Advances in Measuring UV LED Arrays

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EIT Instrument Markets

May 8, 2018

Measurement Expectations

Temperature

- Industrial thermometry: 1% accuracy
- Laboratory thermometry: 0.01% accuracy
- High-accuracy metrology: 0.0001% accuracy

Weights

- Calibration of reference weights (1 mg to 10 kg): Accuracy up to 1 part in 10^6

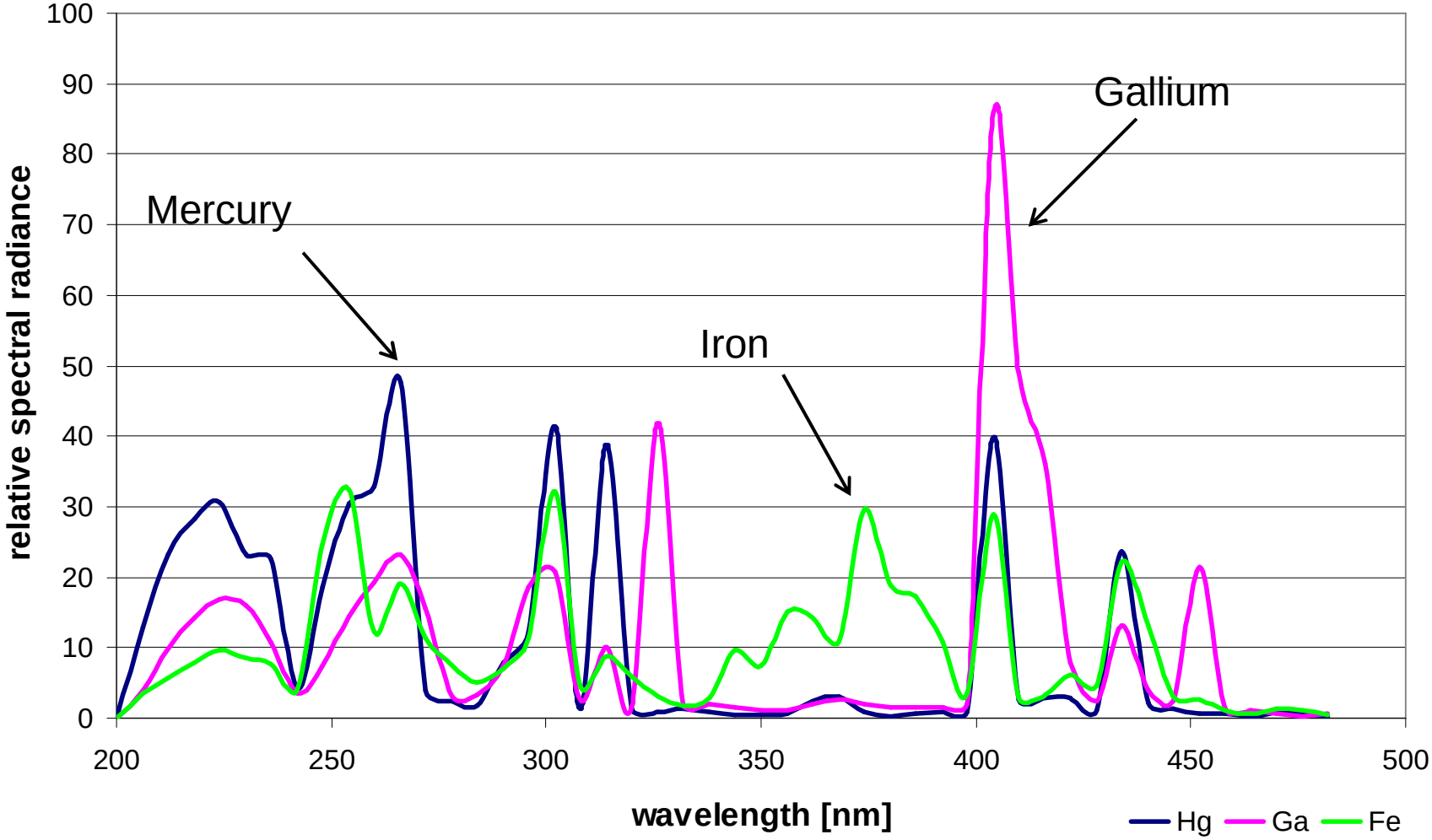
From Measurement Standards Lab of New Zealand

Industrial UV Measurement

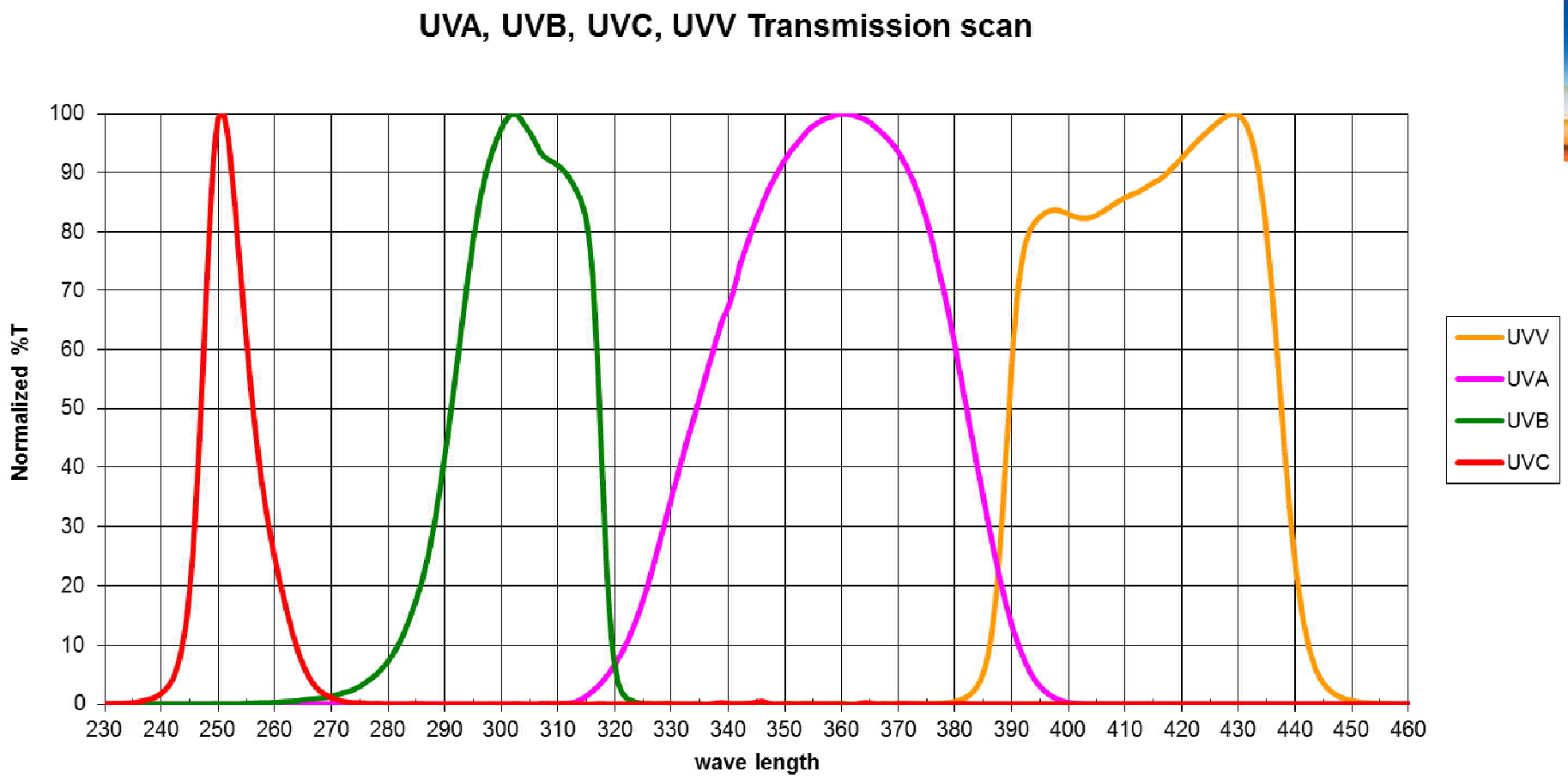
- Easy to use and understand
- Production Environment/Production Staff
- Goal: Improve UV LED Measurement

Broadband Spectral Output

Hg spectra modified with added materials



EIT Broadband Response Curves



Band Name	Wavelength Range
UVA	315-400nm
UVB	280-315nm

Band Name	Wavelength Range
UVC	240-280nm
UVV	400-450nm

Challenges In Measuring UV

Optics

- Different Bands/Manufacturers
- Define response by 10% Power Point or 50% Power Point (FWHM)

Calibration Sources/Points

- One source type does not always fit

Electronics

- Dynamic range
- Sampling rates
- RMS vs. Instantaneous Watts
- Threshold Differences

Data Collection Techniques

- User Errors

How do we improve measurement performance and maintain ease of use in a production environment?

Use Common Sense

Date	Watts	Joules
August '17	7.7 W/cm^2	420 mJ/cm^2
January '18	4.6 W/cm^2	250 mJ/cm^2

- First Assumption: Instrument had gone bad
- Instrument back for evaluation
- Reading very close (<2%) to the EIT master unit

Calibration: Less than a 2% adjustment		
Feb '18	4.6 W/cm^2	250 mJ/cm^2

- Very smart group of researchers
- Reviewed process conditions/process controls
- Reviewed data collection techniques/instrument use

