Absolute Radiance Interferometer:
A prototype spaceflight instrument for achieving GSICS and CLARREO goals

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Topics

- **Benchmarking the Earth's Climate from Space**
  - *The CLARREO mission concept*
  - *The UW-SSEC Absolute Radiance interferometer (ARI)*

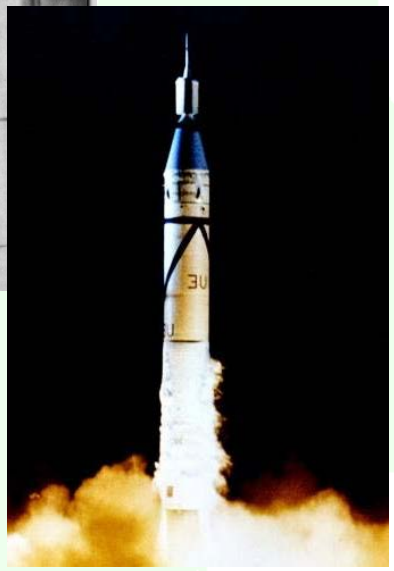
See
Joe Taylor, 14p.01
Jon Gero, 14p.02
for more

13 Oct 1959-Feb 1960 Explorer 7 measured the Earth Radiation Balance

The 1st meteorological satellite instrument to observe the Earth

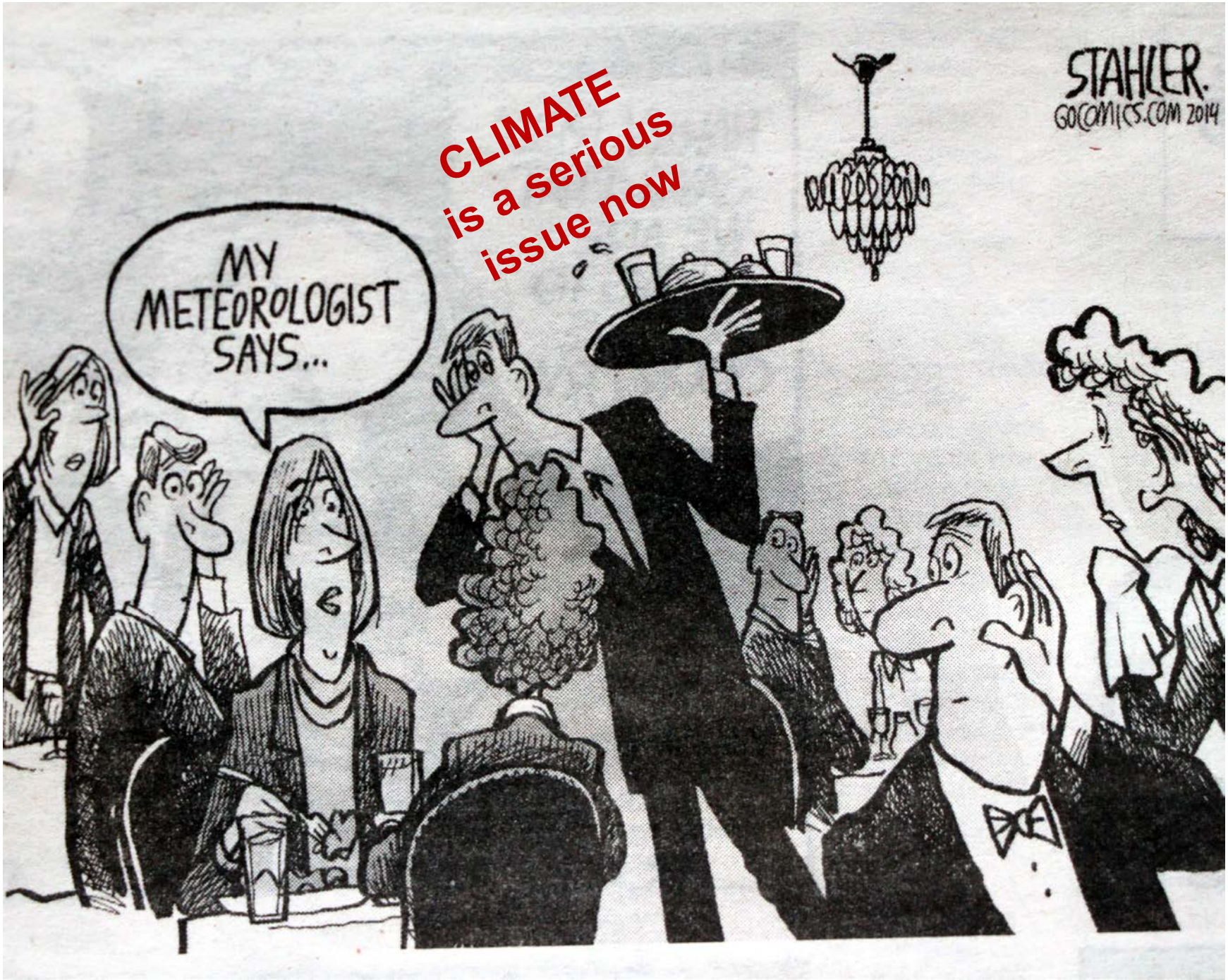
- Radiometer designed by Verner Suomi & Robert Parent
- Omni-directional spheres
- 3-color (black, white, gold)

Spectrally integrated obs continue today



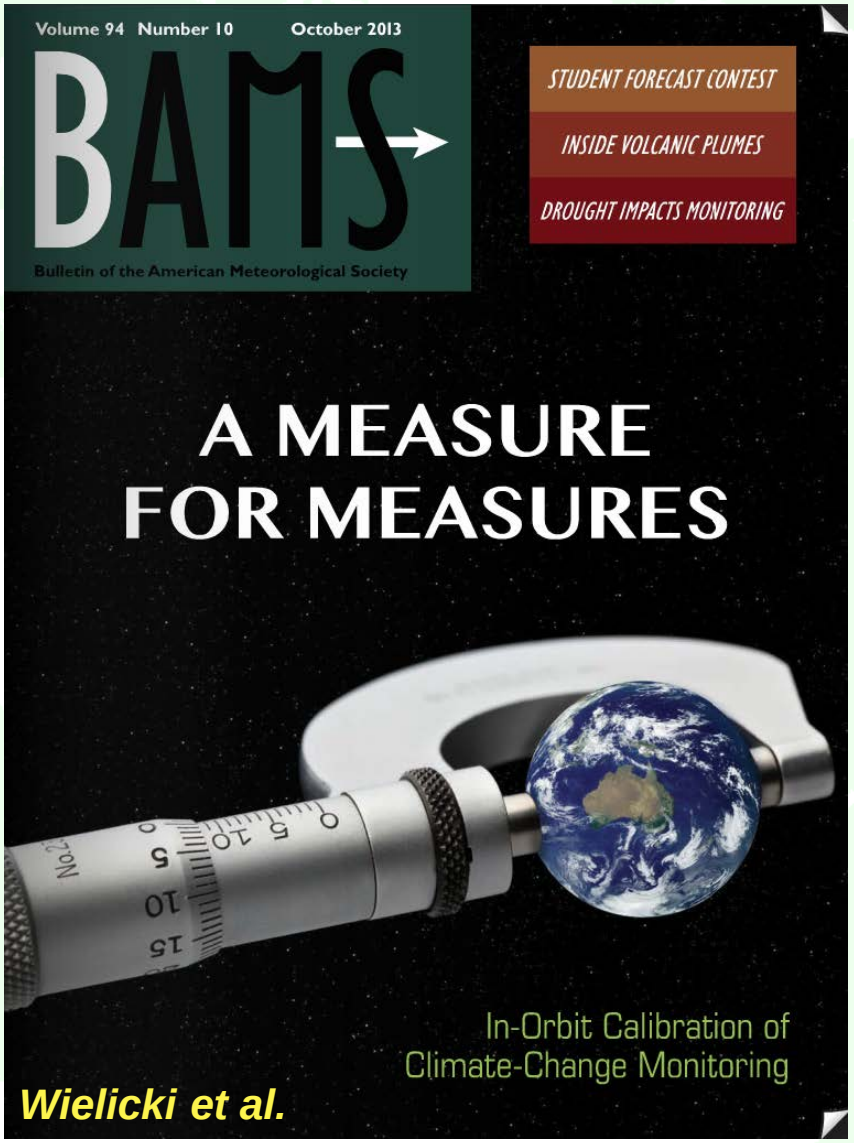
An outgrowth of measuring the energy budget of a corn field

NASA just in its 2nd year


CLIMATE
is a serious
issue now
MY METEOROLOGIST SAYS...
STAHLER.
GOCOMICS.COM 2014

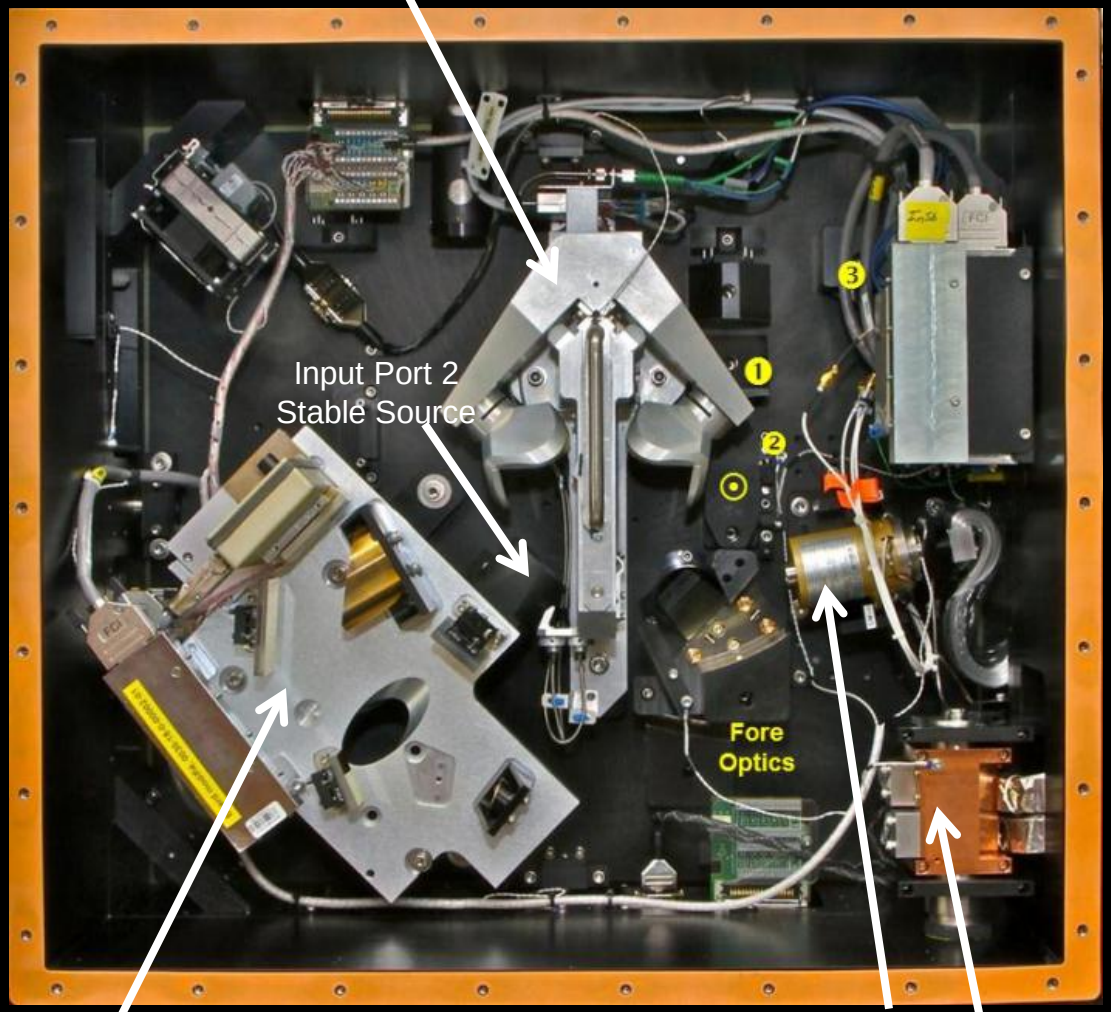
Introduction to CLARREO and ARI

- **CLARREO (Climate Absolute Radiance & Refractivity Observatory) a 2007 Decadal Survey Tier 1 mission**
  - IR & Reflected Solar spectra coupled with GPS occultation data offer unprecedented accuracy & information content to provide much higher climate change sensitivity than existing records (from total integrated IR & Solar data)
  - Metrology lab on-orbit serves as "NIST in orbit"
- **CLARREO to Benchmark the Earth's climate**
  - Analogous to marking a glacier's current extent
- **CLARREO to be an Inter-calibration Standard**
  - GSICS (Global Space-based Inter-Cal System)
  - e.g. Greatly enhancing the value of the climate record from high spectral resolution IR sounders starting in 2002 (AIRS, IASI, CrIS)
- **Absolute Radiance Interferometer (ARI) is an IR prototype instrument with new on-orbit verification technology ready for CLARREO or a pathfinder mission**



