2023-2032 Planetary Science and Astrobiology Decadal Survey: A Smallsat Proposal for Ocean Worlds Program.

Outer Planets Assessment Group Lightning Talk Presentation

Lunar Surface Science Workshop
Fundamental and Applied Lunar Surface Research
in Physical Sciences

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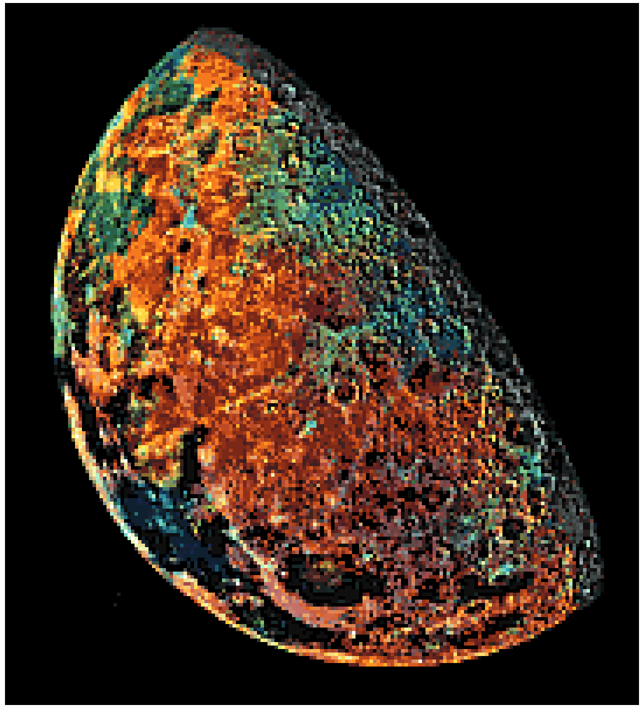
ABSTRACT

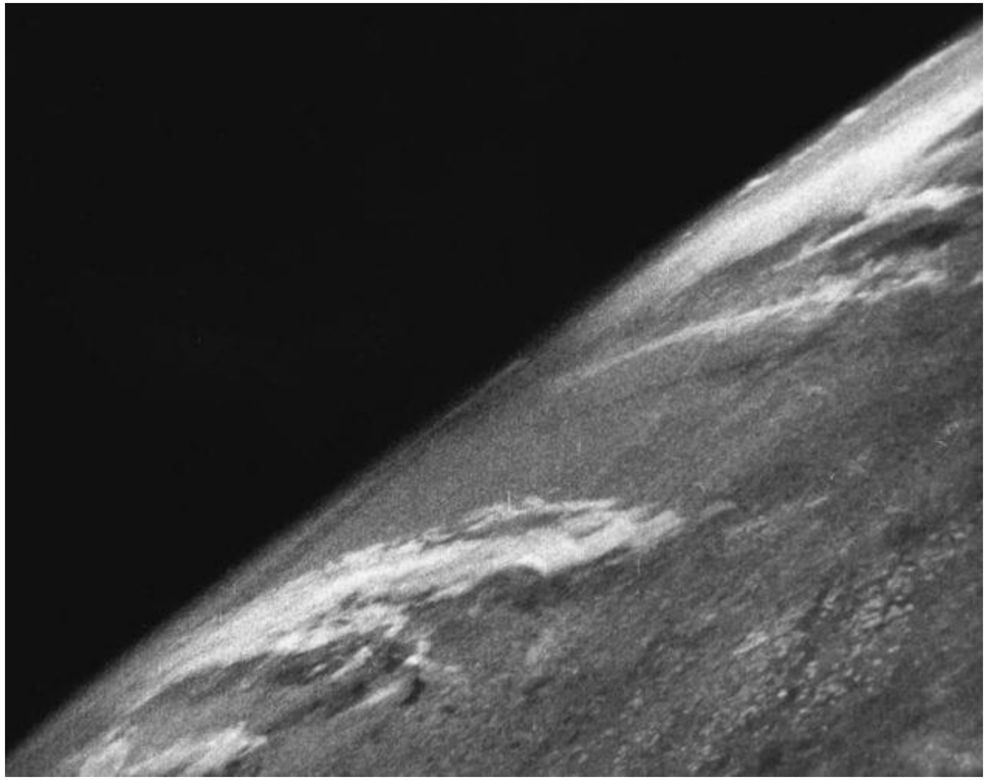
The overarching goal of an Ocean Worlds Program (OWP) is to identify/ characterize ocean worlds and evaluate their habitability. The confirmed ocean worlds Enceladus, Titan, and Europa have known subsurface oceans, as determined from geophysical measurements by Galileo and Cassini space missions. Lessons may be learned from near-term study missions to the Earth's moon in locating water regions. The purpose of this poster is to provide notional smallsat architectures developed for the lunar missions that will address Outer Planets Assessment Group (OPAG) concerns about implementing technologies of observational sensing/ imaging and communications.

Gallileo (1990) vs Cassini (1999) Flybys of Earth's Moon

A false color image of the Moon created by combining 53 images taken from three different filters on Galileo during the 1992 flyby. Pink represents highlands, blue to orange denote volcanic flows. Galileo (1990 and 1992)

