The Lunar GW Antenna

Opening the decihertz band to GW detection

Jan Harms
Gran Sasso Science Institute
INFN National Labs of Gran Sasso

https://iopscience.iop.org/article/10.3847/1538-4357/abe5a7

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

Order of quadrupole mode determines number of nodes along radial direction

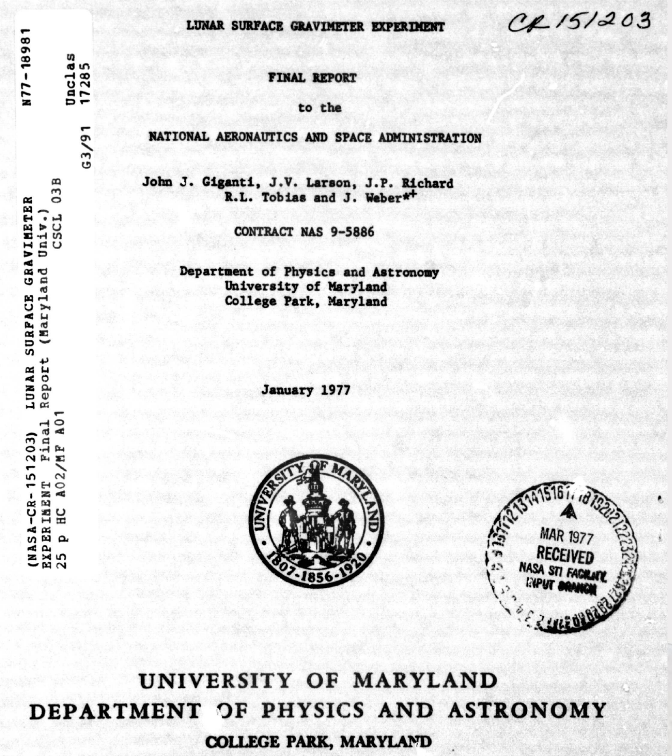
Lower-order modes have larger GW cross section

Horizontal displacement produced by both, spheroidal and toroidal modes

Damping and lateral heterogeneities can significantly alter GW response

Apollo 17: Lunar Surface Gravimeter

NASA, Apollo 17 (1972)



(NASA-CR-151203) LUNAR SURFACE GRAVIMETER EXPERIMENT Final Report (Maryland Univ.) 25 p HC A02/MF A01 CSCL 03B N77-18981 Unclas G3/91 17285

LUNAR SURFACE GRAVIMETER EXPERIMENT CR 151203

FINAL REPORT

to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

John J. Giganti, J.V. Larson, J.P. Richard
R.L. Tobias and J. Weber

CONTRACT NAS 9-5886

Department of Physics and Astronomy
University of Maryland
College Park, Maryland

