Design and development report

EJSM Electro-Magnetic Sensor Study

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1. Introduction

The **EJSM EMSS (ElectroMagnetic Sensor Study) team** has performed a **comparative analysis of electric and magnetic sensors** and assessed their relevance to the Ganymede environment in order to optimize the science return of the Radio and Plasma Waves Instrument (RPWI) investigation. This report shall be used as **a guideline to select the best electric and magnetic sensor set** in the frame of the EJSM/JGO project. This report addresses critical points about radio receiver design and observation planning (sensitivity, dynamic, advanced capabilities, onboard processing and triggering…).

This study also includes three reports of broad interest for the EJSM mission design: an **assessment of the EMC** (ElectroMagnetic Cleanliness) **requirements** for the JGO spacecraft (section 5.3); a study of the **Jovian radio emissions for radar instrumentation** (section 5.4); a report on **synergistic RPW science** aspects at Jupiter (section 5.5).

1.1. Scope Update

The focus has been put on electric and magnetic sensors and receiver design for radio and plasma waves, hence excluding the DC measurements sensors (magnetic and electric). This choice was made because the consortium agreed that the PDD (Payload Definition Document, ESA technical note, issue 1) is adequate for these aspects.

1.2. History of the RPW Jovian exploration

Electromagnetic portrait of the Jovian system

The Jovian radio emissions have been discovered by Burke and Franklin in 1955. Since then, the gigantic electro- and magneto-dynamic machinery of the Jovian system has been continuously studied, either remotely from the earth or closer with space missions. The intense magnetic field of Jupiter indeed induces charged particle acceleration by various processes taking place in the Jovian magnetosphere, that can be mapped by projection along magnetic field lines in the auroral regions (Fig. 1) at radio wavelengths (a few kHz to 40 MHz, see Fig. 2) as well as with visible and ultraviolet (UV) spectro-imaging. The four Galilean satellites also play a role in this system. Io, the closest to Jupiter, is the more intense source of plasma in the Jovian magnetosphere, due to its intense volcanism. Io is the source of the Io plasma torus, which rules the dynamics of the internal magnetosphere of Jupiter. The movement of Io in the magnetic field of Jupiter induces large scale waves called Alfvén wings that structure the plasma around Io. The magnetic field flux tube connected to Io is

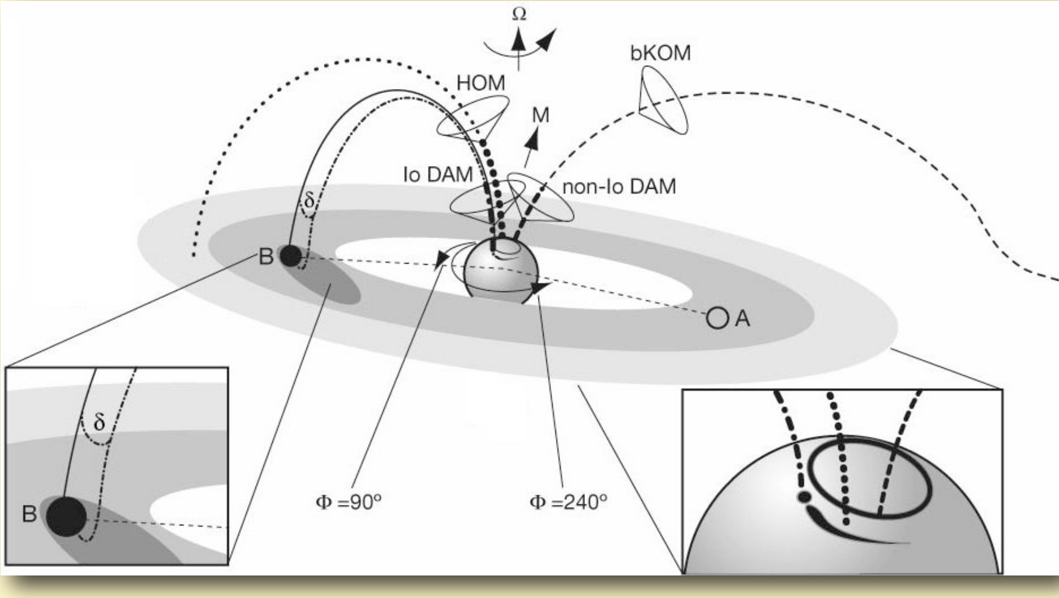

Figure 1.
Synoptic of Jovian radio emissions. The emission pattern of the radio emission are hollow cones aligned with the local magnetic field. The location of Io (A and B) are that for which the Io-DAM is visible for the observer.

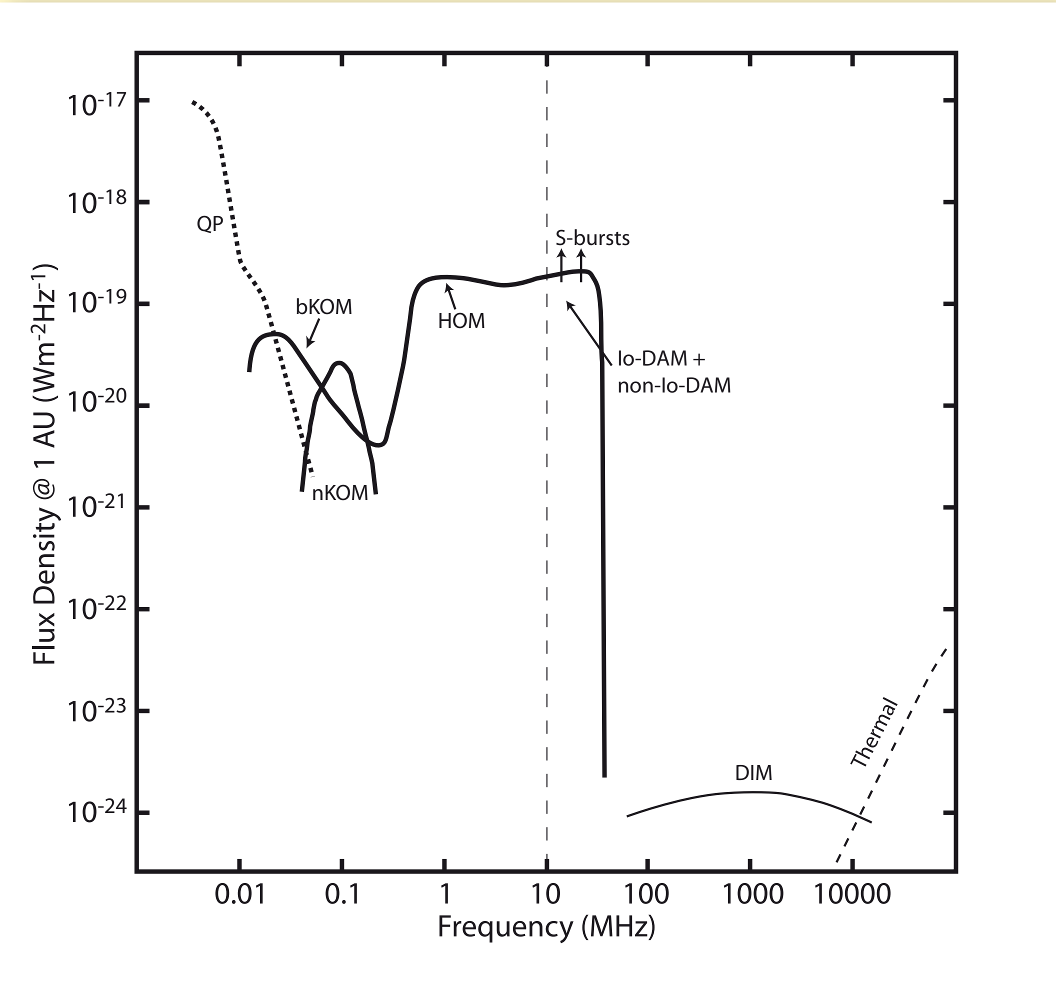

Figure 2.
Jovian radio spectrum The DIM emission is produced by the radiation belts. Thermal: black body emission of Jupiter. The spectrum is the mean spectrum when the emission is active, given in $W/m^2/Hz$ normalized at a distance of 1AU.

guiding accelerated electrons down to the northern and southern ionosphere of Jupiter, where they induce auroral footprints and tails, as well as characteristic decametric radio emissions. The electrons are accelerated in the magnetic flux tube by various phenomena (plasma heating, electron beams or parallel electric field of Aflvén waves). The radio emissions are displaying fine structures that are used as a proxy to observe the structure of the plasma above the Jovian ionosphere in the high latitude magnetosphere. Although less active than Io, Europa, Ganymede and Callisto also have active auroral magnetic footprints and tails. The local plasma environment of Europa and Callisto are characterized by an exosphere. Europa also interacts with the Io torus. An internal conductive layer (possible liquid water) has been detected inside Europa, Ganymede and Callisto, thanks to magnetic measurements. Finally Ganymede is a very interesting case, as it has an intrinsic magnetic field that produces an mini-magnetosphere inside the Jovian magnetosphere. Radio waves and plasma waves have been detected inside and at the boundaries of the magnetosphere of Ganymede. Ganymede is thus a particularly interesting case for comparative analyses of magnetized planetary interactions.

RPW capabilities onboard space missions to Jupiter

Since the Voyager era (in the late 1970's), the Jovian system has been explored by several spacecraft (flybys or in orbit), most of them embarking Radio and Plasma Waves (RPW) instrumentation. A synoptic review of their RPW capabilities is provided in Table 1.

Reviewing these quick facts, it is clear that: (1) only Voyager 1 & 2 and Juno can observe the full frequency range of the Jovian radio emissions; (2) only Ulysses and Cassini have the adequate capabilities to localize radio sources; (3) only Galileo and Juno explore the Jovian system for a long time. There is thus a need for long-term orbiter covering the full radio range with full goniopolarimetric capabilities.

Ground based facilities such as the Nançay Decamater Array (France) are systematically monitoring the Jovian radio emissions: daily survey (6 to 8 hr per day) in the 10-40 MHz range; frequent observations with full polarization (e.g., 6 months during the New Horizons Jupiter flyby); and occasional very high time- and frequency-resolution observations.

1.3. Jovian radio environment for radar studies

The Jovian radio environment is unique compared to that of the other planetary systems. The intense non-thermal Jovian radio emission emanating for the auroral regions of the planet are emitted up to ~ 40 MHz (see Fig. 2). They are much more intense than the galactic radio background, which usually limits the radar capabilities. Therefore, at Jupiter, the natural radio emissions are the background noise of radar measurements. The planetary radio emission experts of the Electro-Magnetic Sensor Study team worked with the JGO/SSR and JEO/IPR study teams to identify the specificities of the Jovian system in terms of radio noise and better define the characteristics of their instrument

Voyager 1 & 2	*Orbit:*	2 close flybys
	Radio Measurements:	YES - **up to 40.5 MHz**. - total flux, sign of circular polarization. - 2 electric monopoles (10m each).
	Plasma Wave Measurements:	YES - Electric component only.
Ulysses	*Orbit:*	1 close flyby (outbound was polar)
	Radio Measurements:	YES - up to 940 kHz - flux, polarization, direction of arrival (**allowing radio source localization**). - 1 spine-plane electric dipole (72.5m) - 1 axial electric monopole (7.5m)
	Plasma Wave Measurements:	YES - Electric and magnetic components.
Galileo	*Orbit:*	**8 years orbital tour**
	Radio Measurements:	YES - up to 5.6 MHz - total flux only - 1 electric dipole (6.6m)
	Plasma Wave Measurements:	YES - Electric and magnetic components.
Cassini	*Orbit:*	distant flyby
	Radio Measurements:	YES - up to 16.125 MHz - flux, polarization, direction of arrival (**allowing radio source localization**). - 3 electric monopoles (10m each).
	Plasma Wave Measurements:	YES - Electric and magnetic components.
New Horizons	*Orbit:*	distant flyby
	Radio Measurements:	NO
	Plasma Wave Measurements:	NO
Juno	*Orbit:*	**polar orbits**
	Radio Measurements:	YES - **up to 40 MHz** - total flux only - 1 electric dipole (2m).
	Plasma Wave Measurements:	YES - Electric and magnetic components.

Table 1.
Synoptic history of the Jovian magnetosphere exploration with RPW instrumentation.

(selection of the appropriate radar frequency range, impact on performances, selection of orbital portion suitable for radar science). This collaboration is presented in some details in Section 5.4, and the outputs of this study are the subject of a peer-reviewed paper that will be submitted in Nov. 2010 to Planetary and Space Science.

1.4. Recent results with RPW instruments

Recent results obtained with space-borne RPW instrumentation in the kronian system with Cassini, or in the inner heliosphere with STEREO are outstanding and reveal all the possibilities of space-based radio astronomy. Radio measurements are traditionally done on the electric component of the wave because the magnetic component is fainter than the electric one by the factor of c (speed of light).

The Cassini mission around Saturn is extremely rich in terms of magnetospheric results. The Saturn Kilometric Radiation (SKR), originating from the auroral regions of Saturn, plays a central role for all magnetospheric studies at Saturn. This role is adequately fulfilled thanks to the quality of the RPWS (Radio and Plasma Wave Science) experiment instrumentation, and in particular that of the RPWS/HFR (High Frequency Receiver), which is a goniopolarimetric radio receivers, thus allowing scientists to retrieve the flux, the full polarization and the direction of arrival of observed electromagnetic waves. We give here a few examples of studies conducted at Saturn by the RPWS team. Illustrations can be found in section 5.5 (slides on *Unique Science Aspects*).

The goniopolarimetric capabilities of the RPWS/HFR instrument, coupled with a model of the kronian magnetic field, allowed us to localize the SKR sources and directly show that they are magnetically connected to the UV aurora in the ionosphere of the planet. This type of analysis also provides electromagnetic mode of propagation, and radio beaming angle in the source. The same localization analysis was done for the saturn low frequency narrow-band emissions, which showed them to be located along the internal edge of the plasma disc. The polarization of the SKR has been used as a proxy to probe indirectly the plasma parameters between the radio source and the observer. The Cassini spacecraft also crossed the sources of the SKR. This observation is unique: it is the first time that direct in situ observations of auroral radio emissions sources is done on another planet than Earth. The whole set of RPW, magnetic and plasma instruments were used altogether for this analysis. This observation proved that the same microscopic mechanism is responsible for auroral radio emissions at Saturn and at Earth. During the kronian radio source crossing, it is clear for the radio experts of the team that the measurement of part of the magnetic component would have helped getting definitive answers on the source locations. Indeed, when close to the wave cutoffs, transverse propagations can not be assumed anymore, hence magnetic measurement would have been critical.

Last but not least, one of the biggest puzzle at Saturn is the variability of the periodicities in its magnetosphere. The rotation period of giant planets is not directly measurable. At Jupiter, the pulsation of the radio emissions, which are linked to the magnetic field topology above the Jovian atmosphere, was successfully used to determine the internal rotation rate of the planet. At Saturn, the magnetic field is axisymetric and aligned with the rotation axis of the planet, but the radio emission are pulsating, with a slow variability. While look for a cause of this variability in the other magnetospheric parameters, it appeared that the plasma data, the ENA images of the plasma ring, as well as the magnetic field data organized very well with the variable longitude system built from the variable radio period. This problematic is certainly not critical at Jupiter, because the sidereal period of Jupiter is very accurately determined (10^{-6} relative accuracy) but we can expect to refine the value or detect small variabilities with long-term RPW observations on the whole frequency range with orbiters like those of the EJSM project.

More recent instrumentation, such as the STEREO/Waves receiver, allows us to retrieve the 3D location of the solar radio bursts, thanks to stereoscopic measurements. Goniopolarimetric inversions that also retrieve the apparent size of the radio source have been developed.

Finally an interesting by-product of a RPW receiver comes from the analysis of the interaction between the antenna and the local plasma. The analysis of the observed spectrum is called Quasi-Thermal Noise (QTN) spectroscopy and provides passive, reliable and absolute local plasma parameters. Illustrations can be found in section 5.5 (slides on *Unique Science Aspects*). These measurements are usually used to calibrate the plasma instruments, which need the absolute plasma density in order to remove the contribution of the photon electrons from the observed core of the electron distribution function, as well as active plasma sensing device, such as the Langmuir Probes.

1.5. State of the art

The latest generation of RPW instrumentation is currently being integrated into Bepi-Colombo MMO (Mercury Magnetospheric Orbiter). The radio receiver (Sorbet) is based on FPGA and ASIC technologies and inherits from a long series of radio receivers (ISEE3, Wind, Ulysses, Cassini, STEREO) that were built with discrete components. The new design allows to save mass, power and volume, which are all critical for space instrumentation. In terms of radiations, the MMO instrumentation was tested for 55 krad under 2 mmAl. The NASA mission RBSP (Radiation Belt Storm Probe) instruments are designed for 100 krad under 4 mmAl. The sensors technology also developed in the past few years. A new generation of dual band magnetic search coils have been developed for Bepi-Colombo/MMO. The electric antennas designed for RBSP are light and radiation-hardened. Recent rocket experiments were conducted to test the high frequency magnetic loop. The TRL (Technology Readiness Level) of recent RPW instrumentation is thus high enough to achieve TRL 5 in the frame of the EJSM timeline.

