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Abstract

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EMISSIVITY COEFFICIENTS IN THE INFRARED REGION OF THE SPECTRUM AND DIFFERENCES IN THE PARAMETER $\gamma = (kpc)^{-1/2}$ FOR THE MARE AND CONTINENTAL REGIONS OF THE LUNAR SURFACE

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1. Until now, determinations of the temperature of the lunar surface have been carried out from measurements of the heat flux transmitted by the "transparency window" of the atmosphere at 8-13 μ, with the emissivity coefficient of the lunar surface taken to be $\varepsilon_{8\text{-}13\mu} = 1$ ($^{1\text{-}4}$). Moreover, variations in the heat flux from different parts of the surface were interpreted as differences in the temperatures of these regions ($^{2\text{-}4}$). It is evident that, if $\varepsilon_{8\text{-}13\mu}$ differs from unity, the true temperature is higher than the brightness temperature determined by the indicated method, and flux variations may be associated not only with temperature fluctuations but also with changes, from place to place, in the magnitude of the emissivity coefficient ε. Generally speaking, in order to determine the dependence of ε on λ and to determine the temperature, it is necessary to study the spectral distribution over the entire region in which the thermal radiation of the Moon is concentrated (3-40 μ); however, observations from the Earth' s surface are hindered by atmospheric absorption. This circumstance forces one to limit the problem to determining the color temperature from the ratio of the radiation-flux values in two spectral intervals. It is of interest to use for this purpose the atmospheric transparency windows 8-13 μ and 3.6 μ. The second interval, for the temperatures of the Sun-illuminated lunar surface, lies in the short-wavelength region of the Planck curve and, consequently, the radiation intensity here depends on temperature much more strongly than in the 8-13 μ window. Thus, measurement of the intensity ratio in these windows is a very sensitive method for determining the color temperature.

2. We have carried out measurements of the radiation of the lunar surface in two regions of the spectrum during the lunar eclipse of 7 VII 1963 with the 125-centimeter telescope of the Crimean station of the P. K. Shternberg Astronomical Institute, as well as measurements of thermal radiation on the unilluminated part of the Moon in July 1963 with the 125-centimeter telescope of the Crimean Astrophysical Observatory. Measurements in two spectral regions were made with a two-beam radiometer; as radiation receivers, a bolometer was used for the 8-13 μ window, and for $\lambda = 3.6\,\mu$ a PbS photoresistor cooled by liquid nitrogen was used. With the aid of a rocking mirror modulator ($f =$ 10 Hz), the radiation beam was divided into two channels, the signals from which were simultaneously recorded on two automatic potentiometers. During the eclipse, four scans across the lunar disk were recorded, passing near the craters Aristarchus, Copernicus, Tycho, and the Sea of Nectar (scanning of the Moon' s image was accomplished by stopping the telescope' s clock drive). The interval between successive recordings for each scan was 6-10 min. The resolving power was about 100 km on the lunar surface and was sufficient for reliable separation of the continental and mare regions. For measurements on the unilluminated part of the Moon, a radiometer analogous to (^{6}) was used, but with a resolving power of about 200 km on the lunar surface.

3. The fluxes measured in both spectral regions from the lunar surface can be represented in the form of the following integrals:

$$I_{3.6\mu} = \omega_1 \int_{3.6\mu} \varepsilon_\lambda B_\lambda(T) k_\lambda^{\mathrm{p}} k_\lambda^{\mathrm{a}}\, d\lambda + \omega_1 \int_{3.6\mu} I_\lambda^{\odot} r_\lambda k_\lambda^{\mathrm{p}} k_\lambda^{\mathrm{a}}\, d\lambda, \tag{1}$$

$$I_{8-13\mu} = \omega_2 \int_{8\mu}^{13\mu} \varepsilon_\lambda B_\lambda(T) k_\lambda^{\mathrm{p}} k_\lambda^{\mathrm{a}}\, d\lambda, \tag{2}$$

where ε_λ is the emission coefficient of the lunar surface; $B_\lambda(T)$ is the Planck function; $k_\lambda^{\mathrm{p}}, k_\lambda^{\mathrm{a}}$ are the transmission functions of the instrument and of the atmosphere in the corresponding spectral regions; ω is a factor taking into account the aperture ratio of the instrument and the size of the area measured on the Moon; $I_\lambda^{\odot} r_\lambda$ is the intensity of solar radiation reflected by the lunar surface (substantial only for the 3.6μ region). Allowance for k_λ^{p} presents no difficulty, but allowance for k_λ^{a} is associated with some uncertainty, especially when the observations are made with a comparatively high content of water vapor in the atmosphere and at a low position of the Moon. We used data on atmospheric transparency as a function of air mass and amount of water vapor from work (5), and, in addition, as an extra-atmospheric source with a known flux in the 8–13μ region, we used the subsolar point of the Moon, the radiation intensity of which had been determined sufficiently reliably in (2). Reflected radiation in the 3.6μ region can constitute a noticeable fraction of the total measured flux. The only possibility for independently measuring the second term in expression (1), and consequently also the reflection coefficient r_λ, arises during the penumbral phase of a lunar eclipse. It is known that during the total phase the surface of the Moon cools to a temperature of about 200° K. In this case the thermal radiation of the Moon in the 3.6μ region is much smaller than the reflected radiation. At the beginning of the penumbral phase, while the illumination has not reached

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

0.2–0.3 of the full illumination outside the eclipse, this ratio is preserved; with further heating of the surface, the intrinsic thermal radiation rapidly increases and becomes much greater than the reflected radiation. By plotting the dependence of the measured flux on illumination during the penumbral phase for a given area of the lunar surface, the reflection coefficient of the lunar surface for $\lambda 3.6\mu$ can be determined from the slope of the rectilinear part (low illumination, reflected radiation) (Fig. 1). Since in this case the observations are carried out under full-moon conditions, the reflecting ability may be characterized by the value of the normal albedo, or brightness, $\rho_{0\,3.6\mu}$ (9).

