A Radar Sounder Instrument for EnVision

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1. Introduction

Many open science questions of the ESA M-class EnVision mission proposal are related to the characterization of the surface and the subsurface of Venus. Given the atmospheric conditions and the properties of the surface, some of the key science questions and the related science goals can be effectively addressed only by using properly designed radar instruments. Currently, the use of a C-band (or S-band) SAR system with interferometric capabilities is considered in the core payload. This is aimed to address science goals related to the measurements of the topography and of the surface displacements according to differential interferometric techniques. However, this system can only study the surface vertical structure and cannot provide any direct measure on the subsurface. Accordingly, in this poster we propose and discuss a complementary radar instrument which is a low-frequency radar sounder.

2. Radar Sounding of Venus

The use of a low frequency nadir looking **radar sounder** can provide the ideal complementary information to both the SAR data obtained by Magellan and the information acquired by the C-band (or S-band) interferometric SAR. This would result in a full and detailed investigation of the surface and subsurface geology of Venus.

A radar sounder, which can operate at VHF or UHF central frequencies, can acquire fundamental information on **subsurface geology** which cannot be achieved with the InSAR system. In particular it can focus on mapping the **vertical structure of geologic units by exploring the subsurface properties of tessera, plains, lava flows and impact debris**. The sounder could analyze the **shallow subsurface of Venus to detect and map geological structures and to identify mechanical and dielectric interfaces**.

A radar sounder instrument also provides information on the **surface in terms of roughness, composition and dielectrical properties** at wavelength completely different from those of SAR, thus allowing a better understanding of the surface properties. Moreover, a fusion of the InSAR data (both intensity, topography and displacement variables) with the sounder data would result in an **exceptional capability to understand the link between the surface and subsurface processes on Venus**. Note that depending on the design of the system, the sounder could also acquire measurements for **characterizing the ionosphere**.

3. Science goals

The Radar Sounder for EnVision can acquire information on the shallow subsurface with the following main scientific goals:

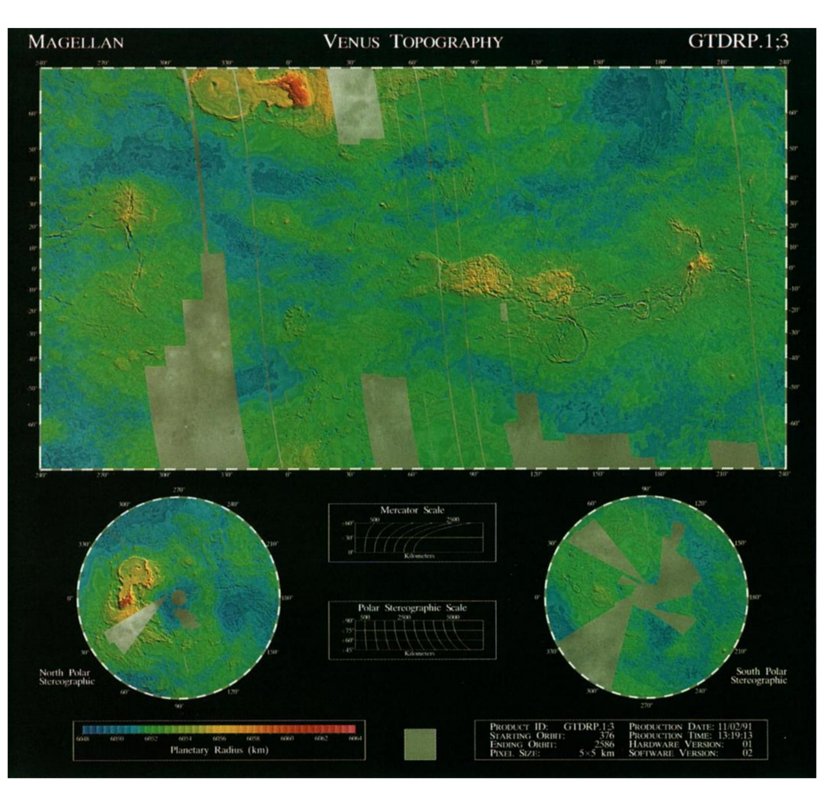
- Characterization of the different **stratigraphic and structural patterns** of the subsurface.
- Study the **volcanism phenomena** and their impact on the geological evolution of the Venusian topography.
- Detection of **subsurface structures** non directly linked with surface.
- Analysis of the **materials in the surface and subsurface** and their metamorphism linked to the burial process.
- Synergistic analysis of the data provided by SAR and radar sounder sensors to study the evolution of the planet.
- Analysis of the total electron content of the **ionosphere**.

