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Magnetic turn as Martian dayside magnetopause

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Abstract

The high temporal measurements of the magnetic field and plasma of Mars are provided by Atmosphere and Volatile Evolution (MAVEN; Jakosky et al., 2015) what allows to analyze the fine layers of Mars. This paper describes magnetic structure associated with dayside Martian magnetopause.

It was shown that the shocked solar wind at the dayside of Mars does not directly interact with ionosphere of Mars. The plasma and magnetic field layer of 200-300 km thickness form the dayside magnetosphere (Vaisberg and Shuvalov, 2019).

Dayside magnetosphere has two types: (1) the dominated type magnetosphere consists mainly of heated and accelerated O^+ and O_2^+ ions having kinetic structure and (2) other type of dayside magnetosphere consists of accelerated O^+ and O_2^+ ions towards the magnetosheath where they form continue accelerated beam forming the plume.

Between the magnetosphere and magnetosheath there is magnetic structure which rotates almost unchanging its magnitude. This structure is located within second part of transition of $n_p/(n_p + n_h)$ from ~1 to ~10^{-2} in logarithm scale.

At the same time the flux of protons diminishes and the heavy ions increase.

This process goes quite smoothly:

1. the shocked solar wind passing around stagnated obstacle
2. the protons dominated magnetosheath and the heavy ions dominated domain
3. no change of magnetic magnitude
4. no change of magnitude, value by rotation
5 smooth change of ion composition

The turn of magnetic structure has the properties and functions are solid candidate for the magnetopause.

Introduction:

MAVEN gives the possibility to investigate the details of the Martian dayside magnetosphere. In this paper we use the data of).

The magnetopause identification was the topic of many investigations. Espley, 2018 considered names based on single phenomena or the essence. His conclusion that that scientific community will understand the physics of the region and refine our terminology to best accurately.

Some steps to that have been done. Hapgood and Bryant, 1990, draw attention to the boundary between the shocked solar wind and the boundary of the obstacle. They noticed that there are always two distinct sections of electrons with the autocorrelation between the temperature and density. The simplest interpretation of this autocorrelation is that, in the majority of cases there is a smooth change of plasma state between the bounding solar and terrestrial plasmas. The alternative interpretation was filaments of magnetosheath plasma penetrating the boundary layer.

Vaisberg et al., 2017 found that the magnetic field at the transition from dayside magnetosphere to the magnetosheath structure the turn.

Chen et al., 2022, analyzed one dayside Martian induced magnetosphere boundary and selected two sides of an interface coincident with the previously defined ion composition boundary. Results indicate the interaction between Mars and the solar wind could induce strong currents in the IMB, which are with antiparallel current directions and separated by an interface where the ion composition changes.

Ma, 2022, and coauthored investigation Rotational Discontinuities in the Magnetopause of an Open Magnetosphere, they found that the inner magnetic structures of rotational discontinue which are closely related to reconnection processes.

These papers may be considered as steps to more confidence of proposed Martian dayside magnetopause.

Magnetopause

Figure 1 is the quick-look from MAVEN data with temporal resolution of plasma of 4 sec resolution. The time interval selected was in northern dayside hemisphere to avoid the influence of significant local magnets. The MAVEN measurements were taken from relatively far from magnetopause in order to minimize the influence of Mars, on one side, to the upper ionosphere to know necessary data for analysis, from other side.

