Building a Spectral Irradiance Scale
- the basis for the measurement of light

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Outline

1. Basic light measurement
   - spectral irradiance
2. Calibration Chains
   - light sources
   - basic NMI techniques
3. NRC-INMS Spectral Irradiance
   - present scale
   - comparison results
   - planned scale

NRC · CNRC

Basic Light Measurement:

Photometry

- how much?
- absolute measurement of a quantity (Q) of light

$$Q = K_m \cdot \int S(\lambda) \cdot V(\lambda) \cdot d\lambda$$

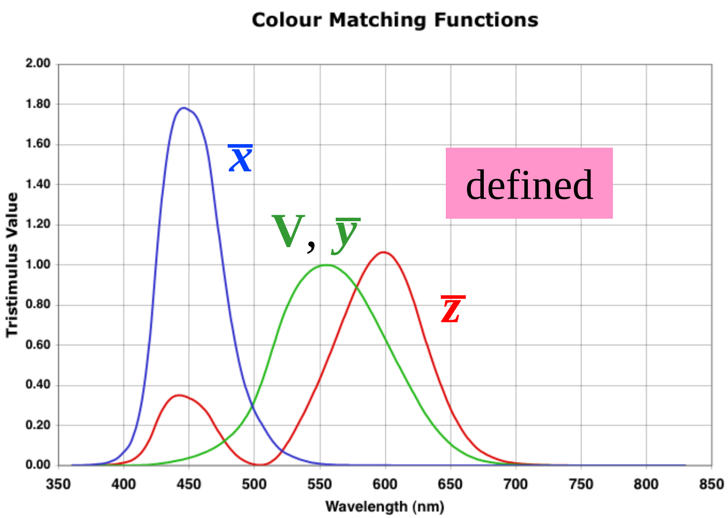
Colorimetry

- what colour?

$$X = K_m \cdot \int S(\lambda) \cdot \bar{x}(\lambda) \cdot d\lambda$$

$$Y = K_m \cdot \int S(\lambda) \cdot \bar{y}(\lambda) \cdot d\lambda$$

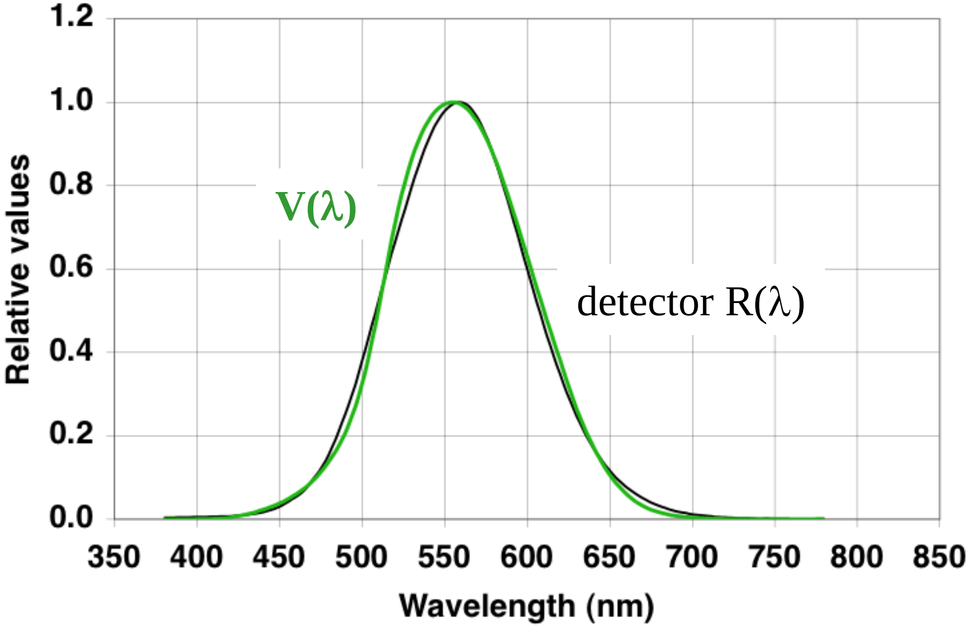
$$Z = K_m \cdot \int S(\lambda) \cdot \bar{z}(\lambda) \cdot d\lambda$$



$S(\lambda)$ = measured output of light source

Basic Light Measurement: filtered detectors

Photometric and Colorimetric detectors are not easy to make

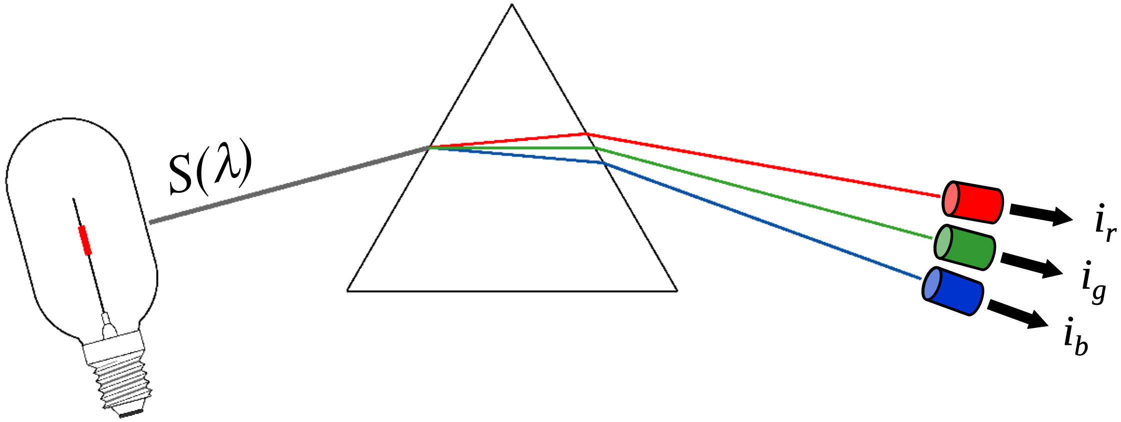


Spectral Correction Factor

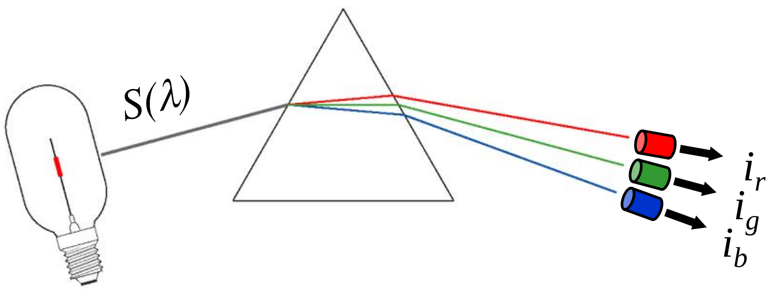
$$\frac{\int S^T(\lambda)\cdot V(\lambda)\cdot d\lambda}{\int S^T(\lambda)\cdot R(\lambda)\cdot d\lambda} \bullet \frac{\int S^S(\lambda)\cdot R(\lambda)\cdot d\lambda}{\int S^S(\lambda)\cdot V(\lambda)\cdot d\lambda}$$

$S^T(\lambda)$ and $S^S(\lambda)$ need to be measured

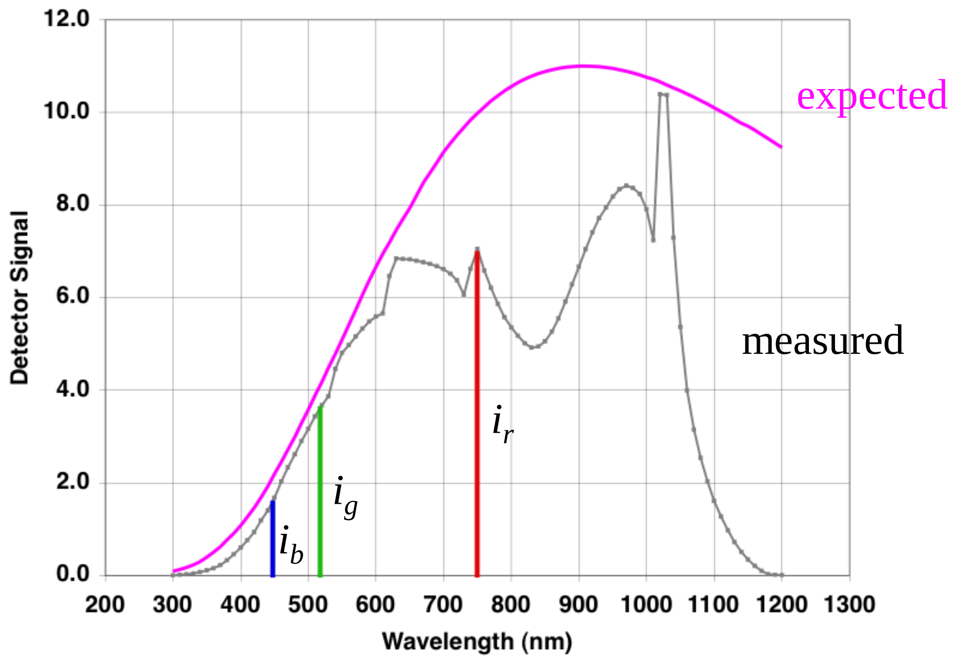
Basic Light Measurement: $S(\lambda)$



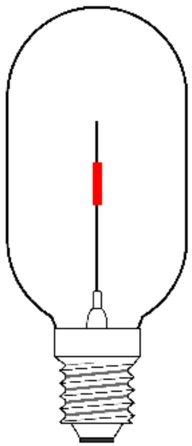
Basic Light Measurement: $S(\lambda)$



Require a <u>known</u> $S(\lambda)$ source
- absolute spectral measurements
- relative spectral measurements

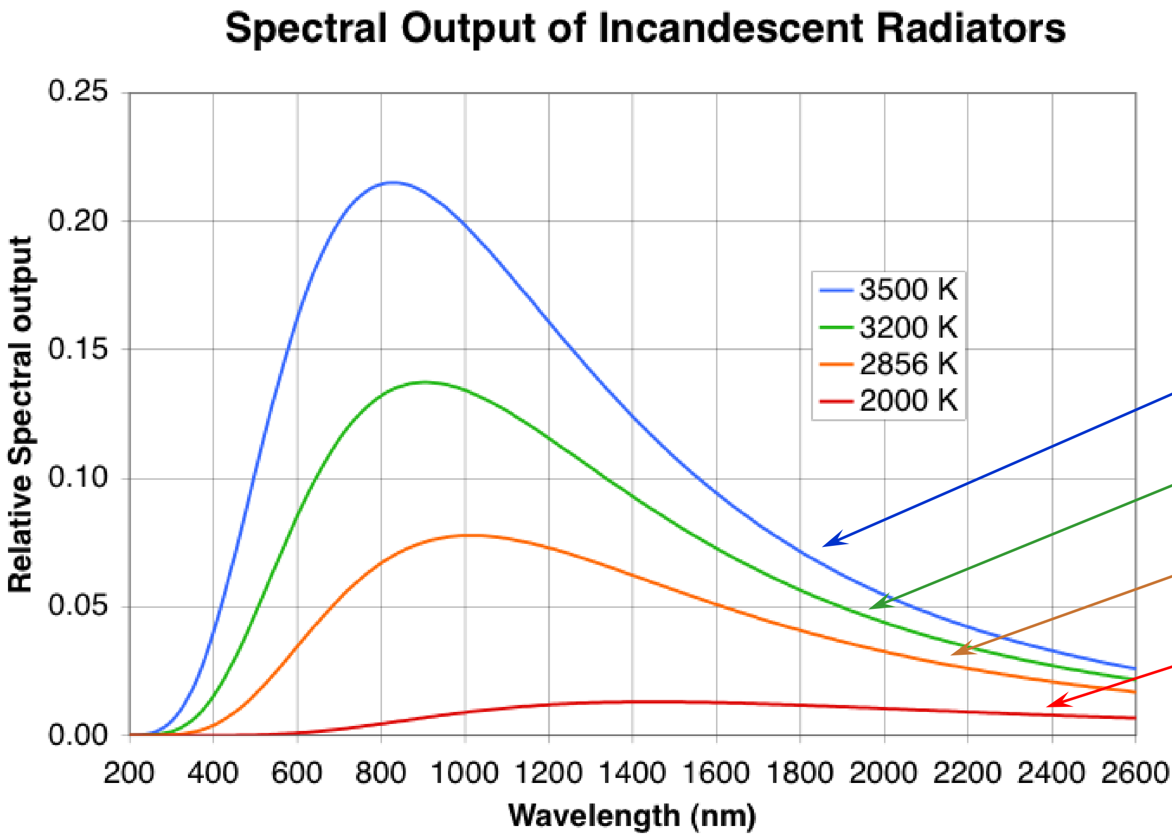


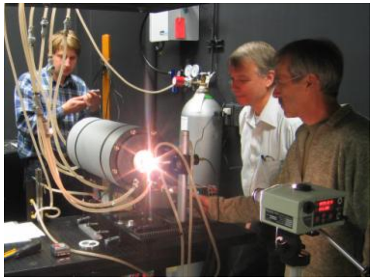
Basic Light Measurement: known $S(\lambda)$ source



