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Processing of the frames archive of the CMO SAI MSU RC-600 telescope to study changes in the sky background brightness

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The paper analyzes the results of measurements of the sky background brightness of the Caucasian Mountain Observatory of the MSU in the optical bands made from the archival frames of the observatory (2019–2025). The importance of controlling the constancy of the bias level in such measurements is shown. In 2024–2025, the median brightness of 1 arcsec^2 of the moonless night sky at zenith is: $B = 21.03$ mag, $V = 20.87$ mag, $R_c = 20.27$ mag, and $I_c = 19.24$ mag. Since 2019, the sky brightness increased by $\Delta B = 0.87$ mag, $\Delta V = 0.40$ mag, $\Delta R_c = 0.31$ mag, $\Delta I_c = 0.04$ mag. The color indices of sky background were found to fluctuate with a period of 1 year and a half-amplitude of $\sim$0.3. The color indices B–V and R_c–I_c change in the same phase and their maximum occurs in July, while the index V–R_c changes in antiphase with them.

Keywords: Photometry, sky brightness, astroclimatic research, light pollution

1 Introduction

The brightness of the sky background is one of the factors that determines the possibility of observing extremely faint objects. The brighter the sky background, the higher the noise and the longer the time required to achieve a given accuracy when observing an object. Characteristic values of background brightness at high altitude observatories are of the order of 22 mag/arcsec^2 in the visual part of the spectrum. For example, Pedani (2009) gives for Mount Graham International Observatory such values of sky brightness at zenith: $B = 22.8$, $V = 21.8$, $R = 20.8$, $I = 19.8$ mag/arcsec^2. Conversion of these values into the number of photons for a 60-cm telescope gives a flux of only a few ADU per second.

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Sky background brightness is influenced by a large number of different factors. These are local and temporal factors (clouds, airglow, Moon phase, shading disturbance at the observatory) and global factors (solar activity, anthropogenic illumination). For example, according to Pedani (2009), the sky background brightness in non-photometric nights is about 2 times higher than in photometric nights. Benn & Ellison (1998) found that at solar minimum, the sky is up to ∼0.5 mag/arcsec^2 fainter than at solar maximum. The influence of the illumination due to urbanization processes has been considered by different authors (see, for example, the review by Angeloni et al. (2024) and references therein). It depends on the altitude of the observatory above sea level, the distance to cities, the population, and the illumination sources used. In addition, the level of backlighting is influenced by local government policies on light pollution control – where they are in place, the contribution of urban backlighting is much smaller.

The Caucasian Mountain Observatory of the SAI MSU (CMO, Shatsky et al. 2020) is located in the North Caucasus (Russia) on Mount Shatdzhatmaz, 20 km from Kislovodsk. The observatory is at an altitude of 2100 m above sea level. The CMO has two telescopes with 0.6-m and 2.5-m mirrors. Observations are made in the optical and infrared wavelengths.

The CMO continuously monitors the astroclimate (Kornilov et al. 2014, 2016a, 2016b), one of the parameters of which is the sky background brightness: in 2008–2013 in V band, the median sky brightness was 21.1 mag/arcsec^2. Studies of sky brightness changes in the $BVRcIc$ bands in the CMO in the later period (up to 2023, Komarova et al. 2024) showed an increase in the sky brightness compared to 2011 up to ∼0.6 mag. Moreover, the main contribution to the background change belongs to the growth of anthropogenic light pollution.

The purpose of our work is to present the methodology of processing the archival frames of the observatory, and the results of measuring the sky background brightness in 2024–2025 and to study the changes in its color indices in 2019–2025.

2 Photometric measurements of sky brightness

Photometric observations on the RC600 telescope with a 600 mm mirror diameter have been ongoing at CMO since 2019. The Andor iKon-L DZ936N-BV camera is used as the detector (it has a frame size of 2048×2048 pixels). The camera is cooled to a temperature of −70° C. It has a low dark current (∼0.001 e$^-$/s) and a low readout noise (6.4 e$^-$). The image scale is ≈0.7″/pixel. A more detailed description of the setup is given in Berdnikov et al. (2020).

The standard procedure of CCD frames processing is known to take into account *bias*, *dark* and *flat* frames. During the photometric processing of the acquired frames, there is an additional consideration of the background, which can be measured, for example, near the object. Therefore, any changes in the average *bias* level will not affect the result, because they are the same throughout the whole frame and will be subtracted during such processing.

