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Development of 2π Total Spectral Radiant Flux Standards at NIST

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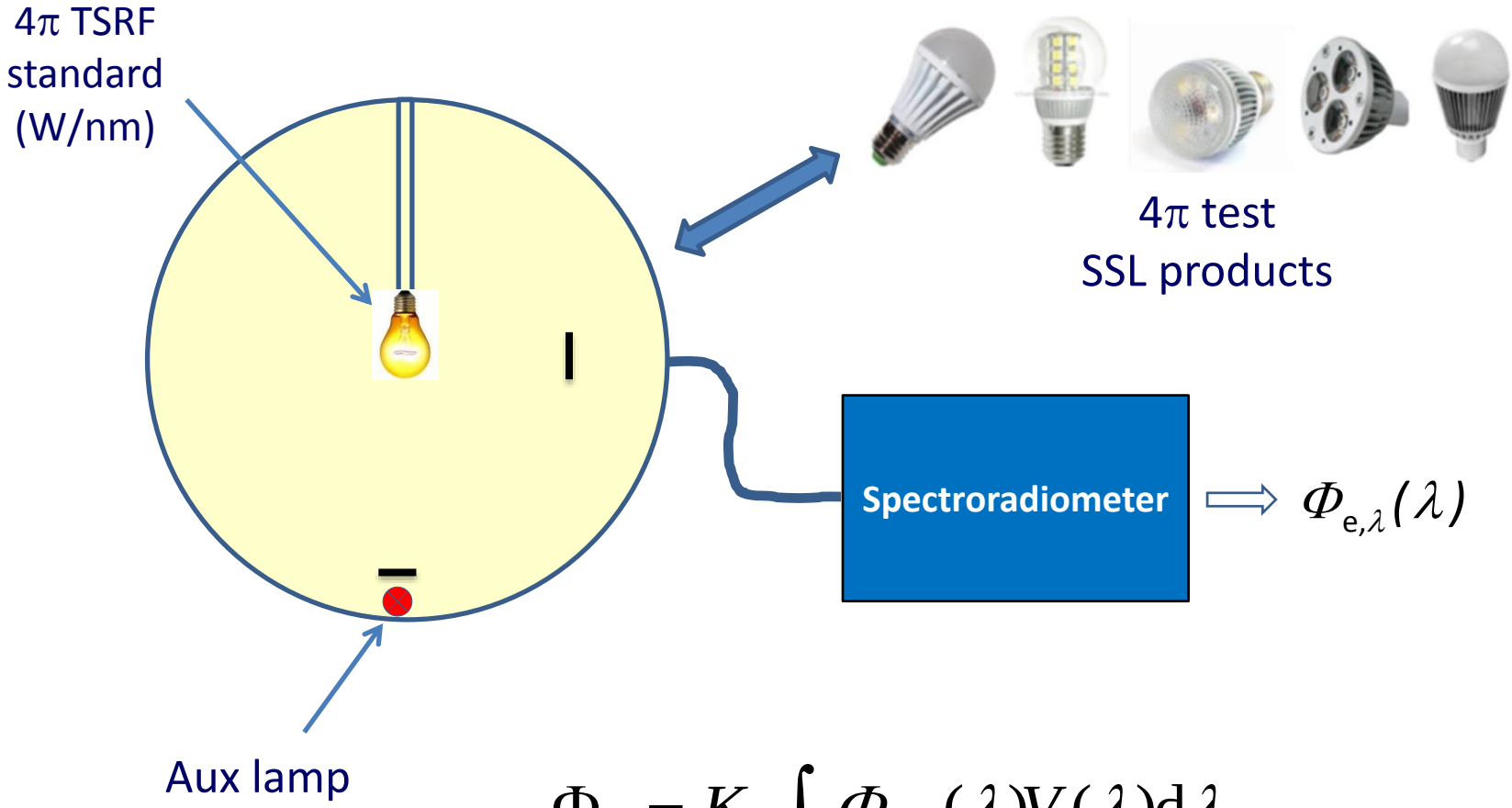
Outline

1. Introduction
2. Method for realization of total spectral radiant flux (TSRF) scale
3. Development of TSRF standards
   - 4π TSRF standard
   - 2π TSRF standard
4. Summary

4π sphere-spectroradiometer system

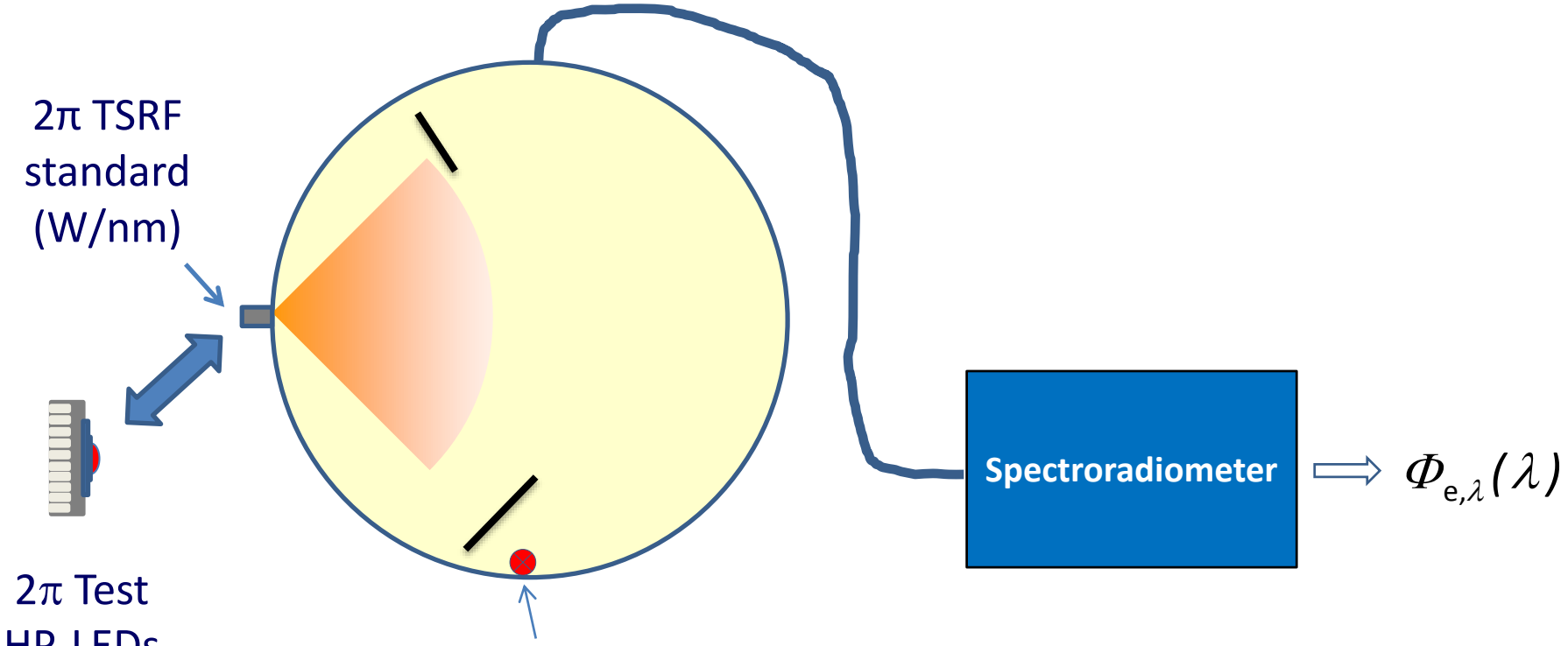


$$\Phi_v = K_m \int_\lambda \Phi_{e,\lambda}(\lambda) V(\lambda) \mathrm{d}\lambda$$

