CLARREO, SI Traceability, and On-orbit Verification

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CLARREO Science Team Meeting

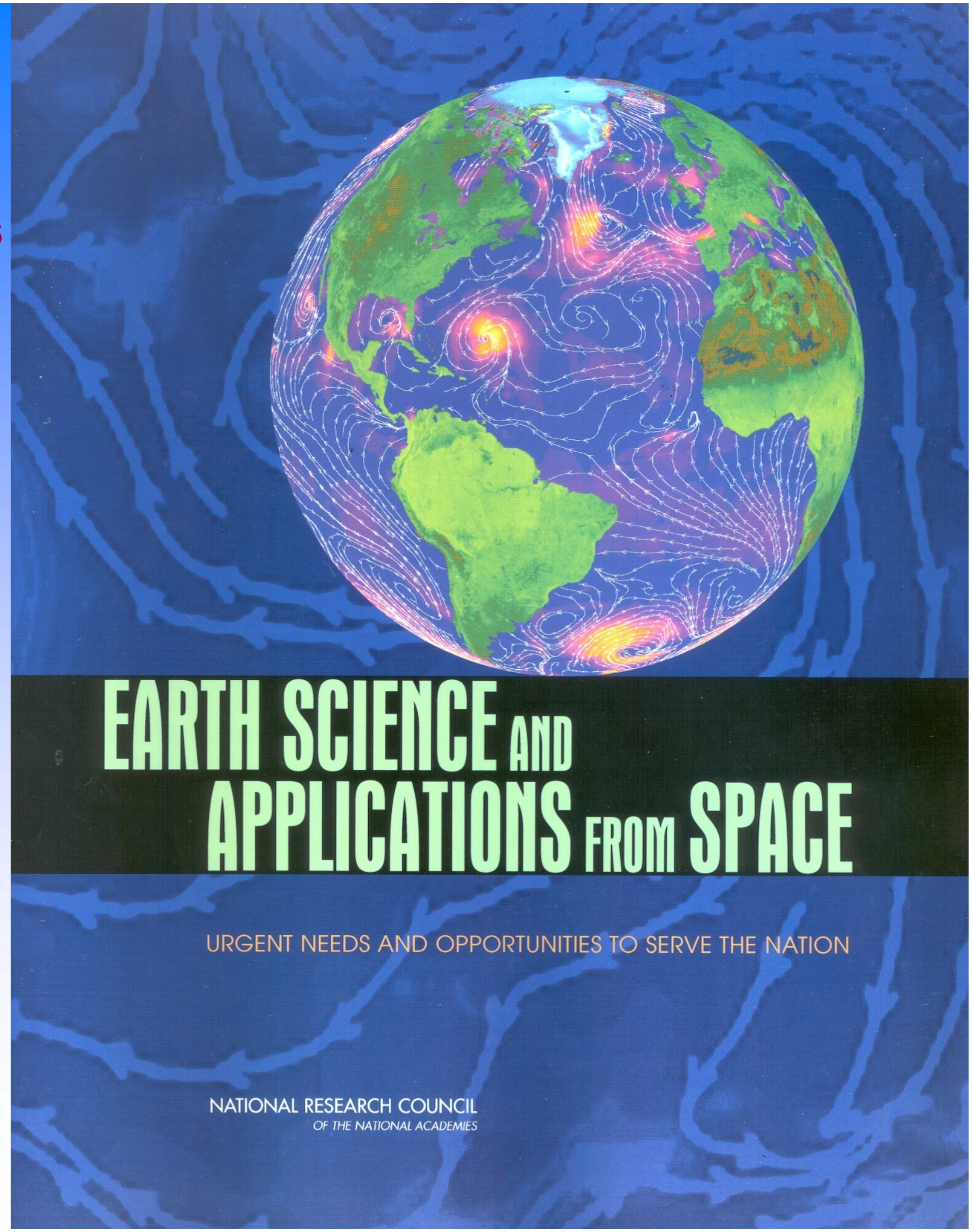
July 7, 2010

VISION

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

"Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important for society as it seeks to achieve prosperity and sustainability."

NRC (April 2005)



Committee found that fundamental improvements were needed to establish a disciplined structure linking:

- *Decision processes that serve societal objectives*
- *The analyses, forecasts and models that provide timely and coherent input to those decision processes, and*
- *Observations selected to test and systematically improve those forecasts*

Strategic Choices Driven by Society's Need for Decision Structures

Decision Structures in Service to Society for:

- Climate Policy
- Energy Policy
- Human health
- Water resources
- Weather and severe storms
- Solid Earth hazards
- Land use, Ecosystems, Biodiversity

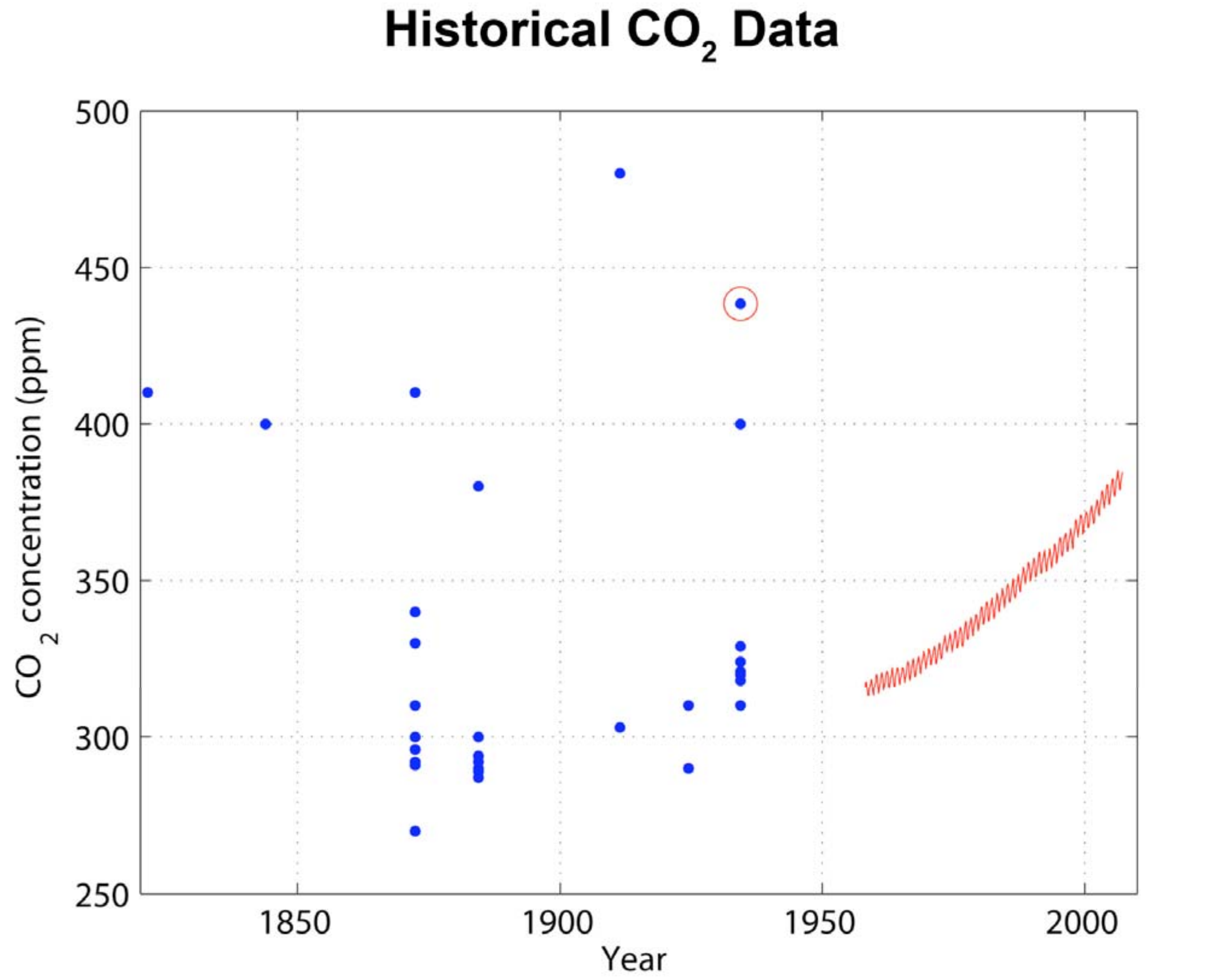
Required Forecasts:

- Rate of Sea Level Rise
- Airborne and water borne toxicity
- Rainfall, river flow, ground water, snow pack
- Regional temperatures, hurricane intensity, optical properties of atmosphere
- Earthquakes, volcanoes, tsunamis

Critical Observations to Specifically Test Forecast Credibility

- Nitrate, sulfate, organics, heavy metal effluents globally
- Index of refraction, absolute spectrally resolved radiance, solar irradiance
- Surface deformation

Keeling Record: Historical CO_2



Slocum, 1955 - NOAA Global Monitoring Division

Keeling Axiom: CLARREO

- ***Without*** an SI traceable (absolute) standard *on-orbit*, time works ***against*** you.
- ***With*** an SI traceable (absolute) standard *on-orbit*, time works ***for*** you.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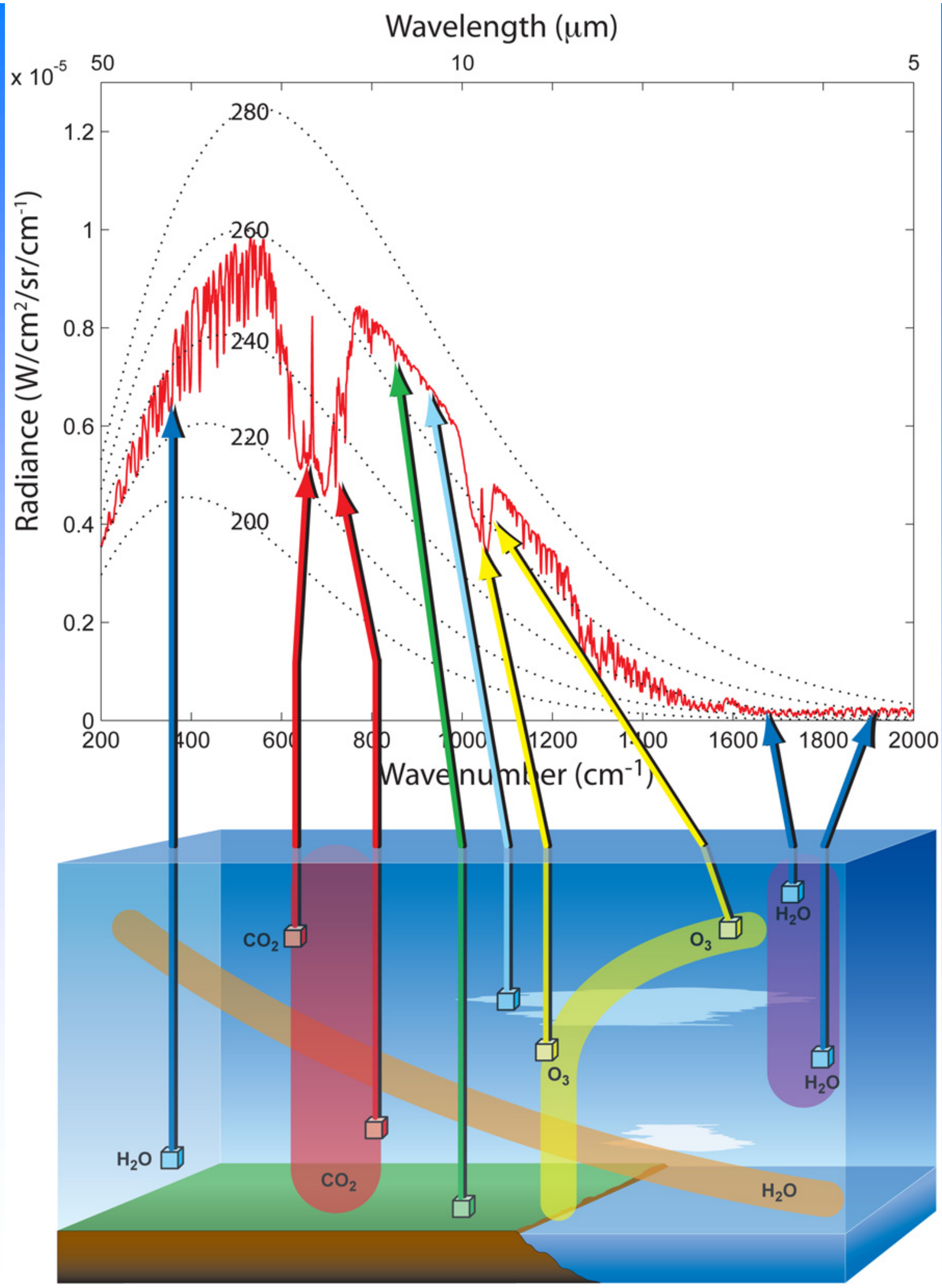
NIST
CLARREO
A Strategic Plan
NRC objective: Global benchmark climate record that is tested and trusted
NRC objective: Testing and systematic improvement of climate forecasts
Mission cost limitation
Mission background, justification and approach
CLARREO Mission
Strategy
Sampling issues and orbit selection
Instrument design to achieve SI traceability on orbit
Integrated spacecraft/ instrument design

