EPSC Abstracts
Vol. 8, EPSC2013-744-1, 2013
European Planetary Science Congress 2013
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RIME: Radar for Icy Moon Exploration

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Abstract

The Radar for Icy Moon Exploration (RIME) has been selected by European Space Agency (ESA) as one of the instruments on board of the JUpiter ICy moons Explorer (JUICE). RIME is a nadir looking radar sounder designed to study the subsurface of the Galilean icy moons, Ganymede, Europa and Callisto. Its main science goals are related to the study of the subsurface geology and geophysics of icy moons and to detect possible subsurface water. This abstract briefly describes the main science goals of RIME, the technical challenges and the expected scientific returns.

1. Introduction

JUICE is aimed to study Jupiter and to investigate the potentially habitable zones in the Galilean icy satellites: Ganymede, Europa and Callisto. One of the most important sets of science goals for JUICE is related to the study of the subsurface geology and geophysics of icy moons and to detect possible subsurface water [1],[2]. According to these goals, in this paper we present the Radar for Icy Moon Exploration (RIME), which has been selected by ESA as one of the JUICE payload. RIME, which will be developed in cooperation between Italian Space Agency and NASA, is a radar sounder optimized for the penetration of the Galilean icy moons, Ganymede, Europa and Callisto, up to a depth of 9 km. This is a nadir-looking active instrument which transmits radio waves with the unique capability to penetrate deeply into the subsurface. When these radio waves travel through the subsurface, their reflected signal varies as they interact with subsurface horizons and structures with differing dielectric constants. These varying reflections are detected by the radar sounder and are used to create a depth image of the subsurface (a radargram). RIME will exploit and further develop the heritage developed for MARSIS [3] and SHARAD [4] currently operating at Mars. RIME is unique as it is the first instrument to Jupiter and the outer Solar System capable of performing direct subsurface measurements. Due to its distinctive subsurface mapping capabilities, RIME can address a large number of fundamental science objectives.

2. Science Goals

Two main operation scenarios are foreseen for RIME: flyby observations of Europa, Ganymede and Callisto and circular orbital operations around Ganymede at the end of the mission. According to these scenarios, RIME will explore the icy shell of the Galilean icy satellites by characterising the wide range of compositional, thermal, and structural variation found in the subsurface of these moons. These subsurface observations will provide insight into the dynamic history of the satellites, test models of the formation of their surface features, and constrain the distribution of deformation in their ice shells as well as global and regional surface ages. RIME may also constrain the ice shell thicknesses and the role of convective processes by detecting the ice-ocean interface if the ice is thin, and the brittle-ductile transition if the ice is thick. Moreover, radar sounding can be used to map the existence of thermal structures in thick ice shells. Liquid water is expected to exist in all of the icy Galilean satellites as a subsurface ocean and possibly inside shallow reservoirs within the ice shells. RIME will search for present and past reservoirs of liquid water. RIME will also relate the distribution of non-ice material to geological features and processes. Non-ice materials alter dielectric and attenuation properties, enabling RIME to characterise the depth profile of non-ice materials. The distribution of ice impurities can constrain the origin of non-ice materials and determine past or present material exchange with the subsurface.

These goals can be achieved by taking into account the observation capabilities of RIME. At interfaces where there is a significant difference between dielectric permittivities, such as at an ice-water interface, incident radar waves will be reflected. Like other electromagnetic radiation, radar waves are subject to scattering by interfaces or objects on the same scale as the radar wavelength. The inferred losses above detected interfaces can constrain the size of scatterers volumetrically within the ice. Attenuation of radio waves in ice is a function of both composition and temperature that change its dielectric properties. Cold pure ice has relatively few crystal defects or ions within its matrix, but as temperatures and dissolved ions (such as chlorine) increase, the electrical permittivity increases and penetration decreases.

3. Instrument Parameters

RIME will operate in a single frequency band, centred at 9 MHz, with a “chirp” pulse of up to 3 MHz bandwidth. The frequency was selected as the result of extensive study of penetration capabilities, surface roughness of the moons, Jovian radio noise, antenna accommodation, and system design. The 9 MHz frequency provides penetration capabilities and mitigation of surface scattering (which can cause signal loss and clutter issues), at the expense of mapping coverage, as it is likely to obtain high SNR observations only on the anti-Jovian side of the target moons due to the Jovian radiation noise. The RIME antenna is a dipole having a length of 16 m. The 9 MHz band also allows a relatively wide chirp pulse of up to 3 MHz, which provides vertical resolution of 50 m in free space, equivalent to ~30 m in ice. RIME will also operate at a lower resolution 1 MHz bandwidth, to reduce data volume when observing deep sounding targets. Within the high and low resolution modes, parameters can be adjusted to change the output data rate. Tab. 1 summarizes the main RIME parameters.

Table 1 – Main parameters of the RIME instrument

Main Instrument parameters	Parameter values
Transmitted central frequency (MHz)	9
Antenna type	Dipole
Optimal antenna length (m)	16 m
Peak radiated power (W)	10
Stand-by power with cont. (W)	13.3
Avg. power during sounding with cont. (W)	25.1
Penetration depth (km)	As deep as 9
Chirp length (μs)	50 - 100
Chirp bandwidth (MHz)	3, 1
Vertical resolution in ice (m)	30 - 90
Cross-track resolution (km)	2 - 10
Along-track resolution (km)	0.3 - 1.0

4. Conclusion

This abstract briefly described the Radar for Icy Moon Exploration (RIME). RIME has the capability of addressing a large number of science goals related to the JUICE mission. It is a key instrument for achieving groundbreaking science on the geology and the geophysics of Ganymede, Europa and Callisto.

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