Intercomparison of TSI Radiometers with Laboratory Cryogenic Radiometers: A Recommended Step

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Outline

- Background and current status of NIST laboratory radiometry
  - Optical power responsivity scales on cryogenic radiometers
  - NIST Primary Optical Watt Radiometer (POWR)
  - Recent power-mode intercomparison of NIST cryogenic radiometers

- Proposed method of intercomparison
  - Outline test procedure
  - What needs to be developed

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:

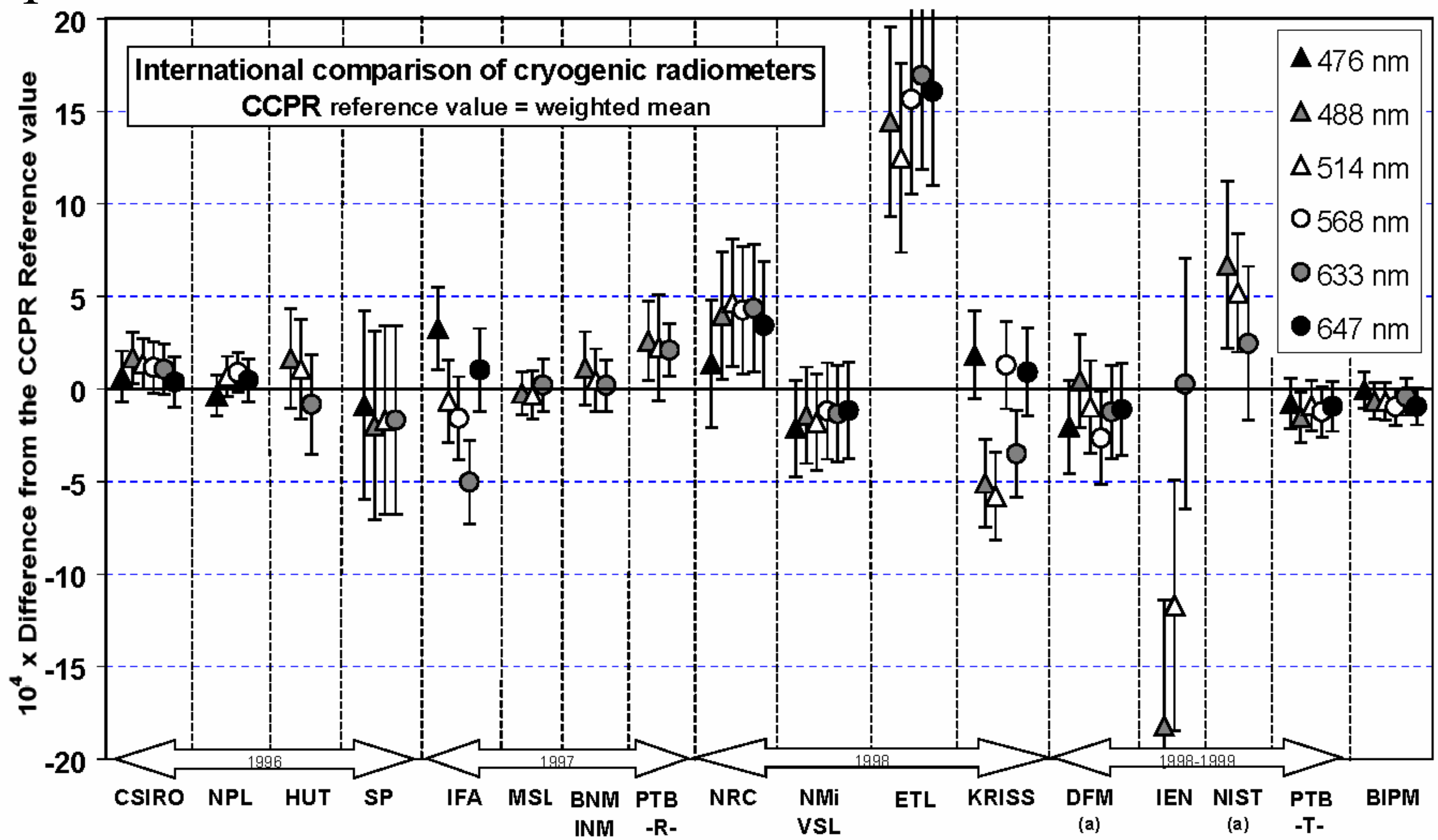

Figure 21 - Relative difference in the calibration of the transfer detectors (average value obtained from three transfer detectors per laboratory). The CCPR Reference value (zero line) is the weighted mean of the relative differences (R_{LAB} - R_{BIPM})/ R_{BIPM} calculated at each wavelength. The uncertainty 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.