Absolute Radiance Interferometer (ARI) Prototype

with a short upgrade path to flight



Calibrated FTS

- Corner-cube interferometer used in 4-port to avoid double pass; Strong flight heritage
  - 0.5 cm^{-1} resolution (±1 cm OPD)
  - 1.55 µm diode laser for interferogram sample control & fringe counting
  - 10 cm CsI single-substrate beamsplitter
- Fore optics designed to
  - minimize polarization effects
  - minimize sizes of calibration/ validation BBs & reflectivity sources
  - minimize stray light by providing effective field and aperture stops
  - maximize energy throughput
- 3-50 µm Spectral Coverage
  - Highly linear pyroelectric detector, all reflective aft optics: 10-50 µm
  - Cryo-cooler for MCT & InSb semi-conductor detectors: 3-18 µm

Absolute Radiance Interferometer (ARI) Prototype

with a short upgrade path to flight

On-orbit Verification and Test System (OVTS) Technologies

❶ On-orbit Absolute Radiance Standard (OARS) cavity blackbody using three miniature phase change cells to establish the temperature scale from -40, to +30 C to better than 10 mK

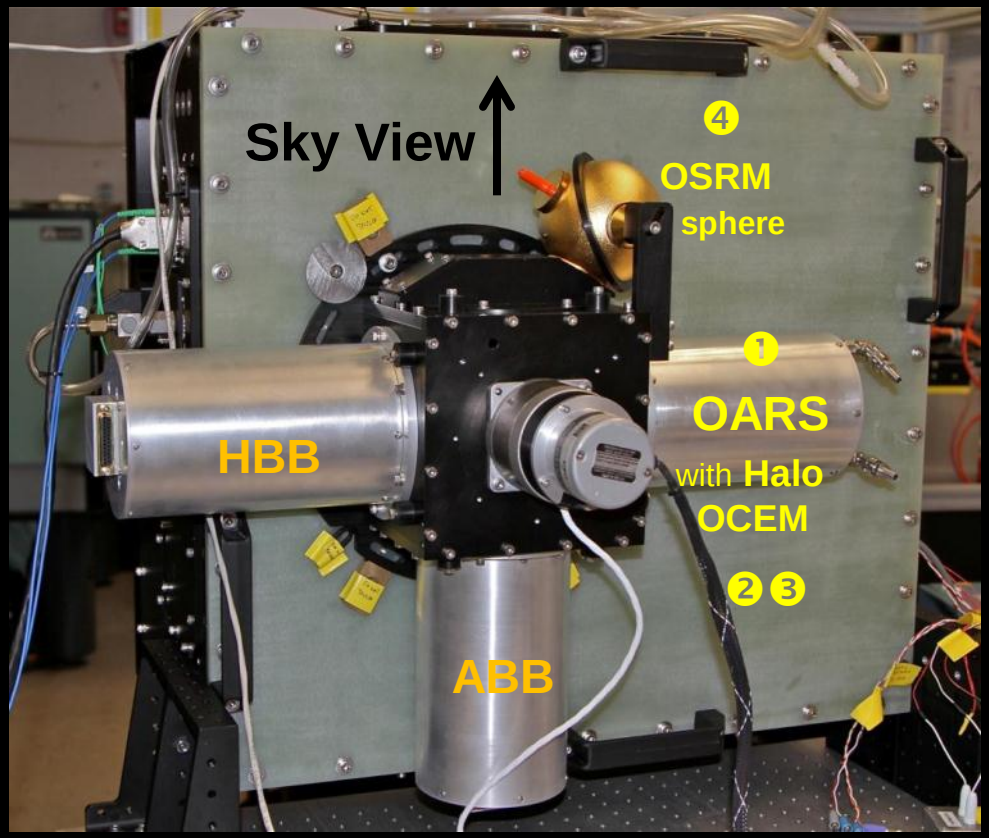
❷ On-orbit Cavity Emissivity Module (OCEM) using Heated Halo source allowing the FTS to measure the broadband spectral emissivity of the OARS to better than 0.001

❸ OCEM-QCL* using a Quantum Cascade Laser source to monitor changes in the mono-chromatic cavity emissivity of the OARS & Cal BB to better than 0.001

❹ On-orbit Spectral Response Module* (OSRM) QCL used to measure the FTS instrument line shape

**** QCL functions demonsttated separately***

OVTS Sources

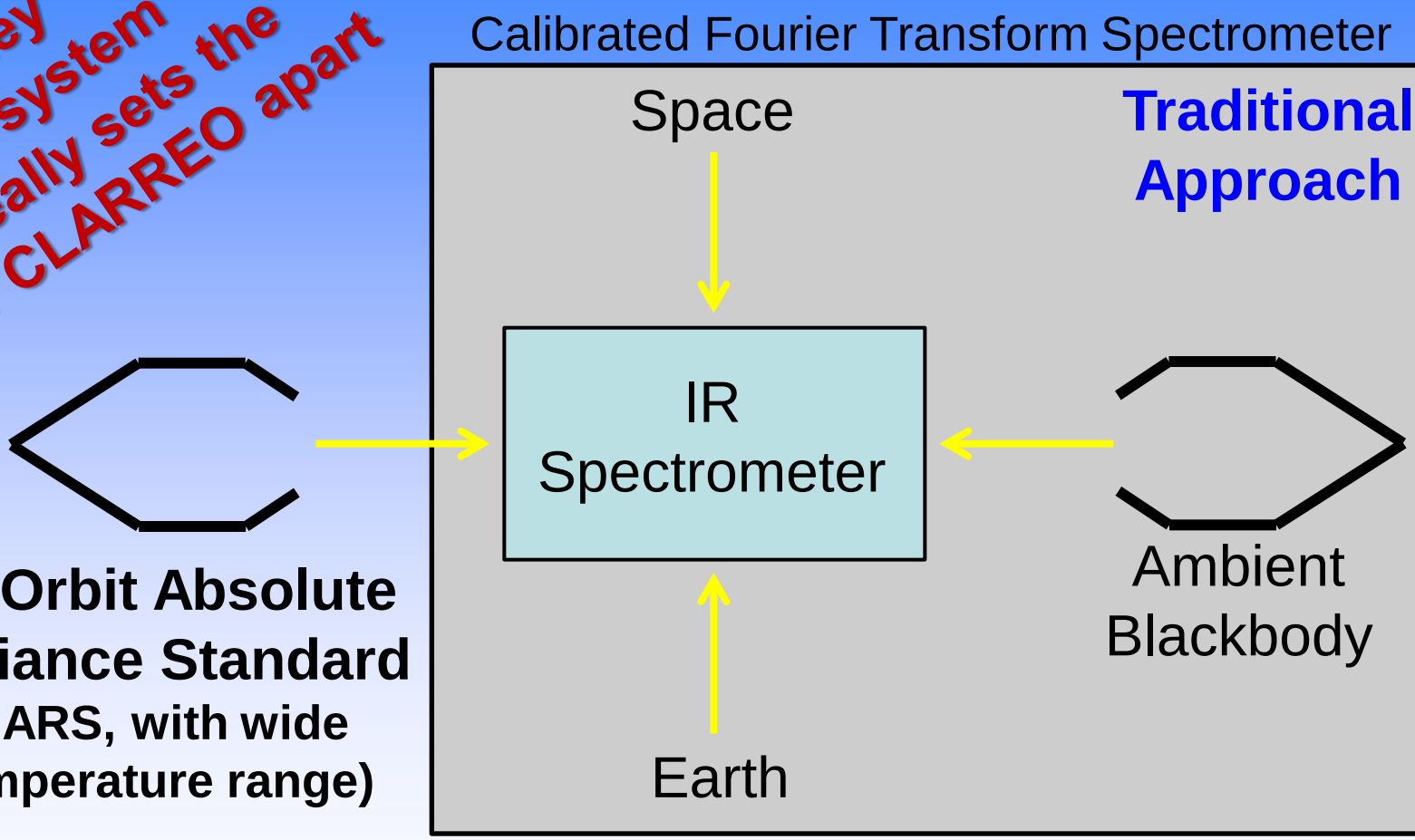


Calibrated FTS Blackbodies (HBB & ABB)

All components at flight scale

On-Orbit Verification and Test System

A key new system that really sets the ARI for CLARREO apart

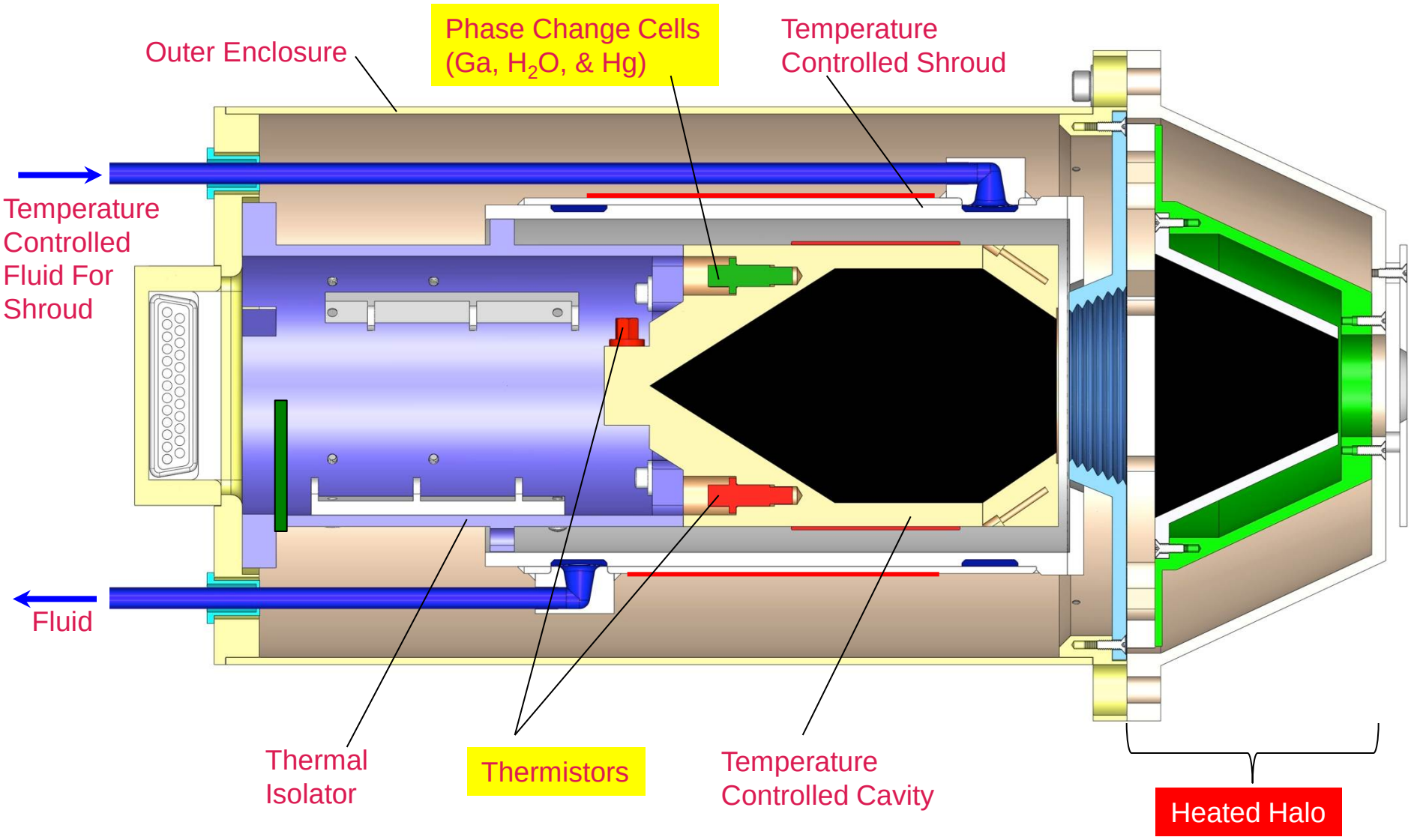


On-Orbit Absolute Radiance Standard
(OARS, with wide Temperature range)

