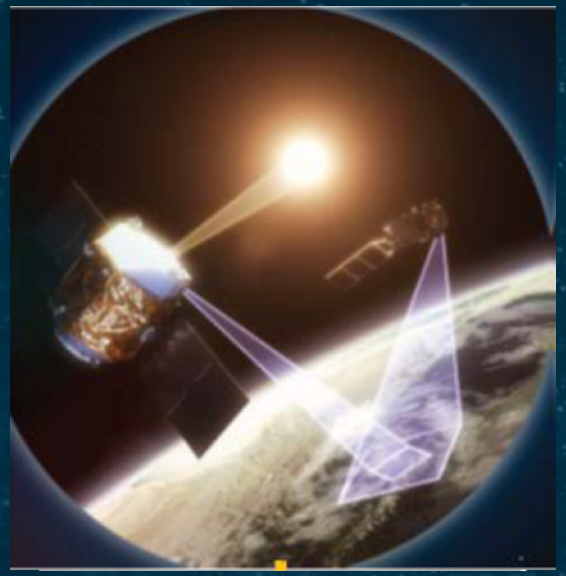


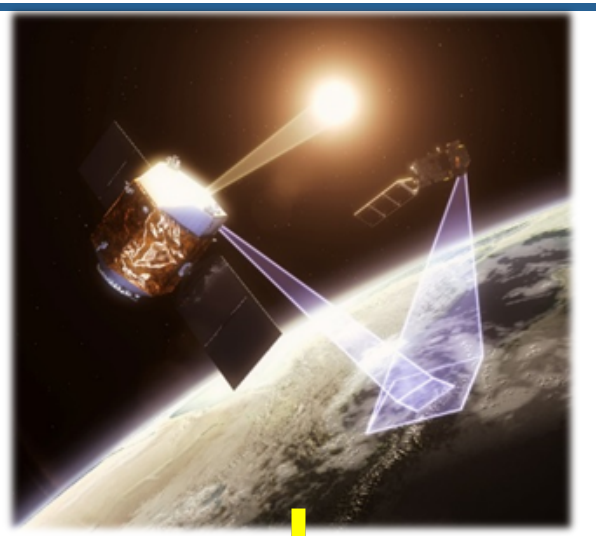
The ESA Earth Watch Mission TRUTHS:
Traceable Radiometry Underpinning Terrestrial- & Helio-Studies

Thorsten Fehr (ESA), Nigel Fox (NPL), the ESA TRUTHS Team

GSICS, 14 October 2021

TRUTHS: Space-based climate and calibration observatory 'Metrology (SI) in Space'

UKSA-led (conceived by N.Fox, NPL) mission being implemented through the ESA EarthWatch program with prospective launch 2026-28 (adopted Space 19+).



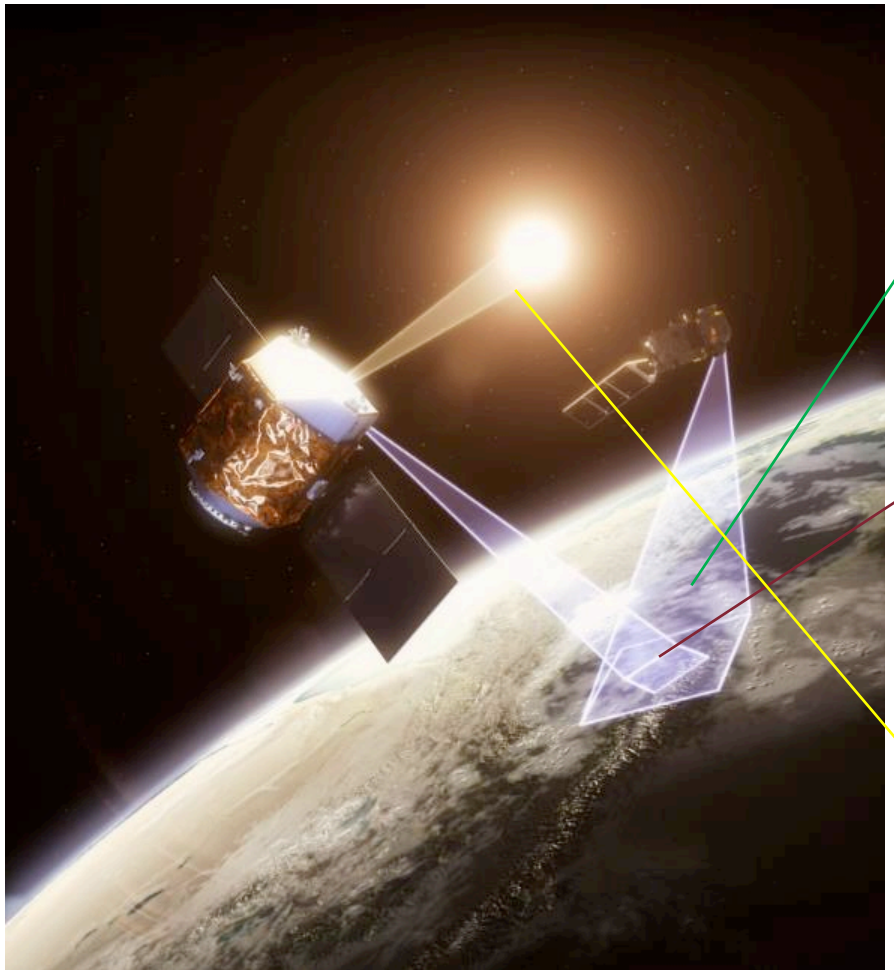
- **First proposed to ESA in 2001 and then to various calls of Earth Explorer**
  - **Initially as CEOS Calibration/Earth imager and Solar mission**

- **Climate science case and operational characteristics heavily influenced and supported by NASA – CLARREO team (Long-Standing partnership)**
  - **Similar driving objectives**
  - **Differences in implementation and means of establishing Traceability**
  - **TRUTHS scope only solar reflective – extends to EO in general**

- **2018/2019 – Down-selected from 32 national (UK) mission proposals for implementation through ESA Earth Watch program**
  - **Uniqueness**
  - **Relevance** **In context of timeliness to UK science agenda**
  - **Maturity**

- **2019 (Nov) TRUTHS Adopted into Earth Watch program (with 85% UK funding)**

Mission Objectives



TRUTHS is an **operational climate-focused mission**, aiming to:

1. **Climate benchmarking:** significantly enhance our ability to estimate the Earth radiation budget (and attributions) through direct measurements of incoming & outgoing energy & reference calibration,
2. **Satellites cross-calibration:** establish a 'metrology laboratory in space' to create a fiducial reference data set to cross-calibrate other sensors and improve the quality of their data, robustly anchored to a primary SI reference in space.

and

3. provide SI-traceable measurements of the **solar spectrum** to address direct science questions and climate.