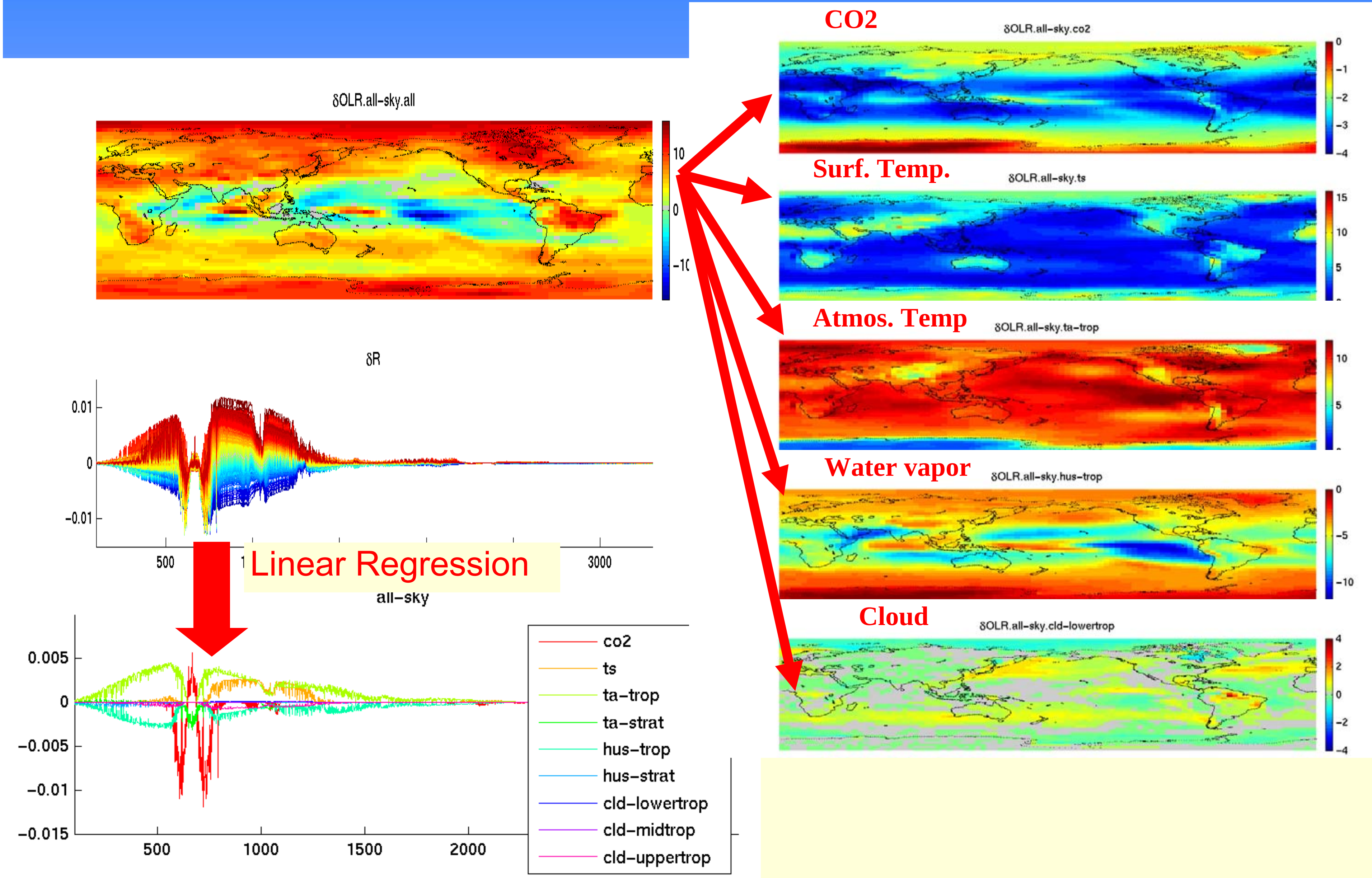
Importance of IR: Why did NRC emphasize for the climate record?



Observable: OLR_{total}, δR_{total} – total change in flux or radiances

$$\delta R = \sum \frac{\partial R}{\partial Xi} \delta Xi$$

Wanted: δOLR_{Xi}, δR_{Xi} – individual contributions



Types of Risk

- Technical
- Schedule
- Cost
- Programmatic
- Political

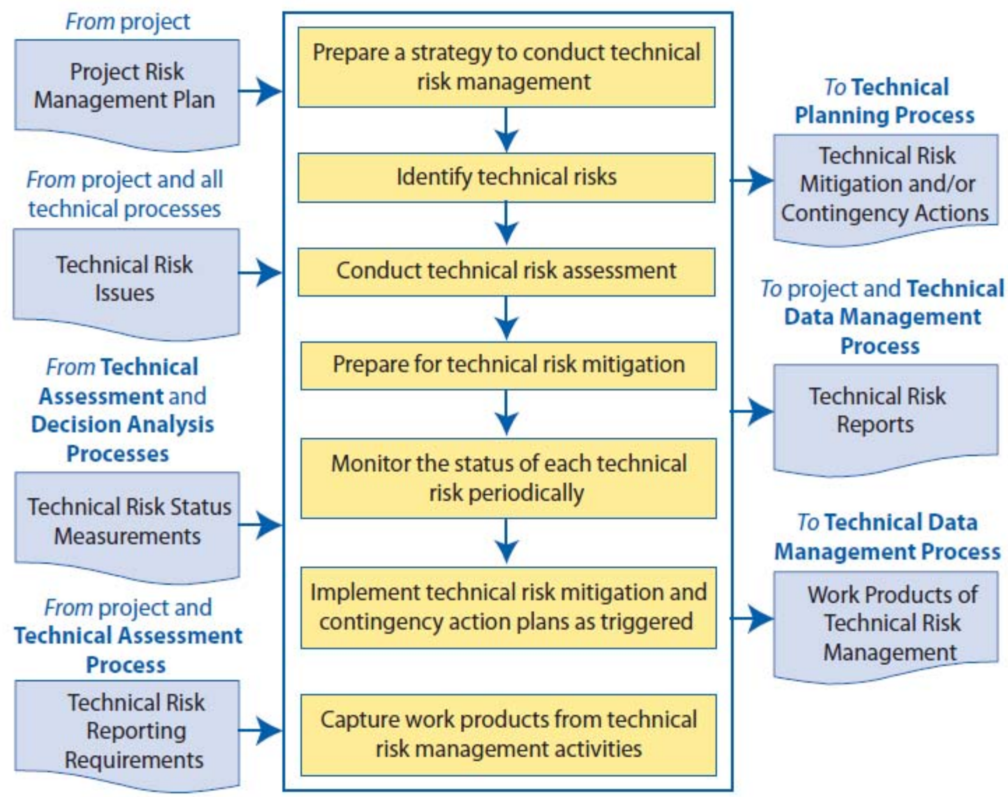
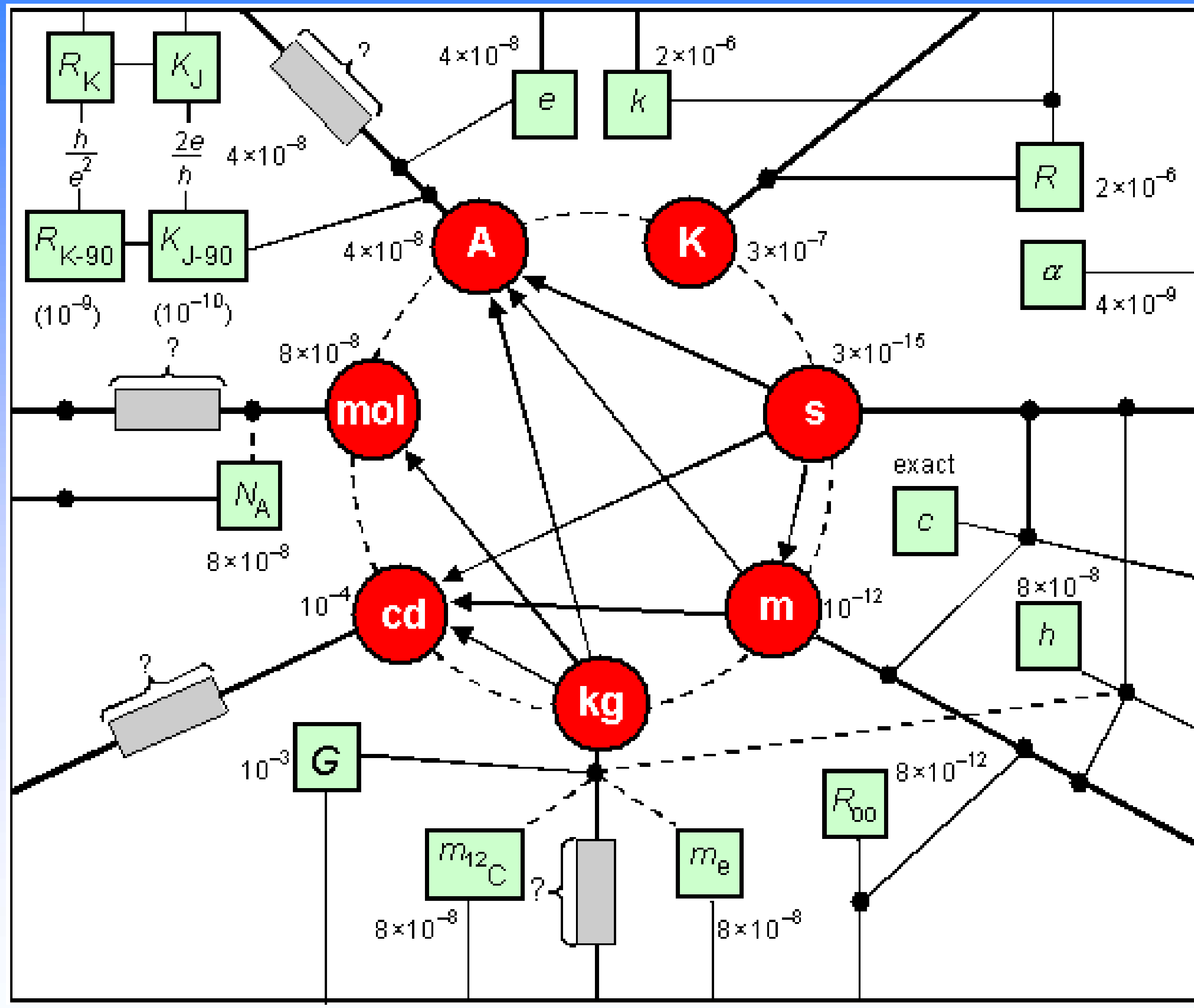


Figure 6.4-1 Technical Risk Management Process

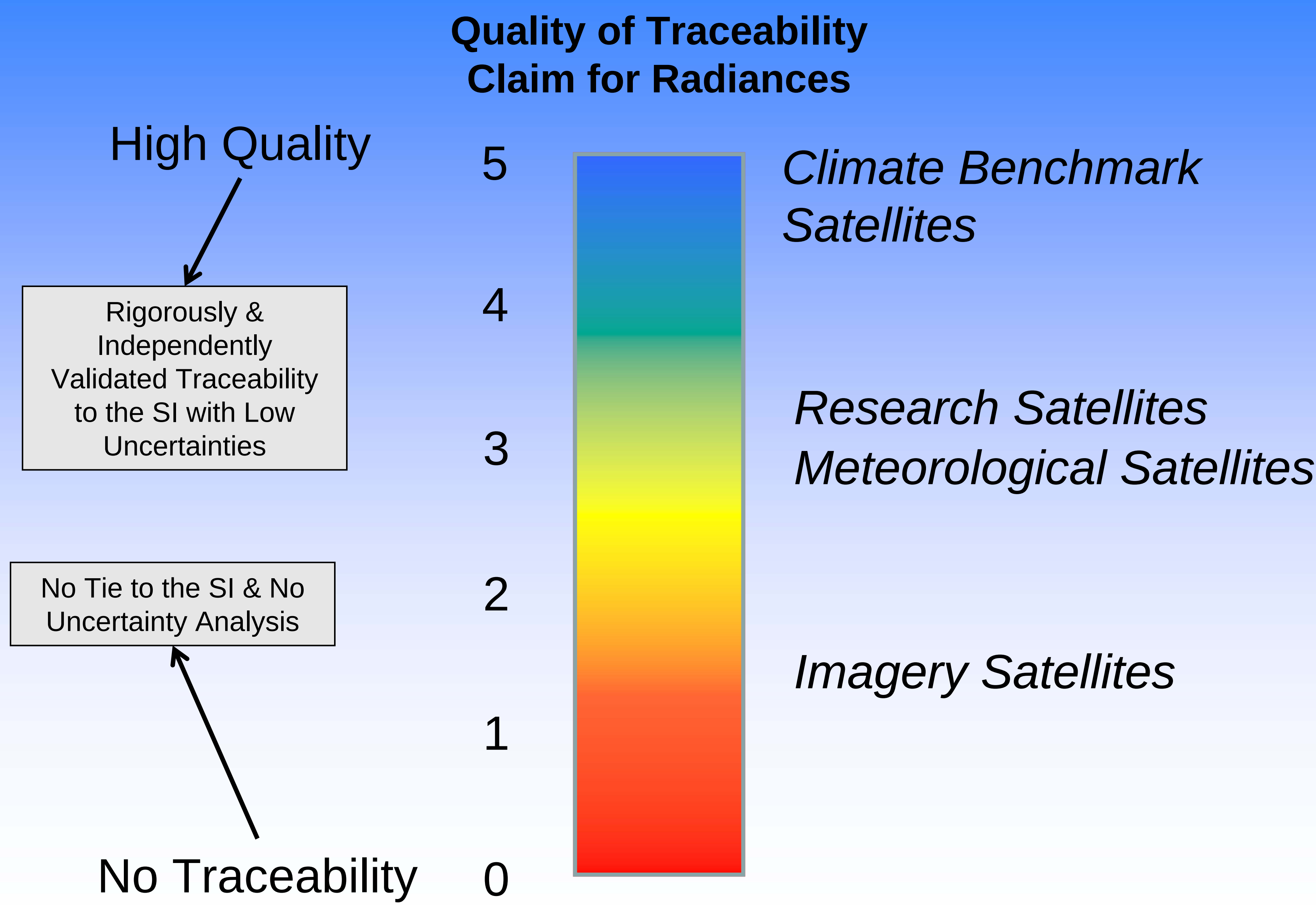
From NASA Systems Engineering Handbook NASA/SP-2007-6105 Rev1

