Danish Meteorological Institute

Ministry for Climate and Energy

Danish Climate Centre Report 08-04

Earthshine Project Document: exposure guide for UBVRI filters

Peter Thejll

Colophone

Serial title:
Danish Climate Centre Report 08-04

Title:
Earthshine Project Document: exposure guide for UBVRI filters

Subtitle:
Authors:
Peter Thejll

Other Contributers:
Responsible Institution:
Danish Meteorological Institute

Language:
English

Keywords:
earthshine, telescope, exposure times, photometry, moon images

Url:
www.dmi.dk/dmi/dkc08-04

ISSN:
1399-1957

ISBN:
978-87-7478-560-6

Version:

Website:
www.dmi.dk

Contents

Colophon . . . 2
1 Dansk resumé **4**
2 Abstract **5**
3 Introduction **6**
4 Estimating the photon flux **6**
4.1 The Earthshine spectrum . . . 6
4.2 Optical transmission of the telescope and CCD camera . . . 7
4.3 The calculation of fluxes, exposure time ratios and exposure times . . . 7
4.4 Results . . . 8
4.5 Discussion and Conclusions . . . 8
5 References **12**
Previous reports . . . 13

1. Dansk resumé

Exponeringstiderne der kræves for at få samme kvalitet fotometri i Johnsons U,B og V filtre ved observationer af jordlyset undersøges ved hjælp af simulerede Måne-spektre, atmosfærisk transmission, og viden om det optiske systems transmission.

2. Abstract

Exposure times needed to deliver uniform-quality photometry in the Johnson UBVRI filters of earthshine are estimated using knowledge of the Lunar spectrum, atmospheric transmission and knowledge of the optical transmission properties of the earthshine telescope and camera system.

3. Introduction

The Earthshine project seeks to build a long-term database of terrestrial albedo data, by observing the earthshine on the Moon. The hardware of the system consists of a series of small autonomous telescopes, now being built at Lund Observatory under a VINNOVA grant. One input to the creation of the hardware system is an estimate of which observing modes are possible - and given constraints on the size of the telescopes it is possible to determine which exposure times are possible, as this is a quantity that can be calculated from telescope specifications and knowledge of the expected fluxes. The system will be photometric in nature and observe the Earthshine through a series of filters, as well as in 'White Light' - i.e. no filtering, except an IR cutoff filter. See DMI Technical report 04-18 for more details on the project

The expected exposure times through given photometric filters is needed. We can estimate the exposure times if we know the expected earthshine spectrum. This can be found form knowledge of the Solar spectrum, reflective properties of the lunar surface, transmission properties of the terrestrial atmosphere, and the transmission properties of the telescope and camera system, with filters. This report estimates the exposure times required in the Johnson UBVRI bands.

4. Estimating the photon flux

4.1 The Earthshine spectrum

The spectrum of the Earthshine is really the spectrum of the Sun, the Earth and the Moon combined into one: This is because sunshine falls on the Earth and is modified by the reflection, then this earthshine falls on the Moon and can be seen on the dark side of the Moon after a reflection there - this reflection modifies the spectrum again, and lastly that spectrum is transmitted through the terrestrial atmosphere and is recorded in a telescope+camera system that in itself modifies the light.

Earthshine spectra have been directly observed (Woolf et al., 2002; Arnold et al., 2002; Montañés Rodriguez et al., 2004; Hamdani et al., 2006) at various wavelengths and in various fashions: Woolf et al. give a raw (i.e. not corrected for instrumental sensitivity across the spectrum) spectrum in the 500-900 nm range and a spectrum of the earthshine in this range divided by the Moonshine spectrum ('Moonshine' is the light from the Solar-lit part of the Moon; 'Earthshine' is the light from terrestrially lit side of the Moon); this effectively removes the solar spectrum and the effects of the instruments used and the lunar albedo itself as well as some of the effects of transmission through the atmosphere. Left over is the effect of the reflection on the terrestrial atmosphere, and the spectrum is referred to as a 'reflectance spectrum'. Such a reflectance spectrum is of interest in itself because it tells us about the reflective properties of the Earth, but in the present context of estimating exposure times for earthshine photometry it can be used, if multiplied by the expected Moonshine spectrum, to give us the expected earthshine spectrum as seen inside the atmosphere. Similar reflectance spectra are shown by Arnold et al (2002) covering 400-800 nm. Hamdani et al (2005) show reflectance spectra from 320-1020 nm.

