An SI-traceable protocol for the validation of radiative transfer model-based BRDF simulation

Vincent Leroy, Sebastian Schunke, Yves Govaerts // Rayference
Robin Aschan, Farshid Manoocheri // Aalto University
Peter Woolliams // NPL

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RAYFERENCE

Aalto University

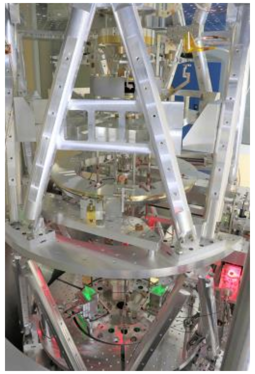
NPL

Metrology for Earth Observation and Climate

Calibration concepts

- In metrology, **calibration** is the comparison of measurement values delivered by a device under test with those of a **calibration reference** of known **accuracy**.
- Such a reference could be
  - another measurement device of **known accuracy,**
  - a device generating the quantity to be measured,
  - or a physical artefact.



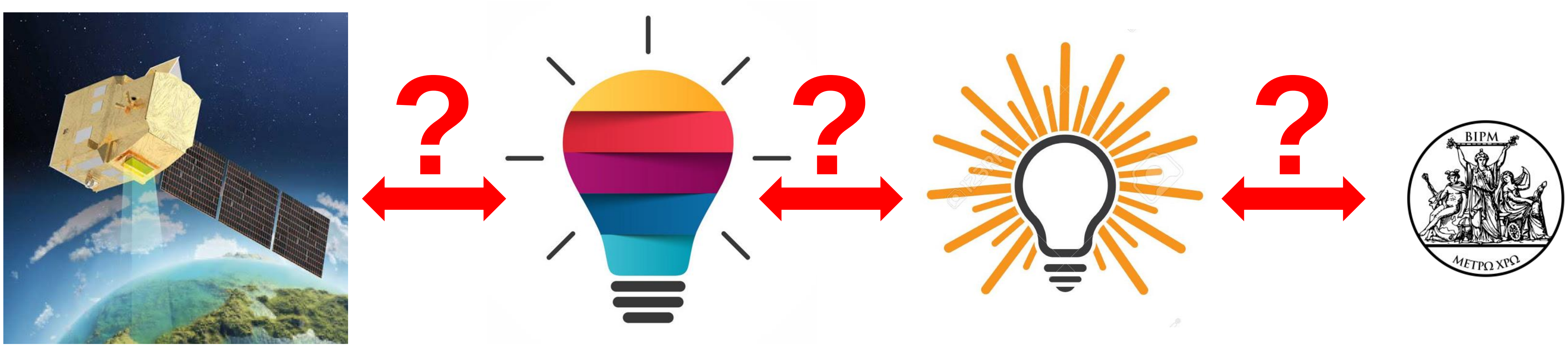