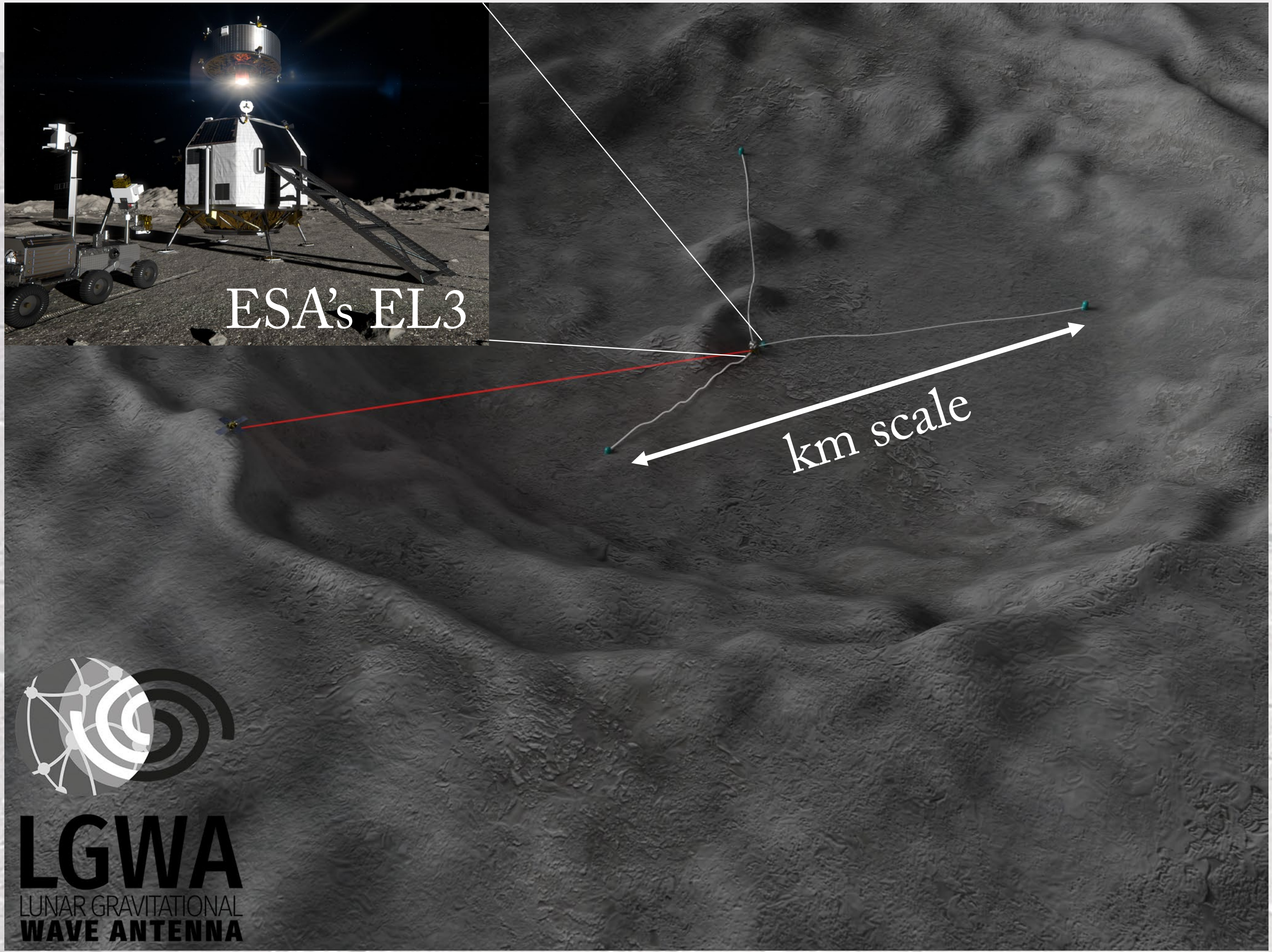
January 1977

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

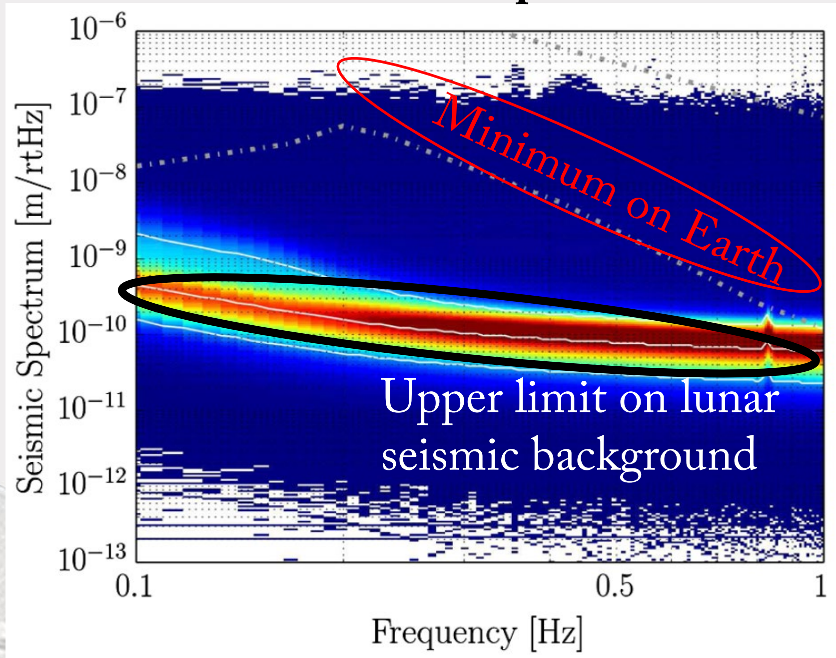
The LSG would have set the most stringent limits on the energy of a GW background at that time, but it had greatly reduced sensitivity to due a design flaw.

It was then determined that an error in arithmetic made by La Coste and Romberg, and known to the firm's highest officials, had not been corrected by La Coste and Romberg. This led to an instrument which had excellent performance in earth g and was just barely outside of the tolerances for variations of lunar site g. This error resulted in the

