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Development of new reference photometers

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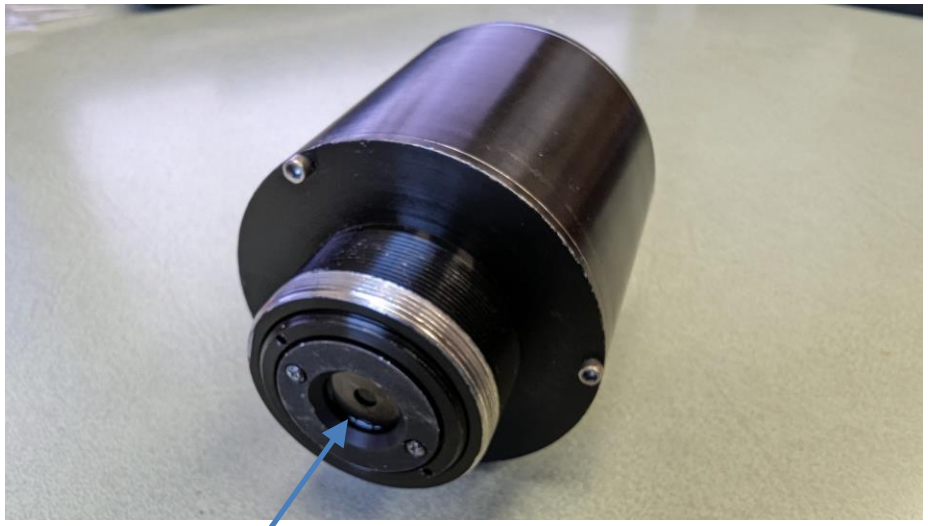
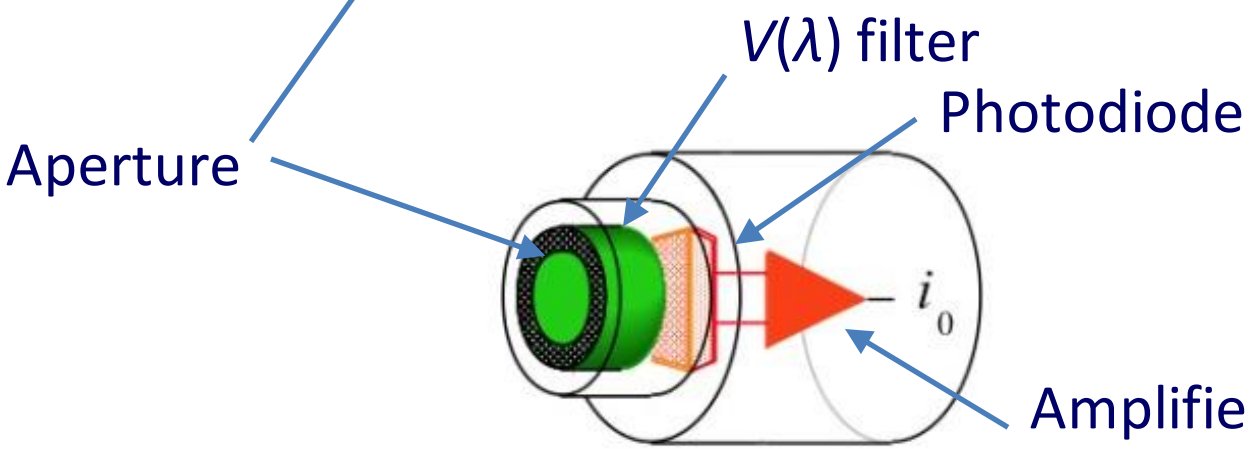
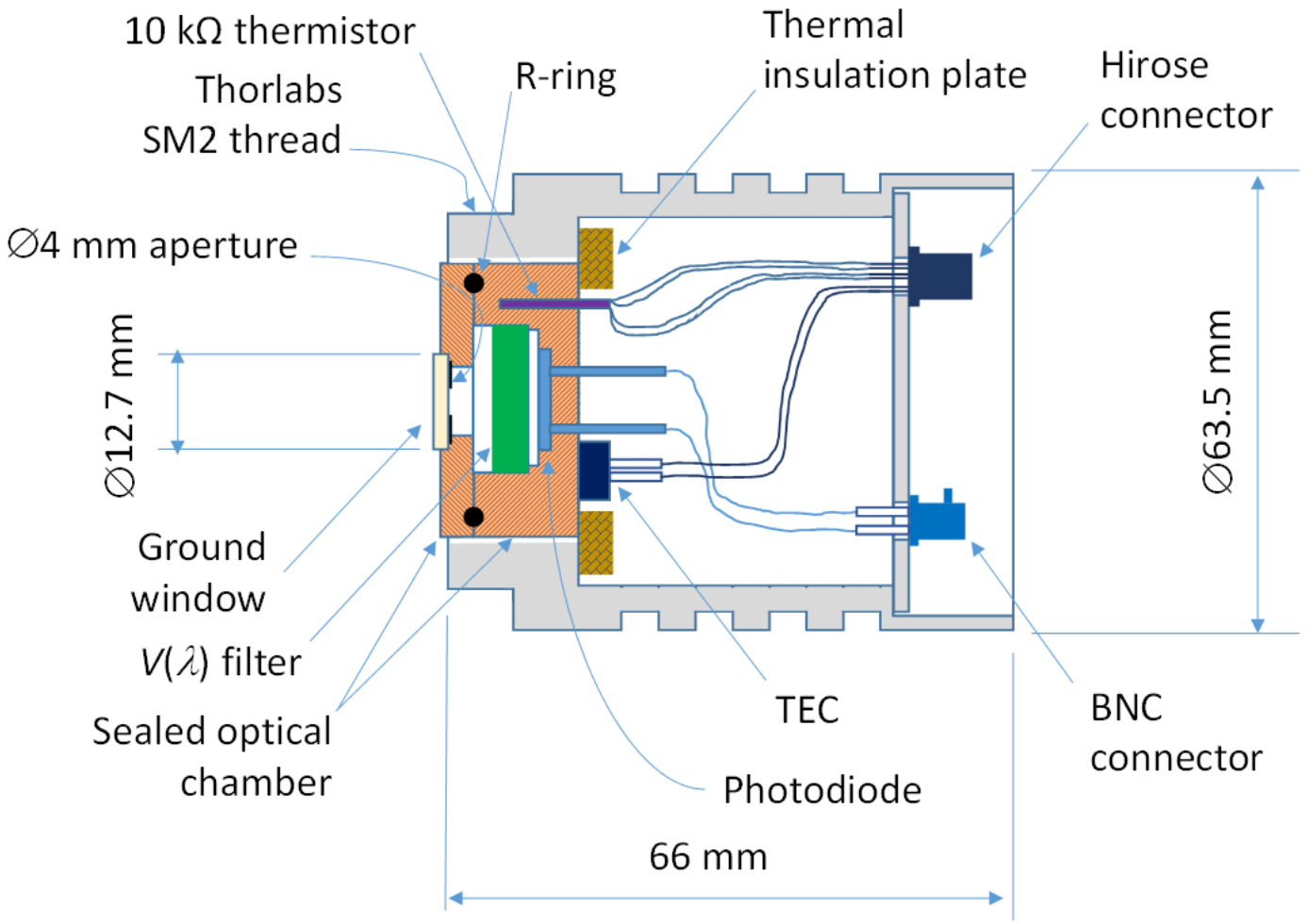
1. Issues with conventional photometers





