Impacts of Cosmic Dust in the Atmospheres of Mars and Venus

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We have shown recently that around 2 tonnes of cosmic dust enters Mars' atmosphere each day, of which 0.7 tonnes ablates around the 1 microbar pressure level; this injects a variety of metal atoms (Mg, Fe, Na etc.) into the upper atmosphere (Carrillo-Sánchez et al., 2020). In the case of Venus, the corresponding input is 31 t d-1, of which 13 t d-1 ablates. These estimates were made using a zodiacal dust cloud model coupled to the Leeds chemical ablation model (CABMOD), constrained by terrestrial measurements of the vertical fluxes of Na and Fe atoms in the mesosphere, and the accumulation rate of cosmic spherules and unmelted micrometeorites at the surface.

Cosmic dust consists of mineral grains that are held together by a refractory organic 'glue', and it has been proposed that loss of the organics during atmospheric entry can lead to the fragmentation of dust particles into sub-micron sized fragments. If this happens, meteoritic fragmentation may supply nuclei for the formation of ice clouds in Mars' atmosphere (Plane et al., 2018); and the amount of organic carbon reaching surface, which has been proposed as a source of atmospheric methane through the action of UV radiation (Moores and Schuerger, 2012), may be significantly lower than current estimates. At Leeds we have developed a new experimental system for studying the pyrolysis of the refractory organic constituents in cosmic dust during atmospheric entry (Bones et al., 2022). The pyrolysis kinetics of meteoritic fragments was measured by mass spectrometric detection of CO2 at temperatures between 625 and 1300 K. The complex time-resolved kinetic behaviour is consistent with two organic components – one significantly more refractory than the other, probably corresponding to the insoluble and soluble organic fractions, respectively (Alexander et al., 2017). The measured temperature-dependent pyrolysis rates were then incorporated into CABMOD. This study shows that most small cosmic dust particles (radius < 100 μm) will not fragment during entry as a result of organic pyrolysis, although a subset of slow-moving, low density particles with a large organic component, as observed in fresh cometary particles such as those in the coma of comet 67/P (Mannel et al., 2019), could fragment into sub-micron meteoritic particles that would then survive entry. Experiments in our laboratory show that meteoritic fragments are very effective ice nuclei.

A Mg+ layer in the upper mesosphere of Mars was discovered in 2015 by the Mars Atmosphere and Volatile Evolution (MAVEN) mission (Crismani et al., 2017). Since then there have been almost continuous observations of this meteoric ion layer over a range of seasons, local times, and latitudes (Crismani et al., 2023). The Mg+ layer is continuously present between 80 and 120 km, with a peak density between 100 and 500 cm-3, dependent on season and local time. There are significant latitudinal variations within a given season, and a clear influence of atmospheric tides, although there is no obvious correlation with remnant crustal magnetic fields. We have recently inserted a module of meteoric metal chemistry into the Laboratoire de Météorologie Dynamique (LMD) Mars global circulation model. This consists of over 100 neutral and ion-molecule reactions of Mg, Fe and Na, many of which have been studied in the laboratory, or with rate coefficients calculated at a high level of theory. Here we will show a simulation of the Mg+ layer over a full Martian year, which is in generally very good agreement with the MAVEN observations.

Lastly, observations in Venus' atmosphere using the SOIR instrument on Venus Express (Mahieux et al., 2015) show that the temperature above 100 km intermittently falls below 100 K, when both H2O and CO2 become supersaturated. Profiles show temperatures can fall below 60 K at heights between 115-125 km. Cosmic dust particles entering the atmosphere are predicted to ablate between 110 and 125 km (Carrillo-Sánchez et al., 2020), which provides a source of metal carbonate molecules ; because these molecules are highly polar, they are excellent nuclei for CO2- and H2O-ice particle formation (Plane et al., 2018). Here we examine the feasibility and kinetics of CO2-ice cloud formation, using both classical nucleation theory (CNT) and bottom-up kinetic nucleation theory (KNT). A 1-dimensional model was constructed to describe the nucleation, growth, sedimentation and sublimation of the ice particles; the model is initiated with a vertical profile of atmospheric density and temperature measured by SOIR. Two categories of cloud are predicted: the first peaks around 120 km with particles around 100-200 nm radius; and the second type persists for longer and peaks around 110 km, with particles that can exceed 2 μm in radius. The optical extinction of these clouds should be readily observable in the near-UV. However, the clouds are short-lived because of rapid sedimentation (typically 300 s, the longest-lived around 1200 s), so that the detection of these ephemeral "hail showers" will be challenging.

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