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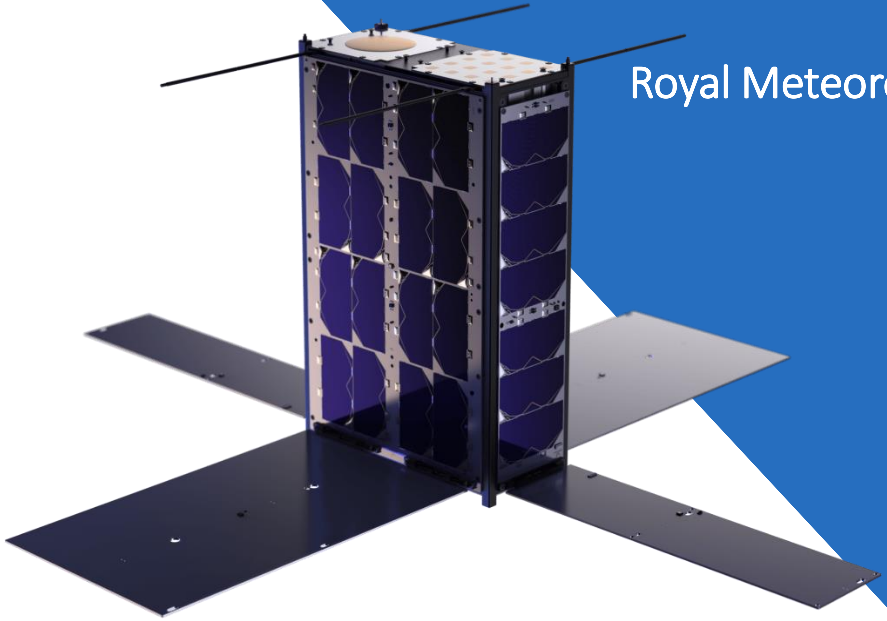
ASTERIX: a CubeSat to measure the Total Solar Irradiance and Earth's radiation budget for climate monitoring



Luca Schifano – Royal Meteorological Institute of Belgium; Vrije Universiteit Brussel, Brussels Photonics

IPC-XIII – October 5, 2021

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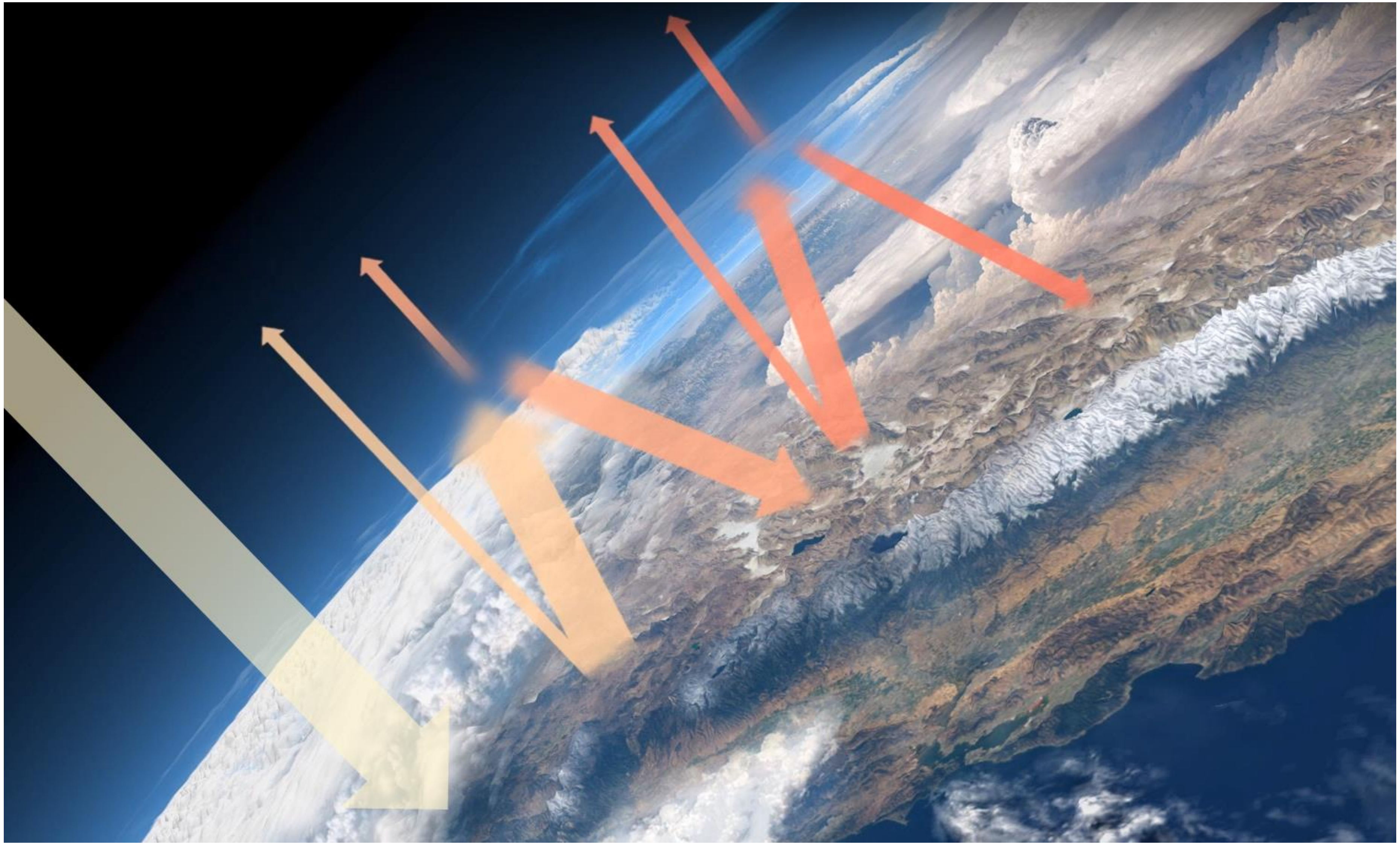
Earth's radiation budget



