Radiometry & few-photon metrology at the National Research Council of Canada

Gamouras, Angela; Todd, Andrew D. W.; Côté, Éric; Gaertner, Arnold A.; Jin, Jeongwan; Dalacu, Dan; Williams, Robin

NRC·CNRC

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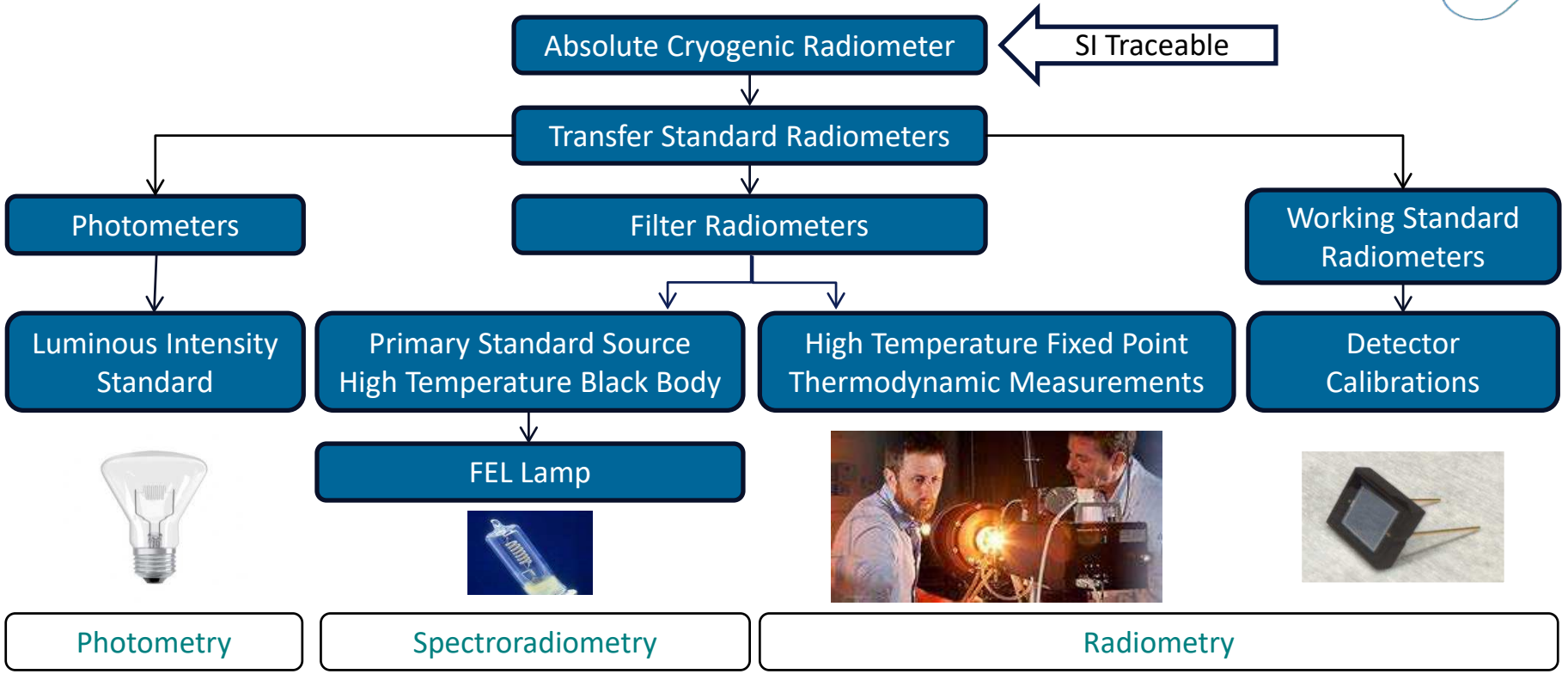
CALCON 2018

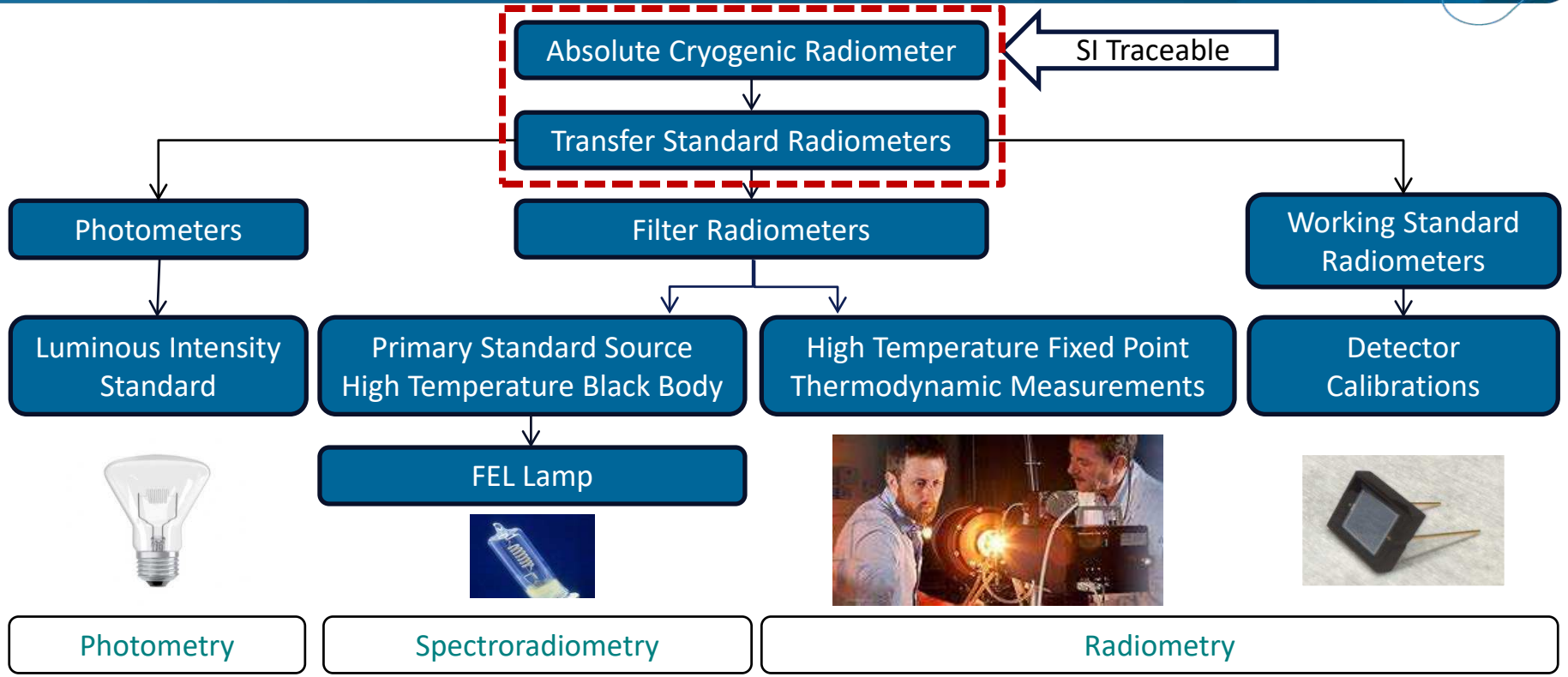
Outline

- Optical radiation calibration chain
  - Primary optical radiant power facility
  - Spectral irradiance facility
- Few photon metrology
  - Traceable characterization of single-photon detectors and NRC quantum dot-based single-photon sources

