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Periodic bursts of Jovian non-Io decametric radio emission

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ABSTRACT

During the years 2000–2011 the radio instruments onboard Cassini, Wind and STEREO spacecraft have recorded a large amount of the Jovian decametric radio emission (DAM). In this paper we report on the analysis of the new type of Jovian periodic radio bursts recently revealed in the decametric frequency range. These bursts, which are non-Io component of DAM, are characterized by a strong periodic reoccurrence over several Jovian days with a period $\approx 1.5\%$ longer than the rotation rate of the planet's magnetosphere (System III). The bursts are typically observed between 4 and 12 MHz and their occurrence probability has been found to be significantly higher in the sector of Jovian Central Meridian Longitude between 300° and 60° (via 360°). The stereoscopic multispacecraft observations have shown that the radio sources of the periodic bursts radiate in a non-axisymmetric hollow cone-like pattern and sub-corotate with Jupiter remaining active during several planet's rotations. The occurrence of the periodic non-Io DAM bursts is strongly correlated with pulses of the solar wind ram pressure at Jupiter. Moreover the periodic bursts exhibit a tendency to occur in groups every ~ 25 days. The polarization measurements have shown that the periodic bursts are right hand polarized radio emission associated with the Northern magnetic hemisphere of Jupiter. We suggest that periodic non-Io DAM bursts may be connected with the interchange instability in Io plasma torus triggered by the solar wind.

1. Introduction

Jupiter has the largest planetary magnetosphere in the solar system and emits radio emission in a wide frequency range. The non-thermal auroral radiation is a product of complex interaction between the dynamic Jovian magnetosphere and energetic particles originated mainly from the internal plasma sources. As such, the auroral radio emission is a valuable tool to survey the energy dissipation in the auroral zones as well as to monitor the global magnetospheric activity.

Decametric radio emission (DAM), the strongest component of Jovian auroral radiation, was discovered more than 50 years ago by Burke and Franklin (1955). DAM is observed in a form of arc shaped radio bursts (in time–frequency domain on timescale of minutes) in a frequency range from few MHz up to 40 MHz (Carr et al., 1983; Zarka, 1998). This emission is thought to be generated by the accelerated electrons characterized by an unstable distribution function via the electron cyclotron maser instability (Wu and Lee, 1979). The hectometric component of Jovian radio emission (HOM) observed below a few MHz can be also interpreted as a low-frequency extension of the DAM (e.g. Lecacheux et al., 1980). Two types of DAM are distinguished: (1) Io controlled component of DAM (Io-DAM), which occurrence is well organized into longitudinal systems related with the Io orbital position (period 42.46 h), is a product of electrodynamic interaction between Jupiter and its moon Io (Crary and Bagenal, 1997; Saur et al., 2004), and (2) Io independent DAM (non-Io DAM) driven by the precipitating electrons accelerated by field-aligned currents caused, most probably, due to the breakdown of rigid corotation of the magnetosphere (Cowley et al., 2003) or reconnection in the magnetotail and the magnetopause. The last component, i.e. non-Io DAM, is the subject of our study.

As a magnetospheric phenomenon, most of the Jovian radio emissions are strongly modulated by the rotation of the non-axisymmetric Jovian magnetic field (System III period, 9.9249 h), as well as by the Io plasma torus (System IV period, ~ 10.224) or controlled by the Io orbital position with respect to the active longitudes of the Jovian magnetic field (Kaiser, 1993). Generally, non-Io DAM is a highly variable and sporadic radio emission which appears in a form of arcs in time–frequency coordinates and modulated by the rotation of the Jovian magnetosphere. Recently, Panchenko et al. (2010) and Panchenko and Rucker (2011) have reported findings of the new type of Io independent radio bursts of DAM—periodic non-Io DAM burst. This emission is observed in the decametric frequency range (typically 5–12 MHz) in the form of arc-like radio bursts. These new non-Io bursts are

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distinguished from other non-Io DAM by the following: (1) have a very regular periodicity that is a few percent longer than the Jovian System III rotation rate and (2) are found to occur in episodes that last only a few days in association with times of enhanced solar wind pressure.

This paper is a summary of all our findings regarding the new type of periodic non-Io DAM radio burst. On the basis of more than 10 years of observation performed by STEREO/WAVES, Wind/WAVES and Cassini/RPWS radio instruments we have investigated the main properties of these radio bursts, such as the periodicity, the dependence on the active Jovian magnetic longitudes, characteristics of the radio sources and their radiation pattern as well as solar wind control. Moreover, we discuss the interchange instability in the Io plasma torus as a possible mechanism of generation of the periodic bursts. It is important to note, that the quasi periodic QP bursts named also "Jovian Type III bursts" (see e.g. Kurth et al., 1989) are not subject of this study.

2. Observations

Several spacecraft are able to detect Jovian decametric radio emission. Our data set consists of observations acquired by the Cassini, Wind and STEREO spacecraft in the frequency range from below 1 MHz to ~ 16 MHz. In particular, we have used the data recorded by the WAVES experiment onboard Wind spacecraft—a mission which was launched on November 1, 1994 as part of the International Solar-Terrestrial Physics (ISTP) program (Bougeret et al., 1995). From 2001 to 2011 Wind was positioned mainly in a sunward location near the Lagrangian point L1 of Earth. Wind/WAVES instruments covers the frequency range from a few Hz up to ~ 14 MHz.

