EPN2020-RI

EUROPLANET2020 Research Infrastructure

H2020-INFRAIA-2014-2015

Grant agreement no: 654208

Deliverable D11.11 - Workflow studies: Magnetospheres science and support to ESA/JUICE mission planning

Due date of deliverable: 31/01/2019
Actual submission date: 30/01/2019

Start date of project: 01 September 2015

Duration: 48 months

Responsible WP Leader: Observatoire de Paris, Stephane Erard

Project funded by the *European Union's Horizon 2020 research and innovation programme*		
Dissemination level		
PU	Public	☐
PP	Restricted to other programme participants (including the Commission Service)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (excluding the Commission Services)	

Project Number	654208
Project Title	EPN2020 - RI
Project Duration	48 months: 01 September 2015 – 31 August 2019

Deliverable Number	D11.11
Contractual Delivery date	31/01/2019
Actual delivery date	30/01/2019
Title of Deliverable	Workflow studies: Magnetospheres science and support to ESA/JUICE mission planning
Contributing Work package (s)	WP11
Dissemination level	PU
Author (s)	Baptiste Cecconi

Abstract: We present the developments and dataset releases in the magnetospheric science topic that are used for prototyping workflow studies. The case of the observation planning and science mode assessment in the frame of the JUICE mission is described. This case shows how Jovian radio emissions observations and simulations are used by the JUICE science and operation teams. Developments using the EOSC infrastructure are also envisaged in the near future.

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Introduction

The JUICE (Jupiter Icy Moon Explorer) is the first L-class ESA space mission of the Cosmic Vision programme. After a launch planned for 2022, and a seven years journey with several gravitational assist planetary flybys, the spacecraft will arrive at Jupiter in 2029, for a four year primary mission dedicated to Jupiter and its Galilean moons Europa, Ganymede and Callisto. Among the many science objectives of the mission, we focus here on low frequency radio related ones: the observation of the Jovian natural radio emissions, linked to the magnetospheric activity and emitted close to the magnetic poles of Jupiter; and the subsurface radar sounding of the icy moons of Jupiter. The VESPA team has set up a series of tools and databases that supports the preparation of the space mission, the validation of the instrument capabilities, and the preliminary orbital planning and science sequencing. We describe in this report the datasets that have been prepared and put online, as well as the tools used to support the mission planning.

Jovian Radio Emissions

The Jupiter is the largest planet of our solar system. It is a fast rotator, with its rotation period of 9h55m. It is also hosting the most intense planetary magnetic field. Hence, the space environment of Jupiter is a huge electro-magneto-dynamic system, with relativistic particle spiraling along the planetary magnetic field lines. This is called the Jovian Magnetosphere. In addition, the moon Io is the most intense volcanic body of the solar system, ejecting out about one tonne per second of ionized material in the Jovian Magnetosphere, thus being its main source of matter. The dynamics of the Jovian Magnetosphere is mainly controlled by three objects: Jupiter (intense magnetic field rotating with the planet), Io (outgassing material into the Jovian magnetosphere) and the Solar Wind (constraining the outer part of the Jovian Magnetosphere). The Jovian Magnetosphere produces strong radiation belts that will prevent the JUICE spacecraft beyond the orbit of Europa. The Jovian Magnetosphere also produces intense particle precipitation around the magnetic poles of Jupiter, as for all other magnetized planets. These precipitation result in strong auroral phenomena that can be observed in radio, UV, IR and X-ray. The particles ejected from Io are interacting with the Jovian Magnetosphere by producing a electro-dynamic current system between the moon and the planet, which also contributes to particle precipitation near the footprint of the magnetic field lines passing by the moon. The Jovian radio emissions are emitted mainly above to the Jovian magnetic poles, on magnetic field lines bearing the magnetospheric field aligned currents. These radio emissions result from plasma instabilities, transferring the free anergy available in the local unstable particle distribution functions into electromagnetic waves. Figure 1 presents the Jovian radio emissions and their schematic location.