Optical radiation calibration chain

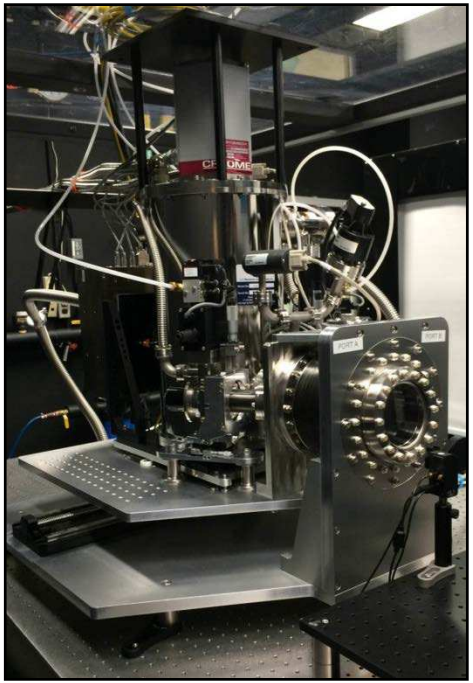


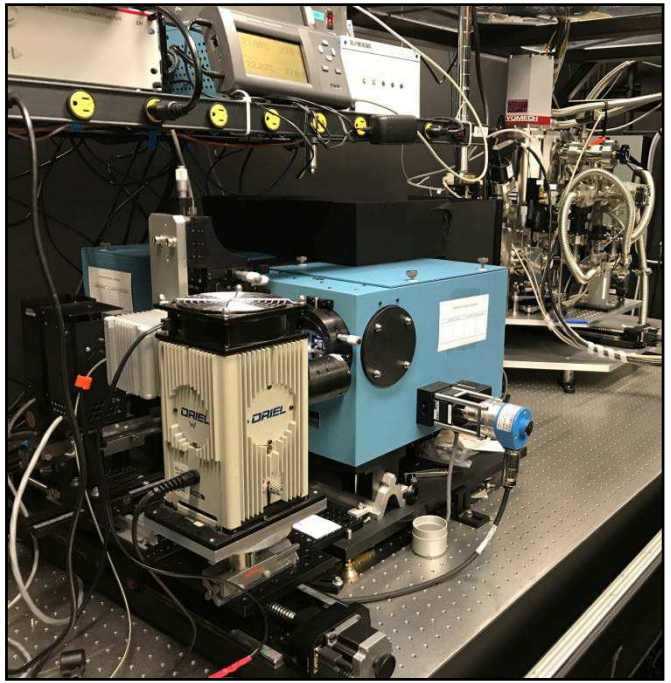
Optical radiant power scale



Advanced radiometry facility

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



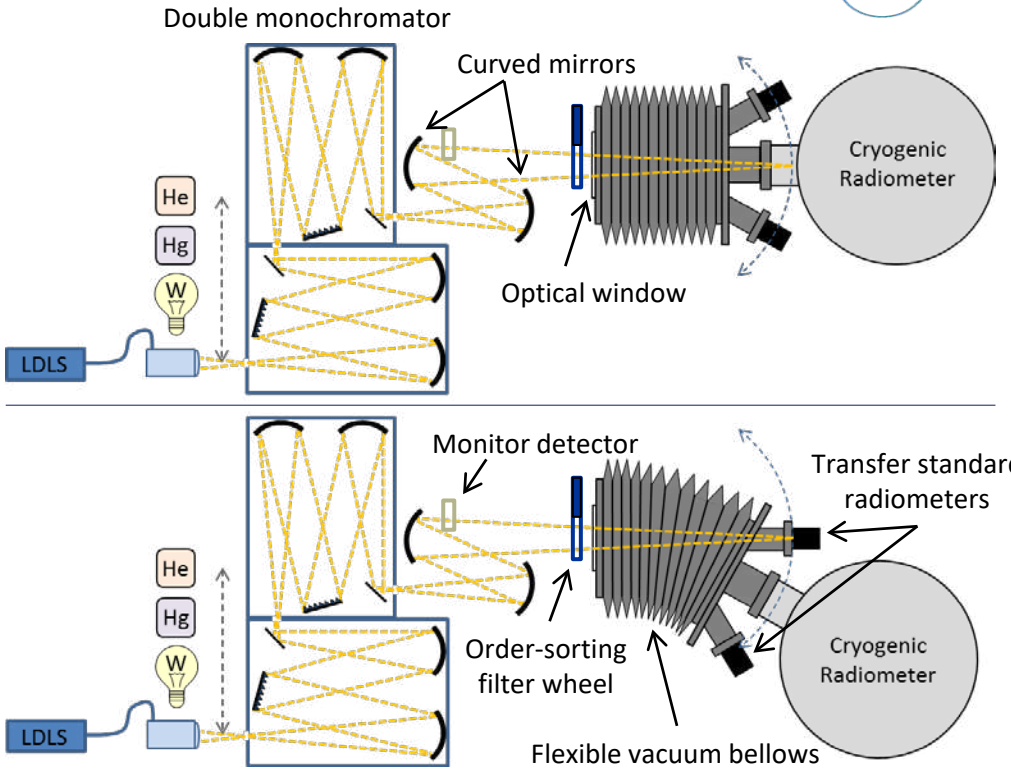


Cryogenic radiometer uncertainty improvements

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

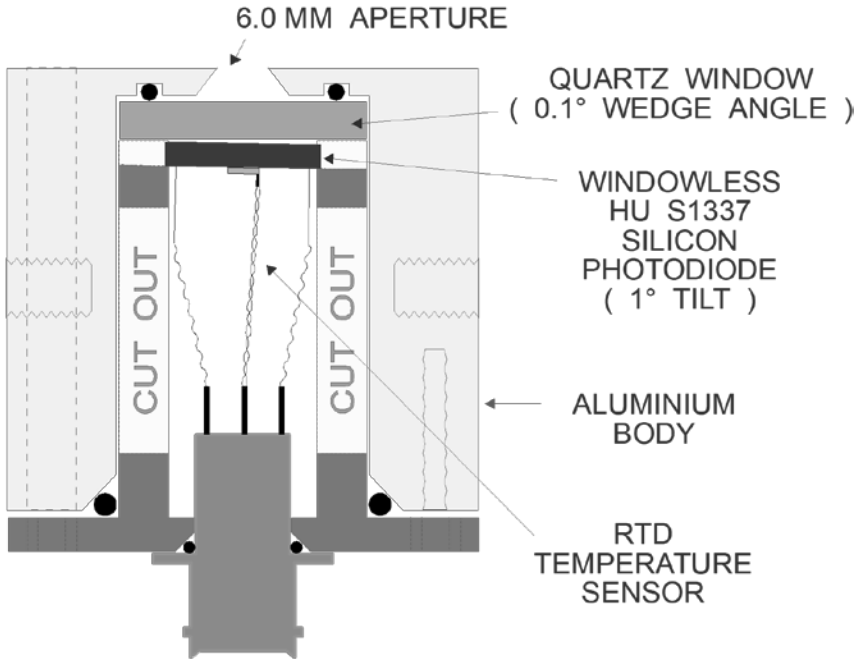
Advanced radiometry facility

- 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

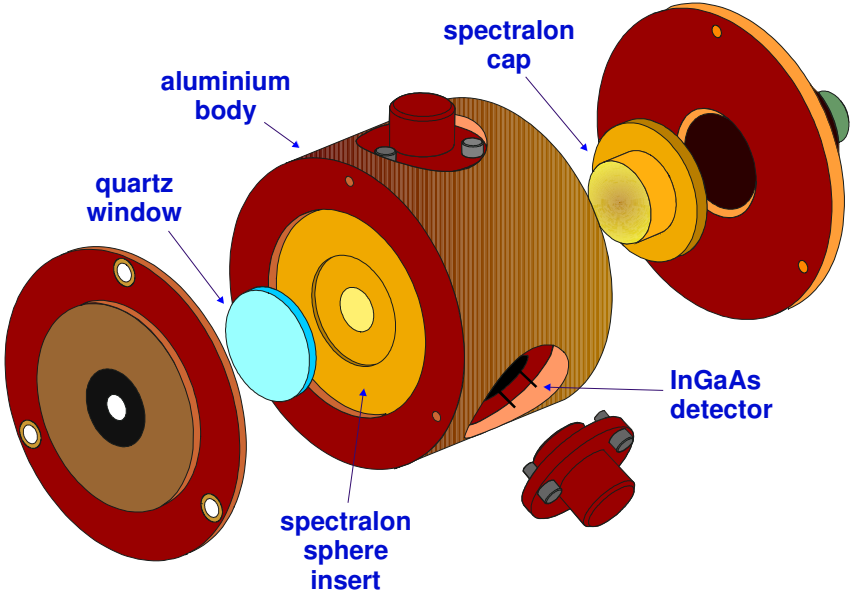
- Single element detector with quartz window
- Vacuum compatible front face
- Temperature monitoring
- Si and PtSi detectors for VIS and UV wavelength ranges



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

Transfer standard radiometers

- Sphere radiometer design
- Small integrating sphere and three 5 mm diameter InGaAs detectors
- Improved spatial uniformity in NIR
- Vacuum compatible front face and temperature monitoring



