Lunar Gravitational-wave Antenna

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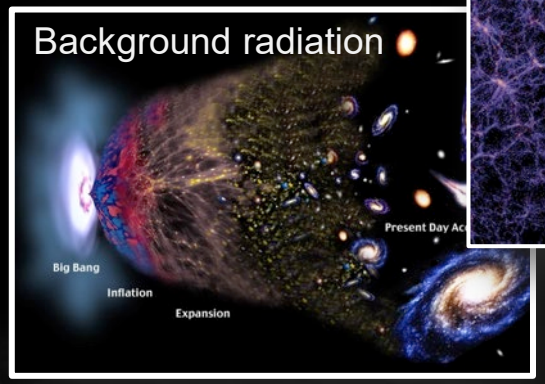
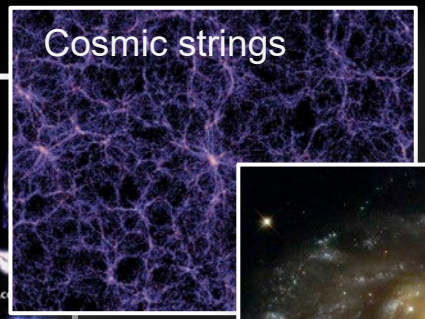
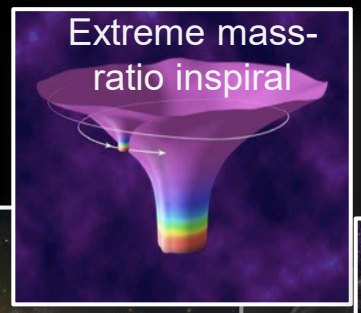
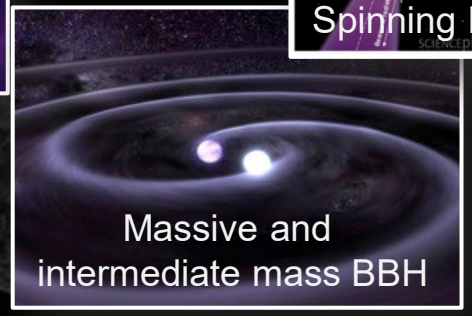
lgwa.unicam.it

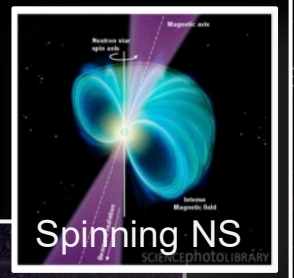
GW Observations

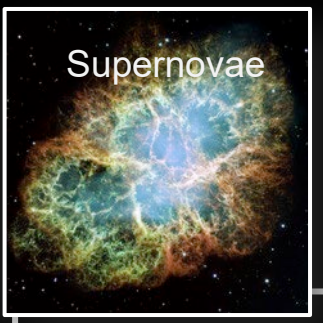


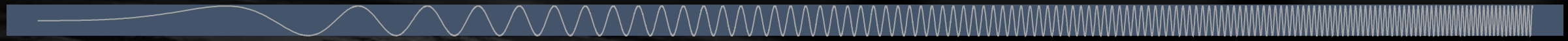






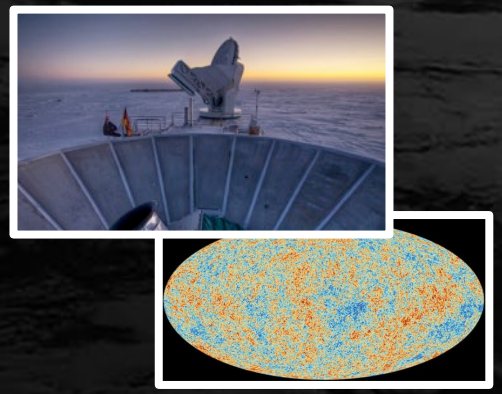




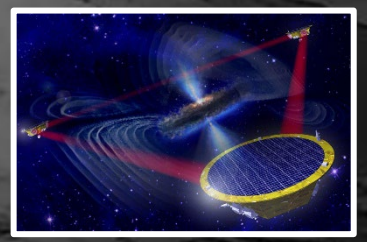


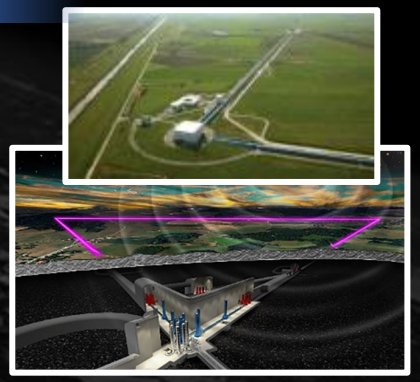
10^{-16} Hz | 10^{-9} Hz | 10^{-4} Hz | 10^{0} Hz | 10^{3} Hz

