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Measuring Diffuse Sky Radiance with An Affordable and Open-Source All-Sky Imager

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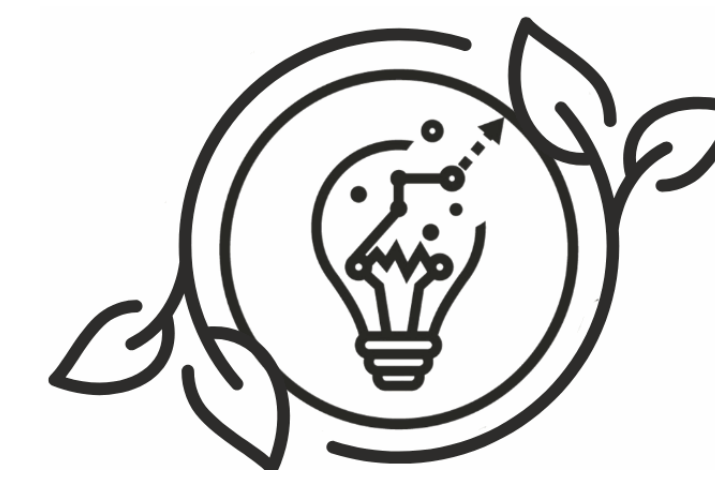
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Measuring Diffuse Sky Radiance with An Affordable and Open-Source All-Sky Imager



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Unlocking Nature's Genius

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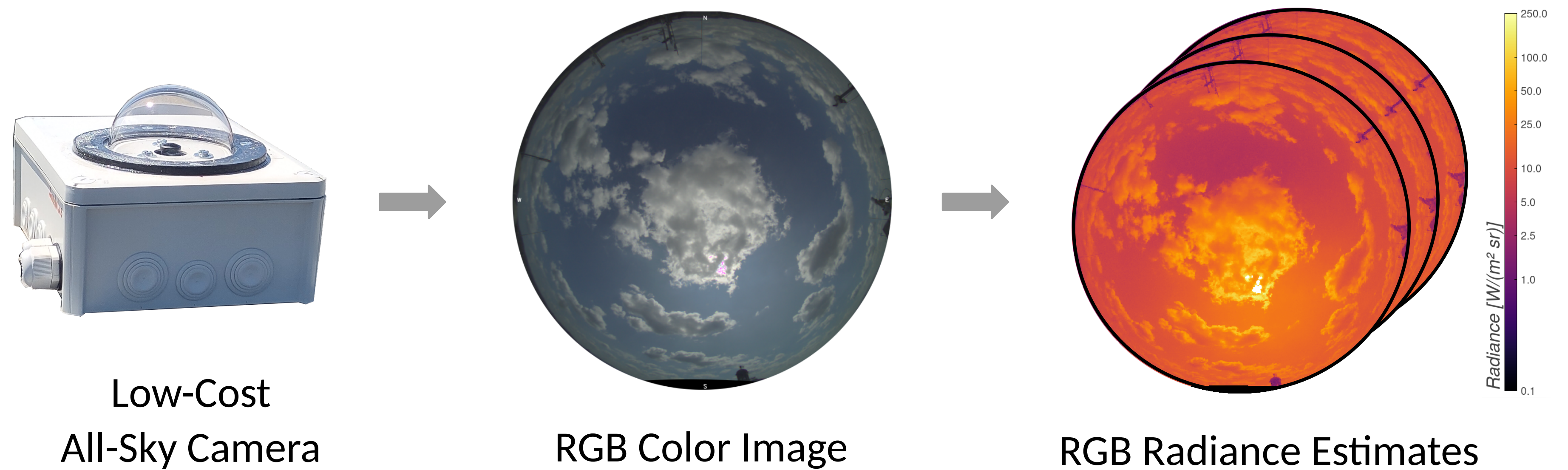
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1. A camera for sky radiance measurement?

State-of-the-art pyranometers and pyrhemimeters can precisely measure broadband surface solar irradiance components [1]. However, their high cost is a barrier to widespread deployment. Also, characterizing the sky's radiance in greater **angular and spectral detail** is necessary [2] for solar forecasting and atmospheric analysis. We designed and assembled a **low-cost** (approx. 300€) fish-eye camera based on a **Raspberry Pi 4**, and propose a methodology using **open-source** software to estimate **pixel-wise diffuse sky radiances in three spectral bands** (Red, Green, Blue).



