2024 Lunar GW Workshop

Laser Interferometer Lunar Antenna Project

Hôtel Le Grand Large, Belle Île en Mer, France
September 30 – October 3, 2024

(Last updated September 20, 2024)

Important links

- Meeting website
https://www.vanderbilt.edu/lunarlabs/2024-lila-meeting/

- Depository for GW detection on the Moon
https://www.dropbox.com/request/8cABYowJLjUjAG8JPdcJ

- Depository for GW science for Geophysicist:
https://www.dropbox.com/request/ZzPTUo7kHX7HfSGMMrrI

- Depository for Geophysics for GW scientists:
https://www.dropbox.com/request/h6Oqc2mO7v8nJJ4GXL66

- Depository for Laser strain and seismometer:
https://www.dropbox.com/request/0sQf2nP2tRrcCVnj2zon

- Depository for Lunar seismology:
https://www.dropbox.com/request/Chj5m2Tza9nB9vG6v8W8

- Depository for seismic scattering:
https://www.dropbox.com/request/8lk0fZppD7x0PighnEWA

- Link to access all folders (read and download only):
https://www.dropbox.com/scl/fo/2fqdoy4gf7bkjf3z3ken6/AJxFobnPTL2kCOQCuO3d0Po?rlkey=35at9zjvji28irzfzb2jy6w1r&dl=0

Monday, September 30th

20:30 Welcome + Meeting Goals
21:00 Dinner

Tuesday, October 1st

9:00 LILA project update:
(Karan Jani, Vanderbilt University, USA)

In this talk, we will review the lunar GW efforts, starting from Apollo era to present day Artemis. We will highlight major milestones from the community that has finally led us to the current concept of laser interferometer on the Moon.

9:30 LILA GW Science Case
(Karan Jani, Vanderbilt University, USA)

In this talk we will discuss the fundamental physics and astronomy goals of the LILA mission, and their urgency in the context of the detection landscape of current GW detector on Earth (LIGO, Virgo, KAGRA) and in space (LISA). This talk would provide the synergy of LILA with LISA and LIGO-Virgo

10:00 LILA Geophysical Goals
(P.Lognonné, IPGP, France)

We present a first list of geophysical goals of LILA, expected to be performed by (i) laser strain measurement of the Moon and (ii) the LOVBB and other seismic sensors of LILA

10:30 Coffee break

11:00 Terrestrial GW Detectors: Current Progress and Future Plans
(E.Capocasa and M.Barsuglia, APC, France)

We will provide an update on the current status of the 2nd generation terrestrial gravitational wave (GW) detector network (which includes LIGO, Virgo, and KAGRA) currently conducting their fourth observation run. Additionally, we will outline the planned upgrades for the near future and discuss the roadmap for the development of 3rd generation detectors.

11:30 Discussion

Complementarities between LILA, LISA and Earth Detector? GW requirement flow and GW minimum requirement for a LILA pathfinder mission.

12:00 LILA LOVBB seismometers
(S. de Raucourt, IPGP)

IPGP is developing the next generation of planetary seismometers. Goal is to propose a seismometer meeting the ILN requirement (10^{-11} $m.s^{-2}/Hz^{1/2}$)) ready to fly in the early 2030. The current status and plan for development are presented. The configuration and adaptation for the LILA project is then discussed.

12 :30Lunch

Working session #1: What GW science below the deci-herz with Lunar response

14:00 Analytical modelling of the lunar response to GWs
(J. Majstorovic IPGP, France)

Gravitational waves (GWs) from astrophysical sources interact with elastic bodies, and there are two theories describing this interaction: following either approach from Dyson, 1969 or Weber, 1960. We discuss the implication of these theories in the context of the measuring principles. Further, we discuss the approximations introduced to get the analytical response lunar solution based on Weber's tidal principle. Finally, we open discussion on the detection of GW induced signal on the Moon and the techniques to optimise this detection.

14:30 Geodetic effects of GWs: example of the Earth
(S.Rosat, ITES, France)

I will show some results for the Earth of the surface deformation, gravity field disturbance and Earth's rotation perturbation induced by double white-dwarf binaries (a work in collaboration with Josipa Majstorovic and Bela Spitalier) based on Dyson's source formalism.

15:00 Discussion:

Can we use the present estimations of GW Lunar response as requirement? What might be missing?

16:00 Coffee break

Working session #2: toward a space qualified deci-hertz-Hertz attenuator

16:30 Seismic attenuation on the Moon
(V.Boschi, EGO, Italy)

We will provide an overview of possible seismic attenuation strategies for Moon based gravitational wave detectors. The main design principle is to use as much as possible the technologies conceived for second and third generation ground based interferometers while keeping the constrains of a space mission.

17:00 Laser strainmeter design and performances
(L.Vidal, APC, France)

Noise budget for LILA : Suspended test mass interferometer and Strainmeter
(i) Noise budget for the LILA suspended mass interferometer with cavities
(ii) Strain measurements and preliminary noise budget for a Michelson optical design

17:30 Discussion:
How to space qualify a seismic attenuator and what are the mass/attenuation ratio of a space qualified attenuator?

18:00 end of day

19:30 Diner

Wednesday, October 2nd

Working session #3: Laser strainmeter design and performances

9:00 Laser RetroReflector (LRR) instruments for LILA
(S. Dell'Agnello, INF, Italy)

Different LRR options are available, of TRL 7, 8 and 9, that will be described along with their optical performances, lunar/launch environment behaviors and space heritage missions. Will present availability of LRR spares for LILA demo/precursor/pathfinder/flight proposals, along with the potential involvement of ASI, ESA or other European agencies.