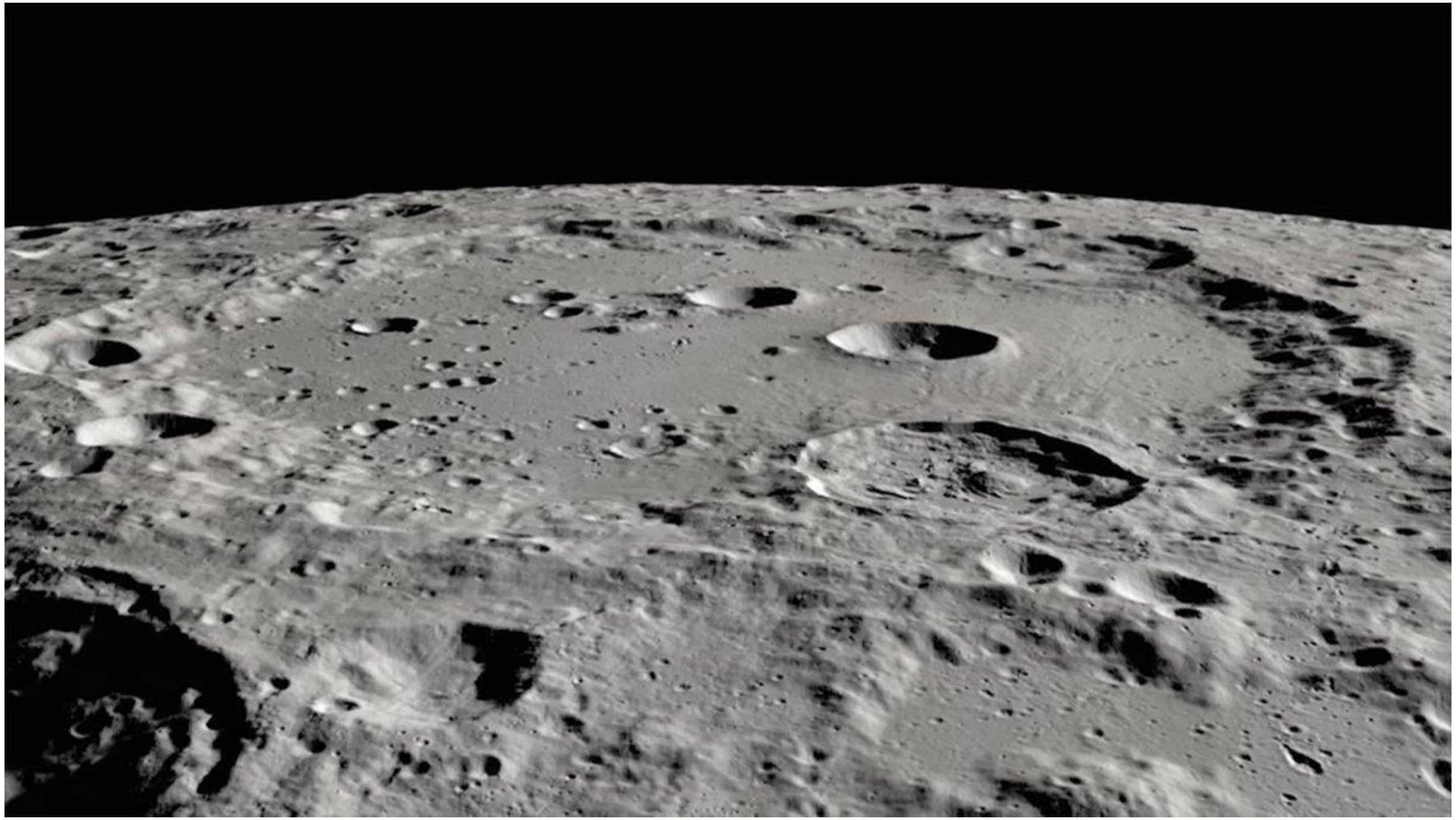


The first photo of the Earth was shot on 24 October 1946 and you wouldn't believe what we used to shoot that photo. It wasn't a space probe, satellite or astronauts in a spacecraft. It was a missile. A Nazi missile.



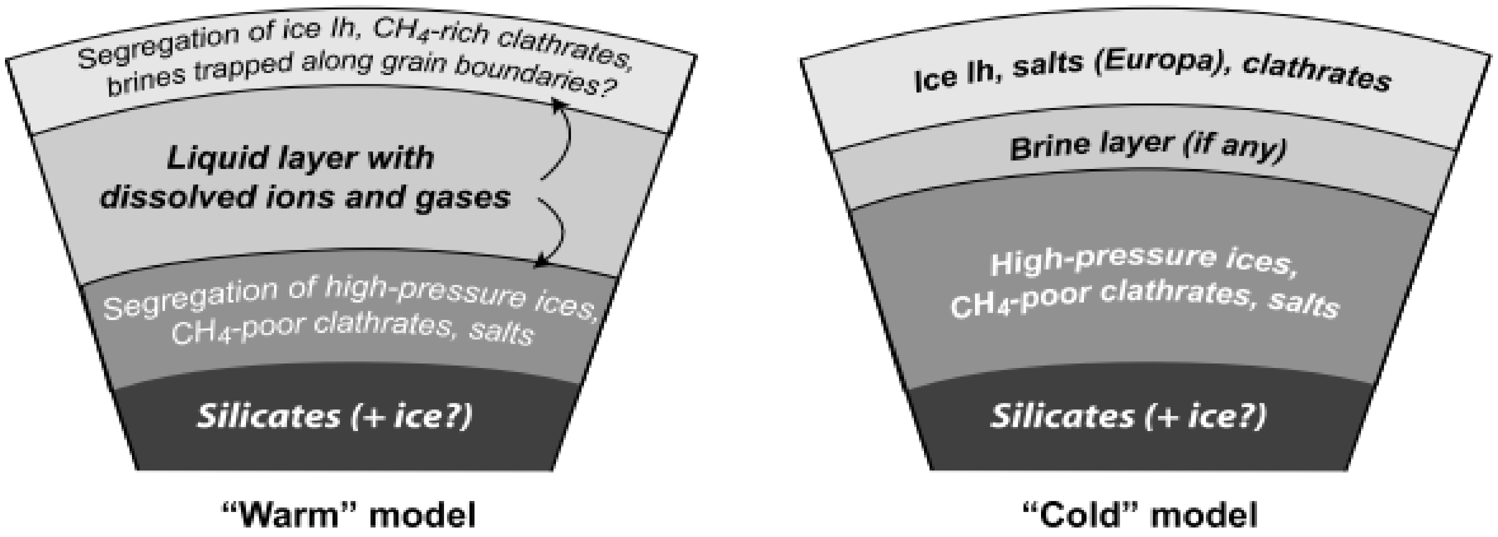
In the late 2000s, a number of missions including the Indian Space Research Organization's Chandrayaan-1, and NASA's Cassini and Deep Impact detected hydration on the lunar surface – but these missions could not determine if the signals were hydroxyl (OH) or water (H_2O).

