

Testing Radiance Calibration Methodology using a High Accuracy Blackbody Source and an Absolute Cryogenic Radiometer

Adriaan Carter^{*}, Timothy Jung^{*}, Solomon Woods[#],
Dana Defibaugh[#], Simon Kaplan[#], and Joseph Rice[#]

^{}Jung Research and Development Corp.*

[#]National Institute of Standards and Technology

JACIE May, 2015

Outline

- *Introduction – Who we are, what we do, and why.*
- *Blackbody Radiance Calibration Basics*
 - *The Simple Test Configuration*
 - *Absolute Cryogenic Radiometers*
 - *High Accuracy Blackbody Source*
 - *The More Complete Test Configuration and the Issues*
- *Test Results and Discussion*
- *Conclusion*

Introduction

- *The Low Background Infrared (LBIR) Facility at the National Institute of Standards and Technology (NIST) maintains the IR radiometric power measurement scale for systems that need to be calibrated in a space-like environment.*
- *Absolute detector standards are used to calibrate the effective radiance temperature of blackbody sources, among other things.*

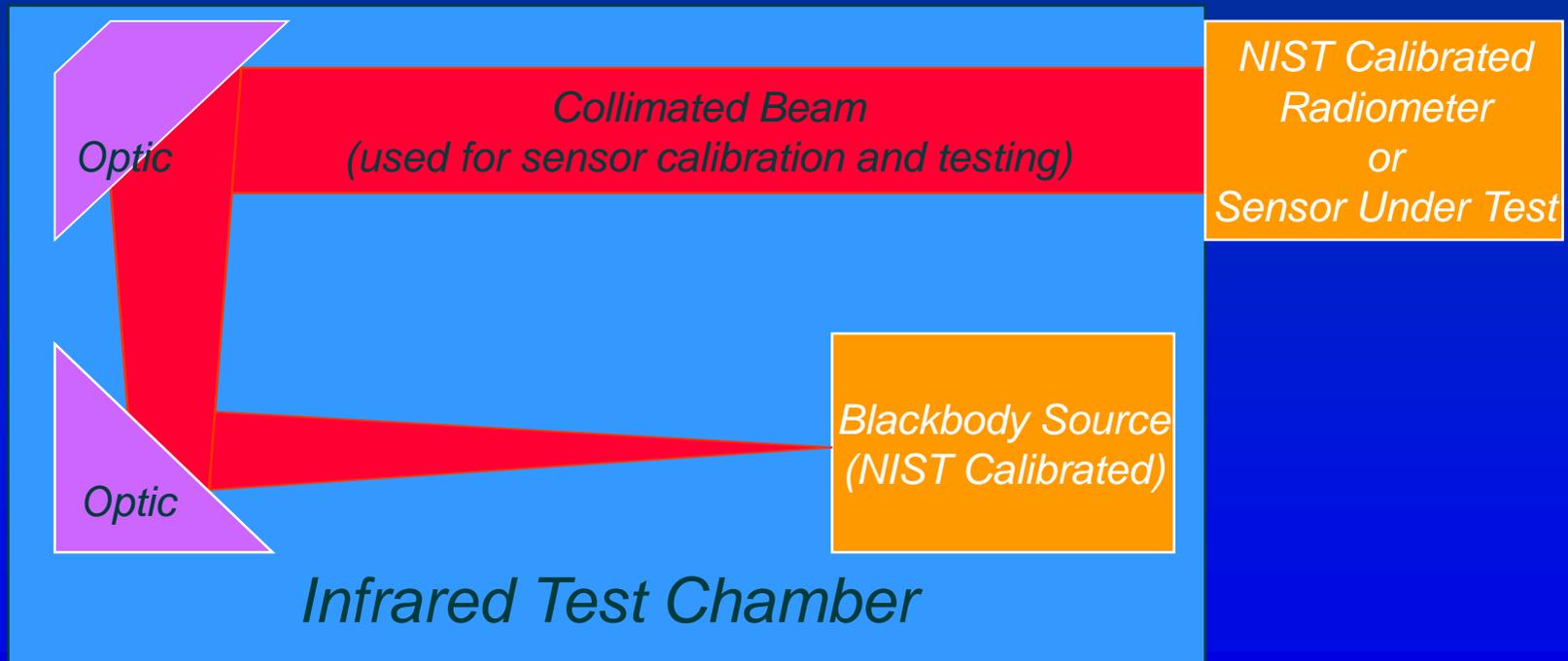
Broadband Calibration Chamber



- ❖ *Used for broadband calibration of blackbody sources in a space-like environment.*
- ❖ *Internal shrouds are capable of creating 20 K to 300 K background environments.*

Introduction (slide #2)

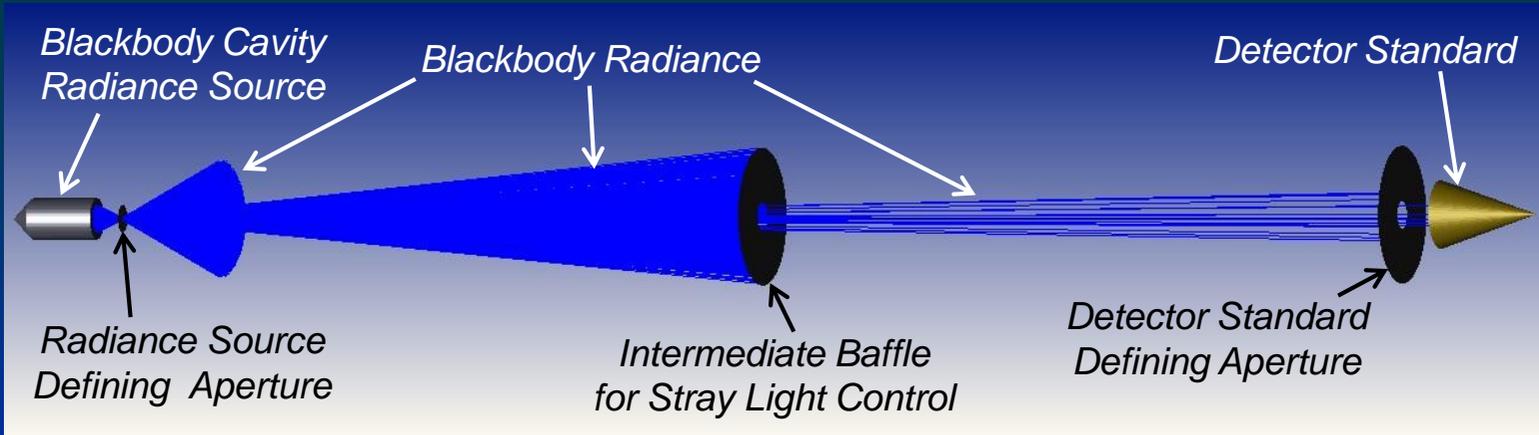
- *The calibrated blackbodies are then often used as radiance sources in test chambers that collimate the output for the calibration of remote sensors or for more complicated scene generators for hardware-in-the-loop testing of missiles.*
- *LBIR also provides calibration of the chamber output so that the chamber throughput models can be validated.*



