Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) – A 'gold standard' imaging spectrometer in space to support climate emergency research

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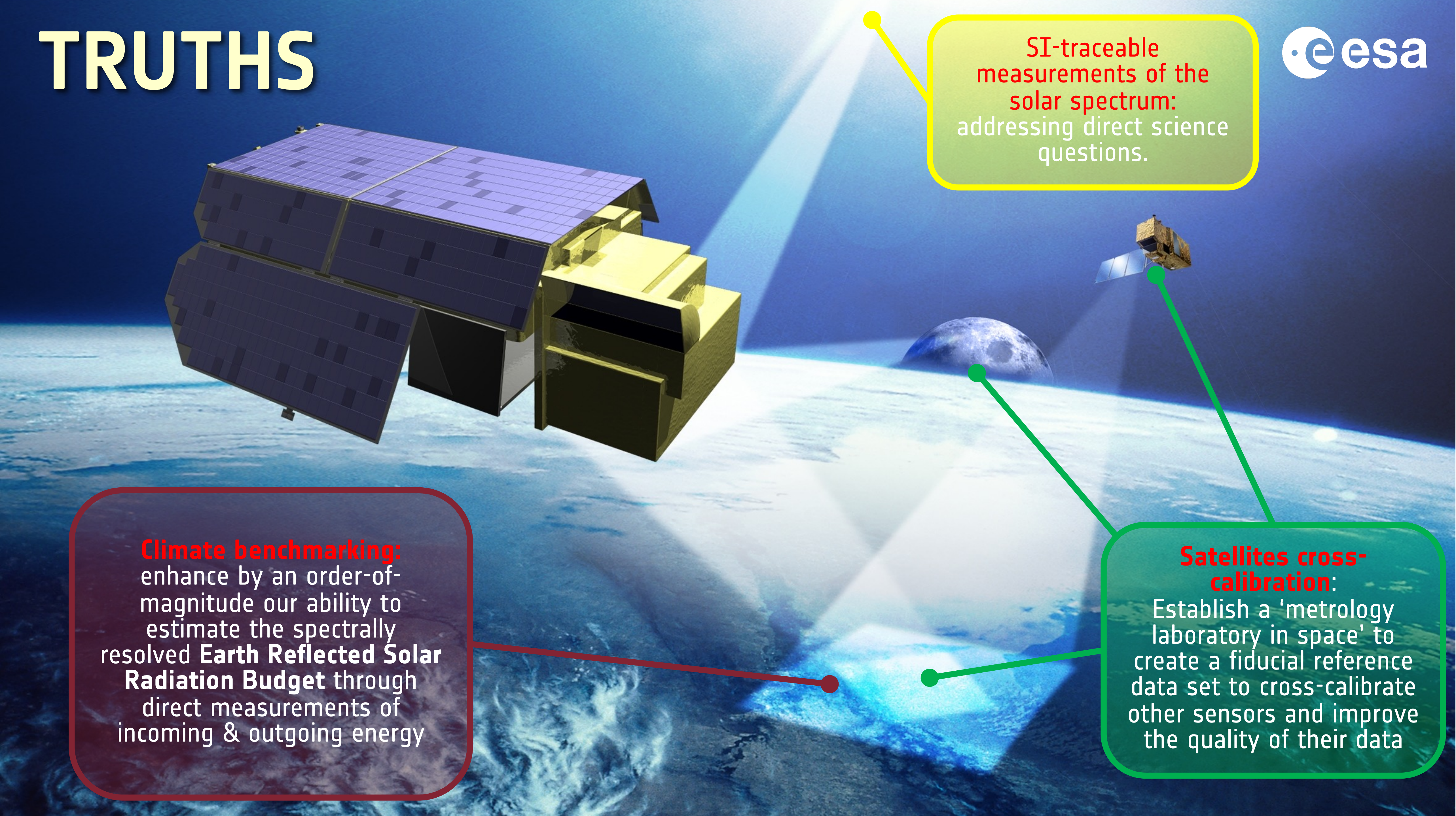
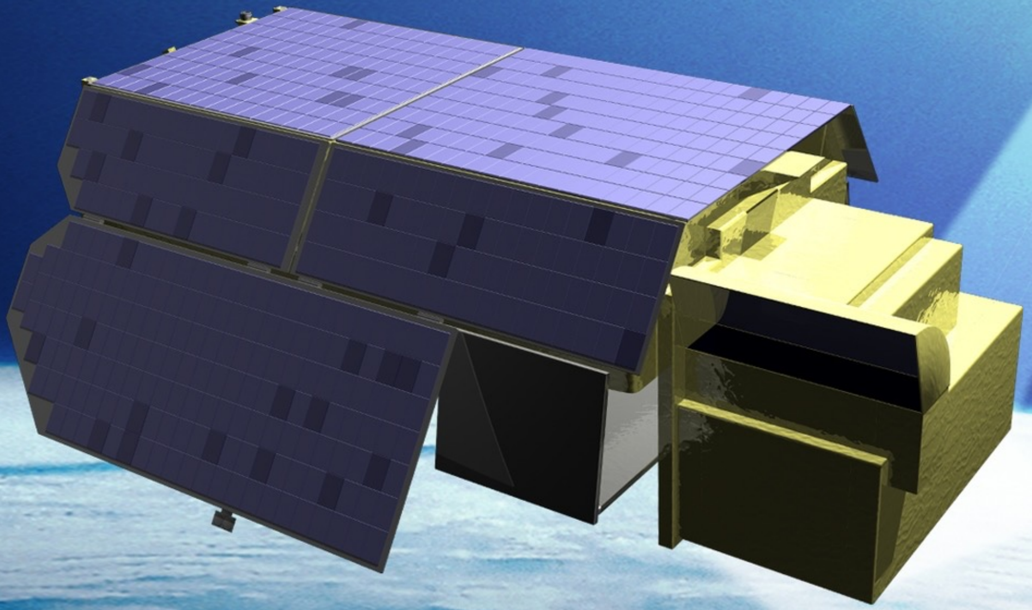
On behalf of the TRUTHS ESA and Science Teams

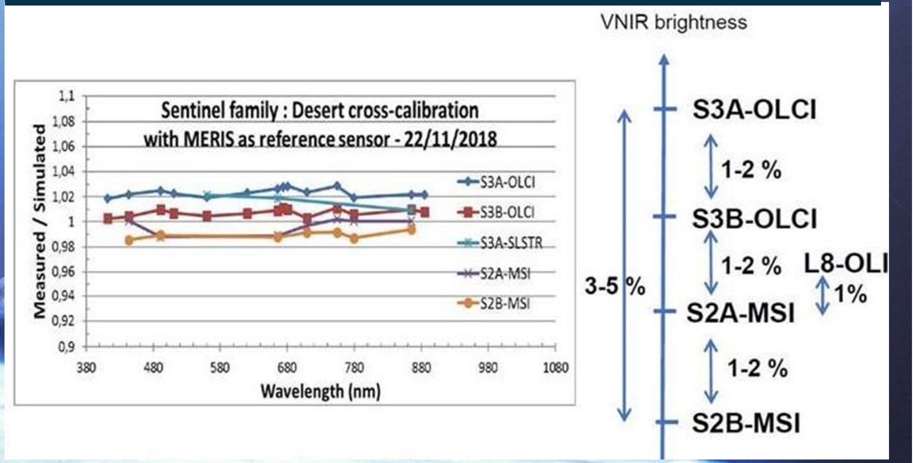
EGU23, 25 April 2023


TRUTHS
esa
SI-traceable measurements of the solar spectrum: addressing direct science questions.
Climate benchmarking: enhance by an order-of-magnitude our ability to estimate the spectrally resolved Earth Reflected Solar Radiation Budget through direct measurements of incoming & outgoing energy
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