LGWA Concept

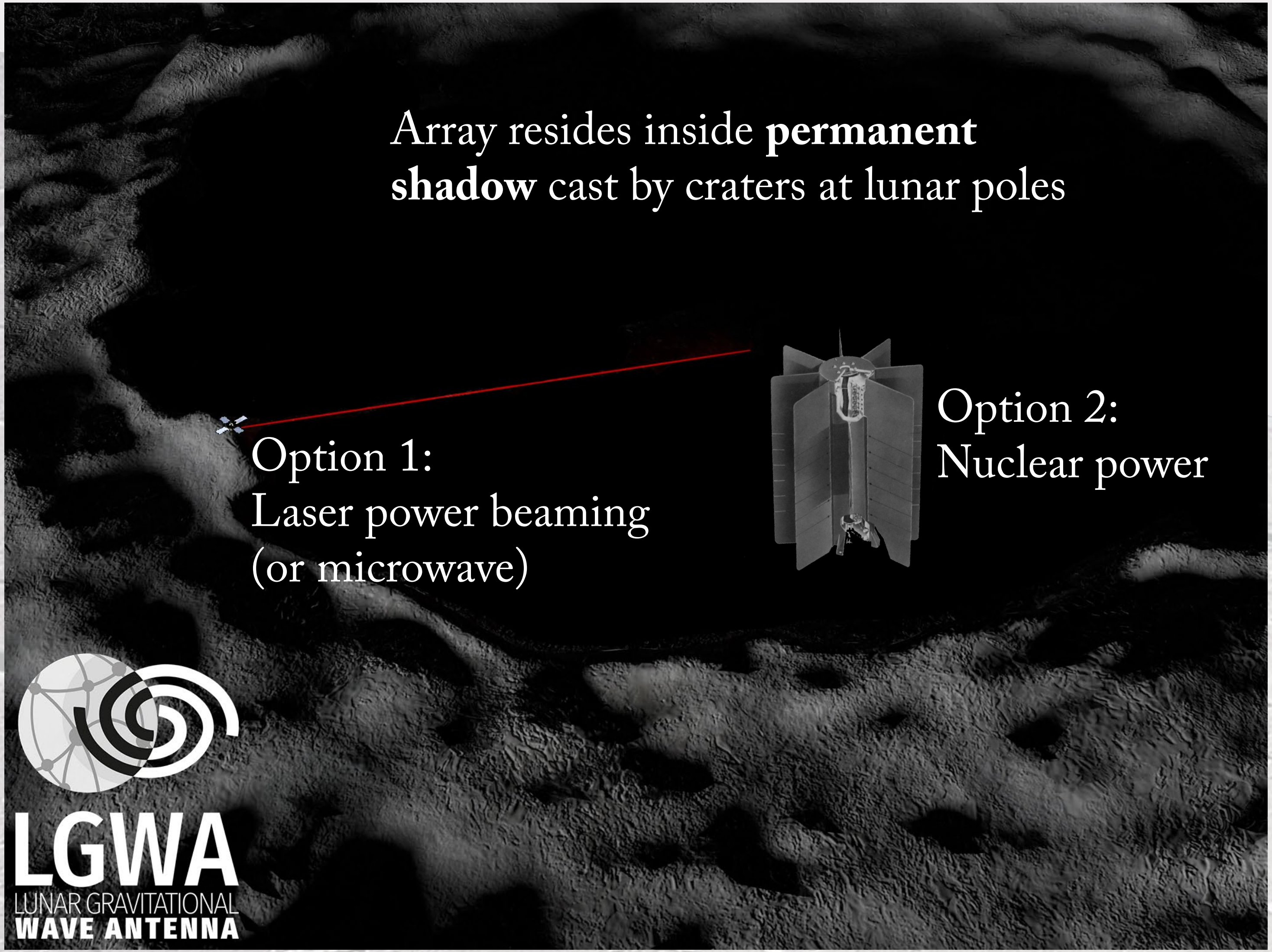


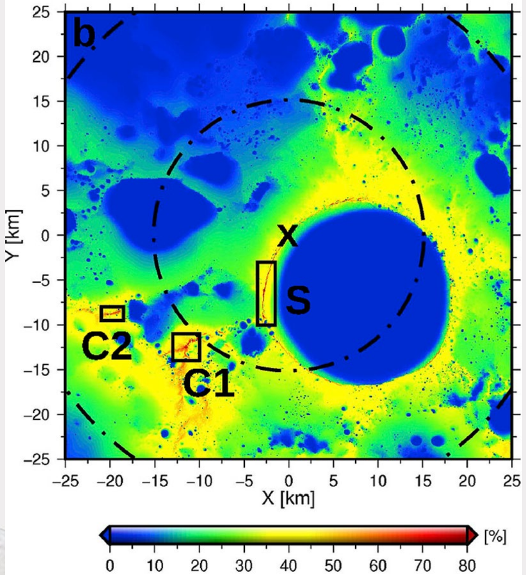
Lunar seismic spectra



- Extremely weak seismic background
- Data stretches with moonquakes, meteoroid impacts etc can be ignored or cleaned using coherent noise cancellation

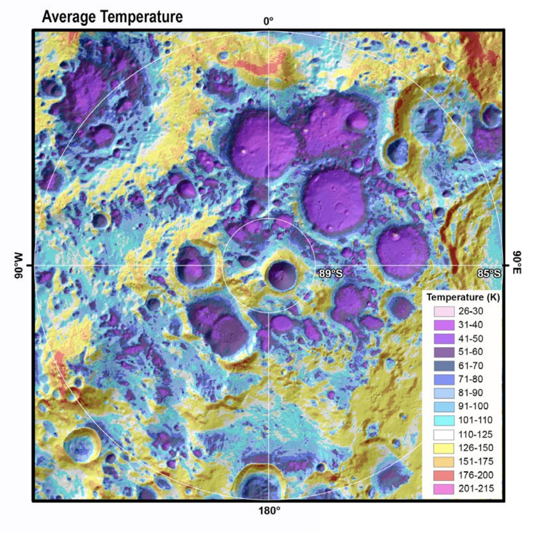
Powering





Gläser et al, 2018

Sunshine illumination near south pole



Temperature <40K in some permanent shadows of the lunar north and south poles.