- Interference fringes when using a tunable-laser-based calibration facility, which limits achievable uncertainty.
- Susceptible to environment conditions such as ambient temperature, dust, and moisture, etc.

2. Design of the new reference photometer



Photometer head

- Ground fused silica window
- Ø4 mm aperture
- Ø20 mm $V(\lambda)$-matching filter
- 10 × 10 mm^2 Si photodiode

- Sealed optical chamber
- Filled with nitrogen gas
- Temperature-controlled (25 °C)

- 5 GΩ shunt resistance for
  - low drift,
  - low dark current,
  - low noise,
  - negligible nonlinearity.

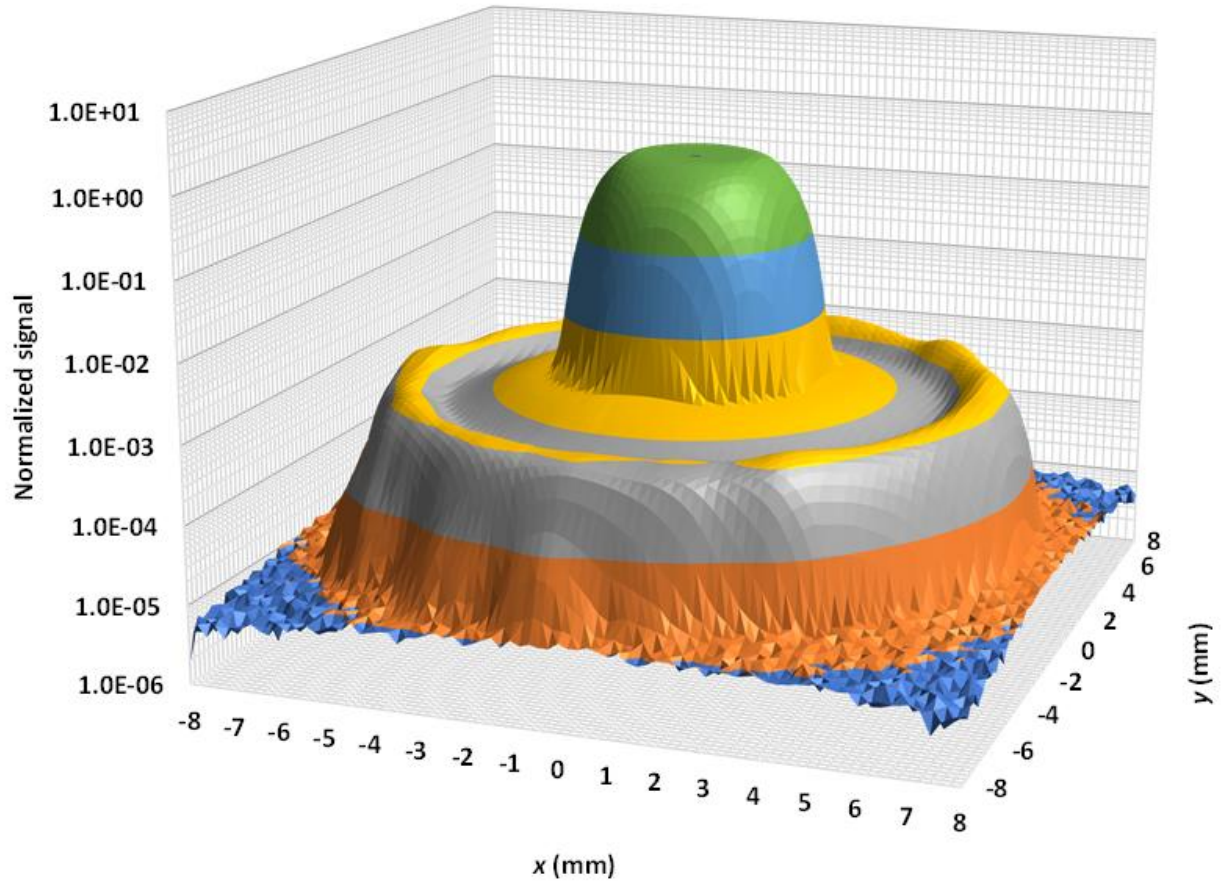
Photometer accessories

- Low noise amplifier cable
- High accuracy transimpedance amplifier
- Temperature controller

