National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No.NAS-5-12487

ST—PS—OA—10841

ON THE DISTRIBUTION OF BRIGHTNESS ON THE DISK OF MARS AND ITS STELLAR MAGNITUDE

by

N. P. Barabashov

(USSR)

31 MAY 1969

ST — PS — OA — 10841

ON THE DISTRIBUTION OF BRIGHTNESS ON THE DISK OF MARS AND ITS STELLAR MAGNITUDE

Astronomicheskiy Zhurnal
Tom 46, No.2, 430 - 434,
Izdatel'stvo "NAUKA", 1969

by N. P. Barabashov
The Khar'kov
Astronomical Observatory

SUMMARY

It is shown in the present work that the integral stellar magnitude of planet Mars is subject to considerable variations as a function of processes taking place on its surface and in its atmosphere.

For the reason just mentioned, one may not use it as a basis for deriving the various parameters characterizing the surface and atmosphere of Mars without resorting to special visual observations.

*
* *

The observations of Mars in the Astronomical Observatory of Khar'kov State University in the name of Gor'kiy, conducted by the author during a time of a series of oppositions, have shown that for a phase angle near zero, the distribution of brightness in red rays ($\lambda = 650$ mμ) over the disk in the interval from 0 to 0.866 of Mars disk's radius differs little from that yielded for the same interval by the Lambert formula.

Utilizing the formula $B = \Gamma \cos^q i$, proposed by N. N. Sytinskaya, we have obtained:

1. By Barabashov at transparent atmosphere of Mars: $0.8 < q < 1.0$ [1].
2. Sytinskaya found $q = 1.18$ and even $q = 1.30$ for continents and $q < 1.0-1.18$ for maria [2].
3. In 1956 Barabashov and Koval' [3] have found $0.83 < q < 1.09$ for continents and $q < 1.0-1.18$ for maria [2].

../..

4. It is shown in work [4] that the average value of q resulting from observations conducted by us in 1932, 1939, 1950, 1954 and 1956 is equal to 0.93. In the years just indicated the observations were conducted only under atmospheric conditions allowing the utilization of the sector 0 — — 0.866 counting from the center of the disk.

Particularly reliable results were obtained during the great oppositions, when the visible diameter of Mars' disk attained 25".

The most probable value, i. e., $0.7 < q < 1.0$ was derived for the same interval by Barabashov, Aleksandrov and Garazha [4], involving the observations of Mars' integral shine.

Starting from the above, the value $q = 0.5$ for the interval 0 — 0.866, admitted by Kovalev [5] without sufficient substantiations, is little probable. (refer to [6]).

However, the value $q = 0.5$ may be close to the one that would be obtained if one did not limit himself to the 0 — 0.866 interval, but utilized the entire radius of the disk, particularly in the moments of time when fairly often observed enlightenings appear at its limbs. They are induced by morning and evening fogs, and also by the settling of frost or hoarfrost. The same can be obtained in the case of turbid atmosphere of Mars.

The points lying outside the interval 0— 0.866 may be comparatively seldom utilized for they are substantially more subject to distorting action of the terrestrial atmosphere.

Let us consider at somewhat further length the methods of determination of q. It is well known that it may be determined as follows.

First of all, on the basis of the study of brightness distribution over the planet's disk at $\alpha = 0$. Secondly, from comparison of the brightness factor of planet disk's center with its stellar magnitude at time of opposition. Following is the formula utilized to that effect:

$$\log (q + 2) = 0.4[m_{♂} (0.1) - m_{♂}) - \log (2\rho_0 a^2).$$

Here $m_{♂}$ (1.0) is the stellar magnitude of Mars in opposition, $m_{\odot}$ is the stellar magnitude of the Sun, ρ_0 is the brightness factor of Mars' disk at time of opposition. Each of these methods has its advantages and shortcomings. Thus, the measurements of brightness distribution over the disk may be distorted by instrumental errors, observation and measurement errors, errors stemming from the method itself and, finally, errors introduced by the distorting influence of the terrestrial atmosphere, i. e. the turbulence. As to the way of getting rid of these errors and obtaining reliable results, refer to our own book [1],: "On Methods of Photographic Photometry of Planets".

