Establishing and Verifying the Traceability of Remote-Sensing Measurements to International Standards

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What is Traceability?

Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties (VIM, 6.10)

NIST Policy on Traceability?

- The provider of the result of a measurement or value of a standard is responsible for supporting its claim of traceability of that result or value.

- The user of the result of a measurement or value of a standard is responsible for assessing the validity of a claim of traceability.

- See http://ts.nist.gov/traceability for more information

Why Would You Want Traceability?

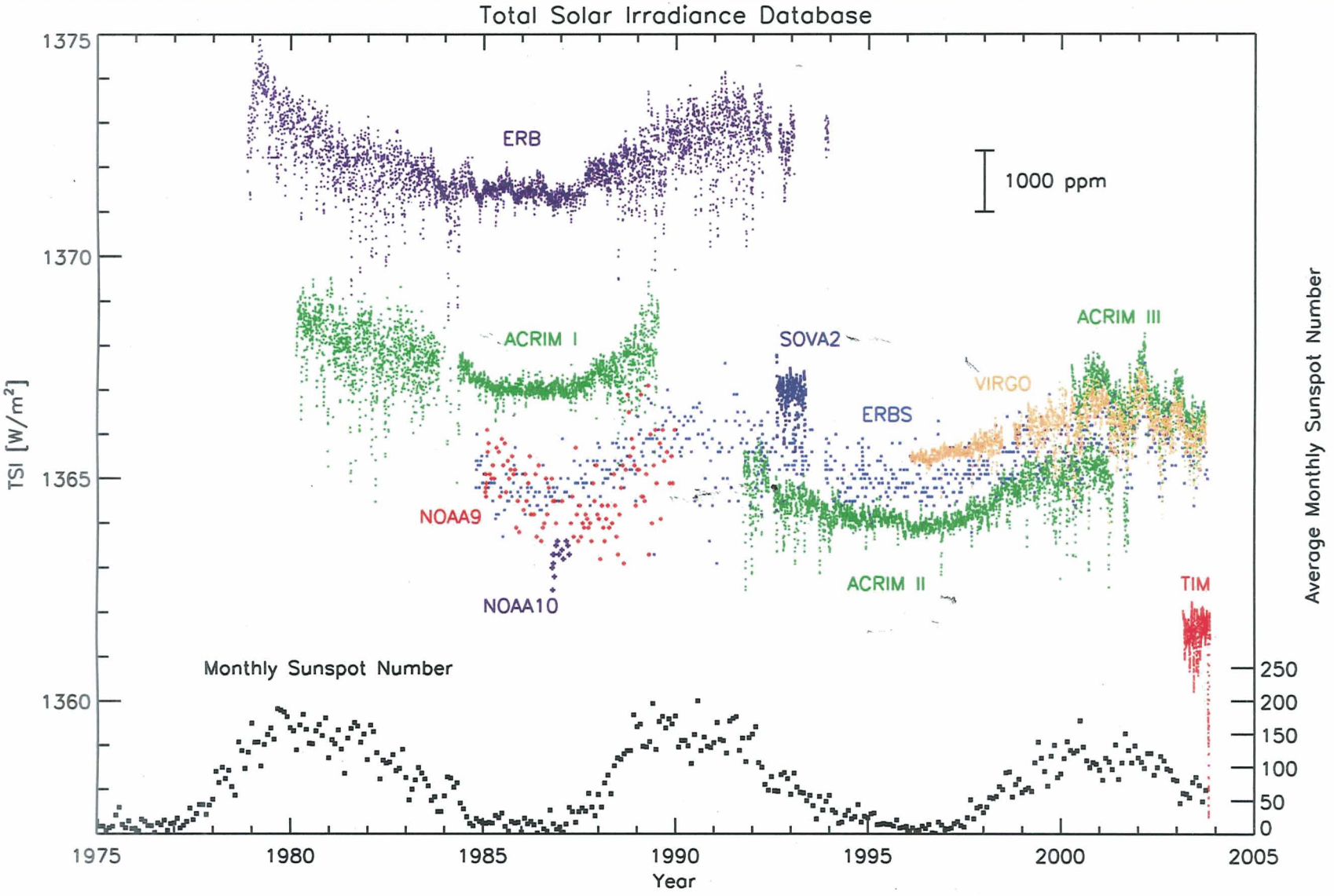
Traceability allows measurements to be rigorously compared with fundamental theory or with other measurements performed at a different time or place.

Climate Changed Research has Challenging Measurement Requirements

Examples

Variable	Accuracy	Stability (Decadal)
TOA Incoming Solar Irradiance	1 W m^{-2}	0.3 W m^{-2}
TOA Outgoing Longwave Radiance	1 W m^{-2}	0.2 W m^{-2}
Surface Albedo	0.01	0.002
Sea-Surface Temperature	0.1 K	0.04

Top-of-the-Atmosphere Solar Irradiance Example



National and International Standards

- Typically maintained and disseminated by the World's National Metrology Institutes (NMIs) such as NIST.

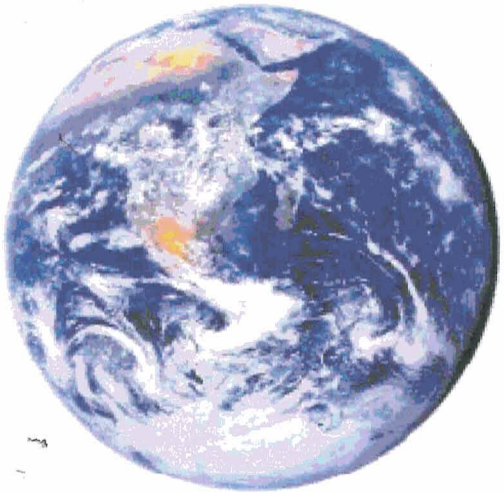
- Includes standards for the fundamental SI Units…

• length	meter
• mass	kilogram
• time	second
• electric current	ampere
• thermodynamic temperature	kelvin
• amount of substance	mole
• luminous intensity	candela

National and International Standards

…and for derived units and non-SI quantities important for climate-change measurements.

- Spectral Irradiance and Radiance
- Optical Power
- Wavelength
- Reflectance
- Pressure
- Humidity
- Chemical Composition