* Certain commercial equipment, instruments, or materials are identified in this paper to specify the experimental study adequately. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

3. Characterization of the reference new photometer

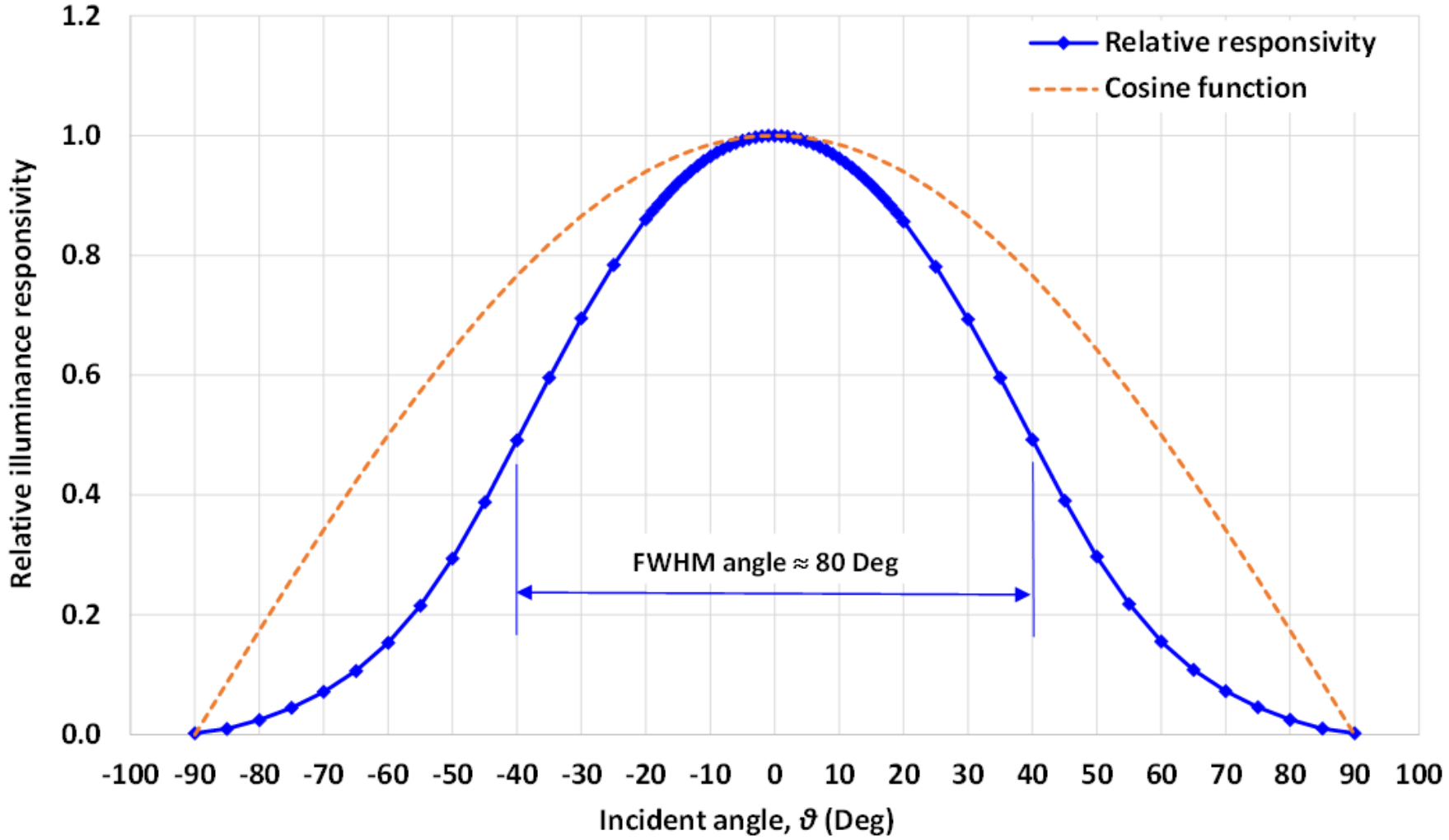
3.1 Spatial response



- The total responses from the outside Ø4 mm aperture is approximately 0.5 %, which is due to the ground glass window.
- Photometer head shall be overfilled over Ø16 window area.