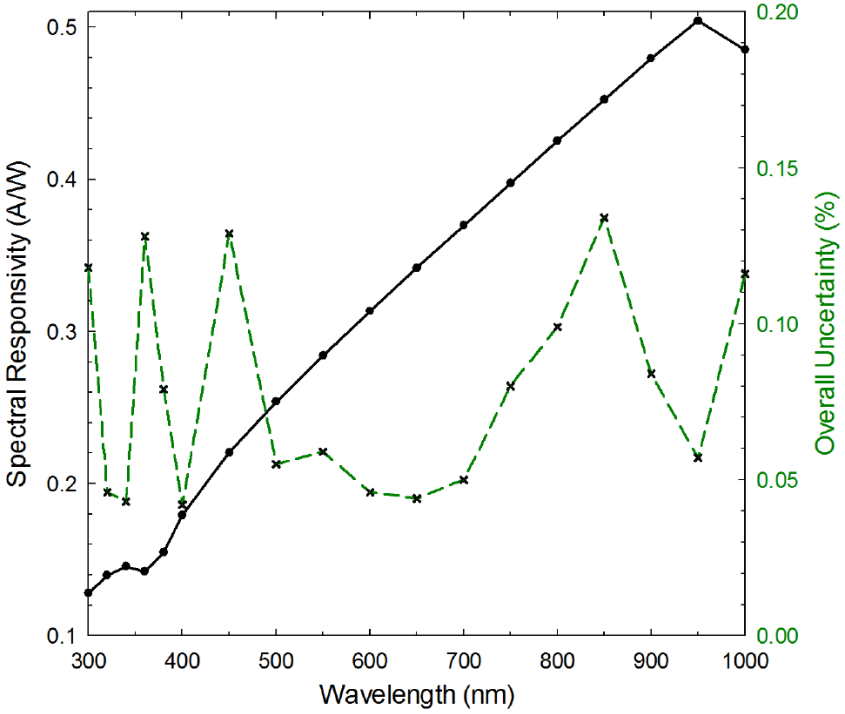
Boivin, Metrologia **37** 237 (2000)

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

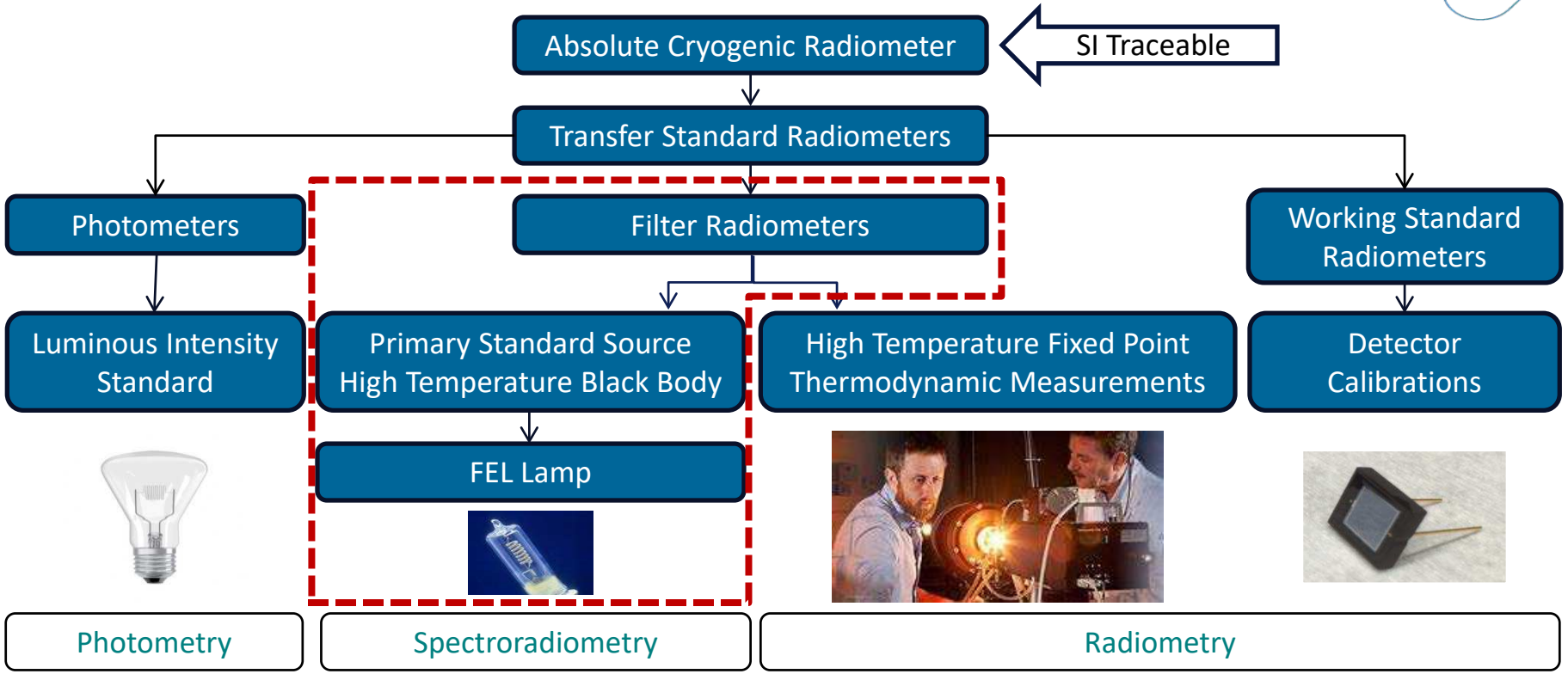
Next step:

- UV scale from 200 nm to 400 nm



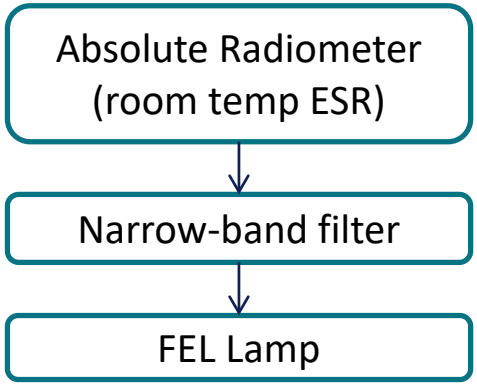
Average of uncertainty components from four Si transfer standard detectors

