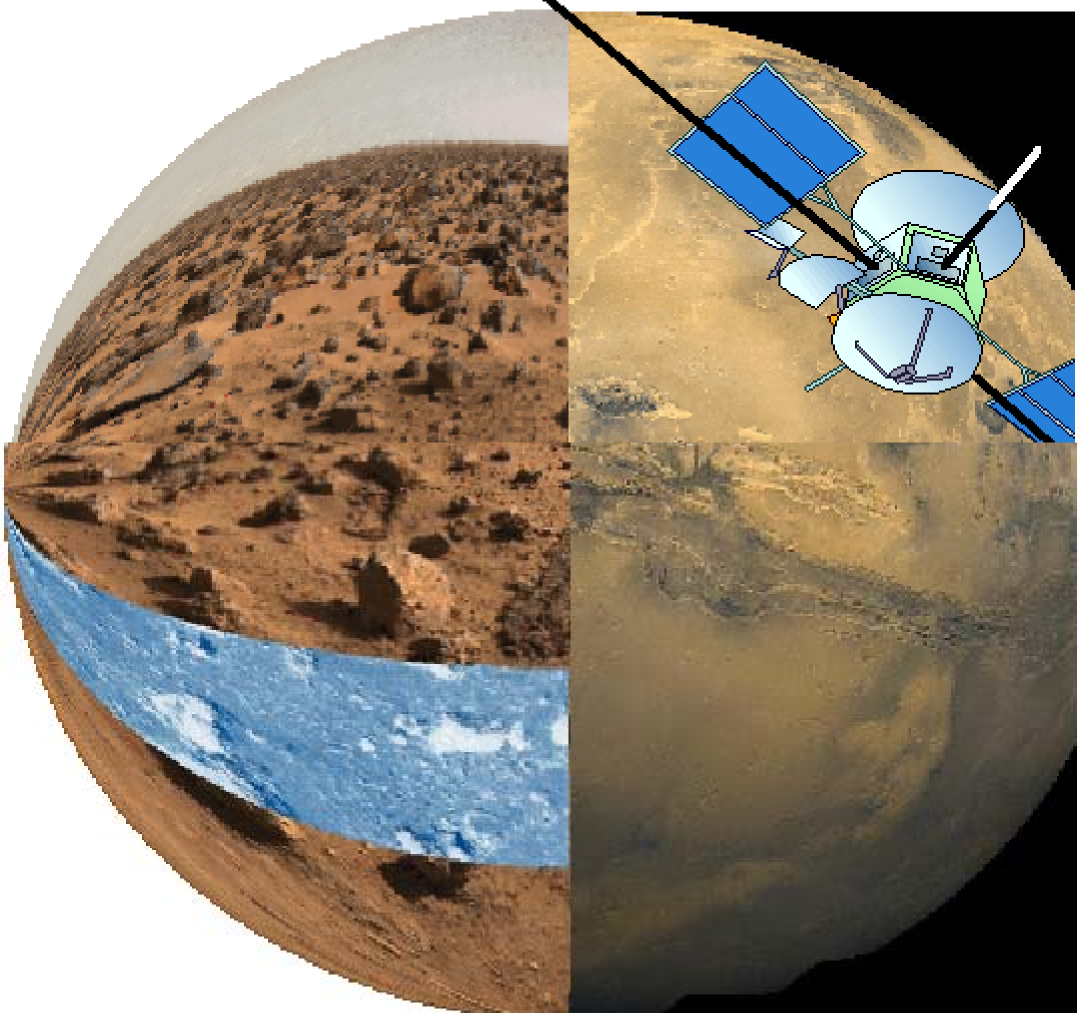
FIRST MARS EXPRESS SCIENCE CONFERENCE
21-25 February 2005, ESA/ESTEC
MARS ADVANCED RADAR FOR SUBSURFACE AND IONOSPHERE SOUNDING (MARSIS)



G.Picardi

asi agenzia spaziale italiana

INFO-COM Dpt.

