International Energy Agency

4E – Energy Efficient End-use Equipment

Solid State Lighting Annex

IC 2017 – Interlaboratory Comparison of Goniophotometers

Topic	Results from Interlaboratory Comparison of Goniophotometers - IC 2017 (This webinar is for the Australian/Asian time zone)
Description	Dr. Yoshi Ohno, NIST Fellow at the National Institute of Standards and Technology will present the key results and findings from the IEA 4E SSL Annex's 2017 Interlaboratory comparison (IC 2017). With 36 participating laboratories from 19 countries with a total of 42 goniophotometric instruments, this is the largest interlaboratory comparison of such equipment ever undertaken. This comparison sought to answer many questions of importance for laboratories as well as for policy makers involved in performance regulations and enforcement. Two identical presentations will be offered, one for the Australian/Asian time zone and one for the European/North American. Both events will be recorded and the recordings will be posted on the SSL Annex website. Note: This webinar is for the Australian/Asian time zone.
Time	Jan 25, 2022 01:00 PM in Canberra, Melbourne, Sydney

Solid State Lighting Annex
Energy Efficient End-use Equipment
International Energy Agency

International Energy Agency
4E – Energy Efficient End-use Equipment
Solid State Lighting Annex

Members (Country governments)

Australia, Canada, Denmark, France, Republic of Korea, Sweden, United Kingdom (Sept. 2021)

Objective: Promote solid-state lighting worldwide for energy saving and quality assurance of products

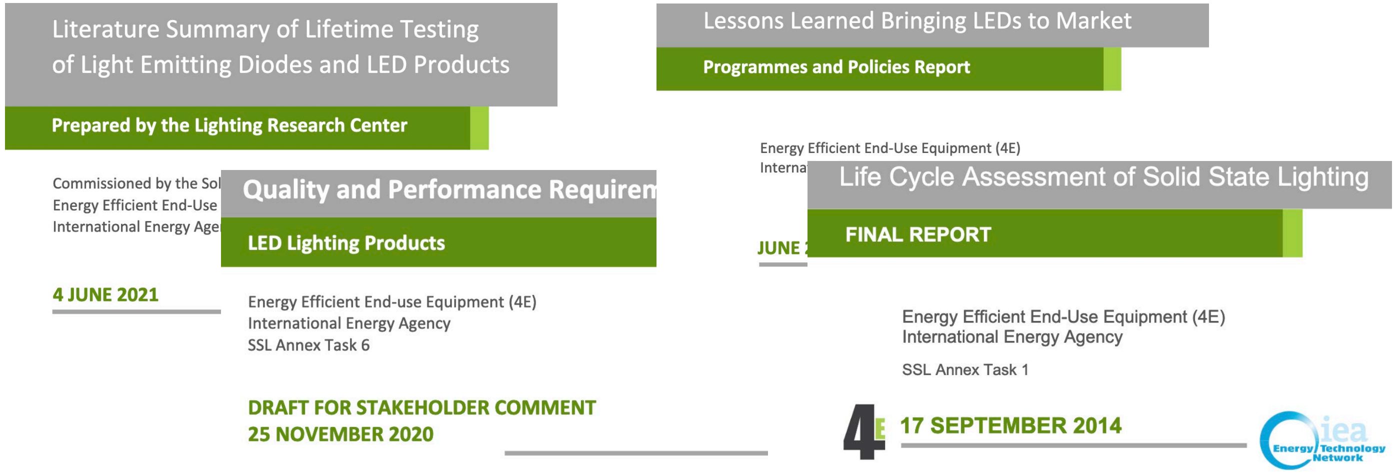
Phase I (2010 – 2014)
Phase II (2014 – 2019)
Phase III (2019 – 2024)

http://ssl.iea-4e.org/

Current Tasks

- **Interlaboratory comparison (IC 2017)**
- Task 1. Human Centric Lighting – Health and Comfort
- Task 2. Lifetime of SSL Lamps and Luminaires
- Task 3. Lighting and Environment
- Task 4. Interlaboratory Comparison of Temporal Light Modulation
- Task 5. Test Methods and Performance Metrics
- Task 6. Quality and Performance Tiers
- Task 7. Smart Solid State Lighting
- Task 8. Database of SSL Products Performance

20 reports published since 2012



Dr. Yoshi Ohno, NIST

- Active in SSL Annex since 2010
- Served as Task Leader for IC 2017 goniophotometer comparison, today's presentation
- Yoshi received his Ph.D. in Engineering from Kyoto University, Japan.
- Since 1992, Yoshi has been working at National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, USA
- Yoshi served as a Group Leader at NIST Optical Technology Division then (now a part of Sensor Science Division) from 2003 to 2012, and is a NIST Fellow since 2010
- He has been very active in international standardization work.
- Since 2007, he served as CIE Division 2 Director, Vice President-Technical, and CIE President for 2015-2019 term.
- Chaired several CIE TCs and led development of CIE S 025 among other CIE publications.
- Active in Consultative Committee for Photometry and Radiometry (CCPR) and chaired CCPR Working Group on Key Comparisons from 2006 to 2018
- Yoshi is a Fellow of Illuminating Engineering Society (IES) and led development of IES LM-79 and LM-85 test methods for SSL products and high-power LEDs, and also ANSI C78.377 (Chromaticity specifications for SSL products).
- He received several awards including CIE de Boer Gold Pin award, US Dept. of Commerce Silver medal award, and US Dept. of Energy SSL Visionary award.

Solid state Lighting Annex
Energy Efficient End-use Equipment
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SSL Annex Webinar Series
January 25, 2022

2017 Interlaboratory Comparison of Goniophotometers Measuring Solid State Lighting Products (IC 2017) – Final Report

Yoshi Ohno
SSL Annex IC 2017 Task Leader,
National Institute of Standards and Technology, USA

Collaborators

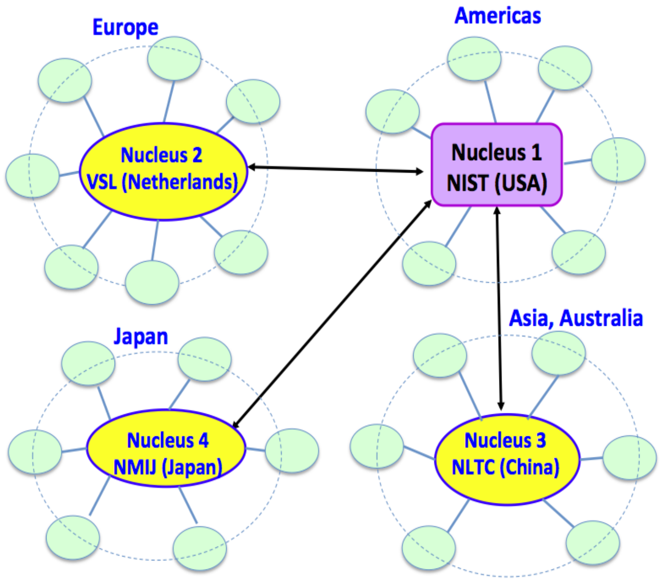
Jean Gaudemer	SSL Annex IC 2017 Nucleus Laboratory Expert, Laboratoire national de métrologie et d'essais (LNE), France
Jun Seok Oh	SSL Annex IC 2017 Nucleus Laboratory Expert, Korea Institute of Lighting and ICT (KILT), Republic of Korea
Jimmy Dubard	SSL Annex IC 2017 Nucleus Laboratory Leader, Laboratoire national de métrologie et d'essais (LNE), France
Sangkyoo Jeon	SSL Annex IC 2017 Nucleus Laboratory Leader, Korea Institute of Lighting and ICT (KILT), Republic of Korea
Michael Scholand	IEA 4E SSL Annex, Operating Agent Support, London, UK

SSL Annex Prior Interlaboratory Comparison (IC 2013)

for measurement of SSL products

Had **54 labs** participating from **18** countries.
Additional **56 labs** results from NIST NVLAP PT and APLAC T088 PT program linked

Total 110 labs' measurements of SSL products compared



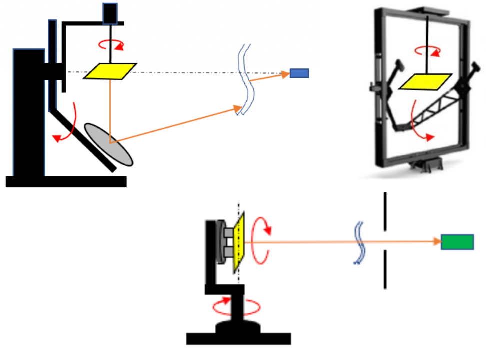
- **Comparison Artefacts**
  Four types of LED lamps -omni-directional, directional, low power factor, and high CCT, plus incandescent lamp

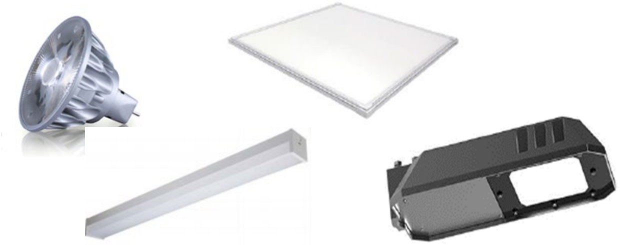
- **Quantities** measured:
  - luminous flux
  - luminous efficacy
  - active power
  - RMS current
  - power factor
  - chromaticity x, y
  - CCT
  - CRI

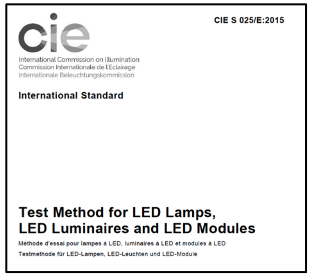
Link to IC 2013 Final Report

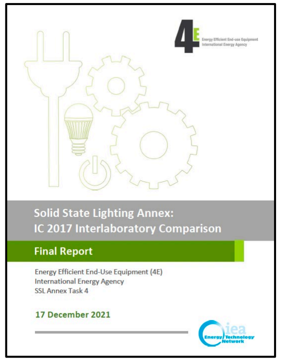
2017 Interlaboratory Comparison of Goniophotometers (IC 2017)
for measurements of SSL products

- Launched in July 2017 (thus, called **IC 2017**).
- **Instruments: goniophotometers only,** three different types (mirror-rotating type, near-field type, source-rotating type) were included
- **Artefacts: 3 LED luminaires + narrow-beam LED lamp**
- **Measurement quantity: 16 quantities including 8 goniophotometric quantities**
- **Participants: 36 labs** from **19 countries** participated with a total of **42 goniophotometers** (gonio-spectroradiometers)
- **Test method: CIE S 025**
- The comparison was designed in compliance with ISO/IEC 17043 to **serve as a proficiency test** for SSL testing laboratory accreditation programs
- **Summary results** presented at CIE 2021 Midterm conference (Sep. 2021)
- **IC 2017 Final Report** published on 20 December 2021







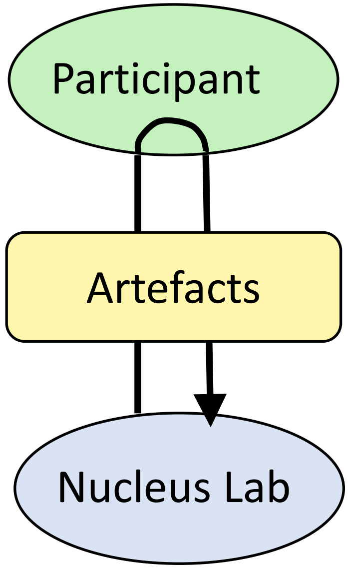


Scheme of IC 2017

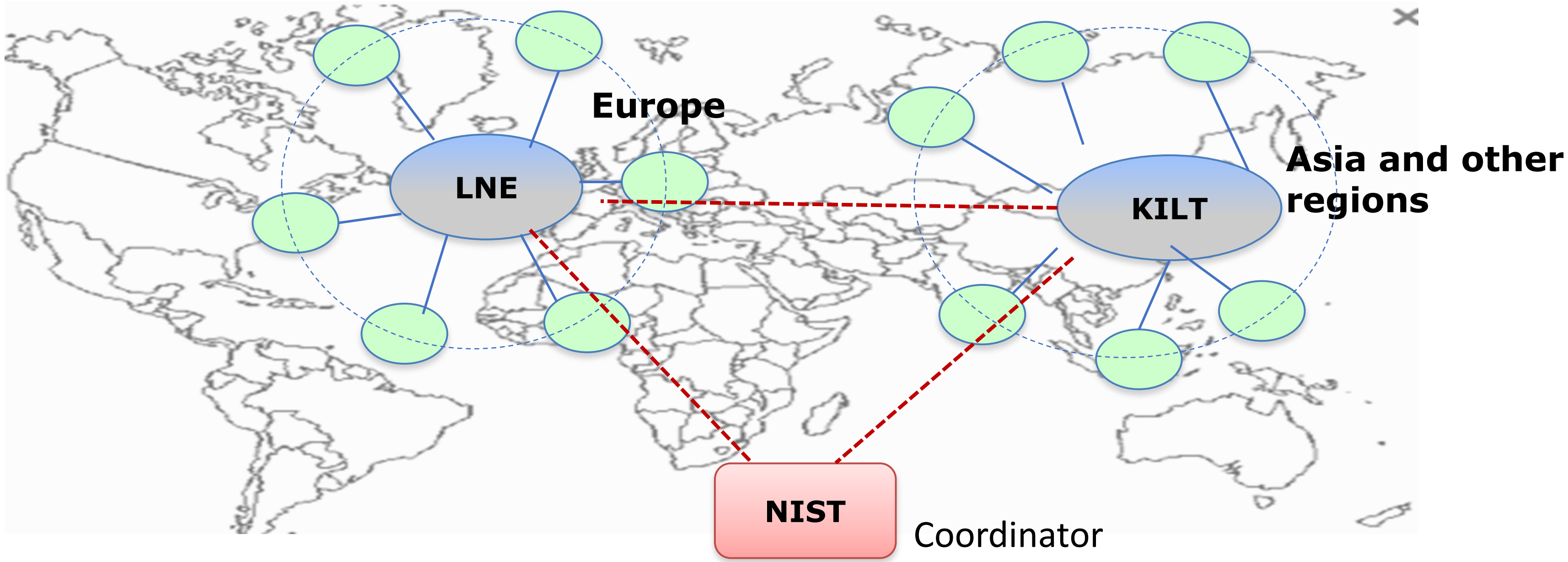
IC 2017 was carried out as a star-type comparison between participants and one of the reference laboratories (called *Nucleus Laboratories* in IC 2017)

Nucleus Laboratories

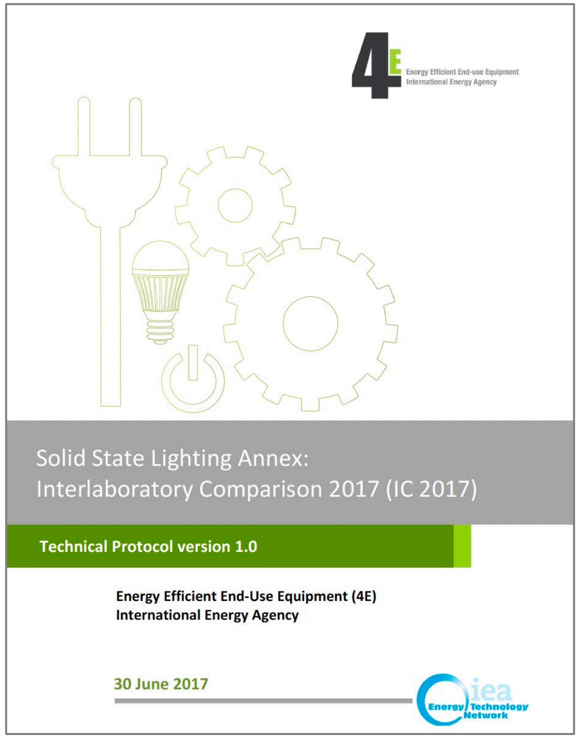
- **LNE** (Laboratoire Nationale de métrologie et d'Essais), France
- **KILT** (Korea Institute of Lighting and ICT), Republic of Korea



Measurements
<Before>
<After>



IC 2017 Technical Protocol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Solid State Lighting Annex:
Interlaboratory Comparison 2017 (IC 2017)

Technical Protocol version 1.0

Energy Efficient End-Use Equipment (4E)
International Energy Agency

30 June 2017

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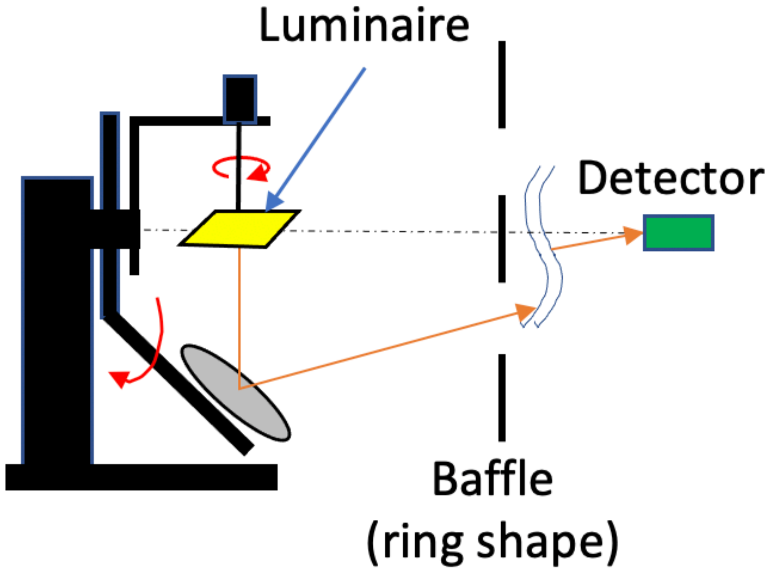
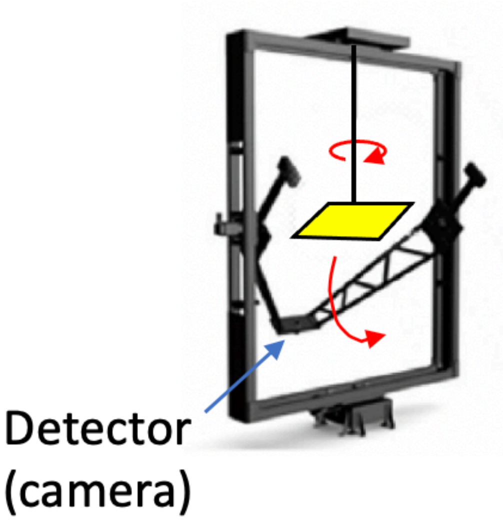
IC 2017 Technical Protocol (June 2017) provided details of

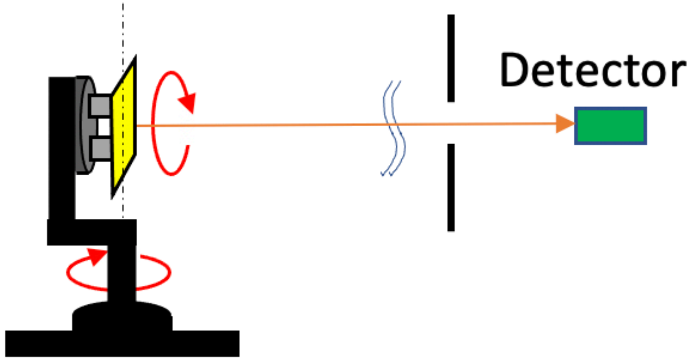
- Measurement Instruments accepted
- Comparison artefacts
- Measurement quantities
- Test Method

IEA 4E Solid State Lighting Annex: Interlaboratory Comparison 2017 **(IC 2017) Technical Protocol** version 1.0; Published: 30 June 2017. Link: https://www.iea-4e.org/wp-content/uploads/publications/2021/05/IC-2017-Technical-Protocol_v.1.0_final.pdf

Goniophotometer Types accepted in IC 2017







<Mirror type>

* Operating position of DUT kept constant
* Large dark room space required

*** Further variations of design**

<Near-field type>

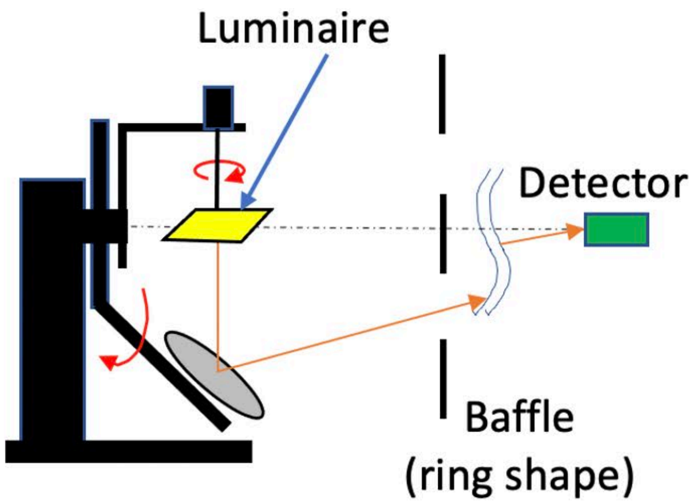
* Operating position of DUT kept constant
* Compact, requires only small space
* Verification of equivalence to a far-field goniophotometer required in CIE S 025.

<Source-rotating type>

* Requires less space, lower cost
* Operating position changes
* Correction for changes of operating position of DUT required in CIE S 025.

* Annex 1 of the Final Report provides further information.

