# PARHELIC HALO ON MARS. THE BRIGHTNESS OF THE PARHELIC HALO AND THE NUMBER OF ICE CRYSTALS IN THE MARTIAN ATMOSPHERE

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## Abstract

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# PARHELIC HALO ON MARS. THE BRIGHTNESS OF THE PARHELIC HALO AND THE NUMBER OF ICE CRYSTALS IN THE MARTIAN ATMOSPHERE

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**I.** At many astronomical observatories observers have occasionally noted the more or less short-lived appearance on Mars of a white spot or point of entirely unusual brightness (see, for example, ([1], [2]), ([3]), p. 95, ([4]), p. 78, ([5])). The interpretation of the shining points that arose in various places on the surface of Mars was reduced to hypotheses which today, for one reason or another, do not withstand criticism: "reflections from icy slopes inclined at an angle suitable for specular reflection" (P. Lowell, 1894, ([6]), p. 46), catastrophic volcanic eruptions (V. and J. Fournier, 1911, ([7]), pp. 156 and 157), light signaling by Martians, and even "forest fires" (([8]), p. 198). According to present-day views, there are no mountain glaciers on Mars. There can be no fires there, since oxygen is practically absent from the atmosphere. Energy estimates reliably rule out the visibility from Earth of Martian volcanic catastrophes of acceptable scale. Meanwhile, all the features of the observed "flashes" can be reconciled with the supposition ([9]) that we are dealing with halo phenomena in clouds in the atmosphere of Mars, i.e., with the "scattering" of solar rays in certain preferred directions, which are determined by the properties and orientation of the halo-forming crystals. The simplest of the many known mechanisms of halo formation in the terrestrial atmosphere is single reflection from the flat faces of ice crystals.

Having adopted the hypothesis of directed, simple single reflection of solar rays from each "shining" detail on the surface of Mars, one can find the orientation of the surface of the hypothetical reflector. The author found that, among the temporary unusually bright spots observed on Mars over the last two centuries, more than 30 possessed the property of verticality (!) of the reflector relative to the Martian horizon. Having discovered ([10]) this circumstance at first as an isolated and parasitic fact, we then encountered the need to explain its typical nature. One of the possible solutions is the parhelic form of halo in the Martian atmosphere.

**II.** In view of the poverty of the Martian atmosphere in water vapor, it would

Fig. 1. Graphs of the functions $E_1$ and $E_2$

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Fig. 2. Ranges of values of the functions $F_1$ and $F_2$

Figure 2: Fig. 2. Ranges of values of the functions $F_1$ and $F_2$

be important to estimate how much water is required to create on Mars a halo spot visible from Earth.

In the world literature on halo phenomena we have not found theoretical estimates of the brightness of the phenomena as a function of the number of halo-forming crystals. Such an estimate was made by the author for the case of a parhelic halo on the side faces of hexagonal plates with a vertical principal axis, with the Sun located near the horizon, for two variants: a) without taking into account diffraction on the crystals; b) taking into account diffraction on small crystals. Omitting the very cumbersome derivations of the formulas, we present the results.

The surface brightness on the central line of the parhelic-halo band is, in the two indicated cases, equal to:

a) $B_1 = E_1(i) R_\odot(\vartheta, i) \overline{B}_{1\odot} \sigma = F_1(i, \vartheta) \sigma$;

b) $B_2 = E_2(i) \dfrac{R_\odot^2(\vartheta, i)}{d_h} \overline{B}_{2\odot} \sigma = F_2(i, \vartheta) \sigma$;

here $\sigma$ is the coefficient of screening of the background by the halo-forming crystals, $E_1$ and $E_2$ are functions whose graphs are shown in Fig. 1; $i$ is the angle, at the ice crystal, between the directions toward the Sun and toward the observer, equal to the phase angle of Mars; $R_\odot(\vartheta, i)$ is the angular radius of the reflection of the Sun from an imaginary ideally flat surface passing through the given point of the parhelic halo and having unlimited extent (for cases of halos in the terrestrial atmosphere, it is obviously equal to the apparent angular radius of the Sun); $\vartheta$ is the heliocentric longitude of Mars; $d_h$ is the diffraction widening of the reflected beam in height; $\overline{B}_{\odot 1}$ is the surface brightness of the Sun averaged over a narrow diametral strip of the solar disk (for clouds in the terrestrial atmosphere it is necessary to take atmospheric extinction into account); $\overline{B}_{\odot 2}$ is the surface brightness of the Sun averaged over the entire solar disk.

**Fig. 1.** Graphs of the functions $E_1$ and $E_2$

**Fig. 2.** Ranges of values of the functions $F_1$ and $F_2$

The products of all the factors, calculated as applied to Mars as a function of the phase angle, are presented in Fig. 2 in the form of ranges of values of the functions $F_1$ and $F_2$. The diffraction parameters entering into $F_2$ and $E_2$ are chosen for crystals with a height of the vertical faces of 0.06 mm.

