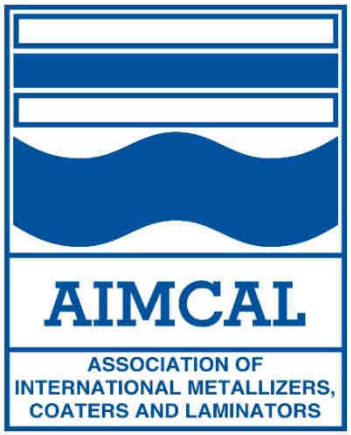
UV LED Measurement Status Update



Jim Raymont

September 19, 2016

Presentation Overview

- UV Measurement Fundamentals & Variables
- UV LEDs
- Measurement of UV LEDs

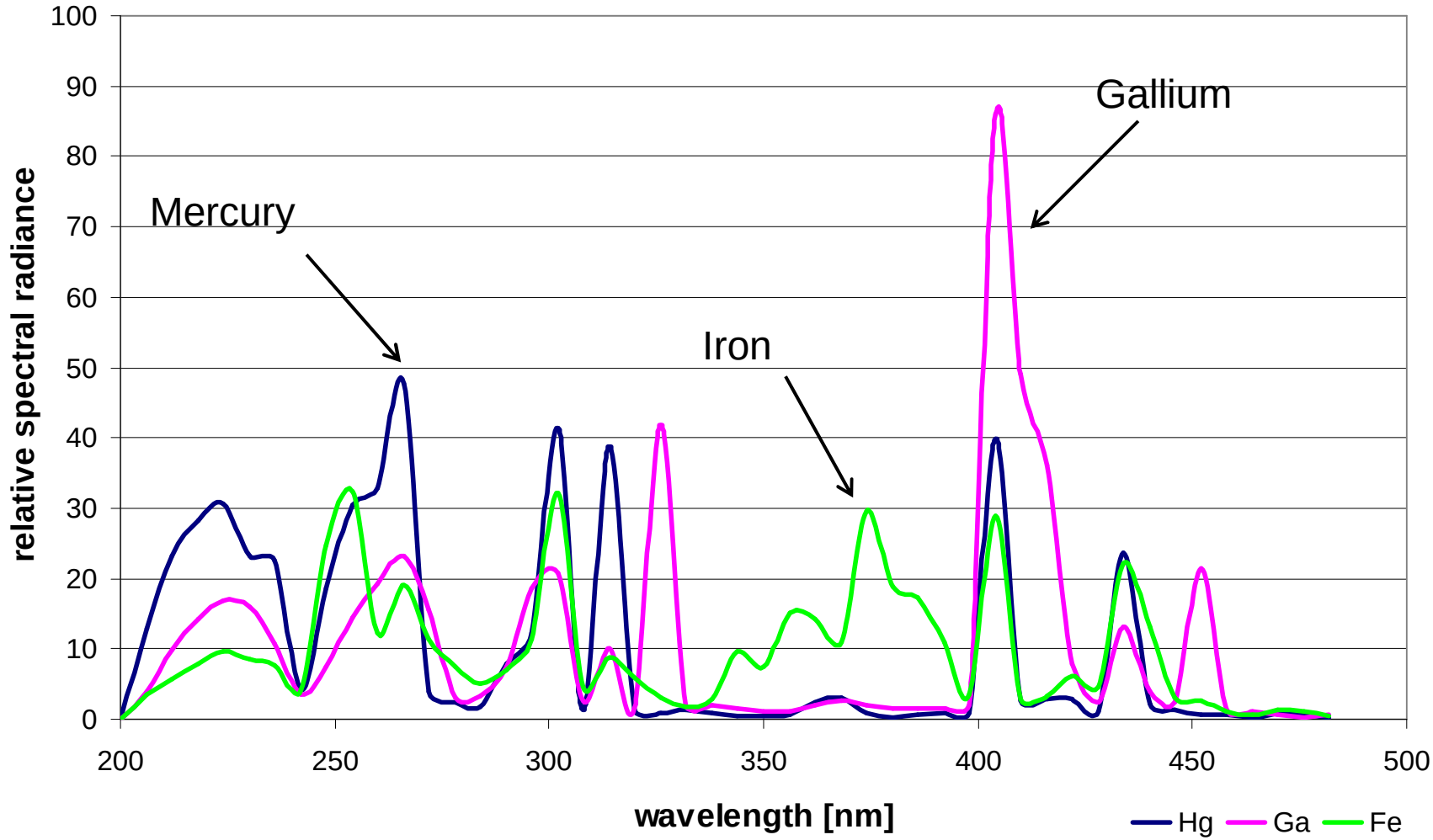
Save Time & Money

Copy of Presentation email: uv@eit.com

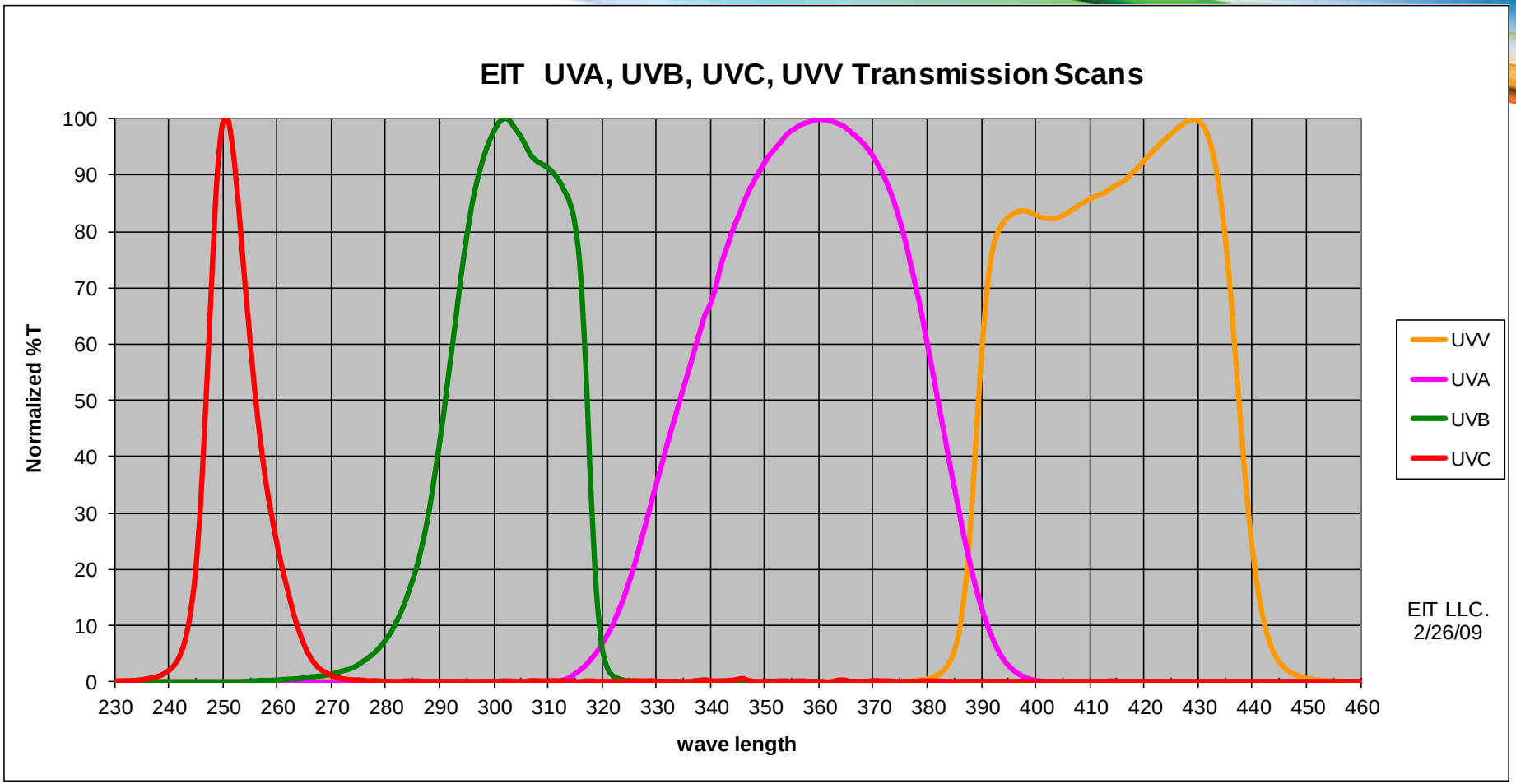
Broadband Spectral Output

Arc, Microwave, Spot Sources

Hg spectra modified with added materials



Instrument Responses

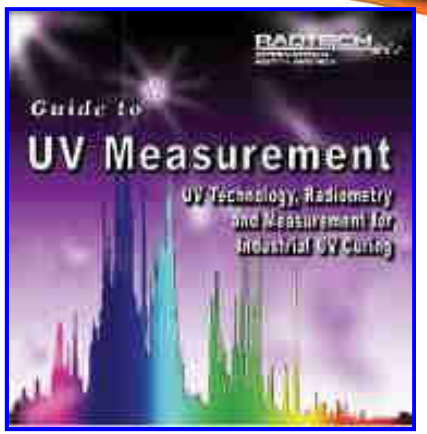


The traditional approach has been to define the band response based only on the filter response

Challenges Measuring Broadband UV Sources

Work in past to improve & understand UV measurement

- 3M, Heraeus, International Light, EIT
- RadTech Measurement CD
- Educate & Communicate



Why are there differences between instruments?

