NRC·CNRC

Current Research Activities at the National Research Council of Canada

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Luke Sandilands, Joanne Zwinkels, Éric Côté, William S. Neil, Li-Lin Tay

CORM 2018

Outline

- Capabilities and calibration services
- Research activities and new facilities
  - Fluorescence: impact of instrument geometry on total radiance factor (J. Zwinkels)
  - Absolute reflectometer facility update (L. Sandilands)
  - Solid state lighting lab (A. Gaertner)
  - Primary optical radiant power facility
  - Spectral irradiance facility
  - Few photon metrology

Capabilities and Calibration Services

Sources & Photometric Instruments

- ✓ Luminous Intensity, Luminous Flux, Colour Temperature
- ✓ Illuminance Meters, Luminance Meters
- ✓ Spectral Irradiance (200-2500 nm)
- ✓ Spectral Radiance (380-1060 nm)

Detectors

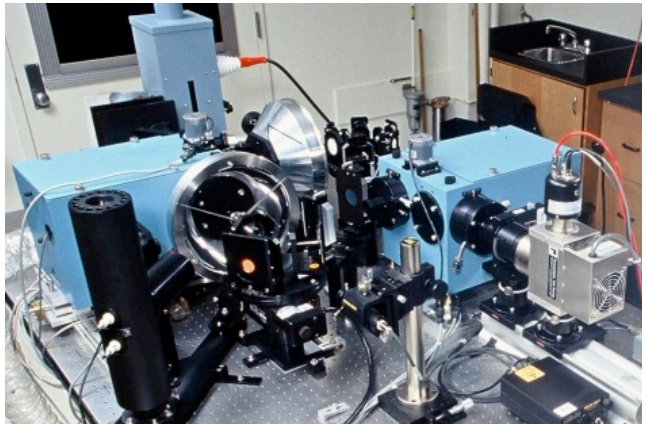
- ✓ Spectral Responsivity (250-2700 nm)

Optical Properties of Materials

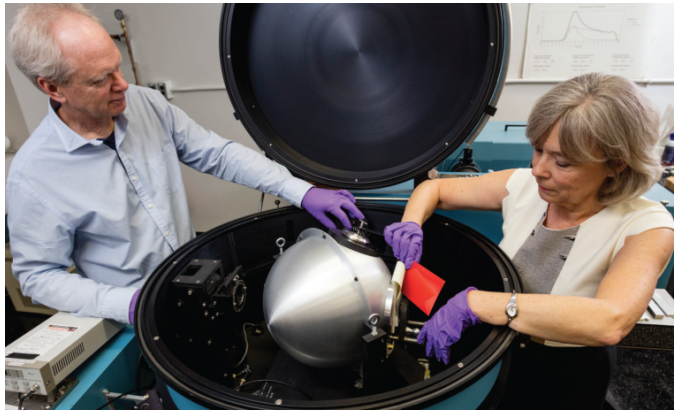
- ✓ Regular Transmittance (190-3200 nm); (4000-2000 cm^{-1})
- ✓ Specular Reflectance (220-2500 nm)
- ✓ Diffuse Reflectance (250-2500 nm); (5000-600 cm^{-1})
- ✓ 45:0 Radiance Factors (360-1100 nm)
- ✓ Specular Gloss (20°,45°,60°,75°,85°; ASTM, ISO, TAPPI)
- ✓ BRDF (380-780 nm)
- ✓ Fluorescence (300-850 nm; 45a:0, 8:d, 8:t)

NRC Fluorescence Facilities, Current R&D

Bidirectional (45a:0)



Sphere (8:d or 8:t)

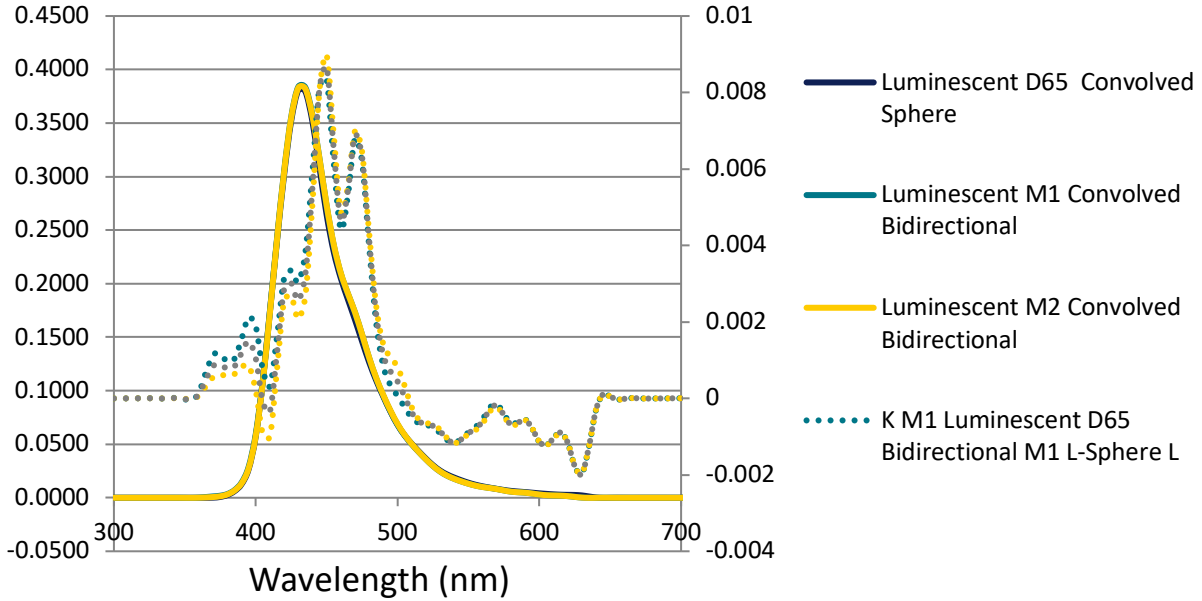


Current NRC R&D in Fluorescence Measurements:
Investigation of Impact of Instrument Geometry

- Fluorescent paper standards
- Fluorescent textile standards (planned)

Impact of instrument geometry (45:0 c.f. 8:d) for fluorescent paper standards: Luminescent component

CIE D65 radiance factor and absolute difference (45a:0 – 8:d)

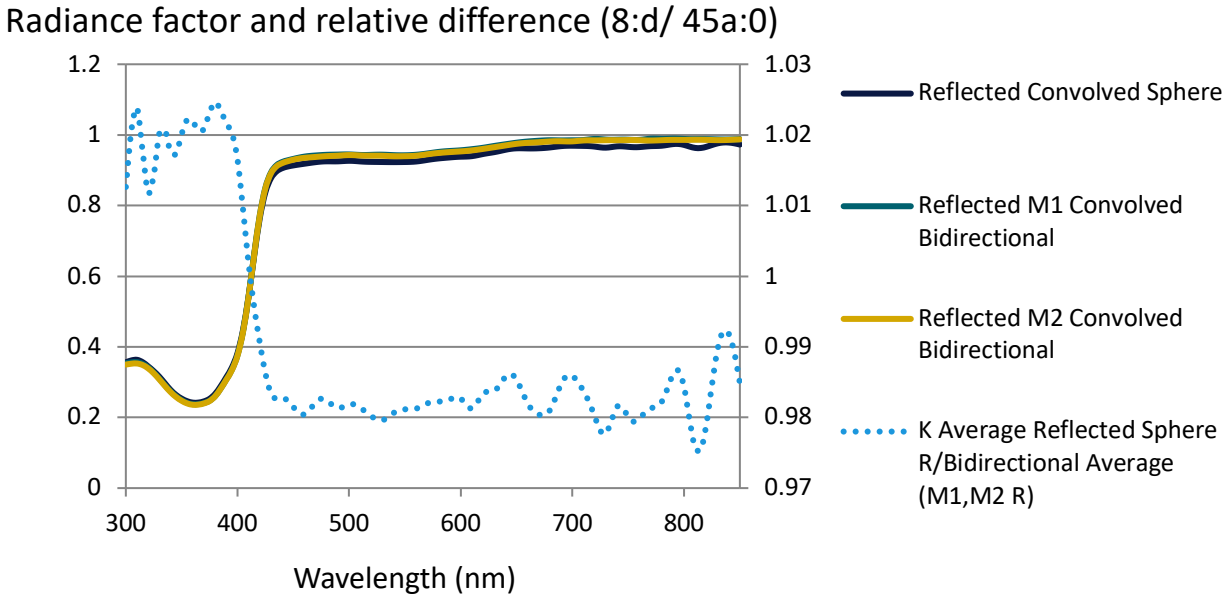


Measurement sequence:

1) 45a:0 (M1)
2) 8:d (sphere)
3) 45a:0 (M2)

- Conclusion: insignificant impact on luminescent component

Impact of instrument geometry (45:0 c.f. 8:d) for fluorescent paper standards: Reflected component



Ratio to average 45a:0 measurements (M1 and M2)

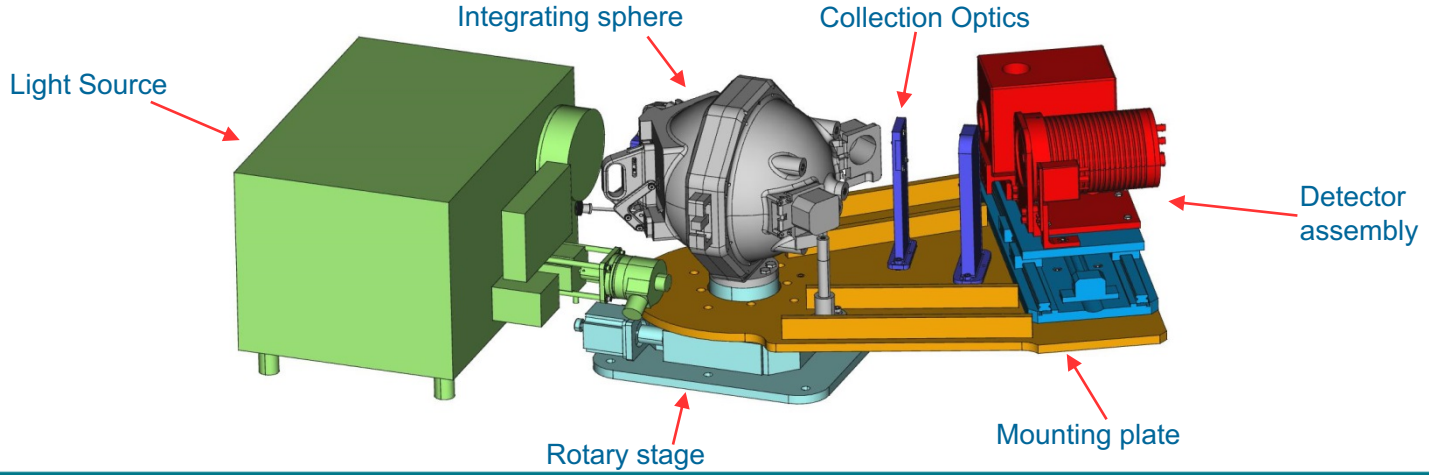
- c.f. current AL geometric correction factor for diffuse geometry (ISO 2469, d:0) to bidirectional geometry (45:0):
  - *K* is calculated from 620 nm to 700 nm, assume wavelength-independent
- Conclusion:
  - *K* ~ wavelength-independent for $\lambda > 420$ nm; $K = 0.984 \pm 0.002$ (620-700 nm); for $\lambda < 420$ nm (excitation range), ratio is ~$1/K = 1.02$

