Lava Tubes and Moon Bases

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ThalesAlenia Space
A Thales / Finmeccanica Company

2nd International Convention of Technologies of the Frontier

"A New Renaissance: colonizing the Moon and the Near Earth Asteroids"

Belgirate (Lago Maggiore) - June 7th 2008 / 9:30 ÷ 20:00

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Missions to the Moon -1

The Moon has been extensively visited, since the very beginning of the space era, by remote sensing techniques from orbiting satellites, in-situ analysis from landed bases, etc. Furtehrmore, it is the only celestial body visited by human crews :

5 Fly-by	**12 Impact (-2)**	**5 Probes**
2 Test flights (-2)	**11 Landers (-3)**	**19 Orbiters**
3 Sample Return	**1 Crewed Orbiter**	**7 Crewed Landers (-1)**
2 Rovers		

1959-2007: 66 (+1) missions attempted (8 aborted/failed)

Missions to the Moon -2

1959: Luna 1; Pioneer 4; Luna 2; Luna 3
1961: Ranger 1; Ranger 2
1962: Ranger 3; Ranger 4; Ranger 5
1963: Luna 4
1964: Ranger 6; Ranger 7
1965: Ranger 8; Ranger 9; Luna 5; Luna 6; Zond 3; Luna 7; Luna 8
1966: Luna 9; Luna 10; Surveyor1; Lunar Orbiter 1; Luna 11; Surveyor 2; Luna 12; Lunar Orbiter 2; Luna 13
1967: Lunar Orbiter 3; Surveyor 3; Lunar Orbiter 4; Surveyor 4; Lunar Orbiter 5; Surveyor 5; Surveyor 6
1968: Surveyor 7; Luna 14; Zond 5; Zond 6; Apollo 8
1969: Apollo 10;Luna 15; Apollo 11; Zond 7; Apollo 12

1970: Apollo 13; Luna 16; Zond 8; Luna 17
1971: Apollo 14; Apollo 15; Luna 18; Luna 19
1972: Luna 20; Apollo 16; Apollo 17
1973: Luna 21
1974: Luna 22; Luna 23
1976: Luna 24
1990: Hiten 
1994: Clementine
1997: AsiaSat 3/HGS-1
1998: Lunar Prospector
2003: SMART 1 
2007: SELENE  ; Chang'e 

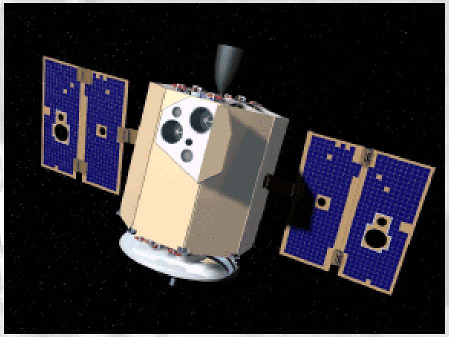
Missions to the Moon -3

Such a large number of missions have produced a large amount of data about our natural satellite, providing an overall knowledge of its nature and phenomena.

In the mid of '70s, the moon exploration program was discontinued (similarly to what happened to the Mars exploration). A stop which lasted until the '90s, when new missions have been implemented.

The new missions have been focused on specific investigations, also in view of a possible manned return to the moon.

Missions to the Moon -4



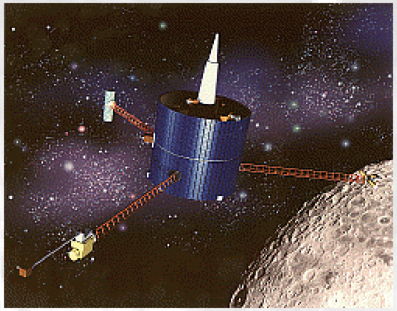
Clementine (NASA, 1994): Cartography, Composition.

An experiment obtained data (at the poles) compatible with water

Main Payload: Laser Altimeter, IR,VIS&UV cameras

Lunar Prospector (NASA, 1998): Composition, Magnetic properties. Further evidence of water ice.

Main Payload: Magnetometer, γ-spectrometer



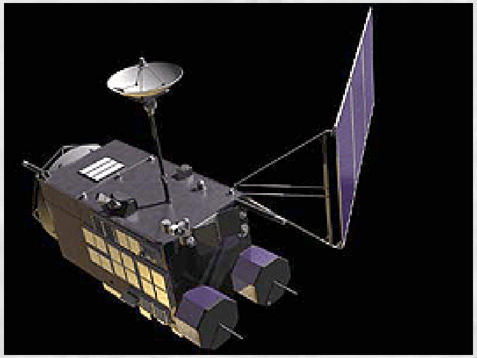
SMART-1 (ESA, 2003): Technology mission. Topography, Morphology, Geology, water in craters

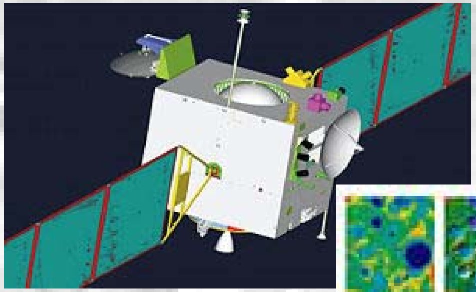
Main Payload: IR Spectrometer, X-Ray Spectrometer, Microcamera

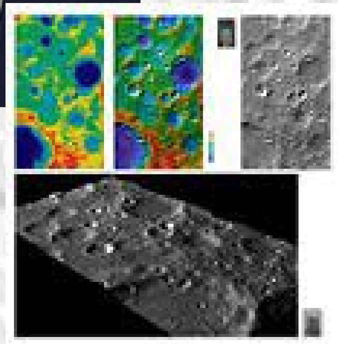
Missions to the Moon -5

SELENE (Kaguya) (JAXA, 2007): Origin, Geology, Environment

Main Payload: HR Camera, Laser Altimeter, Magnetometer, Radar sounder







Chang'e (CNSA, 2007): Geology, Structure, Composition, He^3

Global coverage, including poles

Main Payload: Stereo Camera, Laser Altimeter, Imaging-/gamma-/X-ray spectrometers, microwave radiometer, High energy particles detector

