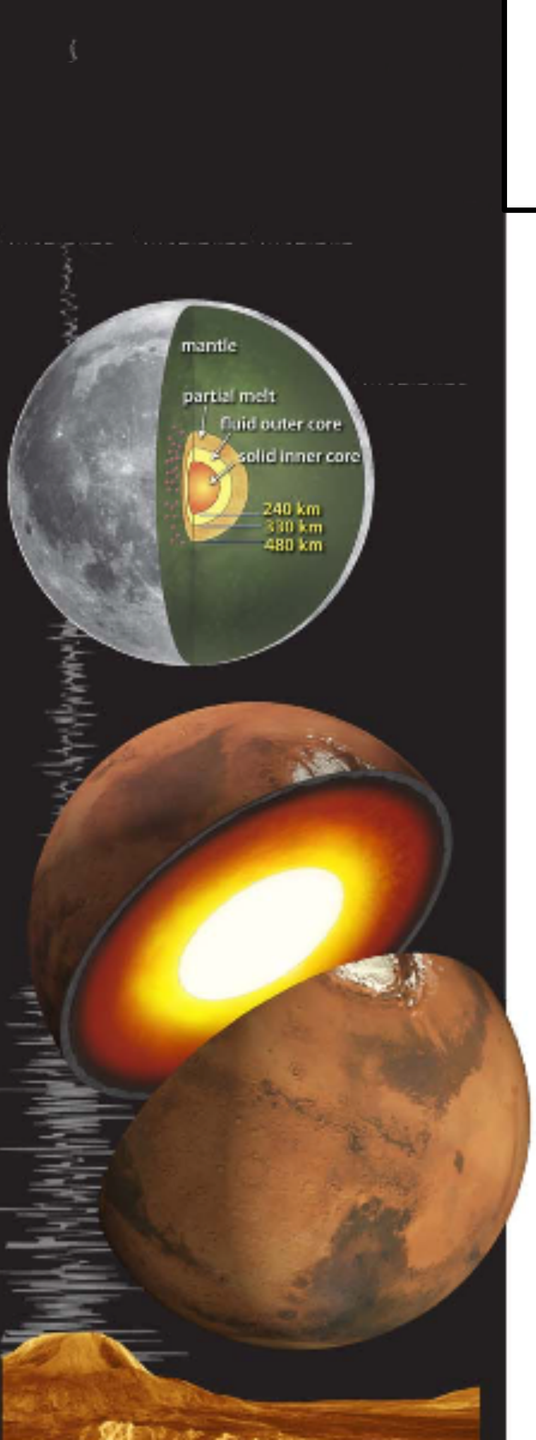


From Moon seismology to Mars with the SEIS Instrument on the NASA InSight mission

Prof Philippe Lognonné

Institut de Physique du Globe de Paris

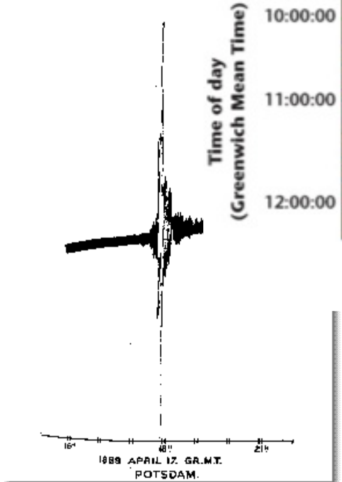
Université Paris Diderot- Sorbonne Paris Cité

Institut Universitaire de France

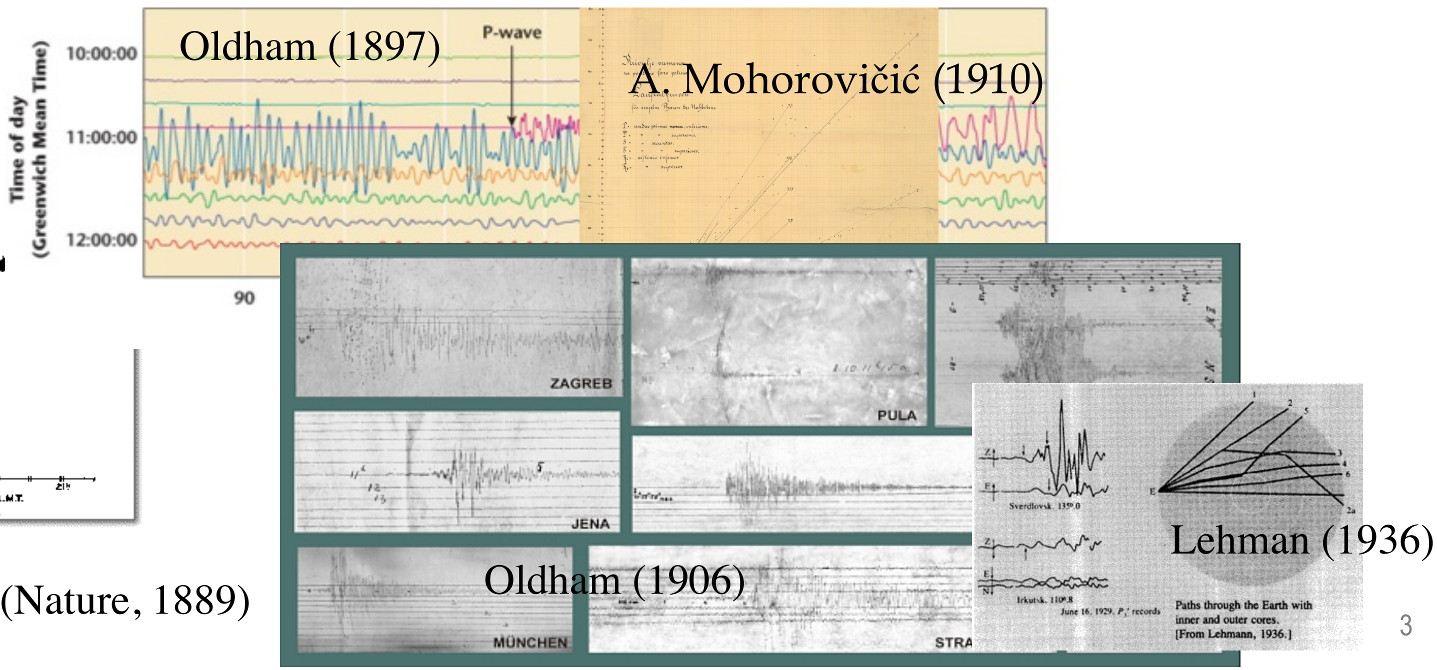
New frontiers of Planetary Geophysics

The interior of the terrestrial planets…

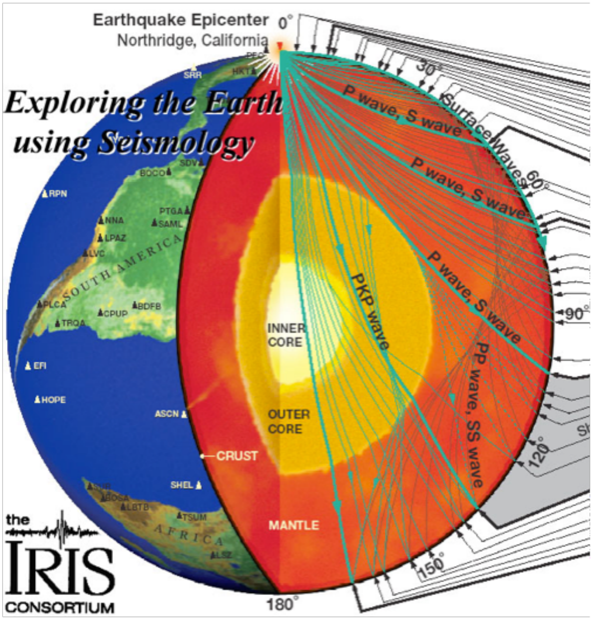
The first success story

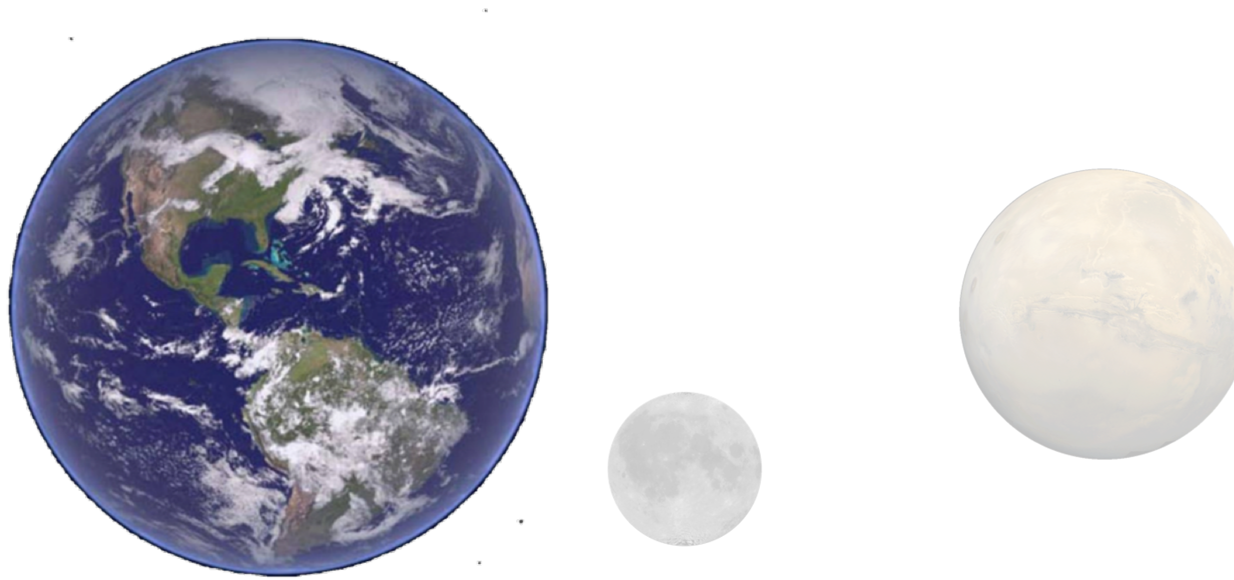


von Rebeur-Pacshwitz (Nature, 1889)



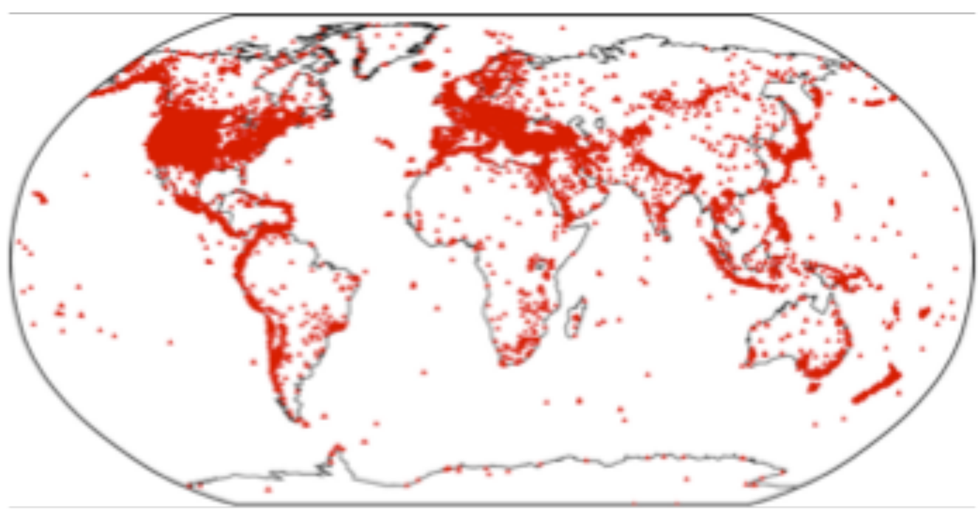
The first success story





1980-90

geoscope



>20000 stations, many of them with direct access to data

The second success story

THE WHITE HOUSE

WASHINGTON

April 20, 1961

MEMORANDUM FOR

VICE PRESIDENT

In accordance with our conversation I would like for you as Chairman of the Space Council to be in charge of making an overall survey of where we stand in space.

1. Do we have a chance of beating the Soviets by putting a laboratory in space, or by a trip around the moon, or by a rocket to land on the moon, or by a rocket to go to the moon and back with a man. Is there any other space program which promises dramatic results in which we could win?

2. How much additional would it cost?

3. Are we working 24 hours a day on existing programs. If not, why not? If not, will you make recommendations to me as to how work can be speeded up.

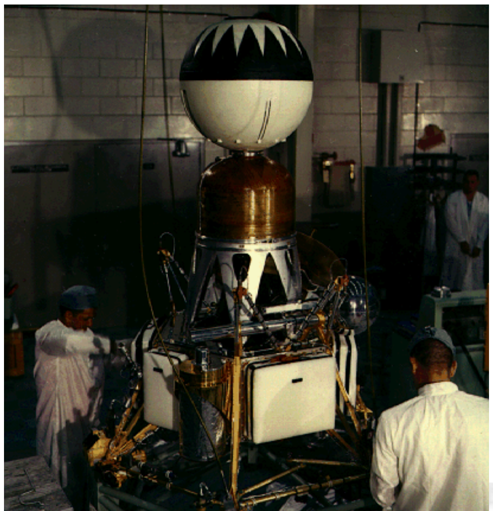
4. In building large boosters should we put out emphasis on nuclear, chemical or liquid fuel, or a combination of these three?

5. Are we making maximum effort? Are we achieving necessary results?

I have asked Jim Webb, Dr. Weisner, Secretary McNamara and other responsible officials to cooperate with you fully. I would appreciate a report on this at the earliest possible moment.

Definitively NOT driven by Geophysics…

But with piggy back Geophysics inside

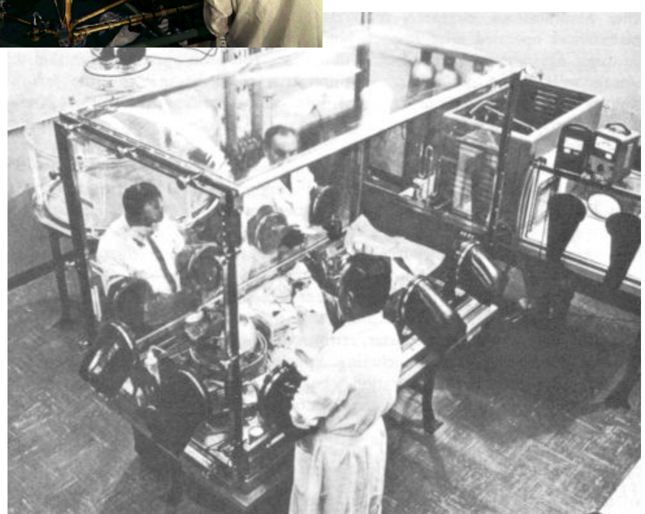


Seismometer and Ranger at JPL

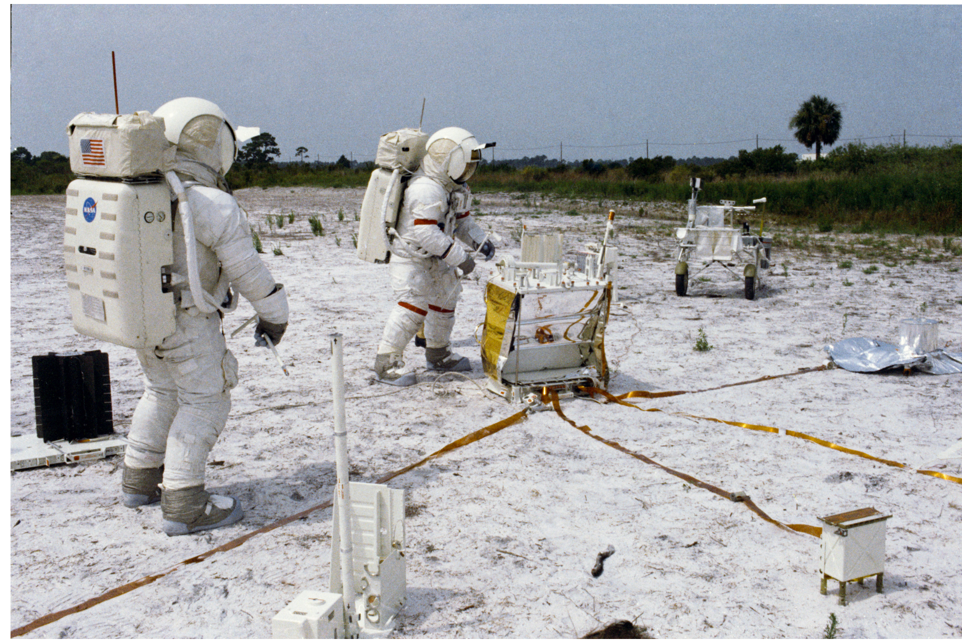
Ranger 3
1/26/1962

Ranger 4
4/23/1962

Ranger 5
10/18/1962



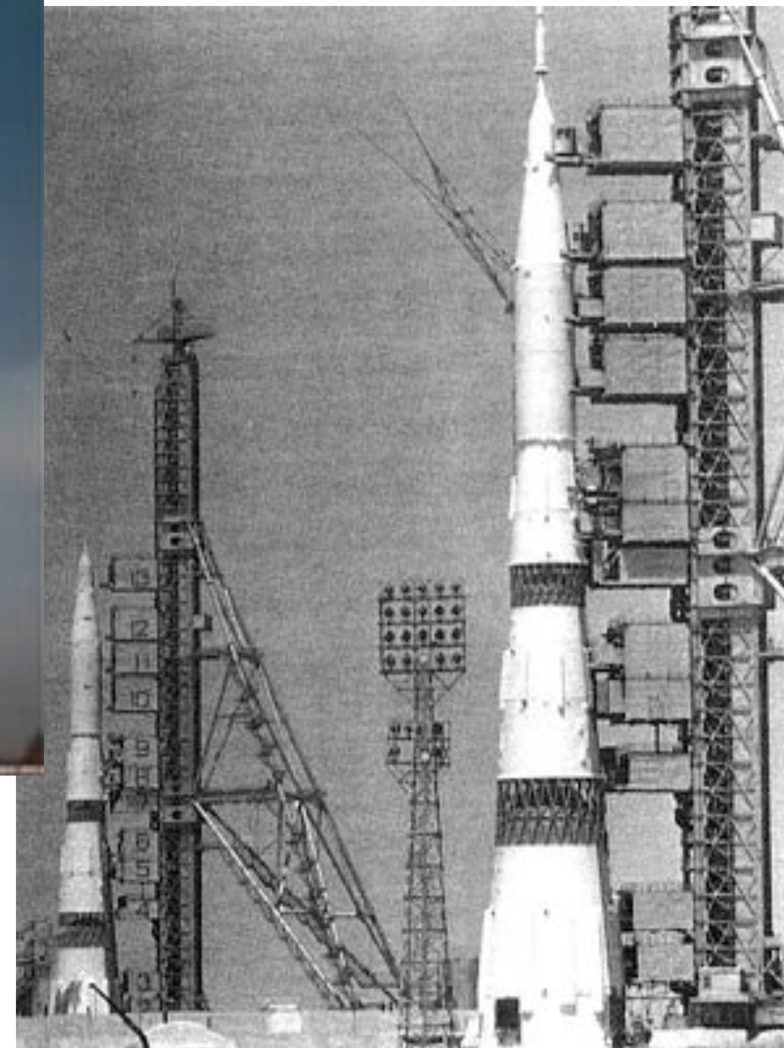
Sterile seismometer assembly at Aeronutronic



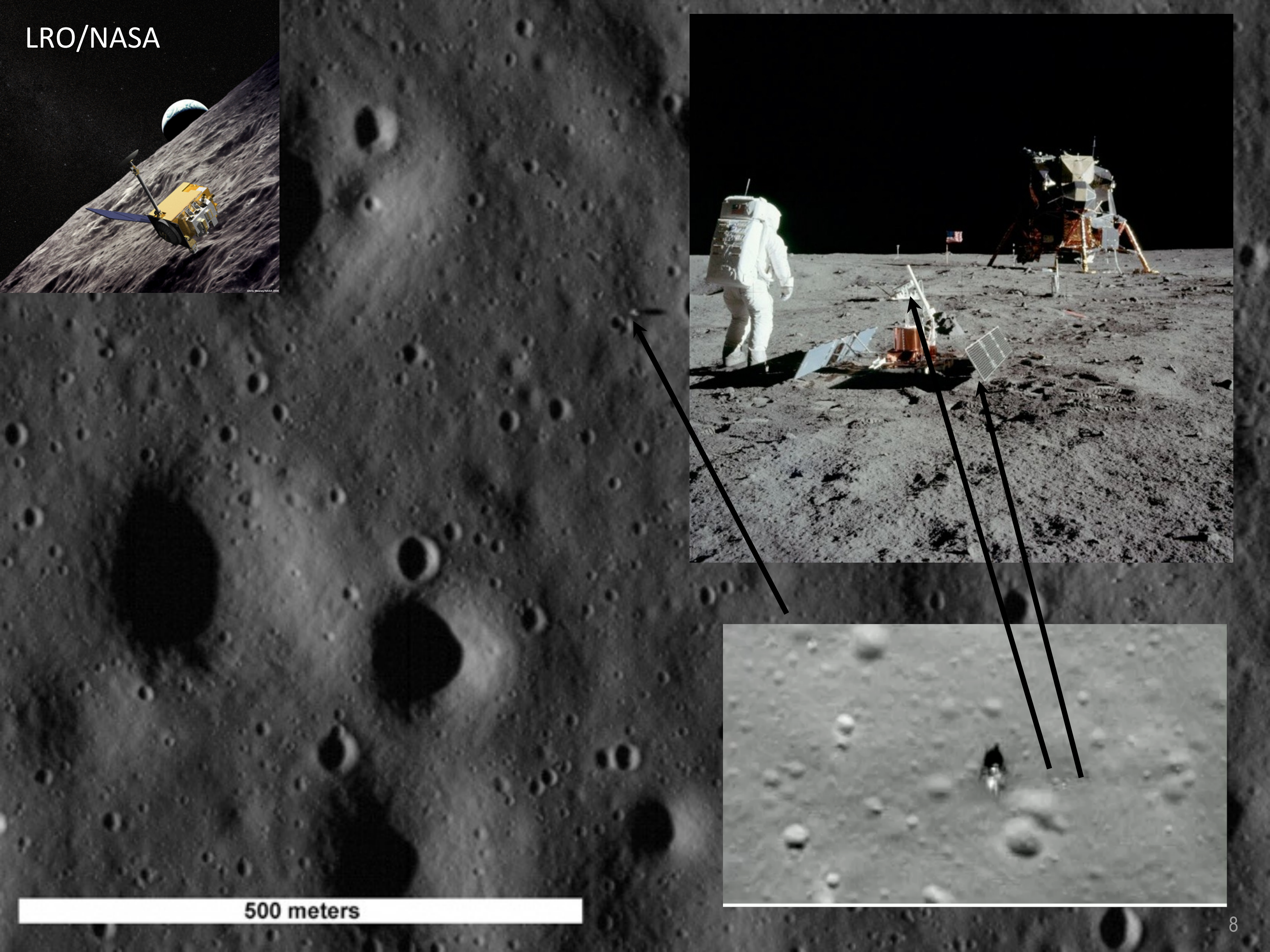
Apollo 14 crew training the ALSEP (and seismometer) deployment

