

HE++ BEHAVIOR ON THE AN INTERPLANETARY SHOCK WAVE

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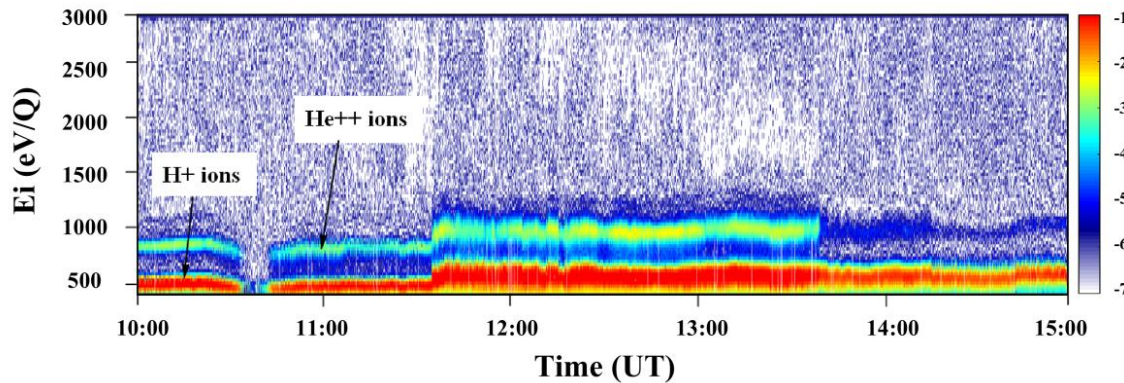


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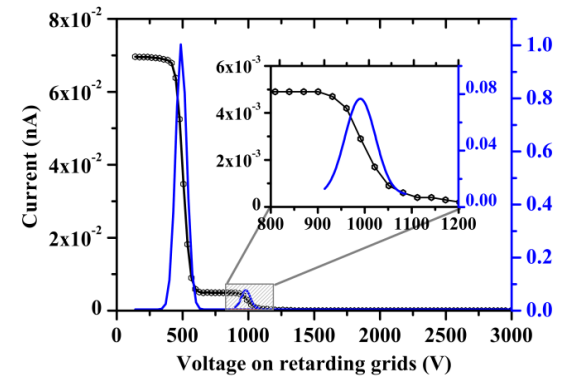


DATA SOURCES

For the study, we used data obtained by the BMSW (Bright Monitor of Solar Wind) plasma spectrometer, which operated since August 2011 to 2019. BMSW is intended for measurements of the energy spectrum of ions in the range of 0.2–2.8 keV/Q, proton bulk velocity in the range from 200 to 750 km/s, ion isotropic temperature from 1 to 100 eV and ion density from 1 to 100 cm⁻³. The time resolution of the BMSW instrument was 0.031 s for the ion flux magnitude and direction and 1 s for the velocity, temperature, and density of protons and He⁺⁺ ions. A detailed description is presented in several papers (e.g., Nemecek, 2013; Zastenker et al., 2013; Safrankova et al., 2013b; Eselevich, 2017).



Energy time spectrogram of ion flux measured on September 30, 2012 by the BMSW instrument.



An example of 3-second spectrum of the BMSW instrument.

Two populations are clearly distinguished on the spectrogram and are indicated by arrows. Both populations, protons and He⁺⁺ ions, exist before, during, and after the IP shock front crossing at 11:31 on September 30, 2012. The BMSW instrument data allows one to distinguish the distribution of ions if the temperature and velocity of protons are small (Safrankova et al., 2013a).

Nemecek, Z., Safrankova, J., Goncharov, O., Prech, L. and Zastenker, G. N.: Ion scales of quasi-perpendicular interplanetary shocks, *Geophys. Res. Lett.*, V. 40 N. 16. P. 4133–4137, doi: 10.1002/grl.50814, 2013.