OVTS Provides On-Orbit, End-to-End Calibration Verification & Testing Traceable to Recognized SI Standards

OARS Design with GIFTS Spaceflight Design Heritage

(laboratory version)



On-orbit Absolute Radiance Standard OARS

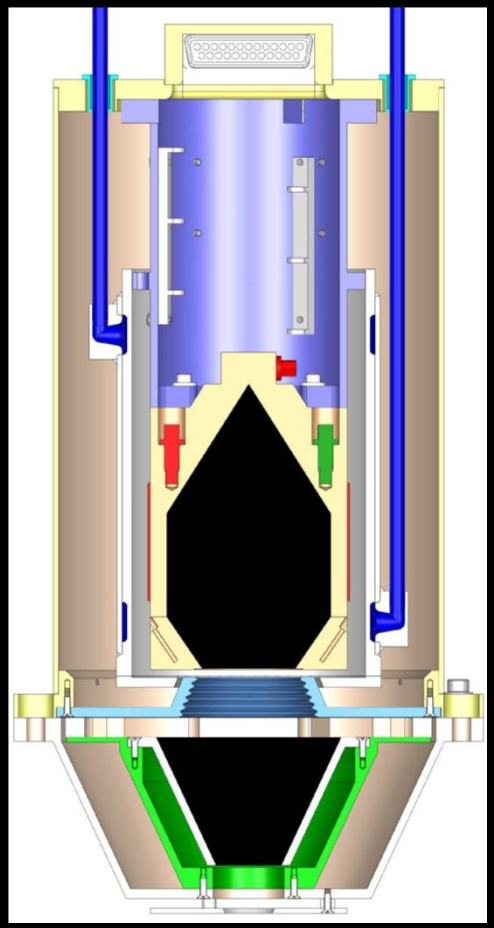
Phase Change Cell

Heated Halo & Halo Insulator

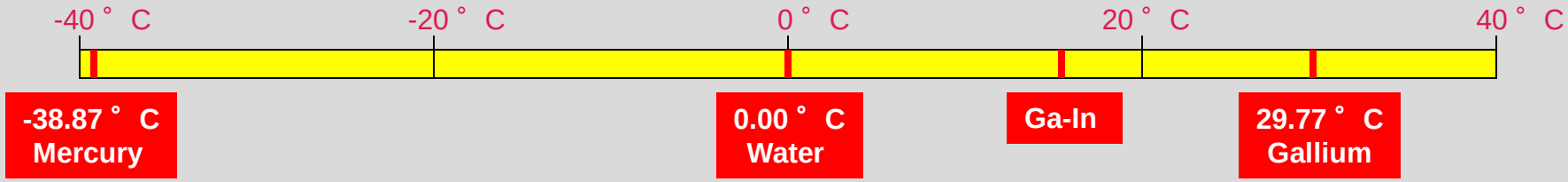
Cavity

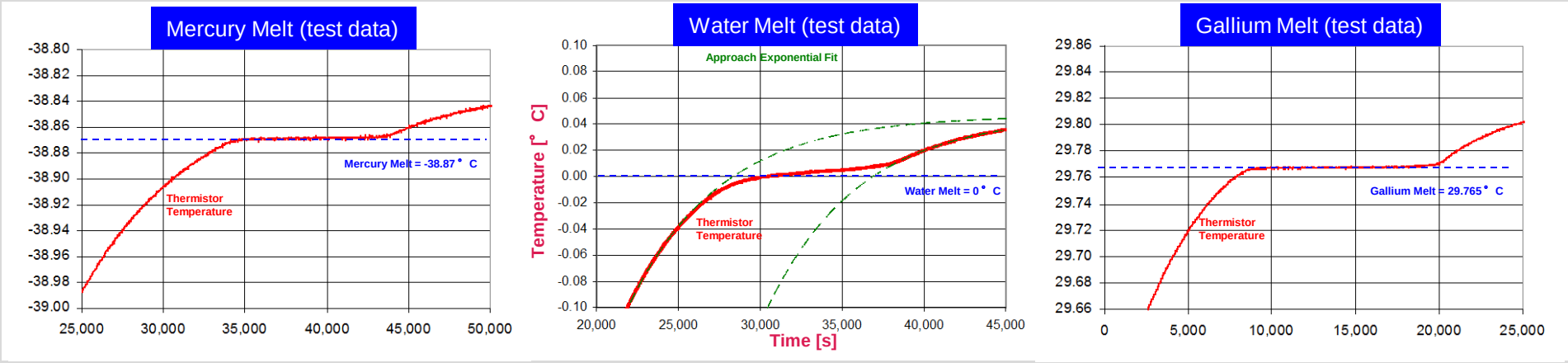
Inner Shield & Isolator

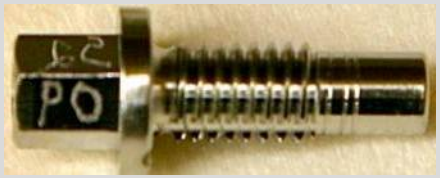
Assembly Diagram



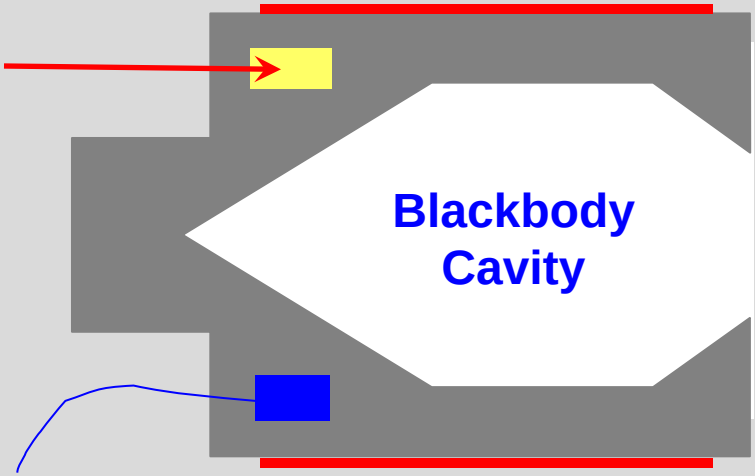
Melt Signatures Provide Temperature Calibration







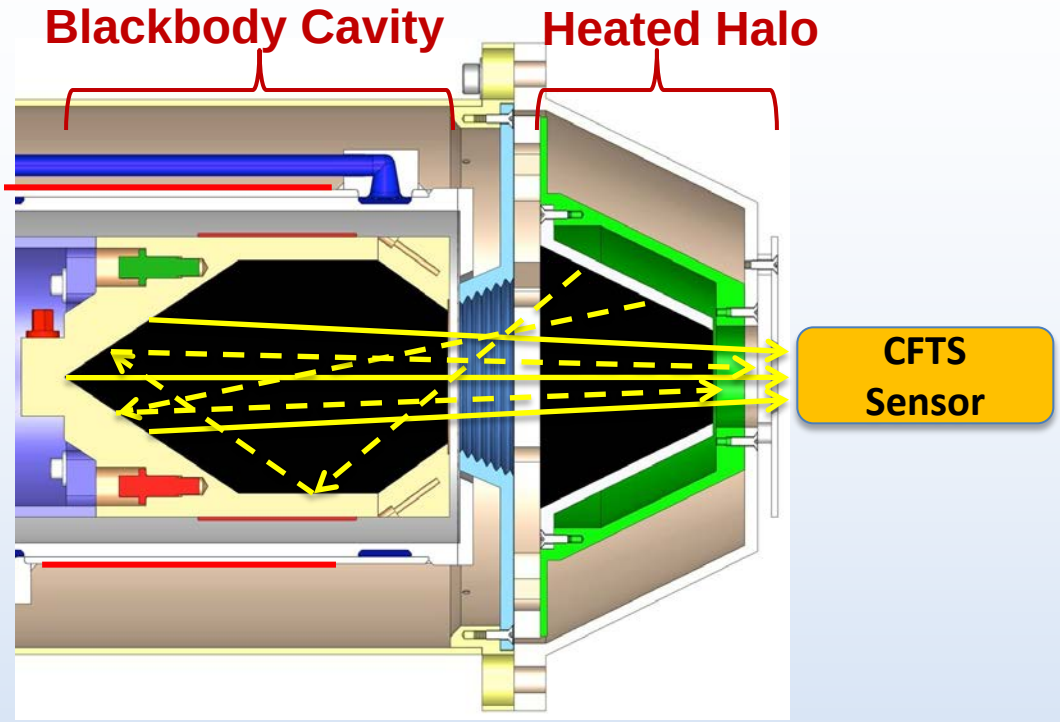
Phase Change Cell (Ga, H_2O, or Hg)



Thermistor (plotted above)

Plateaus (shown in plots) provide known temperatures to better than 10 mK

Heated Halo Concept



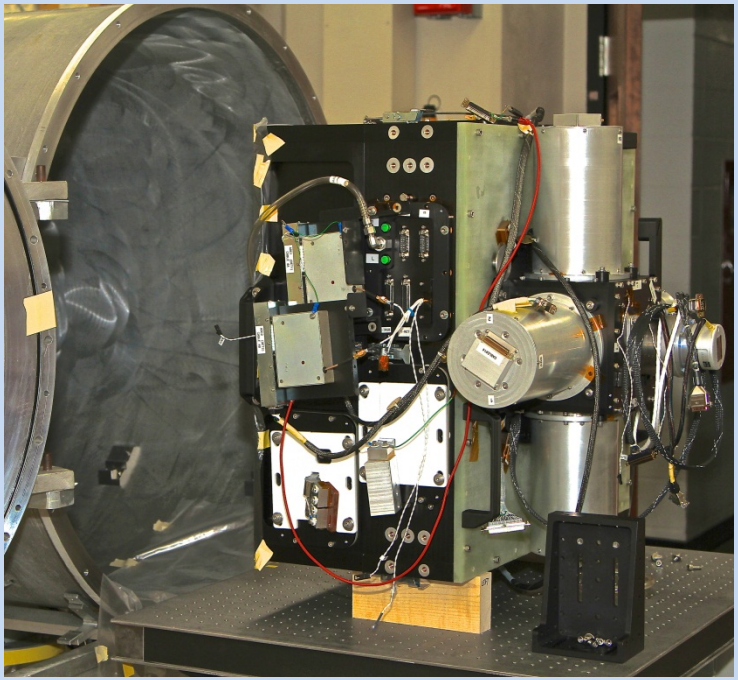
$$R_{\text{scene}} = \varepsilon \bullet B(T_{\text{BB}}) + (1-\varepsilon) \bullet [F \bullet B(T_{\text{Halo}}) + (1-F) \bullet B(T_{\text{room}})]$$

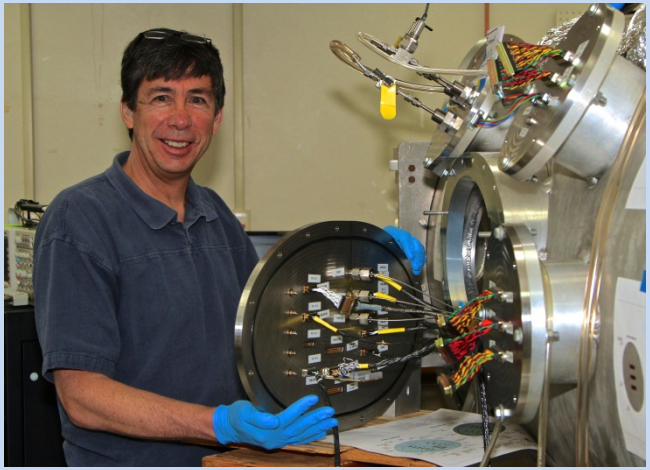
Radiance emitted from BB *Background Radiance Reflected from BB*

$$\left\langle 1-\varepsilon_{\tilde{\nu}}(t) \right\rangle_t = \left\langle \frac{R_{\text{scene}}(t) - B[T_{\text{BB}}(t)]}{R_{\text{background}}(t) - B[T_{\text{BB}}(t)]} \right\rangle_t$$