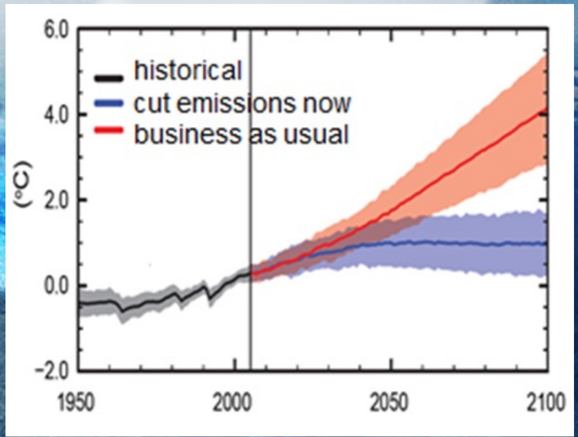
TRUTHS

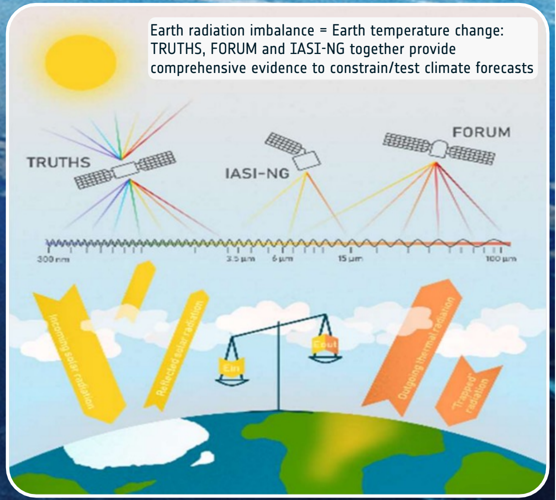


TRUTHS cross-calibration:
bias removal, improving accuracy of other sensors, datasets re-calibration



TRUTHS climate Benchmarking:
more precise predictions





- Optical mission for measuring incoming solar and outgoing reflected radiation
- **Metrology lab in orbit**: flying a primary calibration standard traceable to SI Units

What does TRUTHS do?

Measures incoming and Earth/Moon reflected radiation from the Sun
- 320 to 2400 nm @ ~4 nm intervals (1 nm for solar UV)
- Global nadir @ 50 m ground resolution with 100 km swath (capability)
- Target radiometric uncertainty of 0.3% (k=2)

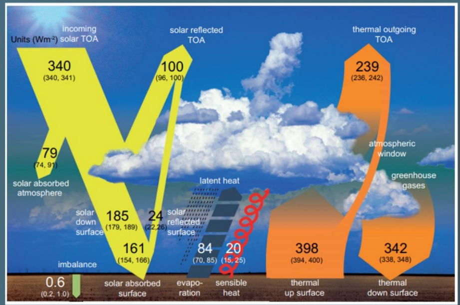
Establishing a benchmark of the radiation state of the planet at ToA (radiance/reflectance) & BoA surfce reflectance to help enable:

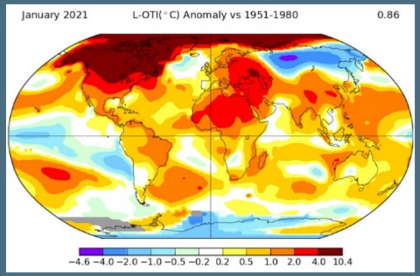
Observations
- Benchmark
- monitoring
- Litigation
- algorithm improvement

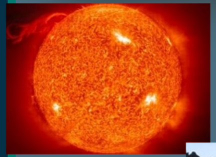
Calibration
- Interoperability
- data-gaps
- performance
- Utility

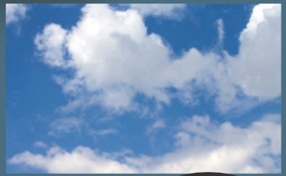
Climate action: Supporting 'Net Zero'

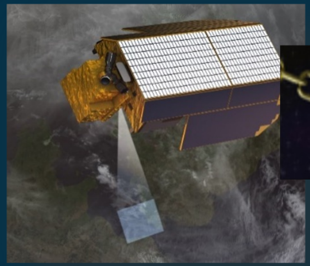
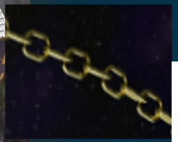
Climate sensitivity/response









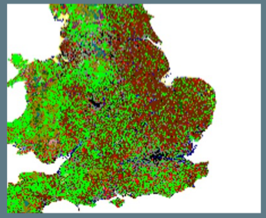
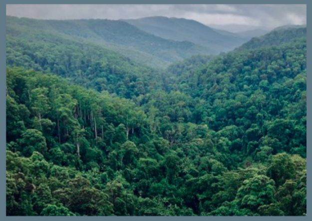




Adaptation/sustainability



Climate action/mitigation

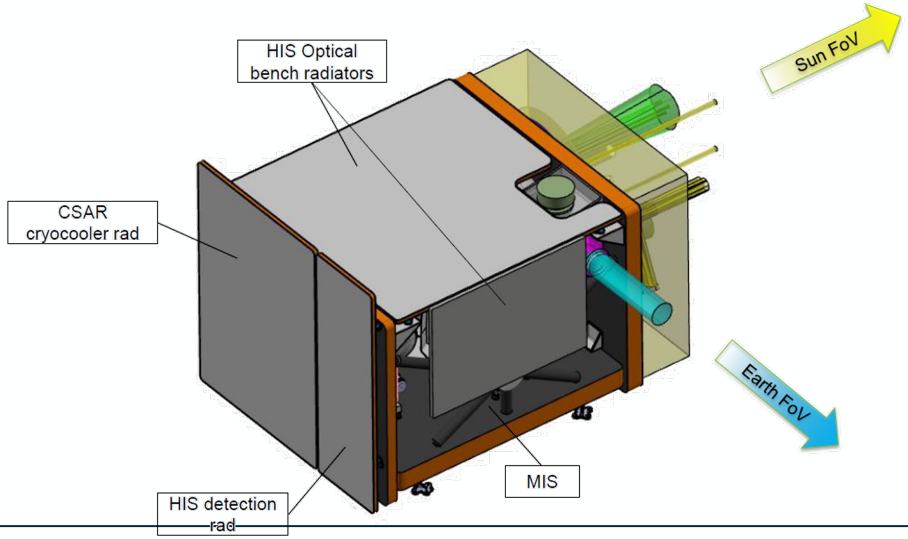


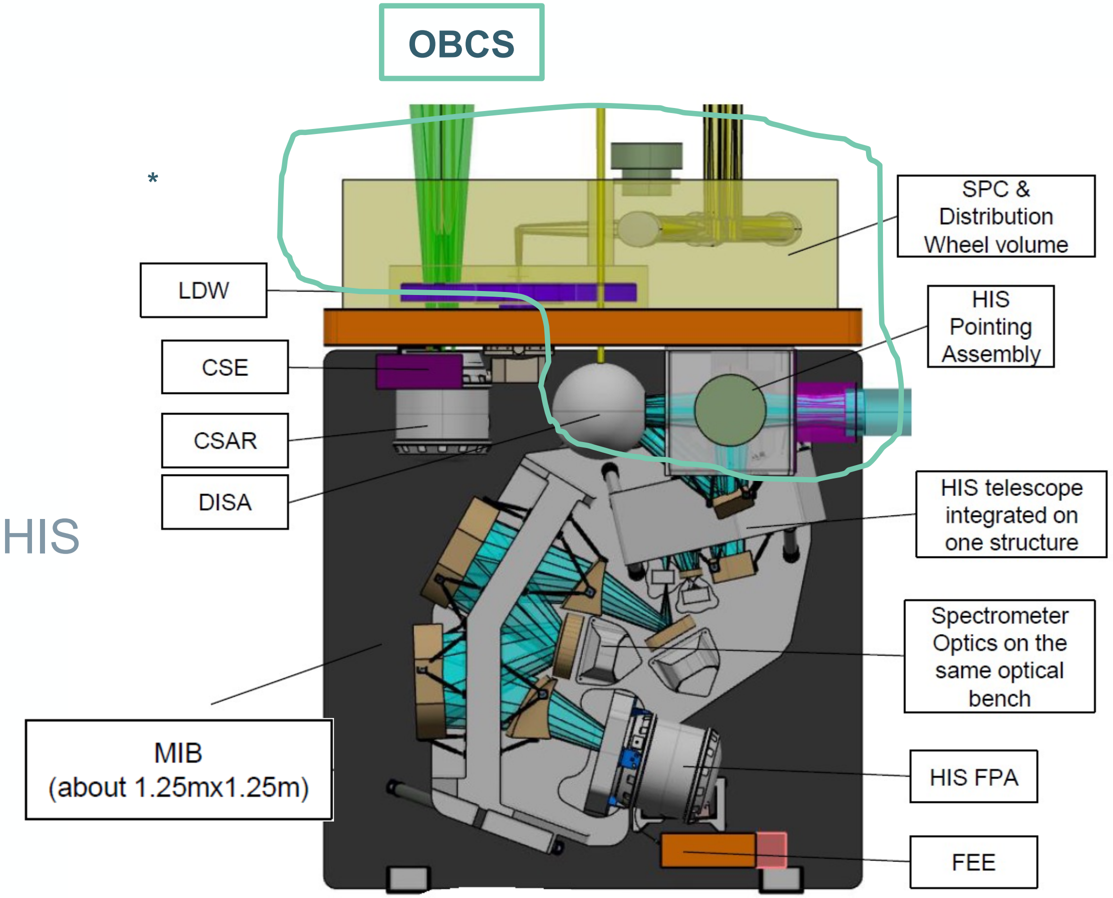




Payload Overview

Payload, composed of three elements:

- **CSAR** (Cryogenic Solar Absolute Radiometer) – operated at 60 K (cryocooler*), the "primary standard"
- **HIS** (Hyperspectral Imaging Spectrometer) – UV to SWIR (**320-2400 nm**), single detector, **50 m** resolution, **100 km** swath. Detector actively cooled at 150 K
- **OBCS** (On-Board Calibration System) – transferring the CSAR solar absolute (SI) measurement to the HIS

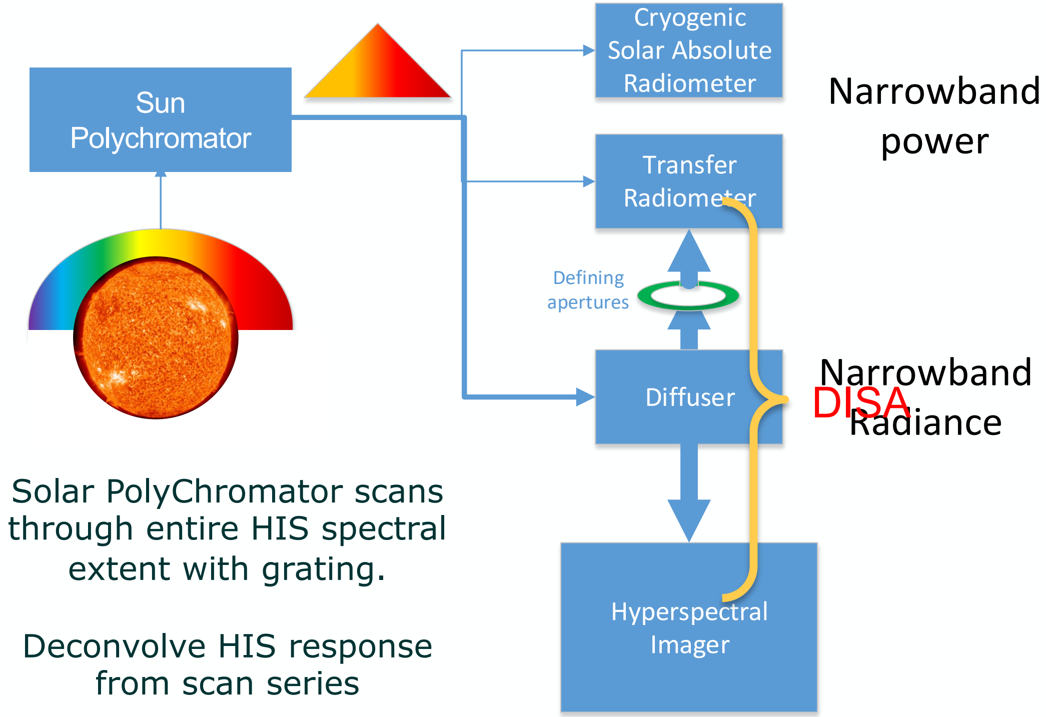


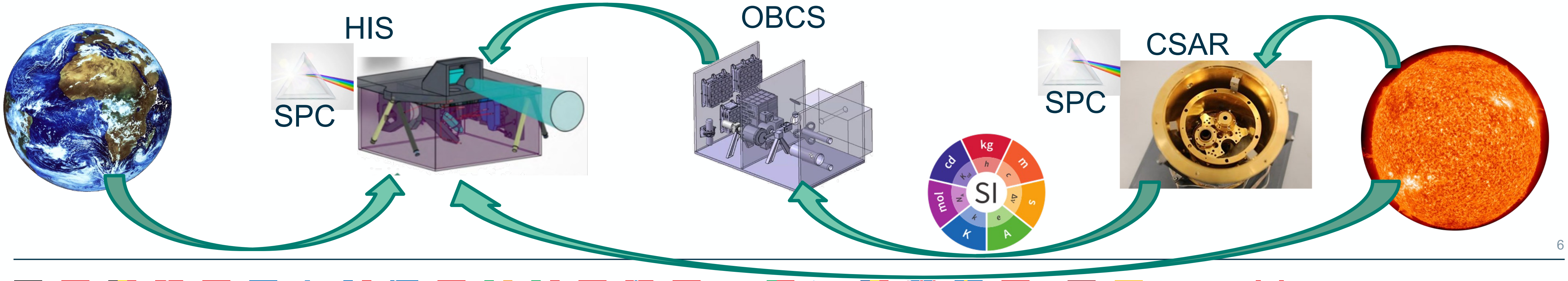


*Cryo-cooler Assembly – recurrent from THRISHNA mission at ISRR baseline

TRUTHS in-orbit calibration philosophy

1. Cryogenic Absolute Solar Radiometer (CSAR)
   - Measures optical power in Sun Polychromator (SPC) output
   - SPC generates beams of ‘monochromatic’ radiation from sun distributed to different parts of the calibration system.
2. Double Integrating Sphere Assembly (DISA)
   - Conversion from power to radiance.
   - Calibrated, relative mode, via direct sun + HIS measurement.
   - Calibrates HIS gain via SPC output.
3. Concept of Operations based on geometric knowledge & stability
   - Calibrating out in-flight degradation only.
   - Repeatability assumptions based on mechanical and thermal control.



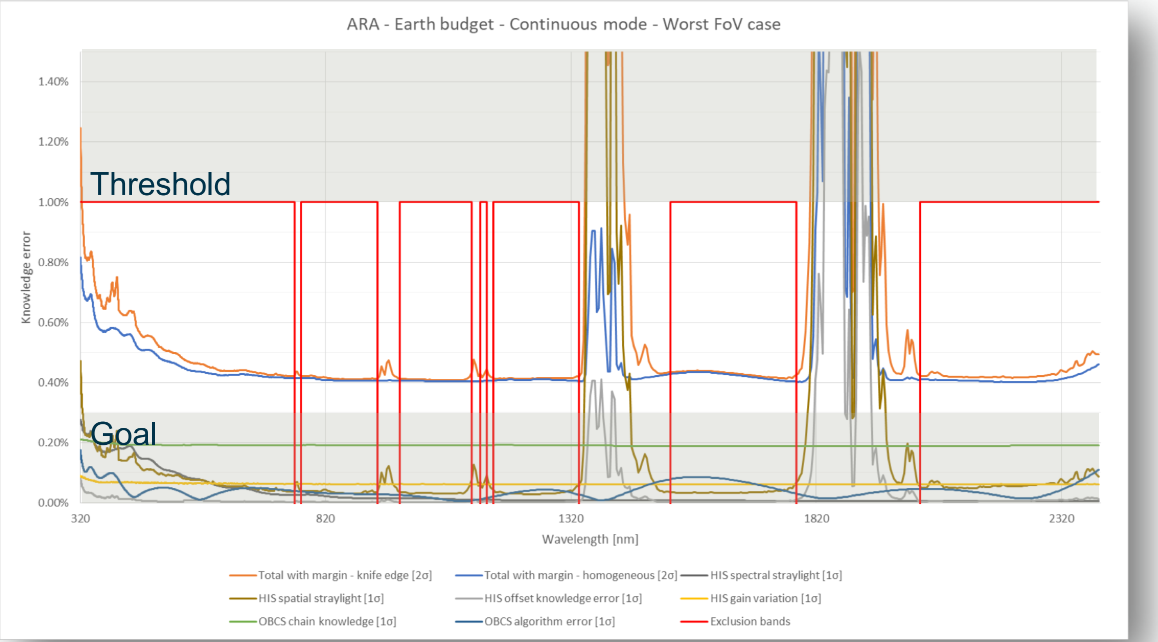


Absolute Radiometric Accuracy (ARA)