K_m = 683 lm/W

$V(\lambda)$: CIE spectral luminous efficiency function

2π sphere-spectroradiometer system



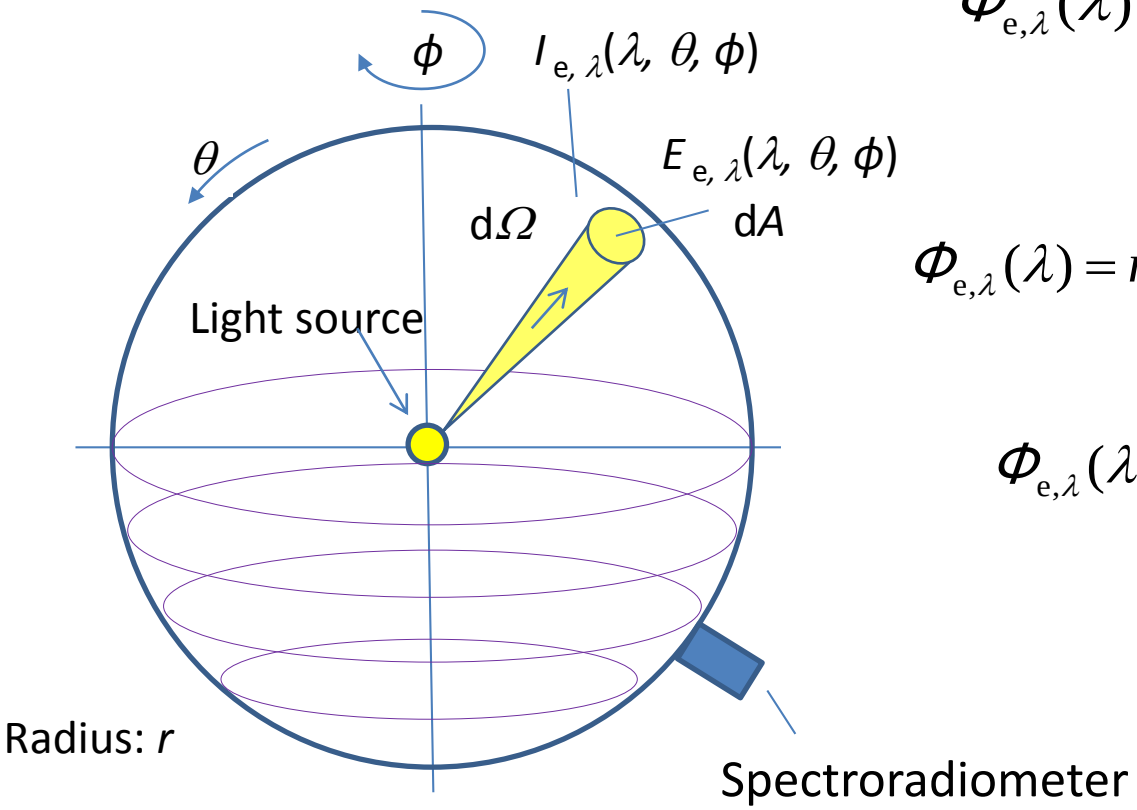
$$\Phi_v = K_m \int_\lambda \Phi_{e,\lambda}(\lambda) V(\lambda) \mathrm{d}\lambda$$

Km = 683 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 (θ, ϕ) using a absolute **gonio-spectroradiometer**.



$$\Phi_{e,\lambda}(\lambda) = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} I_{\lambda}(\lambda,\theta,\phi)\sin\theta \mathrm{d}\theta \mathrm{d}\phi$$

or

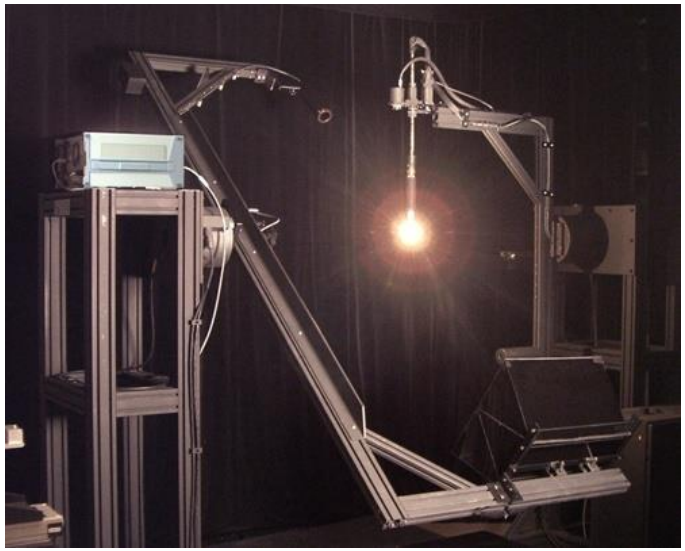
$$\Phi_{e,\lambda}(\lambda) = r^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} E_{\lambda}(\lambda,\theta,\phi)\sin\theta \mathrm{d}\theta \mathrm{d}\phi$$

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

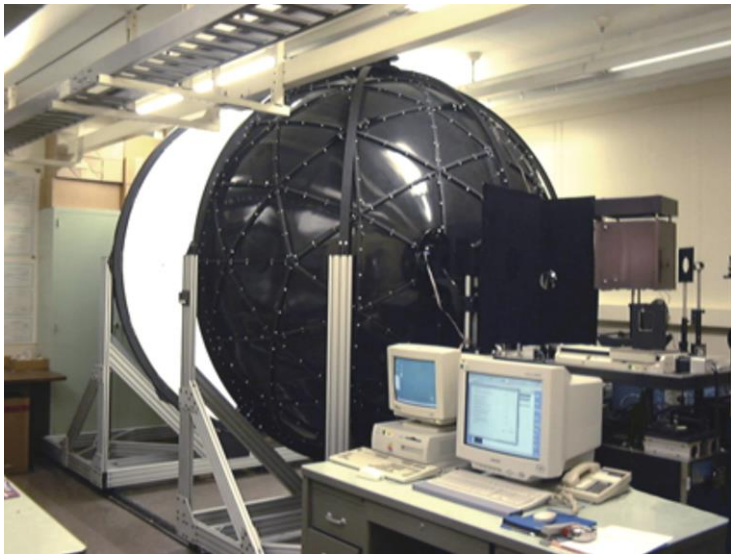
However, an absolute gonio-spectroradiometer is costly!