Vacuum Testing Configuration

thanks to Dan McCammon for chamber loan



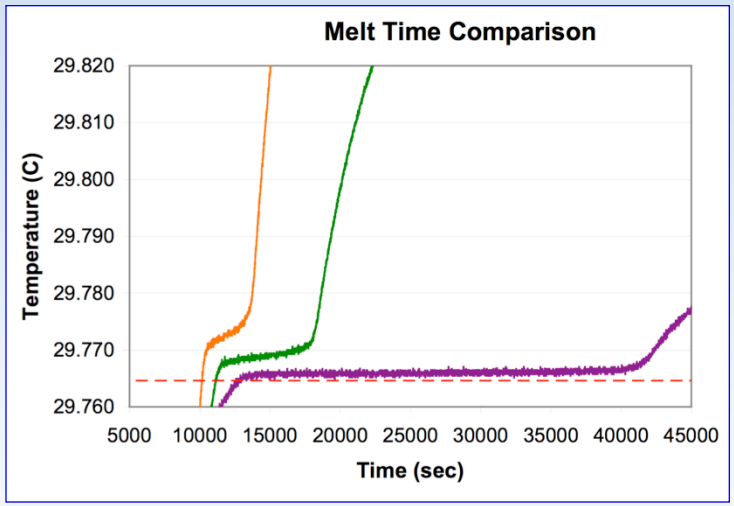


Vacuum Test Results
On-orbit Absolute Radiance Standard (OARS) Phase Change Cells

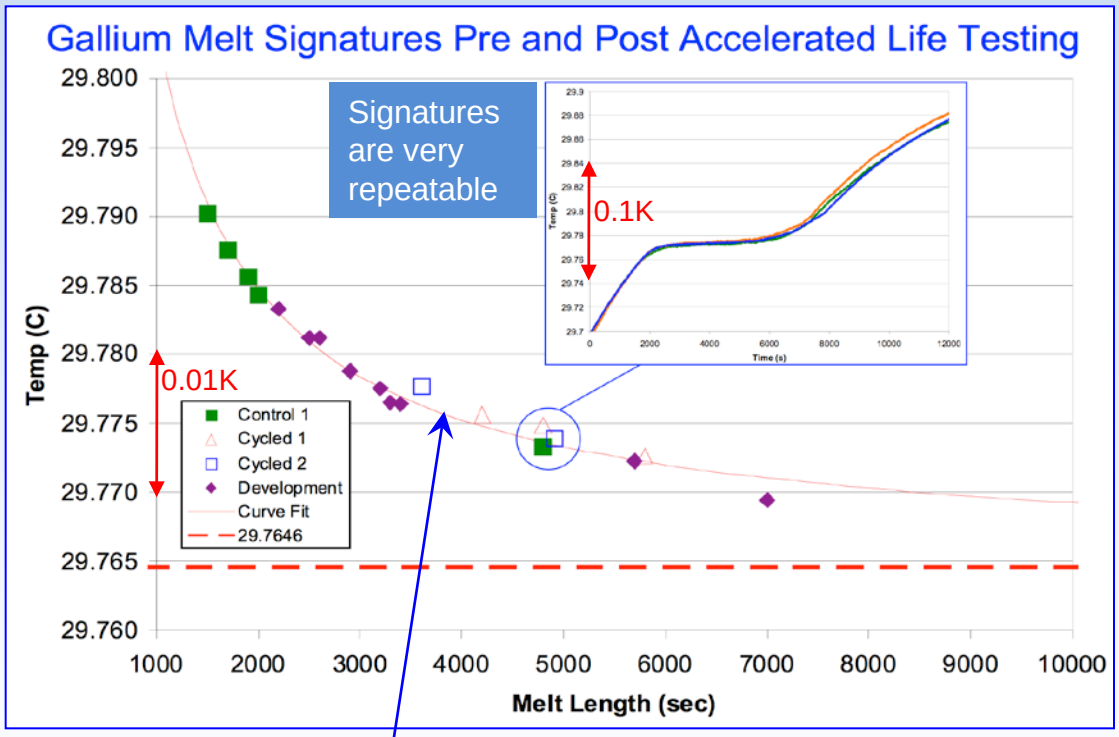
Demonstrate ability to establish Temperature Scale to better than 10 mK on-orbit

See Jon Gero, 14p.02 for more

Signature Dependence on Melt Length the Characteristic Curve

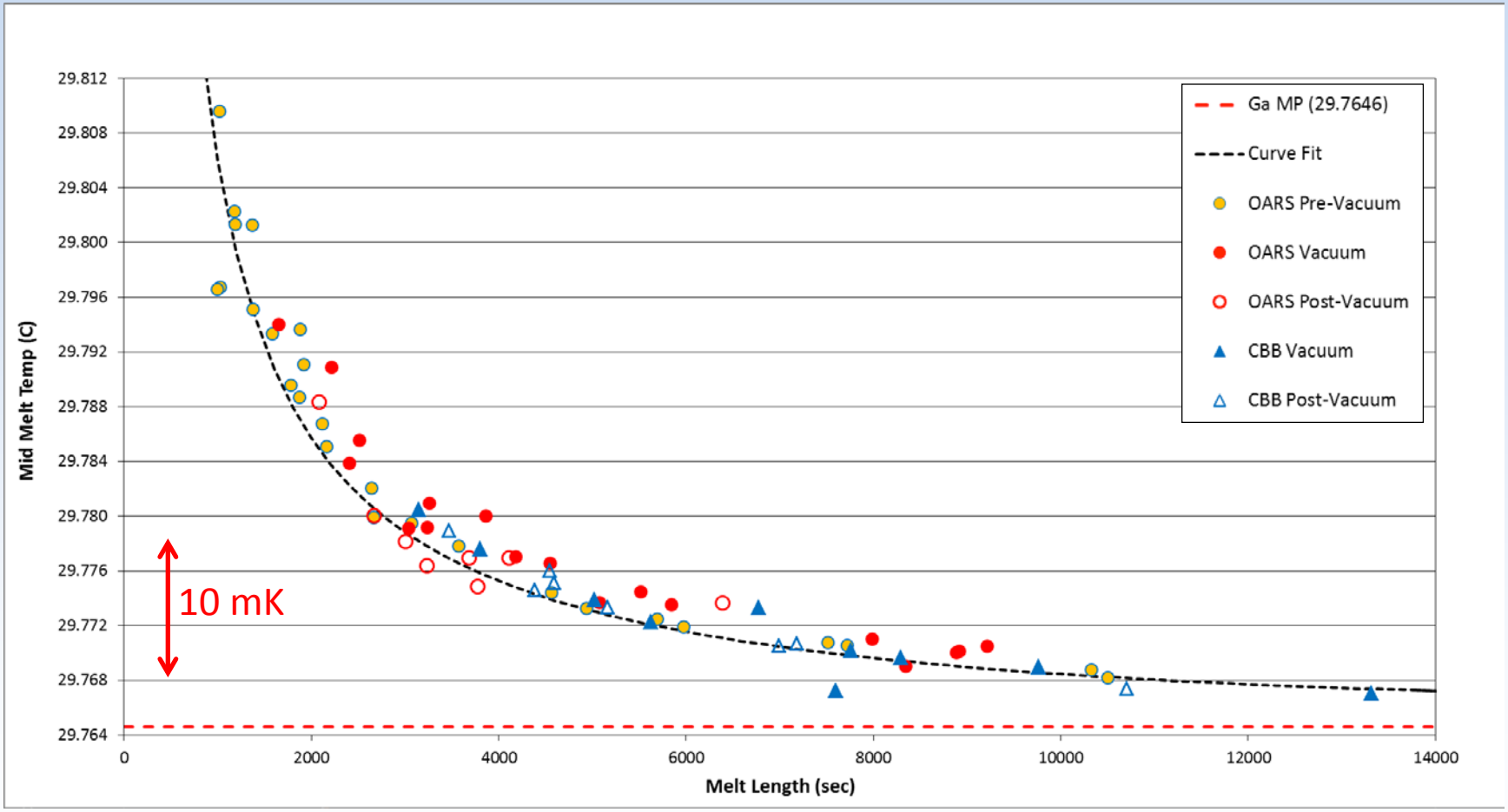


Melt curves that are flatter and approach the theoretical melt temperature are obtained with longer melt times.



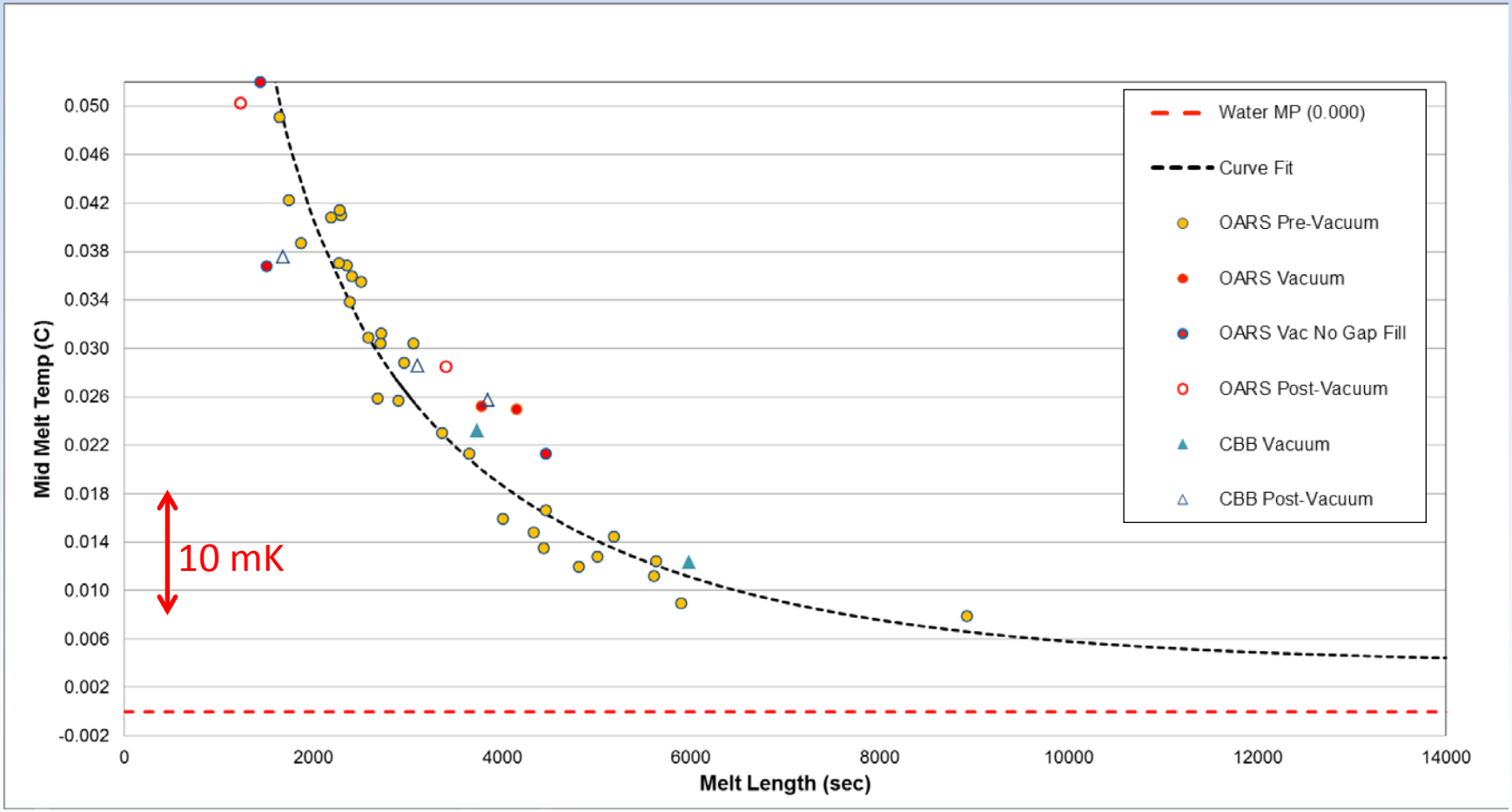
The Characteristic Curve defines the mid-melt temperature vs melt length relationship. This relationship has been shown to be very stable for a given physical configuration and it can be very well characterized.