Development of a new (d°, 0) absolute reflectometer

Features:
- Based on the Sharp-Little method
- Realizes a (d°, 0) reflectance scale
- Extended spectral range (250-1900 nm)
- Full automation
- Improved spectral resolution
- Custom PTFE integrating sphere

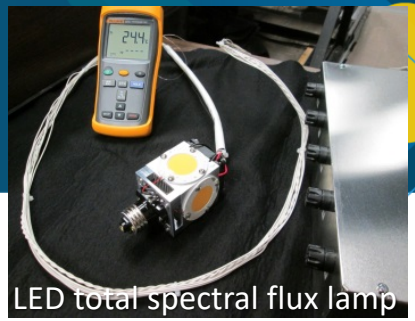
To date:
- Optomechanical design and fabrication
- Characterization of light source & detectors
- Software

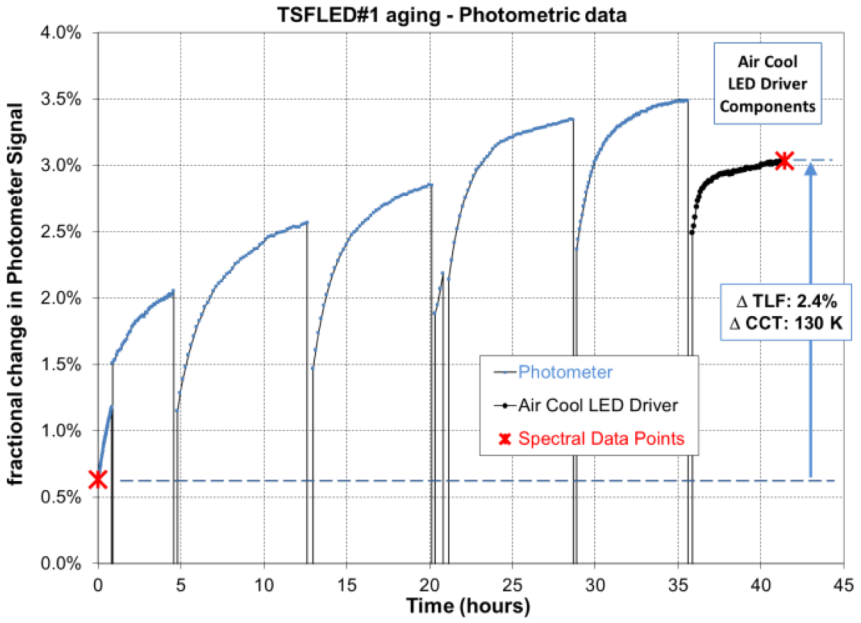
Ongoing
- Assembly of full system
- Preliminary data acquisition
- Sources of uncertainty

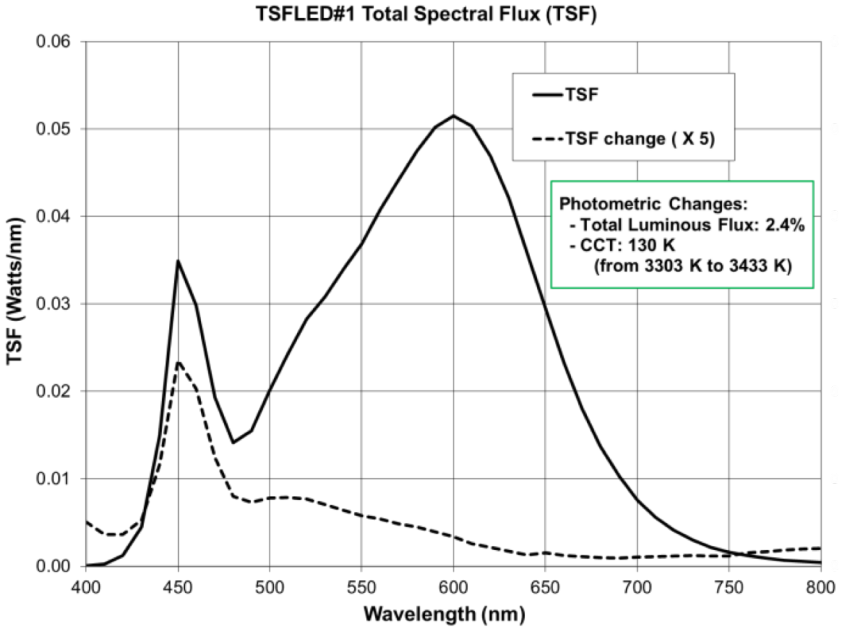


NRC solid state lighting lab

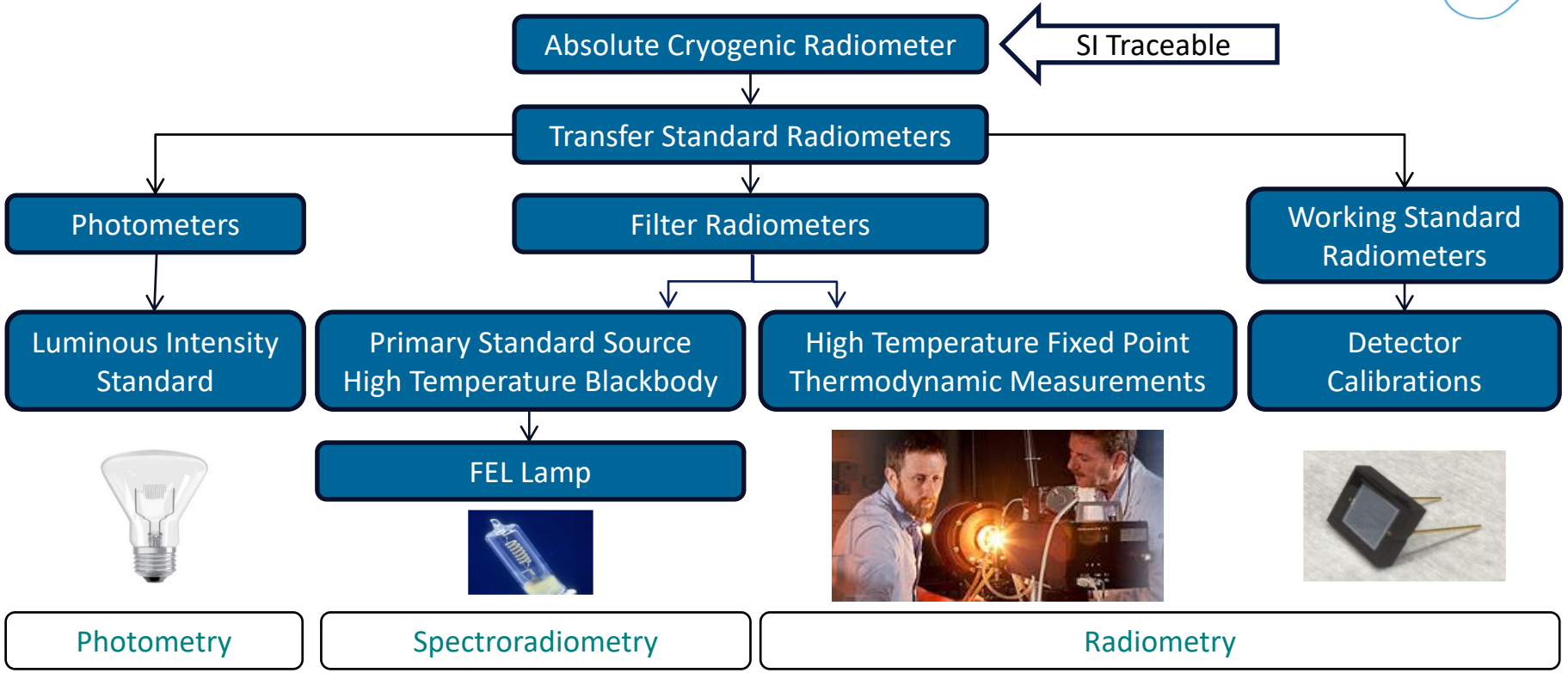
- Testing chip-on-board LED modules for use in prototype total spectral flux standard sources