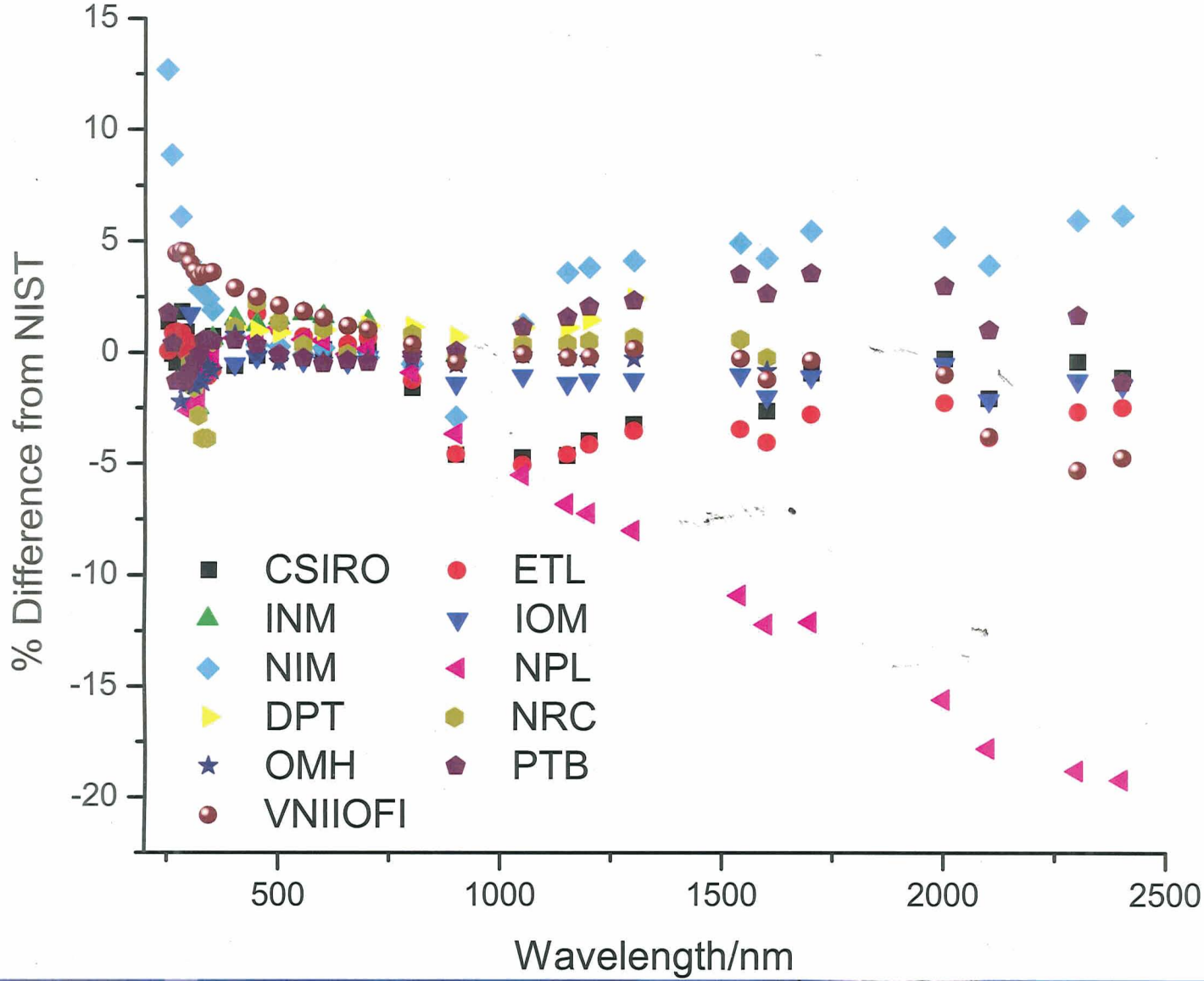
Comité International des Poids et Mesures (CIPM) Mutual Recognition Arrangement

Objectives:

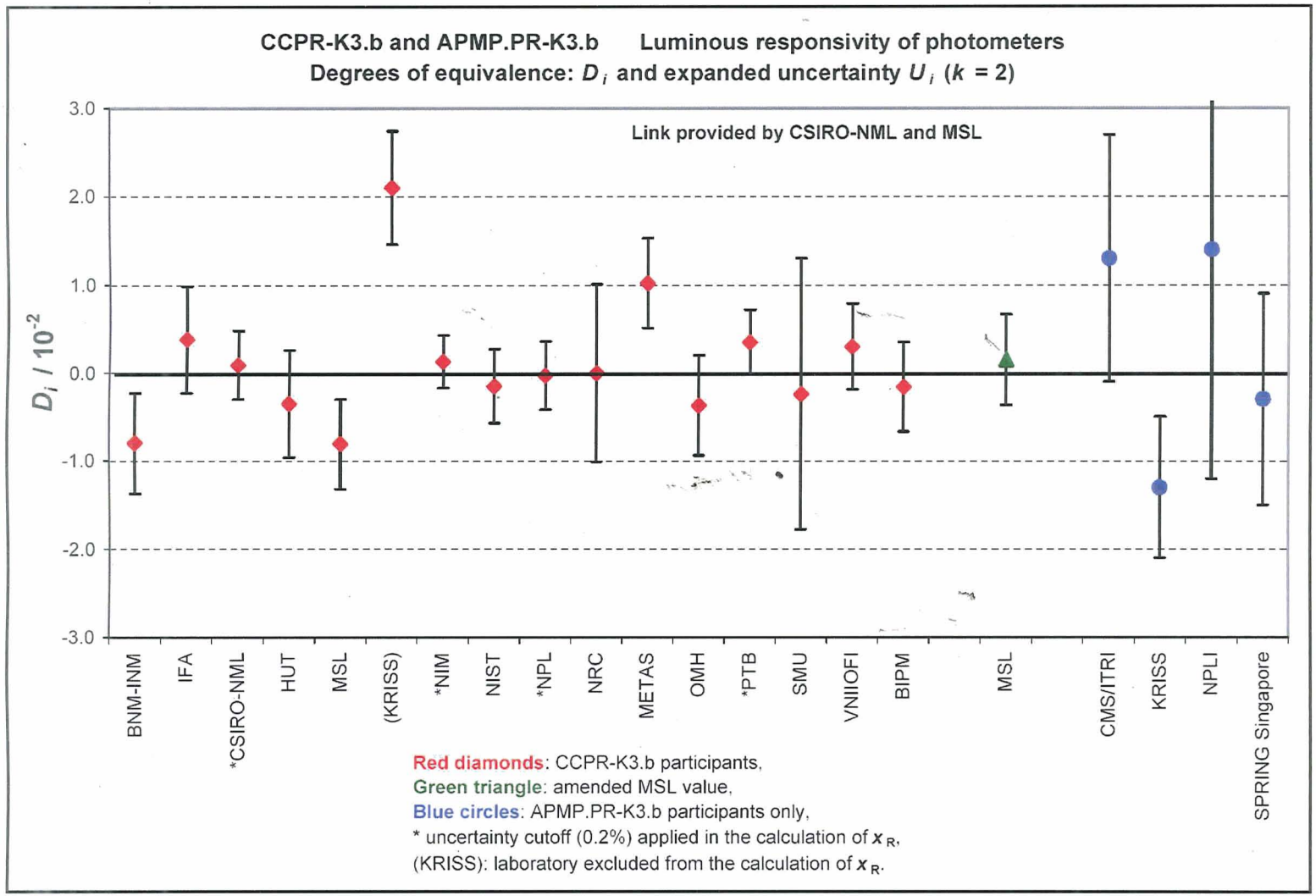
- Establish the degree of equivalence of national measurement standards maintained by NMIs
- Provide for the mutual recognition of calibration and measurement certificates issued by NMIs
- Provide a secure technical foundation for wider agreements related to international trade, commerce and regulatory affairs

The CIPM Mutual Recognition Arrangement (MRA) was signed in October, 1999 by the directors of the NMIs of thirty-eight member states of the *Metre Convention,* and representatives of two international organizations.

