Laser Power Beaming for Applications on the Moon

Geoffrey A. Landis

NASA Glenn Research Center

Cleveland, OH

Collaborators: the NASA Glenn Compass engineering team

Steven R. Oleson, Ben Abshire, Bushara Dosa, Brent Faller, Ryan McDonough, Lucas Shalkhauser, Peter Simon, Elizabeth Turnbull, Natalie Weckesser, Anthony Colozza, John Gyekenyesi, Thomas Packard, David Smith, James Fittje, and David Squires

Future In-Space Operations Seminar

~~October 8, 2025~~

January 14, 2026

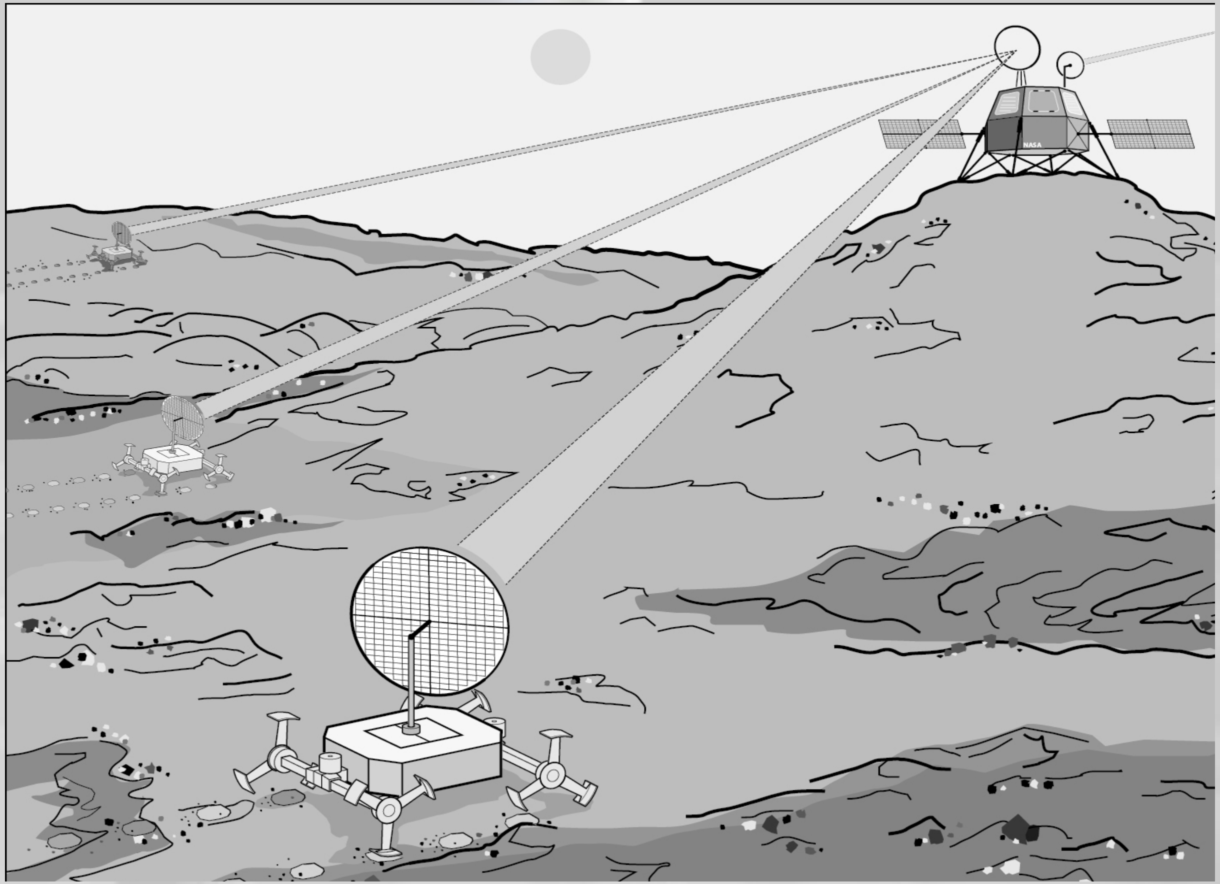
Power Beaming for the moon

A **beamed power** system could be used to send power directly to a rover, science station, or lunar base

- Power source at the illuminated rim of permanently dark crater
- Collector on rover converts the beamed energy to electrical power

Possible Beaming approaches:

- Microwave
- Laser
- Millimeter Wave



Sketch of the possible use of a base station on a crater rim beaming power to multiple rovers exploring the permanently shadowed craters of the moon.

Power Beaming: Comparison of Approaches

Microwave:

- High transmitter efficiency
- Efficiency depends on frequency– but 85-95% DC to RF efficiency has been achieved
- Possible to make high conversion efficiency receivers
- Well-developed technology at longest microwave wavelengths; in progress at X-band and shorter
- But: transmitters and receivers are large

Millimeter wave:

- Systems are ~10 times smaller than microwave
  - But: transmitters and receivers still quite large for beaming over significant distances.
- Low Technology Readiness level (but tech is progressing fast)

Laser:

- Power efficiency is lower
  - roughly 50% transmitter efficiency, 50% receiver efficiency
- Technology is developed (but needs space qualification)
- Narrow beam width means **much** smaller systems– cm to meter scale optics

Quick summary: different technologies are best for different applications

Different technologies for different applications

Microwave Power beaming

- Large systems, where sizes are large and efficiency is important
- Short distances, where beam spread is less important

Millimeter Wave power beaming

- Next generation beyond Microwave: smaller size for same transfer distance
- but needs technology development

Laser Power beaming

- Small systems, where size is an important parameter
- Long distances, where beam spread is an issue

Note that near-field power coupling approaches, such as inductive coupling, were not considered here. These power coupling methods can have very high energy transfer efficiency, but only transfer power over small gaps (essentially requiring nearlydirect contact)

Power Beaming: Laser

Laser systems have narrow beam width, and can beam power to photovoltaic cells that can also convert sunlight

- Typical wavelengths proposed: 500 to 1100 nm
  - Laser efficiency is 50-60% (electrical to optical power)
    - Slightly higher efficiencies for lower beam quality diode lasers
  - Depends on wavelength

- Receiver technology: photovoltaic cells
  - Efficiency about 50% if cell is matched to laser
  - Cell will also convert solar light (but at lower efficiency)
  - Well developed technology

Laser choice: Beam Quality

- **Low coherence** light sources project can only focus to a spot size based on classical object/image optics
  - (but not less than diffraction limit)

- **High coherence** light sources can project a spot size as small as the diffraction limit

- Beam quality is critical if you are beaming a long distance

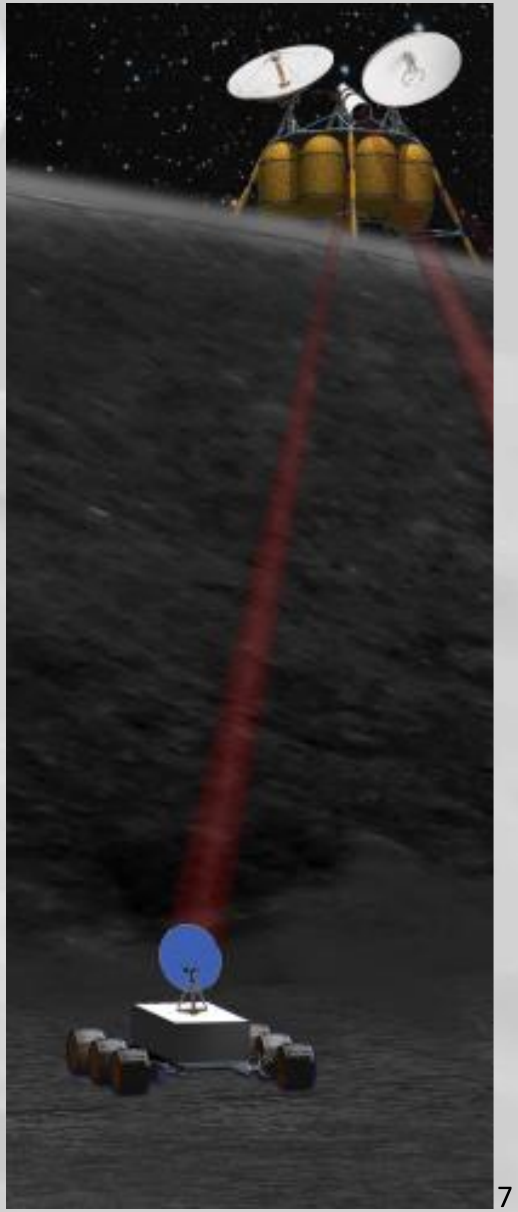
Beam quality is typically measured by the parameter "M^2", a measure of the minimum spot diameter that can be produced by a source
M^2 equals 1 for a perfect (diffraction-limited TEM00) beam

Laser Power Beaming:
Case 1: near term demonstration

short distance beamed power to small rover

At short distances, we can use a laser with low beam quality

- higher beam divergence less important if the distance is short
- Trade off the beam divergence for higher efficiency and lower cost laser

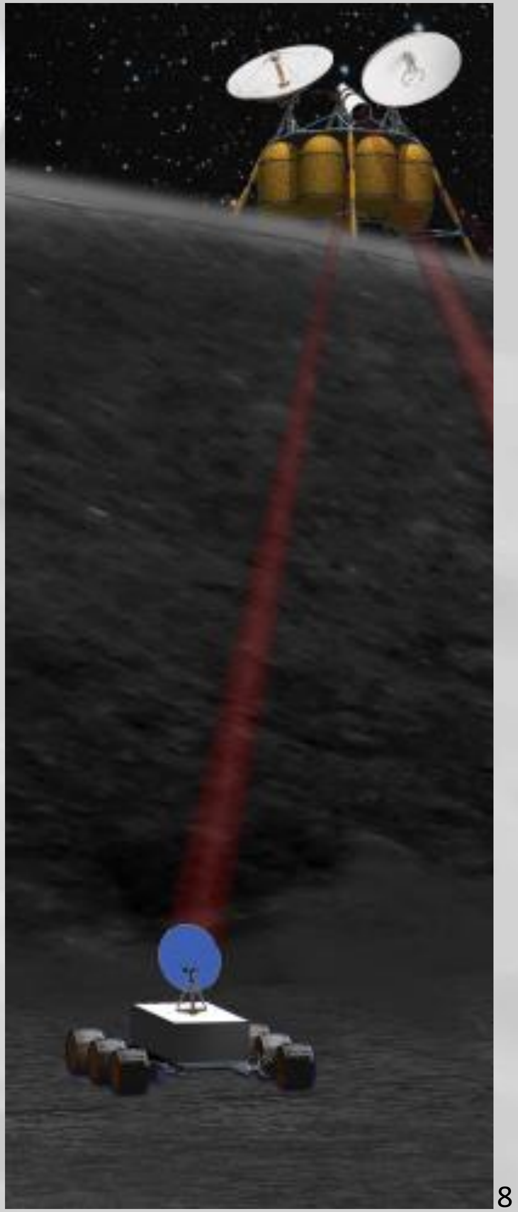


Laser Power Beaming:
Case 1: near term demonstration
short distance beamed power to small rover

For short distances, we can use a laser with low beam quality

Parameters

- Power level: 50 W
- Distance: up to 100 m
- Laser: semiconductor diode laser at 860 nm
    - Energy conversion efficiency (DC to optical power): 70%
- PV receiver: GaAs solar cell
    - Energy conversion efficiency (optical to DC power): >50%
    - Well developed technology



Laser choice: Semiconductor diode laser

- Semiconductor Diode lasers have high efficiency but low coherence (low beam quality)
  - Essentially a classical light source: light output is not in phase
  - Efficiency is very good and cost is very low
  - Well developed technology for other purposes (CD readers, etc.)
  - Available in hundreds of watts optical output

Why this technology?

