Making Sense of Claims of SI Traceability

John A. Dykema, James G. Anderson

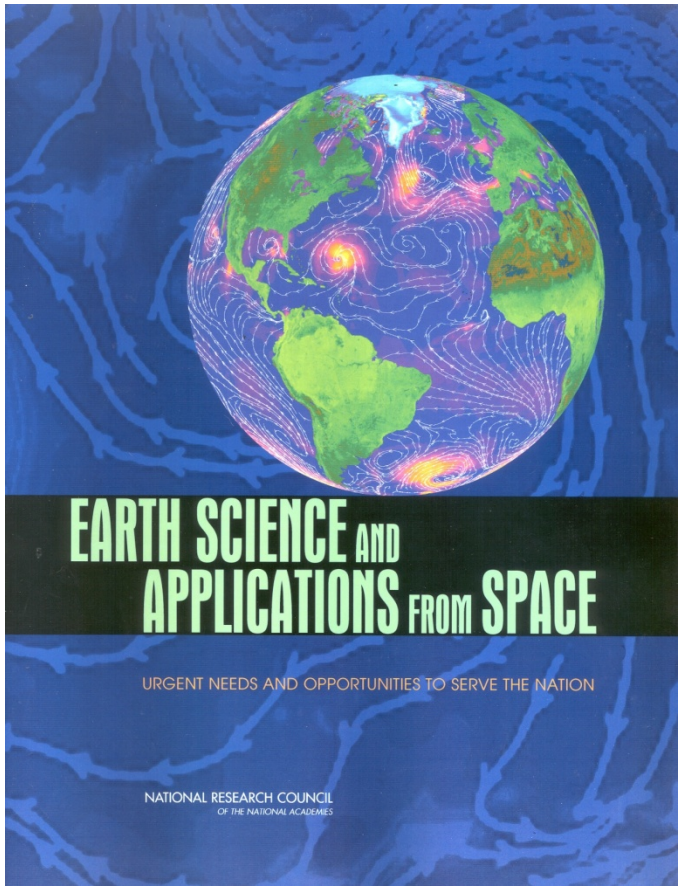
dykema@fas.harvard.edu

VISION

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

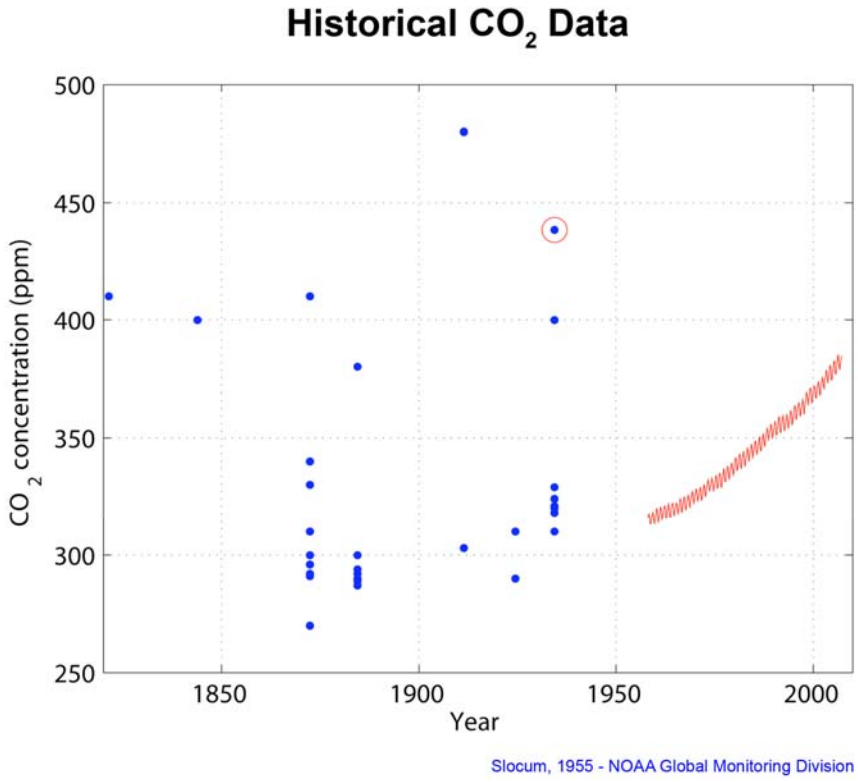
"The United States does not have, nor are there clear plans to develop, a long-term global benchmark record of critical climate variables that are accurate over very long time periods, can be tested for systematic errors by future generations, are unaffected by interruption, and are pinned to international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