NMI Intercomparison Example: Spectral Irradiance



NMI Intercomparison Example: Luminous Responsivity



The Approach Used by the NMIs (NIST, NPL, PTB, etc.) Provides a Model for the Remote Sensing Community

Measurements are

- Intercompared
- Validated by Independent Approaches
- Rigorously Assigned Uncertainties
- Carefully Documented through Quality Systems and in Peer-Reviewed Reports and Publications

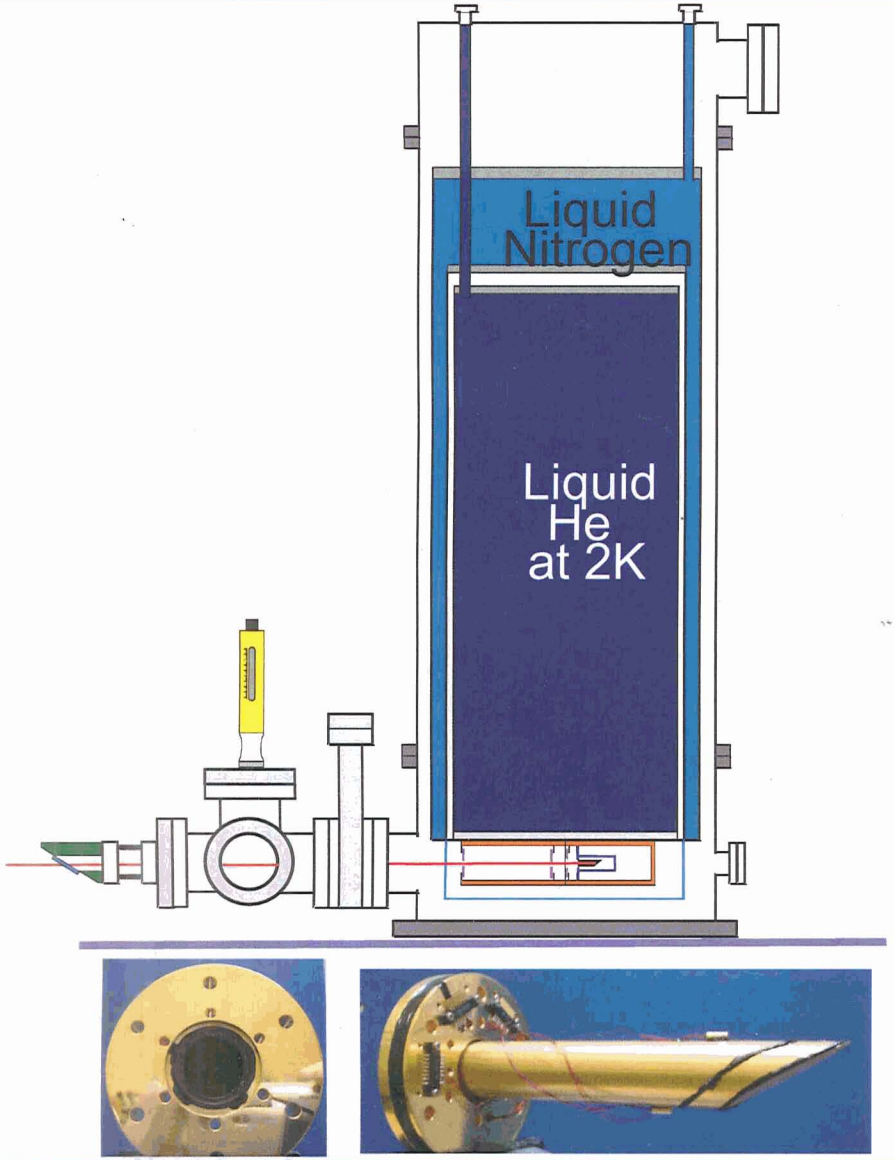
Strategic Plan for the U.S. Climate Change Science Program

Objectives to help Observing and Monitoring System Goal 3: Provide Stewardship of the Observing System

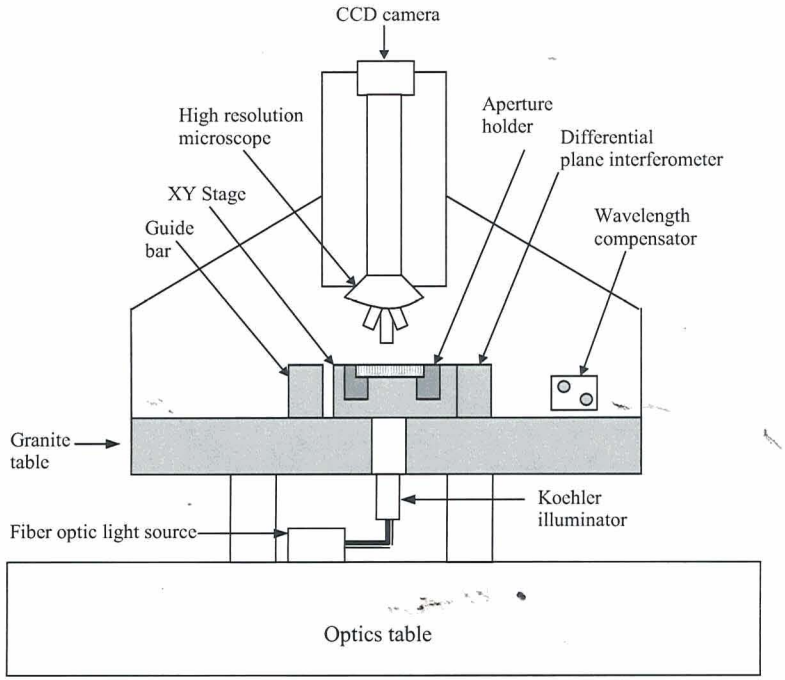
Objective 3.1. Follow climate monitoring principles. … *Instrument calibration, characterization, and stability become paramount considerations. Instruments must be tied to national and international standards such as those provided by the National Institute of Standards and Technology (NIST). … Agreed-upon measurement protocols and procedures (e.g., continuous data validation and intercomparisons) are required to produce climate quality data.*

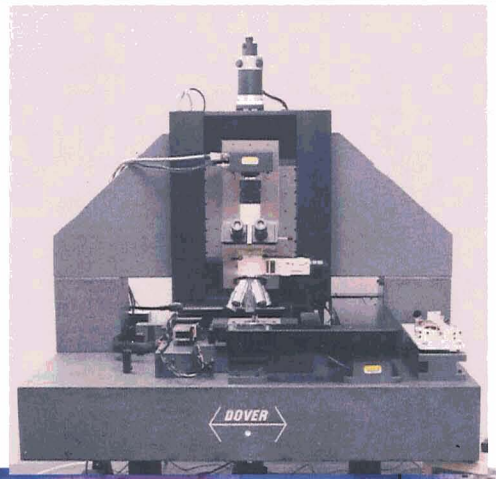
Objective 3.2. Provide independent measurement and analysis. … *Experience from previous scientific assessments, the NIST, and other national standards laboratories have shown that actual accuracy is only known after comparison of independent measurements and analysis from multiple laboratories. …*

