THE MEASUREMENTS OF SKY BRIGHTNESS ON LUNOKHOD-2*

A. B. SEVERNY, E. I. TEREZ, and A. M. ZVEREVA
Crimean Astrophysical Observatory, Nauchny, Crimea, U.S.S.R.

Abstract. An astrophotometer was used for measurements of lunar sky brightness in visible and ultraviolet range during day and night. The data obtained showed unexpectedly high values of brightness during the lunar day in the visible region. From measurements during lunar 'twilight' conditions and from the dependence of excessive flux on $\cos Z_{\odot}$ we have concluded that the effect is due to scattering of solar radiation by dust particles above the surface of the Moon. Some evidence in favour of dust clouds around the Moon is presented.

1. Instrumentation

An astrophotometer was installed on Lunokhod-2 for measurements of sky brightness during lunar day and lunar night. The instrument is a double lensless telescope of which one tube is sensitive to visible light ($\lambda_{\text{eff}} = 5440$ Å, $\Delta\lambda = 700$ Å) and the other tube is sensitive to ultraviolet ($\lambda_{\text{eff}} = 2680$ Å, $\Delta\lambda = 730$ Å). Special blinds against outside and scattered light restrict the field of view to 12.5° for visible light and 17.4° for ultraviolet light. These blinds are designed in such a way as to diminish the fraction of scattered light to 2×10^{-6} for off-axis angles $\geqslant 40°$. Corresponding photomultipliers preceded by a rotating, disk light chopper were used. A yellow-filter was placed in front of the tube for visible light. A 4-position programme disk which could be stopped every 3 s provided a choice of: (i) a large stop, (ii) an artificial calibrated light source (radioactive luminofor), (iii) a small stop and (iv) a luminofor for dark current measurements to which the photomultiplier filter set was insensitive.

The astrophotometer was calibrated with the aid of a lamp calibrated against a laboratory black-body and using the luminiscence of a solution of rhodamine B in ethylene glycol. For visual light the absolute sensitivity was 4.3×10^{-6} erg s^{-1} cm^{-2} V^{-1} (accuracy $\pm 5\%$); for ultraviolet light the sensitivity was 4.3×10^{-6} erg s^{-1} cm^{-2} V^{-1} with an accuracy of $\pm 15\%$. The channel for visual light was also calibrated by measuring the night sky brightness from the ground; the brightness of the luminofor was estimated as 267 ± 40 stars of 10th magnitude per square degree. The dependence of luminofor brightness and of parameters of the electronics on temperature was previously investigated in the laboratory (from -50°C up to $+50$°C) for both channels. Practically the same dependence of luminofor brightness on temperature was obtained later on Lunokhod-2, thus pointing out the stability of the astrophotometer responses.

* Paper presented at the Conference on 'Interactions of the Interplanetary Plasma with the Modern and Ancient Moon', sponsored by the Lunar Science Institute, Houston, Texas and held at the Lake Geneva Campus of George Williams College, Wisconsin, between September 30 and October 4, 1974.

The Moon **14** (1975) 123–128.

The astrophotometer was looking at local zenith on the Moon and the measurements used in the present work were all made in the shadow of the panel of the solar cell.

An astrophotometer of this type was first used on board of satellites Kosmos-51 (1964) and 213 (1968) and described in detail by Dimov and Severny (1972).

2. Results of Measurements

From the moment of landing of Lunokhod-2 (16 January, 1973) till 20 March 1973 twelve telemetric records were obtained, nine of which were made during the lunar day, two during the lunar night and one during 'lunar twilight', when the upper border of the Sun was 1.0° below the local horizon. For all lunar day measurements the readings in the visible (or V) channel were so large that they were off the scale; whereas, for ultraviolet light the readings were quite distinct and comparable with the reading of the luminofor. This means that even when measured in shadow, the visible sky brightness was very large, far above 4400 units (1 unit-brightness of 1 star of 10th magnitude per square degree).

The only visible light measurement of sky brightness which was within scale was realized for the 'twilight' lunar sky, after the Sun was 1° below the local horizon. The visible light brightness of approximately 9900 units appeared to be ten times larger than the brightest part of night sky observed from the Earth. The upper boundary of the shadow at that time was 260 m above the point of observation. This measurement was made 30 hr after Lunokhod had been stopped for night rest. The estimate of scattered light arising inside the blind of the astrophotometer from the radiation of the Earth (taking into account the zenith distance and phase-angle of the Earth) showed that it could not have exceeded 5250 units, which is approximately 50% of the observed brightness. Also, V-brightness cannot be ascribed to reflections from specific features of the lunar landscape: the nearest mountain was 30 km away, and only some small hills, less than 200 m in height, were within 20 km of the Lunokhod. In the immediate vicinity of Lunokhod there were no hills.

