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SPECTROPHOTOMETRY OF LUNAR FORMATIONS

by

A. N. Sergeyeva

Akademiya Nauk SSSR Komissiya Po Fiziki
Planet Izvestiya, pp. 59-66 (1959)

Translated from the Russian

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SPECTROPHOTOMETRY OF LUNAR FORMATIONS

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Preliminary results of the spectrophotometry of lunar details are given. The observations were carried out with the help of a quartz spectrograph and a horizontal telescope having a spherical mirror (f = 8 meters).

It was found that the color contrasts are absent in most cases. Sometimes they amount to 10 to 15 percent and in rare cases reach 20 percent. The lunar cirques and mountain formations have reddish hues in comparison with the seas. The last are bluish-greenish but the Sea of Serenity and the Sea of Rains proved to be reddish.

The question of the existence of color contrasts on the lunar surface is apparently being solved positively at the present time. However, because of a small range of the coloration, its quantitative evaluations are difficult and greatly differ from each other with different authors. A review of the works pertaining to the color contrasts on the Moon is available in the works by N. P. Barabashev [1, 2] and in the article by V. I. Yezerskiy and V. A. Fedorets [3]. We will list in a brief form their chief results.

In 1953, N. P. Barabashev secured at the Khar'kov Observatory a number of photographs of the Moon on a color film. On the prints, there are regions with a gamma of colors from green to reddish which make it possible to trace the most diverse hues on the surface of the Moon.

N. P. Barabashev and A. T. Chekirda made thorough observations of the colors on the Moon through four and later through five light filters — from an infrared filter to an ultraviolet filter [4]. The aim of their investigation was the determination of more exact numerical values of the coloration of lunar formations and their comparison with earlier determinations by N. P. Barabashev, G. A. Tickhov, and A. V. Markov. The luminances of all regions selected were expressed in terms of the luminance of one definite point located in the Ocean of Storms. The investigation showed that in relation to this region the craters with the ray systems, some seas, the floor of the craters, and the light ring around Tycho are reddish, whereas the mountainous regions and irregularly outlined seas are on the average greenish.

The observations of these same authors revealed a variation of the color along the light rays of the craters Tycho, Copernicus, and Kepler [5]. It turned out that the rays of Tycho are as reddish to a distance of 7.7 of its diameter as the floor of the crater. In the crater Copernicus, blue color begins to predominate almost at the distance of its diameter. The whitish color of the rays of the crater Kepler changes already at the very crater in the direction of becoming blue.

The results of processing several spectrograms obtained by V. I. Yezerskiy and V. A. Fedorets [3] also indicate the presence of perceptible color contrasts on lunar surface.

Different results were reached by L. N. Radlova [6] in a colorimetric investigation of the lunar surface. According to her observations the entire gradation of colors on the Moon is contained in the range of from $1.^{m}16$ to $0.^{m}95$ according to the color indices or from G_5 to G_0 according to the spectral classes of the Harvard classification.

In 1956 L. N. Radlova and V. V. Sharonov [7] investigated the threshold of color differentiation in a visual observation of the lunar surface and the maximum difference in the coloration of lunar objects. The authors found that the distinctions in the coloration for which the difference ΔC of the normal color indicators exceeds $0.^{m}1$ are perceived by the eye at once while with a ΔC smaller than $0.^{m}01$ they are not recognized at all. It follows from this that for a maximum distinction of color on the lunar surface the values for ΔC must be contained between the limits indicated and that they amount merely to a few hundredths of the color index. Direct measurements of the lunar objects which differed most in color confirmed this conclusion.

The spectrophotometric investigations of lunar surface started by V. G. Teyfel' [8] in 1956 with the help of the spectrograph ASP-9 on a mirror and lens telescope AZT-7 indicate that most of the objects reveal very slight color contrasts — from 1 to 8 percent. Only the separate regions on the Moon differ in color considerably more and the contrasts between them reach 15 percent and sometimes even 18 to 20 percent.

DESCRIPTION OF THE APPARATUS AND OF THE OBSERVATIONS

Work on the spectrophotometry of the Moon started at the astronomical observatory of Kiev University in 1956. Observations are conducted on a quartz spectrograph ISP-22.