Alenia SPAZIO

NASA

JPL

Iowa

TRW

MARSIS Scientific Objectives

- Primary Science Objective
  - To map the distribution of H_2O (solid and/or liquid) in the upper portions of the crust of Mars

- Secondary Science Objectives

Three secondary objectives are defined for the MARSIS experiment:

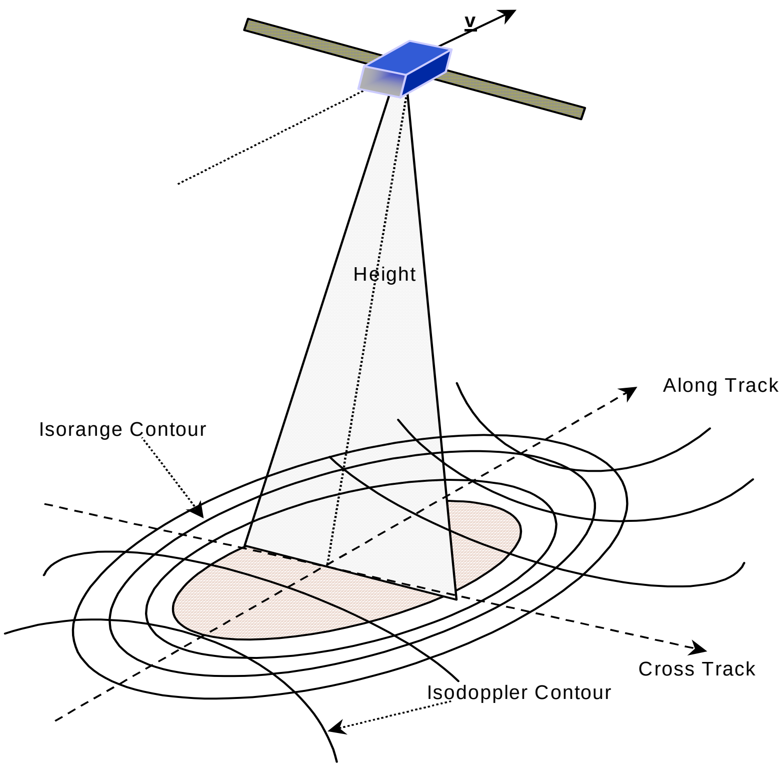
  - Subsurface geologic probing
  - Surface Characterization
  - Ionosphere sounding

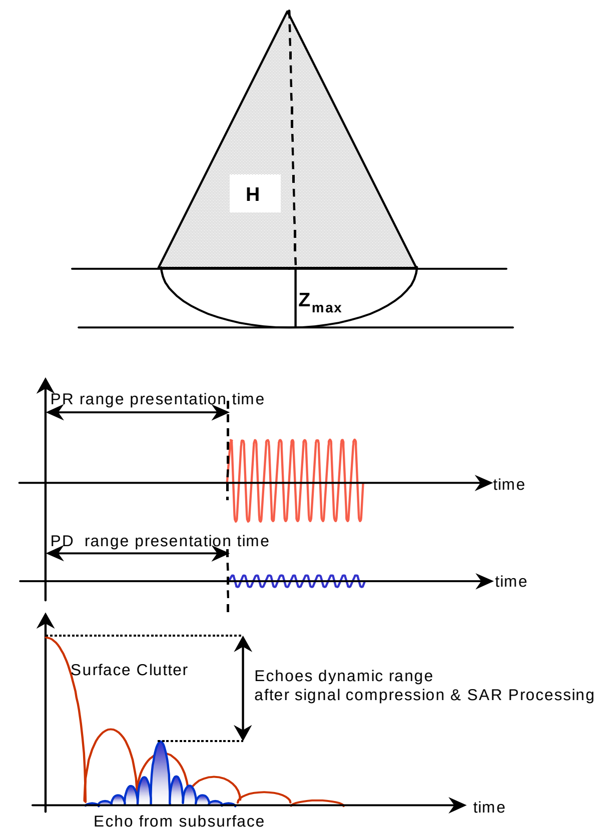
Subsurface E.M. Characterization

According to the well known subsurface radar, a short pulse of electromagnetic energy is directed toward the ground:

- **The pulse reflects off an electrical boundary, and the reflected signal is received at an antenna and recorded.**
- **The time delay of the echo can be converted to depth, assuming the propagation speed of the medium is known**
- **The intensity of the reflection can be analysed to estimate the reflectivity at the interface and the attenuation properties of the intervening layers.**
- **Obviously surface return echoes can reduce the visibility of the subsurface echoes**.