An Agile platform allows observations of Sun, Moon and Earth with the same sensor together with view angle matching for optimum cross-calibration & ability for surface BRF characterisation

Mission Products

L1: Earth-reflected Spectral Radiance (ToA), Solar Spectral Irradiance, Lunar Spectral Irradiance – all in the range <320nm to ~2400nm; across Earth diurnal and lunar cycles

L1: Total Solar Irradiance integrated in the range 200nm to 30000nm;

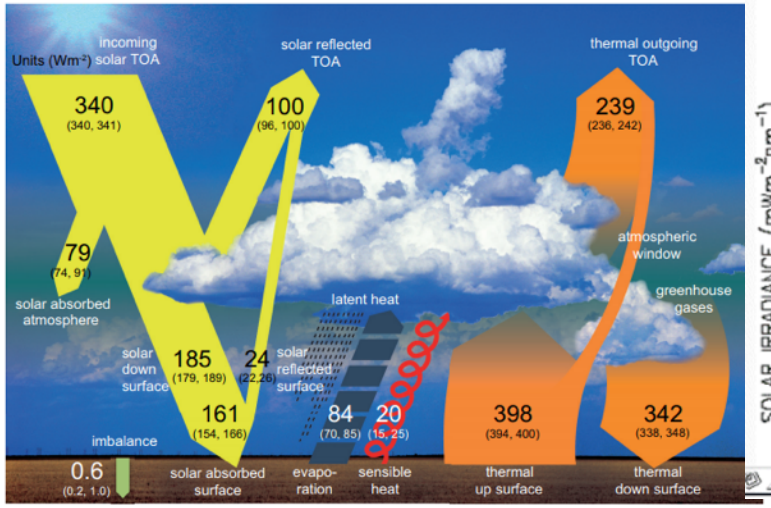
→ **Climate benchmark, solar measurement**

L2: Spectral Surface Reflectance, at ground level (~400nm to ~2400nm); primarily as a reference

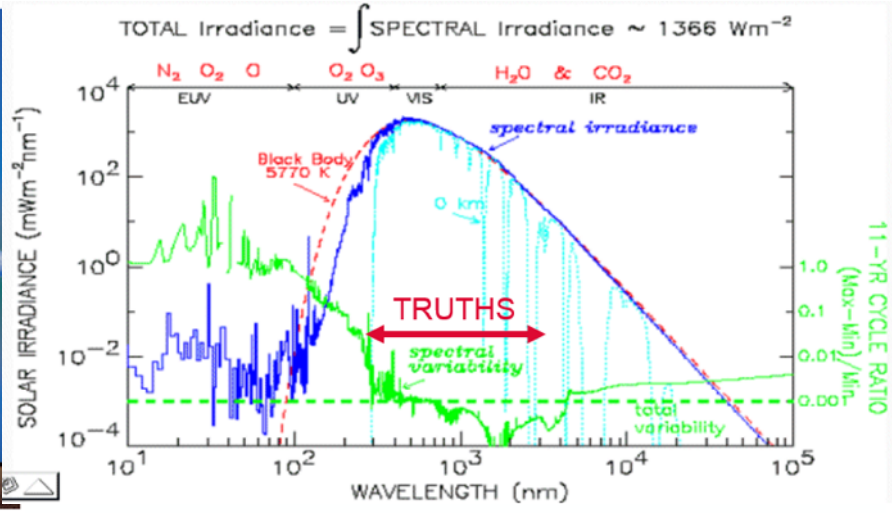
→ **Earth science**

Calibration coefficients & match-up products to determine biases for TBD other sensors over multi-scene types and view angles, (climate sensors & geo-spatial).