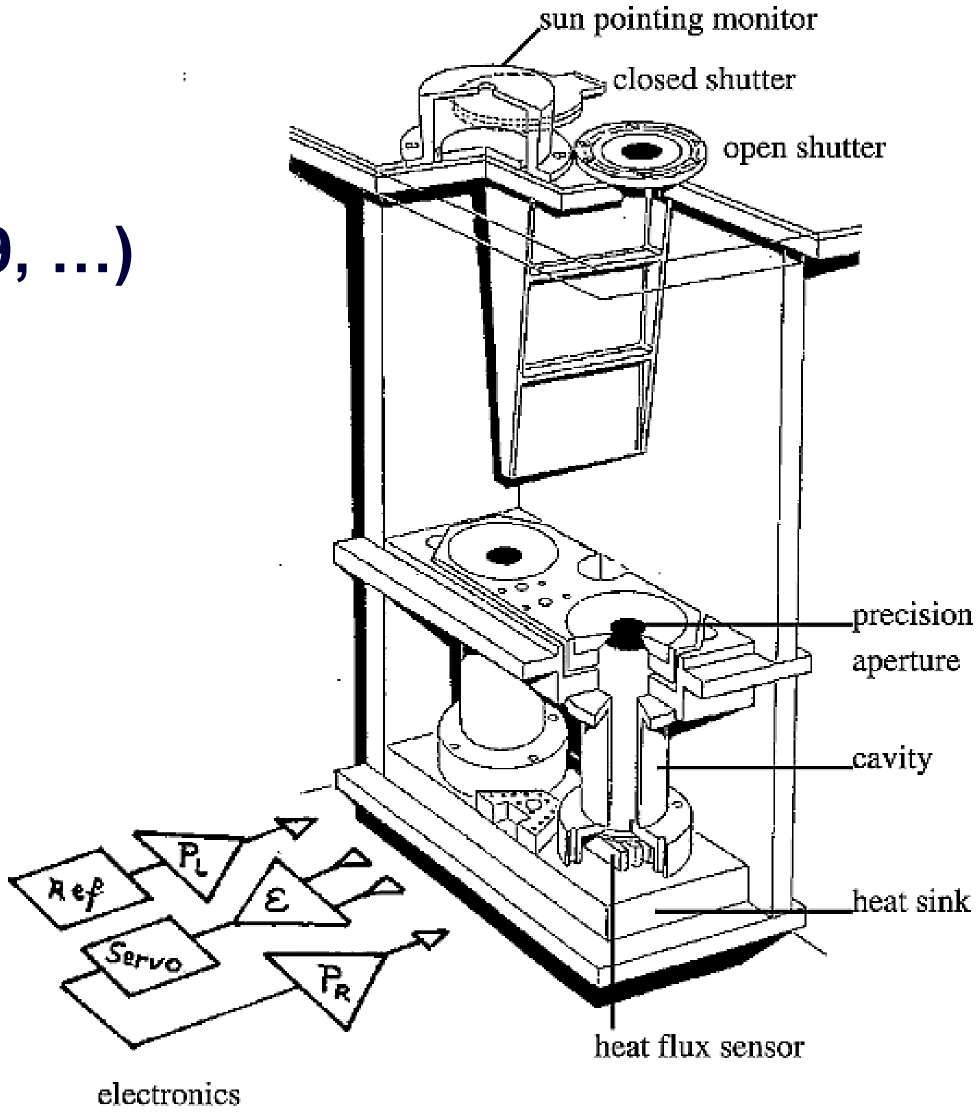
Heritage of Crommelynck: TSI monitoring

- Ground-based radiometers:

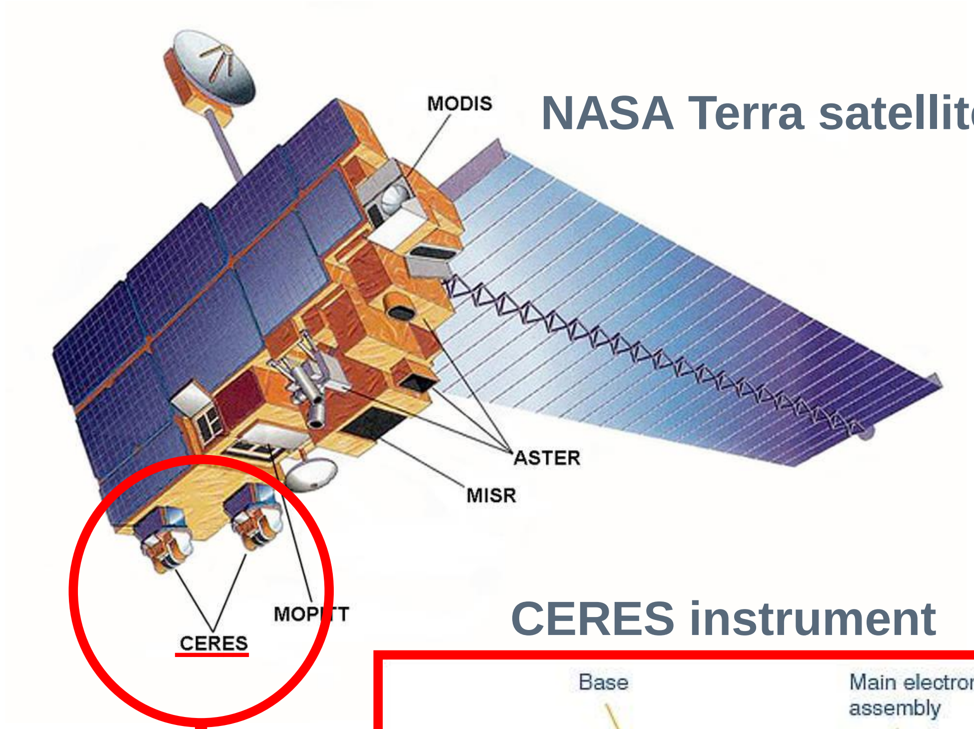
  CROM (CR02, CR05, CR09, …)

- Space-based radiometers:

  Diarad/SOVA
  Diarad/SOLCON
  Diarad/VIRGO
  Diarad/SOVIM
  Diarad/SOVAP

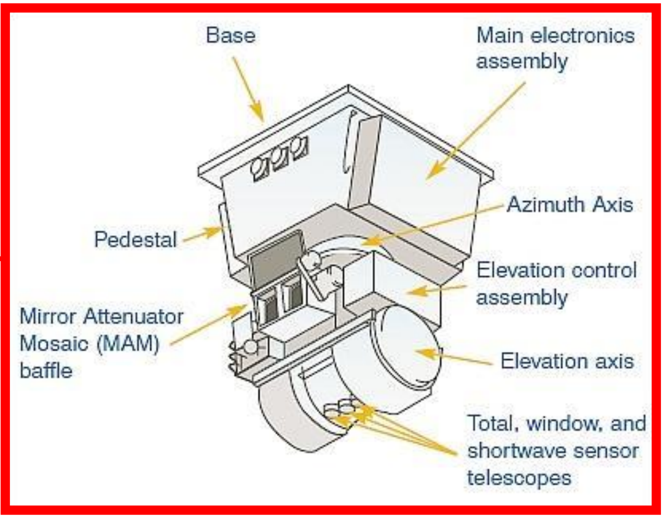


Scanning vs non-scanning radiometers?



NASA Terra satellite

CERES instrument



<u>Scanning (narrow field of view)</u>

- Earth-observation satellite
- Spatial resolution = 20 km on Aqua and Terra (at 700 km altitude)
- Spatial resolution = 10 km (TRMM)
- 3 channels: Total, SW and LW

<u>Does not measure TSI</u>

Heritage of Crommelynck: TSI monitoring

- Ground-based radiometers:

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  Diarad/SOVA
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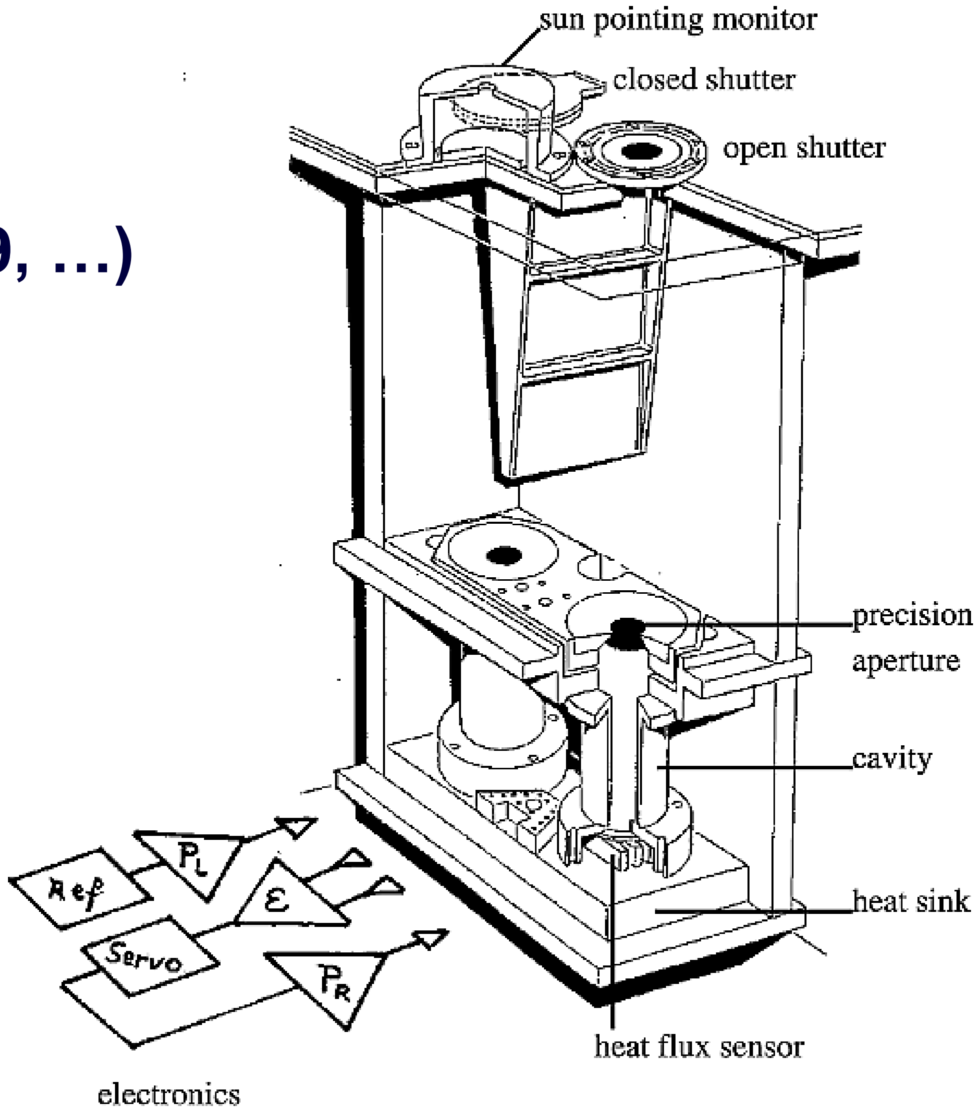
  SIMBA