1.6. We can do better than before at Jupiter.

It is clear to us that the RPW instrument for EJSM can significantly enhance our understanding of the Jovian system as a whole. With EJSM we indeed have a unique opportunity to go beyond what previous missions have achieved by covering the full frequency range of the Jovian radio emissions and taking advantage the radio source localization techniques (such as those developed for the Cassini or STEREO missions). The technology is ready for such capabilities.

Coupling electric and magnetic measurements both in the plasma wave range and in the radio range would be very innovating, especially during the last phase of the JGO mission, when the spacecraft will be close to or inside the ionosphere of Ganymede.

Multipoint observations also proved to add considerable science return, as recently shown by the STERO mission, either for stereoscopic observations, or for distant environment monitoring (Jovian magnetosphere space weather in our case). At the moment, RPW instrumentation is only planned on JGO, but stereoscopic radio measurements could be available for the EJSM mission, if some RPW capabilities (even minimal) are put on JEO. Our EJSM EMSS Team strongly advocated the inclusion of RPW instrumentation on JEO which could dramatically improve the overall science return of the joint mission. This was discussed at various conferences (section 5.6). Finally, the JMO mission projected by JAXA would be a very good opportunity for synergetic and stereoscopic observations of the Jovian magnetosphere.

Concerning low frequency plasma wave observation, the simultaneous observation of electric and magnetic component is essential in order to determination the characteristics of observed waves.

It is clear from the various points detailed in this introduction that it is possible to do better than before. The various teams gathered in that Study have all a strong heritage in space mission, and are participating to the latest projects, such as Bepi-Colombo/MMO, RBSP or JUNO.

2. Scientific Performance Requirements

In the plasma wave frequency range (from a few Hz up to the local plasma or cyclotron frequency), the full electric and magnetic components are required in order to fully determine the complete wave properties. Waveform measurement are possible in the frequency range, and onboard data analysis could help identifying key parameters to reduce telemetry.

In order to obtain radio direction finding and wave polarization measurement, the radio receiver needs goniopolarimetric capabilities. For a 3-axes stabilized spacecraft such as EJSM/JEO or JGO, this implies that the radio receiver performs auto- and cross-correlations between the voltages sensed on 2 channels simultaneously. Such a receiver provides 4 instantaneous measurements per pair of antenna at a given observing frequency. With fast antenna switching, it is possible to perform goniopolarimetric measurements

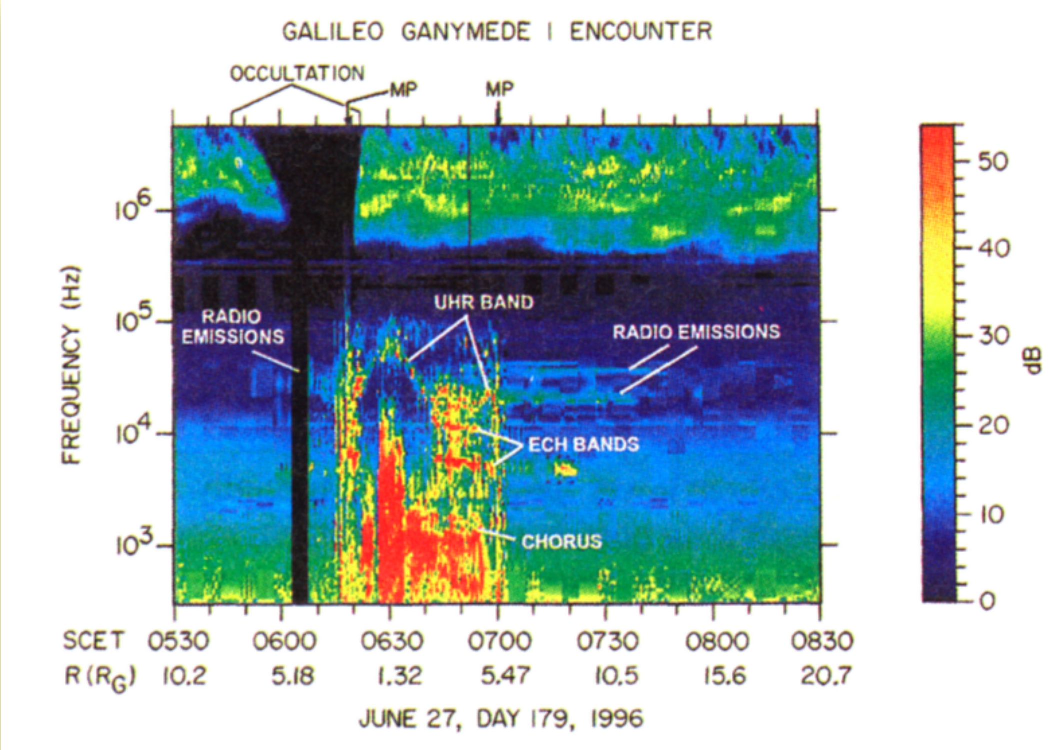

Figure 3. Galileo Ganymede encounter that occured on June 27, 1996. The PWS instrument onboard Galileo observed local plasma waves, radio emissions from Ganymede and an occultation of the Jovian radio emissions. Figure taken from Kurth et al. [1997].

on more than 2 sensors quasi-instantaneously with a 2-channel receiver. It is also possible to increase the number of channels in the receiver, but this has a cost in terms of mass, power and footprint. Assuming transverse propagation for the observed wave, 3 electric components are sufficient to determine the wave direction of arrival. However, when close to the waves' cutoff frequencies, the transverse propagation assumption is not valid anymore and at least 1 additional magnetic component is necessary in order to get the wave vector direction. Figure 3 shows a Ganymede's ionosphere occultation of Jovian radio emissions. The radio waves are occulted up to 5 MHz. Hence, in the last phases of the mission, measurements of the magnetic field up to this frequency will be very useful.

Hence, the scientific requirements are the following:
- 3 electric and 3 magnetic component measurement (with waveform receivers) in the plasma wave range (a few 10's of Hz to a few 100's of kHz)
- 3 electric and 1 (or more) magnetic component measurement (with auto- and cross-correlation) in the radio range (a few 10's of kHz to 45 MHz)

3. Instrument Description

As the EMSS aims at defining guidelines to get a science optimized electric and magnetic set of sensors, we will not fully describe RPW instrumentation. Please refer to the RPWI Design and development report for a full description. We will rather point out some critical aspects and possible improvements from the current PDD.

3.1. Instrument Concept

RPWS instrumentation may includes several types of receiver. The LF range (from a few 10's of Hz to a few 100's of kHz), which is the plasma wave range (i.e. below the local plasma frequency), can be observed by waveform receivers that sample directly the voltage on the electric and/or magnetic sensors with ADCs. The current space qualified technology allows to record waveforms with a maximum resolution of 3 Msample/s with 10MHz ADCs. The HF range (from a few kHz to 45 Mhz), which is the radio range (i.e. above the local plasma frequency), can be observed either by direct sampling with high speed ADCs, or by use of a heterodyne system, which down-converts a filtered portion of the spectrum to a lower frequency range, that can be more easily digitized.

Due to the limited telemetry rate, it is not possible to record and send back to ground the full waveform data. Hence, full resolution waveform data are usually sent to ground in form of snapshots selected by predefined triggers (intensity threshold, spectral shape...). The rest of the data is transformed into the spectral domain using several possible algorithms (FFT, wavelet transforms, polyphase filters...) and temporally correlated, in order to get power spectra or cross-spectra between channels. These spectra can be sent to ground as is, or can also be processed onboard with higher level data analysis algorithm extracting higher level key parameters (e.g., minimum variance analysis).

The list of sensors for RPW range is recalled here, stating their status in the current EJSM/JGO PDD:

- electrical antennas:
    - SEAT (Short Electric Antenna Triad):
      Triad of mutually orthogonal short dipole (in PDD).
      NB: named RWI in RPWI.
    - SSR dipole: long dipole (in PDD, SSR section).
      NB: named RA-PWI in RPWI.
- magnetic antennas:
    - SCM: triaxial dual band magnetic search coil (in PDD)
    - MLA: HF magnetic loop (not in PDD, but now present as an option in RPWI)

A complete description of the sensors can be found in the Letter of Intent of the EMSS, as well as in the RPWI Design and Development Report. Table 2 summarizes the planned frequency range, the RPW planned capabilities, as well as accommodation remarks, that are developed below.

Sensor	E	B	Frequency Range	Radio	Gonio-polarimetry	Plasma Waves	Plasma Param.	Accommodation remarks
SEAT	x		0.1 Hz - 45 MHz	yes	yes	yes[3]	no	boom or spacecraft body
SSR Dip.	x		0.1 Hz - 45 MHz	yes	no[2]	yes	yes[4]	accommodation risk[5]
SCM		x	0.1 Hz - 20kHz	yes[1]	yes	yes	no	on boom
MLA		x	100 kHz - 45MHz	yes	no[2]	no	no	on boom

Table 2.
Synoptic of the various RPW sensors with planned capabilities and accommodation remarks. Notes:
1. The SCM can be used for radio emissions up to 20 kHz (such as QP bursts).
2. Not available if used alone.
3. The current SEAT design (2m antennas) may not have enough gain for Plasma Waves measurements.
4. Such capabilites requires long and thin dipole antenna. Final design not decided yet.
5. Risk for SSR team: loosing the only sensor. Risk for RPWI: burning attached preamplifier or worse.

3.2. *Instrument Design*

We review here the critical design aspect for the receiver design, and for the various sensors.

RPW Receiver Design Constraints

As the observed signals are very variable in intensity and very sporadic, the RPW receivers are required to have a high dynamic range. The current receiver designs allow to have 90 dB to 120 dB dynamic range. In order to achieve these high values, The simple ADC sampling technique is usually not enough. Although a 14 bits ADC has a 84 dB raw dynamic range, other factors have to be taken into account to evaluate the effective dynamic range of a receiving chain:
- The 1/f natural noise decreasing as 10dB per decade reduces the effective dynamic range at lower frequencies. With a 3 Msample/s ADC, a dynamic range of 90 dB at 3 MHz implies a dynamic range reduced to 60 dB at 3 kHz and 30 dB at 3 Hz.
- The preamplifier and receiver noises reduces the effective dynamic range by adding noise on the low intensity signals.
- The input gain of the preamplifier shall be well adjusted in order to sample high intensity as well as low level signals. Saturated sample are not usable. In particular, if intense RFI are present in the band, they have to be properly sampled to be able to analyze the lower level natural signals. The variation of the distance between the observer and the sources will also induce strong variations of the peak intensity measured by the receiver.

In order to address the first point, RPW receivers shall be designed with reduced instantaneous frequency bandwidths. In this case, several sub-bands are need to cover the band directly sampled by an single ADC. The second point can be addressed be using an AGC loop, which amplifies the signal at an input level adapted to that of the ADC. The last point can be addressed by a combination of the two preceding solutions: having narrow analysis bandwidths (which are observing between the RFI lines), and using an AGC loop to avoid signal saturation. These techniques have been successfully used for years on the radio receivers onboard Ulysses, WIND, Cassini or STEREO. A critical aspect to AGC design is its linearity, in terms of gain and phase shift, which have to be calibrated in any case.

Mixing Electric and Magnetic Signals

The magnetic component of an electromagnetic wave is fainter by a factor of *c*, as already discussed before. We compare here the signal strength that will have to be compared after being sensed by the sensors and the preamplifiers. Typical electrical sensor preamplifier with recent technology can achieve a noise level of a 5 to 10 nV/√Hz. Figure 4 show the various noise levels for a plasma frequency of 20 kHz, in function of frequency. SSR dipole antenna has been used for simulation. Shorter antenna will lower the various external sources of noise (dashed lines) by a factor proportional to the antenna length, but not the receiver noise level, which is mainly fixed by the preamplifier noise.

According to the current technical reports, the magnetic sensors noise is at best as low as ~10 fT/√Hz for SCM to ~1 fT√Hz for MLA. If we convert this into units comparable with electric measurements, we get: ~ 3 µV√Hz for SCM and 300 nV√Hz for MLA. The magnetic signal noise level is thus at least 2 to 3 orders of magnitude higher than that of electric signals. Electric

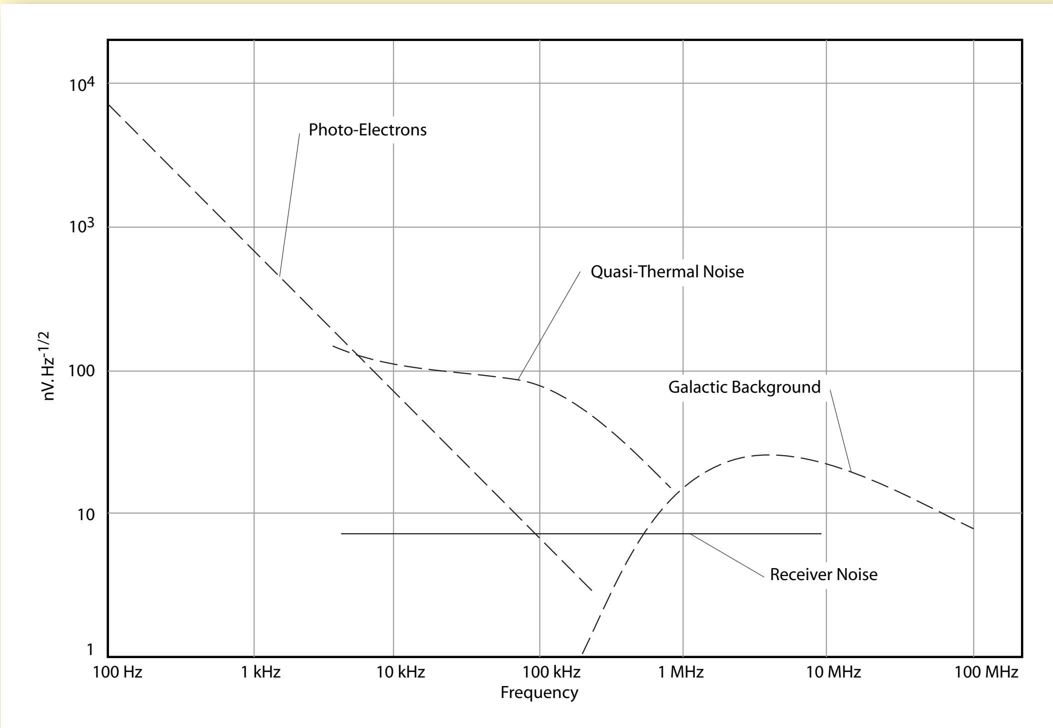

Figure 4. Various sources of noise observed by a radio receiver with electrical antennas. Here we have taken a 2x5m dipole (like the SSR dipole) and a 20 kHz local plasma frequency (i.e., ~5 particles/cm^{-3}).

and magnetic coupled measurements can thus only be conducted on string signals.

Electric Antennas Constraints

The electrical antennas used for the RPW range used on 3-axes stabilized spacecraft are straight conductive booms. Monopole or Dipole antennas can be used. In the case of monopole antennas the second pole of the antenna is the spacecraft body. The electrical antenna is characterized by its gain, which depends on the antenna length, shape and on the fixation device impedance, and its effective orientation, which depends on the location of the antenna and on the spacecraft shape.

The gain of the antenna is a function of the antenna impedance and that of the fixation device. The antenna indeed acts as a voltage divider converting the wave electric field into a voltage fed to the preamplifier. This is illustrated on Fig. 5. Considering that the antenna and fixation device impedances are purely capacitive, the voltage sensed by the preamplifier is then:

$$V_h' = V_h \frac{C_a}{C_a + C_b}.$$

where C_a and C_b are the antenna and fixation device (or base) capacitances respectively. In order to get the highest level signal output, we need to reduce C_b compared to C_a. C_a is fixed by the antenna shape and length. C_b is fixed by the fixation device mechanical and electrical design.

The effective length of the antenna proportionally fixes the overall gain: the longer the higher gain in the short antenna case. The receiving pattern is more complicated at higher frequencies.

