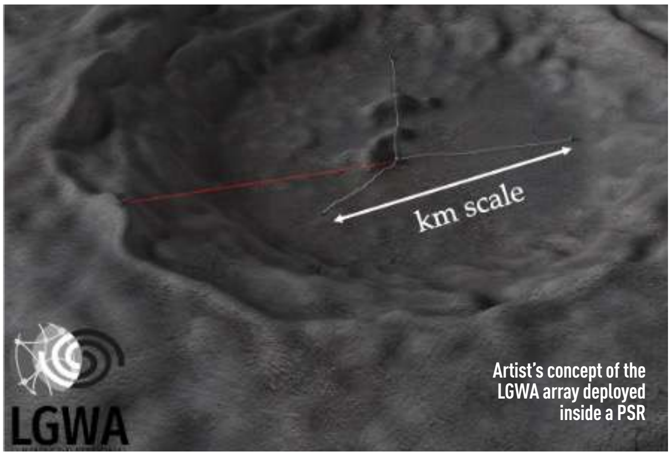
LUNAR GRAVITATIONAL-WAVE ANTENNA

LGWA is a detector aimed at catching the tiny ripples in the spacetime generated by massive accelerating objects in accordance with Einstein's General Relativity. It will be deployed in one of the PSRs (Permanently Shadowed Regions) of the Moon where temperature is stable at ~40K and ambient noise is several orders of magnitude smaller than on Earth.

GRAVITATIONAL WAVES AT A GLANCE

Gravitational waves are 'ripples' in space-time caused by some of the most violent and energetic processes in the Universe. Massive accelerating objects (such as neutron stars or black holes orbiting each other) disrupt space-time generating 'waves' of undulating space-time that propagate away from the source. These cosmic ripples travel at the speed of light, carrying with them information about their origin, and about the nature of gravity itself. The Moon can be used as a large resonant bar to detect GWs. Its environment offers a range of key advantages, such as low noise and low seismicity. Permanent Shadow Regions (PSRs) inside craters offer a cold and stable environment with no day-night and seasonal temperature fluctuations, natural cooling for cryogenic technology and low cooling-induced noise and power consumption.

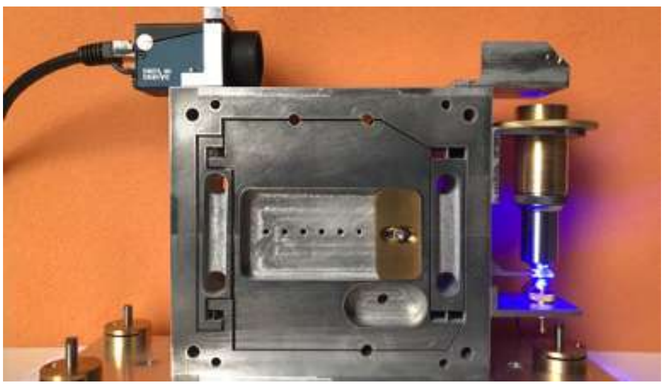


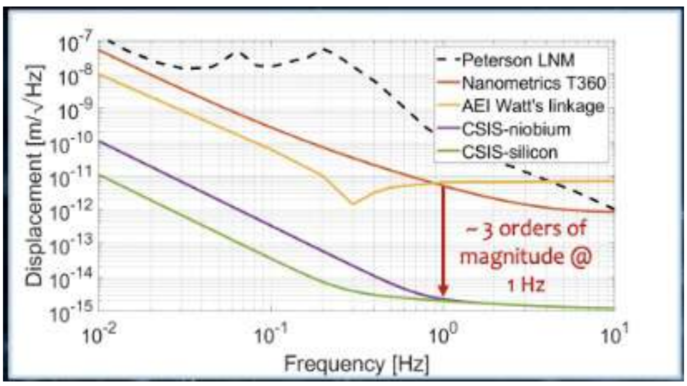
Artist's concept of the LGWA array deployed inside a PSR

LGWA CONCEPTS AND IMPLEMENTATION

In an homogeneous Moon, GWs excite the spheroidal quadrupole modes. The effective baseline is connected to the shear-wave length and it depends on the normal modes amplitude. Assuming a strain amplitude of 10-21 m for loud galactic double white dwarfs, this gives a displacement of ~ 10-13 m on the Moon surface. A network of 4+ seismic stations deployed in one of the permanent shadow regions (PSRs) at the lunar south pole, equipped with a next generation seismometer in a cryogenic environment (currently under development), can reach from sub-picometer to femtometer sensitivity. A key aspect is the discrimination between correlated GW signals and uncorrelated noise of Moon-related signals.

The LGWA science case will also focus on improving knowledge of the interior of the Moon since the network will detect moonquakes and meteoritic impacts. Key aspects will be the Moon's core nature and structure and the rate and distribution of moonquakes in the far side. Given the sensitivity of the seismometers, the first noise model of the Moon is aspect to be one further deliverable. Thermal stability and tides will be also observed. The LGWA science case will also focus on improving knowledge of the interior of the Moon since the network will detect moonquakes and meteoritic impacts. Key aspects will be the Moon's core nature and structure and the rate and distribution of moonquakes in the far side. Given the sensitivity of the seismometers, the first noise model of the Moon is aspect to be one further deliverable. Thermal stability and tides will be also observed.





graphic design Laboratorio Grafica e Immagini | INGV

Lunar Gravitational-Wave antenna

Currently ongoing activities within the LGWA collaboration

The soundcheck project, which aims at sending a preliminary version of the seismometer on the Moon to test the instrument, to measure the background noise and to better constrain the GW detection capabilities. LGWA soundcheck will be based on a single instrument instead of an array, and it will be hosted onboard a lunar lander instead of being deployed to the Moon surface. LGWA soundcheck has been selected within the ESA AO-2022-Reserve Pool of Science Activities for the Moon and the technical requirements of the payload are currently being defined.

	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

Numerical models based on state-of-the-art computational seismology codes are under development with the aim of reproducing and characterizing the background noise in the PSRs. Further research activities are aimed at modeling the thermal and mechanical perturbation caused by the lander itself and by the other operation equipment.

A next generation seismometer is under construction and test. The instrument design is based on Niobium Watt's linkage with laser-interferometric readout at cryogenic temperatures and will be tested in Liège at the end of 2023 as part of the E-TEST project.

All the space-related INGV flyers are here!

STATUS OF THE LGWA COLLABORATION

The collaboration currently includes more than 180 people from 18 countries including Italy, India, Germany, Switzerland, and the USA. About 30 students and postdoc are dedicating time to LGWA.

The first annual LGWA was recently held in Catania, October 9-13, 2023 (www.ct.ingv.it/lgwa2023)

LGWA is represented in the ESA Geophysics Topical Team and in the ESA Astronomical Lunar Observatory Topical Team, strong collaboration with India and China.