A refraction halo on Mars

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Introduction

The Mars rover *Perseverance*, which has been exploring the surface of the Jezero Crater (18.43°N, 77.44°E) since February 2021, took, by chance, three photographs of a halo, which appeared in the Martian sky. This happened on 15 December 2021 and represents the first time that a halo has been observed from the surface of a planet other than Earth. On the day in question, it was the Northern Hemisphere summer on Mars, the solar declination being +15.2° and 72 (terrestrial) days before the start of autumn. The halo photos were taken by the left navigation camera of the rover, on Sol 292 – thus on the 292nd Mars day since the landing of the *Perseverance* – between 08:26:47 and 08:30:20 local mean solar time, at the rover's position elevation of 39.1°. The halo appeared in the thin Martian clouds; only the lower part of the halo is visible in the pictures. Two of them also show the Mars horizon. One minute after the first photograph, the second one was taken, followed 2 min later by the third one (NASA Mars 2020 Mission, n.d.) – this time with the horizon out of view. The three halo pictures were spotted almost immediately by the American space artist Donald E. Davis from California, who posted his finding two days later on Twitter.

The images

Figure 1 shows a picture of the halo. It is a combination of the first and second image, on which a sharpening filter is applied to further enhance the contrast. Only the overlapping parts of the two images are shown. The original images of the navigation camera consist of 960 × 1280 (8-bit) pixels, covering a field of view of 73° × 96° (Maki *et al*., 2020); in the combined version, a field of view of 73° × 32° remains. As the navigation cameras are so-called technical cameras, being designed to support the autonomous navigation of the rover (Maki *et al*., 2020), the image is less aesthetic than the *Perseverance* images taken by its scientific cameras instead. However, the image still contains all the information needed to quantitatively analyse the halo and to extract physical information from it.

CO_2-ice or water-ice?

Halo phenomena can be roughly divided into two types: spectrally coloured halos, where the sunlight on its path to the observer passes through the crystals (the 'refraction halos'), and uncoloured halos (the 'reflection halos'), where sunlight reaches the observer via a reflection at the crystal. The first type contains information about the chemical and/or crystallographic composition of the crystals; the second type does not contain this information (Können, 2017). The Mars halo depicted in Figure 1 belongs to the first type: the distance of its (red) inner edge to the Sun yields information about the chemical composition of the halo-making cloud particles.

The cold, very CO_2-rich Mars atmosphere allows for two possible cloud compositions: those consisting of water-ice crystals and those consisting of CO_2 crystals. Refraction halos can distinguish between these two possibilities: randomly or poorly oriented water-ice hexagonal crystals generate halos with their inner edge at 22° (and 46°) from the Sun (Tape, 1994); random or poorly oriented CO_2 cuboctahedral crystals create halos with their inner edge at 26° (and 39°) from the Sun (Whalley and McLaurin, 1984; Doherty and Bennett, 1986; Cowley and Schroeder, 1999; Cowley and Schroeder, 2000).

The Mars-rover halo appeared at an inner radius of 22.5° ± 0.8° below the Sun. This strongly suggests that this halo, just like the circular terrestrial halos, was caused by randomly oriented water-ice crystals. The halo observation, therefore, also shows that relatively large ice crystals (Tape, 1994) can exist in Martian clouds. The earlier observation (Können, 2006) of a Martian reflection halo from oriented crystals support this.

Figure 2 compares the Martian water-ice halo with a terrestrial water-ice halo. The somewhat more diffuse appearance of the former suggests a smaller size of halo-making particles in the Mars clouds. Of course, our conclusion about the origin of the present Mars halo does not exclude the possibility of an occurrence of CO_2-crystal halos under different meteorological conditions on Mars.

Sixteen years ago, a reflection halo (the subsun) was recognised on pictures taken

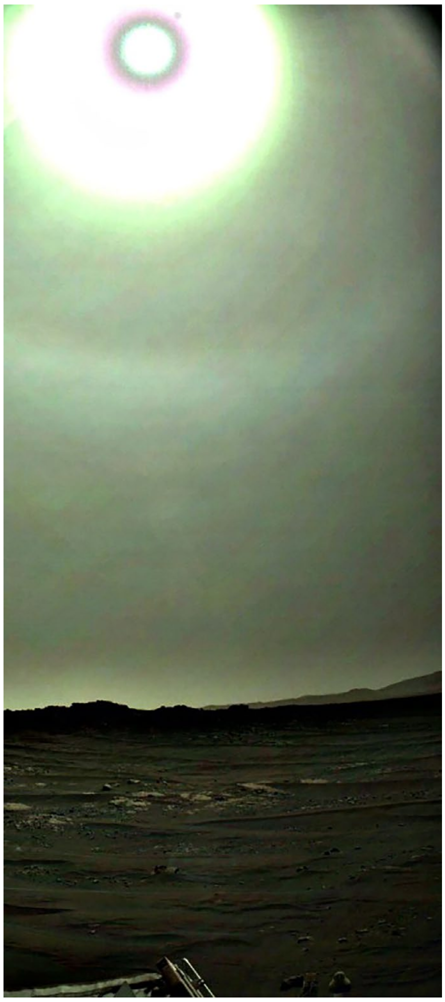

Figure 1. A Mars halo, 22° below the Sun, visible in a photograph taken on 15 December 2021 by the left navigation camera of NASA's Mars rover Perseverance. *The field of view is 73° × 32°. Near the Sun, the image is saturated. (Photo credit: NASA/JPL-Caltech.)*

RMetS Royal Meteorological Society

Figure 2. The Martian halo (left) compared with a terrestrial water–ice 22° halo (right), the latter photographed by Les Cowley with the Sun at an elevation of 50°.

by a Mars probe in orbit (Können, 2006). The present observation represents an important novelty: the first observation of a refraction halo in the atmosphere of another planet.

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