Variations of Mirror Type Goniophotometer Design



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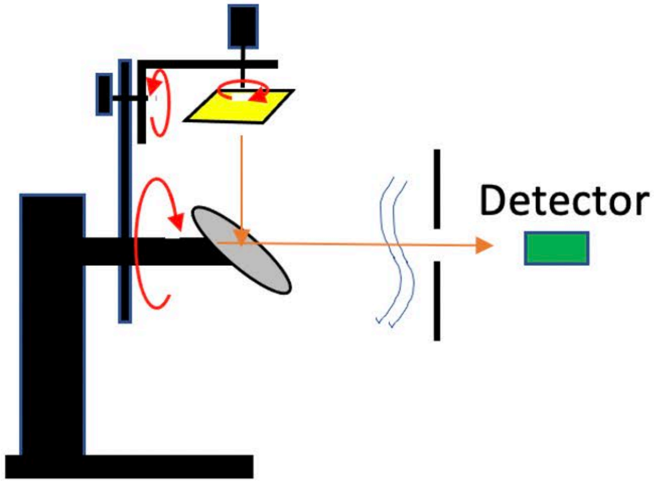
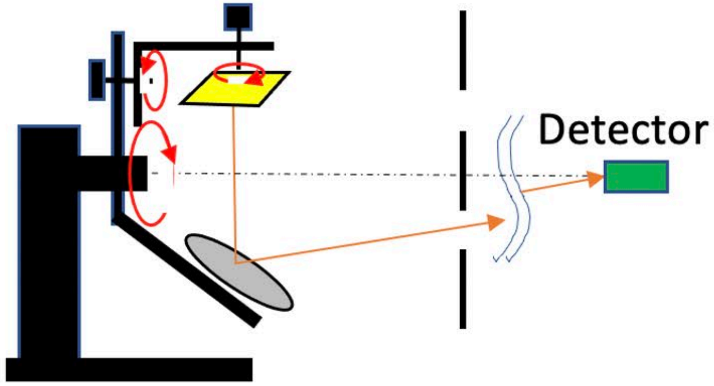


< Design 2>



< Design 3 >

* Detector position (distance) is fixed

- Detector position can be changed.
- Easier handling of stray light

- Requires less space (height) than the other two.

* Annex 1 of the Final Report provides further information.

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Goniophotometers Used by the Participants

Table 2-2. List of Goniophotometers used by the participants (alphabetical order) [1]

Goniophotometer Type	Goniophotometer Model	Count	Total
Mirror Type	EVERFINE GO-R5000	6	19
	GMS2000 SENSING INSTRUMENT	1	
	GMS3000 SENSING INSTRUMENT	1	
	Custom-made	1	
	LMT GO-DS 2000	6	
	LMT GO-DS 1600	2	
	Oxytech T4	1	
	UL/LSI 6440T	1	
Near-field Type	Custom-made	2	12
	TechnoTeam RiGO 801 (size varies)	10	
Source-rotating Type	Gerh. Döbele (modified)	1	10
	Custom-made	1	
	Instrument Systems LGS1000	2	
	LMT GO-V 1900	2	
	LMT GO-R 3060	1	
	PSI model ASG-3.0, C/gamma geometry	1	
	SSL Resource Oy, SSL C-1R.1600.2A	1	
	Viso Systems / LabSpion	1	
Other Type	Custom-made (detector rotates, source fixed)	1	1

[1] The company and product names are listed for technical information to assist in understanding the results presented in this report. They do not represent endorsement of any particular models of goniophotometer of any manufacturer, by the National Institute of Standards and Technology, by the IEA 4E SSL Annex or any of its member governments.

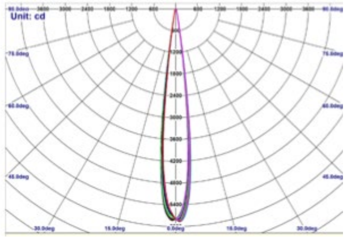
Goniophotometer type	Design	Total number
Mirror (Design 1)	Mirror rotates around luminaire	9
Mirror (Design 2)	Light source rotates around mirror	1
Mirror (Design 3)	Both mirror and lumianire rotate	8
Near-field	Near-field type	12
Source R	Source rotates with fixed detector	10
Detector R	No mirror, detector rotates, burning position kept	1

IC 2017 Comparison Artefacts

ART-1: Narrow-beam lamp (MR-16)

5 cm ϕ x 4.5 cm

12V DC
7.5 W
2700K

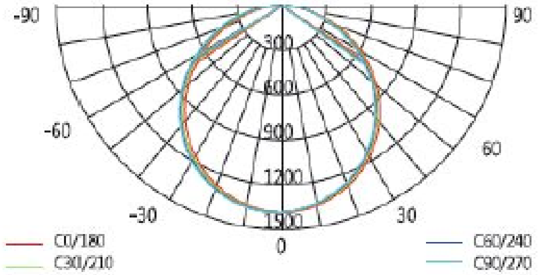


Beam angle ≈ 12°

ART-2: Planar luminaire

62 x 62 x 2 cm

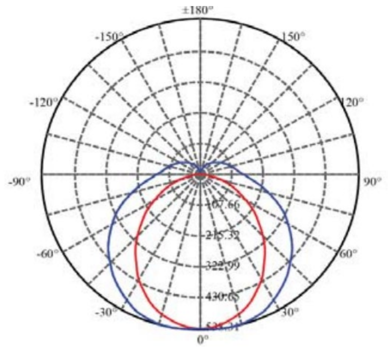
220V AC, 60 Hz
40W
5700K



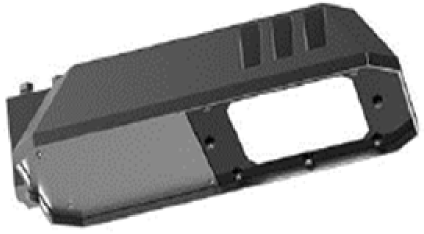
ART-3: Batten luminaire

63 x 6 x 8 cm

220V AC, 60 Hz
20W
4000K

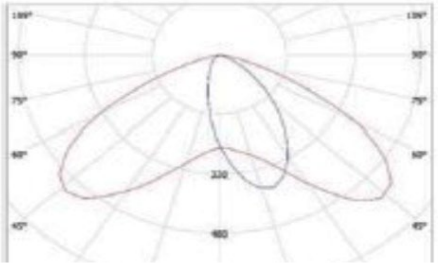


ART-4: Street lighting luminaire



50 x 25 x 11 cm

220V AC, 60 Hz
30W
4000K



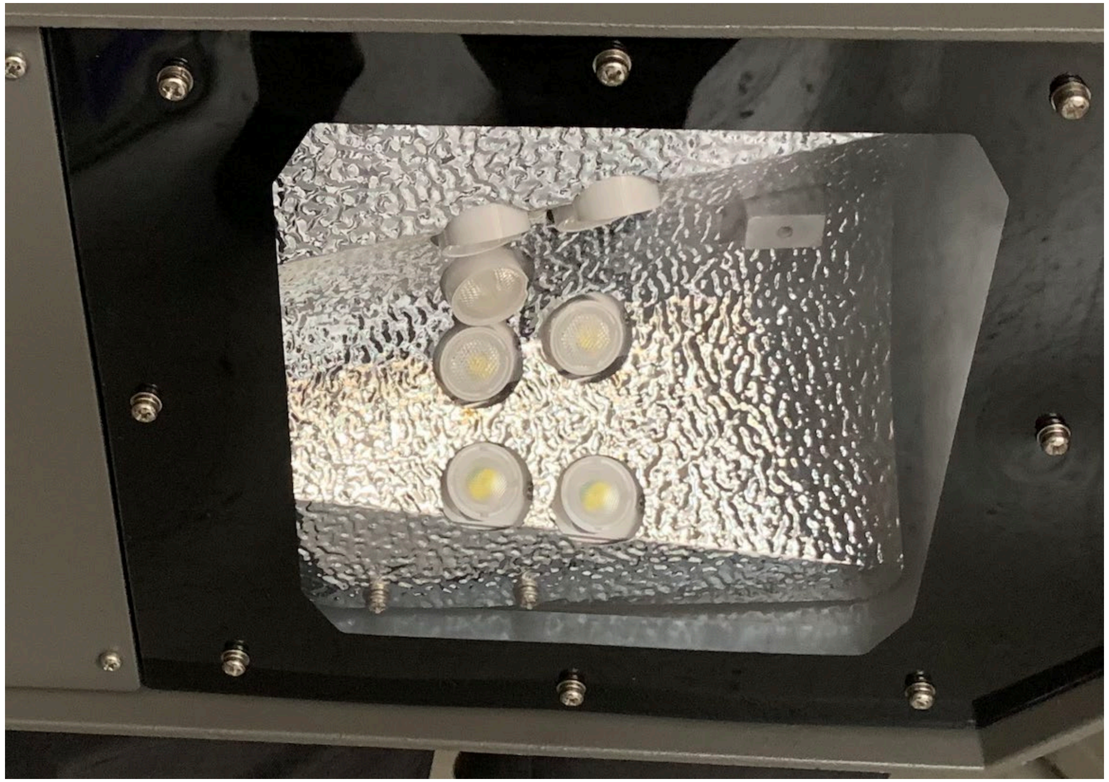
* Details available in Section 3.2 of Final Report and IC 2017 Technical Protocol (June 2017).

IC 2017 Comparison Artefacts

Light-emitting areas of ART-1 lamp and ART-4 street lighting luminaire

ART-1

ART-4



IC 2017 Measurement Quantities

General quantities						Unit
1	Total luminous flux					lm
2	Luminous efficacy					lm/W
3	Active power					W
4	Root-mean-square (RMS) current (DC current for ART-1)					A
5	Power factor					1
6	Chromaticity coordinate (*u'*,*v'*) - spatially averaged					1
7	Correlated colour temperature (CCT) - spatially averaged					K
8	Colour rendering index (CRI) R_a - spatially averaged					1
Goniophotometric quantity		**ART-1**	**ART-2**	**ART-3**	**ART-4**	
9	Luminous intensity distribution, value at (0,0)	X	X	X	X	cd
10	Partial luminous flux (15° cone)	X				lm
11	Centre beam intensity	X				cd
12	Beam angle	X				°
13	Street-side downward flux (Forward light*)				X	lm
14	House-side downward flux (Back light*)				X	lm
15	Upward flux (Uplight*)				X	lm
16	Angular spatial colour uniformity $\Delta_{u'v'}$	X		X		1

* These quantities (for street lighting luminaire) are defined in IES TM-15.

Same as IC 2013 Used in IC 2017 for proficiency testing (z', En number calculated)

For technical study

IC 2017 Measurement Quantities

- Participants were allowed not to measure some of the quantities if they are not capable (some gonio quantities).
- Measurement uncertainties were required but participants were allowed not to report for some quantities if they have difficulty.
- Some guidance was give on goniophotometric quantities in IC 2017 Technical Protocol.

Information for goniophotometric quantities (IC 2017 Protocol)

For the details of some of these goniophotometric quantities, please refer to the following sections in CIE S 025 [ref. 4]:

- Partial luminous flux: section 3.33
- Centre beam intensity: section 6.6 (including NOTE in this section).
- Beam angle: section 3.17 and section 6.6. Report the average beam angle from the two C planes (0°/180°, 90/270°).
- Angular colour uniformity: section 7.1.4

Street light partial flux (three partial fluxes) is defined in IES TM-15-11[14]. This is illustrated in Figure 1.

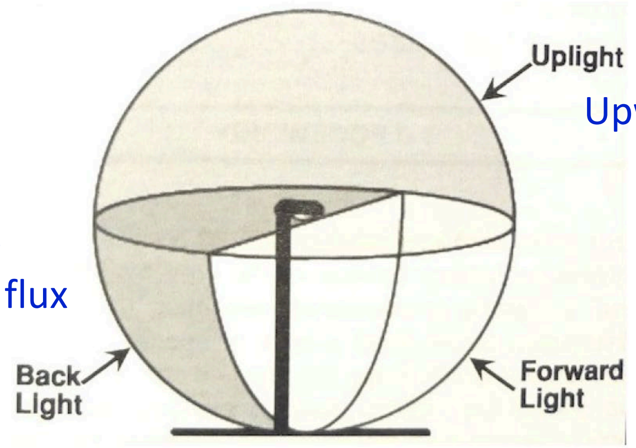


Figure 1. The three primary solid angles of the Luminaire Classification System (LCS)

Test Method of IC 2017

CIE S 025/E:2015

cie

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

International Standard

Test Method for LED Lamps, LED Luminaires and LED Modules

Méthode d'essai pour lampes à LED, luminaires à LED et modules à LED

Testmethode für LED-Lampen, LED-Leuchten und LED-Module

CIE S 025 (or EN 13032-4, equivalent European standard) was used as the Test Method for IC 2017

- **Participants were required to perform measurements in compliance with this test method**
- **Participants were required to report any incompliance to CIE S 025**

Compliance to CIE S 025

If your measurement system does not comply with any of the requirements in CIE S 025 (e.g., operating condition tolerances, requirements for goniophotometer characteristics, sphere-spectroradiometer characteristics, etc.), please wright below the conditions that are not fulfilled and relevant section numbers of CIE S 025. This information may be considered if your lab submits your IC 2017 result report as proficiency test for an accreditation program.

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Nucleus Laboratory Facilities

Goniophotometer used at KILT

Figure 4-1. A photo of the goniophotometer at KILT

- PSI / LG-2.0 Mirror Goniophotometer (Design 1 in slide 7)
- Photometric distance 12 m (same for spectral measurement)

Goniophotometer used at LNE

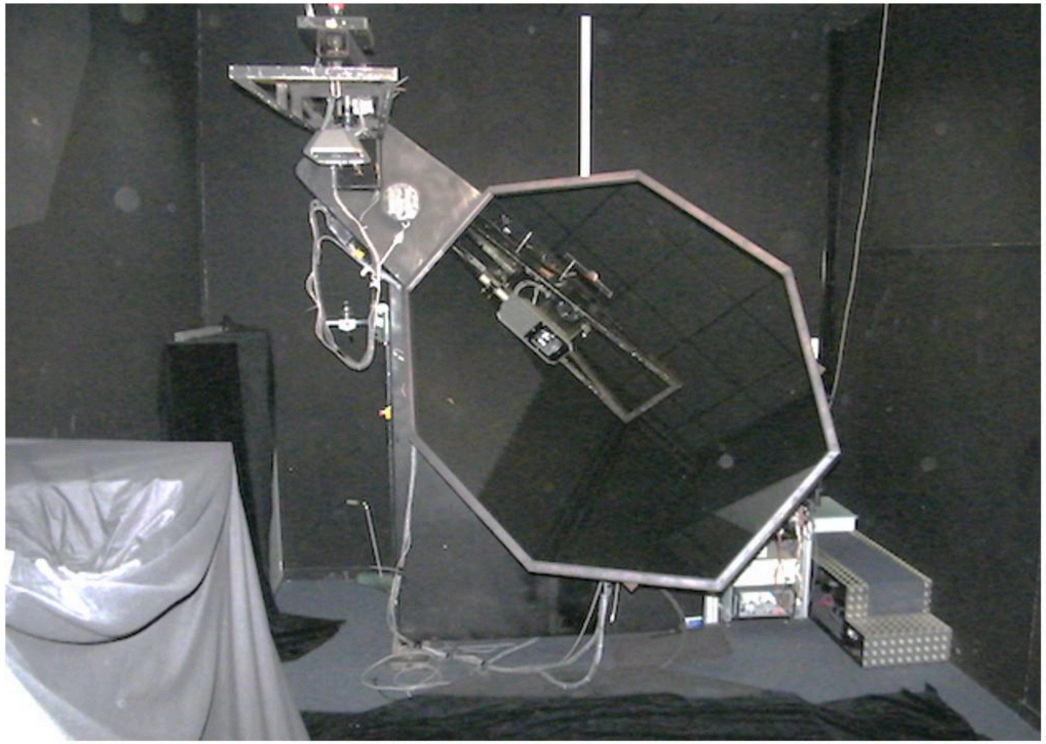


Figure 4-2. A photo of the goniophotometer at LNE, with ART-4 sample mounted

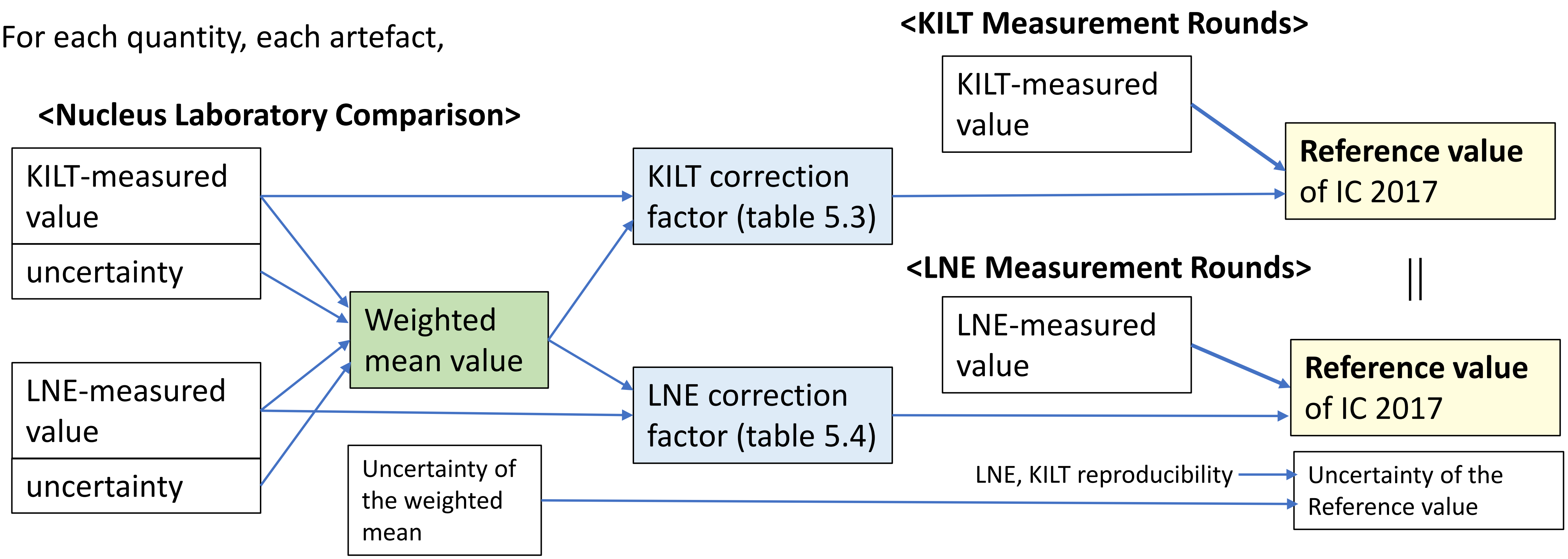
- Designed and built by LNE (Design 2 in slide 7)
- Photometric distance 25 m (6 m for spectral measurement)

* Details available in Section 4 of Final Report and IC 2017 Technical Protocol (June 2017).

Nucleus Laboratories Comparison

Prior to IC 2017 measurement round, ***Nucleus Laboratory Comparison*** was carried out. KILT and LNE compared measurements of 2 sets of 4 artefacts for all measurement quantities.

For each quantity, each artefact,



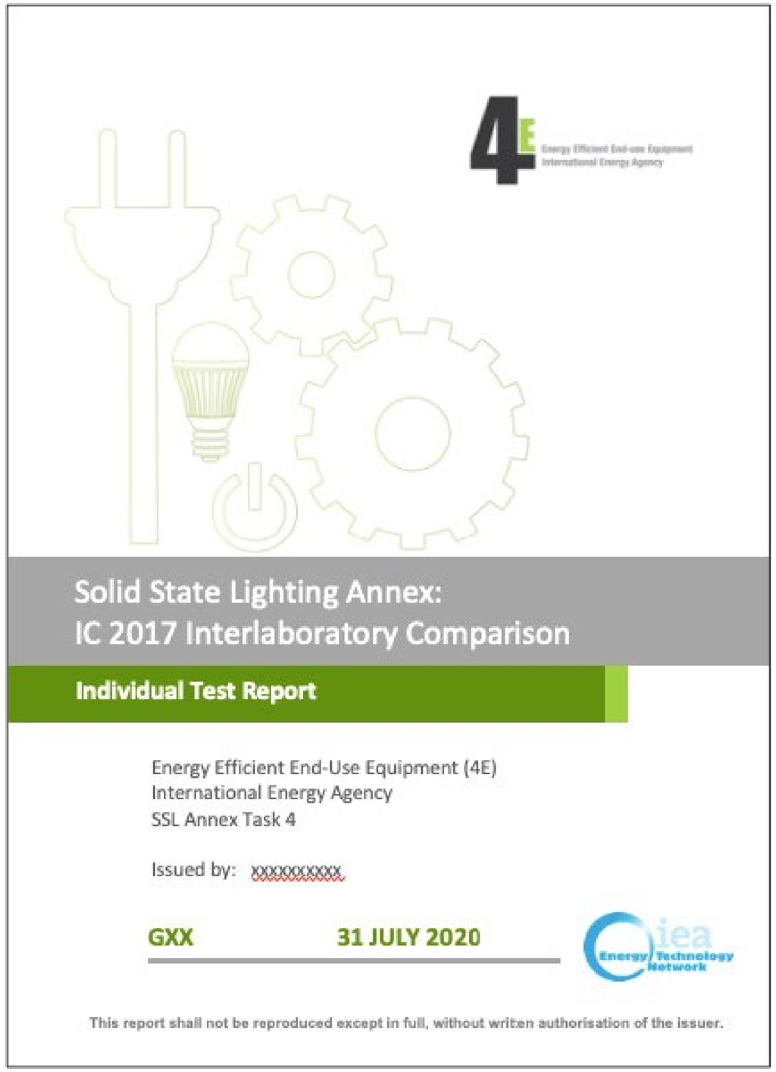
Details are available in IEA 4E SSL Annex, **IC 2017 Nucleus Laboratory Comparison Report**. Published 28 May 2019. Link: https://www.iea-4e.org/wp-content/uploads/publications/2021/01/IC_2017_Nucleus_Lab_Comparison_Report_-Final_Revised_-_2019-09-30.pdf

Measurement Rounds

Table 3-4. Measurement Rounds of IC 2017

Measurement Rounds	KILT participants	LNE participants	Period
Round 1 (KILT, LNE)	5	7	Jan – April 2018
Round 2 (KILT, LNE)	4	9	April – July 2018
Re-measurements of ART-1	9	-	Oct 2018 – Mar 2019
Re-measurements of ART-2	-	2	Jun - Oct 2018
Round 3 (LNE)	-	11	Aug 2018 – Oct 2019
Re-measurements of ART-1	-	3	Nov 2019
Round 4 (LNE)	-	6	Dec 2018 – Mar 2019
Re-measurements of ART-1	-	2	April – Aug 2019
Re-measurements of artefacts other than ART-1	2 (ART-2) 1 (ART-4)		Feb – July 2018

Individual Test Report (ITR)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Solid State Lighting Annex:
IC 2017 Interlaboratory Comparison

Individual Test Report

Energy Efficient End-Use Equipment (4E)
International Energy Agency
SSL Annex Task 4

Issued by: xxxxxxxxxx

GXX 31 JULY 2020

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Issued to each of all 42 instruments/participants in April – July 2020, a few revisions later. ITR Reported the comparison results (of only the participant) directly to each participant in detail.

