living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) – A ‘gold standard’ reference for an integrated space-based observing system for environment and climate action

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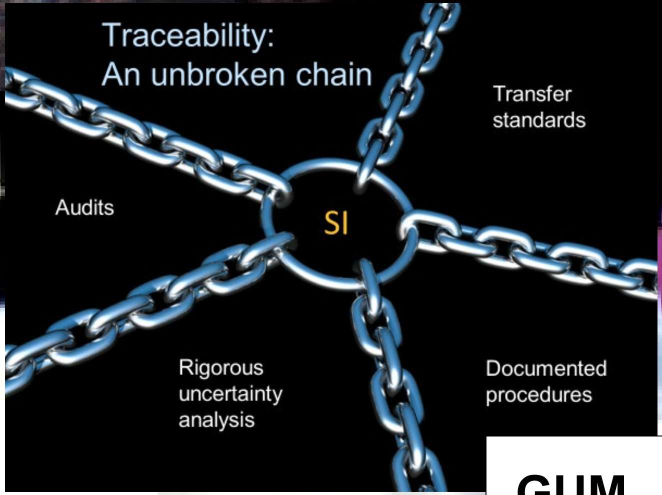
27 May 2022

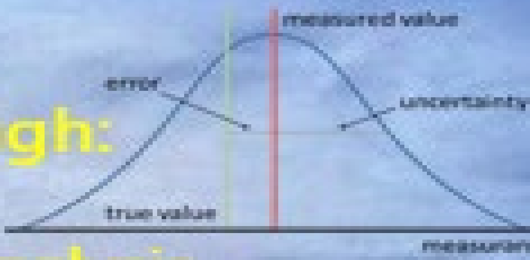
Long-time-base & societal/economic critical applications like Climate require robust 'trustworthy' data:

e.g detection of small signals of change out of a noisy background of nat variability

At location of observation



- Interoperable
- Century-long stability
- Coherence
- Absolute accuracy

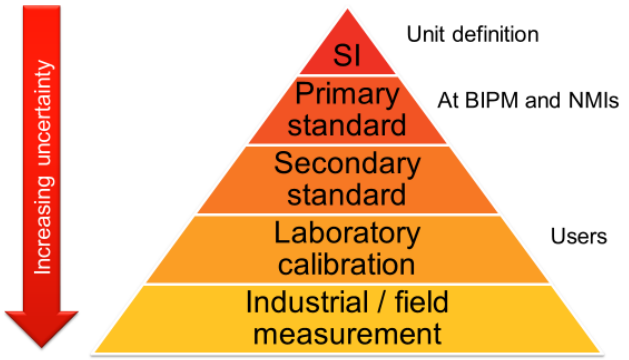


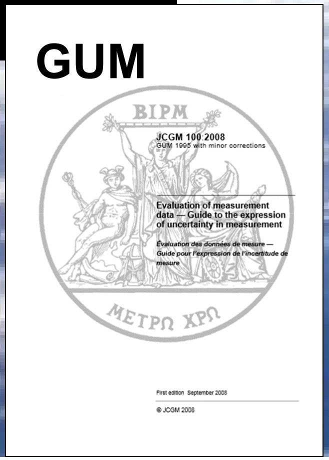
Achieved through:
- Traceability
- Uncertainty Analysis
- Comparison

All documented and accessible

NPL National Physical Laboratory

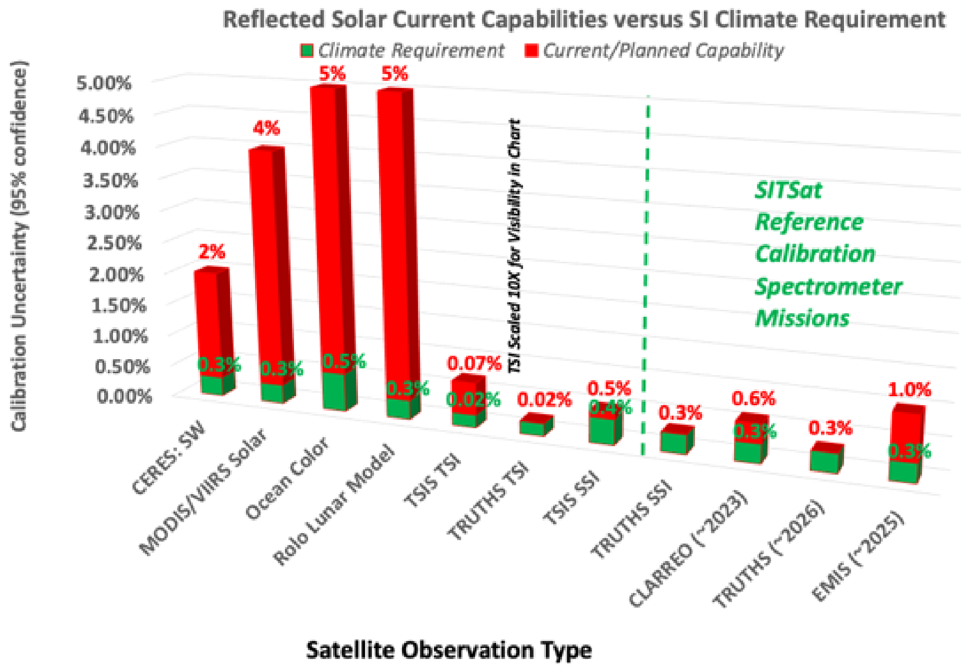
Traceability



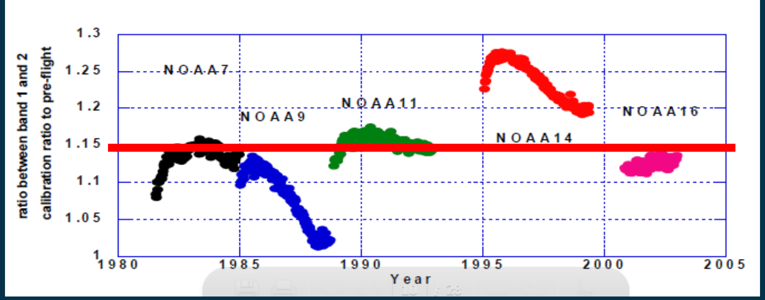


CEOS QA4EO A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

Climate Need & observation challenges



Libya 4, a CEOS PICS site is a desert with a stable long-term reflectance. Vegetation index measured below should be horizontal red line i.e. none!