Microwave background | Pulsar timing | Space detectors | Terrestrial



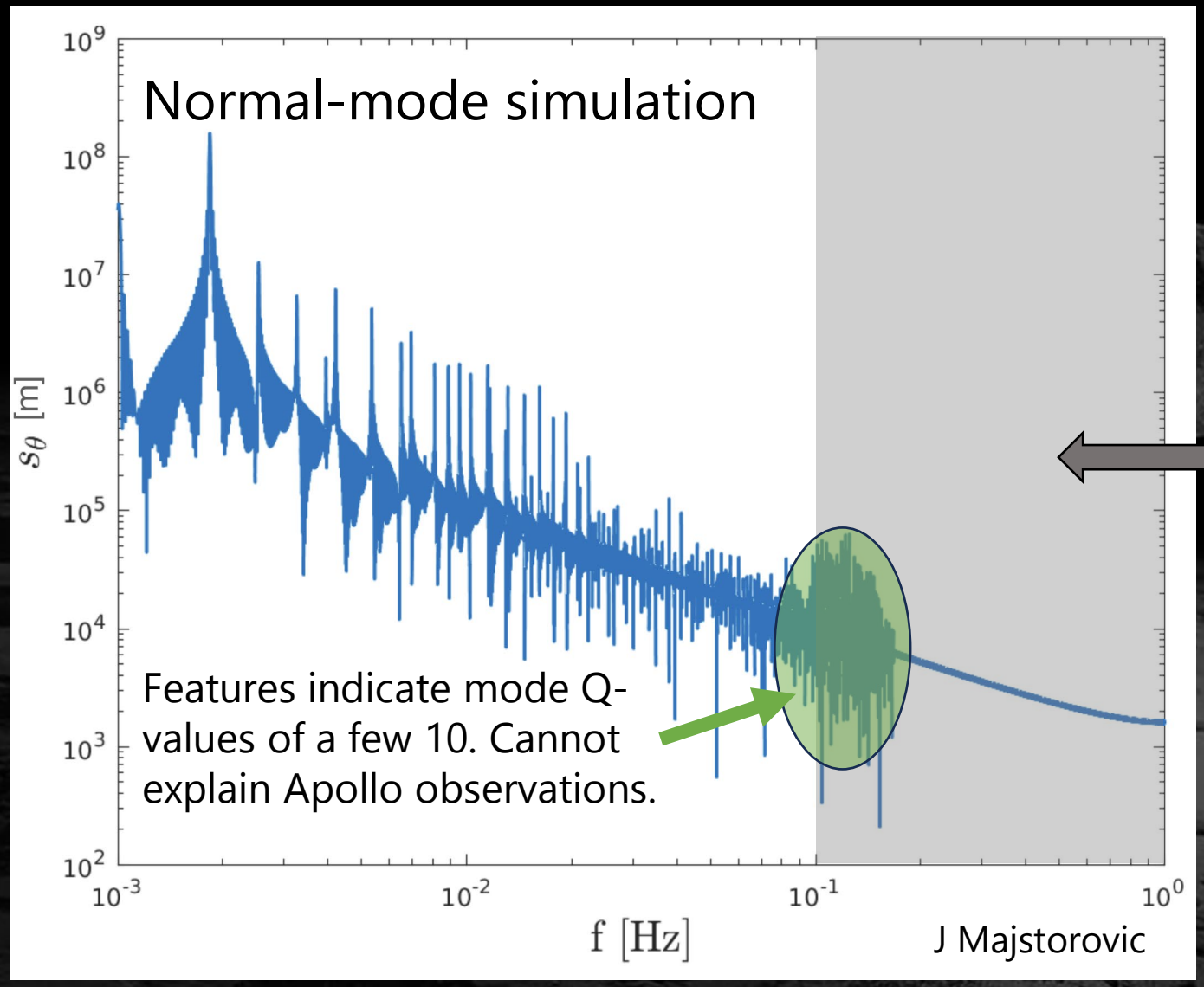
Missing link





Quadrupolar vibration induced by a GW
(here showing spheroidal mode)

GW Response Model

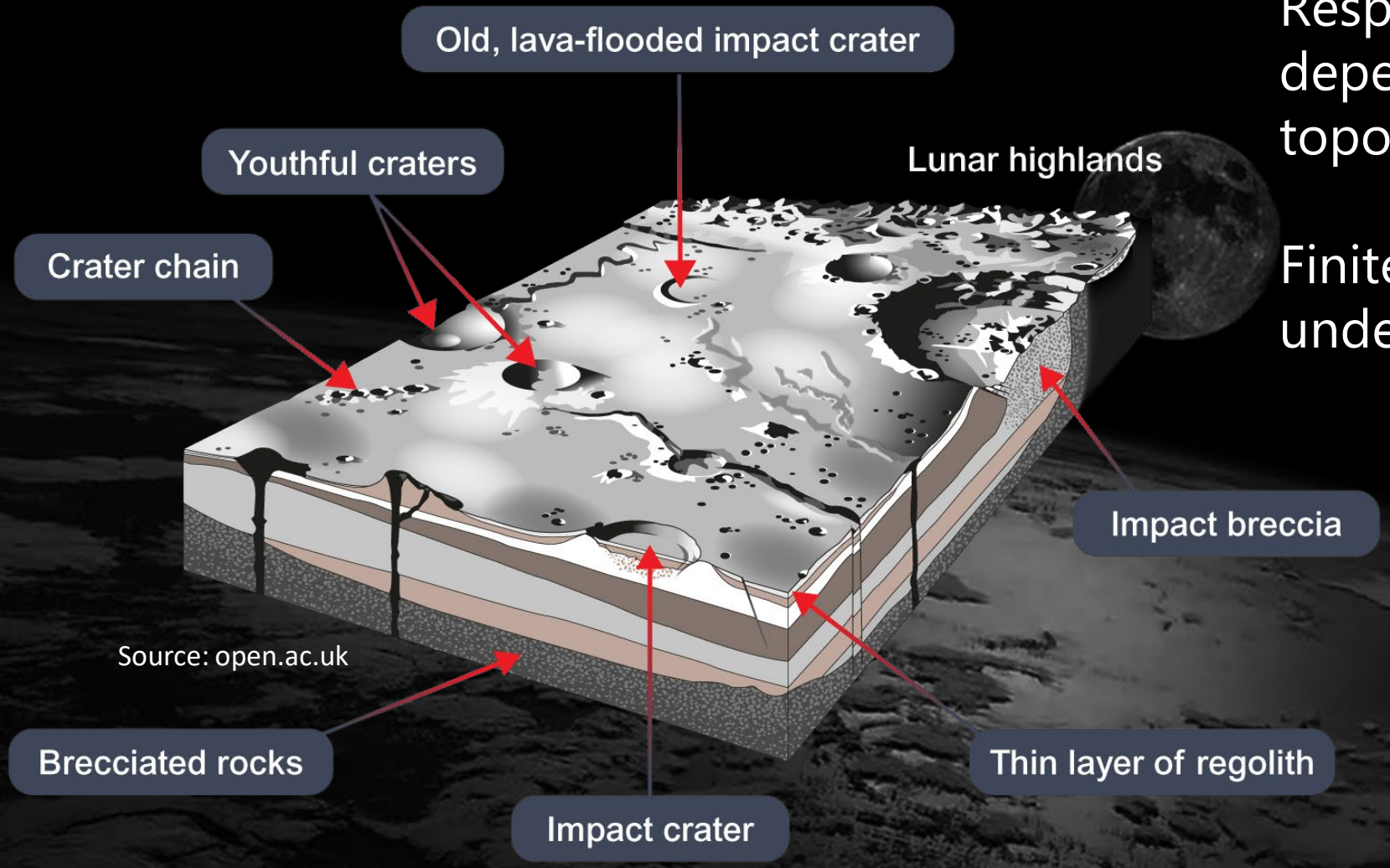


Q-values of ground medium up to a few 1000 inferred from Apollo seismic observations.