The following optical arrangement is used in our apparatus. Reflecting from the coelostat mirror and an auxiliary mirror (the diameters are 30 and

35 centimeters respectively), lunar light strikes a spherical mirror having a focal distance of about 8 meters. At a distance of 6 meters from the spherical mirror the light is intercepted by a plane mirror and is directed toward the spectrograph slit where the image of the Moon with a diameter of about 8 centimeters is created. To make the setting of the detail selected in the plane of the slit easier, there is a white screen with an aperture for a beam of rays. The lunar detail selected is positioned on the slit by the micrometric motions along α and δ.

The cassette section of the spectrograph has been modified in such a manner that an ultraviolet spectrum of up to 7200 Å inclusive is accommodated on a plate measuring 9 by 12 centimeters. The dispersion amounts to 50 Å per millimeter near a λ = 5000 Å. The width of the slit is 0.75 millimeters; the length, 1 centimeter. In the center of the Moon disc the slit cuts out a section of lunar surface measuring 33 by 435 kilometers.

The photographing was done on the plates Agfa Spectral Platten Rot rapid. The exposure was 15^s. Some of the lunar objects were photographed twice with the exposures of 15^s and 30^s. Not more than five spectra were accommodated on one plate.

After photographing the spectrum, we positioned a plate isoortho in front of the slit. On this plate we photographed a direct image of the Moon with an exposure of 10 seconds. After this, without moving the plate, we obtained on it an image of the slit illuminating it from within the spectrograph. There is no need to repeat the last operation each time since the photographic plate is always positioned in front of the slit in the same manner and, therefore, the position of the slit on the plate is defined uniformly.

The photographs of the spectra were developed under standard conditions in a metol-hydroquinone developer. After the fixing, the plates were rinsed in running water and dried at the usual room temperature.

Relative spectrophotometry was used for the investigation of the hues of various lunar details. The curves of intensity distribution relating to the spectrograms which had been obtained one after another at an interval of not more than 15 to 20 minutes were compared with each other. As the experience showed, with long time intervals between the exposures the results of the comparison were distorted because of a change in the atmospheric transmission. Altogether 38 spectrograms of various lunar details suitable for processing were selected.

In Table I are given a list of these details and the dates of the observations along with an indication of the phase of the Moon. In Figure 1 a

Table I

Order No.	Name of Lunar Detail	Observation Date	Lunar Phase
1	The crater Tycho	9-10 Sep 57	1.00
2	The Sea of Moisture	9-10 Sep 57	1.00
3	The Sea of Clouds	9-10 Sep 57	1.00
4	The crater Copernicus	9-10 Sep 57	1.00
5	The Ocean of Storms	9-10 Sep 57	1.00
6	The crater Grimaldi	9-10 Sep 57	1.00
7	The crater Aristarchus	9-10 Sep 57	1.00
8	The Sea of Rains, and the environs of the crater Maupertuis	9-10 Sep 57	1.00
9	Apennines	9-10 Sep 57	1.00
10	The Sea of Crises	9-10 Sep 57	1.00
11	The ray of the crater Tycho	10 May 57	0.81
12	The crater Walter	10 May 57	0.81
13	The crater Plato	9-10 Sep 57	1.00
14	The crater Manilius	9-10 Sep 57	1.00
15	The crater Menelaus	6 May 57	0.37
16	The crater Menelaus	9-10 Sep 57	1.00
17	The crater Proclus	6 May 57	0.37
18	The crater Langrenus	6 May 57	0.37
19	The Sea of Serenity	20 Sep 56	1.00
20	The region to the S of the Sea of Cold (between Aristoteles and Plato)	6 May 57	0.37
21	The crater Plato	10 May 57	0.81
22	The crater Menelaus	10 May 57	0.81
23	The crater Tycho	10 May 57	0.81

photograph is given of the Moon in which the positions of the spectrograph slit are shown. The numerals at each image of the slit correspond to the order number of the lunar details in Table I.