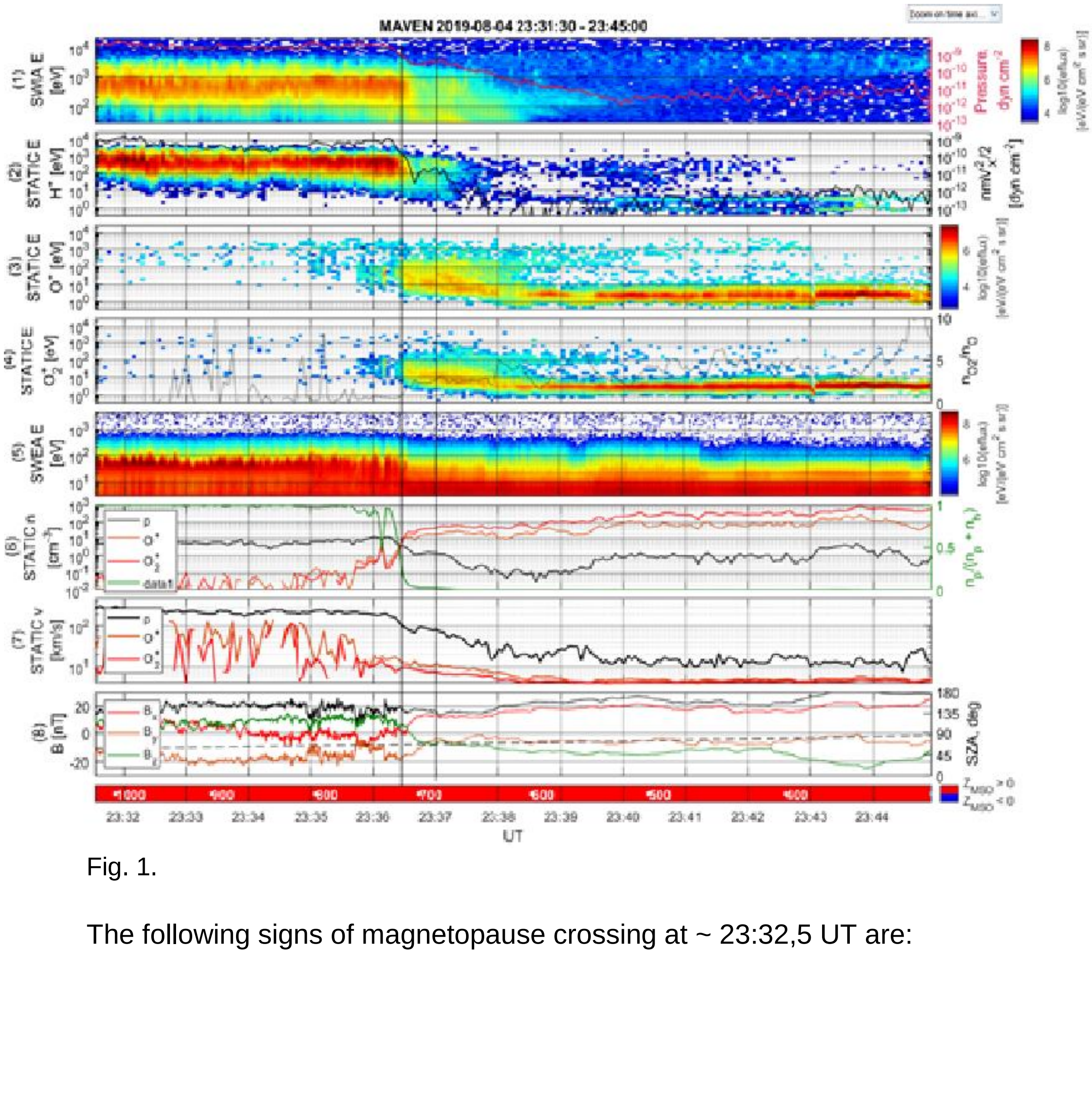
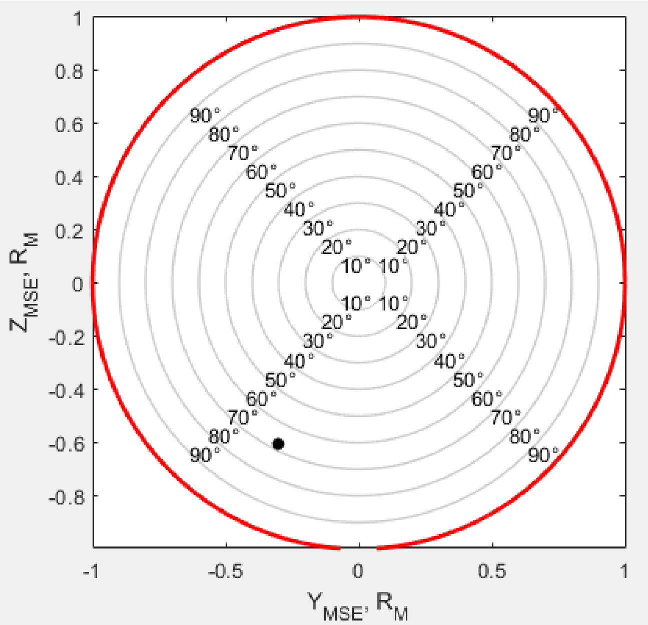


Fig. 1.

The following signs of magnetopause crossing at ~ 23:32,5 UT are:

- terminated differential energy flux of all ions at panel 1 and of H^+ densities values at panel 2,
- strong increased of the energy flux of O^+ and O_2^+ on panels 3 and 4; also n_{O2}/n_O ratio increase,
- decrease of electrons energy, panel 5,
- the change of dominance density of protons by the heavy ions, $n_p/(n_p+ n_h)$; protons number density, and O^+ and O_2^+, panel 6,
- velocities of p, O^+ and O_2^+ , panel 7,
- magnetic field components change, fluctuations drop and magnetic field value increases - panel 8.

Allowing for above signs is seems appropriate to estimation of magnetopause to accept it as from ratio ~ $n_p/(n_p+n_h) = 1$ where $\boldsymbol{n_p}$ is protons number density and $\boldsymbol{h_e}$ is the number density of heavy ions.



Fig, 2. MSE coordinate system with X axis directed to the Sun, Z axis directed along vector X × BSW, and Y completing to the right system between the solar wind motional electric field vector. The black point shows approximate location of spacecraft was crossing magnetopause.

- Figure 2 shows the location of the spacecraft in magnetic coordinates. The approximate SZA angle of ~ 63^0 shows that the dayside magnetosphere is well developed. Allowing for above properties it is reasonably possible to estimate the thickness of magnetopause by criterion interval within the range $0.9 > n_p/(n_p+ n_h) < 1$. Allow one needs that plasma layer are moving during the spacecraft crosses the specific layers moving the thickness of the above layer can be estimated as ~ 40 km.

