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LunaRevolution-Role of the Moon in the Future of Human Space Activity

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Abstract

The Moon, our closest celestial neighbor, was visited by astronauts nearly half a century ago, and a new wave of robotic missions are mapping it in extraordinary detail. Many nations and even private entities are in advanced stages of robotic lunar missions, deploying orbiters and landers to utilize, evolve and refine advanced space technologies and capabilities with the intent to set up permanent extraterrestrial infrastructure. LunaRevolution is a series of visions offered by USC graduate students in Astronautical Engineering in the fall of 2015 about what kind of projects are possible on the Moon in the near term(2015-2025) using the knowledge and systems that we already possess, and the ambitions of a new generation of space explorers and space professionals. The role of private space sector is seen as the key enabler for sustainable space activity. It is clear that a paradigm shift from "open-ended scientific exploration that drives the programs of the world's space agencies to one of self-sustaining utilization is the key for this 21st century space activity.

Topics explored in this six-week study spanned concepts in lunar science and relevance to evolution and climate change on Earth, cislunar laser communications, fuel production, advanced lunar agriculture and nuclear power testbed technologies. Creative robotic systems for construction and safe lander systems were proposed. An incremental strategy for evolving lunar tourism was presented. Planetary defense based on the Moon was also addressed.

The team project slides may be accessed at : http://denecs.usc.edu/hosted/ASTE/527_20111/ under the topic "08 -LunaRevolution-Role of the Moon in the Future of Human Space Activity."

The presentation will include highlights of these topics and show the potential of our Moon as the stepping stone for advancing human and robotic space activity. The Moon could develop into an ideal staging location for a variety of activities including enhancing planetary defense of Earth and providing critical support for testing and certifying vehicles and their critical systems for long duration expeditions, in preparation for more ambitious interplanetary missions in a timely manner.

Return to the Moon by human beings is absolutely fundamental and necessary for our evolution as a space faring species. The astronomical and biological sciences would also benefit from a renewed human presence on the Moon, especially from the establishment of a permanently occupied international scientific outpost. A permanent Overview Effect from the Moon will make us a more refined species that is ever more sensitive Earth's fragile biosphere and to the needs and aspirations of all humanity.

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Introduction

The Moon, our closest celestial neighbor, was visited repeatedly by astronauts nearly half a century ago, and a new wave of robotic missions are mapping it in extraordinary detail. Many emerging spacefaring nations are collaborating with established space powers to plan and execute missions. And even private entities are in advanced stages of robotic lunar missions, deploying orbiters and landers to utilize, evolve and refine advanced space technologies and capabilities with the intent to set up permanent extraterrestrial infrastructure.

LunaRevolution™ is the title of a team project by USC graduate students in Astronautical Engineering created in the fall of 2015 that offers glimpses of a series of visions about what kind of projects are possible on the Moon in the near term(2015-2025) using the knowledge and systems that we already possess, and the ambitions of a new generation of space explorers and space professionals. The role of private space sector is seen as the key enabler for sustainable space activity. It is clear that a paradigm shift from “open-ended scientific exploration” that drives the programs of the world’s space agencies today to one of “self-sustaining utilization” is the key for this 21st century space activity.
Topics explored in this six-week study spanned concepts in lunar science and relevance to evolution and climate change on Earth, cislunar laser communications, fuel production, advanced lunar agriculture and nuclear power testbed technologies. Creative robotic systems for construction and safe lander systems were proposed. An incremental strategy for evolving lunar tourism was presented. A new idea that explores Planetary defense of Earth that based on the Moon was also addressed. A series of synopses of concept architectures presented for review by the LunaRevolution participants are listed below.

Moon or Mars ?

The Moon or Mars debate continues despite every single report or recommendation(Thangavelu 2015) including latest references from NASA[Cruzan 2016], NRC or other independent study that point to the Moon as the next logical destination for human space exploration and settlement[NSS Space Policy Library]. Once we hone the technologies to live there, “this time to stay" as the Bush administration of yore put it, we would have all the tools to live on Mars, return resources from the asteroids, homestead on Ceres or even the much prettier outer gems in our solar system like the satellites of Jupiter or Saturn, where the vistas are far more spectacular and seasonal changes more dynamic than anything that Mars or Venus can offer. If an incrementally evolving and sturdy self- sustaining space infrastructure that is able to progressively mount ever more complex missions like interplanetary expeditions is the goal, then it is time now to extend our operations beyond low Earth orbit, build and test and evolve those reliable space and extraterrestrial systems that can support endurance-class missions. There are many simulations being carried out on Earth and on the international space station that offer valuable lessons but such activity cannot assure nor certify all the critical systems for an interplanetary expedition. Cislunar space and the lunar environment offers the most proximal regime to develop and evolve sturdy systems and protocols for endurance-class missions beyond LEO. See NASA EMC vision.[Cruzan, Craig 2016]While a direct to Mars campaign seems exciting and even feasible, progressive simulations in cislunar space and the lunar surface have much to offer in a economic buildup toward an interplanetary campaign while also promoting the evolution of a self-sustaining model for space activity beyond LEO that provides ample opportunity for global governmental and private sector commercial partnerships.[Miller etal 2015]

MUST: Moon Utilization for Science and Technology

Since ancient times, the Moon has always been a prominent celestial orb in our skies that the human beings dream to visit and explore. There are many aspects to list for its scientific importance. First of all, our dormant Moon, devoid of dynamic weathering processes, keeps a geologic record of its evolution and that of the near-Earth cosmic environment.[Paulikas et al 2007] Our dormant Moon holds chronicles of our Solar System history in the lunar regolith. Through the Moon, we can learn about the geological processes that have shaped all of the terrestrial planets. Lunar paleoregolith, unperturbed by tectonics or atmospheric weathering processes, holds a record of billions of years of solar activity that will forever change the way we understand and forecast climate change on Earth. Secondly, the negligible lunar atmosphere mass and density causes the lunar surface to be fully exposed to ultra high energy galactic cosmic rays and high energy particles released from the solar atmosphere, which makes the Moon a perfect location for high energy particle physics experiments. The lunar TWINS detector facility is proposed for such an experiment that uses naturally occurring ultra high energy cosmic rays instead of a particle accelerator to study the internal structure of the atom. Moreover, the Moon is also a unique platform for making fundamental astrophysical measurements relating to gravitation, neutron stars, pulsars, black holes, and the entire Universe. Unhampered by the Earth's atmosphere, and shielded by the lunar surface, lunar solar observatories could augment space based solar observatories and provide valuable solar activity information. Last but not the least, to make Mars or any other planet a new habitation for human beings, a lunar research base would give space agencies of the world expertise in engineering and operating life-support systems, supplying food and recycling water, creating sustainable energy sources, allow accurate, round the clock monitoring and Earth Planetary Defense system, as well as essential expertise in troubleshooting and malfunction recovery from system anomalies. The Moon could also be a site for conducting experiments deemed hazardous on Earth, and could be a staging point for a multitude of missions, both outbound and inbound, including those that require biological quarantine measures.

Figure 1. Our Moon holds an unperturbed record of solar activity. Access to it would allow us to predict and forecast solar behavior. This data can dramatically inform our understanding of climate change, as well as space weather that our evolving, high value space assets are vulnerable to.(image credit JAXA)

ELLComm: Elliptical Lunar Laser Communication

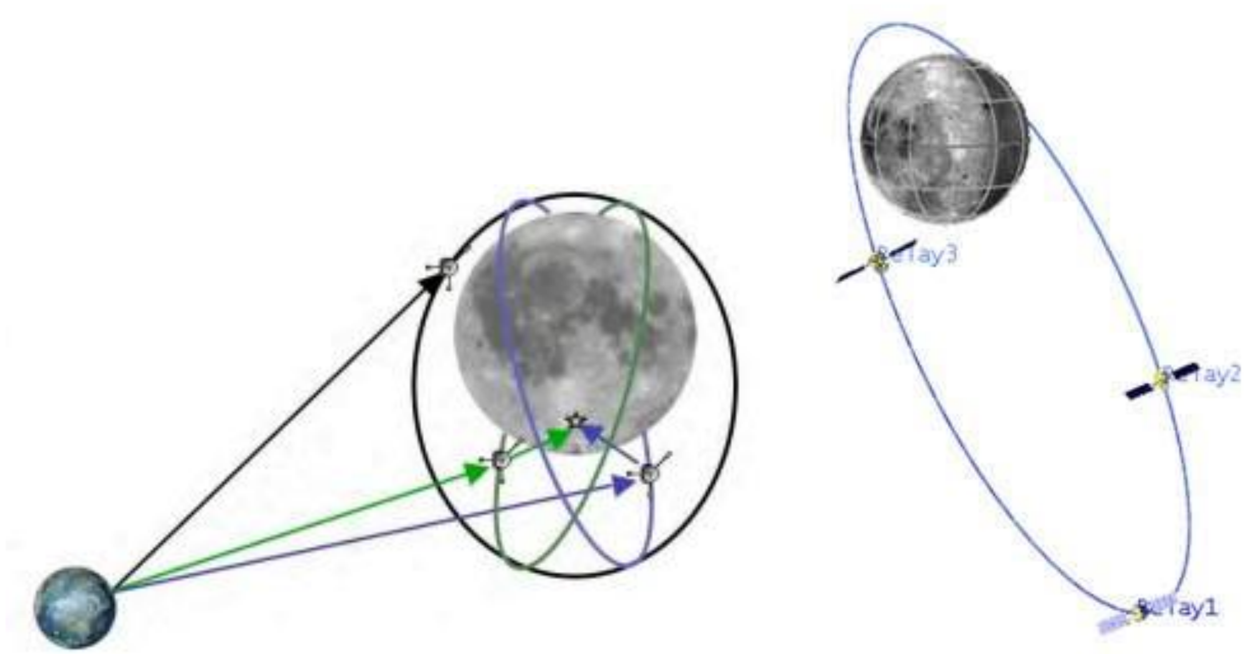

Figure 2. A three satellite lunar polar "frozen orbit" constellation can provide 100% Earth-Moon connectivity as well as high bandwidth laser links all around the polar highland regions.

"Communication is the key to success". "Loss of Link = Loss of mission". These heuristics remain true for space travel and lunar exploration. With several proposed Moon based experiments, including real time robotics, fast, reliable communication is necessary. There are several different approaches to lunar communication; from a communication station at Malapert Mountain in the South Polar Region, L1-L2 Halo Orbit constellation, laser satellite communication, and elliptical orbit satellite constellations. This proposal suggests that best option for continuous, fast, reliable Moon to Earth communication is a three laser communication satellite architecture in an elliptical lunar orbit constellation.[Fig.2]

Putting a satellite in orbit around the Moon is difficult. The Earth's gravity and lunar mascons cause irregular gravitational pulls along a lunar satellite's orbit. However, lunar "frozen orbits" exist that are not impacted by either the Earth or mascons, allowing satellites to stay in stable, steady and specific orbit for very long periods. These elliptical orbits with a high eccentricity makes good candidates for a lunar South Pole communication satellite constellation. Laser communication has been used on Earth for high speed Internet and other communications for many years. The Lunar Laser Communication Demonstration(LLCD) experiment, tested on September 27th, 2013, was the first use of this technology in space. It was a laser communications module putting out a 0.5 watt infrared signal onboard NASA's Lunar Atmosphere and Dust Environment Explorer(LADEE) spacecraft. [Fig.3] LLCD clocked data downlink rates of 622 megabits per second.