Optics

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

Electronics

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

Calibration Sources/Points

- One source type does not always fit

Data Collection Techniques

- User Errors

User Expectations

- Fraction of a percent?

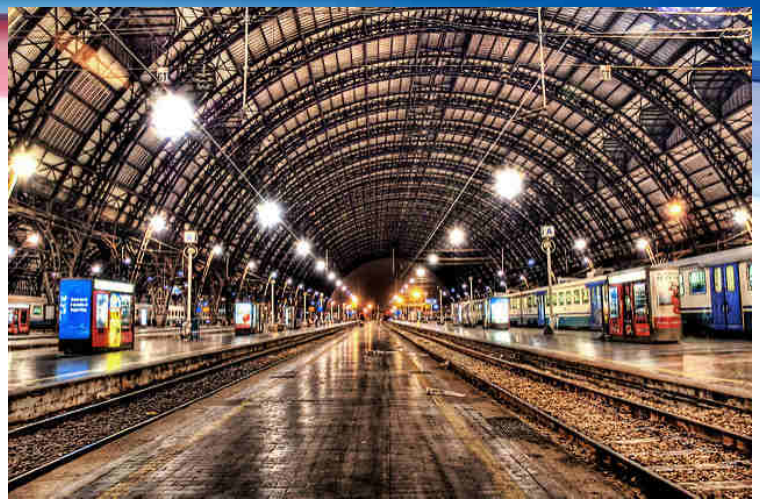
UV LEDs

Wide variety of UV LED sources

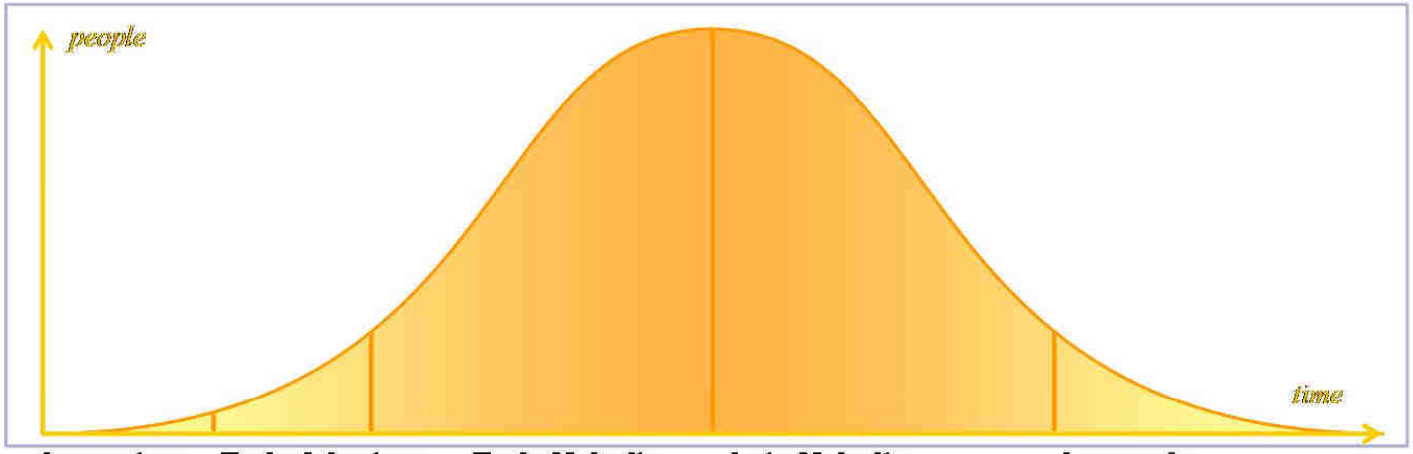
- Multiple suppliers with wide level of expertise, support, finances
  - More than someone with SMT equipment?
- Experience in industrial UV, visible lighting, semiconductor industry?
- Ties to formulators?
- Match source to your application & process
- Economics of source selected (ROI)

Images courtesy Baldwin, Dymax, Integration Technology, Excelitas & Phoseon Technology

UV LED Adoption



The UV LED train has left the station



Innovators
(2.5%) are risk takers who have the resources and desire to try new things, even if they fail

Early Adopters
(13.5%) are selective about which technologies they start using. They are considered the "one to check in with" for new information and reduce others' uncertainty about a new technology by adopting it.

Early Majority
(34%) take their time before adopting a new idea. They are willing to embrace a new technology as long as they understand how it fits with their lives.

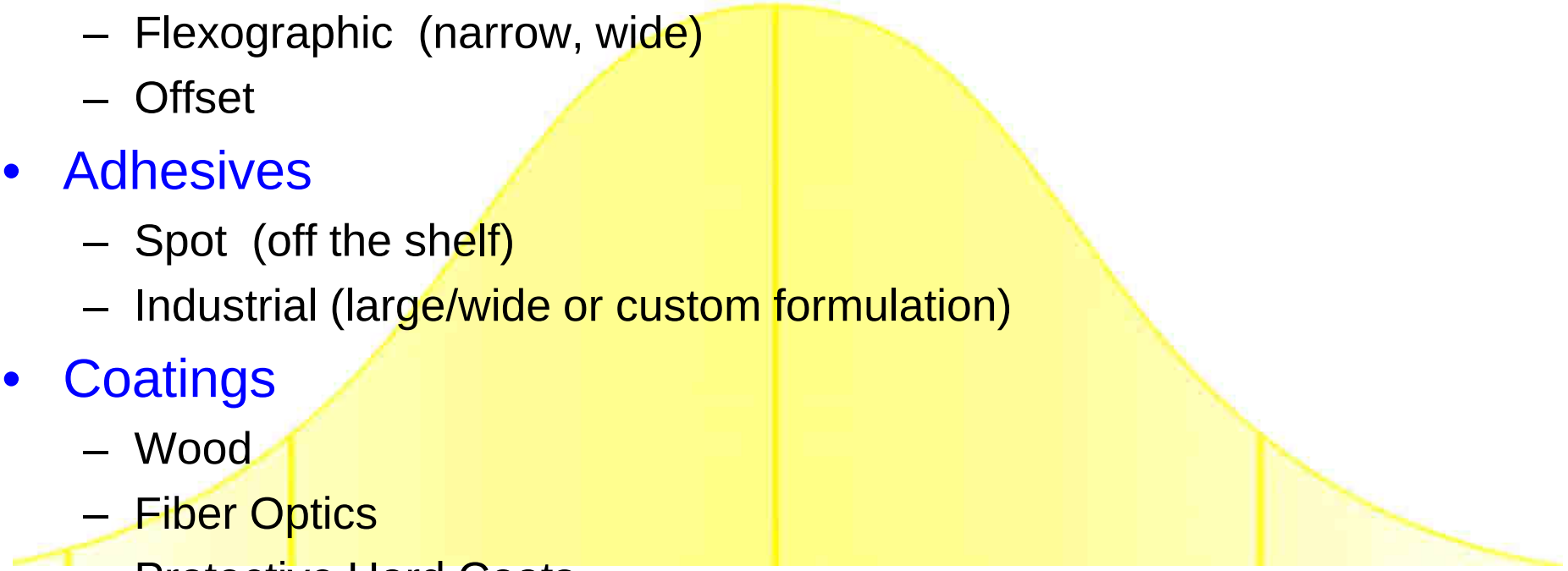
Late Majority
(34%) adopt in reaction to peer pressure, emerging norms, or economic necessity. Most of the uncertainty around an idea must be resolved before they adopt.

