# Farside Explorer : Unique Science from the Farside of the Moon

M. Wieczorek(1)(*), **R.F. Garcia**(2), D. Mimoun(3), D. Baratoux(2) and the Farside Team(4)

(1) IPGP (*) Mission Proposer

(2) IRAP-OMP

(3) ISAE

(4) see next slide

Mimoun et al., Experimental Astronomy, 2011

See http//farside.space-campus.eu for full team

# The Team

**Proposing team**

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S. C. Solomon, Department of Terrestrial Magnetism, Carnegie Institution of Washington, DC, United States
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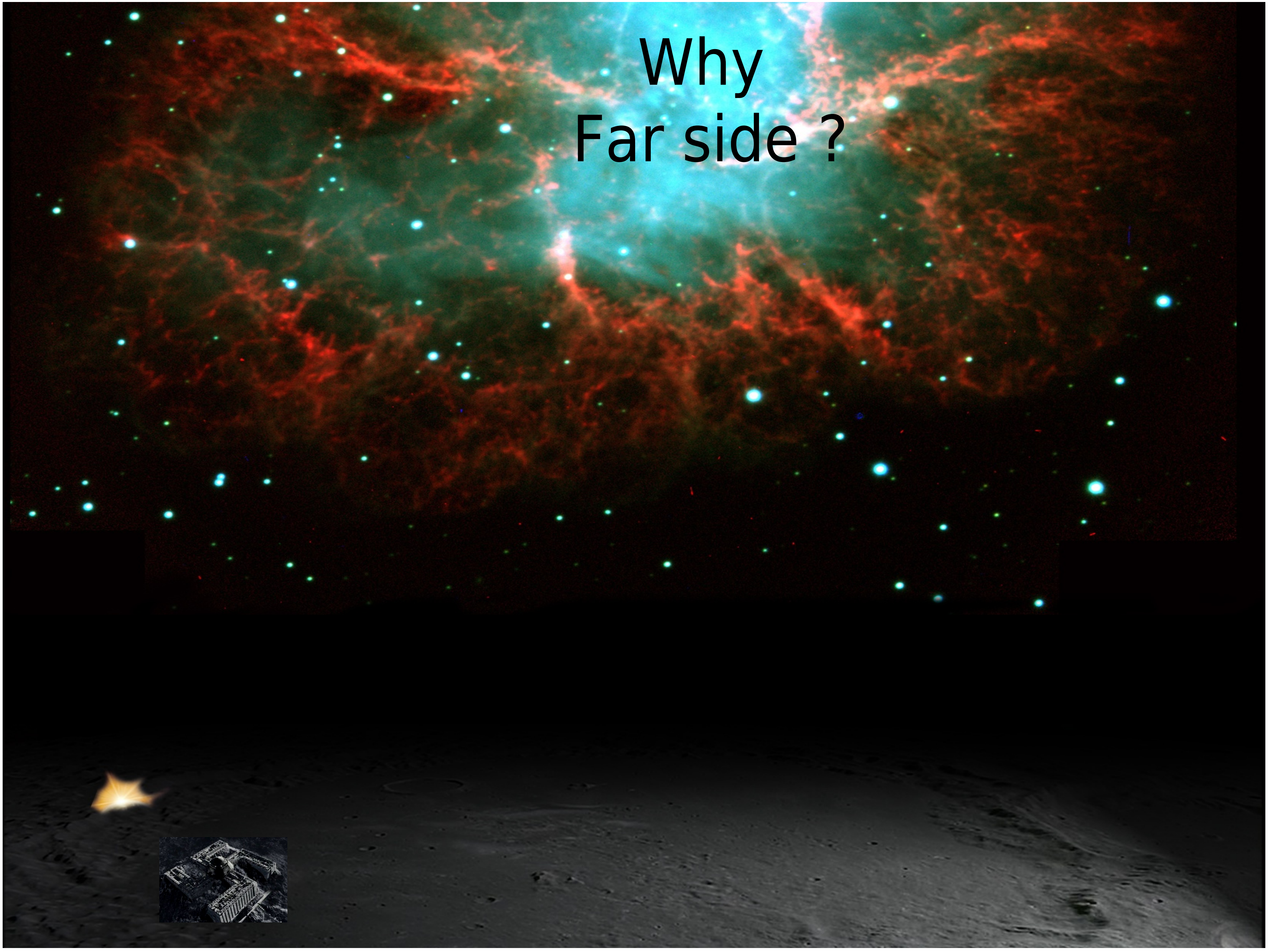
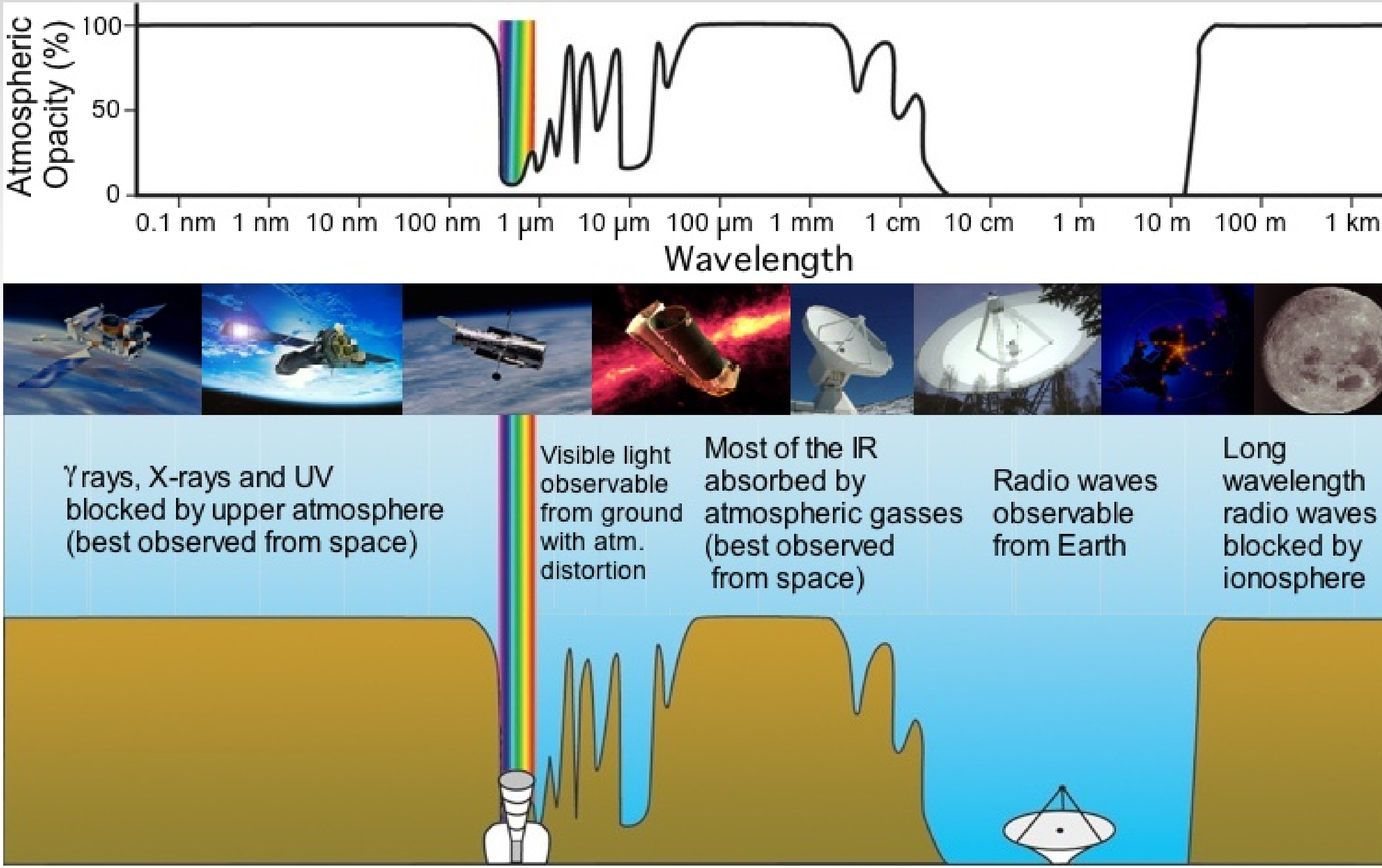
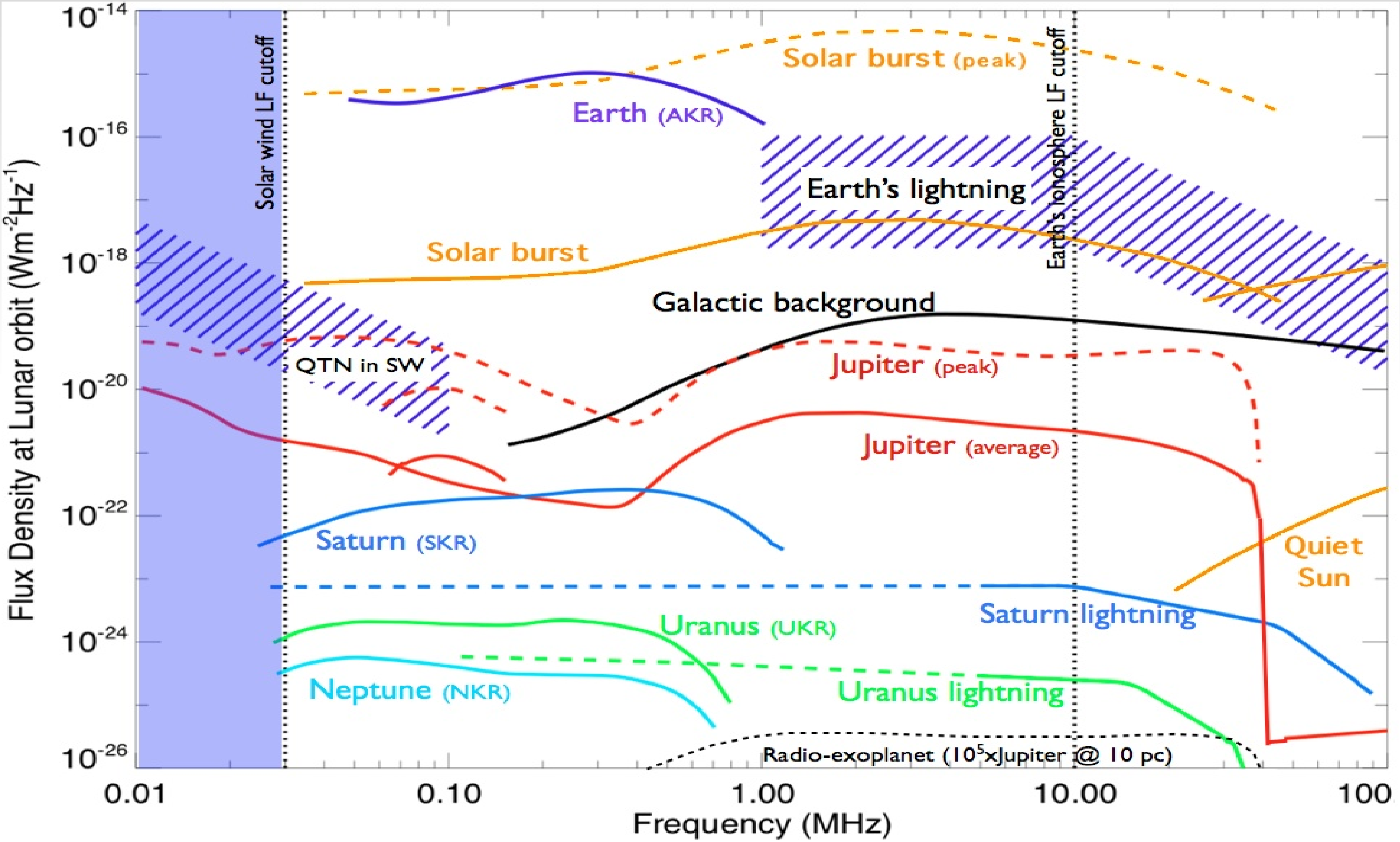

Why
Far side ?