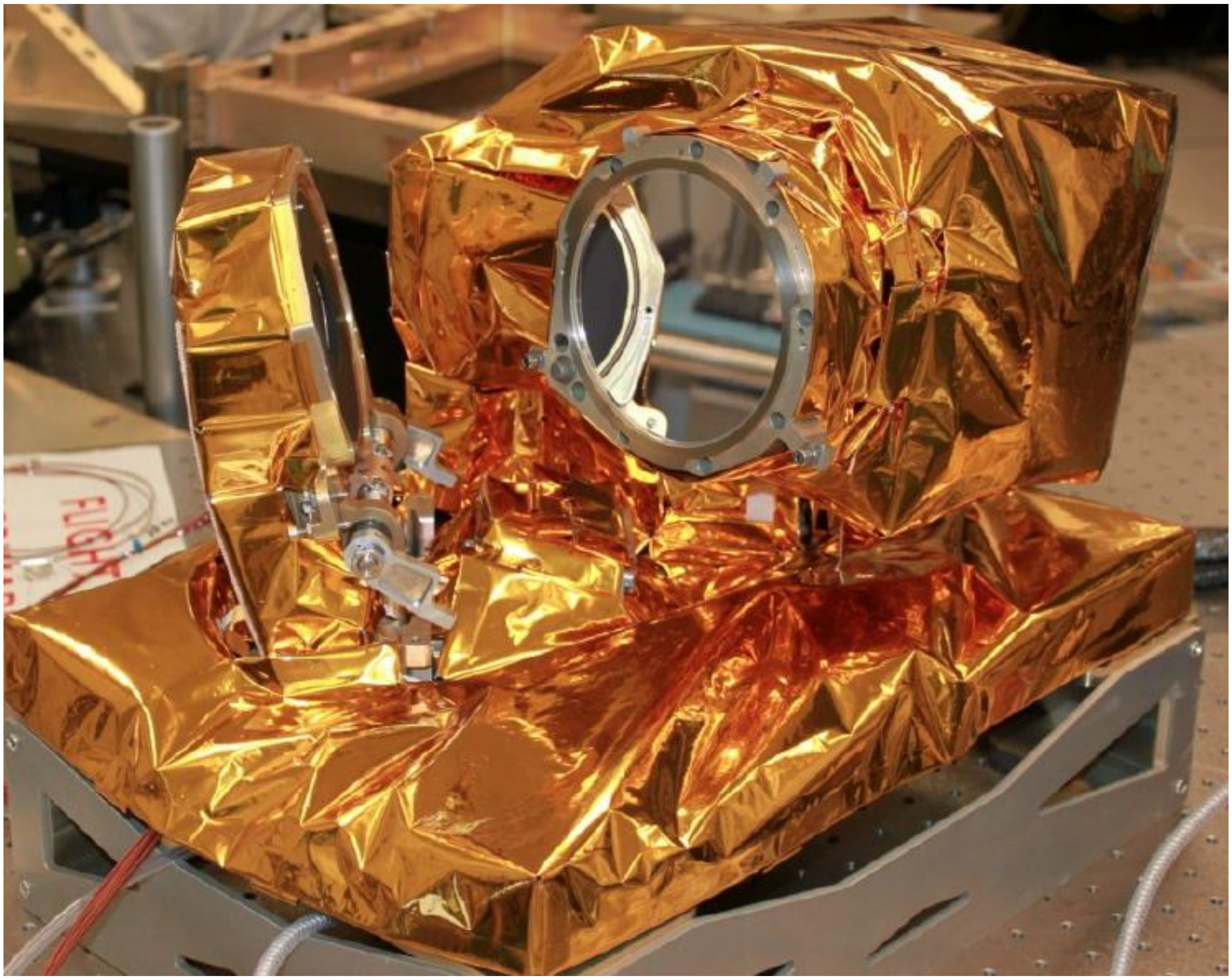

Figure 3. The LADEE Lunar Laser Communications Demonstration (LLCD) is an engineering demonstration experiment that was included in the LADEE payload as a proof-of-concept of long-range laser communications in space. LLCD proved that it is possible for a low power laser communication system to deliver very high throughput data rates between lunar orbit and ground stations on Earth.(credit MIT -LL)

This is a vast improvement over existing technology; a standard HD movie would take 639 hours to transfer using traditional S-Band technology and could be done in less than eight minutes using this free space Earth-Moon laser communication link. Both NASA and the European Space Agency have invested in future research of laser communications for satellites.

As well as being fast, LLCD was also a lightweight design, with low power requirements and weighing only 65 pounds. It was also made using commercial off- the-shelf parts, making it highly cost efficient. Three ground terminals were created to test this technology (White Sands, Table Mountain Facility, and El TeideObservatory), [Fig.4-5]so little to no additional cost would be necessary to create a ground station for the proposed Elliptical Lunar Laser Communication Constellation – ELLCOM.

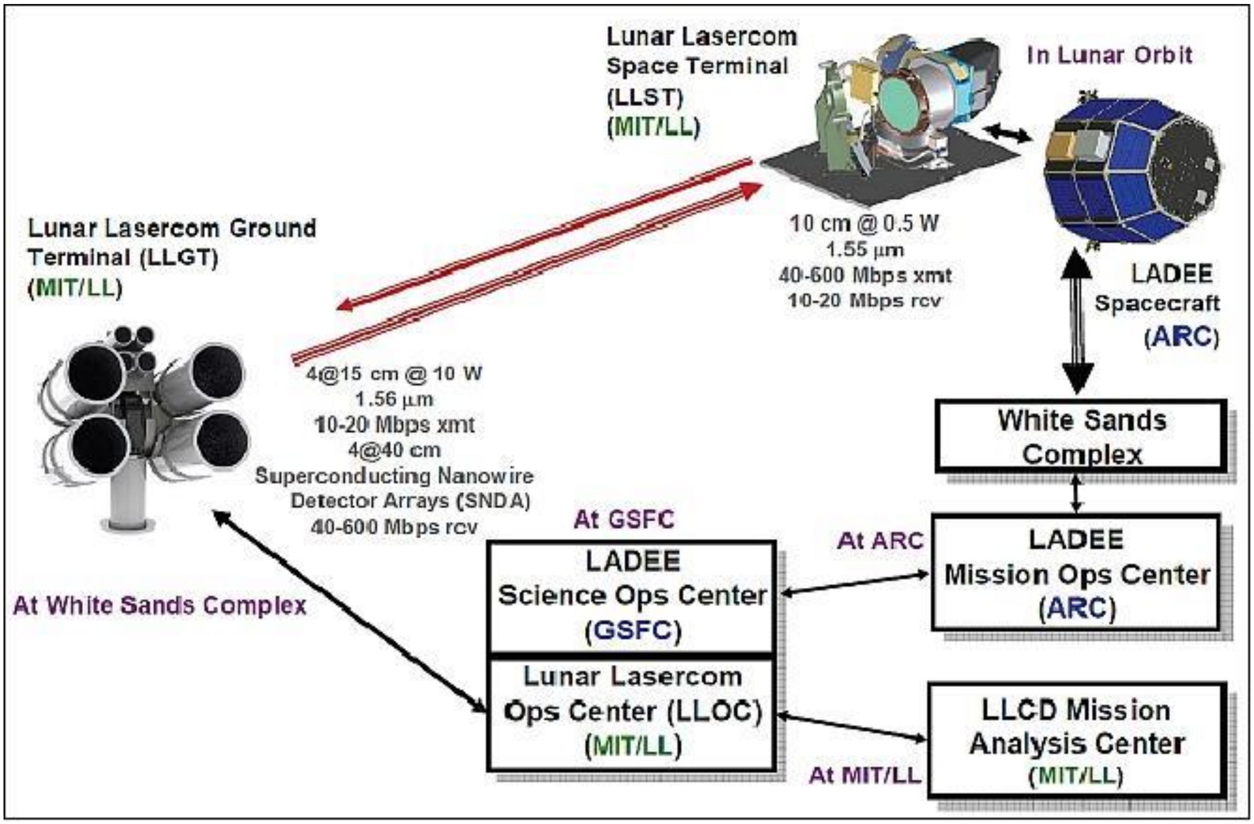

Figure 4. Three ground terminals were created to test the LLCD technology at White Sands, Table Mountain Facility, and El Teide Observatory.[Image credit NASA]

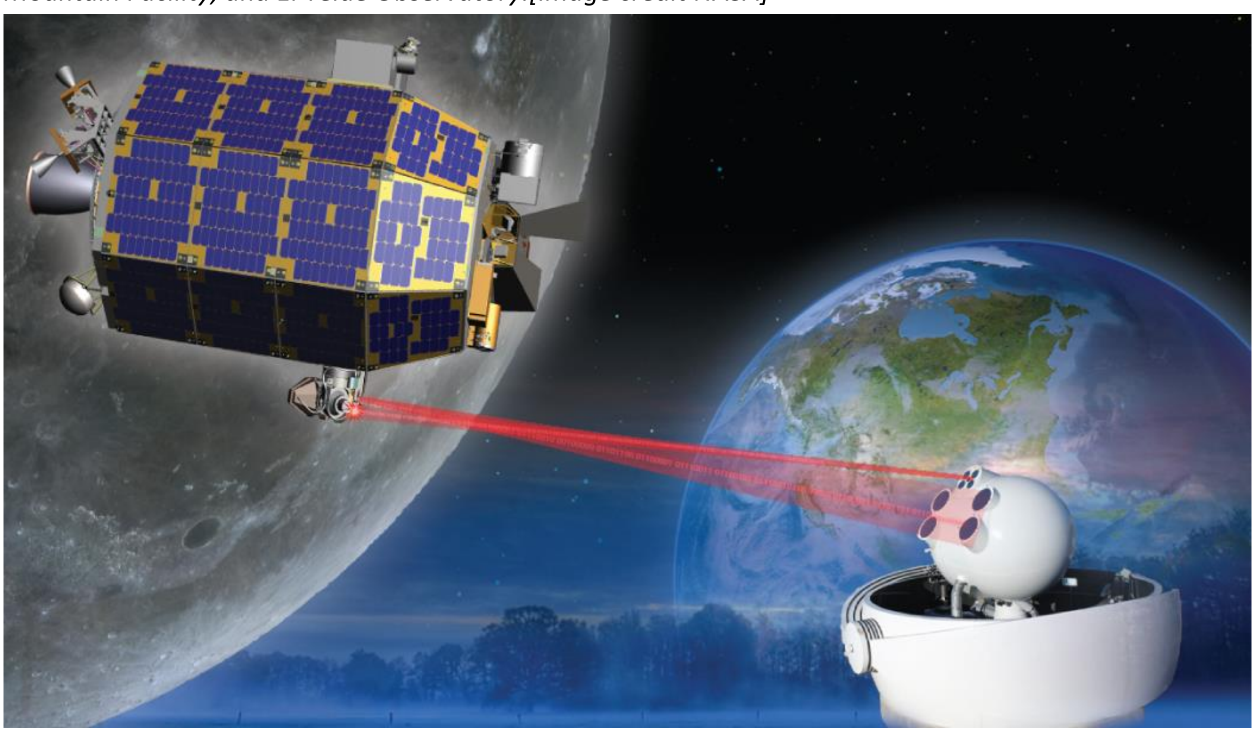

Figure 5. The LLCD experiment proved that a reliable high bandwidth free space laser link is possible between the Earth and the Moon.(image credit NASA GSFC)