In order to judge the threshold value of the surface brightness of a halo on Mars and, consequently, the threshold value of $\sigma$, it is necessary to compare the brightness of the halo with the brightness of the background, which is the daytime surface of Mars.

The limits of variation of the surface brightness of Mars $\overline{B}$, averaged over the daytime part of the visible disk, are indicated in Fig. 3 as a function of the phase angle of Mars. (The widening of the band is due not to the distribution of brightness over the disk, but to the change in the linear distance of the planet from the Sun.) The graph was constructed using the compilation ($^{11}$) of determinations of the stellar magnitude and phase function of Mars.

As the threshold for guaranteed detectability of a solar halo in the form of a non-long-lived bright spot on Mars, which would attract the attention of observers, we shall take a 50% excess of the surface brightness of the spot over the brightness of Mars, i.e. the condition

$$2B = \overline{B}_{\odot} \quad \text{or} \quad \sigma = \overline{B}_{\odot}/2F.$$

Comparing the graphs of $F_1$ and $F_2$ with the graph of $\overline{B}_{\odot}$, we obtain the threshold values $\sigma_1$ and $\sigma_2$ of the coefficient of screening of the background by ice crystals

depending on the phase angle of Mars, without and with allowance for diffraction by the crystals. The results are shown in Fig. 4. We come to the conclusion that halo spots, substantially brighter than the surface of Mars, could arise even on practically transparent clouds.

III. Relying on $\sigma_1$ and $\sigma_2$, one can find the threshold mass of halo-forming crystals in the atmosphere of Mars along a line of sight of unit cross section. The sizes and shape of the crystals have a noticeable influence on the result. Taking, for definiteness, the length of the base edge to be 5 times greater than the height $b$ of a hexagonal ice plate (such halo-forming crystals occur in the terrestrial atmosphere and are mentioned in (12)) and substituting the values $\sigma_1 = 0.010 \div 0.013$, $\sigma_2 = 0.014 \div 0.022$ ($0 < i < 30°$), $b_1 = 0.28$ mm, $b_2 = 0.06$ mm (according to (13)), we obtain $m_{\text{p}1} = (2.0 \pm 0.2) \cdot 10^{-3}$ g/cm$^2$, $m_{\text{p}2} = (6.7 \pm 1.5) \cdot 10^{-4}$ g/cm$^2$.

**Fig. 3**

**Fig. 4**

**Fig. 3.** Brightness of the daytime portion of the disk of Mars

**Fig. 4.** Regions of threshold values of the shielding coefficient of the surface of Mars by halo-forming crystals according to the criterion of a 50% excess in the brightness of the halo spot. Region $\sigma_1$ is for large crystals, $\sigma_2$ for crystals with a height of the vertical faces of 0.06 mm

Let us compare the threshold mass of halo-forming crystals with the mean content of vapor-like water in the atmosphere of Mars above the daytime hemisphere. According to (14), the latter corresponds to $10 \div 20\ \mu$ of precipitable water layer, i.e. $\bar{m}_c = (1 \div 2) \cdot 10^{-2}$ g/cm$^2$ in a **vertical column of the atmosphere of Mars**. Our values $m_{\mathrm{p}1}$ and $m_{\mathrm{p}2}$, corresponding to the threshold visibility of the halo, are one to two orders of magnitude smaller than $\bar{m}_c$. This means that, at least over some regions of Mars, the conversion of atmospheric water vapor into halo-forming crystals can give an ice-crystal density along the line of sight quite sufficient to create a halo visible from Earth.

Taking into account that the parhelic halo can be observed only on the limb of Mars, we gain at least one more order of magnitude owing to the air-mass coefficient in passing from a vertical column to one inclined and grazing with respect to the surface of Mars.

On the other hand, the relative increase in the apparent sizes of the spot due to the combined effects of irradiation lowers the visible surface brightness of the solar glint, which may fall below the threshold for objects whose true angular sizes are substantially smaller than the image of a point in the field of view of the telescope. The 2–3 orders of magnitude that we have "in reserve" for the validity of our main conclusion may be regarded as the upper limit of the ratio of the apparent and true areas of a halo spot on Mars noticeable from Earth. From this one can find the lower bound of the threshold sizes of the halo spot in each particular case.

The estimates given here apply only to the parhelic type of halo phenomena; meanwhile, in the terrestrial atmosphere, on the same ice crystals, optical mechanisms operate that form several different types of halo phenomena.

forms of halos, including forms considerably brighter for the same number of crystals. Transferring the brightest halo forms to Mars, we find that for them to be visible from Earth an even smaller threshold number of crystals is required than for the visibility of the parhelic circle. This argument strengthens the grounds for the validity of our main conclusion.

Nevertheless, it does not follow in any way that all, without exception, cases of the appearance of halo spots on Mars can be explained by the transition of atmospheric water vapor into the solid state. In the case of the flare on Mars on 4 VI 1937, an order-of-magnitude estimate of the abundance of crystals in the cloud (13) gave a value two orders of magnitude greater than the average content of water vapor in the Martian atmosphere. Such a high density may be evidence in favor of the volcanic origin of some ice clouds on Mars.

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