Safrankova, J., Nemecek, Z., Cagas, P., Prech, L., Pavlu, J., Zastenker, G. N., et al.: Short-scale variations of the solar wind helium abundance, *The Astrophysical Journal*, 778, 25, <https://doi.org/10.1088/0004-637X/778/1/25>, 2013a.

Safrankova, J., Nemecek, Z., Prech, L. et al.: Fast Solar Wind Monitor (BMSW): Description and first results, *Space Sci. Rev.*, V. 175 N. 1–4. P. 165–182, 2013b.

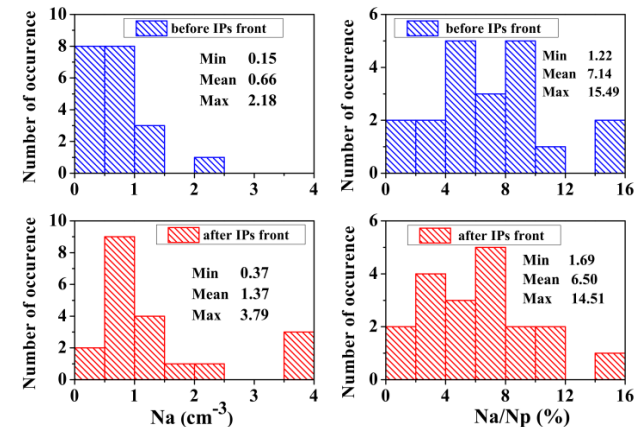
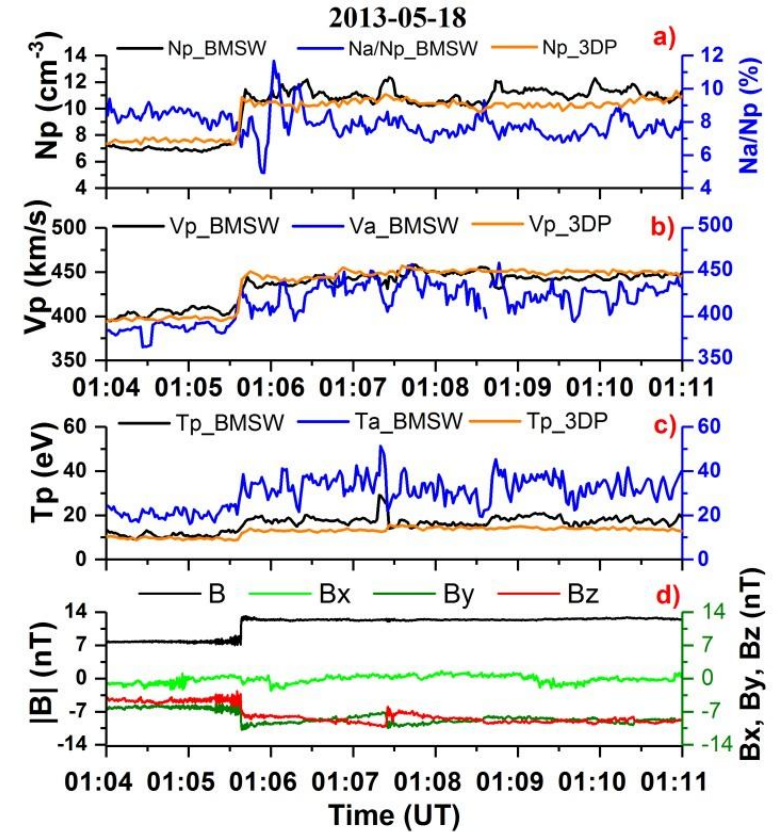
Zastenker, G. N., Chesalin, L. S., Karimov, B. T., Agafonov, Y. N., Borodkova, N. L., Gavrilova, E. A., Gagua, T. I., Gagua, I. T., Dalin, P. A., D'yachkov, A. V., Koloskova, I. V., Leibov, A. V.: Fast measurements of parameters of the solar wind using the BMSW instrument, *Cosmic Res.*, V. 51 N. 2 P. 83–175, 2013.

