Modulation of the Solar Wind Velocity by Mercury

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Abstract
To study the variations in the solar wind velocity during inferior conjunctions of Mercury and Earth, we analyzed 54 events in the period 1995 to 2012 by the superimposed epoch method. We have found a noticeable increase in the velocity both before and after the conjunctions as well as decrease in the velocity within 3–4 days after them, which seems to be associated with Mercury’s “shadow”. The results obtained might be used to improve a forecast of the solar wind velocity.

Keywords: Solar wind, Mercury, magnetospheres

1. Introduction
Mercury is a small planet (0.055 terrestrial mass) closest to the Sun, which possesses the largest eccentricity (0.206) and orbital inclination to ecliptic (over 7 degrees) among the 8 planets of the Solar system (Allen, 1976). Mercury has also a global (but very weak) magnetic field and has almost no atmosphere. All this properties as well as its proximity to the Sun attract a special interest to the interaction of Mercury with the solar wind, the model of the respective ambient flow, and the possibility of survival of the hermean trace (or “shadow”) in the interplanetary medium in the course of propagation of the solar wind (SW). The weak hermean magnetosphere as well as the absence of an appreciable atmosphere and ionosphere enable the enhanced solar wind to actually approach the planetary surface, as it takes place in the interaction of SW with Moon (Kabin et al., 2000; Fujimoto

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et al., 2007). It is the aim of the present paper to study the interaction of SW with Mercury by using the variation in the SW velocity in the Earth’s neighborhood during inferior conjunctions, i.e., at the distance of 1 AU from the Sun.

The solar wind is a quasi-steady radial supersonic outflow of the solar coronal plasma through the entire Solar system; its velocity being a few hundreds km/s, and the density, about a few particles in a cubic cm. In this process, SW carries the “frozen” magnetic fields, which interact with the planetary magnetospheres.

SW velocity is one of the most difficult parameters for a reliable forecast. Even in the clearest (most evident) cases, the amplitude and duration of the increase after a flare will depend on many parameters, such as a magnitude of the flare, its position on the solar disk, magnetic field structure in the active region and interplanetary space, direction of the outburst, its solid angle, etc. Therefore, the introduction of one more parameter affecting SW velocity should enable us to get an improved forecast.

2. Material and Methods

To reveal the effect mentioned above, the mean daily velocities were analyzed by the superimposed epoch method for the periods of inferior conjunctions in 1995 to 2012. The superimposed epoch method (or the “synchronous detection”) is based on the separation of the time interval under consideration into the equal subintervals of the specified duration $T$; and then the observational data in the same temporal points from the beginning of the above-mentioned subintervals are summed up or averaged. As a result, if the data vary with $T$ or a comparable period, the corresponding effect is accumulated; while the data varying in time randomly or with the periods incomparable with $T$ are smoothed out.

The mean daily velocities were derived from the mean hourly ones, which were measured by ACE satellite in L1 Lagrangian point in the vicinity of the Earth (ACE, 2013). (Such a location of ACE in the L1 point between the Earth and Sun enables one to perform a continuous measurement of the SW parameters and gives approximately an one-hour-advance warning of the impending geomagnetic activity.) At last, let us mention that differences in the space weather and in the relative positions of the planets and Sun above ecliptic and with respect to the perihelion of hermean orbit were not taken into account in our analysis.
3. Results

Despite of the restrictions outlined in the previous section, analysis of 54 oppositions (inferior conjunctions), presented in Fig. 1, shows a noticeable increase in the SW velocity within 4 days before the oppositions (∼10%) and 8 days after them (∼12%) along with a decrease in the velocity (∼4%) within 3–4 days after the oppositions (which is the Mercury’s shadow). Such a delay corresponds to the average SW velocity about 300–400 km/s, at which the radial SW passes the distance from Mercury to the Earth.

To verify this effect and to reveal its probable dependence on the solar cycle phase, we have performed the same processing separately for 3 data sets: from the minimum to maximum of the 23rd cycle, for the period of its decay, and for the minimum and the onset of the new 24th cycle (Fig. 2). The above-mentioned characteristic features of the velocity variations were found to survive in all 3 periods, although the ratio of velocities before and after the oppositions as well as their temporal localization with respect to the conjunctions slightly varied.

These general tendencies are less expressed at the stage of the cycle increase (1995–2001), most probably, because of the weakness of the solar wind in the respective period. Nevertheless, a position of the velocity minimum remains the same, i.e., it takes place in the third or fourth day after the opposition; the average SW velocity being 415 km/s for the entire sample of 54 intervals of oppositions.
Figure 2: Characteristic features in variations of SW velocity in different phases of the solar cycle. Upper curve refers to 1995–2001; middle curve, 2001–2008; lower curve, 2008–2012. The values in parentheses represent the numbers of inferior conjunctions in each data set.

4. Discussion and Conclusions

The results presented demonstrate that the trace of a planet in the form of SW variation survives in the course of its propagation in the interplanetary space up to the distances of, at least, 0.6 AU, i.e., about 90,000,000 km, which can hardly remind a hydrodynamic flow around the ball. The presence of even a relatively weak hermean magnetic field evidently makes the flow of the solar wind around the planet more regular and results in its laminar behavior.

The model of the flow of the solar wind around Mercury, which takes into account the approximate axial symmetry of the process and the excess of SW velocity by an order of magnitude over the hermean orbital velocity, is shown in Fig. 3. The perturbation of SW velocity in space looks like a conical surface, similar to the paraboloid of revolution (Erkaev, 2006); the Mercury being located, roughly speaking, in its focus, and the solid angle equaling about $37^\circ$ (12 days × $360^\circ/116$ days). The Mercury’s “shadow” goes approximately along the axis of the cone of the SW velocity fluctuation.

It seems that the revealed nonuniformity of the solar wind can be treated as a tail of the hermean magnetosphere, extending, at least, up to the Earth. Such size of the tail substantially exceeds the value 2,500,000 km, which was derived from the sodium emission in the work by Baumgardner et al. (2008).

It would be very interesting to compare the features established for Mer-
Figure 3: The model of the solar wind flow around Mercury. SW is the solar wind, Me is Mercury, E is the Earth, dashed curve is the Mercury’s shadow.

ccury with the flow of the solar wind around Venus, which does not have a global magnetic field (as distinct from Mercury) but possesses an extremely dense atmosphere.

It is reasonable to assume also that the same phenomena may take place in the solar wind flow around the Earth, and their consequences can be observed on the outer planets or by the remote spacecraft.

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