Ink was coated onto the LED window

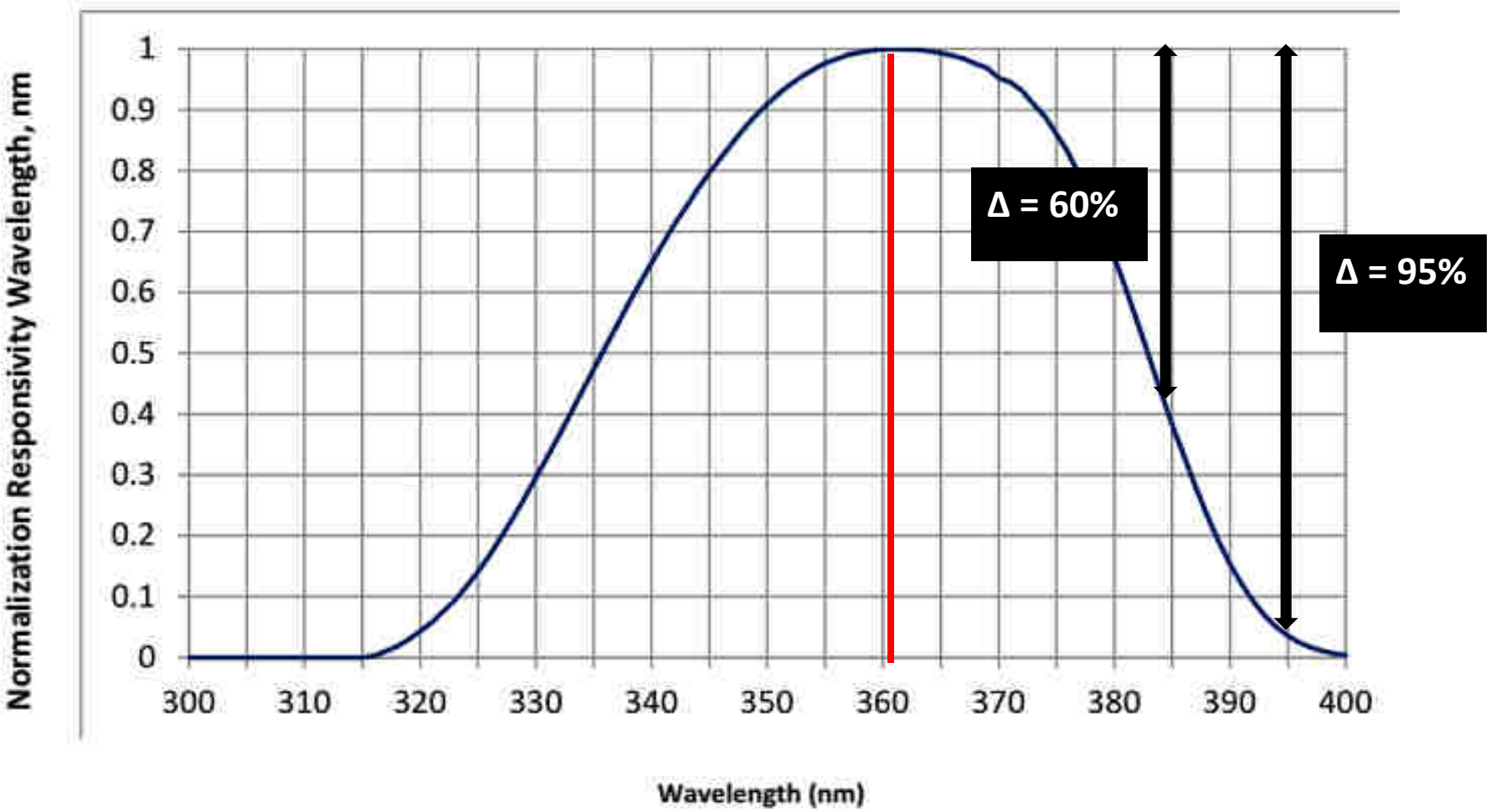
UV LEDs

Wide variety of UV LED sources

- Multiple suppliers with wide level of expertise, support, finances
- Match source to your application & process
- Economics of source selected (ROI)

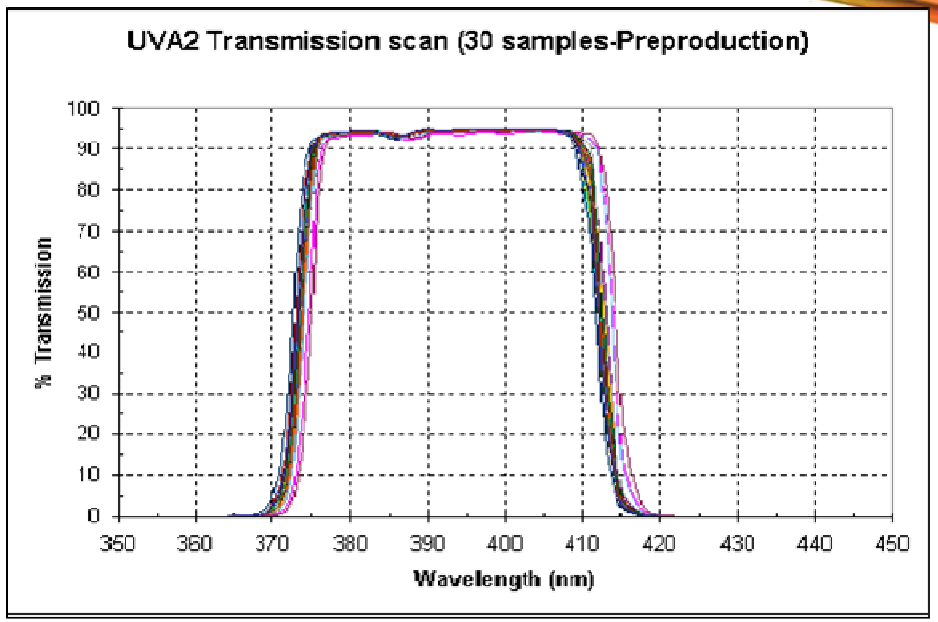
Measurement of 395 nm LED

Using UVA to measure a 385 nm or 395 nm LED

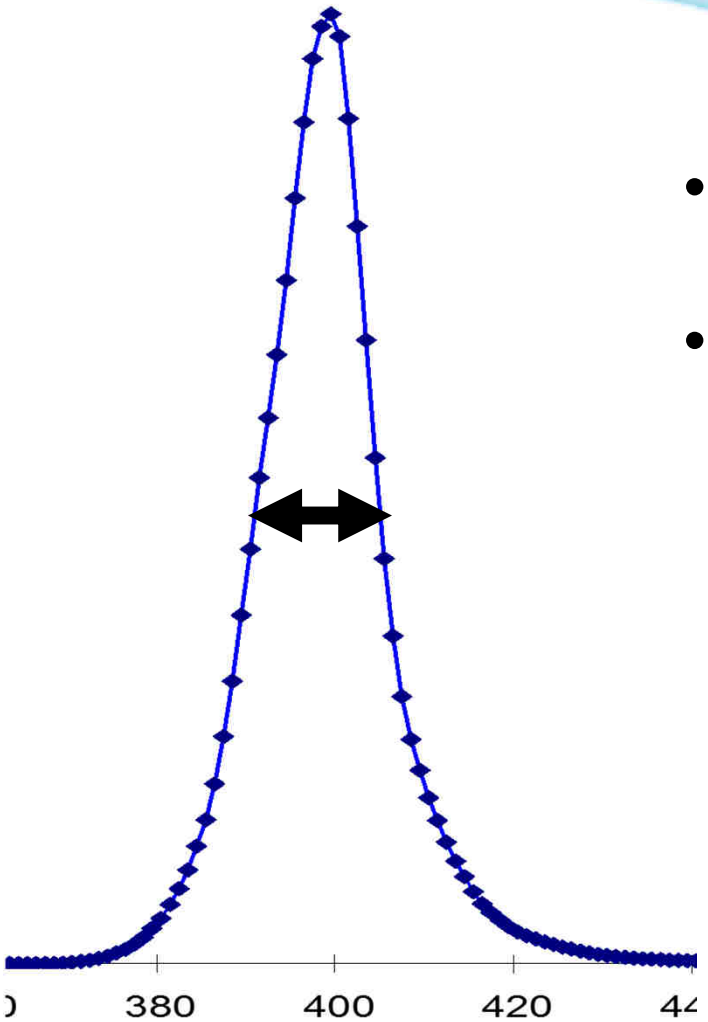


Initial Approach to LED Measurement

- Initial EIT Approach for LEDs was UVA2 Band
- Response +/- 380-410 nm
- Filter Only Response
- Calibration Source
  - Uniformity of LED Sources for calibration
  - Irradiance Levels
- Start from the beginning and take a new approach
- With improvements we have phased out new sales of UVA2



Step One: Evaluate LED Output



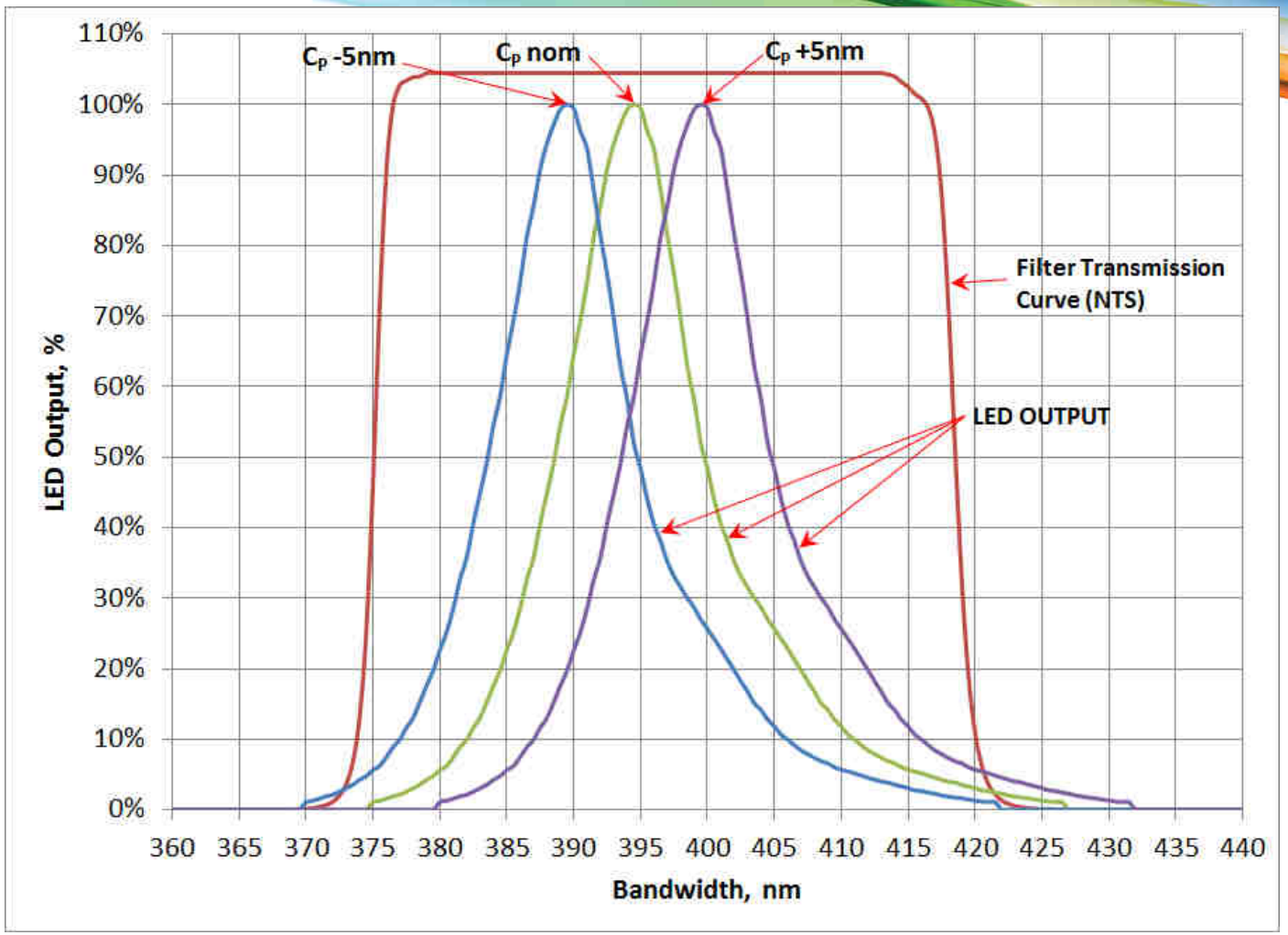
395 nm LED array output measured on a spectral radiometer at EIT

- Width of the LED at the 50% Power Point
- Variations between suppliers:
  - Binning
  - Longer wavelengths
  - Sold as +/- 5 nm from center wavelength (CWL)

Define the right band?