Outline

- *Introduction – Who we are, what we do, and why.*
- *Blackbody Radiance Calibration Basics*
 - *The Basic Radiance Calibration Test Configuration*
 - *Absolute Cryogenic Radiometers*
 - *High Accuracy Blackbody Source*
 - *The More Complete Test Configuration and the Issues*
- *Test Results and Discussion*
- *Conclusion*

The Basic Radiance Calibration Test Configuration



- *The sizes of the blackbody and detector standard defining apertures are measured with high precision.*
- *The distance between the apertures is also measured with high precision.*
- *No optics are contained in the beam path.*
- *Non-limiting baffles are used to control stray light.*
- *The test configuration is designed to be very simple in order to add minimal complications to the calibration effort.*

Radiance Temperature Calibrations

- The Stefan-Boltzmann law is used together with the known test geometry to deduce the radiance temperature.

$$E_0 = AF \sigma_M T^4$$

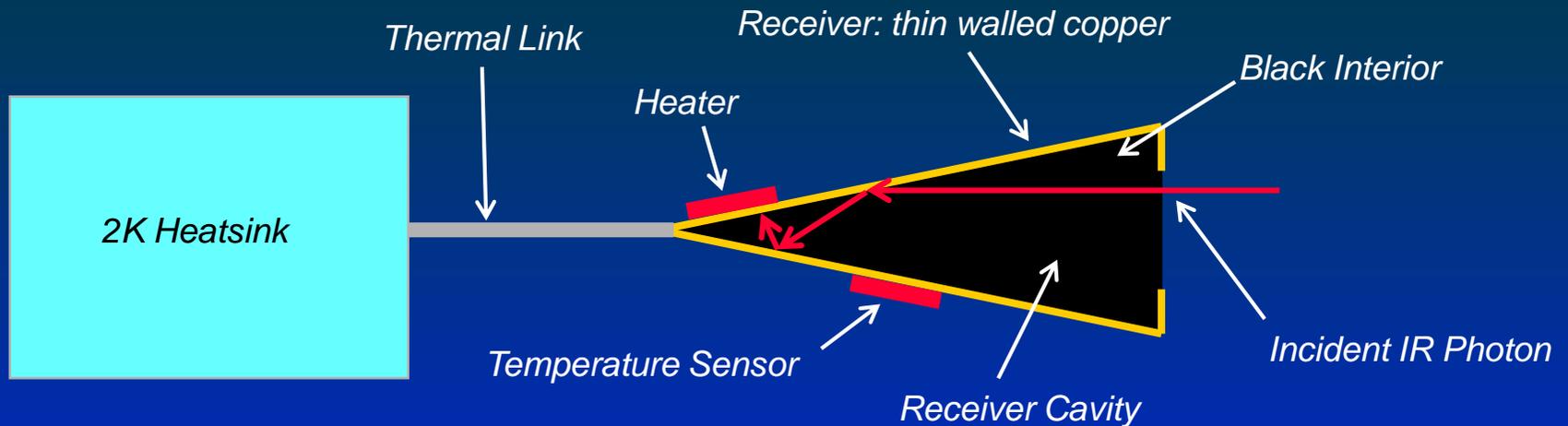
- σ_M is the Stefan-Boltzmann constant, A is the blackbody aperture area and F is a configuration factor determined from the radius of the ACR defining aperture, the radius of the blackbody defining aperture, and the distance between the apertures.
- E_0 is the expected ACR power assuming no diffraction.
- In practice, diffraction corrections are made to the actual ACR power measurements to obtain E_0 . The above equation is then inverted to obtain the radiance temperature of the cavity.

$$T = \left[\frac{E_0}{AF \sigma_M} \right]^{1/4}$$

Outline

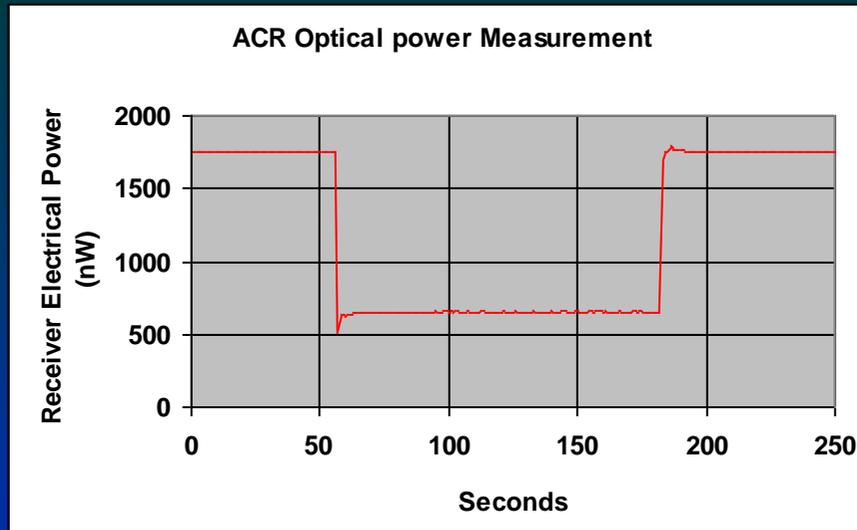
- *Introduction – Who we are, what we do, and why.*
- *Blackbody Radiance Calibration Basics*
 - *The Basic Radiance Calibration Test Configuration*
 - *Absolute Cryogenic Radiometers*
 - *High Accuracy Blackbody Source*
 - *The More Complete Test Configuration and the Issues*
- *Test Results and Discussion*
- *Conclusion*

