Photonic Extension Cords – Directed Energy for Lunar Power Distribution

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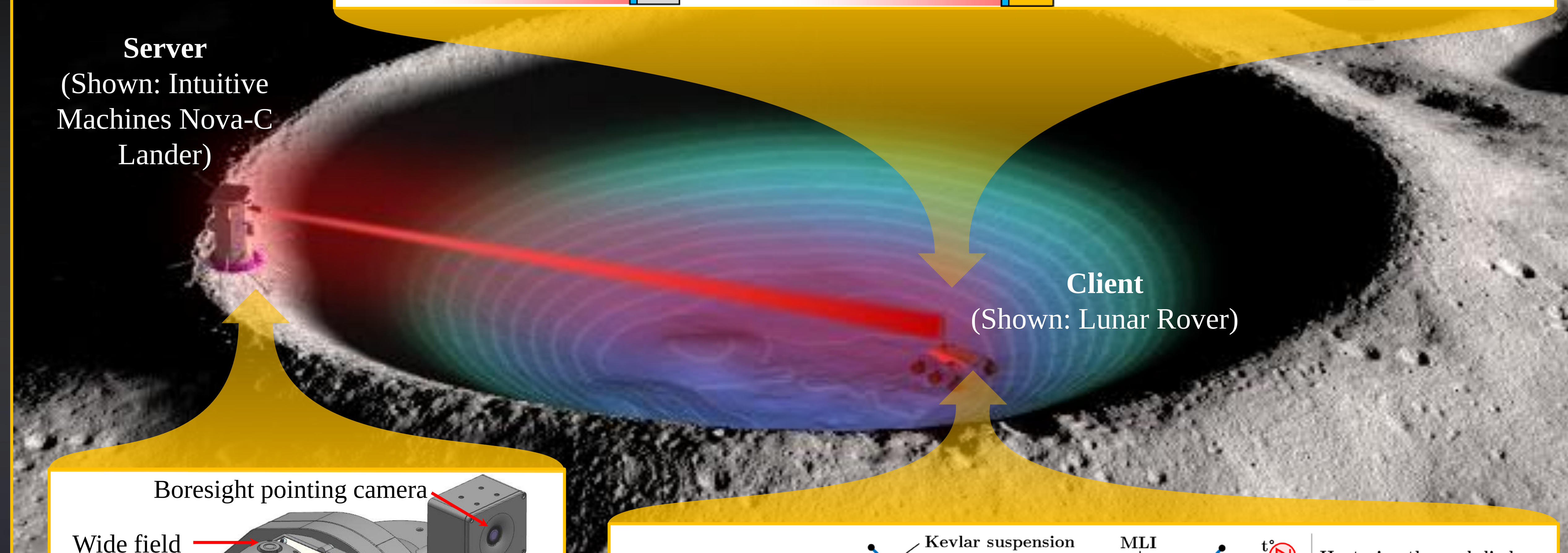
Lunar Surface Innovation CONSORTIUM

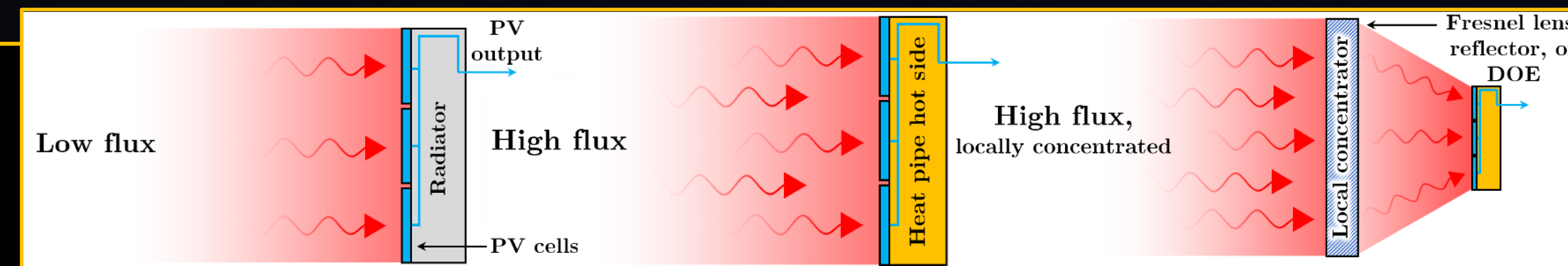
Overview: In order to sustain extended operations on the lunar surface, a scalable method of power distribution is required. As part of our NASA-supported power beaming program, we propose the development of directed energy (DE) power distribution systems capable of transmitting power across kilometer-scale distances for difficult-to-reach and mobile applications on the Moon. Such applications include beaming power from crater rims into permanently shadowed regions (PSR) where large deposits of water have been shown to exist, as well as beaming power from stationary sites to mobile assets such as rovers and other surface vehicles. The system we propose is effectively a "photonic extension cord" which beams near-infrared laser light to distant assets, at which it is converted via tuned high-efficiency photovoltaics (PV) into useful electricity. Such DE systems are now efficient, low-mass, practical, cost-effective, and continue to rapidly improve due to exponential growth in photonics which is driven by vast consumer and industry demand. A wide range of other applications can be enabled by a scalable DE power distribution system: tower-to-tower "photonics power lines" with distances exceeding 100km and power levels exceeding 10kW; lunar surface-to-orbit or orbit-to-surface power beaming; and ultra-high speed laser communications for all of the above configurations. Even longer ranges and higher powers are possible with coherent combining of single mode lasers. Looking to the near future and beyond, a range of other applications can be enabled by our single mode coherent beam combining systems: tower to tower, "photonic power lines" with distances exceeding 100km and power levels exceeding 10 kW; lunar surface to orbit; orbit to surface; ultra high speed laser communications for point-to-point on the Moon as well as to Earth; long range lunar surface laser ablation with remote composition analysis; LIDAR of craters and "cracks," etc.

