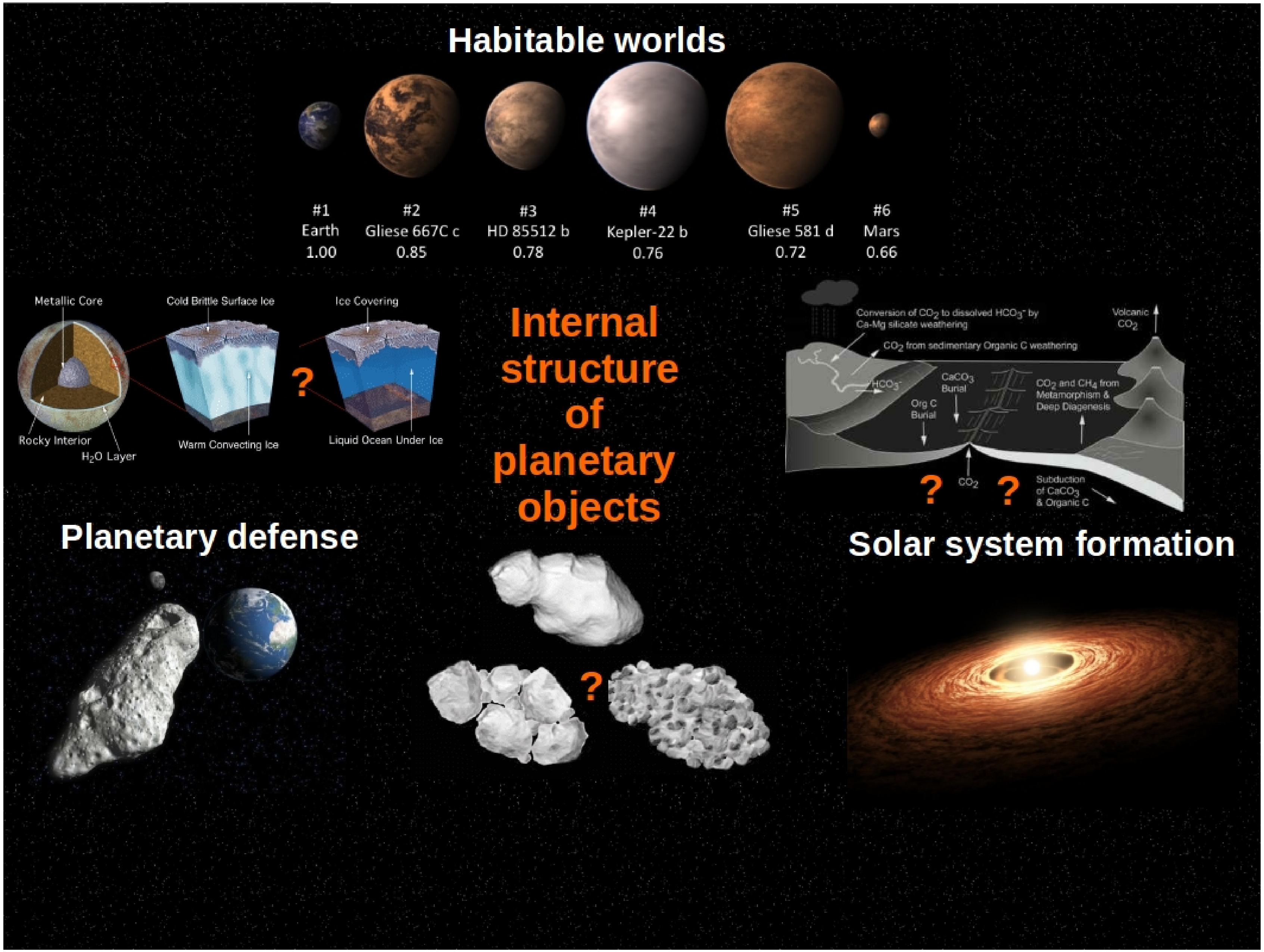
PIONEERS – 6DoF ground motion sensors for planets and asteroids