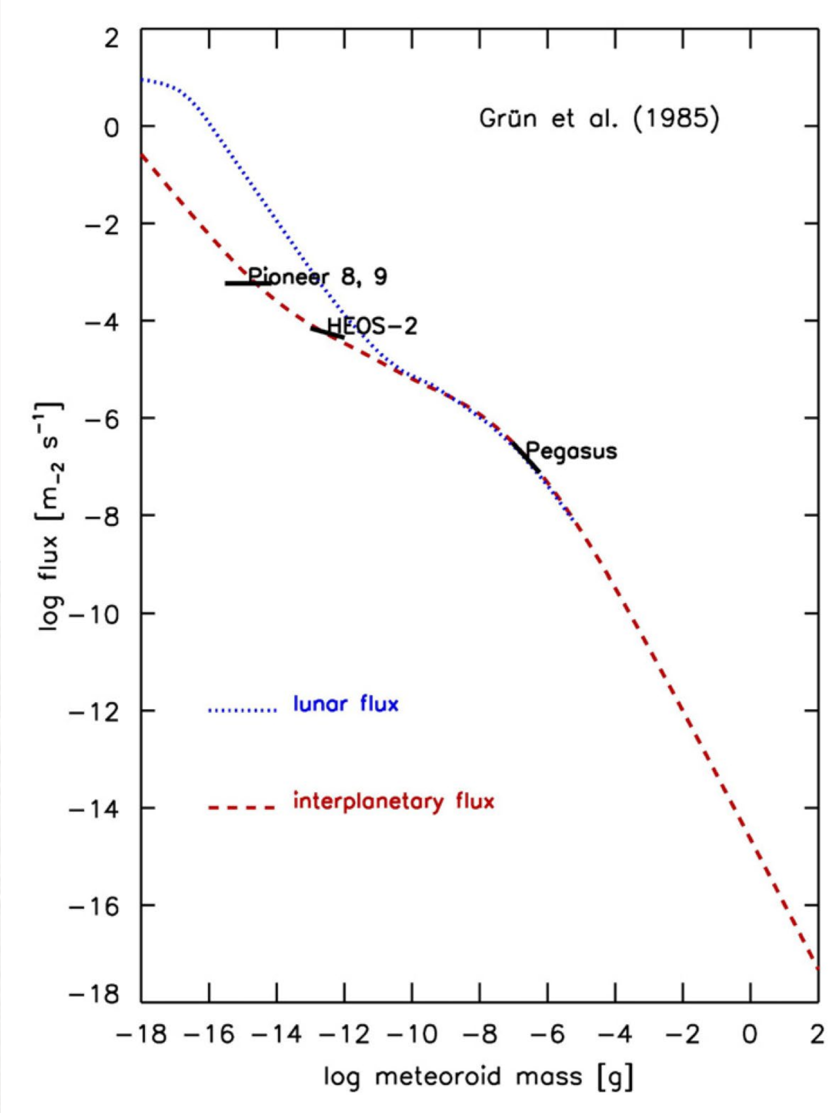
Seismic Background

Seismic background

- Predicted to be formed by meteoroid impacts
- Background estimation requires meteoroid mass and velocity distributions, and accurate Moon response model
- Might be relevant >0.1Hz (Lognonné et al., 2009)

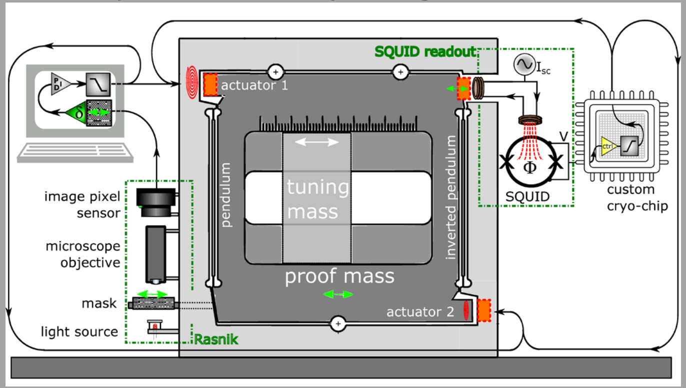
Noise-cancellation techniques

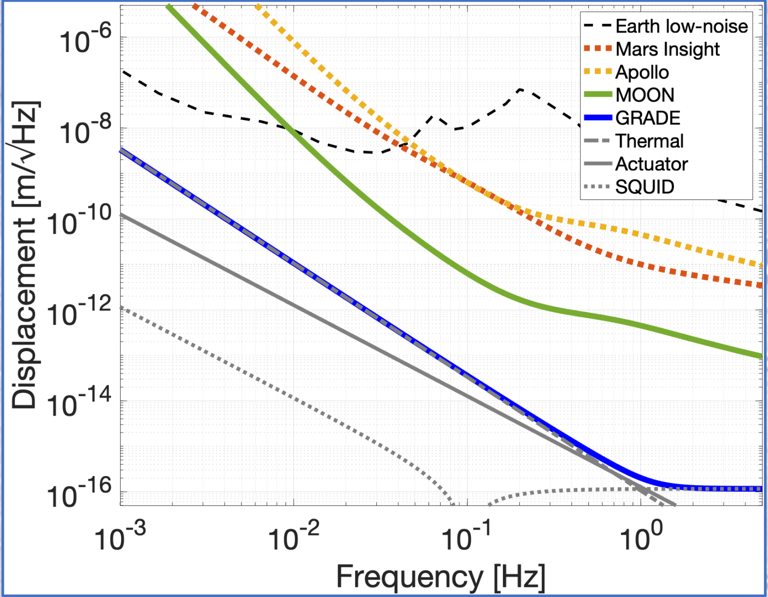
- Limited by number of seismometers on the Moon
- Several orders of magnitude reduction possible, but with only 4 sensors, the reduction will greatly depend on properties of the seismic field