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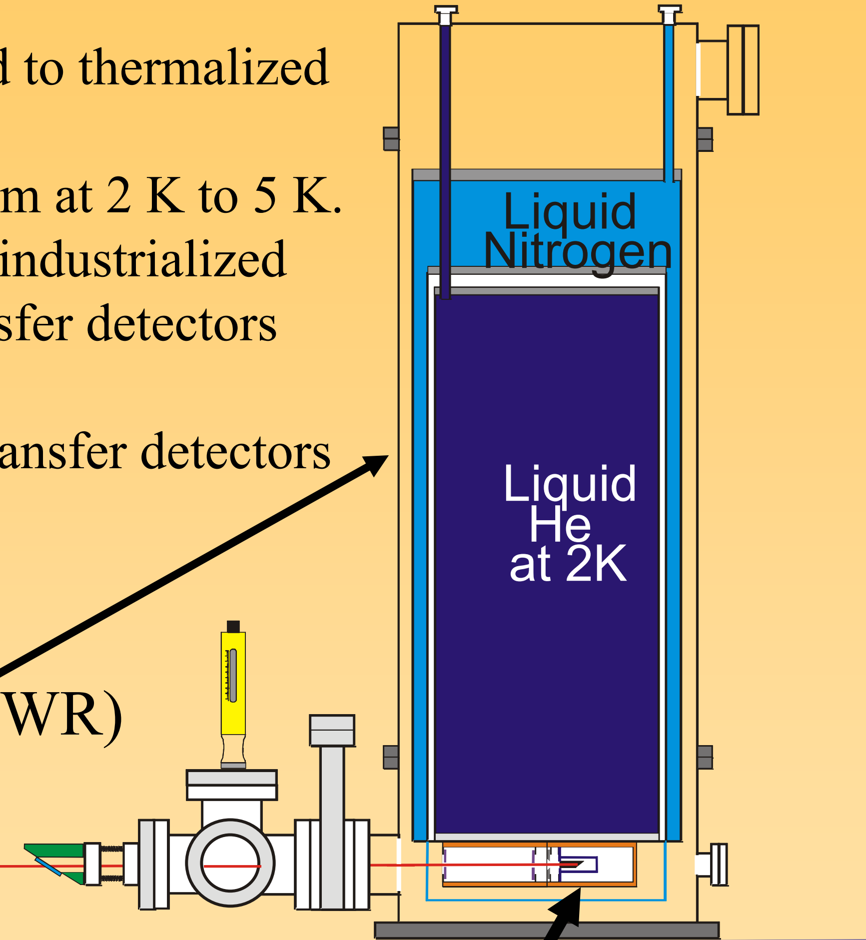
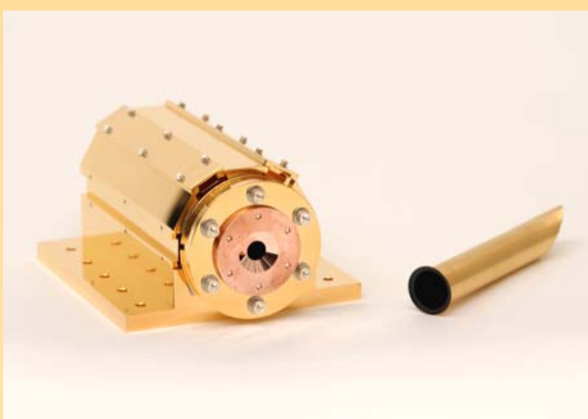
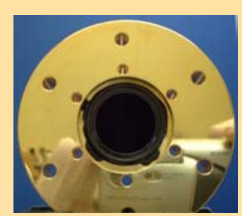
Cryogenic Electrical Substitution Radiometry

- Thermalized optical laser power is compared to thermalized electrical power in a black cavity.
  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.

