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North/South flux ratio of Saturn kilometric radiation

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Abstract

It is well–known that Saturn kilometric radiation (SKR) has two periods varying with time; one is attributed to the northern hemisphere, and the other to the southern hemisphere [1]. The hemispherical origin of SKR can be clearly identified by its polarization, measured with the Cassini RPWS instrument. SKR predominantely emits X-mode radiation, which is right–handed polarized coming from the north (N), and left–handed polarized from the south (S) [2]. In this way one can gain frequency–integrated N–SKR fluxes and S–SKR fluxes (unit of W/m^2). The SKR periods can be found by a periodicity analysis using the integrated SKR flux, which can be averaged over certain time intervals. To show the typical 10.7 h periodicity close to Saturn's rotation period, a frequency–integrated SKR flux with a resolution (averaging interval) of 10 minutes is used. The integrated SKR flux also shows a 25–27 day periodicity due to the rotation of the Sun, and in this case it is sufficient to use SKR fluxes averaged over one day. The N and S–SKR intensities highly depend on the latitude of the observer, and so we determined orbital averages of SKR fluxes in a restricted latitude interval within 5 degrees around the equatorial plane. From this we determined the North/South (N/S) SKR flux ratio from 2004 until the end of 2016, to see which hemisphere is dominating the SKR emission. We see a clear southern dominance until mid-2007, an oscillation around a ratio of 1 from mid-2007 until mid-2012, and a switch to northern dominance after mid-2012. This behavior is thought to be caused by the changing season at Saturn, and the summer hemisphere is the dominant one. Interestingly, the N/S SKR flux ratio also shows an oscillation of around 200 days, which could be related to external influence from the Sun or to an oscillatory energy exchange between two weakly coupled oscillators.

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Refurbishing Voyager/PRA data

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Abstract

Voyager/PRA (Planetary Radio Astronomy) data from digitized tapes archived at CNES have been reprocessed and recalibrated. The data covers the Jupiter and Saturn flybys of both Voyager probes. We have also reconstructed goniopolarimetric datasets (flux and polarization) at full resolution. These datasets are currently not available to the scientific community, but they are of primary interest for the analysis of the Cassini data at Saturn, and the Juno data at Jupiter, as well as for the preparation of the JUICE mission. We present the first results derived from the re-analysis of this dataset.

1. Introduction

The Planetary Radio Astronomy (PRA) experiment [6] onboard the Voyager 1 and 2 spacecraft were the first radio instruments to explore the low frequency radio emissions of the giant planets. The PRA experiment is observing radio waves up to 40.5 MHz, and is capable of measuring the sense of circular polarization of the observed radio waves.

The Voyager 1 spacecraft approached Jupiter in March 1979 and Saturn in November 1980. The Voyager 2 spacecraft approached Jupiter in July 1979, Saturn in August 1981, Uranus in January 1986 and Neptune in August 1989. During each planetary flyby intense radio emissions of auroral origin were observed [7, 8, 9, 10, 11, 12]. The Jovian radio emissions reaches 40 MHz, as discovered from ground [1], whereas all other giant planets are showing radio emission up to $\sim$1 MHz, as in the case of terrestrial auroral radio emissions [15]. Atmospheric radio flashes (lightning electrostatic discharges) were also observed at Saturn, Uranus and Neptune [13, 14].

The PRA data were analyzed by the Voyager 1 and 2 team and were partly archived at the NASA/PDS (Planetary Data System) PPI node (Planetary Plasma Interactions). Two PRA datasets are available in the archive: the full resolution Low Frequency band (LF) data[1] covering 1.2 kHz to 1.3 MHz, and 48 s average spectra High Frequency band (HF) data[2] covering 1.2 MHz to 40.5 MHz.

While managing "orphaned" datasets in its repository, the CNES long term archive service (SERAD, *Service de Référencement et d'Archivage des Données*, Data Referencing and Archiving Service) identified a series of digitized Voyager PRA magnetic tape dumps. This paper described the refurbishment of this dataset.

2 Datasets and Access

The refurbished Voyager PRA full resolution data collection is composed of 5 datasets: Level 1 dataset (temporally sorted DEDR scans re-dispatched into daily files and operating modes); Level 2 dataset (daily files of "POLLO" mode DEDR individual records); Level 3f dataset (daily files of flux and polarization derived from "POLLO" mode DEDR Level 2 data, using L3f inversion); Level 3t dataset (daily files of flux and polarization derived from "POLLO" mode DEDR Level 2 data, using L3t inversion); Ephemeris dataset (daily files of planetary ephemeris, one file per planet, in the spacecraft frame); Summary plot dataset.