F. Bernauer and the PIONEERS team

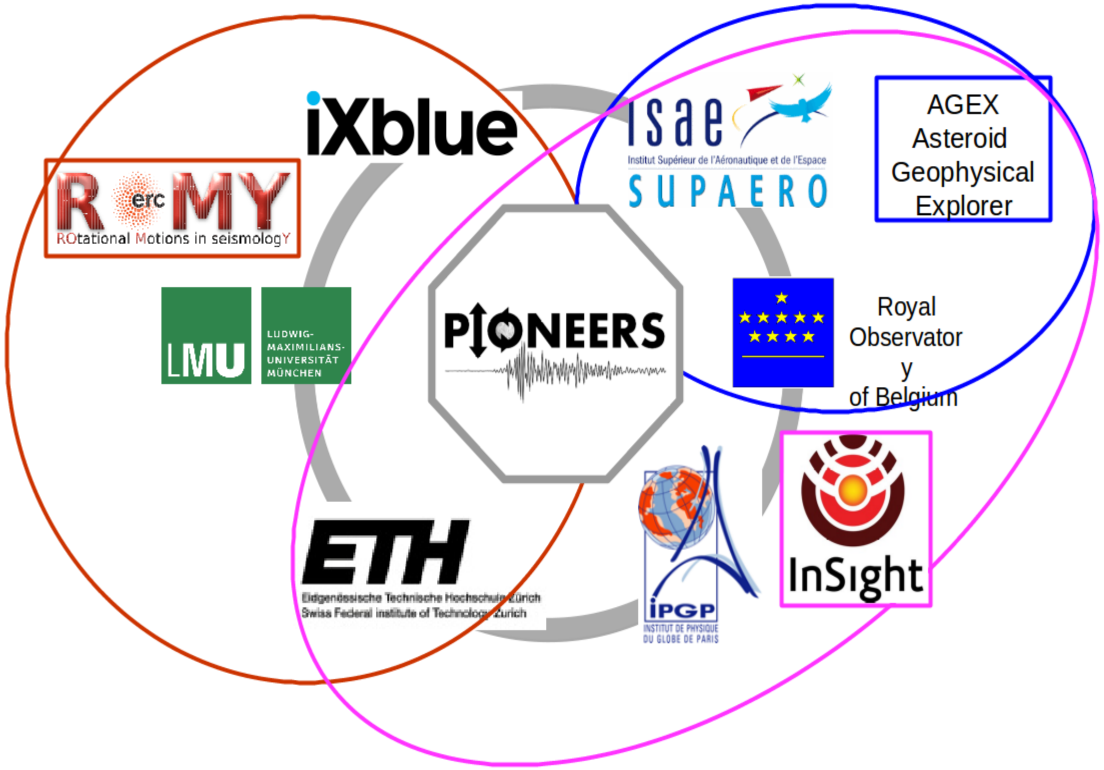
Motivation


Habitable worlds
#1
Earth
1.00
#2
Gliese 667C c
0.85
#3
HD 85512 b
0.78
#4
Kepler-22 b
0.76
#5
Gliese 581 d
0.72
#6
Mars
0.66
Metallic Core
Cold Brittle Surface Ice
Ice Covering
?
Rocky Interior
H_2O Layer
Warm Convecting Ice
Liquid Ocean Under Ice
Internal structure of planetary objects
Conversion of CO_2 to dissolved HCO_3^- by Ca-Mg silicate weathering
Volcanic CO_2
CO_2 from sedimentary Organic C weathering
HCO_3^-
$CaCO_3$ Burial
Org C Burial
CO_2 and CH_4 from Metamorphism & Deep Diagenesis
? CO_2 ?
Subduction of $CaCO_3$ & Organic C
Planetary defense
?
Solar system formation

The Partners

1. **European leading teams in planetary seismology, rotational sensors and rotation dynamics of planetary objects**
2. **Teams already involved in the development of state of art instruments (SEIS/INSIGHT, BlueSeis)**

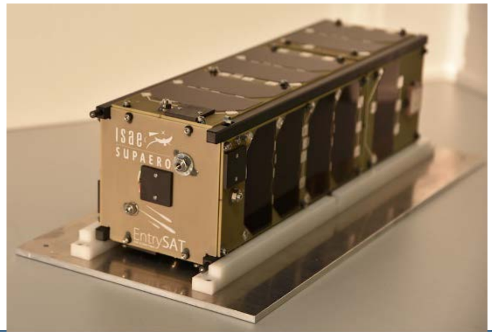
Consortium partners
and their links through already existing projects