However, Q-value of a medium does not necessarily determine response amplification.

We need better models!

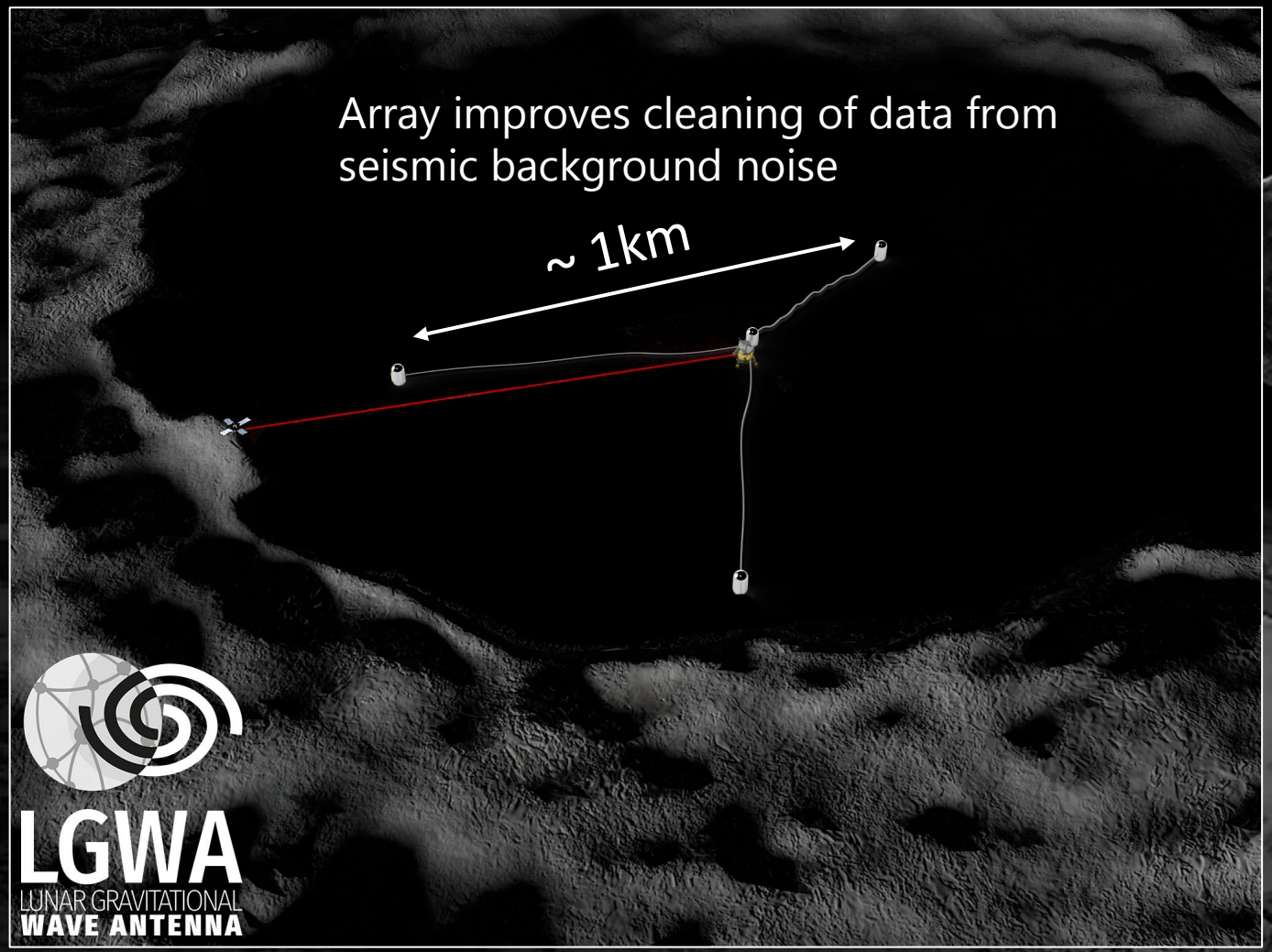
Decihertz Response Modeling



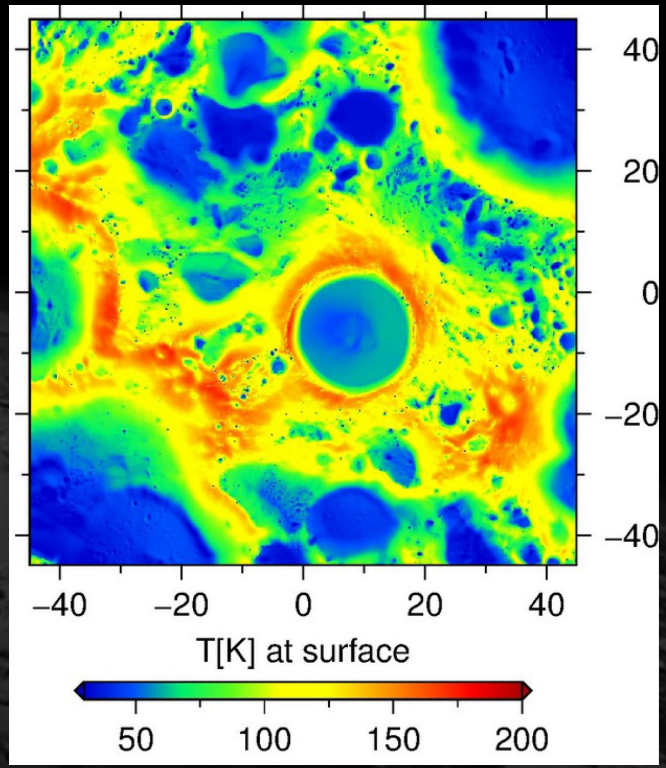
Response in the dHz band depends on geology and topography.