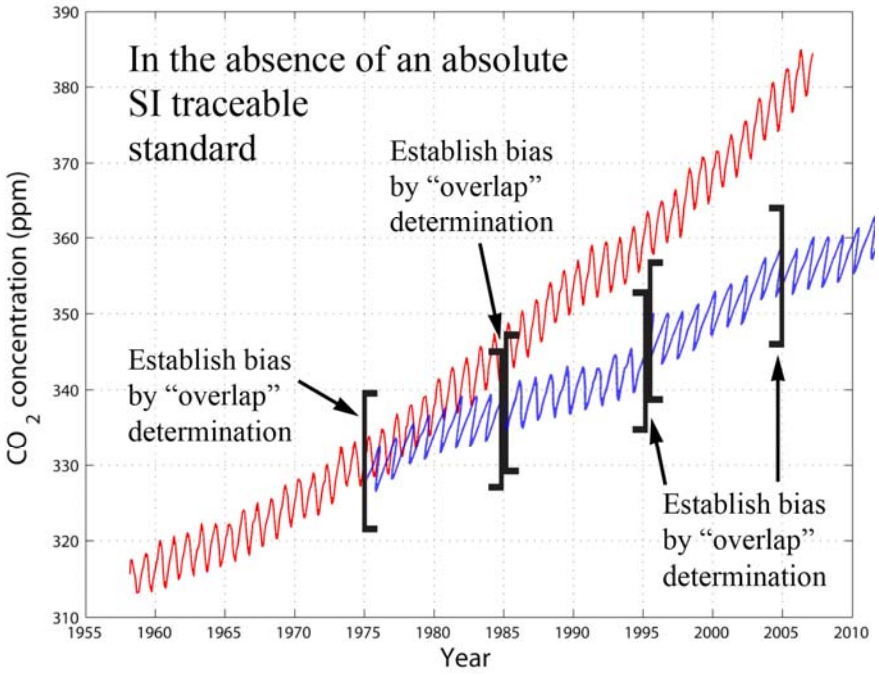
NRC

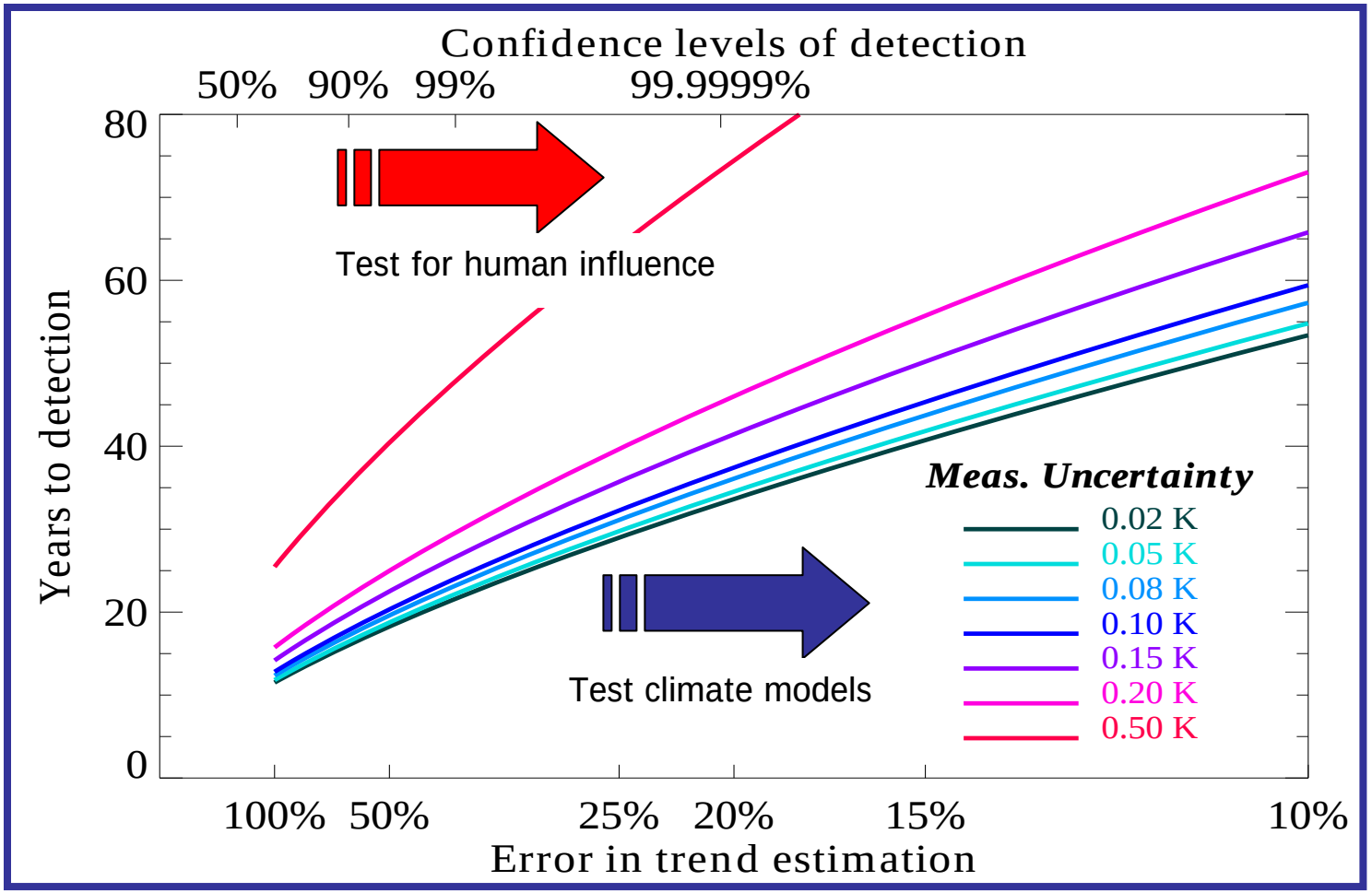


Systematic Errors?

- "Bias" in the language of metrological science
- Accuracy vs. precision






Confidence levels of detection
50% 90% 99% 99.9999%
80
60
40
20
0
Years to detection
Test for human influence
Test climate models
Meas. Uncertainty
0.02 K
0.05 K
0.08 K
0.10 K
0.15 K
0.20 K
0.50 K
100% 50% 25% 20% 15% 10%
Error in trend estimation

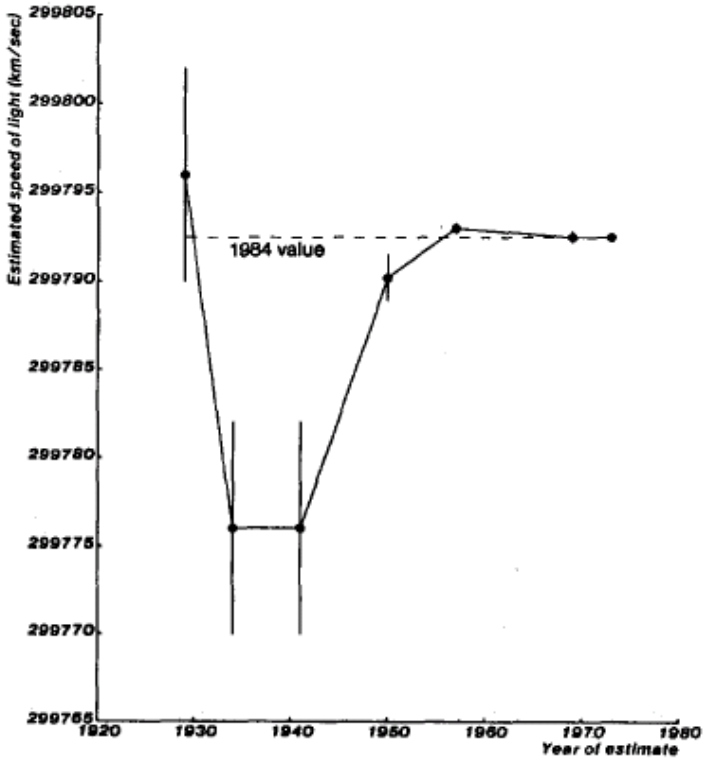
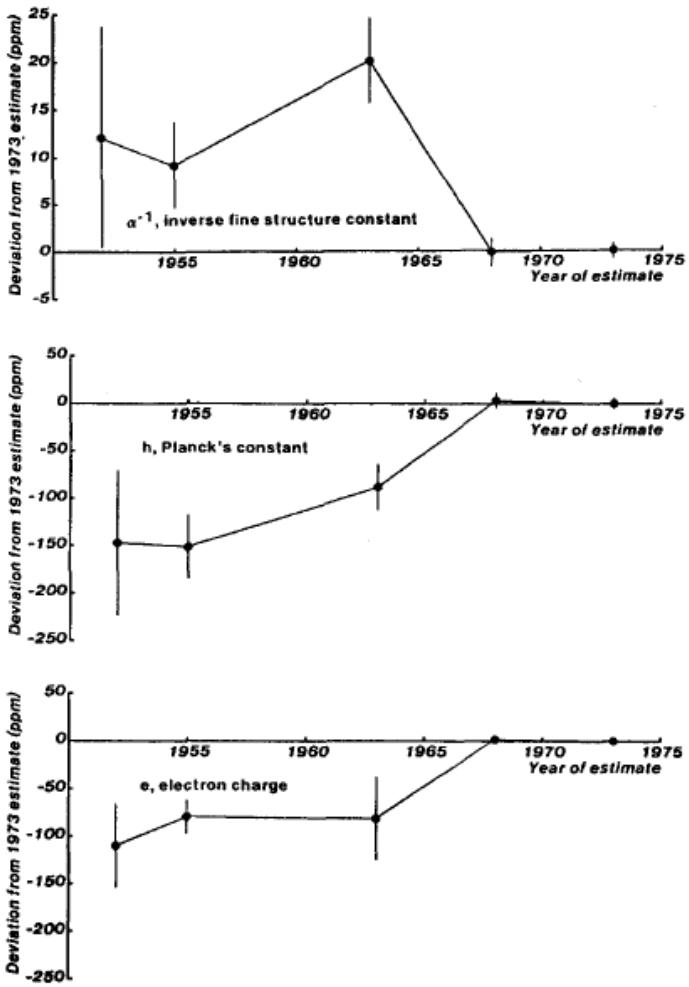


Fig. 2. Recommended values for the velocity of light; 1929–1973.



from Henrion and Fischhoff, 1986, Am. J. Phys.

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.