MoundBuilder^{TM}: Lunar Habitat Construction via Biomimicry

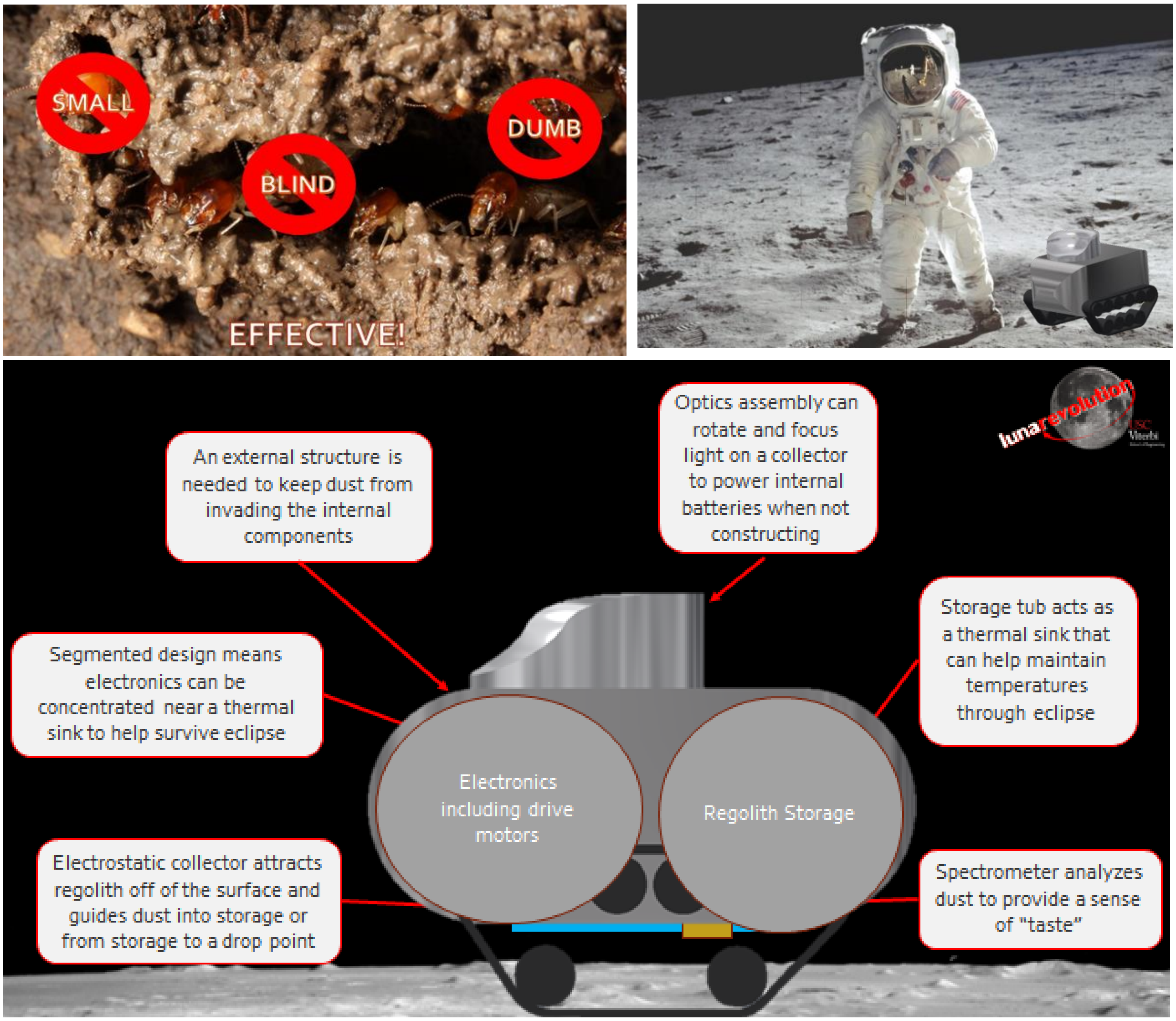

Figure 6(a,b.c). The three images above show how nature may be imitated(biomimicry) to perform complex building operations on extraterrestrial surfaces. Termite moundbuilders, without complex programming, build complex structures. A swarm of robotic MoundBuilders^{TM}, using similar principles, could be deployed on the Moon to do the same, without the need for constant supervision, command and control.

Manned expeditions to the moon will require the packing of four heavy necessities: food, water, breathable air, and shelter. Various proposals exist to create an artificial circle of life to provide a generally endless supply of the first three requirements via aquaponics or similar systems. However, for any long duration stay on the lunar surface, we will need a significantly sized habitat in order to maintain the psyche of our brave colonists. Life has evolved and been optimized over geological time in harsh environments. As we extend our reach into space, we need systems optimized to even harsher environments. In many cases, the solution evolution has arrived at is not applicable nor achievable.

However, sometimes, we can find an appropriate starting point and apply biomimicry, the art and science of imitating nature. Mound-building termites thrive in the harsh African savannah, despite the fact that the builder termites are completely blind and many thousand times smaller than the towers they construct. As component electronics shrink and sensors and microelectromechanical systems become more capable and economical, it may be possible to mimic this architecture in even more extreme environments like the surface of the Moon and beyond. MoundBuilder™ technology proposes a small robot that could be used to build physical infrastructure including large structures in which astronauts could safely reside. These habitats could house scientists, tourists, miners, providing shielding from solar radiation and enough space to maintain high crew morale. These mound builder robots would rely on three key technologies: cast regolith, freeform optics, and swarm intelligence. Cast regolith has been simulated in the lab and is a relatively simple concept melt regolith into a building block for structures. Freeform optics allow light to be focused to a small point in order to melt the regolith with high efficiency in a compact package. Biomimetic principles are introduced into the system via swarm intelligence. By applying concepts that already exist in the lab to a swarm beyond a critical population point, a collection of agents can construct great works with little human supervision. This concept can easily be expanded to construct any simple infrastructure such as roads, silos, and sunshade walls. Once it is demonstrated on the lunar surface, similar systems could be deposited on other bodies like large asteroids or maybe even Mars. This would be a hugely enabling technology that could significantly reduce our colonization expenses while producing expanded capabilities and improved comfort for settlers.[Figure 6]

Fueling our Future: An Architecture for Lunar Extraction of Water for Liquid Propellant Production

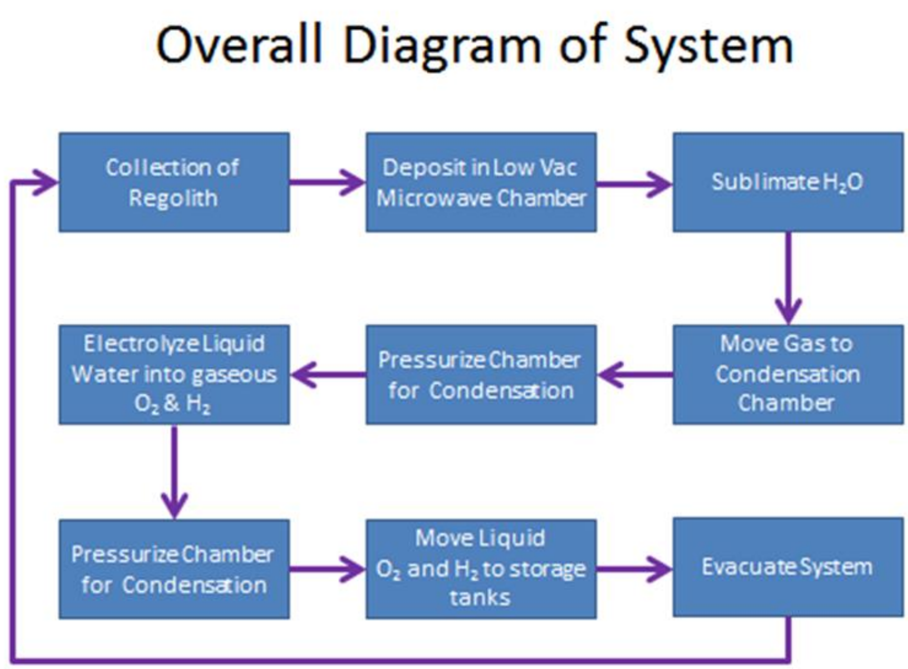

Figure 7. Simplified process schematic for lunar propellant production and storage through sublimation extraction, beneficiation and purification

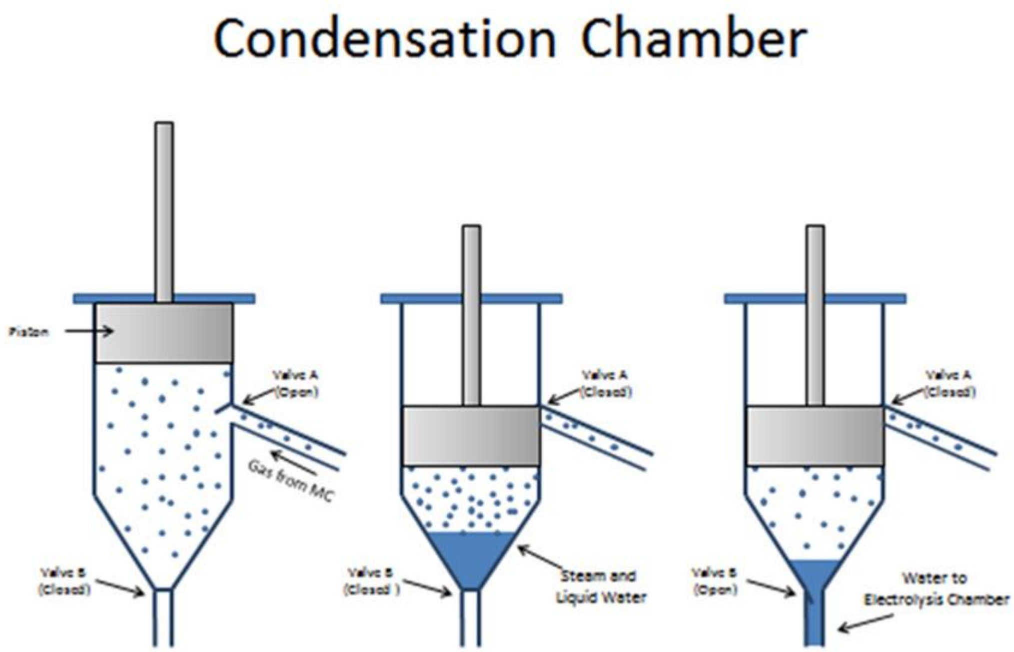

Figure 8. Schematic of lunar water condensation system

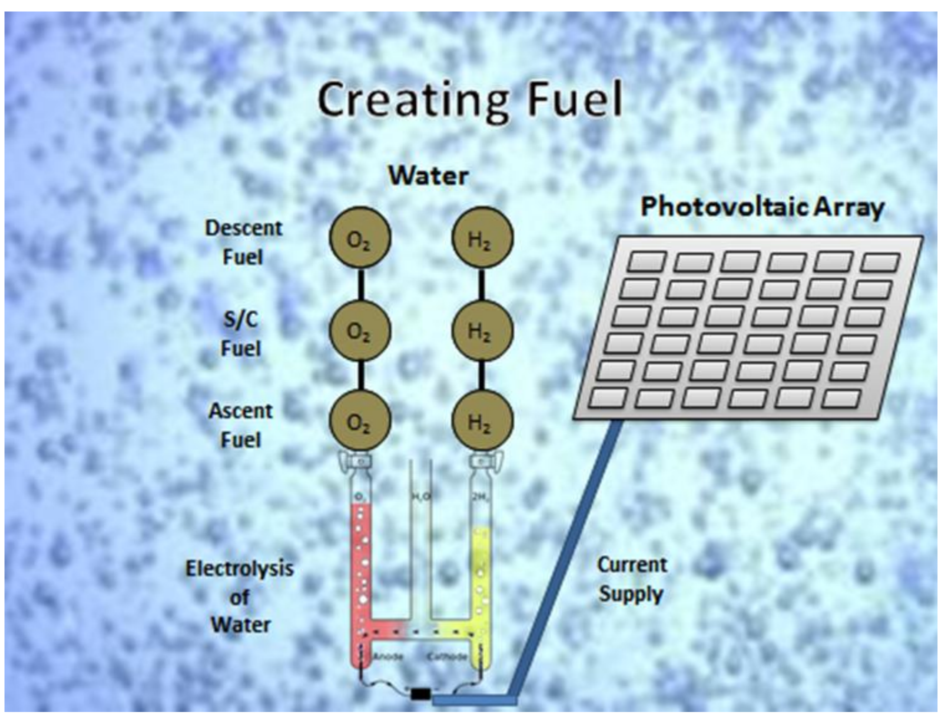

Figure 9. Electrolysis is employed to split lunar water into its components for fuel and other lunar volatiles can be combined for Earth normal atmosphere production. Continually operating photovoltaic arrays in the lunar polar regions power the system for this purpose.