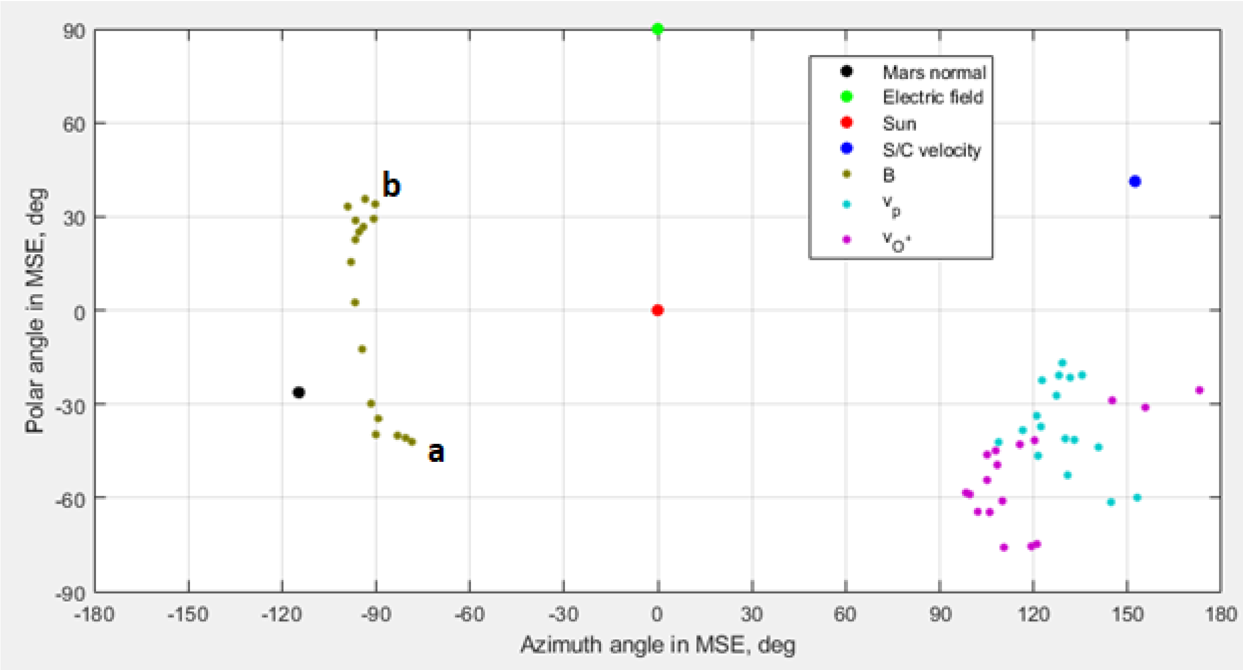


Fig. 3. DeCart map shows the directions of parameters from in MSW coordinates within time interval of spacecraft from 700 km to 680 km. Directions of the magnetic channel is shown by dots from :"a" to "b". The magnetopause is seen from the set of dots with larger gaps (the nearly straight line is really curved).

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Figure 4 shows the Minimum Variance Analysis of magnetic field in the region one can case to check what happens with the magnetic change in tentative variation. Figure 3 shows the strong change of magnetic field components approximately between 23:36.27 – 23:36.58 at 2019:08.04 UT: a – 3D in MSO coordinates, b – minimum variance L and N components, and 3 components and magnetic magnitude. Figure a shows the magnetic field in 3D view with vector approximate perpendicular to AB plane of minimum variance approach, b – A and C views in minimum variance, c – 3 component in MSE coordinate system, and d – different vectors of .minimum variance.

Minimum analysis showed that this part of magnetic field is flat of two-dimensions, L and N:

- there is rotation of magnetic field
- the magnetic field value is changing not significantly during only rotation
- rotation of magnetic field takes only ~ 22 km.

