Validated data and removal of bias through traceability to SI

Nigel Fox

Quality of Life Division
National Physical Laboratory
Oct 04

Resolution adopted by CEOS Plenary 14 (Nov 2000)

- 1/ All EO measurement systems should be verified traceable to SI units for all appropriate measurands.
- 2/ Pre-launch calibration should be performed using equipment and techniques that can be demonstrably traceable to and consistent with the SI system of units, and traceability should be maintained throughout the lifetime of the mission.

Traceability – *Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually through an unbroken chain of comparisons all having stated uncertainties*

"Vocabulary for International Metrology (VIM) ISO"

serco

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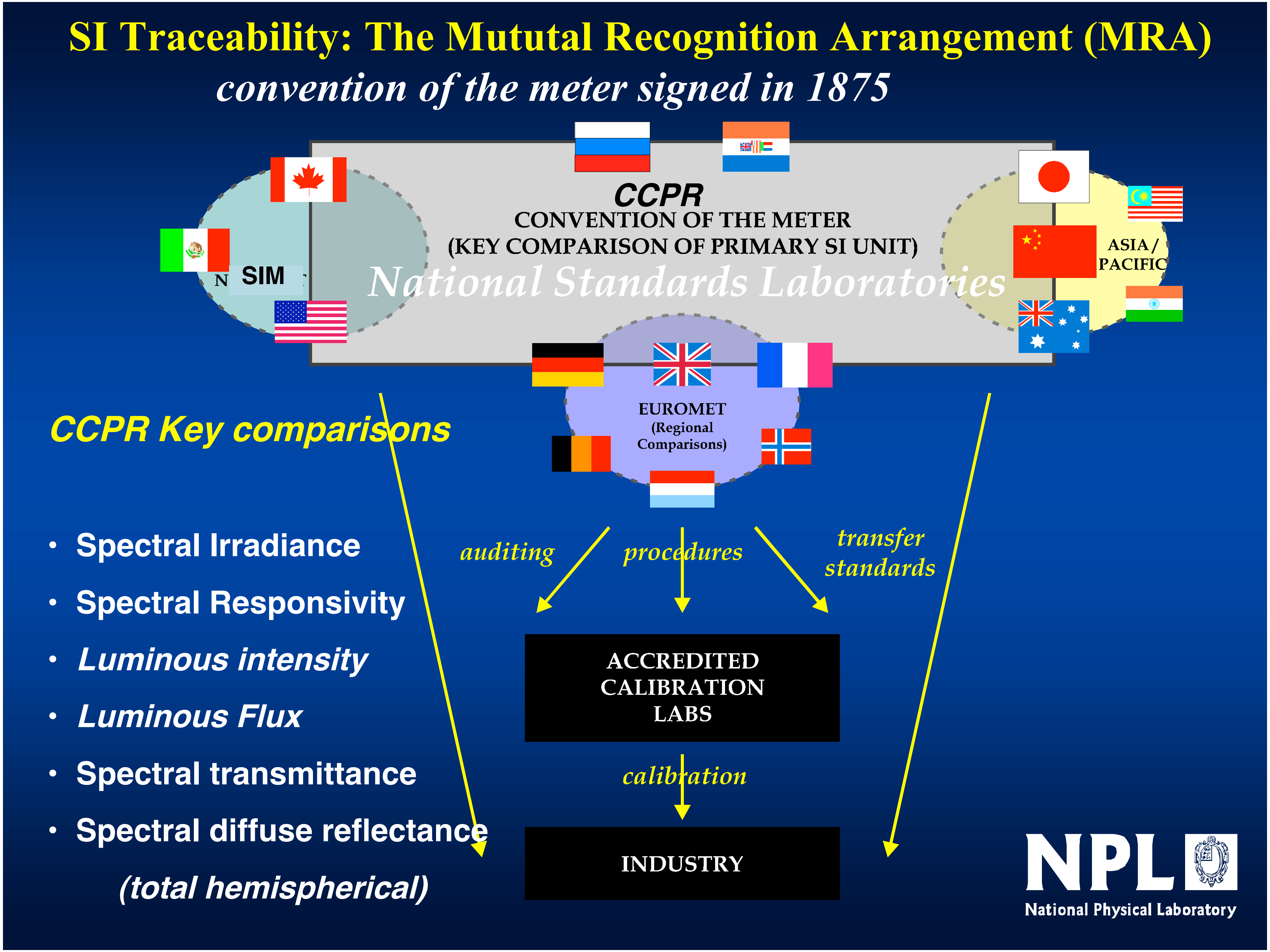

SI Traceability: The Mututal Recognition Arrangement (MRA)
convention of the meter signed in 1875
CCPR
CONVENTION OF THE METER
(KEY COMPARISON OF PRIMARY SI UNIT)
National Standards Laboratories
SIM
ASIA / PACIFIC
EUROMET
(Regional Comparisons)
CCPR Key comparisons
• Spectral Irradiance
• Spectral Responsivity
• Luminous intensity
• Luminous Flux
• Spectral transmittance
• Spectral diffuse reflectance
(total hemispherical)
auditing
procedures
transfer standards
ACCREDITED CALIBRATION LABS
calibration
INDUSTRY
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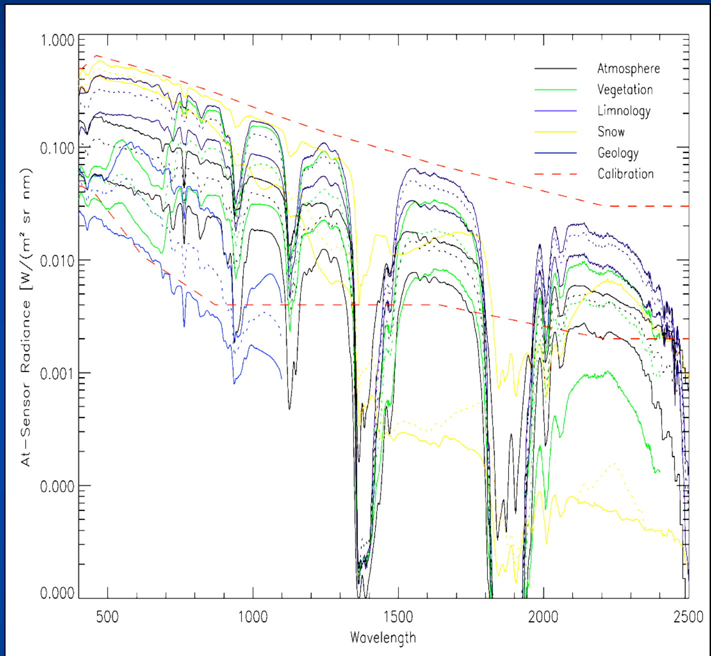
Monitoring and interpreting the Earth’ systems

Incoming Solar Radiation

Drives all the processes of the Earth System and potentially damaging (UV) to Biosphere (Human health)



Spatial variability requires good stability and SNR (signal to noise ratio) from a single sensor - but long term studies “climate change” need accuracy and consistency

Engineering specification of SNR

Solar Reflected Radiation

Atmosphere - Aerosol (size & distribn)
- Clouds
- Pollution (impact on health)

Water - Pollution (originator)
- Algae plumes

Land - Useage / condition
- Type/quantity of vegetation
- Minerals
- Carbon & hydrological cycles

Governments – Treaties, Tax, Planning

Thermal Emitted Radiation

Atmosphere – Atmospheric chemistry

Water – Temperature

Land – Fires, Volcanoes, Pollution,

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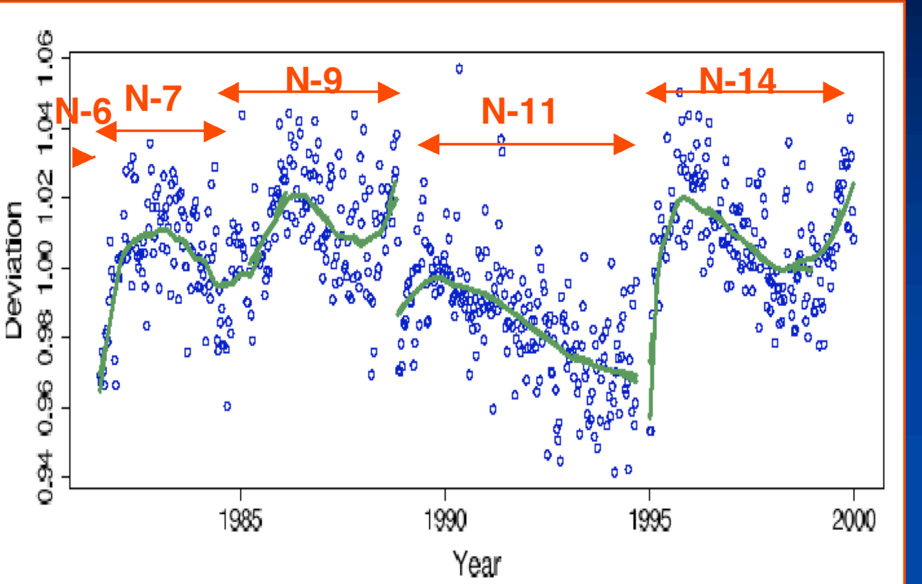
Anomalies in NOAA/AVHRR data

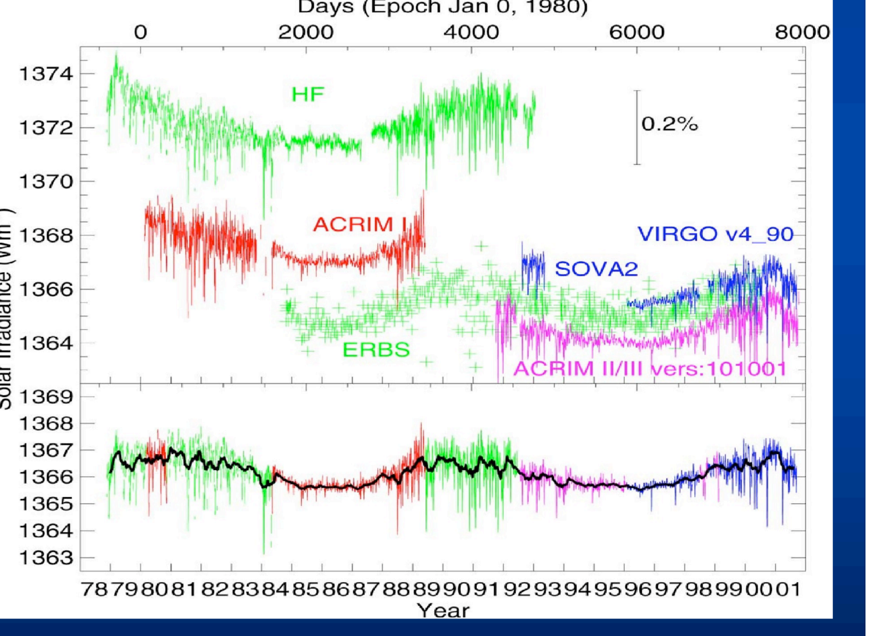


LOS 1998 IEEE Trans G & RS

Normalised Difference Vegetation Index (NDVI) over "stable" desert as measured by AVHRR

– Demonstrates both in-flight "ageing" and initial calibration biases

Total solar Irradiance (Solar constant) – only normalisation allows a long term record to be established (Biases are 10 X larger than necessary to detect impact on climate change)



