

Tilt-insensitive optical seismometer for the Lunar Geophysical Network

R. Weber¹, S. H. Bailey², D. DellaGiustina², V. Bray², S. Otterbacher², K. Burke², B. Avenson³, N. Schmerr⁴, M. Benna⁴, A. Marusiak⁴, M. Siegler⁵, K. Zacny⁶, C. Neal⁷

¹NASA MSFC, ²Univ. of Arizona, ³Silicon Audio Inc., ⁴Univ. of Maryland, ⁵PSI, ⁶Honeybee Robotics, ⁷Univ. of Notre Dame

Science Objectives and Significance

Understanding the structure and composition of the lunar interior has been designated a high priority for lunar science in 2 National Academies studies and the LEAG Roadmap. To that end, the Planetary Decadal Survey recommends the Lunar Geophysical Network concept as a prioritized mission under New Frontiers 5.

Apollo-era seismic data have provided an important glimpse of the Moon's structure, which has bearing on its thermal, petrological, and rotational history. Further investigation hinges on the development of advanced seismic sensors and deployment systems.

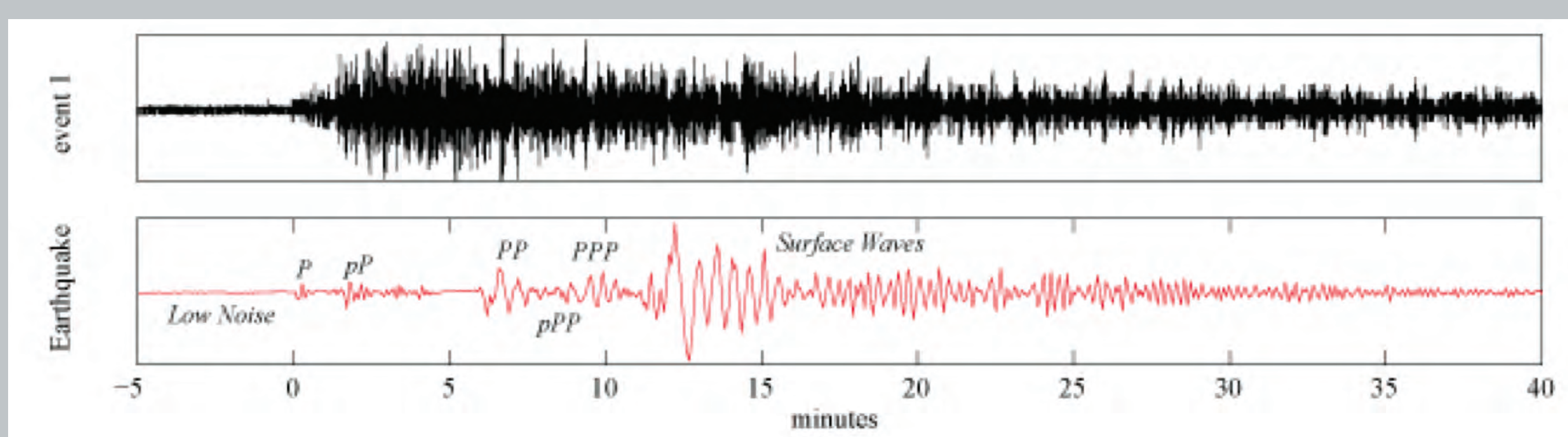


Figure 1: (top) Typical high-quality deep moonquake waveform. (bottom) Typical Earth seismogram. Notice that on the lunar seismogram, the effects of scattering and reverberations in the regolith layer obscure all but the primary P arrival.

The Moon is covered with a remarkably low-density regolith layer. Combined with very low P-wave seismic velocities, this near-surface regolith structure has profound effects on seismic science for the proposed LGN mission, greatly increasing the near-surface trapping and scattering of seismic signals. Multiple reverberations effectively “smear” important secondary signals. Distant and low magnitude quakes are lost in this noise-train (Figure 1).

