The Metrological Foundation for System Vicarious Adjustment of Satellite Ocean Colour Data (part 1)

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esa

fiducial reference measurements for satellite ocean colour

CEOS

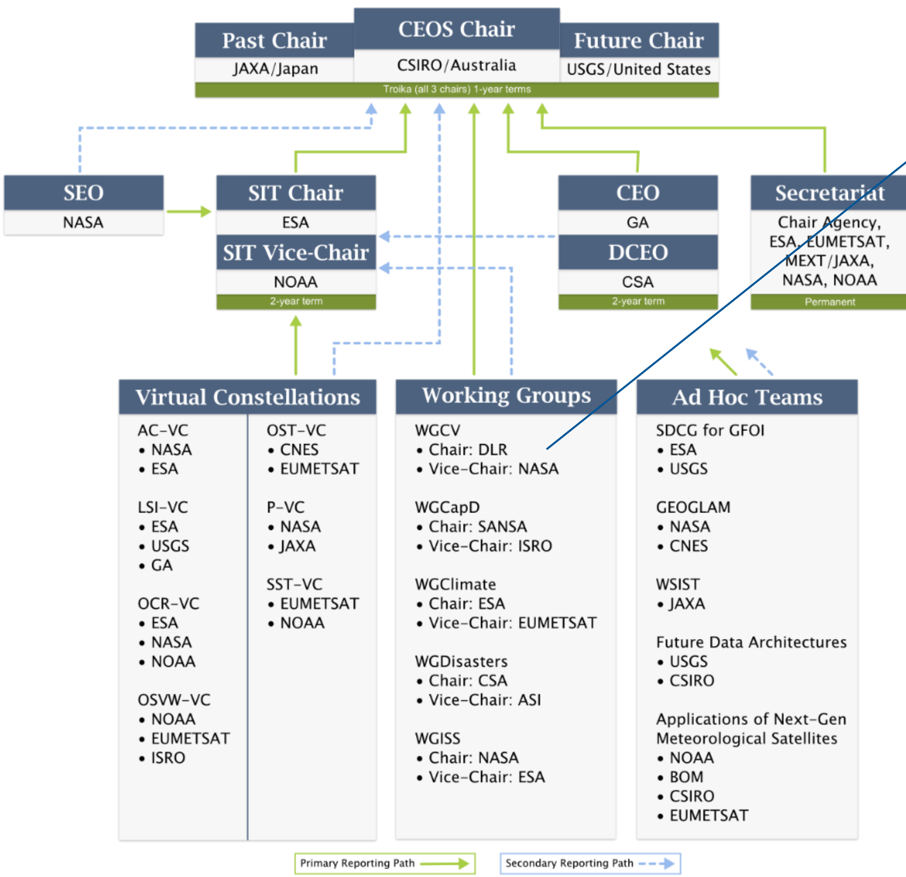
International EO community

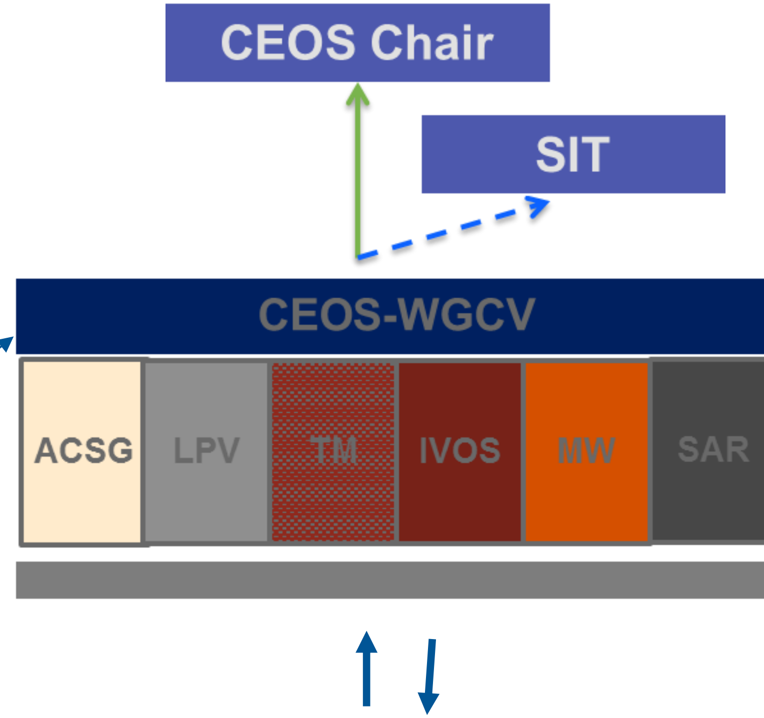
GROUP ON EARTH OBSERVATIONS

103 member countries + 90 organisations

CEOS Committee on Earth Observation Satellites

31 member Agencies + 28 organisations





GSICS Global Space-based Inter-Calibration System

Operational (Meteorological space agencies)

Magna Carta - 1215

"There is to be one measure of wine and ale and corn within the realm, namely the London quarter, and one breadth of cloth, and it is to be the same with weights."

'measurements' (as opposed to observations) of the Earth if they are to be trusted, meaningful and

should be treated in the sa

to international agreed sta

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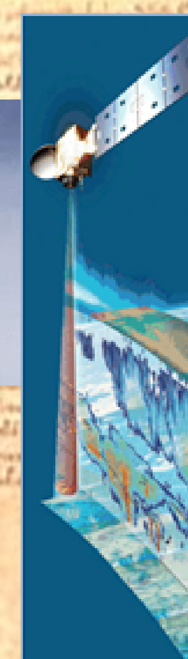
supporting evide



One of the oldest documents formalising measurement in the UK

For EO and Climate ECVs needs some translation & adaptation of standards and methods:

The Metre convention (système International d' unités (SI)

BIPM, Sèvres, Paris

- Created 1875
- Currently 58 member states, 41 associates
- Mutual Recognition Arrangement (MRA)
  - Created 1999 to ensure equivalence of measurements between countries
  - Includes: WMO, IRMM, IAEA & ESA

Governance

Conférence Général des Poids et Mesures (CGPM) 4 yrly

2018 Change definition of Kg, K, Mol, A to fixed constants

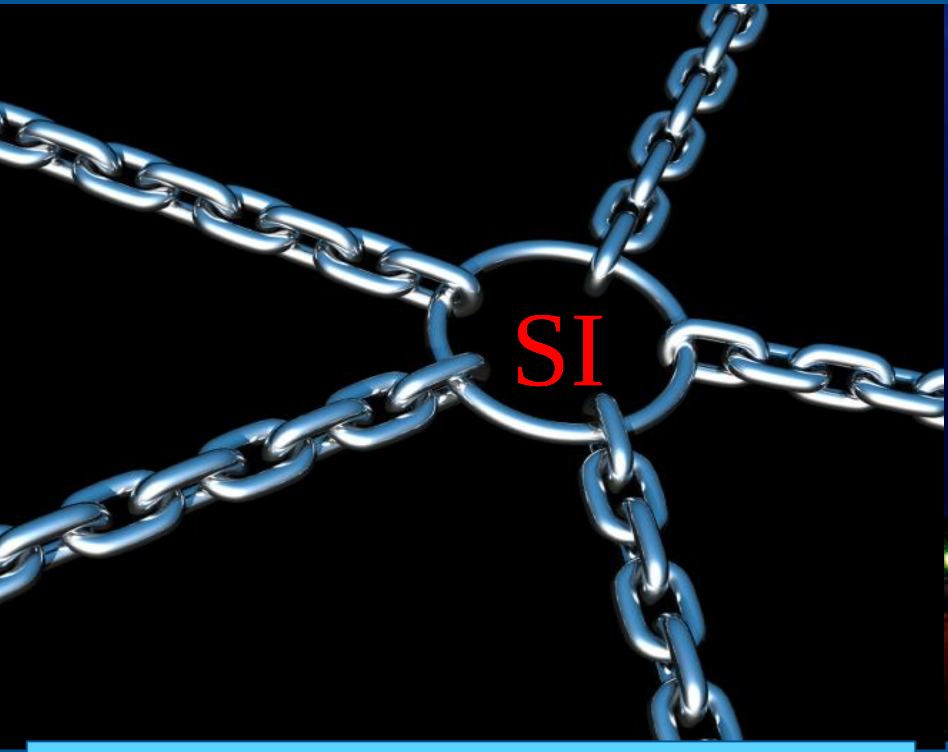
Comité International Poids et Mesures (CIPM)