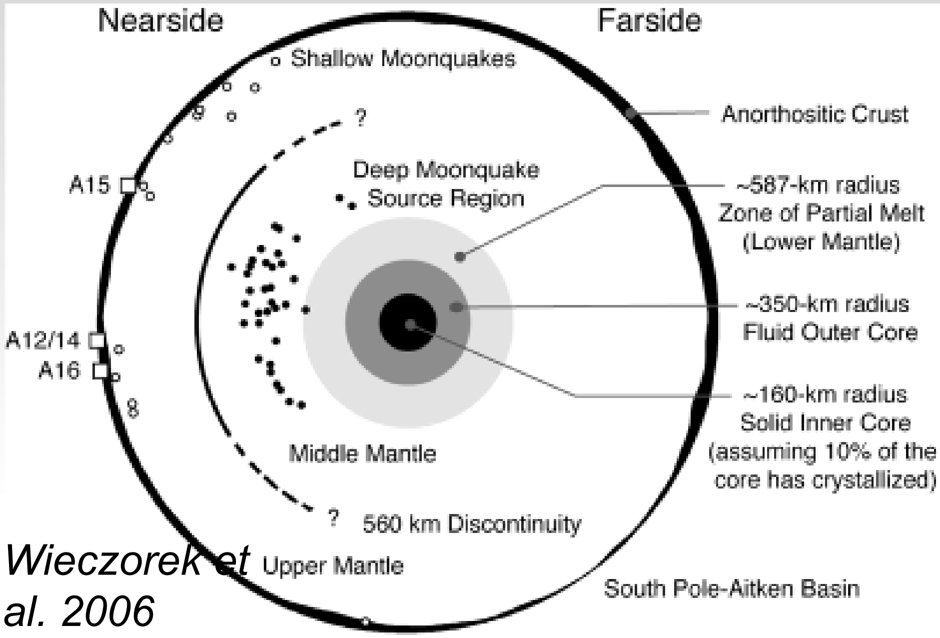
# Ideal place for radioastronomy



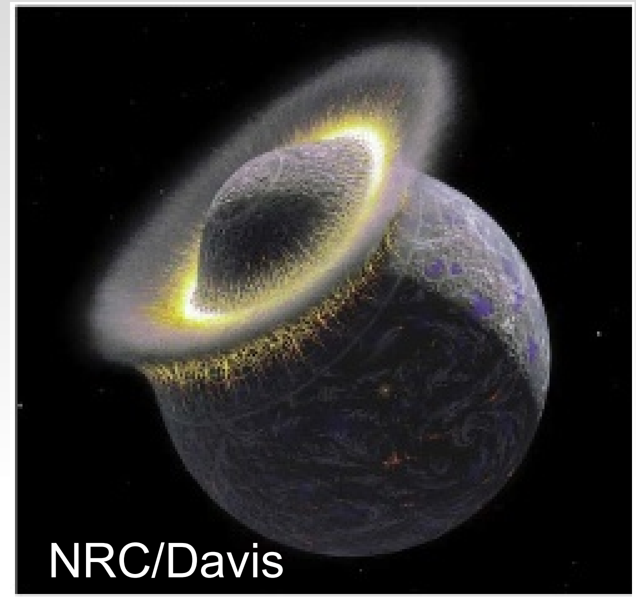
# Ideal place for radioastronomy



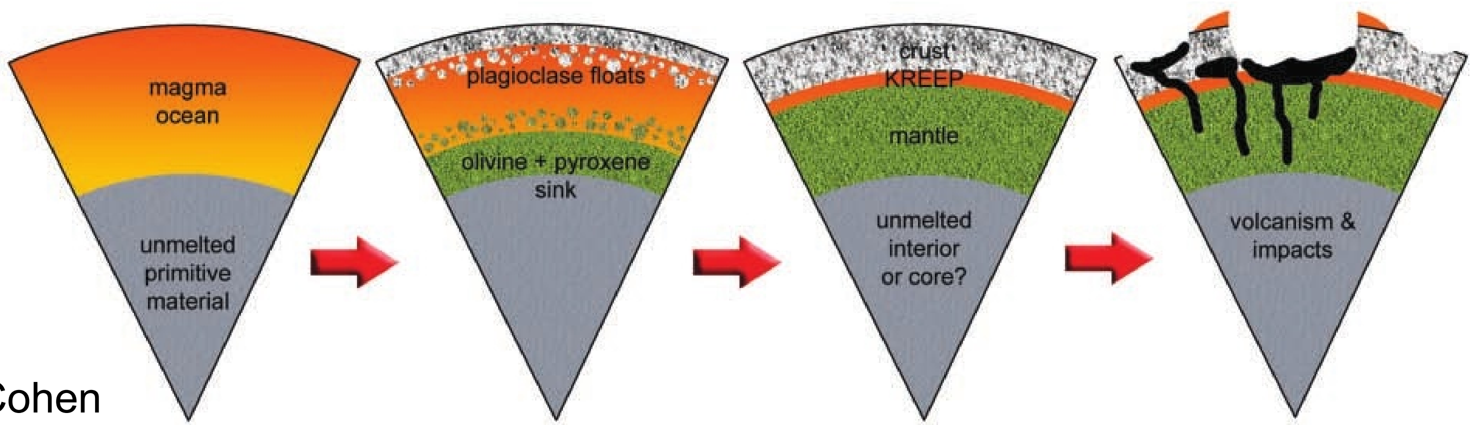
# ...and for geophysics




*Wieczorek et al. 2006*



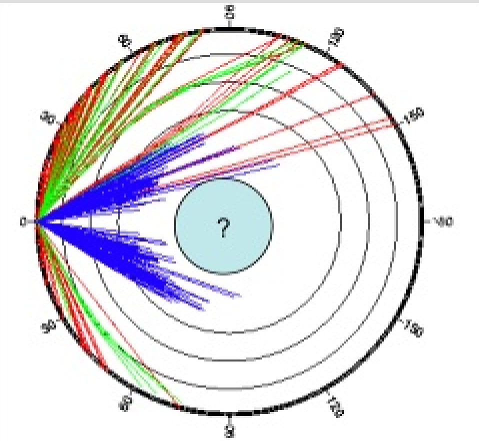
NRC/Davis




NRC/B. Cohen

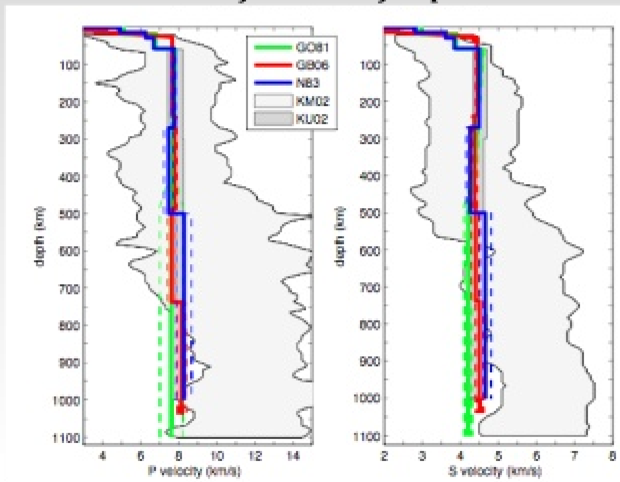
# What's left to learn ?

***Existence and Size of the lunar core***

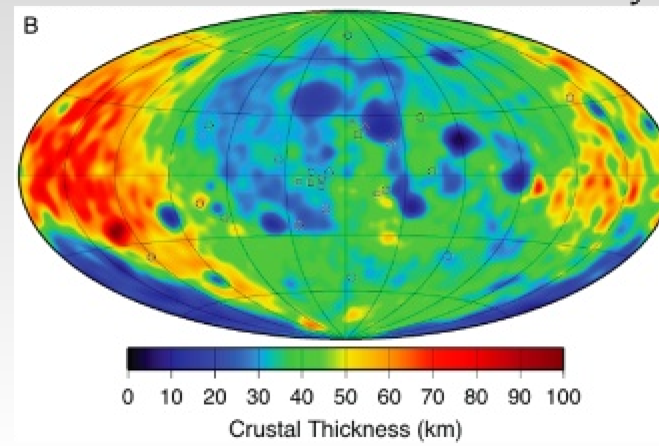



All ray paths available in the Moon. Blue is for deep events, red for impacts, green for superficial moonquakes.