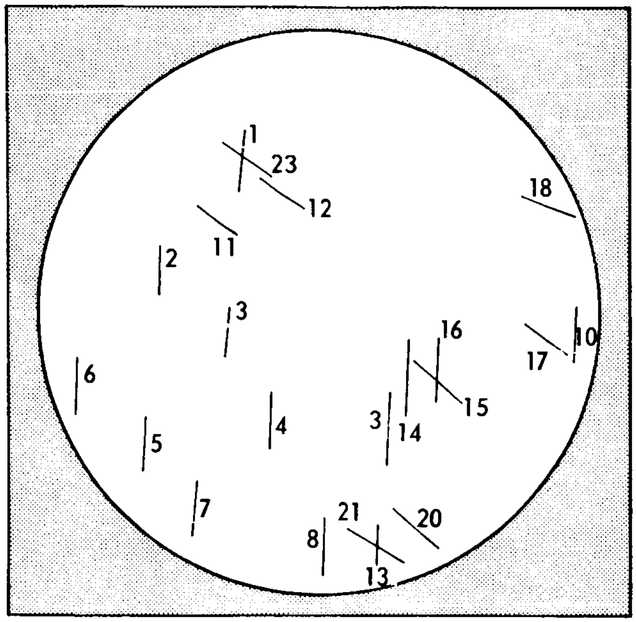


FIGURE 1. THE POSITION OF THE SPECTROGRAPH SLIT ON THE DISC OF THE MOON. The numbering of the details corresponds to the numbering in Table I.

THE PROCESSING OF THE MATERIAL AND THE RESULTS

The photometric measurements were taken on the recording microphotometer MF-4.

The photometric processing of the spectrograms was done both with the help of a common characteristic curve and with the help of the characteristic curves constructed in 15 different wavelengths.

The spectra of the Moon measured along the dispersion (longitudinal sections) were processed with one characteristic curve. Usually several (from 3 to 8) microphotometric sections along the dark and light bands on the spectrum were made on one spectrogram.

The characteristic curves were constructed from a photograph of the spectrum of an incandescent lamp. The photograph was obtained by means of the same spectrograph ISP-22 on the plates Rot rapid with the exposures of 15 and 30 seconds.

As it turned out, the characteristic curves constructed for different wavelengths could be reduced to one curve covering the regions of the strong and slight blackenings. The curves of intensity distribution were constructed with the help of this characteristic curve. These curves were reduced to one scale by a proportional change in the ordinates. In doing so, in the wavelength λ = 6500 Å the same intensity was taken for all lunar details. Eighty curves of intensity distribution were constructed in this manner.

In comparing these curves with each other, it turned out that in most cases the color contrasts are not revealed; sometimes they amount to 10 to 15 percent and only in rare cases reach 20 percent.

The following preliminary comments may be made regarding the color contrasts of various lunar details.

The crater Walter is bluer than the crater Tycho. The raised rim of the crater Tycho is somewhat redder than its slopes and rays. The floor of the crater Plato is also redder than its slopes but coincides in color with Menelaus, Manilius, and the Sea of Serenity. In color Copernicus does not differ from the slopes of the Apennines. The center of the crater Langrenus coincides with the crater Menelaus but is redder than the neighboring Sea of Plenty. The Sea of Tranquillity and the Sea of Crises are bluer than the craters Proclus and Menelaus. The continent to the south of the Sea of Serenity is bluer than the Sea itself. Aristarchus is a little yellower than the Ocean of Storms. The crater "sea" Grimaldi and its vicinity do not differ from each other in color. The Sea of Moisture, the Sea of Clouds, and the Ocean of Storms have no perceptible color distinctions between them. The Sea of Rains coincides with the Apennines but is redder than the Ocean of Storms.

In general the observations show that the craters and mountainous formations have reddish hues in comparison with the "seas." The latter on the other hand are bluish-greenish. True, the Sea of Serenity proved to be 20 percent redder than the continent to the south of Menelaus and the Sea of Rains is reddish in comparison with the Ocean of Storms.