Due to the peculiarity of processing observations for sky brightness measurement, when the background cannot be subtracted, all *bias* changes will eventually be included in the result. As shown in Komarova et al. (2024), for the camera used on

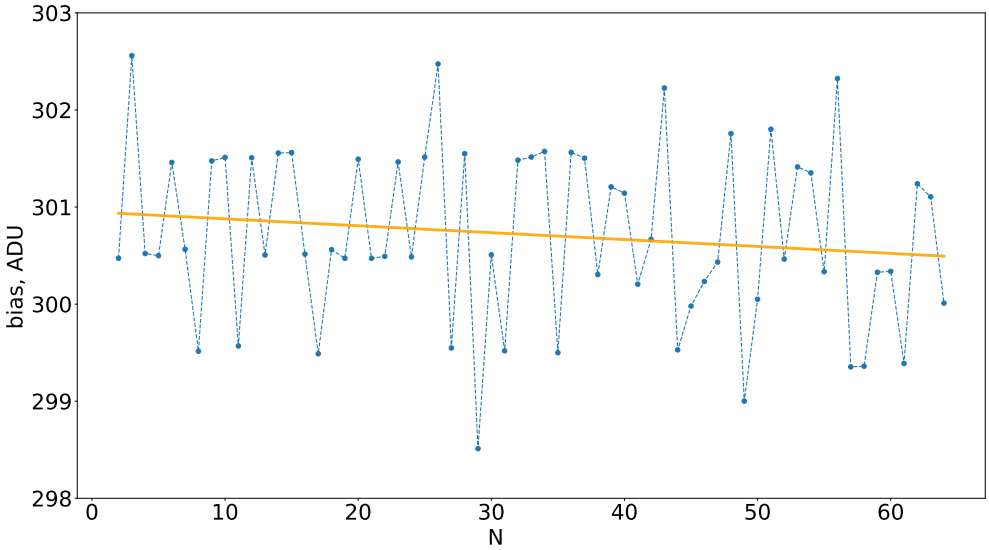


Figure 1 Average signal level at bias frame recorded in one series to obtain master bias frame.

the RC600, random variations in the overall *bias* frame level can be observed at an average of ±1 ADU. We tested this not on the average signal level overnight, but within a series of *bias* frames acquired on a single night (see Fig. 1). We can clearly see that, relative to the average signal level of 360.7 ± 0.9 ADU, there are variations up to ±1.5 ADU. Since it is impossible to predict the exact level of *bias* at the moment of observation of a particular object, these fluctuations limit the accuracy of background measurements at short exposures.

In recent years, as the sensitivity of CCDs has increased, as their noise has decreased, and due to the use of more and more rapid optics telescopes, there has been a tendency to decrease the accumulation time on small telescopes. Figure 2 shows the distribution of the number of frames acquired over the accumulation time for the RC600 telescope at CMO. It can be seen that there are a large number of observations with short exposures, especially in the long-wavelength bands R_c and I_c.

To be able to use such observations to measure the background brightness in mountain observatories, where it has low surface brightness, it is necessary to control the detector *bias* level and the dark current if we are talking about archival observations with old CCDs, which had a large dark current. A sky brightness of 22 mag/arcsec^2 for the RC600 telescope, for example, corresponds to a signal of <2 ADU/s/pixel. In this case, changes in *bias* can introduce significant errors in the measurement results, and it is better not to use frames obtained with exposures of <10 s in such work.

To estimate the mean sky background brightness in 2024–2025, we processed about 8000 frames in band B and about 6000 frames in band V obtained with an accumulation time of >30 s, as well as about 9000 frames in band R_c and nearly 8000 frames in band I_c obtained for 10 s or more. To convert the measured signal to magnitudes, following Komarova et al. (2024), we used one of the standard stars frequently observed

