SPACE INITIATIVES

Matching Funds Opportunity

On 6th March2020 our small Florida company Space Initiatives Inc (SII) was awarded a 3 month contract (of $50,000) by the US Air Force (AFWERX) as STTR to study a sensor network on the surface of the Moon, and a ballistic delivery system for the same. This system will afford significant new science opportunities for NASA and will be making use of CLPS lander opportunities. Our partner research institution for the STTR is Florida Institute of Technology. A great deal of high value science can be accomplished using these hard landers or penetrators, to augment the soft-lander capabilities of CLPS.

The AFWERX Phase-2 Solicitation was released 12th July 2020 and proposals must be submitted by 10th August 2020.

Description of System Proposed

For the Phase-2 AFWERX STTR effort, Space Initiatives Inc (SII) proposes a system to hard land a set of nodes onto the lunar surface either with or, in advance of a new landing, either crewed or robotic. The network provides the following services: terminal navigation and landing positioning; local PNT for astronauts and robots and communications relay. This system is self-organizing after being dropped into place (e.g. from orbit) inexpensive and requires low- or zero-maintenance. The system is be expandable to larger areas or to link existing areas of coverage, e.g. two separated landing sites.

Each node of the network is encapsulated in a small (300 mm long x 40 mm dia) kinetic penetrator projectile designed to survive and operate following an un-braked fall after dispensing from a host (CLPS) lander during its descent. Each node has on-board processing, communications, and imaging and many other sophisticated science instruments and sensors. They would be carried on a host CLPS lander within a standard COTS Cubesat dispenser. The following mission profile has been discussed with several CLPS contractors and appears feasible.

- The CLPS lander performs its main de-orbit braking burn about 20 km kilometers above the lunar surface then continues to gently decelerate.
- A carrier package containing one to twelve penetrators will be ejected from a 6U cubesat dispenser on the CLPS lander during descent at approximately 5 km altitude; then within a minute or two the individual penetrator nodes are ejected from the carrier thus dispersing the nodes. We expect the scatter pattern to be a circle of few kilometres diameter, centered roughly five to ten kilometres downrange of the CLPS lander point.
- A few seconds after deployment from the CLPS lander, while free falling, the nodes boot up and establish a local MESH network using Lora RF, estimating direction and distance between each node as they fall to the lunar surface. A camera and a set of science instruments will operate during descent through impact.
- After descent of about 2 minutes the nodes impact into the lunar surface at about 300 meters/sec. A sudden deceleration occurs which could be up to 10,000g, accelerometers measure the deceleration profile, which represents valuable science data on the mechanical properties of the lunar regolith.

After impact, the nodes re-establish the local network using both low-frequency RF (1-10 MHz which can penetrate lunar regolith) and the Lora link (where possible), and use onboard RF and imaging systems to determine their relative positions to each other and the lunar surface from surface features and astronomical sightings.

After impact each penetrator can continuously send up to 300 kbps to a Lora (915MHz) receiver gateway box provided on the lander via a dedicated channel. Up to twelve channels of data (one channel from each penetrator node) will be combined in the gateway box (totaling 3.6 Mbps) and routed on to the CLPS RS-422 bus, and from there it will go on to the CLPS Earth downlink. For the operational version, the data stream is designed to continue for 5 years. The penetrator will be solar powered to achieve this lifetime. During impact, the aft compartment of the penetrator is separated and remains on the lunar surface, containing antennas and solar power array, as well as camera and any other instruments requiring surface access.

SII additionally proposes to use its COMPASS Very-Long-Baseline-Interferometry (VLBI) concept to precisely locate the nodes from Earth-based radio telescopes and calibrate their onboard timing and positioning systems. SII has a working relationship with the international VLBI consortium, including Haystack and NRAO in the USA, and there is a consensus that the Compass concept is feasible and viable, and can be scheduled into the observing program.

The first proof of concept flight might not survive the lunar night. However, the next version will be designed for a 5-year life, using PV solar power with rechargeable cells.

Purpose and Benefits of System Proposed

Once active, the surface nodes offer accurate positioning signals to descending spacecraft, communications to humans and robots, site security, emergency detection, and environmental monitoring. The network offers an open subscriber service, where any suitably equipped astronaut, rover or lander in range could connect, register and communicate with any other node or connected user. A sophisticated suite of science instruments within each node will collect a variety of science data. We anticipate the USAF will seek to deploy large numbers of networks across the lunar surface, affording widespread science opportunities for NASA scientists.

