Earth Energy Imbalance Explorer (EAGER)

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Summary

We propose the **EArth enerGy imbalance ExploreR (EAGER)** mission, which will for the first time determine the Earth energy imbalance (EEI) through measuring both solar TSI radiation and infrared and reflected solar radiation from the Earth with the same instrument type. To ensure the highest possible accuracy and stability, in-flight calibration for the solar observations will be enabled through applying stable TSI sensors in combination with transfer filters as a reference for the SSI observations. Similarly, for the Earth observations, fast Bolometric sensors will be calibrated by the stable Earth-pointing instrument.

Scientific Rationale

Human activities have led to rising levels of heat-trapping greenhouse gases in the atmosphere with less terrestrial radiation being able to escape, creating the so-called positive EEI. EEI has been identified as a fundamental diagnostic for analyzing climate variability and anticipating future changes.

Its observation requires the detection of the global energy budget at the top of the atmosphere (TOA) and the Solar Spectral Irradiance (SSI) at an accuracy and long-term stability not available from current observations.

Observation Concept

Observables: Daily TSI and SSI, monthly maps of TOR and OLR. OSR calculated from TOR.

Instrument	Observable	Instrument Team	Heritage	New technology
SOLACER	SSI	IPM, ROB, LATMOS	ISS/ SOLACES (Schmidtke et al., 2014)	SI-traceable calibration scheme for SSI; disruptive IR cryogen-ic detector technology
DARA/TSI	TSI	PMOD/WRC, LATMOS	NORSAT-1/ CLARA (Finsterle et al., 2014)	Nanotube-technology for black coating of the cavity
EASY/DARA	TOR, OLR	PMOD/WRC, ROB	NORSAT-1/ CLARA (Finsterle et al., 2014)	SI-traceable calibration scheme for TOR, OLR, and derived OSR, Nanotube-technology for Earth observation
EASY/BOS	TOR, OLR	ROB, IPM, LATMOS	PICARD/ BOS (Zhu et al., 2015)	nanotube-technology for black coating
VIC	TOR angular distribution	LATMOS, PMOD/WRC, NPL		
Precision Pointing Control Unit	Solar high precision pointing	ROB, LATMOS		differential pointing, excellent stability

Tab. 1: Summary of the scientific instruments, their heritage, and technologic innovation. Also listed is the necessary pointing control unit for the solar and nadir pointing. SSI and TSI are observed by SOLACER, Earth observations are made by the Earth Albedo System (EASY) package.

Nominal: Main Spacecraft SC1 (Earth + Sun): midnight noon orbit; with SOLACER, DARA/TSI, EASY.

Optional: SC2-6 (Earth): small EO satellite(s) with the EASY payload, providing temporal coverage of 2 hrs.