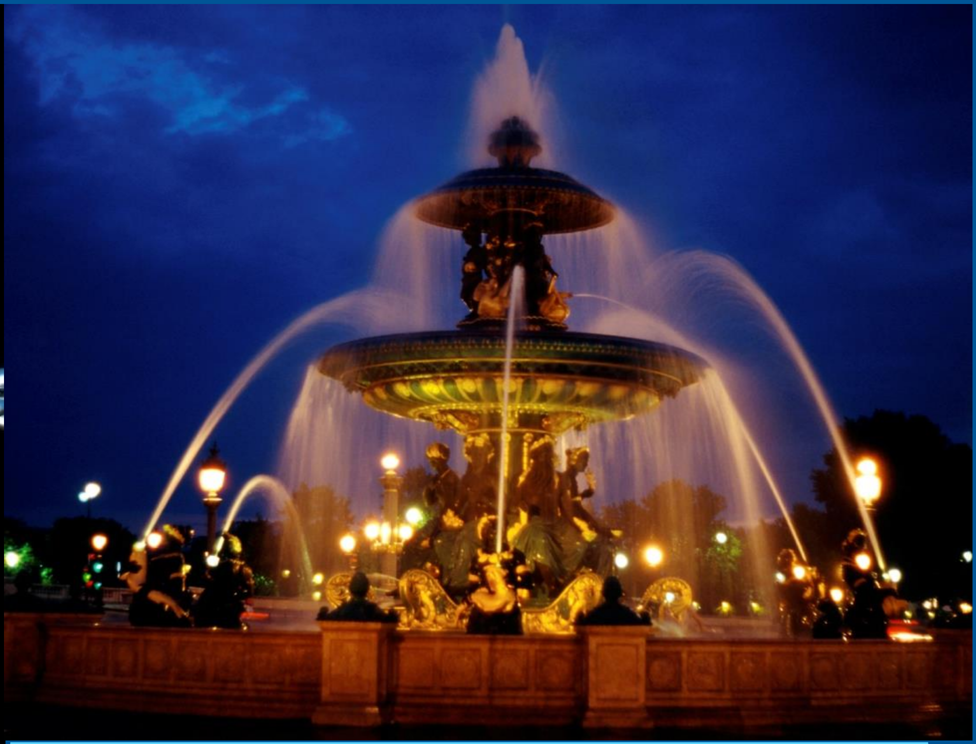
Consultative committees (for each unit) (technical from NMIs)

propose definitions, decide on and organise comparisons etc

(CCPR 'Photometry and Radiometry') (optical measurements)

Metrology





Traceability

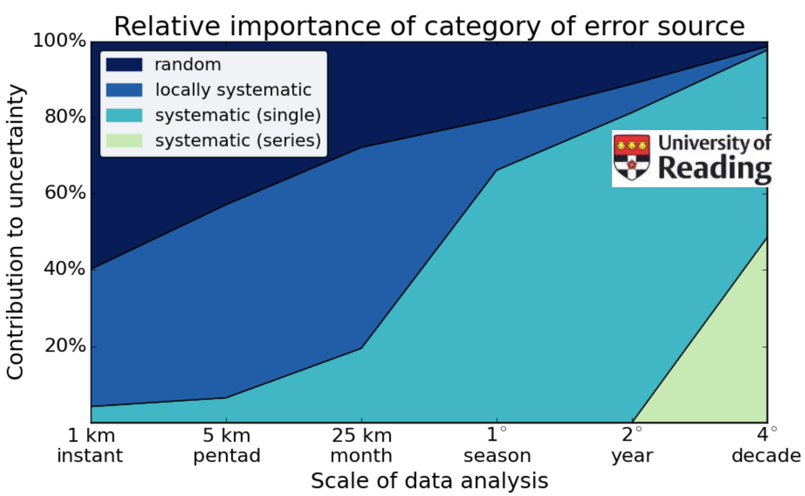
Uncertainty Propagation

Why SI Traceability?

Unequivocally linking an ‘**observation**’ to an invariant constant of nature (international system of units) with a robust estimate of **uncertainty** ensures the ‘**measurement**’ can be: trusted, coherent and comparable with others, have longevity ‘improves with age’

NEEDS to be evidenced at point of use - i.e. in space

Some applications MAY not need radiometric SI Traceability or high accuracy – reliant on data from a single mission/image where SNR and relative pixel to pixel variances are enough (still need Uc/error corrections stray light, MTF ….)



Merchant (SST example Fiduceo)

- Single mission measurements over time,

- Mission to mission interoperability

- Multi-decadal climate

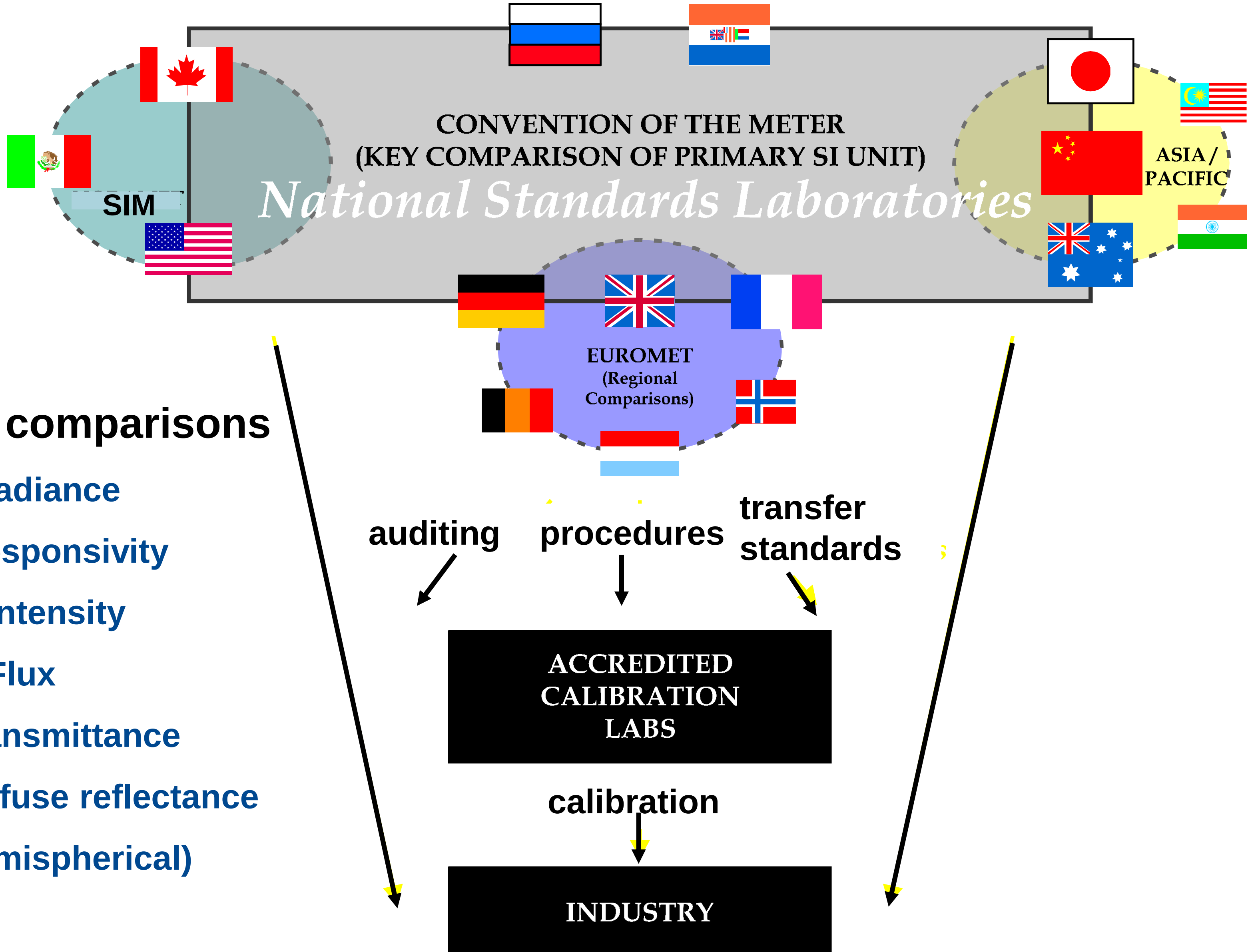
- Litigation/treaties/large investments…

In the absence of an SI traceable sensor in space (of sufficient accuracy) an ‘unequivocal reference data set’ that can anchor all sensors is necessary to enable an Integrated EO System of climate quality

Equivalence in International metrology

Cannot compare everything, representative sampling of types of method with quality system and ‘peer review’ / formal accreditation

National Physical Laboratory



CCPR Key comparisons

- Spectral Irradiance
- Spectral Responsivity
- Luminous intensity
- Luminous Flux
- Spectral transmittance
- Spectral diffuse reflectance

  (total hemispherical)


Bureau International des Poids et Mesures

Home | Key and supplementary comparisons | Calibration and Measurement Capabilities - CMCs

KCDB home — Version française

The BIPM key comparison database

in support to the Mutual Recognition Arrangement of the CIPM (CIPM MRA) of national measurement standards and of calibration and measurement certificates issued by national metrology institutes

What's new ?
- Length - SIM
  10 February 2017
- Key Comparison - CCQM-K115
  9 February 2017
- All news

Related links
- KCDB Statistics
- KCDB FAQs
- KCDB Reports
- CIPM MRA
- JCRB
- Find my NMI
- Metrologia

Contact us
- BIPM.KCDB@bipm.org

Participants in the CIPM MRA (Appendix A)

List of national metrology institutes and designated insitutes that are participant in the Arrangement.

access to the list

Key and supplementary comparisons (Appendix B)

Information on CIPM (Comité International des Poids et Mesures) and RMO (Regional Metrology Organization) key and supplementary comparisons, together with results interpreted in terms of equivalence.

Search comparisons :

advanced search

Calibration and Measurement Capabilities – CMCs (Appendix C)

Quantities for which calibration and measurements certificates are recognized by institutes participating in the Arrangement.

Search CMCs :

advanced search

List of key comparisons (Appendix D)

List together with a short description of the key comparisons recorded.

access to the list

Top of the page

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http://kcdb.bipm.org/

Appendix B: results of comparisons

Appendix C: All measurement services

Mesures

Home | Key and supplementary comparisons | Calibration and Measurement Capabilities - CMCs

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Home > Comparisons Search

Key and supplementary comparisons

KCDB

What's new about comparisons ?