National Infrared Power Standard: Absolute Cryogenic Radiometer (ACR)



- The Absolute Cryogenic Radiometer (ACR) traps 99.995% of the photons entering its aperture and converts them into thermal power.
 - The changes in thermal power are converted into changes in electrical power, thus tying optical power to the electrical power standard.
 - This can be done at LBIR with an absolute accuracy of 0.02% at the entrance of the ACR defining aperture.
- Note: In almost all cases the “quality” of the calibration is determined by all that happens before the ACR defining aperture; that is problems with the blackbody source and the management of stray light.

ACR Power Measurement Example



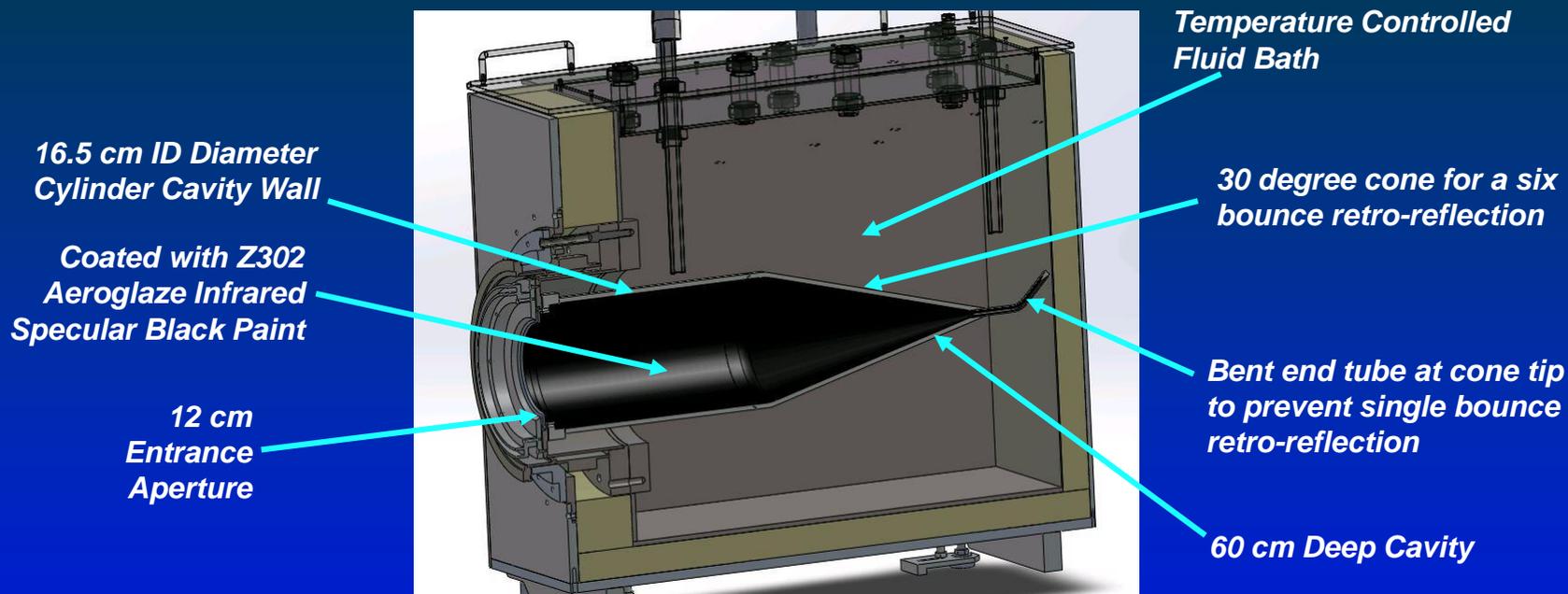
- The ACR receiver is controlled at a constant temperature above the heat sink temperature using an electric heater in an active control loop.
- The applied electrical heat, the heat from the background radiation, and the heat drain through the thermal link create a steady state, thermal condition.
- The shutter to a source is opened and additional radiation enters the receiver cavity defining aperture which causes the receiver to warm up.
- The temperature controller then lowers the electrical power to the receiver to bring the ACR back to the same steady state thermal condition except the increase in optical power has been offset by an equal drop in electrical power.
- The electrical power difference is then the change in optical power.

Outline

- *Introduction – Who we are, what we do, and why.*
- *Blackbody Radiance Calibration Basics*
 - *The Basic Radiance Calibration Test Configuration*
 - *Absolute Cryogenic Radiometers*
 - *High Accuracy Blackbody Source*
 - *The More Complete Test Configuration and the Issues*
- *Test Results and Discussion*
- *Conclusion*

Large Aperture Fluid Bath Blackbody

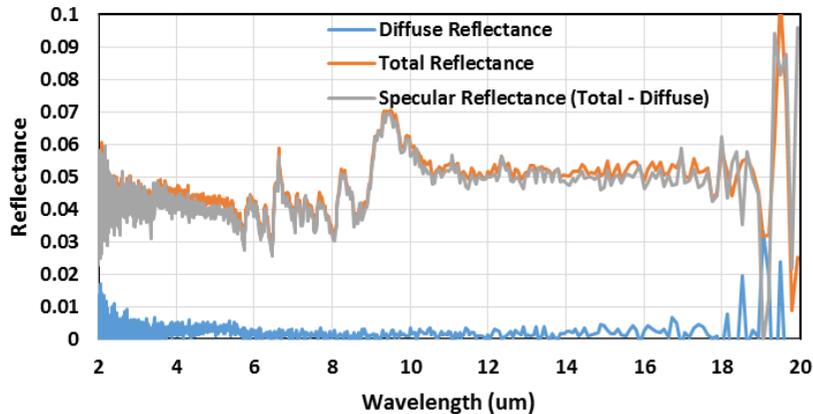
- Goal: Provide national metrology standard grade blackbody cavity radiance source for radiance calibration activities.



