Radiometric uncertainty analysis of the GLAMR calibration facility

GLAMR: Goddard Laser for Absolute Measurement of Radiance

Brendan McAndrew[a], Julia Barsi[b], Andrei Sushkov[c], and Joel McCorkel[a]

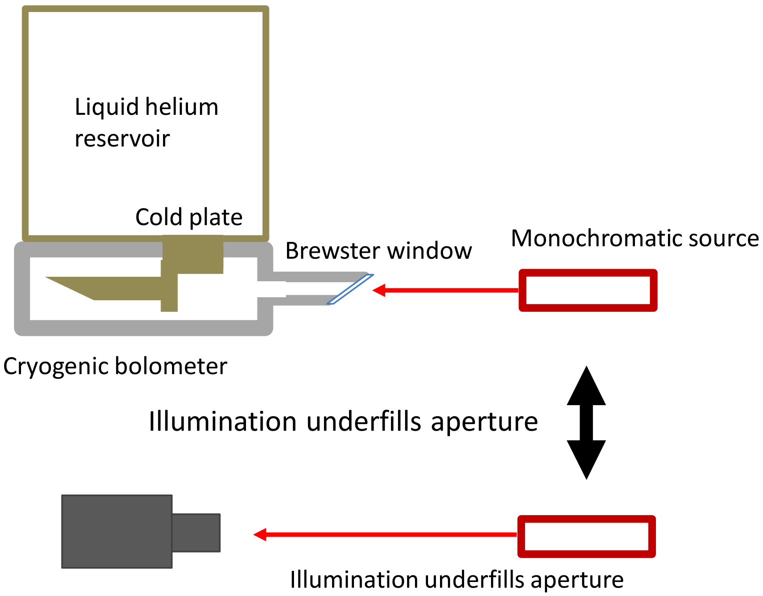
[a] NASA Goddard Space Flight Center
[b] Science Systems and Applications, Inc.
[c] Genesis Engineering, Inc.

Basic calibration scheme

NIST Primary Optical Watt Radiometer (POWR)

electrical substitution optical power meter

Optical watts referenced to electrical watts



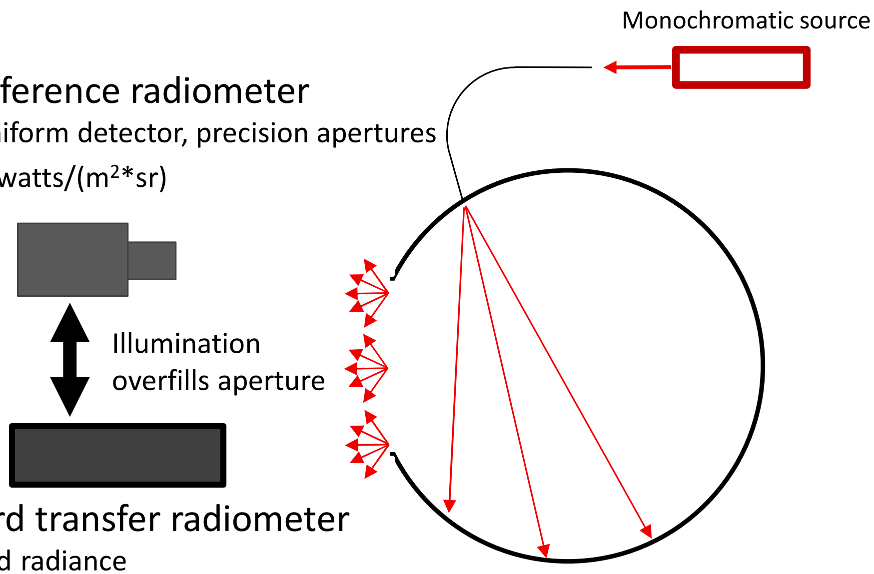
NIST reference radiometer

Calibrated watts

NIST reference radiometer

Highly uniform detector, precision apertures

watts → watts/(m^2*sr)

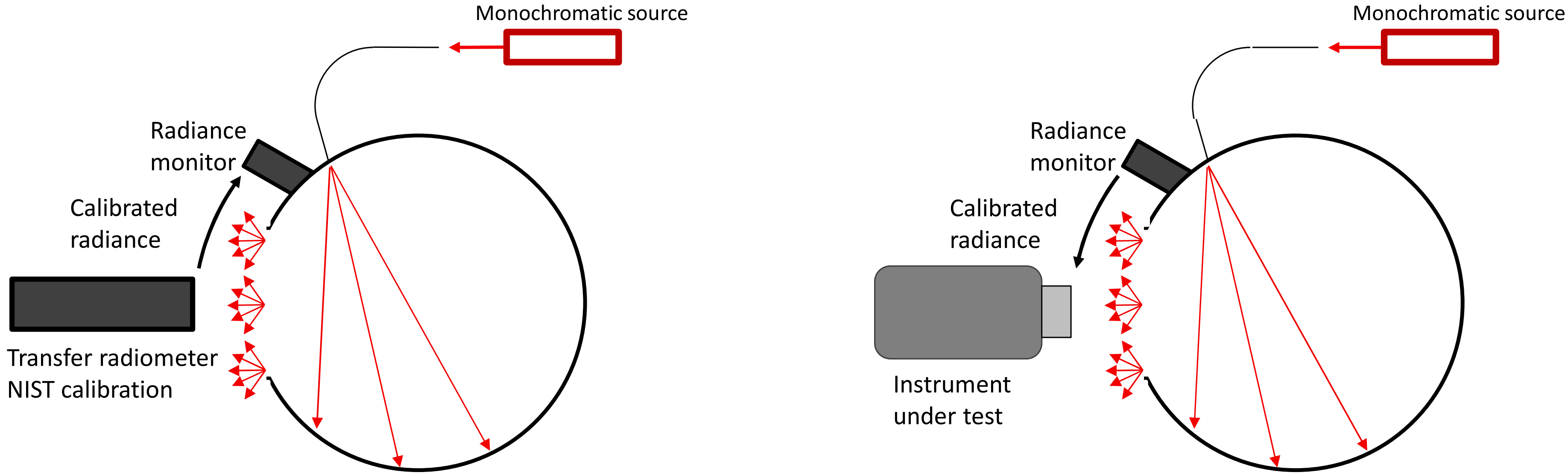


Goddard transfer radiometer

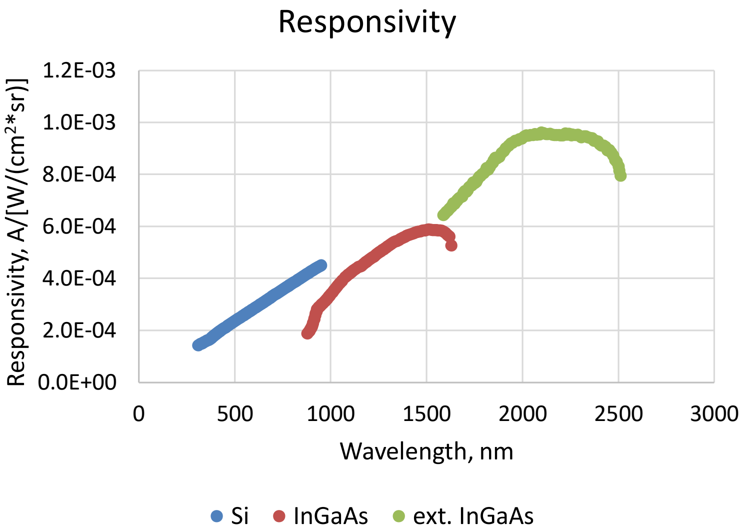
Calibrated radiance

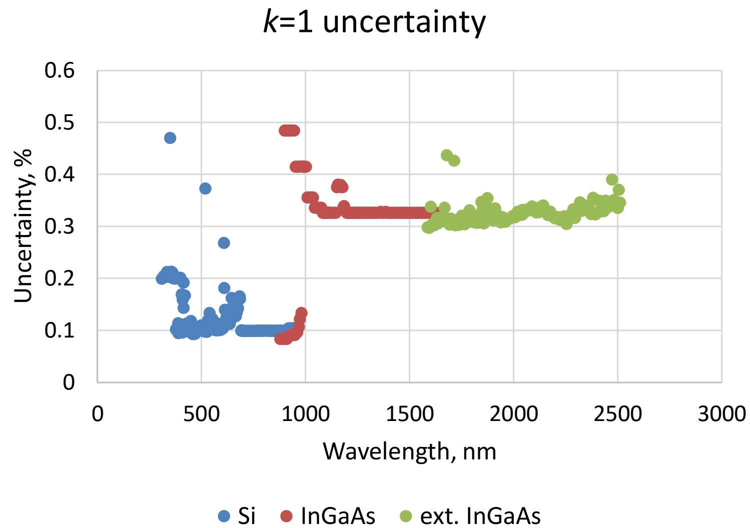
Basic calibration scheme

Goddard/instrument manufacturer integration and test facility

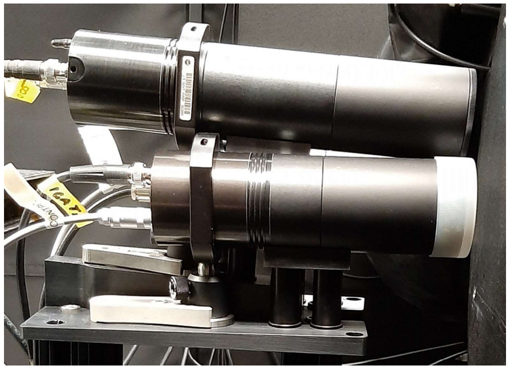


Transfer radiometer absolute calibration





Calibration is based on the electrical substitution method: optical power is matched to electrical power in a bolometer.


