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Geoscientific Instrumentation Methods and Data Systems Discussions

Results from the intercalibration of optical low-light calibration sources 2011

B. U. E. Brändström[1], C.-F. Enell[2], O. Widell[3], T. Hansson[3], D. Whiter[4], S. Mäkinen[4], D. Mikhaylova[1], K. Axelsson[1], F. Sigernes[5], N. Gulbrandsen[6], N. M. Schlatter[7], A. G. Gjendem[8], L. Cai[9], J. P. Reistad[10], M. Daae[8], T. D. Demissie[8], Y. L. Andalsvik[11], O. Roberts[12], S. Poluyanov[13], and S. Chernouss[14]

[1]Swedish Institute of Space Physics, Kiruna, Sweden
[2]Sodankylä Geophysical Observatory, University of Oulu, Sodankylä, Finland
[3]SSC, ESRANGE, Kiruna, Sweden
[4]Finnish Meteorological Institute, Helsinki, Finland
[5]The Kjell Henriksen Observatory, UNIS, Longyearbyen, Norway
[6]University of Tromsø, Tromsø, Norway
[7]School of Electrical Engineering, Royal Institute of Technology, Stockholm, Sweden
[8]Norwegian University of Science and Technology, Trondheim, Norway
[9]Department of Physics, University of Oulu, Oulu, Finland
[10]University of Bergen, Bergen, Norway

[11]Department of Physics, University of Oslo, Oslo, Norway
[12]Aberystwyth University, Aberystwyth, UK
[13]Polar Geophysical Institute, Murmansk, Russia
[14]Polar Geophysical Institute, Apatity, Russia

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Correspondence to: B. U. E. Brändström (urban.brandstrom@irf.se)

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Abstract

Following the 38th Annual Meeting on Atmospheric studies by Optical methods at Siuntio in Finland, an intercalibration workshop for optical low-light calibration sources was held in Sodankylä, Finland. The main purpose of this workshop was to provide a comparable scale for absolute measurements of aurora and airglow. All sources brought to the intercalibration workshop were compared to an international standard source (Fritz-Peak) using the Lindau Calibration Photometer built by Wilhelm Barke and Hans Lauche in 1984. The international standard source is on loan from Michael Gadsden, Aberdeen. The results were compared to several earlier intercalibration workshops. It was found that most sources were fairly stable over time with errors in the range of 5–20 %. To further validate the results, two sources were also intercalibrated at UNIS, Longyearbyen, Svalbard. Preliminary analysis indicate good agreement with the intercalibration in Sodankylä.

1 Introduction

Following the first absolute measurement of night airglow by Rayleigh (1930), accurate absolute measurements of airglow and aurora have become increasingly important. These measurements are traditionally expressed in Rayleighs as proposed by Hunten et al. (1956). In SI-units the Rayleigh is defined as follows (Baker and Romick, 1976):

$$1\,\text{Rayleigh} \equiv 1\,\text{R} \triangleq 10^{10}\,\frac{\text{photons}}{\text{s}\,\text{m}^2\,\text{column}} \tag{1}$$

The word column is often inserted in the units above and denotes the concept of an emission rate from a column of unspecified length along the line of sight. The apparent spectral radiant sterance, $L_\gamma(\lambda)$, can be obtained from the spectral column emission rate, $I(\lambda)$, (in R/Å) according to Baker and Romick (1976):

$$L_\gamma(\lambda) = \frac{10^{10} I(\lambda)}{4\pi} \frac{\text{photons}}{\text{s}\,\text{m}^2\,\text{sr}\,\text{Å}} \tag{2}$$

Note that neither the Rayleigh nor the Ångström ($1\,\text{Å} = 10^{-10}\,\text{m}$) are proper SI-units, yet they are frequently used and will be used in this paper in order to avoid confusion with earlier intercalibration results.

Optical instruments are usually calibrated by exposing the instrument to a calibration light source with a well-known spectral radiant sterance corresponding to a certain column emission rate. Comparing these calibration light sources against each other and against traceable national standards is done at intercalibration workshops. Following initial efforts in the 1960s by Michael Gadsden and by Torr et al. (1976, 1977), regular intercalibration workshops were organised (Torr, 1981, 1983; Torr and Espy, 1981). After the intercalibration workshop in Katlenburg-Lindau in 1983, Lauche and Barke (1986) constructed a calibration photometer for low brightness sources (Fig. 1). This was done in order to support the work by M. Torr in the European sector. When Hans Lauche retired, Widell and Henricson (2003) took over the responsibility for the intercalibration photometer, and following Ola Widell's retirement in 2011, this responsibility was handed over to the corresponding author of this paper. All technical documentation and drawings, raw data and results from the calibration photometer as well as previous intercalibration workshops are archived and available upon request. Table 1 is an attempt to list all known intercalibration workshops up to now.

