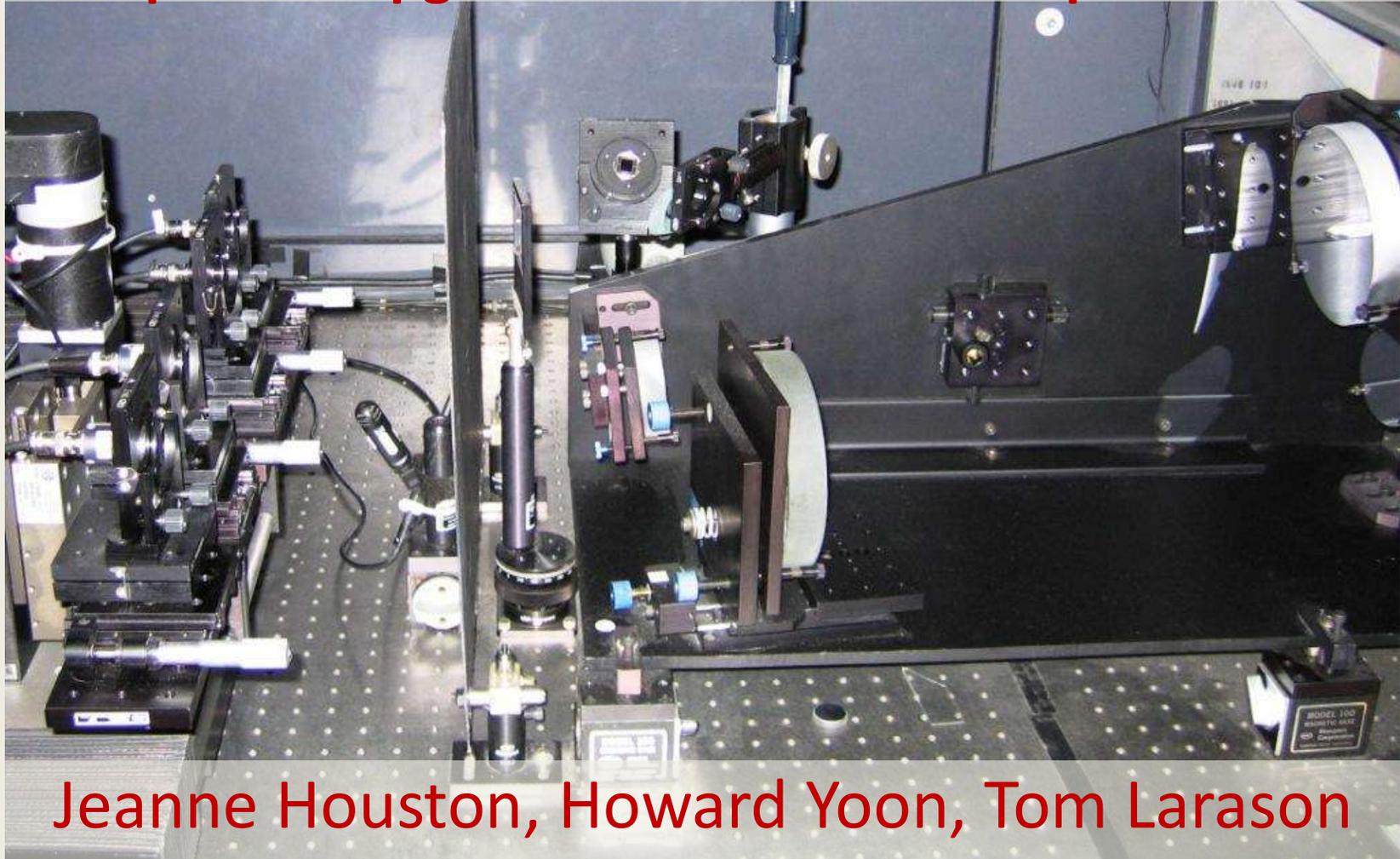


# Uncertainty and Performance Results From a Component by Component Upgrade to the Visible Comparator Facility



Jeanne Houston, Howard Yoon, Tom Larason

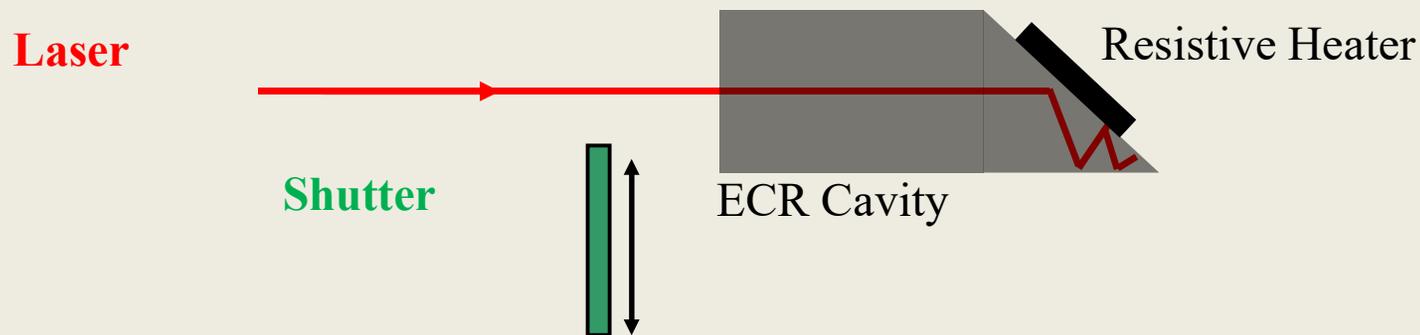
CORM: August 2017

# Outline

- **Background:** Determination of the Optical Spectral Power Responsivities Scales
- **The Visible Spectral Comparator Facility (VisSCF)**
- **Upgrades to the VisSCF— Equipment Improvements**
- **Resulting Performance and Uncertainty Improvements to the VisSCF**
- **Summary and Customer Impact**

# Optical Spectral Power Responsivity Scales

- Optical Power is Determined by Equating Optical Power [W] to the better known Electrical Power [W] using a Cryogenic Radiometer (Electrical Substitution Radiometer Run at Cryogenic Temperatures)
  - Based on Electrical Substitution Radiometry



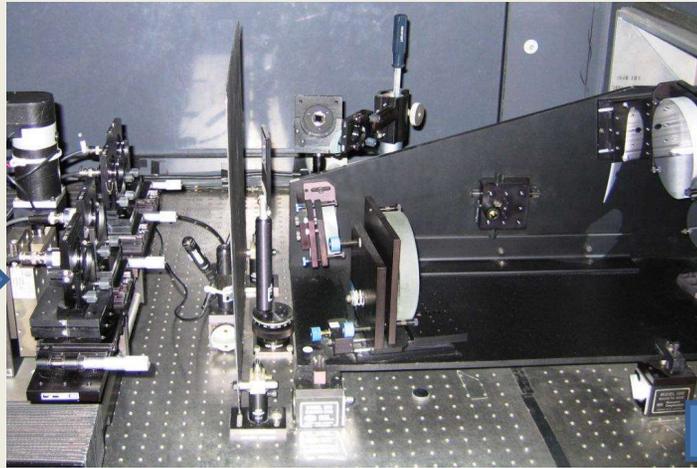
Electrical Substitution Radiometry:

1. Light is absorbed into a cavity creating a temperature increase
2. The light is blocked.
3. Electrical Resistive heating is substituted creating the same magnitude temperature change.
4. Power [W] to cause the same temperature change: Optical Watt (determined) = Electrical Watt (known)

