TECHNICAL CHALLENGES IN THE DESIGN OF AN ICE PENETRATING RADAR FOR THE JUPITER ICY MOON

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Overview

- Radar for Icy Moon Exploration (RIME) is one of the proposed instrument for the JUpiter ICy moons Explorer (JUICE) mission.

- RIME is a radar sounder optimized for the penetration of the Galilean icy moons, Ganymede, Europa and Callisto, up to a depth of 9 km.

- Recently (Oct. 2012) a proposal to ESA for the development of the instrument has been sent, in response to the AO

- The proposal consortium is lead by the University of Trento (L. Bruzzone, PI)
Overview

- The RIME Lead Funding Agency (LFA) is the Italian Space Agency (ASI).
- The RIME Consortium includes the important institutes involved in the development, operation and data analysis of planetary radar sounders of the last decade, from both the European and the US side.
- From the technical point of view, the instrument will be developed by two main partners: a Prime Italian Industry selected by ASI and the Jet Propulsion Laboratory (JPL) of the US National Aeronautics and Space Administration (NASA).
Heritage

Example of radargram (SHARAD, 1069002)

MARSIS (ESA MARS express)

SHARAD (NASA MRO)
<table>
<thead>
<tr>
<th>Goals</th>
<th>Science Objectives</th>
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</thead>
</table>
| **Characterise Ganymede as a planetary object and possible habitat** | Characterise the extent of the ocean and its relation to the deeper interior  
Characterise the ice shell  
Determine global composition, distribution and evolution of surface materials  
Understand the formation of surface features and search for past and present activity  
Characterise the local environment and its interaction with the jovian magnetosphere |
| **Explore Europa's recently active zones** | Determine the composition of the non-ice material, especially as related to habitability  
Look for liquid water under the most active sites  
Study the recently active processes |
| **Study Callisto as a remnant of the early jovian system** | Characterise the outer shells, including the ocean  
Determine the composition of the non-ice material  
Study the past activity |
Science objectives

North pole of Mars as seen by SHARAD
Science objectives

Examples on the Earth
# Instrument Main Characteristics

<table>
<thead>
<tr>
<th>Specification</th>
<th>JUICE RIME</th>
<th>MARSIS</th>
<th>SHARAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating altitude (km)</td>
<td>200-1000</td>
<td>300-800</td>
<td>300</td>
</tr>
<tr>
<td>Antenna length (m)</td>
<td>16 desired (other lengths possible)</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Central frequency (MHz)</td>
<td>9</td>
<td>1-5</td>
<td>20</td>
</tr>
<tr>
<td>Bandwidth (MHz)</td>
<td>1, 3</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>PRF (Hz)</td>
<td>200-500</td>
<td>130</td>
<td>700</td>
</tr>
<tr>
<td>Chirp length (μs)</td>
<td>50-100</td>
<td>250</td>
<td>85</td>
</tr>
<tr>
<td>Peak radiated power (W)</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>ADC bits</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>ADC speed (MHz)</td>
<td>12</td>
<td>2.8</td>
<td>26.7</td>
</tr>
<tr>
<td>Sampling scheme</td>
<td>Direct</td>
<td>Down conversion</td>
<td>Direct</td>
</tr>
<tr>
<td>On-board process</td>
<td>Pre-summimg</td>
<td>Doppler filtering</td>
<td>Pre-summimg</td>
</tr>
<tr>
<td></td>
<td>Closed-loop tracking</td>
<td>Closed-loop tracking</td>
<td>Closed-loop tracking</td>
</tr>
<tr>
<td>Spatial resolution (km)</td>
<td>0.3-1 (ground processing)</td>
<td>3 (on-board process)</td>
<td>0.3 (ground process)</td>
</tr>
<tr>
<td>Data rate (kbps) in Ganymede orbital phase</td>
<td>216-250</td>
<td>10-30</td>
<td>2200</td>
</tr>
<tr>
<td>Data rate (kbps) in flyby phases (special operation)</td>
<td>2400</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>Profiling depth (km)</td>
<td>9</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Flat surface SNR (dB)</td>
<td>55 @ 200 km</td>
<td>50 @ 300 km</td>
<td>46 @ 300 km</td>
</tr>
</tbody>
</table>
The penetration capability of a radar sounder depends on the power ratio between the signal coming from a generic sub-surface interface (a change in the dielectric constant) and, generally speaking, noise that is related to disturbing and unwanted signal sources.
Jovian radio noise

Four radio components:
• Non thermal Jovian radio emissions emitted on high latitude magnetic fields line (Io-DAM, non-Io-DAM, and S-burst)
• Synchrotron radiation from the Jovian radiation belts (DIM)
• Solar radio emission (Solar type III bursts)
• Galactic noise background emission

Natural Jovian radio emission:
• Cutoff frequency at 40 MHz
• Sporadic
• Beamed (beaming pattern is a thin conical sheet)

Antenna temperature of the radio emissions at Jupiter observed at Ganymede in K (Cecconi et al 2010)
The radio background coming from Jupiter and Ganymede is localised and it should be weighted by antenna pattern considering its angular extension.
Surface clutter is generated by off-nadir echoes (B) recorded at the same time of subsurface returns coming from the nadir direction (A).

Off-nadir returns are caused by surface topography and roughness.

The discrimination between clutter and sub-surface echoes can be done on the basis of the knowledge of the surface topography.
Surface clutter

Example of SHARAD radargram of the North Pole of Mars

Clutter can be:
- reduced by “reducing” the surface roughness, i.e. decreasing the central frequency of the radar.
- predicted by exploiting Digital Elevation Models of the surface.
Evaluation of clutter is based on expected terrain backscattering, that can be calculated by estimating the statistical parameters of the surface (either classical or fractal)
Radio noise and clutter issues mainly driven the choice of a low transmitted frequency and the radar operation in the anti-Jovian part of the orbit.
Signal attenuation in ice


- It permits to evaluate ice attenuation as a function of ice temperature and for different concentration of impurities
- It gives suitable ice temperature profile for Europa and Ganymede


- It gives suitable ice temperature profile for Europa and Ganymede
• Both the references supposed that the top ice shell is divided in a conductive stagnant lid and a convective layer.

• In the conductive layer, the temperature follows the heat diffusion law (including possible tidal heating). The convective layer is expected to be well-mixed, and its temperature profile follows the adiabatic transformation of water ice, where the temperature is almost constant for the expected pressure range.
Signal attenuation in ice

- For Europa two different scenarios in term of ice temperature profile have been considered.
SNR results

Ganymede

Detection threshold

Europa

Detection threshold
SNR results

Altitude = 500 Km
Volume scattering = 3 dB/Km
Subsurface contrast = 0.1

Absorption (@250 K) = 0.05 dB/m
Conclusions

• RIME is a crucial instrument for the JUICE mission. This is the only instrument capable of direct measures of the icy moons subsurface. These measures are acquired for the first time in the Jupiter system!
• RIME is associated with fundamental science goals with potential strong impact on the science returns of the mission.
• Recently (Oct. 2012) a proposal to ESA for the development of the instrument has been sent, in response to the AO
• The performance of the instrument have been evaluated taking into account the expected signal attenuation in ice and the effects of disturbing contribution such as surface clutter and Jovian radio noise
• The resulting trade-off analysis has allowed the choice of transmitted frequency, bandwidth and radar operation (anti-Jovian part of the orbit) strategy