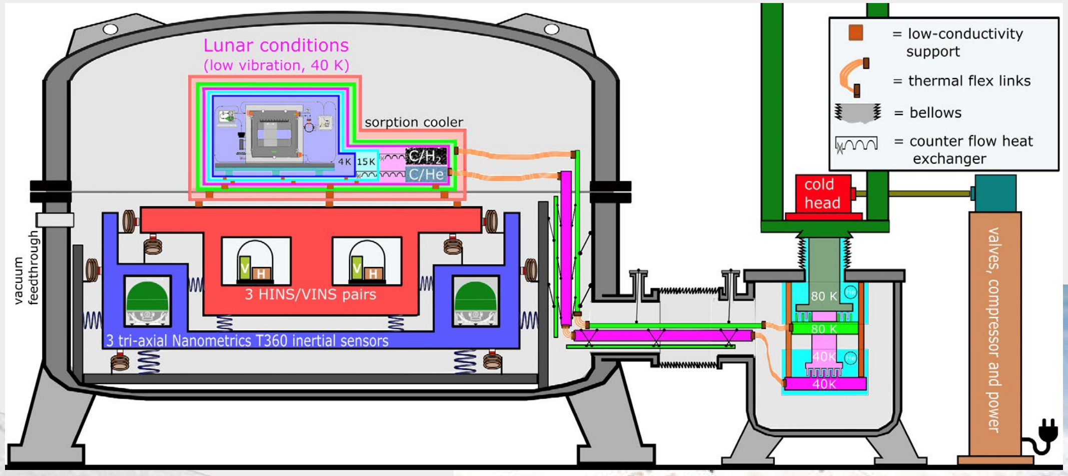
LGWA Payload

LGWA inertial sensor (talk by J van Heijningen tomorrow)



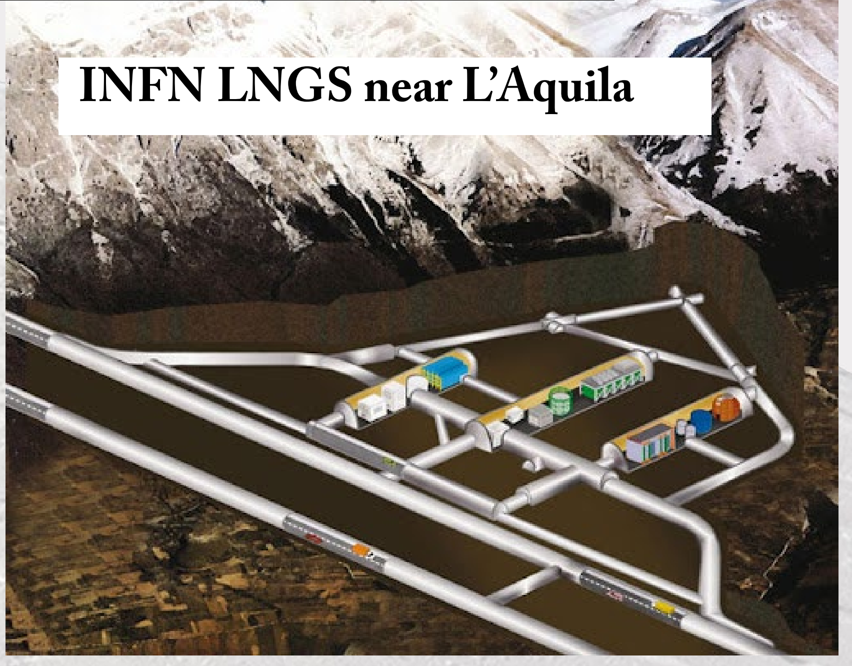


Underground seismic isolation platform



There is no natural environment on Earth where LGWA seismometers can be operated.

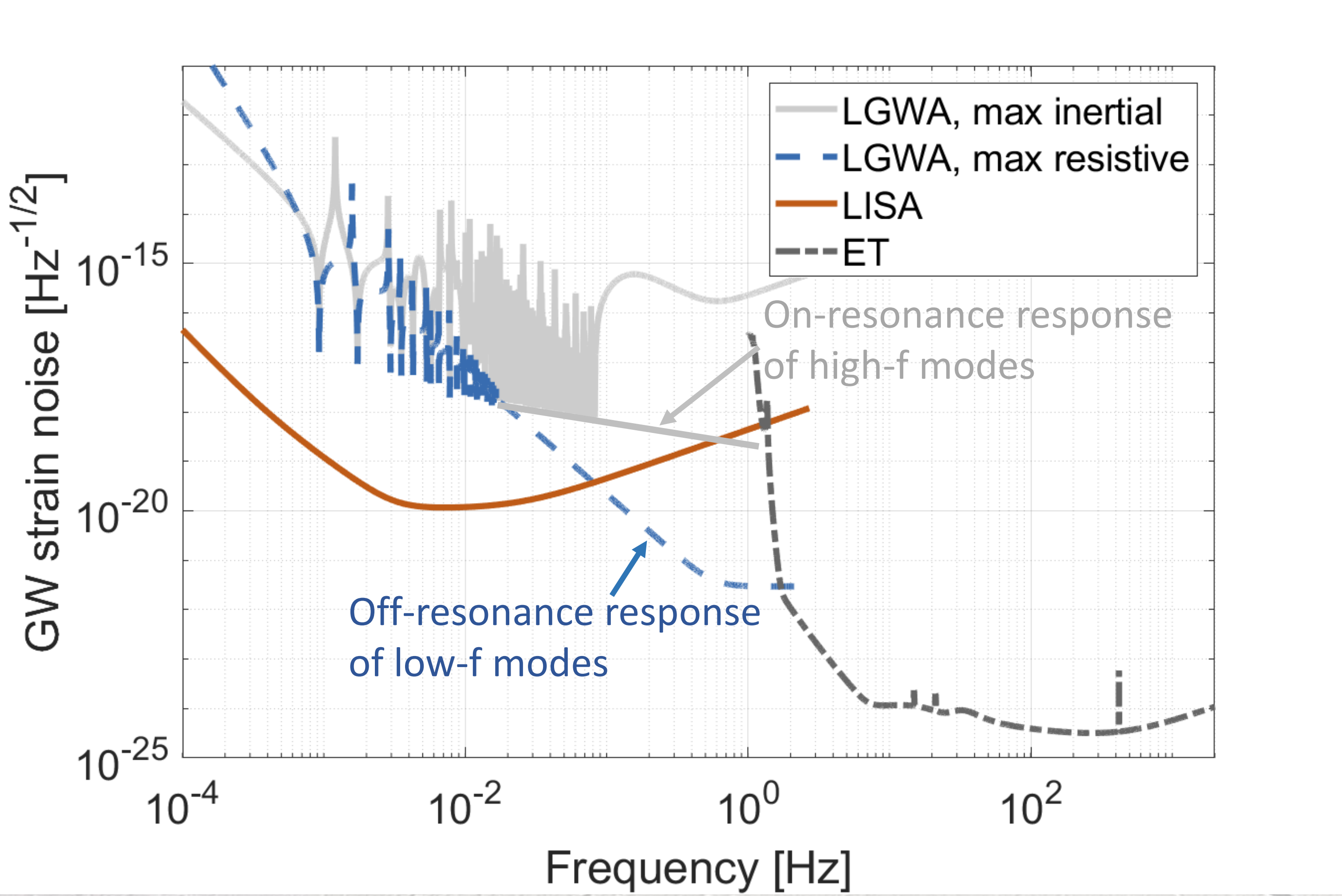
Emulator of lunar seismic and thermal environment will be realized underground at LNGS.