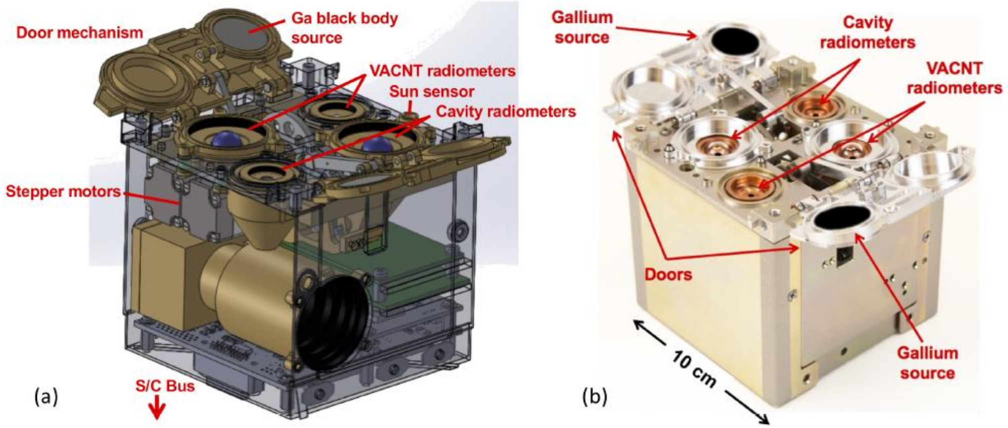


Scanning vs non-scanning radiometers?

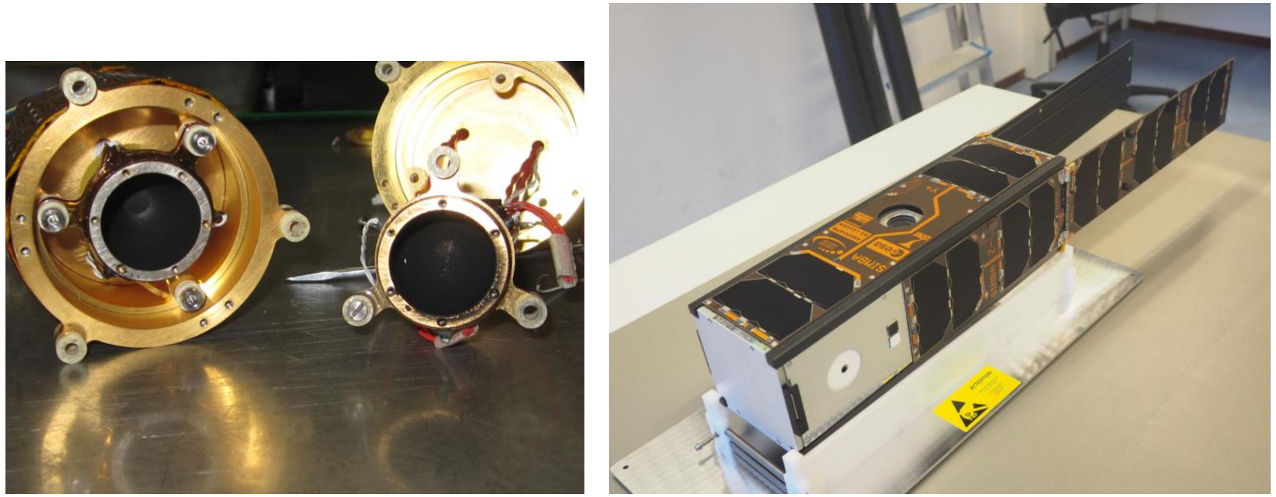
Observing the Sun and the Earth with the same instrument

Scanning vs non-scanning radiometers?

Non-scanning (wide field of view)



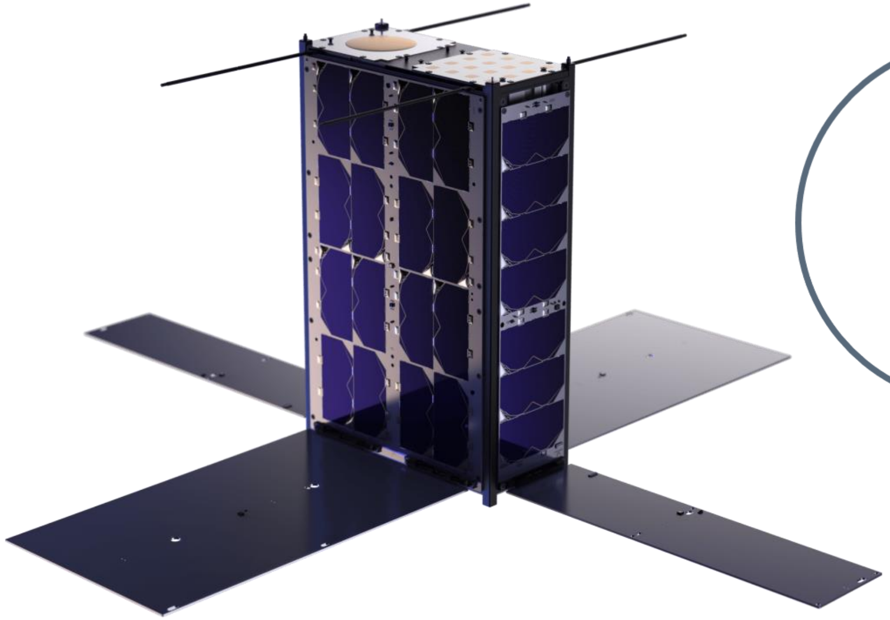
RAVAN (LASP)



SIMBA (RMIB)

CLARA/NorSat-1 (PMOD/WRC)

Next space mission at RMIB?



