SATELLITE BEAMED POWER FOR THE MOON AND MARS. M. H. Hecht[1] and Philip Lubin[2]. [1]MIT Haystack Observatory, Westford, MA, [2]Univ. of California at Santa Barbara.

Introduction: Solar power satellites have long been promoted for terrestrial use [1], but the advantage over ground-based assets has never been convincingly demonstrated. In contrast to the terrestrial case, orbiting infrastructure for space power satellites is less expensive and simpler to emplace than ground facilities for use on other worlds. While beamed power systems for the moon and Mars have been studied in the past [2], the confluence of several factors now make them practical for solar system exploration in the near-term.

Mission architecture: For the architecture described here, the orbital element collects solar radiation with photovoltaic panels and uses the electrical power to direct a high power laser at a photovoltaic array on the surface (Fig 1). This allows surface instruments to maintain full operation without access to sunlight.

Since the divergence of the power beam is proportional to the wavelength, the need to limit the size of the surface receiver favors optical over microwave transmission. With a coherent optical beam, the angular dispersion can be made equal to or less than the pointing accuracy of the projector, which is typically of order 1 arcsecond. That limitation suggests placing the satellite in a low orbit rather than in a stationary location, transmitting only when the orbiter passes over the ground station. The result is low duty cycle transmission and high duty cycle solar collection, which eliminates the need for an oversized solar collector for the orbiter and makes it possible to deliver significant power to the ground from a modest sized spacecraft with a small aperture (20-50 cm for 1 arcsecond).

To meet the power needs of larger missions (such as crewed surface operations), the best scaling strategy is to position a necklace of solar power satellites in a common orbit, each radiating to the surface in turn. These satellites could also provide near-continuous communications and GPS-like navigational support to a ground station. The same technology can be applied with little modification to point-to-point power beaming across the lunar surface.

Orbital element: For the orbital element we postulate a self-contained small spacecraft with ~ 6 m^2 of solar arrays in a low lunar orbit, nominally 200 km perilune. The solar panels would charge a battery during most of each orbit, except when in eclipse, and would discharge for ~4 minutes during each pass over the landed station while homing in on a retroreflector mounted on the station. With a 2.2 hr orbital period, this strategy corresponds to a 3.2% duty cycle. An optical system with ~1 arcsecond pointing accuracy could project ~6 kW to the surface with 1 arcsecond dispersion using a 20-50 cm mirror, illuminating a spot on the surface as small as 1 m (though in practice, 2-3 m is more realistic allowing for jitter, aberration, and elongation from an angle up to 45º). On the surface, this flux density is comparable to overhead sunlight.

Laser power of 3-6 kW can be readily achieved today by joining the outputs of multiple fiber lasers via spectral combining [3], a technique capable of producing tens of kW of output. Other components needed for an operable system, including steerable optics compatible with high power loads, are commercially available for space applications. The telescope, pointing and tracking elements, radiator, battery, and solar panels are high TRL commercial components that can be adapted to a free-flyer platform. The major technology challenge appears to be thermal management of the laser system, which might notionally be accomplished with phase change materials.

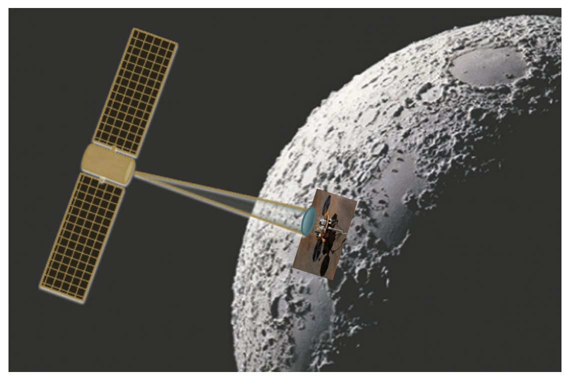

Fig.1. A laser-equipped SmallSat illuminates the photovoltaic panels of an InSight-like lander from low orbit.

Landed element: Assets on the ground need not be different from those used on a typical solar-powered mission, such as the UltraFlex family of deployable solar arrays such used for the Phoenix and InSight missions. Those missions used 2.1 m diameter arrays, but up to 6m implementations have been developed by the manufacturer, Orbital STK (the specific size needed would depend on the dispersion and pointing accuracy of the incident beam).

Projected Performance: Table 1 estimates the requirements for a power system designed to deliver 3 kW-hr to the lunar surface every 24 hrs, comparable to an MMRTG such as on the Curiosity mission at Mars. The SmallSat orbiter requires only 2.5 m^2 of solar panels and a 1 kW-hr battery to radiate 7 kW power to a conventional surface station. Pointing feedback can be delivered with various schemes, but the simplest is to provide a radio link from the lander to the orbiter, directing the beam to optimize received power with input from photocells at the edges of the surface solar collector.

Spot size	
Pointing accuracy (arcsec)	1
Wavelength (μm)	1
Orbit height (km)	200
Mirror diameter (cm)	20
Dispersion (arcsec)	1.03
Minimum spot size (m)	1
Pointing accuracy (m)	0.97

Broadcast power	
Link time per orbit (min)	4
Orbit period (min)	132
Orbiter panel area (m^2)	2.5
Solar constant (W/m^2)	1361
Orbiter panel efficiency (%)	25%
Illumination duty cycle	50%
Energy collected (kW-hr/orbit)	0.94
Laser wall plug efficiency (%)	50%
Radiated power (kW)	7.0
Lander panel efficiency (%)	50%
Geometric collection efficiency	80%
Surface illumination (kW/m^2)	8.9
Average surface power (W)	108.3

Table 1: Left: A 1-m target can be acquired and illuminated with a 20-cm focusing mirror from a height of 200 km and 1 arcsec pointing accuracy. Right: Average surface power comparable to an MMRTG can be deliverd from a SmallSat with a few square meters of solar panels, a small battery, and a 7-kW fiber laser.

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