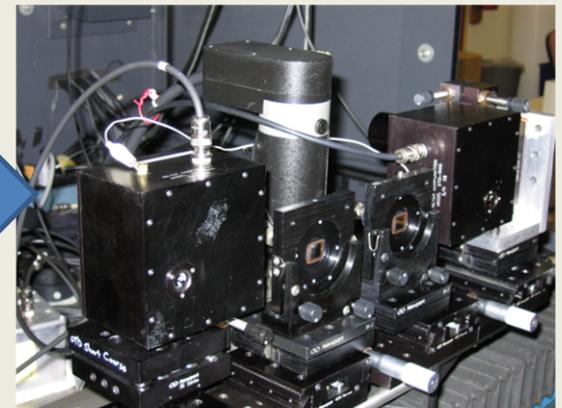
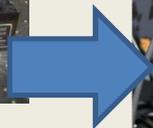
# Optical Power Calibration Chain



POWR (Primary Optical Watt Radiometer): A Cryogenic Radiometer: Absolute Standard for Optical Power Measurements

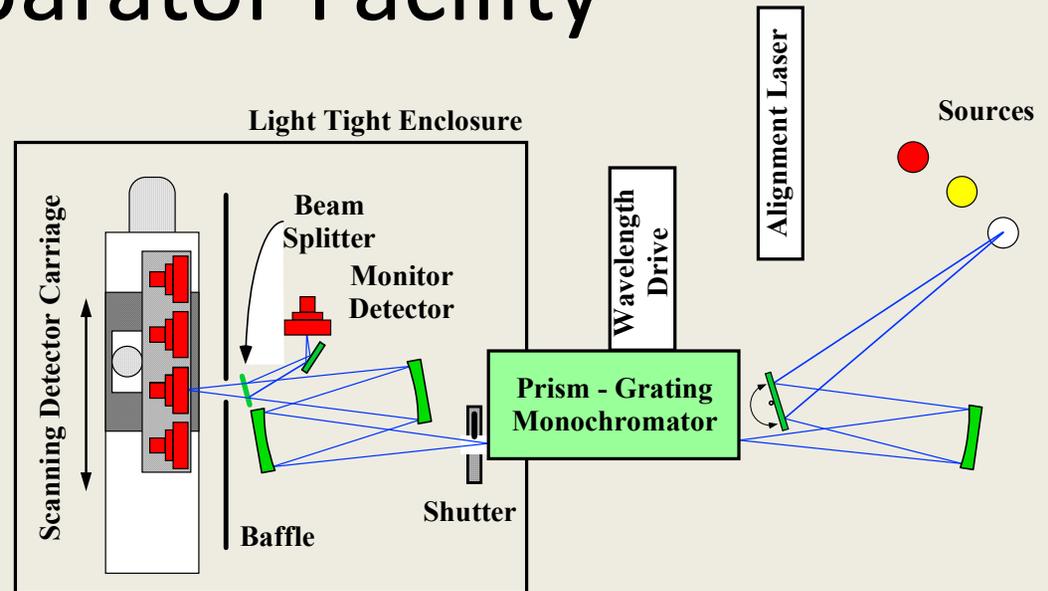
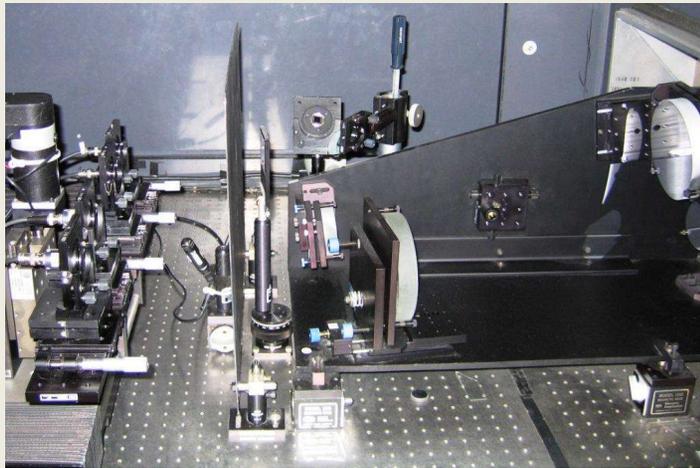


VisSCF (Visible/NIR Spectral Comparator Facility): A transfer facility for the optical power measurements [A/W]. A calibration facility of optical detectors



Optical Power Scale: from Working Standard detectors to Customer Devices

# The VisSCF: Visible/NIR Spectral Comparator Facility



A facility that provides optical spectral power responsivity [ $A/W$ ], spectral irradiance responsivity [ $A/(W/cm^2)$ ], and spatial uniformity calibrations of optical detectors from 350 nm to 1800 nm.

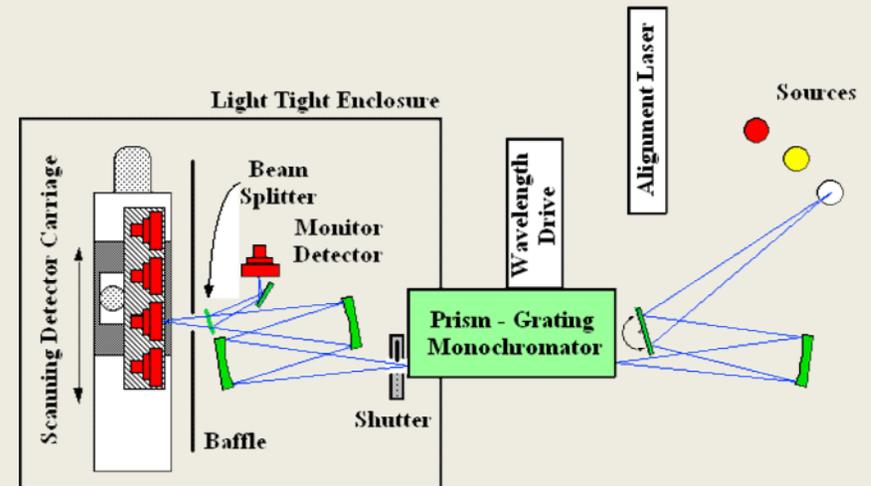
Originally designed and built in the late 1980's.

A heavily used optical calibration facility, supporting both internal and external customers.