Temporal change difficult to identify even using "identical" instrumentation without normalisation

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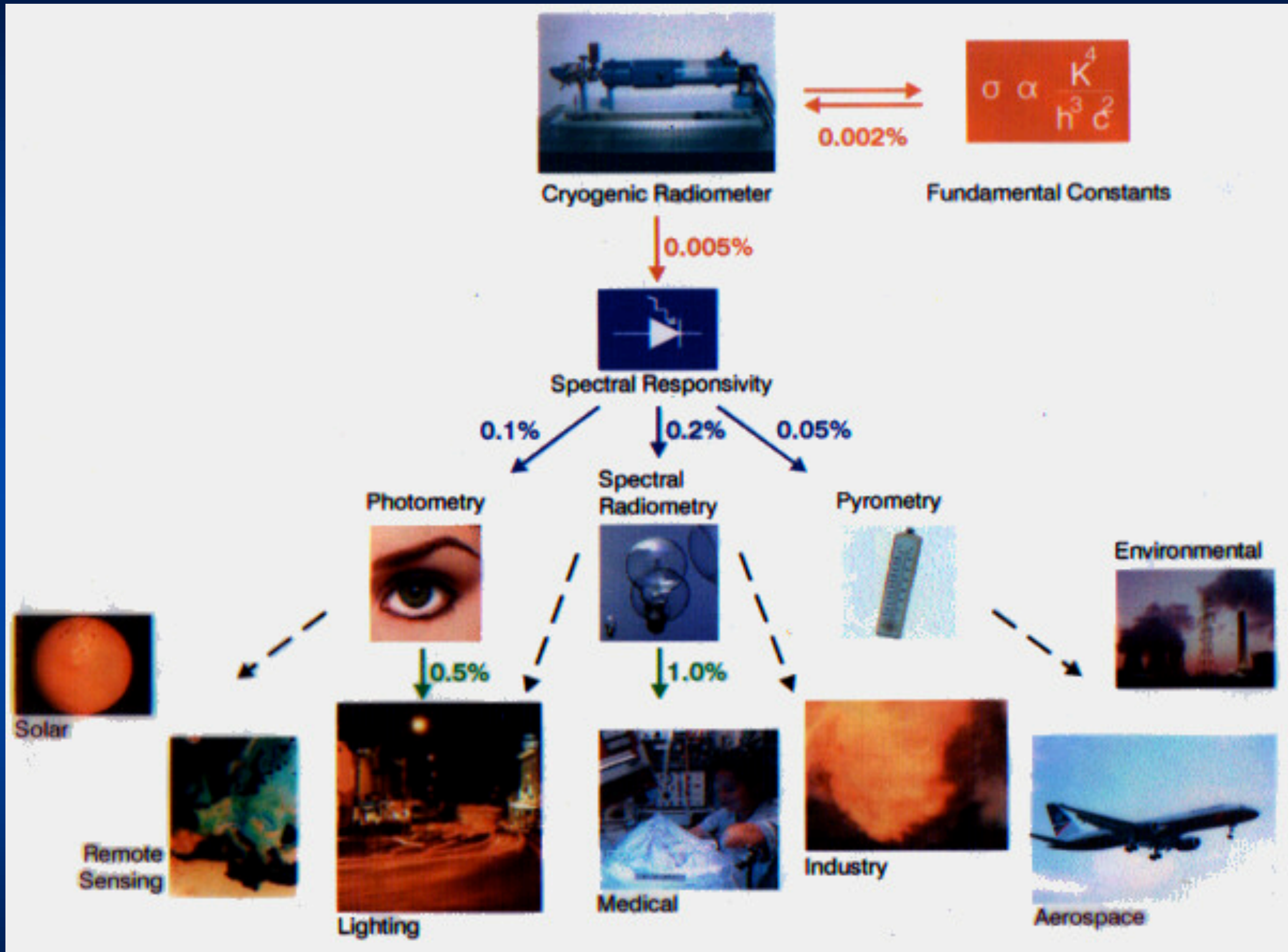
Traceability chain for optical radiation measurement



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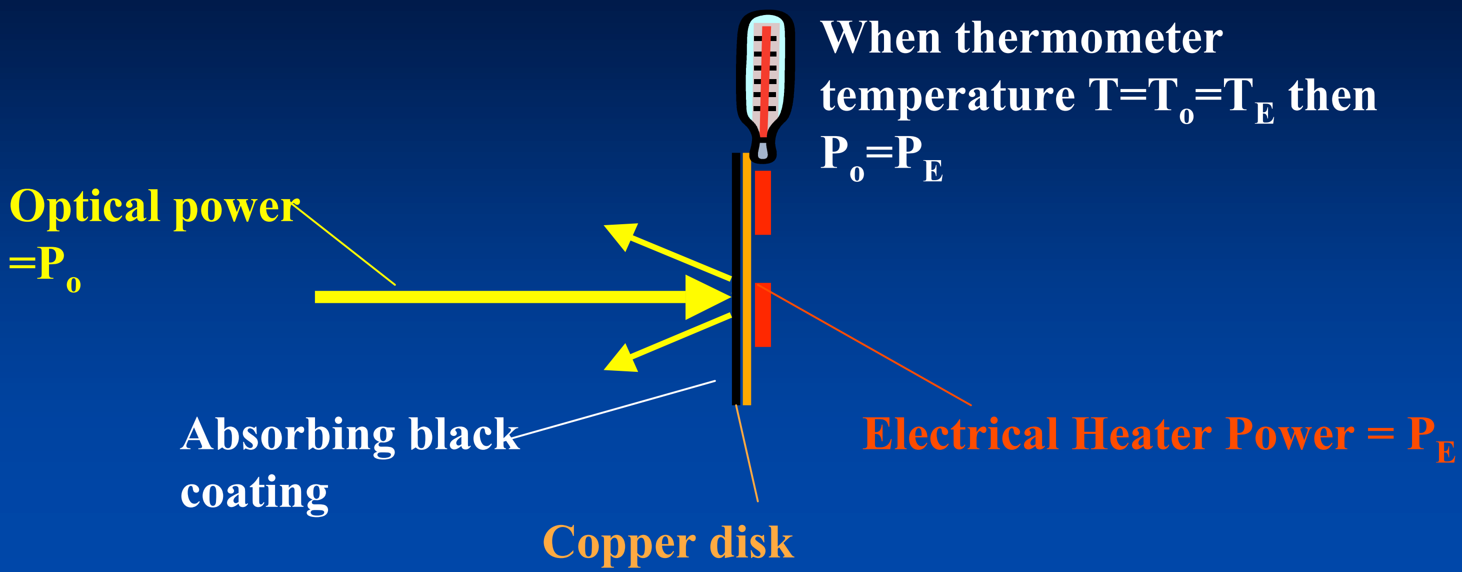
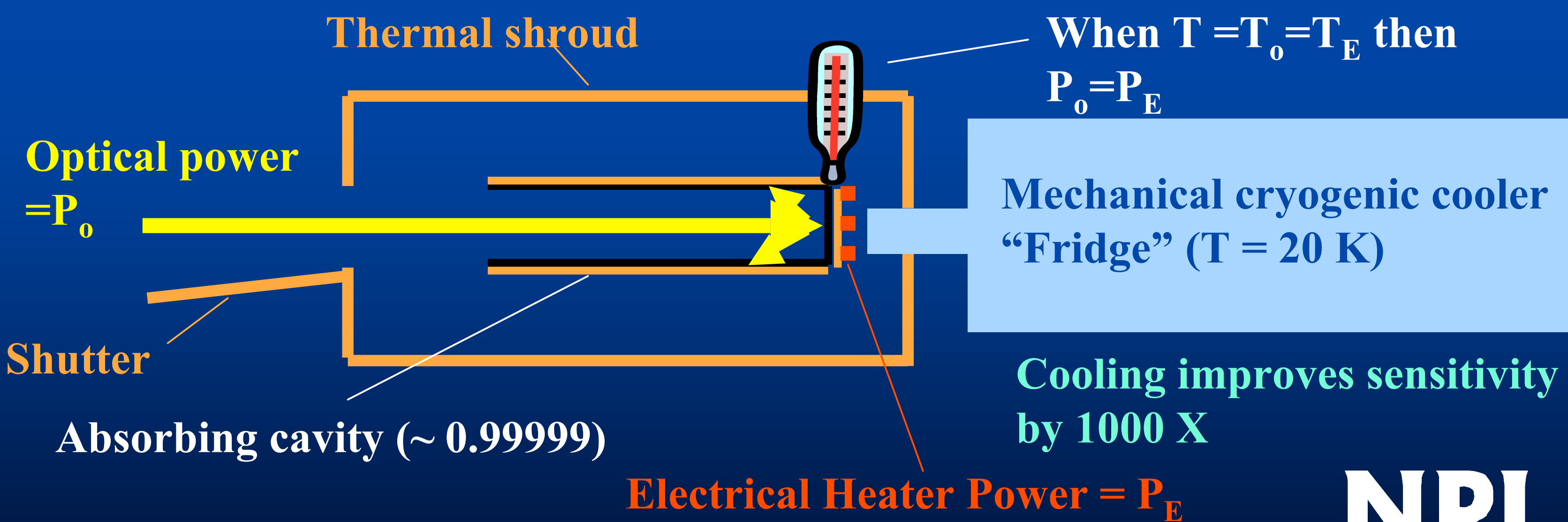
Electrical Substitution Radiometry a 100 yr old technology