3. Characterization of the reference new photometer

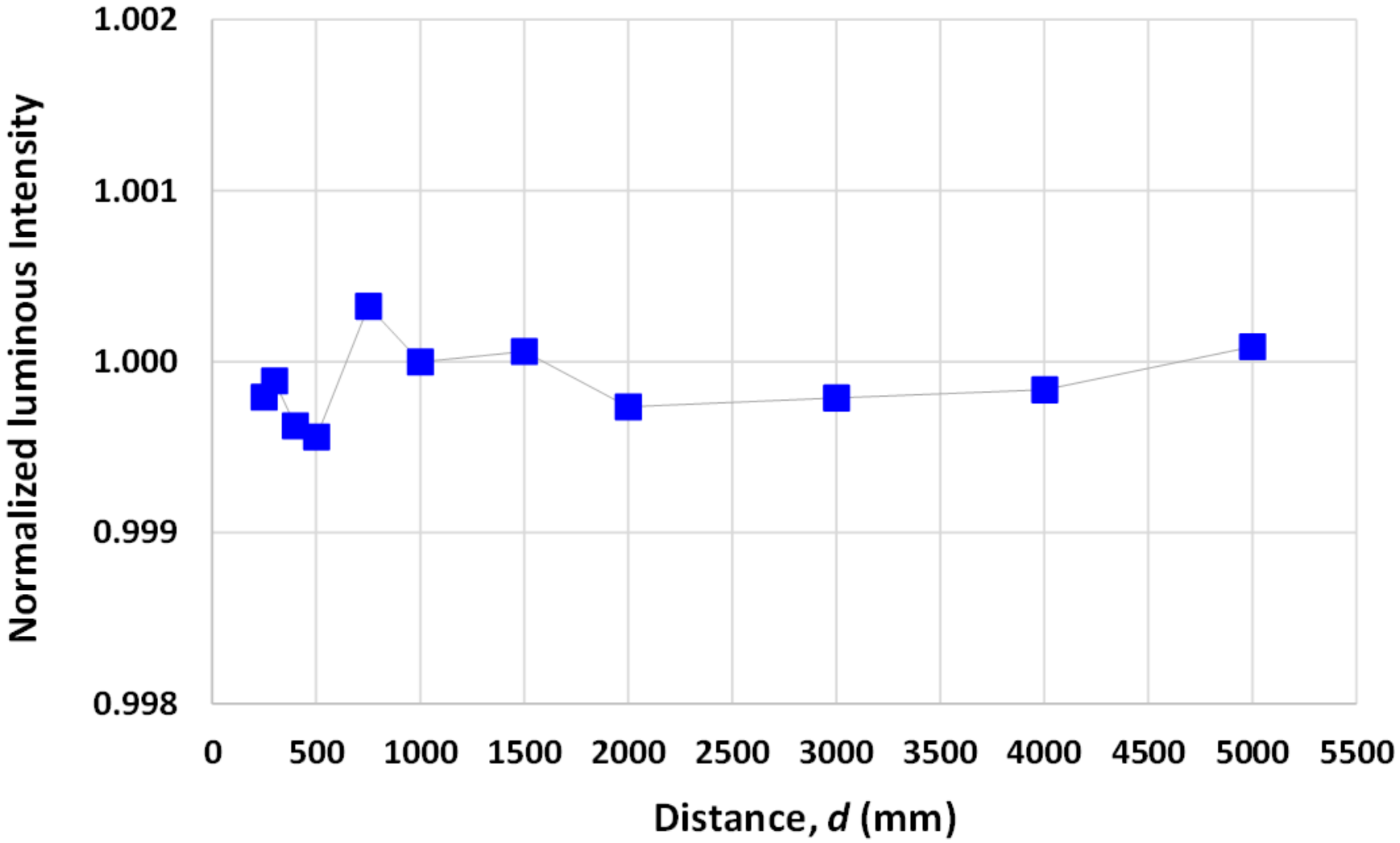
3.2 Directional response



The full wave at half maximum (FWHM) angle, ϑ, is approximately 80 degrees.