Our analysis also uses the data from the Radio and Plasma Wave Science (RPWS) instrument (Gurnett et al., 2004) operated in a frequency range up to 16 MHz onboard the Cassini/Huygens mission, launched on October 15, 1997. We have analyzed the observations recorded in the years 2000–2003, when Cassini flew by Jupiter (the closest approach was on December 30, 2000) and was able to detect relatively weaker radio bursts of the DAM which are inaccessible for observation by the Earth orbiting spacecraft.

The other source of the radio data which have been examined in our study is the WAVES experiment onboard two STEREO spacecraft (Bougeret et al., 2008). STEREO (Solar TErrestrial RElations Observatory) consists of two nearly identical 3-axis-stabilized spacecraft (STEREO-A and STEREO-B), launched on October 25, 2006 into heliocentric orbits with one spacecraft ahead and another behind the Earth in its orbit. The STEREO/WAVES covers the frequency range up to 16 MHz. The special interest represents simultaneously stereoscopic observation of the Jovian DAM by the two STEREO spacecraft located at different Jovicentric longitudes. In contrast to the observations from a single point, the stereoscopic measurements facilitate unambiguous recognition of the Jovian decametric radio emission in the observed dynamic spectra as well as identification of its components. Using the fact that Jovian radio emission is emitted in a hollow cone attached to the Jovian magnetic field or to the Io flux tube and the known rotation rate of Jovian magnetosphere (9.925 h) or Io's orbital period (42.46 h) as well as distances between Jupiter and each of the spacecraft the DAM emission can be identified by means of the time difference between sequential detection of the radio emission from the same radio source by the two spacecraft separated in space. In particular, this time delay consists of the light travel time difference between a radio source and an observer and the time interval which is necessary to rotate the radio beam by the angular separation (as seen from Jupiter) between the two spacecraft (see Panchenko et al., 2010). Therefore, the stereoscopic observations allow to (1) separate Jovian arc-like radio emission from the solar radio bursts and (2) unambiguously distinguish between Io and non-Io controlled component of DAM.

In addition to the above radio instruments we have also used the Ulysses/URAP and Ulysses/SWOOPS instruments onboard Ulysses spacecraft launched in October 1990. Ulysses/URAP (Ulysses Unified Radio and Plasma Wave Experiment) is a radio receiver which operates in a frequency range from 1.25 to 940 kHz (Stone et al., 1992). Solar Wind Observations Over the Poles of the Sun experiment, Ulysses/SWOOPS, investigates the solar wind plasma (Bame et al., 1992). In our study we examined Ulysses/URAP and Ulysses/SWOOPS observations acquired during the Ulysses second flyby at Jupiter (in the year 2004).

3. Observations and properties of DAM periodic bursts

As was mentioned in the previous section, we have examined the data recorded in the decametric frequency range by the Cassini/RPWS, Wind/Waves and STEREO/WAVES. By means of the visual inspection of the dynamic radio spectra we have found intense radio bursts in the decametric frequency range from $\sim 4-5$ MHz up to 12–16 MHz (16 MHz is the higher frequency limit of the Cassini/RPWS and STEREO/WAVES). These bursts recurred very periodically during several Jupiter rotations (the examples are shown in Fig. 1). The duration of each periodic burst at the same frequency was several minutes.

In total, 107 episodes of periodic bursts (or 492 individual bursts) have been detected between October 2000 and August 2011. One episode means continuous repetition of the periodic structures in the dynamic spectra. In particular, the Cassini/RPWS observed 36 episodes (185 bursts) during the period of time between October 2000 and December 2003, Wind/WAVES detected 24 episodes (95 bursts) during January 2004 to December 2006, and 47 episodes (212 individual bursts) have been found in STEREO/WAVES radio spectra during January 2007 to August 2011.

Out of the stereoscopic observations performed by the pair of STEREO/WAVES spacecraft the detected periodic decametric radio bursts have been classified as the non-Io controlled component of DAM. In particular the measured time difference (after correction on signal travel time difference) between sequentially detection of the same radio bursts onboard STEREO-A and STEREO-B spacecraft corresponds to the time required for the Jupiter magnetosphere to rotate through the angular spacecraft separation.

Almost all detected periodic bursts have very similar spectral features: 'burst-like' structures with small negative frequency drift in the time–frequency coordinates, similar to the vertex late arcs of non-Io DAM (Queinnec and Zarka, 1998). Such type of bursts has been observed in 96 episodes out of all 107 episodes with periodic bursts. In this study we have analyzed only this most observed group of the bursts—i.e. periodic radio bursts with negative frequency drift. As seen in Fig. 1, the periodic radio features were observed as single bursts (Fig. 1c, e, f), multiple bursts (Fig. 1a, d), or more complex periodic structures consisting of the single and multiple bursts (Fig. 1b). On average, each episode consists of 4–5 bursts.

Besides that, we have also found 11 episodes with periodic radio bursts with positive frequency drift as well as broad non-arcs periodic radio features. These more rare observations are discussed in Section 3.5.