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DEPENDENCE OF MAGNETOPAUSE AND BOW SHOCK POSITIONS ON SOLAR WIND PARAMETERS AND MAGNETOPAUSE PLASMA STRUCTURE

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An experimental investigation of magnetopause and bow shock crossings revealed that their variations were correlated with solar wind pressure variations having characteristic times of more than 5—10 minutes. Bow shock velocities corresponding to such variations of dynamic pressure appeared to be of the order of 10—20 km s^{-1}. Gradual decreases of the total ion flux and spectral softening recorded were identified with a diffuse magnetopause; of 93 crossings of the magnetosphere boundary, 49 were of this type. The thickness of the diffuse magnetopause was $0.2—3R_E$. It increased with the angular distance from the sun-earth line.

1. Introduction

Sets of ion traps, each including a modulation trap measuring the differential spectrum (with eight intervals) of ions up to 3.85 keV each 5.44 min, and three integral traps were installed on board the Prognoz and Prognoz 2 satellites for the measurement of ion characteristics in the solar wind and the earth's magnetosphere. The detailed description of the equipment and sensors is given in [1].

In this paper the results of such measurements in the region of the bow shock and magnetopause in April—October 1972 (from 29 June to 17 September the results of simultaneous measurements) are analysed.

2. Study of Variations of Shock Front and Magnetopause Positions

The crossings of the shock front and magnetopause observed from one of the satellites were compared with the changes of these boundaries calculated from the data on the solar wind dynamic pressure obtained by the other satellite; the results of comparison are shown in Figs. 1 and 2. The insets to Figs. 1 and 2 show the approximate positions of the shock front (dashed curves), the magnetopause (solid line) and the positions relative to each other of the two satellites (blackened parts of orbits).

It follows from the gas dynamic calculations [2] that for sufficiently great Mach numbers the distances to the shock front R_s and magnetopause R_m (if an angular distance φ of the point from the direction to the sun is not too large) can be

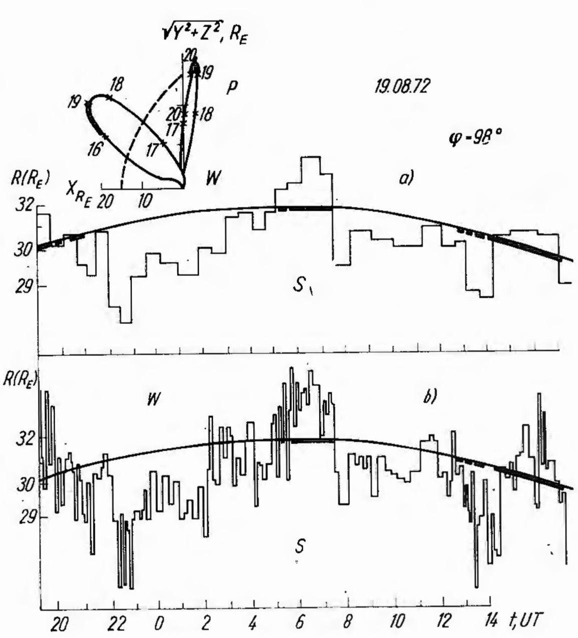

Fig. 1. Comparison of the observed positions of the bow shock and calculated ones using the averaged (a) and unaveraged (b) solar wind pressure data. Inset shows approximate positions of the shock front (dashed curves), magnetopause (solid line) and positions relative to each other of the two satellites (blackened parts of orbits).

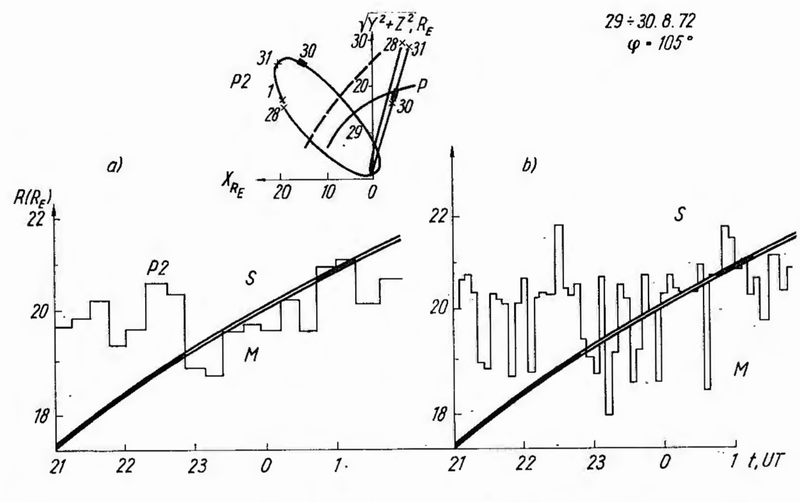

Fig. 2. Comparison of the observed and calculated magnetopause positions. Inset, as in Fig. 1.