3. Characterization of the reference new photometer

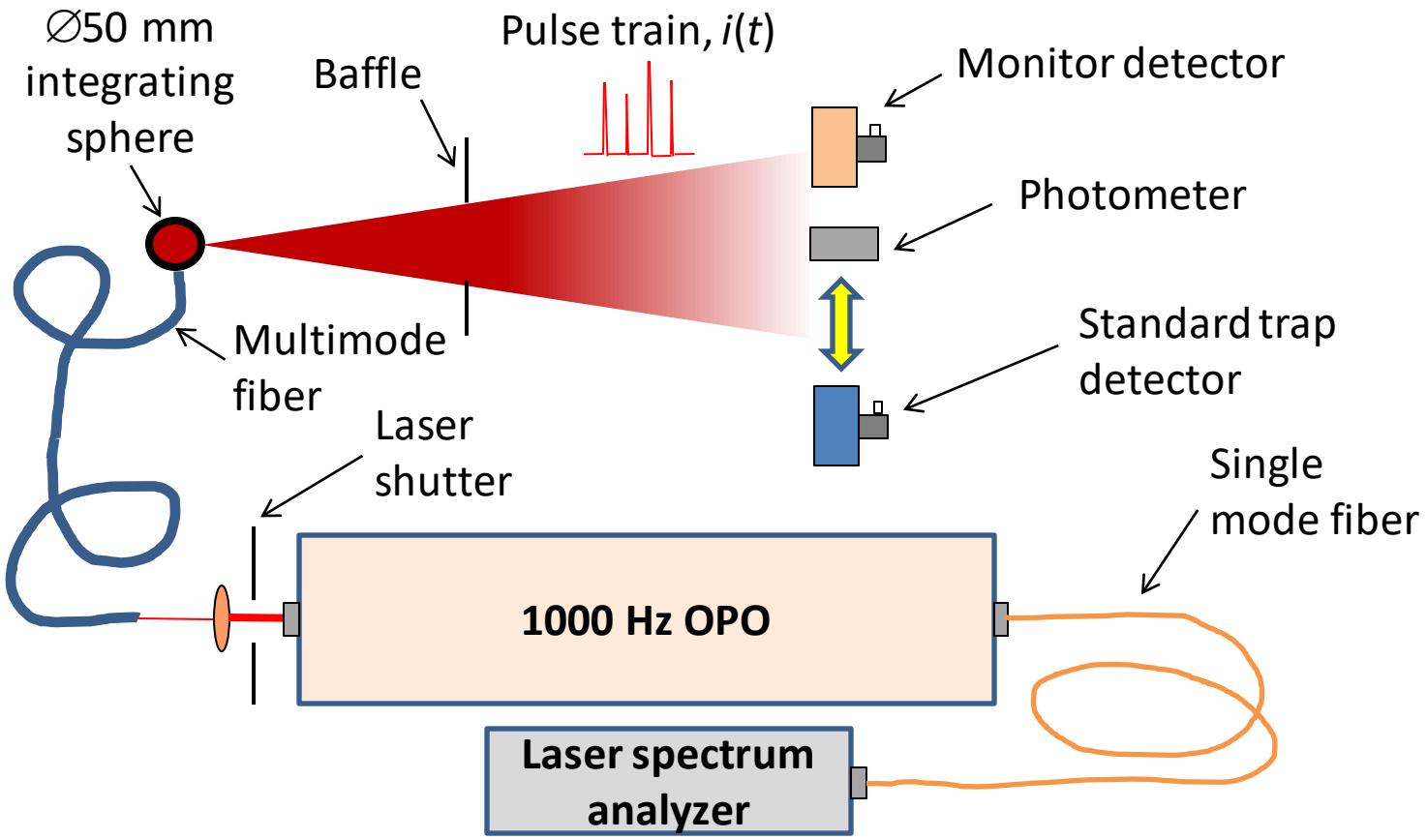
3.3 Inverse square law

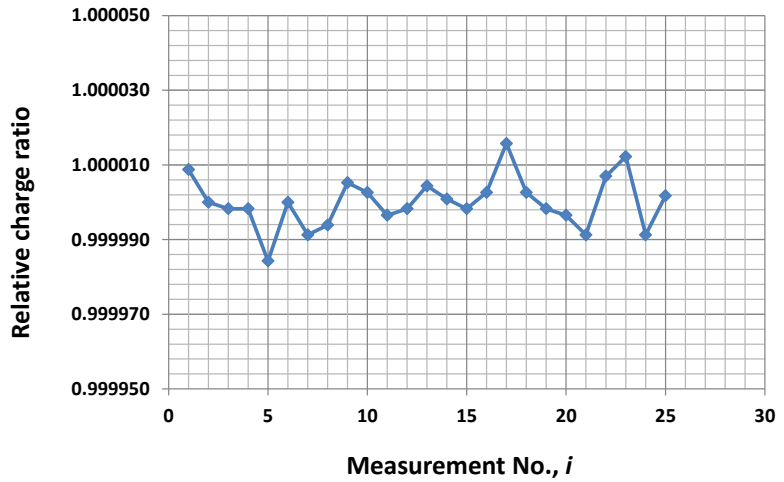


The measured illuminance follows the inverse square law within +/- 0.05 % from 0.25 m to 5 m.