Theoretical Band

Account for variation in the LED CWL



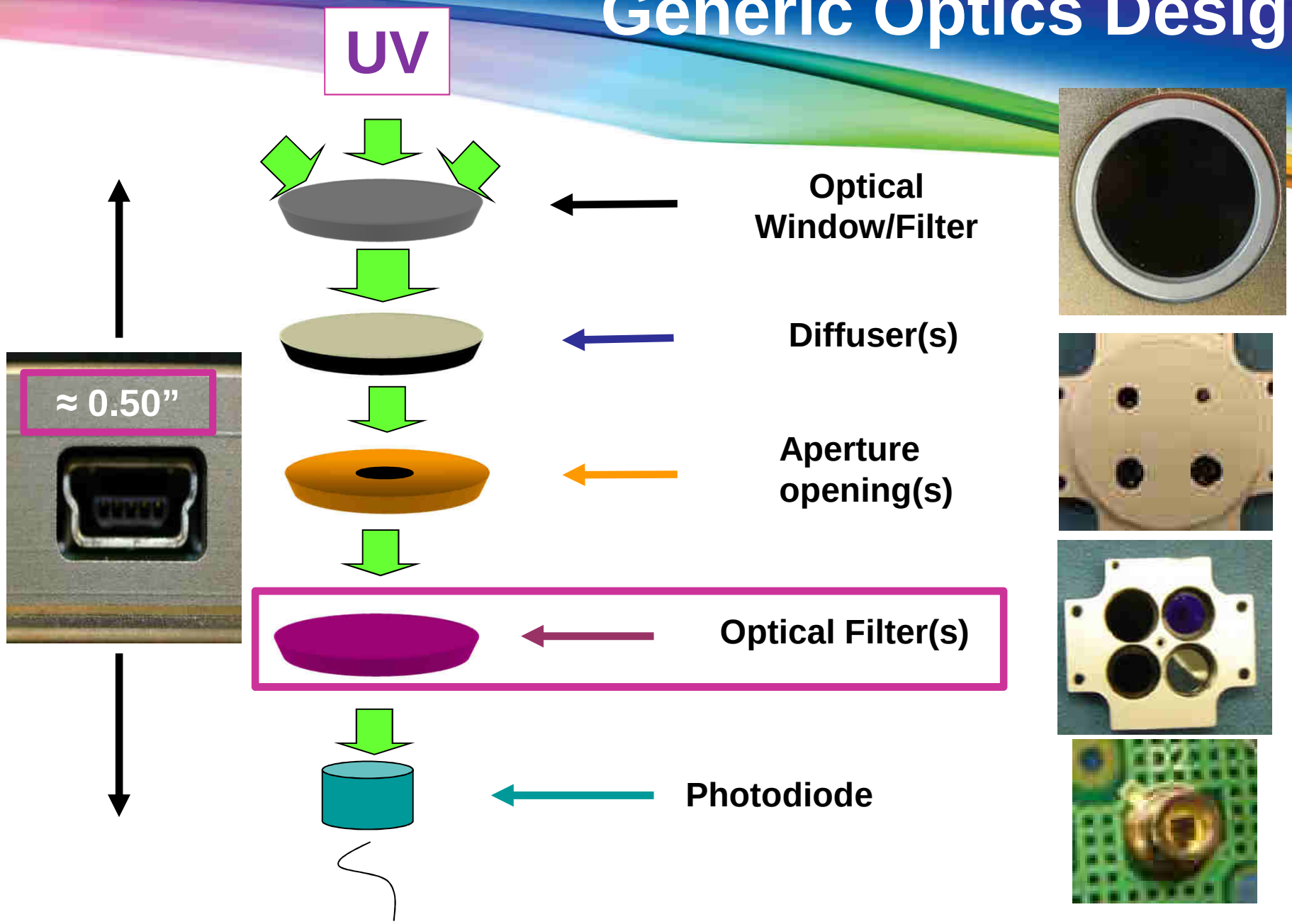
L395 LED Output Spectra Showing ± 5nm Spread of Cp Along with Required Filter Response to Obtain 2% Measurement

Step Two: New Approach to Optics Design

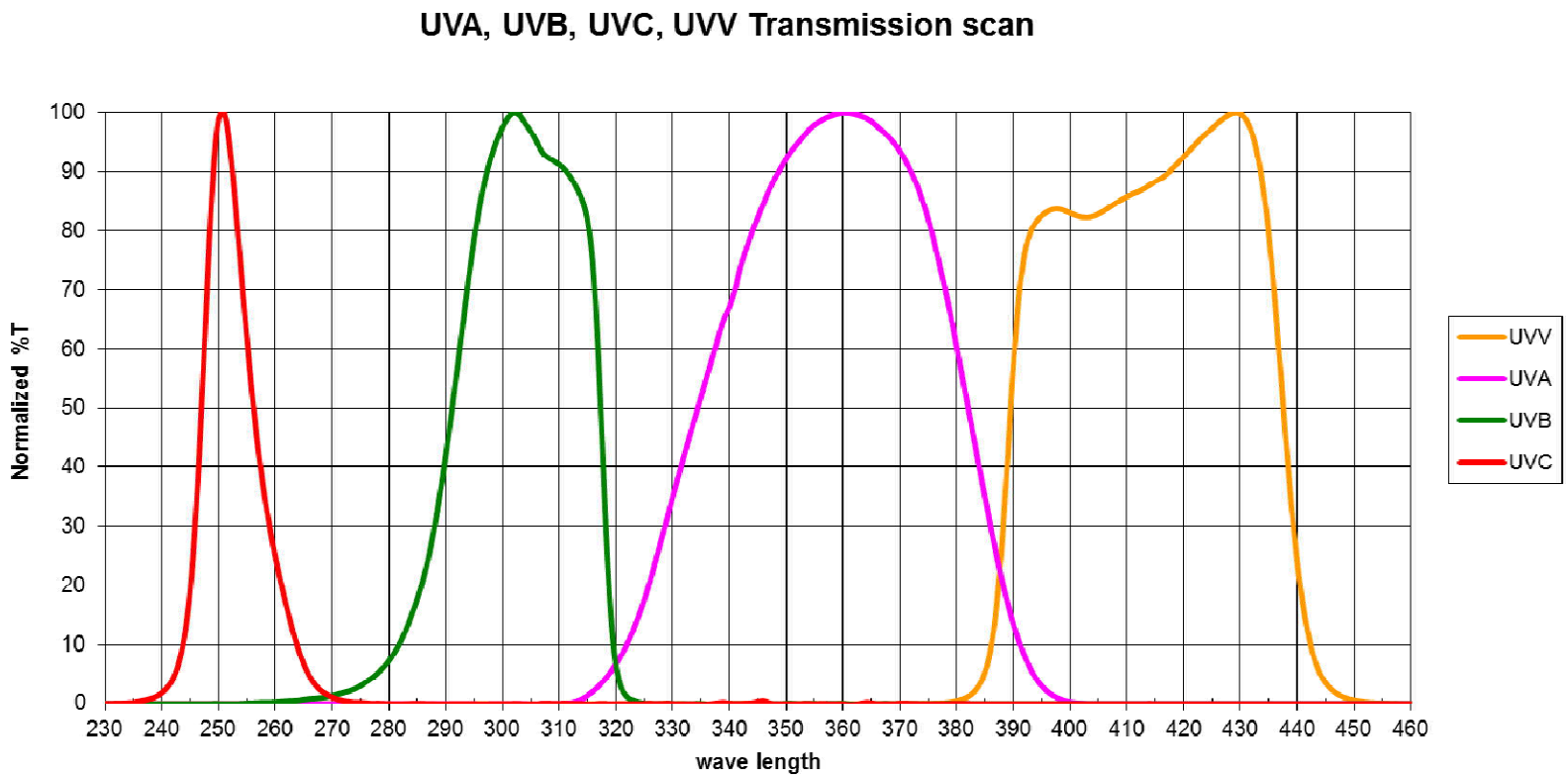
Challenges

- Optics: Combination of multiple optical components
  - Outer filter
  - Diffuser
  - Intensity reduction
  - Optical filter
  - Detector
- Each component has its own response

Generic Optics Design

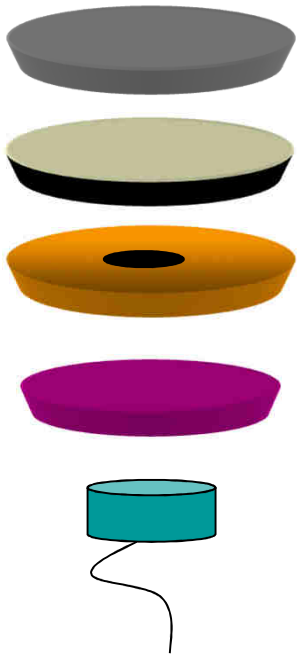


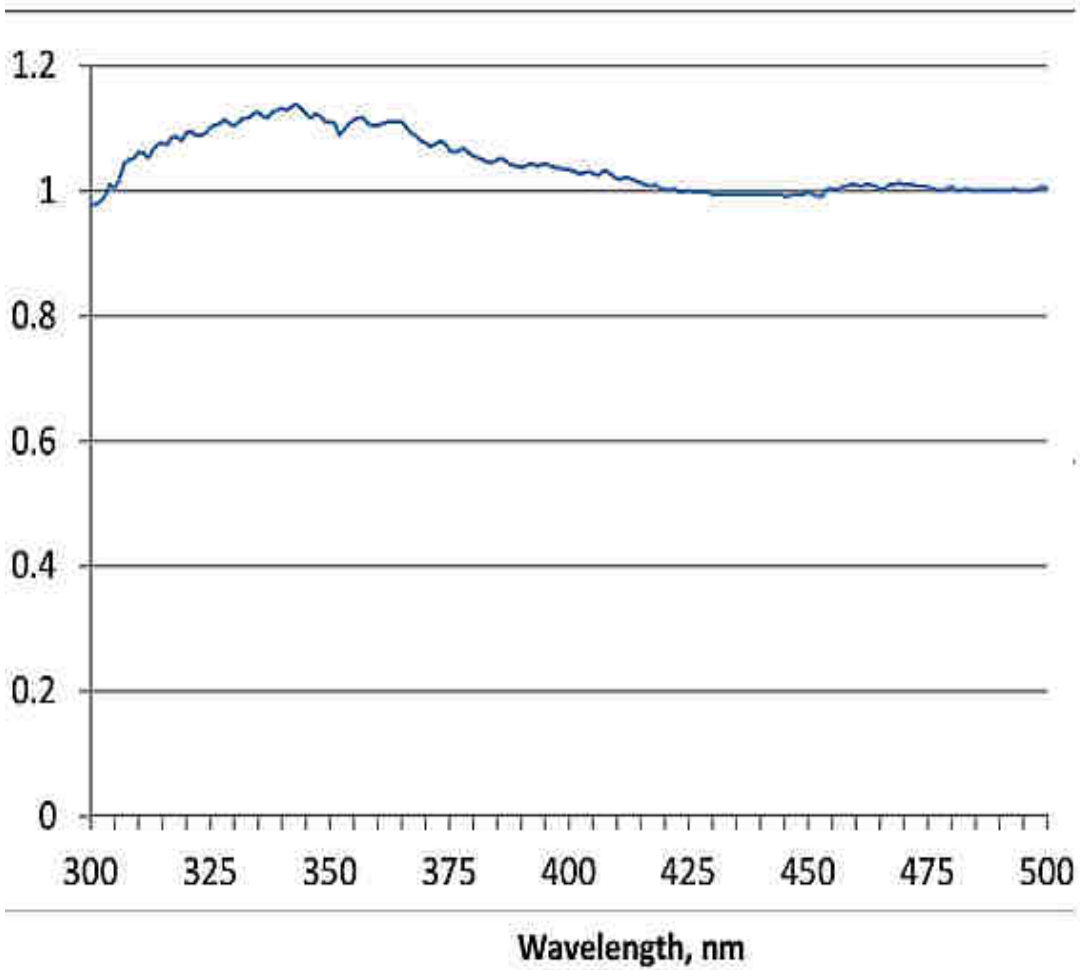
Step Two: Address and Improve Optics Design



