TRUTHS: - Traceable Radiometry to Underpin Terrestrial- and Helio- Studies

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TRUTHS objectives:

- **Establish benchmark measurements in solar reflective domain for decadal climate change through:**
  - **Direct sampling**
  - **Reference calibration of other sensors**

- **Support global Earth observing system through:**
  - **Facilitating upgrade in performance and/or traceability of other sensors for both climate and operational measurements**
    - **Calibration via near simultaneous overpass**
    - **Radiometric calibration of Moon**
    - **Radiometric calibration of CEOS reference standard test-sites (Land and Ocean)**
    - **BoA Surface studies, atmospheric correction, spot calibrations**

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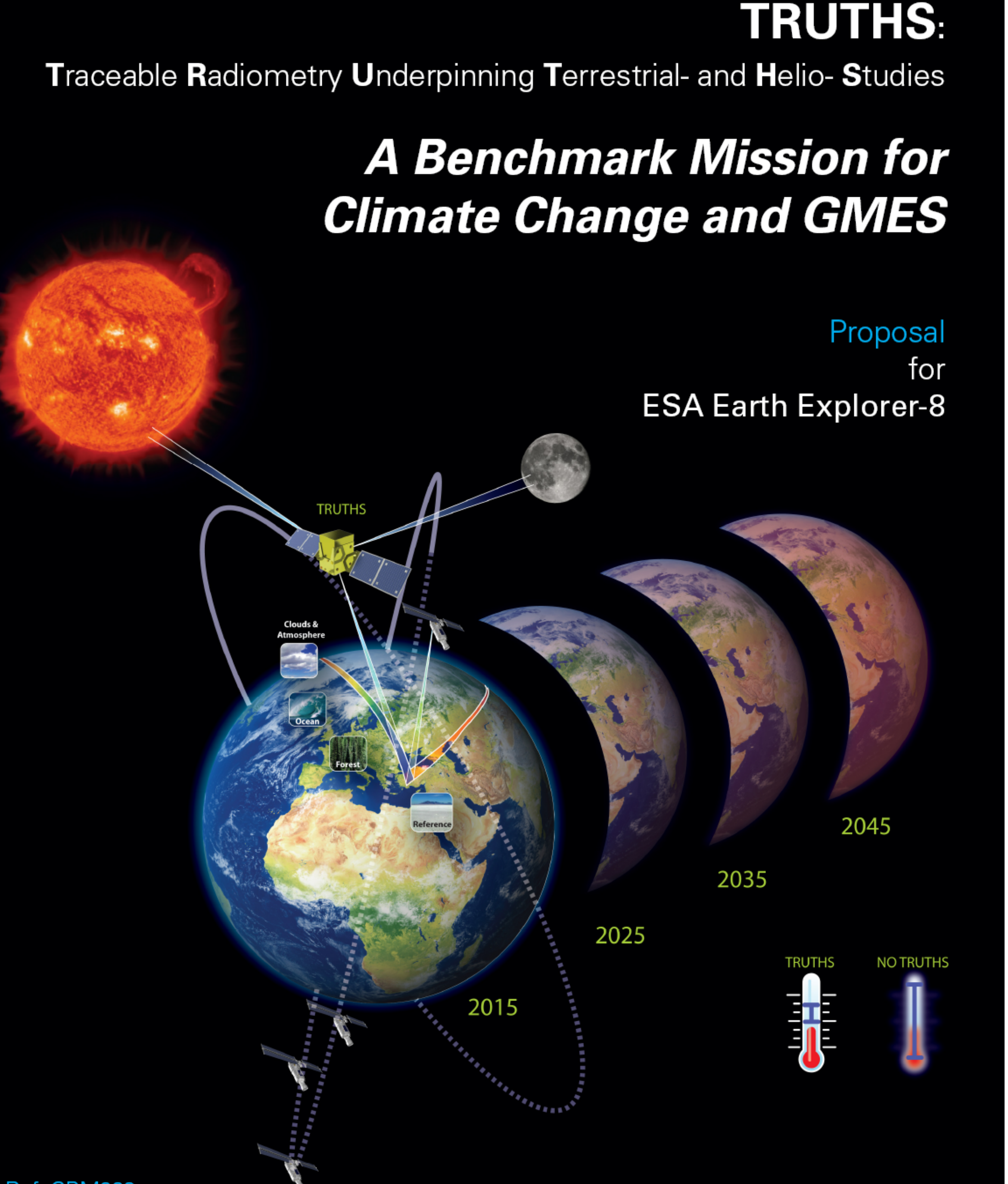

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Climate studies require:

- Global coverage
  - *observations (insensitive to time/location/scale)*
- Decadal time scales
- Uncertainties close to primary SI standards/realisations

Solution:

Establish and maintain SI traceability directly in Space on-board the spacecraft

– Adapt terrestrial methodologies and primary standards

What is TRUTHS? (& CLARREO)

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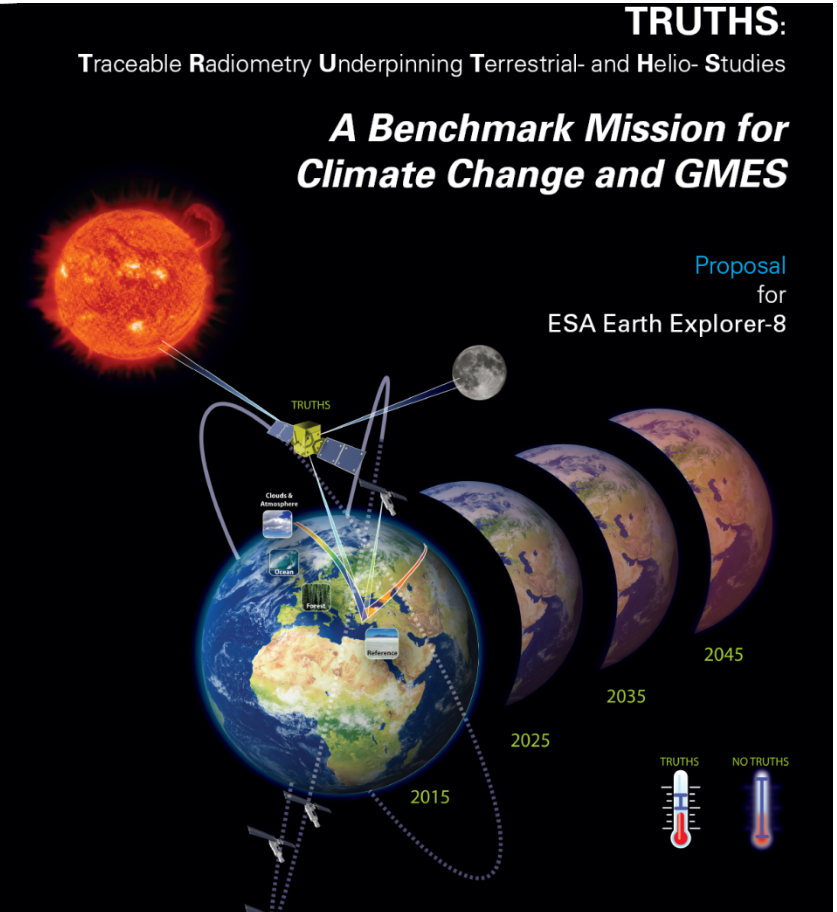
Mission to establish benchmark measurements of SI traceable high accuracy spectrally resolved; incident & reflected solar and emitted thermal radiation as well as atmospheric refractivity through GNSS-RO.



"A Metrology Lab (SI) in space"

To allow observation of decadal climate radiative: forcings, responses and feedbacks from a background of natural variability from:

- **its own measurements**
- **through upgrading of performance of other observing systems: sensors and in-situ by in-flight reference calibration underpinning, CEOS, GMES & GEOSS**

UNCERTAINTY DRIVERS (Climate)

Total Solar Irradiance	- 0.02 %	(2σ)
Spec solar Irradiance	- 0.2 %	(2σ)
Reflected Solar Radiance	- 0.3%	(2σ)
IR and GNSS-RO	- 0.1 K	(3σ)

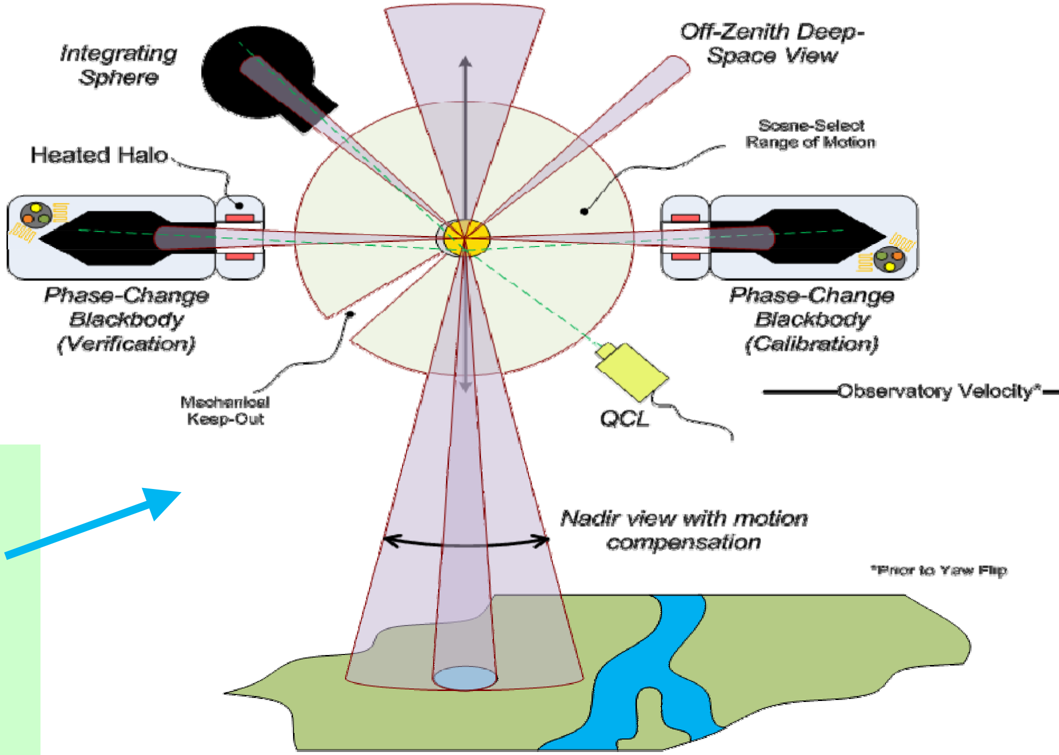
Climate Absolute Radiance and Refractivity Observatory

4 small satellites: 2 off IR + GNSS RO & 2 off Solar Reflective (SR)

Orbits in pairs 90 deg polar and 90 deg separation at 609 km

Global averages - Nadir spectrally resolved 0.32-2.3 μm <10 nm & 5-50 μm 0.5 cm^{-1}

Expect to Start Phase A 2011 with Launch 2018 – 2020



CLARREO

IR full on-board SI primary standard

SR relative to another satellite

SR GIFOV (500 m)

Global mean nadir averages

Ref calibration (multi-angle)

IR Spectrometer calibrated on-board against "transition point" (Ga freeze) blackbody - emissivity monitored using Quantum cascade laser.