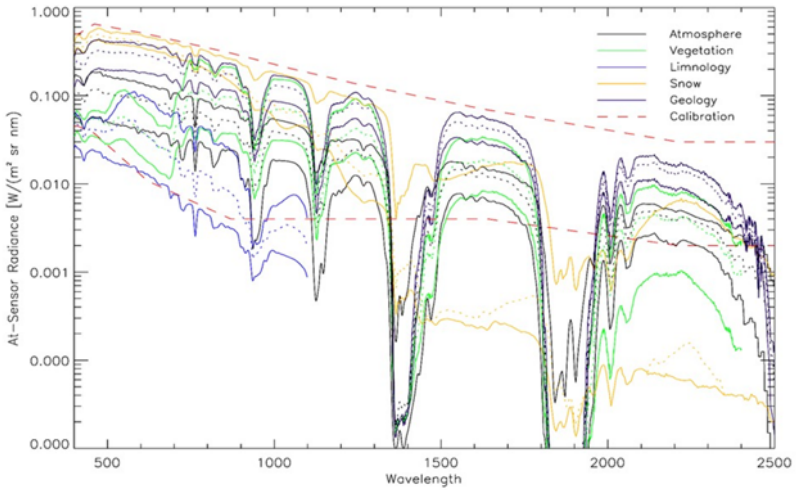
→ **Cross-calibration**



Radiation balance



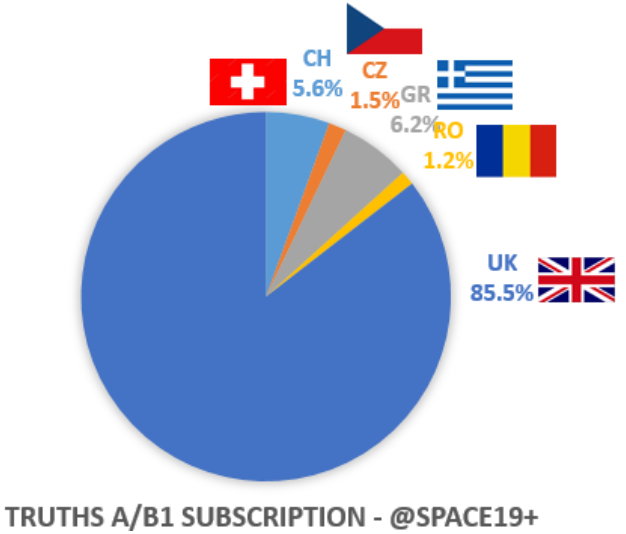
Solar spectral irradiance



Surface reflectance

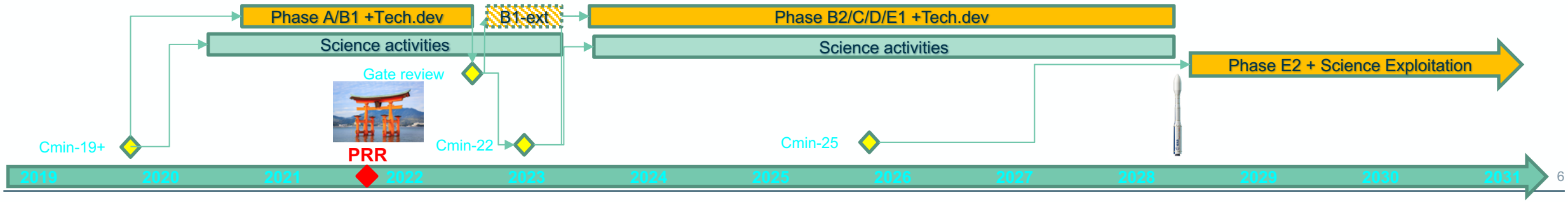
TRUTHS as an Earth Watch element

- TRUTHS was proposed by UKSA in May 2019 as a new **Earth Watch** (EW) Element, in order to realise a “climate and calibration observatory in space”
  - TRUTHS was included as an **operational mission** in the EO programme proposals of Space19+
  - Operational climatology – operational traceable cross-calibration
- Introduction of new services in the EO portfolio of ESA participating states / Europe.
- TRUTHS Phase A/B1 has been fully subscribed at Space19+: by 5 Participating Countries: UK (85.5%), GR (6.2%), CH (5.6%), CZ (1.5%), RO (1.2%)
- Mission Development 2020-2028 (with a goal launch in 2026)
  - Lifetime of 6 years (including 6 months Commissioning)



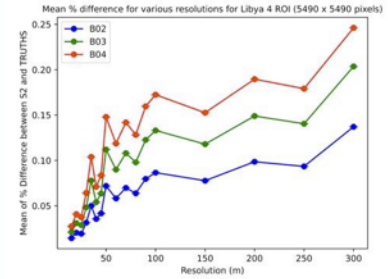
TRUTHS Programme Status

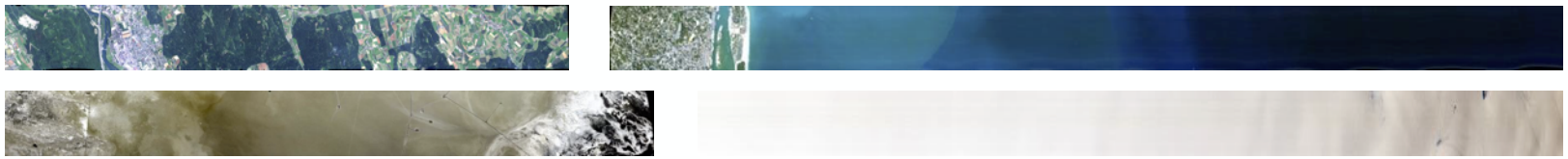
- Industrial Phase A/B1 has been implemented
  - Kicked-off in autumn 2020, with Preliminary Requirements Review passed in September 2021
    - Complexity of the mission now fully understood
    - Mission Concept Selected with tailored spectral ranges in UV-SWIR and high resolution SSD (see later slides)
    - Updates Hyperspectral Instrument (HIS) optical design revised
    - On-board calibration system (OBCS) design consolidated, with further trade-offs being analysed
    - Performance consolidated with realistic contributors and margins
  - Phase B1 activities entering with challenging schedule
    - Final requirements consolidation and start of detailed design and analysis
    - Hardware pre-development on-going, including detectors, mirror coatings, OBCS components, HIS diffuser and Breadboard elements, CSAR voltage reference and black coating
    - Implementation of algorithms and code simulators, including metrology and cross-calibration modules
  - Programmatic “Gate Review”: Go/No-Go decision by mid-2022, including an Independent Science Review

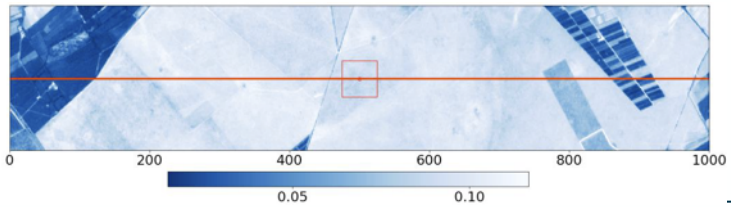


TRUTHS Science Status

- Science Studies have been implemented
  - Independent user requirements study completed in 2020 resulting in a “Traceable Mission Requirements Review Document”
  - TRUTHS Mission Accompanying Consolidation (TMAC) Study providing scientific support to the ESA Project ongoing since Feb. 2021, with PRPR milestone passed
    - Reference scenes (sand, coastal water, vegetation, land, ice, clouds, crops) for E2E Simulator
    - Support to define the interface and requirements of L1c product to generate level 2
    - Support to the Sensor-to-Sensor intercalibration priorities
    - FIDUCEO methodology developing the metrological method for TRUTHS uncertainty tracing
    - Level 2 Surface reflectance product algorithm baseline
    - Support to TRUTHS Project Reviews and Science Readiness Level Assessment
- TRUTHS Mission Advisory Group (MAG) established in December 2021
  - Essential support to the TRUTHS project in the science and performance assessment







Key performance parameters: ARA, Spectral Resolution

- Mission Concept #1 (MC1): To be iterated with TRUTHS MAG
  - Absolute Radiometric Accuracy (k=2)

ARA	1% (T), 0.3%(G)	320nm	350nm	1000nm	2400nm
MC1	*Earth Heterogeneous Scene*	*1.200*	*0.797*	*0.329*	*0.328*
	Earth Homogeneous Scene	*0.894*	0.524	0.226	0.260
	Sun	0.597	0.481	0.203	0.224