Calibration concepts

User | **Factory** | **Country** | **BIPM**

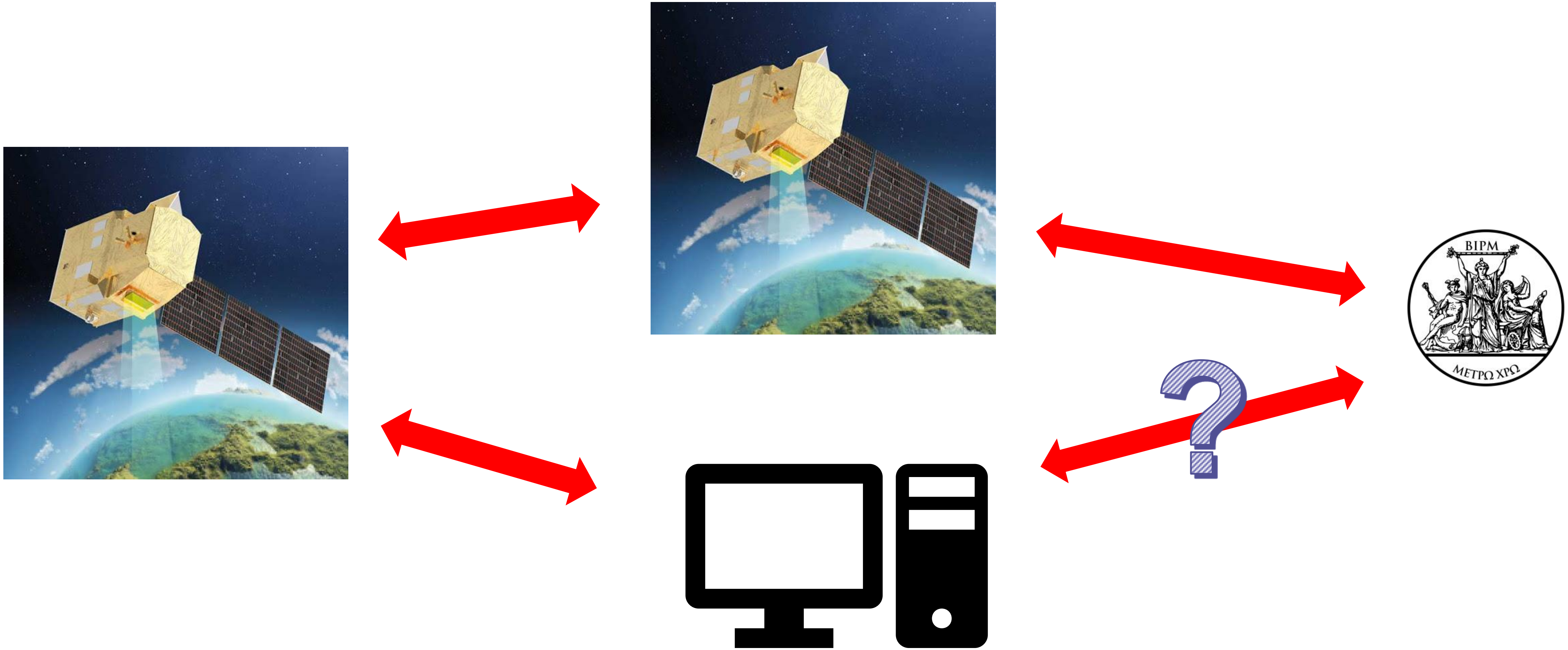
ε''' ε'' ε' ε

Calibration concepts

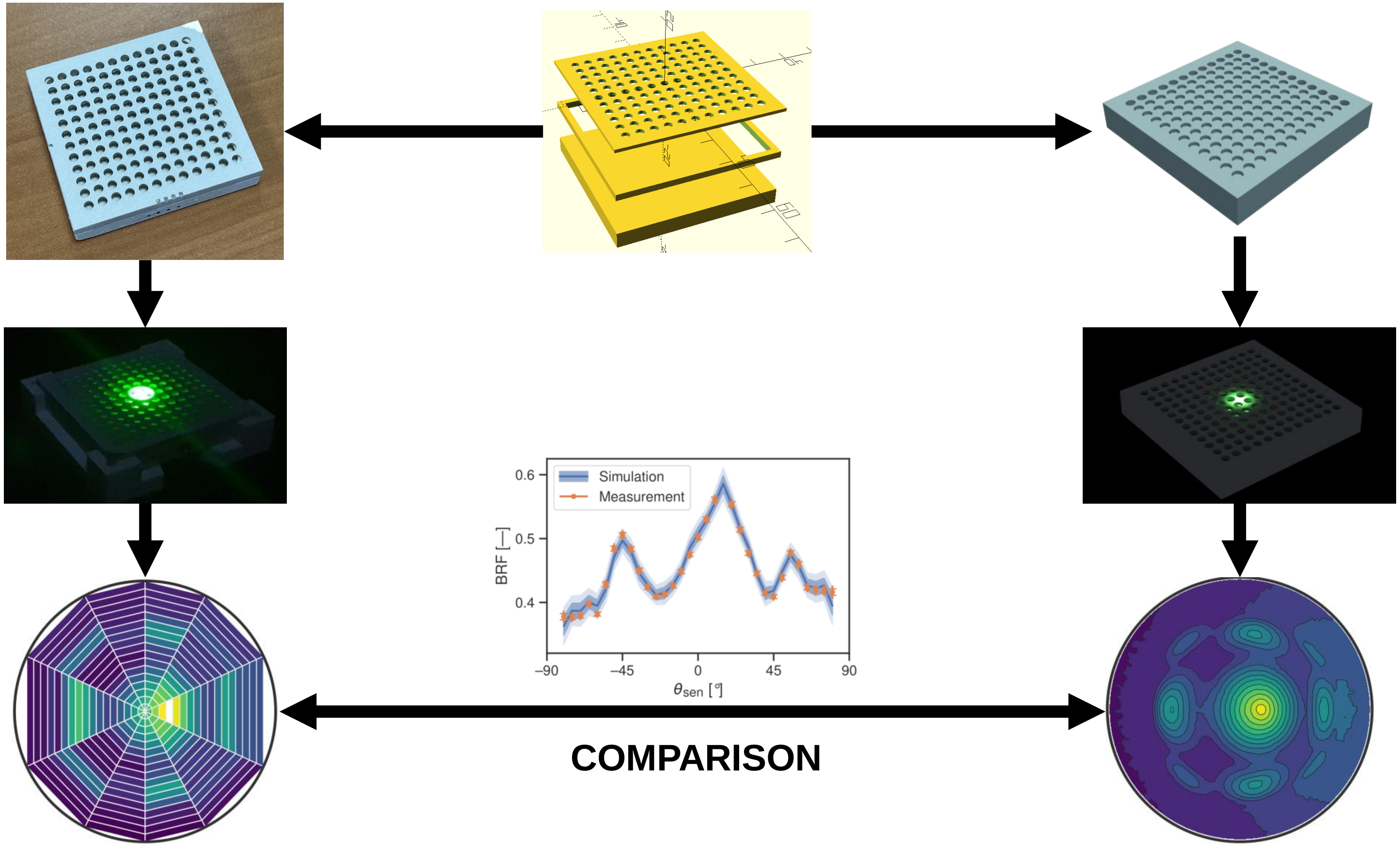


ε''' ε'' ε' ε

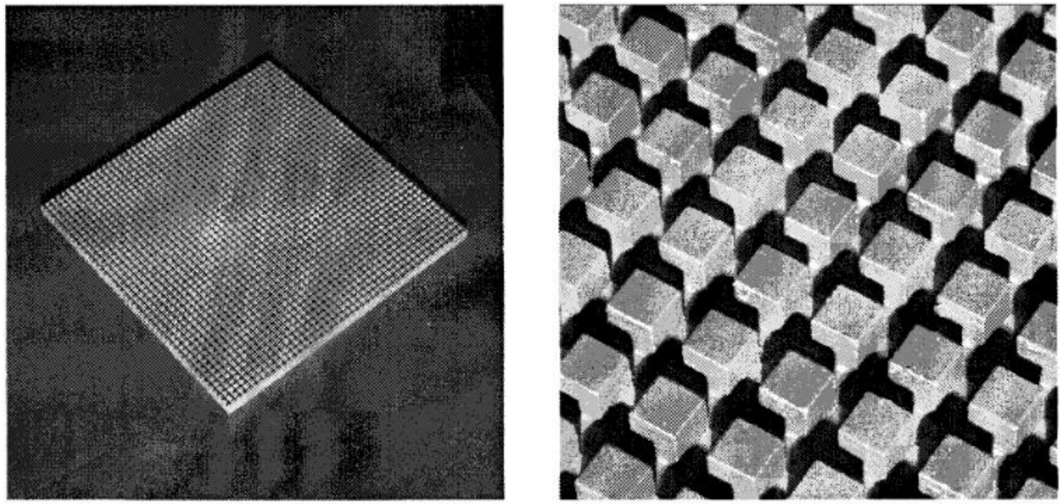
Vicarious calibration



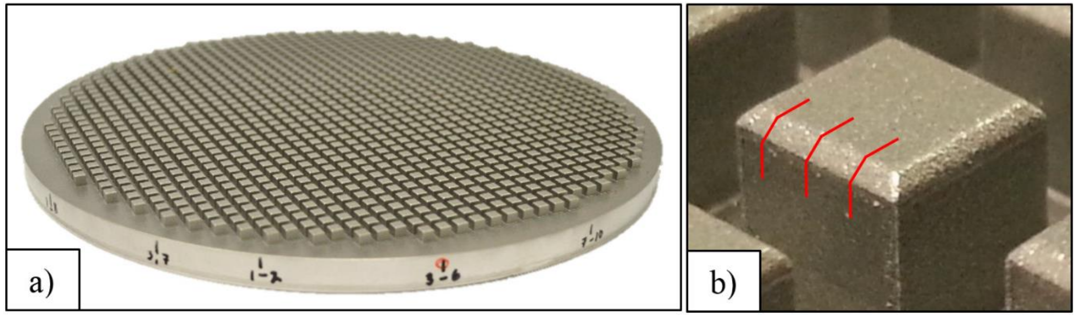
RTM validation protocol



Prior attempts



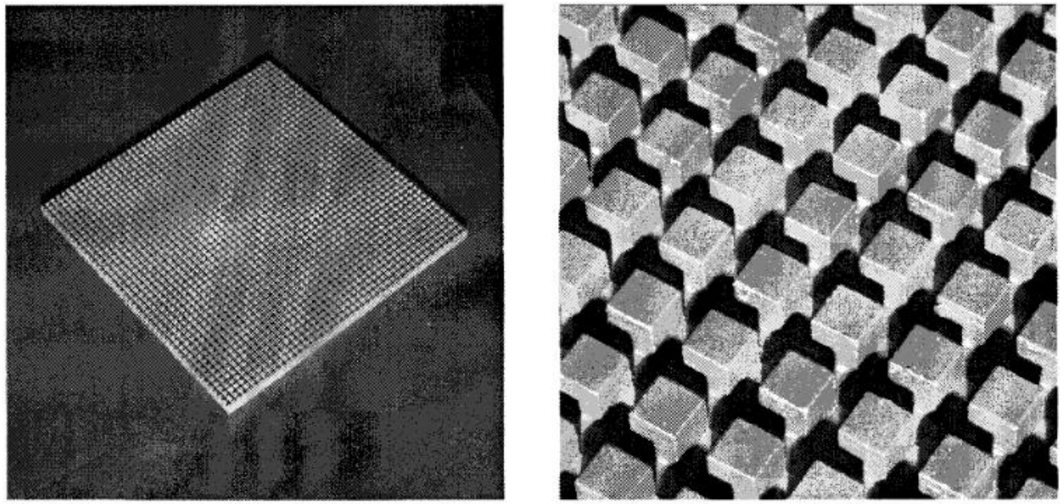
Govaerts & Verstraete (1998) DOI: 10.1109/36.662732



Jaanson et al. (2018) DOI: 10.1109/TGRS.2017.2761988

- RTM: Raytran
- Target: grooved design (“waffle”), metallic material (strong specular reflective lobe)
- Material model: fitted Torrance-Sparrow

Prior attempts



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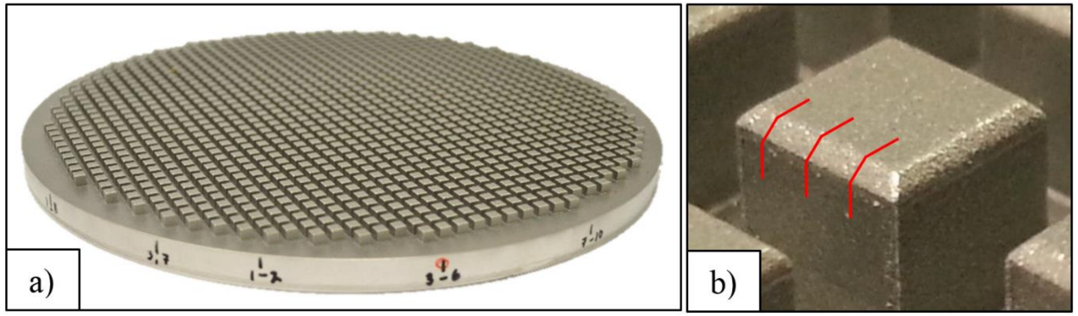
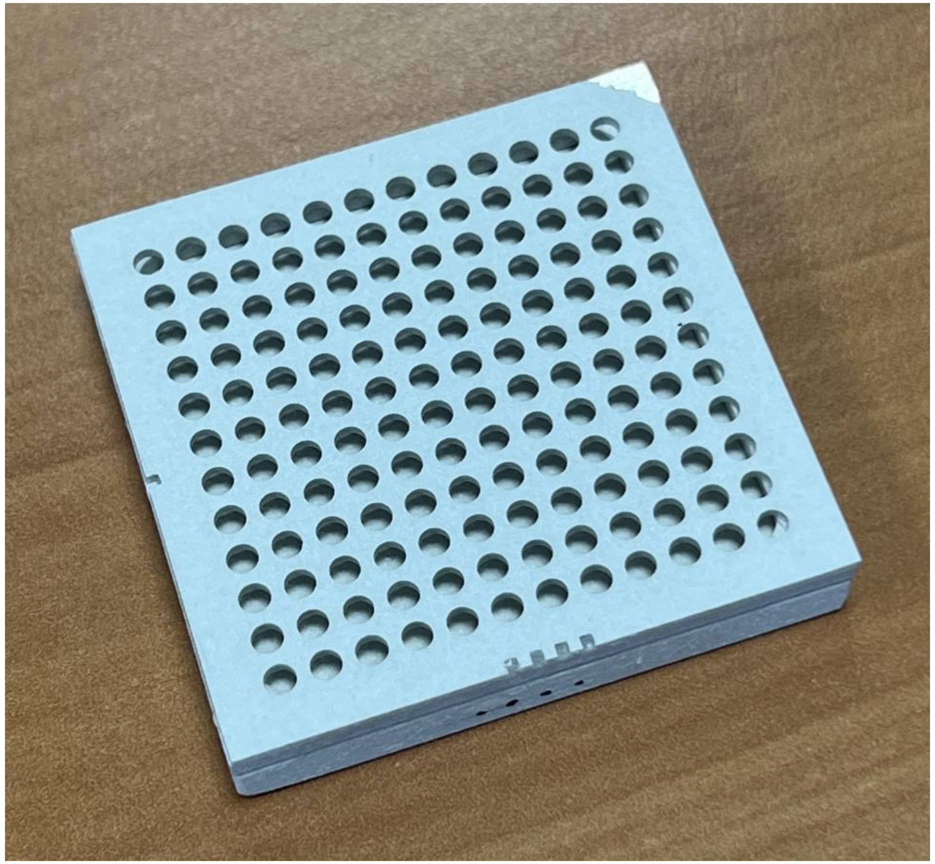