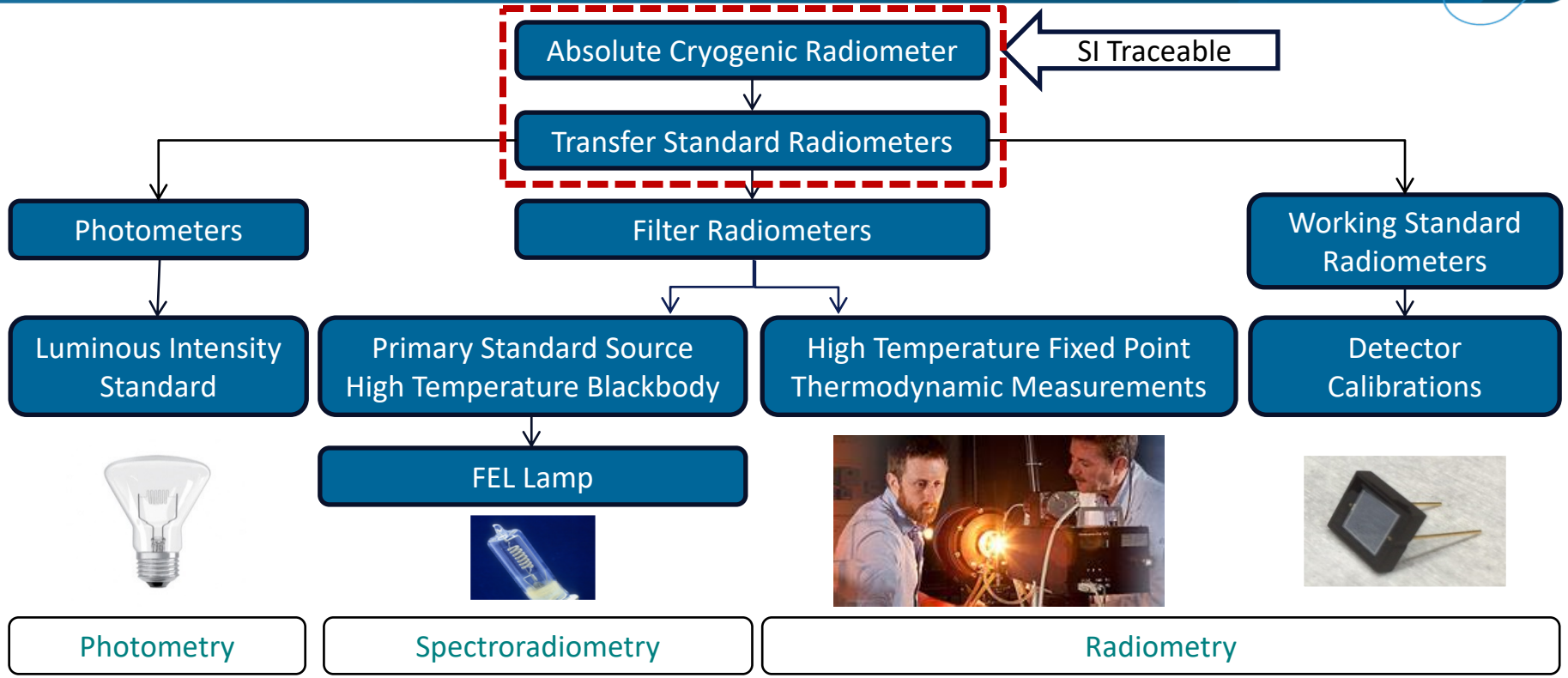




Optical radiation calibration chain



Optical radiant power scale

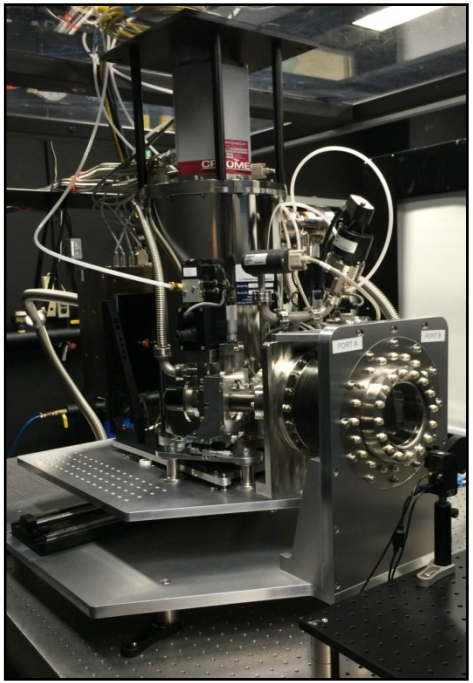


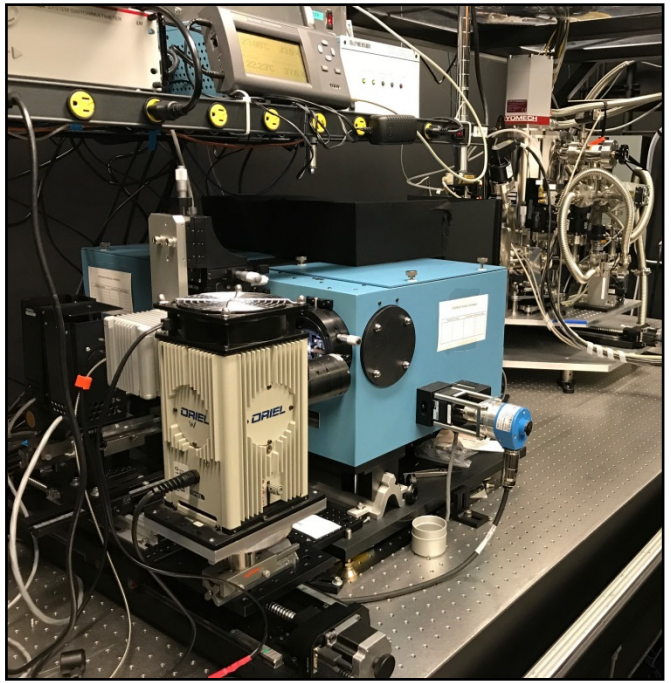
Advanced radiometry facility

- New cryogenic radiometer with closed-cycle helium cryocooler
- Double-subtractive monochromator
- Custom-designed motion apparatus for optical alignment

Cryogenic radiometer uncertainty improvements

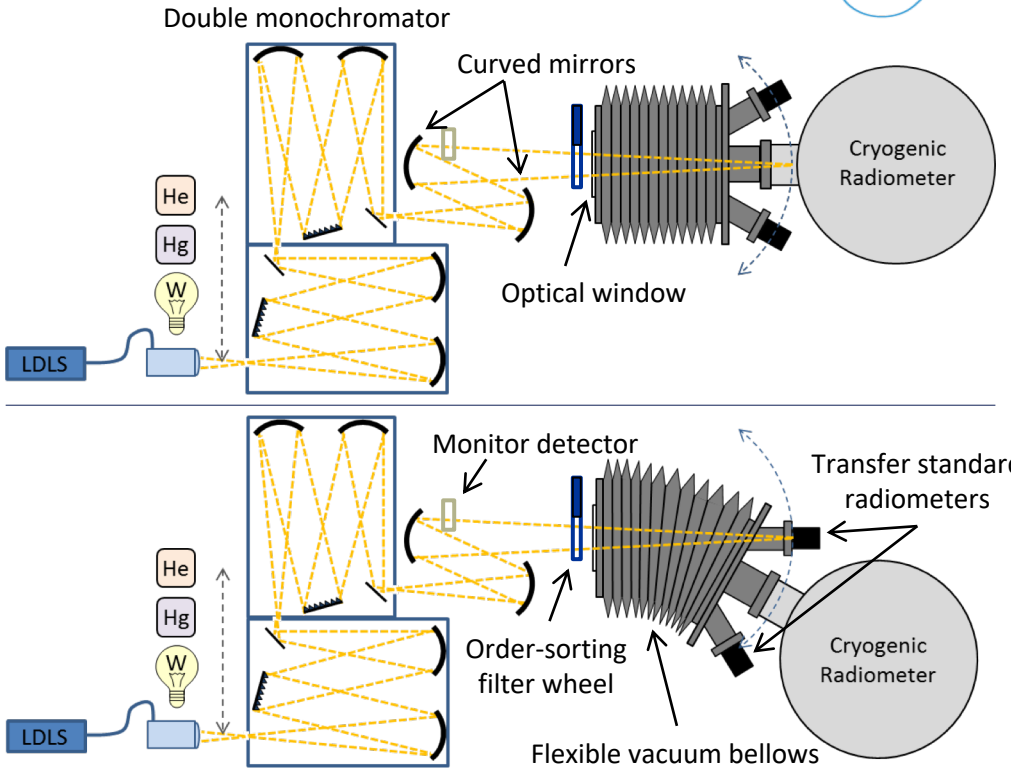
Source	old (%)	new (%)
Cavity absorptance	0.01	0.004
Nonequivalence effects	0.01	0.001





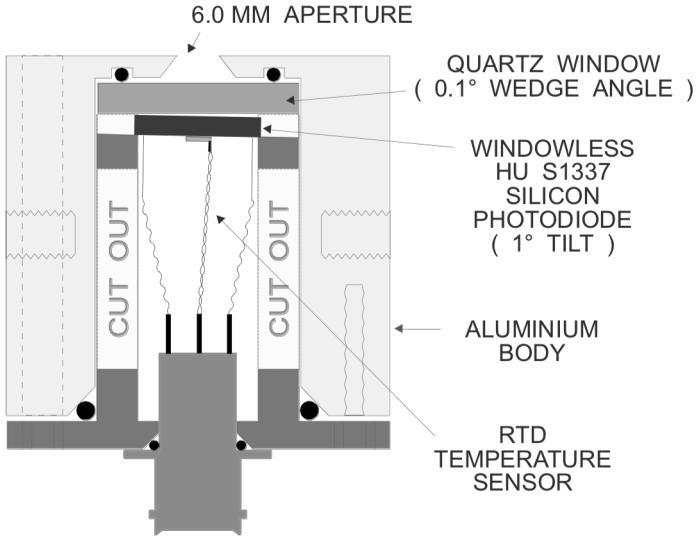
Advanced radiometry facility

- Broadband laser-driven light source (LDLS) and tungsten lamp
- Linear stage with pin and pivot system facilitates alignment to the common optical path (30° motion)
- Gate valves between the bellows vacuum chamber and the transfer radiometer mounting ports allow for detectors to be changed during system operation



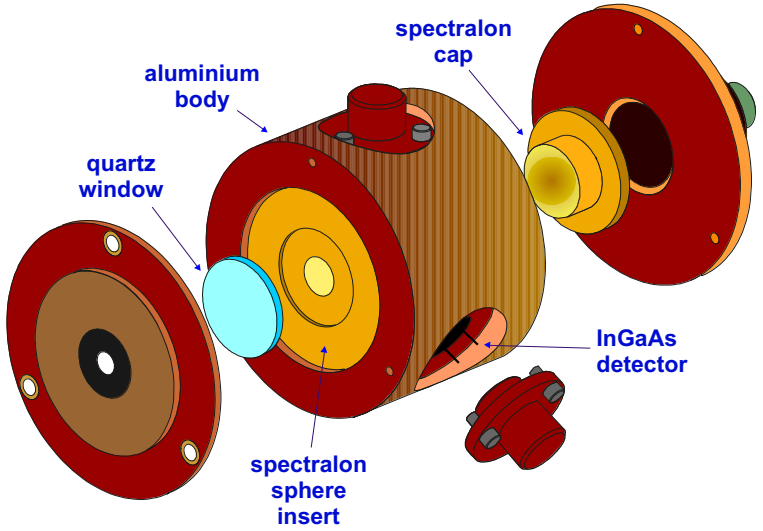
Transfer standard radiometers

- Single element detector with quartz window - Si and PtSi for VIS and UV



Boivin, Metrologia **32** 565 (1995)

- Sphere radiometer design for improved uniformity - three 5 mm InGaAs detectors



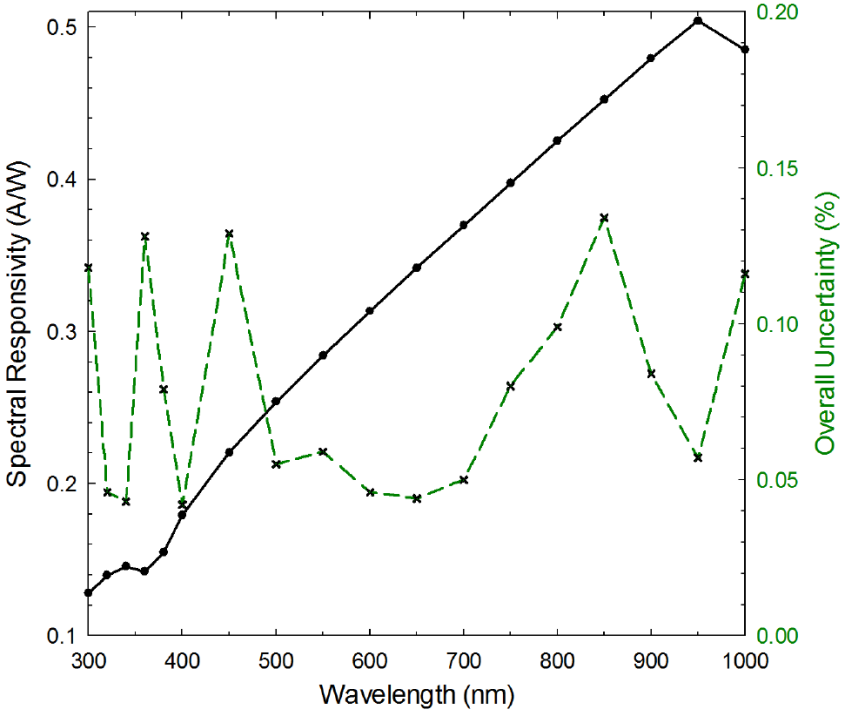
Boivin, Metrologia **37** 237 (2000)