WFOV radiometer

WFOV SW camera

WFOV LW camera

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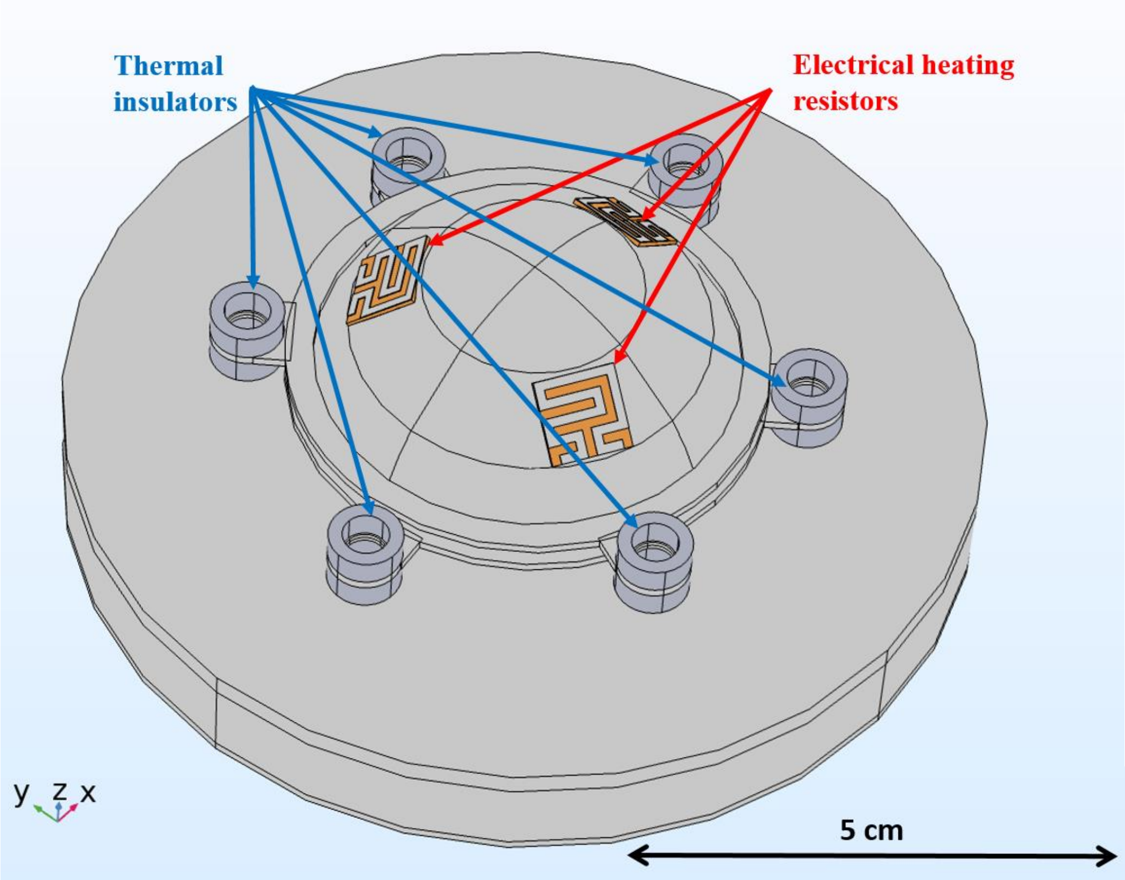
- Monitoring the Earth’s radiation budget and its components from space, in the context of climate change
- **Low-cost** space mission: **6U CubeSat**
- **High scientific yield**

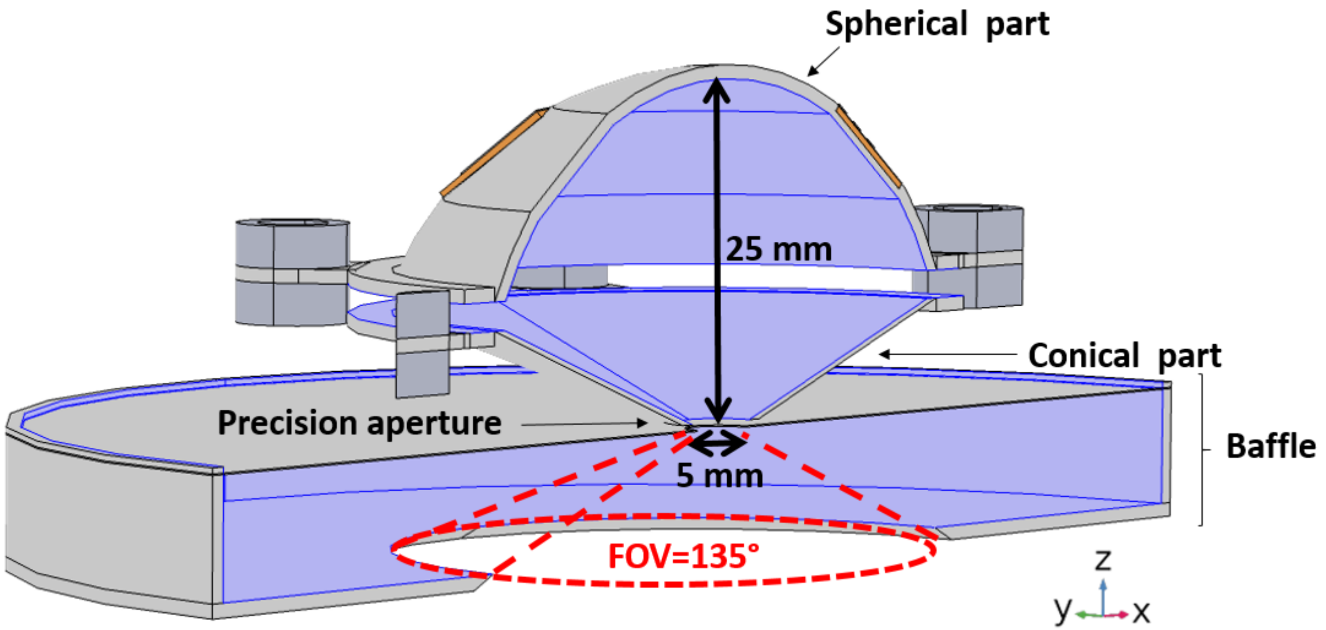
General targeted specifications

- **CubeSat size: 6U (1U per instrument)**
- **Targeted accuracy: 1 W/m² (global annual mean ERB)**
- **Targeted spatial resolution: 5 km (in SW and LW)**
- **Targeted launch date: 2026-2030**

WFOV radiometer

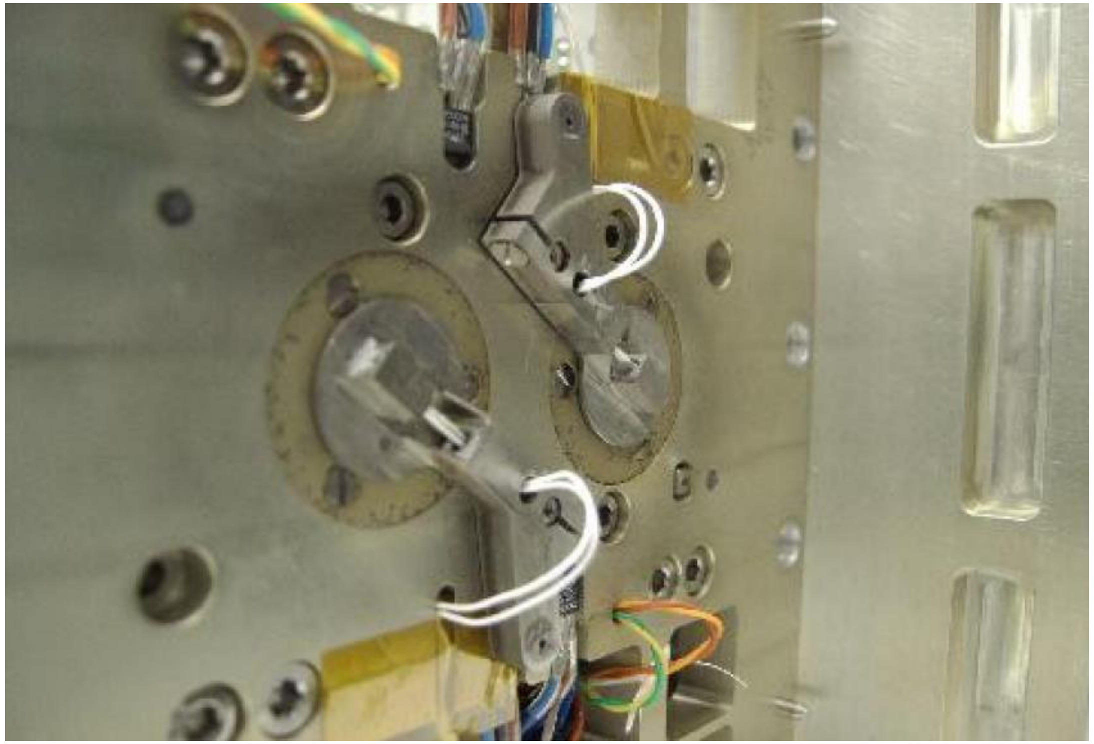
Our in-house developed radiometer





L. Schifano et al. (2020), Design and Analysis of a Next-Generation Wide Field-of-View Earth Radiation Budget Radiometer

Shutter operation



- Major issue: **thermal offset**
- **Solution: shutter**

→ Measure = open – closed
→ removes slowly varying thermal offsets

- Absolute accuracy
  estimated to 0.44 W/m² (<1 W/m²)