Purposes

- Participants may use this as **Proficiency Test report** for accreditation applications.
- Participants can find problems and improve their measurement systems.

Contents

20 pages
15 tables of results
24 figures (6 x 4 artefacts) of LID curves
Comments on LID results of each artefact

17

Solid State Lighting Annex
Energy Efficient End-use Equipment
International Energy Agency

Results of IC 2017

- **IC 2017 Final Report** published December 20, 2021.

  155 pages

  166 figures

  18 tables

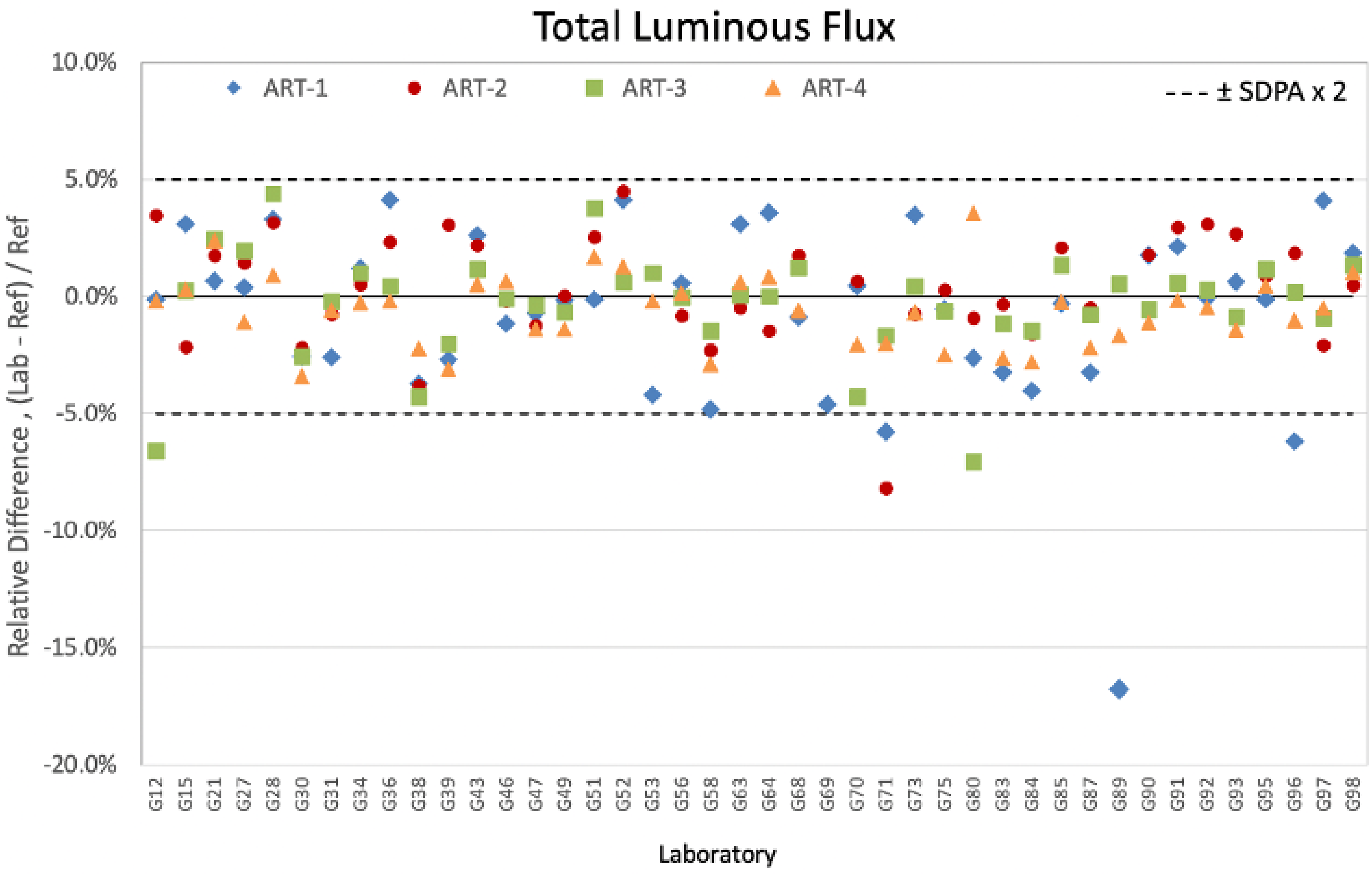
  Available on SSL Annex website.

Results of comparison of all **42 instruments** for all quantities are presented in anonymous manner. (analysis I)

Comparisons of **different instrument types** are analyzed (Analysis II and III)

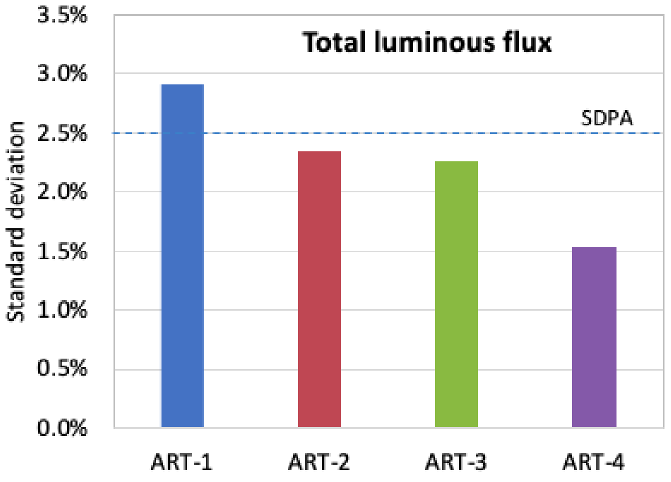
Analysis I – (Relative) differences comparing all 42 instruments

– Results of all artefacts in one graph–



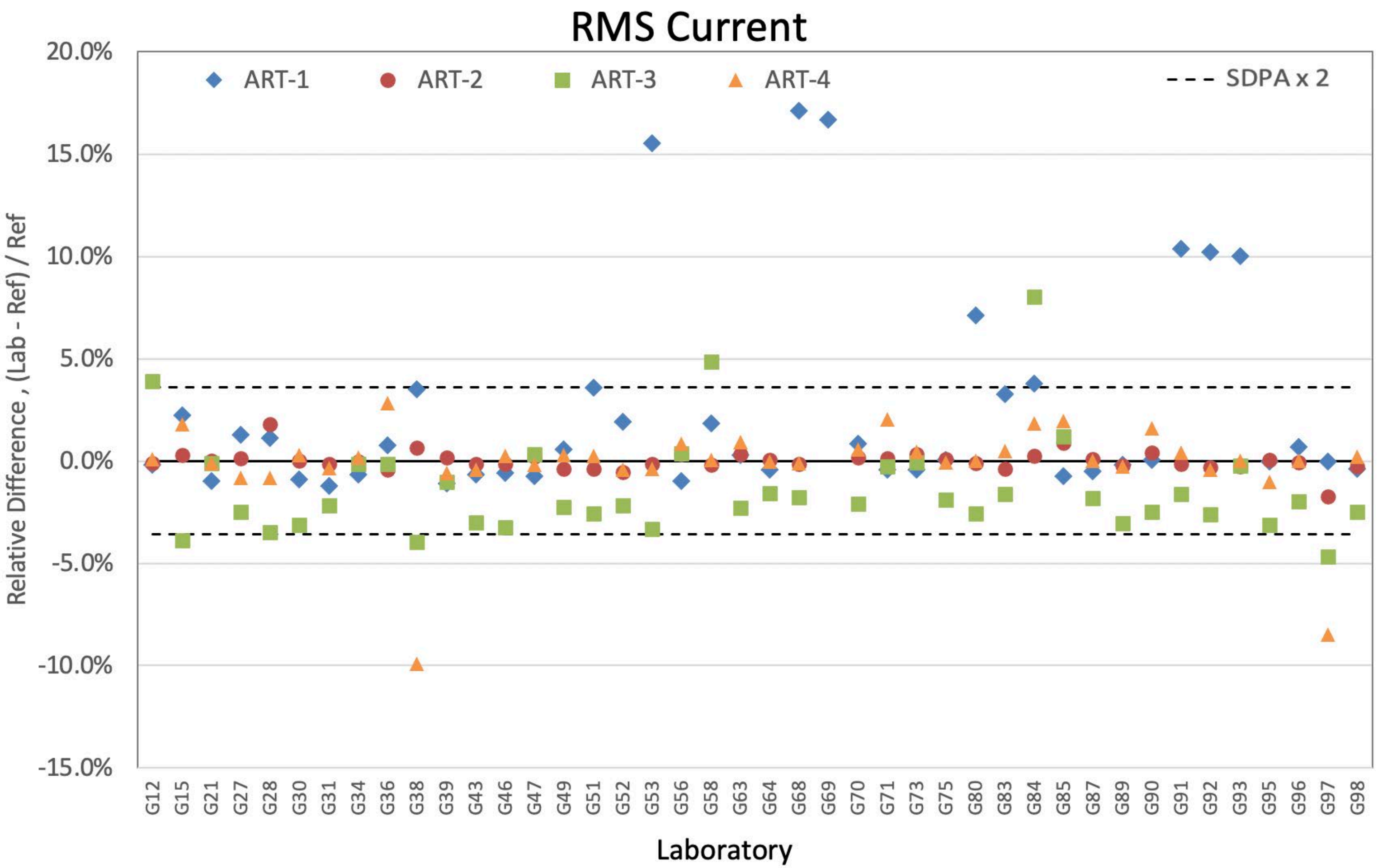
SDPA: Standard Deviation for Proficiency Assessment
(pre-determined to calculate z' scores in proficiency test)

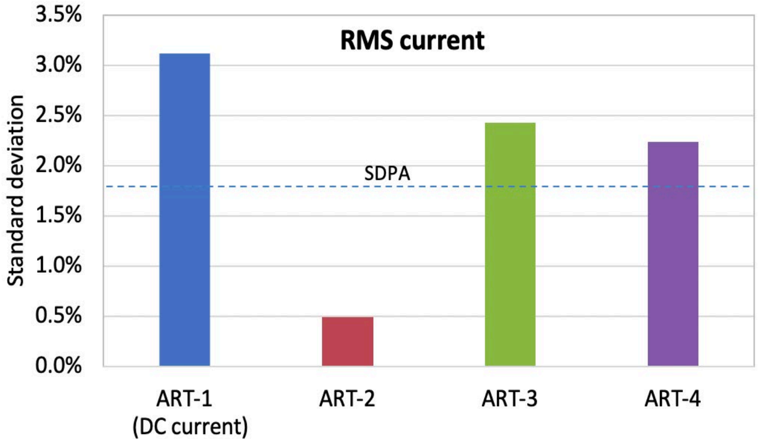
(Expected variation of participants' measurements)



Analysis I – (Relative) differences comparing all 42 instruments

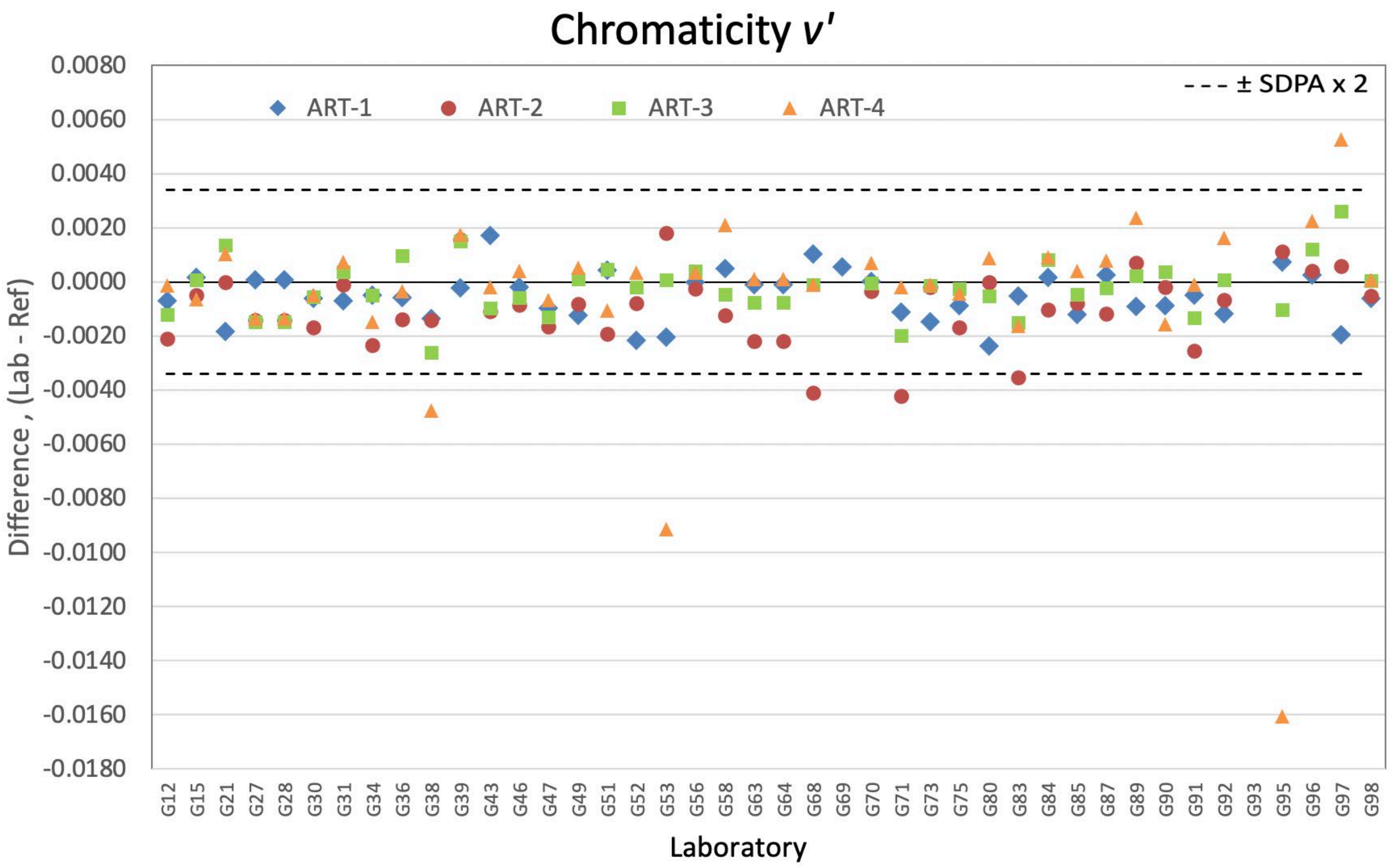
– Results of all artefacts in one graph–

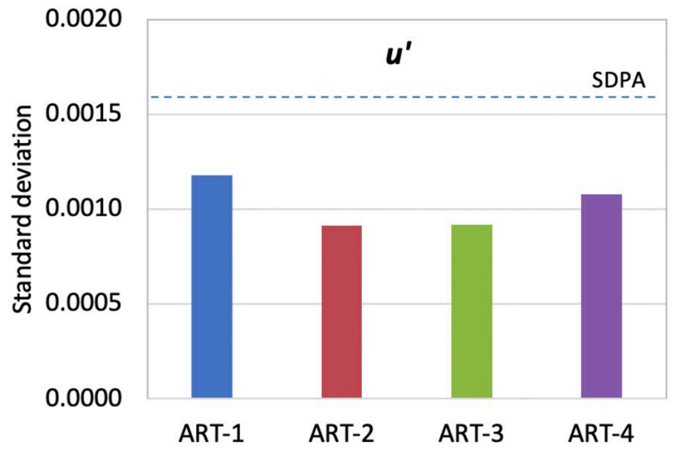


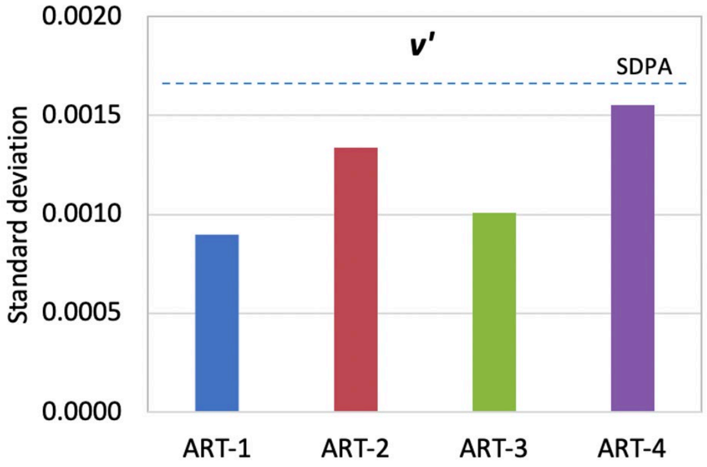


Analysis I – (Relative) differences comparing all 42 instruments

– Results of all artefacts in one graph–

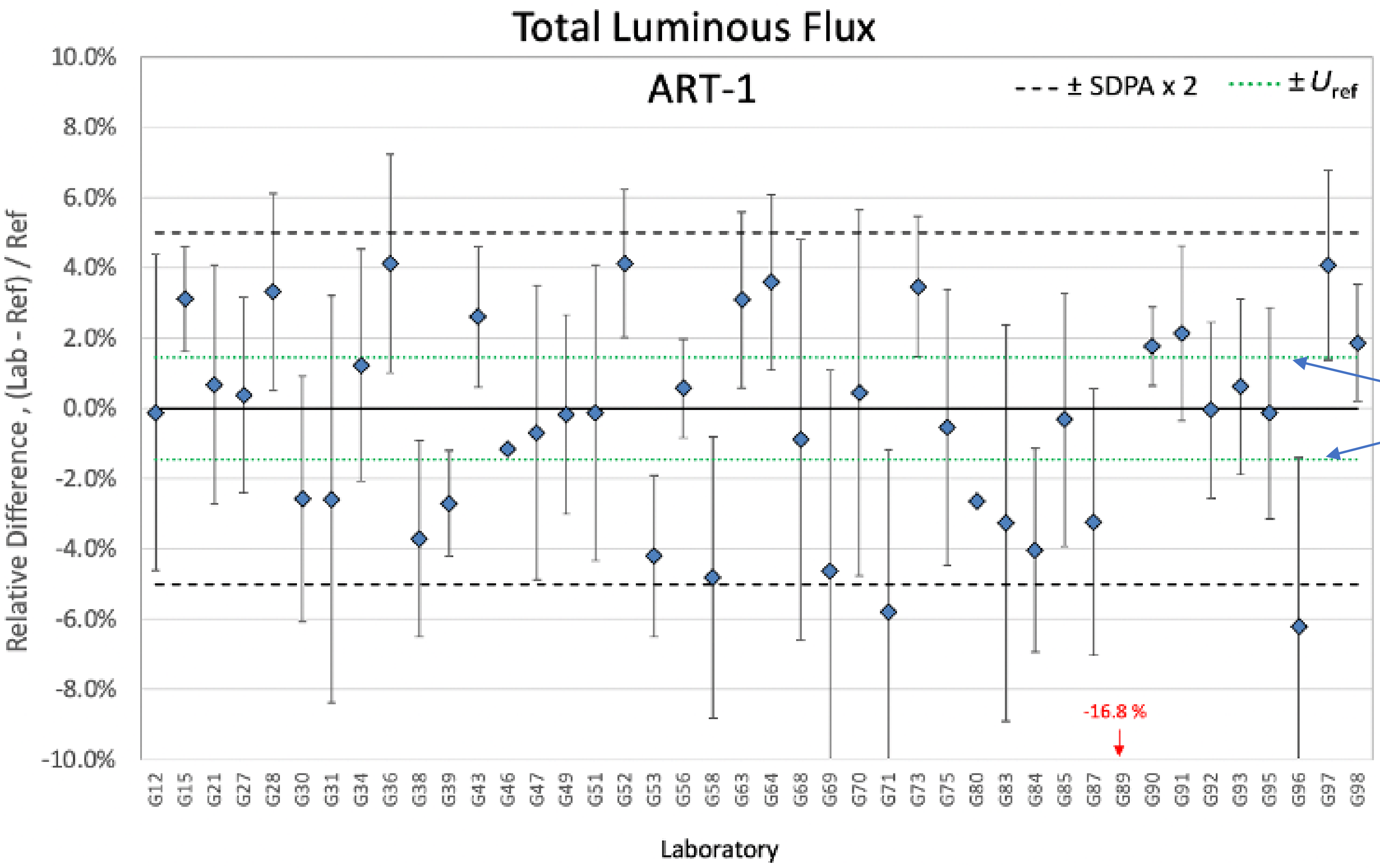






Analysis I – (Relative) differences comparing all 42 instruments

– Graph for each artefact –



Error bars: each participant's reported expanded uncertainty (*k*=2)

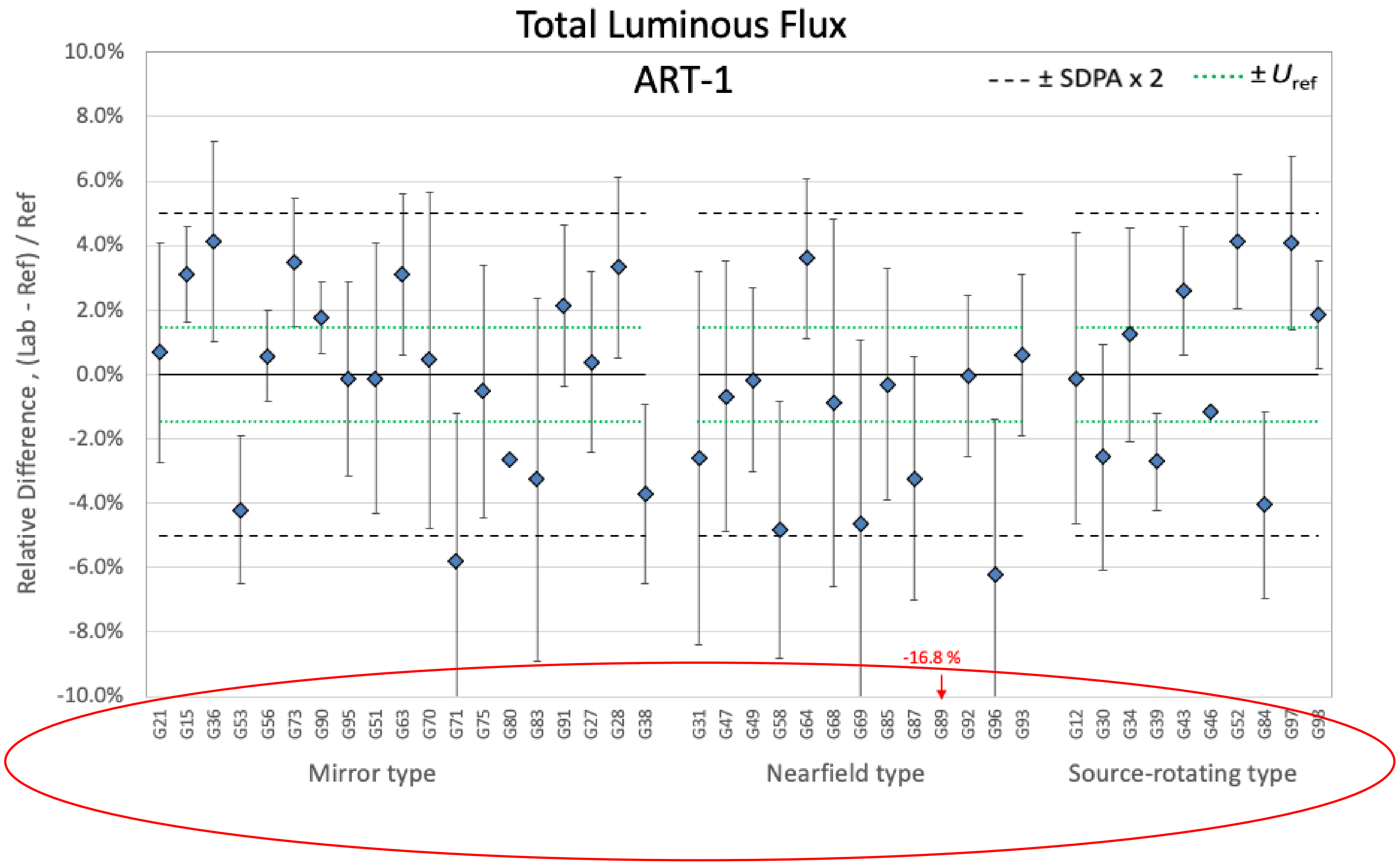
Range of expanded uncertainty (*k*=2) of Reference value

Outliers were excluded from the averages

~60 figures of these for all 16 quantities x 4 artefacts presented in Final Report.