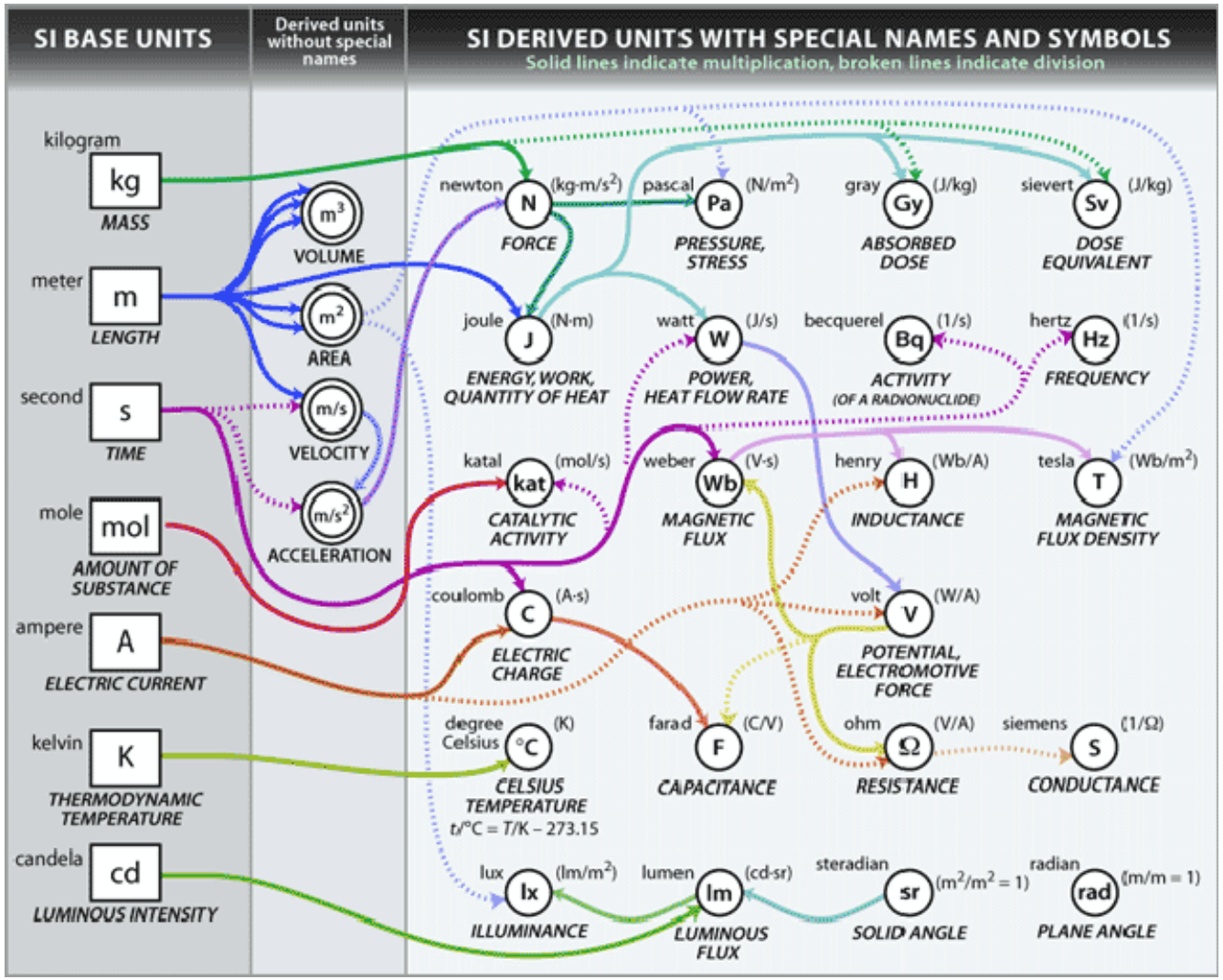
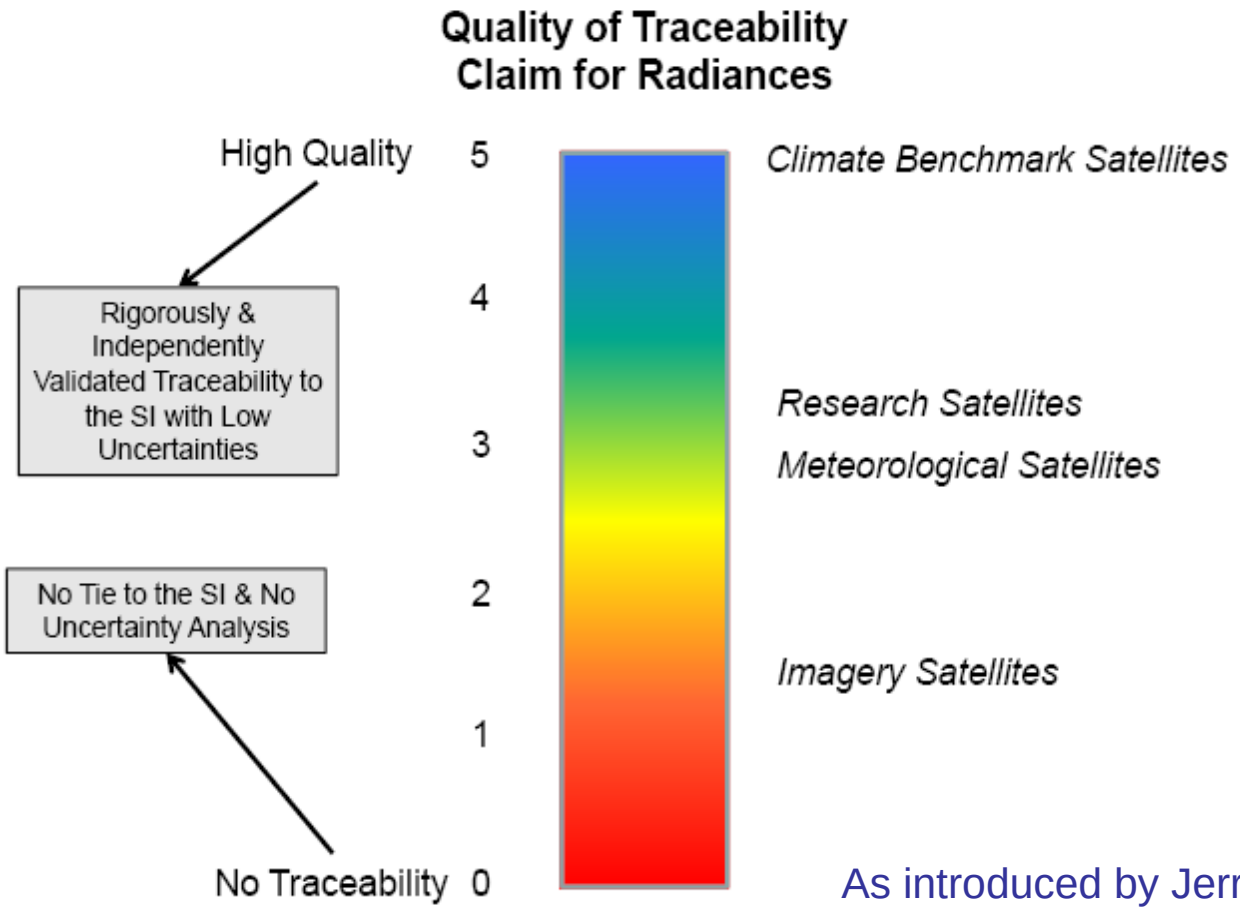


Figure courtesy Eric Shirley

Quality of Traceability Claim

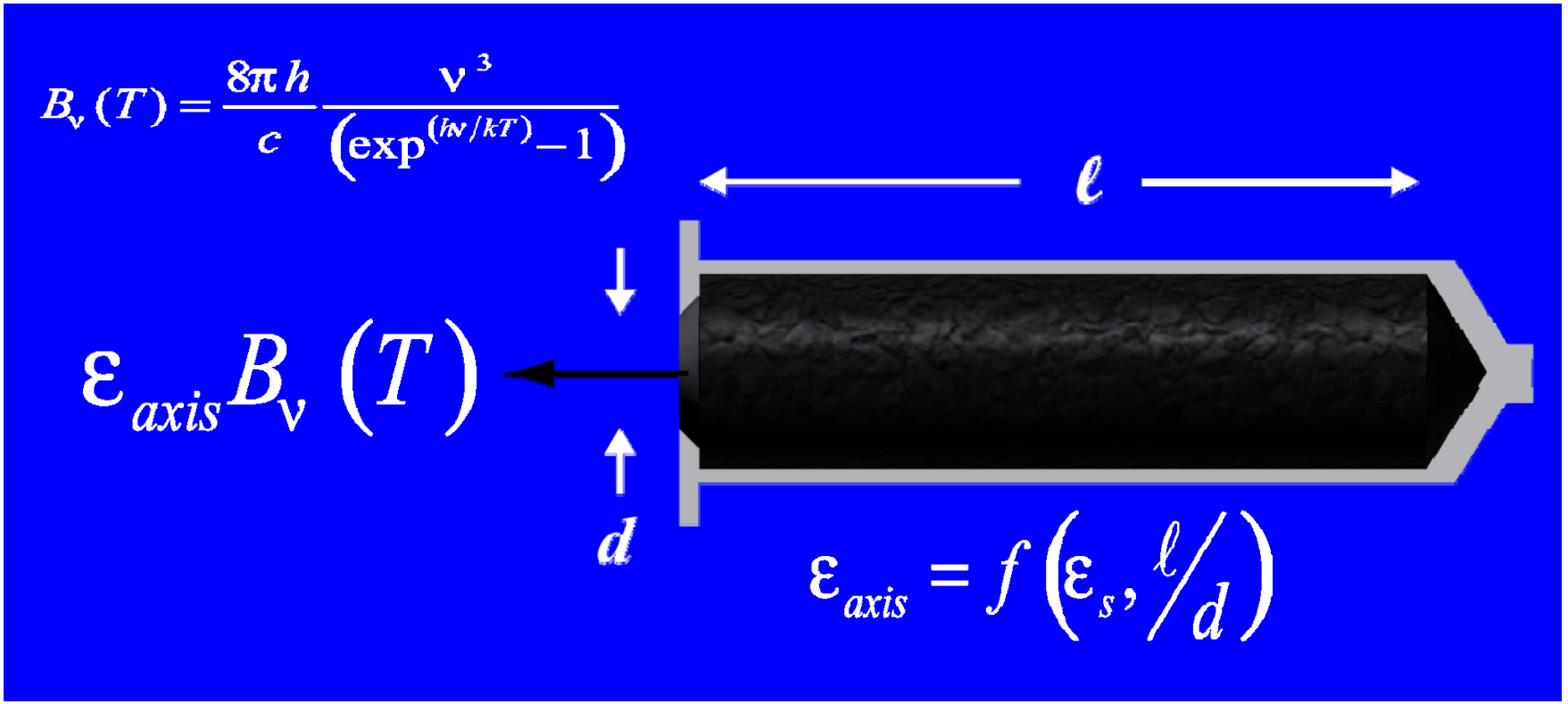


As introduced by Jerry Fraser et al.