Depending on the monopole/dipole design choice various science aspects may be addressed. The dipole configuration is easier to calibrate and the effective antenna characteristics are less perturbed by the spacecraft body. V-shaped dipole can also be used to simulate a dipole orientation, which would have been in the field of view of another instrument. Monopole antennas are more

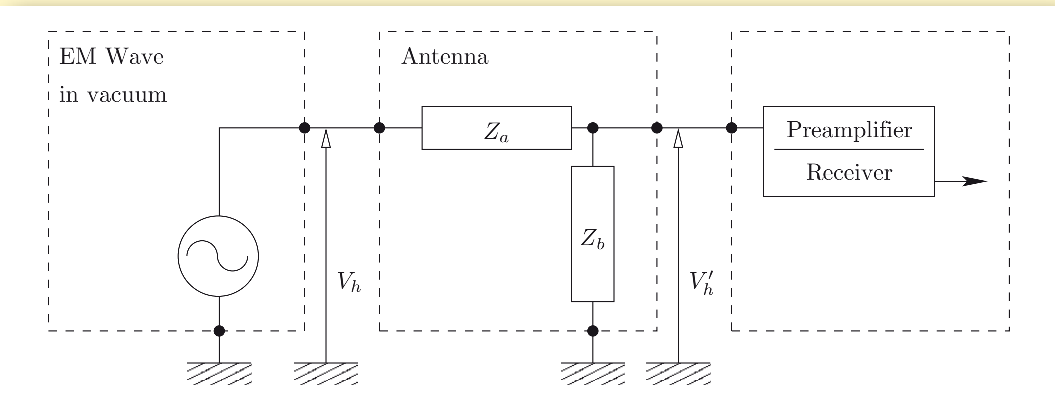

Figure 5. Electrical antenna system seen as a voltage divider.

sensitive to the spacecraft body, but are also more sensitive to plasma physics observables which need a large cross section, such as dust monitoring or shot noise.

Radar SSR Dipole Accommodation

EMSS and RPWI team members participated to a SSR team meeting in Trento (March 2010), where EMSS presented the Jovian natural radio emissions to the radar team. The accommodation of the SSR dipole with RPWI was also discussed.

The SSR dipole has been proposed as an additional sensor for RPWI. The critical issue of this accommodation is the insulation of RPWI when SSR is operating. As the dipole is the only sensor of SSR, they can not take the risk to loose it. Hence the final technical solution must be failsafe for the SSR team.

A second issue concerns this time the RPWI system. The accommodation must also prevent SSR pulses to go into the connected RPWI preamplifier, resulting in the loss of this preamplifier (or even worse). One solution would be to put a circuit breaker in the preamplifier.

The University of Iowa, which is part of the RPWI and EMSS consortia already worked with the SSR team for the Mars Express radar instrumentation. There are solutions that have been developed for that project, but these are still ITAR protected. We thus urge ESA to discuss with NASA for us to be able to review these solutions.

A third issue is the matching network used by the SSR team. This device is adapting the SSR antenna to the frequency bandwidth used for radar science. It adds a significant impedance in parallel to the base capacitance and thus should be insulated from the RPWI preamplifier input when RPWI is operating in this sensor. Discussions are still on going on this critical aspect.

Finally, the geometrical design of the antenna has impacts on the RPWI science return. In order to get the best of QTN spectroscopy, the dipole antenna diameter shall be negligible (at best) compared to its length. This constraint is not fully compatible with the mechanical constraints (antenna sturdiness requires thick antennas) and radar science constraints (wide band science requires thick antennas).

Specific Goniopolarimetric Constraints

The goniopolarimetric capabilities discussed above have some requirement on the antenna and receiver design. The goniopolarimetric inversions are valid only in the so-called short-antenna frequency range (also referred to as quasi-static range). This range is defined by the antenna length: the antenna must be small compared to the wavelength of the observed wave. Hence, for a 10m, 5m and 2m antennas, the high frequency limit of the short-antenna range is ~2 MHz, ~4MHz and ~10MHz, respectively. In that frequency range, the effective antenna pattern can be approximated by that of a perfect dipole. At higher frequencies, the antenna pattern is more complex and can not be easily modeled.

Specific QTN Constraints

In order to achieve accurate QTN analysis, 2 factors are required. The first is high spectral resolution ($\delta f/f \sim 1\%$) on at least 1 decade around the local plasma frequency. The second is linked to the sensor itself. Long (longer than the Debye length of the medium) and thin (compared to the antenna length) antenna is required. The actual SSR dipole characteristics are not compatible with accurate QTN spectroscopy when JGO is in the final Ganymede orbital phase.

3.3. Physical resources and interfaces to spacecraft

Electric Antennas Constraints

Two options have been proposed by the industry for the implementation of SEAT.

One option is to put monopoles on the spacecraft body. This option has been selected on several 3-axes stabilized spacecraft in the past (such as Cassini or STEREO) and proved to be efficient. However, the precise location of the SEAT fixation shall be carefully studied with electromagnetic antenna response simulation using realistic spacecraft models. For Instance, in the case of the JUNO spacecraft, the physical dipole antenna is a V-shaped set of two monopoles. The proximity of the spacecraft solar panels changes the effective antenna diagram and the effective antenna length (which drives the gain of the antenna) is significantly smaller than the expected one.

The other option presented was to place 3 monopoles on a boom. In this case, the monopoles are paired to be used as dipoles. Three possible dipoles can be synthesized with this configuration. These three effective dipoles are coplanar, and not mutually orthogonal. They are thus useless for goniopolarimetric analysis ! A satisfying fix would be to use physical dipoles instead of monopoles in this configuration, but this doubles the mass to be placed on the boom. As the spacecraft body is far from the antennas, the measured effective direction may not be far from the expected one. The drawback is that the preamplifiers are deported on the boom, which adds mass (shielding, cables) and noise on the signal (length of cable, more sensitive to RFI).

A final aspect, which has not been studied yet is the impact of the SSR beam on the RPW instruments. According to the current design of the SSR instrument will emit 20W during 150 µs in a 10 MHz bandwidth. This will cause huge electromagnetic fields (in the near field) that may have incidence on the RPW sensor preamplifiers. The intensity of the field at each sensor have to be carefully modeled. For this, we need to have the possible locations of the various sensors, as well as a realistic spacecraft model and SSR dipole antenna characteristics. Finally, if the field strengths are too large, we may need to modify the preamplifier designs in order to switch them off and disconnect them from the receivers when SSR is operating.

Magnetic Sensors Location Constraints

The main constraint on magnetic sensors is to be far enough from the spacecraft body to avoid spacecraft RFI. This is particularly critical for the SCM which will be sensed with wide-band waveform analyzers, according to the RPWI report. As the MLA shall be sensed with a sweeping frequency receiver, this is less critical: the RFI lines will only be polluting certain frequency channels.

However, because the magnetic component of an electromagnetic wave is c times fainter compared to its electric one (c^2 if comparing powers), it is crucial to place the magnetic sensors in a clean (as clean as possible) magnetic environment.

3.4. Operations and calibration procedures

The receiver and the sensors must be carefully calibrated before launch. Procedures to recalibrate them during flight must also be foreseen.

Receiver Calibration

The receiver chain (including the preamplifiers and all the stages of the receiver) must be calibrated in gain and in phase. This is done with tests on the Flight Model using the EGSE. During ground measurements, experience proved that it is essential to report operating conditions along with the measurements (system temperature, antenna mode...). All possible sensor input combination must be tested and calibrated. Input signals must be adequately chosen when calibrating a receiver (white noise preferred to spectral lines; testing dipole mode configuration requires adapted input signal strengths on each monopole feed...)

Onboard noise generator as usually used to check the aging of the receiver after launch and update its calibration if necessary.

Electrical Antenna Calibration

Several techniques are available to calibrate the effective electrical antenna parameters, which are the antenna length and the antenna direction.

Before launch, simulations of the antenna diagram is usually done either with wire-grid electromagnetic simulations, or with rheometric measurement using a miniaturized model of the spacecraft and its antennas in a dielectric medium.

After launch, inflight calibration are necessary in order to confirm the parameters provided by the simulation techniques. The calibration can be done as soon as the spacecraft is in space. Early deployment of the electrical antennas not only improves the science return of the mission (during the cruise, radio emissions from Earth, from the Sun or from Jupiter are visible), but also allows to have several occasions to calibrate these antennas: Right after launch, the AKR can be used as a calibration source (when the spacecraft is further than 50 r_E from Earth) in the 100-700 kHz range; during cruise, solar radio bursts can be used as a calibration source in the high frequency range (>5MHz); during the approach at Jupiter, the Jovian radio source can also be used for calibration while the spacecraft is further than ~ 100 r_J from Jupiter. These calibration are more efficient if they are done during spacecraft rolls. In that case, we can accurately calibrate the effective antenna direction. It is thus recommended to plan several spacecraft rolls dedicated to the electrical antenna calibration, after they are deployed.

The effective antenna length is calibrated using the galactic radio background. This calibration procedure requires that the antenna resonance is included into the frequency range of the radio receiver. For instance, the STEREO/Waves electric antenna resonance is right at the upper bound of the receiver range. Because of this there is still debate in the team (4 years after launch) on the actual effective length of the antennas.

Antenna gain can also be calibrated comparing space-based measurements to ground-based calibrated radio observatory observations. There are 3 large facilities in Europe for such a calibration: the Nançay Decameter Array in France, the Kharkov Radio Telescope in Ukraine and the new Dutch/European LOFAR facility, currently in commissioning phase. Any portion of the orbit may be used, as far as the spacecraft in aligned and in-between Earth and Jupiter. Due to the modulation of the Jovian radio emission, such an alignment must be conjugated with the visibility of the Jovian radio emission at Earth, which can be planned well in advance.

Note that LOFAR will also be used for Jovian radiation belts monitoring, with DIM observations.

Magnetic Antenna Calibration

The effective parameters of the magnetic sensors are less influenced by the spacecraft. This is mainly due to the fact that these sensors are generally far from the spacecraft body. Calibration procedures are planned in order to check the preamplifier stability.

3.5. Cleanliness and specific requirements

See EMC report (See section 5.3) and RPWI report.

3.6. Radiation mitigation and shielding

See RPWI report.

3.7. Planetary Protection Issues

See RPWI report.

3.8. Heritage

See RPWI report.

4. Results and status of instrument study

Although well advanced, the results presented here are not final. The EMSS team will continue working on delivering inputs and guidelines directly to ESA and to the RPWI consortium as well as to the interested scientific community via conference presentations or peer-reviewed science papers.

5. APPENDICES

5.1. List of acronyms

- **ADC**. Analog to Digital Converter
- **AGC**. Automatic Gain Control
- **AKR**. Terrestrial Auroral Kilometric Radiation
- **ASIC**. Application Specific Integrated Circuit
- **bKOM**. Broad band Jovian Kilometric radio emission
- **DAM**. Jovian Decametric radio emission
- **DIM**. Jovian Decimetric radio emission
- **DC**. Direct Current
- **EGSE**. Electrical Ground Support Equipment
- **EJSM**. Europa-Jupiter System Mission
- **EMC**. Electro-Magnetic Cleanliness
- **EMSS**. Electro-Magnetic Sensors Study
- **ENA**. Energetic and Neutral Atoms
- **ESA**. European Space Agency
- **ExPRES**. Exoplanetary and Planetary Radio Emission Simulator
- **FPGA**. Field-Programmable Gate Array
- **HF**. High Frequency
- **HFR**. High Frequency Receiver
- **HOM**. Jovian Hectometric radio emission
- **Io-DAM**. Jovian Io-controlled Decametric radio emission
- **IPR**. Ice Penetrating Radar
- **ITAR**. International Traffic in Arms Regulations
- **JAXA**. Japan Aerospace Exploration Agency
- **JEO**. Jupiter-Europa Orbiter
- **JGO**. Jupiter-Ganymede Orbiter
- **JMO**. Jupiter Magnetospheric Orbiter
- **LF**. Low Frequency
- **LOFAR**. LOw Frequency ARray
- **MAG**. Magnetometer
- **MLA**. Magnetic Loop Antenna
- **MMO**. Mercury Magnetospheric Orbiter
- **NASA**. National Aeronautics and Space Administration
- **nKOM**. Narrow band Jovian Kilometric radio emission
- **non-Io-DAM**. Jovian auroral-oval Decametric radio emission
- **OPFM**. Outer Planet Flagship Mission
- **PDD**. Payload Definition Document
- **QP**. Jovian Quasi Periodic Bursts
- **QTN**. Quasi Thermal Noise
- **RBSP**. Radiation Belt Storm Probe
- **RFI**. Radio Frequency Interferences
- **RPW**. Radio and Plasma Waves

- **RPWI**. Radio and Plasma Waves Instrument
- **RPWS**. Radio and Plasma Waves Science
- **SCM**. Search Coil Magnetometer
- **SEAT**: Short Electric Antenna Triad
- **SKR**. Saturn auroral Kilometric Radiation
- **SSR**. Sub-Surface Radar
- **STEREO**. Solar TErrestrial RElation Observatory
- **TRL**. Technology Readiness Level
- **UV**. Ultraviolet

- c. Speed of light
- r_E. Earth radius (6371 km)
- r_J. Jupiter radius (71492 km)

5.2. Team Composition

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Sébastien Hess
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Yuto Kato,
Atsushi Kumamoto,
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Kanazawa University
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S. Yagitani

5.3. EMC Plan

It was decided with the EJSM MAG study team to write a common guideline that would gather the recommendation of both teams (RPW and MAG). The version provided here (see next 5 pages) is a draft version, additional inputs may be included later.

NB:
The latest version is available on demand to the EMSS leader (baptiste.cecconi@obspm.fr).

EJSM EMC requirements

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V1.1

27 July 2010

1 General Concept

The Radio and Plasma Waves (RPW) and Magnetometer (MAG) instruments will deal with low levels of electric and magnetic field, leading to sensitive receivers. Thus, electromagnetic cleanliness (EMC) is one of the most important requirements to the spacecraft system. In order to insure EMC, the EMC concept must be considered early by the EJSM project. In this purpose, an EMC board composed of experts from the spacecraft system and the PI instruments must establish a dedicated control plan and update it throughout the design and testing process. This control plan should contain all the needed assessments/analysis to demonstrate that the instruments are compliant with the EMC requirements, the design rules, the frequencies control plan, the testing concepts and the procedures. The EMC board will also consider and make recommendations on deviations and waivers to the EMC control plan.

2 Design Requirements

2.1 Grounding

The radio package should be compatible with the S/C system of the distributed single-point grounding scheme in accordance with the following guidelines:

- The main primary power bus return will be connected to the S/C ground structure at a single point.
- The radio analysers secondary power will be isolated from the primary power.
- The secondary power supply returns will be grounded to the spacecraft structure by a single point connection using an external and removable jumper.
- The spacecraft structure shall not be employed as a ground or signal return.

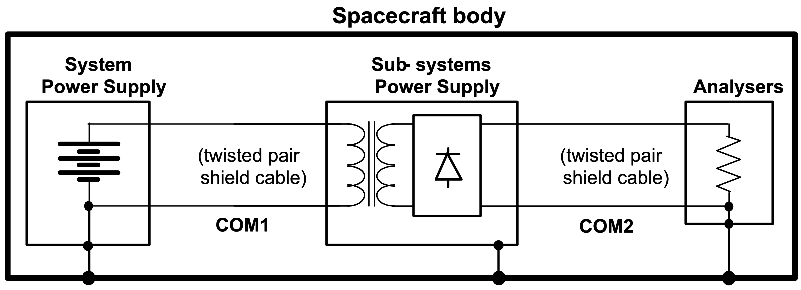


Figure 1 : Grounding diagram

2.2 Shielding and Electrical Bonding

- The radio experiment will be housed in a metallic box using non-magnetic materials that will form an electromagnetic shield.
- The apertures will be avoided and minimised when necessary
- The connectors will include a metallic outer shell bonded to the chassis.
- The electronic box will be grounded to the spacecraft structure, with a as low impedance as possible (i.e. 2.5mOhm max.)

2.3 Cable Shielding and Separation

- The lines of different EMC classes will be routed through separated harnesses and connectors.
- All the harnesses will have an over-shield grounded to the electronics box chassis.
- The active wires will be twisted with the return wire or inverted signal for differential signals. In order to minimize the wire loop, the twisted wires must be routed through a same connector on adjacent pins.
- The cables shield shall not be used as the return path for signal or power.
- The Harnesses layout shall permit the termination of cable shields at both ends on the connector metallic shell all-over 360 deg. If pigtails are necessary, their length shall be less than 5 cm.
- The ground connection of the shield via a connector pin is forbidden.
- The resistance between the harnesses shield and the radio units shall be less than 7.5mOhm.

2.4 Frequency Selection

The DC/DC converters are potentially a strong source of switching noise. They must be designed so that the global background noise level is as low as possible. Therefore, the power supply unit from all PI experiment should be crystal-controlled at a common frequency (e.g. 200kHz.)

