NIST Radiometry/Metrology/Perspective

in other words…

What does SI Traceability Mean for Radiometry from Space?

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Special thanks also to Jim Butler of NASA GSFC

Traceability According to the NIST Website

•"Traceability requires the establishment of an **unbroken chain** of comparisons to stated references."

•Here an "**unbroken chain** of comparisons" means:

"the complete, explicitly described, and documented **series of comparisons** that successively link the value and uncertainty of a result of measurement with the values and uncertainties of each of the intermediate reference standards and the highest reference standard to which traceability for the result of [the] measurement is claimed."

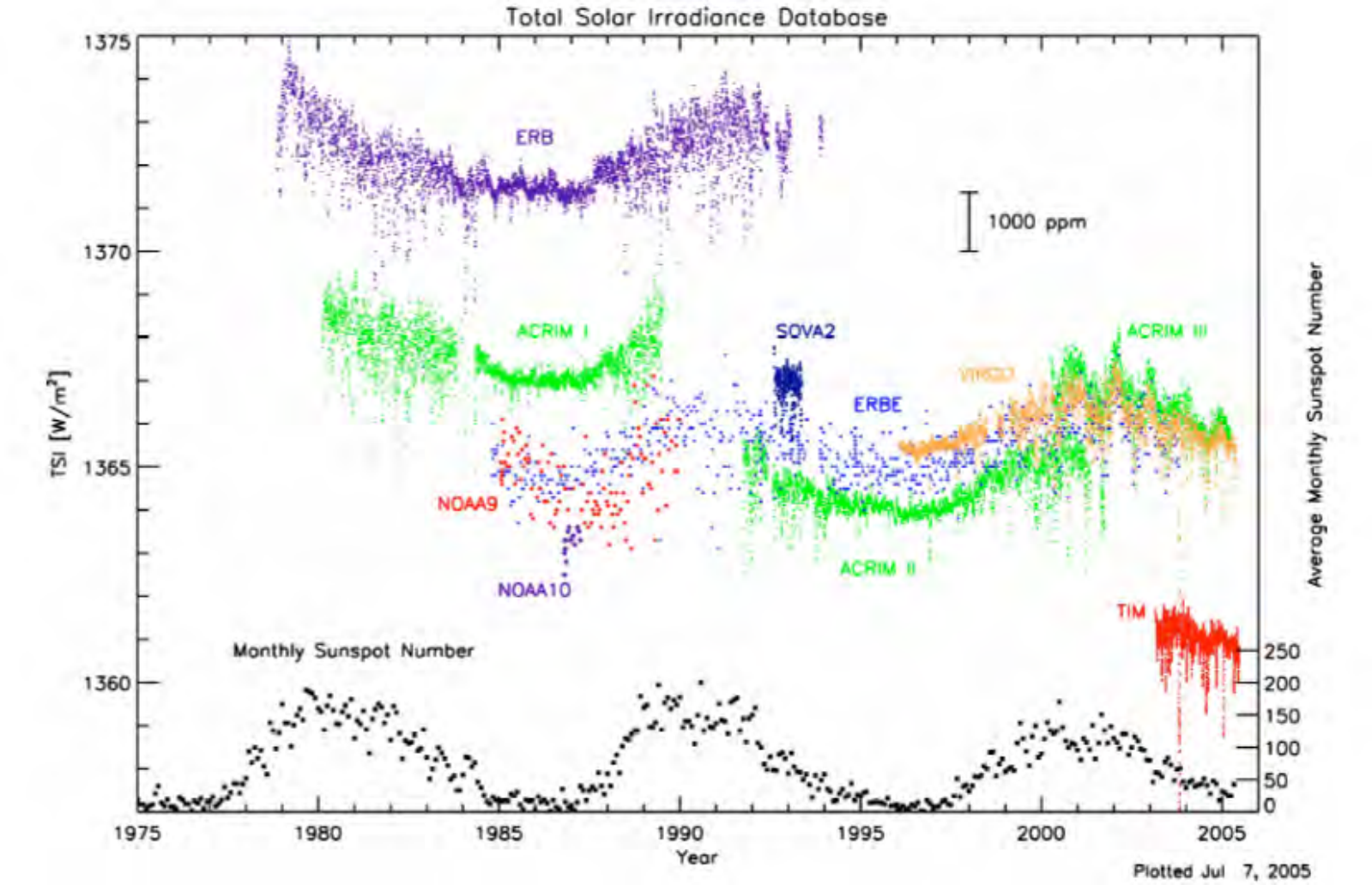
•"References" here means that having the "highest metrological quality available at a given **location**." (remember location, location, location?)