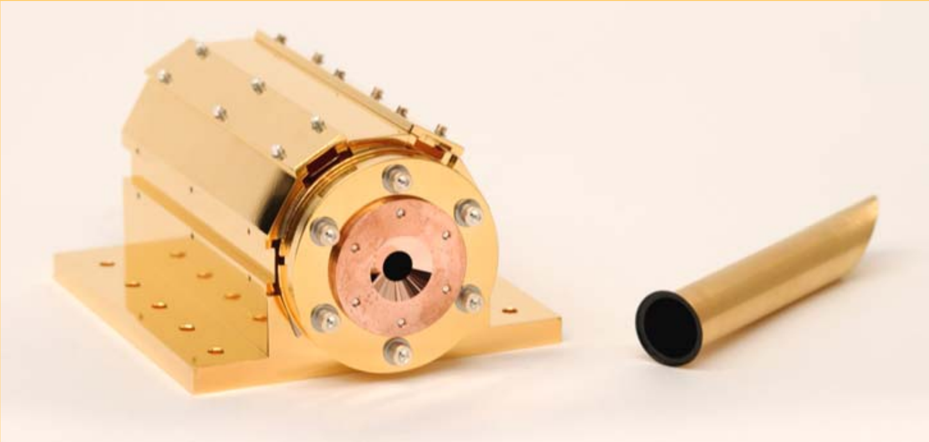


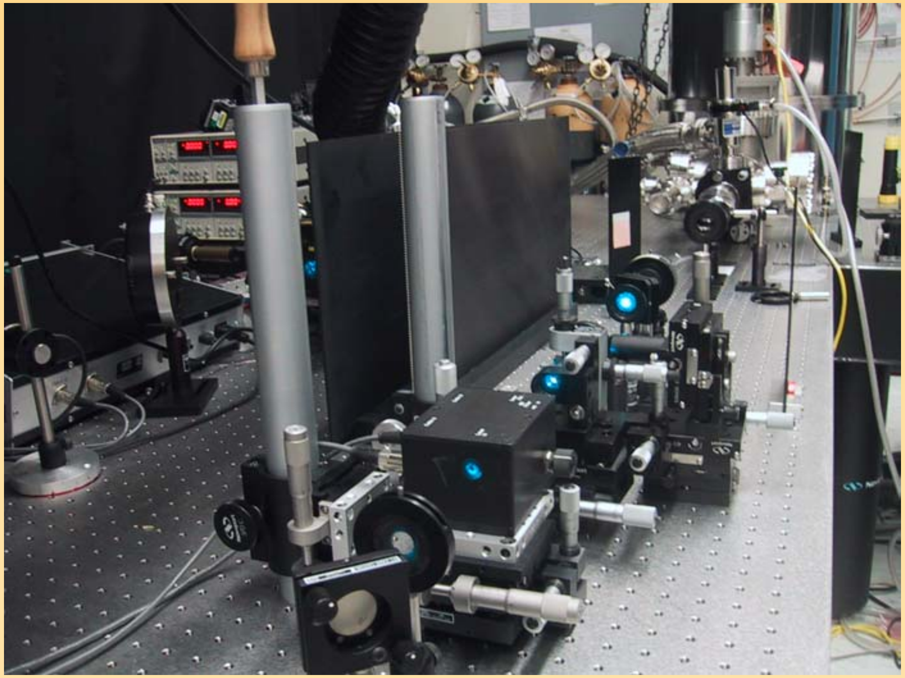
Primary Optical Watt Radiometer (POWR)



