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Plasma Dynamics in Mercury's Magnetosphere

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Abstract. Mercury is in all sense of the words still Terra Incognito, its magnetosphere is hence little known. The only source of knowledge came from the in-situ measurements by the Mariner 10 close encounters in 1974. This has been complemented since by ground-based observations of the atomic sodium and potassium emissions in the vicinity of the planetary disk. This series of optical observations has produced intriguing evidence of magnetospheric and/or solar wind effects on the surface-plasma interaction processes. In this review we will describe the current theories of the corresponding space weather effects.

Most of our knowledge on Mercury's magnetosphere came from the Mariner 10 encounters in 1974 and 1975 (Ness et al. 1974; Simpson et al. 1974). The plasma and magnetic field measurements during the nightside crossing on March 29, 1974, have been analyzed and reviewed in many places (Connerney & Ness 1988; Russell et al. 1988; Christon 1989) we will not repeat this feat here. What we want to do is to give an update of the recent development in connection to the preparation for the new space missions to Mercury, namely, the MESSENGER Project of NASA and the BepiColombo Project of ESA and ISAS. There are several noteworthy results. On the observational side, the most important result which has generated a lot of discussions has to do with the discovery of a long lasting (week-long) event in the sodium brightness enhancement (Potter & Morgan 1997). A number of theoretical models have been proposed to expound the physical cause of such dramatic time variability in the surface brightness of atomic sodium emission. These include (1) the work by Luhmann et al. (1998) who applied the Tsyganenko model of the terrestrial magnetosphere to explore the driven mechanism of the solar wind at Mercury; (2) Kabin et al. (2000) who used the Michigan MHD code to study the response of Mercury's magnetosphere to different solar wind parameters; (3) Killen et al. (2001) who adapted the "Rice model" to study the changes of the configuration and position of Mercury's magnetospheric polar cusp because of the variabilities in the interplanetary magnetic field direction and dynamic pressure of the solar wind; (4) Ip & Kopp (2002) who produced resistive MHD models of Mercury's magnetosphere for the "open" and "closed" cases; (5) Kallio & Janhunen (2003) who used a 3D quasi-neutral hybrid model (to deal with the finite gyro radius effect) to explore the impact geometry of solar wind protons and "trapped" magnetospheric ions on the planetary surface; and (6) Leblanc et al. (2003) who simulated the recycling process of magnetospheric ions via surface sputtering and near-planet ionization.

Another issue of emerging interest has to do with the possible existence of field-aligned current (FAC). Slavin et al. (1997) reported the finding of strong FAC in the magneto-tail region by reanalysis of the Mariner 10 data. In the numerical simulation by Ip & Kopp (2002), FAC systems can be generated with different configurations under different solar wind conditions. But how could they be supported since there is no ionosphere to speak of at Mercury? They argued that the closure of such FAC can be maintained by the pickup ion current from ionization of the neutral exosphere (Ip & Kopp, 2003). The initial displacements of the new ions and electrons lead to the establishment of a current flow transverse to the magnetic field. According to Cheng et al. (1987), the equivalent integrated conductivity could be as much as 0.1-0.3 Mho. This value may be compared to a value of 1-10 Mho of the dayside integrated Pedersen conductivity of the terrestrial ionosphere. In this case, the path of FAC being organized by localized ionization process could be very patchy. Janhunen & Kallio (2003) proposed instead that partially closure could still be achieved at the planetary surface since the electrical conductivities of some minerals are not negligible (Glassmeier 2000). Another important topic, seldom addressed, concerns the magnetosphere-surface coupling effect via surface charging and photoemission (Grard et al. 1997) which could introduce strong day-night asymmetry in the magnetic and electric field structures of Mercury's magnetosphere. Without in-situ measurements it is difficult to assess the electric fields and plasma wave activity at Mercury (Blomberg 1997). However, it is interesting to note that Potter et al. (2002) reported that the radio of sodium to potassium in the Mercury exosphere is highly variable and that it's average value of about 100 is much higher than that for the moon. Furthermore, the potassium column density was observed to decrease with increasing level of solar activity. We might draw the inference that Mercury's polar caps are infected with ion cyclotron waves because of solar wind interaction. As a result, the potassium ions would be preferentially accelerated because of its lower gyrofrequency in comparison with that of the sodium ions (Ip & Kopp 2002). From this point of view, there are a great number of interesting phenomena to be explored by the new Mercury missions, to be supplemented by ground-based observations and spacecraft remote-sensing measurements.

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