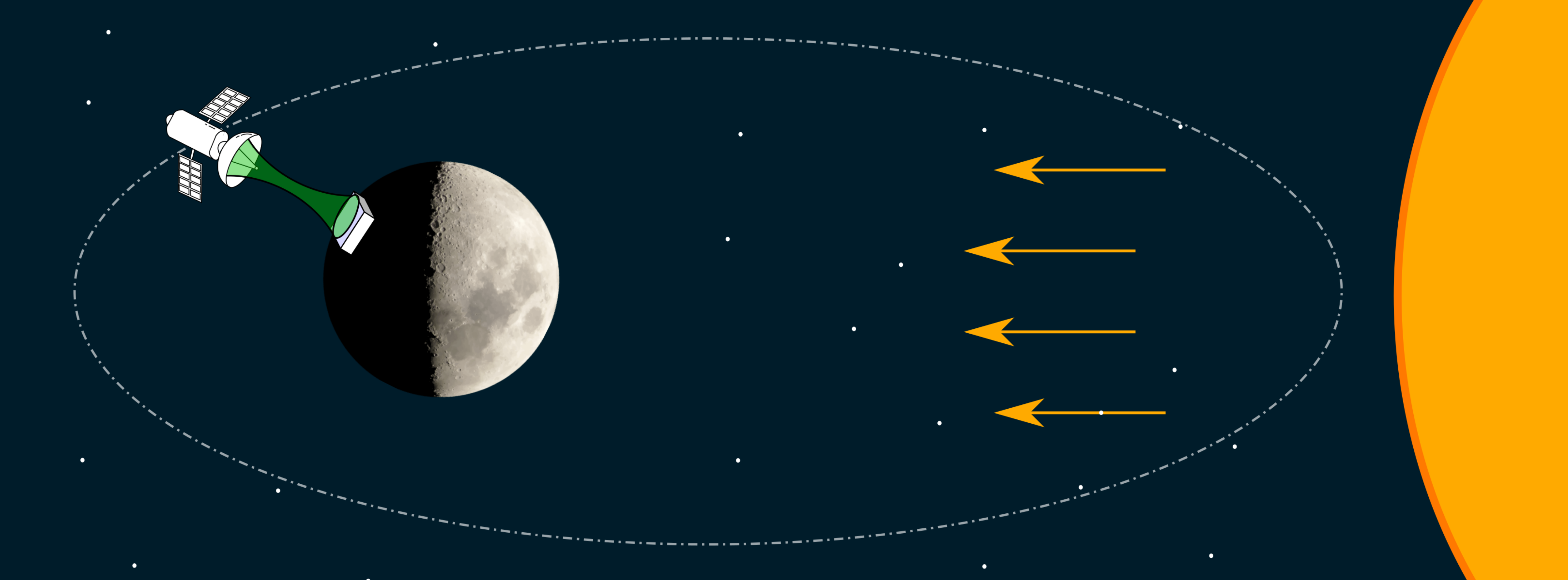

ENERGY MULES, A NOVEL SOLAR POWER SATELLITE SYSTEM ARCHITECTURE CAPABLE OF ENERGY STORAGE

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um campus que pensa
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OUTLINE

1. Introduction
2. Power Generation
3. Energy Storage
4. WPT Transmitter
5. Quasioptical Approach
6. Power Reception
7. Energy Overview
8. Environmental Impact
9. Near Term Demonstrator

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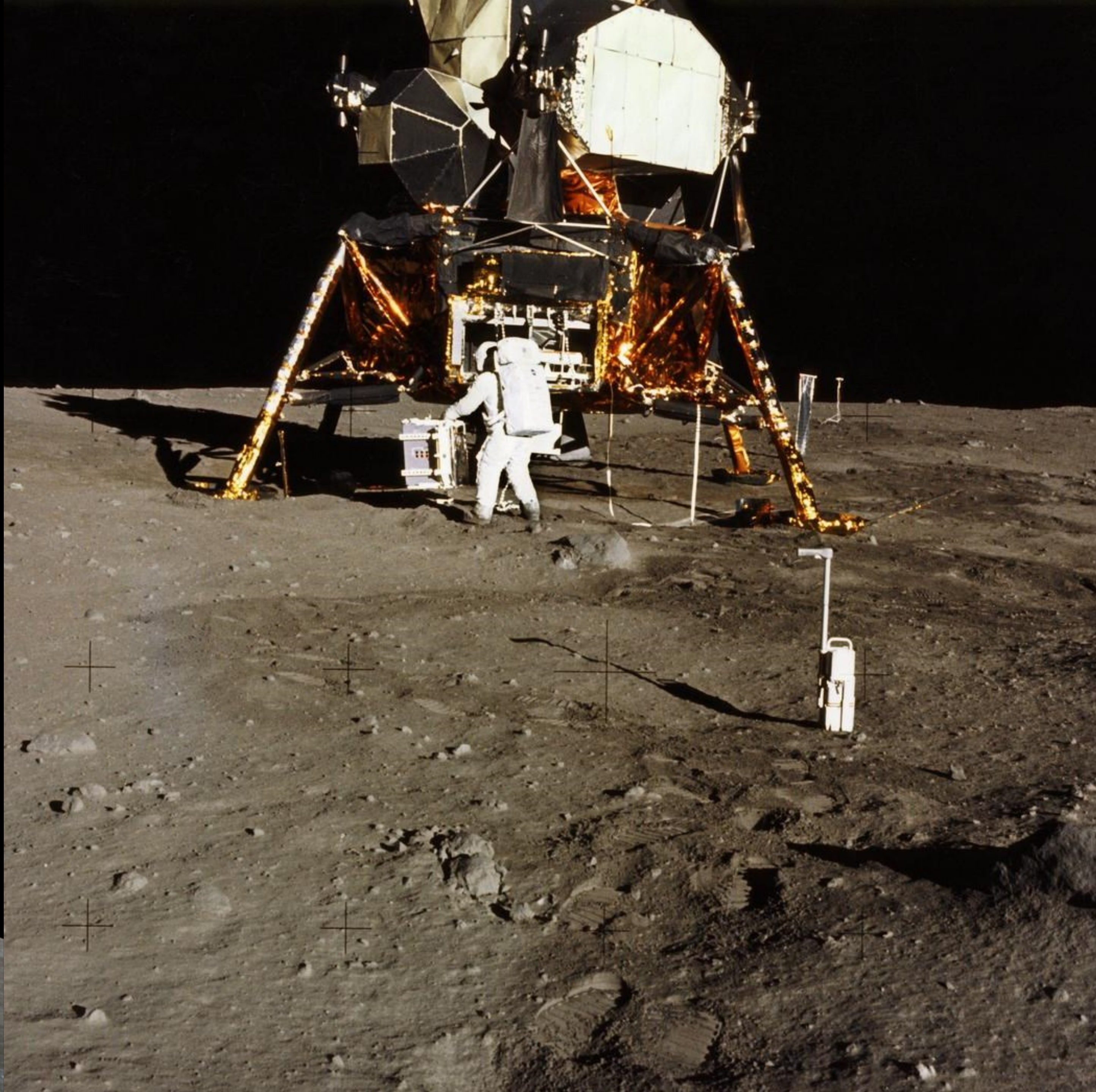
Moon – Our distant companion