A double success

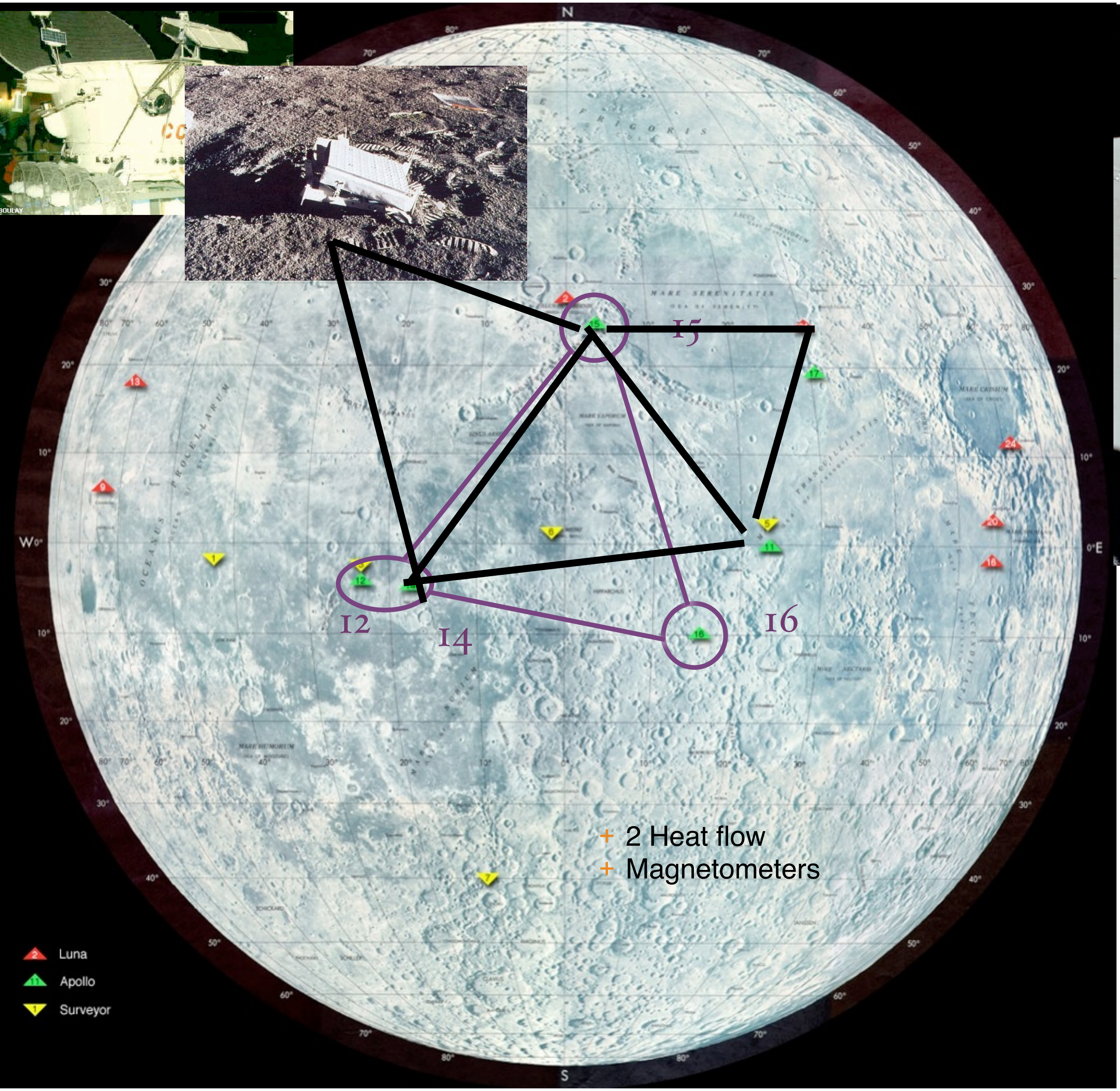
Cape Canaveral, USA, 7/16/1969

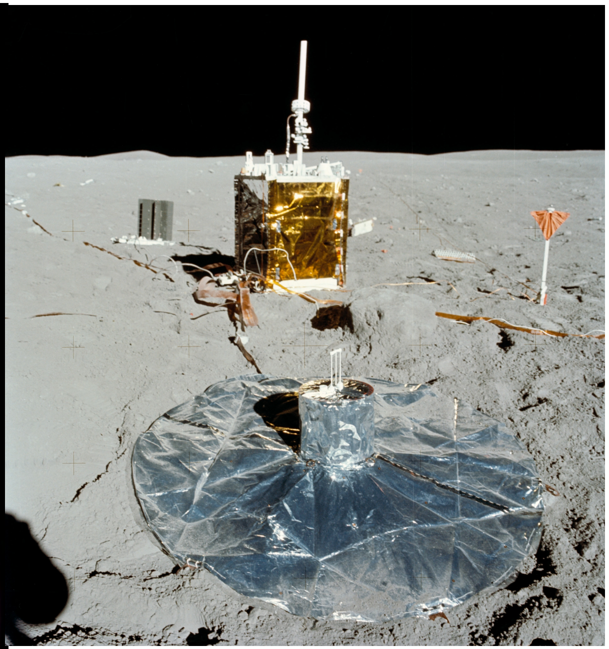


Baïkonour, USSR, 7/3/1969

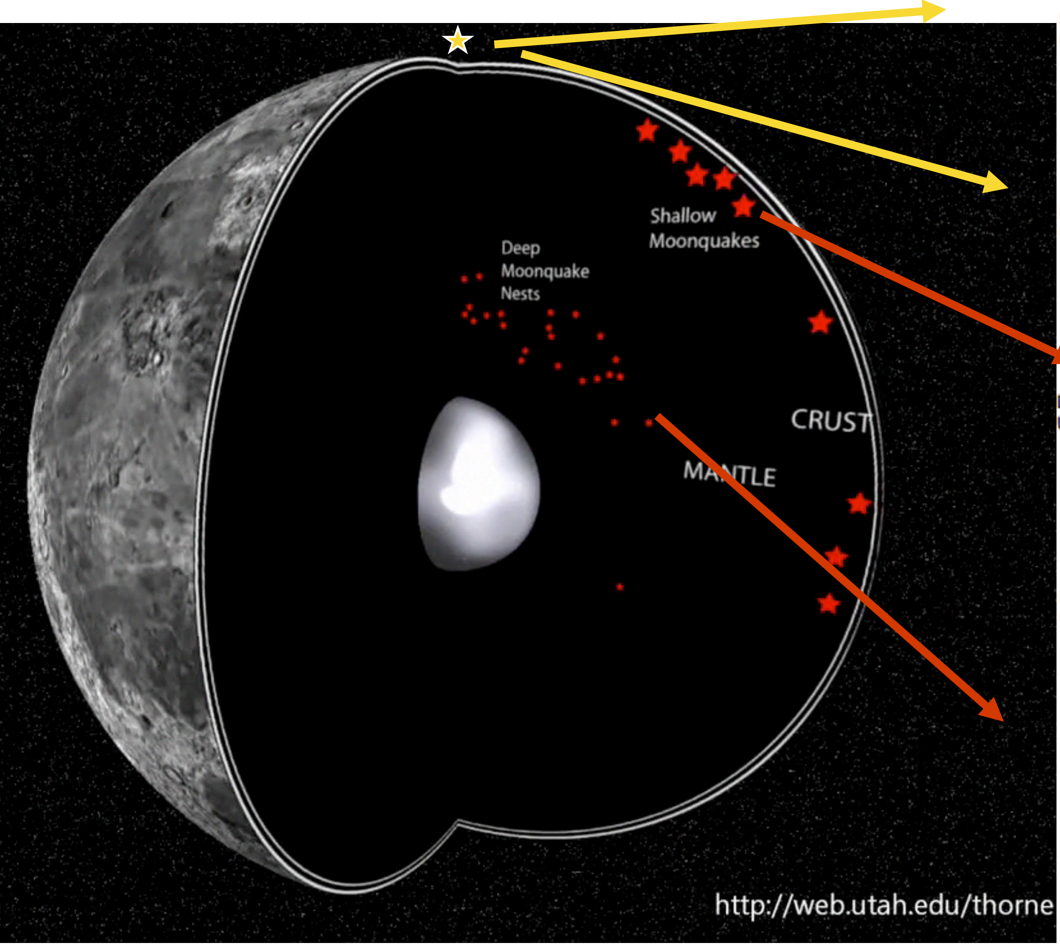

LRO/NASA
500 meters

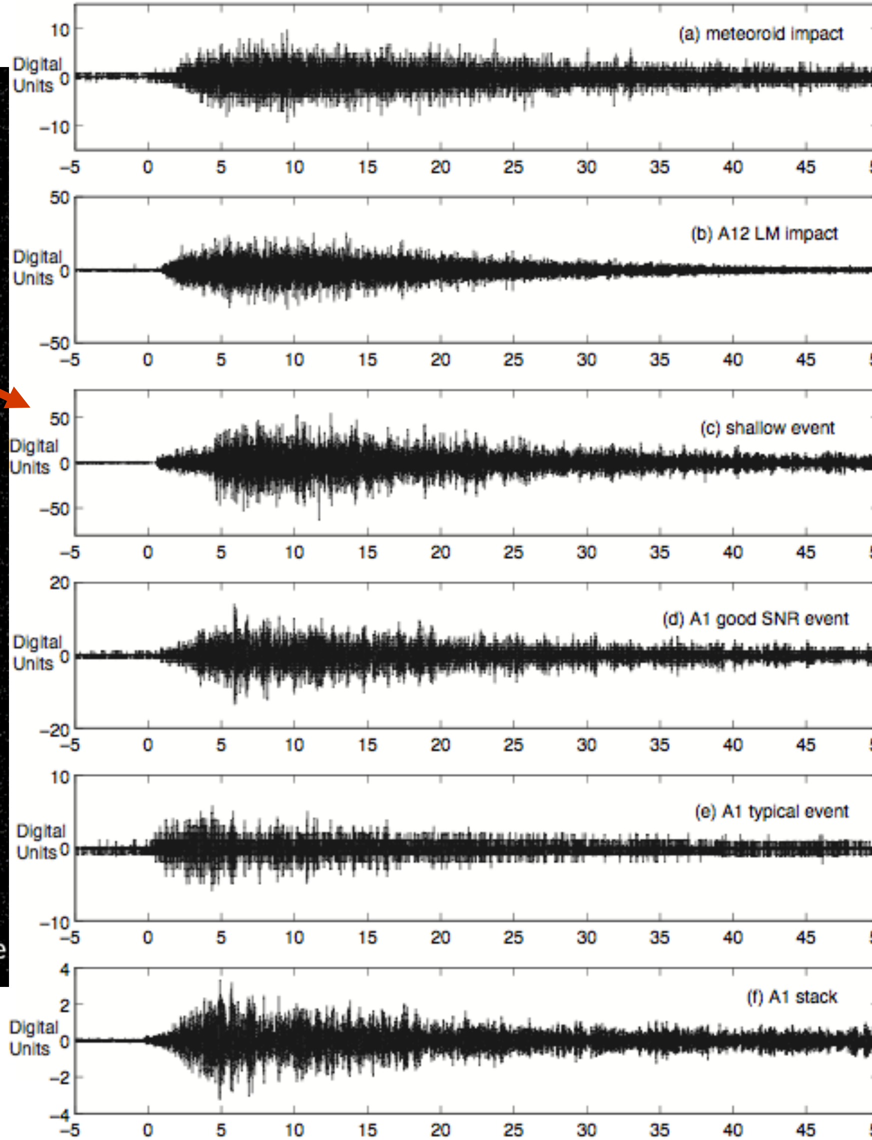
Apollo Geophysical network





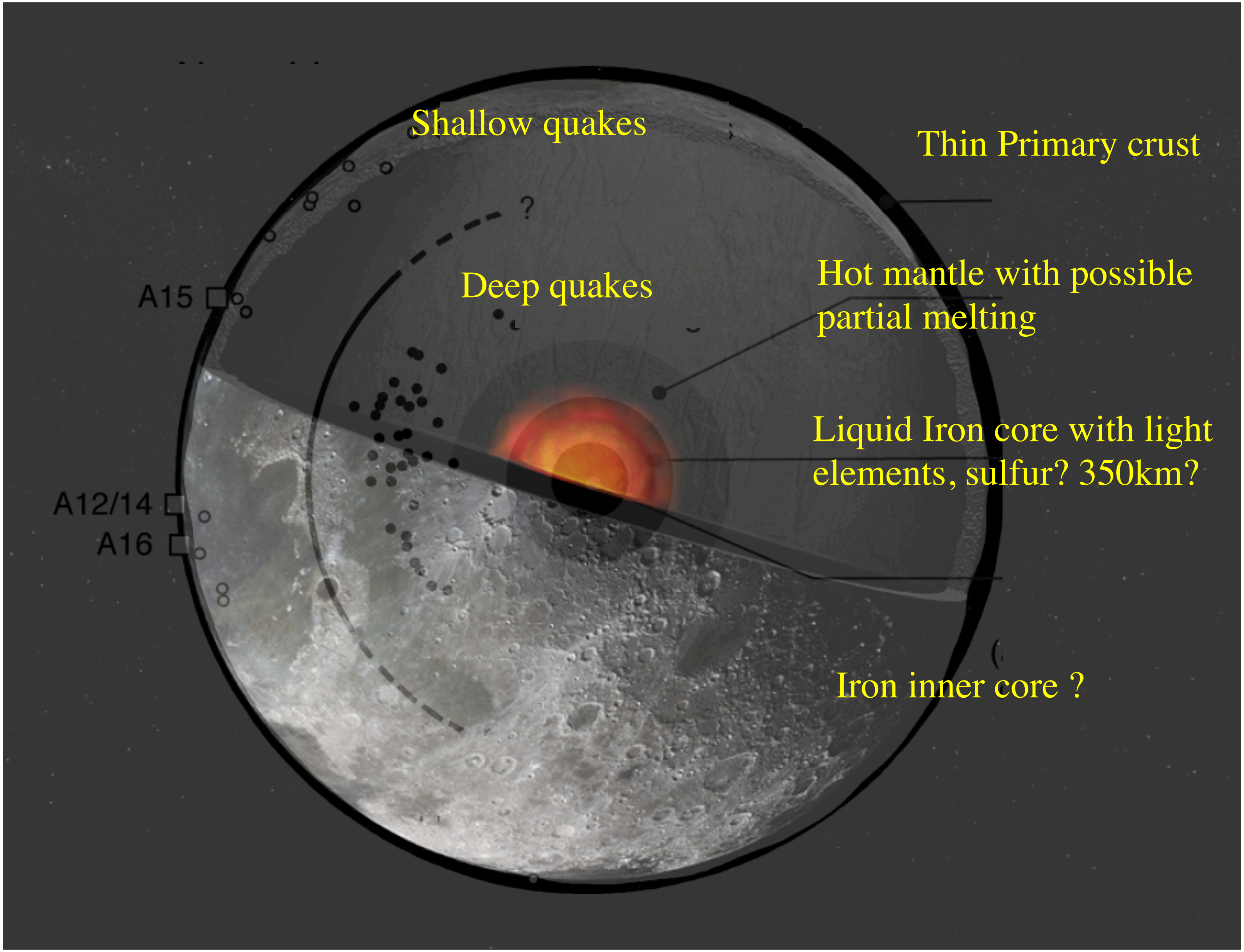
Lunar quakes zoology

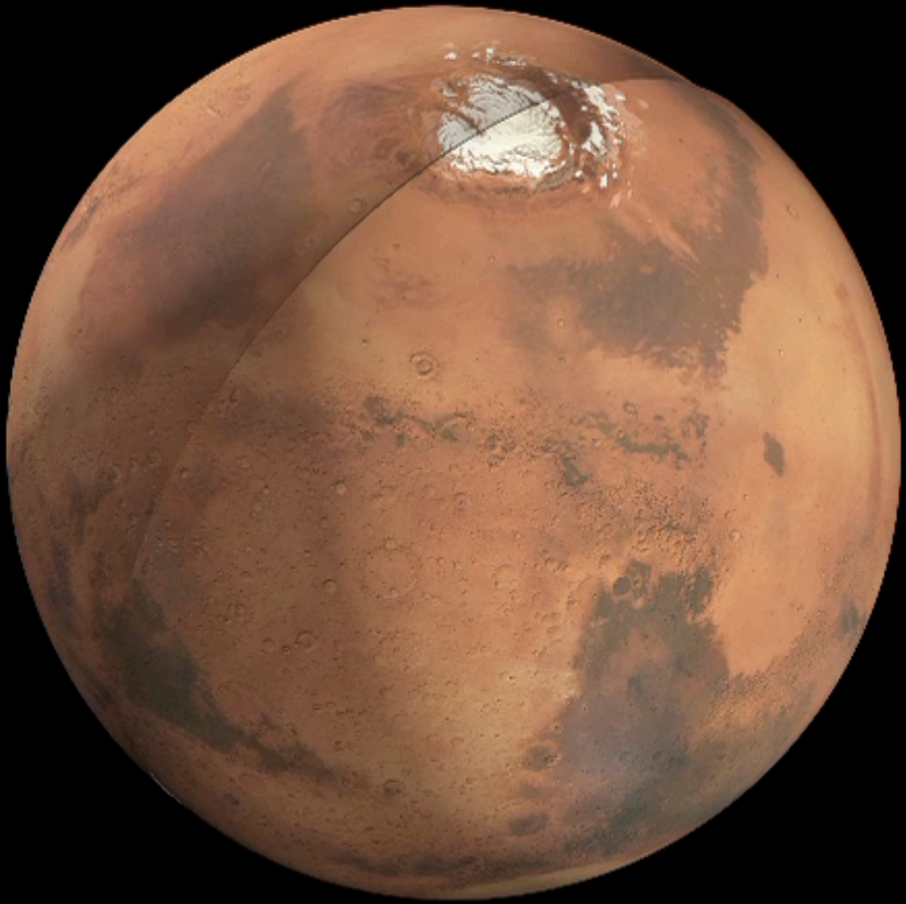




Lognonné & Johnson, 2007

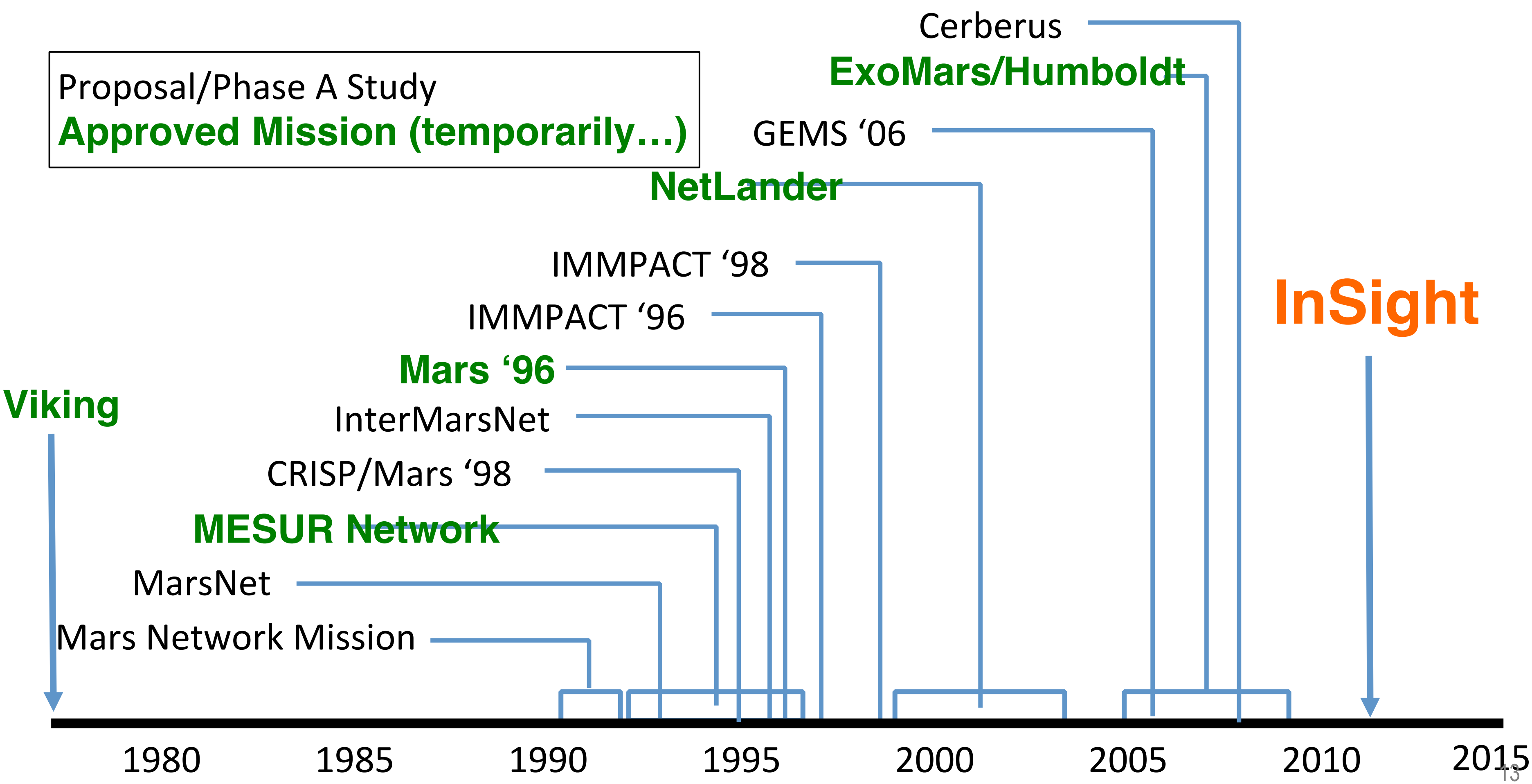
Our view of the Moon





1977 – Present

- Over the 35 years since Viking and Apollo, despite many proposals and several mission starts, there have been no further seismic investigations of the interior of any planet… until now!