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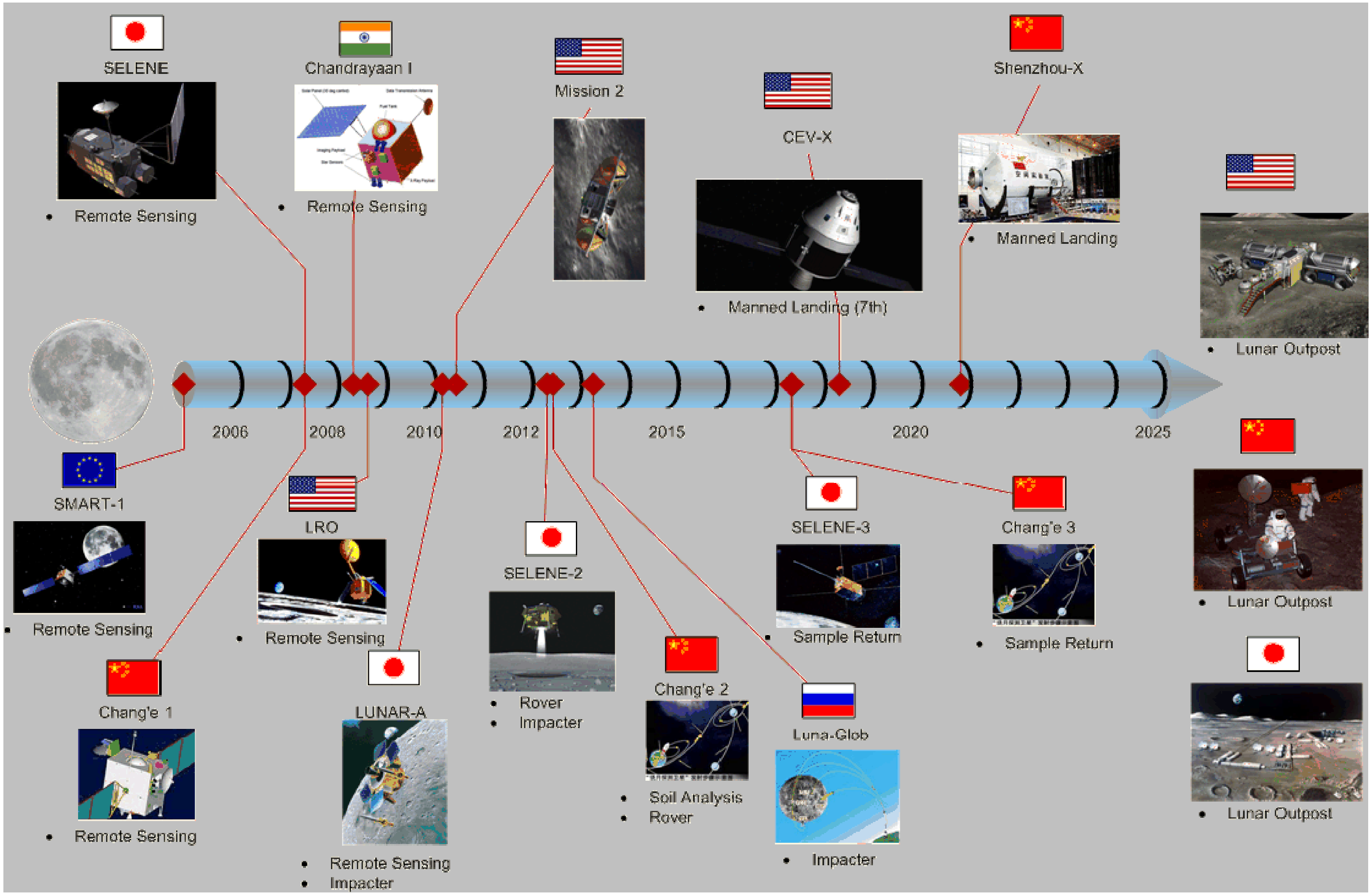
Moon Exploration



Courtesy M. A. Perino

A Manned Base on the Moon

In the frame of the manned exploration of the Moon, some precursor missions have to be implemented, which shall be focused on the acquisition of further usefull information to be used to decide upon the location and design the human habitat.

Investigation (jointly performed by scientific and industrial communities) have been activated in Italy on various aspects of the moon exploration and, in particular, on the information needs and of the relevant gathering techniques.

An example of information of possible important use is the location and characteristics of the lava tubes

Lava Tubes on Earth….

Lava tubes are formed by a flowing low-viscosity lava stream. It develops a hard crust, which becomes the roof covering the still flowing lava. As a final result an empty buried channel is left.

These structures are common on Earth.

Malpais National Monument, New Mexico – The entrance of a lava tube

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… and on Mars …

Mars, Pavonis Mons: possible lava tubes (Mars Express – HRSC, 23.5.06)

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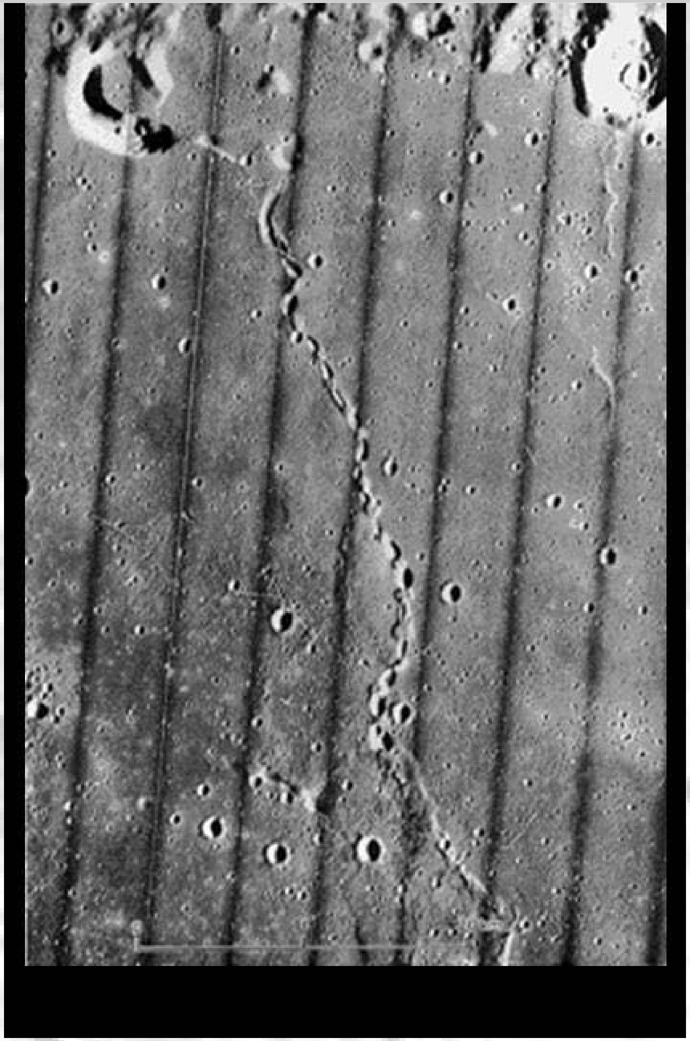
… and on the Moon



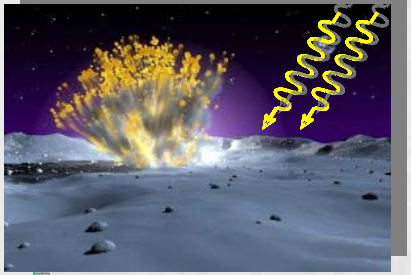
Lunar Orbiter Image V-182-M

(USGS, 1987)

Lava Tubes for Lunar Bases

Several authors support the idea of utilizing the lava tubes on the Moon to build the first lunar base.