- reproducible
- stable during operation
- uniform spatial output
    - sensitivity to alignment
    - inverse square law behaviour
- uniform (‘smooth’) spectral output
- sensitivity to electrical operating parameters (current, voltage)
- robust
    - sensitivity to handling
    - small aging effect
- safety
    - high internal pressure ?
    - kilowatts of UV ?
- ease of use
    - simple to operate

Basic Light Measurement: known $S(\lambda)$ source



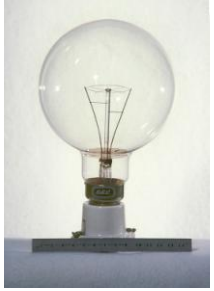


high-temperature black-bodies (HTBB)

tungsten-halogen lamps

gas-filled lamps

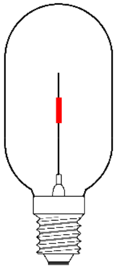
vacuum lamps

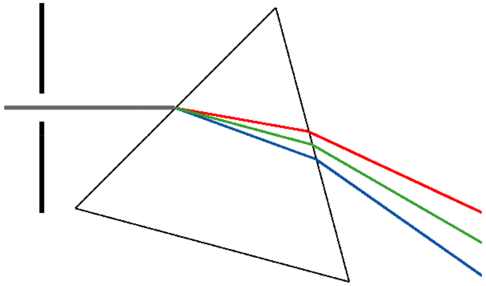


Basic Light Measurement: known *S(λ)* source

- **geometrical quantity**
    - what part of (flux from) the light from the lamp is to be measured?

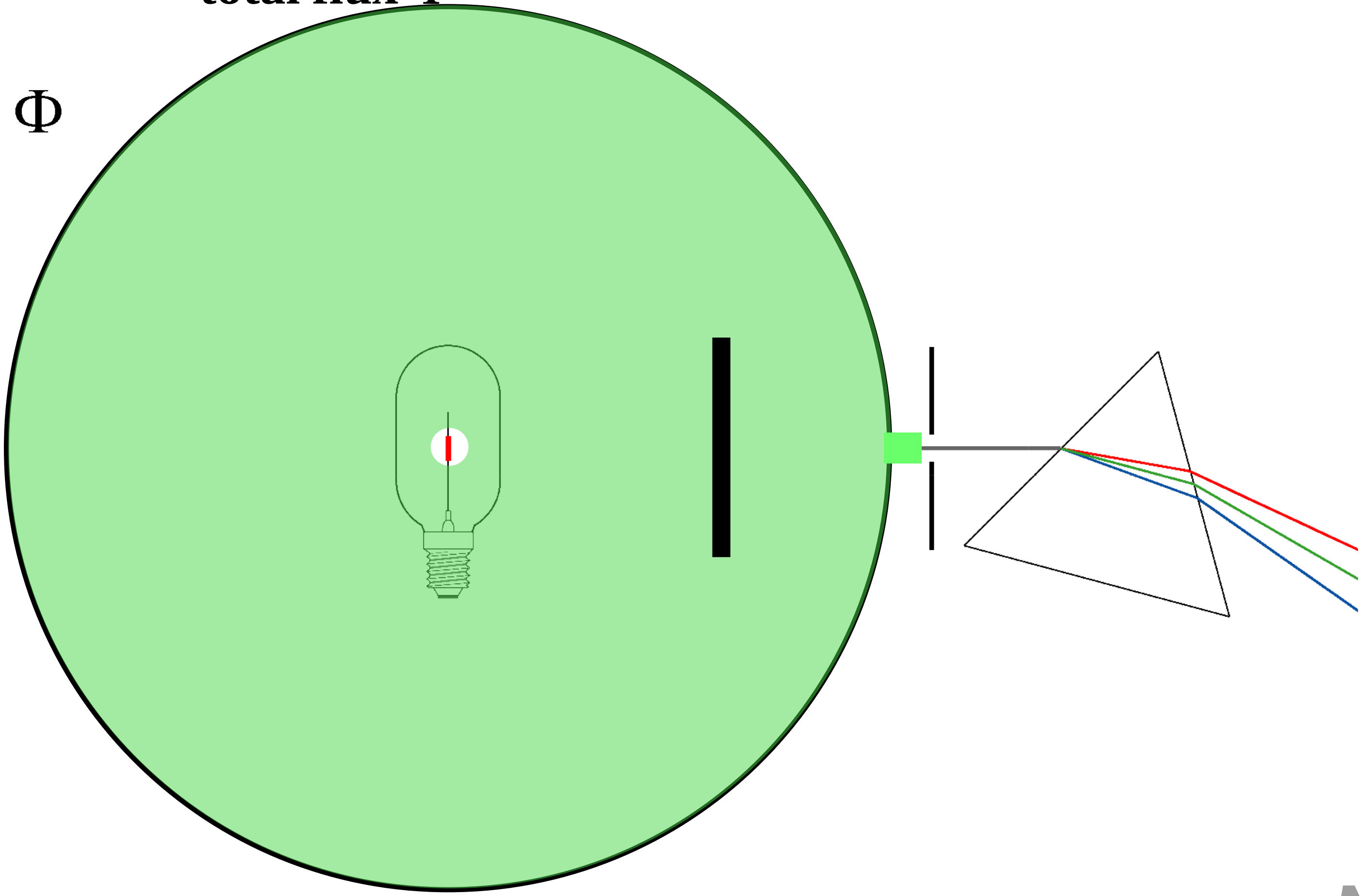
- total flux
- intensity
- radiance
- irradiance





Basic Light Measurement: known *S(λ)* source

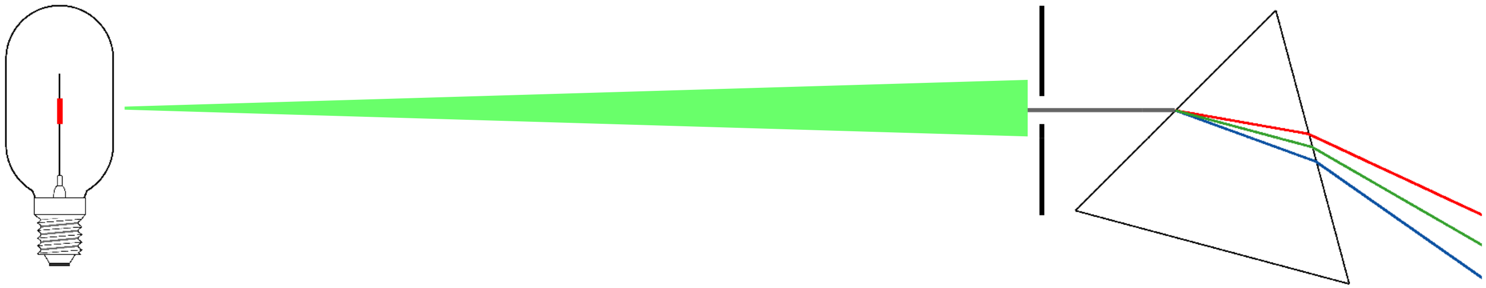
- total flux Φ



Basic Light Measurement: known $S(\lambda)$ source

- intensity

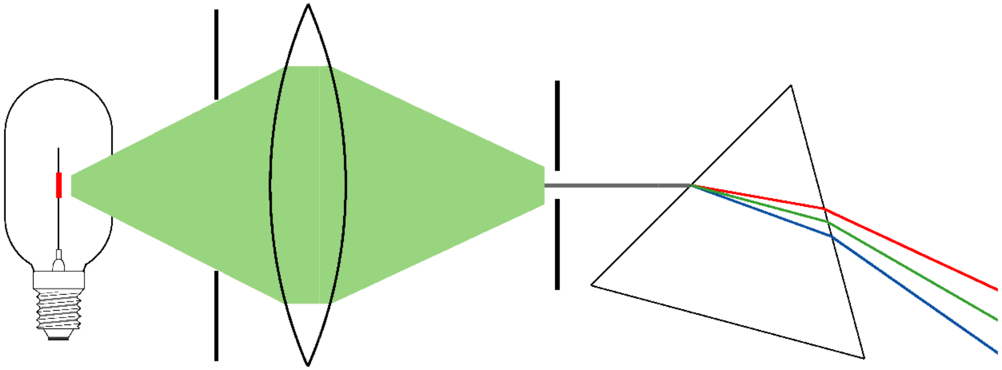
$$I = \frac{\Phi}{\Omega} \equiv \frac{flux}{solidangle}$$



Basic Light Measurement: known *S(λ)* source

- radiance

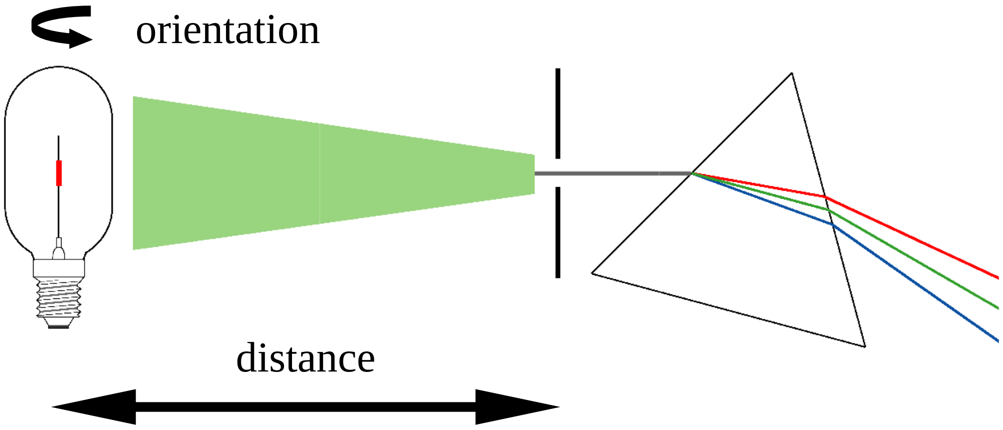
$$L = \frac{\Phi}{\Omega \cdot A_p}$$



Basic Light Measurement: known $S(\lambda)$ source

- irradiance

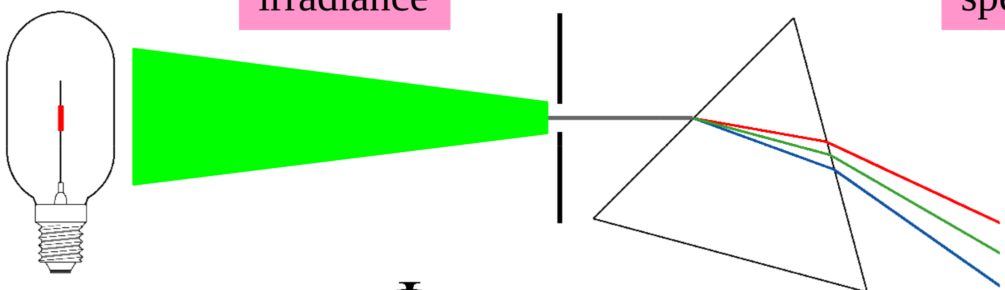
$$E = \frac{\Phi}{A} \equiv \frac{flux}{receiverarea} \qquad unit = watt \cdot m^{-2}$$



