Development of $2\pi$ Total Spectral Radiant Flux Standards at NIST

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Outline

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3. Development of TSRF standards
   - $4\pi$ TSRF standard
   - $2\pi$ TSRF standard
4. Summary
4π sphere-spectroradiometer system

\[ \Phi_v = K_m \int_\lambda \Phi_{e,\lambda}(\lambda)V(\lambda)d\lambda \]

\[ K_m = 683 \text{ lm/W} \]

\[ V(\lambda): \text{CIE spectral luminous efficiency function} \]
$2\pi$ sphere-spectroradiometer system

\[ \Phi_v = K_m \int \Phi_{e,\lambda}(\lambda)V(\lambda) d\lambda \]

$K_m = 683 \text{ lm/W}$

$V(\lambda)$: CIE spectral luminous efficiency function
Realization of the TSRF scale

Measure spectral radiant intensity or spectral irradiance of a test lamp in many directions \((\theta, \phi)\) using a absolute \textit{gonio-spectroradiometer}.

\[
\Phi_{e,\lambda}(\lambda) = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} I_{\lambda}(\lambda, \theta, \phi) \sin \theta d\theta d\phi
\]
or
\[
\Phi_{e,\lambda}(\lambda) = r^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} E_{\lambda}(\lambda, \theta, \phi) \sin \theta d\theta d\phi
\]

\(\Phi_{e,\lambda}(\lambda)\): total spectral radiant flux (W/nm)

However, an absolute \textit{gonio-spectroradiometer} is costly!
Realization of TSRF scale at NIST

Relative gonio-spectroradiometer  Absolute 2.5 m integrating sphere

Two-step approach, based on both
- Candela scale
- Spectral irradiance scale

\[
\Phi_{e,\lambda}(\lambda) = k_{\text{scale}} \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} S(\lambda, \theta, \phi) \sin \theta \, d\theta \, d\phi
\]

\[
k_{\text{scale}} = \frac{\Phi_v}{K_m \int_{\lambda=0}^{\infty} V(\lambda) \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} S(\lambda, \theta, \phi) \sin \theta \, d\theta \, d\phi \, d\lambda}
\]

The relative gonio-spectroradiometer

Rotation radius: 1.25 m

Angle coverage
$3^\circ \leq \theta \leq 180^\circ$

$0^\circ \leq \phi \leq 360^\circ$

Spectroradiometer:
CCD array system (300 nm - 1100 nm)

Speed:
1 hour per scan with 10° step

Stray light is serious in NIR! Good baffling is critical.
Stray-light correction for the spectroradiometer

Stray-light error vs lamp CCT

Stray-light error in calibration results (for a 3200 K test lamp)
Spectral responsivity vs viewing angle
Signal nonlinearity of the array spectroradiometer

![Graph showing signal nonlinearity over different wavelengths and time periods.](image.png)
Stability of the gonio-spectroradiometer

![Graph showing stability over time](image_url)

- **Day 0**
- **Day 14**
- **Day 23**
- **Day 34**
- **Day 35**
Aging curves of radiant intensity at 3100 K CCT at six wavelengths.

NIST $4\pi$ TSRF standard
- 75 W, 28 V, 3100 K QTH lamp
- First developed in 2006
The newly developed $2\pi$ TSRF standard

First $2\pi$ standard

- 20 W, 12 V, 3000 K reflector halogen lamp
- Modified for a near Lambertian beam pattern
Measured beam profile of the $2\pi$ TSRF standard

Angular intensity distribution

Viewing angle, $\theta$ (Deg)

Lambertian source

The $2\pi$ standard lamp
Measured CCT of the $2\pi$ TSRF standard
Aging curves of spectral radiant intensity at 430 nm, 555 nm, 720 nm, and 830 nm over 24 h operation time.

Aging of CCT over 24 h operation time.
Uncertainty of NIST TSRF standard lamps

![Graph showing expanded uncertainty as a function of wavelength for 2π and 4π TSRF standard lamps.]

- Expanded Uncertainty (%, K=2)
- Wavelength, $\lambda$ (nm)

2π TSRF standard lamp
4π TSRF standard lamp
- Use energy mode (dose) instead of power mode.
- Use charge amplifiers instead of trans-impedance amplifiers.
- 10 ppm repeatability with >20% laser power fluctuations.
Summary

- NIST has developed a new $2\pi$ total spectral radiant flux calibration standard from 360 nm to 1100 nm with uncertainty between 2.9% to 1.3% ($k=2$), using a relative gonio-spectroradiometer, based on the NIST total luminous flux scale and the NIST spectral irradiance scale.

- The calibration service is available for either submitted lamps or NIST issued new lamps.

- Research is still going on to
  1) Improve the facility of further reducing uncertainties.
  2) Extend to the spectral range to deep UV.
References


Thank you