4. Calibration of the reference new photometer

4.1 Detector calibration laboratory using automated pulsed lasers



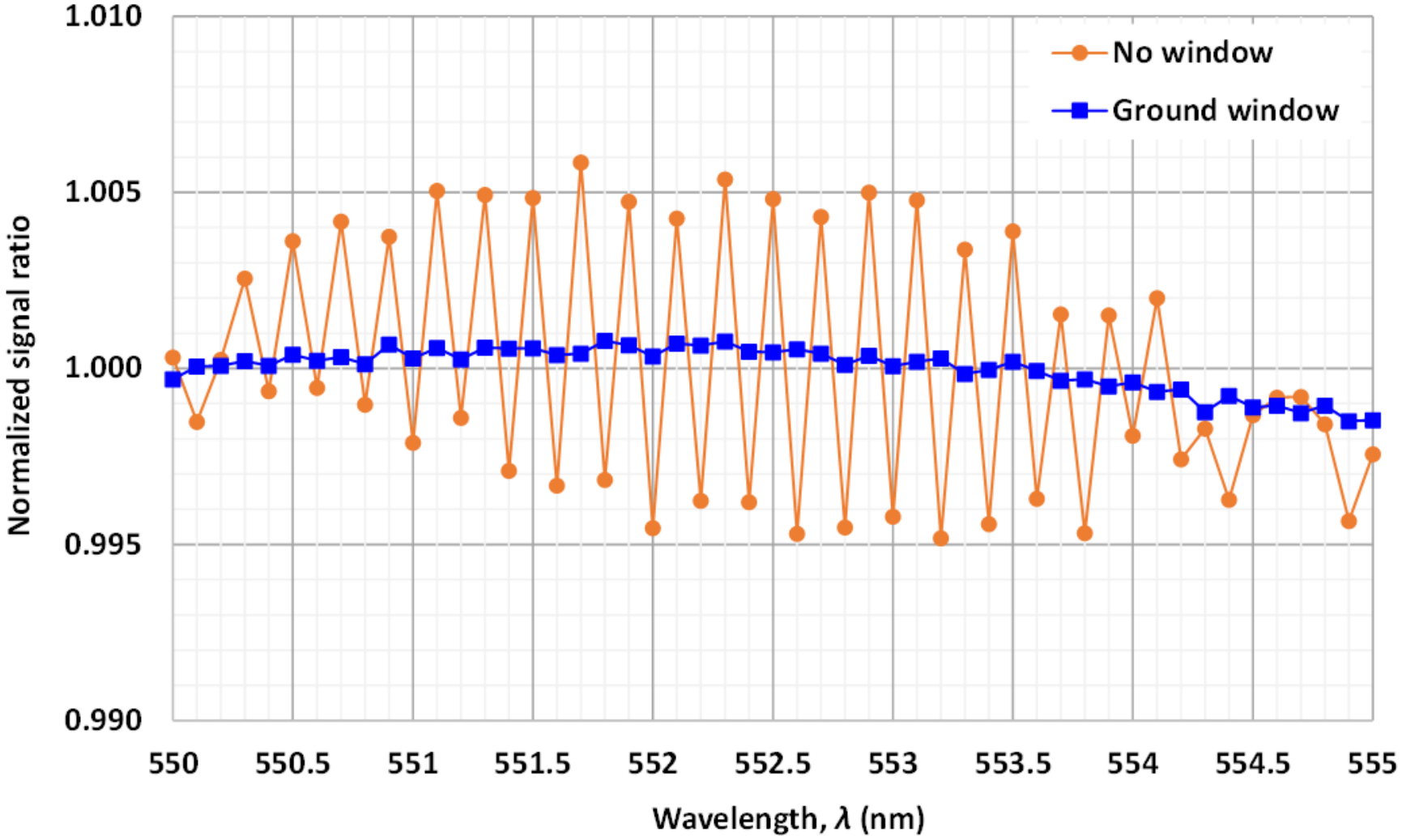


- Use energy mode (dose) instead of power mode.
- Use charge amplifiers instead of trans-impedance amplifiers.

Measurement repeatability

4. Calibration of the reference new photometer

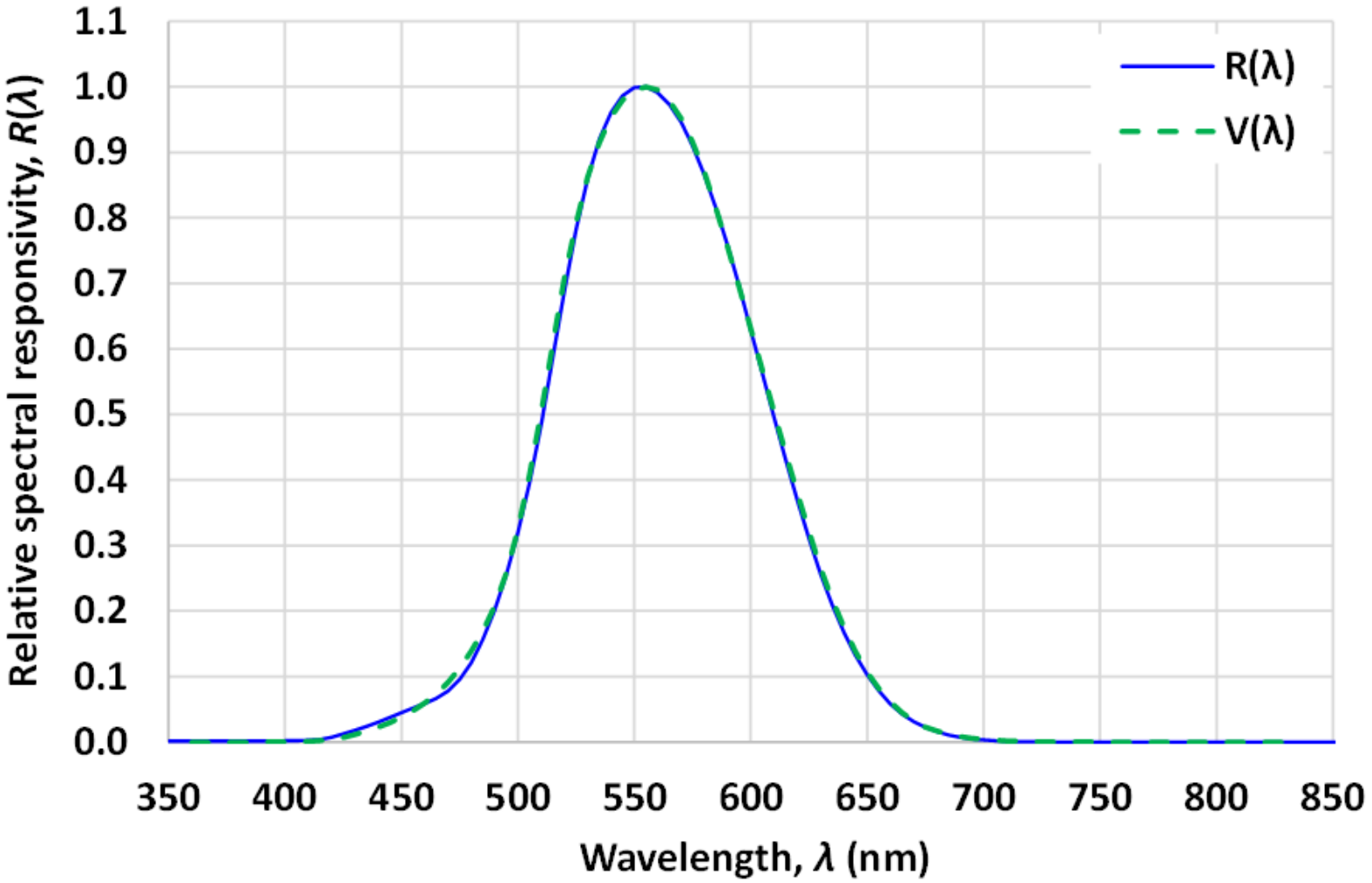
4.2 Effect of laser interference fringes



The ground glass window reduces the effect of laser interference fringes from ±0.5 % to a negligible level.

