Comparison of detector-based and source-based absolute radiance standards

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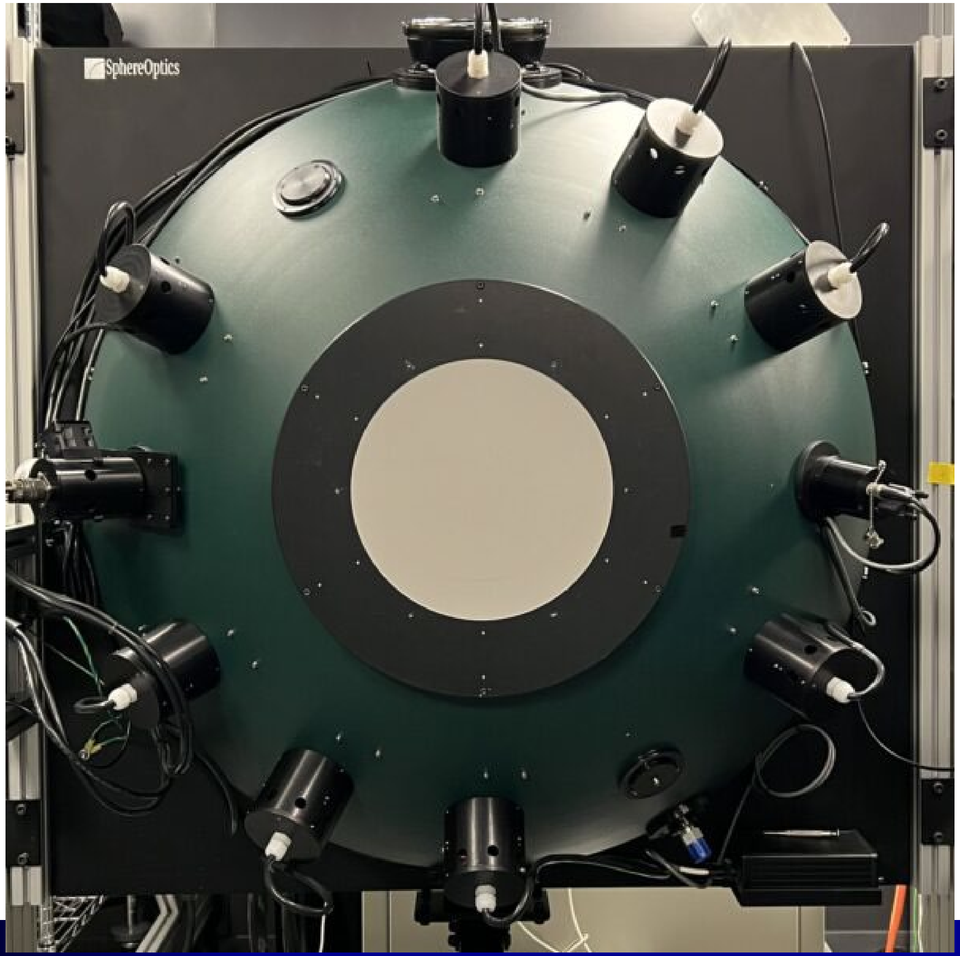
Grande broadband source and GLAMR monochromatic source

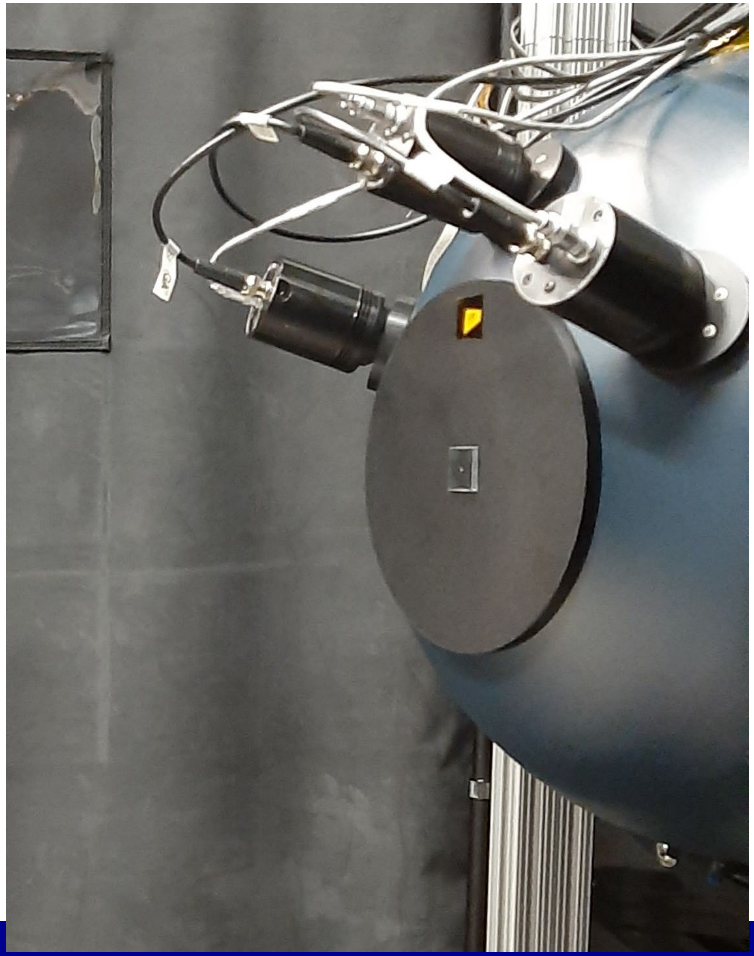
Grande

1-m sphere
Source: Nine QTH lamps
Calibration reference: FEL



GLAMR

50-cm sphere
Source: Monochromatic tunable laser
Calibration reference: transfer radiometers

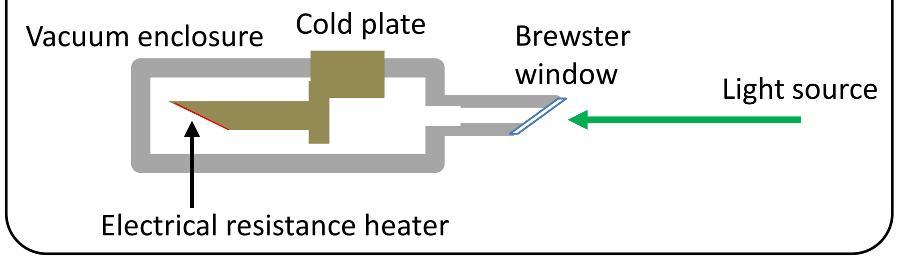


Detector-based radiance calibration with tunable monochromatic light

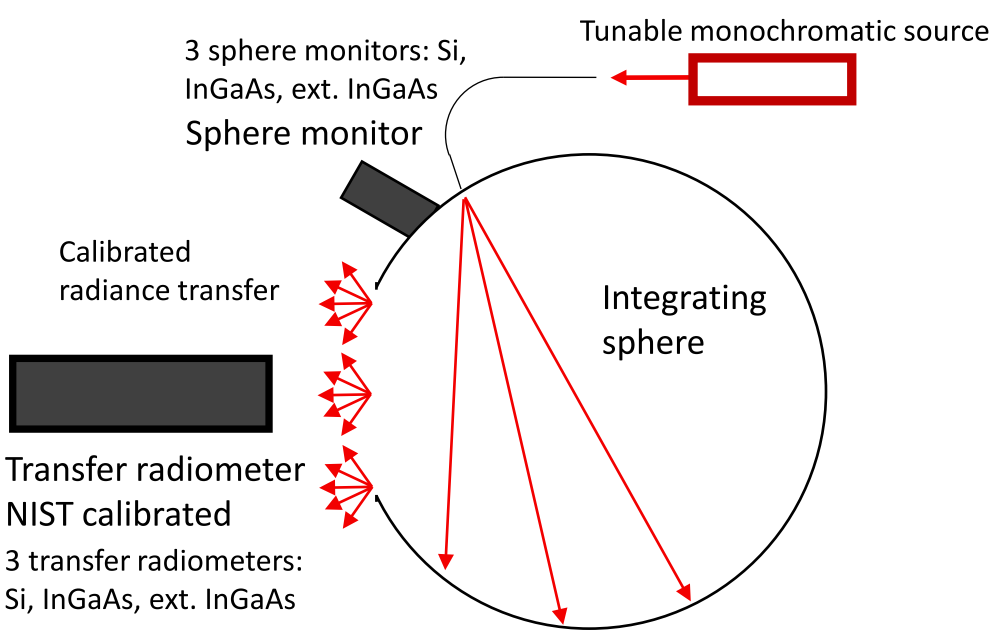
NIST transfer radiometer calibration based on electrical substitution radiometry traceable to fundamental physical units