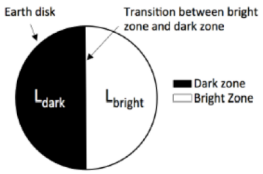
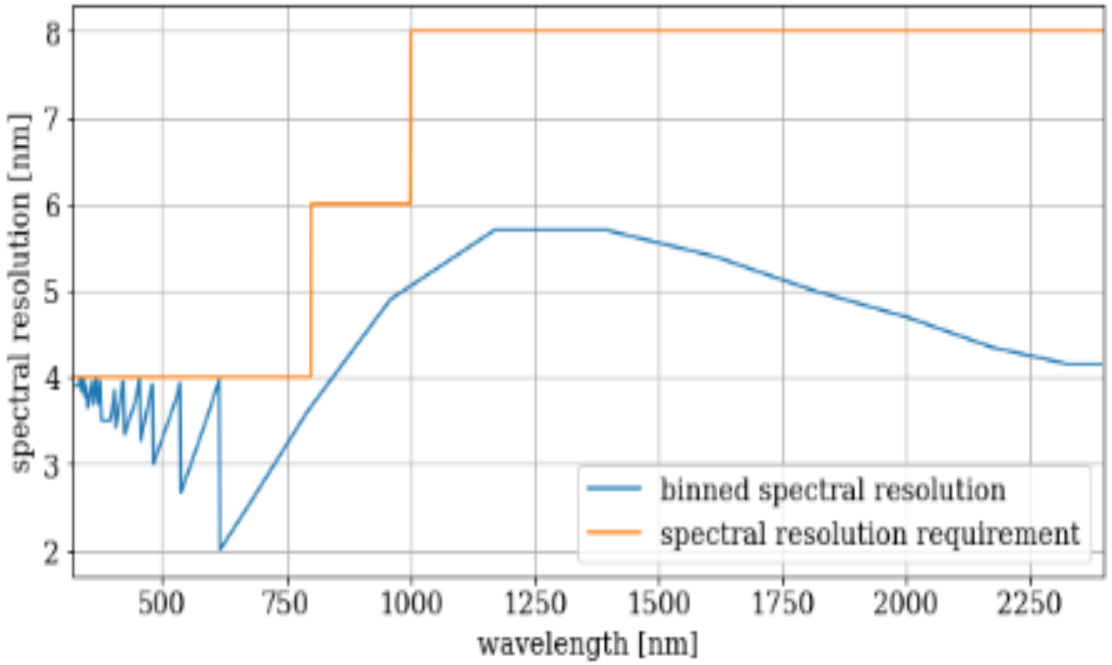


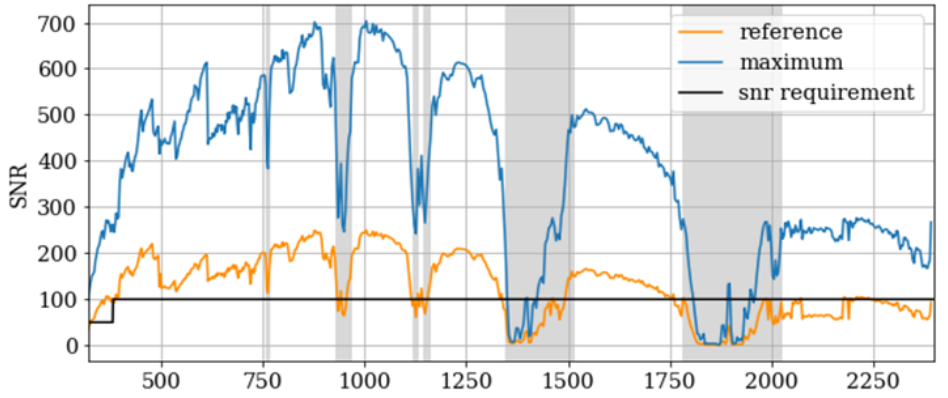
Figure 2: Non-uniform scene.

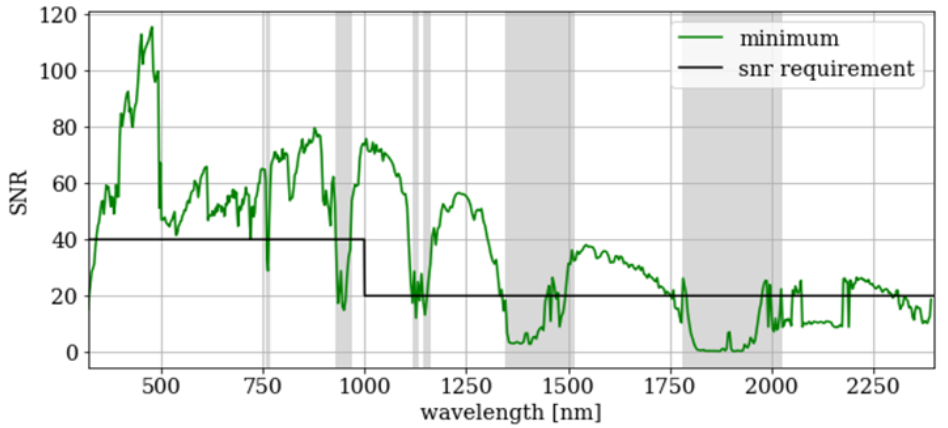
Note:

Heterogeneous definition considers only stray-light at 40 SSD distance from bright/dark zone transition

- Spectral Resolution (binning in the UV variable): SNR:@50m





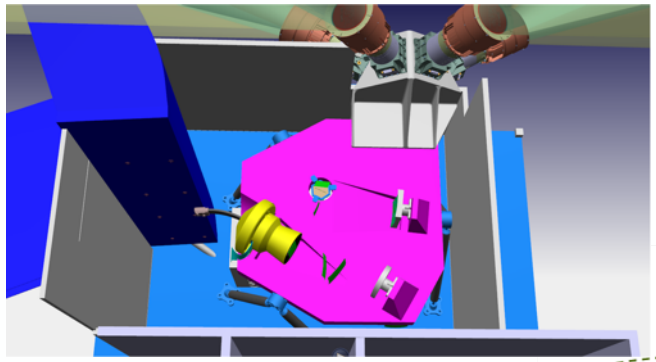


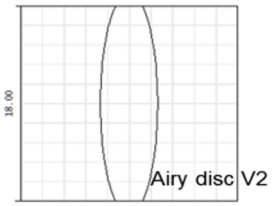
HIS revised Optical design

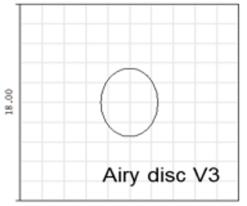
HIS designed with natural vertical telescope: **HIS v3**

