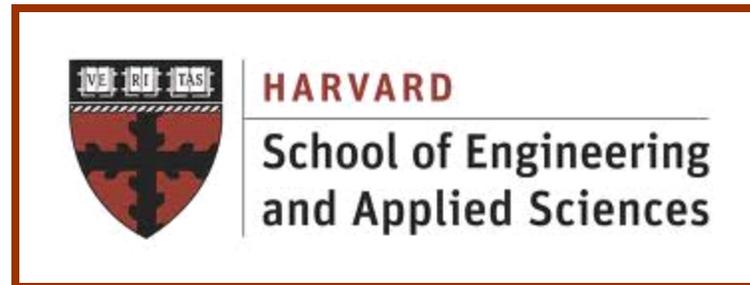
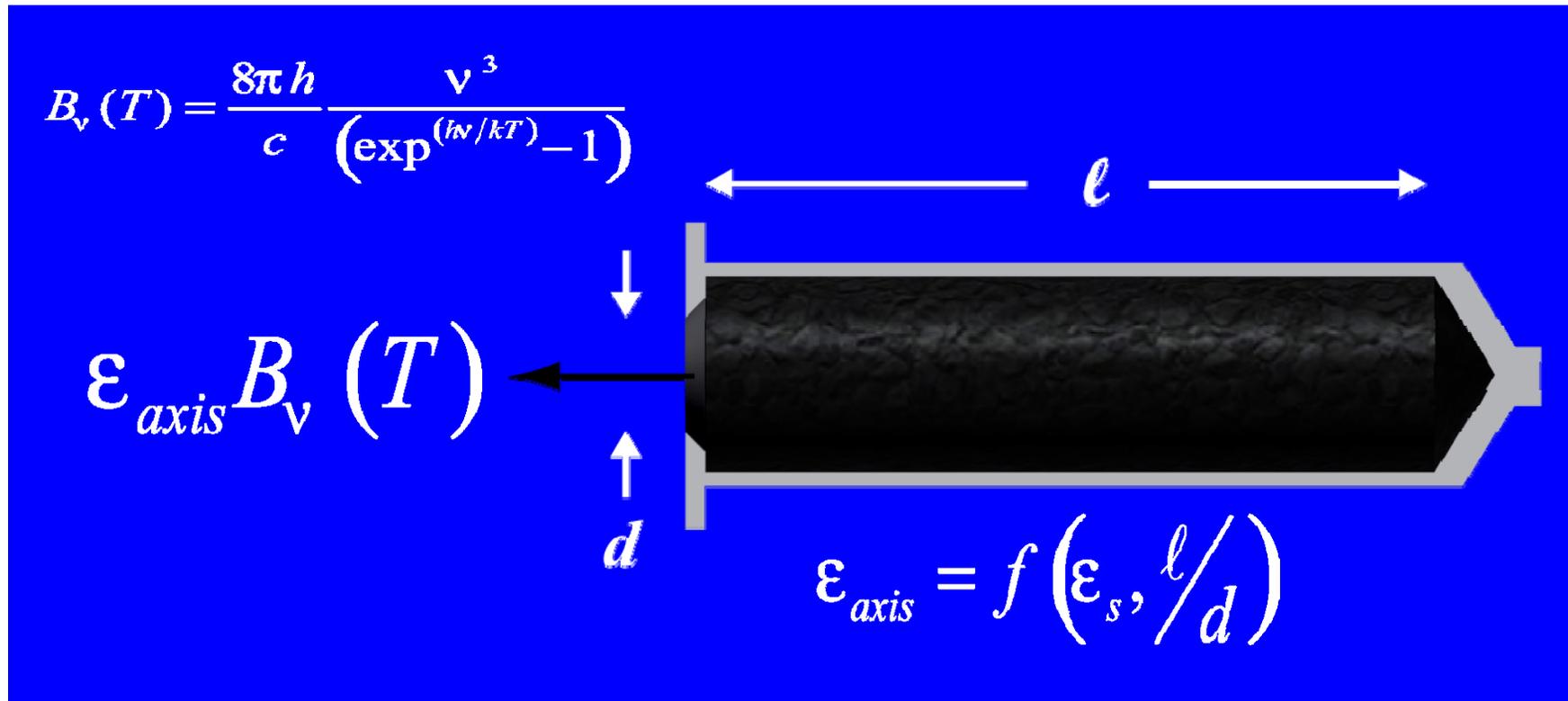