We shall point out here that in the case of obtaining q by way of determination of the stellar magnitude and brightness factor of the center of Mars' disk in opposition, special observations of Mars disk's marginal zone and of contrasts on its surface are quite indispensable with the view of ascertaining whether or not there are enlightenings to which we already alluded, or turbidities in the atmosphere. Turbulence hardly influences the determination of the stellar magnitude of the planet, provided the whole image of the planet enters the slot of the photometer or spectrograph. The brightness factor of the center of the disk will be so small that it may be neglected, for although it is subject to the influence of washing by the terrestrial atmosphere, it is to a substantially lesser degree than the limbs, since near the center the brightness gradient is smaller. Therefore, if we adhere to indications given by us in [1], this influence will indeed be small enough to be disregarded.

The matter is notably more serious when we have to do with observations of the integral shine of Mars in the case, when enlightenings at the limb of the planet and turbidities in its atmosphere are not taken into account. They may be taken into account when measuring the brightness distribution over the disk. Moreover, as was shown by our observations, enlightenings seldom spread beyond 0.10 - 0.15 of the radius counting from the edge of the disk. If only the determination of the intergal shine is conducted without visual observations, the indicated phenomena remain unnoticed and the stellar magnitude is obtained in a distorted form in any portion of the spectrum. At the same time, the degree of distortion remains unknown.

We observed enlightenings of the disk's limb in different rays of the spectrum. In red rays these are either full rings, occupying 360°, or parts of them occu ying 180° on the eastern or western edges of the disk. Similar formations are most frequently seen in green or blue rays. In the latter and in ultraviolet rays we sometimes observe enormous clear regions on the western and eastern edges of the disk, suggesting polar caps at their optimum development. In these regions of the spectrum the clear formations exceed in brightness that of the center of the disk by almost a factor of 2. With Mars appearing as having four nearly contiguous caps this is something that is observed at certain times. In red rays they even appear rather often, exceeding in brightness that of the center of the disk by a factor of 1.2 as an average, but may be even brighter. Computations of differences in stellar magnitudes Δm were conducted for two moments of time. First, when there were no enlightenings on the limb at all, and the distribution of brightness was normal, corresponding to the most transparent atmosphere of Mars; secondly, in the presence of enlightenings in the following two cases: the width of enlightening is equal to 0.015 and 0.060 of the Mars disk radius.

In 1939 and 1956 the enlightening brightnesses relative to the center of planet's disk were 1.2 and 0.90 in red rays, 1.50 and 1.35 in green rays and 1.44 and 1.85 in blue ones.

The results of calculations are compiled in Table 1. Given in the first column is Δr, i. e. the width of the rim, in the second and third columns are the values of Δm in red rays respectively for the years 1939 and 1956 and in the fourth and the fifth is the same for a green light filter and in the sixth and seventh — for the blue one.

TABLE 1

Δn	red		green		blue	
	1939	1956	1939	1956	1939	1956
0.015	$0^m.09$	$0^m.12$	$0^m.10$	$0^m.14$	$0^m.11$	$0^m.12$
0.060	0 .17	0 .24	0 .19	0 .25	0 .22	0 .25

It is clear that the greatest extension of rims must take place near the opposition, when the Sun stands at both limbs low above the horizon. When a is great, only half of the rime is often observed.

From the above data we see that enlightenings at the limbs of Mars' disk notably enhance its integral stellar magnitude even when these enlightenings have a width of only 0.15 of disk radius. In this case the error in the determination of q attains 0.3. But if the enlightening of the limb spreads to 0.060 of disk radius, the error will already attain 0.6, that is, a great magnitude. Obviously, in this as in the previous case, such observations cannot be utilized for the study of brightness distribution over Mars' disk at $\alpha = 0$. We are faced with about the same errors in the determination of q for the green and blue portions of the spectrum. We had recalled that the variation of Mars' stellar magnitude may be linked not only with the presence of clear rims at disk edges, but generally with atmosphere turbidity.

Observing Mars we often notice that its atmosphere goes turbid, the details become poorly visible and the ratio B_0/B_{60} decreases, that is, brightness distribution over the disk notably changes in the sense that its incidence from center to limb becomes less abrupt. This takes place at observations in red, green and blue rays.

We could break down our numerous observations of brightness distribution over the disk of Mars into the following three groups: 1) of most transparent atmosphere, 2) of atmosphere with average transparency, and, finally 3) of very turbid atmosphere [7].