Principle of Cryogenic radiometry

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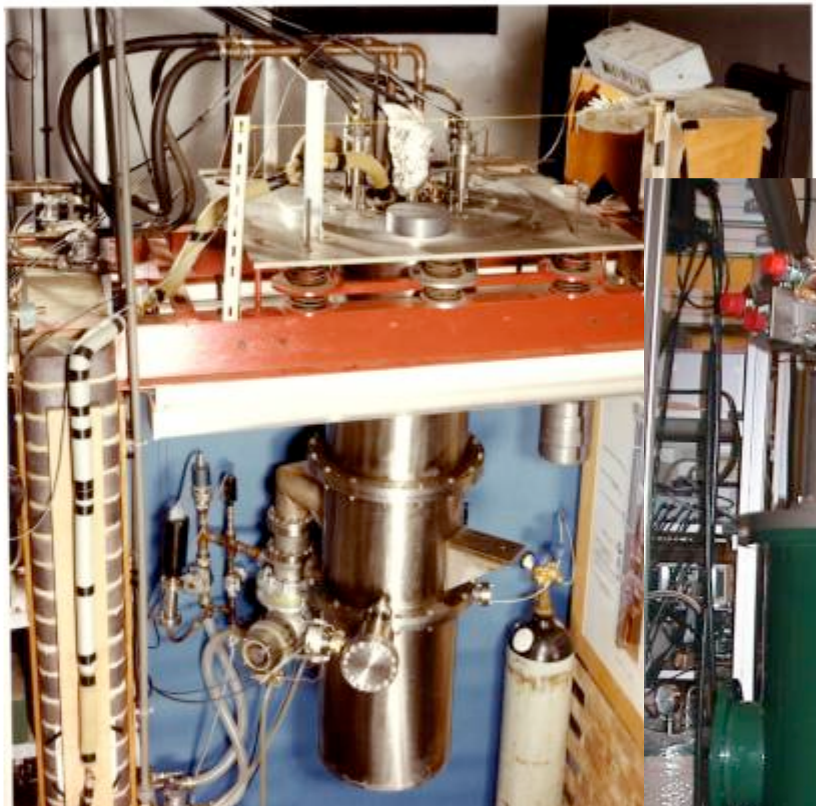
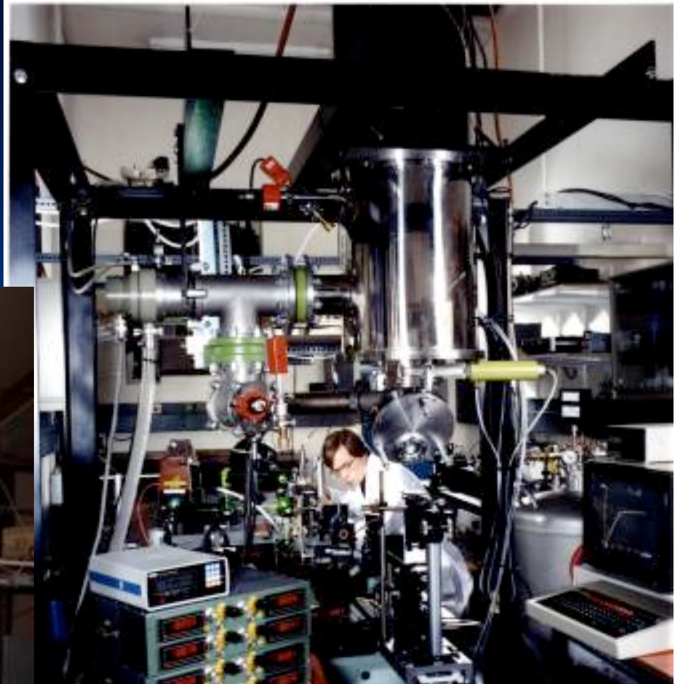
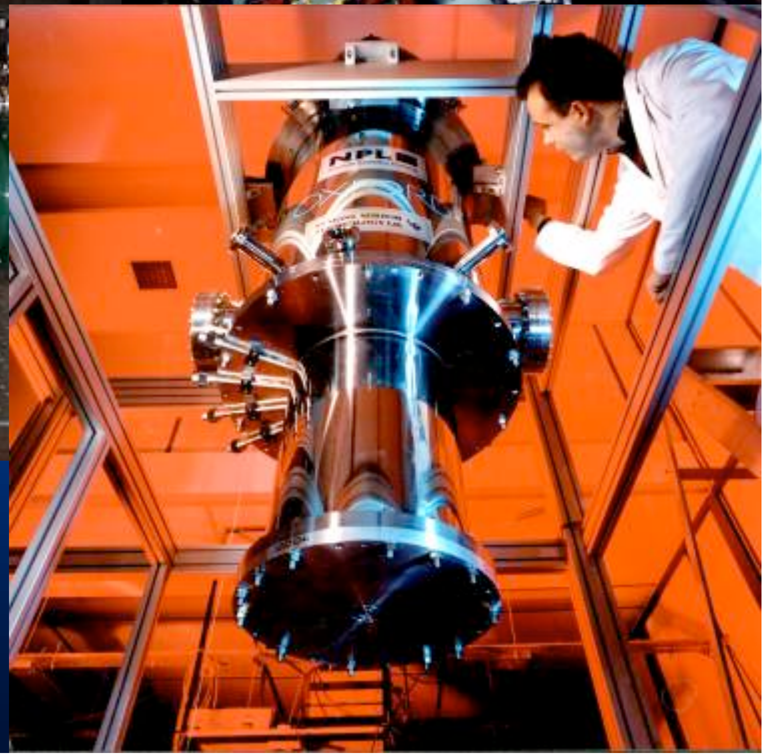
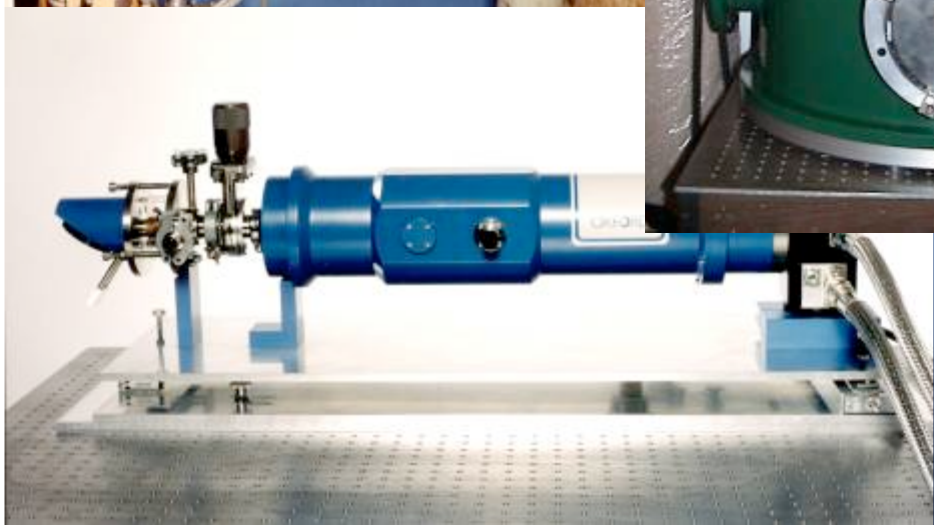
25 yrs of cryogenic radiometry at NPL

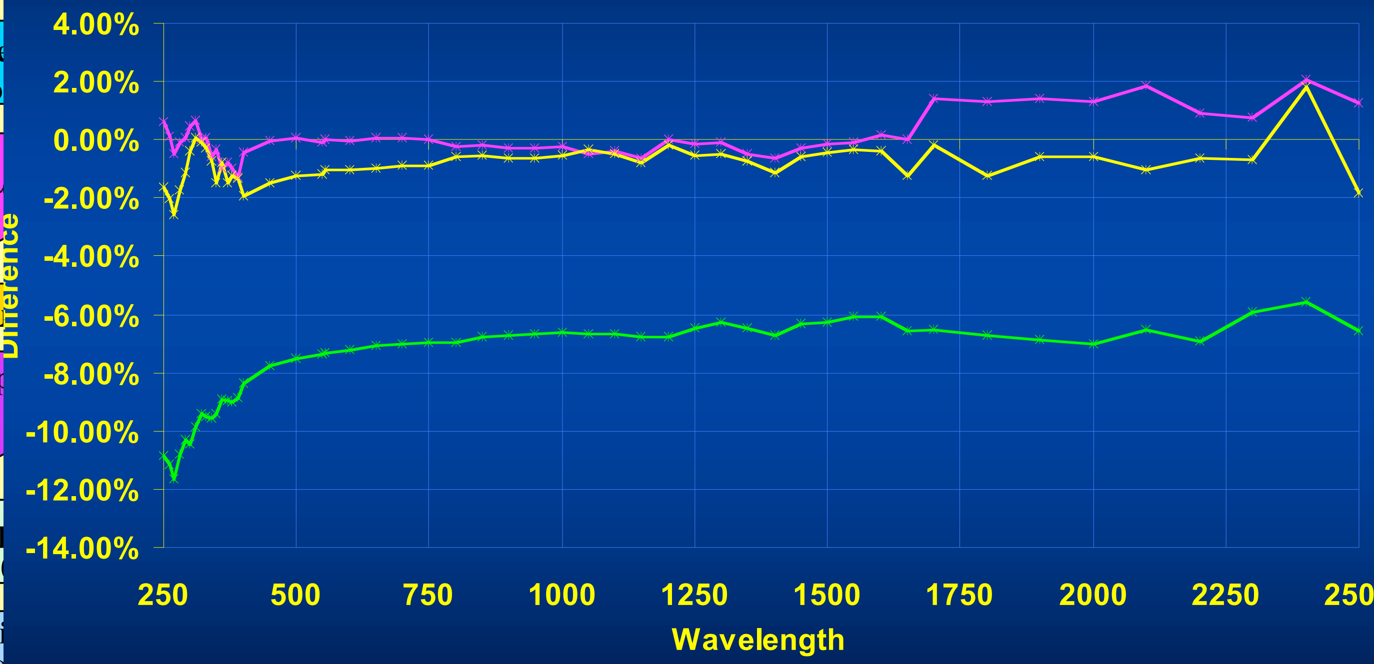








Lamp performance: FELs (approx 1 in 3 show a deviation)



Fundamental constants (SI)

Primary standar
cryogenic radion

Laser
Cal interval ~

Photodiode
(spectral respo

Laser
Cal interval ~

Filter Radior

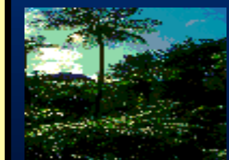
Radiance Temp

Ultra High Temp
Black Body (350

Radiance conti
(Planck)

Spectroradiometer
(multi-band filter radiometer

Spectral Radiance/Irradiance
calibrations



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Fundamental constants (SI)

Primary standard cryogenic radiometer

Laser
Cal interval ~100nm

Photodiode
(spectral responsivity

Laser
Cal interval ~0.1 nm

Filter Radiometer

Radiance Temperature

Ultra High Temperature Black Body (3500 K)

Radiance continuum
(Planck)

Spectroradiometer
(multi-band filter radiometer

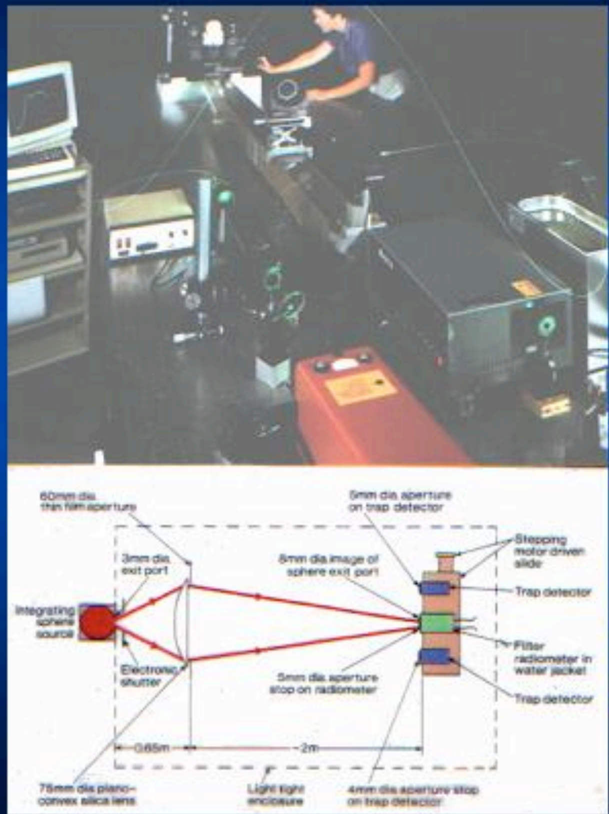
Spectral Radiance/Irradiance calibrations

Primary standard lamp

Spectroradiometer

Satellite Pre-flight Calibration

APPARATUS FOR CHARACTERISATION OF FILTER RADIOMETERS



NPL has established a spatially uniform, depolarised tuneable monochromatic source based on the use of solid-state and dye lasers to calibrate the radiance or irradiance response of filter radiometers.

The source utilises an optical fibre to decouple the source from the laser facility and also to remove speckle.

Uncertainties of 0.02% have been achieved for filter radiometers and lower for more conventional spectro-photometric applications.

