B. EMISSION

THE NIGHT SKY BRIGHTNESS MEASURED FROM SATELLITES KOSMOS 51 AND 213

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Abstract. (1) The minimum measured brightness of the night sky (in the visual region) is about 100 stars of the 10th magnitude per square degree near the galactic poles.

(2) The ratio of fluxes in the ultraviolet (2300–3000 Å) and visual regions is approximately in agreement with expected theoretical data based on the models of stellar atmospheres for spectral classes B0 to G5 and on the distribution of stars of the different spectral classes over the sky.

(3) The nature of possible deviations (theory minus observation) is discussed.

The survey of night sky brightness was designed more than 5 years ago to obtain from space observations the following: (1) Data about the limiting magnitudes of night sky brightness, which are important not only for the choice of cosmological models of the Universe, but mainly for having an idea about the penetrating power of space telescopes. (2) Information about the ultraviolet radiation and possible sources in a sky which is free of the influence of the Earth's atmosphere. The preliminary communications were made in [1].

The measurements of night sky brightness were made twice with the aid of photoelectric photometers installed on spacecrafts Kosmos 51 (December 1964) and Kosmos 213 (April 1968). The necessary data about these satellites and the character of the observations are presented in Table I. The device consists essentially of two similar tubes especially designed to reduce the scattered light to minimum (10^{-5} in the case of the solar beam making the angles larger than 70° with the axis of the photometer) and having a photometric half-width of the field of view equal to 18° (see Figure 1). Behind these tubes there is a disk, common for both photometers with two circular diaphragms with the ratio 7.6 for the transmitted flux. For absolute calibration of brightness we have also the small circular area covered by radioactive luminofor (Carbon-14). Each cycle of observation consists of successive settings of the disk in

TABLE I
Data about experiments

Data	K 51	K 213/212
Date	December 10, 1964	April 15, 1968
Period of revolution	$92^{m}5$	$89^{m}16$
Max. distance	554 km	291 km
Min. distance	264 km	205 km
Inclination	$48^\circ.8$	$51^\circ.4$
Stabilization	No	around sun-satellite axis
Period of observation	Dec. 10–31, 1964	April 17–22, 1968
Type of information	Direct telemetry	Tape

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four positions: first diaphragm ('large' sky), the second one with reduced flux ('small' sky), the radioactive standard, and 'darkness' (no diaphragm). All this is done by motor; the duration of the cycle is 15 sec.

To stabilize the electronic system we have a rotating disk with four equal diaphragms producing fast modulation of the light (120 cycles per second). Just behind these disks we have two photomultipliers, the first one sensitive to the ultraviolet (2000–3000 Å) and the second to the visual part of the spectrum. The general view of the photometer can be seen in Figure 2.

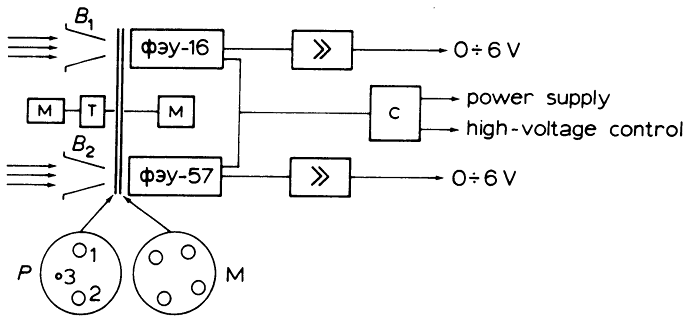

Fig. 1. Scheme of the photometer: B_1, B_2, visual and ultraviolet photometers resp., M = motors driving the programme-disk P and modulating disk M. C = electronics for B_1 and B_2-photometers.