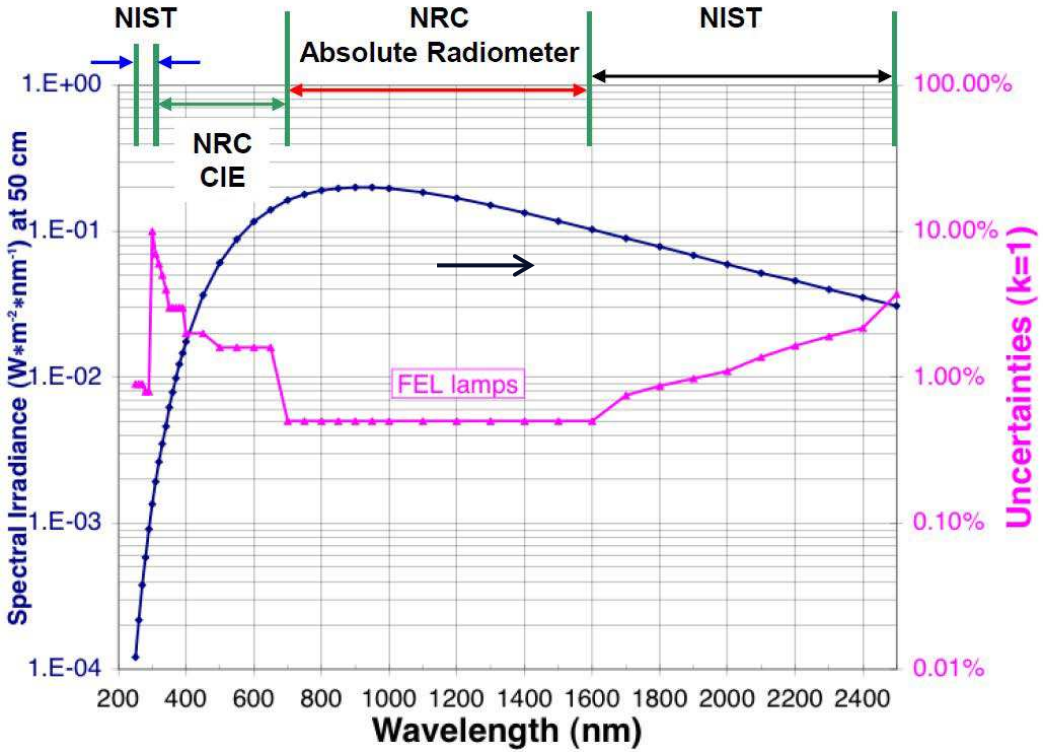
Spectral irradiance scale



Spectral irradiance scale transition

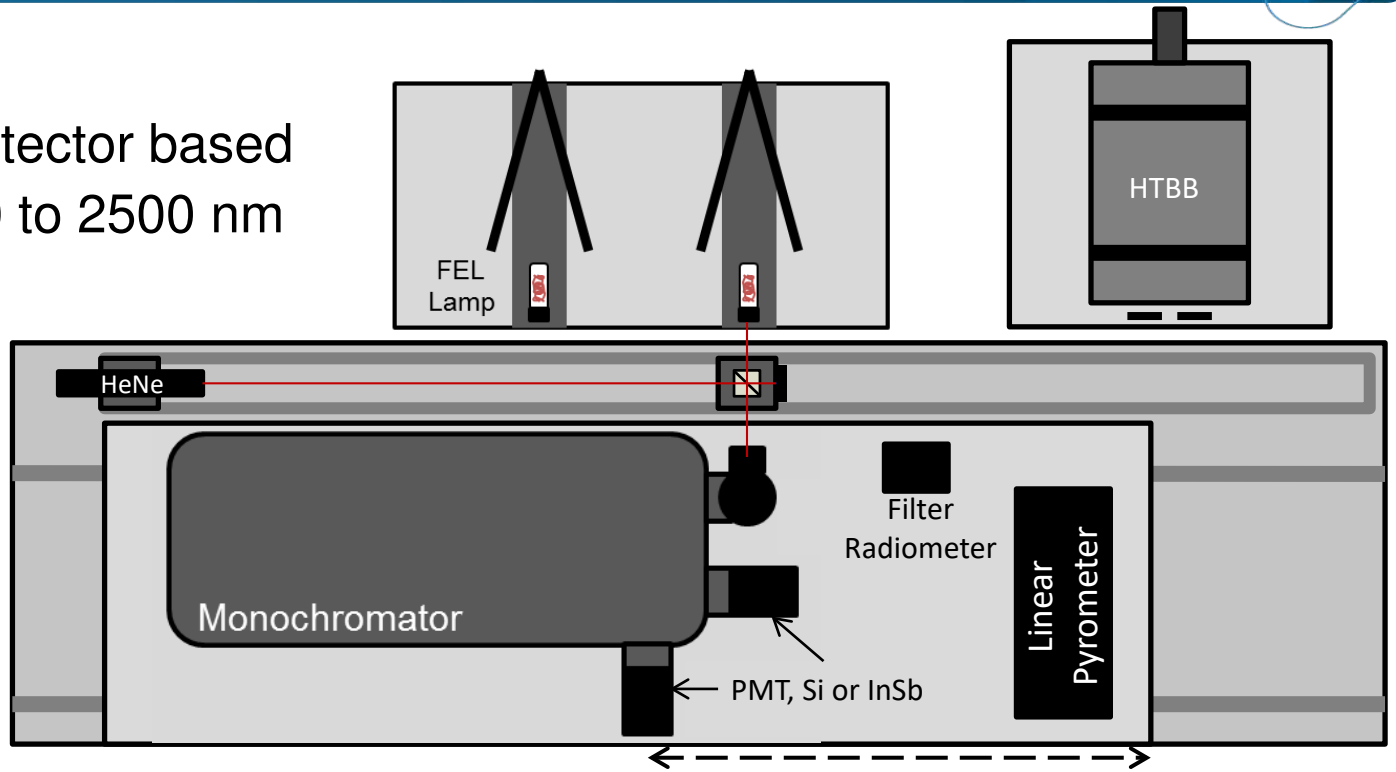
Detector based scale 700 -1600 nm





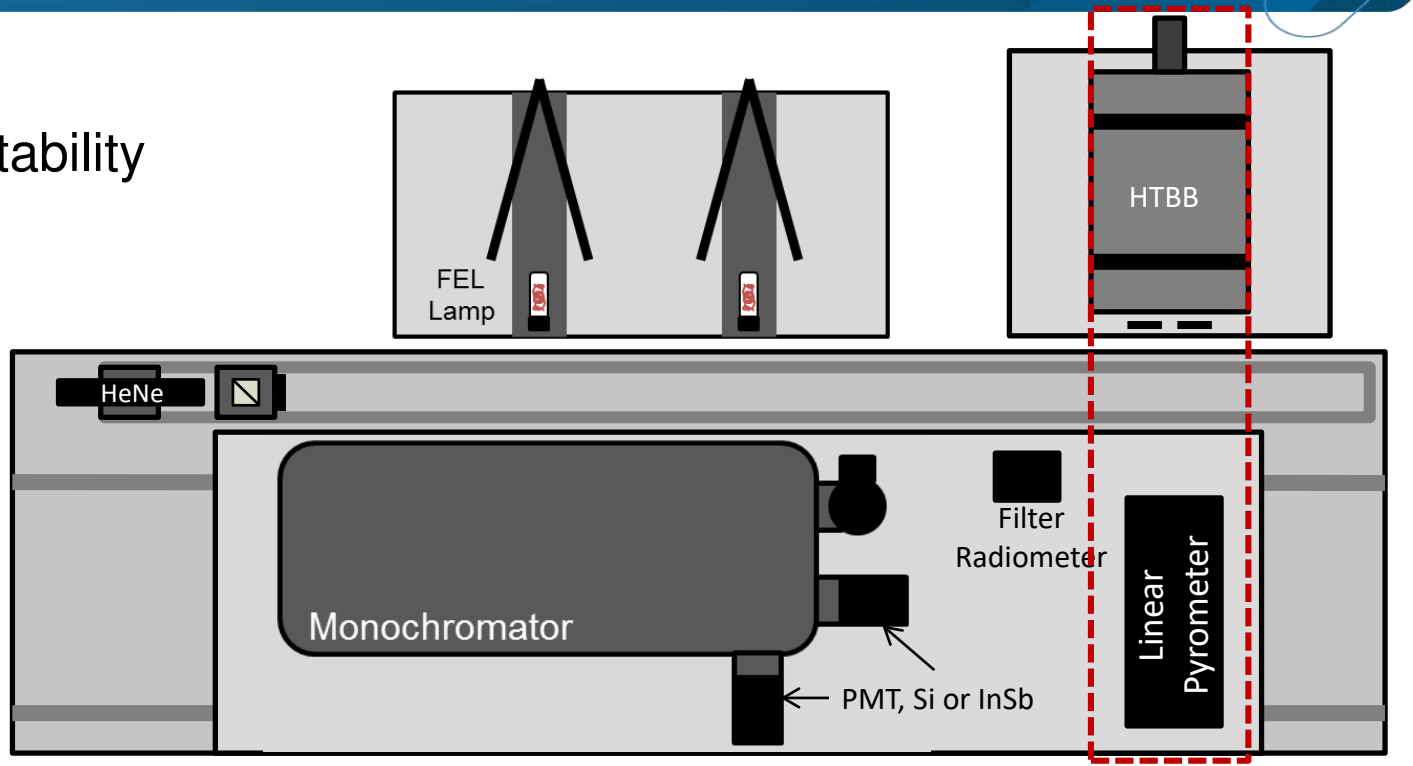
Spectral irradiance facility

- Source and detector based scale from 250 to 2500 nm