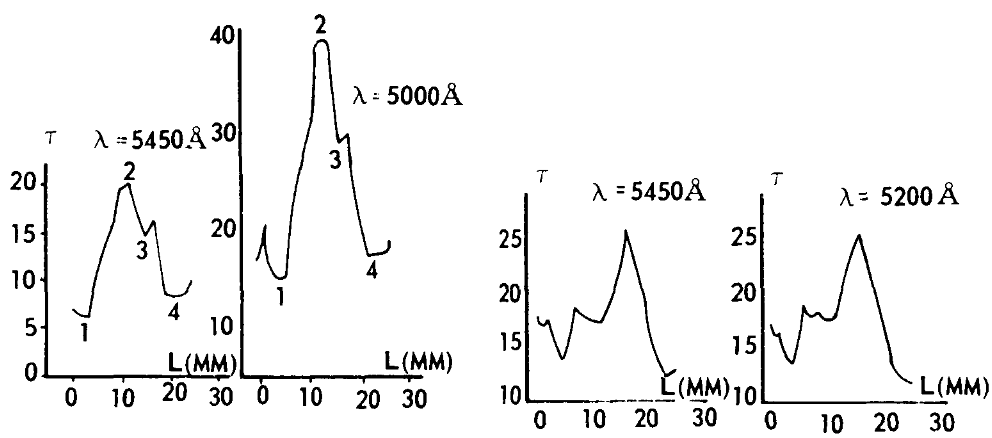
For a greater certainty in the results obtained, a portion of the photographic material was processed in a different manner.

The lunar spectrograms were measured photometrically not along but across the dispersion line in 15 different wavelengths shown in Table II.

Table II

Cross Sections	λ(Å)	Cross Sections	λ(Å)	Cross Sections	λ(Å)
1	6350	6	5200	11	4340
2	6100	7	5000	12	4200
3	5880	8	4800	13	4100
4	5700	9	4640	14	3980
5	5450	10	4500	15	3800

The conversion of the blackenings into the intensities for each cross section was done by the characteristic curve constructed for the same wavelength. The cross sections in the intensities for the crater Proclus and the ray of the crater Tycho are shown in Figures 2 and 3. Distances along the section expressed in millimeters are laid off on the x-axis and the intensities — on the y-axis.



FIGURES 2 AND 3. CROSS SECTIONS IN THE INTENSITIES FOR THE CRATER PROCLUS (A) AND THE RAY OF THE CRATER TYCHO (B)

The points 1, 2, 3, and 4 in Figure 2 correspond to different lunar details: 1 — the Sea of Tranquillity, 2 — the crater Proclus, 3 — the vicinity of the crater Proclus, 4 — the Sea of Crises. The curves pertain to the wavelengths of 5450 and 5000 Å. The distribution of intensity with the wavelength may be obtained by making use of the values of the surface luminance in all of the 15 wavelengths. In Figure 4 is shown the distribution of intensity with the wavelength for the detail 2.

This distribution is distorted by the difference in the scale since for each wavelength the intensity was determined by its characteristic curve. The fact is that different energies correspond to a unit of intensity of each characteristic curve. However, the difference in the scales does not play an important role inasmuch as the comparison of all curves is done each time in the same wavelength.

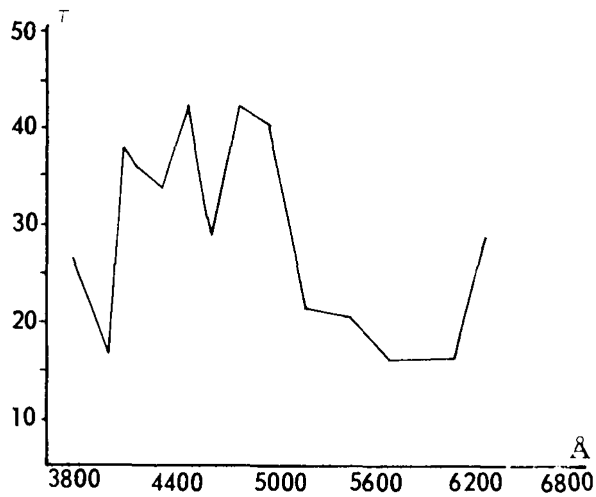


FIGURE 4. THE DISTRIBUTION OF THE SPECTRUM INTENSITY FOR THE DETAIL 2 (THE SEA OF MOISTURE)

Similar curves are constructed for the details 1, 3, and 4.

We shall compare these curves. We shall take the detail 2 as the standard and reduce in the wavelength of 5450 Å the intensities I_i of all details to the intensity I_2. For this purpose we shall find the coefficient

$$k_i = \left(\frac{I_9}{I_i}\right)_{\lambda = 5450Å}.$$

Multiplying I_{λ_i} by k_i where I_{λ_i} is monochromatic intensity of the i^{th} lunar detail we shall reduce all curves of the surface luminance to the curve pertaining to the detail 2.