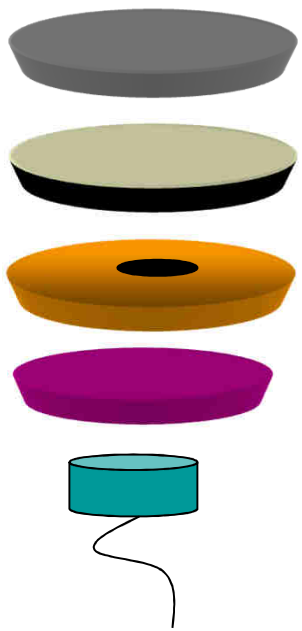
The traditional approach has been to define the band response based ONLY on the filter response

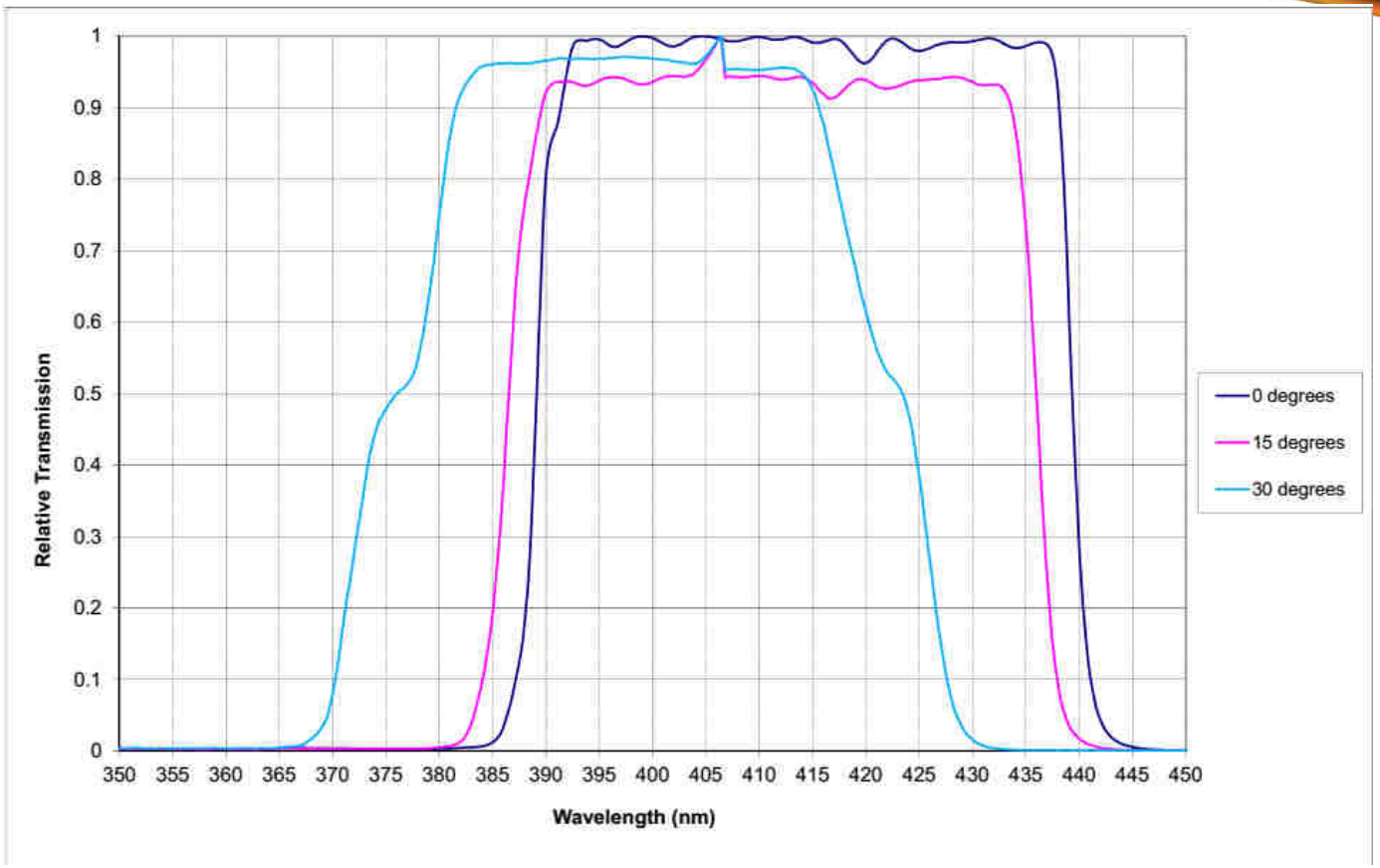
EIT Optics Design





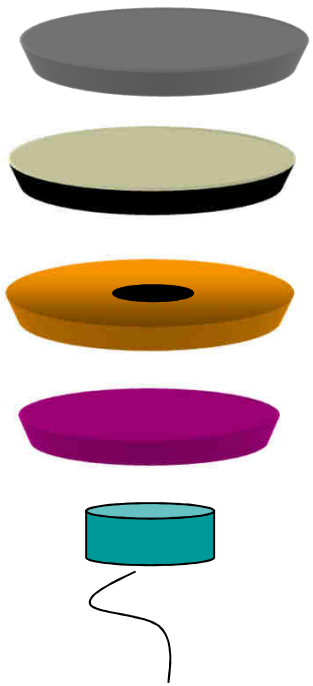
EIT Optics Design

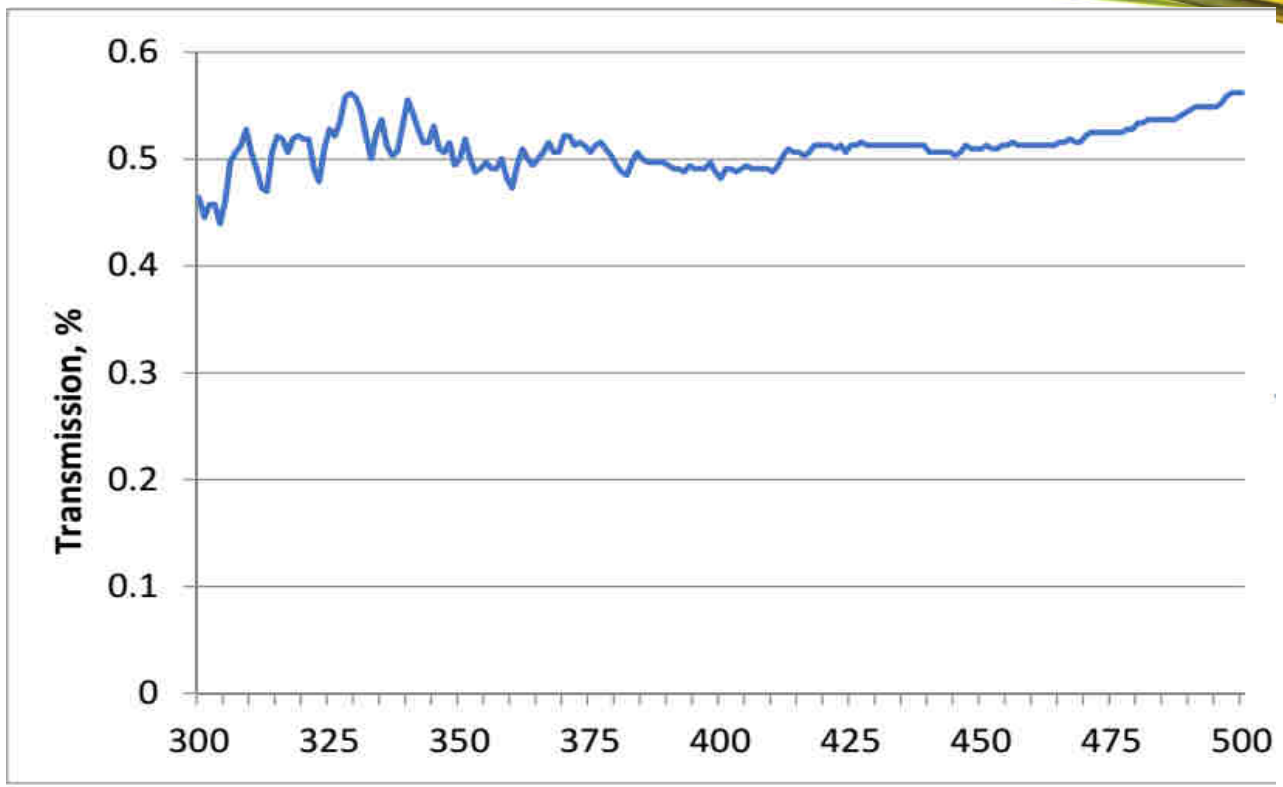




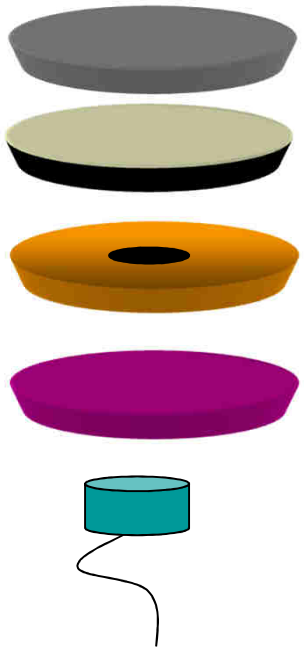
- **Maintain Cosine Response**
- **Avoid changes in low angle Energy**