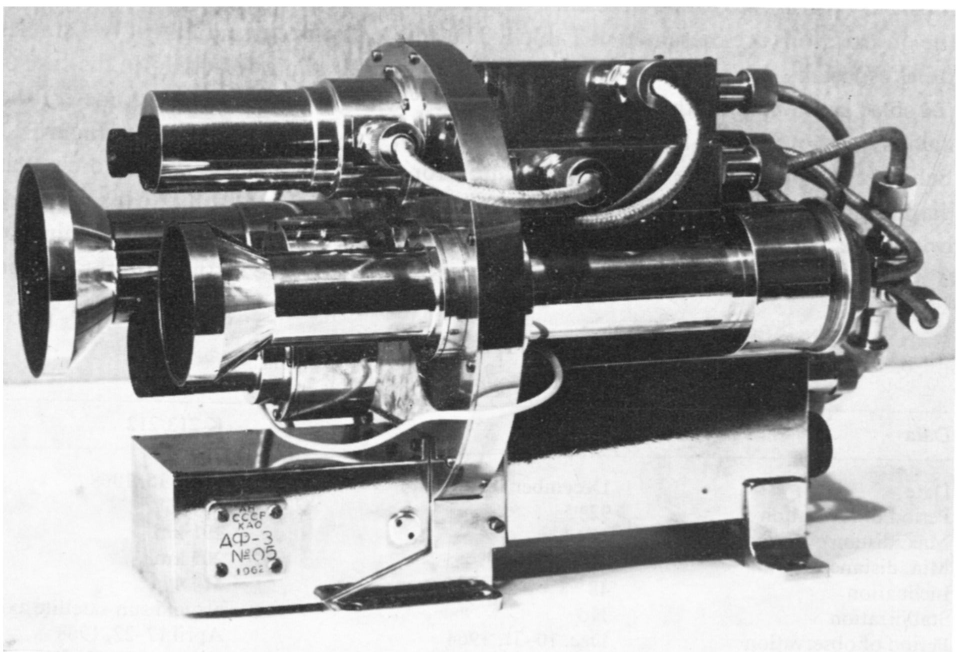

Fig. 2. General view of the photometer.

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The most difficult and laborious task in the whole experiment is the calibration of the photometers. In the first experiment with Kosmos 51 the following procedure was adopted (see Figure 3). For the U photometer we measured first the spectral characteristic of a hydrogen lamp and of the double-monochromator with the aid of sodium salicylate, and green-blue filter transmitting the luminescent radiation of sodium salicylate (the quantum yield of this material is constant for $\lambda \leqslant 3200$ Å). With the aid of the same monochromator the response of the U photometer was recorded in the same spectral region. Comparing responses in channels I and II we obtain the spectral sensitivity $\varphi_1(\lambda)$ of the U photometer.

The same procedure was used for the visual photometer. We used a tungsten-filament lamp. Besides, we simply measured the response of channel II and compared it with the known spectral characteristics of the hydrogen lamp in the region 3000–4000 Å and with the measured spectral sensitivity of the photomultipliers (in the region 4000–7000 Å). Additional measures in the interval 3000–3200 Å of the visual channel with sodium salicylate were also used. This procedure gives us the spectral sensitivity $\varphi_2(\lambda)$ of the visual photometer as well as the ratio of the maximum transmissions b_u and b_v in the U- and V-regions (about 0.08). With these data the telemetry reading (in volts) and the ratio U/V can be transformed into the ratio of fluxes. A somewhat different procedure of calibration was adopted for the second experiment with Kosmos 213. The spectral characteristics for both experiments are presented in Figure 4.

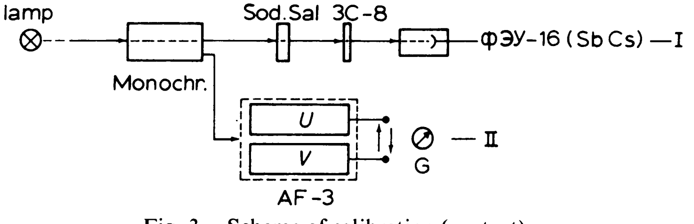

Fig. 3. Scheme of calibration (see text).

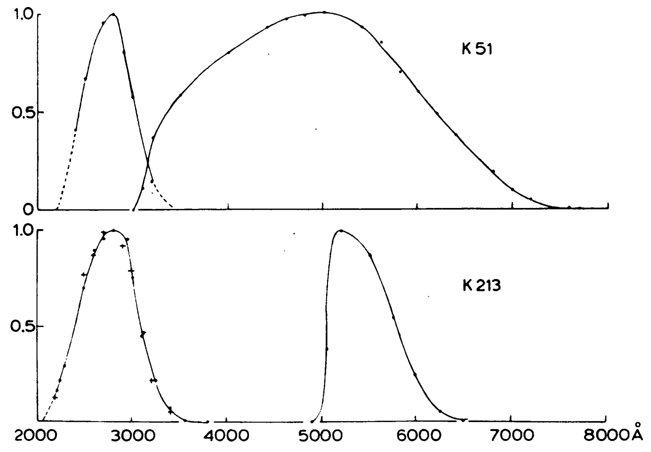

Fig. 4. The response curves of the photometers for both experiments.