DESCRIPTION OF OPERATING GEOMETRY





MARSIS Overview (1)

INSTRUMENT CAPABILITIES

- MARSIS is a multi-frequency nadir - looking pulse limited radar sounder and altimeter, which uses synthetic aperture techniques and can use a secondary receiving antenna to isolate subsurface reflections. The MARSIS can be effectively operated at any altitude lower than 800 km. In standard operative mode the instrument will be able to transmit any of the following bands*: 1.3-2.3 MHz (centered at 1.8 MHz), 2.5-3.5 MHz (centered at 3 MHz), 3.5-4.5 MHz (centered at 4 MHz), 4.5-5.5 MHz (centered at 5 MHz).*
- The **1 MHz** bandwidth allows a **vertical resolution of 150 m** in vacuum which corresponds to 50-100 m in the subsurface, depending on the e.m. wave propagation speed in the crust. **The typical spatial resolution of the MARSIS will be 5-9 Km x 15-30 Km** in the along track and cross track directions respectively. In standard operative mode, up to four echo profiles will be produced at intervals of ~ 1 second, resulting in a **spatial sampling rate of 5-9 Km** and stored for downlink. The possibility of downlinking raw data for small region of particular interest is also offered. Ground processing will extract from the downlinked profiles significant information on the surface topography and composition, as well as on the location and possibly the dielectric properties of subsurface discontinuities.
- A simple ionosphere sounding mode is also proposed to generate ionosphere plasma frequency profiles with a **vertical resolution of 15 Km** and a spatial sampling step of **~30 Km**.

MARSIS Overview (2)

SUBSURFACE SOUNDING

- On the dayside of Mars, the ionosphere does not allow the use of frequencies < ~3.5 MHz for sounding. Hence on day side operations only the 4 MHz and 5 MHz bands will be able to penetrate the ionosphere and will be used for subsurface sounding. The best penetration capabilities will be obtained during night side observation, when also the longest wavelengths can be operated.
- The multi frequency observation will allow the estimation of the material attenuation in the crust and will give significant indications on the dielectric properties of the detected interfaces.
- In order to maximise the sounding depth against rough surfaces, the MARSIS uses three different methods to separate subsurface reflections from synchronous echoes coming from off nadir surface reflections (*surface clutter*):

  1- **Doppler Beam Sharpening**: the doppler azimuth processing significantly reduces the surface echoes coming from along track off nadir reflections. The improvement on the overall surface clutter attenuation has been shown to be ~ 10-12 dB depending on the depth.

  2- **Secondary Monopole Antenna**: a secondary antenna, oriented along the nadir axis will receive mostly the off-nadir surface returns, that could be thus subtracted by the primary antenna composite signal, further reducing the surface clutter level (about ~15-20 dB).

  3- **Dual Frequency Processing**: echo profiles collected at two slightly different frequencies can be processed to separate the subsurface reflections, which are strongly dependent on the frequency, from the surface reflections, which are mostly frequency independent. The achieved improvement can reach 10-15 dB.

MARSIS Overview (3)

SURFACE ALTIMETRY

•The first surface reflection echoes of the MARSIS in sounder operations will be processed to give estimations of the average height, roughness and reflection coefficient of the surface layer, according to the classical altimetric approach.

• By measuring the time delay of the echo, it will be possible to estimate the average distance of the radar from a reference flat surface level, while the duration of the waveform leading edge will be proportional to the large scale surface roughness averaged over the pulse limited spatial resolution cell. Finally the peak value of the average echo waveform will be used to estimate the backscattering coefficient and, in conjunction with the roughness value to estimate the Fresnel reflection coefficient of the surface.

•The estimation of the relevant surface parameters will be carried out in the MARSIS by means of a Sub-Optimum Maximum Likelihood Estimation (SMLE) technique or non-parametric techniques, such as de-convolution which treat the height and subsurface inversion as a unified problem.

