Comparison of detector based and source based absolute radiance standards

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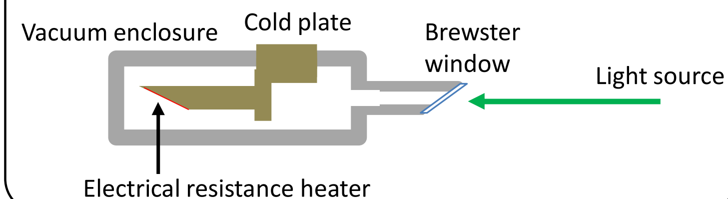
Detector based radiance calibration with tunable monochromatic light

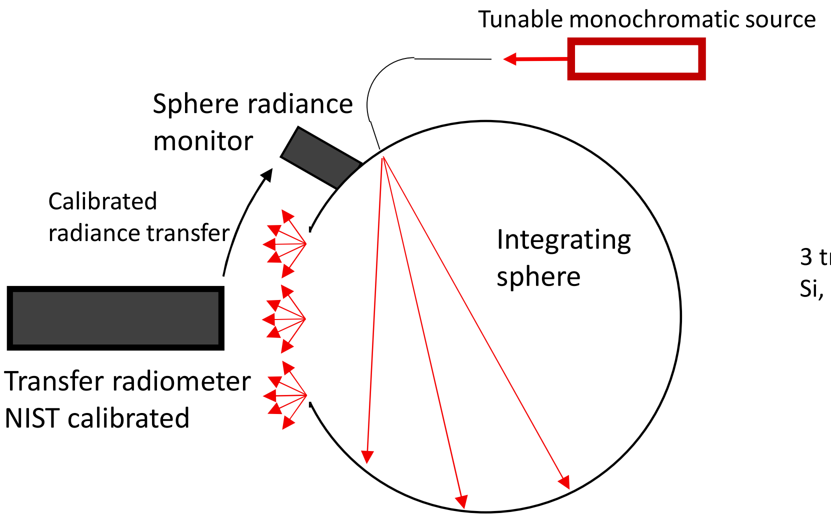
Transfer radiometers calibrated at NIST at closely spaced wavelengths covering 310nm to 2500nm

Calibration transferred to integrating sphere radiance monitors in 2nm to 5nm wavelength intervals
Radiance at output port proportional to sphere monitor signal

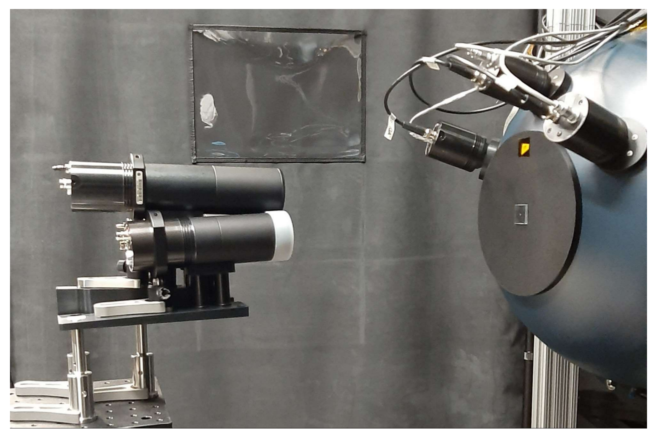
NIST transfer radiometer calibration based on electrical substitution radiometry traceable to fundamental physical units