It should be noted that as brightness distribution over the disk varies, the brightness factor of disk center remains nearly constant. Comparing the computed integral stellar magnitudes of Mars for the most and the least transparent atmosphere of Mars in red, green and blue rays, we find:

$$\Delta m_{red} = 0^m.30; \quad \Delta m_{gr} = 0^m.21; \quad \Delta m_{bl} = 0^m.26,$$

i.e. that variations are nearly identical for all filters. The value $\Delta m = 0^m.30$ corresponds to variation of q by 0.7, i.e. it induces about the same variations as does the rim spreading to 0.060 of the disk radius, counting from the limb.

Let us examine what oscillations of Mars' integral shine were registered to date by various observers.

Gutnik and Prager [8] have found that the stellar magnitude of Mars may vary as a function of the central meridian by $0^m.14 - 0^m.15$ in red rays. This would correspond to q variation by 0.3.

The value of $0^m.12$ was found for visual rays at Lovell and MacDonald observatories in 1954. It is easy to show that, taking into account the magnitude of the contrast between continents and maria, it is possible to approximately compute the variations of Mars' stellar magnitude in red rays as a function of the position of the central meridian. These variations are found to be of the order of 0.08 – $0^m.10$. In blue and ultraviolet rays they are hardly noticeable, since in these rays the contrast is very small. All this fully corroborates the Jones and Gardiner ideas.

Jones and Gardiner note that the discrepancies in the estimates near the median curve are greater than could be explained by obs rvation errors. They consider that if the atmosphere of Mars is more transparent than usual, the observed integral shine is obtained weaker than average, while the lowering of transparency ("dimness") results in greater shine. This fully corroborates our own conclusions.

They consider as extreme the case of 3 – 4 May 1954 observation, when the integral shine of Mars was greater than average in visual rays by $0^m.1$, in blue rays by $0^m.2$ and in ultraviolet by $0^m.3$. Consequently, the amplitude of shine fluctuations constitutes, according to their observations, $0^m.2$ in red rays and $0^m.4$ in blue ones. Our calculations yielding $0^m.21$ for the green and $0^m.26$ for the blue rays are not in contradiction with the former.

Vaucouleurs [9] writes that the "stellar magnitude of Mars", reduced to the time of mean opposition, undergoes substantial fluctuations, reaching according to Bekker [9], $0^m.7$, i. e. 50%), without showing a noticeably expressed periodicity. These fluctuations do not allow us to derive a reliable result from data related to a small number of oppositions.

If we construct curves of Mars' integral shine for photored, photovisual and photographic stellar magnitudes on the basis of Gordeladze and Gurtovenko observations conducted in 1956 and 1957, after breaking them down into three parts: from 1 to 3 September 1956, from 1 to 31 October 1956 and from 26 December 1956 to 2 January 1957, one may notice that at certain dates the shine of Mars clearly rose and the points, describing this rise, are substantially higher than the average curves.

It should be noted that the stellar magnitudes of Mars, obtained by Gordeladze and Gurtovenko, are abnormally overrated near the opposition [10].

According to conclusions of observers, this increase is the consequence of abnormally enhanced Mars' tubidity and strong variations of its transparency. However, since we need only to catch short-term enhancements of Mars' shine, relative to the average course of curves representing the variation of stellar magnitude, without pausing at causes of rise of the entire curve, we thought it possible to make use of these data also, and the more so, since in 1956 I personally conducted visual observations of Mars and kept a diary of such observations. On curves corresponding to the first time interval, the enhancement of shine falls on 2 September. For the second interval, there were two of them, respectively on 7 - 8 and 24 October. In the third time interval the enhancement fell on 28 December 1956. The increase of shine was observed in photored, photovisual and photographic rays.

It is curious that in the above diary, the following was written in graphs on dates of shine enhancement:

2 September 1956. "A clear rim is observed around the entire planet disk". 7 September 1956. "In the red filter maria are as pale as without filter. The paleness of maria is exceptional". 8 October 1956. "A clear rim is noted at the western edge". No observations were conducted by me on 24 October and 28 December.

I shall note that in the course of a series of years, beginning with 1918, we more than once observed clear rims at times wide and shining, during every observation conducted in time of opposition.

Examining the observations by Ibragimov [11], plotted in the graph, we may notice the presence of a great scattering of points relative to the average curve, which substantially exceeds the acceptable departure for the kind of precision that characterizes the observations. Thus, for waves 636, 550 and 534 m , we obtain the respective digressions 0.075, 0.110 and $0^m.105$.