# SI traceability: relevant definitions and current implementations in the infrared

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**On-Orbit Blackbody:**

- Finite Aperture
- Temperature Gradient

Dykema and Anderson,  
*Metrologia* **43** 287 (2006)

# What is “traceability”?

*The 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**.*

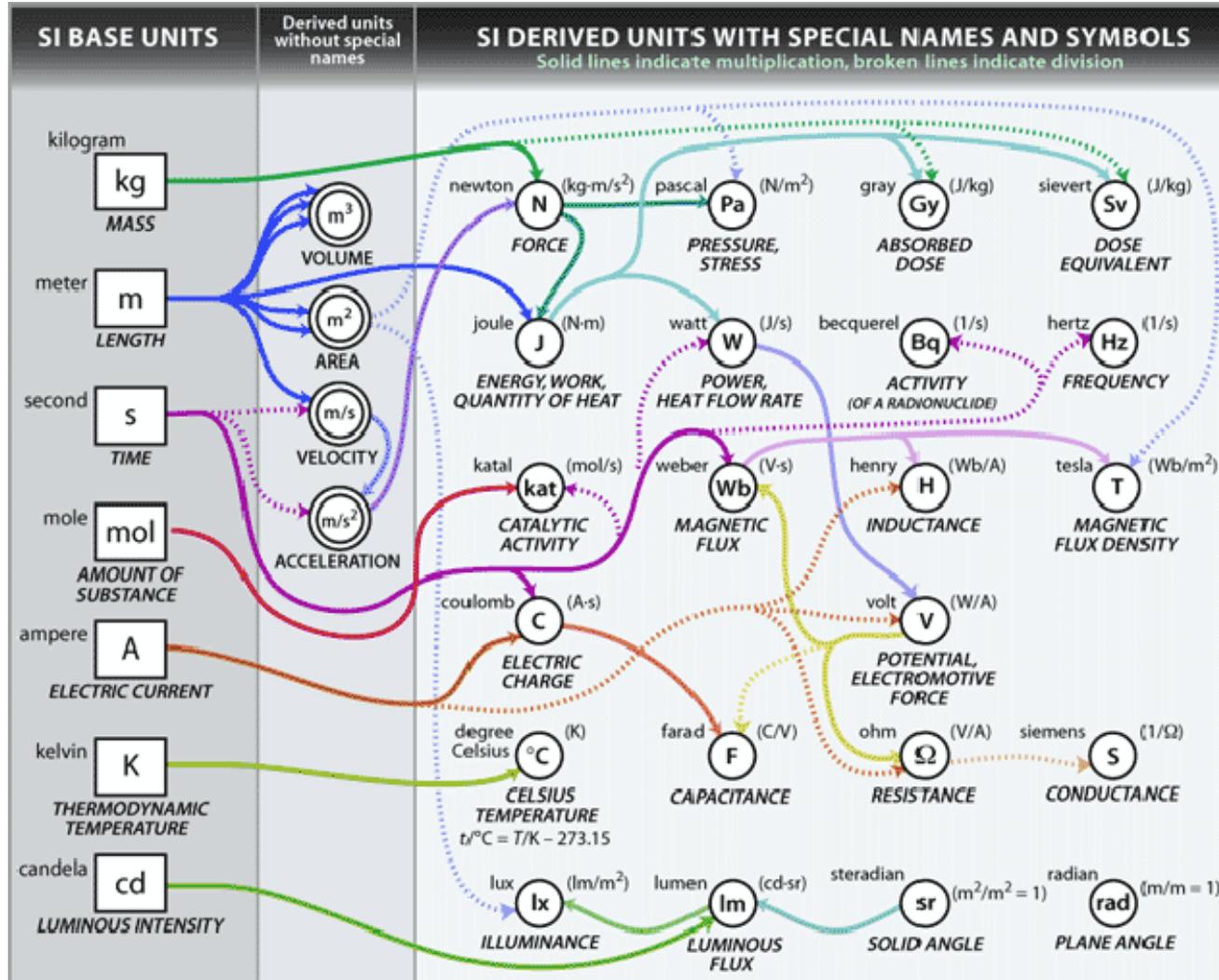


Figure courtesy Eric Shirley

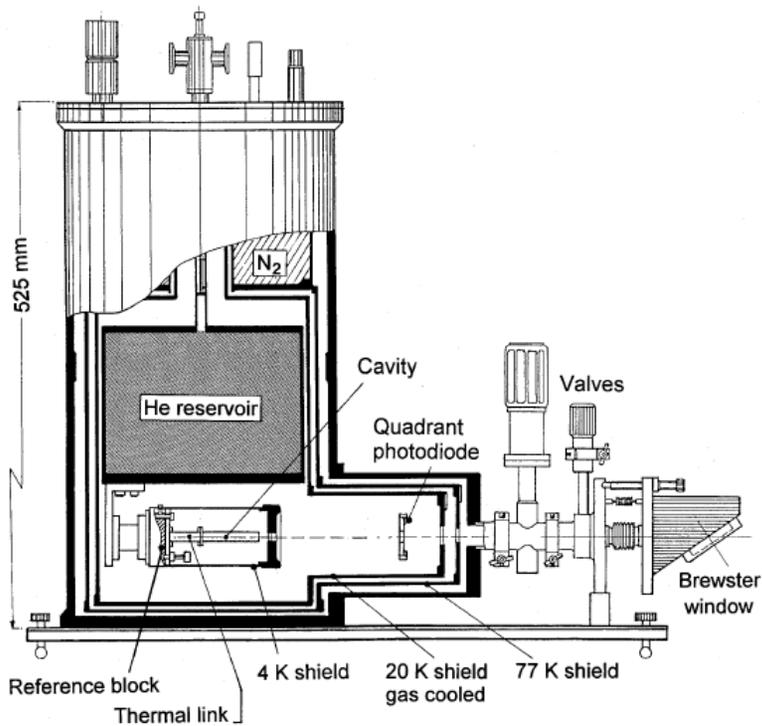


Figure 1. Schematic of Radiox radiometer.

**Table 1.** Uncertainty budget of the Radiox radiometer, expressed as relative standard uncertainties in parts in  $10^4$ .

Source	Relative uncertainty $\times 10^4$	
	Type A	Type B
Electrical power		0,07
Heating nonequivalence		0,3
Brewster-window transmission		0,5
Cavity absorption		0,1
Diffuse light		0,2
Repeatability	0,3	
Quadrature sum	0,3	0,6
Total uncertainty		0,7

## SI traceable emissivity?

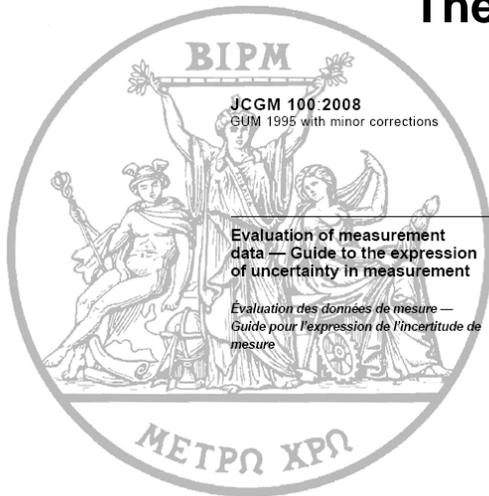


### 2.2.3 Units for dimensionless quantities, also called quantities of dimension one

Certain quantities are defined as the **ratio of two quantities of the same kind**, and are thus dimensionless, or have a dimension that may be expressed by the number one. The coherent SI unit of all such dimensionless quantities, or quantities of dimension one, is the number one, since the unit must be the ratio of two identical SI units. The values of all such quantities are simply expressed as numbers, and the unit one is not explicitly shown. Examples of such quantities are refractive index, relative

Another class of dimensionless quantities are numbers that represent **a count**, such as a number of molecules, degeneracy (number of energy levels), and partition function in statistical thermodynamics (number of thermally accessible states). All of these counting quantities are also described as being dimensionless, or of dimension one, and are taken to have the SI unit one, although the unit of counting quantities cannot be described as a derived unit expressed in terms of the base units of the SI. For such quantities, the unit one may instead be regarded as a further base unit.

In a few cases, however, a special name is given to the unit one, in order to facilitate the identification of the quantity involved. This is the case for the **radian** and the **steradian**. The radian and steradian have been identified by the CGPM as special names for the coherent derived unit one, to be used to express values of plane angle and solid angle, respectively, and are therefore included in Table 3.