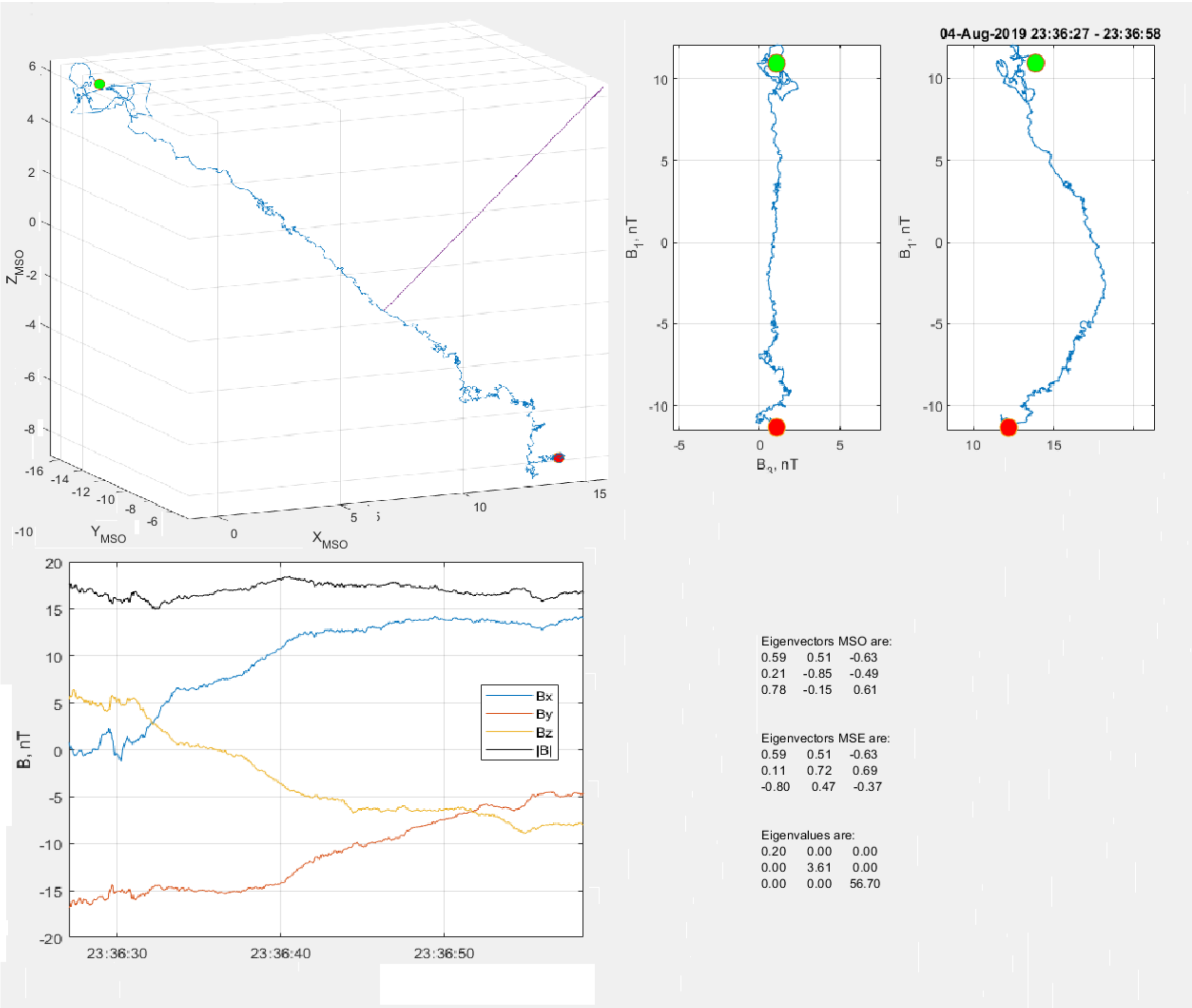

Fig. 4. Three diagrams of the magnetic fields components: a – 3D view of the long magnetic field structure, b – A and C components of minimum variance the long magnetic field of ~ 24 km, c – three components and magnetic field during rotational of magnetic field.

Estimated the time from rotation of the magnet ~ 23.36.32 UT and concludes of the magnetic line ~ 23:36:56 UT, give time interval in ~ 24 sec. The time of flight the fight in 24 sec was passed the height 720-690 km).

Figure 5 shows the number densities n^+ and O^+ distributions in the sector from N to N within sector of magnetopause. The protons density decreases and the density of O^+ smoothly decreases and the density of O^+ smoothly increases within the order 20-30 sec. No sharp jump within this time interval is observed. It shows that process within curative is smooth one.

Fig. 5 shows the change of ions mass and the number densities of magnetospheres protons and the number densities of O^+ magnetosphere ions within magnetosphere. It is interesting that magnetosheath density smoothly decreasing while magnetospheres' ions density smoothly increases. This crossing smoothly happens along with spacecraft crossing magnetopause in approximate 16-20 sec. or ~ 20 km.

Fig. 5. The number densities n$^+$ and O$^+$ distributions in the sector from ~23.36.30 UT to 23.36.44 UT within sector of magnetopause.

Another example of 1-th type of magnetosphere is shown in Figure 6 The quick-look covers the parts of magnetosheath and dayside magnetosphere. The panels are in the same sequence as in Figure 1.