CEOS

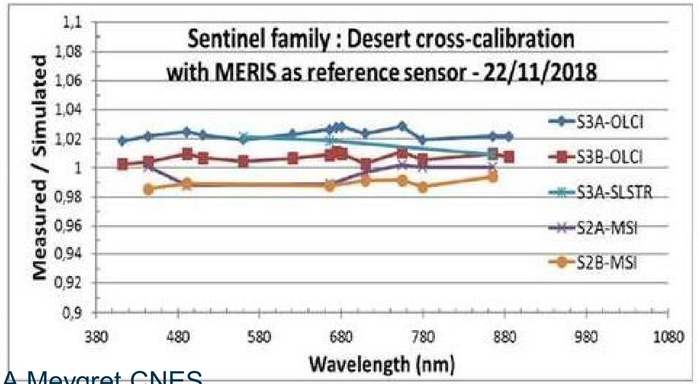
SI-Traceable Space-based Climate Observing System:
a CEOS and GSICS Workshop
National Physical Laboratory,
London, UK,
9-11 Sept. 2019

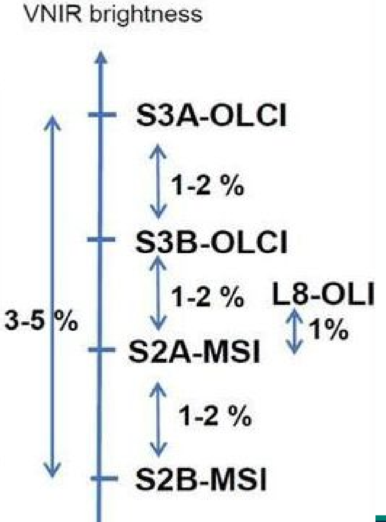
SITSCOS Workshop Report

Editors: Nigel Fox, Tim Hewison, Greg Kopp, Bruce Wielicki

https://doi.org/10.47120/npl.9319

Most satellites not designed for climate: performance to suit application





A Meygret CNES

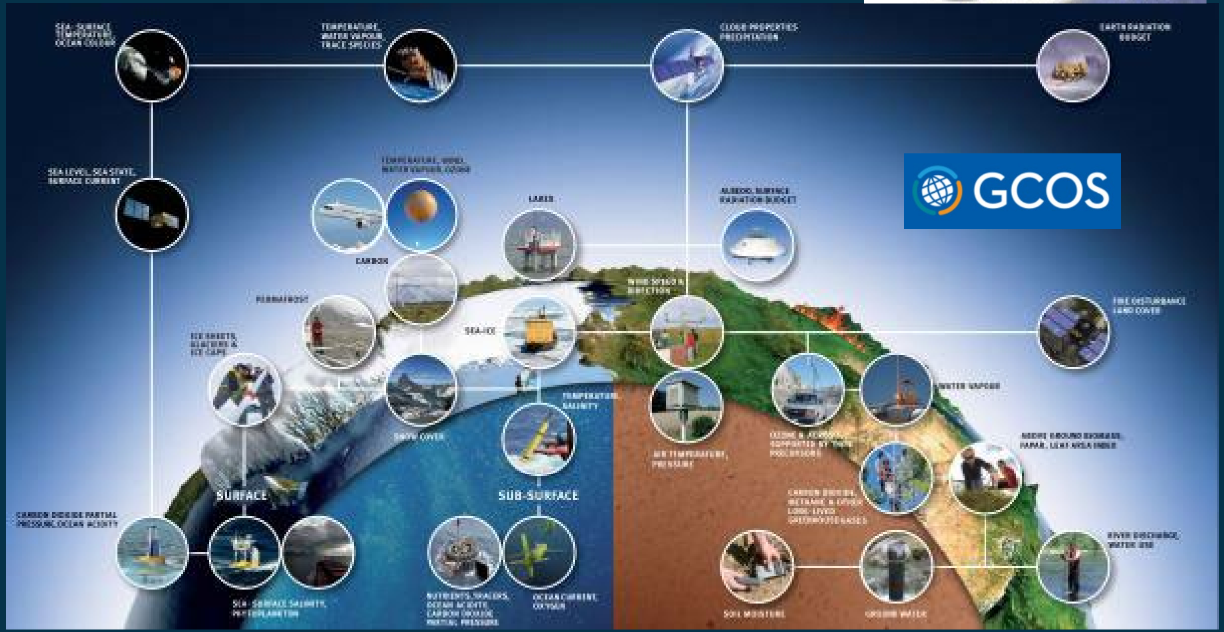
What is the Truth?

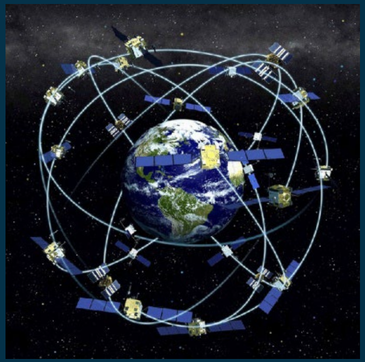
Trustable harmonised time series require stable/understood sensors anchored to invariant references

http://calvalportal.ceos.org/report-and-actions

https://doi.org/10.47120/npl.9319

Interoperable observing system





Maximise utility of data

>60% of ECVs requires space observations (TRUTHS supports ~>1/2 of these)

Satellites can suffer biases and degradation in performance due to launch and harshness of space.

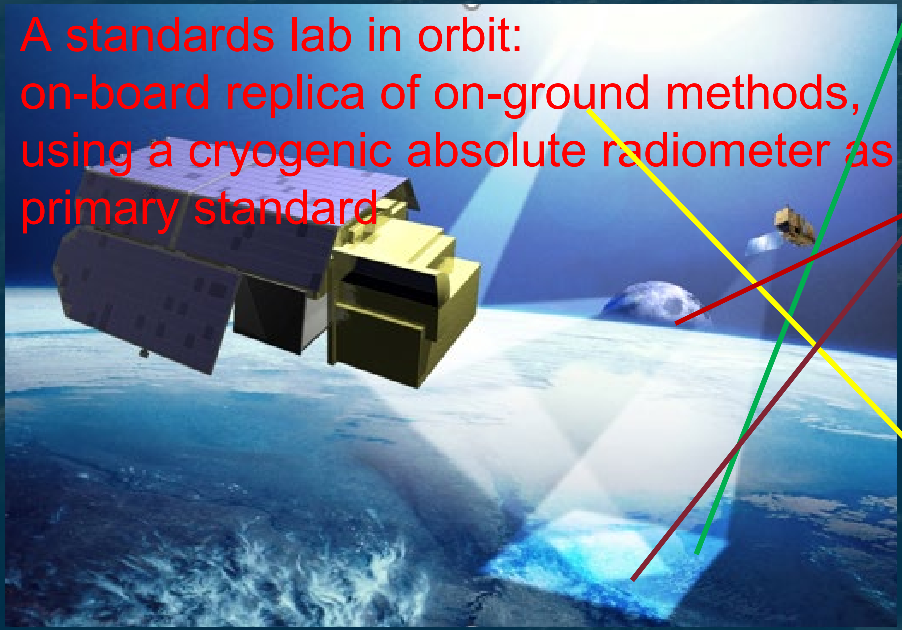
SITSats such as TRUTHS can help enable a new epoch for space-based Earth Observation

SITSats and TRUTHS Mission Objectives

esa

*What is a SITSat?: 'Space borne missions specifically designed, characterised and documented to provide **high accuracy SI-Traceable** 'reference' measurements.' (Evidencing comprehensive uncertainty to SI, 'in-space', of all contributors to observations made from the satellite)*

TRUTHS is an **operational climate mission**, aiming to:`



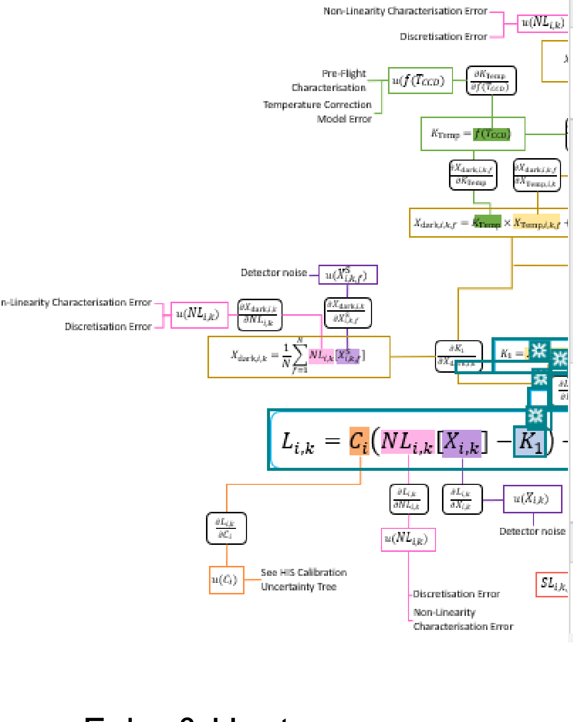
1. **Climate benchmarking:** enhance by an order-of-magnitude our ability to estimate the **Earth Radiation Budget** (and attributions) through direct measurements of incoming & outgoing energy and reference calibration.