## The GUM: evaluating uncertainty for SI-traceable measurements

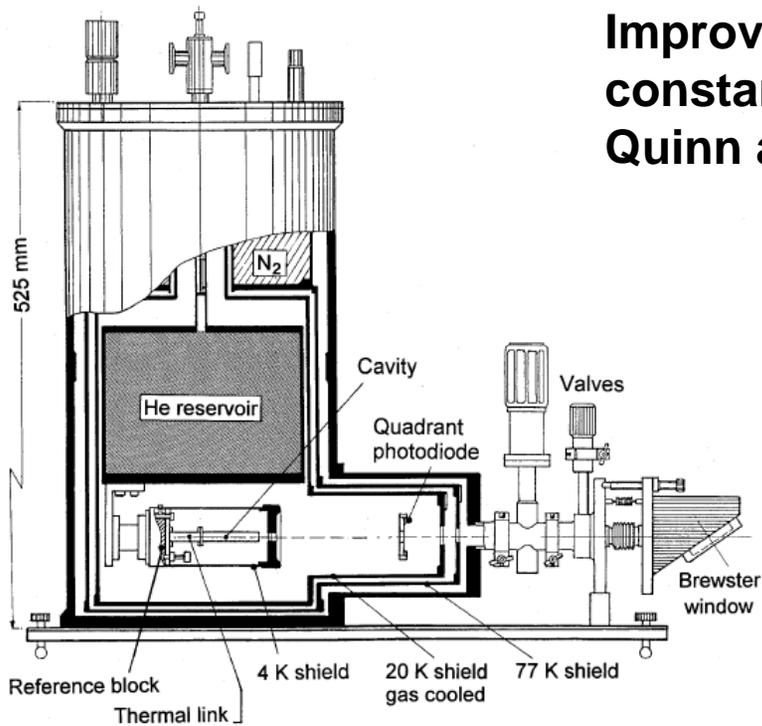
### 4.3 Type B evaluation of standard uncertainty

**4.3.1** For an estimate  $x_i$  of an input quantity  $X_i$  that has not been obtained from repeated observations, the associated estimated variance  $u^2(x_i)$  or the standard uncertainty  $u(x_i)$  is evaluated by scientific judgement based on all of the available information on the possible variability of  $X_i$ . The pool of information may include

- previous measurement data;
- experience with or general knowledge of the behaviour and properties of relevant materials and instruments;
- manufacturer's specifications;
- data provided in calibration and other certificates;
- uncertainties assigned to reference data taken from handbooks.

### F.2.1 The need for Type B evaluations

If a measurement laboratory had limitless time and resources, it could conduct an exhaustive statistical investigation of every conceivable cause of uncertainty, for example, by using many different makes and kinds of instruments, different methods of measurement, different applications of the method, and different approximations in its theoretical models of the measurement. The uncertainties associated with all of these causes could then be evaluated by the statistical analysis of series of observations and the uncertainty of each cause would be characterized by a statistically evaluated standard deviation. In other words, all of the uncertainty components would be obtained from Type A evaluations. Since such an investigation is not an economic practicality, many uncertainty components must be evaluated by whatever other means is practical.