# Scope of the VisSCF Upgrade

## Plans :

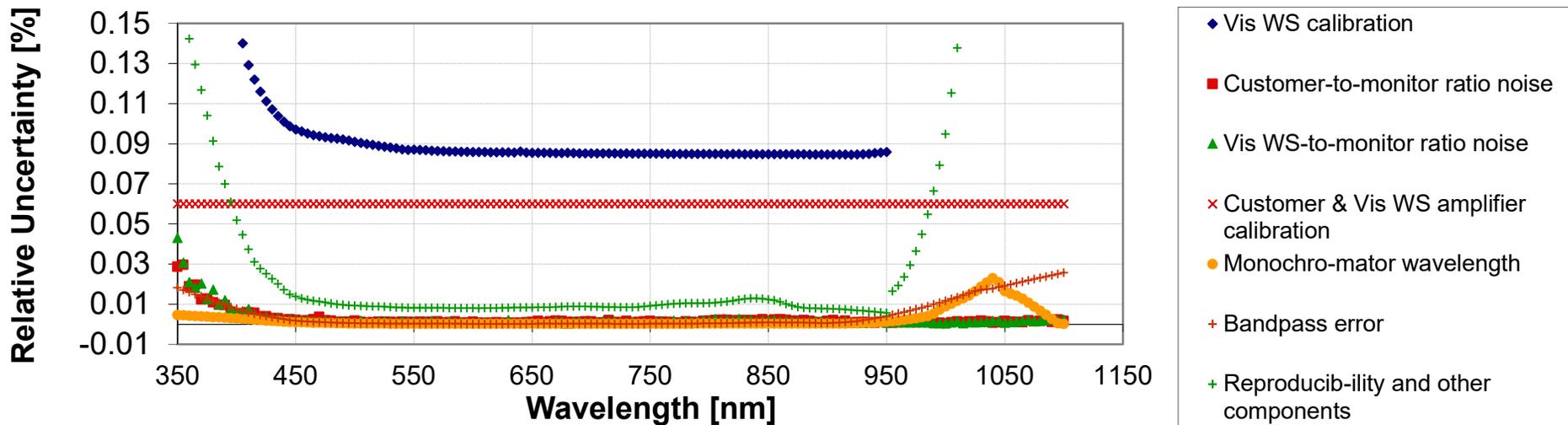
- Keep both the existing design and layout of the facility as well as the major critical equipment
- Upgrade to the individual components to improve the system performance
- Change from 1990's available technology and materials to 2016 technology and materials



# How Do You Determine the Needed Performance Improvements?

*Look at your uncertainty budget with respect to your measurement goals.*

Customer Visible Si Photodiode (Hamamatsu S2281/S1337-1010BQ) Uncertainty Components 2011

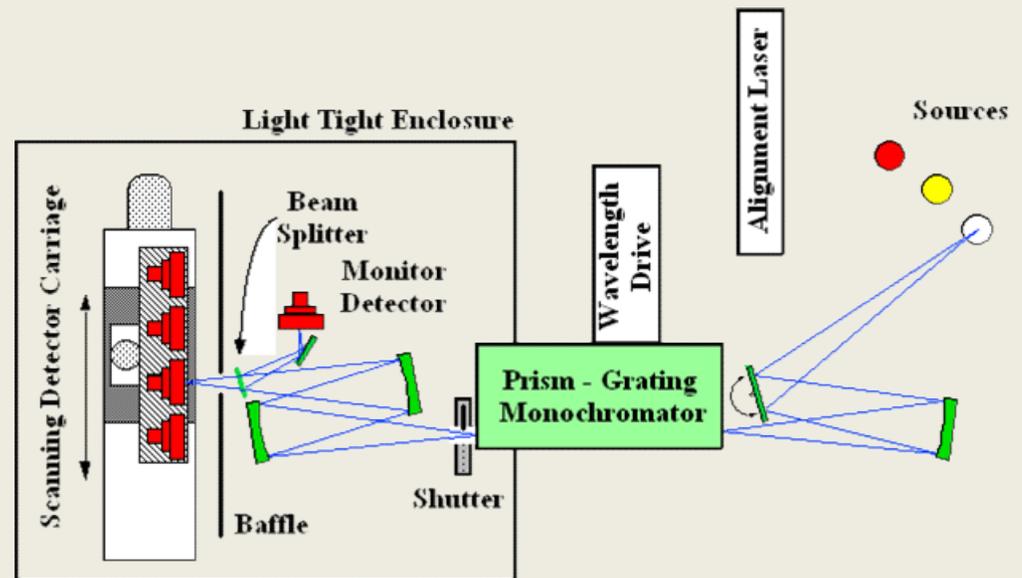


- Increase the UV throughput in the system:
- Extend the measurement range down to 300 nm
- Reduce the scatter in the optical beam
- Improve the reproducibility in the measurements
- Reduce the monochromator wavelength uncertainties
- Reduce the temperature dependence of the detectors, especially in the NIR

# Measurement Equation and Impact of the Beamsplitter

- Lowest Uncertainty obtained by using a “2 beam method.”
- 2 Beam Method: Split the optical beam between the Detector Under Test and a Monitor Detector.
- Measure the Test Detector and the Monitor Detector Simultaneously.
- Fluctuations in the optical beam power can be accounted for by using Ratios of the Test Detector to the Monitor detector,  $Y_x/Y_m$ .
- Beamsplitter is required for a 2 beam method of measurement.
- Best measurement reproducibility is obtained using a 50/50 beamsplitter due to the reduction of noise in the signals

$$S_x = \frac{R_x}{R_s} \cdot S_s = \frac{\frac{Y_x}{Y_s} \frac{Y_{mx}}{Y_{ms}}}{\frac{Y_s}{Y_{ms}}} \cdot S_s = \frac{\frac{V_x}{V_s} \frac{V_{mx}}{V_{ms}}}{\frac{V_s}{V_{ms}}} \cdot \frac{G_s}{G_x} \cdot S_s$$

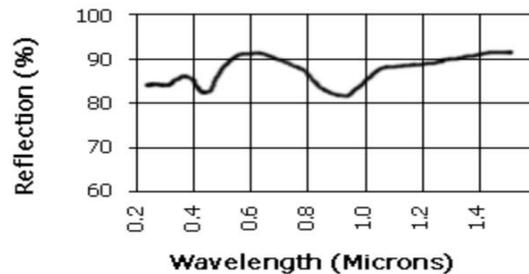


# Increasing the Optical Throughput in the UV: the Beamsplitter and the Mirrors

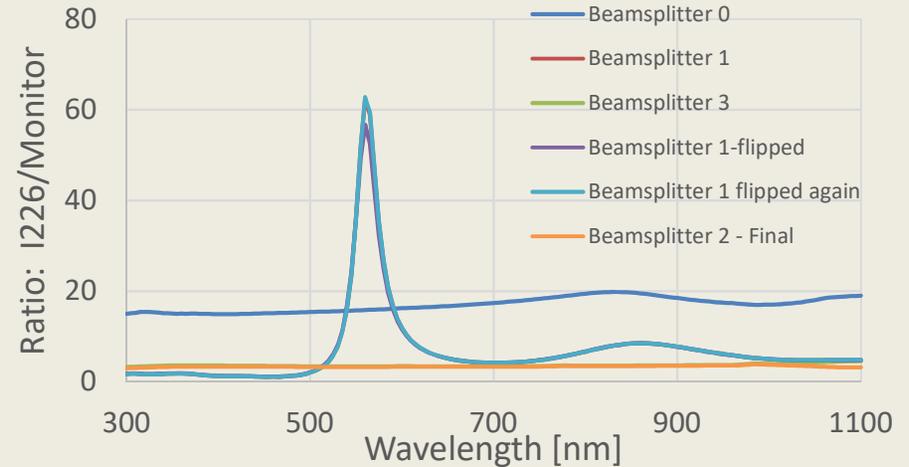
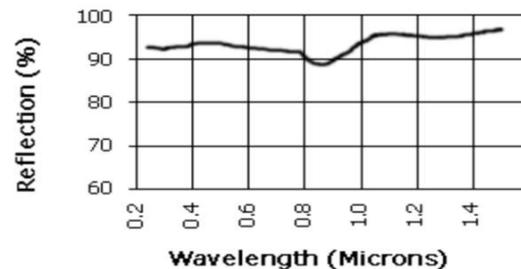
## Beamsplitter Found for the VisSCF:

- Beamsplitter = Metal ND filter, 50/50
- Beamsplitter thickness = 1 mm
- Directionality of Reflective Surface: Towards the incoming beam

