Science and Engineering Investigations with the Lunar GNSS Receiver Experiment (LuGRE) Payload. J. J. K. Parker[1], F. Dovis[2], [1]NASA Goddard Space Flight Center, M.S. 595.0, Greenbelt, MD 20771, USA, j.parker@nasa.gov, [2]Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy, fabio.dovis@polito.it.

Introduction: In July 2020, the NASA-Italian Space Agency (ASI) Lunar GNSS Receiver Experiment (LuGRE) was selected as the 10th payload of CLPS Task Order 19D. In February 2021, NASA awarded this task order to Firefly Aerospace. [1] Firefly's Blue Ghost Mission 1 (BGM1) will deliver LuGRE and the other CLPS 19D payloads to 18.6° N, 61.8° E in the Moon's Mare Crisium.

The goal of the LuGRE project is to extend GNSS-based navigation and timing to the Moon. [2] As a technology demonstration payload on the Blue Ghost lunar lander, LuGRE will fulfill this goal by gathering and processing GNSS data across several mission phases with a receiver developed by Qascom specially for lunar use. GNSS-based navigation would improve autonomy for vehicles on and around the Moon, enabling new mission conops in an era of increasing lunar exploration. LuGRE activities are codified in three science objectives:

OBJECTIVE 1: Receive GNSS signals at the Moon. Return data and characterize the lunar GNSS signal environment.

OBJECTIVE 2: Demonstrate navigation and time estimation using GNSS data collected at the Moon.

OBJECTIVE 3: Utilize collected data to support development of GNSS receivers specific to lunar use.

Payload Description: The ASI-supplied payload consists of a GNSS receiver, high-gain L-band antenna, front-end assembly, and radio frequency cable harnesses, as illustrated in Figure 1 and Figure 2. The receiver is specially designed and built for lunar applications by Qascom srl, based on their low altitude QN400-SPACE receiver product line, and will receive and process both Global Positioning System (GPS) and Galileo signals in the L1/E1 and L5/E5a bands.

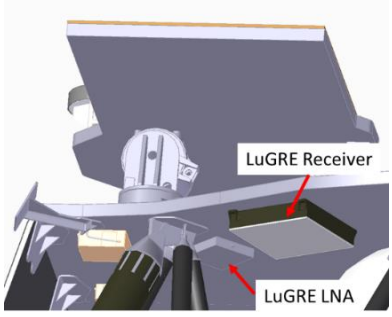

Figure 1. LuGRE receiver and LNA on BGM1 lander

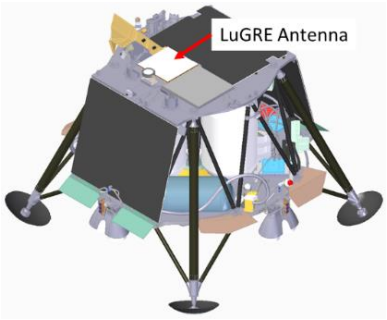

Figure 2: LuGRE antenna on BGM1 lander

The LuGRE payload has a total mass of less than 4 kg, and a total steady-state power consumption of less than 14W.

Science Investigations: The LuGRE project formed an internal Science Definition Team that worked from summer 2021 to late 2022 to define a set of 20 discrete science and engineering investigations to be undertaken by the project. The investigations are mapped to the mission objectives and are prioritized as driving (P1), baseline (P2), or best effort (P3). For clarity, the investigations are grouped by category as related to the signal processing level, the measurement level, the navigation level, and unique analyses.

Signal processing level. At the signal processing level, six investigations are defined, including: measuring signal strength and availability throughout the mission; calibrating ground models of lunar GNSS reception and transmit antenna patterns; processing snapshots of raw GNSS I+Q samples using ground-based tools; and investigating variations between lunar orbital and surface signal strength, such as due to environmental effects.

Measurement level. At the measurement level, three investigations are defined, including measuring and characterizing GNSS pseudorange and Doppler profiles throughout the mission.

Navigation level. At the navigation level, eight investigations are defined, including the driving investigations demonstrating and characterizing least-squares and Kalman-filter based navigation onboard, comparing those solutions against independent sources of lander state knowledge, and processing on-orbit data with ground-based navigation systems. Additional investigations in this area include evaluating dilution of precision (DOP), evaluating potential post-processed navigation performance using ground tools, and forming navigation solutions incorporating other state

knowledge estimates, e.g. from other payloads on the platform.

Unique investigations. In addition, three unique investigations are defined. LuGRE will assess the effects of the lunar dust environment on L-band GNSS signal strength, including short-term and long-term effects over the two-week surface duration. At the best-effort level, the project will evaluate the presence and, if possible, the characteristics of multipath due to the lander and/or surface, and will investigate the benefits of use of the GPS-Galileo Time Offset for multi-GNSS navigation solutions.

These core investigations will be augmented by additional investigations proposed by the scientific community under the auspices of the full LuGRE Science Team, which is planned to be formed in 2023.

References:

[1] NASA (2021) "NASA Selects Firefly Aerospace for Artemis Commercial Moon Delivery in 2023," https://www.nasa.gov/press-release/nasa-selects-firefly-aerospace-for-artemis-commercial-moon-delivery-in-2023. [2] Parker, J. J. K. et al. (2022) *ION ITM 2022*, 420–437, doi: 10.33012/2022.18199