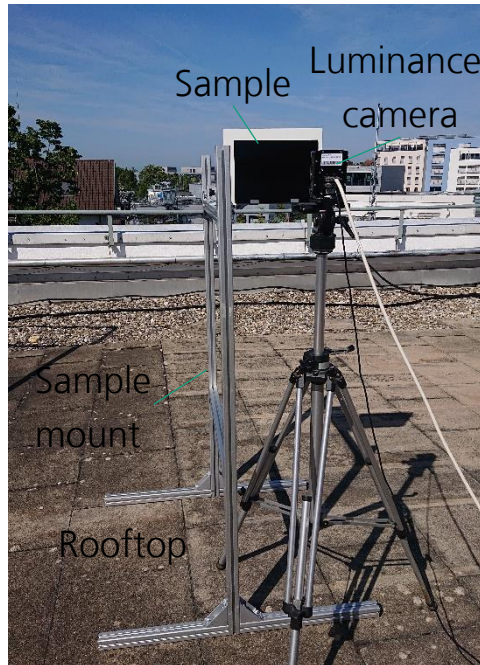| Sample Grooves	Sample Pyramids	Sample Pits	Sample Laser
Slightly textured	Moderately textured	Moderately textured	Strongly textured

- **Samples blackened on the back**

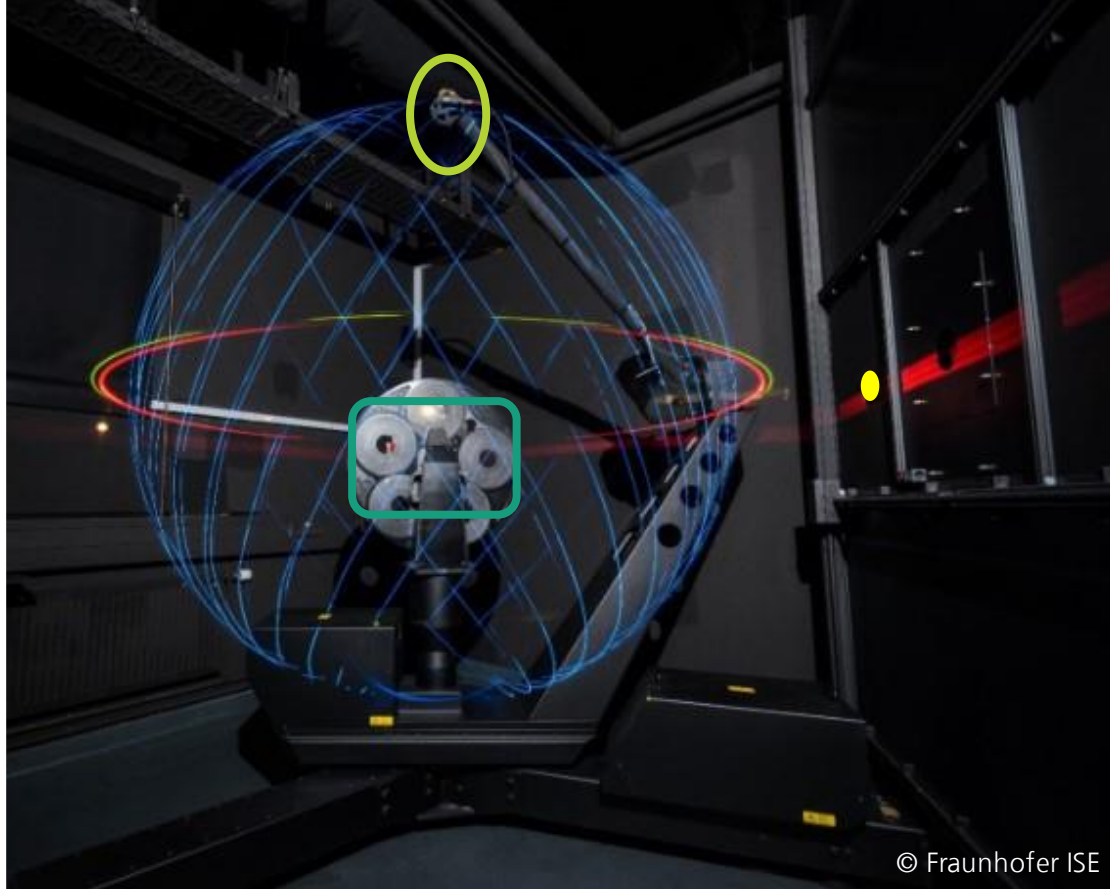→ **Imitate PV module, but homogeneous surface (without connectors)**

Luminance images: Experiment setup

Measured results

Take luminance images on a sunny day with the luminance camera for four different scenes

Sample

Luminance camera

Sample mount

Rooftop

Luminance images: simulation workflow and experiment setup

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Simulated results

BRDF measurement with photogoniometer pg2

- Halogen lamp

- Polar angle $\theta \in [8°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°]$

- Azimuth angle φ (depending on sample symmetry)