4. Calibration of the reference new photometer

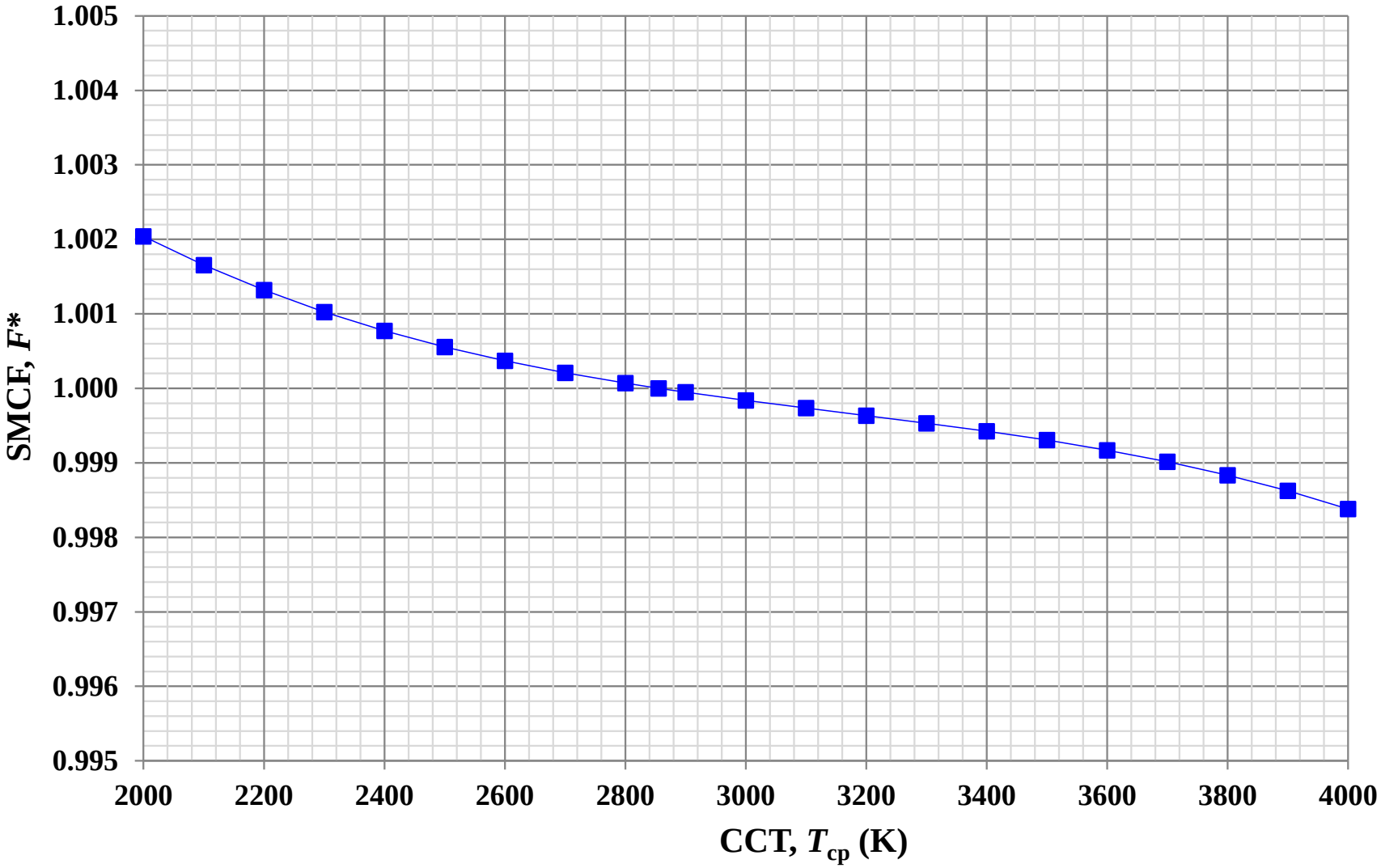
4.3 Relative spectral irradiance responsivity



- The f_1' is 1.83 %.
- The expanded uncertainty (k = 2) of the absolute illuminance responsivity is 0.20 %.

