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Interactive comment on "Terrestrial ion circulation in space" *by* Masatoshi Yamauchi

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Thank you very much for valuable comments with references. I try to implement individual comments as much as possible (e.g., dropping Figure 16 and 4) within the 25 page limit for this proceeding-type paper of the Medal lecture.

Before revising the paper (and before answering individual comments), I need to define the general direction toward the revision. My motivation for both lecture and this paper is condensed §5 and §4:

(1) Give good estimate for the ion loss rate from viewpoints of terrestrial evolution (§5.1), to show that it might have substantially affected on the evolution or fluctuation of the biosphere (including to stop the paradigm of "geomagnetic field protect the Earth from escape", §5.3) and ionosphere plays active role even at the high-altitude cusp due to the mass loading effect (e.g., test-particle method may mislead the cusp dynamics,

§5.2). The last viewpoints is the only realistic argument in proposing future missions to ESA because the magnetospheric/ionospheric "physics" cloud not be used for the argument for future missions under Cosmic Vision, and most likely in Voyage 2050. Relevant proposals and white paper are found at

http://www.irf.se/%7Eyamau/future/m5/ESCAPE_M5_Proposal_submitted.pdf
http://www.irf.se/%7Eyamau/future/f1/Fate_phase1_final.pdf
http://www.irf.se/%7Eyamau/future/whitepaper_i_n_final.pdf

(2) Showing importance of low-energy ion circulation in the inner magnetosphere, for which much less scientists worked during past 2 decades compared to the crowded fields such as magnetotail, radiation belt, and magnetopause (this is the main reason that self-siting references becomes too much and I will reduce them, §4). Since the return rate (lifetime of ions) strongly depends on energy, local energizations in the inner magnetosphere are included as much as possible if they are never introduced in review papers.

To stress on these points with 25 page limit, I have to skip many new development on the ion circulation such as what reviewers suggested (e.g., simulation, tail dynamics). Therefore, I would like to keep the present structure (and I noticed that title does not really much with the content). In this sense, I am flexible in changing the title such as "Ion loss process from the Earth" or something more adequate.

The make sure my motivation, I would revise the beginning of the Introduction as follows.

Introduction: Circulation and roles of ionospheric heavy ions have long been an important subject in the magnetospheric physics since they are found at almost everywhere in the magnetosphere (Chappell et al., 1972, Shelley et al., 1972) and even in the high-latitude magnetosheath and plasma mantle (Lundin, 1985, Eklund et al., 1997). There are many works on this subject with many reviews, but with relatively well covered subjects and less covered subjects. The former includes suprathermal ion outflow from the ionosphere (Moore et al., 1999; Moore and Horwitz, 2007; Lotko, 2007; Darrouzet et al., 2009; Maggiolo, 2015; Welling et al., 2015), plasmaspheric cold ions (Darrouzet et al., 2009; Welling et al., 2015), plasma sheet dynamics including energization in the magnetotail and resultant ring current ions in the inner magnetosphere (Blanc et al., 1999; Walker et al., 1999; Ebihara and Ejiri, 2003; Kronberg et al., 2014), fate of cold supersonic ion outflow (AndreÌĄ, 2015) and the inner magnetospheric low-energy hot ions that are directly supplied from the auroral ionosphere (Moore et al., 1999). However, very little reviews discussed the total amount of the ionospheric ions to the space and its effect on the evolution of the planetary atmosphere (Moore and Horwitz, 2007; AndreÌĄ, 2015), which is a large contrast from the cases for Mars (Jakosky et al., 2015). In this viewpoint, there are two subjects that have nearly no review during past two decades: the outflowing ions directly accessing the solar wind in the magnetosheath, cusp, and outer part of plasma mantle, and fate of trapped hot ions that have much lower energy than the ordinary ring current. The Cluster's orbit and instrumentation allowed us to investigate these missing subjects with statistical significance. This paper reviews these missing parts in the context of the total amount of ion escape to the space based on Bartels Medal lecture at EGU General Assembly 2019, with stress on finding by Cluster and are not covered by above reviews (direct escape from the high-latitude magnetosphere and fate of hot ions in the inner magnetosphere).

Since Cluster Ion Spectrometory (CIS) COmposition DIstribution Function (CODIF) is not designed to separate more than four main species H+, He++, He+, and atomic ions of the CNO grounp (ReÌĂme et al., 2001), all heavy ions are pedagogically called oxygen ions O+ as is in the conventional manner, although heavy ions include nitrogen ions N+, and molecular nitrogen ions N+2 as the secondary component that becomes significant during geomagnetic storms (Chappell et al., 1982; Craven et al., 1985; Hamilton et al., 1988; Yau and Whalen, 1992). The paper is organized as following

If my revision strategy with new introduction (with possible new title) is acceptable, I start to define how to implement individual comments my within the discussion period.

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