EIT Optics Design





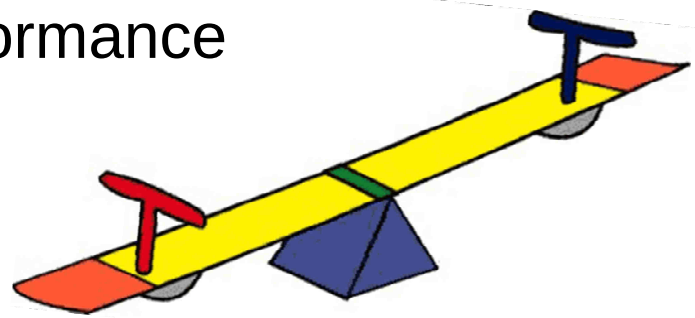
Total Measured Optic Response



- EIT Patented design and approach
- Address Issues **ALL** Optical Components in the Optic Stack included in the measured instrument response
- Not a theoretical response, actual measured instrument response

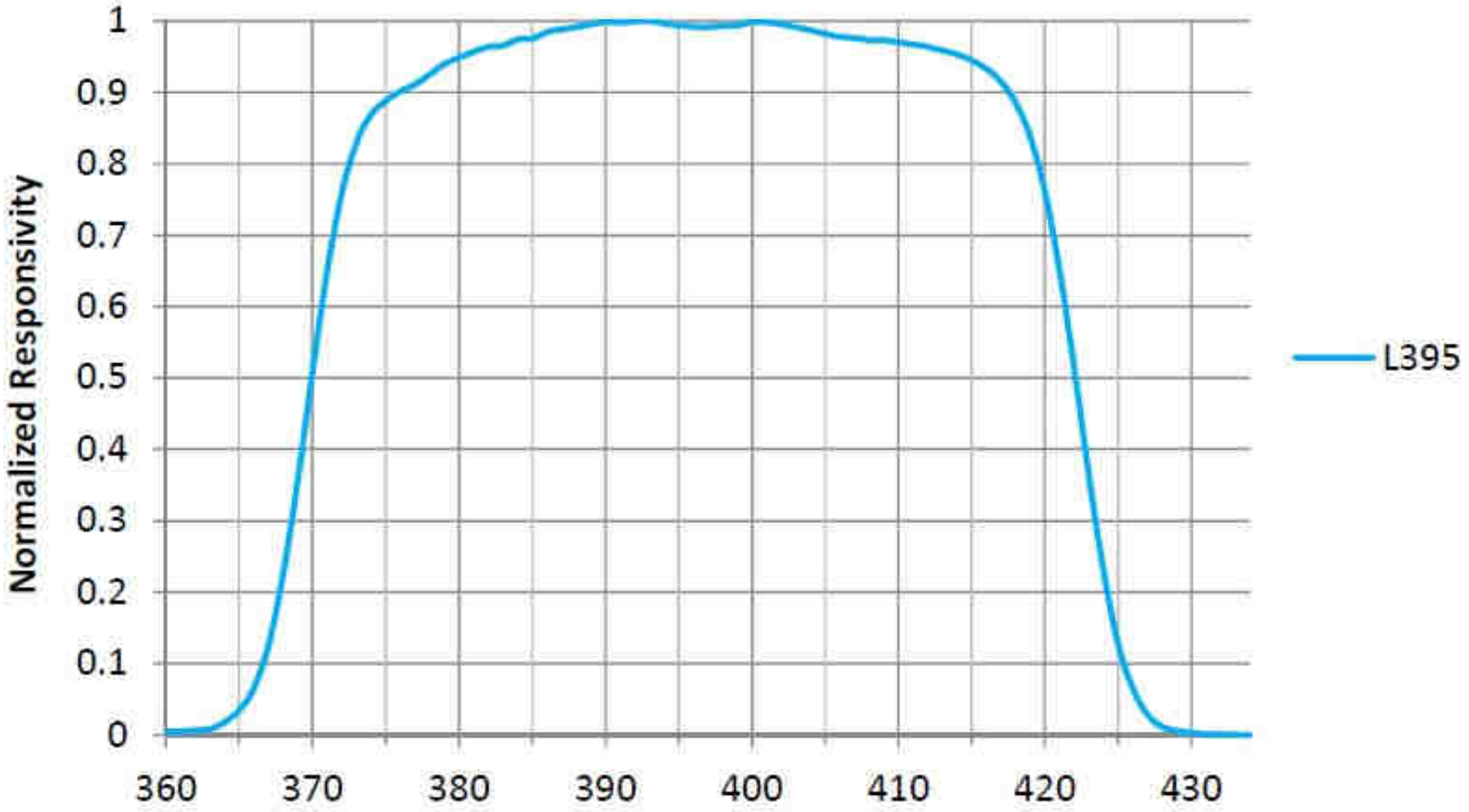
Why not have a wider width response?

- Balance the Flatness
- Balance the Performance



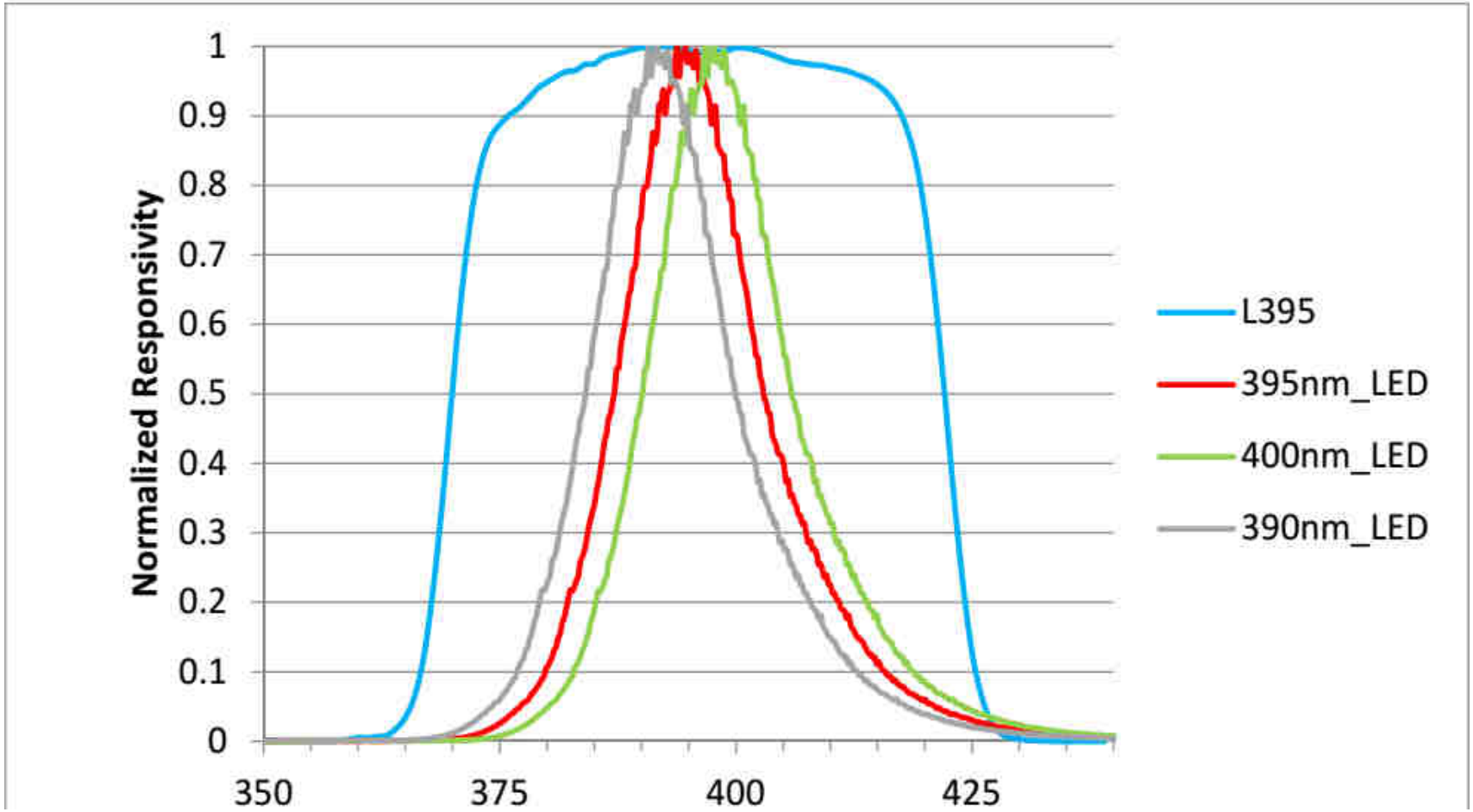
L395 Instrument Response

Total Measured Optical Response (370-422 nm)



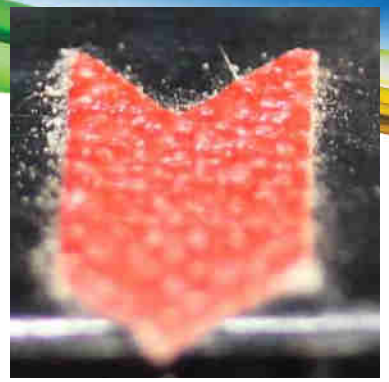
L395 Instrument Response

Total Measured Optics Response

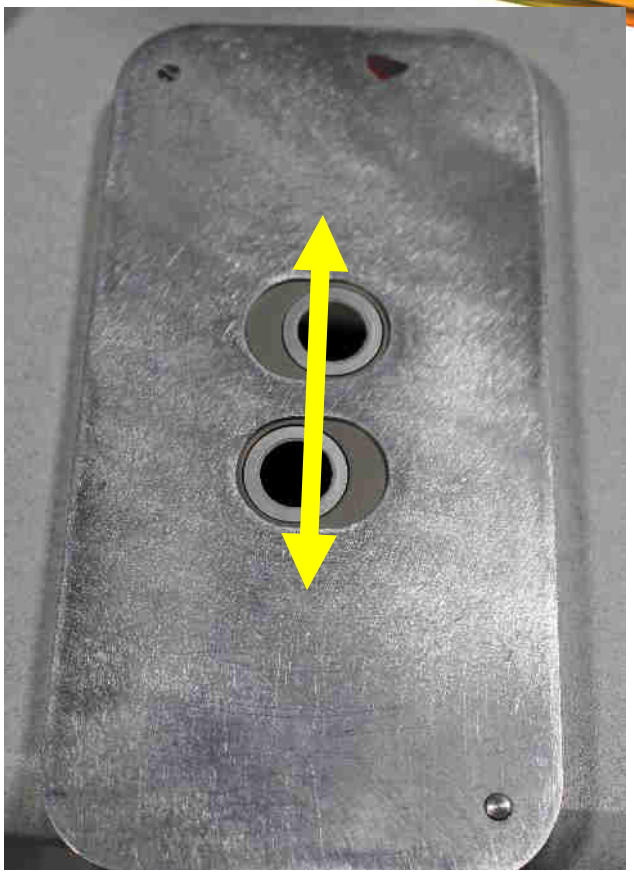


Step 3: Improve the Calibration Process

- Industrial 395 nm LED sources pushing 50W/cm^2
- Typical irradiance levels, sources and standards that NIST has worked with are much lower (mW/cm^2-µW/cm^2)
- Reduce variation and errors introduced in transfer process
  - Fixtures
- Direct evaluation of EIT master unit by NIST from 220 nm past visible region
- **Uniformity of UV LED source used with working standard and unit under test different than LED uniformity needed for curing**
- LEDs are cooler but not heat free