The phenomenon of very bright 'twilight' radiation is, probably, similar to the phenomenon observed by Surveyor 7 in January 1968 (Rennilson and Criswell, 1973). A bright rim or halo was seen around the dark lunar horizon just after sunset. The bright rim was vertically narrow but azimuthally wide. The preliminary conclusion we have reached is that in visible light the lunar sky is bright during lunar day and immediately after sunset. This bright radiation can probably extend up to the heights of at least 260 m.

Ultraviolet brightness was recorded in seven cases with one case corresponding to lunar twilight (see Table I). The ultraviolet brightness appeared to be several (from 2 to 16) times greater than would be expected from the stars and zodiacal light corresponding to the local zenith regions of the sky if one assumes the mean spectral distribution was the same as that of the Sun. The infiltration of the scattered light from the Earth in the 'tail' of sensitivity of the ultraviolet channel was estimated to be less than 10% of the total flux of light in the ultraviolet. In 'twilight' conditions the

TABLE I

The measured luminous flux F in the ultraviolet channel

Date	α^a	δ^a	$\cos Z_\odot$	F (erg $s^{-1} \times 10^5$)
23.I.73	0^h25^m	32°	0.24	14.0
				11.3
24.I	1 40	39	−0.02	4.68
9.II	16 55	4	0.31	4.83
19.II	0 55	35	0.52	6.51
22.II	2 55	44	0.15	25.8
11.III	19 00	3	0.39	10.4
12.III	20 00	6	0.59	6.46

[a] α, δ – for local zenith.

brightness exceeded the expected value by only a factor of 3 whereas in the visible part of the spectrum the brightness was 20 times larger.

The most important result of the ultraviolet measurements is the specific dependence of the excess brightness on zenith distance from the Sun – i.e., the decrease of the brightness with $\cos Z_\odot$ (Figure 1). One can consider this dependence as evidence that

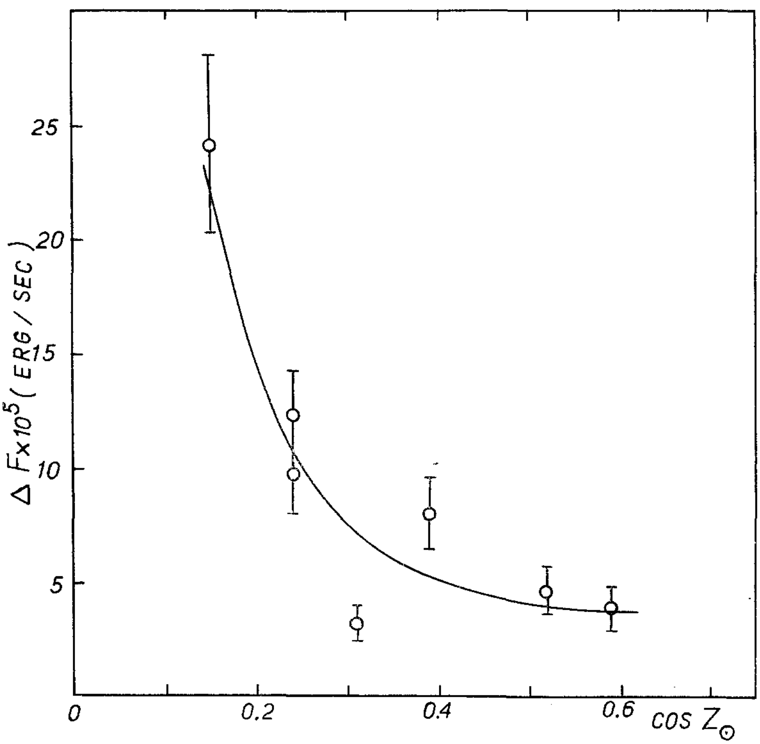

Fig. 1. The dependence of excessive ultraviolet brightness from $\cos Z_\odot$ (vertical bars are rms errors).

excessive brightness is connected with some media scattering the solar radiation, and having the diagram of scattering more elongated in the direction perpendicular to the direction of the Moon-Sun line than along the Moon-Sun line.

The comparison of illuminances for ultraviolet and visible channels for 'twilight' conditions leads to the ratio of albedo's of this scattering media $a_V/a_U = 6.0$. This ratio agrees quite well with the value of 7.0 for lunar dust according to Carvar and Horton (1967), and 5.5 according to Lucke *et al.* (1973). This is an additional evidence that excessive brightness can be produced by scattering of solar radiation on dust particles lifted up from the surface of the Moon.