2 Calibration sources

In this calibration effort ten calibration sources were compared against the Fritz-Peak international standard source. This radioactive ^{14}C-activated phosphor source is only used at intercalibration workshops. It is traceable to intercalibrations in the 1960s and the present calibration values, obtained against a national standard source (Q47 tungsten filament lamp, calibrated by the National Bureau of Standards in 1977) at an

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intercalibration made by Torr and Espy (1981). Apart from the Fritz-Peak international standard, the IRF-UJO-920B, L1614, Y275 and the MPI-2 sources are also radioactive ^{14}C activated phosphor sources. The spectral output is continuous and depends on the phosphor. Intercalibration data for some of these sources exists since the 1960s. Although very stable and easy to handle, these sources are nowadays rather difficult to transport due to safety regulations.

The ESRANGE Tungsten-lamp, as well as the IRF Lauche-lamp are both well-known tungsten lamps operated at a predefined lamp current. The ESRANGE Tungsten lamp was powered by an external powersupply, while the IRF Lauche lamp has its own constant-current supply. These sources are not considered as stable as the radioactive sources, but on the other hand, they are much easier to transport. It should be noted that ESRANGE sources were intercalibrated on 16 September 2011 at Swedish Institute of Space Physics in Kiruna, while all other sources except the FMI Sphere were intercalibrated on 19 October 2011, at Sodankylä Geophysical Observatory in Sodankylä, Finland. The FMI Sphere was intercalibrated on the same date at the calibration laboratory at Finnish Meteorological Institute's Arctic Research Centre (FMI-ARC), also in Sodankylä. The IRF sources as well as the MPI-2 source were intercalibrated at both locations.

Two sources were based on light-emitting diodes (LEDs): the ESRANGE MSP1 and the PGI Chernouss-38AM. The ESRANGE MSP1 has internal current regulators and is powered by a 28 V supply, while the PGI Chernouss-38AM was battery powered. Both participating LED-sources consist of several LEDs. Not much is yet known about the long-term stability of the LED sources.

The FMI-Sphere (Mäkinen, 2001) consists of an integrating sphere, three identical 30 W internal tungsten lamps, a 75 W external tungsten lamp with a mechanical attenuator, and several neutral-density (ND) filters. The ND filters are required to decrease the output of the sphere to acceptable levels for low-light instrumentation. The output of the sphere is calibrated by the manufacturer in foot lamberts (an American customary-unit for luminance: 1 ft-L corresponds to 3.426 cd m^{-2}). Note that this is a photometric unit involving the spectral sensitivity of the human eye, and that this calibrated luminance value is valid at the exit aperture of the integrating sphere, i.e. before the ND-filters. Thus, for the intercalibrating effort described here, the luminance value should only be regarded as a source setting. Yet, knowing the spectral response of the ND-filters, it is possible to compare the calibrated output of the sphere to the results presented in this report. It is our hope that this will be done in the future.

Some of the participating calibration sources are shown in Fig. 2.

3 Intercalibration procedure

The calibration photometer was installed in a darkroom and the Peltier cooler was switched on several hours before measurements, so that the photomultiplier tube (PMT) would be sufficiently cooled and thermally stable. One person operated the photometer and sources in the darkroom, while another person recorded the filter position and PMT-counts using a multimeter and a frequency counter located outside the darkroom. In addition an intercom was available between the darkroom and the outside. Filter position 0 is blocked and corresponds to dark-current, the remaining positions correspond to seven filters from 3914 to 6562 Å listed in Table 2. Position 8 corresponds to a filter with centre wavelength 6707 Å. This filter is included in the intercalibration procedure, but the results are traditionally discarded due to poor signal-to-noise ratio. Each source was then compared to the Fritz-Peak international standard. This was done according to the following procedure:

1. The source was attached to the centering device of the calibration photometer.
2. Three samples were recorded for each of the nine filter-wheel positions. Position 0 corresponds to the dark-current.
3. The Fritz-Peak reference source was replaced with the calibration source and step 2 above was repeated for that source. Meta-data was recorded, and the intercalibration result was calculated.

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This procedure has been unchanged as far as possible since 1984.