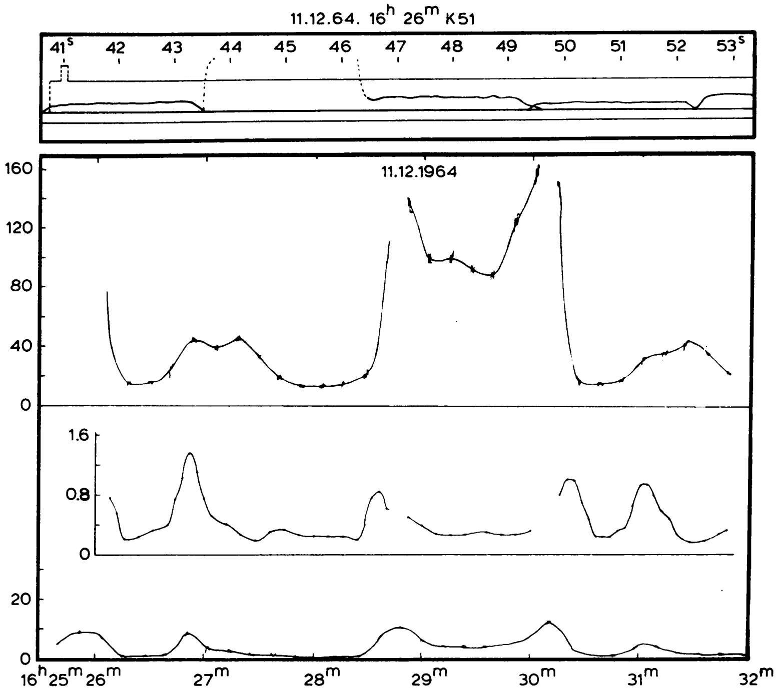

Fig. 5. Example of telemetry above, and below the reduced readings in visual (V), ultraviolet (U) regions, with the ratio U/V in the middle.

Luckily we had a chance to calibrate the ratio U/V also on board the spacecrafts, because in the first experiment we saw Jupiter, and in the second Kosmos 212 receding after junction. As the albedos of both objects are known in the region 2000–3000 Å we have no difficulty in calibrating U/V from actual observed values of U/V and the distribution of intensity in the solar spectrum. In the first case we get the value b_u/b_v which is not quite reliable (because of the absence of reliable values for the albedo of zodiacal light in the region 2000–3000 Å), but still this value is only 30% lower than the experimental one. For the second case we found a value which is in very good agreement with the laboratory calibration.

In Figures 5 and 6 we show examples of telemetry records for both experiments, as the Milky Way at the boundaries of the constellations Lyrae-Cygnus passes across the field of view of our photometers and the corresponding increase of the ratio U/V in these regions. In the first experiment a great amount of recordings was accumulated, but as we did not have any stabilization the identification is extremely difficult and laborious. It is still not completed. In the second case when partial stabilization existed (the only rotation was around the Sun–satellite axis) we could easily identify the band on the sky crossed by the field of view, and this band is shown in Figure 7. It includes also the Milky Way, the constellations Lyra, Cygnus and Aquila and other southern parts of the sky.

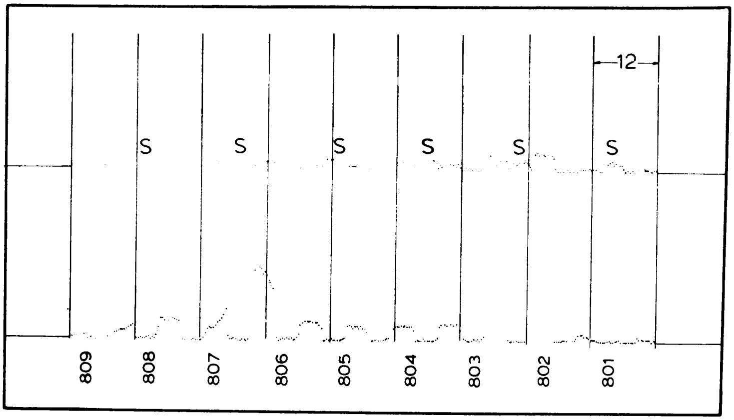

Fig. 6. The same as in Figure 5. The example of telemetry is at the bottom and the reduced readings are at the top. By 'Earth' is denoted those intervals of time when the photometer was directed to the Earth.