2. **Satellite cross-calibration:** establish a 'standards laboratory in space' to create a '**gold standard**' reference data set to cross-calibrate other sensors and improve the quality and interoperability of their data-simultaneous observations, surface reference sites and the moon

3. provide SI-traceable measurements of the **solar spectrum (incoming & reflected)** to address its impact on climate and interactions with the atmosphere and surface

*A **benchmark measurement** is one with characteristics (documentation, SI-Traceable uncertainty, representative sampling) that allows it to be unequivocally considered a 'reference' of the specified measurand against which future measurements of the same measurand, can be compared.*

Open access data with full transparency of uncertainties and traceability – a ‘metrology lab in space’



Fahy & Hunt

TRUTHS HIS Earth Radiance Uncertainty Tree

CSAR power correction						
Name of effect		Cavity temperature characterisation error (Shuttered)	Cavity temperature characterisation error (open)	Sensor reference resistor voltage fluctuation error	Reference resistor characterisation error	Cavity sensitivity characterisation error
Affected term in measurement function		$T_{cav,\,c}$	$T_{cav,\,i}$	$V_{r\_cav,i}$	$R_{r\_h\_cav}$	S_{cav}
Image error-correlation type, form and scale	Across track (k)	Systematic	Systematic	Random	Systematic	Systematic
	Along track (f)	Systematic	Systematic	Systematic	Systematic	Systematic
	Between spectral pixels (i)	Systematic	Systematic	Systematic	Systematic	Systematic
Uncertainty	PDF shape	Rectangular	Rectangular	Gaussian	Rectangular	Rectangular
	units	K	K	V	Ω	KV^{-1}
	magnitude	TBD	TBD	TBD	TBD	TBD
Source						
Sensitivity coefficient		$\frac{\partial L_{i,k}}{\partial T_{cav,\,c}}$	$\frac{\partial L_{i,k}}{\partial T_{cav,\,i}}$	$\frac{\partial L_{i,k}}{\partial V_{r\_cav,i}}$	$\frac{\partial L_{i,k}}{\partial R_{r\_h\_cav}}$	$\frac{\partial L_{i,k}}{\partial S_{cav}}$

‘effects table’ for each error source

Fiduceo like analysis of end to end traceability and uncertainties – an exemplar for other missions

- **Upto ~4 Tbytes a day download**
- **UK ‘Data processing hub’**
- **Baseline ‘archived’ Level 1B products**
  - **ToA Earth, Moon, Sun**
- **Toolbox to enable customisable ‘on-demand’ processing of Level 1B, 1C and 2 (BoA reflectance) with pixel level uncertainties**
- **Coefficients to facilitate sensor SI-traceability and/or recalibration**
- **Unequivocal litigation quality data**

What does TRUTHS do?

Measures incoming and earth 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 uncertainty of 0.3% (k=2)

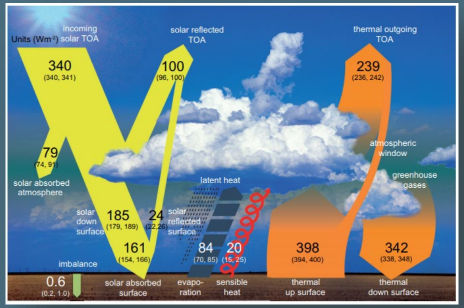
Establishing a benchmark of the state of the planet at ToA & BoA surface reflectance to enable:

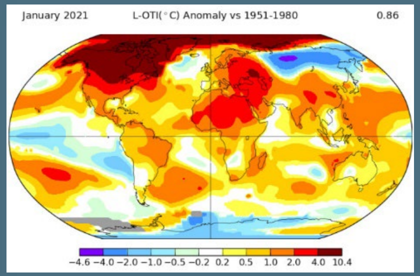
Observations
- Benchmark
- monitoring
- Litigation
- algorithm improvement

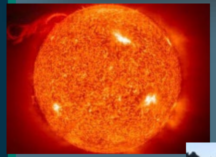
Calibration
- Interoperability
- data-gaps
- performance
- Utility

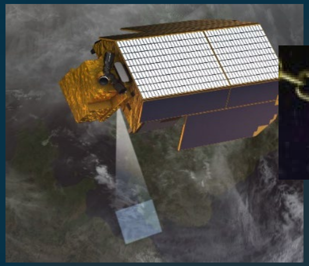
Climate action: Supporting 'Net Zero'