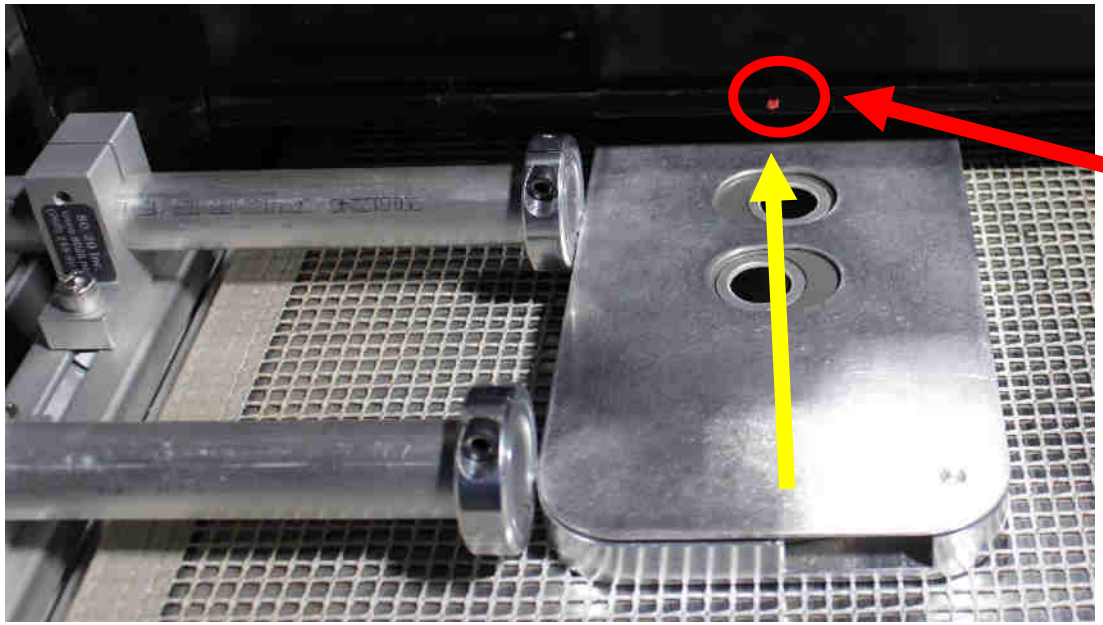
Step 3: Improve the Calibration Process

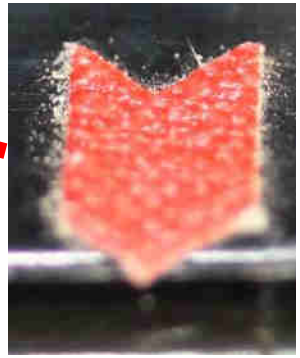


- **Fixture with optic orientation & repeatability**
- **Stability of units**

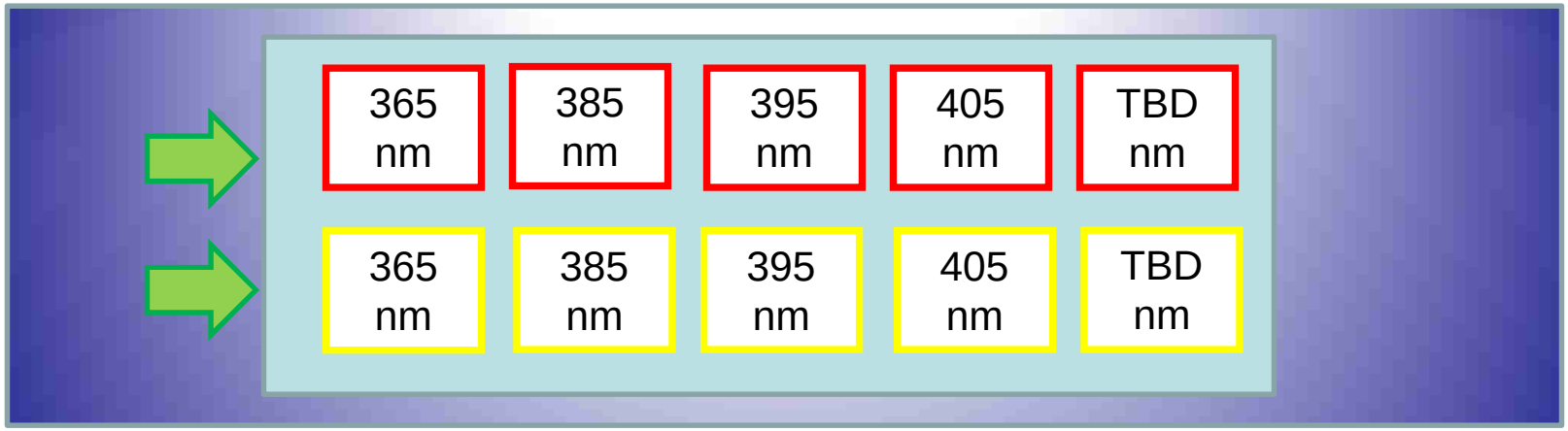
Step 3: Improve the Calibration Process

How do we make sure the fixture is placed in the same location each time?





Step 4: Support Different LED Wavelengths



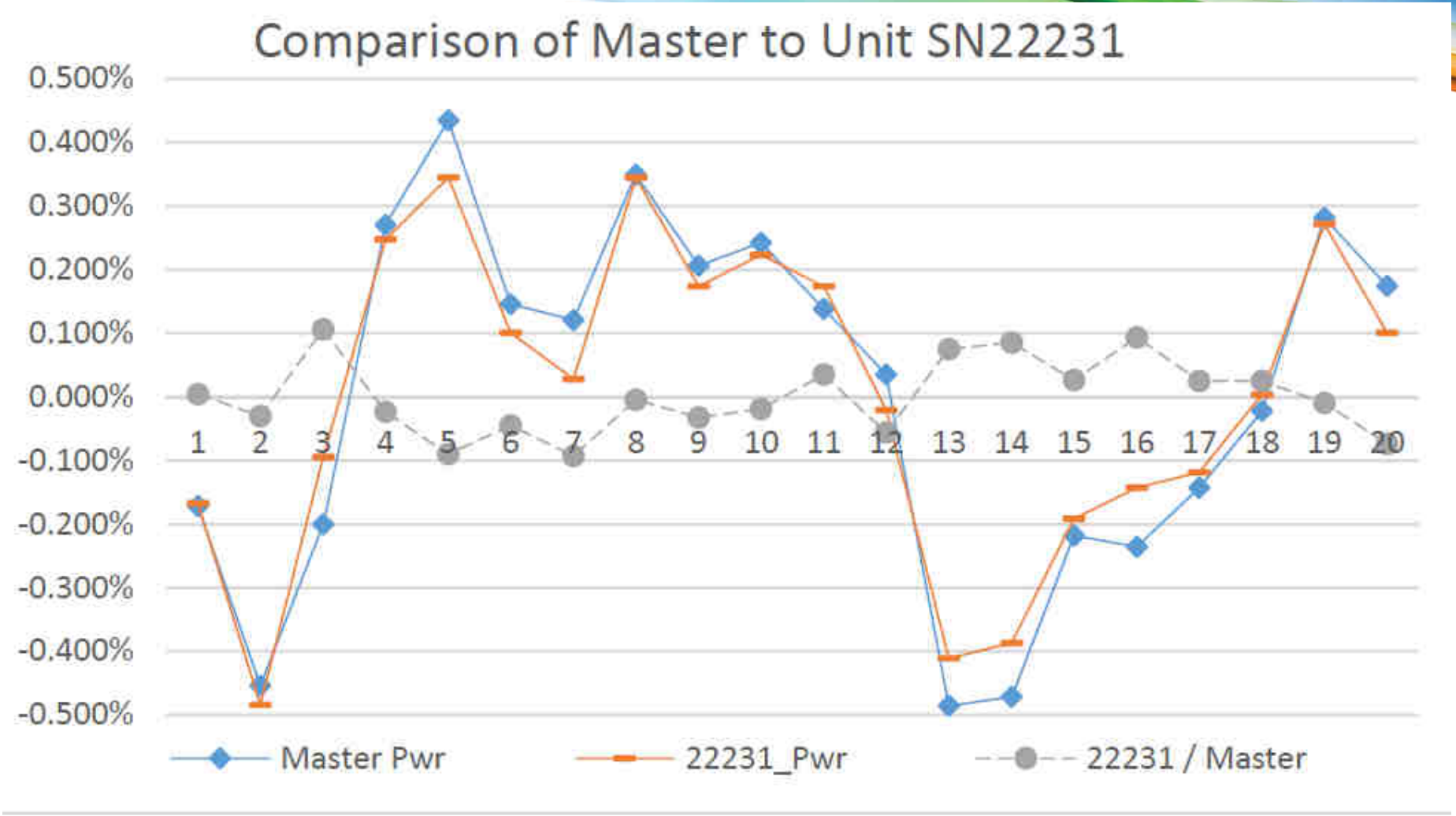
- Working to develop a fixture to support multiple wavelengths
- Adjustable power levels and platform height
- Support multiple brands of LED sources
- Keep instruments properly aligned for repeatability

Why use a Total Measured Optics Response?

Instrument "Wish" List

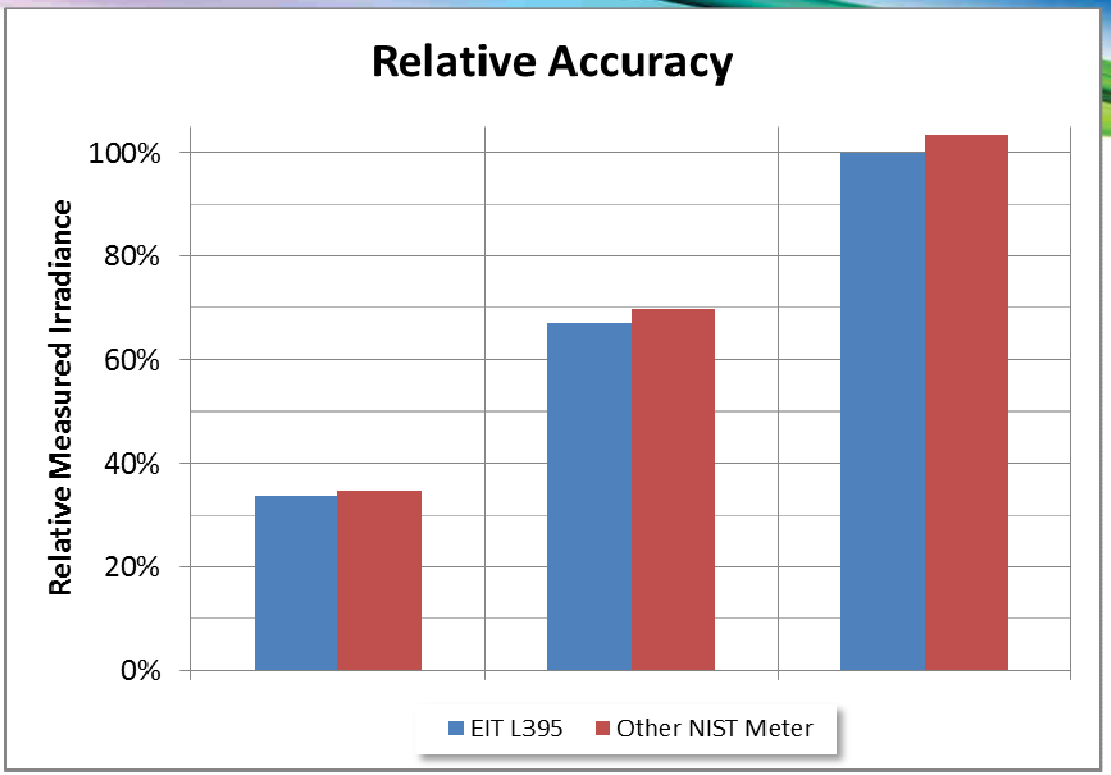
- Easy to Use
- Portable and Flexible
- High Dynamic Range
- Response Allows for Source CWL (+/- 5 nm)
- Use in R&D and Production
- Cosine Response
- Affordable
- Repeatable
    - Unit-to-Unit Matching
    - Source-to-Source
    - Run-to- Run
- Accurate to Standard

