Calibration of Photomultiplier Tubes for Few Photon Applications using Synchrotron Radiation

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Outline

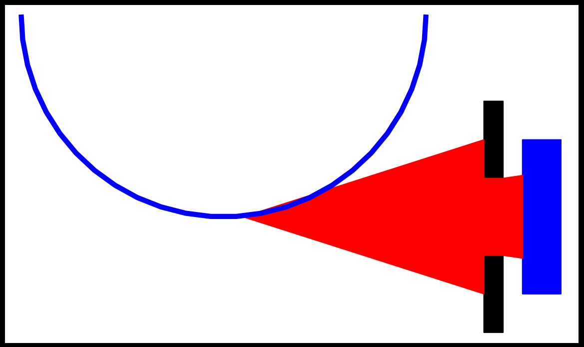
- Synchrotron Radiation
- Synchrotron Ultraviolet Radiation Facility SURF
- Beam Current Measurement
- Beamline 4: Ultraviolet Detector Radiometry
- Calibration of Photomultiplier Tubes
- Calibration of “Geiger” UV Detectors

Why is Synchrotron Radiation useful?

- Electromagnetic radiation emitted by highly relativistic electrons or positrons bend onto an orbit by magnets (Magneto-Bremsstrahlung).
- Emitted spectrum: broadband from microwave (harmonics of driving RF field) to x-rays, highly collimated, polarized, calculable.
- Output scales with electron beam current.
- Extremely clean lightsource operated in oil-free vacuum, which avoids photo-activated polymerization of hydrocarbons.
- Synchrotron radiation provides an absolute source!

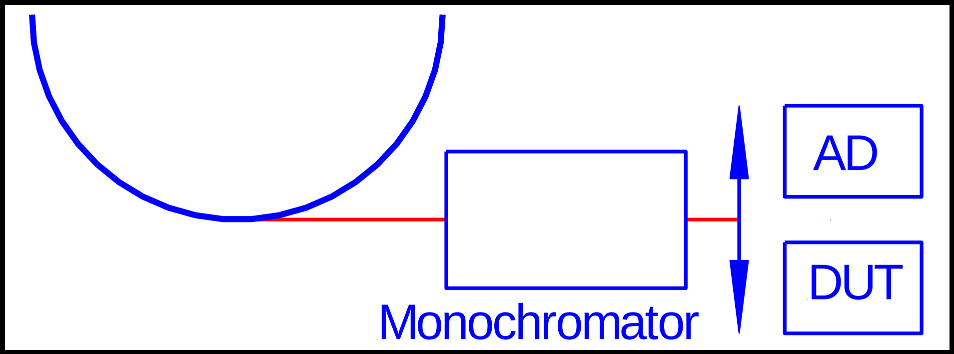
Absolute Radiometry

A Absolute Source-based Radiometry:
Calibration of different standard sources, spectrometers



$$\Phi_\lambda = \iint \frac{\partial^2 P_\lambda(B, I, \nu_{rf}, \lambda, \psi)}{\partial\theta\, \partial\psi} d\theta\, d\psi$$

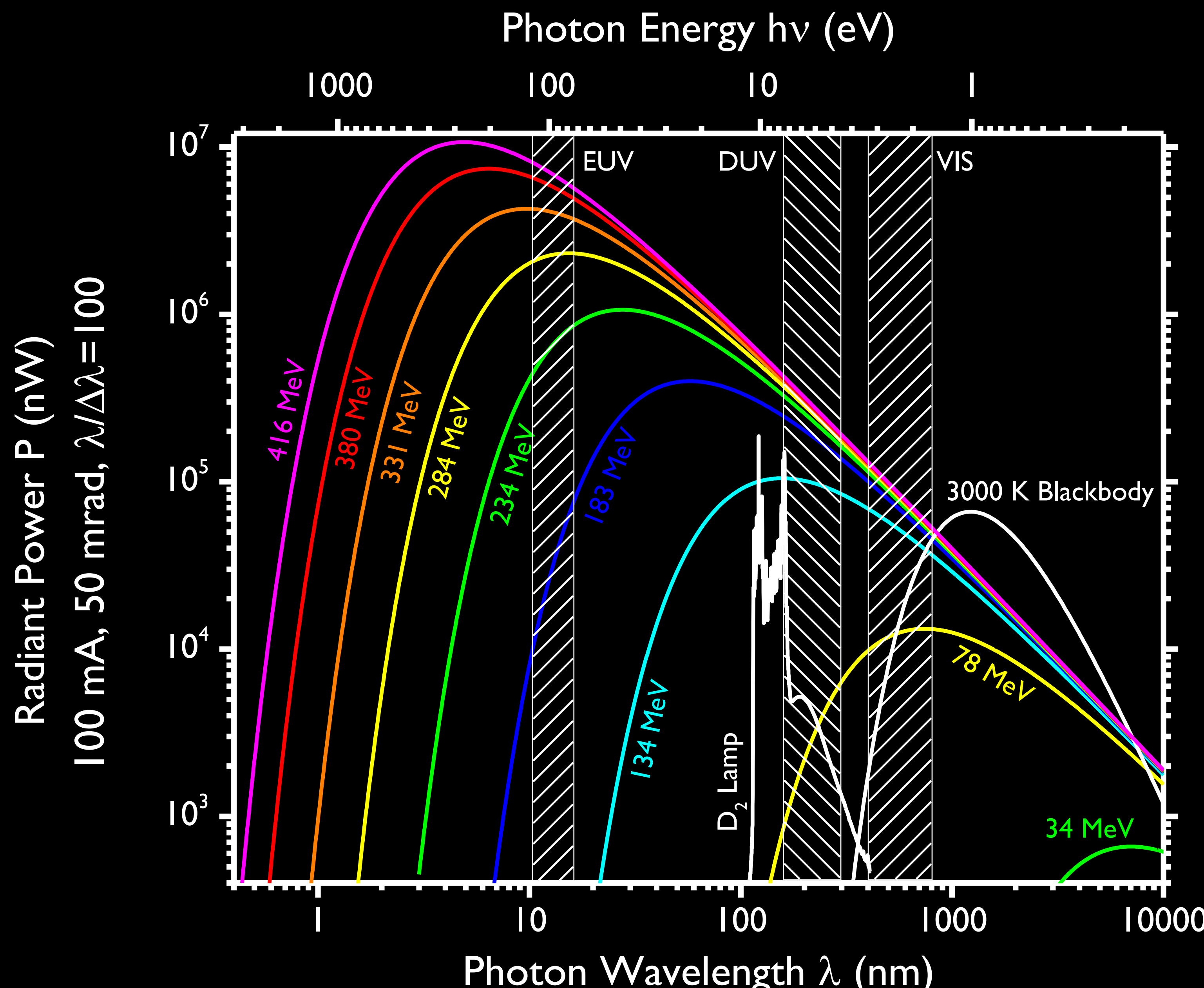
B Absolute Detector-based Radiometry:
Calibration of detectors, filter detector packages



Absolute detector

Detector under test

Custom-Tailored Output Spectrum

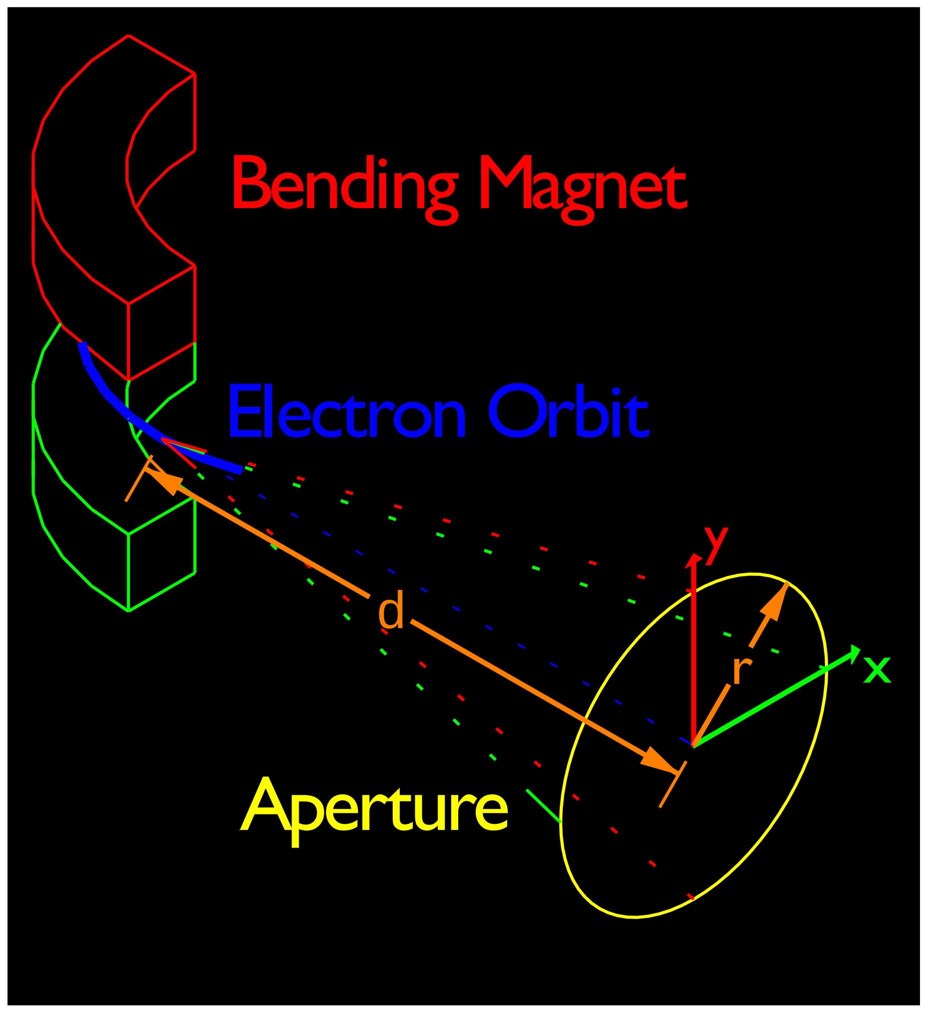


SURF as an Absolute Source

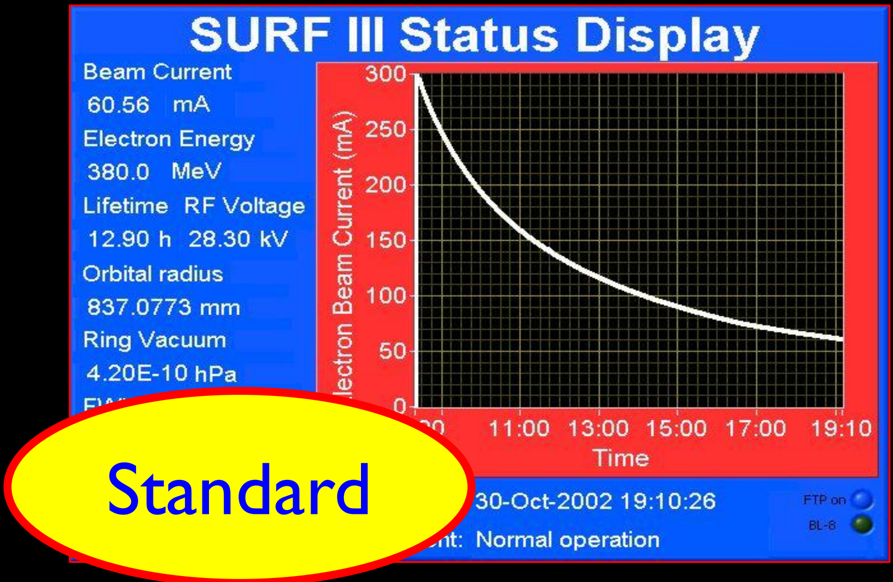
- Magnetic Flux Density ***B***
- Radio-frequency ν_{rf}
- Electron Beam Current I_B
- Source Point Distance ***d***
- Aperture Size ***r***
- Angle Relative to Orbit Plane ψ

