Surface and Exo-Atmospheric Solar Measurements

Alex Farrell, Mitch Furst, Ed Hagley, Tom Lucatorto,

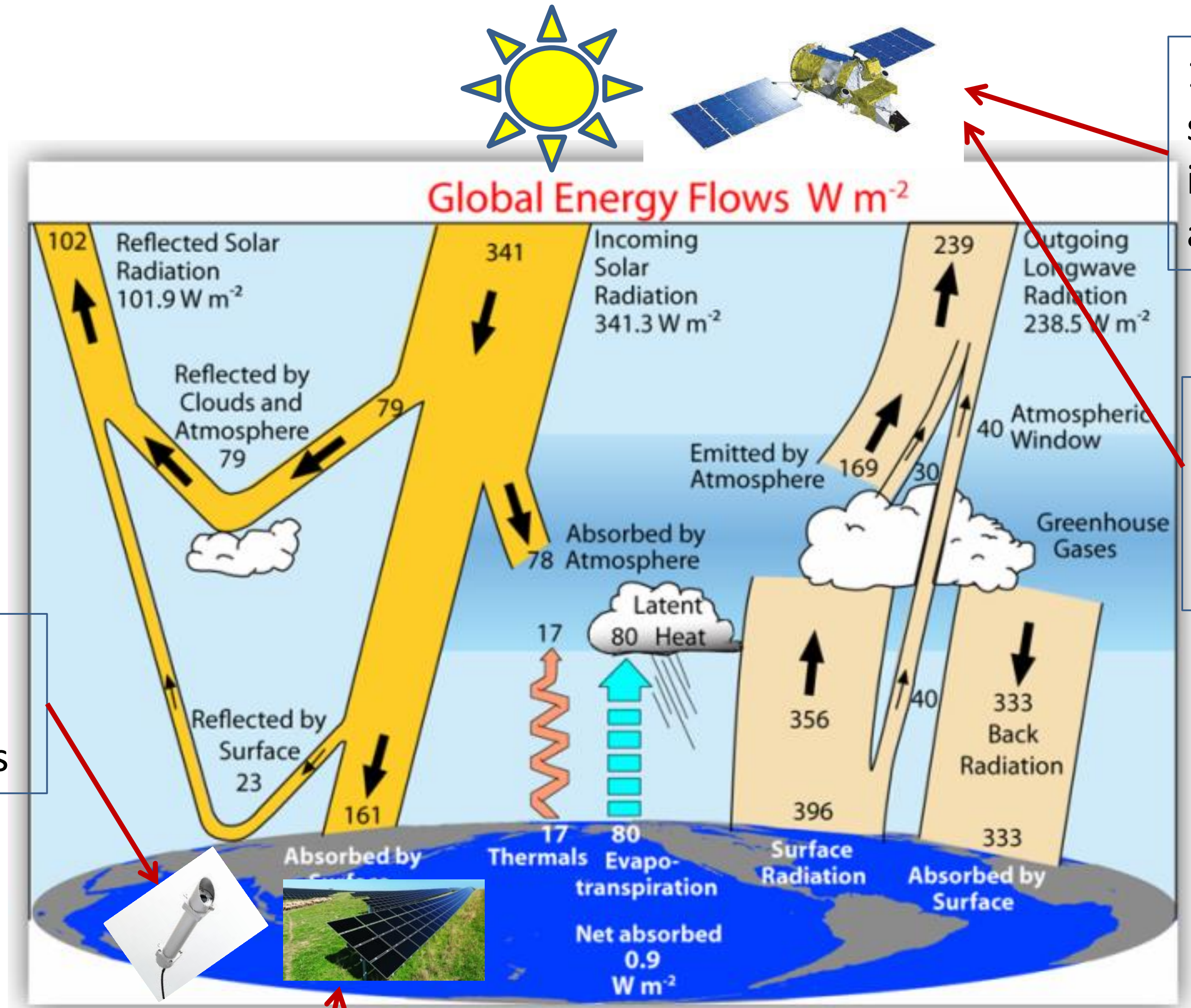
Leonard Hanssen, Joseph Rice, Carol Johnson,

Toni Litorja, Eric Shirley,

Steve Brown, Keith Lykke, ***Howard Yoon***

*Behrang Hamadani, Brian Dougherty, Matt Boyd (**EL**)*

Subject of talk (devices viewing the Sun)



1. Total and spectral solar irradiance (TSI and SSI)

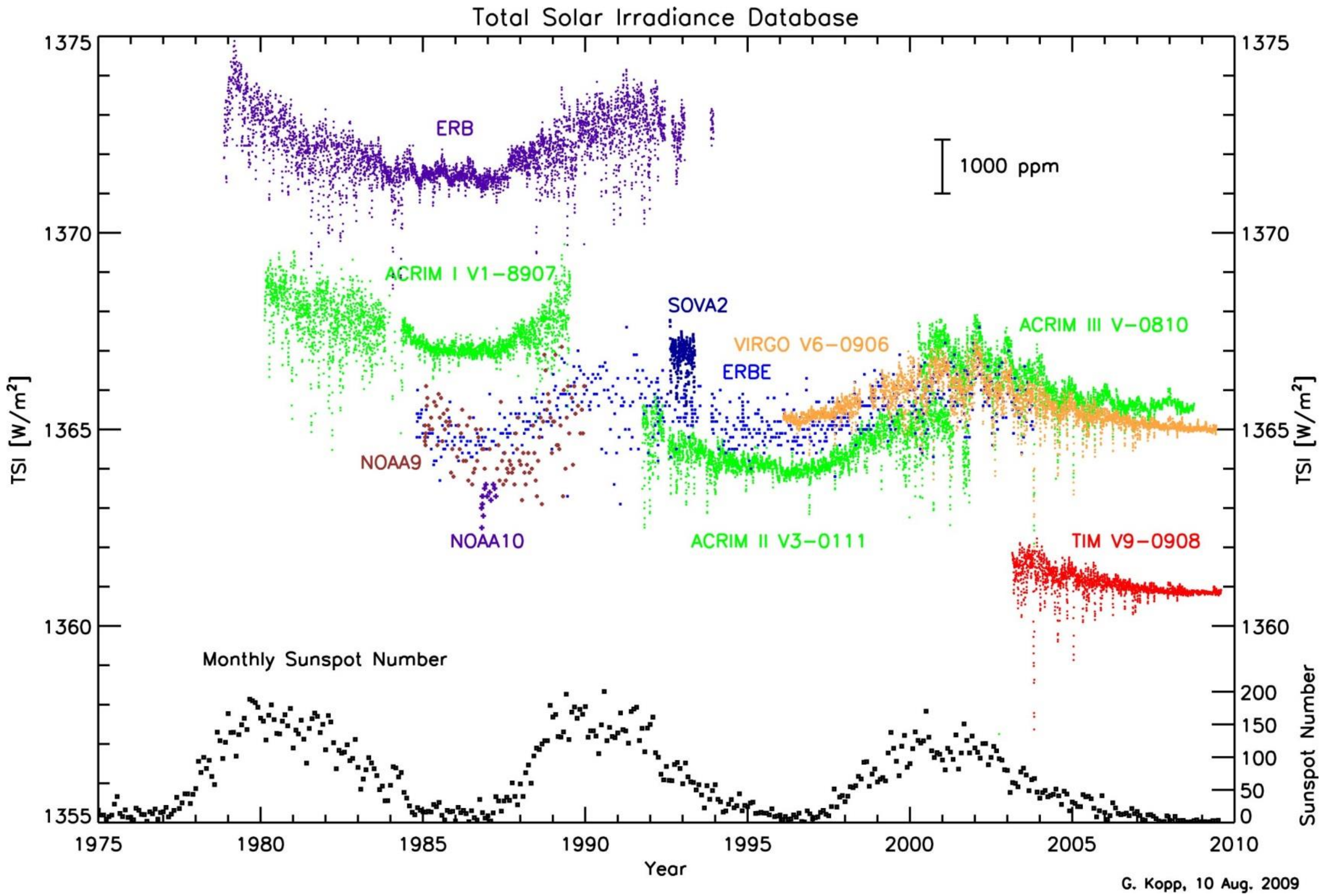
2. Broad-band solar measurements

3. Solar Energy

4. Solar EUV and UV measurements from space

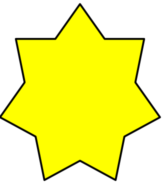
1. Exo-atmospheric Total solar irradiance (TSI) and spectral solar irradiance (SSI)

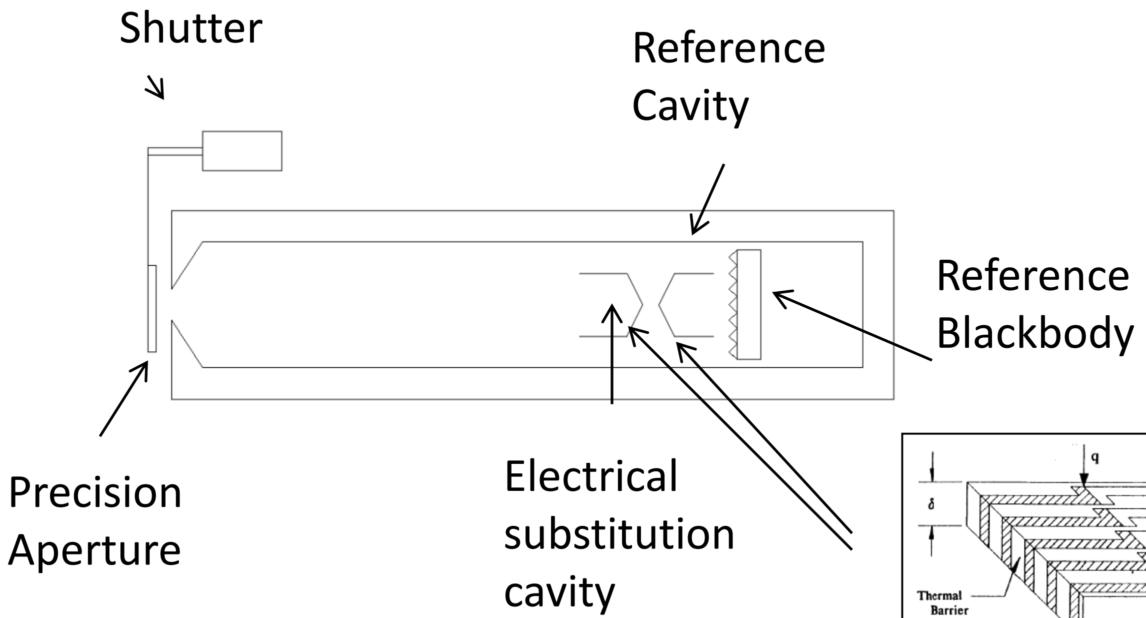
Exo-atmospheric Total Solar Irradiance (TSI) Measurements

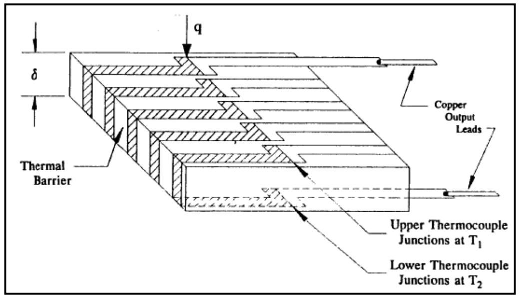


NIST is asked to resolve this problem by NASA

How do you measure the total solar irradiance (TSI)?