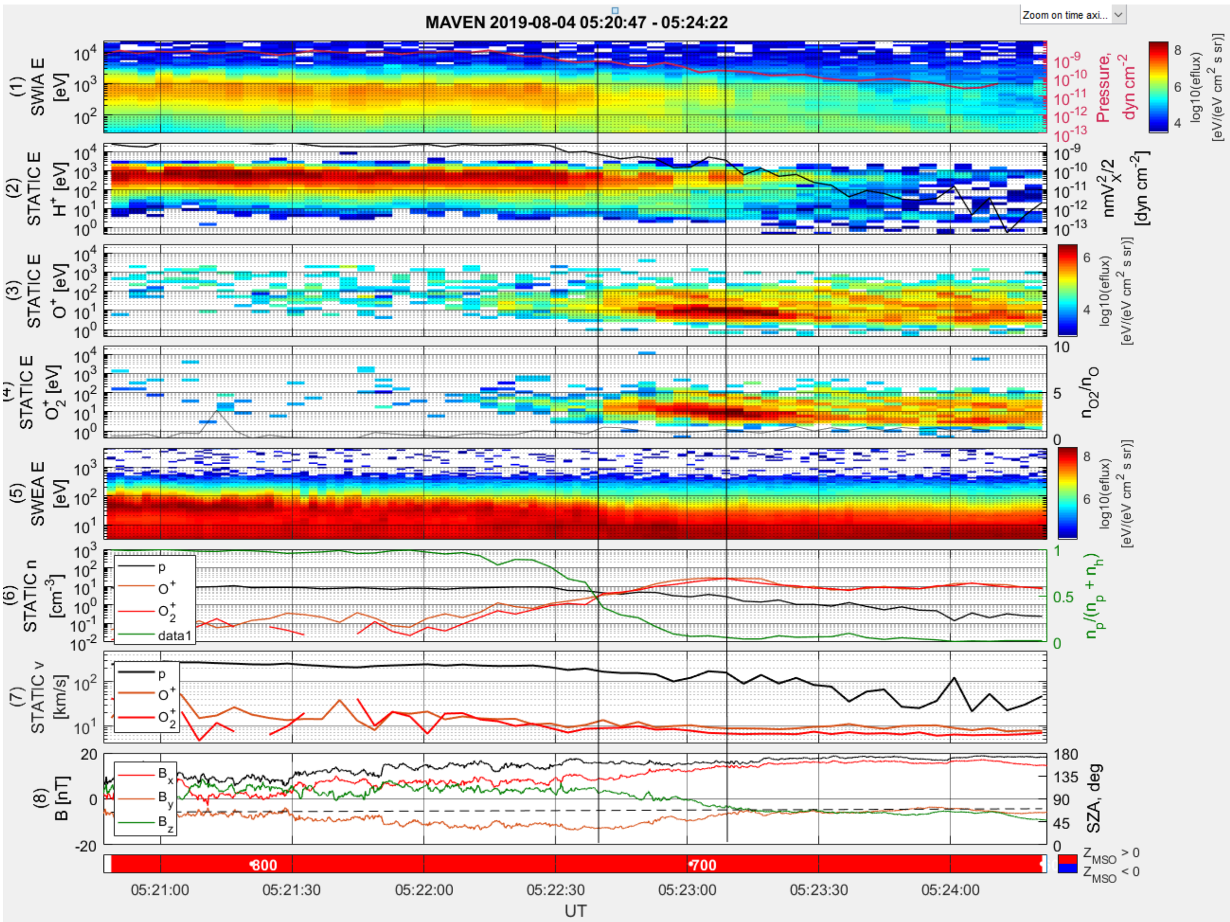

Fig. 6. The MAVEN STATIC and MAG data in the vicinity of the subsolar point on August 17, 2019, 05:21 UT to 05:24 UT. The explanation of plasma and magnetic characteristics is the same as in Fig. 1. The sector between two vertical lines indicates the location where magnetic field rotates.

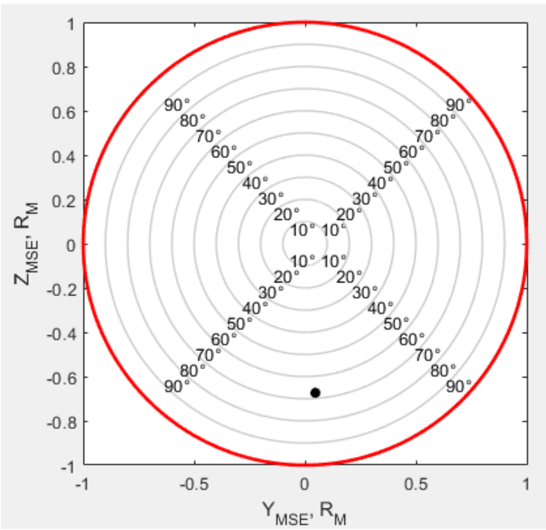

Fig. 7. Location of the magnetopause where spacecraft passed it. MSE coordinate system with X axis directed to the Sun, Z axis directed along vector X × BSW, and Y completing to the right system between the solar wind motional electric field vector E = 1/c V × B direction.

Figure 7 shows that spacecraft was located at BSW at ~ 68^0.

Unlike the first example when several parameters agreed on spacecraft location of magnetopause, in this case only decrease of electron temperature better suggested where the boundary suggested). (It is worth wile to low that many parameters in nature are considered in logarithmic scale).

Another indication of magnetopause location is the rotation of the magnetic lines (Figure 8). The Minimum Variation shows that one magnetic structure quite planar..