1977 – Present

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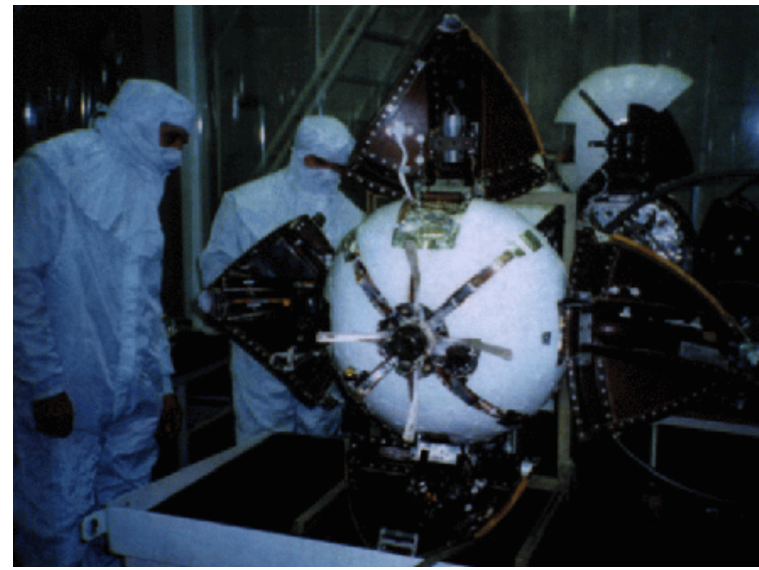
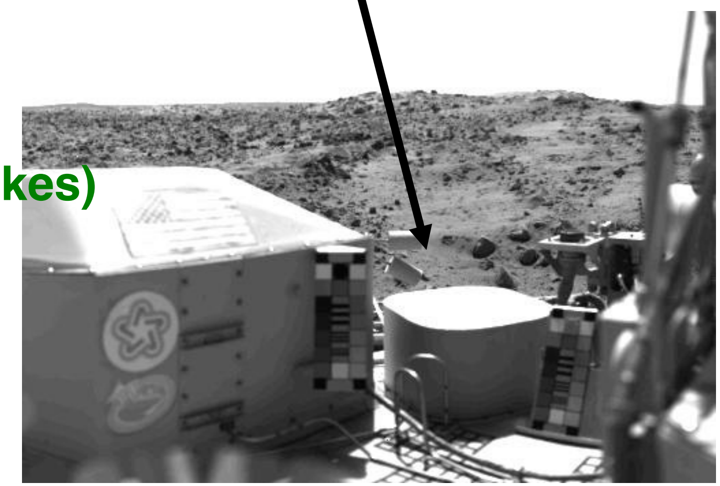
Launched Mission

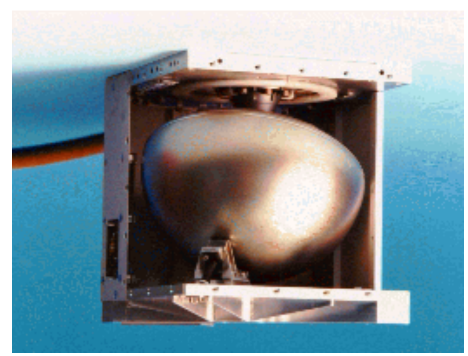
Seismometer

Mars '96 (lost)



Viking (no quakes)



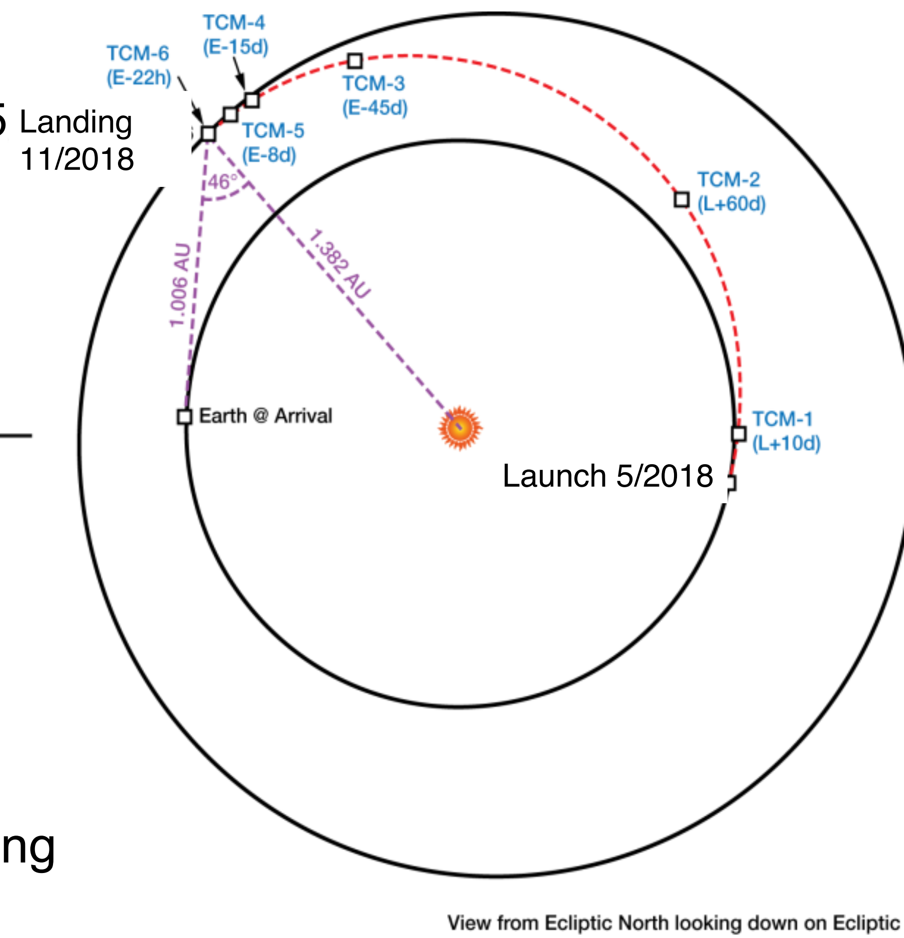


InSigh

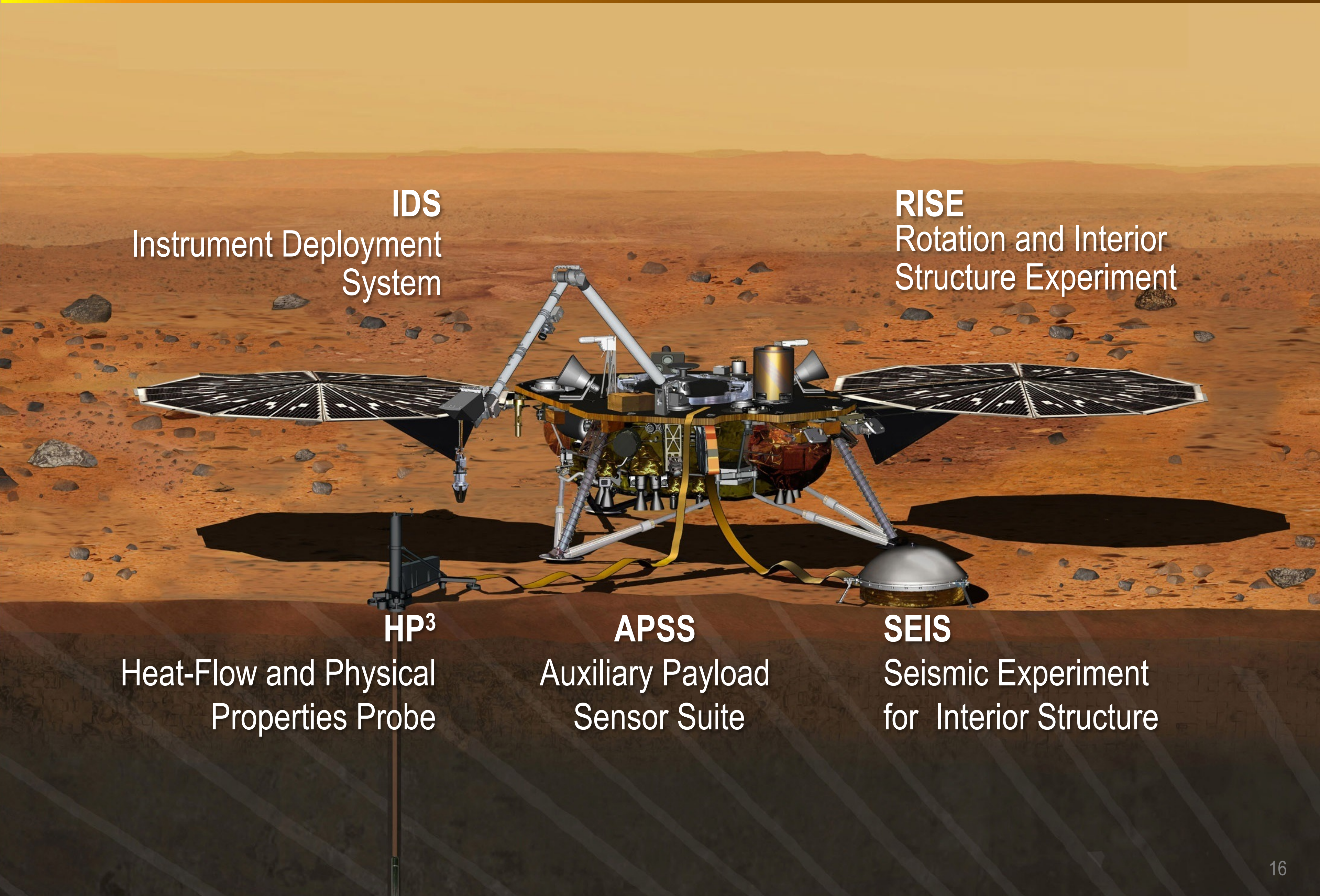
1980 1985 1990 1995 2000 2005 2010 2015

InSight Mission Summary

- NASA selection STEP 1 May, 2, 2011
- NASA selection STEP 2, August, 20, 2012
- Original launch date: March 2016
- 2016 Launch cancellation: December, 22, 2015
- 2018 Launch confirmation: March, 9, 2016
- Launch: May 2018
- Fast, type-1 trajectory, 6.5 month cruise to Mars
- Landing: November, 2018
- 67-sol deployment phase
- One Mars year (two years) science operations on the surface
- Nominal end-of-mission: 2 years after landing

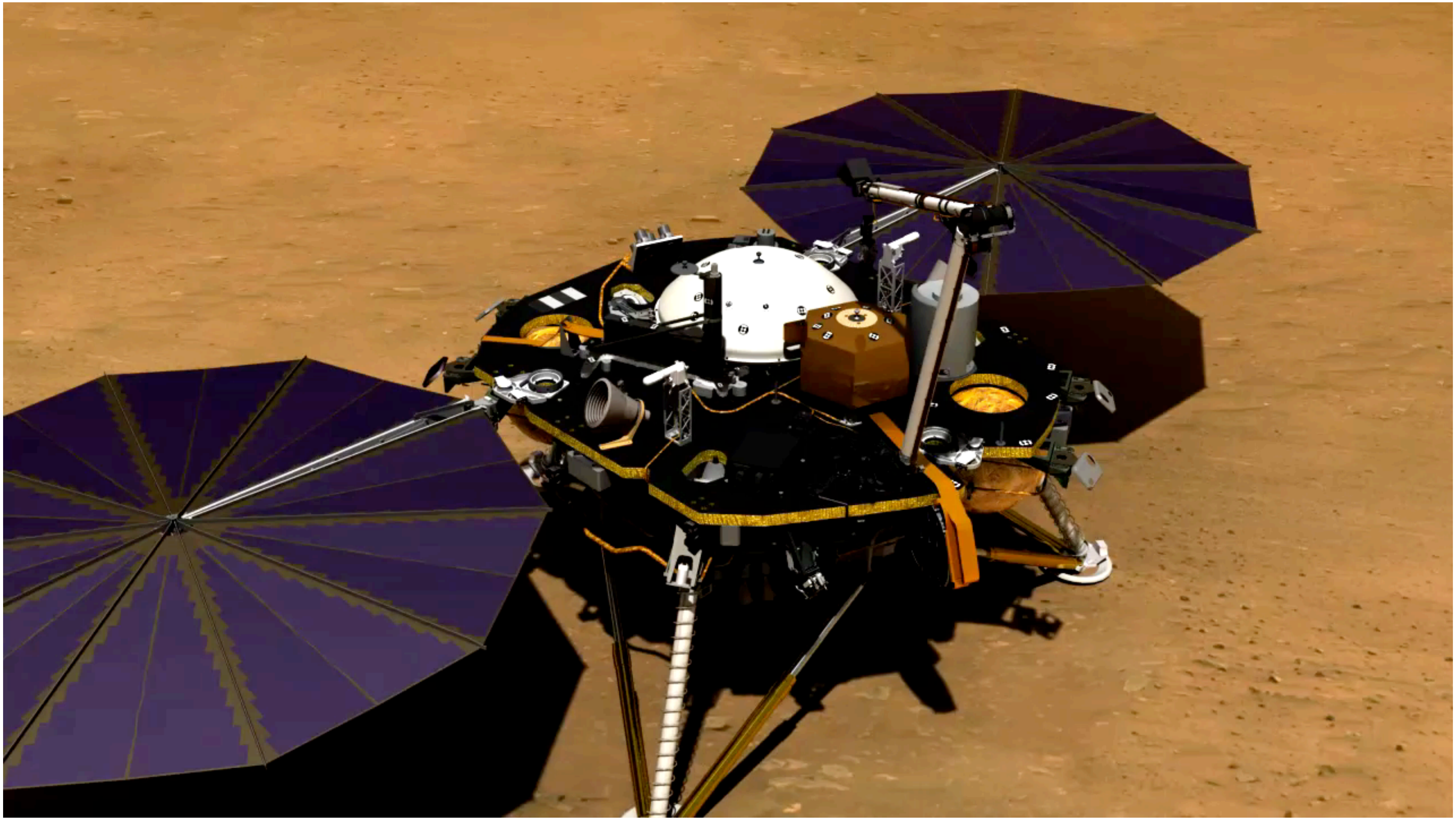


Payload Elements

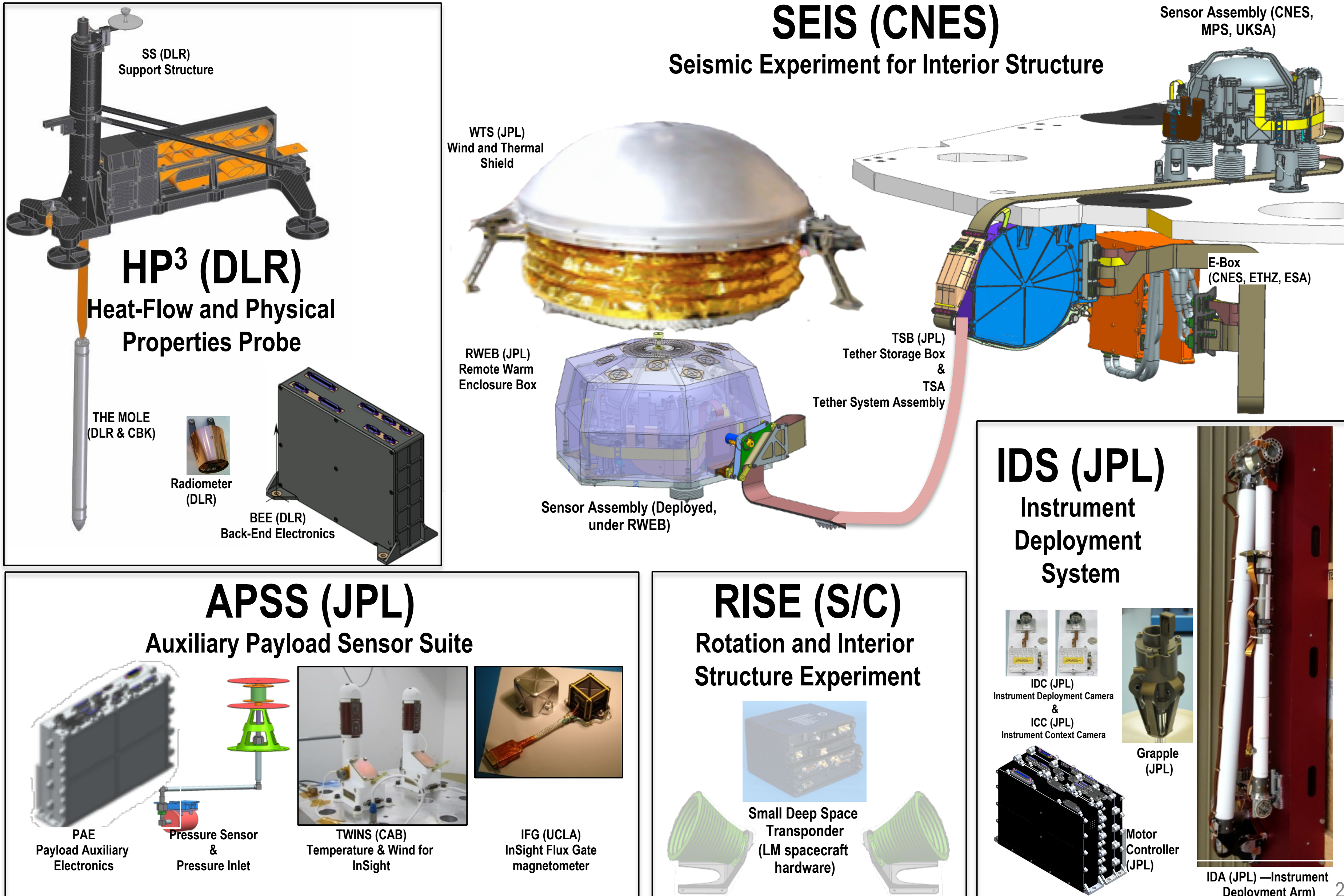


Payload Elements Deployment challenge: Apollo

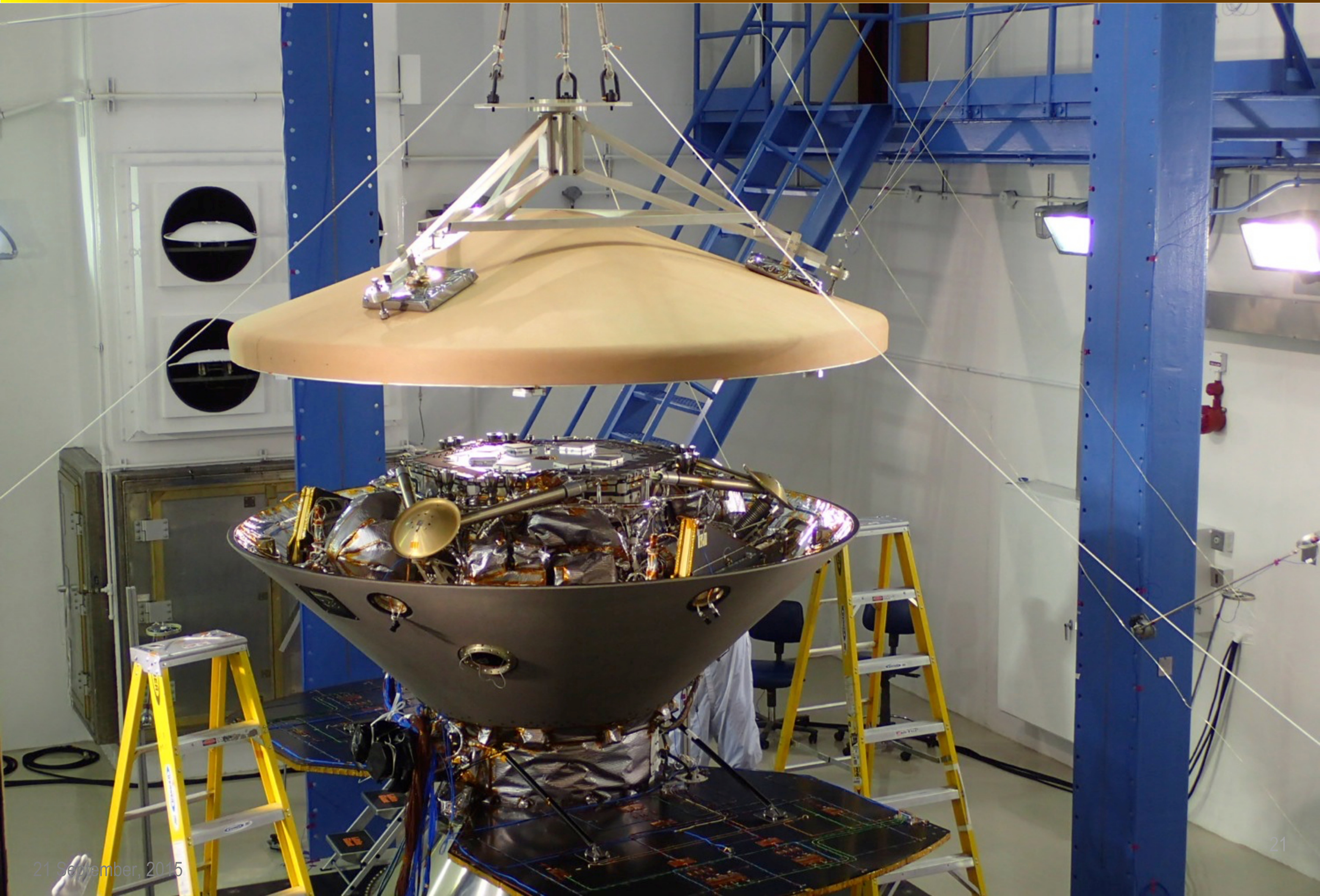
Payload Elements Deployment challenge: InSight