***Refinement of P and S waves velocity profiles as a function of depth***

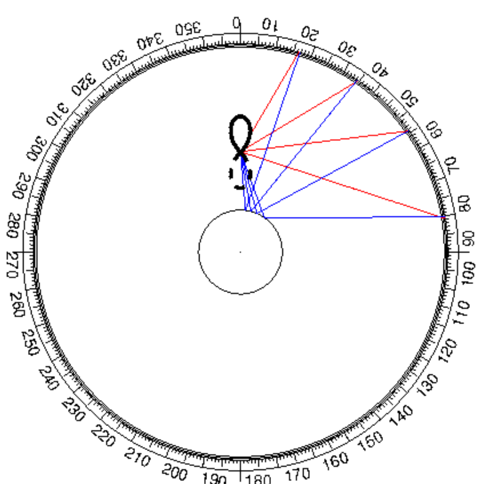



***Determination of the thickness of the lunar crust and characterize its lateral variability.***



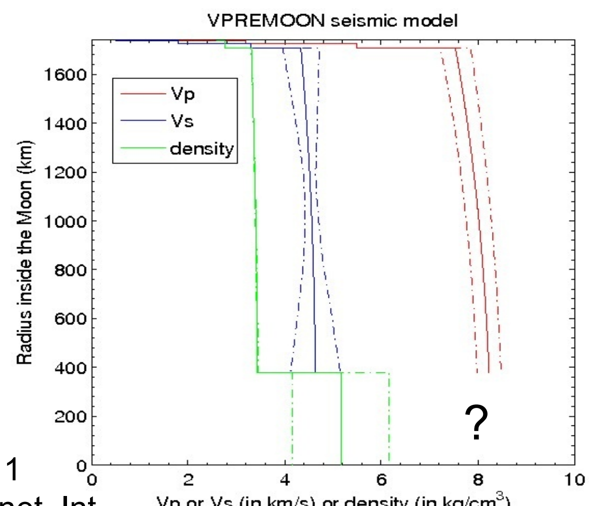

S and ScS rays, SH radiation

r

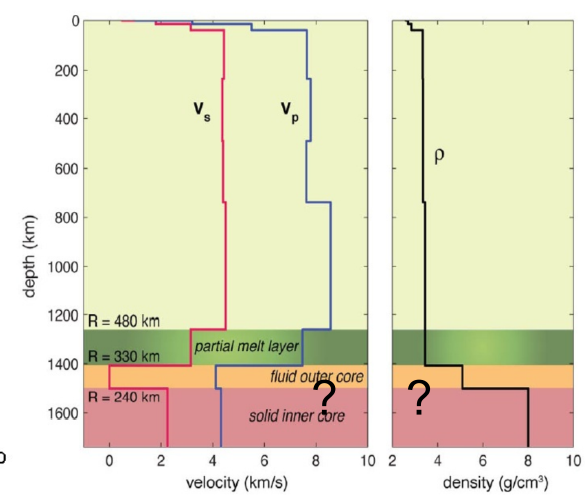


Garcia et al. 2011
Phys. Earth. Planet. Int.

Thickness of the crust (38, 45, 60 km ?)
Upper mantle discontinuities at 500 km ?
Constraints on Mineralogy




Consistency with gravity data, surface composition and heat flux needed

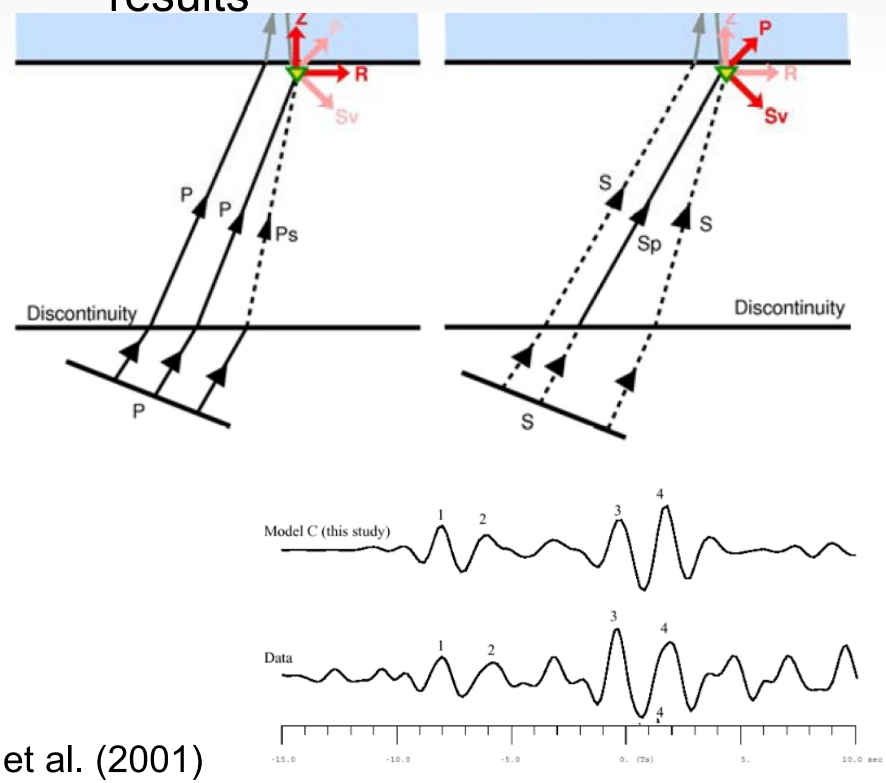



Weber et al. (2011)

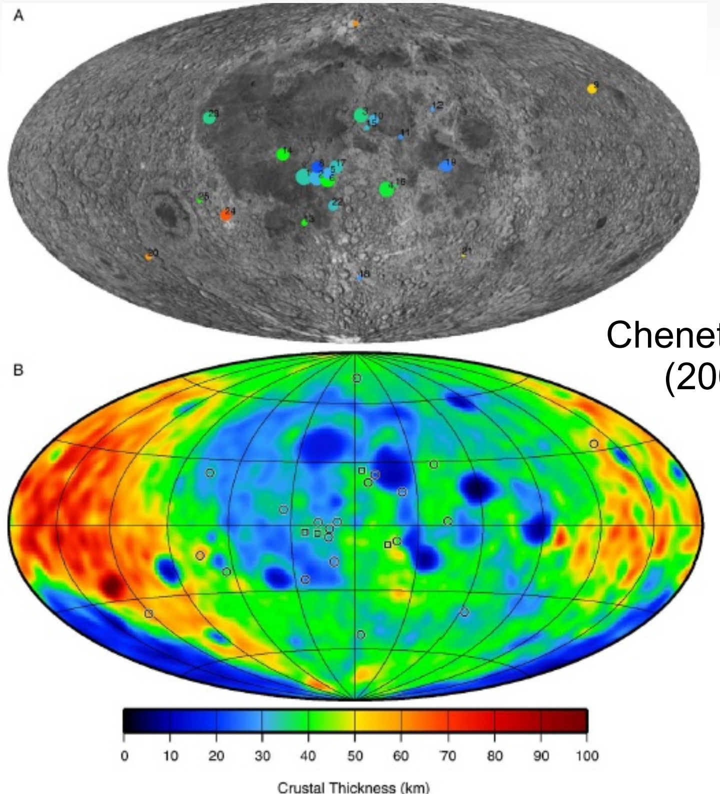
# What's left to learn ?

**Single station** methods can determine the sub-surface structure below it

- H/V and site effects for the first hundreds of meters → highly variable regolith thickness from Apollo results
- Receiver functions and auto-correlation of background noise for the crust structure → Near side crust/mantle interface not constrained by Apollo results

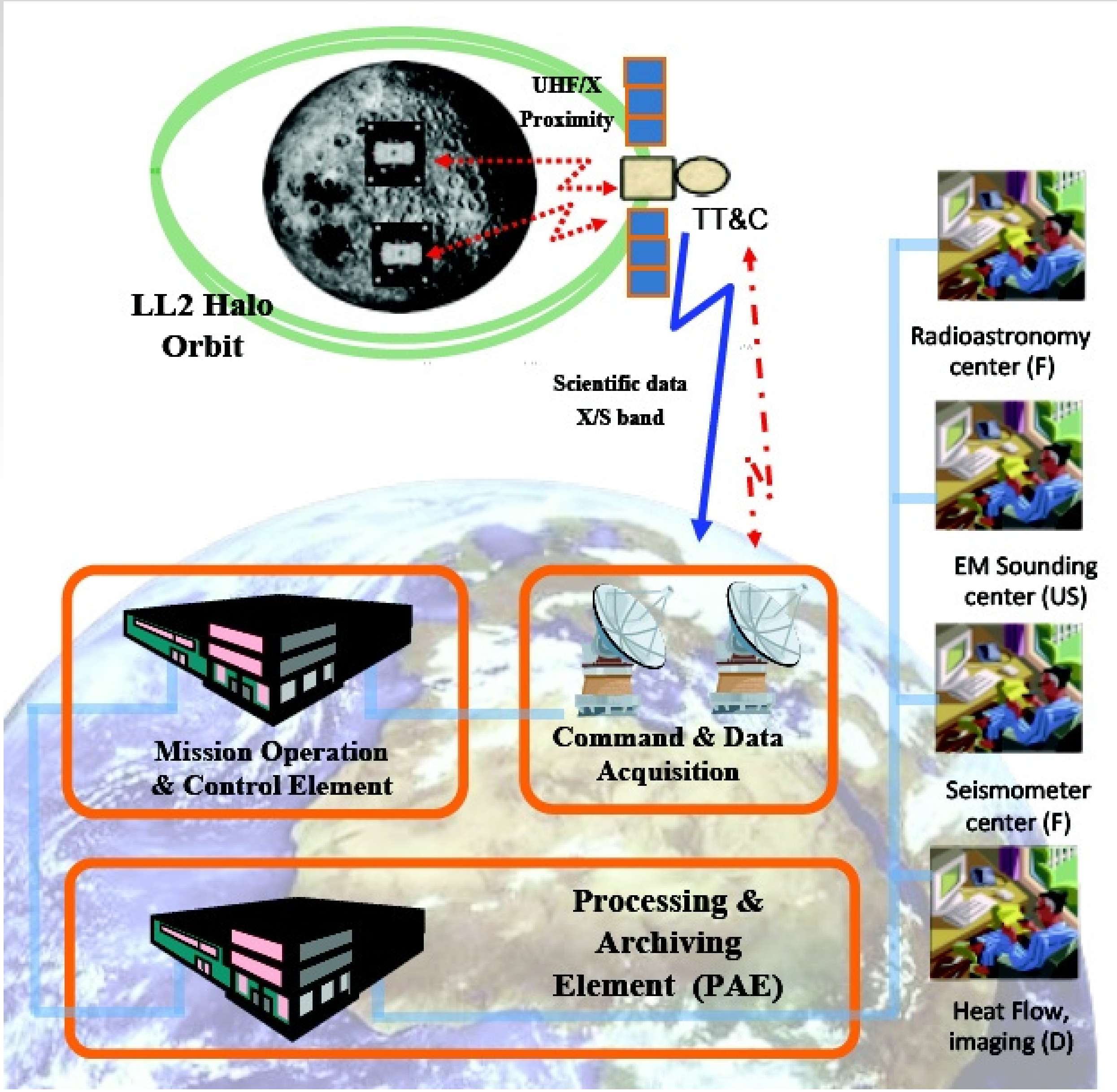



Vinnik et al. (2001)