NIST's Radiometric Measurements are Traceable to the Cryogenic Radiometer…



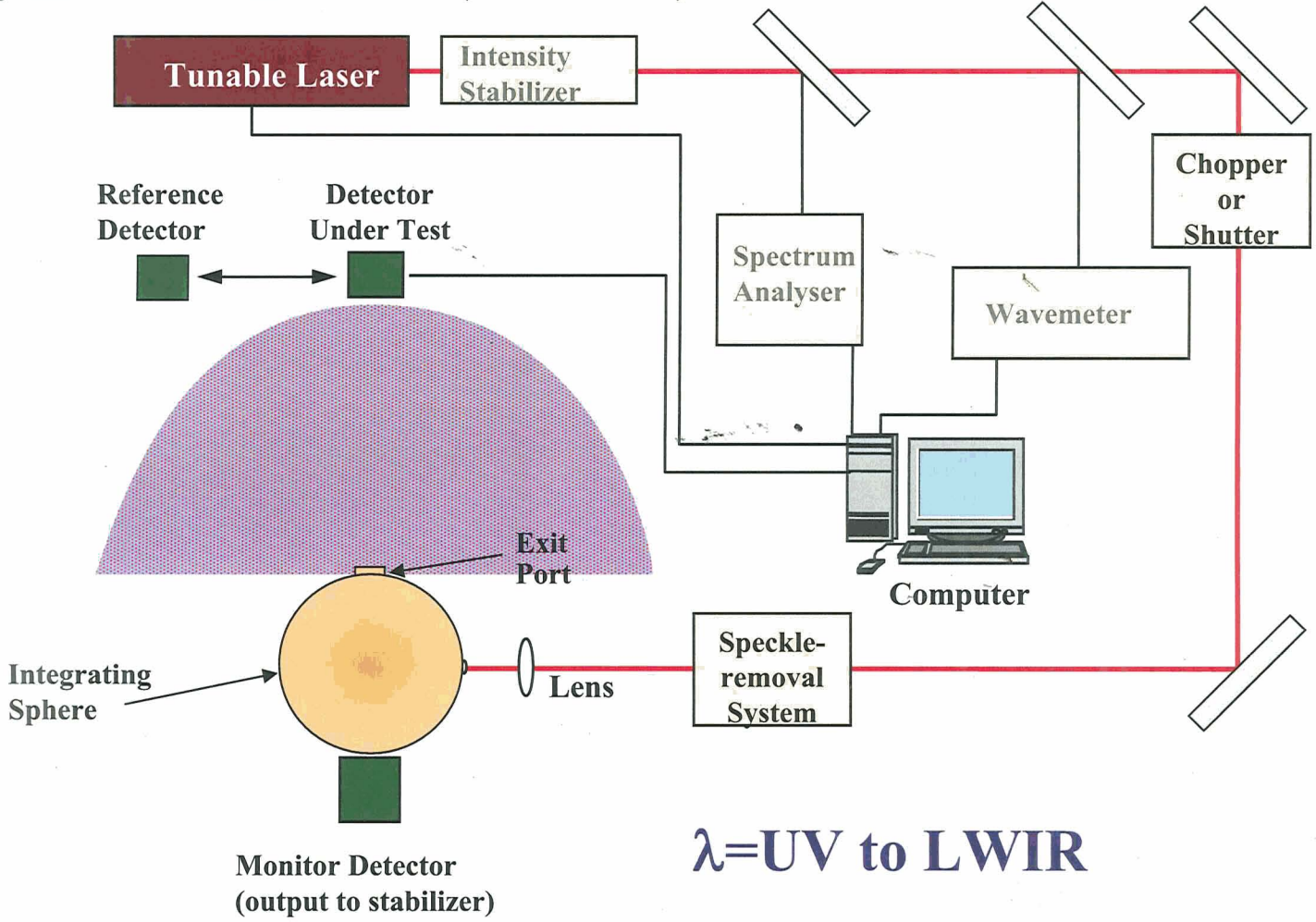
...and to Aperture Area Measurements Performed by the Absolute Aperture Area Measurement Facility.





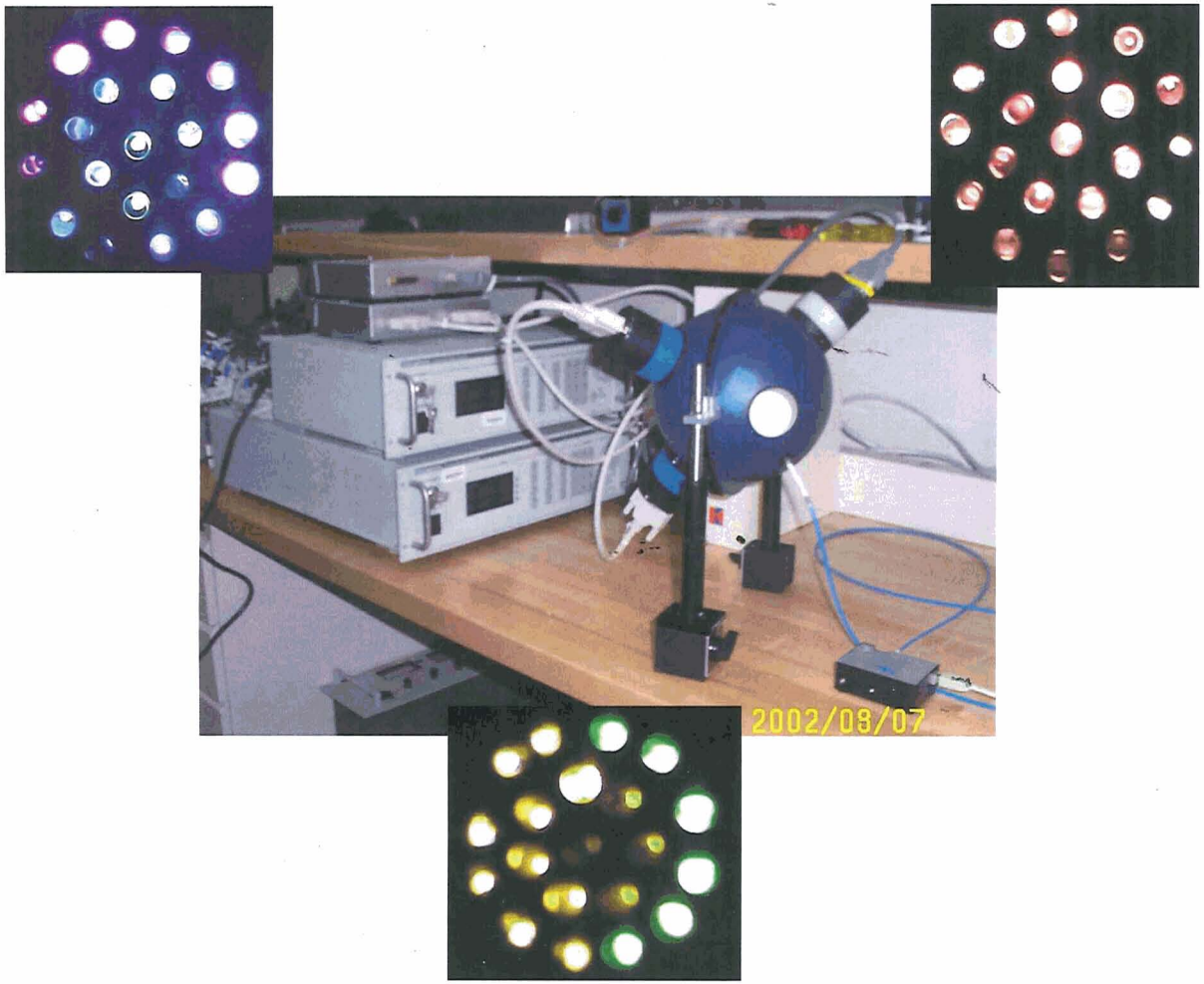
With the aid of SIRCUS

Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS)



λ=UV to LWIR

Alternatives to SIRCUS: LED Integrating Sphere Sources



Click on photo to play movie

Validation: Comparison of Detector-Based and Source-Based Calibrations on a Set of Radiometers