2. Geometric Calibration

Which sky point does a pixel correspond to?

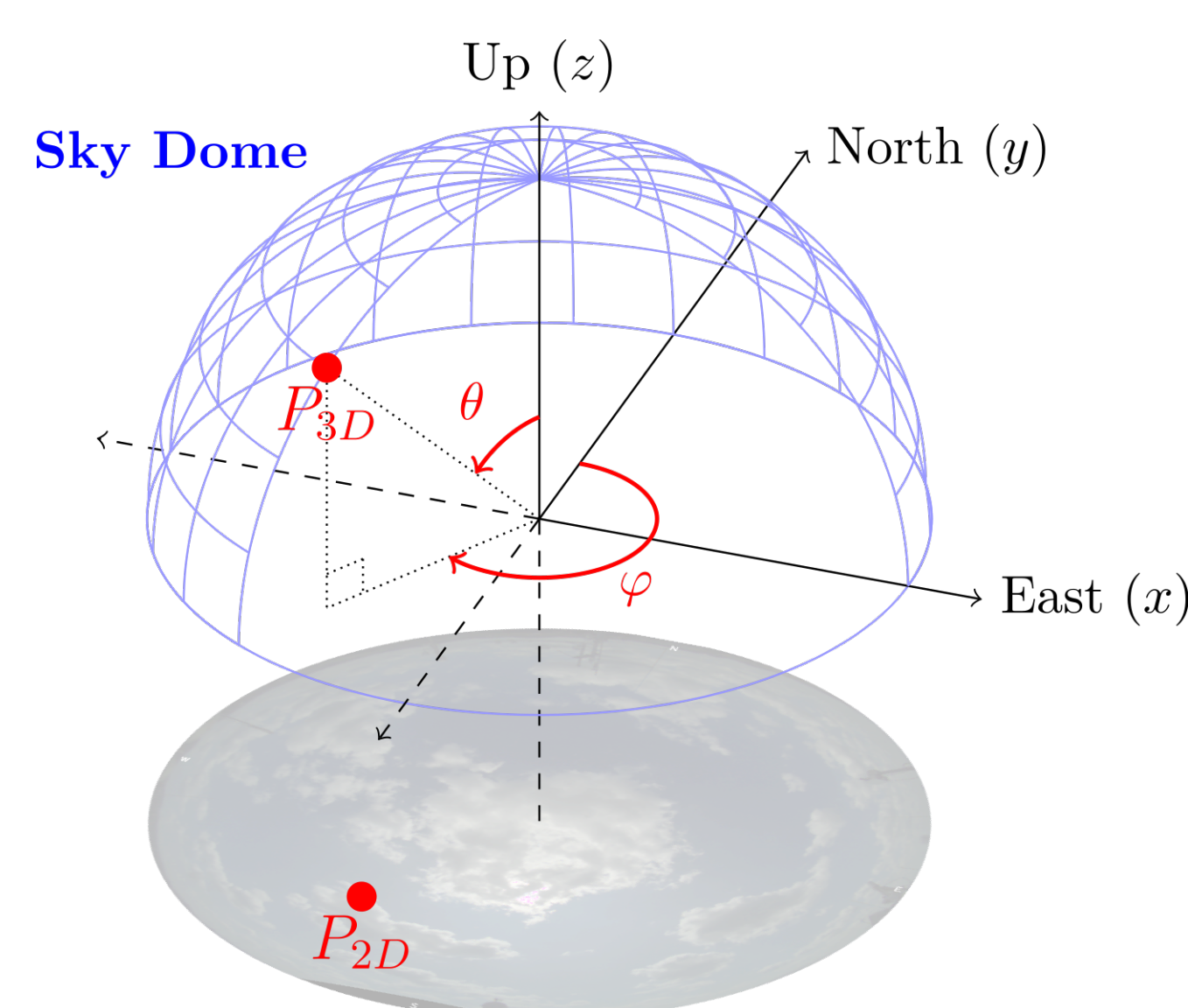
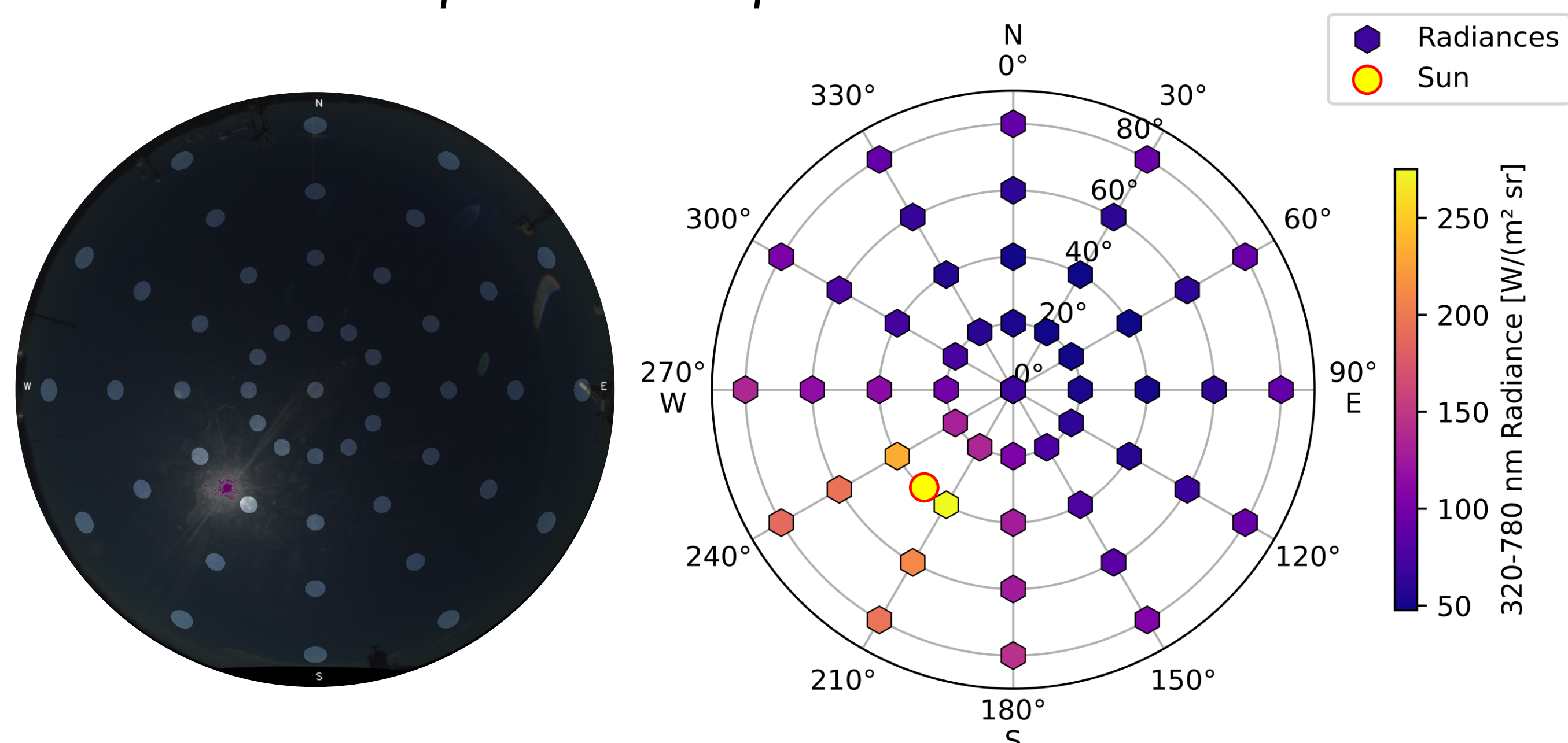