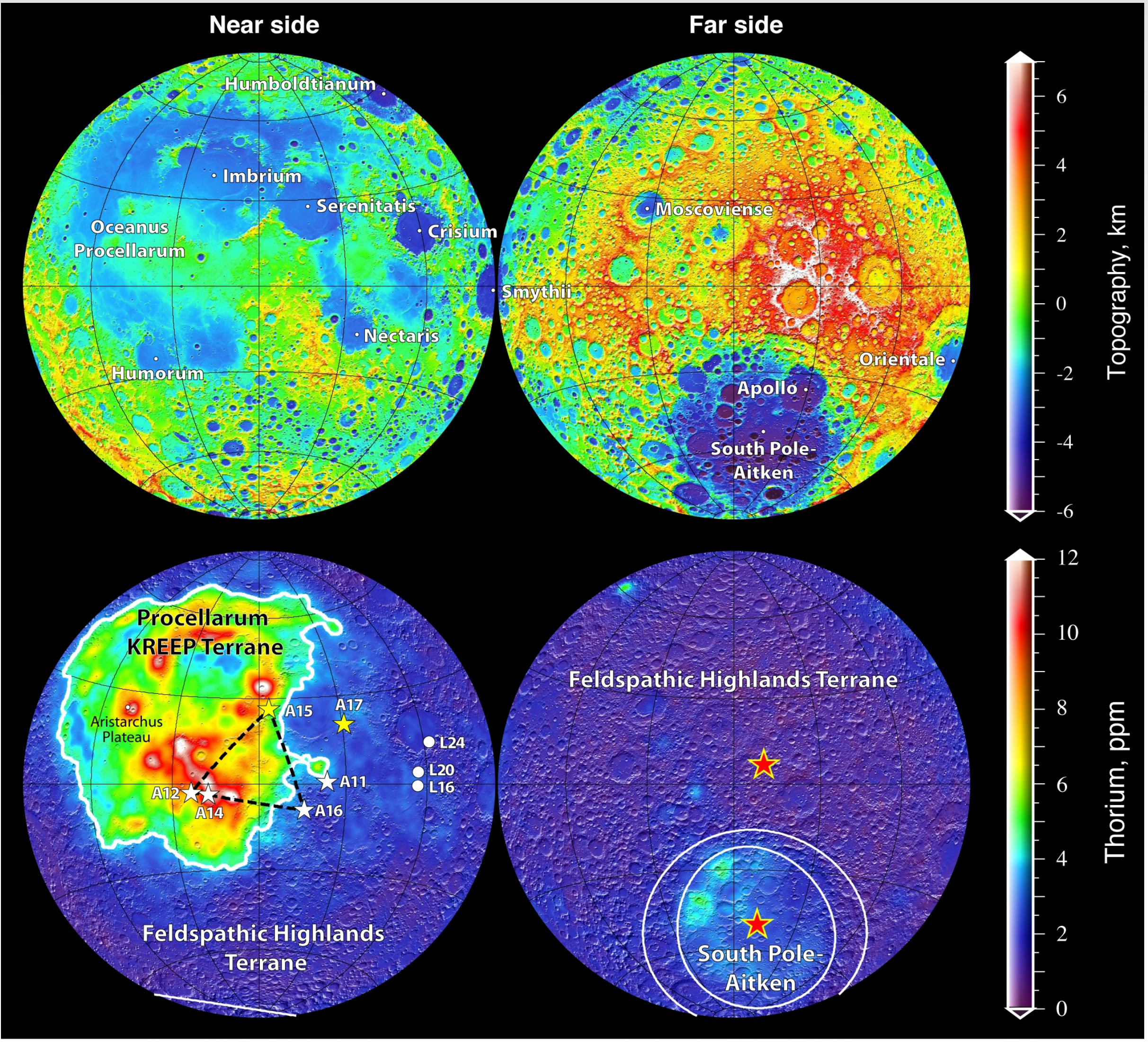

Chenet et al. (2006)

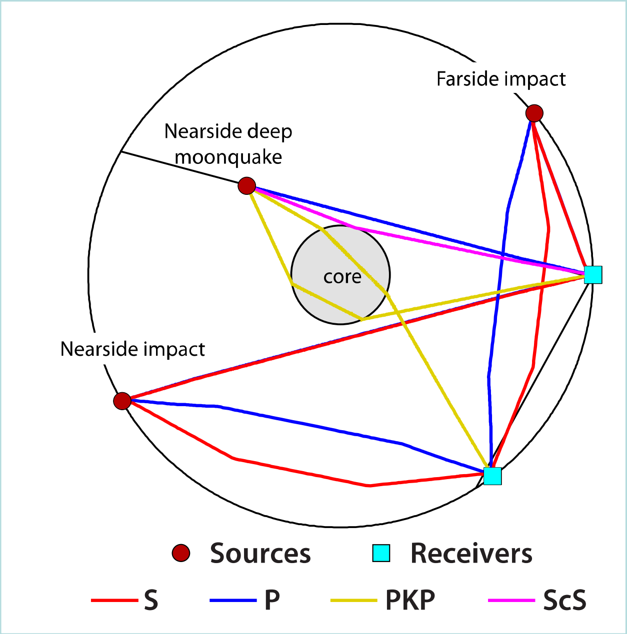
# Farside Explorer



# Proposed Landing Sites

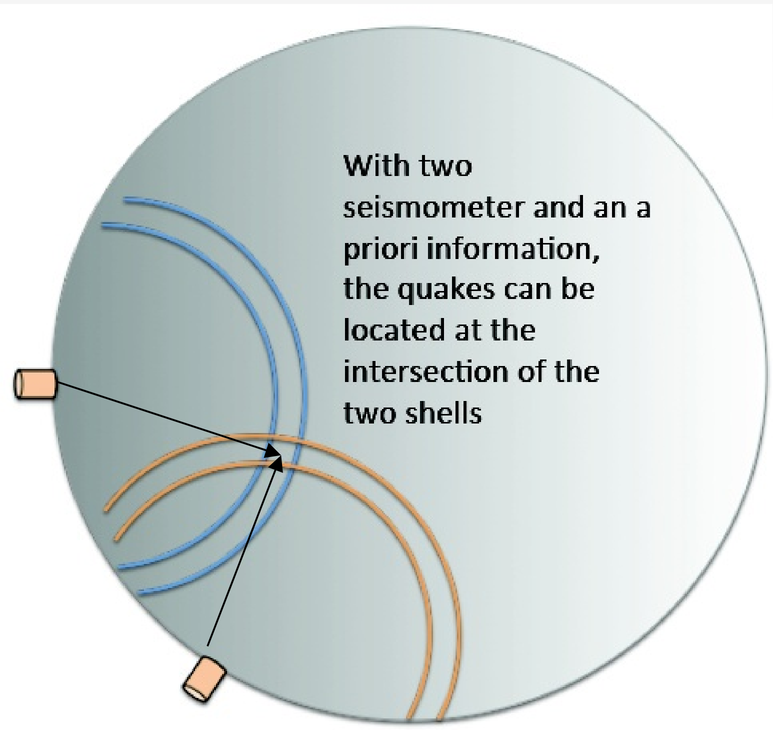
Apollo missions investigated only near side mare regions
→ Feldspathic Highlands Terrane



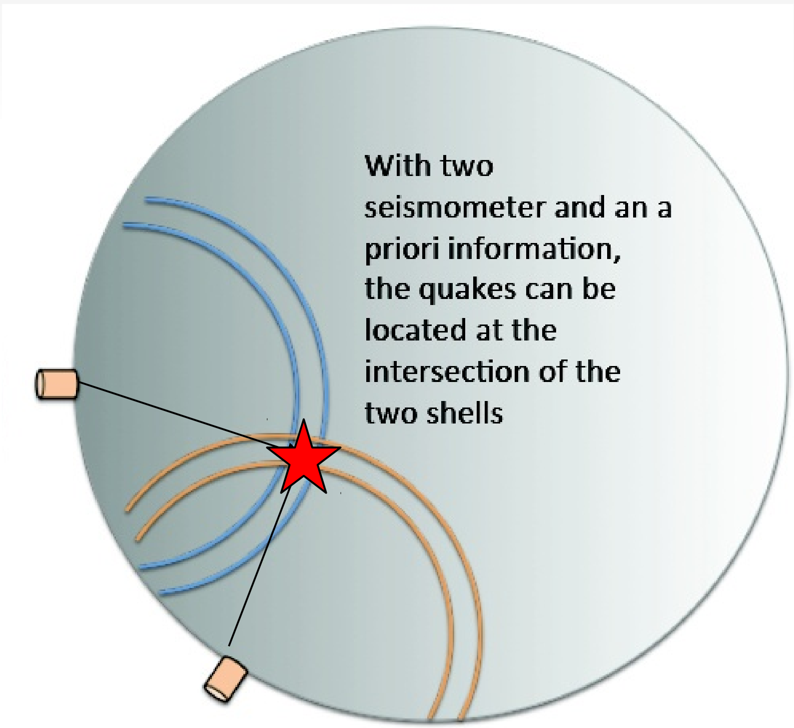
# Two stations seismology ?

1- **Use the wave polarisation** to determine the azimuth of incoming waves => ~10° error bar for each station
It allows **event location** at the intersection of two spheres



# Two stations seismology ?

2- **Locate (time/space) the impact events by monitoring the impact flashes**
=> ~1 ms timing error, <10km location error
It allows **internal structure determination**



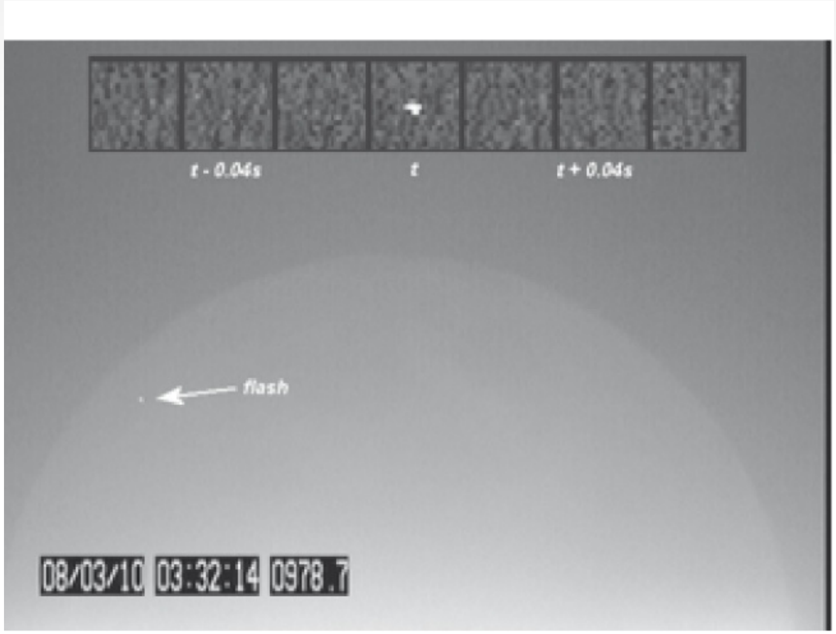
# Impact flash monitoring

Impact flash monitoring from the Earth is an ongoing activity
but only a low number of impacts can be detected because detection
only on night side, and observation geometry is not favourable