Spectral responsivity scale

- Scale realization from 300 nm to 1000 nm using Si transfer standard detectors
- Presently working on scale from 900 nm to 1600 nm

Next step:

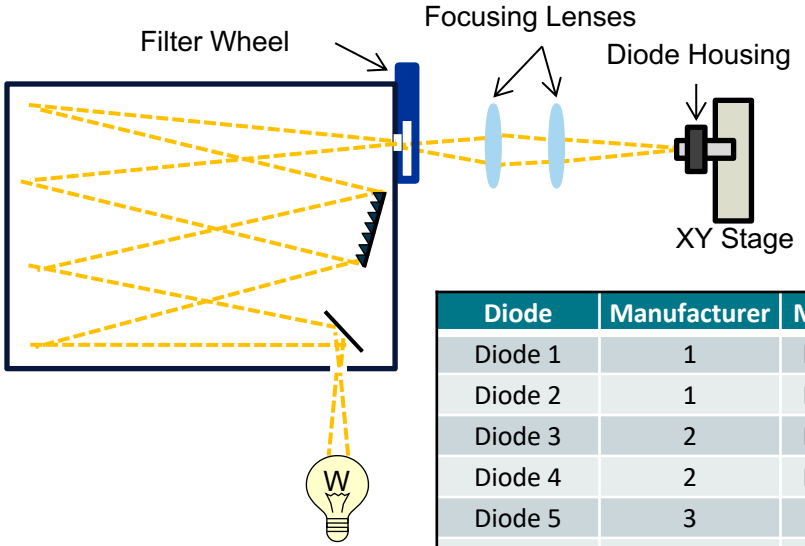
- UV scale from 200 nm to 400 nm



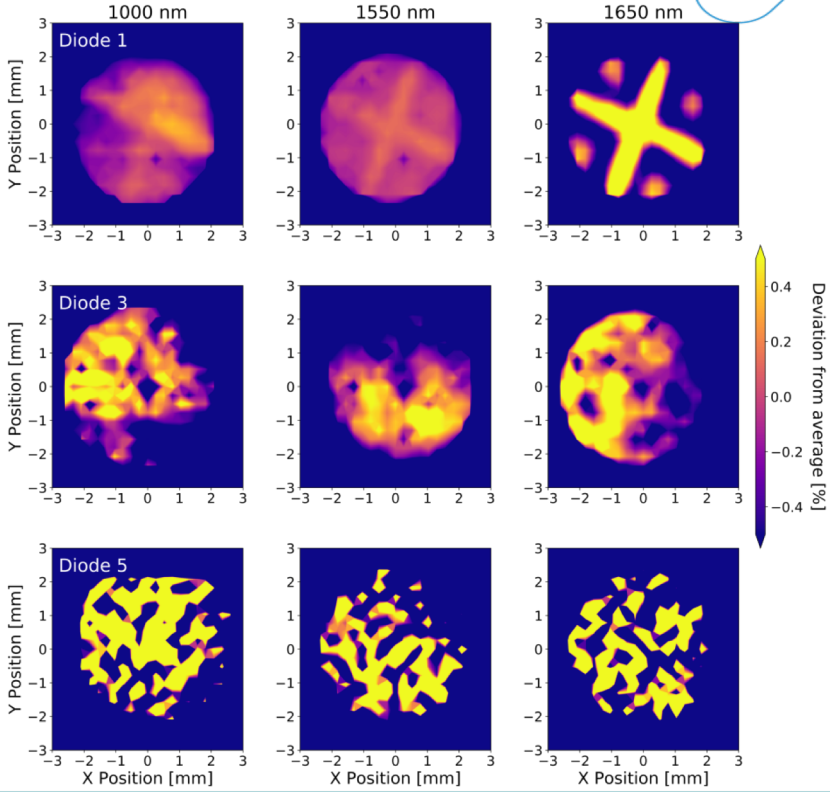
Average of uncertainty components from four Si transfer standard detectors

InGaAs and Ge uniformity

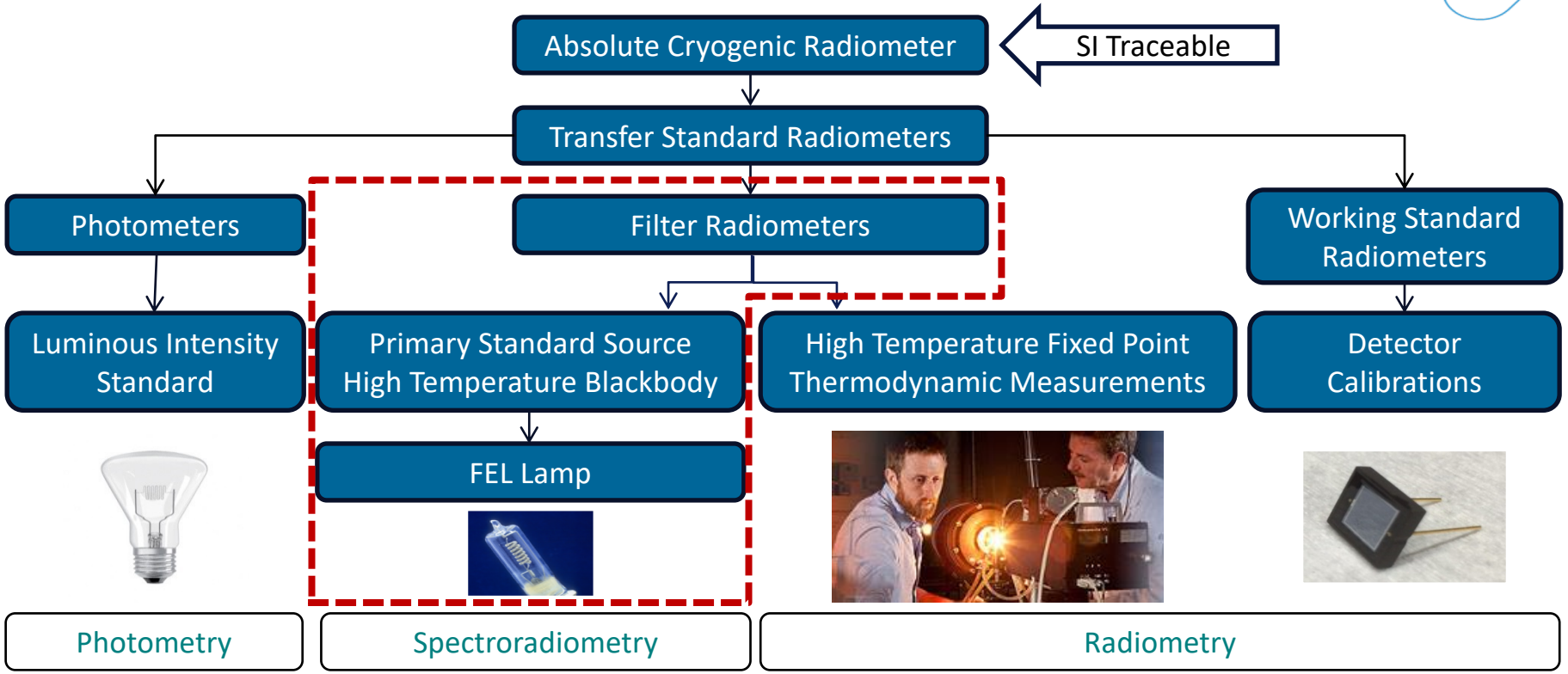
- Photodiode testing for new working standard detectors in the NIR region



Diode	Manufacturer	Material
Diode 1	1	InGaAs
Diode 2	1	InGaAs
Diode 3	2	InGaAs
Diode 4	2	InGaAs
Diode 5	3	Ge
Diode 6	3	Ge