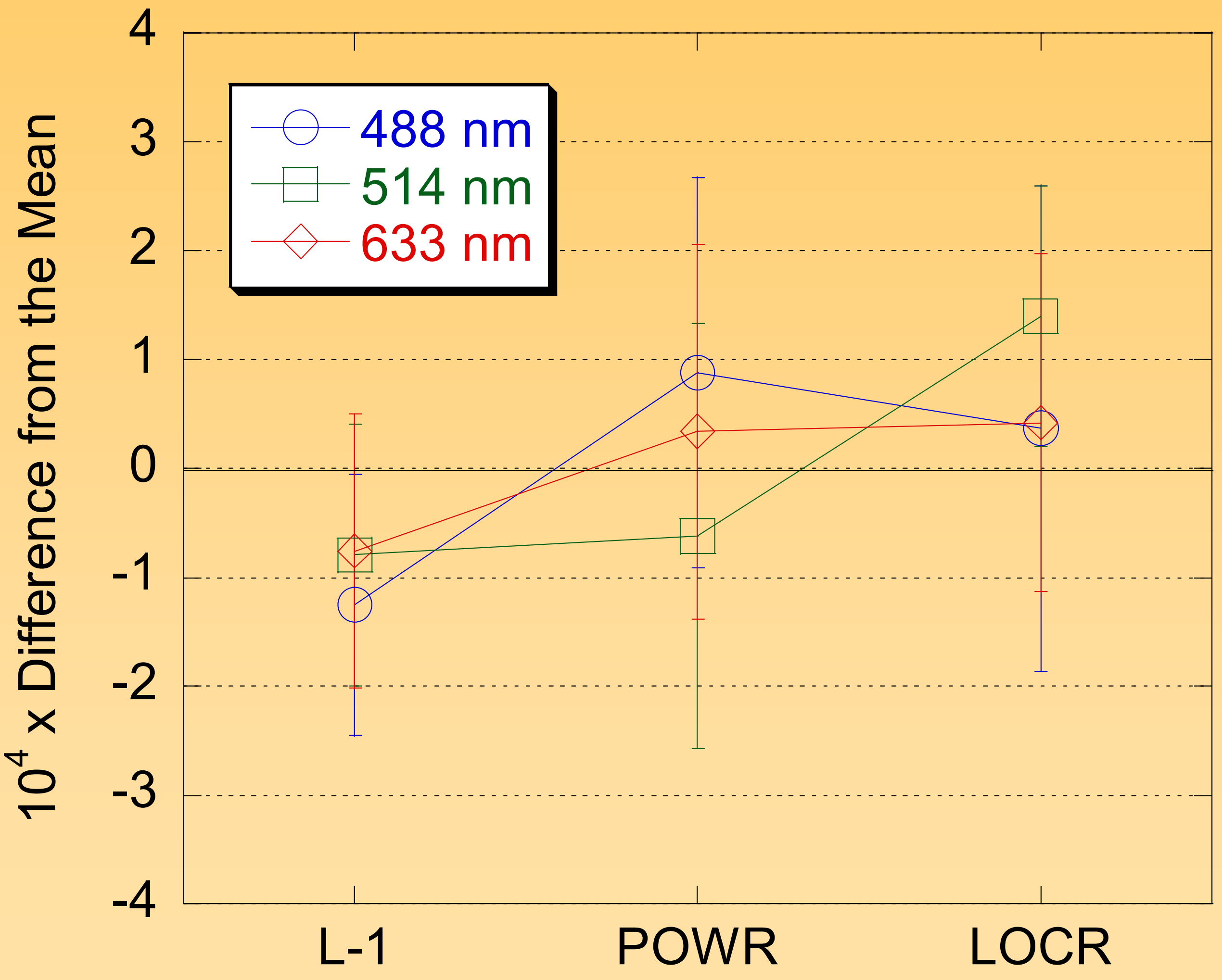


POWR: Primary Optical Watt Radiometer





Intercomparison of NIST Cryogenic Radiometers



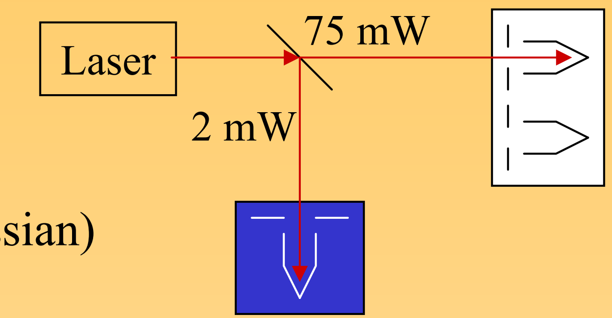
Uncertainty Budget for a Typical Measurement using POWR

