The Lunar WATER Mission: A PSDS3 Feasibility Study of a Solar-Electric Propulsion Small Sat Mission to Characterize the Water on the Moon. Charles A. Hibbitts[1], Brenda Clyde[1], David Blewett[1], Pontus Brandt[1], Laura Burke[2], Barbara Cohen[3], John Dankanich[4], Dana Hurley[1], Rachel Klima[1], David Lawrence[1], Annette Mirantes[1], Dawn Moessner[1], Wes Patterson[1], Jeff Plescia[1], Jessica Sunshine[5], Joe Westlake[1], [1]Johns Hopkins University Applied Physics Laboratory, Laurel, Md., USA. (Karl.Hibbitts@jhuapl.edu); [2]NASA Glenn Research Center, [3]NASA Goddard Space Flight Center, [4]NASA Marshall Spaceflight Center, [5]University of Maryland.

Introduction: We have conducted a six-month study under PSDS3 to evaluate the feasibility of conducting a lunar small satellite mission - The Lunar Water Assessment, Transport, Evolution, and Resource (WATER) mission. The WATER mission is a 18 to 24 month, Solar-Electric-Propulsion (SEP) mission to characterize the water on the surface of the Moon. Since water was first discovered on the illuminated Moon [1,2,3] and confirmed to exist in the permanently shadowed regions at its poles [4], further understanding the origin, evolution, and distribution of water and other volatiles on the Moon became a high priority for NASA.

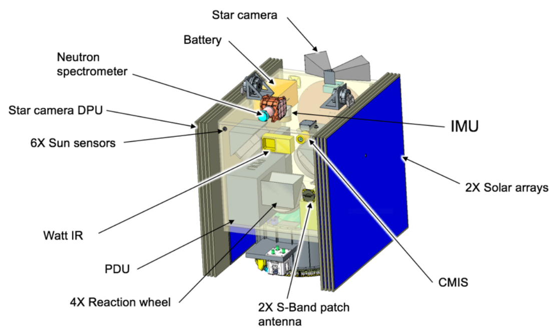

Figure 1. Spacecraft model. Size is 1m x 1m x 1m.

Mission Goals: The goals of this mission concept are to: 1. To understand the history and evolution of water accumulation on the Moon. 2. To spatially map its physical and chemical nature over the surface of the illuminated Moon. 3. To understand the relationship between surface and subsurface volatiles, and their dependencies on the thermal environment. This mission concept that we evaluated directly addresses priorities within the 2013 – 2022 NRC Decadal Survey to “Understand the composition of distribution of volatile chemical compounds” including how volatile elements and compounds are distributed, transported, and sequestered in near-surface environments on the Moon. This mission concept also proposes investigations directly relevant to high priority objectives with Lunar Strategic Knowledge Gaps (SKGs) related to lunar resources to understand the hydrogen in nonpolar mare and highlands regolith, to evaluate the composition, form and distribution of polar volatiles, and the characterize the temporal variability and movement dynamics of surface-correlated OH and H_2O deposits towards PSR retention.

Mission Characteristics: The concept is for an EELV Secondary Payload Adapter (ESPA)-class mission using solar-electric propulsion to conduct Discovery-class science for understanding the water on the Moon leveraging rideshare launch options, new propulsion technology, and miniaturization of instrumentation. Major trades considered include orbital requirements, propulsion, instrument payload, and mission duration.

Rideshare: The primary rideshare concept evaluated was a trajectory directly to the Moon from Earth orbit. This is possible with a mission design that enters lunar orbit from Earth orbit via a Geosynchronous Earth-to-Moon transfer orbit. With this concept, the number of launch opportunities is maximized by leveraging rideshare options on geosynchronous communication and other commercial satellites. We are also exploring the characteristics of a mission that assumes a rideshare into lunar orbit insertion.

Orbit: Upon entering lunar orbit after delivery to the Moon on a rideshare or independently entering from a geostationary transfer orbit (GTO), the spacecraft spirals in to a low-altitude perilune of < 15 km and distant apolune of 1000 km. This elliptical science orbit has a lower periapsis than previous missions and a significantly higher apoapsis. The close perilune enables the characterization of both surficial and near-surface water

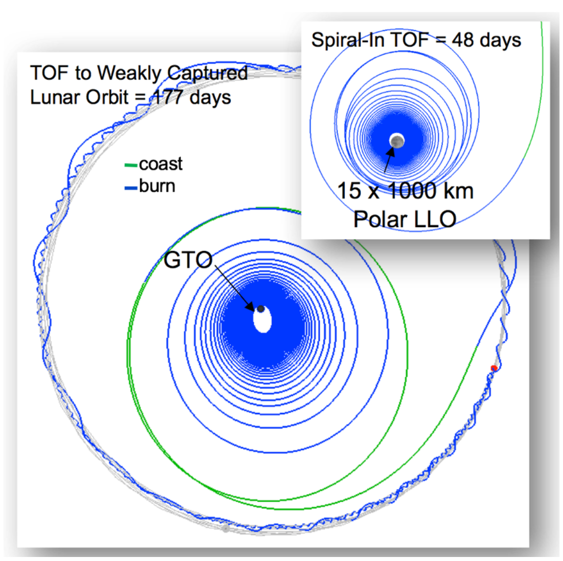

Figure 2. Spiral out from GTO occurs over 177 days (central figure) with lunar capture and spiral in to science orbit (insert).