Table of Typical Science instruments carried within the Penetrator Node

Regolith Physical properties during deceleration	Low Frequency RF (Subsurface properties)/GP	Charged dust detector
Magnetometers (e.g. swirls)	Subsurface bistatic radar	3He Neutron Detector (for Water/Hydrogen)
Seismometer	Attenuation mapping	Plasma Measurements
External/wall Temperatures	Mineralogic sensor – Mineralogic sensors -	Laser Induced Breakdown Spectroscopy (LIBS)
Electrical conductivity	Geiger Counter Gamma counter (Th, KREEP, Cosmic Rays)	Pressure sensors - Neutral Mass Spectrometer - Volatiles detector

Alternative Technical Approaches. The only practical alternative for emplacing a distributed network on the Moon is to soft land on the Moon using a conventional rocket propelled lander (e.g. CLPS) and then dispersing nodes with either a rover or via some catapult or gun. This approach will not cover such a large area anywhere near as quickly as the ballistic penetrator approach. Soft landers have higher cost, risk, and reduced payload capacity versus using a hard lander. Soft landers are complex and have demonstrated reliability and failure mode challenges, as shown by the recent failures of attempts by Indian and Israeli landers which failed at low altitude in the terminal landing phase. Rovers also have some limitation on their ability to traverse rugged terrain, and much of the area in the polar regions is very rugged with steep slopes; the ballistic penetrators can cover these areas more easily with less risk than a rover.

Unique qualifications of the proposer(s)

The SII team has been working on tiny spacecraft and networks for small bodies for several years. SII specializes in PNT and has a strong body of expertise in this field.

- Charles F Radley – President and CEO, 20+ years aerospace industry experience in systems engineering and QA on projects for NASA, USN, ESA, and commercial comm satellites. Associate Fellow American institute of Aeronautics and Astronautics;
- Thomas M Eubanks – Chief Science Officer, specializing in PNT; 30+ years' experience as space science consultant for JPL, MIT, USNO, NASA GSFC, ESA. Former CEO of Asteroid Initiatives Inc. Developed two VLBI networks for the US government in support of spacecraft navigation and worked for the Department of Time at the US Naval Observatory.
- W Paul Blase – led the effort to develop a commercial lunar orbiting spacecraft and surface penetrator (1999 – 2006), collaborating with Charles Radley. 35 years industry experience in electrical engineering, especially imaging systems, image processing, and embedded computer systems.
- Dr Markus Wilde, Florida Institute of Technology, Assistant Professor, Aerospace, Physics & Space Sciences

TRL Military grade electronics in artillery shells routinely handle >10000-g's acceleration. Most components have TRL ranging from 4 to 9. The overall system is currently TRL-2, but the Mesh network should be TRL-4 by the end of AFWERX STTR Phase-1, June 2020.

A major design challenge will be to power and maintain temperature for the nodes through the lunar night, or in the Permanently Shadowed (polar) Regions (PSRs). The first-generation system will use primary chemical batteries, but these are only qualified to **-**100C, and higher performance cells are limited to **-**55C, where PSR temperatures can be as low as 40K (-233C). We anticipate heaters using Strontium-90 isotope decay. This decay generates betas (electrons) so should not interfere with collocated particle detectors which do not look for betas, but instead for Alphas, Neutrons, Gammas and X-rays.

- Phase II STTR will demonstrate small mesh network nodes can survive an un-braked fall from stratosphere and rapidly self-deploy and establish the network. We will design & fabricate a small number of prototype nodes, hardened against the deceleration (but not against lunar environment), and drop them from balloon onto terrestrial surfaces. Two possibilities are desert sand, to emulate mechanical properties of regolith, and the Antarctic or Greenland icecap, to emulate RF characteristics. TRL will increase from 3 to 6.

- Phase II will also demonstrate, using two or more terrestrial radio telescopes, the ability to precisely locate a spacecraft transmitter in the lunar vicinity using VLBI techniques. Decoding any such signal is not necessary, so it should be possible to accomplish VLBI using LRO or the first CLPS landers without modification.

- Phase III will then demonstrate the entire system to TRL9. It will show that low-frequency RF signals penetrate lunar regolith so nodes can communicate beyond the horizon or obstacles. Communications between the nodes and a lander or rover could also be demonstrated.