**Improved value of the Stefan-Boltzmann constant through infrared radiometry: Quinn and Martin 1986**

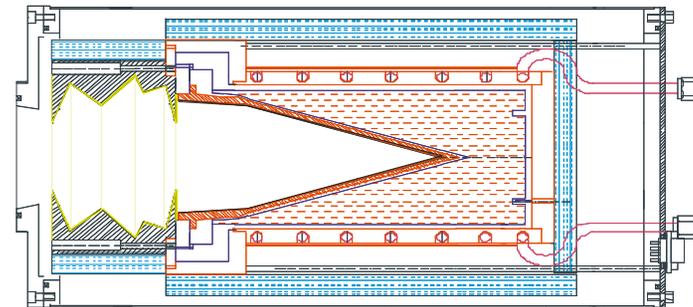
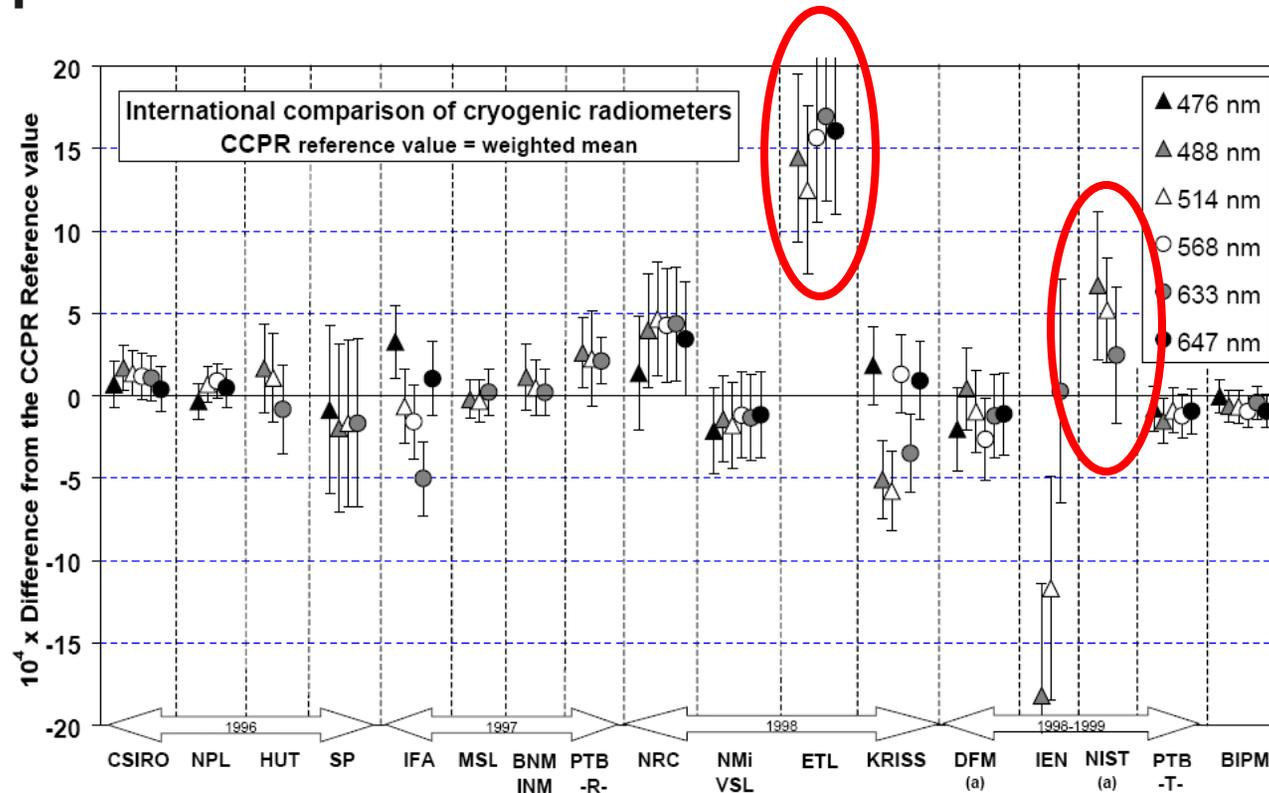


Figure 1. Schematic of Radiox radiometer.

**Radiance from temperature**

**Power from electrical standards**



**Well-founded measurement technique, adherence to GUM**

**Comparison of different detailed implementations of same measurement principle**



**External review of CLARREO  
uncertainty**

- What disciplines of natural sciences will be represented?
- What methods for assessing instrument accuracy will be most credible?

## WORKING GROUP 4 REPORT TO CCT

25 June 2008

**Members:** Joachim Fischer (PTB) chairman, Michael DePodesta (NPL), Ken Hill (NRC), Mike Moldover (NIST), Laurent Pitre (LNE-INM/CNAM), Peter Steur (INRiM), Osamu Tamura (NMIJ), Rod White (MSL), Inseok Yang (KRISS), assisted by Richard Rusby and Marten Durieux (honorary)

**Error type 1:** QM could have made a mistake in the estimation of the **coupling of the calorimeter and the radiator**. Suppose the calorimeter measured 1 mW of radiant power with the radiator at the triple point of water. If they estimated that the effective emissivity/absorptivity factor was 0.9999 and the actual factor was 0.9998, then they would infer that a perfect blackbody would emit 1.0001 mW, but in fact a perfect black body would emit 1.0002 mW. By using their incorrect estimation, they would infer a value of  $\sigma$  that would be too small.

**Error type 2:** One of QM's errors appears to have been overestimating the **efficiency of the light trap**. Suppose the calorimeter measured 1 mW of radiant power with the radiator at the triple point of water. If they estimated that the light trap was perfect, then they would infer that the emitted power from the radiator into the relevant solid angle was 1 mW. However, if the light trap was not 100% efficient, some of the power emitted outside the relevant solid angle would additionally reach the calorimeter. This would cause QM to infer a value of  $\sigma$  that would be too large.

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To bring the QM and MQC temperature estimates into line with the more recent acoustic data would require a correction to their data that is outside any known error. This is not to say that the data must be correct, but it does mean that neither Terry Quinn nor Nigel Fox can give a plausible explanation for how the temperature estimates could be so far out, and although with hindsight they might **enlarge their uncertainties**, they would not enlarge them so greatly as to agree with current acoustic data.