Eighty to ninety-nine percent of mass during a spacecraft launch is fuel. Additionally, mission lifetime is often dependent on propellant stored for attitude adjustments, station keeping, and orbital maneuvers. Despite continual advancements in propulsion technologies, propellant remains the driving factor in both mission launch cost and anticipated mission lifetime. But what if this was not an issue?
Ice particles permanently frozen in the Lunar Polar Regions can be extracted from the surrounding regolith by subjecting the ice to microwave radiation. The radiation will cause the water particles to sublimate, and consequently separate from the other volatile materials. Following sublimation, a slight increase in pressure will liquefy the vapor, allowing for easy separation of the oxygen and hydrogen particles. This is achieved by passing an electric current, provided by photovoltaic cells, through the water in a simple process called electrolysis. Subsequently, the now gaseous hydrogen and oxygen molecules can again be liquefied by subjecting them to another pressure increase or a decrease in temperature. Then the two elements can be used as propellant and oxidizer for spacecraft respectively. Through this process, propellant can be produced from lunar regolith. This combination of commonplace technologies on Earth would provide the fuel to dramatically decrease launch costs, extend mission life, and enable further, faster, and higher fidelity missions than ever before quite literally, propelling the future of space utilization. [Fig.7-9]

Moon Fresh^{TM}: Lunar Cuisine

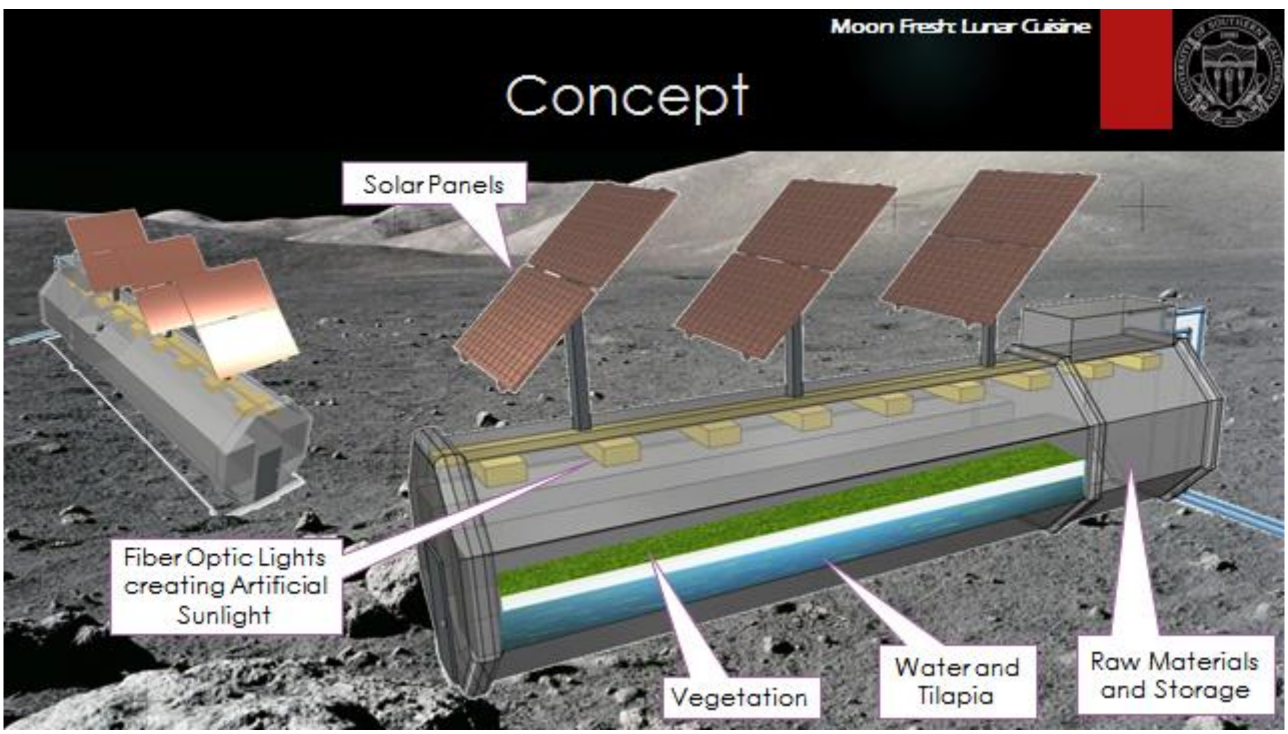

Figure 10. Salient features of the MoonFresh^{TM} bioregenerative lunar greenhouse and aquaponics chamber that is powered by photovoltaic arrays in the continuously available sunlight available in the lunar polar regions.

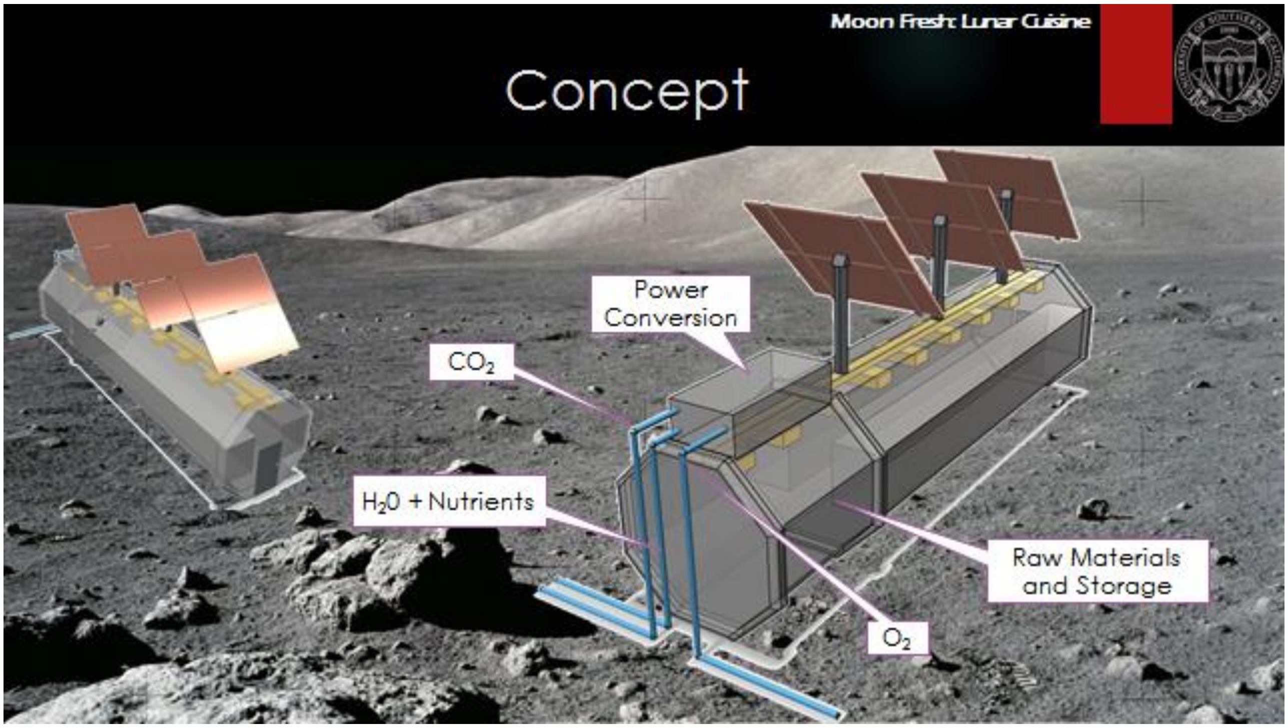

Figure 11. Schematic of the MoonFresh^{TM} lunar greenhouse, PV energy conversion system and products

Human settlement on the Moon has been envisioned long before the space age. Important parameters to be considered for permanent settlement on the Moon are food, water and air for survival. Food is a critical resource for the crew and to future missions and is a vital part of this vision of long term space habitation. This need should be dealt with before taking further step in planning for lunar settlement.

Mankind has reached Space, made temporary settlement in Low Earth Orbit through International Space Station and landed on the moon conducting various studies and experiments. Crew at ISS are continuously supplied with resources from earth. Considering Moon which is 238,855 miles away from Earth, re-supply strategy with economic and logistical effects increases risk of supply chain anomalies and failure. A self-sustaining closed loop architecture employing in-situ resources for replenishment is an important engineering problem. This can be achieved by bio-regenerative greenhouses for life support systems.[Fig.10-11] Lunar Greenhouse can eventually provide majority of the nutritional requirements and can become the primary sources of water, air, and food for the crew. Current strategies use an open loop system for supply of basic necessities for survival in space, which is sufficient for short term space missions. These include crew consumable supplies, food and water, expendable system supplies, maintenance supplies, and replacement of gases. Mass estimate for a single crew member for a period of duration of 1 year is about 13 US tons with 73 lbs. of mass per crew member per day. Considering the cost of launch \$25,000 - \$36,500 per lb., it becomes extremely expensive. Thus a viable plan for long term food supply system is needed. During the last decade, various space agencies have built several plant testing facilities for studying optimal cultivation technology. This concept proposes a new scheme to establish a concrete plan for food supply which is required for a long term settlement. The system uses all available in-situ resources (ISRU) for intensive crop cultivation. The system developed not only produces plants for food supply for the crew but can also fulfill other functions required such as water purification, oxygen production, waste management and can also provide psychological health benefits for the crew. This technology has immense benefit for Earth dwellers as we seek new ways to improve crop cultivation and enhance food production for a growing world production.