Realization of TSRF scale at NIST

Relative gonio-spectroradiometer



Absolute 2.5 m integrating sphere



Two-step approach, based on both

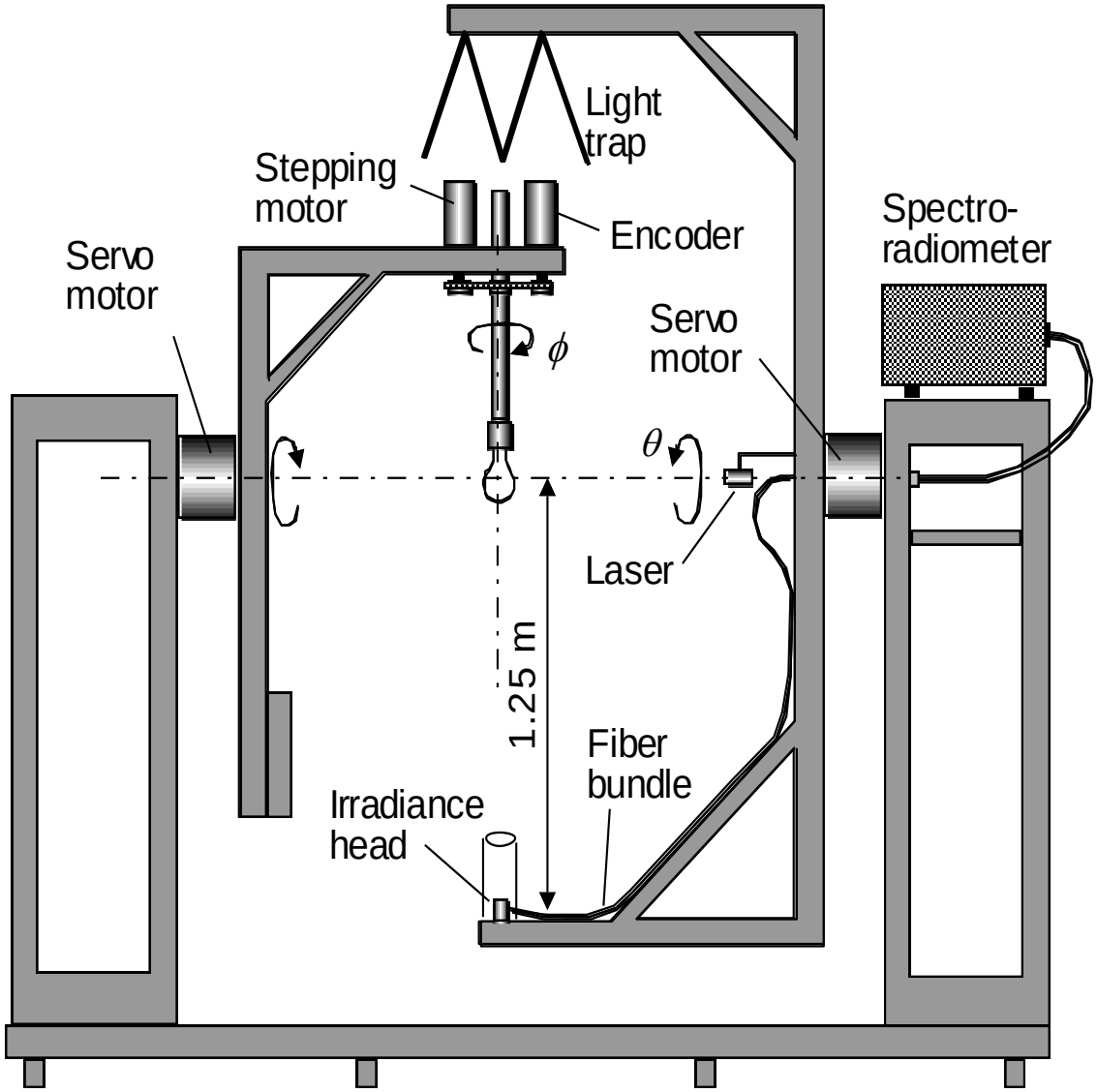
- Candela scale
- Spectral irradiance scale

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

$$k_{\text{scale}} = \frac{\Phi_{\text{v}}}{K_{\text{m}} \int_{\lambda=0}^{\infty} V(\lambda) \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} S(\lambda,\theta,\phi) \, \sin\theta \, \mathrm{d}\theta \, \mathrm{d}\phi \, \mathrm{d}\lambda}$$

Zong Y. and Ohno Y., Realization of total spectral radiant flux scale and calibration service at NIST, in Proc. CIE, July 4-11, 2007, Beijing, China, CIE 178:2007, D2-179 to D2-182. (2007)

The relative gonio-spectroradiometer



Rotation radius:
1.25 m

Angle coverage
$3^\circ \leq \theta \leq 180^\circ$
$0^\circ \leq \phi \leq 360^\circ$

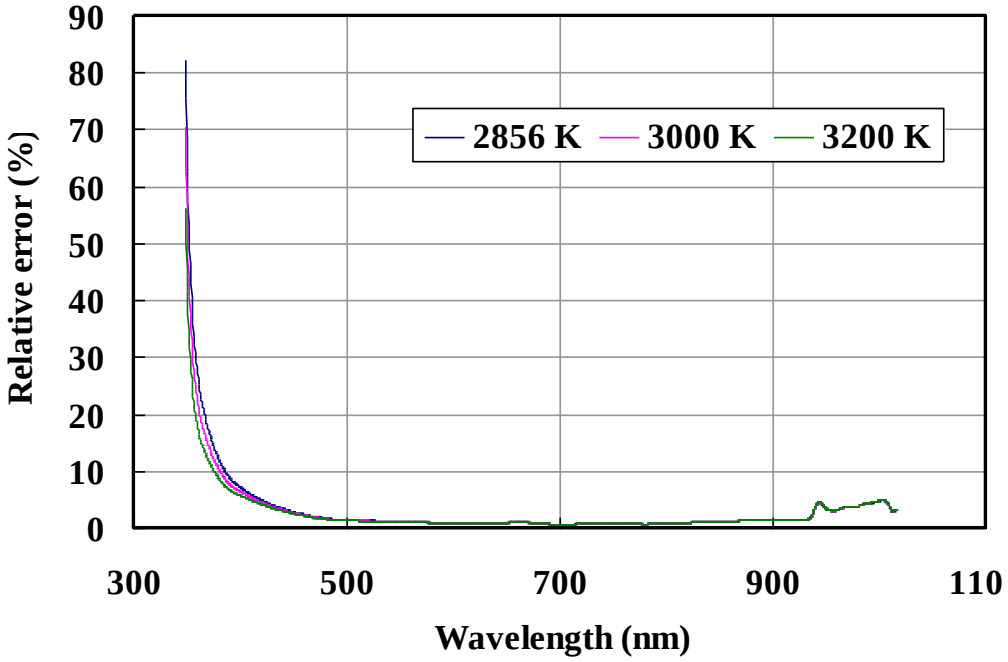
Spectroradiometer:
CCD array system
(300 nm - 1100 nm)

Speed:
1 hour per scan with
10° step

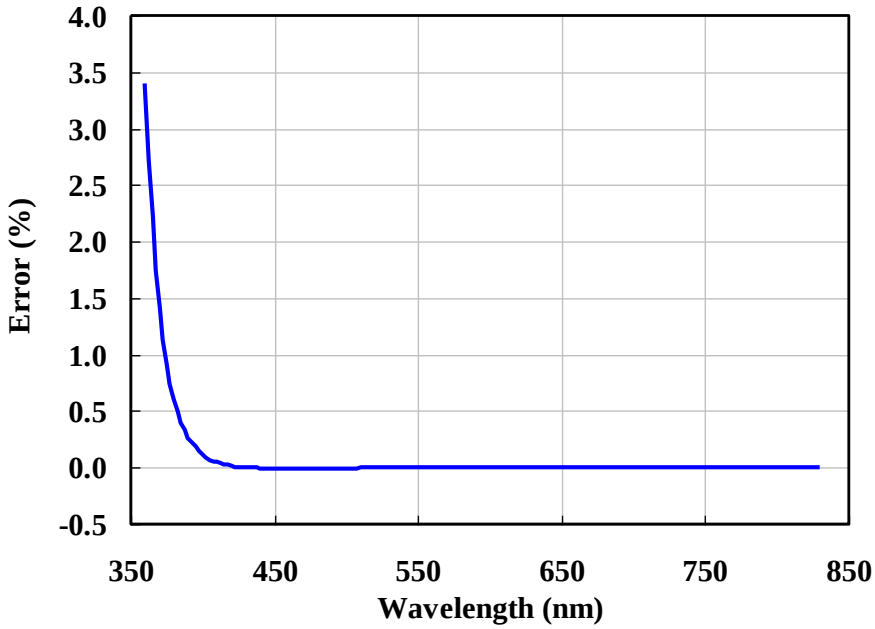
Stray light is serious in NIR! Good baffling is critical.