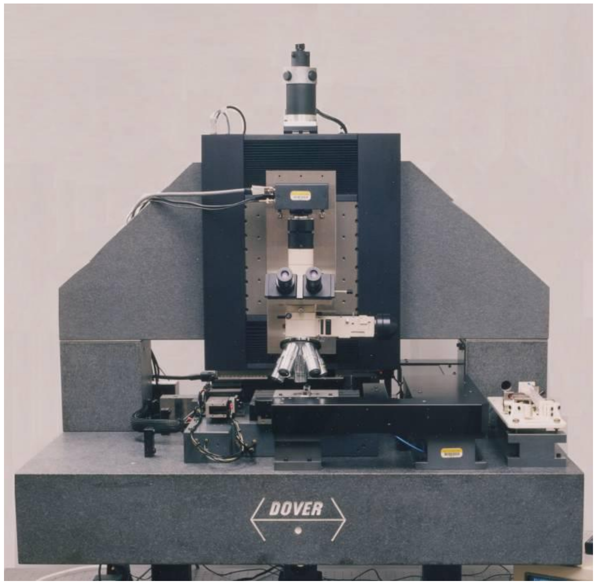


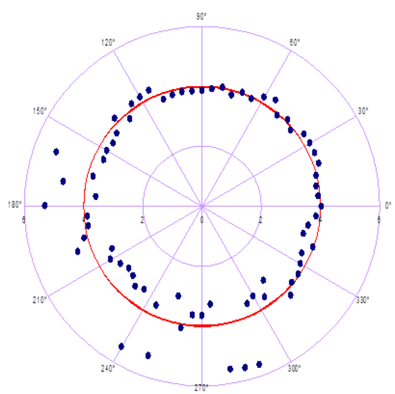
Using calorimetry, the temperature rise using the thermopile in the measuring cavity is determined. The shutter is closed and the electrical power is applied to get the matching rise in temperature.

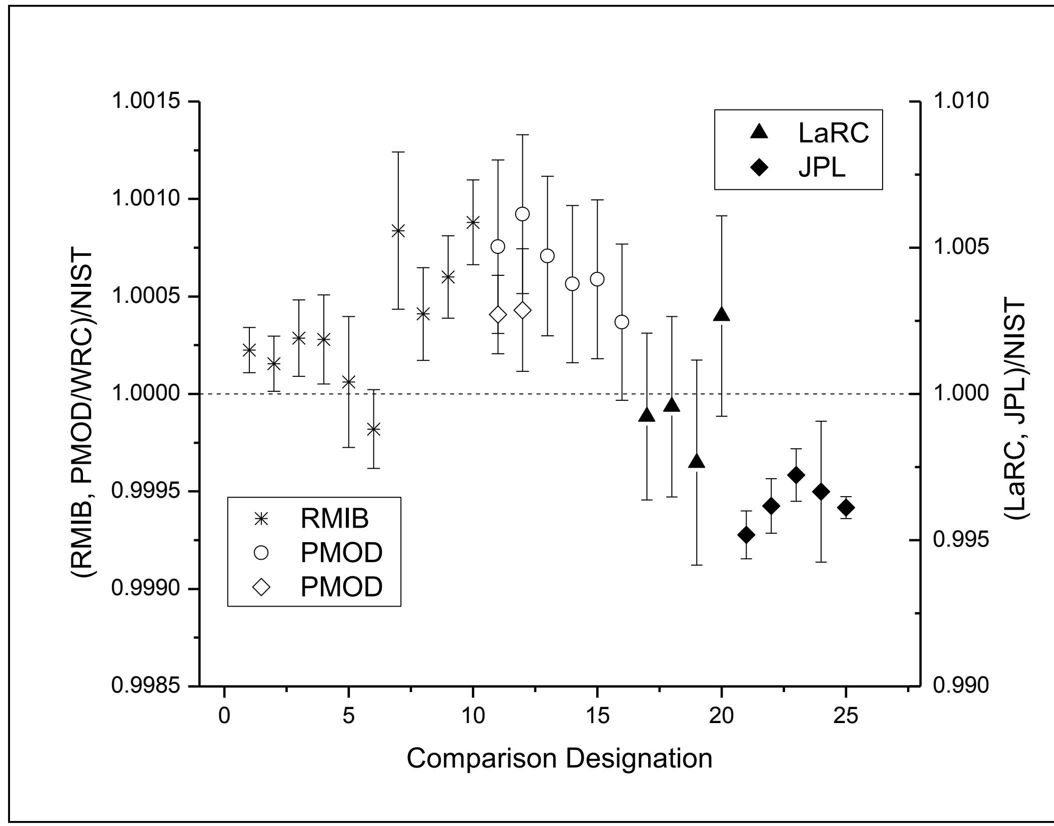
Discrepancies of the TSI of > 0.5 % are due to?

1. Aperture Areas? (Toni Litorja, Carol Johnson)
2. Absolute Power? (Joe Rice)
3. Cavity Absorptance? (Leonard Hanssen)
4. Diffraction? (Eric Shirley)

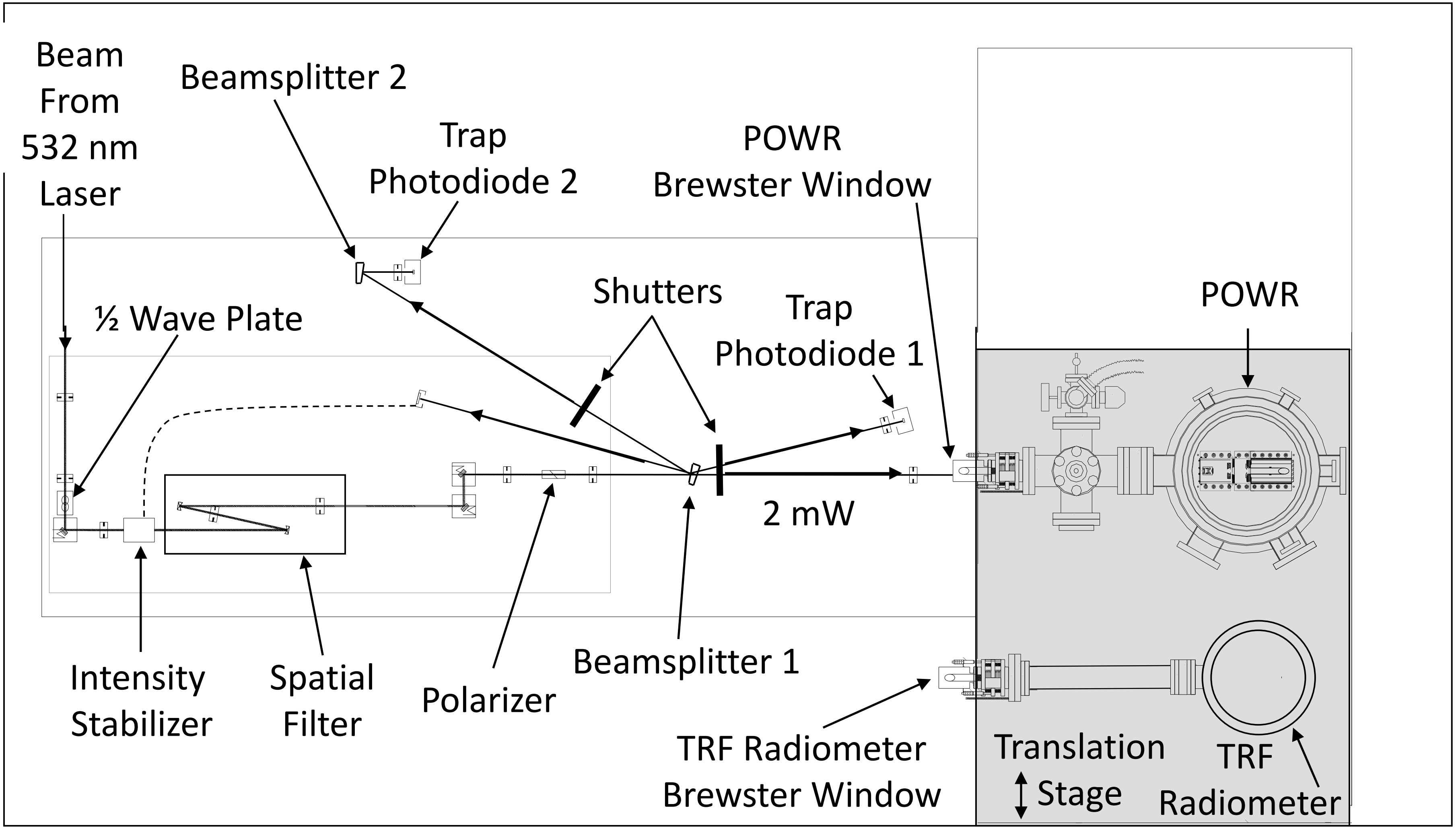
Aperture area measurements at NIST







Calibration of LASP TSI Radiometer Facility Radiometer (TRF) using the NIST Primary Optical Watt Radiometer (POWR)

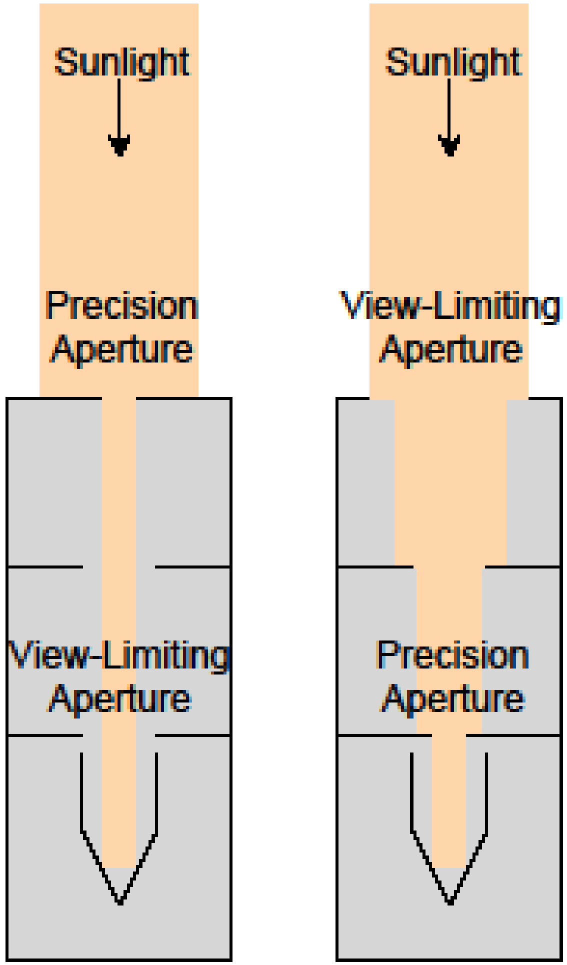


Scattering and Cavity Reflectance

TIM has a reversed order of the defining aperture and the view limiting aperture. compared to other TSI sensors. Scattering is very difficult to model and therefore to calculate the exact contributions.