The effects of noise from the surface can be mitigated by deploying instruments below the scattering layer, as is routinely done on Earth. A lander will continuously expand and contract with the diurnal cycle. This thermal stressing creates noise at many frequencies that contaminates seismic signals of interest. Robotically deployed seismometers will be <1m away from their noisy spacecraft (Figure 2).

Figure 2: Lander concept for the LUNETTE mission, a previous attempt at establishing a Lunar Geophysical Network. Like the current Mars InSight mission, the seismometer is deployed robotically to the ground <1m away from the host lander.



Instrument Description



Figure 3: The Silicon Audio tilt-insensitive optical geophone.

The **Seismometer for a Lunar Network (SLN)** is a NASA/DALI-funded effort to develop a seismometer based on a COTS device manufactured by Silicon Audio Inc. (Figure 3). It is a novel combination of a geophone and a laser interferometer that enables detection of sub-micron-scale motions. SLN is a small, sensitive, tilt-tolerant, broadband instrument competitive with state of the art planetary seismometers (Figure 4).

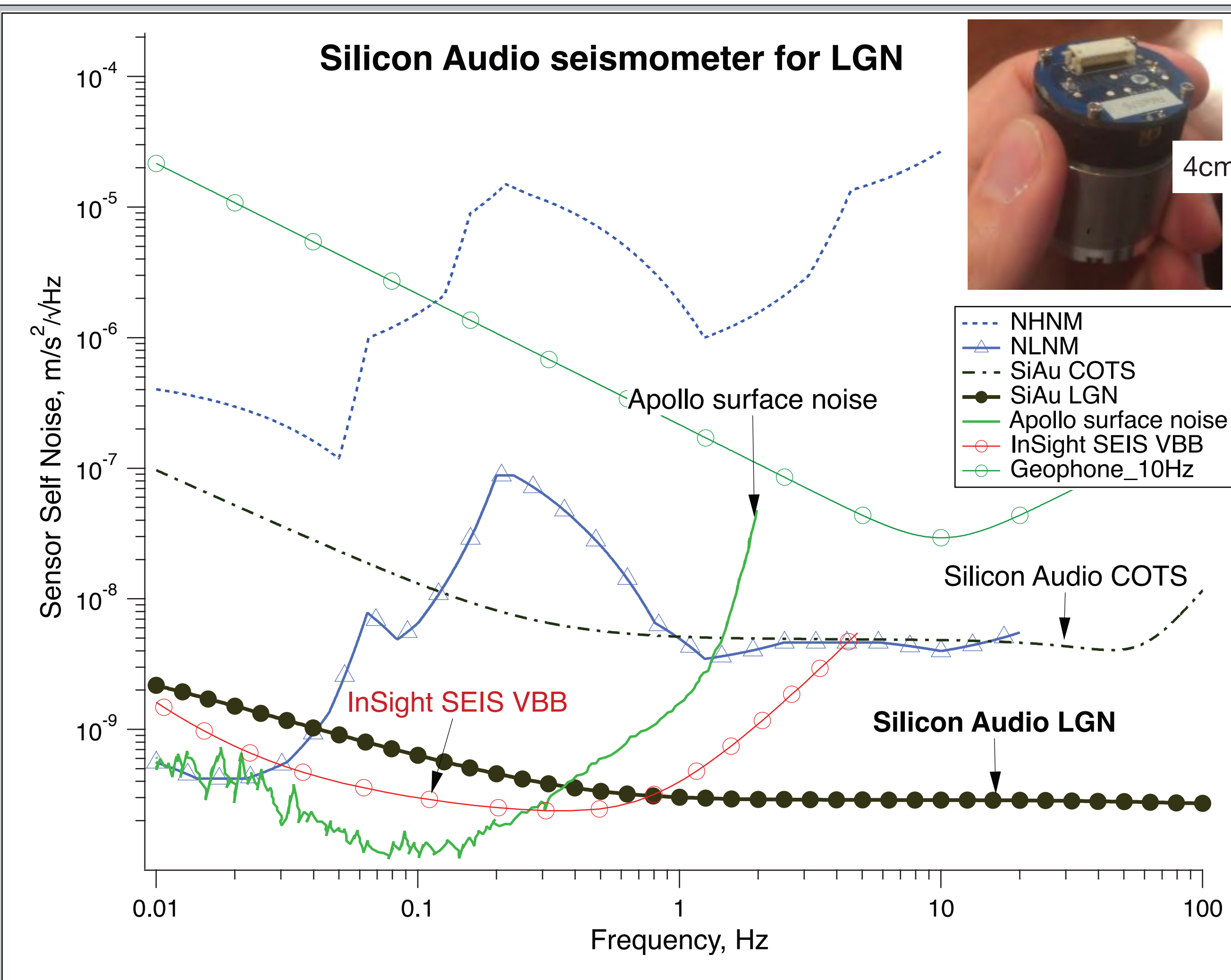


Figure 4: SLN performance compared to Apollo surface noise, the Mars InSight Very BroadBand instrument, and the Earth Low- and High-Noise Models.

Deployment

The SLN team is currently pursuing two main deployment scenarios:

1) Burial: To realize the benefits of sensor burial, including thermal isolation, improved ground coupling, and scattering reduction, SLN adapts a low-mass, low-power burial system developed by Honeybee Robotics for a NASA-funded lunar Heat Flow Probe. The system uses pressurized gas to create a vertical hole in the regolith, into which the instruments can be said to “drop” (Figure 5).