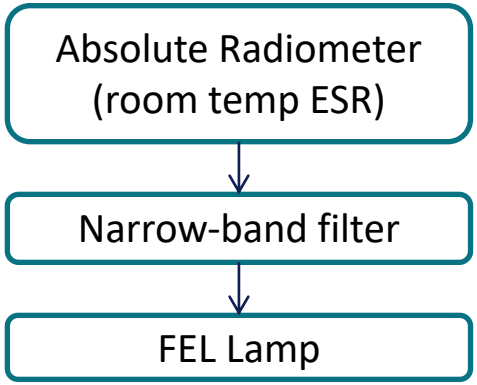


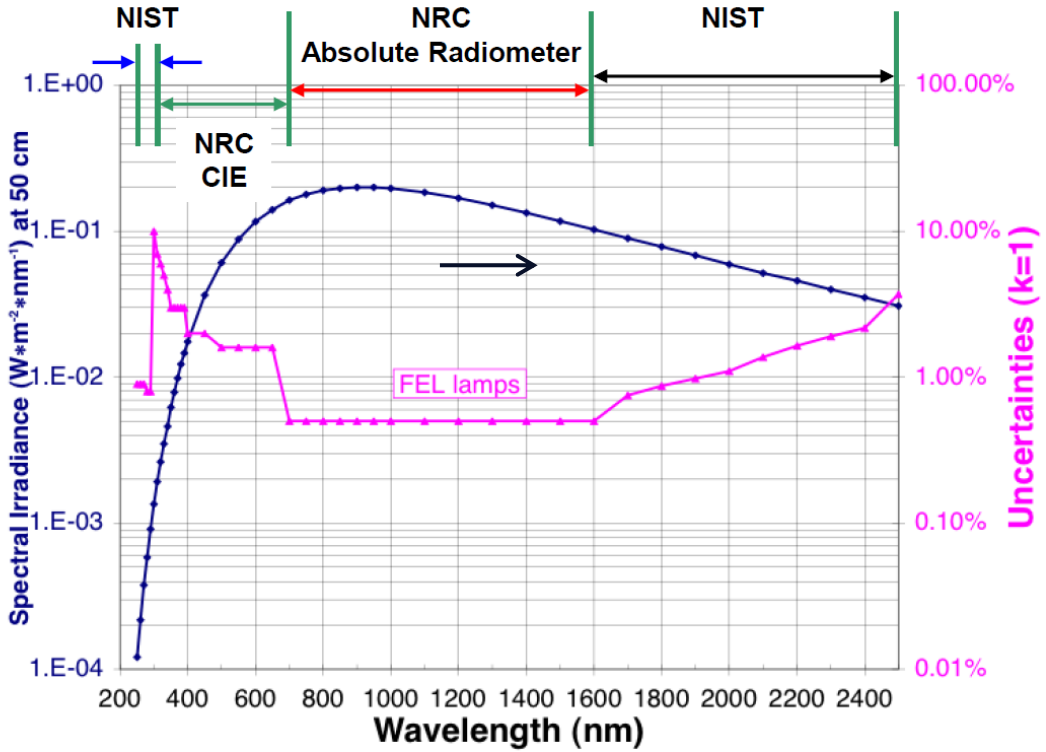
Spectral irradiance scale



Spectral irradiance scale transition

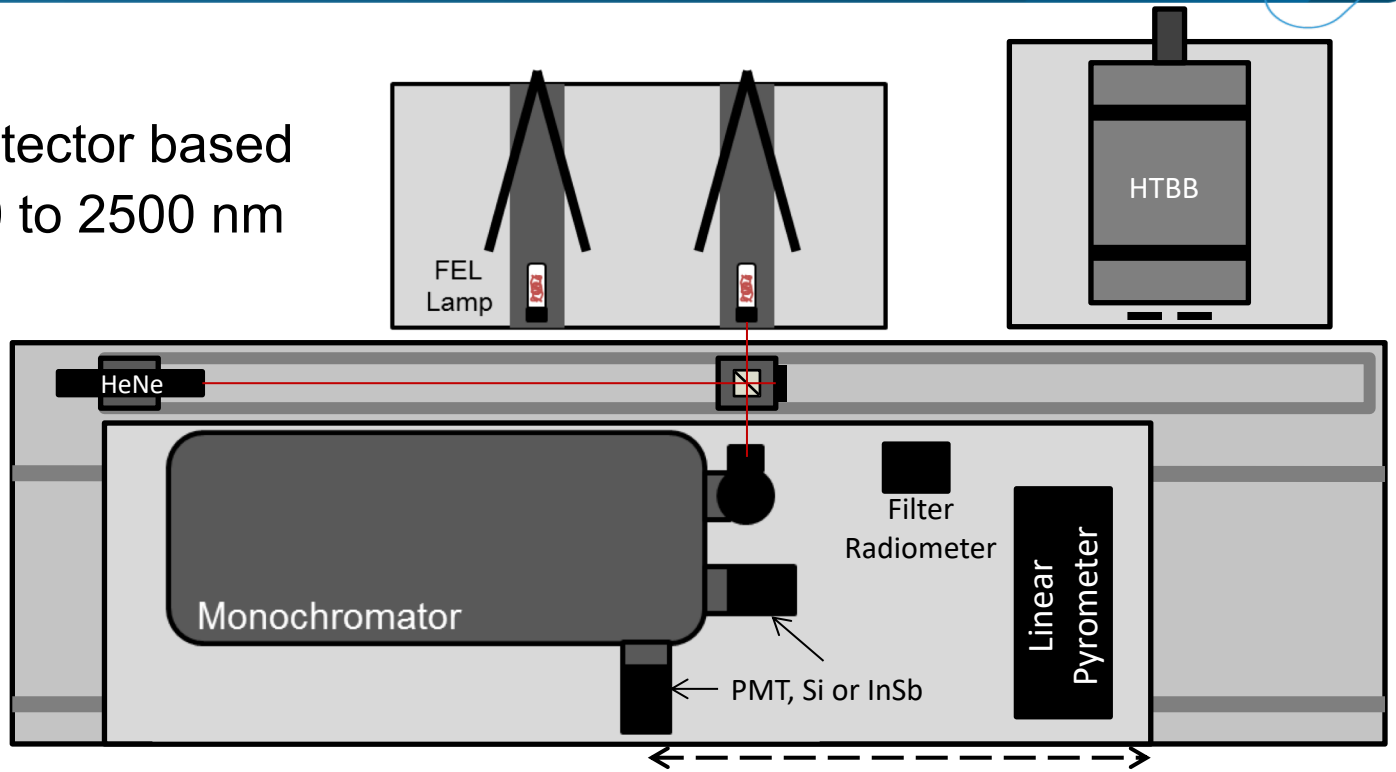
Detector based scale 700 -1600 nm





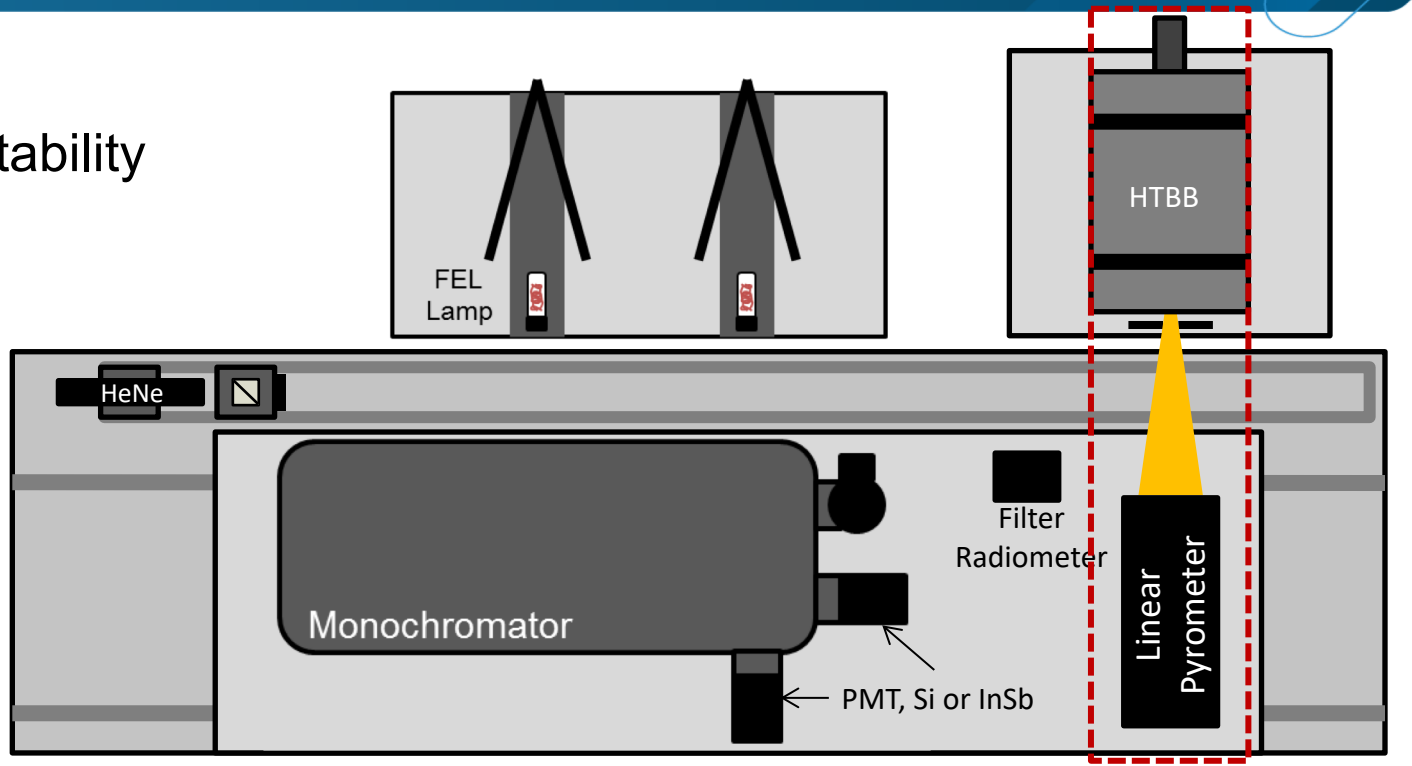
Spectral irradiance facility

- Source and detector based scale from 250 to 2500 nm



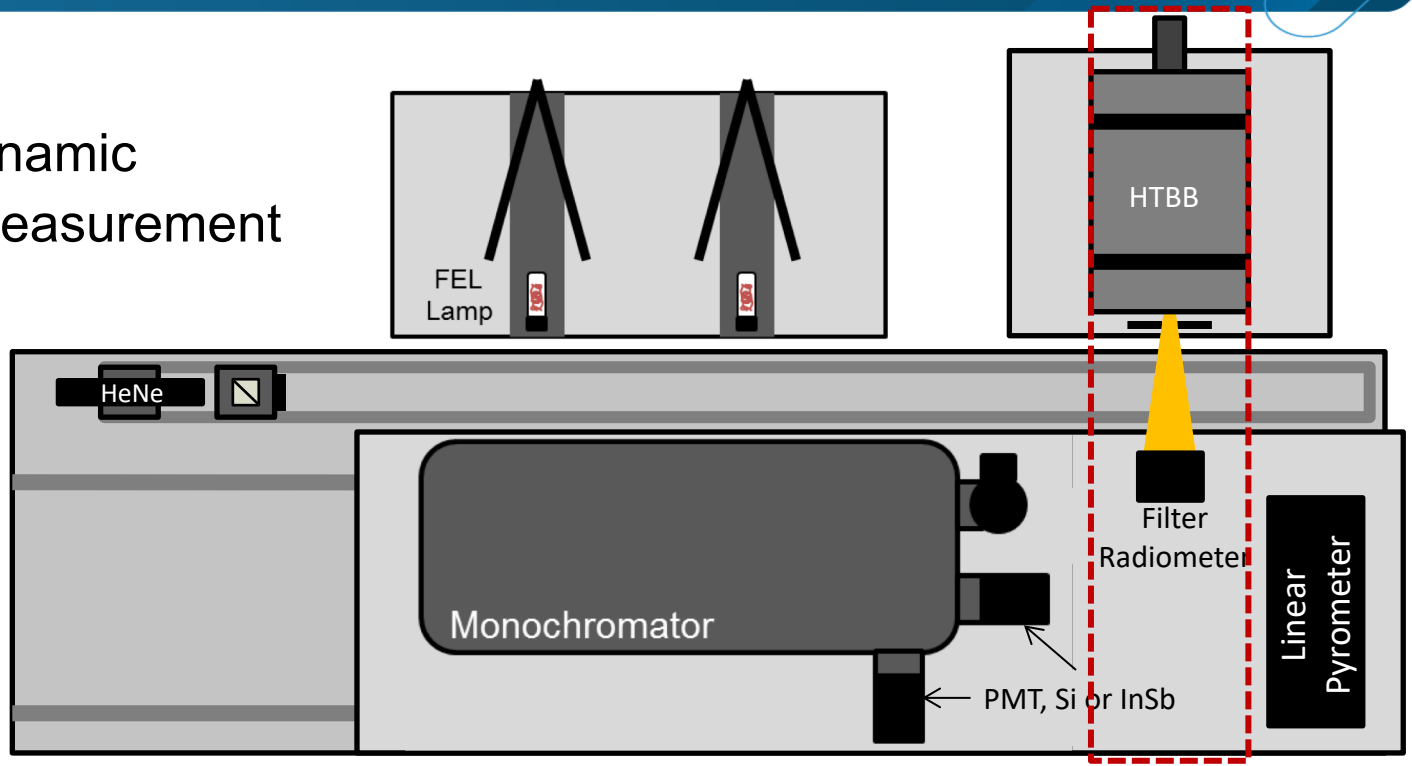
Spectral irradiance facility