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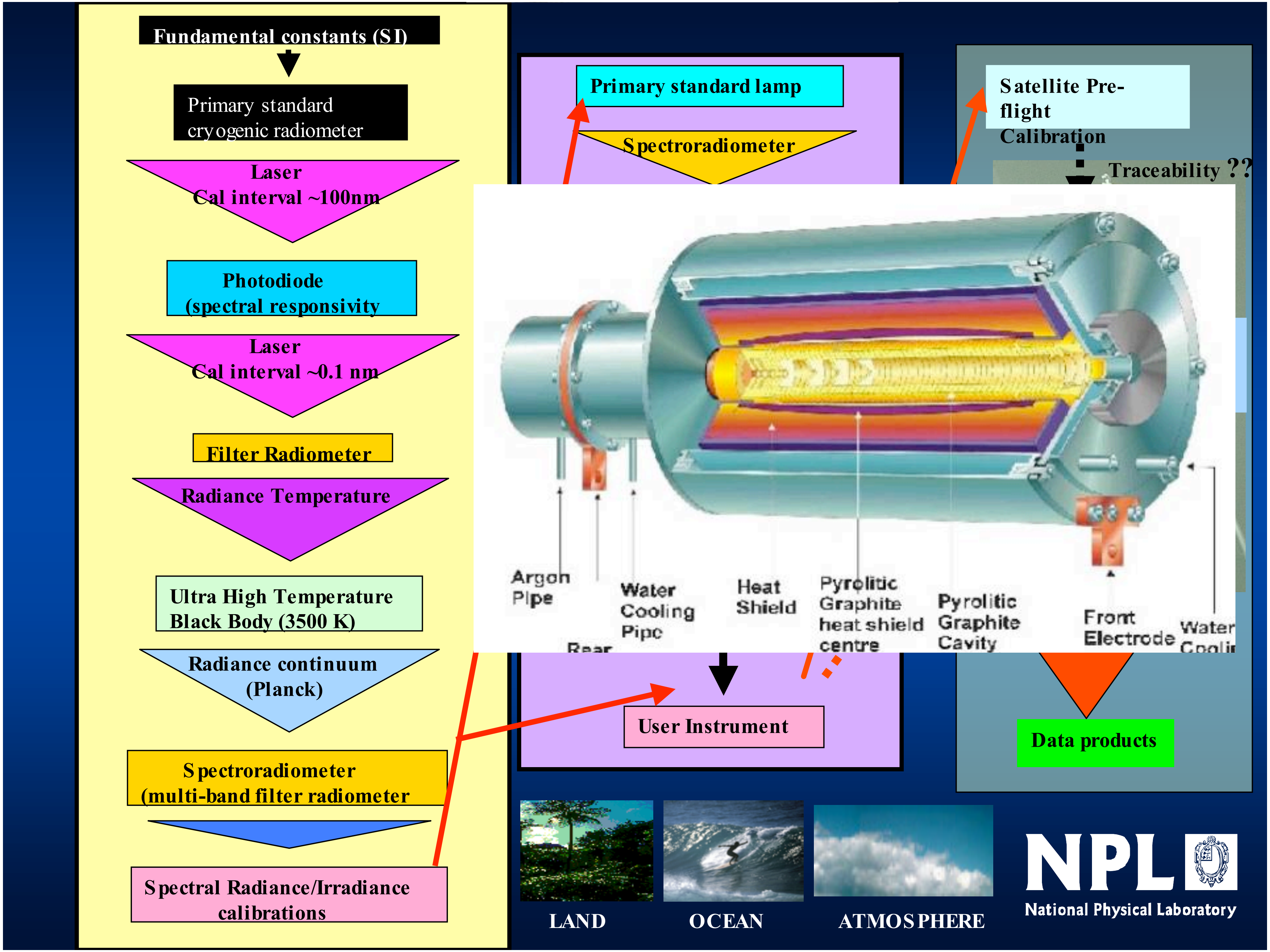
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(multi-band filter radiometer
Spectral Radiance/Irradiance calibrations
Primary standard lamp
Spectroradiometer
User Instrument
Satellite Pre-flight Calibration
Traceability ??
Data products
Argon Pipe
Rear
Water Cooling Pipe
Heat Shield
Pyrolitic Graphite heat shield centre
Pyrolitic Graphite Cavity
Front Electrode
Water
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(Planck)

Spectroradiometer
(multi-band filter radiometer

Spectral Radiance/Irradiance
calibrations

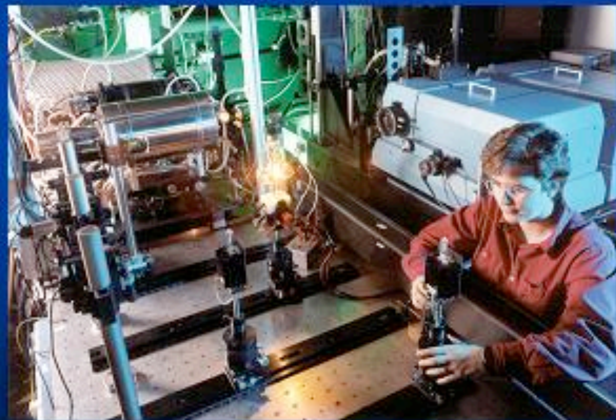
Primary standard lamp

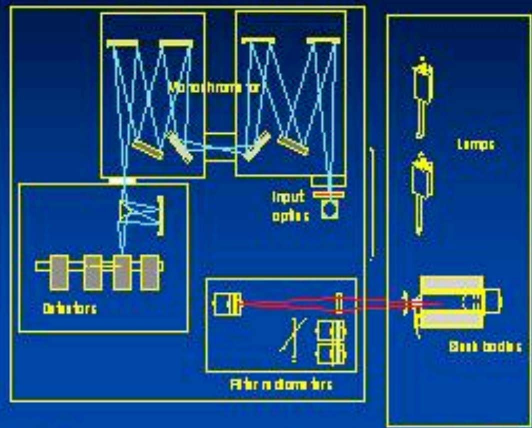
Spectroradiometer

Satellite Pre-flight
Calibration

Primary Spectral Irradiance Calibration Facility

- Black body operates at up to 3500 K to allow spectral range 200 to 2500 nm
- Facility fully automated with spectroradiometer moving between sources





- Radiance temperature of black body determined using filter radiometer
- Black body calibrates spectroradiometer
  - which then calibrates lamp/source
  in terms of radiance or irradiance

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(Planck)

Spectroradiometer
(multi-band filter radiometer

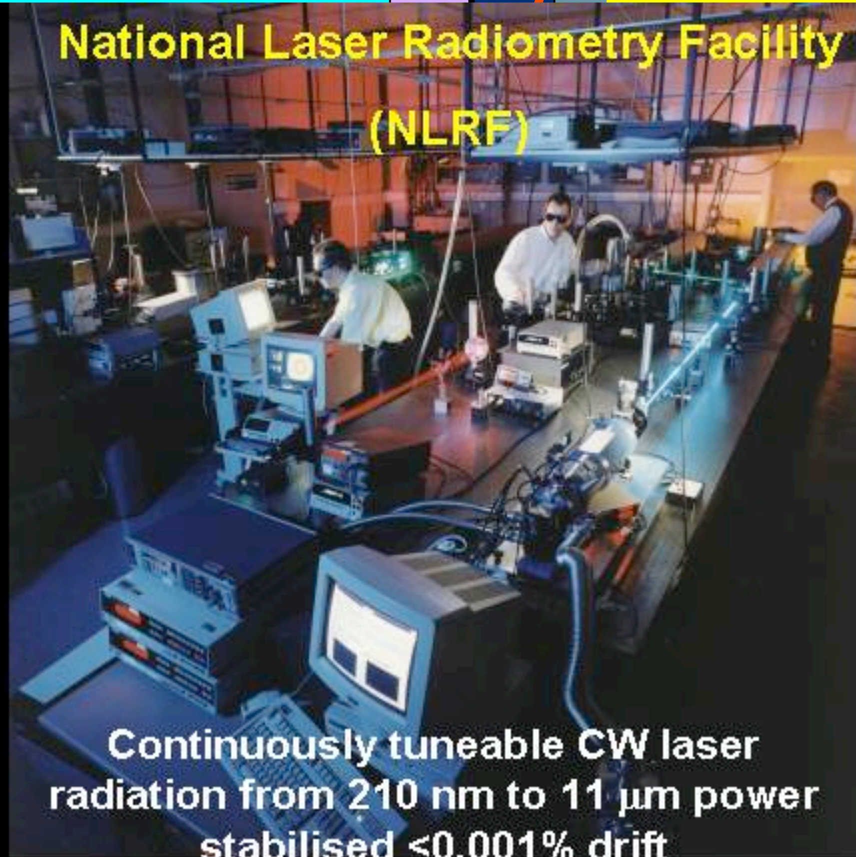
Spectral Radiance/Irradiance
calibrations

Primary standard lamp

Spectroradiometer

Satellite Pre-flight Calibration

Traceability ??



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Laser Cal interval ~0.1

Filter Radiome

Radiance Tempera

Ultra High Temper Black Body (3500 K

Radiance continu (Planck)

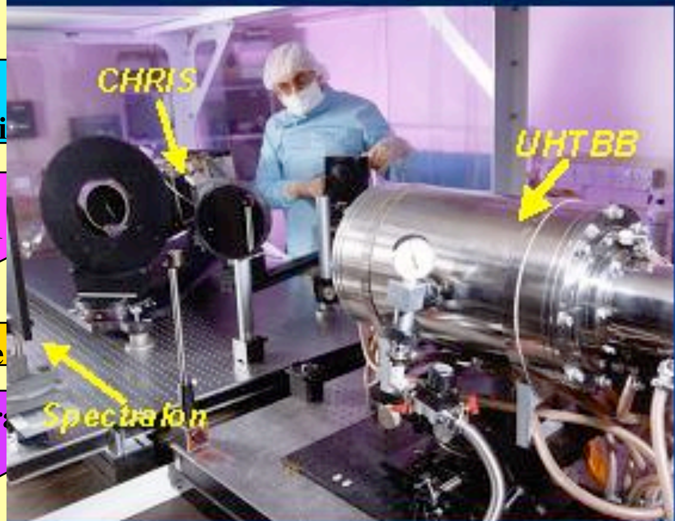
Spectroradiomete (multi-band filter radi

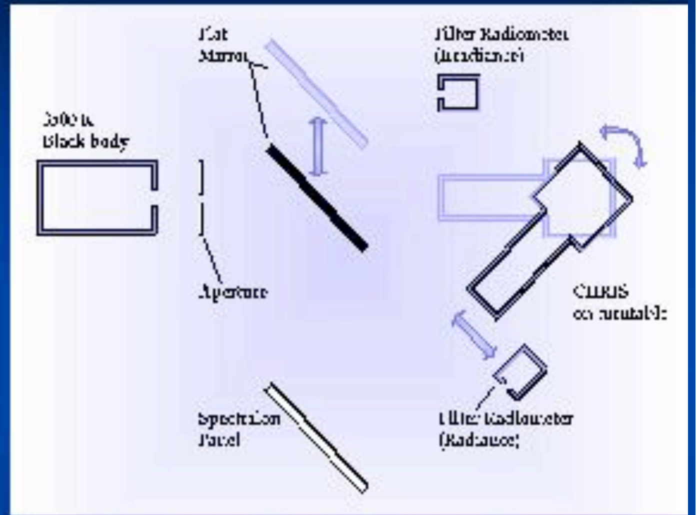
Spectral Radiance/Irradiance calibrations

Primary standard lamp

Satellite Pre-flight

CHRIS (Proba) calibrated directly against NPL primary standard Ultra high temperature black body (UHTBB)





Black body at 3500 K used to determine radiance and also used to simulate solar irradiance for on-board calibration monitor. Out-of-field stray light calibrated using highly collimated laser radiation from UK National Laser Radiometry Facility (NLRF)

During calibration CHRIS was maintained in a class 1000 environment within an NPL laboratory.