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





3 transfer radiometers: Si, InGaAs, ext. InGaAs

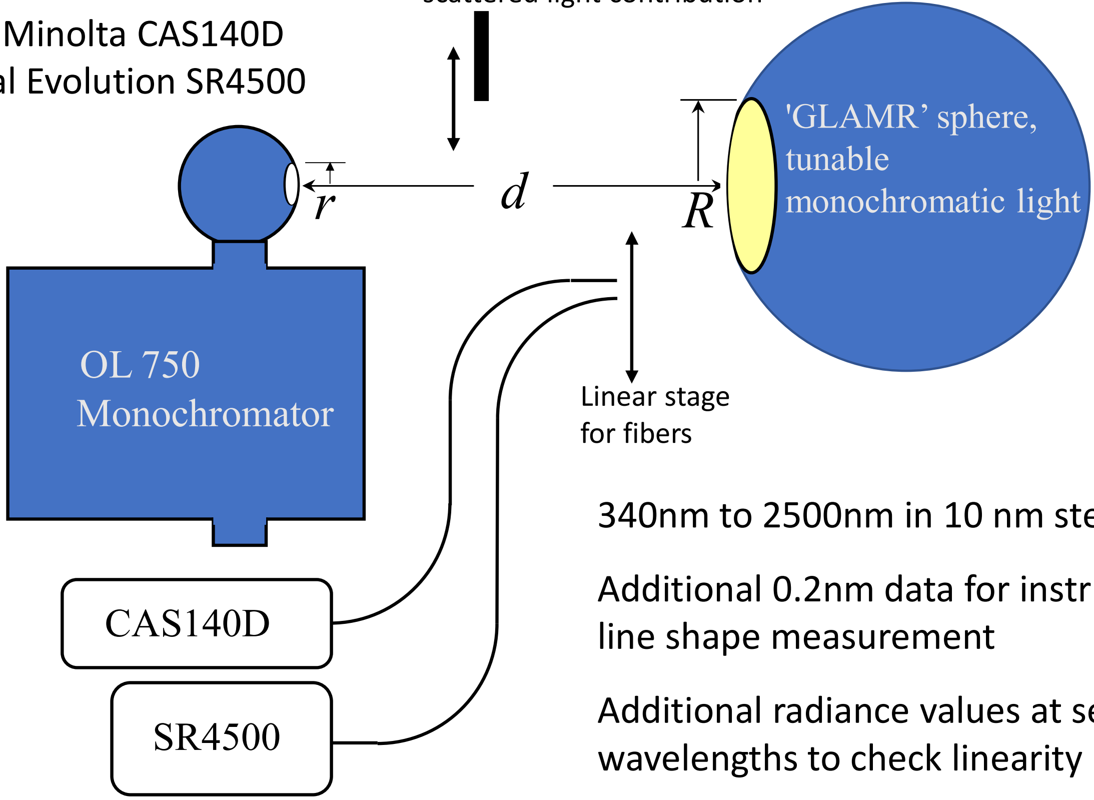


3 sphere monitors: Si, InGaAs, ext. InGaAs

Sphere monitor calibration setup

GLAMR Spectrometer calibration setup

Three spectrometers:
Optronic Laboratories OL 750
Konica Minolta CAS140D
Spectral Evolution SR4500



340nm to 2500nm in 10 nm steps

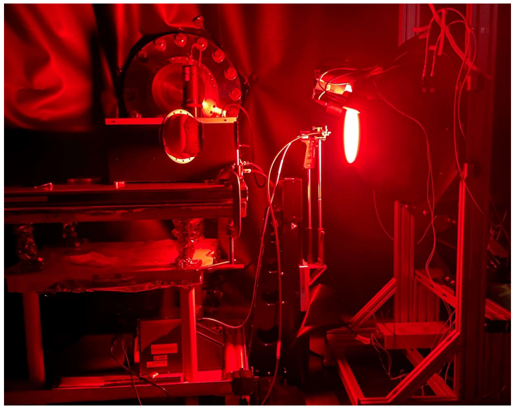
Additional 0.2nm data for instrument line shape measurement

Additional radiance values at selected wavelengths to check linearity

Same wavelength and radiance for all spectrometers during measurement

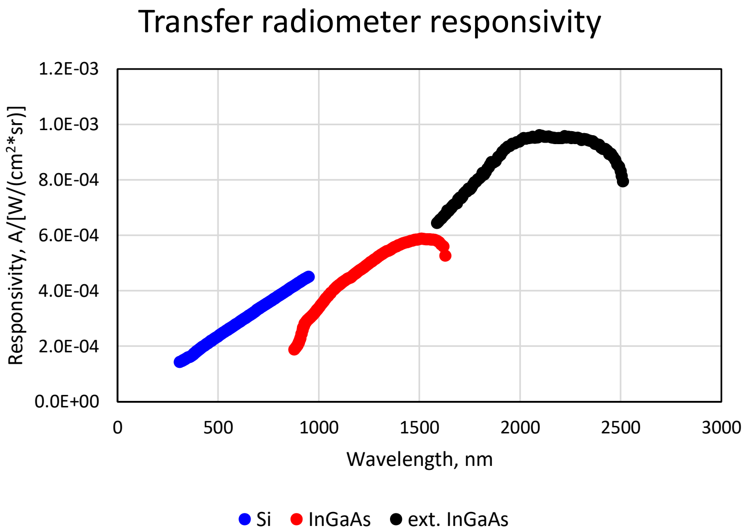
Measurement sequence

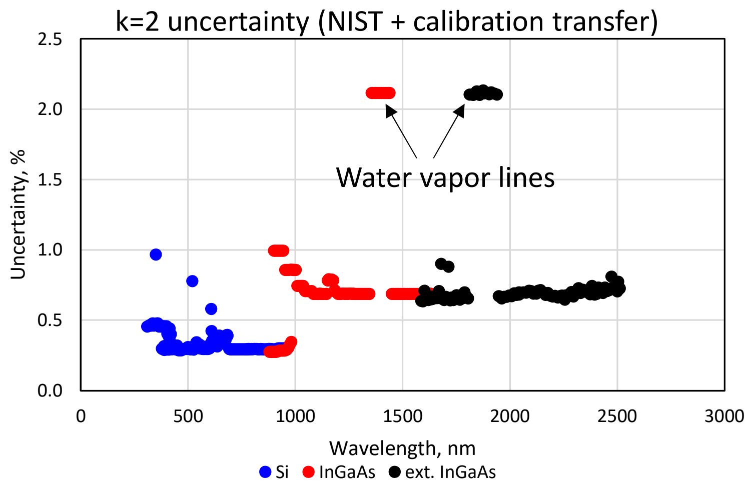
1. Tune source to stable wavelength
2. Illuminate sphere
3. Acquire CAS140 and SR4500 data with fibers centered in sphere aperture
4. Translate stage to move fibers out of OL750 view
5. Acquire data with OL 750
6. Close shutter, translate stage, and tune source to next wavelength
7. Dark and scattered light measurements taken periodically