Finite-element simulations under preparation.

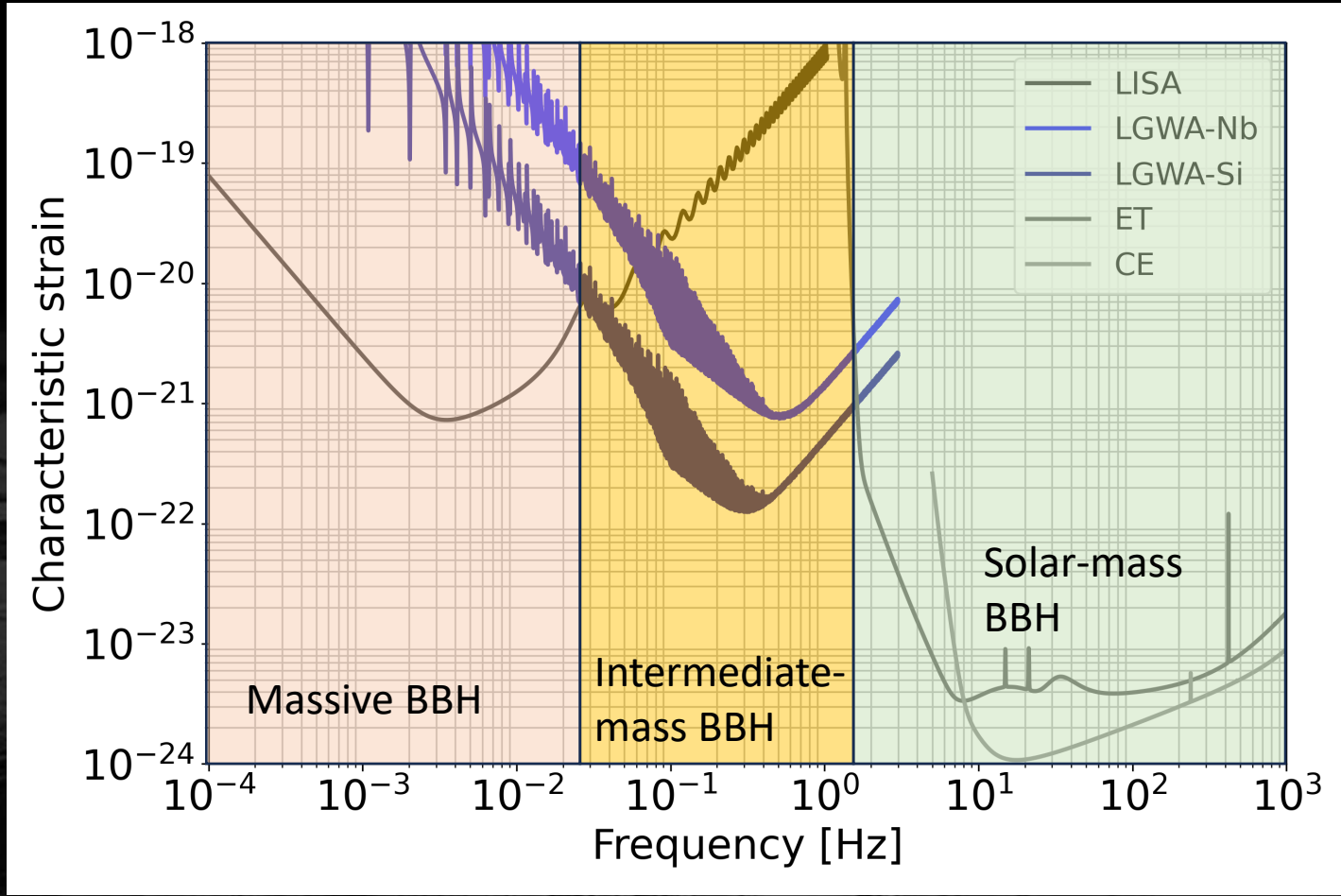
LGWA Concept



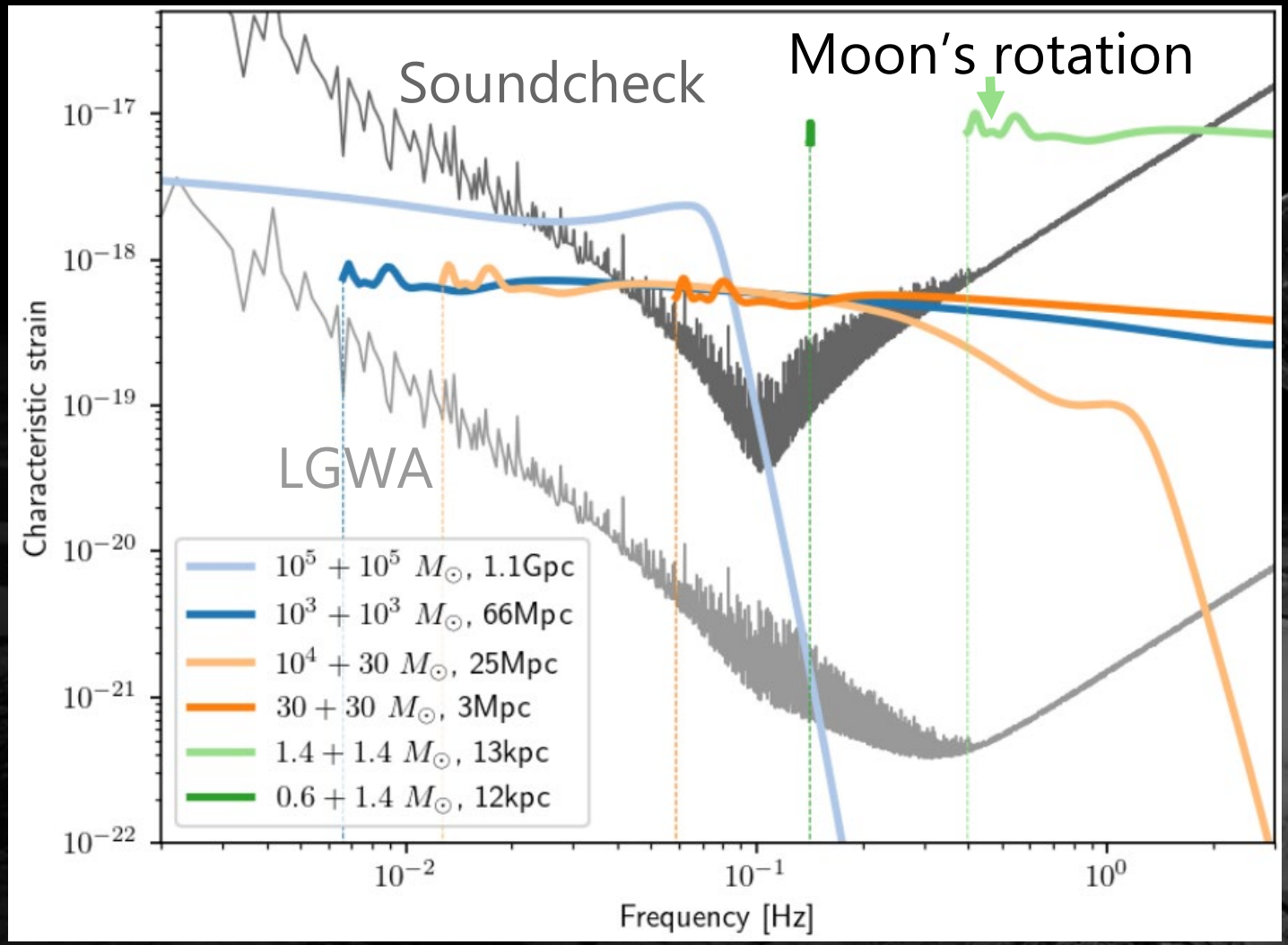
PSR: Extremely cold, stable, and uniform surface temperatures: reduced thermally induced deformations of ground, lander, payload,…