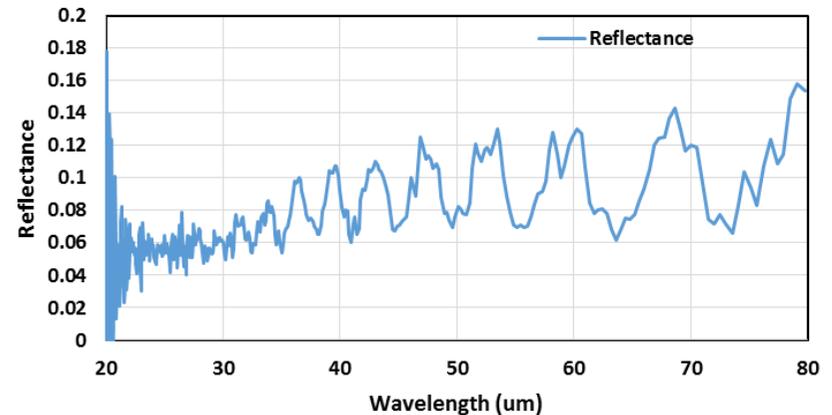
- High effective emissivity is achieved with a specular black paint and a 60 cm deep conical cavity.
- High temperature accuracy is achieved by having the outside of the cavity enveloped in a vigorously stirred and temperature controlled fluid bath whose temperature is measured by a NIST calibrated Standard Platinum Resistance Thermometer (SPRT).

High Emissivity Blackbody Cavity

Z302 Specular Black Paint

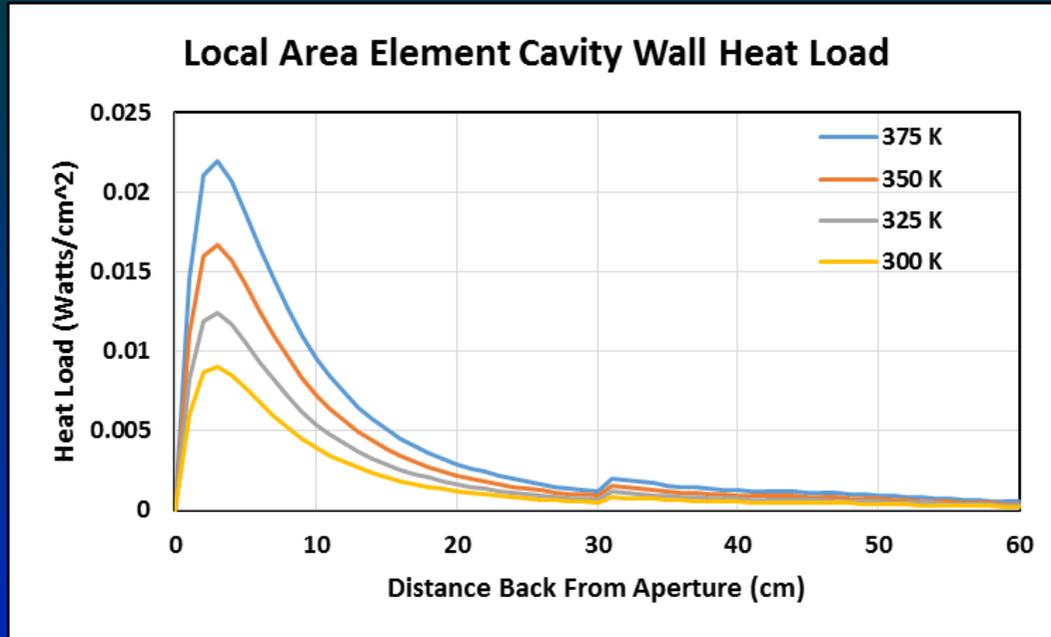


Z302 Specular Black Paint



- The blackbody cavity inner wall was coated with Aeroglaze Z302, which is a highly absorbing specular black paint.
- The reflectance of sample coupons were measured at an angle of incidence (AOI) of 18 degrees.
- Emissivity was computed for the full radiative load from a 12 cm diameter exit aperture.
- The emissivity at 10.6 um was computed to be greater than 0.9999.
- For this measurement a 1.0 cm aperture was used in front of the blackbody cavity, so emissivity should be even greater.