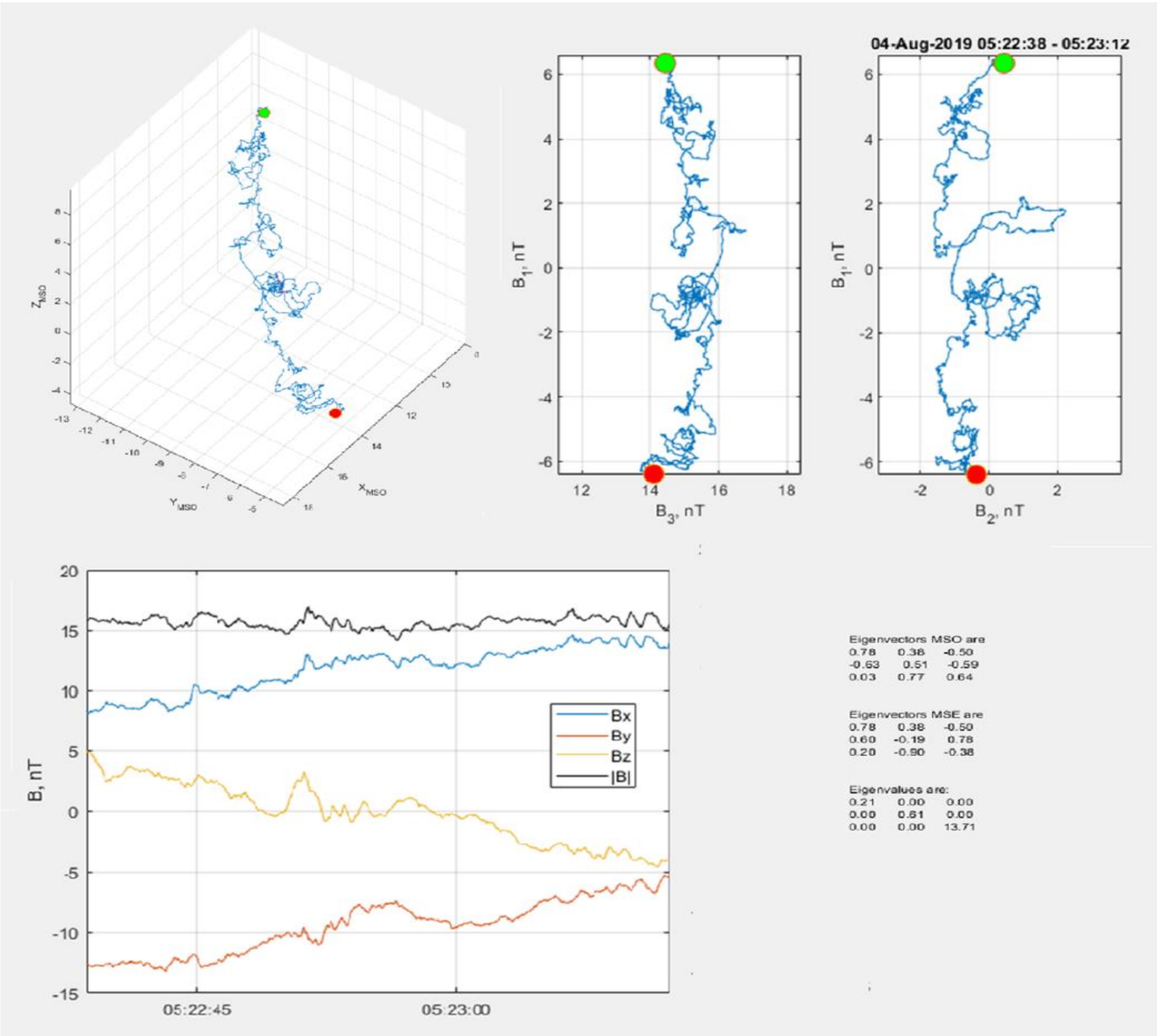

Fig. 8. Three diagrams of the magnetic fields components: a – 3D view of the long magnetic field, b –K and M of minimum variance the long magnetic field, c – 3 components and magnitude of the magnetic field. B1, B2 and B3 are L, M and N are Minimum Variance components.

Two vertical lines at ~ 730 km and 690 km frame within which included rotation of the magnetic field. The average length of 3 transverse components B is ~ 8nT. The pass of spacecraft through location where magnetic layer rotates at about 75^0. It takes ~ 20 sec.

Obtained the thickness of the is possible by taking from the times off spacecraft passing the rotating magnetic layer and the time spacecraft passed the respective time when spacecraft crossed this layer. The estimated value of rotating magnetic layer is ~ 23 km.

Figure 9 shows the number densities n$^+$ and O$^+$ distributions in the sector from N to N within sector of magnetopause. The protons density decreases and the density of O$^+$ smoothly decreases and the density of O$^+$ smoothly increases within the order 20-30 sec. No sharp jump within this time interval is observed. The coinciding phenomena magnetic field rotation without noticeable magnetic amplitude with smooth exchange of different ices is the specific process at boundary of domainse..

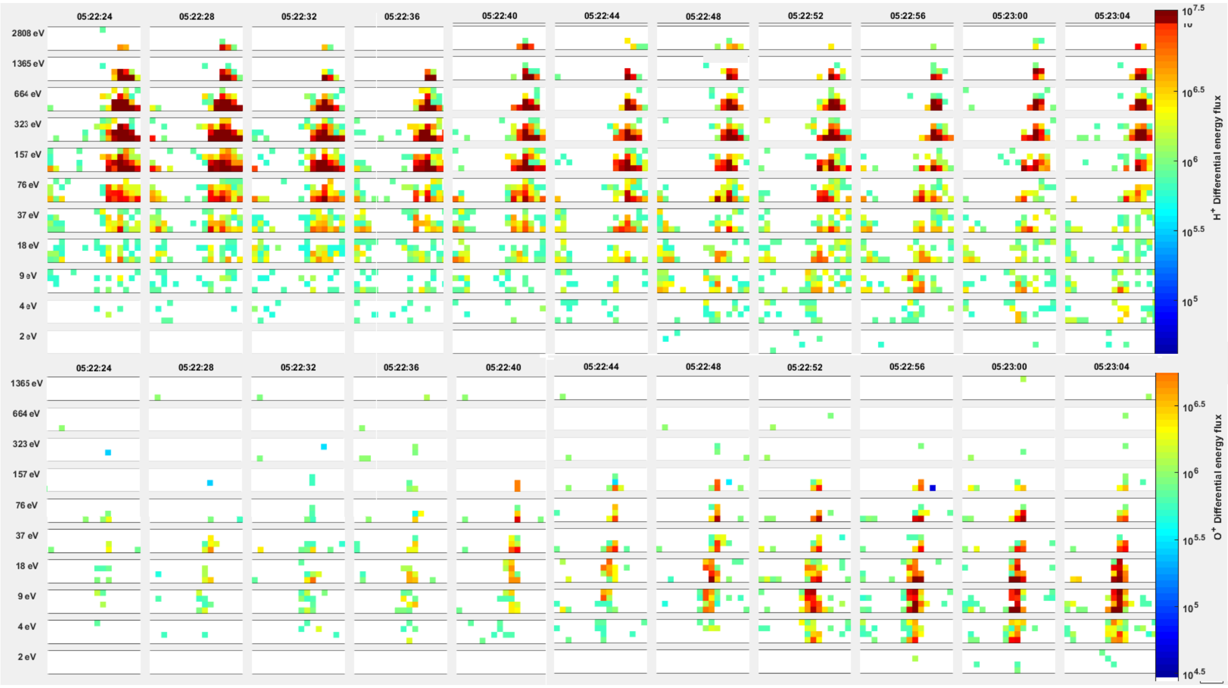

Fig. 9 The number densities n$^+$ and O$^+$ distributions in the sector from 22.24.24 UT to N within sector of magnetopause.

Important part of magnetosheath is the plume (Liemohn et al., 2014, Dong et al, 2015). It was estimation that the plume covers about 1/3 of dayside magnetosheath (Vaisberg and Shuvalov, 2022) . Consequently it is importantly to compare what magnetopause are in these conditions.

Figure 10 quick-look is the same as in previous cases. The important agreement is that between shocked solar and ionosphere there is the layer with the heater and accelerated heavy ions.

The identification of magnetopause in case of plume is quite different compared to the magnetosphere. As in main case there is no direct contact of the magnetosheath to the ionosphere but there is no contact of magnetosheath to ionosphere, The upper boundary of ionosphere is about 500 km when the O+ and O2+ number densities reach high and steadies number densities at ~ 330 km.