Stray-light correction for the spectroradiometer

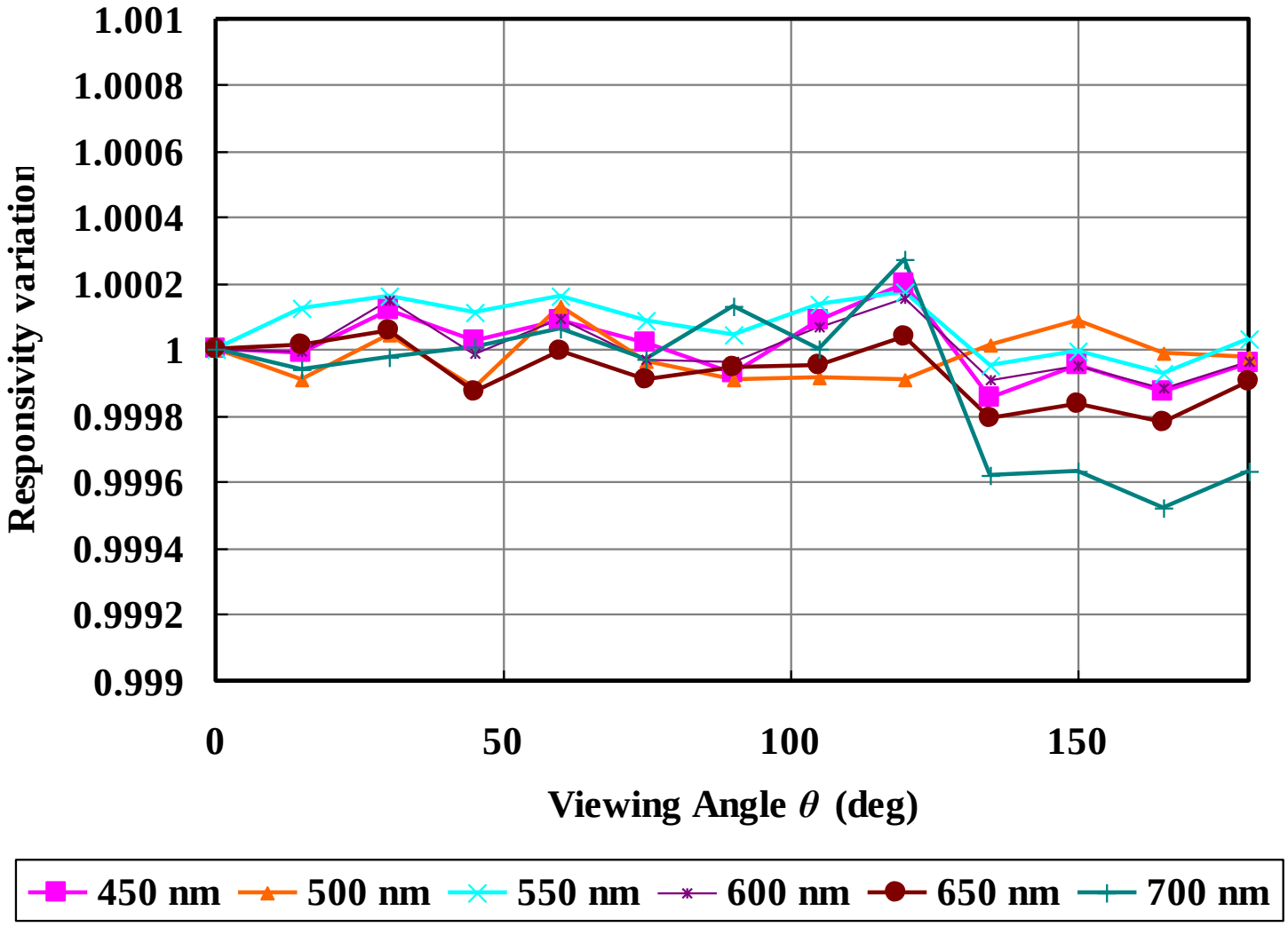
Stray-light error vs lamp CCT



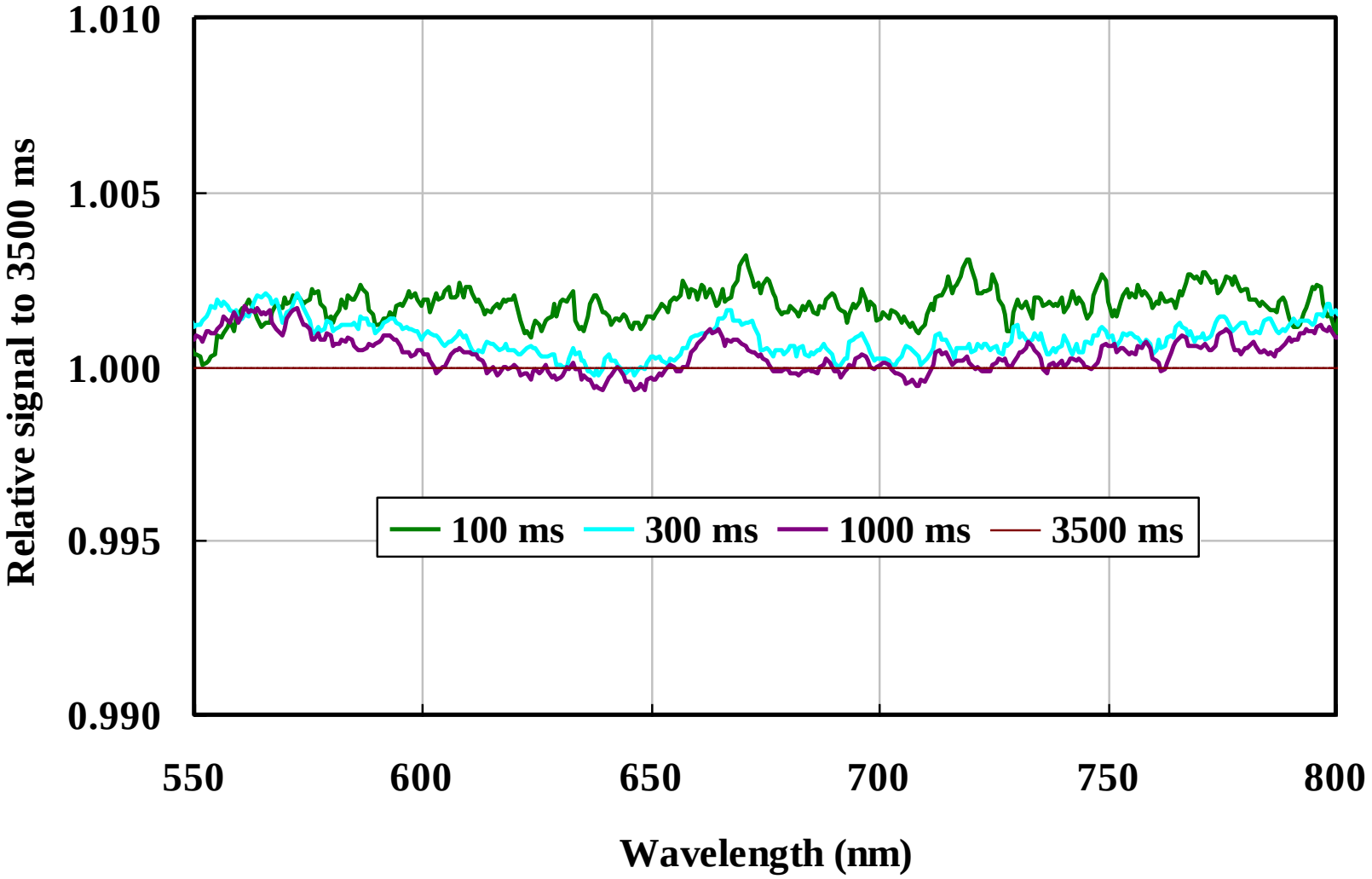
Stray-light error in calibration results (for a 3200 K test lamp)