- Silicon detector with $V(\lambda)$ filter

- Measurement on the fly

- High-resolution path

Luminance images: simulation workflow and experiment setup

Simulated results

BRDF measurement with photogoniometer pg2

Transformation of measured data to tensor tree
pabopto2bsdf -n 50 -s a/b/q pg2data*.txt > sample.sir
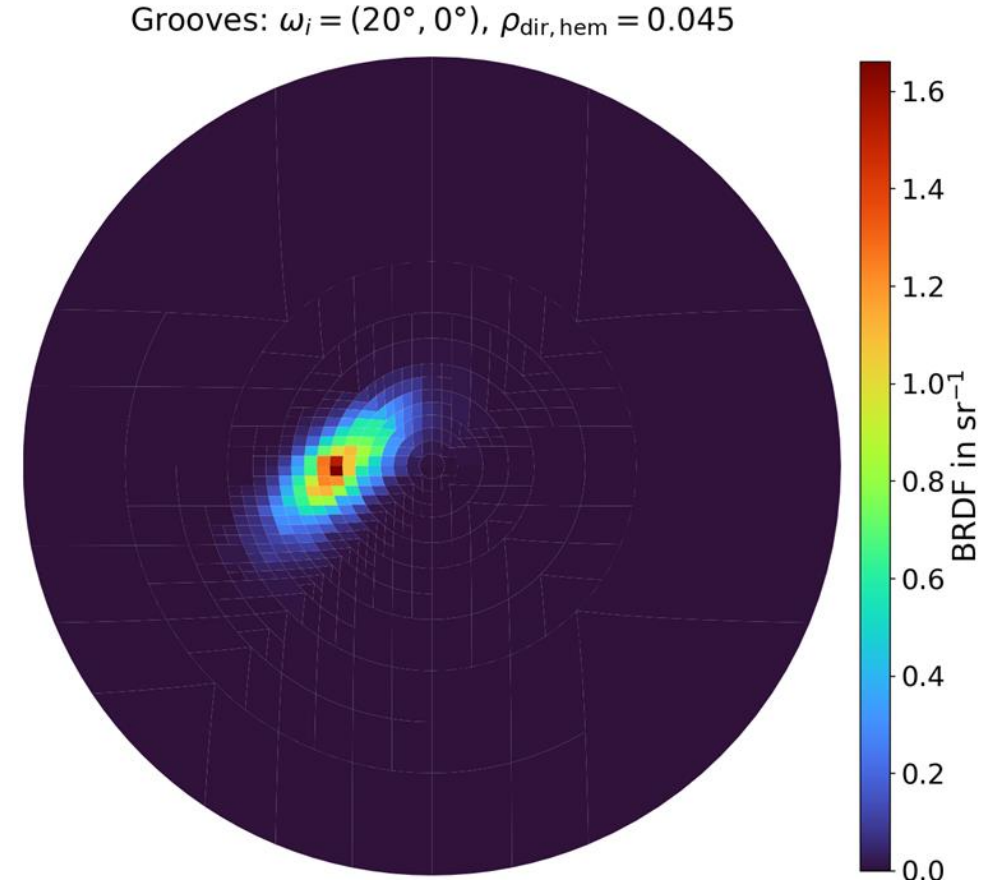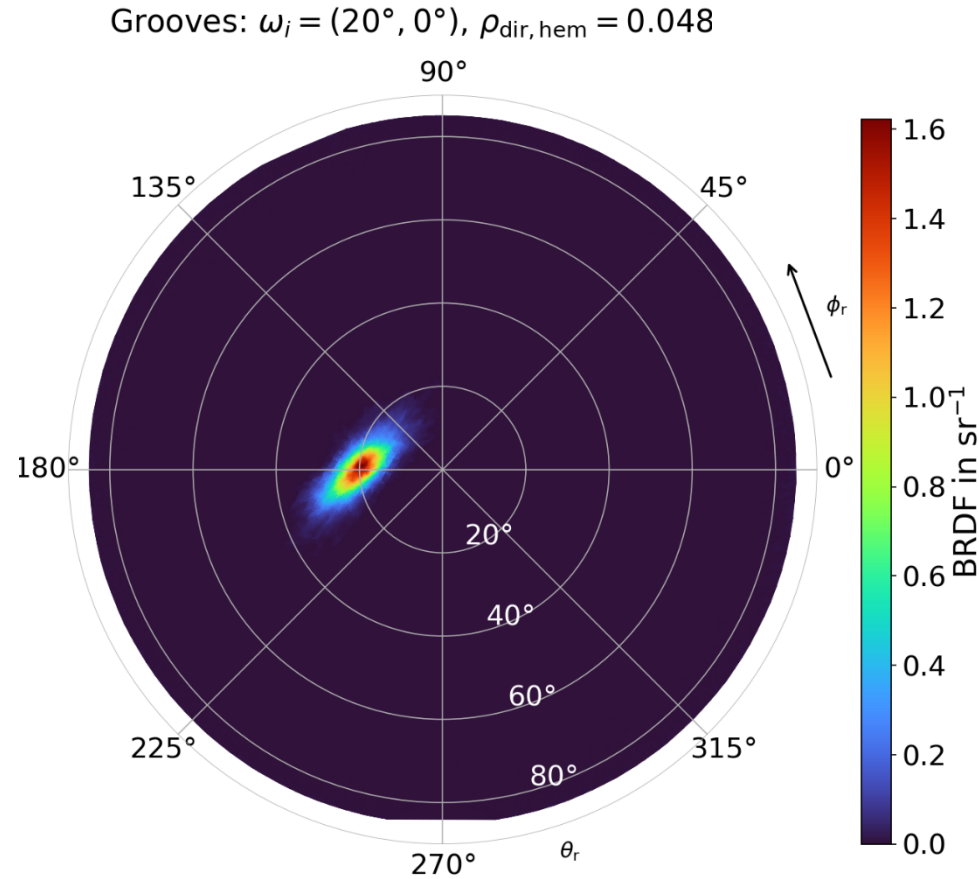bsdf2ttree +a -g 6 -t 95 sample.sir > sample.xml