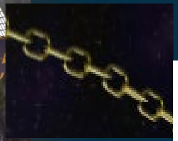
Climate sensitivity/response





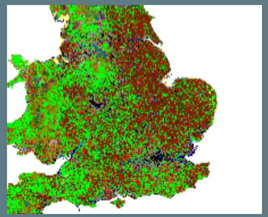


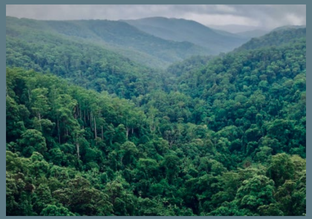




Adaptation/sustainability

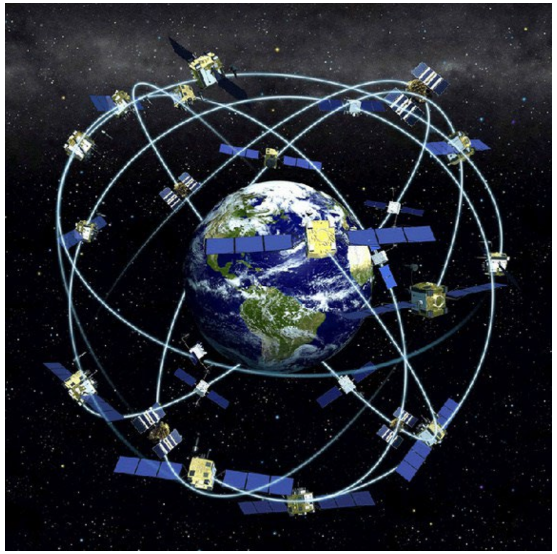
Climate action/mitigation





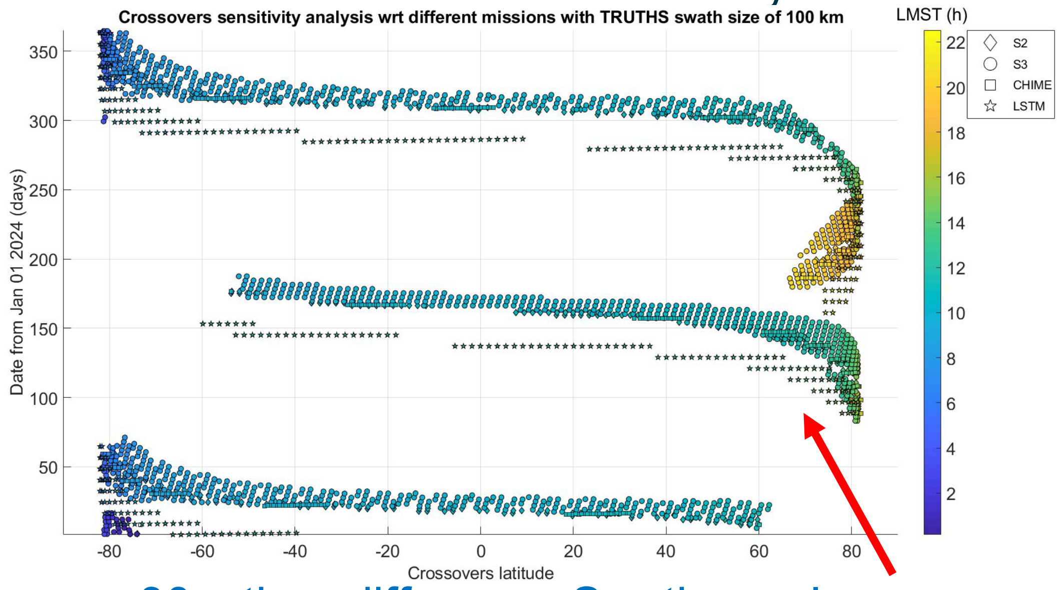
Reference Calibration

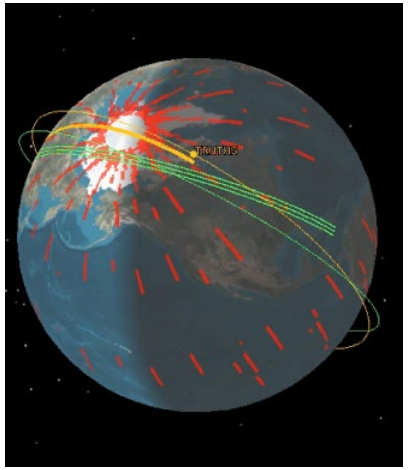
- **Enables interoperability & Harmonisation**
  - **Prospect of 'certified calibration'**



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

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



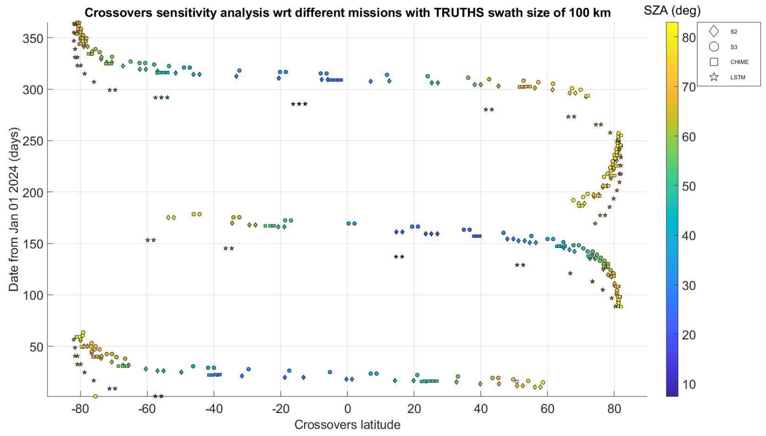


<30 s time difference Swath overlap

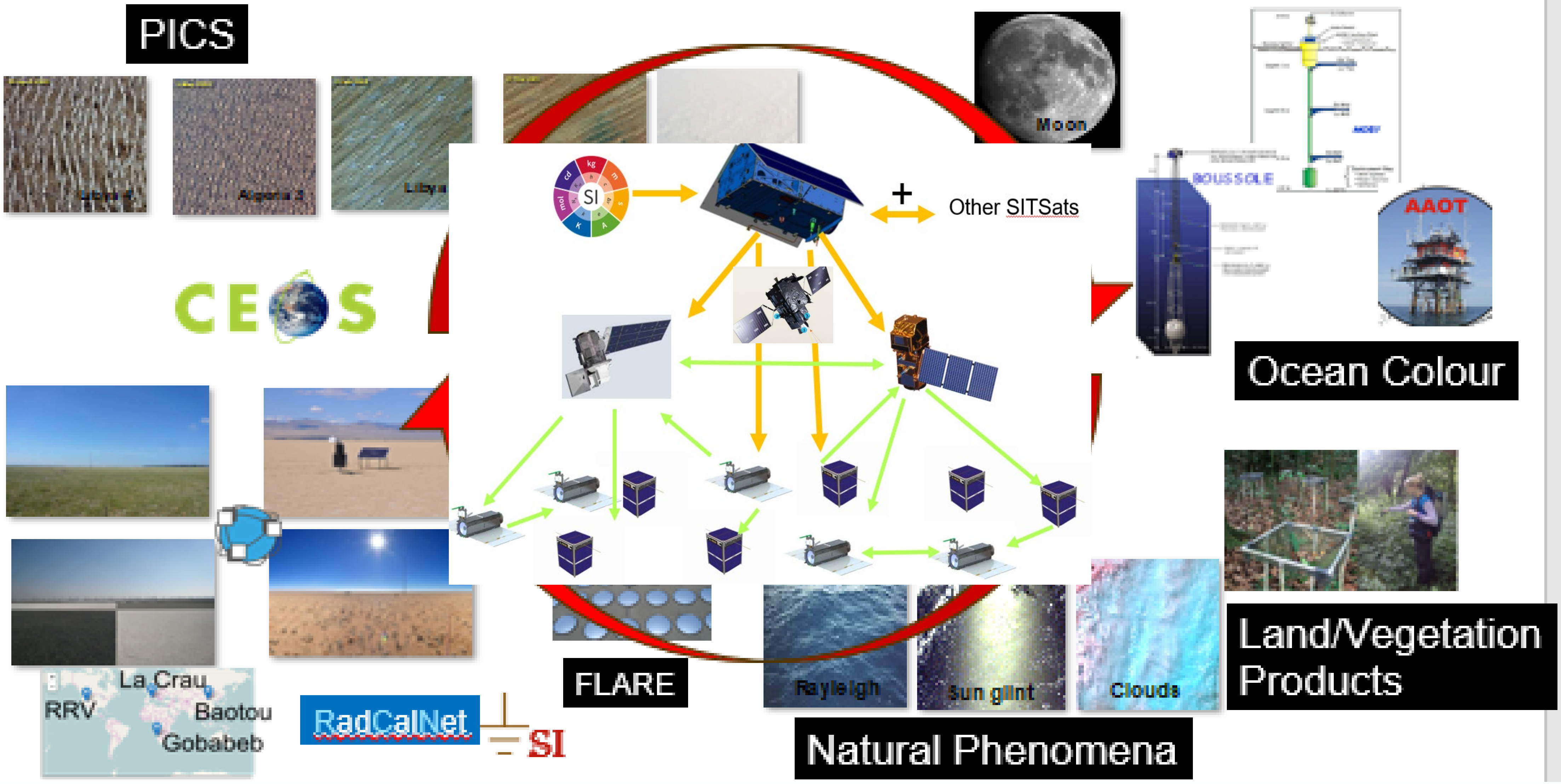
1 year of near perfect nadir overlaps for TRUTHS & satellite under test