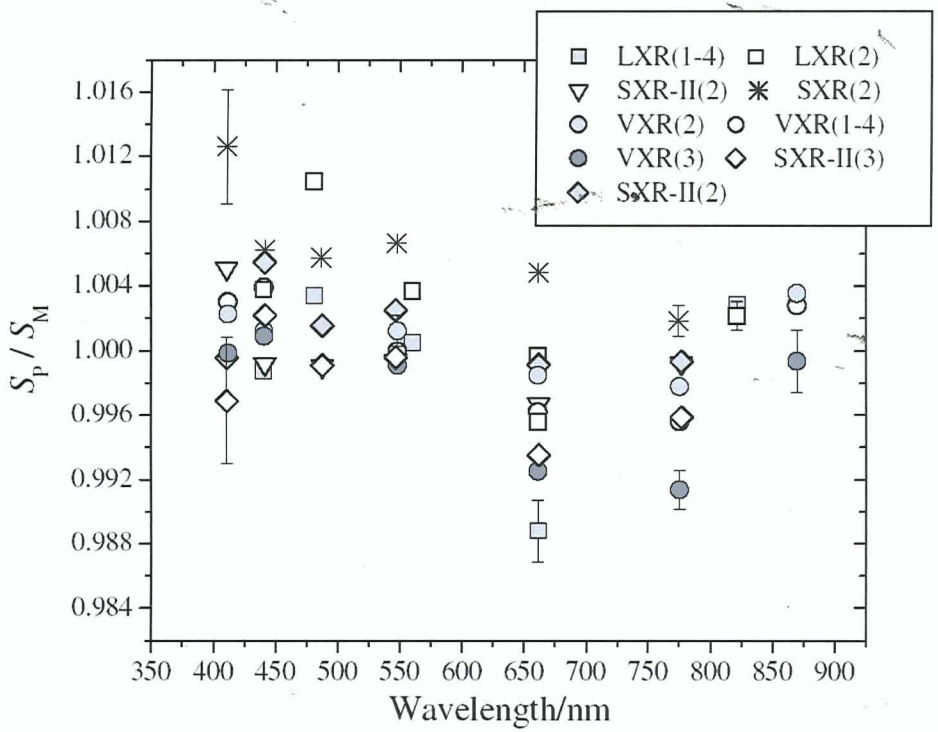
SIRCUS: Detector Based

FASCAL: Source Based

Cryogenic Radiometry

ITS-90

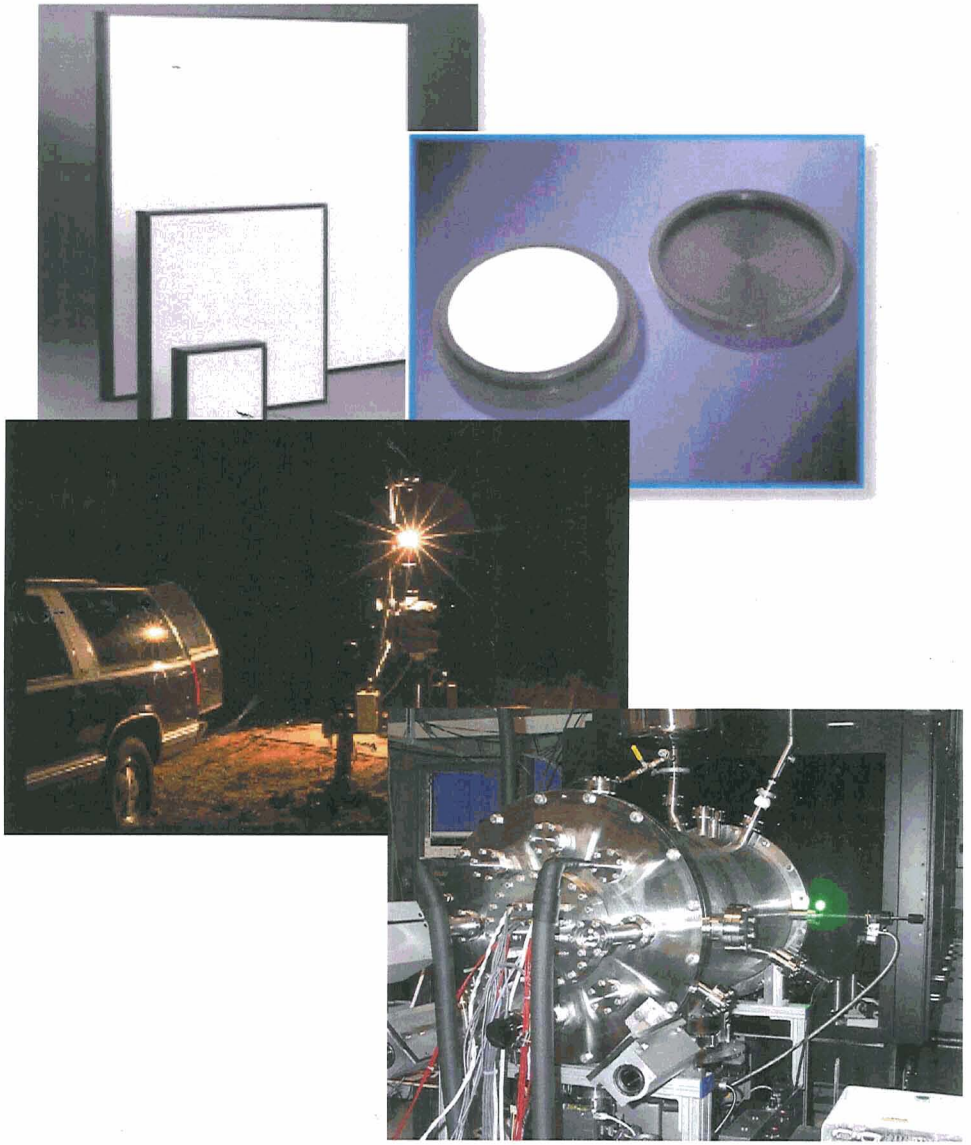
$$S_P = \int r(\lambda) L(\lambda) d\lambda$$



Dissemination of Radiometric Scales

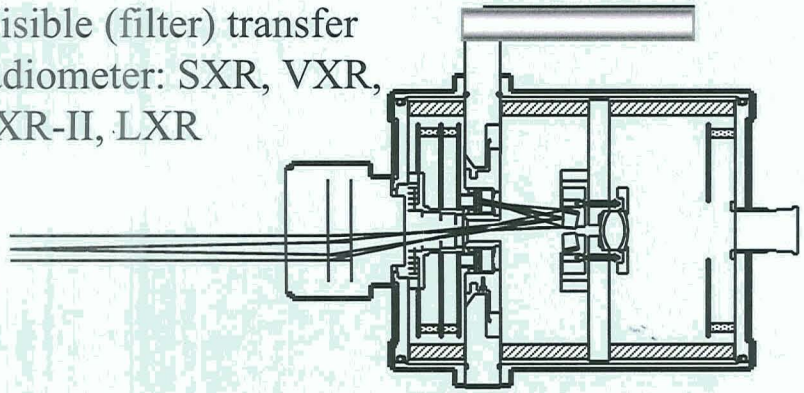
Calibration Services and Standard Reference Materials Include--

- Reflectance Standards (PTFE Plaques)
- Spectral Irradiance Source Standards (FEL and Deuterium Lamps)
- Spectral Radiance Source Standards (Integrating Spheres, Blackbodies, Plaque/FEL Combination)
- Detector/Radiometer Absolute/Relative Spectral Responsivity Standards (Si Photodiodes)