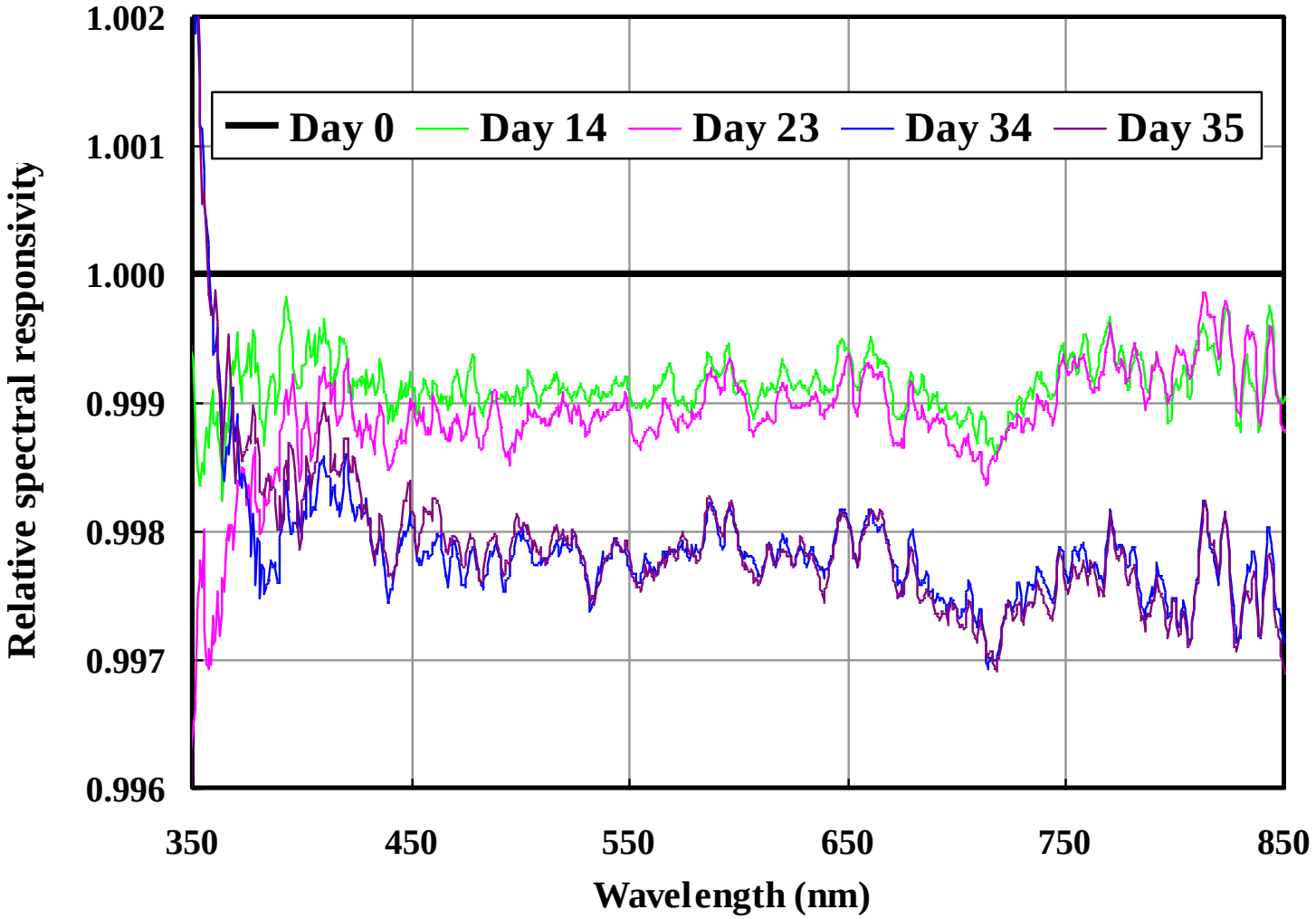
Spectral responsivity vs viewing angle



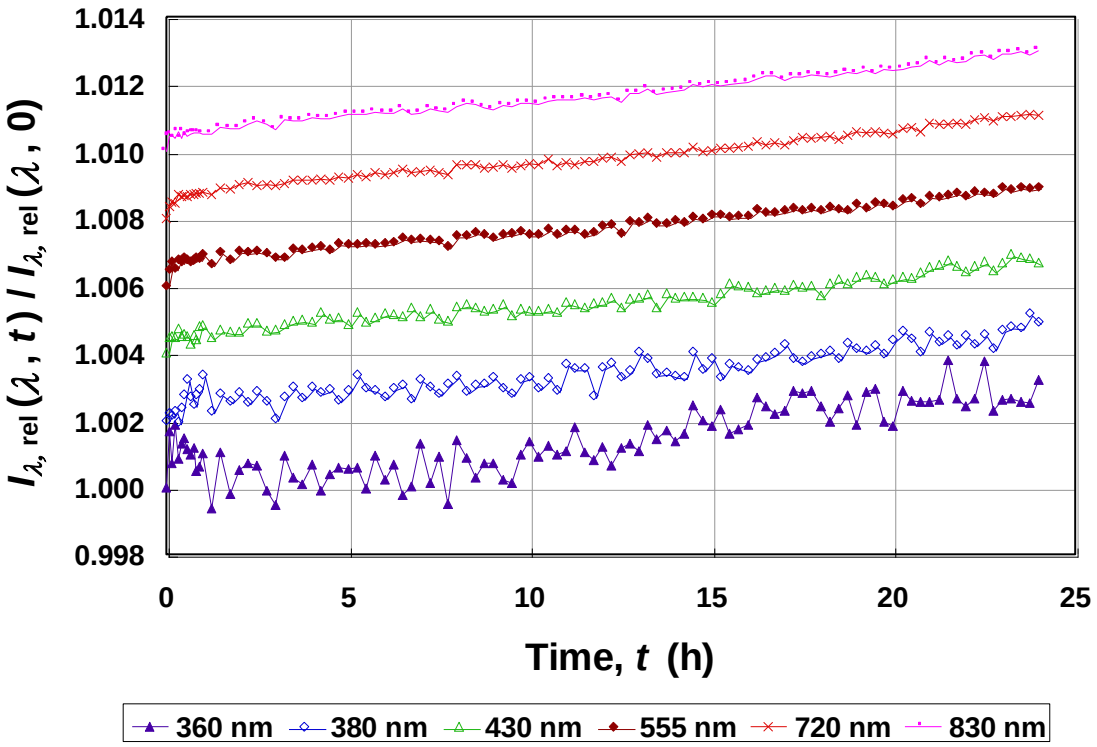
Signal nonlinearity of the array spectroradiometer