### Protected Aluminum Coating



### Bare Aluminum Coating



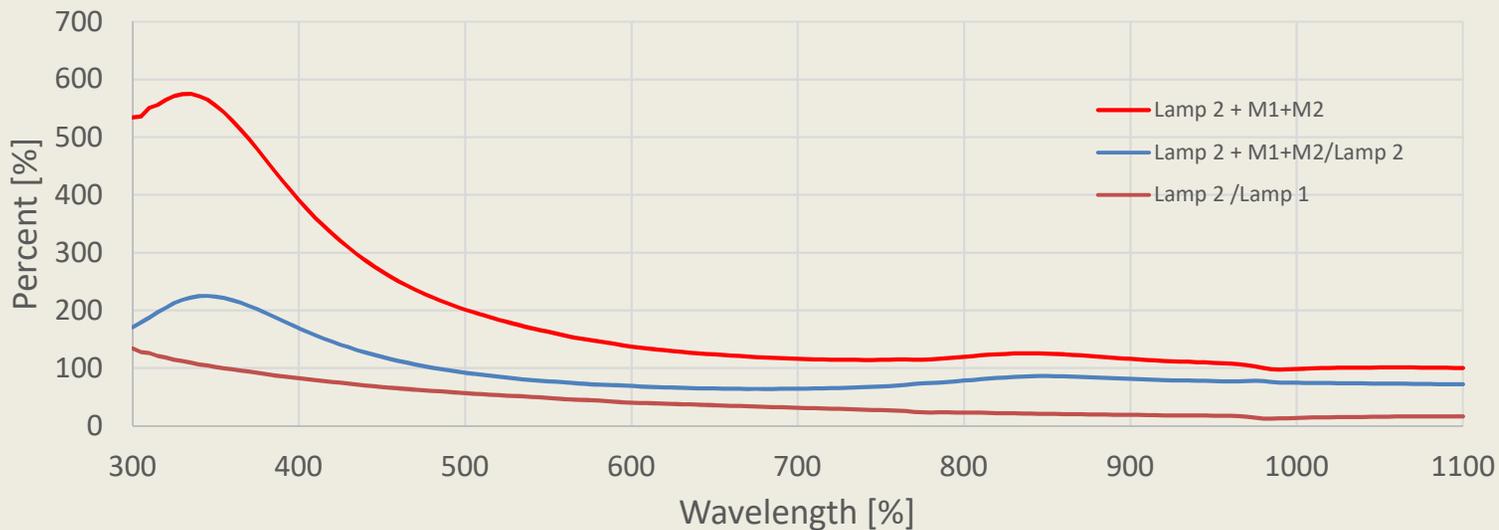
## Decrease the UV losses due to the Mirror Reflections:

- 7 Mirrors external to the monochromator increase the signal losses
- Use a bare aluminum coating
  - to increase uv reflectance x7
  - To eliminate the additional structure in the reflectance x7

# Signal Improvement

Resulting from Recoated Mirrors with a protective coating, a 50/50 Beamsplitter, and a Higher Color Temperature Lamp

Signal Comparison using 3 Improvements , (Percent Difference)



## Results:

- Independently both recoating the mirrors and using the new lamp increase the UV throughput.
- The biggest increase is due to replacing the first two out of 6 mirrors.

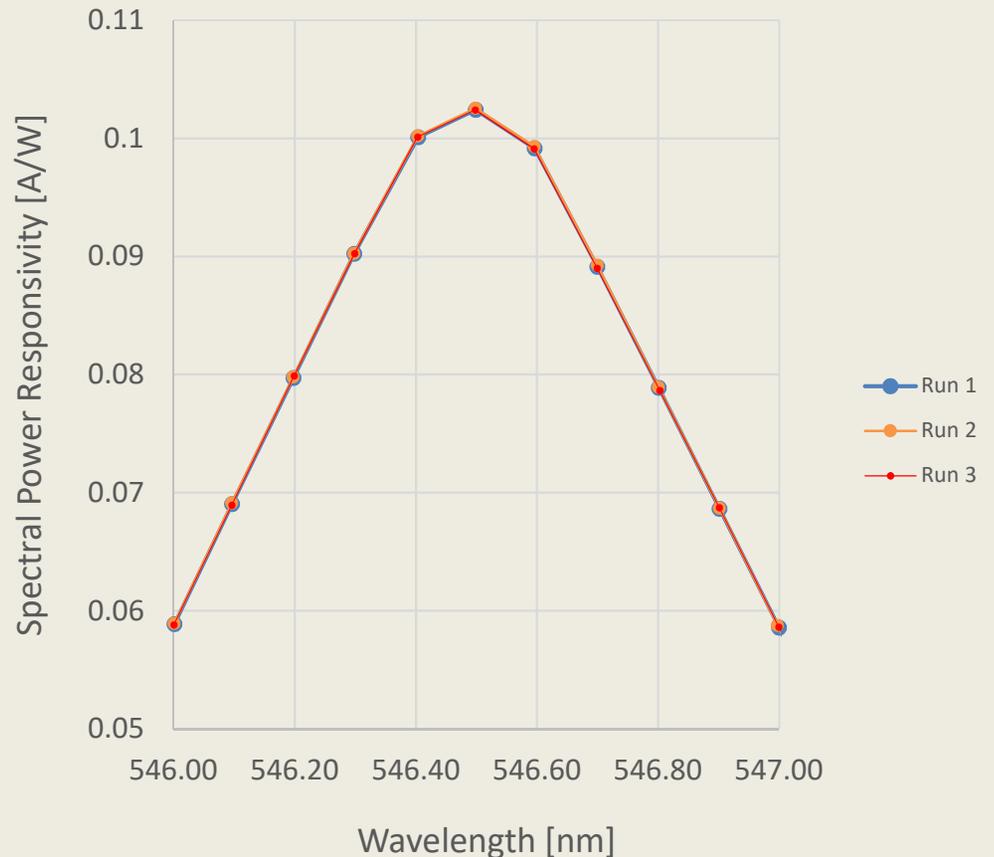
# List of Additional Optical Improvements

- Size of Detector Effect:
  - Match apertures for the Working Standard Detectors the size of the test detector or test aperture
  - Reduces Scatter
- The Intermediate Aperture:
  - Located at the 1<sup>st</sup> image of the monochromator exit slit
  - Use to reduce scatter
- Use Rectangular Apertures instead of Circular Apertures as the Intermediate Aperture
  - Besides reducing scatter the rectangular aperture has less impact on the wavelength calibration.