Electrical substitution radiometer

Heat due to optical absorption balanced by reducing electrical resistance heat to maintain constant temperature: Optical power = change in electrical power



Sphere monitor calibration setup



Transfer radiometers calibrated at NIST at closely spaced wavelengths covering 310nm to 2500nm

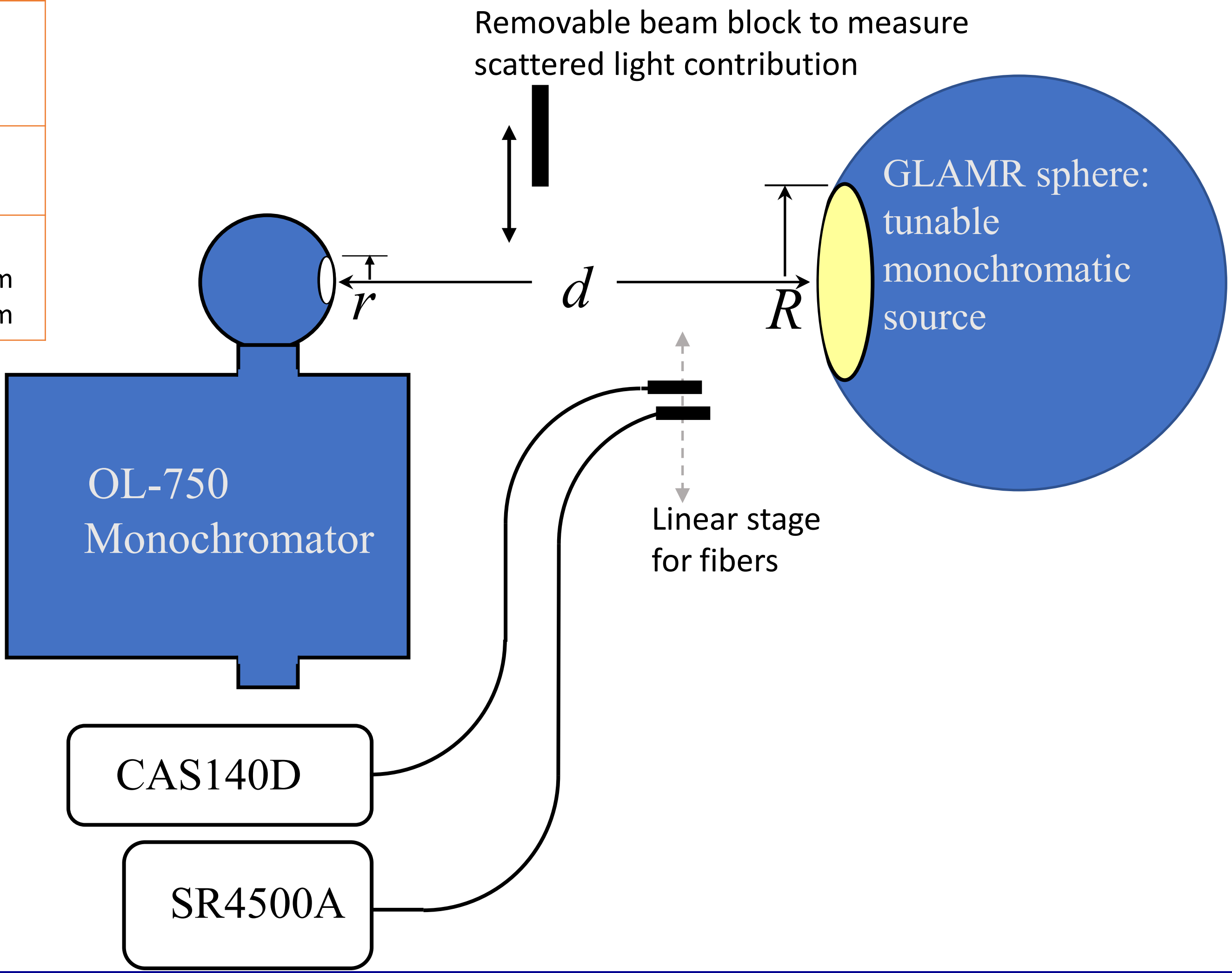
Calibration transferred to GLAMR integrating sphere monitors in 2nm to 5nm wavelength intervals

Radiance at output port proportional to sphere monitor signal

GLAMR

Spectrometer calibration

Spectrometer	Spectral resolution	Detector range
Optronic Labs OL-750 (with 2.5mm slits)	16nm for 300-1390nm 32nm for 1400-2400nm	Si : 300-1000nm PbS : 900-2400nm
Instrument Systems CAS140D	3.7nm	Si : 300-1100 nm
Spectral Evolution SR4500A	3nm at 700nm 8nm at 1500nm 6nm at 2100nm	Si : 350-1000nm Extended InGaAs : 1000-1900nm Extended InGaAs : 1900-2500nm



Spectrometer calibration

Measurement Plan

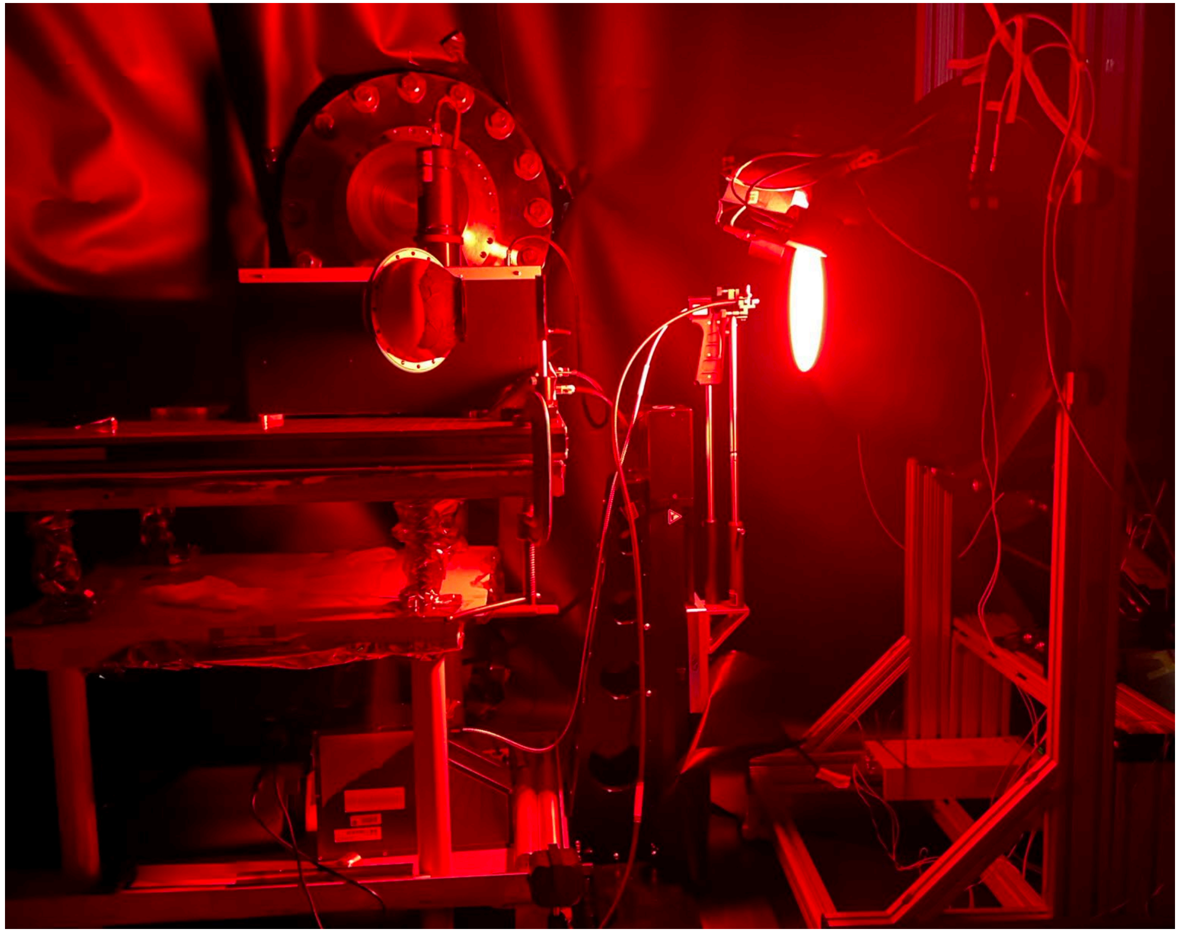
- high power for 340nm to 2500nm in 10 nm steps
- 0.2nm step regions to characterize instrument line shape
- Power step selected wavelengths to characterize linearity