Image coordinates are mapped to local sky coordinates (azimuth φ , zenith θ) by using py-OCamCalib [3] for intrinsic geometric calibration, and a comparison of sun positions from the SG2 algorithm [4] against sun detections for extrinsic geometric calibration. The mapping error is estimated by **comparing detected and estimated sun positions**, and on average **less than 1° of angular error** is achieved.

Angular Error Camera Location	Mean Bias Error [°]	Std. Deviation of Error [°]	Sun Detections #
Sophia Antipolis, France	0.75	0.47	2854
Vienna, Austria	0.41	0.27	3956

3. Radiometric Calibration

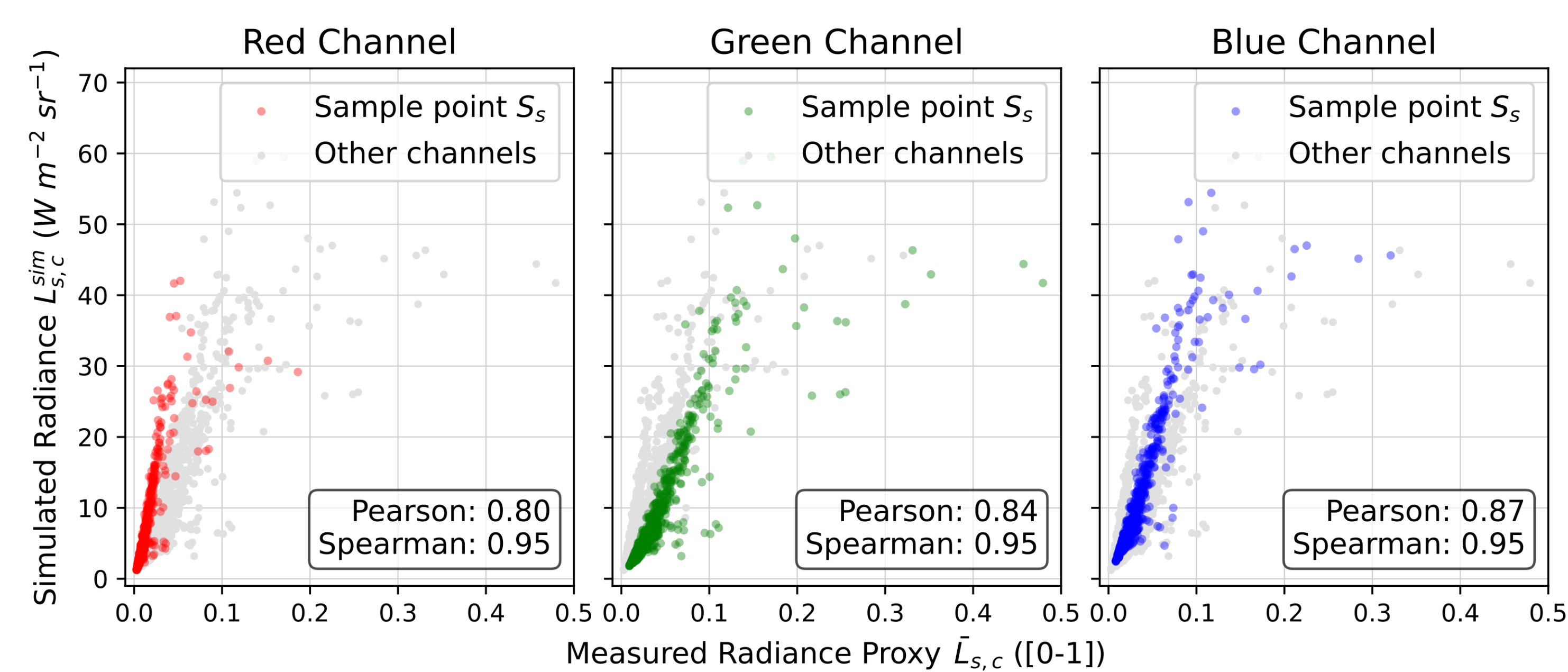
What radiance does a pixel value represent?



Clear Sky Camera Image Patches (left) and Simulated Radiances (right)
(Camera in Vienna, Austria, single point in time, RGB combined)

To calibrate raw image values to sky radiance in $W/(m^2 sr)$, **circular patches of 5° opening angle** are extracted at **fixed sky points** from **high dynamic range images** under clear-sky conditions. For each patch, a corresponding **diffuse sky radiance is simulated** using libRadtran [5], parameterized with data of the atmospheric composition from the Copernicus Atmosphere Monitoring Service (CAM5) [6]. Image values are normalized pixel-wise by solid angle, patches are averaged, and the simulated radiances are filtered and integrated using the sensor's spectral response function.

4. Results and Outlook



Clear Sky Measured Brightness vs. Simulated Radiance
(Camera in Vienna, Austria, 18 time points over two days, N=882 points per channel)

Each **color channel's measured brightnesses** are shown to **relate linearly to the simulated radiances**, which validates our methodology for computing diffuse sky radiance from sky images. Next steps include calibration and validation of the spectral (RGB) and broadband sky radiance with a high-quality pyranometer, and moving to applications like forecasting of the surface downwelling solar resource or atmospheric analysis