Clavius Crater on the Moon. Credit: NASA/USGS



Enceladus, Europa, Titan, Ganymede, and Callisto have known subsurface oceans, as determined from geophysical measurements by the Galileo and Cassini spacecraft. These are confirmed/known ocean worlds. The subsurface oceans of Titan, Ganymede, and Callisto are expected to be covered by relatively thick ice shells, making exchange processes with the surface more difficult, and with no obvious surface evidence of the oceans [2].

The subsurface oceans of Titan, Ganymede, and Callisto are expected to be covered by relatively thick ice shells, making exchange processes with the surface more difficult, and with no obvious surface evidence of the oceans. An energy source is single most fundamental requirements to maintain a present-day ocean on an otherwise frozen world. Observations by the Cassini spacecraft have demonstrated that such heating does, in fact, occur, but the Moon emits an order of magnitude more energy (at the present time) than theoretical models predicted



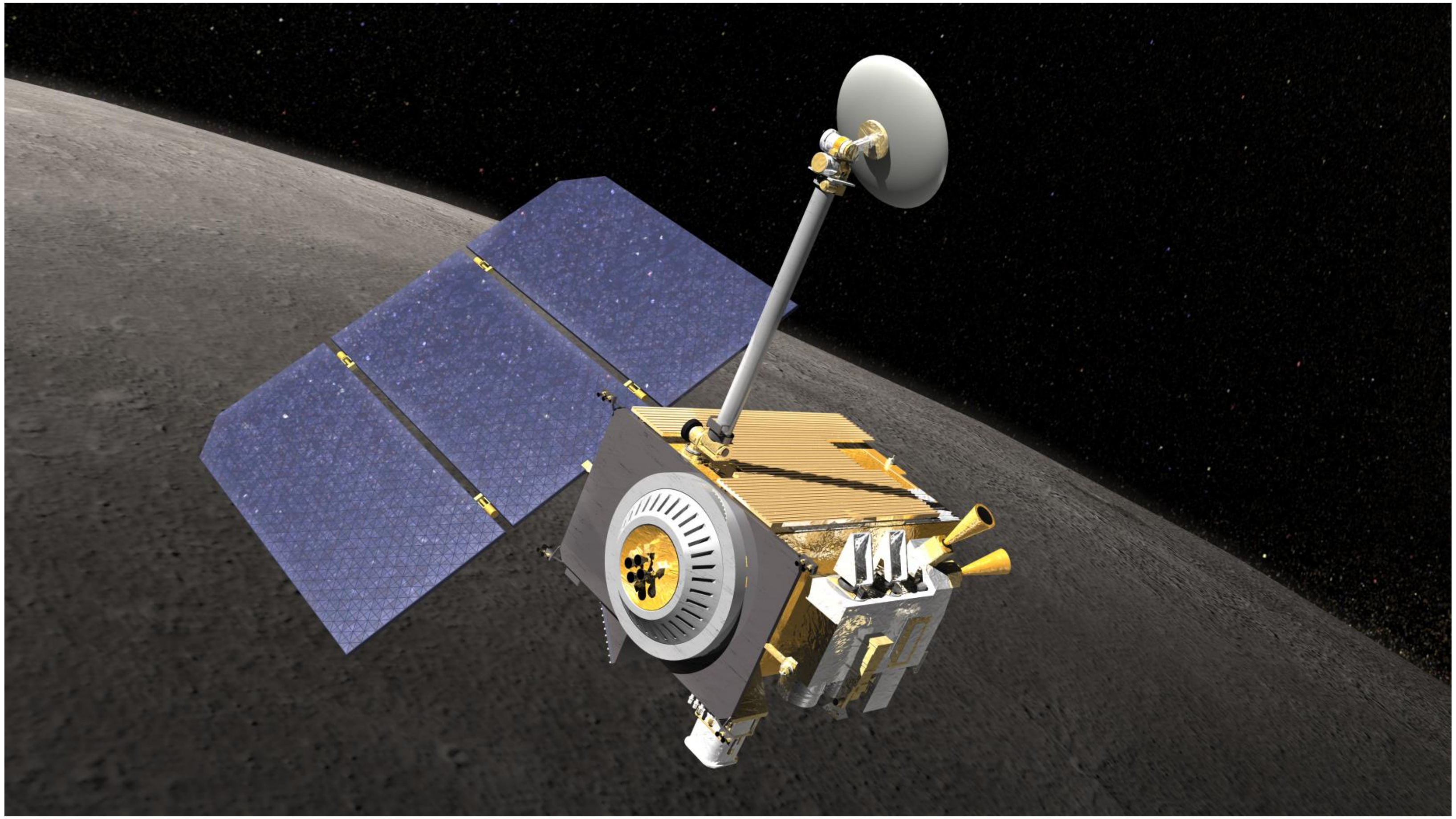
Pathways of subsequent oceanic evolution were mostly dependent on the scale, timing, and locations of heat production in the satellite interiors. The higher the salt/ammonia content of an icy satellite, the colder the thermal profile across its interior will be. The warm model describes the situation within Ganymede and Titan. High-pressure ices can only be generated upon cooling of icy bodies with an H2O mantle larger than that of Europa as shown in the cold model.

Seismology: To detect “vital signs” in Ocean Worlds

Both radiogenic heating (for Europa, Ganymede, Callisto, and Titan) and tidal energy (for Europa and Enceladus) play a role in sustaining oceans. Observations by the Cassini spacecraft have demonstrated that such heating does, in fact, occur. Seismology is the best tool for remotely investigating possible “vital signs” in ocean worlds. Detecting 30 fluid-related seismic signatures similar to those on Earth would provide key information for constraining available redox fluxes and locating possible niches for life. A Europa Clipper mission would include a radar sounding instrument and magnetometer to probe the subsurface structure of Europa. Broad applications of planetary seismology have been well explored at solid silicate bodies, such as the Moon. Comparatively, the Lunar Geophysical Network mission involves the emplacement of four geophysical nodes at geographically diverse locations on the lunar surface, each with a suite of science instruments that probes the Moon’s.