Jaanson et al. (2018) DOI: 10.1109/TGRS.2017.2761988

- No SI-traceability
- No uncertainty quantification

- Added SI-traceability and uncertainty quantification
- Metrics account for uncertainty

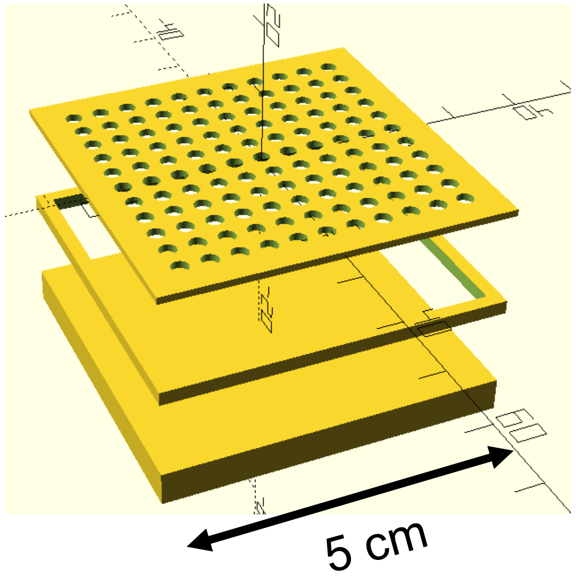
Our method



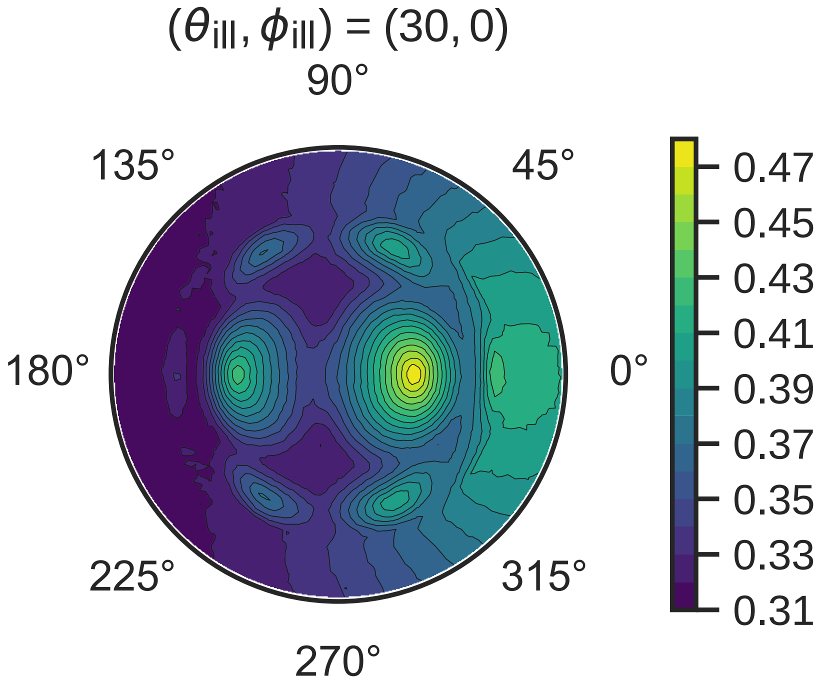
- RTM: Eradiate
- Target: two-layer design, diffuse coating
- Material model: data-driven tabulated BRDF model
- SI-traceable measurements, uncertainty quantification
- Metrics account for uncertainty

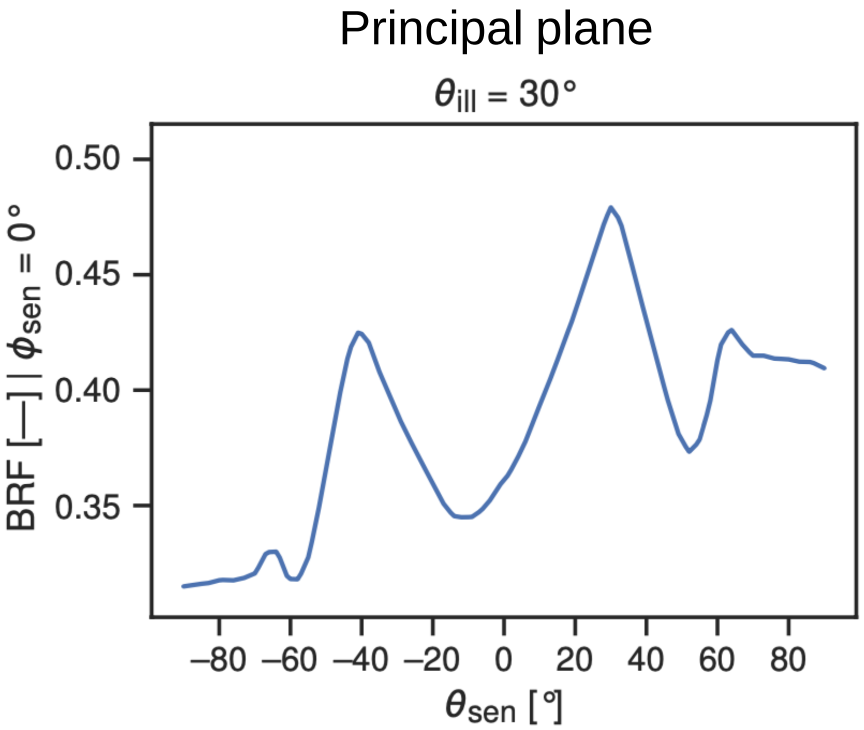
Target design: Controlled reflective peaks