WFOV cameras

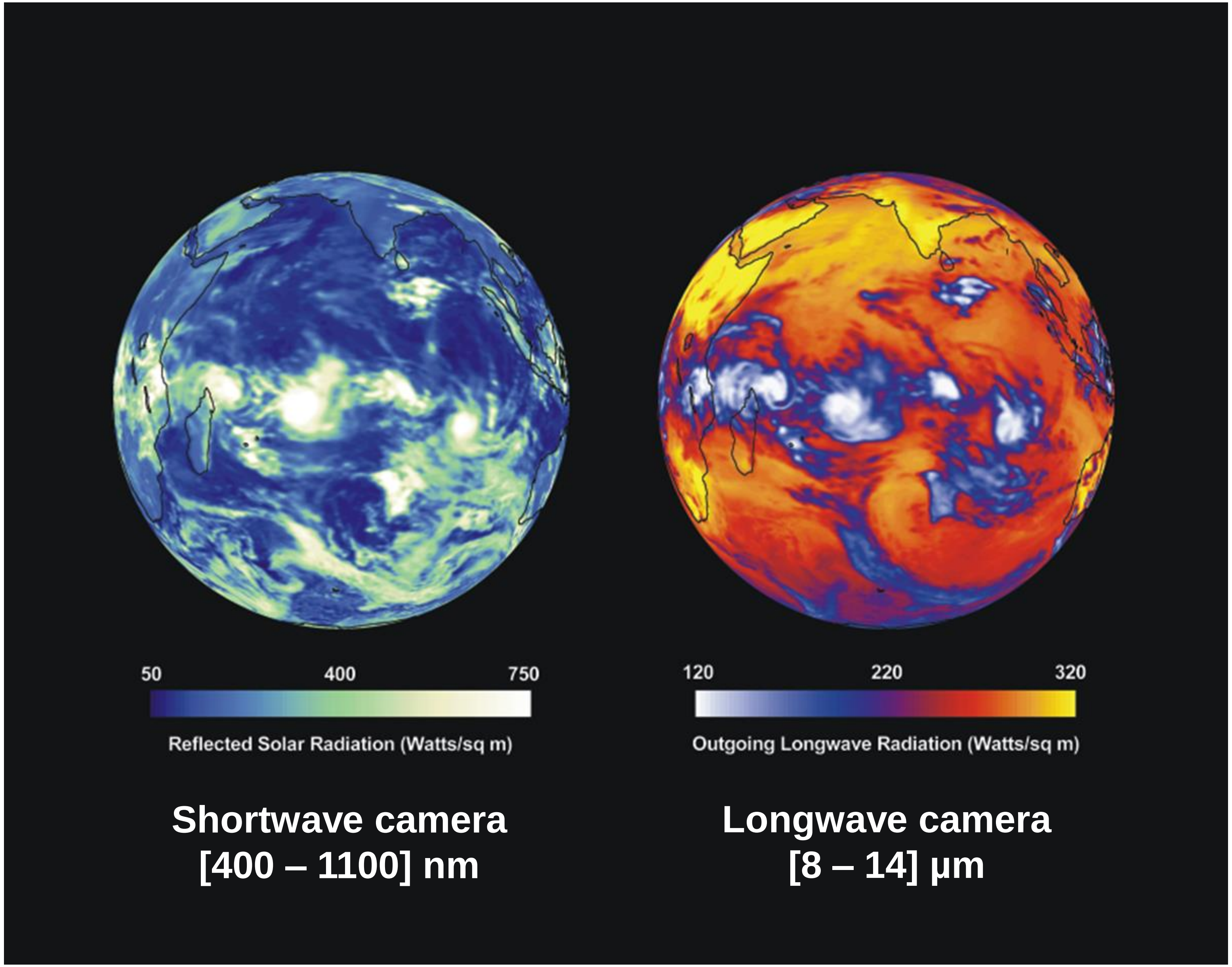
Instruments

Wide-field-of-view (WFOV) radiometer

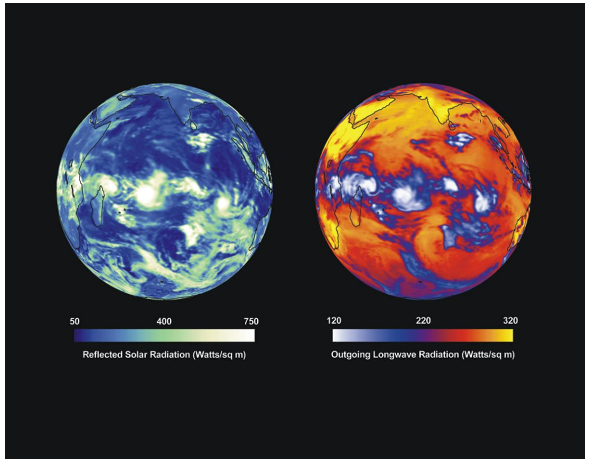
WFOV shortwave camera

WFOV longwave camera

Shortwave vs Longwave



Shortwave vs Longwave



SW camera
[400 – 1100] nm

LW camera
[8 – 14] µm

Wide FOV = **140°**

Total axial length **< 10 cm** (1 CubeSat Unit, 1U)

Spatial resolution **< 5 km** at nadir

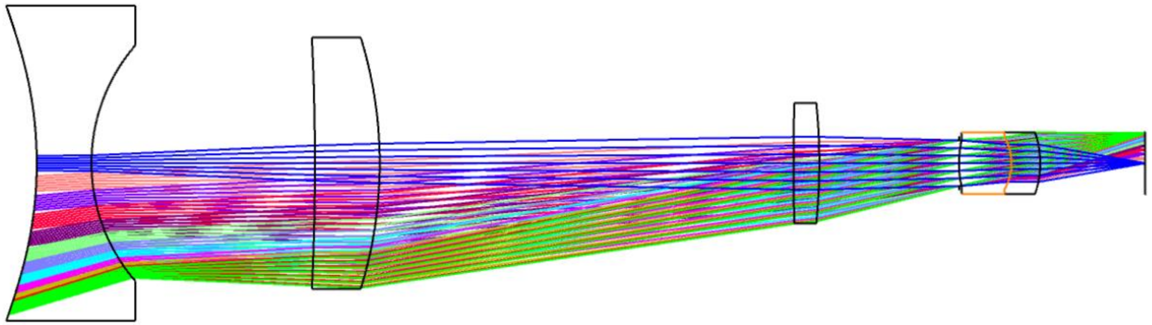
Estimate of broadband radiation uncertainty **< 5%**

Shortwave camera

Fujinon FE185C057HA-1

Shortwave camera

The shortwave camera estimates the Reflected Solar Radiation with a certainty of more than 97%



VIS to NIR [400 – 1100] nm

FOV = 140°

Pixel pitch = 3.2 µm

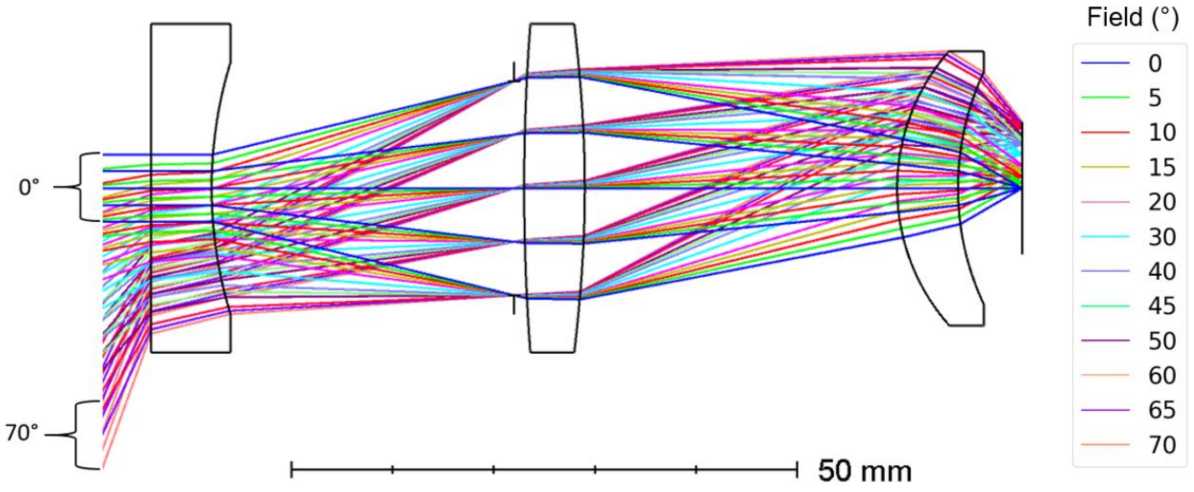
F/# = 2.9

Spatial resolution = 2.2 km

L. Schifano et al. (2020), Optical System Design of a Wide Field-of-View Camera for the Characterization of Earth's Reflected Solar Radiation