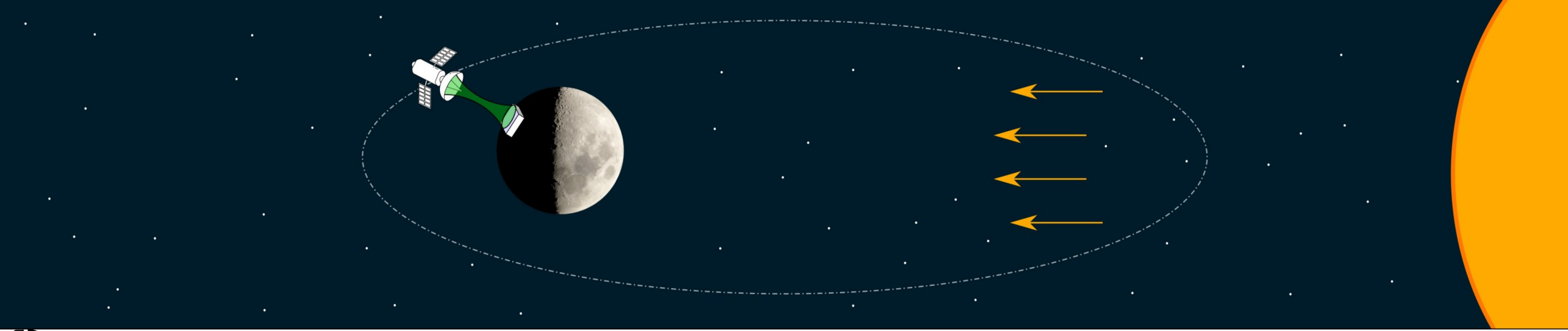
Paradigm shift:

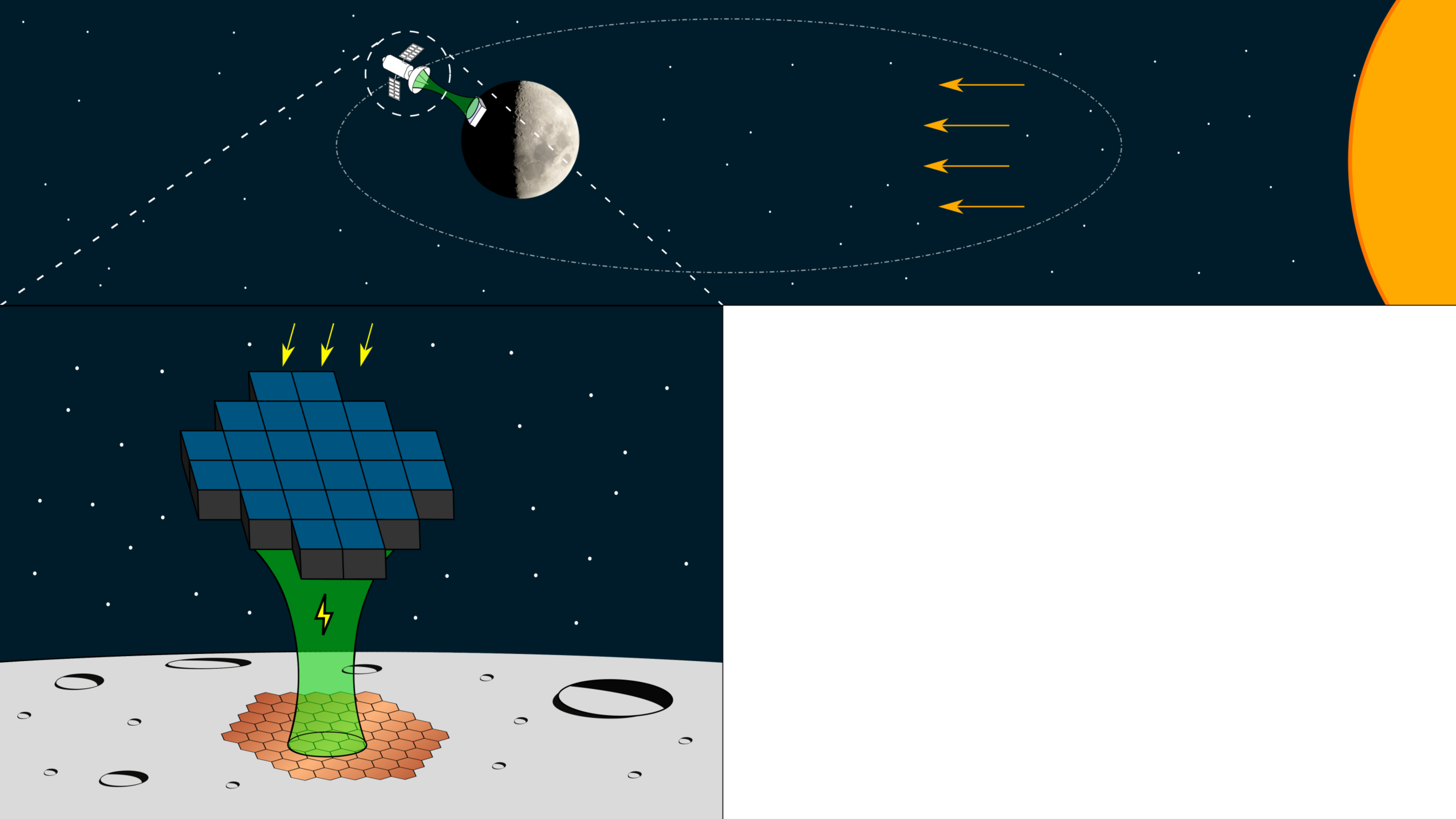
From a distant object
to an explorable body

