CORM annual conference, NRC, Ottawa, CANADA
June 1, 2012

New automated laser facility for detector calibrations

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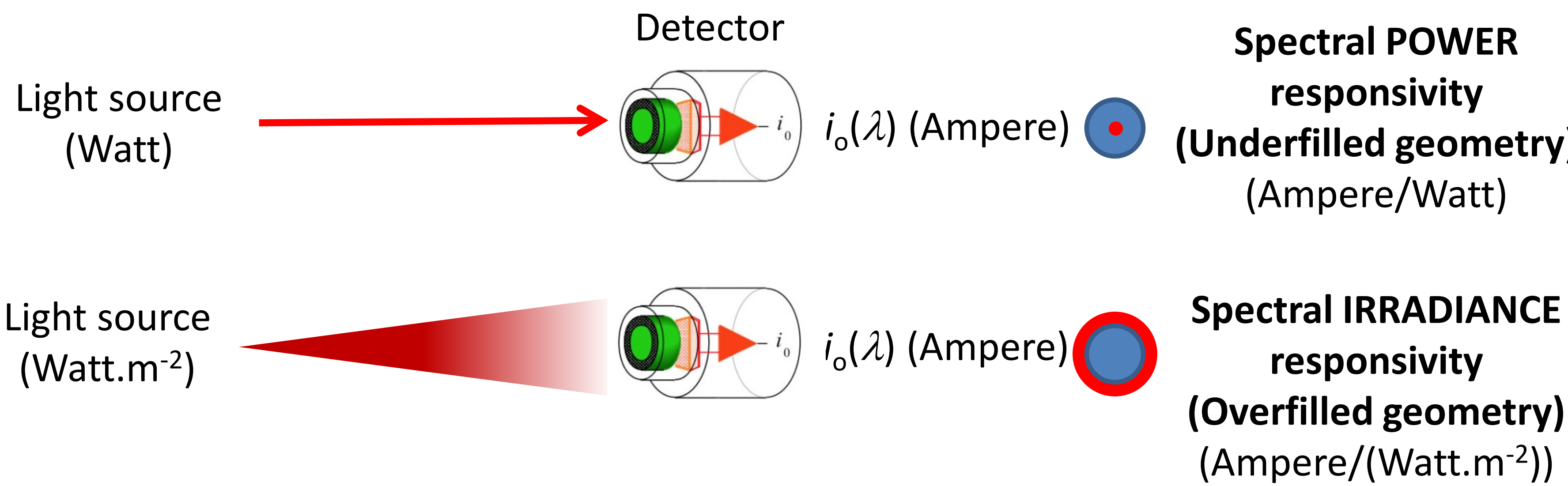
Overview

- Introduction
- Existing spectral calibration facilities
- New 1 kHz optical parametric oscillator (OPO) based calibration system
- Conclusion

Spectral calibration of optical sensors



- SI base unit -luminous intensity: candela
- SI base unit –radiance temperature: Kelvin
- Colorimetry and radiometry
- Spectral irradiance scale (FEL lamps)
- …

Existing NIST spectral calibration facilities

NIST POWR
Cryogenic Radiometer
(Power resp.)
(0.01 %)

NIST SIRCUS facility
Trap detectors
(Irrad resp.)
(0.025 %)*

Irradiance responsivity
(Ampere/(Watt.m^{-2}))
(≈ 0.05 %)*

NIST SCF
Trap detectors
(Irrad resp.)
(0.025 %)*

Traps to photodiodes

NIST SCF
Working std. photodiodes
(Power resp.)

Power resp.
(Ampere/Watt)
(≈ 0.20 %)*

* BEST expanded uncertainty (*k*=2)

POWR: primary optical watt radiometer

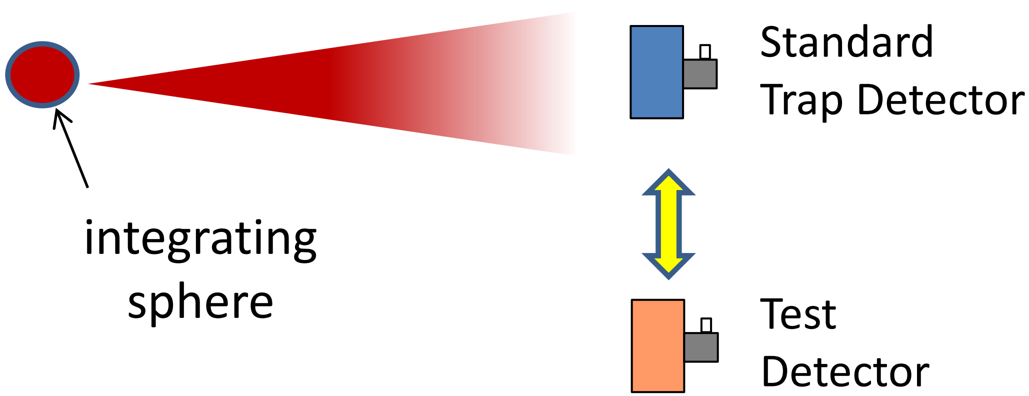
SIRCUS: Spectral irradiance and radiance responsivity calibrations using uniform sources

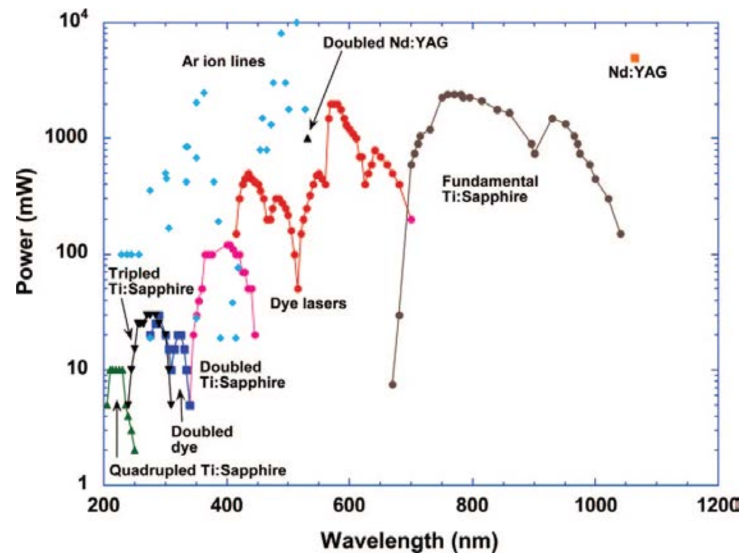
SCF: Spectral comparator facility

Trap detector: specially configured, multi-element silicon photodiodes detector with high performance.