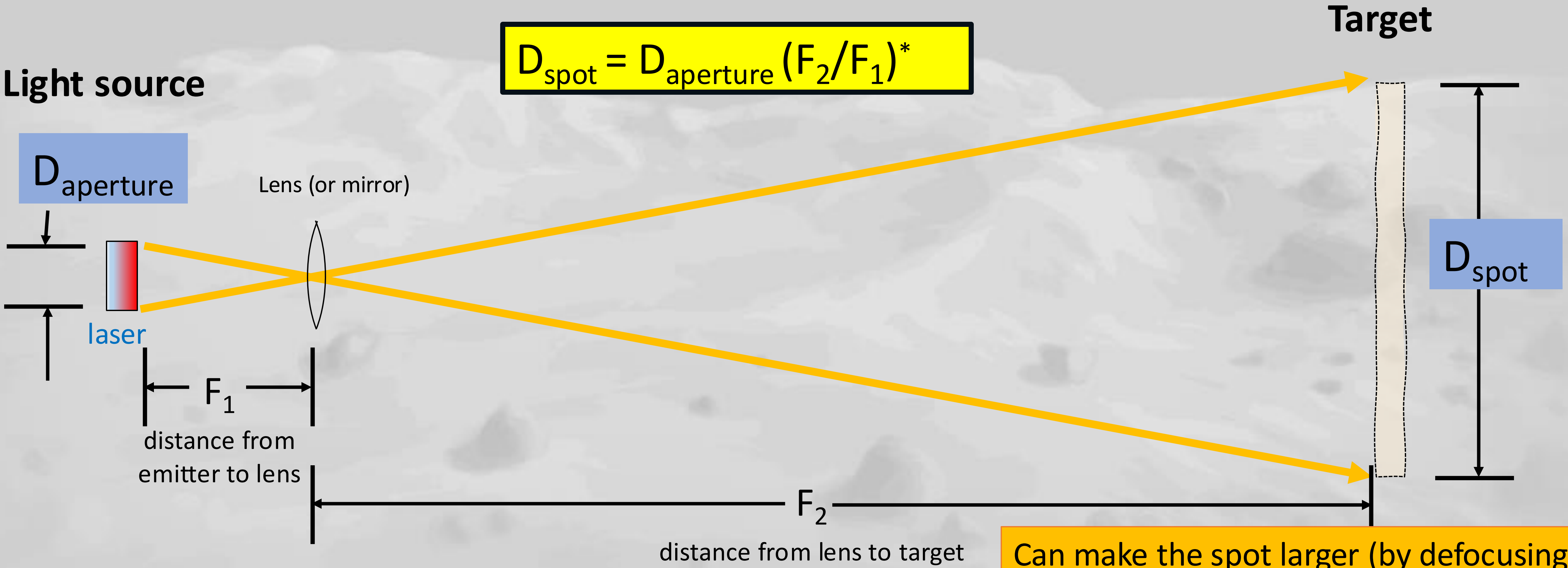
- High beam quality is not needed for short distance
- GaAs solar cells are well matched to diode wavelengths, and are a well-developed technology

Example of high-efficiency semiconductor bar laser

Classical optics spot size

- In classical (incoherent) optics, the size of the beam on target is a ***projected image of the emitting aperture***

$$D_{spot} = D_{aperture}\,(F_2/F_1)^*$$



*for D_{spot} >> diffraction limit

Can make the spot larger (by defocusing) but not smaller

Laser Power Beaming: **Case 1**

short distance beamed power to small rover

How big is the system?

- Mission: beam power of 50 W up to 100 m

$D_{spot} = D_{aperture} (F_2/F_1)^*$

Example case:

semiconductor diode laser with fiber output

$D_{aperture}$ = 50 µm (fiber output)

F_1(focal length) = 10 cm

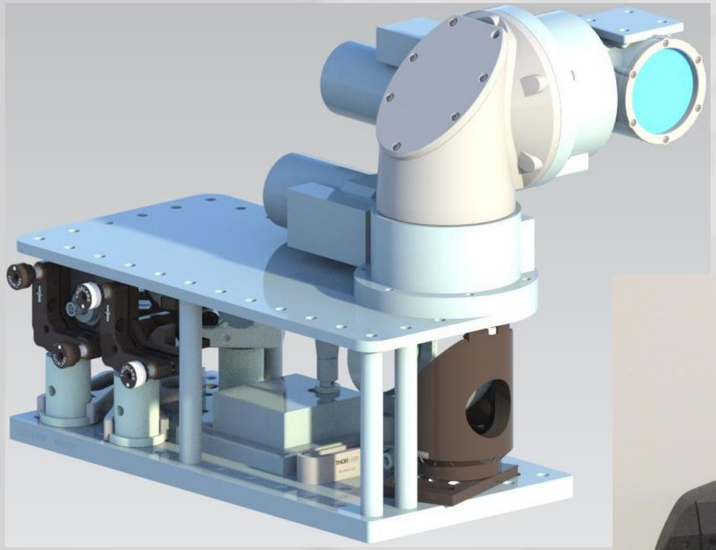
F_2(distance to target) = 100 m

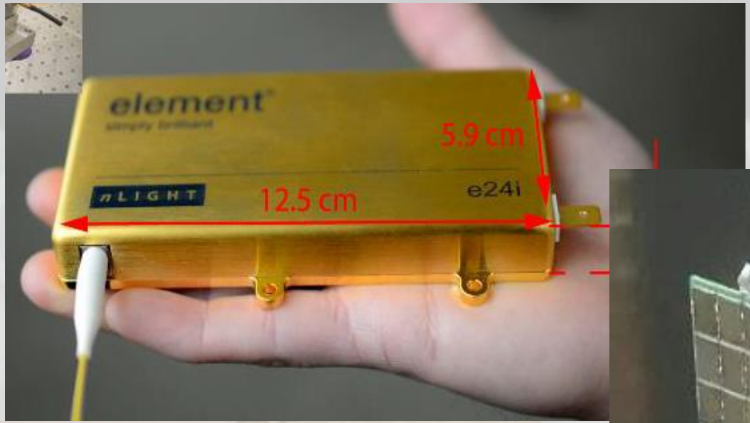
D_{spot} =1000 $D_{aperture}$= 5 cm

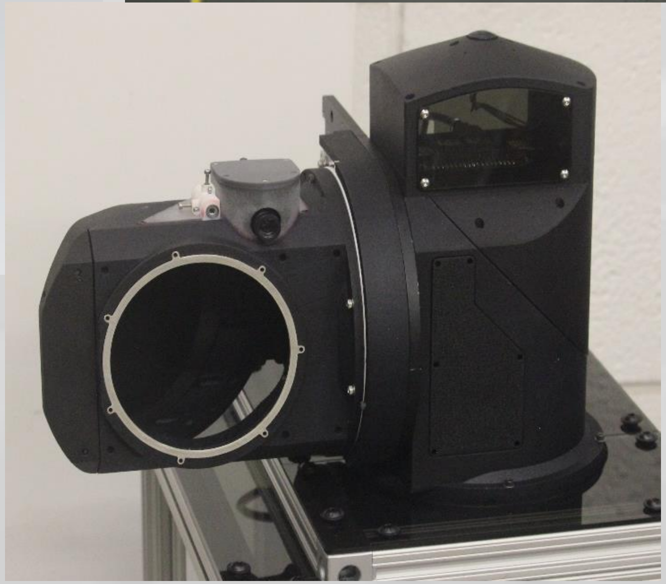
Assuming an 11° half-angle of fiber output (typical for multimode fibers), the lens diameter is .38 times the focal length. This is a very small system, requiring a 3.8-cm lens (easily available off the shelf)

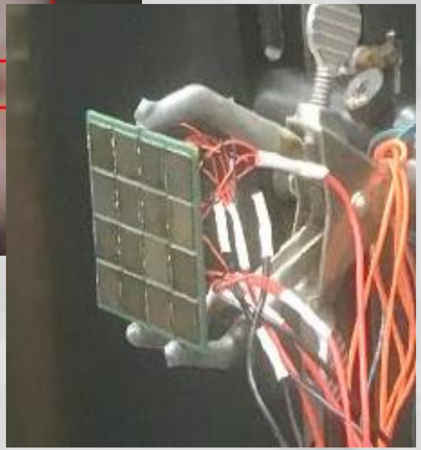
Moonbeam (University of California Santa Barbara)

Technology development & prototype hardware by University of California Santa Barbara "Moonbeam" project, led by Prof. Phil Lubin, under the NASA Lunar Surface Technology Research (LuSTR) program



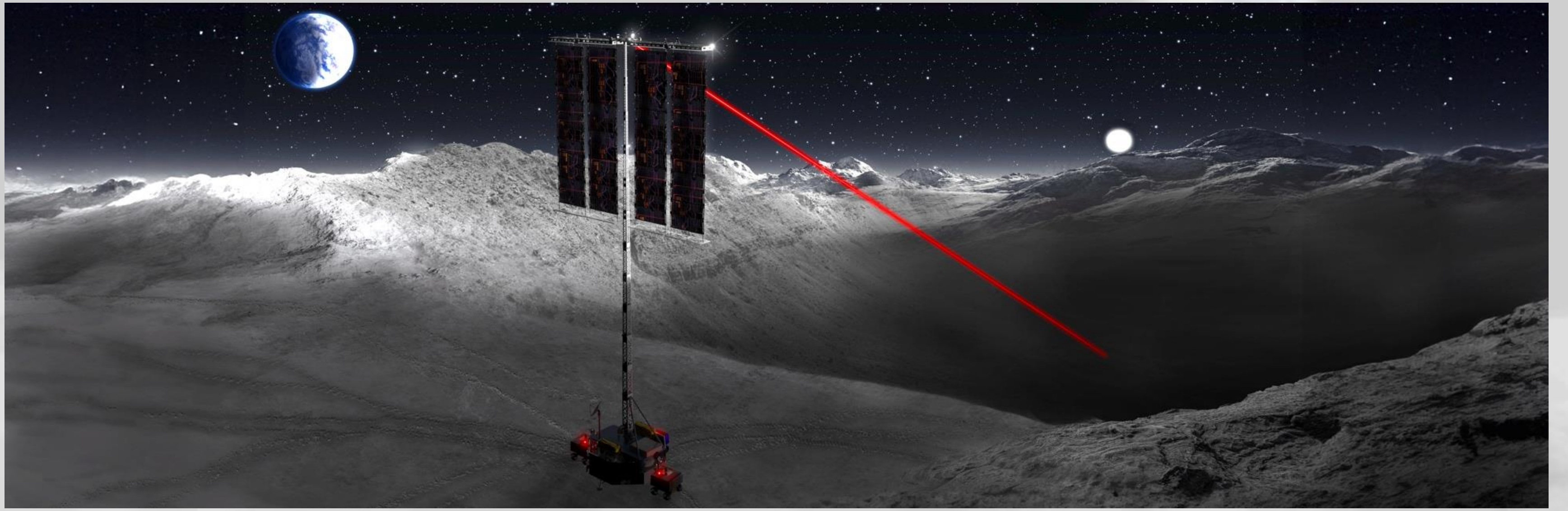






Images from: University of California Santa Barbara "Moonbeam" project, courtesy LuSTR program
Reference: https://lsic.jhuapl.edu/uploadedDocs/presentations/1924-1.13_Lubin_LuSTR%202023%20-%20UCSB%20Moonbeam%20-%20b.pdf

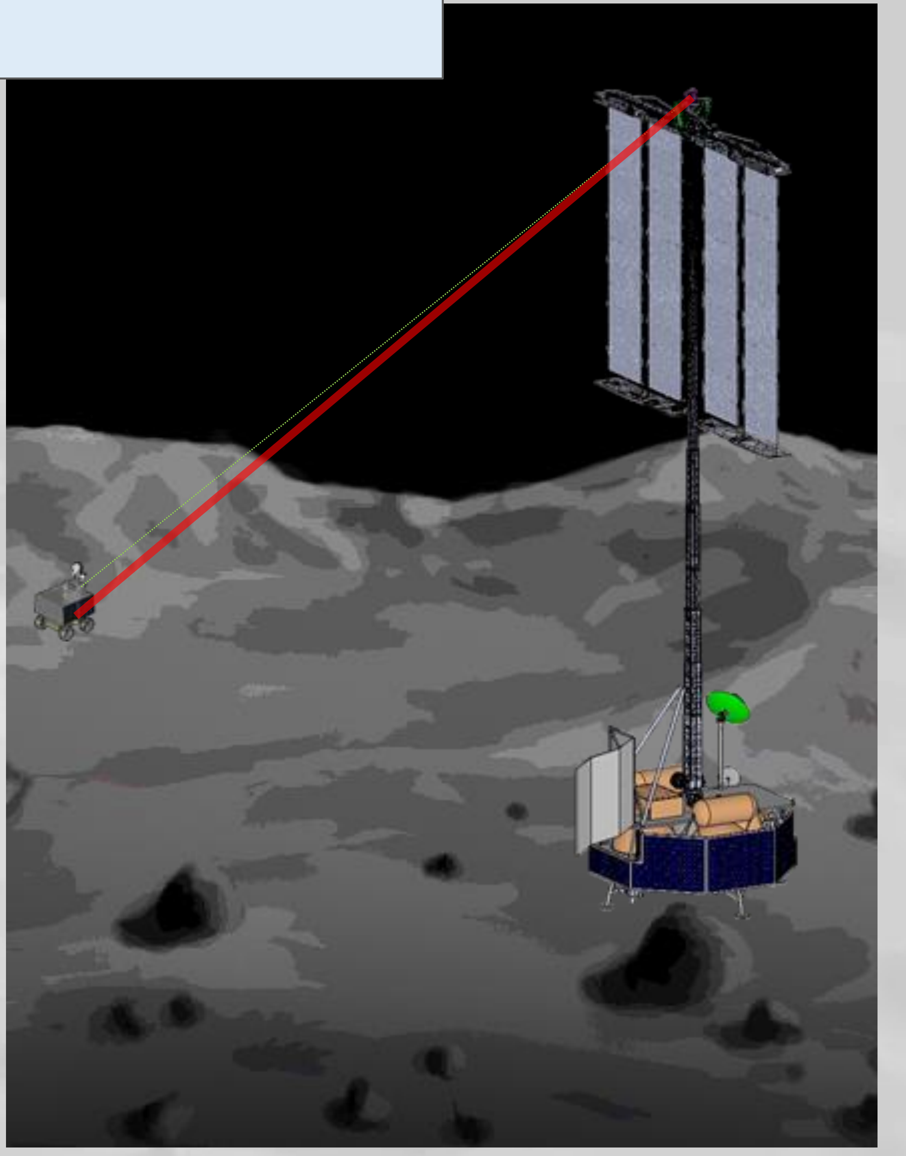
Case 2: Operational Surface to Surface Power Beaming