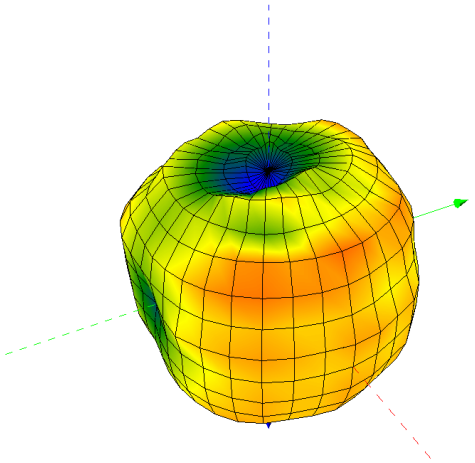


Stability of the gonio-spectroradiometer



4π TSRF standard





Aging curves of radiant intensity at 3100 K CCT at six wavelengths.

NIST 4π TSRF standard

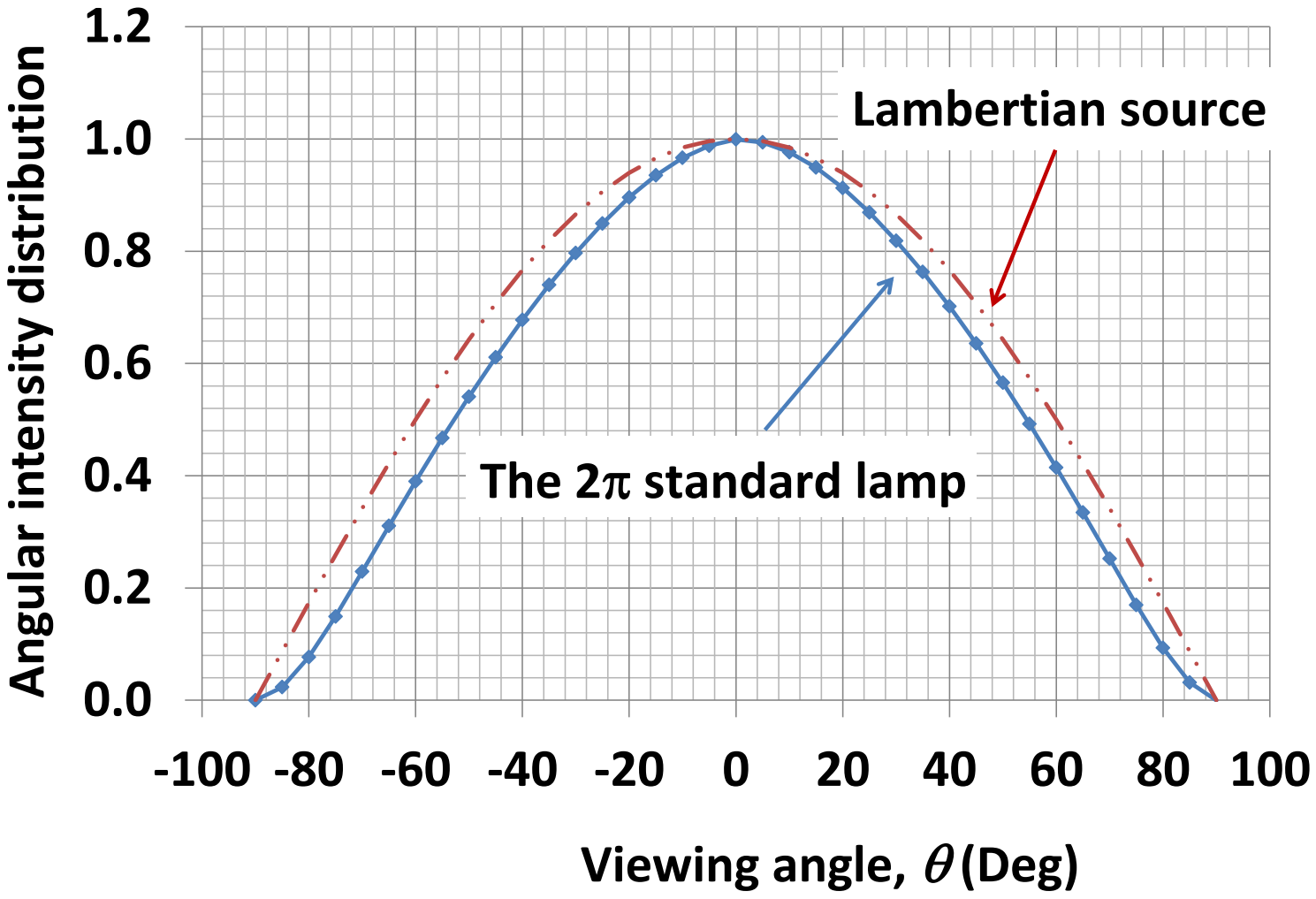
- 75 W, 28 V, 3100 K QTH lamp
- First developed in 2006