As far as possible, the experiments oscillators should be have same fundamental and/or harmonic frequencies. A list of the frequencies used by the overall experiments should be reported in a frequency control plan, and updated throughout the instruments design and test phases.

2.5 DC Magnetic Cleanliness — MAG instrument

The DC magnetometer is assumed to consist of two boom mounted triaxial sensors, one at the end of the boom and one inboard at distance of around half the boom length. Measurement of the magnetic fields to an accuracy of less than or equal to 0.5nT leads to the following requirements on spacecraft interference at the outer magnetometer sensor position.

Spacecraft DC field (as measured at the outboard MAG sensor)	<2nT
Spacecraft AC field (as measured at the outboard MAG sensor)	0.1nT rms in the frequency range DC-64Hz
Sensor location	In sunlight

The presence of two boom mounted sensor will permit the use of a gradiometer mode whereby magnetic vectors are sampled simultaneously from both inboard and outboard sensors. This can be used to estimate the spacecraft moment in-flight by assuming the spacecraft fall off has a dipolar profile. On previous missions where the magnetic cleanliness has been less than fully effective the use of a gradiometer has proved an invaluable tool used in the process of generating well calibrated science data.

2.6 DC Magnetic Cleanliness — SCM sub-system

The use of magnetic materials shall be minimised in the design of the system. As a general guideline, hard magnetic materials such as ferromagnetic (permanent magnets) or stainless steel alloys should be avoided as possible. For DC/DC converters of the Main Electronics Box Power Supply only toroids will be used. These are generating no magnetic stray fields.

As a guideline, the use of magnetic material or high permeability shall be avoided or at least minimised. This concerns: Iron, nickel, stainless steel, inbar, high-permeability nickel-alloys, etc… When the used of magnetic material is unavoidable, the demagnetisation before integration to the spacecraft is required

As a baseline, the following numbers shall be considered:

- Static magnetic field strength at 1 m around SCM: <5nT
- Variation of the magnetic field (4s averaged) at 1m distance: <1 nT

The SCM sensors are located on a boom to stay away from the satellite EMC disturbance. However, this could not be enough for the very sensitive measurements. The experience feedback of the previous missions shows that a magnetic shield could be necessary for the disturbing units like the inertial wheels or the magneto-torquers. A sensor can be supplied for the tests to check if it is necessary. The same attention must be paid to the scientific instruments especially if they have motorized mechanical motions. Such cases should be avoided or otherwise it will be necessary to add a magnetic shield on the motors.

2.7 Electrostatic cleanliness

The target for the maximum differential potential on the spacecraft external surfaces when exposed to space plasma shall be 1 V. For this purpose, the resistance of the spacecraft outer MLI shall be as low as possible and well grounded to the spacecraft structure. If the target value proves not feasible, ESA shall discuss an acceptable alternate with the instrument teams before implementation. Thus:

- Space-exposed conductors shall be bonded to the spacecraft structure.
- Space-exposed harness dielectric shall be minimised.

Furthermore, for the prevention of internal charging, the conductive surface or materials not exposed to the plasma and not grounded to the structure should be bonded to the spacecraft structure with a resistance less than 1 MOhm.

3 Performance Requirements

3.1 Conducted and Radiated Emissions

The main sources responsible to conducted and radiated emissions are the DC/DC converters located in the Main Electronics Box.

An input filter needs to be implemented, both to minimise conducted noise present in the main power lines avoiding susceptibility problems, and to reduce the emission noise to levels fulfilling the relevant EMC requirements. In addition, a common mode filter is foreseen in the power input of the DC/DC converter.

The following guidelines will be adopted to reduce electromagnetic emissions:

- Input filter design with a safety margin.
- Balanced lines to transmit/receive signals within subsystems.
- Use of twisted and shielded pairs.
- Rise and fall time control to reduce spread spectrum emission.
- As far as possible, separated input and output circuits to avoid cross coupling.

Regarding the common mode emissions, limits should be established by the project on the power buses and the signal lines of each experiment.

Hereafter are the requirements regarding the common/differential mode and the radiated electric field:

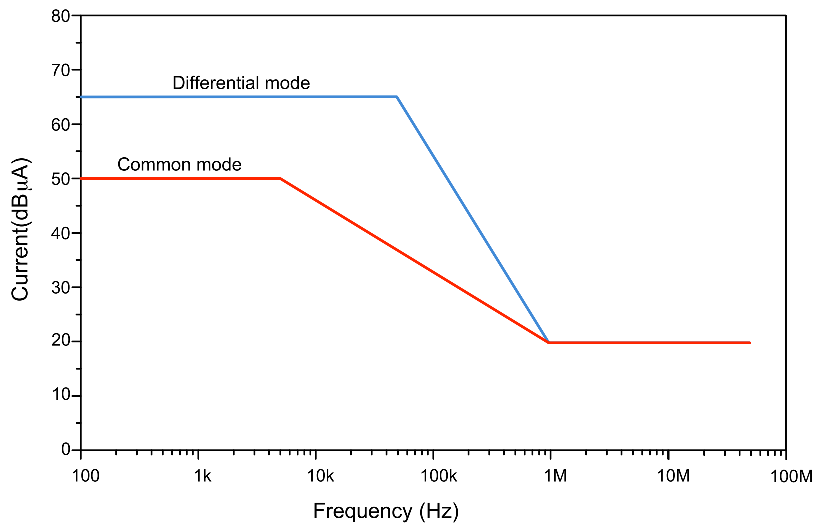


Figure 2 : Differential/common mode limits

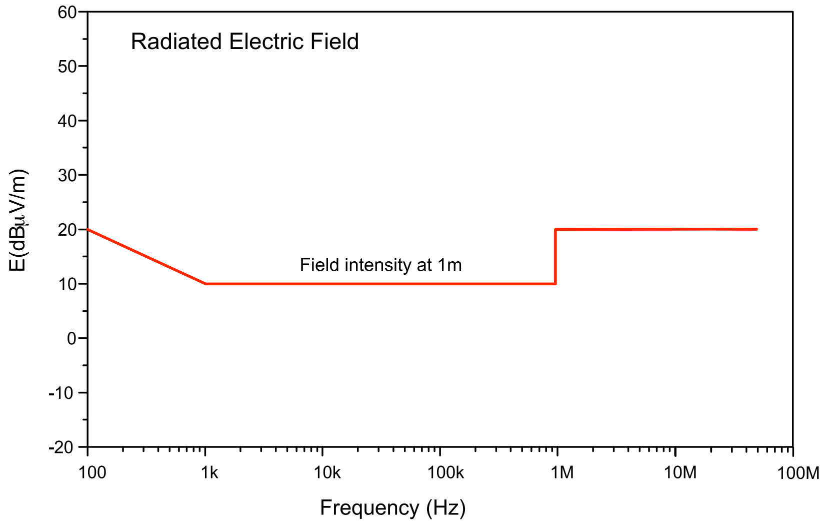


Figure 3 : Radiated electric field at 1m

3.2 Conducted and Radiated Susceptibility

The interconnections between the sensors preamplifiers and the Main Electronics Box are probably the most susceptible to the radiated emissions, depending on the levels of the electromagnetic surrounding fields. The hereafter design criteria will be used for low noise detection:

- Preamplifiers located as close as possible to the source, with a RC filter to avoid input stage rectification, and with sufficient gain to ignore contributions of other noisy sources.
- Balanced lines to transmit/receive interface signals.
- Twisted and shielded pairs with the over-shield grounded at the both ends.
- Over-shields grounded to the spacecraft structure at regular intervals (e.g. <15cm) to minimize high frequencies susceptibility.
- Shields not used as return path for signal or power.
- No current loops.

5.4. Radar Noise

The radar instrumentation that is developed for the EJSM mission is foreseen to transmit at frequencies ranging between 5 MHz to 50 MHz. This frequency range can be split into two ranges at ~40 MHz. Below that limit, the radio spectrum is dominated by very intense and sporadic cyclotron radio emissions (DAM) with sources located along high latitude field lines, close to the planet. At higher frequencies, the radio noise will be the combination of the galactic background and the synchrotron radiation emitted by the Jovian radiation belts. A deep understanding of the natural radio emissions at Jupiter is therefore necessary to prepare the future EJSM radar instrumentation.

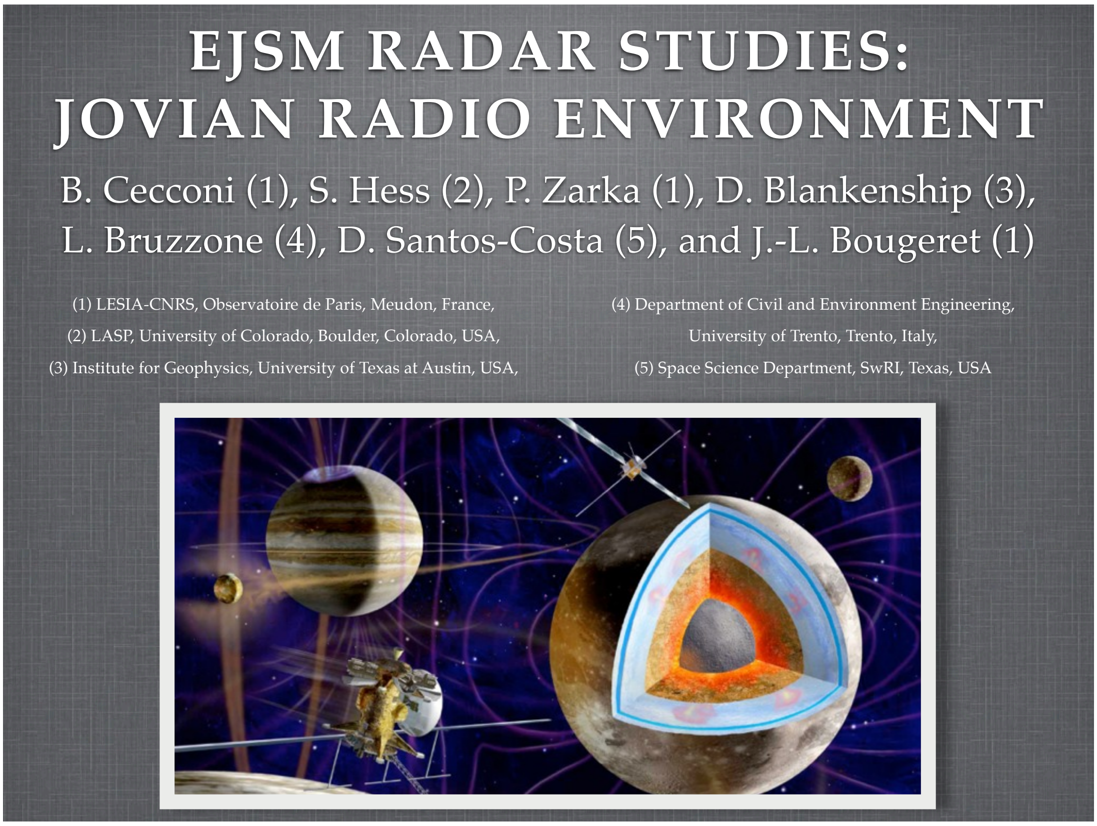
We have reviewed the properties (spectral intensity, variability) of the different natural sources of radio interferences and compared the flux density of these radio waves to the predicted signal strength of radar soundings at Ganymede and Europa. We have then used the ExPRES (Exoplanetary and Planetary Radio Emissions Simulator) tool to predict the occurrences (visibility) of high-latitudes radio emissions, as seen from the orbits of the Galilean satellites. This tool developed at LESIA covers all possible geometric configurations and could be used for operation planning.

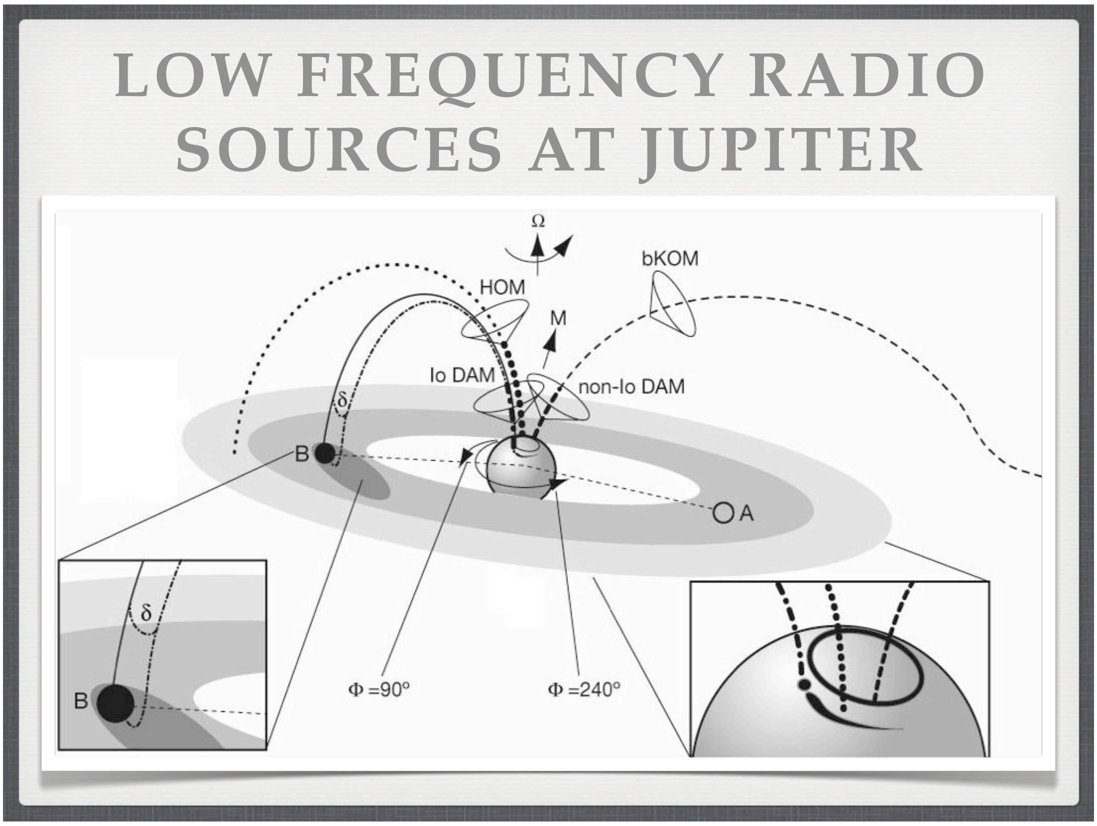
Our modeling indicates some favorable periods below 40 MHz, down to ~23 MHz, radio sources being always visible below this frequency. When the emissions are visible the radar instrument could operate in the satellite shadow zone. Possible ways to operate out of the shadow zones have been proposed (antenna diagram, polarization, localization).

We present in the next pages the slides presented at various meetings (see section 5.6).