- Key Comparison - CCQM-K115
  9 February 2017
- Key Comparison - BIPM.QM-K1
  6 February 2017
- All news

Related links

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Choose your search engine to access comparisons information

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Search

Direct search by comparison identifier

Comparison identifier

Matches exactly No Yes

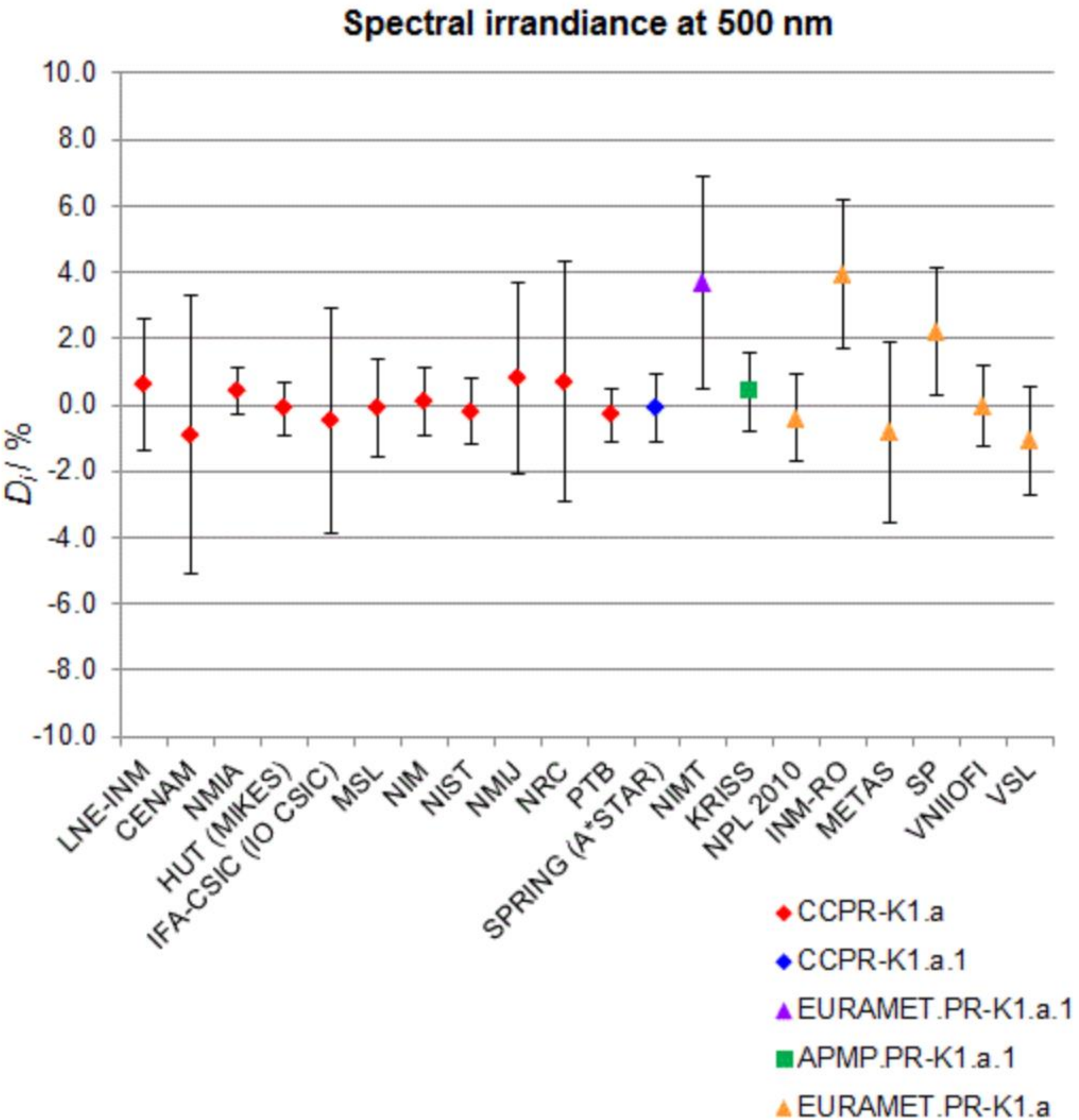
Search

Advanced search

Metrology Area	Photometry and Radiometry
Branch	Radiometry
Comparison type	Key
Organization	CIPM
Validity	Current
Country	All

Reset all | Search

KCDB provides evidence Appendix B and peer reviewed Uc on ‘related services’ in Appendix C



All countries linked through a reference (weighted world mean) with link labs from main comparison to the regions

Mean is good approximation to SI

Ideally need more than one independent realisation to test for unknown systematics for ‘TRUTH’ and long-term reliability

But comparisons can also test for biases and errors in process and in principle be used to ensure consistency

But for long term need to have a stable invariant reference (SI)

Key terminology: simplified

Metrological Traceability: *property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty* *(Vocabulary International Metrology (VIM ISO guide 99)*

- **Error –** difference from a "true" value or a "bias" can often be corrected for.
- **Uncertainty –** how well we believe we know the value
  - **"Type A" or random –** statistically determinable by experiment
  - **"Type B" –** any other means of estimating uncertainty (can be educated guess)
- **Quality Indicator (QI) –** an indicator of performance or quality of the result of a process/activity derived from an uncertainty estimate but can be a text descriptor / flag / numeric value. Can be binary
- **Traceability (metrological) –** documented evidence of uncertainty of the result of a process to a community agreed "reference standard" through comparison
- **Traceability (document link) –** Archived and accessible, complete documentary linkage of all steps in a process chain tied to a result
- **Standard (reference) –** "reference" against which performance can be determined

Reference standards

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Functional testing

- can be simple, not formally calibrated
- for components/sub-systems
- internal consistency
- specified by service provider

Performance testing (e.g. to a specn)

- needs some characterisation, ideally calibrated traceably
- Specified by provider, funder,
- for components sub-systems
- independent operation
- could be considered a calibration

International harmonisation/bias correction

- internationally / community agreed
- Well characterised (and non bias inducing)
- if assigned a value ideally SI traceable
- accessible, relatively few,
- test "systems"

REFERENCE (MEASUREMENT) STANDARD KEY PROPERTIES & EXAMPLES

- Must be characterised (and documented) for the property for which they are a reference
  - ◊ At level commensurate with application
  - ◊ Temporally stable over the period of use
  - ◊ If assigned a value must be SI traceable or community agreed
- Can take any form: data, artefact, gas, natural, man-made, methodology, ….
- Can be formally endorsed for "community" use
- Must be accompanied by procedure on use

Fiducial Reference Measurements (FRM) defining principles also

A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

- have documented evidence of SI traceability (e.g. via round-robin comparison of instruments) using metrology standards

- are independent from the satellite geophysical retrieval process *[noting the exception of L2 product vicarious adjustment that fundamentally depends on FRM ground based measurements],*

- An uncertainty budget for all FRM instruments and derived measurements is available and maintained

- Protocols and community-wide management practices (measurement, processing, archive, documents etc.) are defined, published openly and adhered to by FRM instrument deployments.

- are openly and freely available for independent scrutiny.