MOBIUS™: An Evolutionary Strategy for Lunar Tourism

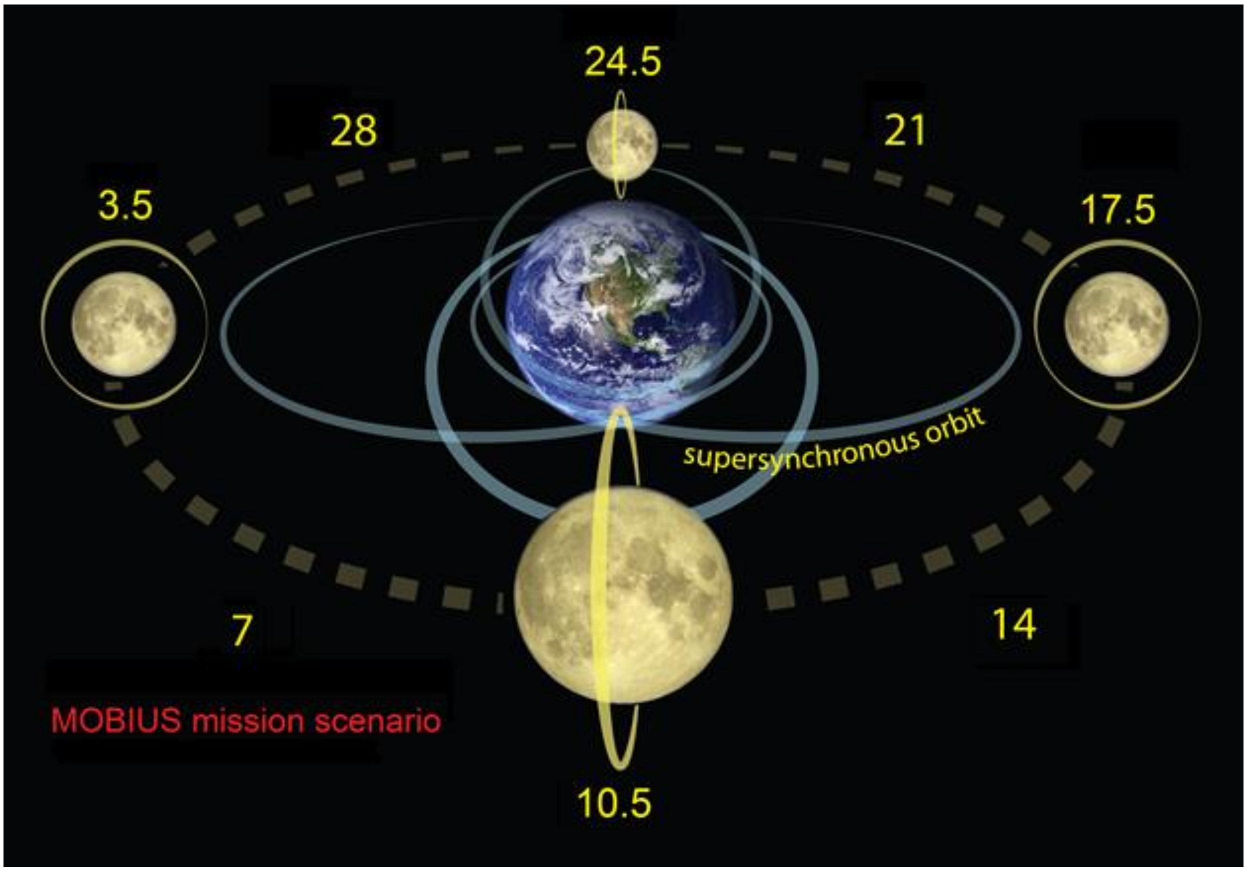

Figure 12. MOBIUS™ mission architecture employs an Earth supersynchronous orbit that is resonant with the lunar orbital period for lunar proximal approach at apogee.[artwork credit Chloe Thangavelu]

The MOBIUS concept architecture presents an evolutionary methodology for lunar tourist missions. In the MOBIUS scenario, a quartet of spacecraft in specific supersynchronous Earth orbit are suggested as flight elements in a nominal trajectory for a cislunar, cycling vehicle system. Earth and lunar shuttlecraft service the cycler at Earth perigee and lunar proximal apogee of the selected supersynchronous orbit. [Fig.12-15]. ISS is suggested as the departure platform to lunar orbit, and eventually lunar lander shuttles will be used to service paying passengers to the lunar surface on a routine basis. A gradual and steady increment in complexity of mission vehicles and operations is proposed, allowing for evolutionary growth and a self-sustaining economic model. We believe that this strategy is optimal and has an enormous commercial potential for future space and lunar tourism. In particular, attention is paid to the viability of employing the International Space Station commercially beyond the currently proposed retirement date, extending the useful life of the $100B facility. The MOBIUS concept is modeled using state of the art tools and proposes a viable profile that attempts to balance available technologies with entrepreneurial needs and capital to make commercial, self-sustaining lunar missions possible, maximizing existing assets and technologies as well as currently operating infrastructures, all in the earliest timeframe. MOBIUS architecture is an example of how government and private sector can partner to create self sustaining and vibrant space activity in the 21st century that caters to the cultural needs of humanity as well as inspiring the new generation of explorers.

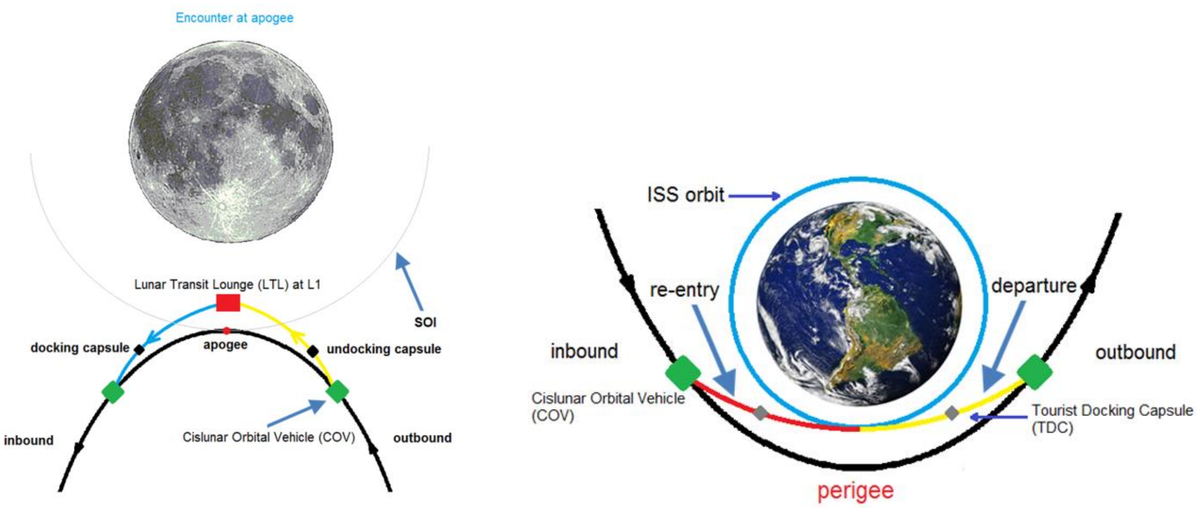

Figure 13. MOBIUS employs a high energy rendezvous at Earth perigee and a low energy rendezvous at lunar proximal perigee to transfer crew and paying passengers between the Earth and the Moon.

Figure 14. The MOBIUS stack with upper stage during translunar injection, departs for the Moon

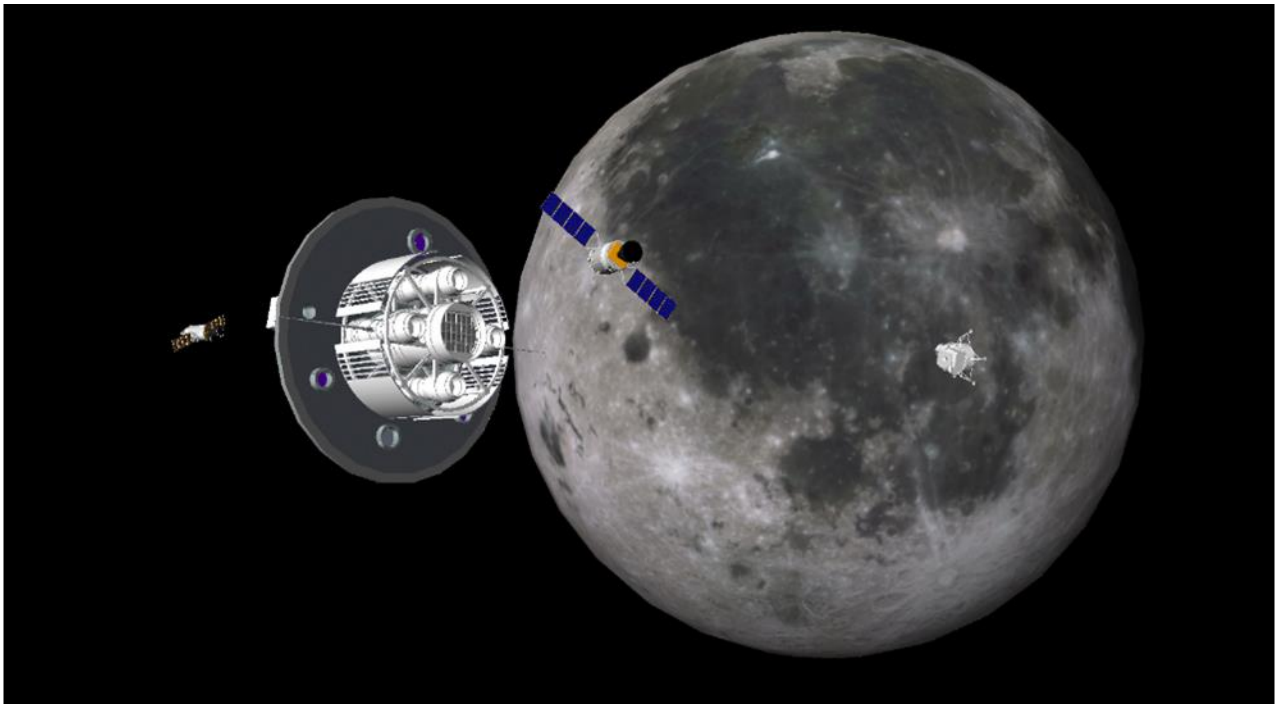

Figure 15. MOBIUS elements in lunar proximity. Eventually, a lunar lander(right) would be used to shuttle passengers between a lunar polar orbiting facility and the lunar surface.

PocketPad™: Concept for an Expendable Safe Lander Touchdown Accessory

The Apollo Moon landing missions and other recent lander missions have indicated that safe, stable landing pads are essential to landing on surfaces. Hyper velocity debris raised from the exhaust plume of the main engine thrusters on pristine, unimproved terrain can pose a hazard, not only to crew and exposed high value assets, but could also severely damage lander components like landing legs and exhaust nozzle or fuel tanks. This problem continues to be neglected in space exploration to this day. NASA has proposed projects to construct solid landing pads on the Moon but this would require that robots first be sent to build these pads. This is counter intuitive as these teleoperated systems also risk breakdown and contamination upon landing on the dusty, debris strewn Moon's surface. The PocketPad concept proposes to eliminate the complexity and deploy a landing mat over unimproved lunar terrain just before landing. As private and public companies express greater interest in space travel, we must establish new techniques to safely land on unimproved surfaces with 100% success rates. A stowable, rapidly deployable landing pad will greatly decrease all the risks found in landing a spacecraft by providing a smoother, dust free zone around the lander.[Fig.16-17] Not only can this technique aid us on the Moon for primary lander missions, but also be applied to any other surface that is proposed to be explored. This concept explores the viability of a cheap, one-time-use only, instantly deployable landing pad and offer advantages it can provide for any landing mission. This presentation explores the merits and limitations of a cheap, one-time-use only, instantly deployable landing pad with proposals for potential future studies.