- **Objective**: design study of a near-term application of power beaming for transmission of electrical power to landers or rovers
- **Baseline requirements:** deliver 300 W user power at up to 10 km distance. Beam station mass <625 kg (to fit on CLPS lander)
- **Constraints:** near-term assumptions (no new technology), incorporating realistic mass growth and margins; target deployment 2028.

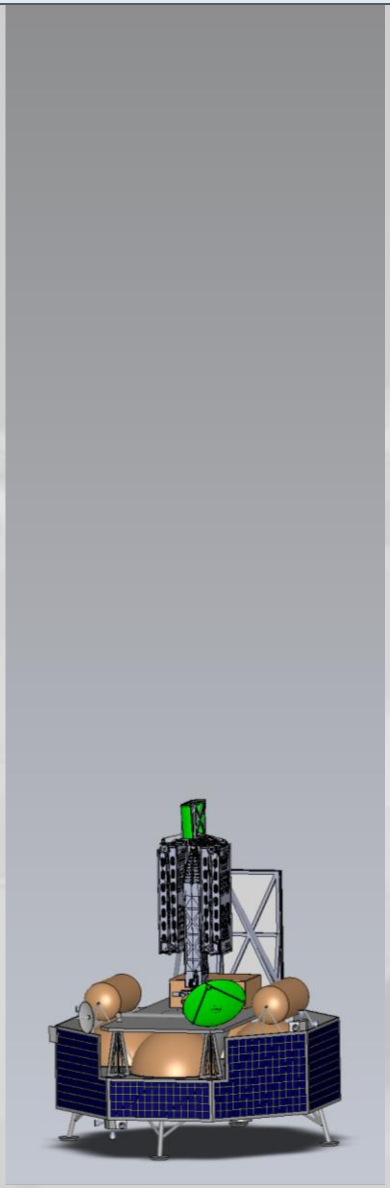
Surface to Surface Power Beaming

Due to surface irregularities and the close horizon of the moon, to achieve 10-km transmission the laser must be elevated above the surface.



Overview of structure

The Vertical Solar Array Technology (VSAT) program is developing a solar array mounted on a 10-m tall mast, intended to fit on a Commercial Lunar Payload Services (CLPS) lander.

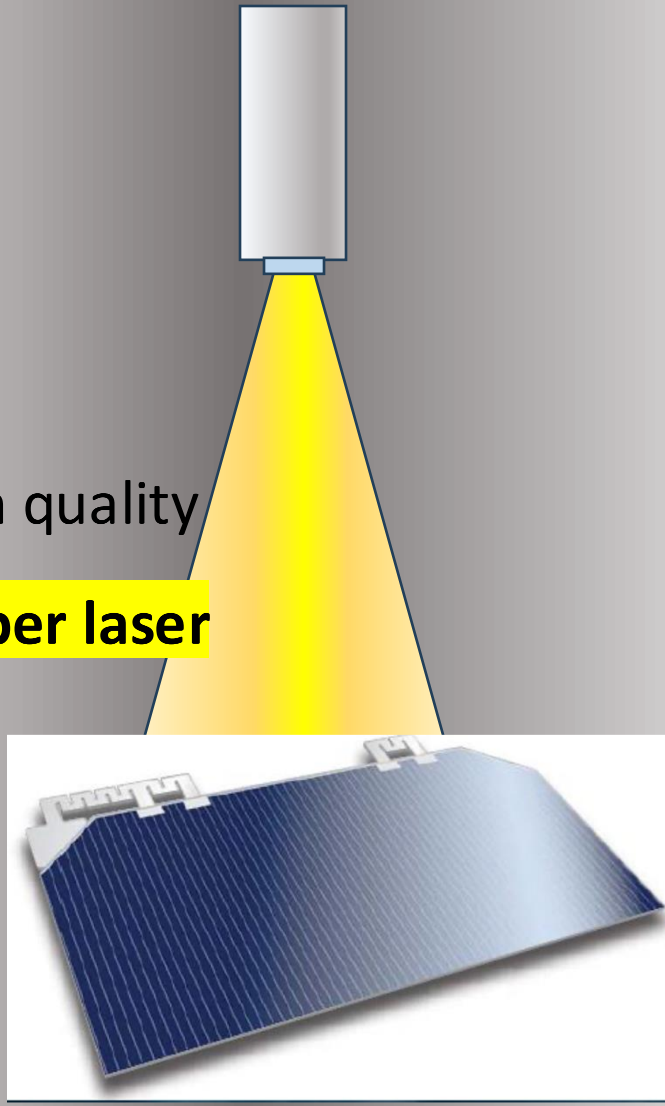


Beaming station stowed

Beaming station deployed

Choice of laser and photovoltaic receiver

- Laser requirements
  - High efficiency (optical power out/electrical power in)
  - Good beam quality
  - Available at high CW power
  - High TRL
- Semiconductor diode lasers have good efficiency but too poor beam quality
- **Choice of laser based on these requirements is a diode-pumped fiber laser**



Laser
baseline: commercially available fiber laser

- This is an example showing specifications for a commercially available laser at the wavelength and power level baselined.
- Note that while this example laser is not space qualified, other lasers using this technology have been flown.
- Higher laser efficiencies (>50%) has been demonstrated, but for this project we baselined a commercially available model

Optical Characteristics

Central Wavelength Range, 1070 nm ±10
Mode of Operation CW/Modulated
Power Tunability, 10-100%
Power Stability, ±0.5%
Output Fiber Core Diameter, 50, 100 and 200 µm
Beam Quality, BPP 2, 5, 10 mm × mrad
Operating Temperature Range, 10-40 °C
Cooling: Water
Supply Voltage, 50/60 Hz, 3-phase, 400-480 VAC

*** Output Power 4 and 6 kW available soon**

General Characteristics

Average Power Mode, 6kW

Dimensions, 448×760×177 mm
Weight, <80 kg
Power Consumption, 16 kW
Efficiency = ~38 %

Average Power Mode, 3 kW

Dimensions, 448×760×88 mm
Weight, <45 kg
Power Consumption, 7.8 kW
Efficiency = ~ 38%

- Spacecraft carries two lasers to give redundancy

Laser station

Design

The diode-pumped fiber laser is mounted on the deck of the lander. Laser output is sent to the apex-mounted beam director by a fiber-optic cable.

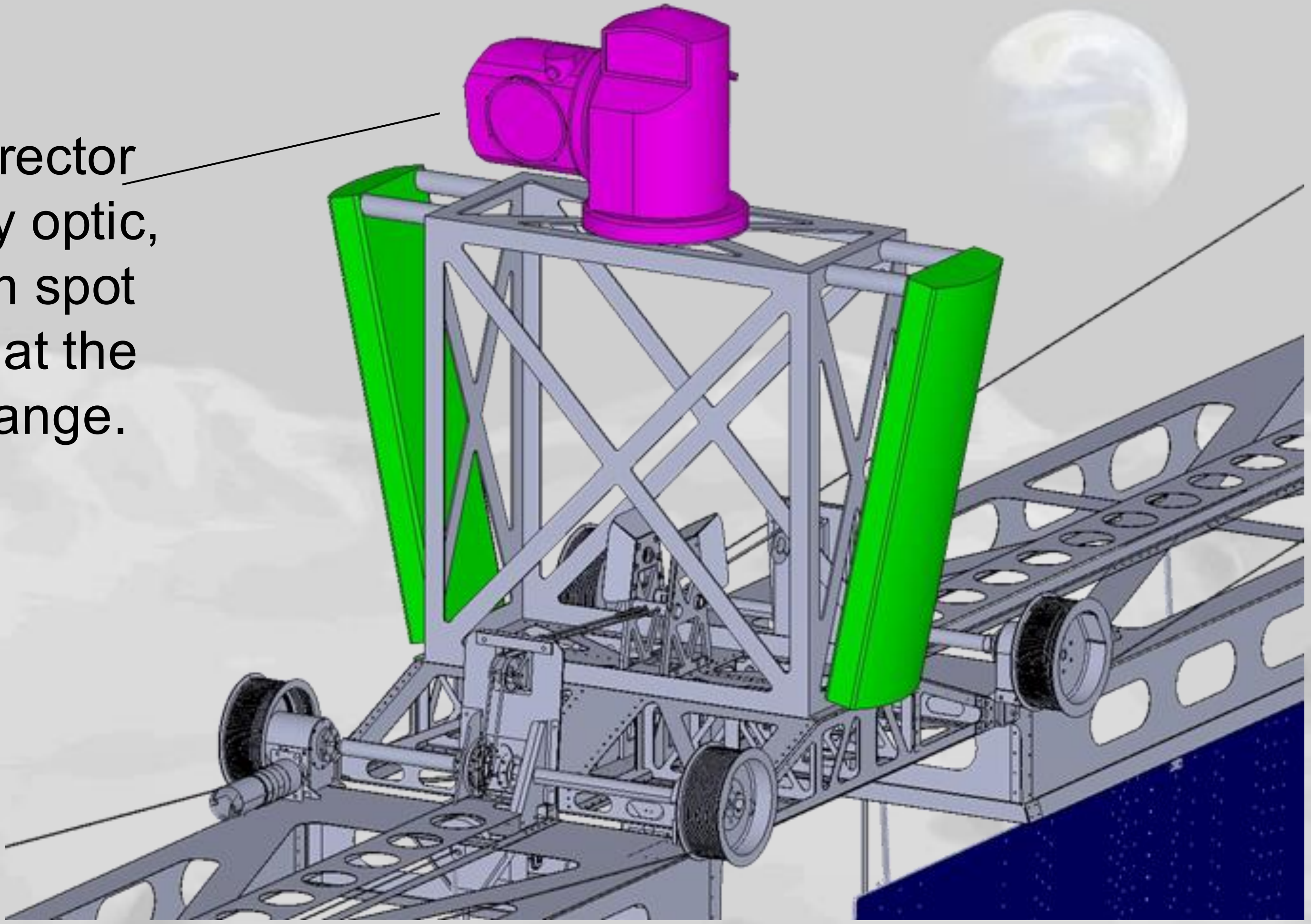
A 7 m^2 deployable radiator keeps the laser within operating temperature limits. 1595 W of laser optical power is directed by a steerable beam director with a 10-cm primary optic, resulting in a 1.5-m spot diameter (FWHM) at the maximum 10-km range.

A 3.4-W diode-laser beacon on the receiver enables precise pointing of the beam. An array of InGaAs photovoltaic cells with conversion efficiency of 50% at the laser wavelength was baselined.

This results in an output of 540-W DC on a 1.5-meter receiving photovoltaic array (slightly more if a larger receiving array is used). Of this received power, 300 watts is directly available to the user, while 242 watts is used to charge batteries for use while the beam is not available.

The system also incorporates a 5G 60-Mbps data relay

Steerable beam director with 10-cm primary optic, resulting in a 1.5-m spot diameter (FWHM) at the maximum 10-km range.