Since this work is still in progress, data are not publicly available yet. The data collection will be available from the MASER (Measurement, Analysis and Simulations of Emission in the Radio range) service[3] at Observatoire de Paris. Direct access to data for download will be available at: `http://`

[1] `VG1-J-PRA-3-RDR-LOWBAND-6SEC-V1.0` and `VG2-J-PRA-3-RDR-LOWBAND-6SEC-V1.0`: Voyager 1 and 2 PRA data during the Jupiter flyby dataset, available at NASA/PDS-PPI.

[2] `VG1-J-PRA-4-SUMM-BROWSE-48SEC-V1.0` and `VG2-J-PRA-4-SUMM-BROWSE-48SEC-V1.0`: Voyager 1 and 2 PRA data during the Jupiter flyby dataset, available at NASA/PDS-PPI.

[3] MASER web site: `http://maser.lesia.obspm.fr`

maser.obspm.fr/data/voyager/pra. Final data products will be prepared in CDF (Common Data Format), so that common tools (like Autoplot [3]) can handle the data easily. The data products are also available from the VESPA [2] query portal (http://vespa.obspm.fr).

3 Discussion

The reprocessing of the Voyager PRA data will provide the community with a unique dataset. The preliminary data samples presented in this paper are clearly showing that the reanalysis of this dataset will be very interesting, especially in light of the discoveries done by the Galileo, Cassini and Juno spacecraft at Jupiter and Saturn. At Jupiter, we will search for the galilean moon's modulated radio emissions, including the study of the polarization of the corresponding radio bursts [5]. At Saturn, the high temporal resolution measurements with polarization will provide crucial clues and new ideas on the still unexplained rotational modulations of the kronian system [4].

4 Acknowledgments

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Synchronous observations of Jupiter decameter radio emission at radio telescopes UTR-2, URAN, GURT with the spacecraft Juno

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Abstract

The paper is devoted to the description of multi-antenna observations on radio telescopes UTR-2 URAN and GURT [1] within the framework of ground support for the Juno space mission. Parameters and some results of observations are given. Time and frequency binding allows to use all the data obtained in a joint processing with the data of the radio receiver of the spectrometer, which is installed on the spacecraft, and simultaneously with other ground-based low-frequency radio telescopes.

1. Introduction

Jupiter radio emission investigations [2] are carried out more than 60 years. But the beginning of the Juno mission launched the integration of all terrestrial telescopes that support space mission (radio, infrared, ultraviolet at the spacecraft, etc.) into a single network to study in the most detail the mechanisms giving rise the Jupiter emission and its satellites and other physical phenomena in the Jupiter ionosphere and magnetosphere. All aspects of spacecraft closest approach to Jupiter (perijove - PJ) and overflight above polar regions are used by ground-based radio and optical telescopes for simultaneous observations with a variety of scientific spacecraft instruments (optical and infrared cameras, low-frequency receivers, particle detectors, etc.). At low frequencies that are accessible for terrestrial observations (8-40 MHz), providing ground support by European radio telescopes NDA, NenuFAR (France), UTR-2, URAN, GURT (Ukraine), LWA1, OLWA (USA), Iitate and Zao instruments of Tohoku University (Japan), etc. which permit to continuous tracking of Jupiter, regardless of time of day. In addition, low-frequency observations at many spaced telescopes provide much better results with a view to overcome the negative effects of local interference and irregularities of the Earth's ionosphere.

2. Observations

Multi-antenna observations at radio telescopes UTR-2, URAN and GURT in the framework of ground support of the Juno mission are conducted under an extensive program, taking into account the presence of S-bursts of Io-controlled emission or L-radiation, effective area of radio telescopes and effective area of a specific radio telescope. Since the closest approach of the spacecraft with the planet is of the greatest interest, the observations are concentrated in the period of ~ 24 hours before and after PJ. However, to obtain a sufficiently uniform and extensive set of observations, some of them are conducted independently from the Juno position. The larger effective area of the radio telescope, the higher time resolution specified. For example, to record L-bursts at the UTR-2 radio telescope, a time resolution of 5 ms is used and Δt =15 ns is used for recording S-bursts. The recording parameters for all Ukrainian radio telescopes participating in the program are given in Table 1. The duration of a single observation session was 6-8 hours.

Table 1: This is the example of an included table

Telescope	Effective area, m^2	Range, MHz	Time res., ms low/high
UTR-2	140 000	8-32	5/0.00015
URAN-2	28 000	8-32	10/1
URAN-3	14 000	8-32	10
GURT	1 000	8-50*	10

* Full band of GURT is 8-80 MHz.