4 Results

The results from this intercalibration effort are given in Table 2.

Note that unreliable data with poor signal-to-noise ratio has been removed. All raw-data and preliminary results before post-processing are available at http://alis.irf.se/ewoc/2011.

Error estimation

The intercalibration was done under two assumptions: (1) the spectral radiant sterance of the Fritz Peak international standard source is stable and sufficiently well known, and (2) the calibration photometer is linear and stable during the calibration.

Aging effects of various components (sources, filters, PMT, etc.) will also contribute to the errors.

Figure 3 plots all intercalibration results from 1981 until the present time for three radioactive- and one tungsten lamp source. Table 3 lists the ratios of this intercalibration to earlier intercalibration workshops as well as to the mean value of all listed workshops. Sources not appearing in Table 3 have only been intercalibrated once, or earlier intercalibration data have not been found. As can be seen the sources are fairly stable over time at wavelengths where they have their peak output. However, for the last two filters (6299 and 6562 Å) the errors appear to be larger. This is believed to be due to lower signal-to-noise ratio resulting from the low output of the Fritz-Peak international standard source combined with the fact that the PMT has lower quantum efficiency for these wavelengths.

During the course "Optical methods in auroral physics research" at the University Centre in Svalbard (UNIS), the IRF Lauche-lamp and the PGI Chernouss-38AM sources were intercalibrated with an SN-1633 NIST-traceable tungsten lamp in the

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calibration laboratory at UNIS (Sigernes et al., 2007). Three measurements of each source were made, and preliminary ratios between the Sodankylä and UNIS intercalibrations are given in Table 4.

5 Conclusions

This paper presents the official result from the intercalibration workshop following the 38th Annual European Meeting on Atmospheric studies by Optical methods in Table 2. Ratios of this intercalibration to earlier work are presented in Table 3.

Preliminary results from an independent intercalibration of two sources in November 2011 at UNIS, Longyearbyen, Svalbard are given in Table 4. For the IRF Lauche source, deviations appears to be less than 15 % for wavelengths from 5573 Å. For shorter wavelengths this source has a very low output, as should be expected from a tungsten lamp. In addition the spectra of the sources were measured with a spectrograph. This should be done for all sources in the future. The spectrum of the PGI-Chernouss-38AM LED source was found to be continuous but with two sharp peaks. The ratios for the PGI Chernouss-38AM source are a bit more puzzling and, in particular, the large difference for 4866 Å remains to be explained. One possible preliminary explanation for the discrepancy is that while the former calibrations were done by a filtered photometer, the UNIS-calibration was done with a spectrograph. The spectrograph had a bandpass of approximately 100 Å while the photometer filters have bandpass around 20 Å. The PGI Chernouss-38AM source will be intercalibrated once more in Kiruna, to check for stability and possible measurement errors. This time all three intensity settings will be calibrated. It will also be powered from a regulated power supply instead of the supplied batteries. A report from the intercalibration session at UNIS will appear in a later publication.

The FMI MIRACLE EMCCD-imager normally operated at Kilpisjärvi was recently calibrated by the manufacturer, Keo Scientific in Canada (T. S. Trondsen, personal communication, 2011). To further validate this intercalibration this imager was calibrated by

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the FMI integrating sphere, and two of the IRF radioactive sources (920B and Y275). Data from this effort are not analysed yet and will appear in a later publication.

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Table 1. Known intercalibration workshops. The 1967–1972 intercalibrations are mentioned by Torr (1983). Regarding later calibration workshops lacking a literature reference, the results and raw data are archived by the corresponding author of this paper. Copies are available upon request.

Year	Sources	Location	Reference/responsible
1967		Fritz Peak	Gadsden and Marovich
1968		Paris	Weill
1969		Tokyo	Huruhata
1970		Kitt Peak	Broadfoot
1970		Harvard	Noxon
1970		Johns Hopkins	Schaeffer and Fastie
1972		MPI	Leinert and Klüppelberg
1979	9	Seattle	Torr (1981)
1981	30	Aberdeen	Torr and Espy (1981)
1983	21	Lindau	Lauche
1985	16	Lysebu	Lauche and Barke (1986)
1987	14	Saskatoon	Lauche
1989	1	Lindau	Lauche
1991	6	Wien	Lauche
1995	4	Boulder	Lauche
1999	18	Lindau	Lauche and Widell (2000b)
2000	9	Stockholm	Lauche and Widell (2000a)
2001	10	Oulu	Widell and Henricson (2003)
2003	8	Longyearbyen	Widell and Mämmi (2003)
2006	7	Kiruna	Widell and Henricson (2008)
2007	6	Andøya	Henricson (2008)
2011	10	Sodankylä	This paper

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Table 2. Results of the intercalibration workshop. All values are spectral column emission rate in R/Å.

