A halo on Mars

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Figure 1 shows a picture of Mars, taken by the wide-angle Mars Observer Camera (MOC) on board the Mars Global Surveyor satellite (MGS). The picture was taken on 28 January 2006, seven days after the start of the Martian Northern Hemisphere spring, from a height of 380 km. Near the centre of the picture, the volcano Arsia Mons is visible. Clouds are present over the volcano, of which the imaging team comments:
"Arsia Mons and the other large Tharsis volcanoes commonly develop afternoon orographic (i.e. topographically-controlled)water ice clouds at this time of year." (Malin et al. 2006).
Just below Arsia Mons, a bright white streak is visible, described by the MGS team as: *"Sunlight [that] glints off the dusty surface and the clouds and aerosols in the [Martian] atmosphere."* (Malin et al. 2006)

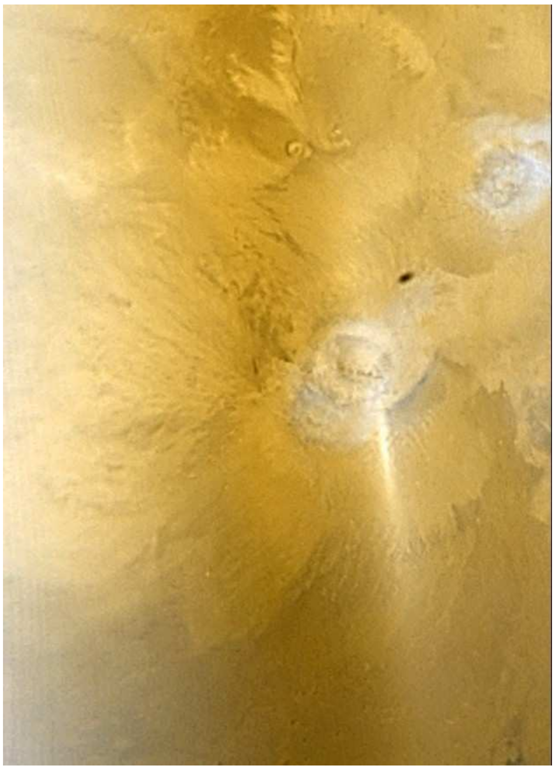

Fig. 1 The subsun on Mars, photographed by the Mars Global Surveyor satellite on 28 January 2006. North is up; the sunlight comes from the left. At the place where the subsun appears, the solar height is 70°. The volcano just above the subsun is Arsia Mons; the volcano near the upper right corner of the picture is Pavonis Mons. The small black dot north of the subsun is the shadow of the Martian satellite Phobos. The picture covers an area of 1800 × 2400 km; its centre is near 9° S, 101° W (Photograph NASA/JPL/MSSS, MOC2-1363)

The white streak in Fig. 1 can be identified as the subsun, which is a halo that appears as the specular reflection of the sun on a cloud. On Earth, this subhorizon halo is often observed from an aeroplane (Fig. 2). To our knowledge, Fig. 1 is the first instance that a halo is identified on a picture of a planet other than the Earth.

The subsun belongs to the class of reflection halos, i.e. halos that emerge without net-refraction. Contrary to refraction halos, they don't show any colouring. The subsun is the simplest among all halos. Its only requirement is the presence of sunlit horizontally-oriented faces of crystals of sufficient size (larger than ~20 μm) of any substance; the crystals do not even need to be transparent (Können 2004). The set of horizontally-oriented crystal faces acts as a giant mirror, in which the image of the sun appears. Because of imperfection in the horizontalorientation of the faces, the sun image is usually somewhat elongated – see Fig. 2.

Figure 2. The terrestrial subsun, as photographed from the cockpit of an aeroplane

The Mars subsun of Fig. 1 has a length of 300 km and a width of 20 km when projected on the surface of Mars. This corresponds to an angular length and width of 40° and 3°, respectively. However, it should be noted that the 40°-length of the subsun is not real, but an artifact of the imaging technique instead. Like the terrestrial NOAA weather satellites, the MGS satellite is in a high-inclination (98°) sun-synchronous orbit (MGS tracks over the sunlit side of the Mars globe from south to north, passing over the equator at 1400 local Mars time), and the images are obtained from pasting together consecutive horizon-to-horizon line scans that are continuously taken by the moving spacecraft in the direction perpendicular to its track (Malin et al. 1992). As the sun's specular point travels over the planet as seen from the moving spacecraft, the position of that point with respect to the surface of Mars has changed between two successive line scans. Therefore, on this type of image of the planetary surface, a specular reflection will become considerably elongated, in a direction that is about parallel to the satellite track. This well-known effect in satellite imaging of the Earth is apparent in Fig. 1: instead of pointing toward the sun as it should (which is at the place of the subsun at 305° azimuth, hence about north-west), the elongated subsun points toward azimuth 350°, hence almost north.

Contrary to the subsun's length, its width does contain physical information. For faces that are ideally horizontally-oriented, the observed subsun's width – for the current imaging technique as measured along a line perpendicular to the satellite track – should equal the angular solar diameter as seen from Mars, which is 0.3°. The observed width of 3° indicates that the face normals have a mean tilt angle of about 1°.

Inspection of the MOC image archive reveals the existence of some other MGS photographs of the Mars subsun. An interesting example is picture MOC2-723 (taken on 1 May 2004 and released 11 May 2004), where the subsun appears at a distance less than 100 km west of the site of the Mars Exploration Rover Opportunity (2° S, 5.6° W). On that day, the left navigation camera of the Opportunity took a south-looking wideangle picture of the Martian sky on 1124 local solar time, hence about 2.5 hours before MOC2-723 was taken. This picture, which can be downloaded from http://marsrovers.jpl.nasa.gov/gallery/all/opportunity_n096.html, covers an azimuthal range of 157°–200° and extends from the horizon to a height of about 40°. The sun's azimuth (32°, hence north-east) and elevation (75°) imply that the photograph covers a region in the sky where only rare halos may appear (Tape 1994). No halos are apparent in the picture, but streaks of the subsun-generating cirrus clouds are clearly visible.

The present paper is a natural follow-up of earlier searches for halos and other meteorological optics phenomena in pictures from space probes. So far, this search had been successful only in images of the Earth, where the subsun (Können and Zwart 1975) and even a glory (Laven 2005) have been unequivocally identified. Despite theoretical studies (Whalley and McLaurin 1984) and simulations (Cowley 2006; Können 2003) of halos from various types of crystals that may occur in the solar system, an exohalo – that is a halo in the atmosphere of a planetary body other than the Earth – has not been detected before on images taken by interplanetary probes. The only planet (other than the Earth) on which meteorological optics phenomena have been seen so far is Venus, where Earth-based instruments have detected signals of a sulphuricacid rainbow (Hansen and Hovenier 1974) and possibly of a weak halo from contaminated water ice (Können et al. 1993). It is encouraging that now a planetary atmosphere is found in which halo scattering distinctly occurs; as can be seen from Fig. 1, the resulting exohalo can sometimes be surprisingly bright. Like the terrestrial halos and the alleged Venus halo, the Mars halo is apparently due to ice. However, halos due to crystals of other compounds still remain possible in the solar system, and perhaps one day such a halo will also be captured by the cameras or sensors of outer-planetary space probes or landers.

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