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

Summary after 6 months

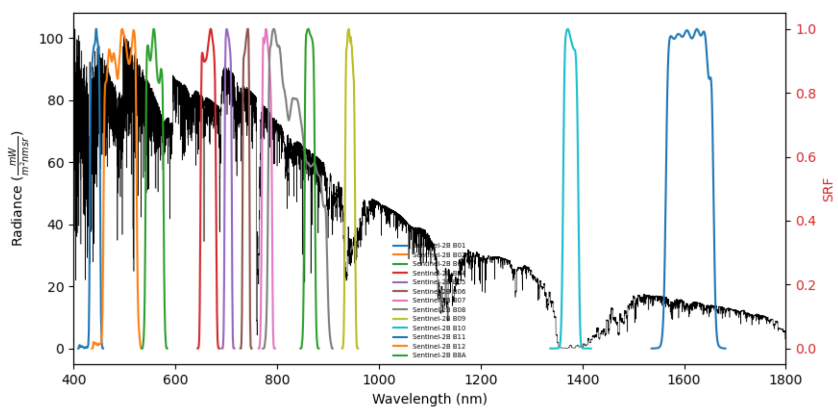


SI-Traceability to Cal/Val infrastructure

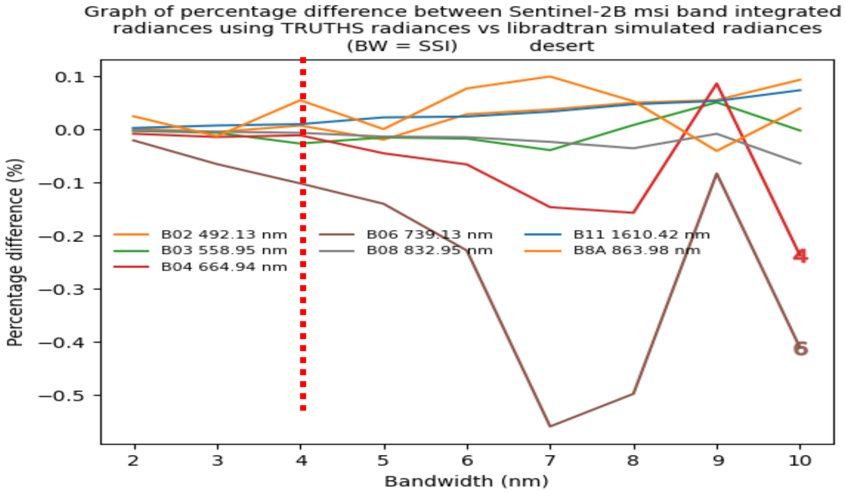


Transferring TRUTHS accuracy to other Sensors

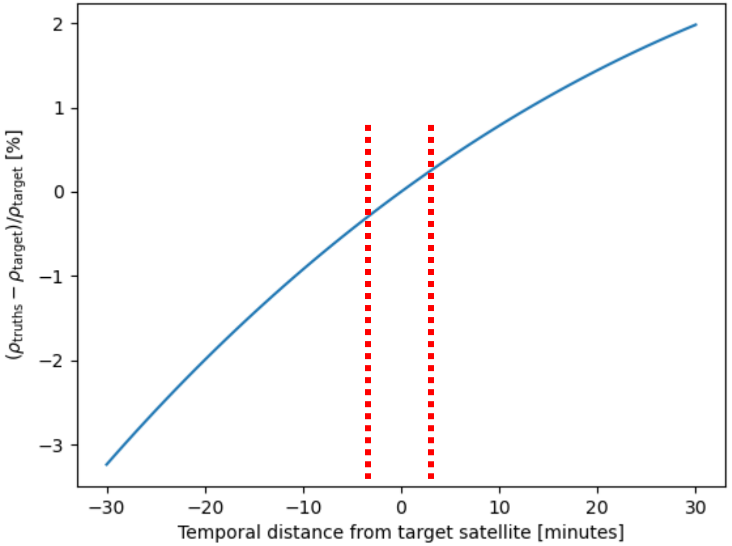
(Fahy, Hunt, Stedman, Gorrono)

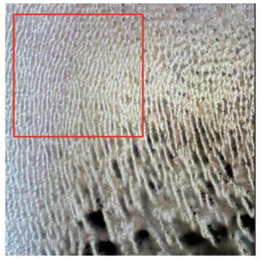


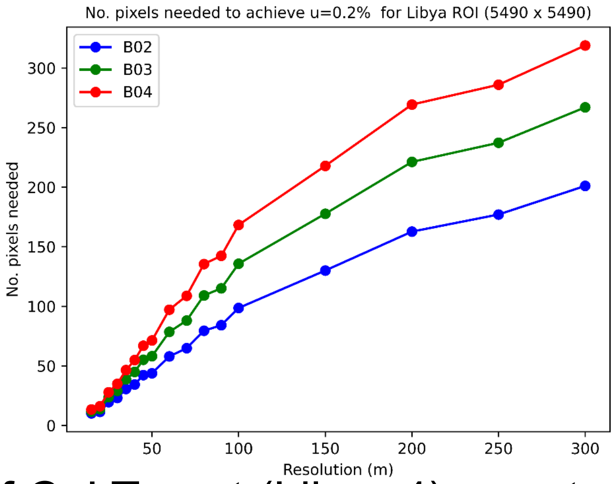
Spectral Bands of Sentinel 2



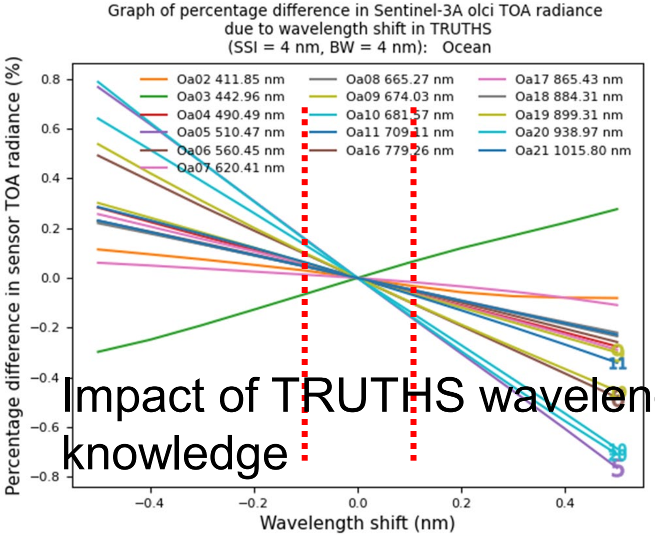
Impact of TRUTHS bandwidth



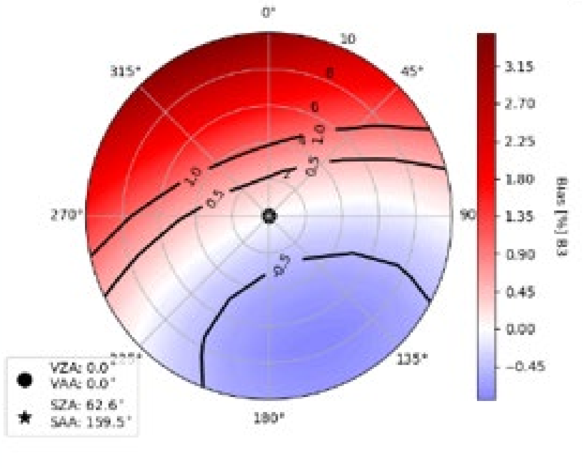




Uniformity of Cal Target (Libya 4) area to be sampled (2.5 km to achieve 0.2% @ 50 m)