Rebuild setup of outdoor measurement → octree

Generation of luminance images with vwrays,
rtrace and parameters
-ds 0.02 -dc 1 -dt 0 -dj 0.5 -st 0 -ss 64 -ab 3 -aa 0.01 -ar 1024
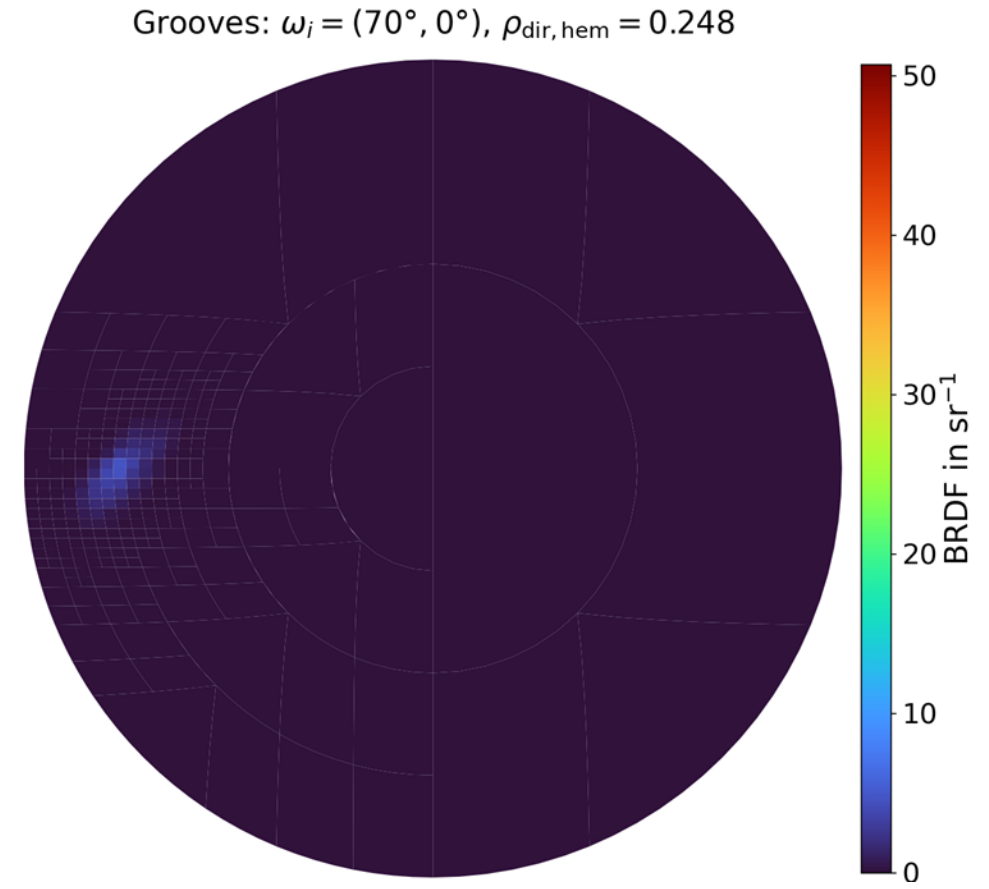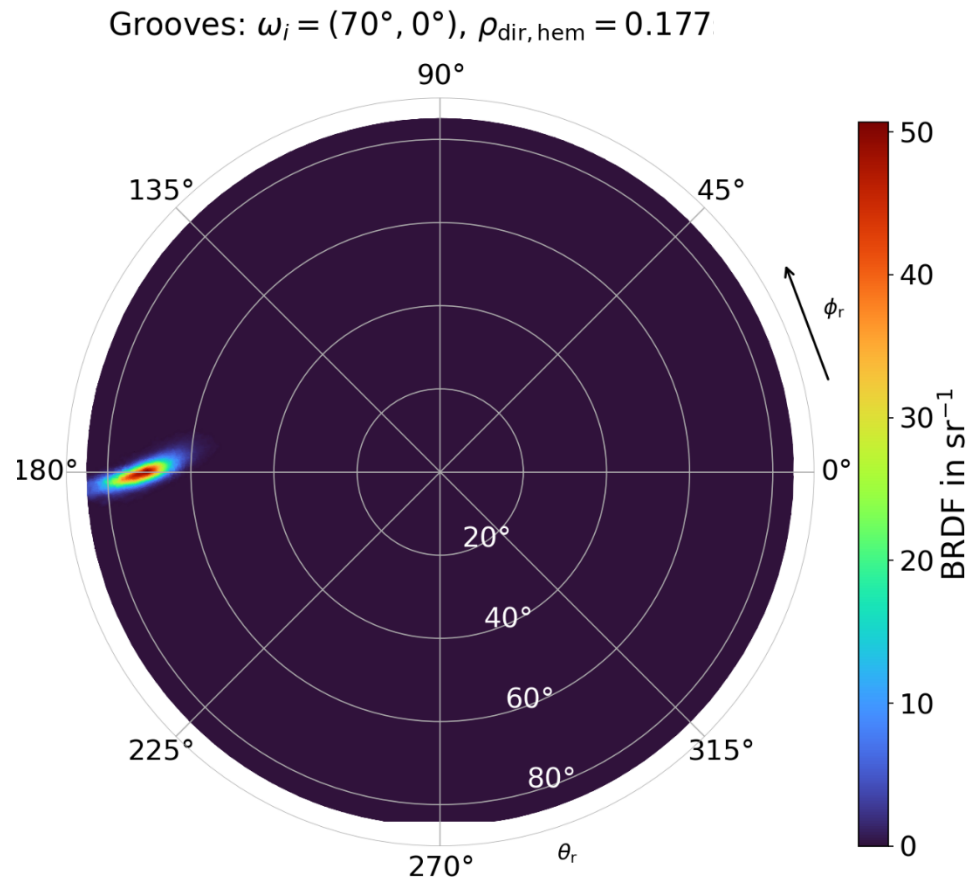-ad 4096 -as 1024 -lw 1e-4