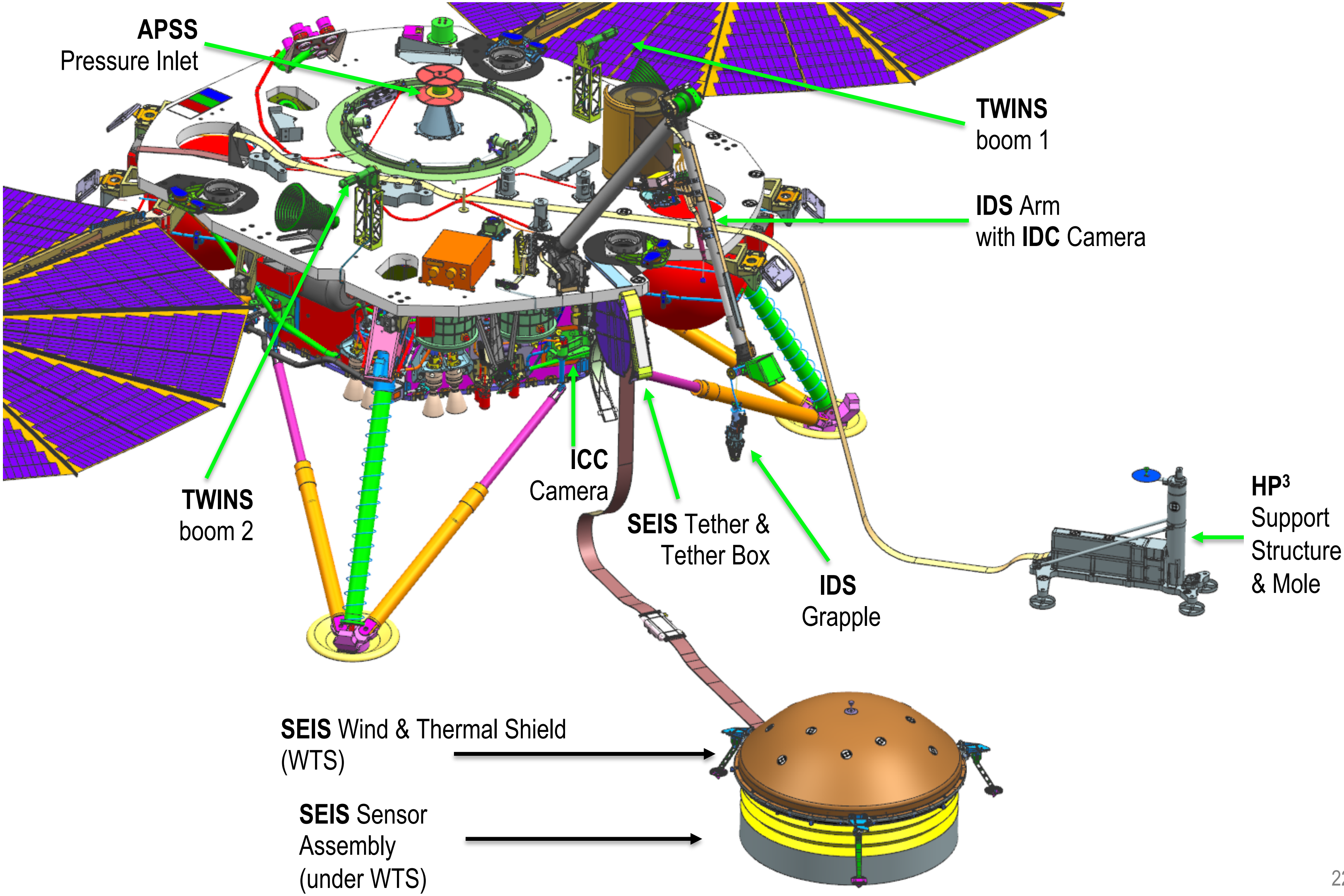
The InSight Payload



Lander: Heat Shield Installation

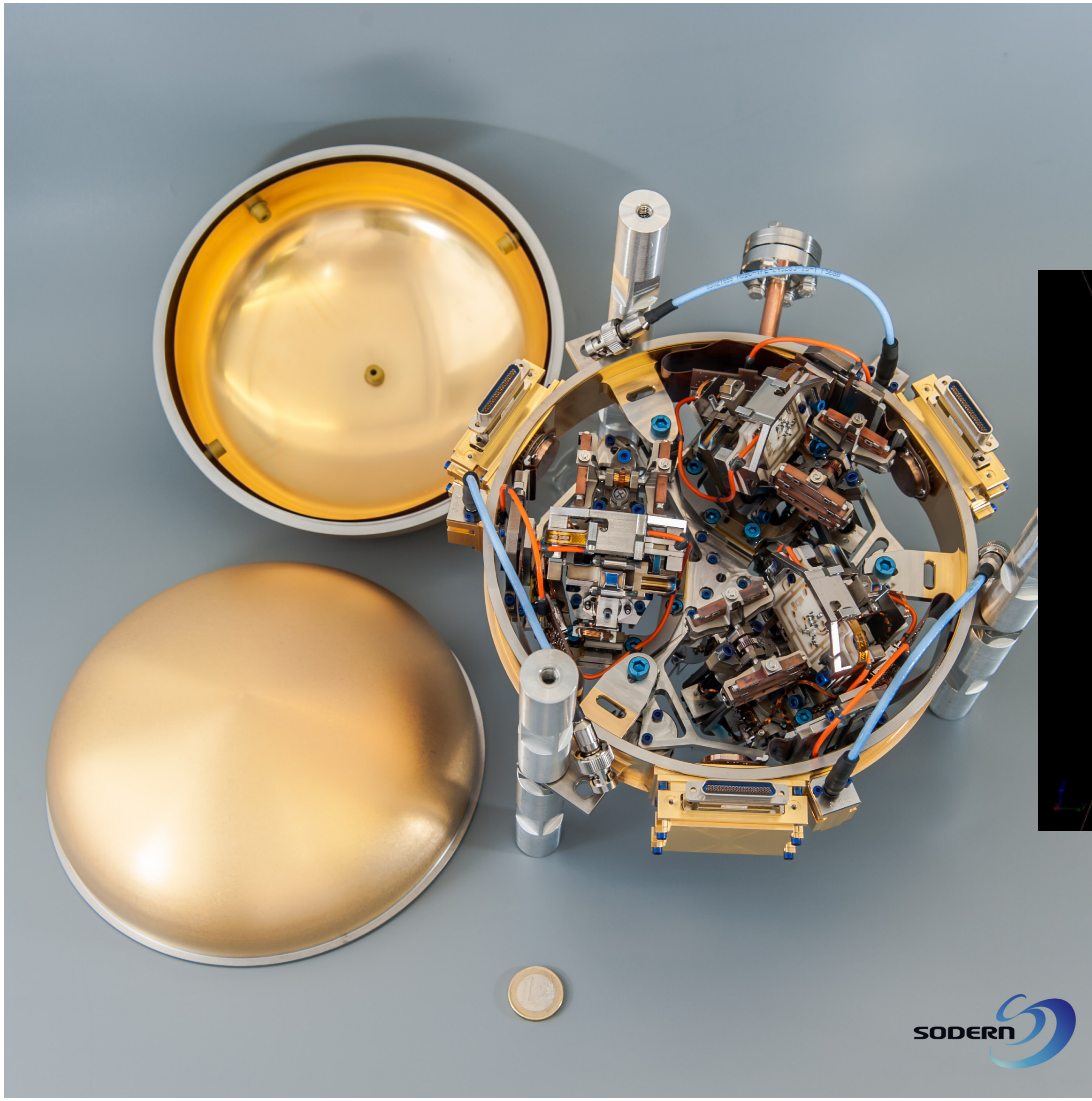


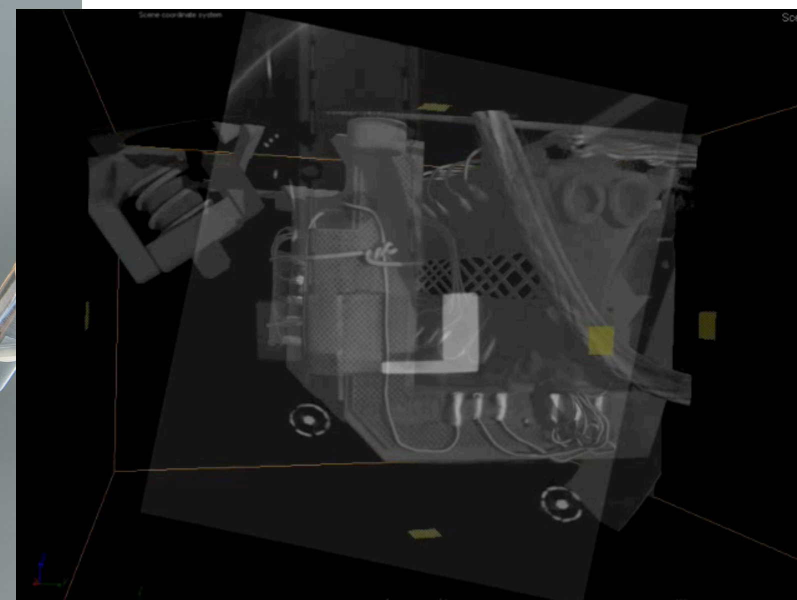
Payload Configuration on Deck—Deployed



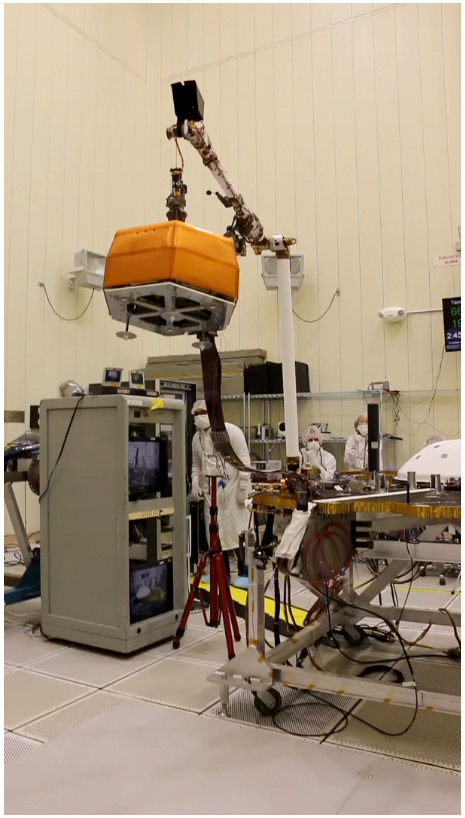
SEIS Instrument

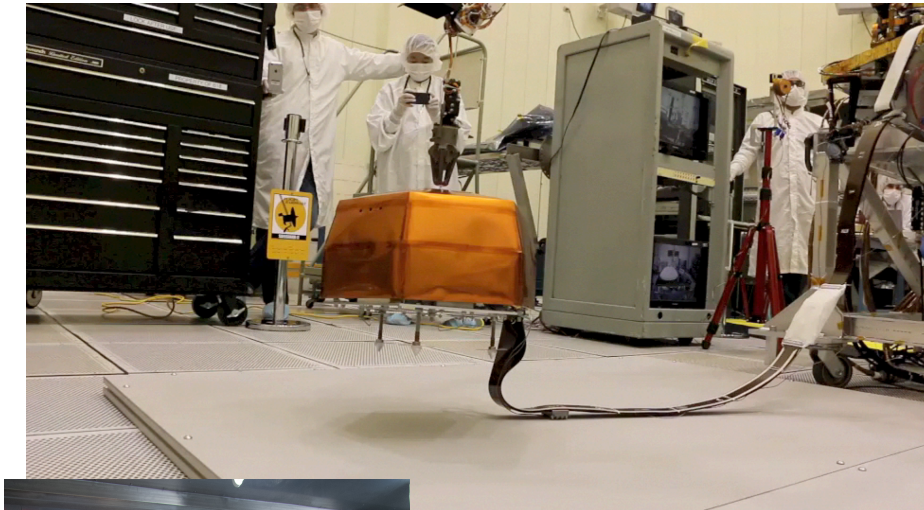
VBB Detail…



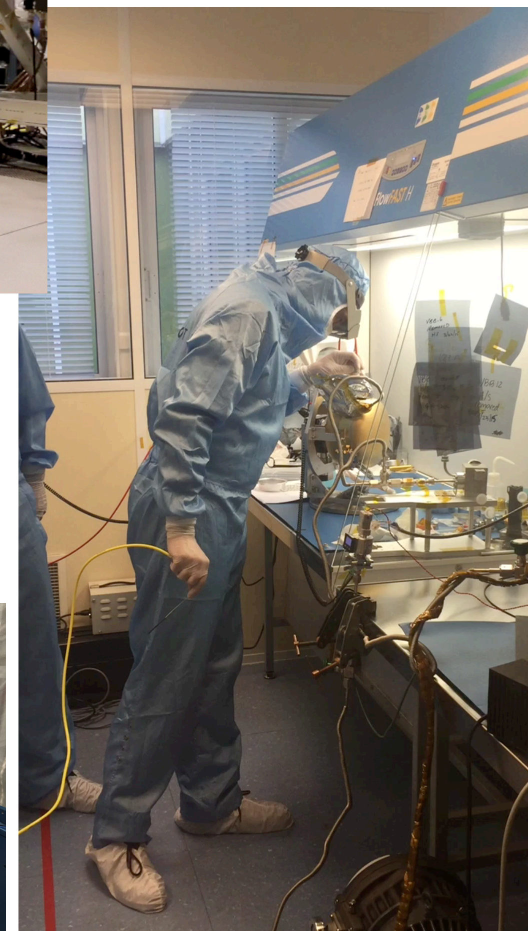


Challenges, Challenges, Challenges (Night and week ends...)

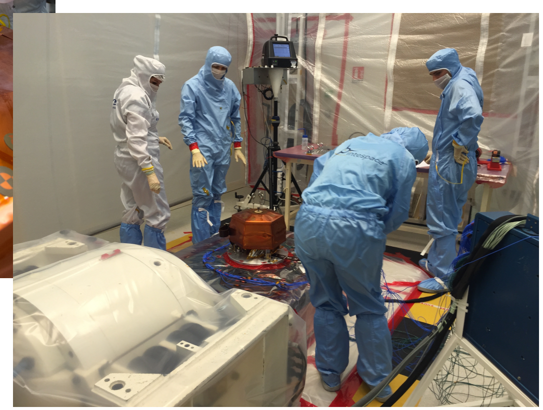




Vacuum leak repair challenge at IPGP



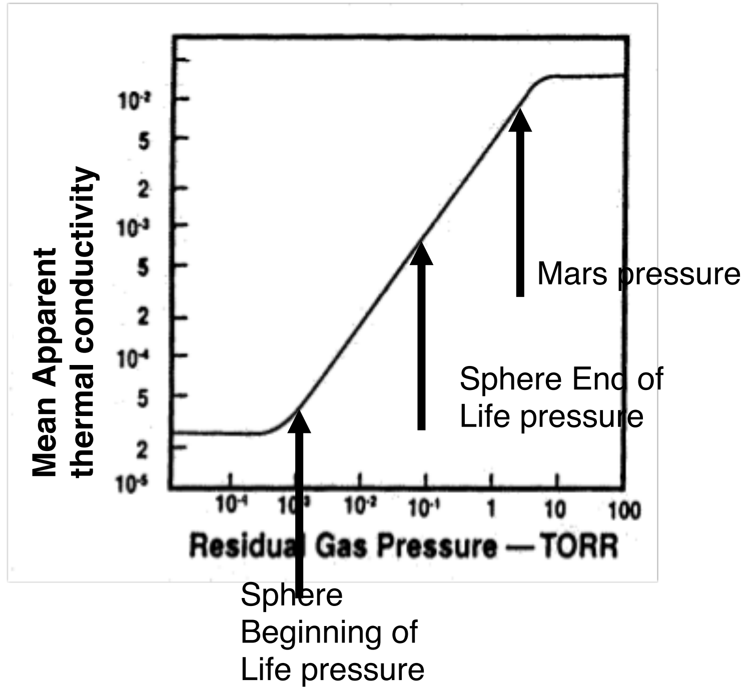
Deployments Challenges at JPL



Sphere/TBK Integration and vibrations tests at CNES

Why vacuum and the origin of the leak…

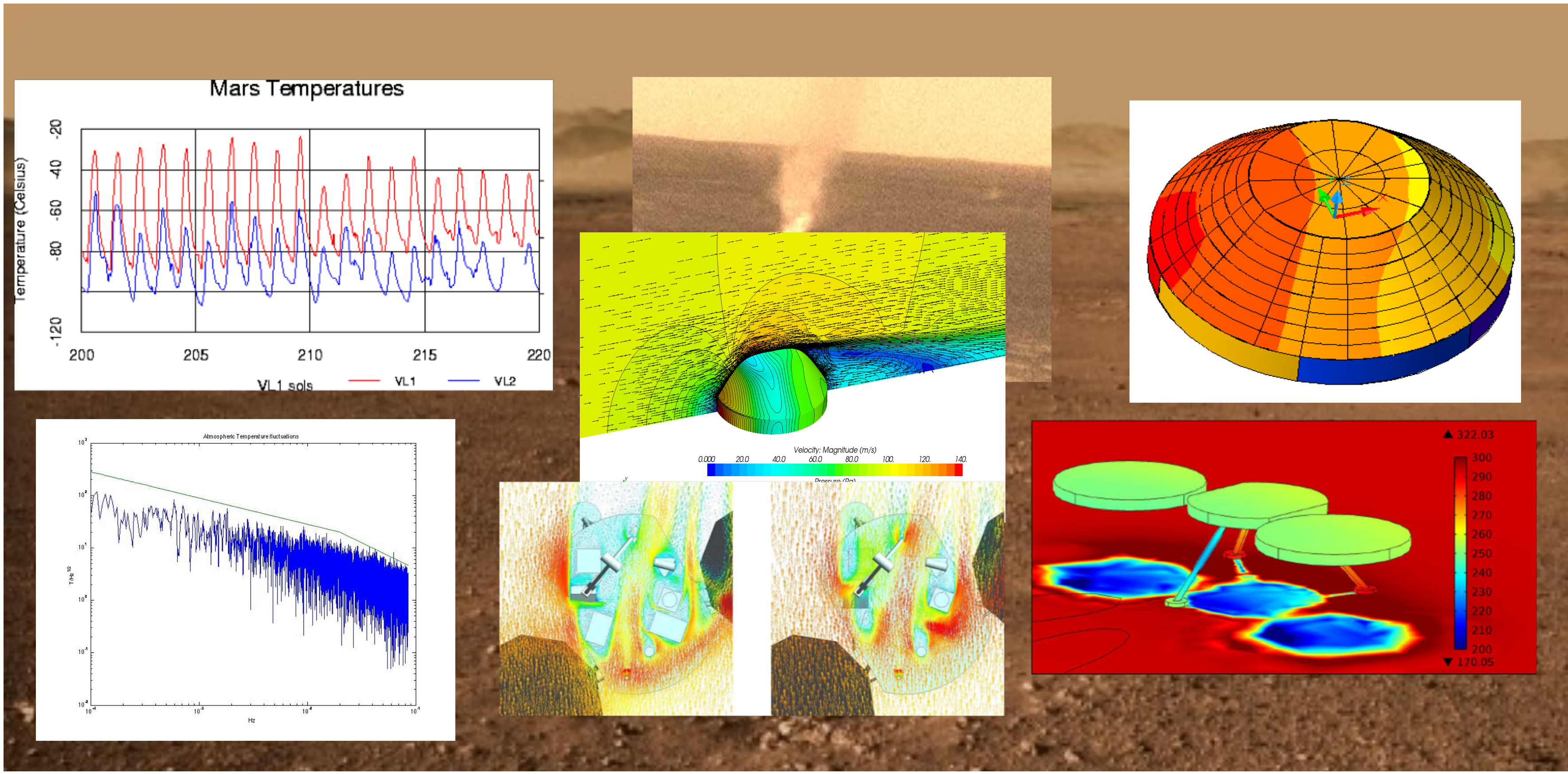
- Thermal protection: Gaz in the sphere make a thermal short between the sphere skin (Mars atmosphere) and the VBBs sensors, increasing the thermal noise
- Gaz damping: Gaz in the sphere generate damping and noise on the seismometer associated to the impacts of the gaz on the pendulum



- The leak was located on of of the connector feed through
- Leak rate was small (such that a tire will loose 5% of pressure in 320 years) but too large to reach requirement
- The project failed to repair the leak with a schedule compatible with all tests requested for 2016, which lead to the 2018 shift