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Climate Absolute Radiance and Refractivity Observatory

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CLARREO

IR full on-board SI primary standard

SR relative to another satellite

SR GIFOV (500 m)

Global mean nadir averages

Ref calibration (multi-angle)

Highly complimentary partnership

TRUTHS

SR full on-board SI primary Standard

GIFOV (40 m) *Land* : (200 m) *Ocean*

Global nadir spectral radiances (275 channels resolution 1-10 nm)

Ref Caln & process studies (multi-angle)

Polarimetric information

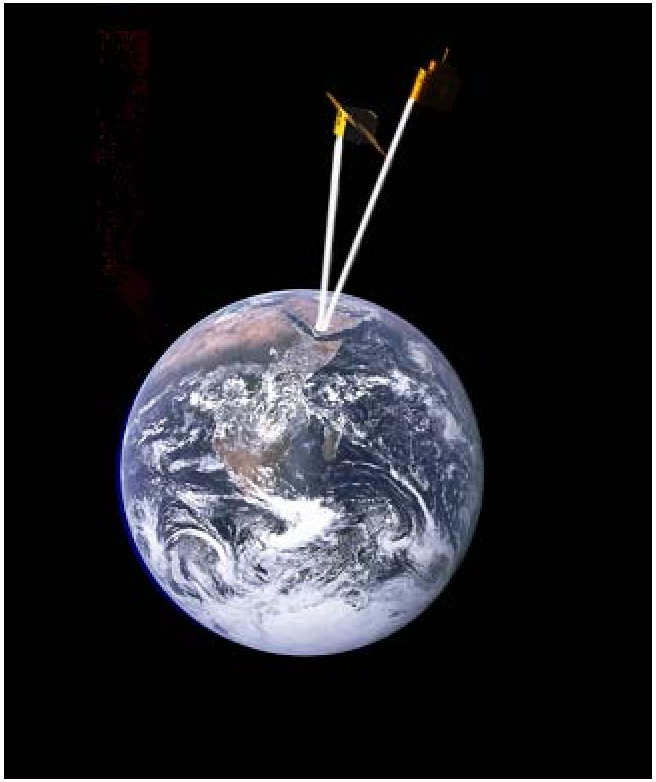
- aerosols

Providing Reference Calibrations

Near Simultaneous Nadir Observation (SNO) sensor Calibration

TRUTHS 90 deg polar orbit

- allows many overpasses with other sensors
    - different cross-over times/locations
    - ToA reflectances/radiances ± 5 mins
- Platform pointing to co-align view angles
- relatively low (609 km) orbit increase dwell time
- high spectral and spatial resolution to match sensor under calibration
- Can upgrade performance of others sensors to facilitate "climate quality" data



Surface sites (Bottom of Atmos.) & (Top of Atmos.)

- Polarimetry improves atmospheric correction
    - Calibrate Aeronet
- High accuracy leads to improved retrieval algorithms
- Multi-angle, hyper-spectral, 40 m spatial, - supports: albedo, canopy structure, FLUXNET, Carbon sequestration….

Operational calibration service through “CEOS standard” sites/methodologies

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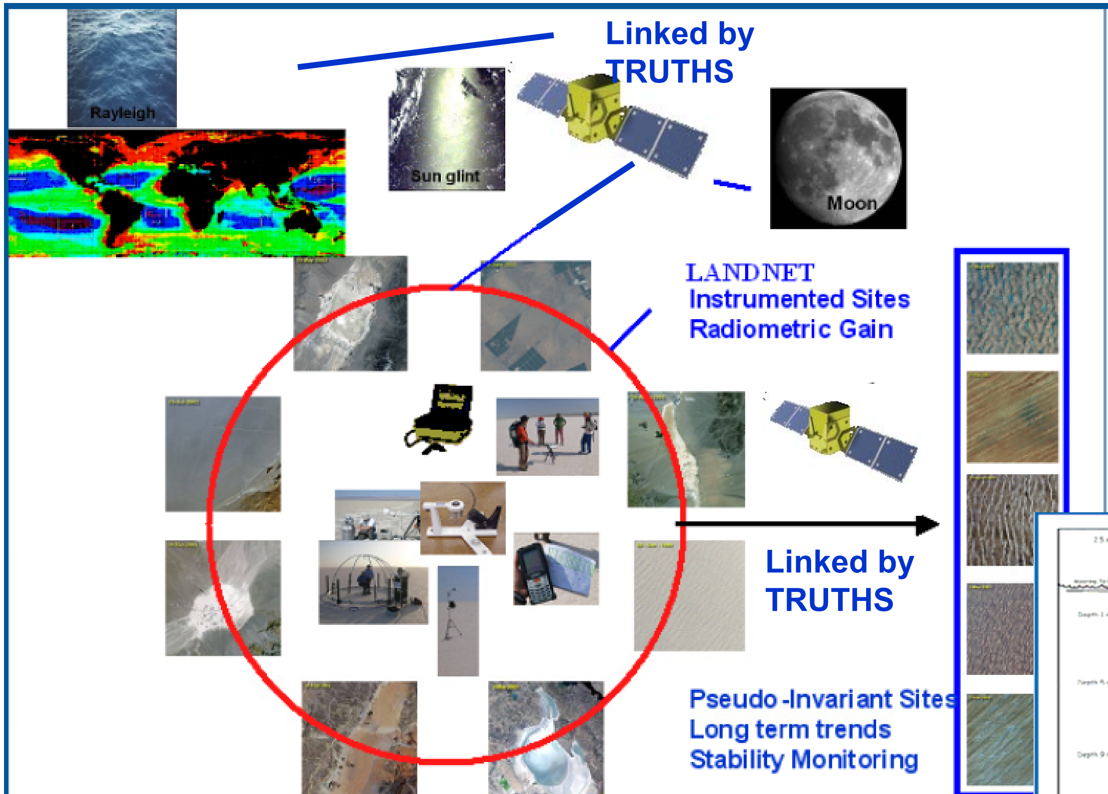
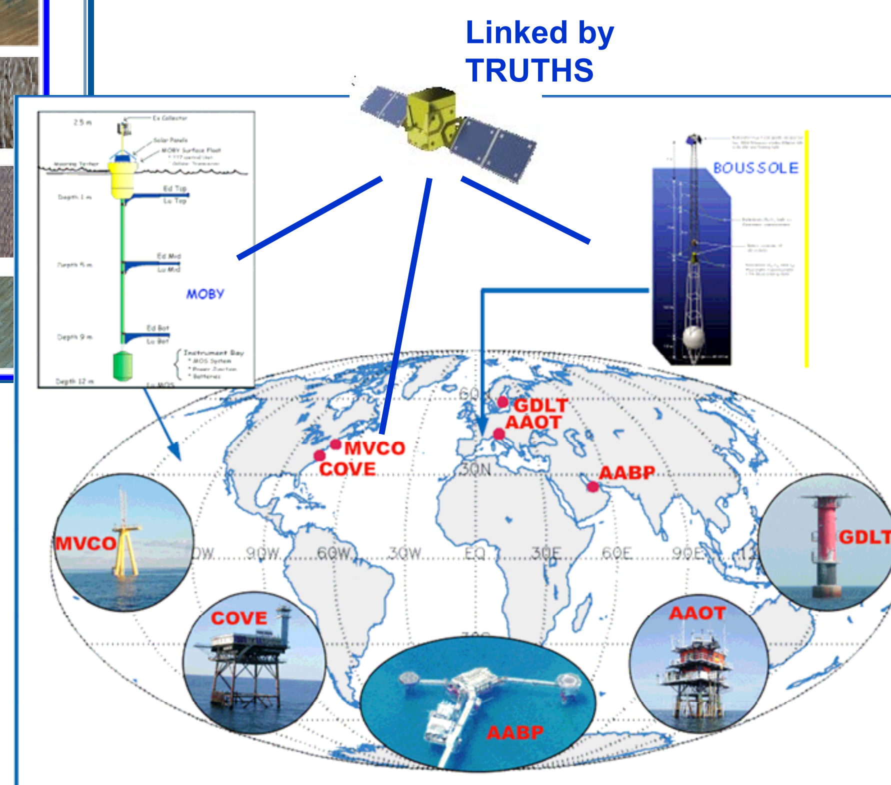


Networks of test sites and methodologies can become operational calibration service

improved through use of reference standard SI traceable sensor e.g. TRUTHS



CEOS endorsed test sites for Land and Ocean can be used as standards to cross-compare between sensors and to ground data providing each site is compared to each other

TRUTHS satellite

~ 1 m^3 – Platform (SSTL 150)