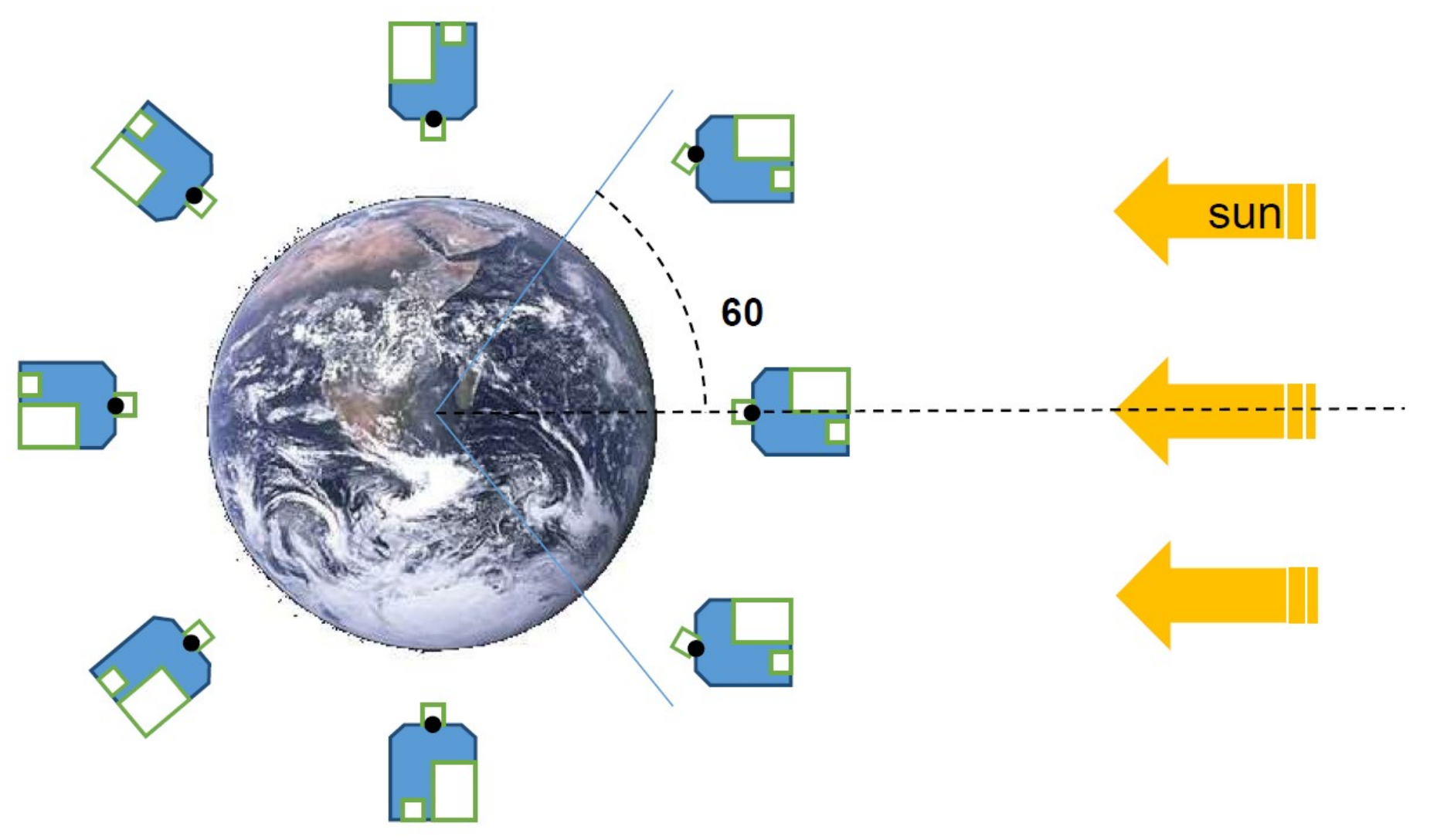


Fig. 1: EAGER SC1 operational scenario. The nadir pointing are always running, while the sun-pointing instruments are operational between +/-60° from the subsolar point.

Instrumentation I: TSI and SSI

TSI:

DARA

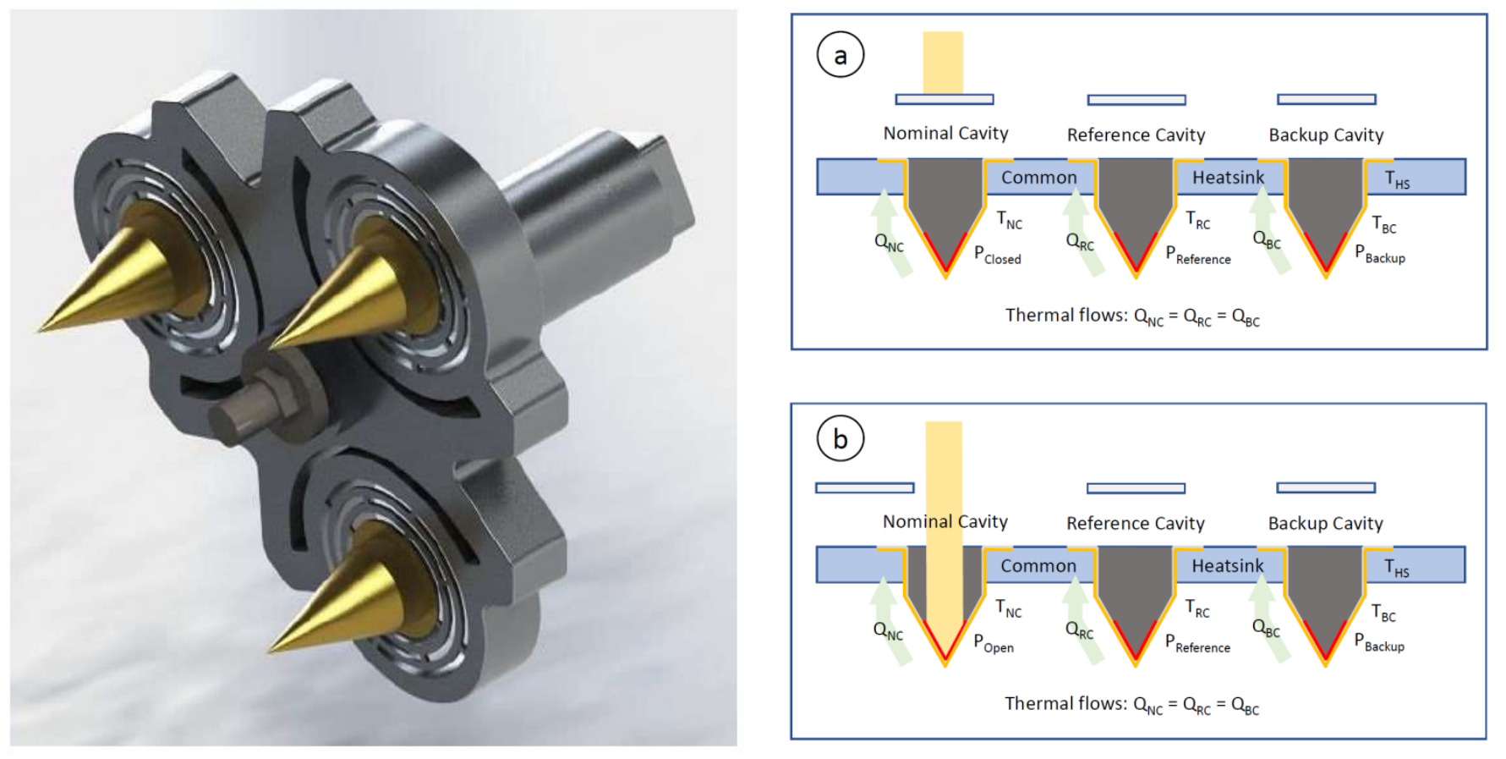
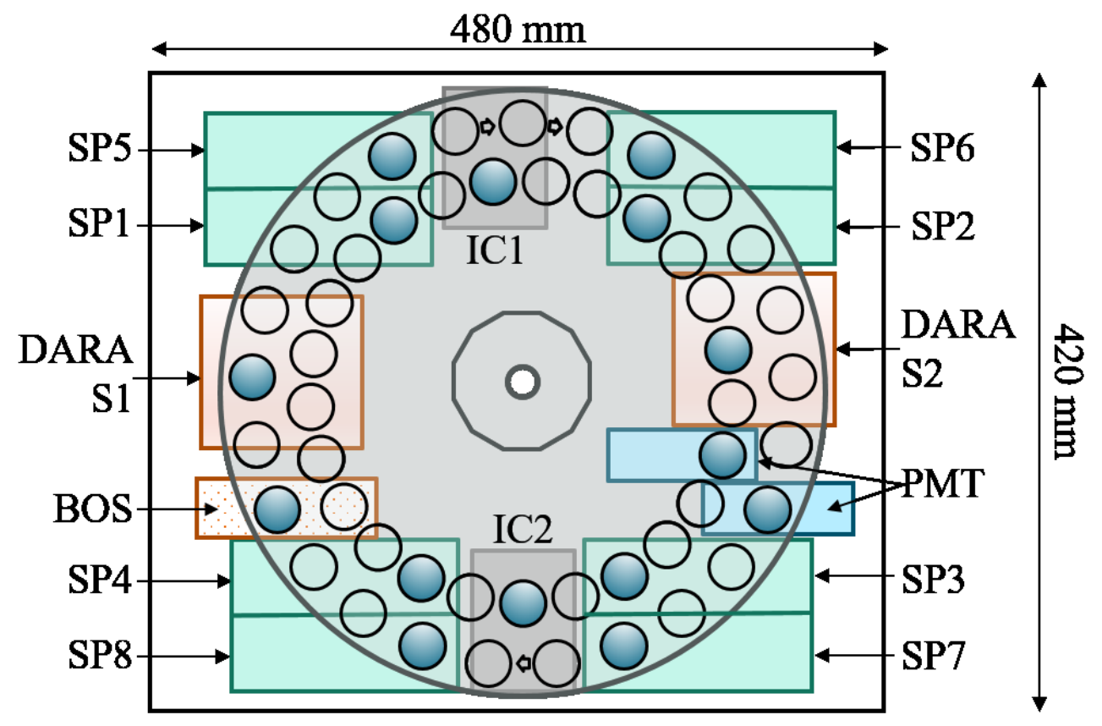