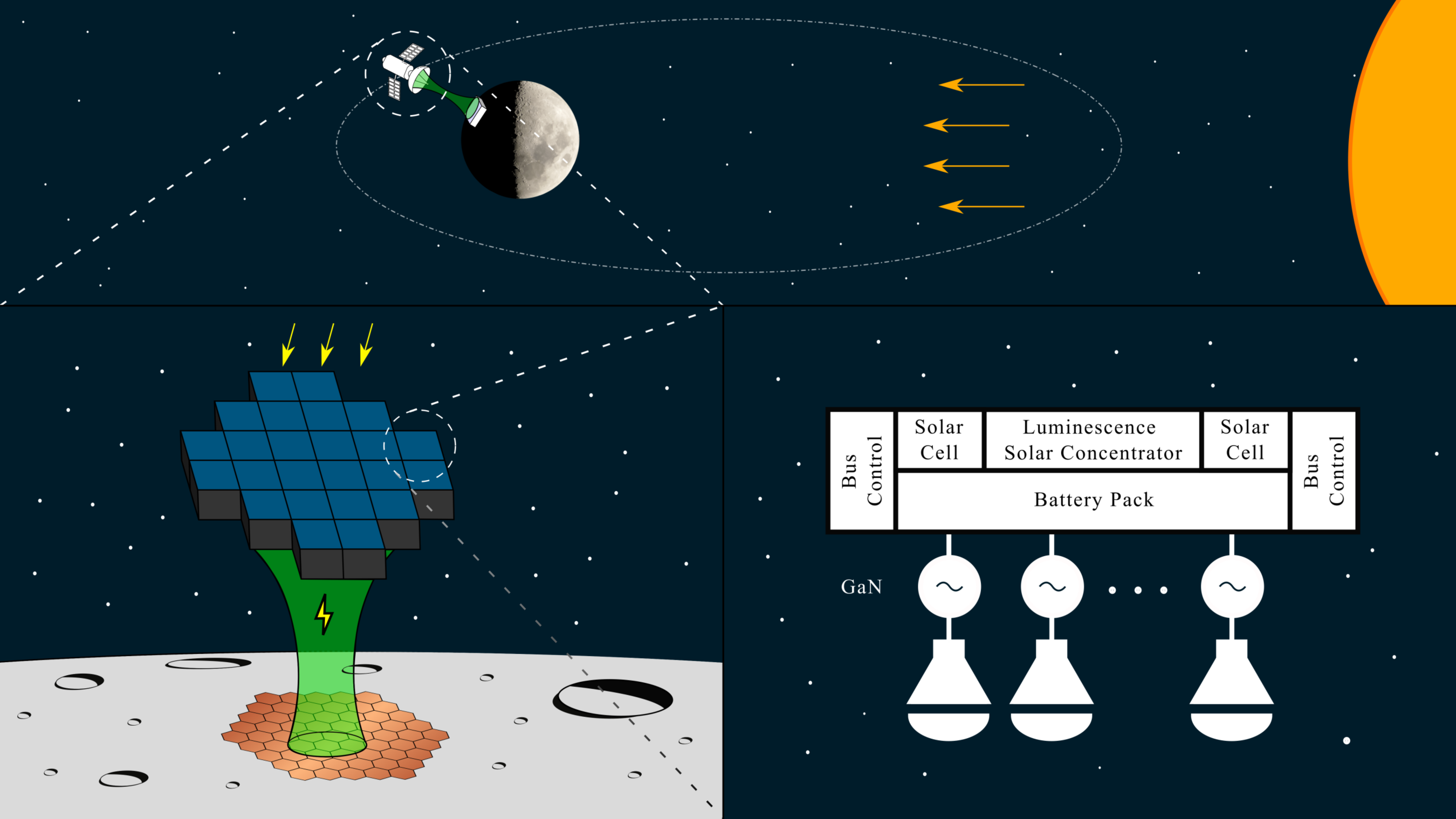


HOW TO SUPPLY ELECTRICAL POWER TO A LUNAR BASE?

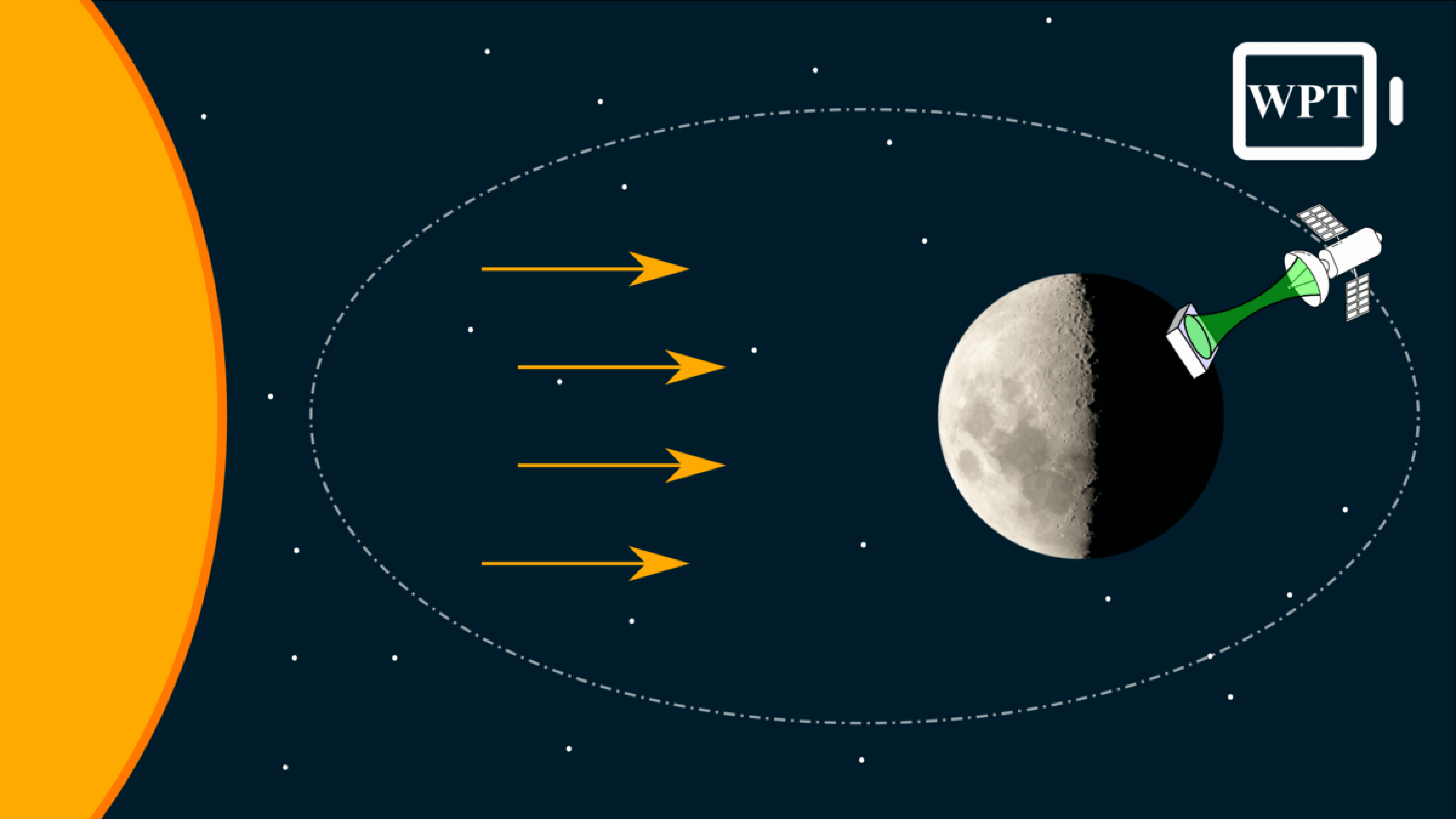
The base will endure 14 days in the dark.







Bus Control
Solar Cell
Luminescence Solar Concentrator
Solar Cell
Bus Control
Battery Pack
GaN


WPT

HOW TO SUPPLY ELECTRICAL POWER TO A LUNAR BASE?

The base will endure 14 days in the dark.