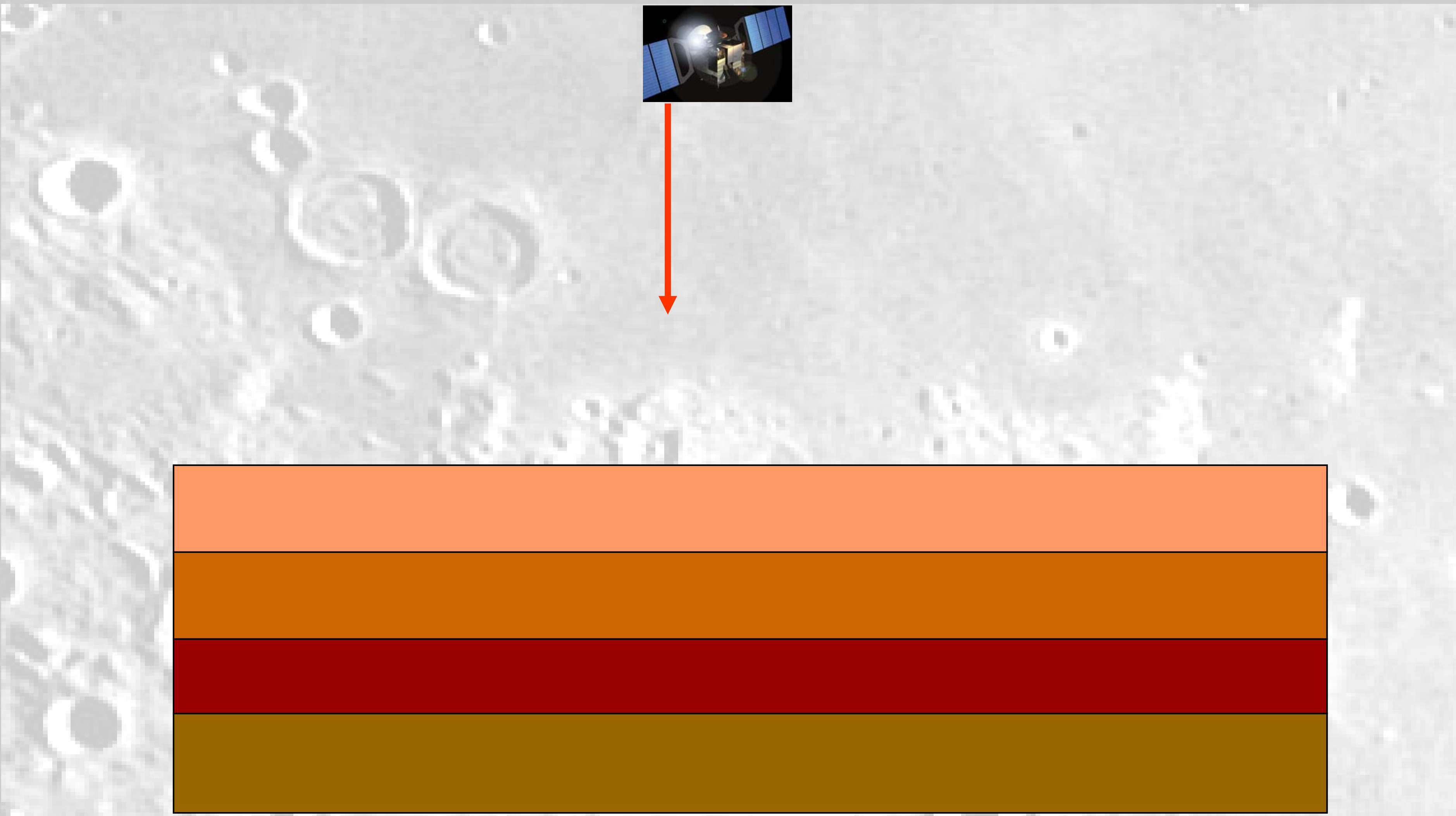
In fact with their roofs, which are tens of meter thick, they represent a natural shield against cosmic radiation and solar flares, as well as against ejecta from meteorite impacts.



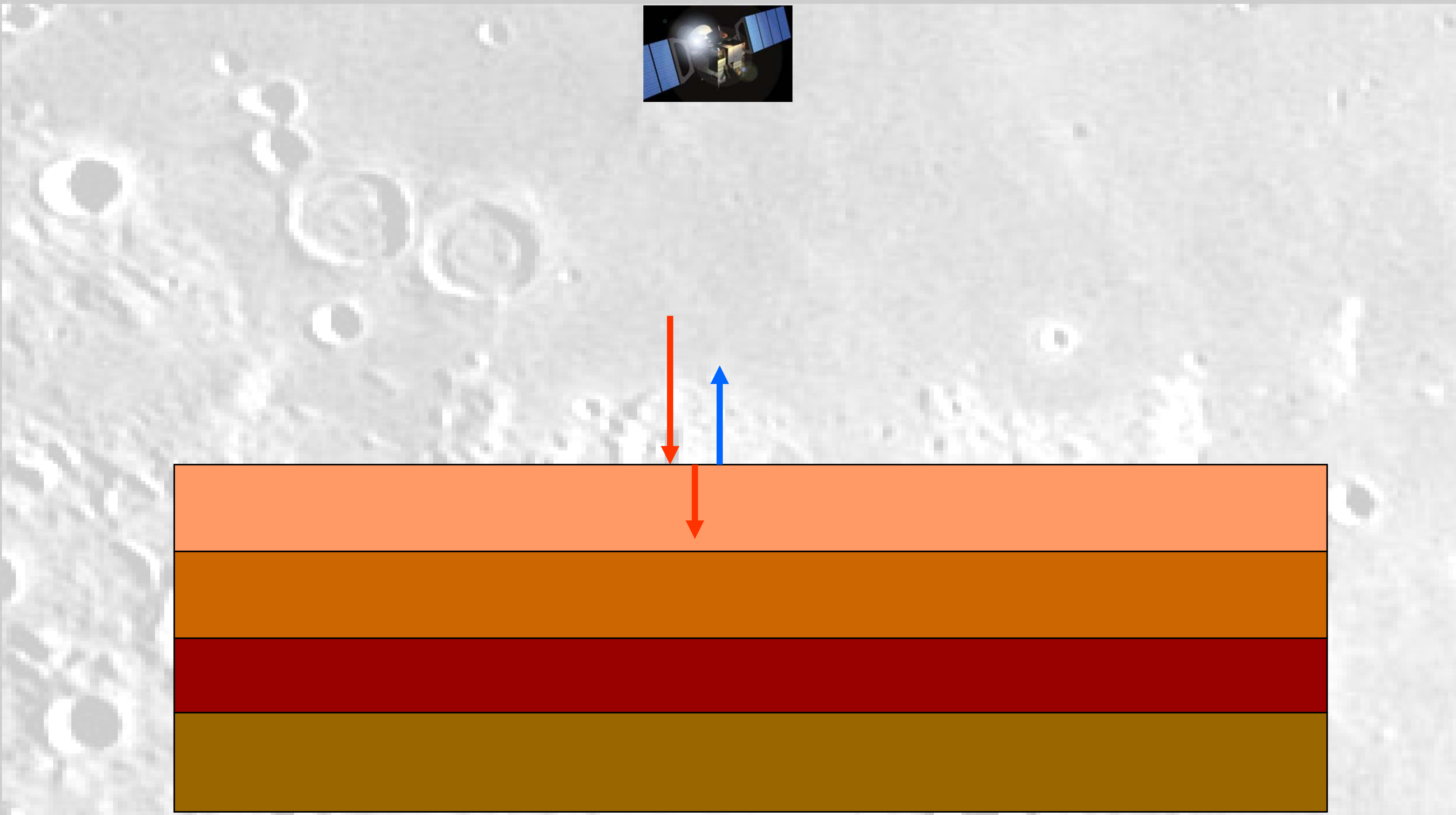
Under lunar conditions of low gravity and absence of atmosphere, lava tubes are espected to be much larger than on Earth (tens/hundreds of meters in cross section and tens of kilometers in length)