Basic Light Measurement: known $S(\lambda)$ source

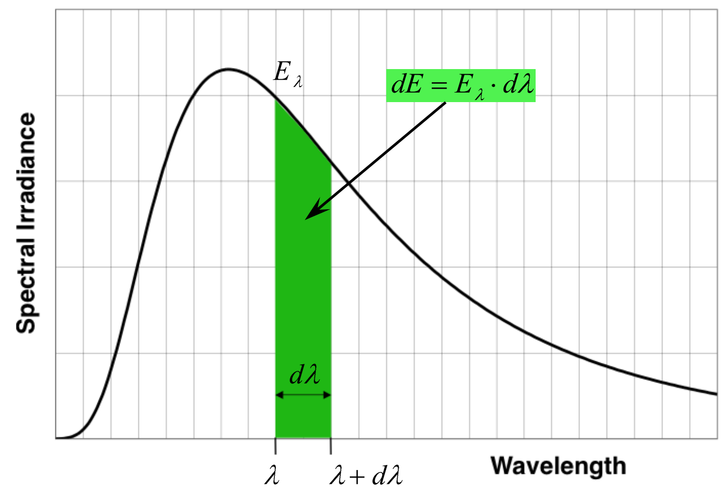
irradiance

spectral irradiance



$$E = \frac{\Phi}{A}$$

$$unit = watt \cdot m^{-2}$$

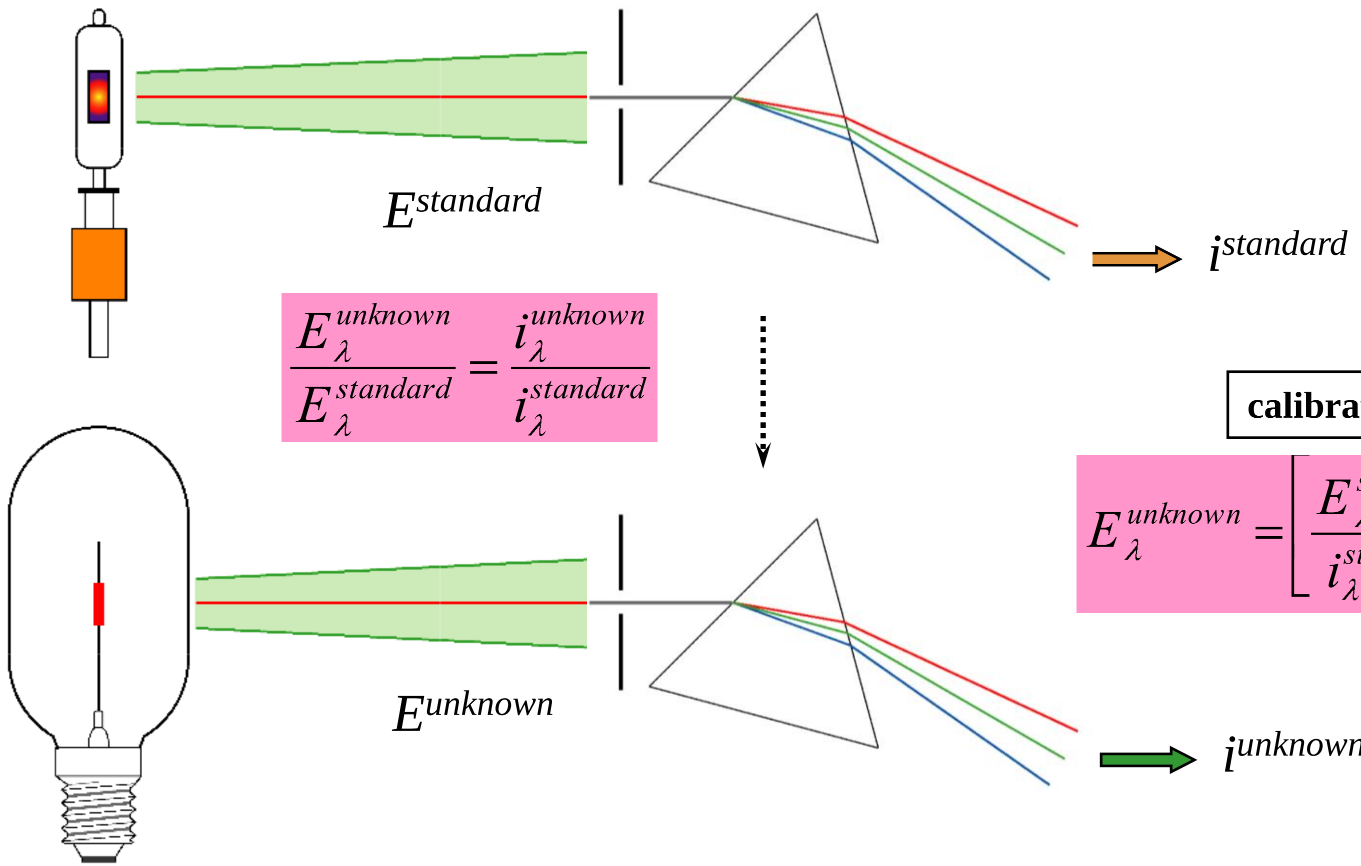


$$E_\lambda = \frac{dE}{d\lambda}$$

$$unit = watt \cdot m^{-2} \cdot m^{-1}$$

$$= \mu watt \cdot cm^{-2} \cdot nm^{-1}$$

Calibration Chain: measurement of unknown lamp

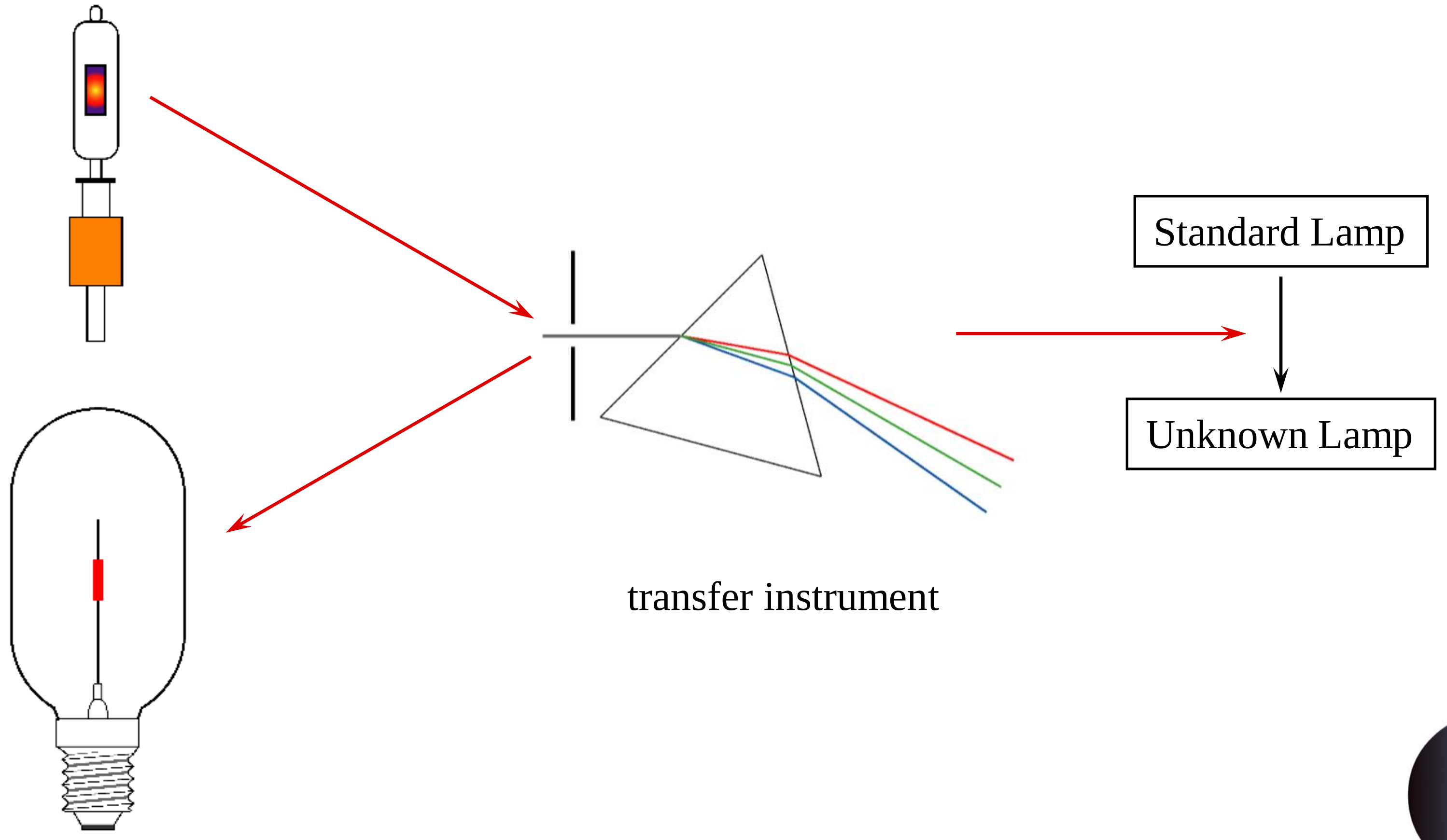


$$\frac{E_\lambda^{unknown}}{E_\lambda^{standard}} = \frac{i_\lambda^{unknown}}{i_\lambda^{standard}}$$