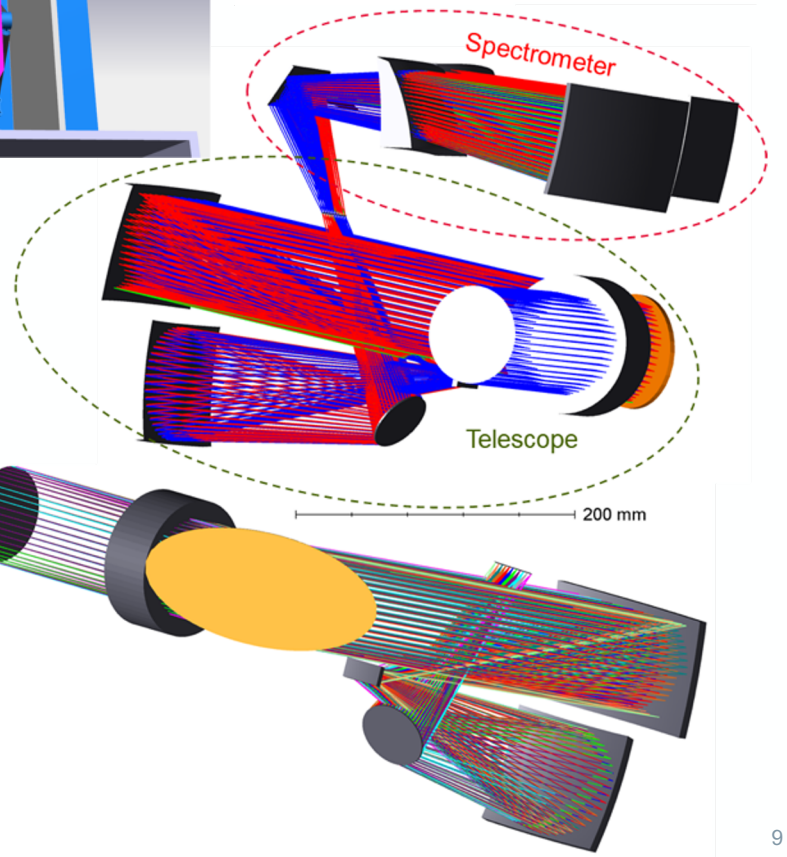
- Fold mirror between scrambler and telescope to fold beam such that detector and slit are positioned near radiator
- Inherent astigmatism of v3 is reduced compared to v2
- Convergence of v3 required to improve imaging performance and optimize polarisation sensitivity (additional fold mirror)