Radiometric traceability for EO sensor

SI

~0.01 %

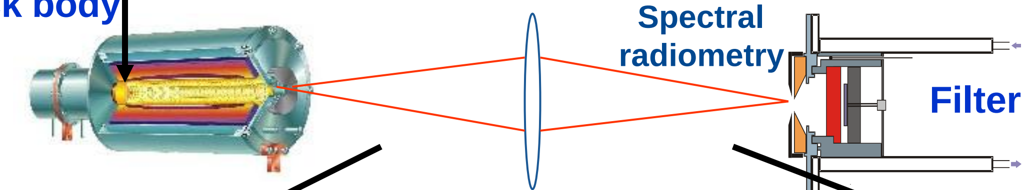
ITS-90

~0.1 %

$$L_\lambda = \frac{2hc^2}{\lambda^5 \cdot (e^{hc/\lambda kT} - 1)}$$

Planck's Law

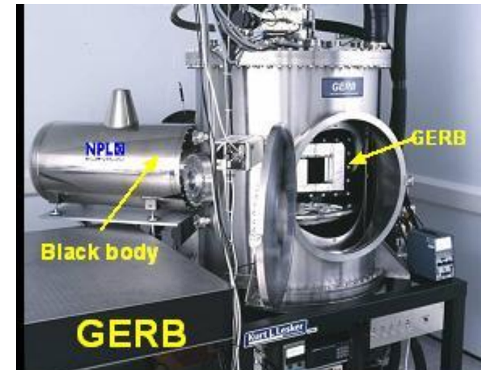
Black body

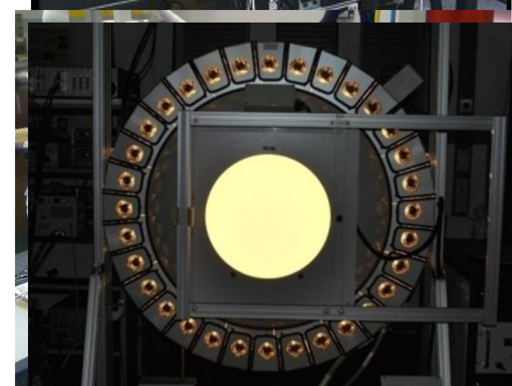


Spectral radiometry

~0.5 %

Filter radiometer



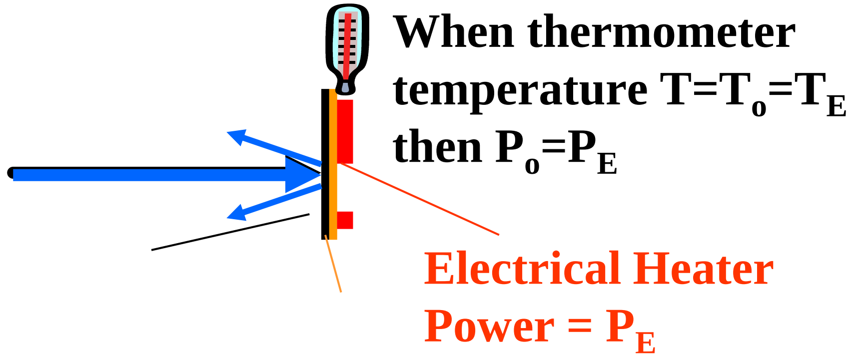


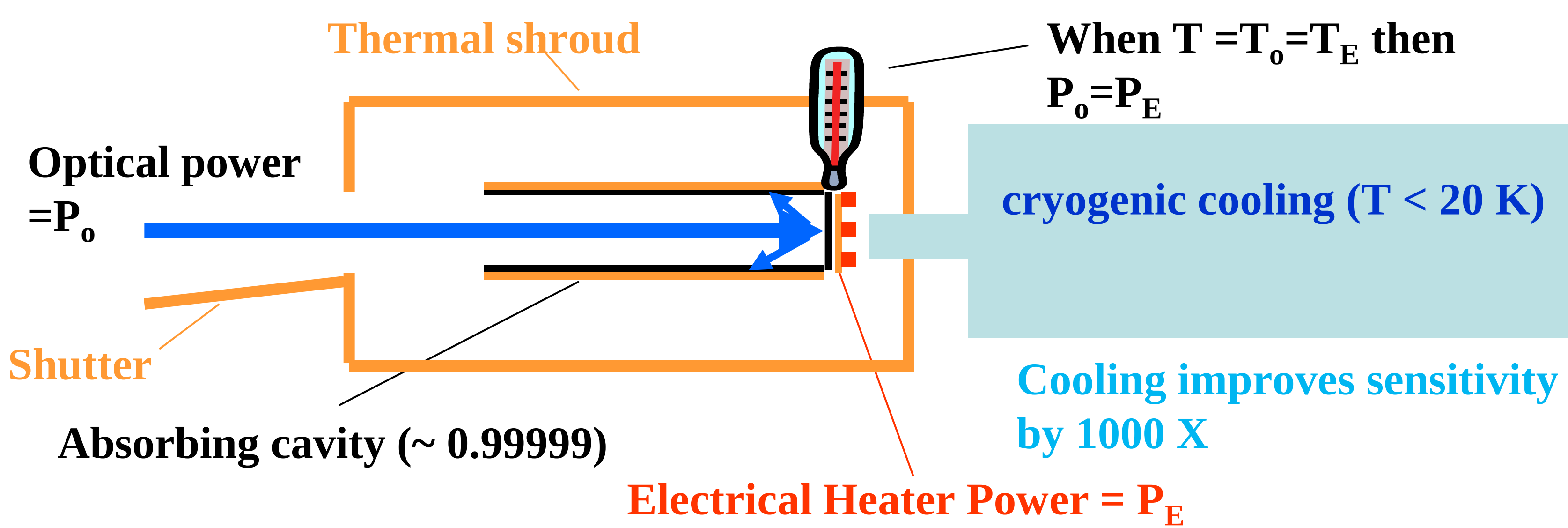
Spectral (IR)Radiances UV-TIR

Electrical Substitution Radiometry: A 100 yr old technology - SI primary standard of choice

Benefits of Cryogenic operation

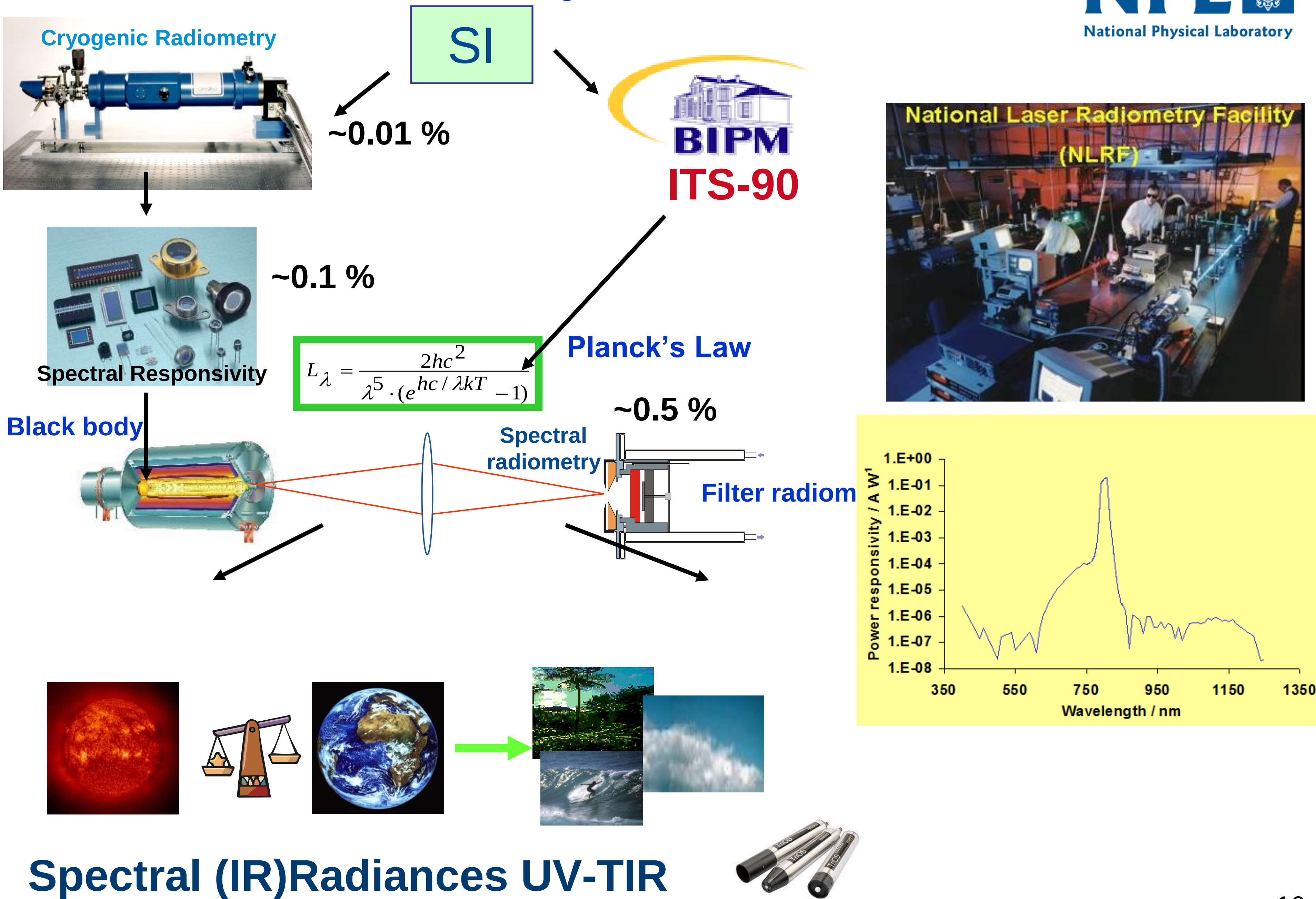
- Super-conducting leads
- High thermal diffusivity
  - Reduced non-equivalence
  - Large cavity – high absorptance
- Low radiative coupling
- Achievable Uncertainty ~ <0.002 %