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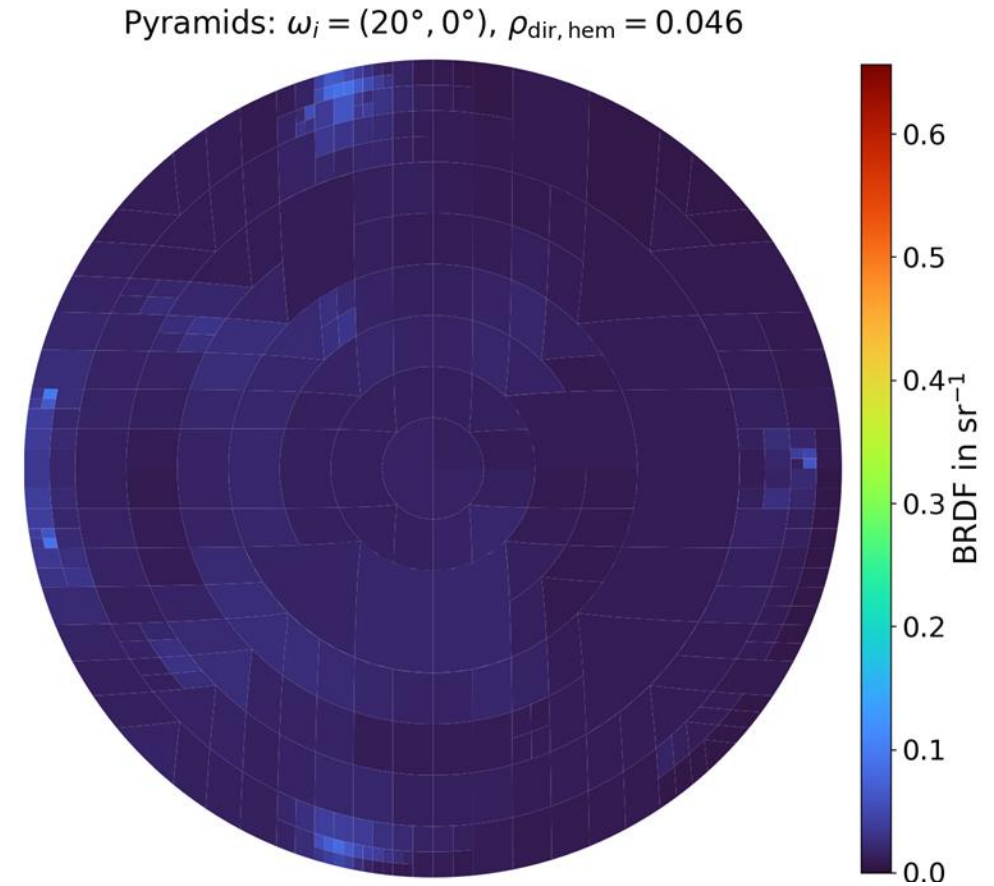
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Comparison of measured and tensor tree BRDFs
Grooves