Two telemetric records during the lunar night were not completely successful: due to the very low temperatures slowing down the rotation of the programme disk only a small amount of information was obtained. The measured visible brightness of the night sky in the region of Leo Minor was found to be 270 ± 54 units instead of 107 as expected from stars and zodiacal light. The difference can partly be related to the scattering of the light of the Earth in the blind of the astrophotometer which contributed no more than 150 units. The tentative conclusion is that there is no essential difference between measured and expected visible brightness during lunar night. The situation is similar to that observed in the Earth shadow with satellites Cosmos 51 and 213 (Dimov *et al.*, 1972).

Our preliminary practical conclusion is that the lunar sky is not appropriate for astronomical observations during lunar day in visible light. Although the lunar sky is dark during the night, there is scarcely any gain in penetrating power of telescopes working on the Moon compared with those working in Earth orbiting satellites. In ultraviolet light the lunar sky is quite dark even during the lunar day, if screened from solar radiation and stray light.

3. Some Conclusions

From the dependence of excessive ultraviolet brightness on $Z_\odot$ and from the measured excessive flux in the visible and ultraviolet channels during twilight conditions we can estimate the optical depth (τ) of some layer producing the excessive brightness due to scattering to be $\tau = 2.67 \times 10^{-6}$. Then for the particles with sizes $d = 10\ \mu$ and $d = 70\ \mu$ (for the size of particles see Jaffe and Strand, 1973; Vinogradov, 1972a) we obtain $nh_0 = 3.4\ \text{cm}^{-2}$ and $0.069\ \text{cm}^{-2}$ respectively, where n is the number density of dust particles (cm^{-3}) and h_0 – some characteristic height of scattering layer ($\geqslant 260$ m). If we assume for h_0 the value of the order of 10^3 km (there exists some reason for this value, see below) and $d = 70\ \mu$, so we obtain the number density $n \simeq 7.0 \times 10^{-10}\ \text{cm}^{-3}$. This is 10^4 to 10^5 times larger than interplanetary density of dust particles with the size $\geqslant 10\ \mu$ at the distance 1 AU (Kaiser, 1968). It is easy to find that in this case the optical depth of such a dust atmosphere in the direction tangential to the limb of the Moon is $\simeq 4 \times 10^{-5}$ (for $70\ \mu$ size), and its brightness will be 10^{-7} of the brightness of the border of the Moon. It is not practical to detect such an atmosphere from ground based observations.

The possibility of the existence of a very rarefied swarm of dust particles around the Moon has been pointed out by several authors (Gault *et al.*, 1963; Vinogradov, 1972b; Nazarova *et al.*, 1966). Some suggestions, were made (Gault *et al.*, 1963) that second ary ejecta, originating from bombardment of lunar surface by high velocity meteors, could form a swarm of dust particles around the Moon with number density 10^5 to 10^7 larger than concentration of meteoroids in interplanetary space, and with velocities of the order of 1 km s^{-1}. Although the production of secondary ejecta proposed by Gault is probably overestimated (Criswell, private communication) the formation of a dust 'atmosphere' above the Moon's surface can hardly be questioned. The evidence in favour of this is the phenomenon of horizon glow observed several times by the Surveyors (Gault *et al.*, 1968; Rennilson and Criswell, 1973) and mentioned above. There are also recent preliminary data indicating the presence of lunar ejecta with speeds in excess of 0.8 km s^{-1}, which displays a 100 fold increase in dust particle concentration near the terminator (Berg, 1974). The most interesting evidence of lunar dust atmosphere follows from Apollo 17 crew observations. They observed, from lunar orbit, the optical effects of some scattering layers – possibly local – extending above their orbital altitude. In particular, from sketches made before sunrise, it follows that dust 'streamers' can extend up to the altitude comparable with an appreciable fraction of the radius of the Moon (McCoy and Criswell, 1974). These observations indicate that the characteristic height $h_0 = 10^3$ km adopted above may not be too unrealistic.

One of the mechanisms of dust layer formation above the surface of the Moon is that of electrostatic levitation proposed by Criswell (1972). It produces, however, only a thin layer of 3–30 cm thickness. It is not clear how the solar wind could interact with the dust particles of this layer and then drag them up to higher levels. It also seems worth considering whether the mechanism leading to formation of dust tail in comets could be at work in the case of the Moon, and in particular in the formation of dust streamers observed by Apollo astronauts.

A detailed report on these observations is being published in volume 53 of *Izvestija Krimskoi Astrophysicheskoi Observatorij.*

Acknowledgment

We wish to express our deep gratitude to Dr D. R. Criswell for many helpful remarks and stimulating discussions.

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