→ 4% of events detected by 1 station

→ 11% of events detected by a worldwide network

Ongoing world wilde impact flash monitoring network

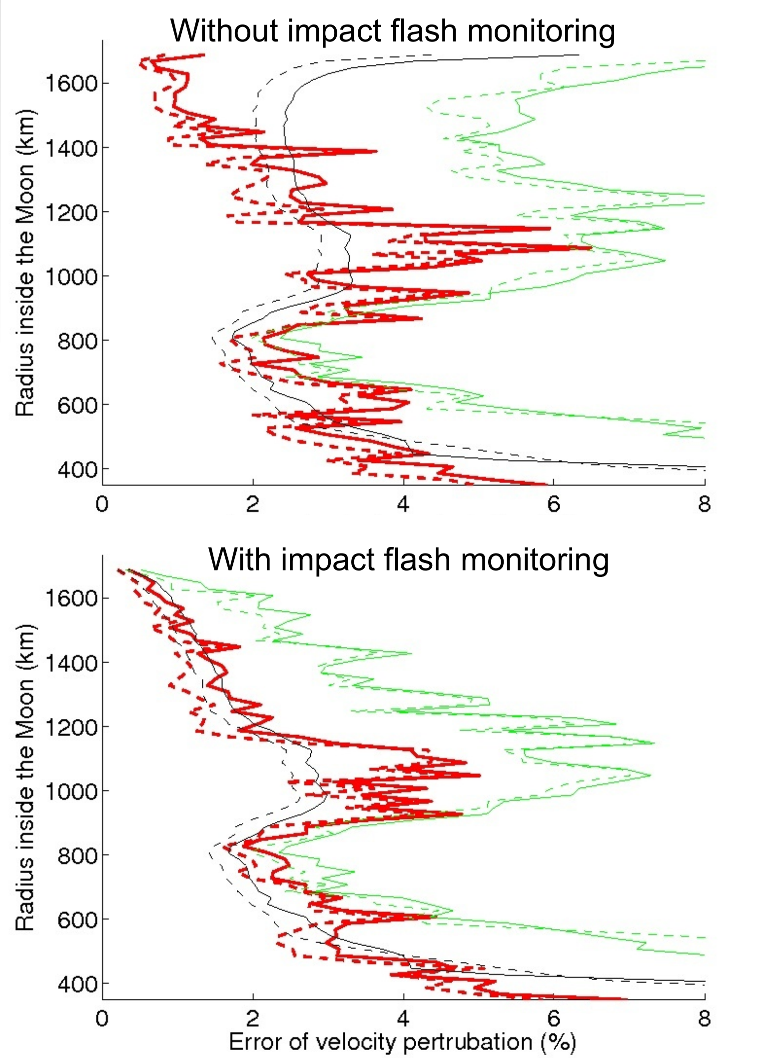


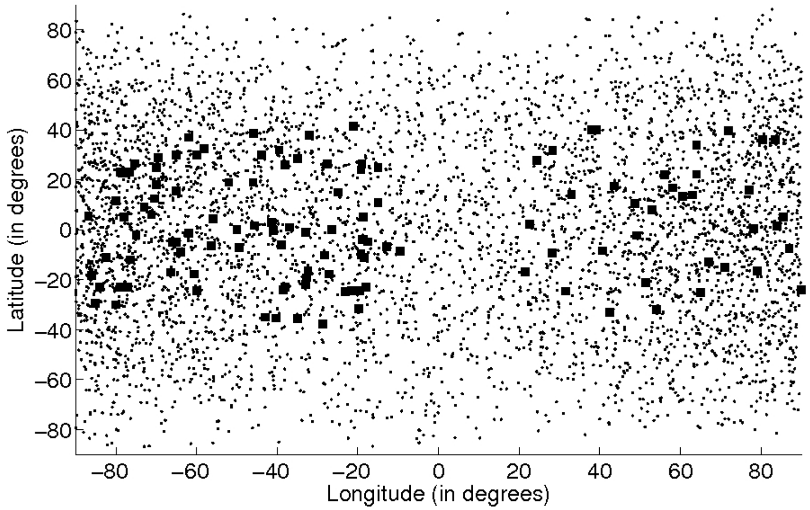

Observation at Uranoscope (France). Courtesy S. Bouley

# Impact flash monitoring

Despite a low percentage of detections, it improves greatly the upper part (crust) of seismic models.
It is absolutely necessary for projects with only 2 seismic stations.

Simulation of seismic model error with 3 stations on the Moon
Yamada et al., 2011




Squares : real impacts detected by US impact monitoring program (4 years)
Dots : simulated impacts detections by a worldwilde network (1 year)

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Despite a low percentage of detections, it improves greatly the upper part (crust) of seismic models.
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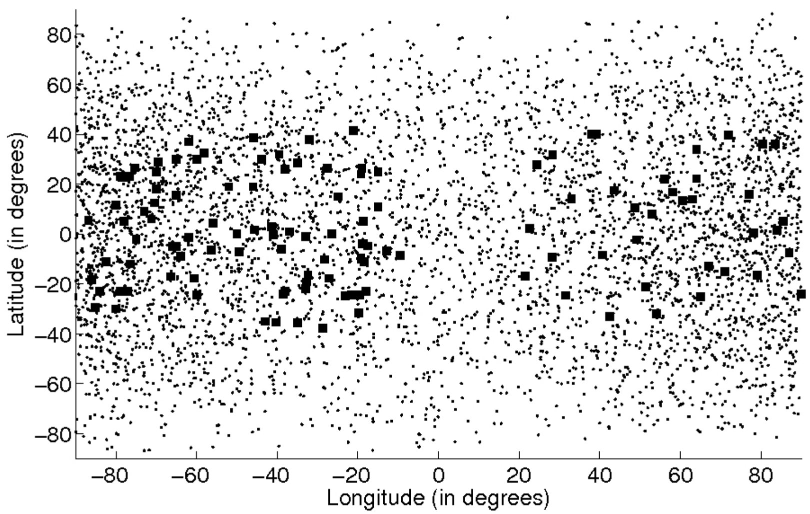
**100 % detections possible from the farside explorer orbiter**

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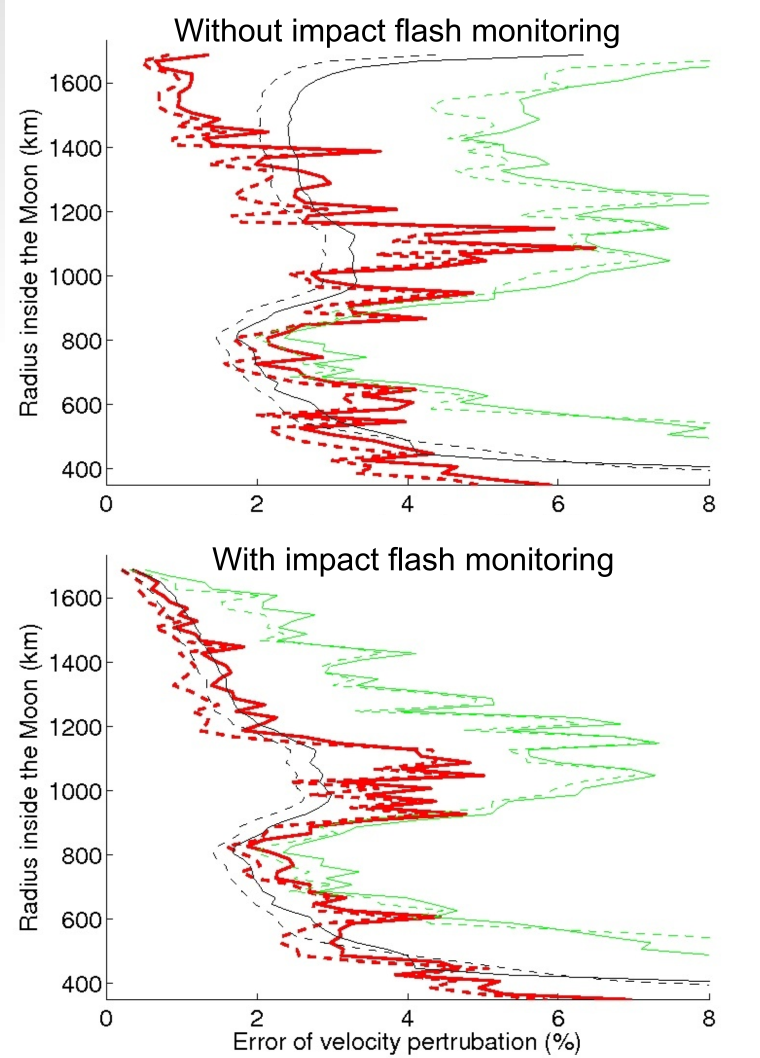

# Far side seismology

Deep moonquakes are repeating with known cycle

→ Future missions may use exactly the **same events**

→ **virtual addition of seismic stations to Apollo network**

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→ Future missions may use exactly the **same events**
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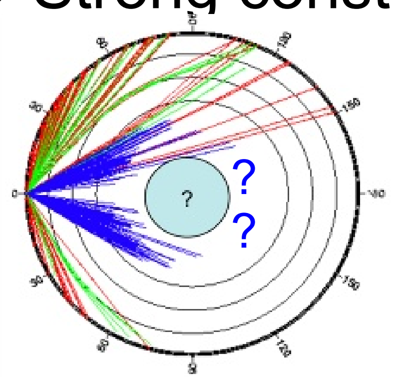
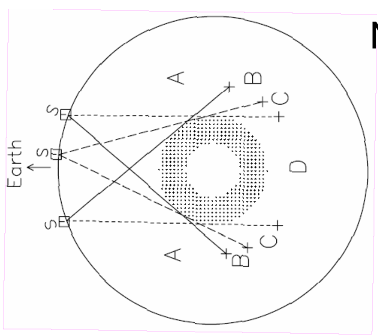
Far side stations may detect :

→ Farside deep moonquakes

→ Strong constraints on deep Moon




Nakamura et al. (2005)