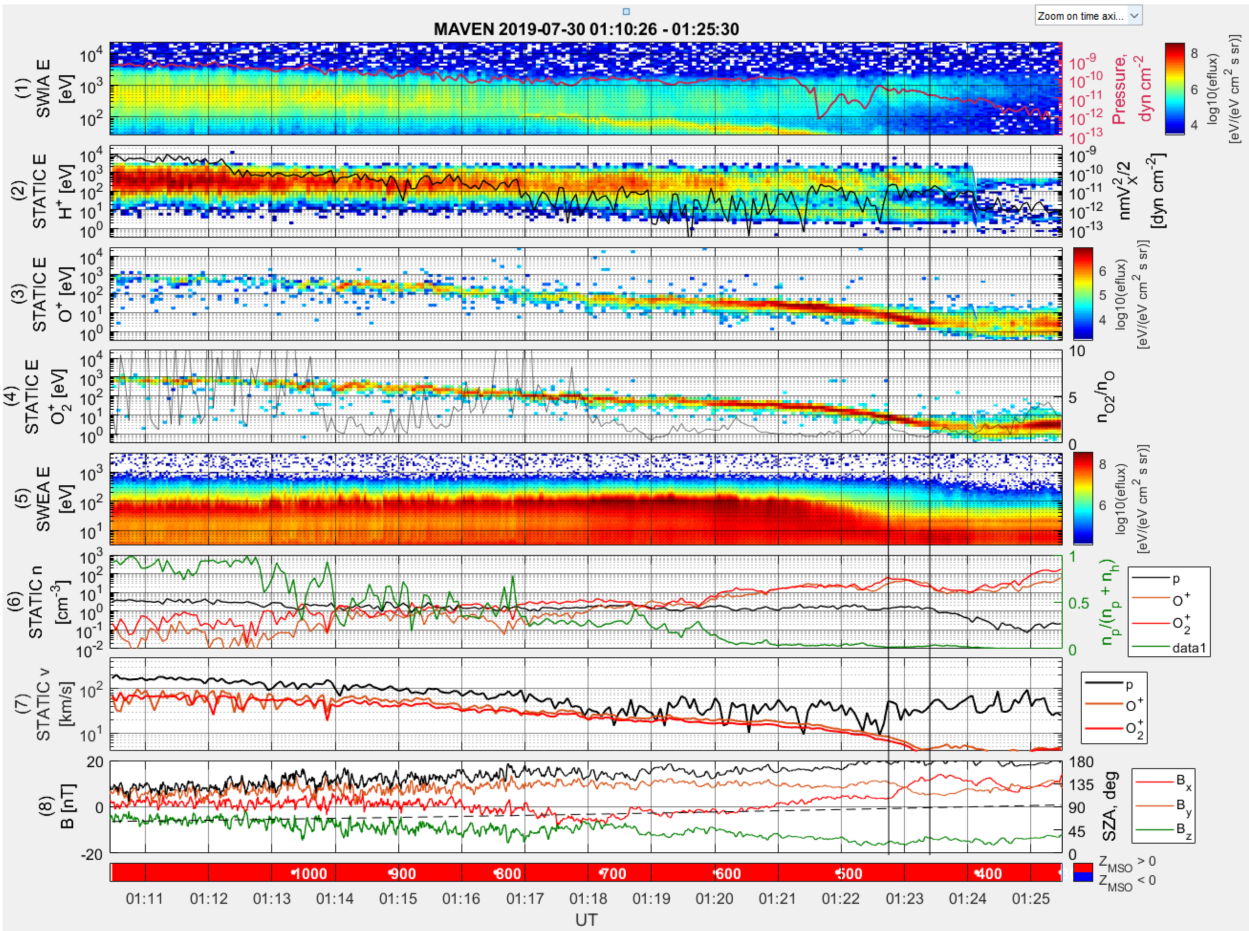

Fig. 1O. Magnetosheath, magnetopause, magnetosphere and ionosphere in case of plume. The same panels as described as in Figure 1. Two vertical line approximate show location of rotation.

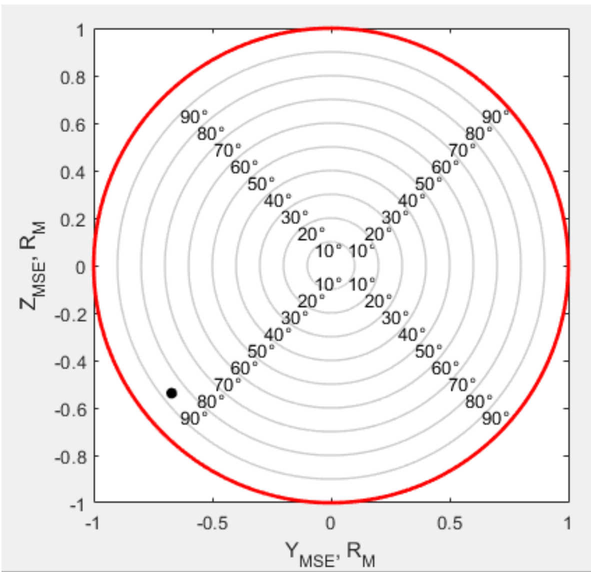

Fig.11. MSE coordinate system with X axis directed to the Sun, Z axis directed along vector X × BSW, and Y completing to the right system between the solar wind motional electric field vector E = 1/c V × B direction.

The magnetopause is quite difficult to identify. Quite solid factor is the boundary between hot and cool temperature of electrons. Another factor is the changes of O^+ and O_2^+ energy fluxes when change from the low energy heat ions to increasing and accelerate ions with the distance of from the magnetosphere.

