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An Ionized Layer in the Upper Atmosphere of Mars Caused by Dust Impacts from Comet Siding Spring

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Abstract

On 19 October 2014, the comet Siding Spring passed within 135,000 km of Mars. This close encounter caused dust from the comet to impact the Martian atmosphere at very high velocities, allowing for major ionization to take place in the upper atmosphere. The Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) aboard Mars Express subsequently observed an unusual transient layer of ionization at altitudes of about 80-100 km on the two ensuing spacecraft orbits. This ionized layer was present on both the dayside and nightside of Mars, and contained peak electron densities of 1.5-2.5 x 10^5 cm^{-3}, higher than densities normally observed in the Martian ionosphere. These results have been compared to ionization produced by meteors at Earth and Mars, leading to the conclusion that this layer was directly produced by the cometary dust impacting and ionizing the upper atmosphere of Mars.

1. Mars Express Radar Sounder

The Mars Express spacecraft carries among its instruments the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS). In its ionospheric sounding mode, MARSIS transmits a short pulse at a fixed frequency and then measures the time delay for the pulse to reflect from the ionosphere and return to the spacecraft. For vertical incidence, the ionospheric reflections occur at the point in the ionosphere where the wave frequency is equal to the electron plasma frequency. By stepping the transmitter frequency through a range of frequencies, a vertical profile of the electron density in the ionosphere can be obtained. As a first order approximation, the location of the reflection point can be calculated assuming the radar pulse travels at the speed of light, in which case the altitude of reflection is called the apparent altitude. However, for precise measurements, plasma dispersion effects must be considered. During the period around closest approach of the comet to Mars, the ionospheric radar soundings started at an altitude of about 1200 km over the nightside northern polar region, then proceeded southward across the terminator, through periapsis at about 375 km, and ended at midlatitudes in the southern hemisphere.

2. Observations

The first evidence of anything unusual was on orbit 13710, 7 hours after closest approach. On this pass, strong radar echoes were observed at an apparent altitude of about 100 km over the nightside polar region at frequencies extending as high as 4.6 MHz. The peak plasma frequency corresponds to an electron density of 2.6 x 10^5 cm^{-3}. Densities this high have never been observed on the nightside of Mars. A few minutes later, similar radar echoes were detected on the dayside of Mars at frequencies well above the normal dayside ionospheric echoes. On the next pass, the enhanced ionization over the nightside polar region had completely disappeared, but there was still evidence of an enhanced ionization layer on the dayside of Mars. On the ensuing orbit, there was no evidence of the ionization layer.

The ionograms in Figure 1 show that on orbit 13710 the transient ionization layer extended nearly continuously from the polar region into the dayside midlatitudes. Electron densities were highly variable, ranging from about 1.5-2.5 x 10^5 cm^{-3}, with two well-defined peaks and two brief periods where no echoes were detected. In all cases, the peak densities of the transient layer were well above the peak density of the Martian ionosphere.

The thickness of the ionized layer is also of interest. While no such measurements can be obtained from the topside echoes, the dispersion of the ground echoes gives a direct measurement of the total electron content (TEC). By subtracting the TEC of the ionosphere, the TEC of the transient layer can be determined. Unfortunately, only three ionograms had ground and ionospheric echoes sufficient to yield reliable measurements of the thickness. These ranged from 13.7 to 42.3 km. Patchy ionization may be the cause of this inconsistency.

3. Figures

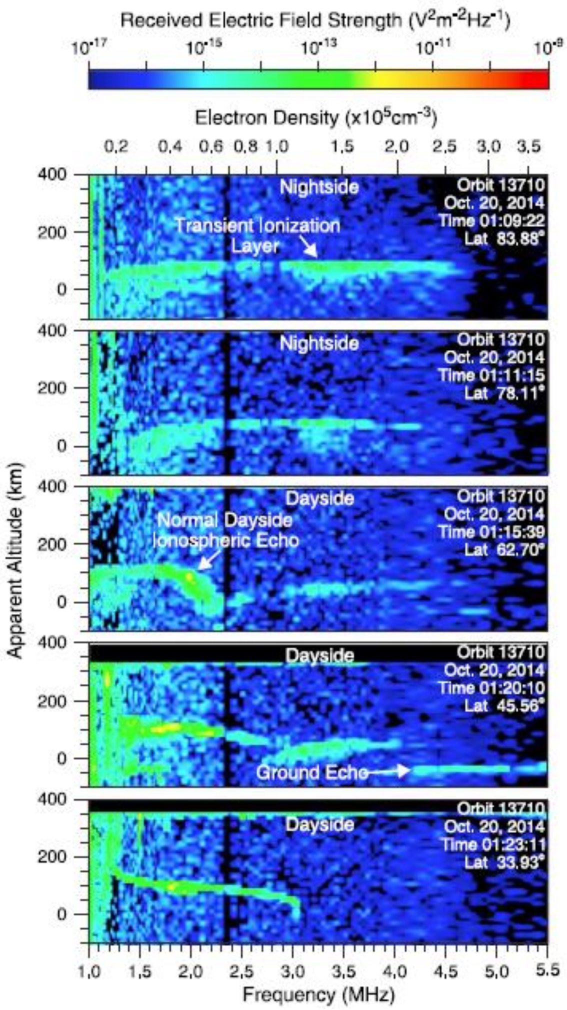

Figure 1: Five ionograms showing the latitudinal variation of radar echoes from the transient ionized layer. The first two ionograms, from the nightside, show the apparent altitude of the reflecting layer to be nearly independent of frequency. Slight dispersion effects below about 2 MHz are due to ionospheric plasma at low densities between the spacecraft and the layer, particularly in the dayside ionograms.

4. Conclusions

Of the two components, gas and dust, released from the comet, only dust can cause this transient layer of ionization. The altitude of this layer is far below the altitudes where the primary interaction with cometary gas was expected. On the other hand, the altitudes are in good agreement with the transient M3 layer in the Martian ionosphere [1]. The M3 layer is believed to be caused by the impact of meteors.

It is interesting to note that the observations obtained here were taken over a local time region that was not exposed to direct impacts of dust from the comet. The main flux of meteoritic particles probably occurred 5-6 hours before our earliest observations [3]. Evidence of the early arrival of the particles is given by the SHARAD radar on the Mars Reconnaissance Orbiter spacecraft, which detected greatly enhanced TECs as early as 3 hours after closest approach [2]. The enhanced TECs lasted almost 10 hours. This means the ionization had to be transported by the rotation of the Martian atmosphere from the main impact region over a period of 10 hours or more, and also in local time.

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