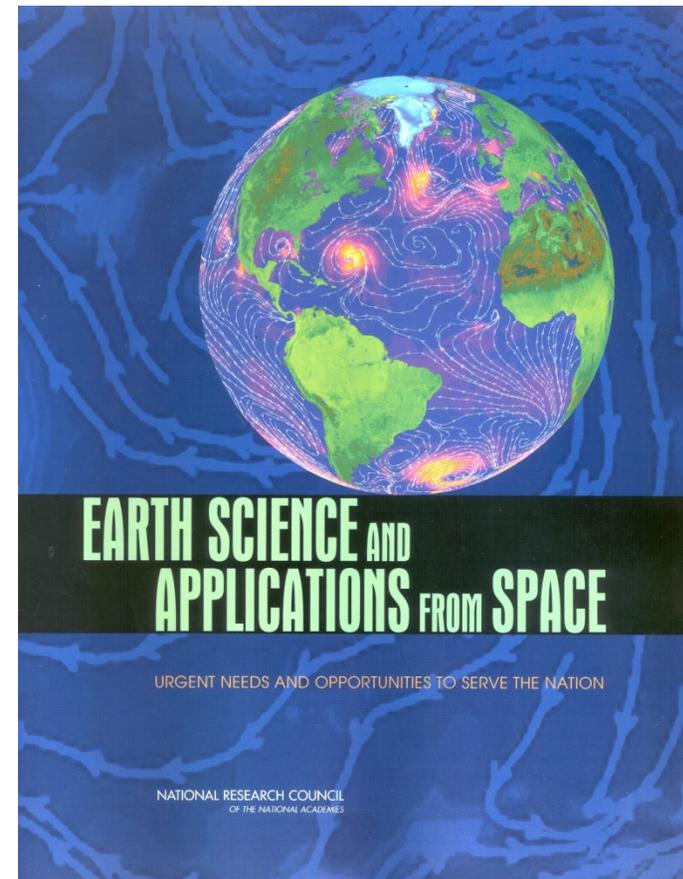
NPL thinks in all probability that the acoustic data is basically correct, but it is a concern that all the data that indicates the QM and MQC work is in error rest only on a **single technique** (albeit with **different implementations** and gases and many **internal consistency checks**). NPL suggests

# VISION

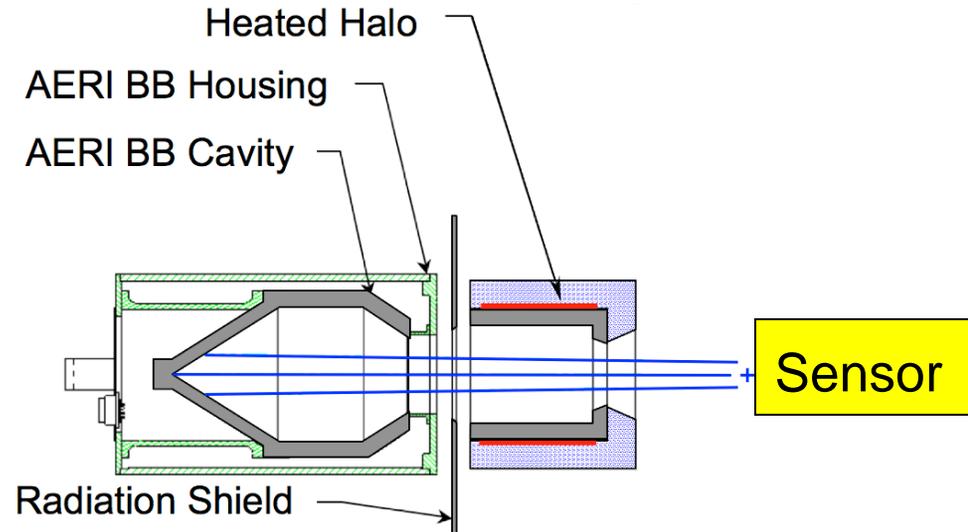
*A healthy, secure, prosperous  
and sustainable society for  
all people on Earth*

*“The United States does not have, nor are there clear plans to develop, a long-term global benchmark record of critical climate variables that are accurate over very long time periods, can be tested for **systematic errors** by future generations, are unaffected by interruption, and are pinned to international standards.”*