We will first show how to calculate the Moonshine spectrum as seen by a terrestrial observer. We employ the fact that since the effects of reflection and transmission combine multiplicatively we can estimate the observed Moonshine spectrum by simulating the reflection on the Moon of a spectrum already prepared to show the effects of transmission through the atmosphere.

The Moonshine spectrum can be estimated from a Solar spectrum given knowledge of the lunar albedo's dependence on wavelength. Per Knutsson (Knutsson, 2008) shows that the lunar albedo is a linear function of wavelength from below 320nm to above 800nm, and calculates the Lunar spectrum by multiplying the solar spectrum by the albedo function. Figure 4.2 shows, in the top row, the solar and lunar spectra outside the Earth's atmosphere. The Lunar spectrum is clearly redder than the solar spectrum, which is the effect of the lunar surface albedo. Introducing the effects of the atmosphere, (middle row in Figure 4.2), shows the appearance of telluric bands due to water, carbon-dioxide and Oxygen and Ozone molecules.

The effect of transmission through the terrestrial atmosphere is introduced by using spectra of the Sun as it would appear inside the atmosphere. This is calculated using the SMARTS model, and the results can be found on the Internet (http://www.nrel.gov/rredc/smarts/). We use the airmass=1.5 spectrum given there.

We are now ready to estimate what the Earthshine spectrum looks like: We have the ratio of Earthshine to Moonshine from the observations cited above and multiply this by the Moonshine spectrum. The result is shown in Figure 4.3. This spectrum can now be used in calculation of exposure times, given detector and filter properties.

4.2 Optical transmission of the telescope and CCD camera

We also need to know the transmission properties of the combined telescope and CCD. We know the sensitivity curve for the CCD camera we shall probably use: the DU-937N-BV camera by Andor. The sensitivity curve is given in the technical specifications of that camera.

The lenses chosen (Edmund 32-327, 32-323 and 45-180) have several different types of glass. The transmission curves are given in the Edmund Optical Co catalog and the longest short-ward transmission cutoff is set by the presence of SF10 and BaFN10 glasses in two of the lenses. This limits the transmission to 80% at about 385 nm or longer.

Additionally, the UBVRI filters have specified transmission properties. These are given e.g. for specific observatories on the Internet or in the literature. We have adopted the U filter from the Johnson system as given in the file ph11.U on the site ftp://obsftp.unige.ch/pub/mermio/filters/ while the BVR filters are the Bessel f/4 filters found at the Las Campanas Observatory site (http://www.lco.cl/telescopes-information/magellan/instruments-1/imacs-1/transmission-curves/pdf-s-filters/data-file/) while the I filter is the f/4 CTIO filter from the same site.

4.3 The calculation of fluxes, exposure time ratios and exposure times

The flux passing through the telescope+CCD system, in band X, is proportional to:

$$n_X \sim \int F(\lambda) \times T_{opt,X}(\lambda) d\lambda, \tag{4.1}$$

where $F(\lambda)$ is the earthshine flux, and $T_{opt,X}(\lambda)$ is the wavelength-dependent throughput of the optical system, CCD camera and filter X.

We can calculate the ratio of exposure times in two bands - this makes it unnecessary to know the proportionality factor s implicit in equation 4.1. We can then calculate actual exposure times in a given band by using the ratios found and exposure times from real observations in known bands, optionally scaled for light-gathering efficiency factors due to telescope design.

We can scale our exposure information to the values found by the BBSO effort. Their telescope has properties (notably focal length) that makes our telescope about 2.6 times more effective - that is, for the same exposure time we capture 2.6 times more light. At a particular lunar phase the BBSO, exposing in 'White Light' - i.e. gathering all light short-ward of an near-IR cutoff set by a filter (700nm) - need 1 minute. By integrating the earthshine flux below this cutoff we can get our simulated flux for White Light observations and scale to this.