Spectrometers and sphere during testing

Detector based uncertainty





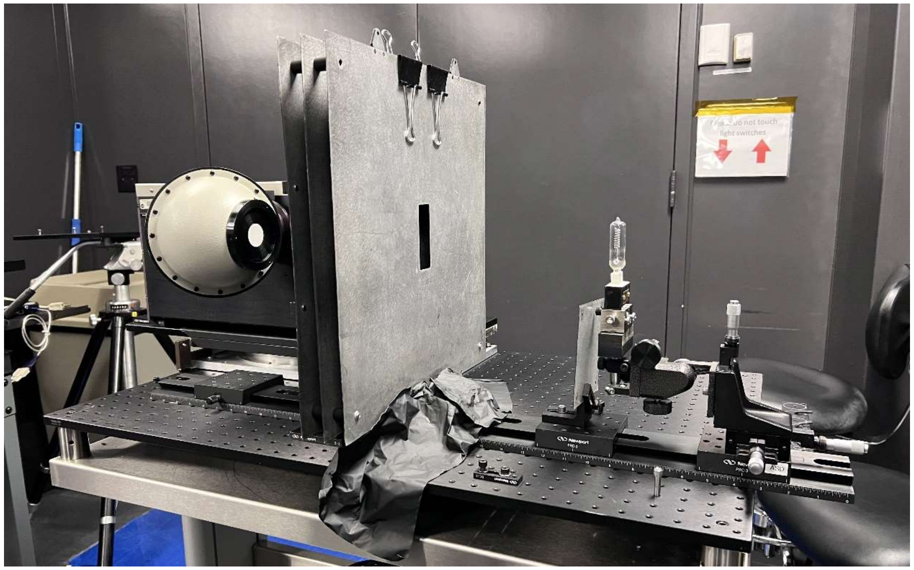
Uncertainty terms[1]
Absolute calibration
Sphere repeatability
Sphere uniformity
Measurement noise

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

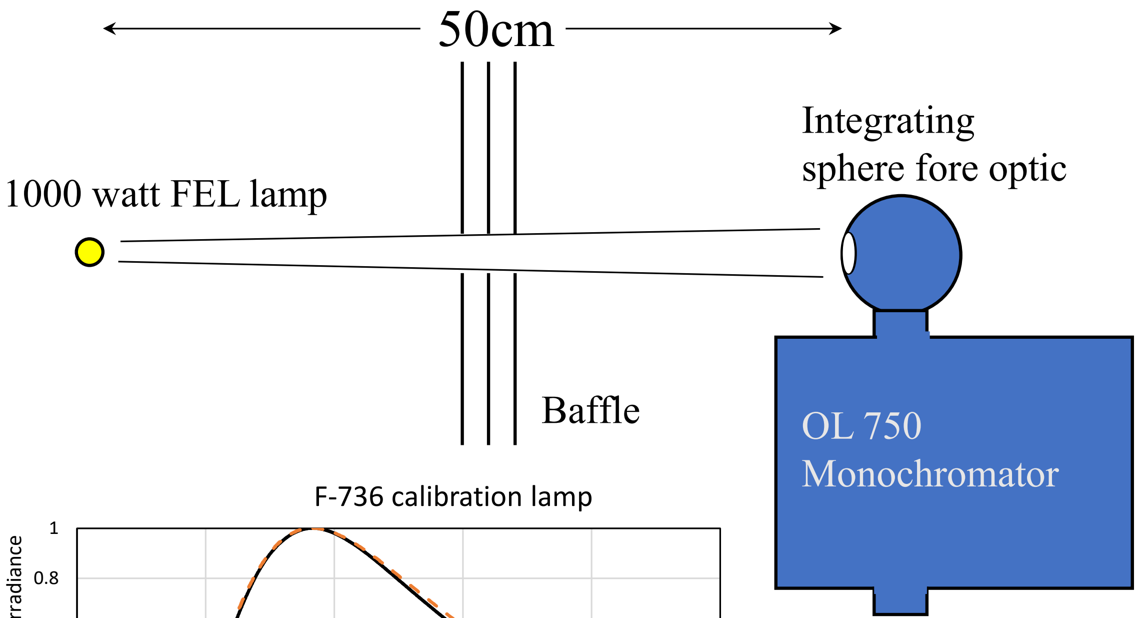
Calibration based on radiometer absolute responsivity measured at NIST using tunable monochromatic illumination

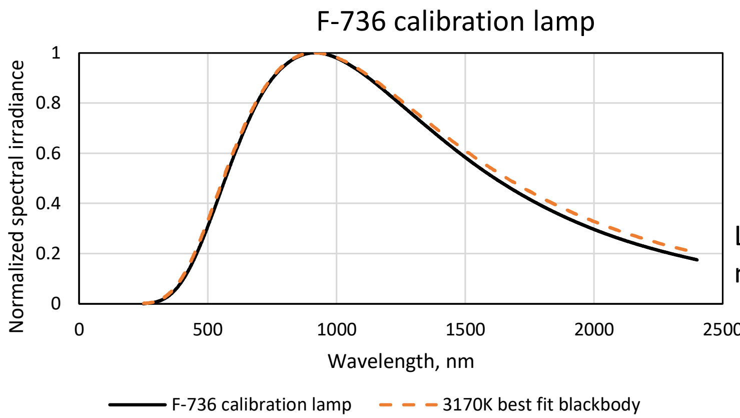
Spectral irradiance calibration from NIST traceable lamp

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
NIST supplied spectral irradiance at 50 cm





Lamp spectrum close match to 3170K blackbody

GLAMR 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:

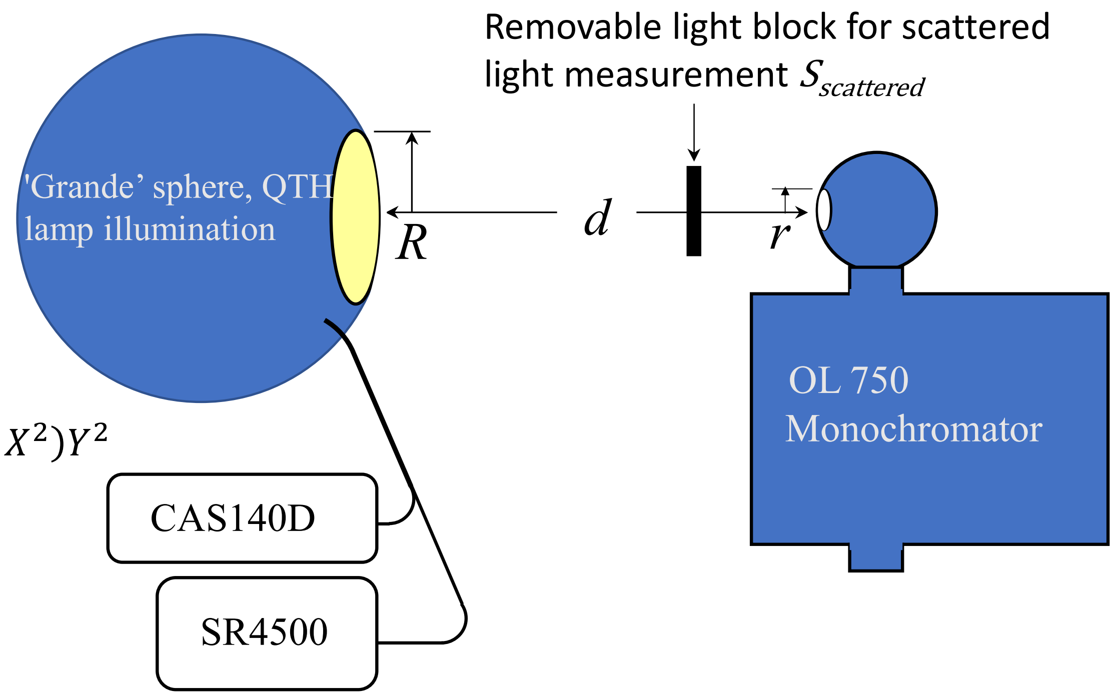
$$F = \frac{Z - \sqrt{Z^2 - 4X^2Y^2}}{2}, \text{ where } X = \frac{r}{d}, \ Y = \frac{d}{R}, \text{ and } Z = 1 + (1 + X^2)Y^2$$

calibration constant to convert to units of steradians:

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

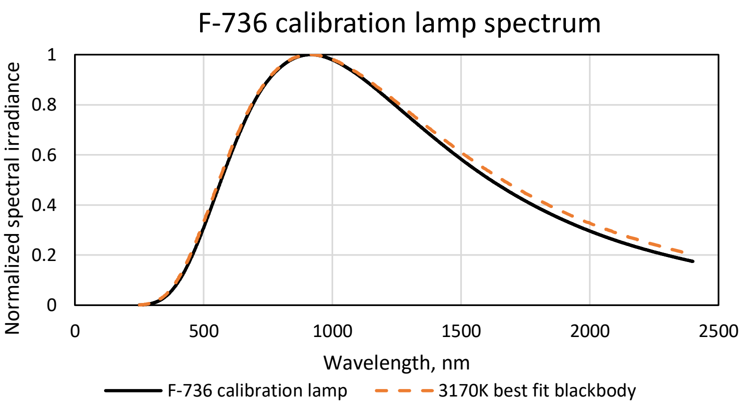
sphere radiance:

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

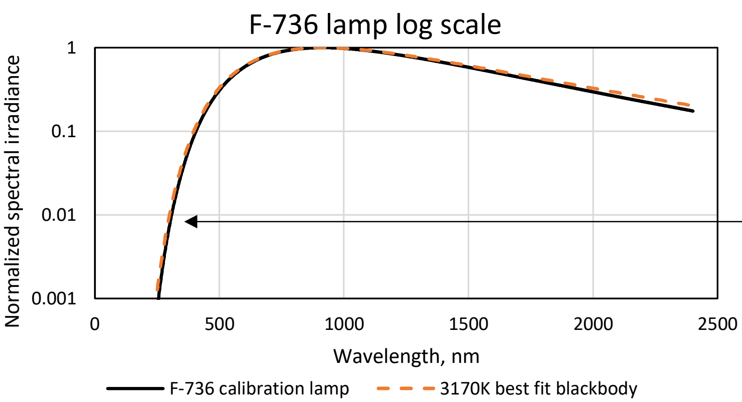


Goddard radiometry lab values: R = 12.7 cm, r = 1.59 cm, d = 50cm
→ F = 0.000946, K = 5.257