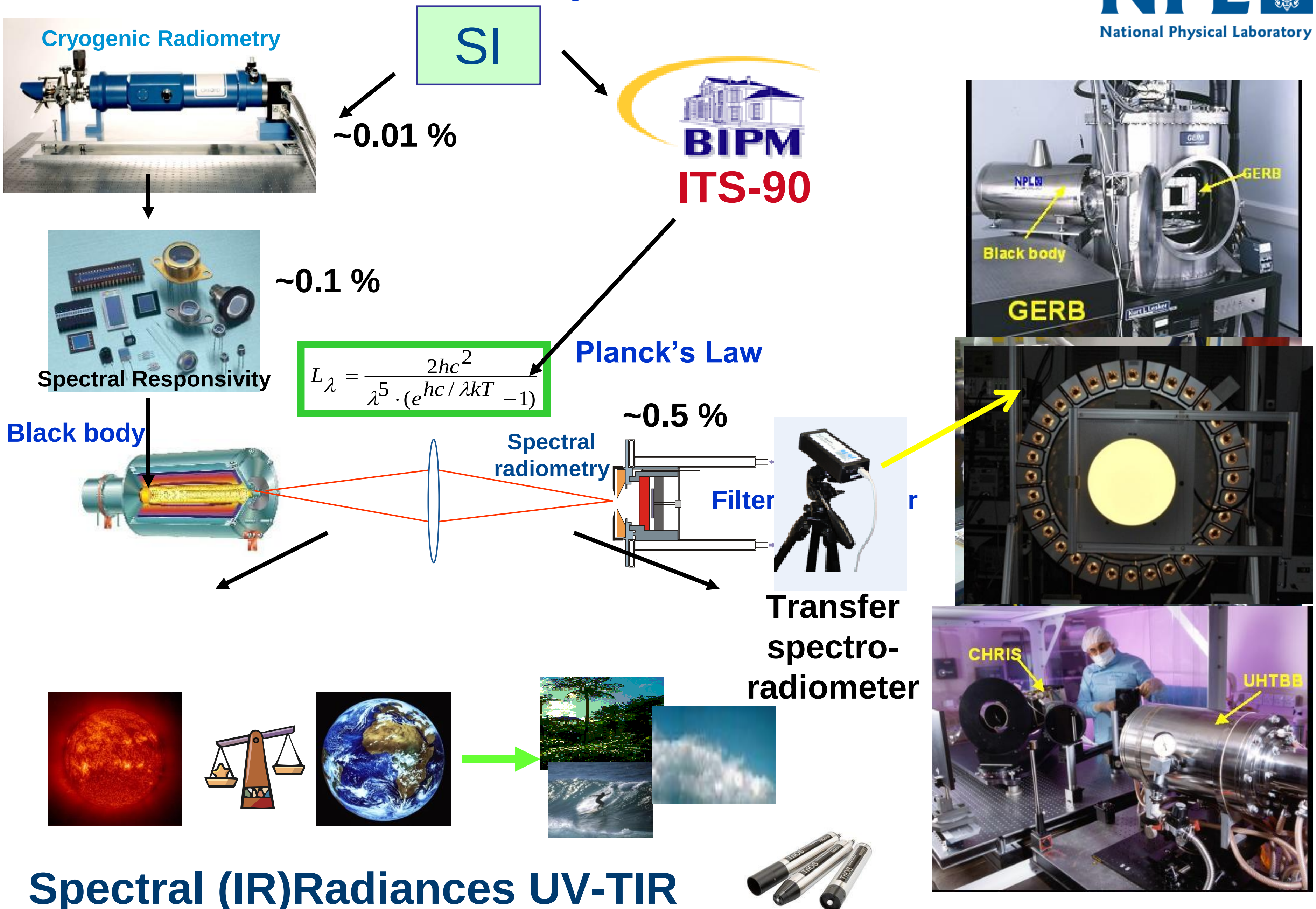


Principle of Cryogenic radiometry

Radiometric traceability for EO sensor



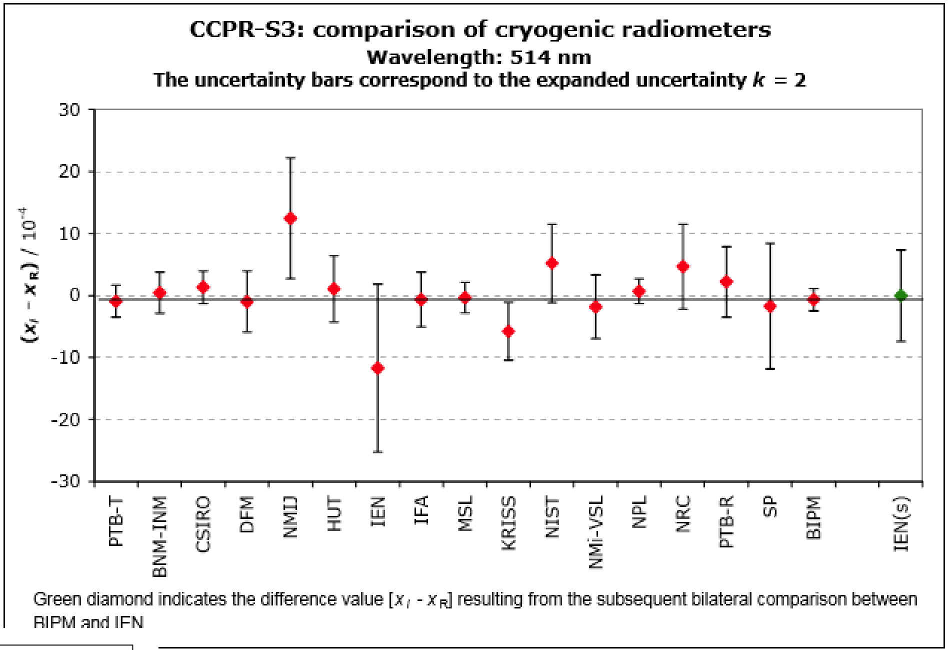
Radiometric traceability for EO sensor



Comparisons to evaluate equivalence and assess unknown systematic Uc for each step in chain

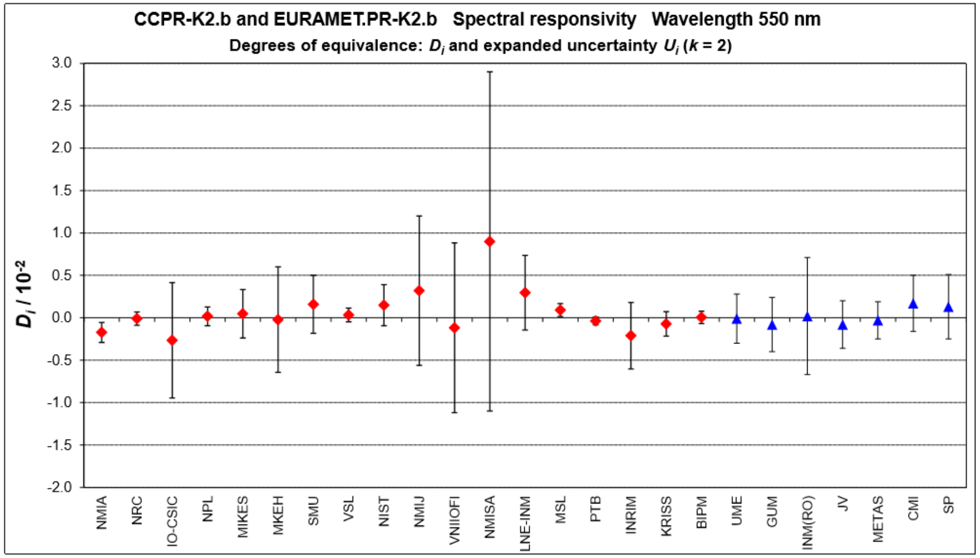
Primary standard: Cryogenic Radiometer

±0.1%



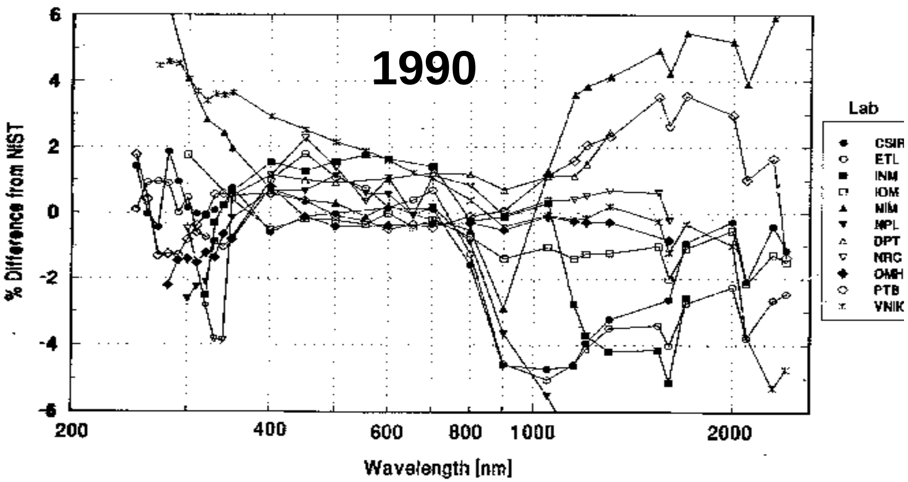
Derived scale of spectral responsivity

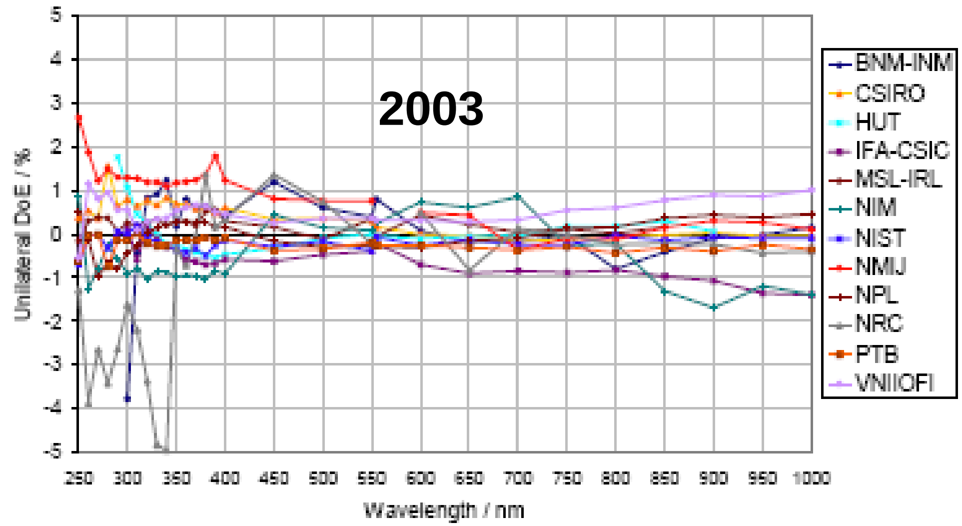
±0.5%



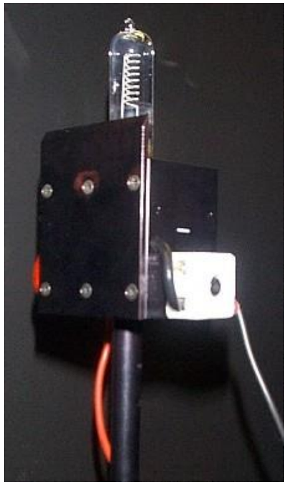
Red diamonds: participants in CCPR-K2.b   Blue triangles: participants in EURAMET.PR-K2.b only