9:30 LILA interferometer readout options (Traditional interferometer vs. phase tracking solutions)
(V.M. Quetschke, Univ. Texas Rio Grande, USA)

The displacement sensitivity requirements for a LILA requires a state of the art optical layout with the sensitivity ultimately being limited through thermal noise. With LILA being in between the frequency bands of LISA and ground based interferometric detectors a comparison of the configurations is presented.

10:00 Discussion:

What necessary to get TRL6 for LILA interferometer? When this can be reached?

10:30 Coffee break

Working session #4: Non-seismic environmental noise

11:00 Lunar-Specific Environmental Noise Sources
(J.Trippe, University Vanderbilt,USA)

These predominantly include radiation and dust. The severity of each effect and possible mitigations will be discussed.

11:30 Thermo elastic noise on the Moon:
(S. Kizhaekke Pakkathillam, IPGP)

Thermo-elastic noise, driven by solar radiation fluctuations, complicates the interpretation of lunar seismic data due to non-periodic temperature variations. Also, the lander's shadowing effect introduces thermal perturbations, impacting surface and subsurface temperatures, making it difficult to filter such noise from seismic measurements. This study aims to model thermo-elastic noise at NASA's Far Side Seismic (FSS) suite landing site on the Moon, aiding future data filtering efforts.

12:00 Discussion:

How much LILA must be shielded from the Sun and anchored to the ground?

12 :30Lunch

13:45-16:00. **Excursion**

Walk to Phare du Goulphar, Aiguilles de Port.Coton, Grotte de l'Etoile (3.5 km) Walk Link.

16:15 Coffee

Working session #5: Decihertz Seismic noise,mitigation and seismic scattering

16:30 Seismic noise of the Moon: state of the art
(P.Lognonné, IPGP)

We present the present knowledge of the seismic noise of the Moon as well as expected background of seismicity

17:00 Coherency of the lunar wavefront and lunar seismic noise properties
(T.Kawamura, IPGP)

We present through modeling, possible properties of the seismic waves on the Moon and shows that the waves loose rapidly coherency, even at a few 100 meters. We then show the evolution of lunar seismic noise with time.

17:30 Attenuation Properties of the Lunar Crust
(S.Menina, IPGP)

This presentation will center on the two main parameters : scattering and absorption. It will provide an overview of the attenuation properties findings derived from Apollo seismic data, while also highlighting the various methods and models proposed over the years.

18:00 Discussion :

How to attenuate the seismic noise? Can we separate seismic noise from GW signal without attenuator with a small network or do we need attenuator and seismic sensors?

19:00 end of day

19:30 Diner

Thursday, October 3rd

Working session #5: Normal modes Geophysical goals

9:00 Lunar Normal modes background
(P.Lognonné, IPGP)

We present the expected amplitude of Normal modes when excited by the different lunar seismic sources, as well the detailed modeling of the long period seismic hum associated to small deep moonquakes. We then discuss lateral variations effects.

9:30 High resolution optical geophones at the end of plurikilometric optic cable
(P.Bernard, IPGP and Guy Plantier, ESEO)

ESEO and IPGP developed an interrogator for opto-mechanical geophones, based on Fabry-Perot extrinsic interferometry. We have qualified 2 Hz and 10 Hz geophones in the field, with up to 5 km long fibers, at the summit of the la Soufrière Volcano, and as Ocean bottom seismometer offshore Les Saintes islands (Guadeloupe). On the moon, this may allow the installation of such sensors in permanently shadowed craters, up to tens of km away from the lander and the interrogator

10:00 Discussion

10:30 Coffee break

Working session #6: Other lunar geophysical goals

11:00 Precision MEMS Sensors for Geophysics
(Abhinav Prasad, IGR)

The Institute for Gravitational Research (IGR), University of Glasgow is developing MEMS sensors for precision gravimetry and seismometry. These sensors are currently being used for terrestrial continuous-time environmental monitoring *(volcanos and groundwater) and survey of buried features (tunnels and voids). In this talk, I will discuss the technology and its potential applications in lunar geophysics.*

11:30 Laser strainmeter deployments for Artemis, CLPS, ESA Call.
(S. Dell'Agnello(presenting)/M. Muccino/L. Porcelli.)

Practical (unmanned) deployments for: Artemis lander, CLPS lander/rover/hopper and ESA Calls (closing 31 Oct 2024) for the PNT payload "NovaMoon" and the ArgoNet lander.

12 :00 Discussion

12:30 Lunch

14:00 Future seismic stations on the Moon
(P.Lognonné, T.Kawamura, S. de Raucourt, IPGP)

We present the near future (FSS, LEMS, LS) lunar seismic stations onboard CP-12, ARTEMIS3 and ChangE'7 as well as future opportunities.

Working session #7: Summary and path forward

14:30 Immediate Next Steps for the LILA Project
(Karan Jani, Vanderbilt University, USA)

In this talk, we will highlight the next major NASA proposals and private foundations grants we would be targeting for the LILA project. This includes Artemis IV, PRISM, NIAC and APRA and more generally LILA Collaboration structure, Calls and communications

15:15 Discussion

16:00 Coffee break

16:30 LILA White paper Discussion
(all, moderator, Karan Jani and P.Lognonné)

18:00 end of day

19:00 Closing drink

19:30 Dinner