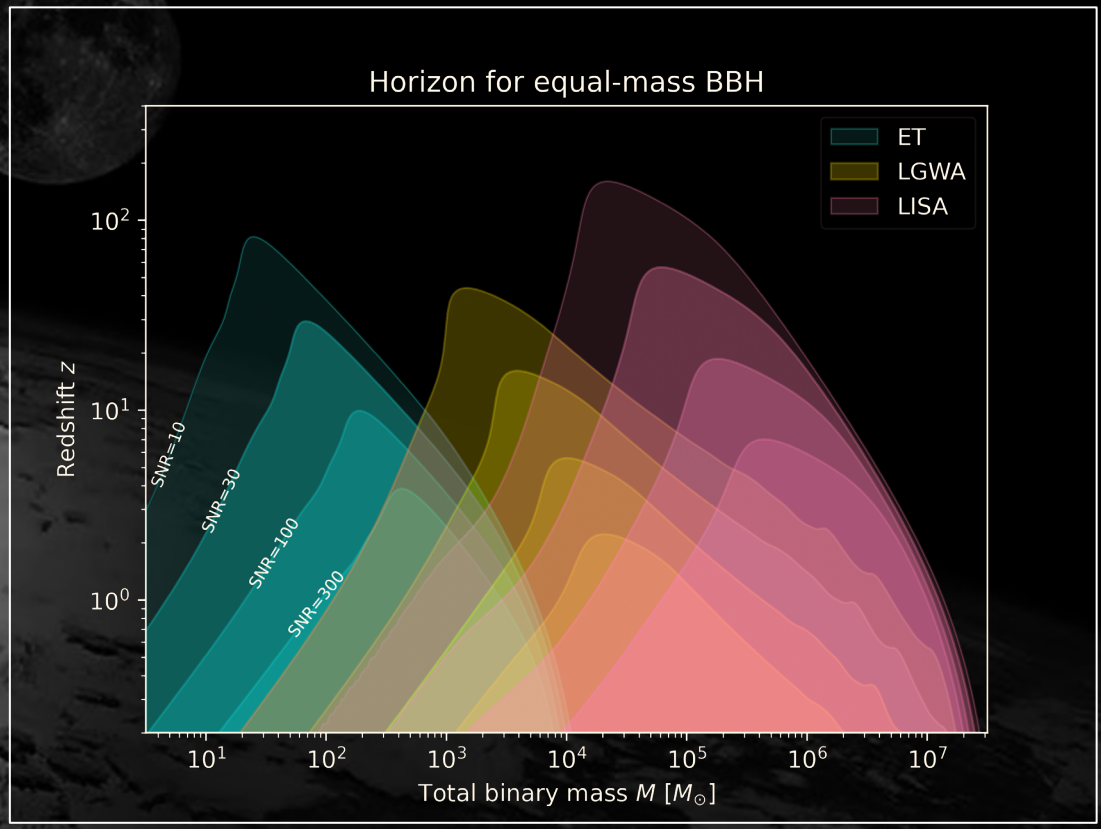
The Missing Link



Sensitivity Targets

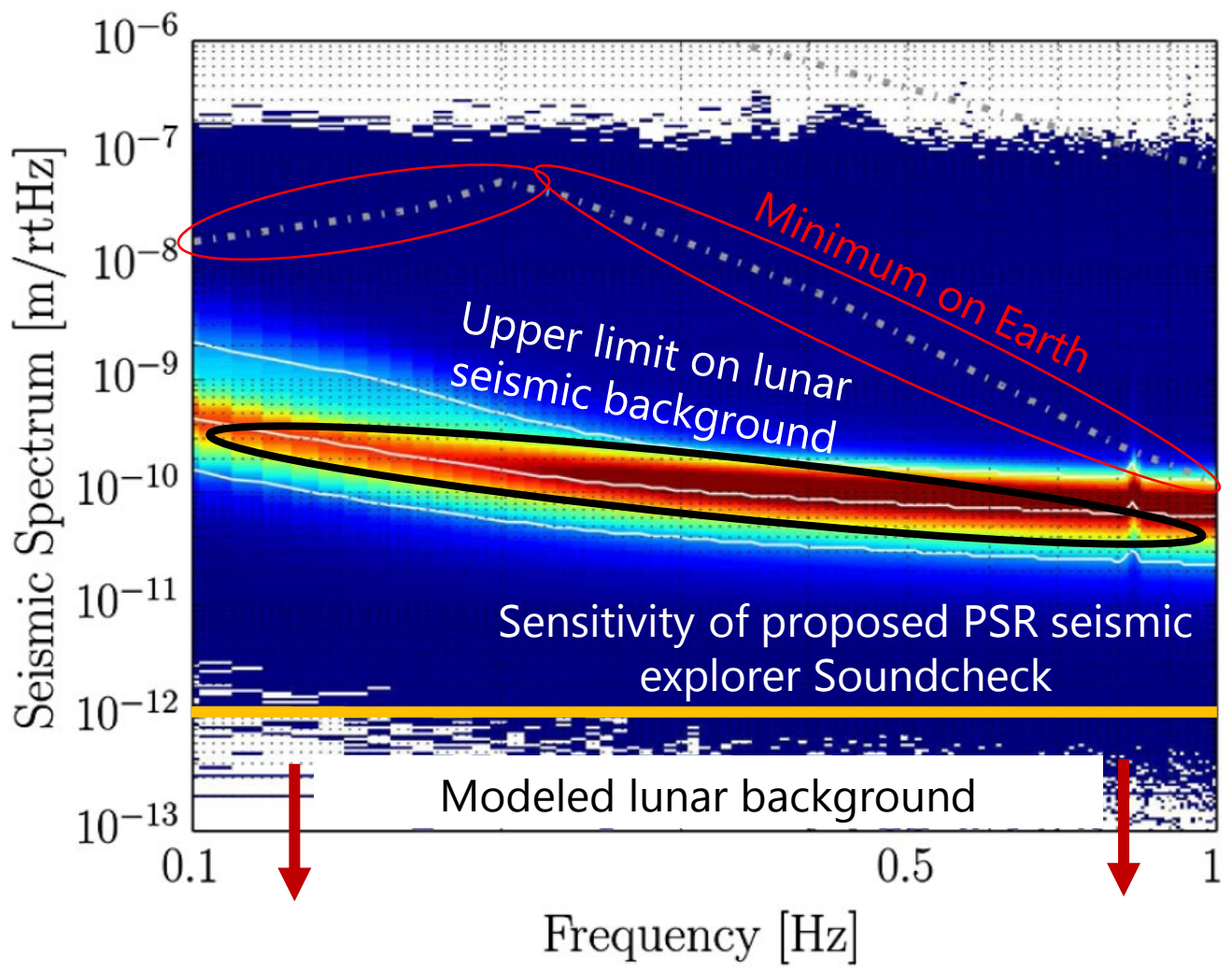


Lunar orbital modulation of GW phase leads to <1deg^2 sky localization.