One of the main issues for the design of the radar sounder instrument for EnVision concerns the physical and electromagnetic modelling of the surface and subsurface targets. Magellan radar measurements provided information on terrain dielectric properties and surface roughness. We can distinguish two main areas:

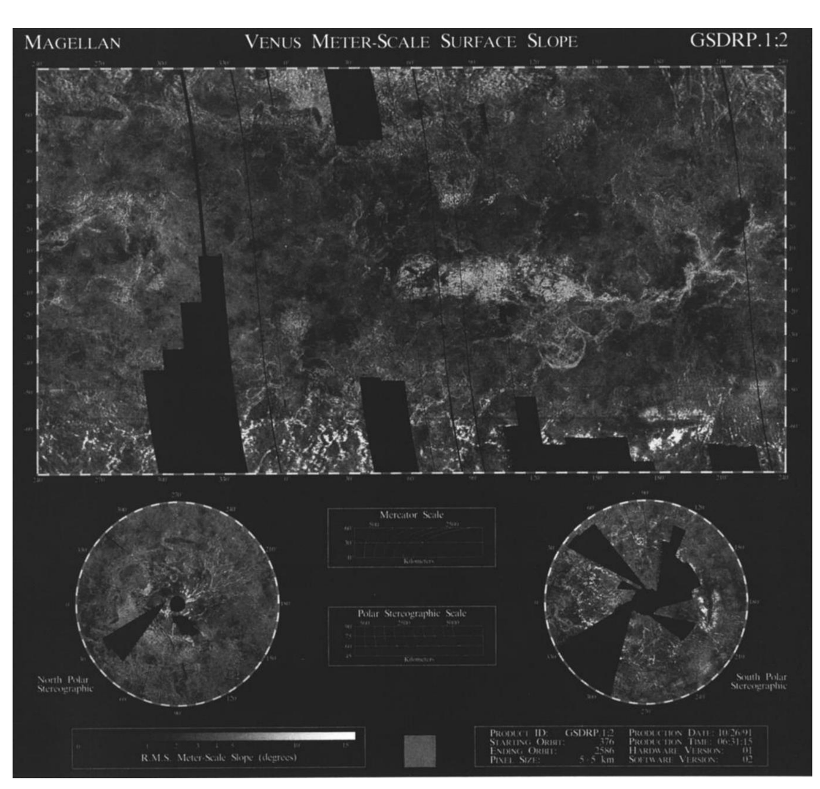
- Highland areas which are mostly characterized by high values of the dielectric permittivity ε (e.g., around 20), supposedly because of rocks with metal content; and high surface roughness.
- Lowland areas are composed by basalt materials with expected high porosity that entails an expected value of ε = 5 ± 0.9. Lowland areas present smoother topography.

Highlands (about 20% of the Venus area) may represent a critical scenario for the penetration the radar electromagnetic waves, whereas lowland (about 80% of the Venus area) have dielectric constants that are suitable for sounding.

The ionosphere of Venus can affect radar signal propagation, but offers additional opportunities for science. The maximum plasma frequency on the day side is around 5-6 MHz, below 1 MHz on the night side. Signals below those frequencies cannot propagate to the surface. Similarly to Mars, a radar signal will be distorted in crossing the dispersive plasma, but such distortion can be corrected, and the correction algorithm can provide information on the total electron content of the ionosphere.



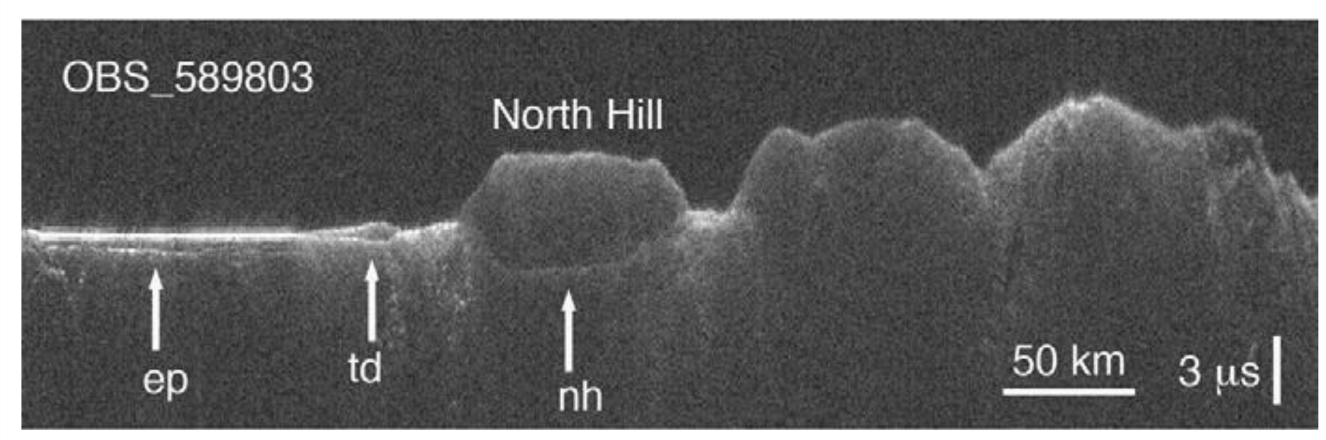
False-color representation of Venus surface topography, data acquired by Magellan satellite [1].



