Study into Ultra-Wide-Band SAR Tomography over Dry, Rocky Terrains

Executive Summary Report

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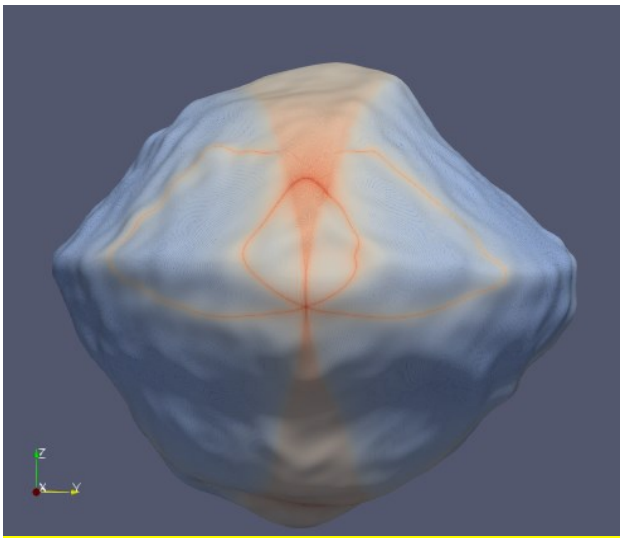
1 PICTURE



2 MOTIVATION

In recent years, surface-penetrating radars have formed a part of several ESA missions in both monostatic and bi-static configurations. Such radars can be found, for instance, on board Mars Express where, using MARSIS the Martian sub-surface is sensed, as well as on board Rosetta where CONSERT has been used to probe the comet 67P/Churyumov-Gerasimenko. In addition, surface-penetrating radars are being implemented for the JUICE mission to Jupiter's moons Ganymede and Europa. Meanwhile back on Earth, the airborne radar IceSAR has been flown over the ice sheets of Greenland and Iceland while – even if it is not actually a UWB radar – the Biomass mission has, as a secondary objective, ground-penetrating radar for determining the geology of arid regions.

Surface-penetrating radar associated with repeat-pass observation and processing opens the way to 3D radar tomography: typically resulting in 3D imagery of the first tens of metres of the sub-surface at metric resolution to understand and to model better the formation processes and post-accretion evolution. This technique has been proposed for several planetary missions to small bodies, especially in the frame of several M-class Cosmic Vision missions (Castalia, Marco Polo, PhoDex), planetary defense missions until phase AB1 on AIM/ESA and Hera/Juventas/ESA, and under-selection for a NASA/Discovery mission.

For both small bodies and airborne radar, the instrument specificity is to be ultra-wide band in range and / or Doppler in association with complex trajectories especially in case of multiple pass observation campaigns. This drives the instrument performance and finally the assessment of the science return as a function of the mission's constraints (in particular orbitography and data volume).

The main objectives of the activity described in the scope of this contract is to study UWB SAR tomography in dry rocky media for Earth and planetary remote sensing. This shall be achieved through:

- Development and implementation of a surface backscatter model for rocky terrains, adapted to ultra-wide band radar signals,
- Development/adaptation of a SAR simulator and
- Development/modification of a tomographic SAR simulator for dry rocky terrains.

3 METHODOLOGY

Each of these three main tasks were performed almost sequentially, as the results of one tasks are the input for the next one. Due to heavy computations, the numerical experiments required to evaluated performances were conducted in parallel to research activities.

The project took place from January 2017 to end of June 2019. Seven progress meetings were organized with ESTEC experts for validation of the intermediate results and fruitful discussions.

Each task was ended with the delivery of a work description and results report (DD1, DD2, DD3). Each task also output software prototypes (in IDL language, SW1, SW2, SW3, SW4, SW5). The prototype and scenarios assessment scripts are based on IPAG's SPRATS radar computing backend which has been delivered in an executable binary form.

4 RESULTS

- Selection, software prototypes and validation of two scattering models applicable to UWB radar signal for the observation of small bodies:
  - Surface mode: **Kirchhoff Approximation**
  - Volume mode: **Born Approximation**

- Scenario definitions for model and processing validation
  - Earth-based observation
  - **Small body case (asteroid 1999 KW4)**

- Selection, software prototype and validation of a tomographic algorithm adapted to the UWB radar signal:
  - **Compressive sensing**

5 HIGHLIGHTS

The particularities of UWB radar observation on small bodies come first from the geometry of observation which deviate significantly Earth Observation and second from the UWB in both Dopper and Range domains which questions the classical speckle model.

UWB radar observation is a classical technique in Earth observation geometry, but no such instrument has ever studied a small body. Yet, the geometry of observation differs significantly from the Earth Observation, and the UWB technique questions the hypotheses usually set in the definition of the speckle model and in the standard SAR synthesis. A specific addition activity was focused on the characterization of the behavior of the scatterers in that context

6 PUBLICATIONS

Gassot O, Herique A, Rogez Y, Buck C, Ultra-Wideband SAR Tomography on asteroids, (2017) ,*5th Workshop on Advanced RF Sensors and Remote Sensing Instruments*, ARSI'17 & 3rd Ka-band Earth Observation Radar Missions Workshop, KEO'17, ESA

Gassot O, Herique A, Rogez Y, Buck C, Ultra-Wideband SAR Tomography on asteroids, (2019), *6th Workshop on Advanced RF Sensors and Remote Sensing Instruments*, ARSI'19 & 3rd Ka-band Earth Observation Radar Missions Workshop, KEO'19, ESA

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