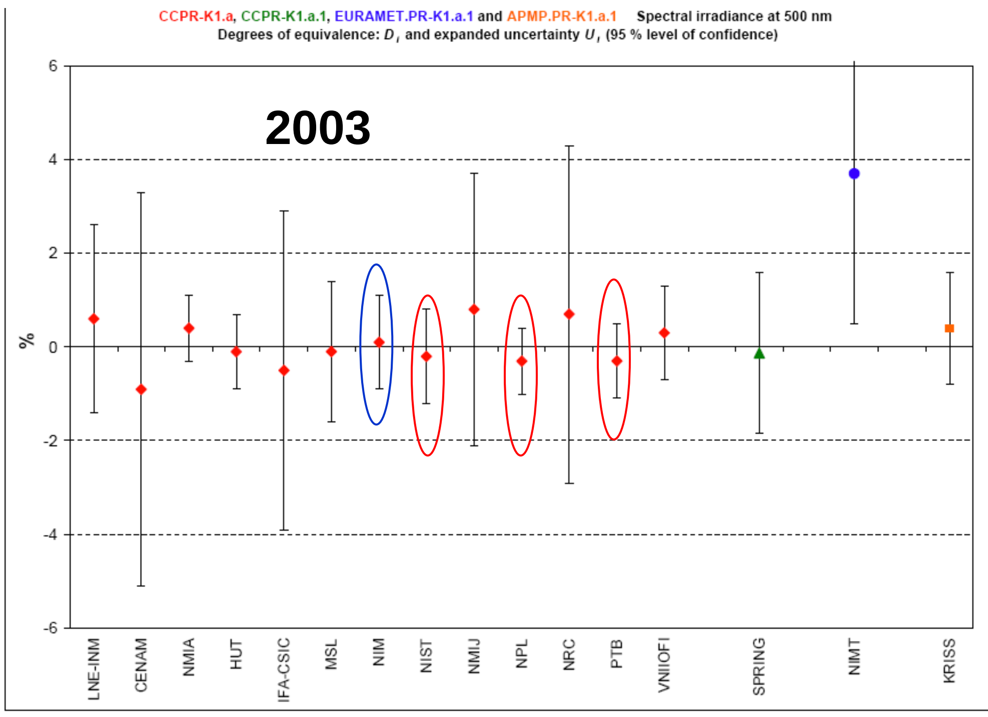
International equivalence



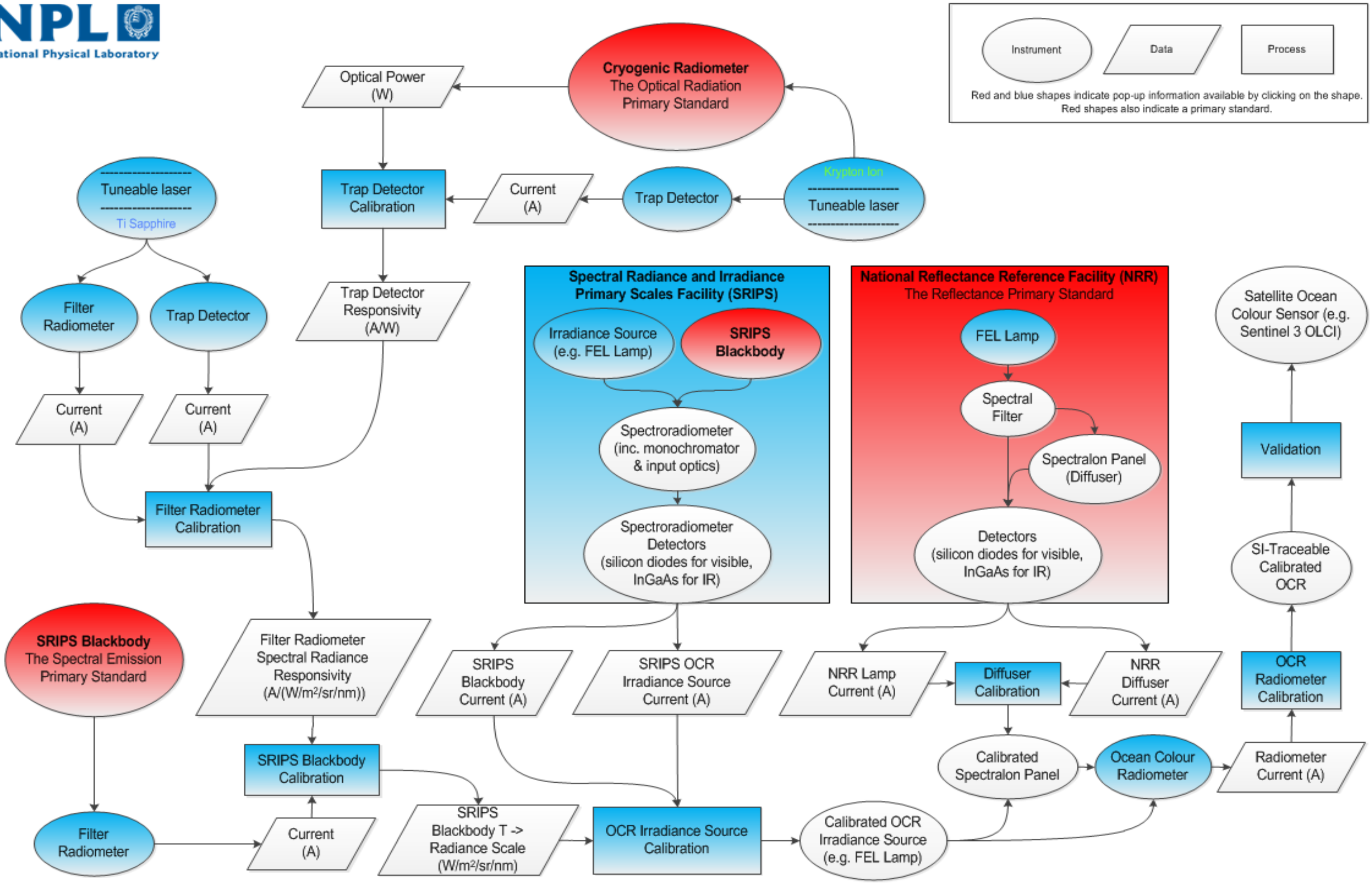


Spectral Irradiance Comparisons between NMIs



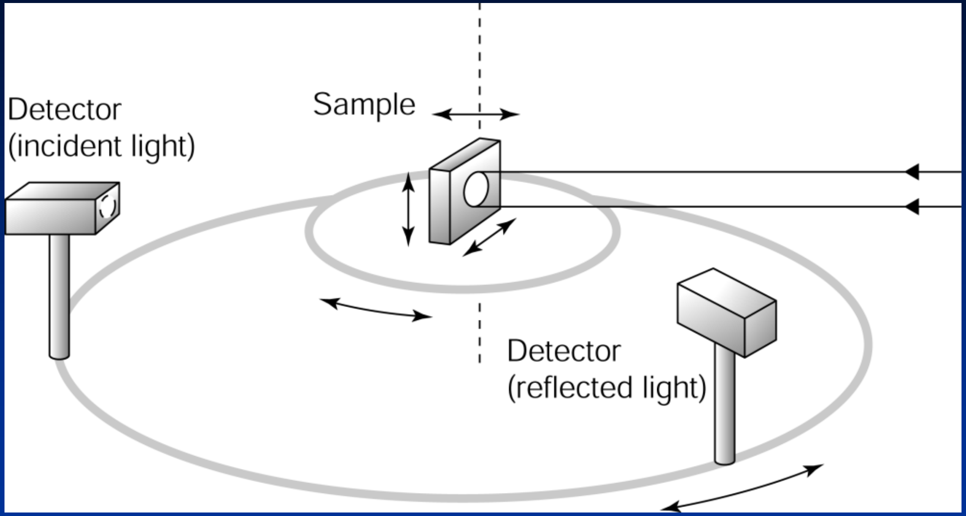


FRM4SOC: Traceability to SI – flow diagram



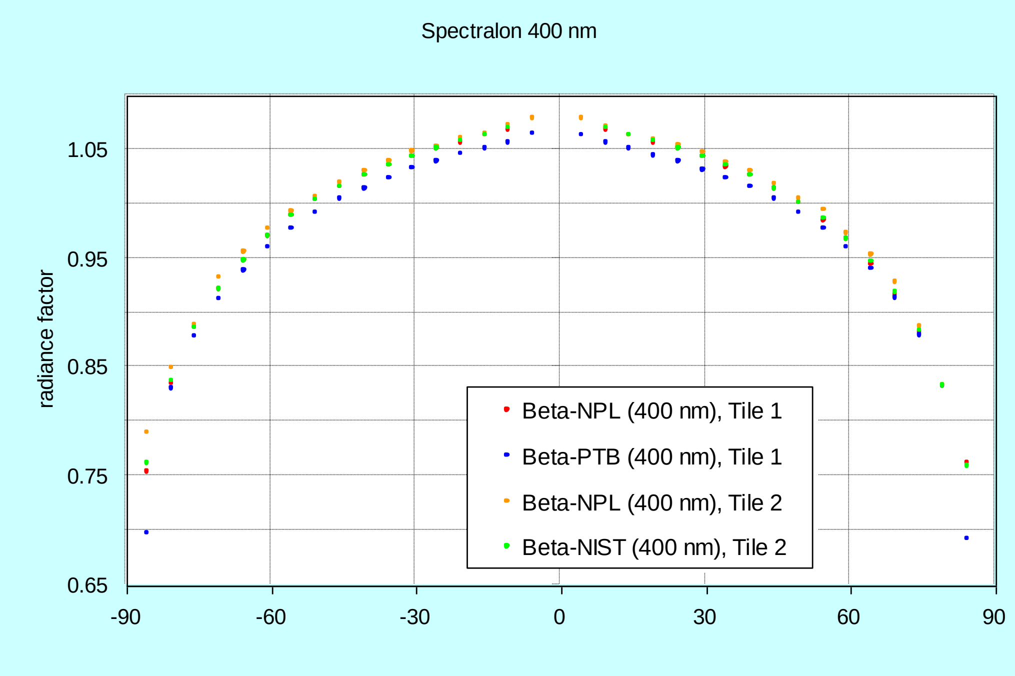
fiducial reference measurements for satellite ocean colour