4.4 Results

We calculate the ratio of the number of photons in the BVRI bands to that in White Light next, We find that the same number of photons will be registered in the B filter as in WL if the B filter is exposed for 6 times longer. For V the factor is 3.4, for R it is 2.3 and for I it is 2.9. For the U filter the required exposure time is a huge factor - and it is also very sensitive to the transmission cutoff at short wavelengths. With a cutoff at 380 nm 3600 times longer is needed than in WL, while with the cutoff at 320 nm the factor is 140.

As our system is 2.6 times 'faster' than the BBSO system we expect to have exposure times, at the same lunar phase as the scaling example from BBSO, of 2.3,1.3,0.9 and 1.1 minutes in the BVRI bands, respectively, while the U band might be done in 55 minutes, at that particular lunar phase.

4.5 Discussion and Conclusions

The throughput of the CCD camera and atmosphere are such that we can expect to get reasonable fluxes in the visual and near IR - i.e., if we wanted to observe the vegetation red edge photometrically we can expect to have enough flux - while fluxes in the UV are so low that extremely long exposures are needed.

The intensity of the Earthshine is a function of the terrestrial phase, which is complementary to the lunar phase; thus, at small lunar phases the earthshine is bright and we can hope for shorter exposure times than the 1-minute example (for the dark side, that is! Bright side exposures are MUCH shorter and give us no problems) given by the BBSO experience. We may hope to observe earthshine that is perhaps 5 times brighter at smaller lunar phases and could thus see exposure times of tens of seconds in the BVR and I filters. The U filter might then become observationally accessible - but this requires a UV-cutoff in the system that is very low (near 320nm), probably requiring a choice of very special optical glasses for lenses.

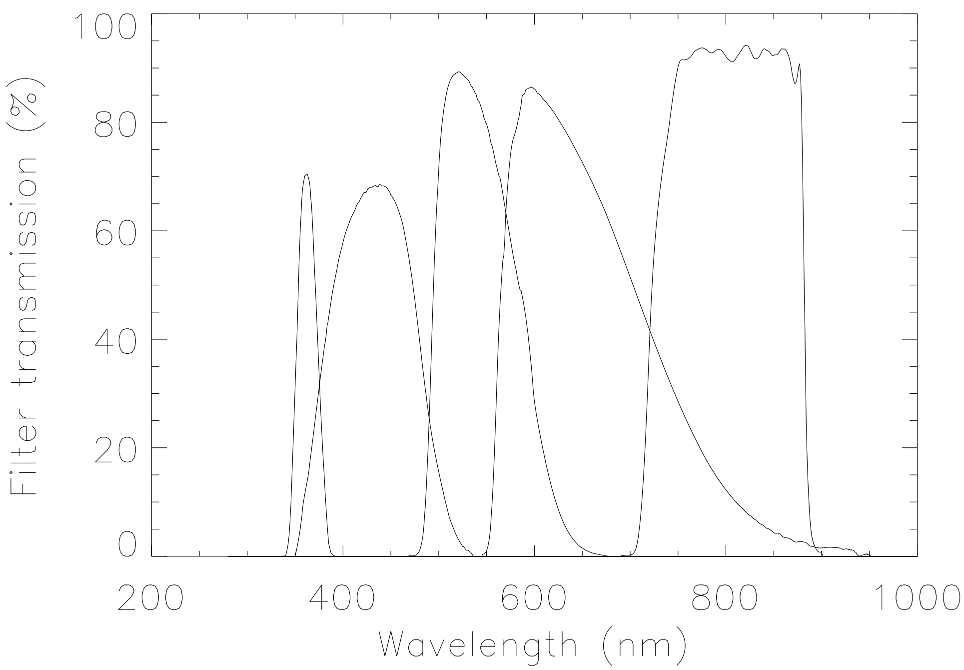

Figure 4.1: The Johnson UBVRI filter system transmission curves. The transmission is given in percent, and the wavelength in nm.

