

Introduction: The Moon maintains a thin, collisionless neutral exosphere generated by several processes including radiogenic outgassing, solar wind neutralization, charged-particle sputtering, photon-stimulated desorption, and micrometeoroid impact vaporization. These neutral source processes are balanced by multiple loss processes including direct ballistic escape, surface adsorption, and photo-, charge-exchange and electron-impact ionization. Among these loss processes, ionization of exospheric neutrals provides a sensitive opportunity for detecting and characterizing the Moon’s exosphere with ion analyzers, especially for species whose equilibrium neutral densities are too low for detection by neutral mass spectrometers. Previous lunar pickup ion detections have been reported by the Wind, AMPTE, Kaguya, ARTEMIS, and LADEE missions, for example; however, a fully comprehensive understanding of both the lunar pickup ion environment and the lunar exosphere are not yet in hand.

Methodology: We have constructed a comprehensive model for the production, distribution, and dynamics of pickup ions at the Moon based on all available existing in-situ and/or remote measurements. First, neutral exospheric densities are analytically generated from one of four possible sources: (1) thermal desorption, (2) charged-particle sputtering, (3) photon-stimulated desorption, and (4) micrometeoroid bombardment. Absolute densities are then constrained by existing in-situ or remote measurements, or by previous theoretical and/or Monte Carlo models, when necessary. Neutral production rates can be set according to the strength of each process (i.e., micrometeoroid fluxes to the Moon based off LADEE/LDEX measurements or charged particle fluxes to the Moon based on ARTEMIS observations). Ionization rates are then calculated for each species for three ionization processes: (a) photo-ionization, (b) electron-impact ionization, and (c) charge-exchange with protons. The rates of these ionization processes are set by solar UV/X-ray irradiance (as measured by e.g., the Solar Dynamics Observatory and FISM model) and charged particle parameters (as measured by e.g., ARTEMIS or other in-situ or upstream plasma monitors). Finally, the spatial distribution of pickup ion fluxes and associated velocity space distributions in near-lunar space are calculated analytically for given solar wind velocity and interplanetary magnetic field orientation conditions.

Results: The figures show the neutral density, ionization rate, and pickup ion flux, respectively, for neutral helium (He) in the lunar exosphere. As a thermally desorbing species that does not condense at relevant lunar temperatures, He has both a day-side and nightside exosphere, with a smaller scale height on the nightside. Ionization of neutral He is primarily via photoionization and thus, the ionization rate is only in sunlit areas; however, notice that ionization is present past the lunar terminators due to the relatively large scale height of He, even on the colder lunar nightside. Finally, He⁺ pickup ion fluxes show the cycloidal motion expected from ion motion in a convecting magnetic field (i.e., the IMF), albeit over a broad region due to the extended neutral He density distribution.

Conclusion: We will present neutral densities, ionization rates, and pickup ion fluxes for all 24 species considered in our model. In particular, we will focus on the variability of these values due to changes in source rates, loss rates, and the ambient electromagnetic fields. We will also present detection limits possible through pickup ion measurements with mass-resolving electrostatic analyzers.