Analysis II – (Relative) differences sorted by goniophotometer types

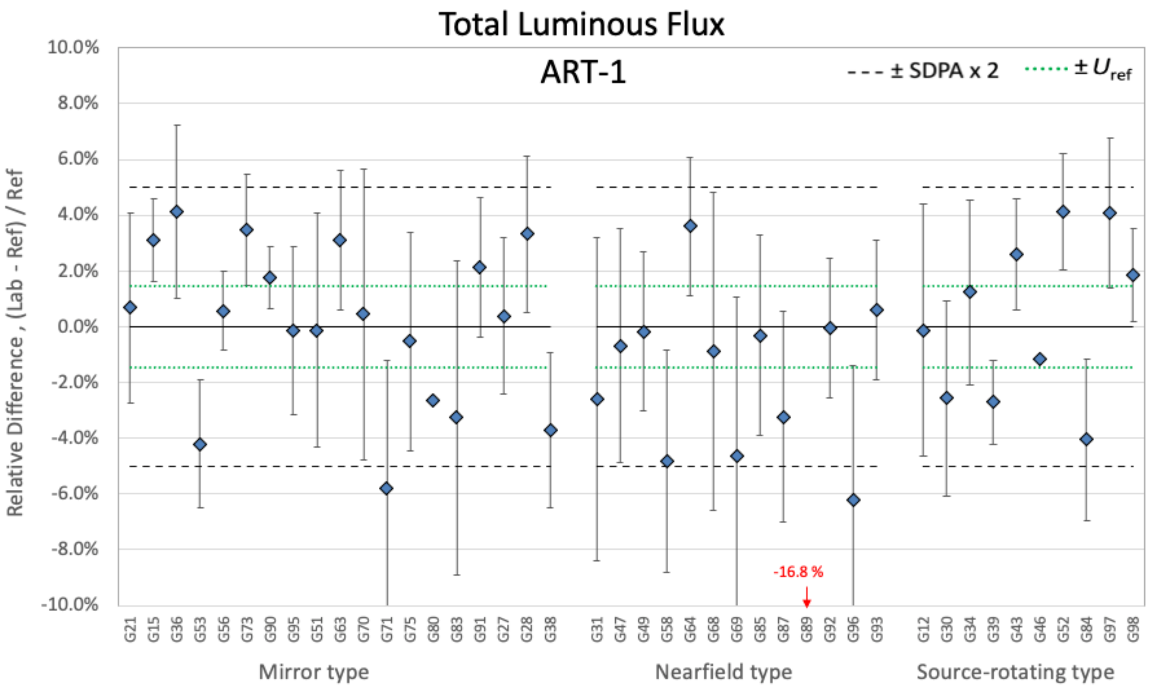
– Graph for each artefact –



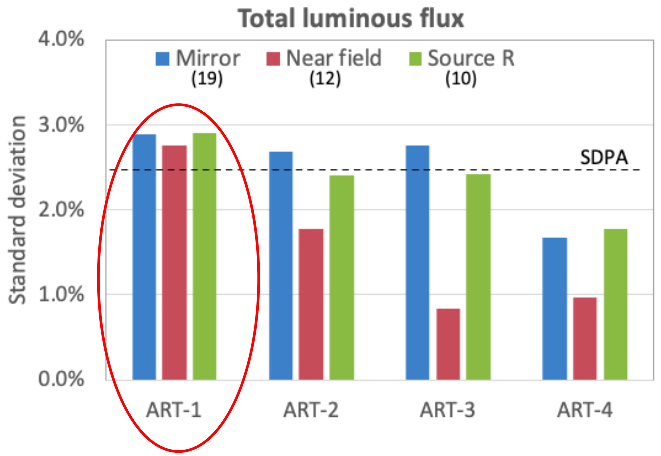
~50 figures of these for 16 quantities and 4 artefacts presented in Final Report.

Analysis III – Standard deviations and Average deviations for each instrument type

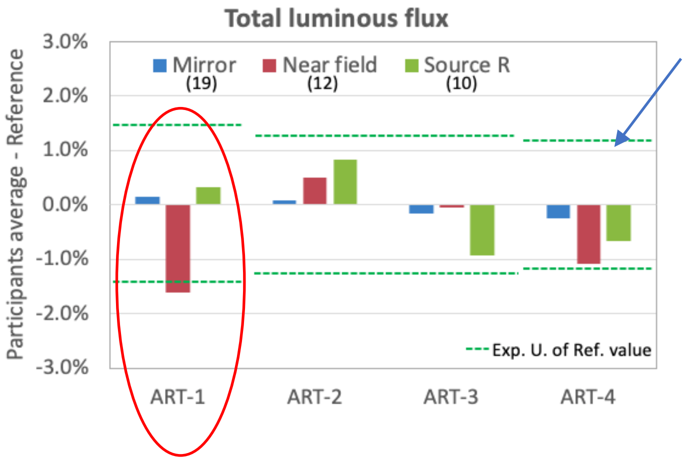
Section 7.4 of IC Final Report



Standard deviations of the results for each goniophotometer type



Average deviations from the reference value for each goniophotometer type

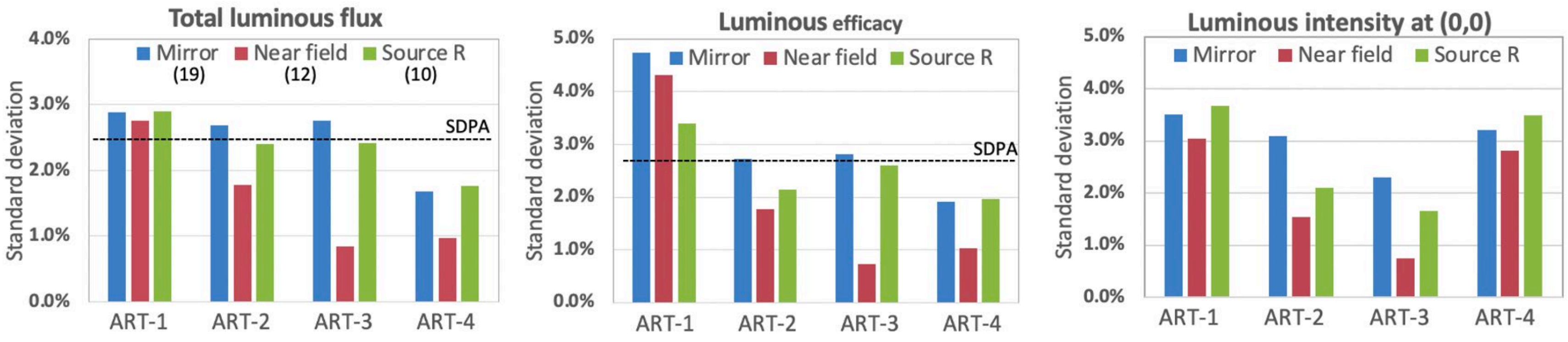


Expanded U(k=2) of Reference value

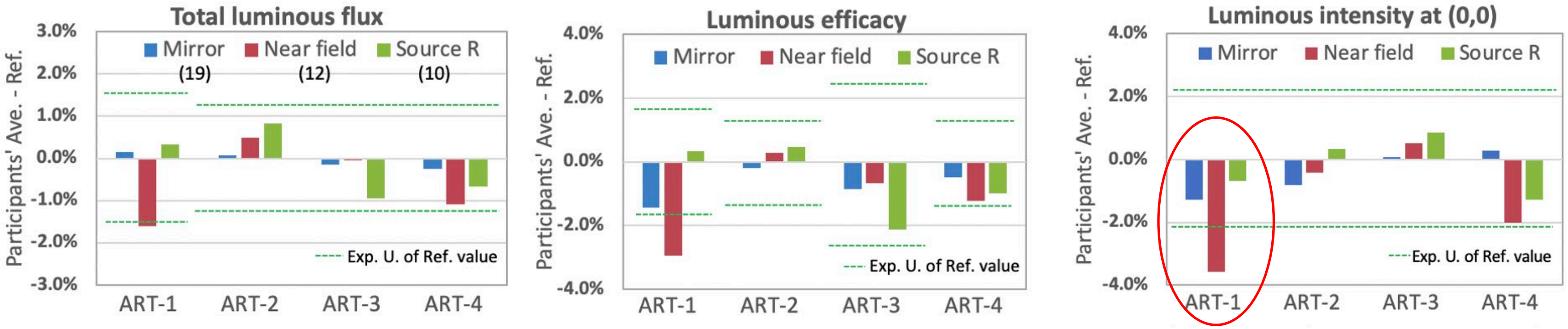
34 figures of these were produced for all 16 quantities.

Analysis III Results (1) – Photometric quantities

Standard deviations of the results



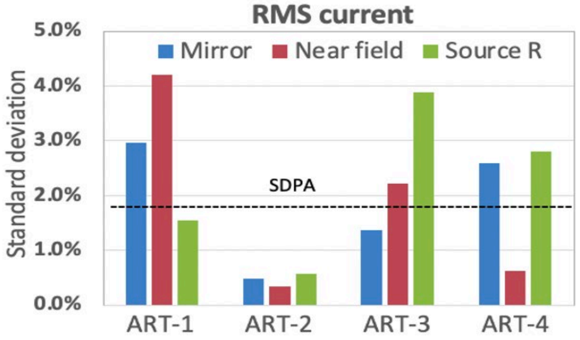
Average deviations from the reference value (bias)



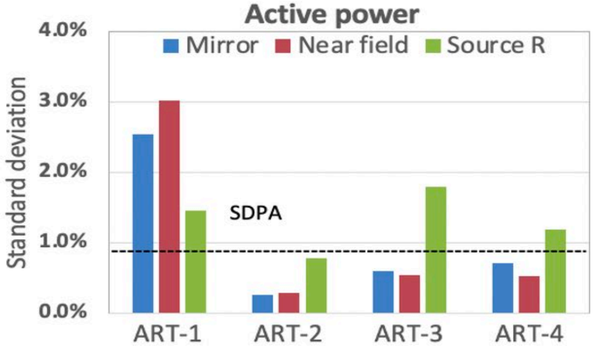
- Total luminous flux: variations appear to be reasonable for all types
- Luminous intensity at (0,0) for ART-1: Near-field type shows notable deviation (negative bias) though this may be still at acceptable uncertainty level

Analysis III Results (2) – Electrical quantities

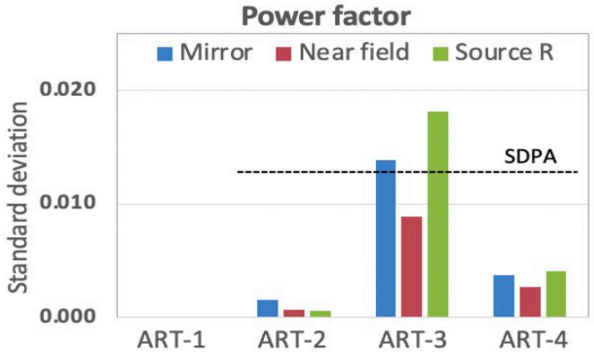
Standard deviations of the results



(DC current)

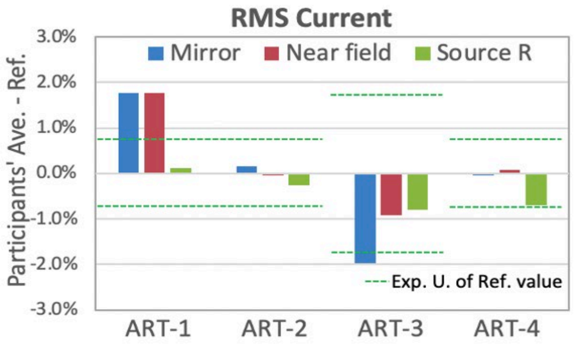


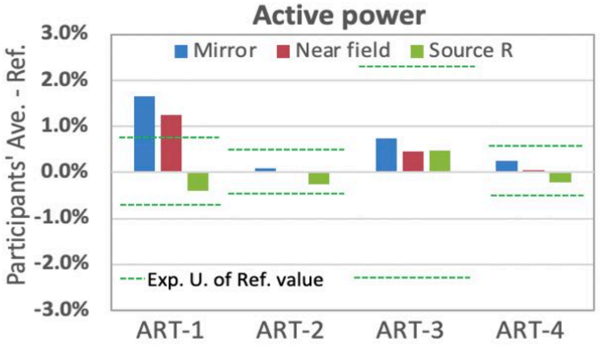
(DC power)

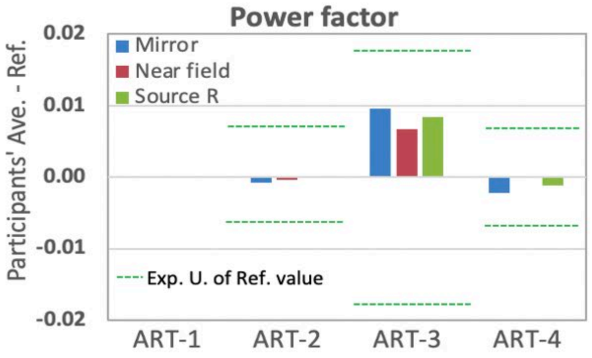


(DC operation)

Average deviations from the reference value





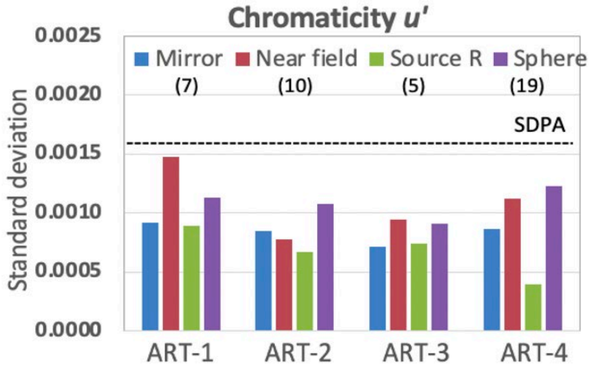


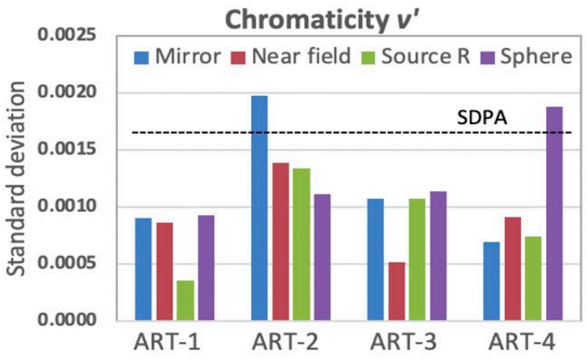
- Large differences between different artefact types (e.g., power factor)
- Variations are much higher than expected in some cases
- Variations of ART-1 are high probably due to small pins and low voltage (DC 12V) thus relatively higher current

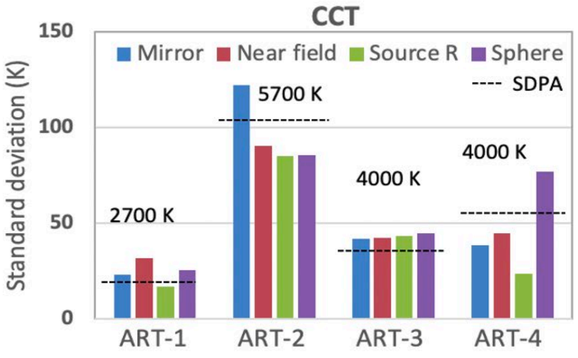
Analysis III Results (3) – Colour Quantities-1

Standard deviations of the results

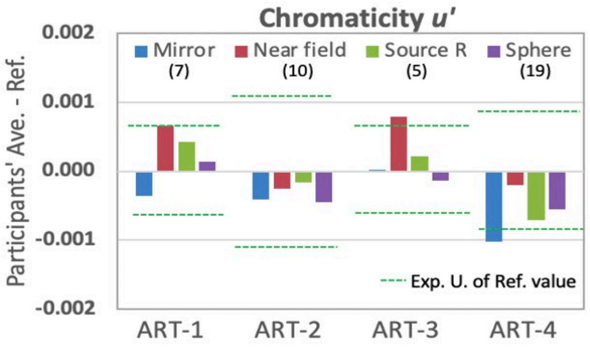
❖ Sphere-spectroradiometer was allowed for measurement of color quantities

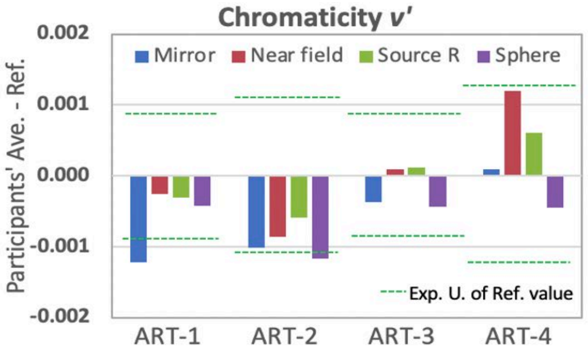


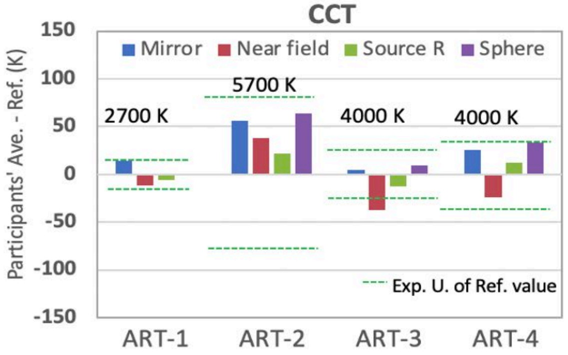




Average deviations from the reference value



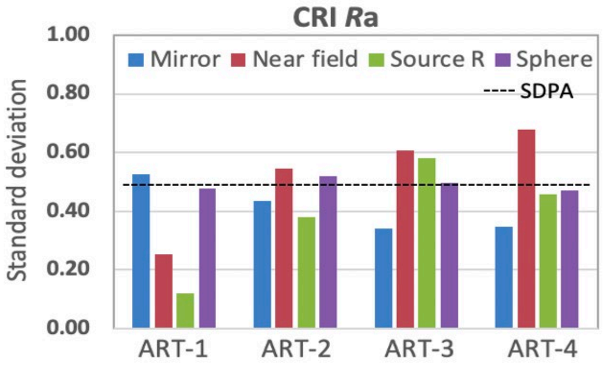


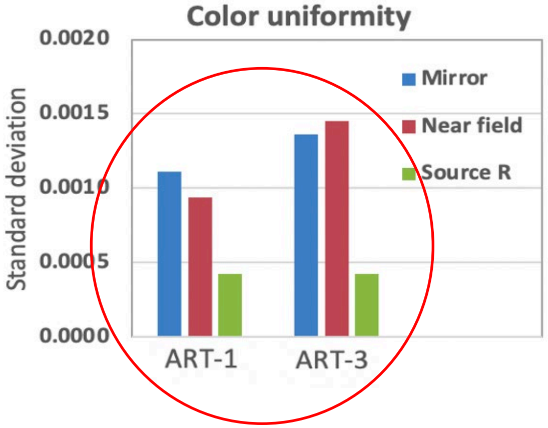


- Variations appear reasonable
- No notable differences between different goniophotometer types
- Variations for ART-4 with sphere system are high