INFN LNGS near L'Aquila

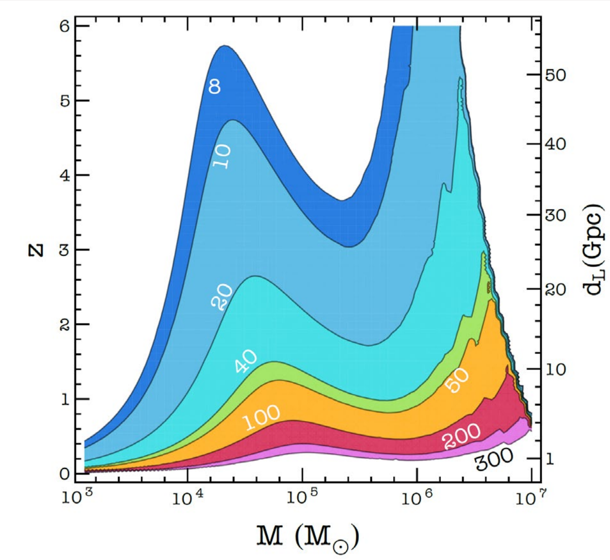
LGWA Sensitivity

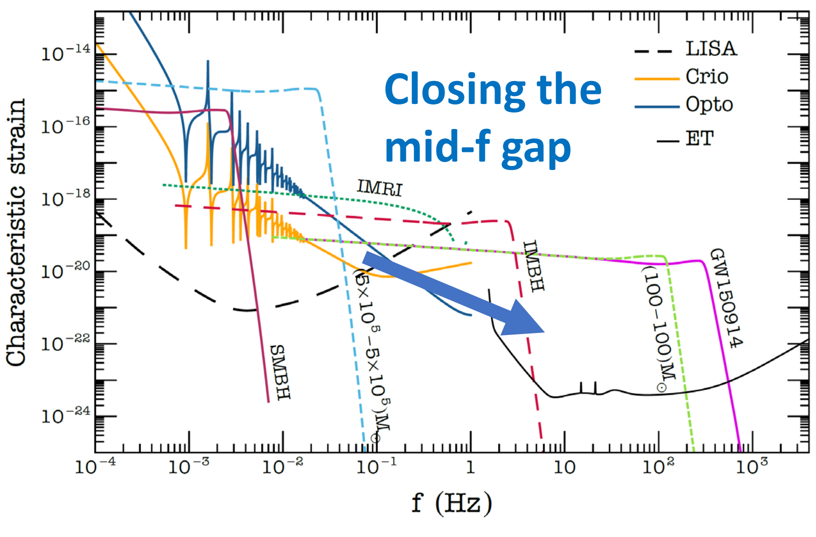
1mHz to few Hz



- LGWA will deliver first GW detections at deciHz
- Synergy with ET/CE on IMBH, solar-mass BBH and BNS
- Potential synergy with LISA (depending on when LGWA will be deployed) on double white dwarfs and massive BBHs