Each spectrometers sees the same wavelength and radiance during measurement

Measurement sequence

1. Tune source to stable wavelength
2. Illuminate sphere
3. Acquire CAS140D and SR4500A data with fibers centered in sphere aperture
4. Translate stage to move fibers out of OL-750 view
5. Acquire data with OL-750
6. Close shutter, translate stage, and tune source to next wavelength

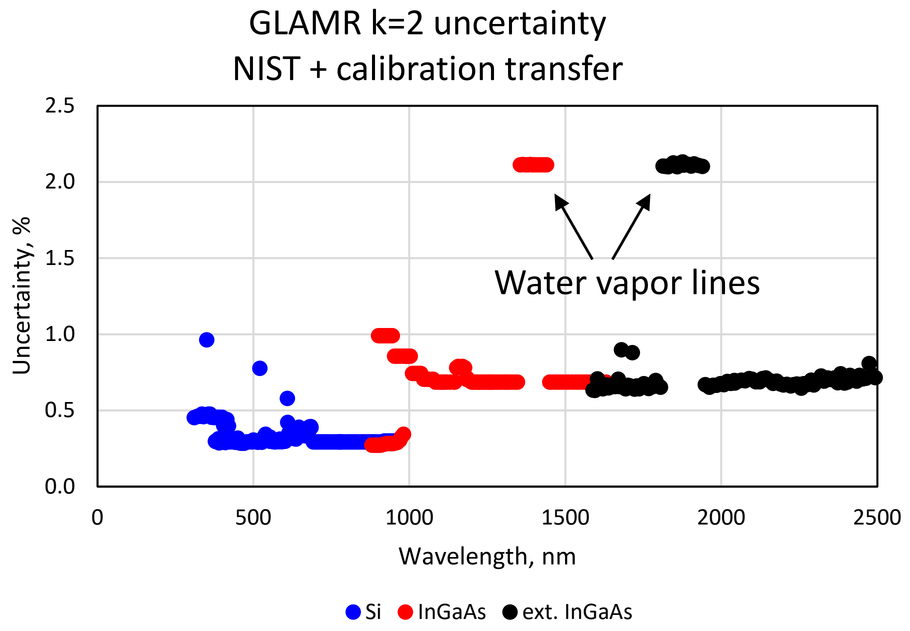
7. Dark and scattered light measurements taken periodically



Spectrometers and sphere during testing

Detector-based uncertainty

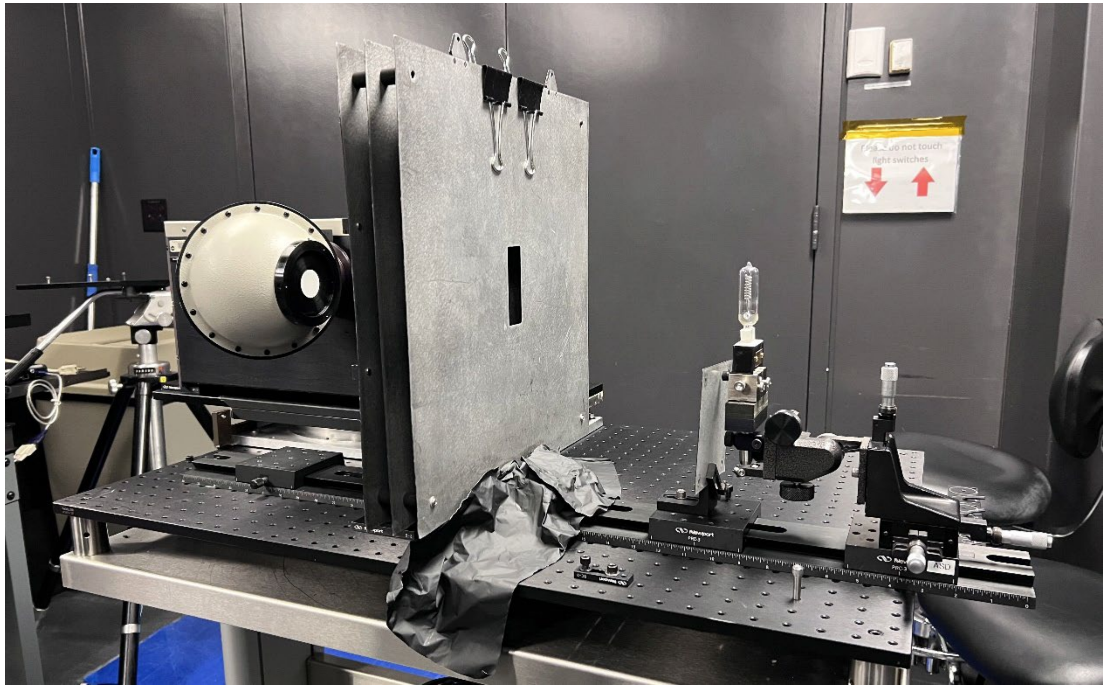
Uncertianty (k=2)	<1000nm	>1000nm
Combined uncertainty terms	**0.3%**	**0.7%**
Transfer radiometer absolute calibration	0.20%	0.6%
Sphere repeatability	0.08%	0.08%
Measurement noise	0.02%	0.02%
Uniformity of the sphere	0.20%	0.20%



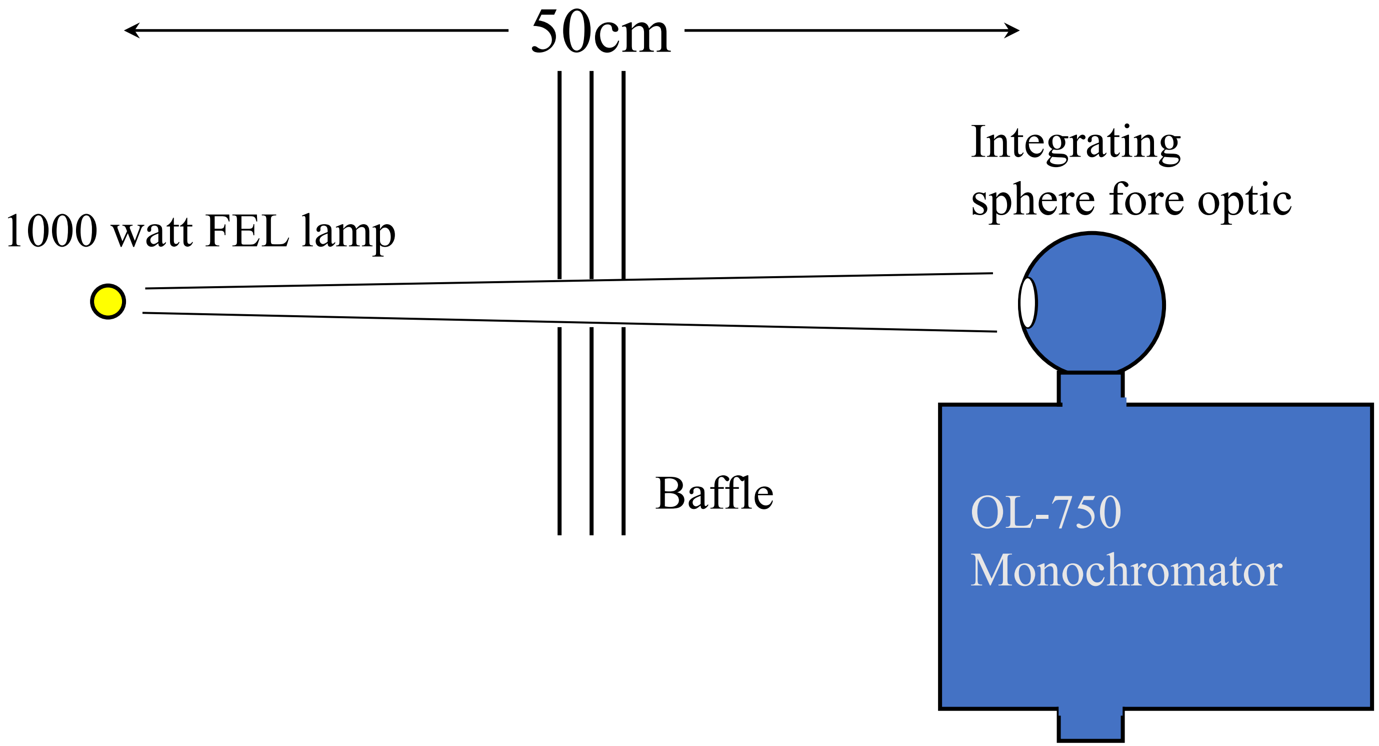
1. B. McAndrew, J. Barsi, A. Sushkov, and J. McCorkel, Radiometric uncertainty analysis of the GLAMR calibration facility, Calcon 2023.