Blackbody Cavity Temperature Uniformity

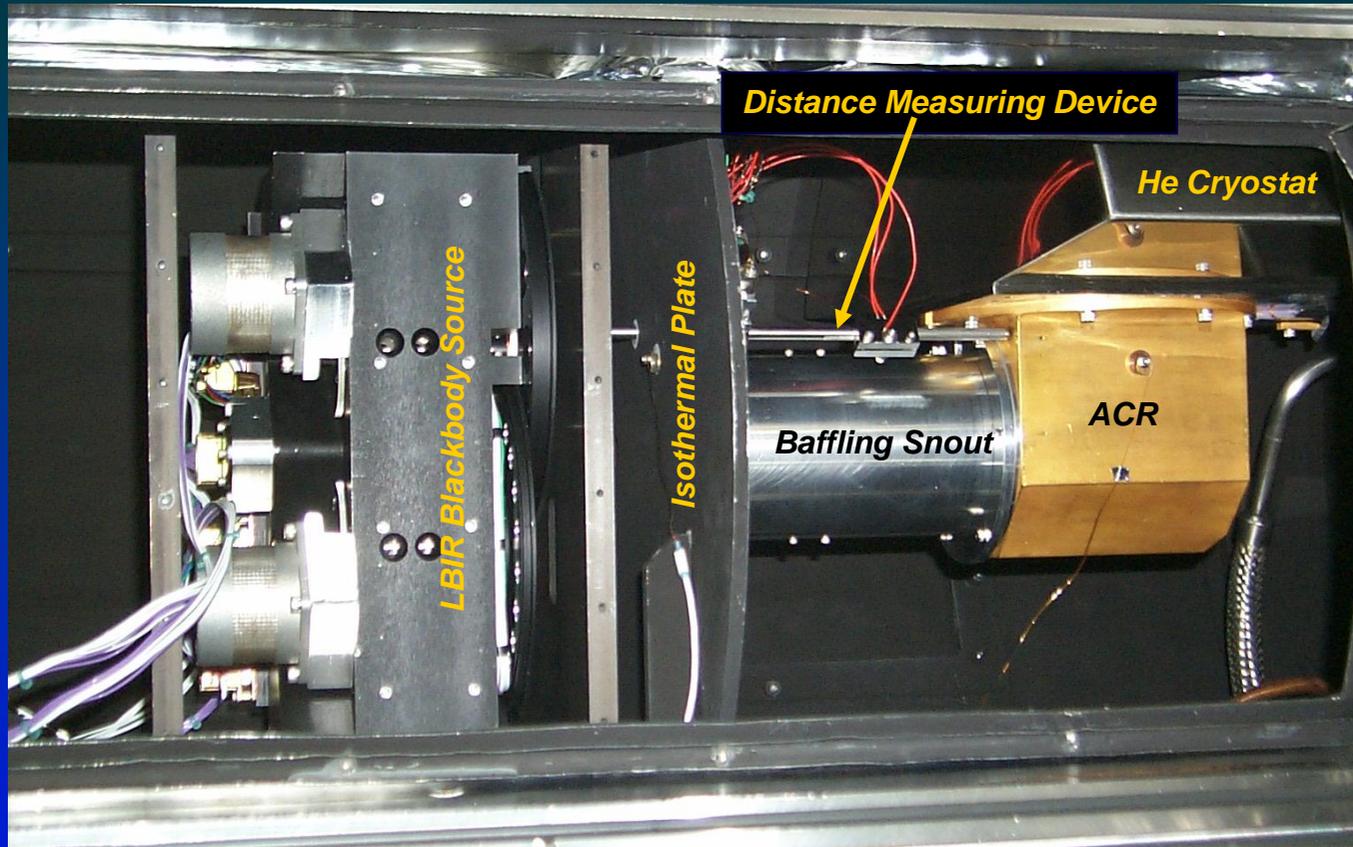


- Optical load from blackbody cavity surface skin was computed for a full 12 cm exit aperture radiative load.
- In the cavity cone area, the thermal gradient through the aluminum blackbody wall is estimated at ~ 1 mK, and the thermal gradient through paint is estimated at less than 1 mK.
- The SPRT was moved around to various locations in the fluid bath and found a temperature non-uniformity of less than 5 mK.
- The radiance temperature uncertainty of the blackbody cavity is less than 10 mK

Outline

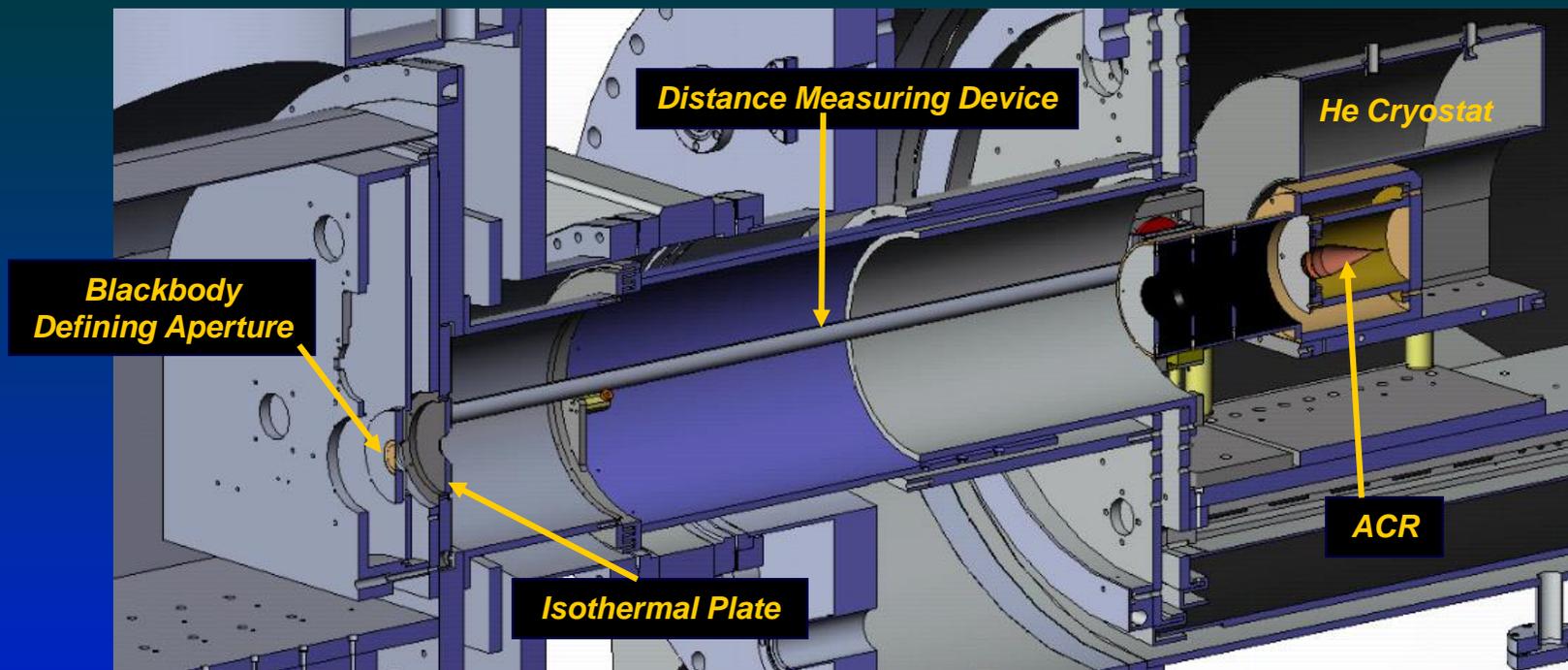
- *Introduction – Who we are, what we do, and why.*
- *Blackbody Radiance Calibration Basics*
 - *The Basic Radiance Calibration Test Configuration*
 - *Absolute Cryogenic Radiometers*
 - *High Accuracy Blackbody Source*
 - *The More Complete Test Configuration and the Issues*
- *Test Results and Discussion*
- *Conclusion*