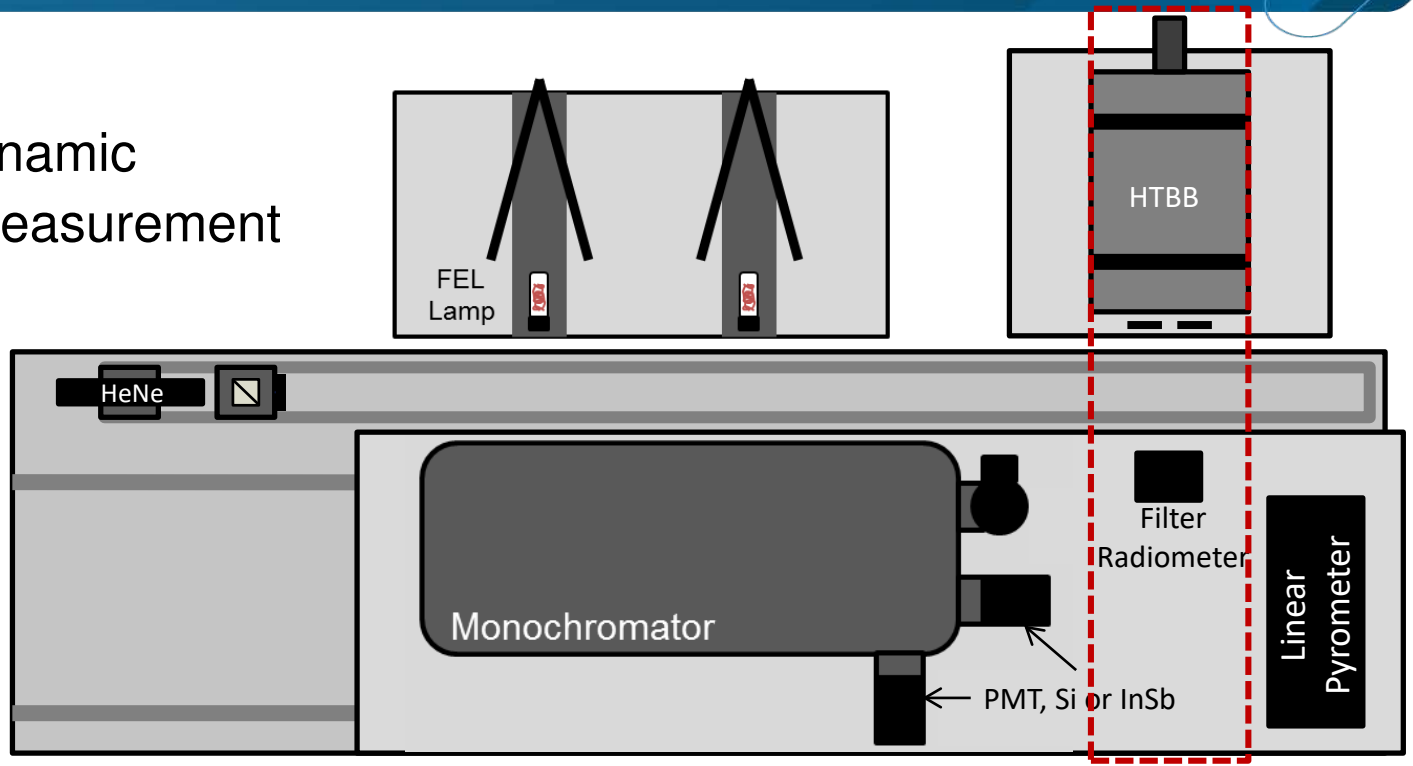
Spectral irradiance facility

- Temperature stability varification



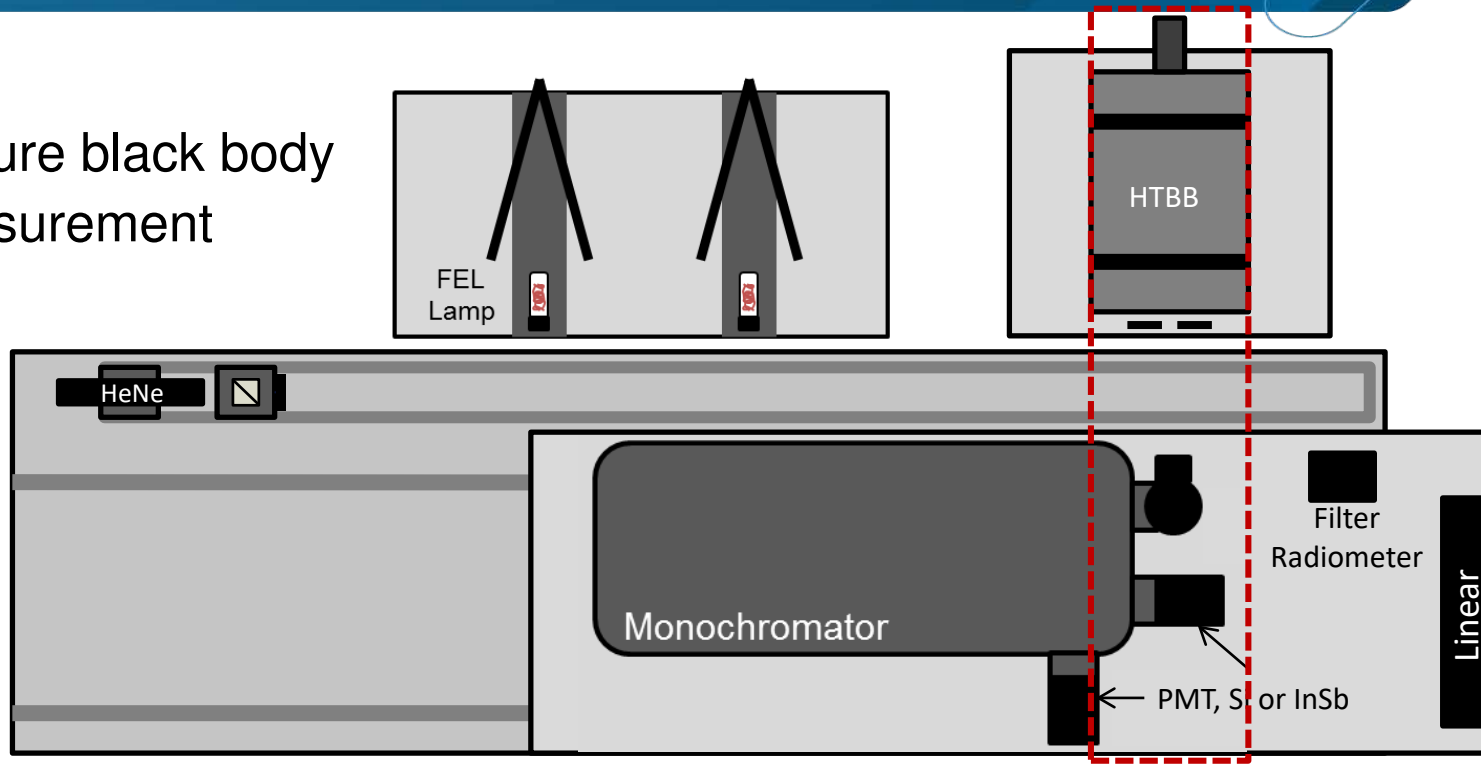
Spectral irradiance facility

- First thermodynamic temperature measurement



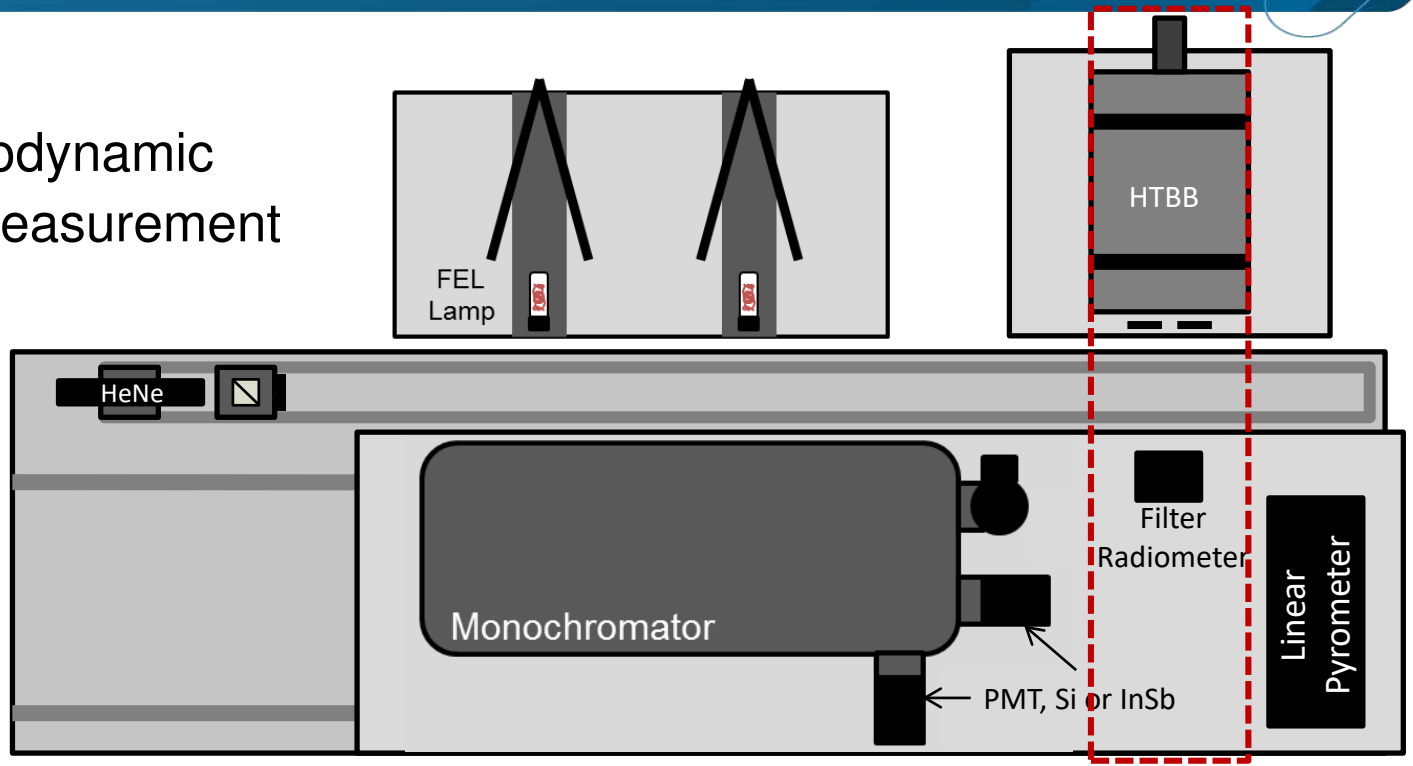
Spectral irradiance facility