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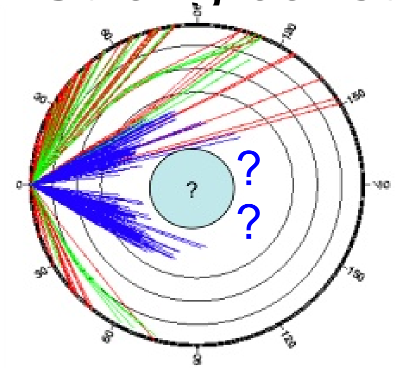
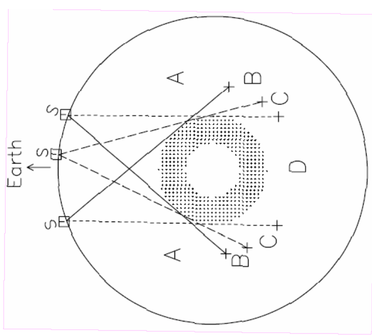
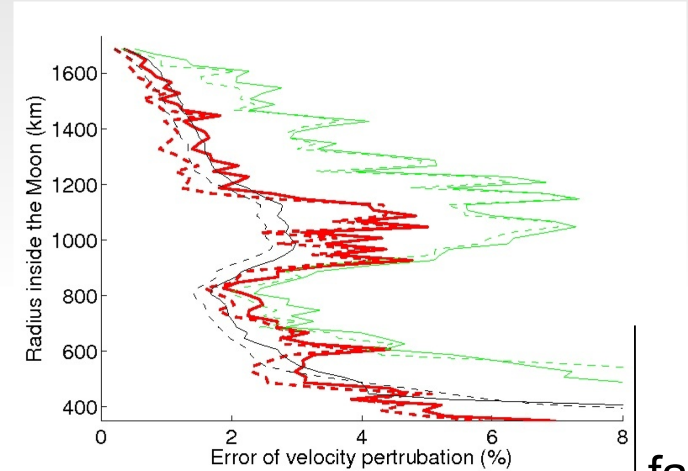
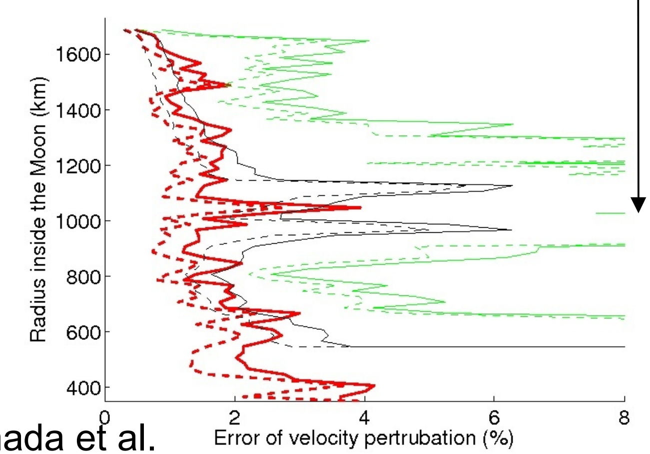



Nakamura et al. (2005)




+1 farside station




Yamada et al. (2011)

**Error bar (in %)**

Add **one** Far side station to a network

→ Divide by 2 the error bar

of deep Moon seismic models

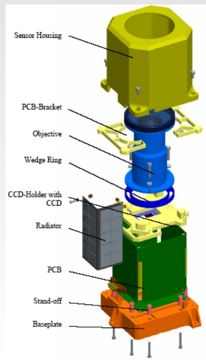
# Science Matrix

| Theme | Farside Explorer Relevance to CV theme | Measurement Objective | Instrument |
|---|---|---|---|
| **Theme 1**<br>***What are the conditions for planet formation and the emergence of life?*** | **1.1 From gas and dust to stars and planets** | | |
| | Farside Explorer will investigate the late stages of planetary formation, including the event that formed the Earth-Moon system and the impact that formed the South Pole-Aitken basin. | Bulk composition of the Moon, crustal thickness, core size, internal structure, surface geology | Seismometer, heat flow probe, electromagnetic sounder, orbiting magnetometer, surface camera |
| | **1.3 Life and habitability in the Solar System** | | |
| | Farside Explorer will quantify impact hazards in near-Earth space, elucidate the consequences of giant impact events that could have frustrated the development of life, and constrain the manner by which single-plate planets lose their heat. | Size-frequency distribution and flux of near-Earth objects, crustal thickness within the South Pole-Aitken basin, heat flow | Impact flash camera, seismometer, heat flow probe |
| **Theme 2**<br>***How does the Solar System work?*** | **2.1 From the Sun to the edge of the Solar System** | | |
| | Farside explorer will measure low-frequency radio emissions from the Sun, uncontaminated by terrestrial radio-frequency interference. | Low-frequency radio monitoring of the Sun | Radio astronomy receiver |
| | Farside Explorer will quantify how the solar wind interacts with atmosphereless bodies. | Electromagnetic measurements from the surface and orbit | Electromagnetic sounder, orbiting magnetometer |
| | Farside Explorer will investigate how planets differentiate into a crust, mantle and core, and how tectonic processes work on single-plate planets. | Internal structure of the Moon, surface heat flow | Seismometer, heat flow probe, electromagnetic sounder, orbiting magnetometer |
| | **2.2 The giant planets and their environments** | | |
| | Farside Explorer will measure the magnetospheric emissions of the giant planets, their time variations, and the coupling with their satellites. | Low-frequency radio monitoring of the outer planets, uncontaminated by solar and terrestrial emissions | Radio astronomy receiver |
| | **2.3 Asteroids and other small bodies** | | |
| | Farside Explorer will constrain the flux, size-frequency distribution, and physical properties of small near-Earth objects. | Monitoring of visual and infrared impact flashes | Impact flash camera, seismometer |
| **Theme 3**<br>***What are the fundamental physical laws of the Universe?*** | **3.3 Matter under extreme conditions** | | |
| | Farside Explorer will detect interactions between ultra high energy cosmic rays and the lunar surface. | Low-frequency radio measurements | Radio astronomy receiver |
| **Theme 4**<br>***How did the Universe originate and what is it made of?*** | **4.1 The early Universe** | | |
| | Farside Explorer will investigate the cosmological dark ages through the red-shifted neutral hydrogen 21-cm line. | Low-frequency radio measurements uncontaminated by solar and terrestrial emissions | Radio astronomy receiver |

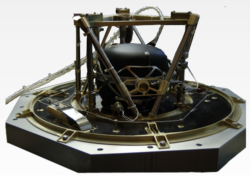
# Strawman Payload

*Lander Payload*

*Orbiter Payload*




**RAR**



***RadioAstronomy***
*Cosmology, Low Frequency Sky Mapping, Solar Physics, Planetary Magnetospheres pulsar and radio propagation, Transient events,Lunar environment*