NB:
The current draft version of the manuscript is available on demand to the EMSS leader (baptiste.cecconi@obspm.fr)

Radar Noise. Slides 1 & 2



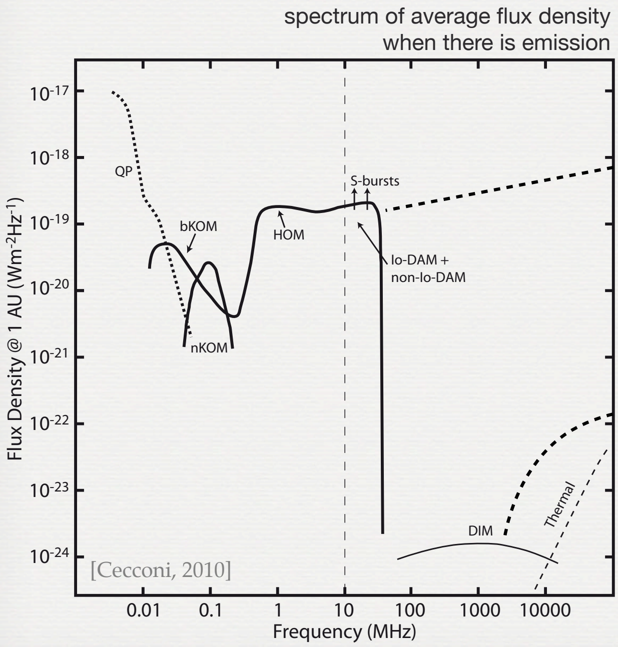


Radar Noise. Slides 3 & 4

RADIO EMISSION PROPERTIES

- Very intense:
  up to ~10 orders of magnitude more intense than jupiter black body (non-thermal).
- Sporadic
- Localized sources:
  auroral sources (above ~3 to ~40 MHz)
- Beamed
- Polarized

JOVIAN RADIO SPECTRUM



Non-Thermal Radio emissions (Auroras)

→ 10^{-19} $Wm^{-2}Hz^{-1}$ @ 1AU

⇒ 20 10^{-15} $Wm^{-2}Hz^{-1}$ @ Io

⇒ 5 10^{-15} $Wm^{-2}Hz^{-1}$ @ Europa

⇒ 2 10^{-15} $Wm^{-2}Hz^{-1}$ @ Ganymede

⇒ 0.6 10^{-15} $Wm^{-2}Hz^{-1}$ @ Callisto

Synchrotron emission (Radiation Belts)

→ 10^{-24} $Wm^{-2}Hz^{-1}$ @ 1AU

⇒ 20 10^{-20} $Wm^{-2}Hz^{-1}$ @ Io

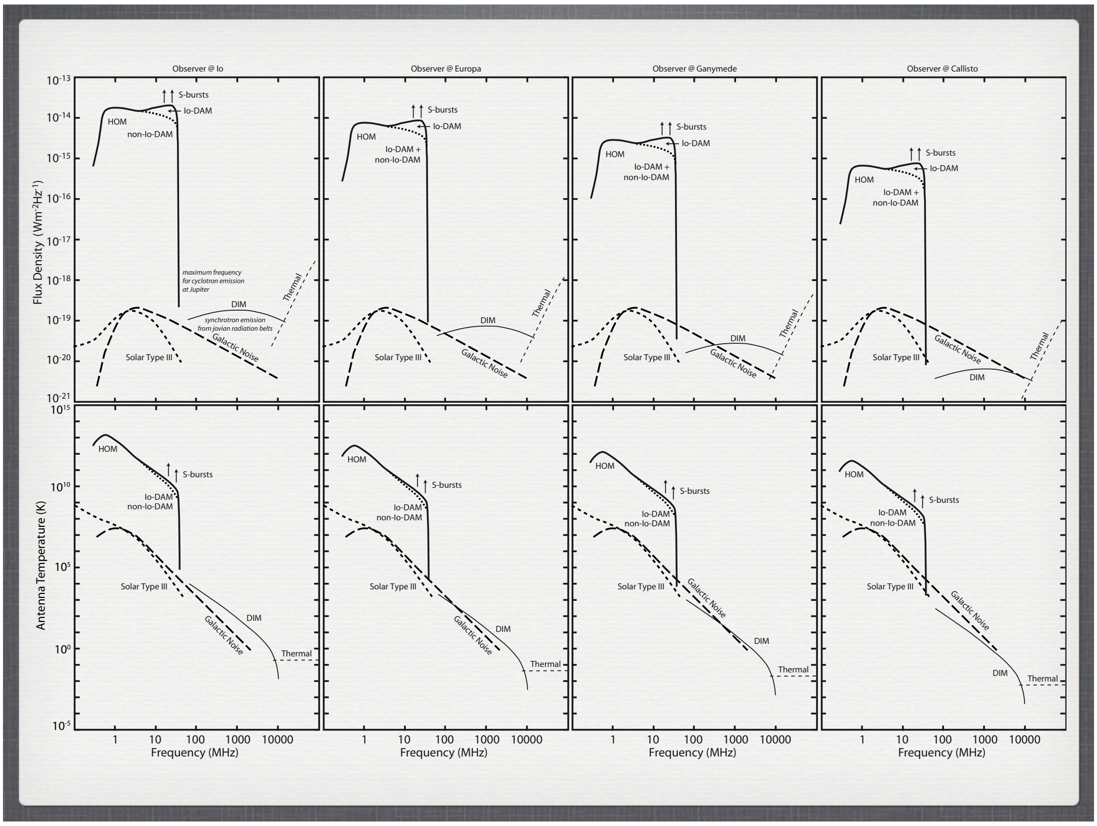
⇒ 5 10^{-20} $Wm^{-2}Hz^{-1}$ @ Europa

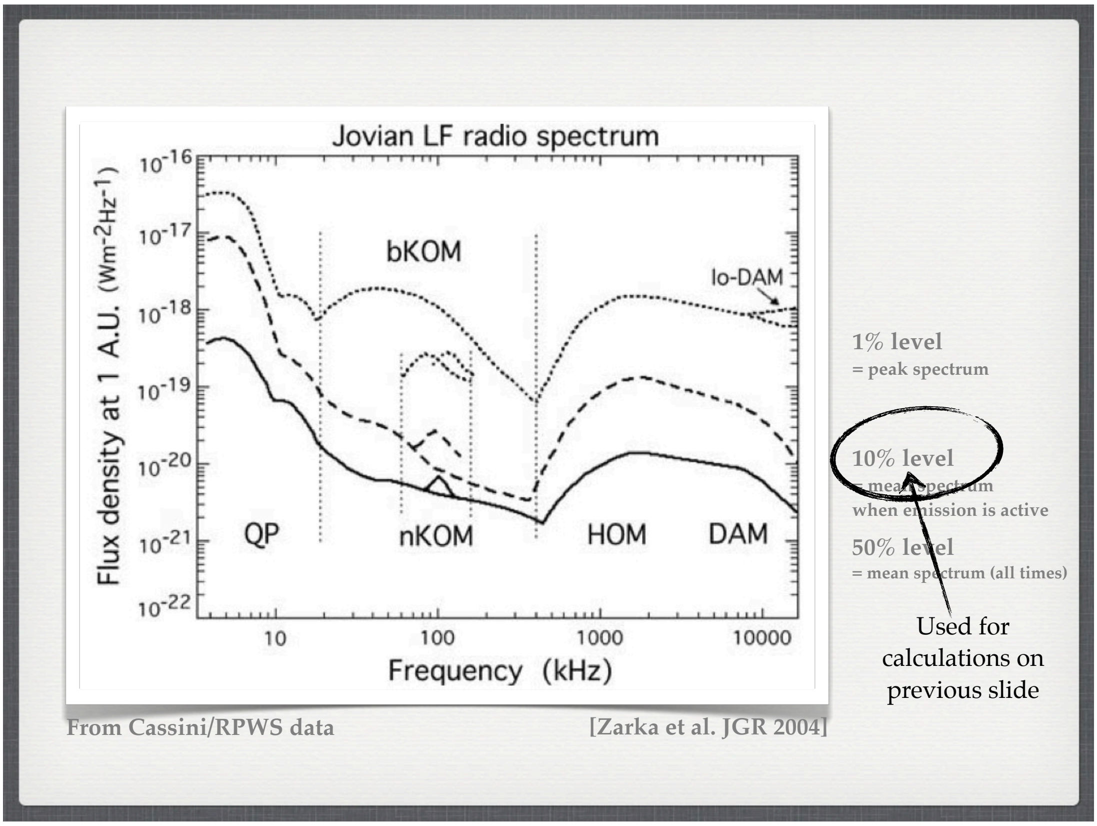
⇒ 2 10^{-20} $Wm^{-2}Hz^{-1}$ @ Ganymede

⇒ 0.6 10^{-20} $Wm^{-2}Hz^{-1}$ @ Callisto

NB: numbers are only orders of magnitudes

Radar Noise. Slides 5 & 6





Radar Noise. Slides 7 & 8

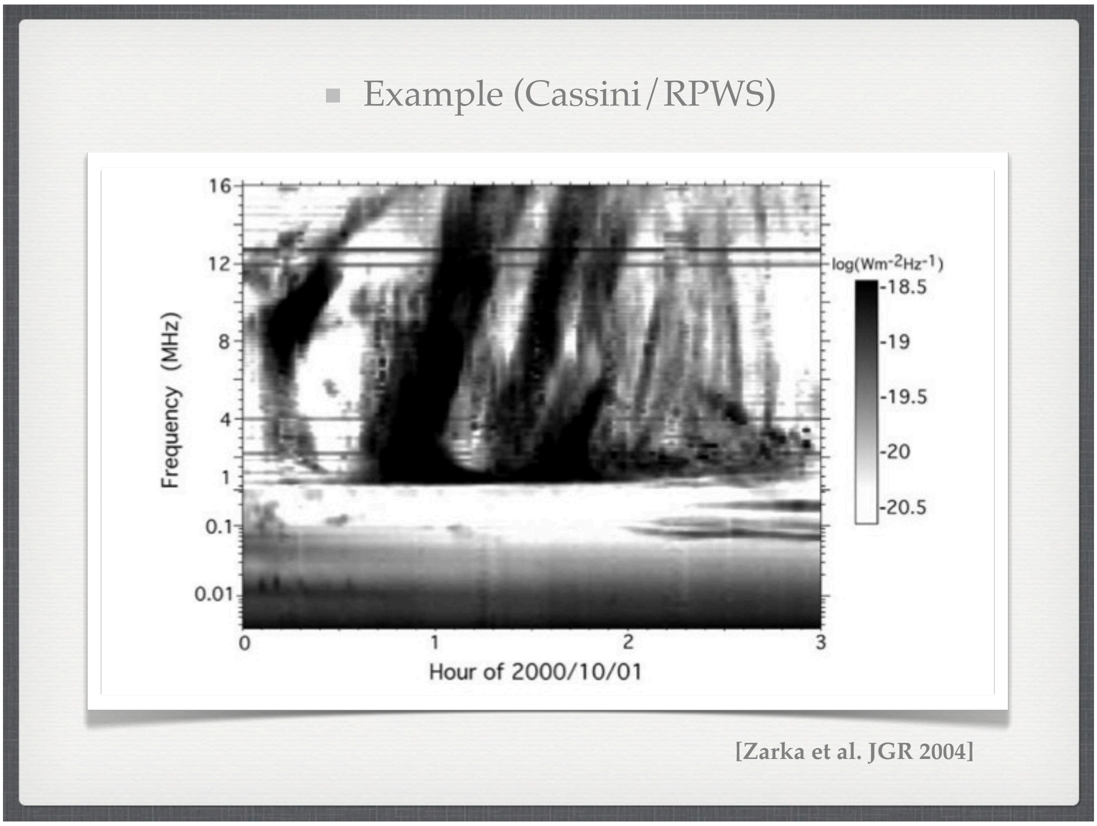
INTERFERENCES FOR RADAR STUDIES ?

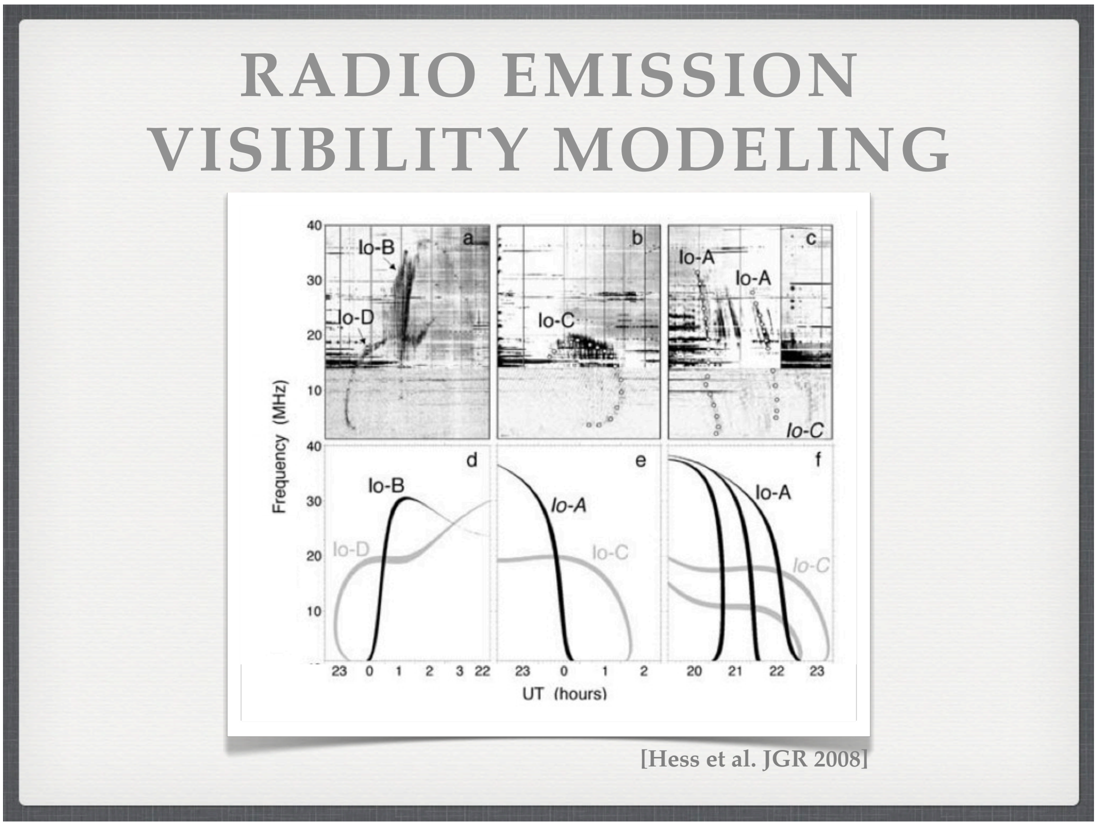
- When the jovian sources are active and visible, peak flux density of radio emissions is evaluated to:
  - 20×10^{-14} $Wm^{-2}Hz^{-1}$ @ Io
  - 5×10^{-14} $Wm^{-2}Hz^{-1}$ @ Europa
  - 2×10^{-14} $Wm^{-2}Hz^{-1}$ @ Ganymede
  - 0.6×10^{-14} $Wm^{-2}Hz^{-1}$ @ Callisto
- (Very) rough estimate of echo signal (20 W, 10 MHz band, 200 km orbit, 1% reflexion): ~10^{-13} $Wm^{-2}Hz^{-1}$
- ***Next step****: realistic radar equation for echo signal level estimates*
  - *input needed from SSR team*

VARIABILITY

- Visibility is predictable (we know where/when we could observe them)
- Occurrence is known on average (we know their periodicities)
- **But:**
  - sporadic
  - absolute occurrence *(within visibility and periodicity patterns)* is not predictable.

Radar Noise. Slides 9 & 10

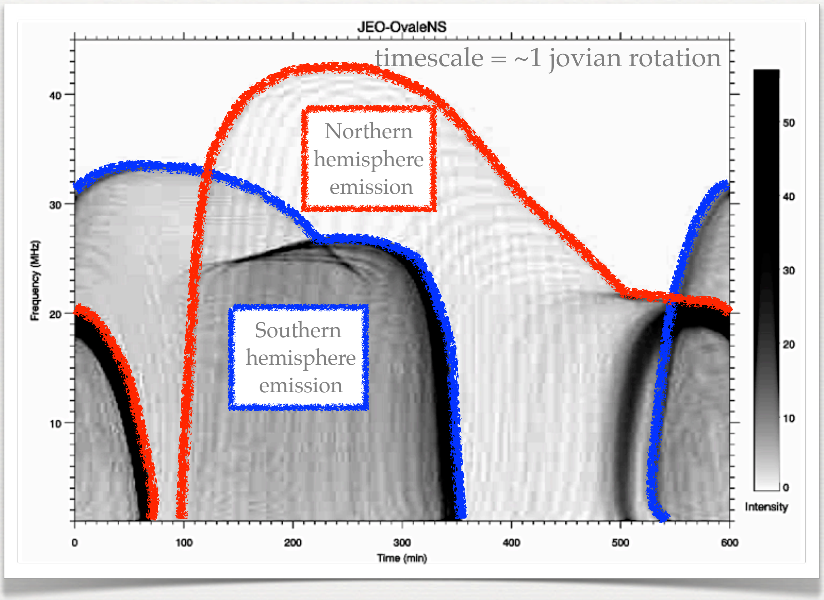




VARIOUS SIMULATIONS PARAMETERS

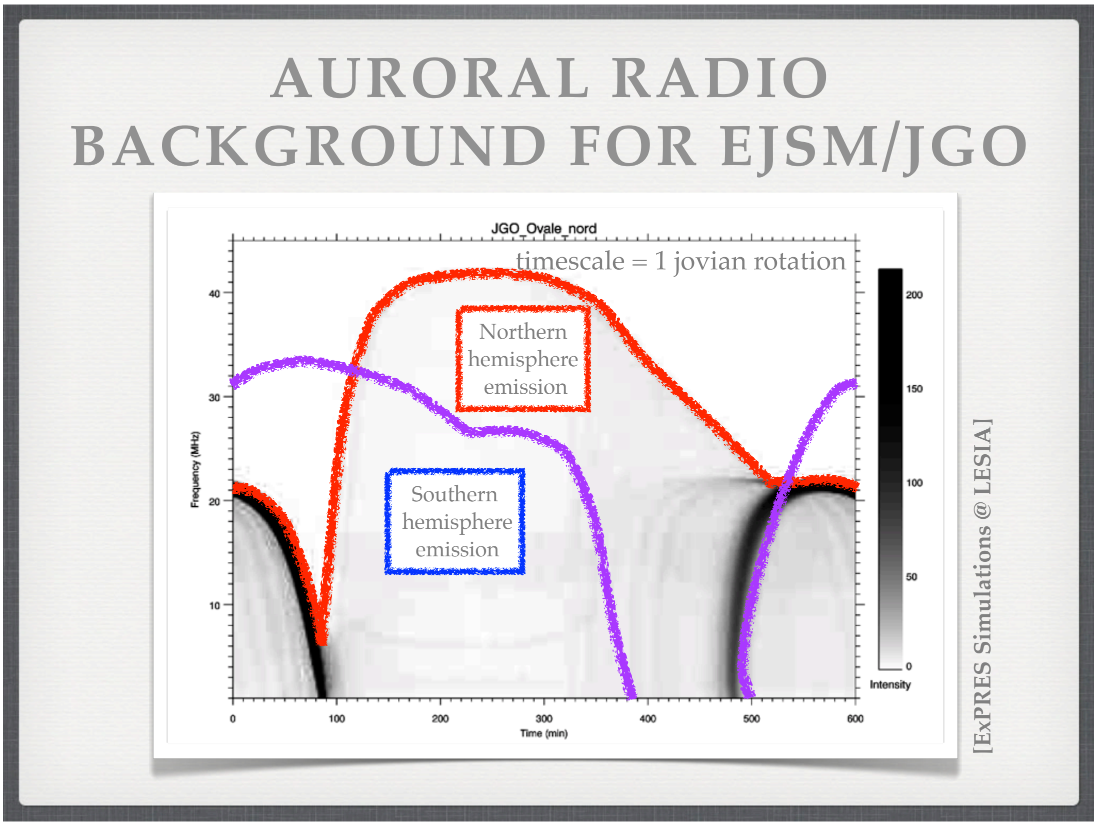
1. Auroral sources (HOM and Non-Io-DAM)
   - located on magnetic field lines with footprints on main auroral oval.
   - variable emission angle [Hess et al. 2008]
   - Model periodicity: 9 hr 55 min = 1 Jovian rotation.
2. Io controlled sources (Io-DAM)
   - located on magnetic field line passing by Io (+ lead angle)
   - variable emission angle [Hess et al. 2008]
   - Model Periodicity: 17 day 13 hr 12 min = 1 Jovian rotation (9 hr 55 min) × 1 Io orbital period (42 hr 29 min).