- High temperature black body spectrum measurement



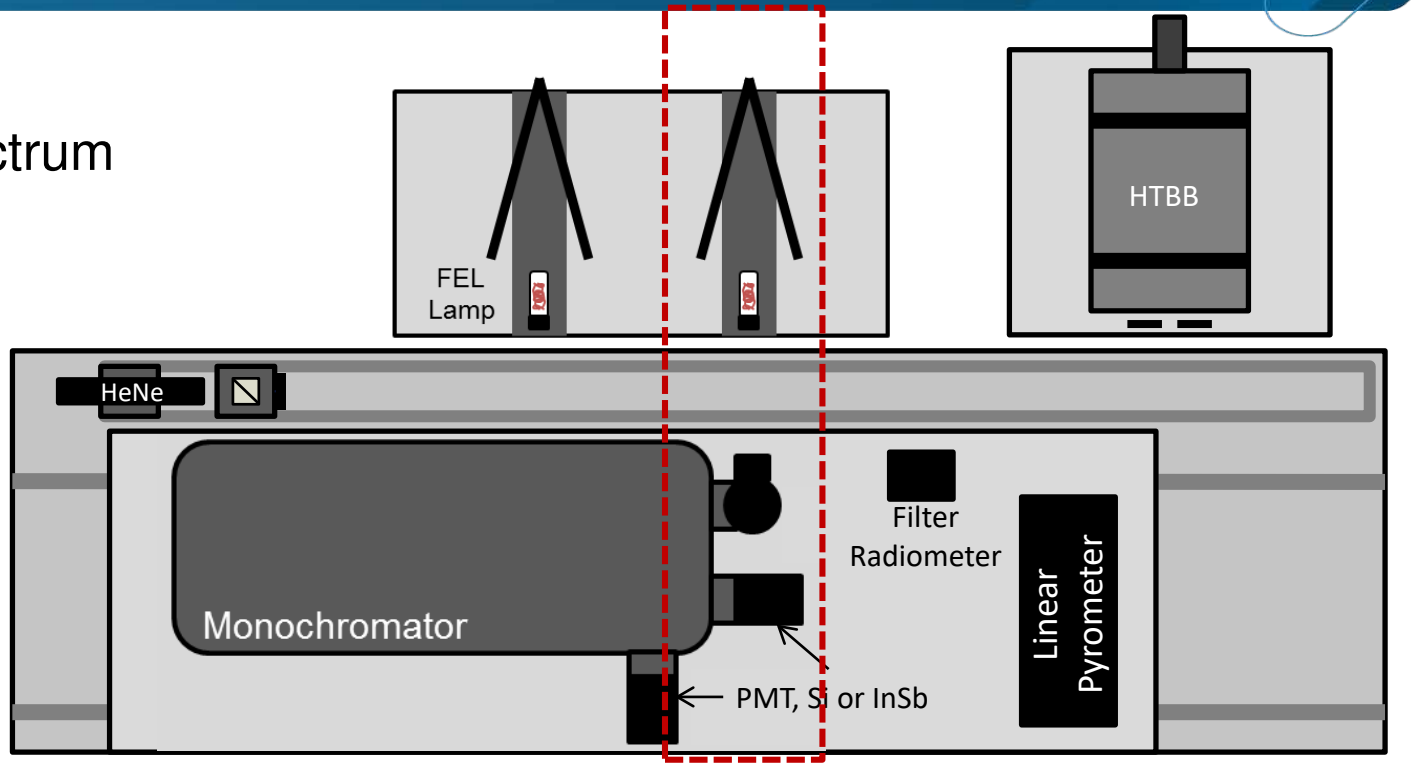
Spectral irradiance facility

- Second thermodynamic temperature measurement

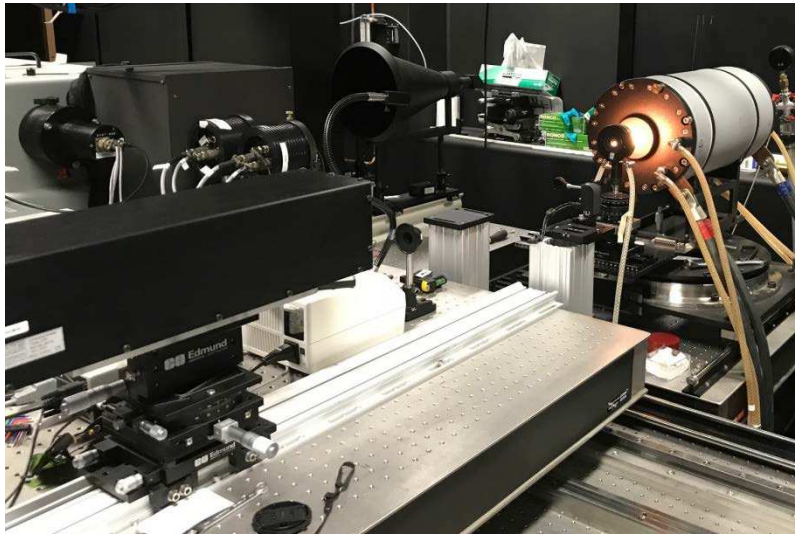


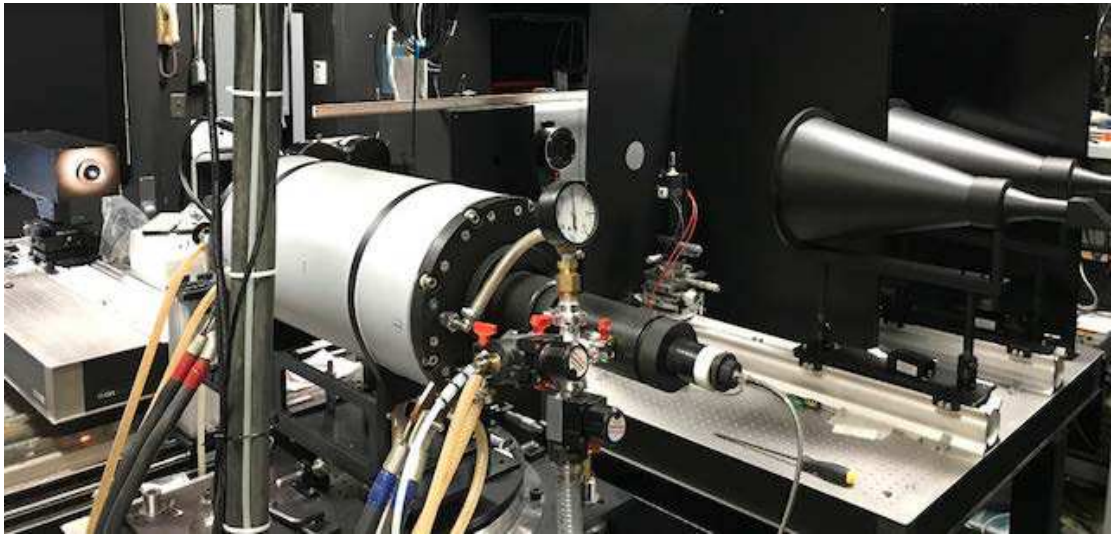
Spectral irradiance facility

- FEL lamp spectrum measurement



