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Erosion of Earth's atmosphere by ion escape: observations, a consistent model, and implications to the atmospheric evolution

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Cluster hot ion observations found that ion loss rate from the open part of the polar magnetosphere increases exponential to Kp, i.e., nearly linearly increase with geomagnetic deviation in nT up to $Kp < 7$, which is consistent with ion outflow observations at low-altitude.

The observations also found the escaping O^+ numbers density is order of 1% of the solar wind H^+ density, i.e., O^+ occupies nearly 20% of the mass density. This is large enough that the mass-loading (momentum conservation in elastic mixing) can convert a substantial amount of the solar wind kinetic energy to the electrostatic energy through the charge separation during the mass-loading deceleration. In fact, Cluster observed substantial deceleration of the solar wind H^+ while acceleration of O^+ in plasma mantle. We calculated the energy conversion through this process and found out that the energy conversion will be proportional to u_{sw}^2 and F$_e scape, whereuisthesolarwindvelocityandFisthetotalmassfluxintotheincidentsolarwind.$

Unlike comets or unmagnetized planets, the separated charge can flow into the ionosphere along the geomagnetic field, consuming the energy by Joule heating that increases the ion outflow from the ionosphere. The amount of the electric energy into the ionosphere quantitatively agree with the energy of the cusp current system that is localized to the cusp, and the expected dependence on u_{sw} agrees with the cusp related Sq current. Furthermore, the resultant ion outflow (and F) with further increase the energy conversion, making the entire system forms a positive feedback, which is the main reason of predicting the observed exponential dependence on Kp.

On the other hand, Cluster also found that the ion escaping flux during extremely strong ion escape events (all during $Kp \geq$ 7+) are outside (no longer the part of) the distribution of the all-time escaping flux, being up to two orders of magnitude above the mean. Since the observation-based model of the past Sun predicts extremely high EUV, high solar wind velocity, and strong and frequent CMEs in the past in the geological scale, this is the condition that we should scale for the past ion escape. A simple calculation with only exponential behavior already predictes the loss of the same amount of oxygen in the present atmosphere, this "extremely high" escape during the severe magnetic storms indicates much higher total loss. Thus the ion escape can not be ignored in the atmospheric evolution.