"Physics of Auroral Phenomena", Proc. XLII Annual Seminar, Apatity, pp. 104-106, 2019
© Polar Geophysical Institute, 2019

Polar
Geophysical
Institute

DOI: 10.25702/KSC.2588-0039.2019.42.104-106

ANALYSIS OF THE INTERPLANETARY SHOCK FRONT FINE STRUCTURE, OBSERVED BY BMSW EXPERIMENT

O.V. Sapunova, N.L. Borodkova, G.N. Zastenker, Yu.I. Yermolaev

Space Research Institute of the Russian Academy of Sciences, Moscow, Russia
e-mails: sapunova_olga@mail.ru, nlbor@mail.ru, gzastenk@iki.rssi.ru, yermol@iki.rssi.ru

Abstract. The study is dedicated to the interplanetary (IP) shock's fronts because of their strong influence on the space weather and renewed interest in the detailed study of the processes taking place in the collisionless plasma. IP shock parameters were not studied by plasma measurement with high-time resolution as good as it were studied from the magnetic field measurement. Spectrometer BMSW (installed onboard SPEKTR-R satellite) solved this problem - it measured plasma flux magnitude and direction with time resolution 0.031 s and allowed us to study fine structure of the ramp region. Data from SPEKTR-R was completed by magnetic field measurements from ACE, WIND, THEMIS and CLUSTER spacecrafts. On the base of BMSW [1] measurements 54 IP shocks were identified from August 2011 to November 2017. Ramp thickness was found to lies in the range from 45 to 450 km. I some cases foot, overshoot, upstream/downstream wave trains structures were observed near the shock font both in plasma and magnetic field measurements. It was found that wavelengths of the precursor waves varied from 55 to 440 km. Four events with large and brief increasing of He^{++} at the shock front were found according to BMSW measurements. These observations were confirmed by the measurements at WIND satellite.

1. Introduction.

Interplanetary shock waves, propagating in the solar wind collisionless plasma, redistribute energy of the directed plasma motion into the thermal energy, and accelerate the part of the particles to the significantly high energies that lead to a large growth of all kinetic parameters of the solar wind plasma and magnetic field. These dramatic changes occur inside the narrow transition layer of the shock, called a ramp. According to the magnetic field measurements ramp can be accompanied by the formation of a foot or overshoot structures. In addition, fast magnetosonic or whistler waves can be formed upstream the ramp [2, 3, 4].

The most important parameters that characterize the shock front structure are: the parameter β (ratio of thermal pressure to magnetic pressure), the angle $\boldsymbol{\theta}_{Bn}$ (angle between the normal to the wave front and the direction of magnetic field in the unperturbed solar wind), magnetosonic Mach number [5, 6]. According to the classification, shocks with $\theta_{Bn} > 45^o$ are called quasi-perpendicular shocks, with $\theta_{Bn} < 45^o$ - quasi-parallel shocks.

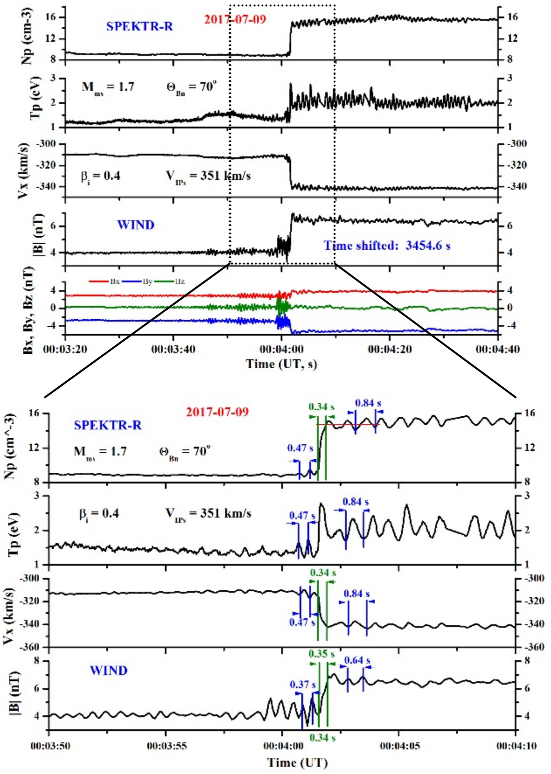
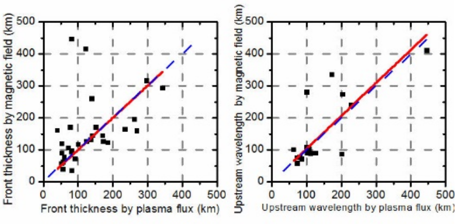


Figure 1. Example of IP shock: 2017-07-09 event. Plasma (density, temperature, Vx velocity) and magnetic field (magnitude and components) parameters.