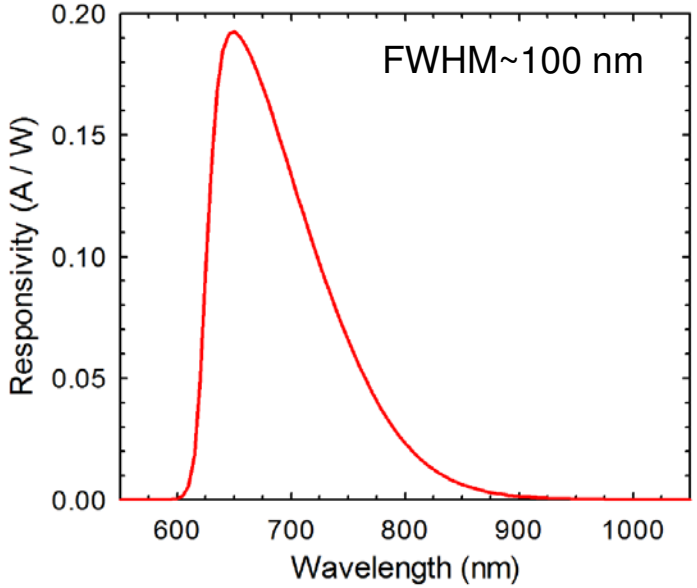
Spectral irradiance facility

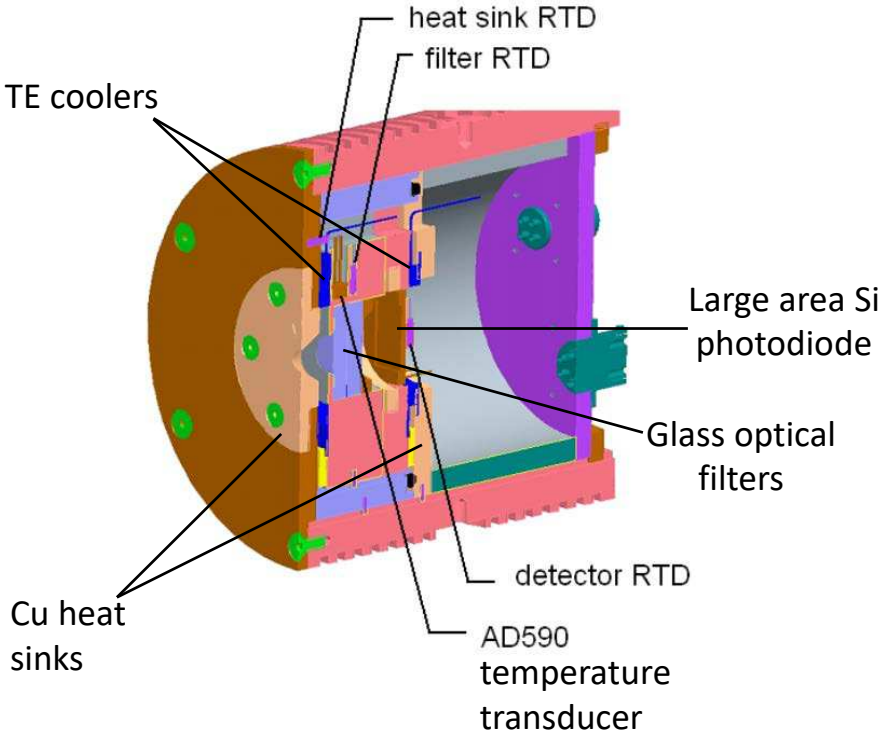




Thermodynamic temperature measurement

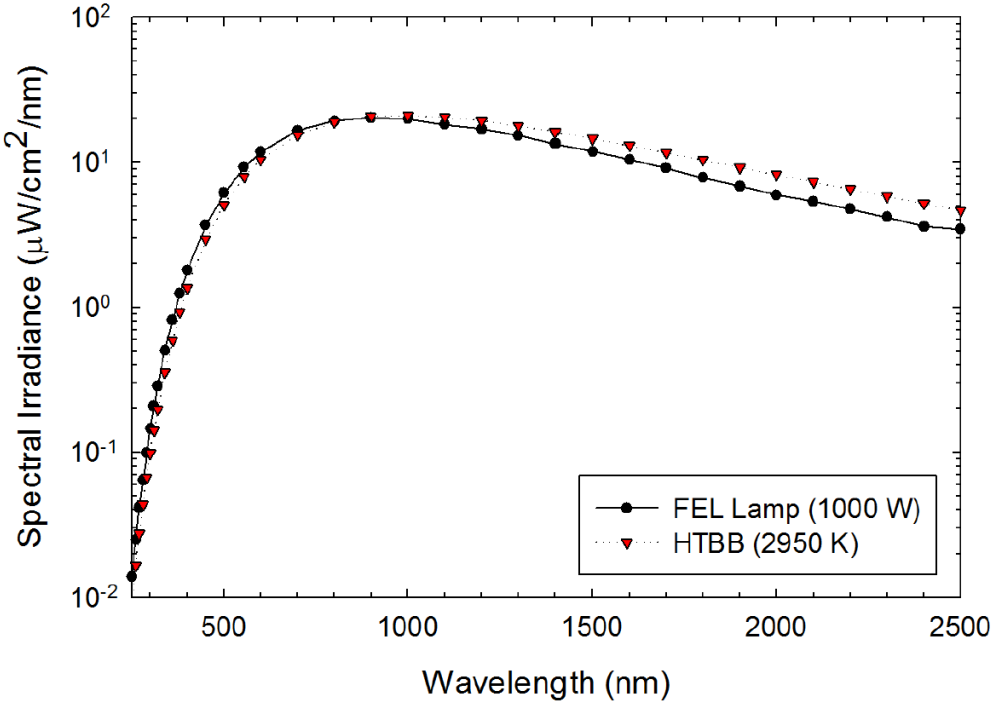
- NRC wideband filter radiometer
- Calibrated using transfer radiometers and monochromator based apparatus