Final design

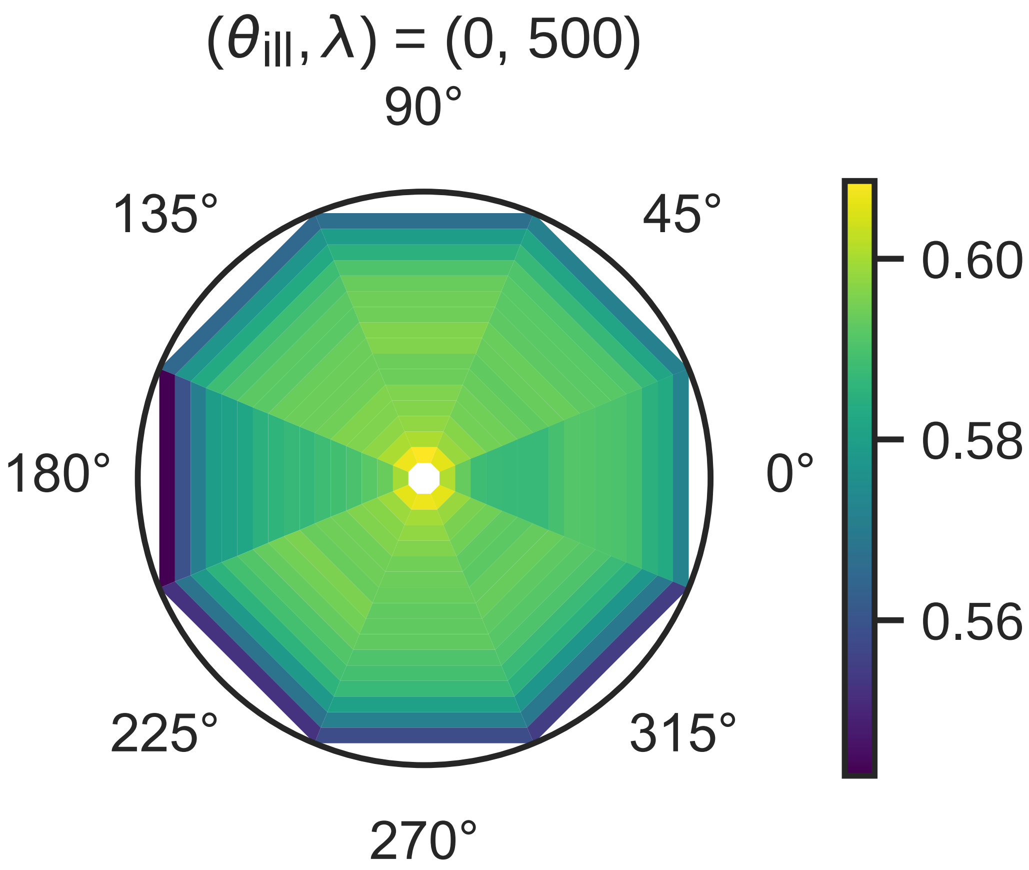


Simulated reflectance





Selected material: As diffuse as possible



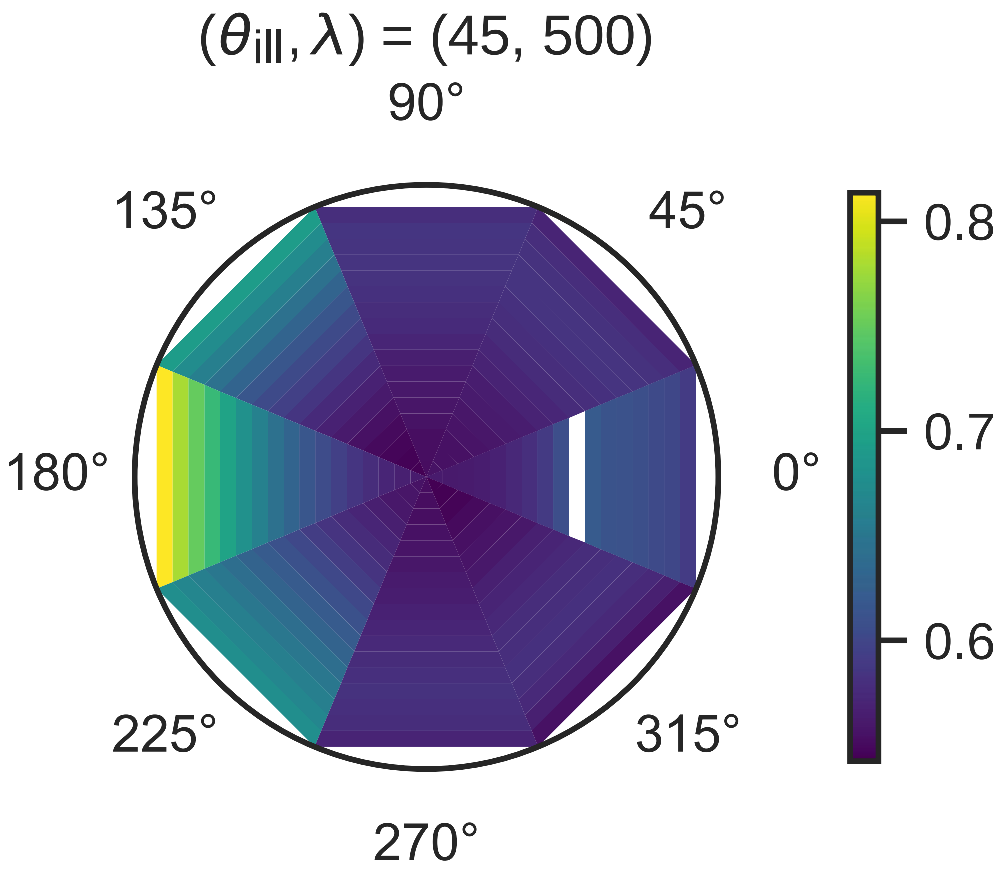
Selected material is as close to Lambertian as possible

⇒ Uniform, isotropic material

⇒ Simple data-driven BRDF model

⇒ No fitting: Reduced uncertainty

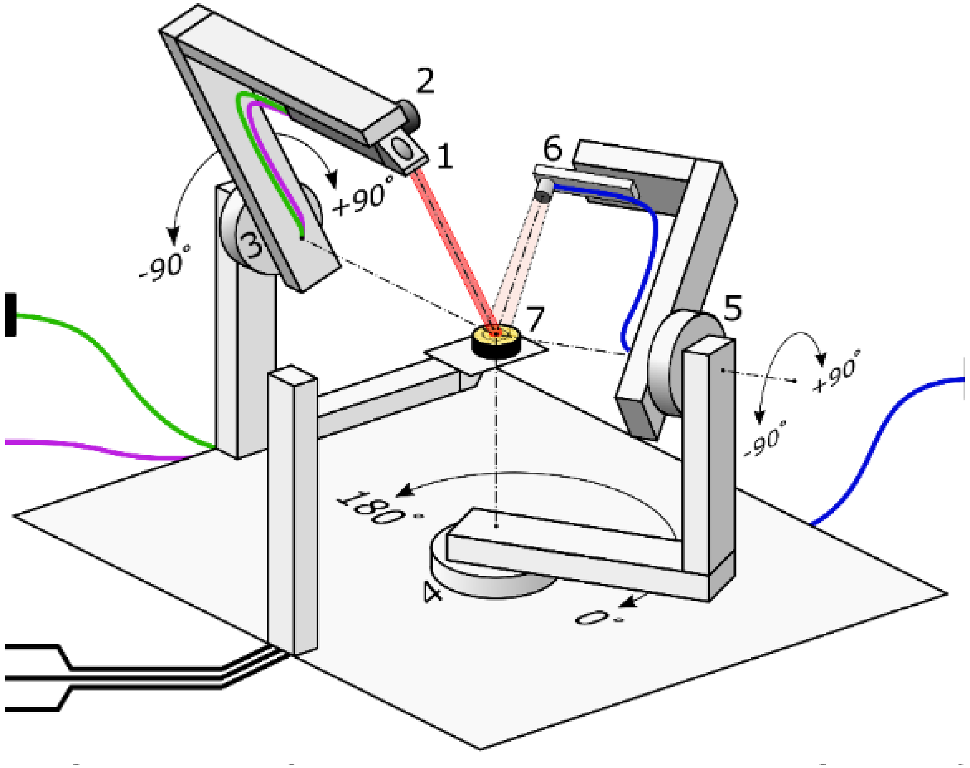
Selected material: As diffuse as possible