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

SI Traceability for Remote Sensing

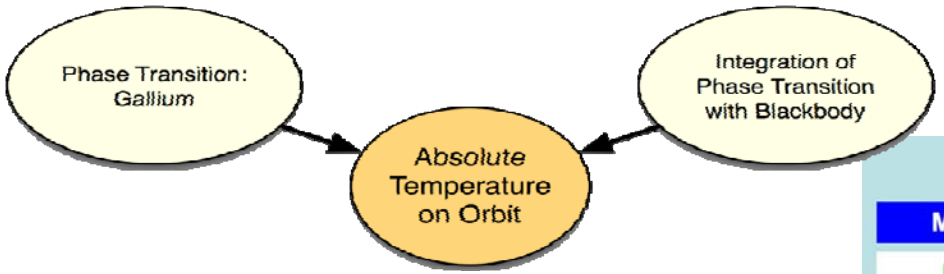
- Fox, 1999, *Adv. Space Res.*
- Pollock et al., 2001, *Metrologia*
- Dykema and Anderson, 2006, *Metrologia*
- Dykema, Shirley, Fraser and Anderson, in preparation for *IEEE Trans. Geosci. Rem. Sens.*

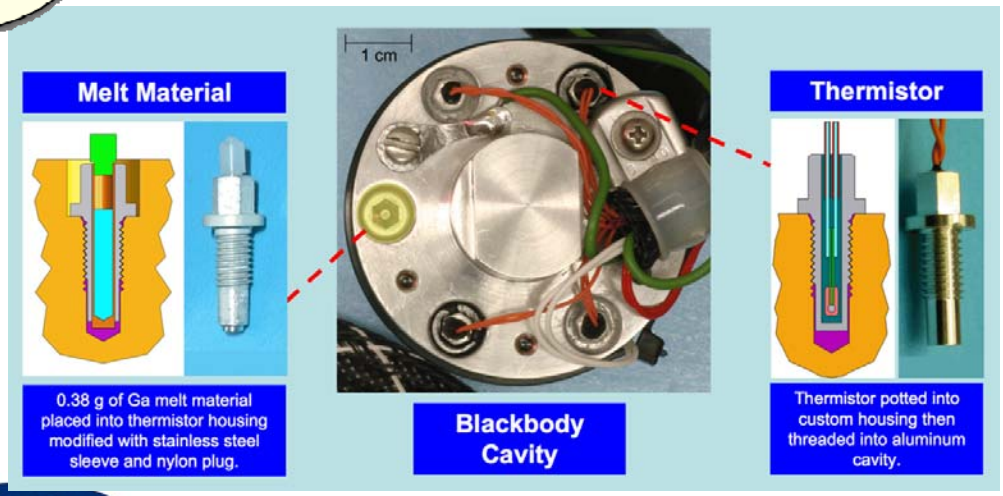


On-Orbit Blackbody:

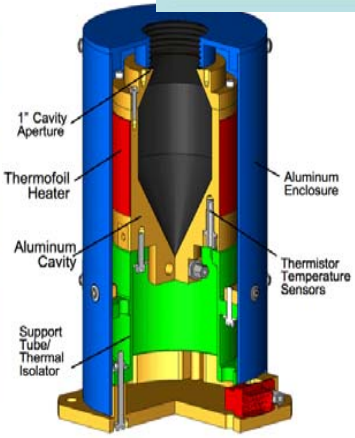
- Finite Aperture
- Temperature Gradient

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



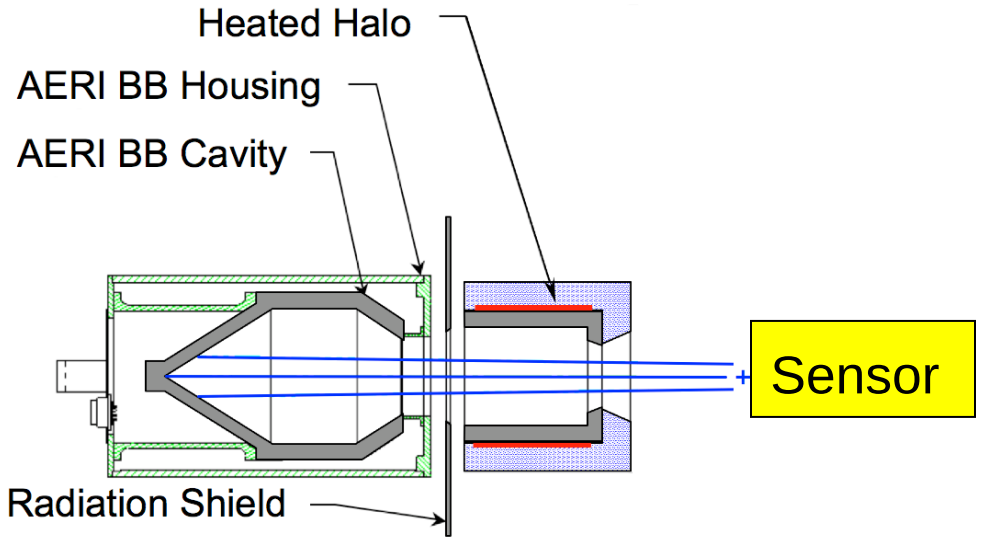


Key Parameter	Specification	As Delivered
Measurement Range	233 to 313 K	233 to 313 K
Temperature Uncertainty	< 0.1 K (3 σ)	< 0.056 K
Blackbody Emissivity	> 0.996	> 0.999
Emissivity Uncertainty	< 0.002 (3 σ)	< 0.00072
Entrance Aperture	1.0 inch	1.0 inch
Mass (2 BBs + controller)	< 2.4 kg	2.1 kg
Power (average/max)	< 2.2/5.2 W	2.2/5.2 W

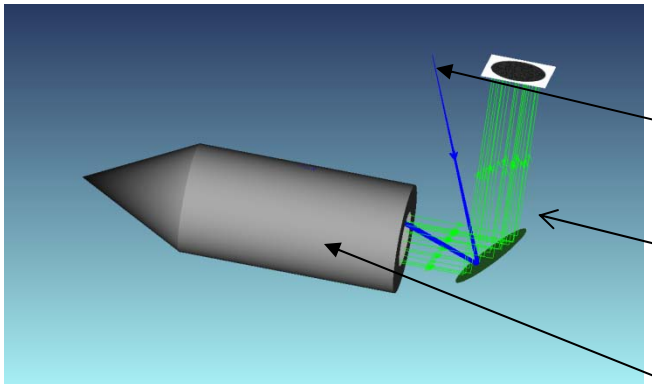


Technology developed by UW-SSEC under IIP

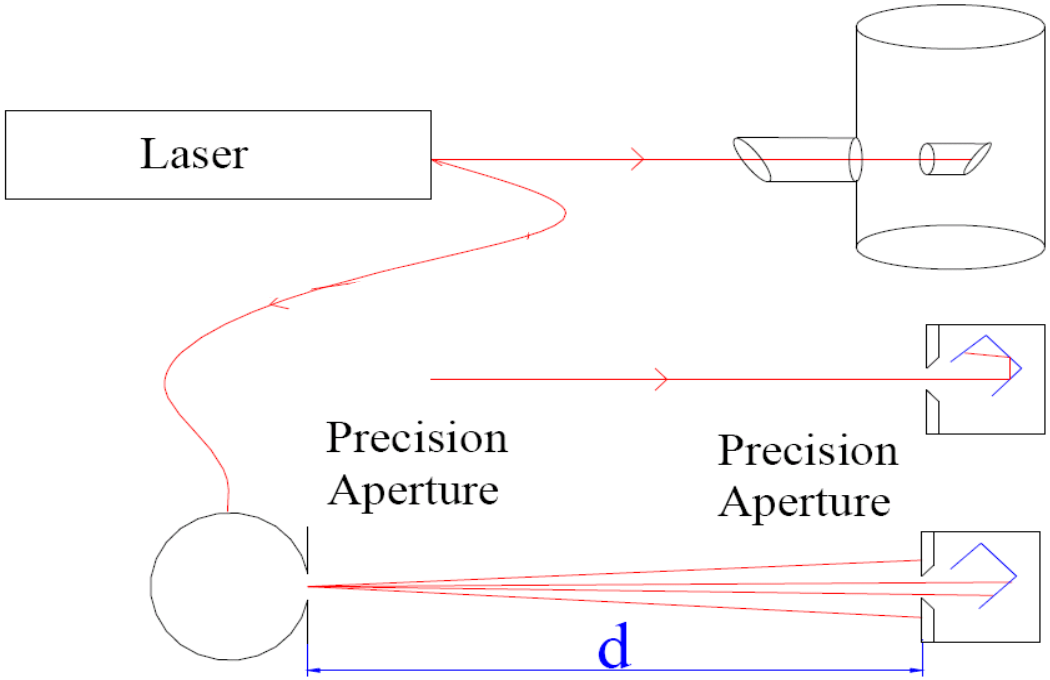
OCEM-Halo: Measures hemispheric normal emissivity