Filter [Å]	3914	4280	4866	5573	5882	6299	6562		
Filter BW [Å]	41	27	25	16	13	12	15		
Source name								Settings	Note
FP transfer	0.34	5.7	3.2	2.6	5.1	9.2	15	Reference source Torr and Espy (1981)	
ESRANGE-MSP1	226	335	150	280	308	523	299	LED 28 V supply	1, 3
ESRANGE-Tungsten-lamp	3	10	61	359	544	728	635	10.9 V, 217.5 mA	1
ESRANGE-Tungsten-lamp			1	6	12	20	32	5.10 V 141.00 mA	1
FMI-Sphere		5	26	72	78	180	353	Lamp C, att. 150, ND7, 1473.3 ft-L	2
FMI-Sphere		9	49	139	150	348	696	Lamps C, att. 255, ND7, 3092.0 ft-L	2
FMI-Sphere	1	13	67	170	189	422	809	Lamps BC, att. 100, ND7, 3388.0 ft-L	2
FMI-Sphere	1	20	100	294	304	682	1311	Lamps BC, att. 255, ND7, 5947.0 ft-L	2
IRF-Lauche-lamp		1	8	54	96	207	352	1.62 V, 198.50 mA	3
IRF-Lycksele-lamp		1	9	72	150	360	489	6.21 V, 22.7 mA	4
IRF-UJO-920B	4	101	62	22	13	8	4	^{14}C Phosphor 920B	
IRF-UJO-L1614		1	38	34	9			^{14}C Phosphor L1614	
IRF-UJO-Y275			4	261	362	201	107	^{14}C Phosphor Y275	
MPI-2			2	173	263	187	93	^{14}C	
PGI-Chernouss-38AM	12	164	382	710	639	1520	1782	LED, setting 3 (max)	5

Notes: 1. Intercalibrated in Kiruna 16 September 2011, 2. Settings refer to lamp(s) in use, attenuator setting, neutral density filters and luminance in foot-lamberts before the neutral density filters, 3. Constant current supply, 4. Adjustable power supply, 5. Battery powered.

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Table 3. Ratios of the measurements in Sodankylä to earlier intercalibrations and to the mean value of all listed measurements. Sources not appearing in this table lacks information of earlier calibration workshops. 2011 refers to the intercalibration in Kiruna 16 September 2011.

Filter [Å] Source name	ratio	3914	4280	4866	5573	5882	6299	6562
IRF-Lauche-lamp	2000	0.95	1.02	1.00	1.07	0.98	0.93	0.78
	2001	1.06	0.93	1.06	1.12	0.84	0.91	0.82
	2007	1.20	1.06	0.98	1.06	0.90	0.92	1.06
	2011	1.06	0.99	0.98	1.02	1.05	0.66	0.37
	mean	1.05	1.00	1.00	1.05	0.95	0.86	0.70
IRF-UJO-920B	1981		0.67	0.95	1.19	1.36	1.12	0.55
	1985	0.77	0.80	1.01	1.17	1.26	1.14	0.49
	1999	0.89	0.99	1.03	0.99	1.10	1.01	1.66
	2000	0.85	0.93	0.97	0.95	1.04	0.77	0.47
	2001	0.75	0.96	0.95	0.99	1.02	0.83	3.32
	2006	0.80	0.95	1.00	0.95	0.94	0.81	0.25
	2007	0.91	1.03	1.01	0.96	0.87	0.65	0.86
	2011	1.81	1.03	0.99	0.84	1.03	0.78	0.83
	mean	1.02	0.91	0.99	0.99	1.05	0.87	0.63
IRF-UJO-L1614	1981		1.24	0.27	1.00	0.91		2.20
	1985	1.14	1.36	1.18	1.24	1.02		0.23
	1999	0.13	0.99	1.04	1.04	0.95		0.49
	2000	1.14	0.99	0.96	0.98	0.92		1.74
	2001	0.80	0.90	1.01	1.28	1.26		0.10
	2006	0.57	0.93	1.00	1.10	0.83		0.25
	2007	1.33	0.99	1.01	1.07	0.91		
	2011	0.80	1.03	1.01	1.13	0.93		
	mean	0.59	1.03	0.78	1.09	0.96		0.52
IRF-UJO-Y275	1981		6.00	1.12	0.92	0.91	0.84	0.77
	1985	0.33	0.70	1.01	1.04	0.96	0.93	0.94
	1999	1.00	1.05	1.01	0.99	0.94	0.71	0.65
	2000	1.00	0.95	0.98	0.95	0.89	0.71	0.59
	2001	5.00	1.17	1.06	1.01	0.75	0.73	0.69
	2006		0.91	1.03	1.03	0.91	0.89	0.72
	2007	1.00	1.11	1.04	1.02	0.87	0.77	0.82
	2011	0.33	1.00	1.03	0.98	1.06	1.21	0.73
	mean	0.88	1.06	1.03	0.99	0.91	0.84	0.75