Gallium Melts - Vacuum



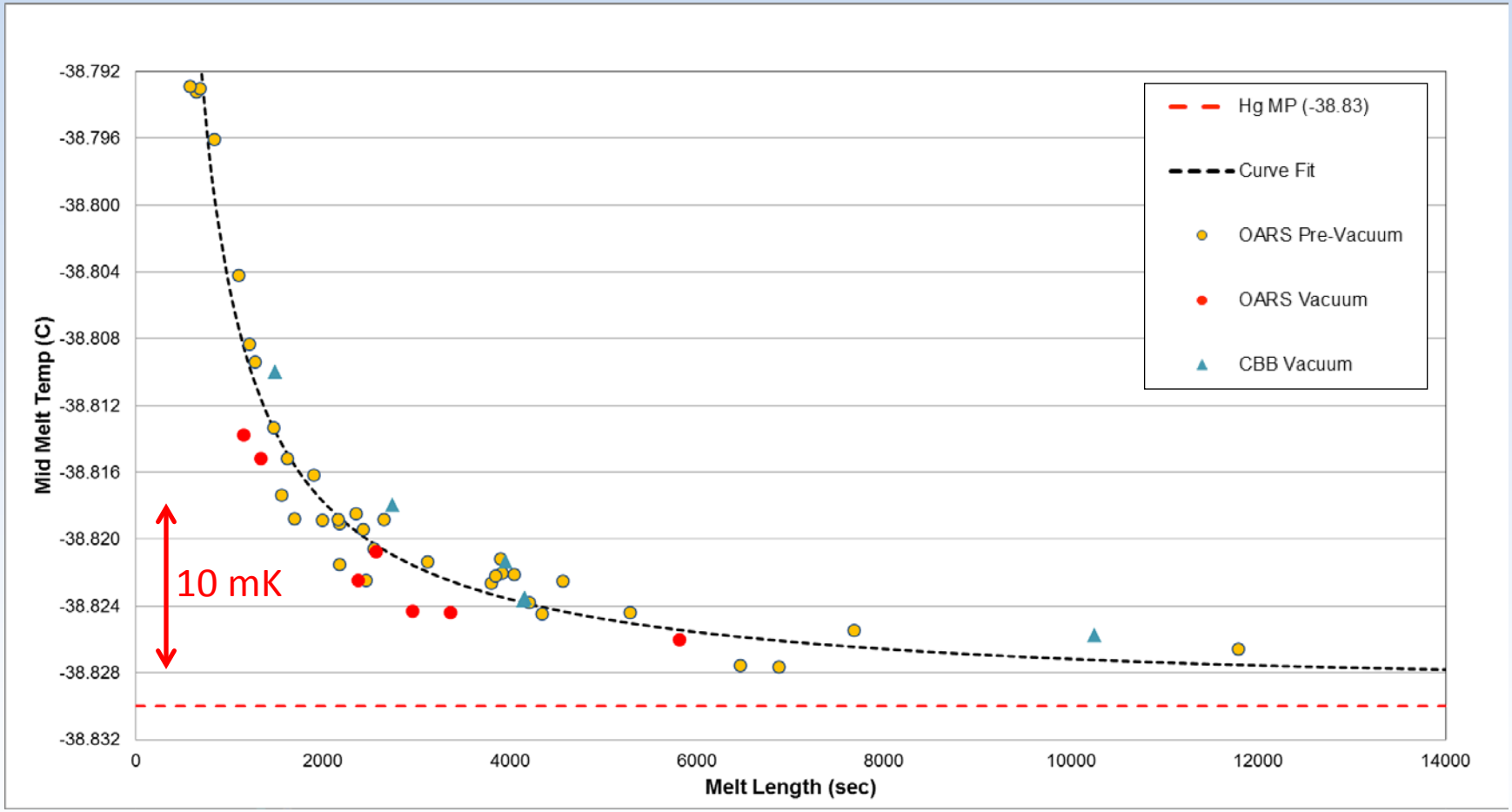
Melt behavior in a vacuum environment is very close to what was demonstrated in 1 atmosphere

Water Melts - Vacuum



Melt behavior in a vacuum environment is very close to what was demonstrated in 1 atmosphere

Mercury Melts - Vacuum



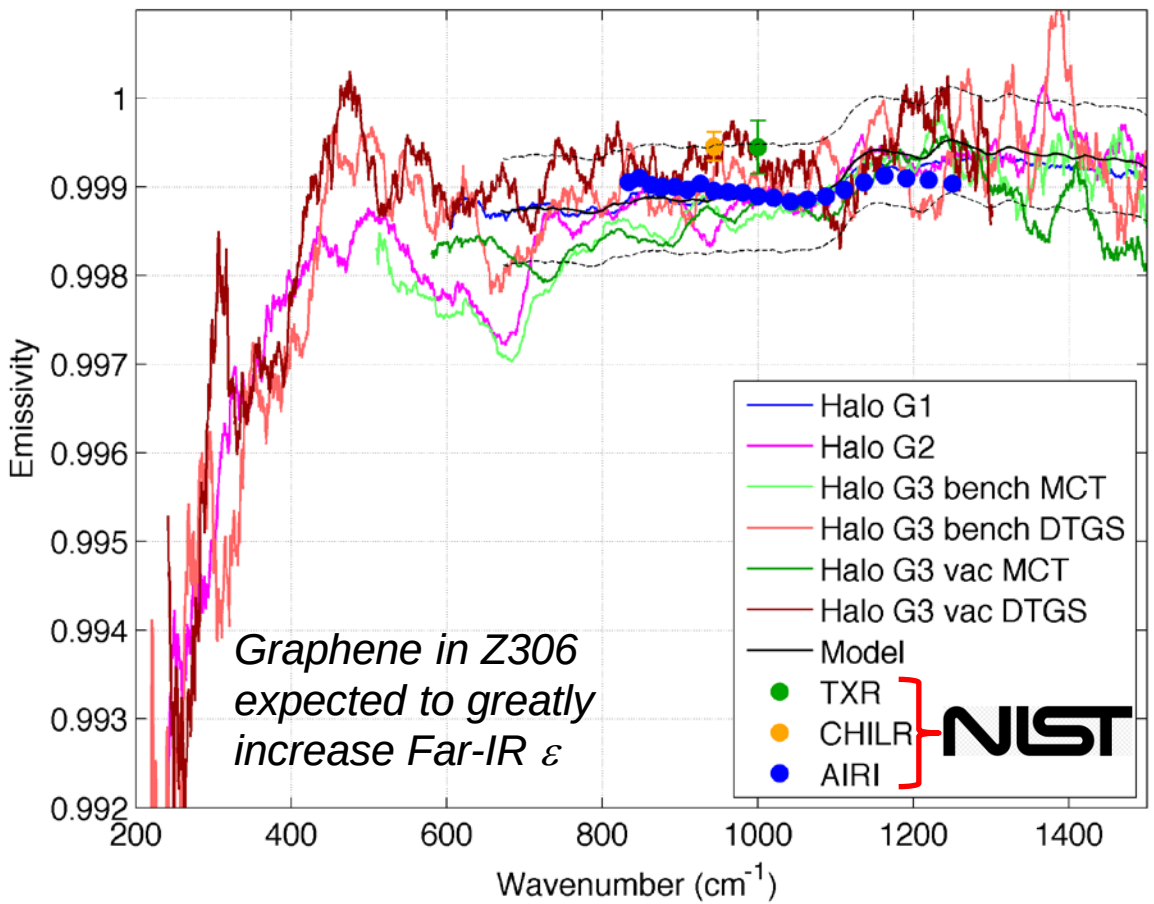
Melt behavior in a vacuum environment is very close to what was demonstrated in 1 atmosphere

Vacuum Test Results
Heated Halo Emissivity Measurement

Demonstrate on-orbit emissivity measurement accuracy of better than 0.001 3-sigma

See Jon Gero, 14p.02 for more

Blackbody Emissivity Comparison

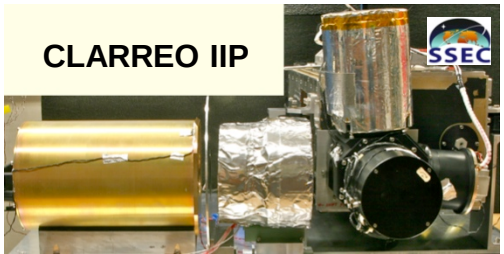


3-σ emissivity of 0.0006 uncertainty indicated by dashed lines applied to model

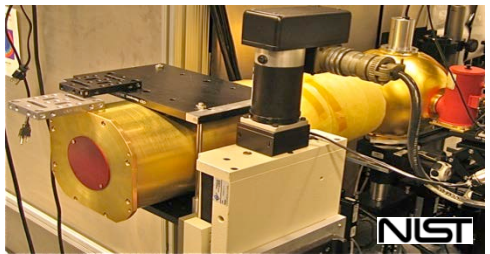
Good agreement with NIST measurements

Continued work corroborates earlier results and helps reduce uncertainty

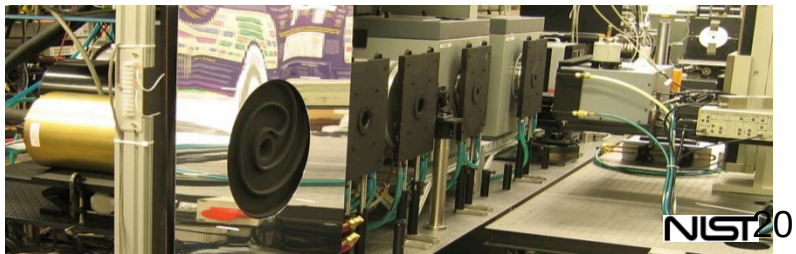
UW Heated Halo



NIST CHILR



NIST AIRI



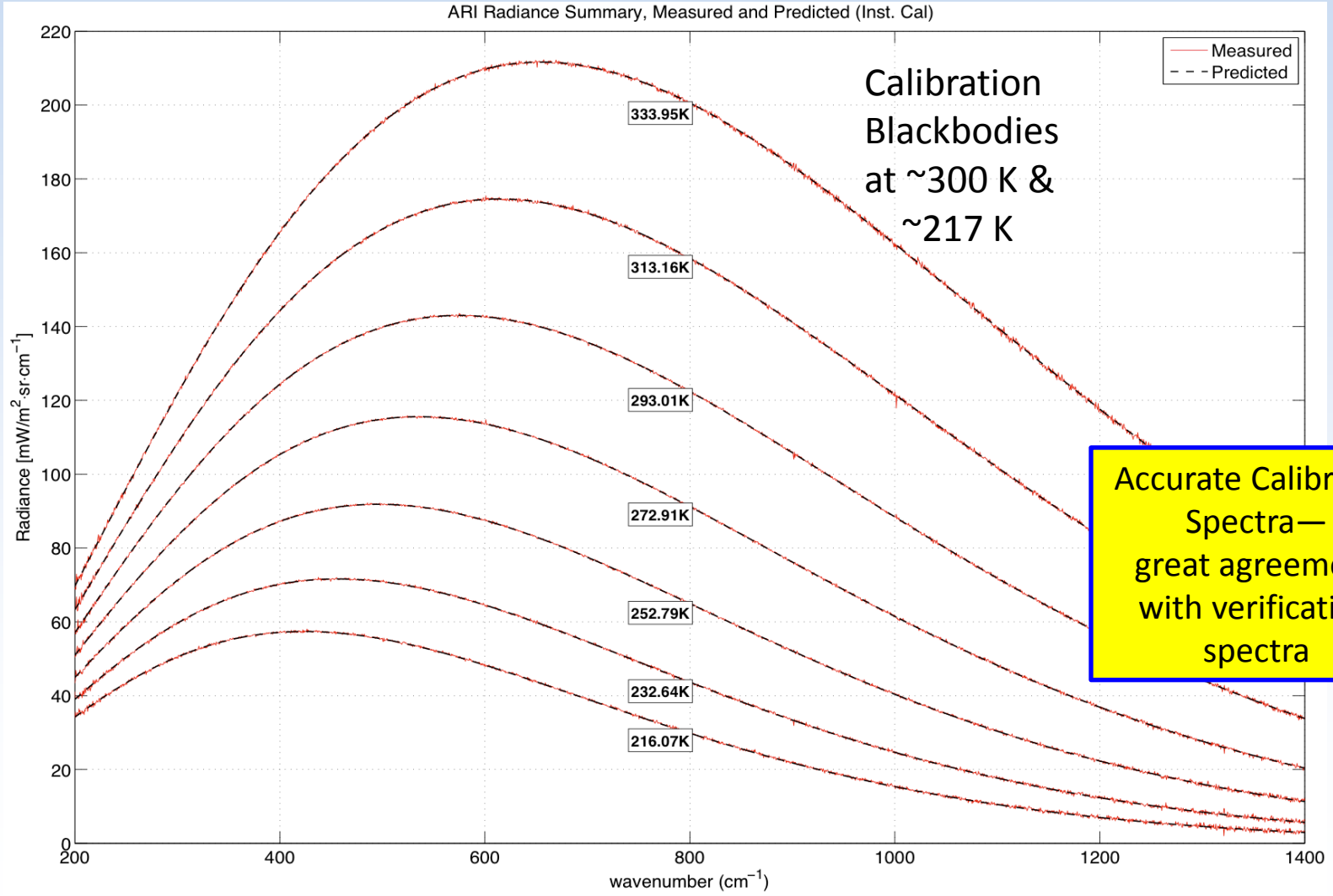
Vacuum Test Results
Radiometric Verification Using OARS