Fig 2: Left: Three cavity detectors (black inside, gold outside) from DARA mounted to a common heat sink. The solar irradiance is absorbed inside the cavities (from Finsterle et al. (2014). Right: DARA working principle: (a) Nominal cavity closed, heater power P_{close} (b) Nominal cavity open, heater power P_{close}. The solar irradiance is then defined as IS = $(P_{close} - P_{open}) / A$, where A is the aperture area.

SSI:

SOLACER



Fig, 6: Schematic view on the SOLACER sub-systems. SP1-8 are planar spectrometers of the same type. Two ionization chambers IC1/2 and two radio-meters DARA-S1/S2 are primary detector standards. The PMTs and the BOS are used as secondary detector standards.

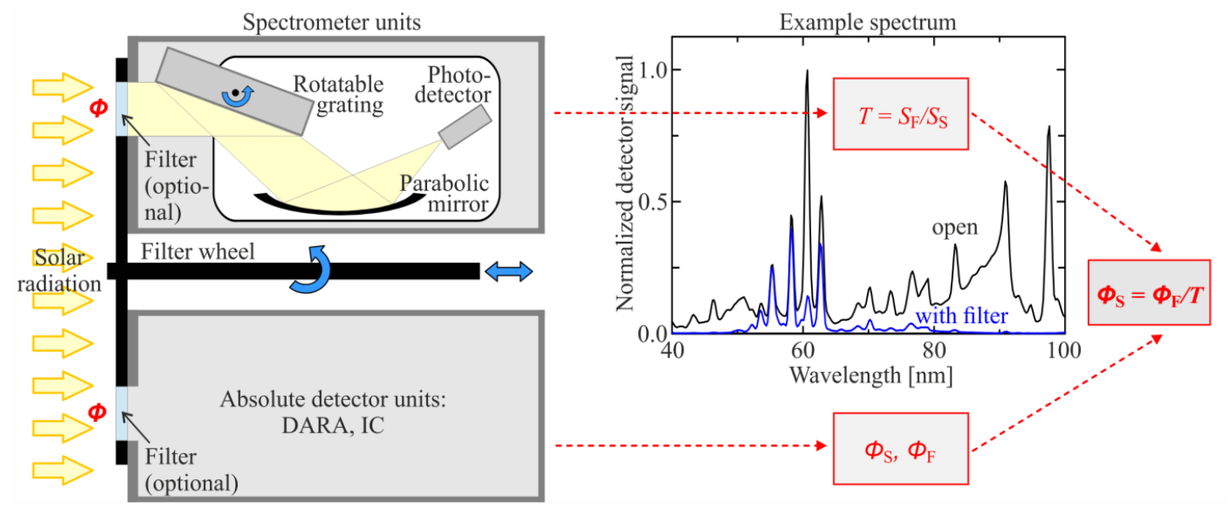


Fig. 2: SOLACER in-flight calibration scheme. Solar flux Φ generates solar and filter signals S_S and S_F, also for determining filter transmission T. From the signals of the absolute detector units (below) the numbers of photons Φ_F are derived for the filters converting S_S to Φ_S. With filters (eight wavelength ranges) of the spectrometers, full calibration of the spectrometers is achieved from the XUV through the IR.

