FARSIDE SEISMIC SUITE: A LONG-LIVED GEOPHYSICAL PACKAGE AND A MODEL FOR A POTENTIAL LUNAR SEISMIC NETWORK. M. P. Panning[1], B. Avenson[2], S. H. Bailey[3], P. M. Bremner[4], D. Bugby[1], S. De Raucourt[5], R. Garcia[6], D. DellaGiustina[3], T. Kawamura[5], S. Kedar[1], P. Lognonné[5], C. Neal[7], W. T. Pike[8], and R. C. Weber[4], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA, [2]Silicon Audio, [3]University of Arizona, [4]NASA Marshall Space Flight Center, [5]Institut de Physique du Globe, Paris, [6]ISAE Supaero, Toulouse, [7]University of Notre Dame, [8]Imperial College, London

Introduction: The Farside Seismic Suite (FSS), selected in 2021 for flight as part of the NASA PRISM (Payloads and Research Investigations on the Surface of the Moon) program and planned for flight in 2025 on a lander provided by a group led by the commercial vendor Draper, would deliver two seismometers (both flight-proven through the InSight mission to Mars [1]) to Schrödinger Basin, as part of a package of payloads called CP-12 by NASA. The vertical Very BroadBand (VBB) seismometer is the most sensitive flight-ready seismometer ever built [2], while the Short Period (SP) sensor is the most sensitive and mature compact triaxial sensor available for space application [2]. FSS delivers a self-sufficient payload, with independent power, communications and thermal control allowing survival and operation over the long lunar night independent of the lander which it will outlive.

CP-12 also includes a magnetotelluric sounding system [3] and heat flow probe [4]. These instruments, in combination with a Next Generation Lunar Retroreflector [5], make up the key proposed instrumentation for nodes of the proposed Lunar Geophysical Network [LGN, 6]. While FSS is only originally proposed to last 4.5 months, the basic thermal design or other proposed lunar nighttime survival systems [e.g. 7] suggest a powerful path forward to implement a lunar seismic network using relatively small payloads with seismic instrumentation designed for multi-year survival delivered by affordable, short-lived landers. The thermal packaging of FSS can additionally be expanded to include electronics for other geophysical instrumentation that may be included in a future Lunar Geophysical Network.

FSS science objectives and relationship to LGN seismology science objectives: FSS was designed to meet 3 key science objectives (Fig. 1):

1. *Investigate deep lunar structure and the difference between near and farside activity*.

2. *Understand how the lunar crust is affected by the development of an impact melt basin*.

3. *Evaluate the current micrometeorite impact rate and local tectonic activity at Schrödinger Basin*.

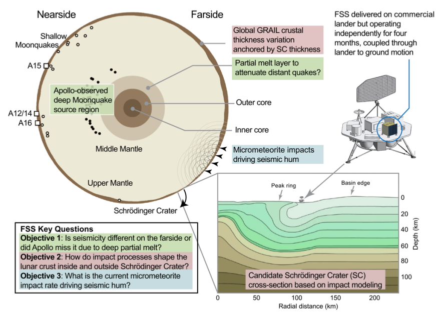

Figure 1. FSS will return data from Schrödinger Basin over multiple lunar diurnal cycles after outliving the delivery lander. FSS provides: (1) The first seismic data probing the deep lunar interior and determining the differences between near and farside activity (green); (2) Measurement of crustal thickness and layering that illuminates the process of crater formation (pink); (3) Current micrometeorite impact rate through recording of background seismic vibrations (blue). Figure adapted from [8] and [9].

These objectives have been described more thoroughly in previous work [10], but it is interesting to compare this explicitly with the overall science objectives of a prospective Lunar Geophysical Network [e.g. 6, 11], which can be summarized with 4 major objectives:

1. *Evaluate the interior structure and dynamics of the Moon*.

2. *Constrain the interior and bulk composition of the Moon*.

3. *Delineate the vertical and lateral heterogeneities within the interior of the Moon as they relate to surface features and terranes*.

4. *Evaluate the current seismo-tectonic activity of the Moon*.

Obviously, the 4.5 months initially planned for a single FSS station can only partially address small, targeted aspects of each of these objectives, and the other geophysical instrumentation is absolutely key to achieving these goals. The contribution of seismic data, however, towards reaching a global, but also high-resolution, view of these major objectives requires networked seismic stations with multi-year nodes.

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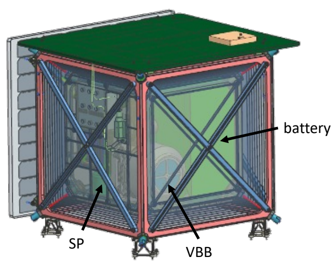
FSS packaging and the path forward for possible lunar seismic network nodes: FSS achieves performance outliving the delivery lander through an innovative thermal design that makes use of a cube suspended within a cube supported by tensioned vectran cables with "spacerless" multi-layer insulation (Fig. 2), as well as an efficient thermal switch and a mini loop heat pipe system connected to a radiator. This setup allows the system to stay cool during the hot lunar days and warm during the cold lunar nights with heating primarily provided through ~5W of dissipation from electronics needed to operate the seismometers through the night. Power for night operations is provided by a ~19 kg battery system which is charged by a solar array during the day.



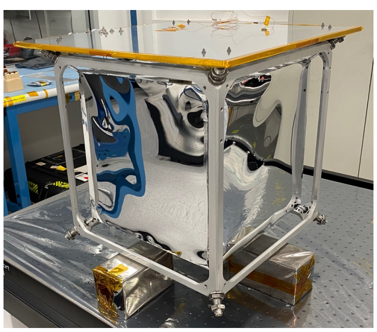


Figure 2. (Top) CAD rendering of FSS design illustrating the cube within a cube design, as well as the locations of the two seismometers and the battery. (Bottom) Image of the prototype mechanical frame of FSS with mounted insulation already tested and intended to be reused for flight.

In order to adapt this configuration for use as nodes of a future lunar seismic network, several key adaptions will be necessary.

Instrumentation: FSS relies on a flight spare VBB from InSight, and therefore only includes a single vertical component sensor at this sensitivity level. For a seismic network to contribute to LGN-like science objectives, horizontal component measurements at this sensitivity level will also be needed, and there are not enough existing VBB components to carry this out. Two systems are currently in development that can meet the performance requirements, with a target of an extremely sensitive vertical component sensor developed at the Institut de Physique du Globe, Paris (called the Lunar Optical VBB or LOVBB) capable of sensitivity of ~10^{-11} m/s^2/rtHz from 0.01 to 5 Hz [12] complemented with a 3-component system with a sensitivity of ~10^{-10} m/s^2/rtHz developed by Silicon Audio and the University of Arizona (the Lunar Very Broadband seismometer, LVBB). In order to maximize the frequency band of sensitivity and decouple the sensors from lander noise, this package may be deployed to the surface, while an SP seismometer system similar to that included in FSS may remain on the lander to monitor what will likely remain a significant local noise source.

With the increase in number of broadband sensing components relative to FSS, the package design will have to be larger, which will increase the power requirements to maintain warmth overnight. Combined with longer desired lifespan leading to greater allowance of battery degradation, a significant increase in battery mass will also be required to use such a design for LGN purposes, but this is an incremental change to the overall design of the package. This suggests that an approach of using self-contained packages delivered by low-cost landers remains a viable and likely affordable option for building a lunar seismic network.

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