Fig. 1. Dependence of $I_{3.6\mu}$ on the eclipse phase for four points on the surface of the Moon. Curves 1 and 2 are for points in a bright, continental region; curves 3, 4 are for dark mare areas. Point 2 is located near the edge of the disk; points 1, 3, and 4 are not far from the center. The dashed line is an extrapolation of the rectilinear part of the dependence (reflected radiation). Here, and also in the remaining figures, the ordinate gives the measured fluxes I_λ without allowance for atmospheric absorption.

The value $\rho_{0\,3.6\mu}$, obtained by the method described above, varies from 0.25 (maria) to 0.55 (continents), which is appreciably higher than the value ρ_0 for vis-

of the visible region of the spectrum (Fig. 2). Darkening toward the limb, as in the visible region of the spectrum, is not observed. There is, in general, good agreement between the variations of ρ_0 from place to place for the visible region of the spectrum and $\lambda 3.6\mu$. Assuming that the phase integral for the region 3.6μ is the same as for the visible region of the spectrum and is equal to 0.694 (7), we obtain variations of the emission coefficient

Fig. 2. 1 –photometric section (in the visible region of the spectrum) through the equatorial region of the Moon; 2 –normal albedo $\rho_{0,3.6\mu}$ for the same section

$\varepsilon_{3.6\mu}$ from 0.83 (maria) to 0.62 (continents). From expressions (1) and (2), the color temperature was determined under the assumption that $\varepsilon_{3.6\mu} = \varepsilon_{8-13\mu}$. For the subsolar point it is from 405 to 440° K (depending on the assumptions about atmospheric transparency). The brightness temperature in the region 3.6μ is, respectively, 407 and 433° K (under the same assumptions about transparency). The approximate agreement of these temperatures supports the assumption that $\varepsilon_{3.6\mu} \approx \varepsilon_{8-13\mu}$. Thus, the Moon may be regarded approximately as a gray emitter.

Fig. 3

Figure 3: Fig. 3

Figure 4

Figure 4: Figure 4

Fig. 3. Record of the fluxes $I_{3.6\mu}$ (1) and $I_{8-13\mu}$ (2) at full moon (40 min after the end of the eclipse) for the equatorial section

Let us consider the variations of the heat flux over the surface of the Moon at full moon in both spectral intervals. Figure 3 shows an equatorial section at full moon (immediately after the eclipse) for two parts of the spectrum, 3.6 and 8–13μ. Let us suppose that the variations of ε in both spectral intervals are identical, $\Delta\varepsilon_{3.6\mu} = \Delta\varepsilon_{8-13\mu}$, for all parts of the lunar surface. In this case we find that, near the subsolar point and under identical illumination conditions, the color temperature of a maria exceeds by 10° the temperature of a continental region. However, from the condition of energy balance (absorbed and emitted), the temperature difference for a maria and a continent should not exceed 4° K. The discrepancy obtained is apparently connected with the fact that the variations of $\varepsilon_{3.6\mu}$ and $\varepsilon_{8-13\mu}$ are not identical, with the variations of $\varepsilon_{8-13\mu}$ being smaller. Thus, although to a first approximation the Moon is a gray emitter in the infrared region of the spectrum, for its individual areas the equality $\varepsilon_{3.6\mu} = \varepsilon_{8-13\mu}$ is not satisfied.

4. During three nights, measurements were made of the heat flux from the unilluminated part of the Moon. On each of the nights, scanning was carried out along one and the same section on the Moon, crossing the Mare Crisium, the Mare Tranquillitatis, and the crater Gassendi. Figure 4 presents curves averaged for each night over 3-4 records. The same figure also shows a recording of the signal from one area of the unilluminated part of the Moon, characterizing the signal-to-noise ratio. As is seen from the figure, the flux from the continental part of the surface, although in all cases it is located closer to the departing terminator, is almost 2 times smaller than from the maria. As was obtained above, the dif-

Fig. 4. *a* –averaged records of heat fluxes from the unilluminated side; *b* – record of flux fluctuations $I_{8-13\mu}$ from the sky background and from a region of the unilluminated Moon

ference $\varepsilon_{3,6\mu}$ for maria and continents is 25%, while for $\varepsilon_{8-13\mu}$ this difference is still smaller and therefore cannot be the cause of the observed difference in fluxes. Apparently, the difference in fluxes should be attributed to the difference in the value $\gamma = (k\rho c)^{-1/2}$ for maria and continents (here k is thermal conductivity, ρ is density, and c is heat capacity). According to calculations (^{8}), at an average value $\gamma = 600$, the observed difference in fluxes corresponds to a difference in γ of about 20%.

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Note: Figure translations are in progress. See original paper for figures.