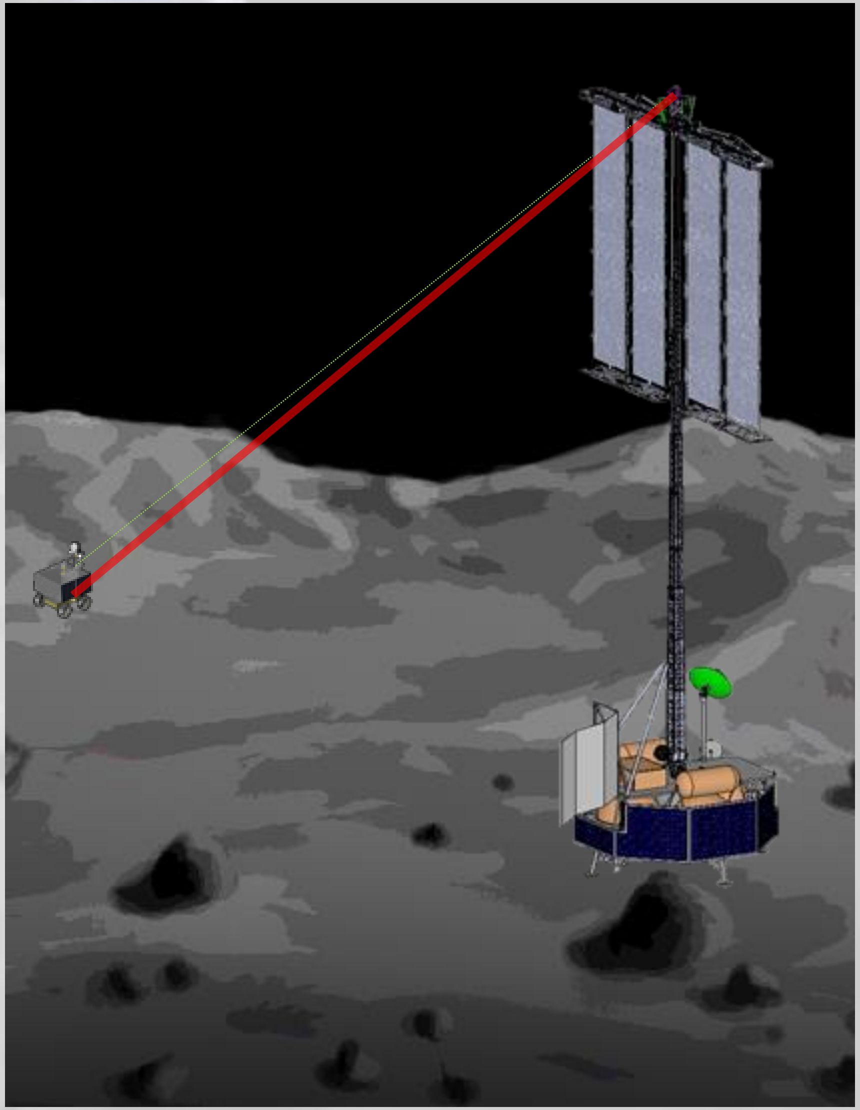
Detail showing beam director (magenta) and data-relay antenna (green) at apex of mast. The laser itself is in the base, and the output fed to the beam director by fiber

Concept of Operations

- The system beams power for 57% of the time, with 44% of the time idle (accounting for the time when the VSAT array is itself in shadow). 1595 Watts of optical power are output in the beam.
- Accounting for receiver efficiency and beam losses, this results in an output onto the 1.5-meter receiving photovoltaic array of 542 watts. Of this, 300 watts is directly available to the user, while 242 watts is directed to the batteries for use while the beam is not available.

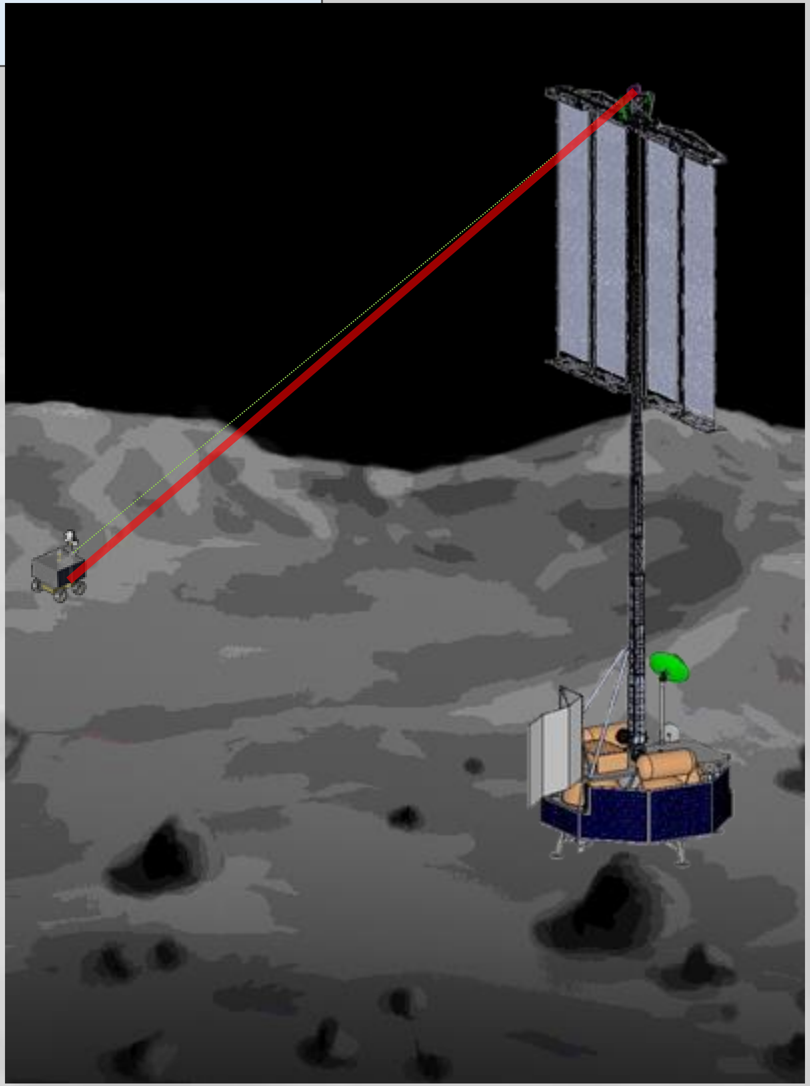
Mass equipment list

MEL Summary: Case 2_VSAT_Beamed_Power_LSR CD-2023-203	VSAT_LSR
Main Subsystems	**Basic Mass (kg)**
Laser and beam director	35.9
Attitude Determination and Control	1.6
Command & Data Handling	13.0
Communications and Tracking	22.5
Electrical Power Subsystem	106.7
Thermal Control (Non-Propellant)	70.9
Structures and Mechanisms	206.1
Element Total	***456.7***
Element Mass Growth Allowance (Aggregate)	98.0
MGA Percentage	21%
Predicted Mass (Basic + MGA)	554.7
System Level Mass Margin	68.5
System Level Growth Percentage	15%
Element Dry Mass (Basic+MGA+Margin)	623.2
Element Inert Mass (Basic+MGA+Margin)	623.2
Total Wet Mass (Allowable Mass)	***623.2***

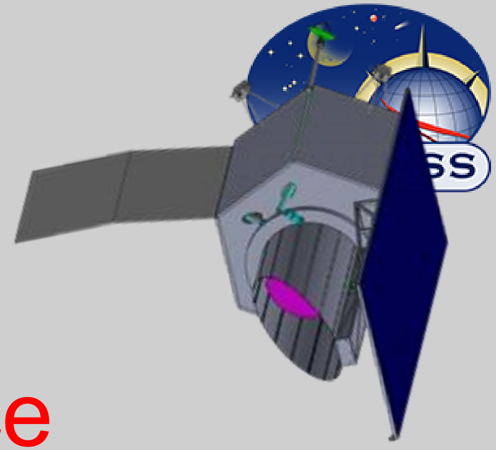


Summary: surface to surface power beaming

- A conceptual engineering design was done for a fiber-laser based beaming station on a VSAT solar array
- Beams power to a photovoltaic array on a rover or lander inside a permanently shadowed lunar crater at a distance of at least 10 km
- System can fit in the constraints of a Commercial Lunar Payload System (CLPS) lander



Case 3: Night power of surface science stations from orbit



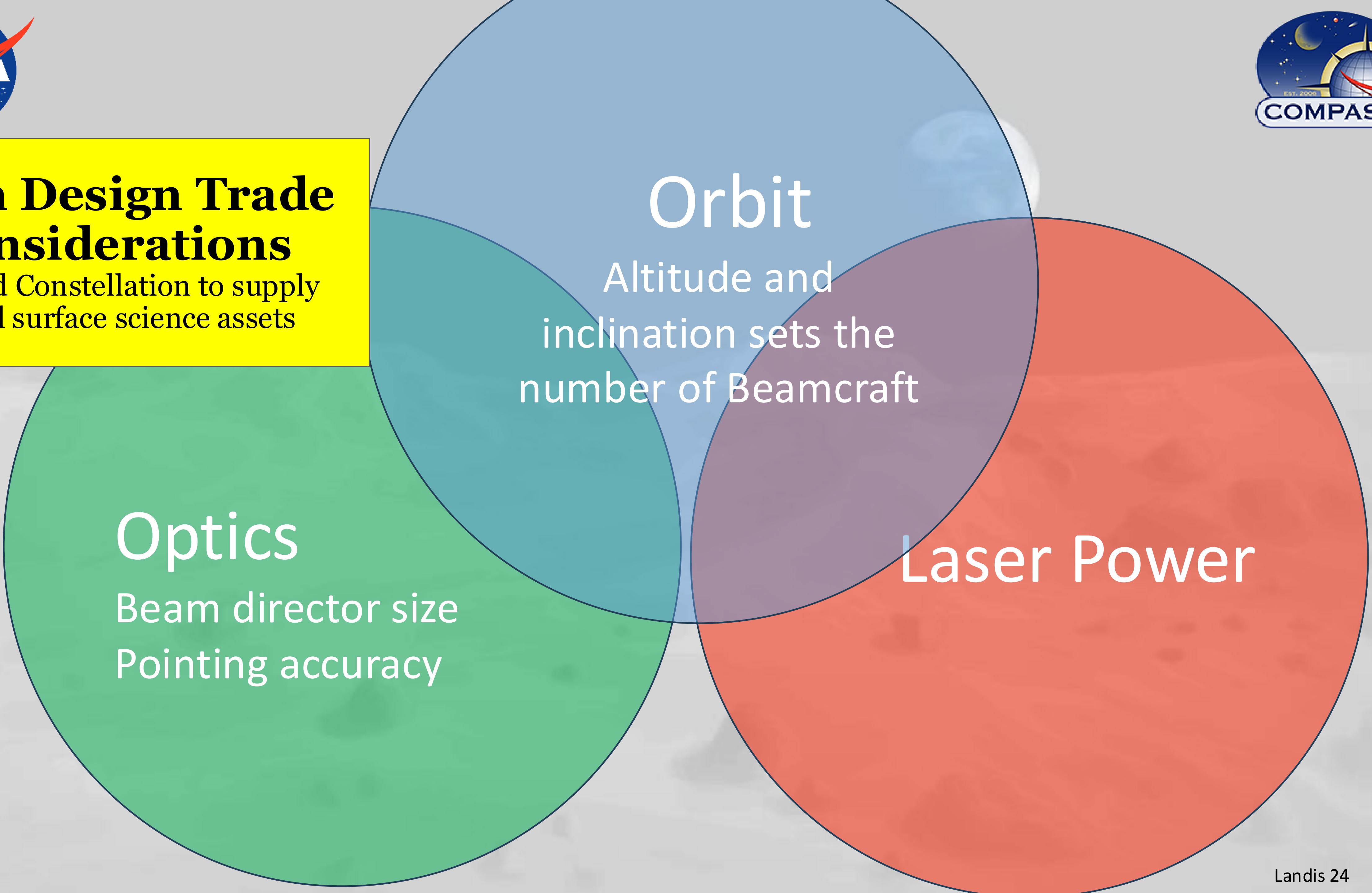
- **Science missions envision a network of surface stations (or rovers) deployed at multiple locations across the lunar surface**
- Could be any location on surface
- Need to operate at all times during the lunar cycle:
  - both day and night operation

Problem statement

- Night time operation is a **severe** problem for small landers
- Explore a power/relay beamcraft for providing ~50W of nighttime power to multiple science landers in the 2030's *anywhere* on the moon