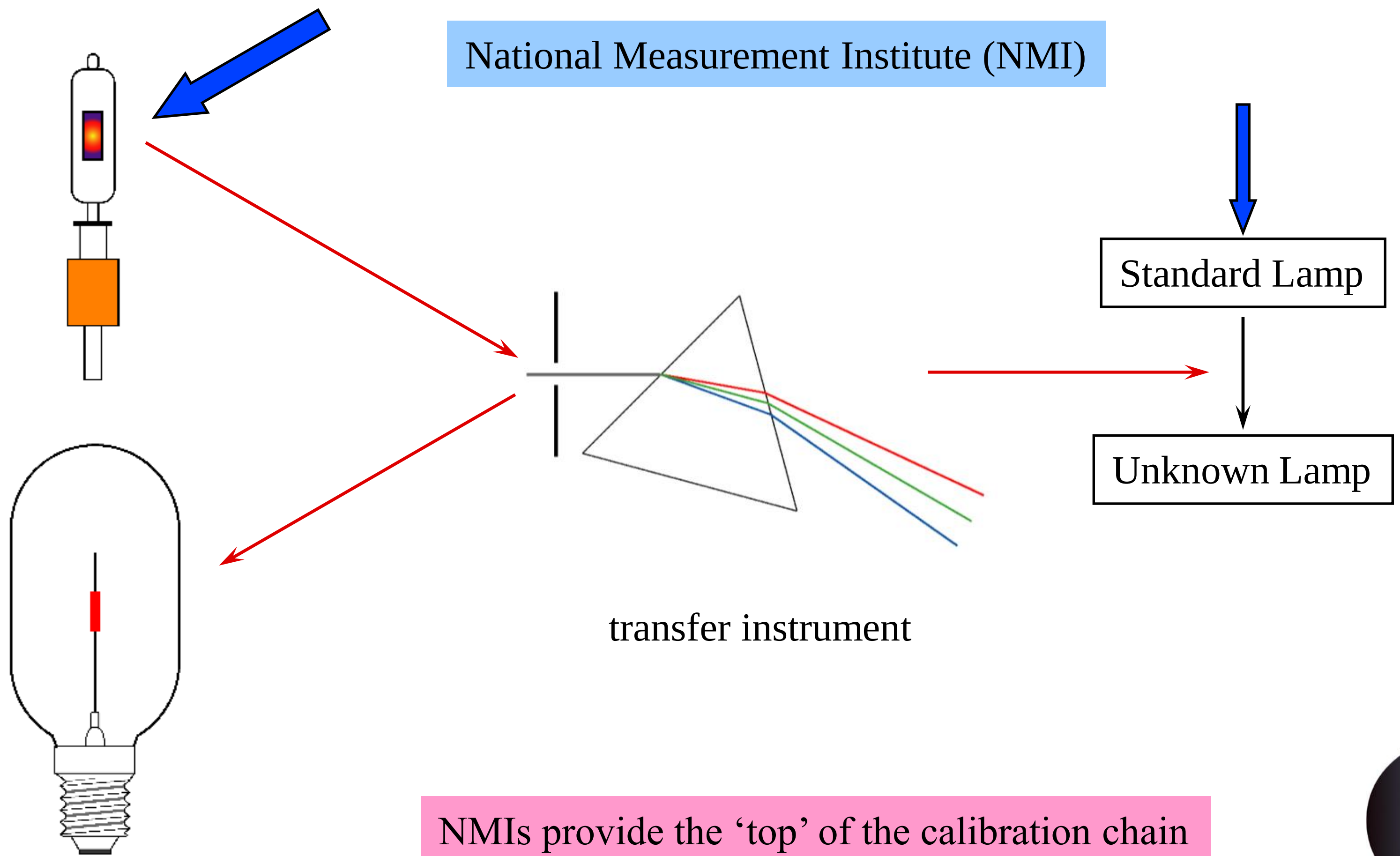
calibration factor

$$E_\lambda^{unknown} = \left[\frac{E_\lambda^{standard}}{i_\lambda^{standard}}\right] \cdot i_\lambda^{unknown}$$

Calibration Chain: one link



Calibration Chain: links to ‘Standard Lamp’



NMIs provide the ‘top’ of the calibration chain

Calibration Chain: links to ‘Standard Lamp’

Possible methods of calibrating the ‘Standard Lamp’

Absolute Radiometer
↓
Calibrated Detector (filter radiometer)
↓
Standard Lamp
↓
Unknown Lamp

detector based

Primary Standard Source
↓
Standard Lamp
↓
Unknown Lamp

source based

Calibration Chain: detector based - direct

Absolute Radiometer

↓

Calibrated Detector (filter radiometer)

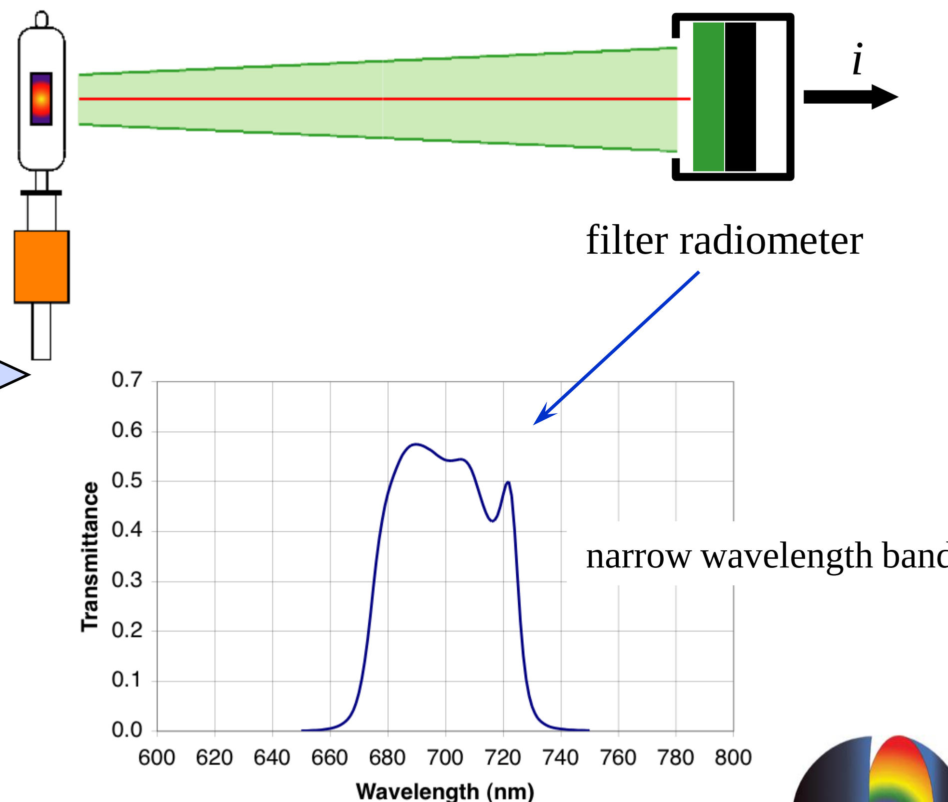
↓

Standard Lamp

↓

Unknown Lamp

detector based



Calibration Chain: detector based - direct

Absolute Radiometer

↓

Calibrated Detector (filter radiometer)

↓

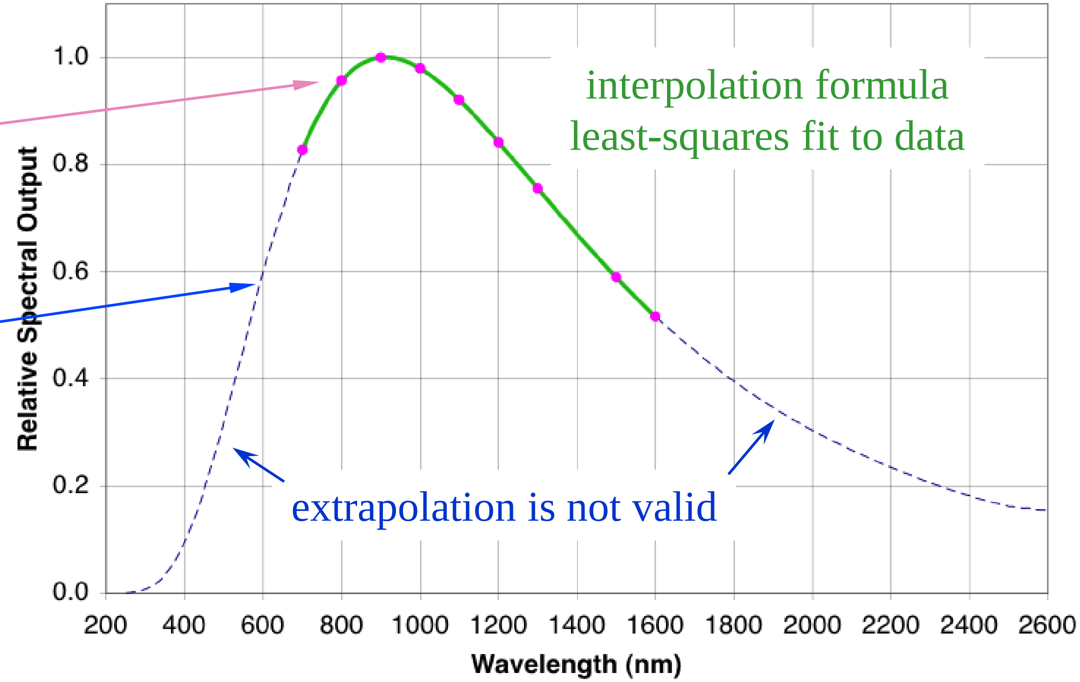
Standard Lamp

↓

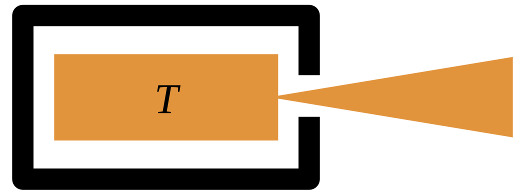
Unknown Lamp

detector based

To calibrate over an extended spectral range many filter radiometers are required



Calibration Chain: source based



Black-Body Source

Primary Standard Source

Standard Lamp

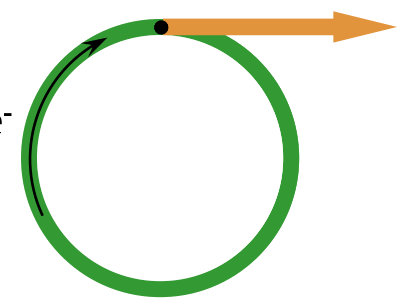
Unknown Lamp

source based

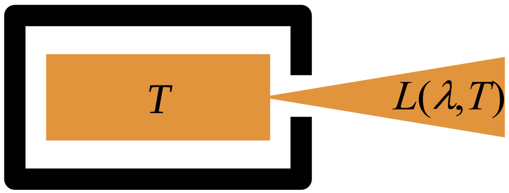
Output can be calculated from first principles

Synchrotron Source

e^-



Calibration Chain: source based - HTBB



T=?

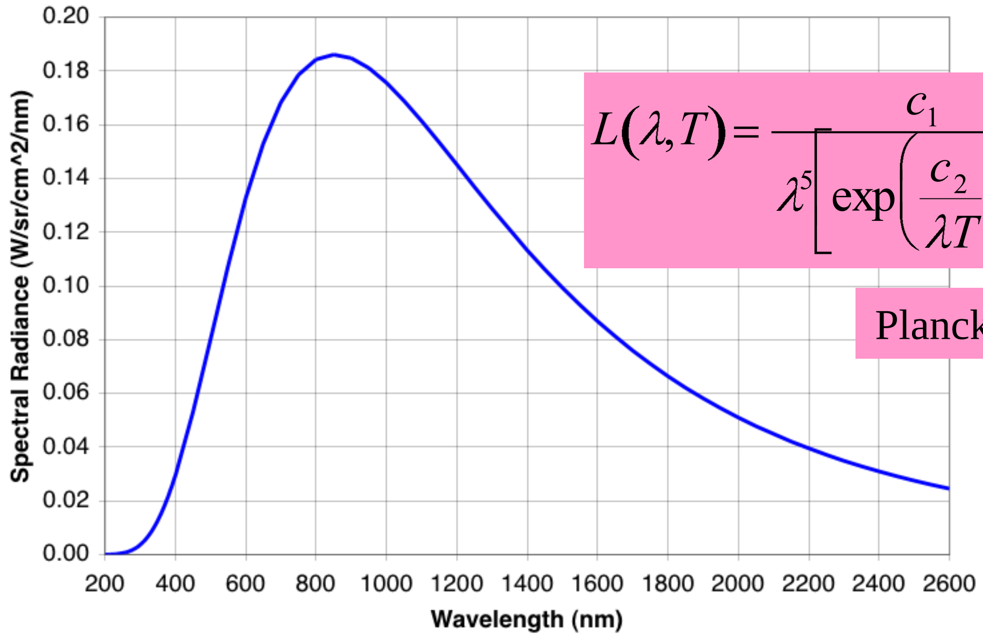
High Temperature Black Body Source

Primary Standard Source

Standard Lamp

Unknown Lamp

source based



$$L(\lambda,T)=\frac{c_1}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T}\right)-1\right]}$$

Planck equation

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Calibration Chain: detector and source based

Absolute Radiometer

Calibrated Detector (filter radiometer)