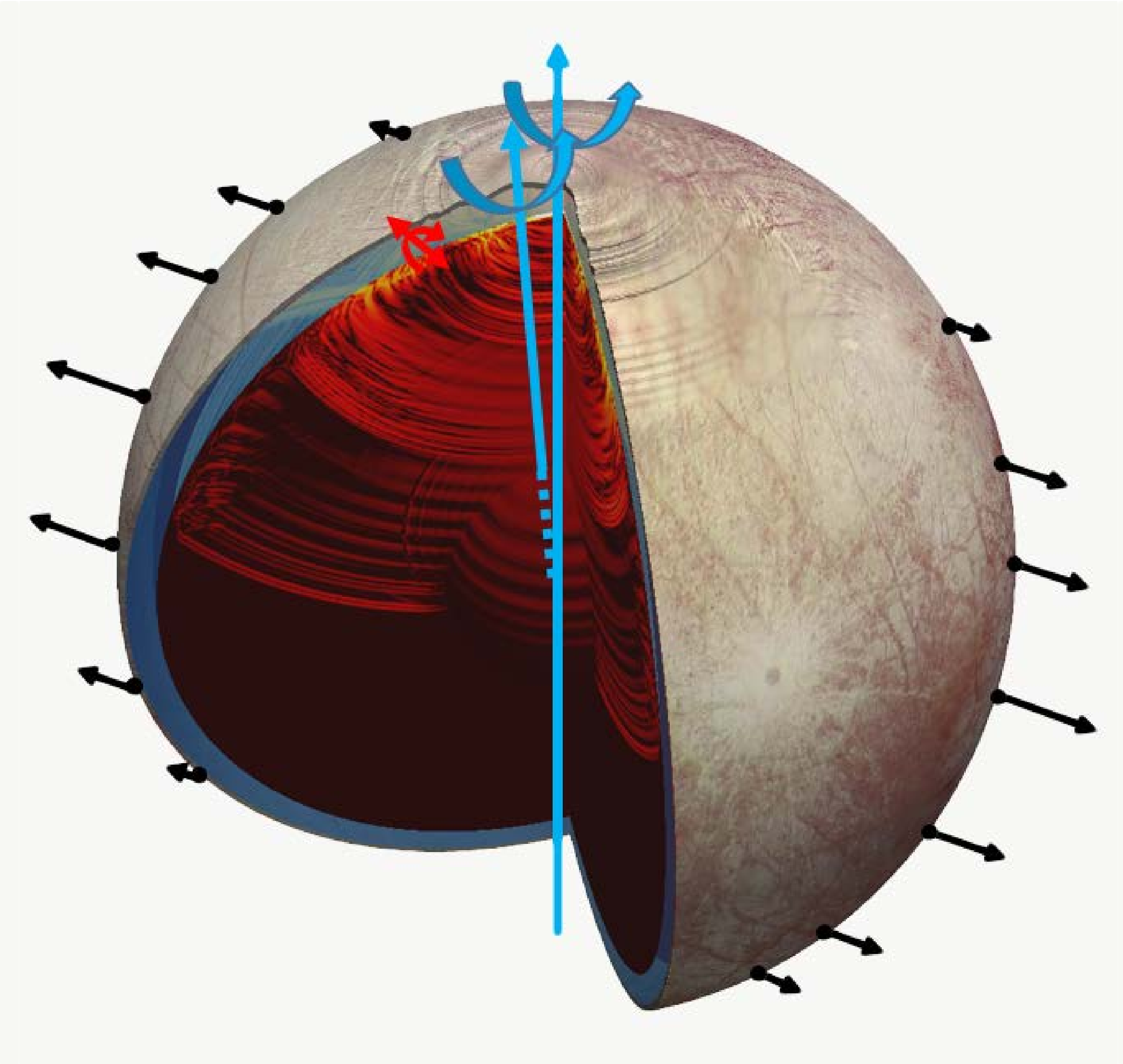
SEIS/InSight

BlueSeis-3A
BlueSeis/iXblue

EntrySat
ISAE-SUPAERO



Scientific Objectives



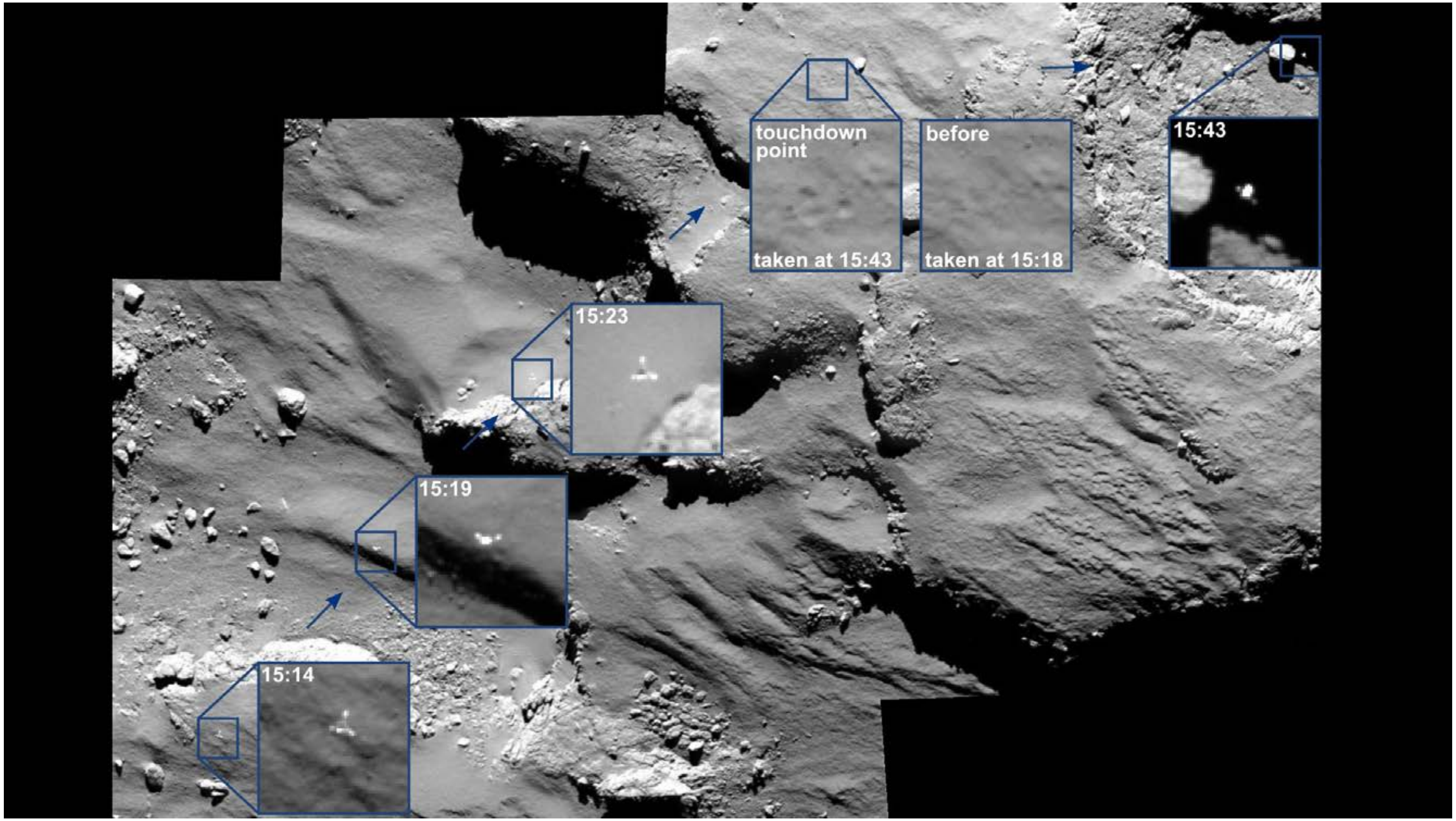
Stähler et al. (2018), JGR

6DoF Seismology

Rotational Dynamics

Lander – Surface Interactions

Lander – Surface Interactions



Rebounds of Philea lander (credits ESA)

Lander - Surface interactions

Observing the trajectory and rebounds of the lander from release by the mother spacecraft to final rest on the surface of the planetary body

Scientific questions:

- Physical properties of the target object surface material
- local gravity field of the target body from the lander trajectory
- requirements on the lander deployment strategy for future space missions

signals to be recorded to address these questions:

- continuous records of accelerations and rotations of the lander (especially before, during and after every touchdown)

Observing the trajectory of a planetary object in space

Scientific questions:

- precise information on orbit (shape and period), spin-lock, moment of inertia, distribution of mass inside the body
- precise rotation and rotation variations (focus on free and forced librations)
- interior global properties such as moments of inertia of the different layers

Signals to be recorded to address these questions:

- Rotation, rotation rate from free and forced librations
- translational accelerations induced by tidal effects