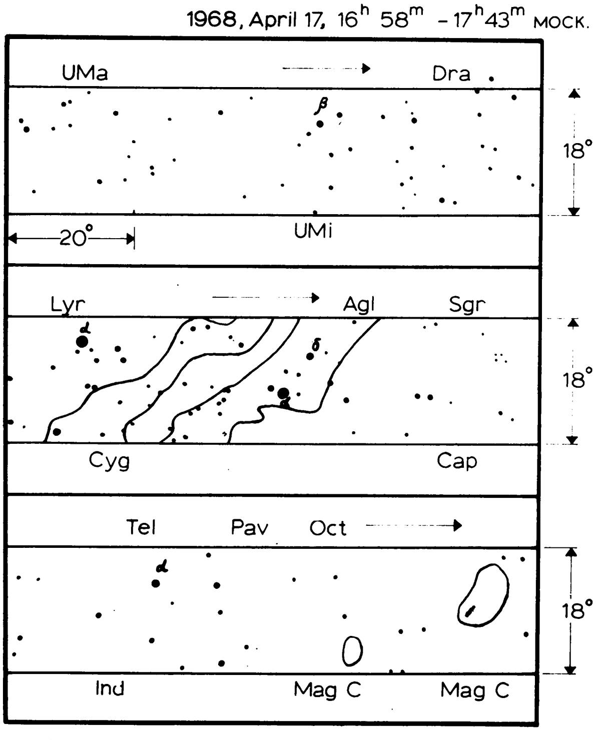

Fig. 7. The region on the sky crossed by the view-field of the photometer (in the direction of arrow) for the second experiment (K 213).

As the telemetry gives us the deflection against the radioactive standard, the brightness of the night sky in the visual region can be evaluated. (The phosphor was calibrated in the number of 10th magnitude stars per square degree at the Earth, by

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comparing the brightness of two different regions of the sky at equal zenith distances with the brightness of the phosphor.) We can see from Figures 5 and 6 that at some places the brightness of the sky is very low (even on the day-side of the Earth). The minimum brightness (near Draco) in the first experiment was estimated to be

$$I\,(\text{visual}) = 85 \text{ 10th magn. stars/square degree.}$$

If we reduce this for zodiacal light (about 50–70 stars at least) we have the very low value of about 15–35 10th magnitude stars.

In the second experiment the same value is estimated at 100, but here we had a loss of sensitivity in the V-channel and this value is more uncertain.

The calculation of expected (theoretical) ratio of fluxes U/V was made by the actual counts of stars of different spectral classes and different magnitudes in the H.D. catalogue and their corresponding contributions to the flux in the regions of U- and V-sensitivity of our photometers according to the formula

$$\frac{U}{V} = \frac{b_u}{b_v} \frac{\sum\limits_{m<0}^{8,0} \sum\limits_{k} v_k(m)\, 10^{-0.4\,m} \int\limits_{0}^{\lambda_0} \varphi_1 F_k(\lambda)\, \mathrm{d}\lambda + U_z}{\sum\limits_{m<0}^{8,0} \sum\limits_{k} v_k(m)\, 10^{-0.4\,m} \int\limits_{\lambda_0}^{\infty} \varphi_2 F_k(\lambda)\, \mathrm{d}\lambda + V_z}, \tag{1}$$

where summation is over all magnitudes m (up to 8th) and spectral classes k with the weighting function $v_k(m)$, characterizing the relative abundance (percentage) of stars of different spectral classes (determined in [2]), and U_z and V_z are the contributions due to zodiacal light. The energy distributions for different spectral classes were taken according to [3], where the scale of effective temperatures was adopted as given in Table II.

