MIT HAYSTACK OBSERVATORY

Satellite Beamed Power for Lunar Surface Assets

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The (weak) case for Earth

- Continuous, sustainable power
- μwave beam is insensitive to atmosphere
- Challenge: Access to space is expensive

The (strong) case for the Moon

- Access to orbit is cheaper than landing
- Nearly continuous solar visibility
- Solves the lunar night problem!

Solar power satellites have long been promoted for terrestrial use, but the advantage over ground-based assets has never been convincingly demonstrated. In contrast to the terrestrial case, however, orbiting infrastructure for space power satellites is less expensive and simpler to emplace than ground facilities for use on other worlds. Moreover, a cost-effective architecture is one that minimizes the surface footprint at the expense of resources in space. The confluence of several factors now make beamed power systems practical for solar system exploration in the near-term. This is particularly true for lunar exploration, where the night is 14 Earth days long and there is both scientific and exploration interest in visiting permanently shadowed regions.

Design drivers for Earth

- Space is expensive → put minimal assets there
- Atmosphere absorbs light → use μwaves
- Want continuous power → place in GEO

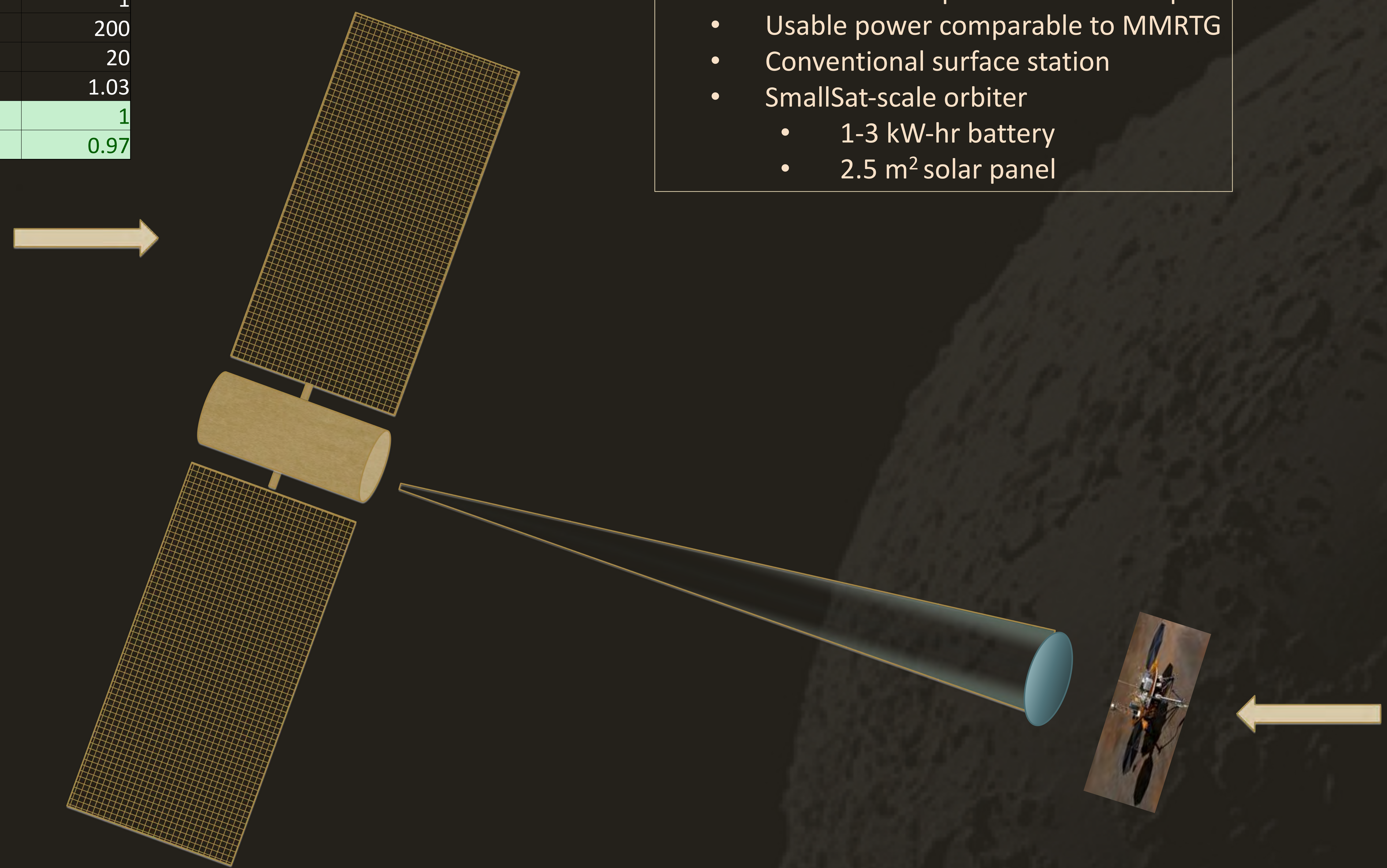
Design drivers for the Moon

- Landing is expensive → minimize footprint
- No atmosphere → use optical transmission for small spot
- Keep orbiter small → low orbit for fine pointing

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

Example: Power for a robotic lander

- 7 kW radiated power in 1 meter spot
- Usable power comparable to MMRTG
- Conventional surface station
- SmallSat-scale orbiter
  - 1-3 kW-hr battery
  - 2.5 m^2 solar panel



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

State of the Technology:

- Lasers:
  - Coherent bundles of fiber lasers deliver 5-50 kW in package appropriate for orbiters
  - Packaging for space, especially thermal management, is an engineering challenge
- Mirror Pointing
  - 1 arcsec gimbaling routinely achieved for SmallSats (e.g. ASTERIA)
  - For power beaming, can use feedback from ground

Scaling up for human missions (Moon & Mars)

- ISRU will need ~25 kW (230x the above example)
- Chain of ~30 satellites provides continuous illumination
- ~8x radiated laser power feasible for each satellite