Longwave camera

The longwave camera estimates the Outgoing Longwave Radiation with a certainty of more than 95%



Thermal IR [8 – 14] µm

FOV = 140°

Pixel pitch = 17 µm

F/# = 1.0

Spatial resolution = 4.5 km

L. Schifano et al. (2021), Wide-Field-of-View Longwave Camera for the Characterization of the Earth's Outgoing Longwave Radiation

SW and LW cameras: summary

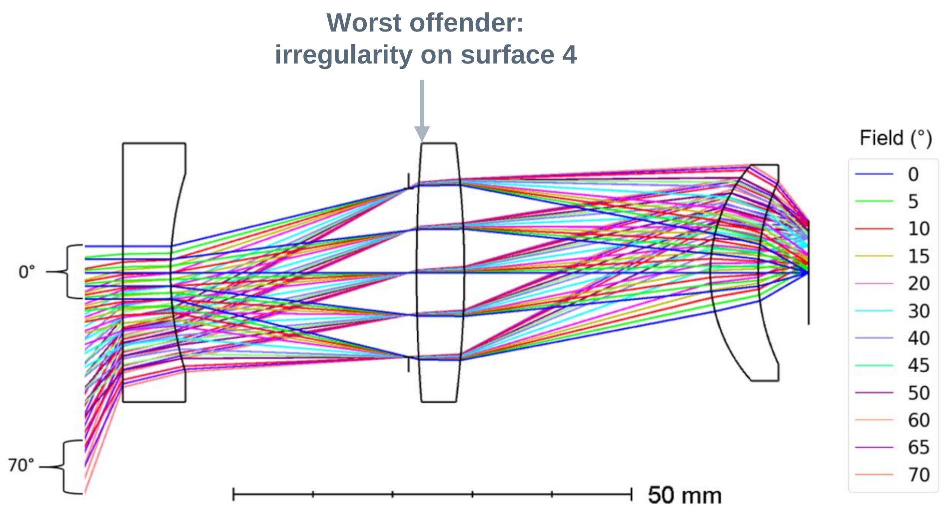
- WFOV cameras: 140° → Earth observation from limb-to-limb
- Improve spatial resolution up to a few km (SW: 2.2 km, LW: 4.5 km)
- SW and LW cameras to distinguish between SW and LW radiations
- Enable retrieving of broadband radiation (SW: 97%, LW: 95%)
- Nominal optical designs: nearly diffraction-limited

Can these optical designs be manufactured…?

Tolerance analysis

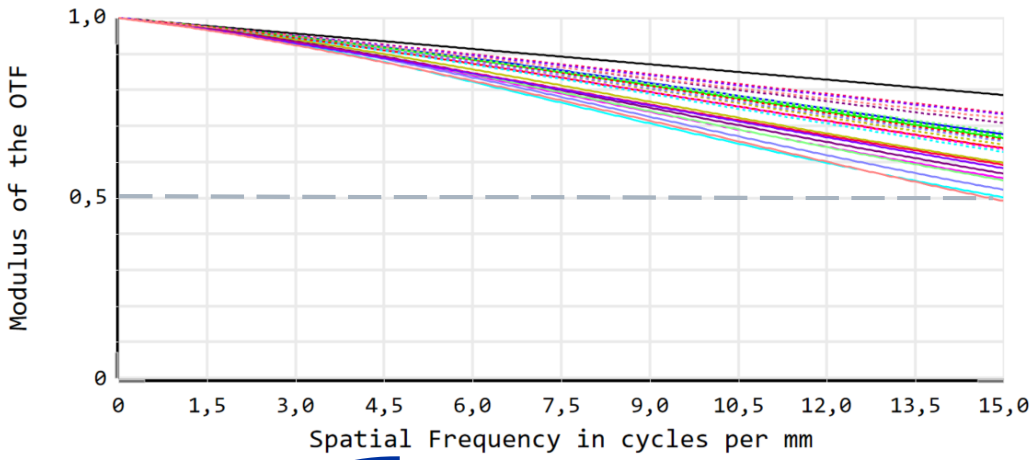
More than 98% of the 1000 simulated designs are tolerant (**diffraction-limited**) to:

- manufacturing errors (radii of curvature, irregularity on surfaces, …),
- refraction index errors,
- misalignment errors (tilts and decenters).



L. Schifano et al. (2021), Compact wide field-of-view camera design for remote sensing of the Earth's emitted thermal radiation