Then we calculate the relative differences by the formula:

$$I^{*}_{\lambda i} \text{ percent} = \frac{k_i I_{\lambda i} - I_{\lambda 2}}{I_{\lambda 2}} \cdot 100.$$

These differences are represented graphically in Figure 5 in which the wavelengths are laid off on the x-axis, and on the y-axis — the relative differences expressed in percent of the intensity of the detail 2.

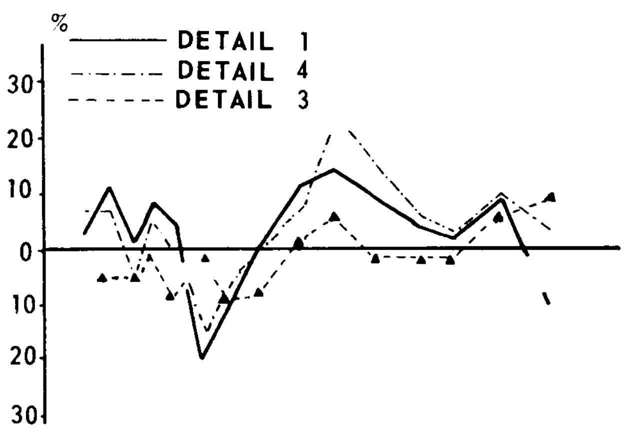


FIGURE 5. RELATIVE SPECTRUM DISTRIBUTION FOR THE DETAILS 1 (TYCHO), 4 (COPERNICUS), AND 3 (THE SEA OF CLOUDS)

In the case under consideration it may be said that the Sea of Tranquillity (1) and the Sea of Crises (4) resemble each other in color but differ from the crater Proclus (2) in the green and blue rays. The environs of Proclus (3) do not differ in color from the crater itself.

An additional spectrogram was processed for the crater Proclus. It was photographed following the first (30-second) one with an exposure of 15^s.

The color tints obtained for both spectrograms proved to be similar with an accuracy to 5 to 7 percent.

The results of the measurements of the other spectrograms showed that the ray of Tycho (intersected across by the spectrograph slit) and its environs do not differ in color. The environs of Aristarchus reflect slightly fewer yellow rays than the crater itself. The floor of the crater Grimaldi proved to be in color the same as its environs.

The results obtained in the processing with one characteristic curve and with the curves in different wavelengths agree well with each other. In both cases it turned out that the Sea of Tranquillity and the Sea of Crises are bluer than the crater Proclus. The crater Grimaldi does not differ in color from its environs. Aristarchus proved to be 13 percent yellower than the Ocean of Storms.

A COMPARISON OF THE DATA OBTAINED WITH THE DETERMINATIONS OF OTHER AUTHORS

It should be remembered first of all that the color contrasts we obtained are relative. We may speak about the color of lunar objects only in relation to each other; therefore, their comparison with the results of other authors is difficult.

A qualitative comparison of the relative hues with the investigations by N. P. Barabashev and A. T. Chekirda [4] on the distribution of color contrasts on lunar surface leads to the results which are shown in Table III.

The comparison was not made for the other objects because of an absence of common determinations. On the whole it may be said that most of our evaluations of the color contrasts coincide with the determinations of previous investigations.

In conclusion the author expresses appreciation to N. A. Yakovkin for guidance and help in the work.

Table III

	Our Determinations		Determinations by N. P. Barabashev A. T. Chekirda
Lunar Object	Color	Specific Details	
The floor of Plato	Reddish	The environs of the crater	Reddish
The Sea of Serenity	Reddish	The region toward S from the Sea of Serenity	Reddish
The Sea of Rains	Reddish	The Ocean of Storms	Spotty structure with reddish, greenish, and rust-colored spots
The raised rim of the crater Tycho	Reddish	The rays of the crater Tycho and the environs	Reddish
The Sea of Tranquillity	Bluish	The crater Proclus	Light bluish
The Sea of Crises	Bluish	The crater Proclus	Greenish in the S portion, rust-colored in the N portion
The Sea of Moisture	Not distinguished	The Ocean of Storms	Reddish
The Sea of Clouds		The Ocean of Storms	Reddish
The Ocean of Storms			Greenish
Aristarchus	Yellowish	The Ocean of Storms	Reddish (according to Miethe and Seegert [9])

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Color contrasts						
Lunar surface						
Light rays						
Quartz spectograph						
Microphotometer						