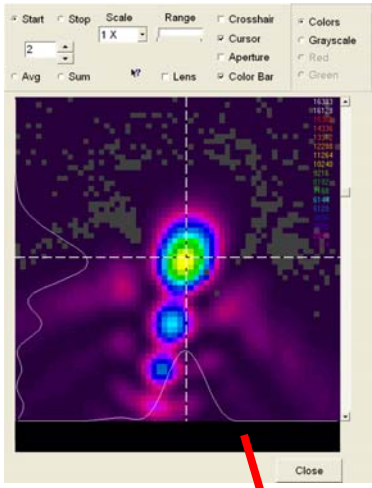


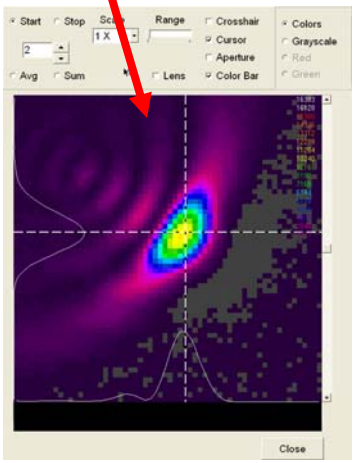
OCEM-QCL: Direct measurement of directional-normal reflectivity



Confounding Factors 1: Measurement Conditions

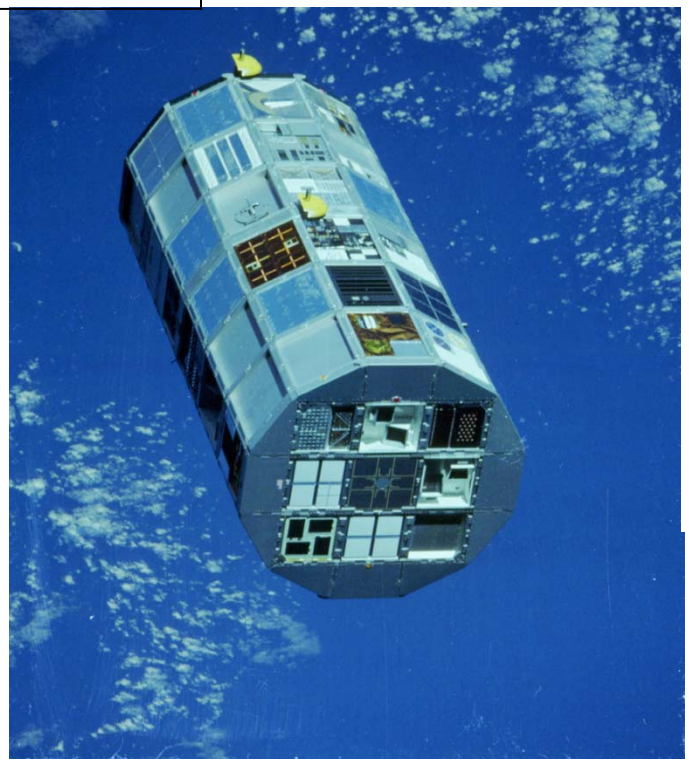


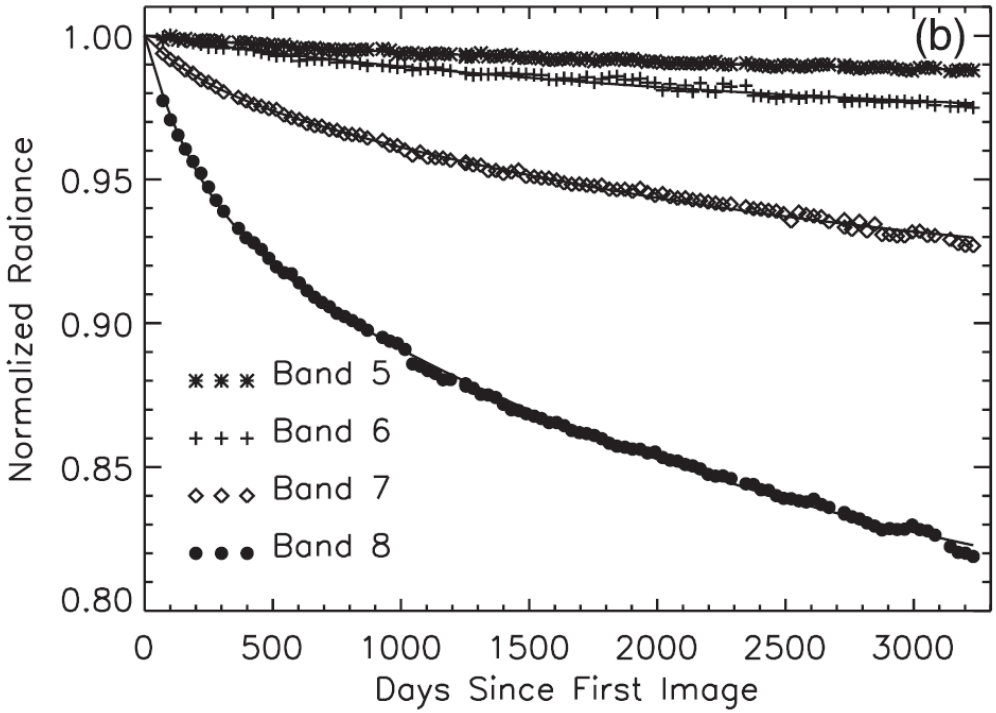




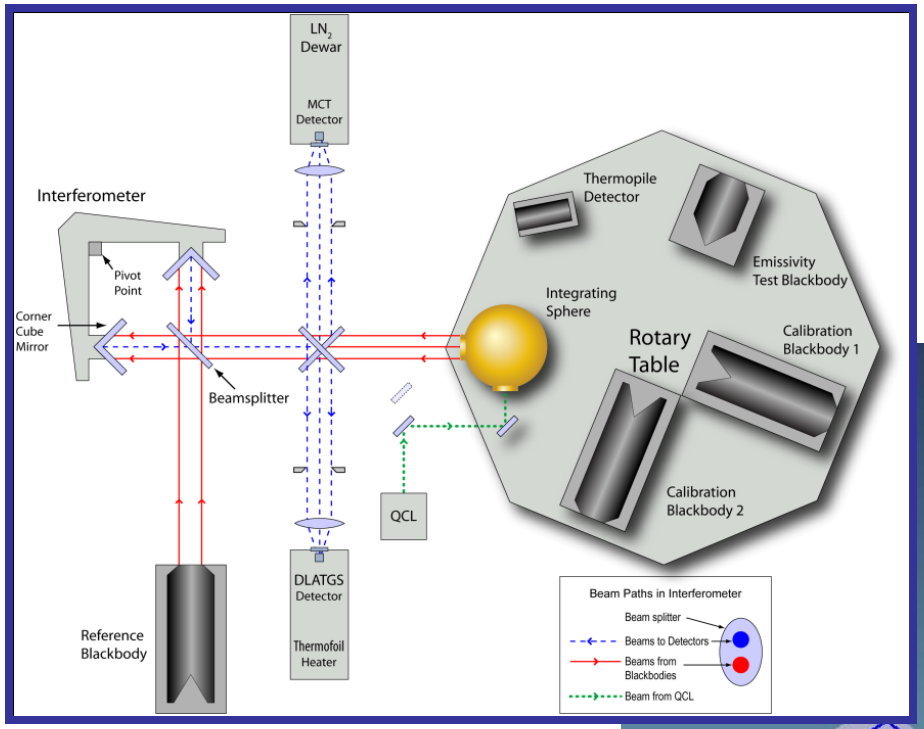
Confounding Factors 2: Aging and Exposure