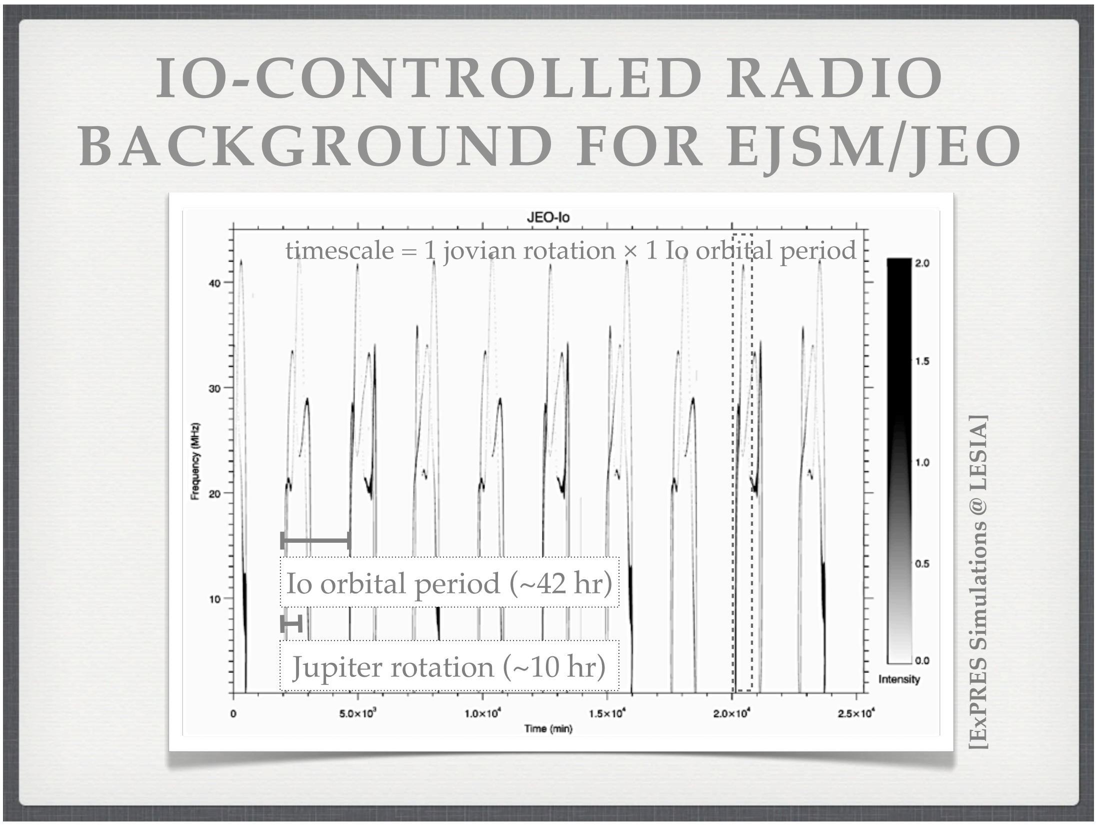
AURORAL RADIO BACKGROUND FOR EJSM/JEO



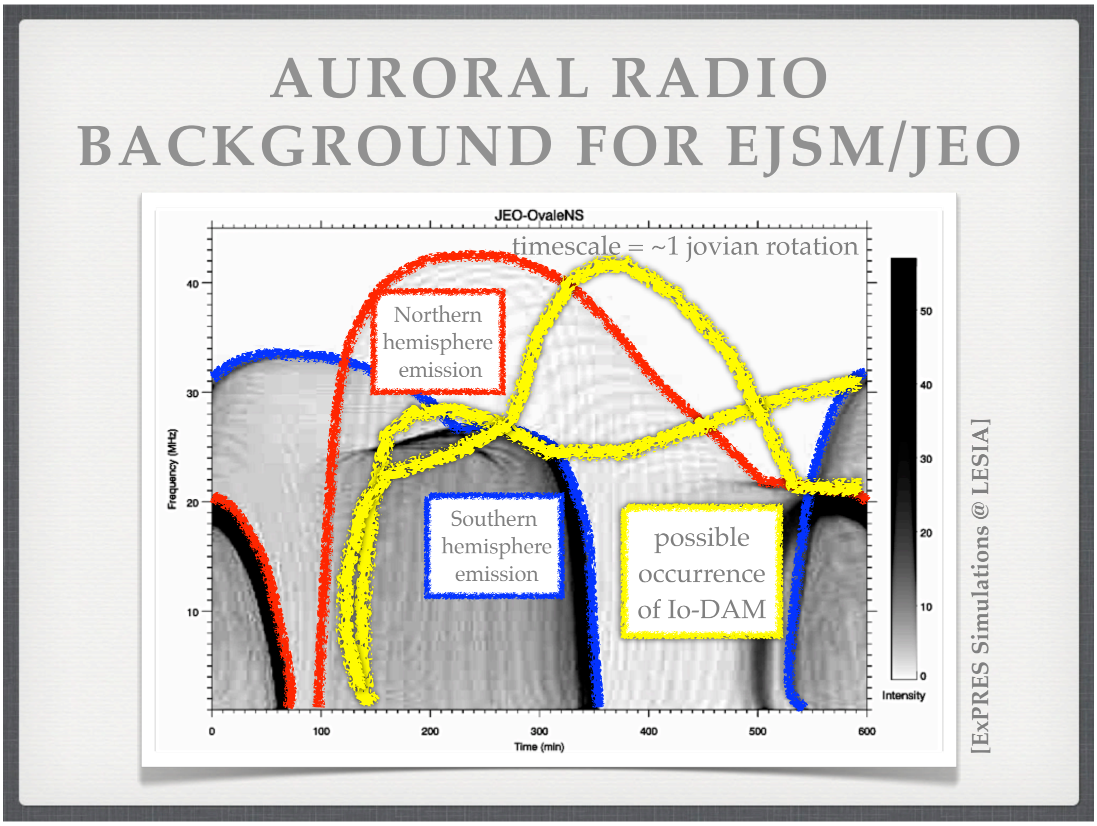
[ExPRES Simulations @ LESIA]

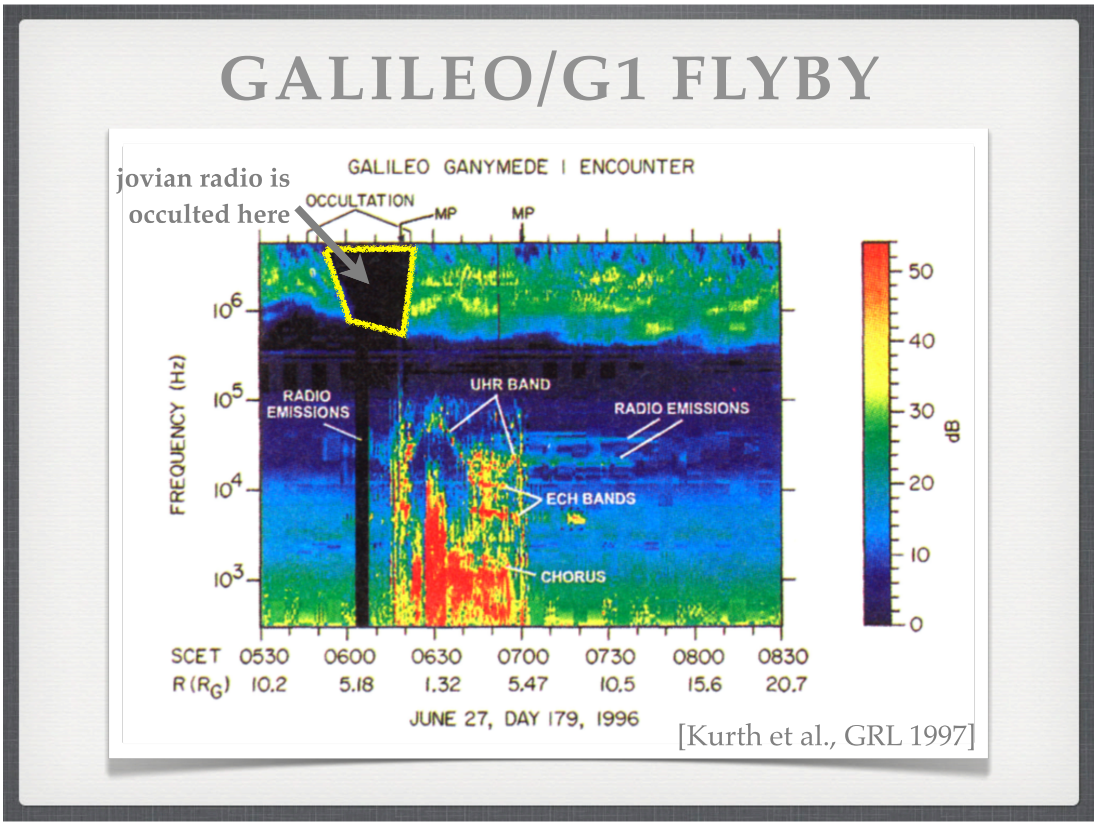
Radar Noise. Slides 13 & 14





Radar Noise. Slides 15 & 16



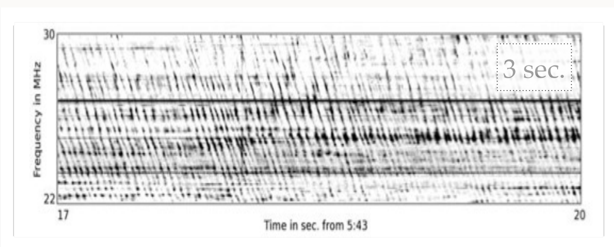


VISIBILITY MODELING CONCLUSIONS

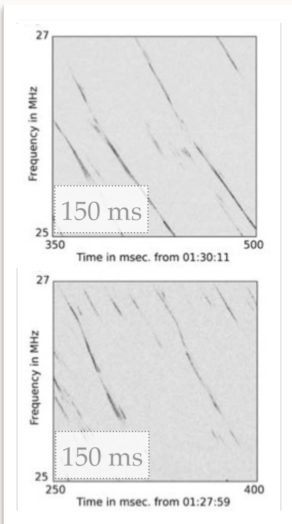
- Auroral emissions:
  visibility enveloppe is predictable.
  - at all times below ~22 MHz.
  - less than 50% of time above ~35 MHz.
  - no noise above ~42 MHz.
- Io controlled emissions:
  clean periods are predictable for entire frequency range.
- Otherwise: physical occultations.

RADIO EMISSION FINE STRUCTURES

- Fine structures in Io-DAM radio emissions: «S-bursts» or «millisecond bursts»



- May this interfere with chirp echoes ?

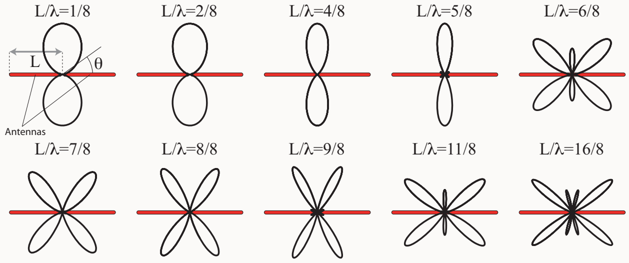


LOCALIZATION & POLARIZATION

- All emissions are fully polarized (circular or elliptical).
- Emission localization is roughly predictable
  (Radio instrumentation can localized accurately)
  => link with RPW instrument for monitoring ?
  (probably too early to decide anything at this point)
- Apparent polarization is thus predictable
  => can this be used to discriminate radar echoes from natural radio emissions ?

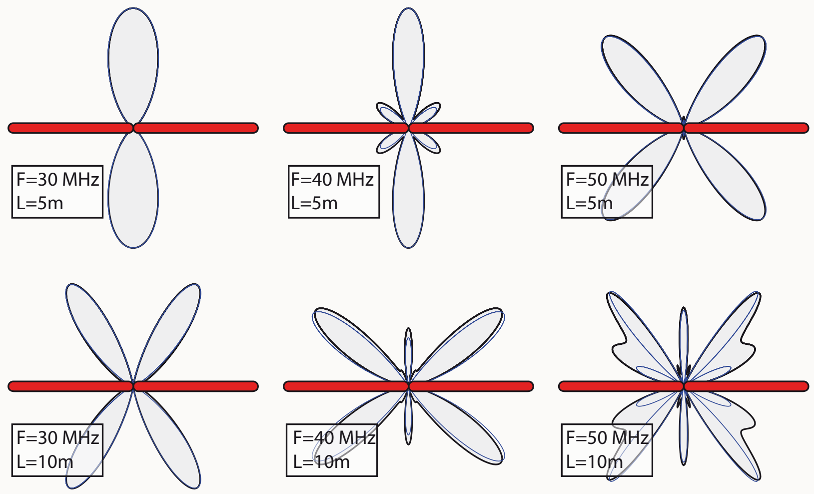
DIPOLE ANTENNA DIRECTIVITY

- The radar antenna is a dipole: in its short antenna regime *(when λ >> L, i.e. F < 2MHz for 10m antenna)* such an antenna shows a null along the antenna axis.
- At higher frequencies, the antenna pattern is more complex, and should be modeled, but the null in the antenna axis still exist.



Radar Noise. Slides 21 & 22

ANTENNA DIRECTIVITY (10 MHZ BAND)



CONCLUSION & PERSPECTIVES

- Echo signals may be of the order of peak flux density of non-thermal radio emissions.
- No interference from radiation belt synchrotron radiation.
- Possible use of physical occultation of jovian radio emissions, and of dipole antenna null.

