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Dynamical approach to Jovian decametric S/NB-emissions

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Abstract

Short (S) bursts and narrow-band events (NB) of Jovian decametric emission (DAM) form oscillating bands near certain frequencies in dynamical spectra. We are testing the hypothesis that there is a connection between the phenomenology of S/NB-emissions and trajectories of an electron in the parallel electric field of the standing Alfvén wave.

1. Introduction

It is believed that the S-burst drift in dynamic spectrum reflects the motion of a radio source (a bunch of electrons) along a magnetic field with a decrease of the emission frequency in accordance with the local gyrofrequency of electrons (e.g., [3]). This motion could be disturbed by a standing Alfvén wave in the ionosphere Alfvén resonator [2]. We are testing the hypothesis that there is a connection between the phenomenology of Jovian narrowband emissions and trajectories of an electron in the parallel electric field of the standing Alfvén wave.

2. Basics of the model

The parallel electric field E_1, generated by a kinetic Alfvén wave in the cold electron case, is proportional to the perpendicular magnetic disturbance δB (Eq. 13 in Hess et al. 2007). This wave disturbance is assumed in the simplest, harmonic form:

$$E_1 = K\delta B = E_o sin[\frac{2\pi}{P}t - \frac{2\pi}{\lambda}(X - Xo)], \quad (1)$$

where K is the factor of proportionality; $E_o = K\delta B_o$ is the amplitude of the electric field corresponding to the magnetic amplitude δB_o; P is the time period of the wave; λ is the wavelength; X is the spatial coordinate along the magnetic field line; X_o is the coordinate of the reference node of the Alfvén wave.

As the Alfvén wave is reflected from the Jovian ionosphere, there is another wave propagating in the opposite direction: $E_2 = E_o sin[(2\pi/P)t + 2\pi(X - X_o)/\lambda]$. The superposition of the parallel electric fields of these waves forms the standing wave as the product of temporal and spatial oscillations $E = E_1 + E_2$:

$$E = 2E_o sin[(2\pi/P)t] cos[(2\pi/\lambda)(X - X_o)]. \quad (2)$$

The electric field (2) creates a coulomb force acting on one electron mass m_e with the charge e: $m_e d^2X/dt^2 = eE$. As the DAM is generated by cyclotron maser instability, in the inhomogeneous Jovian magnetic field, there is certain relation between the spatial coordinate X and the DAM's frequency f near the local gyrofrequency of electrons. In linear approximation at short distances, the substitutions $X \longrightarrow f$ and $X_o \longrightarrow f_o$ are acceptable. Hence, the equation of the motion in dynamic spectrum is:

$$\frac{d^2f}{dt^2} = \frac{2eE_o}{m_e} sin[\frac{2\pi}{P}t + \Delta\varphi] cos[\frac{2\pi}{\lambda_f}(f - f_o)] + \frac{\Delta E}{m_e}, \quad (3)$$

where $\lambda_f = (df_{ce}/dX)\lambda$ is the wavelength in frequency scale; $\Delta\varphi$ and ΔE are the noise additions for a modelling of realistic variations in E. The particle trajectory $f(t)$ in the dynamic spectrum of DAM is found with numerical integration of Eq. 3.

To simulate the dispersion effect, the time delay is introduced in the simplest form:

$$\Delta t = (f - f_o)/D, \quad (4)$$

where D is the frequency drift rate due to the dispersion of DAM.

