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RIME and REASON on JUICE and Clipper: A comprehensive campaign to probe the icy satellites of Jupiter

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Abstract

The RIME and REASON radars that will fly on the JUICE and Clipper spacecraft in the 2020s will probe the icy shells of Europa, Ganymede and Callisto, moons of Jupiter. This paper addresses the complementary nature of the RIME and REASON experiments, and uses the similar complementary observations of Mars by MARSIS and SHARAD to anticipate results from the Jovian moon explorers.

The JUICE (Jupiter Icy Moons Explorer) and Europa Clipper missions both carry radar sounder instruments: RIME (Radar for Icy Moon Exploration) and REASON (Radar for Europa Assessment and Sounding: Ocean to Near-Surface), respectively. The two experiments are complementary in several ways. RIME (and JUICE) is focused on mapping the subsurface of Ganymede during the final phases of the JUICE mission, when the spacecraft is orbiting Ganymede. REASON (and Clipper) is focused on Europa, which will be visited ~40 times during Clipper's 3.7 year tour of the Jupiter system. JUICE is also planned to make a series of science flybys of Europa and Callisto, while Clipper will use Ganymede and Callisto for gravity assists, providing opportunities for calibration of science instruments prior to the main Europa campaign. RIME and REASON both carry a radar sounder that operates in the frequency band centered at 9 MHz, while REASON has an additional radar band centered at 60 MHz. The matched frequencies will allow direct comparisons of data acquired by the two instruments at different locations, on a given moon, or among the various moons. In particular, the dense mapping results from RIME at Ganymede can be compared to the REASON results of many dozens of flybys of Europa, to distinguish the key characteristics of the icy shells of the two moons. The radars will provide constraints on the composition, heterogeneity and structure of the icy shells, to further the understanding of the divergent path taken by the more completely resurfaced Europa compared with well preserved ancient features of Ganymede. A key goal for both missions is to elucidate the processes of exchange of material between the interior and surface of the moons. In the case of Europa, this likely involves relatively recent activity of liquid water at shallow depths, whereas the ice-liquid interface at Ganymede is thought to lie below the reach of the radar signals. Nevertheless, deformation of the upper crust of Ganymede has likely been affected by the mobility of deeper layers that are in contact with liquid water. This deformation should be expressed as the sometimes complex structure in the upper levels that will be mapped by the radars.

The dual-frequency capability of REASON has an analog in the two radar sounders that have been observing Mars for over 10 years, MARSIS on Mars Express, and SHARAD on Mars Reconnaissance Orbiter. While the frequencies of MARSIS and SHARAD (1-5 MHZ and 20 MHz, respectively) are not identical to RIME and REASON, their capabilities have been shown to be complementary in a similar fashion expected for REASON. To first order, a lower frequency system will probe more deeply, while a higher frequency system can obtain a higher vertical resolution due to a higher absolute signal bandwidth. In the Mars case, MARSIS has detected interfaces near 4 km deep below ice in the south polar region, and the strength of such deep echoes indicates a capability to probe even deeper, perhaps by a factor of 2. This deep penetration capability allowed MARSIS to map the basal interface beneath the polar layered deposits across most of both the north and south polar regions. SHARAD signals did not consistently detect the basal interface beneath the polar layered deposits, likely due to scattering losses at the surface and lower interface, as well as in the volume of the deposits.

However, the high vertical resolution of SHARAD provided a spectacular view of the internal structure of the polar deposits, and allowed the detection of thick lenses of remnant glacial ice in the mid-latitudes. The wave velocity and low absorption properties of CO_2 ice allowed its detection in large quantities intermingled with layers of water ice in the south polar region.

The 9 MHz bands on both RIME and REASON will be relatively insensitive to scattering by surface roughness and by buried scatterers. The presence of radio noise from Jupiter in this part of the spectrum may preclude some 9 MHz observations while Jupiter is in view, although we expect this noise source to often be minor or absent. The 60 MHz REASON band is outside the spectral region of Jovian noise and thus can map regions of the sub-Jovian surfaces. The RIME 9 MHz band can be operated at a higher resolution bandwidth (3 MHz), but any 60 MHz REASON observations of Ganymede will be highly complementary to RIME's for its even higher resolution and sub-Jovian capability. While the 9 MHz signals of RIME (and REASON) are not expected to reach the ice-ocean interface at Ganymede (thought to be ~100 km deep or more), there is a real possibility that the 9 MHz signals could directly detect Europa's ice-ocean interface. This depends on several factors, most prominently the depth of the interface, the transmissive properties of the overlying ice, and the thermal structure of the lowest parts of the ice above the ocean, where absorption may be highest.

Acknowledgements

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