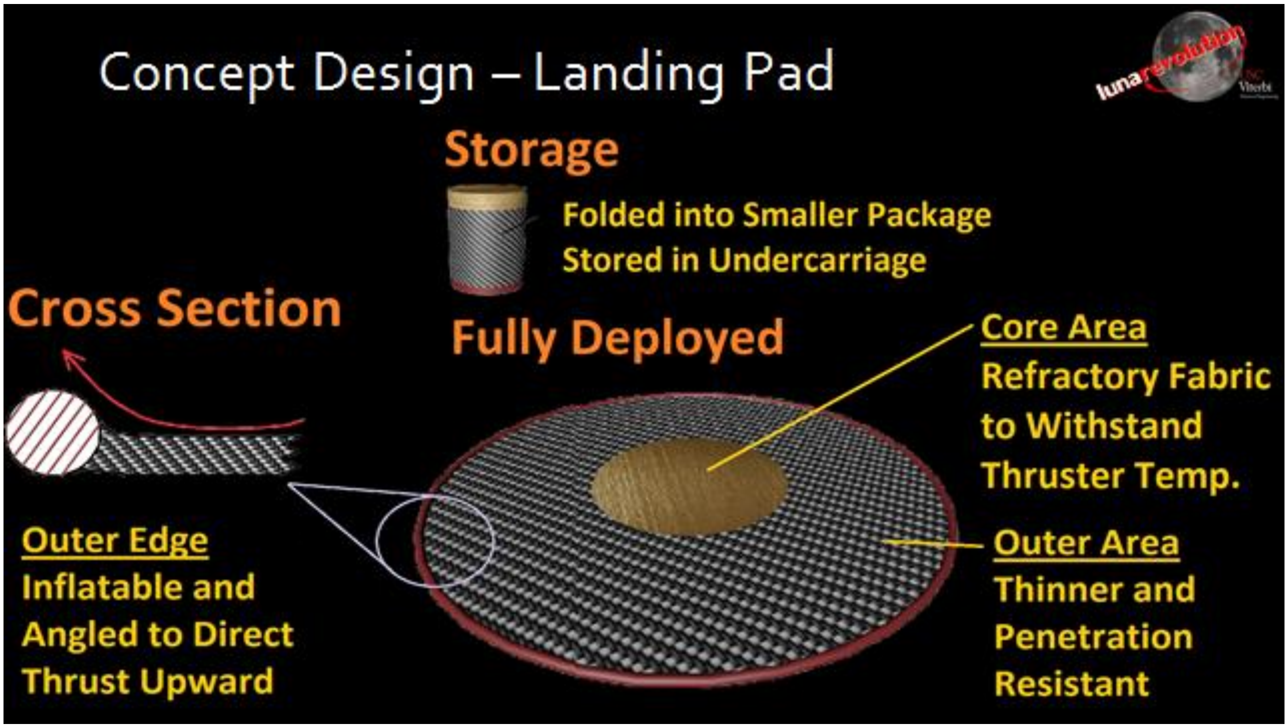

Figure 16. Salient features of a lightweight, stowable, deployable, disposable landing pad to minimize debris effects caused by landing thrusters on pristine, low gravity extraterrestrial bodies like the Moon.

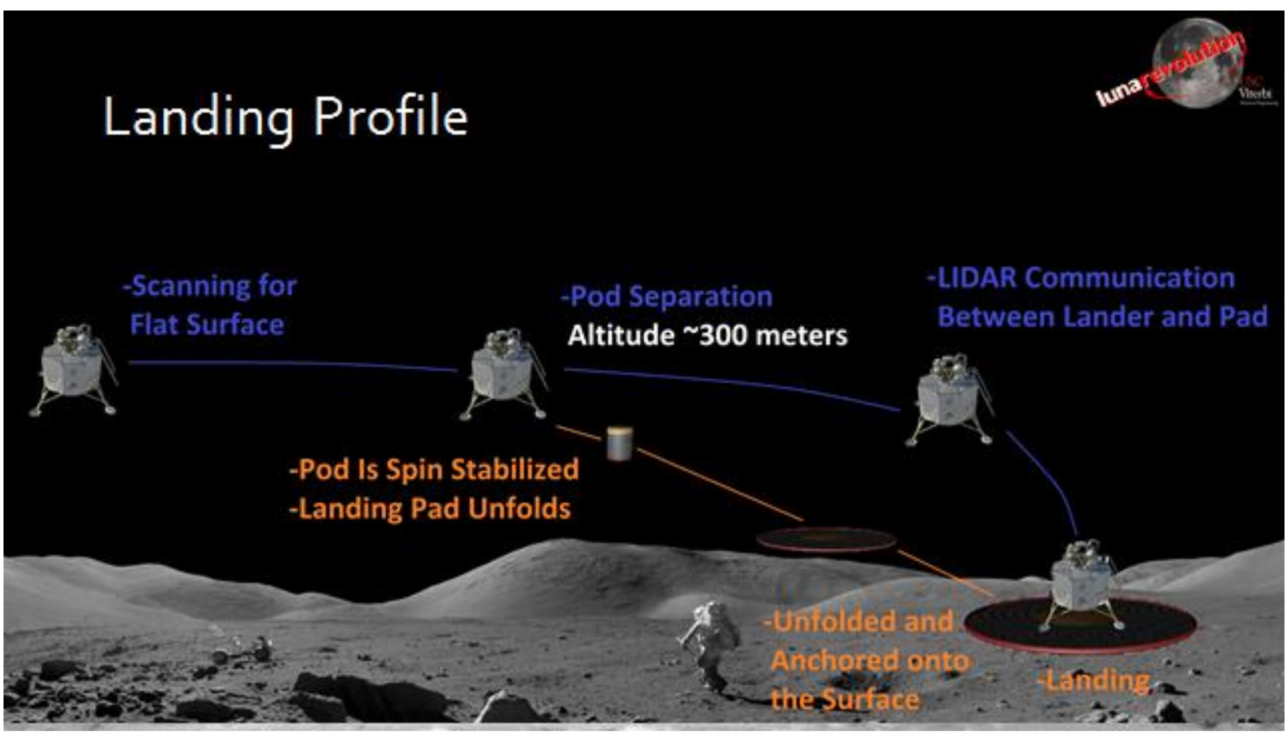

Figure 17. Landing profile and deployment of the PocketPad™ before lander touchdown. Beacons and LIDAR allow automated landing during the final descent and touchdown phase.

Bolts, Slingshots and Roundabouts

Lorentz force associated systems and devices have been the mainstay of ideas to provide propulsive energy delta V for a variety of space related applications. Since the Moon, Mars and asteroids possess low gravity fields, mechanical energy systems, sans electromechanical systems, have been proposed in the literature, to propel vehicles and cargo in ballistic trajectories. Since such systems do not expel reactionary exhaust mass, they are pollution free. Railguns of varying designs have been proposed to launch cargo to locations around the lunar globe. Since lunar escape velocity is low, such systems are capable of injecting payloads from the lunar surface to lunar orbit as well. The Moon, lacking an atmosphere, is particularly suitable for such low delta V applications. Mechanical cross bows, trebuchets, slingshots and roundabouts all offer advantages of pollution free and continuous operations with little maintenance and service requirements. [Fig.18-19]

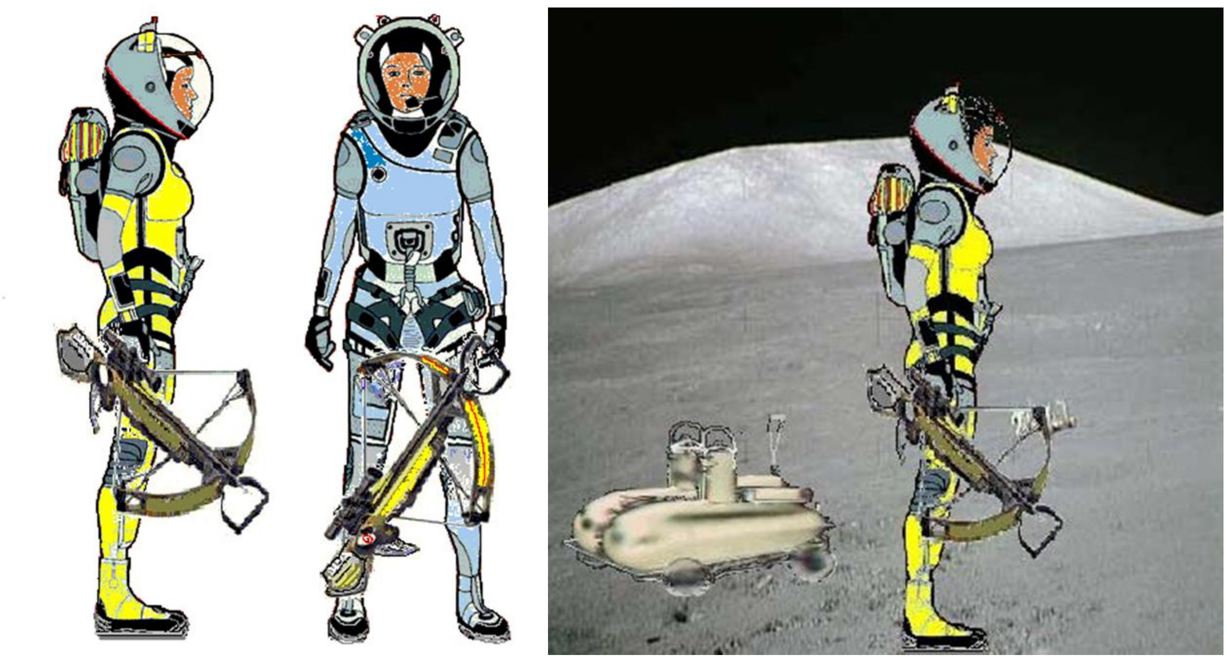

Figure 18. A mechanical crossbow with specialized bolts could be an accessory tool on the lunar surface to fire projectiles with sensors to distances of 6-8km on ballistic trajectories. They could be used with tethers and grapples to anchor long lines that may be useful for a variety of building purposes.

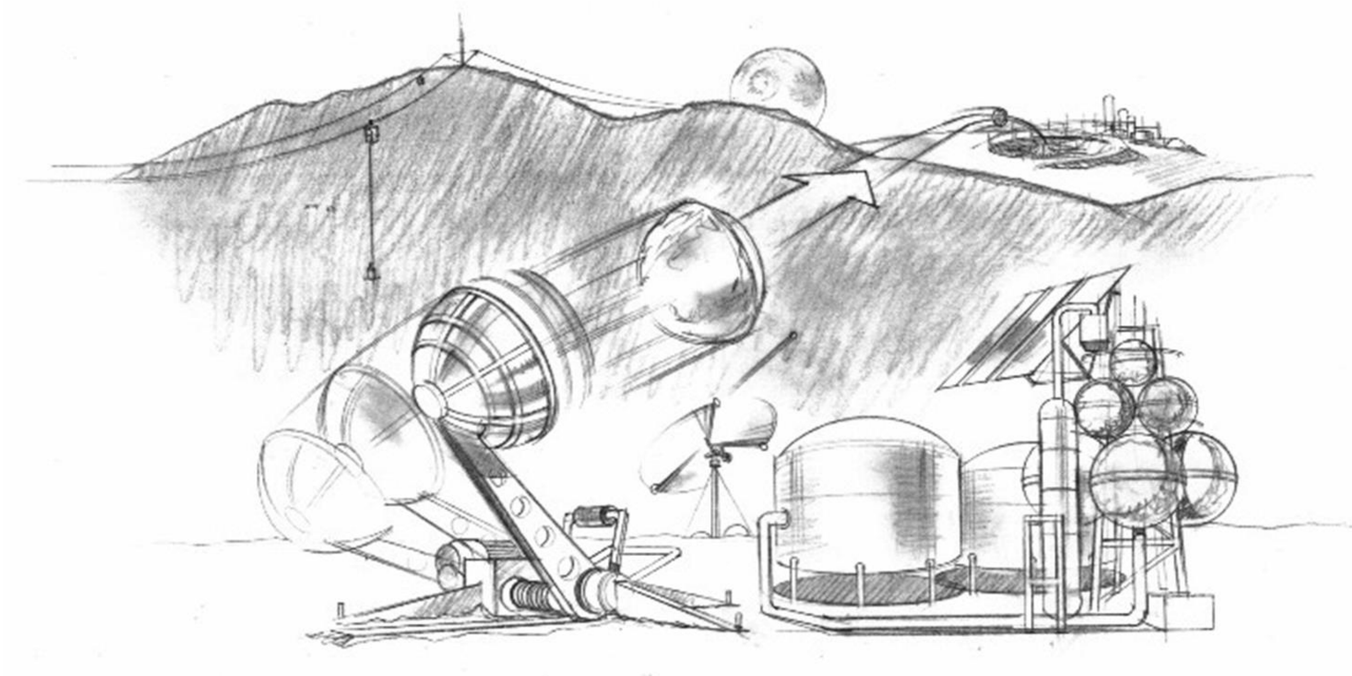

Figure 19. Mechanical trebuchets and slingshots may be very useful mechanical devices for transporting lunar cargo such as ice and volatiles from quarries for beneficiation and purification, in a continuous and pollution free manner

Lunar Sentinel™ - Role of the Moon in Planetary Defense

While early detection of hazardous objects is the preferred goal of all planetary defense initiatives, currently, detection of all hazardous objects that are <0.1- km across may not be possible before they are in close proximity to Earth, giving us a very short warning time in the range of weeks to months. To thwart such a threat, we need agile systems in place that are quick to respond and powerful enough to effectively intervene and diffuse the threat.