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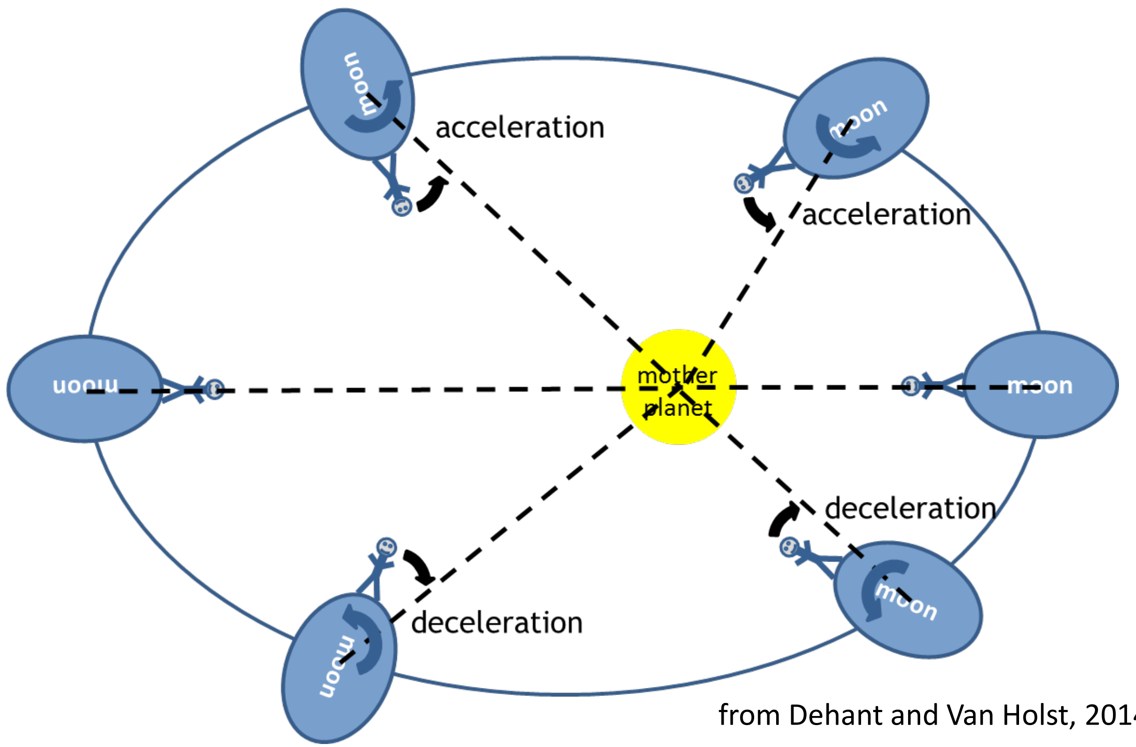
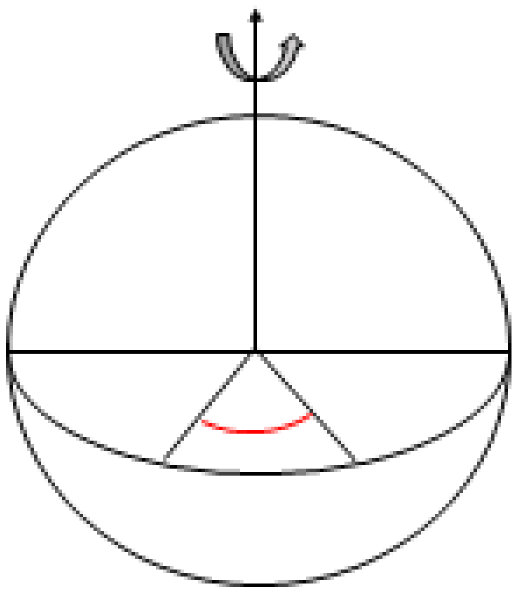
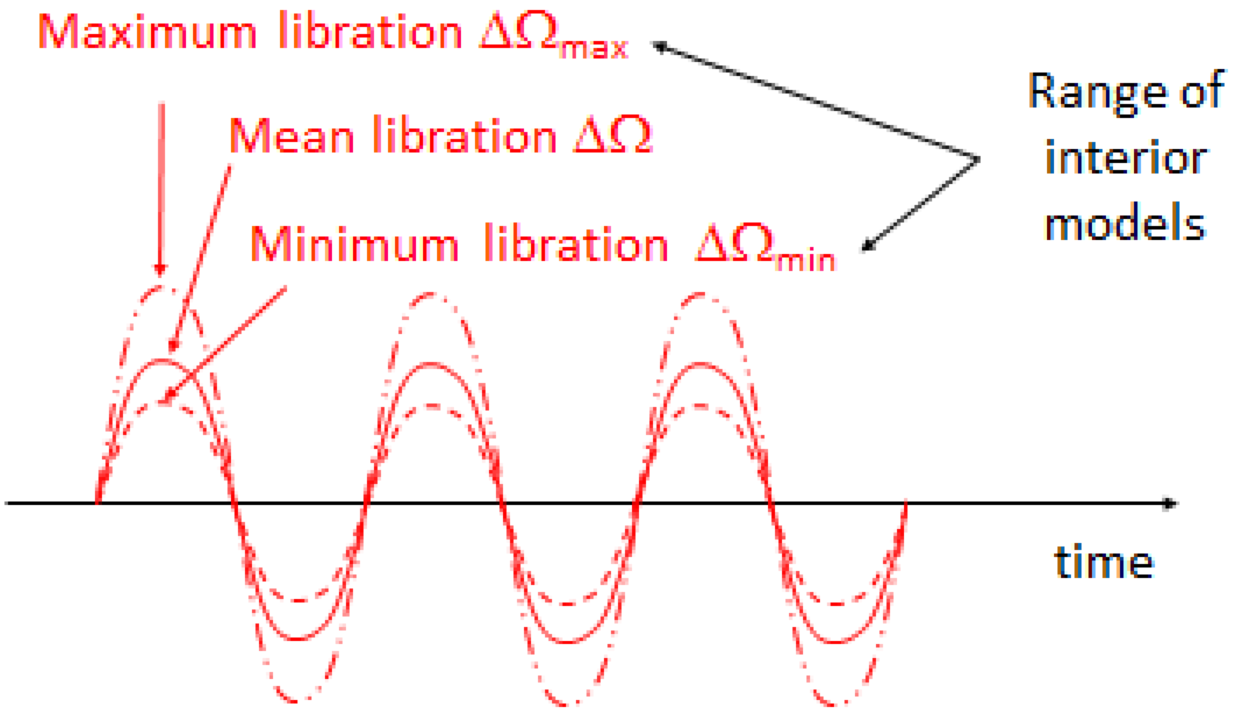
Librations

The central body exerts a gravitational torque on the planet or satellite, which therefore accelerates or decelerates its rotation depending on its orientation with respect to the central body