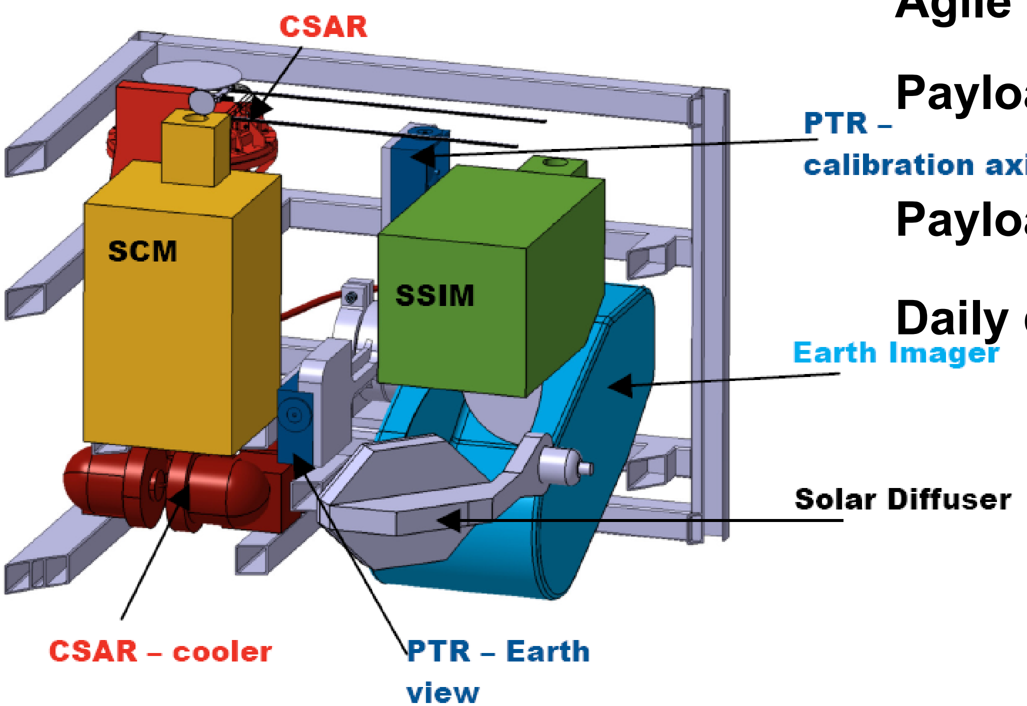
Orbit: 90 deg – 609 km

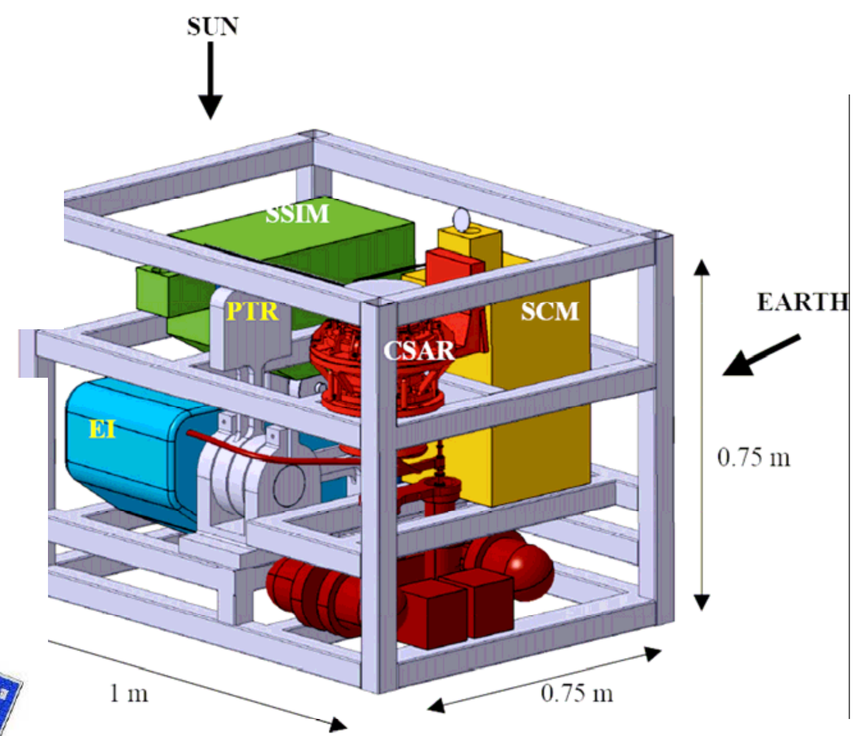
Agile platform >2° /s slew rate

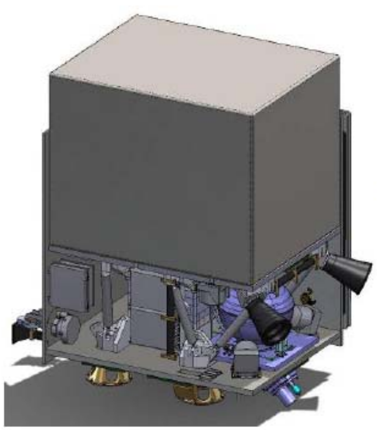
Payload mass – 165 kg including (2 off coolers for redundancy)

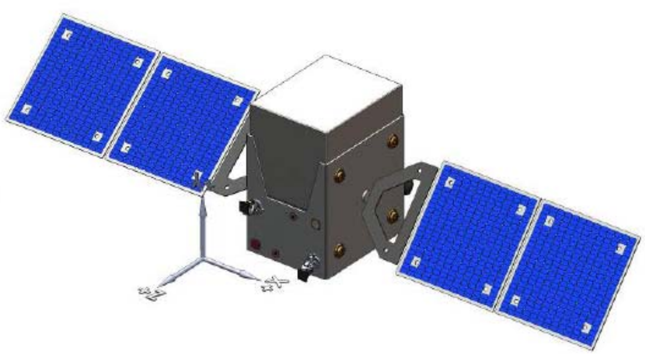
Payload peak power – 185 W

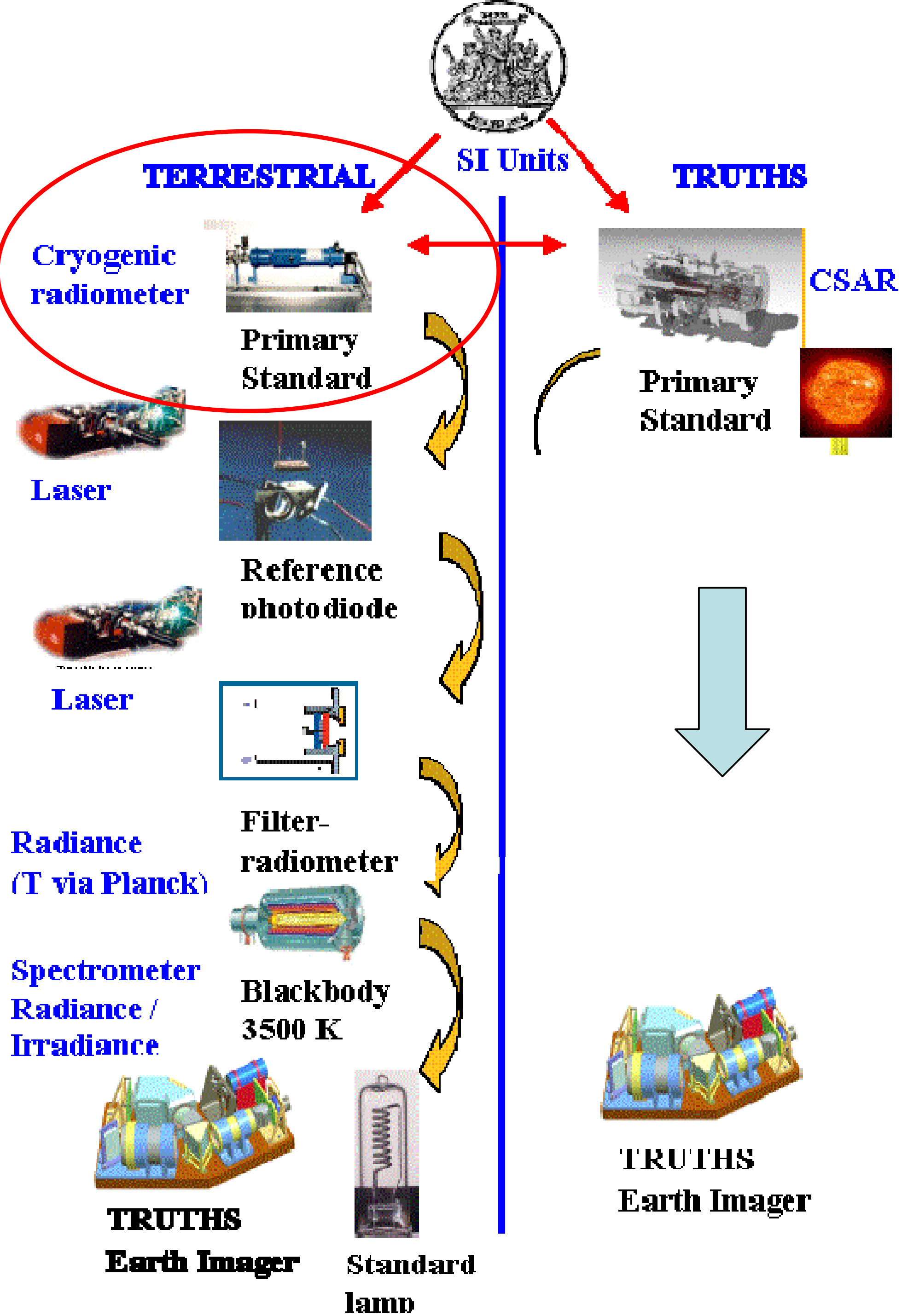
Daily data download – 4500 Gbits per day











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Traceability Strategy:

- mimic that used on ground at standards labs

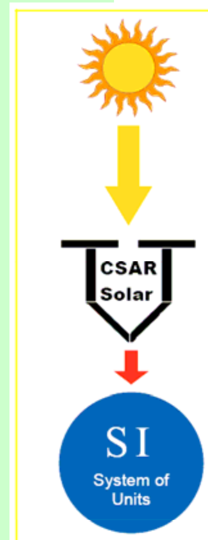
- Primary reference standard is cryogenic radiometer (CSAR) compares heating effect of monochromatic optical power

Also

measures Total Solar Irradiance (TSI)

Directly analogous to the instruments already in space for TSI

(but cryogenic)