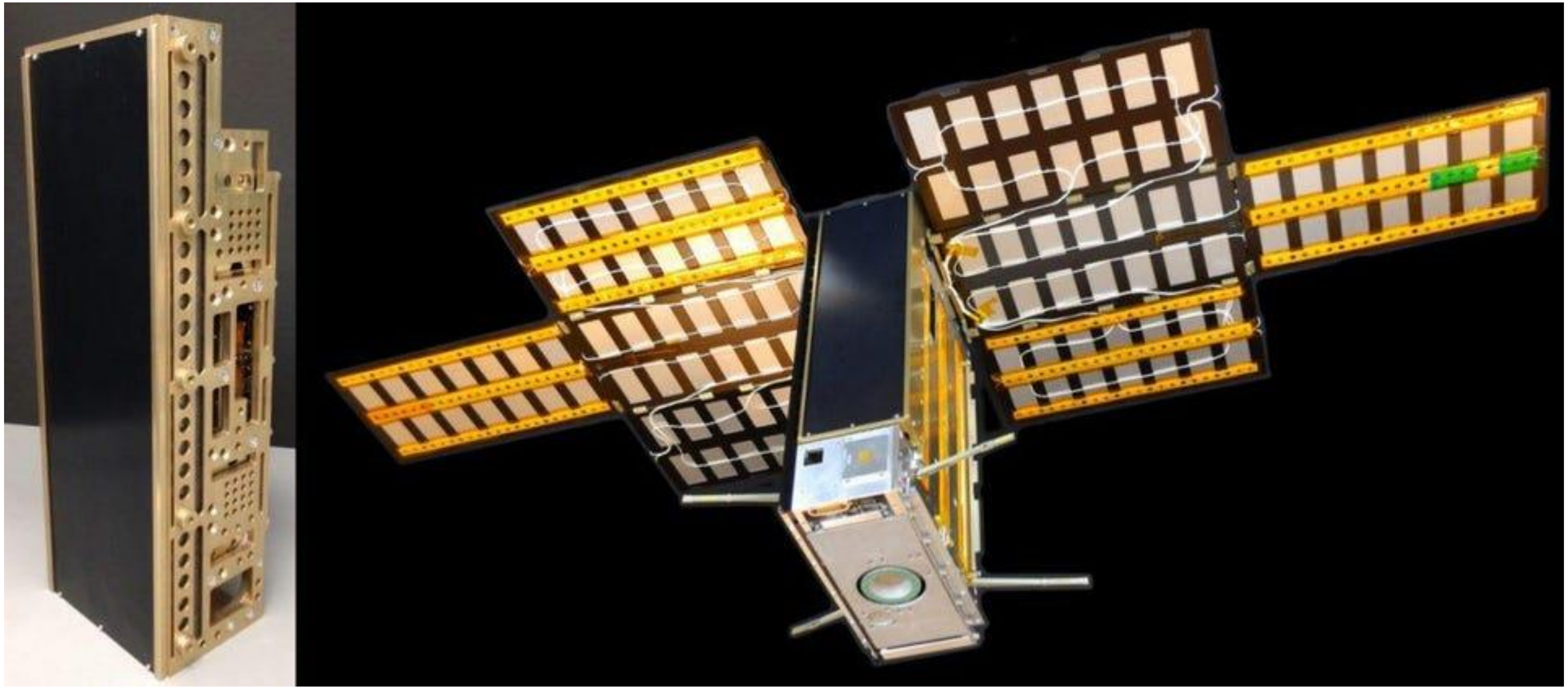
INTRODUCTION

The Lunar Polar Hydrogen Mapper Mission (LunaH-Map), to be launched in November, 2021, as a secondary payload on Artemis 1. LunaH-Map's primary objective is to map the abundance of hydrogen down to one meter beneath the surface of the lunar south pole. It will be inserted into a polar orbit around the Moon. LunaH-Map will provide a high resolution map of the abundance and distribution water, The Lunar Reconnaissance Orbiter (LRO) provided many observations to begin the characterization of lunar water. To date, most understanding of lunar polar volatile abundance, distribution, composition, and physical form is derived from remotely sensed observations of the Moon. Just as LEO smallsats communicate with ground control centers on Earth, lunar orbiters will communicate with relay stations on the lunar surface as the industrial base develops on the Moon. And, there will be a direct lunar-Earth direct link for communications. LRO could be a larger spacecraft able to receive multiple links from a lunar constellation of 20" smallsats, which themselves have aggregated user data, and connect each orbiter to Earth over the larger relay's links with Earth. The Moon provides an interesting possibility because the same part of its surface always faces Earth.