Main Design Trade Considerations

Beamed Constellation to supply global surface science assets



Main Design Trade Considerations

Beamed Constellation to supply global surface science assets

Orbit

Altitude inclination and number of Beamcraft

Altitude drives the required laser optic Size

Dwell Time, revisit frequency

Optics

- Driven by $D_{spot} = 2.44\ \lambda\ \text{Separation} / d_{lens}$
- User Beam Spot Size (limited by size of lander)
- Pointing: higher orbit further separation but slower slew
- Optics size contributes to size/cost/Complexity of beamcraft

Laser Power

- Set by power needed to charge lander batteries, dwell time, and revisit frequency
- *Higher Power Lasers impact size/power /thermal/cost of Beamcraft*

Optics size is not driven by power needed

Main Design T Considerations

Beamed Constellation to supply global surface science assets

Lower orbits: Allow smaller optics BUT require more beamcraft/more ΔV. Longer outages require larger lander batteries

Higher orbits: Require larger optics BUT fewer beamcraft. Shorter outages/longer dwell times allow smaller lander batteries and lower power lasers

Orbit

Altitude inclination and number of Beamcraft

Altitude drives the required laser optic Size

Dwell Time, revisit frequency

Optics

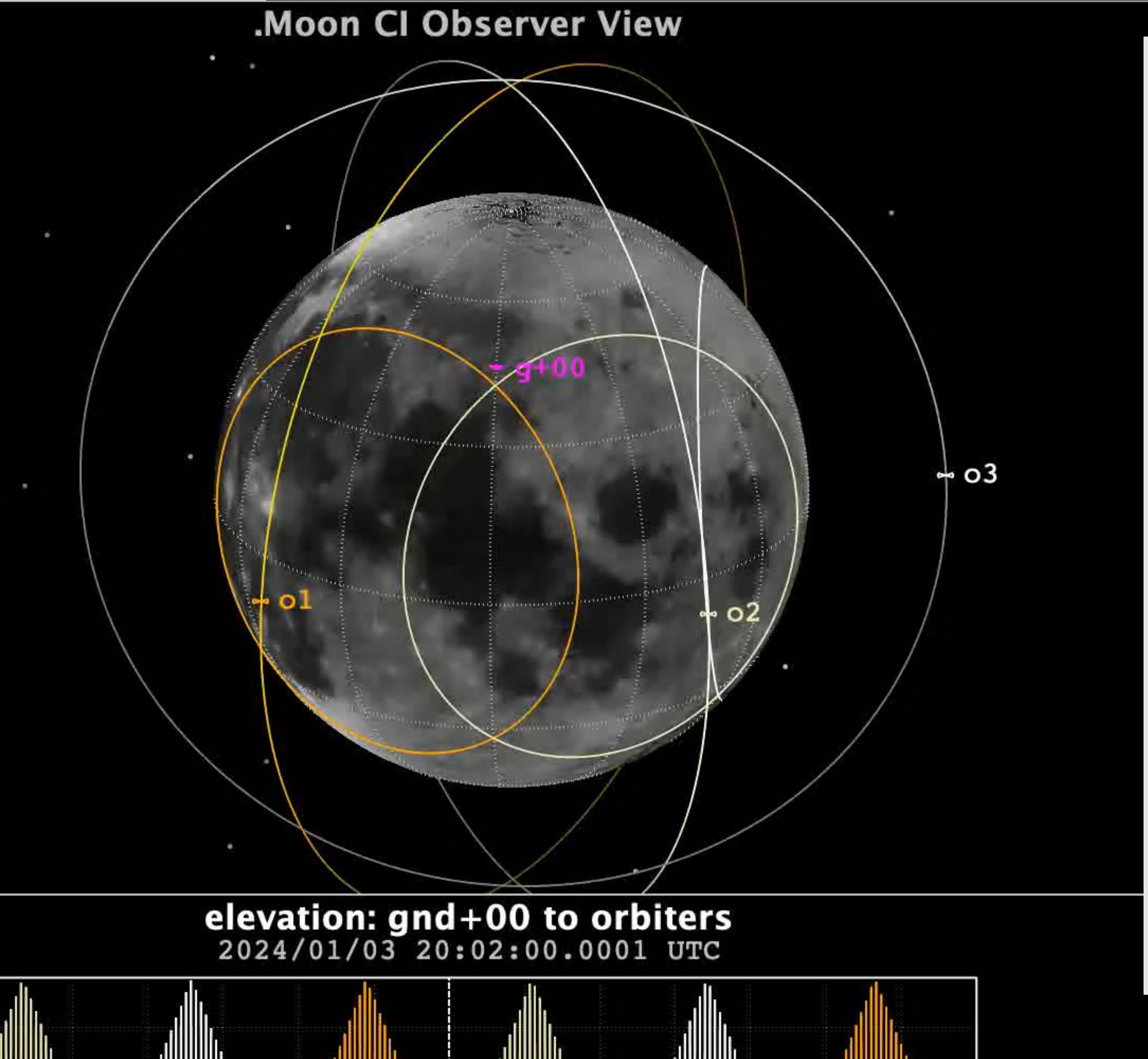
- Driven by D_{spot} = 2.44 λ Separation /d_{lens}
- User Beam Spot Size (limited by size of lander)
- Pointing: higher orbit further separation but slower slew
- Optics size contributes to size/cost/Complexity of beamcraft

Laser Power

- Set by power needed to charge lander batteries, dwell time, and revisit frequency
- *Higher Power Lasers impact size/power /thermal/cost of Beamcraft*

Optics size is not driven by power needed

Mission: SOAP Contact Window Analysis
(3 Polar Orbiters, 90° Inc to Mid-Lat Station)



Satellite Orbit Analysis Program (SOAP) software used to evaluate contact windows between various orbit configurations and surface science stations

- Three satellites in 800-km circular polar orbits
  - The requirement for three orbital planes is driven by the need to service all latitudes. If the science stations are only at near-polar latitudes (or only at near equatorial latitudes, only one beamcraft is needed)

Assumptions

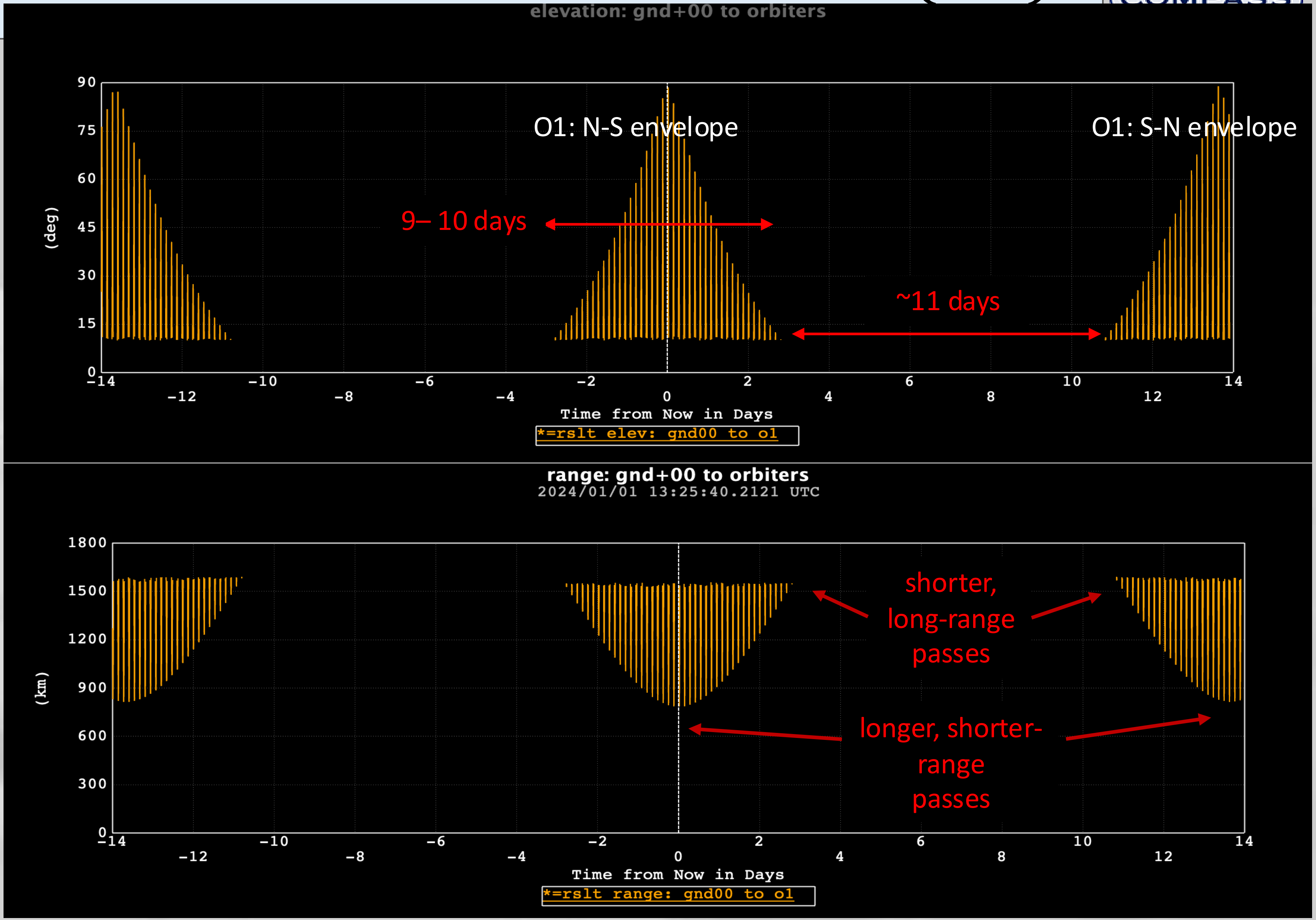
- Operational orbits were determined to be 800 km, circular, polar. Tp = 3.17 hr
- Orbiter station keeping assumed
- RAAN separation:
  - Full coverage for 3 orbiters by spacing orbits 60° apart (3x N-S + 3x S-N passes)
  - Full coverage for 2 orbiters by spacing orbits 90° apart (2x N-S + 2x S-N passes)
- TA spacing: staggering passes for times of overlapping coverage (i.e., station in view of more than 1 satellite) would be beneficial and should be included in future work
- Orbiters simulated with 47.5° half-angle, Nadir-pointer, simple conic sensor (SOAP sensor package)

Mission: Closer Look at Orbiter Passes (O1)

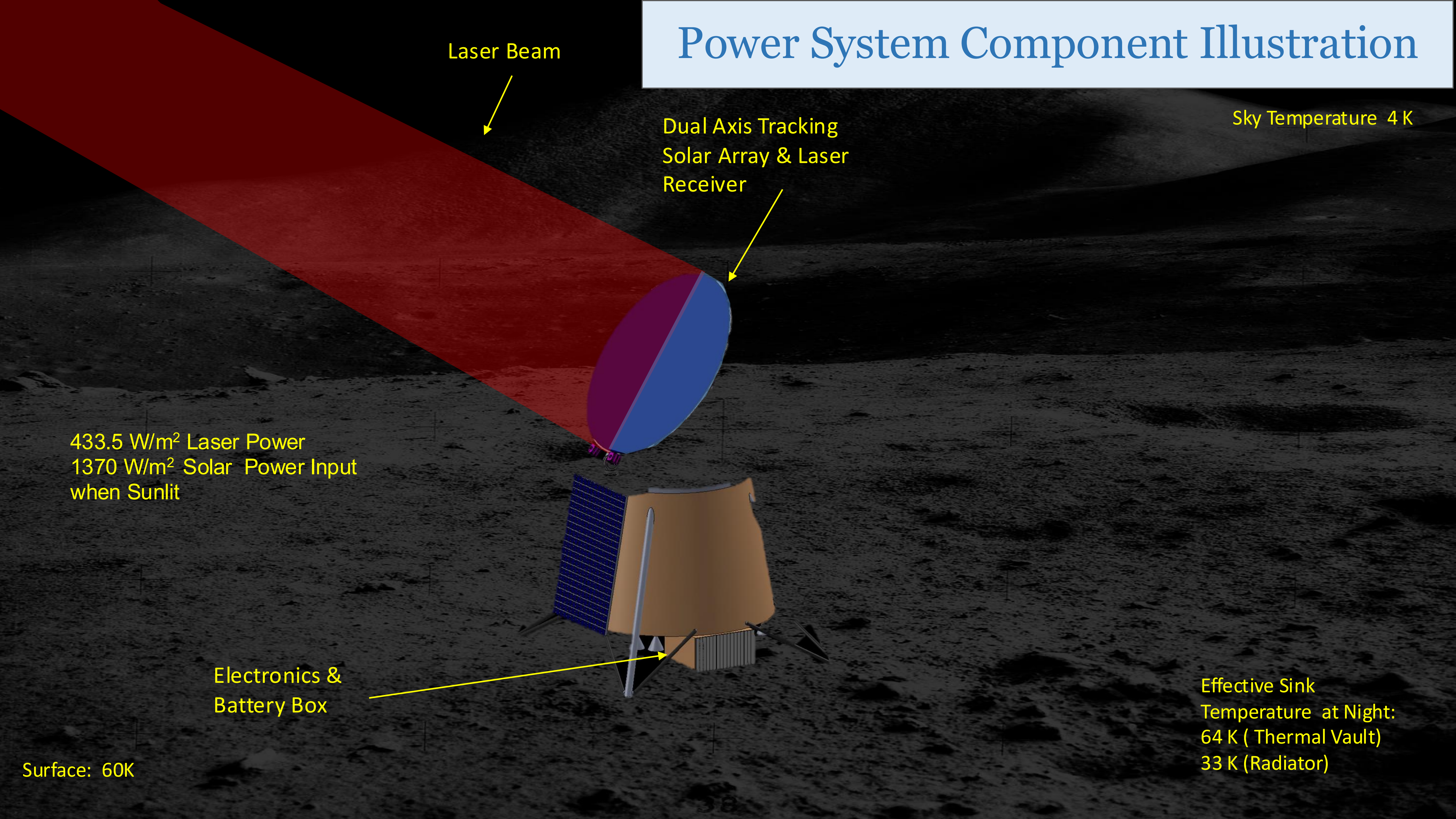
Each orbiter can be seen by the ground station 1x per 3.17 hr orbit until the moon's rotation under the orbital plane drifts the pass to where the orbiter can no longer be seen over the 10° horizon mask