Impact of TRUTHS wavelength knowledge



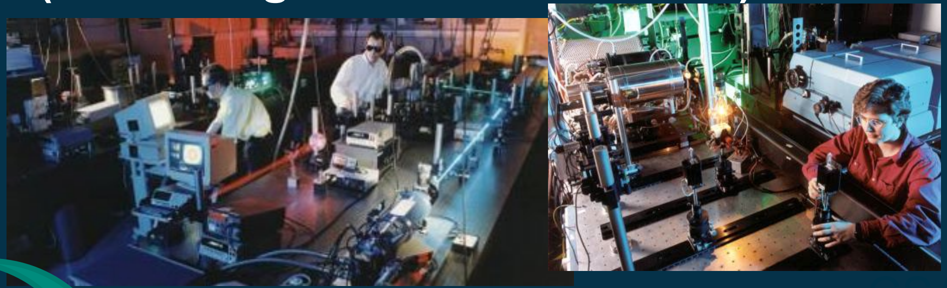
(d) MODIS B3 (460nm); AOT (550nm) = 0.4

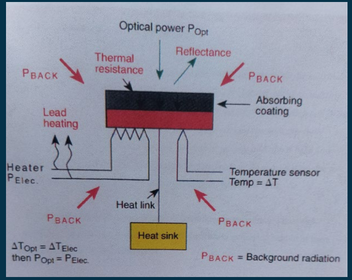
Uncertainty budget for TRUTHS – satellite comparisons (Gorrono et al)

Uncertainty	Best S2 bands	Worst S2 bands
Spectral resolution TRUTHS	0.1 %	0.6 %
Spectral accuracy TRUTHS	0.1 %	0.2 %
Spatial co-alignment mismatch	0.1 % (Libya) 0.12 % (La Crau)	0.1 % (Libya) 0.5 % (La Crau)
30 minute time difference (atmospheric effects)	0.1 % (if corrected) 0.3 % (if atmosphere not known)	0.1 % (if corrected) 2 % (if atmosphere not known)
30 minute time difference (surface BRF)	0.2 %	0.4 %
Combined with reasonable corrections	**0.4 % - 0.5 %**	**0.7 %**

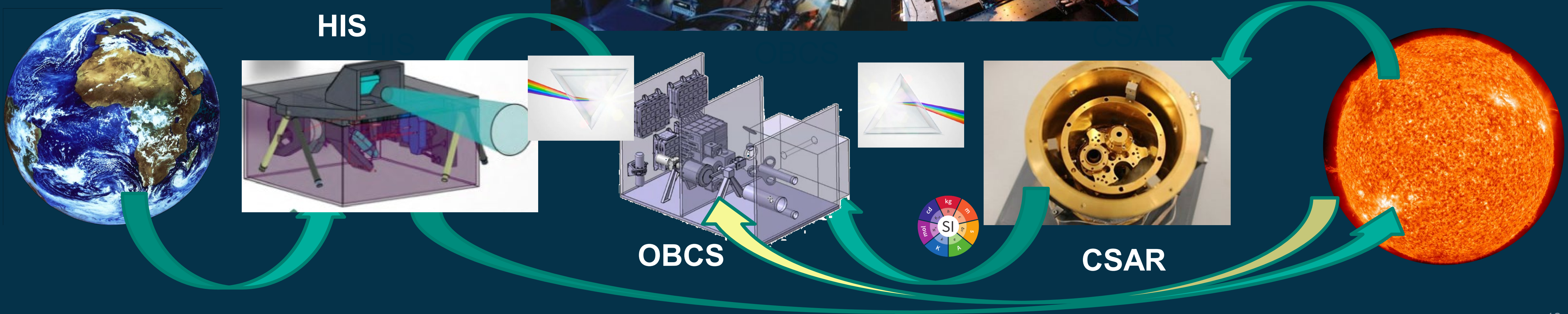
Metrology laboratory in-space

- Measuring energy from the sun, providing the direct traceability to International Standards (CSAR)
    - Compares heating effect of optical power with electrical power (Volt)
- ‘Camera’ (Hyperspectral Imaging Spectrometer, HIS) observing the direct incoming and Earth reflected sunlight at high spectral and spatial resolution
- Novel on-board calibration system (OBCS) ensuring traceability to the absolute reference (Cryogenic, 60K, Solar Absolute Radiometer, CSAR) (mimicking terrestrial methods)





Link to SI = Volt

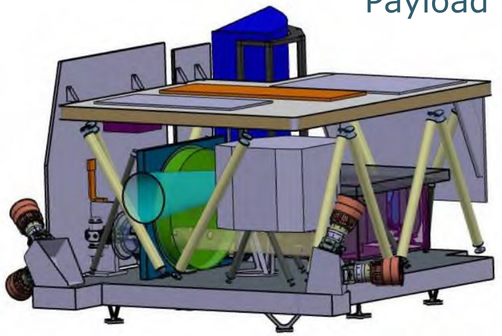


Completing Phase A/B1 to provide a mature concept

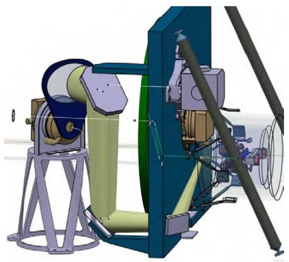
- Agile Platform recurrent from **CRISTAL**
- Payload key technical features:
  - ✓ **HIS:** Four-mirror anastigmatic telescope, Offner (two-prisms) spectrometer, single MCT detector at 150 K, thermally stable optical bench.
  - ✓ **CSAR**– three high-absorbance cavities, operated at 60 K with cryocooler, design heritage of NPL (UK) and PMOD/WRC (CH)
  - ✓ **OBCS** (On-Board Calibration System) – traceable set of absolute wavelength anchors (solar monochromator + TBD filter), high-dynamic transfer radiometer, precise and stable wavelength scanning mechanism, relay optics, diffuser to HIS
  - ✓ **Calibration process:** novel methodology, heritage of metrology lab (NPL), rigorous traceability of uncertainties, need for <u>demanding on-ground calibration</u>
- Pre-developments running for all critical items (detector, coating, CSAR, mirror, calibration detectors…)
- Phase A/B1 led by Airbus UK progressing as planned with final review, the ISRR, started End-April 22 – completes Mid June.
- Gate review (as defined in the EW element) July 22 to confirm technical, scientific and programmatic maturity of the proposed solution ready for subscription in CM 22