Departure from Lambertian behaviour as illumination zenith angle increases

⇒ Source of uncertainty

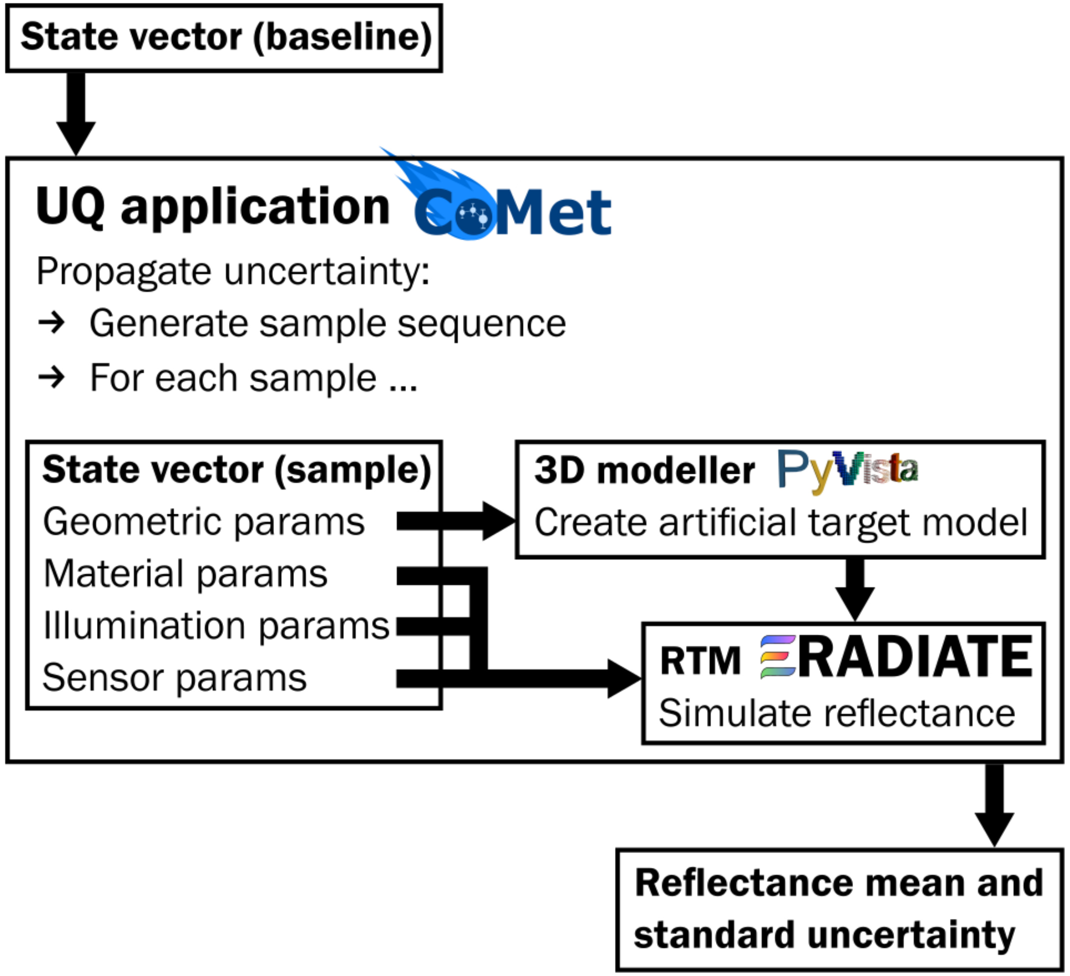
Measurement facility: SI-traceable 3D goniophotometer



Lanevski et al. (2022) DOI: 10.1088/1681-7575/ac55a7

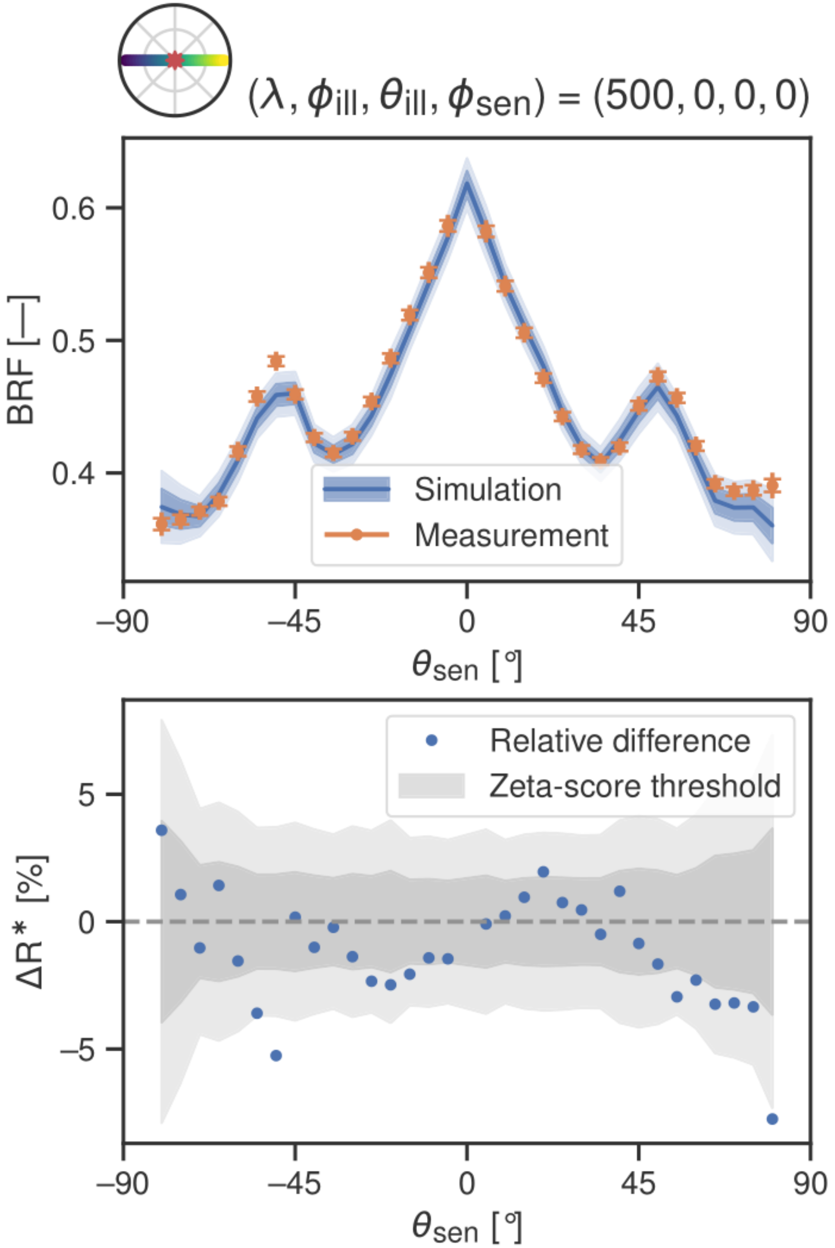
- Measures sample reflectance in 3D (θ_{ill}, φ_{sen}, θ_{sen}) space
- Traceable to SI through reference absolute goniophotometer
- Sample alignment done manually w/ check vs reference goniometer
  ⇒ Additional, unknown uncertainty

Uncertainty propagation



- RTM runs are encapsulated in an uncertainty propagation application based on the CoMet library
- Monte Carlo method required: Highly dimensional state vector (1000+ variables)

Comparison method



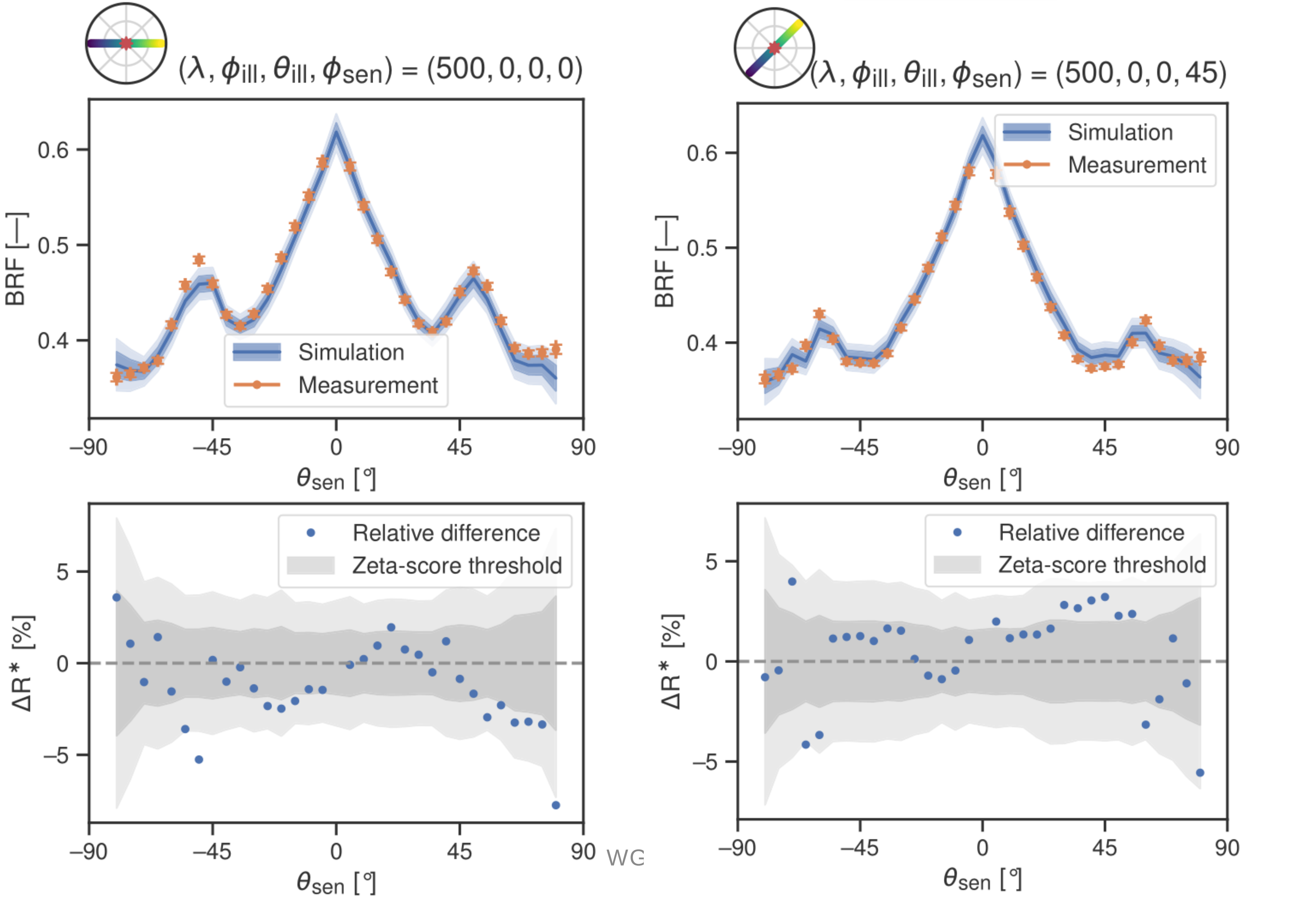
Simulations / measurements comparison metric:

$$\Delta R^* = \left| \frac{R_{sim} - R_{mes}}{R_{mes}} \right| < \alpha \cdot \frac{\sqrt{\sigma_{sim}^2 + \sigma_{mes}^2}}{R_{mes}}$$

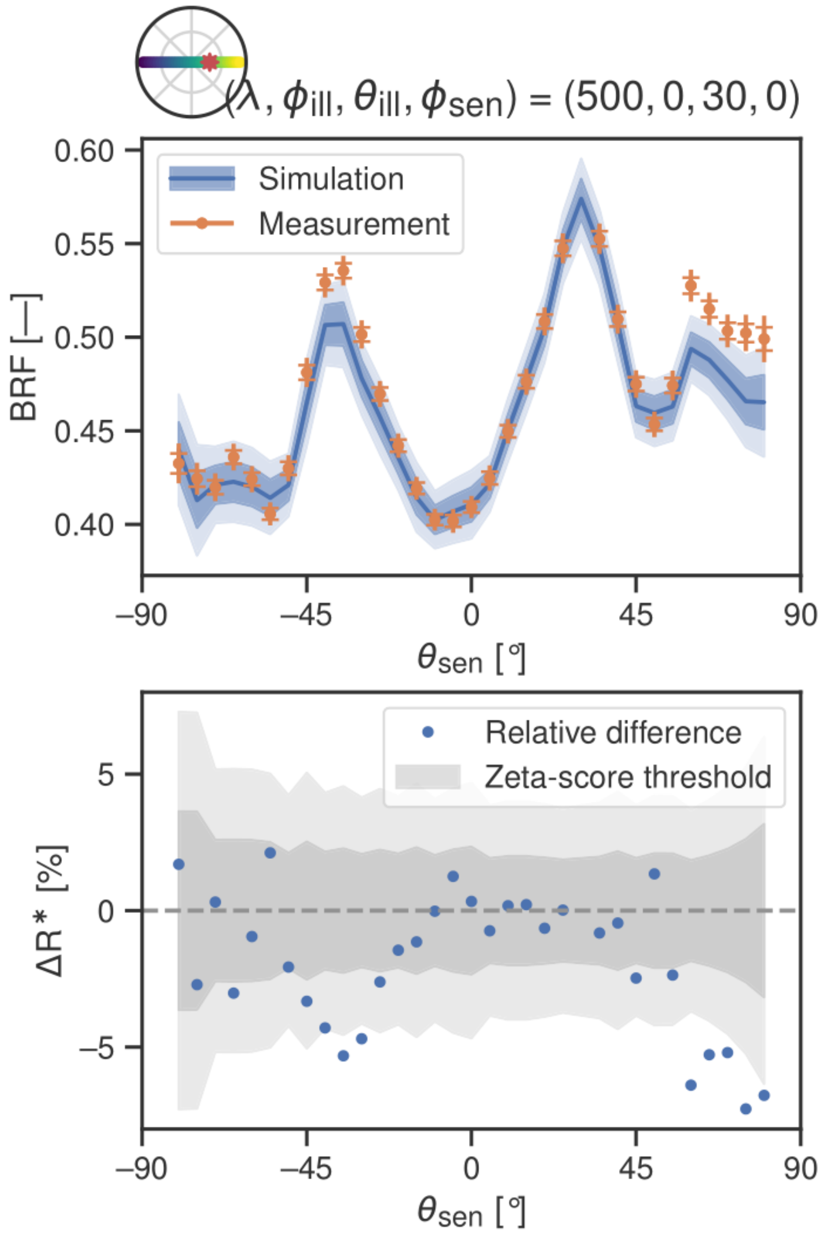
α = 1 or 2

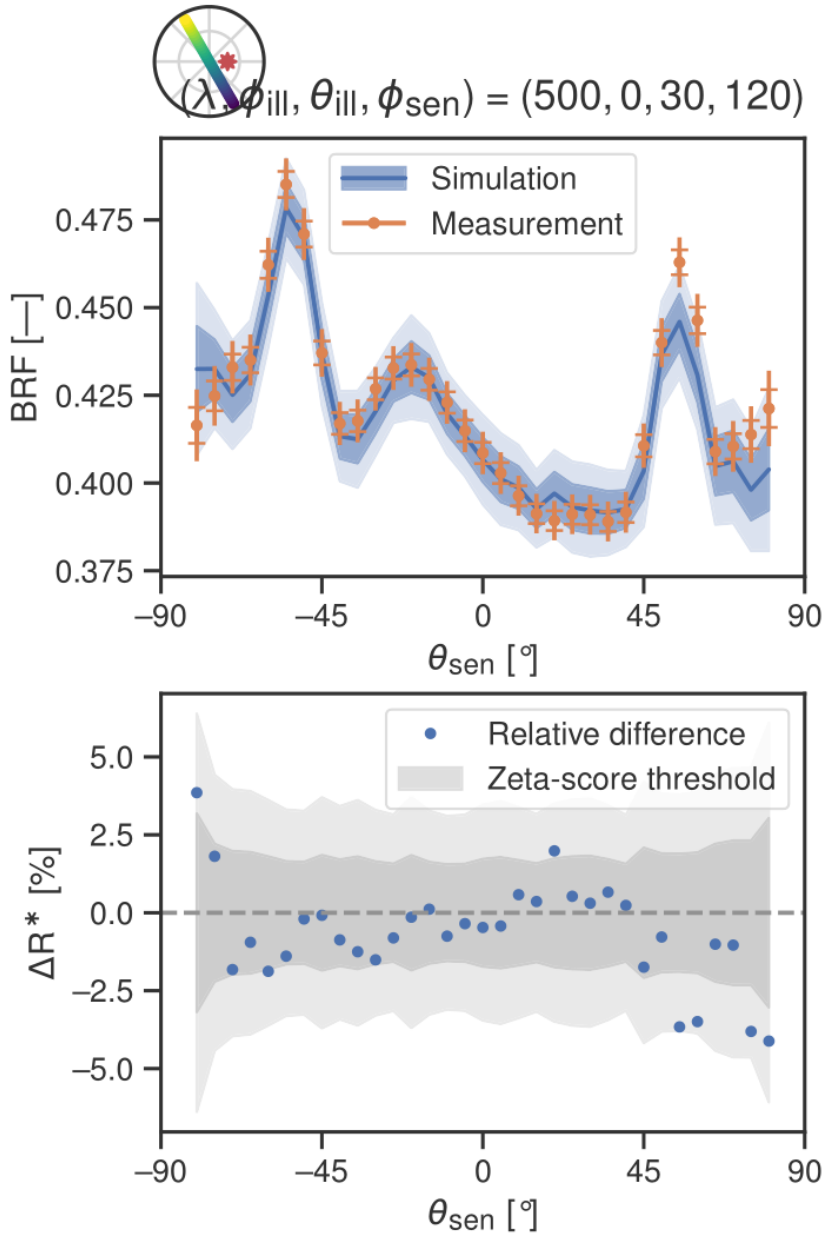
⇒ Account for uncertainties on both series