The newly developed 2π TSRF standard

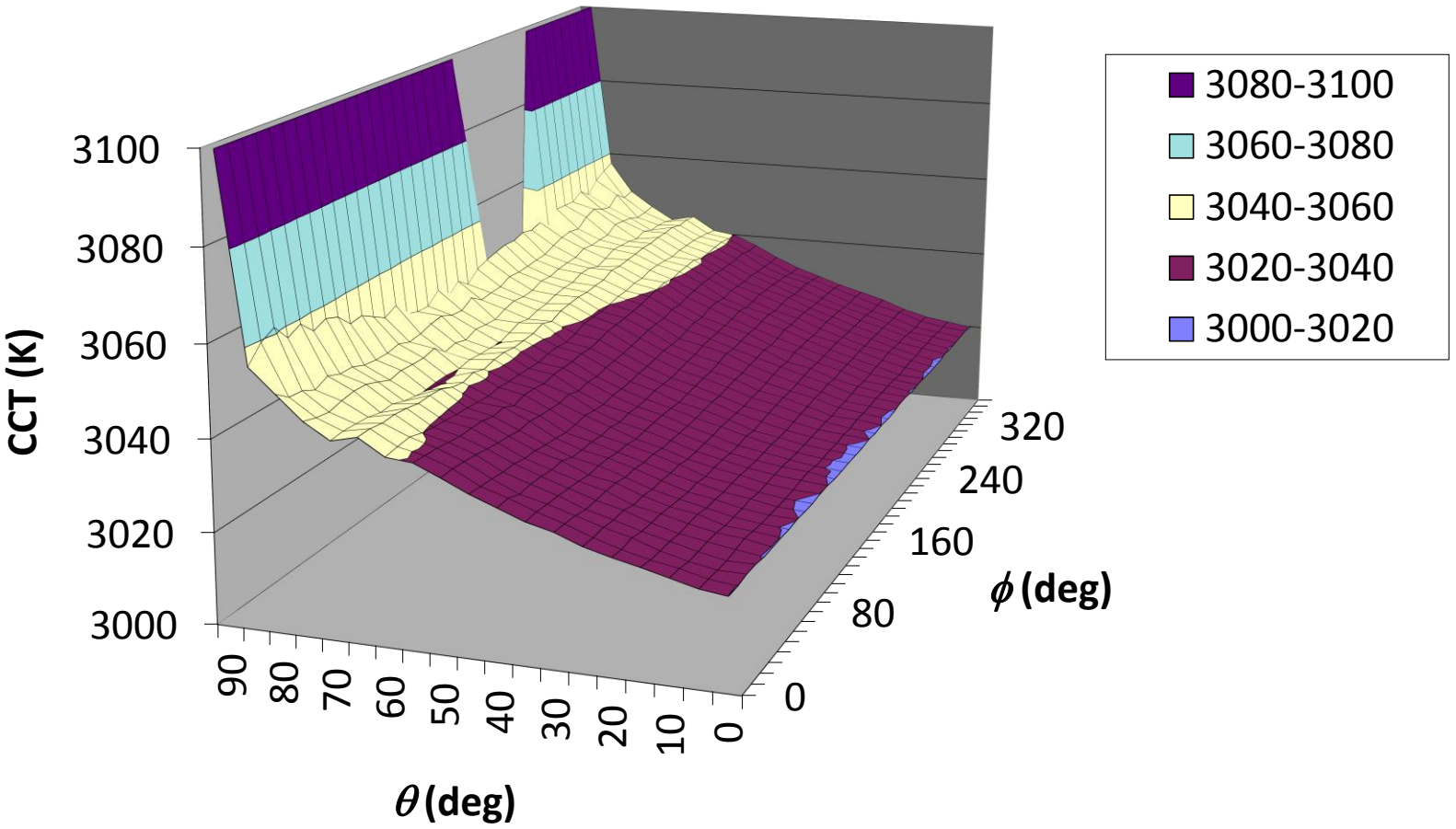
First 2π standard

- 20 W, 12 V, 3000 K reflector halogen lamp
- Modified for a near Lambertian beam pattern

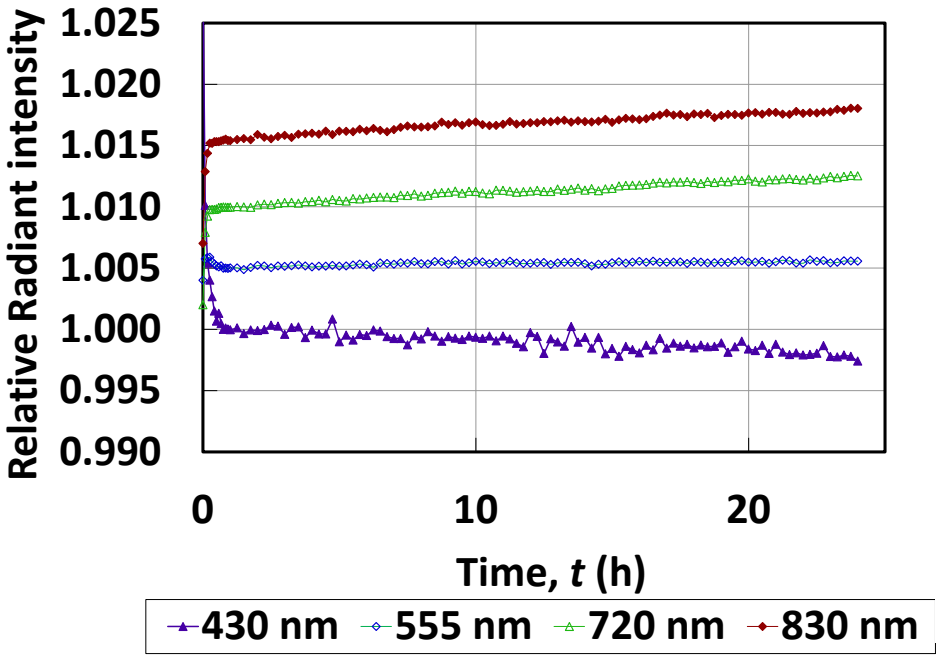
Measured beam profile of the 2π TSRF standard



