Influences of solar energetic particles on the Martian ozone layer

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Solar energetic particles (SEPs) consist of protons, electrons and heavy ions in the energy range between a few tens of keV and GeV. SEPs are originated from solar flares, shock waves driven by coronal mass ejections.

SEPs penetrate the Earth’ s atmosphere down to tens of kilometers at high geomagnetic latitudes. The penetrating SEPs can change the composition in the middle atmosphere. During the large solar flare that occurred in October 2003, penetrating SEPs caused NO_2 enhancement by several hundred percent, accompanied by ozone depletion of tens of percent between 36 and 60 km altitudes (e.g., Seppälä et al., 2004; Rohen et al., 2005).

In the same event, Martian Radiation Environment Experiment (MARIE) onboard Mars Odyssey was disabled by SEPs (Zeitlin et al., 2010). In addition, SEPs emitted by a solar flare in September 2017 reached Mars, where global diffuse-aurora was reported on the entire Martian night side (Schneider et al., 2018). The SEP penetration imposes a critical influence on deep atmospheres and impacts on surfaces of various planets. Considering the increasing human activities in space, like planned national and international missions to the Moon and Mars, understanding the SEP behaviors in the planetary environment is critical to assess influences on the missions and human bodies. In addition, the ozone layer is vital for understanding how NOx increases in the Martian environment. The increase of NOx can have implications on the aspects of astrobiology and the past Martian greenhouse effect.

In this study, we aim to identify the response of the Martian ozone layer to SEP events. We use vertical profiles of ozone number densities observed by stellar occultation measurements by IUVS onboard MAVEN, and the energy fluxes of electrons and ions monitored by Solar Energetic Particle onboard MAVEN (MAVEN/SEP). MAVEN/IUVS has regularly conducted stellar occultation campaigns (1-2 days per campaign) once every ~2-3 months (Groller et al., 2018). MAVEN/SEP can detect electron's and ion's energy spectra from 20 keV to 1 MeV and from 20 keV to 6 MeV in the differential flux range of $3\text{-}3\times10^6$ eV/cm^2 s sr eV (Larson et al., 2015).

As the first step of this study, we focus on a SEP event at Mars measured on 3-4 November 2015. Comparing the data during this SEP event with those during another period when the quiet period of solar activity under similar seasonal and latitudinal conditions, we found no significant differences in the ozone profiles.

We then estimated the amount of ozone depletion by oxygen atoms induced by the SEP flux using a Monte-Carlo model. In this model, we assumed that SEP-induced oxygen atoms would instantaneously destroy ozone for simplicity. The model suggests only ~0.1% of depletion of ozone number density from the background for the event in 2015. The depletion is too low to be detected by IUVS. On the other hand, the model suggests that the depletion of ozone is at detectable levels (about 100 % of the background) during the large flux SEP event in the September 2017 event. Note that the used model is yet simple. For example, we have to consider the ozone depletion by the catalytic cycle of HOx. The cycle

plays an essential role on the Earth. We will further develop a further photochemical model to assess the effect of SEPs on the photochemistry of the Martian atmosphere.

Since the MAVEN data are only available after 2014, we are analyzing the data from Mars Express (MEX). The vertical profiles of ozone number densities can be obtained from the observation by stellar occultation of SPICAM and the SEP flux is from the background counts of energetic particles observed by the Analyzer of Space Plasma and Energetic Atoms (ASPERA-3). MEX/SPICAM stellar occultations are applied to retrieve the ozone profiles since 2004. MEX/ASPERA-3 can record the penetrating energetic particles through the instrument structure as background counts (Ramstad et al., 2018). In this presentation, we will use these data for further analysis to evaluate the effect of SEPs on atmospheric chemistry on Mars.

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