Lifetime of a transient atmosphere produced by Lunar Volcanism. O. J. Tucker[1], R. M. Killen[1], P. Saxena[1], R. E. Johnson[2], and [3]P. Prem, [1]NASA/Goddard Space Flight Center, Greenbelt, MD. (Orenthal.J.Tucker@nasa.gov), [2]University of Virginia, Charlottesville, Va., [3]JHU/Applied Physics Laboratory, Laurel MD.

Abstract: The possibility of harvesting volatiles on the Moon to support manned spaceflight missions has revived interest in remnant volatile inventories on the Moon. Our present day Moon possesses a tenuous exosphere primarily composed of the noble gases. The exosphere is primarily derived from the surface and has a surface pressure only ~10^{-15} times that of the Earth. However in the past, outgassing from volcanic activity early in the Moon's history may have produced a significant collisional atmosphere (Needham and Kring, 2017). Needham and Kring (2017) estimated a lifetime of over 70 million years for such atmospheres and found that even a small fraction of the water released could account for the entirety of the hydrogen observed to be trapped in permanently shadowed regions (PSRs) of the lunar poles.

Needham and Kring (2017), herein referred to as NK17, estimated the atmospheric lifetime using the thermal escape rate of ~10^4 g s^{-1} derived in Vondrak et al. (1974). This escape rate was calculated at the lunar surface for an idealized atomic oxygen atmosphere considering rarefied surface pressures e.g., 10^{-17} – 10^{-10} bar. However, the surface pressures in NK17 are more than ~0.01 bar, therefore, the nominal exobase would be at radial distances of ~0.5 – 4.5 R_M above the surface, where R_M represents the Moon's radius. For such atmospheres, the escape rate must be evaluated in the upper atmosphere because the atmosphere is collisional, loosely bound, and possesses a column capable of absorbing solar radiation. Furthermore, atomic oxygen is much lighter than carbon monoxide, the principal atmospheric component considered in NK17. Here, we reconsider the lifetime of such an atmosphere using recent results obtained from gas-kinetic models of thermal escape rates generalized for application to arbitrary planetary bodies and analytical results for escape limited by the absorption of solar energy in the upper atmosphere (e.g., Johnson et al. 2015, 2016).

Recently, gas-kinetic models have been used to demonstrate that thermal escape from the top of an atmosphere is controlled by the efficiency of thermal conduction and adiabatic cooling due to escape (Volkov et al. 2015). For such conditions it has been shown that the escape rate can be estimated as a function of the surface Knudsen number (Kn_0), degree of rarefaction, and surface Jeans gravitational escape parameter (λ_0) (Volkov et al. 2011). Johnson et al. (2015) used these results with combined continuum and kinetic-theory based approach to evaluate the thermal escape rates from KBO atmospheres for a range of surface conditions Kn_0 ~ 10^{-16} – 10^{-2} and λ_0 = 10 – 30. Here we use this approach to estimate escape from volcanic atmospheres with Kn_0 = 10^{-8} – 10^{-5} and λ_0 ~ 30. We obtain thermal escape rates more than an order of magnitude lower ~ 10 – 10^3 g s^{-1}. This finding is problematic because such an atmosphere would have survived over the history of the solar system.

We have calculated the lifetime of an early lunar atmosphere against thermal escape heated by the surface temperature. Contrary to NK17, we find that such an atmosphere would survive the longer than 4.5 Gyr. Our results differ because we evaluated thermal escape using the mass of CO, the principal atmospheric species in NK17, and our estimate includes the effect of adiabatic cooling on the escape rate. In this presentation, we also include estimates of escape induced by solar heating of the upper atmosphere and atmospheric sputtering.

The formation of a volcanically derived atmosphere on an airless body is an intriguing study and applicable to many planetary bodies, e.g. Mercury and Io. Such an atmosphere is likely mitigated by the initial volcanic outflow conditions, temperature and cooling rate of the surface melt, global transport, upper atmospheric heating, the solar wind interaction and meteoroid bombardment. Each of these processes would have varied in importance during different phases of the Moon's evolution. We will discuss these the role of these processes in the loss of an early atmosphere and for consideration of the fraction of remnant volatiles stored in the polar regions.

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