Transfer radiometers

Transfer radiometers and associated amplifiers are sent to NIST periodically for absolute radiance calibration

Radiometers are used in a set of three: silicon, InGaAs, and extended InGaAs to cover the spectral range 310 nm to 2500 nm

Temperature stabilized, unbiased photovoltaic mode of operation

Integrating Sphere Uniformity

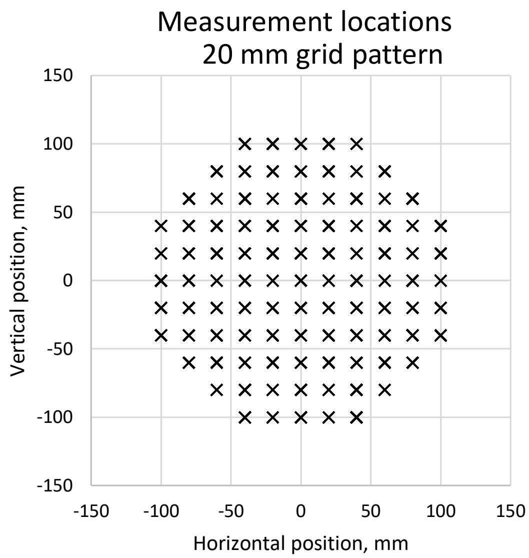
Sphere uniformity measured with combination of fixed radiometers and a narrow field of view scanning radiometer

Scanning radiometer mounted on X-Y-θ motion stages: 2 axis linear and 1 axis rotation

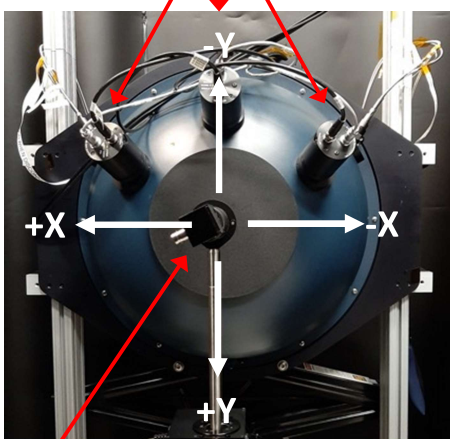
Position scanned in grid pattern with 20 mm step size

Center position repeated every other measurement to account for drift (scanning radiometer not temperature stabilized)

Measurements repeated at several illumination wavelengths between 345 nm and 2000 nm



Fixed radiometers (sphere monitors)



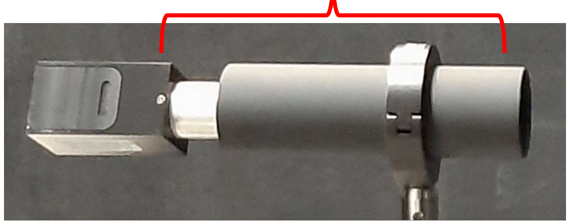
Stage axis directions

Scanning radiometer

GLAMR

Scanning radiometer detail

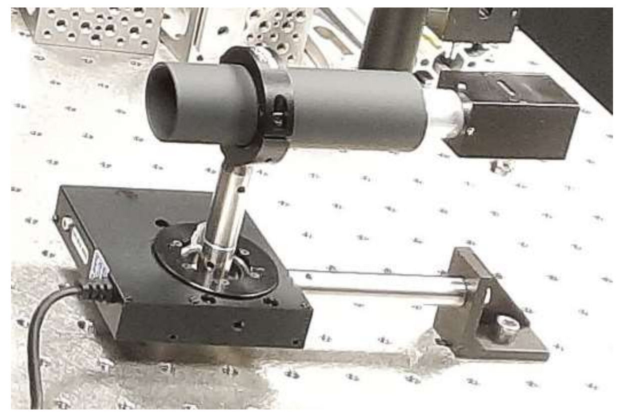
Radiometer design: interchangeable Si and InGaAs photodiodes with 0.75° field of view Gershun tube



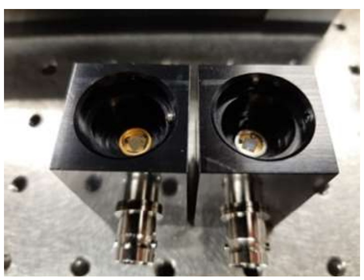
Photodiode with Gershun tube

Non-imaging, no refractive optics

Unbiased, photovoltaic mode operation, same as sphere monitors



Photodiodes



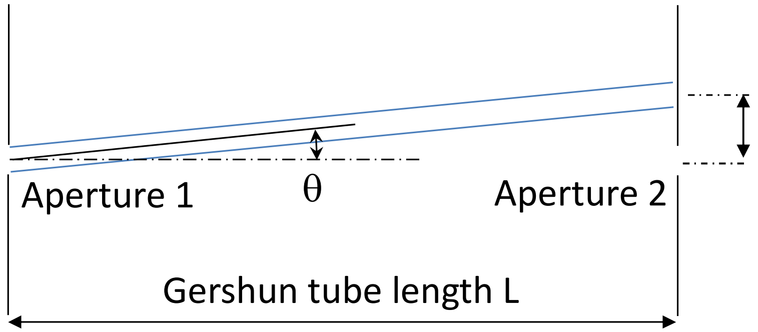
One square (Si) and one round (XIGA) photodiode

Detector	Active area	Size	
Silicon	$4.5\ mm^2$	2.12 × 2.12 mm	Si FOV 6% larger
XIGA	$3.14\ mm^2$	∅ 2mm	

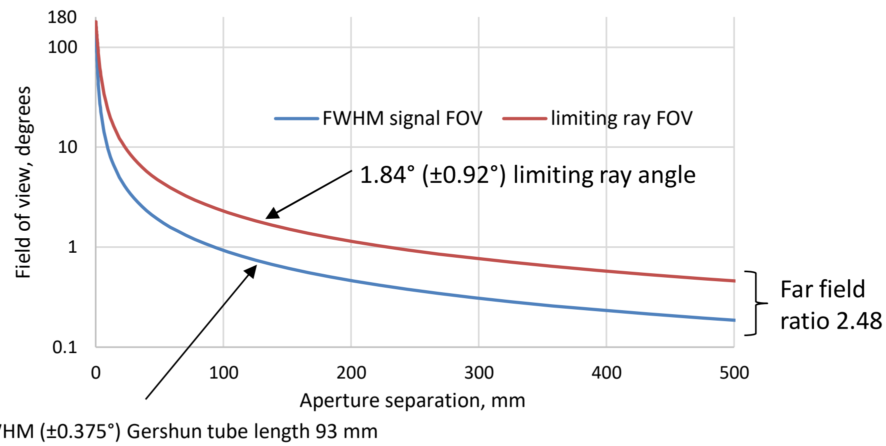
Field of view note

<u>Spatial resolution:</u>
area of aperture 1

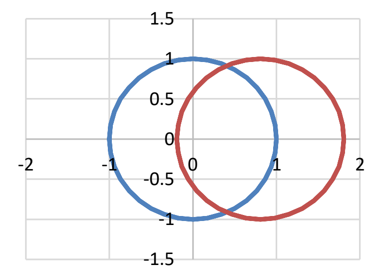
<u>Angular resolution:</u>
$\theta = \tan^{-1}(d/L)$, field of view = 2θ