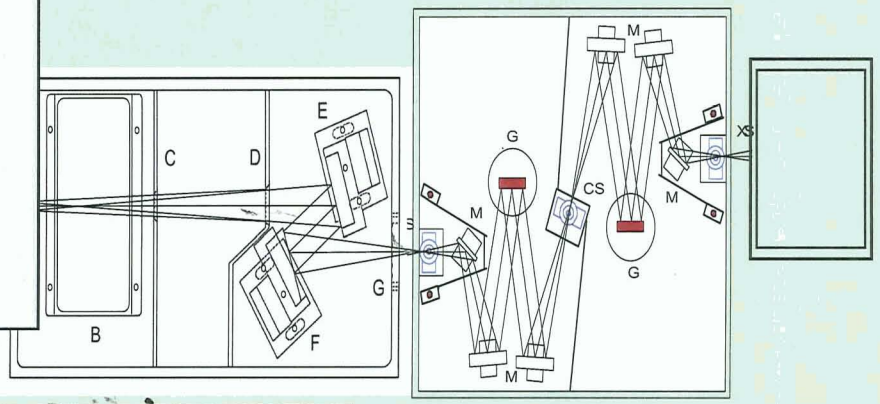


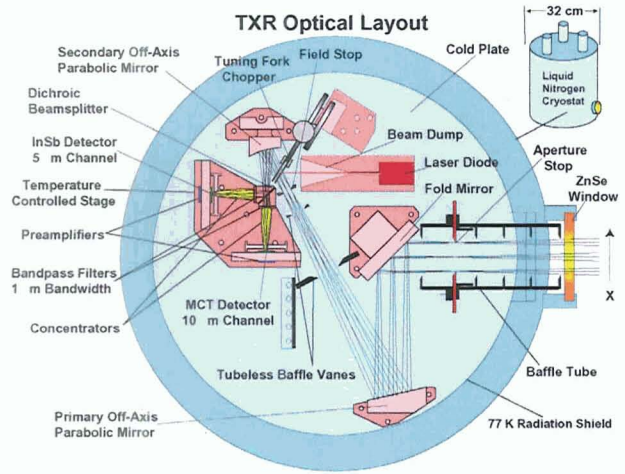
Validation: Transfer Radiometers

Visible (filter) transfer radiometer: SXR, VXR, SXR-II, LXR

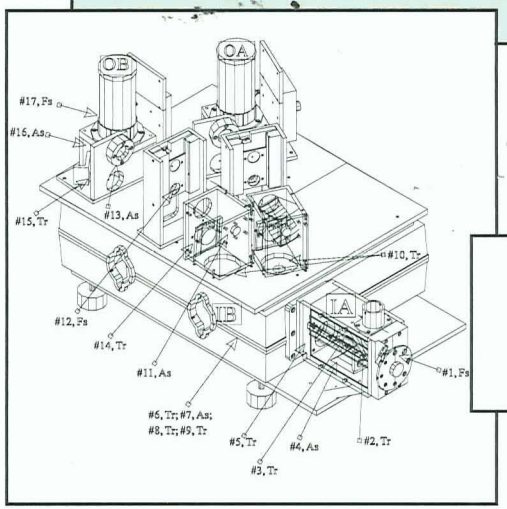


Short-Wave Infrared Transfer Radiometer (SWIXR)





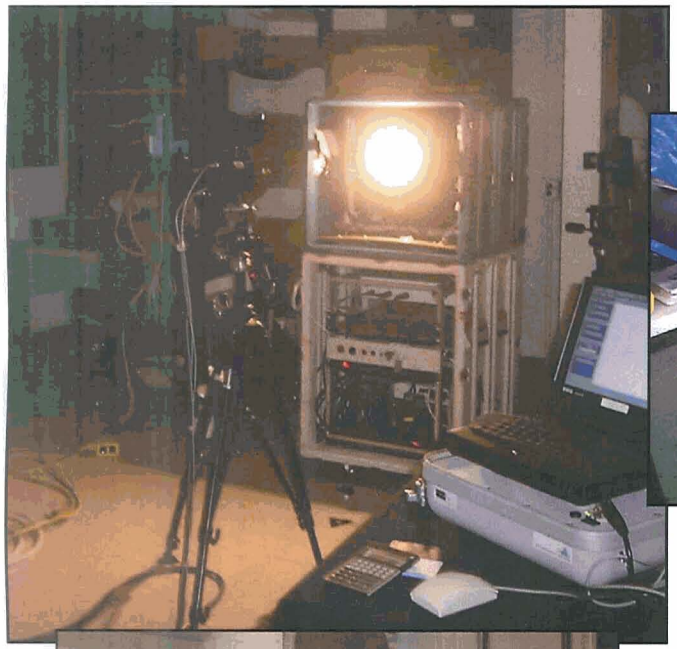
Thermal Infrared Transfer Radiometer (TXR)



Fourier-Transform Thermal Infrared Transfer Radiometer (FTXR)

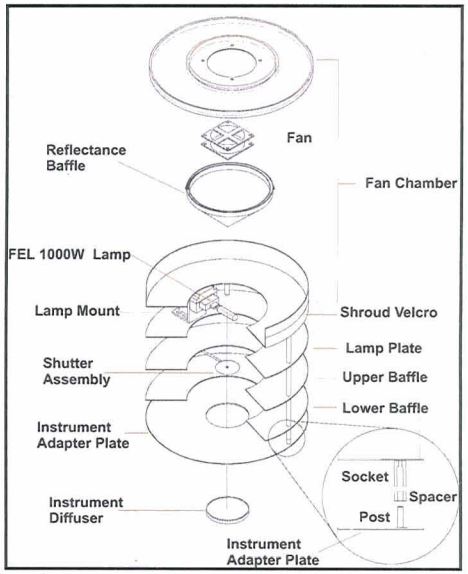
Validation: Transfer Sources

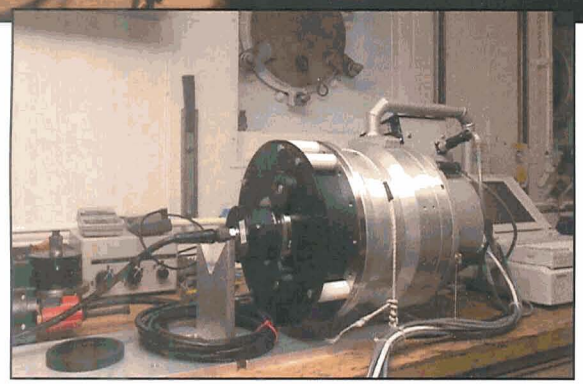
NIST Portable Radiance (NPR) Source



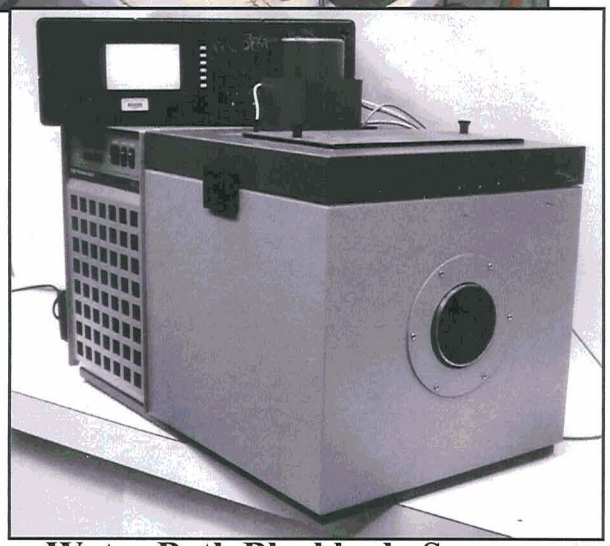
Blue LED Field Stability Source

UV Field Source Calibrator





SeaWiFS Quality Monitor (SQM)