NIST

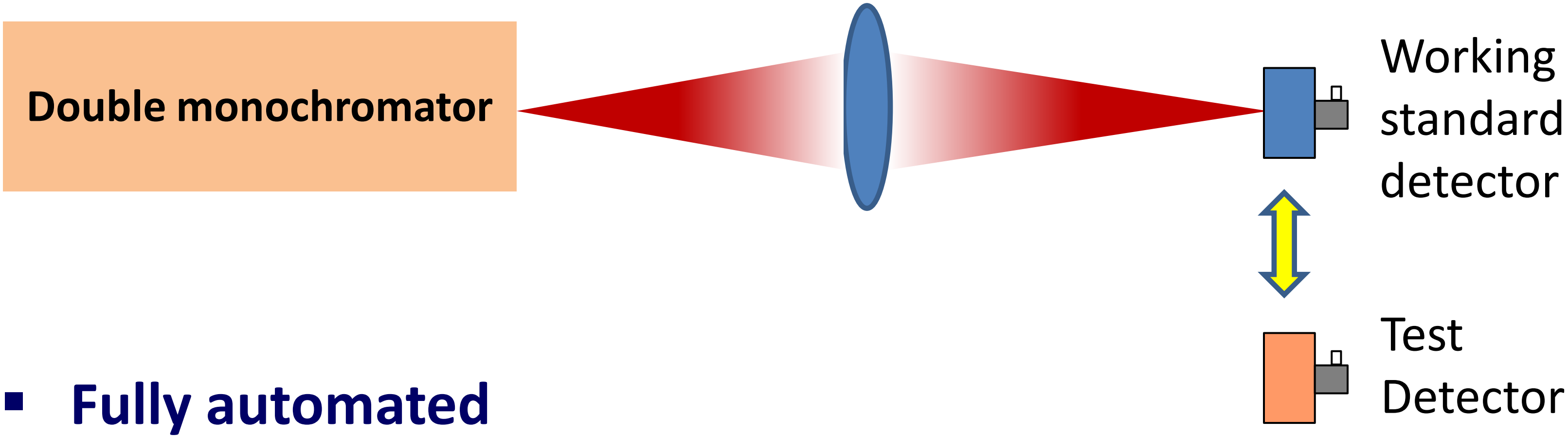
The NIST SIRCUS facility





- Continuous spectral coverage from UV to NIR
- Continuous wave (CW) or quasi–CW tunable lasers based research facility
- high power (e.g., 100 mW), narrow bandwidth (<0.01 nm)
- Used for realization of SI base units: Kelvin and candela
- Provide calibrations for primary radiometric standards and for remote sensing instruments …
- Difficult to automate & high-cost

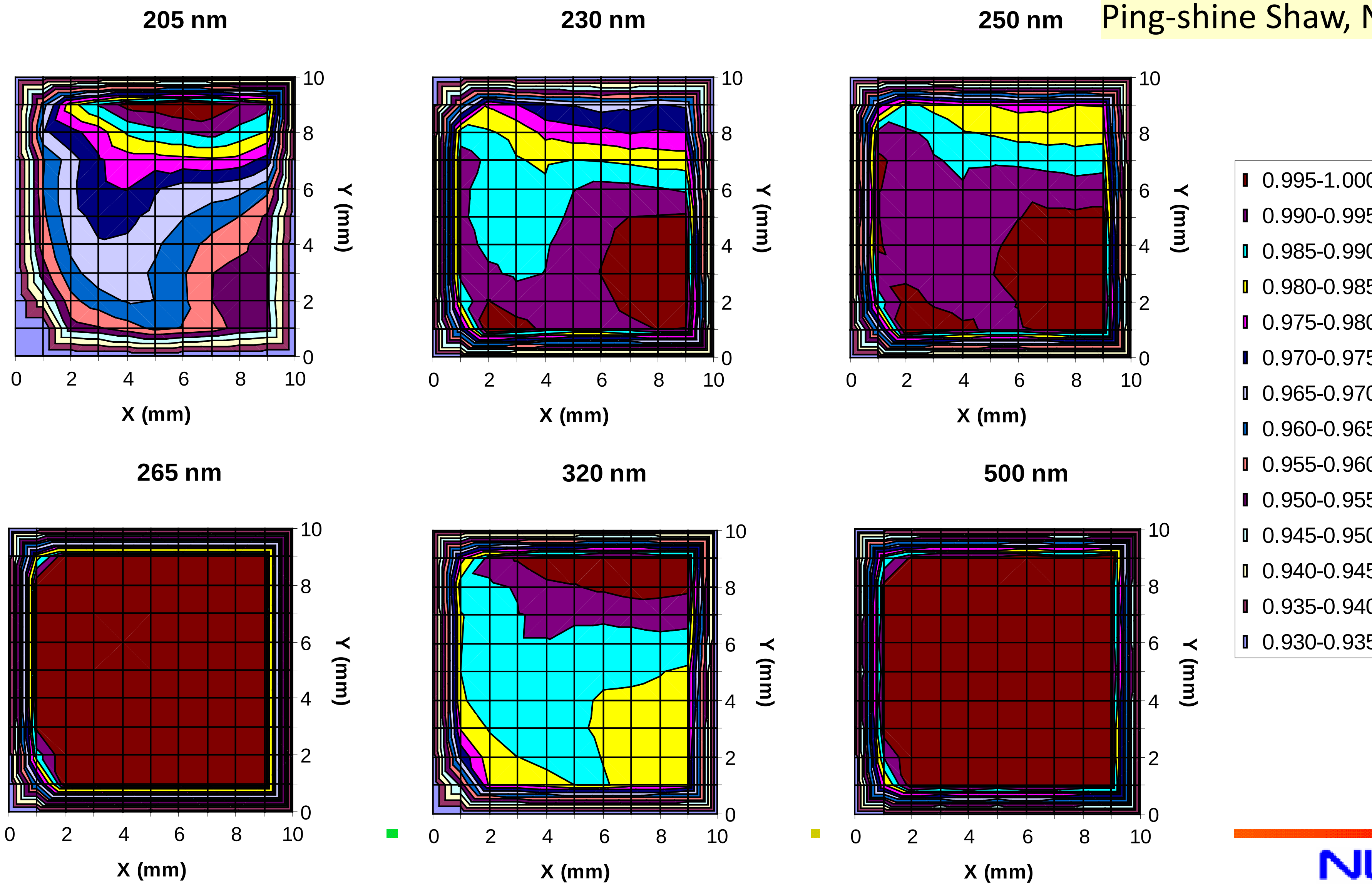
NIST SCF



- **Fully automated**
- Lamp-monochromator based calibration facility, no fringe problem
- Major facility to disseminate NIST Scale to industry
- Low radiant power (μW level), broad bandwidth (4 nm)
- Designed for power responsivity
- Large uncertainties to acquire irradiance responsivities (mapping method does not work well!)