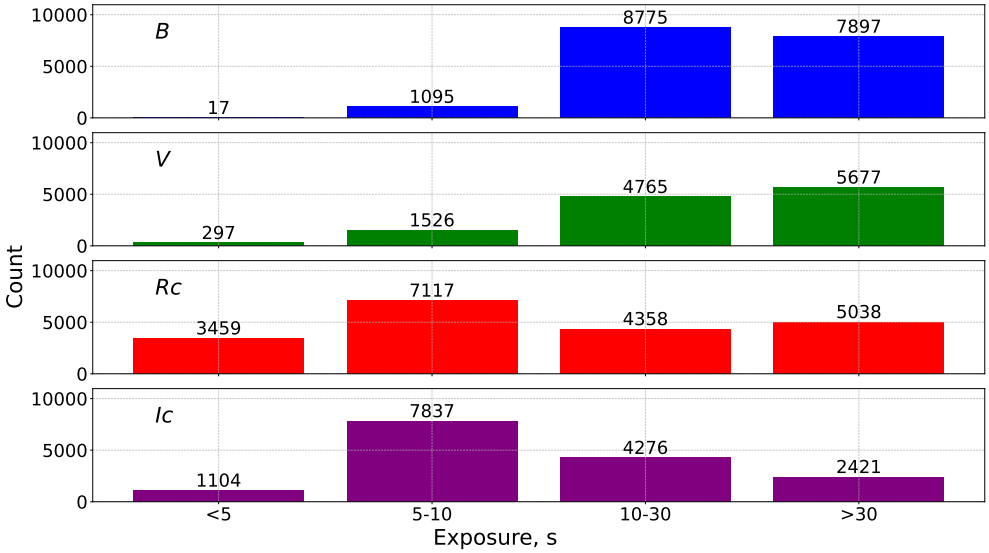


Figure 2 Distribution of observations by the length of accumulation time in 2024–2025.

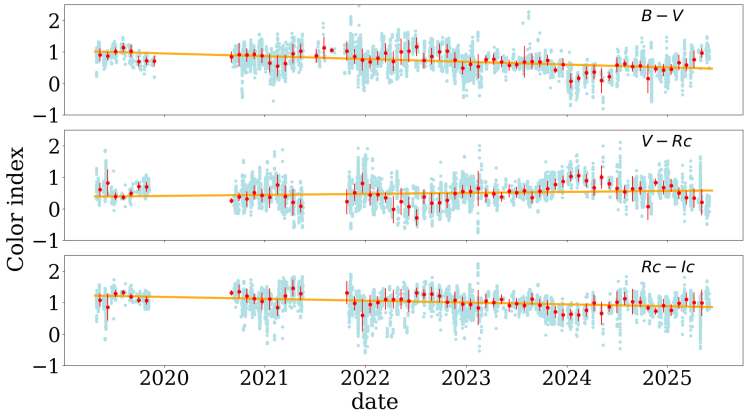


Figure 3 Color indices change in 2019–2025. The red dots show the monthly median of the color indices and the std. dev. of that value.

in the CMO. For this purpose, we made a correction for changes in the reflecting properties of the telescope mirrors (see Komarova et al. (2024) for details). The median surface brightness of the sky is $B = 21.03 \pm 0.28$, $V = 20.87 \pm 0.24$, $R_c = 20.27 \pm 0.26$, $I_c = 19.24 \pm 0.40$. We used only measurements taken when the Sun dipped below the horizon by more than 18° and the Moon was below the horizon and had a phase of <0.5, to obtain these estimates.

We combined the data obtained in this work with those published by Komarova et al. (2024) and examined the curves of changes in the sky color indices (see Fig. 3). It can be seen that, despite the large scatter of individual measurements (blue dots), the std. dev. of the mean monthly values is ∼0.3 mag. Periodic changes in the mean level

of all color indices are observed. Fourier analysis shows that the period everywhere is equal to 365–367 days. The values of (B–V) and (R_c–I_c) change in the same phase, and their lowest values are observed in July, and the value of (V–R_c) changes in the opposite phase, reaching a minimum in December–January.

3 Conclusions

We obtained estimates of the mean surface brightness of the moonless night sky in the CMO in 2024–2025: $B = 21.03 \pm 0.28$, $V = 20.87 \pm 0.24$, $R_c = 20.27 \pm 0.26$, $I_c = 19.24 \pm 0.40$ mag/arcsec^2. Comparison of these values with those published earlier in Komarova et al. (2024) shows that in the bands V, R_c, I_c the surface brightness of the sky in 2024–2025 was approximately at the level of 2022, and in the band B the sky became brighter by almost 30% which is probably due to the accelerated transition to "white" LED illumination (examples of spectra of such radiation sources are available, for example, in Ayuga et al. (2015)).

According to the results of sky brightness measurements in the CMO, we see fluctuations of color indices with a period of 1 year and a semi-amplitude of $\sim$0.3. The color indices B–V and R_c–I_c change in the same phase and their maximum occurs in July, while the V–R_c index changes in counter-phase with them.

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