Spectral irradiance calibration from NIST traceable lamp

E_{Lamp}: *spectral irradiance of lamp at 50 cm (from NIST)*
S_{Lamp}: *OL-750 signal at 50 cm*



OL-750 calibration setup with standard lamp



Conversion to spectral radiance

$$\text{Spectral Irradiance E} = \frac{\text{Optical power per unit wavelength}}{\text{Area}}$$

$$\text{Spectral Radiance L} = \frac{\text{Optical power per unit wavelength}}{\text{Area} * \text{Solid angle}}$$

View factor F: fraction of light emitted at sphere aperture that is received at monochromator aperture

view factor for concentric, parallel circular apertures:

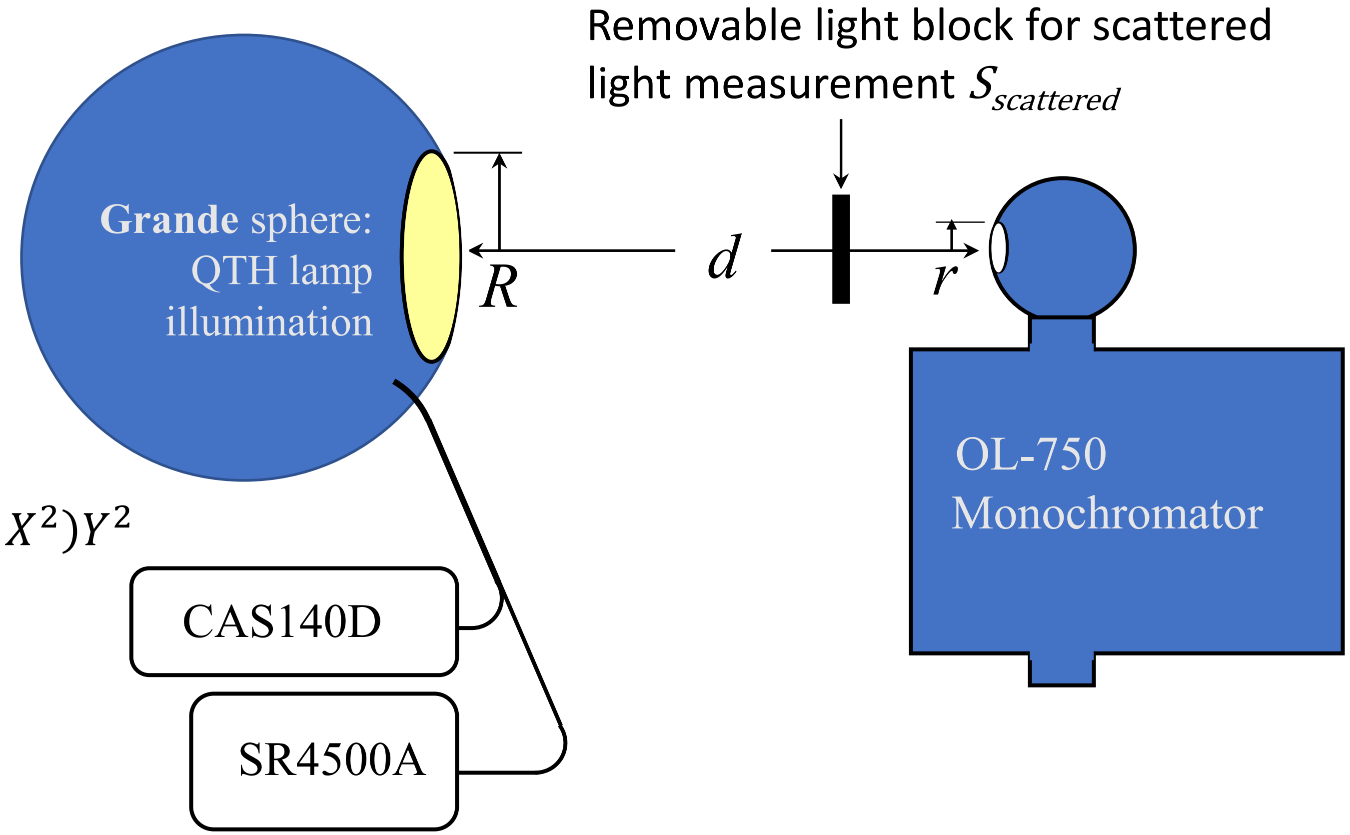
$$F = \frac{Z - \sqrt{Z^2 - 4X^2Y^2}}{2}, \text{ where } X = \frac{r}{d}, \ Y = \frac{d}{R}, \text{ and } Z = 1 + (1 + X^2)Y^2$$

calibration constant to convert to units of steradians:

$$K = \frac{1}{F\pi(R/r)^2}$$

sphere radiance:

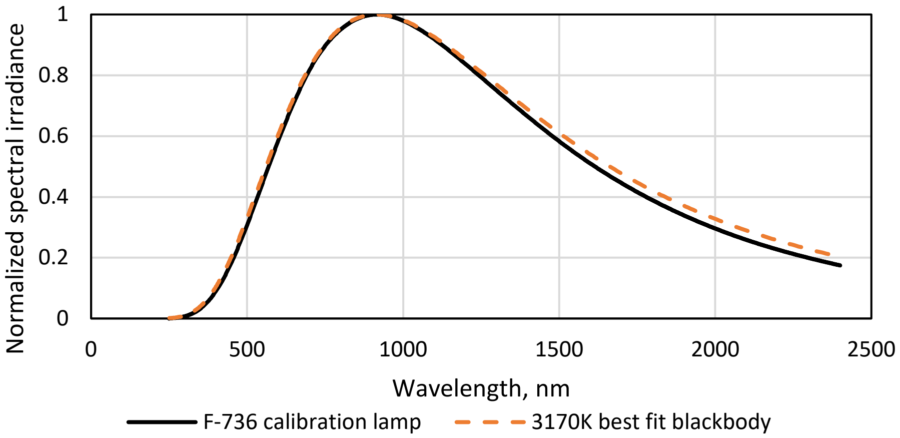
$$L_{sphere} = E_{sphere}K = E_{lamp}\left(\frac{S_{total} - S_{scattered}}{S_{lamp}}\right)K$$



Goddard radiometry lab values: R = 12.7 cm, r = 1.59 cm, d = 50cm
→ F = 0.000946, K = 5.257