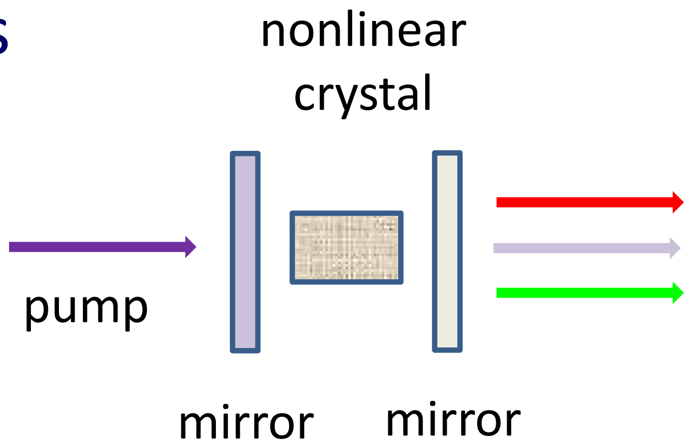
Spatial uniformity of a Si photodiode

Acknowledgement to
Ping-shine Shaw, NIST



Fully automated tunable OPO-based laser sources

- OPO: optical parametric oscillators
- Fully automated
- Large tunable range
- Portable
- Much lower cost



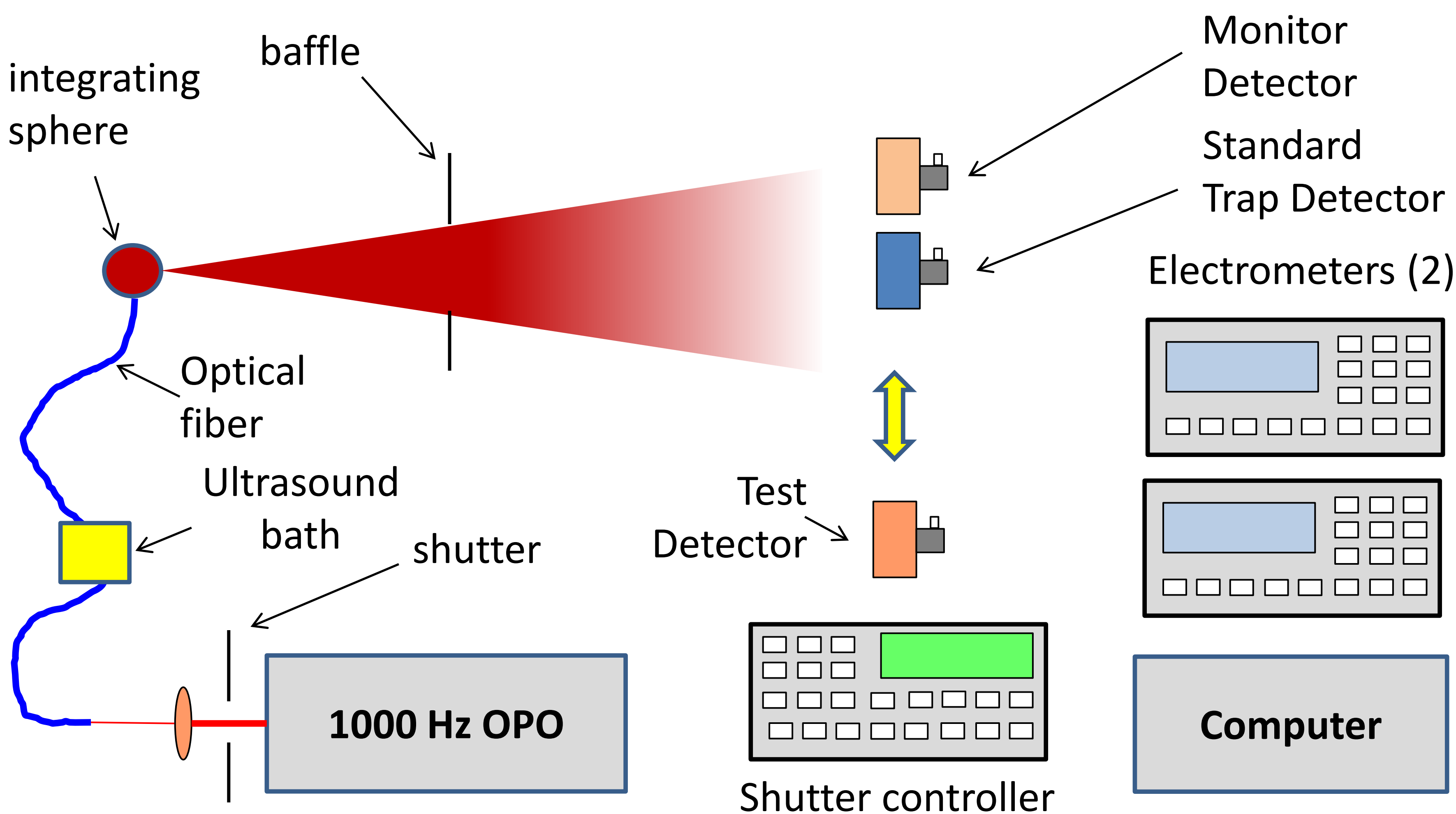
- Low repetition rate (10 Hz to 1000 Hz)
- Narrow pulse width, extremely low duty cycle (e.g., 10^{-6})
- Pulse to pulse variation and difficult to stabilize
- Trans-impedence amplifiers don’t work well

Have not been used as calibration source yet

Key questions

- Can pulse lasers be used for calibration of detectors with small uncertainties?
- How to overcome fluctuation of a pulsed laser and obtain repeatable results?
- Will detectors be saturated?
- Is a pulse laser equivalent to a CW laser for detector calibrations?

Schematic of the new automated calibration system



$$R_{test}(\lambda) = R_{\text{standard}}(\lambda) \times Q^{\text{M}}_{\text{test}}(\lambda) / Q^{\text{M}}_{\text{standard}}(\lambda)$$