We propose a novel Solar Power Satellite System architecture:

- Capable of energy storage
- Compact and efficient
- Applicable to other scenarios
- Clean energy

INTRODUCTION

Solar Power Generation

Energy Storage

Wireless Power Transfer

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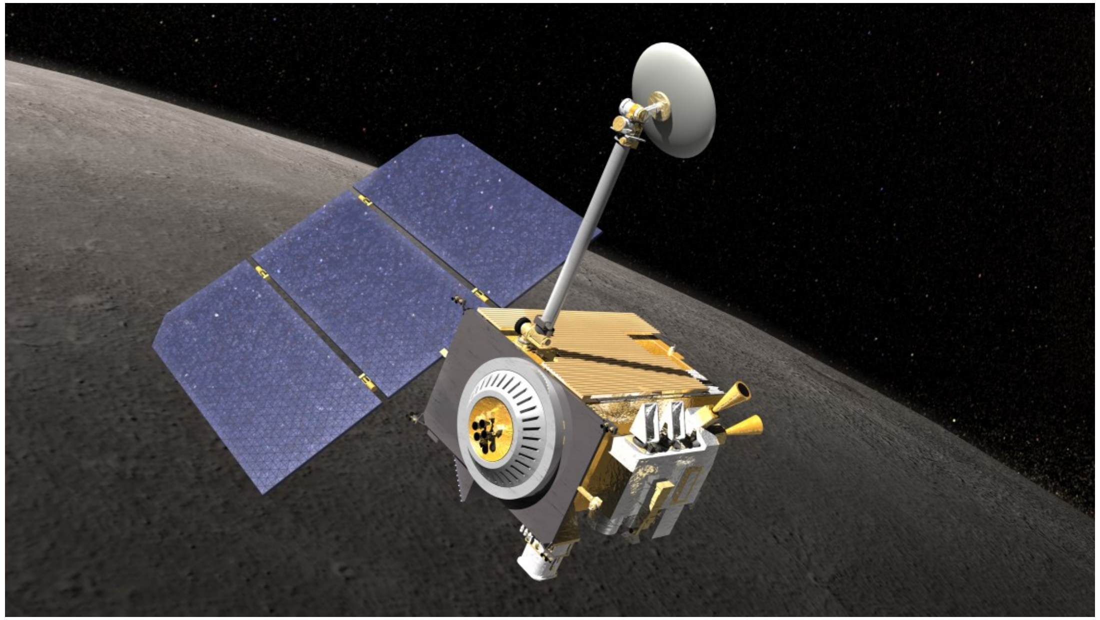
INTRODUCTION



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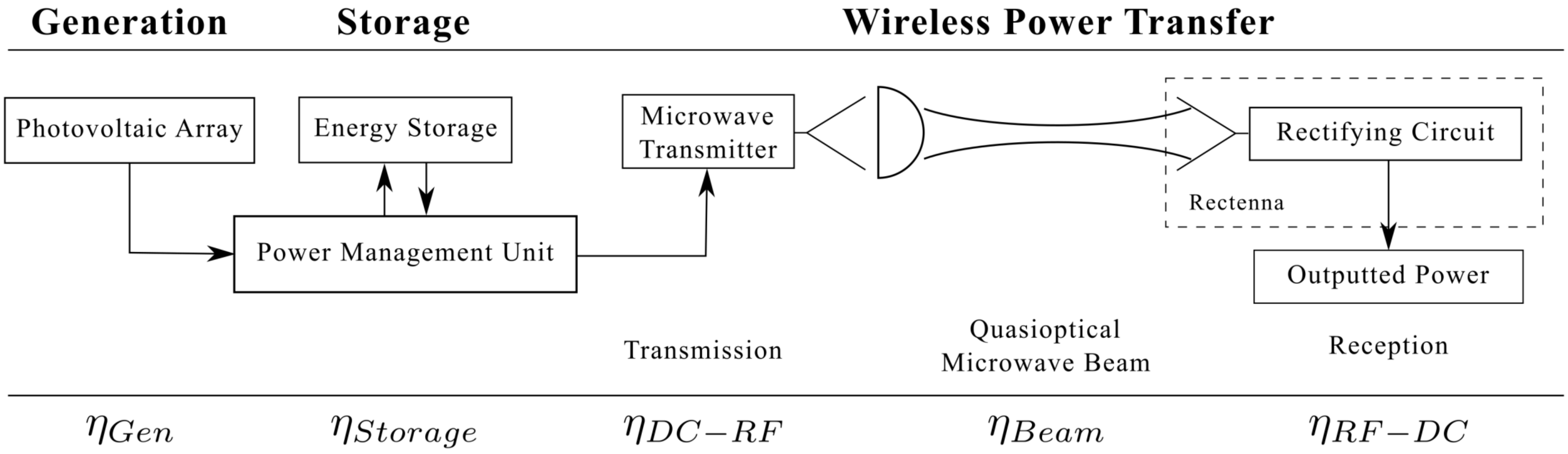
The minimum altitude will be the WPT distance:

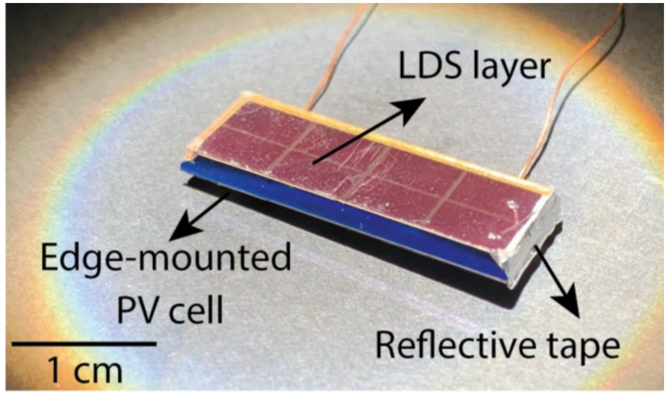
L = 20 km

(2 hour orbit)

INTRODUCTION

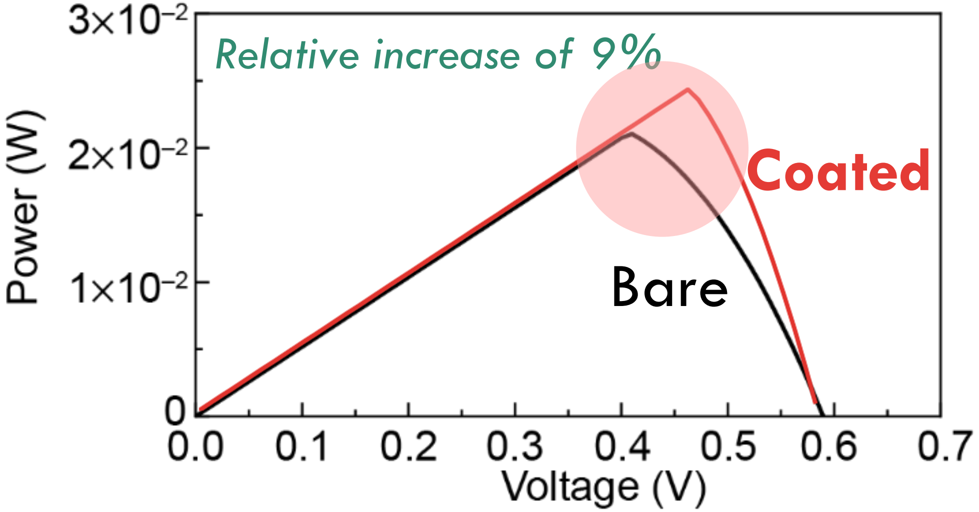


POWER GENERATION

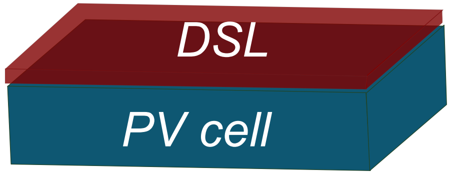


Deposit a luminescent downshifting layer (LDS) on top of the solar cells.