- Temperature stability verification



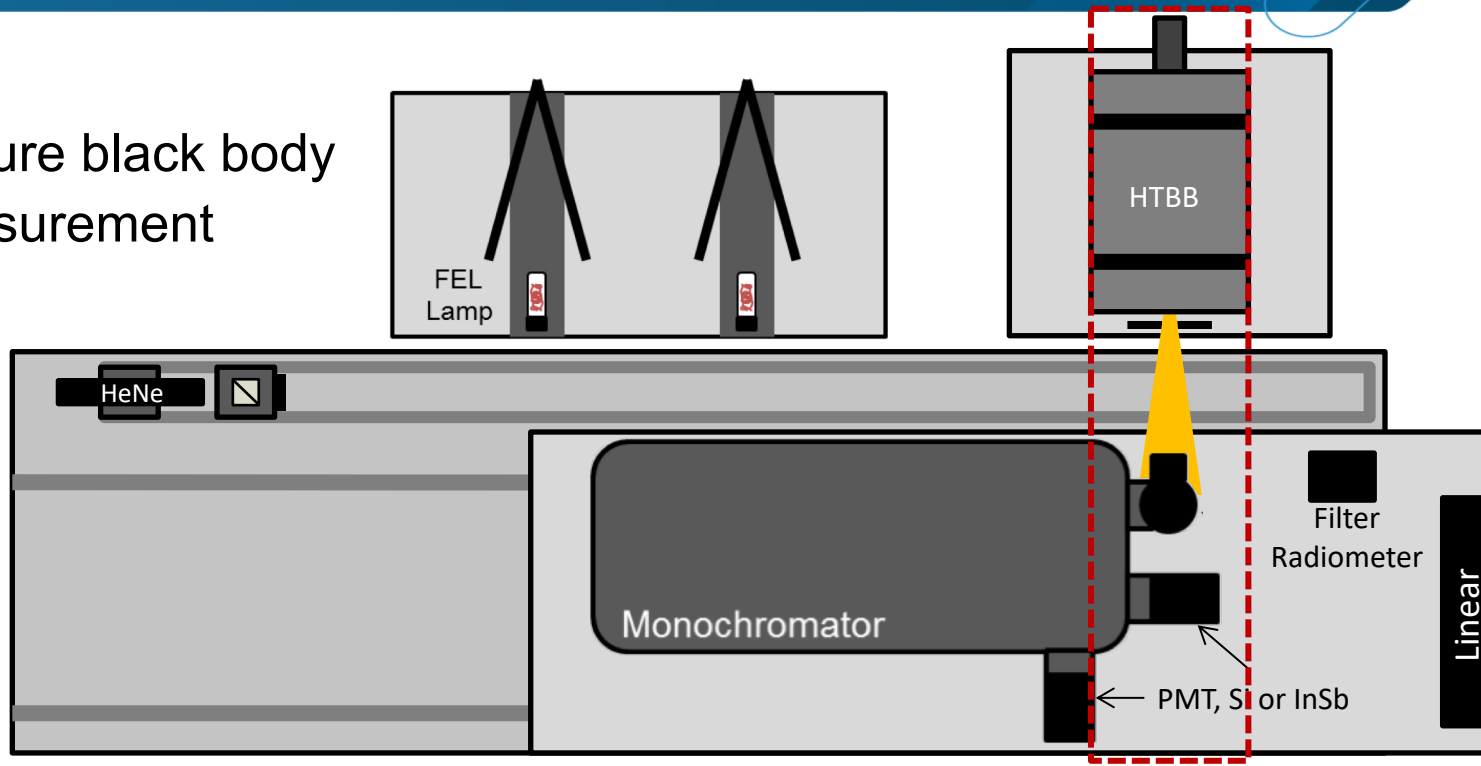
Spectral irradiance facility

- First thermodynamic temperature measurement



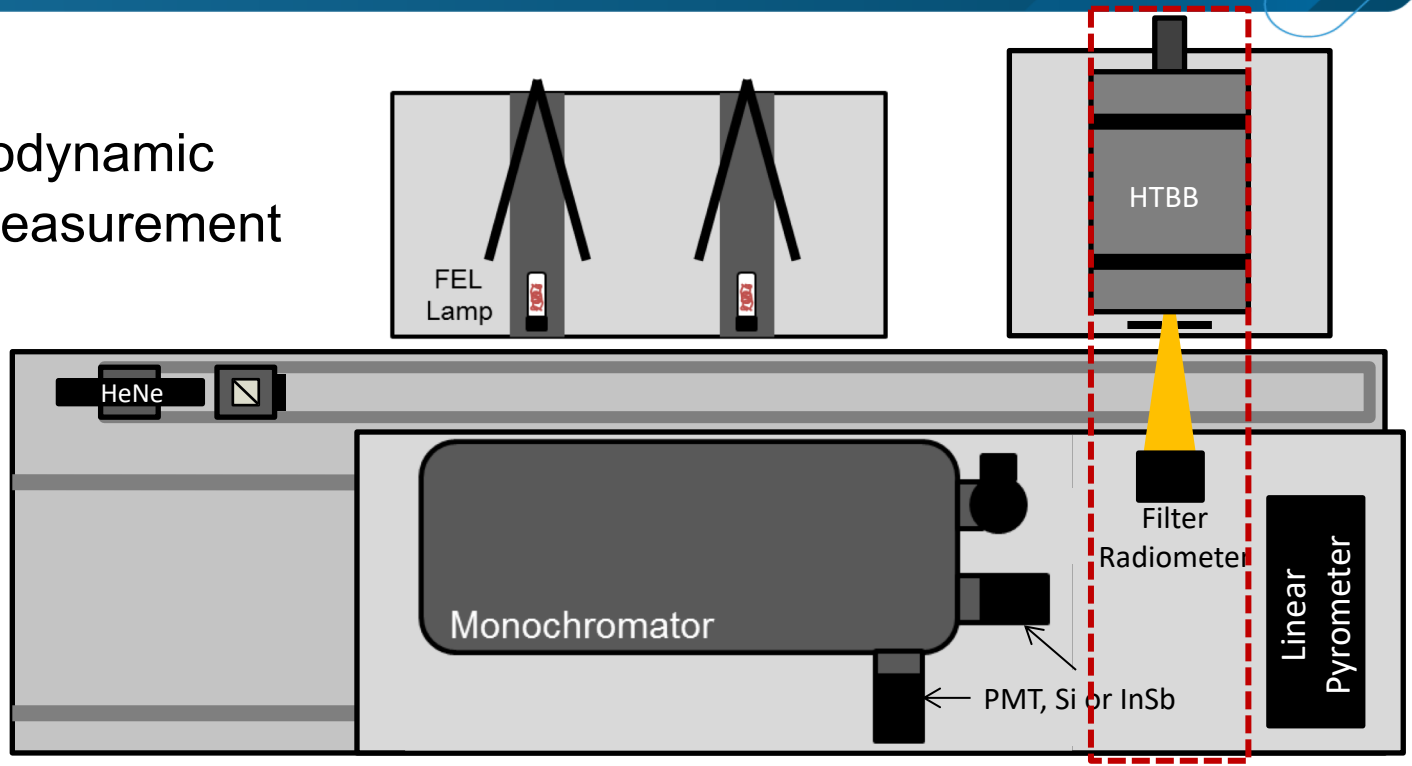
Spectral irradiance facility

- High temperature black body spectrum measurement



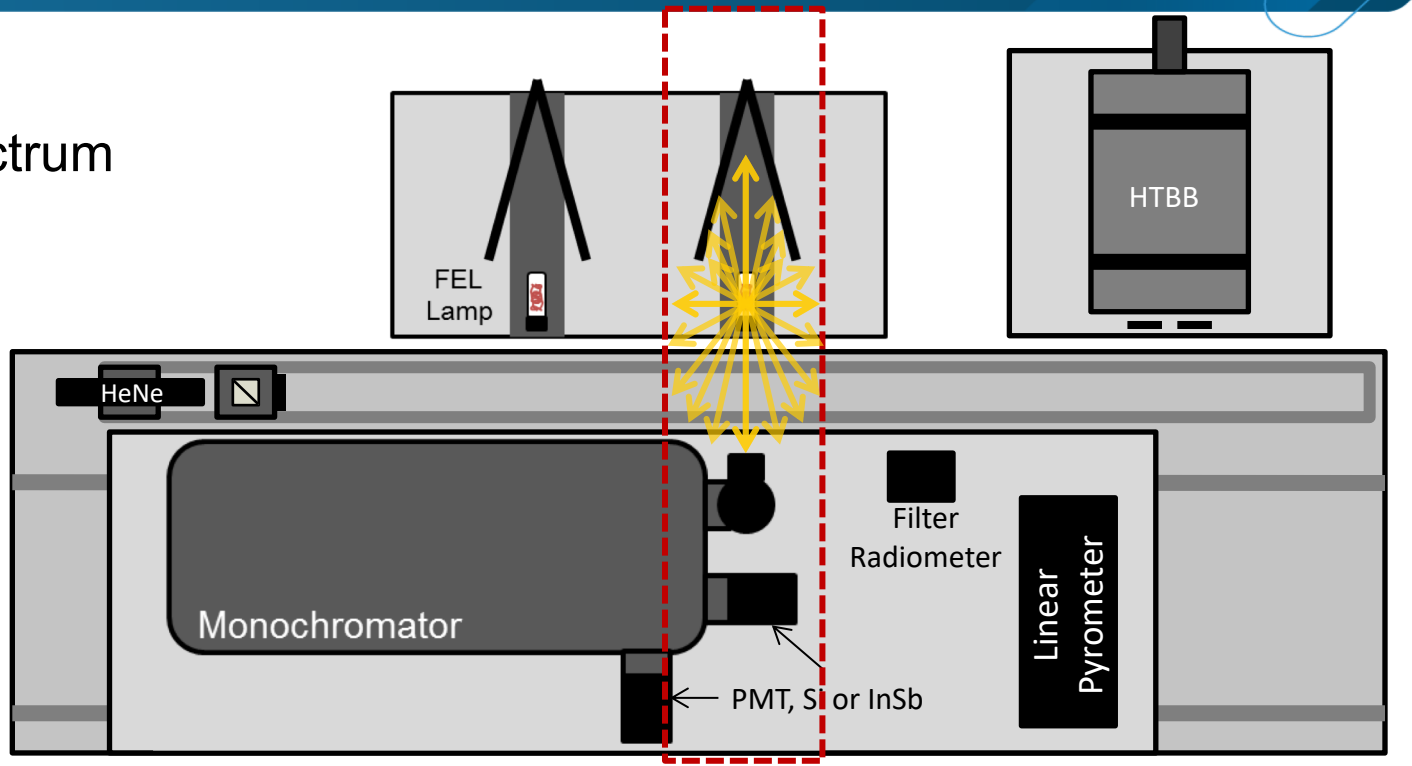
Spectral irradiance facility

- Second thermodynamic temperature measurement

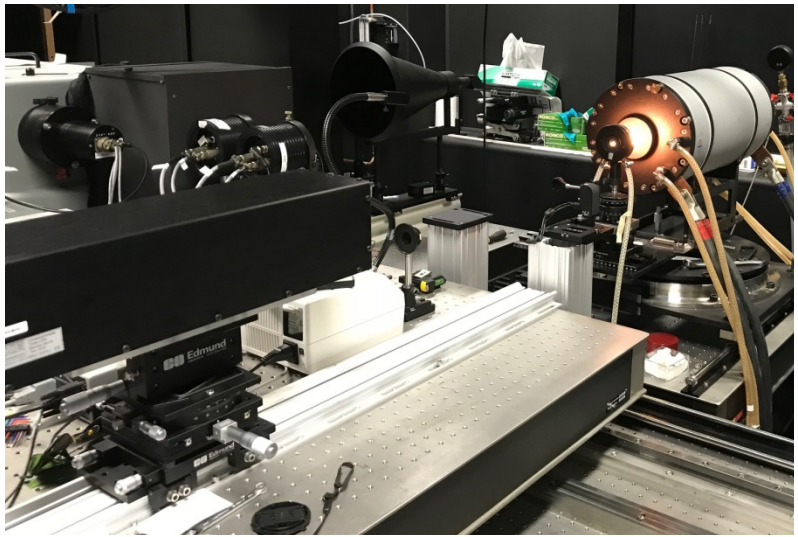