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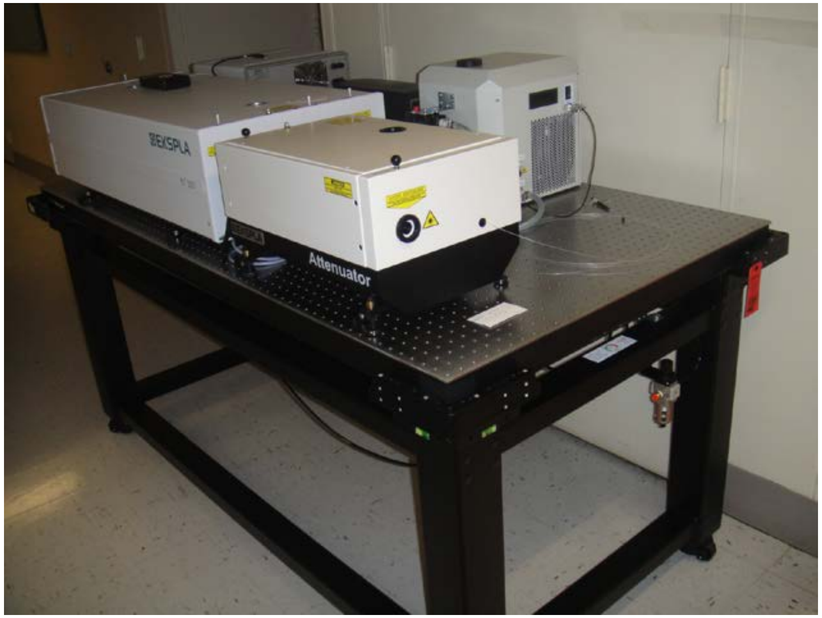
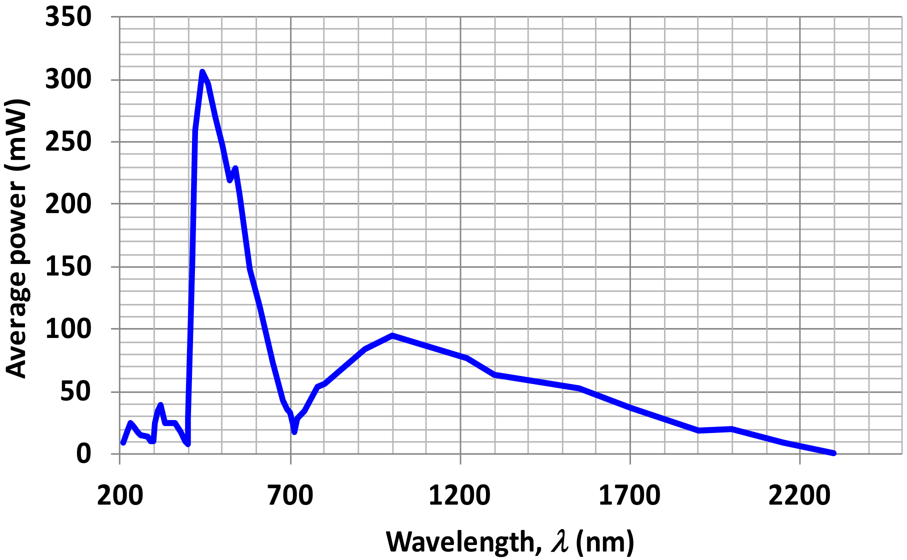
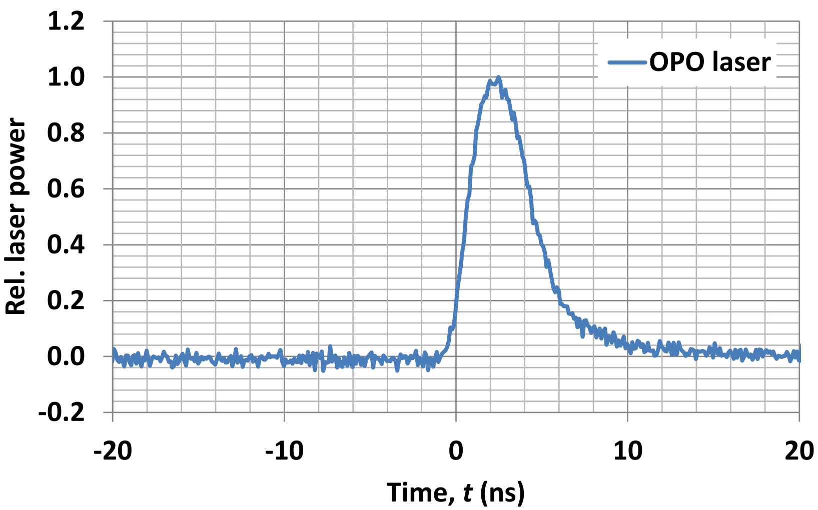
The automated OPO system

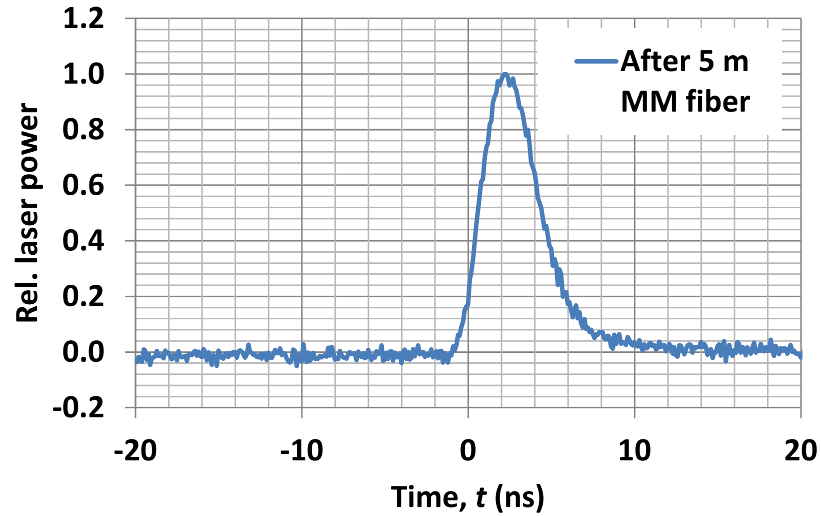


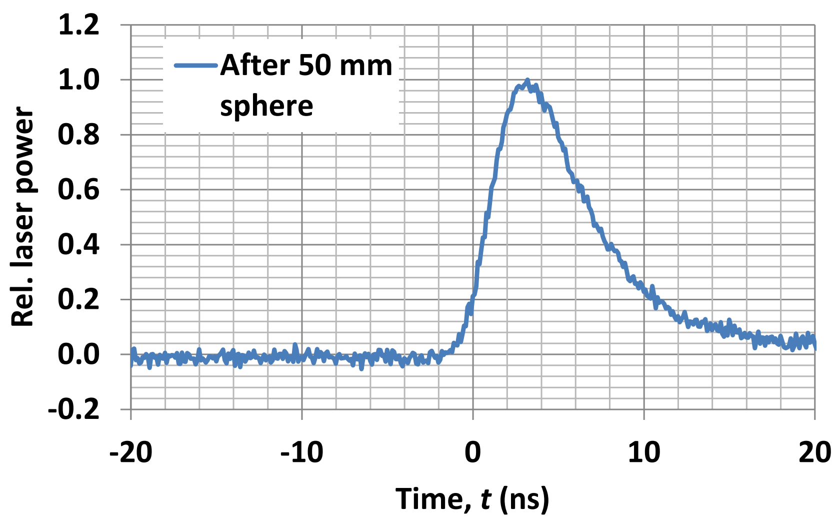


- 210 nm to 2400 nm tunable range
- 1 kHz repetition rate
- 5 ns pulse width
- 5 – 8 cm^{-1} bandwidth (≈ 0.2 nm in visible range)