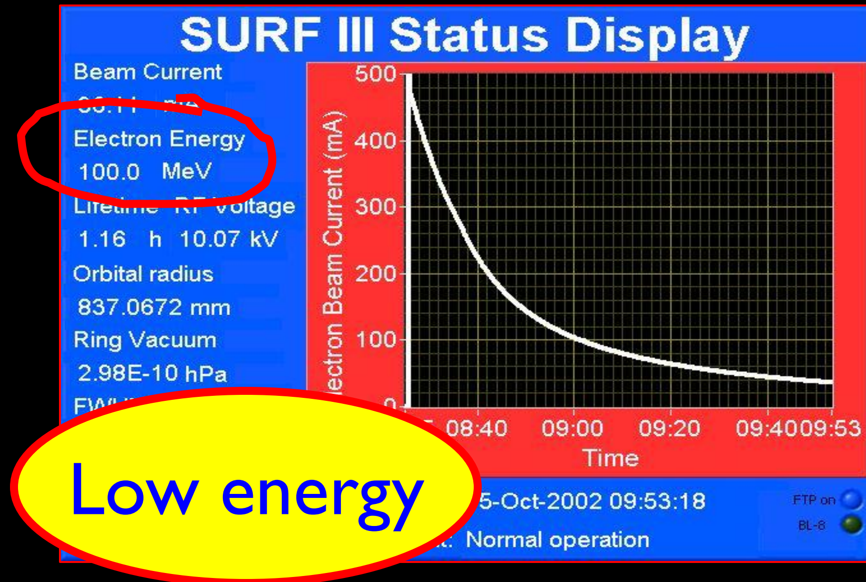
$$\gamma = \frac{E}{m_e c^2} = \frac{B \cdot e}{\pi \cdot \nu_{rf} \cdot m_e} \approx 744 \ @ \ 380 \text{ MeV}$$

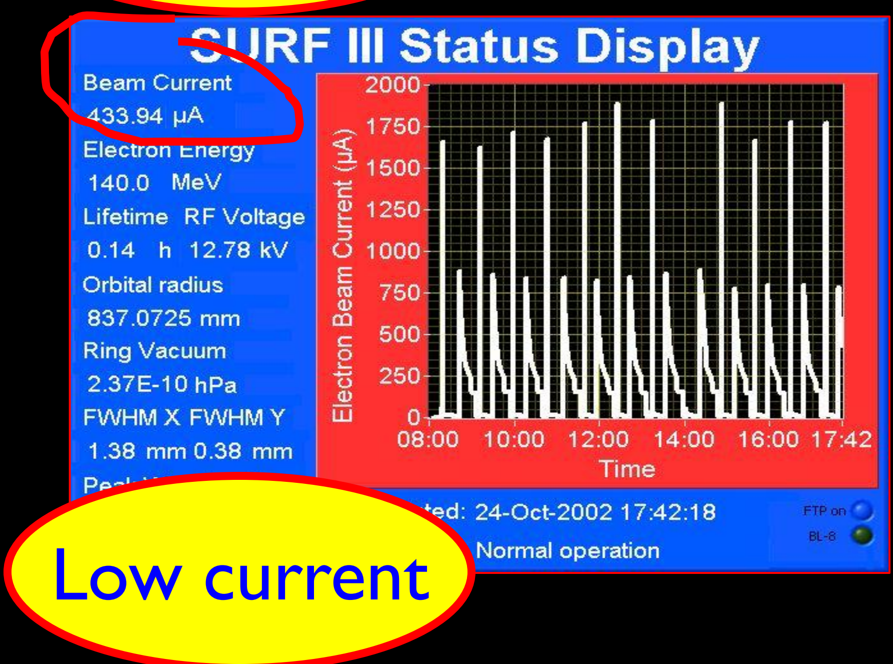
$$\rho = \frac{E \beta}{e_0 B c} = \sqrt{\left(\frac{c}{\pi \cdot \nu_{rf}}\right)^2 - \left(\frac{m_e \cdot c}{B \cdot e_0}\right)^2}$$