4. Calibration of the reference new photometer

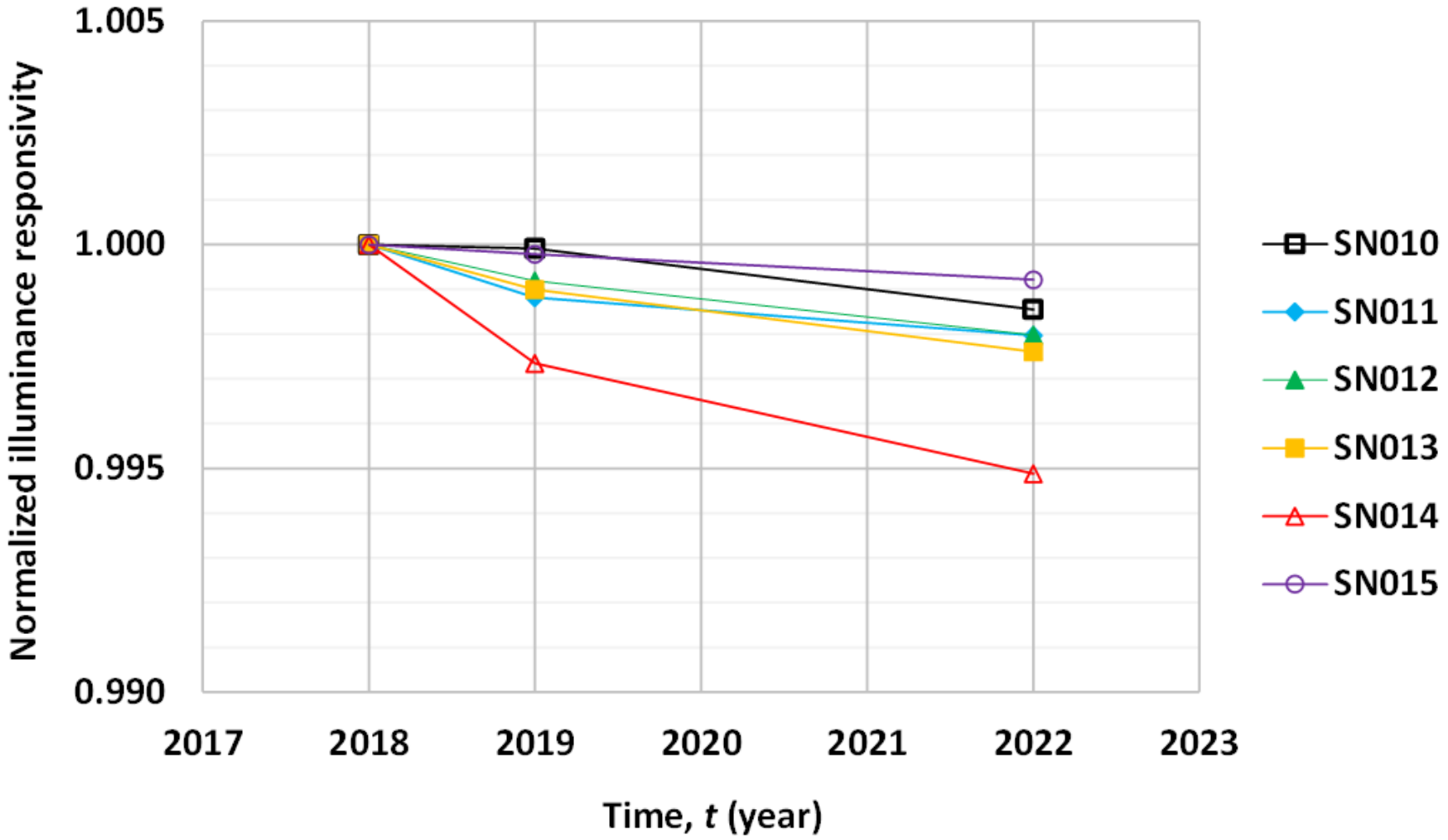
4.4 SMCF, F^*, from CCT, T_{cp}, 2000 K – 4000 K



From 2600 K to 3200 K, the spectral mismatch error is within 0.04 % if it is not corrected.

4. Calibration of the reference new photometer

4.5 Long-term stability



The long-term stability of illuminance responsivity is 0.05 % (or less) per year except that of the photometer head SN014 which is 0.1 % per year.

4. Calibration of the reference new photometer

4.6 Calibration uncertainty

	Type	Relative standard uncertainty at selected wavelengths, λ (nm)									
		380	400	450	500	555	600	650	700	750	780
1. The standard trap detector	B	0.220	0.170	0.121	0.042	0.042	0.042	0.042	0.043	0.045	0.048
2. Calibration of the photometer using pulsed OPO	A	0.111	0.090	0.074	0.076	0.074	0.075	0.075	0.206	1.22	23.2
3. Long-term stability of the photometer (1 year)	A	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Combined uncertainty (%)		0.25	0.20	0.15	0.10	0.10	0.10	0.10	0.22	1.2	23
Expanded uncertainty (k=2) (%)		**0.50**	**0.40**	**0.30**	**0.20**	**0.20**	**0.20**	**0.20**	**0.43**	**2.5**	**46**

5. Summary

- A new generation of reference illuminance photometers were developed for realization and maintenance of the SI base unit – the candela.
- These photometers have a negligible interference fringe effect, therefore, can be calibrated directly against standard trap detectors using tunable lasers.
- The expanded uncertainty of the illuminance responsivity was reduced from approximately 0.50 % (k = 2) to 0.20 % (k = 2).
- The photometers are sealed and temperature-controlled for superior short-term and long-term stabilities.
- The new reference photometer is currently available as a standard reference instrument - SRI 6013.

  https://www.nist.gov/sri/standard-reference-instruments/sri-6013-standard-reference-optical-radiometer
- Luminance photometers, irradiance, and radiance radiometers have also been developed.

Reference

Yuqin Zong, Robin Teitzel, Jeanne Houston, Cameron Miller, "*New generation of reference photometers for reduced uncertainty*," 30th Session of the CIE, Ljubljana, Slovenia, **CIE X050-2023**, p1039 –p1048. (2023)

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Thank you