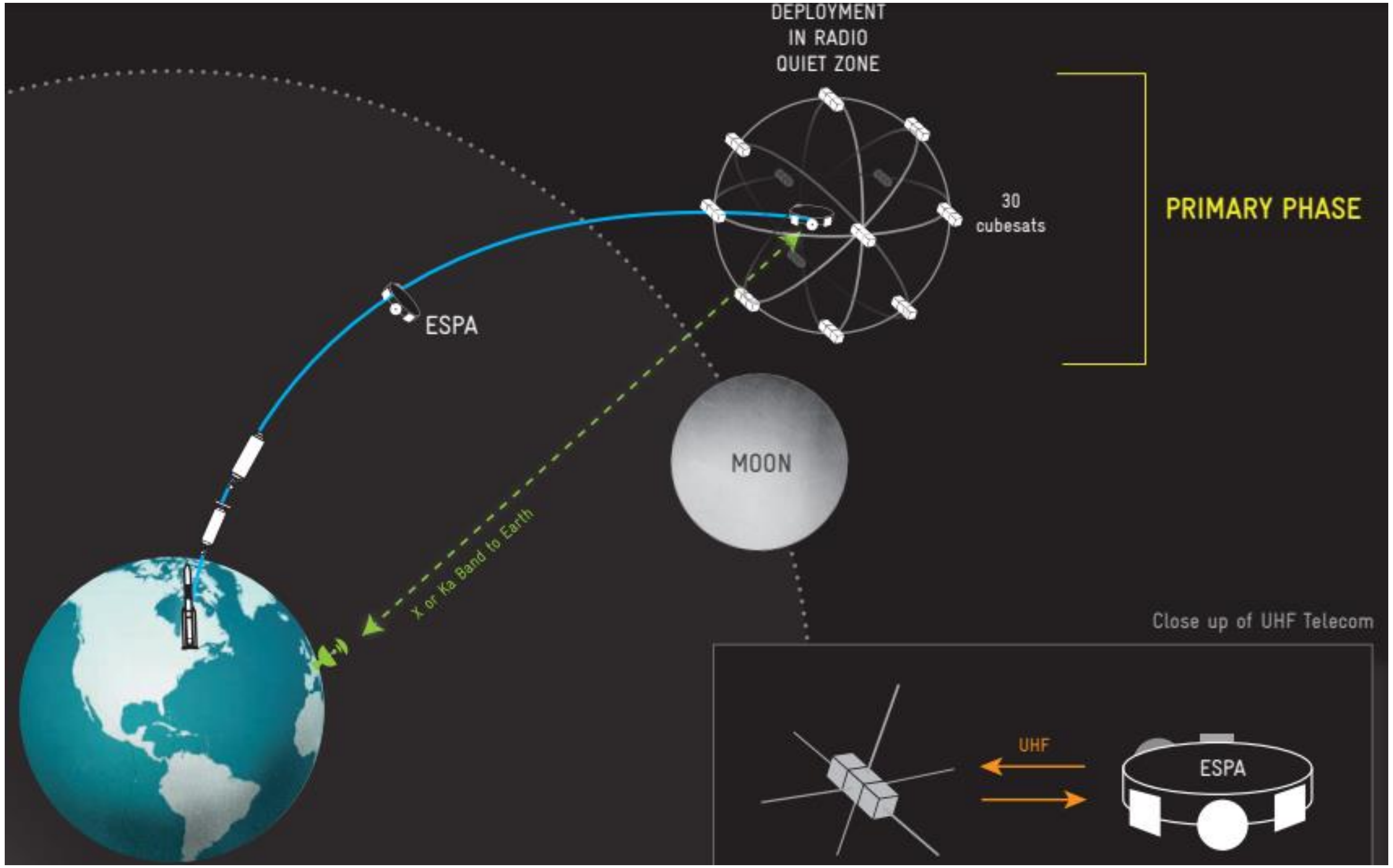


The Lunar Polar Hydrogen Mapper Mission (LunaH-Map), to be launched in November, 2021, as a secondary payload on NASA's Space Launch System (SLS) Exploration Mission (EM-1 or Artemis 1) will spend two months mapping the abundance of hydrogen, and by rote water (H2O) ice, in the lunar South Pole's deep craters. Unlike most conventional CubeSats, LunaH-Map will need to navigate to its desired orbit after leaving the launch vehicle, so it will need to be equipped with its own propulsion system.

During its science mission, LunaH-Map will make repeated flyovers of several well-known South Pole lunar craters ; including, Cabeus, Shackleton, Amundsen, and Sverdrup. The spacecraft will produce maps of bulk lunar regolith water-ice at spatial scales that allow us to "see" into the permanently shadowed regions.