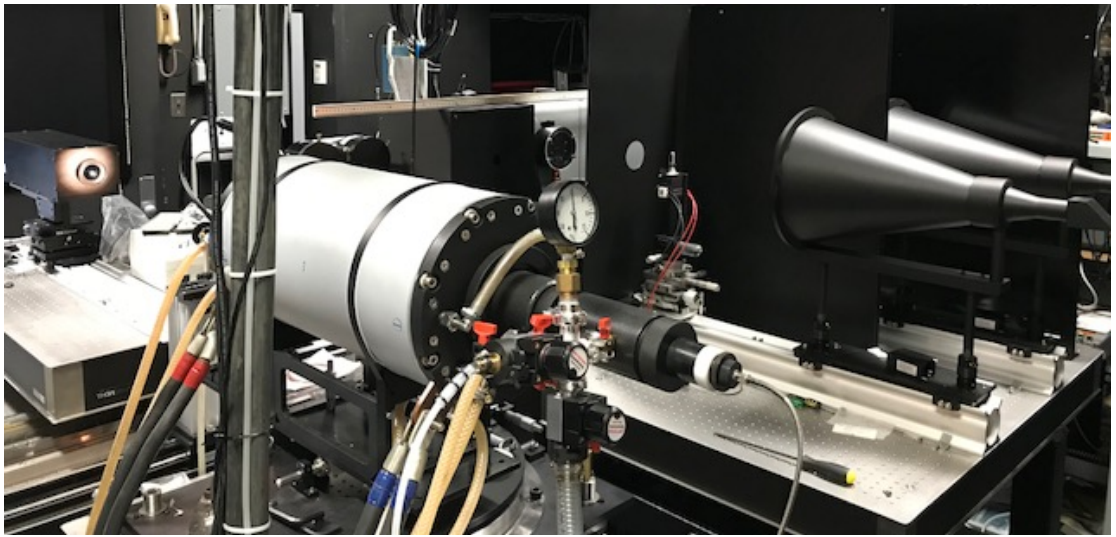
Spectral irradiance facility

- FEL lamp spectrum measurement



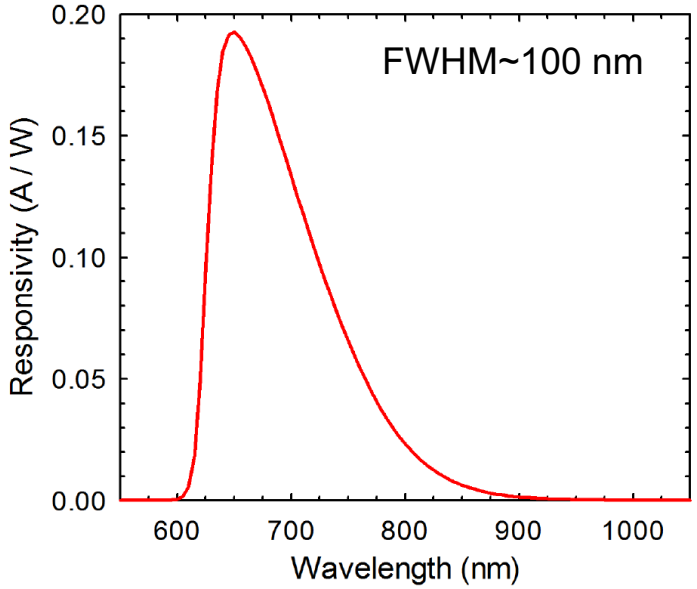
Spectral irradiance facility

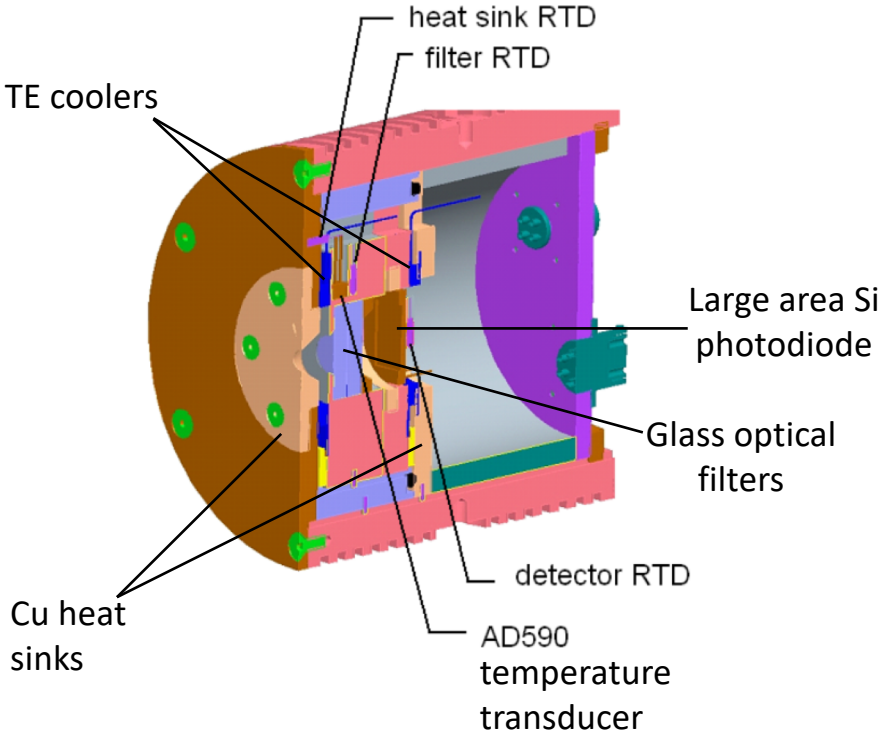




Thermodynamic temperature measurement

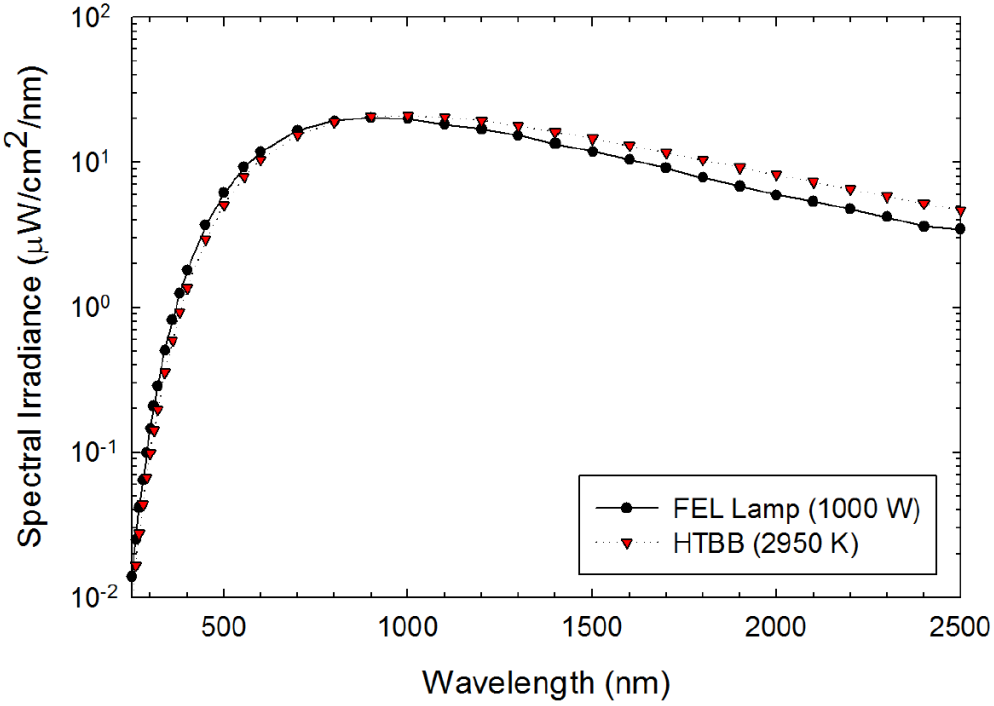
- NRC wideband filter radiometer
- Calibrated using transfer radiometers and monochromator based apparatus