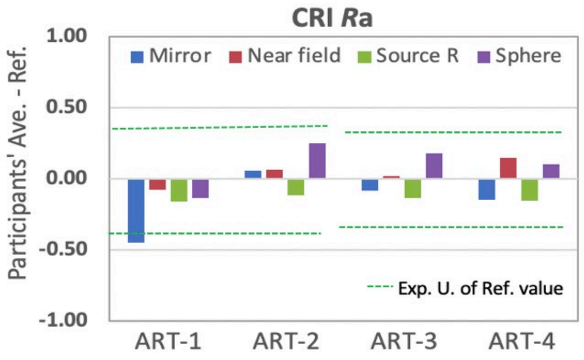
Analysis III Results (4) – Colour Quantities-2

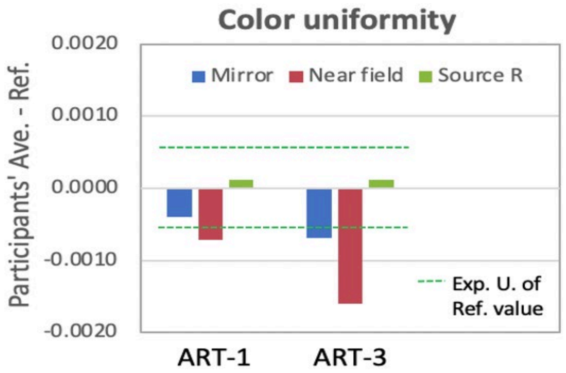
Standard deviations of the results





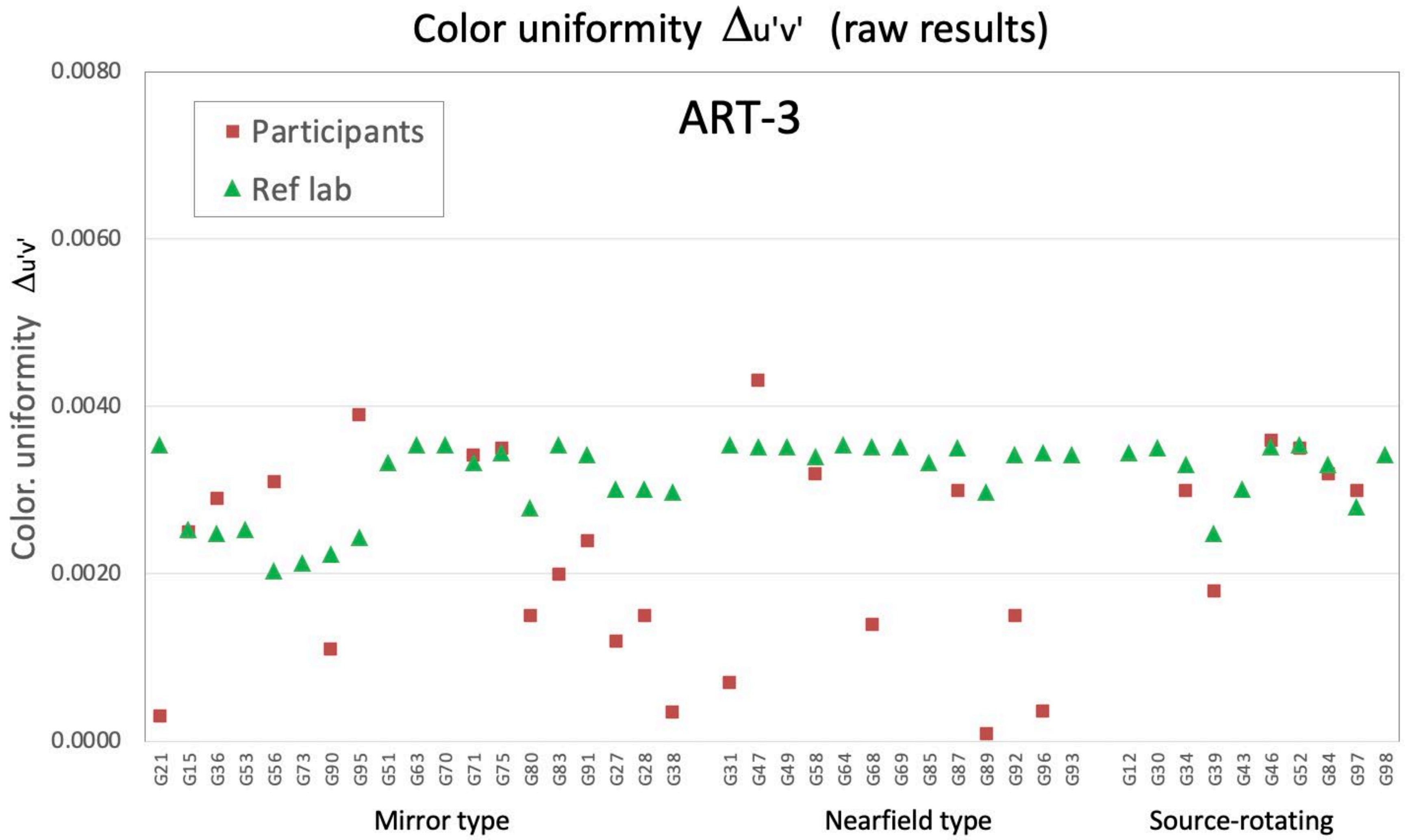
Average deviations from the reference value





- Results of CRI R_a appear reasonable
- Colour uniformity: variations are very high, considering that these are relative color measurements

Colour Uniformity Δu'v' – Raw Results



Summary results of z' score

$$z' = \frac{x - X}{\sqrt{\hat{\sigma}^2 + u_X^2 + u_{\text{drift}}^2}}$$

x: participant's result
X: reference value
$\hat{\sigma}$: SDPA value (expected std deviation of participants)
u_X std uncertainty of reference value
u_{drift}: artefact reproducibility

Generally,

|z'| ≤ 2 : satisfactory
2 < |z'| ≤ 3 questionable
|z'| > 3 : unsatisfactory

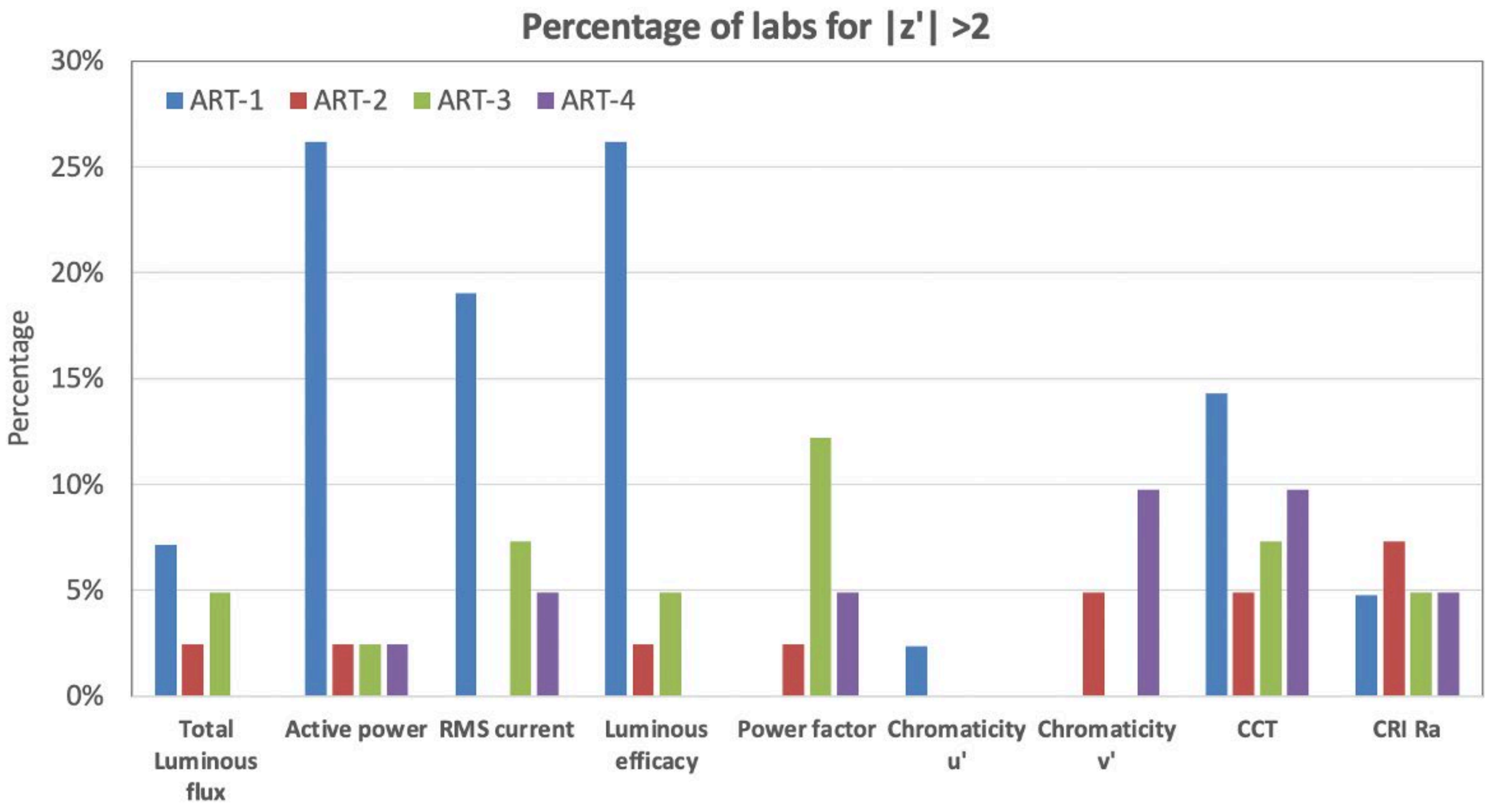


Figure 7-161. Percentage of labs that had z' scores outside -2 ≤ z' ≤ 2

Summary results of E_n number

$$E_{\mathrm{n}} = \frac{x - X}{\sqrt{U_{\mathrm{lab}}^2 + U_{\mathrm{ref}}^2}}$$

x: participant's result
X: reference value
U_{lab}: expanded uncertainty (k=2) of participant's result
U_{ref}: expanded uncertainty (k=2) of reference value

Generally,

$|E_n| \leq 1$: satisfactory
$|E_n| > 1$: unsatisfactory

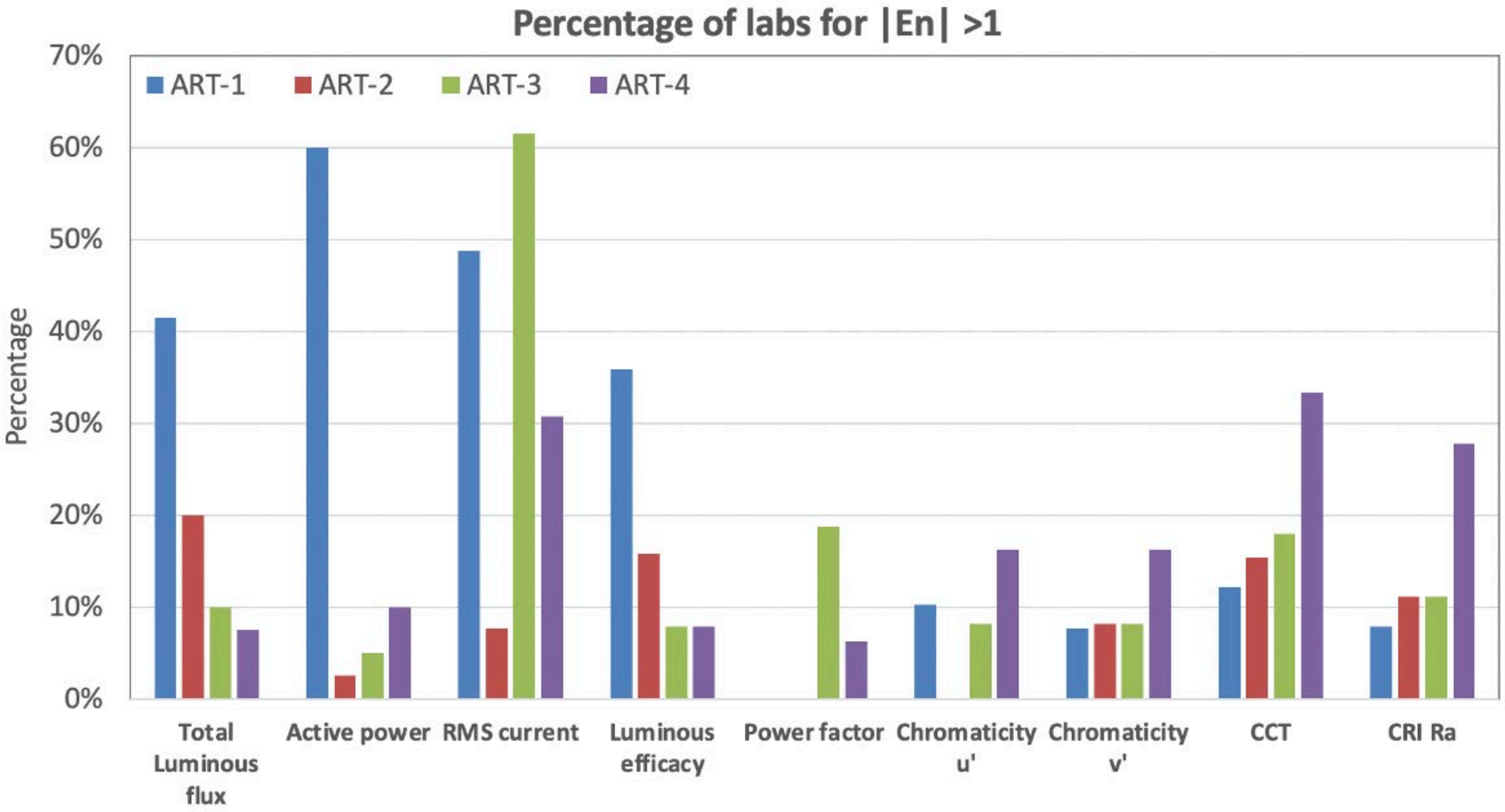
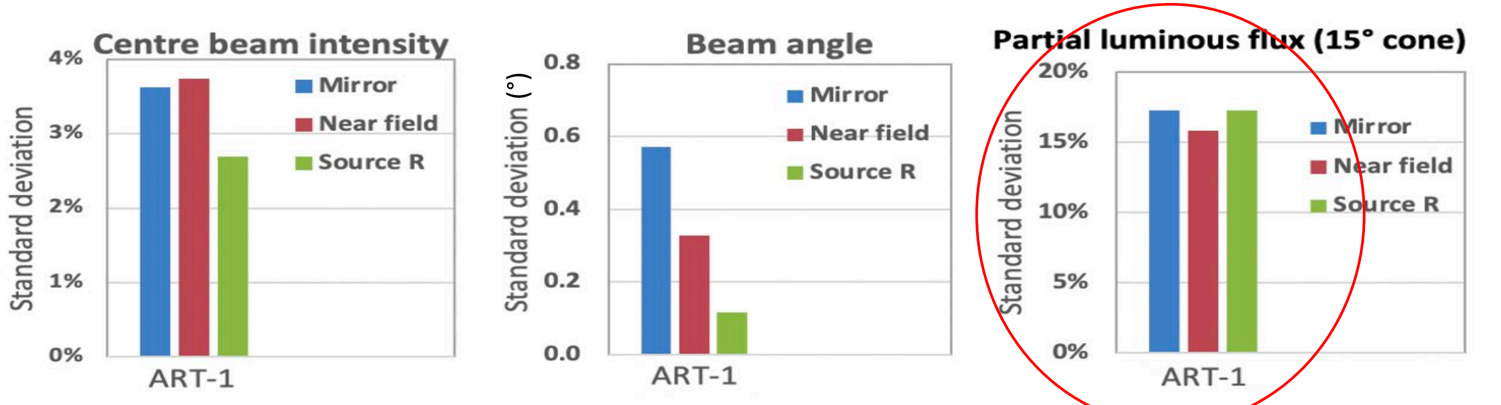


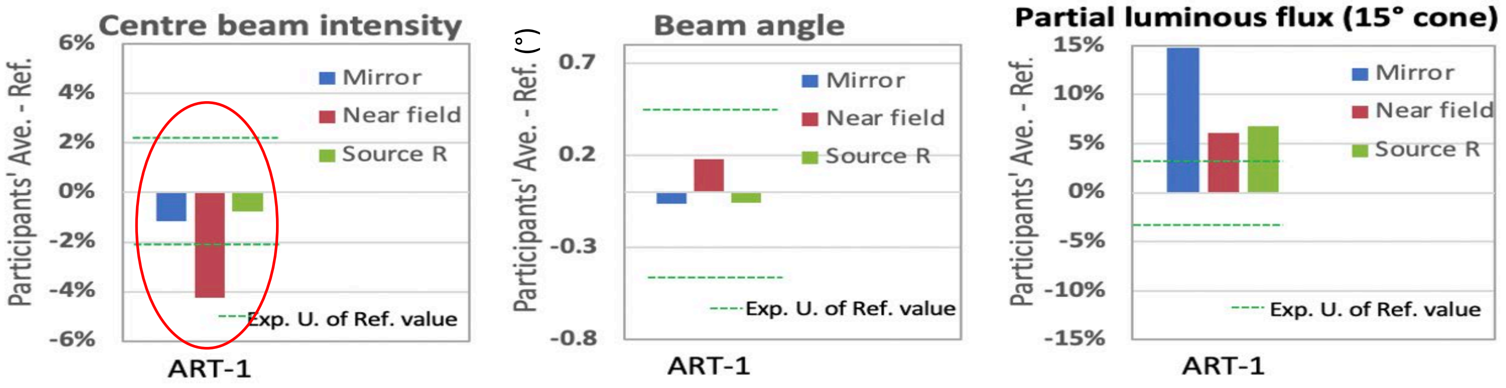
Figure 7-162. Percentage of labs that had E_n numbers outside $-1 \leq E_n \leq 1$

Analysis III Results (5) – Goniophotometric quantities (ART-1)

Standard deviations of the results

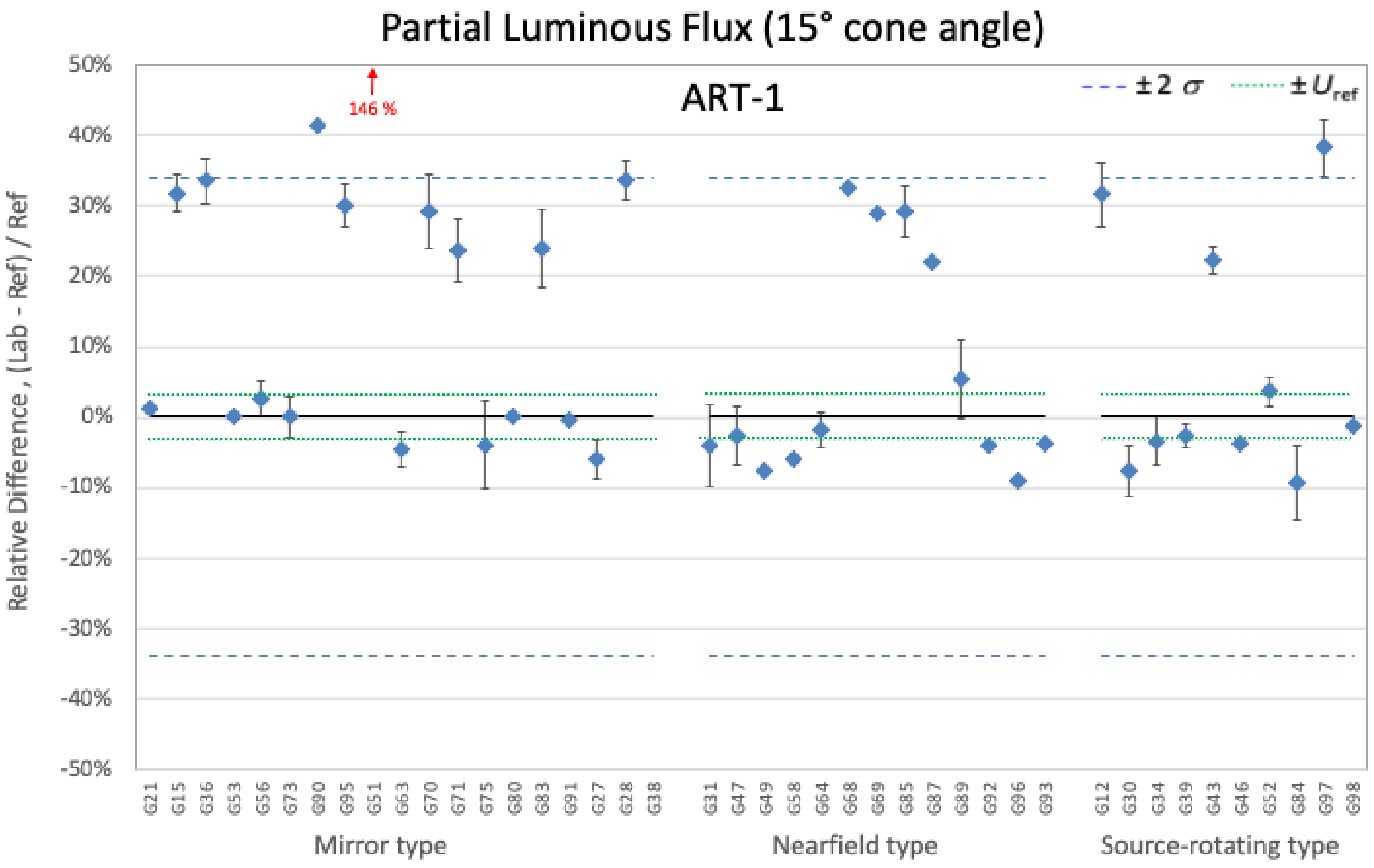


Average deviations from the reference value



- Center beam intensity: notable negative bias for near-field type (luminous intensity at (0,0) was similar).
- partial flux (15° cone angle): Variations are extremely large.