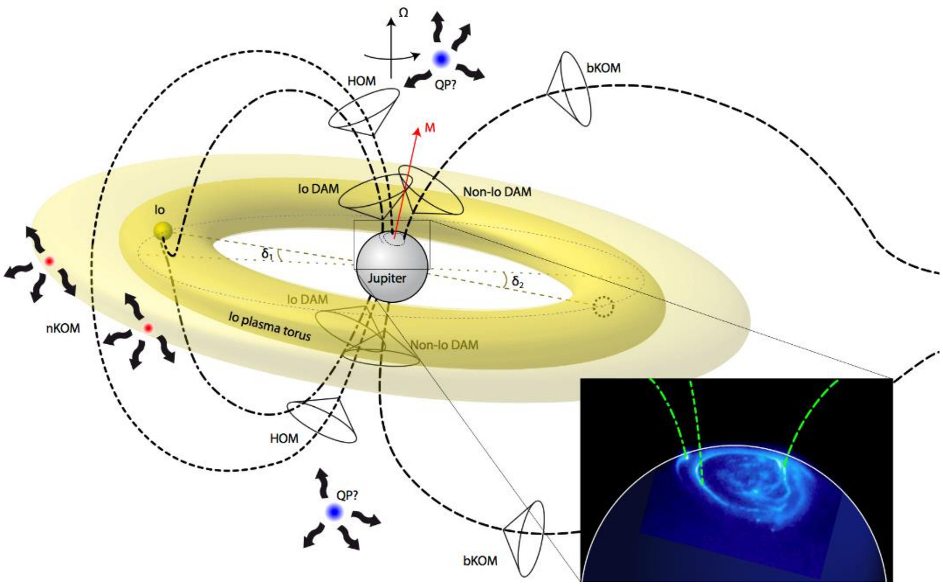


Figure 1. Radio portrait of the Jovian Magnetosphere, with the schematic location of the Jovian Radio emissions.

We focus here on the decametric radio emissions, which are either emitted from auroral magnetic field lines, or from the Io magnetic flux tube. The main specificity of the low frequency planetary radio emission is their source anisotropy. The radio waves are emitted along a hollow conical shape, whose axis is aligned with the magnetic field direction in the source region. This is schematically represented by the cones on Figure 1. There is a strong implication with this fact: the radio waves can only be observed if the observer is located within the thin layer of radio emission of the source. The Jovian radio emissions have been extensively studied with data from space missions like Voyager, Cassini or Juno and ground based observatories like the Nançay Decameter Array, in France. We also mention two services proposing observations of the UV aurora of Jupiter.

As shown in [Cecconi et al., (2012)] Jovian radio emissions will interfere with subsurface radar sounding experiments near the icy moons of Jupiter, as their signal strength overcomes that of the radar echoes. It is thus crucial to be able to understand and predict as much as possible the occurrence and visibility of the Jovian radio emissions. Since 2007, the team at Observatoire de Paris have developed modeling code, called ExPRES (Exoplanetary and Planetary Radio Emissions Simulator), to predict the Jovian radio emissions visibility. The code and the dataset of simulation runs have been put online in the frame of the VESPA activity.

Open Access Datasets

Several observatories and databases are providing observations of the low frequency Jovian radio emissions. We have selected three datasets that covers most of needs for the support to the JUICE mission. Following the VESPA DMP, the data are open-access to the community, with a metadata catalogue using EPN-TAP.

The three datasets are presented in the table below.

