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Decametric modulation lanes as a probe for inner jovian magnetosphere

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ABSTRACT

We use the specific scintillations of jovian decametric radio sources (modulation lanes), which are produced by plasma inhomogeneities in the vicinity of that planet, to probe the inner magnetosphere of Jupiter. The positions and frequency drift of 1762 lanes have been measured on the DAM spectra from archives. A special 3D algorithm is used for space localization of field-aligned magnetospheric inhomogeneities by the frequency drift of modulation lanes. As a result, the main regions of the lane formation are found: the Io plasma torus; the magnetic shell of the Gossamer Ring at Thebe and Amalthea orbits; and the region above the magnetic anomaly in the northern magnetosphere. It is shown that modulation lanes reveal the depleted magnetic tubes in practically unvisited, innermost regions of the jovian magnetosphere. The local and probably temporal plasma enhancement is found at the magnetic shell of Thebe satellite. Hence, the modulation lanes are a valuable instrument for remote sensing of those parts of jovian magnetosphere, which are not studied yet in situ.

1. Introduction

Modulation lanes (MLs) are systems of quasi-periodic and quasi-parallel bands in dynamical spectra of jovian decametric emission (Fig. 1). Typically, these bands have a quasi-period of a few seconds and frequency drift of ~100 kHz/s. Already their discoverers, Riihimaa et al. (1970), interpreted the lanes as an interference fringelike modulation. Imai et al. (1992, 1997, 2002) have shown that most of the lanes are formed by radiation scattering on field-aligned inhomogeneities in the Io plasma torus.

Using a more correct algorithm for modeling, it was found that the frequency drift rate of a modulation lane could be used for space localization of the lane origin (Arkhipov, 2003). This approach allows detecting the formation of MLs outside the Io torus: at low altitudes above Jupiter (Arkhipov, 2004) and at the magnetic shell of the satellite Amalthea (Arkhipov, 2006; Arkhypov and Rucker, 2007). However, these results are based on a limited set of experimental data.

The interior parts of inner jovian magnetosphere are poorly studied. Only Pioneer-11 and Galileo orbiter space missions episodically measured the plasma parameters at the minimal planetocentric distances of $r = 1.48R_J$ and $2.33R_J$ respectively, where $R_J = 71{,}492$ km is the Jupiter's equatorial radius. However, the electron density profile is known only at $r > 4R_J$ (Richards and Gurnett, 2003). The jovian magnetosphere at $r < 4R_J$ includes 4 satellites, 4 rings, radiation belt and decametric radio sources. It seems the promising field for application of ML location method.

That is why this paper is a revision of the modulation lane problem using the high-sensitive records of MLs from the UTR-2 data archive. We explain our method and the data set in Section 2. Section 3 presents the results of our cluster analysis of ML parameters to localize the main regions of ML formation. To determine the nature of the magnetosphere inhomogeneities, which form MLs, we model and analyze the lanes as an interference pattern in Section 4. The results are discussed in the context of data from space missions (Section 5). The conclusions are summarized in Section 6.

2. The method and data

We employ the widely accepted standard model for the production of Io-related decametric emissions (e.g., Imai et al., 1997; Zarka, 1998; Treumann, 2006). The radio emission is generated on the source magnetic line (SML), which is disturbed by the Io satellite (Fig. 2). Practically Io stimulates emission with some time-delay (Goertz, 1980; Neubauer, 1980). Accordingly, the Io's orbital longitude increases on the lead angle $\Delta\lambda_{Io}$ in the frame of jovian magnetic field during this delay (Hashimoto and Goldstein, 1983). Therefore, SML intersects the Io's orbit in the point with longitude of $\lambda_{Io} - \Delta\lambda_{Io}$. The frequency f of each component of the emitted band is approximately equal to the local electron cyclotron frequency at the point of the active line in which it was emitted.

The inner magnetosphere co-rotates with jovian magnetic field. The plasma inhomogeneities exist there in form of thin (~100 km) magnetic tubes with rarefied plasma inside (Russel et al., 2005).