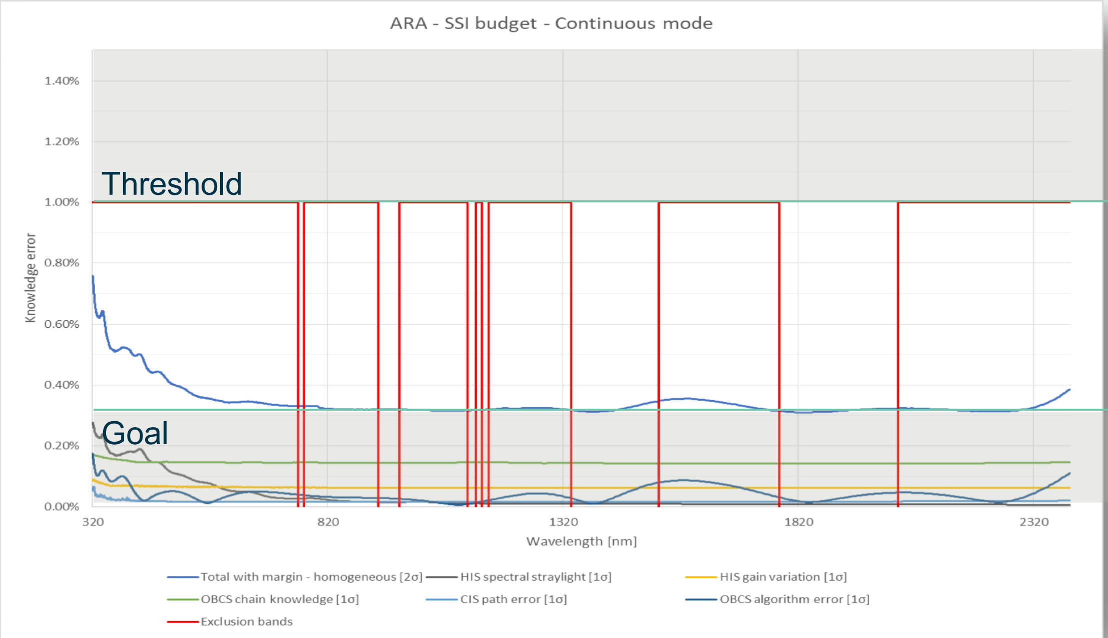
Mission requirement:

MRD-ID	Type	Value
MRD-OBS-310	ERU ERSR, SSI, LSI	The Expanded Radiometric Uncertainty for ERSR, SSI and LSI measurements shall be better than 0.3% (G) / 1% (T).

Earth Reflected Solar Radiance



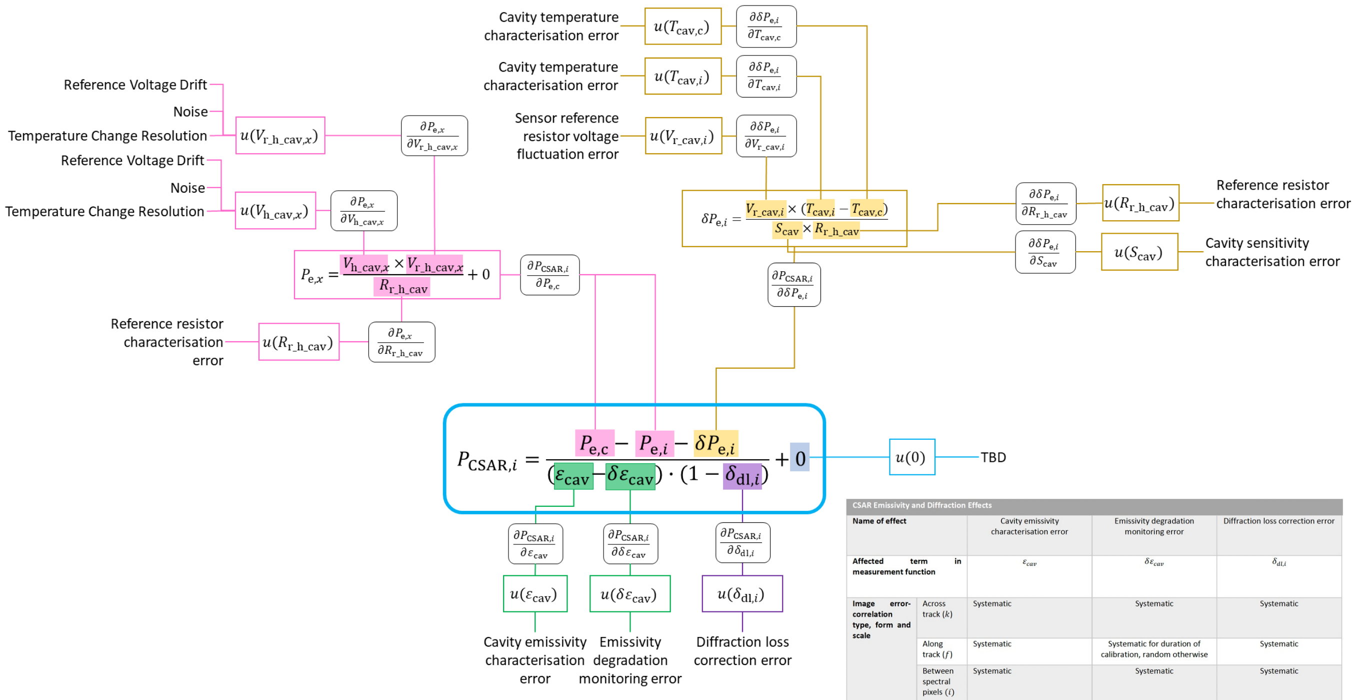
Spectral Solar Irradiance



Application of Metrological principles

FIDUCEO like analysis of end to end traceability and uncertainties establishing measurement equation and errors sources together with associated uncertainties for the end to end measurement.

CSAR power calibration

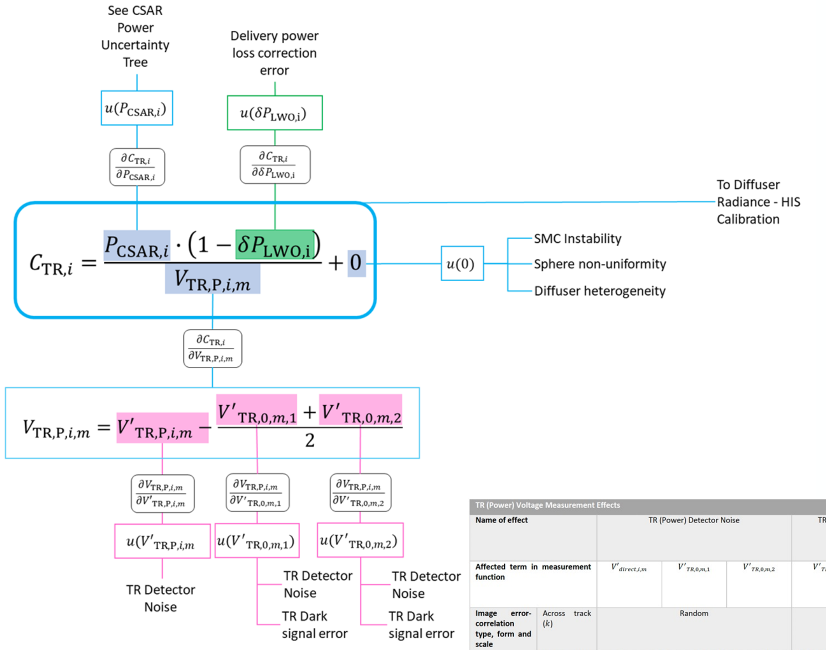


CSAR Emissivity and Diffraction Effects				
Name of effect		Cavity emissivity characterisation error	Emissivity degradation monitoring error	Diffraction loss correction error
Affected term in measurement function		ε_{cav}	$\delta\varepsilon_{cav}$	$\delta_{dl,i}$
Image error-correlation type, form and scale	Across track (k)	Systematic	Systematic	Systematic
	Along track (f)	Systematic	Systematic for duration of calibration, random otherwise	Systematic
	Between spectral pixels (i)	Systematic	Systematic	Systematic
Uncertainty	PDF shape	Rectangular	Rectangular	Rectangular
	units	-	-	-
	magnitude	0.01%	TBD	0 for underfilled case
Source		[RD-10]	[RD-10]	[RD-10]
Sensitivity coefficient		$\frac{\partial L_{i,k}}{\partial \varepsilon_{cav}}$	$\frac{\partial L_{i,k}}{\partial \delta\varepsilon_{cav}}$	$\frac{\partial L_{i,k}}{\partial \delta_{dl,i}}$