Laggards
(16%) are traditional and make decisions based on past experience. They are often economically unable to take risks on new ideas.

Bryce Ryan & Neal Gross (1943)

UV LED Adoption

- Graphic Arts / Printing
  - Digital (standard format, wide format, direct to substrate)
  - Screen (simple carousel machines, complex industrial)
  - Flexographic (narrow, wide)
  - Offset
- Adhesives
  - Spot (off the shelf)
  - Industrial (large/wide or custom formulation)
- Coatings
  - Wood
  - Fiber Optics
  - Protective Hard Coats
  - Other



Courtesy Paul Mills: UV LED Tipping Point

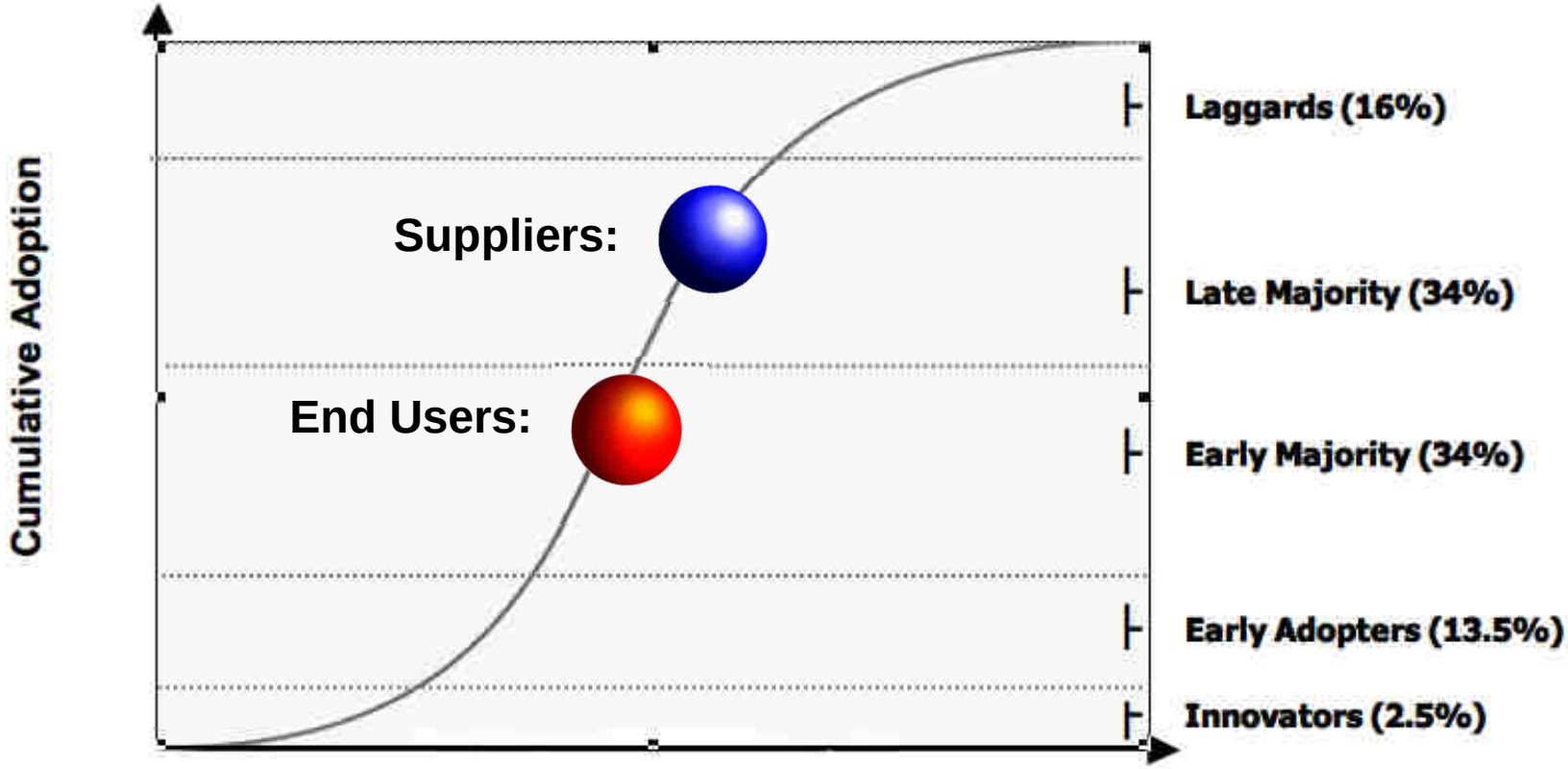
UV LED Curing Community

LED Adoption Rate

Digital Print

- Technical hurdles / Barriers to entry
- Business case for LED is stronger
- Vertical Integration

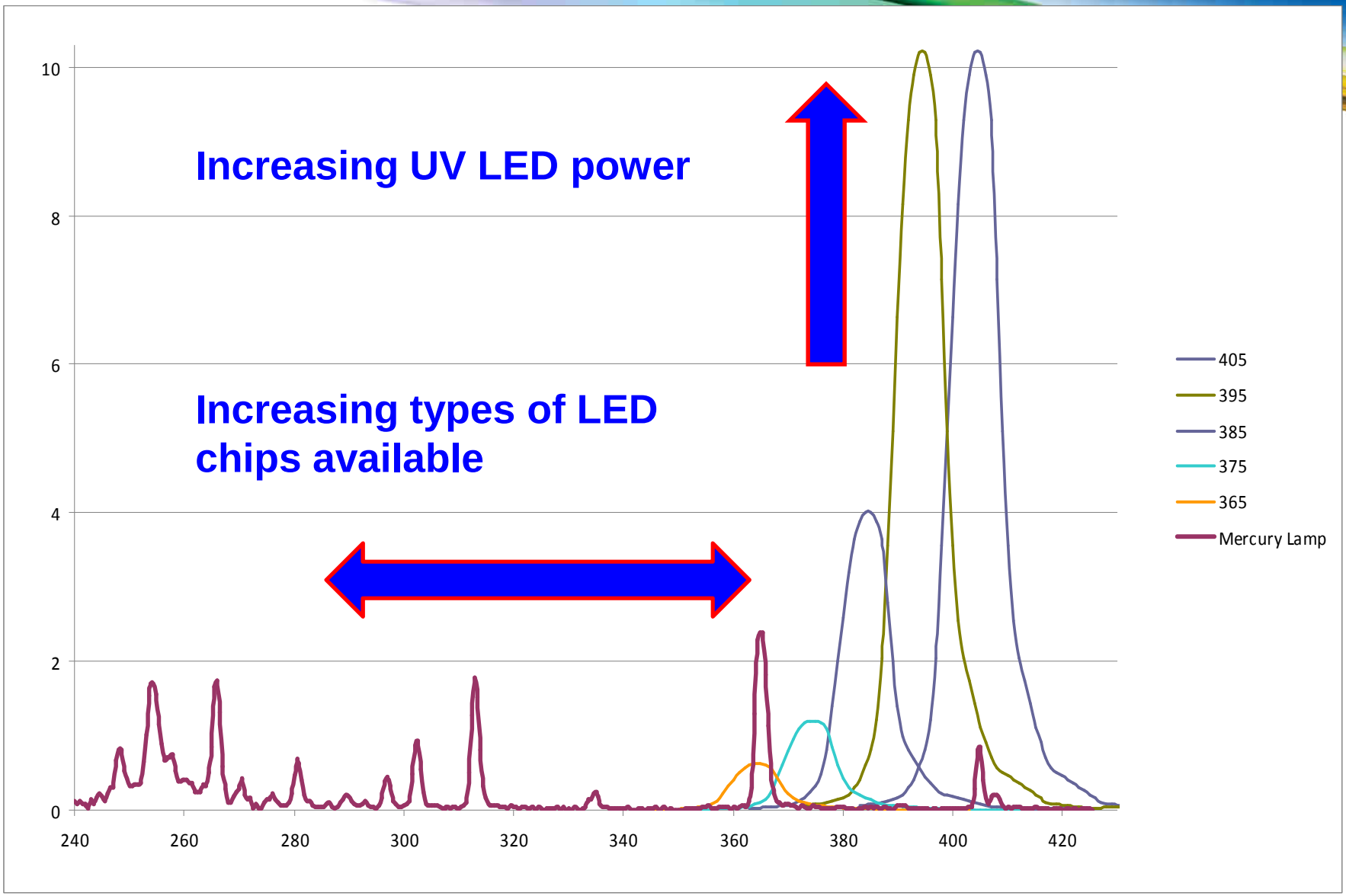
- Competitiveness of users
- Competitiveness of suppliers