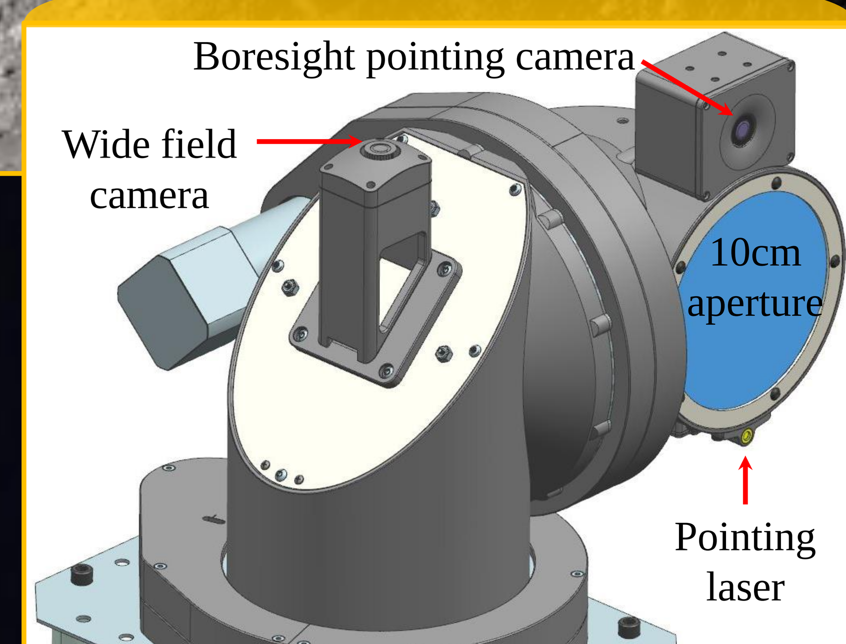
System Level Design: There are two sides to the system. There is the emitter or transmitter of the DE ('server') that converts electrical power to light and there is the receiver ('client') at each target of the DE that converts the light to electrical power. There can be multiple servers and clients. Each client (rover for example) communicates its need for energy via optical or RF to the emitter. In a multiple client with single server situation there is a task scheduler on the server to optimize the client needs. This is a bidirectional communication system that optimizes both server and client energy usage. The system we describe is well suited to providing power to multiple assets from a single source by time multiplexing. In this case, the distant clients communicate with the servers and the power is routed as needed. Switching the beam from one client to another would take only seconds with the beam gated off in between. Use of a higher power laser and faster charge times than those used for a single client would be the appropriate way to scale such a system. In principle a single laser could be split to multiple beams, which would then be directed to different clients, but it's likely that the simpler solution of one server for multiple clients via time multiplexing would be more robust.