Field of view for 2 mm diameter apertures

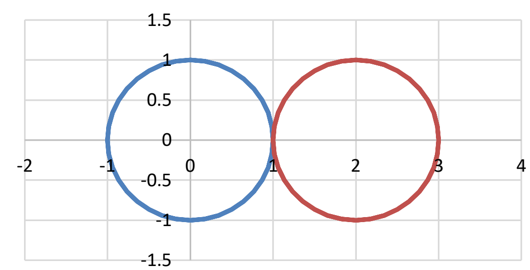


50% area overlap



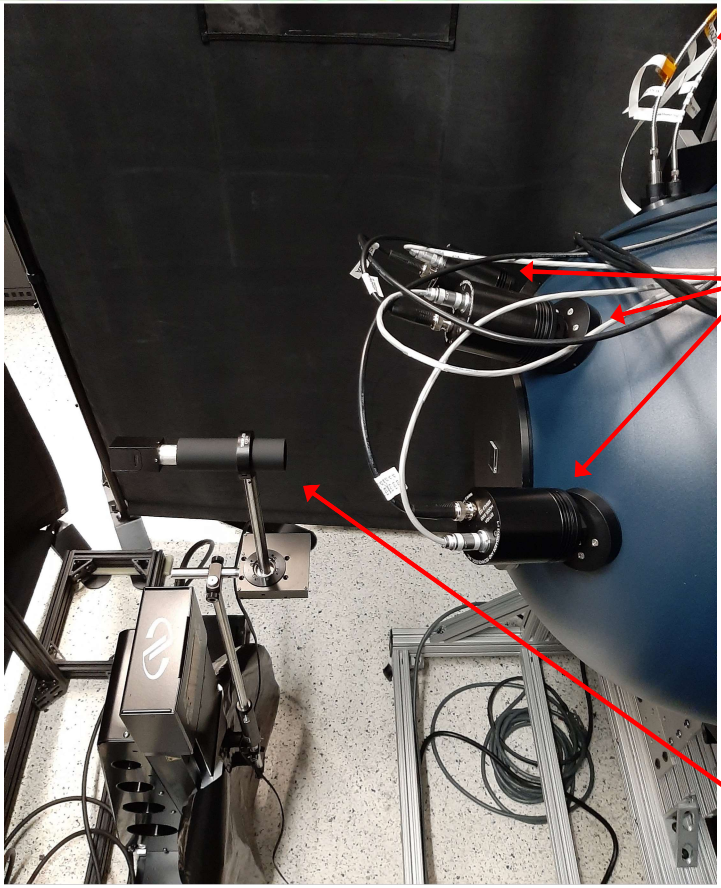
Angle to reach ½ of maximum signal

0% area overlap

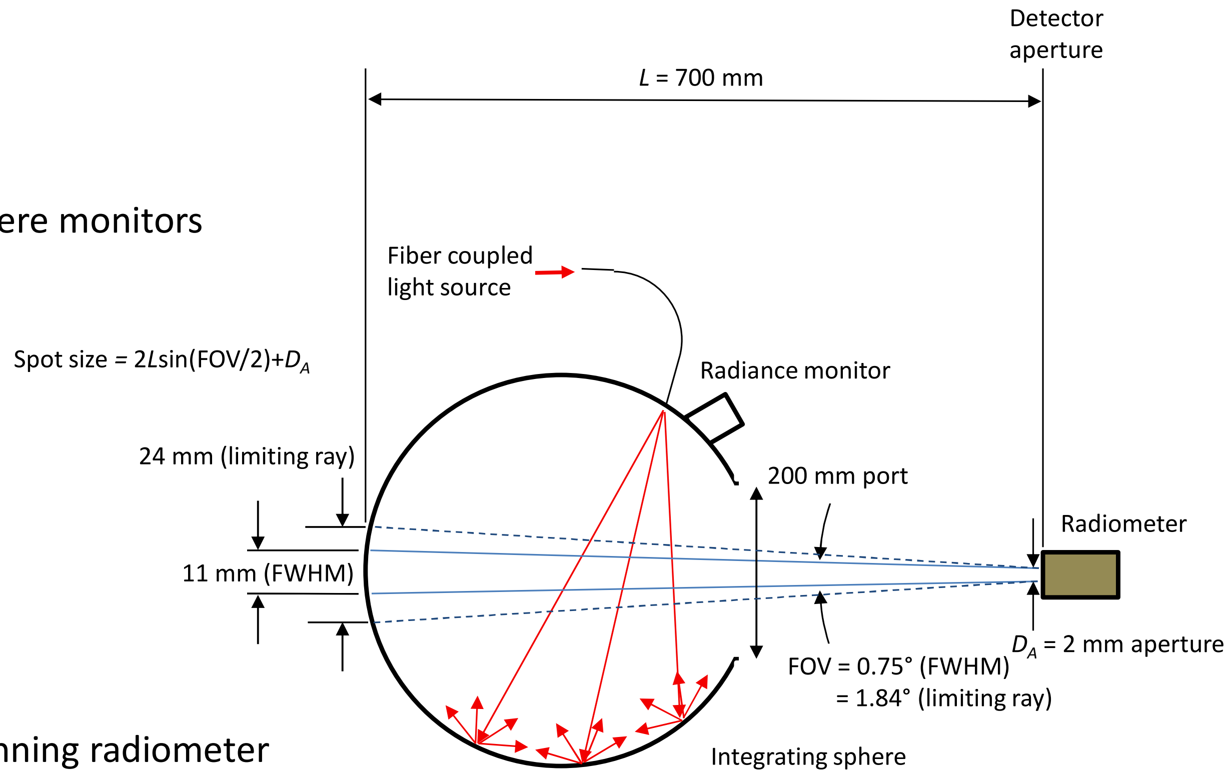


Angle to reach zero signal

Uniformity measurement setup

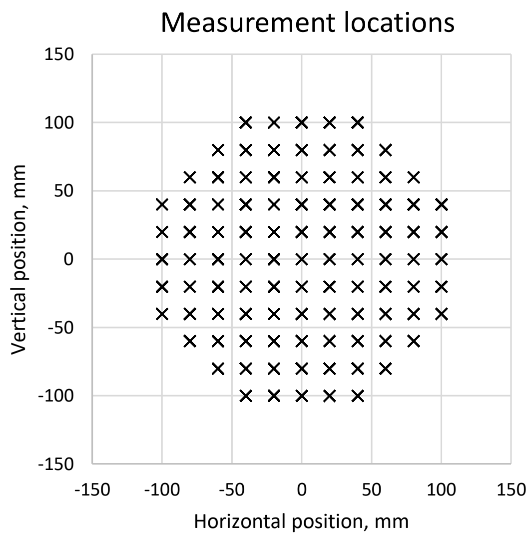


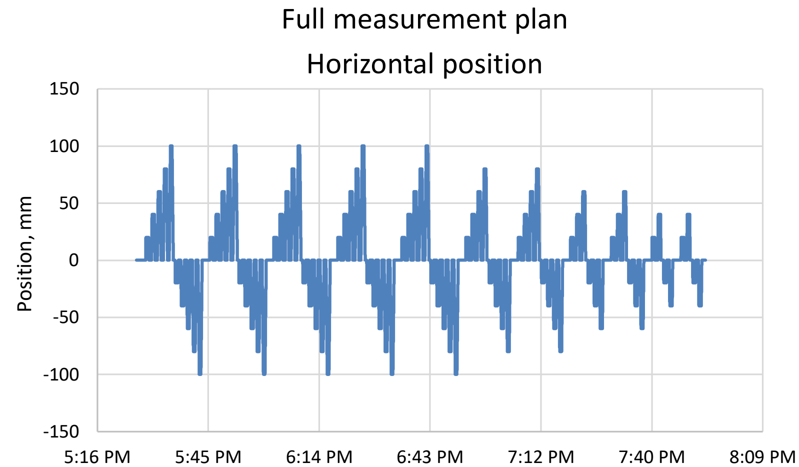
Laboratory configuration

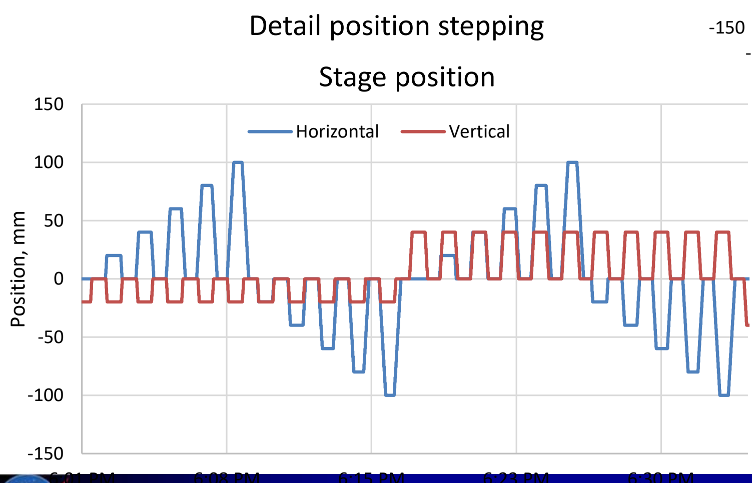


Scan sequence

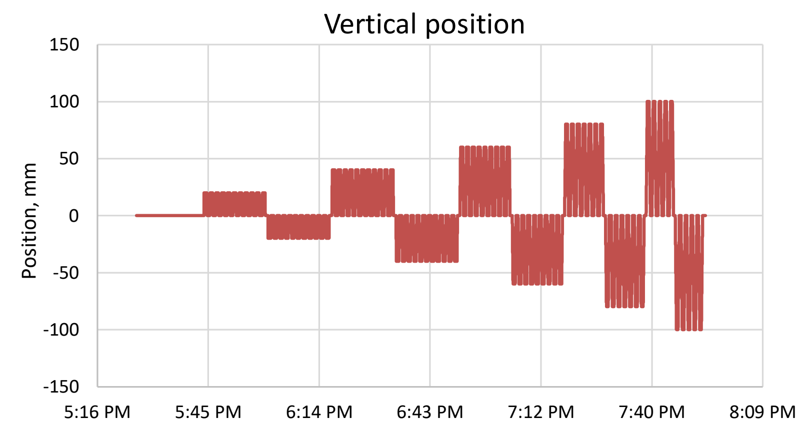
- Automated spatial scan and data collection at constant wavelength and radiance
- 5 Hz radiance data acquisition
- 45 seconds between stage commands
- 26 seconds minimum dwell time at each position