•QUESTION: How do we apply this when the **location** is … space?

•ANSWER: To start, let's look at some examples…to given lessons learned.

Reference: http://ts.nist.gov/Traceability/nist_traceability_policy-external.cfm

Example: Total Solar Irradiance (TSI)



From Greg Kopp's presentation at NIST/NASA TSI Uncertainty Workshop, July 2005

International Intercomparison of Cryogenic Radiometers

- Standards labs can measure responsivity of traps to <1 mW laser power to about 0.02%
- This was in the late 1990's, and NIST numbers are from HACR (predecessor to POWR).

BIPM report:

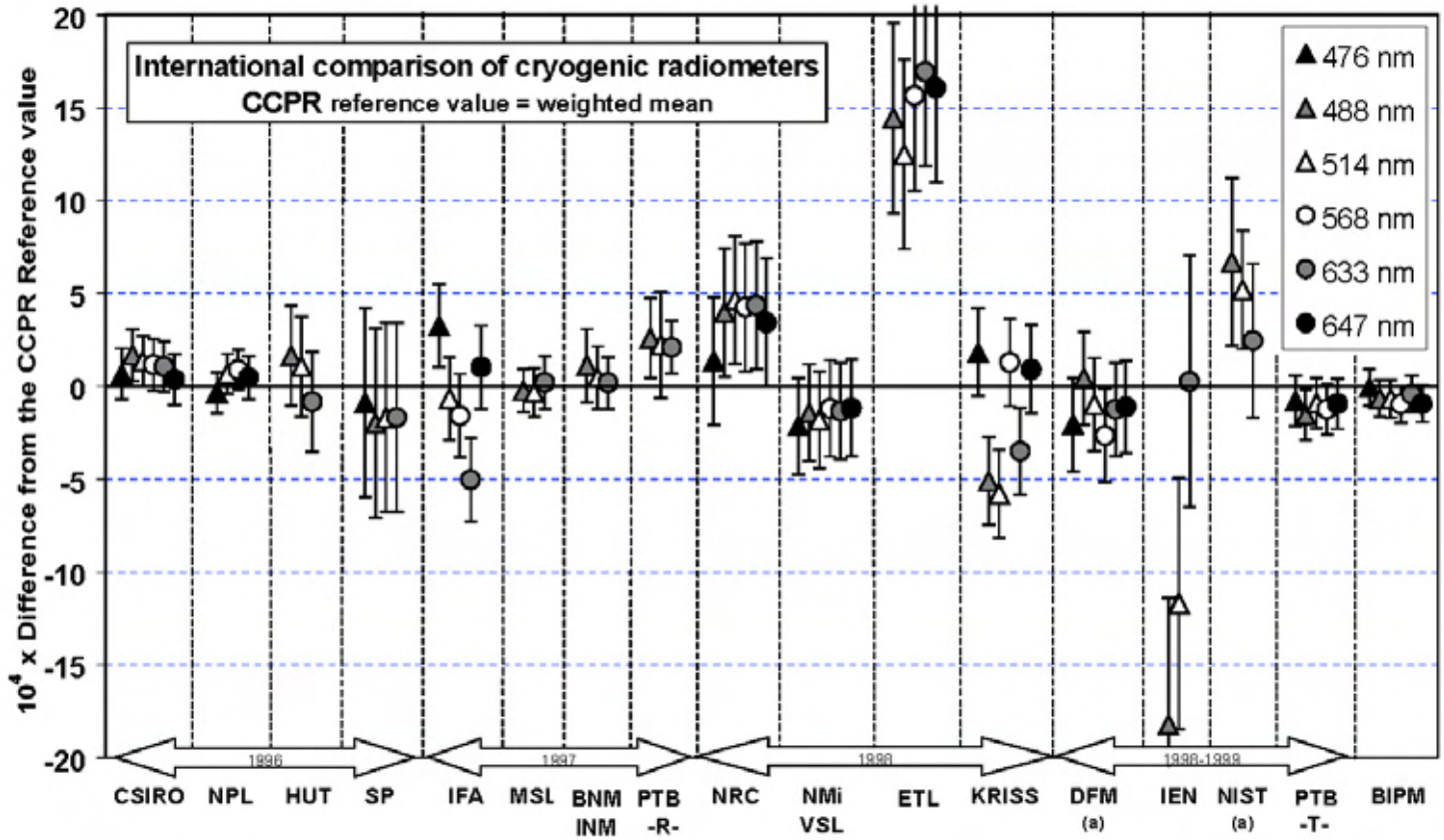
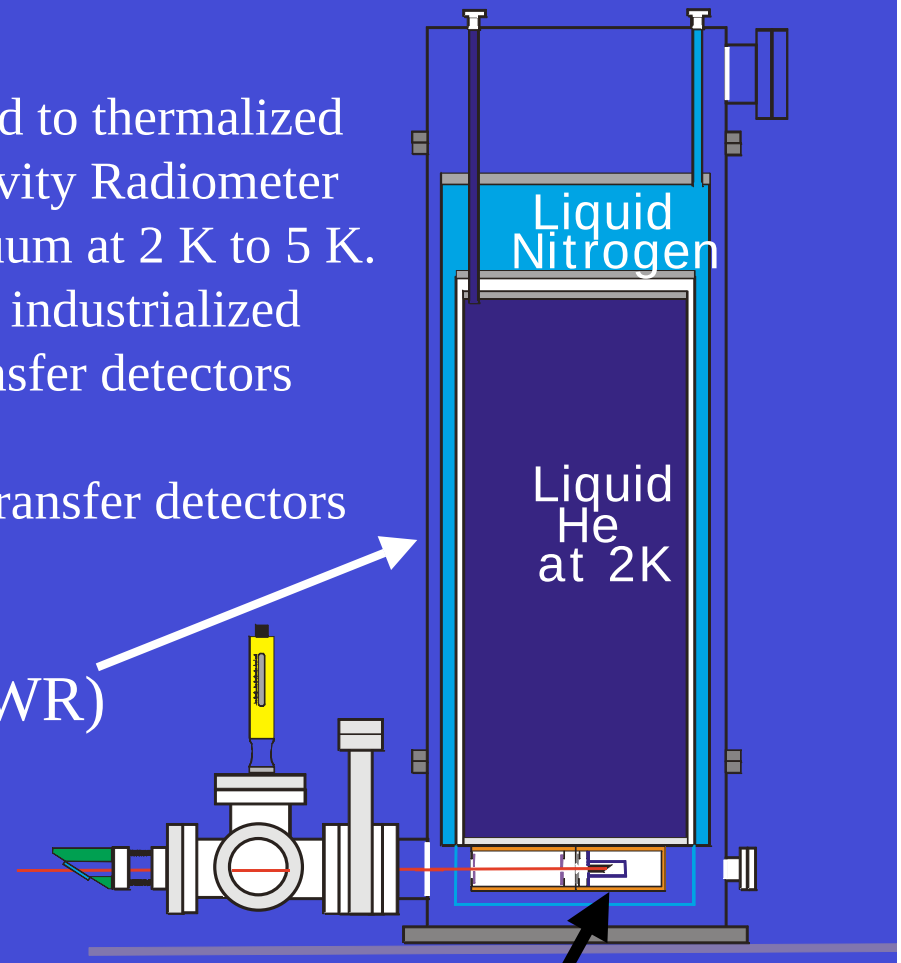