TABLE II

	T_e (K) (adopted)	T_e (K) (Morton-Adams)
B0	34000	30900
B5	18000	15600
A0	10000	9600
A5	7000	
F0	6000	
F5	5000	

Denoting the sum by U^* and V^* we have in the region with large U/V the following approximate expression:

$$\frac{U}{V} \cong \frac{b_u}{b_v} \frac{U^*}{V^*} \frac{1}{1 + \dfrac{V_z}{V^*}}, \tag{2}$$

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TABLE III

Comparison between calculated and observed values U/V

Region	$(U/V)^*$	$(1+(V_2/V^*))^{-1}$	$(U/V)_c$	$(U/V)_0$	$(O-C)$	Remarks
Cyg-Aql, M.W.			K 51			
$\alpha = 19^h25^m$, $\delta = +20°$	0.67	0.82	0.55	0.64	+0.16	C is not corrected for reddening
Cass. M.W.						
$\alpha = 0^h30^m$, $\delta = +57°$	0.60	0.69	0.41	0.47	+0.15	C is not corrected for reddening
α C Ma	0.67	0.80	0.54	0.40	−0.32	C is not corrected for reddening
			K 213			
Lyr-Cyg-Aql						
I, $\alpha = 19^h25^m$, $\delta = +20°$	3.42	0.73	2.50			
II, $\alpha = 19^h45^m$, $\delta = 0°$	3.40	0.48	1.64			
		mean	2.07	1.98	−0.05	C is not corrected for reddening

because the contribution of zodiacal light in U-flux is negligible (type G) as compared to that of the stars. The relation (2) permits us approximately to exclude the influence of zodiacal light by taking V^* (in numbers of 10th magnitude stars per square degree) and V_z (in the same units) from [4] and [5] correspondingly.

The comparison of such calculations with the observations is shown in Table III. The calculated U/V are not reduced for interstellar reddening, because according to [6] there is no essential interstellar absorption for stars brighter than 10th magnitude in the regions considered here.

We see from Table III the satisfactory agreement between O and C in the limits of $\Delta m = \pm 0.15$ Å for the Lyra/Cygnus-area, but there is some ultraviolet deficiency for Sirius and the surrounding stars, which is larger than the probable errors of observations ($\Delta m \simeq \pm 0.15$) (compare with [7]). The most gratifying result is that the data from both experiments in Kosmos 51 and Kosmos 213 are in good agreement.

If, however, we take into account that the Morton-Adams scale of T_e is more adequate for U region data (and thus that $(U/V)_c$ should be diminished), the conclusion about the existence of some ultraviolet excess in the Milky Way seems to be inevitable. (The influence of faint stars and the Milky Way itself on C-values can lead only to the decrease of the ratio U/V, because the mean contribution of the Milky Way to U is much smaller than to V if calculated according to the mean spectral type of our Galaxy.) Further investigations should probably explain the nature and the source of such U-excess.

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Discussion

Malaise: You mentioned sodium salycilate for calibrating your UV channel; this is a laboratory transfer standard. What did you use as the primary standard for calibration in the UV?

Severny: We used a hydrogen lamp calibrated with the aid of a black-body and also a tungsten band lamp calibrated in the same way. The calibration of the radioactive ascintillation was made by comparing two areas on the sky at the same zenith distances and knowing the difference in brightness of the out-of-atmosphere components.

Humphries: I would like to report a measurement obtained by Sudbury with the spectrophotometer which he described yesterday. The background levels of approximately 2000 counts/sec give a measured upper limit for the brightness of a night sky in a broad band from 1700 Å to 2500 Å. The value near the galactic poles was equivalent to that from a 6.5 visual magnitude, early B-type star in a 200 Å band in this spectral region; this is equivalent to about five 10th magnitude B-type stars per square degree. This may include zodiacal light and stray light contributions but the nature of the variations around the sky seems to indicate a largely galactic origin.

Severny: I wish to emphazise that the influence of zodiacal light can be very significant even in the far ultraviolet because sometimes we have appreciable enhancement of UV-emission of the Sun due to flare activity and zodiacal light can probably reflect these variations.

Campbell: (a) Could you repeat the fields of view of your photometers? (b) Is it possible to define the effective passband of the 2700 Å photometers? (c) What is the absolute sensitivity of your photometers?

Severny: (a) the photometric half-width of the field of view of our photometers was large, $\sim 18°$. (b) The effective passband of our UV photometer was about 600–700 Å. (c) I think we are not prepared at the present to specify the absolute values of flux in ergs $cm^{-2} s^{-1}$. (We have made the estimates but we should check them.) But we have made estimates in terms of the number of stars of $10^{m}_{.}0$ per square degree (on the scale of visual magnitudes) and I have presented in my talk the minimal brightness of the stellar component in the vicinity of the ecliptic pole as 15 stars of $10^{m}_{.}0$ per square degree.