Demonstrate 0.1 K 3-sigma performance of Calibrated FTS (CFTS) and On-orbit Verification and Test System (OVTS) needed for CLARREO mission

See Joe Taylor, 14p.01 for more

DTGS

Mean Calibrated Radiance Spectra (DTGS) Compared to OARS Radiance Spectra



Accurate Calibrated Spectra— great agreement with verification spectra

DTGS

Brightness Temperature Comparison (DTGS)
(CFTS calibrated and OARS verification)

334 K

313 K

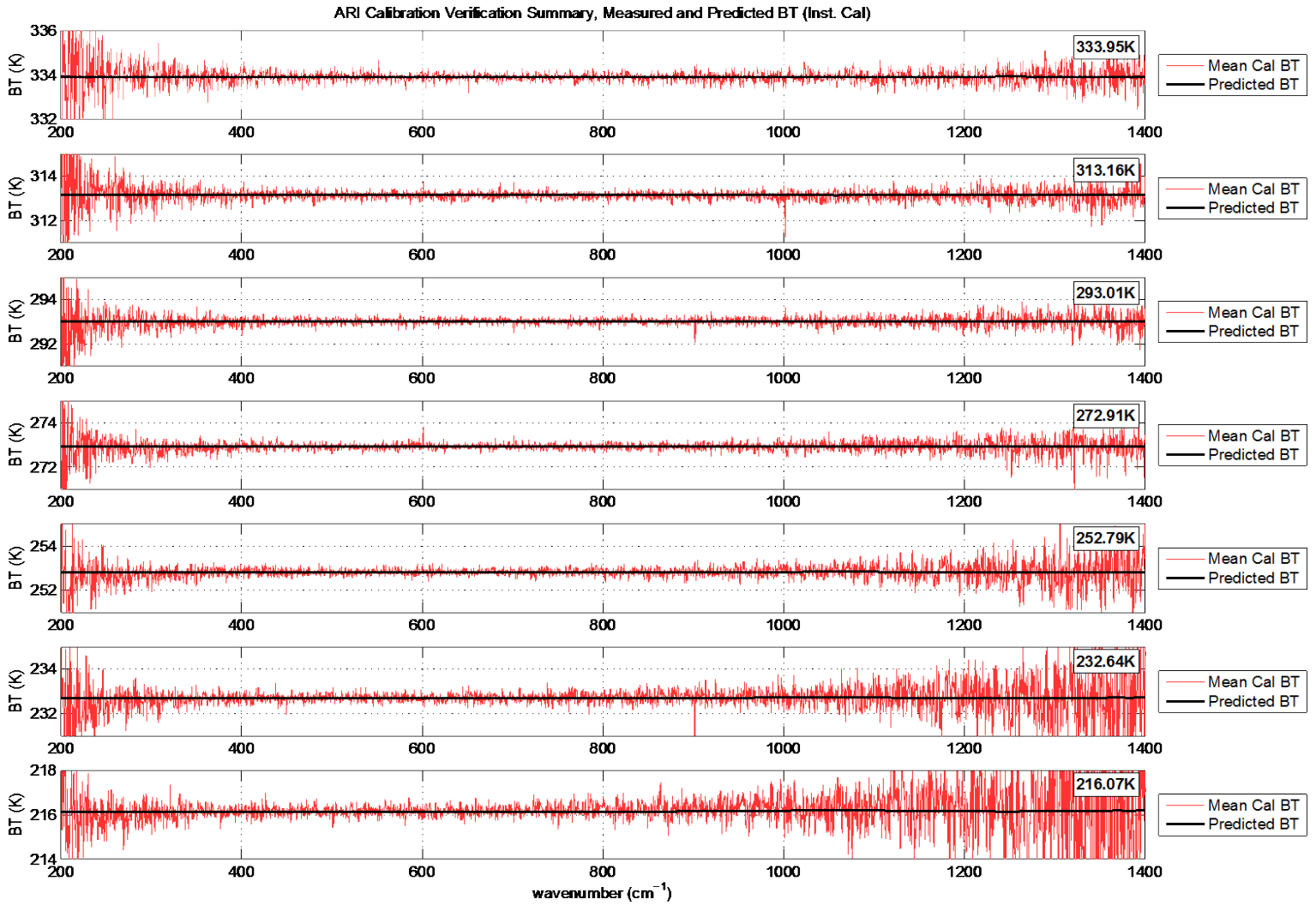
293 K

273 K

253 K

233 K

216 K



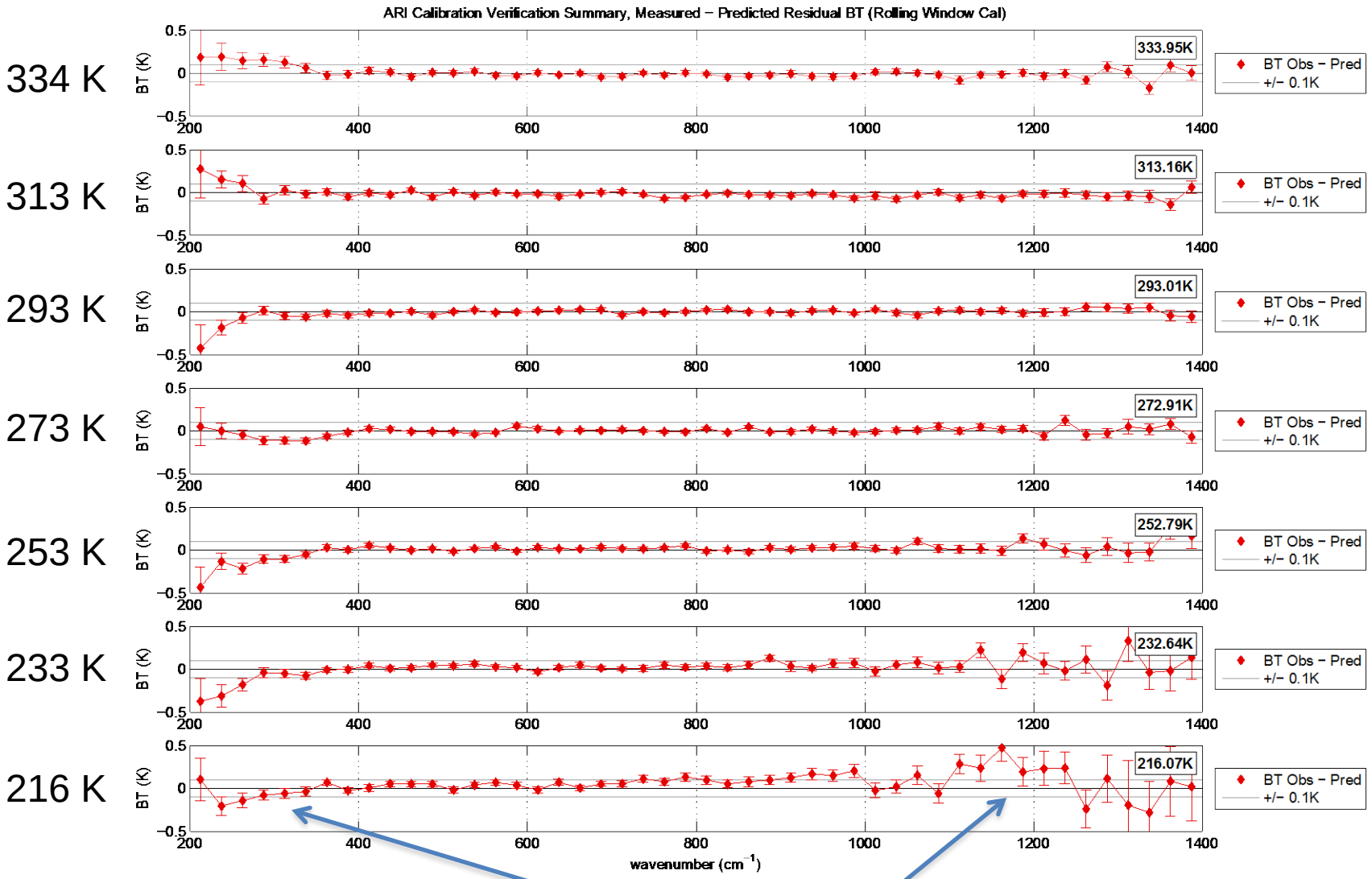
Difference from expected value is very close to zero + random noise

(noise is ~4 x noise for on-orbit noise spec due to shorter dwell times)

DTGS

Brightness Temperature Residuals (DTGS)
(CFTS calibrated – OARS verification)