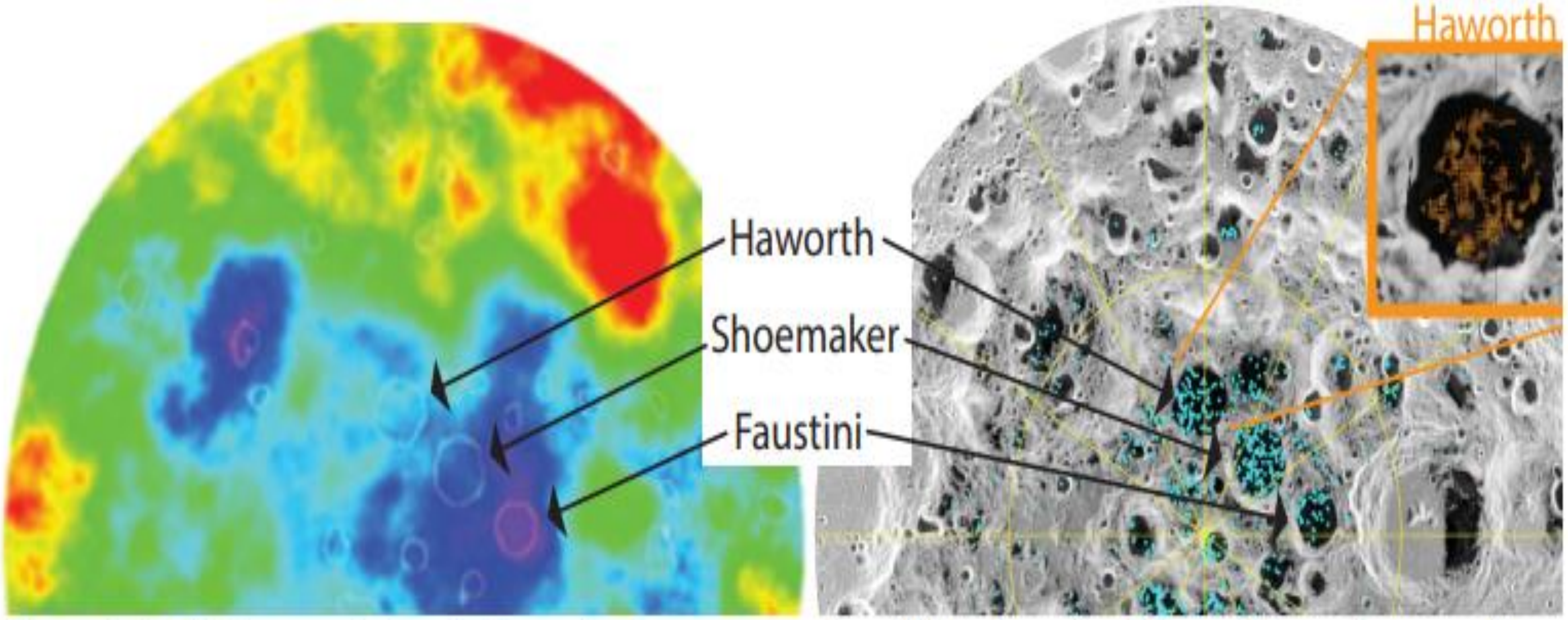


The ESPA ring was developed and flight qualified in the early 2000's as the *Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter*, to utilize excess launch capacity by mounting additional payloads, up to 400 lb each, below a primary spacecraft up to 17,000 lb. Just as LEO smallsats communicate with ground control centers on Earth, lunar orbiters will communicate with relay stations on the lunar surface as the industrial base develops on the Moon. And, there will be a direct lunar-Earth direct link for communications. LRO could be a larger spacecraft able to receive multiple links from a lunar constellation of 20" smallsats, which themselves have aggregated user data, and connect each orbiter to Earth over the larger relay's links with Earth. The Moon provides an interesting possibility because the same part of its surface always faces Earth.



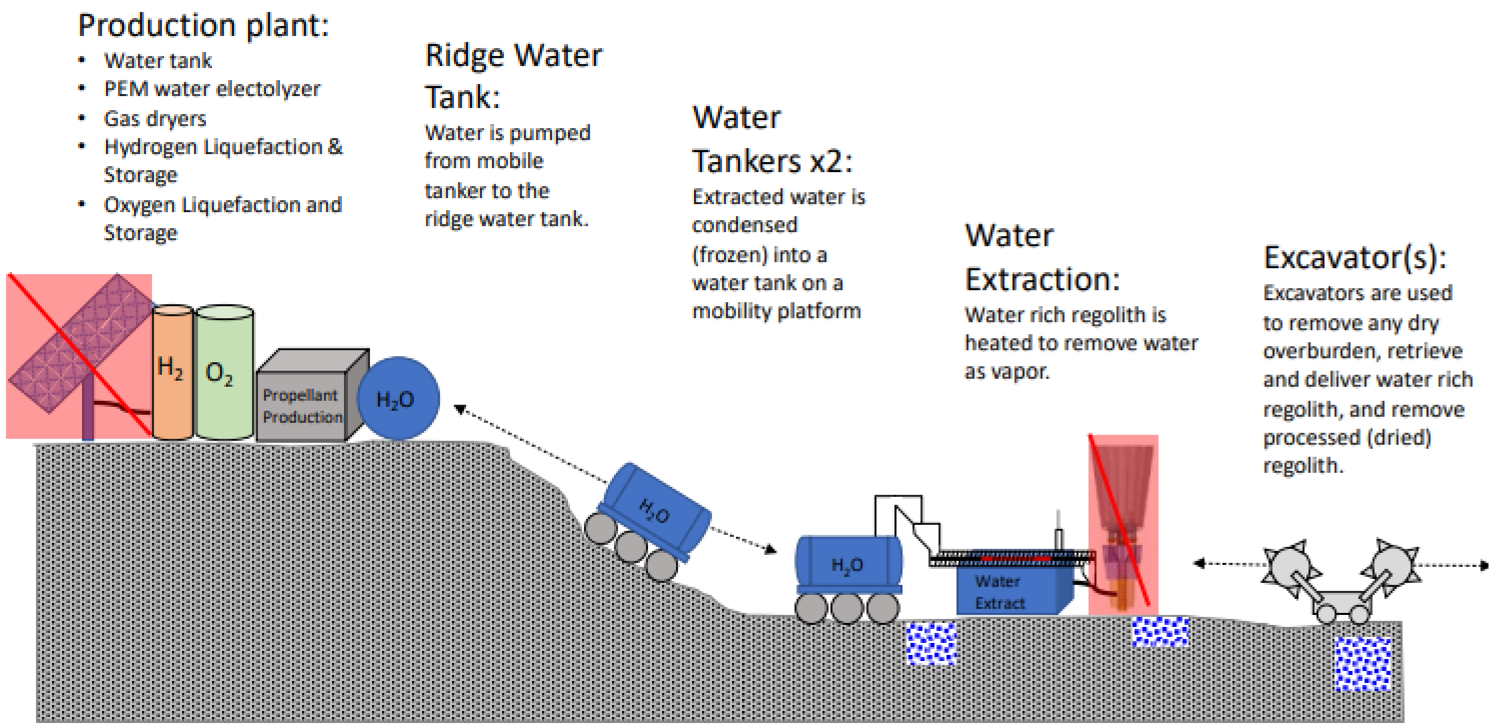
Spacecraft	Mariner 6 and 7	Clementine	Lunar Reconnaissance Orbiter (LRO)/ Lunar Crater Observation and Sensing Satellite (LCROSS)	Lunar Polar Hydrogen Mapper (LunaH-Map)
Year	1969 (Mars flyby)	1994 (Moon)	2009 (Lunar orbit)	2021(Low Lunar science orbit near PSR crater)
Instruments	IR/ UV Spectrometer; Camera; Radiometer	IR/ UV multi-spectral imaging of the entire lunar surface	Neutron detector, radiometer, camera. altimeter	Miniaturized neutron spectrometer
Results	Martian atmospheric and surface water	Lunar water ice in polar cold traps	Global mapping of Moon surface and permanently shadowed regional (PSR) craters to detect polar	Lunar mapping of bulk lunar regolith water-ice at spatial scales to "see" into PSRs.
Communications Earth→ Moon	Deep Space Network	Deep Space Network	Space Communications and Navigation (SCaN)	Deep Space Network (+ Morehead)

Eventually, the lunar permanently shadowed regions of water ice will expand to a lunar mining operation that extracts and processes water ice into liquid oxygen/liquid hydrogen propellant. The availability of space-sourced propellants dramatically lowers the cost of space transportation beyond low Earth orbit, enabling the development of a robust commercial economy in cislunar space.