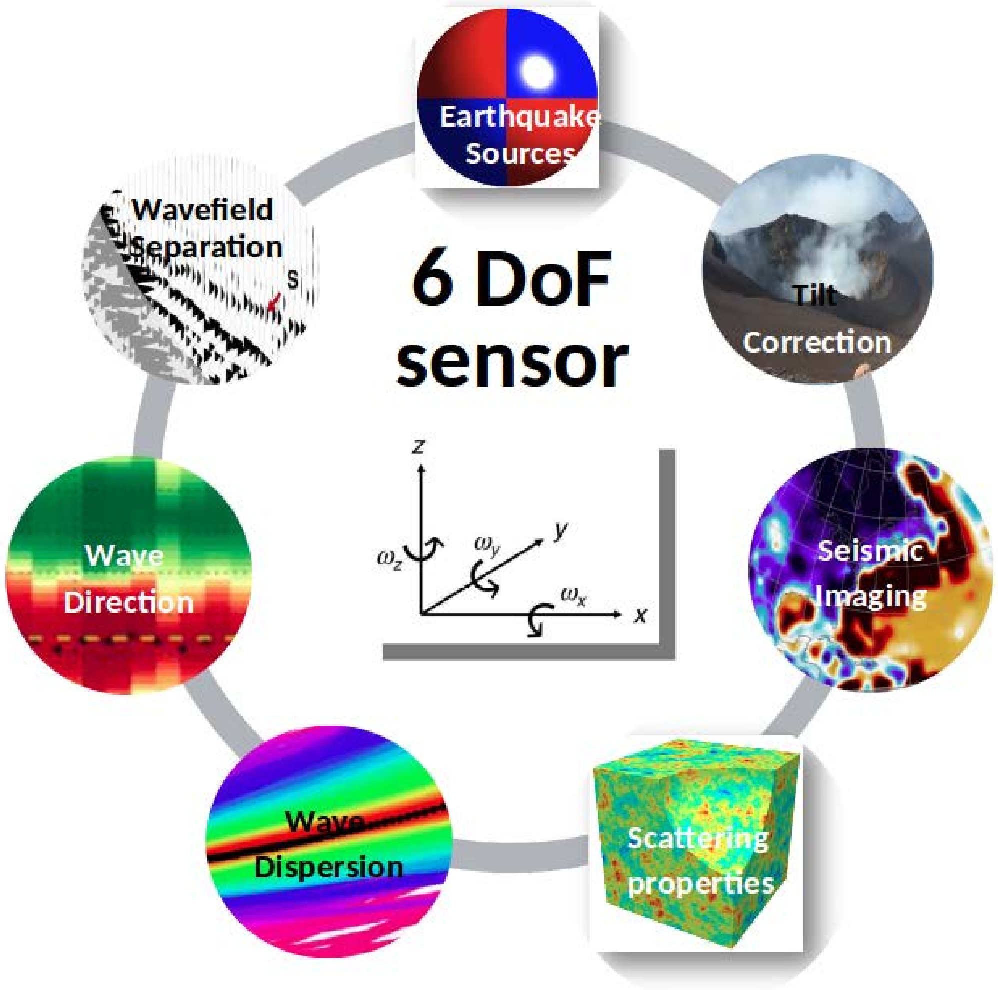
from Dehant and Van Holst, 2014





- forced libration induced by the gravitational forcing
- free librations related to the natural global rotational normal modes of the moon. The amplitudes of the free librations may be excited by geophysical or dynamical mechanisms.

6DoF Seismology



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Observing the trajectory of a point on the target object's surface in 6DoF during the passage of a seismic wave

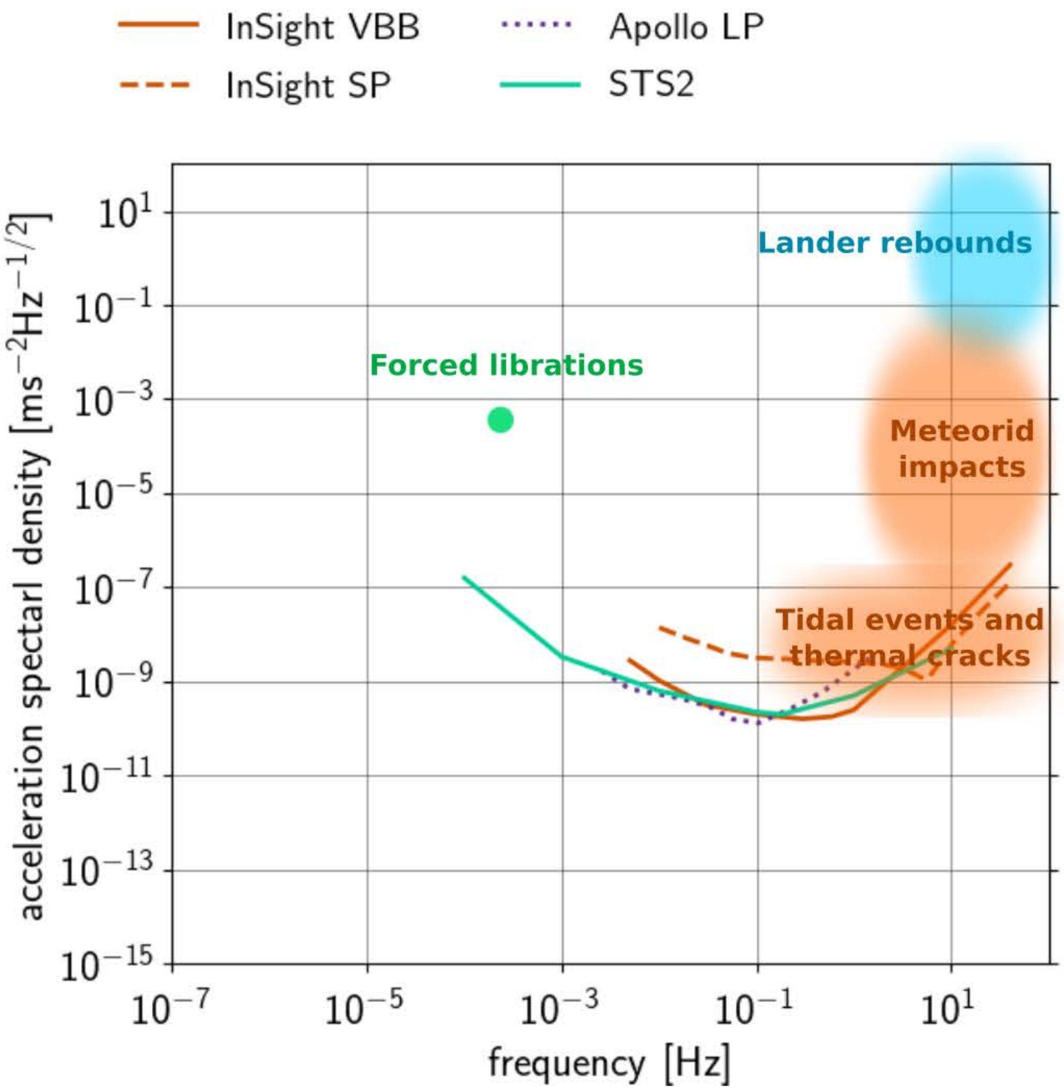
Scientific questions:

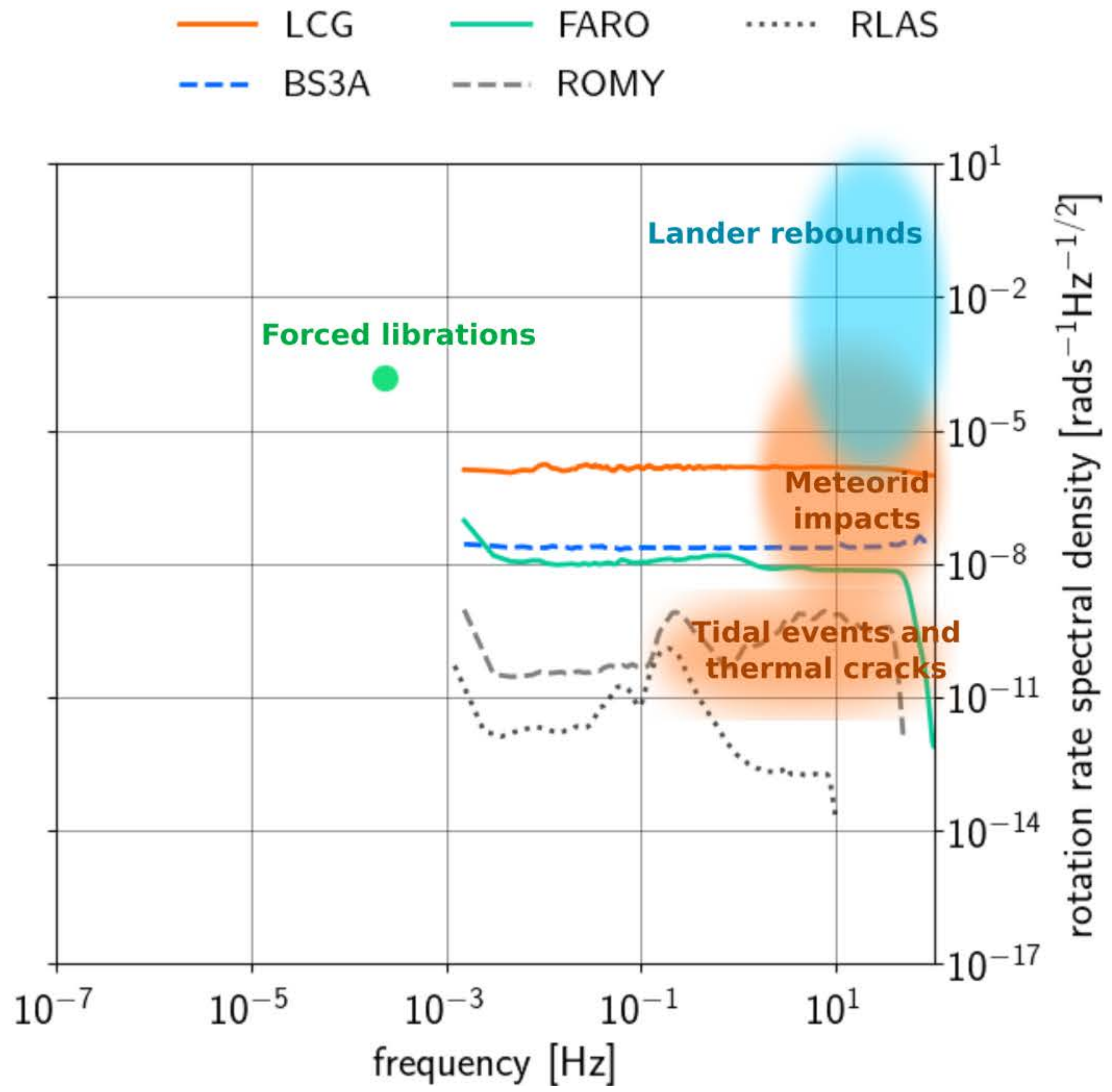
- **Constrain interior structure models for planetary objects**
- **Single station seismology (retrieve sub surface velocity and travel direction information, wave field separation, source localization, tilt correction, static displacement, static rotation, …)**

Signals to be recorded to address these questions:

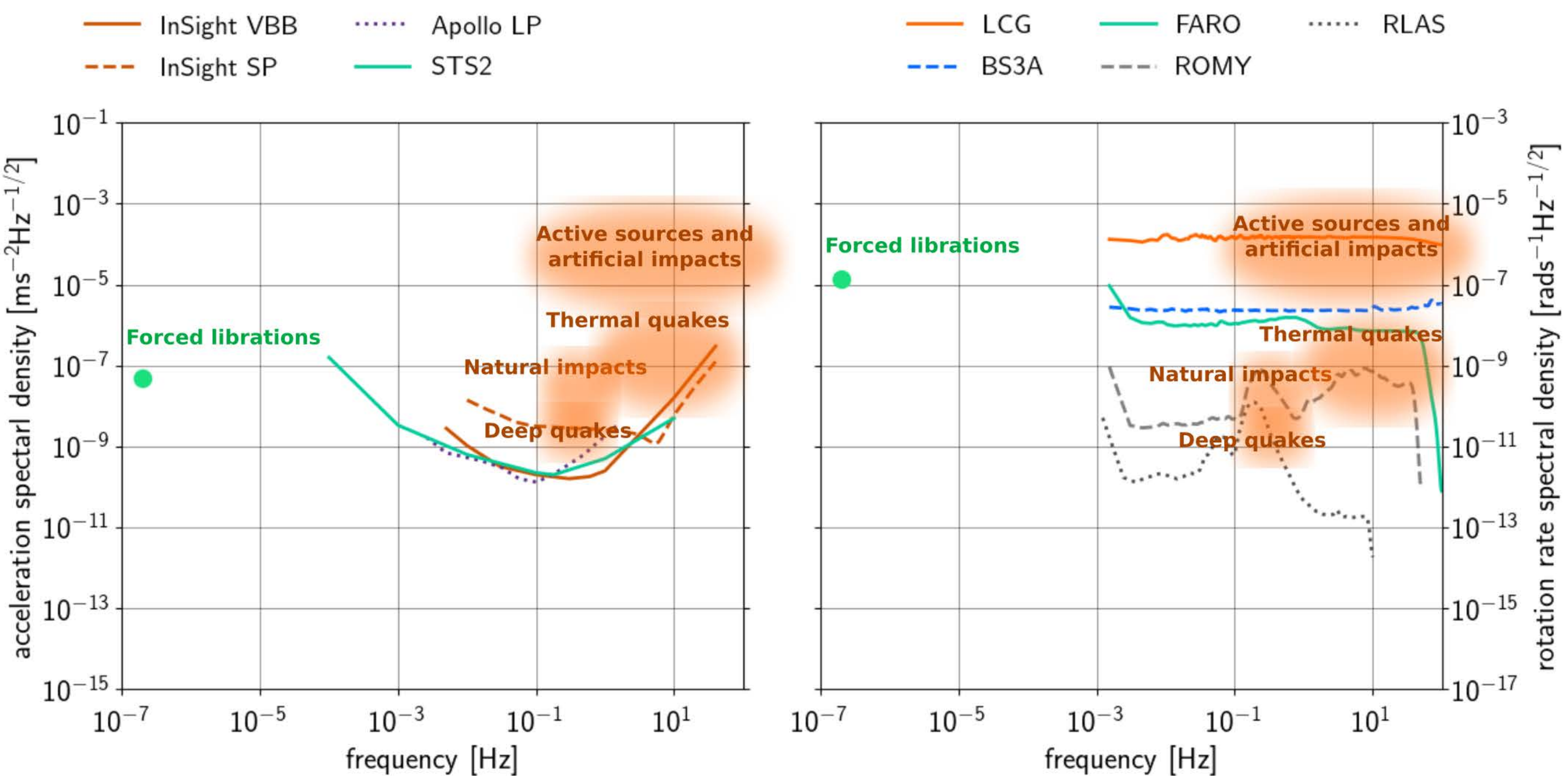
- **Impacts (natural or artificial) onto the object's surface**
- **Active seismic sources**
- **Surface quakes triggered by different mechanisms (ice cracks, temperature induced stress, …)**
- **Deep quakes originating from the object's deep interior**