**SEIS, EMS**

**HP³, EMS**

***Lunar Science***
*Interior structure of the Moon*
*Thermal evolution of the Moon*

**MAG, SPOSH**

**MAG**

**SEIS**

***Impact hazards***
*Impact Flux Impact size Frequency distribution temporal and spatial variations in impact flux*

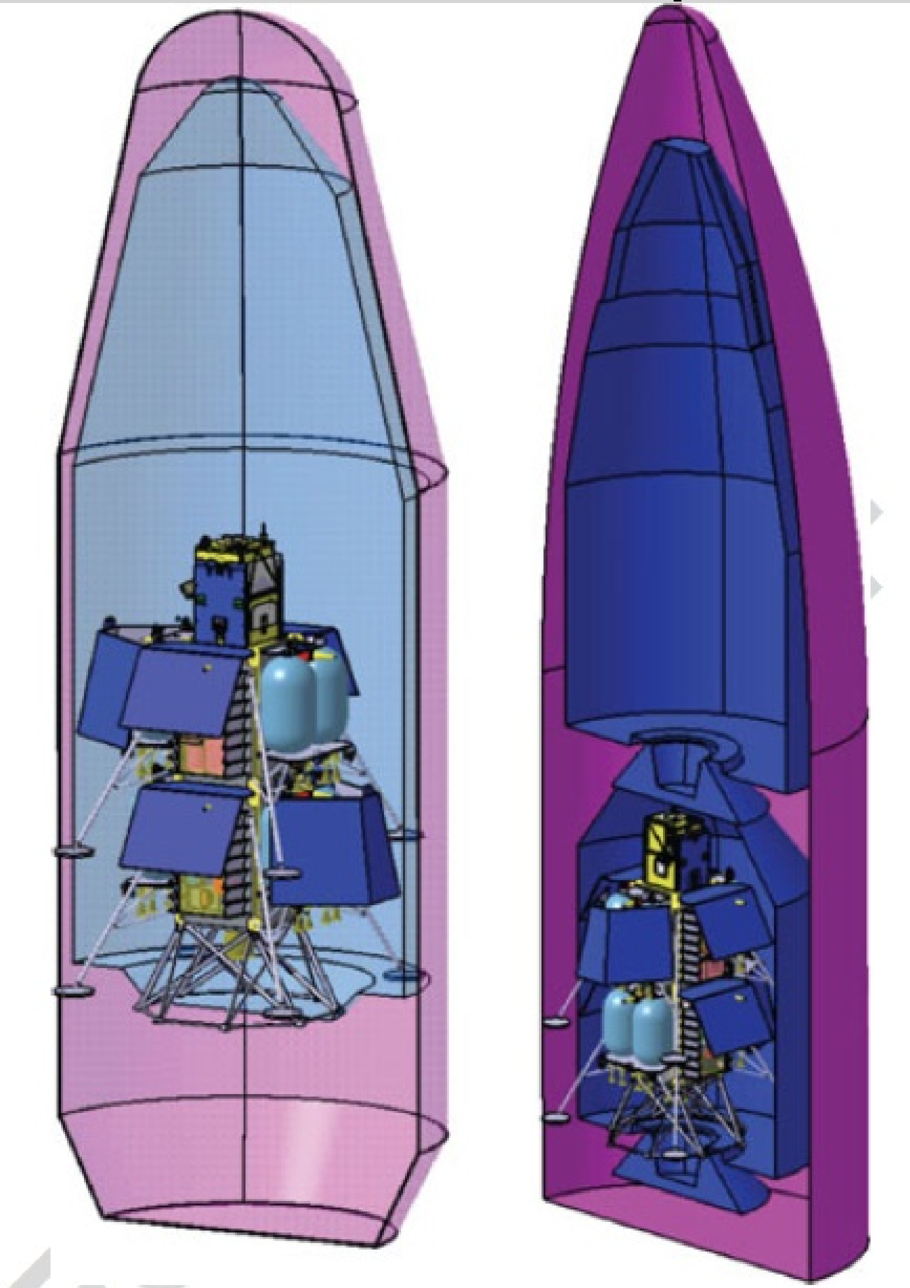
**SPOSH**

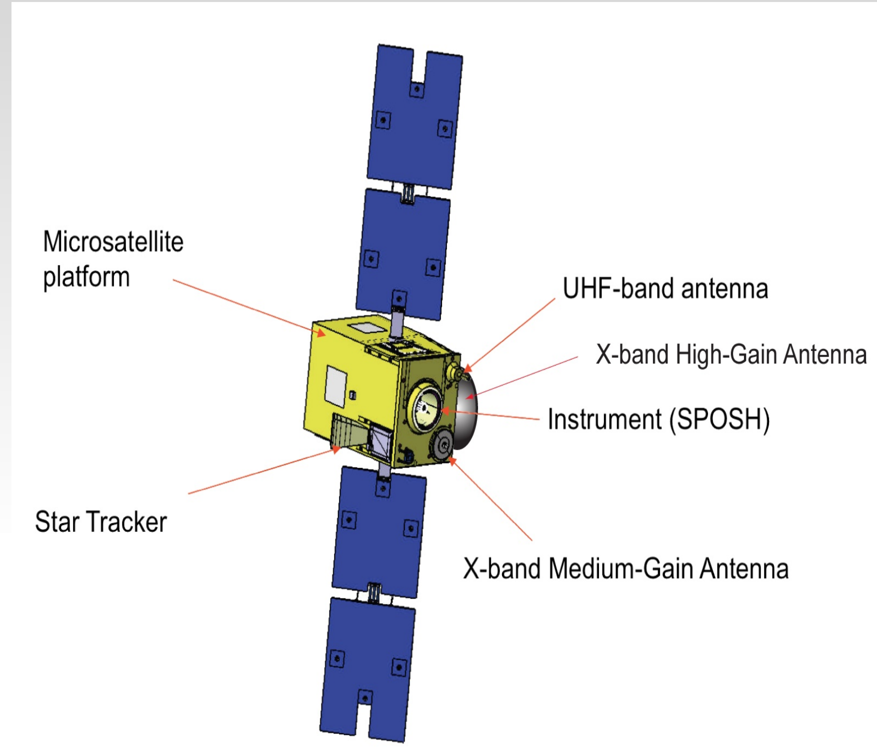
| Full Science Payload | Remark | Mass (kg) | | Avg Power (incl. 20% marg. W) | | Data Rate |
|---|---|---|---|---|---|---|
| | | CBE | w 20% margin | Day | Night | (Gb/Lun) |
| Robotic Arm | | - | 7.0 | - | - | - |
| RAR | Full science | 1.5 | 1.8 | 1.2 | 1.2 | 3.3 |
| EMS | Full science | 7.2 | 8.6 | 4.0 | 0.1 | 1.6 |
| SEIS | Core Payload | 7.0 | 8.4 | 2.6 | 1.6 | 6.3 |
| HP³ | 2 Moles | 2.8 | 3.4 | 3.4 | 0.3 | 0.0 |
| CAM | Core Payload | 1.0 | 1.2 | 1.5 | - | 1.0 |
| Geochemistry | | - | 3.0 | 3.0 | - | 0.2 |
| Total | | | 33.4 | 15.7 | 3.2 | 12.4 |

| Core Science Payload | Remark | Mass (kg) | | Avg Power (incl. 20% marg. - W) | | Data Rate |
|---|---|---|---|---|---|---|
| | | CBE | w 20% margin | Day | Night | (Gb/Lun) |
| Robotic Arm | | - | 7.0 | - | - | - |
| RAR | Core Payload | 1.5 | 1.8 | 1.2 | 1.2 | 3.3 |
| EMS | Core Payload | 6.2 | 7.4 | 3.6 | 0.1 | 1.2 |
| SEIS | Core Payload | 6.2 | 7.4 | 2.6 | 1.6 | 5.3 |
| HP³ | 1 Mole | 1.5 | 1.8 | 1.7 | 0.2 | 0.0 |
| CAM | Core Payload | 1.0 | 1.2 | 1.5 | - | 1.0 |
| Total | | | 26.7 | 10.6 | 3.1 | 10.8 |

| Satellite Payload | Mass (kg) | | Avg Power (incl. 20% marg. - W) | Data Rate |
|---|---|---|---|---|
| | CBE | w 20% margin | | (Mb/Lun) |
| SPOSH | 10.0 | 12.0 | 24.0 | 1.6 |
| MAG | 1.4 | 1.7 | 1.0 | 65.0 |
| Total | | 13.7 | 25.0 | 66.6 |

# Farside Explorer System Elements

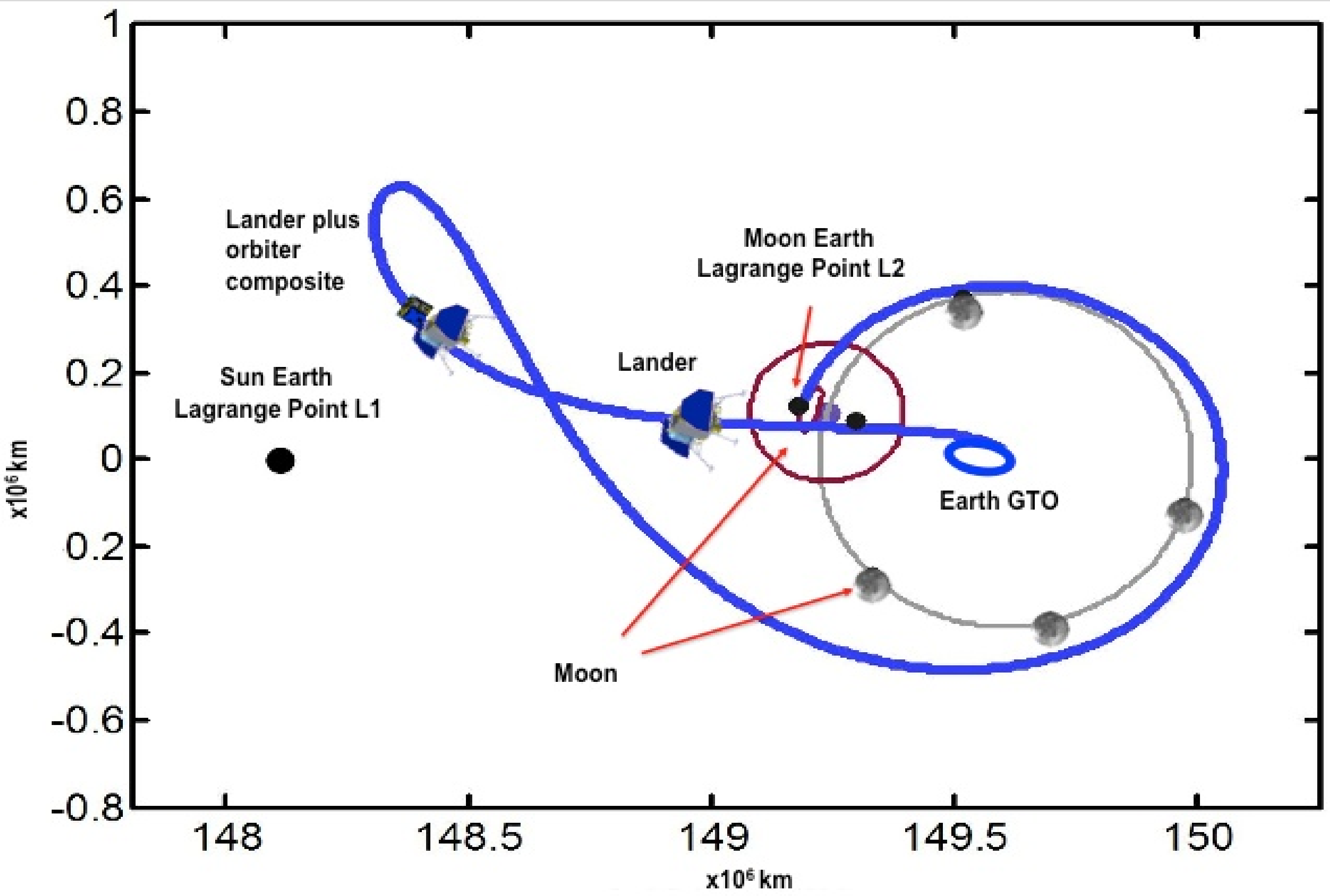




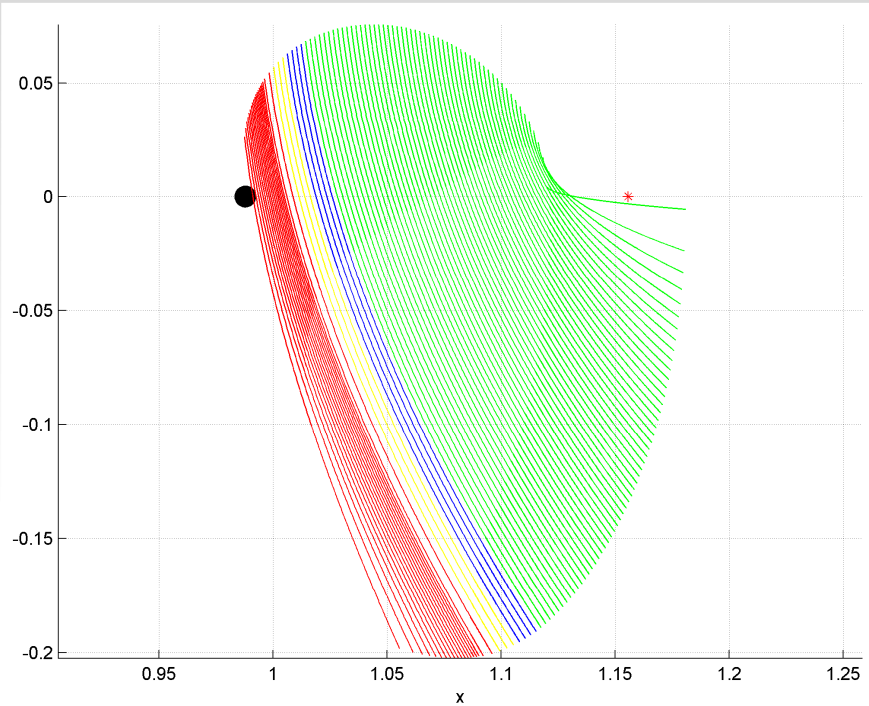

**2 probes :**
**Soyuz, Ariane V configuration**
**(courtesy Astrium)**

**100 kg class**
**LL2 Halo**
**Relay Orbiter**

# Mission Design

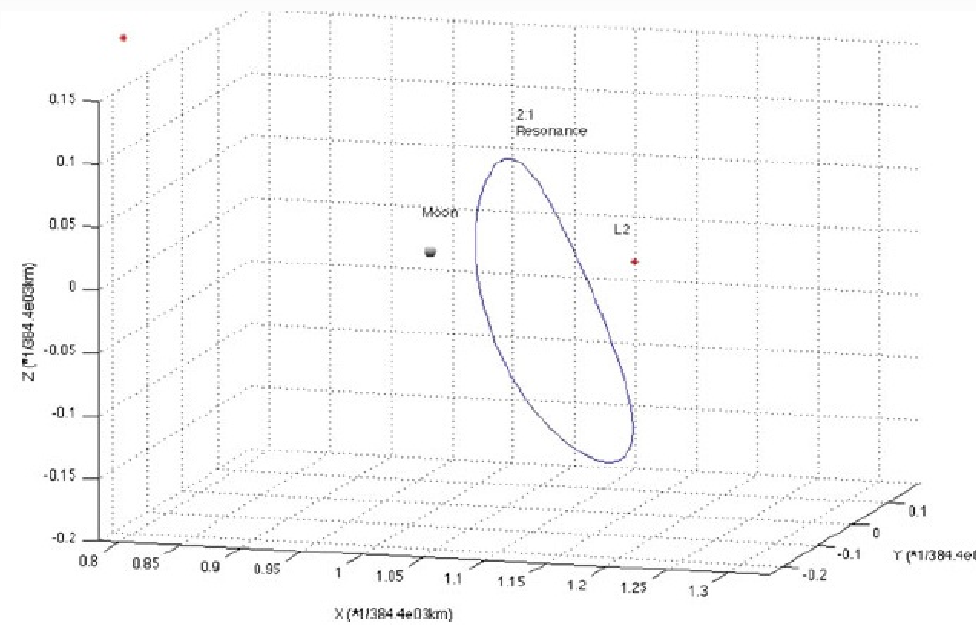


# LL2 Halo Orbits




LL2 Halo Orbits provide coverage of the Farside of the Moon for the impact camera (Green to red : full to partial visibility of both stations)

LL2 Halo Orbits are visible from Earth to provide data relay.