This "series of passes" forms an envelope lasting ~9-10 days with quality of passes ranging from short-long-range, to long- short-range and then back to short-long-range

Each orbiter's contact envelope repeats approximately every 14 days with the first contact during the N-S passage, and the second on the S-N passage.



Power System Component Illustration



Laser Beam Power Requirements

The laser beamed power output (P_{lout}) requirement is based on the continuous power level the load utilizes (P_c) and the total energy that needs to be transmitted (E_t) and the various inefficiencies of the system.

$$E_t=P_c t_b \eta_{bc}+P_c t_t$$

$$P_{Lout}= (E_t/t_t)/(\eta_{ff}\ \eta_{bs}\ \eta_{sc})$$

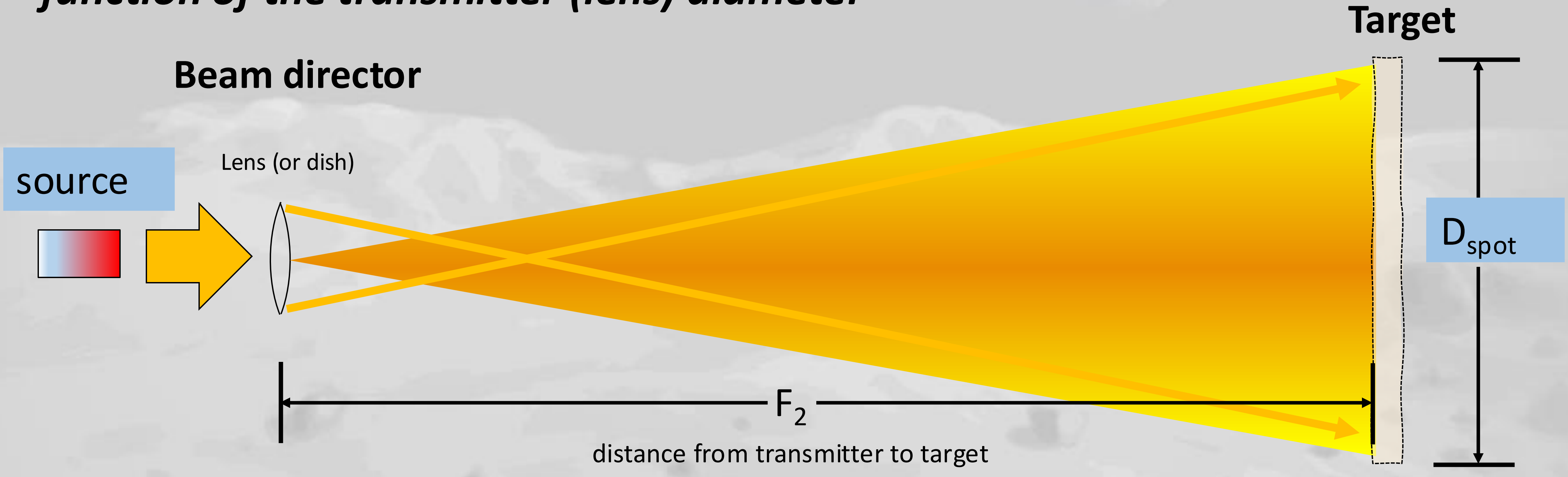
$$P_{Lin}= P_{Lout}\ \eta_L$$

Item	Value
Power Transmission Time (t_t)	0.25 Hr
Shadow (No Power Transmission) (t_b)	2.75 Hr
Battery Charging Efficiency (η_{bc})	0.95
Array Fill Factor (η_{ff})	0.85
Laser Beam Spill (η_{bs})	0.5
PV Cell Efficiency (based on laser) (η_{sc})	0.5
Laser Efficiency (η_L)	0.4

Continuous Load Power (P_c, W)	Laser Beam Power (P_{lout}, W)	Power to Laser (P_{in}, W)	Receiving Array Output (W)	Power to Battery (W)
39.75	3000	7800	637	510

Diffraction-limited spot size (high beam quality lasers)

- In the diffraction limit, the size of the beam on target is a ***function of the transmitter (lens) diameter***



$$D_{spot} = 2.44 \lfloor F_2/d_{lens}$$

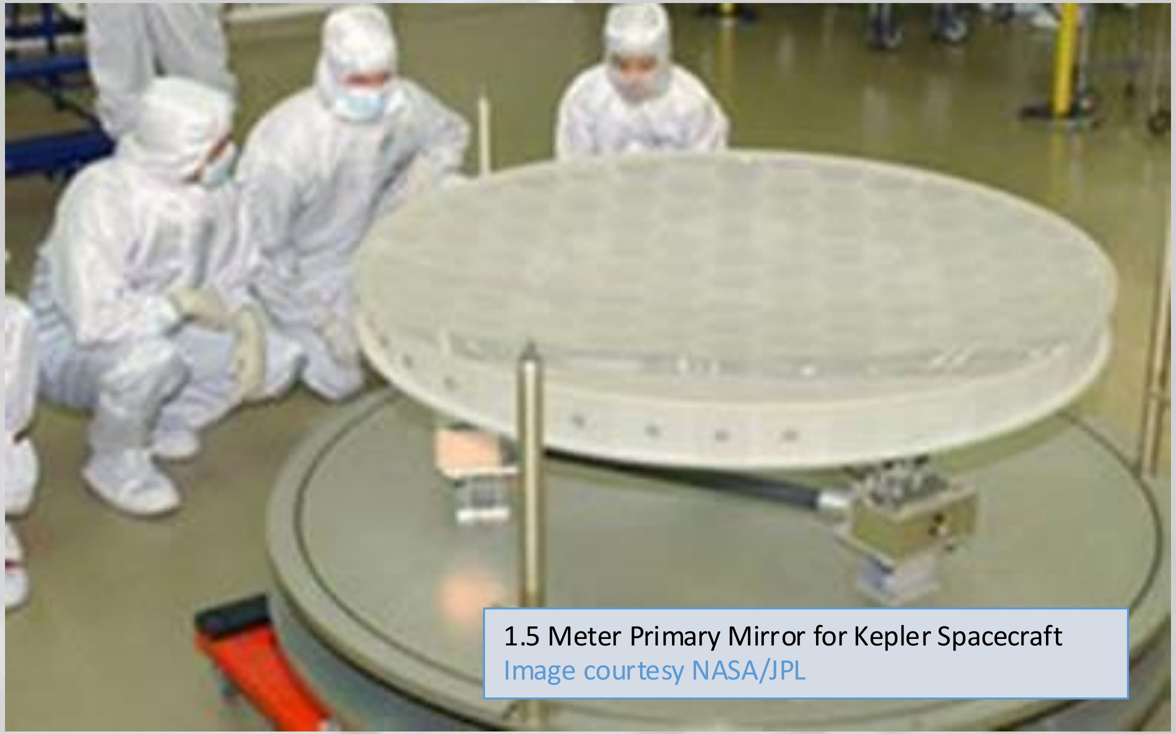
Bigger lens→ smaller spot size at target

D_{spot} is defined here as the first zero of the Airy diffraction pattern (= 84% beam energy.).

Primary Mirror

We are basing the primary mirror on the Kepler telescope mirror:

Diameter of mirror: 1.45 m
Mass: 86 kg
Material: Corning Ultra-low expansion (ULE) glass
Reference: Kosi 2008



1.5 Meter Primary Mirror for Kepler Spacecraft
Image courtesy NASA/JPL

This beam director puts a 1.5-m (FWHM) spot on the receiver array at the maximum beaming distance of 1500 km

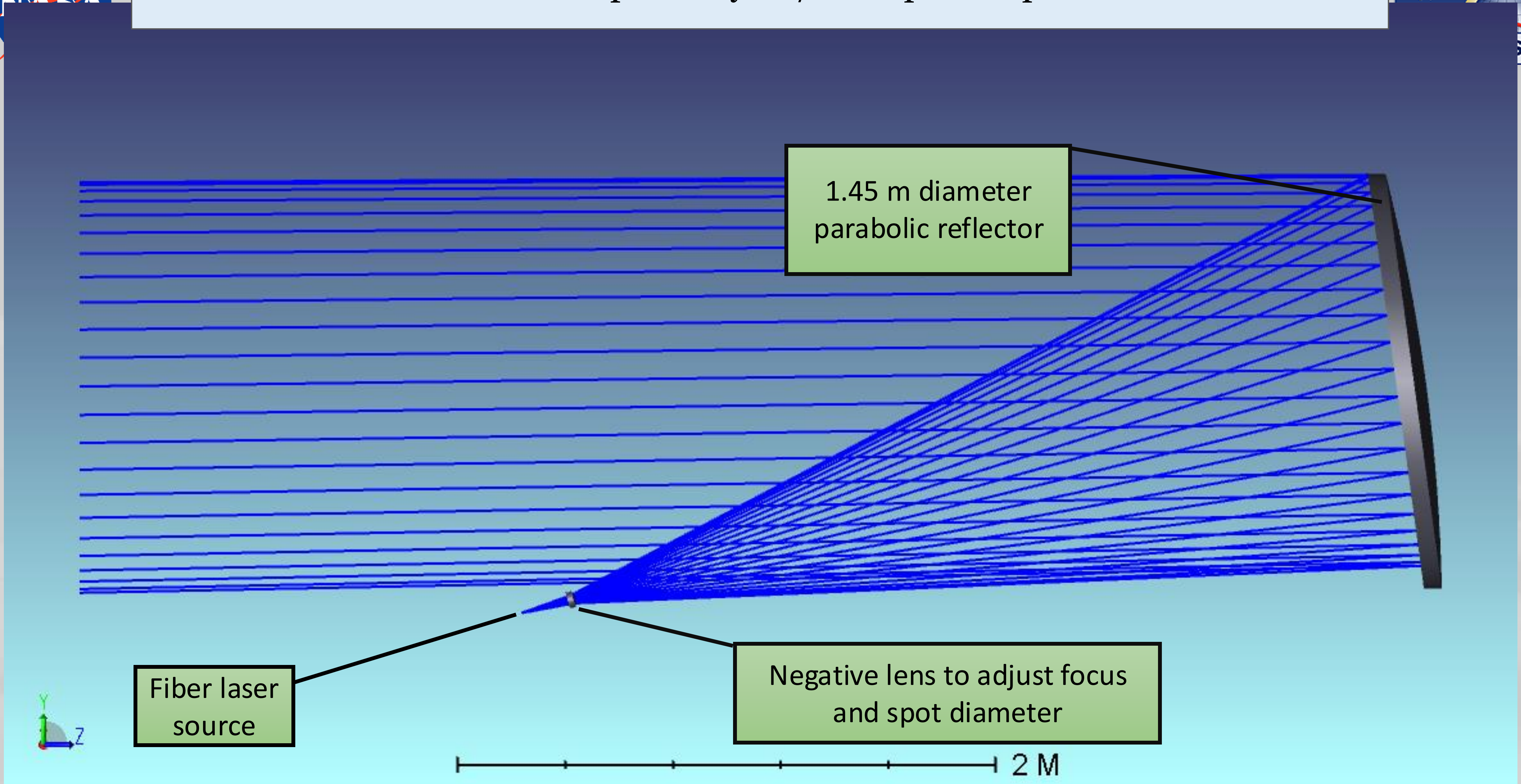
- at shorter distances, the beam can be defocused to keep spot size the same