Cryogenic Solar Absolute Radiometer (CSAR): Primary standard & TSI

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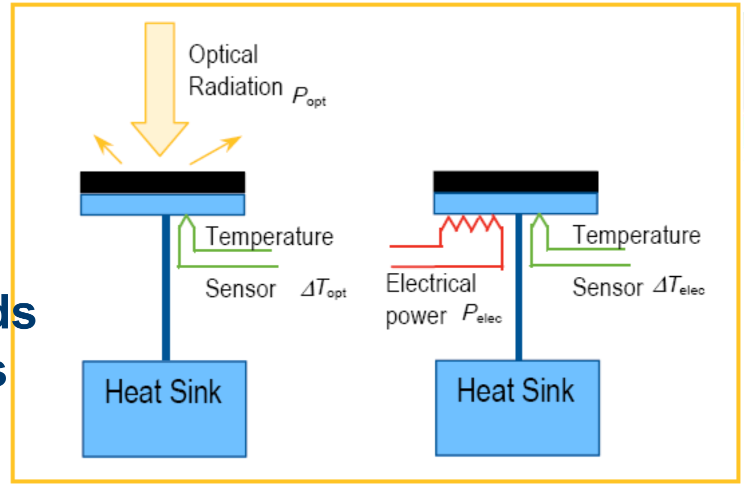
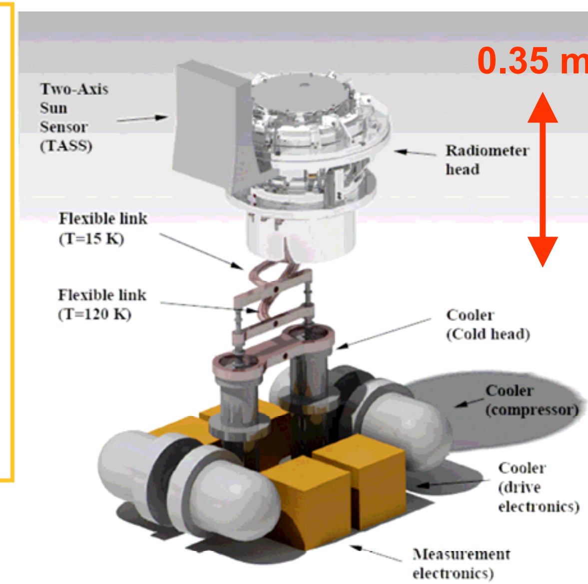
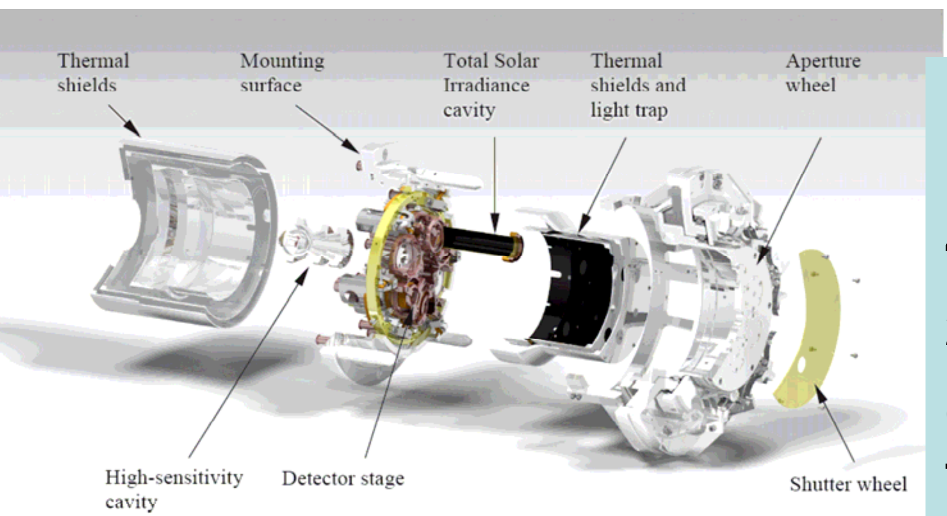
CSAR is an electrical substitution radiometer operating at ~ 20 K.

Technology is same as used for primary standards at national standards labs for 25 yrs *(at ambient temps 100 yrs - also in space: 1970's for TSI)*



If $\Delta T_{opt} = \Delta T_{Elec}$ then $P_{opt} = P_{Elec}$





An "engineering model" designed and built currently operating in a vacuum can at Davos for terrestrial TSI

In space, cooled by Astrium 10 K cooler (dual for redundancy).

4 – TSI cavities (exposure varied)

2 – High sensitivity cavities (μW)

6 – primary Apertures on wheel at ambient temps

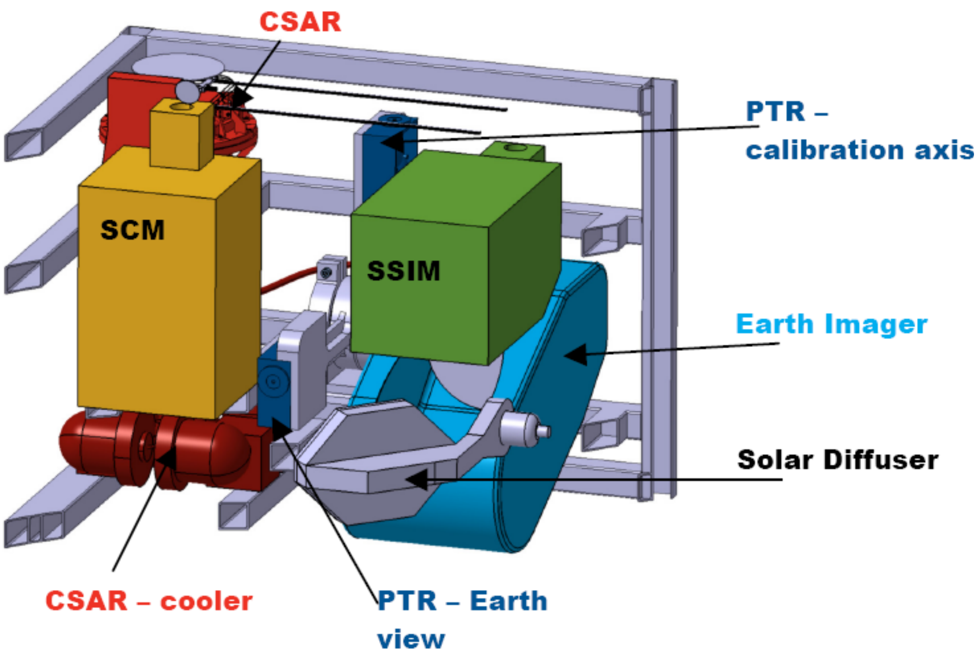
Cavity absorptance only potential source of optical degradation (>0.99998)

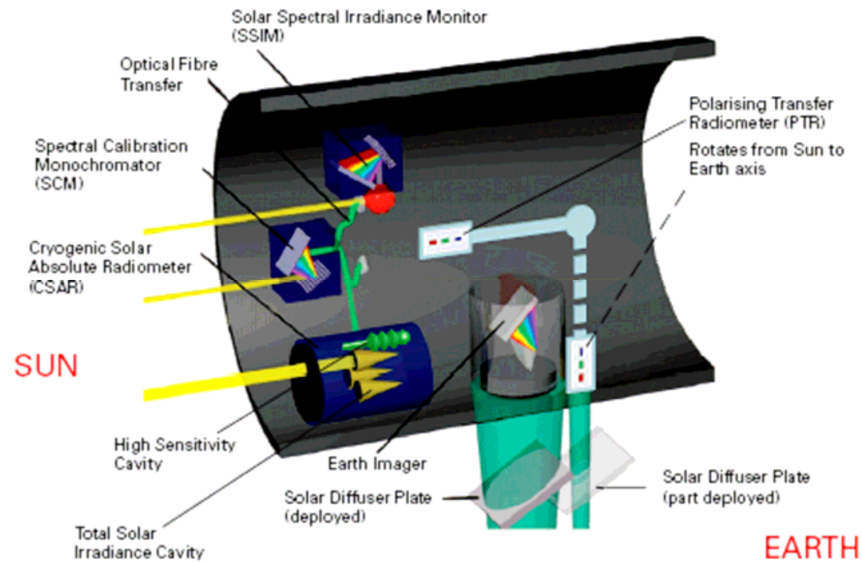
Cryogenic Solar Absolute Radiometer (CSAR): Primary standard & TSI

For Video of CSAR see

http://www.youtube.com/npldigital#p/a/u/0/aQAREkaZjfI

TRUTHS Payload: Solar & Earth view axis





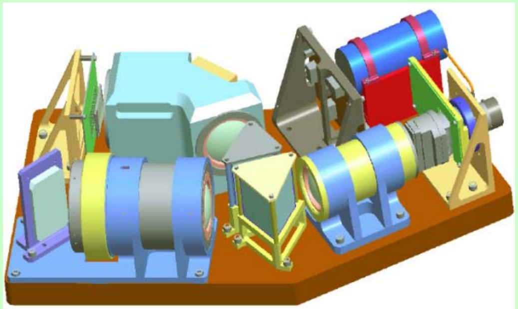
Observation instruments (science)

Cryogenic Solar Absolute Radiometer (CSAR)
- Total Solar Irradiance

Earth Imager
- 320 to 2450 nm (275 channels inc polarisation analysis)
- 40 m at nadir - 40 km swath

Solar Spectral Irradiance Monitor (SSIM)
- 200 to 2500 nm (0.5 to 1 nm bandwidth)

***Polarising Transfer Radiometer (PTR)* (2 OFF)**
- off-nadir polarised radiance (~13 chan's) for aerosols (atmospheric correction)



Baseline imager: APEX
- *Many potential options e.g. CHRIS-2*

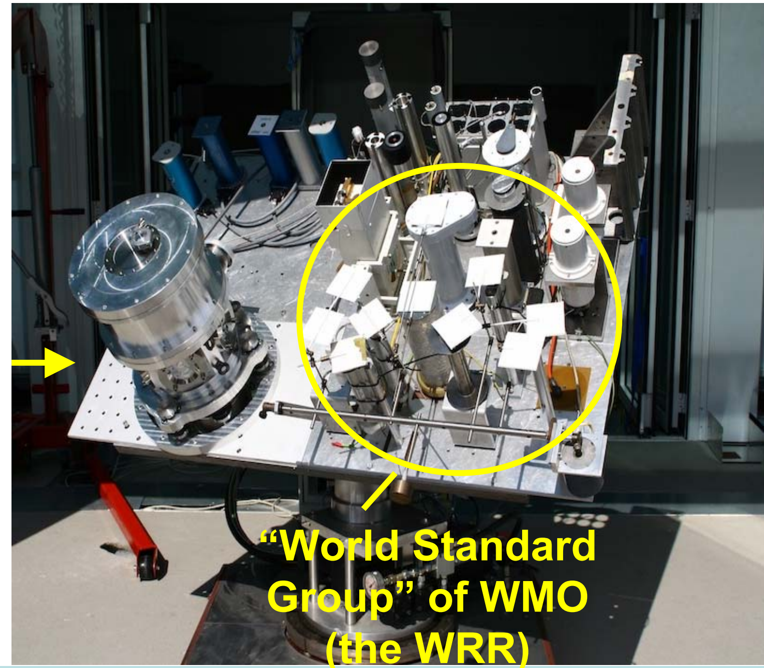
Cryogenic Solar Absolute Radiometer (CSAR): Primary standard & TSI

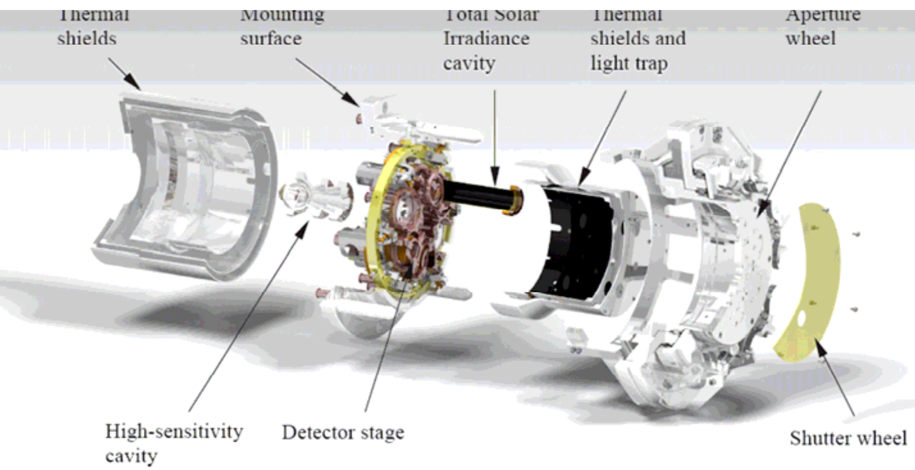
CSAR

(NPL

METAS

PMOD)





