Space solar power

MIT HAYSTACK OBSERVATORY

An alternative power strategy

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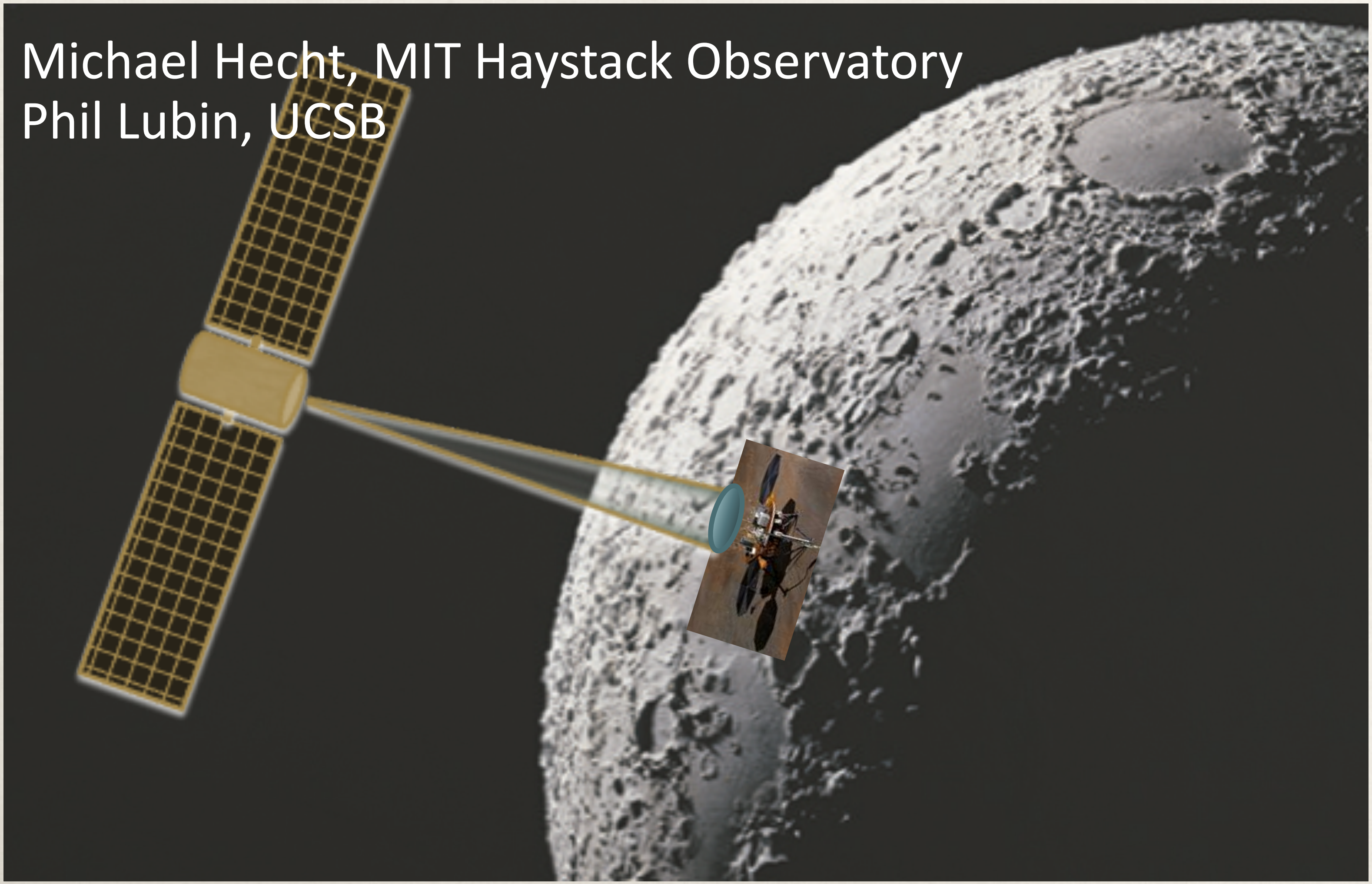

Thanks to TY Fan & Alan Wirth, MIT Lincoln Lab

Why satellite solar power?

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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
- Technology needs are astonishingly modest!
- Also attractive for polar operation on Mars or any other body where landing a power system is impractical

Design drivers

- 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
- One satellite for power, comms, nav, reconnaissance?
  - Space communication relays needed for Far Side, PSRs
  - Navigational support (ala GPS) useful for surface mobility
  - Surface imaging support for e.g. path planning
  - Synergy with scientific surveys?

High Level Requirements

1. On the ground, power shall be harvested from an area consistent with the footprint of a conventional solar-powered surface station.
2. The beamed power spectrum and peak intensity shall be compatible with conventional spacecraft solar arrays on the surface.
3. Sufficient power shall be delivered to provide an average power budget at the surface comparable to a multi-mission radioisotope thermoelectric generator (MMRTG).
4. The illumination cadence shall be no greater than Earth's diurnal cycle (24 hours) .

Example: Power for a lunar lander

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

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

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


SpaceX's first 60 Starlink satellites just before deploying into orbit Image: SpaceX

Backup -Powering a polar mission

Estimates by M. Hecht
Probably optimistic!

Overview

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- Power through the day
  - Solar sufficient for ~ 1 kW-hr / sol.
  - Could gimbal to track sun, but scattering makes horizontal orientation not too bad
- Power through the night
  - Total darkness is ~343 x 24 = 8232 hrs. Figure **10,000 hrs.**

  → For every 10W need 100 kW-hrs.
- Power demands are:
  - Thermal Management, including survival heat
  - Instrument operation and data buffering
  - Telemetry (optional or low duty cycle)
  - Critical spacecraft functions (optional or low duty cycle)

Typical surface energy need

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* Observational instruments typically 10-20W when operating
  * Could make arbitrarily low by reducing duty cycle, but no need if self-heating electronics
* 10-20W to keep warm (comes free from electronics)
* Telemetry can be arbitrarily low by reducing duty cycle, need sufficient nonvolatile memory to buffer data
* Stuff I forgot
* **Bottom line:** need **10-30 watts** continuous without going to extraordinary lengths

MMRTG

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* Thermopile surrounding 8 GPHS units, 250 W (thermal) each for total of 2 kW thermal.
* Typically 100-150 W electric with battery storage, —> ~3 kW-hr/day
* Need to accommodate heat both on surface and in cruise
* Challenging regulatory environment and limited availability.
* Not typically allowed for Discovery-class competitions.
* Stirling cycle ASRG has been under development, same output with only 2 GPHS units. Offered in 2010 Discovery but with large “tax” ($29M?) and not subsequently selected.