Center position (0,0) repeated every other measurement



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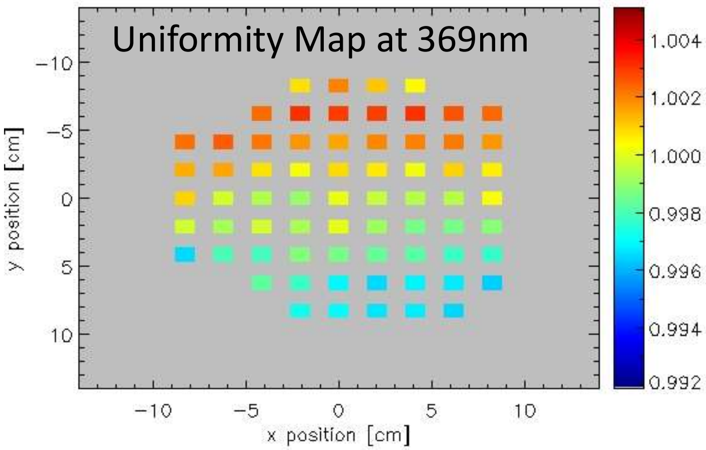
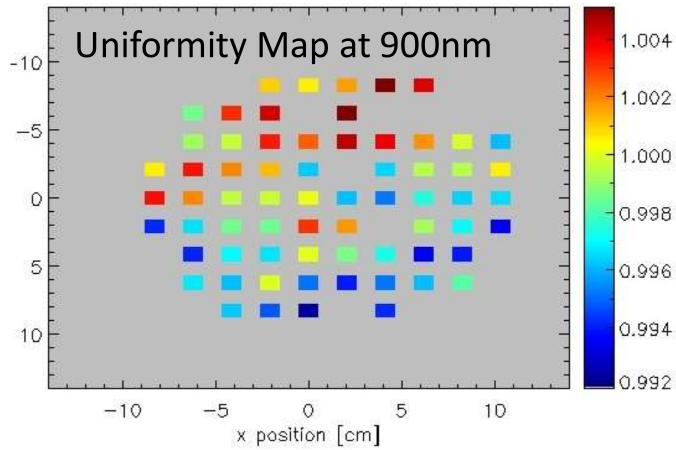
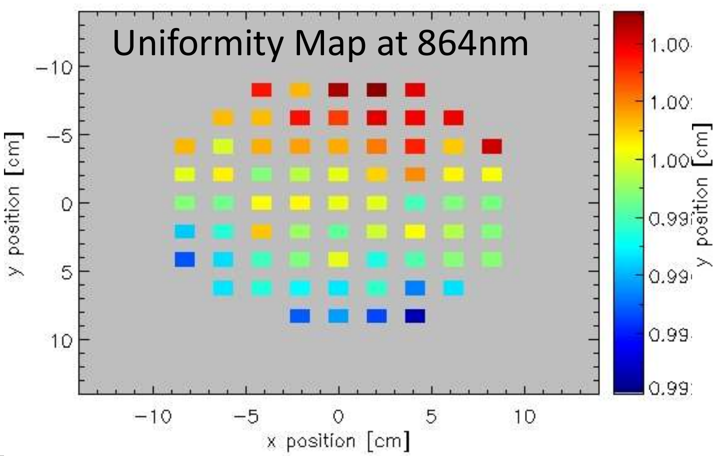
Spatial uniformity data

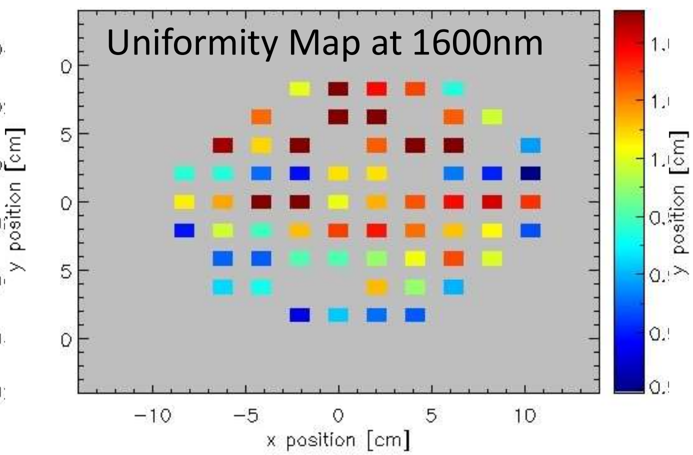


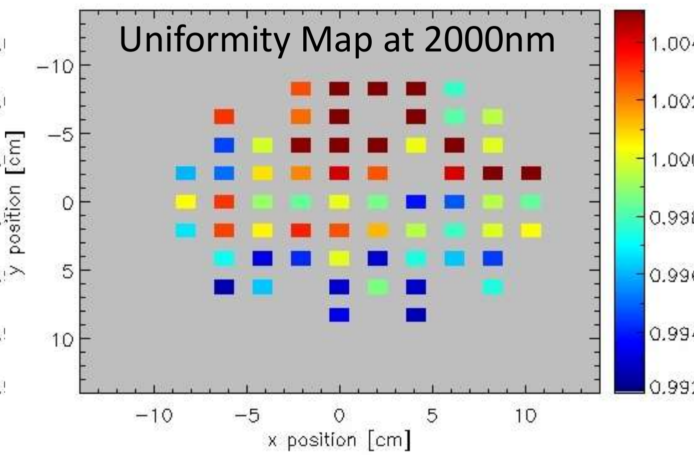


Variation ±0.1% horizontally, ±0.5% vertically

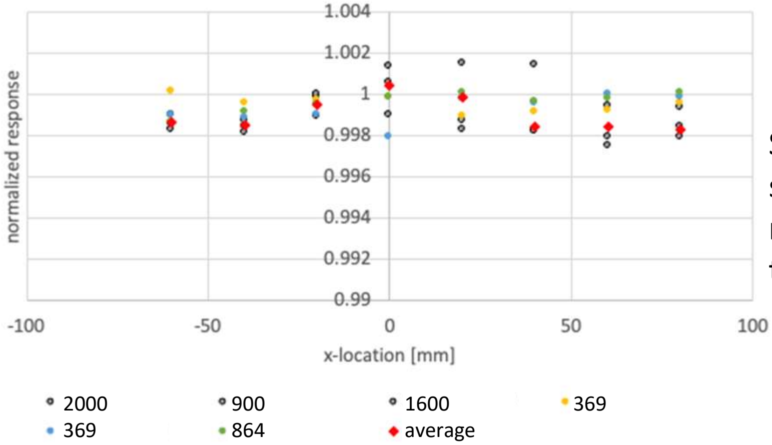
No dependence with wavelength







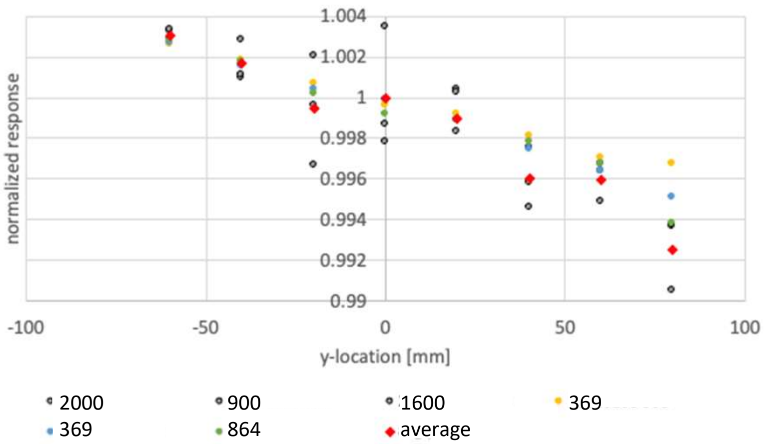
Combined data sets



Sphere close to symmetric left to right, brightest in the middle

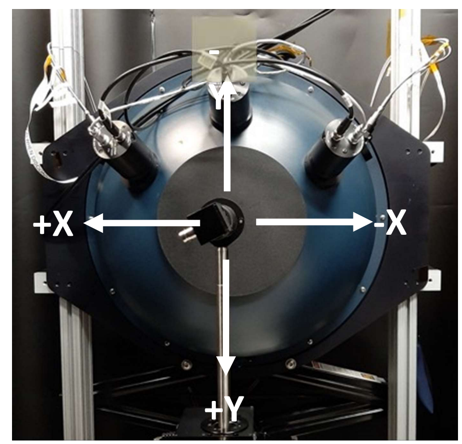
X-direction average: each point is an average of measurements taken along the same vertical column

Y-direction average: each point is an average of measurements taken along the same horizontal row