HIS version 3

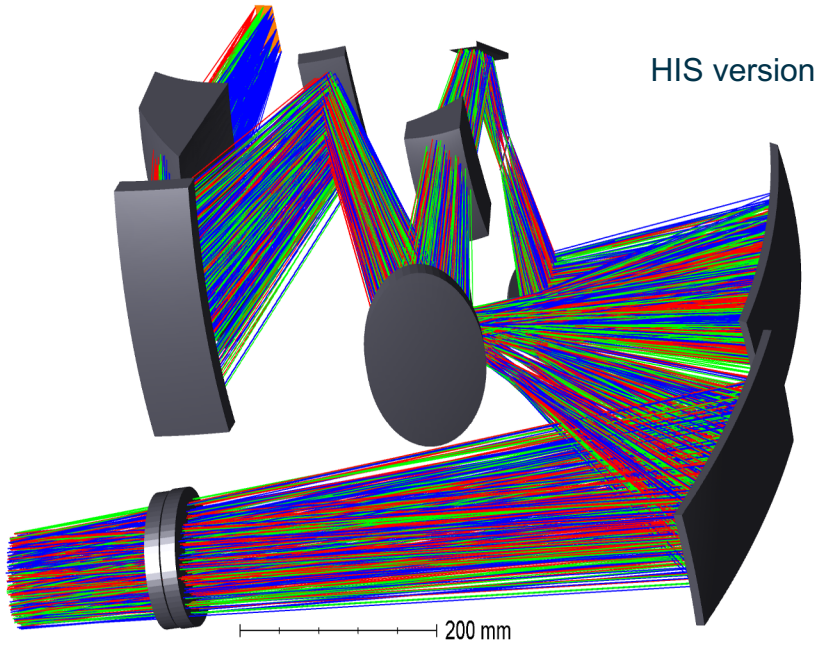


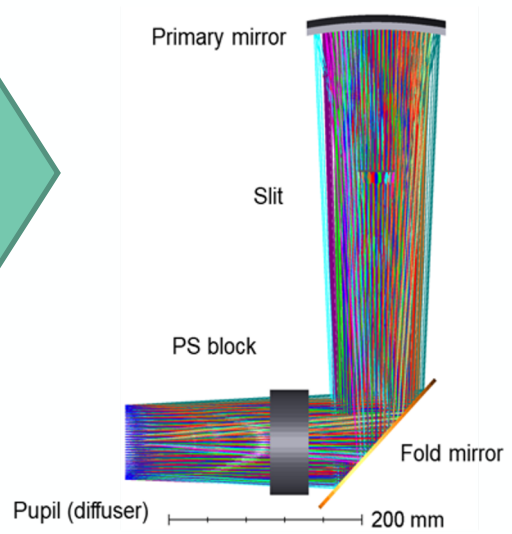




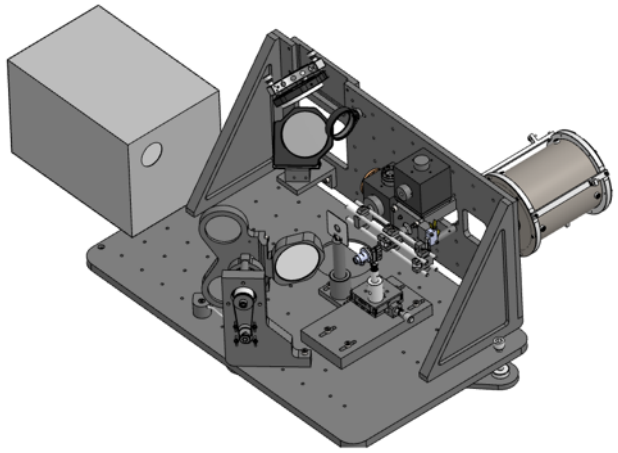


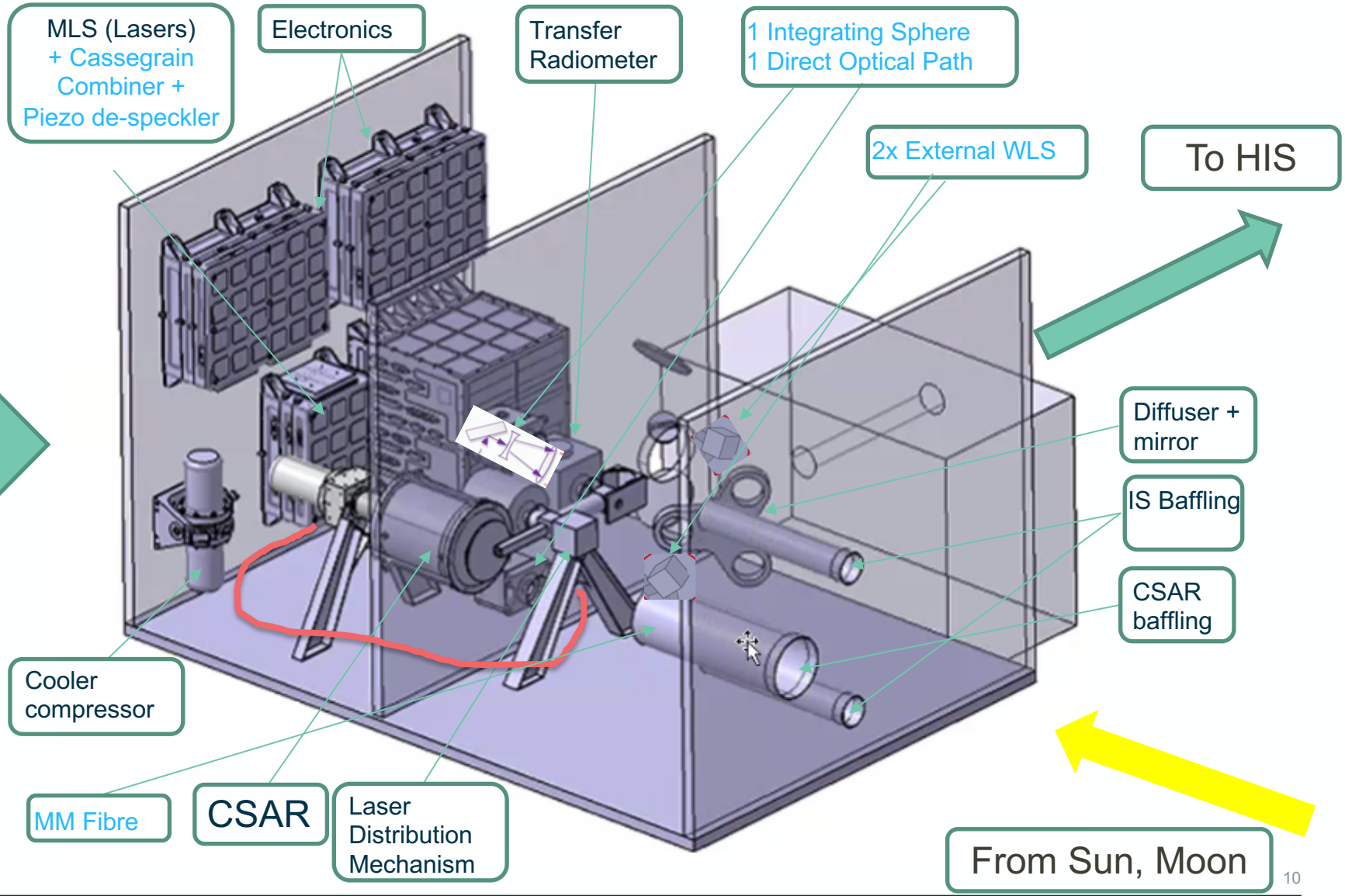
HIS version 2



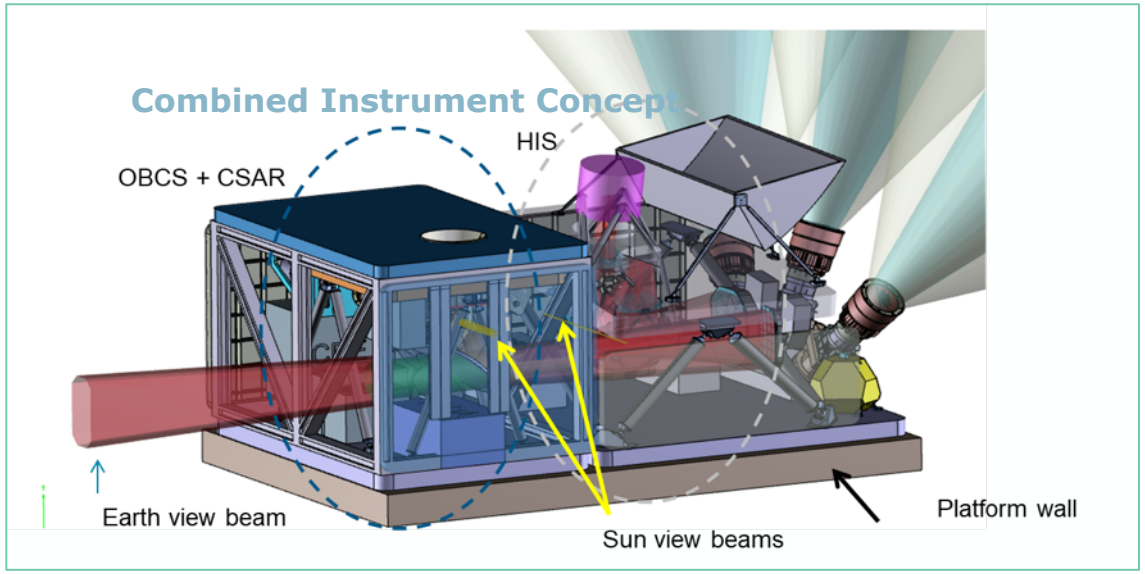