TRUTHS satellite

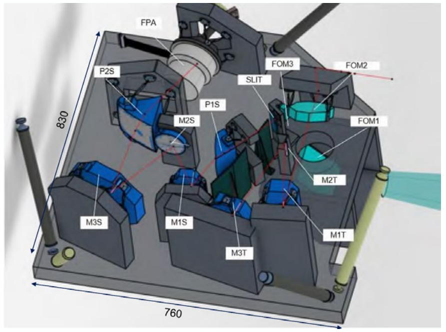
TRUTHS Payload



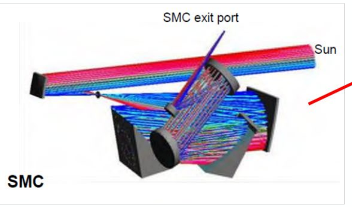
CSAR layout/OBCS I/F

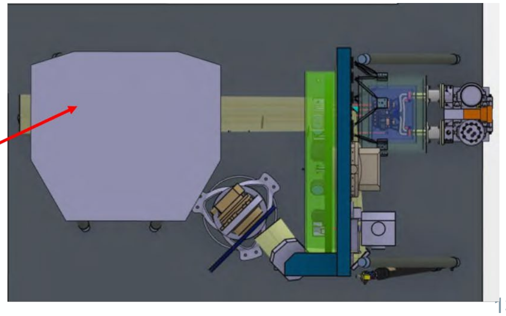


HIS layout



SMC - OBCS layout

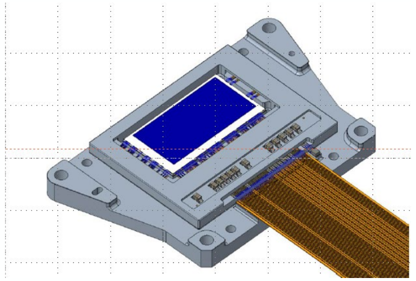


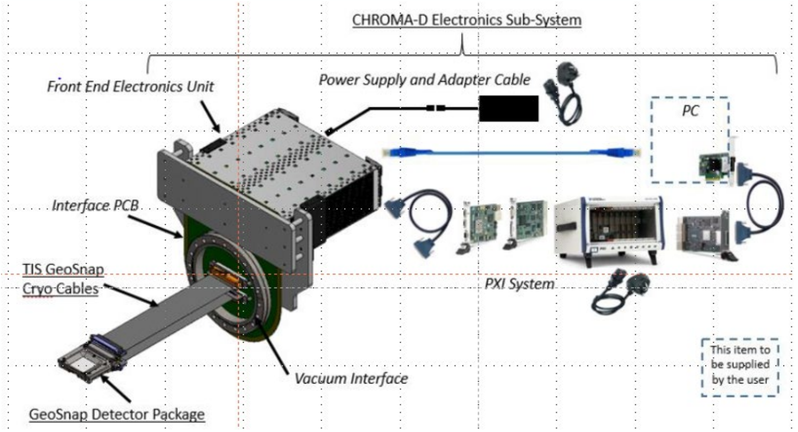


All images courtesy of Airbus, PMOD, NPL

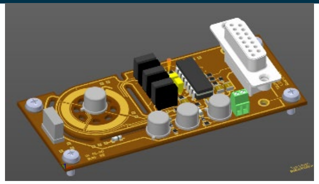
TRUTHS technology gallery

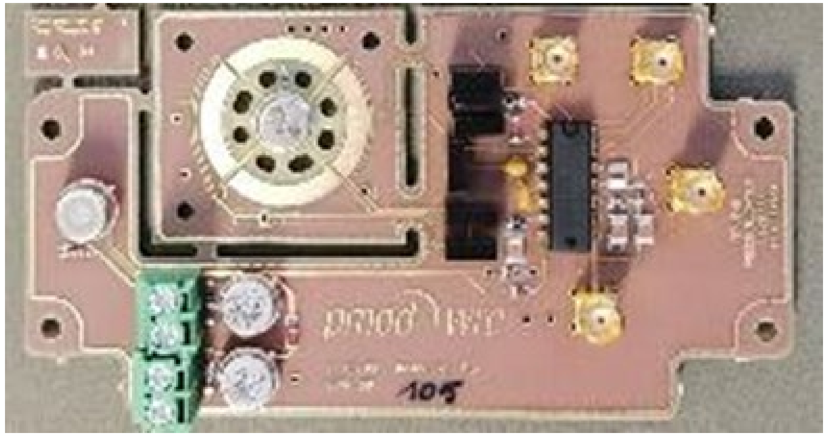
T-E2V Detector layout and FEE test assembly



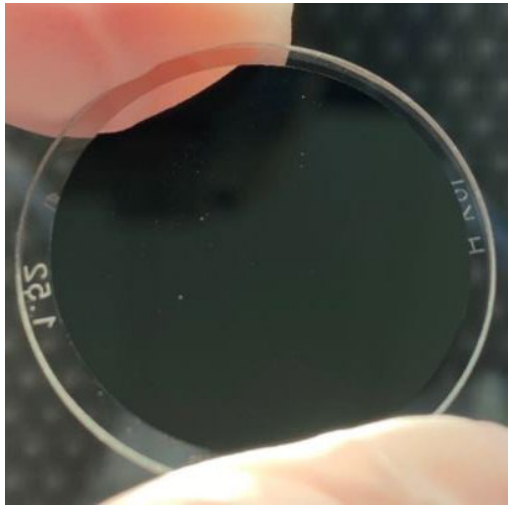


CSAR Voltage Ref: LTZ1000 Board

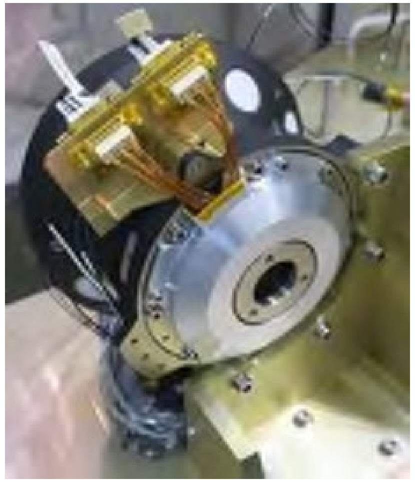




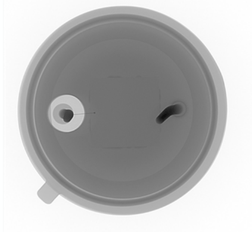
Mirror coatings

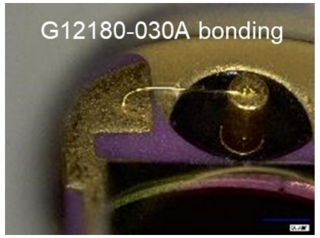


WSM actuator: TRISHNA EM

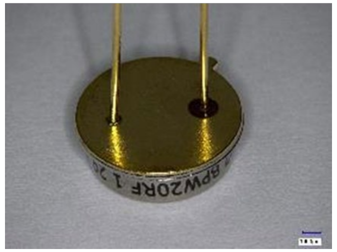


CA OBCS TR photodiodes

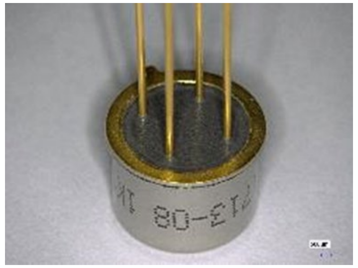




Visual Inspection



X-ray



K -1713-08 dual-colour

International (CEOS?) climate & calibration Observatory

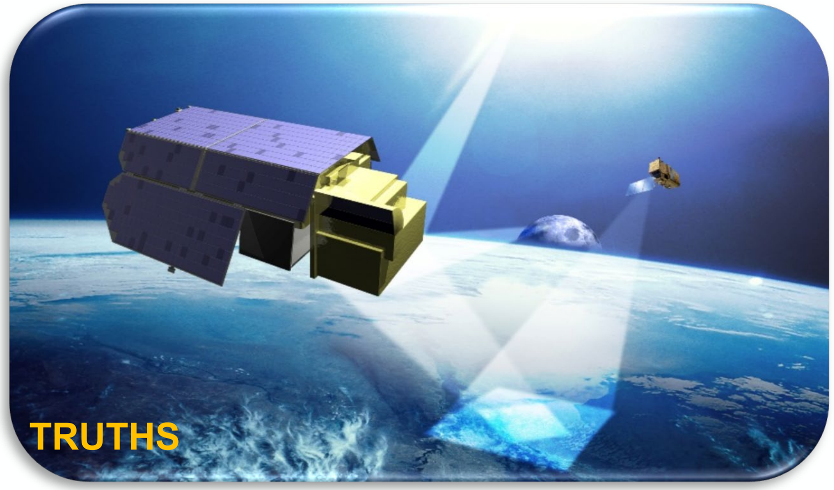
TRUTHS ~ 2029/30 will become a founding element of an international climate & calibration observatory

A direct response to international requests

NASA CLARREO-Pathfinder ‘sister mission’ which will be launched to the ISS in 2023/24.