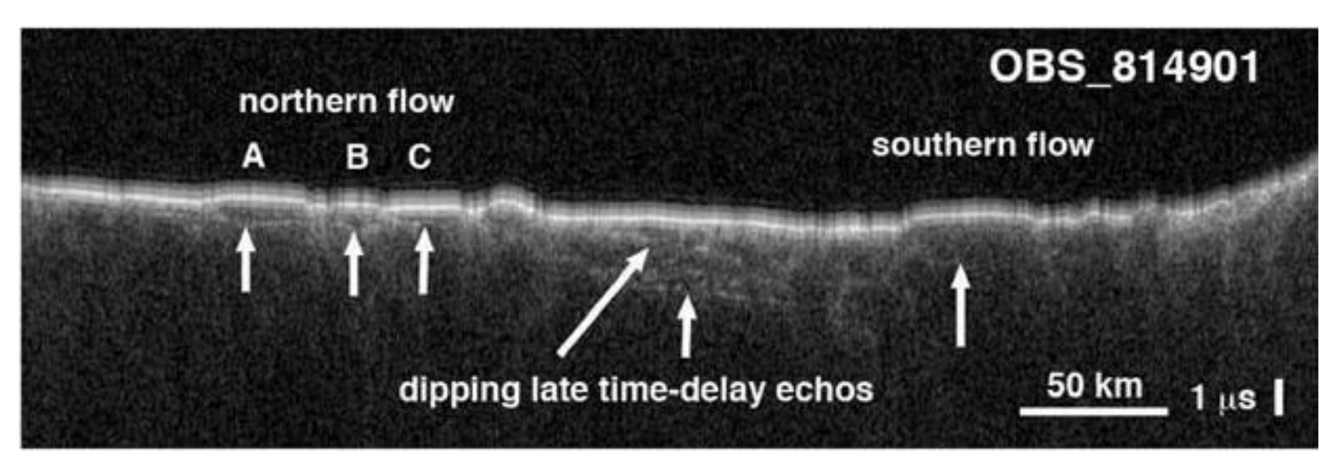
Venus RMS meter-scale surface roughness [1].

4. Heritage and Examples of Radargrams Relevant to Venus

- **MARSIS** (Mars Advanced Radar for Subsurface and Ionosphere Sounding) on ESA Mars Express [2] and **SHARAD** (Shallow Radar) on NASA Mars Reconnaissance Orbiter [3].
- **RIME** (Radar for Icy Moon Exploration) on ESA Jupiter Icy Moon Explorer [4]-[5].



SHARAD radargram over a portion of western Medusae Fossae Formation, a low-density pyroclastic deposit spanning across the crustal dichotomy of Mars. The deposit labelled "North Hill" (nh) is about 500 m thick (taken from [6]).

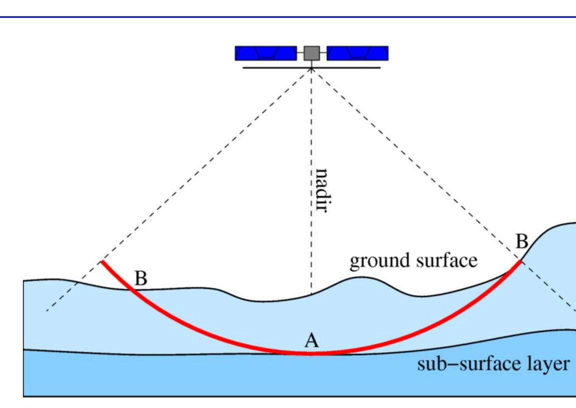


SHARAD radargram across two distinct lava flows emanating from Ascraeus Mons, Mars. Estimates of dielectric permittivity are between 6 and 17, loss tangent is in the range 0.01-0.03. These values are consistent with those of terrestrial and lunar basalts (taken from [7]).