LDEF

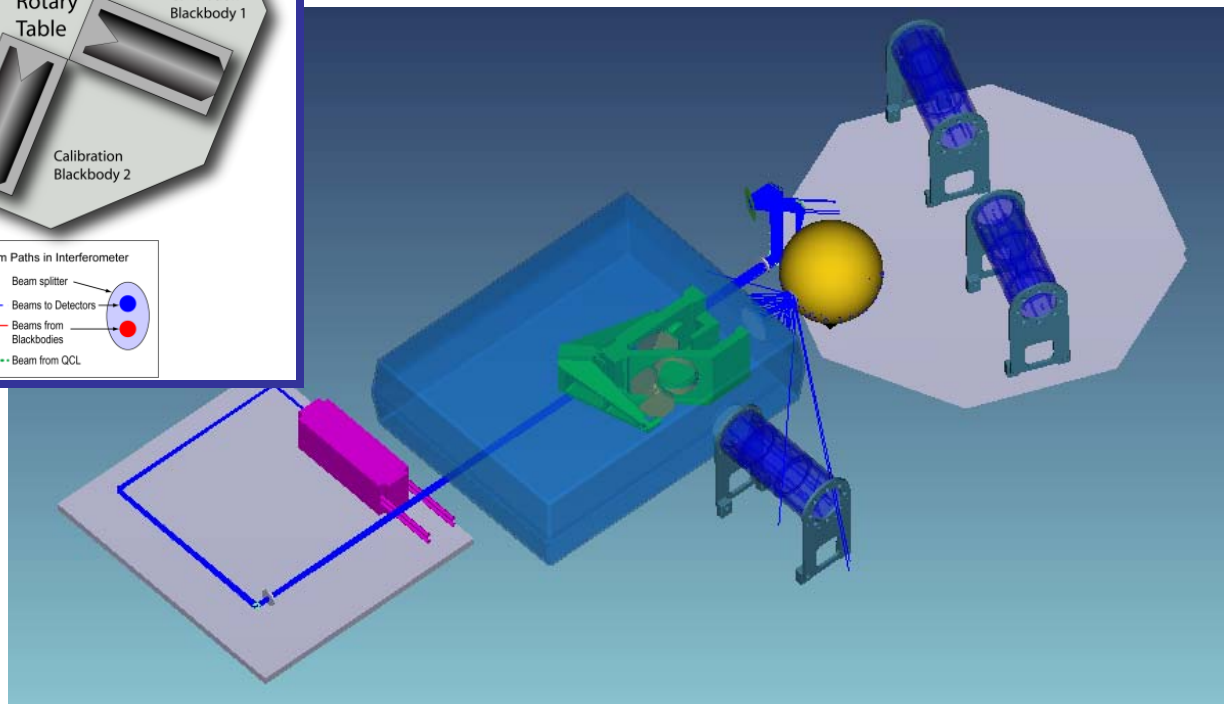




Lunar calibration of SeaWIFS diffuser shows degradation over time (Eplee et al. 2007 *App. Opt.*)

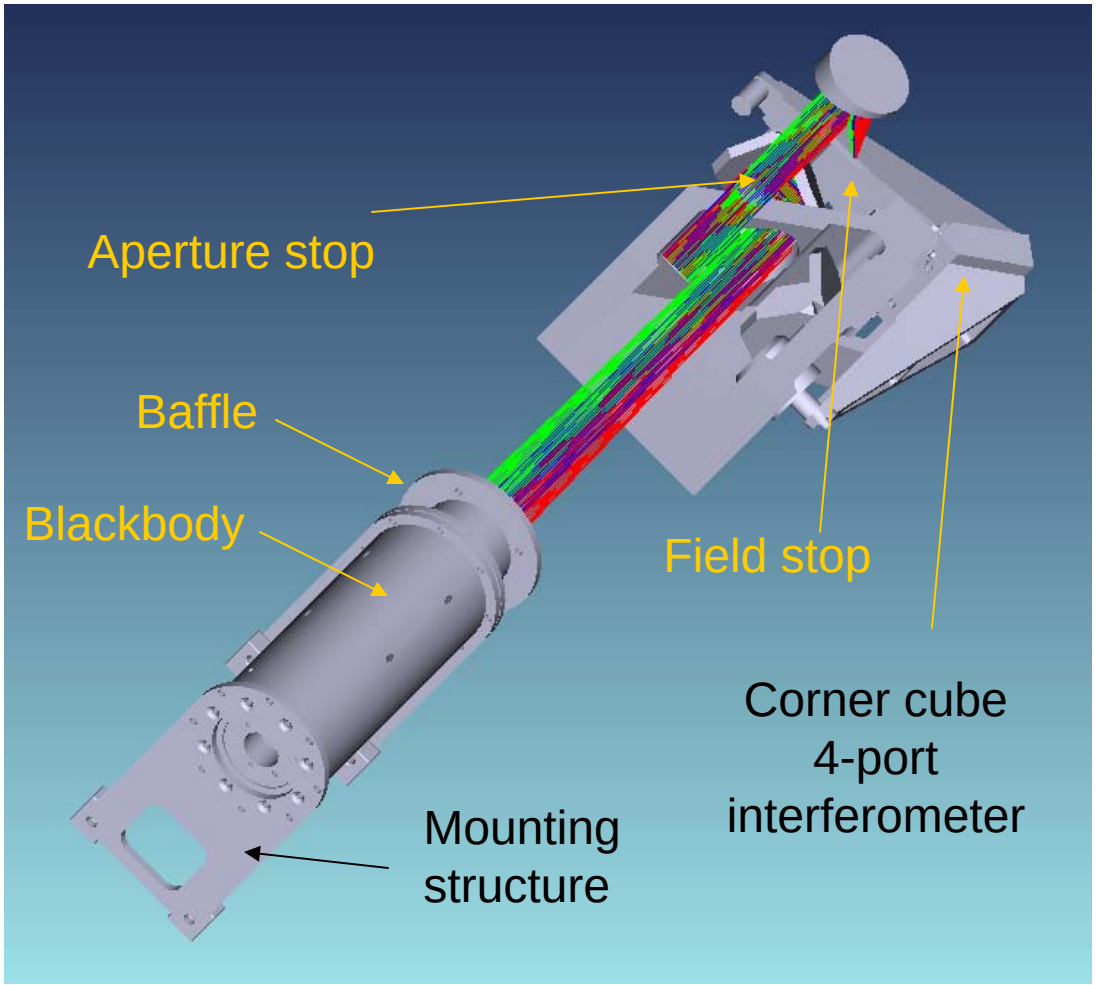


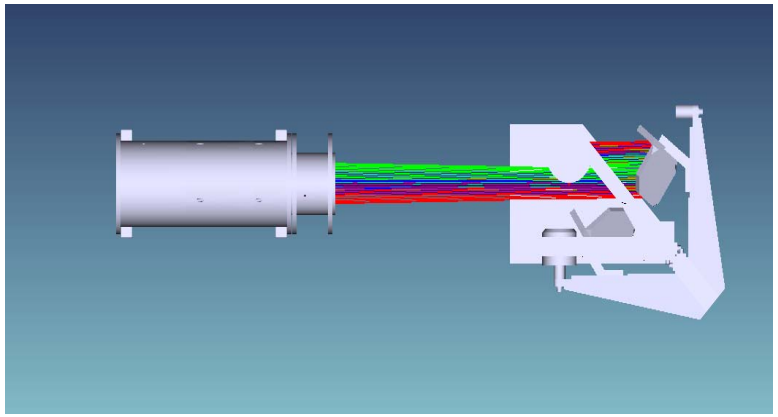
DARI-LW testbed



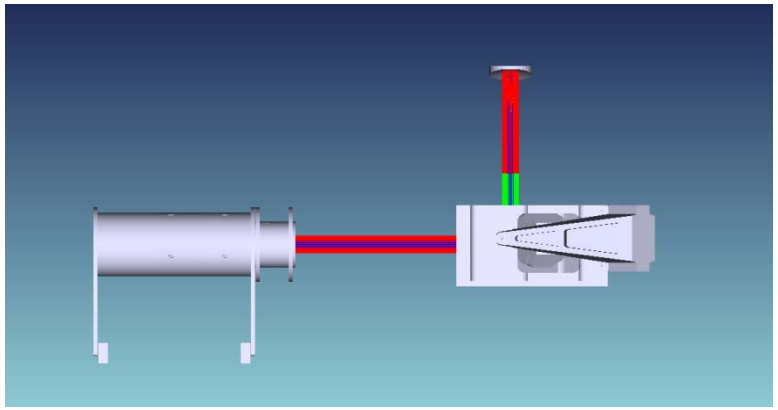
1. Gero, PJ; Dykema, JA.; Anderson, JG, 2008: A Blackbody Design for SI-Traceable Radiometry for Earth Observation, *J.Tech.* **25**(11) 2046

2. Gero, PJ; Dykema, JA.; Anderson, JG, 2009: A Quantum Cascade Laser-Based Reflectometer for On-Orbit Blackbody Cavity Monitoring, *J.Tech.* **26**(8) 1596