The maximum digressions obtained from the observations of [1], are compiled in Table 2 (next page). Considering them, it is easy to detect that 1) their magnitude is substantially greater than the possible errors of photometric measurements; 2) their magnitude is of same order than that obtained by us during calculations with clear rims and with a turbid atmosphere; 3) the Δm values of the first line of Table 2 decrease smoothly from 0^m470 to $0^m.360$ beginning from 10635 and to 4573 A (with exception of 6264 A), and then increase at 3590 A from $0^m,360$ to $0^m.490$ A; 4) the Δm of the second line varies little and 5) Δm of the third line drops from $0^m.170$ to $0^m.110$ at 5012 A, and then increases to $0^m.320$; 6) the ejections for all wavelengths hit the same Δα (difference in phase angles).

TABLE 2

λ	10635	8595	7297	6246	5012	4573	4155	3926	3590	3174	Δα
Δm	$0^m.470$	$0^m.430$	$0^m.350$	$0^m.250$	$0^m.370$	$0^m.350$	$0^m.410$	$0^m.470$	$0^m.490$	—	35—40°
Δm	0.300	0.280	0.240	0.260	0.210	0.210	0.210	0.250	0.250	0.260	26.6—30
Δm	0.200	0.170	0.170	0.150	0.110	0.150	0.210	0.240	0.320	0.320	15—17

Apparently, here we have to do with one and the same phenomenon, taking place on planet surface and engulfing the entire thickness of its atmosphere, or with simultaneously existing surface and atmospheric phenomena. Probably hoarfrost-like precipitations on the surface and the shining high clouds, well seen in short wavelengths are responsible for them. Possible, clear rims around the Mars disk may have taken place at that time. Obviously, one is not in the position to state precisely what was the real cause of such point scattering rims, precipitations, clouds or the turbid atmosphere of Mars? Indeed, we lack both the visual observations and photographs of Mars carried out at that time.

From the above considerations it follows that during the determination of the smoothness factor as well as other parameters characterizing the surface and the atmosphere of Mars with the aid of brightness distribution over the disk and of phase curves, it is absolutely indispensable ta carry out concomittantly attentive visual observations of Mars, to track the transparency of its atmosphere, the clear rims at the limbs and to observe the various kinds of clouds, including the dust haze.

In conclusion I express my gratitude to the aspirant T. Lupishko, who helped me in my calculations.

**** THE END ****

ST – PS – OA – 10841

R E F E R E N C E S

1. N. P. BARABASHOV. O metodakh fotograficheskogo fotometrirovaniya planet. (On photographic photometry of planets). Izd-vo KHGU, 1966.
2. N. N. SYTINSKAYA. Tr.Yubileynoy naychnoy sessii. Izd-vo LGU, 1948.
3. N. P. BARABASHOV, I. K. KOVAL'. Fotograficheskaya fotometriya Marsa so svetofil'trami in 1956 (Photographic photometry of Mars in 1956 with light filters), Izd-vo KHGU, 1959.
4. N. P. BARABASHOV, YU. V. ALEKSANDROV, V. I. GARAZHA. Vestnik KHGU, ser.astronomicheksaya, v.3 1967.
5. I. K. KOVAL'. Attronom. Zh., 34, 3, 1957.
6. I. K. KOVAL'. Ib. 45, 4, 1968.
7. N. P. BARABASHOV, V. I. GARAZHA. Ib. 37, 1960.
8. L. L. GARRIS. Planety i sputniki., IL, M., 248, 1963.
9. ZH. VOKOLER (VAUCOULEUR). Fizika planety Marsa (Physics of Planet Mars). IL (For.Lit.), 227, 1956.
10. [illegible] G. GORDELADZE, E. [illegible] GURTOVENKO. Izv.Glavn. Astronom.Obs. Izd-vo AN USSR. Kiyev, 1958.
11. N. B. IBRAGIMOV. Vestnik KHGU, No.4, ser. astronom., vyp.1, 1965.
12. M. W. IRVIN, Astronomical J. 73, No.4, 251, 1968.

Khar'kov Astronom. Observatory

Manuscript received on
20 October 1968

Contract No.NAS-5-12487
VOLT INFORMATION SCIENCES, INC.
1145 - 19th St.NW
WASHINGTON D.C. 20036.
Telephone: (202)-223-6700 (X-36)

Translated by ANDRE L. BRICHANT

on 30 - 31 May 1969