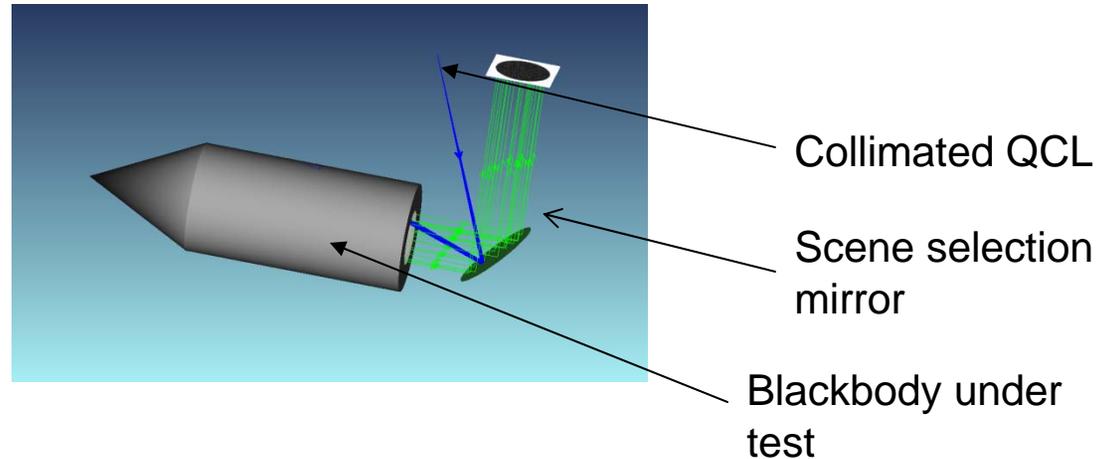
**NRC**



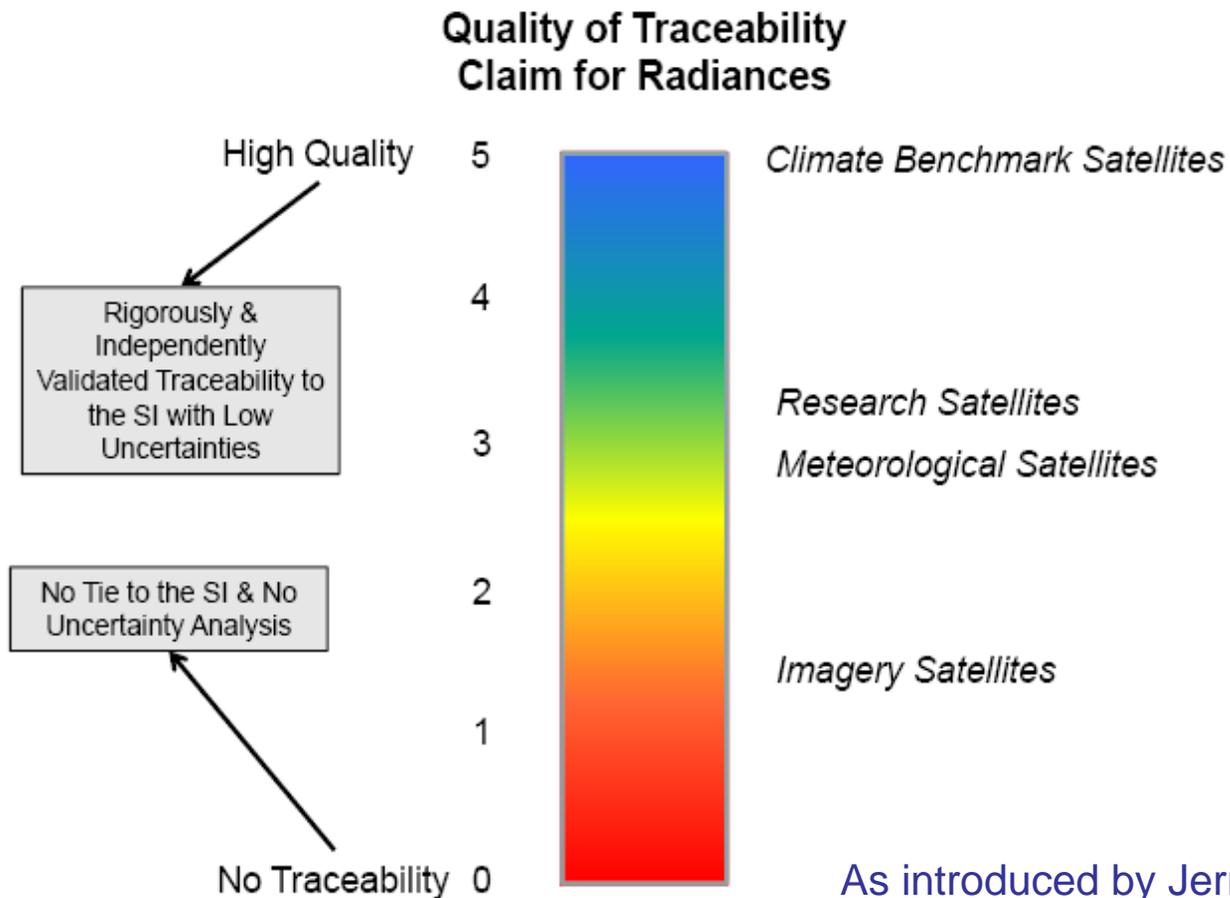
OCEM-Halo:  
Measures  
hemispheric  
normal emissivity