Lunar PSR power beaming scenario in Shackleton Crater

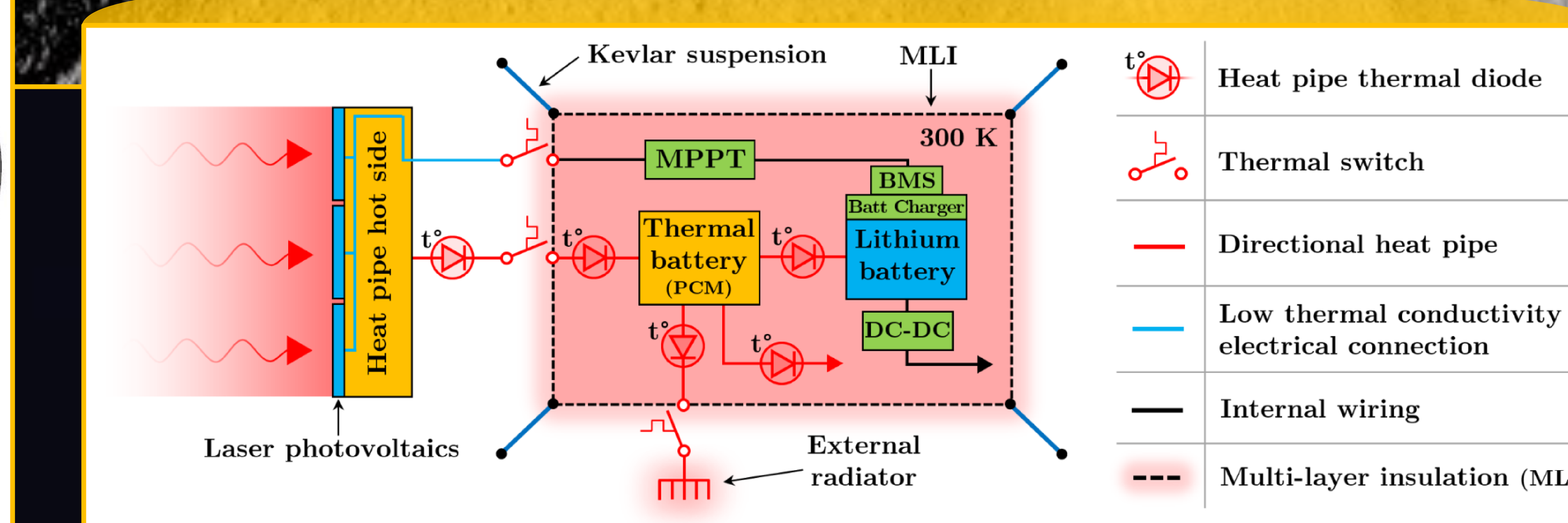


Laser-Tuned Photovoltaics: We have built laser PV converters in our lab using Si and InGaAs cells including novel low mass compact high speed (10kHz) maximum power point tracking (MPPT) electronics, which allows maximizing power in time-varying conditions.