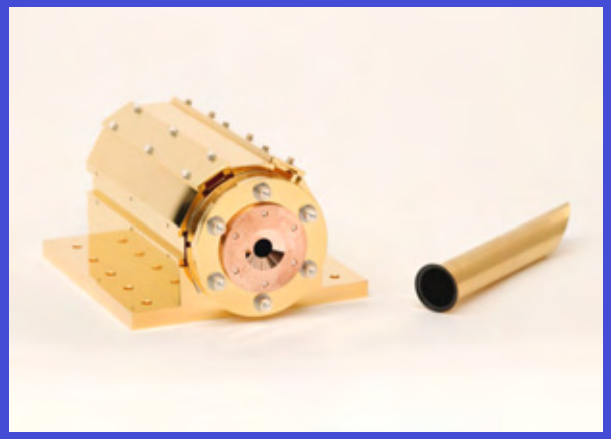
Figure 21 - Relative difference in the calibration of the transfer detectors (average value obtained from three transfer detectors per laboratory). The CCPR Reference value (zero line) is the weighted mean of the relative differences $(R_{LAB} - R_{BIPM})/R_{BIPM}$ calculated at each wavelength. The uncertainty bars combine the relative standard uncertainties from each laboratory and the uncertainty associated with the transfer. The acronyms PTB-R and PTB-T stand for PTB-Radiometry laboratory, and PTB-Temperature Radiation laboratory, respectively. Laboratories marked with a (a) have also participated in a previous round. The uncertainty associated with the reference is about 5 parts in 10^5.

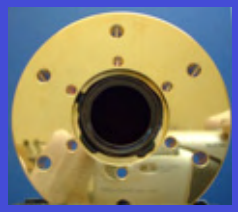
Cryogenic Electrical Substitution Radiometry

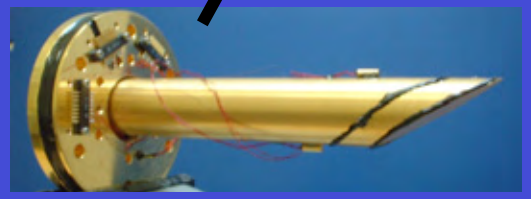
- Thermalized optical laser power is compared to thermalized electrical power in a black cavity: Active Cavity Radiometer
- Generally, active cavity radiometers in vacuum at 2 K to 5 K.
- Primary standard at NIST and in most other industrialized nations for optical power responsivity of transfer detectors such as Si-diode trap detectors
- Intercompared internationally via portable transfer detectors at 0.02% (k=2) uncertainty.



Primary Optical Watt Radiometer (POWR)