Variations of the He^{++} ion parameters during the IP shock

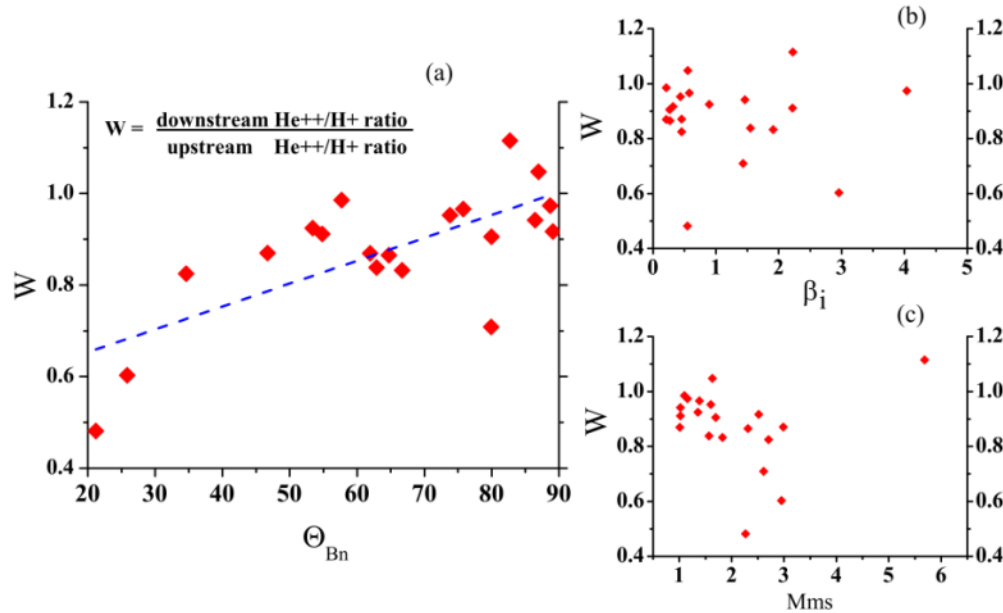
An example of that He^{++} ion variations is shown in right figure for density, velocity and temperature, as well as the magnetic field. Panels a-c) show the plasma data of the SPEKTR-P and WIND satellites measurements. The proton parameters are given in black for BMSW and in orange for the 3DP instruments, respectively. The blue color shows the parameters of alpha-particles according to the data of the BMSW instrument. Panel d) shows the magnitude and components of the magnetic field according to the MFI instrument of the WIND satellite.

There is a slight decrease in the helium abundance Na/Np immediately after crossing the IP shock ramp. It rises up then and levels out in approximately one minute. The velocity of He^{++} ions was, on average, slightly (about 7%) less than the velocity of protons both before and after the front, while proton velocities from different instrument match each other. The temperature of He^{++} ions is 2 times higher than the temperature of protons due to the higher mass of α -particles and significantly rises on the IP shock ramp.

The histograms show the distribution of Na and Na/Np for all events, before and after the front passage. It can be noted that after crossing the IP shock front, the absolute values change quite noticeably. In particular, the average value of the He^{++} ion density increases by about 2 times. However, due to an equally strong increase in the density of protons behind the IP shock front, the Na/Np changes slightly.