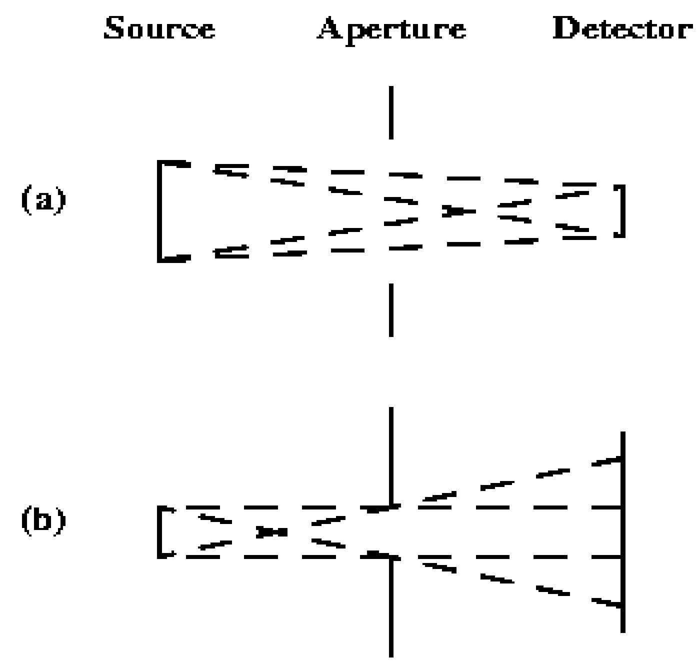
TIM

ERBE, DIARAD, PMO6, ACRIM



Diffraction corrections

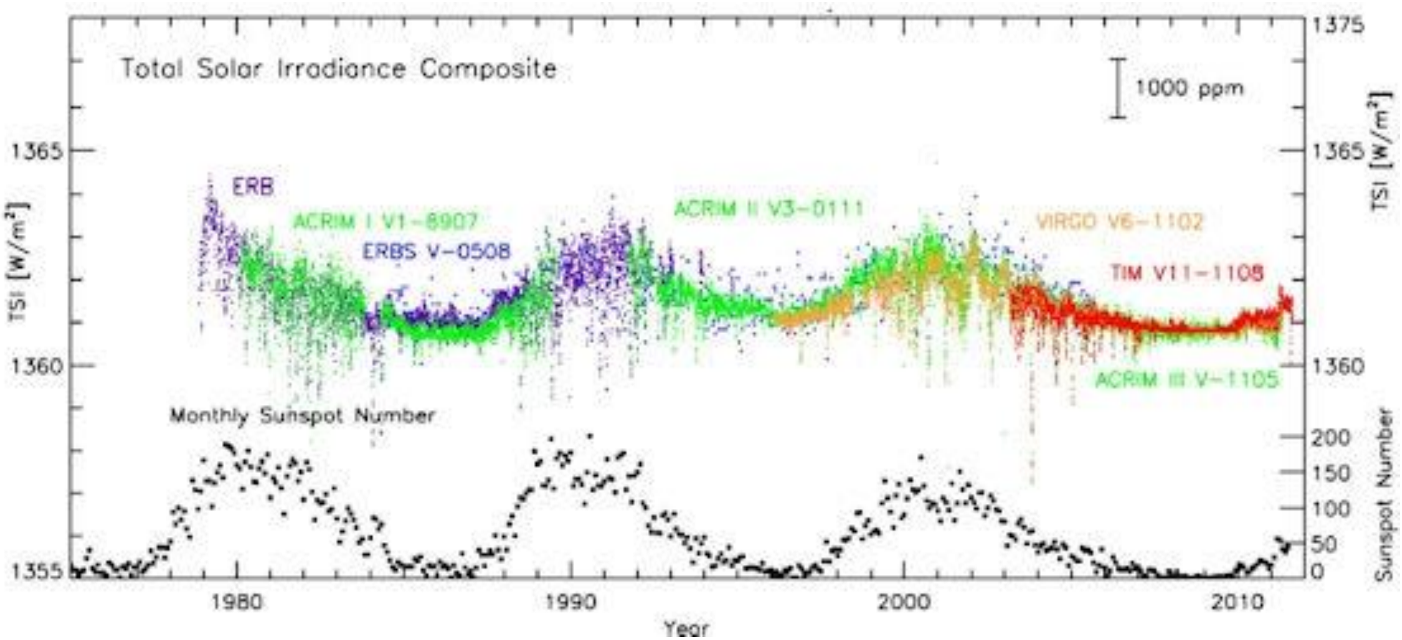
Diffraction had important and oppositely signed effects on 2 NASA instruments; (a) ACRIM and (b) TIM.



Diffraction effect for radiometers: excess (deficit in negative case) flux, ppm

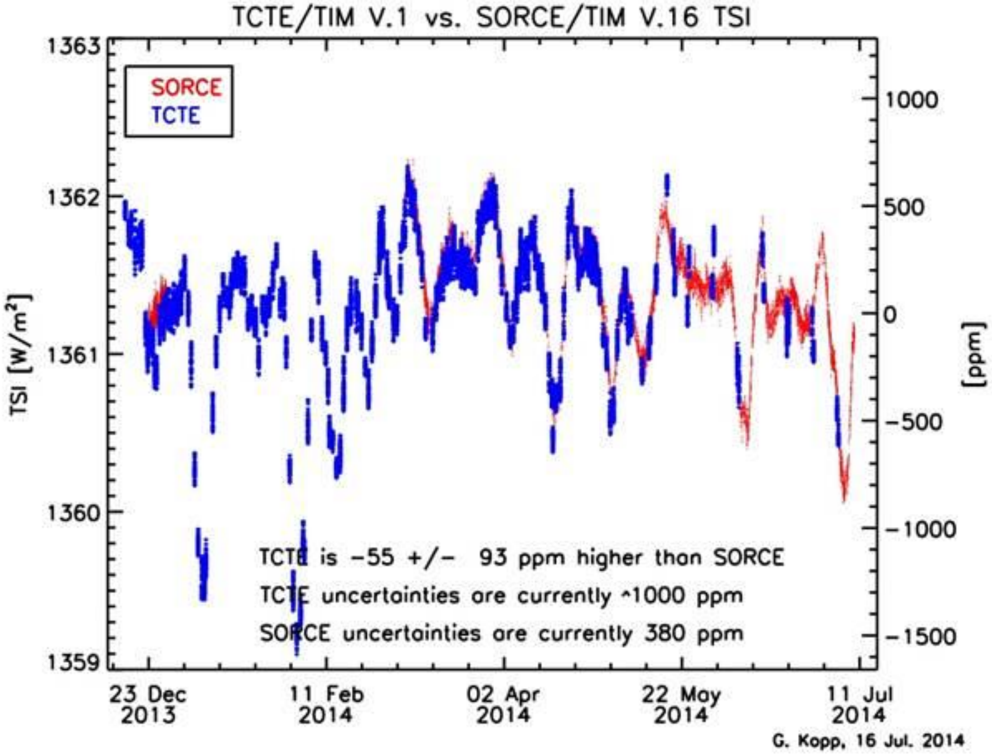
	Instrument	
Calculation	ACRIM	TIM
NIST	1595	-452
NRL	1548	-314
Average	1571(24)	-383(75)

TSI issue is resolved



DoC Gold Medal in 2012 to the team

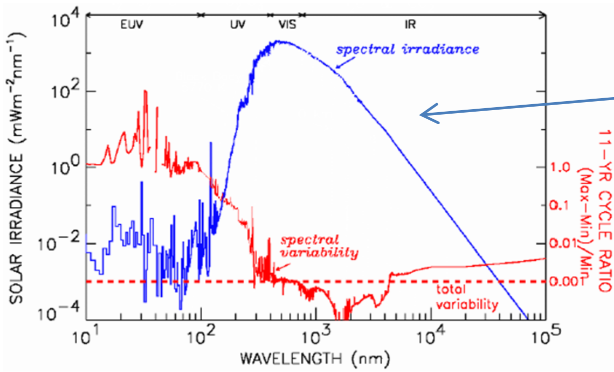
Latest comparison of TCTE/TIM and SORCE/TIM



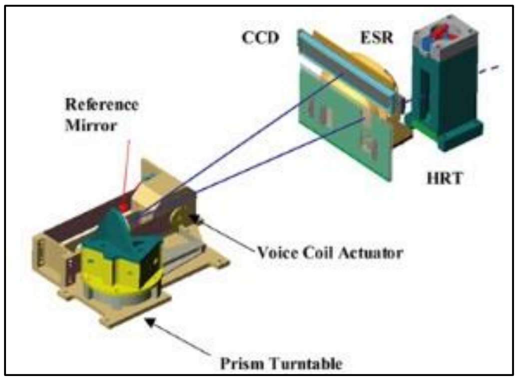
TCTE/TIM measurements are traceable to

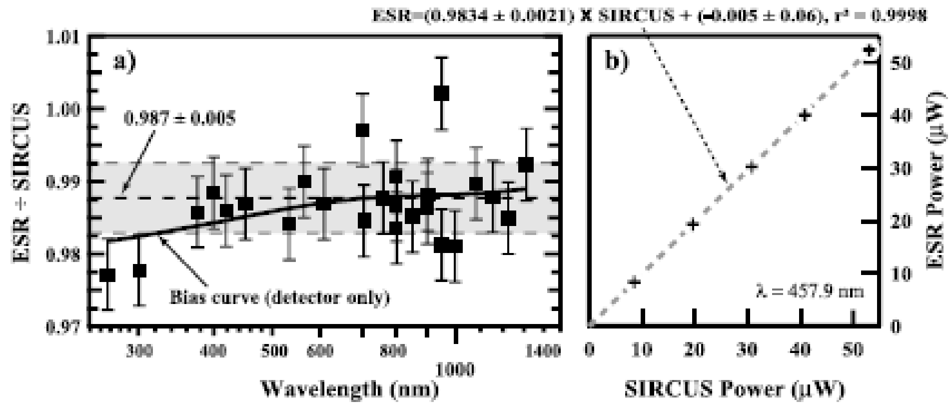
1. NIST Apertures
2. NIST POWR scale

Solar Irradiance Monitor Electrical Substitution Radiometer Efficiency Calibration Results from SIRCUS



Solar Spectral Irradiance (SSI) is only known to about 2.0 % (k=2)





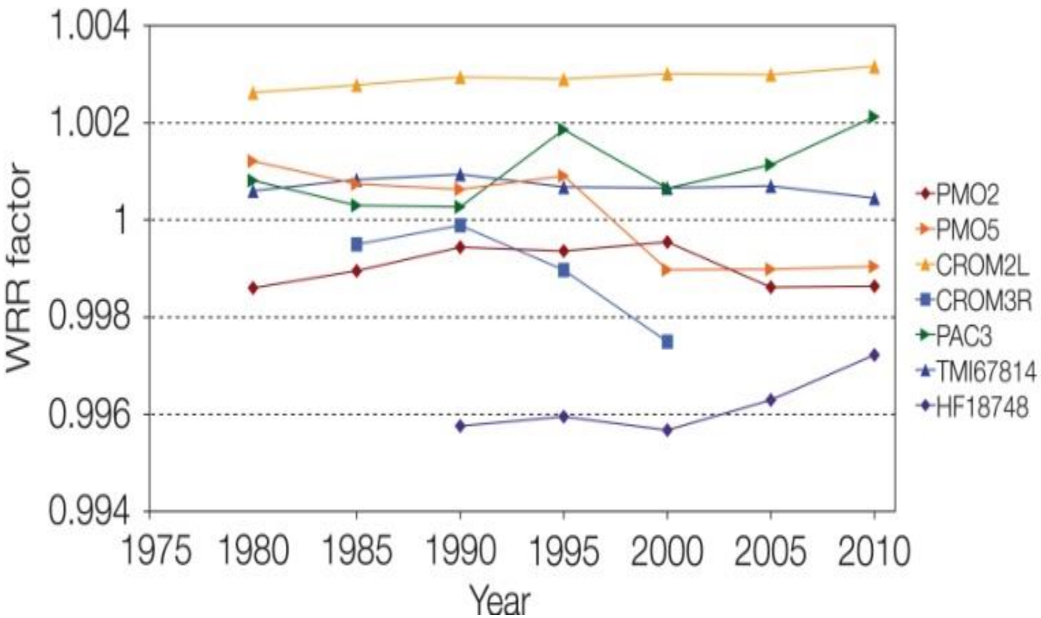
Steve Brown, Keith Lykke

Net result was that the radiometric response of the SIM instrument needs to be increased by a factor of 1.013 across the 258 nm to 1350 nm regime.

