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Meteoric ion layers in the ionospheres of venus and mars: Early observations and consideration of the role of meteor showers

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Abstract

Layers of metal ions produced by meteoroid ablation have been known in Earth's ionosphere for decades, but have only recently been discovered at Venus and Mars. Here we report the results of a search for meteoric layers in earlier datasets from Venus and Mars. We find 13 candidates at Venus in Mariner 10, Venera 9/10, and Pioneer Venus Orbiter data that augment the 18 previously identified in Venus Express data. We find 8 candidates at Mars in Mariner 7 and Mariner 9 data that augment the 71 and 10 previously identified in Mars Global Surveyor and Mars Express data, respectively. These new findings extend the ranges of conditions under which meteoric layers have been observed, support studies of the temporal variability of meteoric layers, and (for Venus) independently confirm the existence of meteoric layers. One of the proposed causes of temporal variations in the occurrence rate of meteoric layers is meteor showers. This possibility is controversial, since meteor showers have minimal observed effect on meteoric layers in Earth's ionosphere. In order to aid progress towards a resolution of this issue, we present a series of tests for this hypothesis.

Keywords: Comets; Meteors; Ionospheres; Venus; Mars

1. Introduction

The chemistry of a planetary atmosphere, an environment dominated by species derived from atoms found in the first row of the periodic table, such as N_2, O_2, or CO_2, is disrupted by meteoroids. The ablation of meteoroids, also known as interplanetary dust particles, due to atmospheric drag and associated heating deposits cosmochemically abundant, but atmospherically deficient, species like Mg and Fe into the atmosphere (Grebowsky et al., 2002; Murad and Williams, 2002). Metallic species are easily ionized, so meteoroid ablation affects the state of the ionosphere. In the absence of meteoroids, the ionosphere at altitudes where meteoroids would be ablated is dominated by non-metallic molecular species, such as O_2^+, whose primary loss mechanism is dissociative recombination with an electron (i.e., $XY^+ + e \rightarrow X + Y$). Metals tend to form atomic ions (e.g. Mg^+), which cannot be neutralized via this fast mechanism for quantum mechanical reasons and are consequently long-lived. As a result, even relatively small production rates of atomic metal ions can maintain a significant plasma population. Hence meteoroids affect the structure, chemistry, dynamics, and energetics of planetary ionospheres.

The existence of a layer of meteoric ions in Earth's ionosphere has been well-known for decades (Grebowsky and Aikin, 2002; Murad and Williams, 2002). Attempts to find analogous meteoric layers on Venus and Mars were frustrated by the scarcity of data: electron density data from other planets are rare and compositional data at the appropriate altitudes are non-existent. Pätzold et al.

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(2009) convincingly identified meteoric layers in Venus observations, although possible candidates were discussed earlier by Witasse and Nagy (2006). Similarly, Pätzold et al. (2005) convincingly identified meteoric layers in Mars observations, reinforced by later, independent identifications by Withers et al. (2008), although possible candidates were discussed earlier by Fox (2004). On Venus, Earth, and Mars, meteoric ions form layers below the main ionospheric peaks.

Meteoric layers form in poorly-understood regions of the ionospheres and neutral atmospheres of Venus and Mars (Brace et al., 1983, 1992; Fox and Kliore, 1997), so these layers can be used as diagnostic tools of these regions. For example, their physical properties are sensitive to the eddy diffusion coefficient of the neutral atmosphere and the chemical composition of the ionosphere (Grebowsky et al., 2002). They are also sensitive to the meteoroid influx rate, something that reflects the dust population of the solar system yet is poorly constrained beyond Earth (Janches et al., 2006; Fentzke and Janches, 2008; Wiegert et al., 2009; Gardner et al., 2011; Nesvorný et al., 2011; Nesvorný et al., 2011). Meteoric layers are only sporadically present in ionospheric observations at Venus and Mars, something that has not been explained to date. This sporadic occurrence could be caused by internal factors, such as changes in neutral atmospheric dynamics that affect layer formation, or external factors, such as meteoroid influx rate. Many discussions of this variability have centered on the possible role of meteor showers, which are visibly impressive at Earth, but do not affect observed properties of Earth's meteoric layers (Kopp, 1997; Grebowsky et al., 1998; Molina-Cuberos et al., 2008).