3. Results

In the framework of the ground support program of the Juno space mission, more than 10 observation sessions were conducted. Of greatest interest were observations of S-bursts that occurred at a time close to PJ. Such data allow us to hope for a detailed comparison of the observations of the spectrometer WAVES on board of the spacecraft and other ground-based radio telescopes. Figure 1 shows an example of a recorded storm using the URAN-2 radio polarimeter.

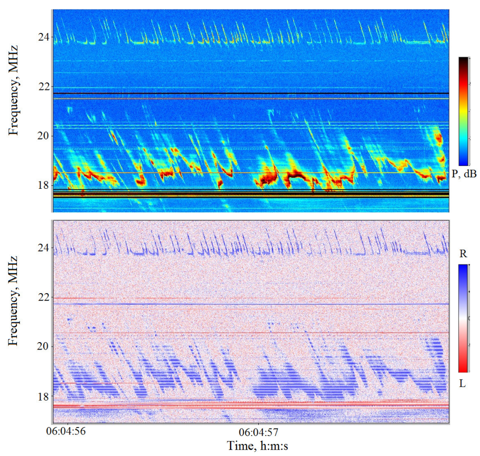

Figure 1: Observations of Io-controlled emission at URAN-2 Dec 12, 2016 (UTC) with a time resolution of 1 ms.

It is very important that the high spatial selectivity of large radio telescopes such as UTR-2 and URAN-2 allows one to obtain recordings with a minimal amount of RFI of artificial and natural origin coming at low angles to the horizon through the side lobes. Such example (a fragment of the recording of the radio emission from Jupiter on the radio telescope UTR-2) is shown in Figure 2. It is interesting that some bursts resemble S-bursts, although the probability of their occurrence was rather low. These and other types of radiation [3] require a detailed further study.

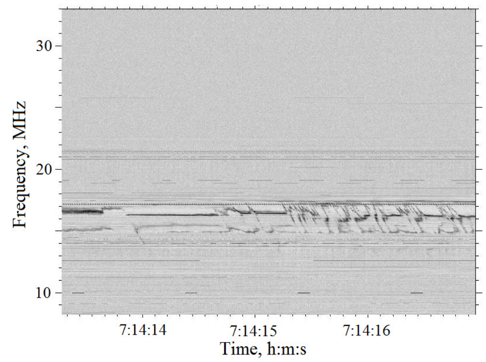

Figure 2: Observations at UTR-2 Oct 19, 2016 (UTC, $\Delta t = 5$ ms).

4. Summary and perspectives

The spacecraft Juno and regular synchronous observations within the framework of ground support of the mission with the help of terrestrial radio telescopes will provide new extremely valuable scientific results on the mechanisms of the formation of radio emission from Jupiter, as well as planets and exoplanets with a strong magnetic field.

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Variations of Synchrotron Radio Emissions from Jupiter's Inner Radiation Belt

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We describe the basic phenommenology of quasi-periodic 40 minute (QP-40) polar burst activities of Jupiter and their close correlation with the solar wind speed variations at the Jovian magnetosphere.

Physically, relativistic electrons of QP-40 bursts most likely come from the circumpolar regions of the inner radiation belt (IRB) which gives off intense synchroton radio emissions in a wide wavelength range.

Such relativistic electron bursts also give rise to beamed low-frequency radio bursts along polar magnetic field lines with distinct polarizations from Jupiter's two polar regions.

Jovian aurora activities are expected to be also affected by such QP-40 burst activities.

We present evidence of short-term (typical timescales shorter than an hour) variabilities of the IRB at 6cm wavelength and describe recent joint radio telescope observation campaign to monitor Jupiter in coordination with JUNO spacecraft.

Except for low-frequency polarization features, we anticipate JUNO to detect QP-40 activities from both polar regions during the arrival of high-speed solar wind with intermittency.

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Addressing the steady and dynamical states of Jupiter's synchrotron radiation from 3D image reconstructions

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Abstract

The tomographic-like technique introduced twenty years ago by Sault et al. [Astron. Astrophys., 324, 1190-1196, 1997] permitted the first 3-dimensional mapping of Jupiter's synchrotron radiation brightness distributions around the planet. This technique has proven to be very valuable for refining Jupiter's planetary magnetic field models or examining the temporal and spatial changes of its synchrotron radiation. We here present our modeling effort to improve 3D image reconstruction techniques and address isotropy assumptions made in the early reconstruction methods. We discuss our image reconstruction results for different bands and observation periods in order to investigate, in the near future, the parameters that control the time and spatial variability of Jupiter's synchrotron emission that occurs on short time scales during observations. We discuss how our 3D tomographic reconstruction method (1) provides new model constraints on the energy and spatial distributions of Jupiter's ultra-relativistic electrons close to the planet and (2) can be used to interpret Juno MWR observations of Jupiter's electron-belt emission and assist in evaluating the background noise from the radiation environment in the atmospheric measurements.