Error bars only include statistical error in measurement



Spectral Averaging Bin Width is 25 cm^{-1}

Bin averaged result subject to low SNR at band edges

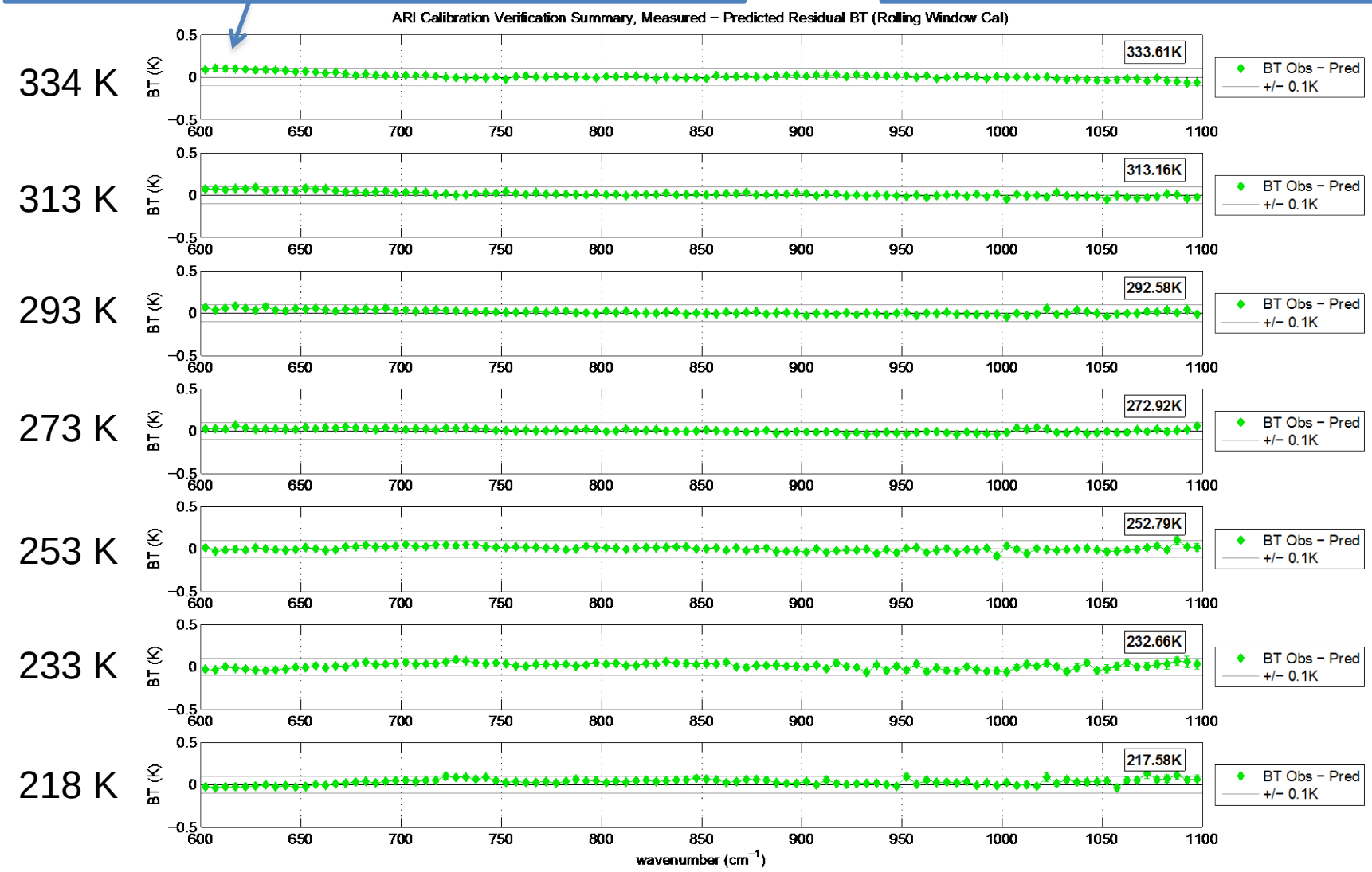
MCT

NLC

Brightness Temperature Residuals (MCT with NLC)
(CFTS calibrated - OARS verification)

Error from identified field stop problem evident for hot target

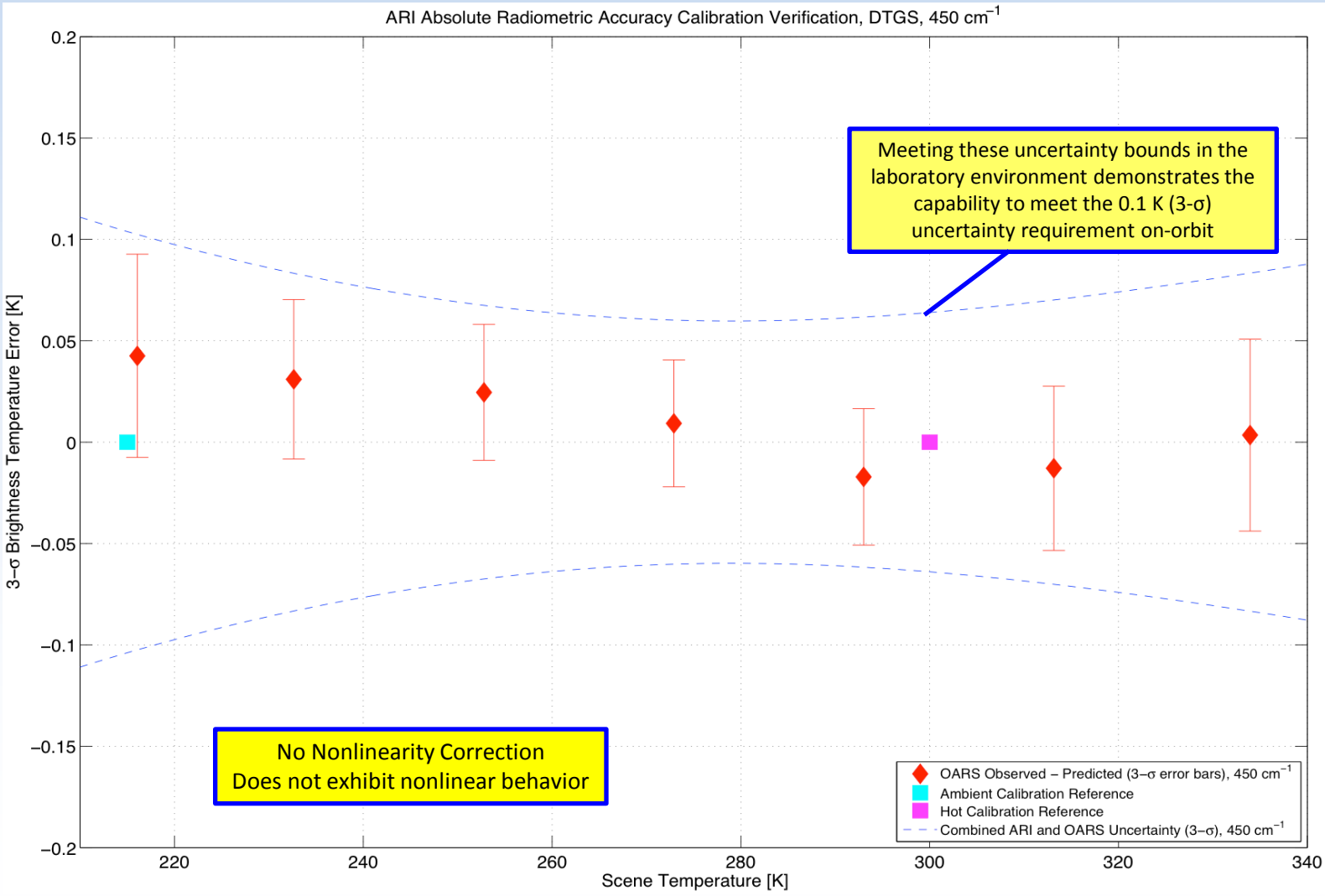
Error bars only include statistical error in measurement



Spectral Averaging Bin Width is 5 cm^{-1}

DTGS

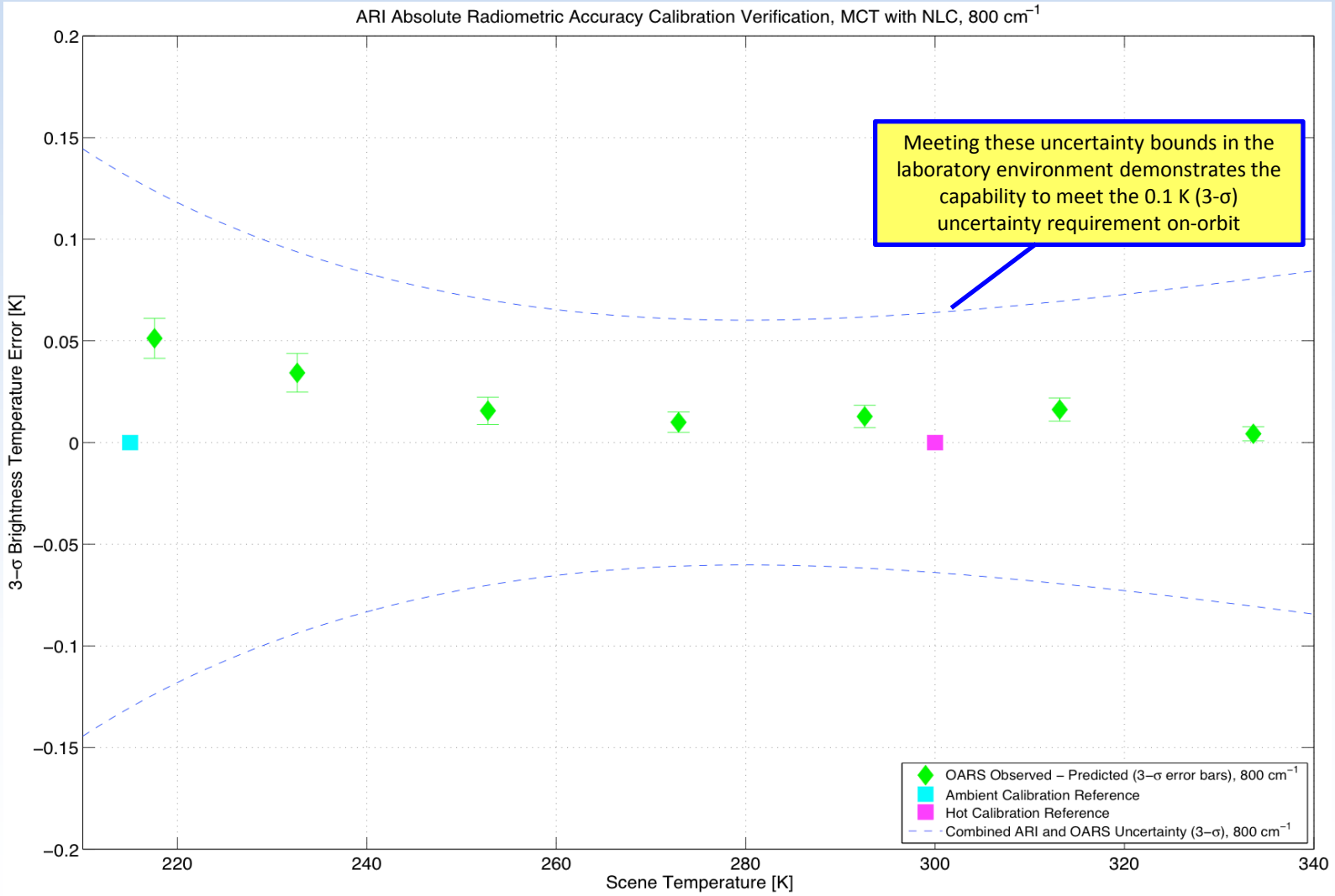
Radiometric Calibration Verification DTGS (400-500 cm^{-1})



MCT

NLC

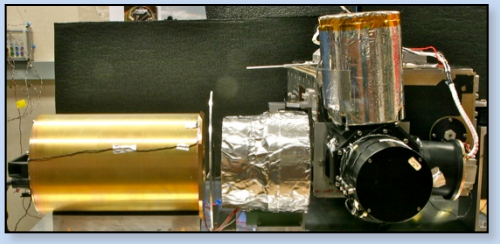
Radiometric Calibration Verification MCT with NLC (700-900 cm^{-1})



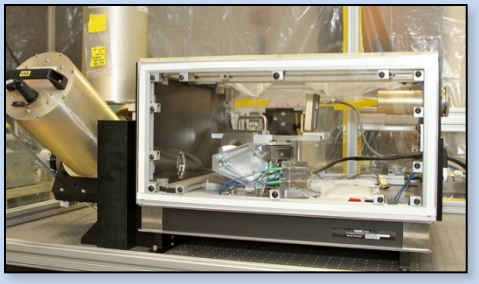
NASA Technical Readiness Level (TRL)

Miniature Phase Change Cell (MPCC)

MPCC Component Integration, Characterization and Accelerated Life Testing

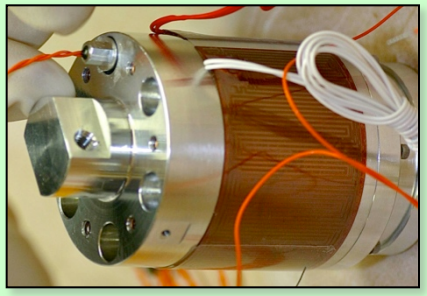


Heated Halo Generation-1 (Breadboard Halo, AERI BB with Scanning HIS Aircraft FTIR)