Sphere brightest at the top

Stage axis directions



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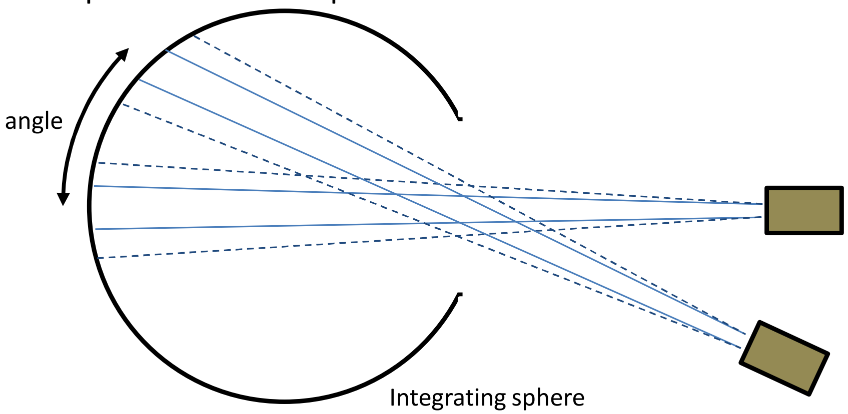
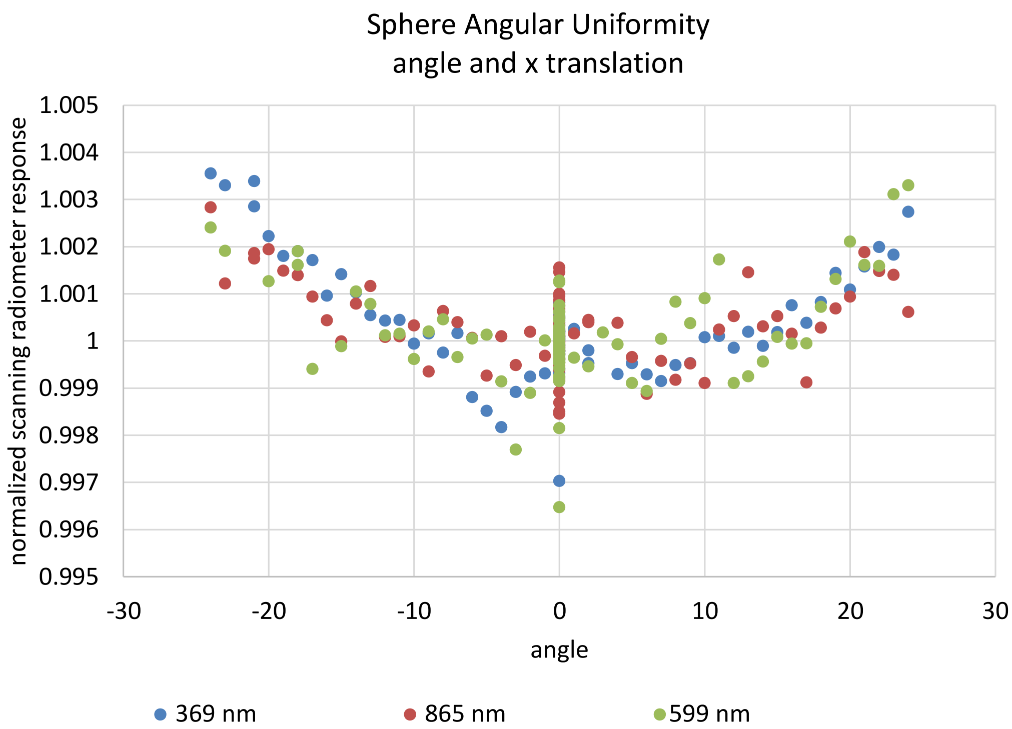
Angular uniformity data

Uniform to 0.1% within ±10°
No dependence with wavelength

Angle measured from port center to sphere relative to port centerline



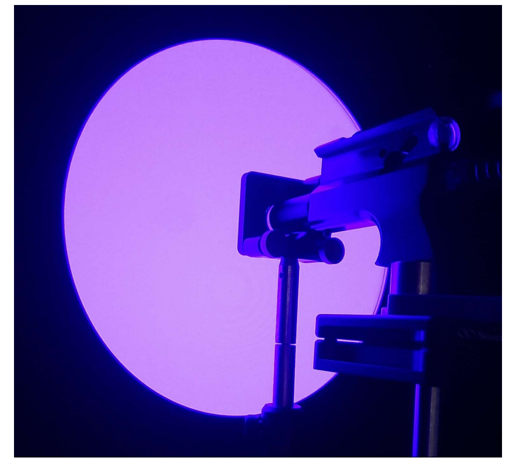


Fluorescence

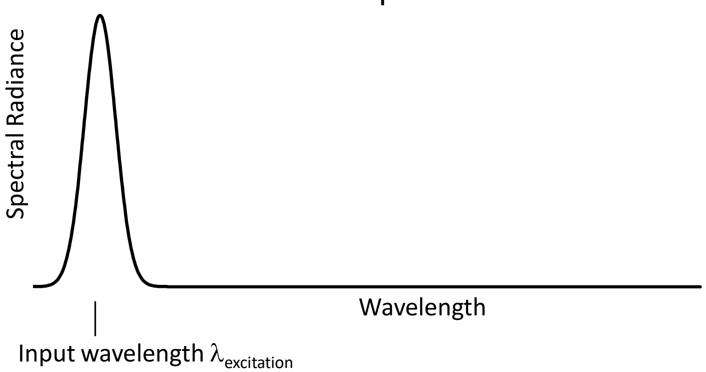
For the GLAMR sphere, average reflectivity $\bar{\rho}$ = 0.95 [$\rho_{Sphere\ material}$*(1-A_{port}/A_{sphere})]

Average number of reflections $r_{avg} = \frac{-1}{\ln \bar{\rho}} \approx 20$

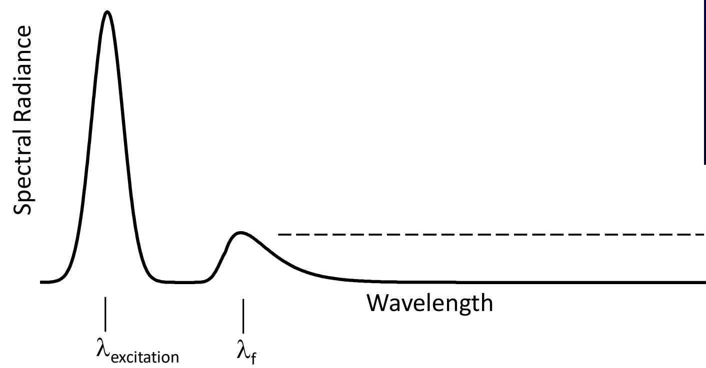
Fluorescence signal scales with average number of reflections, in our case a factor of 20



Ideal spectrum



Emitted spectrum



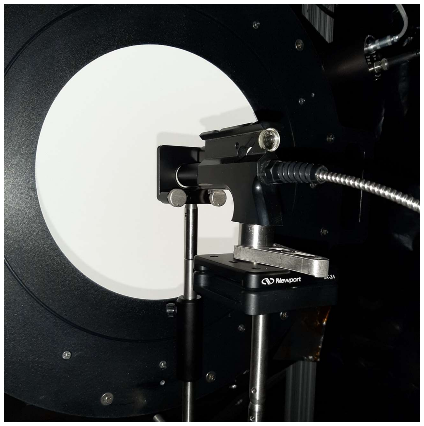
Integrating sphere illuminated with fiber coupled monochromatic light, linewidth < 1 nm

Fluorescence should be observable as light at longer wavelength than incident light and broader linewidth

Test procedure

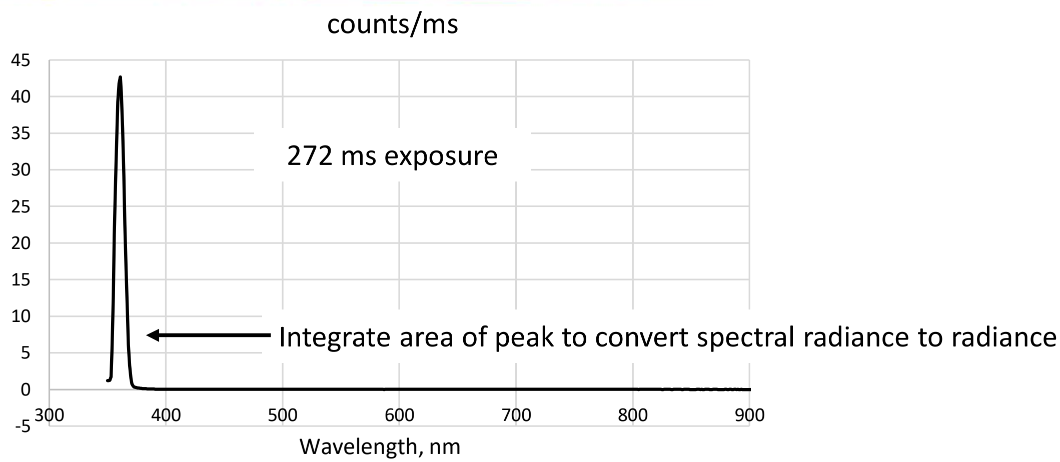
Fluorescence data acquired with ASD spectro-radiometer

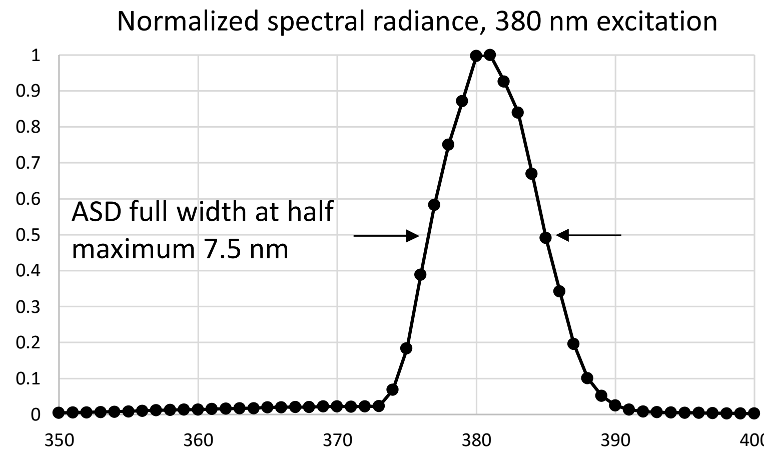
1. Unfiltered data acquired at short exposure time 272 ms
2. Long pass filter data acquired at long exposure time 1.16 minutes
3. Raw data dark subtracted and converted to counts/ms
4. ASD calibration and filter transmission applied
5. Filtered and unfiltered data combined to extend dynamic range
6. Fluorescence *spectral radiance* normalized to laser wavelength *radiance*