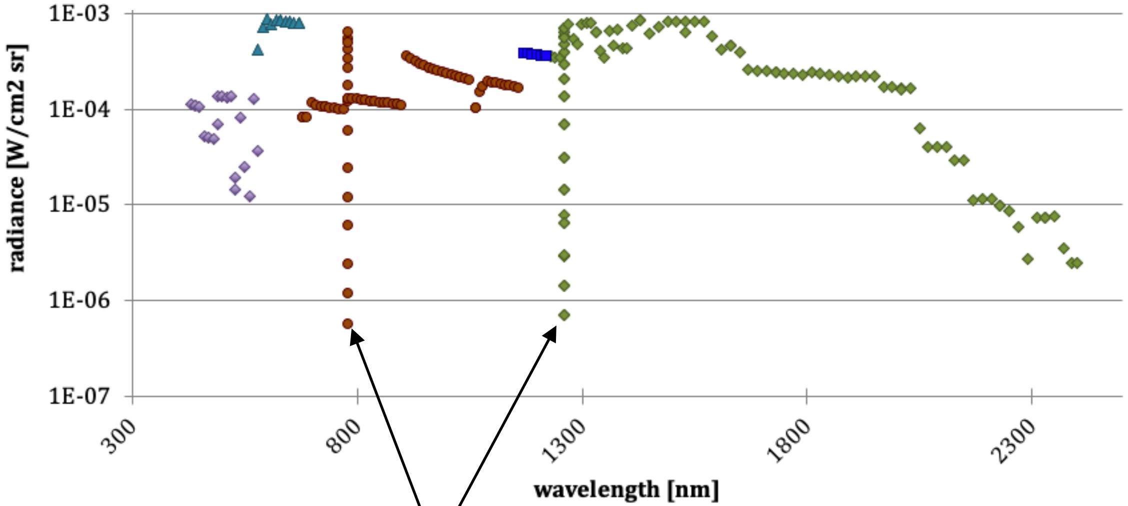
GLAMR Lamp and laser source spectra

F-736 calibration lamp spectrum



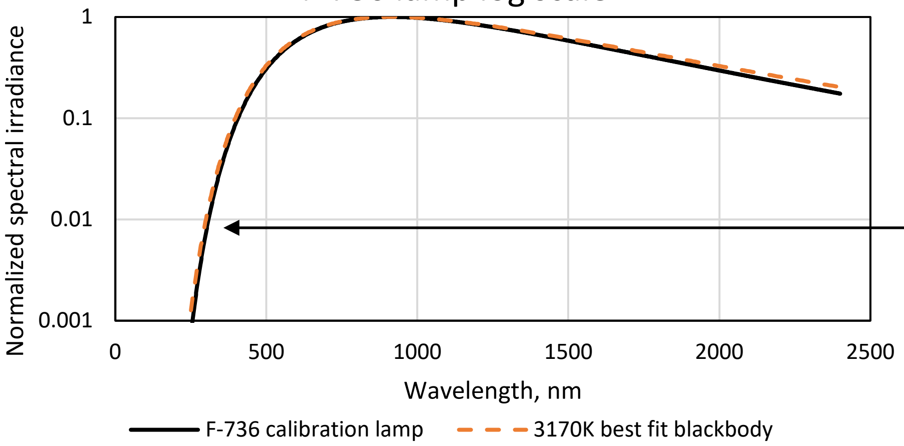
Lamp spectrum closely approximates 3170K blackbody profile

Monochromatic source wavelengths and radiances



Linearity measurements at 780nm and 1260nm to characterize Si and PbS detectors

F-736 lamp log scale

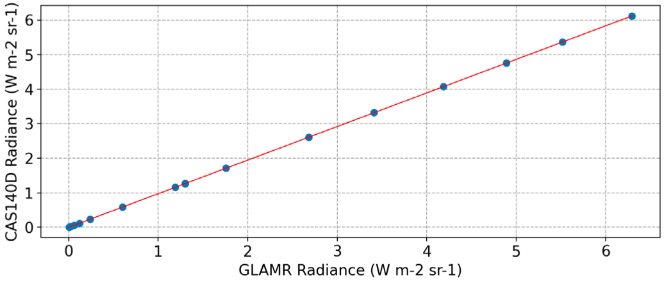


Below 300nm irradiance < 1% of peak

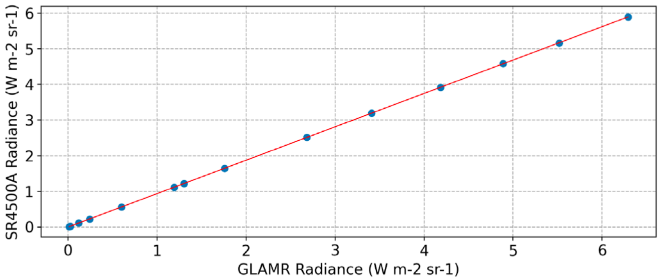
Both linearity and internal stray light become important at short wavelengths

Linearity check

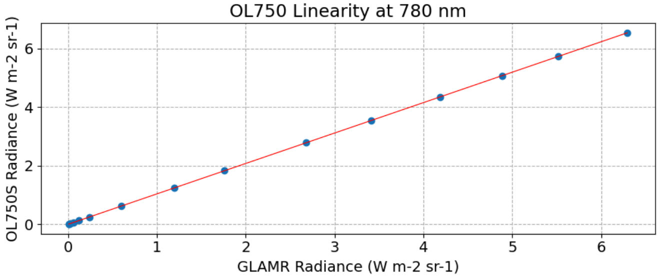
CAS140D Linearity at 780 nm, <0.2% nonlinearity



SR4500 Linearity at 780 nm, <0.2% nonlinearity

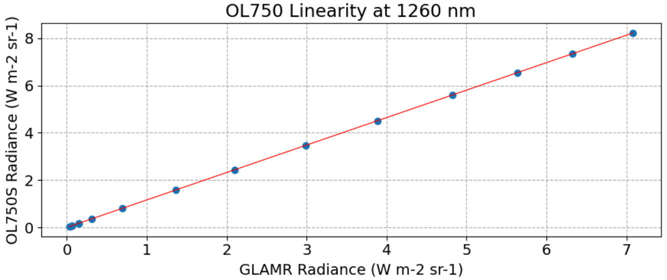


OL750 Linearity at 780 nm, <0.03% nonlinearity



Very good linear performance by all three spectrometers

OL750 Linearity at 1260 nm, <0.05% nonlinearity



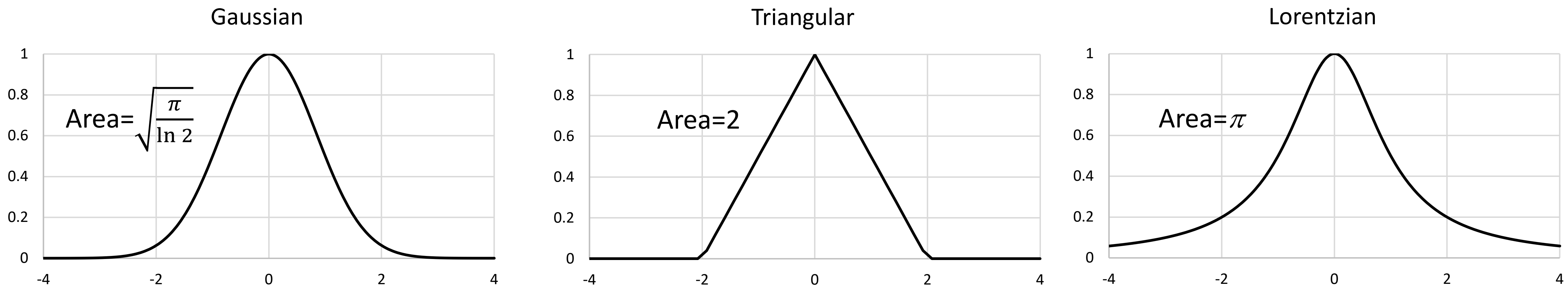
Instrument line shape

Converting between radiance and spectral radiance requires knowledge of instrument line shape