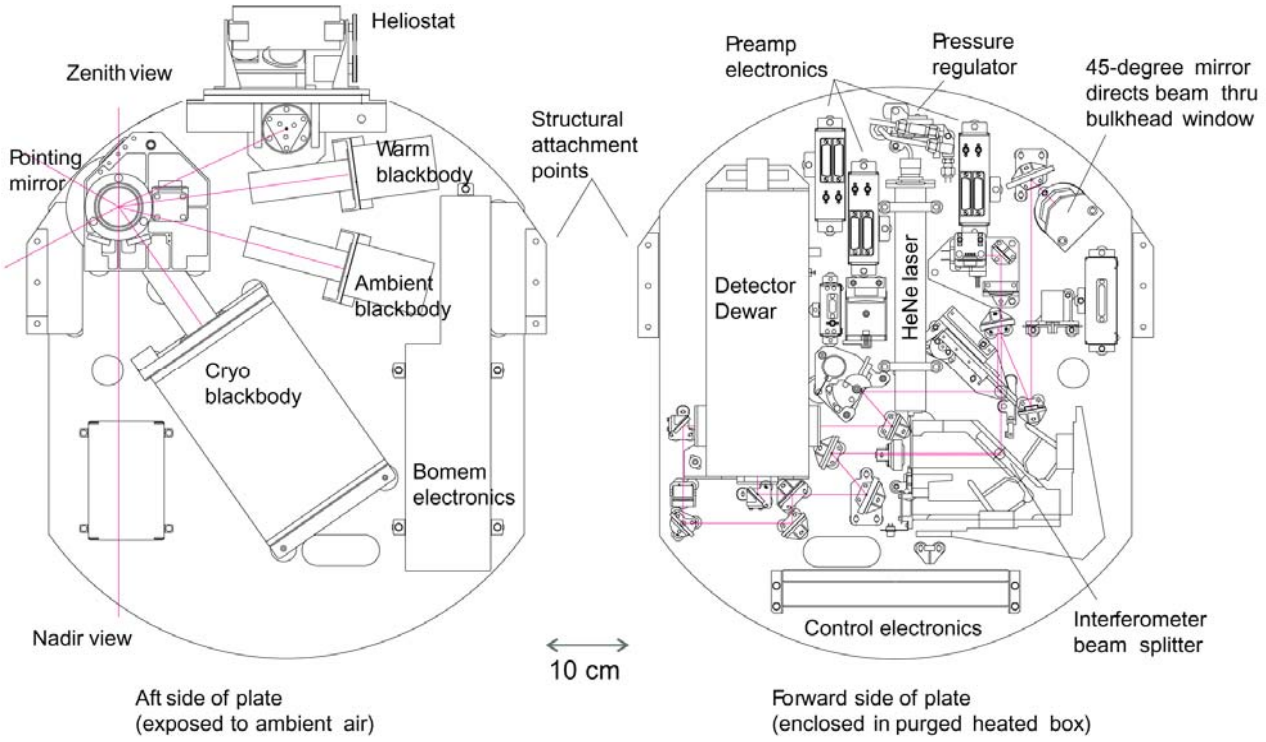


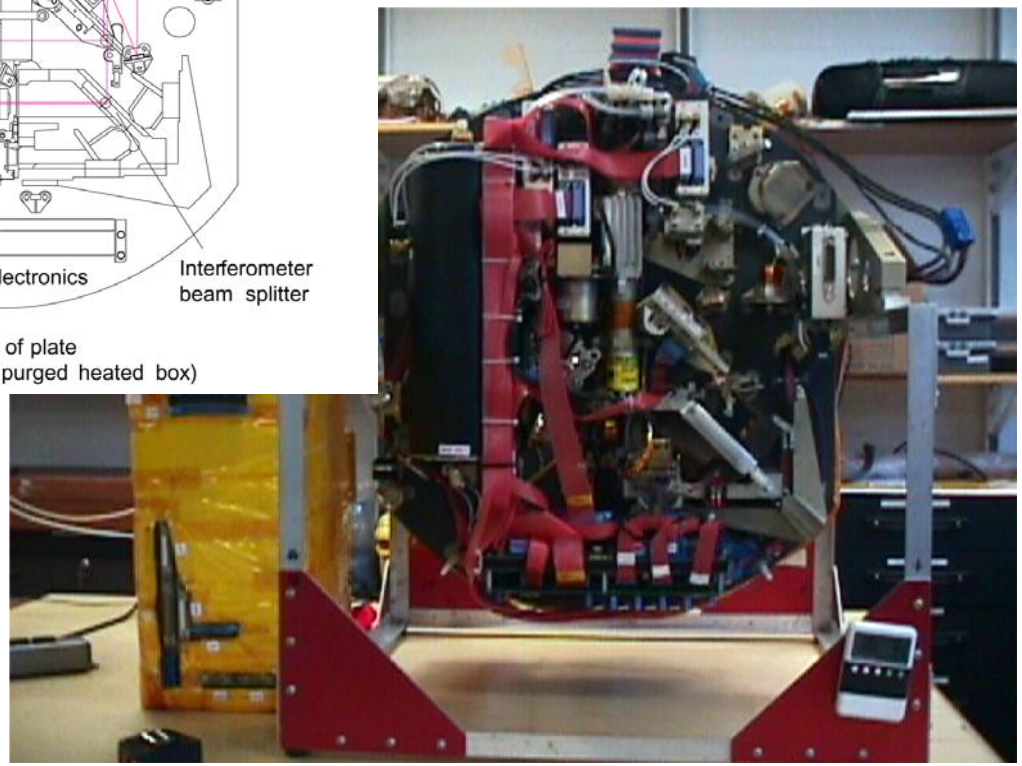


Top View

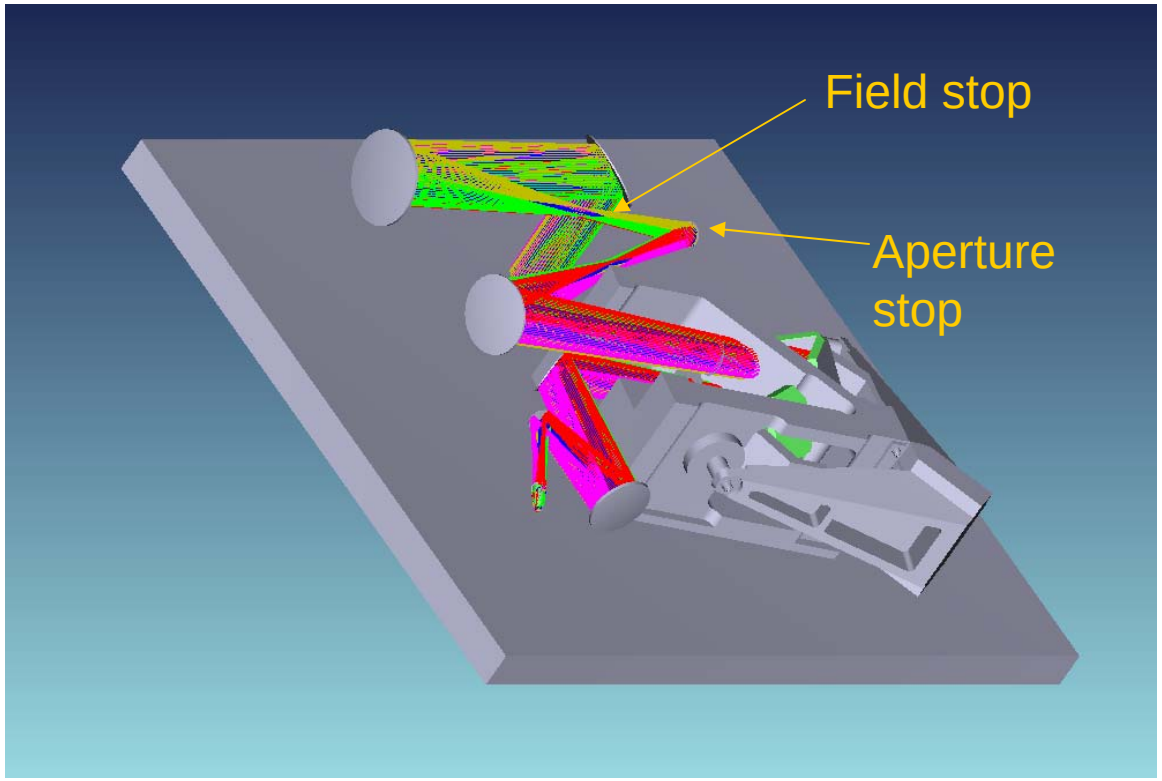


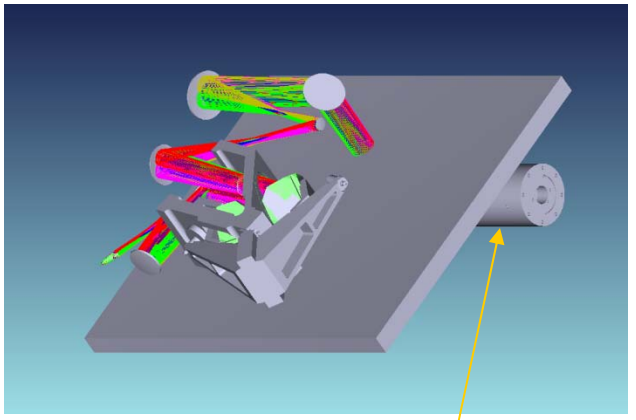
Side View



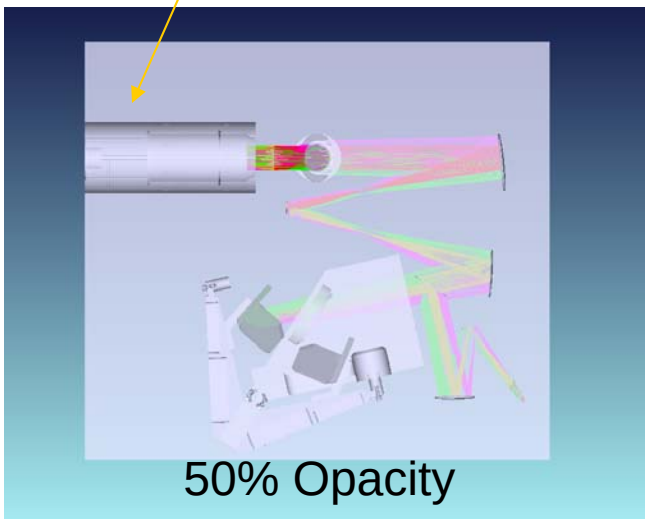


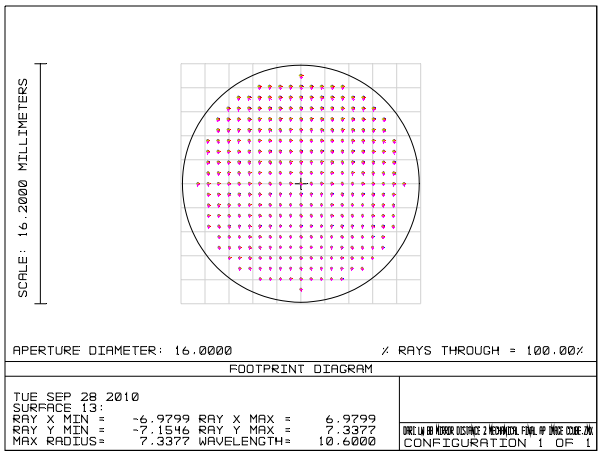
1. Keith, DW, JA Dykema, H Hu, L Lapson, and JG Anderson, 2001: *App. Opt*. **40**(30) 5463
2. Keith, DW, Anderson, JG. 2001: *J. Climate* **14** 979



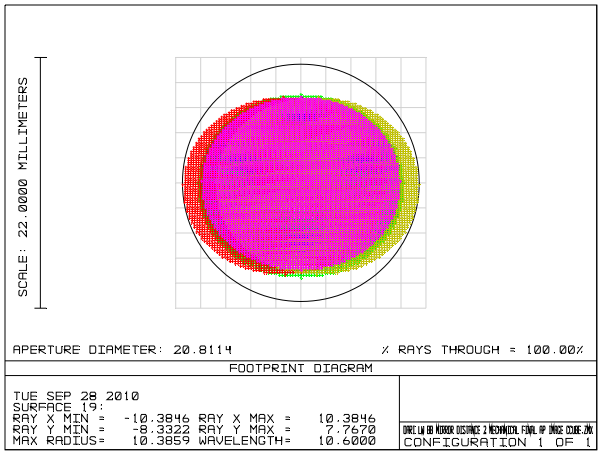


Blackbody

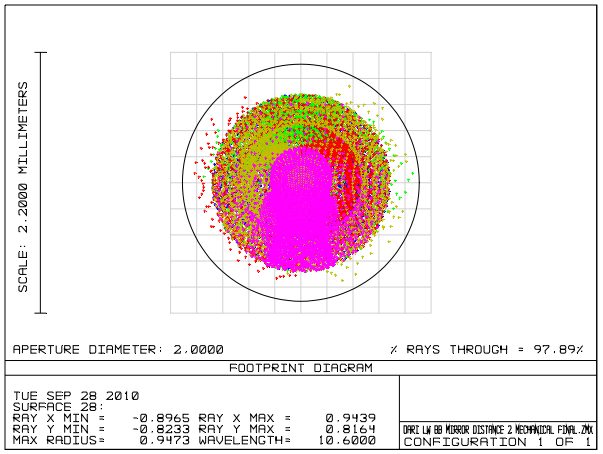




Footprint at aperture stop