References:

K. Kosi (2008), "Focus Mechanism for Kepler Mission," 39th Aerospace Mechanisms Symposium, NASA/CP—2008–215252, p. 373; https://ntrs.nasa.gov/api/citations/20080023060/downloads/20080023060.pdf#page=373

H.P. Stahl (2020), "Advanced ultraviolet, optical, and infrared mirror technology development for very large space telescopes," *Journal of Astronomical Telescopes, Instruments, and Systems*, 6, No. 2, 025001, https://www.spiedigitallibrary.org/journals/Journal-of-Astronomical-Telescopes-Instruments-and-Systems/volume-6/issue-2/025001/Advanced-ultraviolet-optical-and-infrared-mirror-technology-development-for-very/10.1117/1.JATIS.6.2.025001.full

Beam director optical layout/Principle of Operation



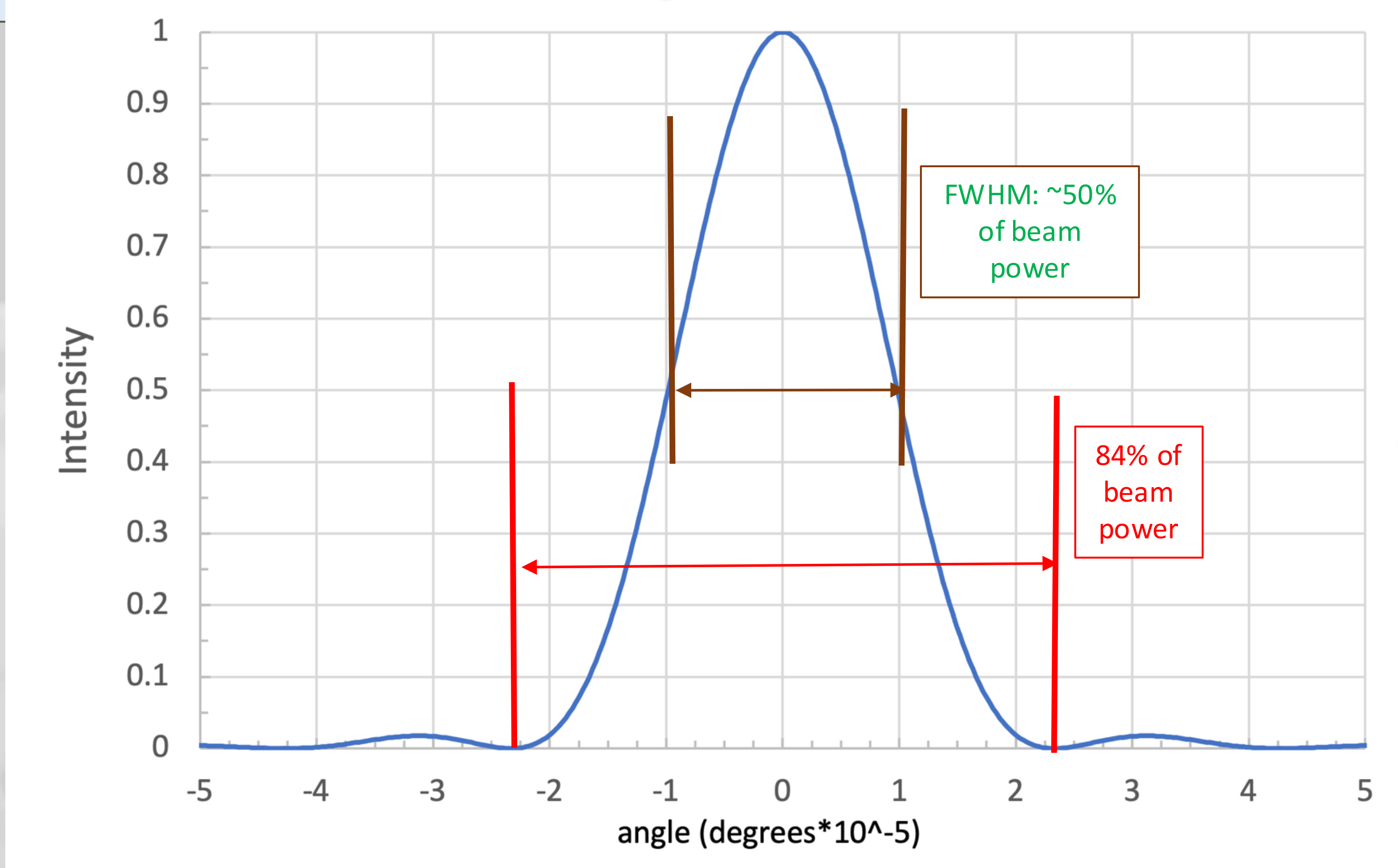
Estimated Power Delivery and Laser/Optic Sizes

Beam spot size		
laser wavelength	1.07	microns
beam director diam.	1.4	meter
beam div angle (full)	1.86486E-06	radians
beam div angle (°)	0.384654397	arcseconds
spot diam. (84% of power)*	2.98	meters
spot diam (FWHM, ~50% of power)	1.49	meters

*Assumes tracking collector. Divide by Cos(45°) if flat.

number of nighttime users per orbit plane	3
nighttime power needed (W)	50
Night length (days)	14
Whr required (for battery if unbeamed)	16800
Surface assets battery mass (if unbeamed)	114
# of Beamcraft per orbit plane	1
Time between Beamcraft visits (hrs)	3.2
W-hr required (for battery if beam serviced)	160.0
Surface asset Battery mass (kg) (if beamed)	0.8
Duration of Beamcraft pass (min)	15
Watts needed at surface asset per pass	640
surface asset receiver size	1.5 - 1.7 m
fraction of array covered with photovoltaic cells	0.9
Laser receiver eff	0.5
Power beam energy needed at receiver (W)	1422
Fraction of beam collected	0.5
Power beam at surface (W)	2844.4
Cosine loss cross track	0.98
Beamcraft beam laser eff	0.38
Beamcraft input laser power (kW)	7.6
Beamcraft energy storage kW h	6
Beamcraft battery tech (Whr/kg)	192
Beamcraft battery mass kg	30
Beamcraft illumination time (hrs)	2.5
Beamcraft solar array size estimate (kW)	2.3

Beam spread



- 1070 nm laser, 1.4 m mirror. Intensity relative to intensity at beam center

Laser spot non-uniformity **challenges**

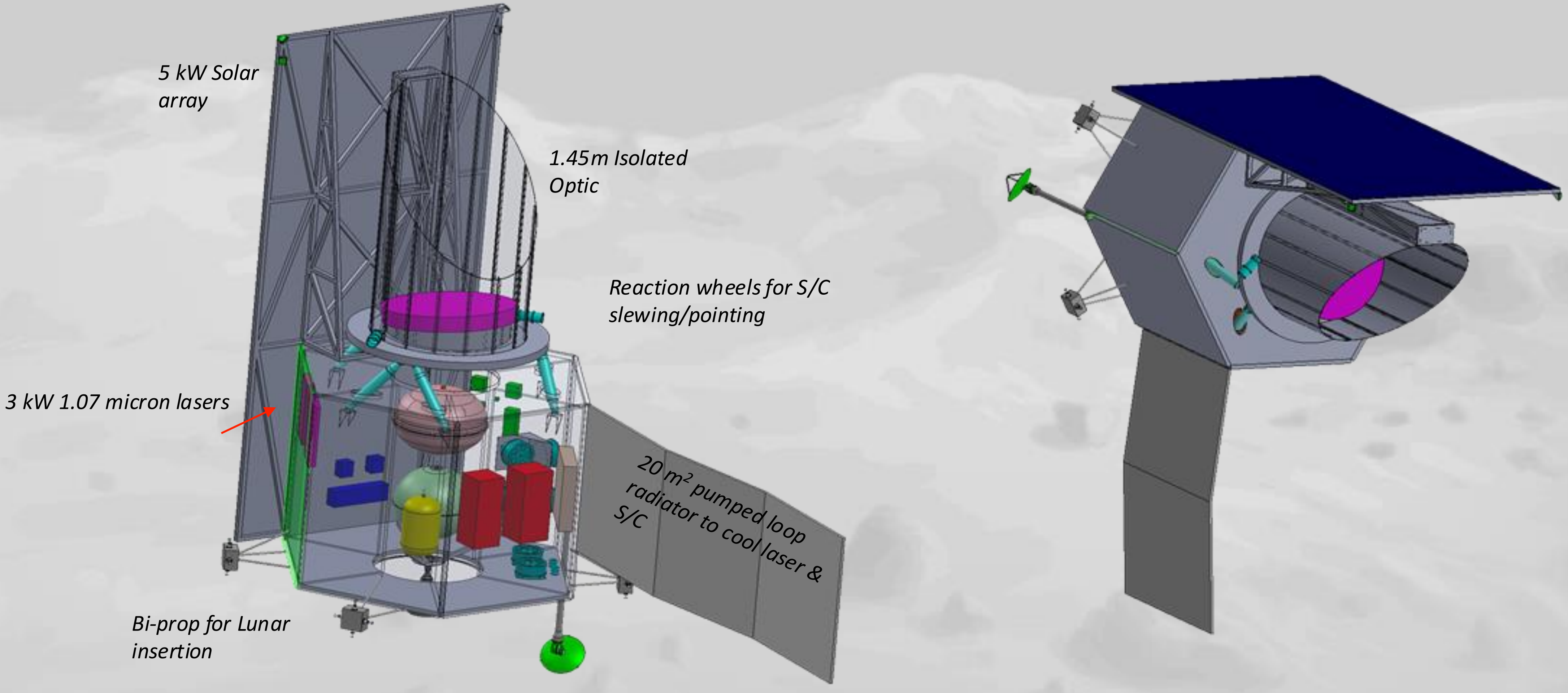
- Laser spot is non-uniform (higher power in center)
  - Could design an array to be tolerant of non-uniform illumination
  - could use a diffuser to remove non-uniformity (adds losses x%)
  - Fresnel lens (makes tracking harder
  - ✓ Active maximum power-point tracking on *sets* of cells for variable illumination intensity using DC/DC convertor
- Distance varies 800-1500 km; changes spot diameter ~ 50%
  - We added focus adjustment to allow spot size to be dynamically controlled
- Pointing accuracy means central spot NOT necessarily in center of array
  - Need to control spacecraft jitter

Pointing: Beacon Option

- Laser beacon on the lander:
  - Beamcraft looks for laser for fine guidance in pointing
  - Diode laser at different wavelength from power beam
  - Coarse pointing to beamcraft (divergence angle ~ 10 mrad)
  - Lander knows roughly where and when to point to the Beamcraft
- Required laser power 7 W
  - Semiconductor diode laser can be used
    - (does not require high beam quality)
- Photon counter on Beamcraft
  - (dichroic beam-splitter uses same main optic)
- This solution allows the beamcraft to correct spacecraft jitter in realtime