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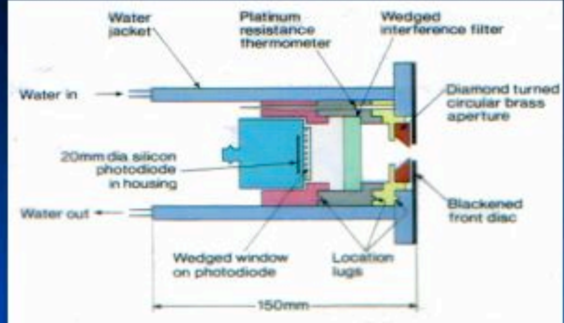
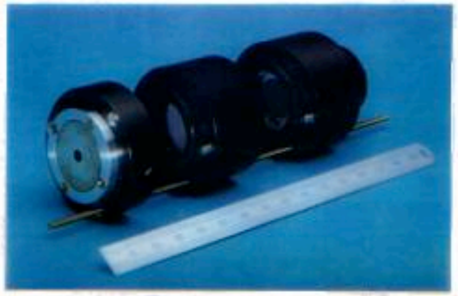
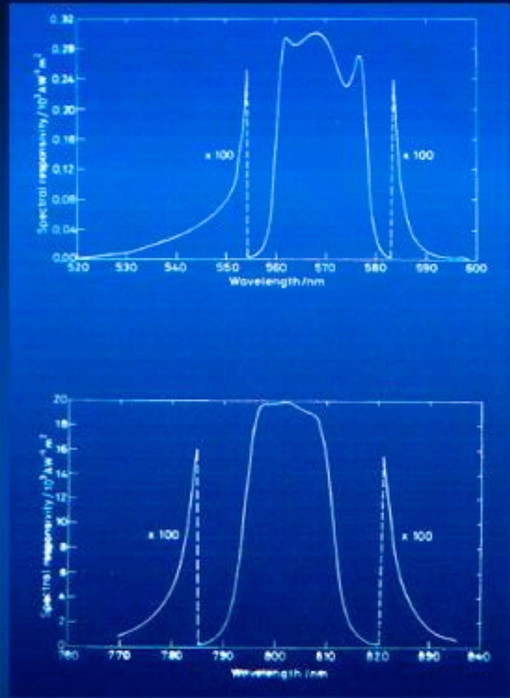
Satellite Pre-flight Calibration





Filter radiometer



Use of lasers allows filter radiometers to be calibrated with uncertainties <0.05 % in terms of radiance

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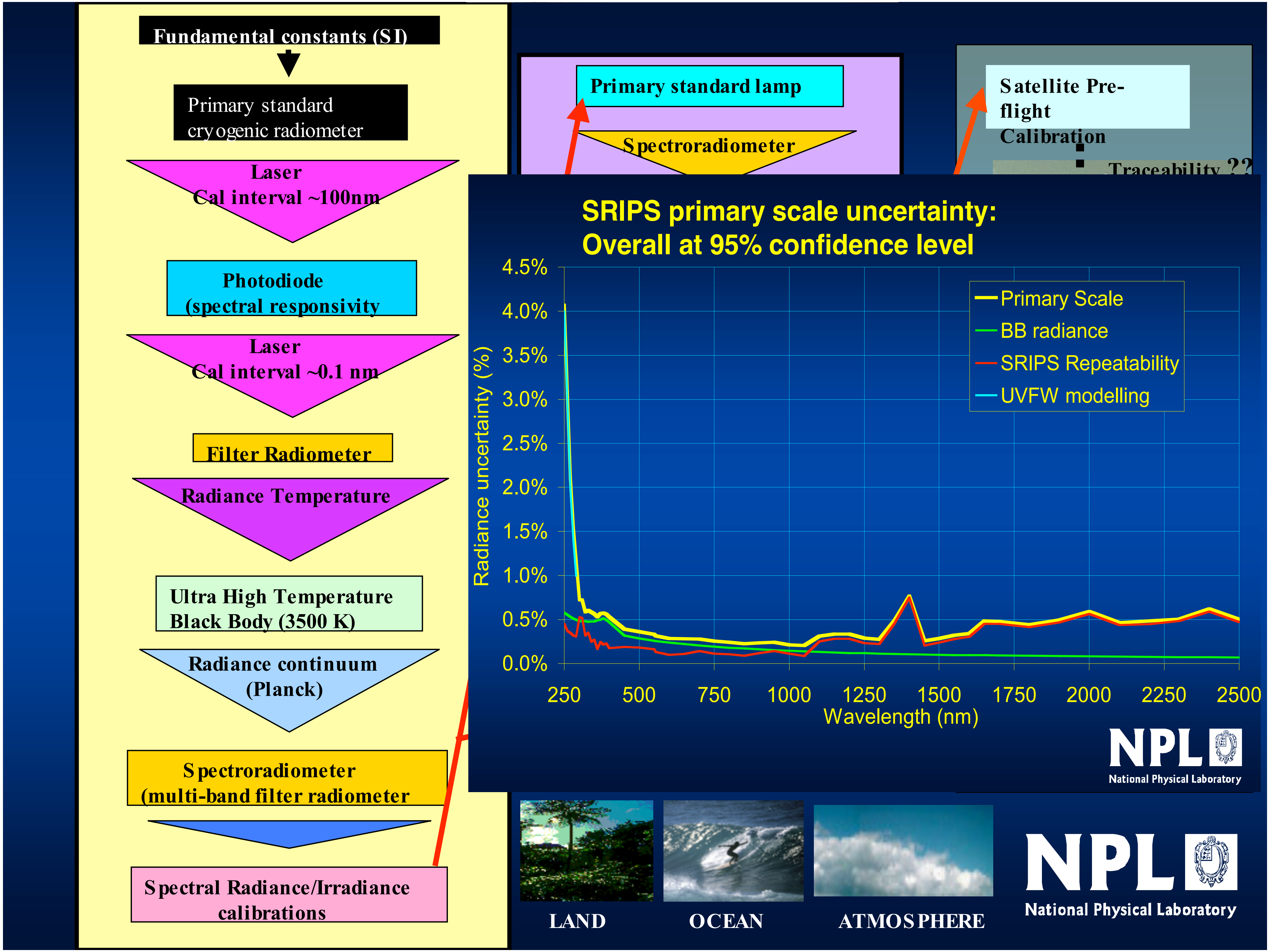
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Primary standard lamp
Spectroradiometer
Satellite Pre-flight Calibration
Traceability ??
SRIPS primary scale uncertainty:
Overall at 95% confidence level
Radiance uncertainty (%)
4.5%
4.0%
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Primary Scale
BB radiance
SRIPS Repeatability
UVFW modelling
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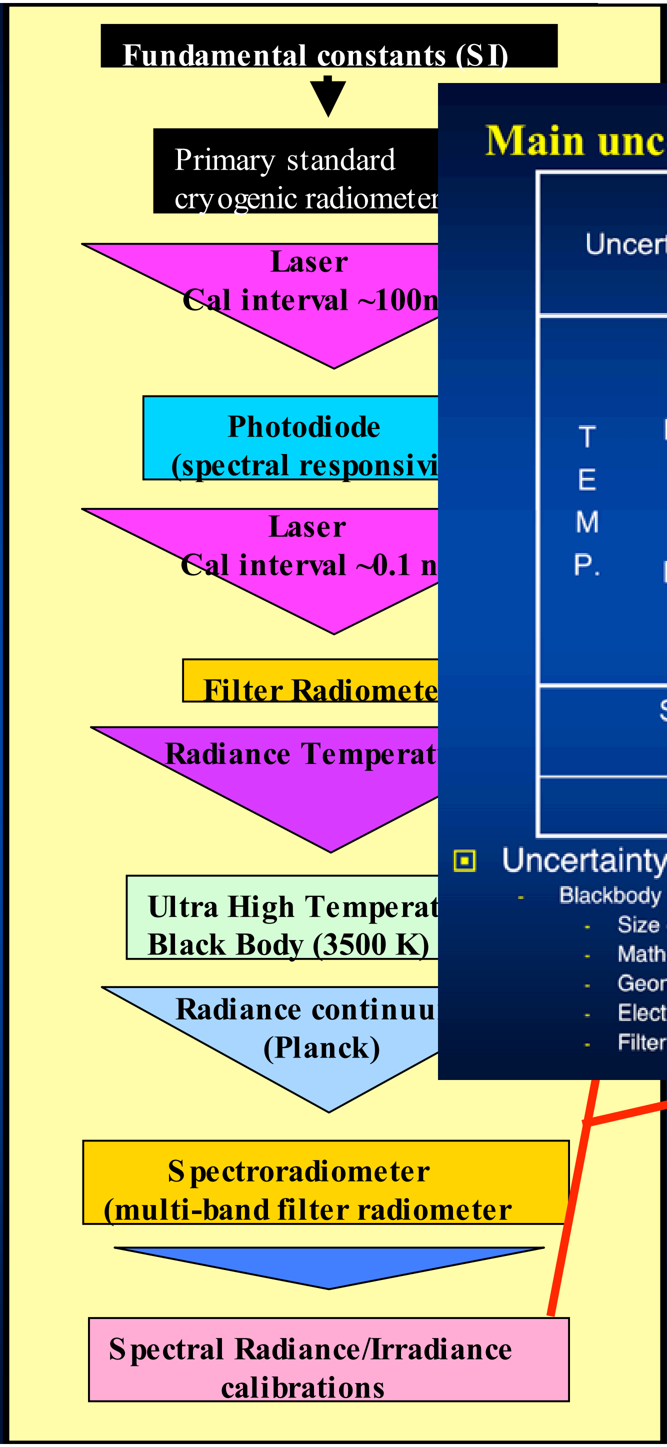
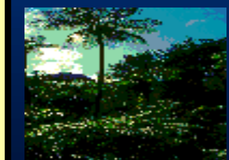
Main uncertainty components: *k* = 1 confidence level

	Uncertainty component	Effective uncertainty, 3050 K BB: Individual uncertainty	300 nm	550 nm	700 nm
TEMP.	Blackbody Uniformity	0.327 K	0.17%	0.09%	0.07%
	Blackbody Stability	0.258 K	0.13%	0.07%	0.06%
	FR absolute responsivity	0.115 K	0.06%	0.03%	0.03%
	Lens Transmission	0.103 K	0.05%	0.03%	0.02%
	Blackbody Emissivity	0.089 K	0.05%	0.03%	0.02%
	SRIPS repeatability		0.26%	0.08%	0.07%
	Lamp alignment		0.06%	0.06%	0.06%

- Uncertainty sources with an effect on irradiance less than 0.03%
  - Blackbody temperature:
    - Size of source effect
    - Mathematical approximations
    - Geometric Factor
    - Electronics
    - Filter radiometer relative shape