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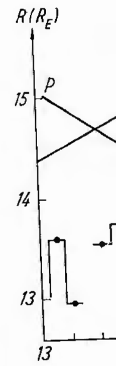

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approximately written as

$$R_{s,m} = C_{s,m}(\varrho V^2)^{-1/6} f_{s,m}(\varphi), \tag{1}$$

where $C_{s,m}$ is a constant, ϱ the density, V the solar wind velocity and $f_{s,m}(\varphi)$ a function that describes the shape of the front of the magnetopause. It is seen from Eq. (1) that with $\varphi = \text{const.}$ the change of the distance to the boundary depends only on the variation of the dynamic pressure of the solar wind ϱV^2.

To exclude the relative change of the positions of the boundaries and the satellites connected with variation of angle φ occurring during the orbital motion

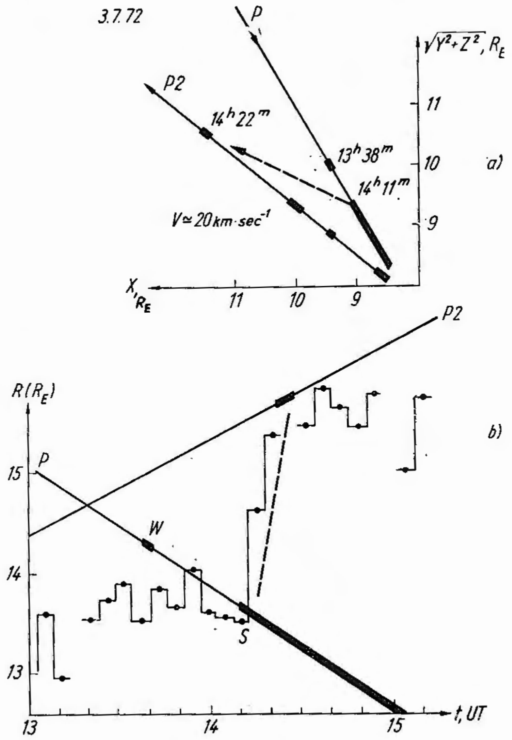

Fig. 3. Plot illustrating the estimation of the bow shock velocity.

of the satellites, the orbits were reduced to the same value of the angle in each time interval analysed. For this form $f_{s,m}(\varphi)$ was used for the average shock front and magnetopause calculated over all the crossings recorded by Prognoz and Prognoz 2. A similar transformation of the trajectory had been used by Binsack and Vasyliunas [3] who first obtained confirmation of the dependence of the shock front position on the solar wind dynamic pressure based on data obtained from three satellites.

In Figs. 1 and 2 the blackened parts of the orbits correspond to the times of satellite passes through the magnetosheath S and the magnetosphere M; the thin parts of the orbits correspond to the satellite locations in the solar wind W and in the magnetosheath S. The scale for distances (along the Y-axis) is logarithmic so that the calculated quantity $-{}^1/_6 \ln (\varrho V^2)$ (stepped line in the figures) is compared with the observed crossings of the front and magnetopause. It should be noted that in the solar wind dynamic pressure calculations intervals with maximum readings make the most contribution (i.e. the time interval $\leq 1-1.5$ min). It is seen that there is a fairly close agreement between the positions of the boundaries as calculated and observed; the agreement is better for the data averaged over several spectra. Hence we can conclude that the characteristic

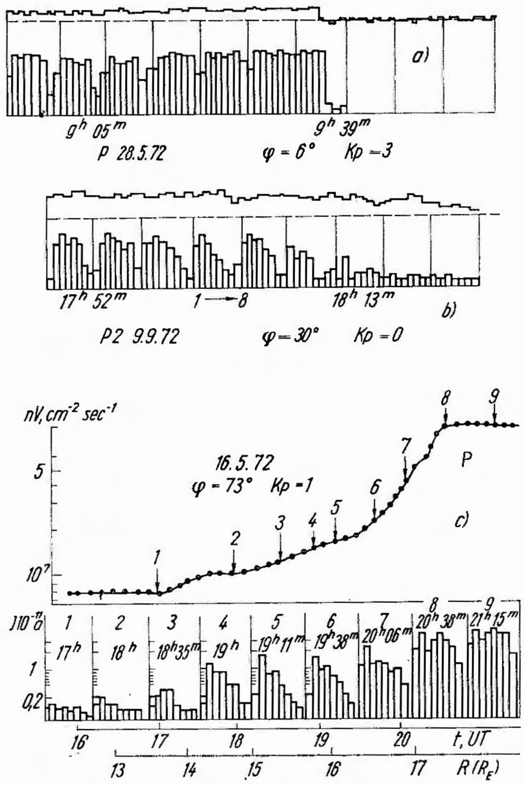

Fig. 4. Characteristic variations of the primary ion spectra of the modulation trap and the currents I of the integral trap corresponding to crossings of the sharp (a) and diffuse (b) magnetopause (shown by stepped line). (c) shows the change of ion flux nV crossing a diffuse magnetopause.

time for the establishment of quasi-stationary positions of both the shock front and magnetopause is about 5—10 min.