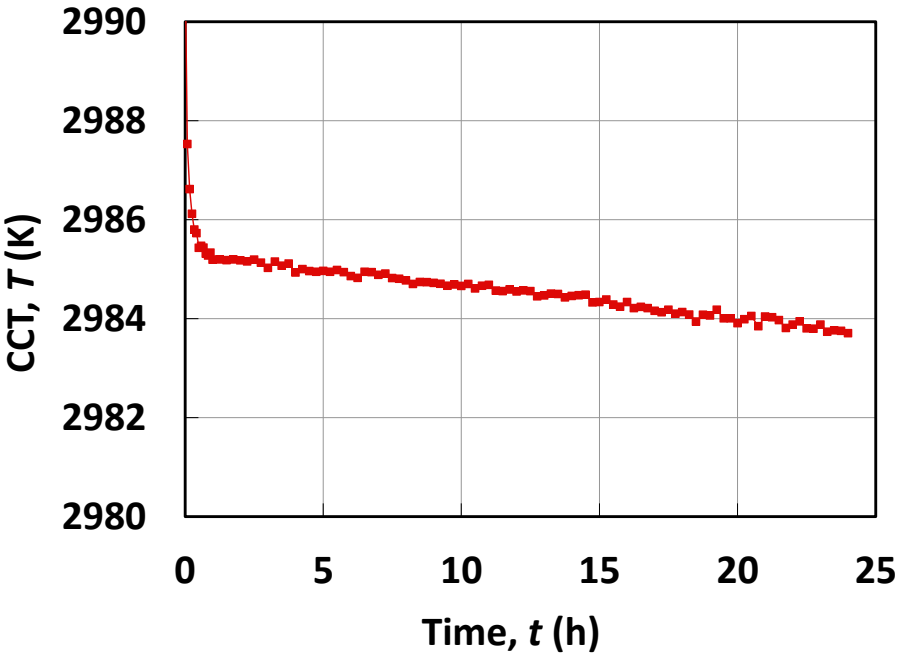
Measured CCT of the 2π TSRF standard



Aging rate of the 2π TSRF lamp

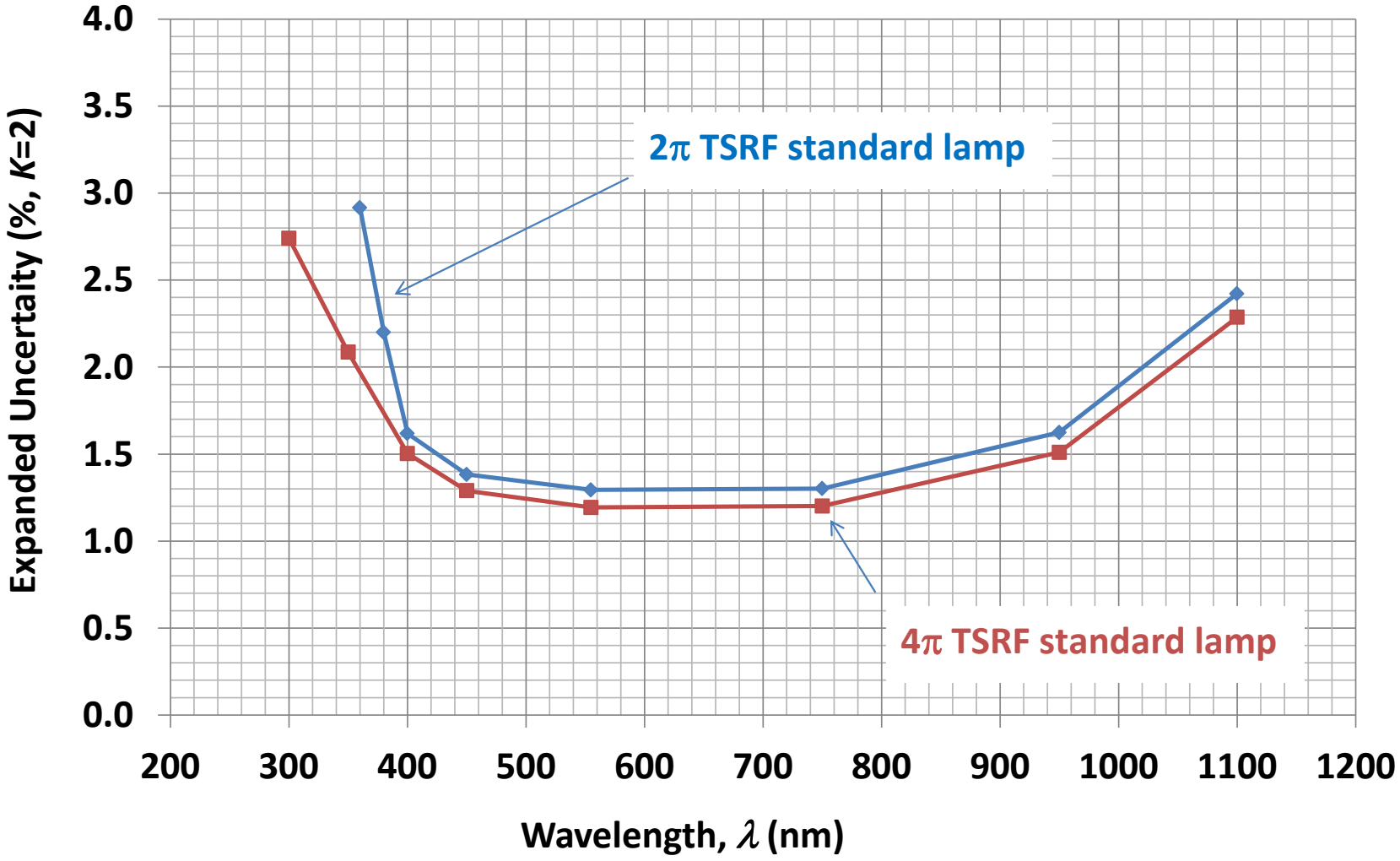


Aging curves of spectral radiant intensity at 430 nm, 555 nm, 720 nm, and 830 nm over 24 h operation time.

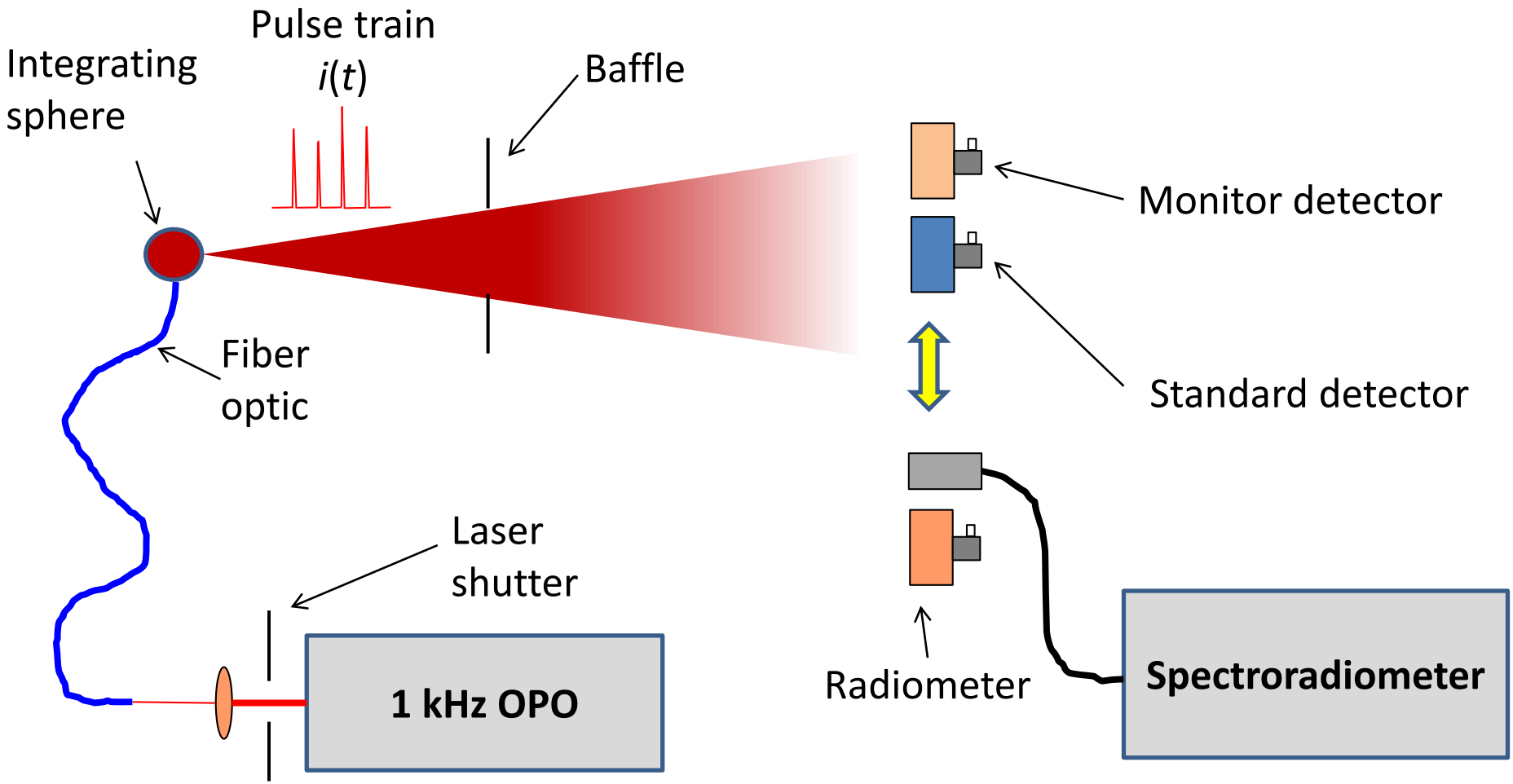


Aging of CCT over 24 h operation time

Uncertainty of NIST TSRF standard lamps



Calibration of sensors using tunable kHz OPO



- **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 2π 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

[1] ZONG, Y. and OHNO, Y. 2007. Realization of total spectral radiant flux scale and calibration service at NIST. CIE 26th Session – Beijing 2007, D2 179-182.

[2] OHNO, Y. and ZONG, Y. 1999. Detector-Based Integrating Sphere Photometry, Proc., 24th Session of the CIE, 1999, 1, Part 1, 155-160.

[3] YOON, H. W., GIBSON, C. E., and BARNES, P. Y. 2002. Realization of the National Institute of Standards and Technology detector-based spectral irradiance scale, Appl. Opt., 2002, 41, 5879-5890.

[4] ZONG, Y., BROWN, S. W., JOHNSON, B. C., LYKKE, K. R., and OHNO, Y. 2006. Simple spectral stray light correction method for array spectroradiometers, Appl. Opt., 2006, 45, 1111-1119.

Thank you