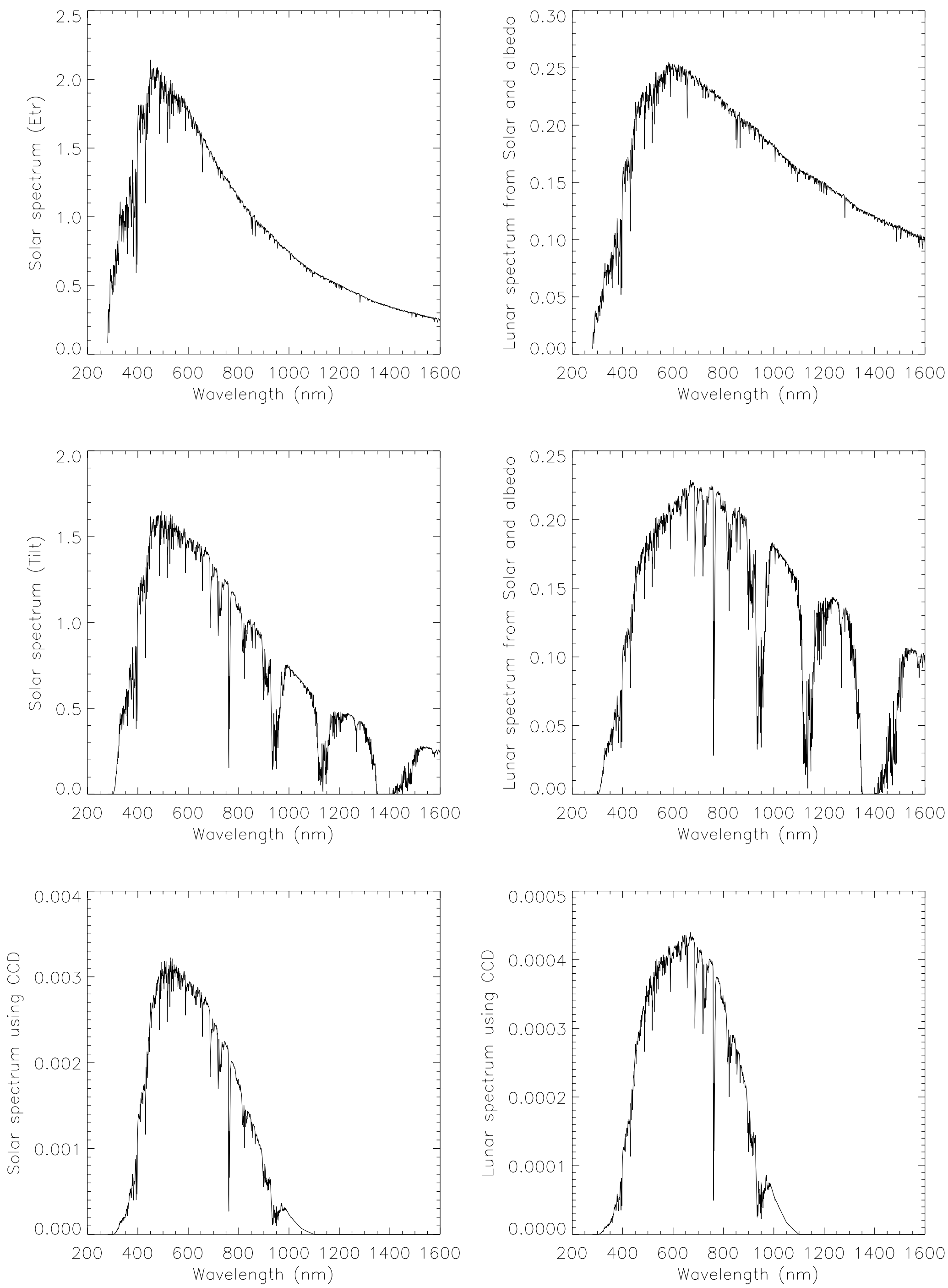

Figure 4.2: Solar and lunar spectra outside Earth's atmosphere (top row), inside the atmosphere at airmass=1.5 /middle row), and (bottom row) the observable spectra after throughput of the system is taken into account.

