Zernike power spectra of urban light-polluted cloudless night skies

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Abstract

All-sky night brightness images can be efficiently analyzed using the Zernike circle polynomials. We present here the results of a one-year campaign of all-sky night brightness measurements taken in several photometric bands at the UCM Astronomical Observatory in Madrid. Our analysis shows that cloudless skies at urban locations with moderate to high levels of light pollution can be well described by low-order expansions in the Zernike basis. The corresponding Zernike power spectra tend to decrease exponentially with the Zernike radial order, n.

All-sky night brightness maps

All-sky night brightness maps are calibrated images of the celestial vault taken at standard photometric bands. They are instrumental for measuring the spatial distribution of the artificial light scattered by the atmosphere, as well as for determining the direct radiance coming from artificial sources present within the field of view (FOV).

Fig. 1: B-band image taken at Nov. 11th 2012, 21:30:54 UT.

The present work analyzes the all-sky maps recorded in moonless and cloudless nights at the Astronomical Observatory of Univ. Complutense de Madrid (40° 27′ 04″ N 03° 43′ 34″ W) during the period Nov. 2012 - Nov. 2013 at the Johnson-Cousin’s B, V and R photometric bands using an all-sky Astronomical Monitor (AstMon) camera. The celestial vault is mapped into a circle using a Lambert’s zenithal equal area projection (ZEA).

Zernike expansion of the all-sky maps

All-sky night brightness maps can be efficiently described by low or moderate order Zernike expansions (Mc100):

\[ \hat{B}(r) = \sum_{k=1}^{R} \hat{a}_k Z_k(r) \]

Fig. 2: Defining the unit-radius circle (left) and excluding obstacles and artificial sources (right) within the FOV of Fig. 1 to fit the anthropogenic radiance scattered by the atmosphere. Scale in mJy/arcsec²

The maps were fitted up to the n=10 radial order (66 individual Zernike modes), using about 36,000 points within the selected region (Fig. 2, right, with R=10, Rn=0.95). These figures display the results for the B, V, R bands.

Zernike power spectra of cloudless skies

240 all-sky maps (80 per band: B, V, R) recorded during this period fulfilled the conditions of being cloudless skies with the Moon below the horizon.

Extending the Zernike power spectrum to the region of high spatial frequencies (n>10) is somewhat troublesome when the horizon rim is blocked by the presence of artificial or natural obstacles. In that case one lacks enough data points close to the horizon as to guarantee an efficient sampling of the high order modes, that only take appreciable values close to the rim. As a consequence the Zernike polynomials lose their orthonormality, the modal and overall noise propagators (Np) increase and noise propagation becomes the dominant contribution to the estimated second-moment matrix C4, masking the true spectrum.

Restricting the Zernike expansion to a circular region free from obstacles (i.e., redefining the unit-radius circle), the orthonormality is retrieved, the noise propagators decrease and the spectrum for this region can be estimated. The results of the power spectrum of the B-band night sky brightness expanded within a unit radius circle with \( R=0.8R \) and \( R_n=0.95 \) (in normalized ZEA radial units) are shown here:

High frequency components of the central region of the sky (\( R=0.80R \))

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