Previous Experimental Arrangement



- Distance measuring device provides critical separation information.
- Baffling snout and isothermal plate function to temperature stabilize the ACR field of view and divert or capture stray light.
- This test configuration has the two defining apertures that are relatively close and provides lateral depth for stray radiance to escape.

New Problematic Experimental Arrangement

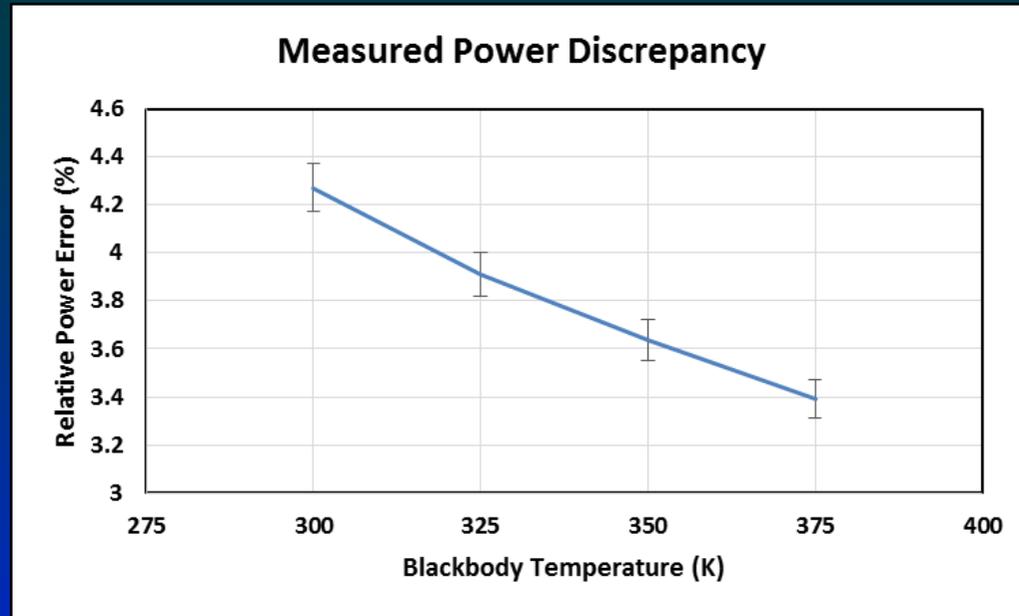


- New test configuration was adopted to accommodate larger sized blackbody systems.
- This test configuration has the two defining apertures relatively far apart and a long cylindrical tunnel that confines the stray radiation.
- Initial stray light simulations indicated there should be no problems;
 - Using 18 degree AOI reflectance data,
 - Assuming lambertian scattering for the diffuse component.

Outline

- *Introduction – Who we are, what we do, and why.*
- *Blackbody Radiance Calibration Basics*
 - *The Basic Radiance Calibration Test Configuration*
 - *Absolute Cryogenic Radiometers*
 - *High Accuracy Blackbody Source*
 - *The More Complete Test Configuration and the Issues*
- *Test Results and Discussion*
- *Conclusion*

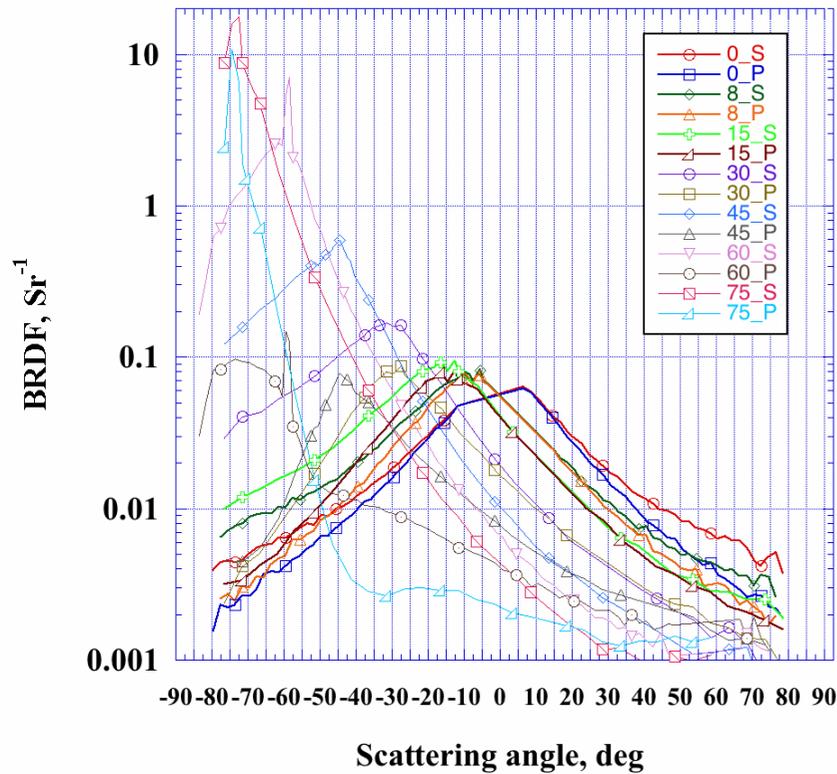
New Problematic Experimental Arrangement