Radiance = $\frac{power}{area{*}solid\ angle}$

Spectral radiance = $\frac{power/spectral\ interval}{area{*}solid\ angle}$

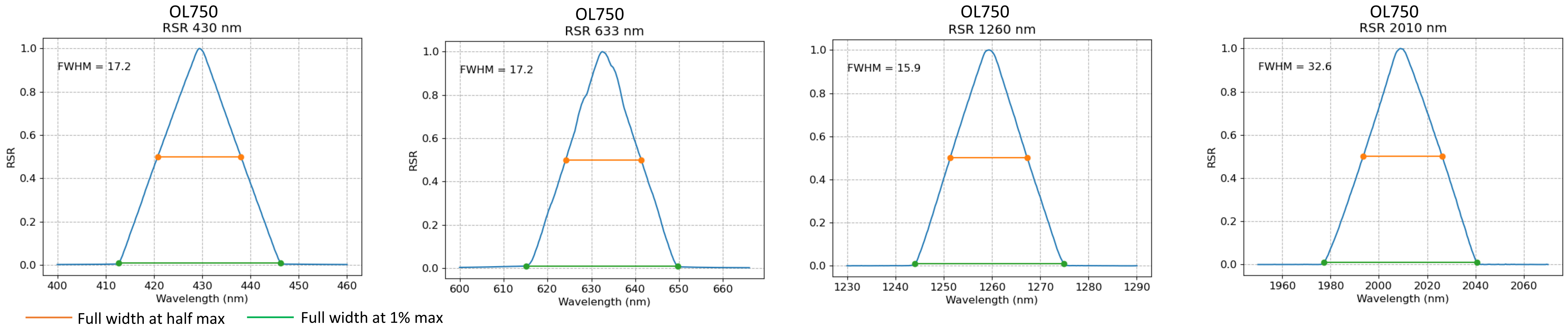
Relevant *spectral interval* is the width of a square wave with same amplitude and area as the instrument line shape

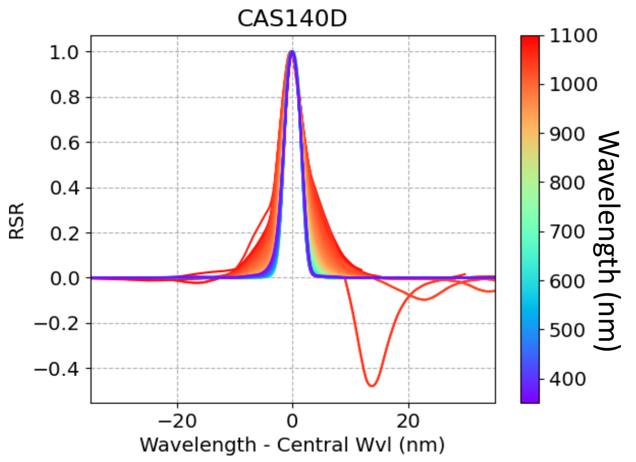


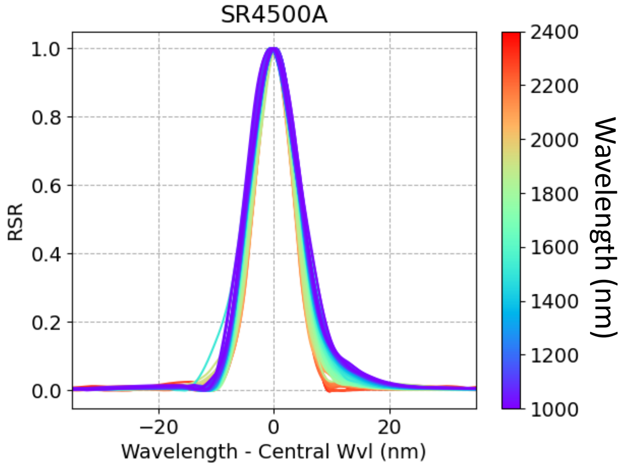
Three example line shapes with same amplitude and FWHM but different areas

Measured instrument line shapes

Line shape measured in 0.2 nm steps at several selected wavelengths





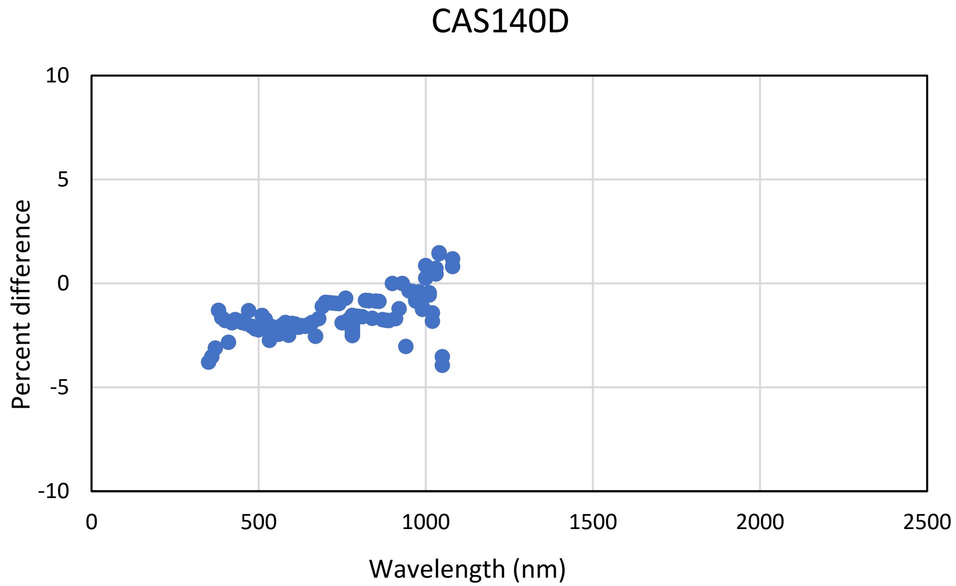


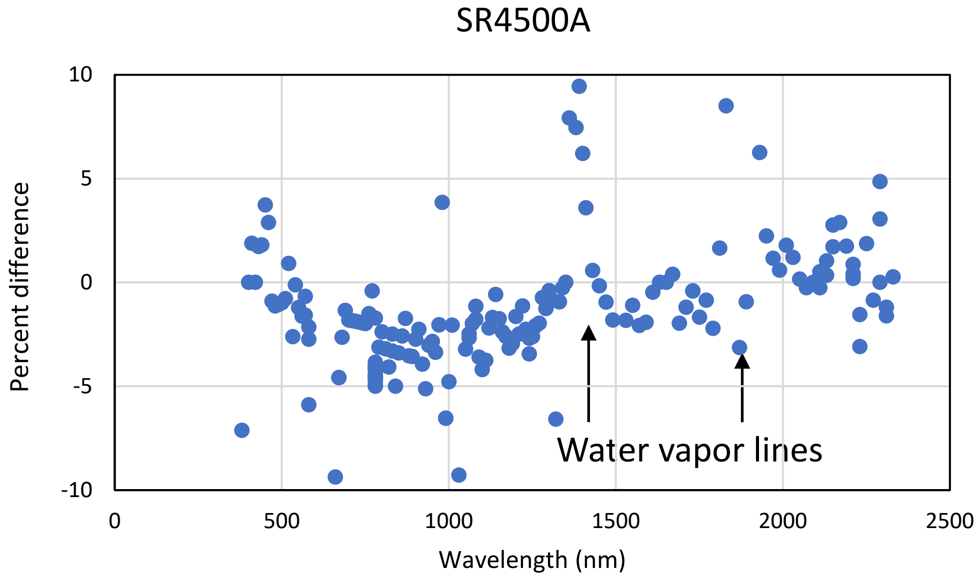
OL-750 has triangular line shape: width varies with grating configuration

CAS140D and SR4500A have gaussian line shapes

CAS140D and SR4500A calibration results

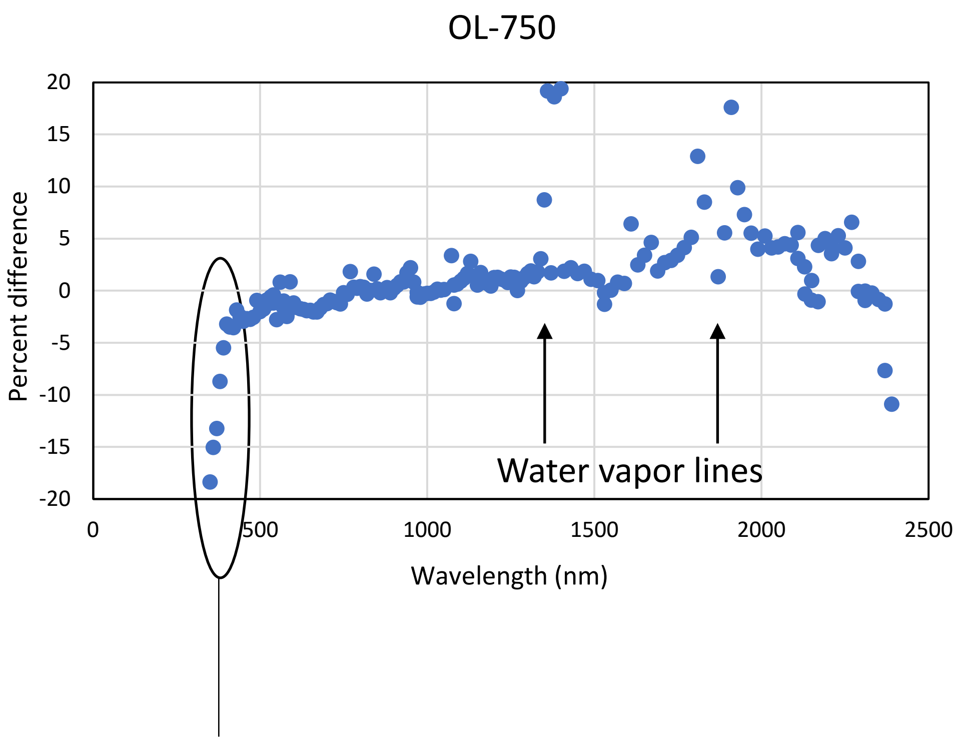
CAS140D and SR4500A calibration comparison between Grande sphere and GLAMR sphere