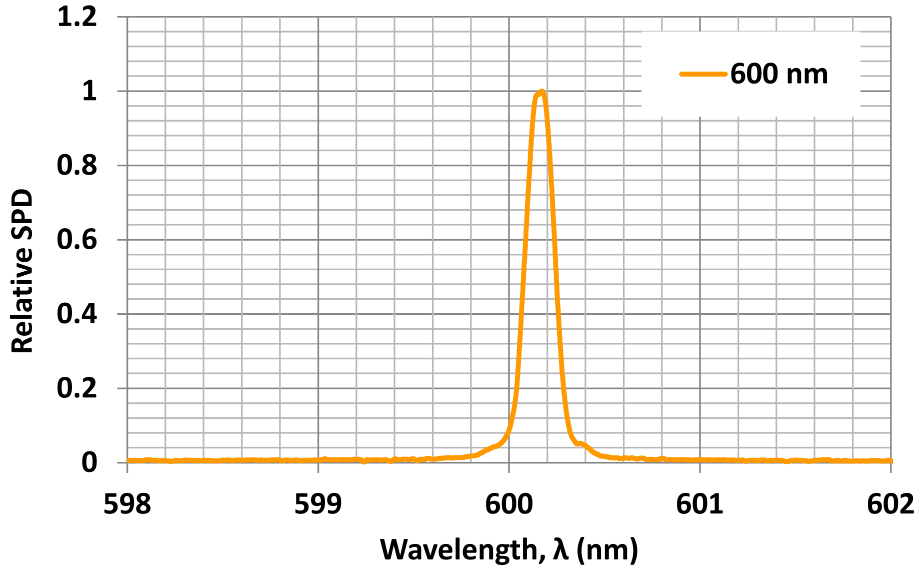
OPO Pulse waveforms

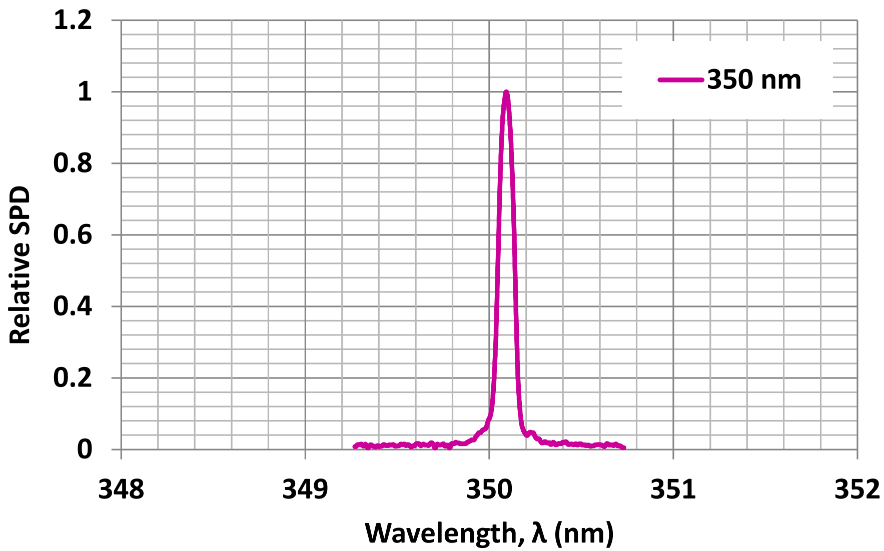


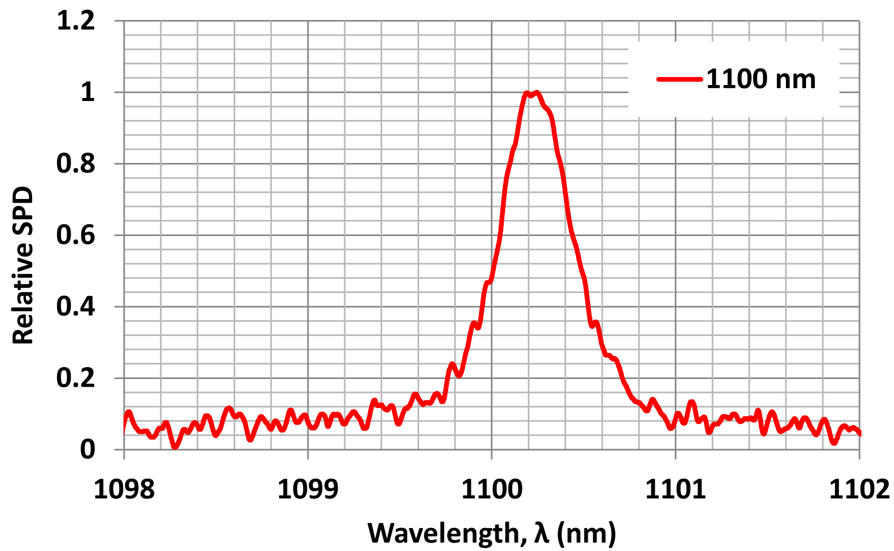




OPO spectra







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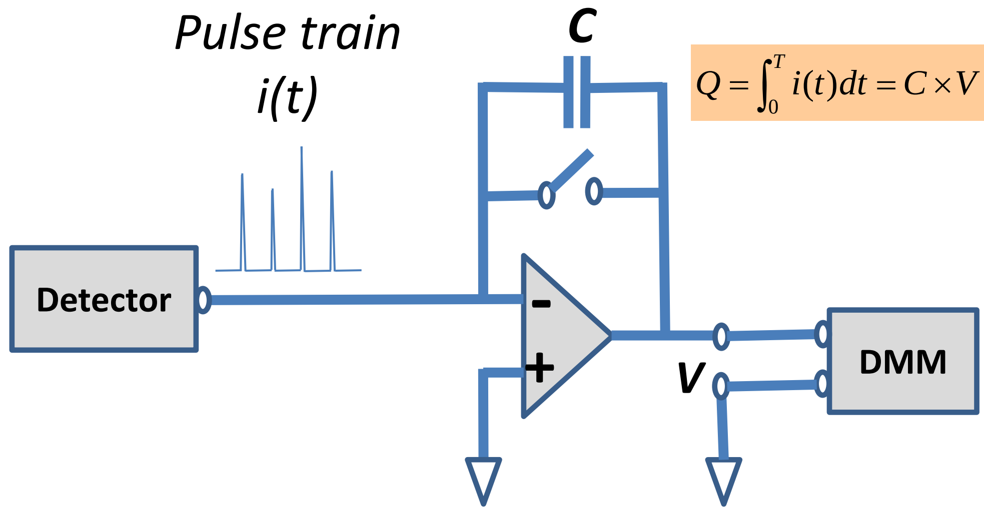
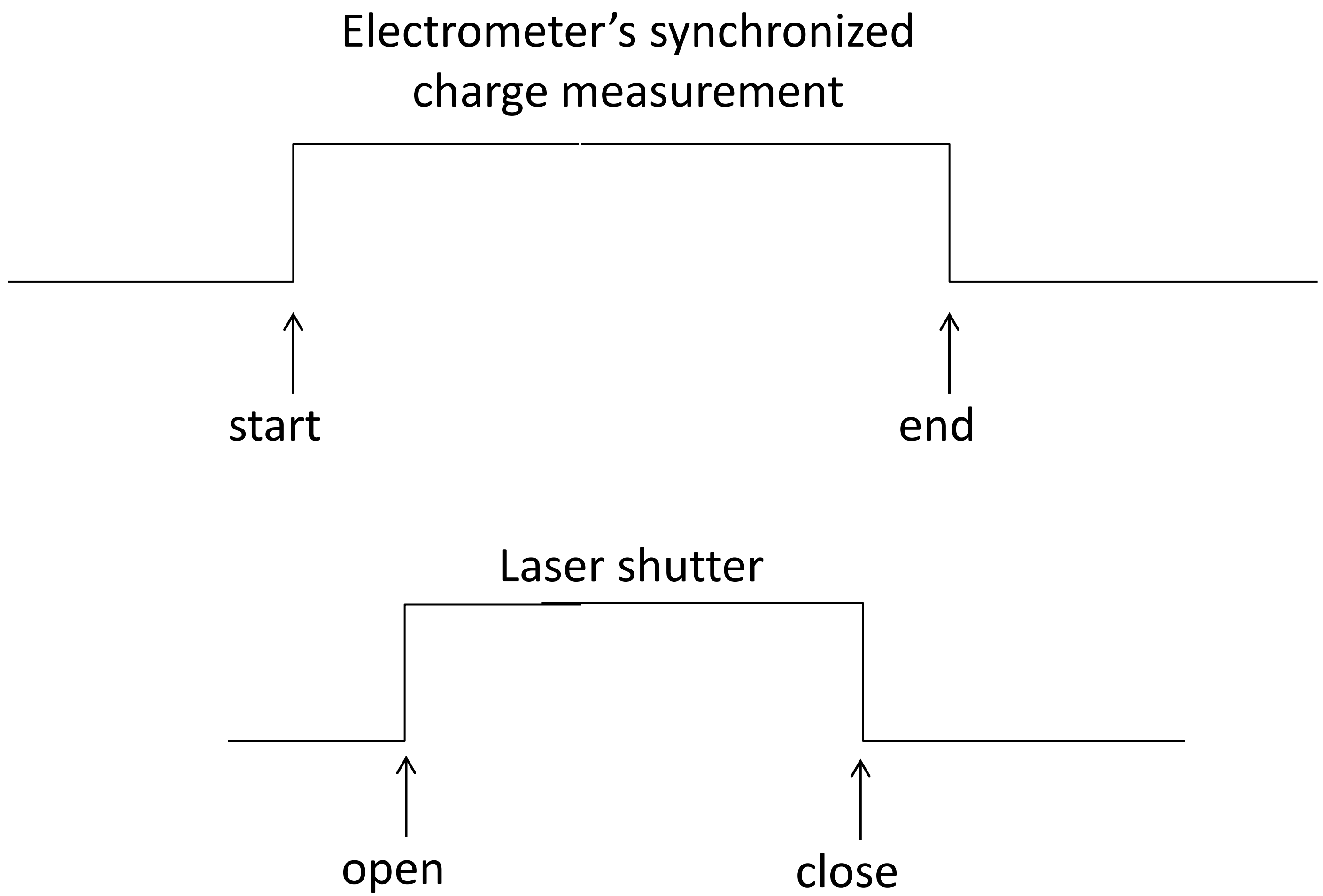
The electrometers