This presentation focuses on using our Moon as an emergency layer of defense for planetary defense; mitigating small "city killer" type NEO/cometary fragment threats that are still difficult to detect well in advance using current technologies. Merits and challenges are addressed.

Recent progress in Directed Energy(DE) systems show promising results. The US Navy demonstrated a 30kW laser weapon system with pinpoint accuracy and instantaneous results and DoD efforts including the US Air Force and the Army are pursuing advanced directed energy systems for warfighting and defense. This technology continues to ramp up in energy levels and deliverable power, not to mention compact overall system footprint, enabling routine fieldability. Several mobile HEL systems are being tested currently. High energy laser(HEL) beams focused on bodies like water-ice rich cometary surfaces and asteroids can analyze constituents, provide accurate morphology and could be used to vaporize it.

A Directed Energy system complex mounted on the far-side equator and poles of the Moon could be a versatile solution to mitigate small asteroids, and especially incoming cometary fragments in high energy trajectories[Figure 18-20]. Interception of PHOs at close range (<1 AU) at short notice and without fielding any physical projectiles become possible. The slow lunar rate of spin and orbit allows long integration periods for laser system and provides more field of view and accurate pointing to engage the target along line-of-sight. Operation in vacuum results in unattenuated DE energy levels, thus facilitating target reach with theoretical maximum energy, unlike in the Earth's atmosphere that causes linear and nonlinear phenomena like thermal blooming to alter the intensity distribution and intended beam direction. Furthermore, 82% of the far-side is out of Earth's view, thus a system based on certain locations of the far-side and the poles cannot be weaponized against the Earth. Lunar Sentinel offers a clear and defined mandate for yet another use of our Moon; to keep watch and protect planet Earth from hazardous impactors.

HEL systems on the Moon can be a versatile asset including support for extreme range communications, illuminating very faint deep space objects, probing and spectrally characterizing asteroids, mitigating micrometeoritic showers and providing protection from impacting debris as well as beaming propulsion and power for spacecraft.

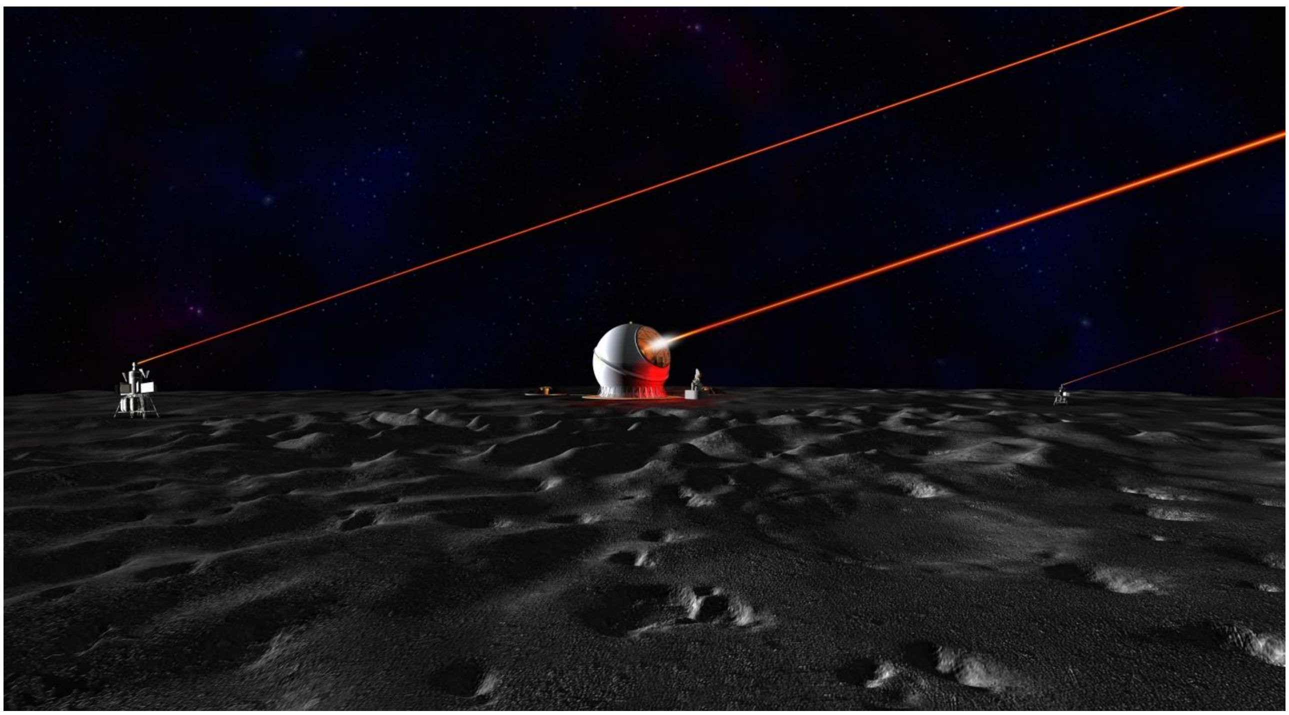

Figure 18. A lunar High Energy Laser(HEL) Complex could be used to thwart asteroid and cometary threats to planet Earth while serving many other scientific functions as well as protecting lunar assets from micrometeoritic impacts.

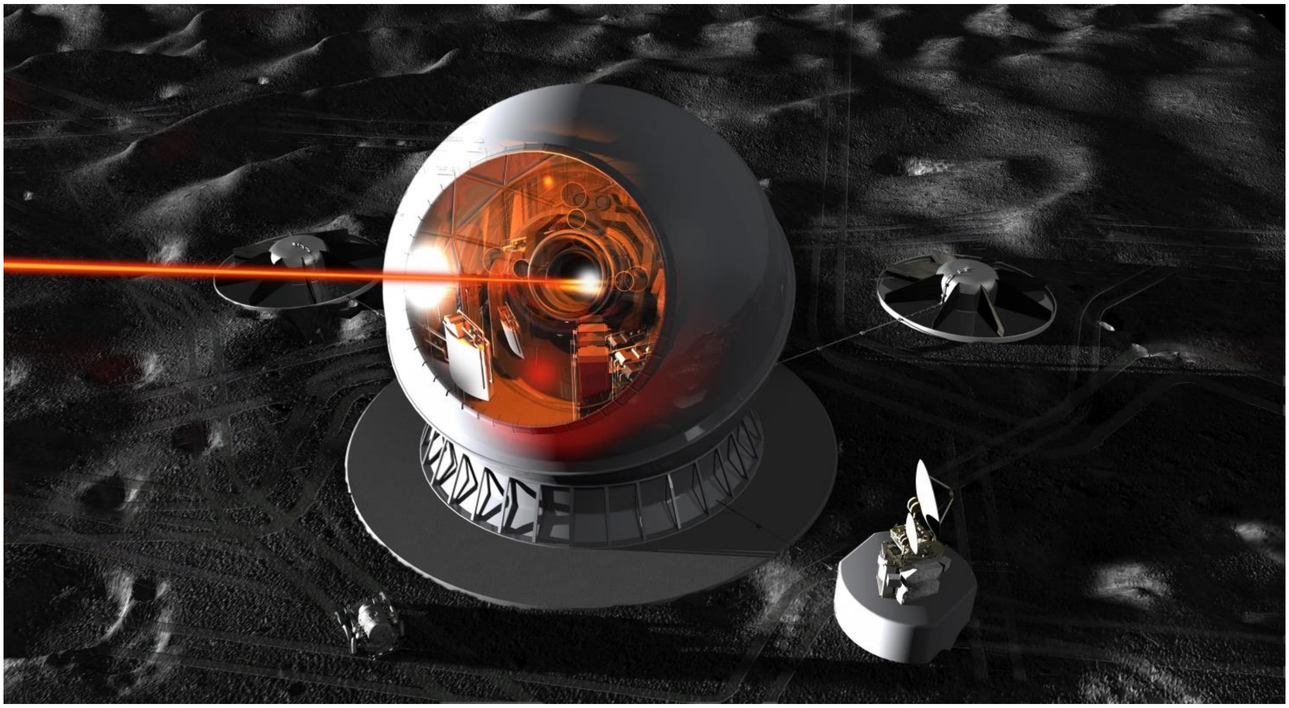

Figure 19. Closeup view of a high energy laser(HEL) system on the Moon

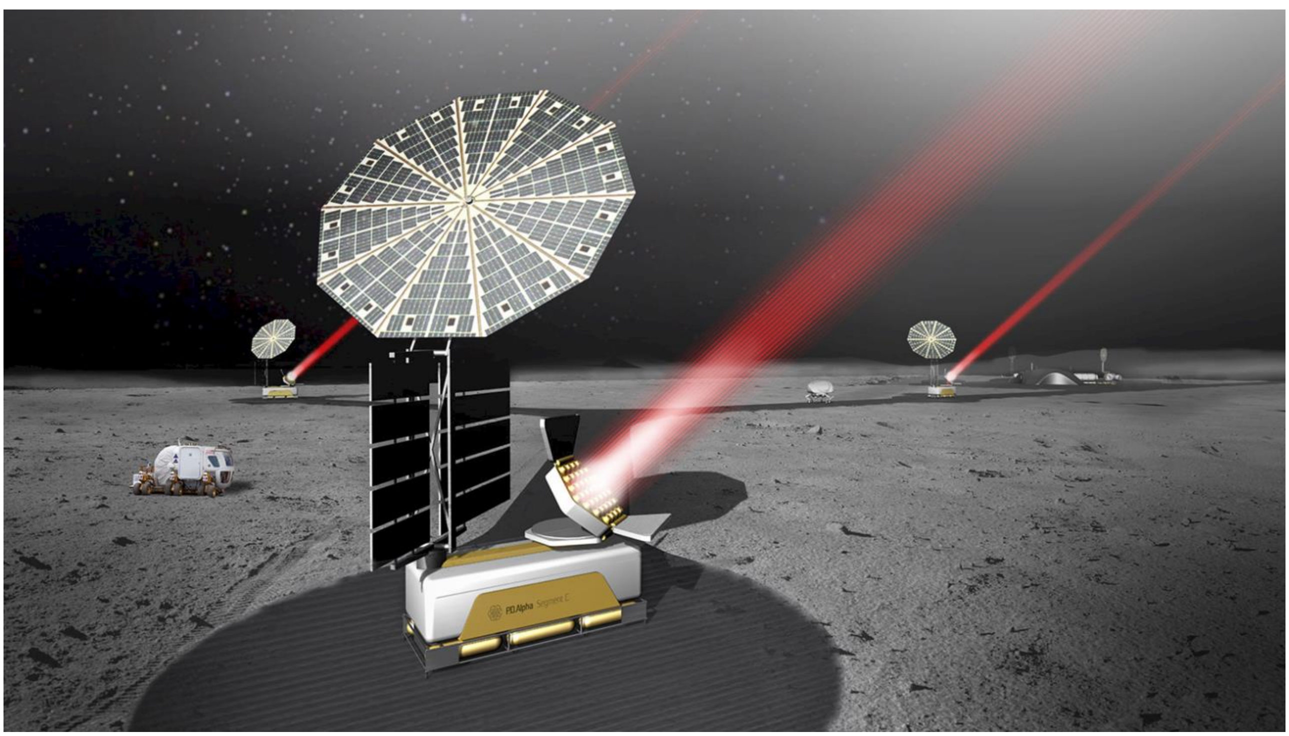

Figure 20. Proposal for an Evolvable Modular Planetary Defense System that employs PV arrays and advanced energy storage technology to be able to operate during the entire lunar diurnal cycle.(image credit Tomas Rousak)