# Monochromator Wavelength Calibration

Improving the repeatability of the wavelength calibration and movement:

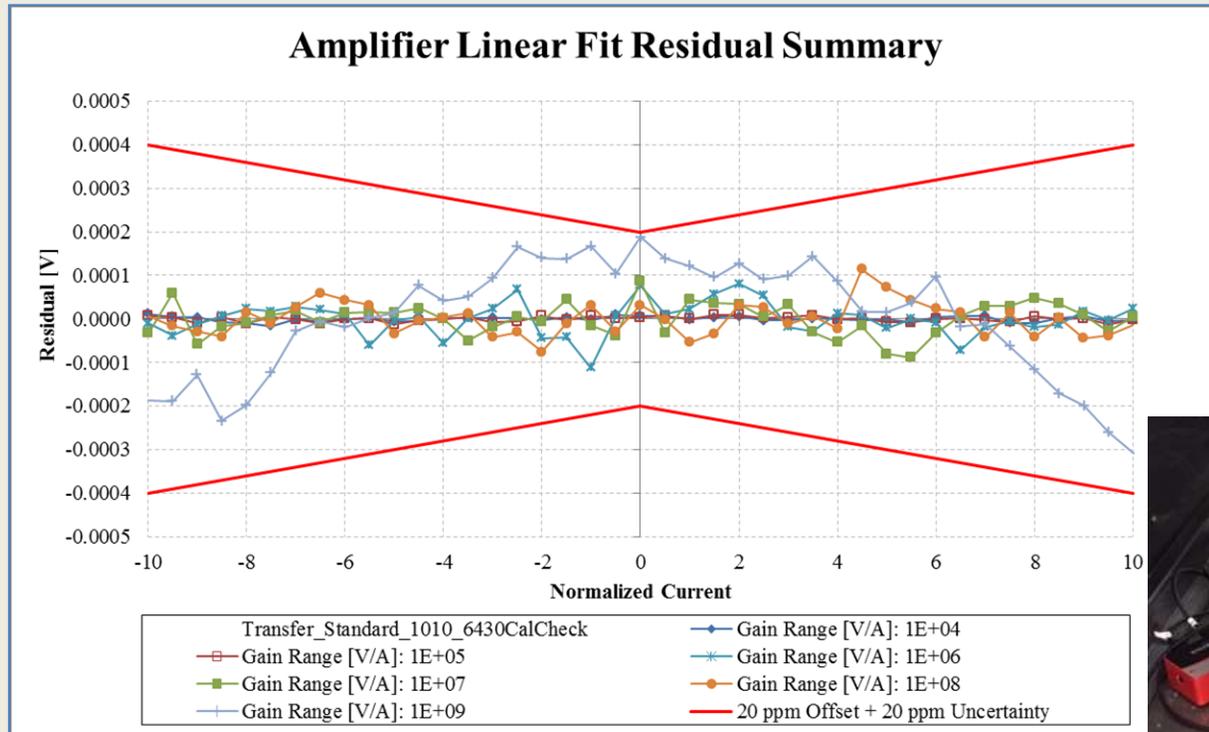
1. Replace the Rotary Encoder with a Linear Encoder
2. Replace the old springs inside the monochromator movement.
  1. New springs with greater tension on the sine bar were installed.
3. The backlash correction was increased to 100 nm
4. Now able to achieve 0.001 nm centroid wavelength repeatability between 5 scans!



**Decreasing the wavelength uncertainty from 0.1 nm to 0.04 nm,  $k=2$**

# The Amplifier Contribution:

A factor of 12 improvement in the Uncertainties



*NEW Calibration Service:*

*Calibration of current-to-voltage converters, aka Amplifiers, for gain 39300S*



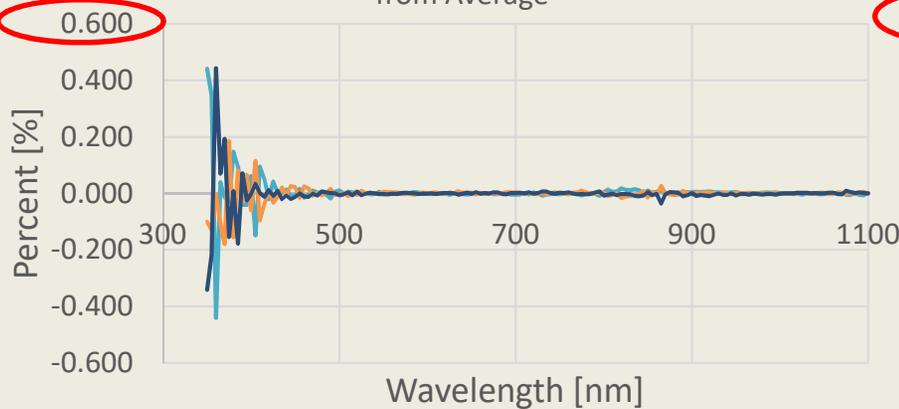
- VisSCF acquired new linear amplifiers with specially chosen resistors
- The Amplifiers were calibrated by Tom Larason.
- Transfer Standard I-V Converter Linear Fit Residuals for the calibrations
- Measured uncertainty = 0.005% (Previously 0.06%)

# Improved Performance: Repeatability and Reproducibility A Factor Of 10 or more Improvement in the UV Uncertainties

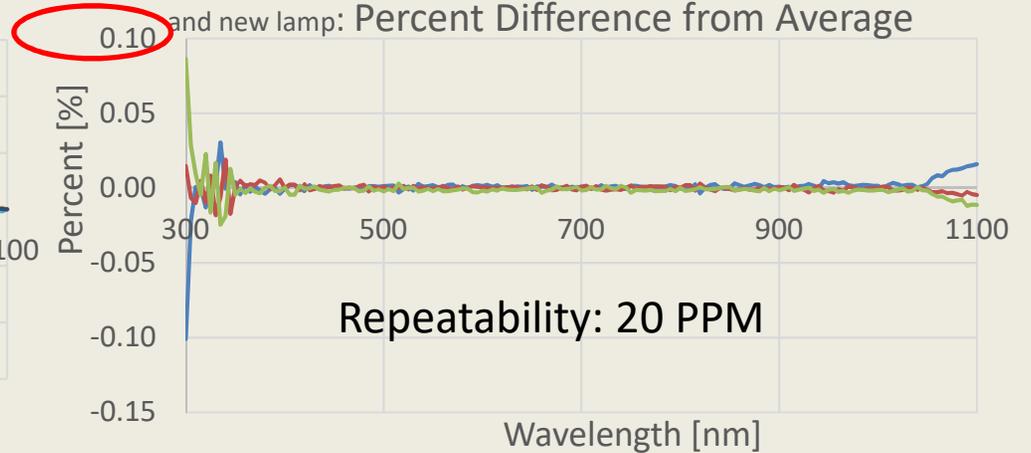
**Old**

**New**

Before all VisSCF Changes: Ratio Percent Difference from Average

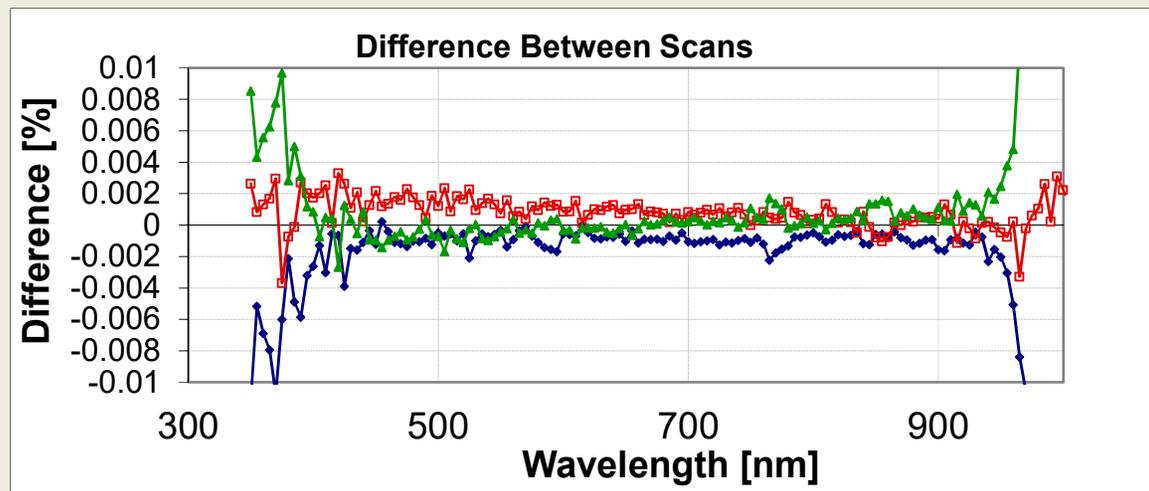


Test to Monitor Ratio: Changed aperture position, New mirrors and new lamp: Percent Difference from Average