OBCS design at PRR

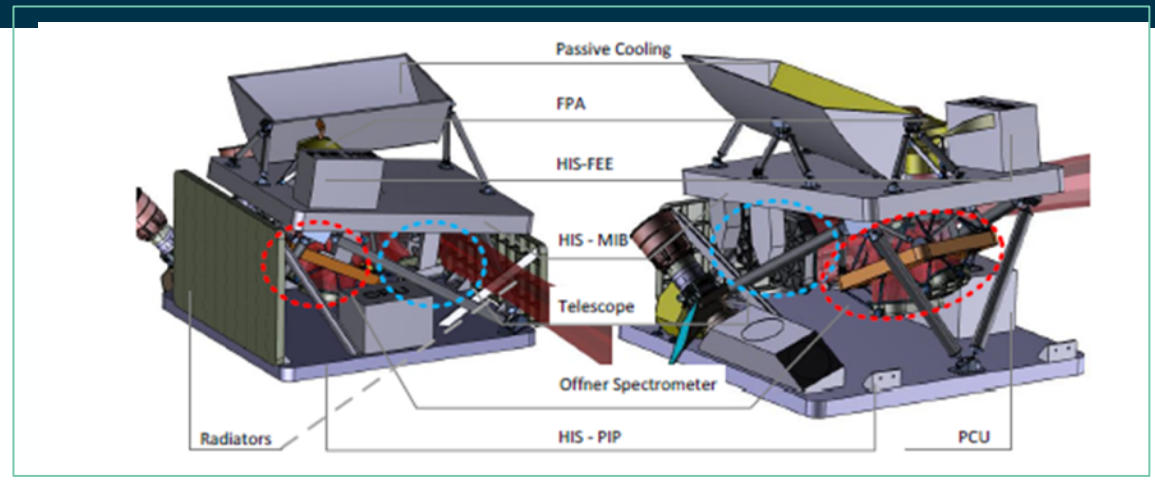




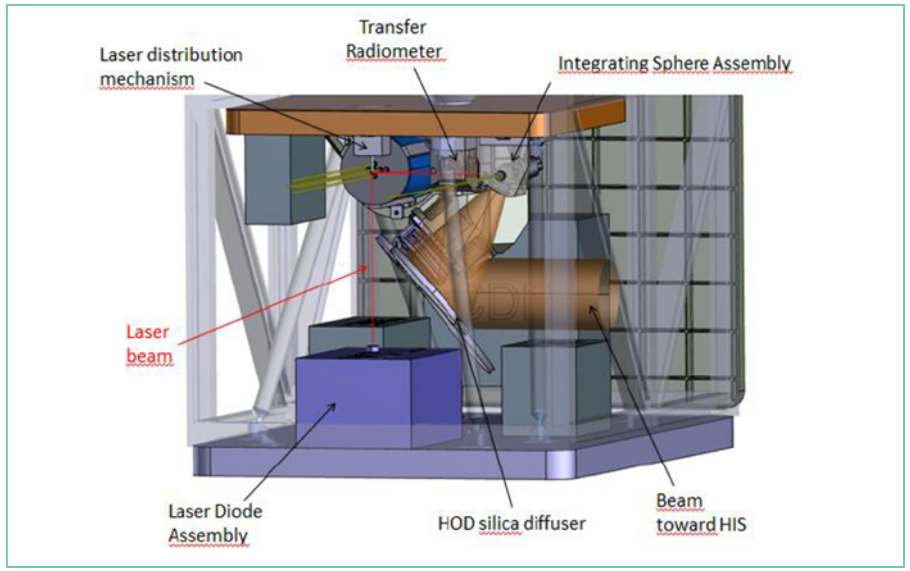
TRUTHS Payload Overview



Courtesy of Airbus Ltd

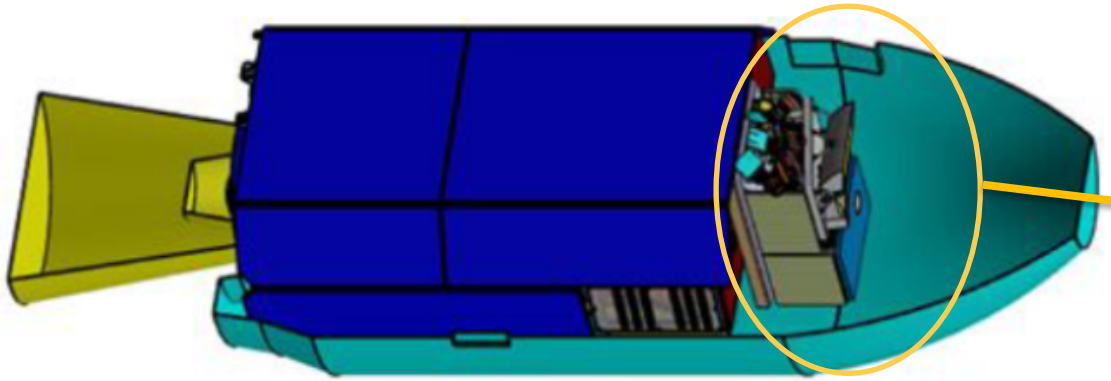


Hyperspectral Imaging Spectrometer (HIS)