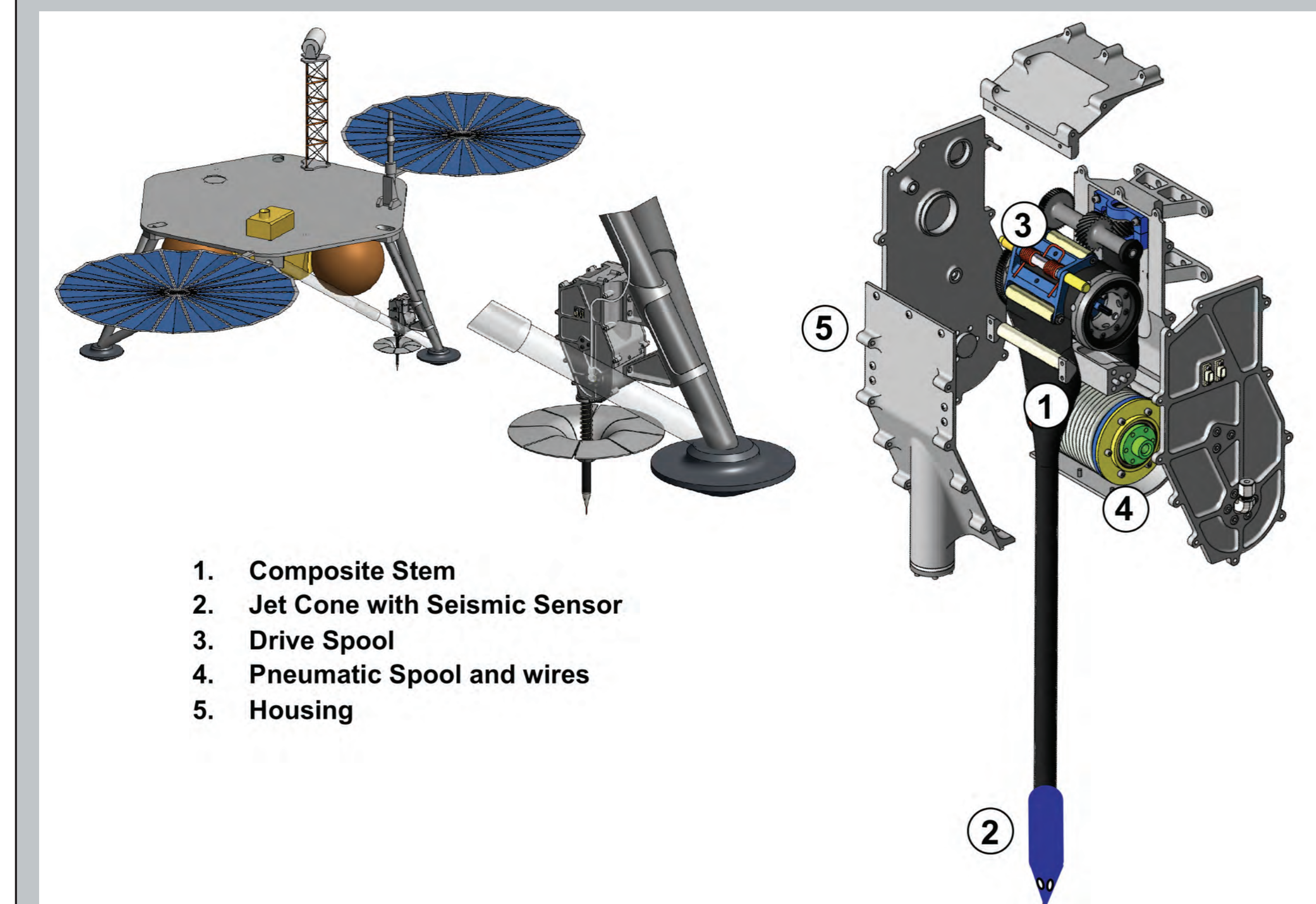


Figure 5: Schematics showing the Honeybee Robotics SLN deployment system. (left) The seismic sensor head is attached to a leg of a conceptual lunar lander. (right) The major components.

2) Autonomous Deployment: The Lunar Environment Monitoring Station (LEMS) is a DALI-funded concept for a compact, autonomous, self-sustaining, deployable instrument suite capable of collecting daily in-situ measurements for a nominal duration of 