Environmental noise

- We are here……



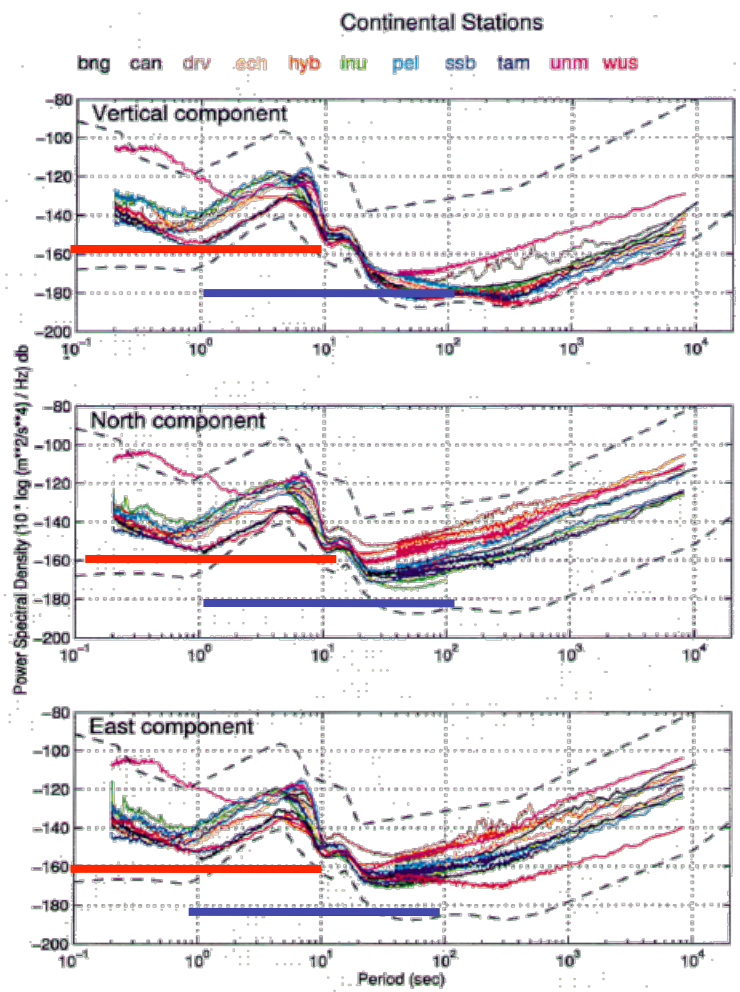
Environmental noise

- but would like to be there……

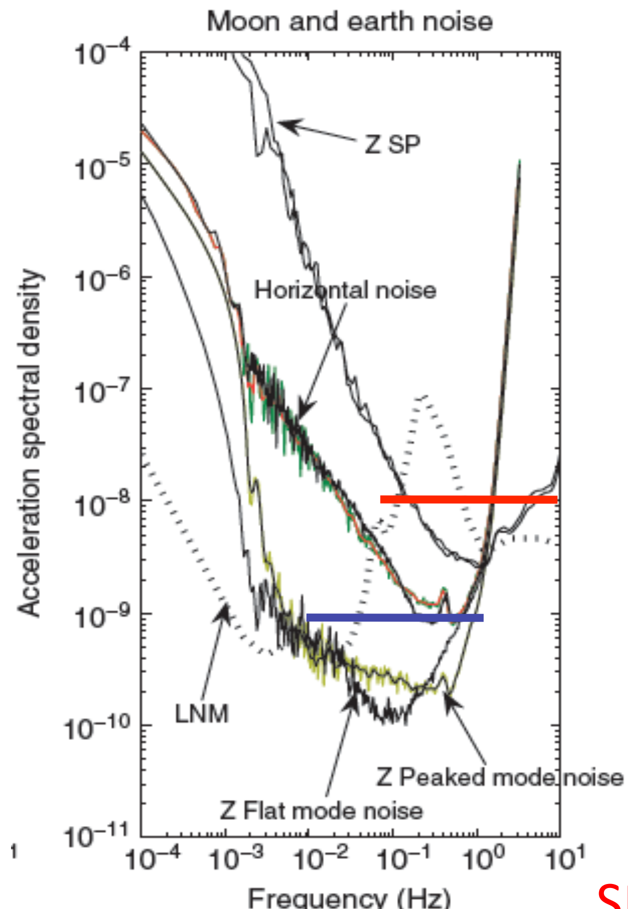
Seismic vault

Environmental noise: installation goals

Planet with Ocean and Atmosphere



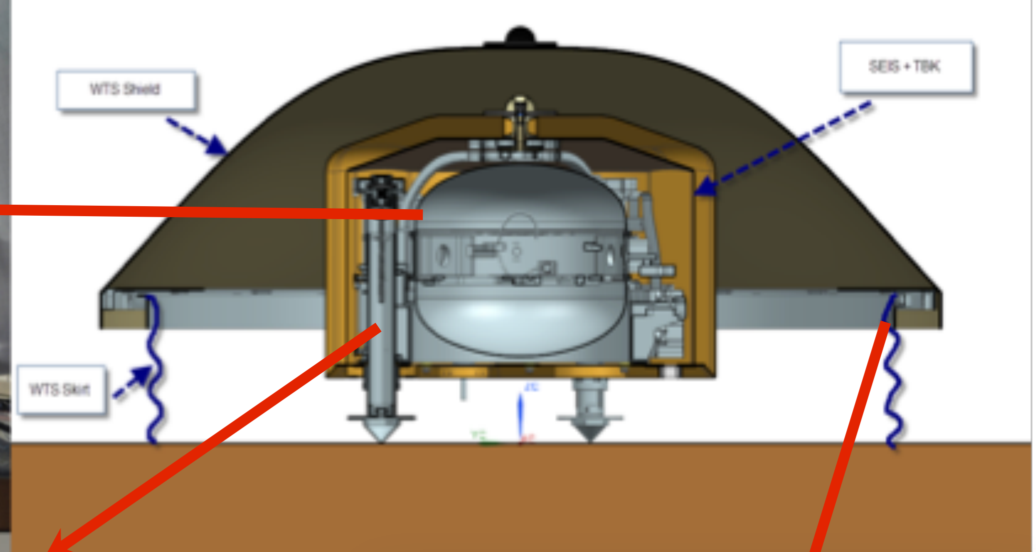
Planet without atmosphere and ocean

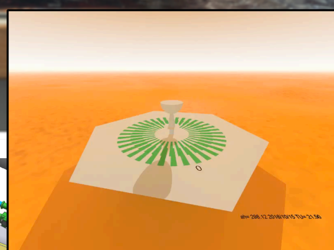


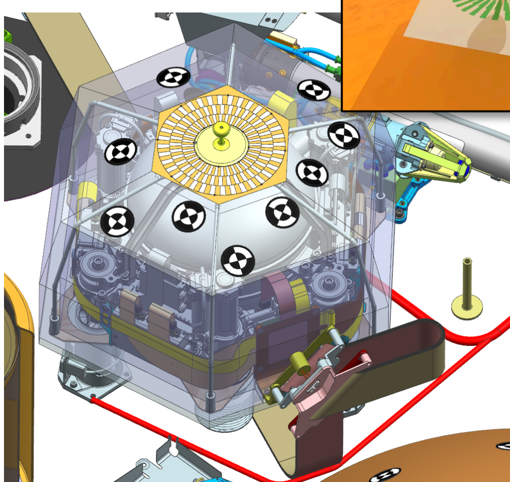
SP VBB

Temperature (± 40°C) and wind (20 m/s) protection

Wind protection

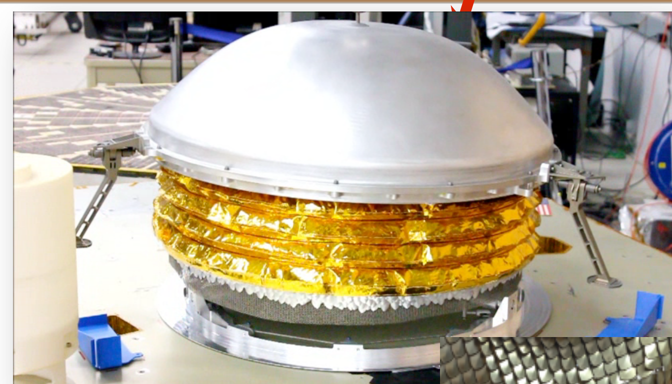






Thermo-elastic service loop

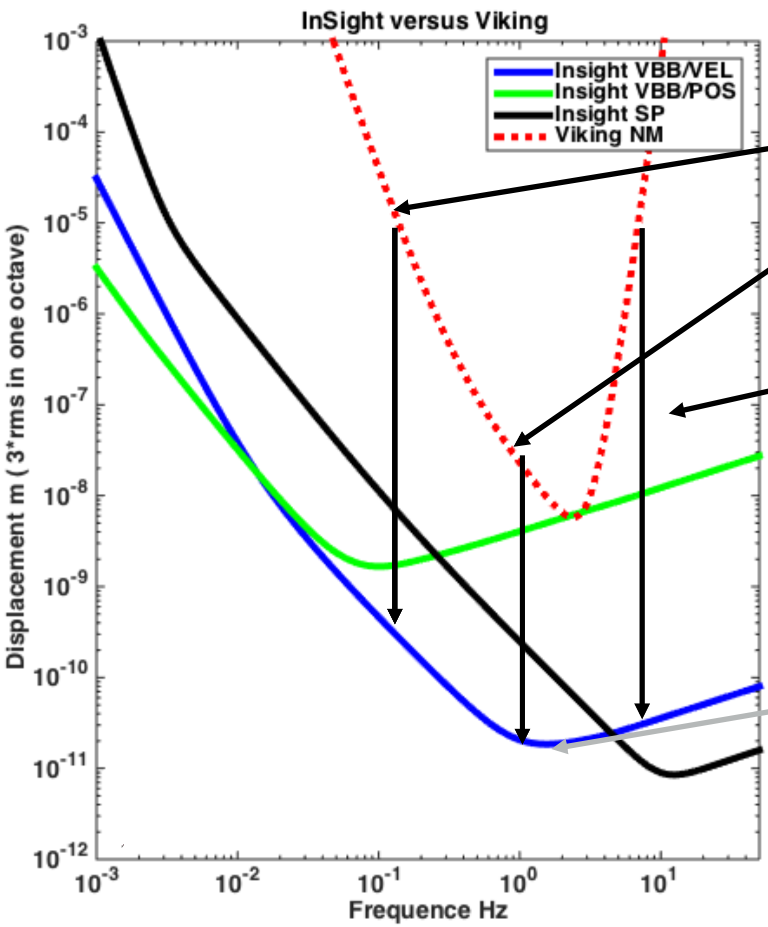
Thermal shield



Sealing skirt

InSight/SEIS performances (3/2016)

• 40 yrs after Viking, SEIS will perform modern Earth seismology, with sensitivity 10^3 to 10^5 larger than Viking NM and with **almost Earth standard** for data products

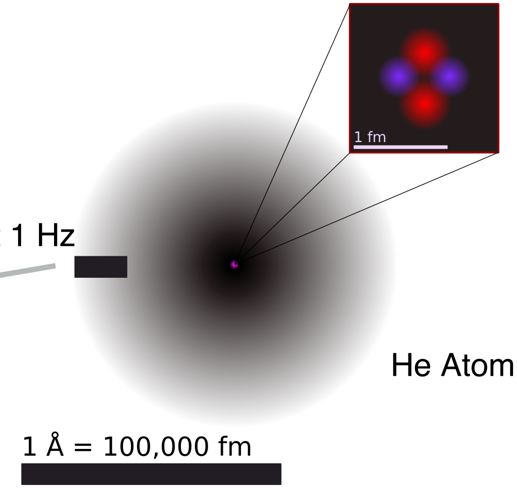


~70 000 x better for regional 10 sec surface waves (and 5 x10^5 ≥20sec)

~1000 x better for remote body waves

> 100 000 better for small quakes

20 pm at 1 Hz



SEIS Expected Natural signals

M~5.5 1-2/yr

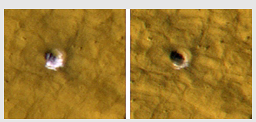
Global

M~4.5 ~ 10/yr

Global to regional

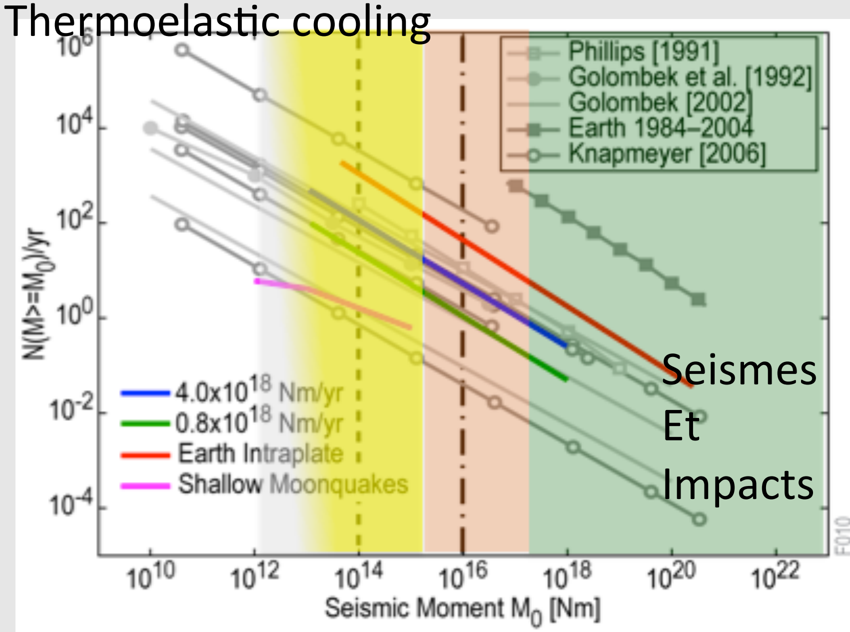
M~3.5 ~100/yr

regional



Impacts
10-15/yr

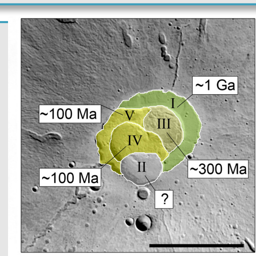
Thermoelastic cooling

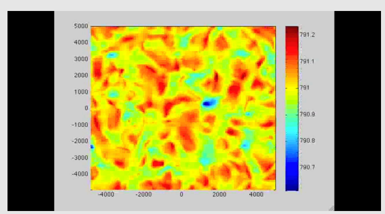


Seismes
Et
Impacts

Phobos tide

Bonus:
Tectonic
activity





Atmospheric loading
Atmospheric generated seismic noise

SEIS Expected Natural signals

Thermoelastic cooling

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Global to regional

M~3.5 ~100/yr

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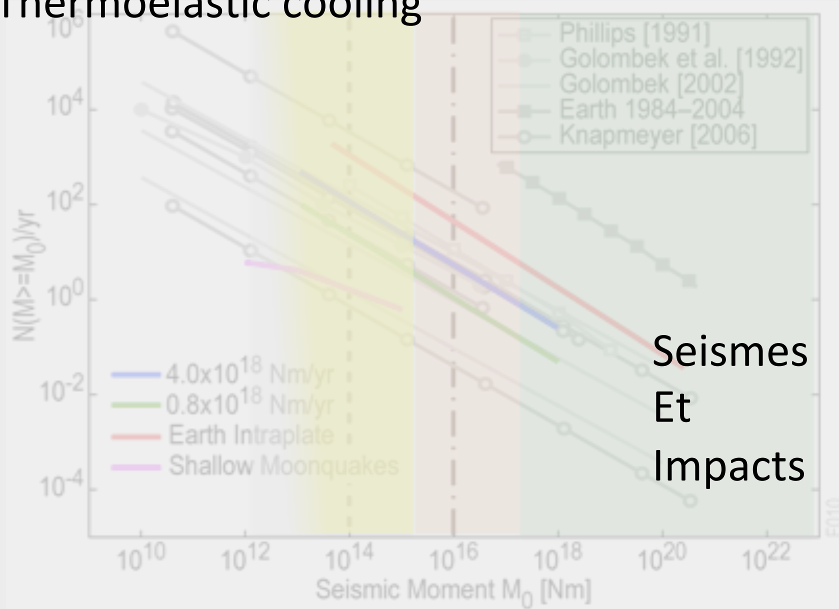
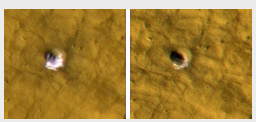