LEDCure L395 Performance



Data collected at EIT February 9, 2017

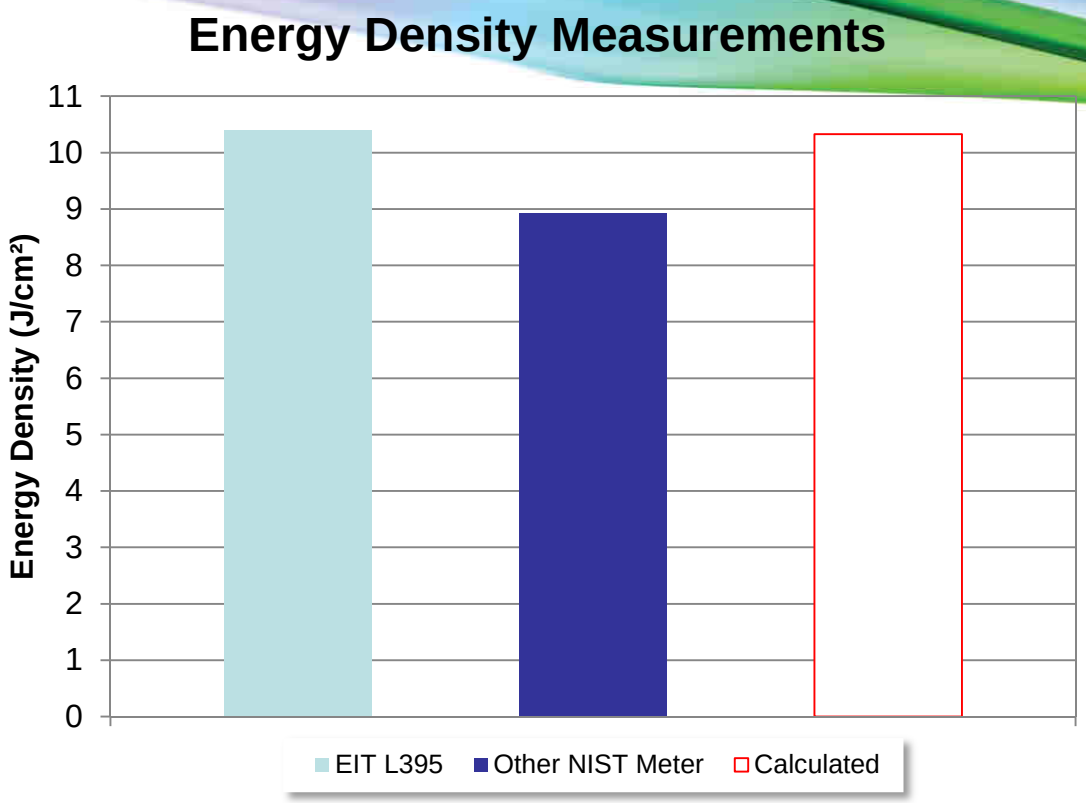
LEDCure L395 Feedback



- A 395nm UV LED source was calibrated to 16W/cm² using the EIT L395.
- The UV LED source was then measured with another NIST traceable radiometer.
- The two radiometers matched to within 4% at different irradiance levels.

Data Courtesy of Phoseon Technology

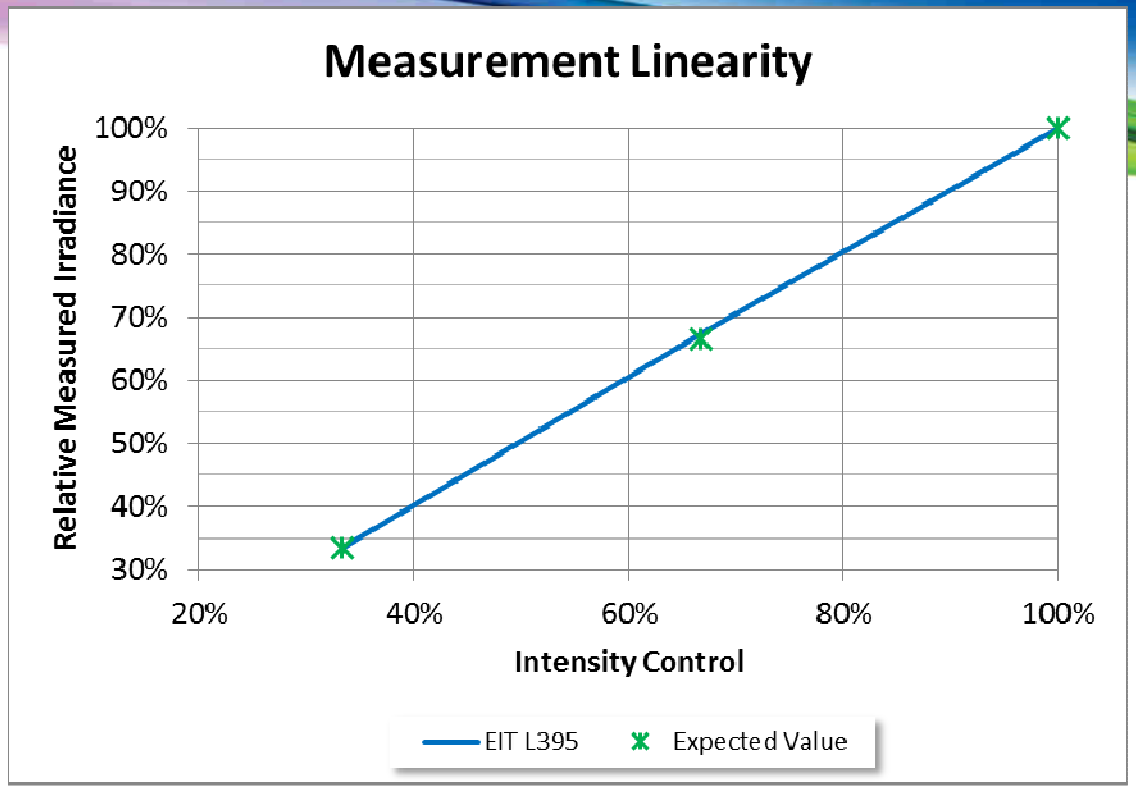
LEDCure L395 Feedback



- The EIT measurement differed from the calculated value by less than 1%.
- The other NIST traceable radiometer differed from the calculated value by more than 13%.

Data Courtesy of Phoseon Technology

LEDCure L395 Feedback



- Measurements at different irradiance settings were made with the EIT L395 radiometer, and compared to the expected values.
- The L395's linearity across a 3:1 dynamic range is excellent.

Data Courtesy of Phoseon Technology

LEDCure L395 Performance

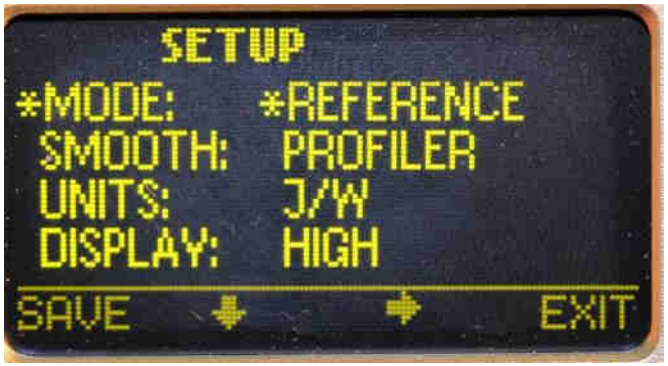
LEDCure vs. National Standard

Working Distance (mm)	Primary Standard: Integrating Sphere (W/cm^2)	LEDCure L395 (W/cm^2)	Difference
5	9.01	9.23	2.4%
10	7.74	7.74	0.0 %
15	6.66	6.63	- 0.5%
20	5.74	5.83	1.6%
25	5.04	5.08	0.8%