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Radio and plasma wave observations during Cassini's Grand Finale

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Abstract

Cassini has commenced its high inclination Grand Finale orbits with perikrones falling between the inner edge of the D ring and the upper limits of Saturn's atmosphere. The Cassini Radio and Plasma Wave Science (RPWS) instrument makes a variety of observations in these unique orbits including Saturn kilometric radiation, plasma waves such as auroral hiss associated with Saturn's auroras, dust via impacts with Cassini, and the upper reaches of Saturn's ionosphere. This paper will provide an overview of the RPWS results from this new and final phase of the Cassini mission with the unique opportunities afforded by the orbit. Based on just the first passage of Cassini, we can already say that the spacecraft has passed through cyclotron maser source regions of the Saturn kilometric radiation, found only small amounts of dust in the micron size range in the equatorial region, and observed plasma densities of order 1000 cm^{-3} in the ionosphere at altitudes of a few thousand km.

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Decameter type IV burst associated with behind-limb CME observed on November 7, 2013

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Abstract

We report the results of observations of type IV burst in the frequency range 22-33 MHz, which is associated with the CME initiated by behind-limb active region (-150° E). This burst was observed also by the radio telescope NDA in the frequency band 30-60 MHz. CME's core was situated at the distance about $3R_s$ at the moment, when type IV burst registered at frequencies 22-60 MHz. We conclude that the radio emission escape from the center of CME's core at frequency 60 MHz and comes from the periphery of the core at frequency 30 MHz due to occultation by the solar corona at corresponding frequencies. We find densities in these regions supposing plasma mechanism of radio emission. We show that the frequency drift of the leading edge of type IV burst is governed by expansion of CME's core.

1. Introduction

Type IV bursts were distinguished in the separate class of bursts by Boischot in 1957 [1]. There are stationary and moving type IV bursts [3]. They consider that high coronal arches are responsible for the former and CMEs are in charge of the latter. At present, the plasma mechanism seems to be the mechanism of type IV bursts. Places of radiations of stationary type IV bursts are coronal arches but from what regions radio emissions of moving type IV bursts escape do not understand. In most cases, observed type IV bursts are connected with active regions, which are on the visible solar disk [2].

Type IV burst, which was observed by STEREO A and B on November 7, 2013, was associated with behind-limb CME [2]. We report about observations of this burst by the radio telescopes URAN-2 and NDA at frequencies 22-60 MHz and discuss the places of CME from which radio emission escapes.

2. Observations

The dynamic spectrum of type IV burst registered by URAN-2 from 10:22 UT to 10:44 UT in the frequency band 22-33 MHz is shown in the Fig.1a.

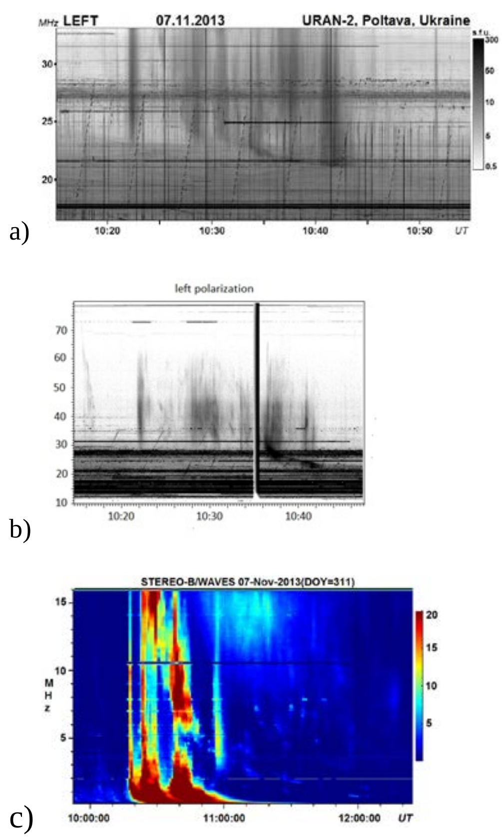

Figure 1: Type IV burst observed by URAN-2 (a), NDA (b) and STEREO B (c) on November 7, 2013.