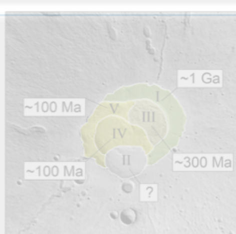
Seismes
Et
Impacts

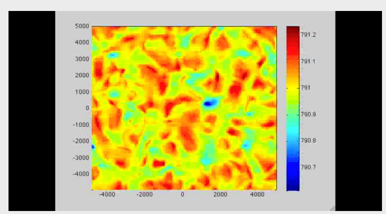


Impacts
~5 /yr

Phobos tide

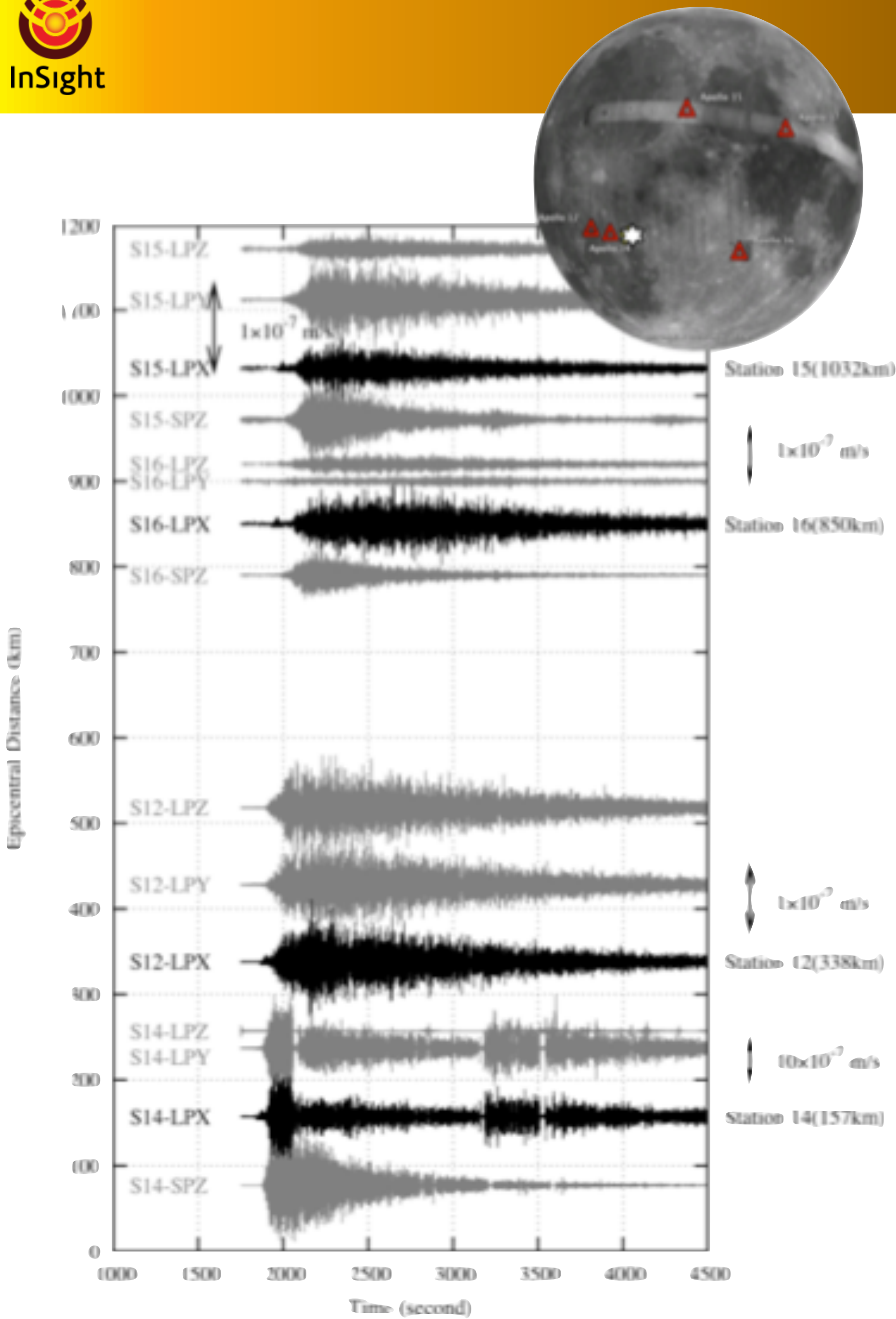
Bonus:
Tectonic
activity



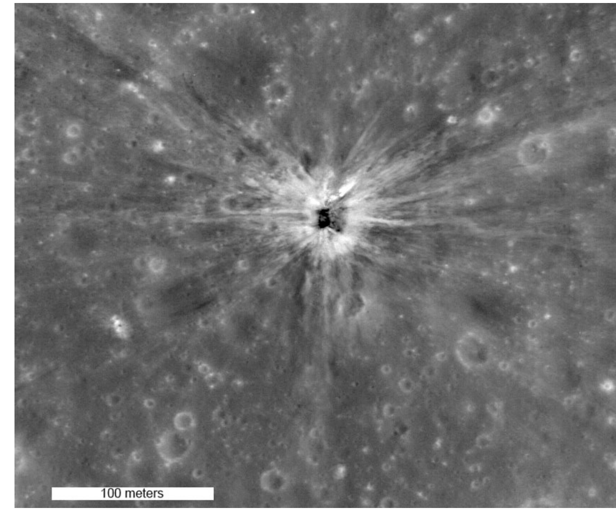


Atmospheric loading
Atmospheric generated seismic noise

Moon and Mars impacts

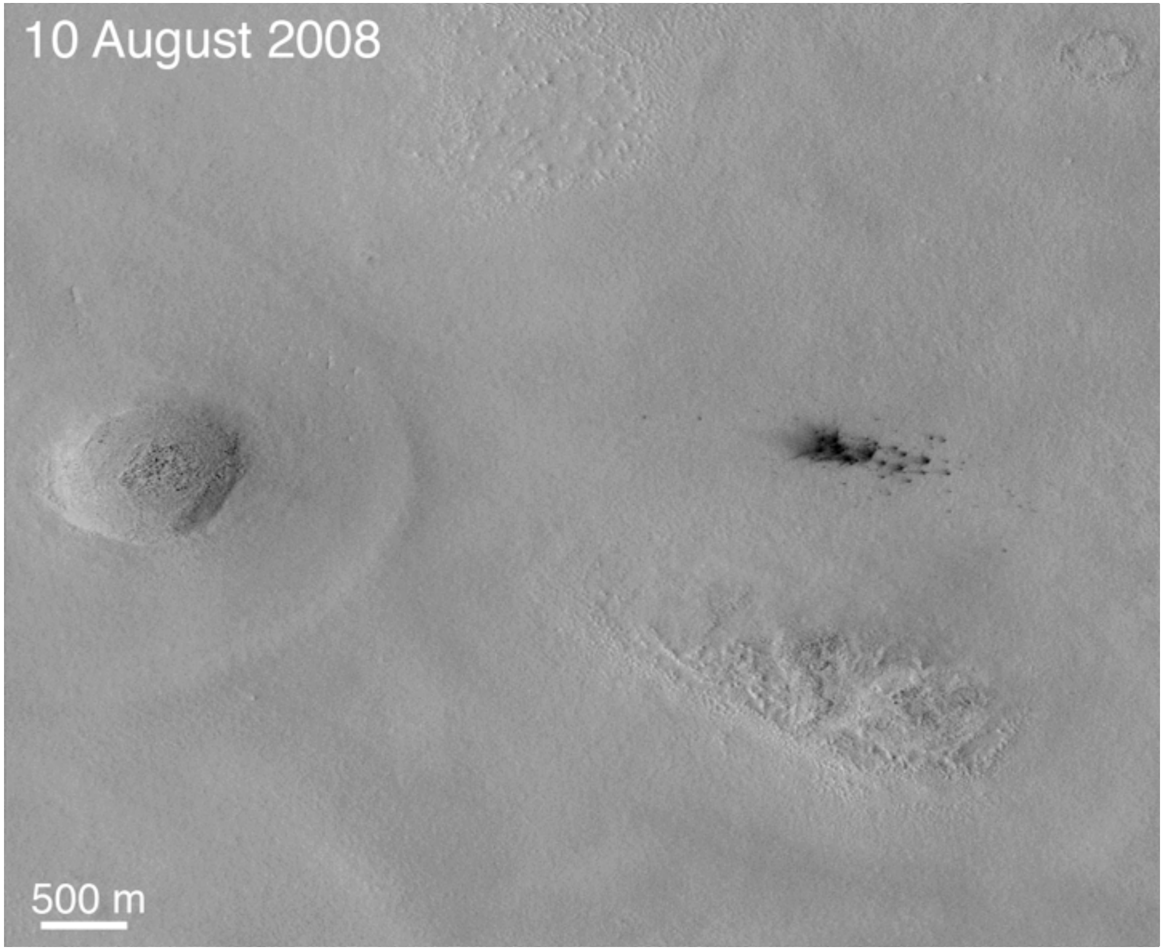


Lunar
Apollo 13
SIVB
Impact



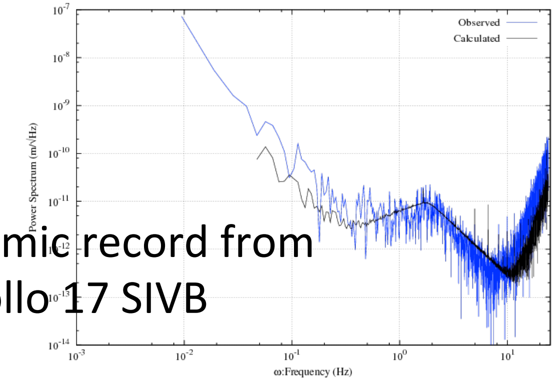
Mars Natural impact: 5.3tons at 10 km/s => 5 10^7 Ns,

Mars impacts (1/2)



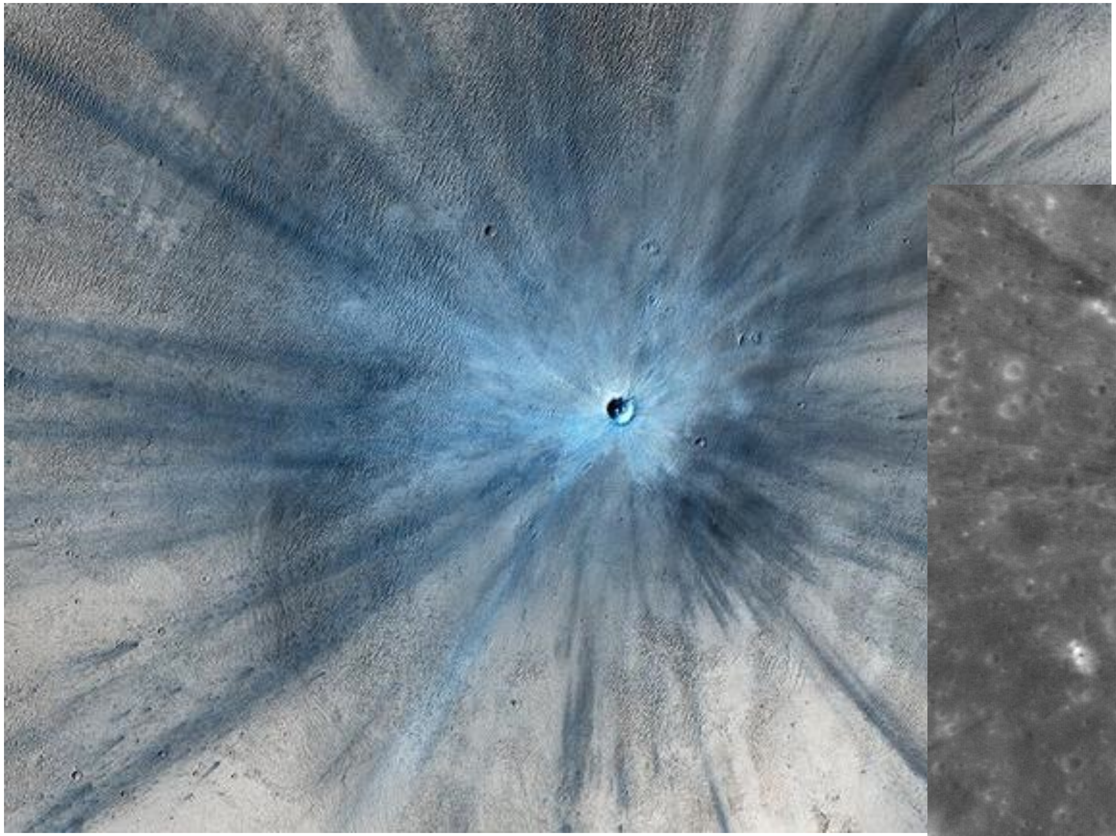
Mars impacts (2/2)

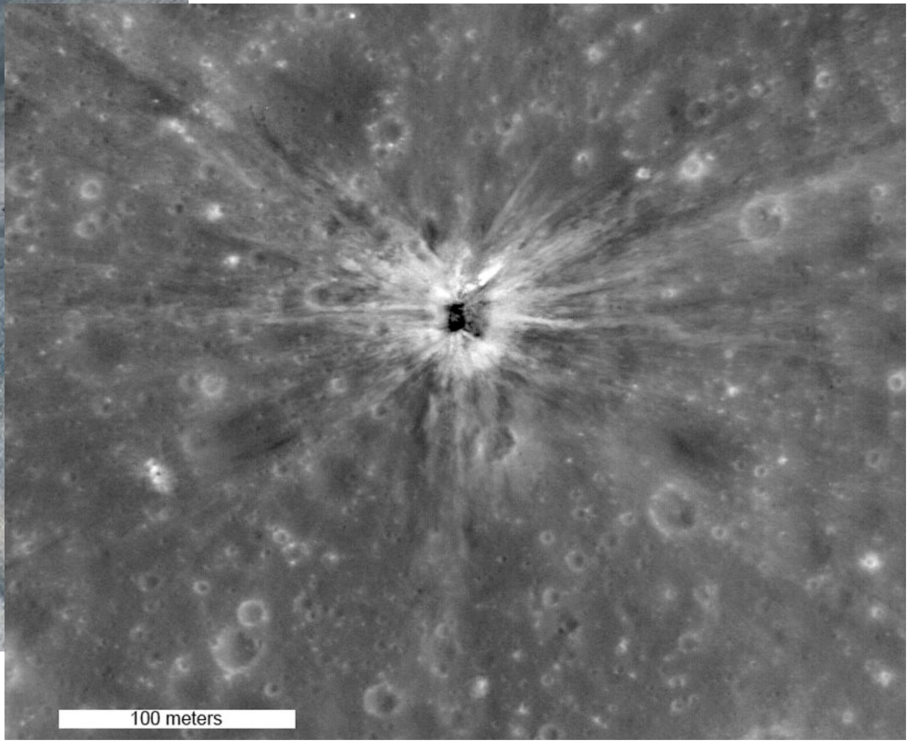
Estimation ~_5.3tons at 10 km/s => 5 10^7 Ns,
plus ejecta effects ~ 10^8 Ns



Seismic record from
Apollo 17 SIVB

Apollo 13 SIVB





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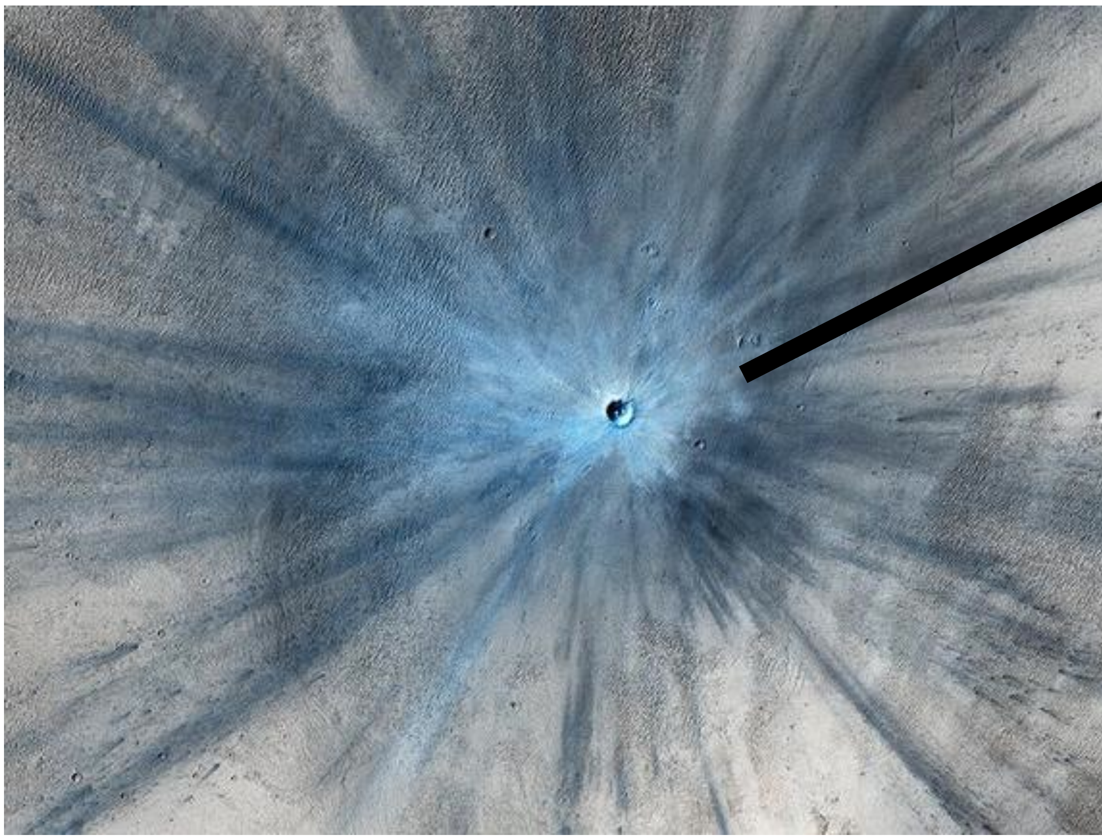

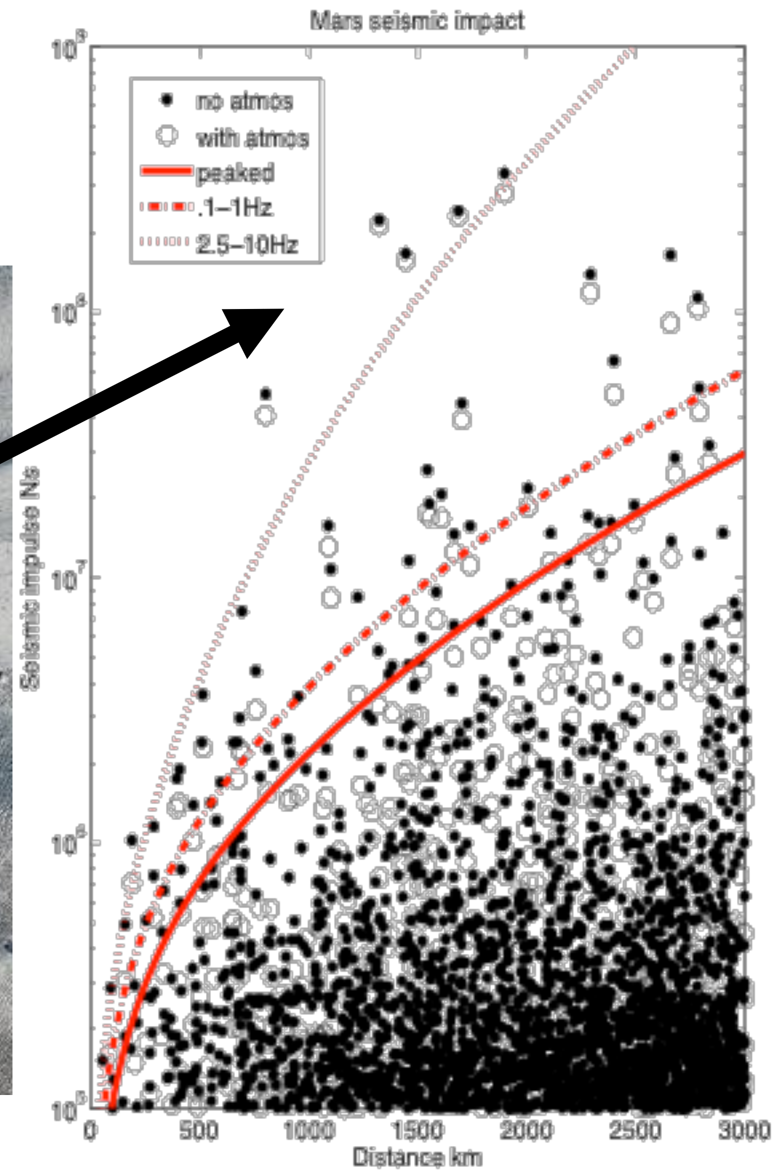

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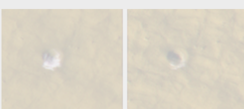
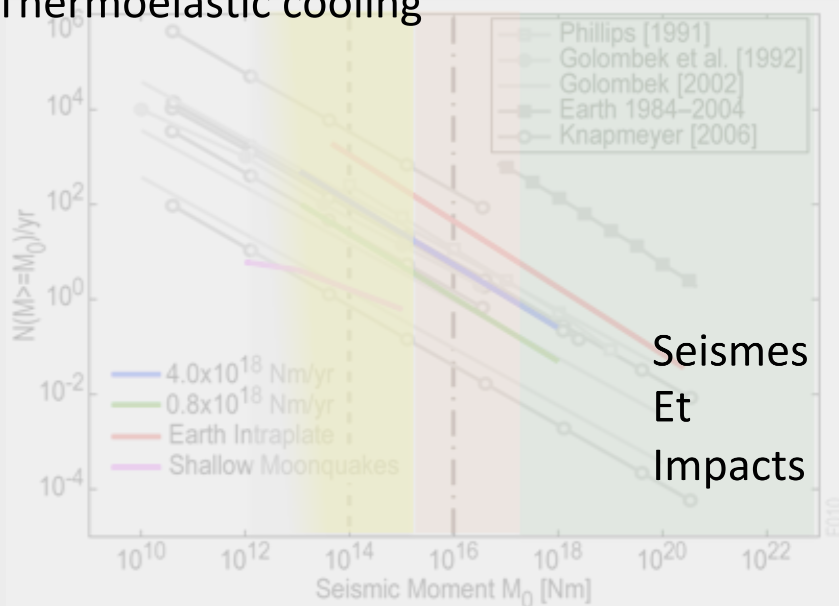


Impacts
10-15/yr

Thermoelastic cooling



Seismes
Et
Impacts

Phobos tide

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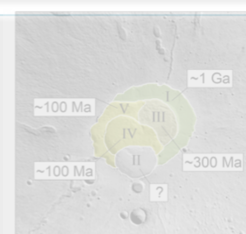
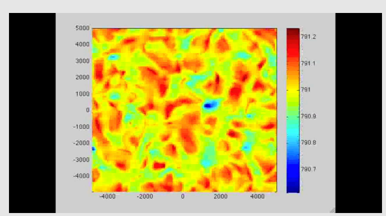
Tectonic
activity





Atmospheric loading
Atmospheric generated seismic noise

Wind/pressure generated seismic waves and static loading

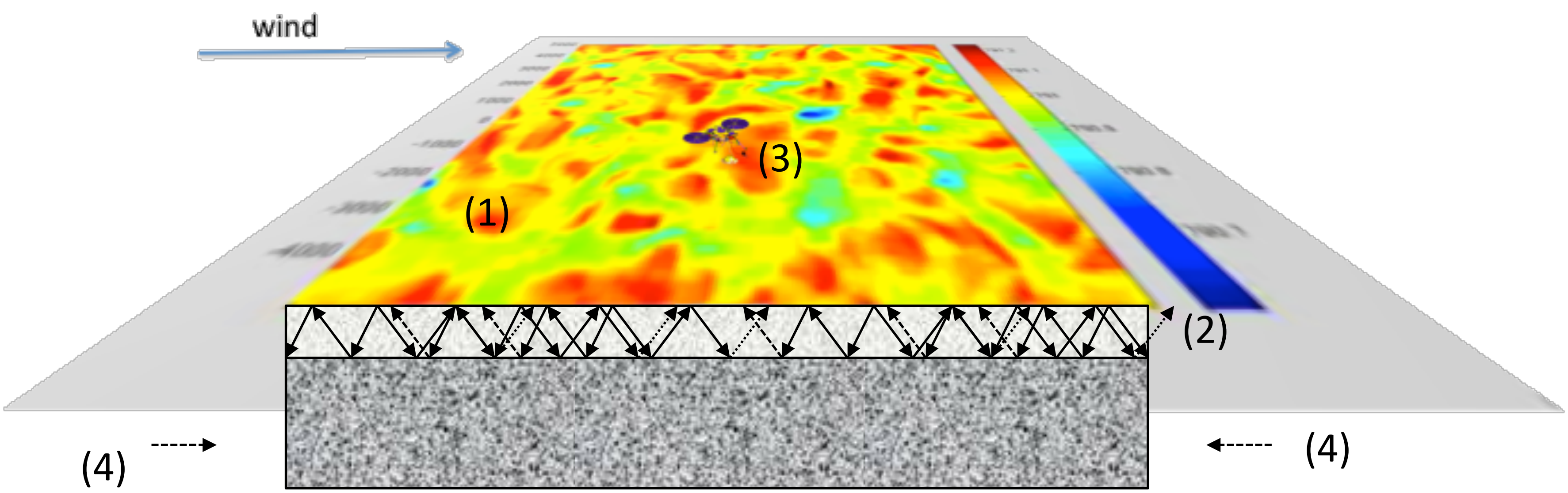
The atmosphere and wind/pressure fluctuations will be a major source of ground displacement for frequencies > 0.02 Hz with:

(1) At long period, static deformations of the surface, associated to wind generated pressure waves (static loading)

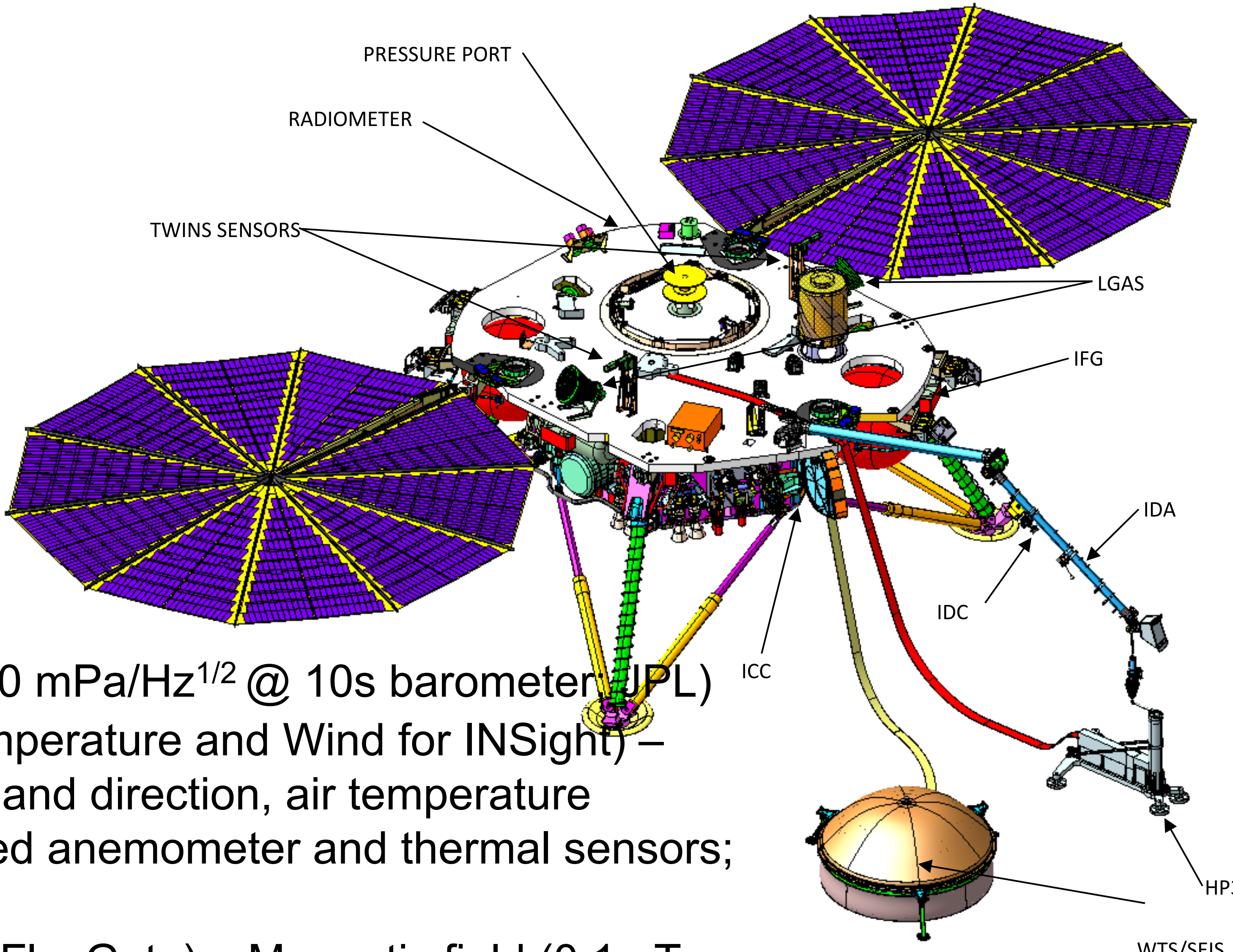
(2) At short period, dynamic ground acceleration, associated to local and possibly regional subsurface trapped surface waves excited by wind dynamic pressure (short period seismic waves)