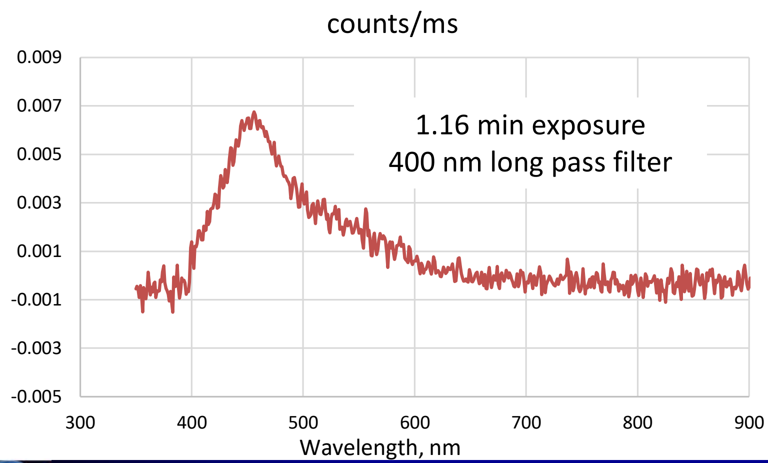


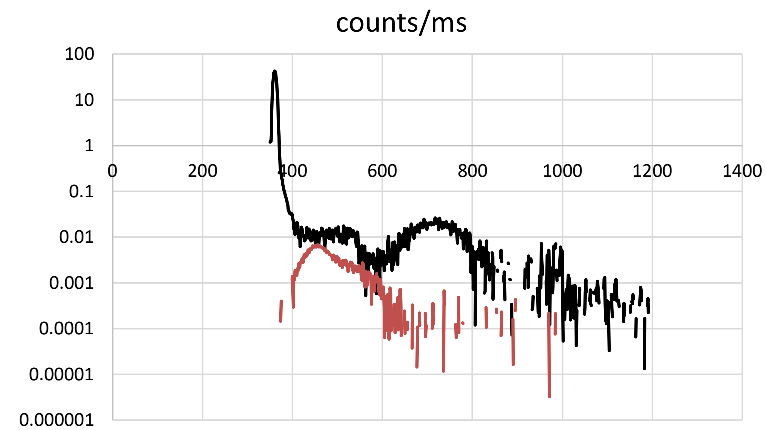
ASD fore optic and filter mount in front of integrating sphere

Example data





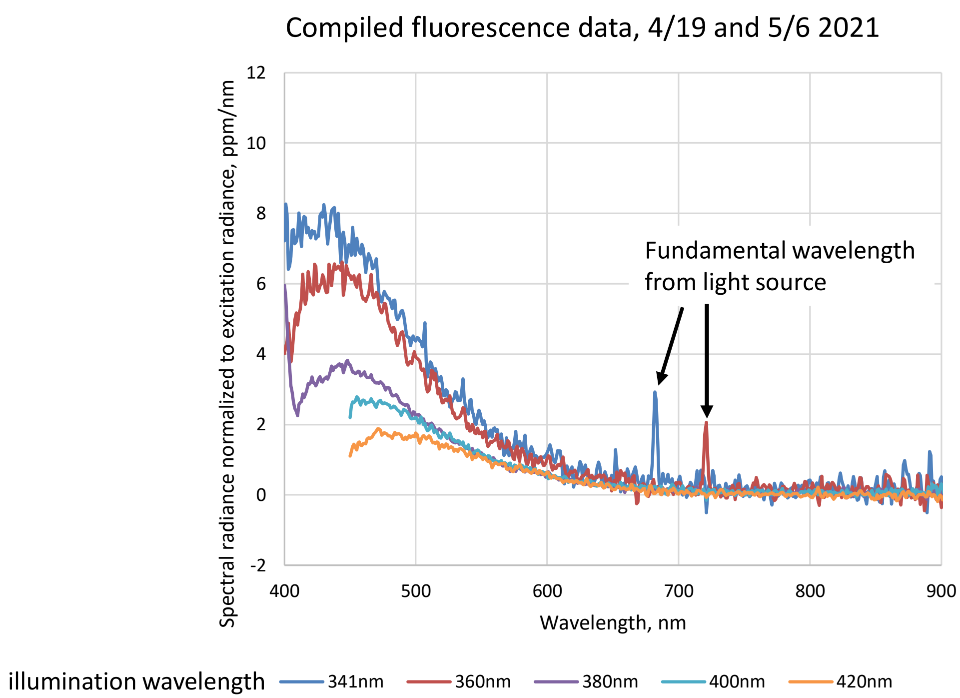


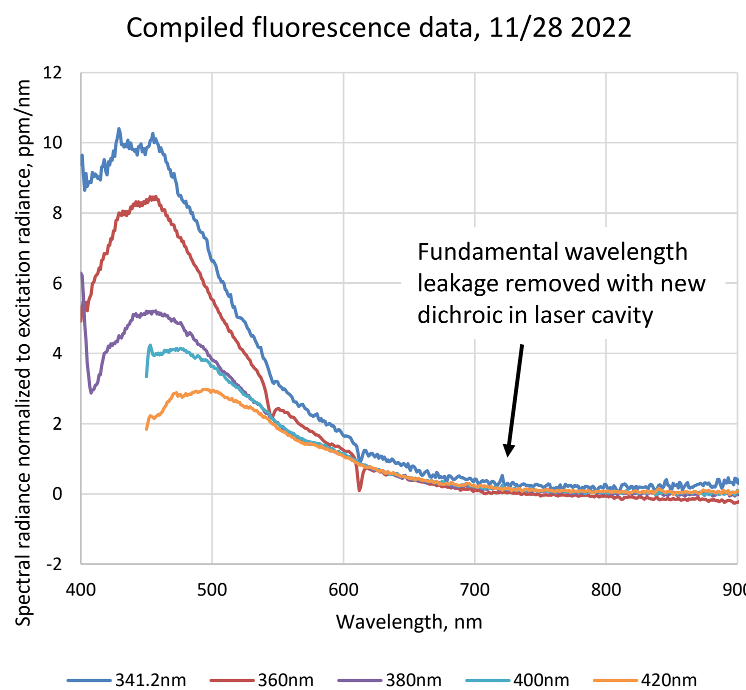


ASD stray light exceeds fluorescence signal in unfiltered data

Applying calibration and normalizing

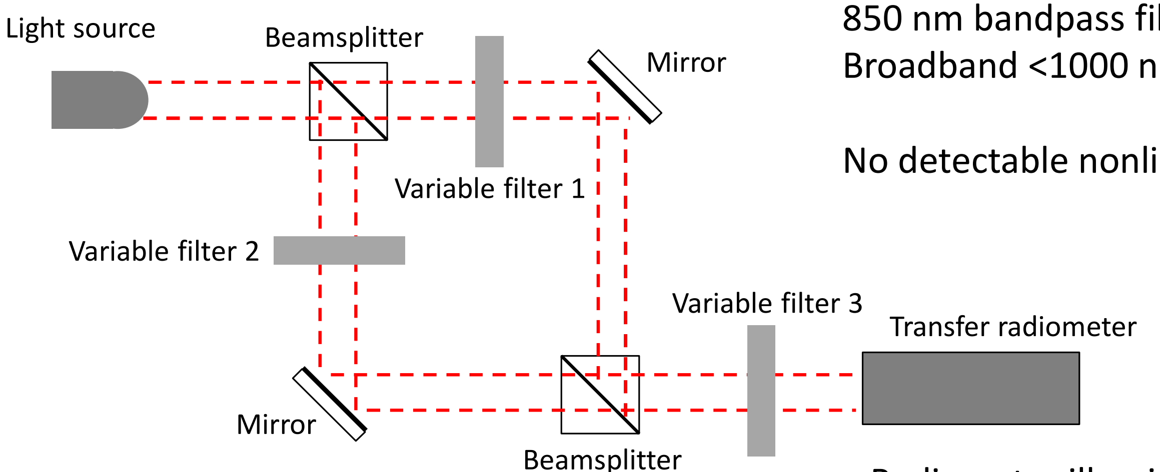
Fluorescence normalized to radiance of illumination wavelength by integrating area of peak at laser wavelength over ASD bandwidth





Linearity

Transfer radiometer linearity checked in NIST beam conjoiner facility (H. Yoon) using superposition principle



NIST beam conjoiner schematic

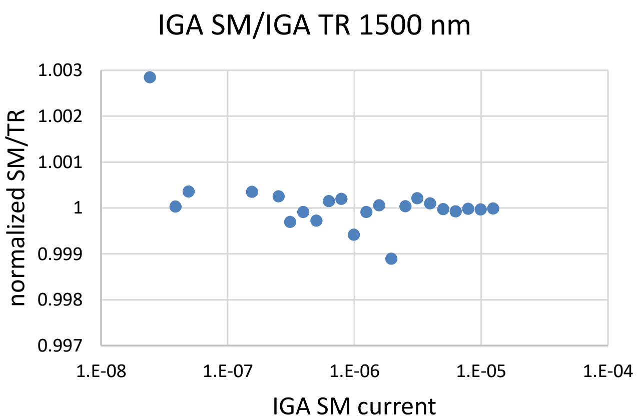
<u>Silicon radiometer</u>
850 nm bandpass filter
Broadband <1000 nm