3. Some results

Figure 1 shows the results of our numerical integration of Eq. 3 with $\Delta E = \Delta\varphi = 0$. The motion of the electron at a distance from antinodes of the Alfvén wave appears as the inclined oscillations in dynamic spectrum (Fig. 1c). These features resemble the wave-like NB-events (Fig. 1a). However, the clipped form appears (Fig. 1d) if antinodes are at the borders of the

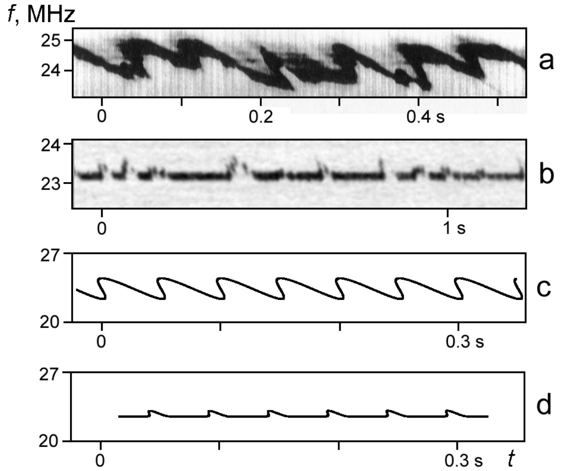

Figure 1: Resemblance between NB-events of DAM (a and b [5, 6]) and the calculated electron's gyrofrequency oscillations in the standing Alfvén wave (c and d).

motion range. In this case the flat parts of the curve depict the capture of the electron at the antinode of the standing Alfvén wave, where E inverts its sign and creates the potential well for the particle. Resembling emissions at $f = const$ are typical for NB-events of DAM [5, 6].

The noise $\Delta E(t) \neq 0$ irregularizes the trajectory permitting the electron's transfer from one node region to another. If the amplitude of NB-oscillation is much longer than $\lambda_f/2$, the electron is captured at successive antinodes, and the step-like trajectory is formed in dynamic spectrum. The shadow modulation [1] retains only observed zig-zag forms in dynamic spectrum (Fig. 2). This modulation in our model reflects the empiric fact of DAM invisibility in certain regions of the dynamic spectrum. These regions are located after S-bursts or NB-oscillations at lower frequencies resembling the shadows with certain frequency drift rate $d < D$.

If the random jumps in $\Delta\varphi \neq 0$ are added in Eq. 3 with $\Delta E(t) \neq 0$, the realistic S-burst train is a result of the integration in combination with the shadow effect (Fig. 3).

4. Conclusion

The resemblance between the calculated curves and real DAM spectra is an argument for the modulation of Jovian S/NB-emissions by standing Alfvén waves.

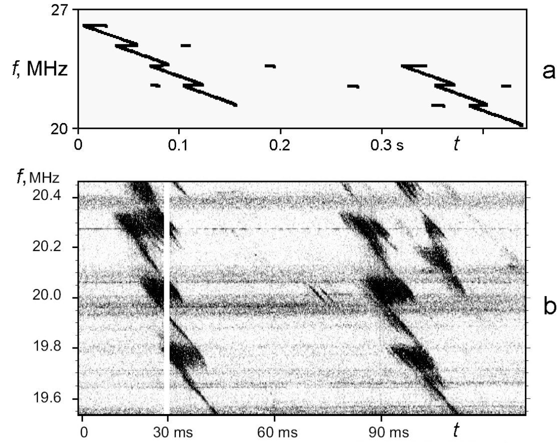

Figure 2: The step-like captures are a result of noise addition ΔE in Eq. 3 (a). The similar features are present in the real dynamic spectrum (b) [4].

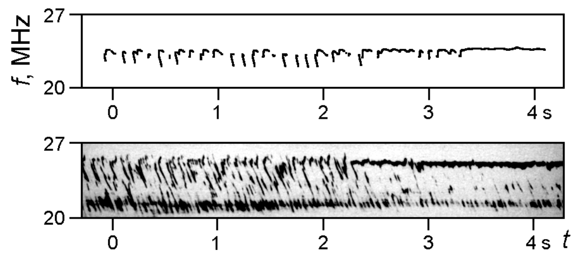

Figure 3: The transition from the S-band-like oscillations of the electron gyrofrequency to the NB-like capture (above, since t = 3.3 s) resembles the real dynamic spectrum (bottom; Fig. 11 in [5]).

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