Data Courtesy Lumen Dynamics/Excelitas

Additional testing has been completed by others

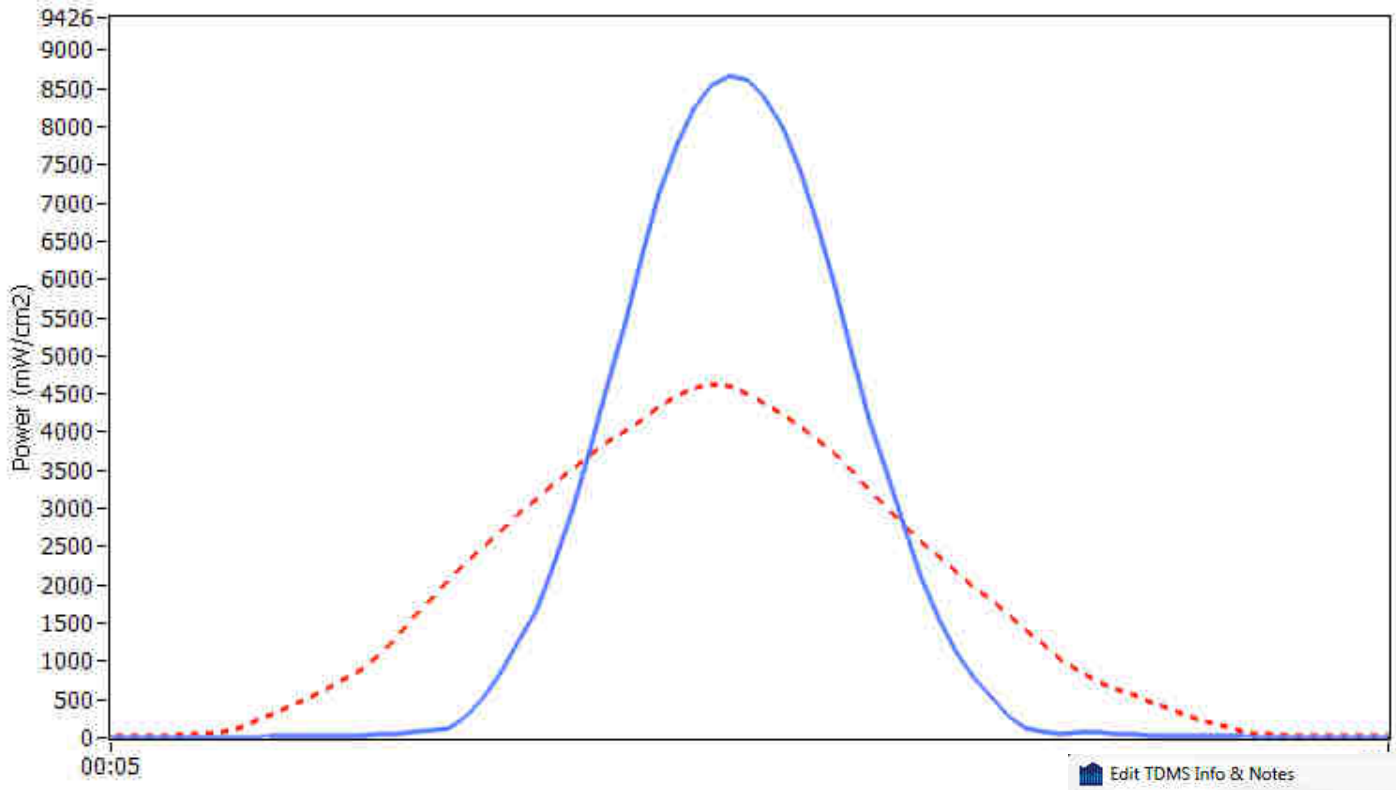
LEDCure L395 Features



Easy to Use

- Familiar button, menu & display
- Graph & Reference Modes
- One button operation on production floor
- Offset optics
- Two User Changeable Batteries (AAA), last up to 30 hours

LEDCure L395 Performance



- **Irradiance Profile**
- **Data**
- **Trial Information & Notes**

Summary (by File)

	Sample File	Reference File	Difference
Power (mW/cm2) - L395	8650.380	4624.257	4026.124
Power (%) - L395	87.1	0	87.1
Energy (mJ/cm2) - L395	1102.985	1032.390	70.595
Energy (%) - L395	6.8	0	6.8
Cursors	On		
Time	00:04.74		
Time - Ref	00:06.24		

Edit TDMS Info & Notes

Info

```
Model LEDCurePlus2 Profiler
Board Temperature 27
Battery Voltage 1.47
Firmware Version 5.01
Serial Number 22232
Calibration Date 2017-03-15
Smoothing Profiler
Date & Time 5/17/2017 4:59:57 AM

        mJ/cm2       mW/cm2
L395   3275.102     9032.793
```

Notes

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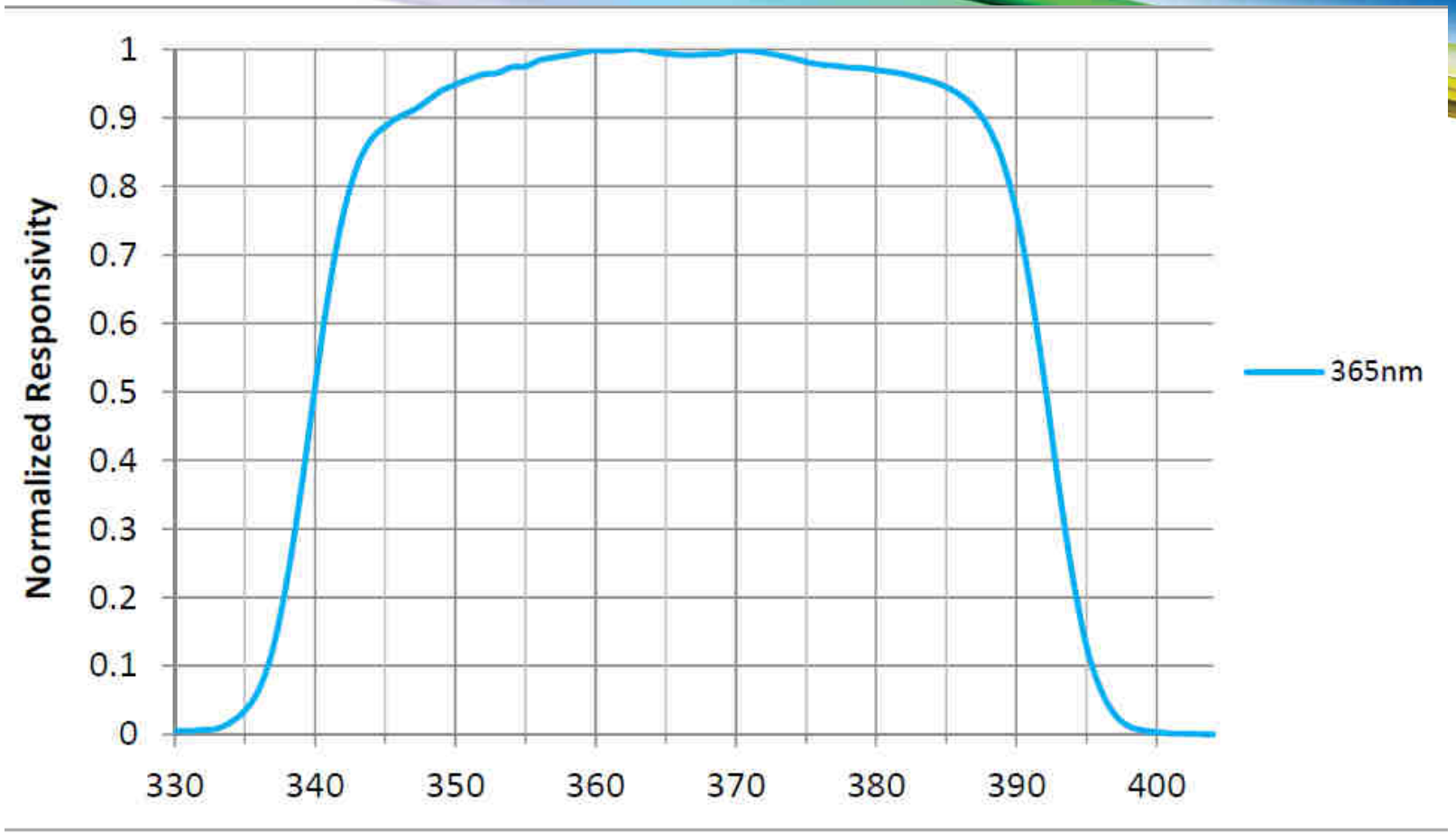
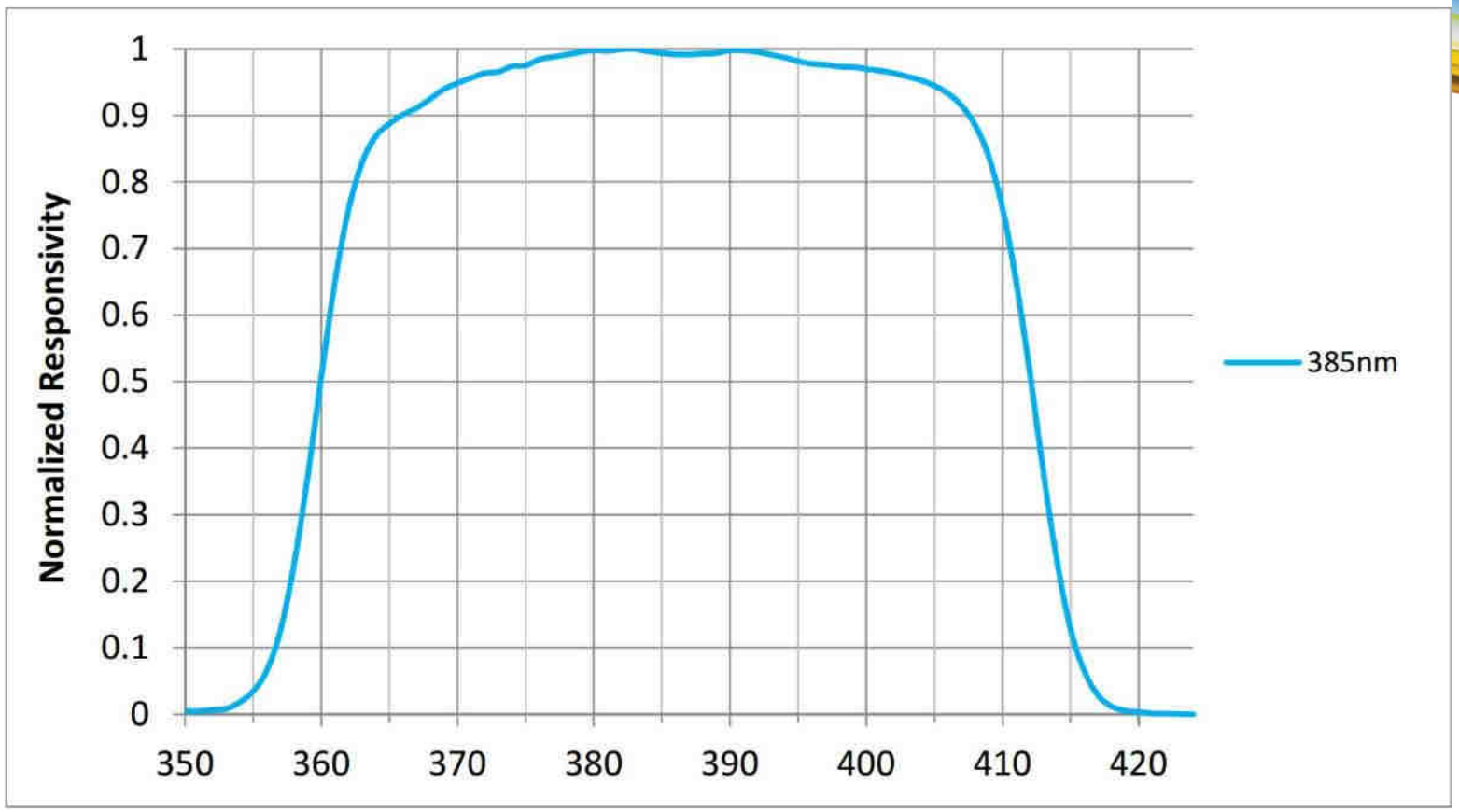
Test at different speeds, lamp heights and power levels
Compare different sources
```

L365 Response



- Total Measured Optics Response Similar to L395
  - **L365: 340-392 nm**

L385 Response



- Total Measured Optics Response Similar to L395
  - **L385: 360-412 nm**

SUMMARY

- The variation in commercial UV LED sources prompted a new approach
- Total Measured Optic Response considers the effects of all optical components in the instrument
- The L-band approach provides exceptional accuracy and repeatability
- L395, L385 and L365 LEDCure radiometers are available L405 LEDCure radiometers and Online Sensors will be available very soon
- Adopt patented Total Measured Optics Response to broad band radiometers in future

Thank You

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New EIT Facility for Manufacturing, Sales and Service