SI Base Units and Fundamental Constants



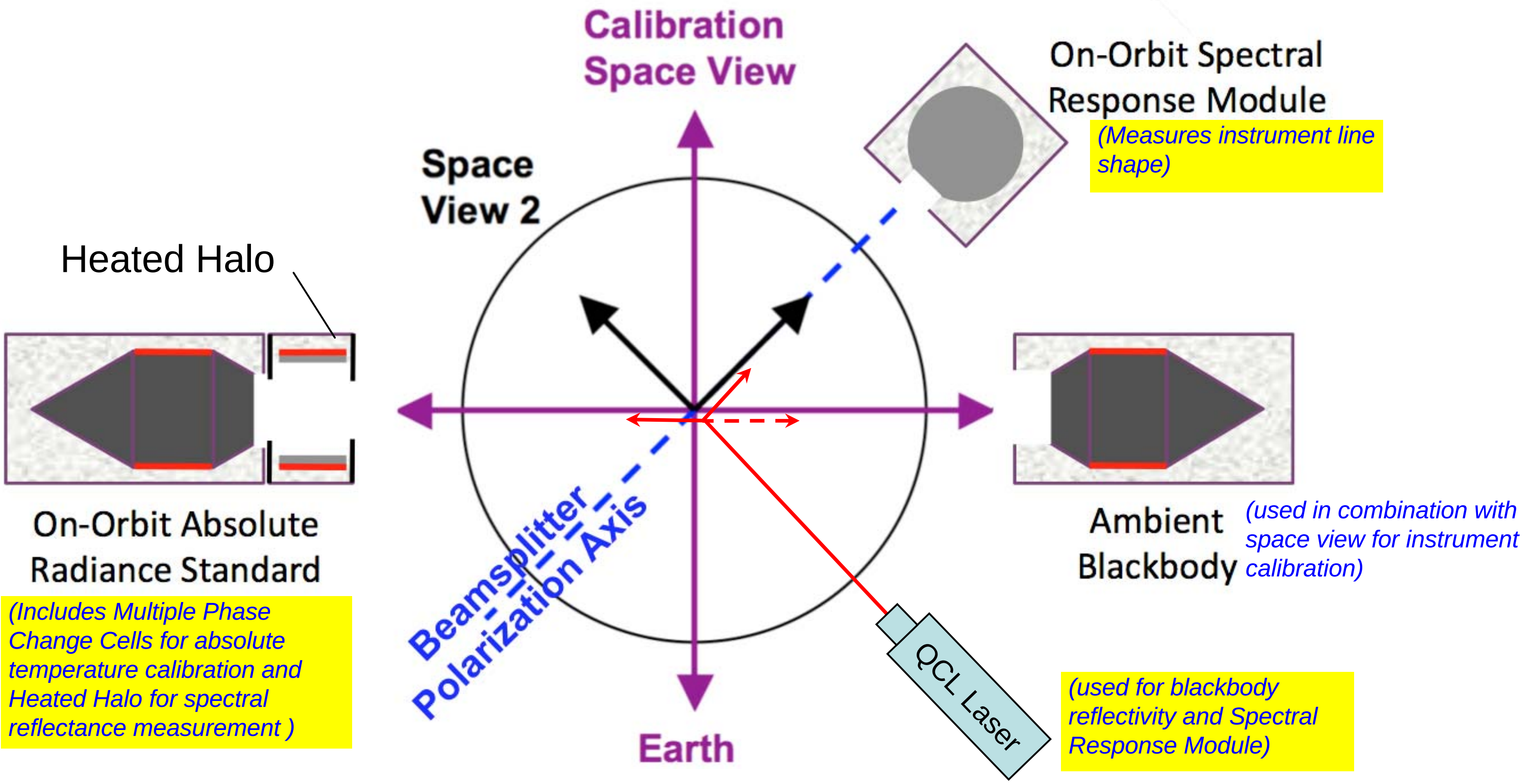
Quantitative relationship propagates uncertainty of measurements

Quality of Traceability Claim



On-orbit Test/Verification (OT/V) Modules

Wisconsin & Harvard Technology Developments Under NASA IIP



Viewing configuration providing immunity to polarization effects.

What Can Be Learned from Past Experiments?

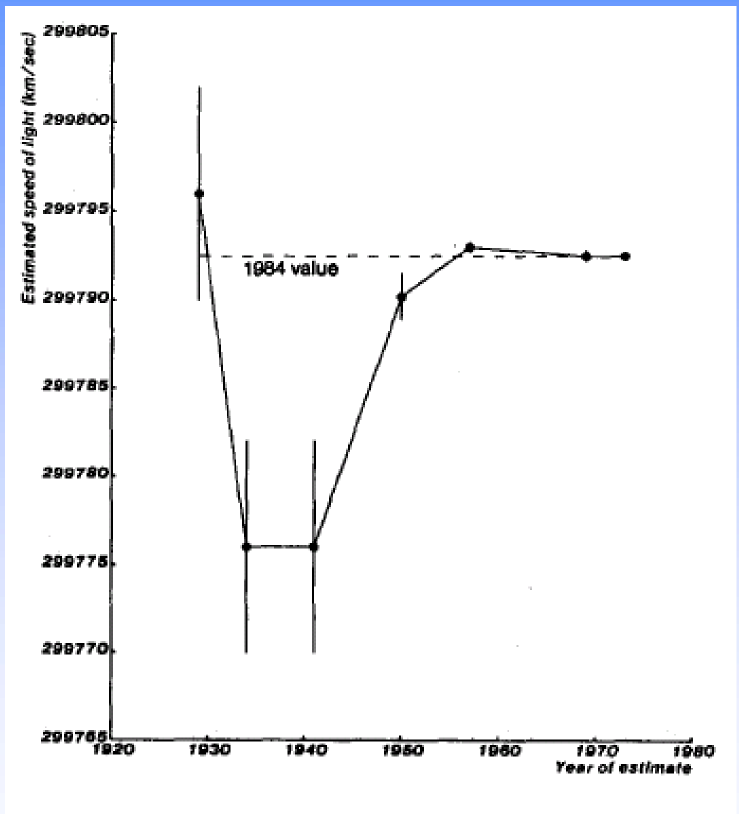
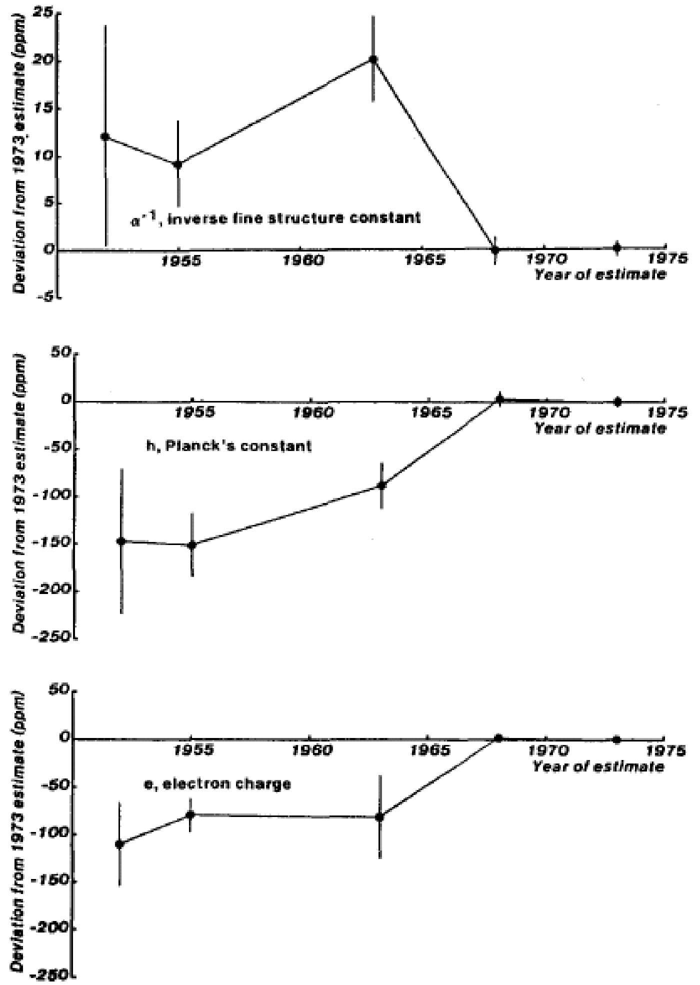


Fig. 2. Recommended values for the velocity of light; 1929–1973.



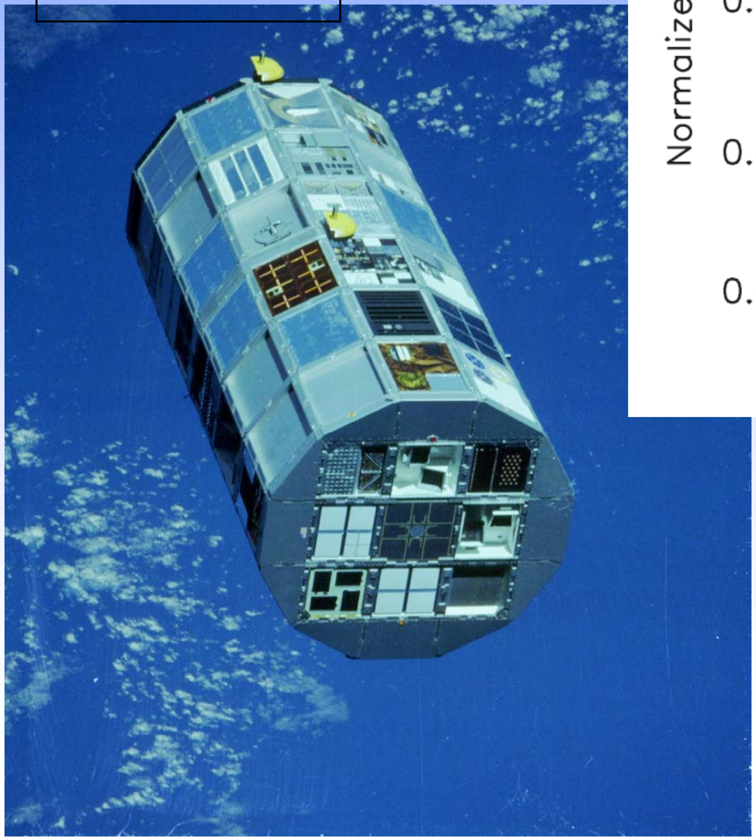
from Henrion and Fischhoff, 1986, Am. J. Phys.