J. W. Harder, G. Thuillier, E. C Richard, et al., “The SORCE SIM Solar Spectrum Comparison with recent observations,” Solar Phys. 263, 3-24 (2010).

2. Surface broad-band solar measurements

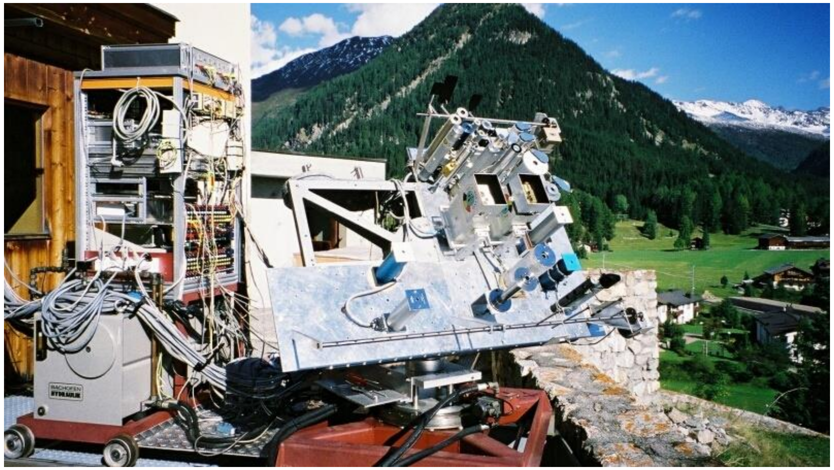
How is the scale maintained now and what is the problem?



The World Radiometric Reference (WRR) is defined as the mean of the World Standard Group of pyrheliometer at Davos, Switzerland which began as a group of 17 of which 6 are used for the latest scale.
The outliers from the mean are discarded. The difference from SI is estimated to be 0.3 % (*k*=1).

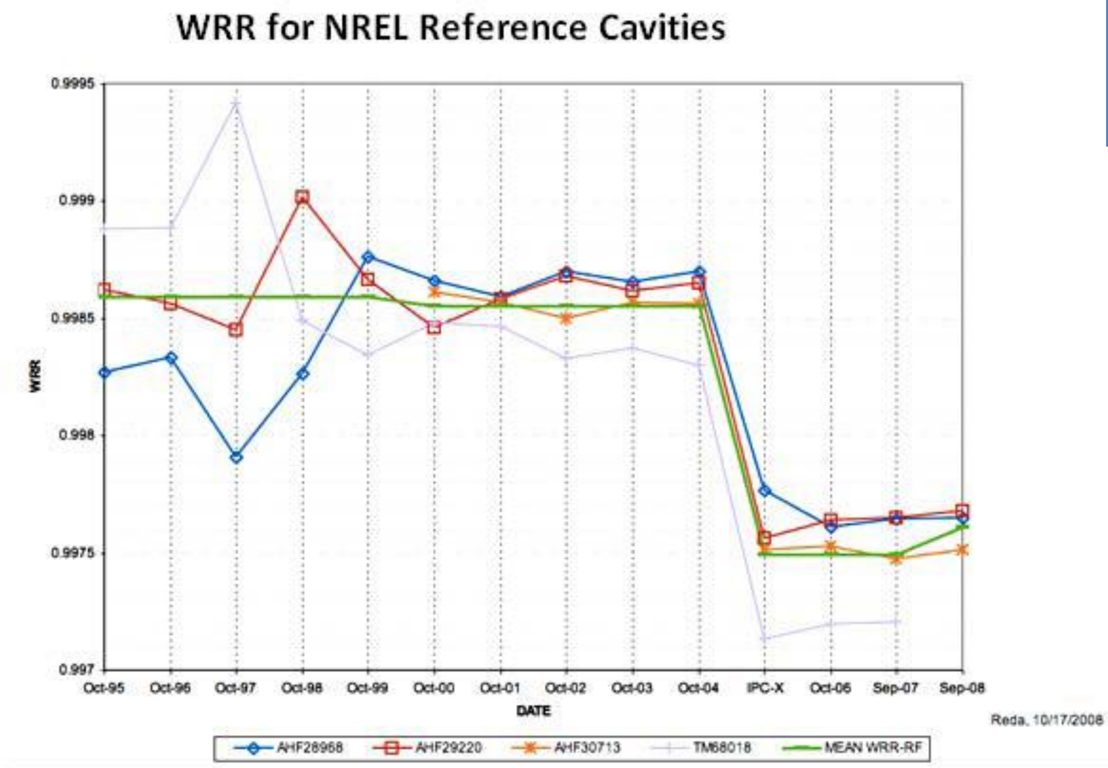
PMOD Annual Report 2010

How is the broad-band total irradiance scale (World Radiometric Reference (WRR)) disseminated?



- Every 5 years the International Pyrheliometer Comparisons are held.
- The Eleventh IPC (IPC-XI) took place at PMOD/WRC (Davos, Switzerland) from September 27 to October 15, 2010.
- Eighty-seven participants came from 40 countries to calibrate 99 pyrheliometers.

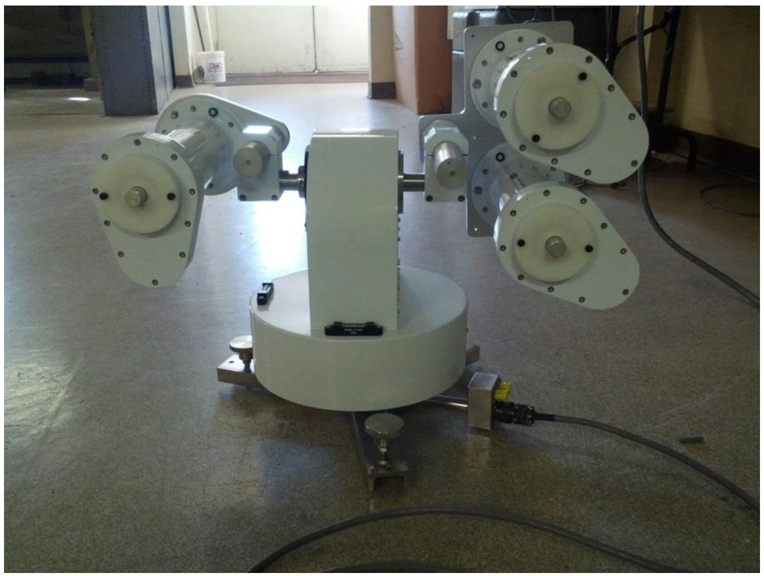
Problems with the WRR



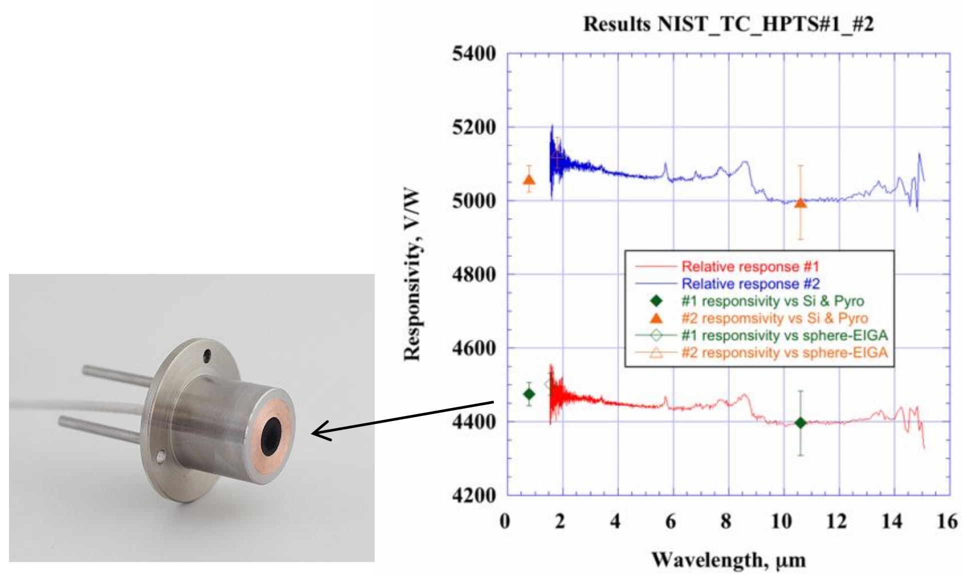
Changes in the WRR can be measured using NREL pyrheliometers

Is it possible to have a NIST-traceable scale?

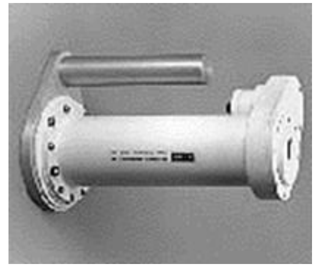
NIST Purchased 3 Eppley AHF pyrheliometers



Recommended by NREL who has provide the custom software to run this unit.