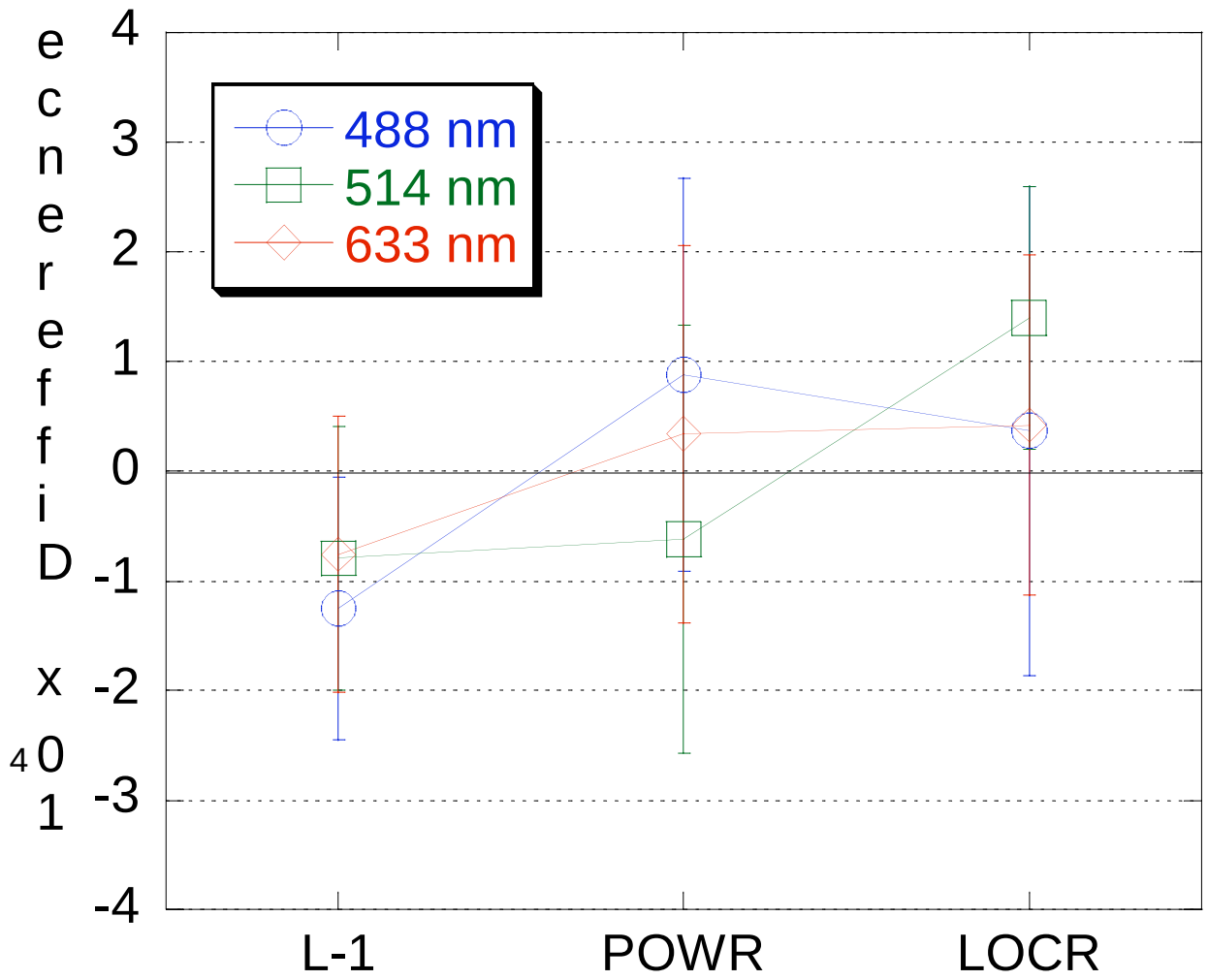
Uncertainty Budget for a Typical Measurement using POWR

- Example for 488 nm, power responsivity of a Si-diode trap detector
- Measurement equation:

$$R_t = \frac{V_t \alpha T_w}{P_H' NG} \frac{P_{meas}}{P_{true}}$$

Component	Symbol	Value	Uncertainty (ppm, 1-sigma)
Raw Measured Responsivity (V/W)	V_t/P_H'	3917.612	34
Cavity Absorptance	α	0.9999953	0.2
Optical/Electrical Equivalence	N	1	139
Electrical Power Scale	P_{meas}/P_{true}	1.000034	23
Window Transmittance	T_w	0.999764	38
Trap Spatial Uniformity		1	97
Trap Pre-amplifier Gain (V/A)	G	10000	10
Final Corrected Responsivity (A/W)	R_t	**0.391680**	**179**

Intercomparison of NIST Cryogenic Radiometers



One Lesson Learned from TSI

- Direct radiometric comparison: Shoot light* into the instrument before you launch it.