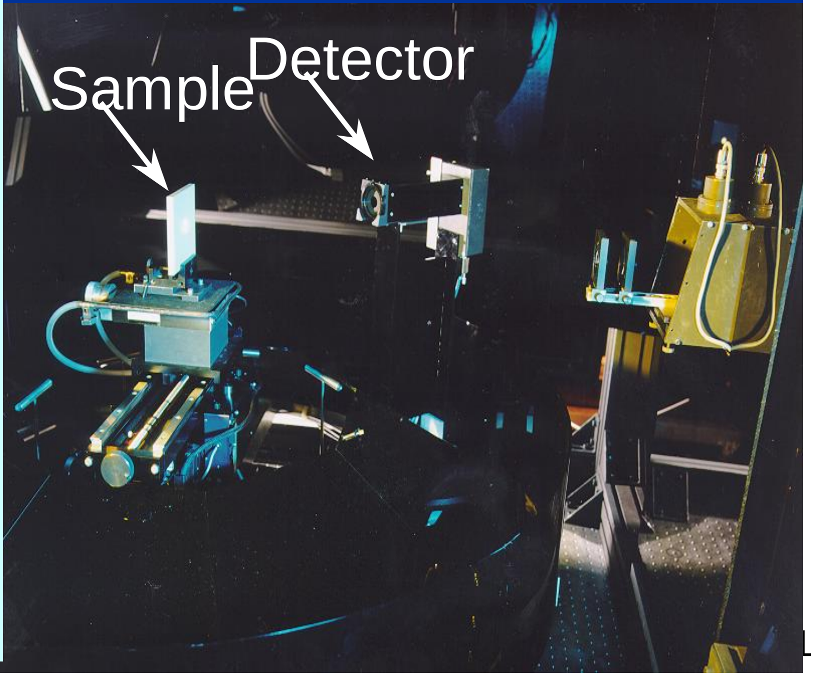
Diffuse reflectance (BRDF)



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





FRM 4 EO : Surface: (Ocean, Land, Ice) brightness Temp (FRM4STS)

fiducial reference temperature measurements

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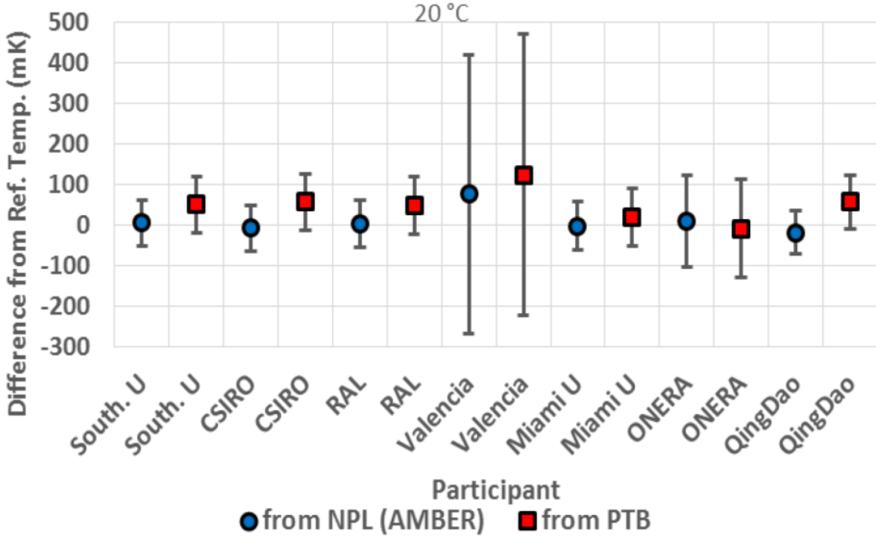
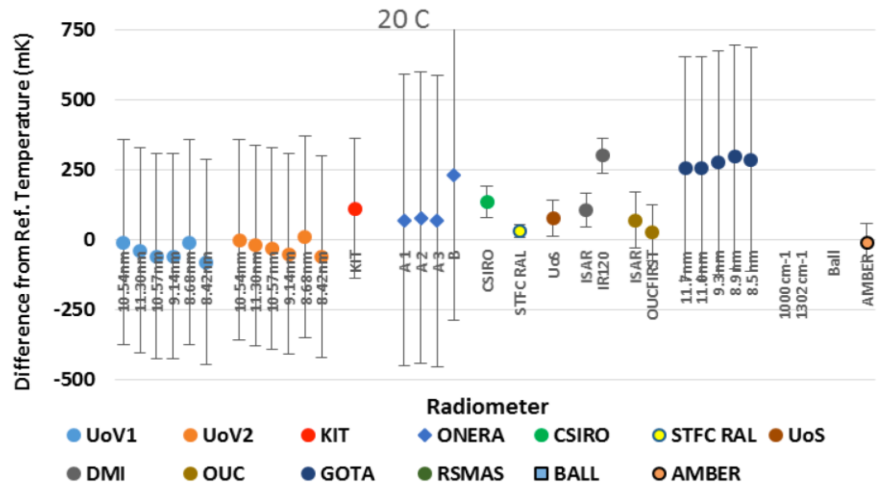
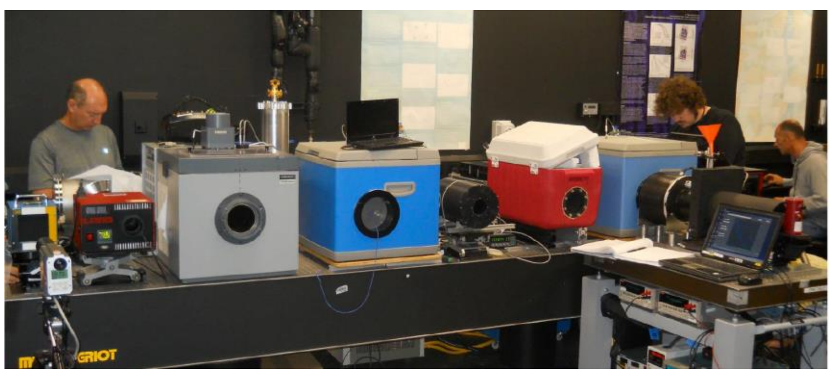
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 20 °C.



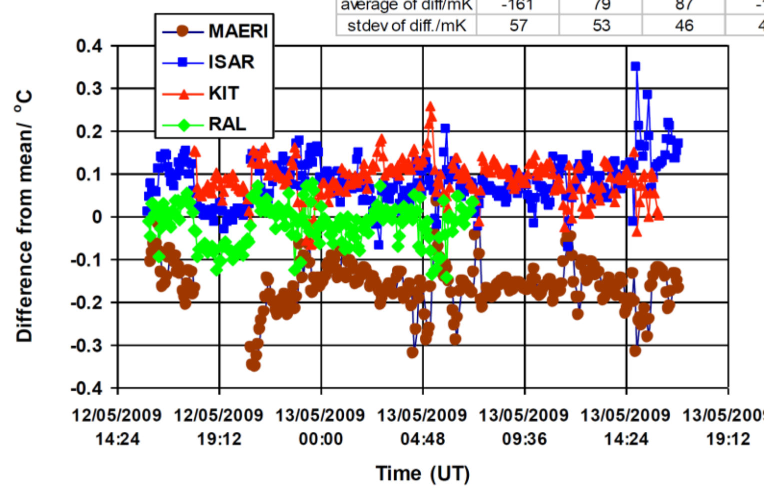
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 20°C.





Difference from mean, 2009 comparison

	MAERI	ISAR	KIT	RAL
average of diff/mK	-161	79	87	-19
stdev of diff./mK	57	53	46	48



esa CEOS

Solar Irradiance:
Replacing the WRR of WMO with SI

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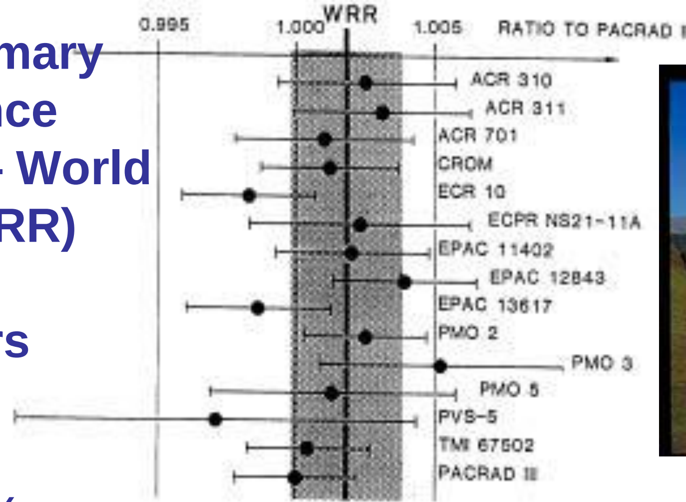
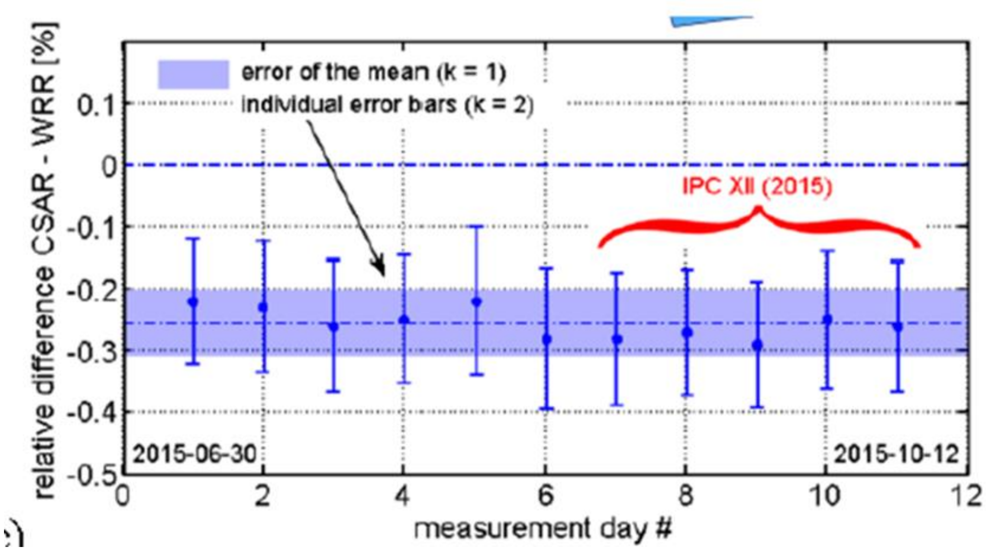
Since 1975 WMO has a primary (independent of SI) reference scale for solar irradiance – World Radiometric Reference (WRR)