Laser Beamcraft for Global Science Landers

~ 3500 kg Beamcraft



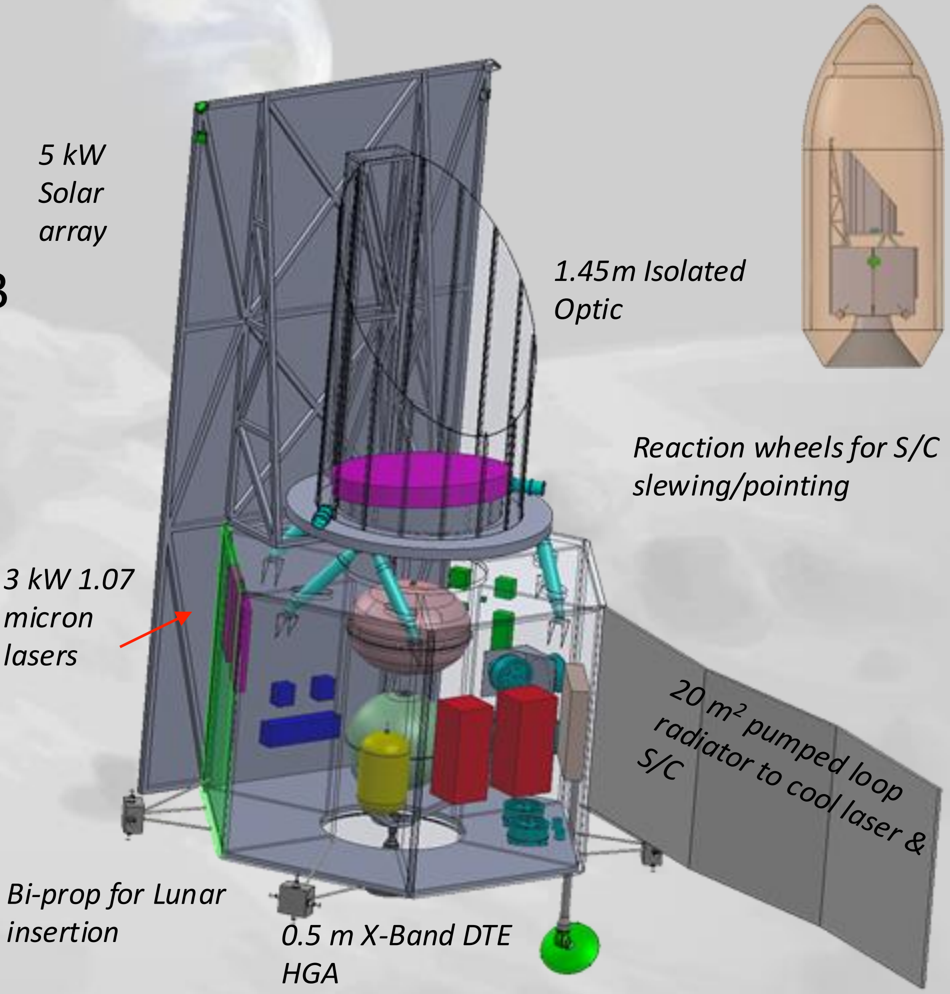
Lunar Beamcraft and Lander Payload Mass Equipment List

Description Case 1_Lunar_Beam_Craft CD-2023-207	Basic Mass (kg)	Growth (%)	Growth (kg)	Total Mass (kg)
Lunar Beam Craft	2905	14%	418	3324
Spacecraft	2818	14%	401	3220
Laser system	186.3	24%	44.6	230.9
Attitude Determination and Control	108.0	7%	7.7	115.7
Command & Data Handling	39.2	36%	14.1	53.3
Communications and Tracking	12.8	11%	1.4	14.2
Electrical Power Subsystem	450.5	35%	157.7	608.2
Thermal Control (Non-Propellant)	197.1	18%	35.5	232.6
Propulsion (Chemical Hardware)	114.1	5%	6.0	120.1
Propellant (Chemical)	964.0	0%	0.0	964.0
Structures and Mechanisms	746.4	18%	134.3	880.7
Lander Modifications	87	19%	17	104
Science	14.6	0%	0.0	14.6
Command & Data Handling	11.6	36%	4.2	15.8
Communications and Tracking	5.3	12%	0.6	5.9
Electrical Power Subsystem	27.5	30%	8.3	35.8
Thermal Control (Non-Propellant)	10.8	18%	1.9	12.7
Structures and Mechanisms	17.3	11%	1.9	19.2

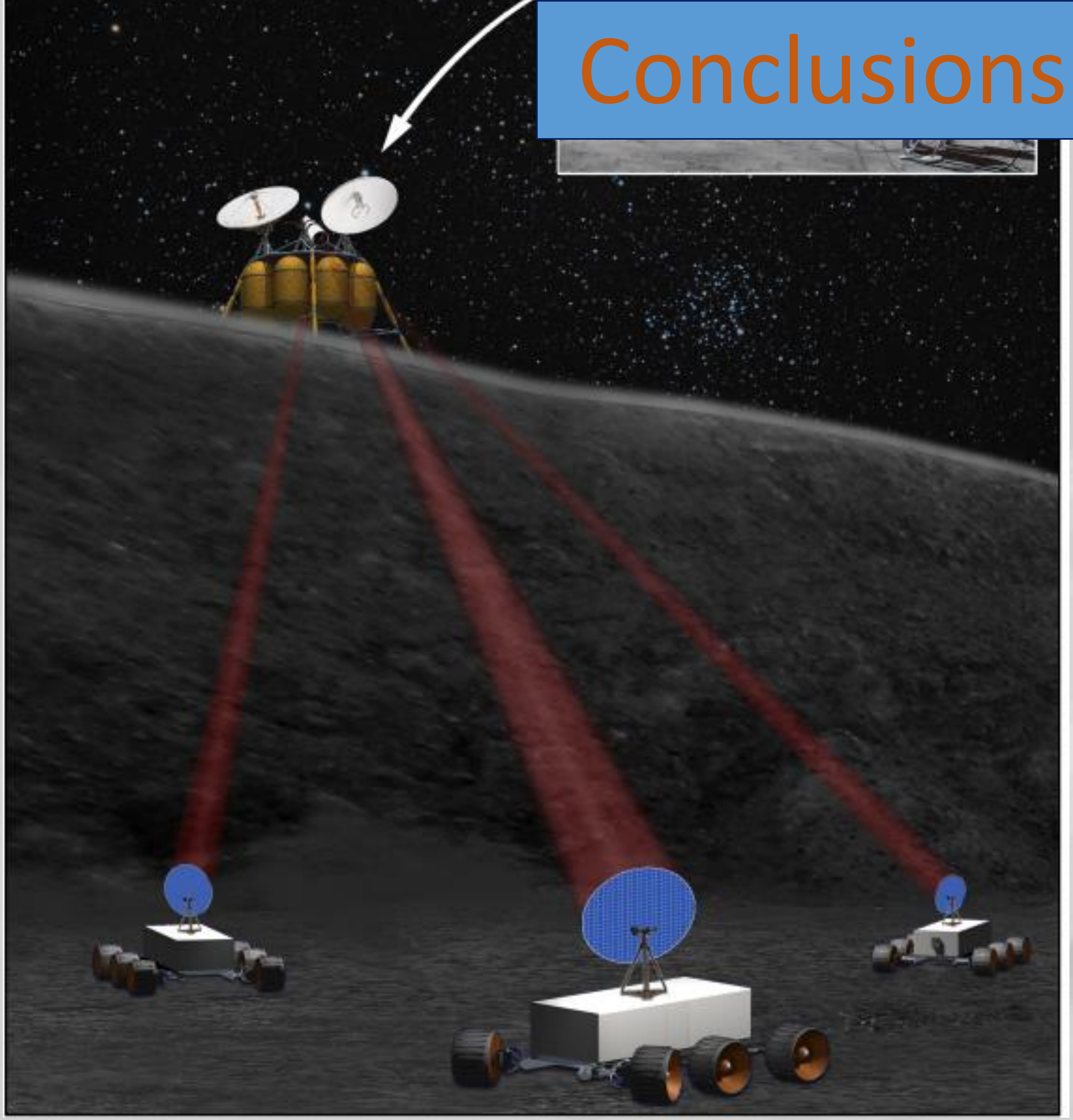
mass growth allowance per AIAA mass estimation standards

Summary: power from lunar orbit

- Feasible to make a 3-kW Laser Beamcraft to power science landers in the dark and relay on the far-side
- Mission: Three Beamcraft launched individually to 800 km polar lunar orbits, offset by 60°, each supports 6 science landed assets at a time (3 shadowed/ 3 sunlit)
  - If surface stations are located only in near-polar or in near-equatorial locations, one beamcraft is needed
  - Three orbital planes are required for mid-latitudes
- Laser: 3 kW (8 kWe input), 1.07 µm terrestrial technology, 38% efficient
- Optics: Based on 1.45 m Kepler telescope, ~2.5m laser spot at maximum 1500 km distance
- Cost analysis: ~ $2.2B for three Laser Beamcraft with 25% reserves, no launch or Phase E
  - Breakpoint showed at least 10 science landers make the beamcraft option attractive
  - Saves ~$2.8B compared to landing large, overnight power systems



Conclusions

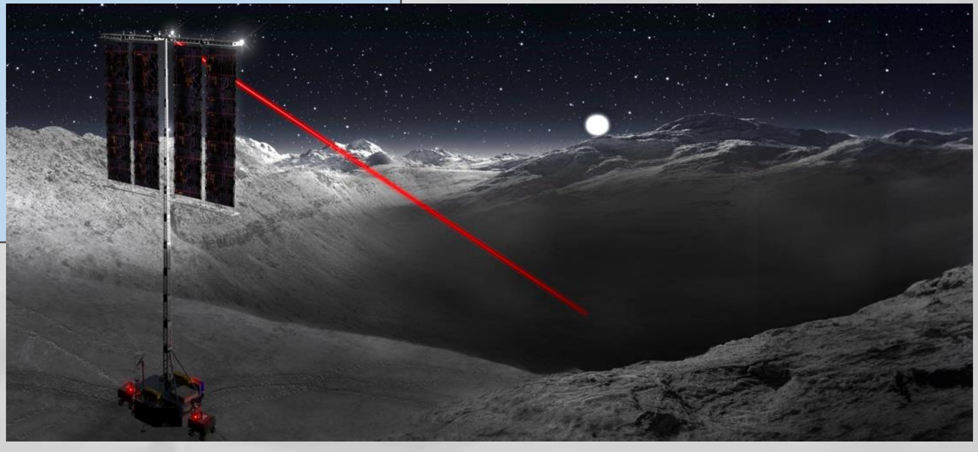


- Laser power beaming is a plausible technology to provide power on the moon in locations where solar power is unavailable
- Possible at a wide range of power and distance scales, from small rovers exploring permanently shadowed lunar craters, to science assets operating in the lunar night
  - Different technologies may be optimal for different applications
- No showstoppers for use of this technology on the moon

Acknowledgement: the NASA Glenn Compass team

- Compass is NASA Glenn's concurrent engineering design team
  - The team includes experts from each discipline of space vehicle and mission design, collected from their respective discipline-area branches (matrix)
  - Branch knowledge and experience is leveraged through review of their representative's product(s)
- Our charter is to do realistic engineering designs to show the value (and difficulties) of new technologies in enabling challenging missions
  - Similar to other spacecraft engineering teams (e.g, JPL's "Team X"), but with focus on implementation of new technologies, rather than on putting together mission proposals
  - Customer oriented:

    starting point is always "what are the user requirements?"



Some references

- Overall reference on power beaming fundamentals: P. Jaffe, T. Nugent, and B. Strassner II, *Power Beaming: History, Theory, and Practice* (World Scientific 2024) https://books.google.com/books/about/Power_Beaming_History_Theory_And_Practic.html
- G.A. Landis, *et al.*, "Laser Power Beaming for Applications on the Moon," *Space Power Workshop 2025*, Torrance CA. https://ntrs.nasa.gov/citations/20250003925
- Case 1: G.A. Landis, "Laser Power Beaming for Lunar Polar Exploration," paper AIAA-2020-3538, *2020 AIAA Propulsion & Energy Forum*, New Orleans LA, August 24-26 2020. https://ntrs.nasa.gov/citations/20205005063
- LuSTR, P. Lubin, "NASA LuSTR Review: Moonbeam Lunar Beamed Power", Lunar Surface Innovation Consortium Spring Meeting https://lsic.jhuapl.edu/uploadedDocs/presentations/1924-1.13_Lubin_LuSTR%202023%20-%20UCSB%20Moonbeam%20-%20b.pdf
- Case 2: S.R. Oleson, G. Landis, E. Turnbull, *et al.*, "Beamed Energy And Communications Optical Node (BEACON) Demonstrator", AIAA Science and Technology Forum, Orlando FL, Jan. 6-10 2025. https://ntrs.nasa.gov/citations/20240014584
- Case 3: G.A. Landis, S. Oleson, *et al.*, "Power Beaming from Lunar Orbit for Small Science Landers," paper AIAA-2024-4938, *AIAA ASCEND (Accelerating Space Commerce, Exploration, and New Discovery) Conference 2024*, Las Vegas NV, 30 July-1 August 2024. https://arc.aiaa.org/doi/abs/10.2514/6.2024-4938
- G.A. Landis, "Space Power by Laser Illumination of Photovoltaic Arrays," Space Photovoltaic Research and Technology 1991, NASA CP-3121, May 1991. https://ntrs.nasa.gov/citations/19910020889