-Blackbody absorption (apart from ~380 nm)
-Blackbody-integrating sphere geometry
-SRIPS linearity
-Monochromator wavelength error
-Monochromator bandwidth and subsequent mathematical approximations
-Lamp current control

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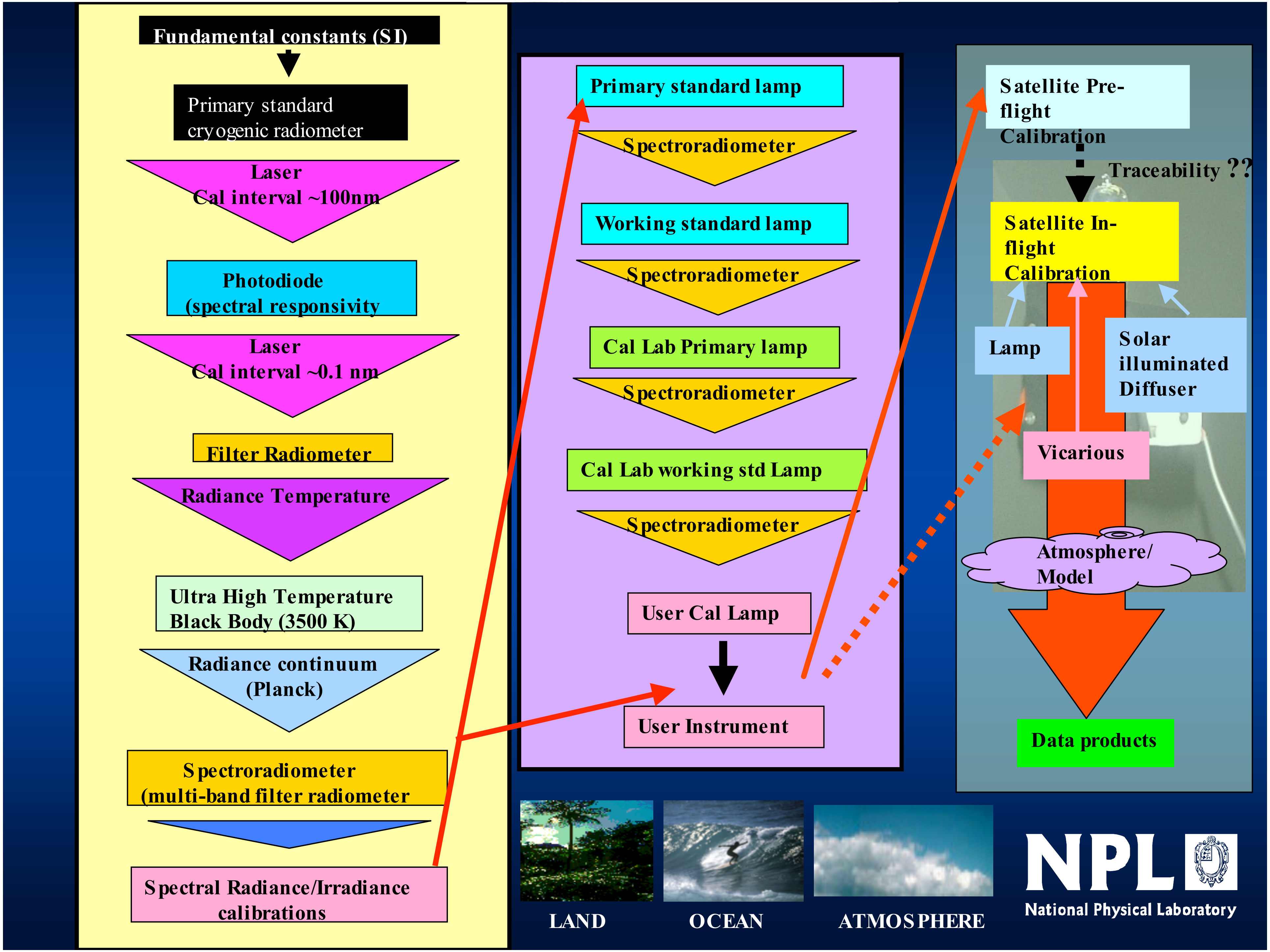

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Photodiode
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Cal interval ~0.1 nm
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Ultra High Temperature Black Body (3500 K)
Radiance continuum (Planck)
Spectroradiometer
(multi-band filter radiometer
Spectral Radiance/Irradiance calibrations
Primary standard lamp
Spectroradiometer
Working standard lamp
Spectroradiometer
Cal Lab Primary lamp
Spectroradiometer
Cal Lab working std Lamp
Spectroradiometer
User Cal Lamp
User Instrument
Satellite Pre-flight Calibration
Traceability ??
Satellite In-flight Calibration
Lamp
Solar illuminated Diffuser
Vicarious
Atmosphere/ Model
Data products
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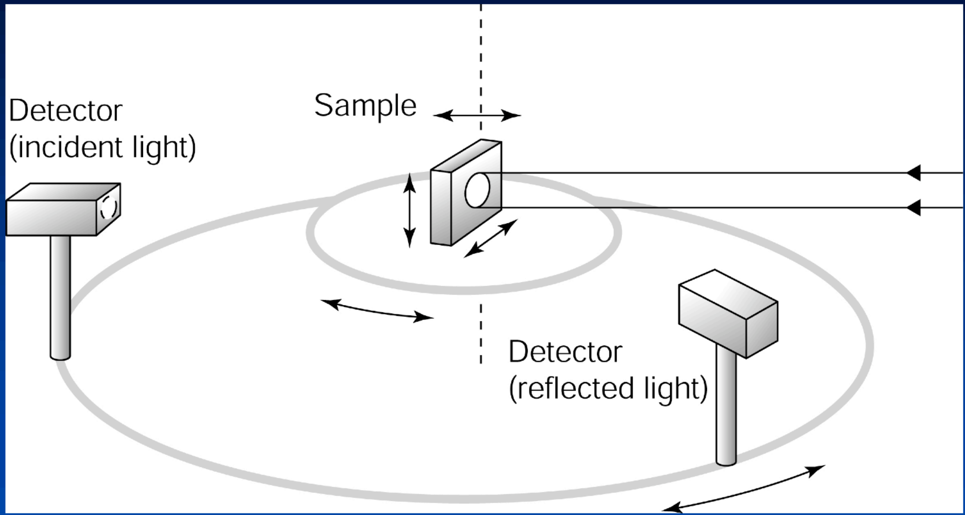
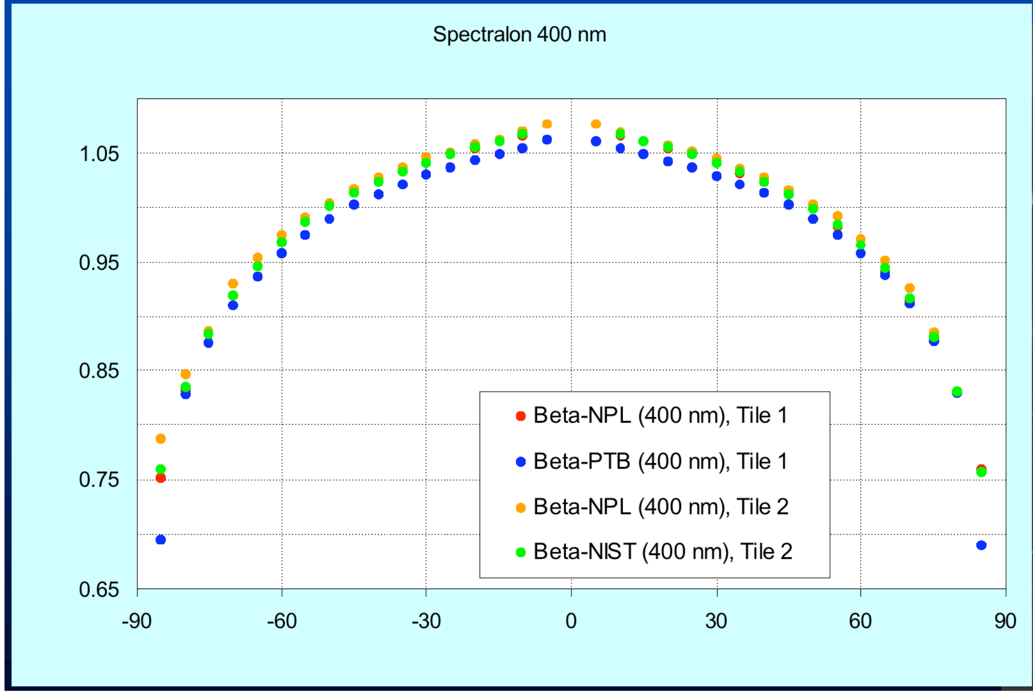
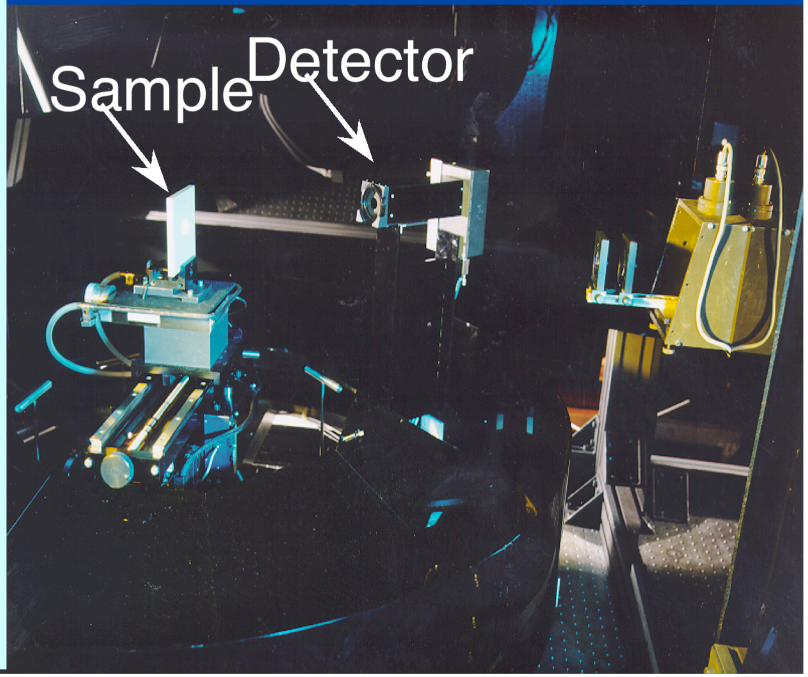
Diffuse reflectance (BRDF)



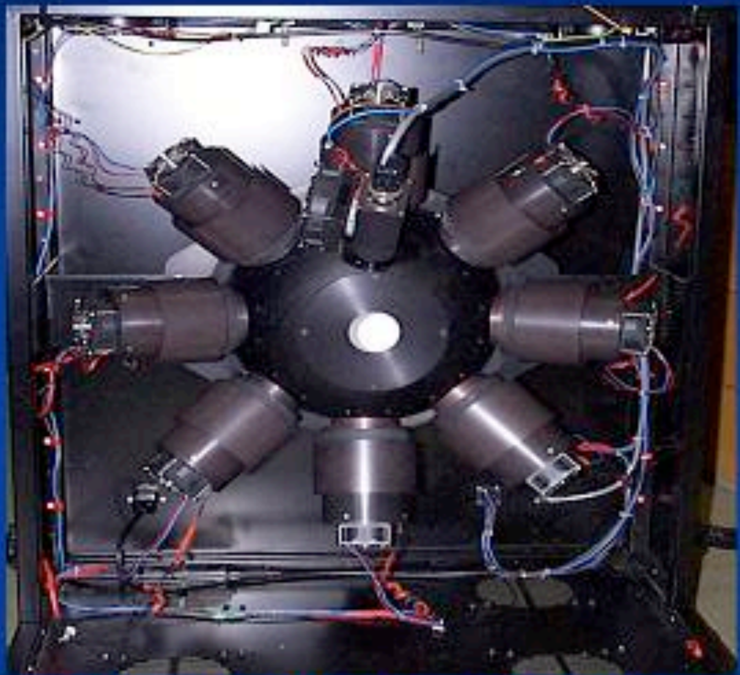
The NPL diffuse reflectance scale is derived goniometrically for the spectral region 300 to 2500 nm