Very good agreement near nadir



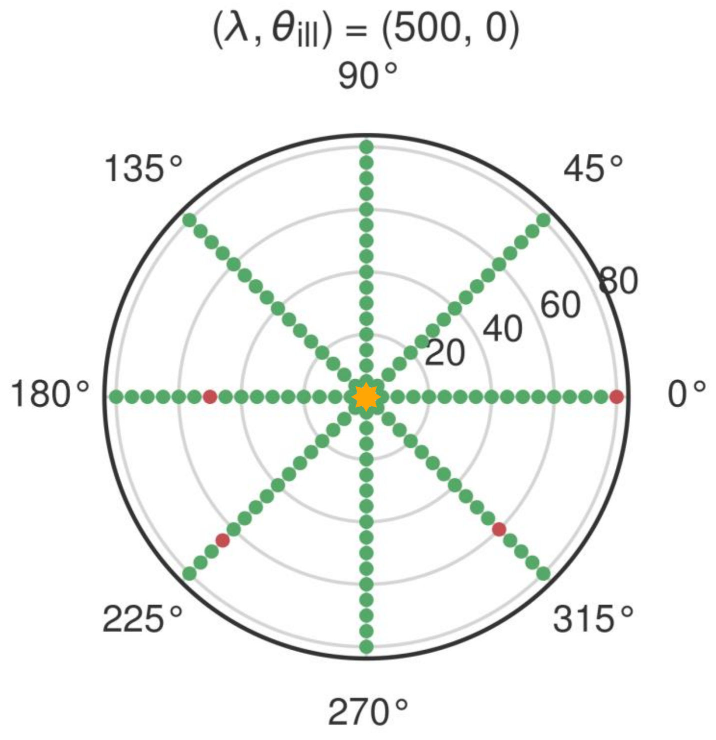
More discrepancies at higher zenith angles

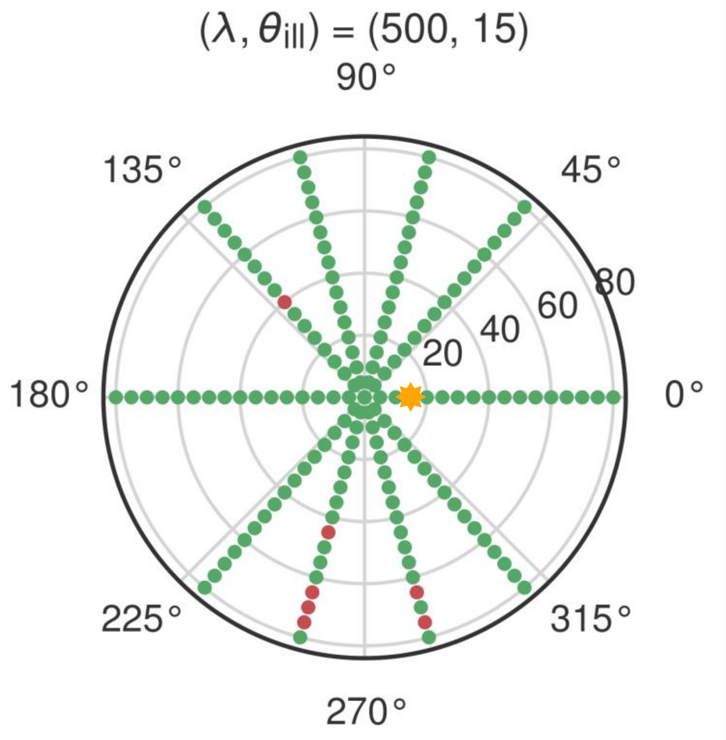


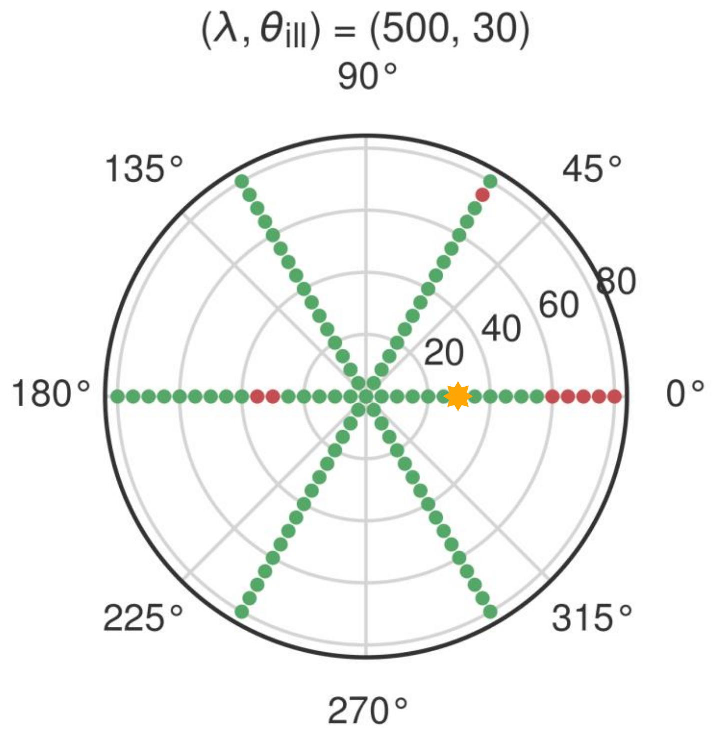


Overall good pass rate

≈ 97% ≈ 96% ≈ 92%







Similar performance in and out of the principal plane

Conclusions

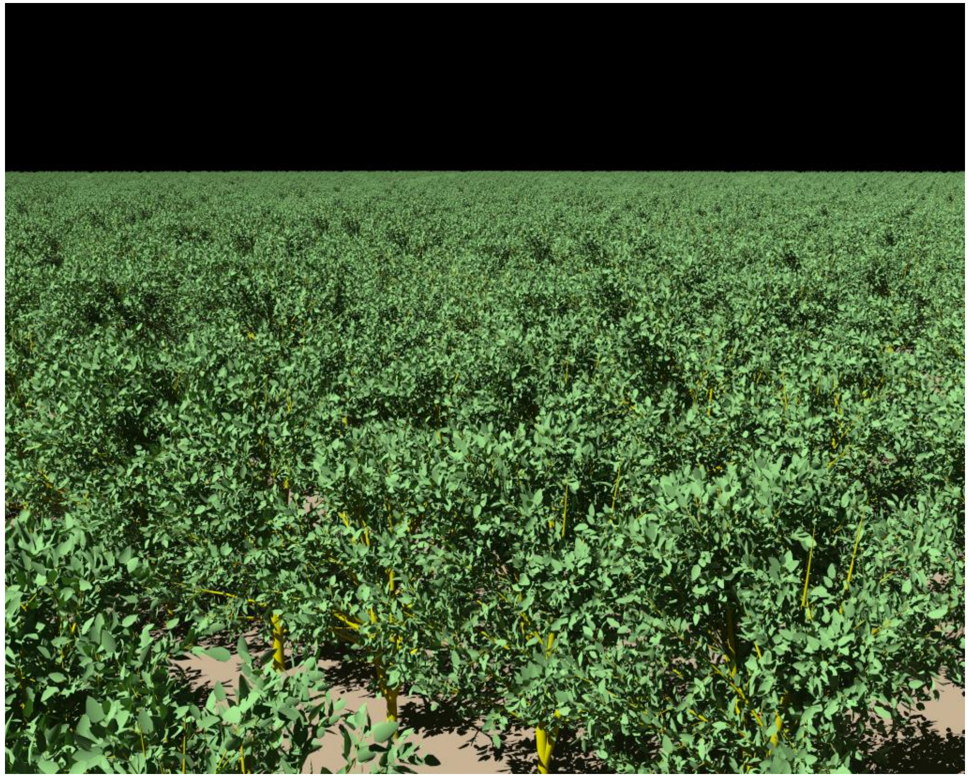
- We present an RTM validation protocol using SI-traceable lab measurements on an artificial target.
- Major point: Improve material characterization and modelling (**data-driven model**) with careful material selection and manufacturing process control.
- Results show general agreement within 2σ (many samples w/ relative bias $\lesssim$ 2%).
  - Similar performance in and out of principal plane.
- Remaining issues:
  - Material reflectance data is sparse and misses critical data points.
    $\Rightarrow$ Increased bias at high zenith values.
  - Sample alignment is manual and introduces hard-to-quantify uncertainty.