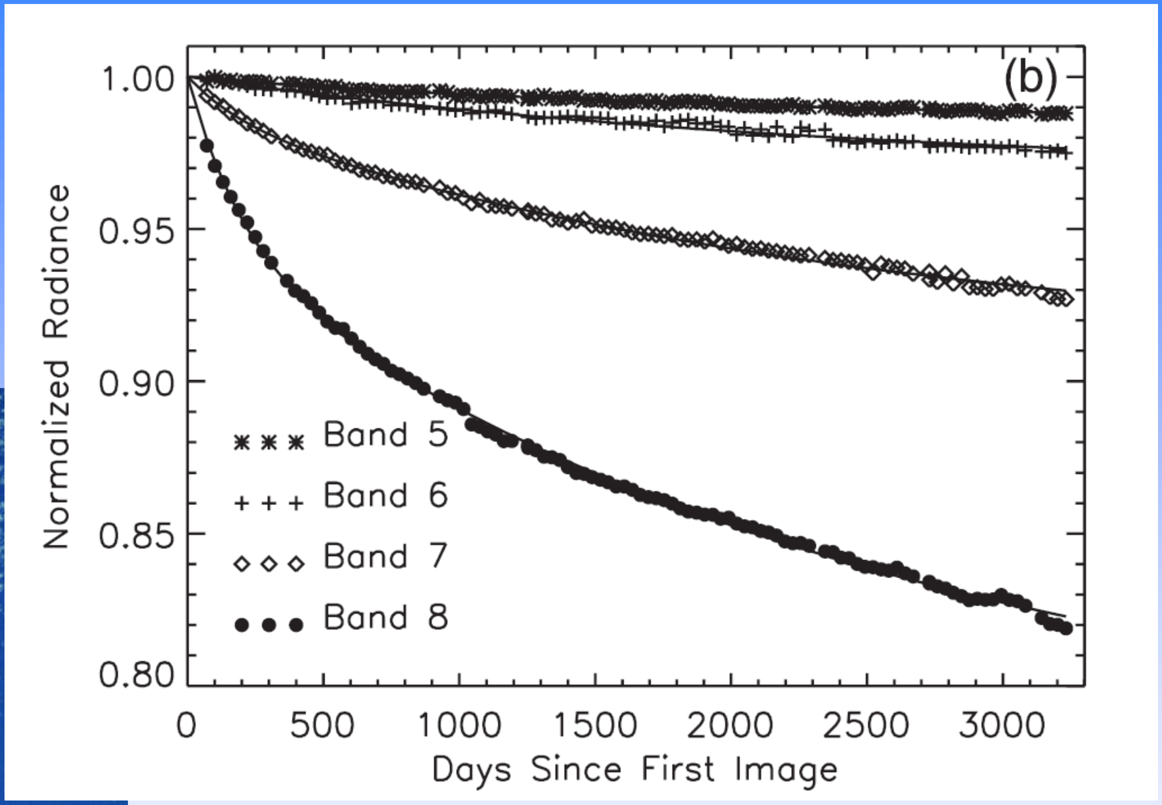
Generic Diagnosis

- Uncertainty affected by details of experimental setup
- Unmeasured parameters influence uncertainty
- Relevancy to given experiment depends on:
  - measurement principle,
  - physics and chemistry of materials and devices

Aging and Exposure

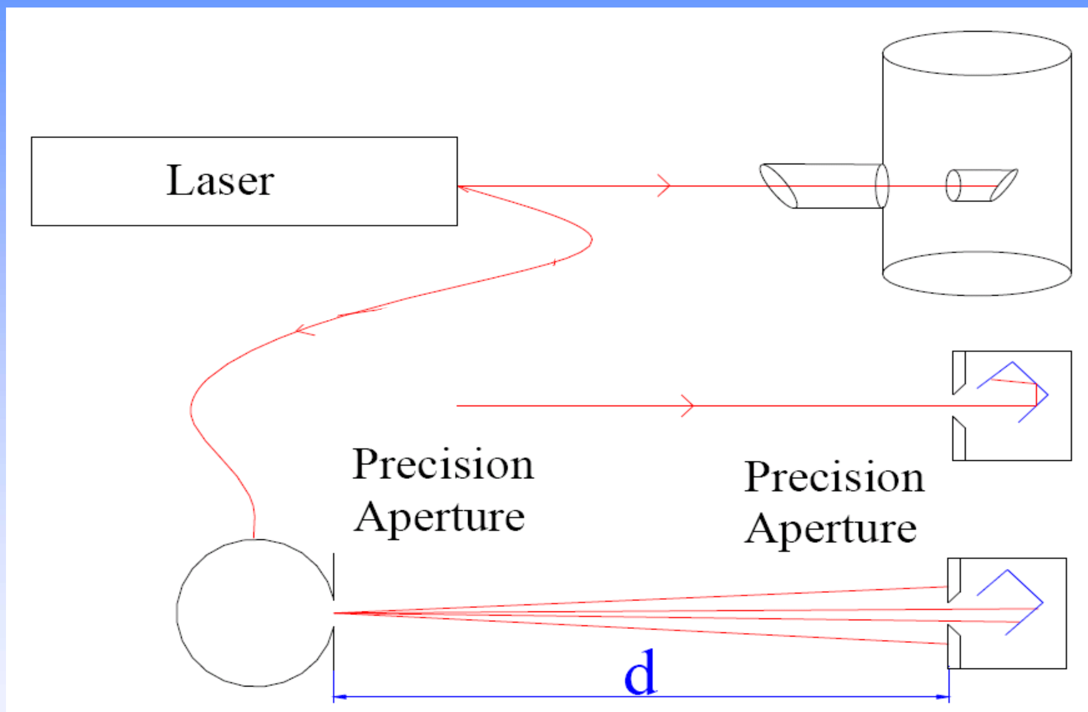
LDEF

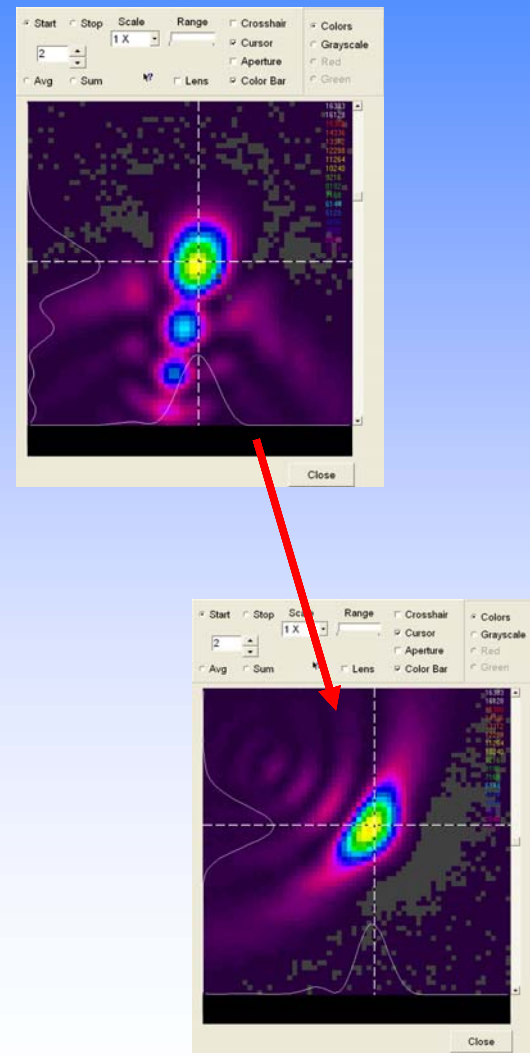




Lunar calibration of SeaWIFS diffuser shows degradation over time (Eplee et al. 2007 *App. Opt.*)

Measurement conditions





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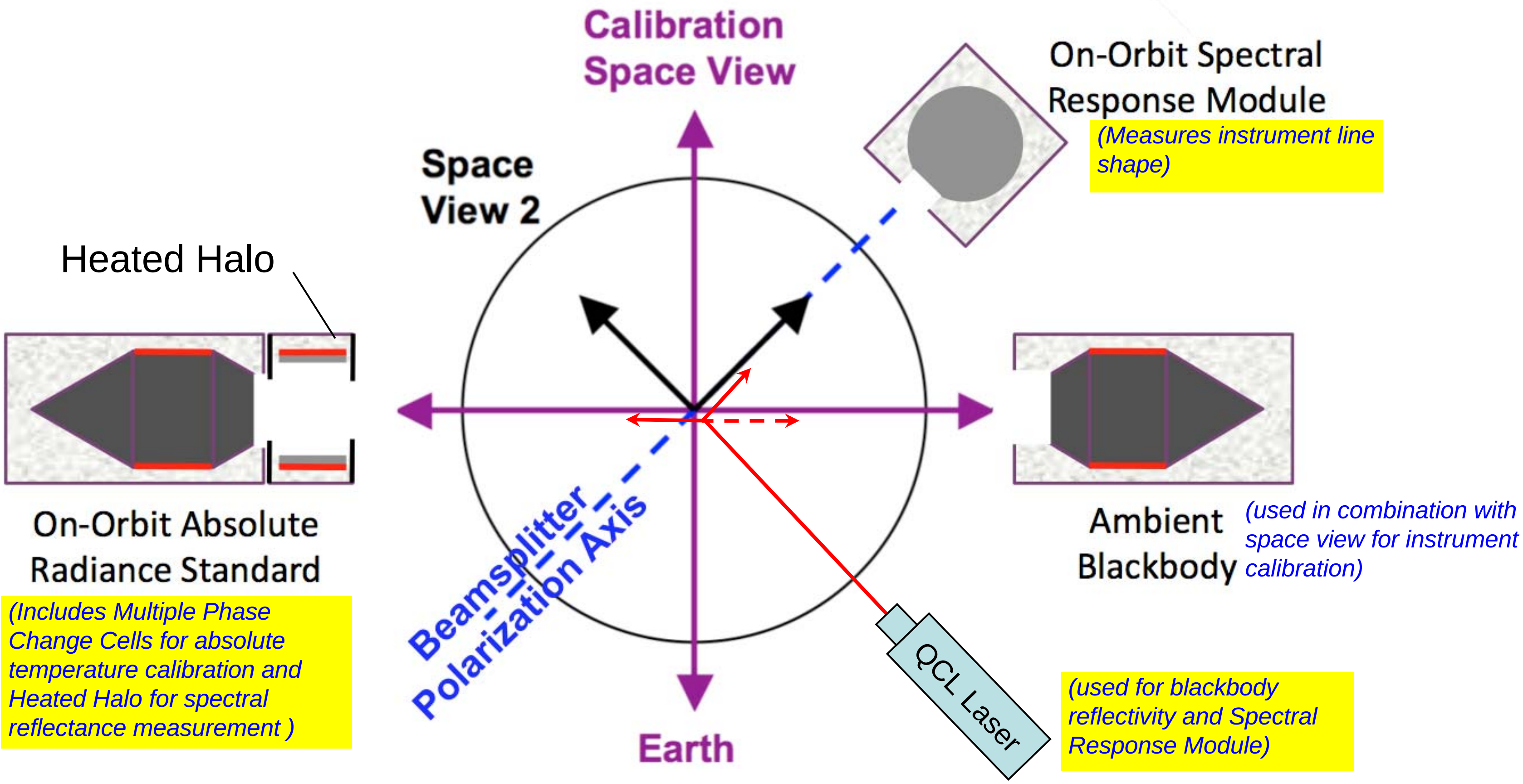
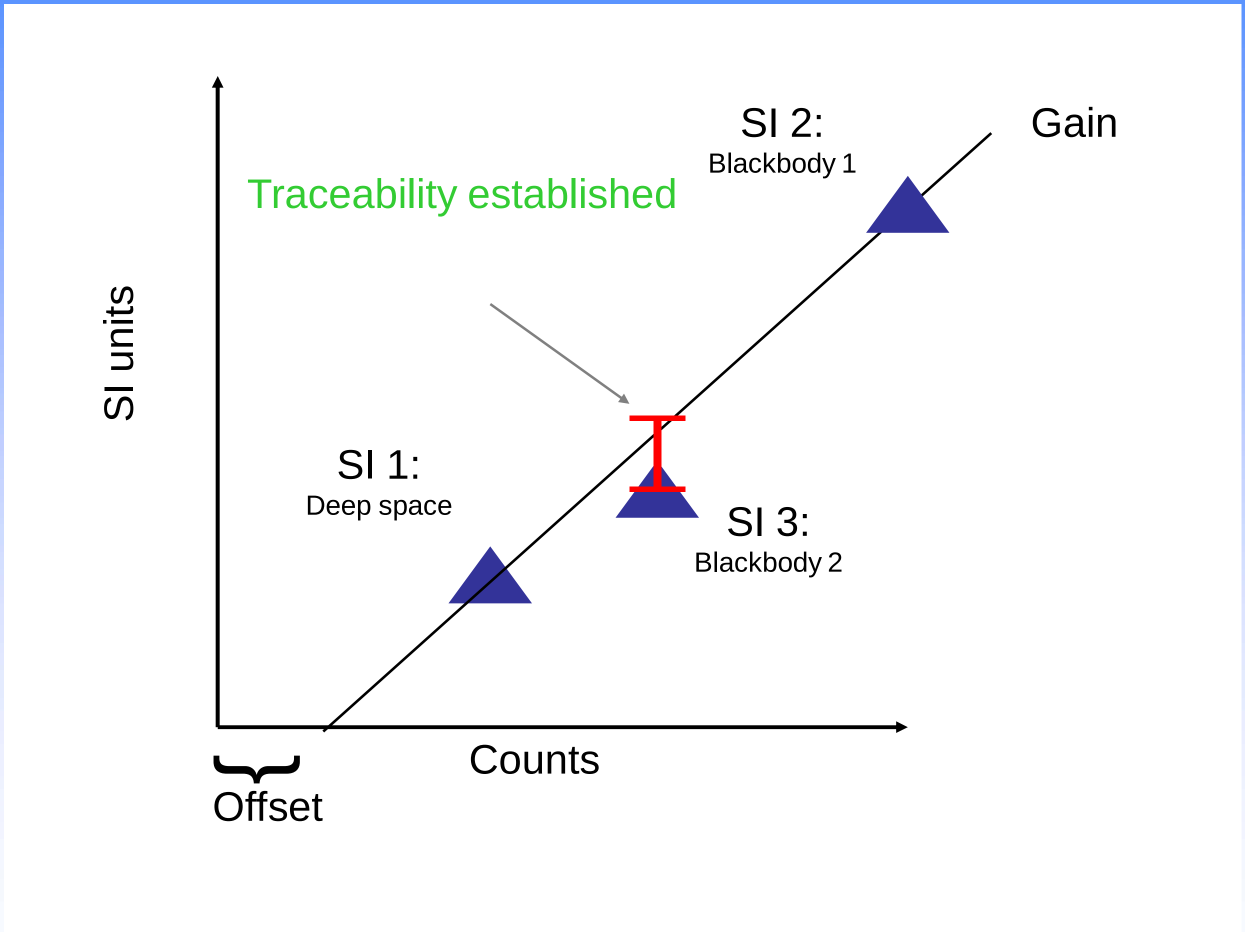


Viewing configuration providing immunity to polarization effects.