Grooves: $\omega_i = (20°, 0°)$, $\rho_{dir,hem} = 0.048$

Grooves: $\omega_i = (20°, 0°)$, $\rho_{dir,hem} = 0.045$

Comparison of measured and tensor tree BRDFs

Grooves

Grooves: $\omega_i = (70°, 0°)$, $\rho_{\text{dir,hem}} = 0.177$

Grooves: $\omega_i = (70°, 0°)$, $\rho_{\text{dir,hem}} = 0.248$

Comparison of measured and tensor tree BRDFs
Pyramids

Pyramids: $\omega_i = (20°, 0°)$, $\rho_{\mathrm{dir,hem}} = 0.048$

Pyramids: $\omega_i = (20°, 0°)$, $\rho_{\mathrm{dir,hem}} = 0.046$
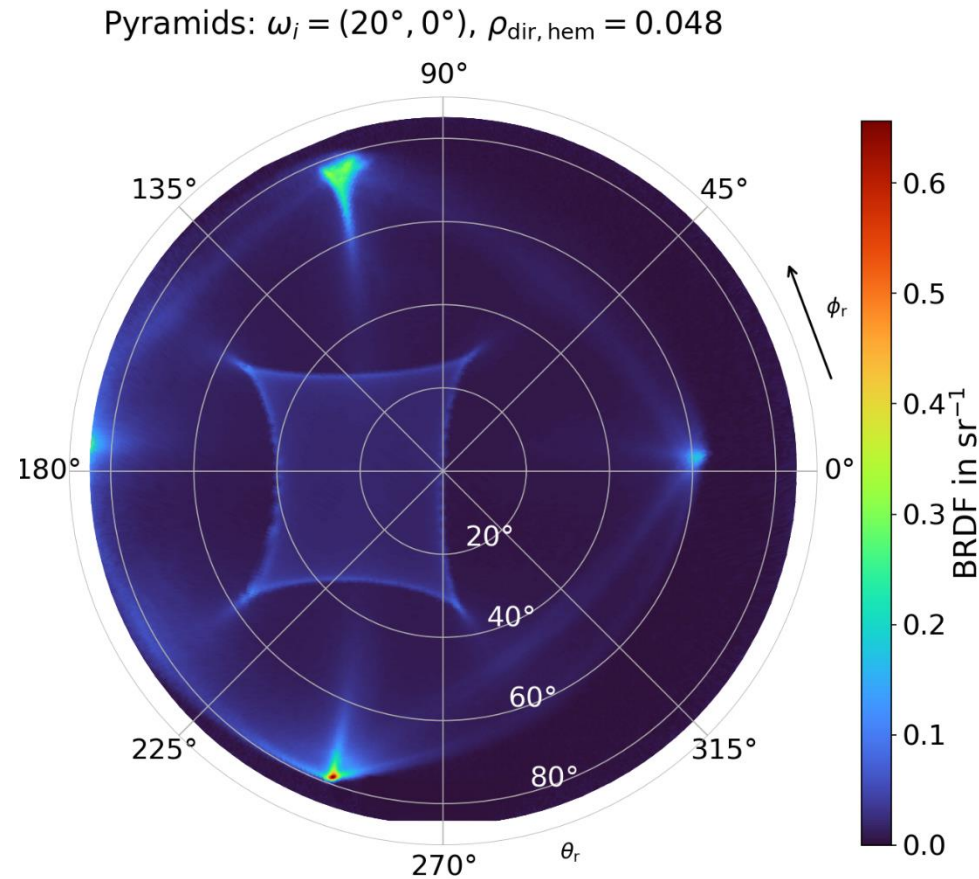
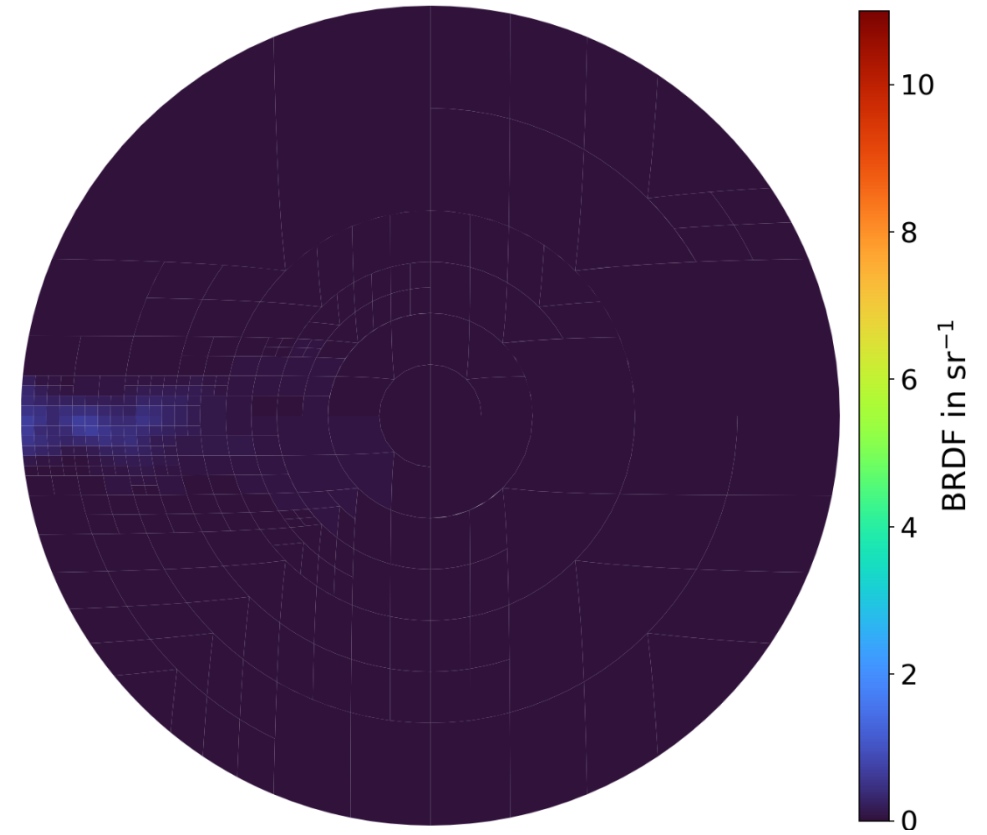# Comparison of measured and tensor tree BRDFs