When beta is low, the shock is laminar (or quasi laminar), and the processes occurring at the shock do not appear to be turbulent in nature. Value of Mach number determines mechanism of energy dissipation at shock front. A lot of studies have been performed on the low Mach low beta quasi-perpendicular shocks. It was shown that quasiperpendicular low beta, low Mach shocks ($M < 3$ and $\beta_1 << 1$) can dissipate required energy entirely through anomalous resistivity within the shock current sheet. When increasing Mach number approaches the first critical Mach number M_{C1} anomalous resistivity within the shock current sheet becomes unable to transform the necessary amount of energy from directed bulk flow into thermal energy because the value of the downstream flow speed along the shock normal approaches the value of downstream sound speed. As a result, reflected ions appear leading to a foot structure formation upstream the ramp and an overshoot-undershoot structure downstream the ramp.

Many works were devoted to study the thickness of the wave front according to magnetic field measurements [7, 8, 9, 10] with high time resolution. The thickness of the ramp according to plasma measurements was investigated in

[11] and depends to excessively steep spatial gradients, and their steepening is determined by the interaction between nonlinear processes of dispersion and dissipation. The definition of the characteristic scale of the shock front is an important task, because it allows us to determine the dominant processes in the interaction mechanism and its characteristics. The main aim of this study was to determine plasma parameters behavior through all structures of IP shock front.



2a **2b**

Figure 2. Comparison of measurements by plasma flux and by magnetic field module.

2. Experimental data. For this study we used measurements of plasma spectrometer BMSW [12] (Bright/Fast Monitor of Solar Wind) placed onboard the SPEKTR-R satellite. The BMSW device has time resolution 1.5 s for the velocity, temperature and density, and 0.031 s for the ion flux (magnitude and two angles). According its measurements we identified 54 interplanetary shock waves registered from August 2011 to November 2017.

The BMSW data was complemented by magnetic and plasma measurements at other satellites, if they were in the solar wind at the same time with the highest possible time resolution. We usually used data from WIND, THEMIS-B/C, CLUSTER 1 – 4 satellites.

3. Example of IP shock and fine structure of the IP ramp region. The example of IP shock, observed by BMSW is shown in Fig. 1 upper part. It presents, from top to bottom, the behavior of the solar wind density, temperature and velocity (in the GSE coordinate system) measured onboard SPEKTR-R and magnetic field propagated from WIND satellite. The shock normal direction was determined as: **n** = (-0.810, 0.373, -0.452). The IP shock was registered at 23:06:26.4 (08.07.2017) by the WIND s/c and at 00:04:01.0 by the SPEKTR-R s/c. Time scale for magnetic field was shifted on 3454.6 s for usability.

A sharp increase of all solar wind parameters at the time of shock passage was observed. Solar wind speed increased by 30-35 km/s. The temperature of protons increased by 2 times after the passage of the shock wave. The ion density also increased by almost 2 times. Angle θ_{Bn} was about 70º, according to that the interplanetary shock was determined as quasiperpendicular. Magnetosonic Mach number Mms was about 1.7, which corresponds to a supersonic wave. The ratio of thermal to magnetic pressure was small: β = 0.4.

The extended time period of the same event is presented on bottom part of Fig. 1. It includes density, temperature, Vx velocity, magnetic field magnitude through period of 20 seconds. The figure shows its parameters: the duration of the ramp by plasma measurements: tδ = 0.34; by magnetic field measurements: tδ = 0.35 s; IP shock speed: IP_{vel} = 351 km/s. One can see waves or oscillations before (upstream) and after (downstream) the ramp. Wave length (or period) of these oscillations seen to be similar on different spacecrafts, so we can say, that the front structure is sufficiently sustainable during propagation from WIND s/c to SPEKTR-R s/c.