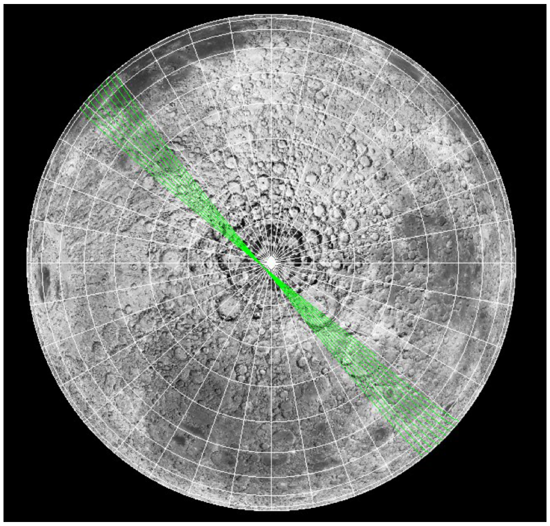

Figure 3. One day of orbits over the South Pole shown to 75°S.

at unprecedented spatial resolution to characterize the water/geologic/temperature dependencies. The high apolune, compared to other missions, enables a distant perspective to obtain both a global perspective of the Moon with a wide range of terrains seen at one time at different local times of day.

Propulsion: We baseline solid iodine solar electric propulsion (SEP), the Busek BHT600W thruster; operating two each at 400W, together providing adequate margin for the mission duration. SEP enables an efficient, if slow, spiral from GTO to a weak lunar capture in ~ 180 days, and then a ~ 50-day spiral down to the science orbit of 1000 km x 15 km at a 90° inclination over the south pole. The argument of perigee is maintained within 5° of the pole during the 6-month science phase. The total ΔV is ~ 4.6 km/s. Each orbit duration is ~ 1.5 hours, with approximately one orbit per week devoted to orbit maintenance. The low cadence is enabled by allowing the argument of periapsis to drift to 5° from the pole, and allowing the perilune to drift up to no more than 25 km.

Instrument	Role	Heritage
3-μm spectral imager	Surficial OH/H_2O	ESTO IIP
MidIR Multispectral Laser	Surface ice and water	*Lunar Flashlight*
Neutron Spectrometer	Near surface H abundance	*MESSENGER* NS

Instruments. Mass is a significantly limited resource on a smallsat mission, whereas power is available as this is an SEP mission and large data volumes are possible because of the proximity of the spacecraft to Earth. The baseline instruments are low mass, and consist neutron spectrometer to measure near surface hydrogen deposits at high resolution and signal to noise in the south pole, a multispectral IR laser (WattIR) to characterize surface water in dark PSR, and a multispectral mid-IR imager (CMIS/MIMSI) for characterizing the distribution, abundance, and temporal variation of water on the portions of the Moon illuminated by sunlight or Earth shine. A 15-km polar perilune will enable high-spatial-resolution measurements of polar volatiles such as with a neutron spectrometer (NS), an active IR multispectral imager to characterize the water in the PSRs. At apolune, global information would be obtained on the formation and loss mechanisms and evolution of OH and H_2O on the illuminated Moon using the mid-infrared multispectral imager formed on the Moons' illuminated surface and in areas of the PSRs that are illuminated by earth shine.

The neutron spectrometer requires ~ 6 months to obtain high signal-to-noise neutron maps of the south pole. This is the primary driver for the duration of science orbit. The NS will operate continually with science measurements occurring within 15° of the pole near perilune to produce maps of hydrogen abundance at a spatial resolution of between 15 and 25 km. This instrument This instrument is a simplified copy of the MESSENGER NS.

The WattIR peers into the shadows at the poles on the Moon. It will obtain strips (noodles) several km long only several meters wide at wavelengths in the water absorption bands, including near 3 μm, to characterize the nature and distribution of molecular adsorbed water, water ice, and hydroxyl on the surface regolith. It will only operate at latitudes greater than 75° because this is both where PSRs are most common and altitude sufficiently low to obtain high signal from the reflected laser illumination. The short orbit average operation limits the average orbit power to under 5 W even though the instantaneous power would be up to ~ 100 W.

The CMIS/MISMI is a passive midIR (1.7 to 4 micron) multispectral imager based upon and APL development. It will operate continually to observe the Moon at high resolution at the south pole and at lower resolution of ~ 200 to 300 m/pixel at apolune, to characterize geologic relations as well as temporal/global dependencies of water on the illuminated Moon. It will generate the majority of all the instruments' data volume of ~ 1Gbit/orbit. The data will be transmitted back via x-band communications. Together these instruments use an average of ~ 20W per orbit and have a total mass of ~ 20 kg, both without margin.

References: [1] Pieters et al., (2009), Science, DOI: 10.1126/science.1178658; [2] Sunshine et al., (2009), Science, 10.1126/science.1179788; [3] Clark, 2009, Science, 10.1126/science.1178105; [4] Colaprete et al., 2010, Science, pp. 463-468.