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Adiabatic Betatron deceleration of ionospheric charged particles: a new explanation for (i) the rapid outflow of ionospheric O ions, and for (ii) the increase of plasma mass density observed in magnetospheric flux tubes during main phases of geomagnetic storms

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Using European arrays of magnetometers and the cross-phase analysis to determine magnetic field line resonance frequencies, it has been found by Kale et al. (2009) that the plasma mass density within plasmaspheric flux tubes increased rapidly after the SSC of the Hallowe'en 2003 geomagnetic storms. These observations tend to confirm other independent experimental results, suggesting that heavy ion up-flow from the ionosphere is responsible for the observed plasma density increases during main phases of geomagnetic storms.

The aim of our contribution is to point out that, during main phases, reversible Betatron effect induced by the increase of the southward Dst-magnetic field component ($|\Delta$ B$_z|$), diminishes slightly the perpendicular kinetic energy (W$_\perp$) of charged particles spiraling along field lines. Furthermore, due to the conservation of the first adiabatic invariant (μ = W$_m$/ B$_m$) the mirror points of all ionospheric ions and electrons are lifted up to higher altitudes i.e. where the mirror point magnetic field (B$_m$) is slightly smaller. Note that the change of the mirror point altitude is given by: Δ h$_m$ = -1/3 (R$_E$ + h$_m$) Δ B$_m$ / B$_m$. It is independent of the ion species and it does not depend of their kinetic energy.

The change of kinetic energy is determined by: Δ W$_m$ = W$_m$ Δ B$_m$ / B$_m$. Both of these equations have been verified numerically by Lemaire et al. (2005; *doi: 10.1016/S0273-1177(03)00099-1*) using trajectory calculations in a simple time-dependant B-field model: i.e. the Earth's magnetic dipole, plus an increasing southward B-field component: i.e. the Dst magnetic field whose intensity becomes more and more negative during the main phase of magnetic storms. They showed that a variation of B$_z$ (or Dst) by more than - 50 nT significantly increases the mirror point altitudes by more than 100 km which is about equal to scale height of the plasma density in the topside ionosphere where particles are almost collisionless (see Fig. 2 in Lemaire et al., 2005).

From these theoretical results we infer that all ionospheric electrons and ions species (including the O+ ions) experience an outward flow along geomagnetic field lines whose angle of dip is not too large. Since above 500 km altitude the various ions densities decrease almost exponentially with altitude with characteristic scale heights (H$_{ions}$) of the order of 100 km or less, the main phase uplift of all mirror points increases the local mass density all along these field lines. This changes the plasmaspheric concentrations of the O+ ions as well as of others heavy ions in the topside ionosphere and plasmasphere.

We will outline experimental tests to check this new hypothesis and physical mechanism to enhance the plasma mass density during the main phases of geomagnetic storms. A subsequent decrease of the plasma ion mass density is expected following the geomagnetic storm event, due to inverse Betatron effect during the recovery phase, and due to the effect of gravity pulling the heavier ions back to lower altitudes.