Uncertainty of <0.2 % in the visible and shown equivalence with NIST





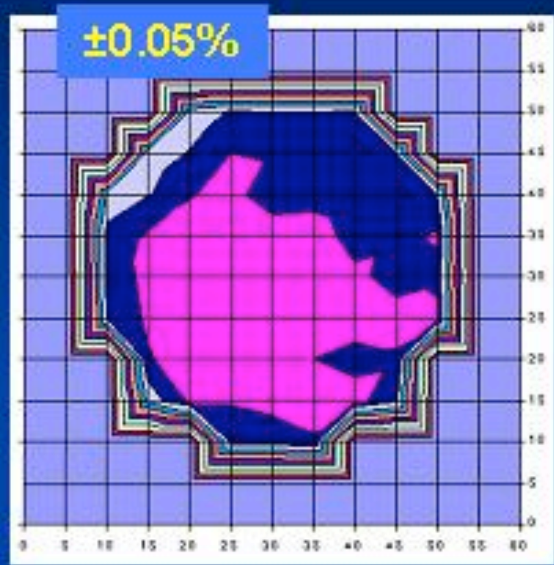
Radiance transfer standards for instrument calibration on the ground: satellite, aircraft and "field"



Transfer Standard Absolute Radiance Source (TSARS)

High spatial uniformity and use of filter radiometer stabilisation allow accuracies approaching 0.1%

50 mm Exit port



Traceability for in-flight / in-situ / vicarious calibration

Spectral Radiance

- lamp illuminated spheres

- Filter radiometers (spectroradiometers)

- Irradiance source + diffuser

Lamp + spectralon or ….

Sun + spectralon or ….

Sun + Moon

“on-board”

“ground truth” – via a reference site

e.g Desert like

Utilising Aircraft / in-situ teams/instruments

To bio/geophysical quantities (refelectances)

Spectral Reflectance

- in-situ absolute ratio (using radiometers)

- Ratio to “standard” reflector/diffuser

CAUTION

High reflectance values of the diffuser can lead to errors due to inter-reflections and stray light

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Reference test-sites: e.g. GIANTS (Global Integrated Automated Network of Test Sites) (P. Teillet of CCRS)

- **Identify a few (5 ?) Spatially Uniform, temporally stable (radiometrically) "large" sites at various latitudes**

  e.g. Railroad valley, Libyan desert, La Crau, Dome C …

  Longer-term add vegetated sites

- **Characterise site (in-situ team, aircraft, satellite?) multi-angle & time**

  - ideally instrument with automated monitoring equipment

- **Archive and provide web access to test-site radiometric data and its associated uncertainties (ideally with high spectral and spatial resolution to allow easier reformatting to spectral bands and pixels of other sensors) inc environmental conditions.**

  CEOS WGCV / WGISS test facility / ESA NILU Data centre

- **Encourage all EO satellite sensors to view and compare its readings with those of ground site and publish results**

  - Understand biases,

  - Allow lower cost sensors

  - Improve user confidence

  - Concentrate efforts on improving accuracy of test site data and atmospheric transmission

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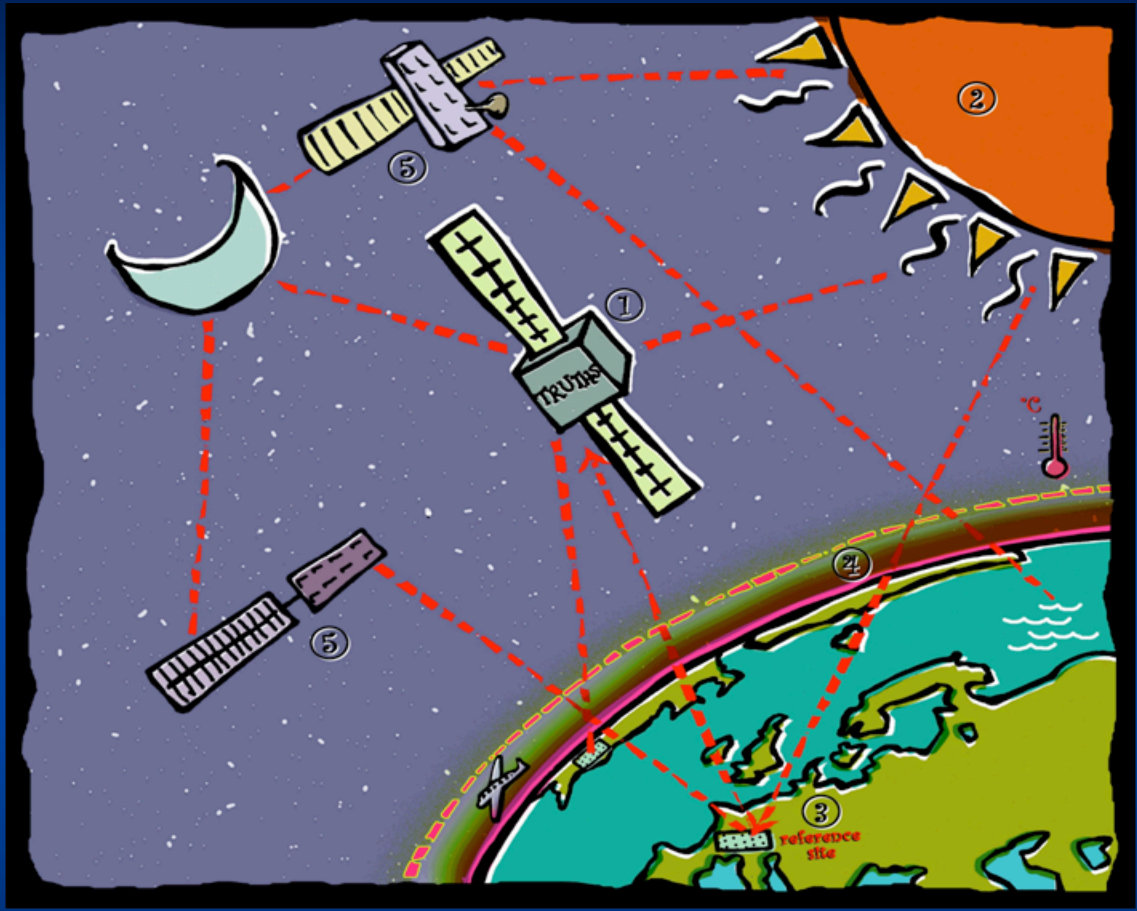
TRUTHS: Traceable Radiometry Underpinning Terrestrial- and Helio- Studies

Satellite based mission to make SI traceable measurements of solar radiation incident on and reflected from the Earth and to transfer its unprecedented calibration accuracy to other satellite based EO instruments through the calibration of reference targets such as the Sun, Moon and Earth desserts.



- Hyper-spectral (380 to 2500 nm)

~ 25 m spatial resolution

- Spectral radiance uncertainty < 0.5 % (all bands)

(use of novel in-flight calibration system)

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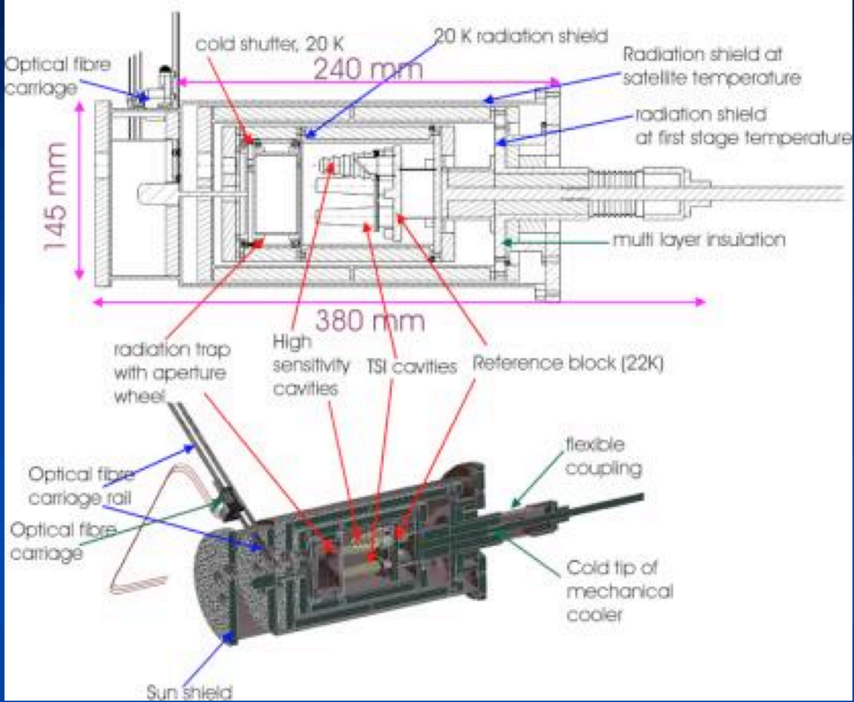
Cryogenic Solar Absolute Radiometer



CSAR cooling from Astrium 20 K cooler

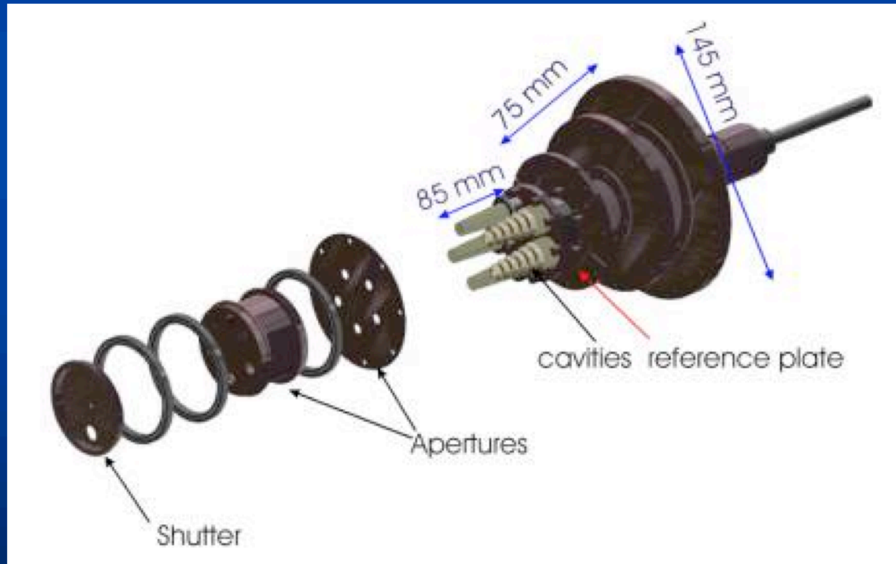
3 cavities for TSI – t ~ 15 s

- operating range 10 mW to 100 nW

2 cavities for spectral response – t ~ 0.5 s

- operating range 0.1 mW to 10 nW

3 off 5 mm precision apertures + 2 off 0.5 mm



Use of electrical substitution makes traceability to SI through convenient electrical units – optical interface via black cavity absorber, coated with 'NPL super-black' Solar weighted absorbtance >0.99998.