Mapping of lava tubes, (location and size) can be an important mission objective

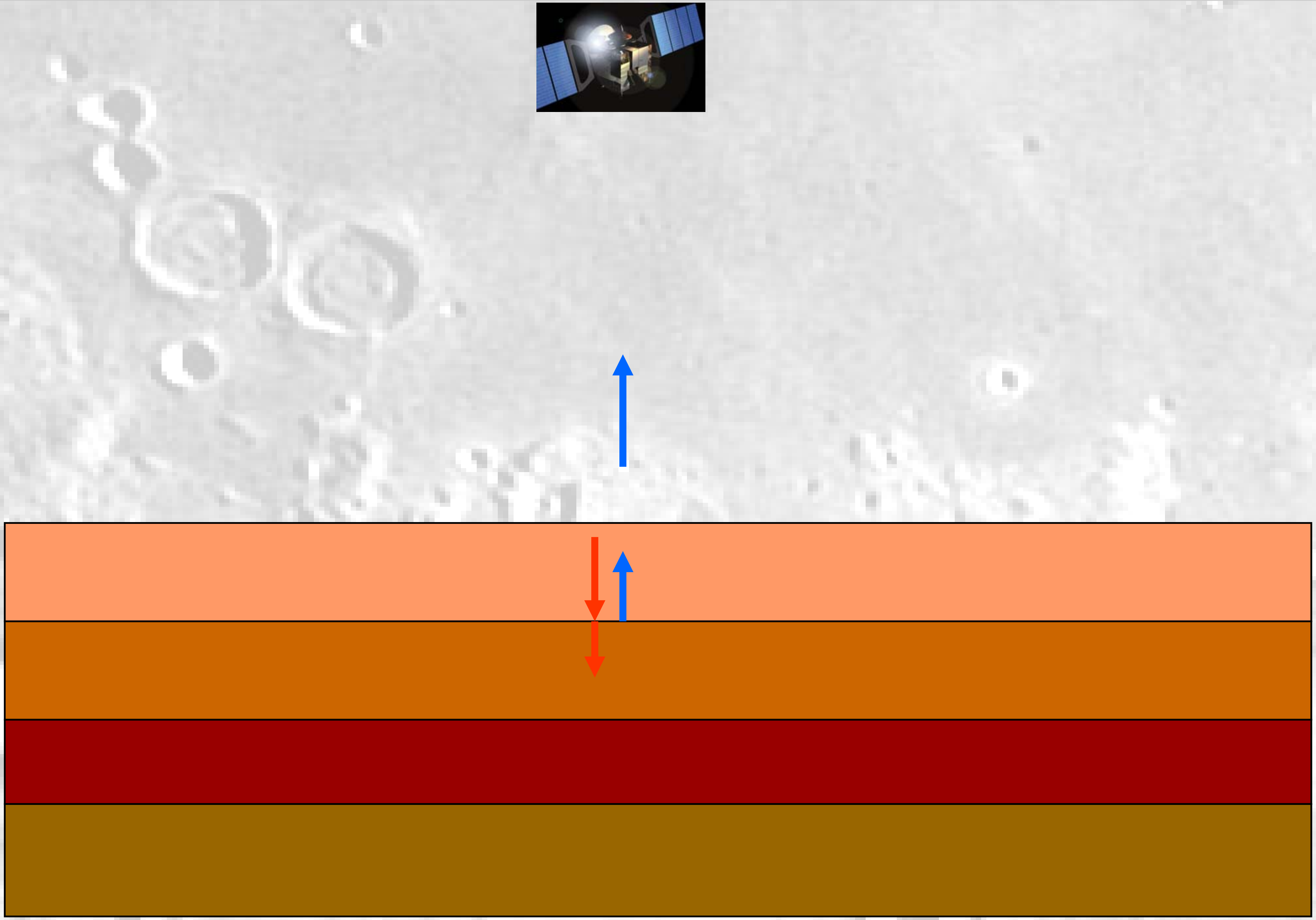
Sounding Radar



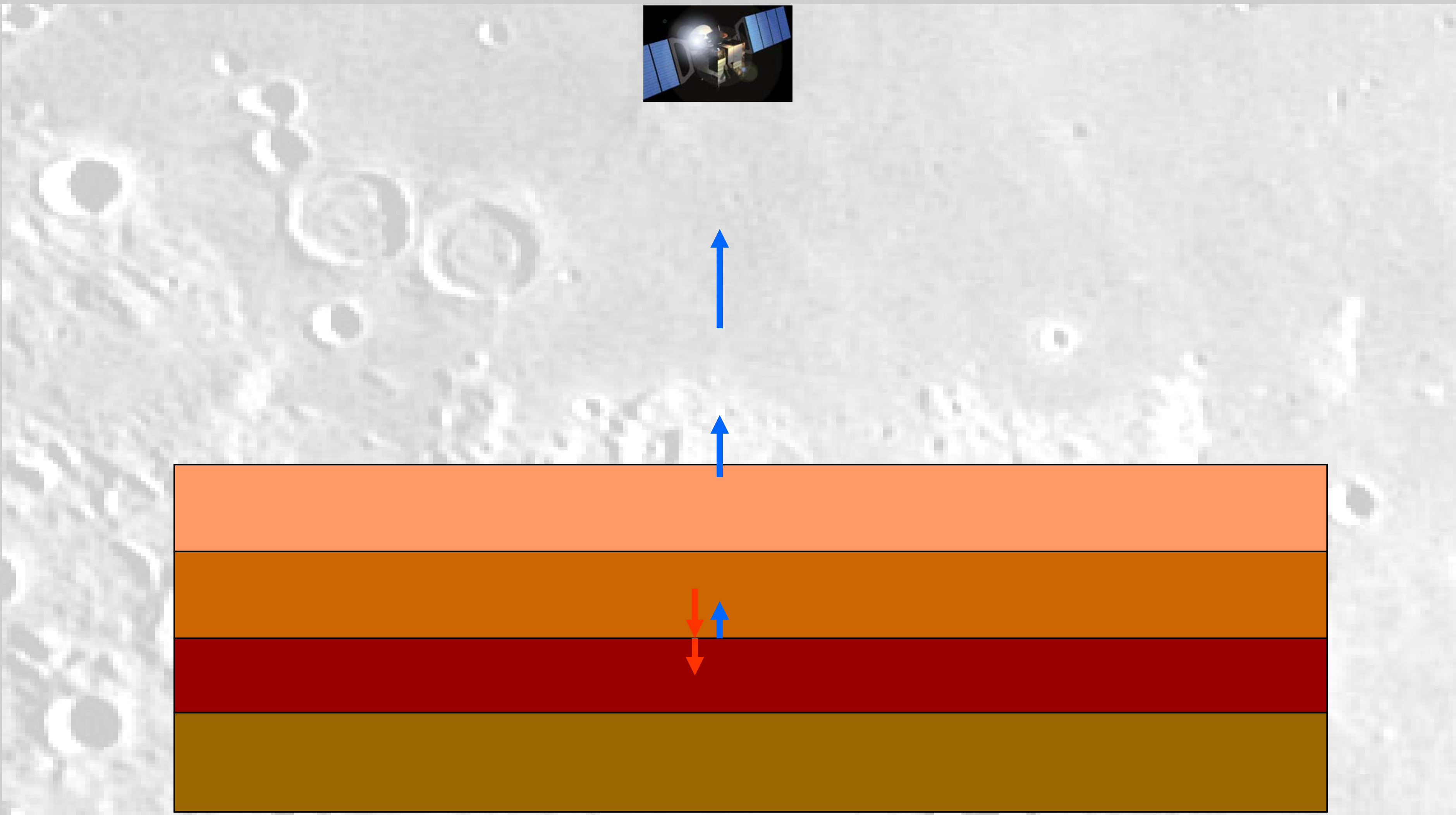
Sounding Radar

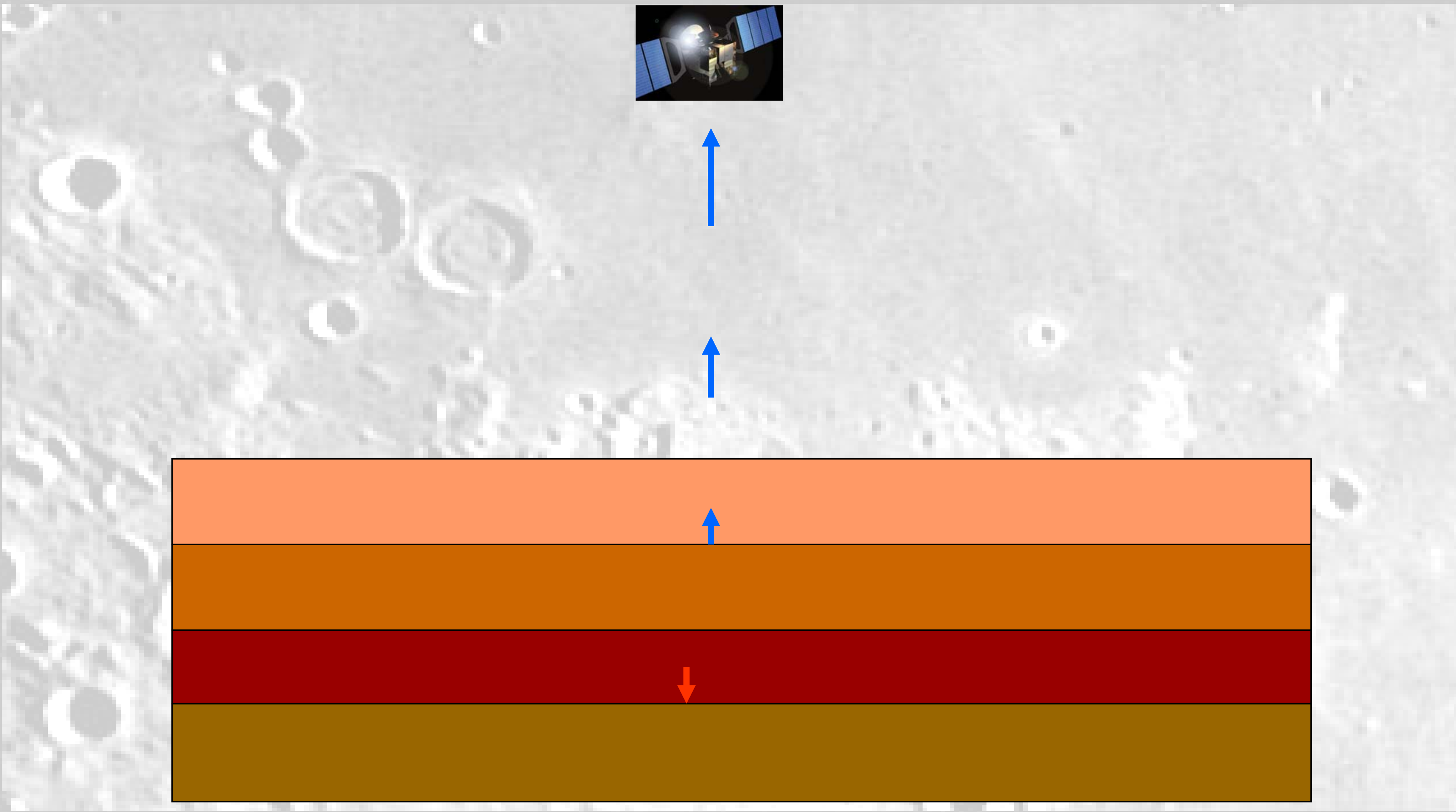


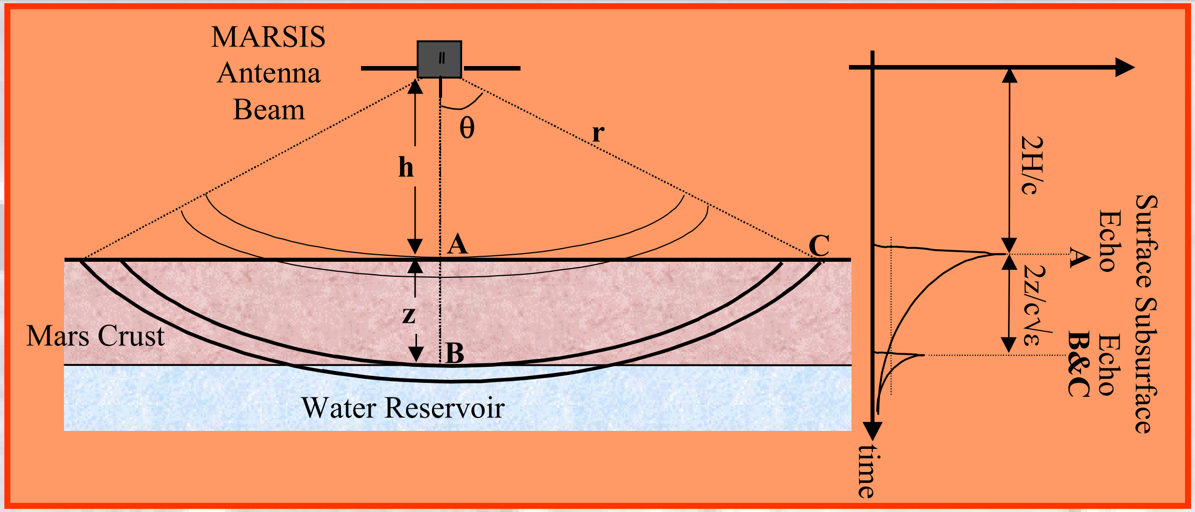
Sounding Radar

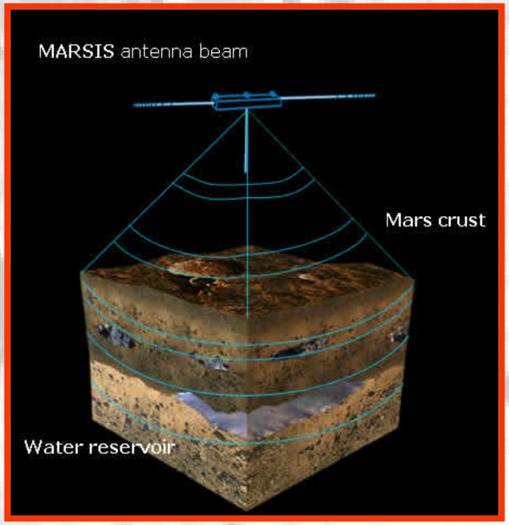