Dependence of He^{++} ion parameters on β_i , M_{MS} , θ_{Bn} for IP shocks



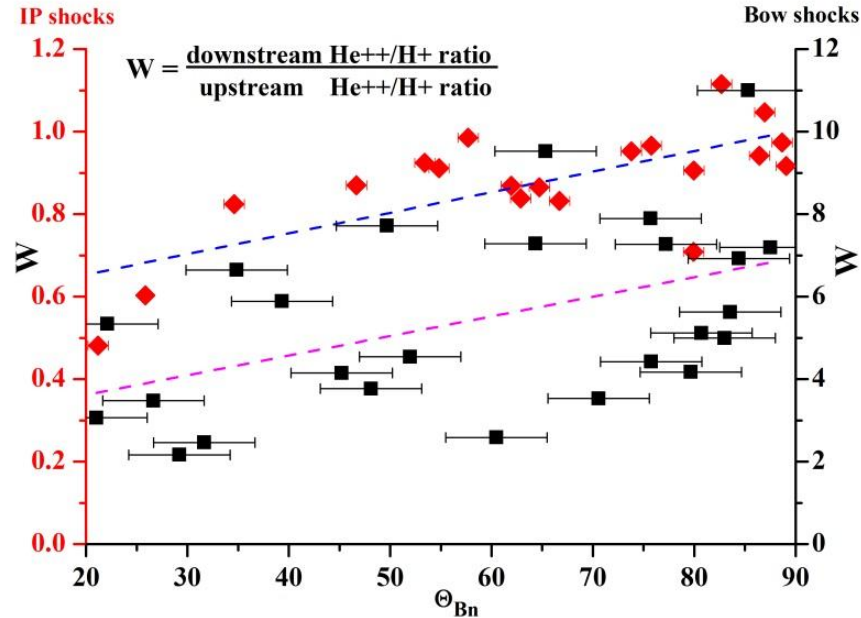
The dependence of the helium abundance Na/Np change during the IP shock front passage on the θ_{Bn} (a), β_i (b), and M_{MS} (c) parameters.

For all these events it was considered the changes in the helium abundance Na/Np during the passage of the IP shock front depending on the values of β_i , θ_{Bn} and M_{MS} . The results are shown on right figure.

It can be noted that there is no explicit dependence of the change in the relative density of He^{++} ions on the β_i parameter (see panel b). For both small and large values of the parameter β_i , a large or small change in the relative density of He^{++} ions is possible. There is also no clear correlation with the M_{MS} parameter (see panel 7c). However, if we exclude an event with a large parameter value ($M_{\text{MS}} = 5.8$), there is a tendency for the helium abundance Na/Np to fall behind the IP shock front as the M_{MS} increases. This issue requires further research.

However, we can see an obvious correlation between the change in the helium abundance Na/Np and the angle θ_{Bn} (panel a). The smaller the angle θ_{Bn} is, the more the value falls. In other words, the Na/Np will fall much more (2–2.5 times) behind the front of quasi-parallel IP shocks than behind the front of quasi-perpendicular IP shocks.

Dependence of He^{++} ion parameters on θ_{Bn} for Earth's bow shock



The dependence of the helium abundance Na/Np change on the θ_{Bn} angle at the intersection of the shock front. Red marks show the events of the IP shock fronts crossings, black marks - the Earth's bow shock front crossings. The blue dashed line shows the trend for the first set, and the purple dashed line shows the trend for the second set.

Because of the small number of events we increased the statistic, and processed data of the Earth's bow shock crossings by the SPEKTR-R satellite during the period from 2011 to 2013. This slide shows obtained results, superimposed with the existing data set. The estimation of the θ_{Bn} angle for the new events was made using the model (Verigin et al., 2003a.) for the shape of the bow shock and data from nearby satellites, including an estimate of the magnetic field direction. The new data set allowed us to supplement the area of quasi-parallel events, with an angle of $\theta_{\text{Bn}} < 45^\circ$. Despite the uncertainty of these estimates (shown in the figure), there is a trend - the larger the θ_{Bn} angle is, the more helium abundance Na/Np will increase after IP shock front. This trend coincides with the one already mentioned in the set of the IP shock fronts crossings - the helium abundance Na/Np changes less in the quasi-parallel cases. These results correspond with ones, showed in model by Ofman et al. (2019).

Ofman, L., et al.: Understanding the Role of α Particles in Oblique Heliospheric Shock Oscillations, JGR: Space Physics, 124, 2393-2405, <http://doi.org/10.1029/2018JA026301>, 2019

Verigin, M., Slavin, J., Szabo, A. et al.: Planetary bow shocks: Gasdynamic analytic approach, JGR., V. 108(A8), P. 1323., doi:10.1029/2002JA009711, 2003a.

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for your
attention!**