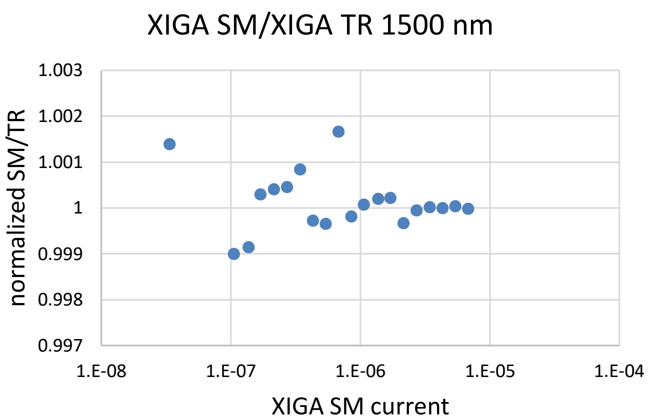
<u>InGaAs and ext. InGaAs radiometers</u>
broadband >1000 nm

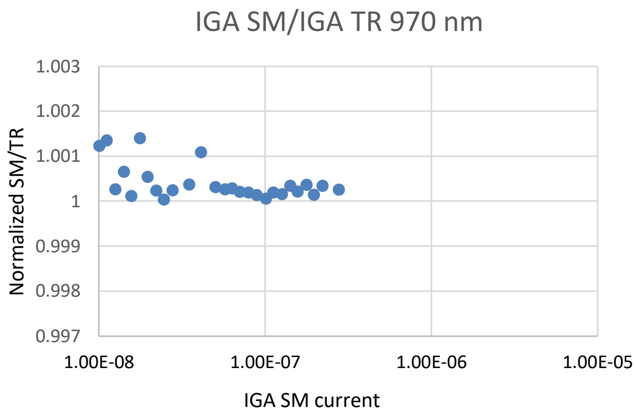
No detectable nonlinearity found in transfer radiometers

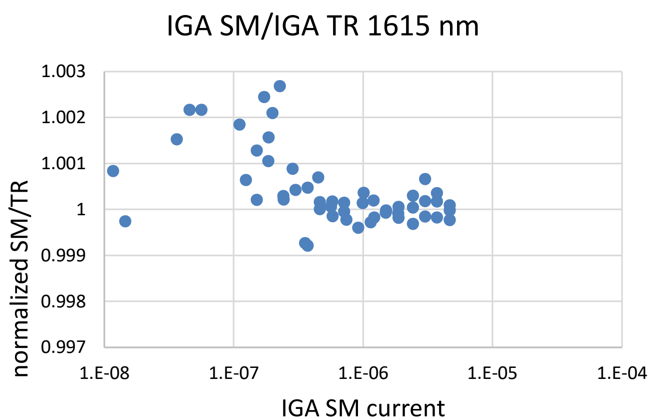
Radiometer illuminated by light from two different paths with identical spectrum and field of view: flux from combined paths equals sum of flux from each path separately.

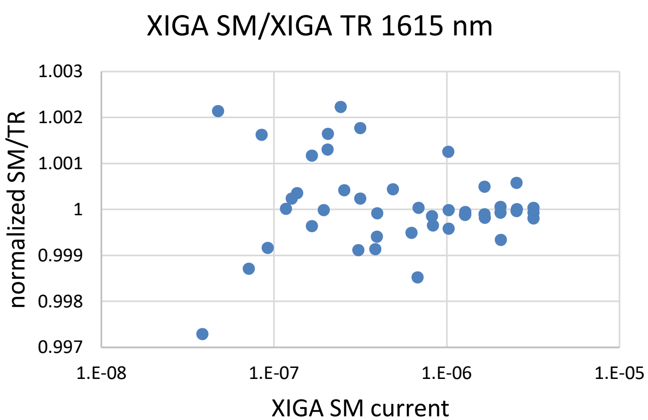
Sphere monitor linearity









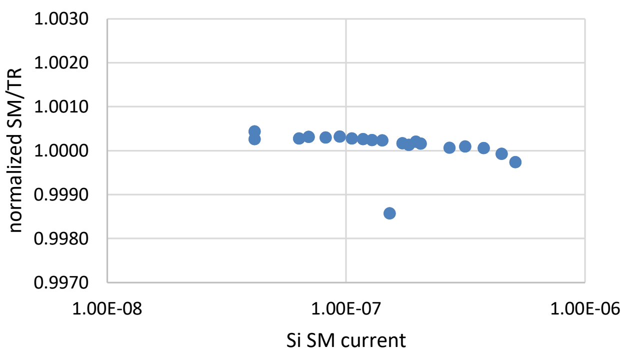


InGaAs and extended InGaAs sphere monitors linear over all conditions tested, 970 nm – 1615 nm