Design of the Eppley AHF



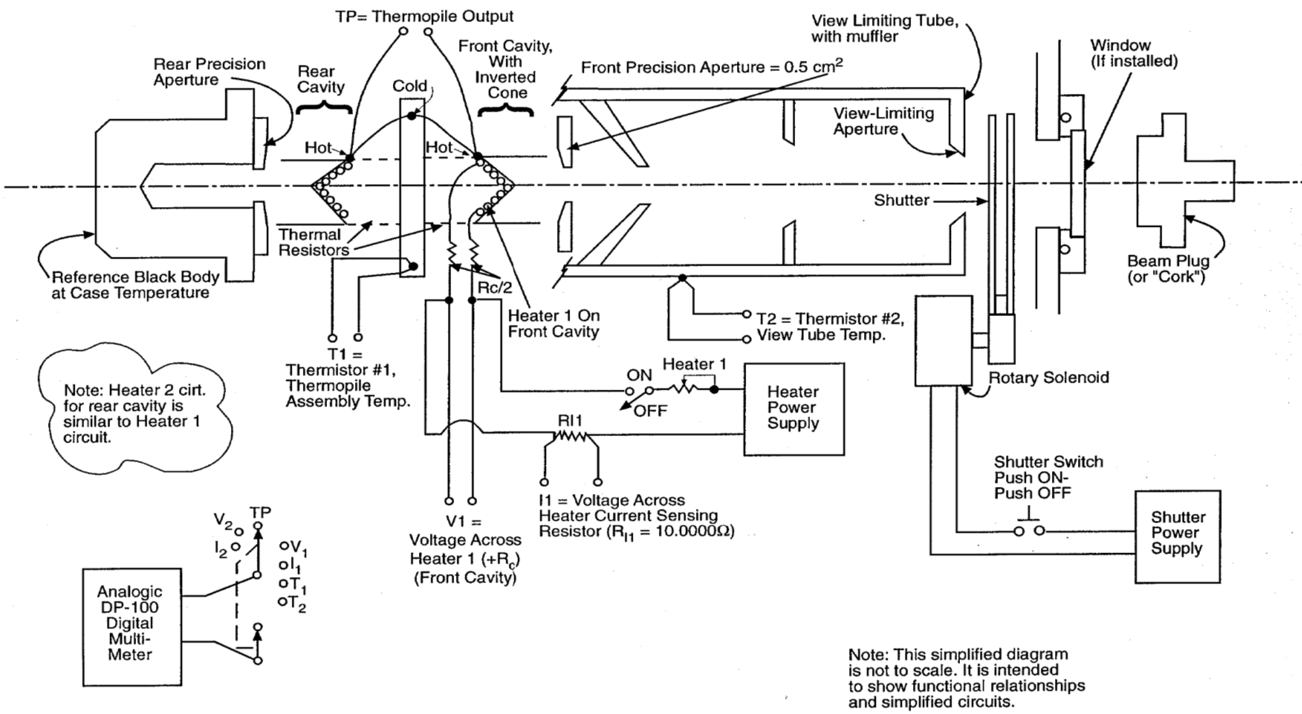


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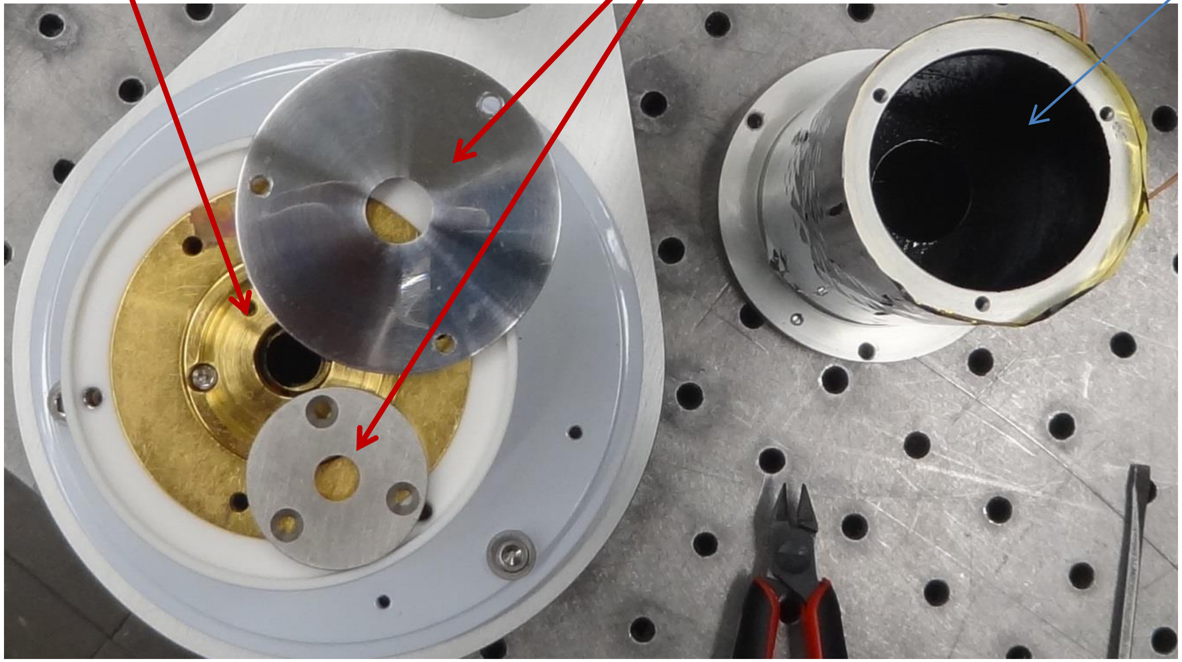
Fig. 3.3 Eppley Hickey-Frieden System Diagram

NIST Eppley AHF taken apart

Cavity Reflectance measured

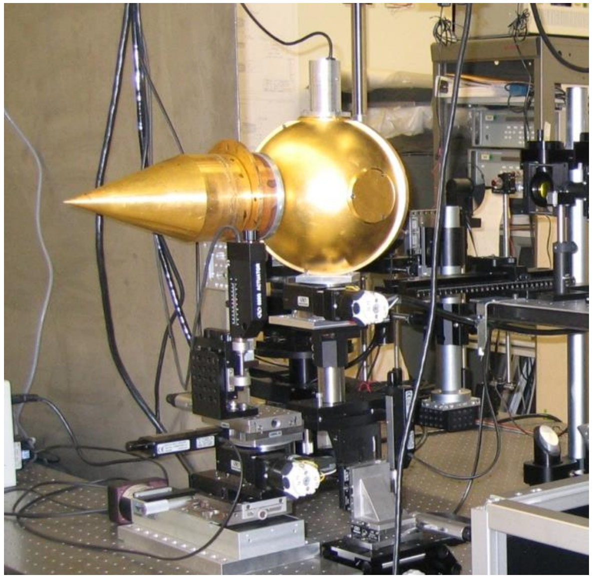
Apertures measured

Baffle scatter measured

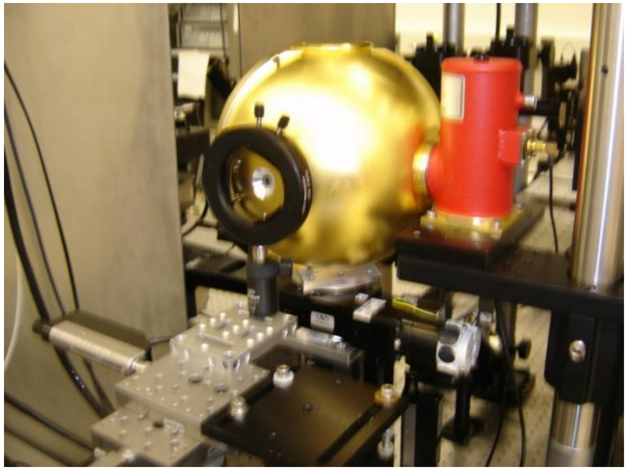


Complete Hemispherical Infrared Laser-based Reflectometer

Rear View w/ Water Bath Cavity



Front View of Sphere

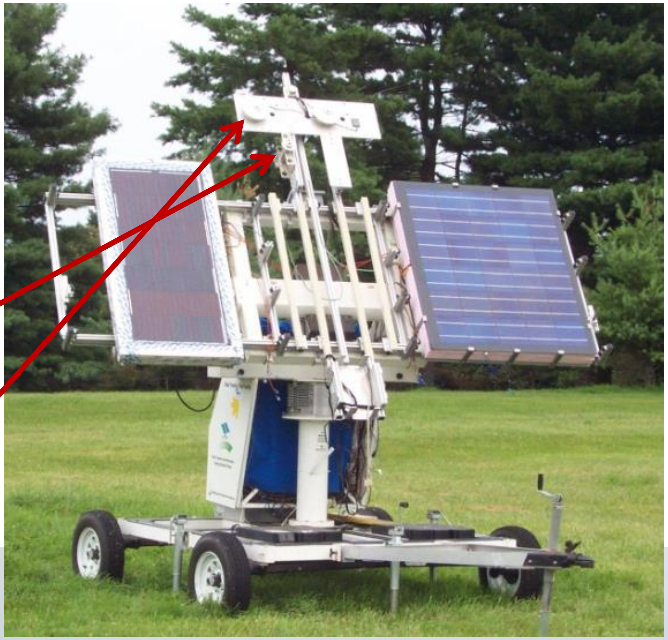


- Can measure reflectance down to approx. 10^{-5} (equivalent to emissivity 0.99999)
- Reflectance expanded uncertainties currently 15 - 20% for 10^{-3} to 10^{-5} range

Calibration of Field Instruments

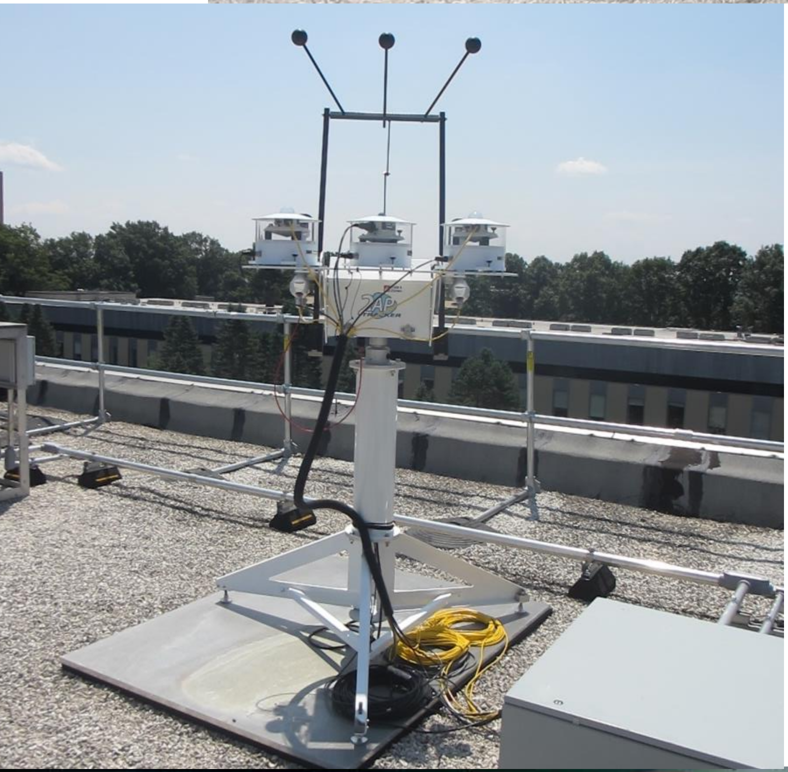
Absolute Cavity Pyrheliometer

Commercial Pyrheliometer



Pyranometer

Measurements on the Rooftop Meteorological Station (EL)

