A Laboratory of Photometry and Radiometry of Light Pollution (LPLAB)

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Abstract. We present the Laboratory of Photometry and Radiometry of Light Pollution (LPLAB) that we set up to provide the Light Pollution Science and Technology Institute (ISTIL) of instruments and calibration services to support its scientific and technological research on light pollution and related environmental effects. The laboratory equipments are characterized by low light intensity measurement and calibration capabilities and by the portability typically required by on-site measurements. Some of them have been set up for the specific needs of this field of study. Photometric and radiometric calibration services are provided by the laboratory to ensure that instruments are accurate and traceable to the National Institute of Standards and Technology (NIST). With the instruments of the laboratory a number of studies and collaborations are carried on, like the project "Global monitoring of light pollution and night sky brightness from satellite measurements", supported by the Italian Space Agency, and the project "Light pollution and the situation of the night sky at astronomical sites" carried on at the University of Padova, Italy.

Key words. atmospheric effects – light pollution – site testing – instruments – spectrophotometry

1. Introduction

The Laboratory of Photometry and Radiometry of Light Pollution (LPLAB) was set up to provide the Light Pollution Science and Technology Institute (ISTIL) of instruments and calibration services to support its scientific and technological research on light pollution and related environmental effects. Started in late 2001, it is probably the first laboratory born specifically and exclusively to study light pollution.

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2. Measurements and Instruments

The laboratory in practice consists of different instruments and calibration equipments. The measurement capabilities are:

- Measurements of luminance in CIE Photopic and CIE Scotopic passbands
- Measurements of illuminance
- Measurements of irradiance
- Measurements of Photosynthetic Active Radiation (PAR) photon irradiance
- Measurements of photon radiance
- Mapping of night sky brightness at sites in CIE Photopic passband, CIE Scotopic passband and UBVRI astronomical photometrical bands with atmospheric extinction
- Hyperspectral mapping of the night sky at sites
- Measurements of night-time radiance of the Earth surface
- Measurements of upward light emissions by polluting areas
- Imaging of light emissions in CIE Photopic response, CIE Scotopic response, UBVRI photometrical astronomical bands and other passbands
- Measurements of veiling luminance and disability glare
- Hyperspectral imaging of polluting areas and lighting installations
- Spectroradiometry of light sources
- On-site goniophotometry of upward light intensity of individual luminaries
- On-site measurements of bi-directional reflectance (BDRF)
- Measurements of the screening angle of a luminaire due to buildings

Fig. 1. WASBAM imaging camera

Main instruments are:

- SLR spot portable Luminance Meter (1 degree field)
- Spot portable Luminance Meter (6 degree field)
- Portable Quantum Radiometer and Illuminance Meter
- WASBAM (Wide Field Sky Brightness Automatic Mapper)
- WASBAM configured as spectrophotometer with Small Spectroscopic Head (SSH)
- WASBAM configured as an hyperspectral imaging camera (HIC)

WASBAM is a portable automatic instrument for monitoring night sky brightness and atmospherical transparency in astronomical photometrical bands. Main values are: fast and automatic coverage of the entire sky, lightness, transportability and quick set-up in order to take measurements from more sites in the same night (Cinzano, Falchi 2003a). A spectrographic head (SSH) with a De Amici prism and a tunable slit allows WASBAM to take spectra of the sky background with a dispersion better than 0.7 nm pixel^{-1} at 550 nm. This allows automatic mapping of the entire sky of a site with a sequence of spectra.

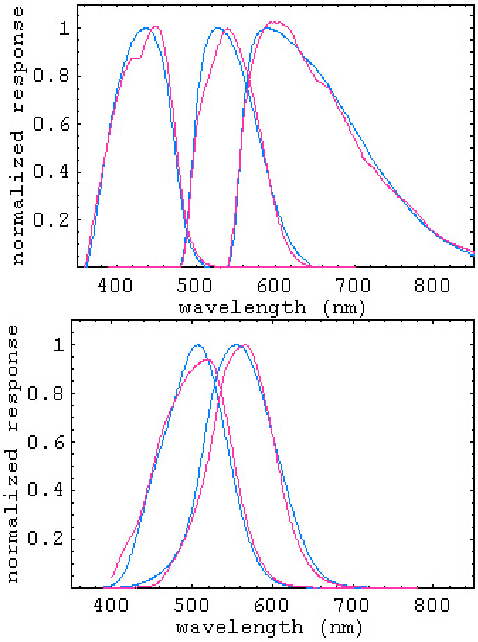

Fig. 2. WASBAM spectral responses (red) compared with the standard responses (blue): B band (Landolt 1992), V band (Landolt 1992), R band (Landolt 1992), CIE Photopic (1924), CIE Scotopic (1951)

Obtained spectra are reduced with IRAF (Cinzano 2003).

Hyperspectral imaging of polluting areas with WASBAM-HIC allows not only to have at one's disposal the complete spectra of each point of a lighted area but also to recover at any time, with a simple integration along the wavelength, an image of the area in any spectral response passband, including "Hg light" and "HPS light". It also allows to obtain an image of the colour indexes.

WASBAM also allows imaging of the luminance distribution of the visual field of an observer. Based on the luminance and the angular position of each pixel in respect to the direction of observation, the veiling luminance and disability glare can be easily evaluated. This method allows - when needed - to relax the hypothesis of spherical symmetry around the direction of observation in glare evaluation. The software is still under test.

Fig. 3. WASBAM-SSH spectrophotometer

The luminance meter, if accurately characterized, allows goniophotometric measurement on-site of luminaries, when on-site testing of lighting installations is required. In pratice it allows to measure the illuminance produced by a luminaire entirely contained inside its field of view. Subtracting the background luminance, and accounting for the distance measured with a laser distance meter, it is possible to evaluate the intensity of the light emitted by the luminaire in the direction of the observer. A digital inclinometer allows to evaluate the emission angle of the measured light.