Pits

Pits: $\omega_i = (70°, 0°)$, $\rho_{\text{dir, hem}} = 0.129$
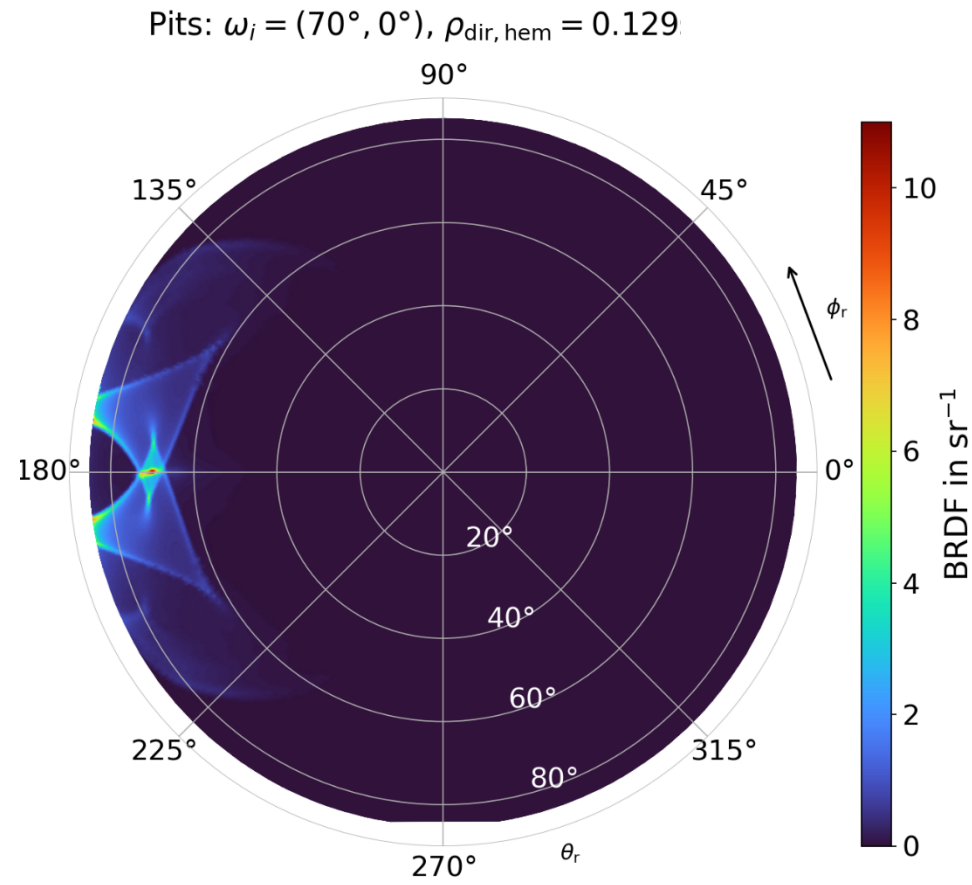
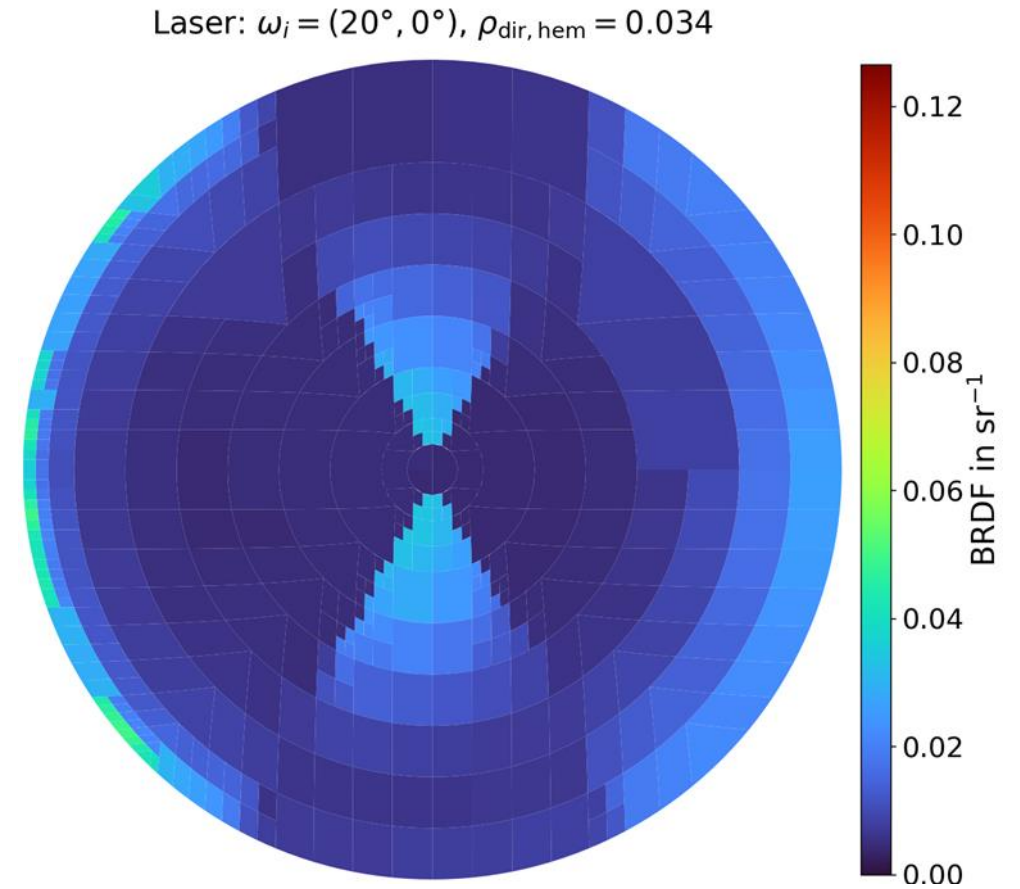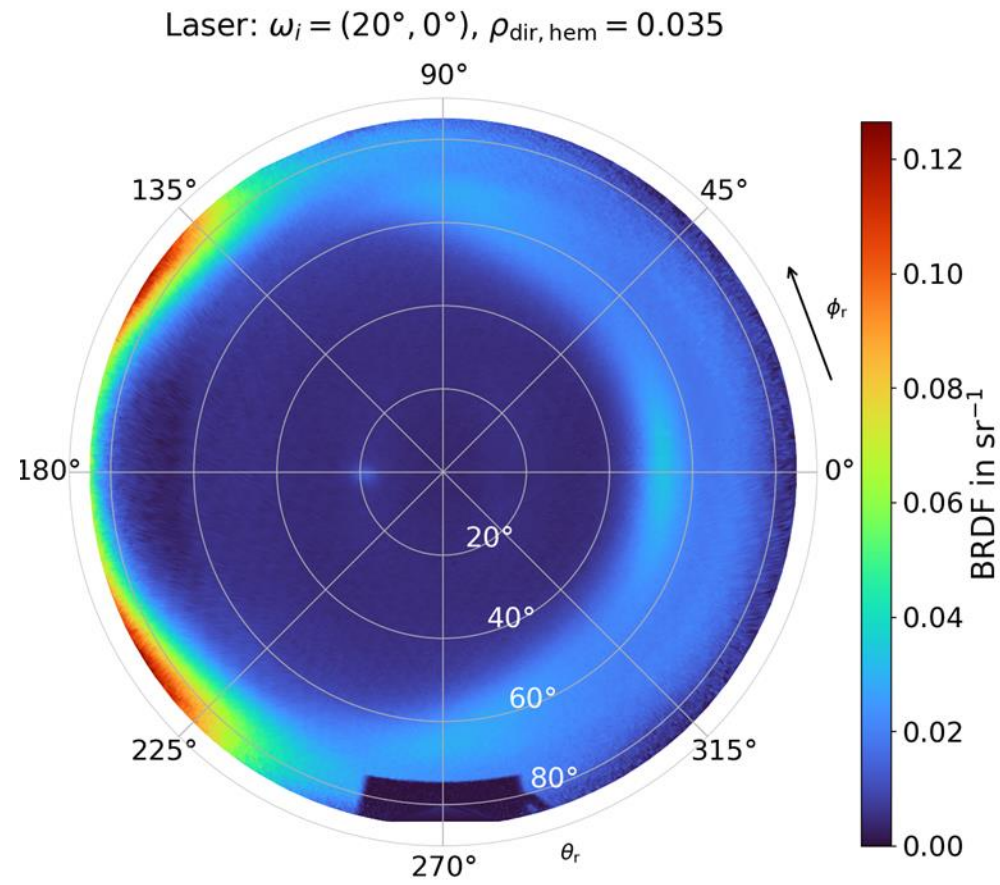Pits: $\omega_i = (70°, 0°)$, $\rho_{\text{dir, hem}} = 0.079$