Instrumentation II: TOR and OLR

TOR, OLR:

BOS sensors
DARA sensors
VIC camera

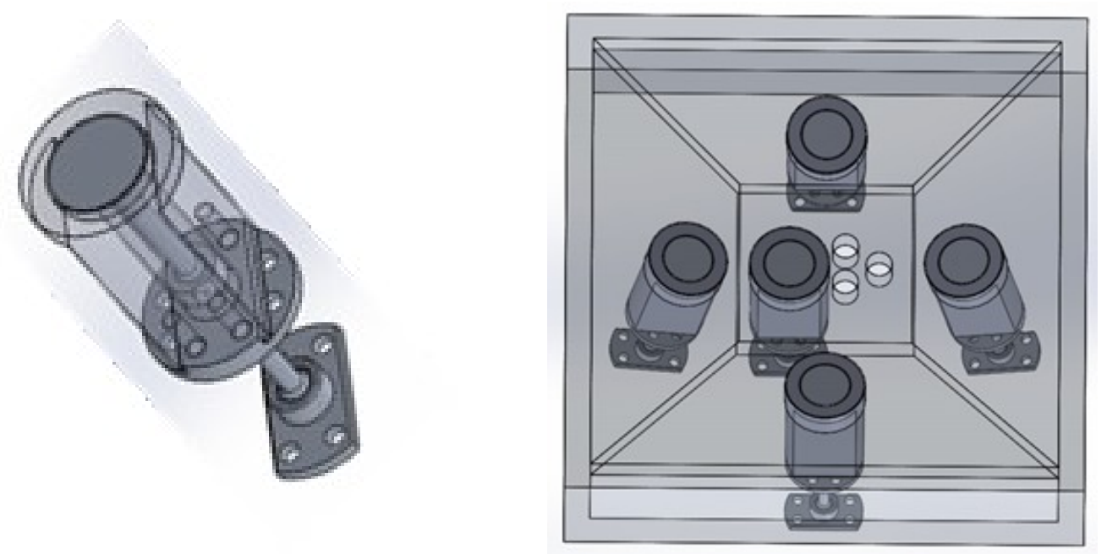


Fig. 3: Left panel: principle of the µKC bolometer geometry with a thermal shield casing surrounding the shunt. Right panel: example of a multi-angle configuration of µKC bolometers in combination with an EASY/DARA in the centre for reference. This configuration allows angle-resolved observations for 2D profiles.

In order to correctly quantify TOR at the TOA the angular distribution (AD) of the outgoing radiation needs to be determined by a Visible-IR bolometric Camera (VIC) with a minimum of 50x50 pixel array and a fish-eye optic to cover the Earth's visible horizon.

OLR will be observed with a DARA with white coating, only absorbing longwave radiation only.