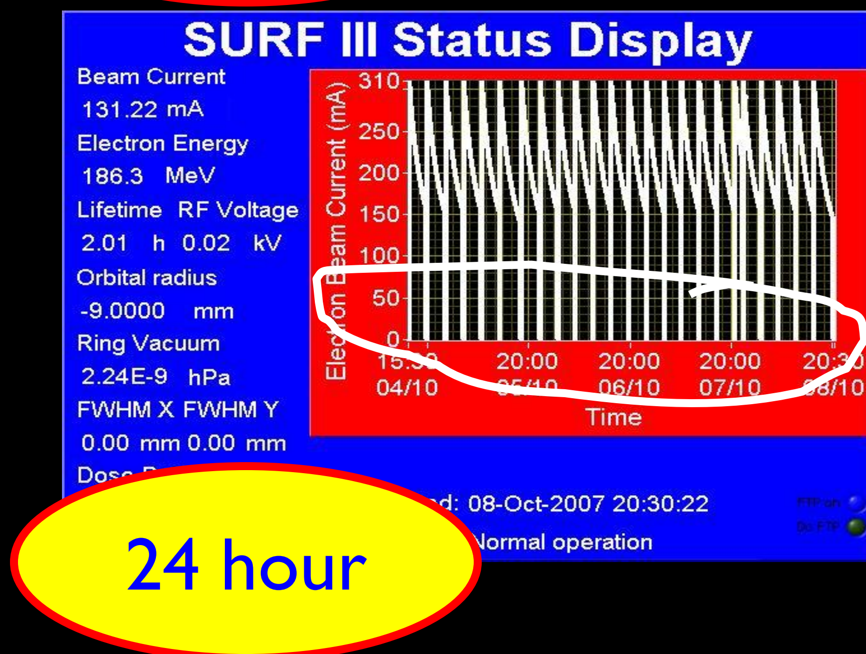


Flexibility in Operation





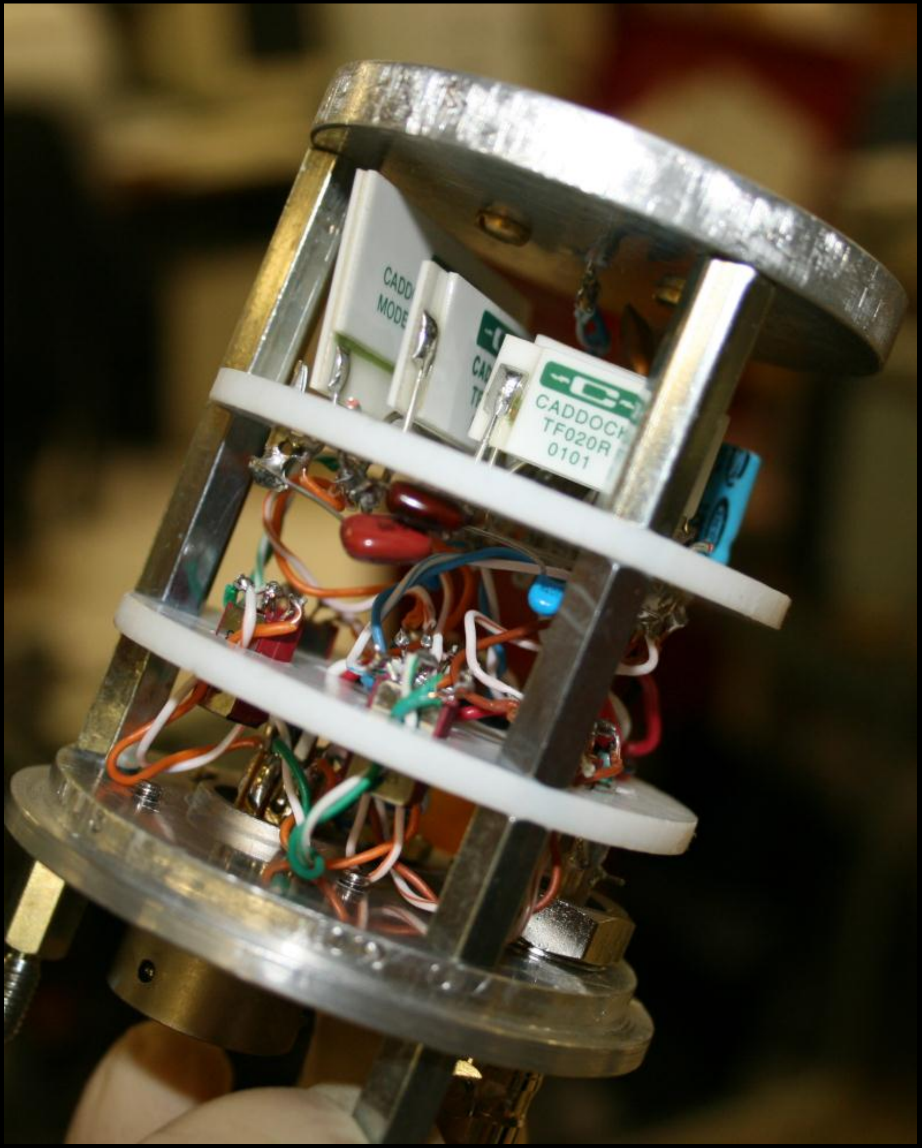




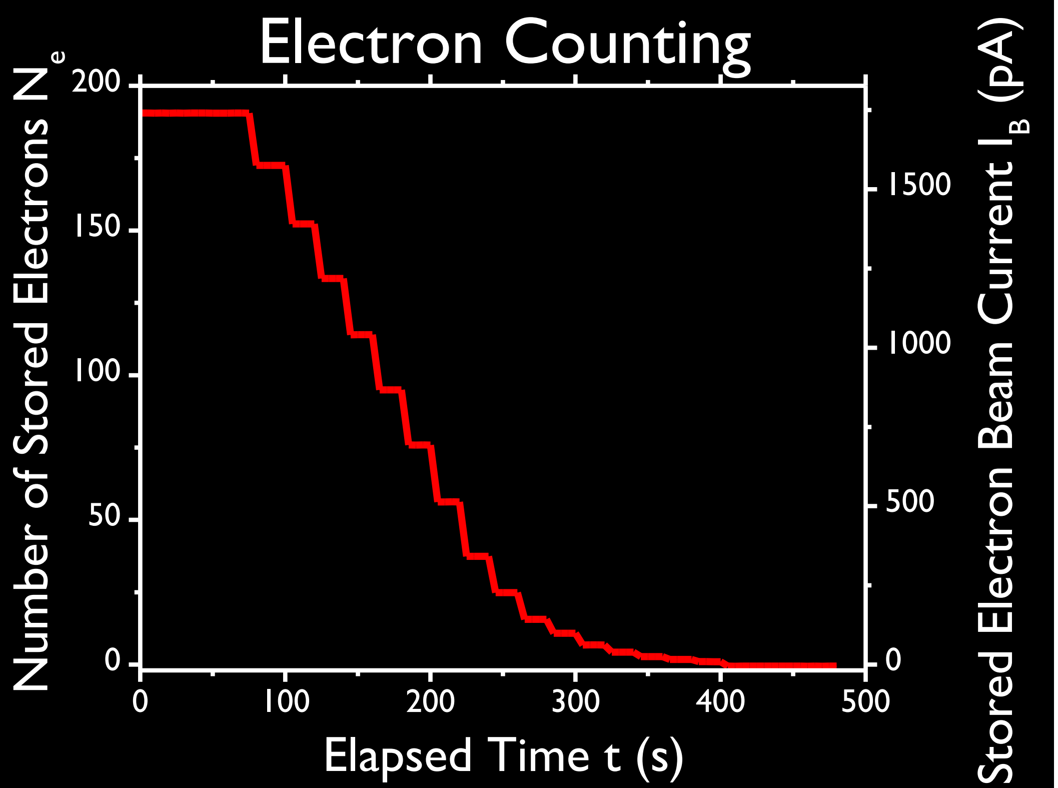
SURF Electron Beam Current Monitor

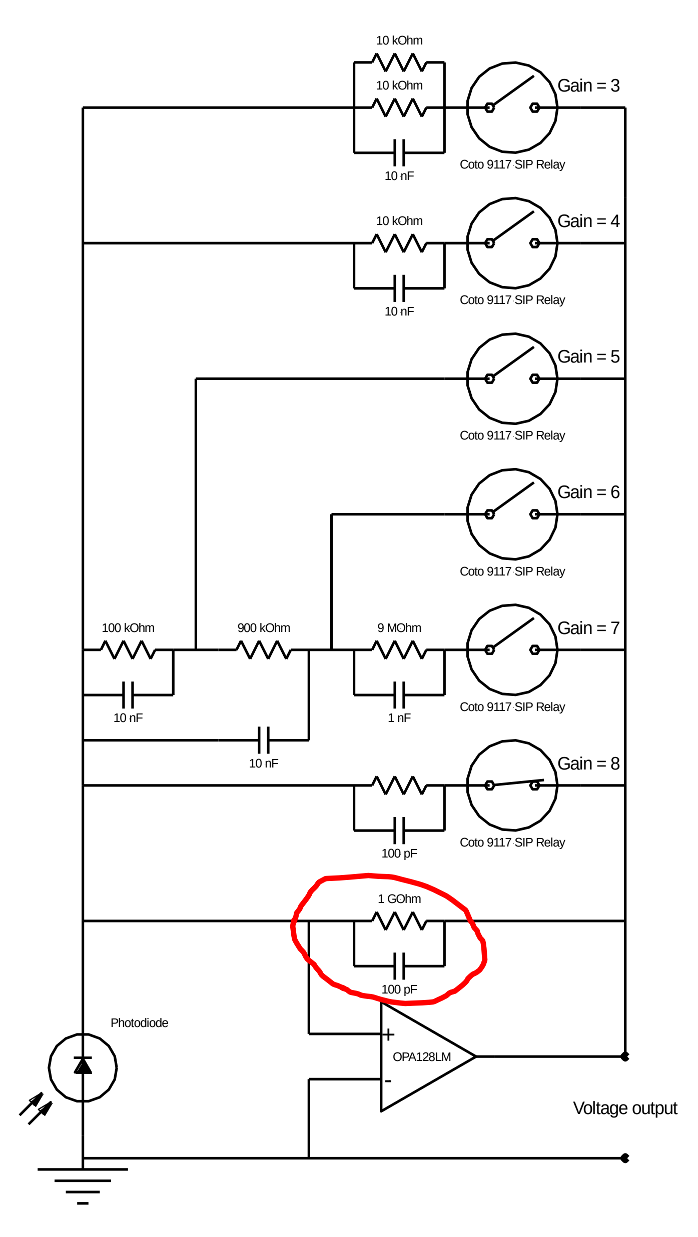
- Beam current is measured optically using ND filter + Si diode + operational amplifier (Eppeldauer and Hardis, *Appl. Opt.* **30** (22), 3091-9 (1991)). Relative standard uncertainty 0.2 %.

- System is linear over 11 orders of magnitude. Extrapolate from the light from a single electron to that of 10^{11} electrons.



Measuring Current by Electron Counting

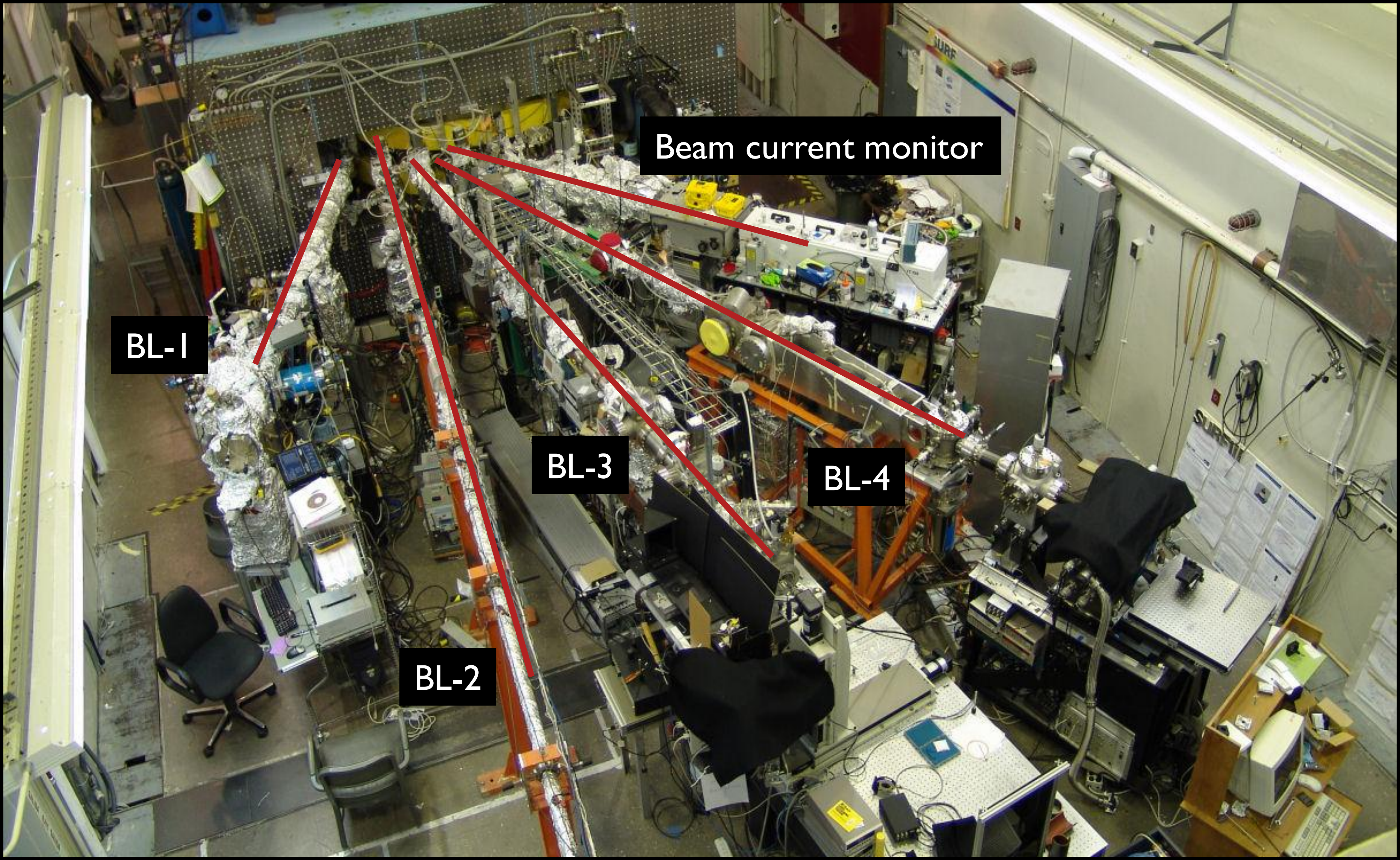




Hughey and Schaefers

Nucl. Instrum. & Meth. 195, 367 (1982)

Synchrotron Ultraviolet Radiation Facility



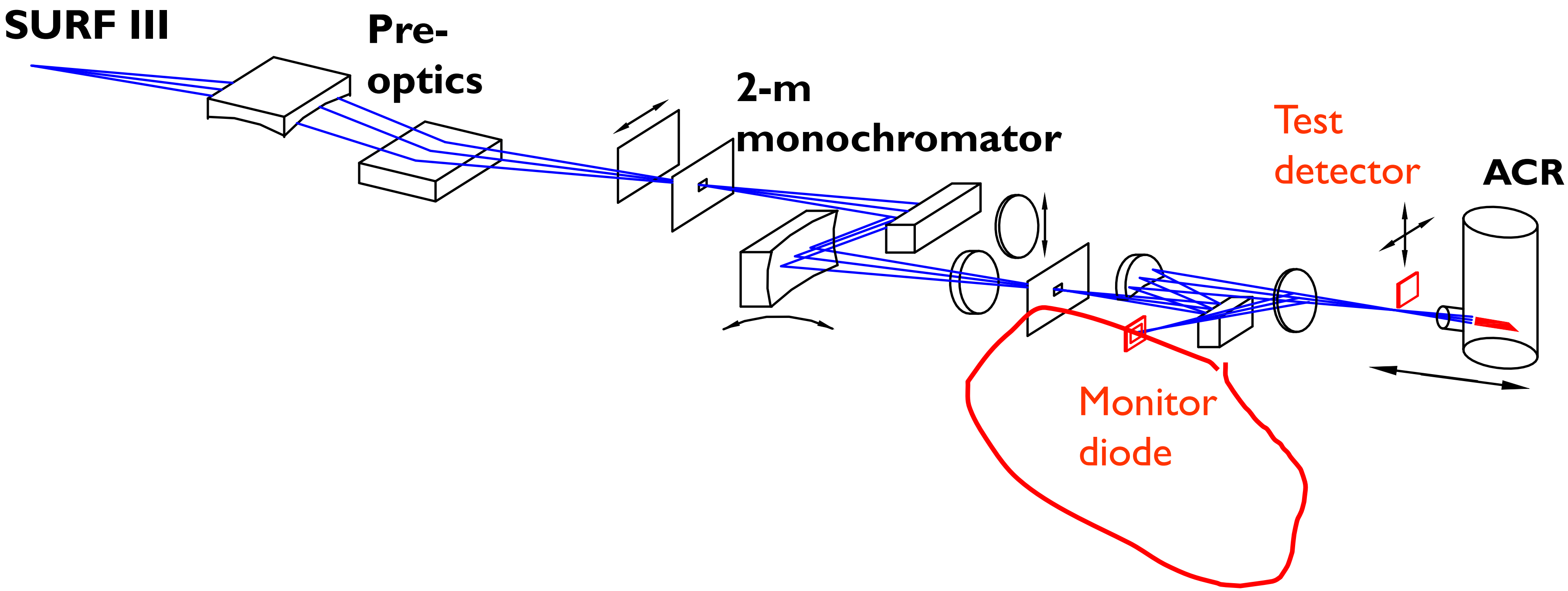
BL-4 – Absolute Cryogenic Radiometer-based Beamline for UV and VUV Radiometry