Repeatability: 20 PPM

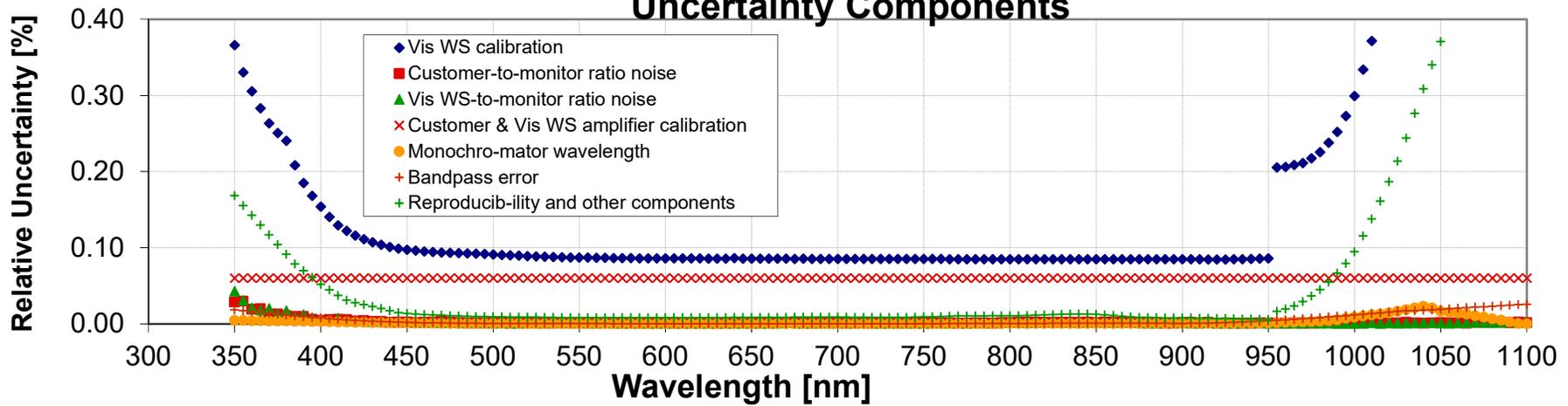
**Reproducibility over 2 weeks and 3 alignments:**  
**20 PPM**



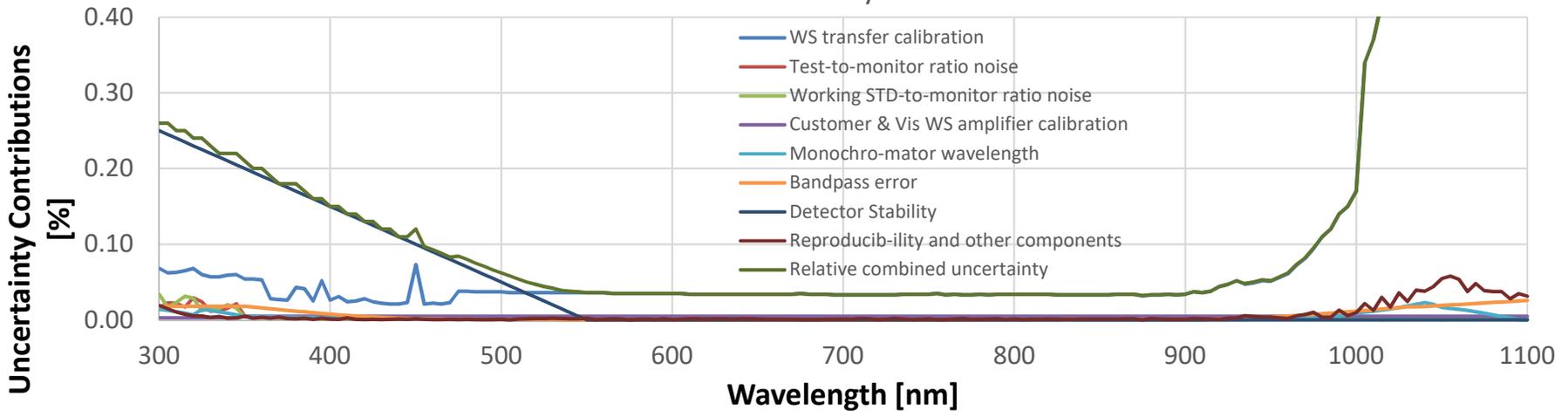
# VisSCF Performance Improvements: Impact on the Uncertainties

## A factor of 2.5 less in the Visible Range

### Customer Visible Si Photodiode (Hamamatsu S2281/S1337-1010BQ) Uncertainty Components

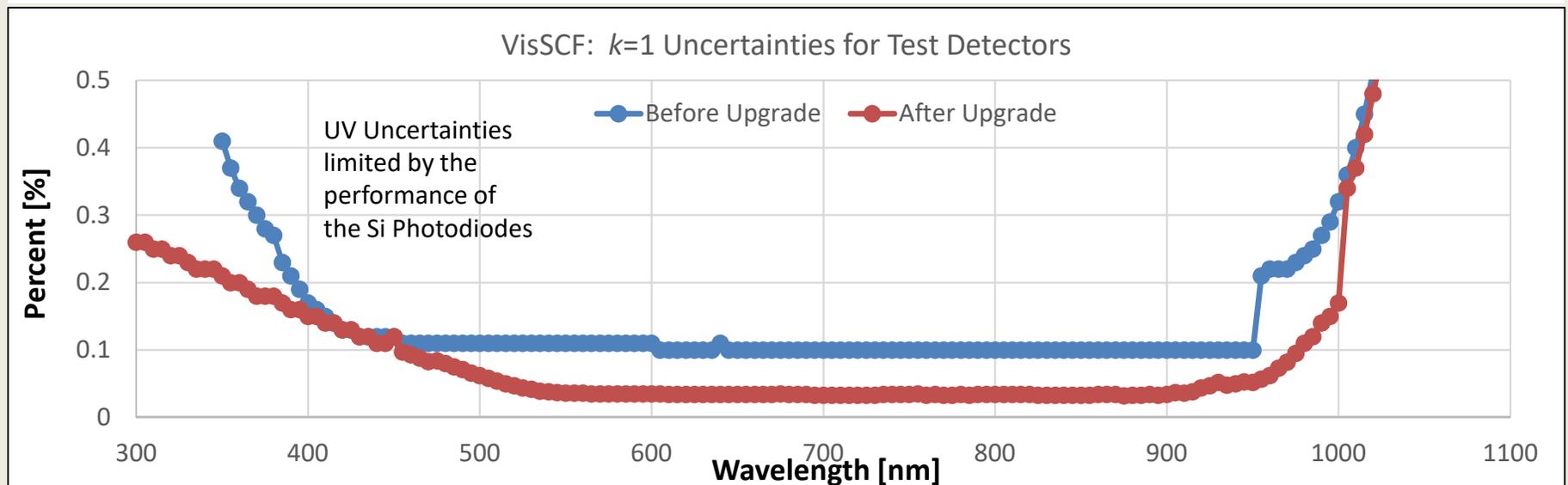
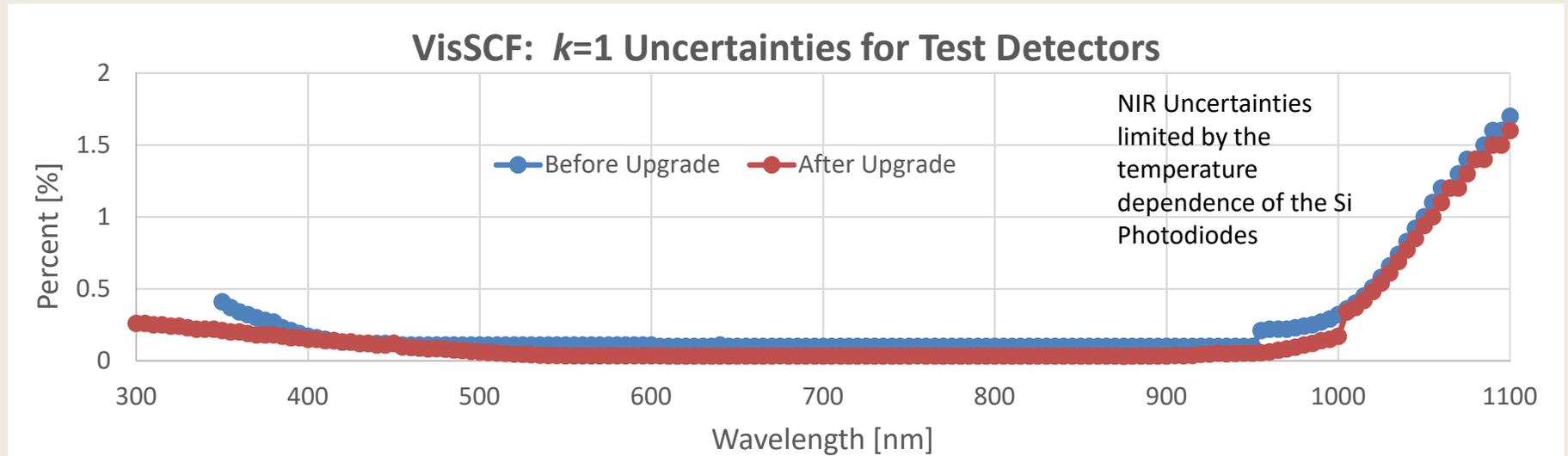


