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On the Effect of IMF Turning on Ion Dynamics at Mercury

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Abstract

We investigate the effect of a rotation of the Interplanetary Magnetic Field (IMF) on the transport of magnetospheric ion populations at Mercury. We focus on ions of planetary origin and investigate their large-scale circulation using three-dimensional single-particle simulations. We show that a nonzero B_X component of the IMF leads to a pronounced asymmetry in the overall circulation pattern. In particular, we demonstrate that the centrifugal acceleration due to curvature of the $\mathbf{E}\times\mathbf{B}$ drift paths is more pronounced in one hemisphere than the other, leading to filling of the magnetospheric lobes and plasma sheet with more or less energetic material depending upon the hemisphere of origin. Using a time-varying electric and magnetic field model, we investigate the response of ions to rapid (a few tens of seconds) re-orientation of the IMF. We show that, for ions with gyroperiods comparable to the field variation time scale, the inductive electric field should lead to significant nonadiabatic energization, up to several hundreds of eVs or a few keVs. It thus appears that IMF turning at Mercury should lead to localized loading of the magnetosphere with energetic material of planetary origin (e.g., Na^+).

1. Introduction

With an orbit comprised between ~0.3 and ~0.47 astronomical units, Mercury is located in a region of the Parker's spiral where the radial component of the IMF is dominant. Because of its appreciable though weak (about 1000 times smaller than that of Earth) intrinsic magnetic field, a miniature magnetosphere forms around the planet that is expected to be very dynamical and subjected to prominent reconfigurations due to variations of the IMF or variations of the solar wind dynamical pressure. In this study, we examine the response of magnetospheric ions to variation of IMF B_X.

2. Nonadiabatic Ion Energization

We show that, for ion species with cyclotron period comparable to the field variation time scale, prominent nonadiabatic heating may be achieved under the effect of the short-lived electric field induced by the IMF variation. This is illustrated in Figure 1 that shows the color-coded density (top) and energy (bottom) of Na^+ ions at distinct times of a 20 s rotation of the IMF.

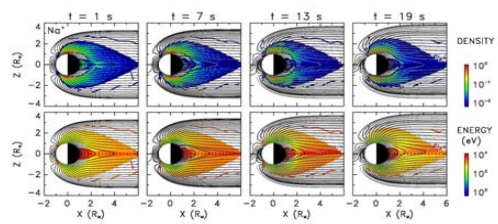

Figure 1: Computed color-coded density and energy of Na^+ ions in the noon-midnight meridian plane.

The leftmost panels of Figure 1 that relate to the initial state depict symmetrical flows above the polar cap and gradual centrifugal acceleration up to the keV range before entering the nightside plasma sheet. Moving from left to right in the bottom panels of Figure 1, it can be seen that, in the course of the IMF turning, the average Na^+ energy in the magnetospheric lobes rapidly increases up to several keVs. This nonadiabatic energization results from resonance between the induced electric field and the ion gyromotion. Because it depends upon gyroperiod versus field variation time scale, it preferentially affects heavy ions (e.g., Na^+ of planetary origin) and is negligible for protons.