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Comparison of properties of small-scale ion flux fluctuations in the flank magnetosheath and in the solar wind

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Abstract

We present a comparison of spectral and statistical properties of ion flux fluctuations in the turbulent solar wind and in the flank Earth's magnetosheath. We use the data of the BMSW device operating in frame of the SPECTR-R mission with an extremely high-time resolution (up to ~30 ms). Fourier spectra of ion flux fluctuations are systematically analyzed both in the solar wind and in the magnetosheath on the inertial scale and on a transition to the dissipation scale in the range of 0.01–10 Hz. We show that ion flux fluctuation spectra in the flank magnetosheath are similar to those observed in the solar wind and we demonstrate the presence of the break at frequencies of ~1–2 Hz. Spectra are slightly steeper in the flank magnetosheath but the break frequency is near twice less in a comparison to the solar wind. The magnetosheath ion flux turbulent flow is intermittent as it was shown earlier for the solar wind. We discuss the level of intermittency of ion flux fluctuations in both regions and we determine the characteristics of structure functions. Finally, we demonstrate extended self-similarity in the magnetosheath.

Keywords: Magnetosheath; Solar wind; Plasma turbulence; Intermittency; Kinetic scales

1. Introduction

The Earth's magnetosheath (MSH) delivers solar wind (SW) plasma into the magnetosphere, thus solar-terrestrial investigations need the analysis of variations of SW parameters and their modifications in the MSH. A study of SW and MSH turbulence presents an opportunity to analyze the dynamics of the space plasma for different boundary conditions. SW turbulence freely developes in the space during long-time intervals, whereas MSH turbulence developes between two boundaries – the magnetopause and bow shock. A large number of various types of waves originate at these boundaries and inside the MSH (Omidi et al., 1994; Lacombe and Belmont, 1995). A high level of plasma and magnetic field fluctuations are constantly observed in the MSH as a result of these processes (Němeček et al., 2001; Zastenker et al., 2002; Shevyrev et al., 2003), thus they cannot be described by traditional models of a laminar plasma flow (Němeček et al., 2000; Zastenker et al., 2002).

The recent hybrid models (e.g., Karimabadi et al., 2014) demonstrate the presence of a high level of turbulent fluctuations downstream the quasi-parallel bow shock. The

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quasi-parallel bow shock modifies and amplifies SW fluctuations, so the level of fluctuations is increased behind it (Shevyrev et al., 2003; Alexandrova, 2008). Shevyrev and Zastenker (2005) show that the amplitudes of high frequency fluctuations are also higher behind the quasi-parallel bow shock as well as in the foreshock located in front of it. Fluctuations of different nature are observed in the MSH because all outer regions, the bow shock (e.g., Němeček et al., 2002) foreshock (e.g., Blanco-Cano et al., 2006) and magnetopause (e.g., Rezeau et al., 1999; Gutynska et al., 2012) contribute to the formation of MSH turbulence. A high level of turbulent fluctuations in the MSH leads to a low level of correlations between the magnetic field and plasma in the MSH and SW (Gutynska et al., 2012; Rakhmanova et al., 2015a,b). Moreover, the magnetic field near the magnetopause can strongly differ from that in the SW (Šafránková et al., 2009; Pulinets et al., 2014) and this fact significantly complicates a creation of adequate models.

In the MSH, the fluctuations of the SW origin and the fluctuations born on boundaries of the MSH and within it are mixed (Zastenker et al., 2002). Low-frequency fluctuations come mainly from the SW, whereas high-frequency fluctuations have as a rule a local origin (Gutynska et al., 2012; Rakhmanova et al., 2015a,b), however, it is rather difficult to separate these sources in each specific case. For example, the dynamics of some significant structures in the SW (as the interplanetary shocks, or large amplitude discontinuities) can be traced (Koval et al., 2006; Šafránková et al., 2007; Rakhmanova et al., 2012) also in the MSH. However, the understanding of the dynamics of small SW plasma and magnetic field structures downstream the bow shock requires a joint analysis of the turbulent properties of the SW and the MSH (Savin et al., 2014). The power character of the spectra of turbulent fluctuations are similar in the SW and in the MSH (Shevyrev and Zastenker, 2005; Alexandrova, 2008) with significant differences for so called inertial and dissipation scales and with the break between them (Alexandrova, 2008). Different types of waves can influence the spectra formation in the MSH (Alexandrova et al., 2008), e.g. the presence of Alfven vortices in the MSH often leads to the observation of the spectrum peak near to the spectral break (Alexandrova et al., 2004, 2006). An Alfvenic fluctuations dominate in a wide frequency range in the MSH for small plasma β parameters and the spectra become anisotropic (Anderson et al., 1994), whereas the spectra are practically isotropic for large β plasma.

High-resolution plasma measurements of the BMSW instrument open a possibility to analyze and to compare the turbulent properties of plasma fluctuations in the SW and in the MSH up to the frequency ~10 Hz. Such comparison is necessary to study the dynamics of small-scale SW fluctuations in the MSH and also for understanding the reasons of frequently observed low correlations of the SW and the MSH simultaneous data series.

2. The experimental data set

We use the ion flux measurements by the BMSW (Bright Monitor of Solar Wind) spectrometer of the Plasma-F experiment on board of the SPECTR-R spacecraft (Šafránková et al., 2008, 2013a; Zastenker et al., 2013; Zelenyi et al., 2013). The regular systematic measurements in the SW and the MSH are available due to the high-apogee orbit and due to the long-term employment of the device (it operates since August 2011 until present). The main advantage of the BMSW instrument is a possibility of measurements of the ion flux value and its direction with high-time resolution up to 31 ms. The plasma parameters (as the ion density, bulk velocity and ion temperature) are measured in a part of time with the same high-time resolution (in the adaptive mode). In the rest of time, the same set of parameters and also the density of helium is determined with a 3 s time resolution from the energy distribution of ions (in the sweeping mode). The BMSW is directed to the Sun with a precision of 5–10° (the orientation of the device relative to the Sun direction is determined with the accuracy of ~1° by the special solar sensor). The ion flux deflection from the device axis can be determined from the ratio of currents from the three multidirectional sensors. If the deflection is large (as often in the MSH), the currents may be sufficiently small on some of sensors and the noise can become significant in these cases. It can lead to the errors in a determination of plasma parameters. So we consider only the cases with the angle between the SW stream direction and main axis of the BMSW instrument less than 20°.

We selected rather long time intervals (more than 3 h) of the SW and the MSH flank measurements. Then we smashed these intervals in pieces with the length of ~17 min (i.e., 32768 points because it is better to use the time series with a number of points equal to a power of two for the Fourier transform) with overlapping by a half of their length with respect one to another. As the next step, we analyze the ion flux fluctuation properties for 363 17-min intervals in the SW and for 427 intervals with the same length in the flank MSH. Note that we used the statistics presented earlier in Riazantseva et al. (2015) for the SW analysis. We compute the fast Fourier transform for a spectral analysis and smooth the spectra using a Hanning window in the frequency domain. We focus on the behavior of the power spectra at frequencies less than 10 Hz to exclude a noticeable contribution of the instrumental noise to higher frequencies. This frequency limit is obtained from the in-flight calibration and in laboratory tests (Šafránková et al., 2013a; Chen et al., 2014). A low-frequency limit is determined by a length of intervals and becomes near 0.01 Hz. A study of features of probability distribution functions and structure functions of ion flux fluctuations is performed for the same intervals and for the same frequency ranges.