It is interest of seeing again the rotation of the magnetic field lines rotate keeping slightly change of the magnitude. This effect repeats again at the place of changing the mass and transition from speed flow of one charged element to slowly moving another element.

In Figure 11 we see the same magnetic configuration in quite different material and different dynamics playing the same goal.

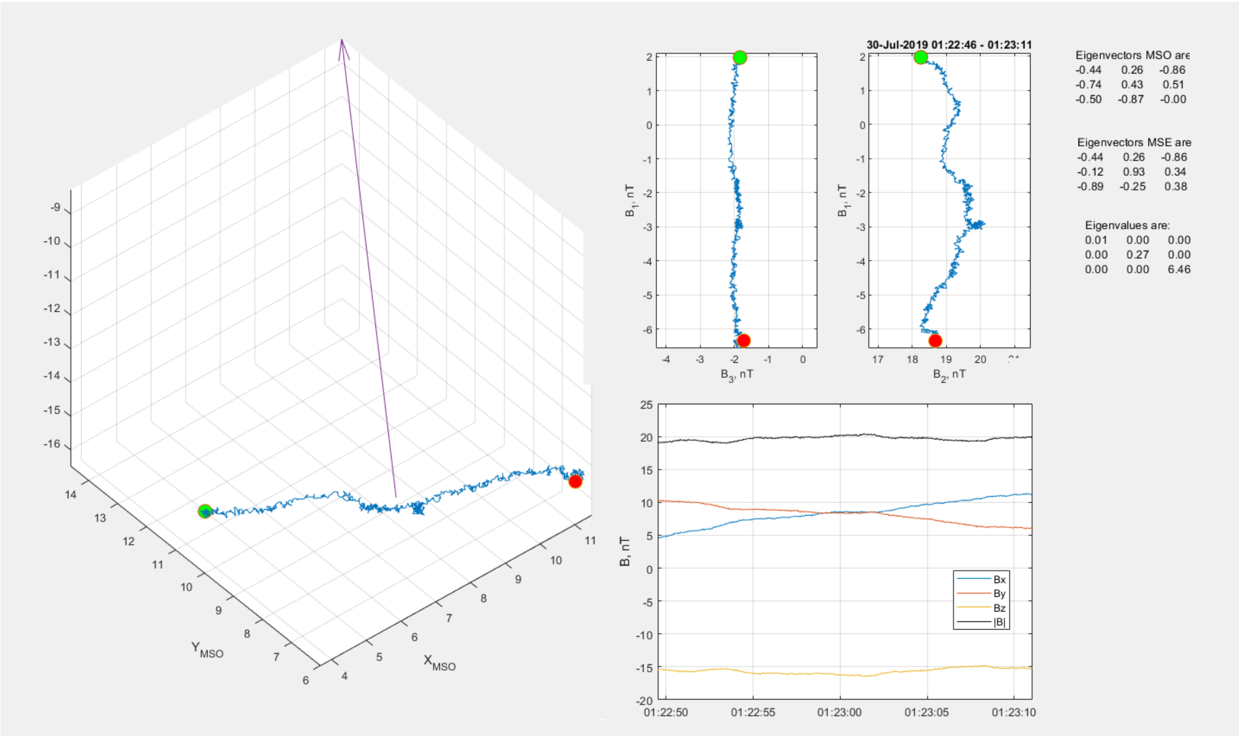

Fig. 12. Three diagrams of the magnetic fields components: a – 3D view of the long magnetic field, b – A and C components of minimum variance the long magnetic field of ~ 25 km, c – three components and magnetic field during rotational magnetic field.

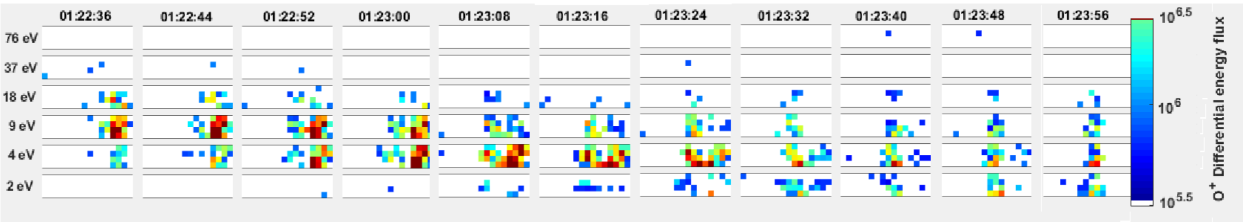

Fig.13. O^+ ions moving from magnetosphere to the right to left through curved magnetic channel to magnetosheath.

Summary

There is solid evidence that between Martian magnetosheath and dayside magnetosphere there is elongated magnetic structure that provides rotation of the magnetic field between magnetosheath and magnetosphere.

This process goes quite smoothly:
- the shocked solar wind passing around stagnated obstacle that is dayside magnetosphere
- the protons are dominate magnetosheath and the heavy ions dominate

- no change of magnitude, value by rotation
- smooth change of ion composition

Two types of dayside magnetosphere with the heavy ion population

The change of ions composition in the flow is n_p / (n_p+n_h) that ~ 50 km.

The rotation of the magnetic structure goes in the second half: from $n_p/(n_p+n_h)$ = ~10^0 to $n_p/(n_p+n_h)$ = ~ 10^{-2}.

The thickness of the magnetic sheet is ~ 25 km.

The quite consistent magnetic structure in transit from magnetosheath to dayside magnetosphere of Mars allows considering as magnetopause.

Very consistent structure of transition from magnetosheath to magnetosphere. This is basic property to attractor.

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