### Visible Test Detector k=1 Uncertainty Contributions 2017- fall



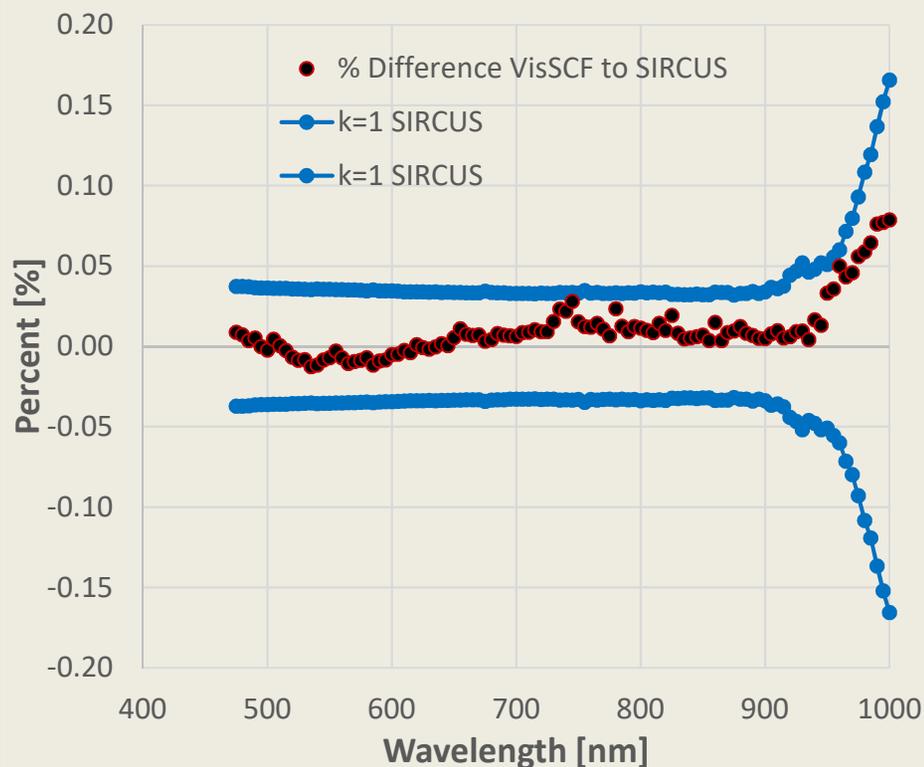
**VisSCF k=1 TRANSFER UNCERTAINTIES AT THE LEVEL OF THE ABSOLUTE DETECTOR'S k=1 UNCERTAINTIES!**

# Vis SCF $k=1$ Uncertainty Improvement

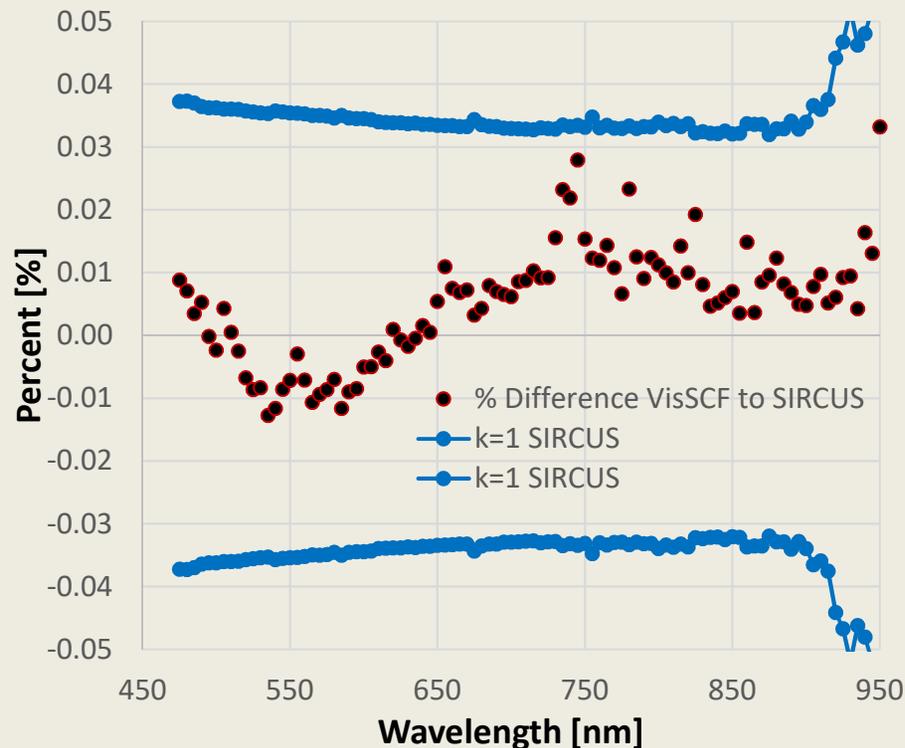


# VisSCF: Calibration Transfer Abilities 2017

% Difference of ASR Ratios of T06/T04 from SIRCUS and VisSCF



% Difference of ASR Ratios of T06/T04 from SIRCUS and VisSCF



Ratios Agree within  $k=1$  of the Absolute Standard, or  $< 0.02\%$  in the visible