Dataset name	Data Archive	Description	Access	Rights
Nançay Decameter Array – Jupiter Routine	Obs. Nançay, France	Daily observations of Jupiter between 10 and 40 MHz. This dataset covers 28 years of data (from Septembre 1990 to date), and observations are recorded every day.	EPN-TAP, das2, web	open access
Calibrated Cassini/RPWS flyby of Jupiter	Obs. Paris, France	Six months of quasi-continuous observations from 3 kHz to 16 MHz, acquired by Cassini during its Jupiter flyby in 2000-2001	EPN-TAP, das2, web	open access
Cassini RPWS/WBR dataset	NASA/PDS, USA	Cassini RPWS Wide Band Receiver data from NASA/PDS (no VESPA integration yet)	web	open access
Voyager PRA Jupiter datasets	NASA/PDS, USA	Voyager 1 & 2 PRA (Planetary Radio Astronomy) datasets acquired during the Jupiter flyby of each probe. This dataset covers the spectral range: 1 kHz to 40 MHz.	EPN-TAP das2, web	open-access
IItate Radio Observatory	Tohoku Univ., Japan	Continuous (24 hrs / 7 days) decametric observation using the Iitate radio observatory antenna, near Fukushima, Japan.	EPN-TAP, web	open-access
Hisaki/EXCEED	Tohoku Univ., Japan (and JAXA)	Observations in UV range of planetary targets, using the Hisaki UV spectrometer.	EPN-TAP, web	open-access (with embargo period)
APIS database	Obs. Paris, France	Auroral Planetary Images and Spectra: Hubble Space telescope images and spectra of planetary targets in UV range. It includes a mirror of the Hisaki database, with extra planetary ephemeris parameters.	EPN-TAP, web	open-access (open registration)

ExPRES simulation runs	Obs. Paris, France	ExPRES precomputed simulation runs for various observers (on ground or in space)	EPN-TAP, das2, web	open-access

Other datasets containing Jovian signal has been identified: Wind/Waves, STEREO/Waves, Galileo/PWS, RadioJOVE, LWA or LOFAR. They have not been processed for VESPA distribution, as we have focussed on the datasets with the higher potential return.

For each dataset, two access means have been setup: an EPNcore metadata catalogue and a das2 data streaming service. An extra EPN-TAP service has been setup to share the das2 end-points of the selected datasets.

Dataset Name	**EPN-TAP**	**das2**	**web**	**source code**
Nançay Decameter Array – Jupiter Routine	X	X	https://www.obs-nancay.fr/-Mise-a-disposition-des-donnees-dam-.html	https://github.com/maserlib/maser4py
Calibrated Cassini/RPWS flyby of Jupiter	X	X	http://maser.lesia.obspm.fr/bases-de-donnees/jeux-de-donnees-locaux-17/cassini-rpws-jupiter-encounter.html	https://github.com/maserlib/maser4py
Voyager PRA Jupiter datasets from NASA/PDS	X	X	http://maser.lesia.obspm.fr/bases-de-donnees/jeux-de-donnees-locaux-17/repository-voyager-pra-datasets.html	https://github.com/maserlib/maser4py
IItate HF Radio Observatory	X			
Hisaki/EXCEED	X	N/A		
APIS database	X	N/A	http://apis.obspm.fr	
ExPRES simulation runs	X	X	http://maser.lesia.obspm.fr/tools-services-6/expres	https://github.com/maserlib/ExPRES

The TAP server end-point URL, the table names and the ivo-id of each dataset are:

Dataset name	TAP server end-point URL	table name	ivoid
Nançay Decameter Array – Jupiter Routine	http://vogate.obs-nancay.fr/tap	nda.epn_core	ivo://vopdc.obspm/usn/nda/epn
Calibrated Cassini/RPWS flyby of Jupiter	http://voparis-tap-maser.obspm.fr/tap	cassini_jupiter.epn_core	ivo://vopdc.obspm/lesia/maser/cassini_jupiter/epn
Voyager PRA Jupiter datasets	http://voparis-tap-maser.obspm.fr/tap	voyager_pra.epn_core	ivo://vopdc.obspm/lesia/maser/voyager_pra/epn
IItate HF Radio Observatory	http://thebe.gp.tohoku.ac.jp/tap	iitatehf.epn_core	ivo://tohoku.univ.jp/iitatehf/q/epn_core
Hisaki/EXCEED	http://thebe.gp.tohoku.ac.jp/tap	hisaki.epn_core	ivo://tohoku.univ.jp/hisaki/q/epn_core
APIS database	http://voparis-tap-planeto.obspm.fr/tap	apis.epn_core	ivo://vopdc.obspm/lesia/apis/epn
ExPRES simulation runs	http://voparis-tap-maser.obspm.fr/tap	expres.epn_core	ivo://vopdc.obspm/lesia/maser/expres/epn
Das2 end-points	http://voparis-tap-maser.obspm.fr/tap	services.epn_core	ivo://vopdc.obspm/lesia/maser/services/epn