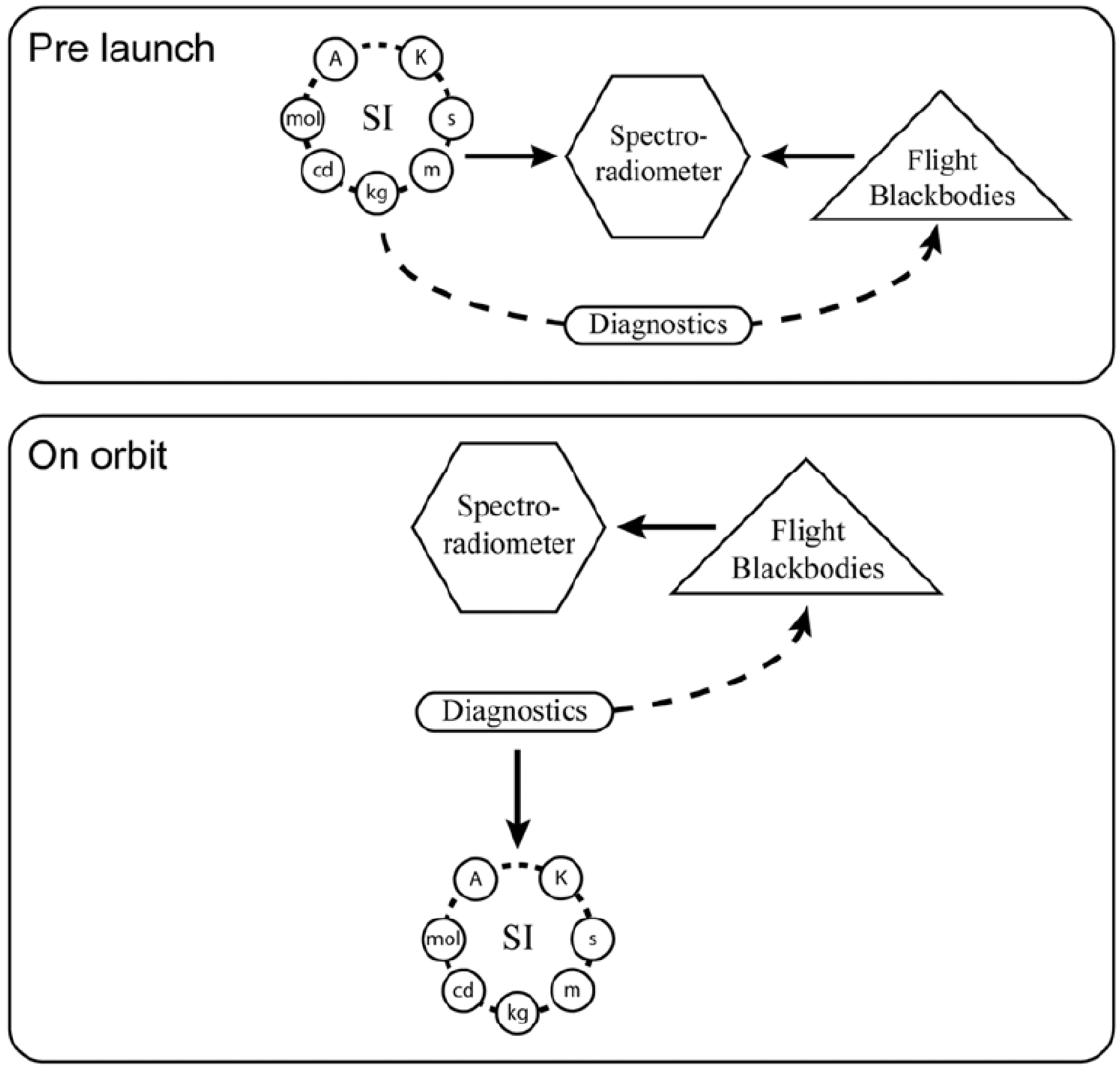
Managing Technical Risk: Objective First-order Measure of Uncertainty

- Suggested by Pollock, D. B., T. L. Murdock, R. U. Datla, and A. Thompson, Data uncertainty traced to SI units. Results reported in the International System of Units, *International Journal of Remote Sensing, 24*(2), 225-235, 2003.
- ***Implemented on INTESA***



Managing Technical Risk: Ruling Out Undetected Systematic Uncertainties

- Suggested by Henrion and Fischhoff, 1986
- ***Applied to CLARREO-like IR sensor by Dykema and Anderson, Meterologia, 2006***



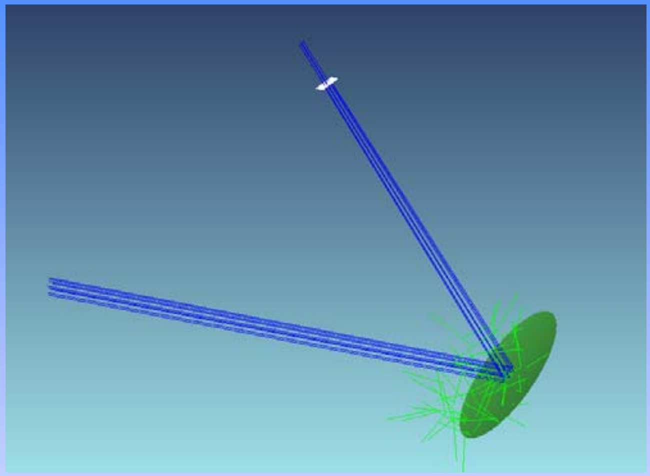
Managing Technical Risk: Detecting Dependence of Uncertainty Estimates on Measurement Conditions

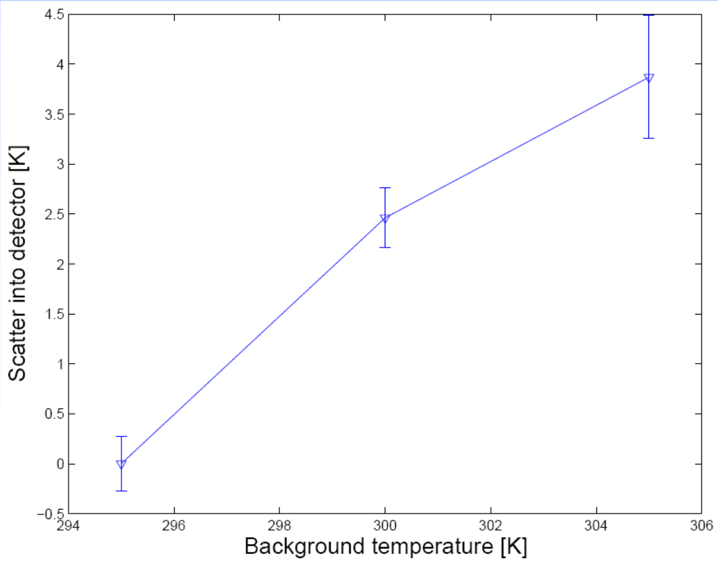
•Suggested in Petley (*Fundamental Physical Constants and the Frontiers of Measurement* 1985), Youden (*Technometrics* 1972)

•Influence of these parameters treated in Butler et al. *The Calibration and Characterization of Earth Remote Sensing and Environmental Monitoring Instruments* (2005)

Spatial Parameters
Spatial responsivity Within field Out-of-field
Spatial response uniformity Within field Out-of-field

Abbreviated Table 10.2 from Butler et al.





Blackbodies Provide SI-Traceable Calibration

$$B_\nu(T) = \frac{8\pi h}{c}\frac{\nu^3}{\left(\exp^{(h\nu/kT)} - 1\right)}$$

$$\varepsilon_{axis} B_\nu(T)$$

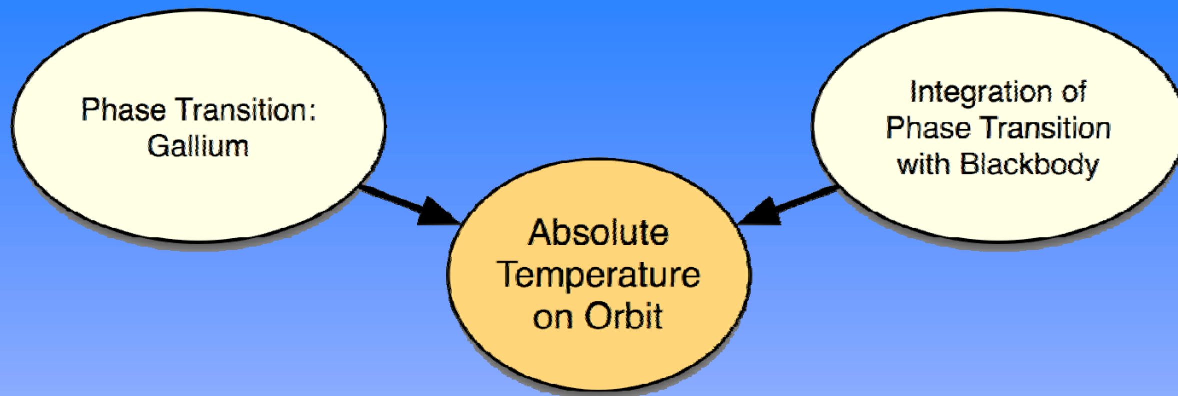
$$\varepsilon_{axis} = f\left(\varepsilon_s, \ell/d\right)$$

On-Orbit Blackbody:

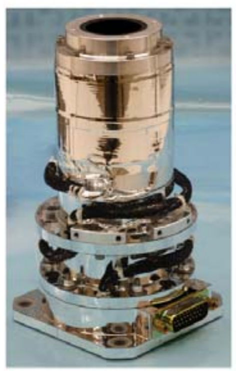
•Finite Aperture

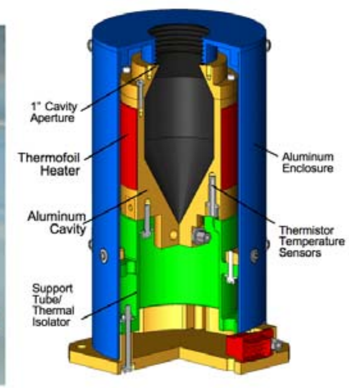
•Temperature Gradient

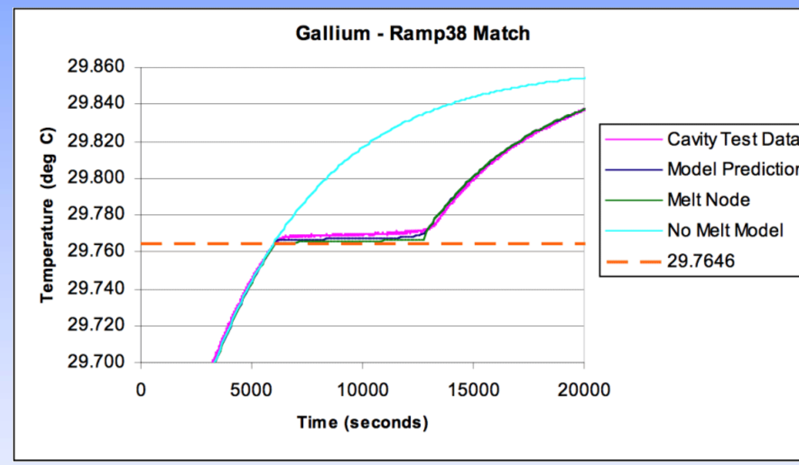
SI Temperature On-Orbit: Integration of Phase Transition Cell with Blackbody