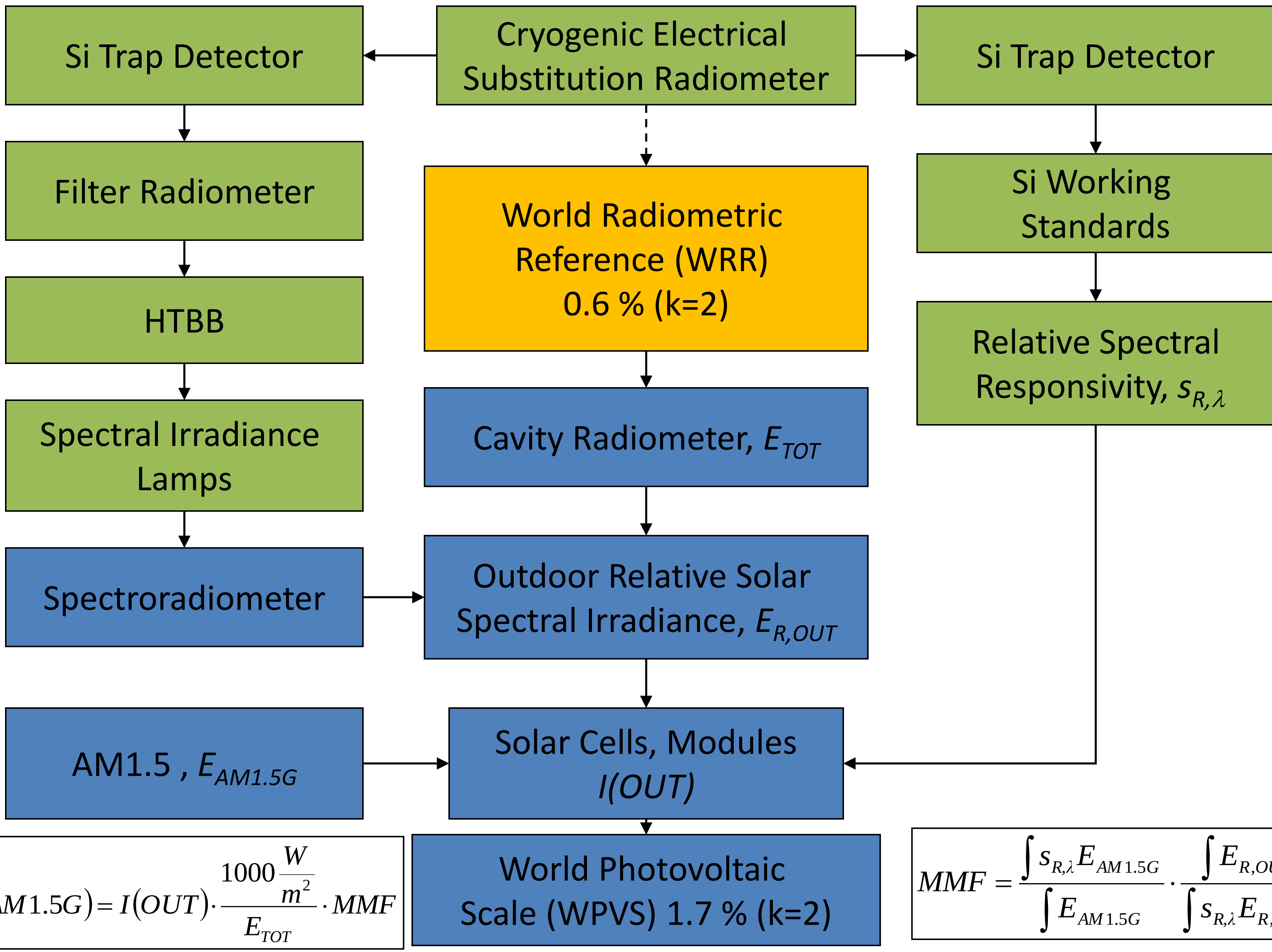


- Solar Irradiance
  - Global Horizontal
  - Beam
  - Diffuse Horizontal
- UV and Long-wave Radiation
- Spectral Irradiance – Global Horizontal
- All Sky Camera
- Wind Speed & Direction
- Air Temperature, Pressure, Rel. Humidity
- Rain & Snow Accumulations

3. Solar Energy

1. Global Sunlight Method (NREL)

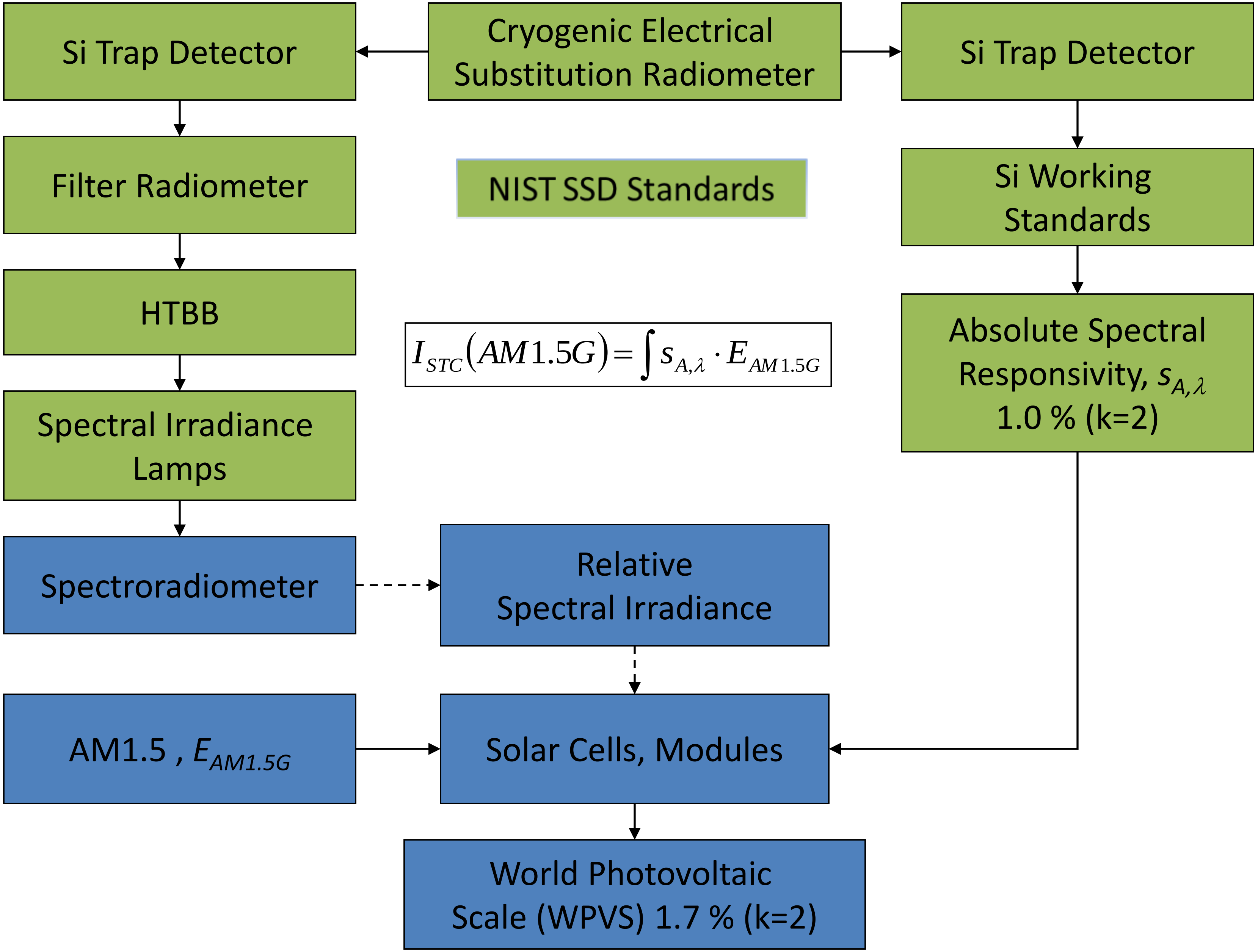
NIST SSD Standards



$$I_{STC}(AM1.5G) = I(OUT) \cdot \frac{1000 \frac{W}{m^2}}{E_{TOT}} \cdot MMF$$

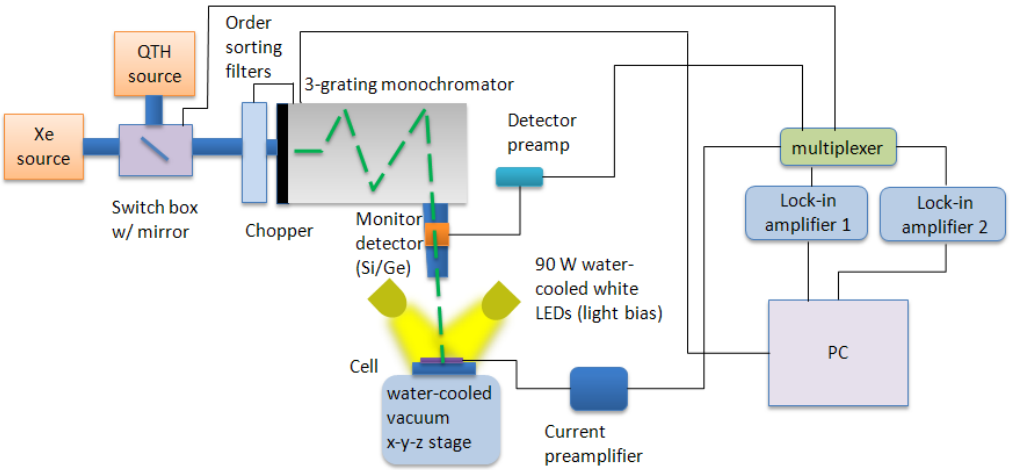
$$MMF = \frac{\int s_{R,\lambda} E_{AM1.5G}}{\int E_{AM1.5G}} \cdot \frac{\int E_{R,OUT}}{\int s_{R,\lambda} E_{R,OUT}}$$

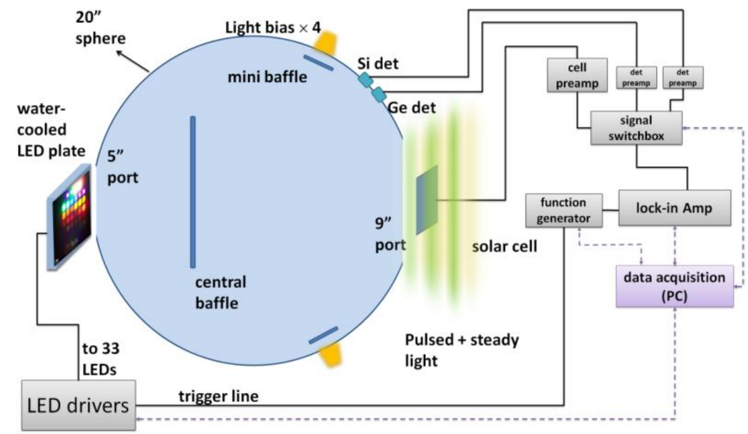
2. Differential Absolute Responsivity (DSR) NIST Method



Differential Irradiance Spectral Responsivity (DSR) measurement facility, NIST EL

Monochromator-based DSR system combined with LED-based integrating sphere system
Suitable for relatively large device areas





Monochromator-based system:

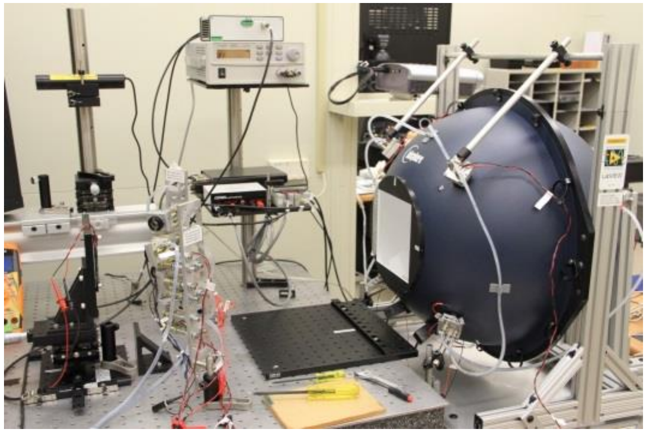
- Dual (Xe and QTH) light source
- Calibration range: 300 nm – 2500 nm
- Custom current preamp capable of separating dc and ac components.
- Light bias currents up to 1.6 A
- 2 lock-in amplifiers for simultaneous measurement of cell and monitor detector response

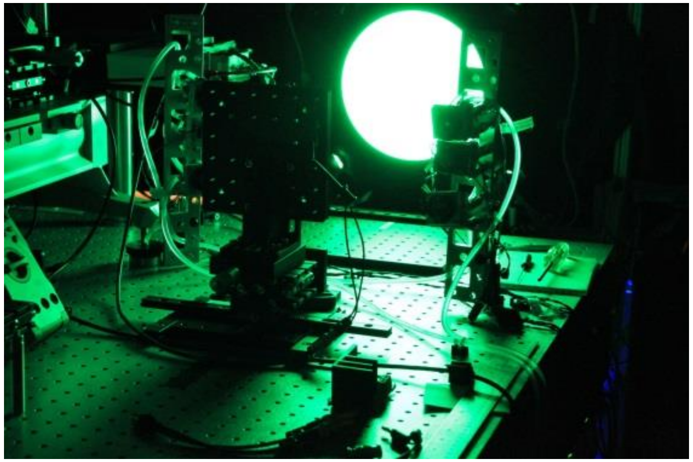
LED-based integrating sphere system:

- 33 unique monochromatic LEDs covering the wavelength range 360 nm – 1200 nm
- LEDs are pulse modulated sequentially.
- White and IR LEDs operated in DC for light bias
- Output port diameter of 22.9 cm
- Si and Ge monitor detectors.
- Lock-in based measurement

Behrang Hamadani, Brian Dougherty, EL

NIST EL DSR system images



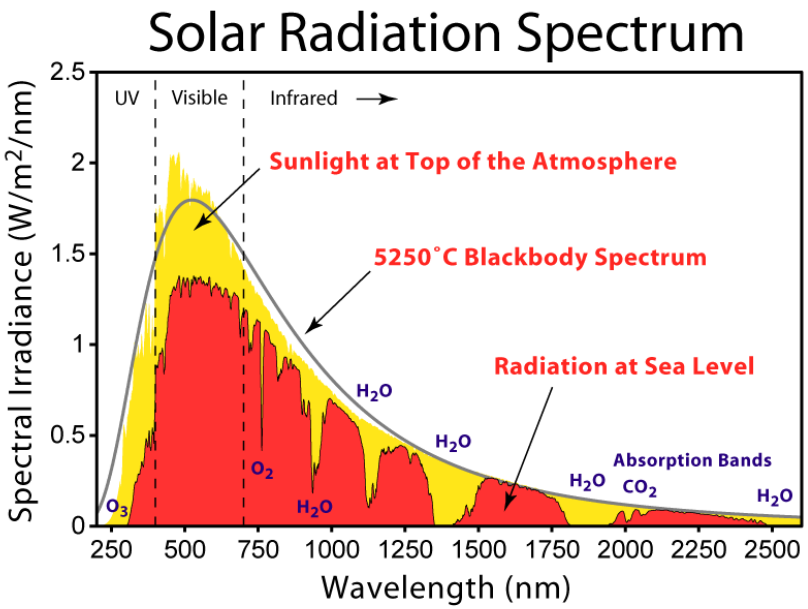


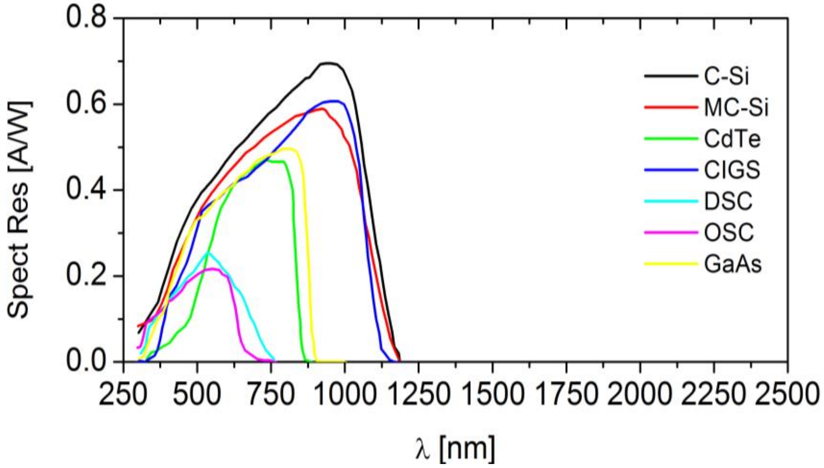
- Currently under final testing and evaluation
- Preliminary measurements have demonstrated excellent performance
- The LED sphere-based system used for determining the irradiance scale.
- Intercomparisons with international NMIs ongoing.

Spectral responsivity

Solar cell spectral responsivity R(λ): *The measurement of the wavelength dependence of the photocurrent relative to the # of incident photons.*

$R(\lambda) = I_{ph}(\lambda)/P(\lambda)$





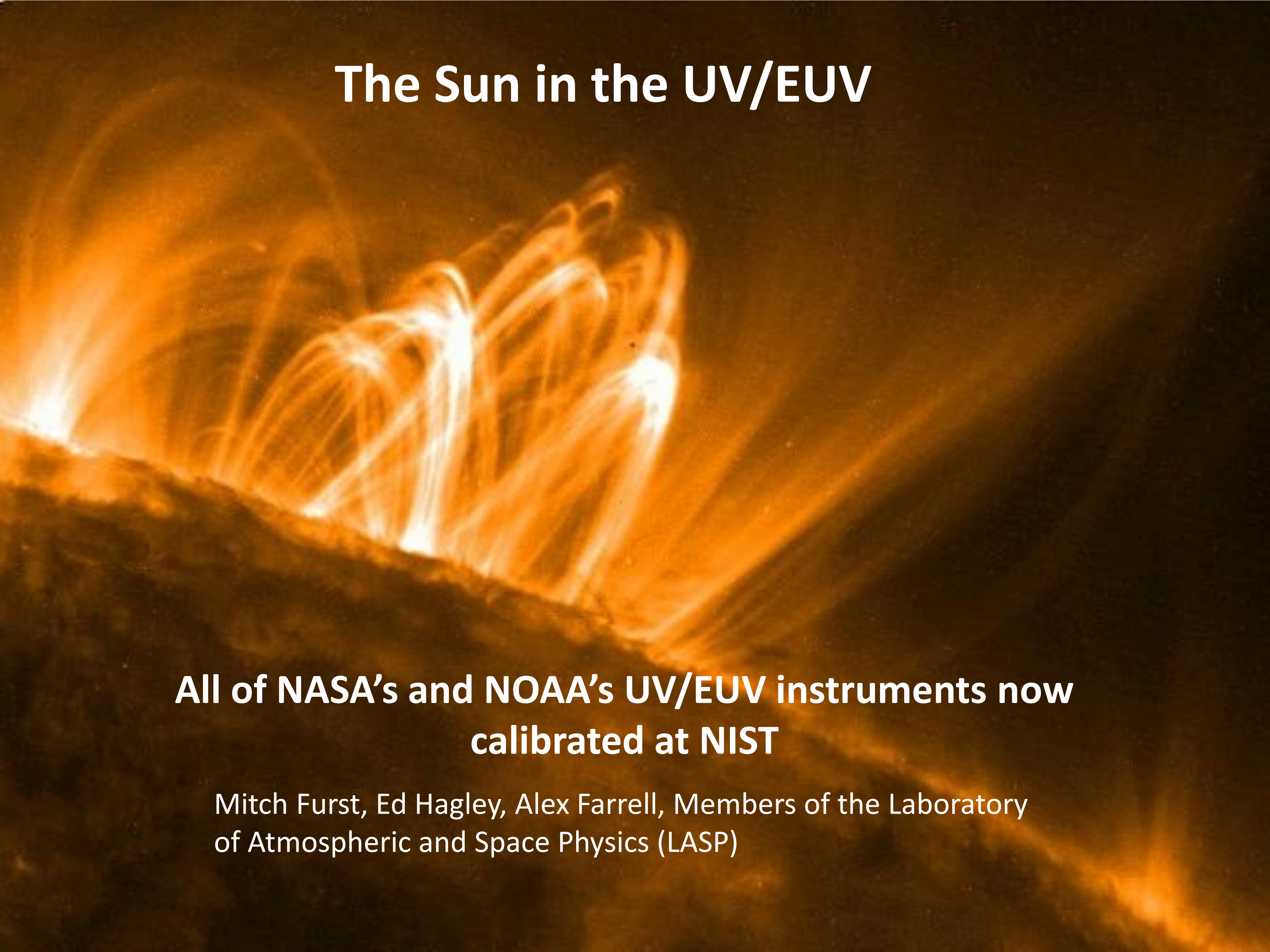
Cell ID	I_{sc} [NIST measurement]	Certification Laboratory [21]	I_{sc} [Certification Laboratory]	Percent Difference
VLSI10510-0193	125.03 ± 0.92 mA	VLSI Standards	125.6 ± 1.8 mA	0.45 %
VLSI10540-0144	134.2 ± 1.02 mA	VLSI Standards	134.3 ± 1.9 mA	0.074 %
US1	10.02 ± 0.076 mA	NREL	9.9985 ± 0.09099 mA	0.21 %

NIST Solar simulator (EL) for solar module testing

1. IEC Standard 60904-9 Class AAA Simulator
   A. Spectral match: 0.75-1.25 for 6 wavelength-intervals
   B. Irradiance non-uniformity: ≤ ±2 %
   C. Irradiance temporal instability: ≤ ±2 %
2. Flash Plateau: 36 ms
   A. IV scan interval: ≤ 1 ms
   B. Variable scan delay : 1 – 12 ms
3. Irradiance Range: ~ 500 – 1100 W/m^2
4. Maximum irradiated area: 2.4 m diagonal
5. Spectral composition filter