Lamp and tunable source spectra

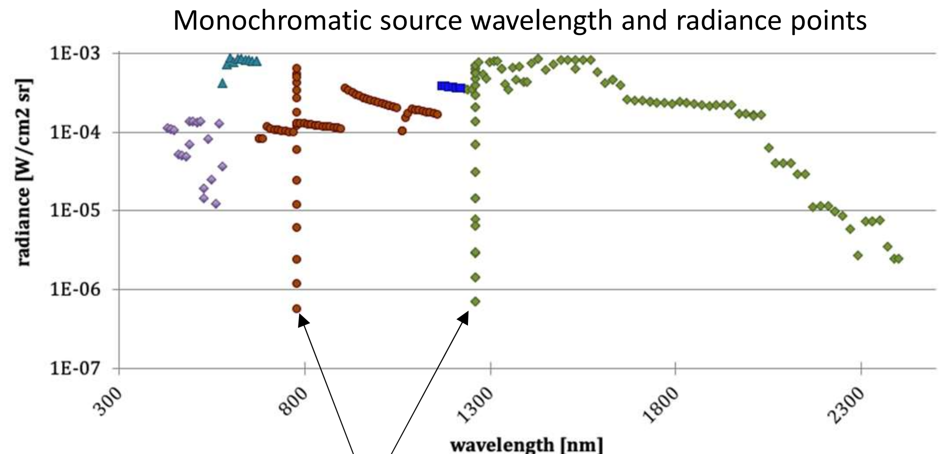


Lamp spectrum closely approximates 3170K blackbody profile



Below 300nm irradiance < 1% of peak

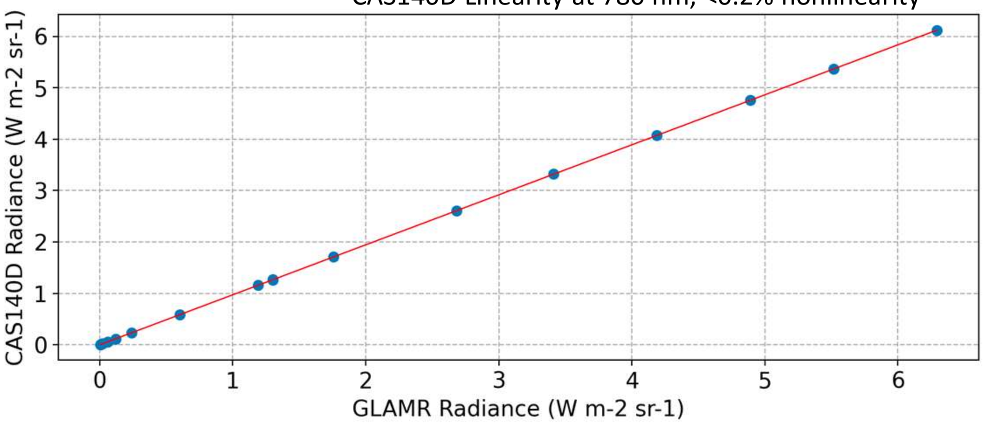
Both linearity and internal stray light become important at short wavelengths



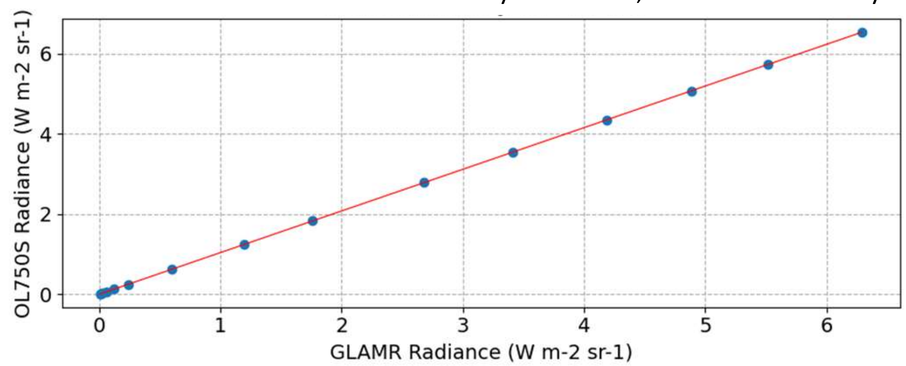
Linearity measurements at 780 nm & 1260 nm to characterize Si and PbS detectors

Linearity check

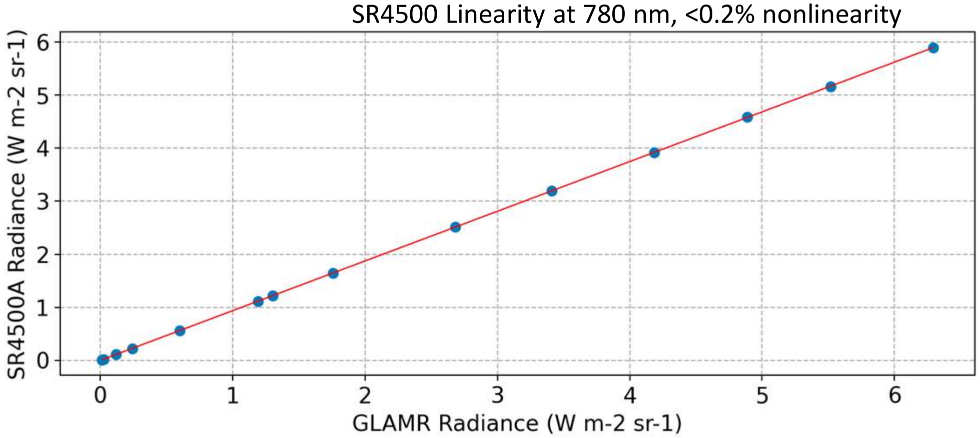
CAS140D Linearity at 780 nm, <0.2% nonlinearity