This manuscript has two main objectives. First, to find additional examples of meteoric layers on Venus and Mars by examining early ionospheric observations. Second, to develop specific tests for the hypothesis that meteor showers influence the occurrence rate of meteoric layers.

2. Early observations

There are few reported examples of meteoric layers at Venus and Mars. Finding additional meteoric layers will better define the physical properties of meteoric layers, increase the likelihood of finding atypical examples, increase the range of conditions at which meteoric layers have been observed, support studies of inter-annual repeatability, and independently confirm the existence of meteoric layers. Datasets from the Venus Express (VEX), Mars Global Surveyor (MGS) and Mars Express (MEX) radio occultation experiments have been carefully examined for meteoric layers in recent work (Pätzold et al., 2005, 2009; Withers et al., 2008). Many earlier datasets exist from similar experiments, but have not been systematically surveyed. At least, they have not been systematically surveyed since these recent observations revealed what meteoric layers on Venus and Mars actually look like. Here we report the results of a search for meteoric layers in earlier datasets from Venus and Mars.

We examined electron density profiles shown in published figures and used subjective criteria to determine whether a profile contained a meteoric layer. These procedures are not optimal, but result from the lack of archived digital electron density profiles from many planetary radio occultation experiments. Since previous work has demonstrated that meteoric layers are present near 110 km on Venus and 90 km on Mars (Pätzold et al., 2005, 2009; Withers et al., 2008), regions where electron density usually increases monotonically with altitude (Brace et al., 1983; Barth et al., 1992; Fox and Kliore, 1997; Withers, 2009), we first identified local maxima in electron density near these altitudes. With a few exceptions that are discussed in Sections 2.1 and 2.2, all of these local maxima were interpreted as possible meteoric layers. The identification of possible meteoric layers was not influenced by the measurement uncertainties, since these are rarely shown on the available figures. Anyway, published electron density profiles generally include only datapoints that exceed the measurement uncertainty. Meteoric layers in published profiles generally occur only a short vertical distance above the bottom of the profile, which might be considered to indicate that electron densities in meteoric layers are close to the detection limit and should be viewed with caution. However, this is not necessarily true as vertical gradients in electron density at the bottom of typical published profiles are very large, similar to the bottomside of a Chapman layer.

2.1. Results for Venus

Pre-1995 dayside ionospheric electron density profiles were obtained by Mariner 5, Mariner 10 (M10), Venera 9/10 (V9/10), Pioneer Venus Orbiter (PVO) and Venera 15/16. Mariner 5 recorded 1 dayside profile on 19 Oct 1967 (Kliore et al., 1967; Fjeldbo and Eshleman, 1969; Fjeldbo et al., 1975). Mariner 10 recorded 1 dayside profile on 5 Feb 1974 (preliminary profile in Howard et al. (1974), revised profile in Fjeldbo et al. (1975)). Venera 9/10 recorded at least 16 dayside profiles from 27 Oct to 7 Dec 1975 (Ivanov-Kholodnyi et al., 1977, 1979; Keldysh, 1977; Aleksandrov et al., 1977, 1978; Iakovlev et al., 1977; Kolosov et al., 1978; Savich, 1981; Savich et al., 1982). Venera 15/16 recorded 29 dayside profiles from 12 Oct to 1 Nov 1983, 20 from 19 Mar to 3 Apr 1984 and 24 from 29 Aug to 24 Sep 1984; 12 profiles have been published (Samoznaev, 1991). PVO recorded 148 dayside profiles from 1979 to 1989 (Cravens et al., 1981; Kliore and Luhmann, 1991). 7 are plotted in Kliore et al. (1979) and 90 are plotted in Kliore and Luhmann (1991). 20 of these 90 profiles are also plotted in Kliore (1992). Magellan (Steffes et al., 1994; Jenkins et al., 1994) recorded 14 dayside profiles from 1992 to 1994; one on 7 Dec 1992, one on 24 Jun 1994, three on 16 Jul 1994 and nine on 9 Aug 1994 (pers. comm, Jenkins, 2008). These have not been published and are not discussed here.