(3) again at short period, wind interaction with the shield and the lander (seismic noise)

(4) on the global scale and at long period, surface waves excited by the global weather pressure fluctuations (long period seismic waves, called hum)

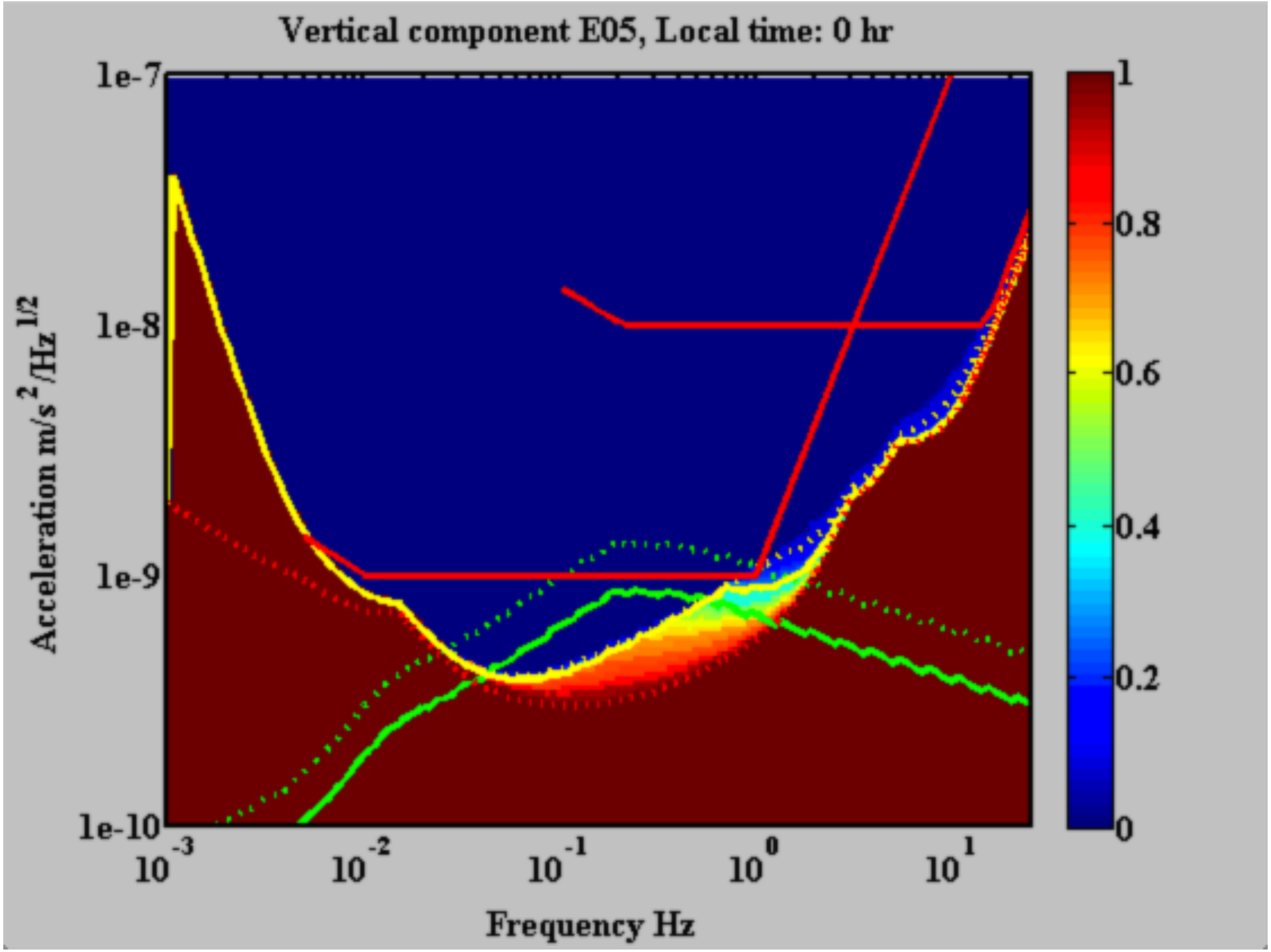


Environmental sensors for SEIS support

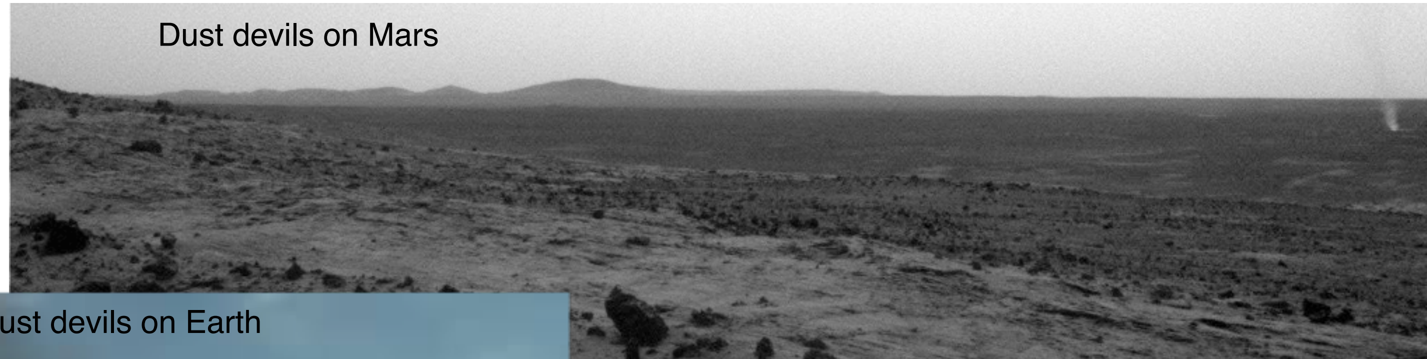


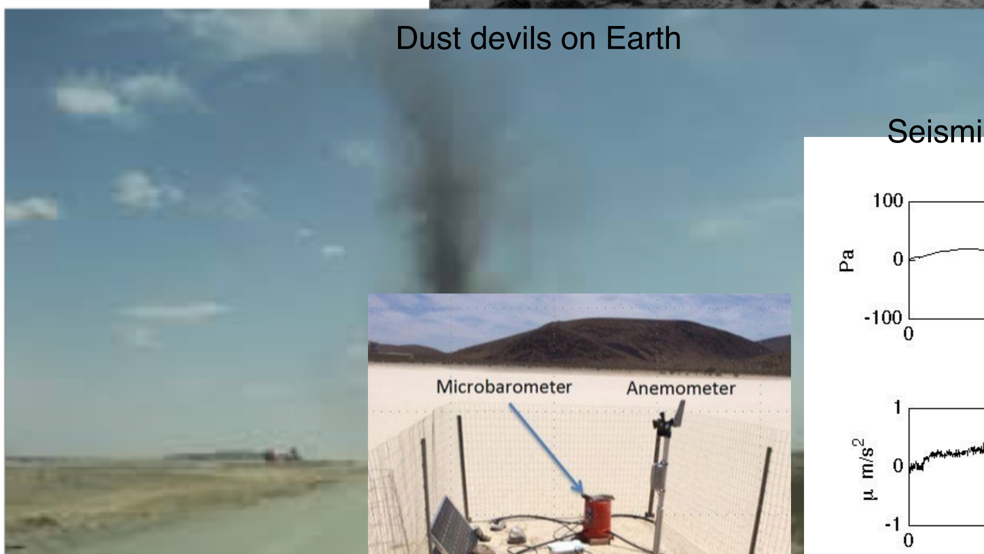
- **Pressure** (10 mPa/Hz$^{1/2}$ @ 10s barometer; JPL)
- **TWINS** (Temperature and Wind for INSight) – Wind speed and direction, air temperature (REMS-based anemometer and thermal sensors; CAB, Spain)
- **IFG** (Insight FluxGate) – Magnetic field (0.1 nT vector magnetometer; UCLA)

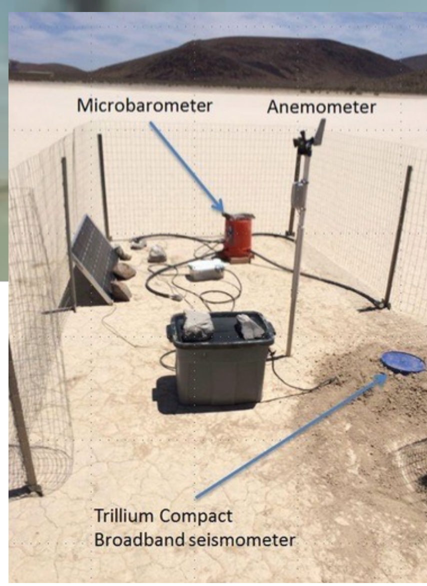
Planet breathing estimation



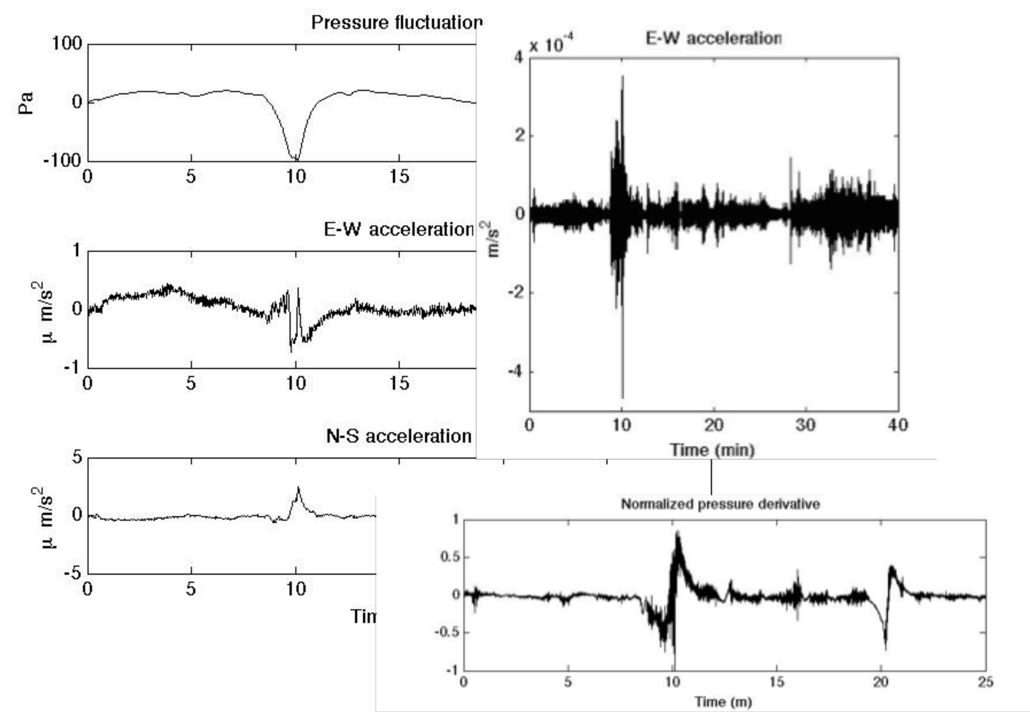
Dust devils as seismic sources: Earth Observation





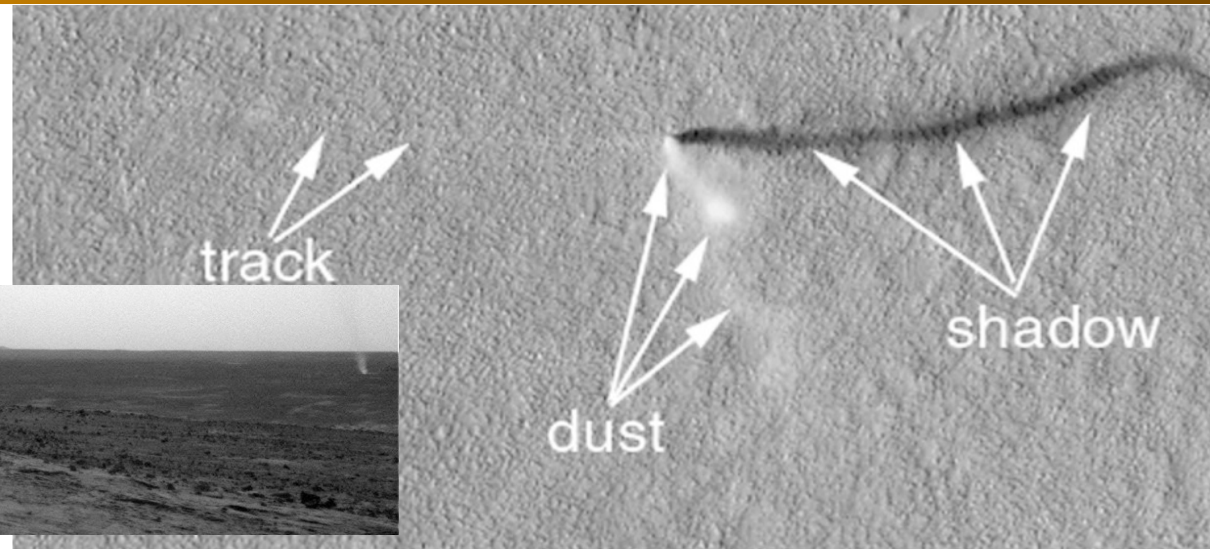


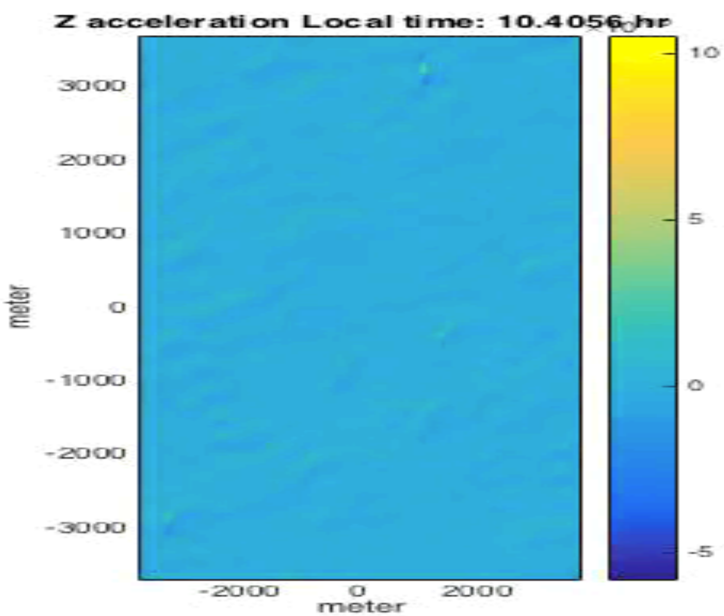
Seismic Static loading of Dust devils (Lorenz et al., 2015)

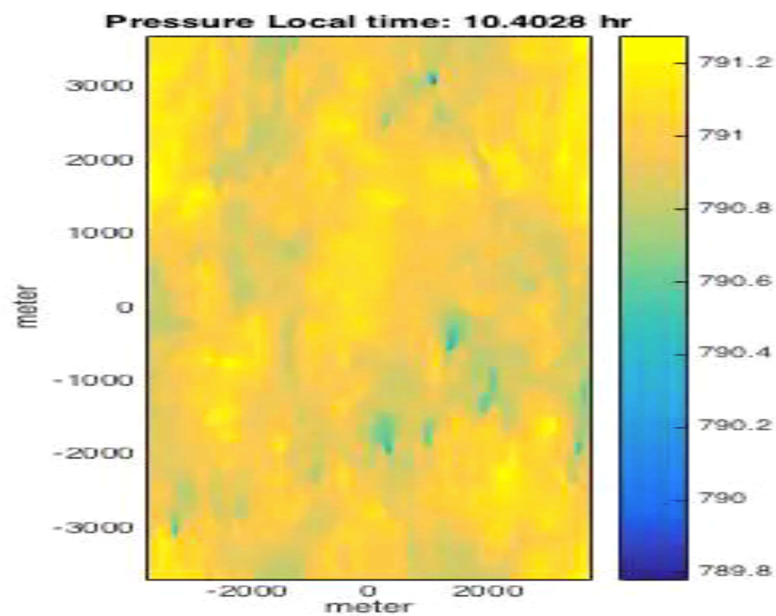


Surface waves generated by Dust devils (Kenda et al., 2015)

Dust devils as seismic sources: simulation







SEIS Expected Quakes…

M~5.5 1-2/yr

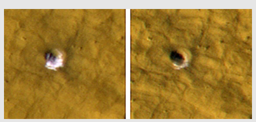
Global

M~4.5 ~ 10/yr

Global to regional

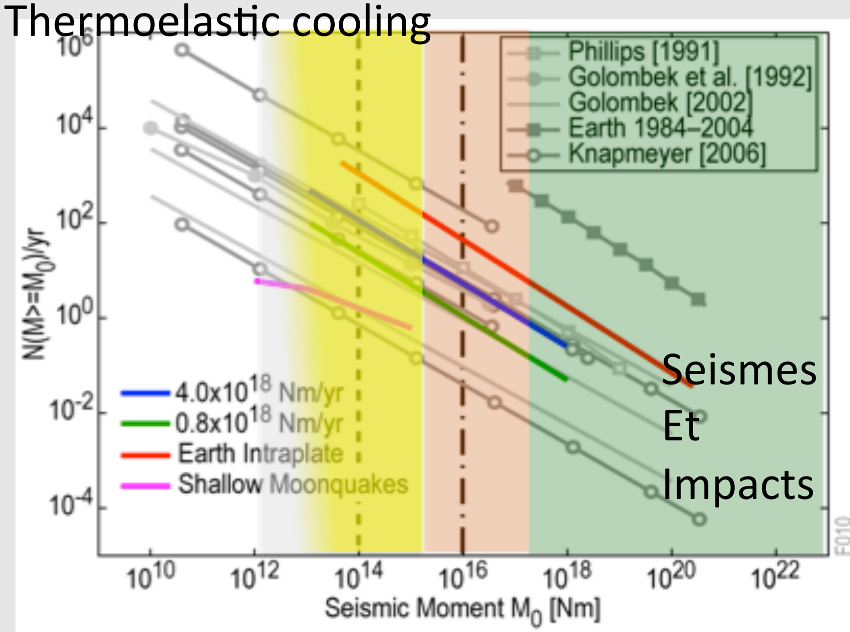
M~3.5 ~100/yr

regional

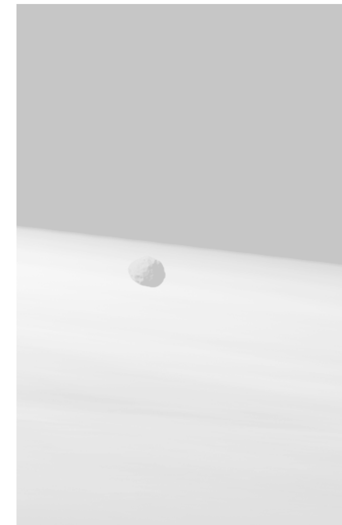


Impacts 10-15/yr

Thermoelastic cooling

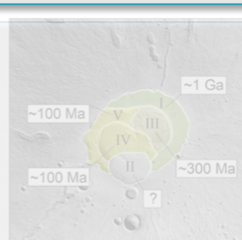


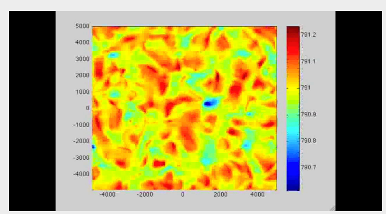
Seismes
Et
Impacts



Phobos tide

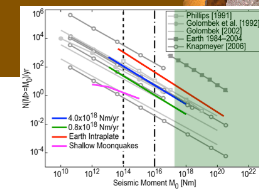
Bonus:
Tectonic
activity



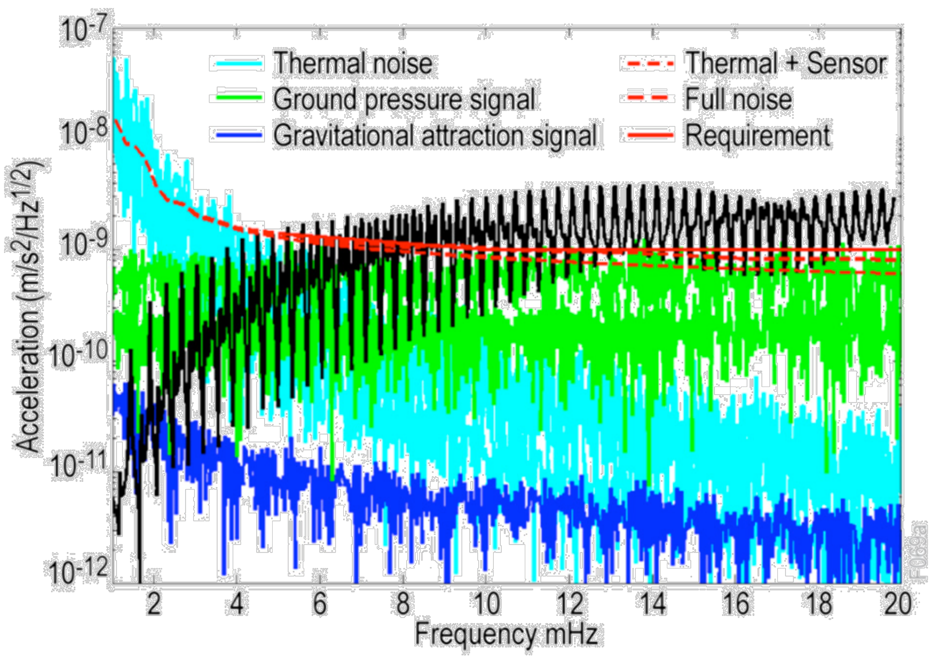


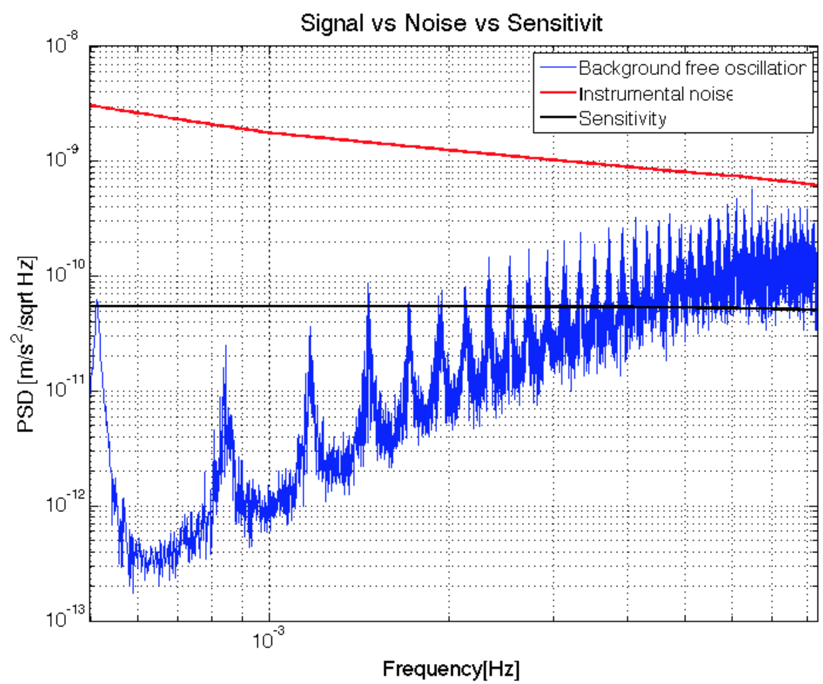
Atmospheric loading
Atmospheric generated seismic noise