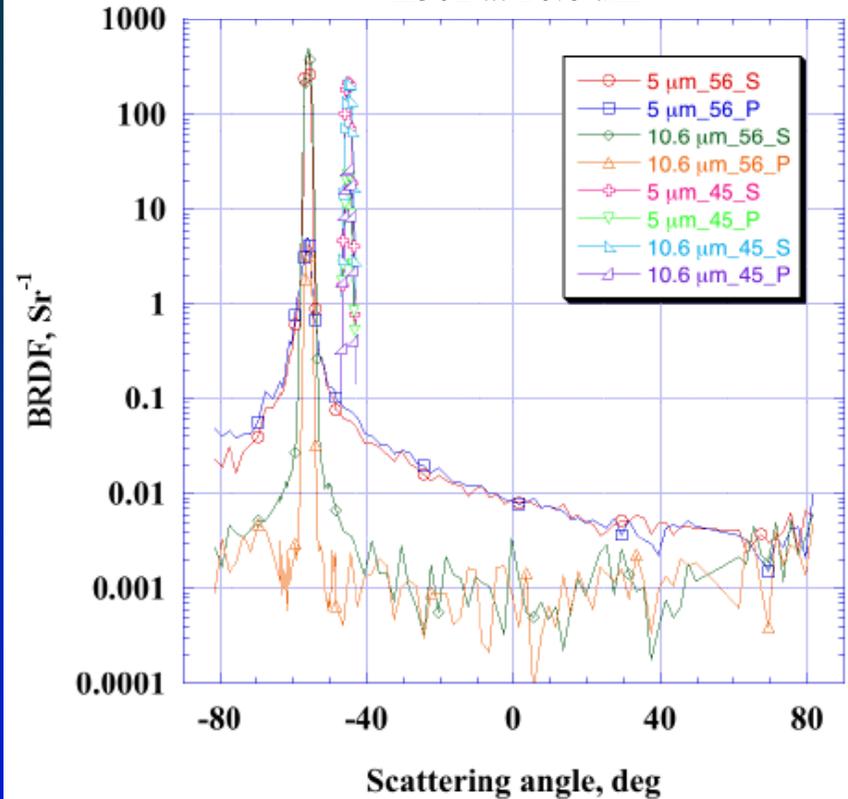
- Why does the new test configuration show excess power at the ACR?
 - Extra power rules out low blackbody cavity emissivity.
 - Extra power rules out low ACR absorptivity.
 - ~1% diffraction effects are too small to explain the error size.
 - Stray light can not be ruled out.
- Higher reflectance of “black” paints at longer wavelengths is consistent with larger error at lower blackbody temperatures where the Planckian shifts to longer wavelengths.