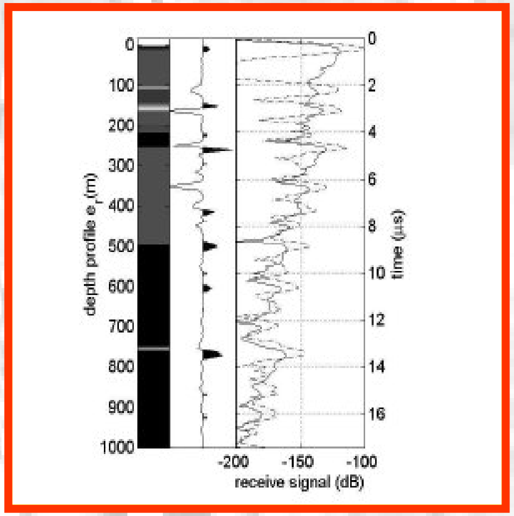
Sounding Radar






MARSIS
Antenna
Beam
θ
r
h
A
C
z
B
Mars Crust
Water Reservoir
2H/c
2z/c√ε
time
Surface Subsurface
Echo Echo
A B&C


MARSIS antenna beam
Mars crust
Water reservoir

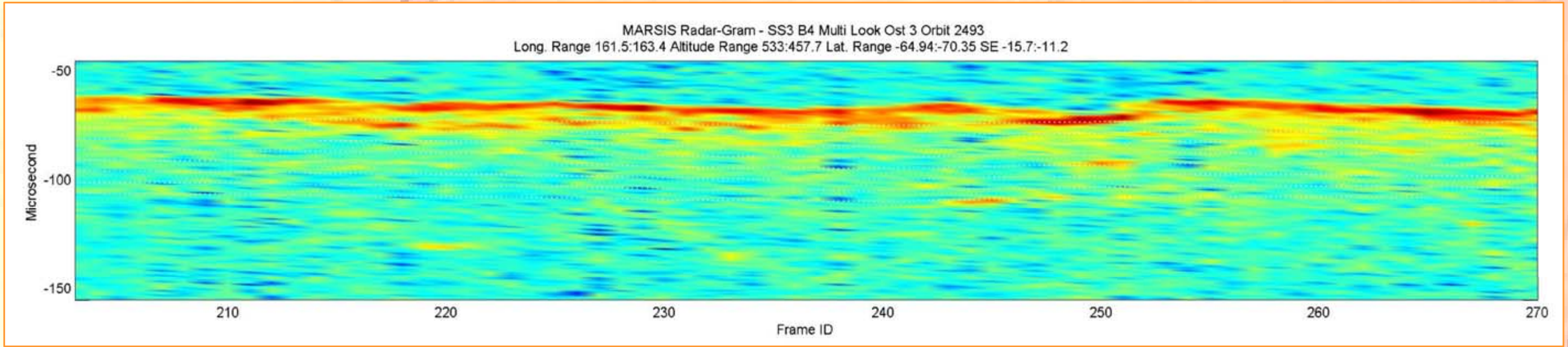

depth profile (m)
time (µs)
receive signal (dB)