*The right kind of light: for TSI, full pupil uniform illumination, where you know the (at least relative) amount light.

Note: some instruments (for example, AIRS) basically did this sort of thing, at least for relative spectral calibration.

A Few Other General Lessons Learned

(based on last decade of reviewing and testing EOS and other instruments)

- End-to-end tests, if done right, give "better traceability" than piece parts scales.
  - Stray light (spectral and spatial) always gets you in the end.
  - When possible, do both. Independent routes to establish a scale is best.
  - Design the instrument with calibration in mind.

- Blackbodies can work well in the infrared, at least to 0.1 K 1-sigma.
  - But piece-parts approach to establishing traceability might be "broken".
    - Witness sample paint job may not be indicative of cavity: example: CrIS
  - Fixed point thermometry + on-orbit reflectance would be a welcome advance.

- Cavity radiometers can get 0.02% 1-sigma uncertainty, especially cryogenic.
  - SIRCUS and TRUTHS type concepts enable traceability to this in solar-reflected band.
  - Filter radiometers can be harder to calibrate than spectral instruments.

- In the solar-reflected band, look at the moon on orbit.

- Need preflight calibration, on-board calibrators, and, especially, **validation**…

Laboratory sources do not match reality very closely

We calibrate with uniform sources…

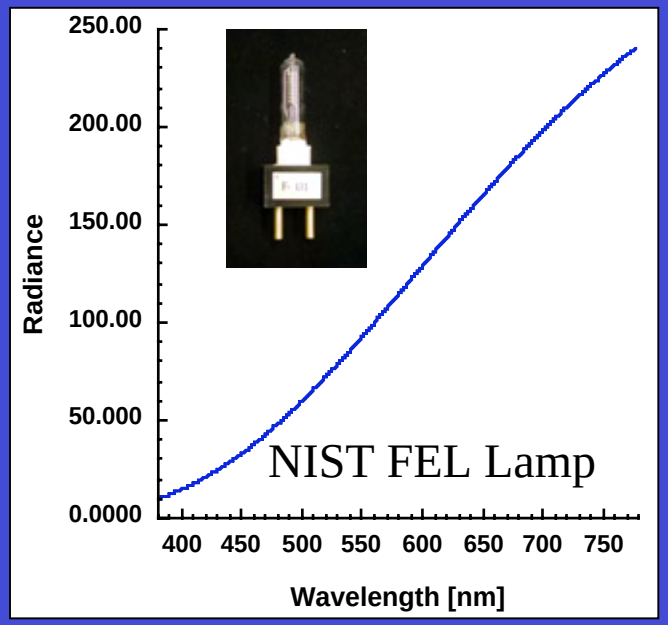
Example: lamp-illuminated integrating sphere for reflective bands, (or blackbody for emissive bands)

But reality is spatially non-uniform:

Example: AVIRIS image of North Island Naval Air Station, San Diego, CA

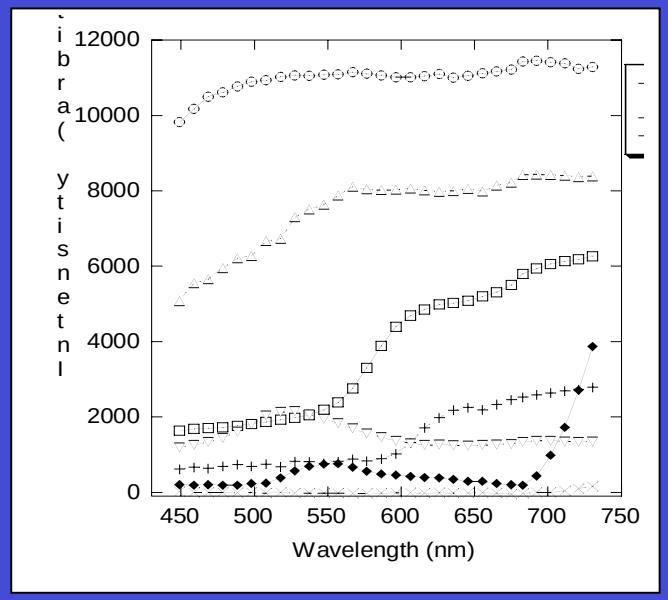
The same situation applies spectrally

Lamp standards peak in the near-infrared…



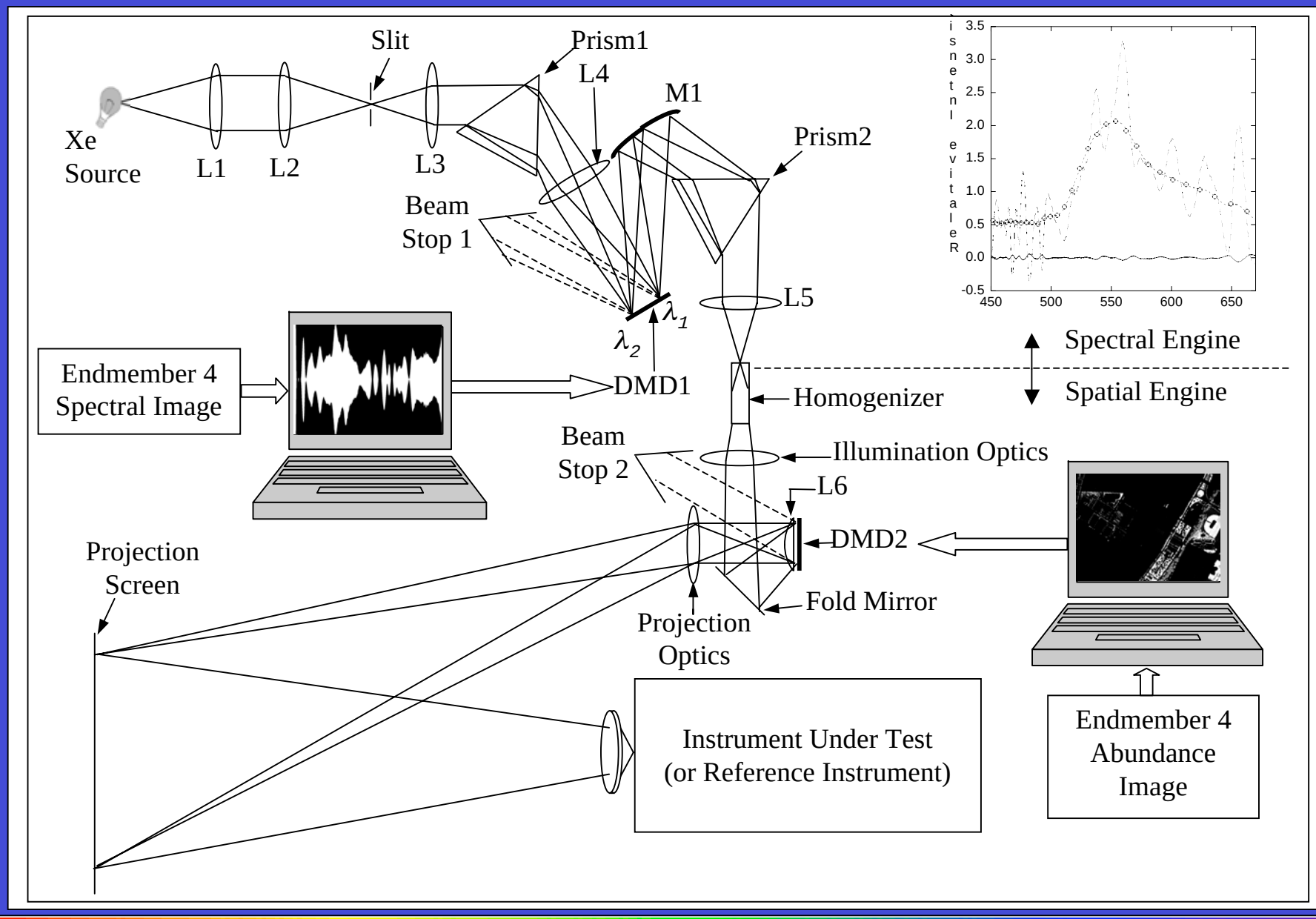
But reality has many different spectra…

Example: ENVI/SMACC was used to find these 7 endmember spectra from the San Diego Naval Air Station data cube.