↓

Primary Standard Source

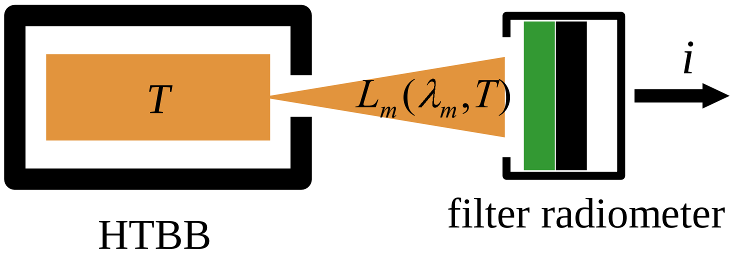
↓

Standard Lamp

↓

Unknown Lamp

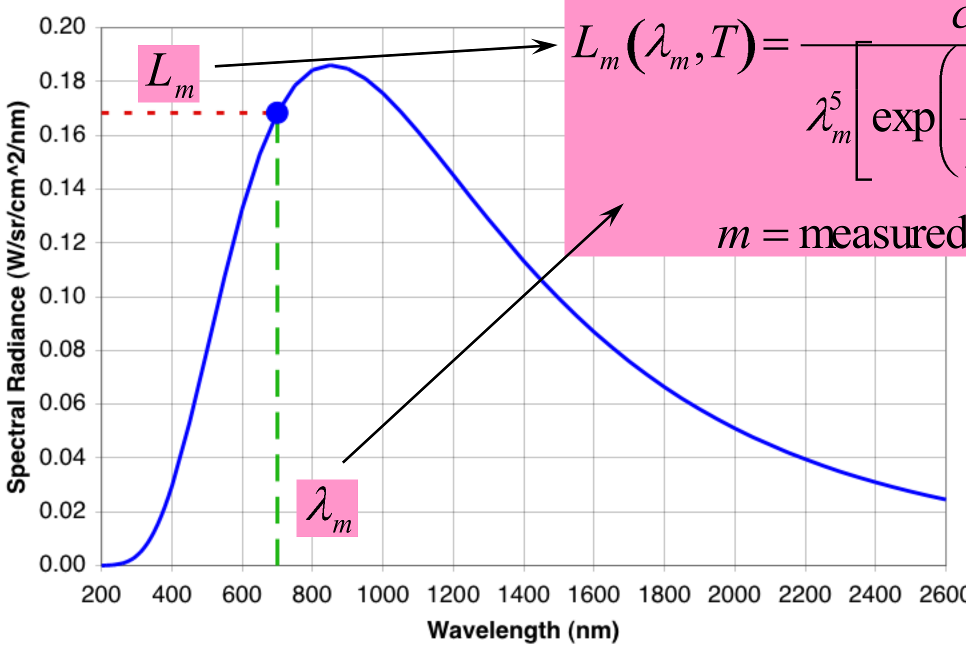
and source based / detector based



T

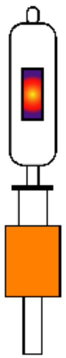
$$L_m(\lambda_m,T)=\frac{c_1}{\lambda_m^5\left[\exp\left(\frac{c_2}{\lambda_m T}\right)-1\right]}$$

m = measured value

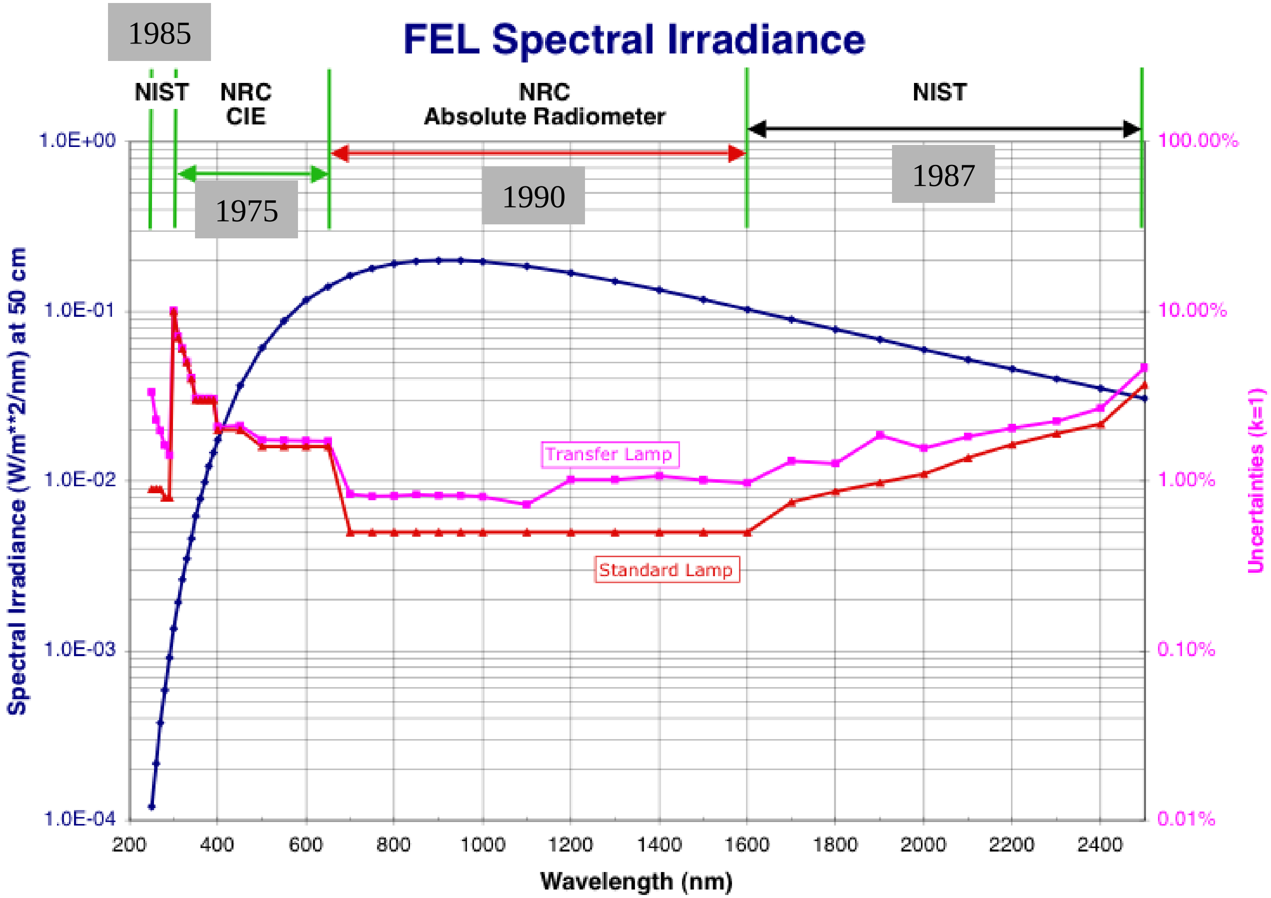


Measure the BB output at one wavelength

Calibration Chain: present NRC scale

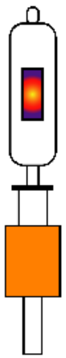


FEL
1000W
incandescent
quartz-halogen



NRC · CNRC

International Comparisons (CCPR)



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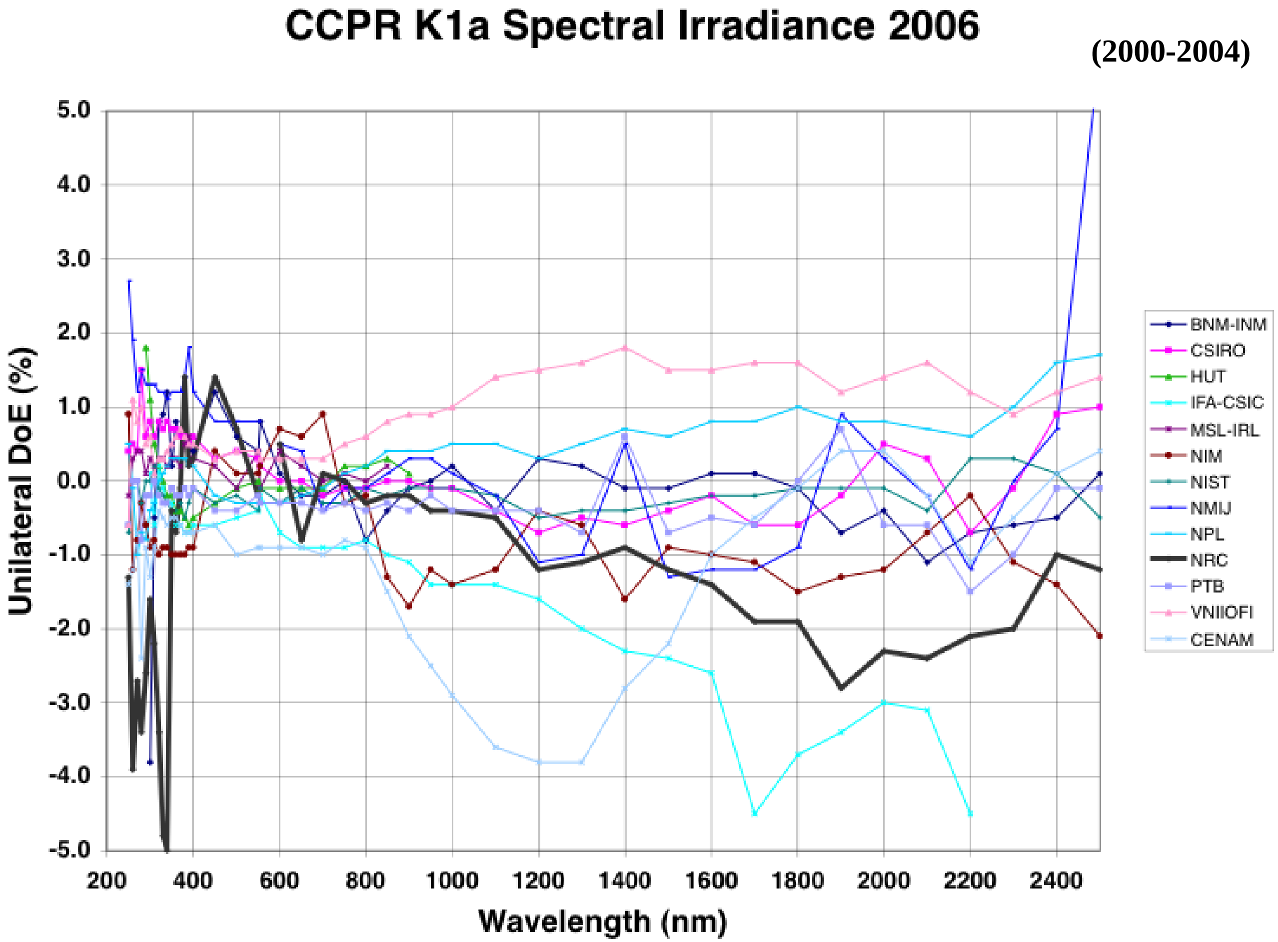

CCPR = Consultative Committee for Photometry and Radiometry

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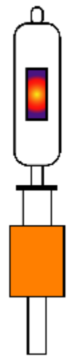