2 years from its deployment on the surface of the Moon. SLN is now baselined as the seismometer on LEMS. LEMS provides an opportunistic investigation that can be deployed as a secondary payload from either crewed or robotic, commercial or scientific missions. Once delivered and deployed on the lunar surface, LEMS will require no additional support from the primary mission (Figure 6).

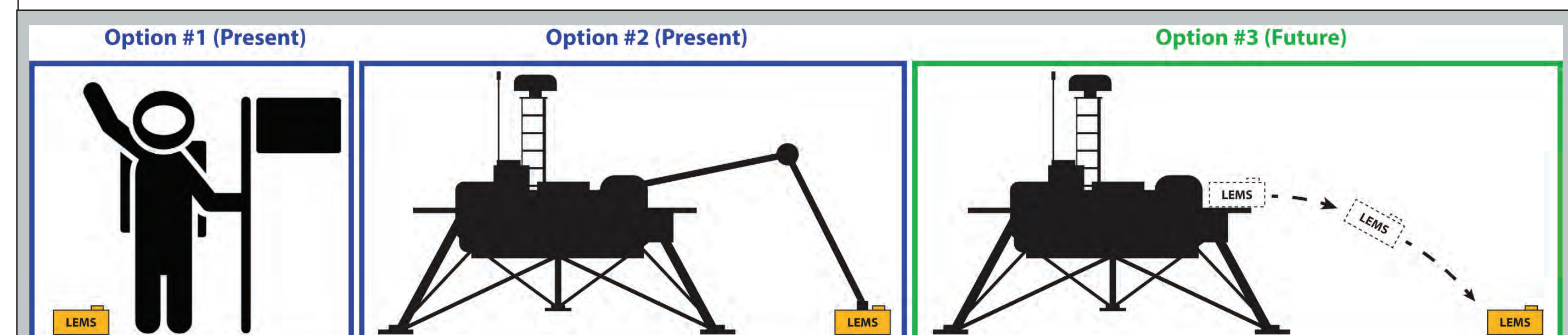


Figure 6: LEMS conceptual deployment options.