$$\mathbf{A_{PV} = 0.91\ A_{tile} = 6x160x138\ mm}$$

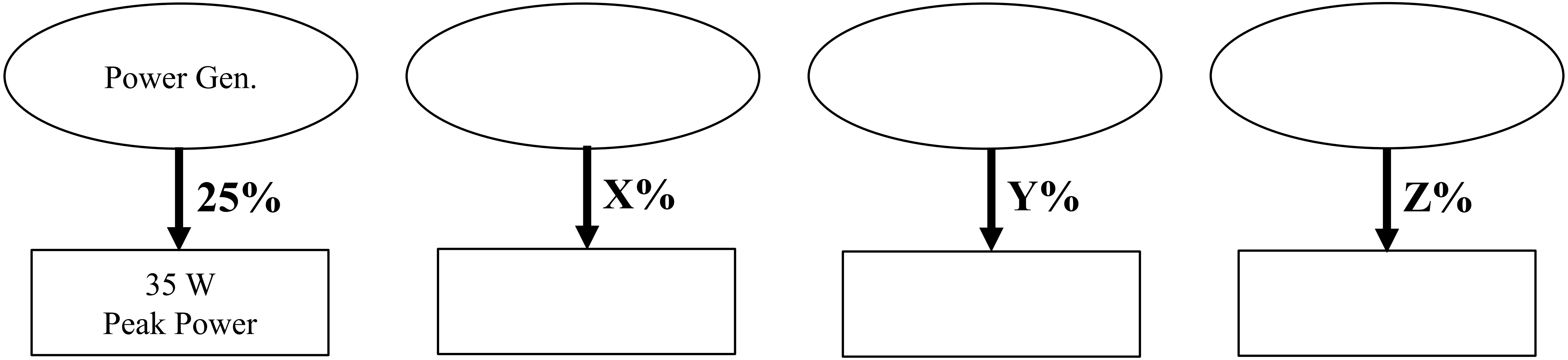


Solar generation: 25% conversion efficiency



Correia *et al.*, *Opto-Electron. Adv.*, 2, 190006 (2019)