- Slight positive slope with wavelength, 2% per micron
- Good agreement between spectrometers in overlapping spectral range

OL-750 calibration results



OL-750 calibration comparison between FEL lamp and GLAMR sphere

OL-750 also used to calibrate Grande sphere

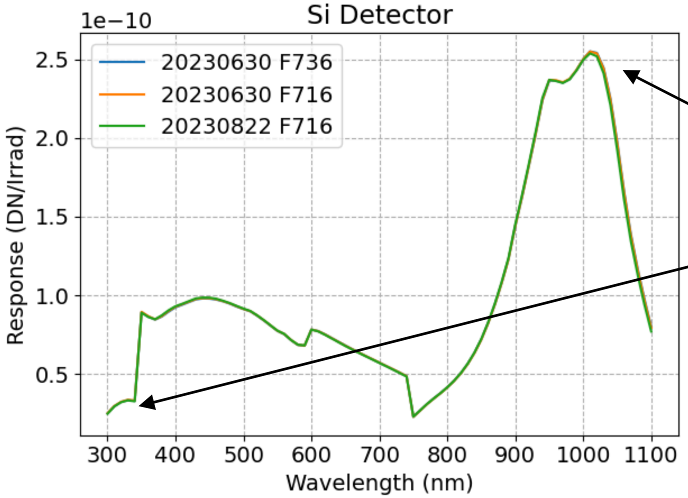
1.5% over 400 - 1500 nm

Slight positive slope with wavelength, 3% per micron

Instrument artifact, stray light internal to instrument

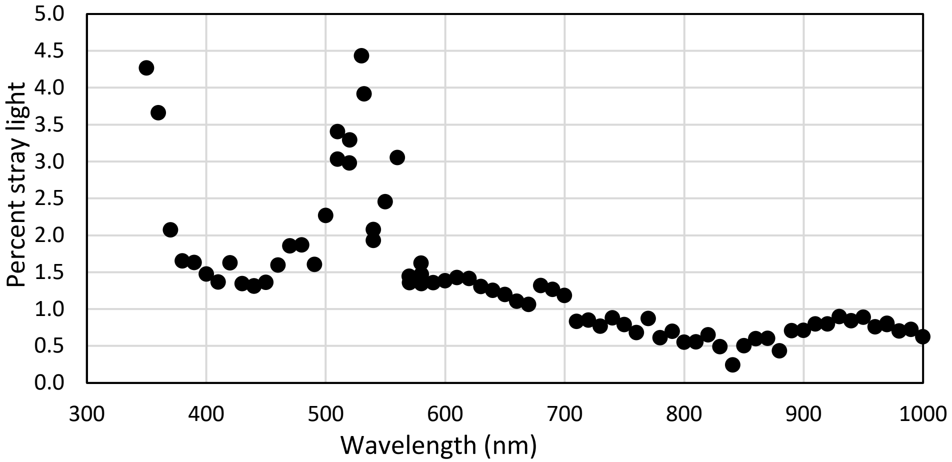
Note for Grande sphere calibration with same lamp spectrum as FEL calibration lamp, stray light error cancels but for other illumination spectra it would not. Most apparent with monochromatic light.

OL-750 RSR, stray light, and wavelength

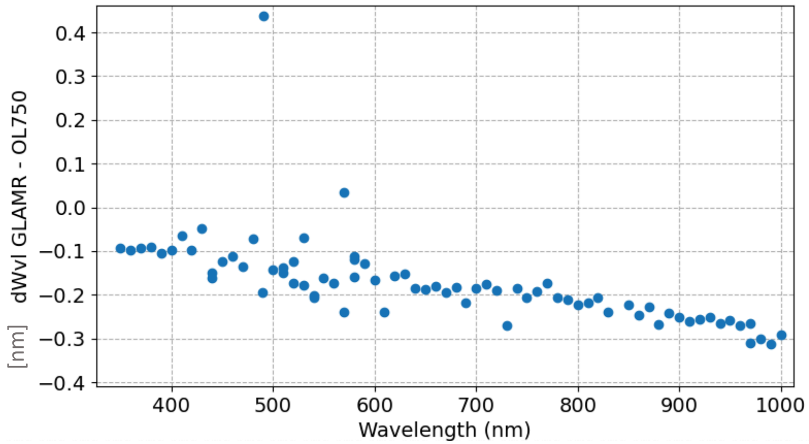


Large drop in responsivity in UV range compounds stray light contribution: OL-750 most sensitive where lamp is brightest, least sensitive where lamp is dimmest

Si detector stray light, %
(Percent total light outside 1% response points)



OL-750 wavelength calibration

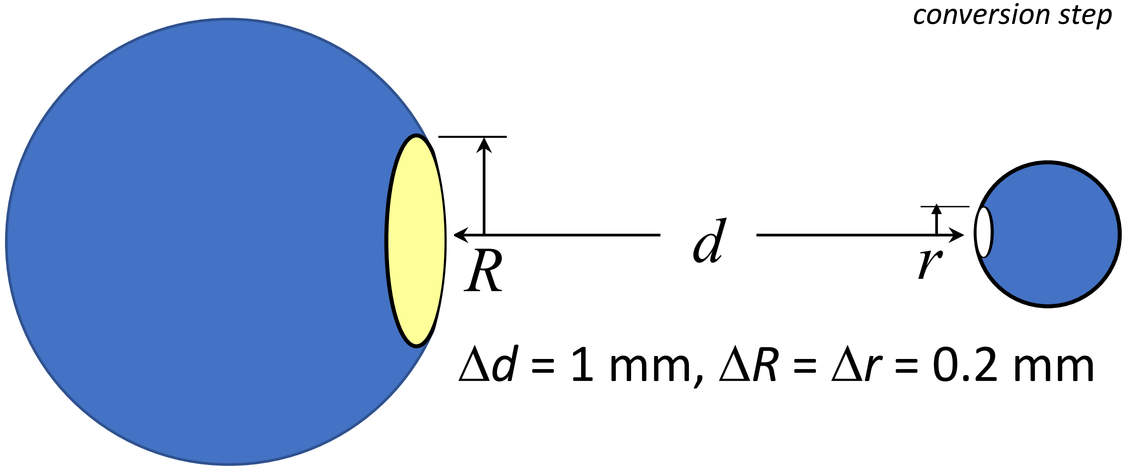


Slight drift in wavelength calibration
Possibly a 0.5% contribution to radiance.