- Detector responsivity calibration
- Irradiance meter calibration
- Detector radiation damage studies
- Detector internal quantum efficiency measurements
- Optical characterization of materials
- Physics of photon detection by photodiodes

So far all work based on solid-state photodetectors

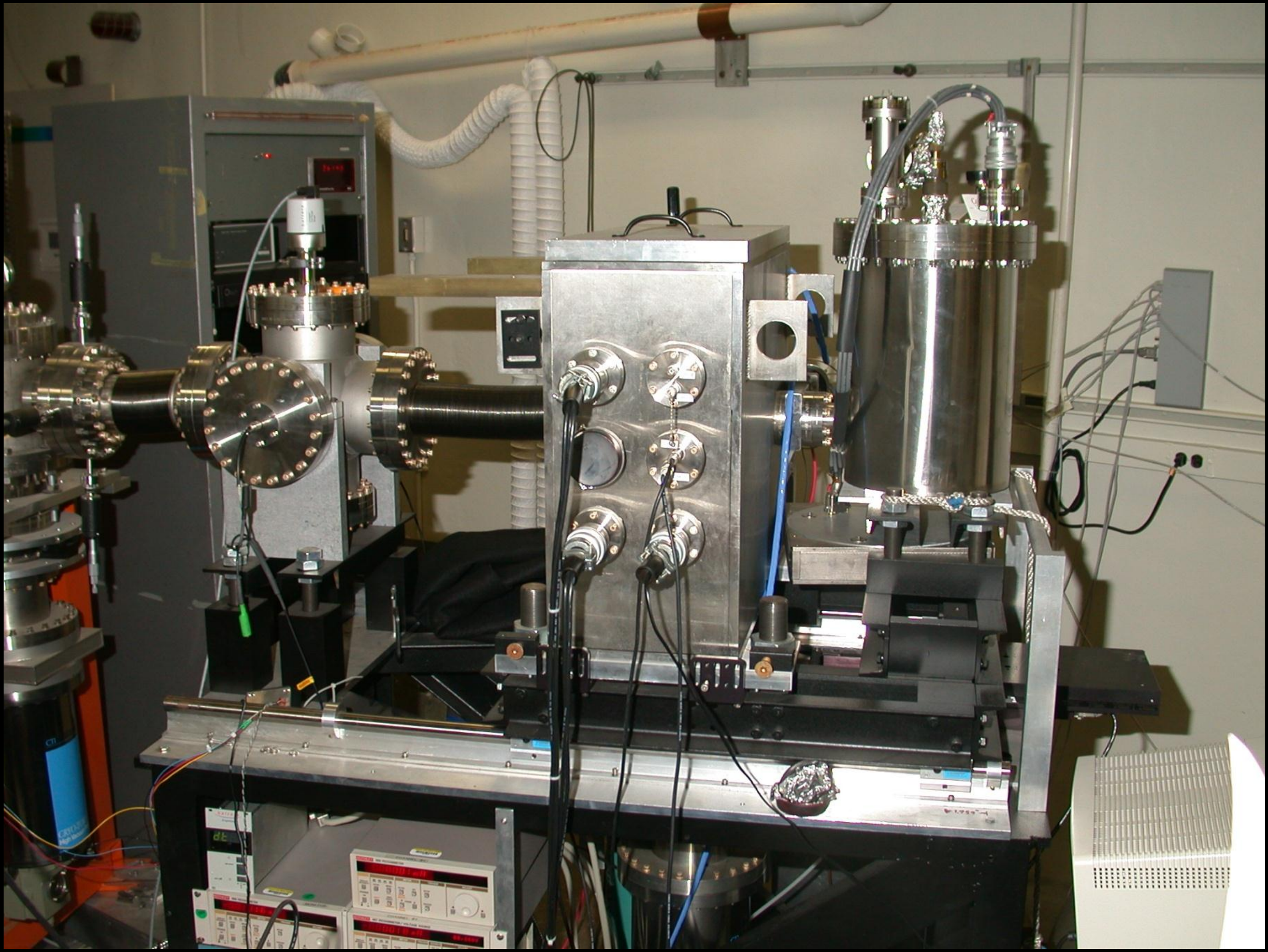
ACR-based Beamline at SURF III

Wavelength range 140 nm to 320 (400) nm

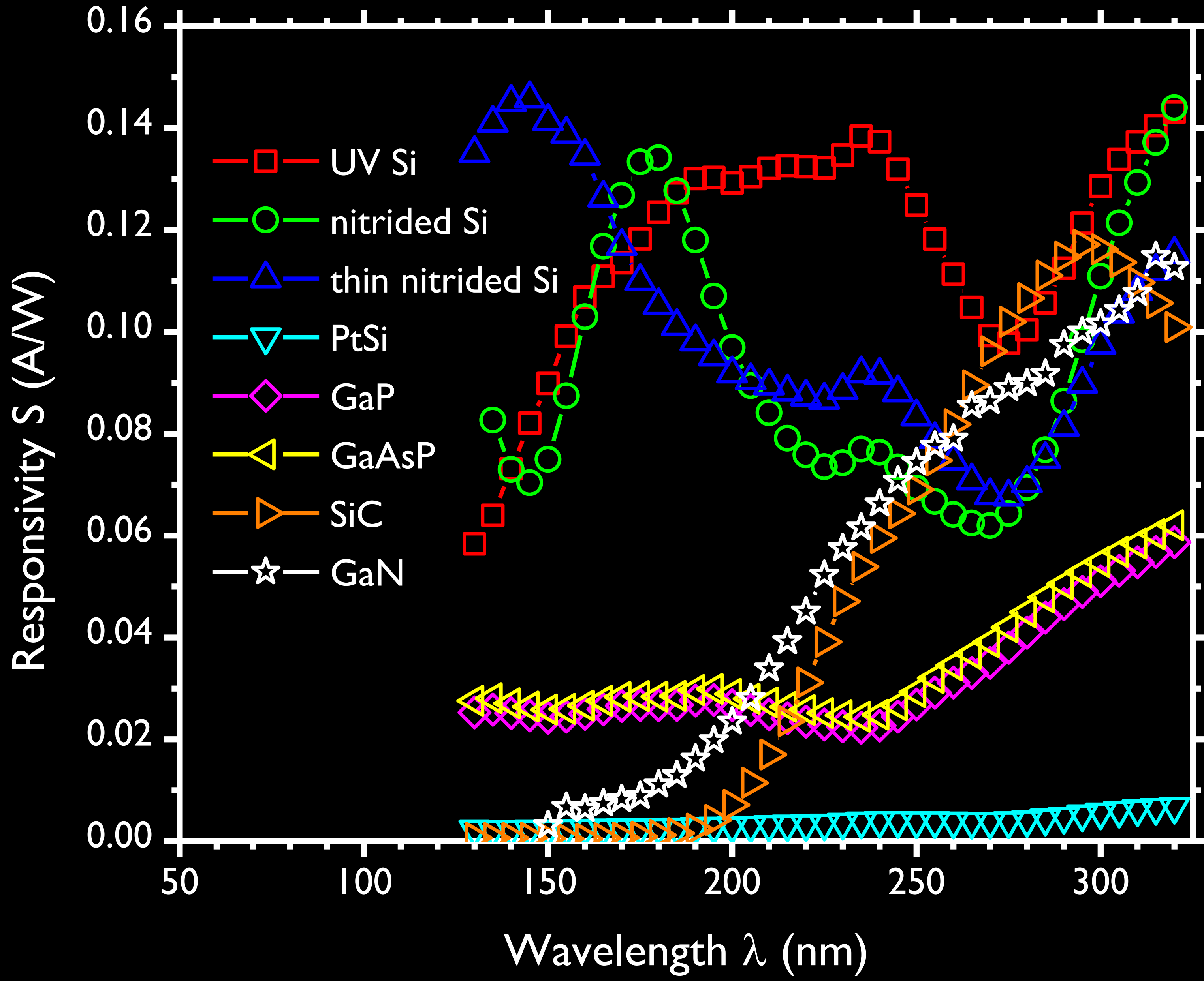


Shaw P.S. et al.,
Applied Optics 38, 18 (1999) and Metrologia 35, 301 (1998).

BL-4: Absolute Cryogenic Radiometer



BL-4: Detector Responsivity Calibration



BL-4: Absolute Cryogenic Radiometer

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A Gottwald *et al* 2011 *Metrologia* **48** 02001 doi: 10.1088/0026-1394/48/1A/02001

Bilateral NIST–PTB comparison of spectral responsivity in the VUV

A Gottwald[1], M Richter[1], P-S Shaw[2], Z Li[2] and U Arp[2]

