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STATISTICAL ANALYSIS OF LANGMUIR WAVES ASSOCIATED WITH TYPE III RADIO BURSTS: I. WIND OBSERVATIONS

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Abstract. Interplanetary electron beams are unstable in the solar wind and they generate Langmuir waves at the local plasma frequency or its harmonic. Radio observations of the waves in the range 4–256 kHz, observed in 1994–2010 with the WAVES experiment onboard the WIND spacecraft, are statistically analyzed. A subset of 36 events with Langmuir waves and type III bursts occurring at the same time was selected. After removal of the background, the remaining power spectral density is modeled by the Pearson system of probability distributions (types I, IV and VI). The Stochastic Growth Theory (SGT) predicts log-normal distribution for the power spectrum density of the Langmuir waves. Our results indicate that SGT possibly requires further verification.

Key words: Sun: wind, flares, radio radiation, Langmuir waves

1. INTRODUCTION

We used the measurements obtained by four different experiments on-board the Wind spacecraft – a laboratory for long-term solar wind measurements, launched on 1994 November 1. Our focus is on radio observations obtained by the WAVES experiment (Bougeret et al. 1995). In the study of locally generated Langmuir waves we use the data from two multi-channel thermal-noise receivers (TNR), which cover the frequency range from 4 kHz to 256 kHz in five logarithmically-spaced frequency bands. Each band covers two octaves with one octave overlap. Each of these bands is divided to either 32 or 16 logarithmically-spaced channels. TNR provides rapid measurements of the plasma electric field. The Langmuir waves that are converted to electromagnetic waves – type III bursts, can then be observed with two radio receivers, RAD1 and RAD2. The RAD1 frequency range, from 20 to 1040 kHz, is divided into 256 linearly spaced channels of 3 kHz bandwidth each. The frequency range of the RAD2 radio receiver, from 1075 to 13 825 kHz, is divided in the same number of channels as RAD1, but with 20 kHz bandwidth.

For the selection of sample events (Figure 1) we used: (1) one minute averaged measurements of interplanetary magnetic field vector in the Geocentric Solar Ecliptic (GSE) cartesian coordinates from Magnetic field investigation (MFI), Lepping et al. (1995); (2) for the particle measurements, i.e., for the full three-dimensional distribution of suprathermal electrons and ions, we used the 3-D Plasma and Energetic Particle Investigation (3DP) experiment, Lin et al. (1995); (3) for the solar wind velocity we used the data from the Solar Wind Experiment (SWE), Ogilvie et al. (1995) which provides three-dimensional velocity, density and temperature of the solar wind ions. As the solar wind velocity, we used proton velocity averaged over the time interval when our events occurred. The measurements, taken simultaneously by the four experiments, allow a qualitative analysis of the events.

In order to remove the background from the TNR observations consisting of thermal noise, type III bursts and Galactic background, we have developed a heuristic algorithm based on numerical techniques with a few parameters only.

2. ANALYSIS, THE PEARSON SYSTEM OF DISTRIBUTIONS

Karl Pearson (1895) defined a distribution system by the following equation for the probability density function $p(x)$:

$$-\frac{p'(x)}{p(x)} = \frac{b_0 + b_1 x}{c_0 + c_1 x + c_2 x^2},$$

where b_0, b_1, c_0, c_1 and c_2 are real parameters. The form of solutions of this differential equation depends on the parameter values, resulting in several distribution types. The classification of distributions in the Pearson system is entirely determined by the two moment ratios, square of skewness, β_1, and kurtosis, β_2:

$$\beta_1 = \frac{\mu_3^2}{\mu_2^3}, \quad \beta_2 = \frac{\mu_4}{\mu_2^2}.$$

The coefficients of the probability distributions were calculated by using the following methods: the method of moments and the maximum likelihood estimation method. We have shown that the probability distributions of the power spectral density of the Langmuir waves belong to the three main types of Pearson's probability distributions: type I, type IV and type VI.

3. RESULTS AND CONCLUSIONS

We have shown that for 36 events – intense locally formed Langmuir waves associated with type III radio bursts – the probability distributions of the power of these waves in the spectral domain belong to the three main types of the Pearson probability distributions: type I, type IV and type VI, Figure 2 (see similar results in Krasnoselskikh et al. 2007 and Musatenko et al. 2007). The goodness of the fits test (e.g., χ^2) shows that the Pearson probability distributions fit the data better than the log-normal ones for all of the considered events. The performed uncertainty analysis also is in favour of the use of Pearson's system of distributions to model the data.

This result indicates that the Stochastic Growth Theory proposed by Robinson (1992), which assumes log-normal distributions for the wave energy, possibly requires additional verifications and examinations.