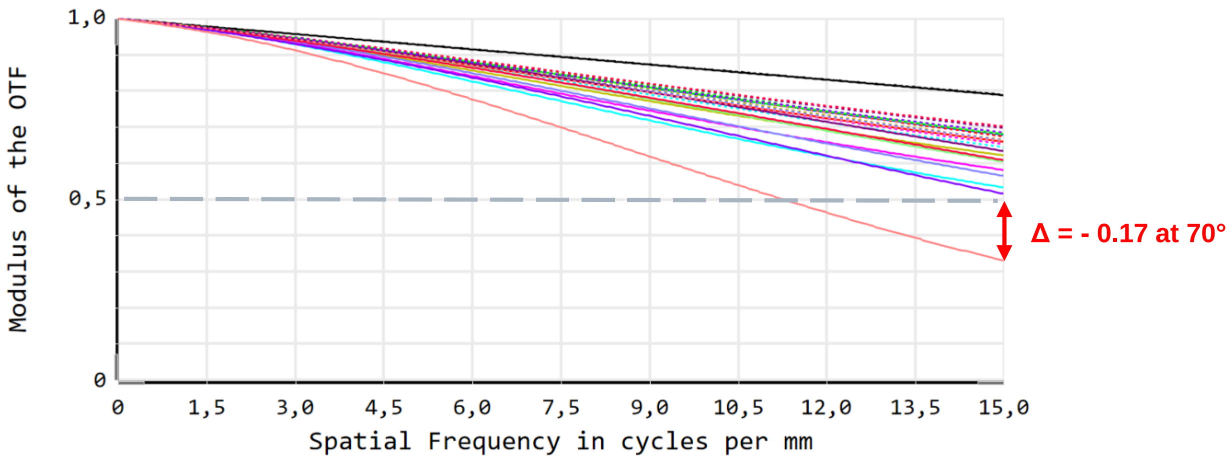
Tolerance analysis: MTF degradation



MTF for the nominal optical design

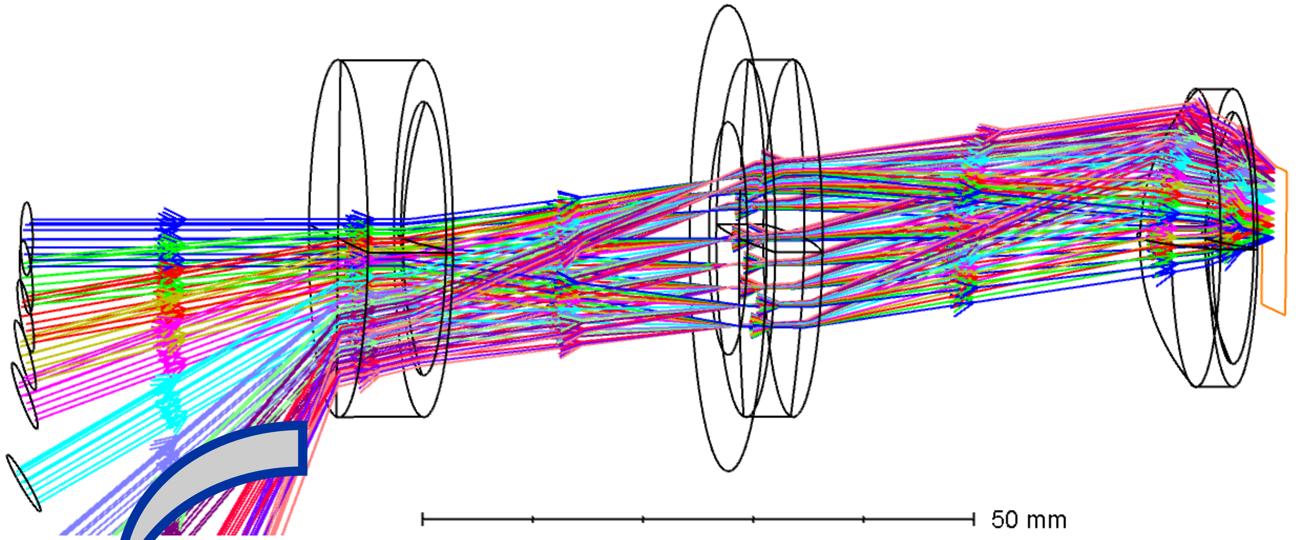
with tolerances…

Worst case scenario over 1000 designs



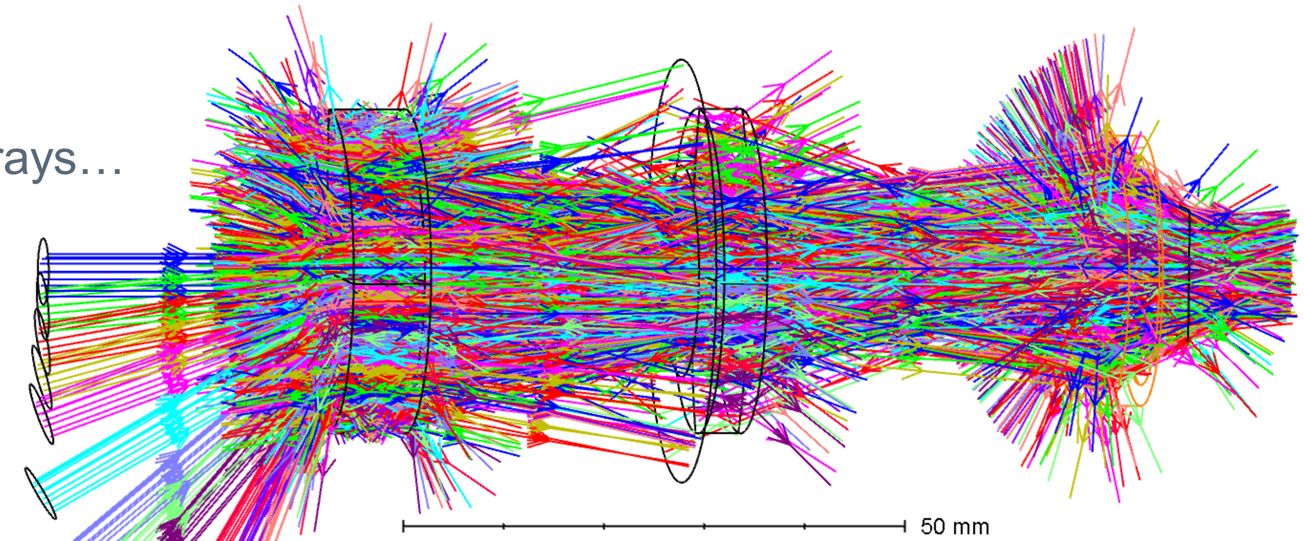
L. Schifano et al. (2021), Compact wide field-of-view camera design for remote sensing of the Earth's emitted thermal radiation

Stray-light analysis



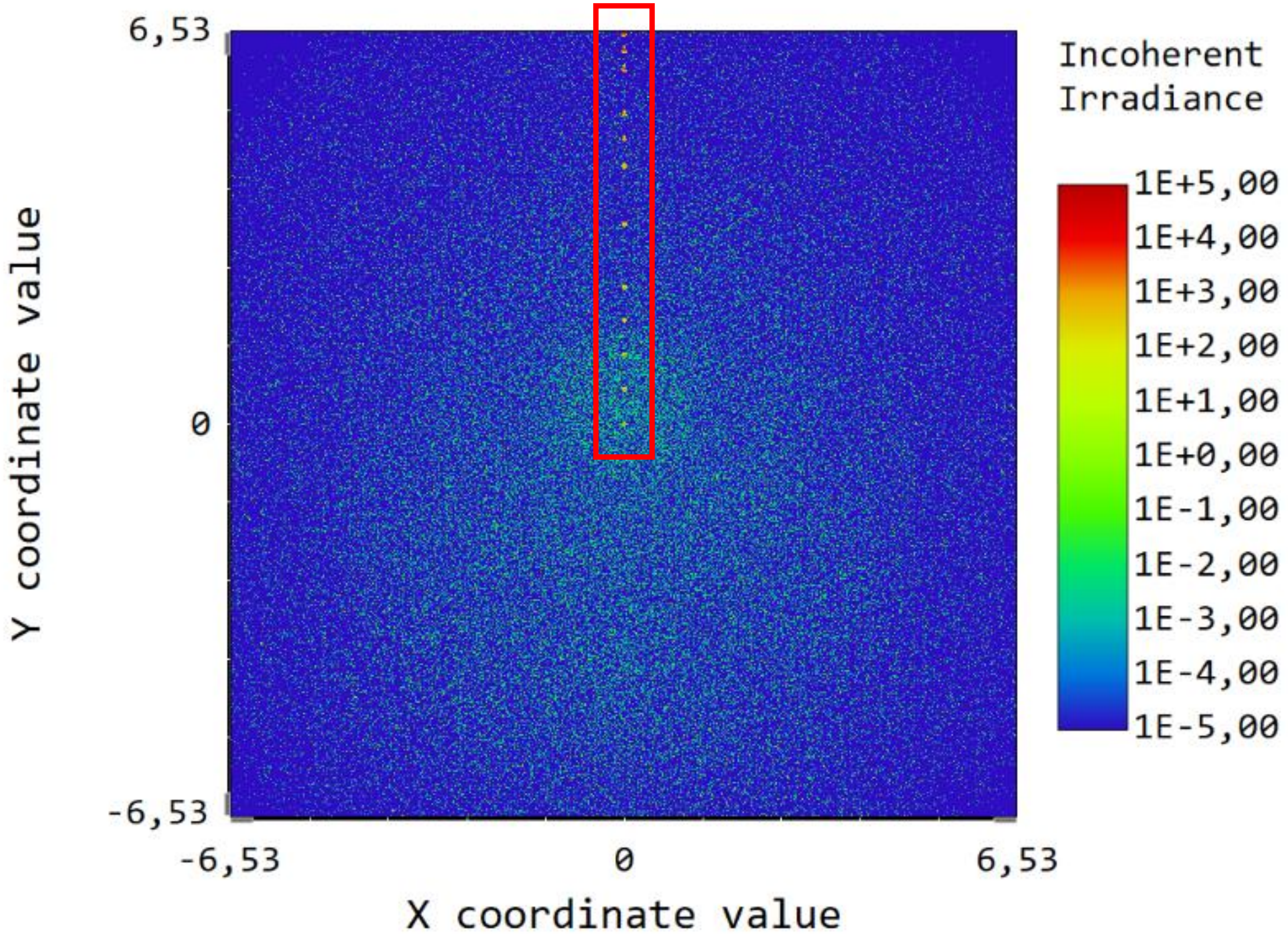
nominal optical design

with non-sequential rays…



Stray-light analysis

Ghost analysis with the detector viewer



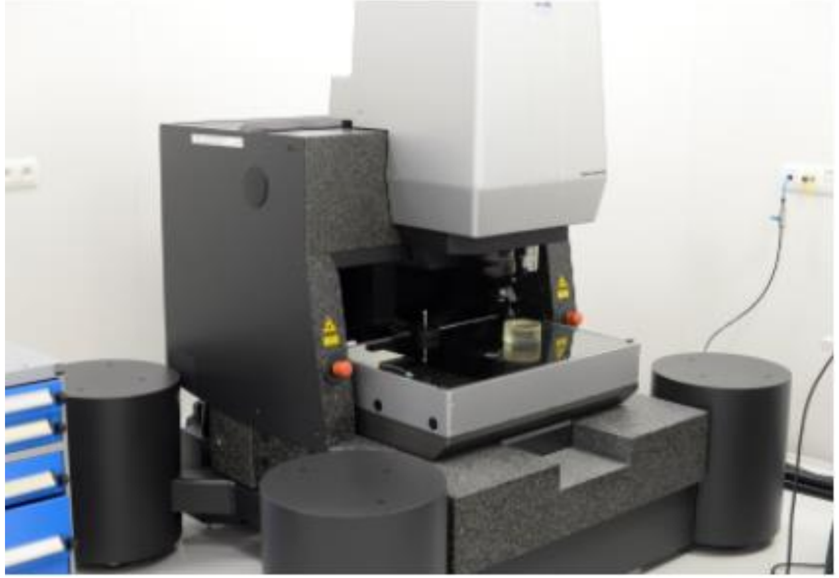
Next steps

Proof-of-concepts demonstrators can be in-house manufactured, characterized and assembled