https://github.com/janosch314/GWFish

Lunar Seismic Background

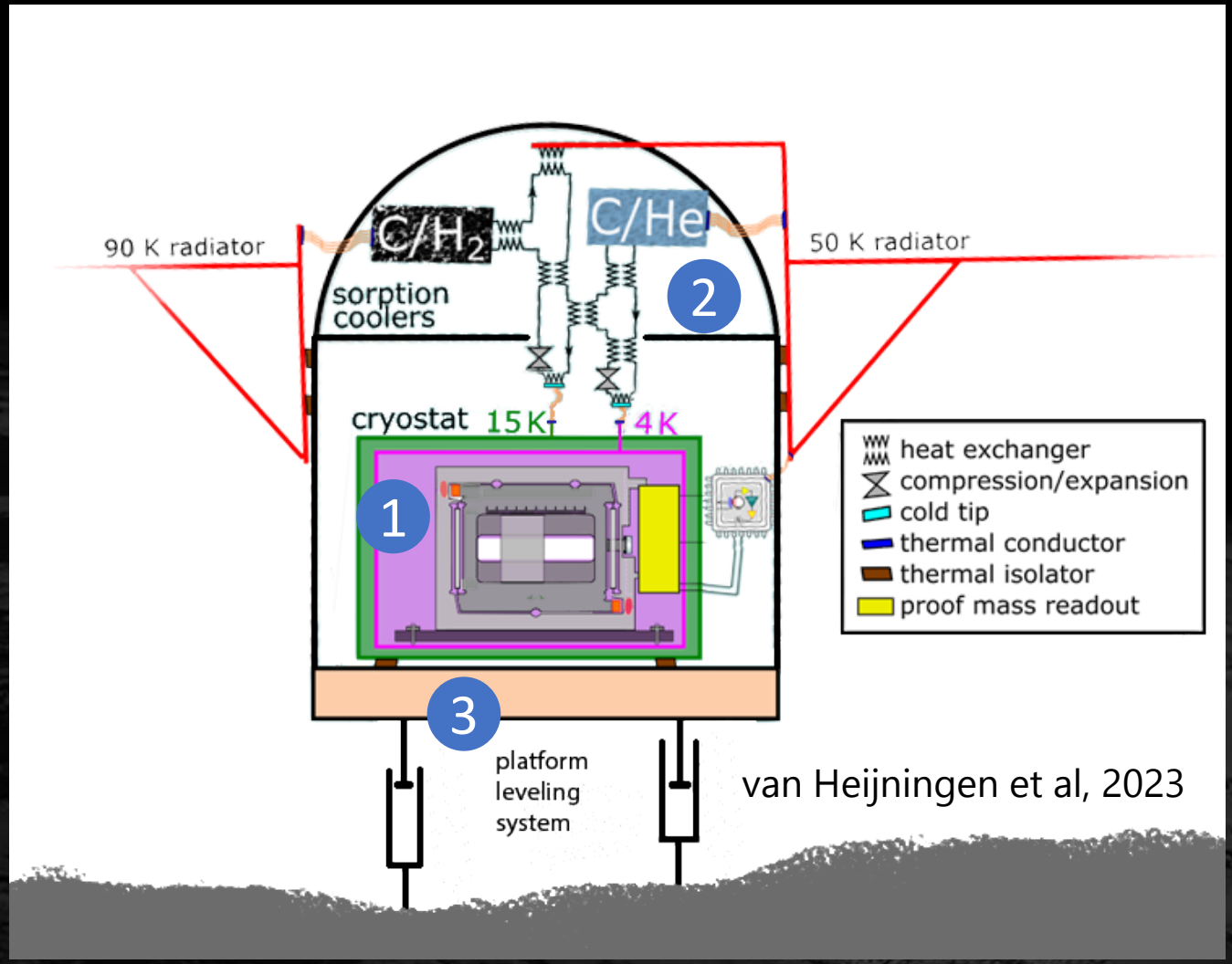


Seismic background from meteoroid impacts, thermally triggered events, deep&shallow moonquakes.

The seismic background is extremely weak, but likely not weak enough to be able to neglect it.

Model-based and data-based (and mixed) background reduction techniques are being used and further developed for terrestrial GW detectors.

The Payload of the Lunar Gravitational-wave Antenna
(J Appl Phys 131, 244501, https://doi.org/10.1063/5.0144687)



1. Inertial sensor

2. Sorption cooling and thermal management

3. Seismometer leveling system

Soundcheck: ESA Selection

- LGWA proposal for LGWA pathfinder mission/payload *Soundcheck* was submitted in September 2022
- ESA selected Soundcheck into the «Reserve Pool of Science Activities for the Moon» waiting for a flight opportunity
- The selection activates the ASI commitment given in their endorsement letter to consider the full or partial support for the activities
- ESA requests the submission of an Activity Requirements Document early November 2023
- The payload team identified technology gaps, and we will request funding from national space agencies to close the gaps

Soundcheck vs LGWA

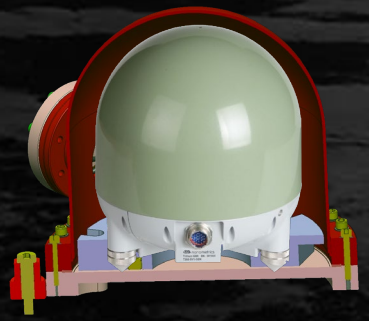
	Soundcheck (PSR geophysical explorer)	**LGWA** (GW observatory)
Number of seismic stations	1 seismic station (two horizontal channels) with sensors on lander	4 seismic stations (each with two horizontal channels) deployed on ground and forming a kilometer-scale array