Characteristic BRDF of Aeroglaze Paints

Z306 at 10.6 μm



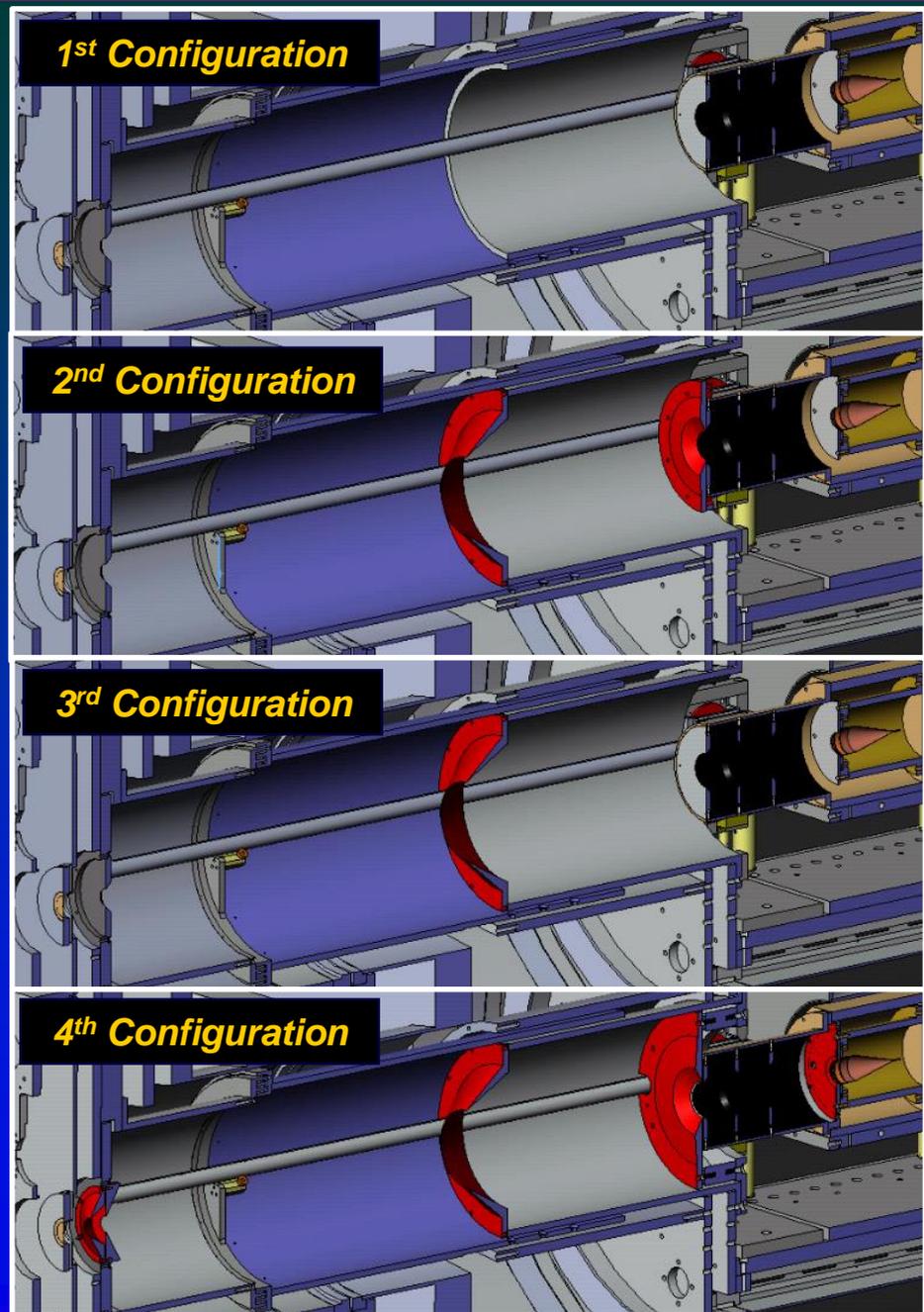
Z302 at 10.6 μm



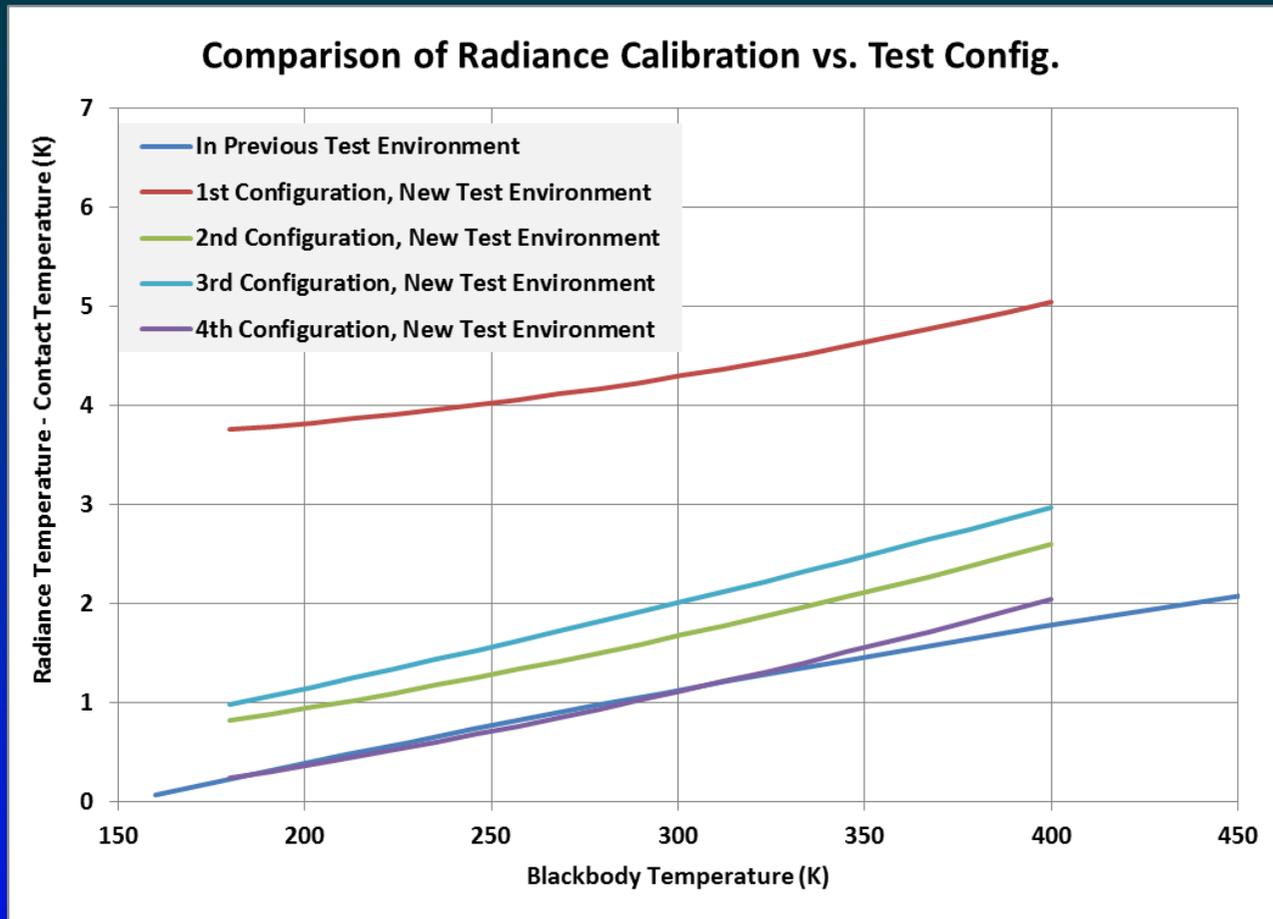
- BRDF indicates reflectance as large as 0.75 at 70 degrees AOI
- Standard total, diffuse, and specular reflectance data measured at 18 degrees AOI are poor measures of reflectance at low angles.

Tested Configurations in New Test Environment

- New baffles (colored red) were tested in various places in an effort to understand and control the stray radiation that was reaching the ACR.
- Very long test turn-around times prevented a completely systematic study.
- The fourth tested configuration was an effort to do “as much as reasonably possible” to mitigate the stray light.



Baffling Configuration Tests on User Blackbody



- These test results were from an LBIR customer's blackbody
- Fourth test configuration in the new test environment was able to recreate the results from the previous test environment.

Conclusions

- Stray light can have profound influence on radiance measurements.
- Standard reflectance measurements, such as total, specular and diffuse are not sufficient for accurate stray light modeling
- Relatively simple changes in baffling can be used to at least determine the existence of a stray light issue.
- An absolute characterization of stray light issues is very difficult.
- Future Direction:
 - Short Term: Test 4th baffling arrangement with Fluid Bath Blackbody
 - Long Term: Improve stray light modeling by incorporating real BRDF data at longer wavelengths in the stray light models.