Hunt and Fahy, NPL, 2022

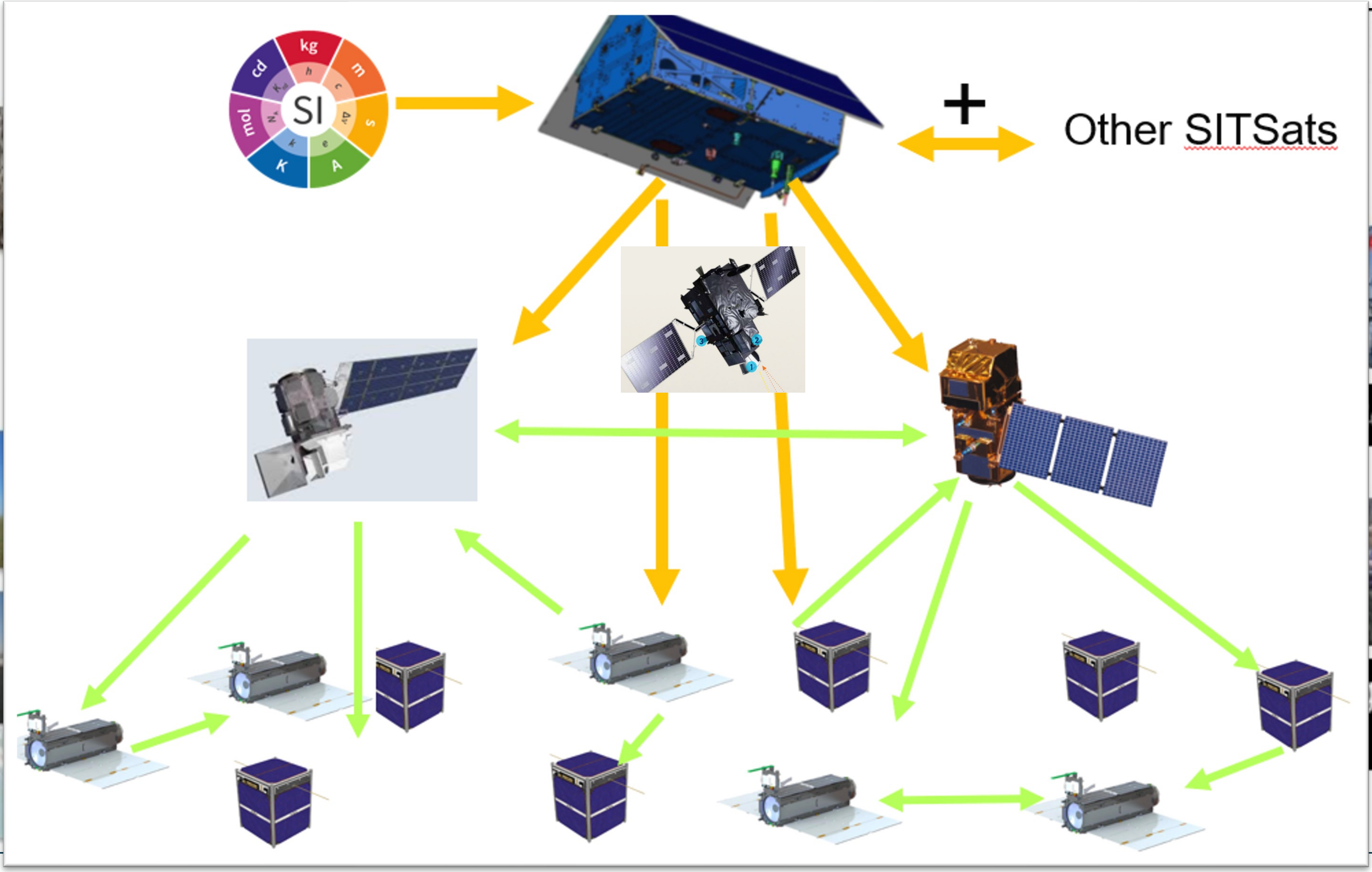
Transfer Radiometer power transfer

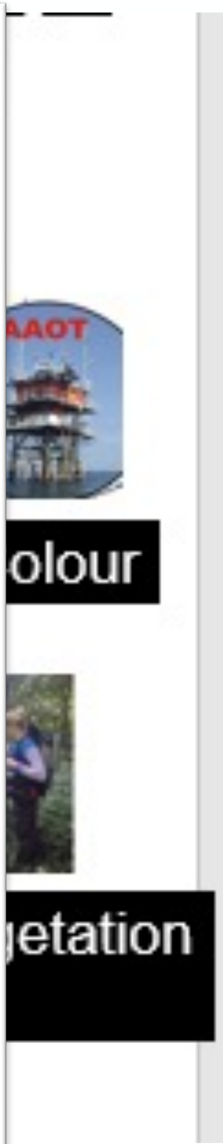
(to be updated)



TR (Power) Voltage Measurement Effects						
Name of effect		TR (Power) Detector Noise			TR (Power) Dark Signal Error	
Affected term in measurement function		$V'_{direct,i,m}$	$V'_{TR,0,m,1}$	$V'_{TR,0,m,2}$	$V'_{TR,0,m,1}$	$V'_{TR,0,m,2}$
Image error-correlation type, form and scale	Across track (k)	Random			Random	
	Along track (f)	Systematic for duration of calibration, random otherwise			Systematic for duration of calibration, random otherwise	
	Between spectral pixels (i)	Random			Random	
Uncertainty	PDF shape	-			Rectangular	Rectangular
	units	-			pA	pA
	magnitude	TBD			5	5
Source		[RD-9]			[RD-9]	[RD-9]
Sensitivity coefficient		$\frac{\partial L_{i,k}}{\partial V'_{direct,i,m}}$	$\frac{\partial L_{i,k}}{\partial V'_{TR,0,m,1}}$	$\frac{\partial L_{i,k}}{\partial V'_{TR,0,m,2}}$	$\frac{\partial L_{i,k}}{\partial V'_{TR,0,m,1}}$	$\frac{\partial L_{i,k}}{\partial V'_{TR,0,m,2}}$

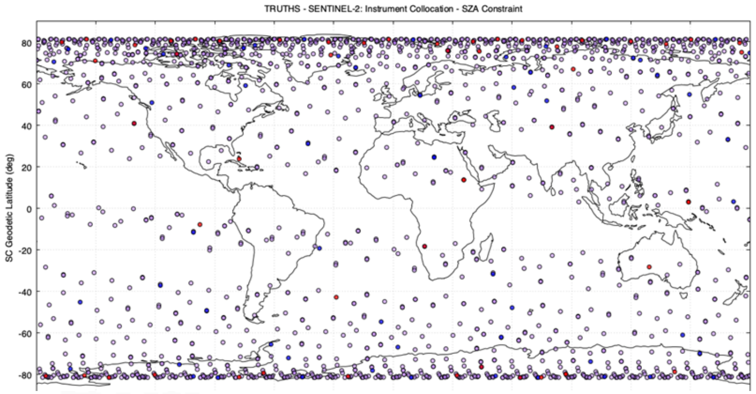
SI-Traceability to Cal/Val infrastructure