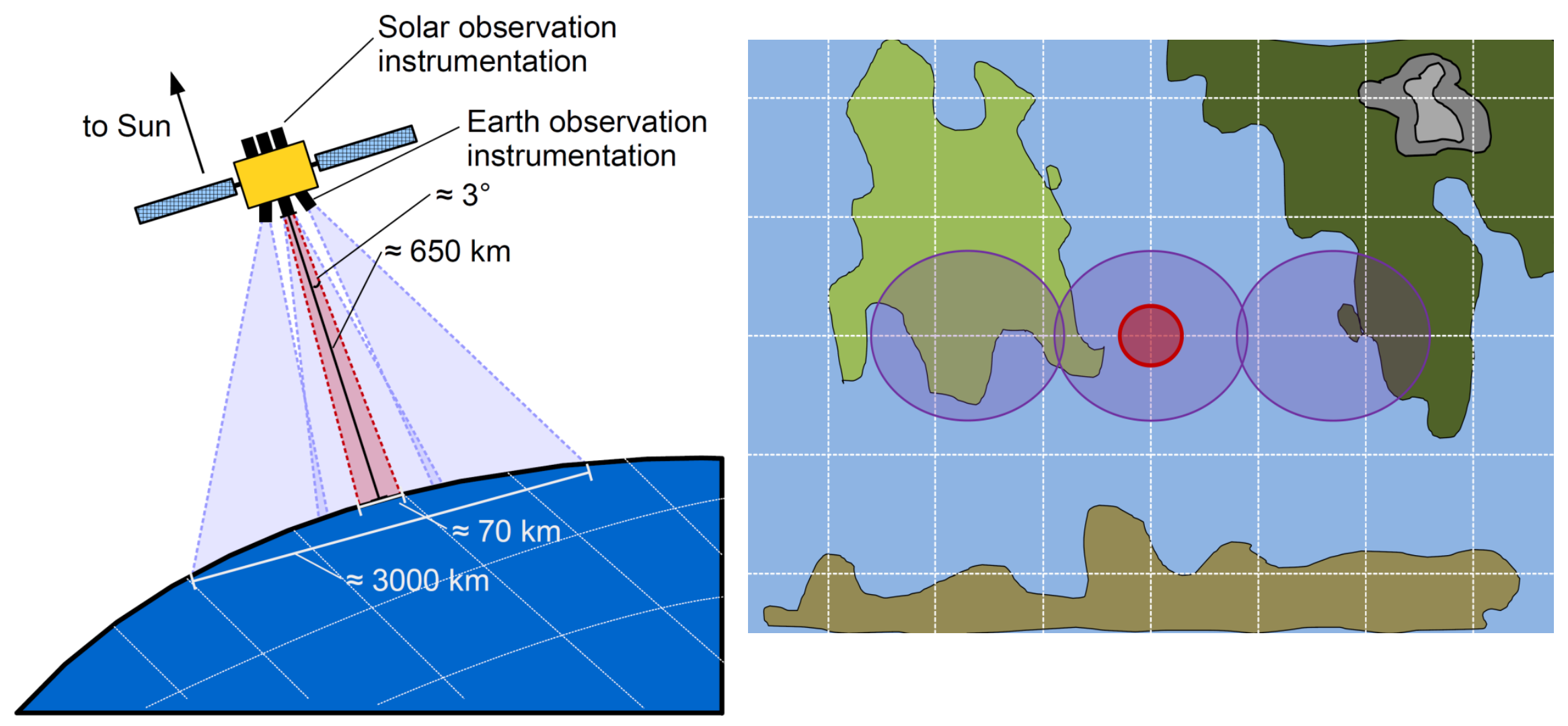


Fig. 4: Left panel: Schematic view of the Earth observation example. The red shaded area shows the DARA and BOS1 (with baffle limiting its aperture) FOV, the purple shaded areas mark lambertian FOV for three BOS; Right panel: Schematic view of the Earth observation. The red circle shows the FOV from the DARA and the reference bolometer BOS1, the purple ellipses show the FOV of three other bolometers.

Perspective

- TSI and SSI variability benchmarks for Earth radiation budget studies,
- updated solar proxies
- instruments characterization for future long-term observations

References

Finsterle, W., et al., Proc. SPIE, 9264, Earth Observing Missions and Sensors: Development, Implementation, and Characterization III, 92641S, doi:10.1117/12.2069614, 2014.

Schmidtke, G., Nikutowski, B., Jacobi, Ch., Brunner, R., et al., Solar Phys., 289, 1863–1883, doi:10.1007/s11207-013-0430-5, 2014.

Zhu, P., van Ruymbeke, M., Karatekin, Ö., Noël, J.-P., Thuillier, G., Dewitte, S., Chevalier, A., Conscience, C., Janssen, E., Meftah, M., and Irbah, A., Geosci. Instrum. Method. Data Syst., 4, 89–98, doi:10.5194/gi-4-89-2015, 2015.