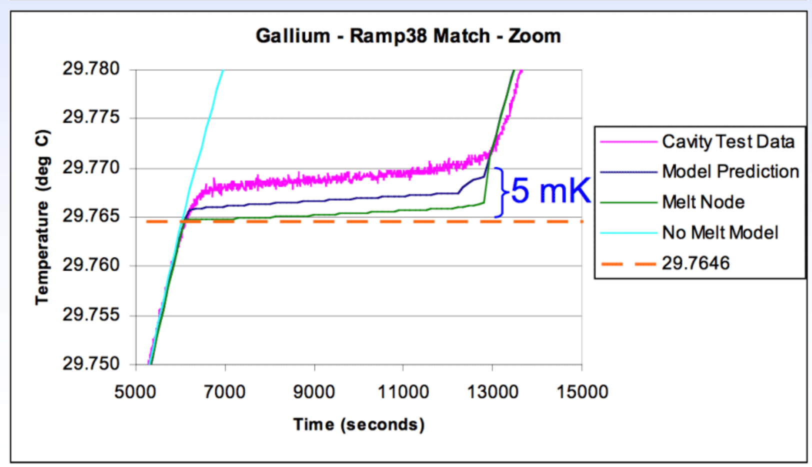


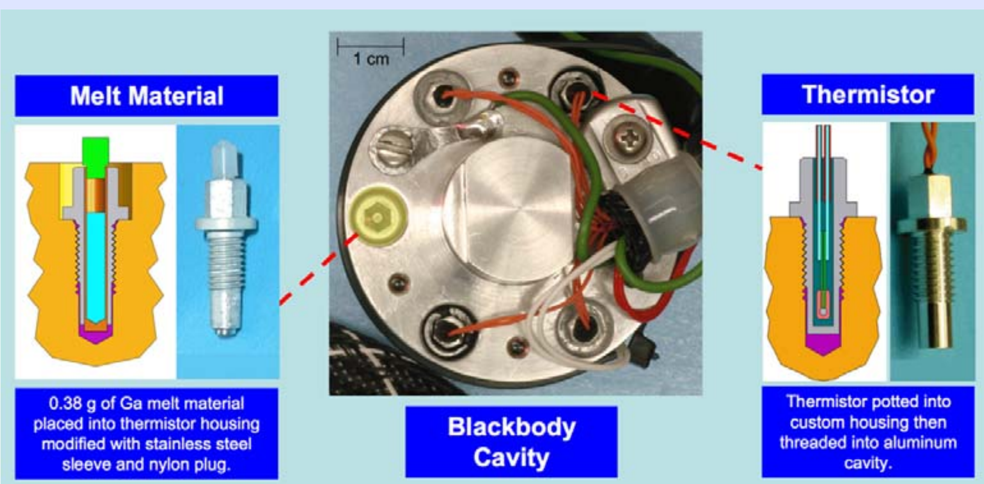
Key Parameter	Specification	As Delivered
Measurement Range	233 to 313 K	233 to 313 K
Temperature Uncertainty	< 0.1 K (3 σ)	< 0.056 K
Blackbody Emissivity	> 0.996	> 0.999
Emissivity Uncertainty	< 0.002 (3 σ)	< 0.00072
Entrance Aperture	1.0 inch	1.0 inch
Mass (2 BBs + controller)	< 2.4 kg	2.1 kg
Power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





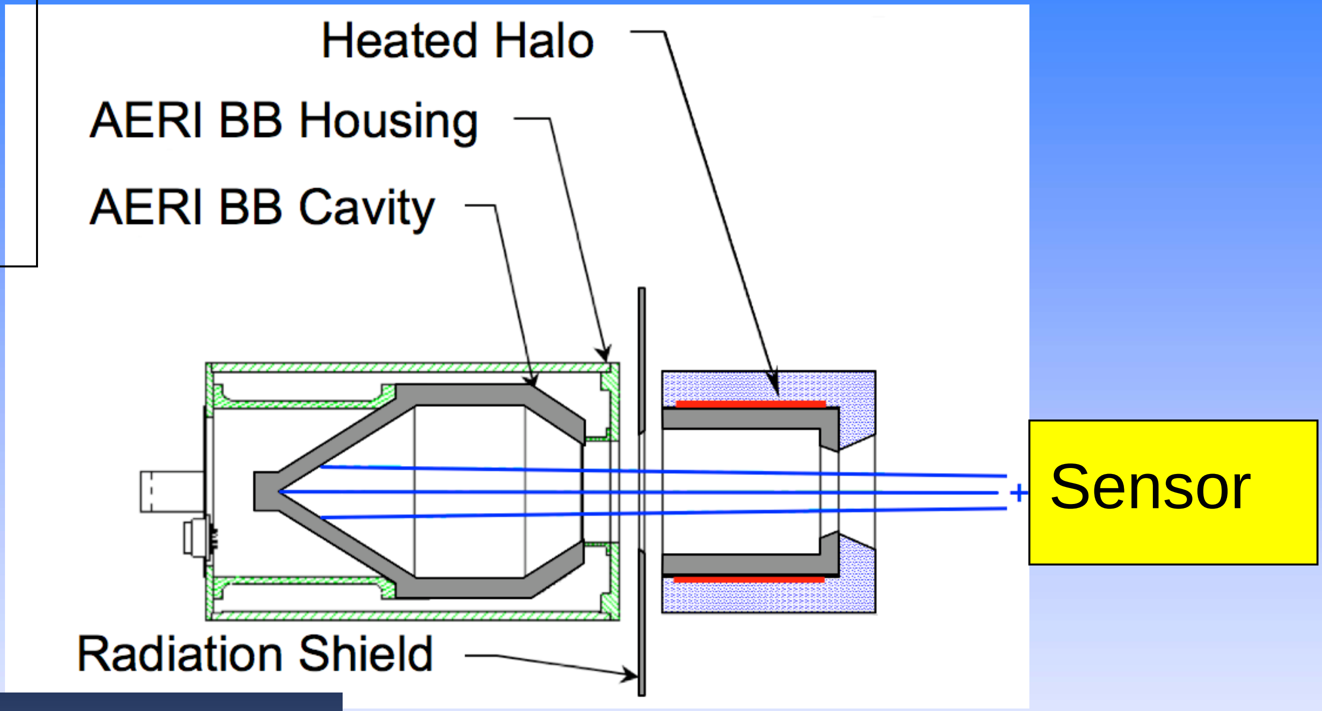


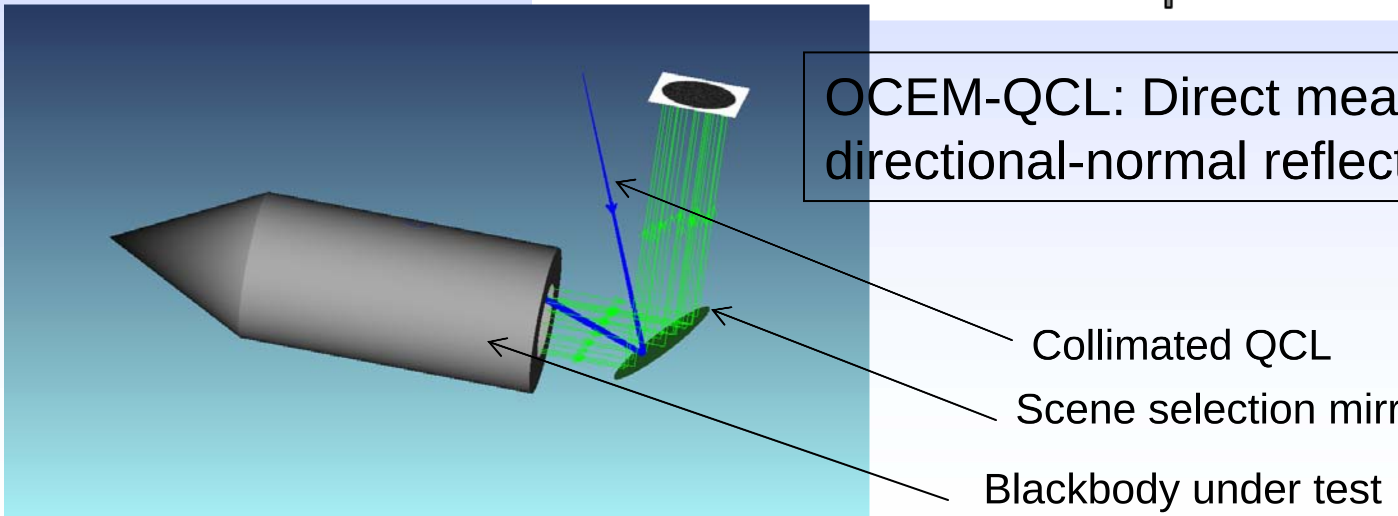




Blackbody Emissivity

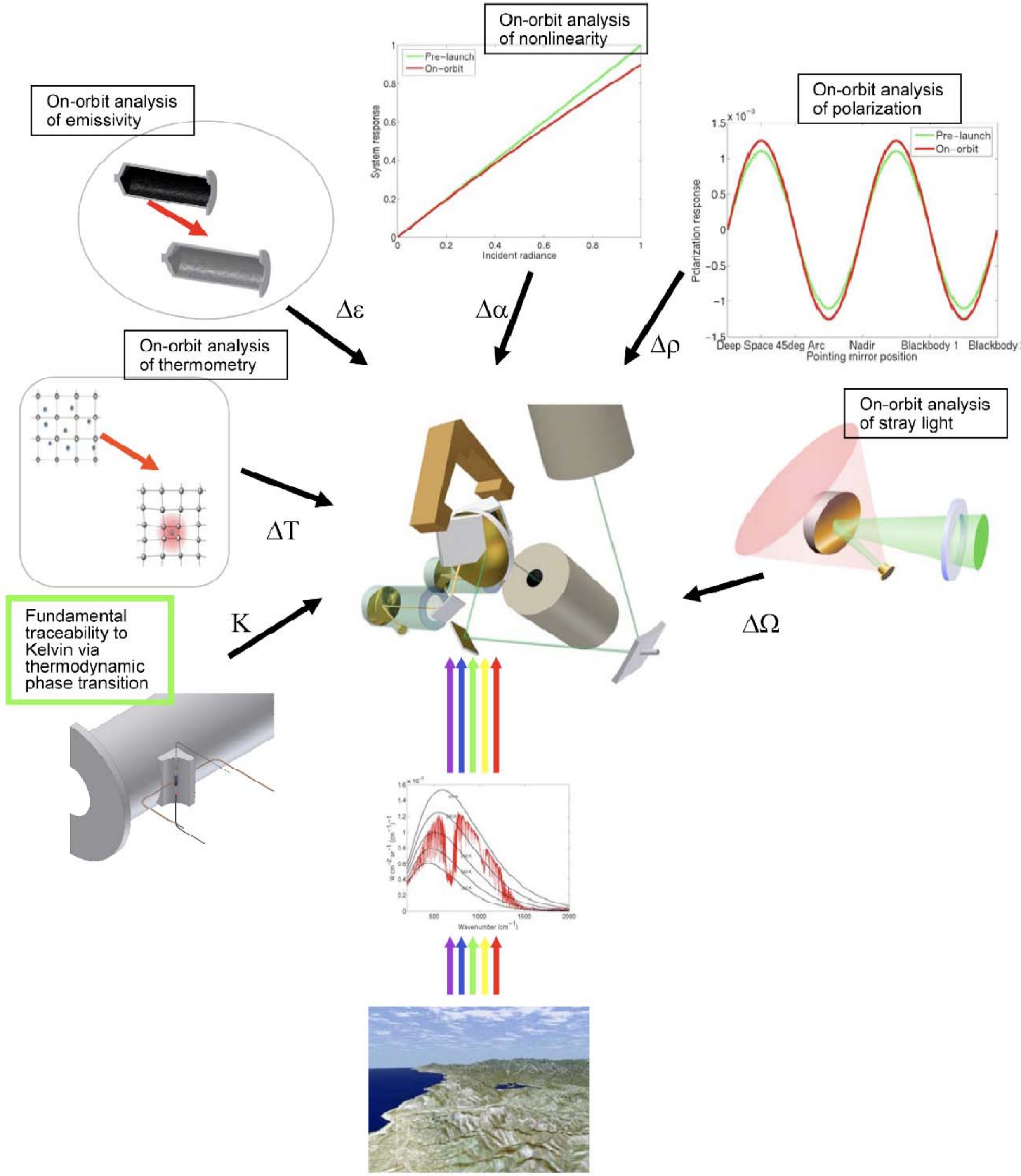
OCEM-Halo: Measures hemispheric normal emissivity



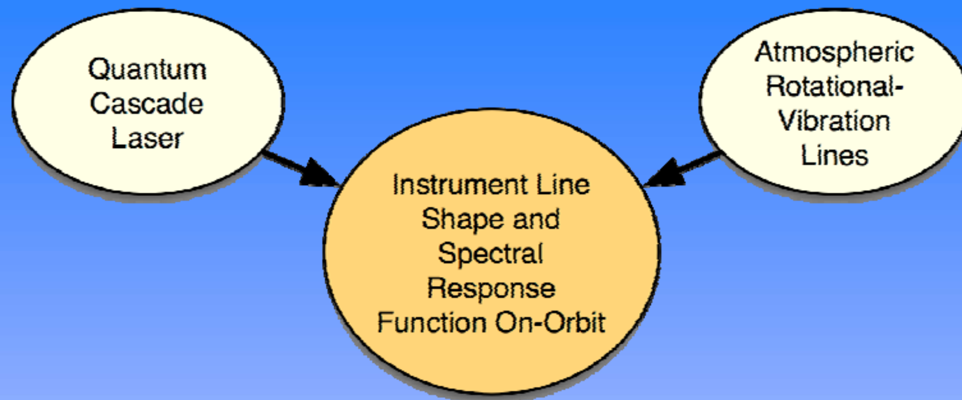


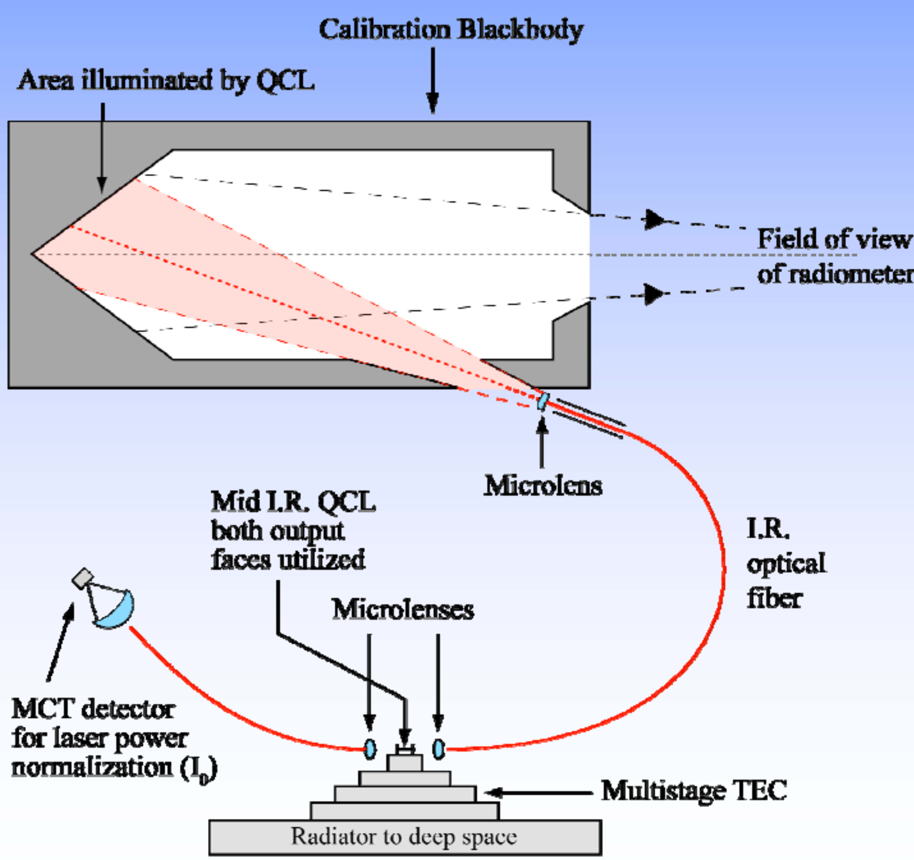
OCEM-QCL: Direct measurement of directional-normal reflectivity