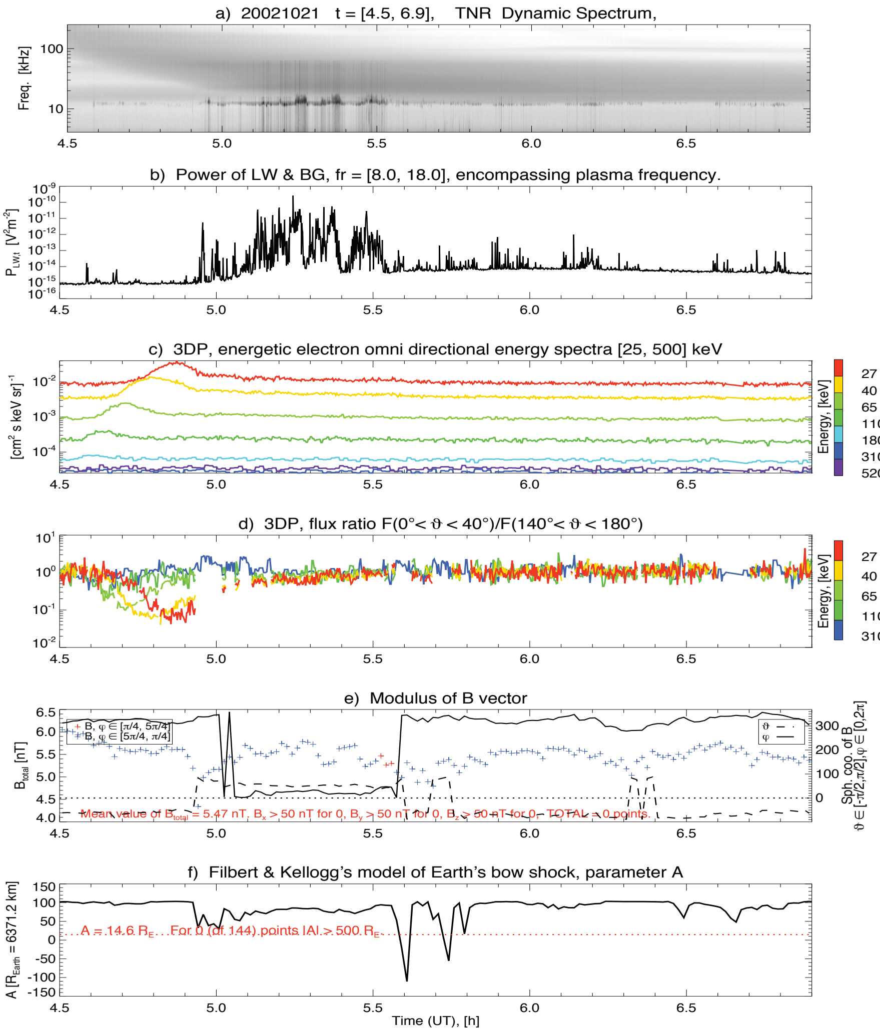

Fig. 1. WIND observations on 2002 October 21 (Bougeret et al. 1995): (a) dynamical spectra, only TNR receiver observations (4–256 kHz), (b) power spectral density integrated over narrow frequency band (8–40 kHz) around the plasma frequency ($\sim$12 kHz), (c) Omni directional spectrum of energetic electron fluxes, 3DP experiment. The energies are indicated on the right-hand side of the panel (the units on the left-hand side are cm^2, s, keV, sr^{-1}), (d) Energetic electron flux ratio $F(0^\circ < \vartheta < 40^\circ)/F(140^\circ < \vartheta < 180^\circ)$, (e) magnetic field intensity. Plus (+) symbols indicate the direction of magnetic field vector from the Sun (light gray) or from the Earth (dark gray). Solid and dashed lines indicate two spherical coordinates (ϑ, φ), respectively, (f) Parameter A of the Filbert & Kellogg (1979) model of the Earth's bow shock, i.e., the position of the nose-cone of paraboloid along x-axis in the GSE coordinate system. Its tangent (solar magnetic field line) goes through the WIND spacecraft. The dotted line indicates the distance along x-axis, from the Earth to the nose-cone of the Earth's bow shock in steady state. If A is greather than 14.6 Earth's radii, it means that the WIND spacecraft is out of the Earth's bow shock.

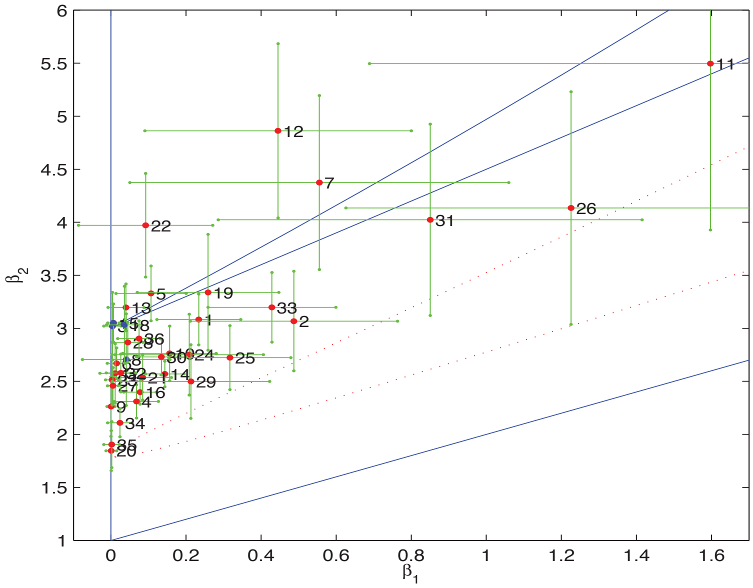

Fig. 2. Beta plane. From the 36 events: 28 belong to Pearson's type I, 1 to type VI and 7 to type IV probability distribution. Error bars are calculated by the method of moments. Most of the events are close to normal distribution – $(\beta_1, \beta_2) = (0, 3)$, but only for 4 events their error bars intersect the point of normal distribution.

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