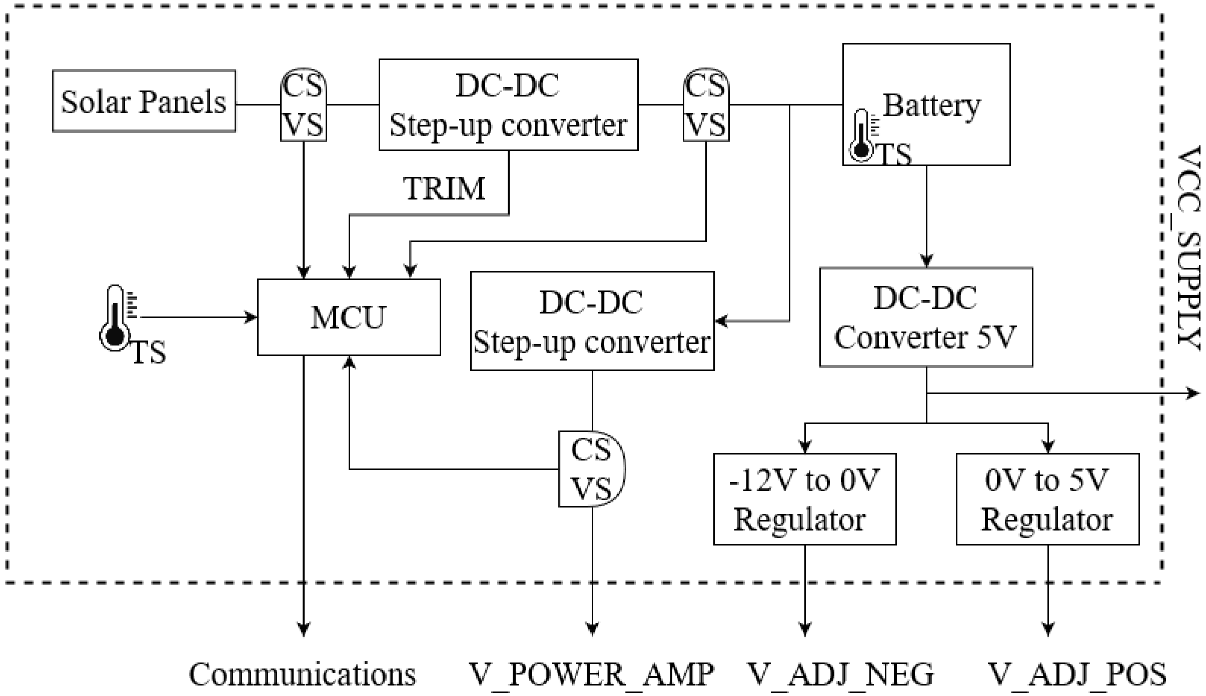
POWER BUDGET

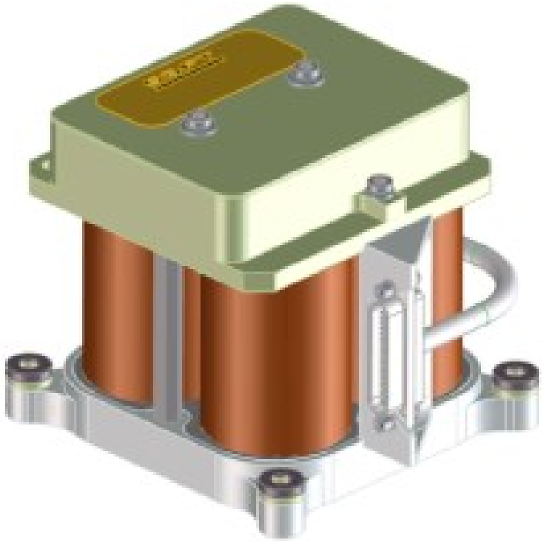


- Per tile & Per orbit

ENERGY STORAGE

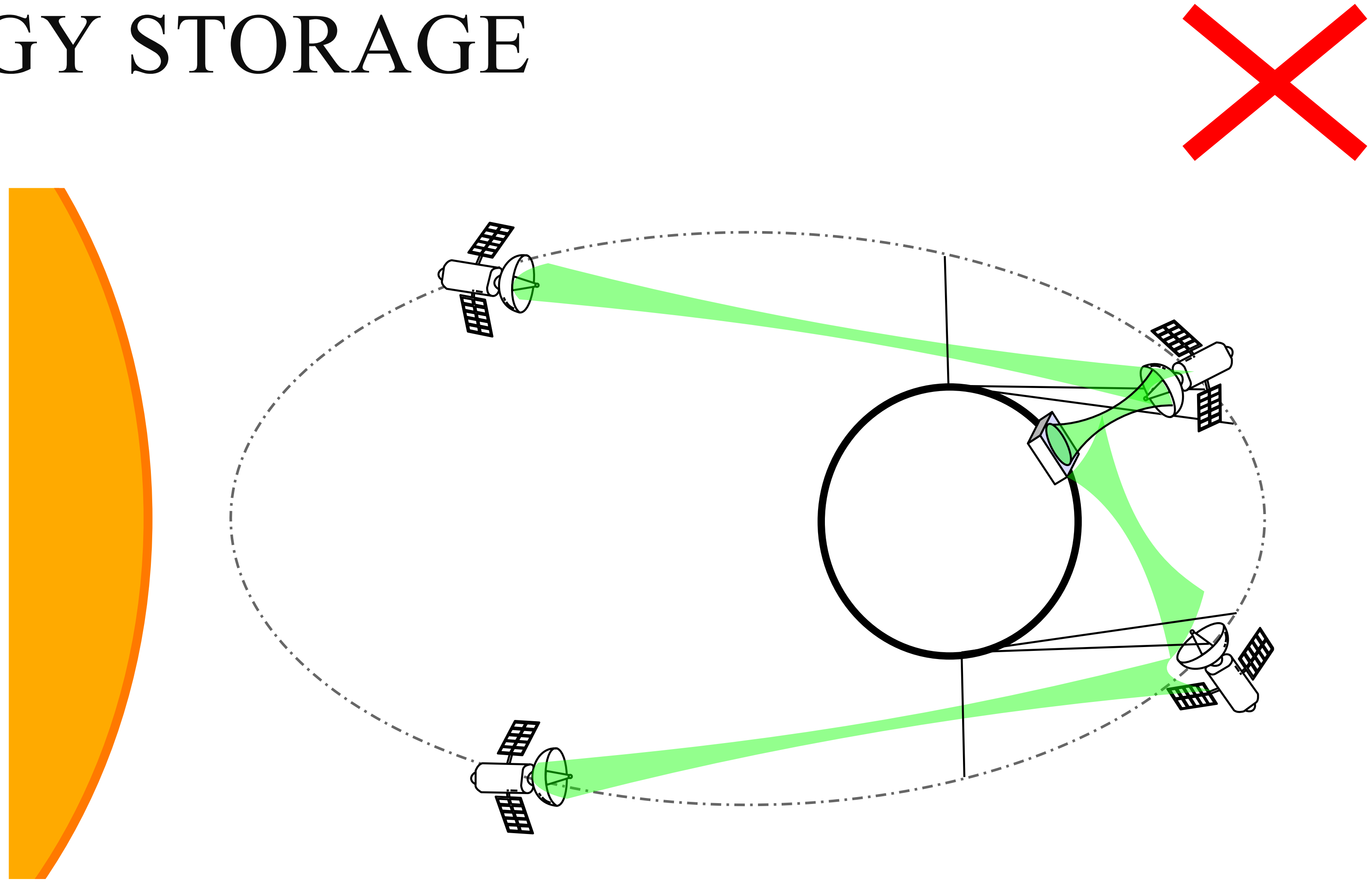
- Space-graded battery pack
- Designed in-house power management unit (PMU)