Sounding Radars on Mars

Mars Express (ESA, 2003): MARSIS

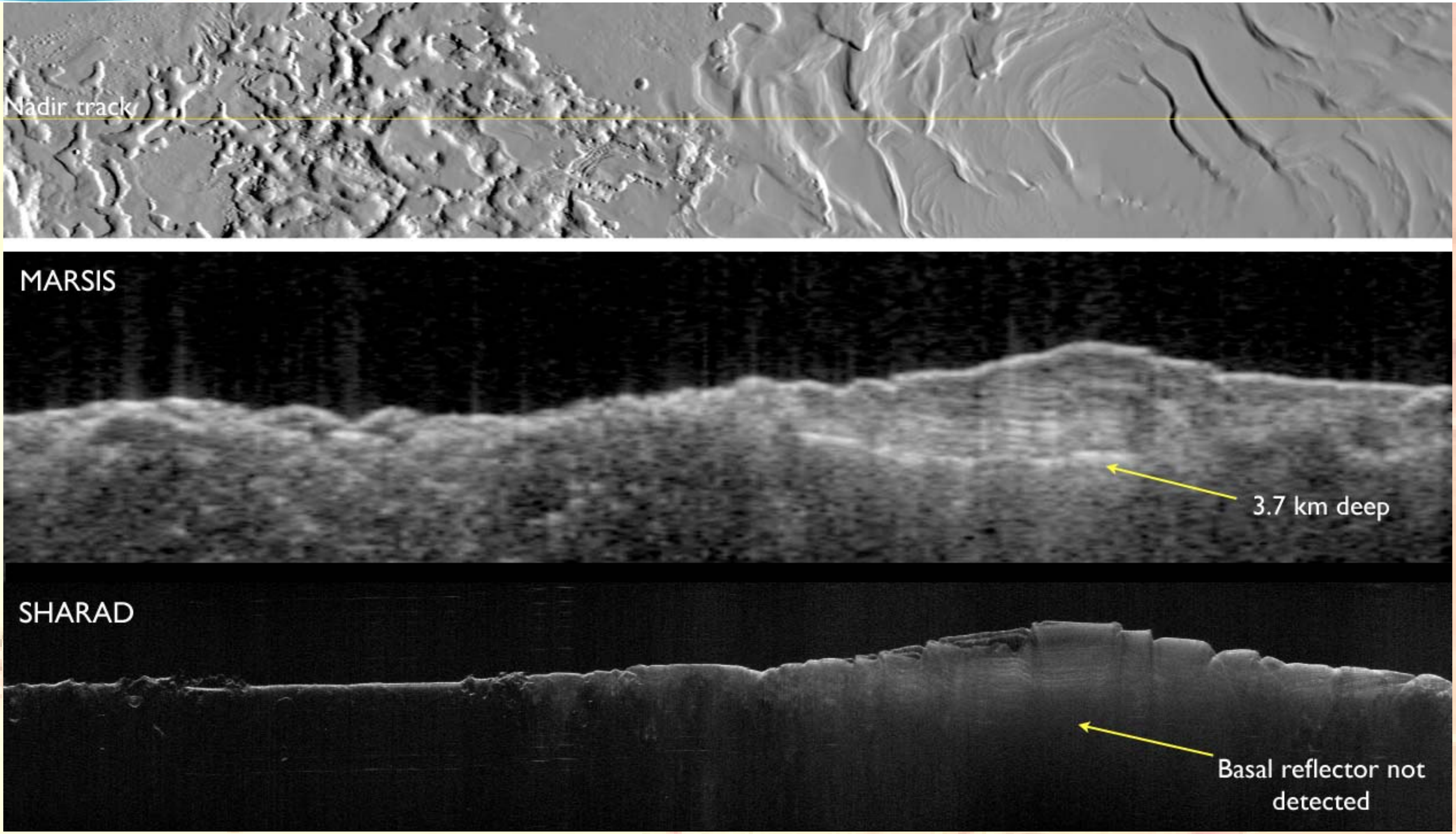
MRO (NASA, 2005): ShaRad

MARSIS Radargram

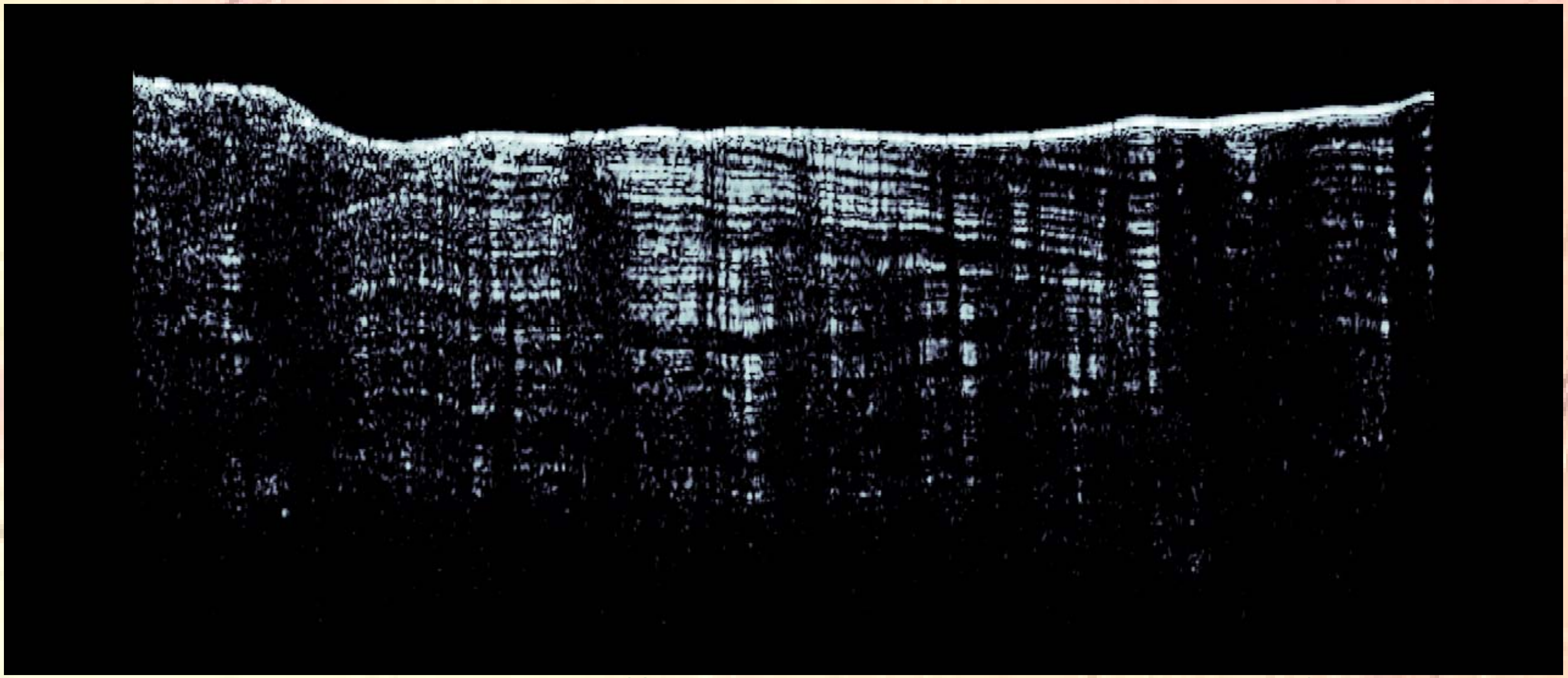


Echo power level in color scale. Surface returns are stroger (deep red), potential subsurface echoes are weaker and at different range

ShaRad vs. MARSIS



ShaRad Radar Gram



Example of SHARAD radargram relevant to an area with several subsurface layers

Further to the mapping/characterization of lava tubes, the processing of the Radar Sounders echoes can provide information on interesting geological properties (e.g. thickness of regolith layer)