Measurements at Campus Solar Arrays

4. Exo-atmospheric solar EUV and UV measurements



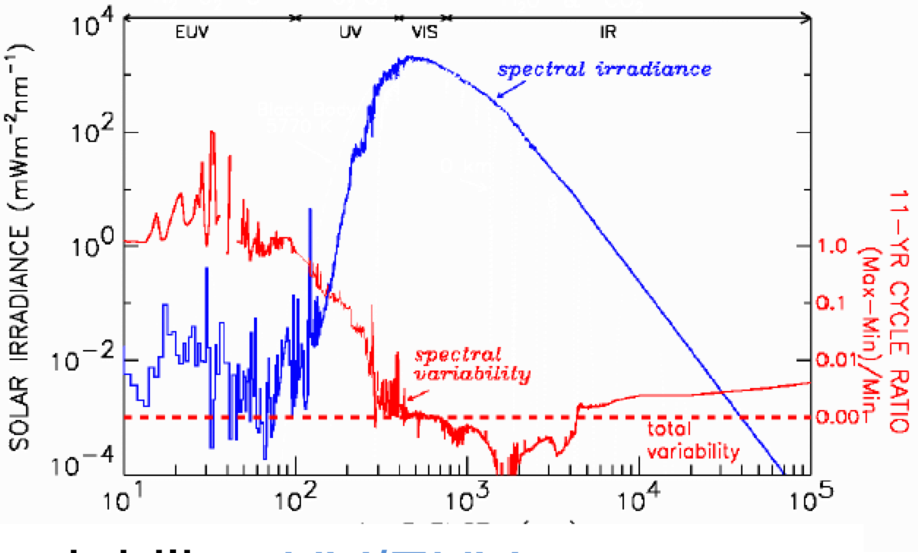
The Sun in the UV/EUV

All of NASA's and NOAA's UV/EUV instruments now calibrated at NIST

Mitch Furst, Ed Hagley, Alex Farrell, Members of the Laboratory of Atmospheric and Space Physics (LASP)

UV/EUV and Earth Climate

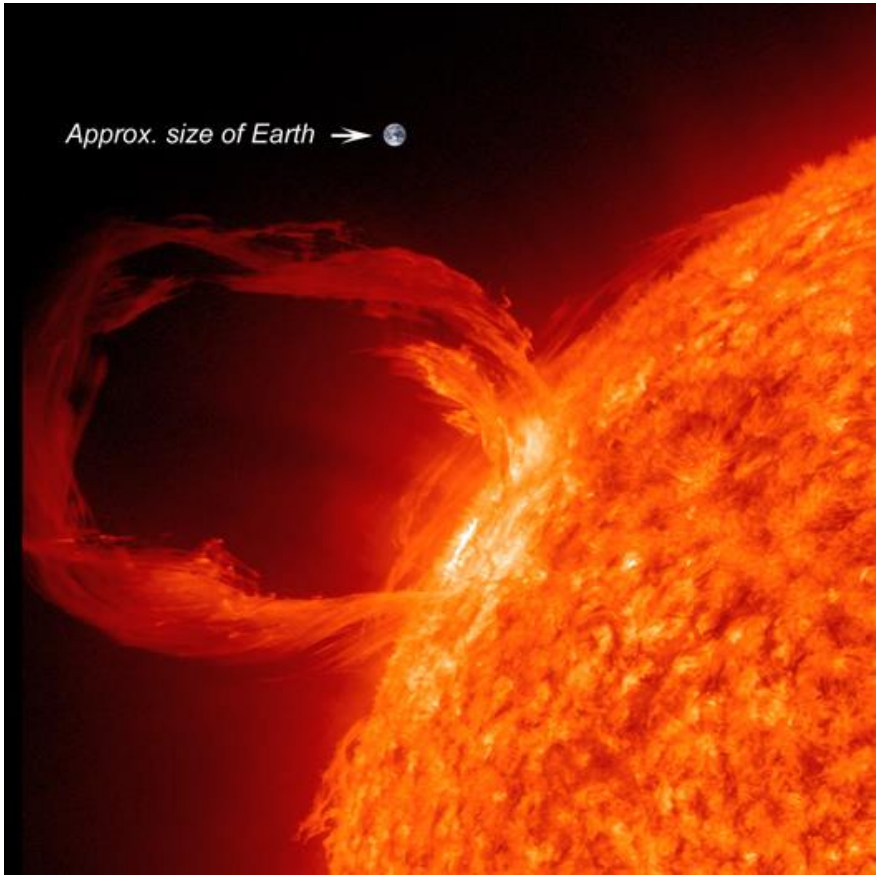
- Top-down heating of the earth's surface & ozone production: Radiation from 120 – 200 nm absorbed in mesosphere layer; radiation from 200 – 320 absorbed in stratosphere layer.



- Sensitive measure of Solar variability: UV/EUV accounts for <0.1% of TSI but ≈ 1/3 of TSI variation.
- Historical record of Solar variability: Data on Mg II line at 280 nm recorded since 1978.
- Accurate time sequence of Solar variability of TSI important for separating out impact of Solar variation (from GHG & other forcings) on surface temperature in climate model.

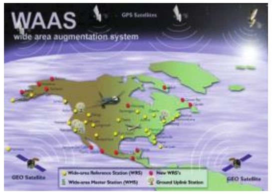
EUV monitoring of the Sun's Dynamics

- Best observed by monitoring in EUV (2 – 120 nm)
- Important in modelling Sun Climate
- Important in the "nowcasting" and forecasting of space weather

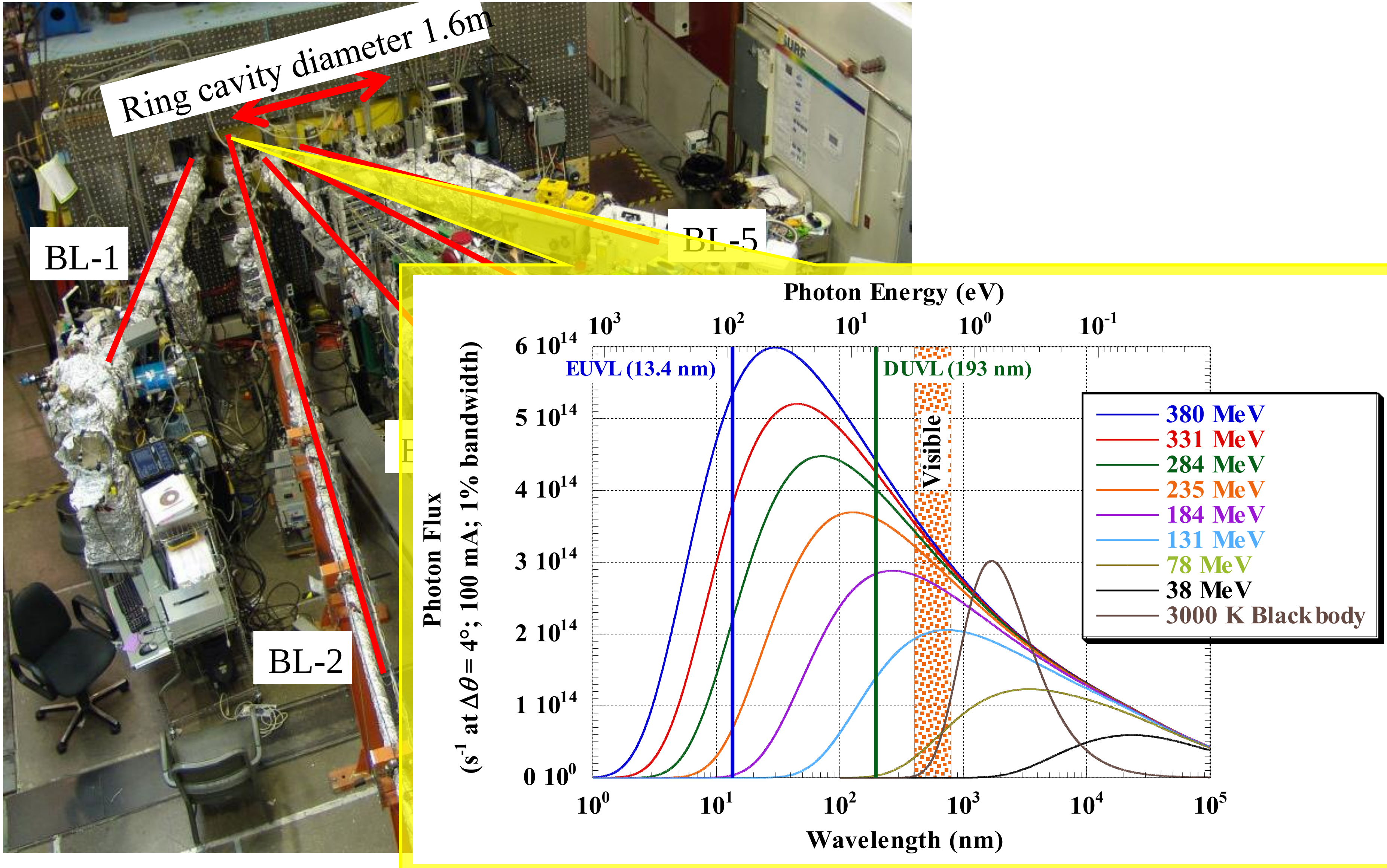


Impacts of Space Weather

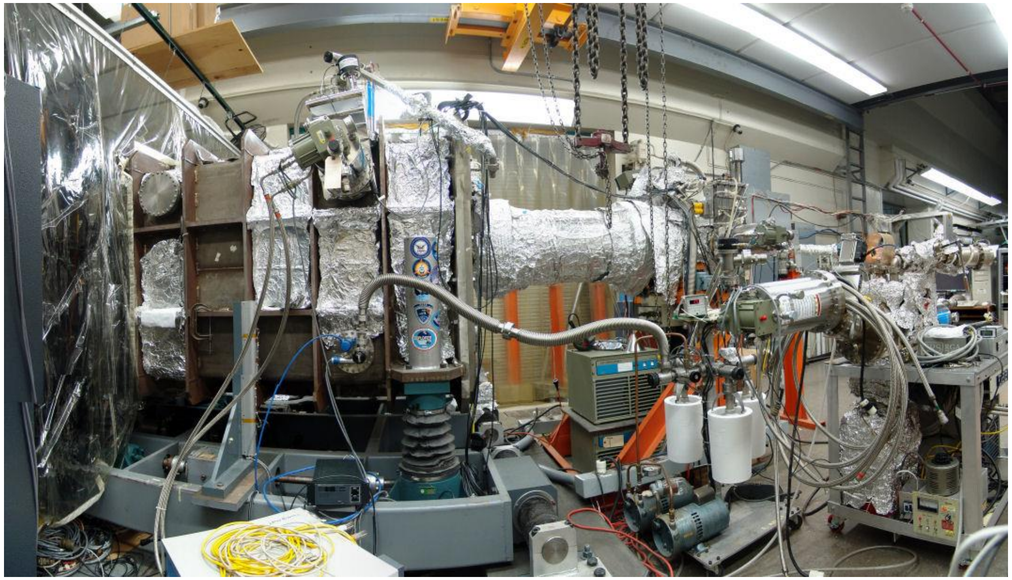
- **Space Weather Effects:**
  - Satellite tracking
  - Satellite operations
  - Navigation
  - GPS location
  - Ground-space communications
  - Ground-ground communications
  - Total Electron Content
- **Some specific users:**
  - NASA
  - Military (all branches, but specifically AFWA, NORAD)
  - Shipping industry
  - Airlines
  - Commercial satellite industry
  - Power companies
  - Emergency responders
  - Space weather research community



Synchrotron Ultraviolet Radiation Facility (SURF III)



BL-2: Large chamber and clean room



Recent UV/EUV Calibrations at SURF III: Missions and Collaborators

Collaborators: NOAA; NASA Goddard Space Flight Center; Laboratory for Atmospheric & Space Physics; Naval Research Lab; USC Space Flight Center; Jet Propulsion Laboratory.

Summary

1. NIST has resolved and is working to resolve long-standing calibration issues in exo-atmospheric and surface solar measurements.
2. Continuing support for Climate Science Measurements at NIST is critical in understanding and mitigating issues due to climate change.