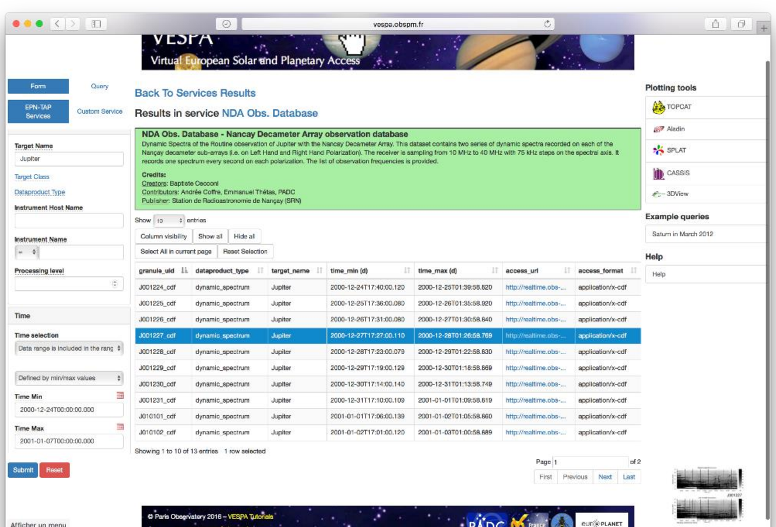


Figure 2. Result of a query on the NDA Routine Jupiter dataset, with a time selection criteria set up as:
"*Data range is included in the range 2004-12-24 00:00:00 to 2001-01-07 00:00:00*".

Run-on-Demand Service

The radio emission modeling code (ExPRES) is available on GitHub: https://github.com/maserlib/ExPRES.

It is available for Run-on-Demand operations on the MASER UWS server (https://voparis-uws-maser.obspm.fr/). This portal is using the OPUS framework, which implements a UWS (Universal Worker Service) server, as defined by the IVOA. The server is connected to a computing cluster at Observatoire de Paris, and runs the ExPRES code using a input configuration file provided by the user from the submission interface.

To launch a new run, go to: https://voparis-uws-maser.obspm.fr/client/job_form/ExPRES and provide a well-formed ExPRES input configuration file. ExPRES input configuration files must follow the ExPRES 1.0 JSON-Schema: https://voparis-ns.obspm.fr/maser/expres/v1.0/schema#. Examples of ExPRES input configuration files are available in the `expres.epn_core` table: each pre-computed ExPRES simulation run is available together with its ExPRES configuration file. For instance, the ExPRES simulation run expres_earth_jupiter_io_jrm09_lossc-wid1deg_3kev_20180101_v01.cdf has been produced with expres_earth_jupiter_io_jrm09_lossc-wid1deg_3kev_20180101_v01.json.

The MASER UWS server manages the job, provides status information while the code is running, and allows to retrieve the run results (a cdf file) once the job is finished.

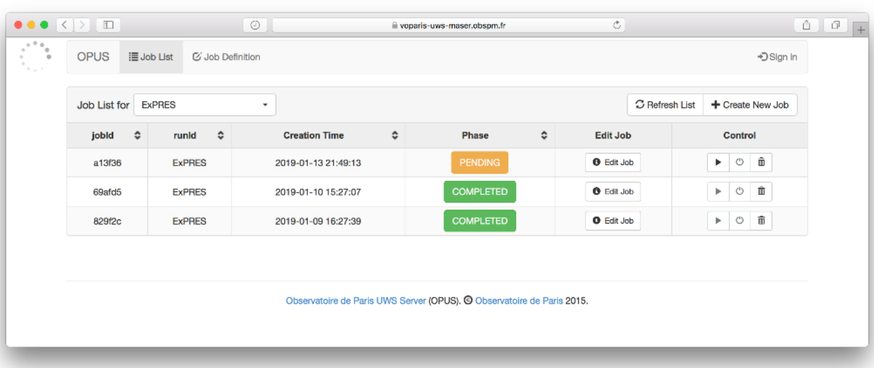


Figure 3. MASER UWS server Job list control panel.