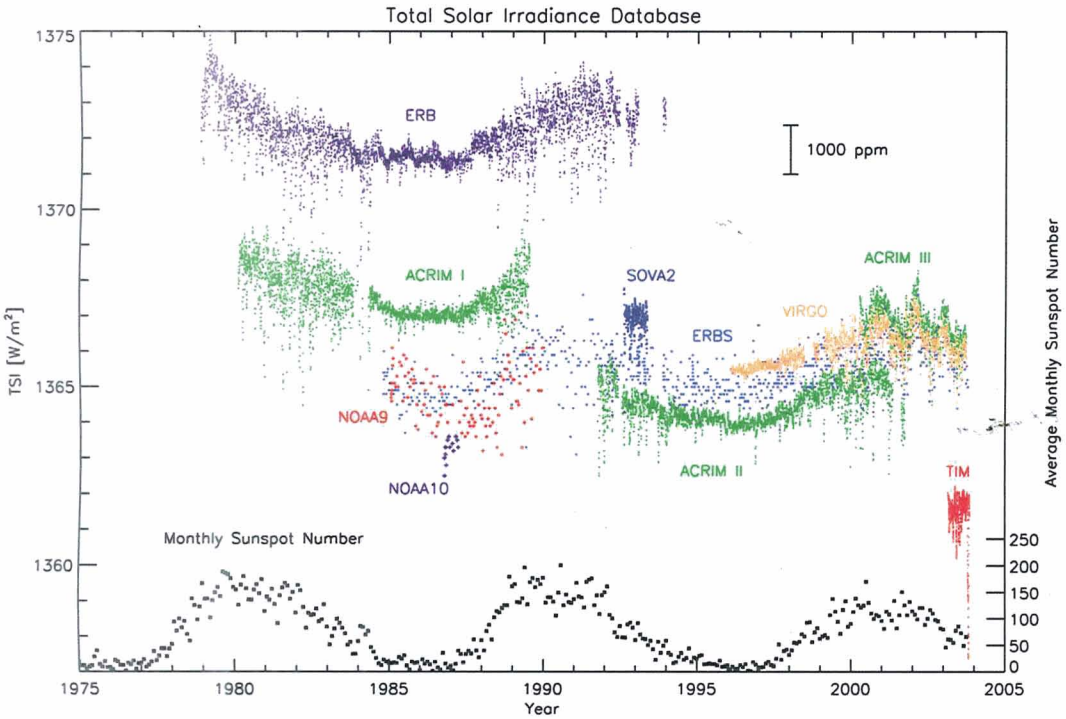
Water Bath Blackbody Source

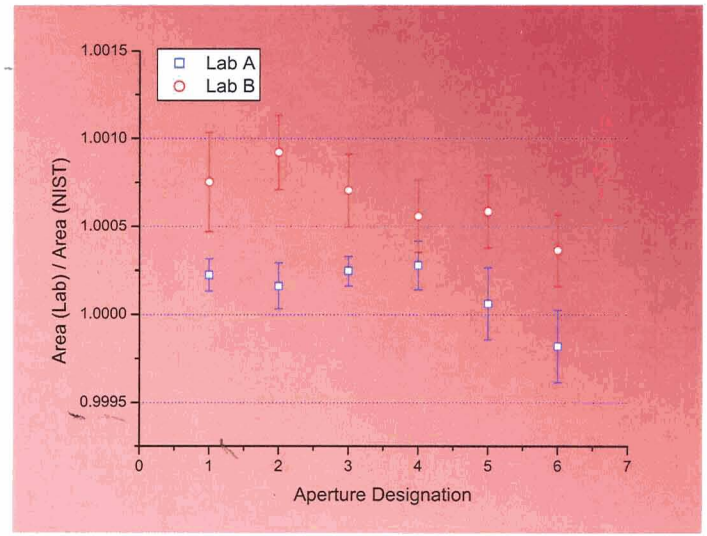
Intercomparisons: SIMBIOS Ocean Color Radiometric Scales

Laboratory	Primary Calibration Source
NRL Optical Sensing Section	FEL
NASA Code 920.1 Calibration Facility	FEL NIST
Wallops Flight Facility (NASA)	Non FEL Irradiance Standards
Moss Landing Marine Laboratory	Integrating Sphere NIST
Scripps	Integrating Sphere
Biospherical Instruments	FEL NIST
UCSB	FEL NIST
U. South Florida	Integrating Sphere
University of Miami	FEL
Satlantic	FEL

The Second SIMBIOS Radiometric Intercomparison (SIMRIC-2), March – November 2002, Meister *et al.*, NASA/TN-2002-210006, Vol. 2, Aug. 2003

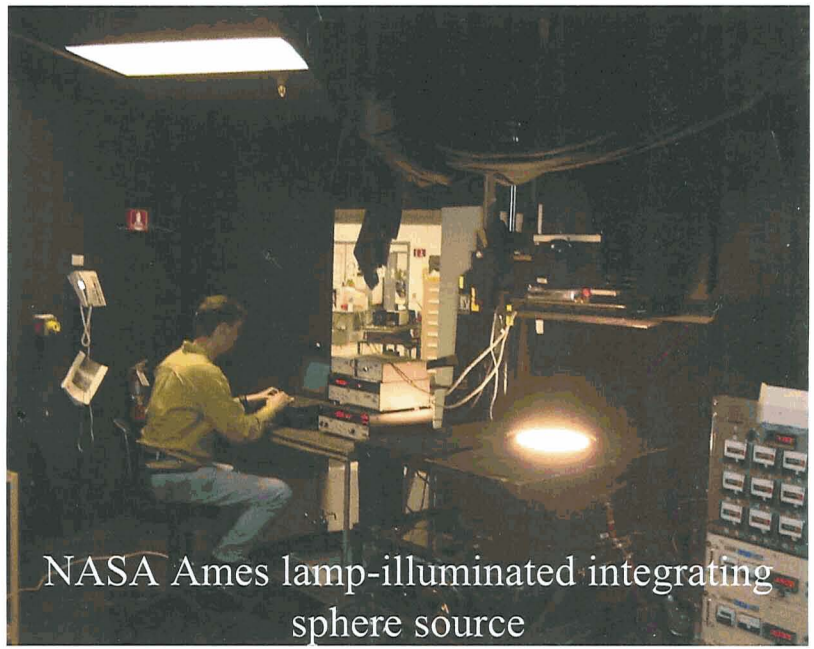
Intercomparisons: Aperture Measurements for Solar Irradiance





Intercomparisons: Spectral Radiance—Visible and Near Infrared

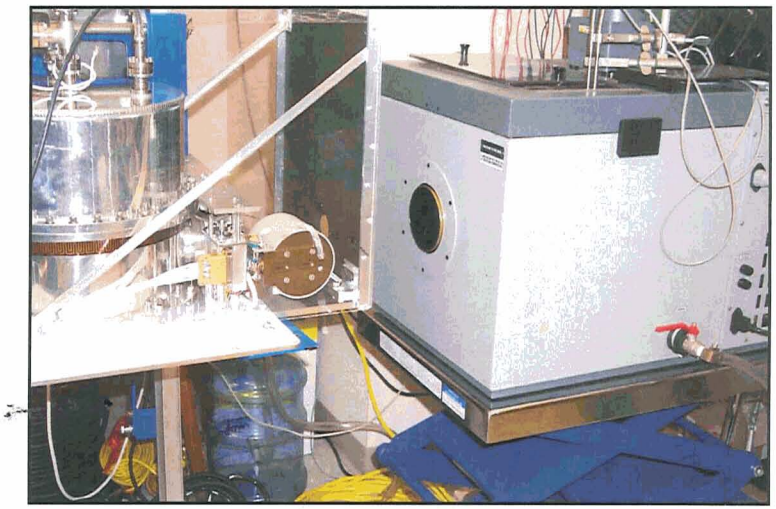
- Spectral range: 250 nm to 2500 nm
- Protocol: Assess accuracy of user calibration of working standard radiance sources using calibrated transfer radiometers
- Key Participants: NIST, UA, NASA/GSFC
- Comparisons held: Multiple, since 1993
- Characterizations: spatial and angular uniformity, temporal stability, repeatability
- Typical agreement: ~3% (visible), 4% to 10% (near infrared)