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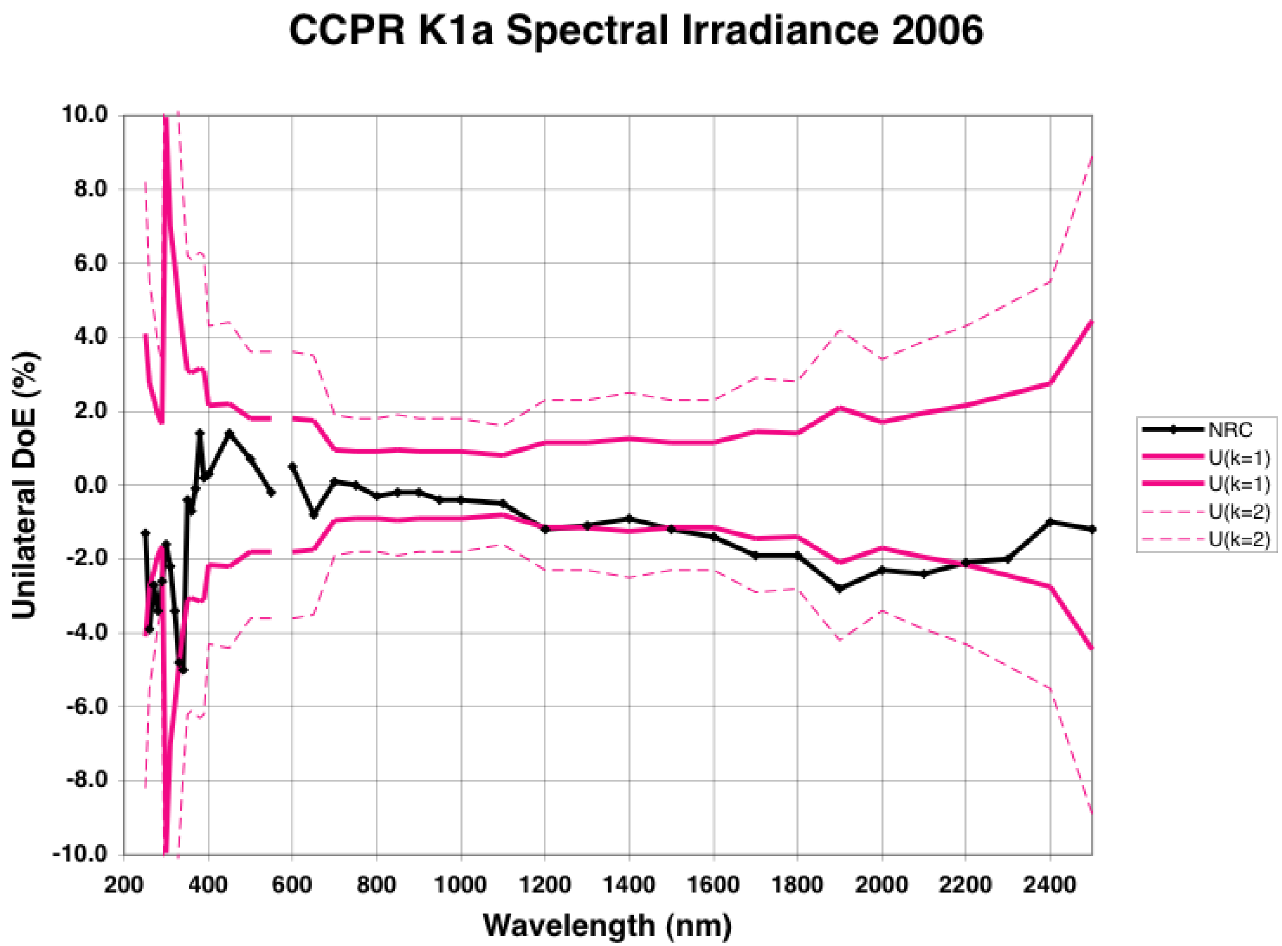

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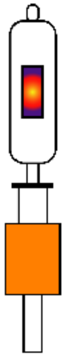

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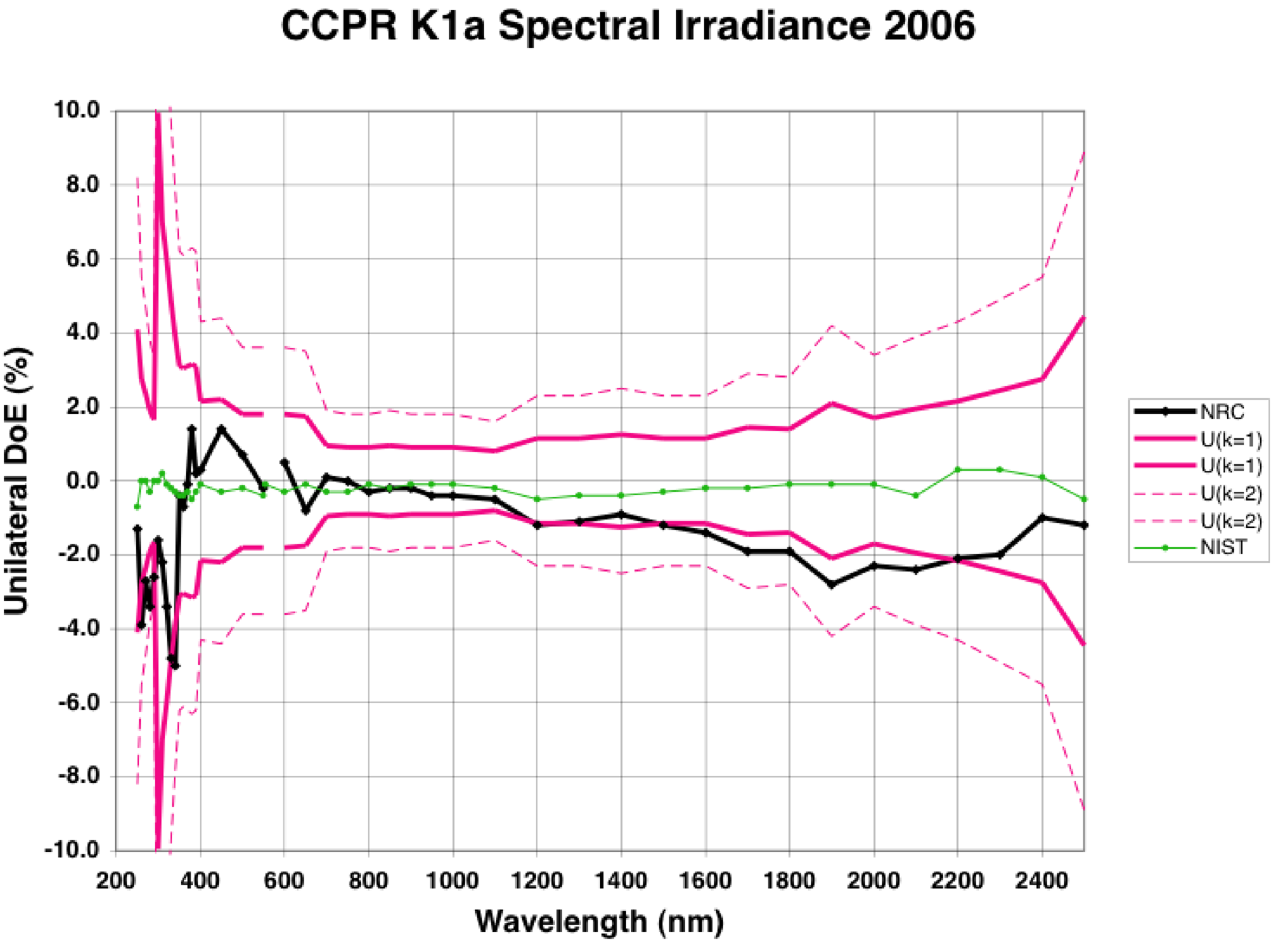
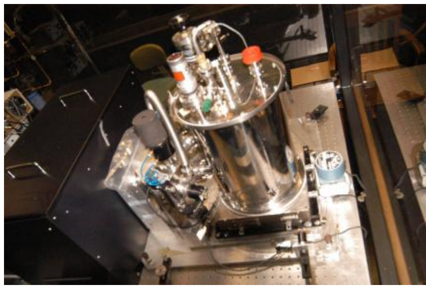
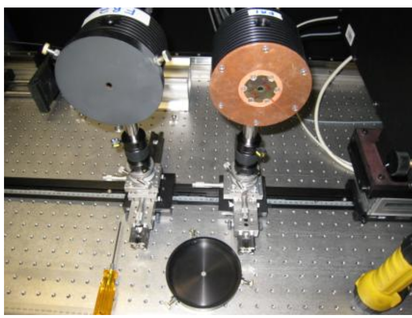
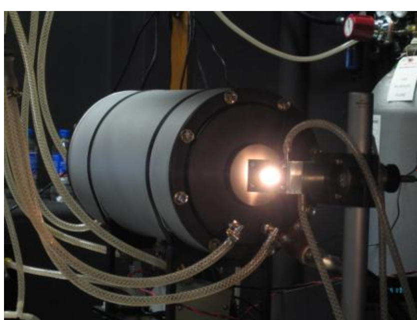


Calibration Chain: next NRC spectral irradiance scale







Cryogenic Radiometer — absolute detector

Transfer Radiometer — transfer detector

Filter Radiometer — temperature measuring detector

High-Temperature Black-Body — calibrated source (irradiance mode) (incandescent)

Detector and **Source** based

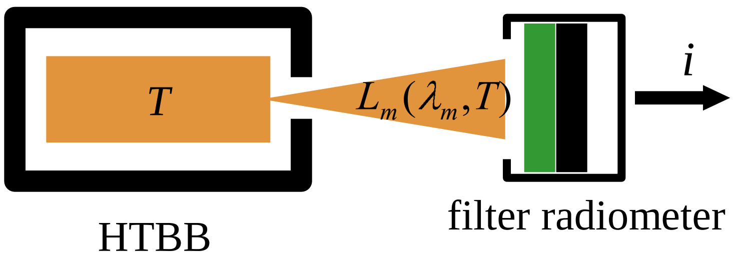
transfer lamps (incandescent)

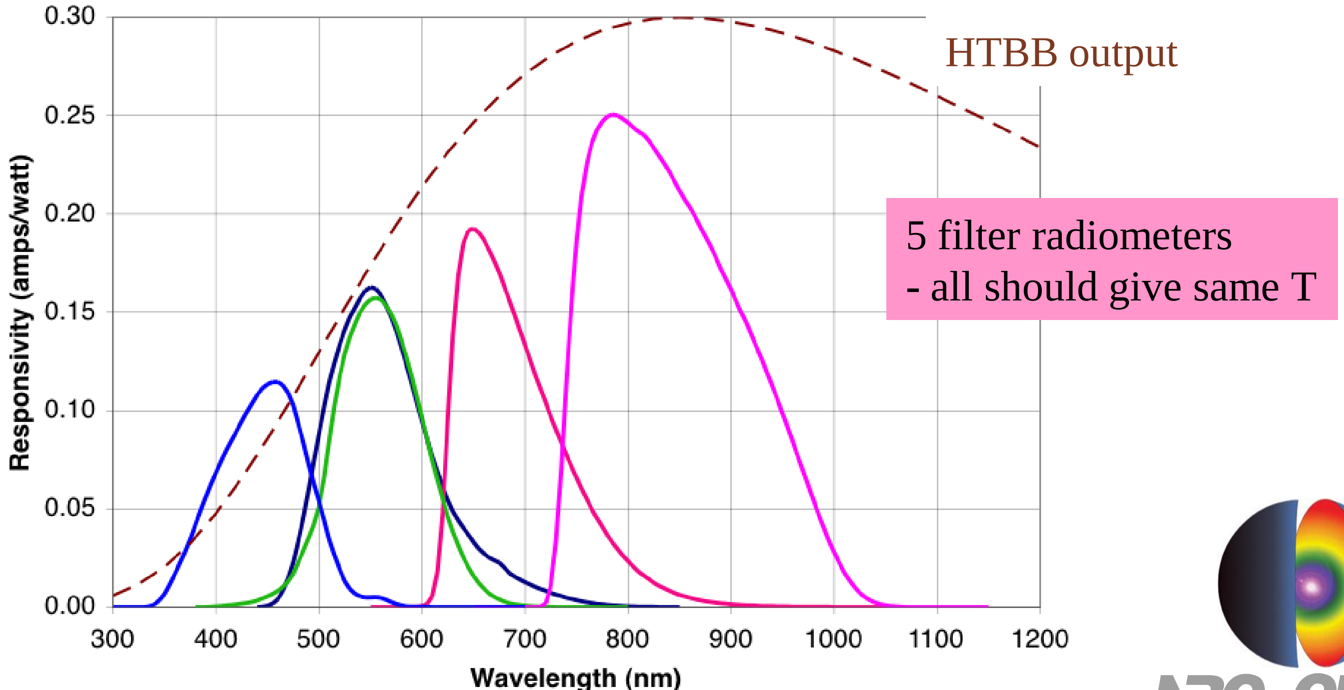
working standard lamps (incandescent)

client lamps (incandescent)

