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Mercury's magnetosphere-solar wind interaction for northward and southward interplanetary magnetic field: Hybrid simulation results

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An analysis of 3-D hybrid simulations of Mercury's magnetosphere-solar wind interaction has been presented for northward and southward IMF orientations. The overall magnetospheric features of the simulated system are similar to those in the terrestrial magnetosphere. The simulated results are in good qualitative agreement with in situ observations of MESSENGER spacecraft in terms of magnetospheric structure and plasma kinetic effects. The intrinsic magnetic field constitutes an obstacle to the supersonic solar wind and a typical series of thin and thick transition regions appear including bow shock, magnetosheath, magnetopause, magnetotail, magnetosphere itself, plasma belt, etc.

The oblique/quasi-parallel bow shock region is a source of backstreaming protons filling the foreshock where they generate strong wave activity (likely through the ion-ion magnetosonic instability). These large-amplitude waves are transported with the solar wind to the adjacent magnetosheath. In the quasi-perpendicular magnetosheath, waves are generated near the bow shock and locally by the proton temperature anisotropy. For the low-β plasma considered here, the dominant instability is the proton cyclotron instability, a result confirmed by the density-magnetic field $\langle n_p, B \rangle$ correlation analysis. The positions of the foreshock and the quasi-parallel and quasi-perpendicular bow shock regions are determined by the IMF orientation so their locations are naturally different in the two presented simulations. Magnetospheric plasma also exhibits a proton temperature anisotropy (loss cone) with a signature of (drift) mirror mode activity.

For both orientations magnetospheric cusps form on the day side, at higher latitudes for northward IMF compared to southward IMF, the day side magnetosphere has a smaller size for southward IMF. These differences are likely related to different locations of reconnection regions for the two orientations. Also in the case of southward IMF the night-side magnetospheric cavity in the Z direction is wider. We found strong sunward plasma flows within Mercury's magnetotail at somewhat different locations for the two IMF orientations. For southward IMF the sunward plasma flows is stronger owing to a presence a strong sunward proton beam, a signature of the reconnection process occured further downtail in the thin current sheet (along with the formation of plasmoids). These energetic protons likely contribute to the thermal and dynamic pressure of the magnetospheric plasma widening the magnetospheric cavity in the case of southward IMF.

Both IMF configurations lead to a quasi-trapped plasma belt around the planet. Such a belt may account for the diamagnetic decreases observed on the inbound passes

For southward IMF, reconnection leads to plasmoid-like structures in the magnetotail, consistent with the second MESSENGER flyby observations in Mercury's magnetotail. On the other hand, we have not found signatures of a dayside flux transfer event. This may be a consequence of the assumed stationarity of the solar wind in our numerical model. For the northward IMF we have not found any Kelvin-Helmholtz type structure, but in an earlier simulation Hyb0 traval09 with the IMF confined to the ecliptic plane ($B_z = 0$), signatures of Kelvin-Helmholtz instability were present. Furthermore, in both the cases the transition between the dayside magnetosheath and the magnetosphere occurs in two phases, the ion density decrease precedes the magnetopause current sheet. This is at variance with the first MESSENGER flyby where two clear current sheets (double magnetopause) are observed.

This particular observation could be related to a presence of heavy planetary ions (Na^{+}) missing in our model. Further investigation of these problems will be subjects for future work.