Expected signals - Phobos





Expected signals – The Moon



High performance planetary breadboard

1. **Two sensors :**
   - Translational sensor based on optical interferometry readout
   - Giant Fiber Optics Gyroscope for high performance rotation sensing

2. **Development up to breadboard for :**
   - Technology demonstration of performances
   - Demonstration of scalability of performances
   - Identification of key difficulties

3. **Science targets :**
   - Background seismological noise of large planetary objects
   - Precise global rotation dynamics of large planetary objects
   - Improvement of planetary seismological methods by adding rotation (environment noise removal, network analysis, scattering characterization...)

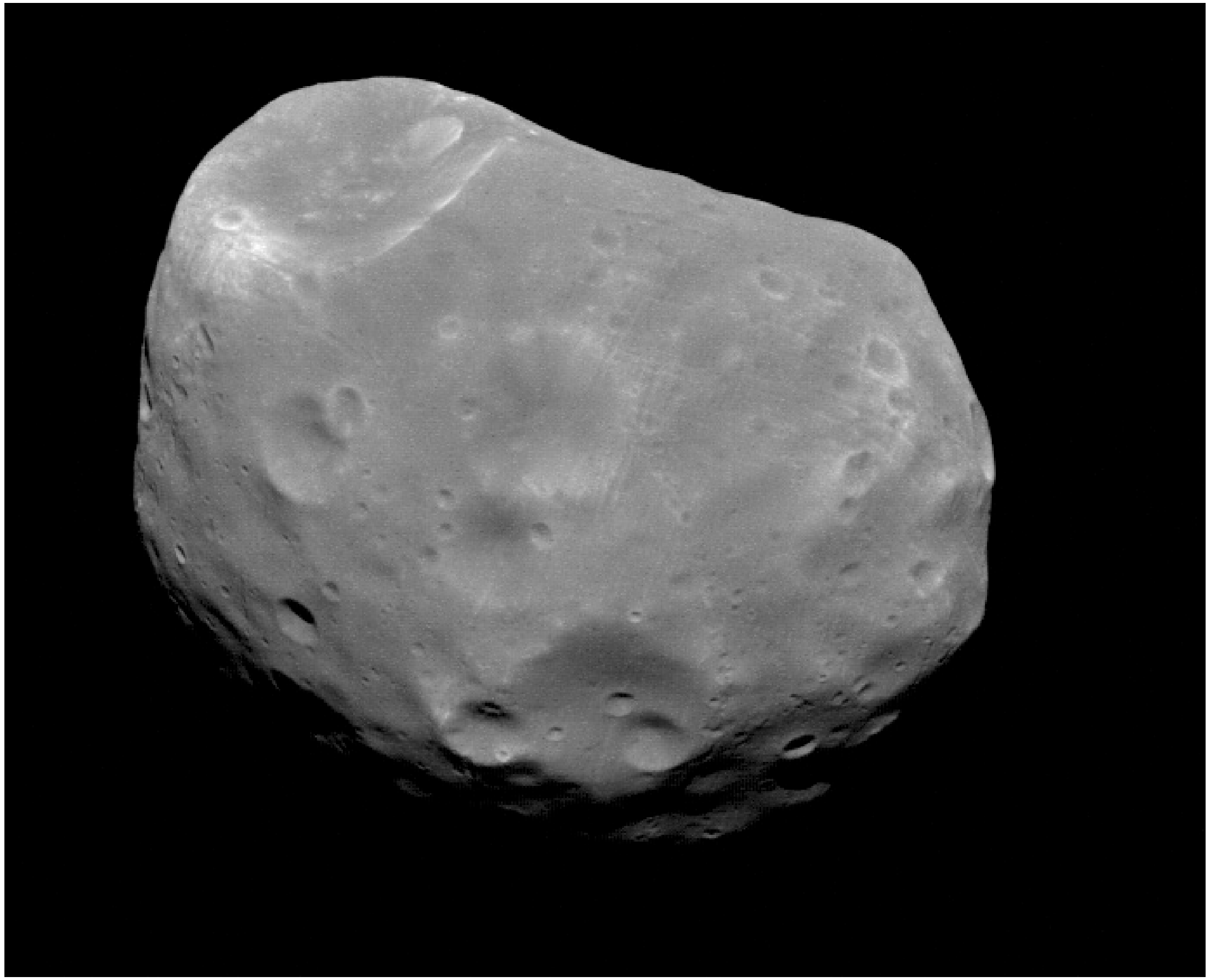
High TRL compact model for small bodies geophysics