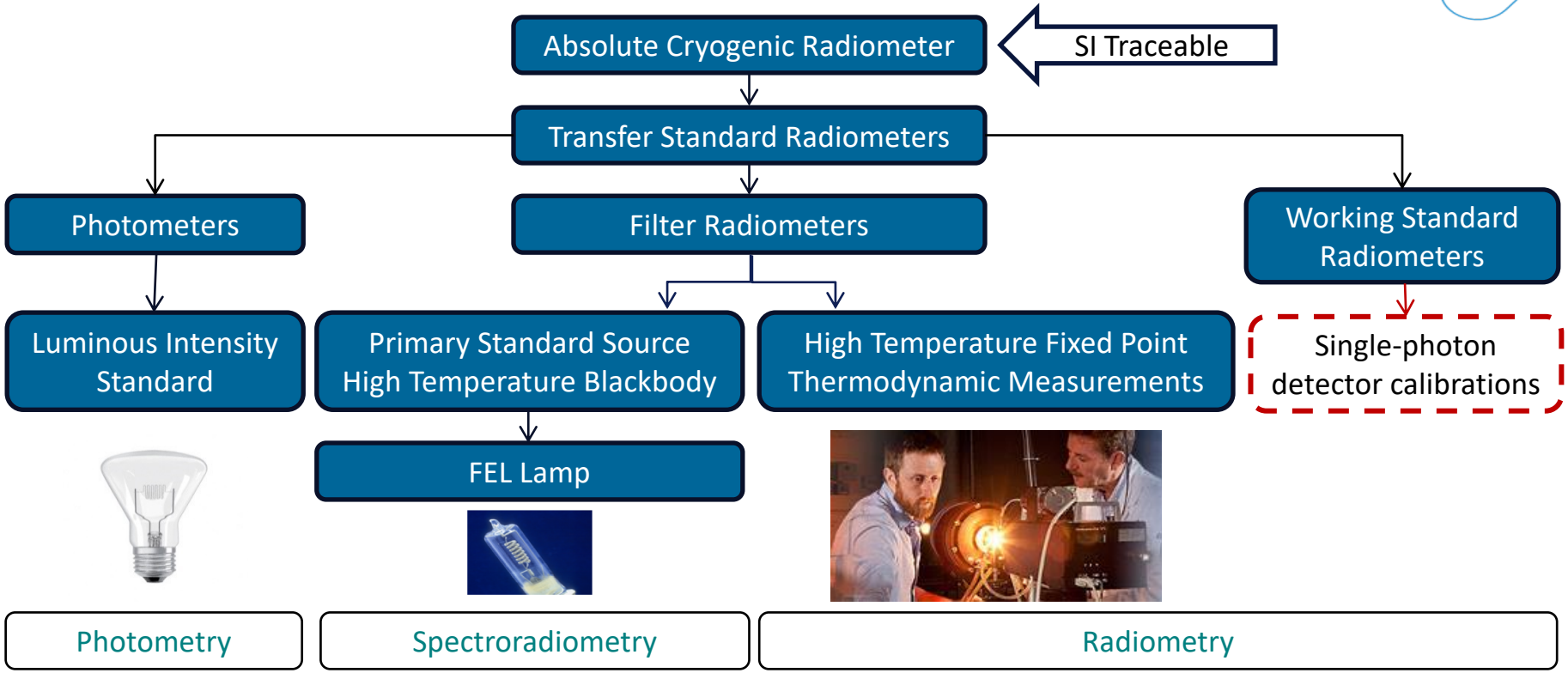


Spectral irradiance facility

- HTBB temperature stability 0.1 K/h
- Monochromator wavelength accuracy ± 0.05 nm
- Lamp distance of 50 cm
- Uncertainty budget in progress



Optical radiation calibration chain



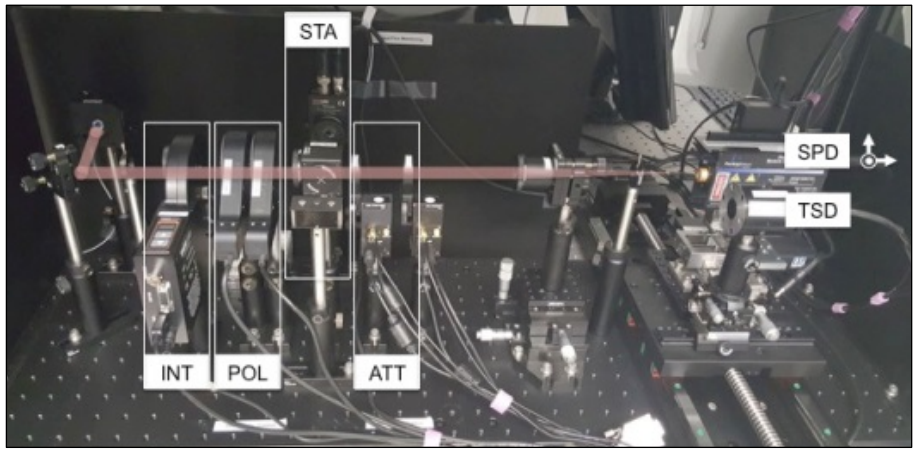
Few Photon Metrology at NRC

- **Project Goals**:
  - Single-photon detector efficiency measurements
    - Free space and fibre-coupled detectors
  - Construction of superconducting nanowire single-photon detector system (Collaboration with NIST)
  - Characterize single-photon sources (NRC)
- *Looking forward:*
  - Multi-particle quantum state measurements

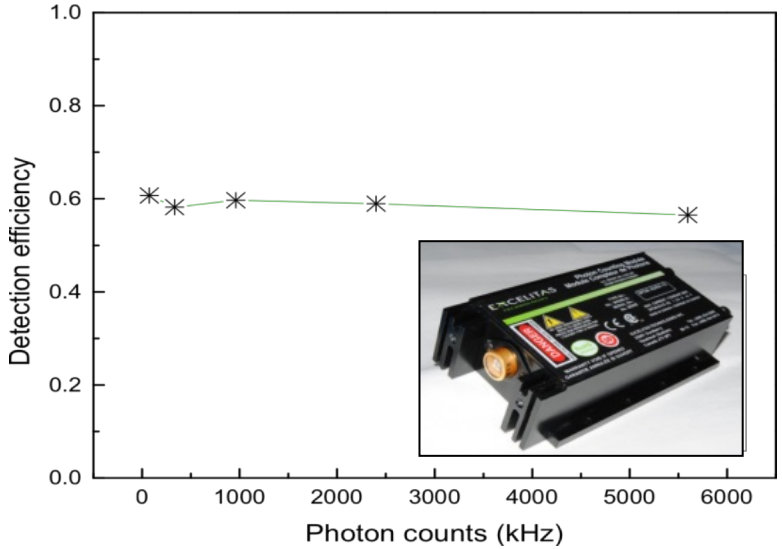
Single-photon detector characterization

Single-photon detector calibration capabilities → Free space Si SPADs

- Multiple filters are used to attenuate the input of a nano-joule laser beam to a level measurable by the single photon detector

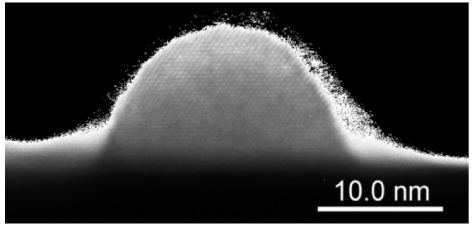


Efficiency measurements by substitution method

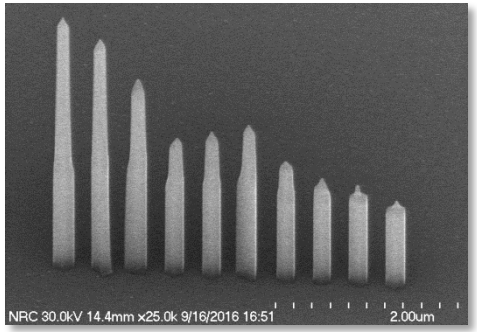


Quantum dot single-photon source

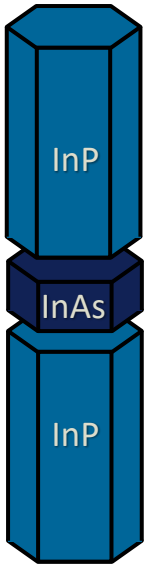
- Dan Dalacu and Robin Williams at NRC - quantum information applications



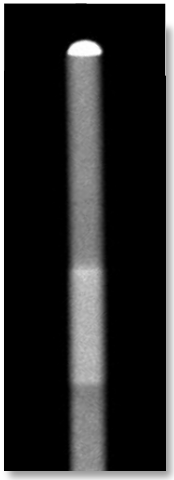
Self-assembled quantum dot



Site-controlled nanowires



Structure of QD embedded in nanowire



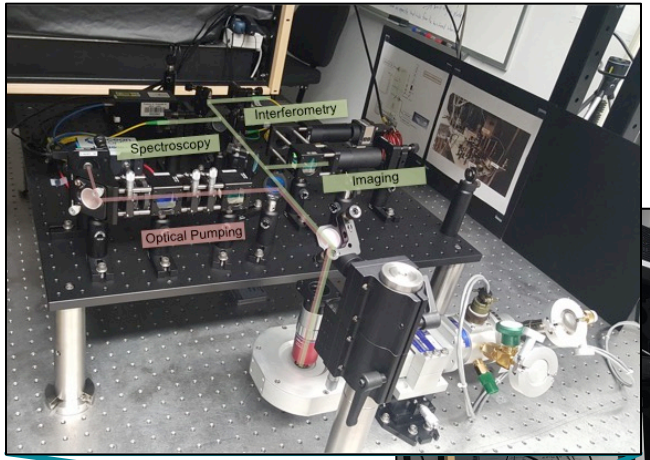
- Potential for use as on demand single-photon source for absolute radiometry
- Emission λ=980 nm
- Working on telecom band emission

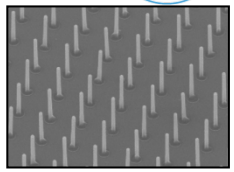
Single photon source efficiency

- Presently no *standard* way to characterize source efficiency

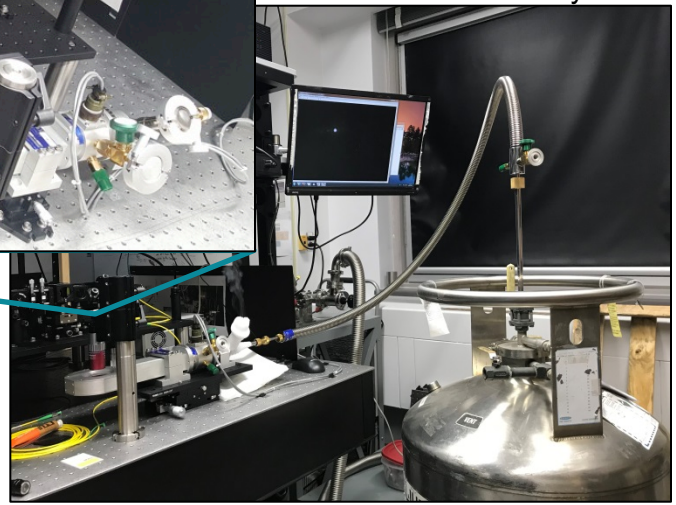
→ what has been accounted for?

- Efficiency ε: probability of collecting a photon
- Brightness β: number of photons collected per pump excitation pulse





QD nanowire array



Single photon source characterization apparatus

Summary

- Capabilities and calibration services
- Research activities and new facilities
  - Fluorescence: impact of instrument geometry on total radiance factor
  - Absolute reflectometer facility update
  - Solid state lighting lab
  - Primary optical radiant power facility
  - Spectral irradiance facility
  - Few photon metrology

Acknowledgements:
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Rhys Emms

Thank you

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