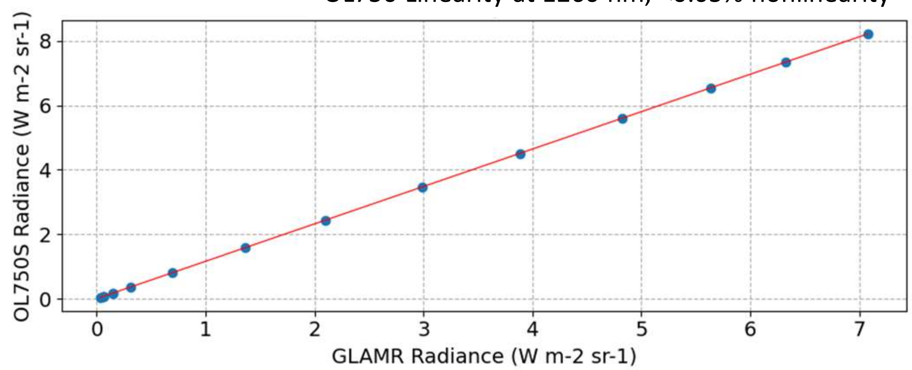
OL750 Linearity at 780 nm, <0.03% nonlinearity



SR4500 Linearity at 780 nm, <0.2% nonlinearity



OL750 Linearity at 1260 nm, <0.05% nonlinearity



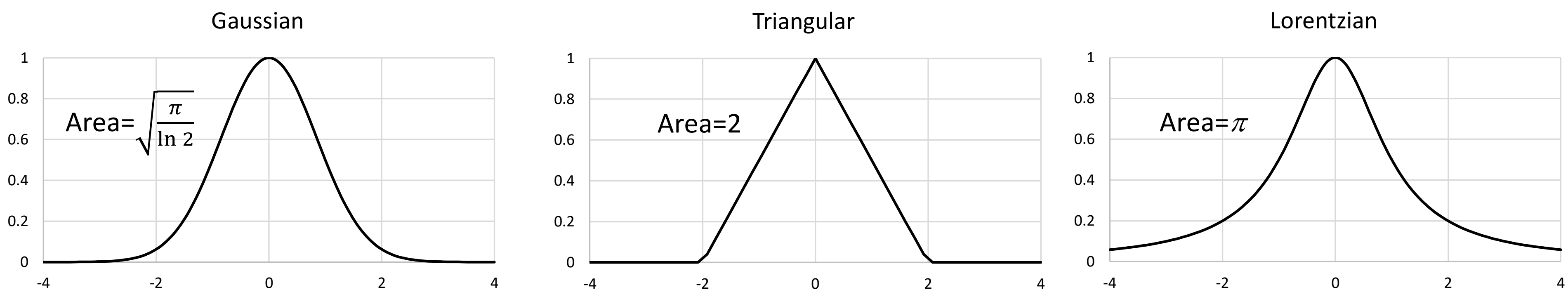
Instrument line shape

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

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

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

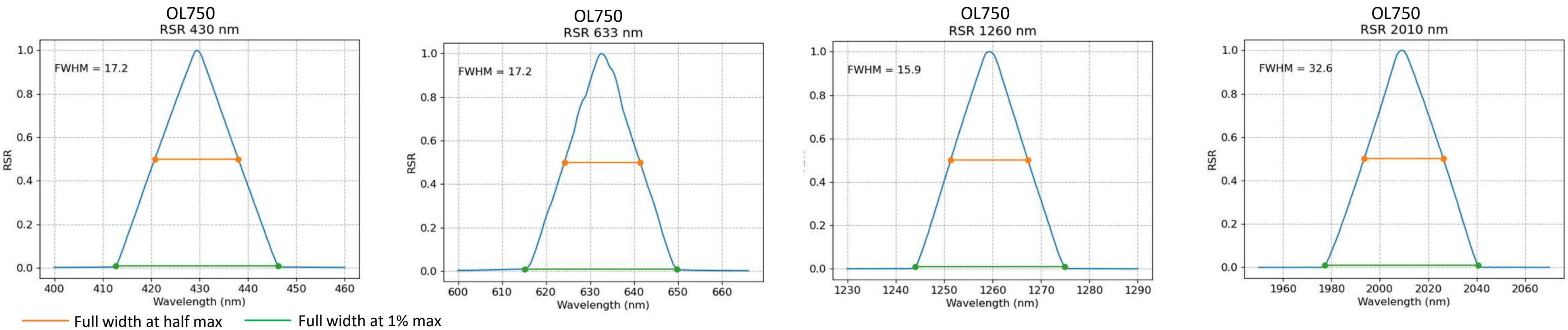
Relevant *spectral interval* is the width of a square wave with same amplitude and area as the instrument line shape

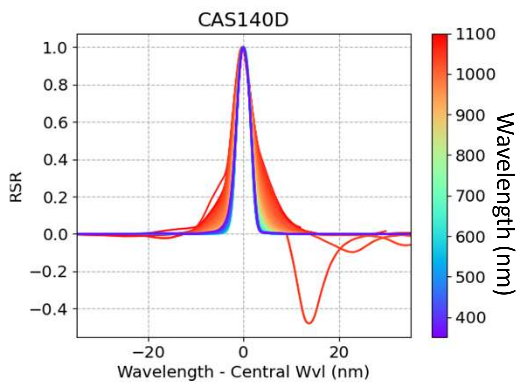


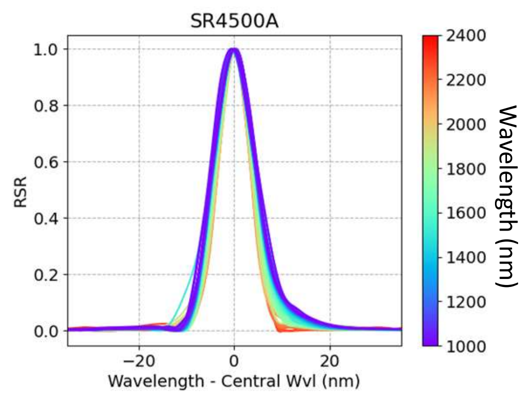
Three example line shapes with same amplitude and FWHM but different areas