Courtesy Paul Mills: UV LED Tipping Point

UV LED Curing Community

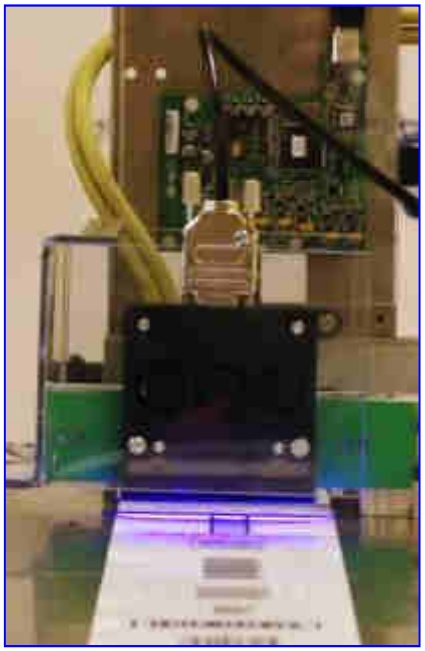
UV LED Power Output vs. Wavelength



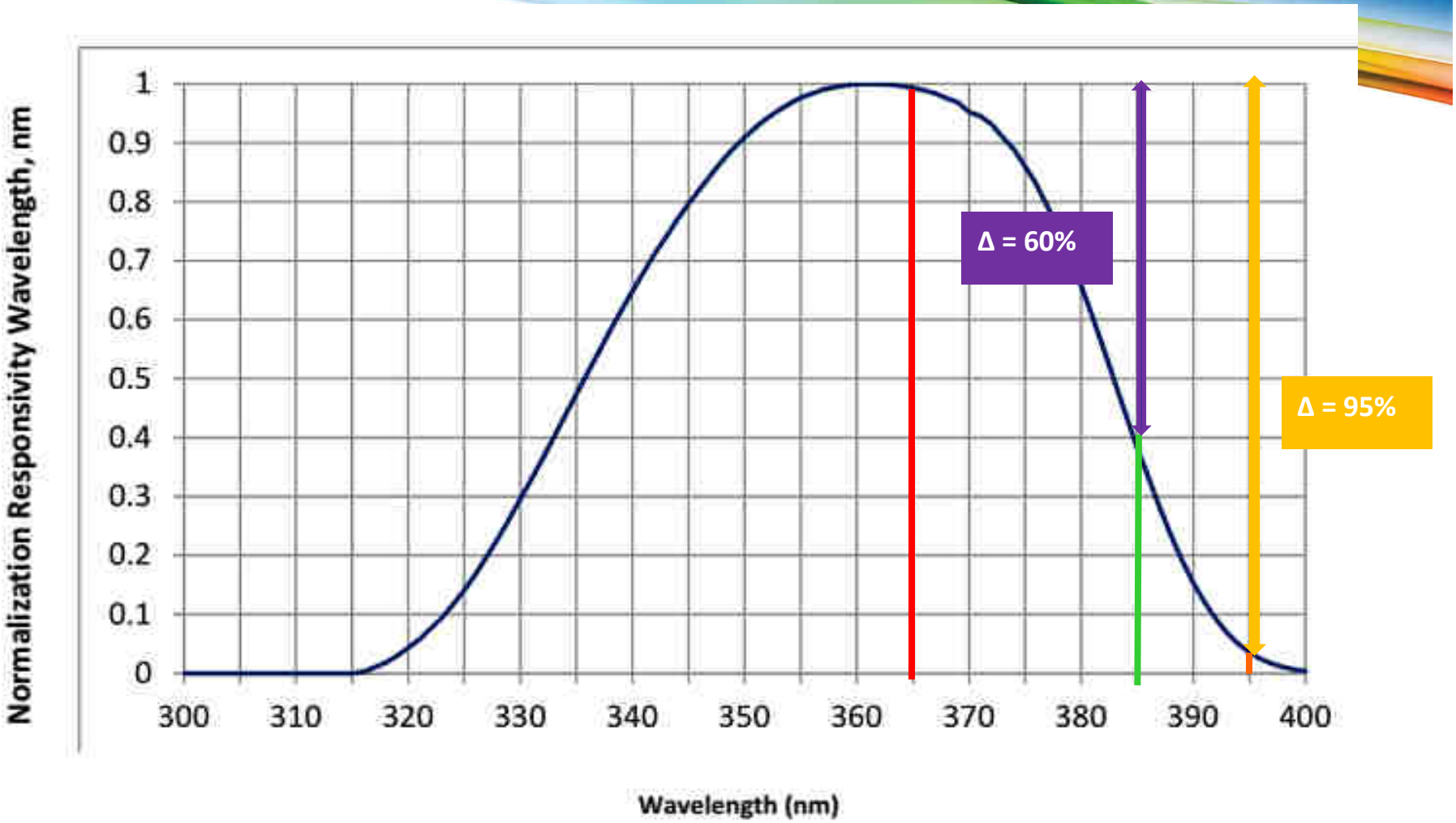
UV LEDs: Measurement

What do you want to measure?

- What do you want to measure?
  - Individual LED
  - Array
  - **Production system**
- Where do you measure?
- What values do you want?
- Industrial UV: W/cm^2 & J/Cm^2
- Visible LEDs: Flux?/Color?