Data Usability

The shared radioastronomy datasets are not available with standard file format for most of the cases (see table below). We have thus setup Python modules to load the datasets when necessary. These Python modules are available through the MASER GitHub Repository. They are used to distribute the datasets through the das2 interfaces, or to extract the metadata from the files to fill in the VESPA EPNcore catalog table.

Dataset name	MASER python module	data format
NDA Routine	`maser.nda.routine`	CDF, or binary
Cassini RPWS/HFR Calibrated Jupiter Flyby	N/A	CDF
Cassini RPWS/WBR raw data	`maser.pds.cassini.rpws.wbr`	binary
Voyager PRA LowBand	`maser.pds.voyager.pra`	Text or binary
Iitate HF Radio Observatory	N/A	CDF
ExPRES simulation runs	N/A	CDF

Examples of use of the modules are available on Jupiter Notebooks, as presented on https://github.com/BaptisteCecconi/maser-tutorials. Python module documentation is still to be completed thoroughly.

Applications

As presented above, it is possible to predict the visibility of Jupiter decametric radio emissions. We present here a few applications allowed by the datasets and tools developed and released through this activity.

JUICE Mission Science Operation Planning

During the last JUICE mission phase, the spacecraft will be in orbit around Ganymede with many science objectives including (a) the study of the sub-surface of the moon and (b) the study of its ionosphere. The JUICE/RIME instrument is dedicated to the sub-surface sounding. However, the Jovian radio emissions will interfere with the radar pulse echoes. The instrument can thus be operated in optimal conditions only when the Jovian radio sources are occulted by the moon. The geometrical configuration is shown on Figure 4. The ExPRES code can provide the 3D location of the visible radio source, as an optional parameter. The JUICE/SGS (Science Ground Segment) team in charge of the science operations and mission phase segmentation will use this optional output to plan the "radio-clean" intervals allowing optimal operations for JUICE/RIME.

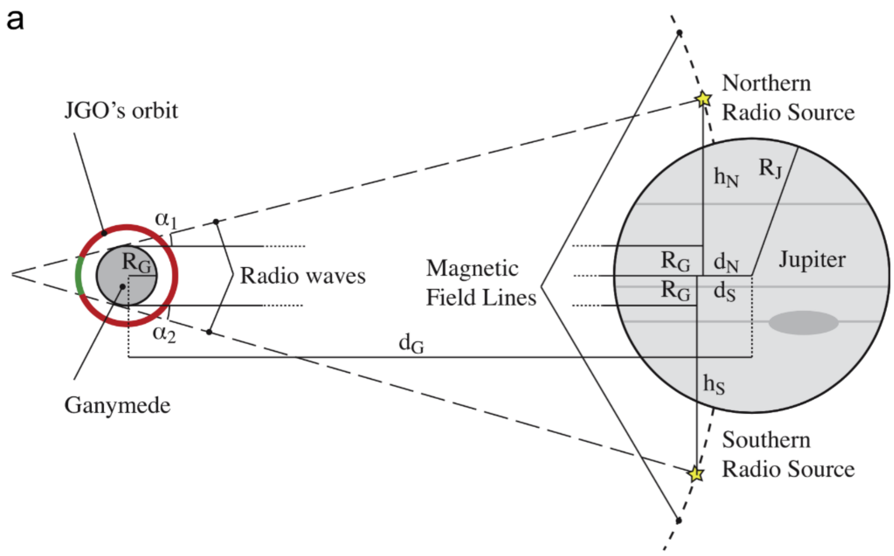


Figure 4. Simplified geometry of an orbit of JUICE around Ganymede, with radio source locations. Figure extracted from [Cecconi et al. PSS, 2012].

Another application is the observation of Jovian radio sources occultation ingress and egress by JUICE/RPWI to probe the ionosphere of the moon. The JUICE/SGS team will also use ExPRES output to plan higher resolution JUICE/RPWI modes at the predicted times on occultations.

Passive Radar Assessment for Galilean moons with JUICE

The presence of Jovian radio emissions is usually considered as a noise for sub-surface radar instruments. However, they could be used as external radio sources in a "passive radar mode" . The JUICE/RIME and JUICE/RPWI teams are currently studying this observation setup opportunity. We have released datasets and python modules to help the assessment team to evaluate the feasibility of this measurement.

