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Sputter Loss of an Early Transient Lunar Atmosphere

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Abstract

Needham and Kring [1] estimated the lifetime of a transient lunar atmosphere resulting from volcanic eruptions that peaked 3.5 Ga ago to be 70 million years using a crude approximation to estimate thermal escape. They estimated the early Moon atmosphere could have obtained a surface pressure 1.5 times that of current Mars. Tucker et al. [2] used the energy limited escape approximation and found that such an atmosphere could be lost on the order of years to 1000’s of years. Here we have reconsidered escape rates of the purported early volcanically derived lunar atmosphere considering evidence that the early sun was much more active than today.

1. Introduction

Sun-like stars are expected to have shorter rotation periods early in their lifetimes, with resulting greater activity and significantly greater frequency of large energy flares and CMEs than our present day sun. Although the early sun was probably a "slow" rotator [3] its rotation rate was significantly higher than today, especially in the first billion years, resulting in significant solar activity precisely during the time period when a transient lunar atmosphere was most likely to have been produced by volcanism. Previous estimates of sputter loss due to CME activity [4] assumed a Moon devoid of an atmosphere. In this study we look at the estimated loss of an atmosphere due to sputtering during the first billion years..

2. Results

The young sun was expected to have a rate of X Class CMEs approaching one per day for the first 2 - 5 hundred million years [3]. The solar wind at that time had a particle density of about 100 cm^{-3} and a velocity of ~3000 km/s. Although H^+ is not as efficient, the He^{++} sputter rate is about 0.003 atom/ion. Thus the sputter rate is about $1.8x10^6$ atoms/ion assuming a conservative He fraction of 0.02 and a CO atmosphere. Multiplying by the Moon's cross sectional area, $9.5x10^{16}$ cm^2, the loss rate due to sputter is about 8 g/s. Using $[He^{++}]=0.04$ and accounting for heavy ions and potential sputtering the rate could easily have been four times this conservative estimate [4]. This conservative loss rate exceeds the thermal loss for temperatures less than 300 K and represents a significant additional loss. Although we have assumed that the solar wind only impinges on the dayside of the Moon, this is not strictly true, although most ions will not hit the nightside. At 3.5 Ga the CME rate falls to about one per week but is still significantly elevated compared to present day.

3. Summary and Conclusions

During the first billion years of the Moon's history when the lunar volcanic activity was high the early Sun was highly active. Therefore when considering the lifetime of an early transient atmosphere, sputtering should be considered as an important loss process. This will be true for early Mars as well [5].

Acknowledgements

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