Mapping Lava Tubes with GPR

SUBSURFACE GEOPHYSICAL IMAGING OF LAVA TUBES, LAVA BEDS NATIONAL MONUMENT, CA

Todd M. Meglich*, Misti C. Williams*, Steve M. Hodges**, and Matthew J. DeMarco***

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SCHodges@ecentral.com
*Central Federal Lands Highway Division, FHWA, Denver, CO
Matthew.DeMarco@FHWA.dot.gov

Figure 7 – GPR data collection at Hercules with the 400 MHz antenna and survey wheel

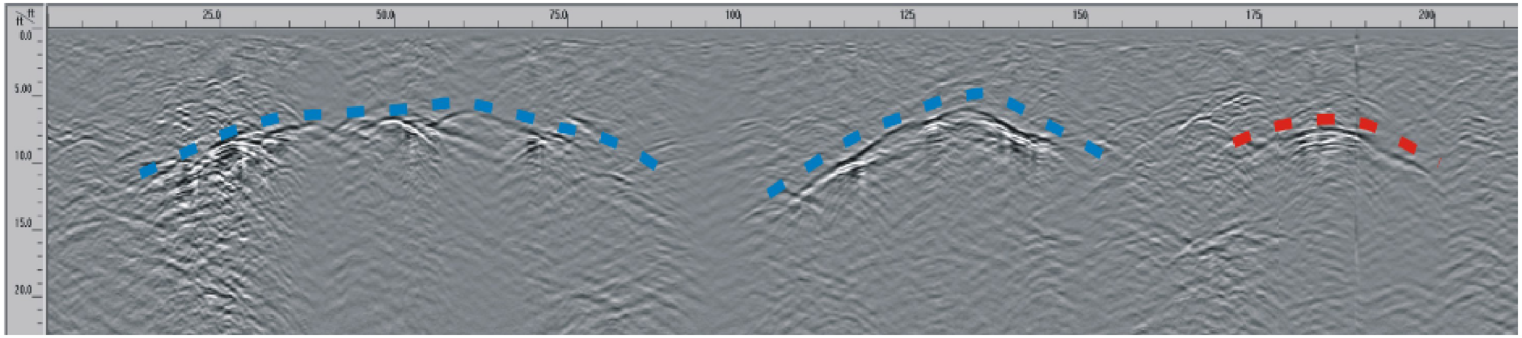
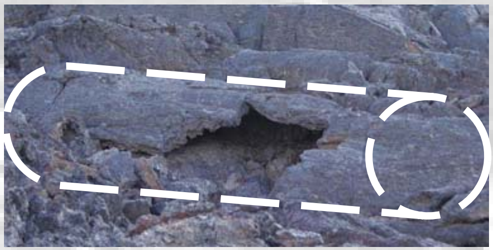


Figure 11 – GPR profile over Hercules Leg Cave (known caves are outlined in blue while an additional anomaly is outlined red)

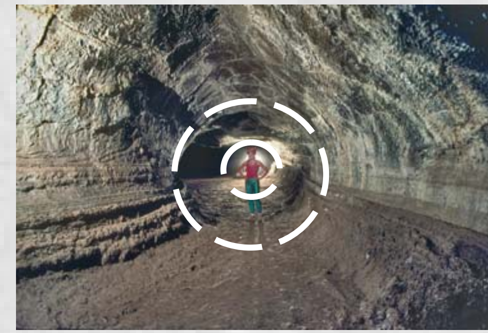
Modeling Lava Tubes - 1

Entrance of lava tube cave at *Craters of the Moon (USA)*



Thurston Lava Tube in *Hawaii Volcanoes National Park*

Lava Beds National Monument

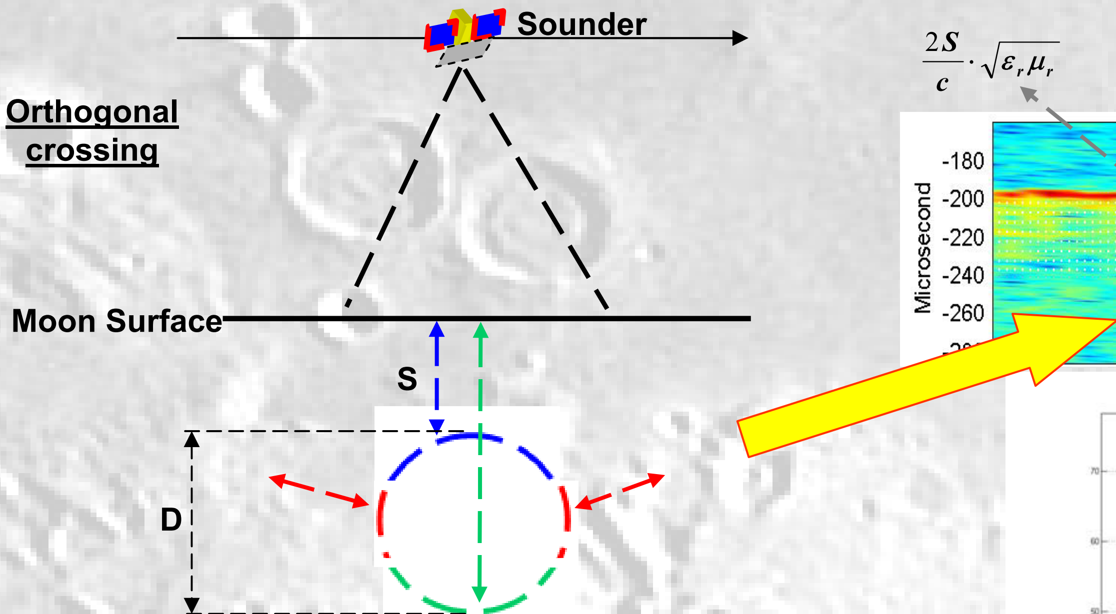


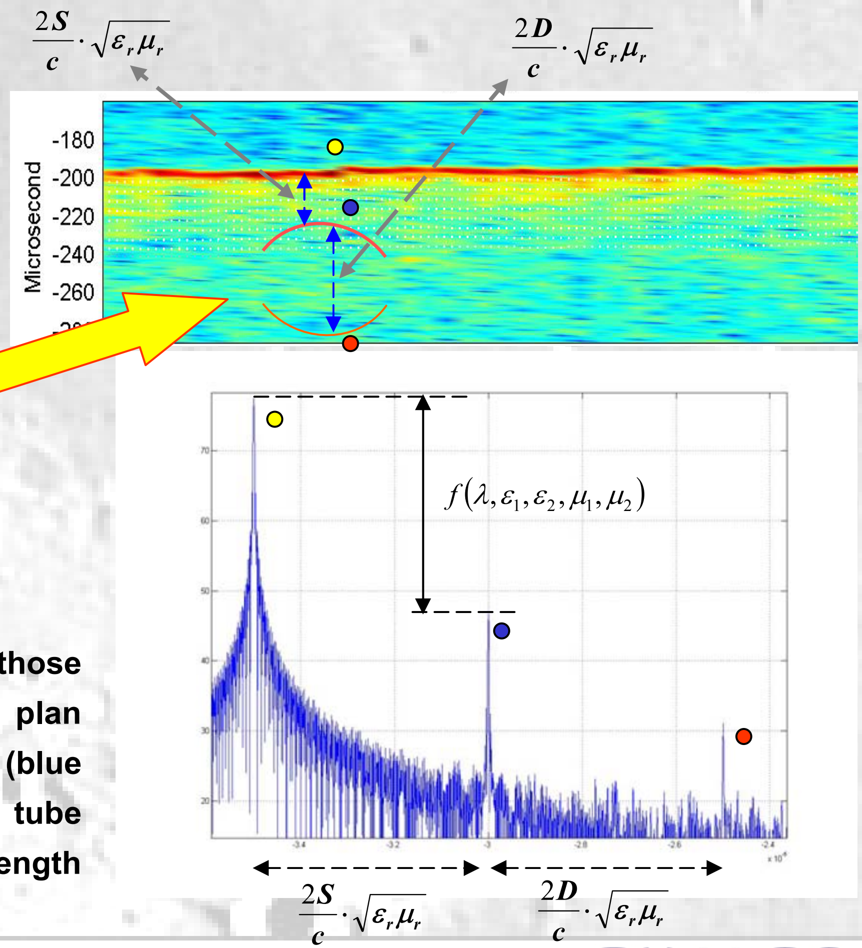
Lava Tubes can be modeled using a cylindrical shape

