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Studies of lunar soil composition, together with numerical simulations, indicate the presence of a volatile element source with an abundance signature (N, H, and certain noble gases) distinct from that of the solar wind. Recent studies propose that implantation of material from Earth's atmosphere could serve as a viable mechanism during periods of sustained geodynamo activity (https://www.nature.com/articles/s43247-025-02960-4). I will describe how we use this to also constrain the net duration of Earth's geodynamo and present our computational framework for investigating the relative terrestrial atmospheric escape during magnetized and hypothetical unmagnetized phases of Earth under varying strengths of the impinging solar wind. The framework combines three-dimensional magnetohydrodynamic simulations, conducted using the highly parallelized, multi-physics code AstroBEAR, with complementary theoretical analyses. We incorporate solar XUV–driven atmospheric photoionization in our ionosphere models to represent both early Eoarchean and contemporary Earth atmospheres in order to estimate the transport and deposition of different volatile species on the Moon's nearside. Using our models, we compute the orbit-averaged Earth-wind mass flux at the Moon across a range of physically plausible solar wind parameters to which the current magnetosphere and the Archean paleoatmosphere may have been subjected, and we compare the results with Apollo lunar samples and other observational data. We constrain the duration of an unmagnetized Earth by combining results from simulations of three cases: (1) a late-to-early Archean epoch atmosphere with strong solar wind and geomagnetic field; (2) a late-to-early Archean epoch atmosphere with strong solar wind but no geodynamo; and (3) a contemporary magnetized Earth with weak solar wind. Our findings suggest that argon imposes the most stringent constraint on how long Earth could have remained unmagnetized while still allowing its presence in lunar soil to be explained by an atmospheric source from Earth. If these volatiles have a terrestrial origin, our models suggest that the geomagnetic field was already present by 3.9 billion years ago.
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