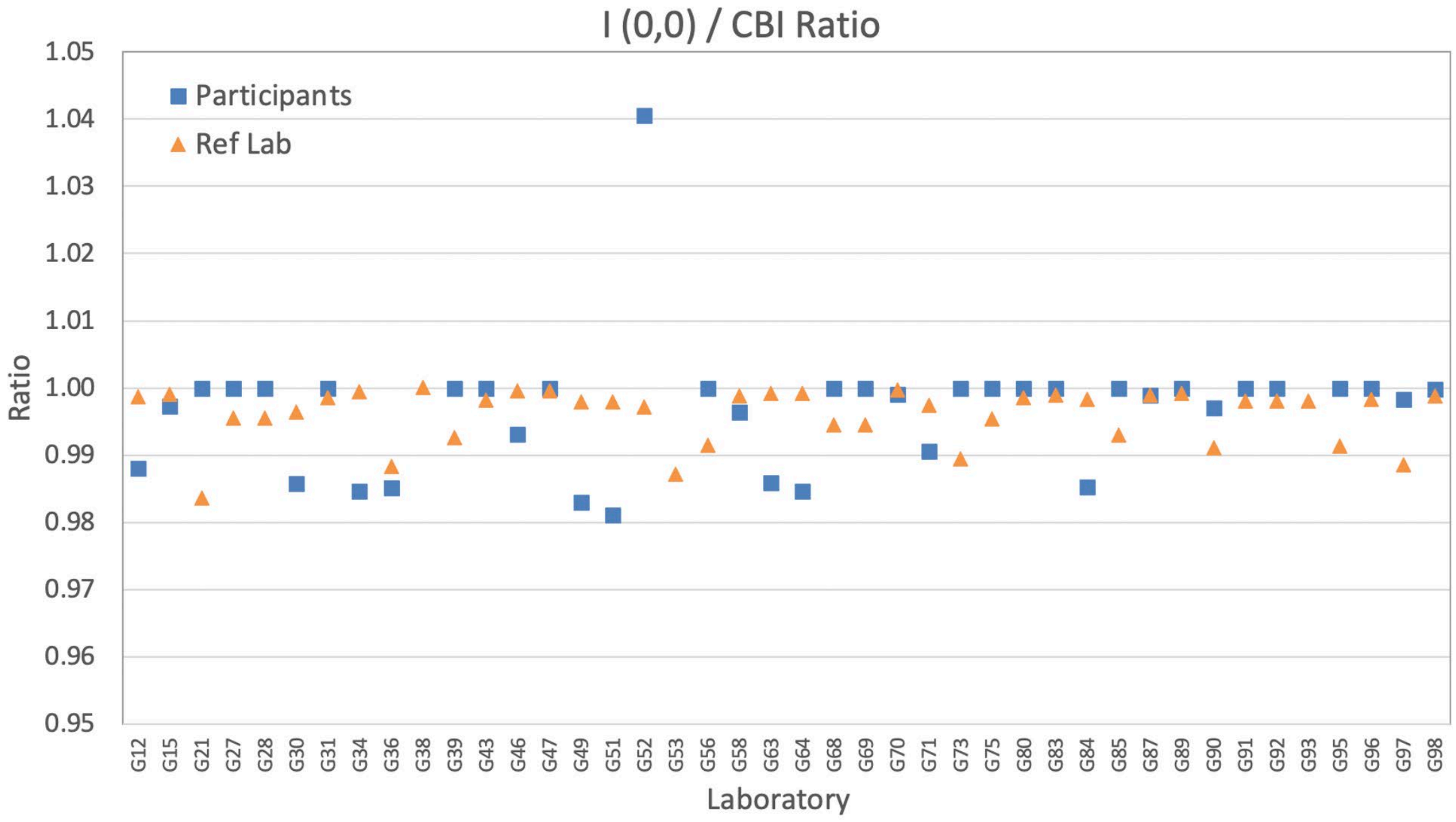
Results of partial luminous flux (15° cone angle)

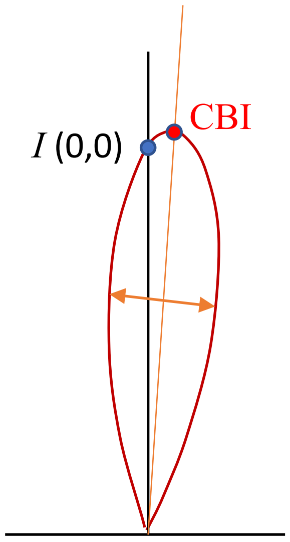


30° cone angle

It seems many labs calculated 30° cone angle

Ratios of luminous intensity at (0,0) to centre beam intensity (CBI)

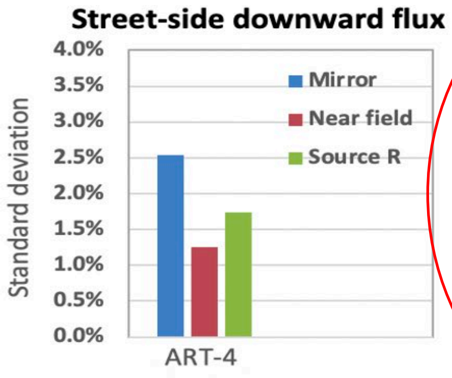


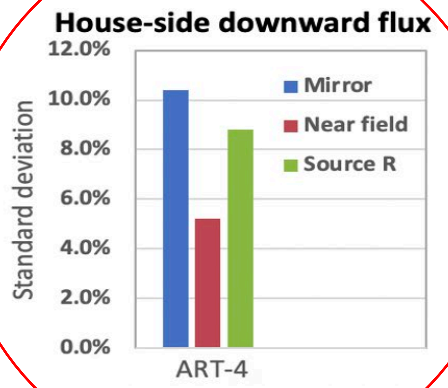


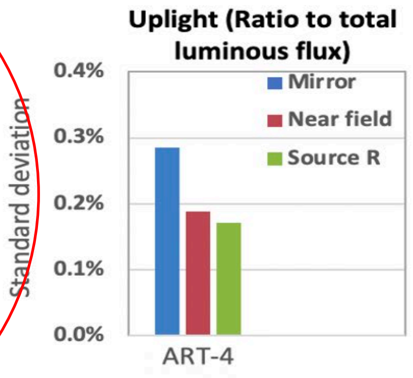
- 21 out of 42 labs reported exactly the same values for I(0,0) and CBI. (Many participants did not calculate CBI as defined)

Analysis III Results (6) – Goniophotometric quantities (ART-4)

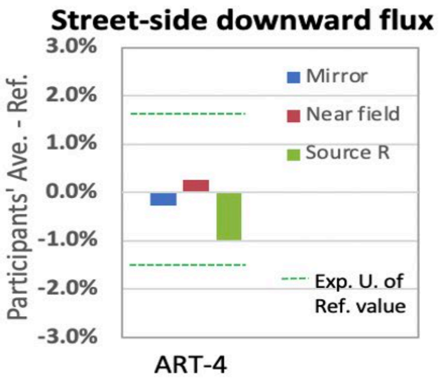
Standard deviations of the results

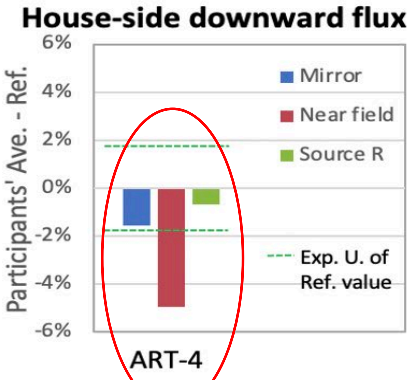


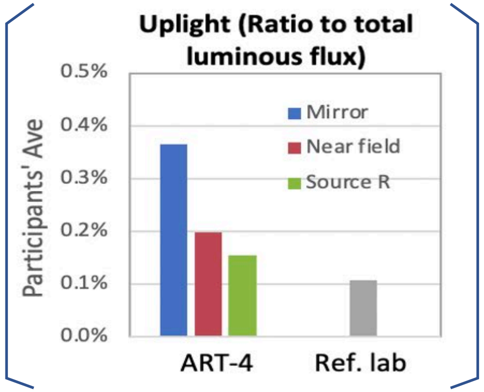




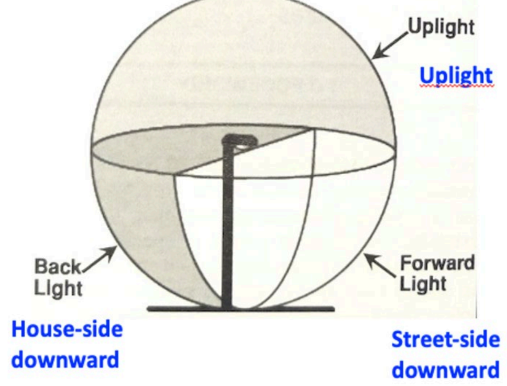
Average deviations from the reference value





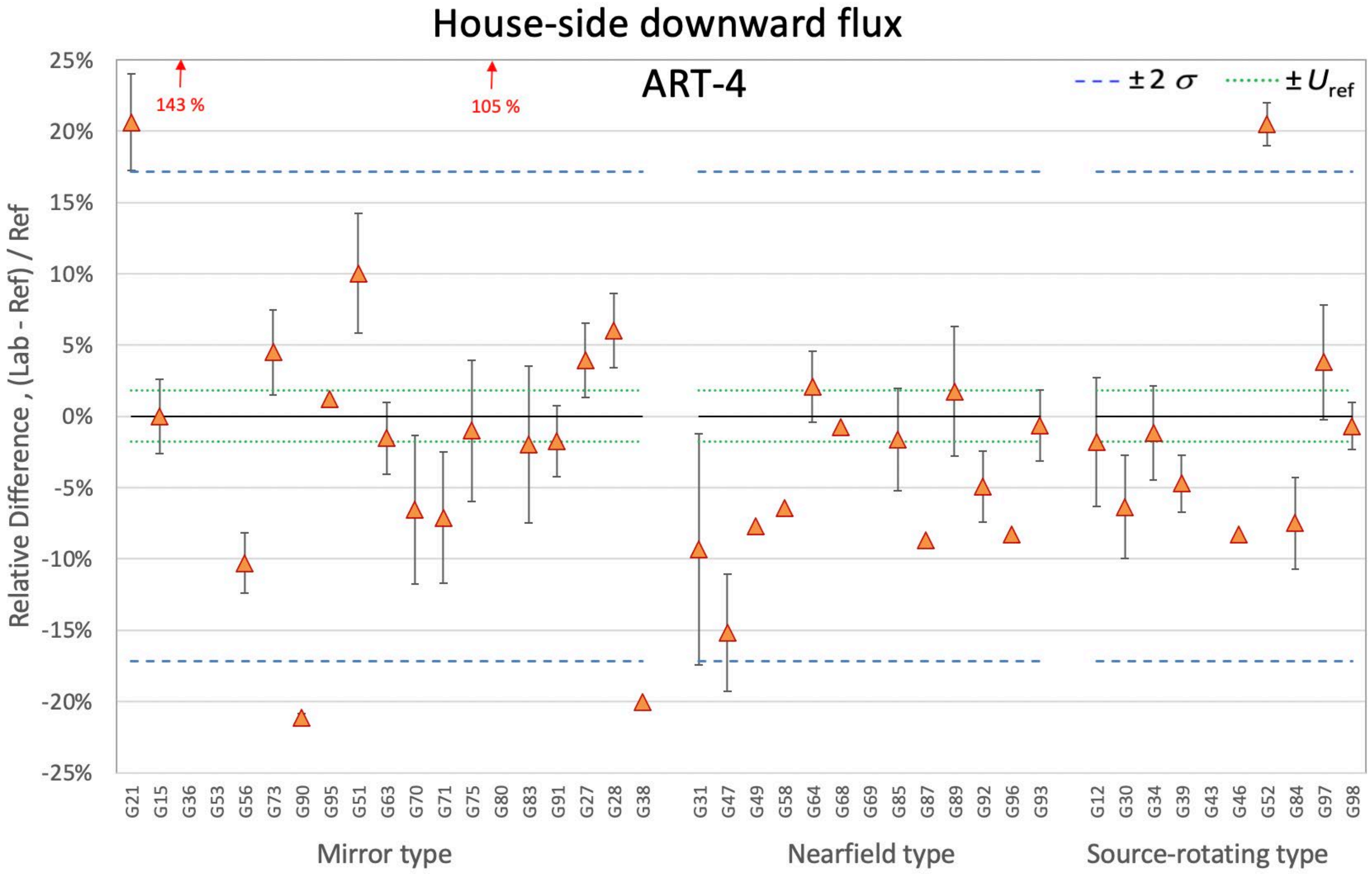


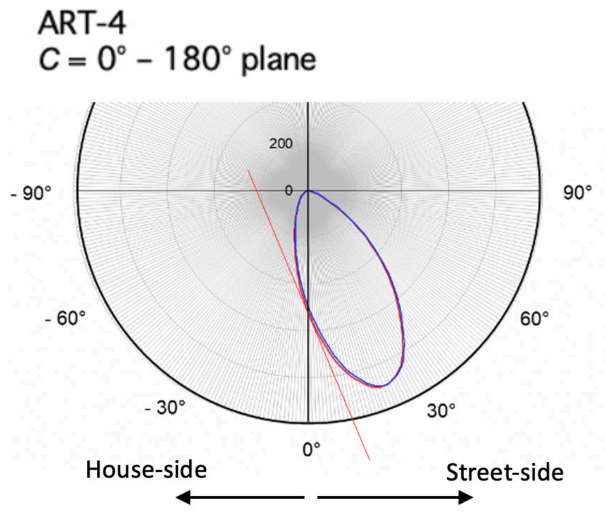
IES TM-15-11



- House-side downward flux:
  - Large variations (4 x than street side)
  - Notable negative bias of near-field type (but uncertainty is also high for this quantity)

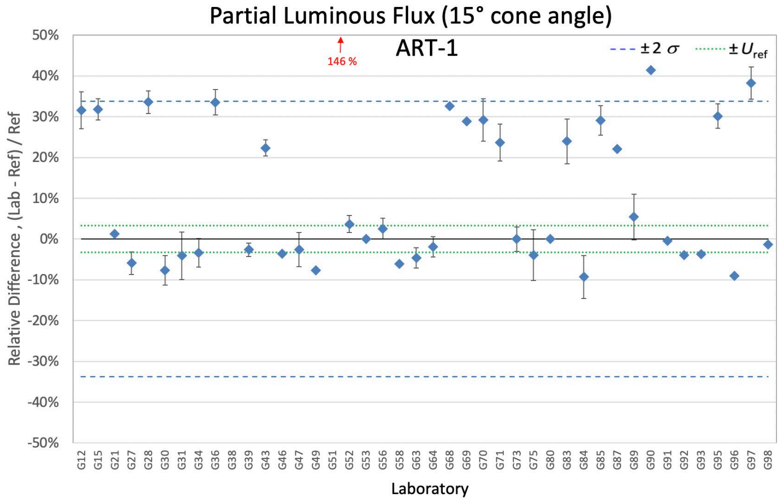
Results of House-side downward flux

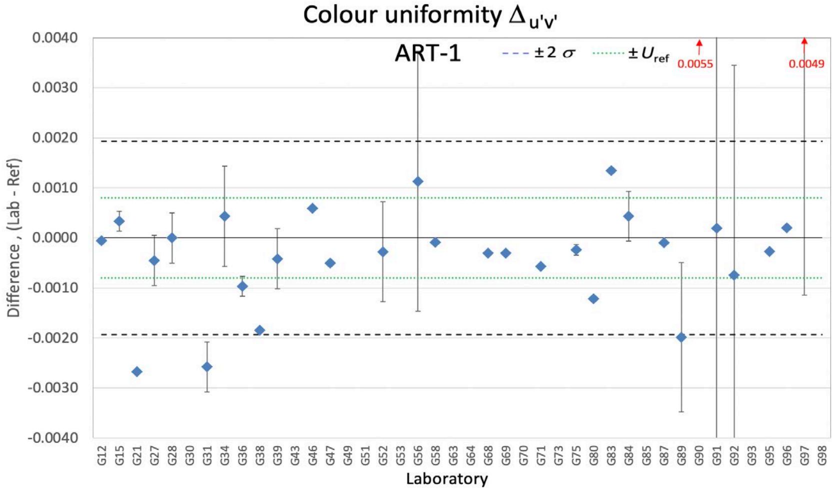


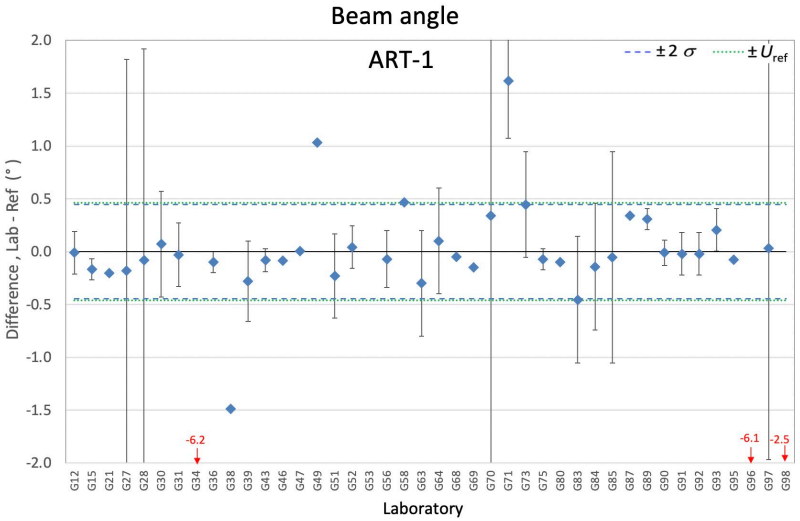


Large variations due to sharp decrease of intensity on house side

Uncertainty reporting for goniophotometric quantities







Partial luminous flux	16 out of 40 labs (40 %)
Beam angle	14 out of 41 labs (34 %)
Centre beam intensity	10 out of 40 labs (25 %)
Colour uniformity	15 out of 30 labs (50 %)

did not report uncertainties.

Analysis IV – Luminous Intensity Distributions

Format of LID results report (with example data)

Lumionous intensity distributions

ART-1				
	luminous intensity (cd)			
γ angle (°)	C = 0°	C = 180°	C = 90°	C = 270°
0	5733.46	5733.46	5733.46	5733.46
1	5563.40	5791.00	5535.92	5876.89
2	5243.34	5623.24	4980.81	5825.93
3	4850.26	5390.77	4546.23	5677.92
4	4059.83	4933.00	3630.97	5266.24
5	3017.75	4122.81	2943.88	4860.86
6	2285.14	3535.92	1968.51	4160.31
7	1660.17	2592.32	1212.71	3010.59
8	1030.06	1677.92	729.17	2229.88
9	580.02	1022.04	423.42	1270.83
10	445.18	700.83	338.39	913.25
11	318.92	419.12	254.79	593.19
12	258.52	338.10	224.16	418.55
13	226.45	259.09	192.67	317.78
14	188.66	219.58	176.07	241.91
15	170.63	197.25	151.16	211.57
16	144.86	168.34	130.83	181.79
17	131.41	153.16	120.81	158.60
18	113.66	131.41	109.93	139.42
19	103.35	120.81	103.35	120.53
20	97.34	109.36	93.90	107.93
21	88.46	98.20	89.32	98.48
22	84.45	93.33	81.59	92.76
23	77.87	85.31	75.29	86.46
24	74.15	80.73	71.29	82.16
25	69.57	75.01	68.14	76.15
26	65.85	70.71	66.42	71.86
27	63.56	68.42	64.99	66.99
28	60.12	66.13	63.56	64.41
29	58.40	65.85	61.27	62.12
30	55.25	63.56	57.83	59.83
31	52.10	58.97	56.40	58.40
32	50.39	58.40	55.83	54.97
33	49.53	57.83	56.11	53.25
34	48.10	57.54	54.11	52.39
35	45.52	56.40	53.25	51.25
36	42.66	54.97	50.96	50.39
37	39.51	52.96	47.24	47.24
38	36.93	50.96	44.66	44.95
39	32.64	47.52	40.08	40.94
40	30.06	45.52	34.93	37.79
41	26.05	38.36	30.63	33.78
42	23.19	32.64	27.20	29.20
43	21.47	29.77	24.33	26.62

ART-2				
	luminous intensity (cd)			
γ angle (°)	C = 0°	C = 180°	C = 90°	C = 270°
0	1672.10	1672.10	1672.10	1672.10
5	1659.68	1661.68	1669.39	1662.25
10	1635.12	1638.83	1649.11	1635.69
15	1595.13	1600.27	1613.98	1593.99
20	1548.01	1546.86	1556.86	1538.30
25	1480.89	1480.32	1501.45	1473.75
30	1400.92	1401.20	1425.77	1393.78
35	1309.52	1310.66	1338.37	1301.53
40	1207.56	1209.56	1241.83	1199.28
45	1096.46	1117.31	1133.30	1087.60
50	977.07	980.50	1015.91	963.93
55	851.12	855.69	890.82	837.12
60	726.59	739.73	760.58	718.88
65	593.21	599.49	626.63	584.64
70	459.83	472.11	492.39	450.69
75	329.31	333.31	360.15	320.17
80	205.07	208.21	240.20	195.64
85	89.97	91.68	119.96	77.69
90	3.71	4.86	12.28	3.43

ART-3				
	luminous intensity (cd)			
γ angle (°)	C = 0°	C = 180°	C = 90°	C = 270°
0	641.44	641.44	641.44	641.44
5	641.18	637.13	633.37	633.08
10	637.71	630.47	619.77	619.48
15	626.71	618.03	598.07	599.22
20	608.48	599.51	568.84	570.00
25	585.05	575.21	533.83	534.41
30	556.98	549.17	493.04	493.90
35	527.18	519.08	448.48	449.06
40	495.93	487.83	402.76	402.18
45	464.39	456.00	354.73	354.15
50	431.98	423.88	306.41	306.12
55	400.74	390.32	259.54	261.27
60	365.15	355.02	212.66	214.98
65	326.95	317.98	168.98	170.13
70	286.45	280.08	124.71	126.44
75	244.49	238.71	82.75	85.07
80	202.54	198.20	44.56	46.87
85	164.63	162.61	14.47	16.20
90	139.46	141.78	2.03	1.74
95	124.13	125.57	1.45	1.45
100	111.40	113.42	1.45	0.87
105	99.53	103.00	1.16	0.87
110	89.69	93.75	1.45	0.87
115	81.31	85.36	1.74	0.87
120	73.49	77.54	1.74	1.16
125	66.55	70.60	1.74	1.74
130	59.89	63.94	2.32	1.74
135	53.82	57.58	2.60	2.32
140	47.74	51.21	2.89	2.32
145	41.38	44.85	3.18	2.89
150	35.01	38.48	3.76	3.18
155	28.65	32.12	4.05	3.47
160	22.57	26.04	4.63	4.05
165	15.91	17.94	4.92	4.63
170	10.42	11.28	5.21	4.92
175	5.79	6.66	5.50	5.50
180	5.00	5.00	5.00	5.00