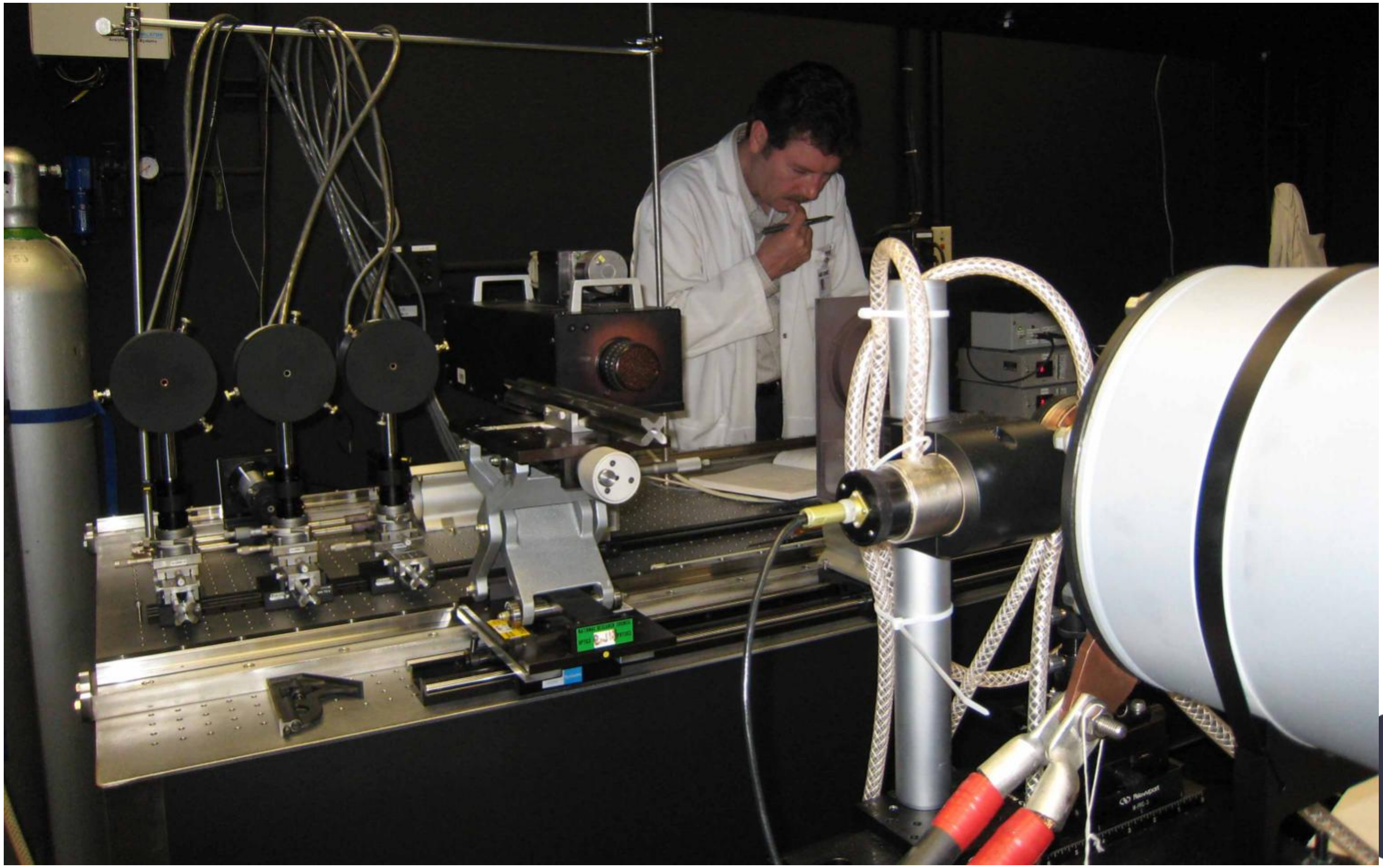
NRC · CNRC

Calibration Chain: measurement of HTBB temperature





Calibration Chain: measurement of HTBB temperature



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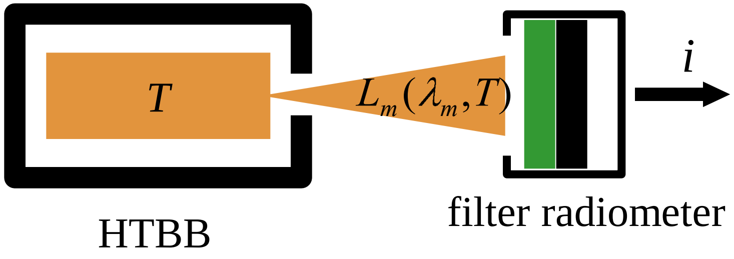
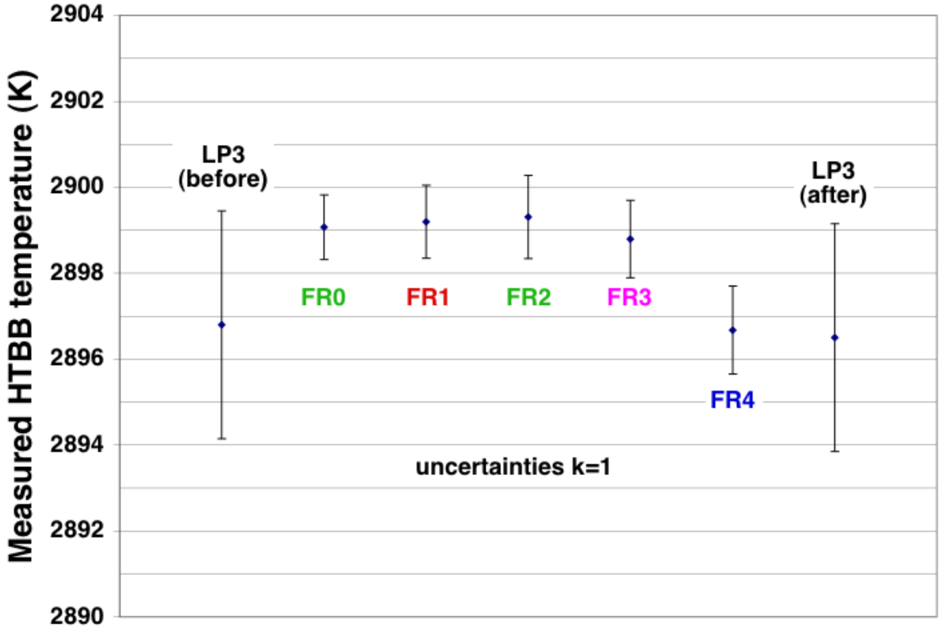


Initial Measurements
- 5 filter radiometers
- linear pyrometer (LP3)
  - Thermometry Group



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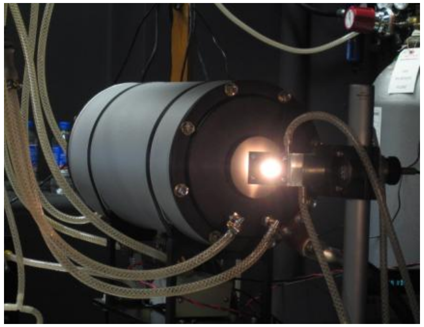
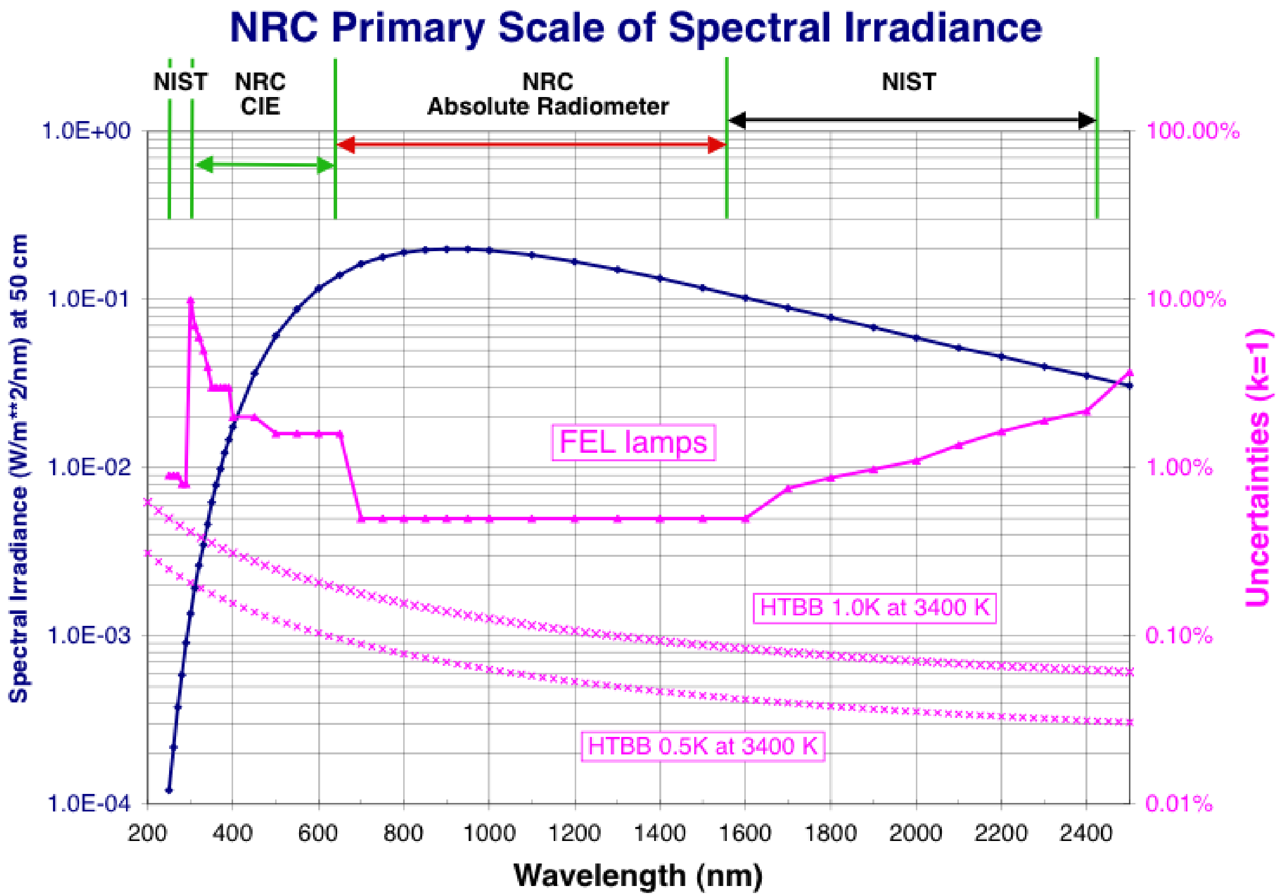
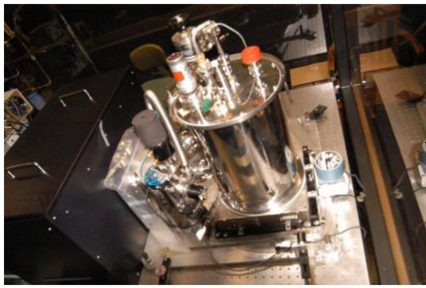
Calibration Chain: present/next NRC scale comparison