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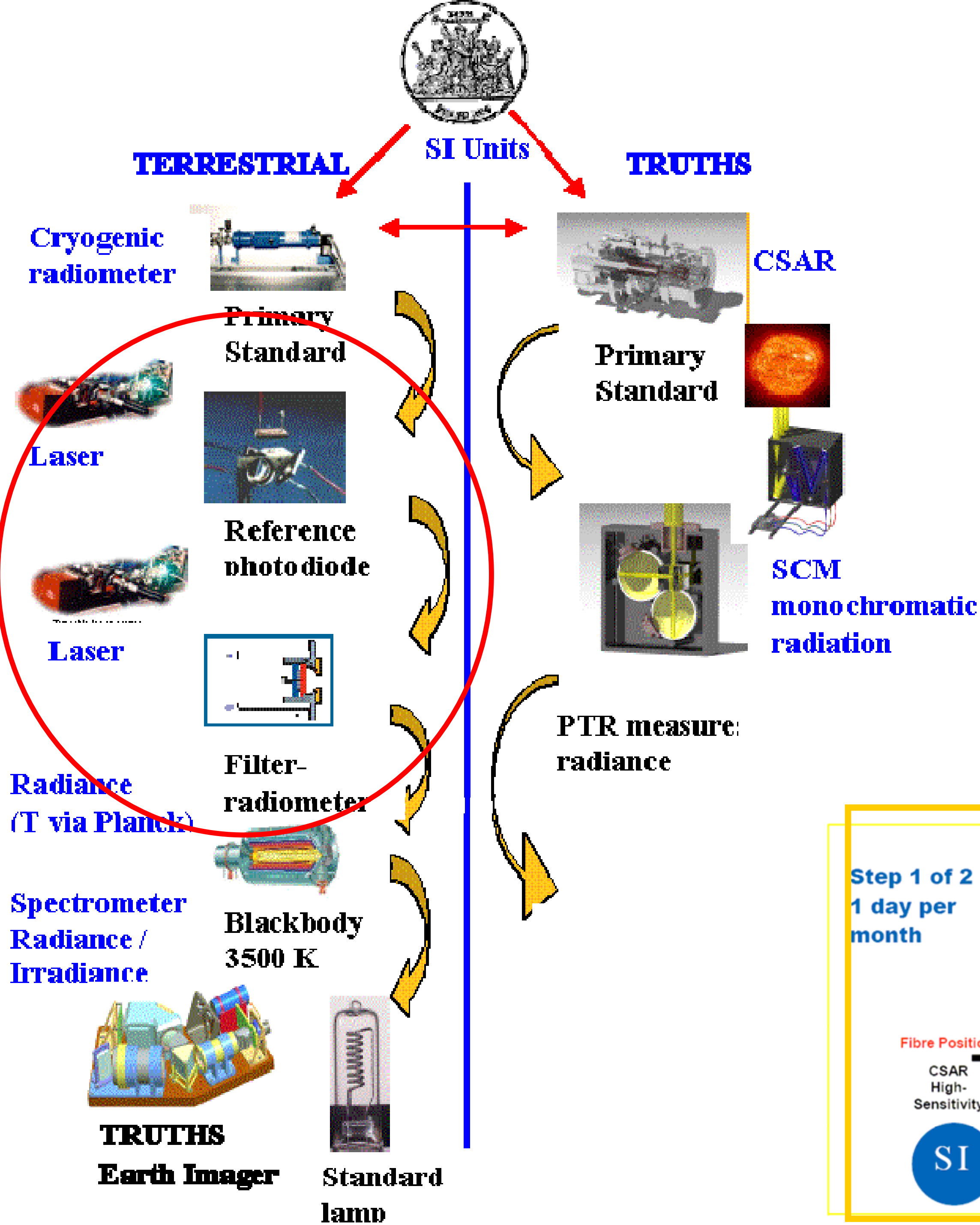

Traceability Strategy:

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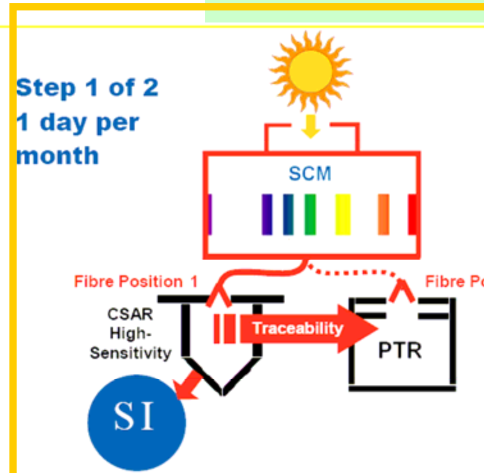
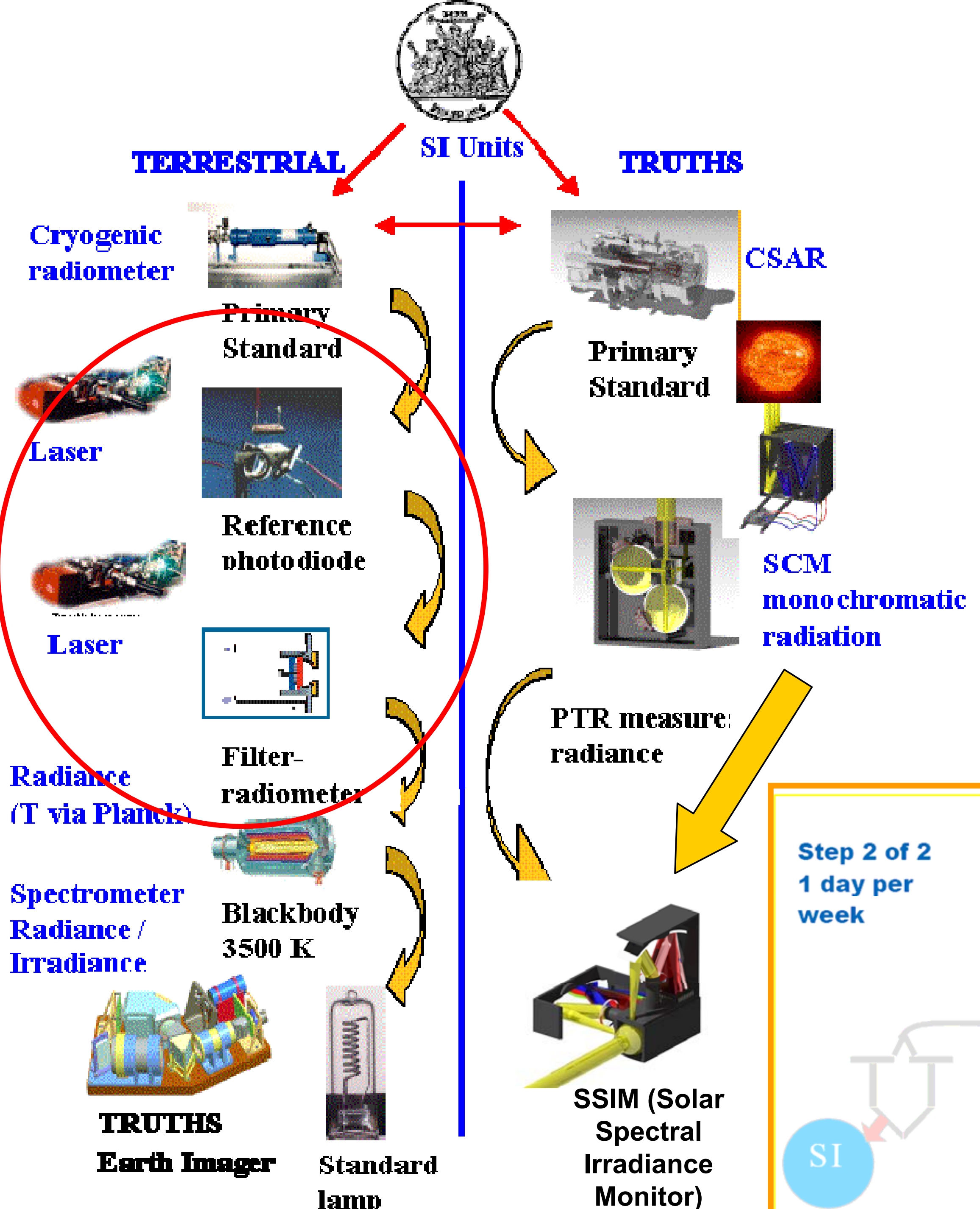
- Primary reference standard is cryogenic radiometer compares heating effect of monochromatic optical power to electrical power
- Tuneable monochromatic Optical beam (monochromator dispersed solar) calibrates other TRUTHS instruments



Optical fibre bundle moves "monochromatic" radiation between CSAR and Transfer radiometer (PTR)