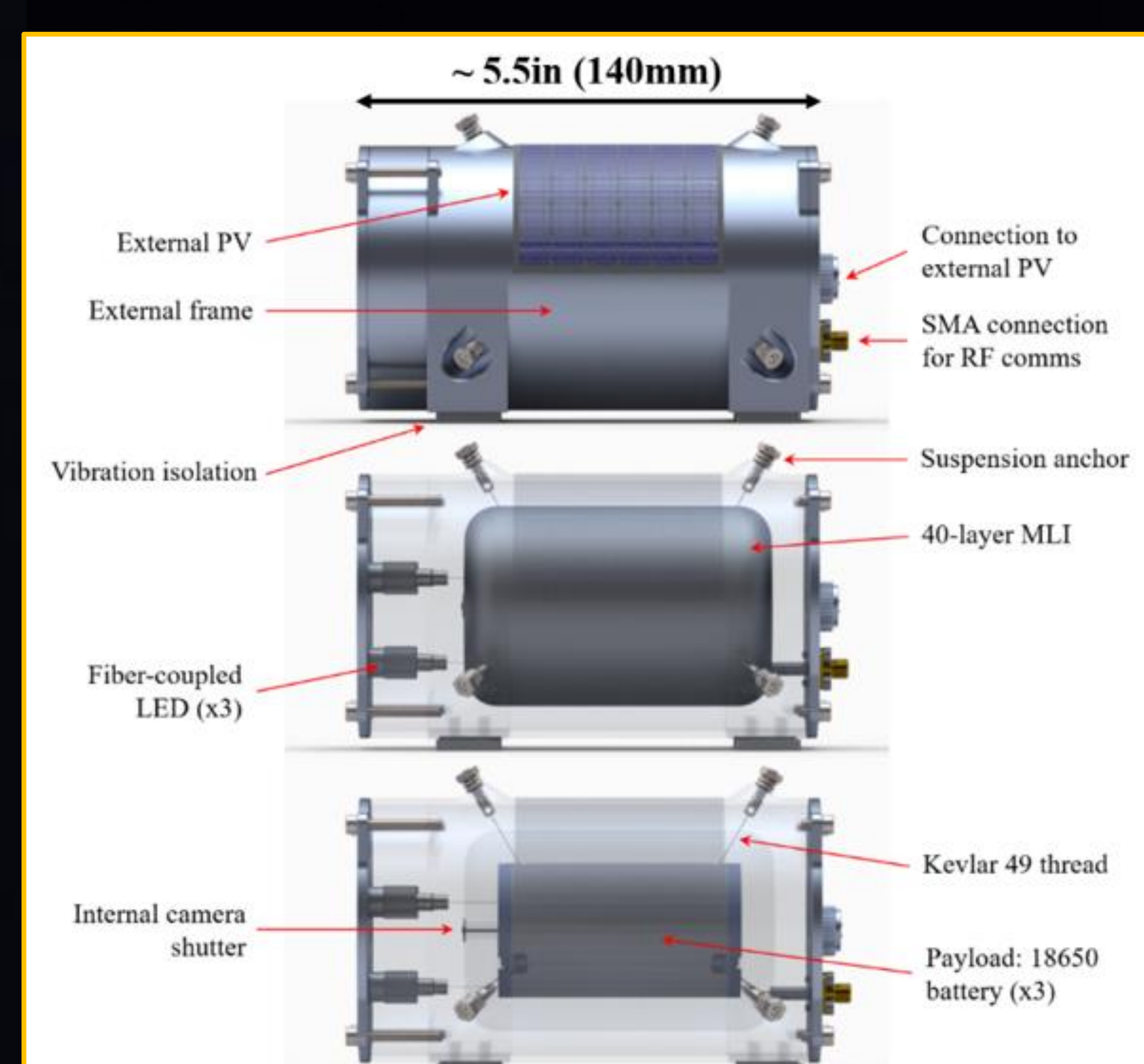




Periscope Beam Director: We have developed a demonstration laser power beaming and tracking system capable of near-4π FOV steering and active target tracking. It is compact (<30cm cube), low mass (~20kg), and highly capable with optical power output of up to 400W, with extension to >1kW, and can operate in either single or multi-mode. If multi-mode, a 10cm aperture can project an ~80cm diameter spot at 1km distance, and a similar unit with a 1m aperture operating in single-mode could be used to project power at 100km range with a sub-meter diameter spot.