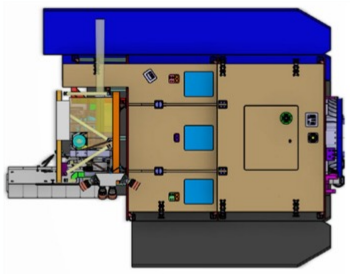


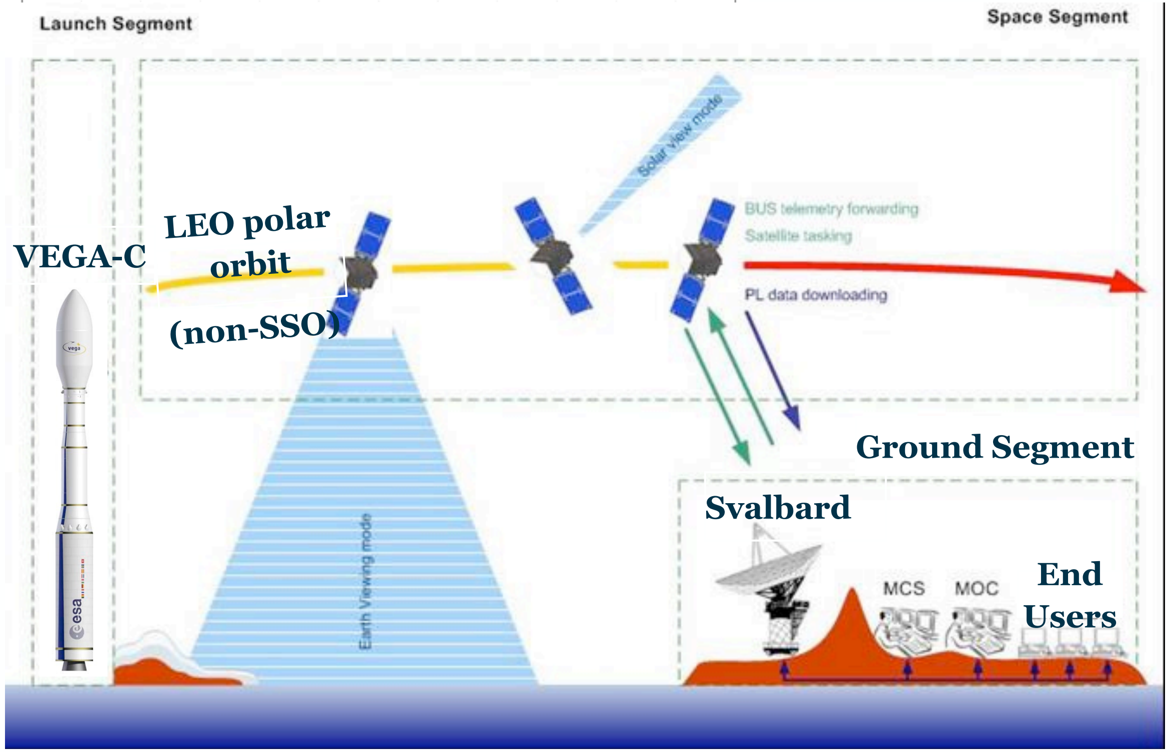
System Architecture Overview

- Lifetime 5 years + 3 extension
- Launch foreseen in 2030
- Space Segment:
  - Orbit 614 km, polar (90º) non-SSO
  - 1 satellite – agile, design for non-SSO
  - Novel Payload (CSAR, OBCS, HIS)
- Launch Segment:
  - Vega-C (-E) single launch
- Ground Segment
  - 1 polar station (baseline)
  - lossless compression (baseline)
  - Routine FOS in UK
  - PDGS in UK + data access at ESRIN
  - **ESA free and open data access policy**

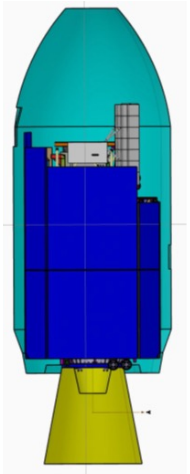


Space Segment





Launch Segment



International Climate & Calibration Observatory

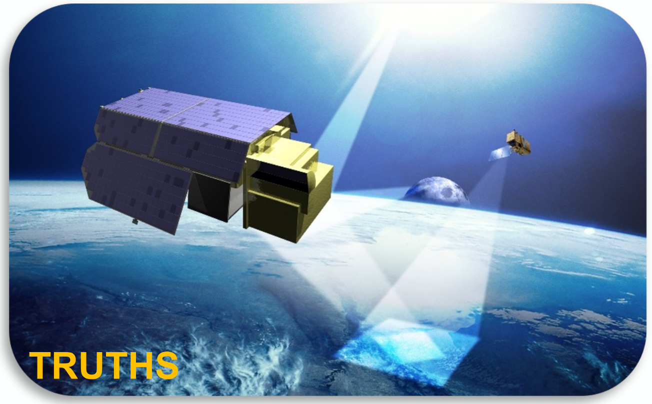
TRUTHS from 2030 onwards will help initiate a sustainable long-term international climate & calibration observatory as direct response to international requests

Guaranteeing the future of space activities by protecting the environment

NASA CLARREO-Pathfinder (CPF) 'sister mission' which will be launched to the ISS in 2025.

- Hope for overlap!
- Also potential overlap with Chinese Libra and othere SITSats

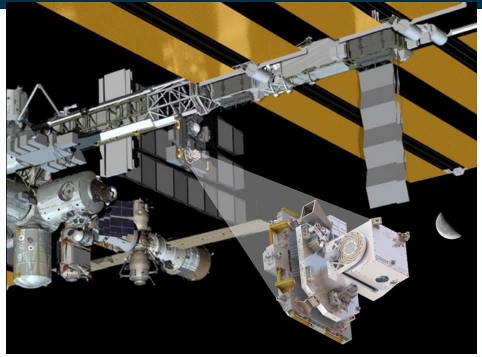
TRUTHS & CPF SITSats will provide unique and critical information for understanding and monitoring Climate and Environmental change from space and support climate action

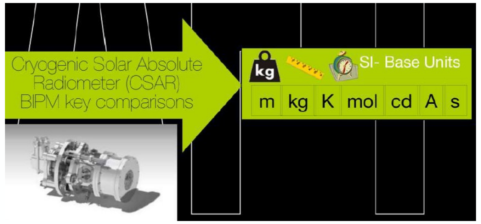


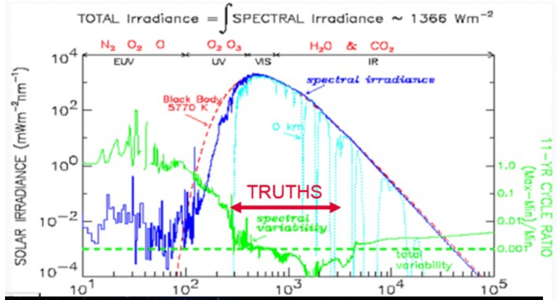
Backup Slides

TRUTHS Vision: mission assets and perspectives

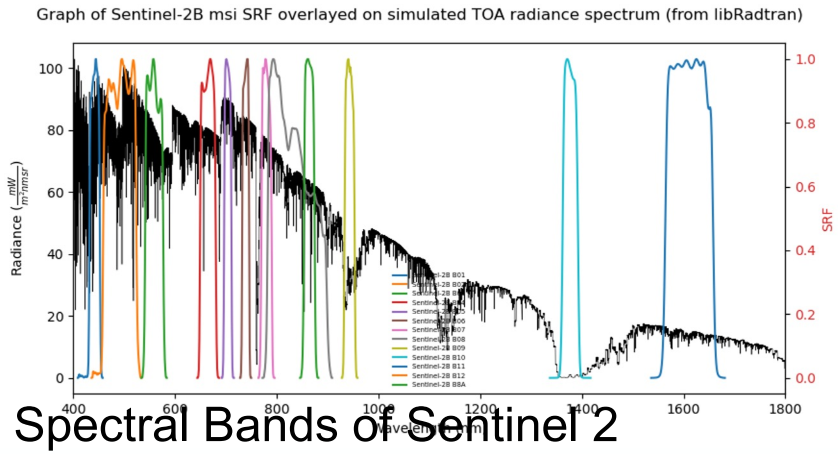
- **An international climate observatory**
  - The need to cover **long time series** and many solar cycles calls for long-term operation.
  - International cooperation and data interoperability among different missions worldwide will be implemented
  - NASA already agreed to a TRUTHS/CLARREO-Pathfinder framework.
  - Initiating CEOS WGCV (& GSICS hopefully) task group on SITSats in general.
- **An operational service for institutional and commercial satellites**
  - The capability to cross-calibrate other satellites opens up to an operational service for improving the quality of other optical satellites, either institutional (e.g., Copernicus and Eumetsat series) and commercial.
  - The traceability to SI units and rigorous uncertainty tracing makes the measurements unambiguous and trustworthy
- **A new concept for next generation optical missions**
  - An optimized TRUTHS calibration system might become a novel package for optical instruments calibration.
  - Smaller satellites might opt to fully rely on calibration from TRUTHS data service and optical payload can be conceived lighter and simpler,
- **A step towards a System of Systems**
  - Efficient use of space and data assets: TRUTHS improves the performance of many others and the TRUTHS data on calibration sites permit to improve new and existing datasets, even taken in the past.
  - TRUTHS concepts fits in the strategic view of making space assets interconnected and result of a distributed effort