ART-4				
	luminous intensity (cd)			
γ angle (°)	C = 0°	C = 180°	C = 90°	C = 270°
0	477.23	477.23	477.23	477.23
1	479.80	443.31	494.45	497.61
2	505.65	417.16	493.87	498.47
3	522.32	387.00	496.17	499.91
4	550.47	377.52	497.32	502.49
5	568.57	363.44	499.05	504.79
6	599.60	345.91	501.34	508.81
7	617.13	332.98	505.08	511.97
8	640.97	309.71	508.24	518.01
9	668.84	287.30	512.84	521.74
10	685.22	275.24	519.16	528.35
11	711.65	259.43	524.33	533.81
12	726.30	247.65	531.51	539.84
13	744.69	229.27	538.98	551.05
14	761.35	218.64	549.61	558.52
15	776.58	202.84	555.93	568.28
16	785.48	191.34	566.85	574.32
17	797.84	181.86	577.48	582.94
18	808.18	172.96	585.52	592.71
19	814.22	165.49	602.19	602.76
20	818.81	153.99	613.10	614.83
21	817.66	147.67	631.20	624.02
22	816.23	137.90	643.27	638.39
23	810.19	130.43	660.22	647.58
24	804.45	125.26	683.21	660.80
25	796.98	117.22	696.13	677.75
26	790.66	112.62	719.12	687.52
27	786.92	105.15	732.91	702.46
28	780.03	101.13	755.32	713.95
29	768.25	95.67	771.12	726.88
30	757.04	89.93	792.67	735.78
31	744.11	86.76	818.81	754.17
32	719.98	81.59	833.75	763.94
33	705.33	78.43	857.31	784.34
34	680.62	74.70	871.68	797.55
35	659.65	71.25	888.63	813.35
36	639.25	68.09	898.97	825.42
37	622.01	64.07	918.79	836.63
38	604.48	62.06	935.74	851.57
39	588.97	59.47	947.52	863.34
40	561.68	56.89	962.46	871.68
41	537.54	54.30	975.97	881.16
42	513.98	51.71	998.95	886.04
43	489.85	49.99	1011.59	892.65

C-angle Problem

CIE coordinate system

3.4.3 C-planes

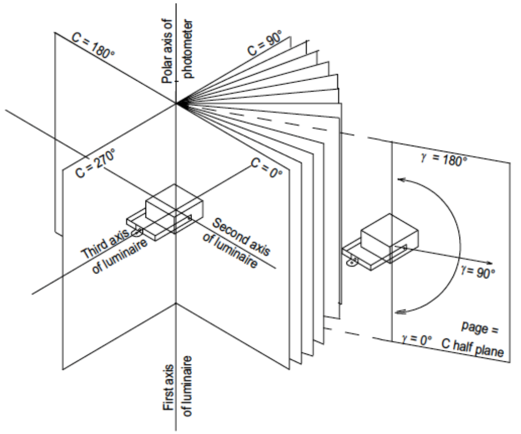
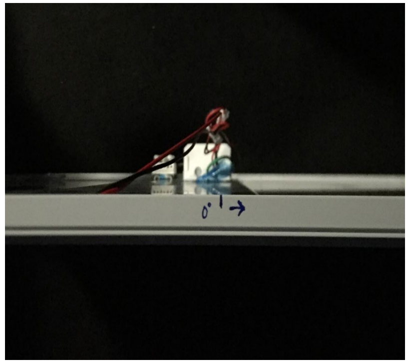


Figure 3.3. Luminaire orientation for C,γ goniophotometry.

C-angle origin and rotation marked on each artefact

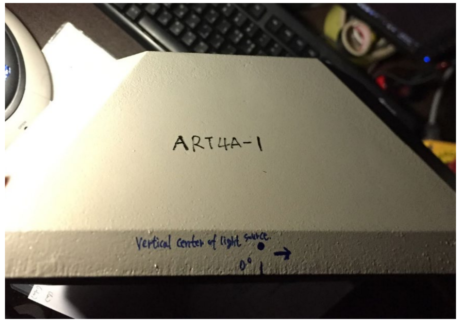
ART-1

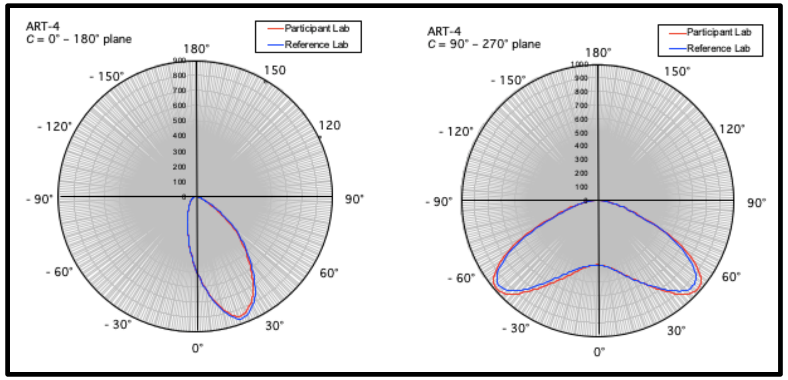
ART-2



ART-3

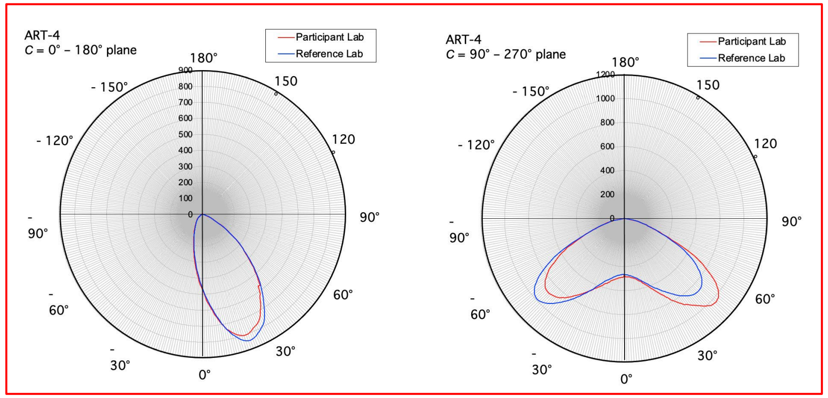
ART-4



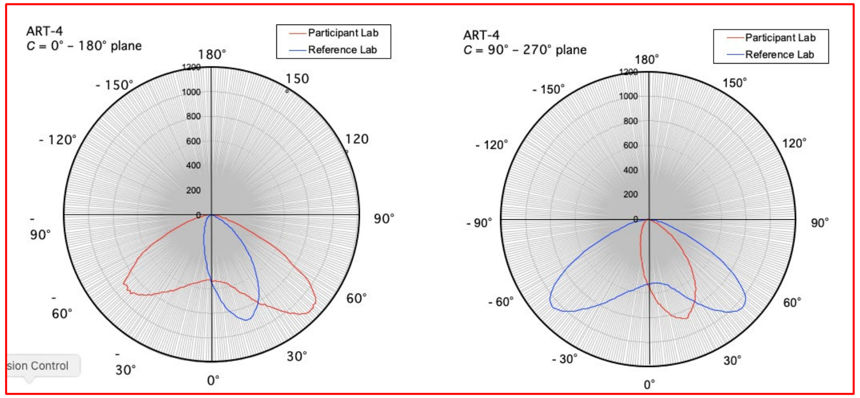


Correct setting

Problematic participants' data for ART-4



90° and 270° are opposite
(wrong rotation direction)

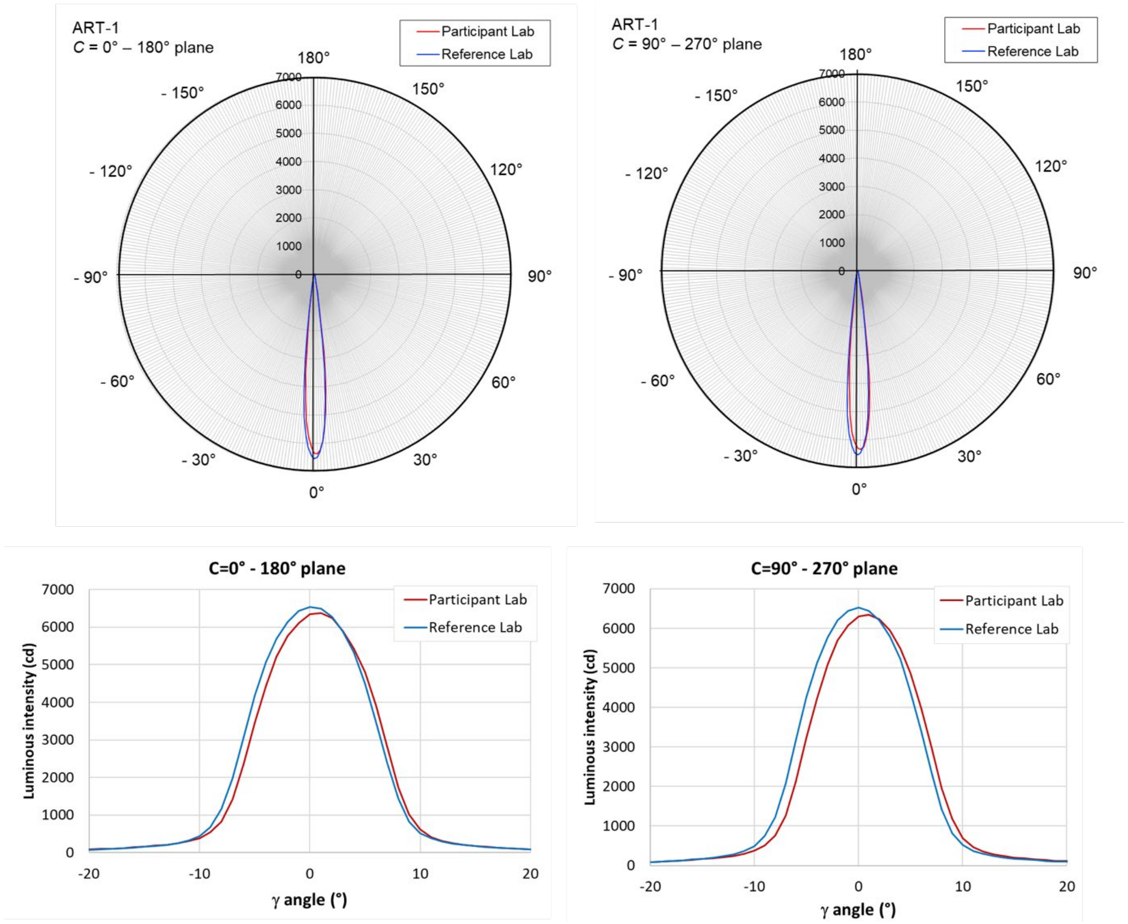


0° and 90° are opposite
(wrong 0° origin)

Analysis IV – Luminous Intensity Distributions

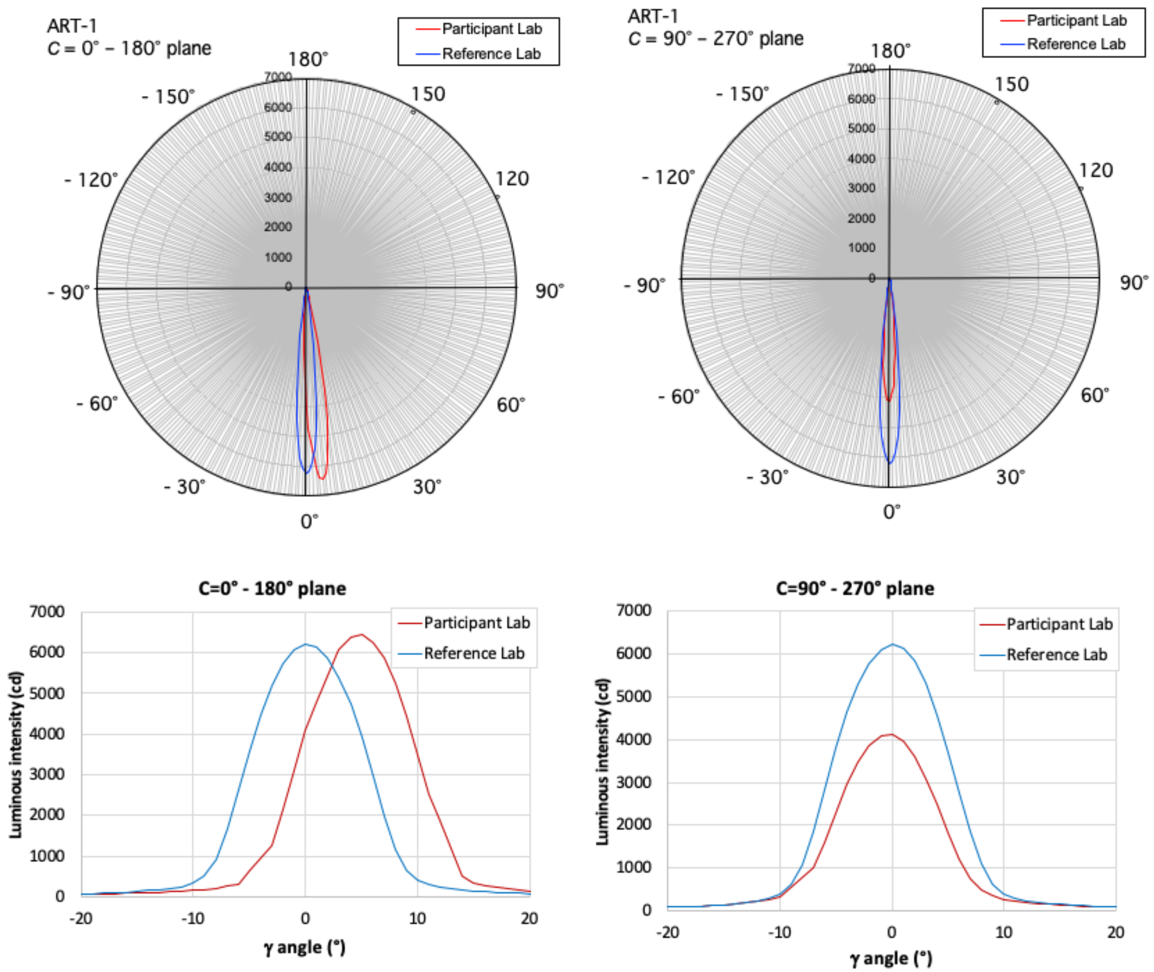
ART-1

(Typical example)



(Source-rotating type)

(Problematic example)

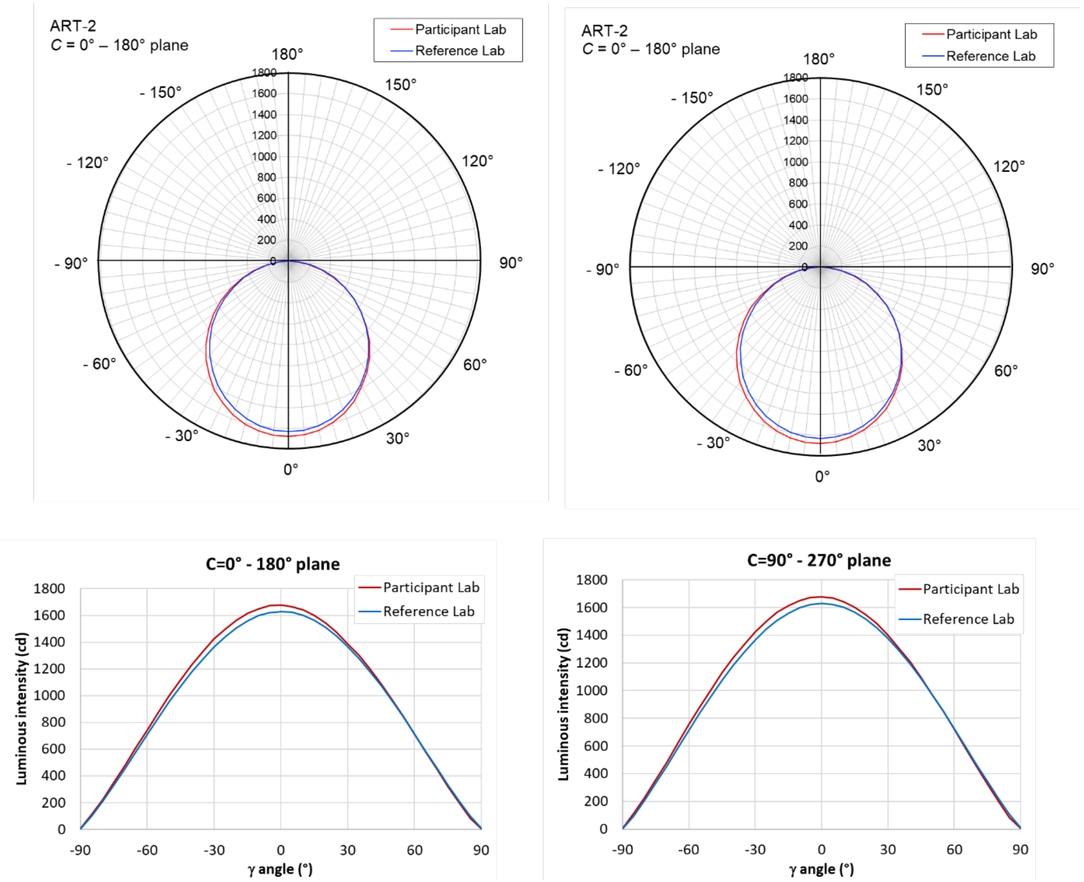


(Mirror type)

Analysis IV – Luminous Intensity Distributions

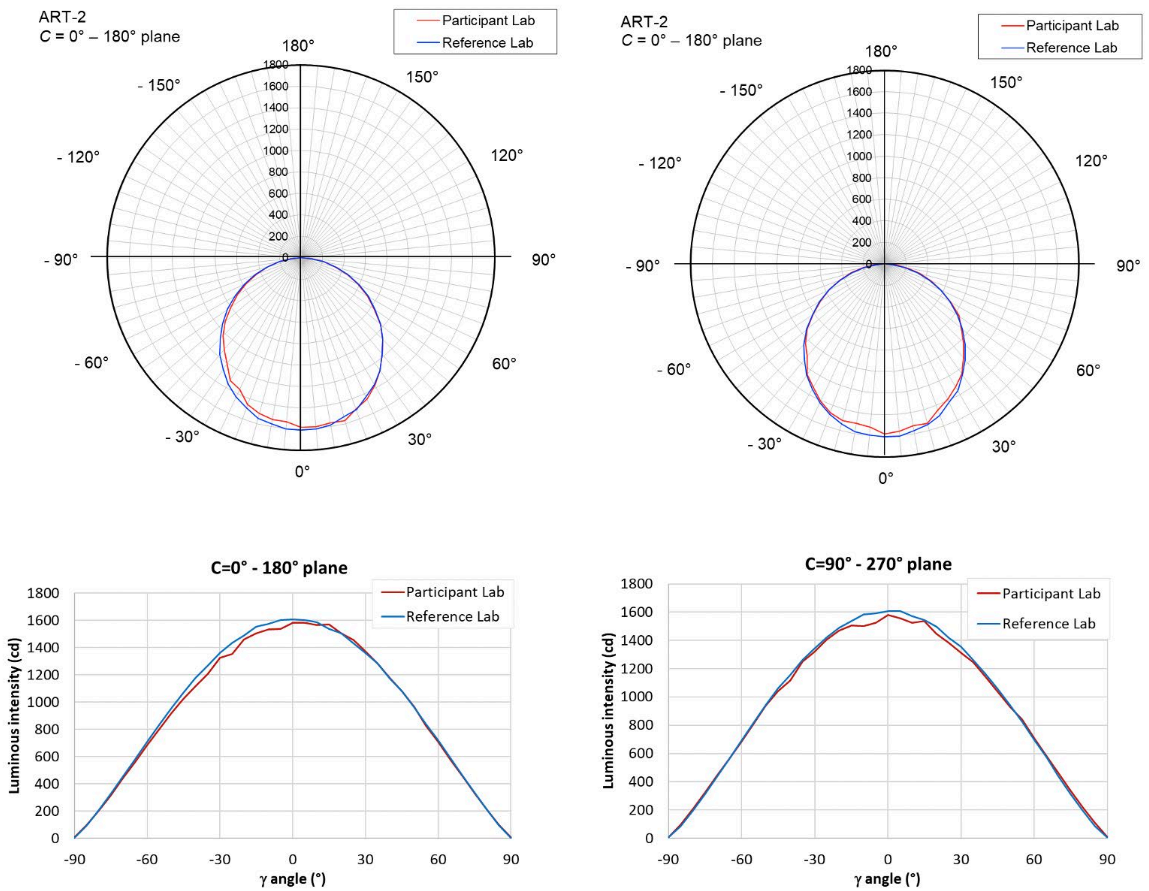
ART-2

(Typical example)



(Mirror type)

(Problematic example)