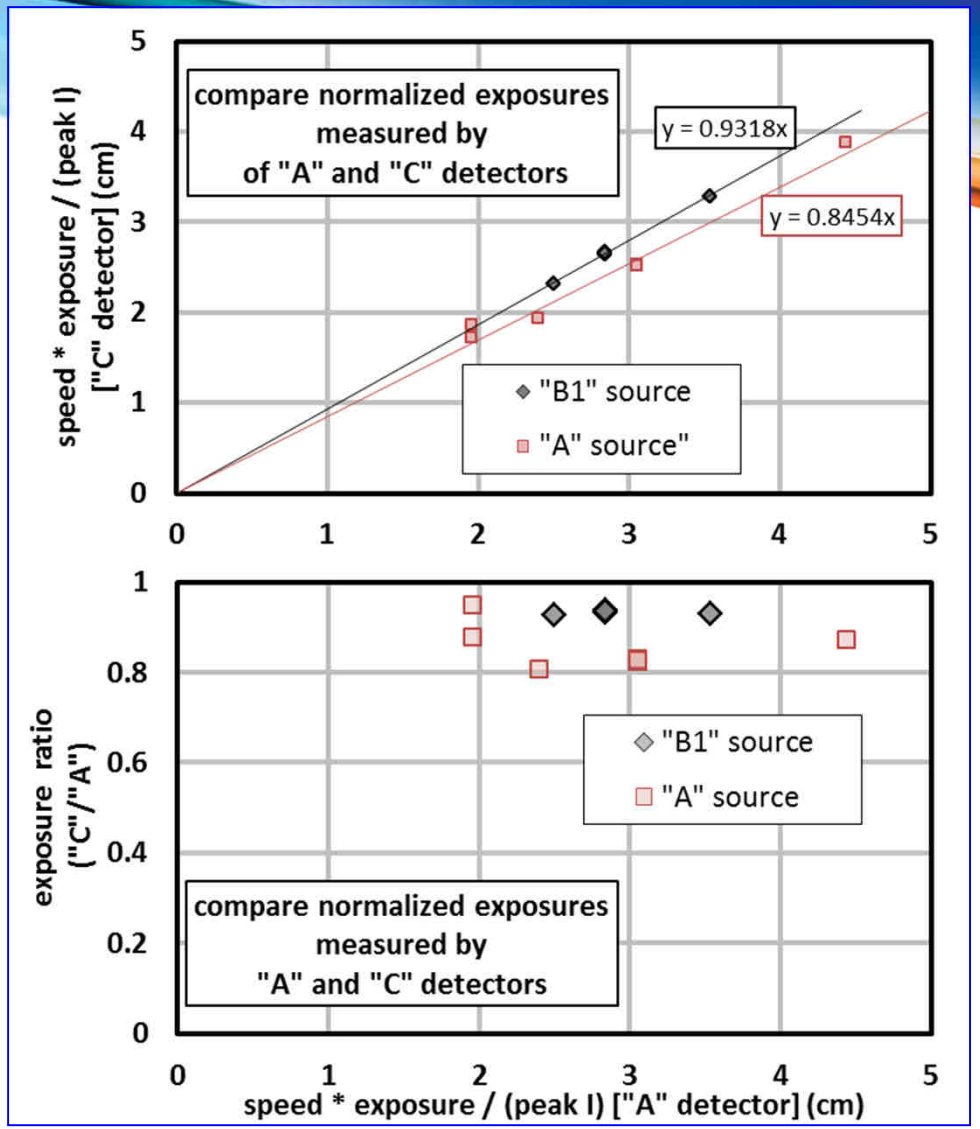
Measurement of 395 nm LED



Using UVA to measure a 385 nm or 395 nm LED

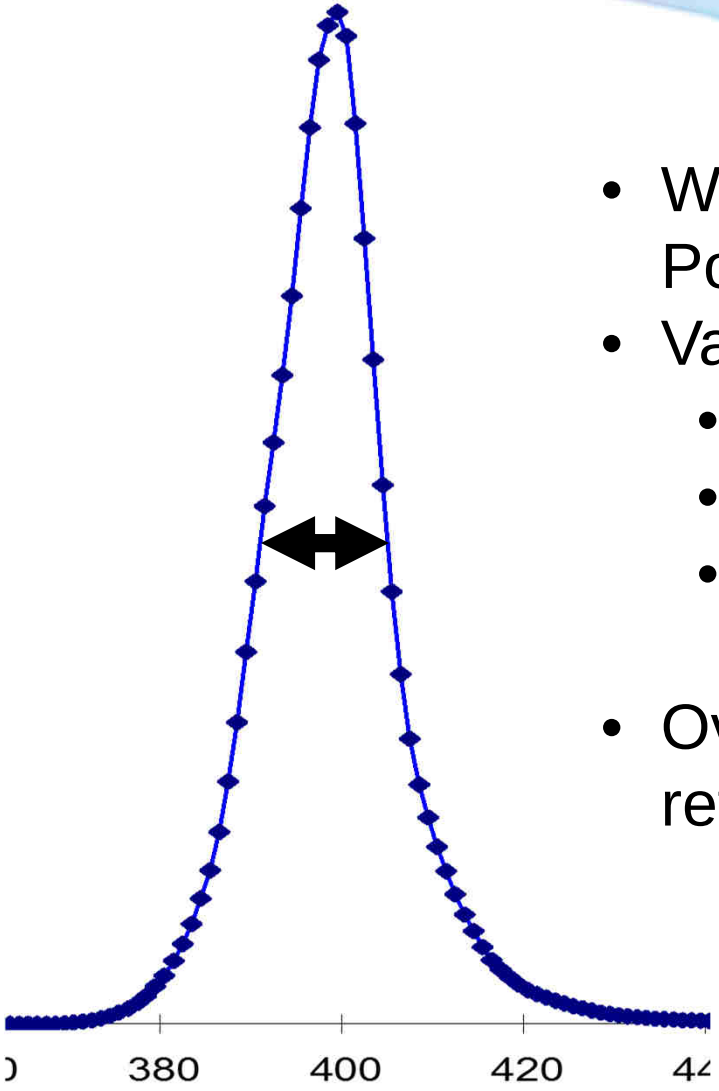
NIST comparison of UV LED sources

- Study completed by Robert F. Berg, NIST
- Looked at three LED units with two different radiometers
- Right Upper: Detector C exposure vs. detector A exposure
- Right Lower: The ratio of the two detectors' exposures vs. the exposure of detector A
- No surprise there were differences



From NIST report generated by Robert F. Berg (Figure 9 in report)

UV LED Emission Spectra

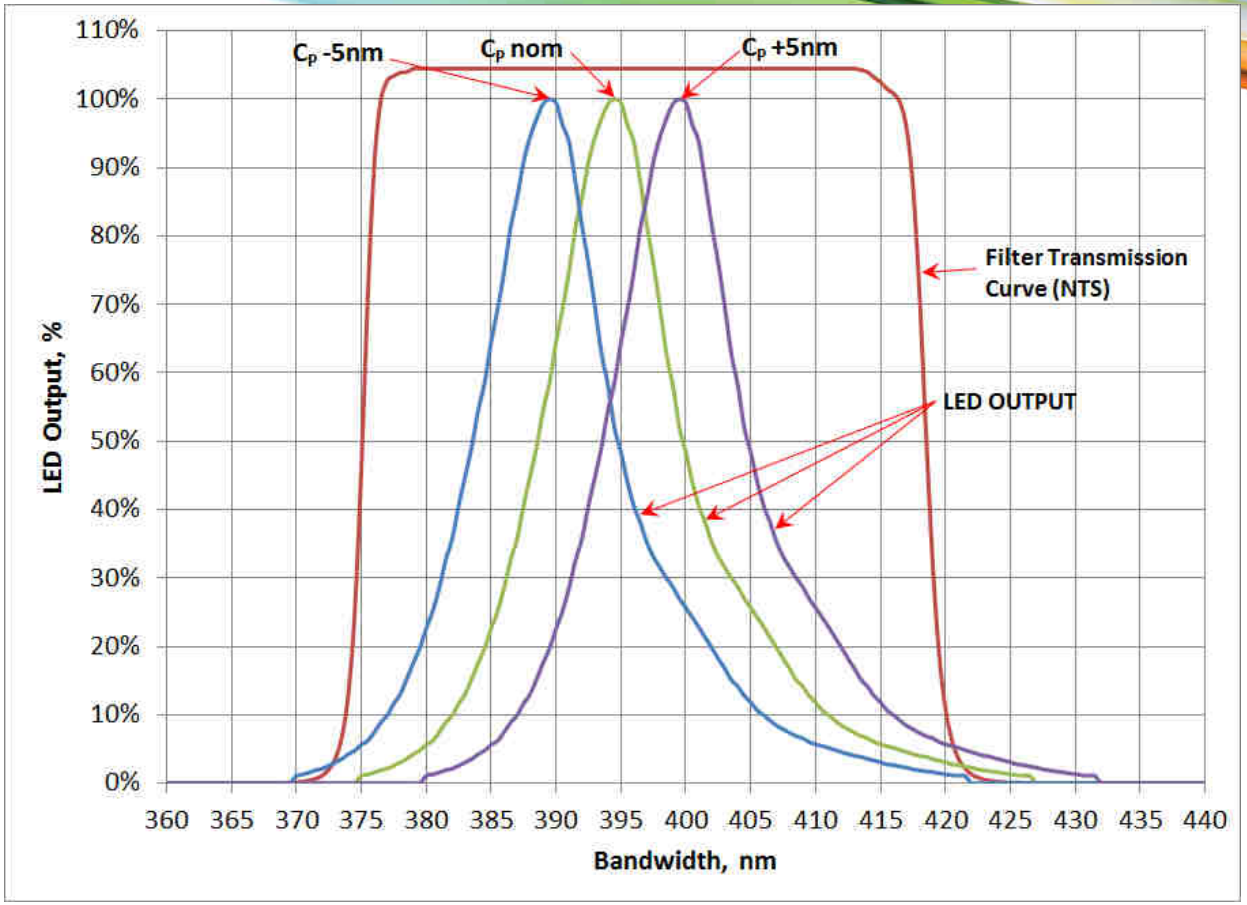


- Width of the LED at the 50% Power Point
- Variations between suppliers:
  - Binning
  - Longer wavelengths
  - Sold as +/- 5 nm from center wavelength (CWL)
- Overall spread of UV LED made us rethink width of UVA2 band