- **Having a known geometry, the Lava Tube echo to a sounding radar can be properly modeled and therefore detected**
- **Moreover analyzing the electromagnetic characteristic and correlating the echoes coming from the Moon surface, the upper and lower part of the tube, is possible to understand the physical composition of:**
  - ✓ **the tube cavity (e.g. if empty or not)**
  - ✓ **the tube perimeter**
  - ✓ **the rock between the Lava Tube and Moon surface**

Modeling Lava Tubes - 2

- Being a sounder nadir looking, the typical observation geometries of a lava tube can be parallel, orthogonal or diagonal with respect to the ground track. Depending on that, the radargram will present different features

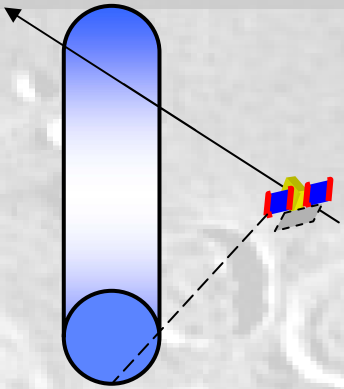


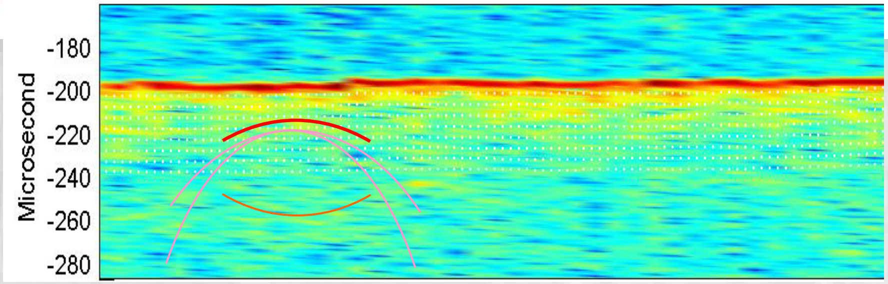


- In this type of geometry, the radargram will show only those regions that appear to be flat and with the local plan orthogonal to the direction between satellite and target (blue and green part of the cylinder); the visible portion of the tube which will depend on the ratio between the radar wavelength and the tube diameter (D)

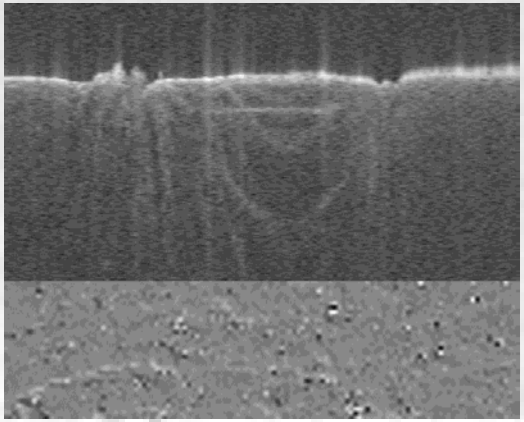
Modeling Lava Tubes - 3

Diagonal crossing



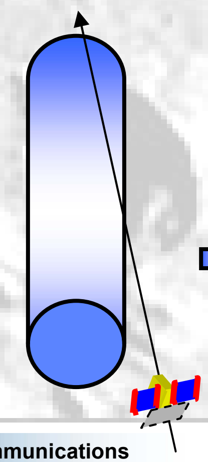


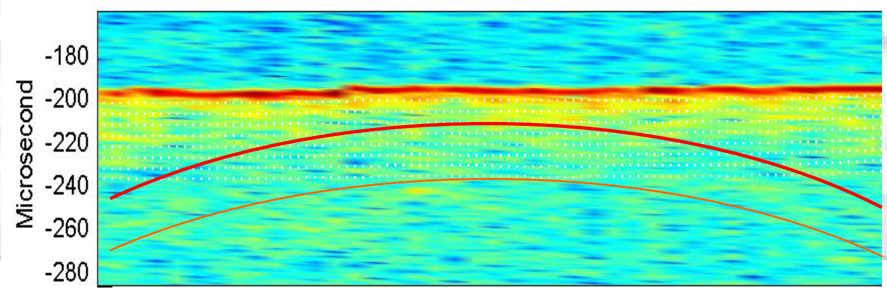
➢ **Buried Crater found by Marsis Instrument**



➢ **In this type of geometry, the radargram will show the rings (known phenomenon observed by MARSIS and SHARAD sounders when flying over craters). Intensity of these rings will be function of the inclination (maximum at 45°, close to zero when parallel or orthogonal)**

Quasi-Parallel crossing

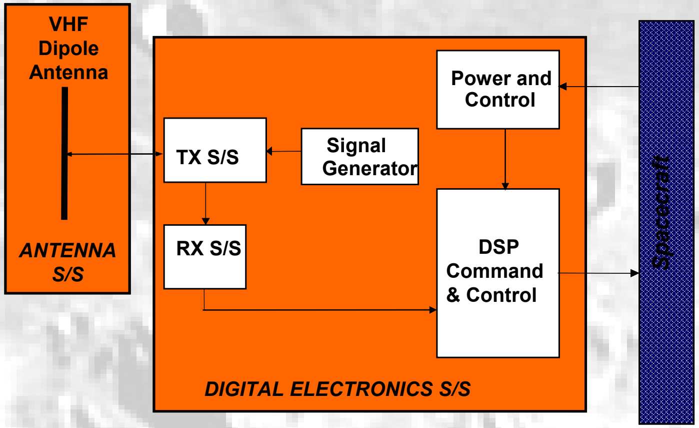




Radar Sounder: preliminary requirements

In the frame of Italian Vision for Moon Exploration Program funded by Italian Space Agency, an evaluation of a Radar Sounder on a lunar orbiter with the objective to map the lava tubes has been performed.

An assessment of the preliminary radar parameters and possible instrument architecture has been carried out.



In order to optimize the main instrument parameters (carrier frequency, signal bandwidth, power, etc.), a deeper modeling of lunar subsurface dielectric characteristics will be necessary

Main Parameters	
Carrier	100 MHz
Bandwidth	25 MHz
PRF	700 Hz
Vertical Resolution	6 m
Range Resolution	2.2 Km
Azimuth resolution	50 m
Max Penetration Depth	0.3 Km
Pulse Width	75 μsec
Peak TX Power	20 W
DC Power	55 W
Mass	13 Kg
Size	0.40(L)x0.45(W) x0.2(H) mxmxm
Antenna Length	1.5 m
Nbit	12
Data rate	46.8 Mbits/sec

Conclusions

- ***A complete map of lunar lava tubes is an important information in view of the exploration and colonization of the Moon***
- ***As lava tubes are subsurface structures, they are difficult to be identified on surface images and, in any case, a catalogue obtained only by surface images would inevitably be incomplete***
- ***The potential of low frequency radar technology to identify lava tubes has been demonstrated on Earth applications***
- ***Radar sounder technology for planetary exploration can be considered at a maturity stage and is presently successfully in operation in Mars orbit***
- ***A small lunar orbiter, embarking a radar sounder for lava tubes mapping, can be based on existing (or easily derivable) technologies, with obvious advantages in economical and programmatic terms***

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