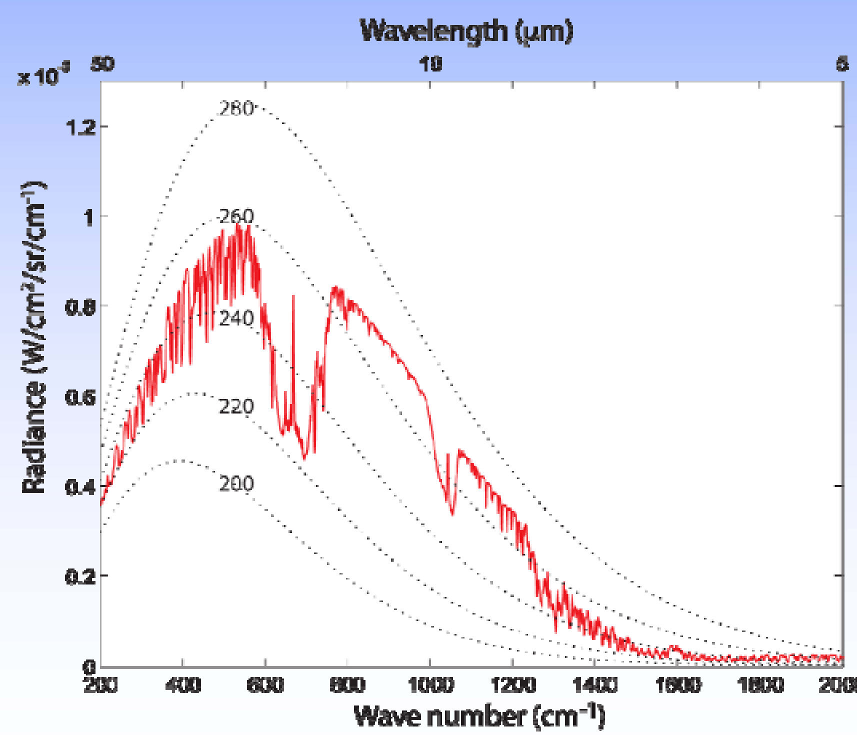
Constellation of Error Analysis Contributions



Instrument Line Shape and Spectral Response Function On Orbit: Quantum Cascade Laser and Atmospheric Rotation-Vibration Lines







Polarization Determination

Amplitude of modulation from polarization

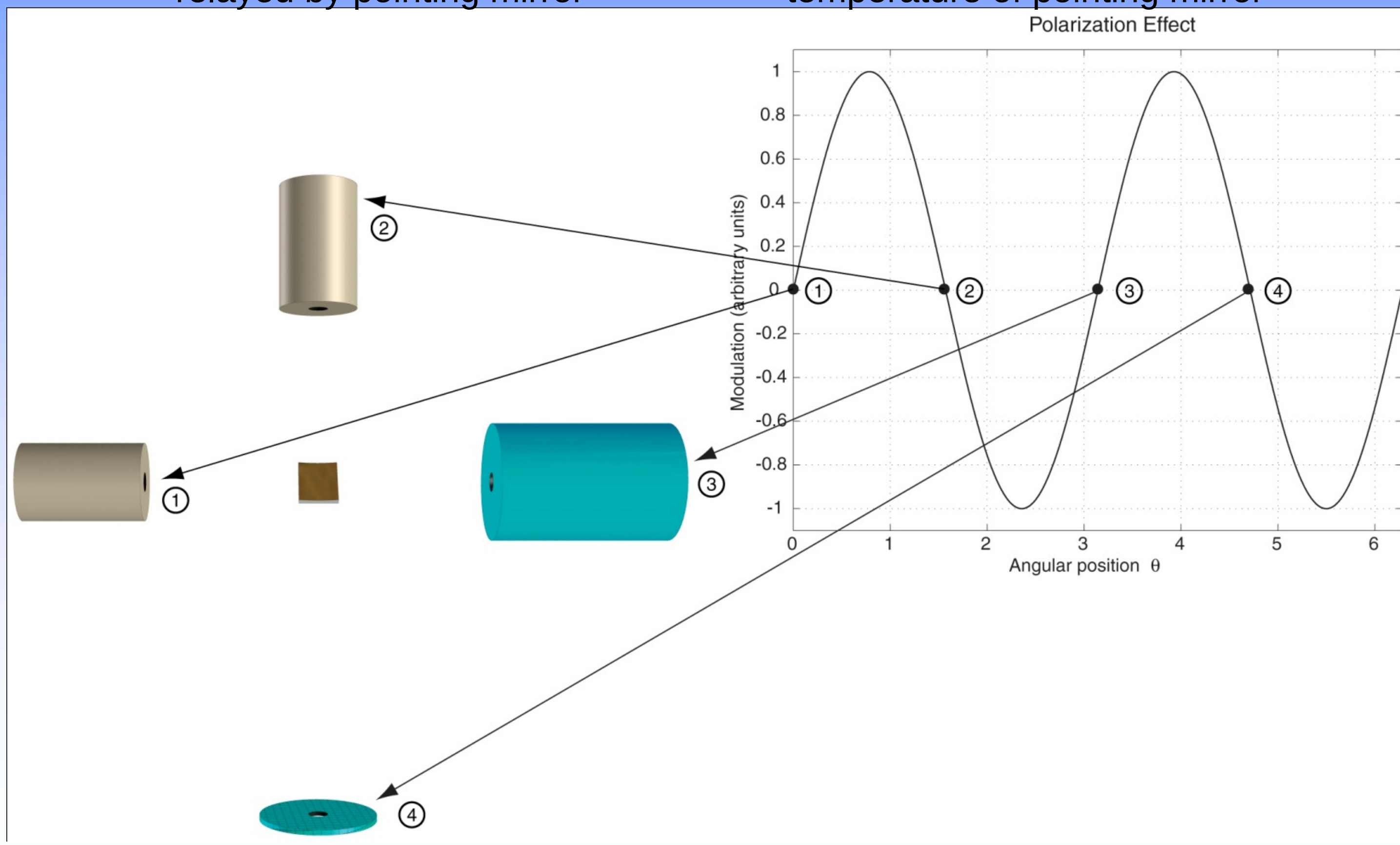
Angular position of mirror

$$S = S_0 + \rho\left(S_0 - B\right)\cos 2\theta$$

Observed signal

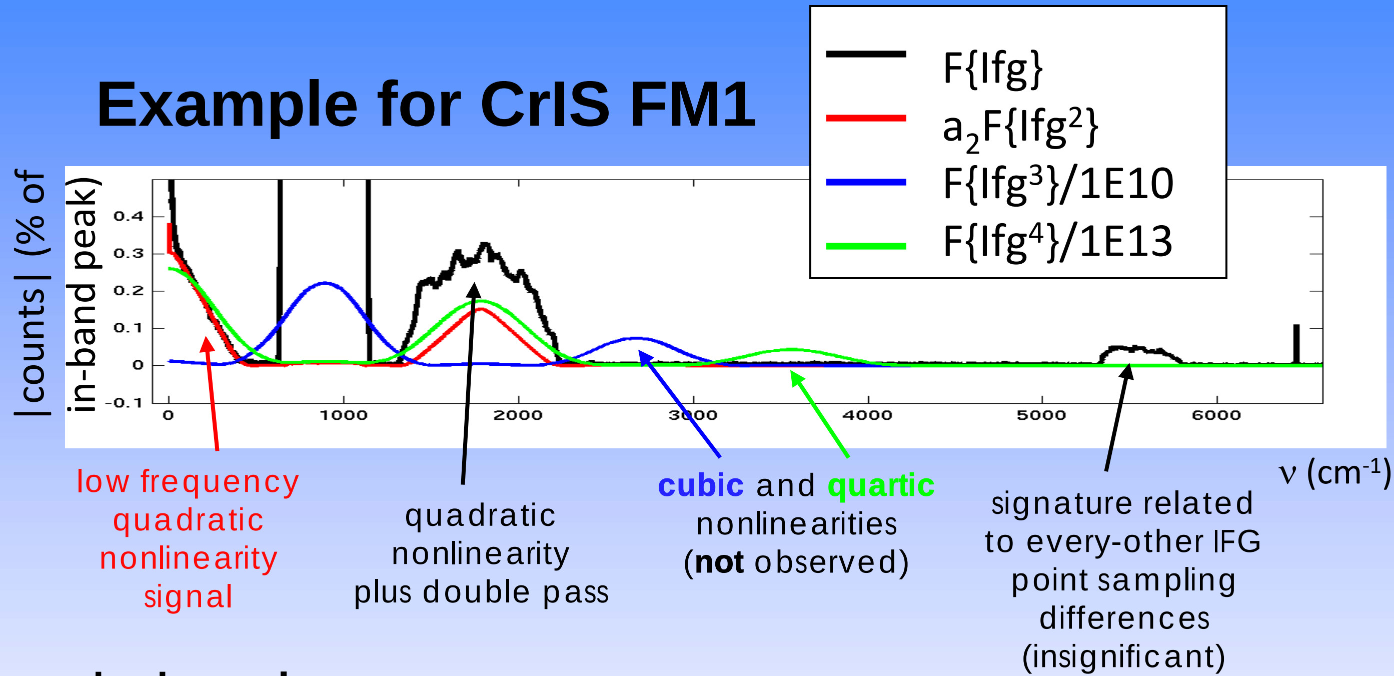
Polarized radiance relayed by pointing mirror

Planck function at measured temperature of pointing mirror



Detector Signal Chain Nonlinearity

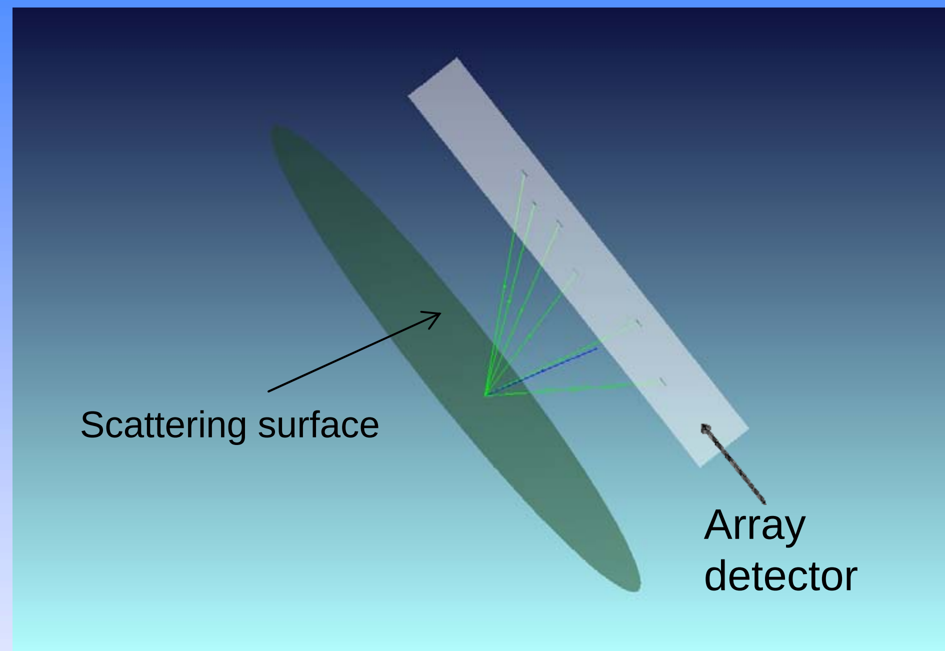
Example for CrIS FM1

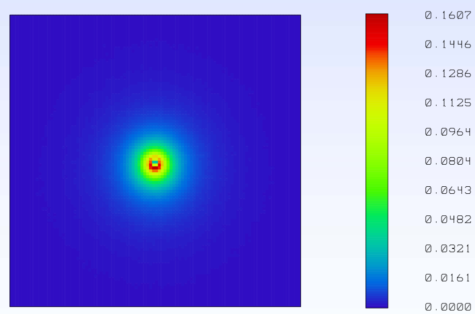


- Out-of-band signal
- Scanning OARS over range of temperatures
- QCL at two (or more) powers

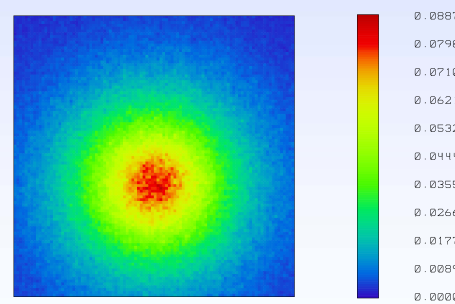
Stray Light

- Stray light in the infrared is dependent on the temperature contrast between target and out-of-field objects
- It can be minimized by good design, leaving a small residual uncertainty
- The residual uncertainty is determined by scatter, multiple reflections, diffraction, and optical defects
- How do we objectively test this uncertainty?