5.5. RPW Science Synergies

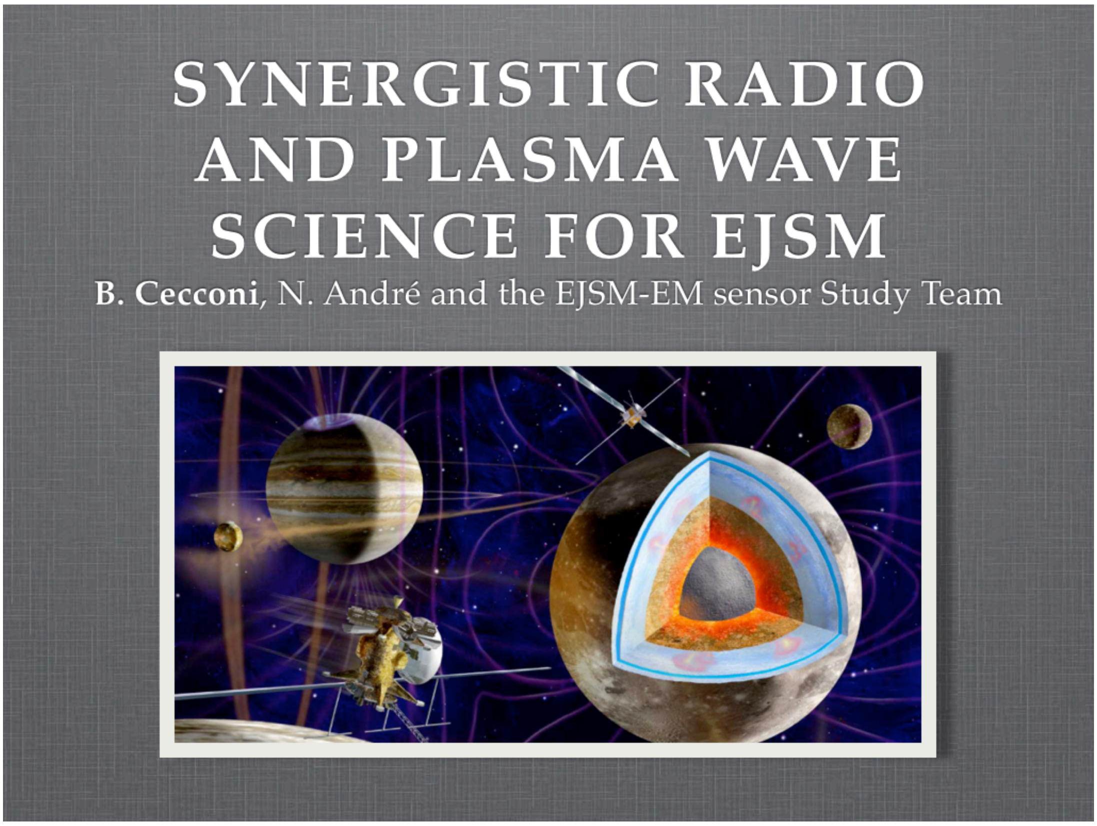
The radio and plasma wave (RPW) diagnostics provide a unique access to critical parameters of space plasma, in particular in planetary and satellite environments. Concerning giant planets, this has been demonstrated by major results obtained by the radio investigation on the Galileo and Cassini spacecraft, but also during the Ulysses, Voyager, and Pioneer flybys of Jupiter. Several other missions, past or in flight, demonstrate the uniqueness and relevance of RPW diagnostics to basic problems of astrophysics.

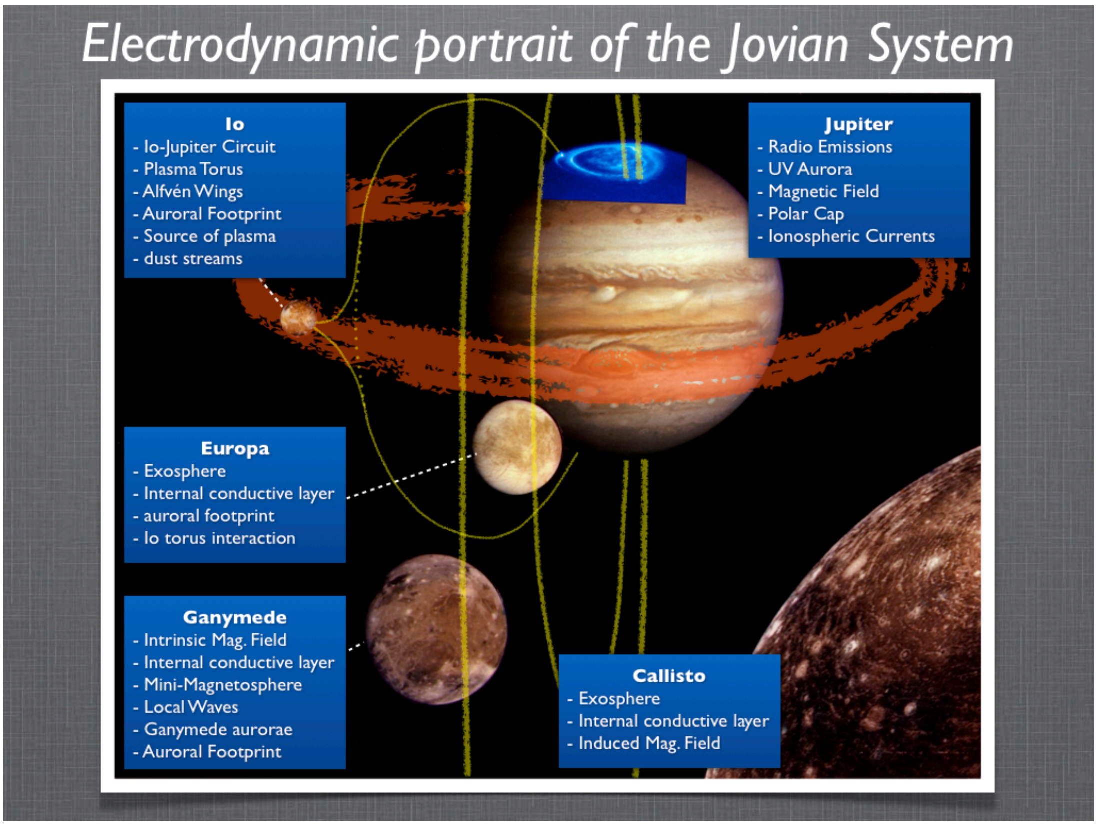
The EJSM mission consists of two platforms operating in the Jupiter environment: the NASA-led Jupiter Europa Orbiter (JEO), and the ESA-led Jupiter Ganymede Orbiter (JGO). JEO and JGO will execute a choreographed exploration of the Jupiter System before settling into orbit around Europa and Ganymede, respectively. The EJSM mission architecture hence offers unique opportunities for synergistic and complementary observations that significantly enhance the overall science return of the mission.

We review hereafter new and unique science aspects of the Jupiter system that may benefit from different capabilities of RPW investigations onboard JGO and/or JEO: spectral and polarization information, mapping of radio sources, measurements of in situ plasma waves, currents, thermal noise, dust and nano-particle detection and characterization.

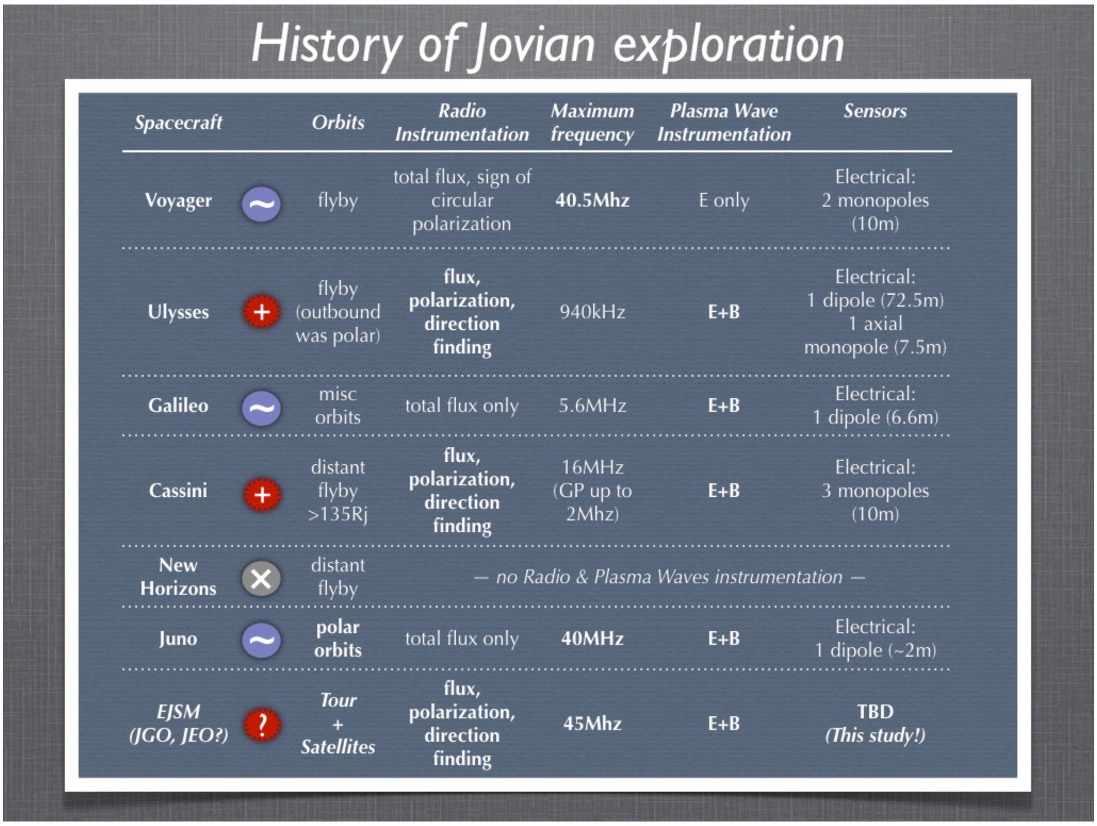
We then illustrate unique synergistic and complementary science opportunities offered by RPW investigations onboard JGO and/or JEO, both in terms of Satellite science and in terms of Magnetospheric Science.

We present here the latest version of the slides presented at several occasions (see section 5.6).


SYNERGISTIC RADIO AND PLASMA WAVE SCIENCE FOR EJSM
B. Cecconi, N. André and the EJSM-EM sensor Study Team

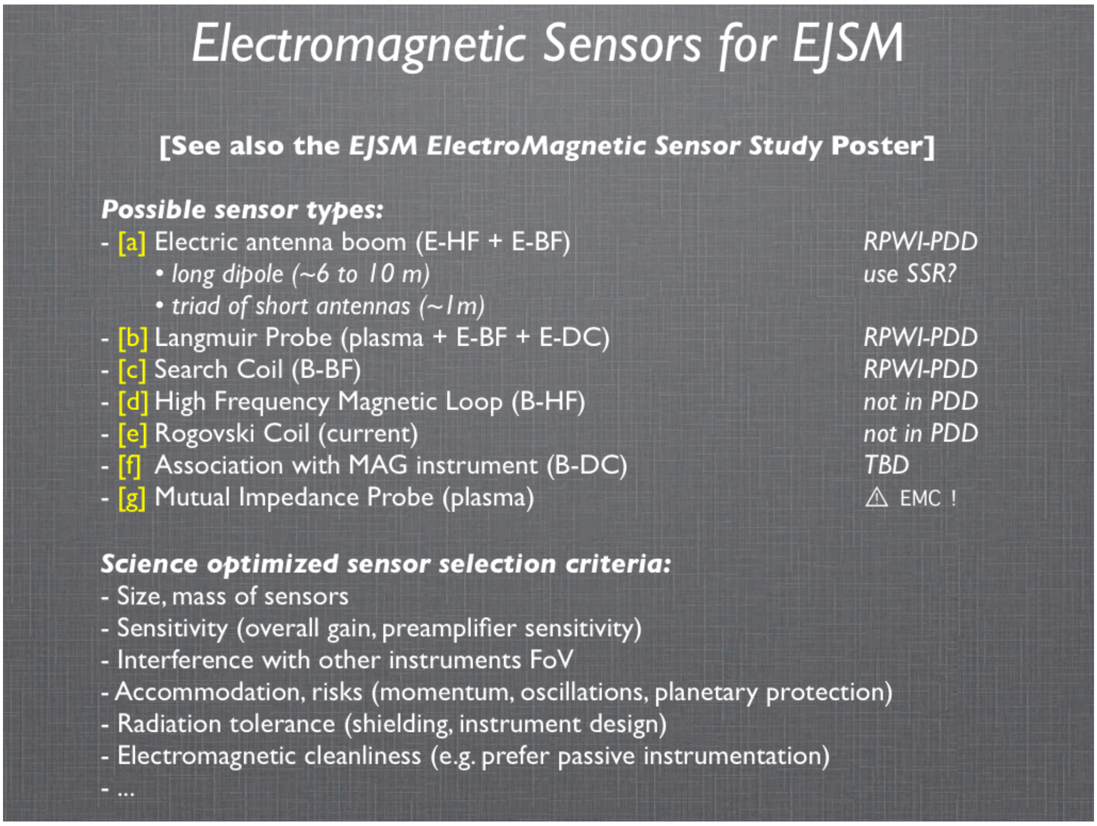

Electrodynamic portrait of the Jovian System
Io
- Io-Jupiter Circuit
- Plasma Torus
- Alfvén Wings
- Auroral Footprint
- Source of plasma
- dust streams
Jupiter
- Radio Emissions
- UV Aurora
- Magnetic Field
- Polar Cap
- Ionospheric Currents
Europa
- Exosphere
- Internal conductive layer
- auroral footprint
- Io torus interaction
Ganymede
- Intrinsic Mag. Field
- Internal conductive layer
- Mini-Magnetosphere
- Local Waves
- Ganymede aurorae
- Auroral Footprint
Callisto
- Exosphere
- Internal conductive layer
- Induced Mag. Field

RPW Synergies. Slides 3 & 4



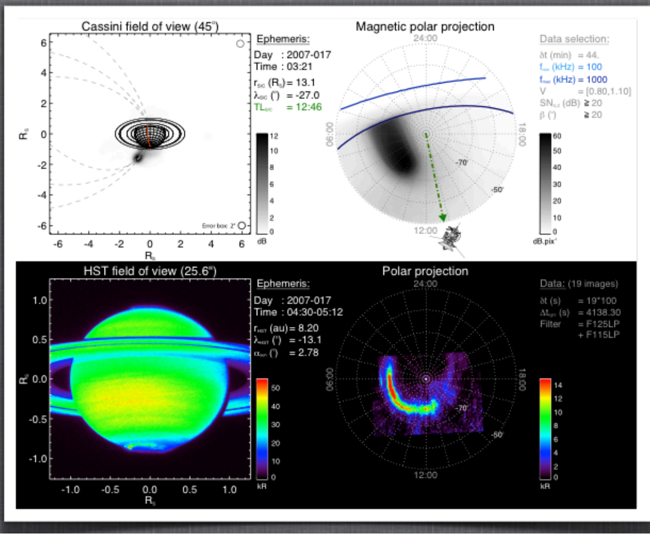
History of Jovian exploration

Spacecraft	Orbits	Radio Instrumentation	Maximum frequency	Plasma Wave Instrumentation	Sensors
Voyager	flyby	total flux, sign of circular polarization	40.5Mhz	E only	Electrical: 2 monopoles (10m)
Ulysses	flyby (outbound was polar)	flux, polarization, direction finding	940kHz	E+B	Electrical: 1 dipole (72.5m) 1 axial monopole (7.5m)
Galileo	misc orbits	total flux only	5.6MHz	E+B	Electrical: 1 dipole (6.6m)
Cassini	distant flyby >135Rj	flux, polarization, direction finding	16MHz (GP up to 2Mhz)	E+B	Electrical: 3 monopoles (10m)
New Horizons	distant flyby	— no Radio & Plasma Waves instrumentation —			
Juno	polar orbits	total flux only	40MHz	E+B	Electrical: 1 dipole (~2m)
EJSM (JGO, JEO?)	Tour + Satellites	flux, polarization, direction finding	45Mhz	E+B	TBD (This study!)