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Abstract

PILOT STUDY

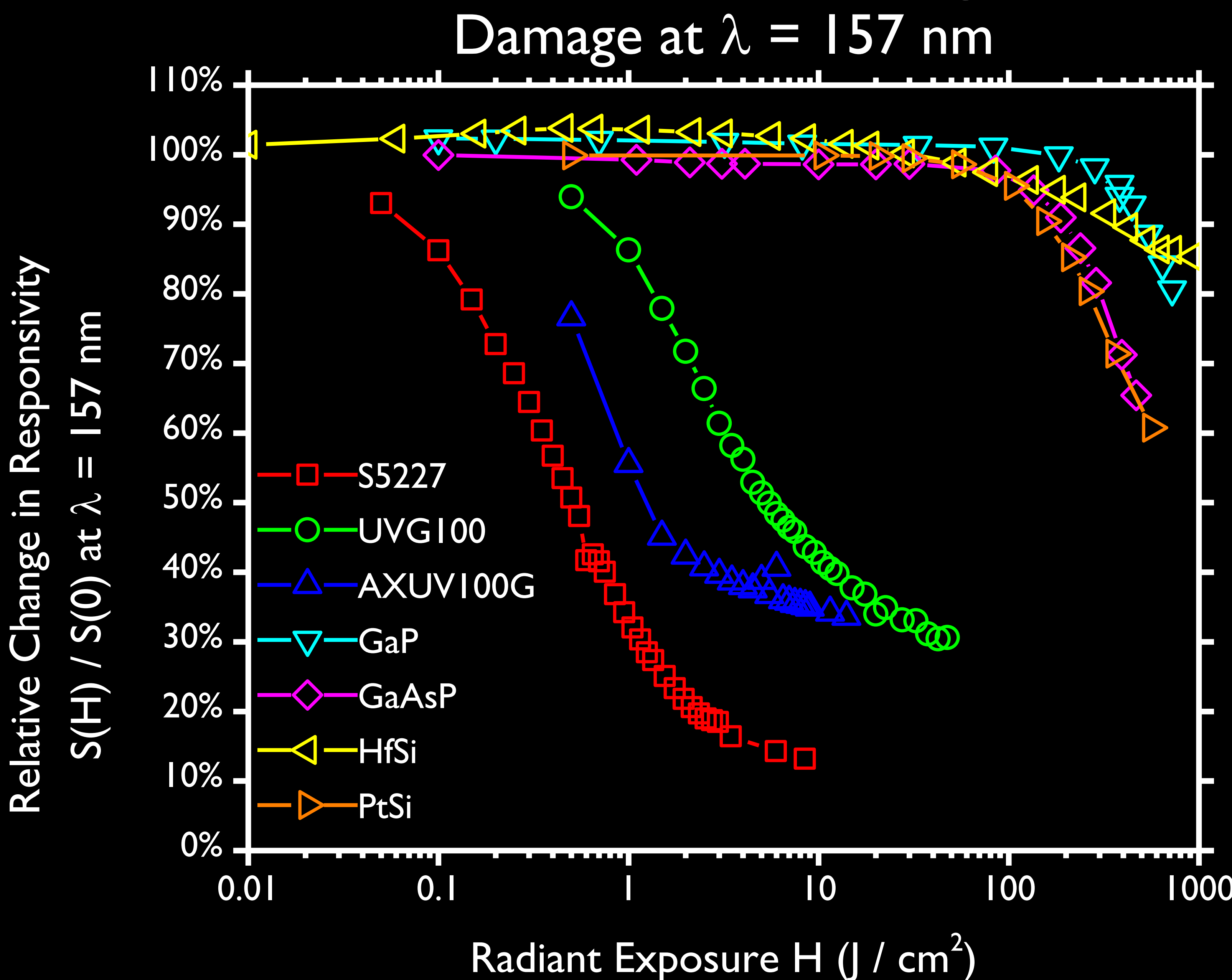
To compare the calibration capabilities for the spectral responsivity in the vacuum-ultraviolet spectral region between 135 nm and 250 nm, PTB and NIST agreed on a bilateral comparison. Calibrations of semiconductor photodiodes as transfer detectors were performed using monochromatized synchrotron radiation and cryogenic electrical substitution radiometers as primary detector standards. Great importance was attached to the selection of suitable transfer detector standards due to their critical issues in that wavelength regime. The uncertainty budgets were evaluated in detail. The comparison showed a reasonable agreement between the participants. However, it became obvious that the uncertainty level for this comparison cannot easily be further reduced due to the lack of sufficiently radiation-hard and long-term stable transfer standard detectors.

Main text. To reach the main text of this paper, click on **Final Report**.

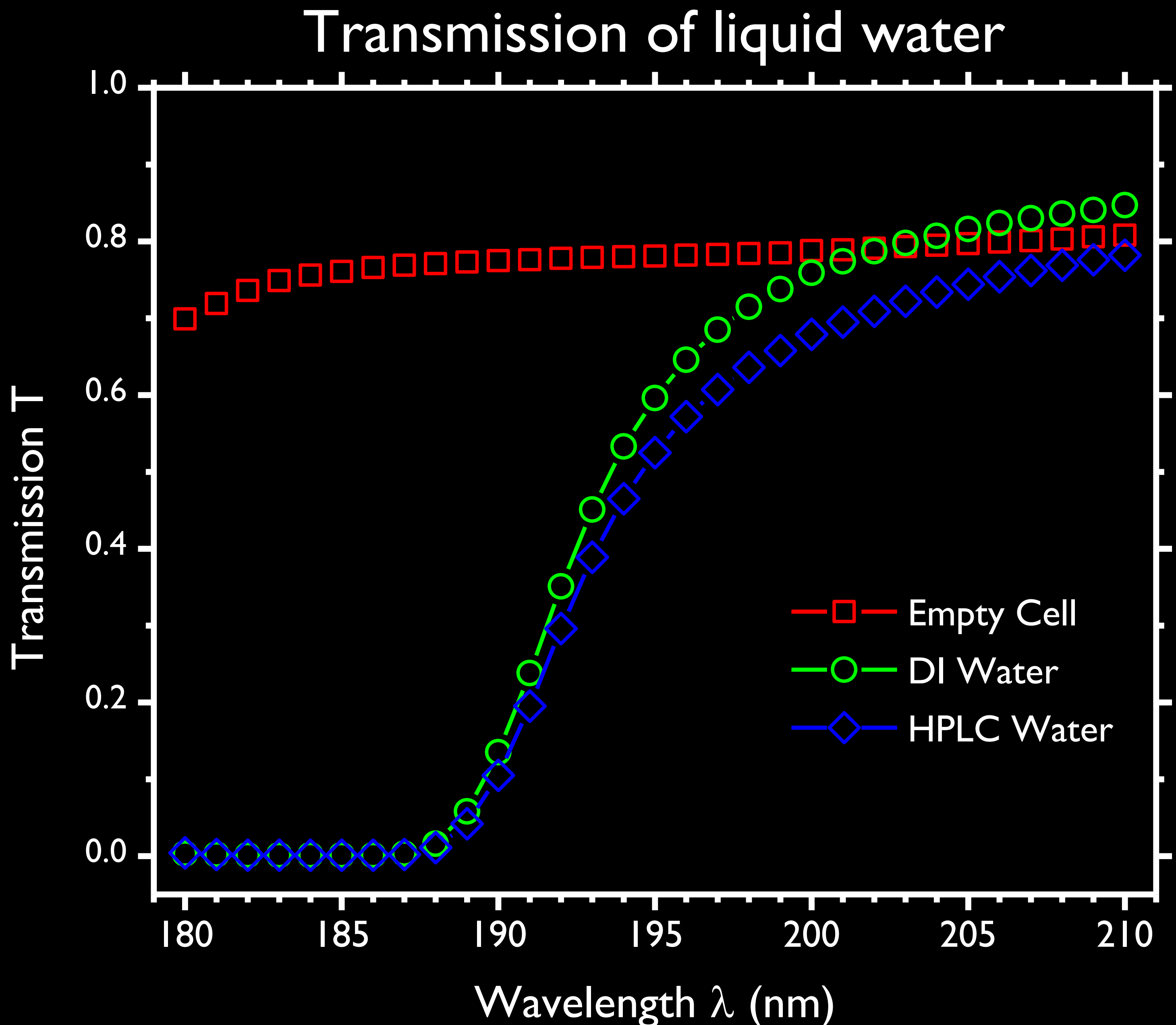
The final report has been peer-reviewed and approved for publication by the CCPR-WGKC.

Dates Issue 1A (Technical Supplement 2011)