We this provide access previous dataset containing observations of Jovian radio emissions: Cassini/RPWS, Nançay/NDA, Voyager/PRA. The selected dataset are representative of the diversity and variability of these emissions:

- Voyager/PRA data include data measured close to the planet, up to 40 MHz;
- Nancay/NDA data provides statistical datasets over almost 3 decades, as well as high resolution data observations representative of the fine structure of the data;
- Cassini/RPWS is the most sensitive instrument that ever flew by Jupiter; it provides both high dynamical range spectral observations and snapshots of waveform data at the JUICE/RIME operating frequency.

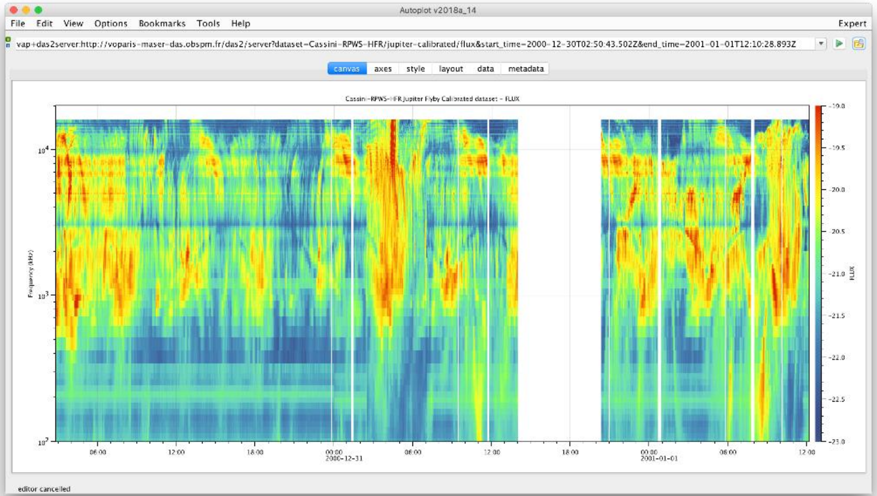
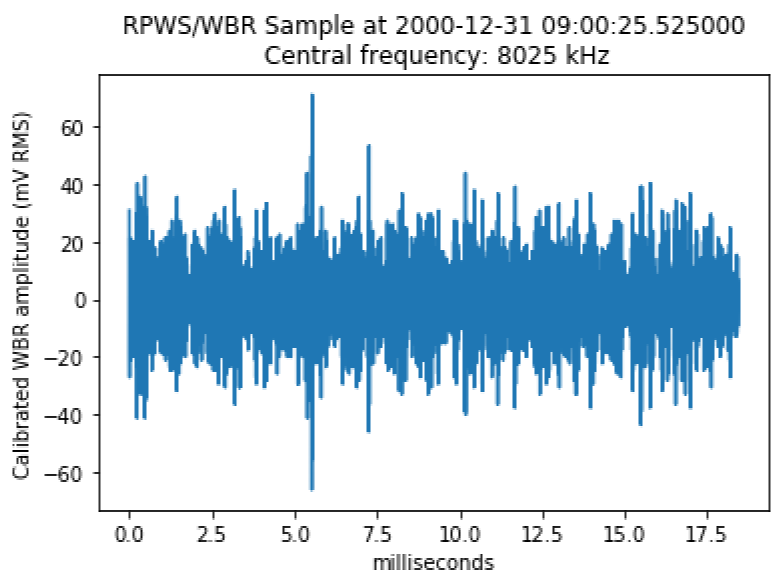


Figure 5. Cassini RPWS/HFR Jupiter Flyby Calibrated Dataset displayed in Autoplot, using the das2server interface.

As an example, we have provided the JUICE Passive Radar assessment team the following tutorial to use the Cassini/RPWS waveform data products: Cassini-RPWS-WBR-sample-plot.ipynb. The data are available from the NASA/PDS, but the knowledge of the VESPA team at Obs. Paris allowed to provide a more complete calibration of the data samples than the one described in the NASA/PDS archive documentation.



