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Early Mercury’s magma ocean atmosphere

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The large iron core of Mercury and the low iron contents on the surface inferred from MESSENGER data suggest the presence of a magma ocean after accretion. We modeled the lifetime of an early Hermean magma ocean as well as the structure and loss rates of an atmosphere that is sourced by degassing. We use a large range of initial conditions including several bulk compositions associated with varying degrees of differentiation, the inclusion of carbon and hydrogen degassing volatiles such as CO2 and H2O, as well as considering a larger proto-Mercury size. After obtaining the magma ocean lifetime and volatile vapor pressures, the result is passed on to further models to obtain metal oxide vapor pressures, a complete atmospheric photochemical speciation and ultimately the mass loss rate of the atmosphere.

We show that magma ocean cooling times are sensitive to the size of the planet and the efficiency of radiative heat transfer in the atmosphere. A volatile-free proto-Mercury radiating as a blackbody with its present-day size would cool down within 400 years from an assumed initial surface temperature of 2500 K to an early crust formation threshold of 1500 K. In contrast it takes 9000 years for a volatile rich proto-Mercury with a greenhouse atmosphere and a mantle size representing Mercury before the occurrence of a mantle stripping event. Volatile-rich cases reach massive atmosphere pressures, whereas volatile-free cases are dominated by Si, Na, K, Mg, and Fe species degassed from the magma ocean and end up at a maximum pressure of 0.1 bar at 2500 K. There is however only a small difference in the atmospheric extent, as the absence of volatile species in the thin metal oxide atmosphere causes it to become extended to a degree, where an upper atmosphere height comparable to the volatile cases is reached. In terms of mass loss we found that upper atmospheric loss due to photoionization is highly efficient in the environment of a young Sun, ionizing 100% of the particles reaching Mercury’s exosphere. This leads to loss rates of up to 10^6 kg/s, which are however diffusion limited by the supply from the homopause, reducing them by 2-3 orders of magnitude. In regards to Na and K loss, we found that a thin, volatile-free atmosphere is most efficient with its extended structure allowing for large loss rates as well as the high Na and K mixing ratio.