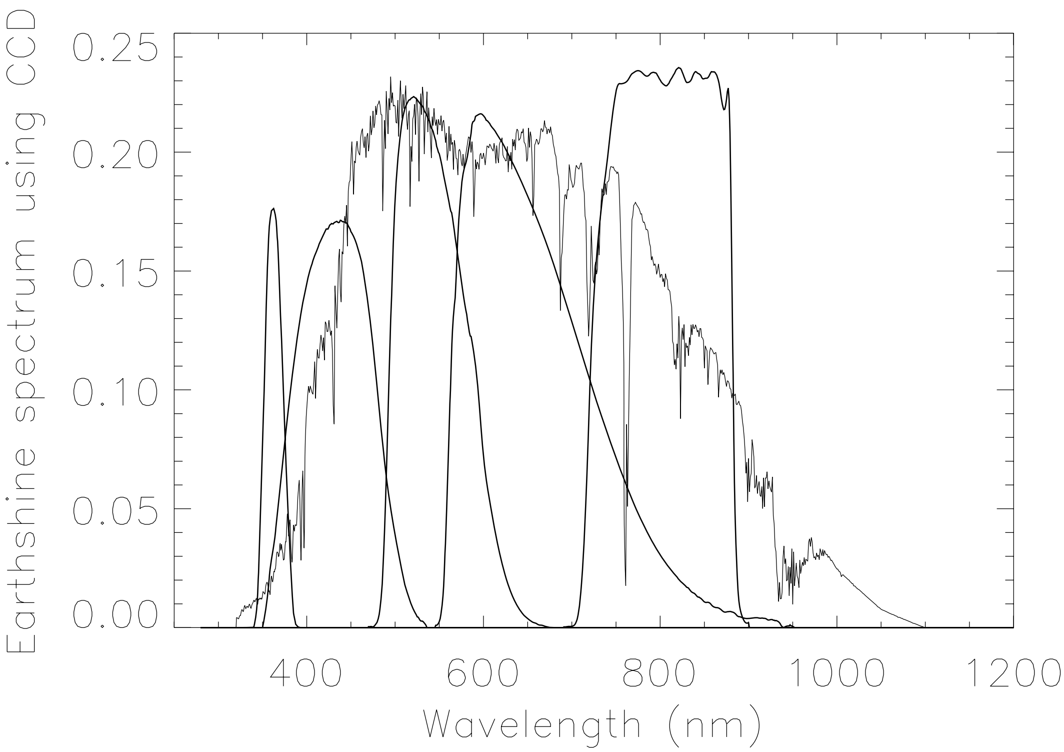

Figure 4.3: Earthshine spectrum as seen on Earth through a specific optical system (telescope and CCD camera). Overlaid are the UBVRI filter transmission curves.

5. References

[Arnold et al., 2002] L. Arnold, S. Gillet, O. Lardière, P. Riaud, J. Schneider, "A test for the search for life on extrasolar planets: Looking for the terrestrial vegetation signature in the Earthshine spectrum", Astronomy and Astrophysics, 392(1), p. 231-237, 2002.

[Hamdanai et al., 2005] S. Hamdani, L. Arnold, C. Foellmi, J. Berthier, D. Briot, P. François, P. Riaud, J. Schneider, "Near-UV to near-IR disk-averaged Earth's reflectance spectra", IAU Colloquium 200 (IAUC 200) 'Direct Imaging of Exoplanets: Science and Techniques', October 3-7, 2005, Nice, France, C. Aime and F. Vakili, Eds., Cambridge University Press (CUP), p. 83-88, 2005.

[Knutsson, 2008] Knutsson, P., "Experimental Adaptive Optics. A test facility for adaptive optics on a small telescope", PhD thesis, Lund Observatory, 2008.

[Montañés Rodriguez, 2004] P. Montañés Rodriguez, E. Pallé, P. R. Goode, J. Hickey, J. Qiu, V. Yurchyshyn, M. C. Chu, E. Kolbe, C. T. Brown and S. E. Koonin , "The earthshine spectrum", Advances in Space Research Volume 34, Issue 2, Pages 293-296, 2004.

[Woolf et al, 2002] Woolf, N.J., P.S. Smith, W.A. Traub, and K.W. Jucks, "The spectrum of Earthshine: A pale blue dot observed from the ground", Astrophysical Journal 574, pp. 430-433, 2002.

Previous reports

Previous reports from the Danish Meteorological Institute can be found on:
http://www.dmi.dk/dmi/dmi-publikationer.htm