Measured instrument line shapes

Line shape measured in 0.2 nm steps at several selected wavelengths





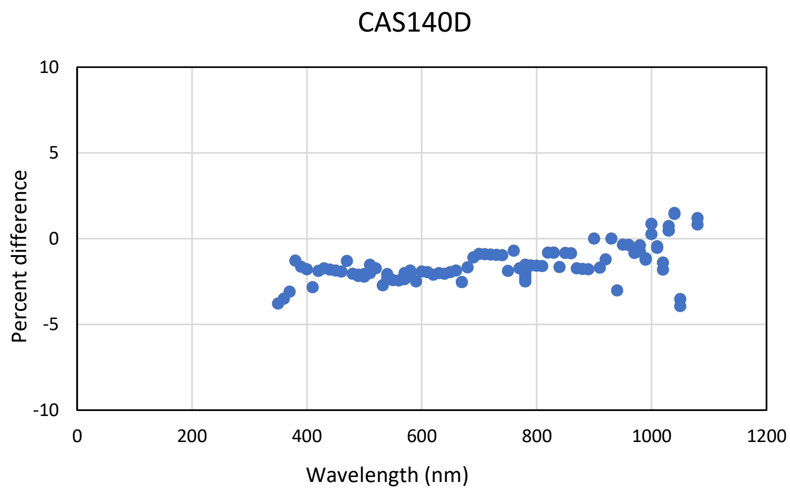


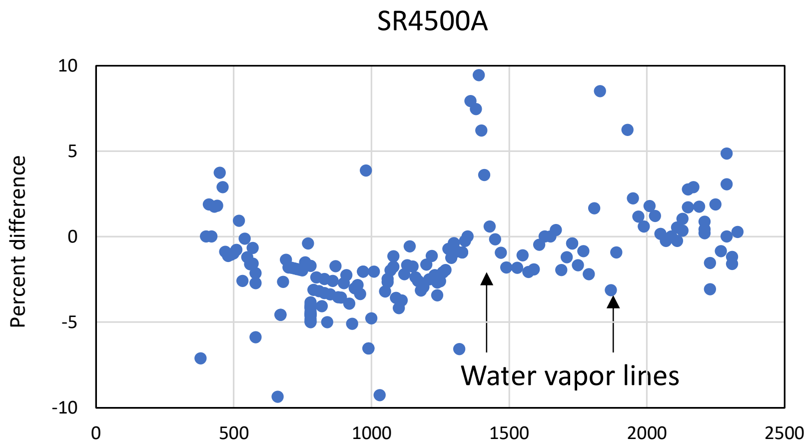
OL750 triangular line shape, width varies with grating configuration

CAS140D and SR4500A gaussian line shapes

CAS140D and SR4500A calibration results

CAS140D and SR4500A calibration comparison
between Grande sphere and GLAMR sphere



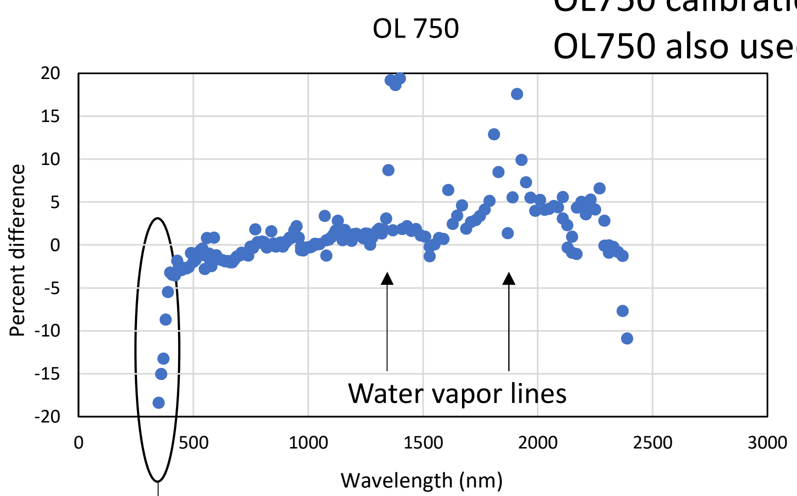


- Slight positive slope with wavelength, 2% per micron
- Good agreement between spectrometers in overlapping spectral range

GLAMR

OL750 calibration

OL750 calibration comparison between FEL lamp and GLAMR sphere
OL750 also used to calibrate Grande sphere