Nuclear Reactor on the Moon

NASA's goal to send humans to Mars has huge challenges and obstacles. A human mission beyond the sphere of influence of Earth has great physiological and safety concerns for the crew. Current mission architectures involving 1000 days round trips using Solar Electric Propulsion (SEP) and multiple Space Launch System (SLS) launches will be operationally expensive and cumbersome. Current experience show that such long duration human missions would have very adverse detrimental effects on the physiology and the well being of flight crew. For a human habitat on Mars, the power requirements for critical life support systems, ISRU operations, Oxygen production systems, etc. require a huge amount of power, which cannot be supported by solar photovoltaics. The only way it could be made possible is by using a nuclear reactor. A lot of theoretical research work has already been accomplished for space nuclear fission reactors, nuclear thermal rockets, and bimodal systems that generate both power and propulsion for long duration missions. But except for the NERVA program there has been no real experimental research or testing done on these technologies. Hence the TRL on these technologies have not been able to exceed over 3- 4 in the past few decades after NERVA. The major roadblock to achieve high TRL for these technologies is money, regulation and policies, which are controlled politically. If ever these technologies have to take o_, it would need a step by step approach and a platform close enough to home for various economic and safety reasons.

The lunar surface offers an ideal platform for a space nuclear test bed. The moon is just 3-4 days away and is in a tidally locked orbit around Earth. It offers great potential to serve as the practice playing ground for NASA and other space agencies across the world to enable and accelerate critical technologies and operations for deep space human missions. Establishing a lunar colony can have great advantages for science & research including the continuation of permanent presence of humans in space after the decommissioning of the International Space Station.

This proposal advocates the landing of a low enriched uranium nuclear fission reactor on the lunar surface within the next 10 years. According to policies set by the US Congress, high-enriched uranium fission reactors(above 20 % enrichment) are barred to be launched into space. Hence a low enriched uranium fission reactor(below 19 % enrichment) should qualify to fly. Contrary to popular belief, a launcher failure anomaly will not cause widespread dispersal of radioactive material in the atmosphere.

The reactor will be housed on a lander cargo vehicle, which will be the stepping stone vehicle to enable the landing of a reactor on the Martian surface in the future. A phased approach to implementing a reliable space nuclear power system is proposed, starting as an auxiliary system to lunar photovoltaics that is currently proposed for lunar polar settlements. Waste heat from the reactor can be used to heat a lunar human habitat. Electricity produced from the reactor could be used to power the life support systems of the lunar habitat and various ISRU plants that could be implemented on the Moon. Such a nuclear power capability could power all the diverse needs for a lunar settlement as well as lay the foundation for Mars expeditions and more ambitious missions to the outer solar system.[Fig.21-22]

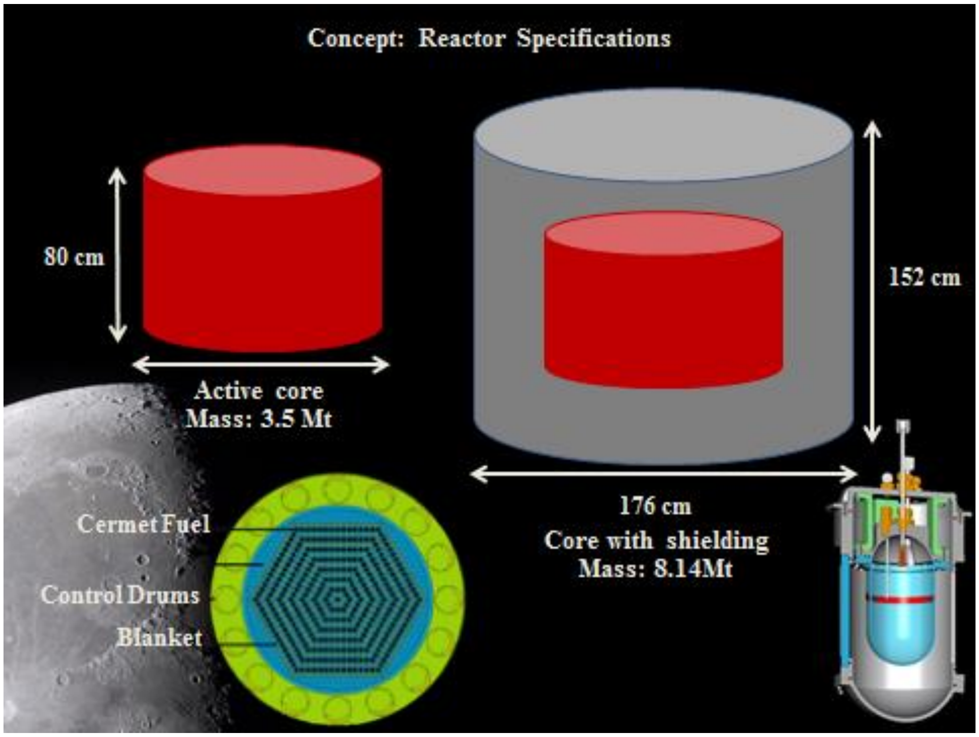

Figure 21. A small nuclear fission reactor on the Moon could provide all the backup power needed for a lunar settlement.

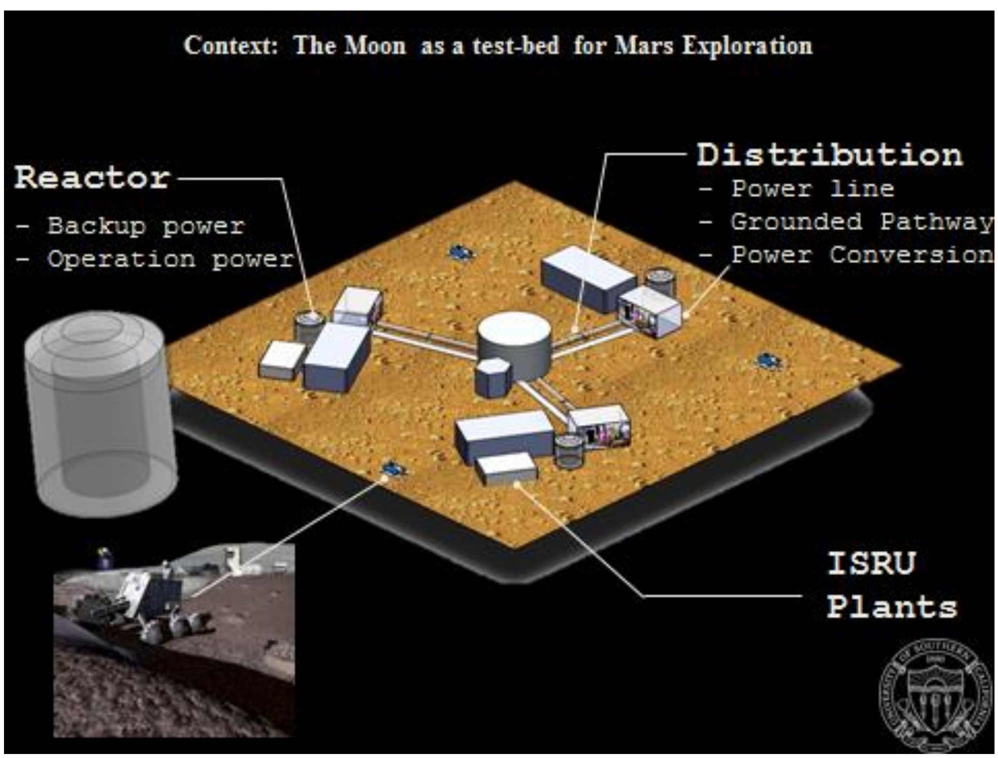

Figure 22. A nuclear reactor testbed could provide backup power for a lunar settlement while it is being evolved and certified for extraterrestrial settlements like establishing a Mars settlement, where long lasting dust storms would hamper solar photovoltaic power generation.

Conclusion

This paper highlights topics that show the potential of our Moon as the stepping stone for advancing human and robotic space activity. The Moon could develop into an ideal staging location for a variety of activities including enhancing planetary defense of Earth and providing critical support for testing and certifying vehicles and their critical systems for long duration expeditions, in preparation for more ambitious interplanetary missions in a timely manner. Cislunar and lunar surface mission operation experience will provide the hard engineering data that is essential for more ambitious missions as we venture out into interplanetary space.

Return to the Moon by human beings is absolutely fundamental and necessary for our evolution as a space faring species. The astronomical and biological sciences would also benefit from a renewed human presence on the Moon, especially from the establishment of a permanently occupied international scientific outpost. A permanent Overview Effect from the Moon will make us a more refined species that is ever more sensitive Earth's fragile biosphere and to the needs and aspirations of all humanity. It is clear that a paradigm shift from "open-ended scientific space exploration" that drives the programs of the world's space agencies today to one of "self-sustaining space utilization" aided by global partnership and commerce is the key to this 21st century space activity.

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under the topic "08 -LunaRevolution-Role of the Moon in the Future of Human Space Activity."

In closing….

*"I am always puzzled by debates over the vision for space exploration because the choices are so constrained by physical reality. We humans dwell in a vast universe whose chief features only became apparent during the twentieth century. We have known for a long time that a huge gap separates the objects trapped by the gravity of our star, the Sun, and everything else. Information about phenomena beyond that gap can come to us only through the rain of photons and other elementary particles spewed out by the awesome processes of the cosmos. Our observations of that part of space began in prehistoric times and they continue to sustain the growth of science in our era. Phenomena on our side of the interstellar gap, in what we call the Solar System, are potentially amenable to direct investigation and manipulation through physical contact, and can reasonably be described as falling within humanity's economic sphere of influence. As I see it, questions about the vision boil down to whether we want to incorporate the Solar System in our economic sphere, or not. Our national policy, declared by President Bush and endorsed by Congress last December in the NASA authorization act, affirms that, "The fundamental goal of this vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program." So at least for now the question has been decided in the affirmative." –**John Marburger lll, excerpt from Goddard Memorial Lecture, March 2008, Director OSTP, Science Adviser to President George H.W.Bush and former Physics Department Chairman and Dean of the College of Letters, Arts and Sciences, USC.***

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