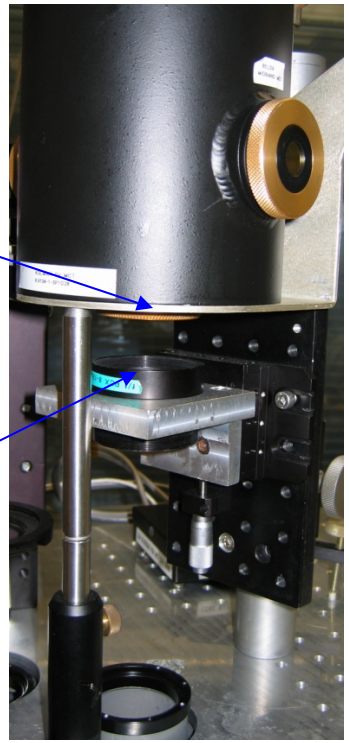
Footprint at corner cube



Footprint at far-IR detector

Cooled detector

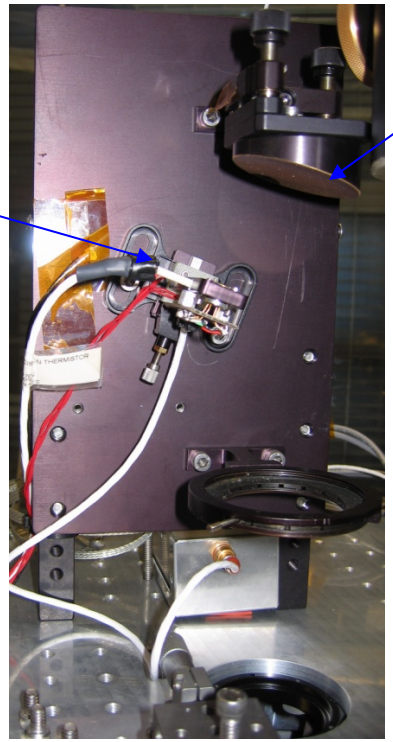
Refractive aft optics



MCT detector

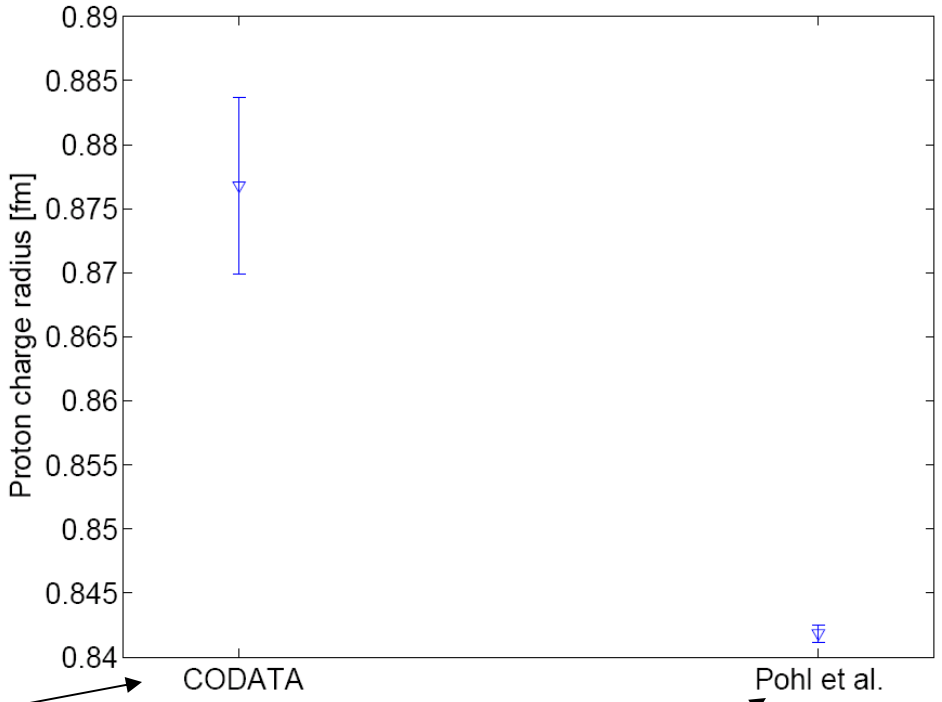
Uncooled detector

Reflective aft optics



Pyroelectric detector

Even today, unpleasant surprises still happen!



Accepted international value of proton radius

New measurements made in different conditions for lower uncertainty (2010)

- 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 Johnon, Alan Little
  - David Keith, Eric Cornell