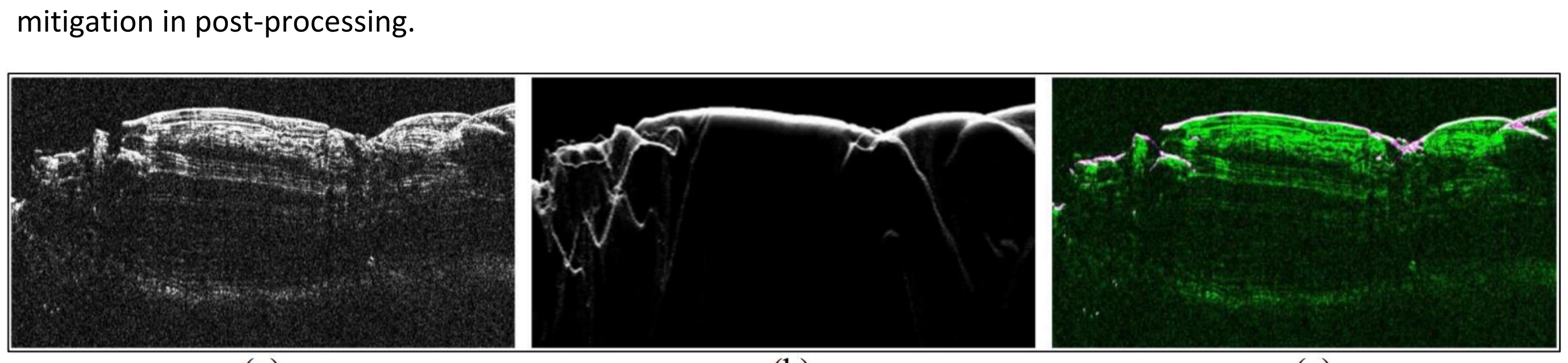
5. Clutter

Clutter is given by off-nadir surface reflections reaching the radar at the same time as subsurface nadir reflections, thus potentially masking them. The strength of clutter is controlled by statistical parameters of the topography of natural surfaces scattering the radiation.

The signal ambiguity introduce by the clutter could limit data analysis and interpretation.



Different approaches are possible for identifying and reducing clutter effects. These approaches require the availability of Digital Terrain Model (DTM) for identifying clutter features in areas where the surface is rough with respect to the considered wavelength. This should not be a problem in EnVision given the SAR instrument and its interferometric capabilities that can acquire topographic information at the scale required for clutter mitigation in post-processing.



(a) (b) (c)

Example of L2 products on SHARAD data: (a) radargram obtained by azimuth and range processing; (b) simulation of clutter effects based on the DTM of the target; (c) false color composition that superimposes the radargram with the detected clutter (in green the measured data, in white the surface reflection and the detected surface clutter) [8].

6. Preliminary Instrument Parameters

The sounder can be designed to study either the shallow subsurface with high vertical resolution or to obtain moderate penetration with reduced vertical resolution. Taking into account the plasma frequency, the lowest central frequency that can be used is of 6 MHz. The table below reports a preliminary identification of the possible ranges in which selecting the sounder parameters.

Transmitted central frequency (fc)	In the range 6 - 30 MHz
Transmitted bandwidth (Bw)	In the range 2 - 10 MHz
Antenna type	Dipole (deployable)
Antenna dimension	TBD (depending on the central frequency)
Power	30 W
Along track resolution	< 1 km
Across track resolution	< 5 km
Vertical resolution	75 m (Bw=2 MHz) - 15 m (Bw=10 MHz) (vacuum)
Estimated maximum penetration depth	1.5 Km (fc=6 MHz) - 600 m (fc=30 MHz)
Data rate	300 – 10000 kbps (depending on selected parameters and operation scenarios)
Mass (without antenna)	10 kg
Size	37×25×13 cm
Pointing requirements	Nadir

7. Conclusions

This poster summarizes the potentials of a radar sounder for Venus. A radar sounder can be a very effective instrument for complementing the suite of payloads in EnVision.

The main gain in terms of scientific return is that the radar sounder can perform measurements at either shallow or moderate depth of the subsurface of Venus. These measurments integrated with all the information extracted by the C-band SAR system would result in an exceptional capability to study jointly surface and subsurface properties and phenomena of Venus.

Preliminary studies and experience gained with MARSIS and SHARAD on areas on Mars having similar properties to what expected in some part at of Venus point out the feasibility of the sounding and the rich amount of information that can be extracted. Further studies are currently in progress for reducing the uncertainty on the expected subsurface scenario.

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