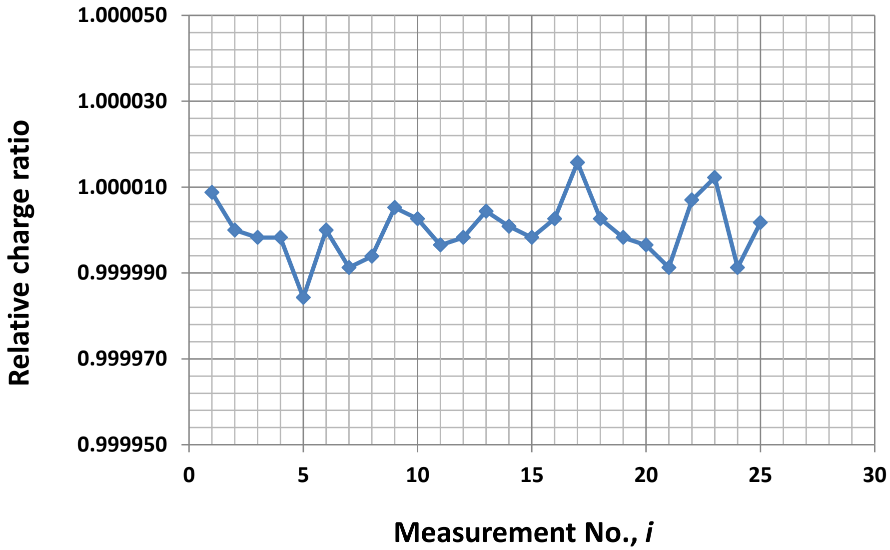
- Charge measurement function from 2 nC to 2 µC using a charge amplifier
- < 3 fA bias current
- < 20 µV burden voltage
- High performance multichannel switching card

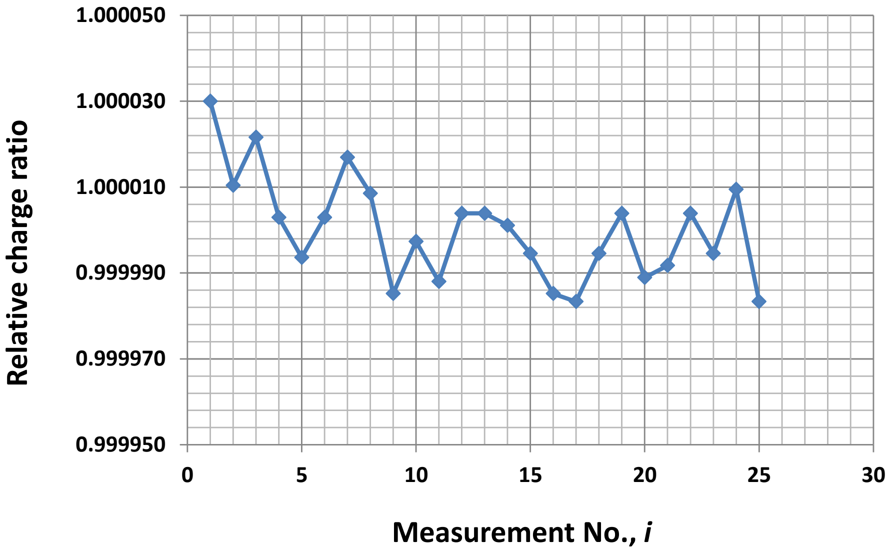
Measurement Timing



Measurement repeatability

1 s integration time for each point





- two Hamamatus S2281 silicon photodiodes (PD)
- standard deviation = **7** ppm!

- one 3 silicon PD trap and one S2281 Si PD
- standard deviation = **12** ppm!