Ultraprecision diamond tooling machine

White-light interferometry

Coordinate measurement metrology

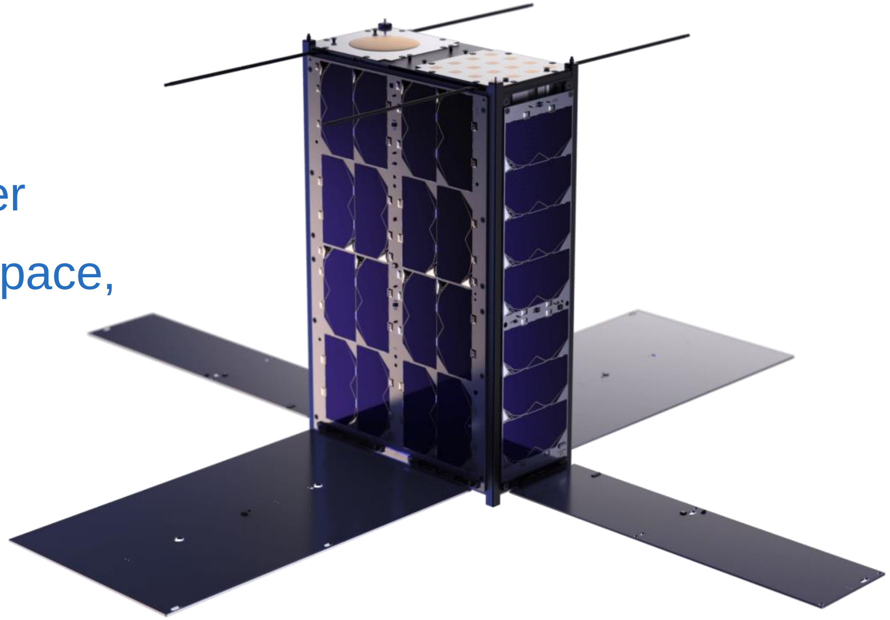


VUB

B-PHOT BRUSSELS PHOTONICS

Conclusion

Conclusion



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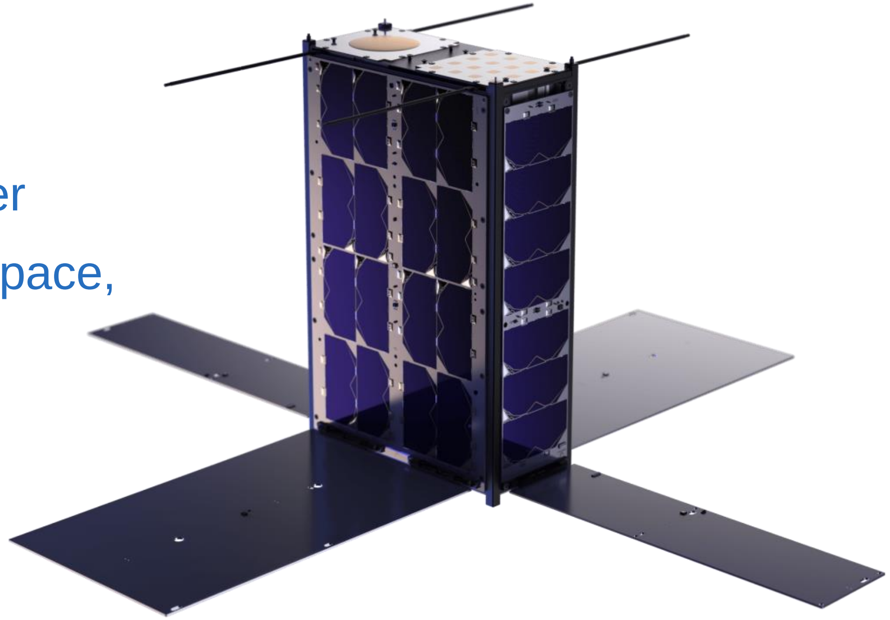
- **WFOV** (limb-to-limb) **compact** (1U) instruments:
  - WFOV radiometer → 10-fold-improved accuracy (**0.44 W/m²**) on the measurement of the Earth’s energy imbalance
  - WFOV SW camera → improved spatial resolution up to **2.2 km** and estimation of the RSR with **>97%** of certainty
  - WFOV LW camera → improved spatial resolution up to **4.5 km** and estimation of the OLR with **>95%** of certainty

Conclusion



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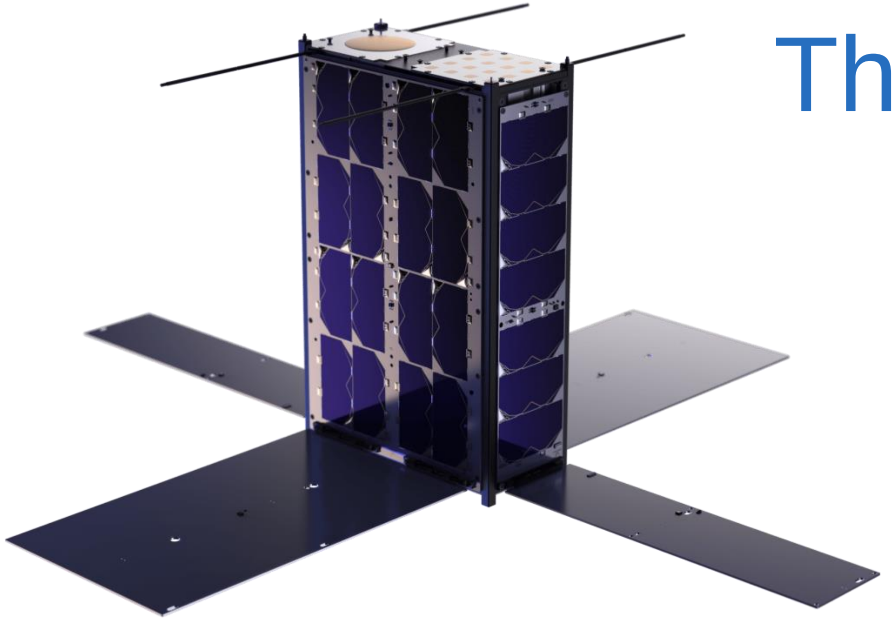
Future perspective → How to improve the accuracy up to 0.3 W/m² (climate accuracy)?

1. L. Schifano, L. Smeesters, T. Geernaert, F. Berghmans, S. Dewitte, “**Design and Analysis of a Next-Generation Wide Field-of-View Earth Radiation Budget Radiometer**”, Remote Sensing, 12(3):425, (2020).

2. L. Schifano, L. Smeesters, F. Berghmans, S. Dewitte, “**Optical System Design of a Wide Field-of-View Camera for the Characterization of Earth’s Reflected Solar Radiation**”, Remote Sensing, 12(16):2556, (2020).

3. L. Schifano, L. Smeesters, F. Berghmans, S. Dewitte, “**Wide-Field-of-View Longwave Camera for the Characterization of the Earth’s Outgoing Longwave Radiation**”, Sensors, 21(13):4444, (2021).

4. L. Schifano, L. Smeesters, F. Berghmans, S. Dewitte, “**Compact wide field-of-view camera design for remote sensing of the Earth’s emitted thermal radiation**”, Proc. SPIE 11859, Remote Sensing of Clouds and the Atmosphere XXVI, 118590C (2021).



Thank you for your attention!

Any questions?