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

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

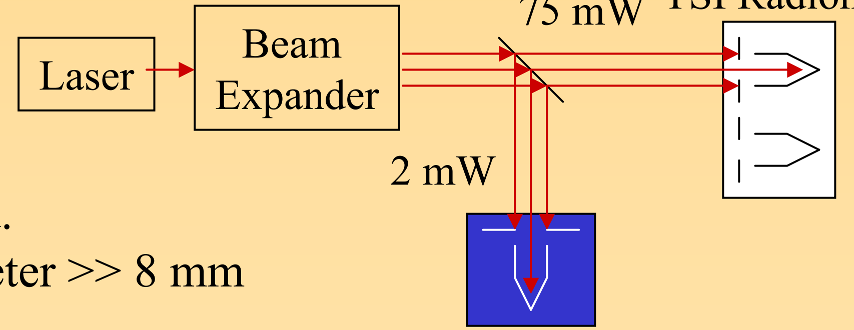
Component	**Symbol**	**Value**	**Uncertainty (ppm, 1-sigma)**
Raw Measured Responsivity (V/W)	V_t/P_H'	3917.612	34
Cavity Absorptance	α	0.9999953	0.2
Optical/Electrical Equivalence	N	1	139
Electrical Power Scale	P_{meas}/P_{true}	1.000034	23
Window Transmittance	T_w	0.999764	38
Trap Spatial Uniformity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

Laboratory Intercomparison



Cryogenic Radiometer Standard (POWR)
or Power-Mode Si-Diode Trap

- Power-mode: Beam underfills apertures.
- Laser is intensity-stabilized, spatially filtered.
- Beam diameter set to about 6 mm (at foot of Gaussian)
- Beamsplitter ratio measured with trap.
- Most straightforward approach.
- Main development is integration of TSI Radiometer into NIST vacuum chamber.



Cryogenic Radiometer Standard
(L-1 with cold standard aperture)
or Irradiance-Mode Si-diode Trap

- Irradiance-mode: Beam overfills apertures.
- Laser is intensity-stabilized, spatially filtered.
- An enhanced beam expander for beam diameter >> 8 mm
- In addition to integration of TSI Radiometer, need to develop beam expander and measurement details.

Conclusion

- Laboratory cryogenic electrical substitution radiometers are at or below 0.02% uncertainty.
- It is straightforward to compare with TSI radiometers in power mode, and possible in irradiance mode.
- We have outlined a plan to perform laboratory intercomparisons with TSI scales.
- We seek your scientific support to carry out the plan.

Additional Slides

A possible, More Complex Intercomparison Configuration

- Top-hat irradiance beam at TSI level used.
  - 10 W, 532 nm Gaussian-profile laser used.
  - Transformed to 3 cm diameter, 150 mW/cm^2 Top-hat profile.
- SIRCUS ACR used as for NIST standard irradiance radiometer.
  - Power mode uncertainty known to <0.02%.
  - Aperture area measured at NIST primary aperture area measurement facility, and change with temperature measured using see-through cryostat.
- TSI Module installed in POWR cryostat.
  - Capable of measuring up to 150 mW/cm^2 irradiance levels.
  - Fitted with an aperture having 0.5 cm^2 area.
- Y-bellows connects POWR cryostat to guest radiometer vacuum.
  - Both radiometers use the same window: Removes window uncertainty.

Proposed Intercomparison Procedure

1. Calibrate POWR TSI Module responsivity against SIRCUS ACR
   a. In irradiance mode at 532 nm, at 2 mW power level.
   b. Linearity of POWR TSI Module characterized up to 75 mW.
   c. Aperture area of SIRCUS ACR measured to high accuracy.
   d. In common vacuum.

2. Measure Guest TSI Radiometer against POWR TSI Module
   a. In irradiance mode at 532 nm, at 75 mW (e.g., 150 mW/cm^2).
   b. In common vacuum.

What needs to be developed

- POWR TSI Module
- Top-hat irradiance beam
- Y-bellows
- Aperture area vs temperature measurement