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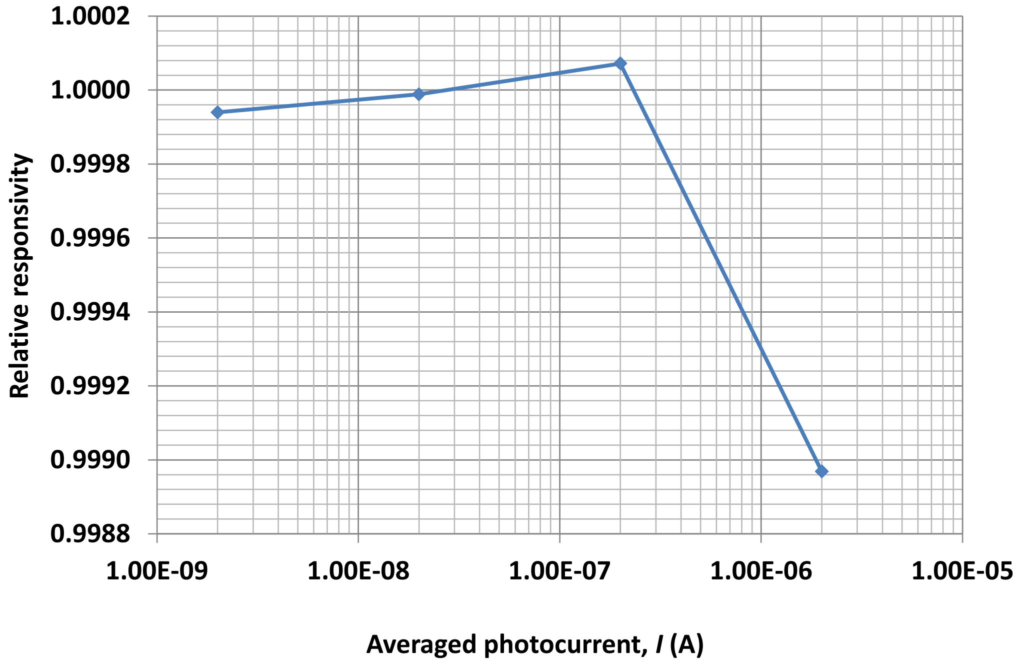
Detector non-linearity test

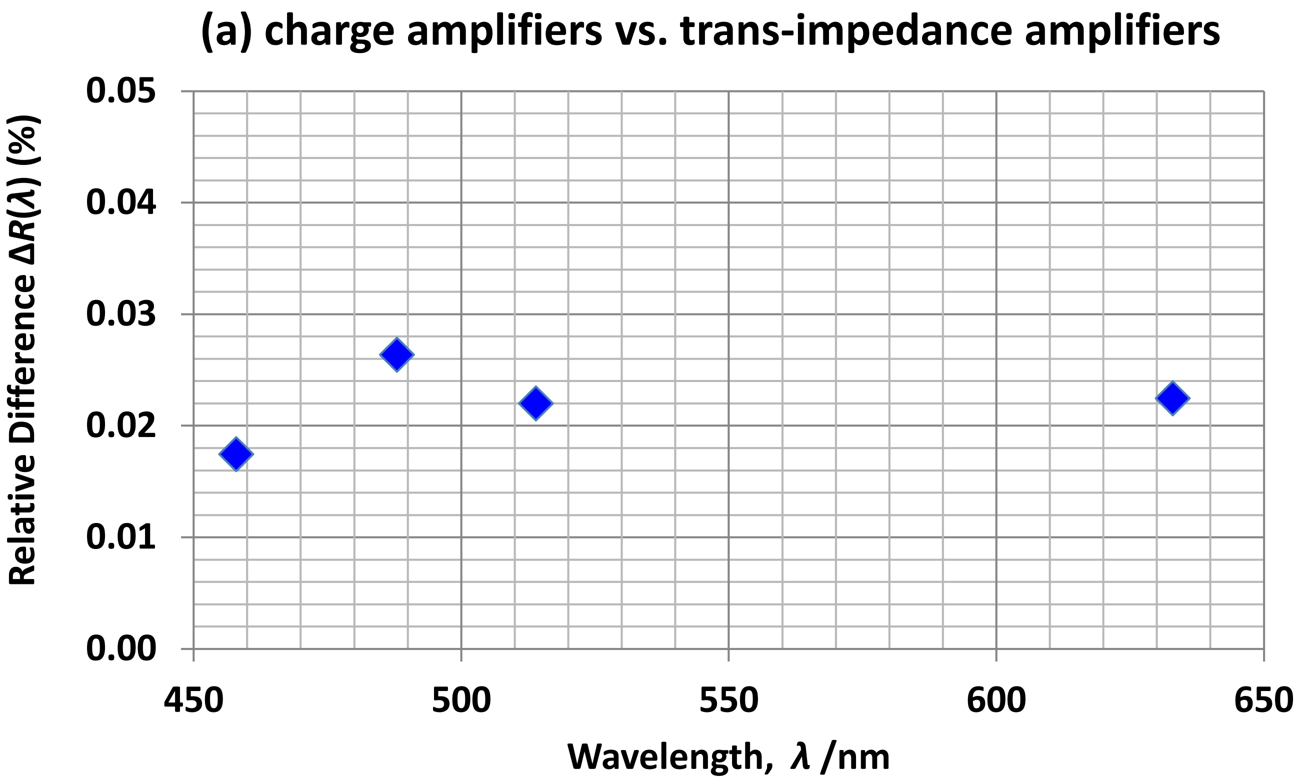


Obtained by normalizing the charge ratio $r(P_i)$ of the test detector (S2281 PD) to reference detector (S2281 PD with 2 orders of magnitude lower signal).

OPO at 450 nm.
Saturation starts at peak=100 mA, averaged=1 μA.

1) Nonlinearity depends on the detector and laser wavelength.
2) The instantaneous photocurrent without causing nonlinearity is several orders of magnitude higher than the threshold nonlinear DC photocurrent (0.1 – 1 mA typically).
3) The level of allowed averaged photocurrent is several orders of magnitude lower than the threshold nonlinear DC photocurrent.