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

UV L395 nm Band

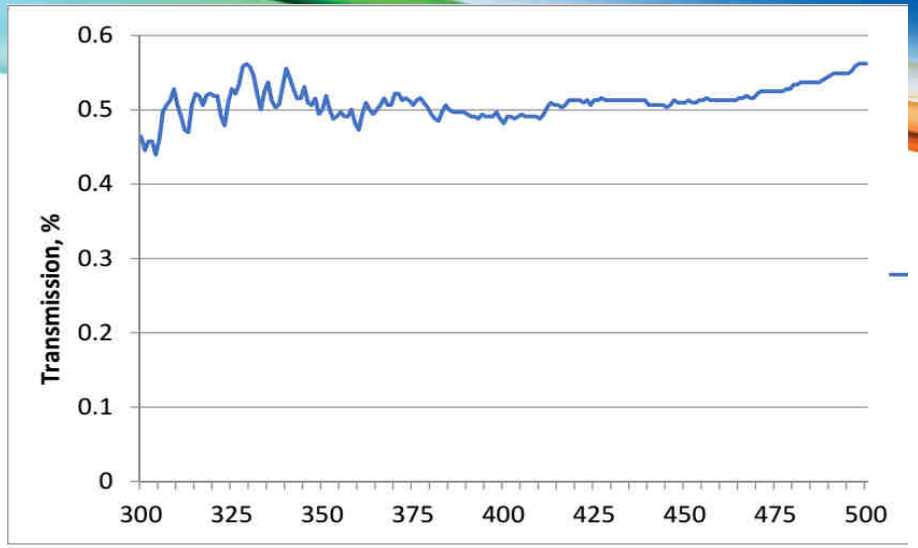
- "L" Band
- "Wide" (+/- 100 nm) vs. "Narrow" (+/- 50 nm) Approach
- Advantages & Disadvantages to each approach
- **Goal: Flat Response**

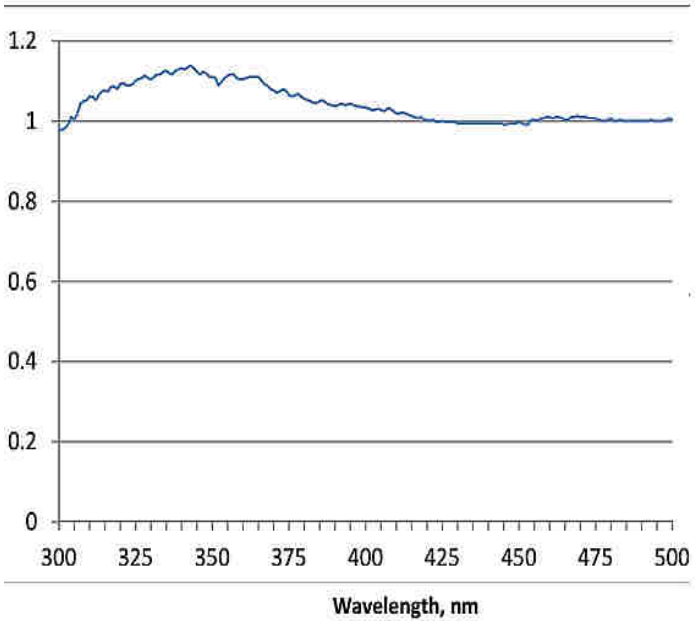


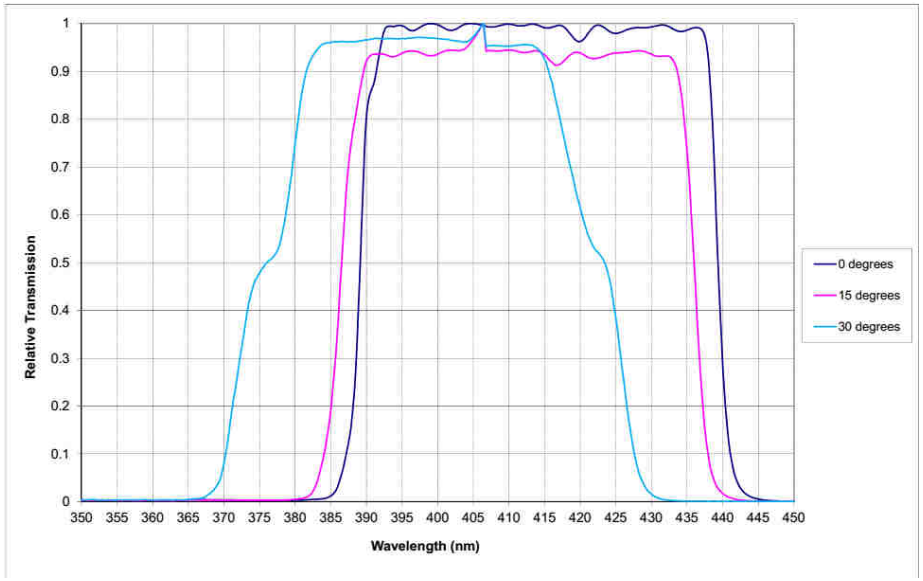
L395 LED Output Spectra Showing ± 5nm Spread of Cp Along with Required Filter Response to Obtain 2% Measurement

Total Instrument Response

- Control of overall optics to flatten OVERALL response of instrument
- All Optical Components not just the filter