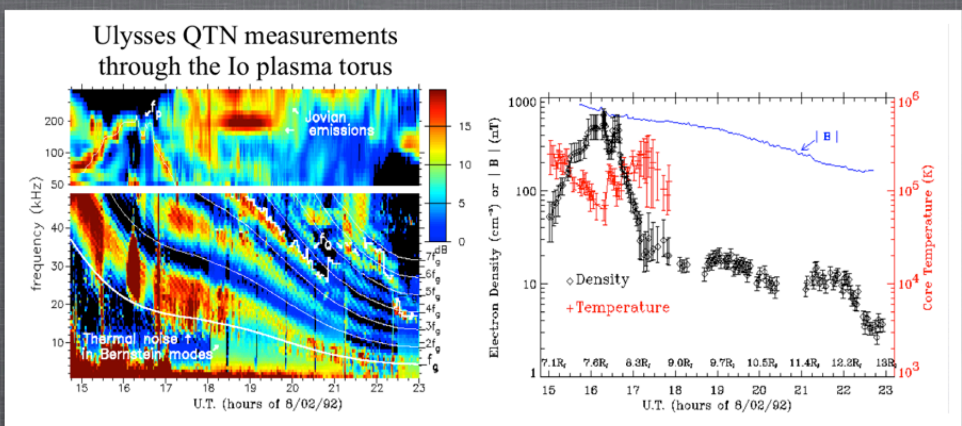
Unique Science Aspects

- **Goniopolarimetry**: [a] or [d], monopole or dipole, (*depending on EM-Sensor Study outcome*)
- **Thermal Noise Spectrometry**: [a] *with long antennas*
- **Dust, nano-dust**: [a] *with long monopole*
- **Plasma waves / waveform** [a] [b] [c] *with long dipole*
- **Local plasma parameters**: density [a] [b], temperature [a] [b], speed [e], S/C potential [b], magnetic field [a] [f], core/halo electron distribution [a]

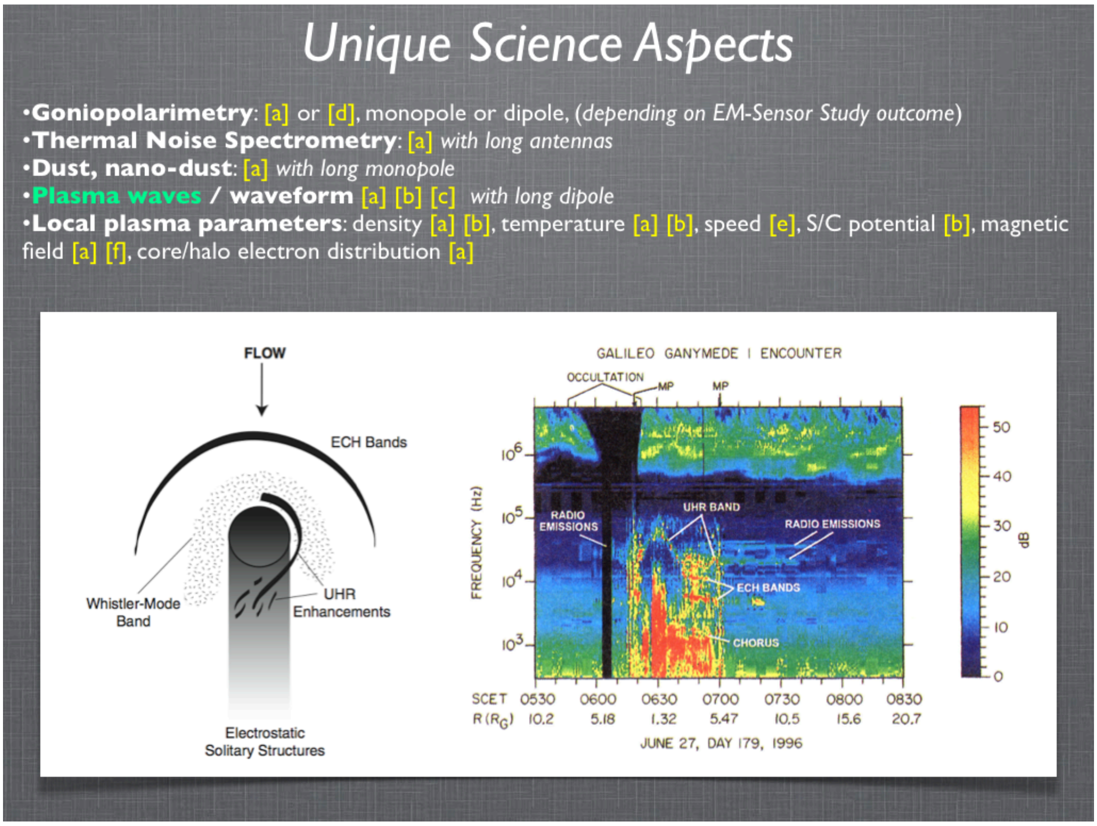


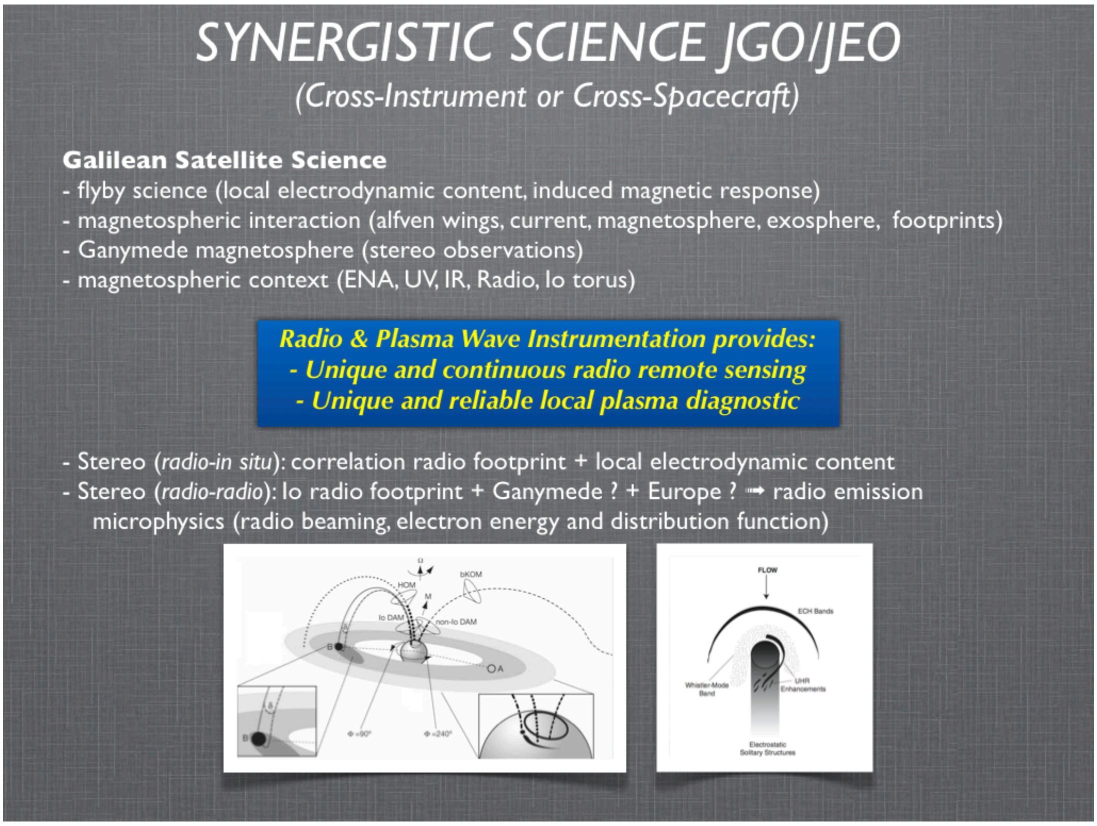
Unique Science Aspects

- **Goniopolarimetry**: [a] or [d], monopole or dipole, (*depending on EM-Sensor Study outcome*)
- **Thermal Noise Spectrometry**: [a] *with long antennas*
- **Dust, nano-dust**: [a] *with long monopole*
- **Plasma waves / waveform** [a] [b] [c] *with long dipole*
- **Local plasma parameters**: density [a] [b], temperature [a] [b], speed [e], S/C potential [b], magnetic field [a] [f], core/halo electron distribution [a]



RPW Synergies. Slides 7 & 8



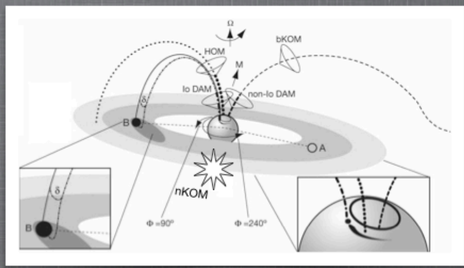


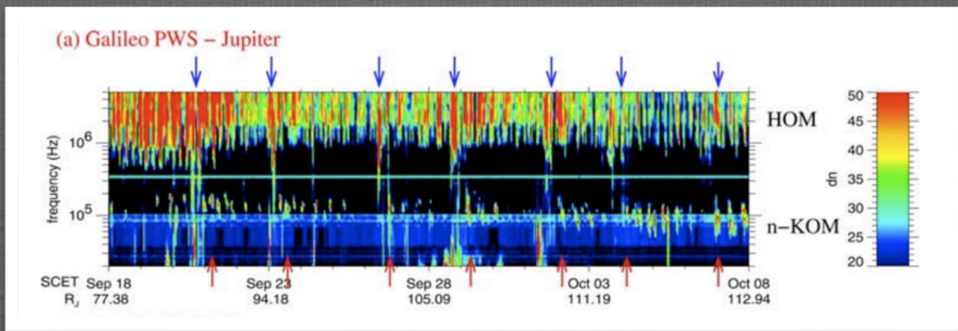
SYNERGISTIC SCIENCE JGO/JEO

(Cross-Instrument or Cross-Spacecraft)

Magnetosphere Science

- Stereo (*radio-radio*):
  - both inside magnetophere;
  - Solar Wind Spaceweather;
  - Io torus Spaceweather
- Latitudinal coupling (*radio* & *in situ*)
- Plasma wave interactions

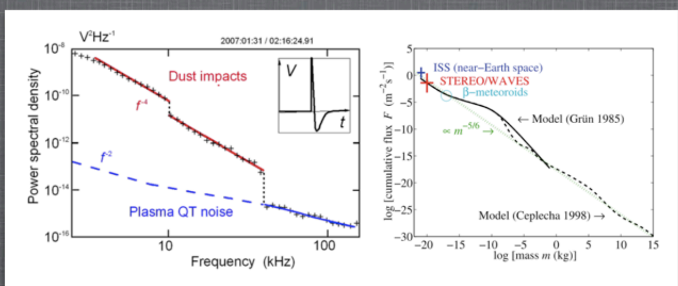




COMPLEMENTARY SCIENCE

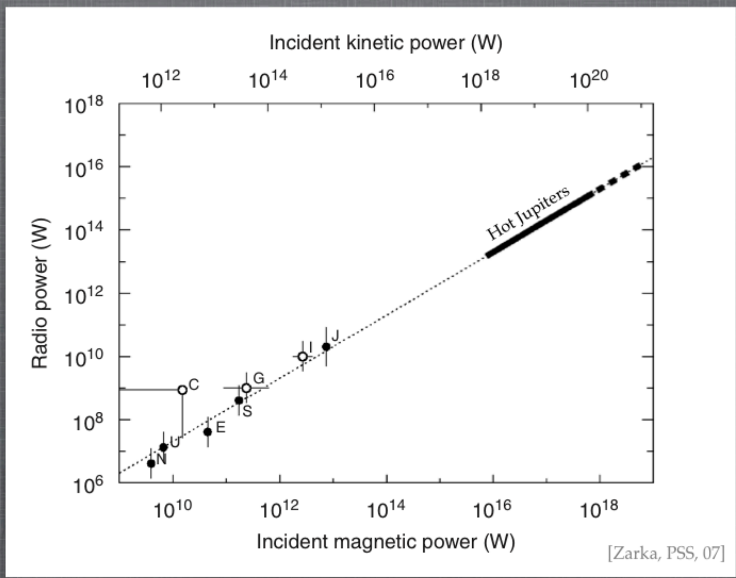
- dust ➟ sputtering ➟ surfaces [Surface]
- radio monitoring ➟ Radar intruments [Surface/Interior]
- calibration reference (plasma density + S/C potential) [plasma particle instruments]
- event triggering: burst mode observation, onboard boundary crossings detection, instrument mode change (cf STEREO, THEMIS) [Engineering]
- current detection ➟ magnetometer data ➟ interior magnetic field (cf ESA/SWARM) [Interior]
- diagnostic of onboard S/C activity/interference [Engineering]
- radio/UV ➟ auroral emission [Atmosphere]
- Ganymede/Io local aurora [Surface/Atmosphere]

Dust detection with STEREO/Waves



BEYOND PLANETOLOGY

"Radio Bode's Law"
astrophysical interest: radio signature of exoplanet



RPW instrumentation added value

- Unique jovian system space weather (Solar Wind, Io torus...) via remote sensing and in situ measurements.
- Unique stereoscopic mission concept opportunity.
- Pluri-disciplinary science.
- Passive and reliable local plasma parameters diagnostics necessary for other instruments.
- Strong collaboration/enhanced science return between instrument teams (see MAPS group on Cassini)
- Strong heritage in the community (Cassini, STEREO, Bepi-Colombo/MMO, JUNO, RBSP...)

5.6. List of Communications

Solicited Conference Presentations

- B. Cecconi, S. Hess, P. Zarka. *Jovian radio emissions modeling and their future investigation with EJSM*. **PRE-VII**, Graz, Austria, **2010**.

Conference Presentations

- B. Cecconi, N. André and the EJSM EM Sensor Study team. *Synergistic Radio and Plasma Wave Science for EJSM*. **EPSC**, Potsdam, Germany, **2009**.
- B. Cecconi, J.-L. Bougeret, T. Chust, M. Dekkali, C. Coillot, A. Marchaudon, C. Cavoit, N. André, H.O. Rucker, O. Santolík, P. Travnicek, J.-E.Wahlund, L. Åhlen, L. Blomberg, J.-P. Lebreton, W.S. Kurth, D. Kirchner, S.D. Bale, P. Turin, K. Goetz, R.E. Ergun, Y. Kasaba, H. Kojima, S. Yagitani. *EJSM Electromagnetic Sensor Study Report*. **3rd EJSM Instrument Workshop**, ESTEC, The Netherlands, **2010**.
- B. Cecconi, N. André. *Synergetic Radio and Plasma Wave Science for EJSM*. **3rd EJSM Instrument Workshop**, ESTEC, The Netherlands, **2010**.
- B. Cecconi, P. Zarka, S. Hess. *EJSM Radar instruments: Interferences from Jovian radio emissions*. **3rd EJSM Instrument Workshop**, ESTEC, The Netherlands, **2010**.
- B. Cecconi, N. André and the EJSM EM Sensor Study team. *Synergistic Radio and Plasma Wave Science for EJSM*. **EJSM Science Meeting**, ESTEC, The Netherlands, **2010**.
- B. Cecconi, S. Hess, A. Herique, M.R. Santovito, D. Santos-Costa, P. Zarka, G. Alberti, D. Blankenship, J.-L. Bougeret, L. Bruzzone, W. Kofman. *Natural radio emission of Jupiter as interferences for radar investigations of the icy satellites of Jupiter.* **AGU Fall Meeting**. San Francisco, California, **2010**.

Conference Posters

- B. Cecconi, M. Moncuquet, P. Zarka, M. Dekkali, J.-L. Bougeret, C. Briand, M. Maksimovic. J*ENRAGE (Jovian ENvironment Radio Astronomy and Ganymede Exploration): A Radio Astronomy Experiment for EJSM*. **OPFM meeting**, JHU-APL, Maryland, USA, **2009**.
- J.-L. Bougeret, B. Cecconi, M. Dekkali. *EJSM ElectroMagnetic Sensor Study*. **OPFM meeting**, JHU-APL, Maryland, USA, **2009**.
- B. Cecconi, N. André. *Synergistic Radio and Plasma Wave Science for EJSM*. **OPFM meeting**, JHU-APL, Maryland, USA, **2009**.
- B. Cecconi, and the EJSM EM Sensor Study team. *EJSM ElectroMagnetic Sensor Study*. **EPSC**, Potsdam, Germany, **2009**.
- B. Cecconi, S. Hess, P. Zarka, D. Blankenship, L. Bruzzone, D. Santos-Costa, and J.-L. Bougeret. *EJSM Radar Studies: Jovian Radio Environment*. **EGU Meeting**, Vienna, Austria, **2010**.

- B. Cecconi, S. Hess, P. Zarka, D. Blankenship, L. Bruzzone, D. Santos-Costa, and J.-L. Bougeret. *EJSM Radar Studies: Jovian Radio Environment*. **EJSM Science Meeting**, ESTEC, The Netherlands, **2010**.
- B. Cecconi, S. Hess, P. Zarka, A. Herique, D. Santos-Costa, G.Alberti, D. Blankenship, J.-L. Bougeret, L. Bruzzone, W. Kofman. *Natural radio emission of Jupiter as interferences for radar investigations of the icy satellites of Jupiter*. **OPFM meeting**, Universal City, California, USA, **2010**.

Peer-Reviewed Articles

- B. Cecconi, S. Hess, A. Herique, M.R. Santovito, D. Santos-Costa, P. Zarka, G. Alberti, D. Blankenship, J.-L. Bougeret, L. Bruzzone, W. Kofman. *Natural radio emission of Jupiter as interferences for radar investigations of the icy satellites of Jupiter.* To be submitted to **Planet. Space Sci. in nov. 2010**.
- B. Cecconi, N. André, J.-L. Bougeret. *Synergistic RPW Science Synergies at Jupiter*. In preparation for **Adv. Space Res**. **2010**
- B. Cecconi, J. Bergman, T. Chust, P. Zarka. *Coupled Electric and Magnetic measurements for planetary radioastronomy*. In preparation for **Radio Science 2011.**

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STEREO RPW Science Papers

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Jupiter Magnetosphere RPW Science Papers

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