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Table 4. Preliminary ratios of this intercalibration to measurements in November 2011 at the calibration laboratory at UNIS, Longyearbyen, Svalbard. The large differences for wavelengths below 5573 Å are expected since the IRF-Lauche-lamp is a tungsten lamp. For the PGI-Chernouss-38AM source the large difference at 4866 Å is more puzzling and remains to be explained.

Filter [Å]		3914	4280	4866	5573	5882	6299	6562
Source name	ratio							
IRF-Lauche-lamp	UNIS	0.02	0.10	0.32	0.85	0.89	0.96	1.11
PGI-Chernouss-38AM	UNIS	0.53	0.86	0.30	0.69	0.75	0.95	1.09

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Fig. 1. The calibration photometer built by W. Barke and Hans Lauche in Lindau 1984. The source under calibration is attached to the centering device on the left. A mirror and an optical path underneath lead the light through the filter-wheel to the photomultiplier tube (PMT) on the right.

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Fig. 2. Some of the low-light sources intercalibrated at this workshop. From left: IRF Lauche-lamp (and powersupply), PGI Chernouss-38AM, IRF UJO-Y275, IRF UJO-L1614, IRF UJO-920B, IRF Lycksele-lamp. Front row: the Fritz Peak international standard transfer source and the MPI-2 source.

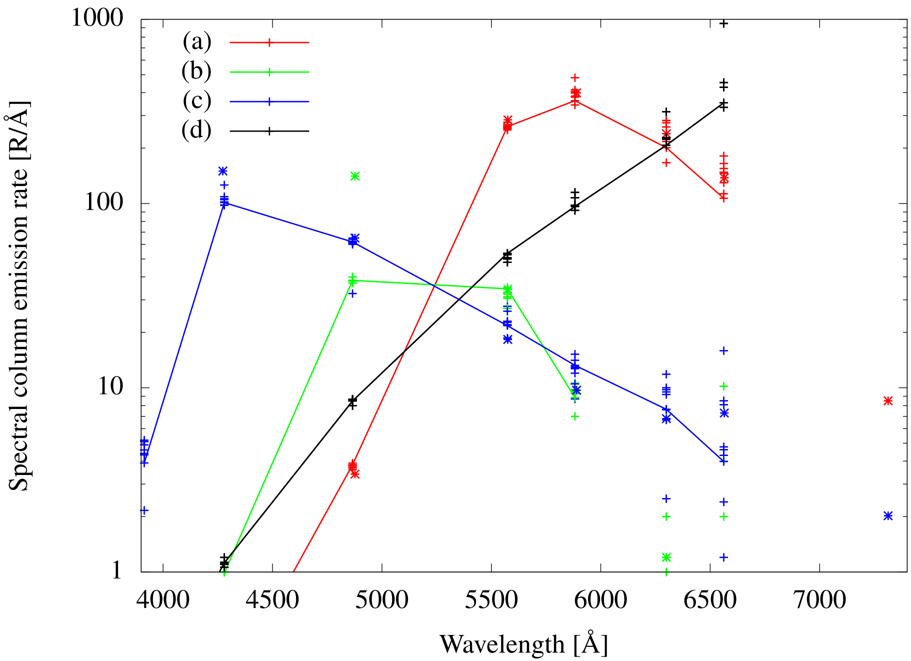

Fig. 3. Intercalibration results for three sources since 1981 **(a)** IRF-UJO-Y275, **(b)** IRF-UJO-L1614, **(c)** IRF-UJO-920B, **(d)** IRF-Lauche-lamp (since 2000) The Sodankylä results are connected with lines giving a rough idea of the spectra of these sources. The 1981 intercalibration used different filters indicated by "*".

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