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Estimation of ion escape rates from non-magnetic earth: On possible contribution of terrestrial ion flows to non-solar components implanted in lunar soils

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Before formation of the global geomagnetic field (GMF), the upper atmosphere of the Earth would have been directly exposed to the solar wind. The direct interaction of the upper atmosphere with the solar wind could cause a significant loss of atmospheric constituents, and some fraction of them would have hit the moon, creating potentially observable effects that last even to the present day. In this study, we theoretically estimated the escape rates of H^+, He^+, N^+, O^+, Ne^+, and Ar^+, i.e., non-solar components observed in lunar soils (see, accompanied paper by Ozima et al. [1]), from the upper atmosphere of non-magnetic Earth.

When the planet has a significant global GMF as in the case of the present Earth, the solar wind approaching to the Earth is stopped by the GMF at the magnetopause (located at about 10 Earth radii), where the magnetic pressure balances against the dynamic pressure of the solar wind. On the other hand, when the planet has no global GMF as in the cases of the present Venus and Mars, the solar wind penetrates deep into the planetary upper atmosphere ($\sim$0.1 planetary radii from the surface), leading to an efficient loss of heavy atmospheric constituents under certain solar wind conditions.

We first calculated escape fluxes from the non-magnetic Earth using an empirical model of the terrestrial upper atmosphere, MSIS00 model [2], assuming ionopause altitude that is expected for the present Earth. Then the fraction of the escaping ions that will hit the lunar surface was estimated, taking into consideration the variation of Earth-moon distance with time, e.g., $\sim$40 Earth radii about 4 Ga ago [3]. If we take account of the fraction of time that the lunar orbit stays inside the Earth's tail, about

0.3% of the terrestrial ion flux would hit the lunar surface. Our estimations indicate that the magnitude of the solar wind dynamic pressure is the most important controlling factor for the escape fluxes. If the solar wind dynamic pressure increases from 2 to 15 nPa, the ionopause altitude decreases drastically from 500 km down to $\sim$250 km, and accordingly the escaping ion flux, especially of heavy ions, undergo significant increase. If the ionopause altitude decreases to 200 km, for example, the average terrestrial N^+ flux at lunar surface is estimated to be, at least, $\sim 2x10^6$, Ne^+ $\sim 5x10^2$, and $^{36}Ar^+$ $\sim$13 ions/cm^2/s, respectively. Such high solar wind pressure as assumed above is still within the range of present variation and hence even higher solar wind flux would be expected from an active young sun. In addition, low O_2 pressure (and possibly CO_2) in the early atmosphere further brings the ionopause closer to the Earth. We will discuss using an early upper atmosphere model that all these factors enhance the ion escape fluxes especially of heavy components from the ancient non-magnetic Earth, and thus they can be the source of non-solar components of N and light noble gases implanted in lunar soils.

References: [1] Ozima et al. (2005) *Geophysical Research Abstracts* (this volume), [2] Picone et al. (2000) *Phys. And Chem. Of the Earth, Solar-Terres., Planet. Sci., 25 (5-6)*, 537-542, [3] Abe and Ooe (2001) *J. Geodetic Soc. Japan, 47*, 514-520.