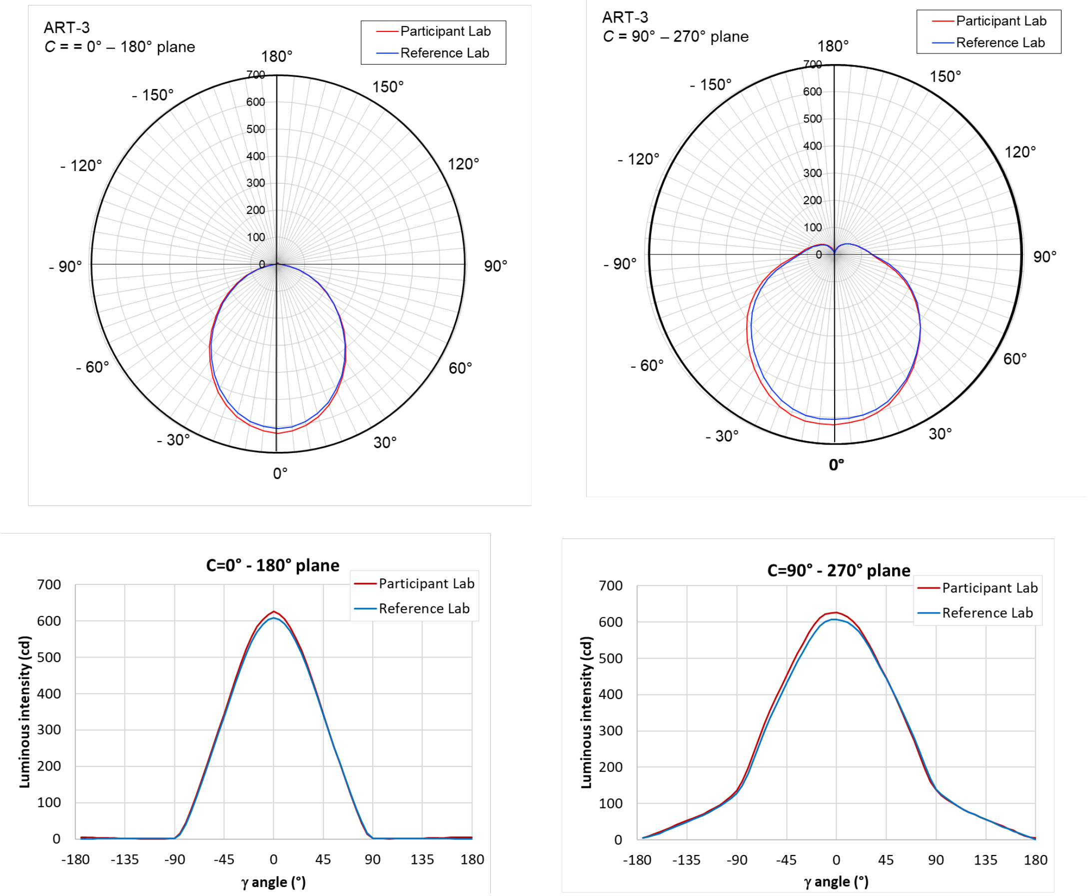


(Mirror type)

Analysis IV – Luminous Intensity Distributions

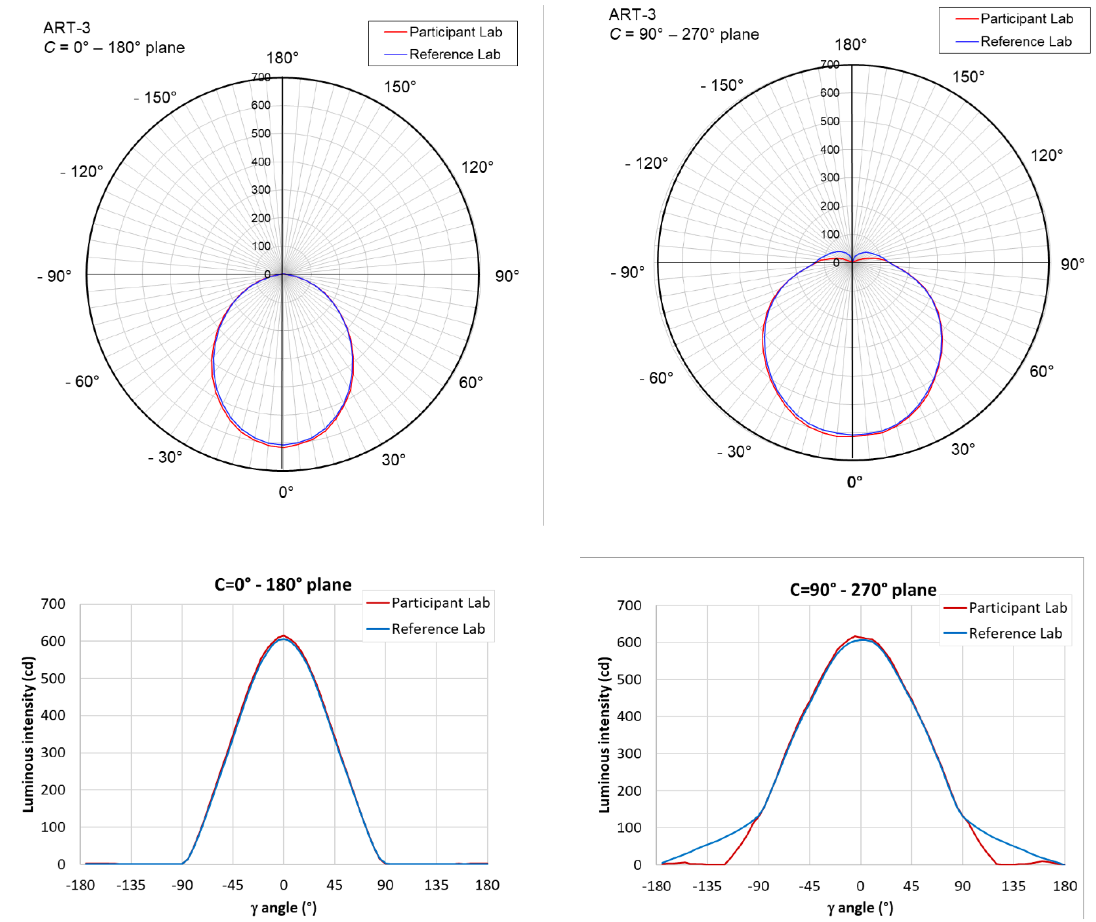
ART-3

(Typical example)



(Mirror type)

(Problematic example)

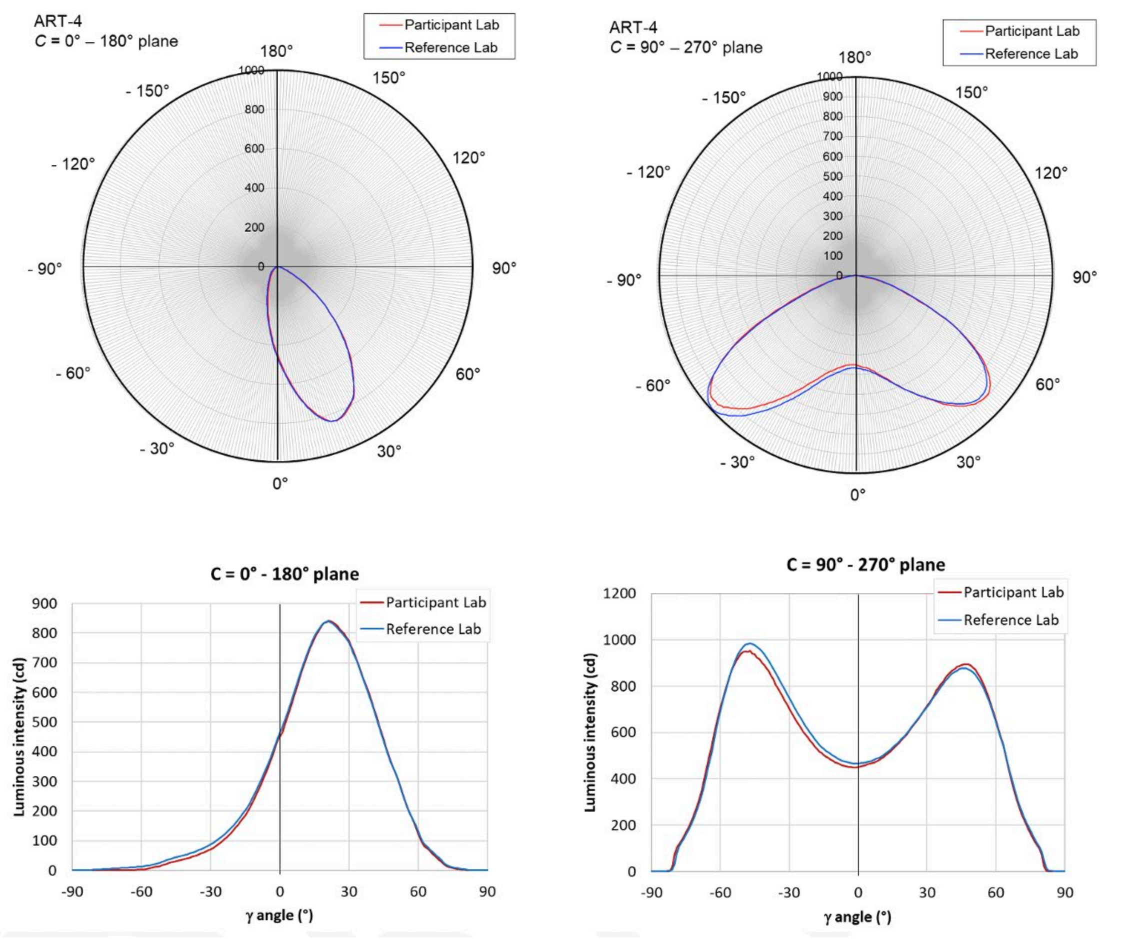


(Source-rotating type)

Analysis IV – Luminous Intensity Distributions

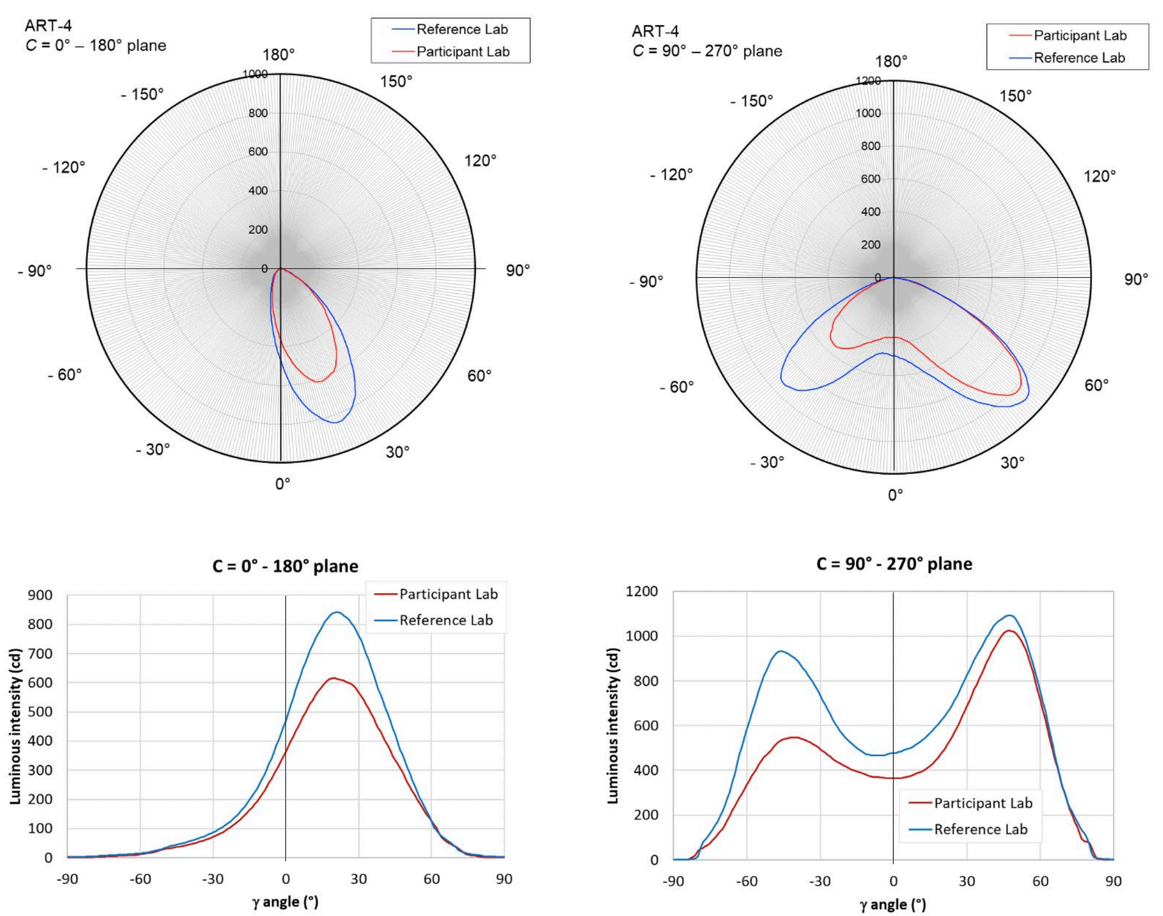
ART-4

(Good example)



(Source-rotating type)

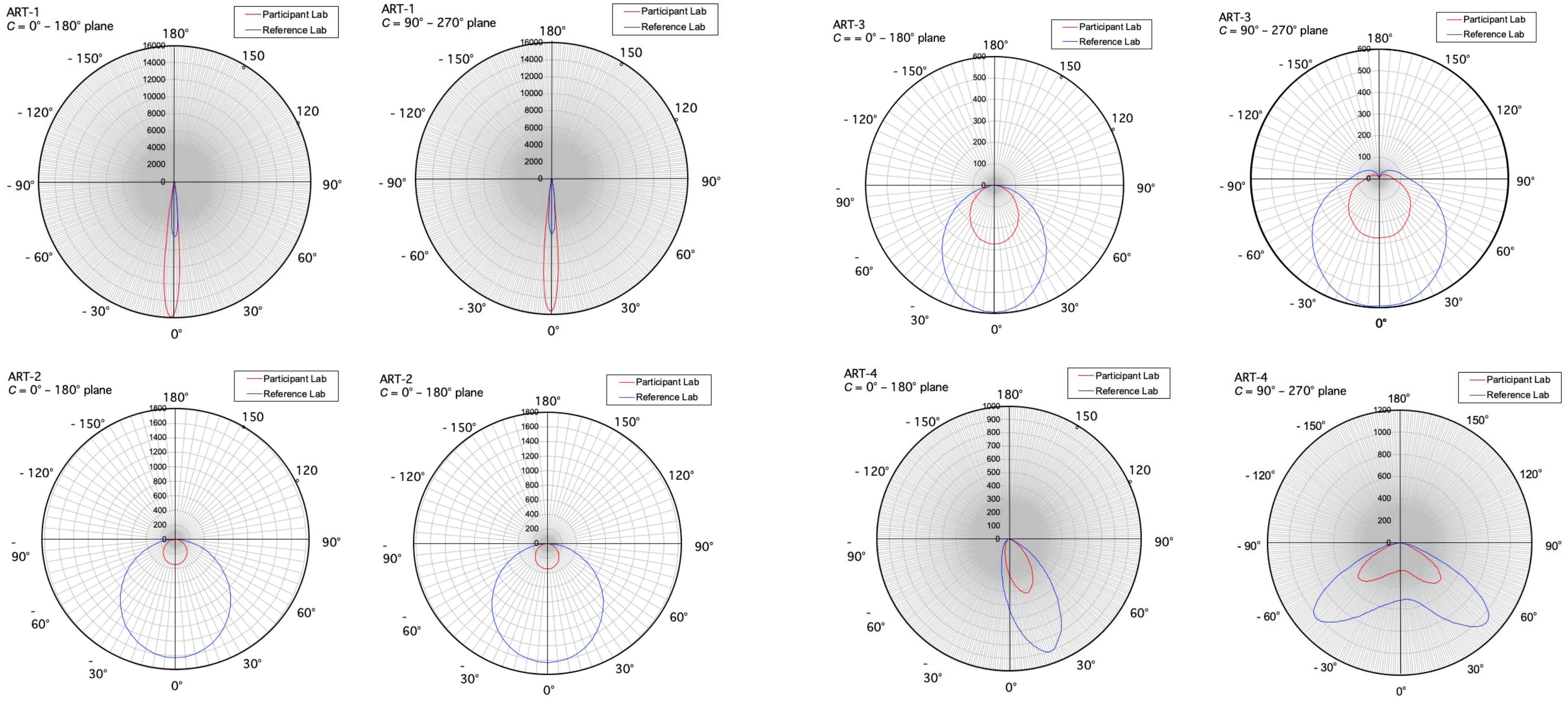
(Problematic example)



(Mirror type)

Analysis IV – Luminous Intensity Distributions

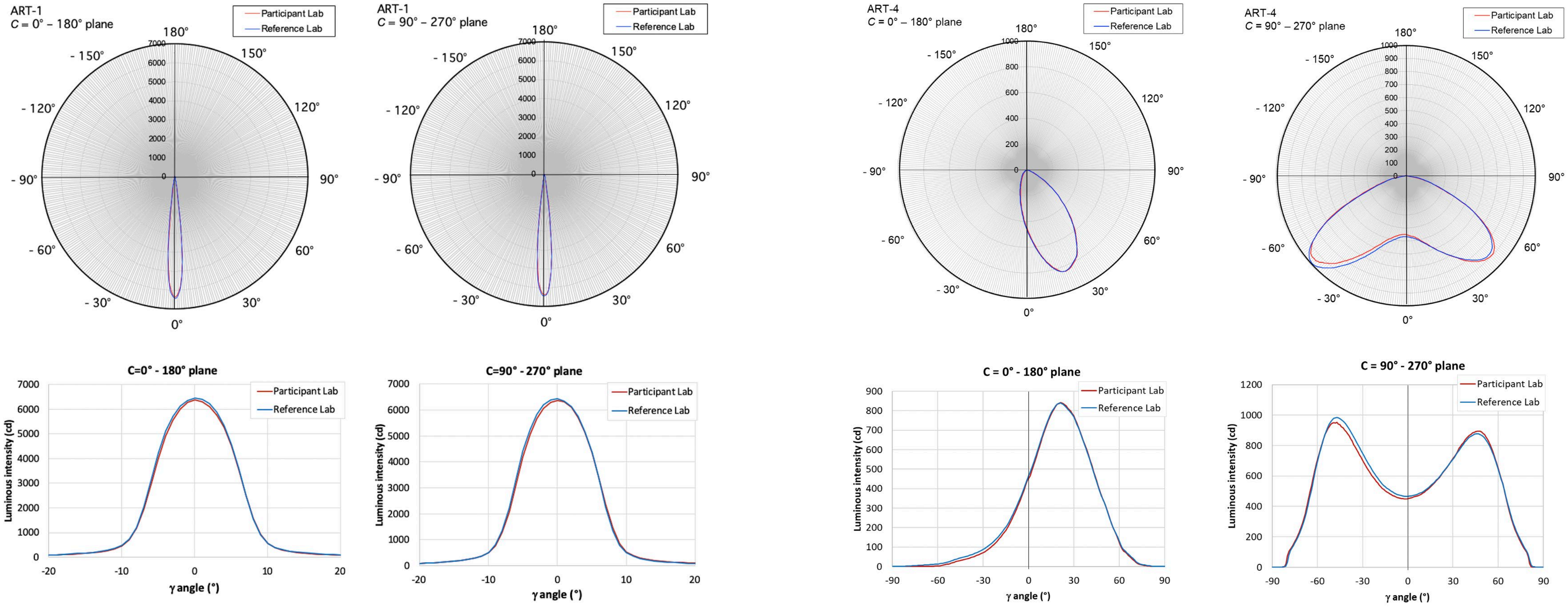
Use of wrong unit (cd/1000 lm)



Analysis IV – Luminous Intensity Distributions

Near-field type ART-1 and ART-4

(Good examples)



Summary of Findings

<Photometric and colorimetric quantities>

- Overall, reasonable agreement (though there were a few outliers for each quantity)
- Reported uncertainties were also reasonable in most cases.

<Electrical quantities>

- Large differences for different artefacts – RMS current, power factor
- Uncertainties were often underestimated

<Goniophotometric quantities>

- Partial luminous flux, beam angle – definitions mistaken by many labs
- Center beam intensity –half of the labs reported exactly equal to I(0,0)
- House-side downward flux – large variations (4x) not considered in uncertainty budget
- Angular color uniformity – deviations too large
- Uncertainties for gonio quantities not reported by many labs

<Luminous intensity distribution>

- C-angle rotation direction wrong (many labs), wrong 0° origin, wrong unit (cd/1000 lm) (some labs)
- Large differences in artefact alignment (ART-1, ART-4 – sensitive to angle)
- Source-rotating type showed dead angle problems in upper directions (4 out of 12 instruments).

<Comparison of different goniophometer types>

- Nearfield type and source-rotating type, overall, showed equivalence to mirror type
- Near-field type showed slight negative bias for ART-1 luminous intensity at its peak and ART-4 in (0,0) direction.
- Source-rotating type did not show any issues (except for the dead angle problem in some cases)

Feedback to CIE S 025

For further improvements of SSL product measurements with goniophotometers, further guidance on the following points in CIE S 025 will be helpful:

- correct settings of C-angle and rotation of LID data
- accurate alignment of beam lamps and luminaires
- calculation of centre beam intensity and beam angle
- uncertainty evaluation for goniophotometric quantities (as well as other quantities)
- acceptance criteria for near-field goniophotometers to demonstrate equivalence to a far-field goniophotometer (CIE Div. 2 working on it in DR2-69 ?); and
- acceptance criteria for source-rotating type goniophotometers (with required correction for operating position) – further investigation on the need for the correction.

Conclusions

- The Interlaboratory comparison of goniophotometric measurements of SSL products (IC 2017), with 36 participating laboratories with 42 goniophotometric instruments, was conducted successfully, making it the largest interlaboratory comparison of this kind ever undertaken.
- This comparison revealed **a number of specific problems** in measurement of **goniophotometric quantities** and indicated that more guidance is needed for these measurements.
- This comparison also verified that, overall, **near-field type and source-rotating type goniophotometers** used in this comparison **had equivalent accuracies** to far-field mirror type goniophotometers for the types of products used in this comparison. (Note: near-field type showed slightly higher uncertainty for a very narrow beam intensity distribution)
- Verification in this comparison did **not cover all types of products** in the market and goniophotometric instruments of all manufacturer/models. Further investigations are needed.
- The results of this comparison may be useful for **future improvements** in metrology, standards and practice in measurements of SSL products

IC 2017 Final Report was published on 20 December 2021, available at https://www.iea-4e.org/wp-content/uploads/2021/12/SSL-Annex-IC-2017-Goniophotometers-Final-Report-2021.12.20.pdf

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Prof. Georges Zissis (France)	SSL Annex Management Committee Chair
David Boughey (Australia)	SSL Annex Management Committee Deputy Chair
Nils Borg (Sweden)	SSL Annex Operating Agent

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Thank you for your attention!