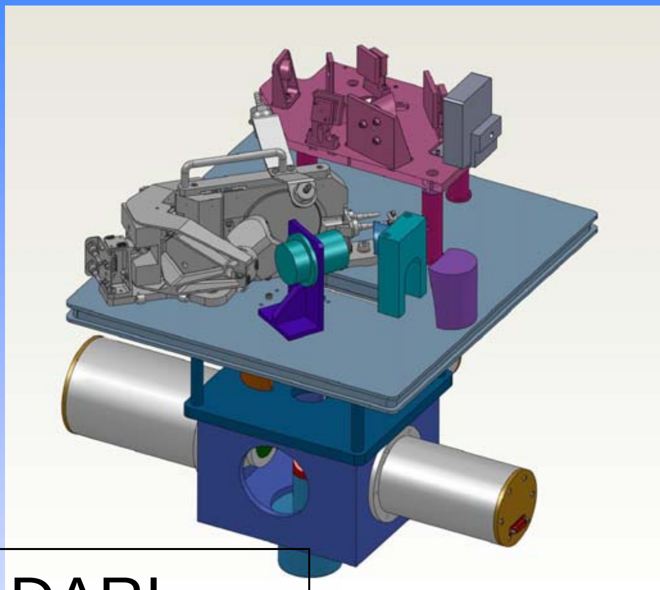


ABg scattering

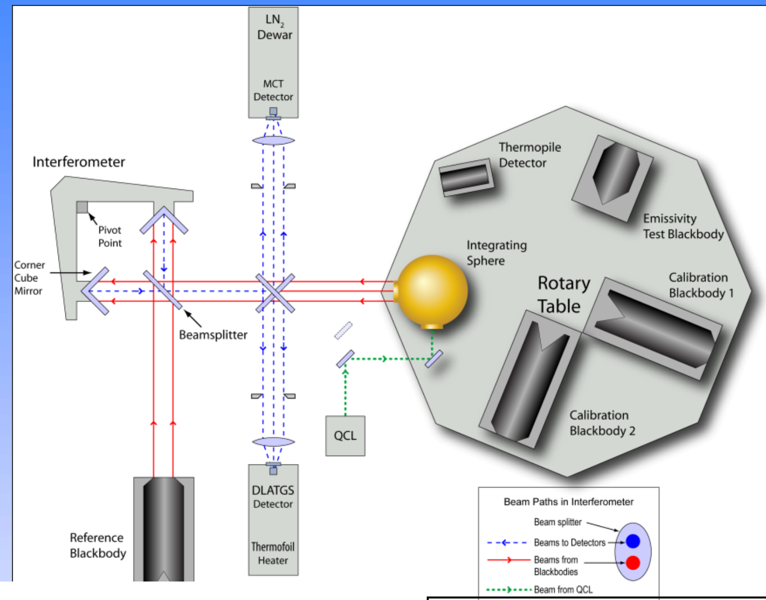


Diffuse scattering

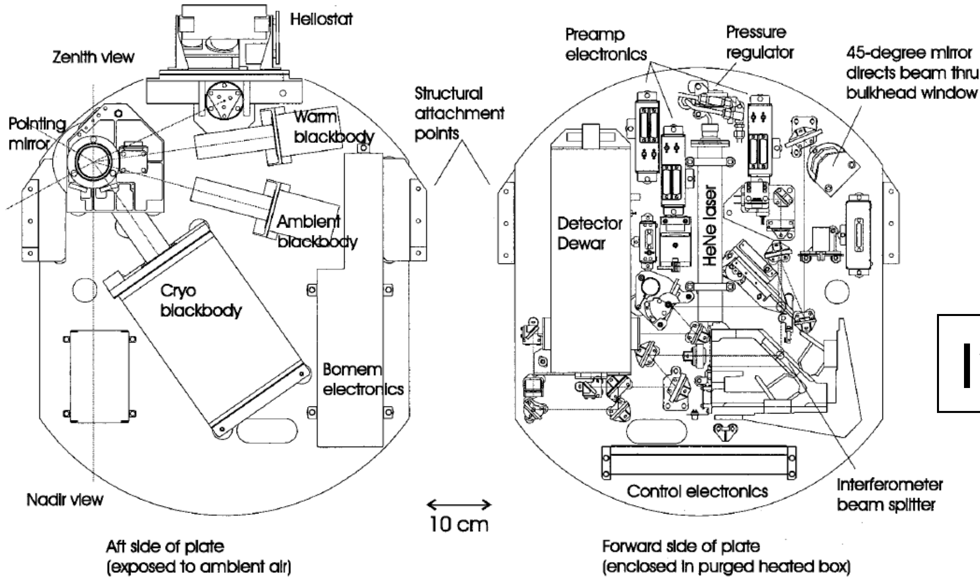
Optical System Uncertainties: Different Detailed Measurement Physics



DARI-HNP/LW



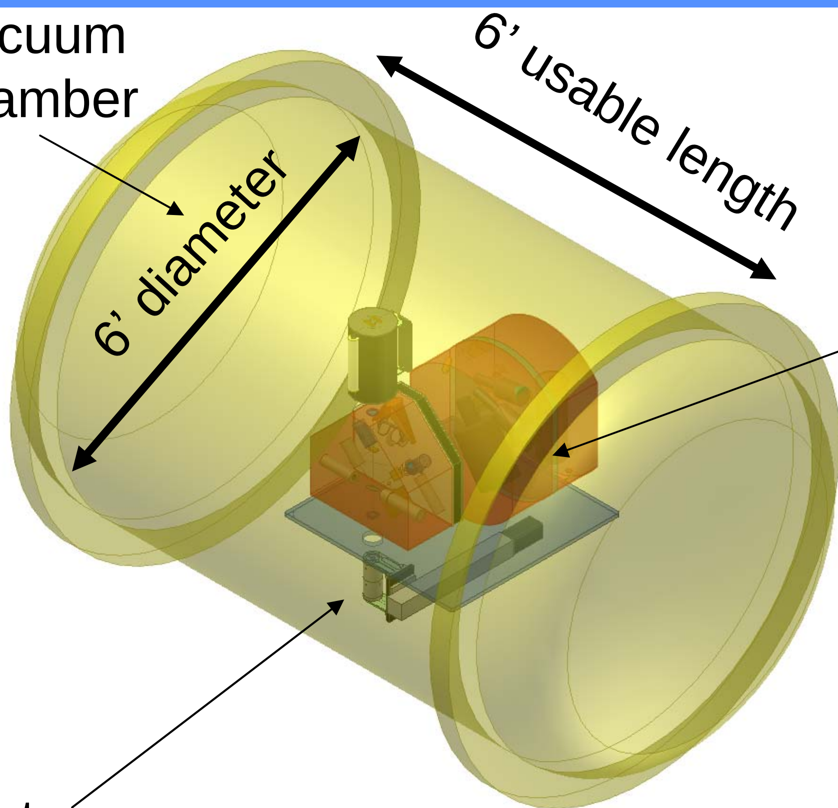
DARI-LW testbed



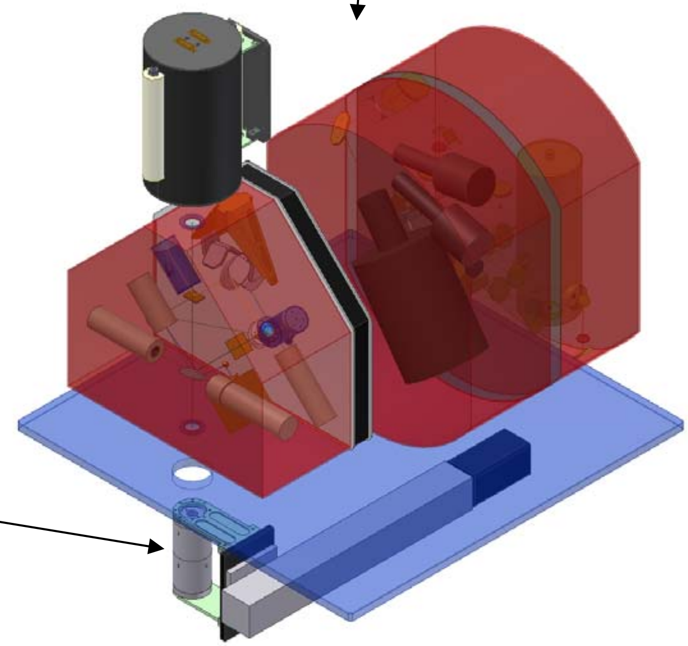
INTESA

Experimental Data to Back Engineering Analysis

Vacuum chamber



Two complete sensor suites with independent calibration

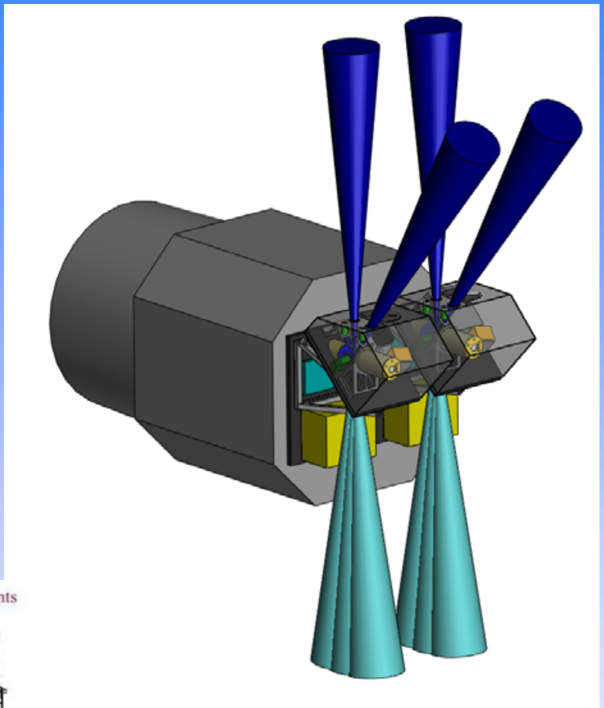


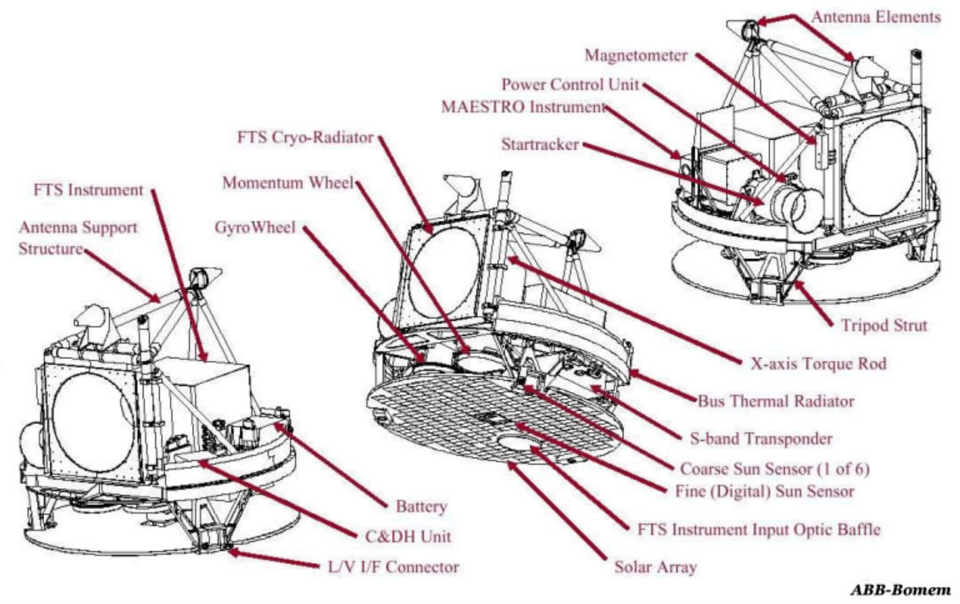
Test blackbody on sliding rail

Summary

Types of Risk

- Technical
- Schedule
- Cost
- Programmatic
- Political





Implementation details make or break the risk reduction