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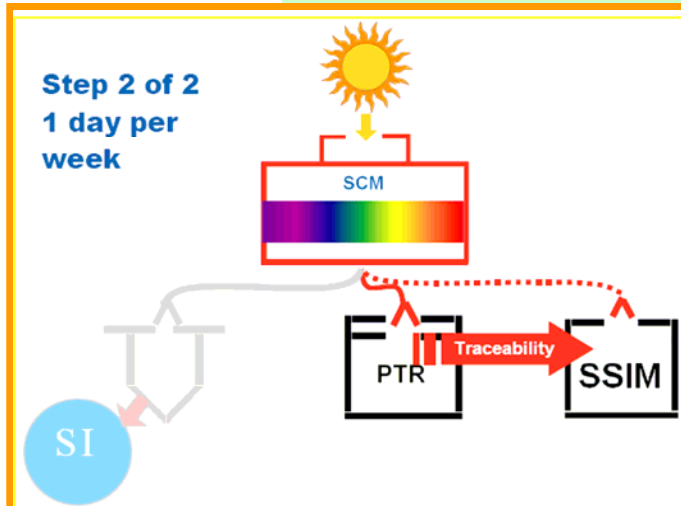
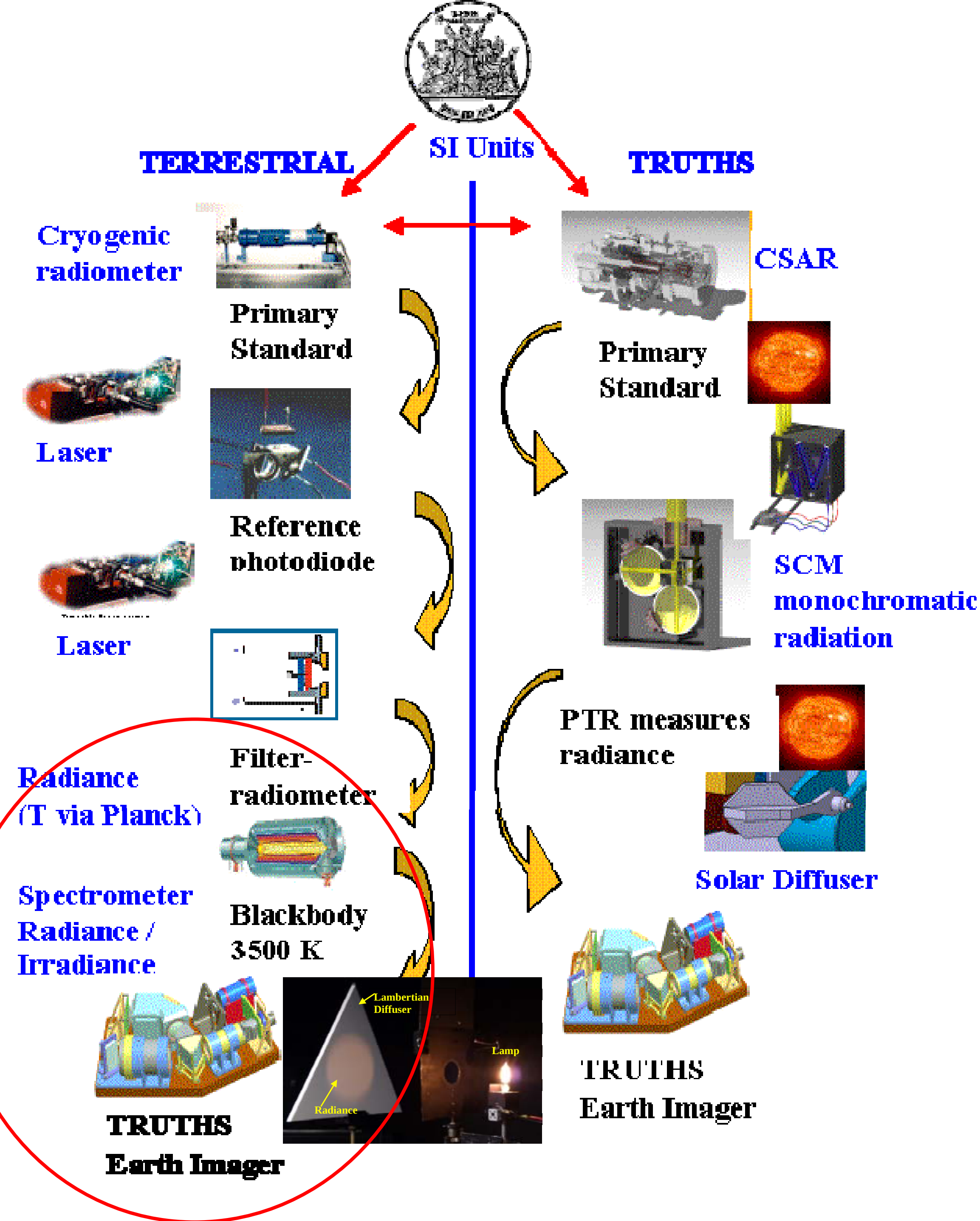
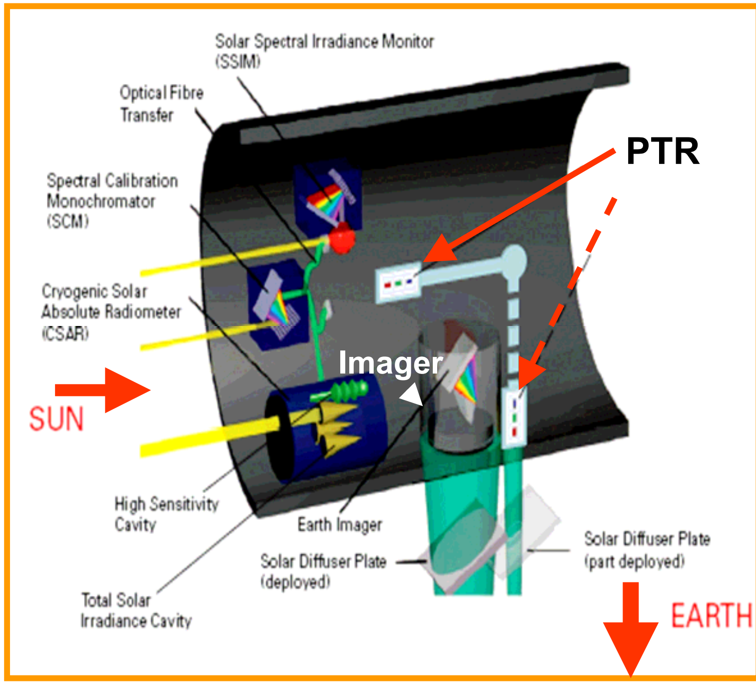


Fibre moves radiation between PTR and Solar Spectral Irradiance Monitor (SSIM)



Traceability Strategy:



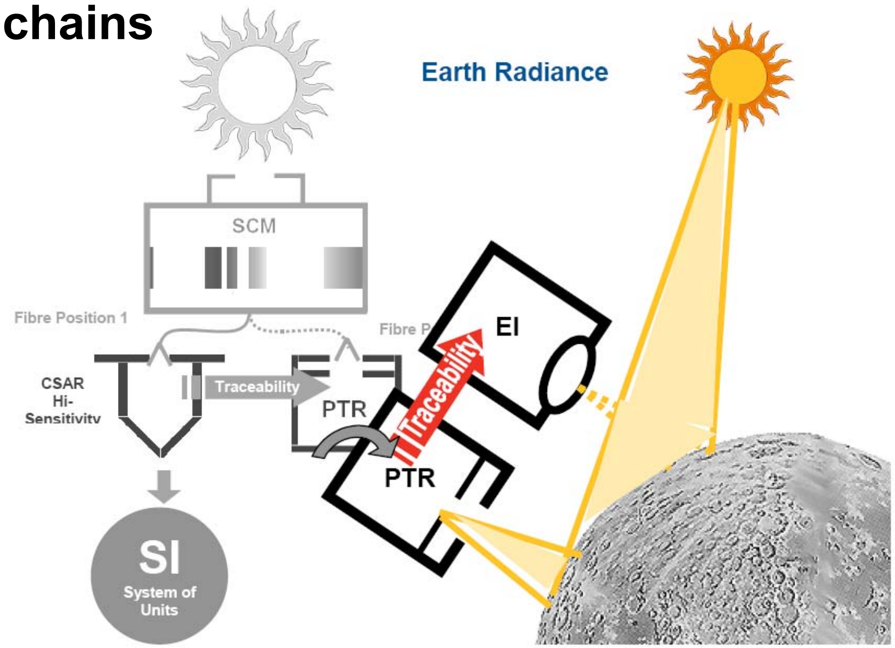
- Earth imager aperture illuminated by diffuse solar radiation from deployable diffuser (or Moon, or Earth)

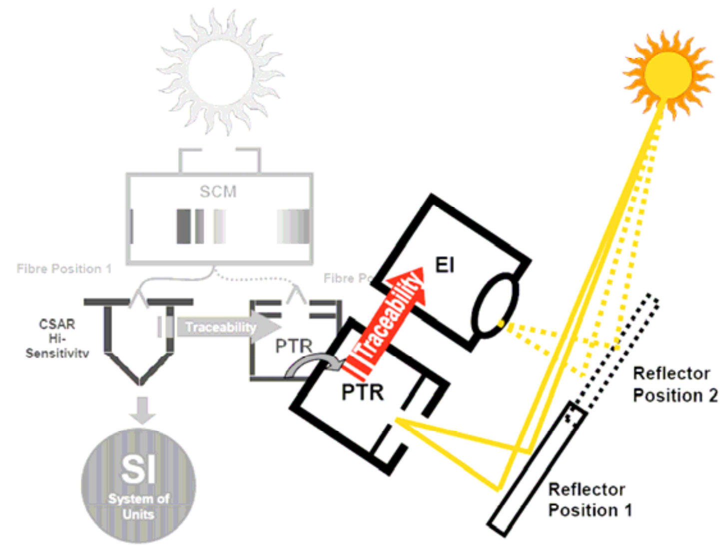
- Radiance measured by multi-channel Polarised Transfer Radiometer (PTR) calibrated traceable to CSAR.

Traceability for Earth Radiances

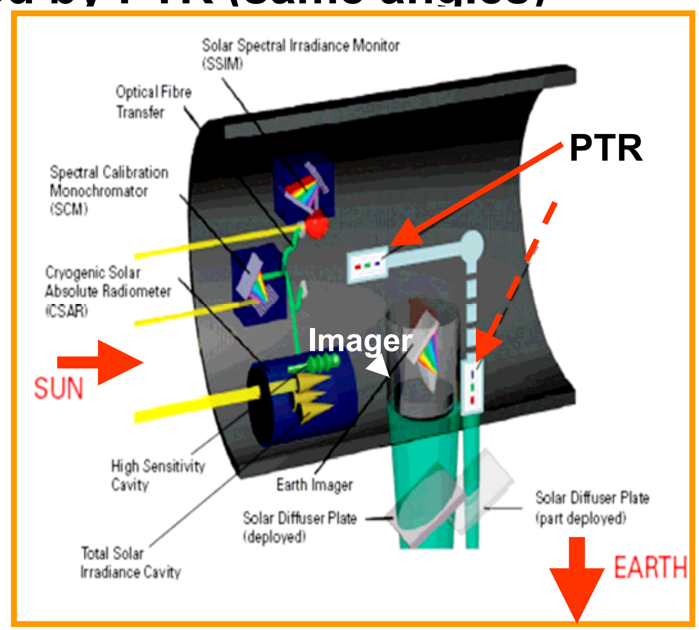
Calibrated PTR moved to view Earth target or Moon simultaneous with Earth Imager. Traceability established/monitored at ~13 bands across spectrum

SSIM can also view Moon to link both instruments and evaluate traceability chains