Only source of uncontrolled optical degradation is cavity absorbtance

can degrade by factor of 100 and still achieve < 0.2 % accuracy to SI units

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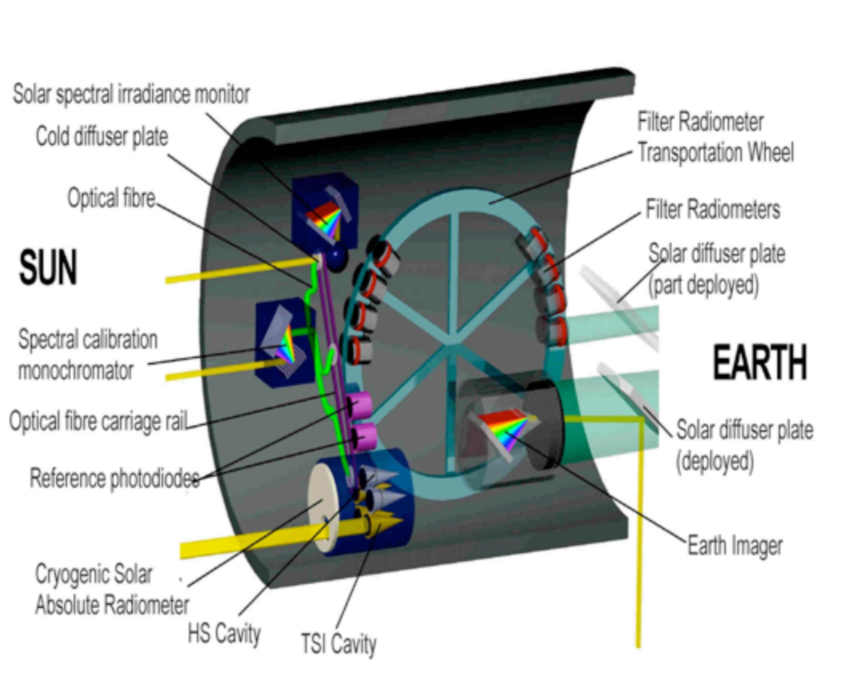
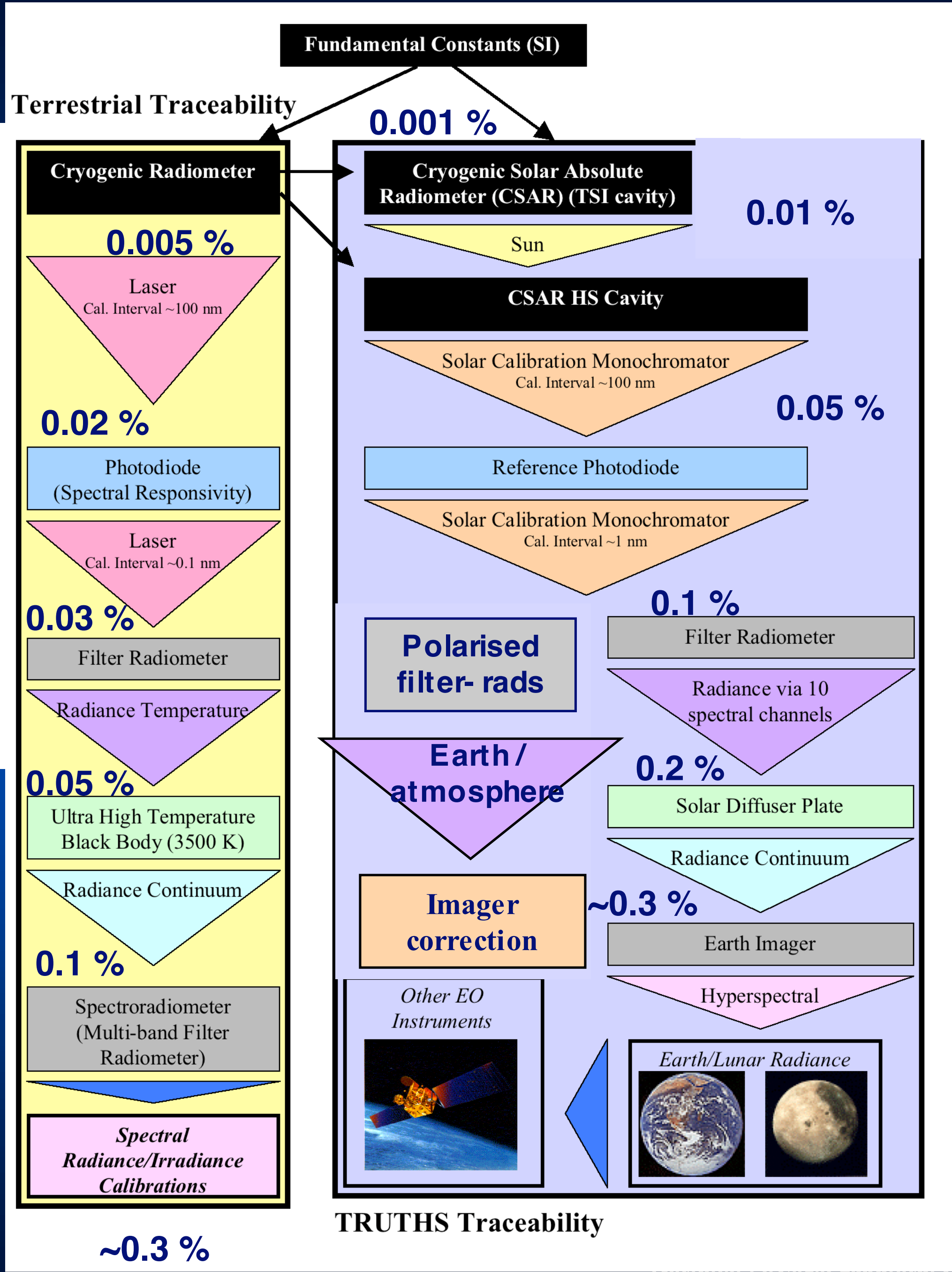
TRUTHS Traceability

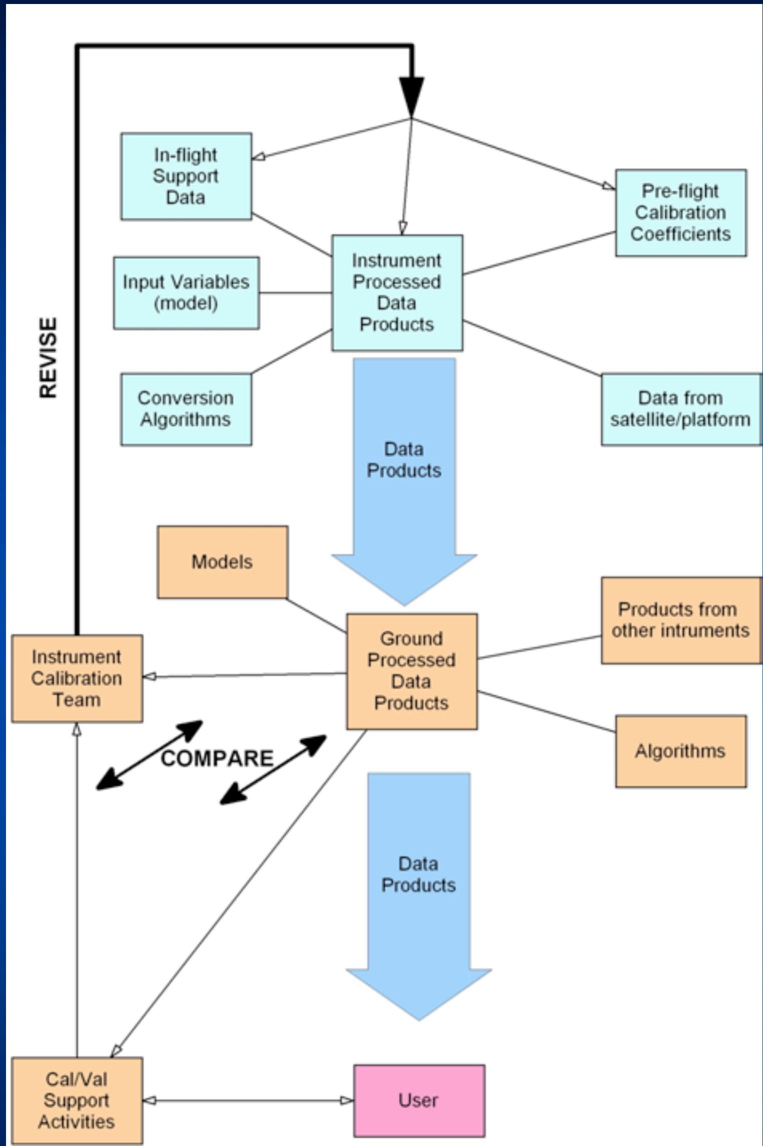




Calibration drift, spectral and gain, removed by performing calibrations in space directly against a primary standard using terrestrial methodologies adapted for space.

Validated data products require all processing steps and data to be QA – Accredited?

- Pre-flight
  - User specification
  - Instrument build compliance
  - Calibration?
- Post-launch
  - In-flight checks
  - Ground "Truth" comparison
  - Inter-sensor cross calibration
- Processed data released
  - "validated"
  - Uncertainty statement?



Rare for all these activities to have been independently reviewed and/or audited

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Global Monitoring Environment and Security (GMES)
Joint initiative of ESA and EU

Aim: to establish "operational services" for Earth Observation data to meet needs of key stakeholders , public services, private industry, academia and the citizen with a view to financial self-sufficiency.

Success requires:

- Combination of data from many sources, (satellites, in-situ, aircraft)
- Efficient production of cost effective, reliable, data products / maps
- Data must provide the evidence to allow decisions to be taken with confidence.
- Innovation in measurement and analysis

Reliability: Implies Quality Assurance and statements of confidence associated with data (not only for end users but also "operational service" providers

Users generally assume QA

Robust evidence
requires
robust QA

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Infrastructure for innovation in measurement, validation and QA of EO data

- Transfer standards
- Comparisons
- Innovation on techniques
- Measurement & test protocols
- International link
- Independence

Modelling &
Data processing

Calibration

QA

Traceability

Audit

Validation

Academia

Advice

Public sector

Private Industry

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Summary

- **Primary scales, transfer standards and techniques now allow high accuracy to be achieved for both pre-flight and vicarious calibration (particularly for radiance)**
- **All aspects/steps of producing EO data products needs validation and traceability (instrument calibration and algorithms/models)**
- **Consistent presentation and breakdown of uncertainty budgets**
- **Flexibility to allow innovation**
- **Regular comparisons to evaluate biases**
- **Establish well characterised ground targets as “reference standards”**
- **Develop improved “in-flight” calibration methods e.g TRUTHS**
  (Fox et al: Proc. SPIE 4881, p395 2003 & Adv. Space Res 32, p2253 2003)

For Earth Observation to provide the evidence to support policy

requires the industry and its data to be as robust as traditional industries

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