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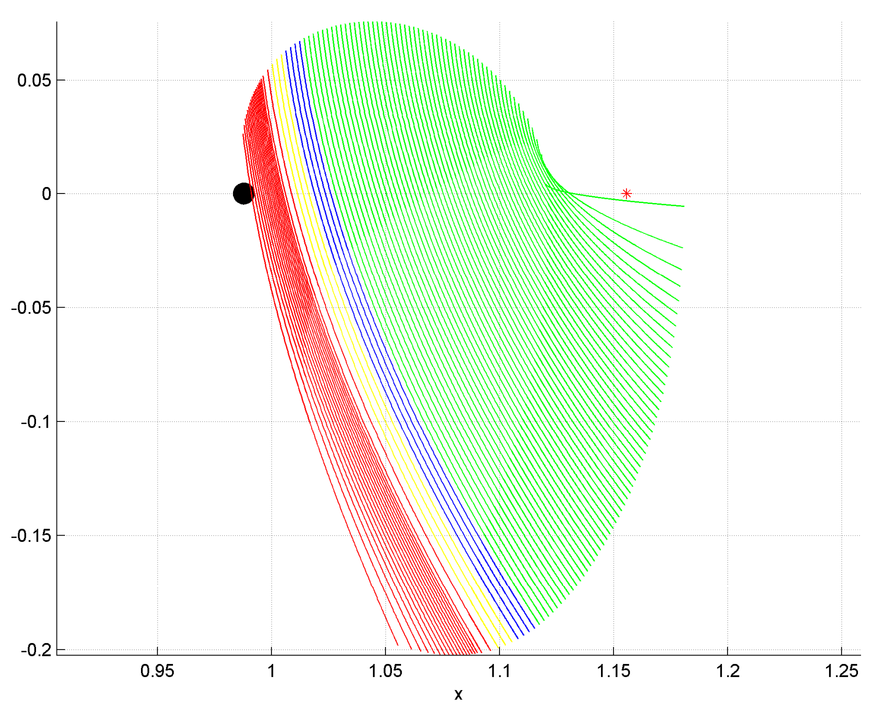
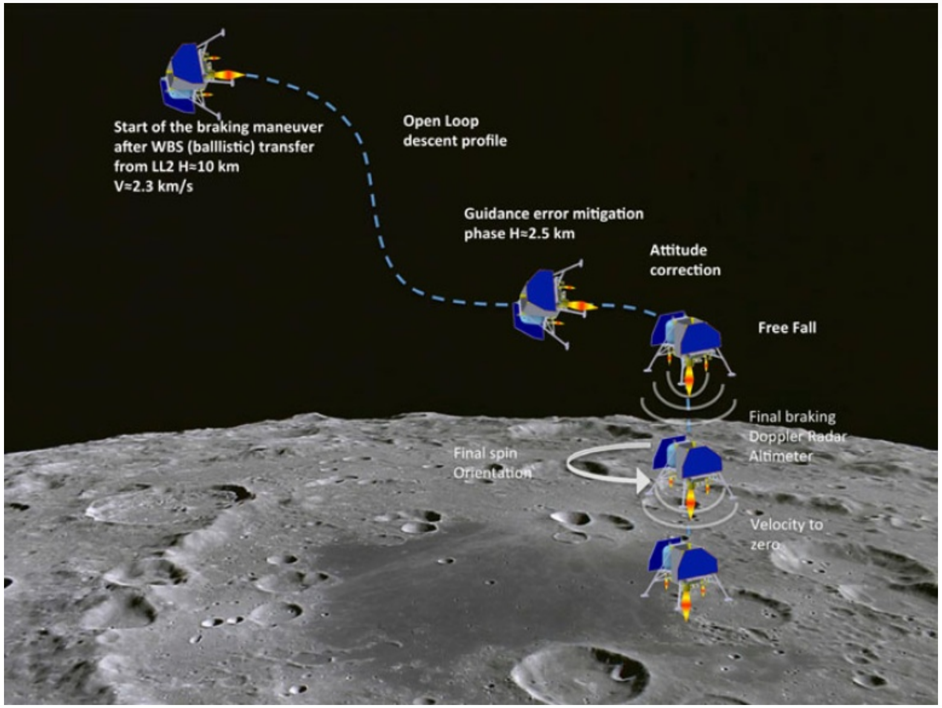
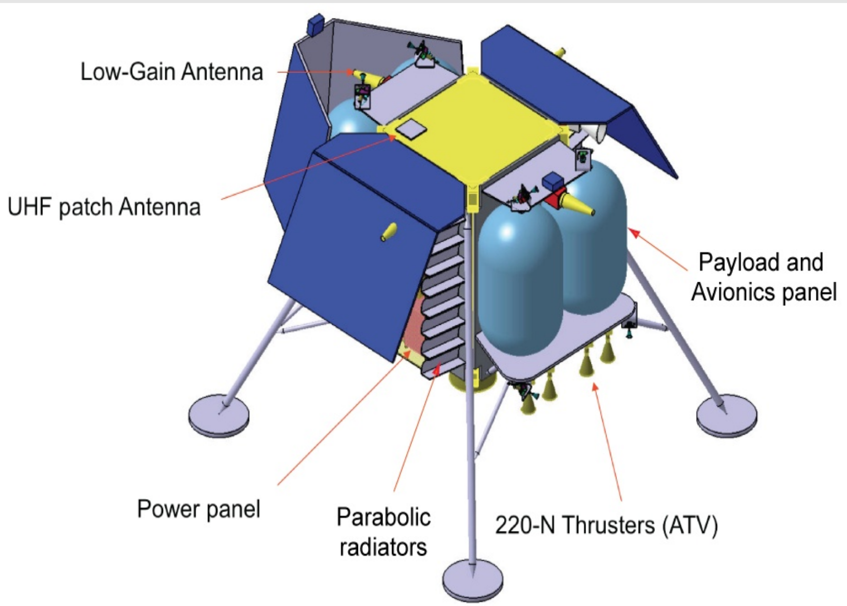



LL2 Halo Orbits provide coverage of the Farside of the Moon for the impact camera (Green to red : full to partial visibility of both stations)

LL2 Halo Orbits are used as waiting orbit before descent



# Lander Outline



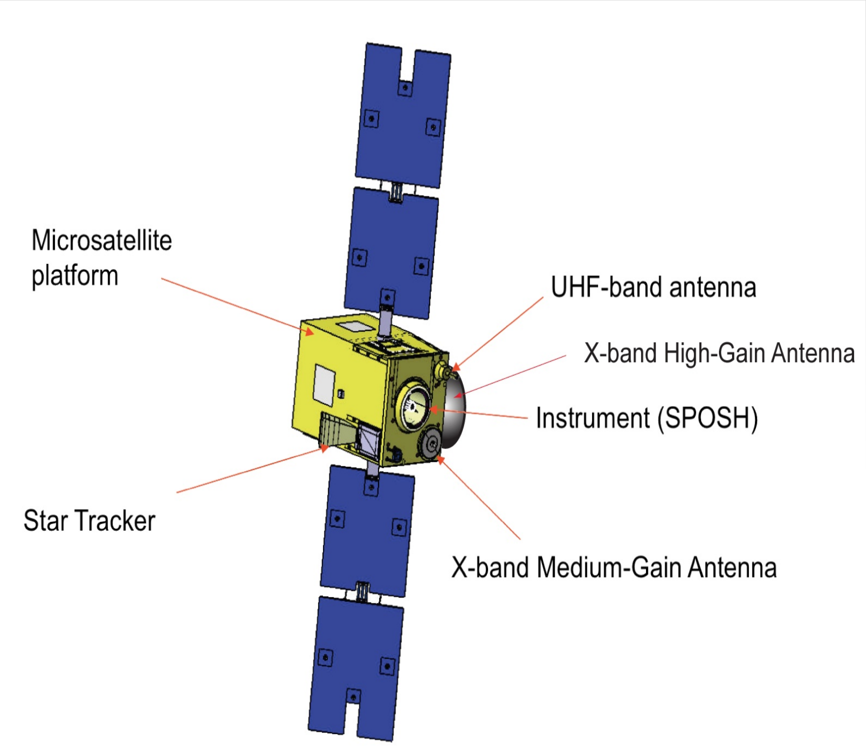

Courtesy Astrium Satellites

Lander dry mass 380 kg
·Wet Mass 1185 kg
·Payload Mass : 26 kg
·Power : 200W (Day) /4W (Night)

Night Power EPS  sizing critical

- Avionics in warm box
- ON/OFF strategy for avionics
- Use of parabolic radiators and thermal switches to keep E-box warm
- Technology developments needed !

# Halo orbiter outline




Courtesy Astrium Satellites

Orbiter wet mass 150 kg
- Payload Mass : 50kg
- Power : 60 W including X/S Band UHF relay

Design derived from low cost small GEO or from low cost LEO.
- SPOSH Camera
- Magnetometer
- Trade –off steerable relay antenna / pointing strategy

# Synergies and Perspectives


include detailed cost information.

**Lunette**

Lunar Geophysical Network

*A dual lander mission to explore early planetary differentiation*

A Discovery Mission Proposal Submitted
in Response to AO NNH10ZDA007O

Clive R. Neal
*Principal Investigator*
*University of Notre Dame du lac*

Prepared for
National Aeronautics and Space Administration
Science Mission Directorate

September 10, 2010

Submitted by
Liz Rulli
*Associate Vice President for Research*
*University of Notre Dame du lac*

Companion Mission with Selene 2 (JAXA) and Lunette proposal (JPL, PI C. Neal)
Moon Network mission prioritized by Decadal Survey for NF5
Mission refined to be proposed with M4 ESA Call