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The Radio & Plasma Wave Investigation (RPWI) for JUICE – From Jupiter's Magnetosphere, through the Ice Shell, and into the Ocean of Ganymede

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Abstract

The Radio & Plasma Wave Investigation (RPWI) for the ESA JUICE mission provides an elaborate suite of electromagnetic fields and plasma instruments. Several different types of sensors will sample the plasma and the electric field, signals from radio and plasma waves, and act as a dust detector by counting transient emissions caused by micrometeorites hitting the spacecraft. RPWI focuses on cold plasma studies and will investigate how the transfer of momentum and energy occur in the different space environments, including the electrodynamic coupling with the icy Galilean moons. In Jupiter's magnetosphere, remote sensing and direction finding of the Jovian decametric radio emissions will be carried out. RPWI is also devoted to the ices and the deep interiors of the icy moons. Investigations of the ice shells will be performed by means of a novel passive ground penetrating radar technique, which utilizes Jupiter's strong decametric radio emissions as the transmitted signal. In Ganymede orbit, continuous measurements of the electric field, simultaneous with the JUICE Magnetometer (JMAG) measurements, will determine the electric coupling between any ocean, the ionosphere, and the magnetosphere, to provide constraints on the physical characteristics of the ocean of Ganymede, if it exists.

1. Introduction

The RPWI suite of instruments was selected by ESA as one of ten science payloads onboard the JUICE mission. The selection was based on our primary science goals [1] , which are focused on magnetospheric and ionospheric physics, as well as the heritage and experience of the RPWI Consortium members from previous ESA and NASA missions. The primary science goals include investigations of plasma electrodynamics in the Jovian system, identification of Alfvén and whistler waves by means of a searchcoil magnetometer, as well as studies of filamentary currents, flux ropes, and electrostatic structures involved in energy and momentum transfer between different particle populations in interaction between the Jovian magnetosphere and the ionospheres of the moons. Using Langmuir probe and mutual impedance measurements to measure the cold plasma characteristics, the proposed methods are also capable of inferring the ion drift speed. A radio antenna will be used to measure high frequency radio emissions in the Jupiter system. Their polarization and source locations in the auroral regions of Jupiter and Ganymede, as well as their variability with time and response to external forcing, will be determined. The Langmuir probes and the radio antenna will furthermore monitor electrically charged dust to identify dust-plasma interactions. Studies on open versus closed magnetic field lines at Ganymede, and observations of the electric field, which accelerate the particles, will give insight into surface sputtering processes. RPWI will as well have the capability to directly measure, *in situ*, the partially ionized gas exhaust of water-rich plumes above any active surface regions on the icy moons. The RPWI science performance is given in Table 1.

1.1. The Deep Interior: Ice and Oceans

After the selection, the RPWI Consortium has come to realize that we can do more than investigating magnetospheric and ionospheric processes, and address the JUICE mission's science goals related to the deep interiors. The RPWI suite of instruments is capable of targeting the ice shells and the oceans of the moons without modifications of the hardware. By operating the radio antenna as a passive ground penetrating radar, using the extremely powerful Jovian radio emissions as transmitter, it will be possible to characterize the electric properties of the ice shell of Ganymede, see Fig. 1, and, possibly penetrate the ice and measure its

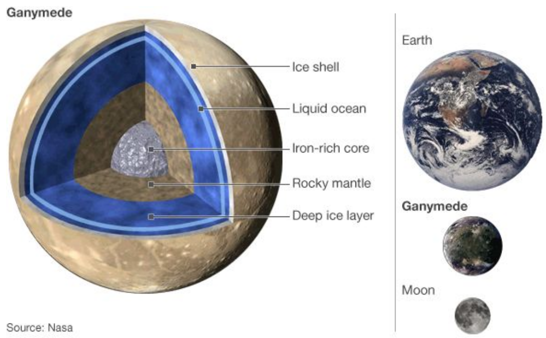

Figure 1: Deep interior of Ganymede (left) and size comparisons with Earth and Moon (right). ©NASA

thickness. RPWI will take snapshots of selected locations and data will be analyzed on ground. If successful, RPWI will ask for more observation time. Detecting the ocean of Ganymede is a primary science goal of JMAG but a detection could also be made by electric field measurements. RPWI will be in operation continuously in Ganymede orbit and work in parallel with JMAG. The salinity of the ocean and possibly the presence of ocean currents should be possible to estimate, or at least constrain. In addition, a double detection of the ocean by JMAG and RPWI, would make the discovery indisputable.

Table 1: RPWI Science Performance.

Quantity	**Range**	**Sensitivity**
Electric field vector, $\delta\mathbf{E}(f)$	DC–1.6MHz	<0.1mV/m, $2\mu\mathrm{V/m}/\sqrt{\mathrm{Hz}}$
Electric field vector, $\delta\mathbf{E}(f)$	80kHz–45MHz	$10\mathrm{nV/m}/\sqrt{\mathrm{Hz}}$ (@10MHz)
Magnetic field vector, $\delta\mathbf{B}(f)$	0.1Hz–20kHz	$20\mathrm{fT}/\sqrt{\mathrm{Hz}}$ (>@500Hz)
Electron density	10^{-4}–10^{5} cm^{-3}	<10%
Density fluct., δn	DC–10kHz	<10%
$\delta\mathbf{E}$ or δn interferometry	<1000 km/s	<10%
Ion density	1–10^{5} cm^{-3}	<20%
Electron temp.	0.01–100eV, <1Hz	<20%
Ion drift speed	0.1–200km/s	<20%
Ion temp.	0.02–20eV	<mVdi^{2}/2e
S/C potential	±100V,<1Hz	<10%
Integrated EUV flux	<1Hz	Res. 0.05 Gphotons/cm^{2}/s
Passive radar dynamic range	85dB	
Ice depth	<20km	<1km
Iceconductivity	2.5–10μS/m	

2. Inter-instrument Collaboration

The three JUICE *in situ* instruments, RPWI, JMAG, and PEP (Particle Environment Package) have been in collaboration from day one. We share similar science goals and will share our data in the future. A thorough investigation of the space plasma environment in the Jovian system is impossible without this collaboration. Our three payloads will also share data onboard. RPWI will receive magnetic field data from JMAG to align our electric field measurements with the magnetic field. PEP will receive the spacecraft potential from RPWI, needed for the charged particle instruments' calibration. RPWI will also receive ion data from PEP, to perform wave-particle interaction analysis on board. The low telemetry rate (1.4 Gbits/day) prevents such correlations to be performed on ground.

3. Summary and Conclusions

RPWI's main objective is to study space physics processes in the Jovian system, with emphasis on Ganymede. By using innovative techniques, RPWI will investigate its ice shell and help detect its subsurface ocean. Thereby, RPWI will contribute to many science objectives not foreseen when the instrument was selected for flight on JUICE. Close collaboration with the other two *in situ* payloads (JMAG and PEP), on ground and in space, will further enhance the value of our combined data sets.

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