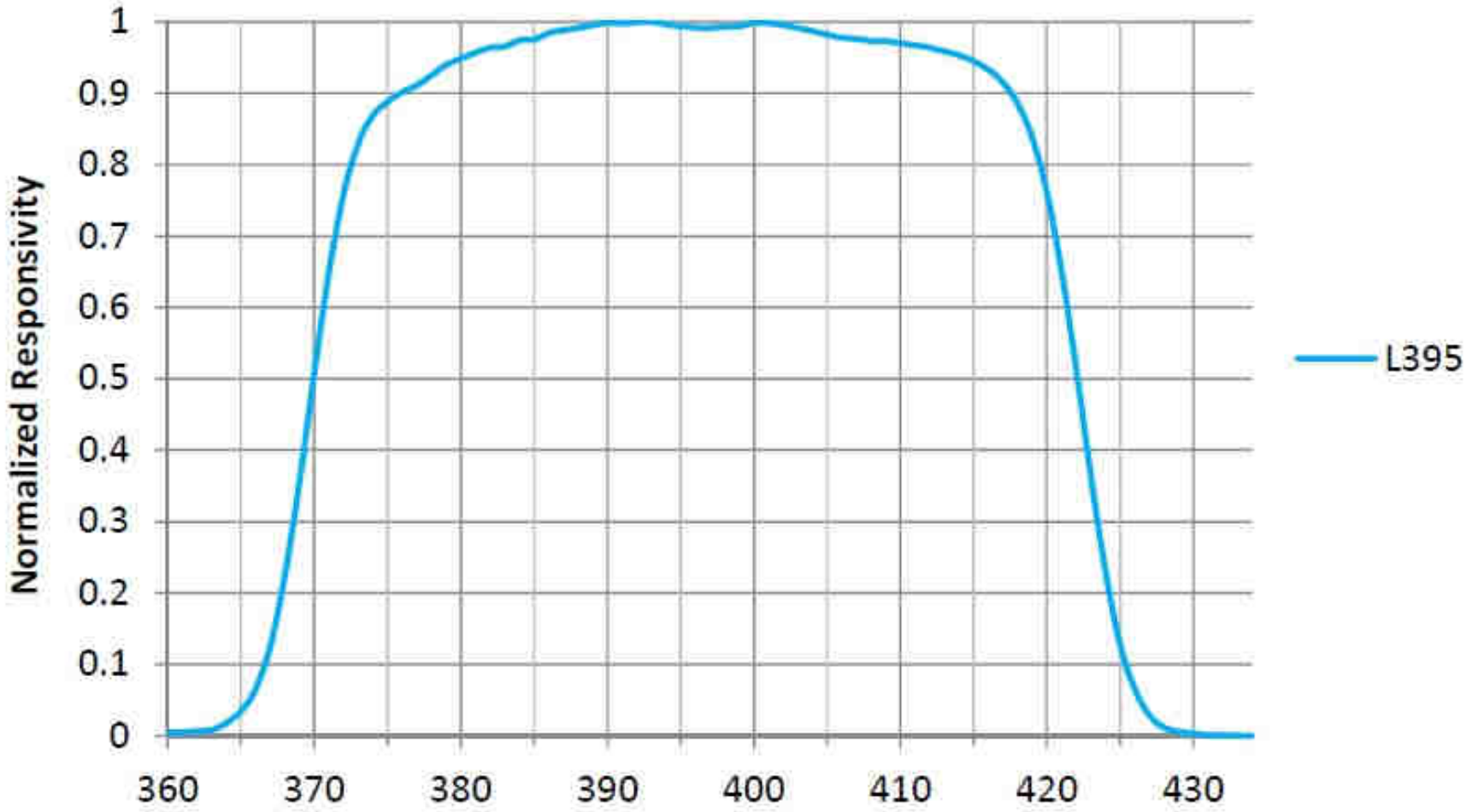






Instrument Response

Total Measured Optics Response



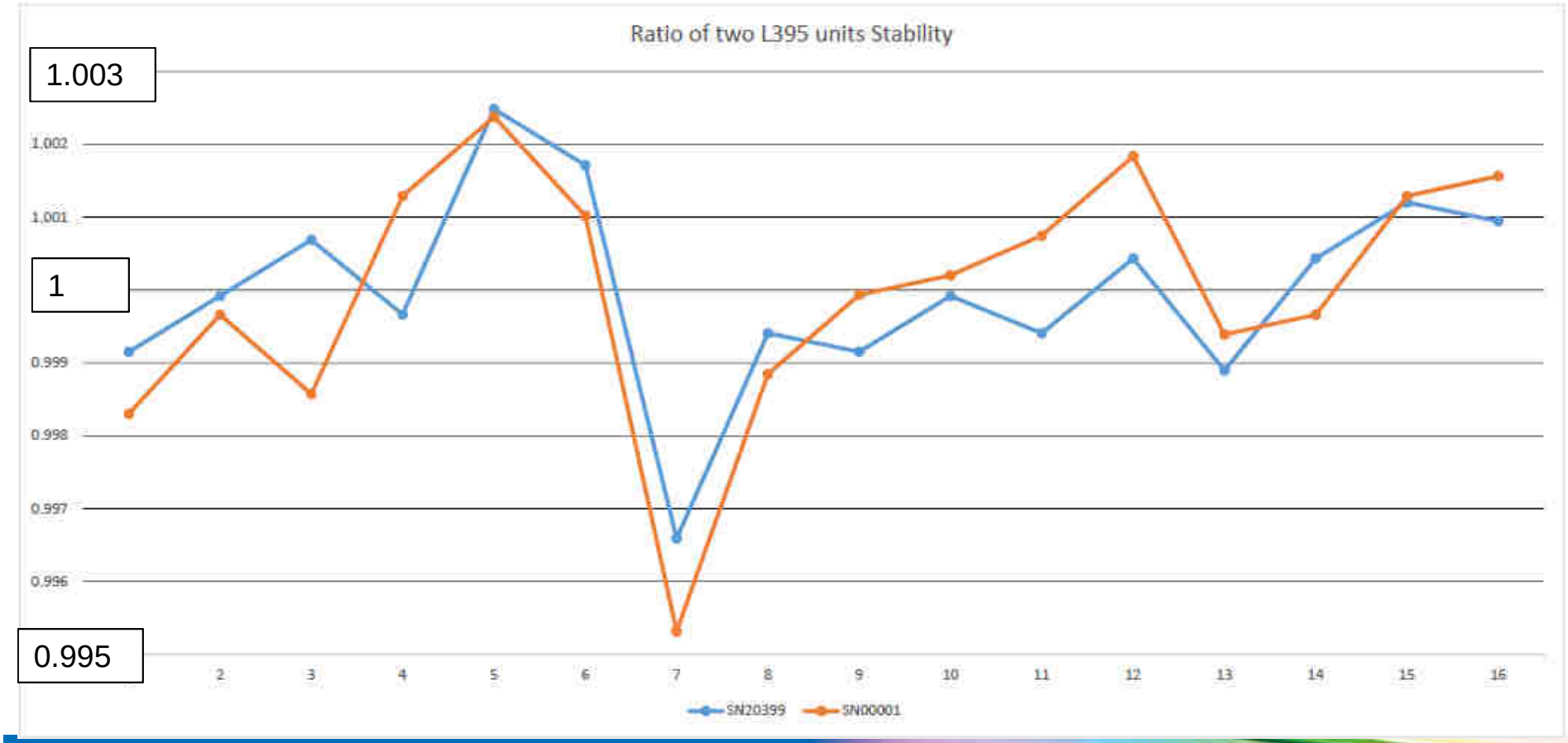
Instrument Feedback

- Spectral response looks very good based on measurements of 385nm, 395nm and 405nm LEDs
- A 365nm lamp showed very little response with the EIT meter, indicating the spectral response has a steep skirt
- Very consistent peak irradiance and energy density measurements at various scan speeds
  - ❑ Scan speeds varied from 1.2 to 6 meters/min
  - ❑ Repeated measurements showed very little variation
- Good correlation to a NIST traceable meter from another manufacturer

Instrument Performance

LEDCure™ Profiling Radiometer

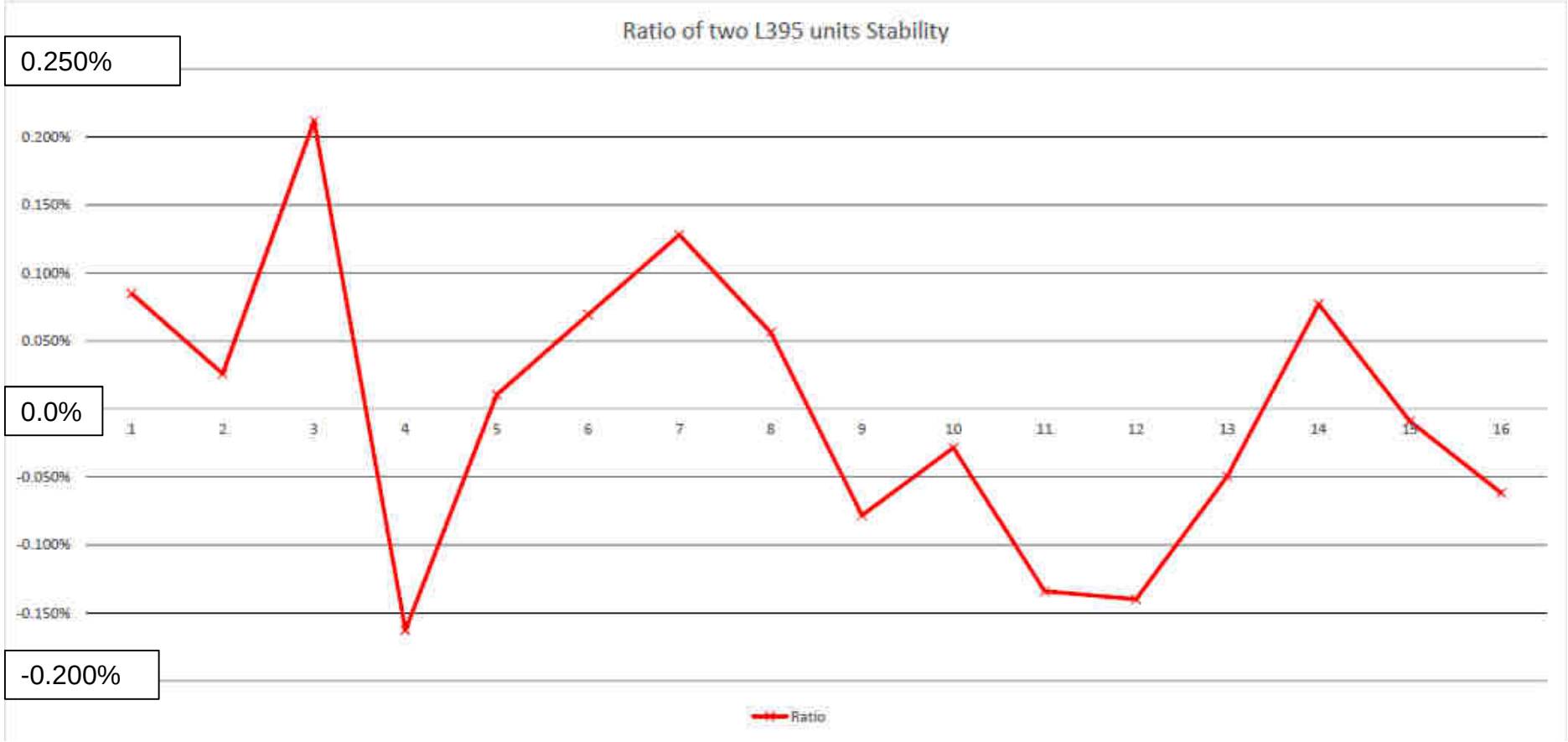
- Stability between two different L395 instruments on 16 runs
- Variation: 0.995 to 1.0025