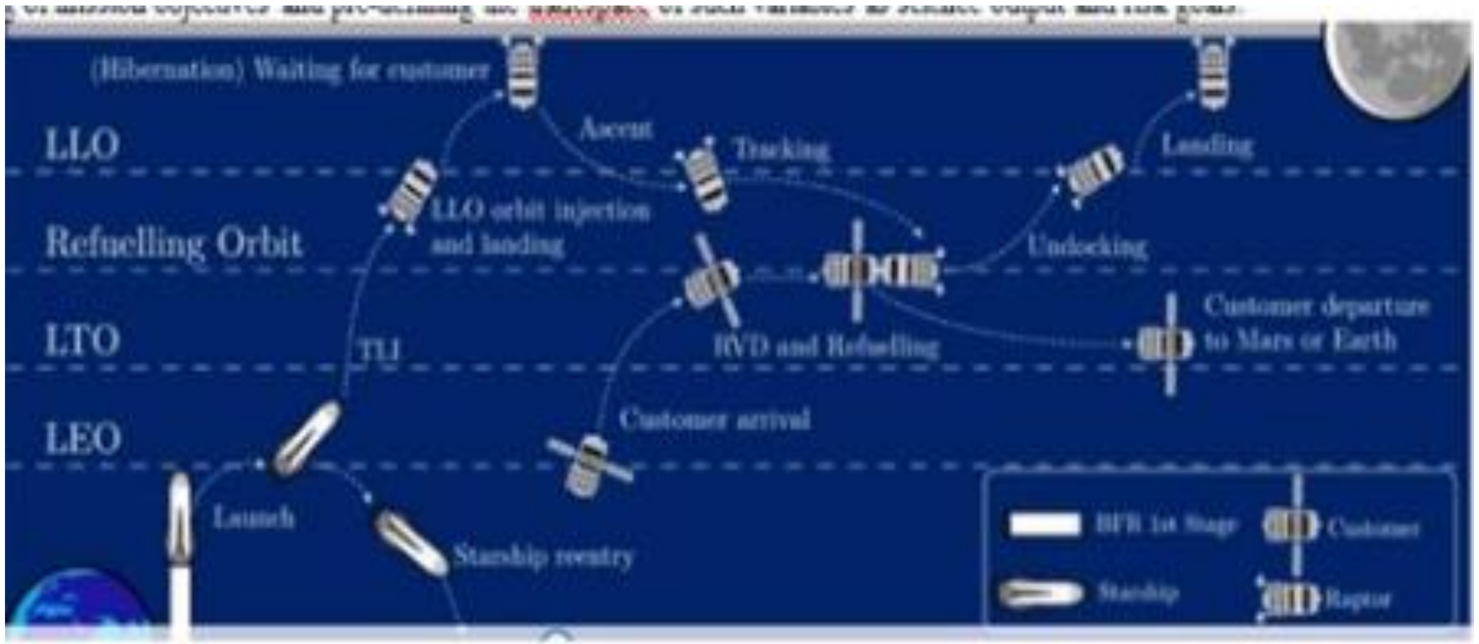


Propellant produced from extracted lunar water remained the main objective. It was asserted that a refueling station would enable the use of the low lunar escape velocity to facilitate further interplanetary exploration. Different mission architectures with crewed and robotic activities were reported, presenting the pros and cons of involving no, partial, or total use of extraterrestrial resources. Although the cost of developing the technologies needed to extract space resources was seen as being as costly as supply from Earth, the ability to produce in-situ propellant was considered a game changer for the economic viability of longer term space exploration.

The ISRU (in-situ resource utilization) system architecture involves two sites: 1. the mine site in a shadowed crater where water ice is excavated and extracted from the regolith; and, 2. the propellant production site at an illuminated ridge to process water into liquefied O_2 and H_2 propellants. Fixed hardware would be emplaced at each site, with two alternating water tankers to transport water between them. Notional lunar sites would be identified for this baseline architecturally-specific environment parameters. The overall concept of operations (Con-ops) involves three systems, the operations at the mine site (water excavation and extraction), operations at the ridge site (propellant production), and the water transport vehicles (tankers) that runs between them.



Constellations based on different configurations of instruments and orbits provide a forward-looking, quantitative, cost-benefit analysis was not intended to deliver a particular point solution with definitive satellite constellation, instrument vendor, or data service provider. Rather, it identified options to inform budget and program decisions. Technology has been developed to “approach, grasp, manipulate, modify, repair, refuel, integrate, and build completely new platforms and spacecraft on orbit. On-orbit servicng of smallsat constellations provide the maintenance infrastructure to sustain lunar operations.