Displacement sensitivity	<1pm/Hz$^{1/2}$ between 0.1-1Hz	<1pm/Hz$^{1/2}$ at 0.1Hz, <fm/Hz$^{1/2}$ at 1Hz
Deployment site	Inside any PSR (<100K)	Inside PSR with T<40K
Proof-mass material	Niobium	Niobium or silicon
Proof-mass temperature	Ambient PSR temperature (<100K)	Cooled to 4K with low-vibration cryocooler
Readout	Laser interferometric	Laser interferometric or through superconducting coils and SQUIDs

Lunar Emulator

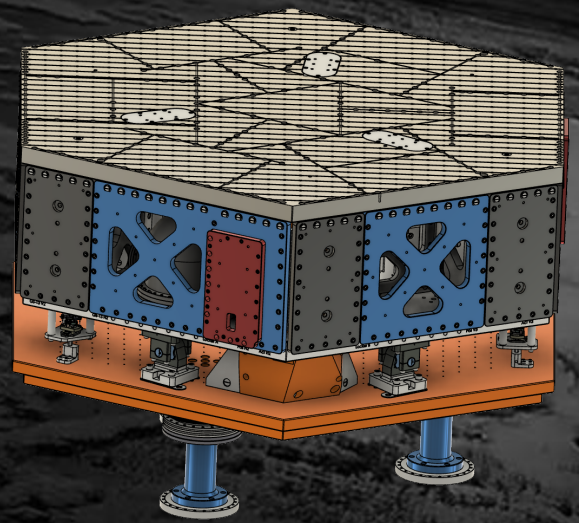
PNRR – ETIC / Vitality-Astra project

For LGWA payload testing, ultra-quiet seismic environment is required: **underground inertial platform**

High-end inertial sensors for platform stabilization



A platform like the Moon (construction starts in 2024)



LGWA Science White Paper

2 The Lunar Gravitational-wave Antenna
2.1 Mission concept
2.2 Sensitivity model
2.2.1 Payload descriptions
2.2.2 Main noise contributions
2.2.3 Reduction of the seismic background
2.2.4 Lunar response to GWs
2.2.5 Sensitivity models of LGWA and Soundcheck

2.3 Observational capabilities
2.3.1 Detection horizons
2.3.2 Detection rates
2.3.3 Sky localization
2.3.4 Merger-time predictions
2.3.5 Multiband GW observations

2.4 Science of the Moon and the deployment site
2.4.1 Topography
2.4.2 Geological model
2.4.3 Solar illumination and surface temperature
2.4.4 Regolith composition
2.4.5 Ground tilt response
2.4.6 Seismic background
2.4.7 Magnetic fluctuations on the lunar surface

2.5 Lunar missions and data relevant to LGWA
2.6 Science requirements
2.6.1 Gravitational-wave science
2.6.2 Lunar science