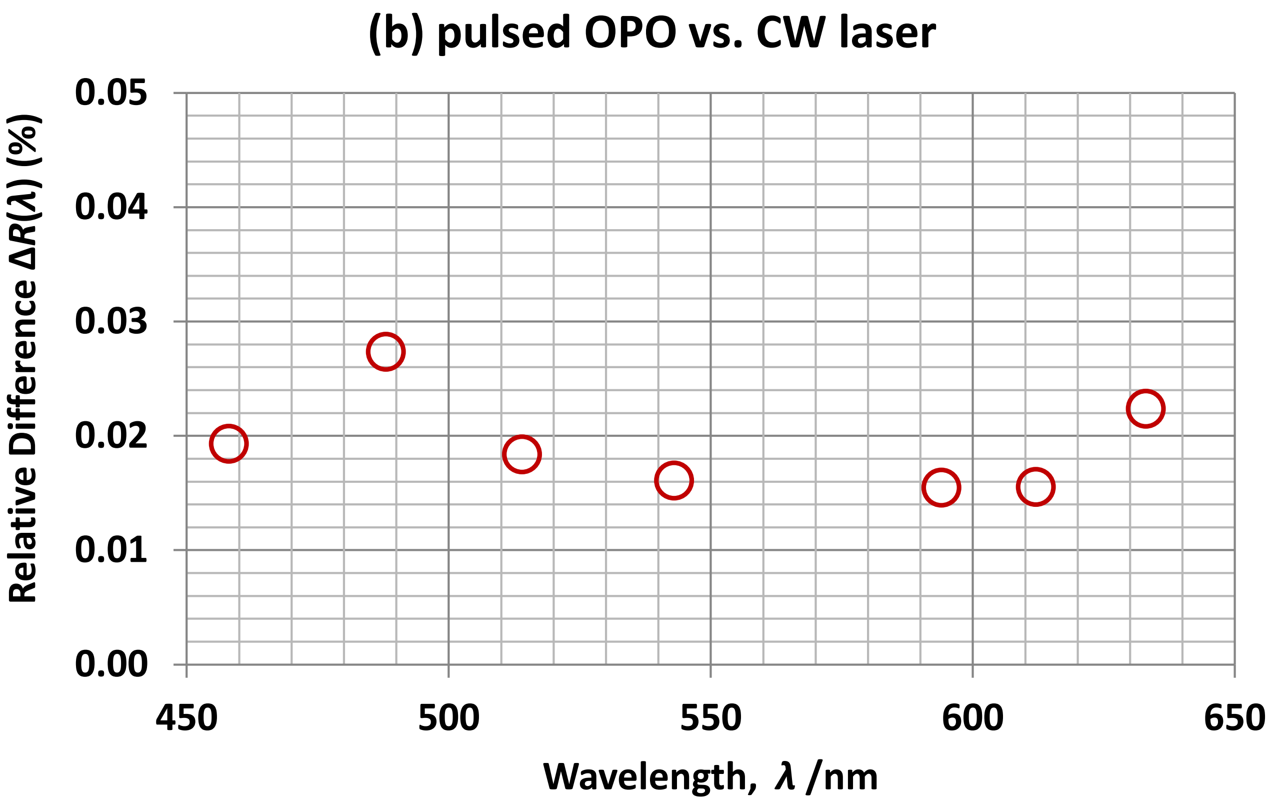
Validation: charge amp vs trans-impedance amp



"**CW laser** + charge amplifiers" vs. "**CW laser** + trans-impedance amplifiers"

Difference in measured responsivity is ≈ 0.02 %.

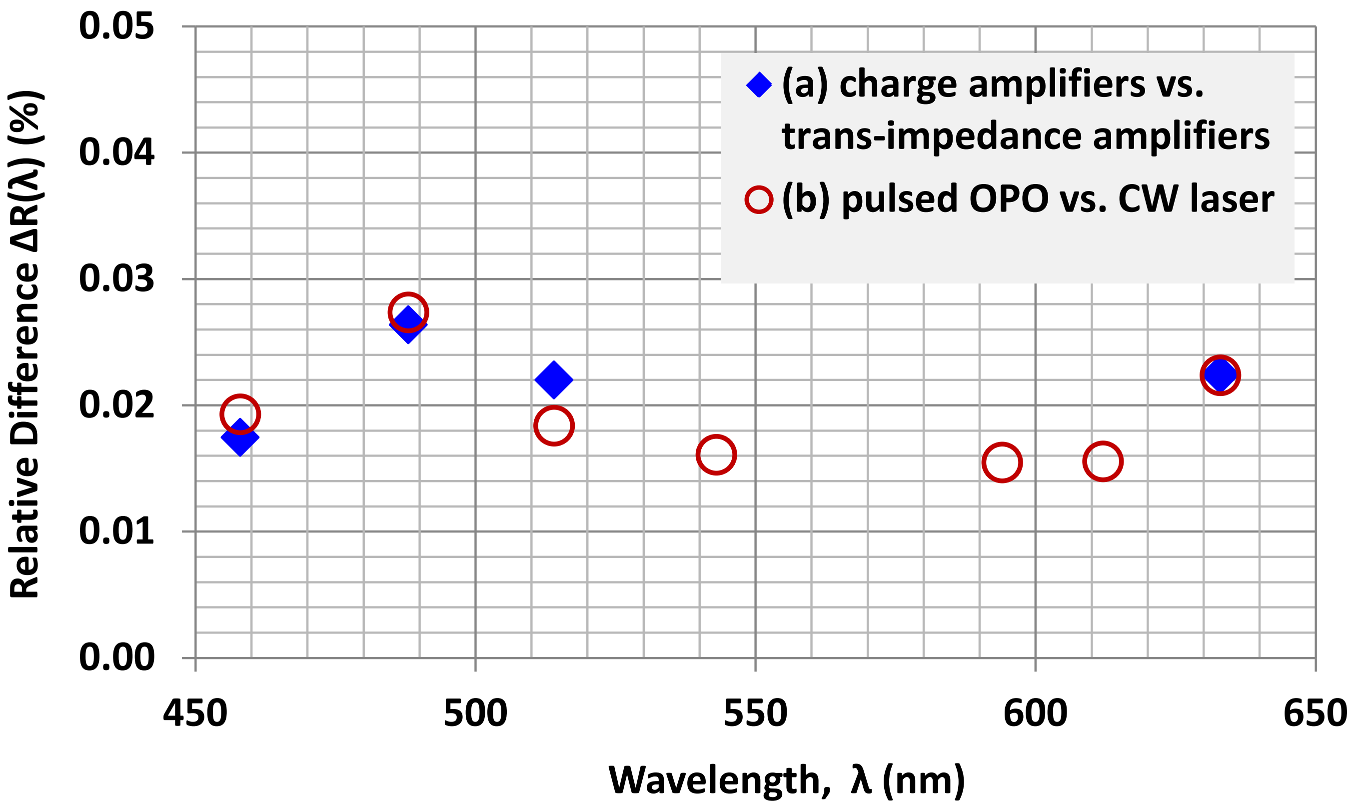
Validation: 1 kHz pulsed OPO vs CW lasers



"**Pulsed OPO** + charge amplifiers" vs. "**CW laser** + trans-impedance amplifiers"

Difference in measured responsivity is also ≈ 0.02 %

Comparison of Results



Replacing **CW laser** with **pulsed OPO** for charge amplifiers does not make difference in measured responsivity.

Pulsed OPO ⟺ CW laser.

Uncertainty budget

	Relative standard unc. (%)	
Uncertainty component	Type A	Type B
Reference trap detector		0.020
OPO wavelength (0.02 nm)		0.005
Sphere source irradiance non-uniformity		0.005
Detector reference plane		0.010
Detector non-linearity		0.005
Transfer to test detector	0.005	
Electrometer (range to range gain error)		0.005
Combined uncertainty (%)	0.025	
Expanded uncertainty (*k*=2) (%)	**0.05**	

Conclusions

- A fully automated laser facility using a kHz pulsed OPO for calibration of detectors and instruments has been developed and validated. The estimated uncertainty is 0.05 % (*k*=2).
- The new facility is to be used for calibration of photometers, colorimeters, and spectroradiometers with significantly reduced uncertainty.
- The developed method may be used in other applications:

  - transmittance and reflectance
  - surface color and appearance
  - optical medical imaging
  - …

Acknowledgements

Keith Lykke

Steve Brown

George Eppeldauer

Yoshi Ohno

and many other colleagues

THANK YOU