• Preliminary evaluations lead to the following performance predictions:

Time delay measurement accuracy	*10-50 m*
Rms height measurement accuracy	*10-20 % (for large scale roughness >150 m)*
Backscattering coefficient accuracy	*+/- 1 dB*

•A further improvement of the altimeter mode performance, in terms of resolution and accuracy can be achieved by means of processing the return echoes collected over the same region during different orbits.

MARSIS Overview (4)

IONOSPHERE SOUNDING

When operating in the Ionospheric Sounding mode the MARSIS will transmit a sequence of pulses with a bandwidth of 10.9 KHz, shifted around a central frequency stepped between 0.1-5.4 MHz with variable step.

A total of 160 pulses will be transmitted for each sweep with a pulse repetition frequency of 130 Hz: the total duration of the acquisition and data processing will be 7.38 seconds

As a consequence the plasma frequency distribution will be mapped with a vertical resolution of 15 Km, a spatial sampling step of 30 Km.

Ionospheric Sounding Mode Parameters

Pulse Duration	*91.43 μs*
Pulse Bandwidth	*10.9 KHz*
Vertical Resolution	*15 Km*
Minimum Frequency	*0.1 MHz*
Maximum Frequency	*5.4 MHz*
Number of Pulses	*160*
Pulse Repetition Frequency	*130 Hz*
Frequency Sweep Time	*7.38 sec.*
Spatial Sampling Step	*30 Km*

Mars Crustal Model Summary

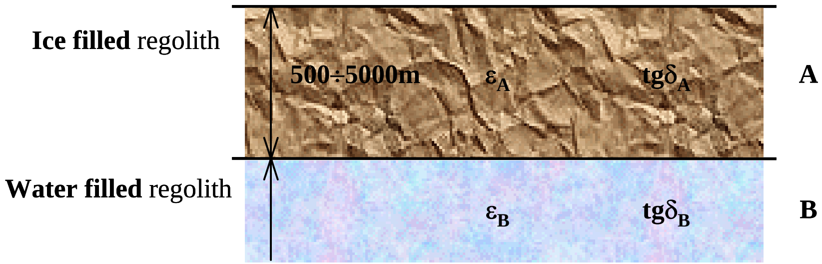
Reference layer models representing the most likely detection scenario :

- ***Ice/water interface detection scenario (I/W)****:* according to this model, the porosity of the Martian megaregolith is maximum at the surface and its decay with the increasing depth is given by an exponential law (the decay constant that can be assumed of the order of 2.8 km). The pores are filled with ice from the surface down to a depth below which liquid water is stable and becomes the pore-filling material. The change of the pore-filling material causes a discontinuity of the overall dielectric constant, which can be detected by the radar sounder.
- ***Dry/ice interface detection (D/I)****:* here the pore-filling material is considered to be gas or some other vacuum-equivalent material up to a depth, below which ice fills the pores. Hence the interface to detect is between dry and ice-filled materials.

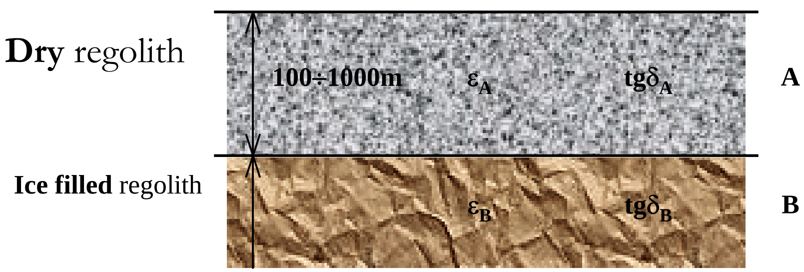
Mars Crustal Model Summary

STRUCTURAL MODELS

- Water Detection Scenario



- Ice Detection Scenario



MATERIAL MODELS

- Porosity at the surface = 20 % … 50 %
- Porosity Decay with depth (K=2.8 Km)

$$\Phi(z) = \Phi(0) e^{-\frac{z}{K}}$$

- *We have assumed bi-phase mixtures:*
  - Host: ranging from Basalt to Andesite
  - Inclusion: Gas, Ice or Water
- *We further have assumed that the inclusion material fills-up completely the pores in the host material*