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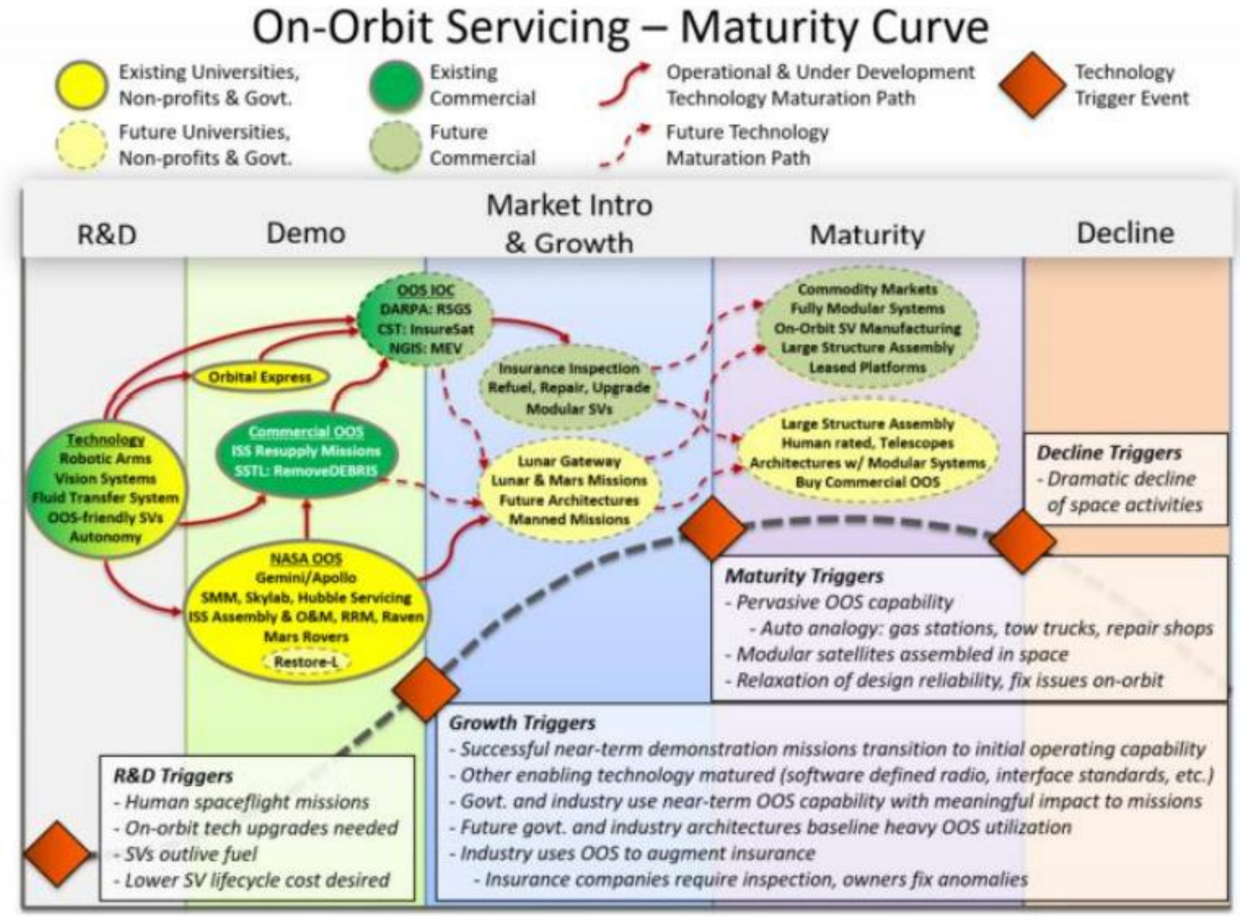


Water-to-Propellant Technology

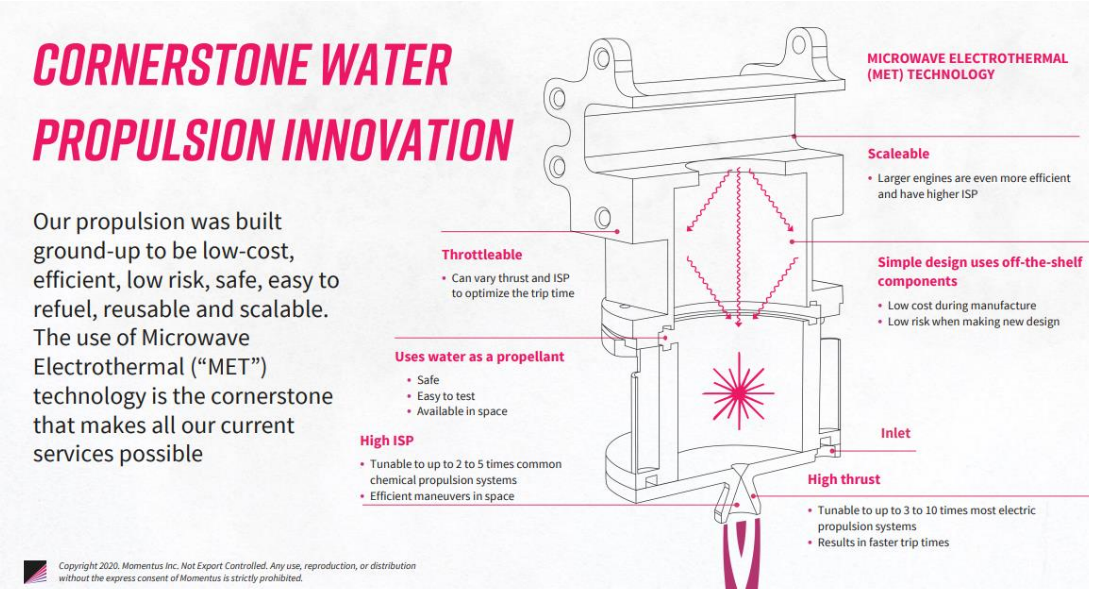
ORBITEC

Advanced Microwave Electrothermal Thruster

Advanced Microwave Electrothermal Thruster (AMET) for use as one of the primary thrusters in the Dual-Mode Water Rocket Propulsion system. The AMET uses an electrodeless microwave discharge to produce thrust from water vapor propellant, delivering specific impulse in excess of 800 seconds with a highly efficient process. Microwave energy is introduced to a resonant chamber via an antenna; the microwave energy is refocused by the chamber at a location immediately upstream of the nozzle. Water vapor (steam) propellant is tangentially injected into the aft (left) half of the resonant chamber, and swirls inward towards the nozzle. A plasma discharge in the water vapor is established at the focal point adjacent to the nozzle, facilitating the transfer of energy from the oscillating microwave energy to the water vapor prior to its expulsion from the nozzle to produce thrust. Microwave electrothermal technology is the only known option for delivering high Isp (over 500 seconds) from water.

Momentus Inc.

Microwave Electrothermal (heated) Water (plasma) to Propellant Technology



Conclusions

- Extraterrestrial Propellant Production-based on lunar supply of water-ice reservoirs.
- Mapping of lunar water-ice reservoirs –based on flyby missions, orbiter remote sensing, lunar seismology studies by surface landers/ rovers.
- Lunar-to-Earth ground communications – based on smallsat constellations in communications with orbiter and with seismology rover missions.
- On-orbit servicing smallsats to sustain / maintain lunar orbit smallsat constellations.
- Lessons learned from lunar mission studies to apply to other Ocean Worlds.