BL-4: Detector Radiation Damage Studies

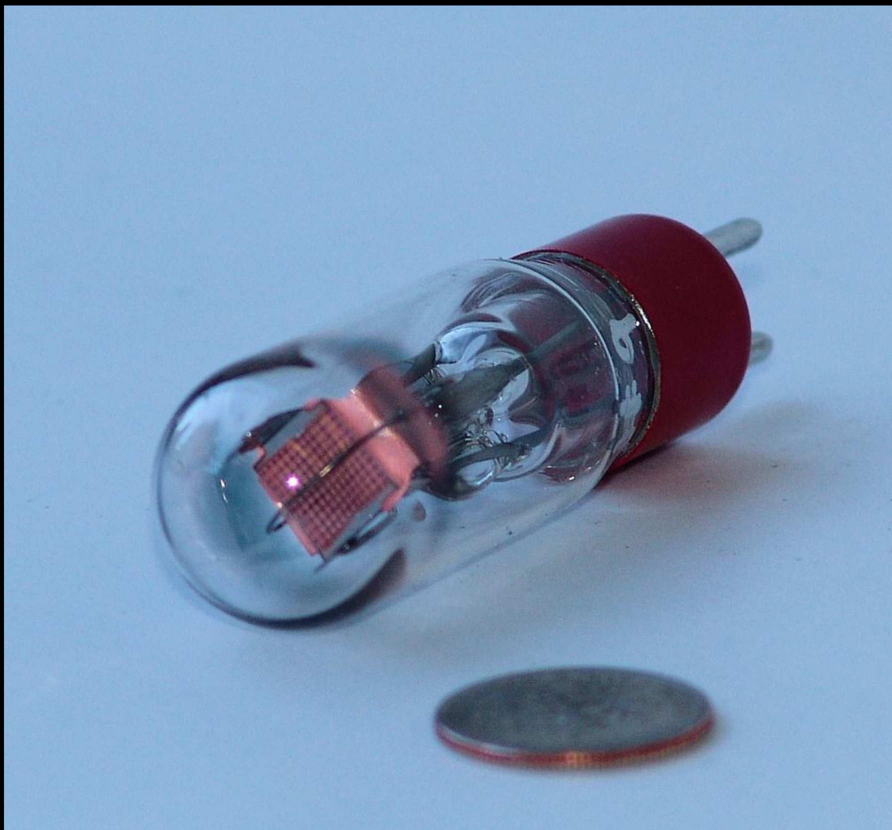


BL-4: Optical Characterization of Materials

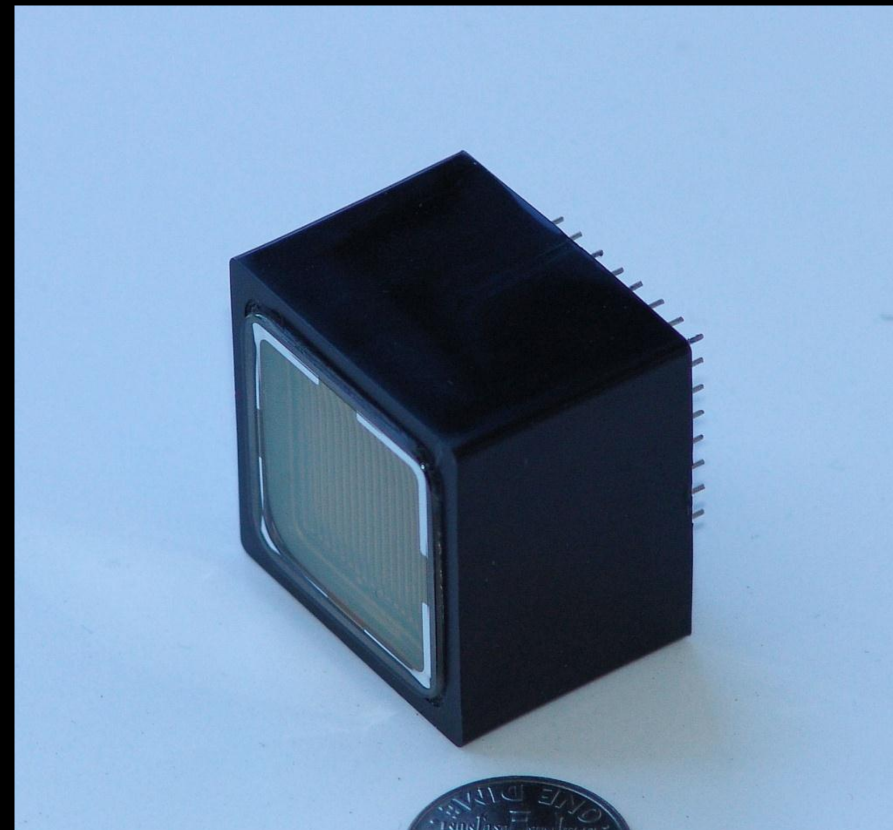


Photodetectors

Honeywell Fire Detector

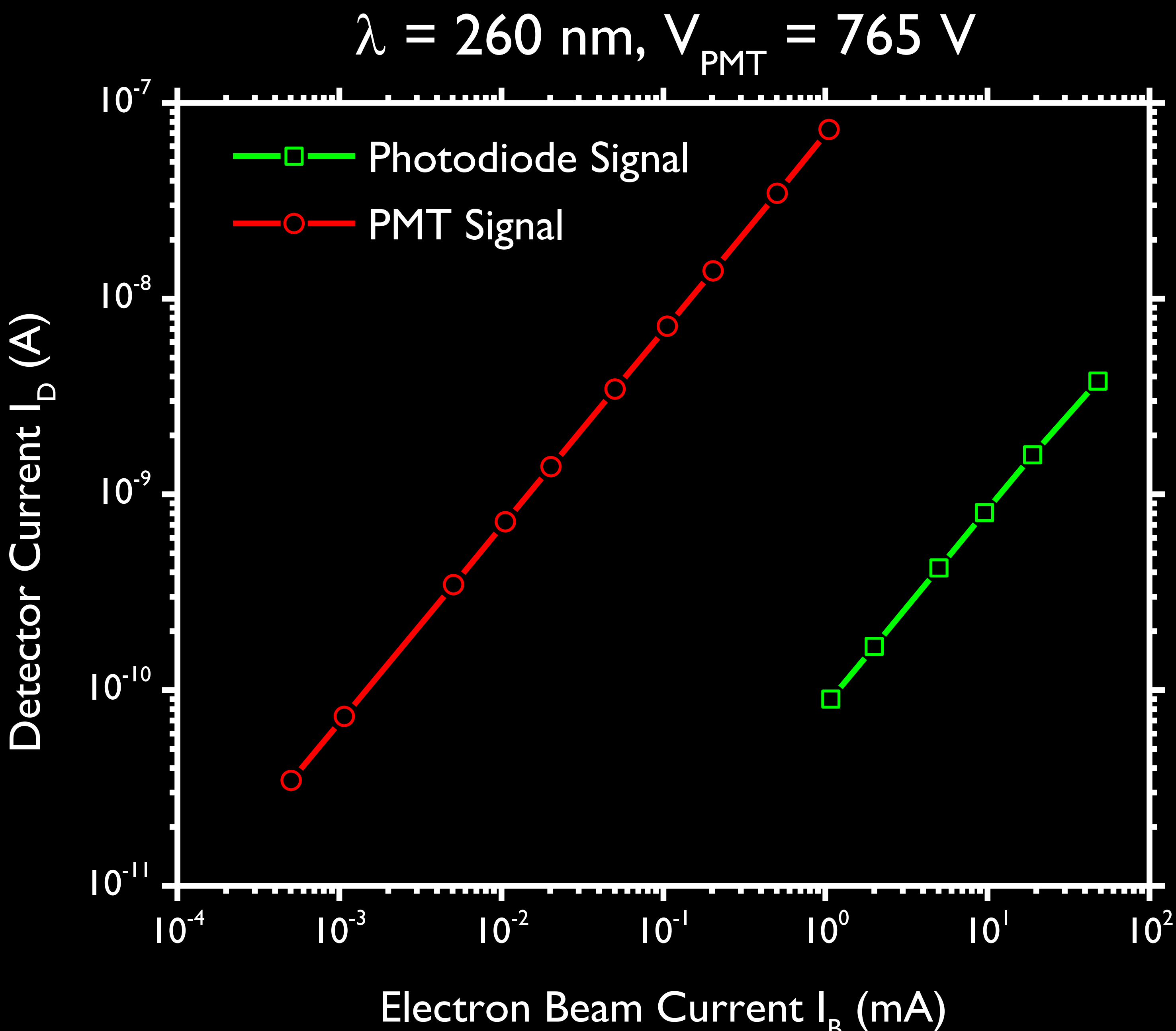


PMT Hamamatsu R7600U-03

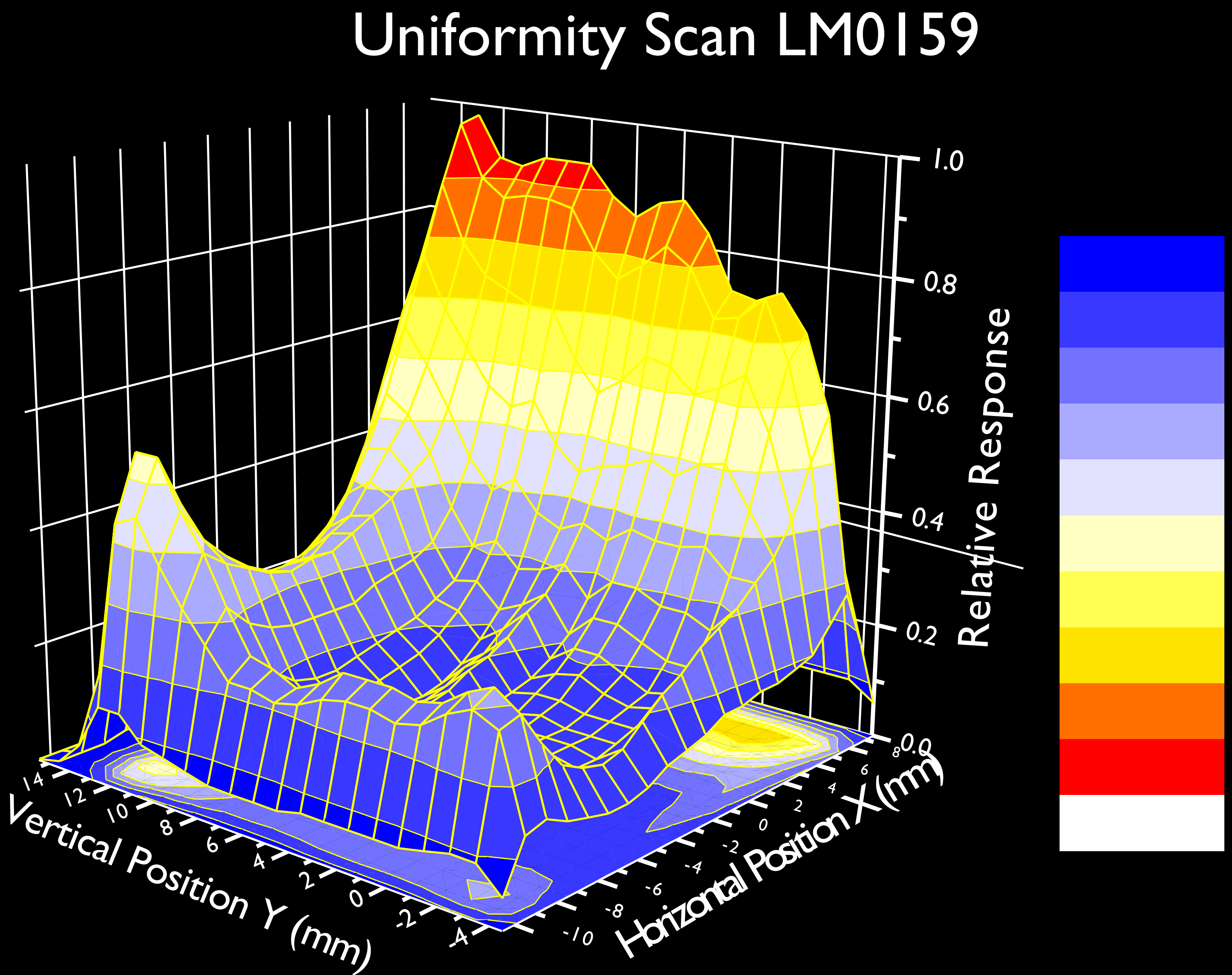


Certain commercial equipment, instruments, or materials are identified to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for the purpose.