Instrument Performance

LEDCure™ Profiling Radiometer

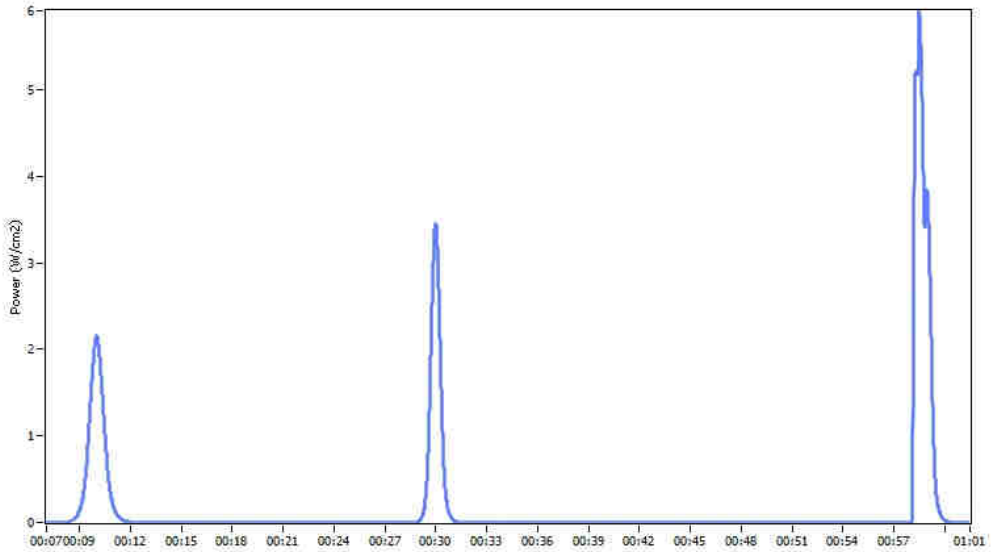
- Stability between two different L395 instruments on 16 runs
- Ratio



EIT LED-R™ Series

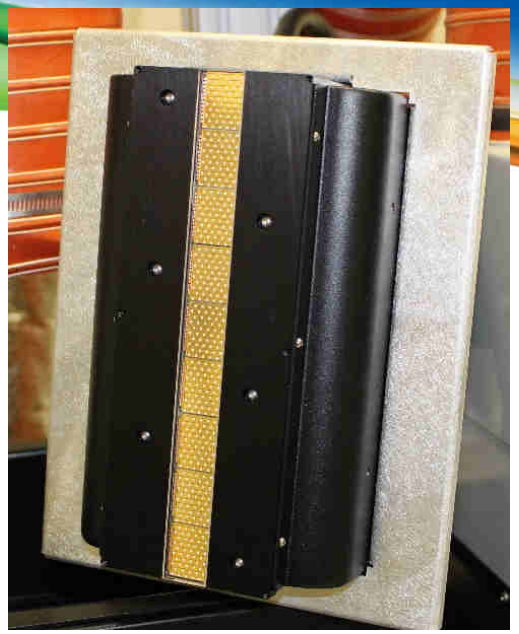
LEDCure™ Radiometer

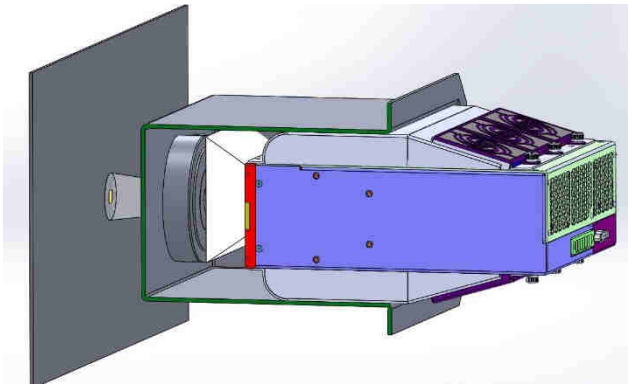
- 40 Watt Dynamic Range
- Display Plus Profiler or Non-Profiler Option
- L395 Total Optics Response
- Additional L-Band Options



Calibration Challenges

- Industrial LED sources have exceeded 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





Council Optical Radiation Measurement

- Worldwide, approximately 20 members
  - USA, Korea, Japan, China, UK, Germany, Denmark, South Africa
- Diverse Well Rounded Membership
  - National Standards Organizations (NIST)
  - Equipment Suppliers (Heraeus, Efsen Engineering)
  - Instrument Suppliers (EIT, Gigahetz-Optik, International Light Technologies)
  - Academic (University of Colorado, Boulder)
  - End Users (3M)
  - Trade Organizations (RadTech, IUVA)

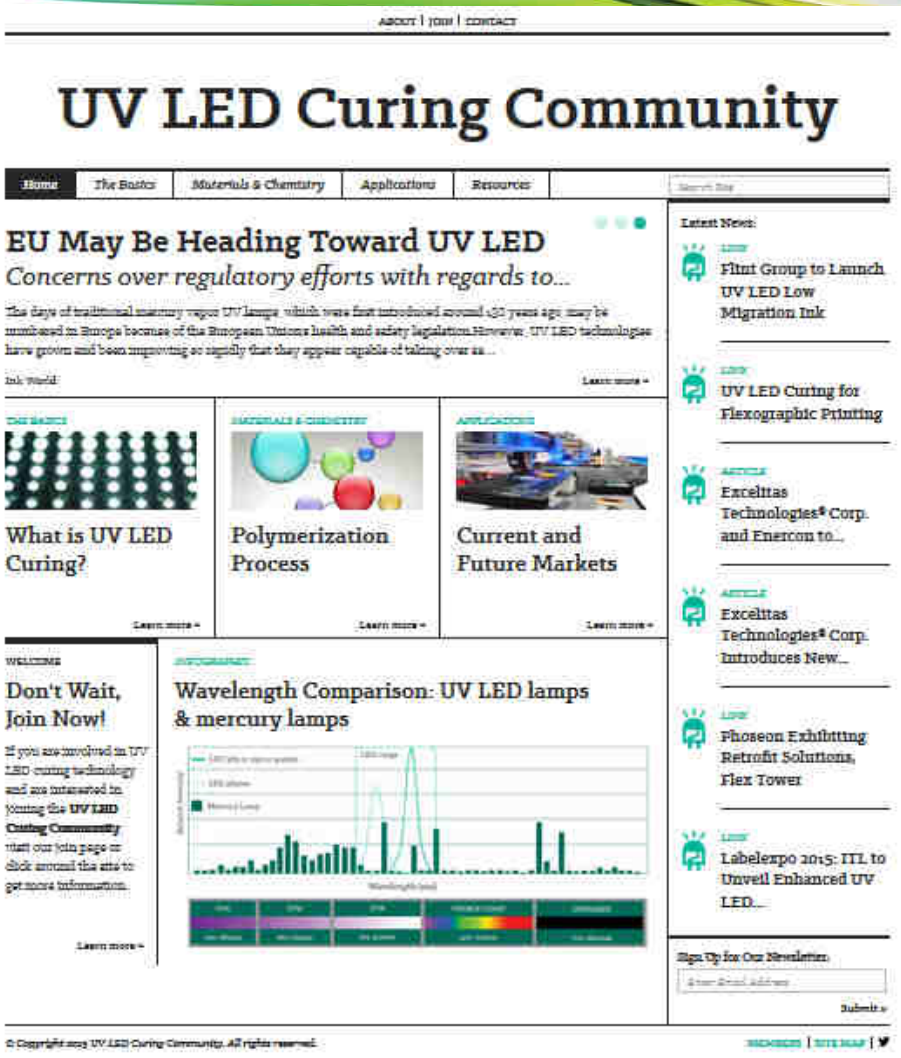
Resources

UV LED Curing Community

- Thousand's of visitors per month
- Hub for information about UV LED technology
- Free to join

www.uvledcommunity.org

www.radtech.org



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