Simultaneous measurements from the two satellites widely separated in space are conveniently used for the direct estimation of the velocity of shock motion. Fig. 3 shows the case when the Prognoz and Prognoz 2 satellites are near the subsolar region and registered multiple crossings of the shock front. At 1411 UT on 3 July 1972 Prognoz crossed the shock front and entered the magnetosheath. At this time Prognoz 2 in the solar wind began to record the monotonic decrease of ϱV^2. This means that the shock front should continuously move away from the earth (without oscillatory motions) — see Fig. 3b. At 1422 UT the front reached Prognoz 2 which was also moving away from the earth. So in 10 minutes the shock front moved about $2R_E$ along its outward normal; its average velocity was consequently equal to ~ 20 km s^{-1}.

In the other case analysed in a similar way, on 31 July 1972, the velocity of the front amounted to ~ 10 km s^{-1}. These estimates agree with experimental estimates previously obtained [4—6] and with theoretical calculations [7, 8].

3. Study of the Magnetopause Plasma Structure

The analysis of magnetopause crossings by the Prognoz and Prognoz 2 satellites showed that in 49 of the 93 cases under consideration a gradual change of the character of the spectra occurred that lasted from 10 min to several hours; such magnetopause crossings are termed diffuse [9, 10].

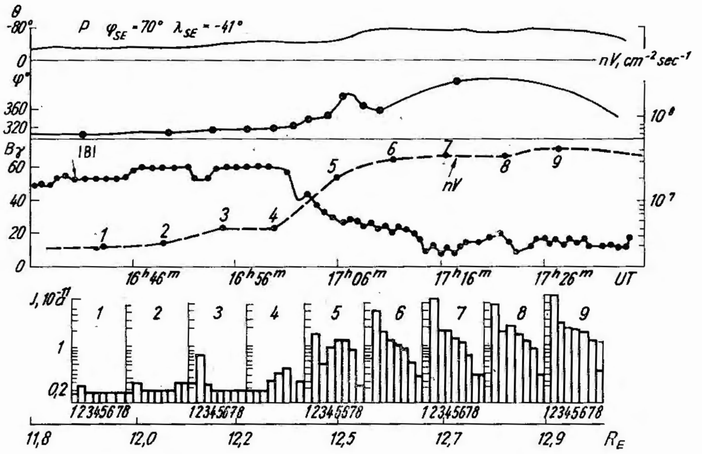

Fig. 5. Comparison of simultaneous plasma and magnetic field measurements of Prognoz during the crossing of the diffuse magnetopause on 8 May 1972.

Fig. 4a gives an example of the characteristic variations of the ion spectra and currents from integral traps oriented towards the sun (upper stepped lines, also in Fig. 4b) for the crossing of the sharp magnetopause on 28 May 1972, Figs. 4b and c for the crossings of the diffuse magnetopause on 9 September and on 16 May 1972. As is seen from Figs. 4b and c, when going from the magnetosheath to the magnetosphere the gradual change (decrease) of ion flux and the gradual softening of the spectra (relative diminution of currents in the higher energy intervals) occur over a distance of about $2R_E$. The maximum gradient of ion flux was observed over a distance of $\sim 1R_E$.

Fig. 5 gives data on simultaneous measurements of the absolute value $|B|$, polar angle θ and azimuth angle of $\boldsymbol{B}$ in the ecliptic plane, ion spectra and ion flux nV from the Prognoz satellite on 8 May 1972 during a crossing of the diffuse magnetopause. The magnetic measurements were kindly provided by Sh. Sh. Dolginov and E. G. Eroshenko. It is seen from Fig. 5 that with the smooth change of ion spectra and ion flux over a distance of about $0.5R_E$ across the diffuse magnetopause no magnetic field parameters show sharp changes. The diffuse magnetopause is frequently observed for sufficiently small angles φ; its thickness, on average, increases as φ increases.

The comparison of diffuse boundary observations with data of simultaneous measurements of the interplanetary magnetic field from HEOS 2 [11] shows that in the presence of a northward component of the interplanetary magnetic field the average thickness of the diffuse magnetopause was about $0.8R_E$; for a southward component its thickness increased to $\sim 2R_E$. Reviewing the published data we can conclude that the magnetopause was considered earlier as a sharp boundary discontinuity at least in the subsolar region, with thickness of the order of the Larmor radius for ions, $\sim$ 100 km (e.g. [4, 5, 10, 12]). The diffuse boundary was observed in the magnetospheric tail with Pioneer 8 [9], Explorer 35 [13] as well as by the Vela satellites [14, 15] at the distant polar magnetosphere by the HEOS 2 satellite [21]. The absence of the sharp boundary (i.e. a diffuse magnetopause) is found from an analysis of the magnetic data obtained on occasional orbits of the IMP 1 satellite [16, 17], OGO 1 (near the equatorial plane at the dawn and dusk sectors of the magnetosphere) [5], the plasma and magnetic data from some magnetopause crossings by IMP 2 [10] in the subsolar region of the magnetosphere.

The interaction of the magnetosheath plasma with the magnetosphere which can lead to the broadening of the sharp magnetopause is discussed in some theoretical works [17—20]. According to our data the dayside magnetopause was diffuse in the latitude interval 0—30° (GSM) in $\sim$50% cases of crossings.

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