The radio telescope NDA was also observed this burst at frequencies 30-60 MHz (Fig.1b). A little later, at 10:50-11:30 UT, this burst was observed by STEREO B at lower frequencies, 11-16 MHz (Fig.1c). It says that this type IV burst was moving but not stationary one (compare with [2]). This conclusion is confirmed by the fact that the forehand of the burst drifted in both frequency bands 22-33 MHz and 11-16 MHz. Their drift rates were 30 kHz/s and 8 kHz/s correspondingly.

3. Discussion

Radio emission of behind-limb type IV burst was occulted by the coronal plasma and therefore this radio emission at 30 and 60 MHz could be observed from the regions, which were situated to the left to dashed and solid lines in the Fig.2. In this Figure the CME's core, the Sun and the Earth are shown at

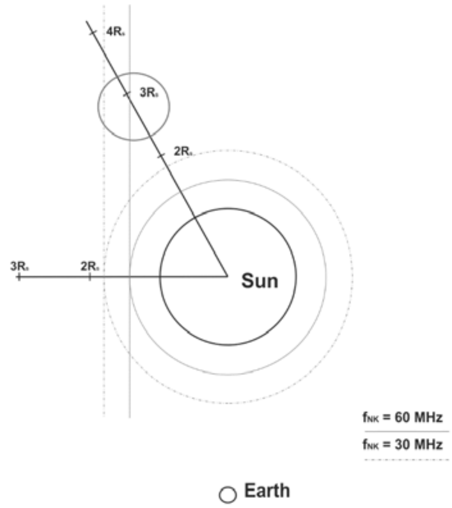

Figure 2. Schematic positions of CME's core, the Sun and the Earth at 10:22 UT, when type IV radio emission occurred at frequencies from 30 to 60 MHz.

10:22 UT, when radio emission of type IV burst began to observe by both radio telescopes NDA and URAN-2 at first. We see that radio emission at 30 MHz escapes from periphery regions of CME's core. So the density $1.3 \cdot 10^7 cm^{-3}$ needed for radio emission at this frequency according to plasma mechanism exists here. It is reasonable to suppose that in the center of the core the plasma density achieves the value of $4.5 \cdot 10^7 cm^{-3}$ providing radio emission at 60 MHz. If this is a case and assuming exponential distribution of the density $n(r) \propto \exp(-\alpha r)$ (where r is the distance from the centre of the core) in the CME's core, we can find that mass of the core equal approximately $\approx 10^{16} g$. This is close to the estimated CME mass (https://cdaw.gsfc.nasa.gov/CME_list/UNIVERSAL/2013_11/univ2013_11.html). The periphery density decreases as $n \propto 1/R^2$ with time according to conservation of core's mass at its inflation. The core keeps the form by magnetic field with the strength $6 \cdot 10^{-2} G$ at the temperature of the core plasma $10^5 K$ and $0.2G$ at temperature $10^6 K$. According to SOHO data, the speed of core inflation is about 400 km/s. If the frequency drift rate of type IV forehand is governed by the speed of inflation then we find the frequency rate in accord with the equation

$$df / dt = f / 2 \cdot dn / ndr \cdot dr / dt \qquad (1)$$

The obtained frequency drift rate for the frequency range 22-33 MHz equals to about 30 kHz/s that is in good correspondence with the observed value.

Thus, we conclude the radio emission of type IV burst really radiated by CME's core. Its density is larger significantly the density of surrounding coronal plasma. The inflation of core is responsible for the observed frequency drift rate. Needed mass of the CME's core is enough for that.

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Rotational modulation of Saturn radio emissions during Cassini's Grand Finale

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Abstract

Despite of the close axial symmetry of Saturn's internal field, modulation periods close to 10.7 hours are observed in all three Saturn radio emissions, Saturn kilometric radiation (SKR), narrowband emission, and auroral hiss. Furthermore, the modulation periods of these emissions have been found to consist of two components, one associated with each hemisphere. The two components show seasonal variation and cross each other after equinoxes. The hemispheric asymmetry arises from different solar illuminations in two polar regions, which leads to different ionosphere conductivities that determine the relative strength of the rotating field-aligned currents in two hemispheres. SKR and auroral hiss are known to be generated by the upward and downward field aligned currents, respectively. In 2016, Cassini shifted to high inclination orbits, providing good opportunities to observe all three radio emissions in both hemispheres. We will show that north hemisphere emissions have become dominant and their modulation rates have slowed to the level of their southern counterparts before equinox. The phase relation between three radio emissions and the local time dependence of their intensities will also be discussed. The Cassini's grand finale orbits would allow in-situ observations of the sources of the radio emissions as well as the field-aligned currents in both hemispheres, which would help confirm the seasonal control theory by showing the hemispherical asymmetry in source strength near the northern summer solstice.