Extragalactic Compact Binaries





Possible detections

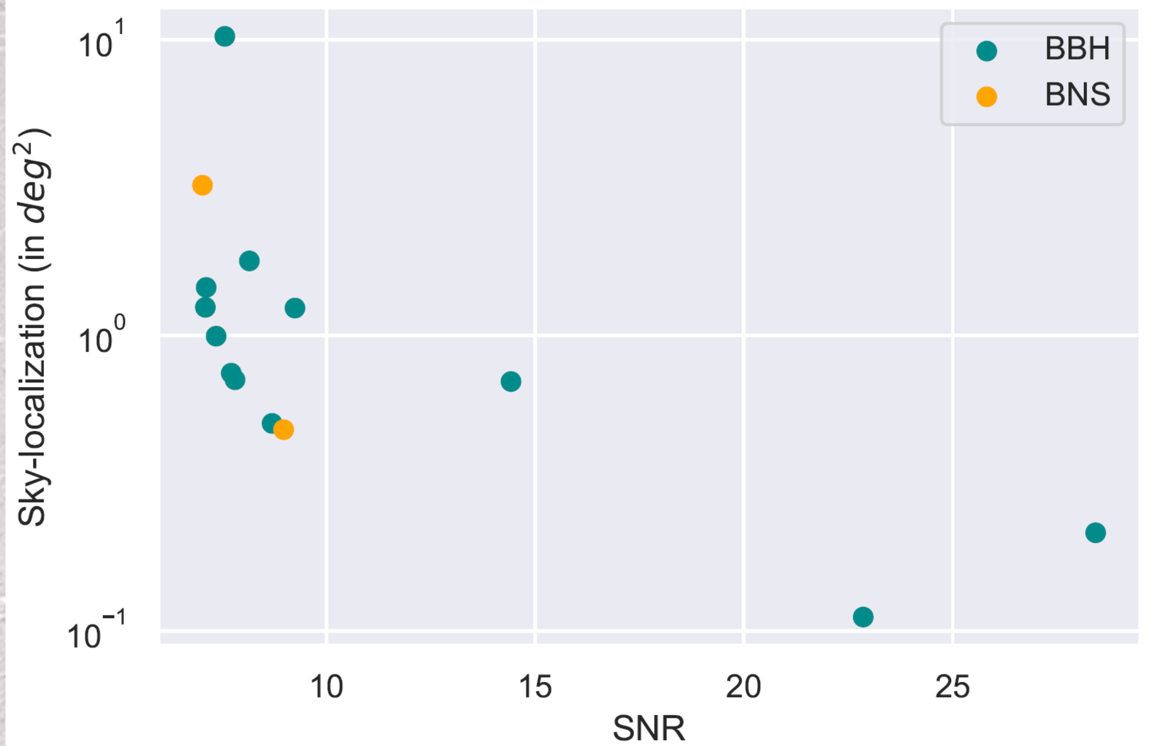
- (Super)massive and intermediate mass BBHs (majority of mergers would be detected)
- Solar-mass BBHs and BNS (few inspirals would be detected)

Impact on science (under study by LGWA WG)

- Early warning for BNS mergers to be observed in multi-messenger campaigns with ET/CE and EM facilities
- Together with ET, confidently detect IMBH mergers for population studies
- Improved sky-localization of massive BBHs compared to LISA

Solar-mass Compact Binaries

BNS and solar-mass BBH detections and sky localization (only those merging within 10 years)



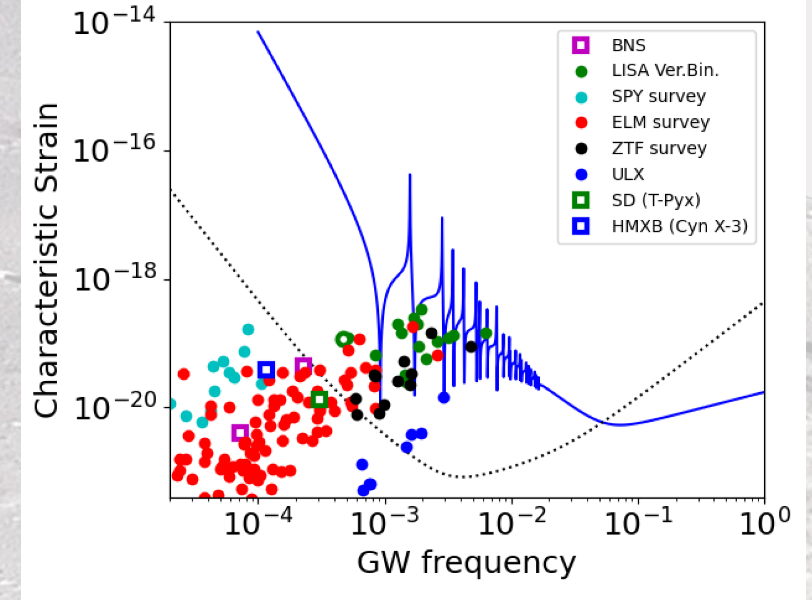
A Oliveira (2021)

Rotation (and orbital motion) of the Moon leads to modulations of GW phase and amplitude over the course of the LGWA lifetime (assumed to be 10 years), which gives LGWA the capability to localize lasting GW sources.