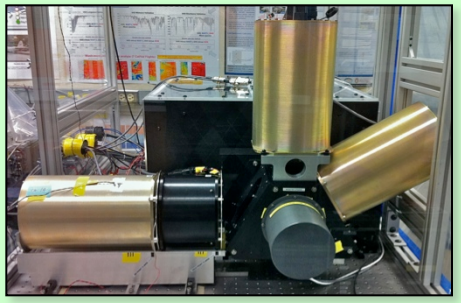


Absolute Radiance Interferometer (ARI) Breadboard

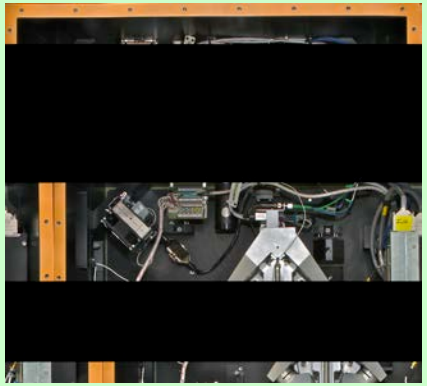
TRL 4



Integration of MPCC into Breadboard Blackbody for Thermal Testing

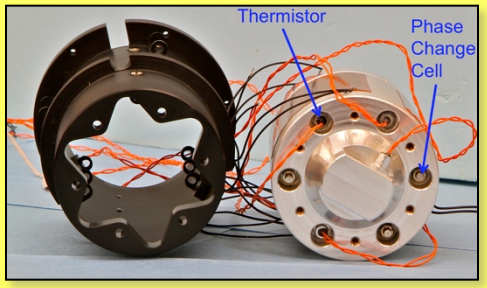


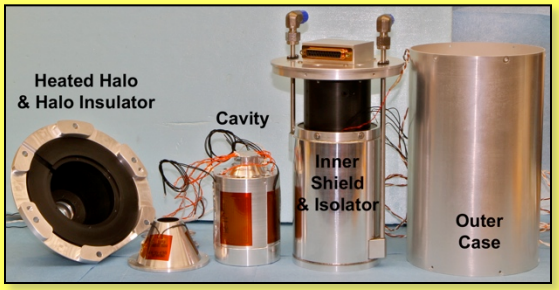
Heated Halo Generation-2 (Large Conical Halo, AERI BB with ARI Breadboard FTIR)



Absolute Radiance Interferometer Prototype

TRL 5





On-Orbit Absolute Radiance Standard: New 30 mm Aperture BB with MPCC integrated into cavity, and Heated Halo

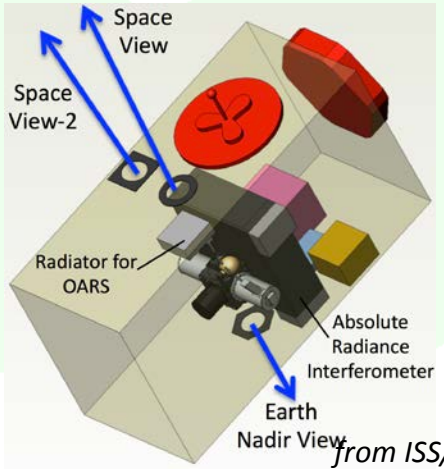
ARI Prototype Tested in Vacuum

TRL 6

Ready for Flight Program

ARI for CLARREO Pathfinder Mission

- **Vacuum Testing of CLARREO Flight Prototype *Absolute Radiance Interferometer (ARI)* has demonstrated 0.1 K 3-sigma performance of the (1) Calibrated FTS (CFTS) and (2) On-orbit Verification and Test System (OVTS), bringing the full ARI system to TRL 6**
- **The next step should leverage NASA ESTO's investment with a spaceborne demonstration as a CLARREO IR pathfinder. Flight on the International Space Station (ISS) is being considered.**

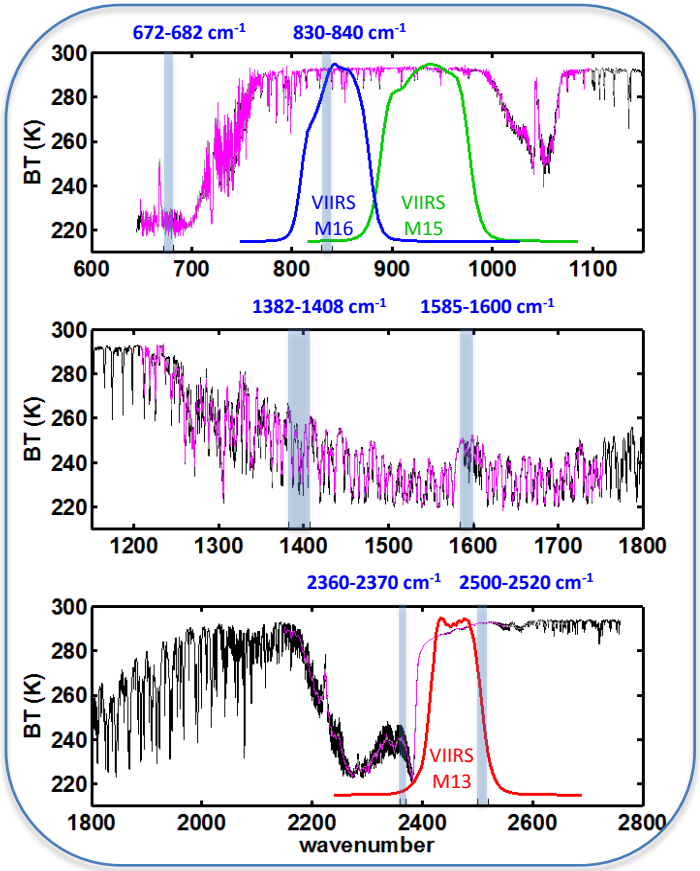


JEM-EF EFU Site #4

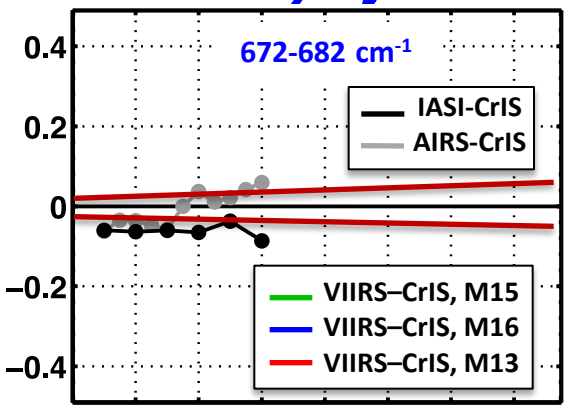
from ISS/DS/ESM Cross Mission Study

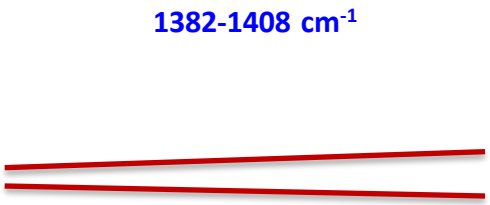
Pathfinder Mission Offers Valuable On-orbit Standard

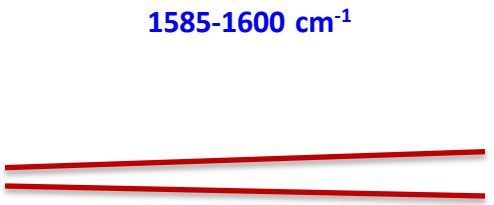
- **ARI not-to-exceed Uncertainty provides better "truth"**
- **Residual from CrIS for:**
  - AIRS
  - IASI
  - VIIRS: M13, M15, M16

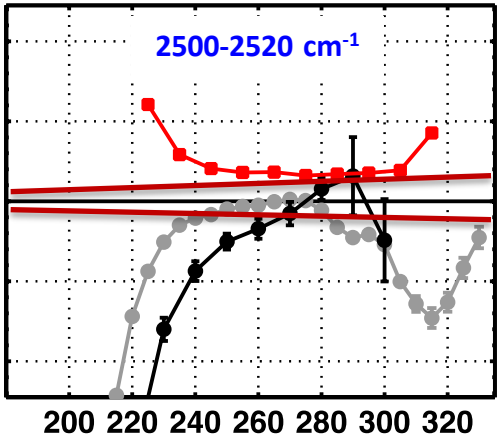


Summary of recent Inter-calibrations



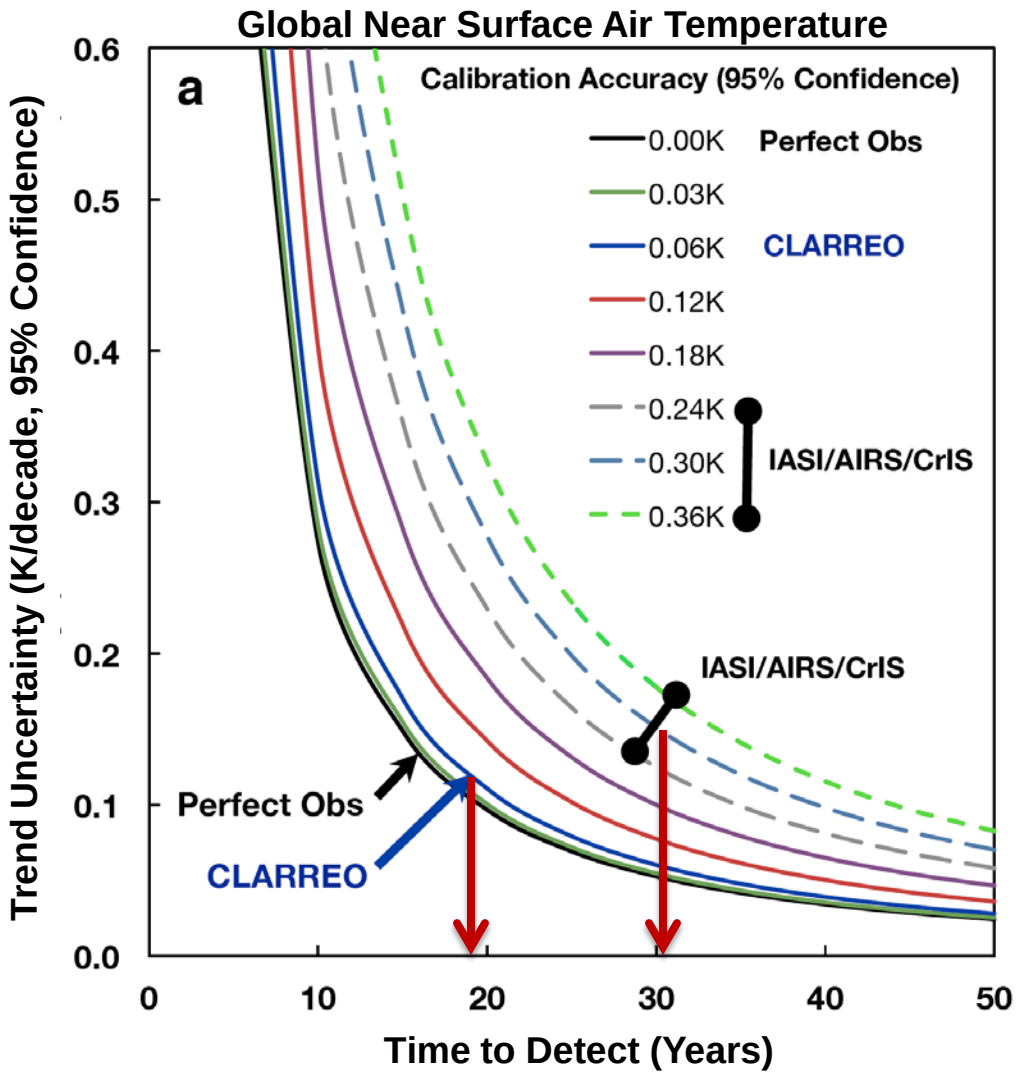






ARI Accuracy Offers Substantially Reduced Time to Detect Global Climate Change

Achieving Climate Change Absolute Accuracy in Orbit,



Wielicki et al., BAMS, 2013

Summary of ARI Status

- **CLARREO:** Efforts of the NASA Science Definition Team have documented compelling science and societal benefits from Benchmarking the Climate State and Inter-calibrating other Satellite Sensors (Wielicki, et al., 2013)
- **CLARREO IR Flight Prototype, ARI:** Recent UW Vacuum Testing combined with prior UW/Harvard IIP technology developments and test results demonstrate capability to meet CLARREO mission performance requirements
- **ARI Technical Readiness:** NASA Earth Science Technology Office (ESTO) has assigned a Technical Readiness Level of 6 supporting readiness for a flight mission
- **International Space station:** ISS offers an attractive and economical avenue to a CLARREO pathfinder mission, especially given the recent ISS lifetime extension until 2024
- **CLARREO pathfinder on ISS:** Would provide economical risk reduction for the full CLARREO mission and a chance to improve the overall accuracy of operational environmental satellite capabilities and leverage them to start a global benchmark record