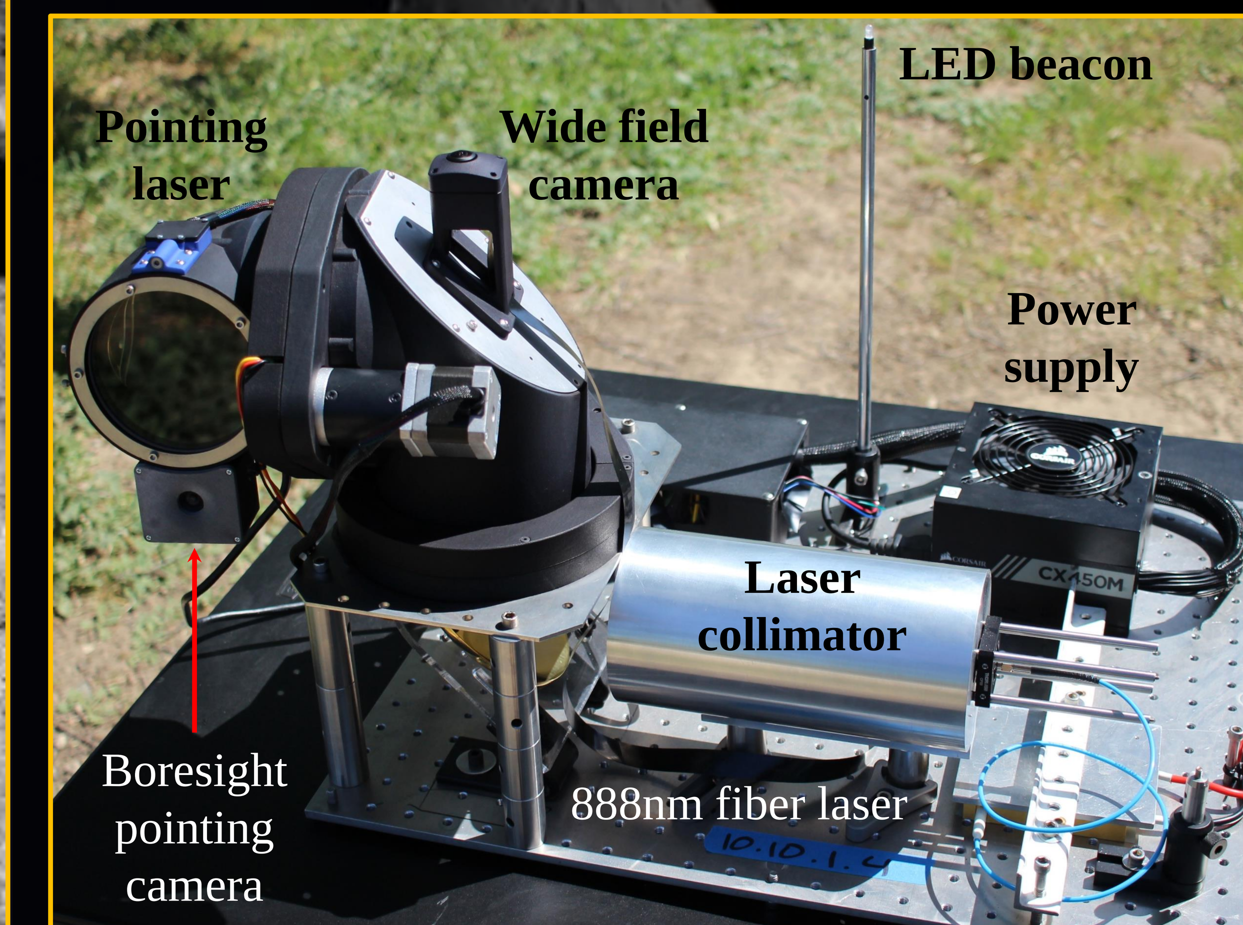


Thermal Energy Capture & Storage: In addition to electrical power, the photon energy not converted to electrical energy can be harvested as thermal energy, which is critical in many applications, including operating at low temperatures during the lunar night or in PSR's. Properly done, capturing and storing this energy can greatly increase the overall efficiency of the system.



Surviving the Lunar Night: System consists of a battery pack isolated from thermal conduction and radiation using a suspended thermal isolation system within an exterior frame. The battery and electronics is kept warm by using the battery energy or a resistive heater to self-heat. The external frame is at the temperature of the "outside" lunar environment while the suspended pack is regulated at near room temperature. Radiative and thermal losses are minimized by the use of multi-layer insulation (MLI) in which the suspended payload is wrapped, and conductive losses are minimized by Kevlar suspension threads with small cross sectional area. Extended operations on the lunar surface will become increasingly important in the coming decade. In addition to surviving regions of interest such as PSR's, surviving the lunar night alone will be crucial for long duration scientific experimentation, as well as commercial and industrial endeavors such as resource mining and water extraction. The ability to independently survive the temperatures of the two-week lunar night and continue operations during and/or afterwards will be transformative for small and large scale lunar surface operations.

Current Labwork: We have built a high-fidelity laboratory demonstration system (server + client) capable of field use and extendable to flight. The server side consists of a power beaming periscope and we have designed and built non-concentrated Si and InGaAs cell arrays with 100W_e capability for the client side.



We recently completed our first end-to-end tests of the server + client operations. Extensive tests are planned for the near future, including increased power transmission, increased range, and multiple client/single server interactions. We also intend to pursue laser-safe ~1km outdoor range testing to further increase the technology TRL. We have also developed a complete electronics solution for power point tracking, battery management, and load control. Work is ongoing to make the packaging more compact and to test in a variety of conditions.

We have made extensive measurements of Si cell efficiency at 888, 976, and 1070nm in out lab, and we have demonstrated high power throughput with consumer grade Si panels. We have also been working with Spectrolabs (Boeing) and with Microlink to acquire high-efficiency InGaAs cells for testing and demonstration. We are currently working on building them into usable arrays with sufficient voltage for our maximum power point tracking (MPPT) electronics.

Vision & Technology Infusion: There is a clear path to infusing this technology into the upcoming generation of small lunar missions based on CLPS landers. In particular, we expect that our collaboration with Intuitive Machines may provide the opportunity to develop an in-situ demonstration mission aboard the Nova-C lander on the lunar surface. Additionally, the same infrastructure which is used for a power beaming system can be used for long range laser communications for point-to-point on the Moon, as well as Earth-to-Moon communications. Other potentially infusion areas include long range lunar LIDAR, ablation of lunar surface for standoff composition analysis, and the search for water via active imaging, reflection, and remote heating.

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