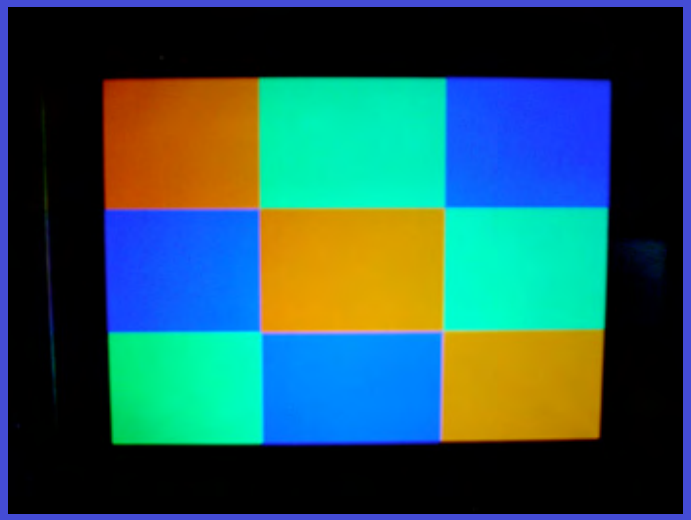
SMACC Reference: J. Gruninger, A. J. Ratkowski, and M. L. Hoke, "The sequential maximum angle convex cone (SMACC) endmember model," *Proc. SPIE* **5425**, 1-14 (2004).

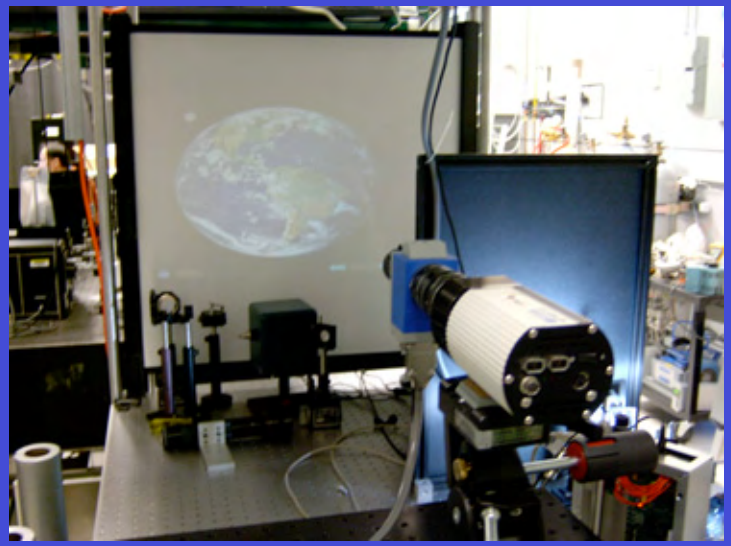
Hyperspectral Image Projector (HIP) Prototype



Example images as projected by the prototype HIP onto a white screen and taken using a digital camera

•HIP operated in 8 bit RGB mode for these images.





Summary

- SI Traceability appears to be a subjective requirement.
- NIST has no regulatory authority: you have to specify the details.
- Chain of comparisons can be broken, especially in space instruments.
- Rely on experience, and attention to details, to give balance.
- New developments at NIST are aimed at pre-flight validation with spectrally and spatially realistic sources, so at least we will know if it broken before you fly it.