- Hope for overlap!
- Also potential Chinese Libra

TRUTHS will provide unique and critical information for understanding and monitoring Climate and environmental change from space and support climate action – A resource for ALL nations




Strategy Towards an Architecture for Climate Monitoring from Space


SI-Traceable Space-based Climate Observing System:
a CEOS and GSICS Workshop
National Physical Laboratory,
London, UK,
9-11 Sept. 2019

SITSCOS Workshop Report

Editors: Nigel Fox, Tim Hewison, Greg Kopp, Bruce Wielicki

CPF & TRUTHS: Similarities & differences

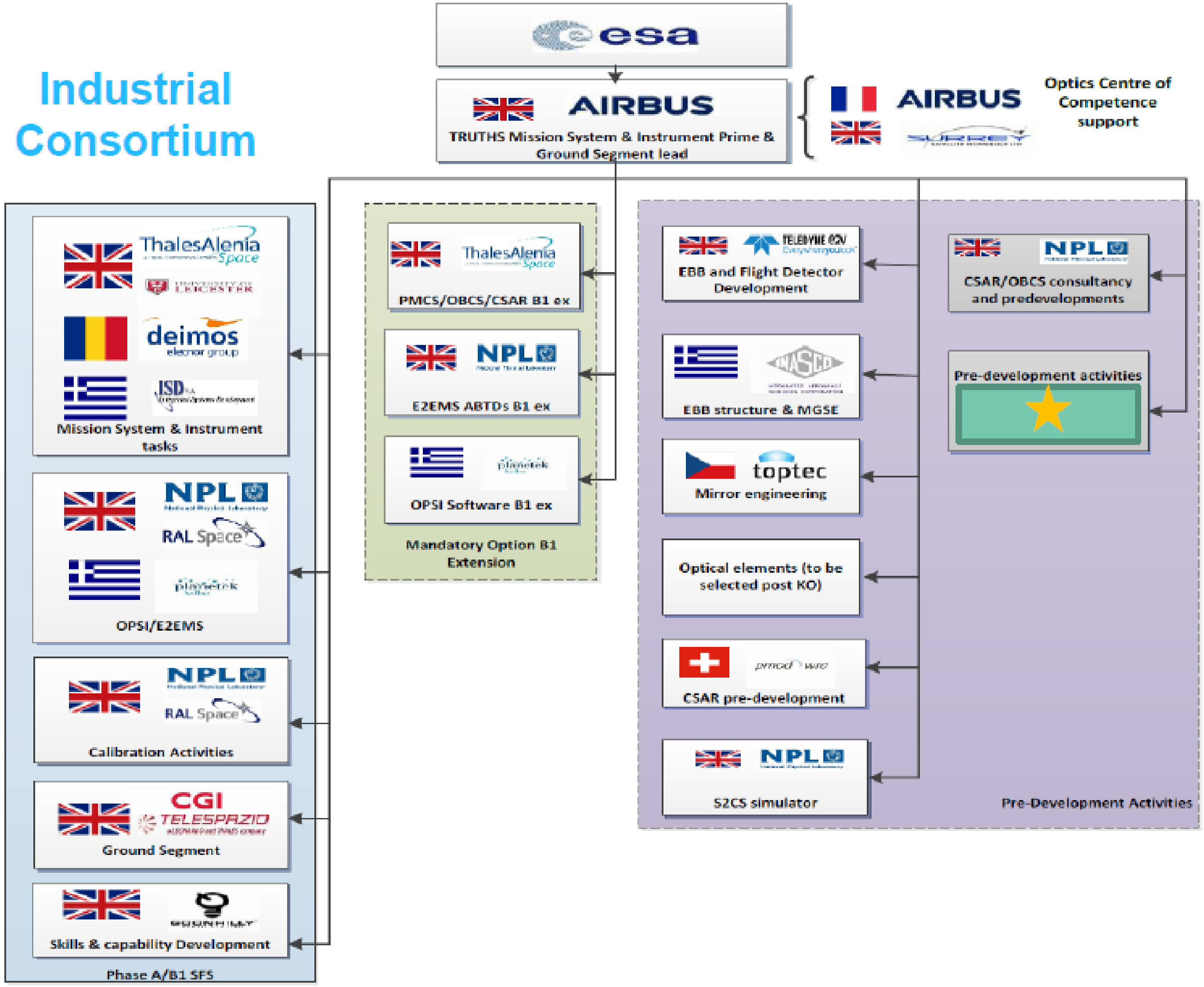
Characteristic	CPF	TRUTHS (some characteristics may change as design develops)	Comment
Platform/orbit	Int Space Station/ 52°	Own sat / 90°	Both asynchronous TRUTHS full globe
Operational / lifetime	2024 (1 yr seeking 5)	2030 (5 – 8 yrs)	Potential overlap if CPF life extended (5+ yrs needed for benchmark)
Spectral range	350 -2300 nm	320 – 2400 nm	
Spectral Resolution	3-6 nm	2–6 nm Earth 1-8 nm Sun	Bandwidths to facilitate cross-calibration
Radiometric accuracy (goal)	0.6 % (k=2)	0.3 % (k=2) 0.02 % (k= 2) (total solar irradiance	Spectrally resolved and band integrated
IFOV / Swath	500 m / 70 km	50 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

Phase AB1 team

Agencies

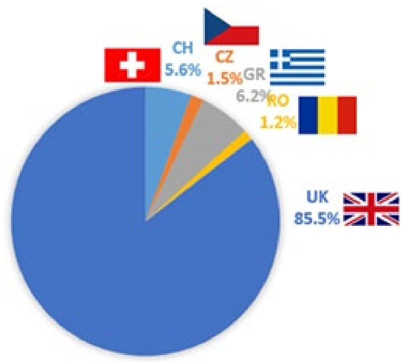
Science institutes

Industrial Consortium



TRUTHS Timeline

- TRUTHS was proposed by UKSA in May 2019 as a new Earth Watch (EW) Element.
- 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%)
- Industrial Phase A/B1 system studies and technology predevelopments initiated in Oct-20.
  - Phase-A kicked-off in Oct-20 and completed at end-July 2021
  - Phase B1 on-going, to be completed in Q2-2022.
- Mission Advisory Group (MAG): Science/Engineering/User expertise primarily from Europe (not limited to funding nations) inc NASA CLARREO Pathfinder
- TRL and SRL assessments in May/June 2022
- Programmatic “Gate Review”: go/no-go decision, in July-22, to submit program to CM-22
- Phase B2/C/D/E to be funded at CM-22/-25 -> Program plan being currently prepared



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