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Zebra spectral structures in Jovian decametric radio emissions

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Abstract

Jupiter with the largest planetary magnetosphere in the solar system emits intense coherent non-thermal radiation in a wide frequency range. This emission is a result of complicated interactions between the dynamic Jovian magnetosphere and energetic particles supplying free energy from planetary rotation and the interaction between Jupiter and the Galilean moon Io. Decametric radio emission (DAM) is the strongest component of Jovian radiation observed in a frequency range from a few MHz up to 40 MHz. Depending on the time scales the Jovian DAM exhibits different complex spectral structures.

Recent observations of the Jovian decametric radio emission using the large ground-based radio telescope URAN-2 (Poltava, Ukraine) enabled the detection of fine spectral structures, specifically zebra stripe-like patterns, never reported before in the Jovian decametric wavelength regime (Figure 1).

In this presentation we describe and analyse these new observations by investigating the characteristics of the Jovian decametric zebra patterns. On basis of these findings the possible mechanism of wave generation is discussed and in particular the value of the determination of local plasma densities within the Jovian magnetosphere by remote radio sensing is emphasized.

1. Analysis of observations of zebra patterns in Jovian decametric radio emission

The data used for the present study are from observations of the radio telescope URAN-2 (Poltava, Ukraine), one of the largest low frequency telescopes in Europe, operated in the decametric frequency range and equipped with high performance digital radio spectrometers. The antenna array of URAN-2 consists of 512 crossed dipoles with an effective area of 28000 m^2 and beam pattern size of 3.5 x 7 deg at 25 MHz [1]. The instrument enables continuous observations of the Jovian radio emission during long periods of time (depending on Jupiter visibility) with relatively high time-frequency resolution (4 kHz, 100 ms) in the broad frequency range (8-32 MHz). Using the large ground-based radio telescope URAN-2 49 events of stripe-like zebra patterns have been observed within the period September 2012 through March 2015 in the frequency range 15 – 25 MHz which correspond to potential radio sources at 0.25 – 0.05 R_J above the Jupiter 1 bar level [9]. The structure in the dynamic spectra is similar to those observed from the Sun [2, 3, 4] and suggests a similar generation mechanism, the Double Plasma Resonance (DPR).

A recent study reported on zebra pattern in low-frequency (tens of kHz) Jovian radio emission, observed by Cassini during the Jupiter flyby 2000/2001 (Kuznetsov et al. (2013) and references therein). On basis of the available URAN-2 observations of zebra patterns in the MHz-range detailed investigations are performed with the aim to fully characterize these stripe-like fine structures (Figure 1) under the following aspects:

a) Occurrence of zebra patterns in dependence of CML (Central Meridian Longitude of Jupiter) and Io phase

b) Frequency range of occurrence of zebra pattern within the observable range of 15 - 25 MHz

c) Modulation in frequency, frequency bandwidth of individual zebra pattern (f_{min}, f_{max})

d) Modulation length in time (duration of zebra pattern and “wavelength” of modulation)

e) Modulation depth in intensity

f) Splitting distance (Δf) between frequency-varying stripes

g) Determination of polarization (indication of Jovian hemispheric source location)

These investigations visualize some general characteristics or even categories of zebra patterns on which a current model scenario can be proven or even improved.

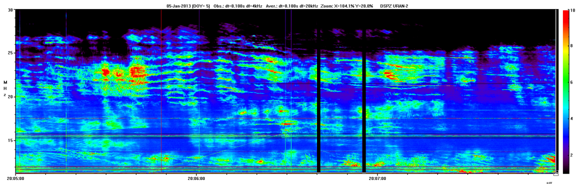

Figure 1: Dynamic spectrum of Jovian decametric radio emission observed on Jan 05, 2013, by the URAN-2 radio telescope (Poltava, Ukraine). Zebra stripe-like patterns occur in the frequency range between 20 MHz and 25 MHz.

2. Investigation of Double Plasma Resonance (DPR) and discussion of results

Stripe-like spectral structures or zebra patterns were first observed in the radio spectra of the Sun as quasi-harmonical stripes. The origin of this emission was suggested to be located in the magnetic loops containing energetic particles which produce the plasma waves generated close to the upper-hybrid frequency. The intensity of these waves is significantly higher in the regions where the local upper hybrid frequency equals the harmonics of the local gyrofrequency of the electrons. This mechanism is known as the Double Plasma Resonance (DPR) [6, 7, 10]. These plasma (upper hybrid) waves are transformed into electromagnetic radio waves due to nonlinear processes and can escape the solar magnetic loops. This theory of generation of the zebra patterns in solar radio spectra is well developed and fits the observations [4].
During its Jupiter flyby 2000/2001 Cassini RPWS (Radio and Plasma Wave Science experiment) registered complex striped spectral structures in the Jovian broad-band kilometric radiation at frequency ranges 30-70 kHz [5]. Recently Kuznetsov and Vlasov (2013) have shown that Cassini RPWS observations of modulated low radio frequencies (tens of kHz) are very similar to the zebra patterns detected in the solar radio spectra at decametric frequencies (tens of MHz). The DPR is supposed to occur in a weakly anisotropic magnetoplasma, where the plasma frequency f_p exceeds the cyclotron frequency f_c: $f_p \gg f_c$. The generation efficiency of the plasma waves is significantly high if their frequency (close to the upper hybrid frequency f_{uh}) is at the harmonics of the electron cyclotron frequency f_c: $f_{uh} \cong s * f_c$ with $s = 2, 3, 4 \ldots$ Based on these findings the investigations of the Jovian dynamic spectra in the decametric frequency range unprecedentedly enable the determination of local plasma density in the vicinity of Jupiter by remote radio sensing.

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