III. Origin of Zebra-Pattern

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Abstract. The results of investigation of the cyclotron wave instability in the corona for Bernstein modes and plasma waves in a hybrid band have been used to interpret zebra-pattern phenomena. Two models of the generation region of parallel drifting bands are considered: the model of the point source localized at the apex of the magnetic trap and the model of a distributed source extended along the magnetic flux tube. In the first model it is assumed that a harmonic character of zebra-pattern appears either in coalescence of excited Bernstein modes at different harmonics of the gyro-frequency or in coalescence of these modes with plasma waves excited in the hybrid band. In the latter case if the magnetic field changes in time a pulsating generation regime occurs. In the second model, the emission bands appear in the regions of double plasma resonance as a result of coalescence of longitudinal waves excited in the hybrid band. Estimations of the magnetic field and the nonequilibrium component density necessary for the zebra-pattern to generate are presented.

1. Introduction

This part deals with interpretation of zebra-pattern of the solar radio emission, the example of which in the event of 2 March 1970 is illustrated on the dynamic spectrum of Figure II.1a*. The figure shows the period followed by the appearance of 'tadpoles', zebra-pattern at this time consisting of tadpoles almost overlapped. In many other events, however, zebra-structure was recorded as continuous bands (see, for example, Slottje (1972a)). Due to this Slottje (1972a) concluded that there were two different kinds of zebra-structure: related and not related with tadpoles.

We may point out two models of generation of parallel drifting bands (zebra-structure): the model of a 'point' source localized at the apex of the magnetic trap (see Figure II.2) and the model of a 'distributed source' extended along the magnetic flux tube. For the first model, the generation region dimensions are assumed to be so small that the magnetic field and plasma density inhomogeneity has no influence on the frequency spectrum. In the second model, it is just the change in the magnetic field and coronal plasma density along the flux tube that plays the main role.

In both models it is taken into account that the emission bands in zebra-pattern

* Here and below a roman II before the number of the formula or figure denotes a reference to the corresponding formula or figure in the paper by Zheleznyakov and Zlotnik (1975b) cited as II. A roman I refers to the paper by Zheleznyakov and Zlotnik (1975a).
are separated by approximately equal frequency intervals. This points to the association of zebra-structure (and tadpoles arising as zebra-structure development and continuation in the event on 2 March 1970) with emission at the harmonics of the electron gyrofrequency $\Omega_H$.


It was shown in Part II that the tadpole generation on 2 March 1970 may take place in the small source where Bernstein modes are excited. To explain the zebra-structure closely related with tadpoles during the event, we use the model of the point source localized at the apex of the magnetic trap (Figure II.2).

The energetic particle distribution in the source is defined by formula (II.3.1). It should be emphasized that a 'banded' dynamic spectrum in such a model may be caused by two different ways. The first generation scheme (II.2.1.) was discussed in Part II. Bernstein modes are generated in the source; the radio emission is generated in coalescence of these modes with different or equal numbers of harmonics $s_1$ and $s_2$. The radio emission frequency is

$$\omega_r \sim s_1 \Omega_H + s_2 \Omega_H.$$  \hspace{1cm} (2.1)

The second way is also based on excitation of Bernstein modes at relatively small harmonic numbers $s \Omega_H$ ($s < 10$). The combination scattering (coalescence) of these waves with plasma waves excited in the hybrid band (near the frequency $\Omega_p \approx \Omega_p = = (4\pi e^2 N_0/m_e)^{1/2}$) gives rise to electromagnetic radiation recorded as zebra-pattern (the generation scheme by Rosenberg, 1972). The radio emission frequency may be represented as

$$\omega_r \approx \Omega_p + s \Omega_H.$$  \hspace{1cm} (2.2)

bearing in mind that the excited Bernstein mode frequency and the plasma wave frequency may essentially differ from $\Omega_H$ and $\Omega_p$ (in the value smaller or comparable with $\Omega_H$).

The minimum frequency of emission which escapes the local source and reaches the Earth is $\omega_{\text{min}} \approx \Omega_p$. The intervals between bands $\Delta \omega \approx \Omega_H$, the frequency band drift is caused by the temporal change in $\Omega_p$ or $\Omega_H$ (i.e. the coronal plasma density and the magnetic field intensity) in the generation region.

After the preliminary remarks have been made, we proceed to direct explanation of zebra-structure observed on 2 March 1970.

The appearance of almost continuous harmonic bands on the spectra in Figure II.1a (instead of well differentiated tadpoles in Figure II.1b) testifies to the fact that the energetic particle injection into the source was quasi-continuous. Some discontinuity turned to be sufficient for Slottje to make a conclusion on the genetic relation between zebra-pattern and tadpoles, the latters being the members of zebra-pattern.

* This equality as well as the formula (2.2) are given under the assumption that $\Omega_H \ll \Omega_p$. 

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