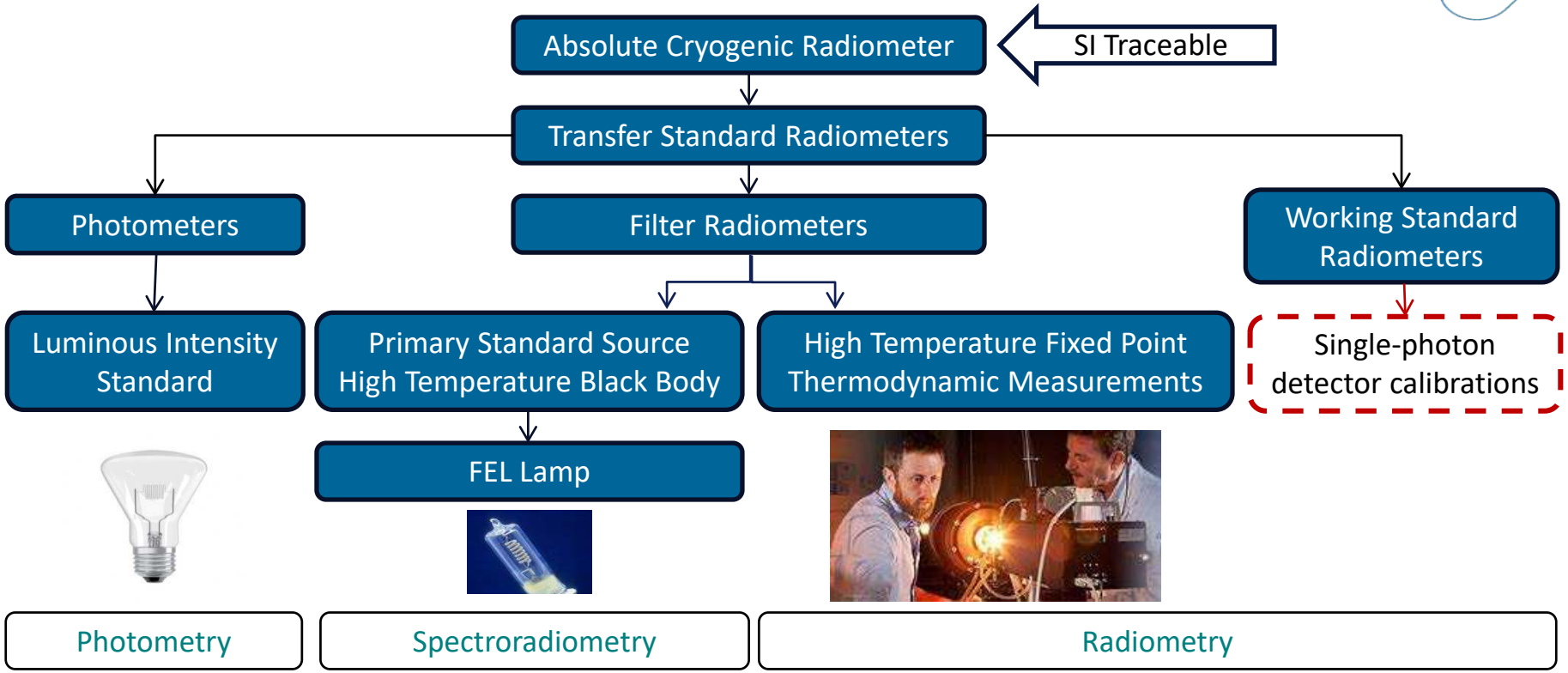


Spectral irradiance facility

- 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



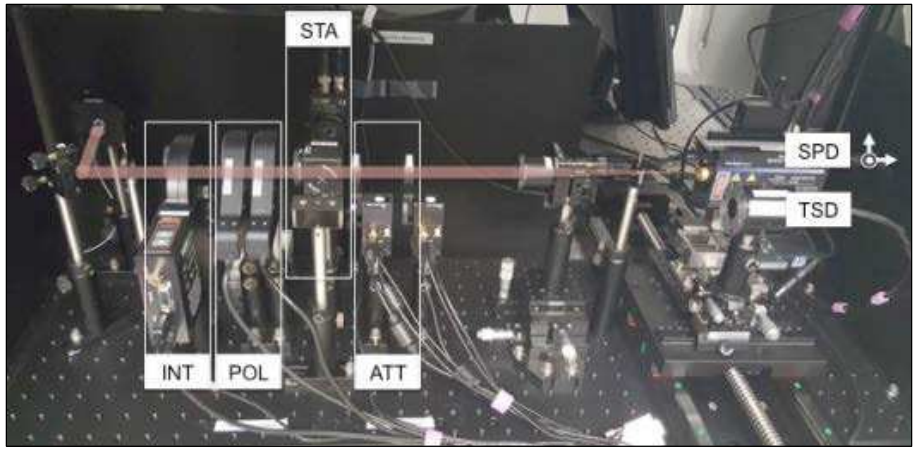
Few Photon Metrology at NRC

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

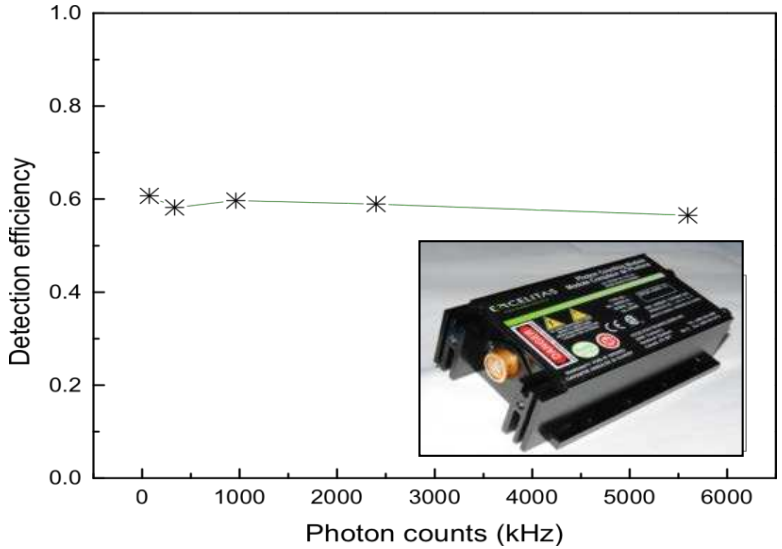
Single-photon detector characterization

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

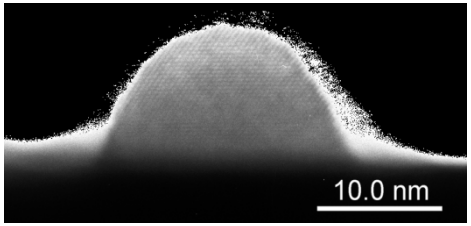


Efficiency measurements by substitution method

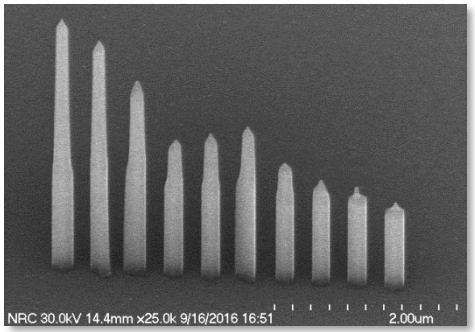


Quantum dot single-photon source

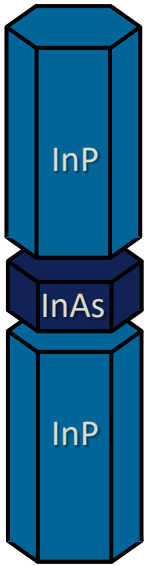
- For quantum information applications - Dan Dalacu and Robin Williams at NRC



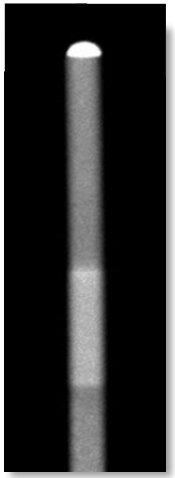
Self-assembled quantum dot



Site-controlled nanowires



Structure of QD embedded in nanowire



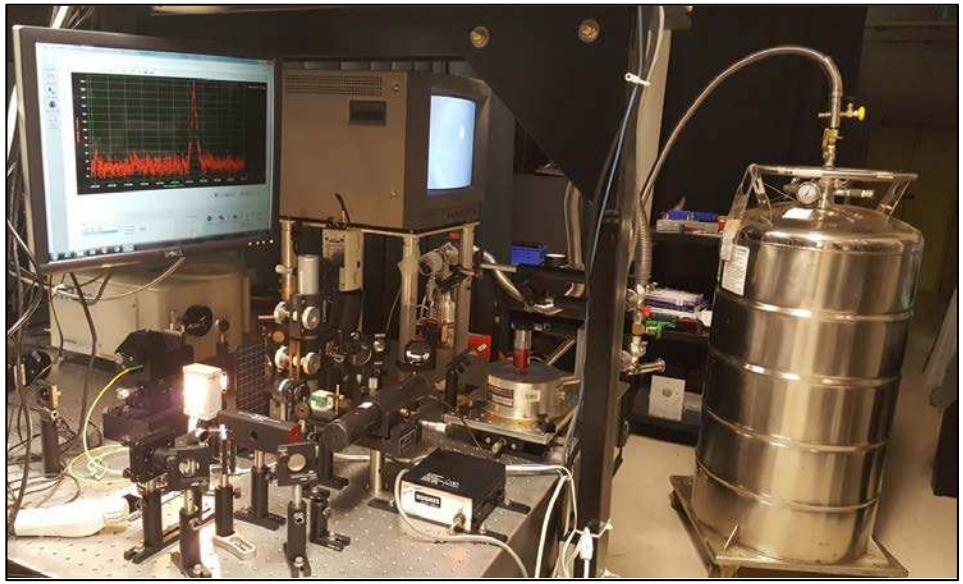
InAs quantum dots within InP nanowire

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



Single photon source characterization apparatus

Few photon measurements

NRC quantum dot photon sources → photons for multiparticle entangled states

Higher-order entangles states - double or triple quantum dots in semiconductor nanowire

New single photon source measurement apparatus

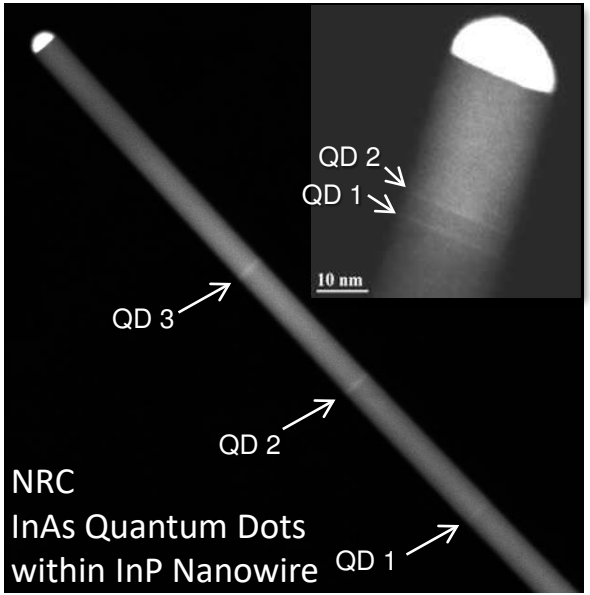


Image: D. Dalacu

Thank you

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