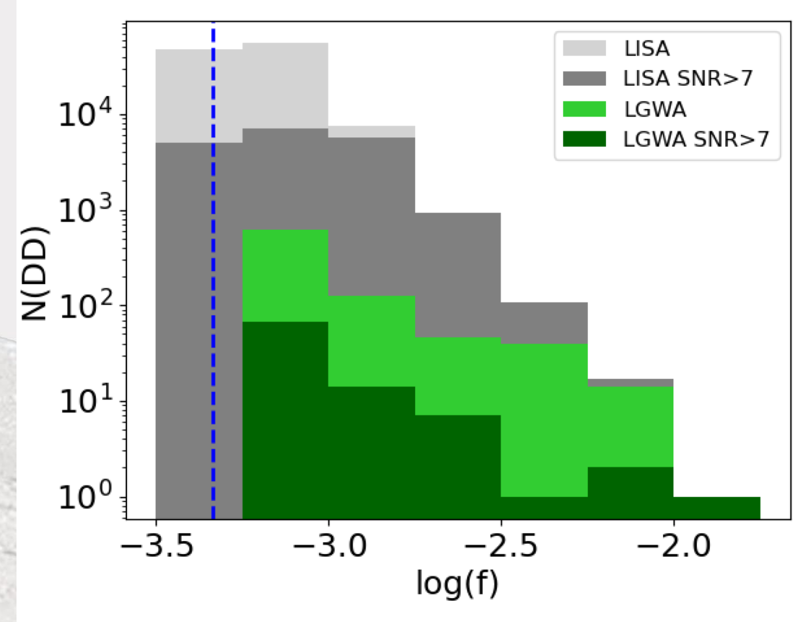
A few BNS could be detected each year with more than a day of warning time of an imminent merger.

Galactic Binaries

Estimated GW amplitudes from known short-period binaries in the Galaxy.

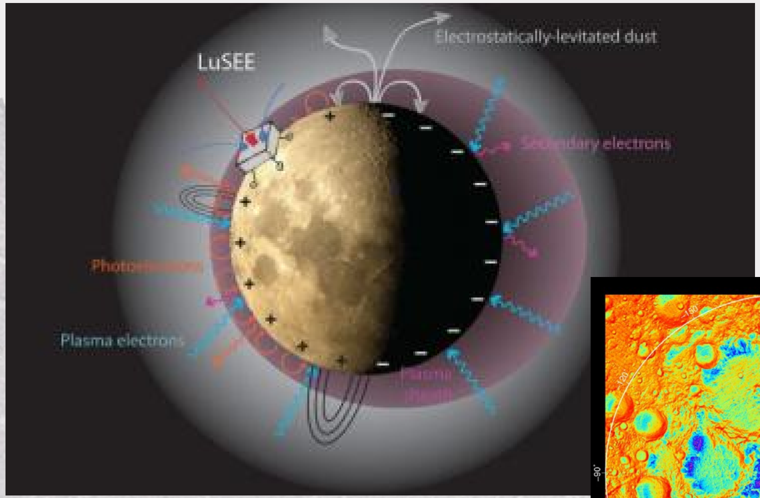


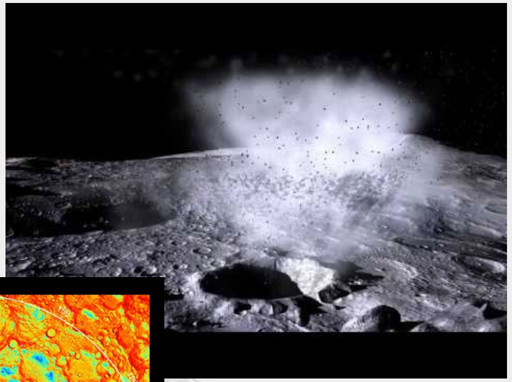
Predicted number of detections per year

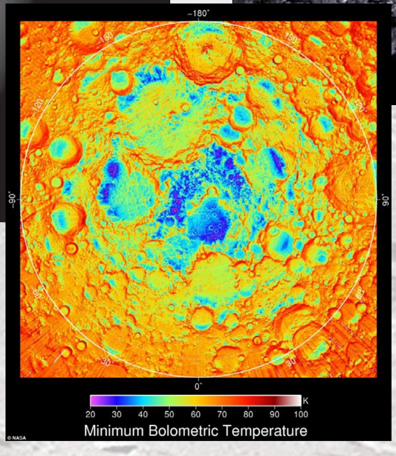


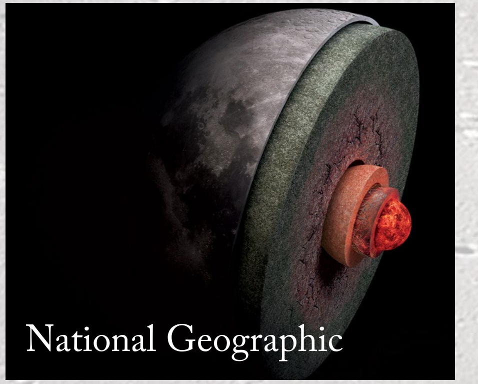
Probability of coincident detection with SN Ia is low, but it would be decisive for SN Ia progenitor identification, and the long lifetime of the LGWA mission is a great benefit.

LGWA's Physical Environment








National Geographic

Moon as a spherical detector
- Seismic background
- Moon's internal structure

Important environmental factors
- Electromagnetic fields and charges
- Temperatures and thermal fluctuations
- Radiation
- Dust

GSSI

Summary of LGWA

LGWA

Property	LGWA
Lifetime	Potentially >10 years, which makes it possible to create a lunar network of GW detectors (possibly with contributions from various space agencies)
Detector motion	Rotation of the Moon is faster than LISA orbital motion, which leads to better sky localization
Observation band	1mHz to few Hz; thereby opening the decihertz band inaccessible on Earth and very challenging to access with space detectors
Role for lunar GW detection	Setting the stage for lunar GW detection with hundreds of GW signals per year and delivering important information about seismic environment
Timeline	Many question marks, but first deployment not before 2035