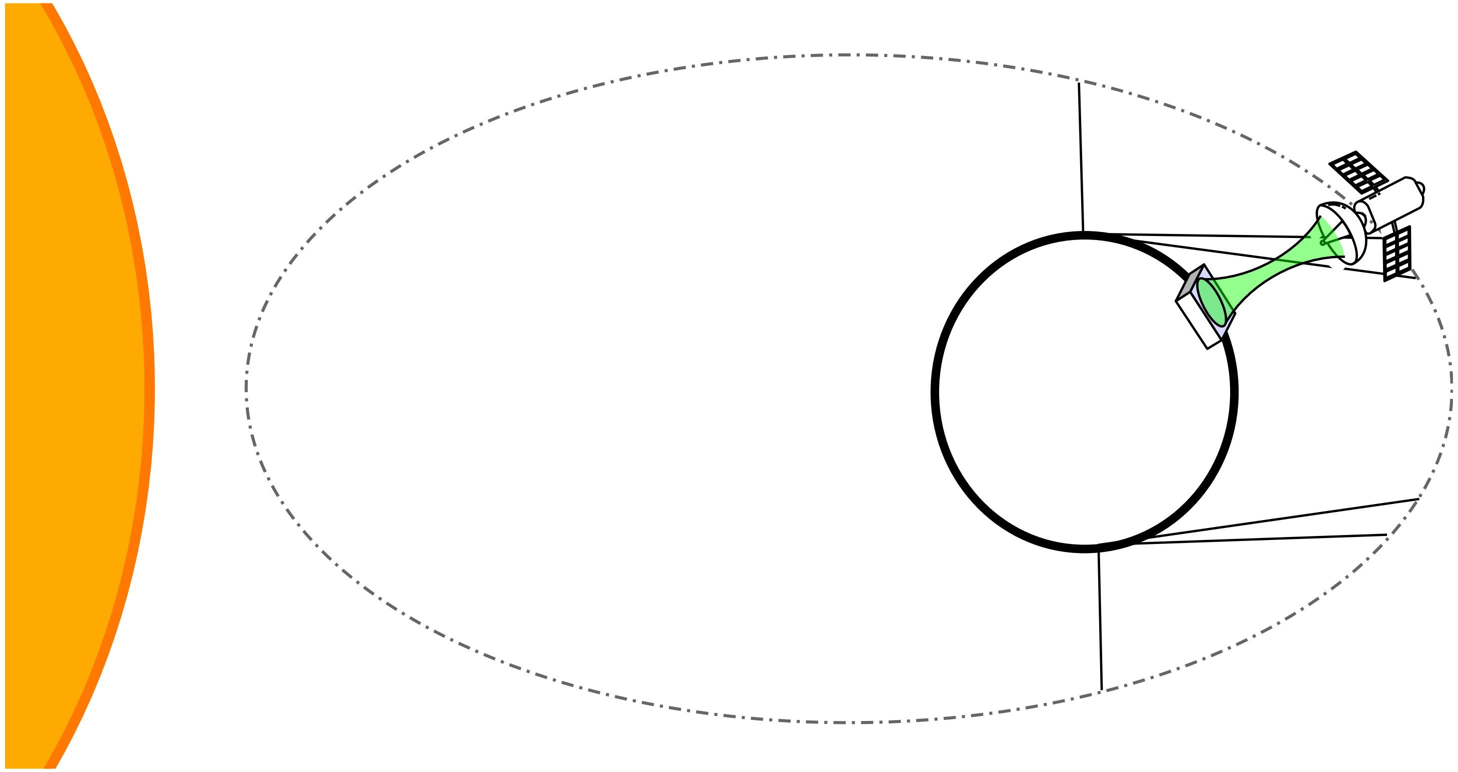


4s1p VES16 battery, Saft batteries

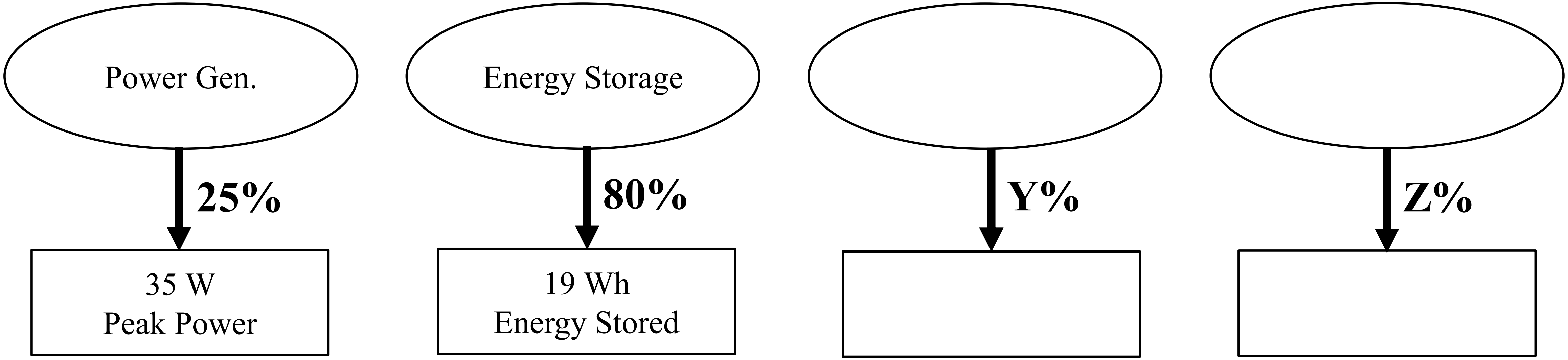
ENERGY STORAGE



ENERGY STORAGE



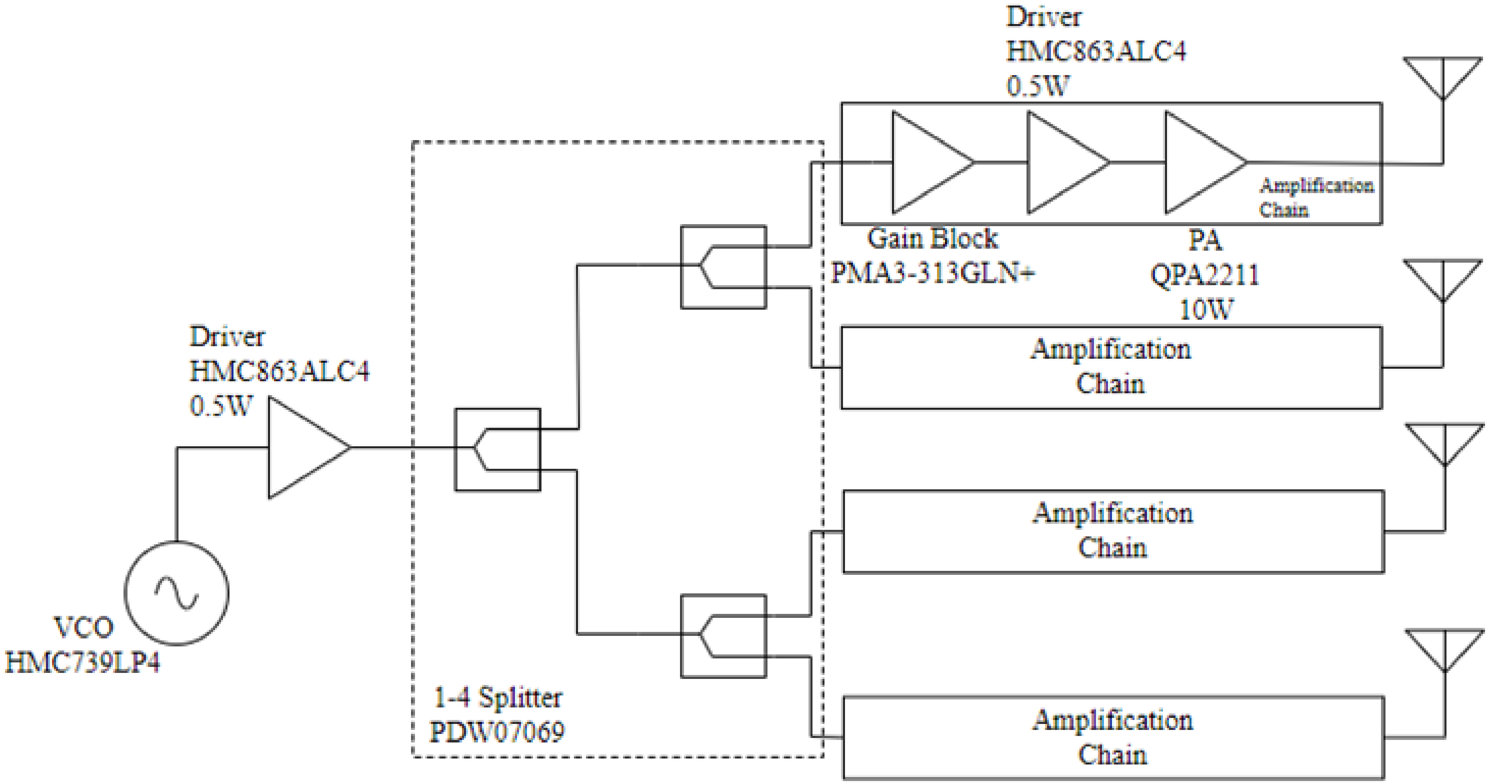
POWER BUDGET



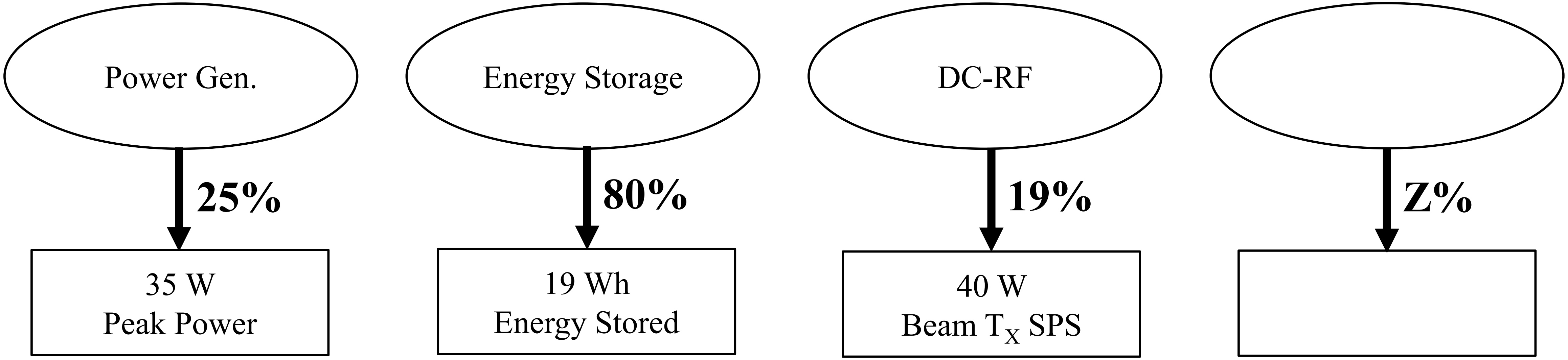
- Per tile & Per orbit

WPT TRANSMITTER

- Transmitter architecture
- 215 W
- Output 40 W
- DC-RF eff. 18%
- Freq = 28 GHz