1. **Two triade of sensors :**
   - High performance accelerometers (translations)
   - Small fiber optics gyroscopes (rotations)

2. **Development up to flight model :**
   - CubeSat format
   - Space qualification

3. **Science targets :**
   - Interactions between lander and ground for small bodies
   - Local gravity field determination from rebounds and trajectories
   - Rotation dynamics of small bodies (rotation rate, forced librations…)
   - Active seismology

Target Mission - Phobos



Recorded with SRC on Mars Express (credits: DLR)

- Larger one of two Mars moons
- Size: 13.0km x 11.4km x 9.1km

Martian Moon eXploration (MMX)

- Collaboration between JAXA, DLR, CNES
- Surface exploration with a rover
- Sample return

Phobos use case: MMX rover

- 20 kg
- 4 non-directional wheel
- 4 moving legs

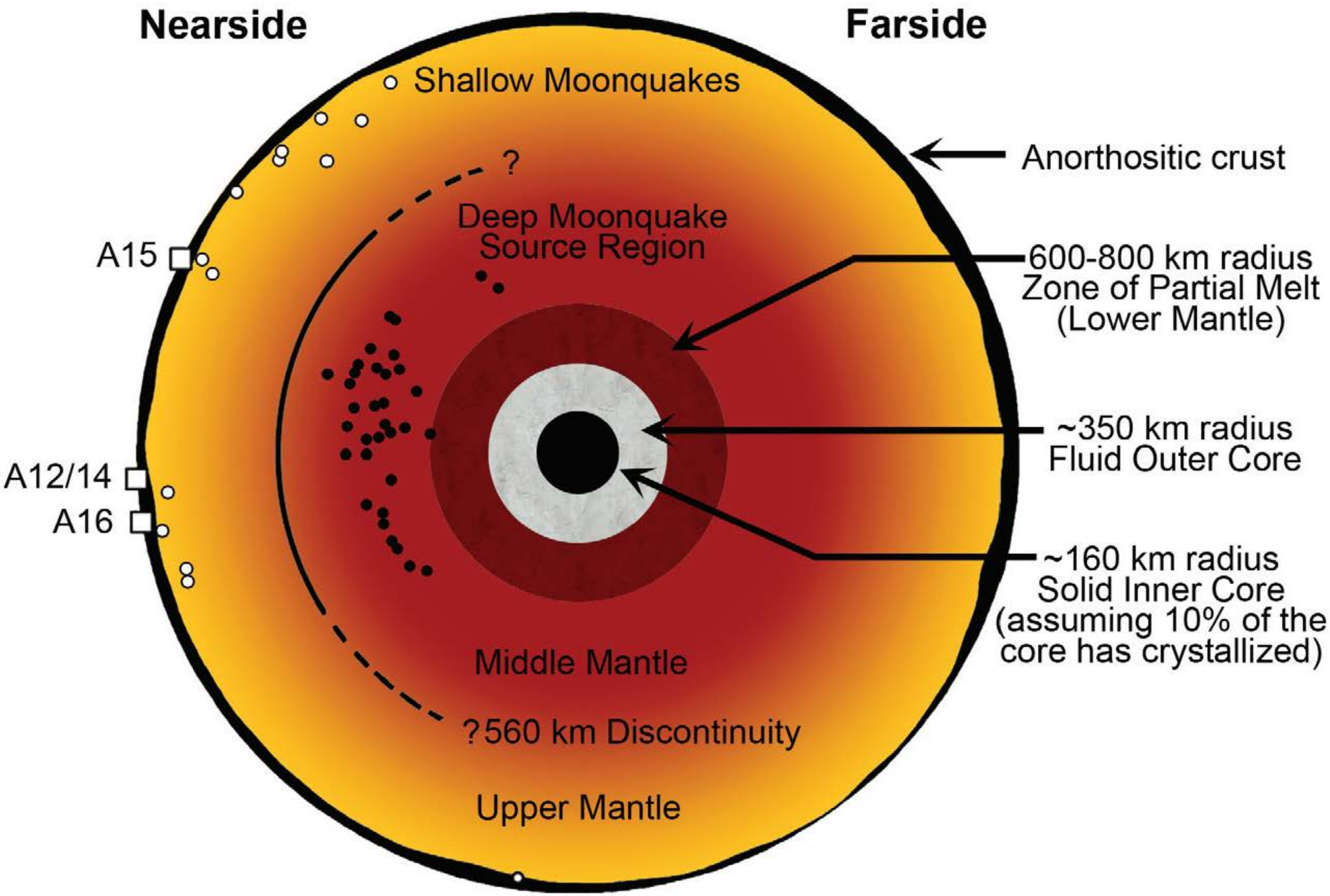
Folded state 22x36x49cm

Operational configuration

PIONEERS compact model will be used to

- Quantify the rebound and locate the rover
- Help the rover to determine the gravity direction
- Science !!

After Apollo many open questions remain



After Wieczorek et al. (2006), Reviews in Mineralogy and Geochemistry

Target Mission - The Earth's Moon

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Strong activity on Lunar Exploration:
- Landing of Chang‘e 4 on the lunar farside in Jan 2019
- Two japanese landers launched early 2020
- Lunar Gateway
- Manned NASA Mission Artemis launched by 2024
- Commercial Lunar Payload Services
- …

With a focus on Geophysics:
- Lunar Geophysical Network including a broadband seismometer, heat flow probe, surface magnetometer/EM sounding and a laser retroreflector (submitted to NASA)
- Autonomous Lunar Geophysical Experiment Package (ALGEP, white paper submitted to ESA)

Conclusions

1. Develop the next generation of planetary ground motion sensors including translations and rotations
2. Rely on european leading teams in this field
3. Target improvement of seismology investigations, but also geodetic studies
4. Target both large planets and small bodies with two different instruments with different performances and different development time scales, but sharing the same electronics for fiber optics gyros.

Outlook:

1. Target missions/objects :
   - Compact model => MMX ?
   - Planetary model => Future Moon seismological sensors ? Planets with atmospheres ?
2. A new type of mission ?
   - Compact model is able to monitor the Asteroid rotations => visit many NEOs, and leave there long lived landers monitoring their rotation (missing parameter for orbit predictions)

Thank You!

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More information at
https://pioneers.oma.be

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MAXIMILIANS-
UNIVERSITÄT
MÜNCHEN

Royal Observatory
of Belgium

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