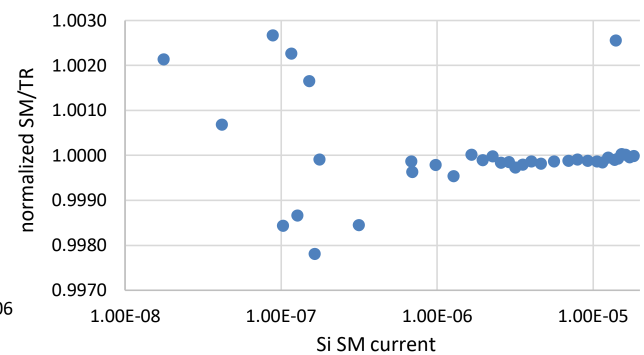
Sphere monitor linearity

Slight wavelength dependent nonlinearity in silicon sphere monitor

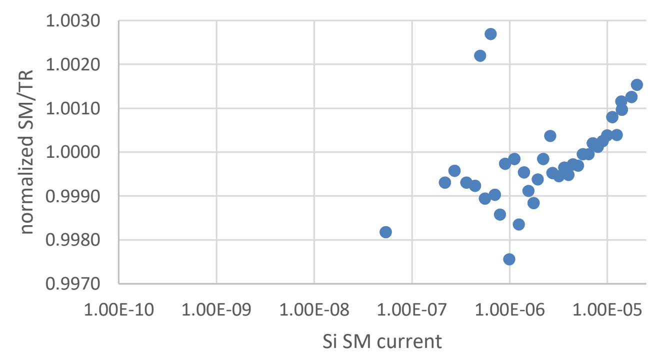
372 nm



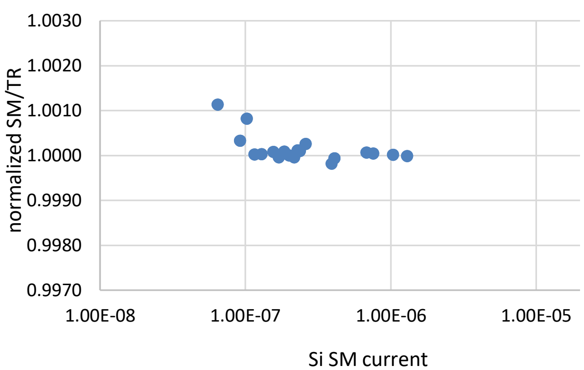
750 nm



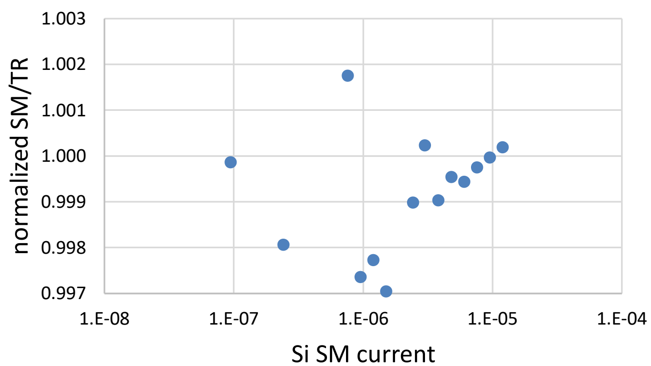
970 nm



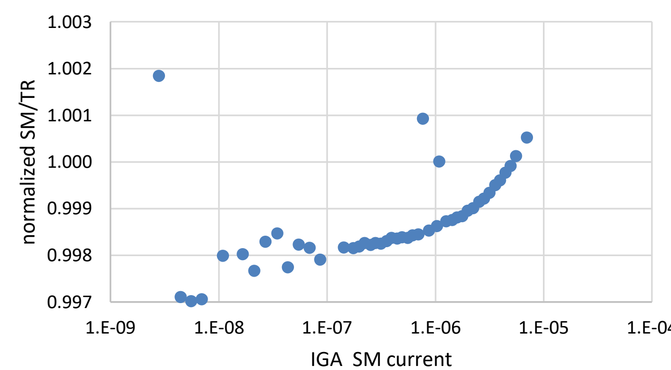
505 nm



865 nm



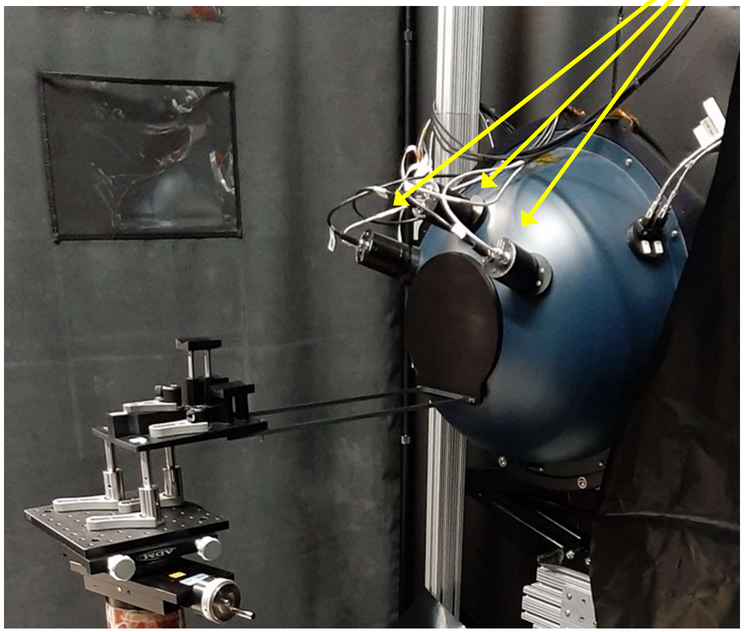
Si SM/IGA SM 970 nm



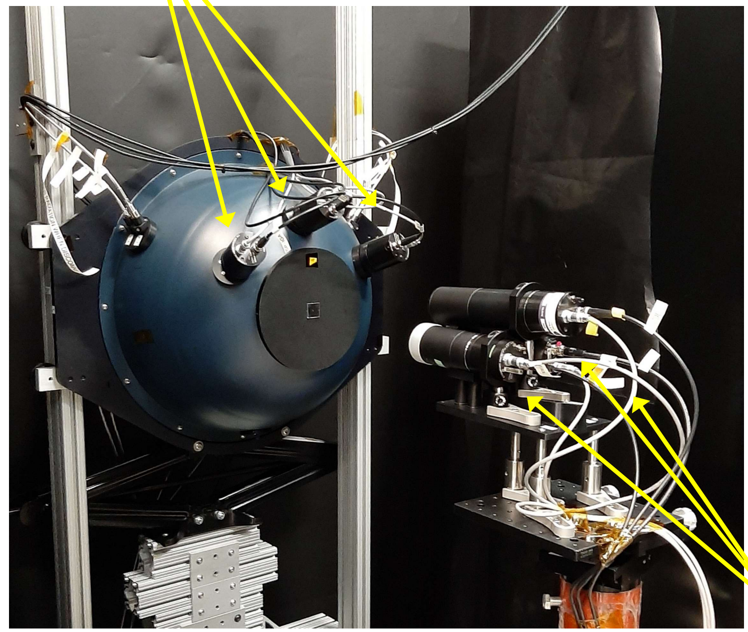
Repeatability

Custom radiometer mount co-aligns transfer radiometer fields of view on integrating sphere

Sphere monitors



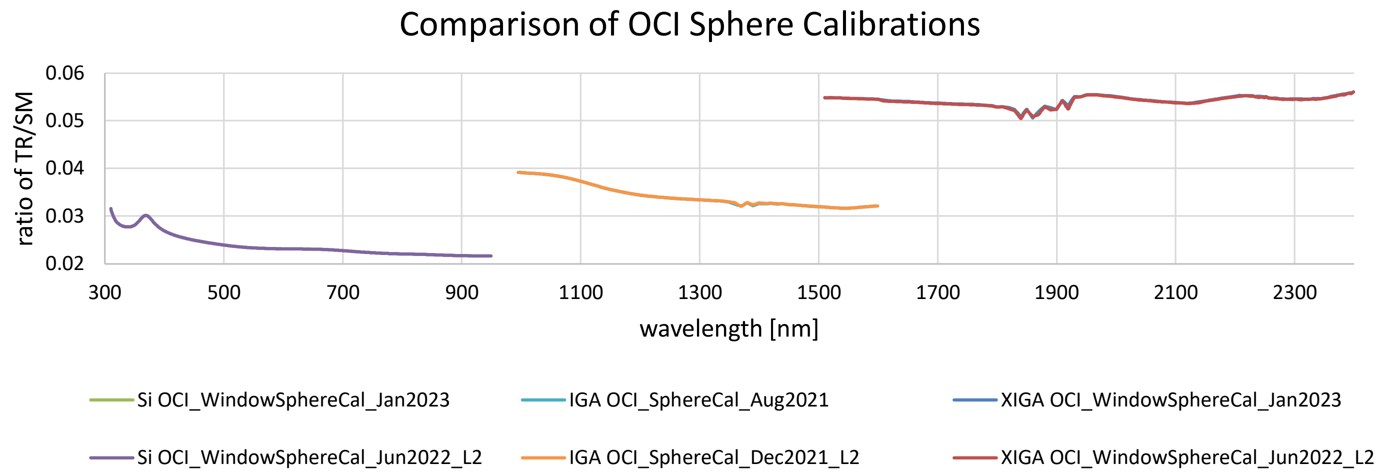
Radiometer mount with alignment guide



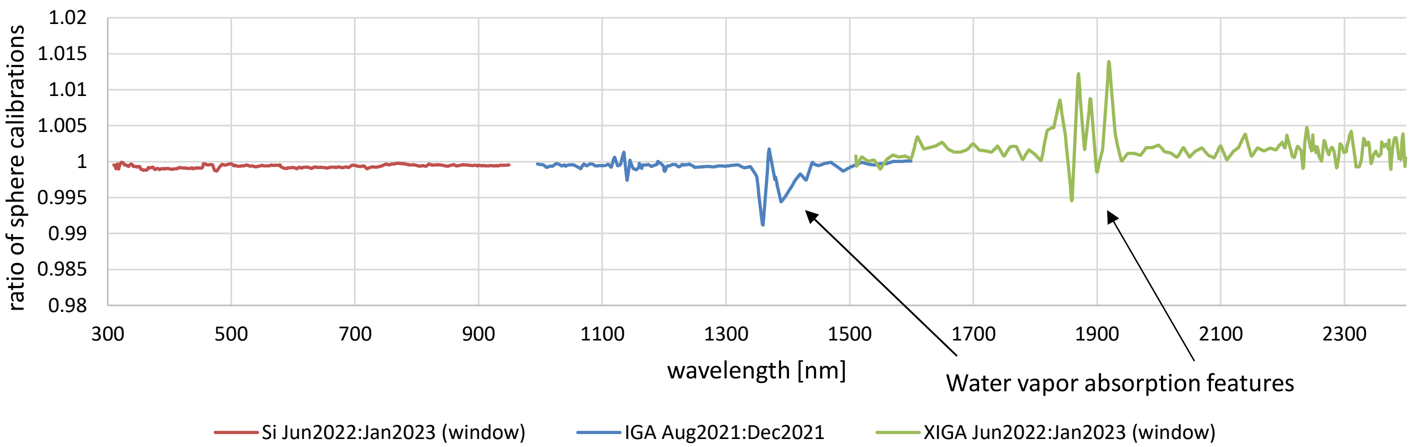
Transfer radiometers

Calibration setup, alignment guide removed

Repeatability



Transfer radiometer to sphere monitor ratio



Ratio of repeat sphere calibrations

Uncertainty terms

Wavelength Range	UV 350nm-400nm	VIS 400nm-820nm	NIR 865nm	NIR 940nm	NIR 1038nm	NIR 1250nm	NIR 1378nm	SWIR 1615nm	SWIR 2130nm	SWIR 2260nm
Combined uncertainty terms (root sum square)	**0.23%**	**0.17%**	**0.15%**	**0.15%**	**0.38%**	**0.35%**	**1.06%**	**0.35%**	**0.36%**	**0.34%**
Transfer radiometer absolute calibration	0.20%	0.13%	0.10%	0.10%	0.36%	0.33%	0.33%	0.33%	0.34%	0.32%
Sphere repeatability	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	1.0%	0.04%	0.04%	0.04%
Measurement noise	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Uniformity of the sphere	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%

Instrument calibration considerations

Aperture and field of view

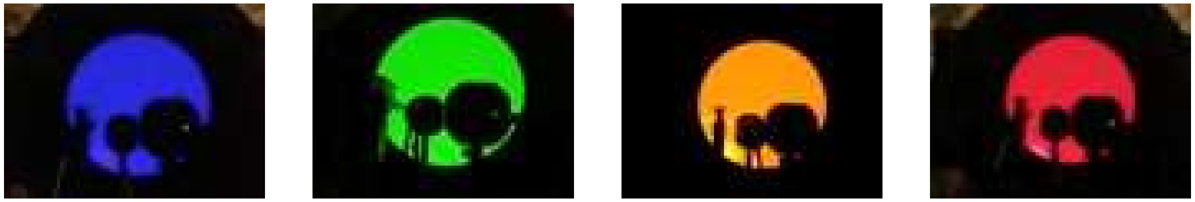
Dynamic range

Frequency bandwidth and sample rate

Measurement averaging time

Out of band fluorescence correction

Questions?



Integrating sphere timelapse during a radiometer calibration