Transfer of Scale from Photodiode to PMT



Photomultiplier Tube Uniformity



PMT Absolute Responsivity

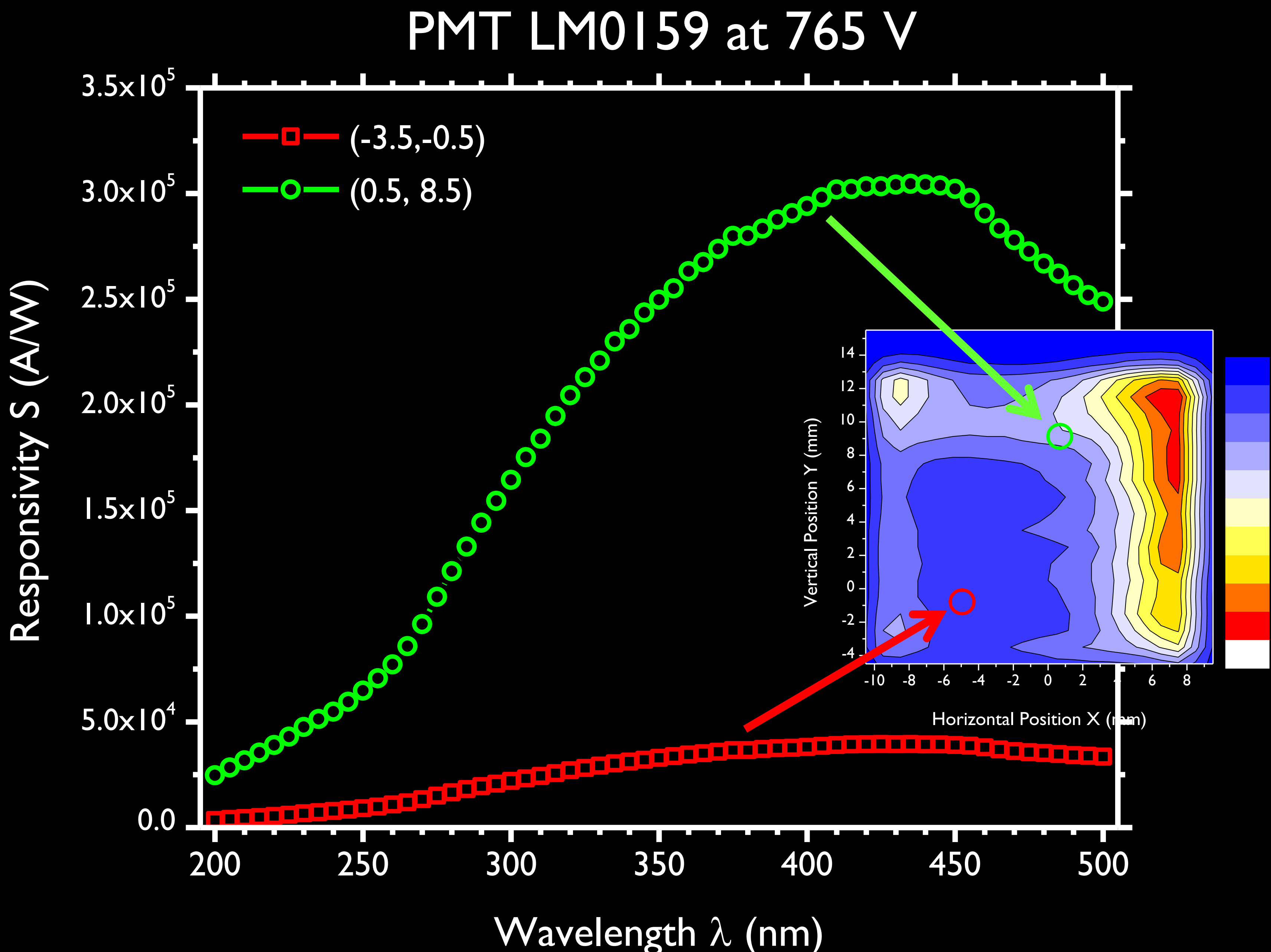
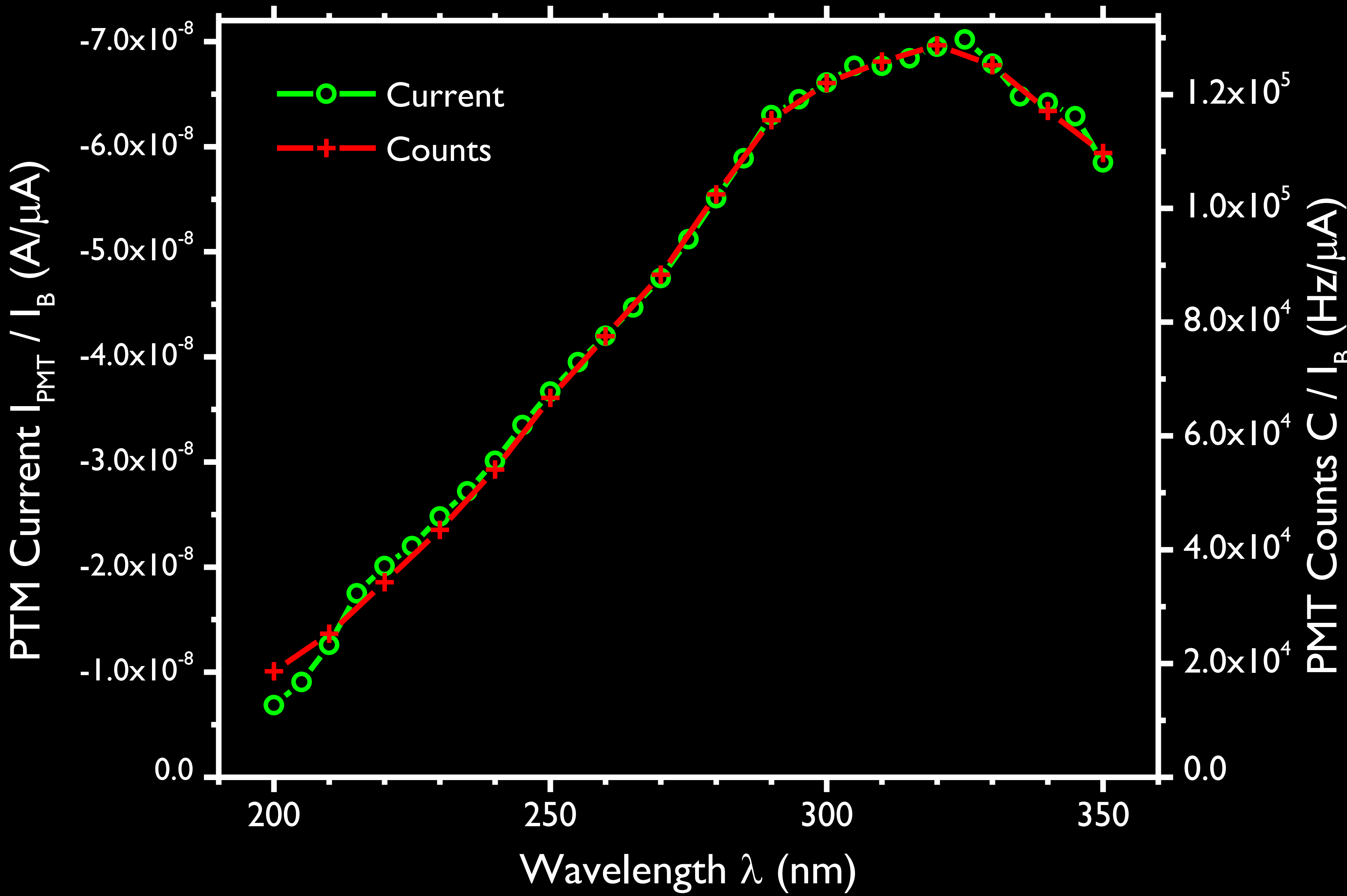


Photo Current and Counting Measurements

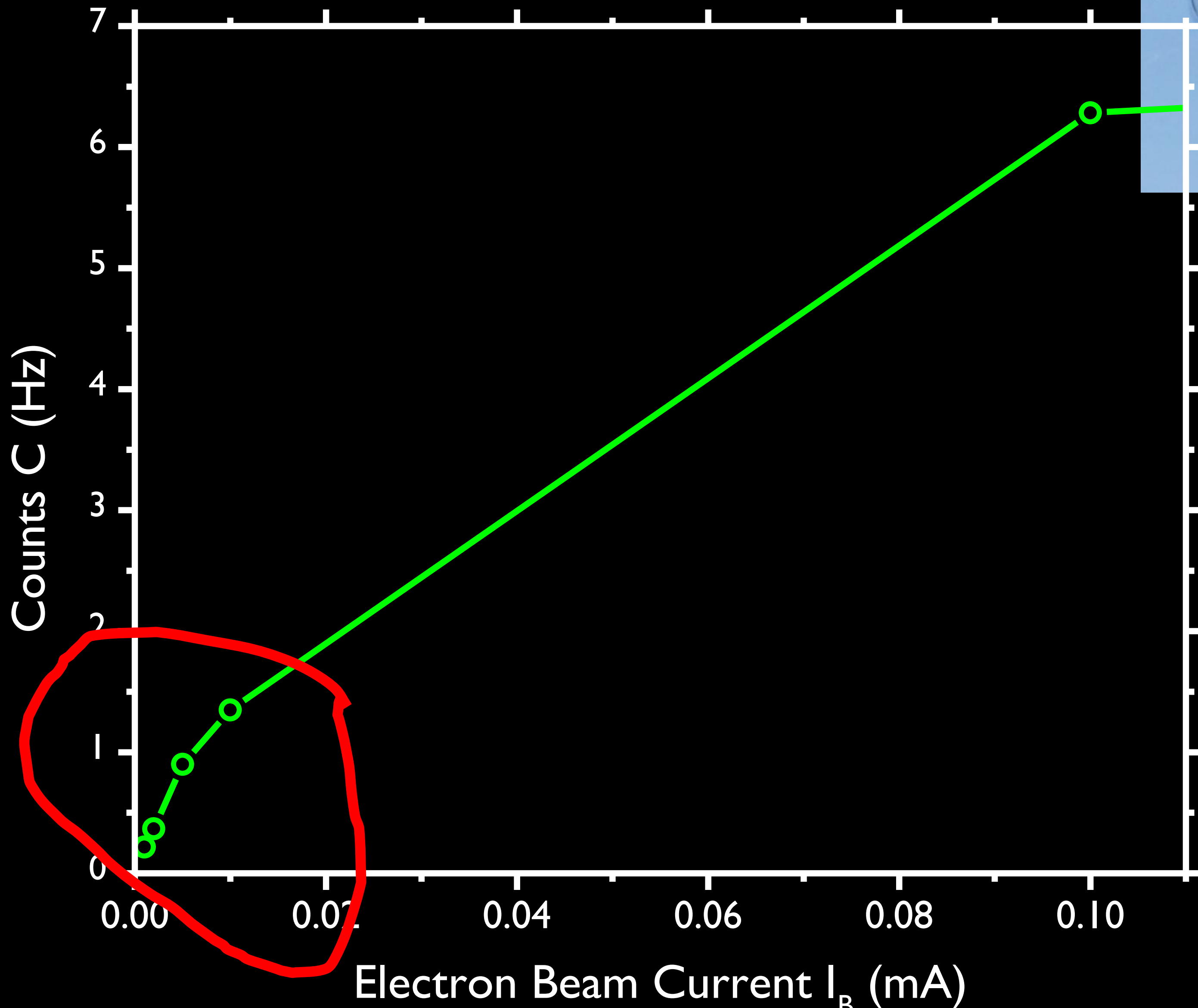
BL-4 @ 2 μA ~ 80,000 photons / s @ 220 nm