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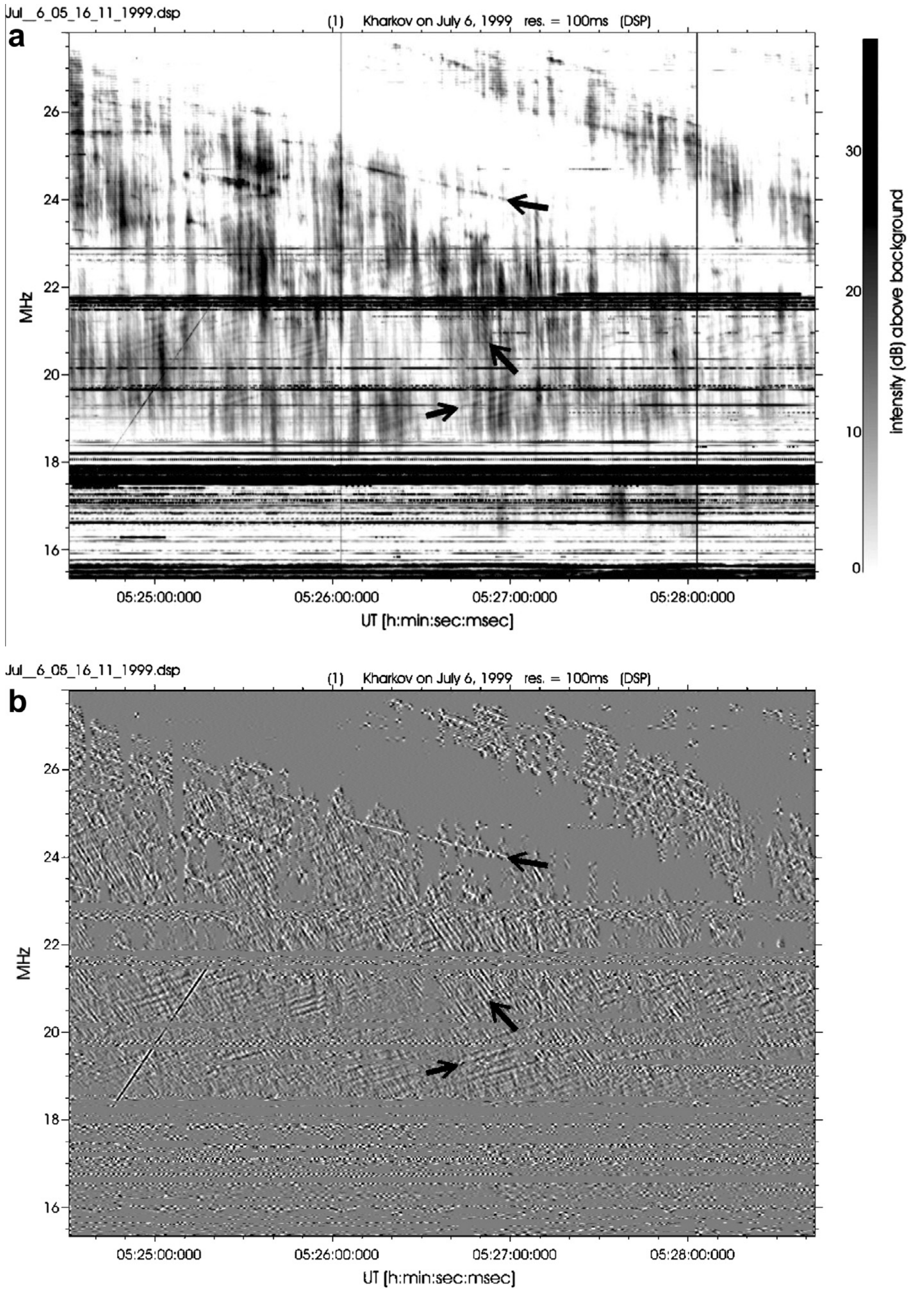

Fig. 1. The example of jovian decametric emission shows 3 types of modulation lanes with different frequency drift rates (arrowed): (a) the original spectrum of Io-A storm (July 6, 1999, UTR-2 decametric array) and (b) the visualization of modulation lanes on the same spectrum using the Photoshop's Emboss filter.

For a terrestrial observer, such tube can be approximated as its axial magnetic-field line. This field-aligned inhomogeneity magnetic line (IML) moves on the background of source magnetic line (SML; Fig. 2). The IML (e.g., the depleted tube) as a lens modifies the radiation flux from the compact region of SML, which is in occultation behind IML. For example, in the time t_1 the Earth-based observer sees the IML occult the SML in the place, where the radio emission is generated at the SML near the local electron gyrofrequency f_1. For time t_2, the occultation point corresponds to another radiation frequency f_2. As a result, the drifting modulation lane is formed in the dynamical spectrum of radio emission.

Our base algorithm DRIFT (Arkhipov, 2003) numerically tracks the magnetic lines using the VIP4 model of inner magnetic field of Jupiter (Connerney et al., 1998). It searches for the point, where IML is projected to the SML. The frequency of emission at this point could be found as the local gyrofrequency of electrons. Such frequency approximations f_1 and f_2 for different times ($t_1 = t - \Delta t/2$; $t_2 = t + \Delta t/2$) lead to the lane drift estimation: $df/dt = (f_2 - f_1)/\Delta t$. The celestial mechanic formulae (Meeus, 1982) are integrated in the algorithm DRIFT to calculate geometrical parameters for any time. Technical details can be found in the previous publications (Arkhipov, 2003; Arkhipov, 2004).

The equality of calculated df/dt and observed drift can be achieved by variations of: (a) the lead angle $\Delta\lambda_{Io}$, if the magnetic shell of IML is known (OPER algorithm); (b) the source-inhomogeneity distance d along the Earth direction, if $\Delta\lambda_{Io}$ is estimated (DL algorithm).

First we calibrate the method using approach (a) above. The most effective lane forming must occur near Io's orbit with a mean radius of $5.91R_J$, where the satellite's volcanoes give the maximal