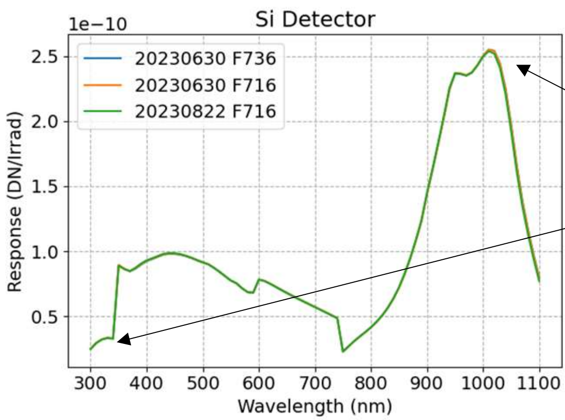
σ = 1.5% over 400 - 1300 nm

Slight positive slope with wavelength, 3% per micron

Instrument artifact, stray light internal to instrument

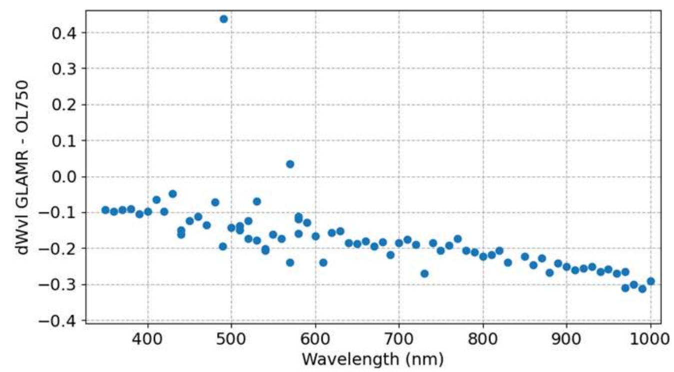
Note for Grande sphere calibration with same lamp spectrum as FEL calibration lamp, stray light error cancels but for other illumination spectra it would not. Most apparent with monochromatic light.

OL750 RSR, stray light, and wavelength

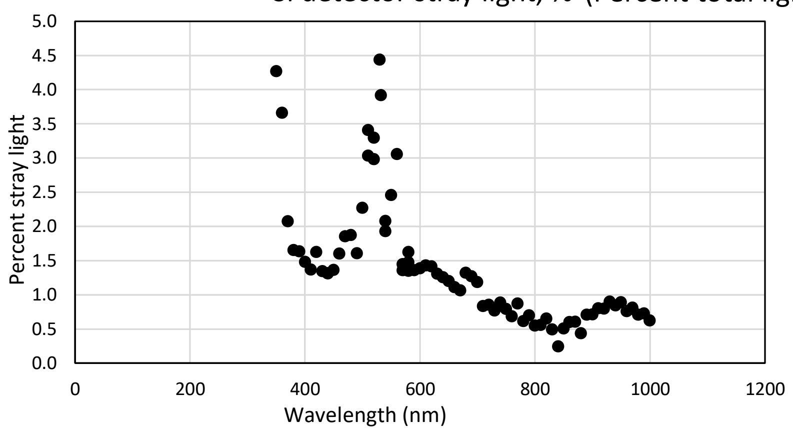


Large drop in responsivity in UV range compounds stray light contribution: OL750 most sensitive where lamp is brightest, least sensitive where lamp is dimmest

OL 750 wavelength calibration



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

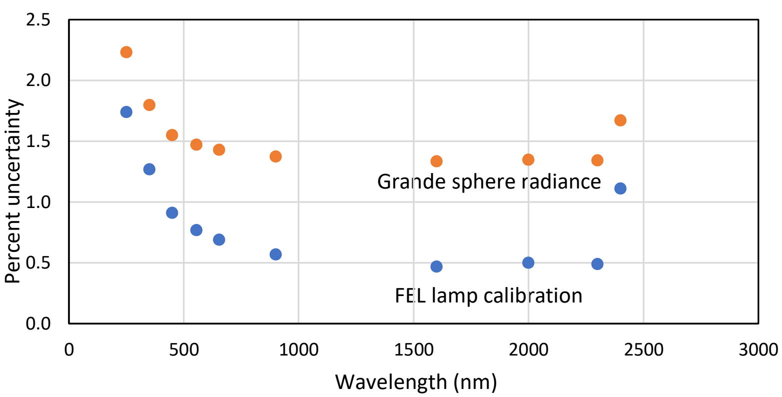


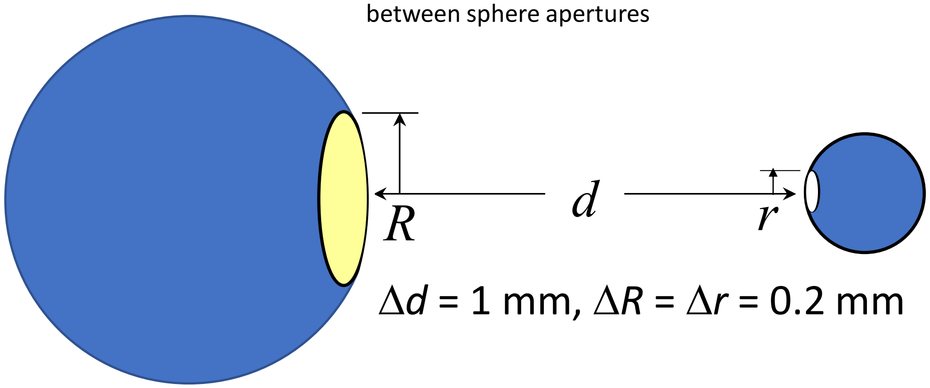
Sources of uncertainty

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

Driven by Δd, separation between sphere apertures

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





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

Conclusions

Observed 1.5% difference between radiometer and FEL lamp based calibrations within combined uncertainty of Grande and GLAMR measurements

Radiance to irradiance conversion adds largest source of uncertainty to the lamp based calibration