Perturbing the Mass and Composition of the Lunar Atmosphere During the Artemis Surface Missions

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The Atmosphere of the Moon: A Surface Boundary Exosphere

The atmospheric pressure on the Moon is only about $3x10^{-15}$ bar, which is equivalent to $2.96x10^{-15}$ atmosphere (atm) (Stern, 1999). For comparison, the mean sea-level atmospheric pressure on Earth is 1 atm, which is equivalent to 1.013 bar. Hence, the surface pressure of the Moon's atmosphere is about 14 orders of magnitude less than the surface pressure of the Earth's atmosphere. The total mass of the very thin atmosphere of the Moon is only about 10^7 g and the lunar atmosphere's surface number density maximum is just below 10^6 particles cm^{-3} (Stern, 1999). The lunar nighttime atmosphere has a surface number density of about $2x10^5$ particles cm^{-3} and the lunar daytime atmosphere has a surface number density of about 10^4 particles cm^{-3} (Heiken, Vaniman and French, 1991).

The Moon belongs to a class of planetary bodies with an atmosphere defined as a "surface boundary exosphere" (SBE) (Stern, 1999). Other celestial bodies possessing a surface boundary exosphere include planet Mercury and three moons of Jupiter, Callisto, Europa and Io (Stern, 1999). The number density at the bottom of an exosphere, called the exobase, is so low that any atmospheric atom or molecule traveling upward from the surface with a velocity greater than the planetary escape velocity (which for the Moon is 2.38 km s^{-1}) is unlikely to experience a collision with another atmospheric atom or molecule and can readily escape to space. The standard definition of an exosphere is the atmospheric region where the atmospheric scale height is less than the collisional mean free path. On Earth, the height of the exobase varies between 500 and 1000 km above the surface depending on the level of solar activity. On Mars, the exosphere begins at about 225 km above the surface (Levine, 1985).

Perturbing the Mass of the Very Thin Lunar Atmosphere

Due to its very low mass, the atmosphere of the Moon is very susceptible to impact by activities associated with human presence and exploration, as first hypothesized by Vondrak (1974, 1988). During the Artemis Program, on each human mission to the Moon, astronauts will spend considerably more time exploring and working on the surface of the Moon than did the Apollo astronauts fifty years ago. The Artemis astronauts will have a greater time on the surface of the Moon to alter the very thin atmosphere of the Moon. Each Apollo landing mission added several tens of percent of additional gas to the mass of the pre-Apollo lunar atmosphere resulting from descent and ascent rocket gaseous exhausts, leaked habitat gases from the Lunar Module, etc. (Vondrak, 1974; Vondrak, 1988, Heiken, Vaniman and French, 1991).

During the Artemis Program return to the Moon currently being planned and to begin in 2024, human presence and exploration of the Moon will continue and at a

greater pace than during the Apollo missions of 50 years ago. The possibility of human activities and exploration increasing the mass of the lunar atmosphere has been discussed, e.g., Vondrak, 1974: Vondrak, 1988, Stern, 1999, Levine and Zawodny, 2007; Weinhold and Levine, 2020.

Critical Measurements

Measurements of the density, structure and chemical composition of the Moon's atmosphere during the first Artemis mission to the lunar surface will provide the Artemis baseline needed to assess the future impact of human exploration on the Moon. Continued routine measurements of atmospheric density and chemical composition will provide the data needed to quantify the impact of human exploration on the Moon's atmosphere. As we continue the human exploration of the Moon with the Artemis astronauts, humankind will begin the inadvertent terraforming of another world. It is critical to understand and quantify the impact of human exploration on the atmosphere of the Moon before terraforming of the Moon's atmosphere becomes a reality.

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