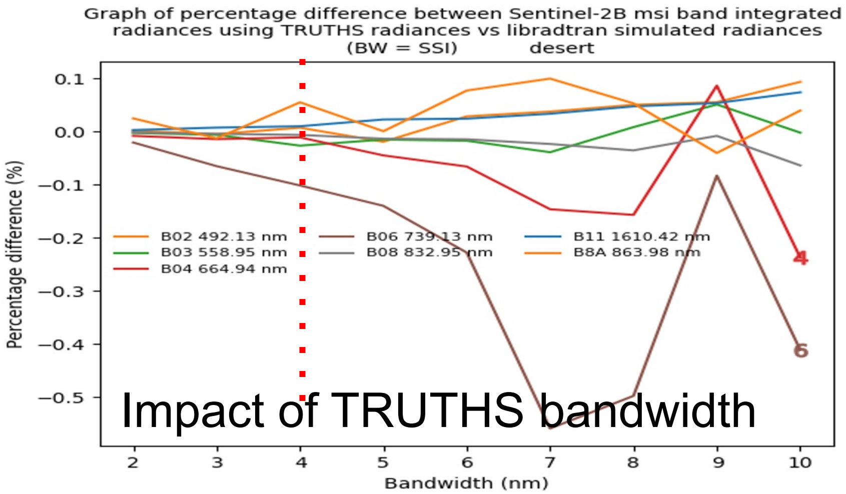




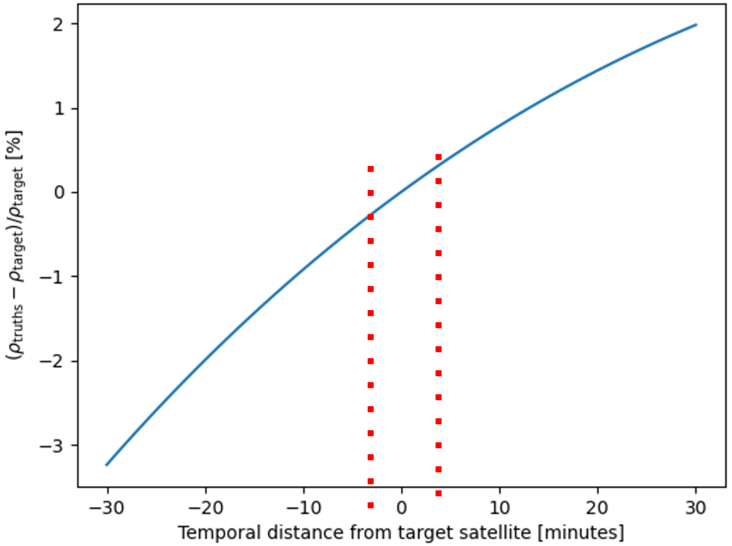
Transferring TRUTHS accuracy to other Sensors: establishing mission requirements (S2S calibration

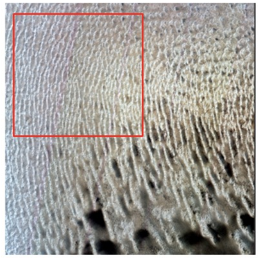


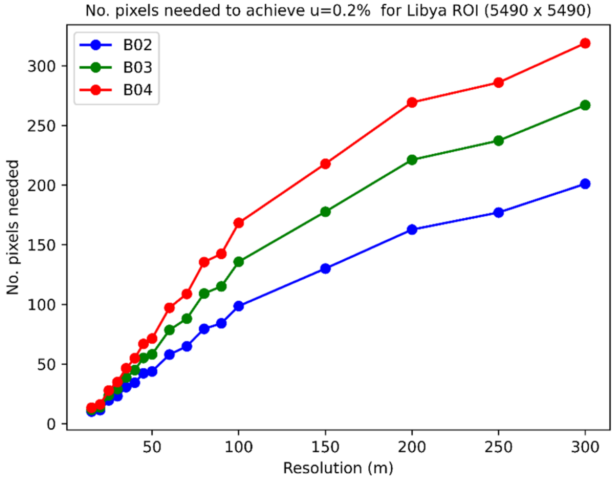
Spectral Bands of Sentinel 2



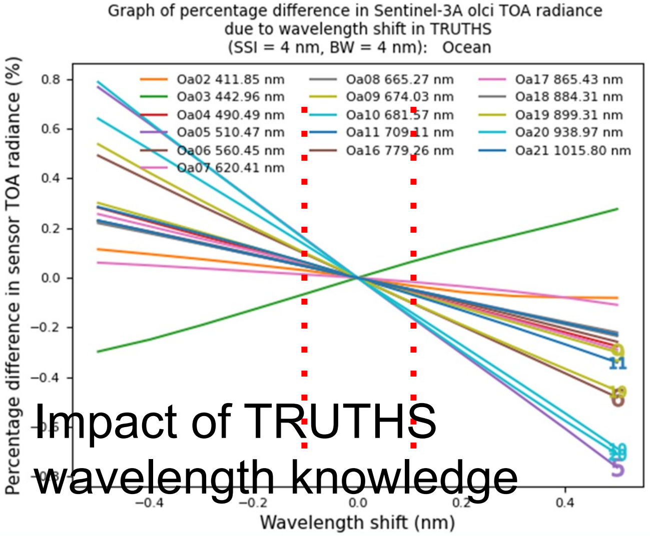
Impact of TRUTHS bandwidth



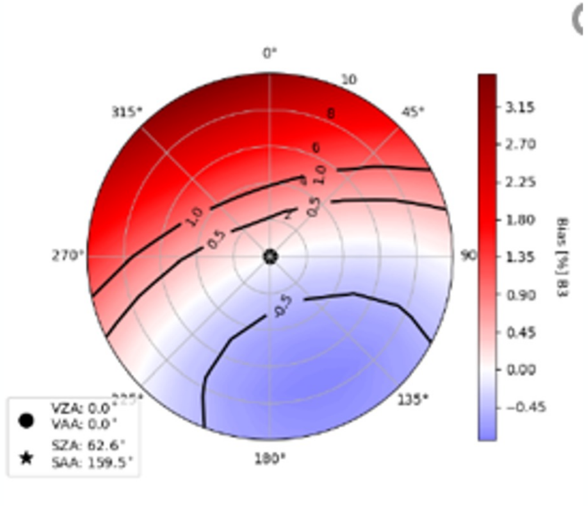




Uniformity of Cal Target (Libya 4) area to be sampled (2.5 km to achieve 0.2% @ 50 m)