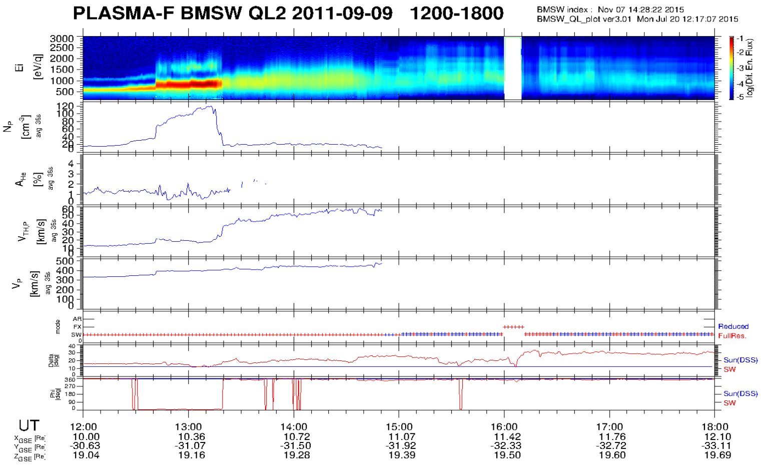


Figure 3. Example of BMSW instrument spectrogram.
http://aurora.troja.mff.cuni.cz/spektr-r/project/quicklook_digital.php#contentTop

4. Statistical study. For all events, the ramp thickness and wavelengths of upstream oscillations were calculated from the magnetic field data and from plasma parameters. Fig. 2 shows a comparison of the parameters calculated from the these two methods of measurements as follows: shock ramp thickness (2a) and wavelengths of the precursor waves (2b). The ramp thickness is between 45 and 450 km. The wavelength of the precursor waves is between 55 and 440 km. In general, close agreement is found between the characteristics calculated from the plasma parameters and the magnetic field data. Measuring the ramp thickness with different methods shows close correspondence which indicates the equivalence of these methods.

5. He^{++} analysis. In some events BMSW device can measure He^{++} (or α-particles) density - it should be more than 0.5% (He^{++} density relative to protons density) in the solar wind and proton temperature should be not very high. Example of BMSW spectrogramm is in Fig. 3. First panel shows energy-time spectrogram of the protons and He^{++} ions during 6 hours from 12-00 to 18-00 on September 9, 2011 where color corresponds the protons and He^{++} ion flux magnitude. Second and third panels show absolute countity of protons and relative to them He^{++} density during the period. Time resolution of He^{++} measurement is the same as for velocity, temperature and density - 1.5 s.

According to BMSW He^{++} data it was found four events with sharp and large increase of He^{++} density (shown in relative units) near the ramp: 03-09-2012, 13-04-2013, 21-06-2015, 12-10-2016 cases (Fig. 4). At the time of front propagation both instruments registered significant increase of He^{++} density (for 4-5 times) which lasted only for few seconds (2-5 data points). Main parameters of IP shocks are shown in the figure: β, the angle $\boldsymbol{\theta}_{Bn}$, magnetosonic Mach number and IP shock speed. So far it is not clearly determined which parameter (or set of them) is more important for this phenomenon. The source of IP shock may have influence in these cases, so it is now analyzing.

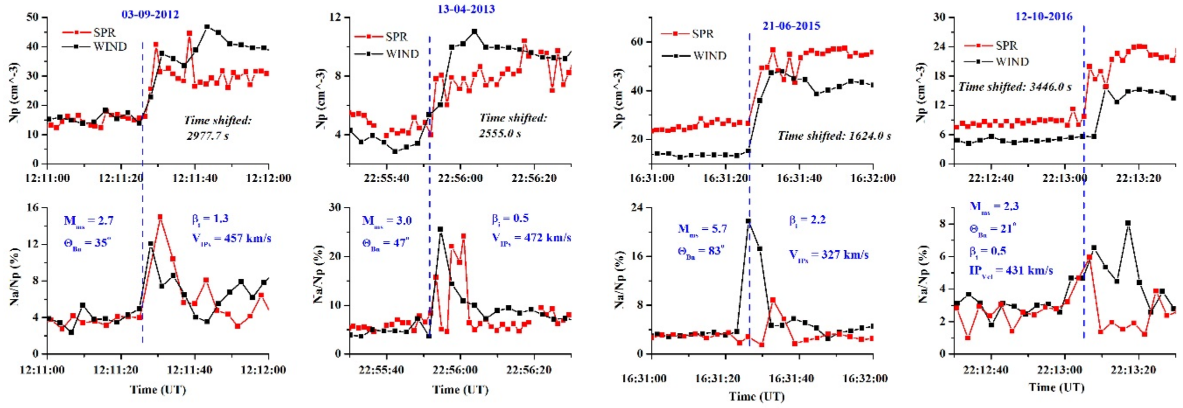


Figure 4. Four cases of He^{++} density major increase. Data obtained by BMSW and 3DP instruments of SPEKTR-R and WIND satellites. Proton (in absolute units) and He^{++} (in relative units) density are shown.