NASA Ames lamp-illuminated integrating sphere source

Intercomparisons: Spectral Radiance—Thermal Infrared

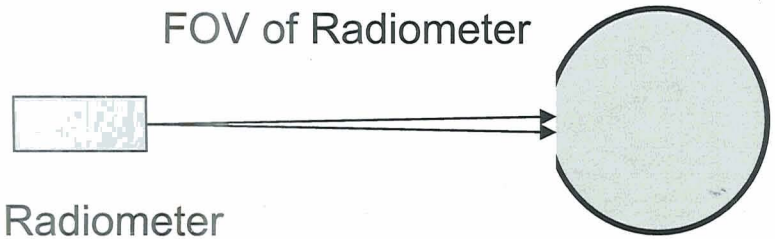
- Spectral range: 5 μm and 10 μm
- Protocol: Assess accuracy of user calibration of working standard radiance sources using calibrated transfer radiometers
- Key Participants: NIST, NASA, NOAA, and affiliates UM, ITT, SBRS, LANL, CEOS/WGCV
- Comparisons held: Multiple, since 1999
- Typical agreement: 0.1 K



The TXR and the NIST WBBB at the Sea Surface Temperature Comparison in 2001 at the University of Miami.

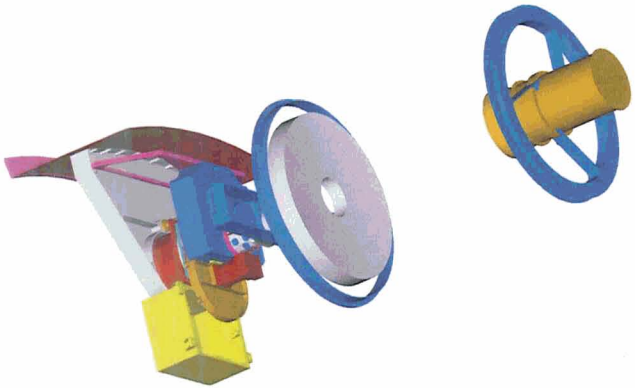
Characterization: Assigning an Uncertainty Requires an Understanding of the Instrument Performance

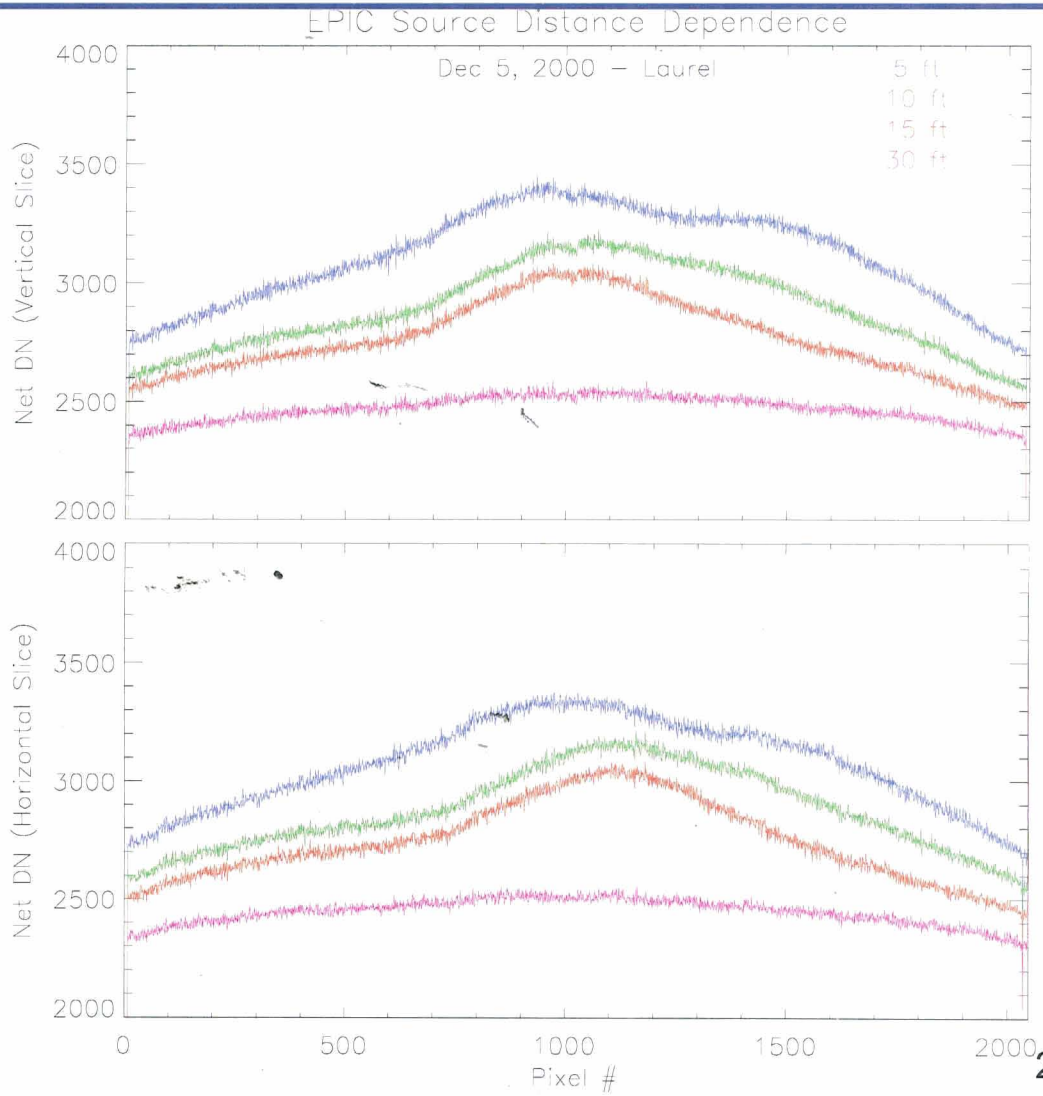
Example—Stray Light



Radiance Standard
(Integrating Sphere,
FEL-Illuminated Plaque,
or Blackbody)

Scripps Earth Polychromatic Imaging Camera





Conclusions

Establishing and Verifying Traceability to National and International Scales

- Allows comparisons to be made independent of time or locale
- Improves understanding of instrument performance
- Provides confidence in the accuracy of the measurements
- Improves measurement accuracy
- Helps contractors understand and meet agency requirements, protecting contractor and customer

NIST Participants

- David Allen
- Steve Brown
- Amanda Cox
- Ted Early
- George Eppeldauer
- Joel Fowler
- Charles Gibson
- Leonard Hanssen
- Carol Johnson
- Simon Kaplan
- Tom Larason
- Keith Lykke
- Jorge Neira
- Joe O'Connell
- Jim Randa
- Joe Rice
- Bob Saunders
- Ambler Thompson
- Toni Litorja
- Howard Yoon
- Jun Zhang

Funding Organizations

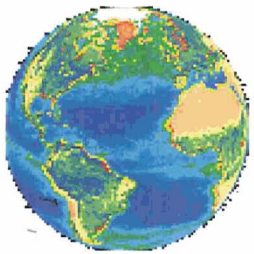
Department of the Air Force
http://www.af.mil/

NPOESS
NORTHROP GRUMMAN
Space Technology
Raytheon
DoD • DOC • NASA

EOS

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

NASA
National Aeronautics and Space Administration
Goddard Space Flight Center


SeaWiFS

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