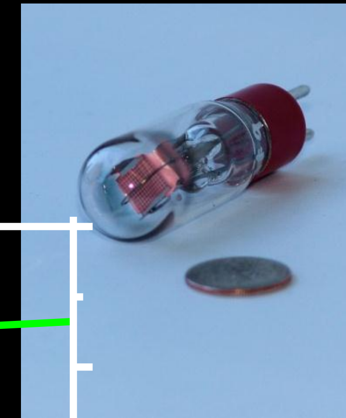



DANGER
NO SMOKING
NO OPEN FLAMES
NO SPARKS

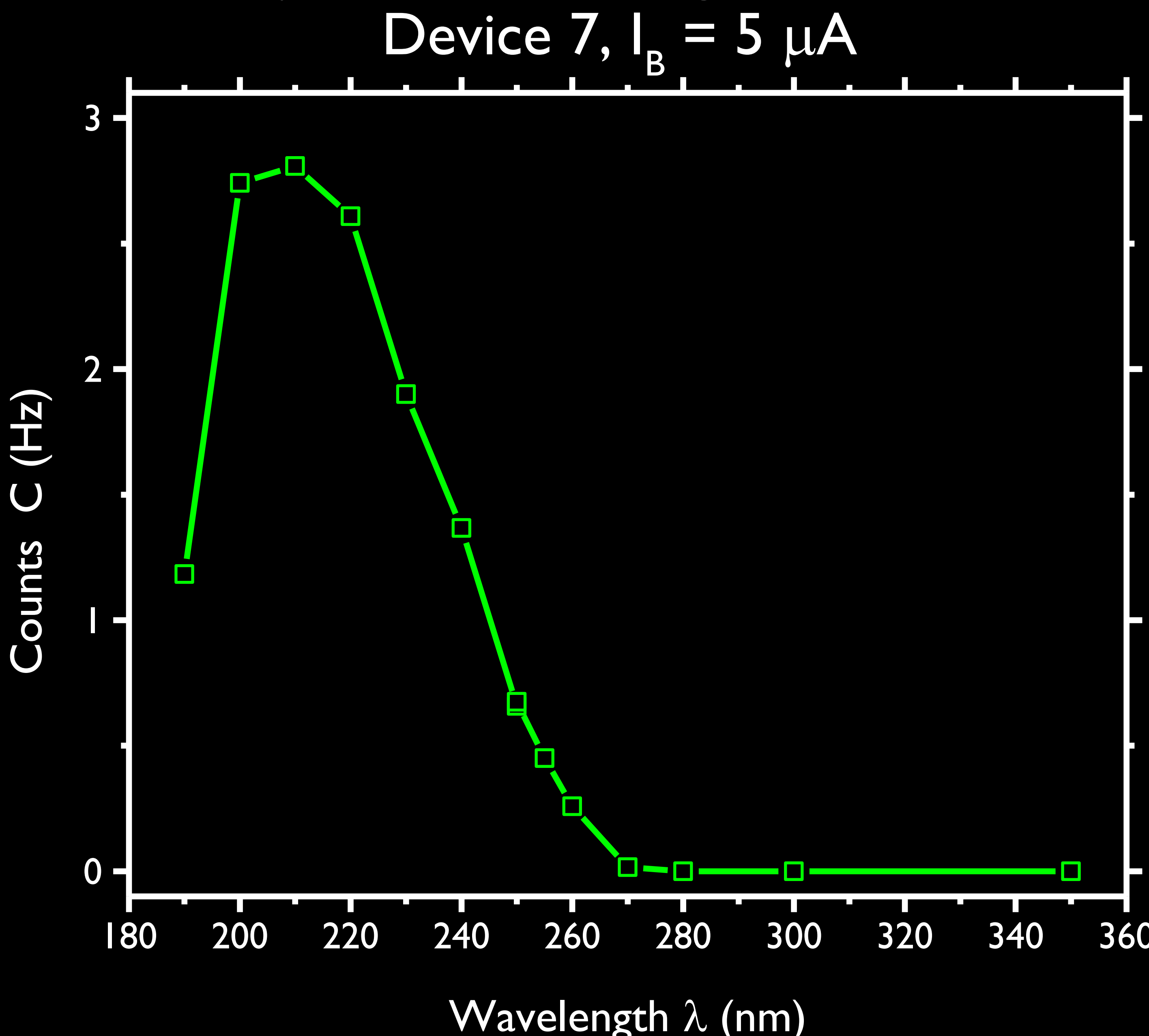
Linearity: Honeywell Detector

Device 7, λ = 230 nm

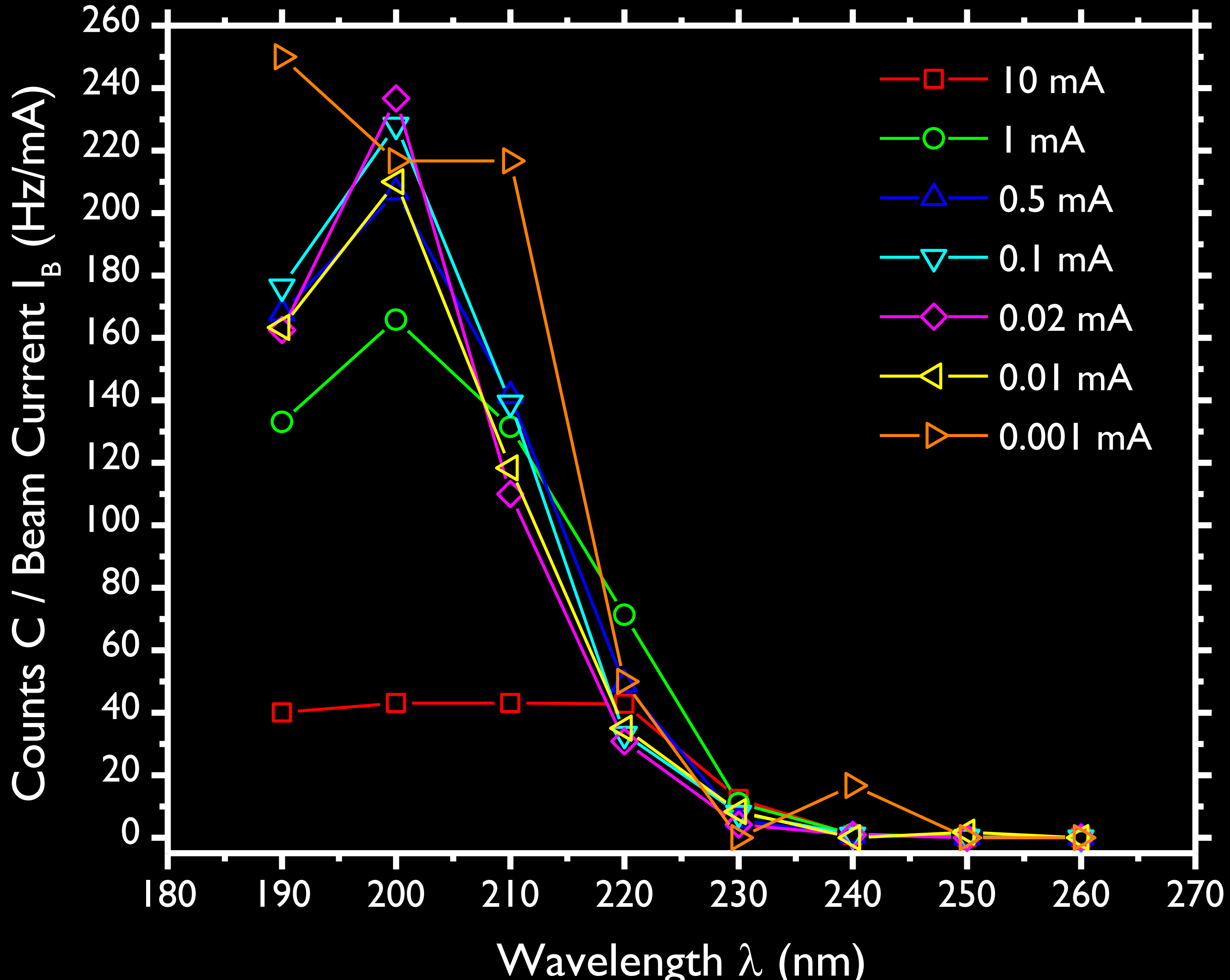




Spectral Response: Honeywell Fire Detector



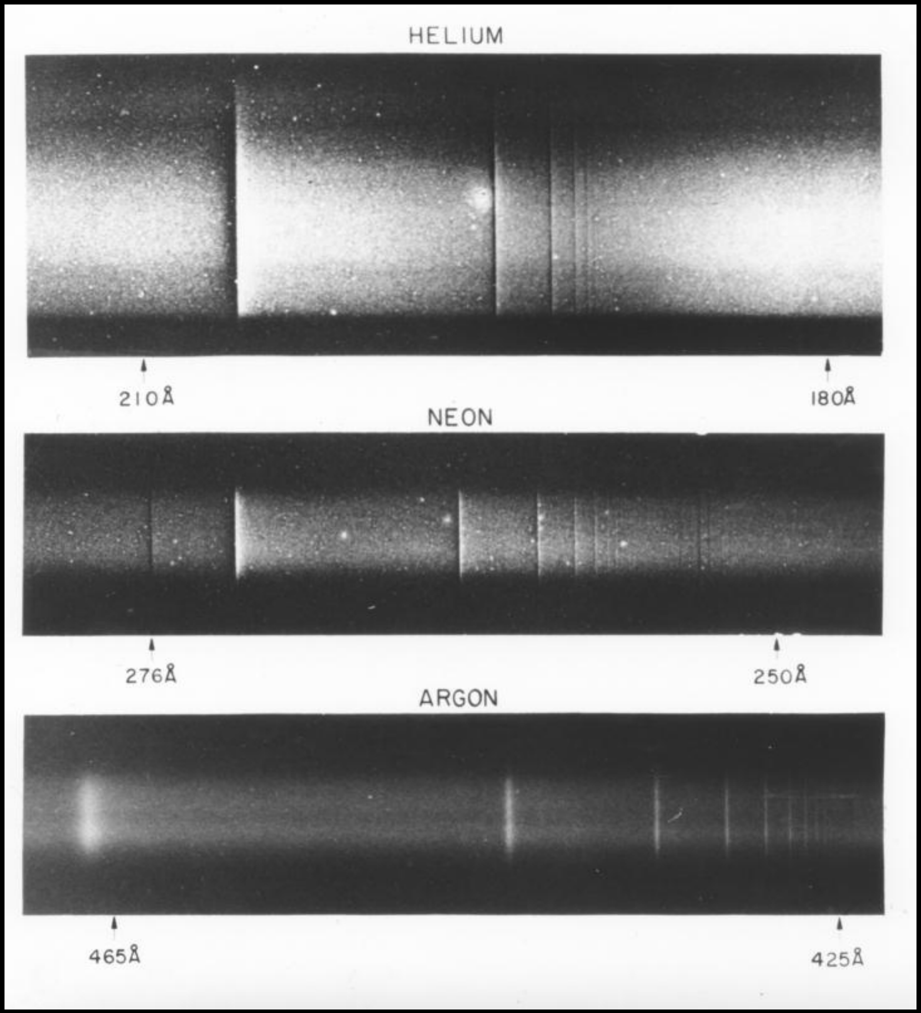
Honeywell: SB 1, W Anode, Solar Blind

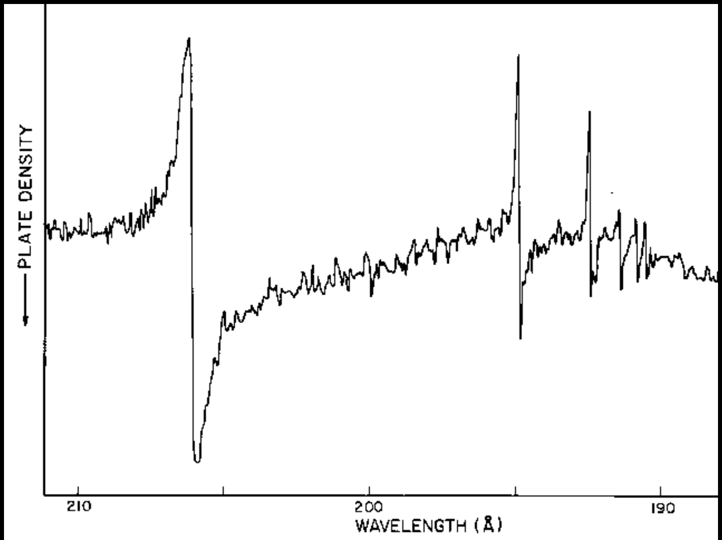


BL-4: Radiometry of Low-Light Detectors

- The primary scale for power responsivity is derived from cryogenic radiometer.
- The primary scale is transferred to low-light level using the linearity of synchrotron radiation to electron beam current.
- SURF III can continuously vary the synchrotron radiation flux in a range up to eleven orders of magnitude.
- Measured PMT's spectral responsivity, uniformity, and linearity.
- Measured UV "Geiger" detectors responsivity and linearity.
- More work in the future for radiometry using PMTs.

Codling & Madden, Phys. Rev. Lett. 10, 516 (1963)





Densitometer trace of the He absorption spectrum.

Fano-Beutler line shape: Interference between direct photoionization and autoionization.

50 Years of Atomic Spectroscopy with SR

- SURF will be hosting the 17th Pan American Synchrotron Radiation Instrumentation Conference SRI2013

- 50th anniversary of R. P. Madden and K. Codling, *New Autoionizing Atomic Energy Levels in He, Ne, and Ar*, *Phys. Rev. Lett.* **10**, 516 (1963) (submitted May 3, published June 15)

- The conference will be hosted jointly with Jefferson Lab and the Cornell High Energy Synchrotron Source