5. Conclusion. The fine structure of IP shock fronts including ramp region and upstream/downstream waves was studied on the base of SPEKTR-R data. According to the solar wind plasma measurements with high-time resolution it was shown that ion ramp scale lies in the range from 45 to 450 km and identical to the magnetic ramp scale. The plasma and magnetic wavelengths of the precursor waves are in the interval from 55 to 440 km and are similar to each other. Four events with brief (5-10 seconds) and large (by 4-5 times) enhancements of He++ in the solar wind plasma were observed by BMSW and 3DP measurements. We are looking for more similar events for further investigation of this phenomenon.

Acknowledgments. This work was funded by RFBR according to the research project No. 19-02-00177.

References

1. Safrankova J., Nemecek Z., Prech L., Zastenker G., Cermak I., Chesalin L., Komarek A., Vaverka J., Beranek M., Pavlu J., Gavrilova E., Karimov B., Leibov A. Fast Solar Wind Monitor (BMSW): Description and First Results. Space Sci. Rev., 175 (1-4), 165–182, 2013.
2. Borrini G., Gosling J.T., Bame S.J., Feldman W.C. An Analysis of shock wave disturbances observed at 1 AU from 1971 through 1978. J.Geophys. Res., 87, A6, 4365, 1982.
3. Volkmer P.M. and Neubauer F.M. Statistical properties of fast magnetoacoustic shock waves in the solar wind between 0.3 AU and 1 AU: Helios-1, 2 observations. Ann. Geophys., 3, 1, 1-12, 1985.
4. Borodkova N.L., Vaisberg O.L., Zastenker G.N. Interplanetary shock waves in the post solar maximum year period (January - July, 1981). Adv. Space Res., V.6, N6, p.327, 1986.
5. Formisano V. Collisionless shock waves in space and astrophysical plasmas, In Proc. ESA Workshop on Future Missions in Solar, Heliospheric and Space Plasma Physics, vol. ESA SP-235 (1985), p. 83.
6. Kennel C.F., Edmiston J.P., Hada T. A quarter century of collisionless shock research, In Collisionless Shocks in the Heliosphere: A Tutorial Review, ed. by R.G. Stone, B.T. Tsurutani Geophysical Monograph, vol. 34 (American Geophysical Union, Washington, 1985), pp. 1–36.
7. Russell C.T., Mellot M.M., Smith E.J., King J.H. Multiple spacecraft observations on interplanetary shocks: four spacecraft determination of shock normals. J. Geophys. Res., Atmos., 88, 4739–4748, 1983.
8. Farris M.H., Russell C.T., Thomsen M.F. Magnetic structure of the low beta, Quasi-perpendicular shock. J. Geophys. Res., V.98, NA9, 15,285-15,294, 1993.
9. Newbury J.A., Russell C.T. Observations of a very thin collisionless shock. Geophys. Res. Lett., 23, 781, 1996. doi:10.1029/96GL00700.
10. Krasnoselskikh V., Balikhin M., Walker S.N., Schwartz S., Sundkvist D., Lobzin V., Gedalin M., Bale S.D., Mozer F., Soucek J., Hobara Y., Comisel H. The dynamic quasiperpendicular shock: Cluster discoveries, Space Sci. Rev., 2013. doi:10.1007/s11214-013-9972.
11. Nemecek Z., Safrankova J., Goncharov O., Prech L., Zastenker G.N. Ion scales of quasi-perpendicular interplanetary shocks. Geophys. Res. Lett., 40, 16, 4133–4137, 2013. doi: 10.1002/grl.50814.
12. Zastenker, G.N., Safrankova J., Nemecek Z. et al. Fast measurements of parameters of the Solar Wind using the BMSW instrument. Cosmic Res., 51. 78, 2013. doi:10.1134/S0010952513020081.