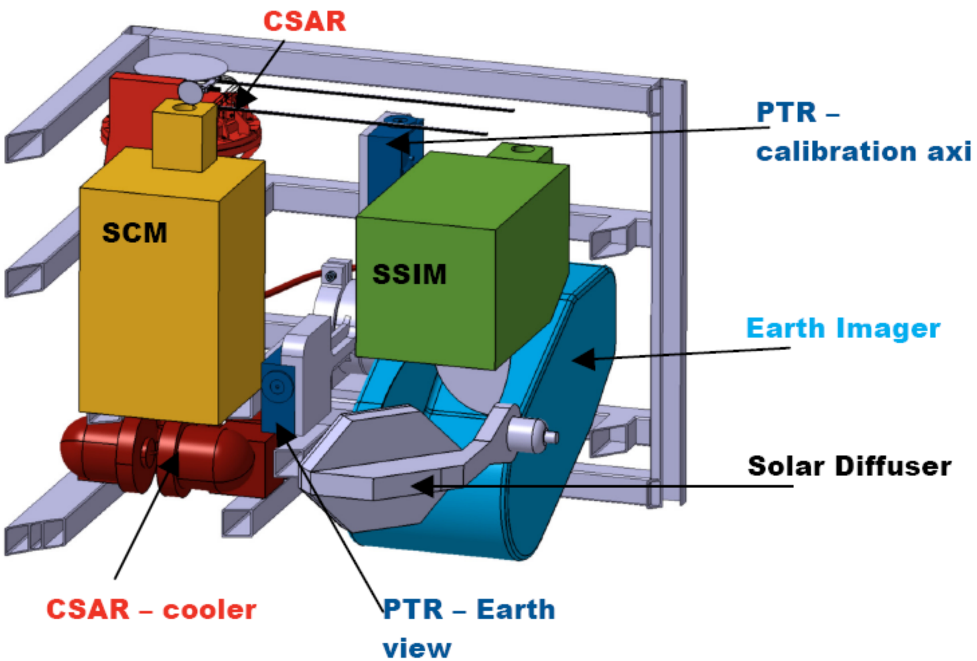


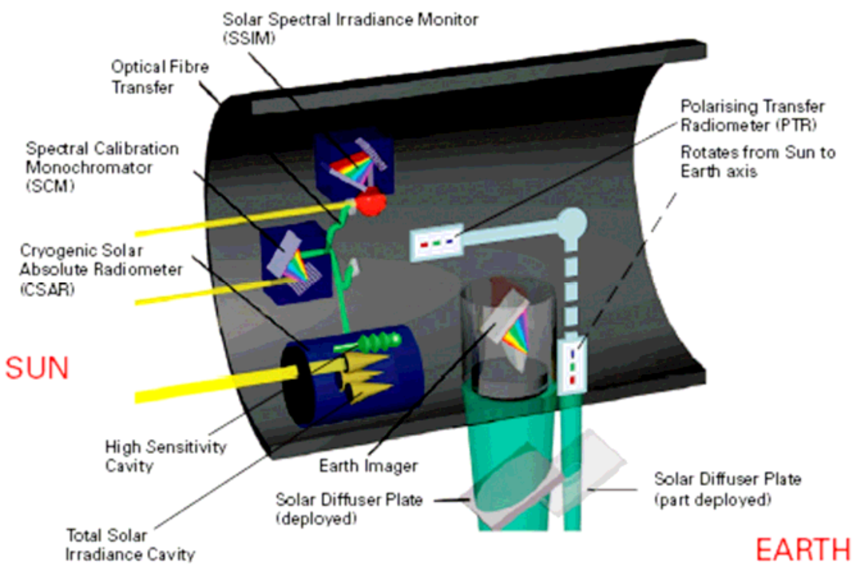


Solar illuminated lambertian diffuser deployed to fill Earth Imager FOV also viewed by PTR (same angles)

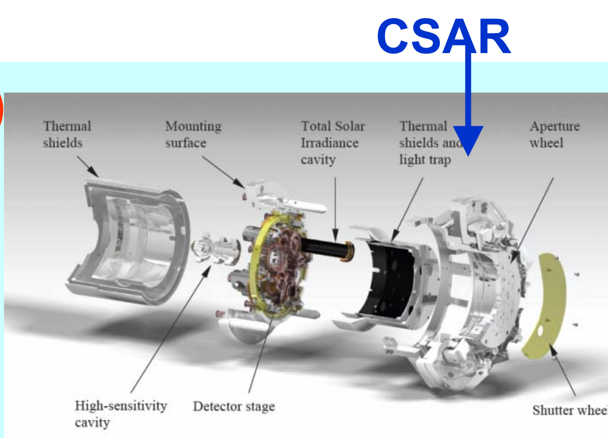


TRUTHS Payload: On-board SI traceability





On-Board SI Traceability (calibration/performance)



Cryogenic Solar Absolute Radiometer (CSAR)

- Primary SI reference standard

Spectral Calibration Monochromator (SCM)

- Spectrally dispersed monochromatic radiation from Sun for calibration system

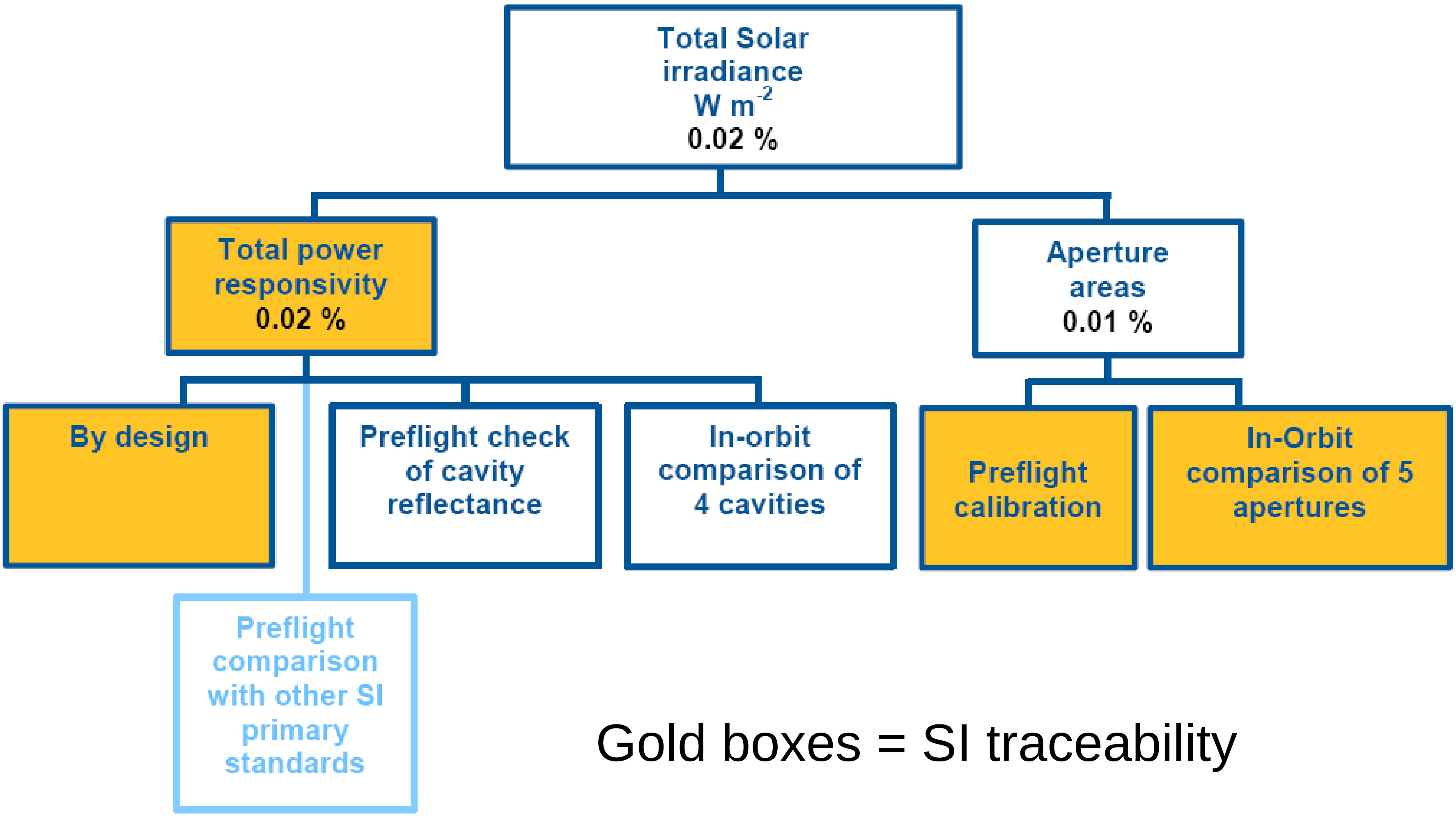
***Polarising Transfer Radiometer (PTR)* (2 OFF)**