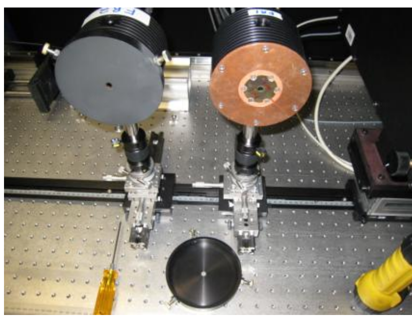


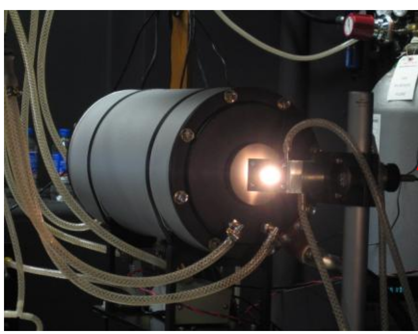


NRC · CNRC

Calibration Chain: next NRC spectral irradiance scale







Cryogenic Radiometer — absolute detector

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High-Temperature Black-Body — calibrated source (irradiance mode) (incandescent)

transfer facility

transfer lamps (incandescent)

working standard lamps (incandescent)

client lamps (incandescent)

Detector and **Source** based

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Calibration Chain: transfer facility (under construction)

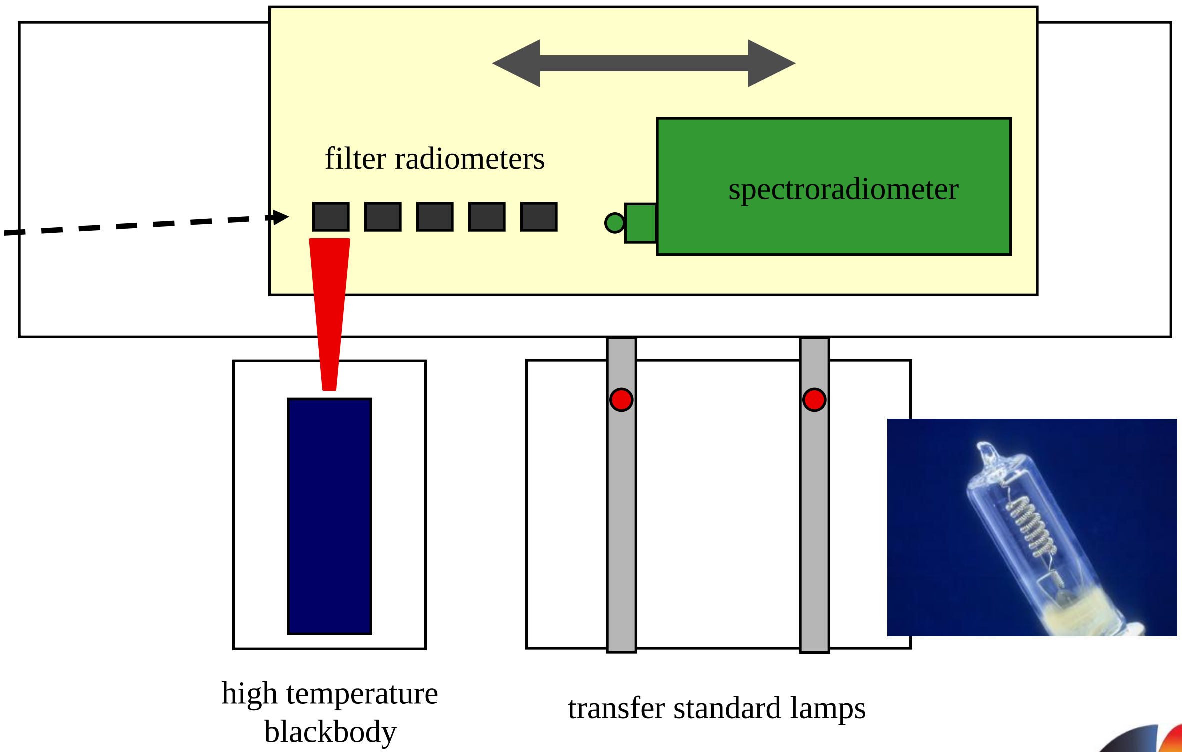
Filter Radiometer

↓

High-Temperature Black-Body

↓

Transfer standard lamps (incandescent)



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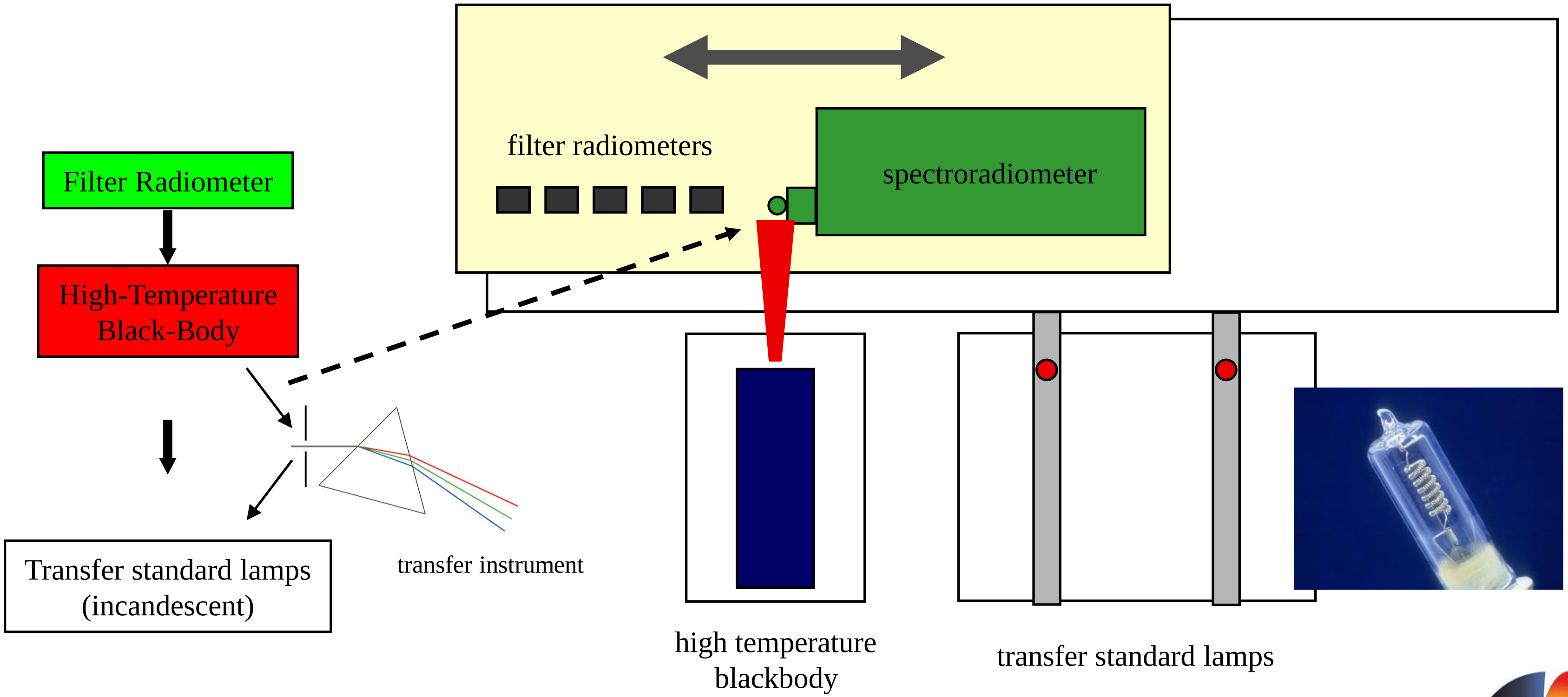

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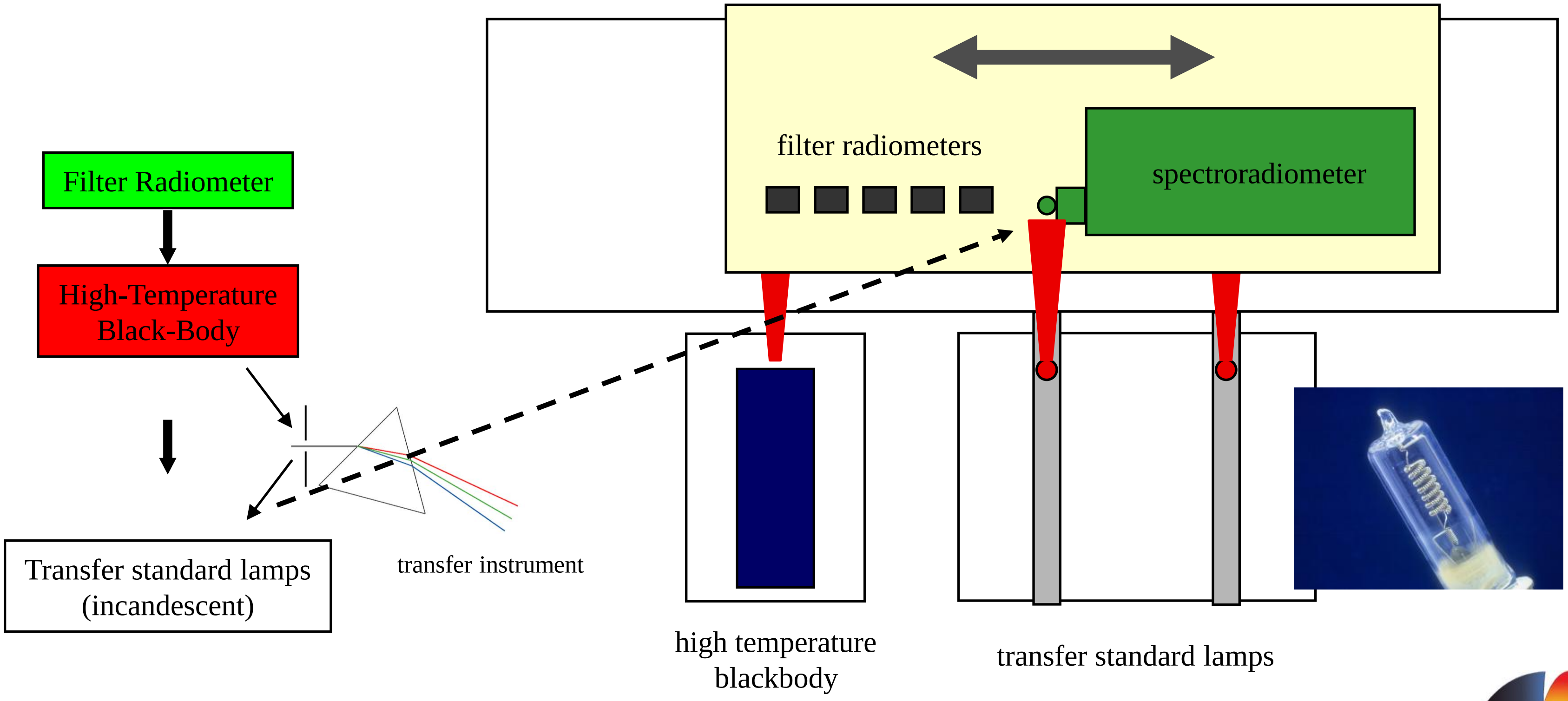

Building a Spectral Irradiance Scale

Summary

1. Basic light measurement
   - why spectral irradiance
2. Calibration Chains
   - light sources
   - basic NMI techniques
3. NRC-INMS Spectral Irradiance
   - present scale
   - comparison results
   - planned scale

Cryogenic Radiometer

Transfer Radiometer

Filter Radiometer

High-Temperature Black-Body

transfer lamps (incandescent)

working standard lamps (incandescent)

client lamps (incandescent)

Building a Spectral Irradiance Scale

Acknowlegments

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J.C. Zwinkels

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