VisSCF Optical Power Transfers Perform at the Level of the Absolute Detector

# Summary

- Increased UV Throughput: incorporating the new lamp, optics, and the beamsplitter
- Decreased the Scatter: New optics, intermediate aperture, apertures on working standards to address size of detector issues
- Reduced the uncertainties in the Wavelength Calibrations
- Decreased the Amplifier uncertainty contribution by a factor of 10

- FOR NOW:

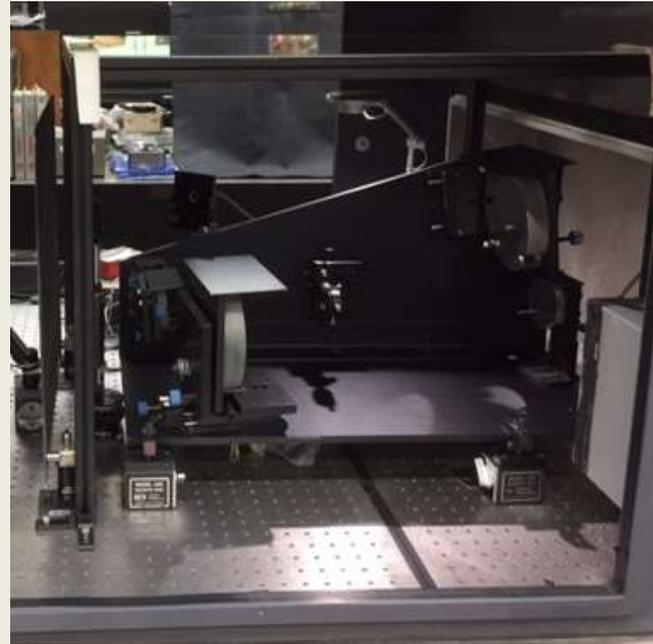
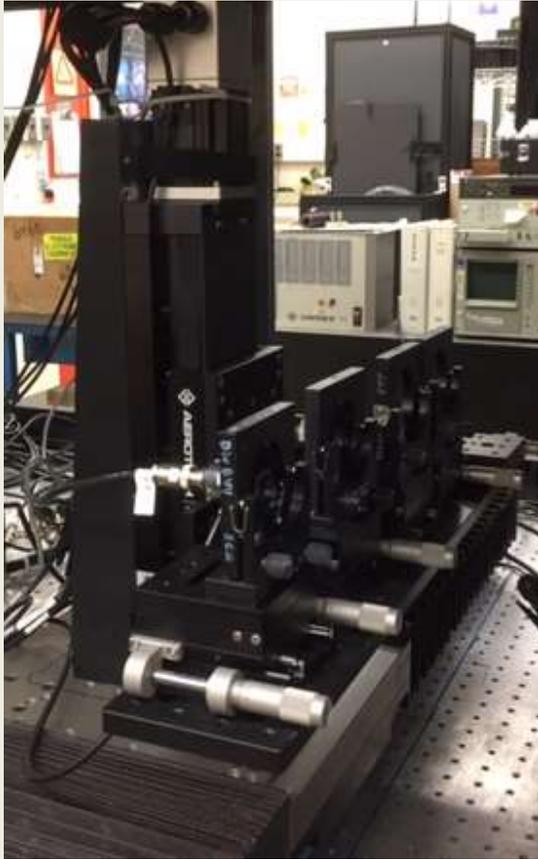
We are able to calibrate customer devices with significantly lower uncertainties.

# Customer Impact

- Reduced the overall customer uncertainty by up to a factor of 2.5
- Customer uncertainties for Certain visible detectors: 0.09%  
 $k=2$  (visible range)
- Wavelength range for the VisSCF will be extended down to 300 nm for routine calibrations – at the same cost as the present visible calibrations to 350 nm (50 nm extension)
  - Will save about \$800 (Present cost difference of VisSCF range and UV extended range)
- Calibrations with expanded wavelength range and decreased uncertainties will be officially issued starting in CY 2018 (requests accepted in Nov. 2017)

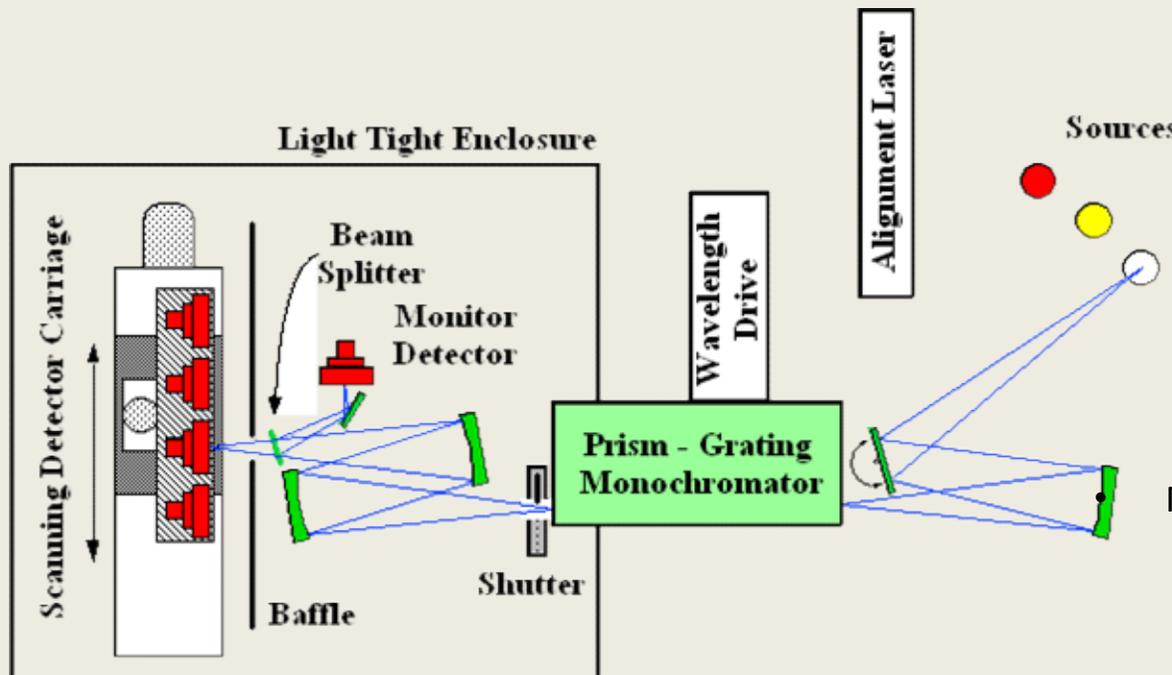
# Thank you

George Eppeldauer for efforts in the development of the amplifiers.



Any Questions?

# Visible Spectral Comparator Facility: VisSCF



- Performance
  - 350 nm to 1800 nm
  - 100 W QTH Lamp – Not stabilized
    - Substitution method
  - Cary 14 Double Monochromator
    - Prism - grating
  - Setup: 2 working standards and calibration of up to 2 test detectors
  - Calibration occurs at the focal plane
    - Focus: 1.1 mm in diameter
  - Automated for operations
  - Working Standards
    - Visible: Si photodiode
    - NIR Temp controlled InGaAs

## Measurement and Customers

- Measurements:
  - Vis and NIR spectral power Responsivity
  - Irradiance detectors
  - Photometers: both ASR and Uniformity
  - Spectral Spatial Uniformity
- Customers:
  - Si photodiodes: All types
  - Photometers
  - NIR devices