- ~13 spectral bands to link calibration from CSAR to Earth Imager

Needs of ECV's

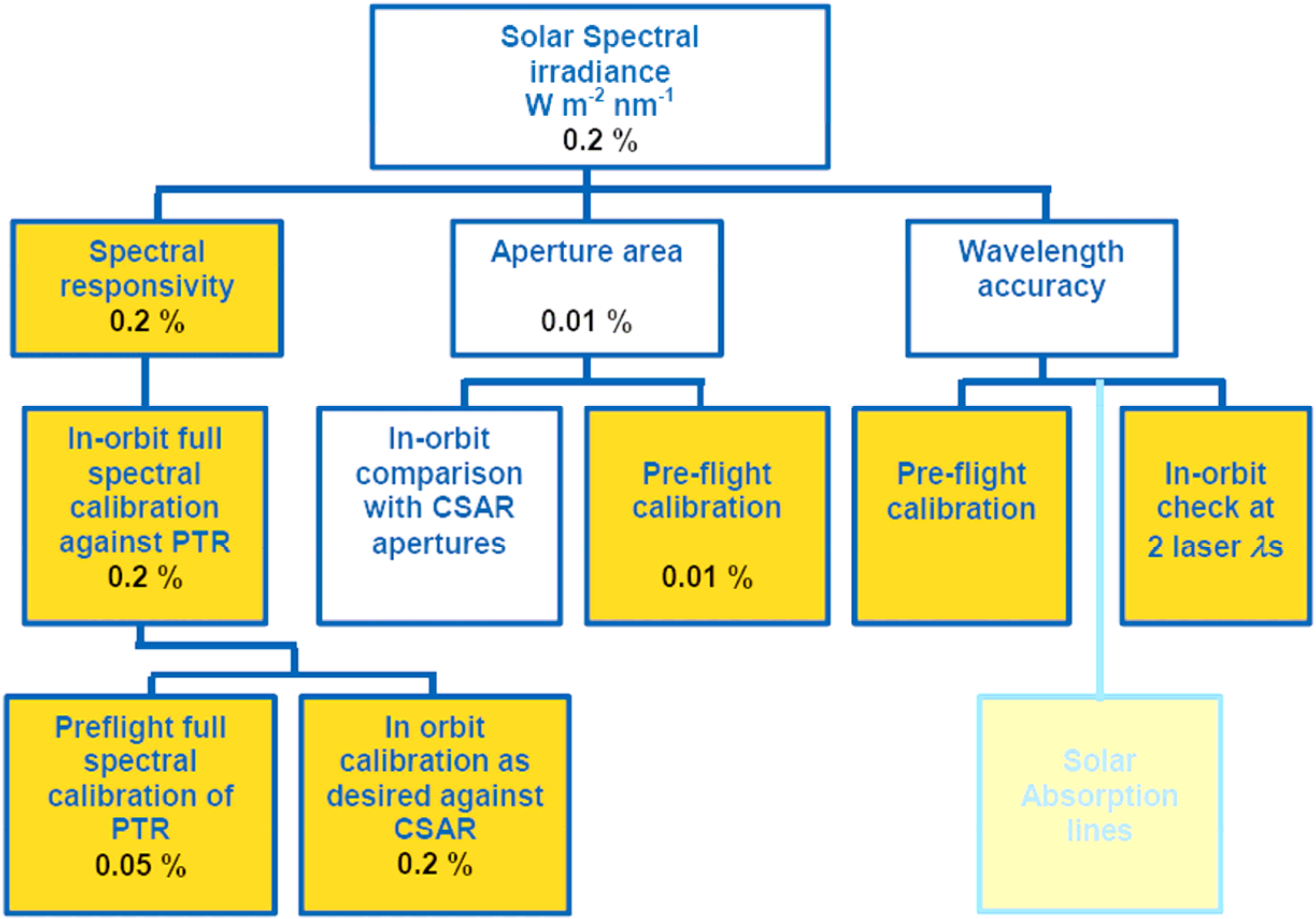
Climate variable	Role	TRUTHS providing direct observation	TRUTHS providing reference calibration
Solar irradiance	Climate forcing	yes	yes
Earth radiation budget	Climate forcing, feedback	yes	yes
Surface albedo	Albedo feedback	yes	yes
Cloud cover	Cloud feedback	yes	yes
Cloud particle size distribution		yes, through spectral benchmarking	yes
Cloud effective particle size			yes
Cloud ice/water content			yes
Cloud optical thickness			yes
Water vapour	Column water vapour response	yes	yes
Ozone	Stratospheric ozone Feedback	no (limited resolution)	yes
Aerosols Optical Depth	Climate forcing Atmospheric correction	no (limited temporal/spatial coverage) yes	yes yes
Ocean Colour	Carbon cycle	yes	yes
Ice and snow cover	Albedo feedback	yes	yes
Vegetation	Carbon Cycle and Albedo feedback	yes	yes
Land Cover/Land Use	surface Radiative Forcing	yes	yes

Traceability for Total Solar Irradiance



Gold boxes = SI traceability

Traceability for Solar Spectral Irradiance



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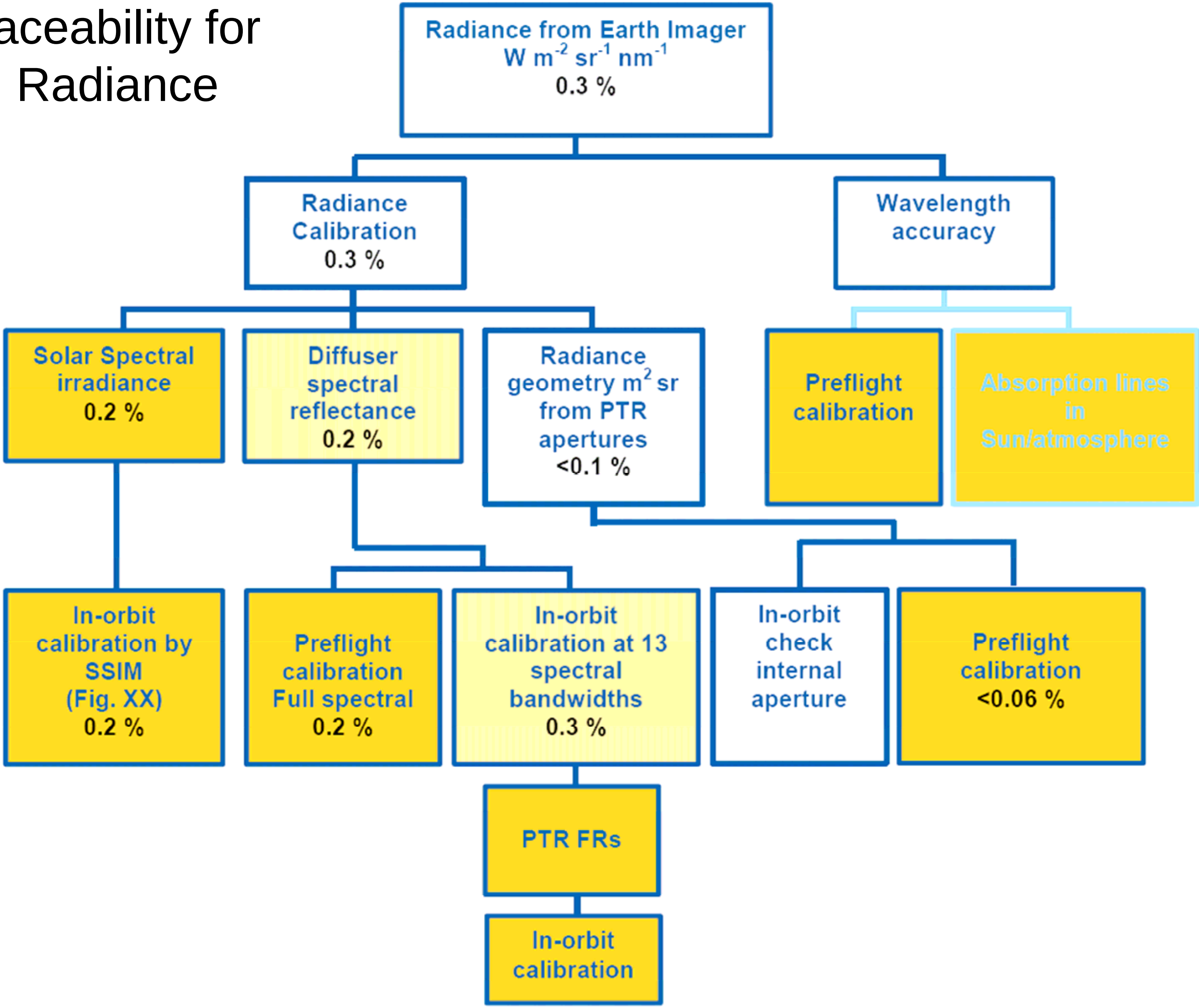
SI Traceability for Earth Radiance



Conclusion

- International community have identified traceability, accuracy and data quality as key drivers for Earth Observation: GEOSS / GMES and in particular for climate studies
  - WMO/BIPM MoU
  - NMIs must work closely with community to develop “transportable/field-solutions”
  - Uncertainty demands (radiometry) most challenging of any sector
- All aspects/steps of producing EO data products needs validation and traceability (instrument calibration (pre- and post- launch) and algorithms/models) QA4EO (http:www.QA4EO.org) provides a focus
  - European Metrology Centre for Earth Observation and Climate (EMCEOC) linked through a Centre for Carbon Measurement (CCM) will be a key facilitator to address this in conjunction with space agencies (CEOS)
- Traceability (benchmark measurements) from space seen as only plausible solution for studies of decadal climate and the data needed by policy makers to make informed decisions on mitigation and adaptation strategies
  - Need international “climate and calibration observatory (constellation) with in-flight traceability to SI (ideally at least two methods to allow comparisons) CLARREO (US) and TRUTHS (Europe)
- A “grand challenge project” demonstrating impact and criticality of metrology and the SI
  - “An NMI in space”

Summary

- **TRUTHS highly complementary to CLARREO**
  - Climate science requirements and key operational characteristics from CLARREO
  - Methodology for SI Traceability based on on-board primary standard
  - Delivers input solar irradiances on same platform
  - Together can provide international benchmark climate and calibration constellation
- **TRUTHS payload based on existing technologies**
  - (baseline) imager upgrade of ESA- APEX aircraft spectrometer
  - CSAR only new technology now built and under test
  - All could be built in 3 yrs
- **Low cost agile platform capable of increased payload both mass and power**
  - Could add CLARREO instruments
- **Currently under review by ESA “Earth explorer”**
  - Small missions < 100M Euro (excluding launch)
  - Decision on three Nov 2010
  - Potential to partner with NASA
- **Support within UK but national funding ???**
  - UKSA
  - New ESA climate office opened in UK
  - New government
  - National debt

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Contributing Science team led by Dr Nigel Fox:

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Dr. Richard Bantges	Imp Coll	UK
Dr. Xavier Briottet	ONERA	F
Dr. Helen Brindley	Imp Coll	UK
Mr. Steve Groom	PML	UK
Prof. Joanna Haigh	Imp Coll	UK
Dr. Patrice Henry	CNES	F
Dr. Andrea Kaiser-Weiss	U of Read	UK
Dr. Steve Mackin	SSTL	UK
Prof. Jan-Peter Muller	MSSL	UK
Dr. Gunnar Myhre,	CICERO	N
Dr. Terry Quinn FRS CBE	BIPM	int
Dr. Jacqueline Russell	Imp Col	UK
Dr. Roger Saunders	Met off	UK
Prof. Michael Schaepman	U of Zur	CH
Prof. Werner K. Schmutz	PMOD	CH
Dr. Andy Shaw	NCEO	UK
Prof. Keith Shine FRS	U of Read	UK
Mr. Greg Stensaas	USGS	USA
Dr. Thomas Stone	USGS	USA
Prof. Philippe M Teillet	U of Leth	Can
Dr. Kurt Thome	NASA	USA
Dr. M Verstraete	JRC	Int
Dr. Bruce Wielicki	NASA	USA
Dr. Jean-Luc Widlowski	JRC	Int
Mr R Winkler	NPL	UK
Dr Emma Woolliams	NPL	UK

Thankyou

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For more details:

www.npl.co.uk/TRUTHS

http://www.youtube.com/npldigital#p/a/u/0/aQAREkaZjfI