Outlook

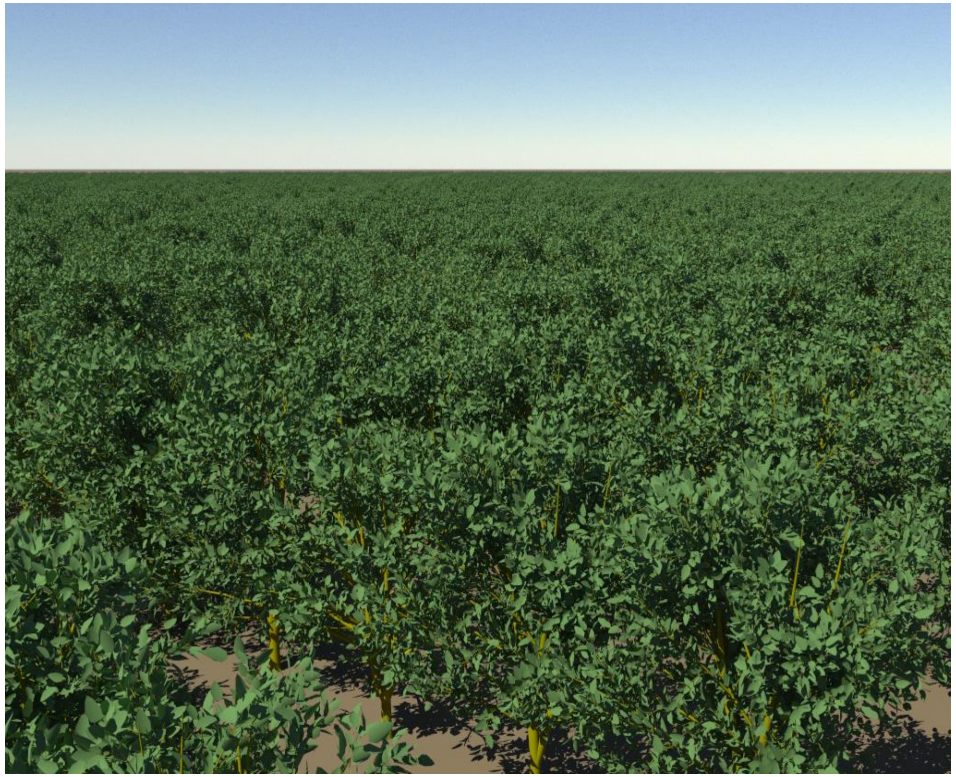
- Further iterate: Generate new material and artefact reflectance datasets learning from this iteration (improve material model and sample alignment).
- **Extension: Develop a similar protocol for validation of satellite measurement simulation.**

Outlook

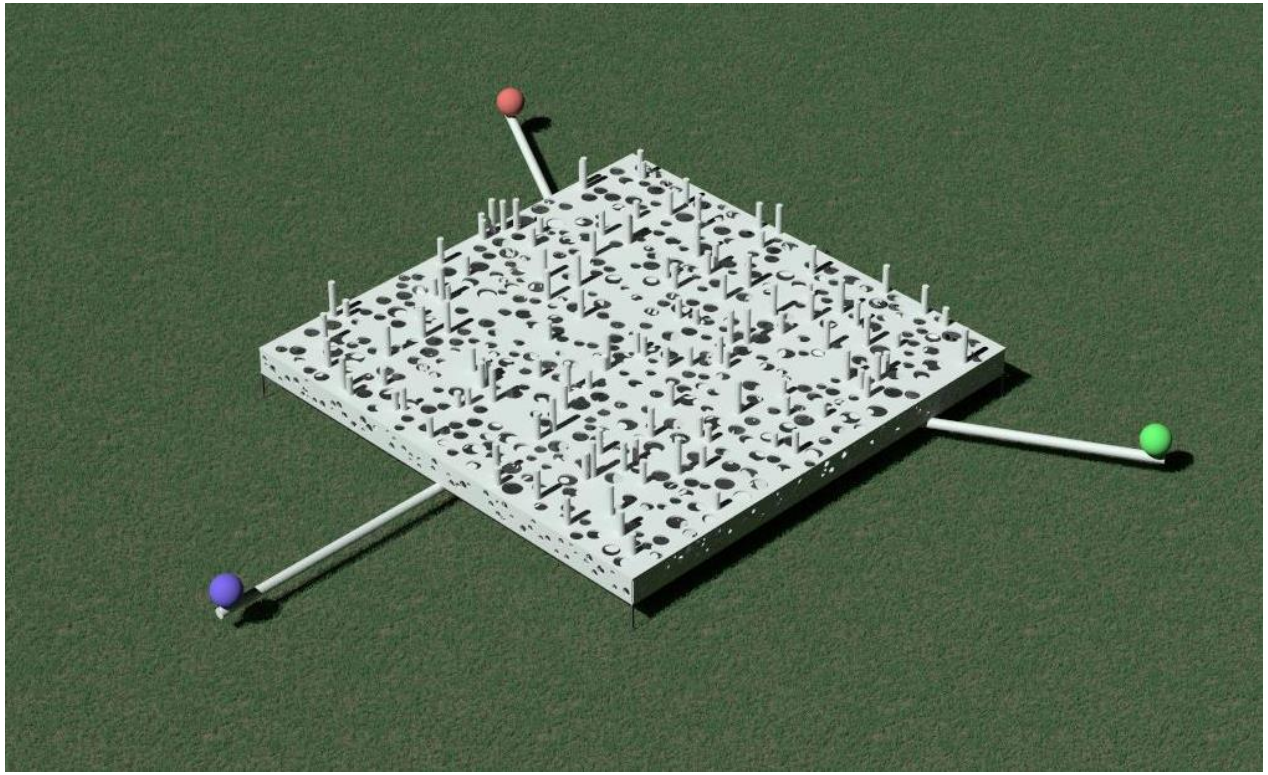
This protocol: no atmosphere



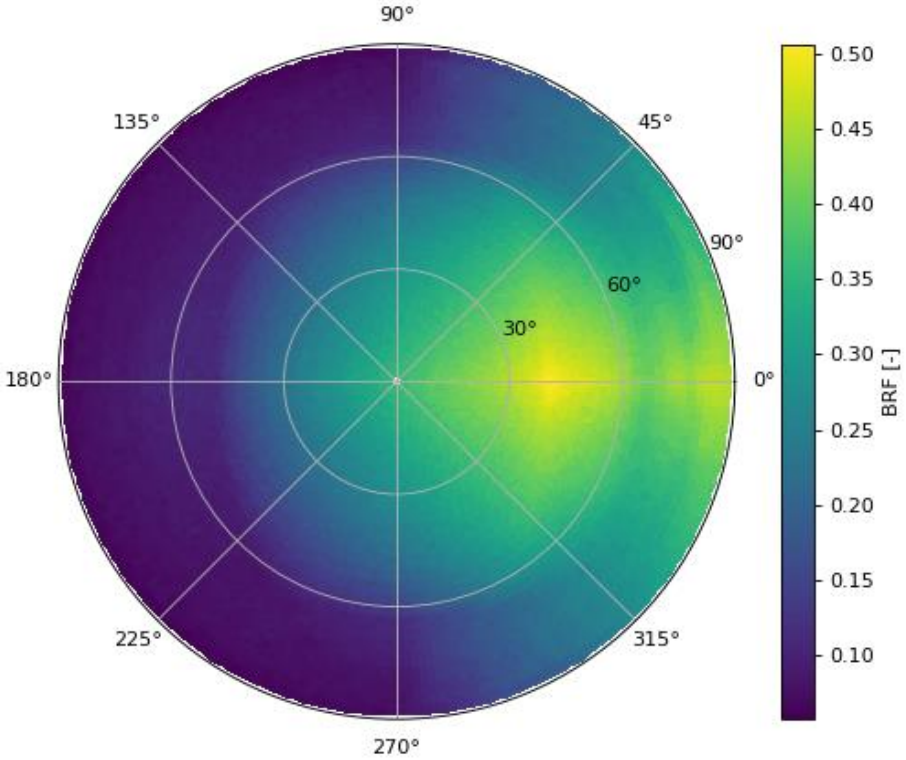
Practical usage: atmosphere!



Outlook



BRF / Black-sky surface reflectance



All simulations done with ERADIATE

Visit **www.eradiate.eu**

Questions?

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EMPIR EURAMET

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