Our surveillance of light pollution is also based on global measurements of the night-time radiance of the Earth surface made by the Operational Linescan System (OLS), an oscillating scan radiometer with a photomultiplier tube detector (PMT) carried by satellites of the Defense Metereological Satellite Program (DMSP) of the United Stated Air Force. We collaborate with the NOAA National Geophysic Data Center of Boulder which archives DMSP data.

Details are available in the web site www.lightpollution.it/dmsp/.

Fig. 4. SLR Spot Portable Luminance Meter

Fig. 5. Portable Quantum Radiometer and Illuminance Meter

3. Calibrations equipments

LPLAB main calibrations equipments are:

- NIST treaceable Spectral Irradiance Standard controlled by an high accuracy Radiometric Power Supply;

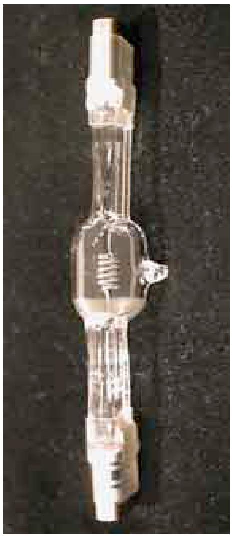

Fig. 6. Irradiance standard lamp

- Radiance calibrating device consisting of a NIST treaceable Spectralon Reflectance Standard illuminated by the Irradiance Standard Lamp controlled by the Radiometric Power Supply;
- Variable Low-Light-Level Calibration Standard consisting of an Uniform Integrating Sphere and some different light sources;
- The Moon and main Planets as illuminance standards.

Illuminating a Reflectance Standard target with a Spectral Irradiance Standard we obtain a radiance or luminance standard. Spectralon surface has one of the more flat spectral reflectance responses and this configuration allows one of the most accurate calibrations. However the radiance cannot be varied quickly, requiring to move the lamp or the target, the use of a non standard distance increase the uncertainty, very low light levels cannot be reached and radiance is not expected to have an outstanding spatial uniformity. So, for calibrating and testing photometers and radiometers to very low light levels, we set up a specific Low-Light-Level Calibration

Fig. 7. The Radiometric Power Supply and the Optical Rail

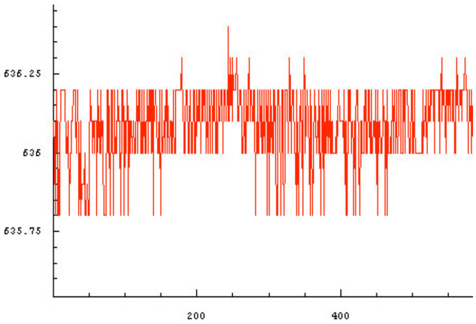

Fig. 8. Relative illuminance stability over 3 minutes (time unit is 0.3 seconds)

Fig. 9. Detail of the Variable Low-Light-Level Calibration Standard

Standard. It consists of an 8-inch diameter Integrating Sphere with the entrance port illuminated by a Spectral Irradiance Standard source or some other lamps (HPS, HQL, QTH, Illuminant A). Integrating spheres are hollow spheres which have their interior coated with a substance that is nearly perfectly lambertian and as much spectrally flat as possible, and are widely used to calibrate spectroradiometric measurement devices. Our sphere with two in-lined ports and an in-lined baffle is specifically made to obtain the best radiance and luminance uniformity over the 2-inch exit port. The radiance/luminance can be varied over a factor of $\approx 10^{10}$. In particular, a fixed aperture wheel provide a calibrated set of relative radiances or luminances to a factor 1:376 and a variable aperture stop with some optical devices allows to continuously regulate the starting luminance to a factor 1:45. The change of source or distance of the source from the input port allows further variation when needed. A shutter allows to measure the background light.

The Moon can be characterized as a spectral irradiance and radiance calibration source. For fixed illumination and observation geometry, the Moon can be considered photometrically stable to 10^{-8} per annum for irradiance and 10^{-7} per annum for radiance at a resolution of about 550 km (Kieffer 1997). The Moon, however, is a variable brightness source with a complicated luminosity function and it is decidedly non lambertian. The challenge in using the Moon as a radiometric standard is in characterizing its variation of radiance and irradiance with illumination and viewing geometry (Kieffer & Wildey 1996, Kieffer & Anderson 1998). Accurate Moon radiometry is carried on by USGS Robotic Lunar Observatory and expected errors on radiance are under 1% relative and 2.5% absolute. The knowledge of the radiance distribution along the lunar disk is not required when the Moon is used only as integral illuminance/irradiance calibration source, as happen calibrating a luminance meter or a radiance meter which usually has a field of view larger than the apparent diameter of the Moon (Cinzano 2003, in prep.). Events that would change the Moon integral illuminance/irradiance by 1% are expected once per 1.4 Gyr (Kieffer 1997) so that stability is of the order of 10^{-9} per annum. The uncertainty on the Moon integral irradiance phase curve (Lane and Irvine 1972) is approximately 5% but can be improved accounting for libration effects. The uncertainties of the calibration of the astronomical V band standards against NIST and the conversion to the CIE photopic response must be accounted too.

LPLAB also has a low intensity Mercury-Argon portable lamp with fiber optic cable for wavelength calibration and the Spectralon diffuse reflectance standard is also used together with a rotation table for reflectance measurements. A laser distance meter and a precision multi-point termohygrometer allow accurate set-up and monitoring during calibrations.

For more details see www.lplab.it and http://dipastro.pd.astro.it/cinzano/papers.html

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