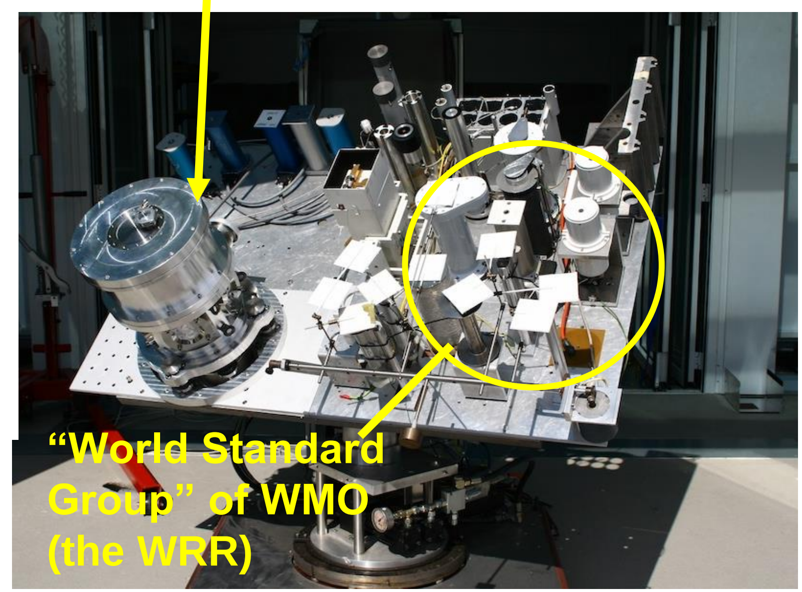
- **mean of ~7 radiometers**
- **aim to be "stable"**
- **5 yearly comparisons**
- **appears stable to <0.1%**





Bias of WRR to SI or ~ 0.27%

SI Primary standard Cryogenic radiometer, CSAR



GUM – Guide to Uncertainty in Measurement

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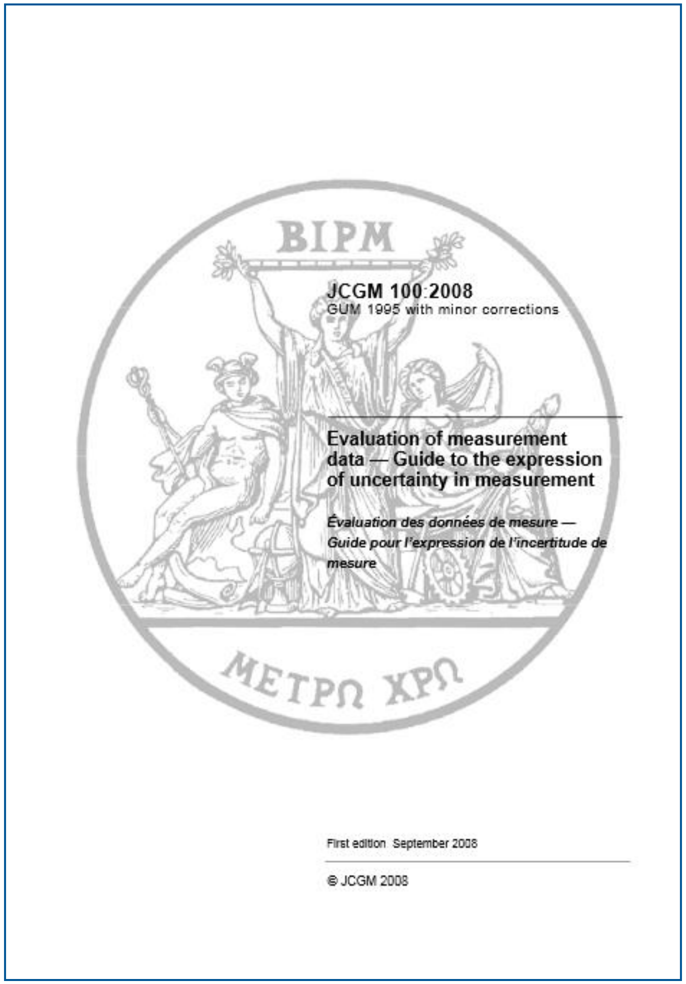

- The foremost authority and guide to the expression and calculation of uncertainty in measurement science
- Written by the JCGM and BIPM

http://www.bipm.org/en/publications/guides/gum.html

The Law of Propagation of Uncertainties

(GUM - BIPM et al., 1995 & JCGM 2008)

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$$u_c^2(y) = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)$$

Adding in quadrature

Sensitivity coefficient times uncertainty

Correlation term

$$u(x_i, x_j) = u(x_i) u(x_j) r(x_i, x_j)$$

Sensitivity coefficients times covariance

$$u(a,b) = u(b,a)$$

2 because symmetrical:

GUM uncertainty framework

National Physical Laboratory

X_1: $x_1, u(x_1), \nu_1$

X_2: $x_2, u(x_2), \nu_2$

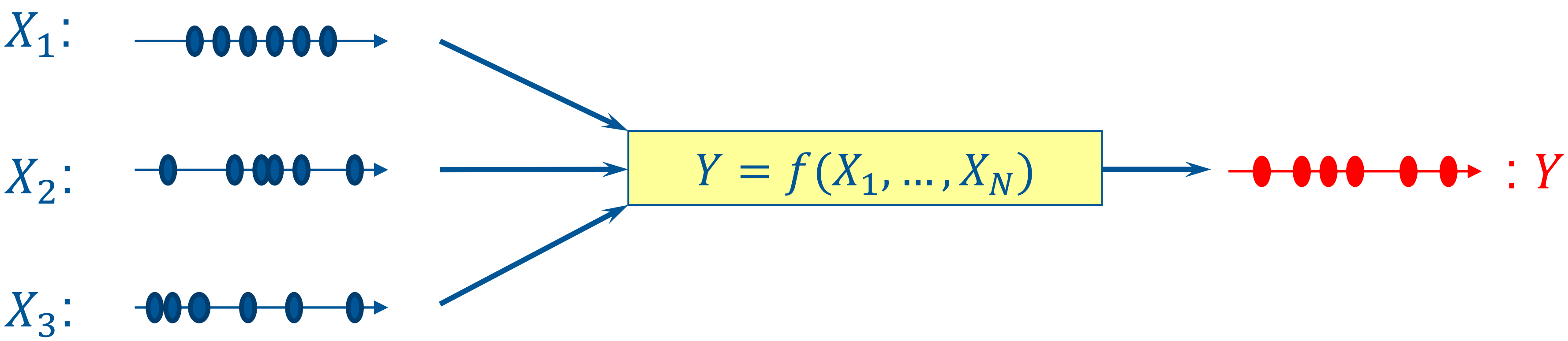
X_3: $x_3, u(x_3), \nu_3$

$$Y \approx c_1 X_1 + \cdots + c_N X_N$$

$y, u(y), \nu_{\text{eff}}$: Y

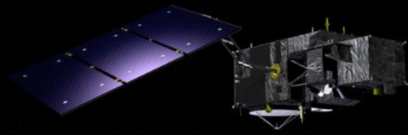
- Propagates summaries of the input distributions through a linear approximation to the measurement model
- Use the summary of Y so obtained to characterise Y by a particular distribution (Gaussian or *t*)

Monte Carlo method



- Propagates random draws from the input distributions through the measurement model
- Use the values of Y so obtained to evaluate summary of Y (approximations to the expectation, standard deviation and coverage intervals)

Metrological Traceability and Uncertainty in Ocean Colour System Vicarious Adjustment



u_{L1} ~ 2 - 5%

Calibration/adjustment gains → L1 radiance at satellite

Some questions:

- Does the u_{L2} after SVA meet the GCOS requirements? and is long term consistency / change monitoring the priority or 'absolute truth'?
- How many 'independent references' needed?

- What implications for u_{L2} are there the further you move away from the conditions at the SVA (water type, atmospheric conditions)?
- If measurements are FRM and Uc is determined should globally distributed SVA (weighted) not be more robust? Potentially different SVA gains for water types?

- Apart from in situ radiometry improvements for SVA, where else could we focus our efforts to improve u_{L2} further? Standardised atmospheric correction/improved Uc of Atmos corn?

- Where do we make surfaceradiometric measurements? In water?, above water?

ssing
ric correction)

rcent?

In situ

ce products at surface

u_{insitu}
Using current technology?

% accuracy & < 0.5%
stability for CDRs over decadal time scales
u_{L2} = too high without SVA