Comparison of measured and tensor tree BRDFs
Laser

Laser: $\omega_i = (20°, 0°)$, $\rho_{dir, hem} = 0.035$

Laser: $\omega_i = (20°, 0°)$, $\rho_{dir, hem} = 0.034$

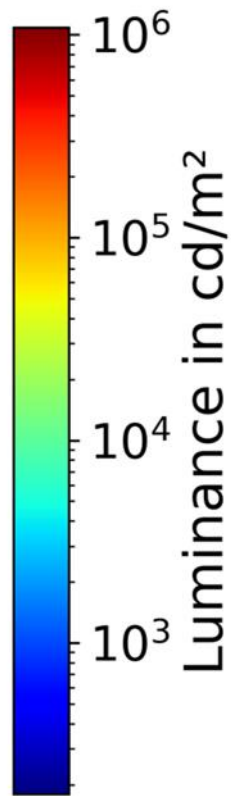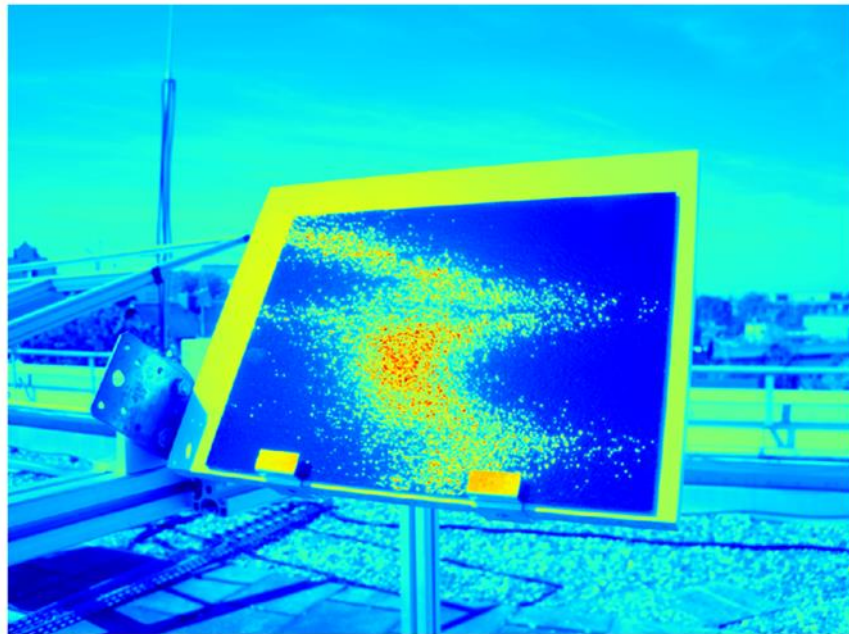# Comparison of simulated and measured luminance images

Scene 2: Sample Grooves

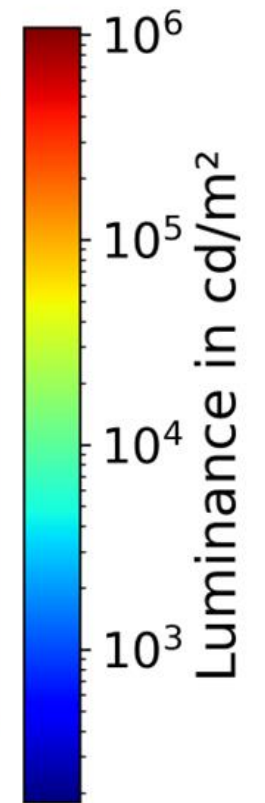# Comparison of simulated and measured luminance images