Largest quakes: Normal modes



- Normal modes might be detected for 2×10^{17} Nm quake
- « spectroscopy » seismology: does not need the knowledge of the source location
- will constrain the upper mantle with the normal modes frequency inversion (e.g. PREM on Earth)
- Might also be coherently excited by the atmospheric circulation and turbulences

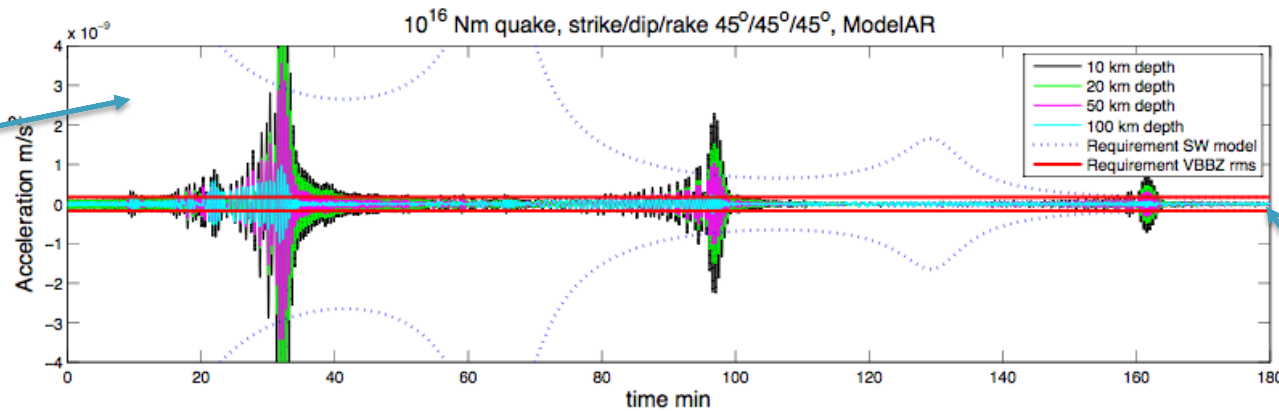


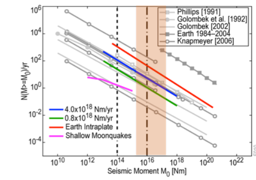


One week 'Hum' spectrum simulation (Nishikawa et al, work in progress, 2015)

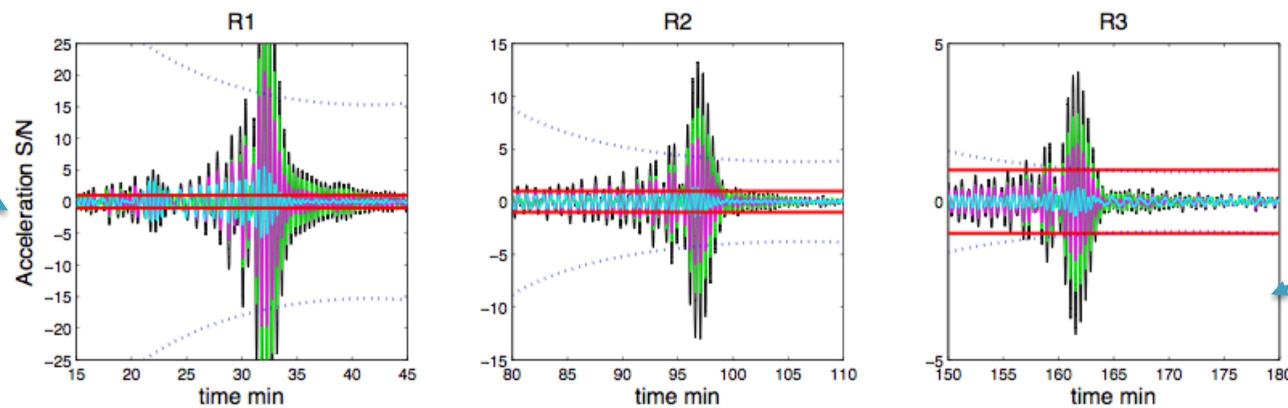
Moderate quakes: Turning waves

Rayleigh





Overtones



Rms Noise in bandwidth

t_{R1} t_{R2} t_{R3}

$$t_{R1} - t_0 = \frac{\Delta}{v_R}$$

$$t_{R2} - t_0 = \frac{2\pi a - \Delta}{v_R}$$

$$t_{R3} - t_{R1} = \frac{2\pi a}{v_R}$$

$\longrightarrow$

$$\frac{\Delta}{\pi a} = 1 - \frac{t_{R2} - t_{R1}}{T_R}$$

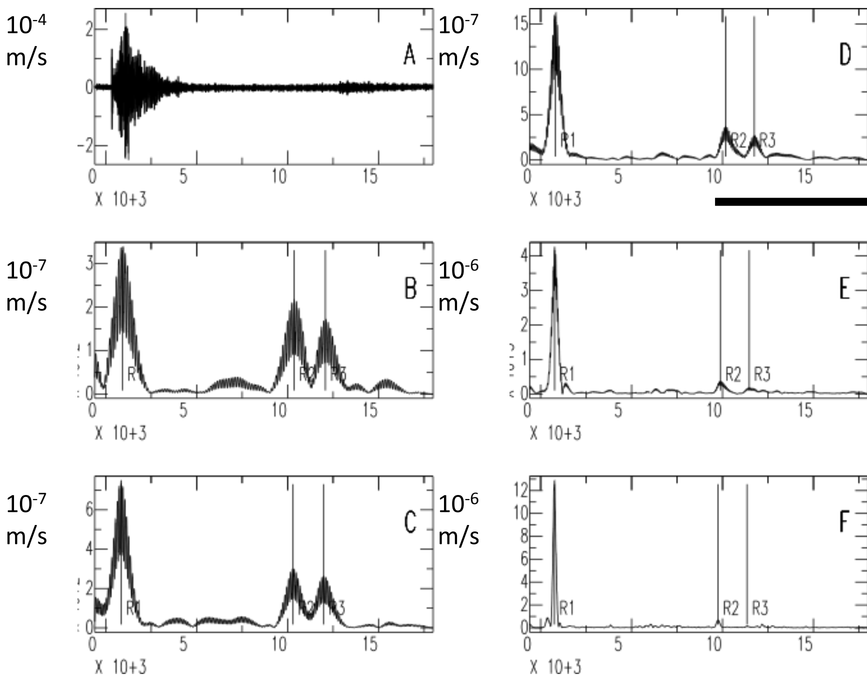
$$t_S - t_P = f_1(\Delta, v_s, v_p)$$

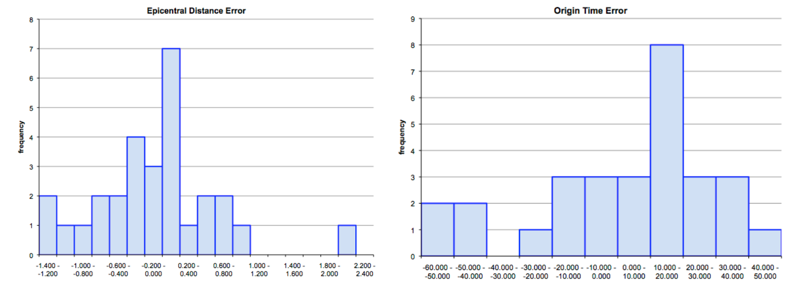
$$t_R - t_P = f_2(\Delta, v_s, v_p)$$

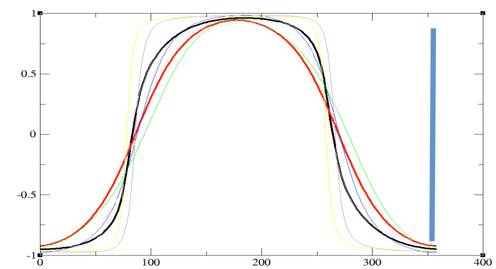
$$T_R = f_3(f, v_s, v_p)$$

$\longrightarrow$ Model

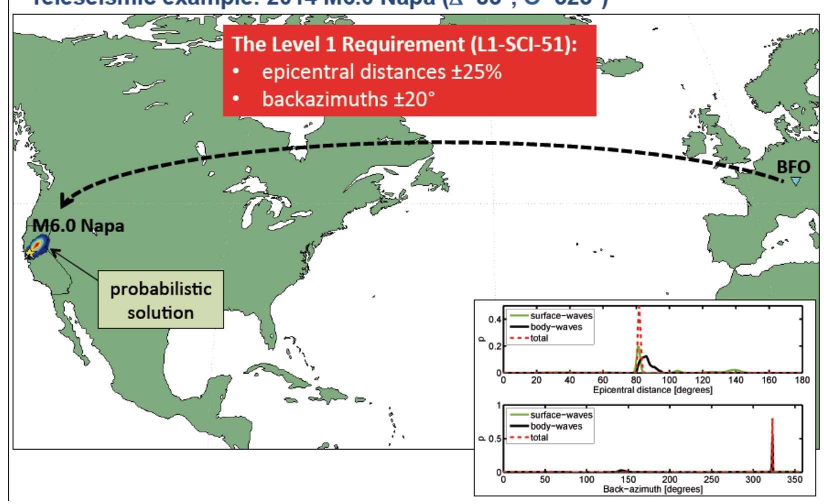
Moderate quakes: Rayleigh waves on Earth







Teleseismic example: 2014 M6.0 Napa (Δ=83°, Θ=323°)



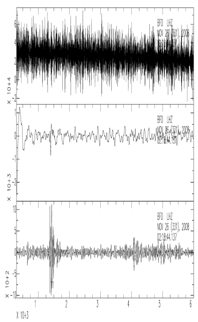
R1 – R2 – R3 provide

- Great circle velocities (R3 – R1) → Origin time
- Estimate of epicentral distance (R2 - R1)
- Back-azimuth estimate (rotation of horizontal components) (Baker & Stevens, 2004)
- and then location

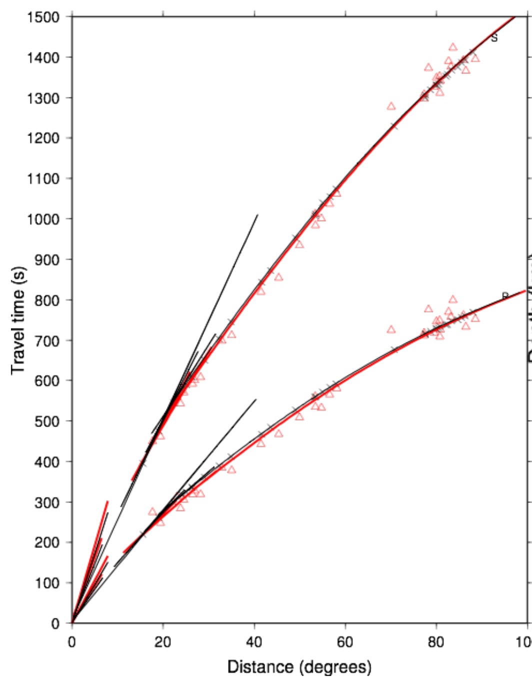
(Panning et al., 2015, Boese et al, 2015)

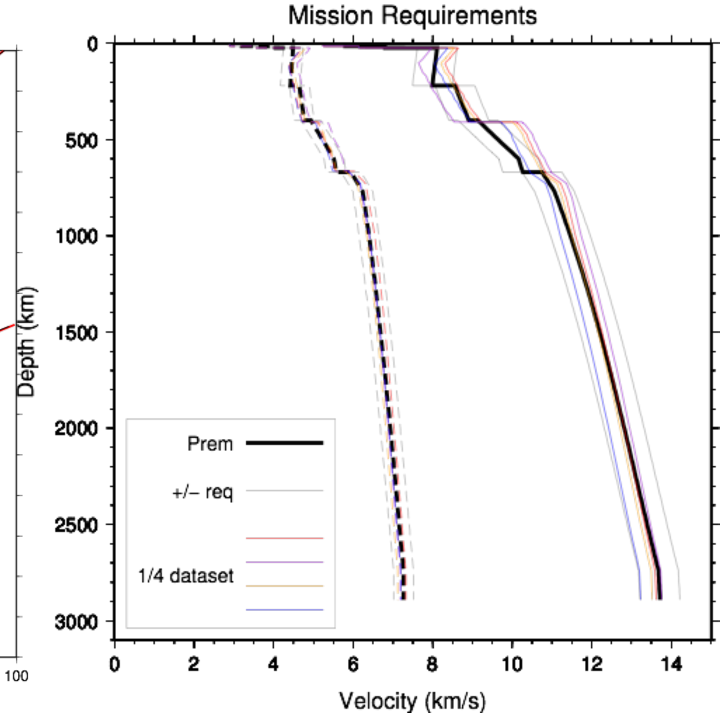
Expected Mantle model

- Inversion strategy has been validated with Earth data
- Results demonstrate that the PREM model can be retrieved within the INSIGHT error bars



Earth data

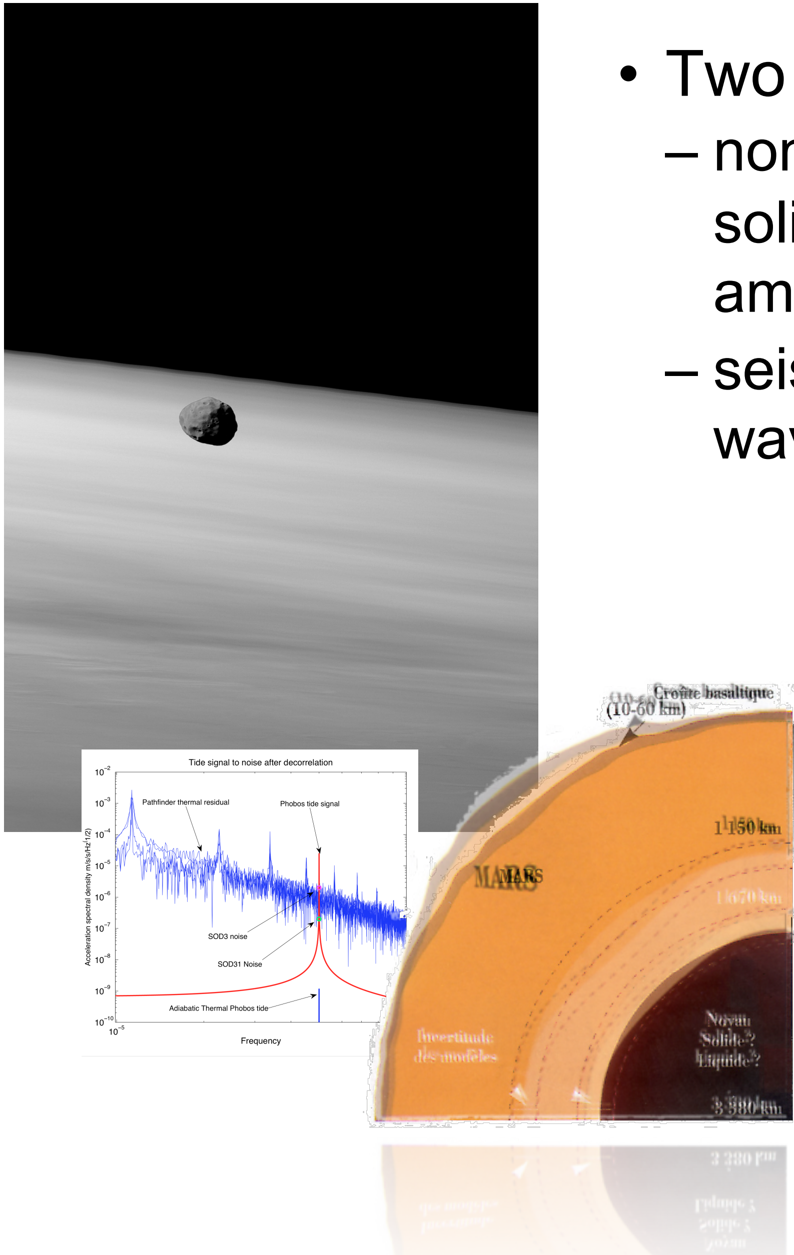


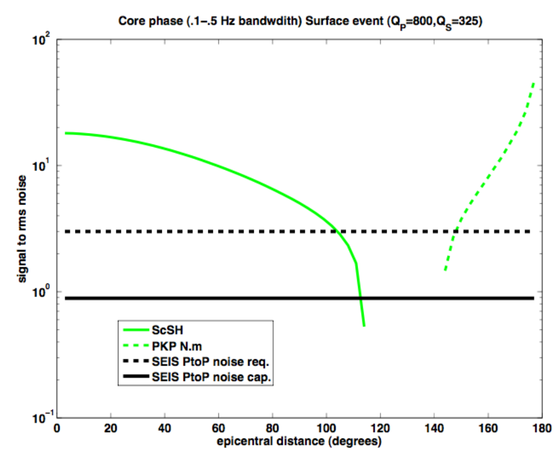


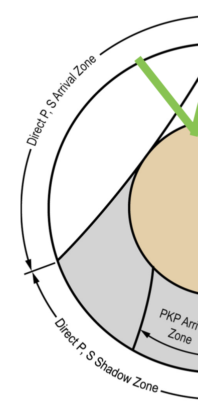
M.Panning, A.Mocquet, E.Beucler et al., 2014

And …. the core

- Two ways investigation:
  - non-seismic by detection of the Phobos solid tide (~mm) and interpretation of the amplitude in term of core size
  - seismic by detection of the core reflected waves (ScS) similar Earth and Moon







EduSEIS goals

- To associate elementary to high schools to the Discovery of a new planet by seismology
- This will be the main goal of the partnership with the international networks of “sismo” at school
- Several phases to built together

Phase 0 prior launch and landing

Phase 1 during the full proprietary period (between November 2018 until June 2019)

Phase 2 after June 20179

Some idea for EPO with SEIS/InSight data

EPO with SEIS data (and Other Planetary seismic data)

- Some idea for Phase 0 (fall 2016 to summer 2018)
  - Release to EPO partners of selected Earth and Moon data, to prepare partners and schools to comparative seismology
  - Release to EPO partners of Booklets on the challenge of a Mars travel
- Some idea for Phase 1 (fall 2018 to summer 2019)
  - Where will go SEIS and HP3 ?
  - Release of the SEIS data on April, 1st, 2019 (Installation + HP3 phase data) and on July, 1st, 2019 (First trimester of 2019)
  - Release to EPO partners of selected SEIS data, such as the data shown or used in scientific publications
    - Might be associated to some of the first project discoveries
    - Will have to follow embargo policies of journals
    - Will allow students to re-do these discoveries at the time of their publication

EPO with SEIS data (Other Planetary seismic data)

- Some idea…. For the phase 2 (after fall 2019)
  - Use of all released data (either validated or non-validated)
    - non validated data will allow continuous data analysis day after day
    - validated data might offer better quality but will be older
  - Selection of several small groups of US-European schools who might be associated in the tactical operations of Event selection
    - Selected groups will have the same data access as Science team members (~ a few day delay) and will be able to perform event request

Want to participate with your school/Highschool?

Contact the SEIS/InSight EPO lead, Jean Luc Berenguer @ University of Nice

(jean-luc.berenguer@ac-nice.fr)