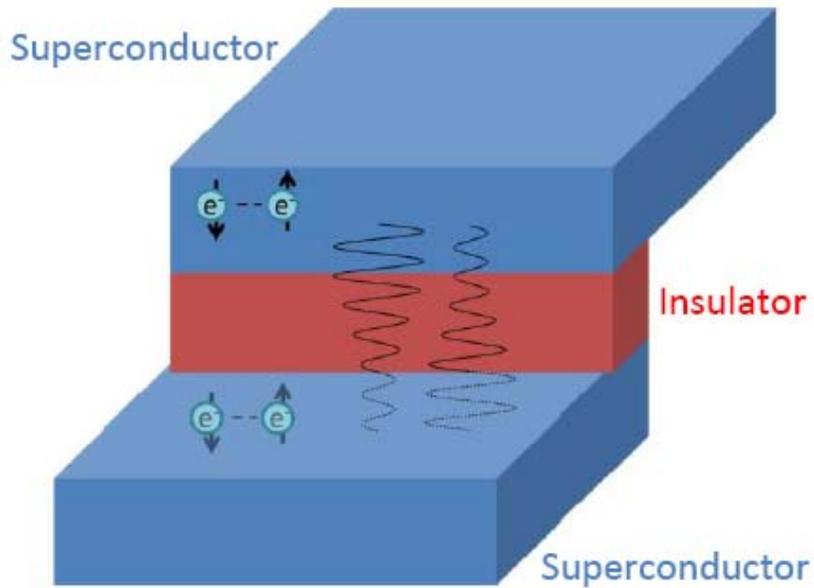


OCEM-QCL: Direct  
measurement of  
directional-normal  
reflectivity

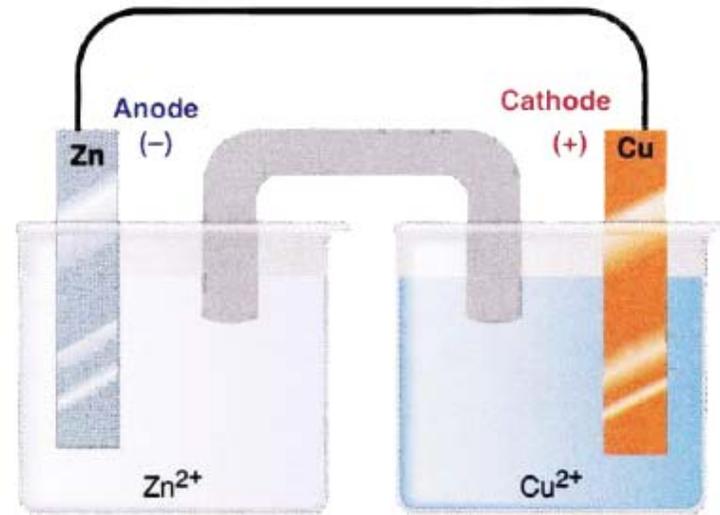


# Quality of Traceability Claim





$$V_{DC} = n \frac{\hbar}{2e} \omega$$



$$V_{cell} = E_{Cu} - E_{Zn}$$

- Thanks to
  - Harvard: Stephen Leroy, Yi Huang
  - NIST: Sergey Mekhontsev, Leonard Hanssen, Eric Shirley, Jerry Fraser
  - UW: Hank Revercomb, Fred Best, Jon Gero, Joe Taylor, Bob Knuteson, Dave Tobin
  - LaRC: Dave Young, Marty Mlynczak, Bruce Wielicki, Dave Johnson, Alan Little
  - David Keith, Eric Cornell