Scene 1: Sample Pyramids

Measured luminance image: Pyramids

Simulated luminance image: Pyramids

Luminance in cd/m²

Luminance in cd/m²

10^4

10^3

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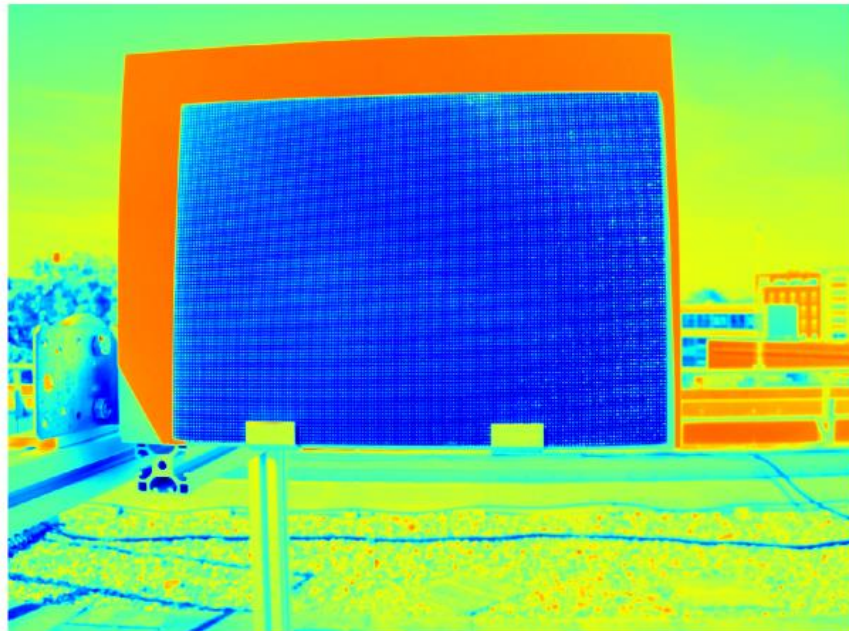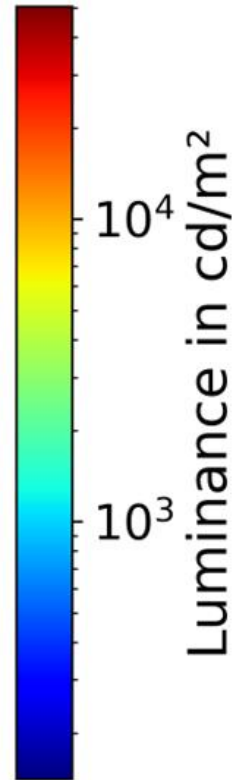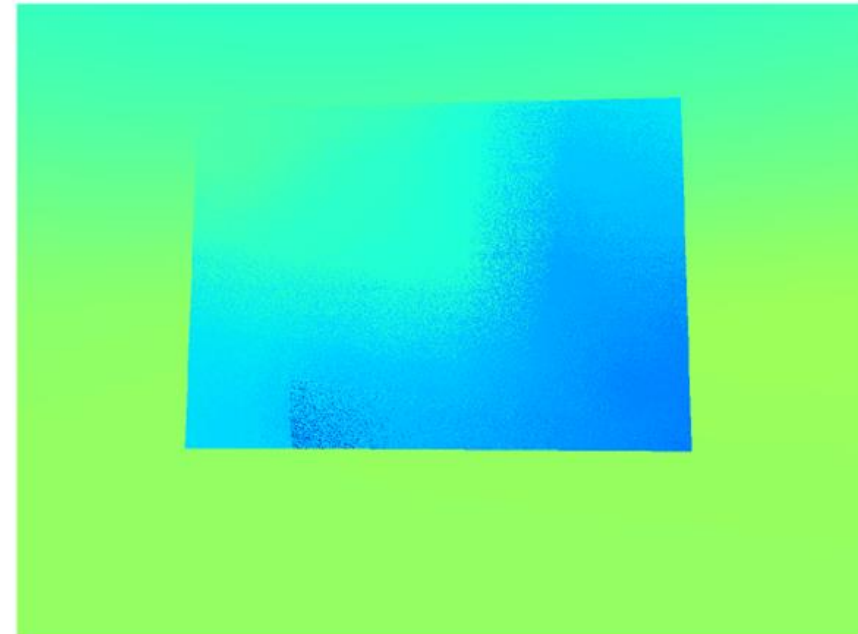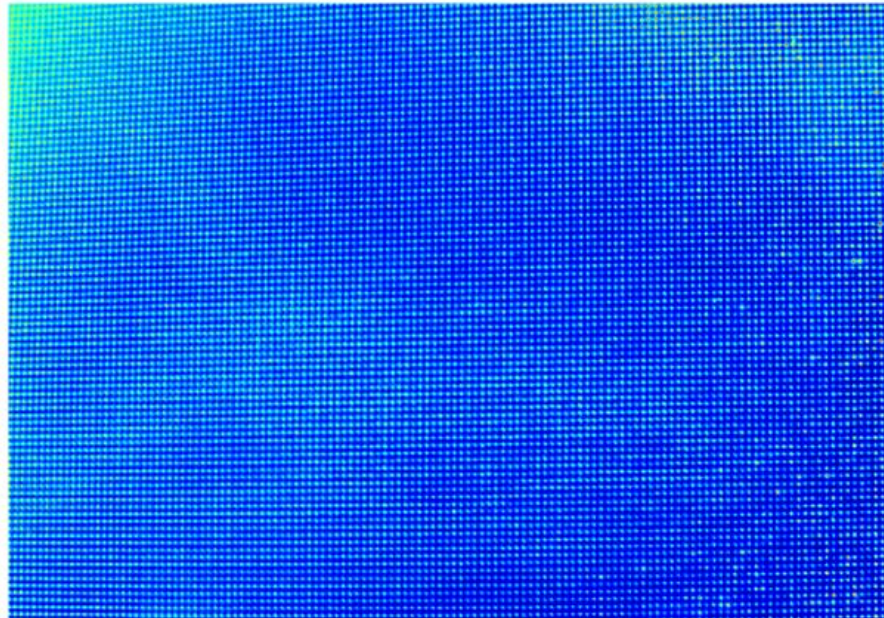# Comparison of simulated and measured luminance images
Image section

Comparison of simulated and measured luminance images
Summary

Sample	Scene	$\overline{L_{\mathrm{sim}}}$	$\overline{L_{\mathrm{meas}}}$	$\overline{L_{\mathrm{sim}}}/\overline{L_{\mathrm{meas}}}$	$L_{\mathrm{sim,95}}$	$L_{\mathrm{meas,95}}$
Grooves	1	1188	291	4.1	1817	494
	2	1878	11860	0.2	2411	1616
	3	1436	7234	0.2	2489	34600
	4	948	370	2.68	1041	471

Conclusion

Tensor tree BRDFs represent measured BRDFs reasonably well

→ Peaks at often underestimated

→ Adjust Radiance parameters?

Luminance images differ significantly

→ (not only) BRDF differences

→ Sky model not representative

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