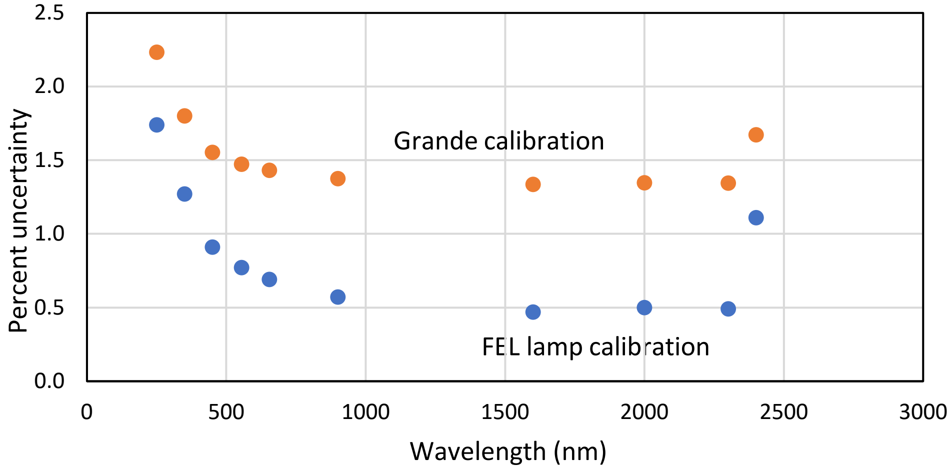
Grande Source-based uncertainty

Uncertainty Terms	
OL-750 Detector Noise u_{750s}	0.1%
FEL Lamp Power Supply Current u_{PS}	0.02%
Wavelength Accuracy $u_{Wl}(\lambda)$	0.17% @ 400nm
NIST FEL $u_{FEL}(\lambda)$	0.5% 900nm-2300nm
ViewFactor u_{VF}	1%
FEL Lamp Distance/Orientation u_{LDO}	0.8%

Dominant error is distance measurement between sphere apertures in radiance to irradiance conversion step

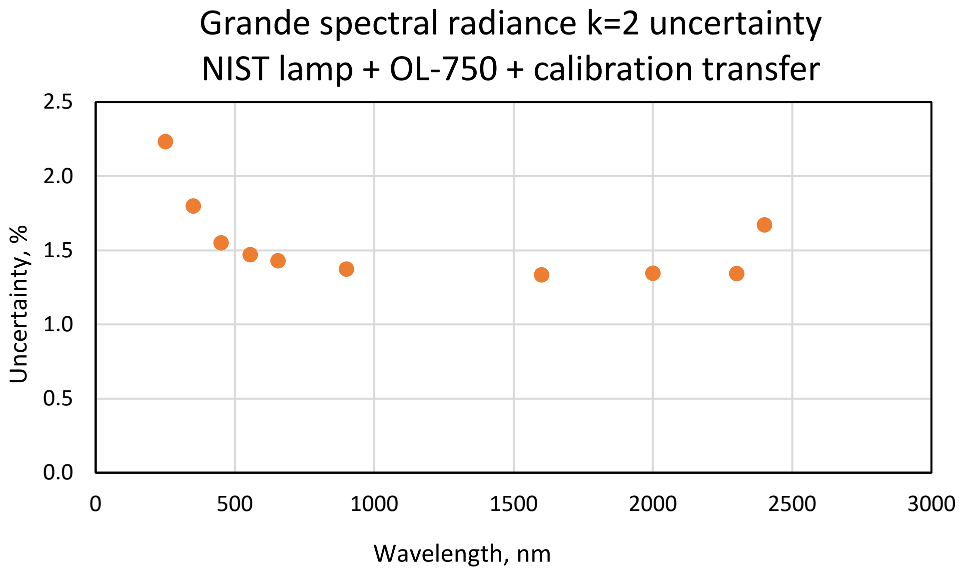


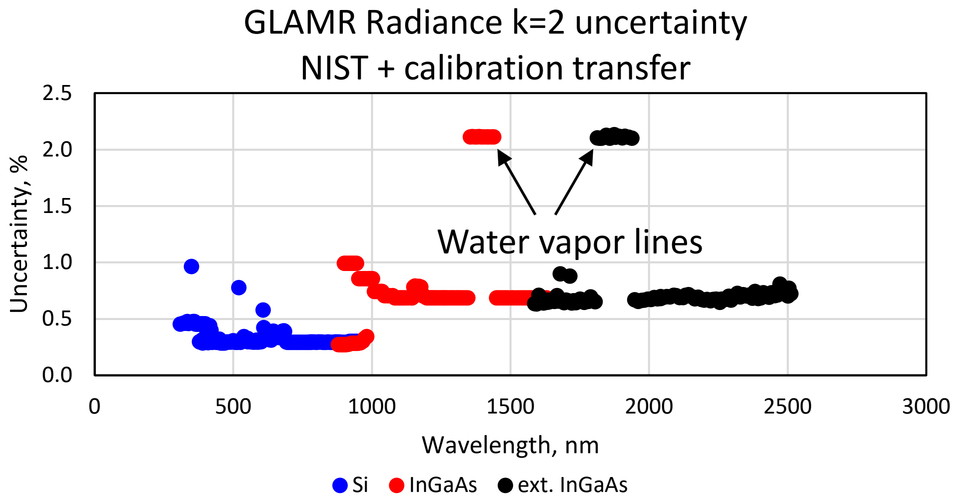
Grande spectral radiance k=2 uncertainty
Δd=1mm,ΔR=Δr=0.2mm



GLAMR Conclusions

- Radiance to irradiance conversion adds largest source of uncertainty to the lamp based calibration
  - Grande uncertainty budget has been revised to account for the reconsidered uncertainty terms
- Observed 1.5% difference between detector and source based calibrations with the OL-750 measurements
- GLAMR and Grande calibration results agree to within the combined uncertainties

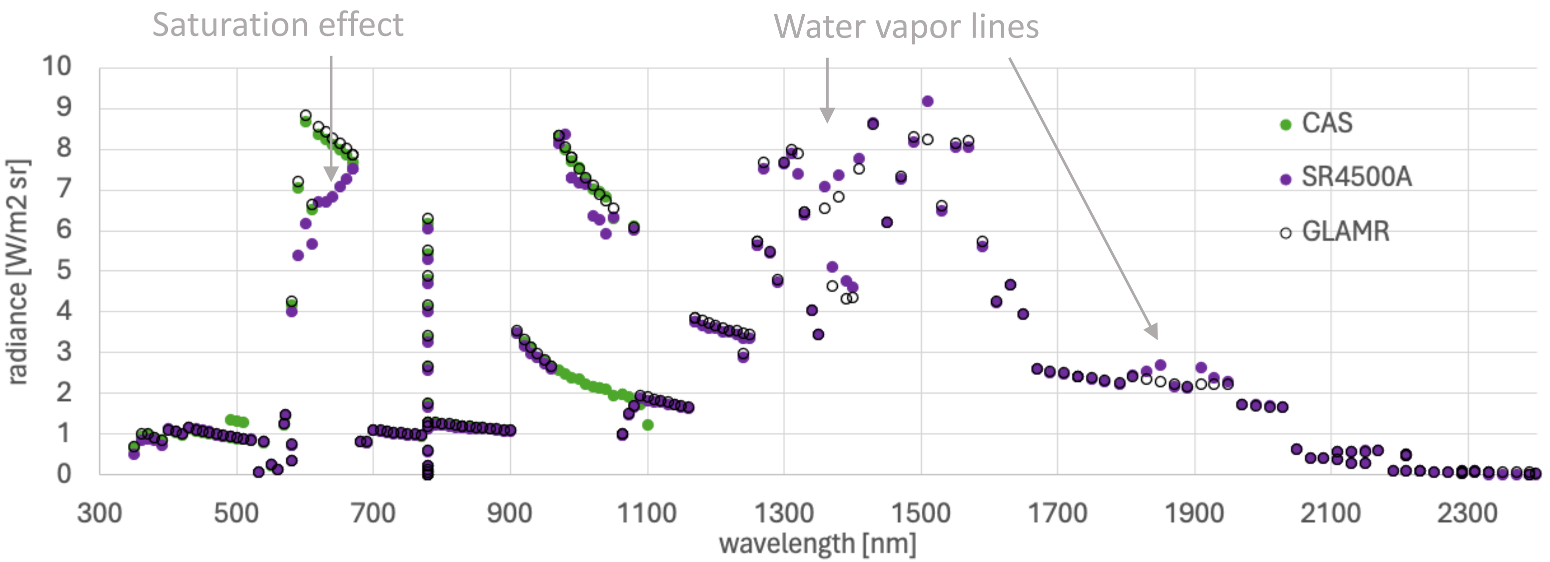




GLAMR backup

CAS140D and SR4500A radiances

Radiances CAS140D and SR4500A as calculated from the Grande calibration and the GLAMR radiances



Ratio of Grande-based radiance to GLAMR-based radiance

- CAS140D: generally agrees to within 2%
- SR4500A: noisier instrument, with general agreement within 2%
- Good agreement between spectrometers in overlapping spectral range