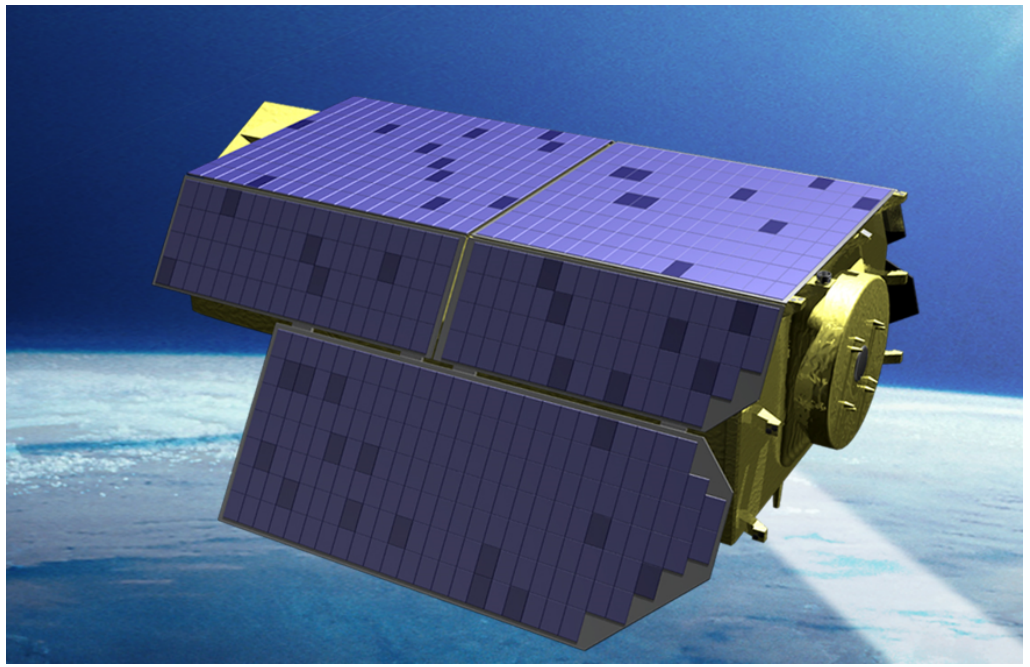


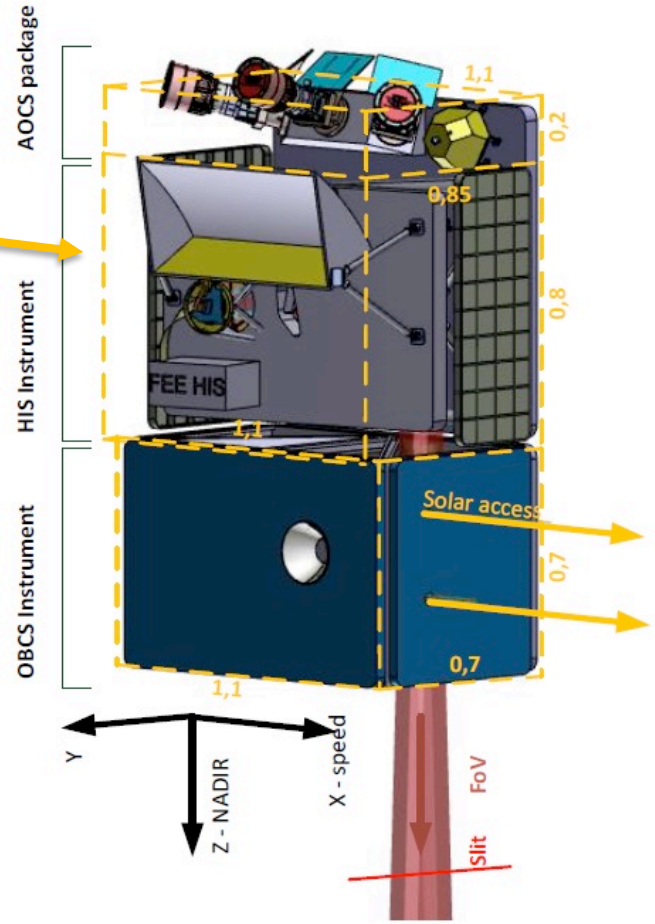
On Board Calibration System (OBCS) & Cryogenic Absolute Solar Radiometer (CSAR)

Preliminary Satellite concept



TRUTHS based on CRISTAL
Platform in Vega-C fairing





CPF & TRUTHS: Similarities and differences

Characteristic	CPF (04/2021)	TRUTHS (PRR)	Comment
Platform/orbit	Int Space Station/ 52°	Own sat / 90°	Both asynchronous with TRUTHS observing the full globe
Operational / lifetime	2024 (1 yr seeking 5)	2028 (5 – 8 yrs)	Potential overlap if CPF life extended (5+ yrs needed for benchmark)
Spectral range	350 -2300 nm	320 – 2400 nm	TRUTHS Performance ranges tailored to products
Spectral Resolution	3-6 nm	4–8 nm Earth, <1 - 8 nm Sun	Bandwidths to facilitate cross-calibration Best realisation in UV < 1 nm, requirements fully met
Radiometric accuracy	0.6 % (k=2)	0.3 % (k=2, G), 1 % (k=2, T), 0.02 % (k= 2) (total solar irradiance)	Spectrally resolved and band integrated
IFOV / Swath	500 m / 70 km	50-60 m / 100 km	50 m to additionally target land imagers, new space, EO applications
Measurands (direct)	Earth/lunar spec reflectance	Earth spec (radiance/reflectance) Solar/lunar Spec (irradiance) Total Solar Irradiance	CPF can obtain radiance/irradiance through solar values from TSIS mission
Route to SI-Traceability	Ratio (sun to earth) with attenuation using apertures & time integration	On-board calibration system mimicking ground including primary standard	Comparison of different methods provides opportunity for rigorous confirmation of uncertainties

GSICS points raised by Dave

1. The TRUTHS schedule ✔
2. The TRUTHS mission objectives, the intercalibration of certain sensors, and climate benchmarking ✔
3. What scan and amount of time where TRUTHS perform for Earth target characterization, sites that have already been selected?
    - List of calibration sites have been identified, including PICS, RADCAL and ocean sites
    - Investigations include nadir and off-nadir observations (up to 40º)
    - Mission time line still to be established based on science requirements and operational constraints
4. Could TRUTHS intercalibrate individual concurrent GEOs while not intercalibrating selected sensors, most GSICS members are responsible for GEO calibration.
    - MTG Sentinel-4 included in the current intercalibration analysis, extension to constellations possible but TBD
5. Lunar scanning and objectives. ✔
6. Will TRUTHS be in a precessionary orbit, what will TRUTHS scanning do while in twilight conditions, are they going to be useful.
    - TRUTHS will be in a circular polar orbit with 61 days repeat cycle
    - Observation requirement is up to a SZA of 83º
    - Limit of twilight conditions by orbit selection
7. If CLARREO is still in operation, will inter-calibration to TRUTHS be of highest priority
    - Yes, the intercalibration of TRUTHS with CLARREO-PF will be of high priority to ensure the continuity of the data set started with CPF
    - TRUTHS-CLEARREO dialogue resulting in an agreed data interoperability scheme.