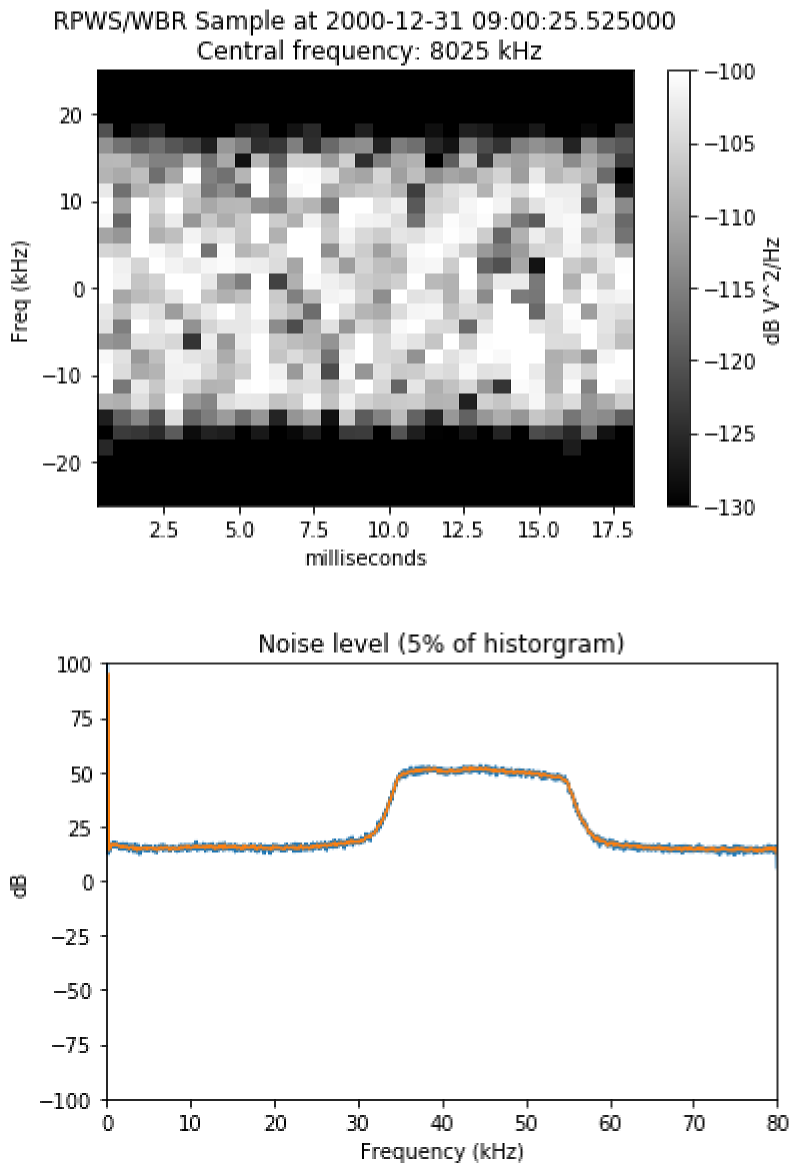


Figure 6. Cassini RPWS/WBR examples, extracted from the example jupiter notebook. From top to bottom: waveform, FFT display and noise level spectral shape.

Perspectives

The collaboration with the JUICE ESA team has been very fruitful, and we plan to connect the ExPRES simulation run-on-demand facility with their mission planning tool MAPPS (Mission Analysis and Planning Payload System). The UWS system can be run programmatically allowing automated workflows.

The list of released dataset will also be consolidated and extended, for instance in view of the preparation of a future mission to Uranus, or future space based radio interferometer covering the low frequency radio range. Supporting databases for Solar missions such as Solar Orbiter (ESA) and Parker Solar Probe (NASA) is under study.

The next step development step will be to work with the EOSC teams to setup prototypes of UWS, das2 and EPN-TAP services on the EOSC infrastructure in preparation of future projects. We have participated to the DI4R (Digital Infrastructure for Research) workshop in Lisbon (2018), where we initiated discussions and contacts with the EOSC-Hub team and the IN2P3 lab in France.

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