3 Science Objectives

3.1 Lunar science
3.1.1 Seismic sources
3.1.2 Lunar internal structure
3.1.3 Moon's formation history
3.1.4 Geologic processes

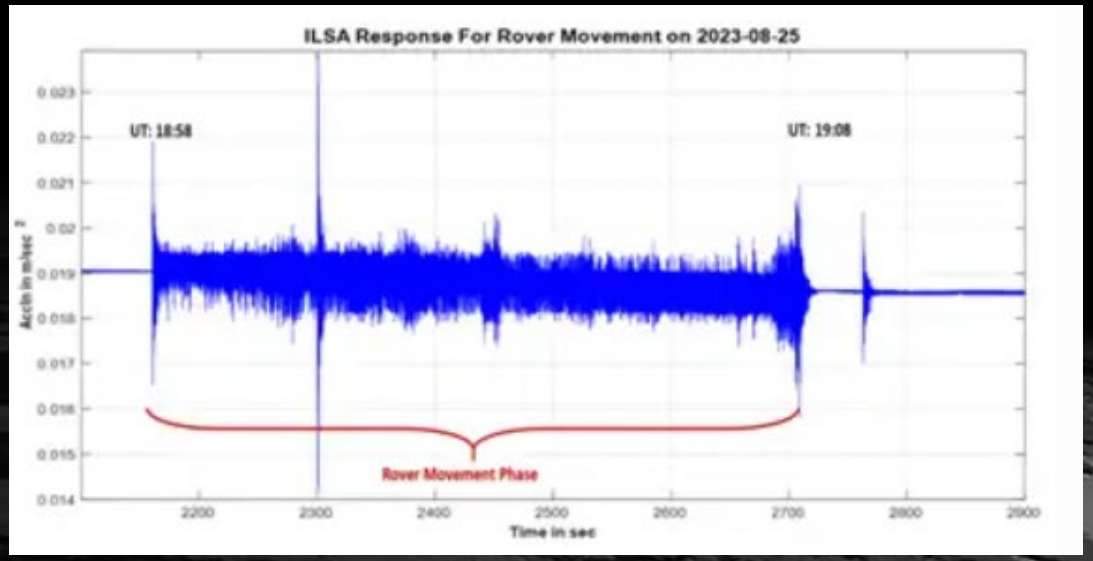
3.2 Gravitational-wave science.
3.2.1 Populations and formation channels of GW sources.
3.2.2 GW astrophysics
3.2.3 GW cosmology
3.2.4 Fundamental physics with GWs
3.3 Multi-messenger Observations
3.3.1 Compact Binaries with Neutron Stars and White Dwarfs
3.3.2 Tidal Disruption Events
3.3.3 Intermediate and Massive Black Hole Binaries
3.3.4 Extreme/intermediate Mass-ratio inspirals
3.3.5 Supernovae

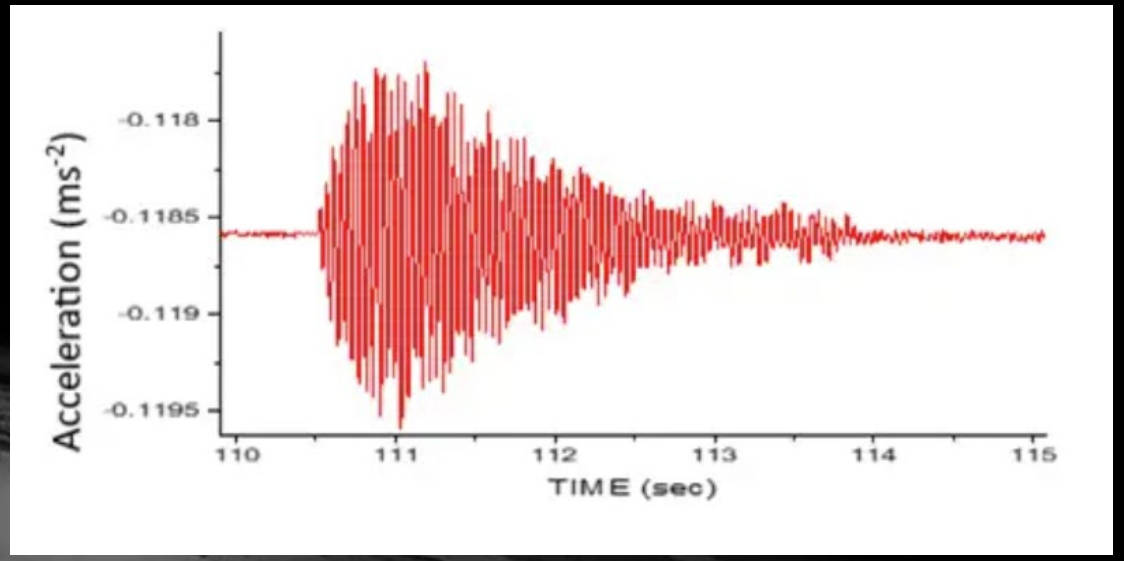
3.4 Synergies with Other Missions and Terrestrial Observatories
3.5 Other Science

- Goal: First complete and internally reviewed draft by the end of 2023
- Content: Research to prepare for LGWA, science with LGWA data, relations/synergies with other observatories and lunar missions

Chandrayaan-3!

Mission is a great success.
ILSA observed ground acceleration.





Chandrayaan-3 is a complex mission. Deployment location is the lunar south-pole region. The total mission cost is <70M€.

The LGWA Collaboration

- Now 186 members from 18 countries (Italy, India, USA, Germany, Switzerland,...)
- Three working groups: «GW science and multi-messenger astronomy», «Lunar science and deployment site», «Payload»
- Important contributions from early-career scientists
- Recent and future meetings:
  - ISSI Forum in Bern, October 5-6, 2022
  - LGWA white-paper kick-off meeting at GSSI, February 9-10, 2023
  - Workshop on Lunar GW detection at ICTS, April 17-20, 2023
  - LGWA meeting in Catania, October 9-13, 2023 (www.ct.ingv.it/lgwa2023)