Impact of TRUTHS wavelength knowledge

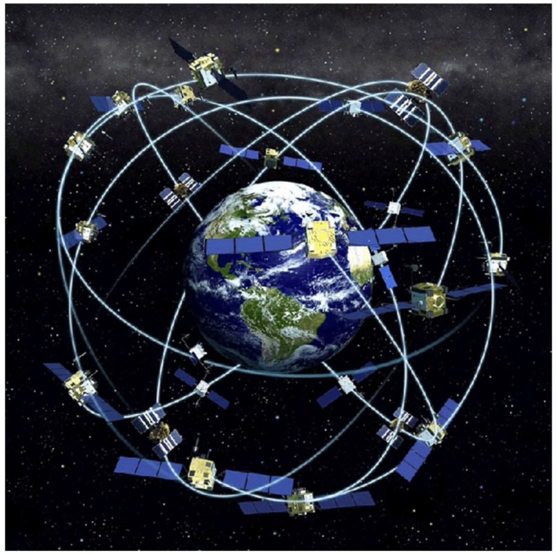


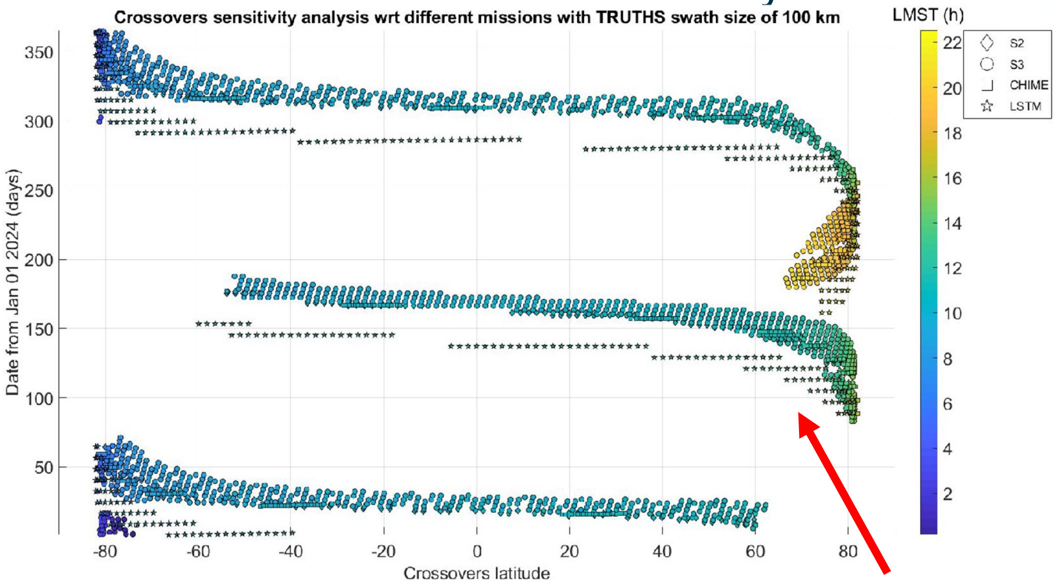
(d) MODIS B3 (460nm); AOT (550nm) = 0.4

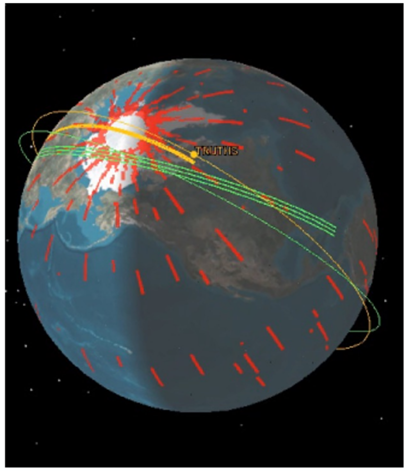
Reference Calibration

- **Enables interoperability & Harmonisation**
  - **Prospect of 'certified calibration'**

TRUTHS 90°pole to pole orbit, observing through the diurnal cycle, allows many opportunities to overpass orbit of sun-synchronous sensors







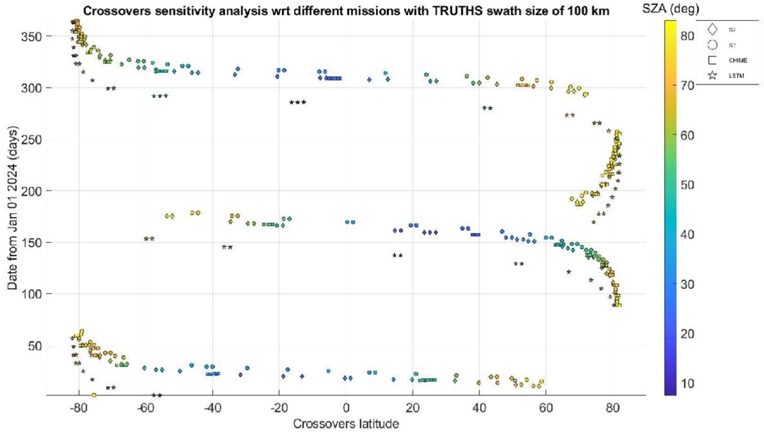
Summary after 6 months

TRUTHS provides the means to transform global EO system, including constellations of micro-sats so they deliver traceable scientific/climate quality observations -

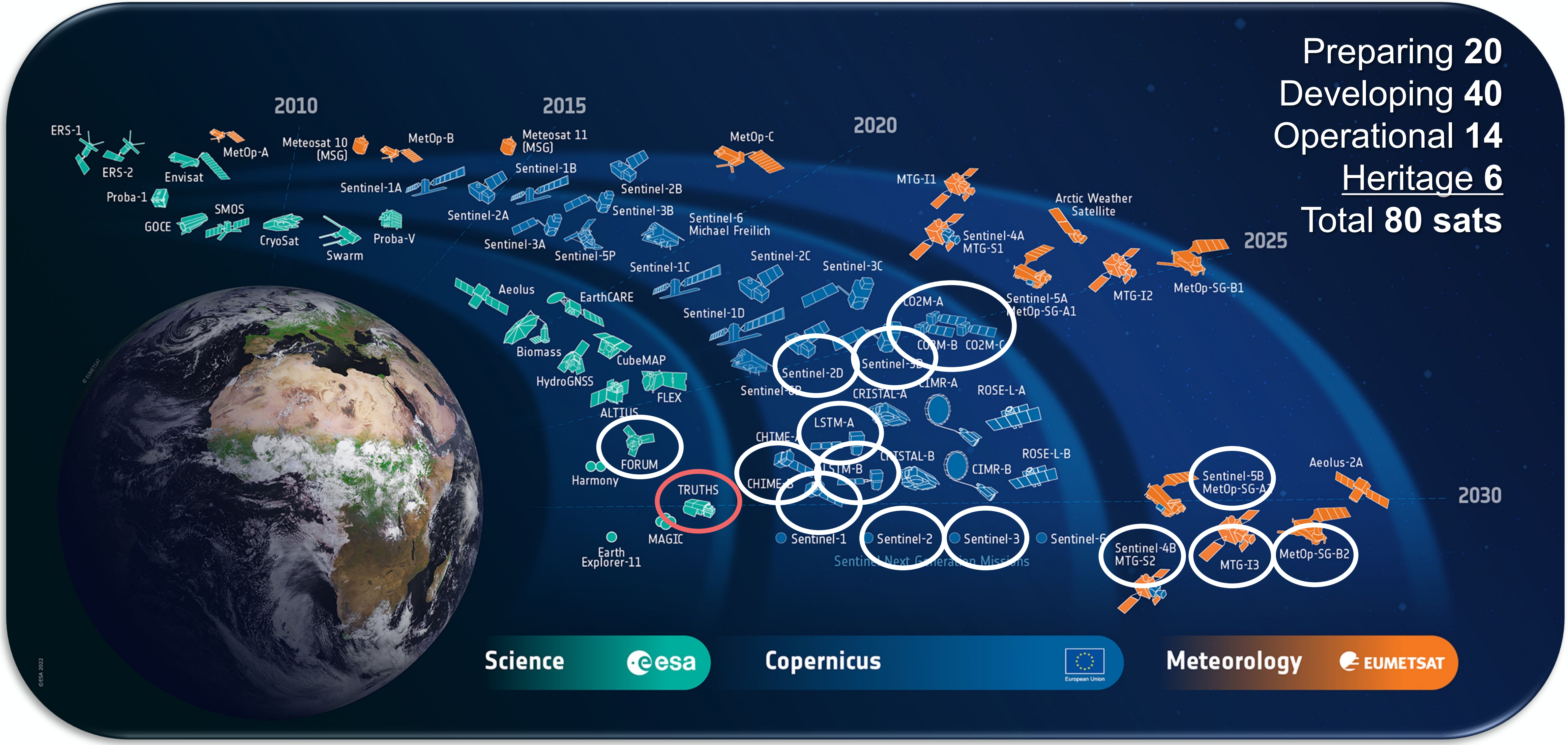
<30 s time difference Swath overlap

1 year of near perfect nadir overlaps for TRUTHS & satellite under test

(<1° (no pointing) <30 s time difference



ESA-developed Earth Observation Missions



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