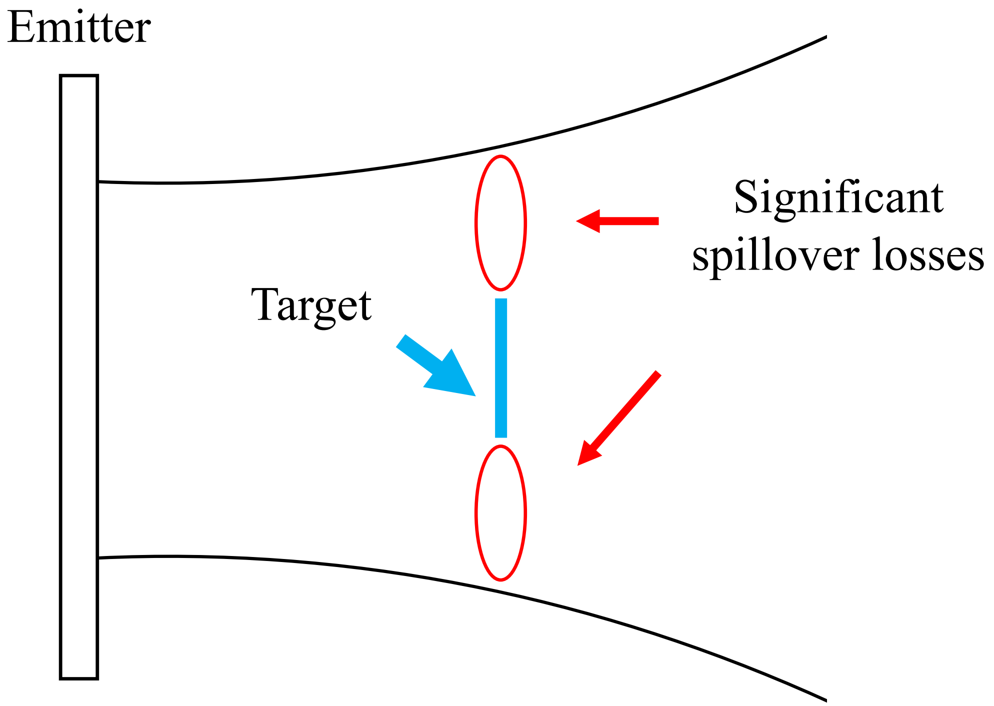


POWER BUDGET

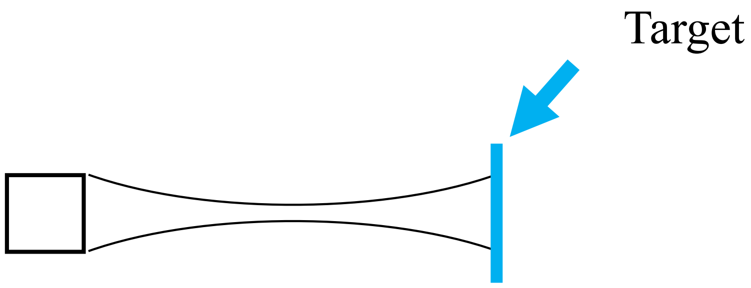


- Per tile & Per orbit

QUASIOPTICAL APPROACH

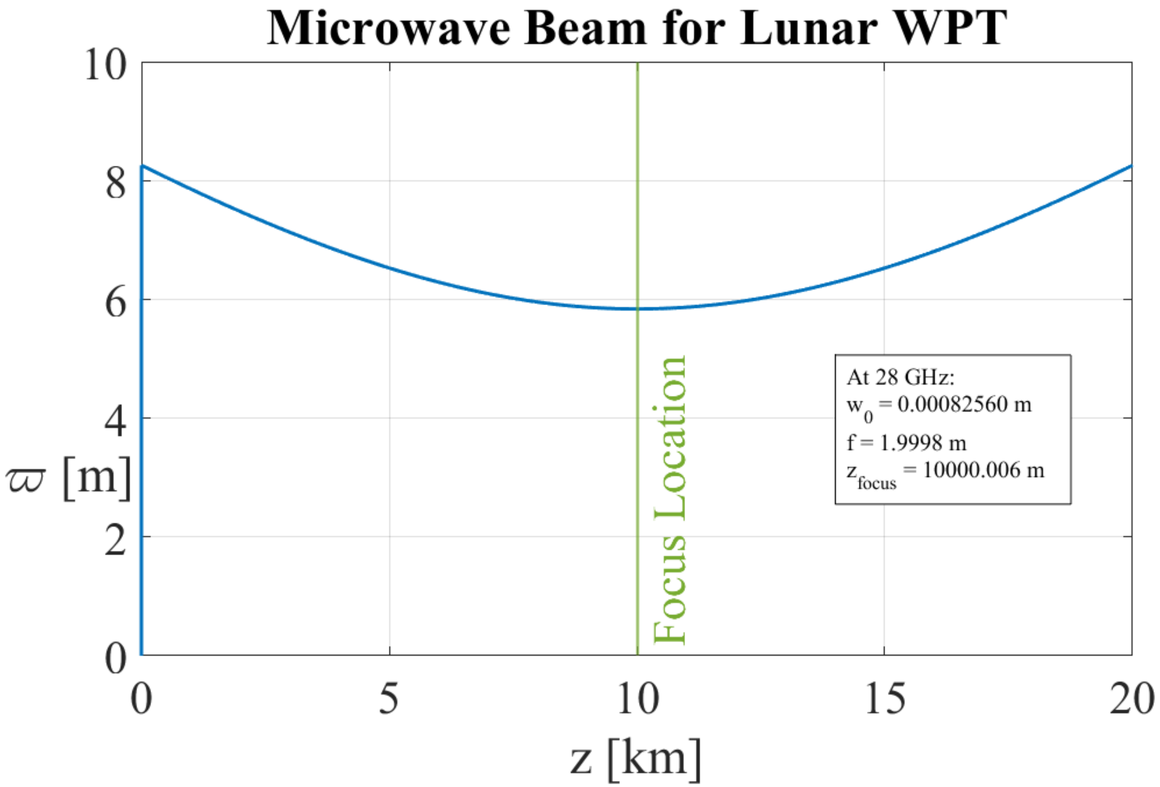


Without considering the beam's divergence



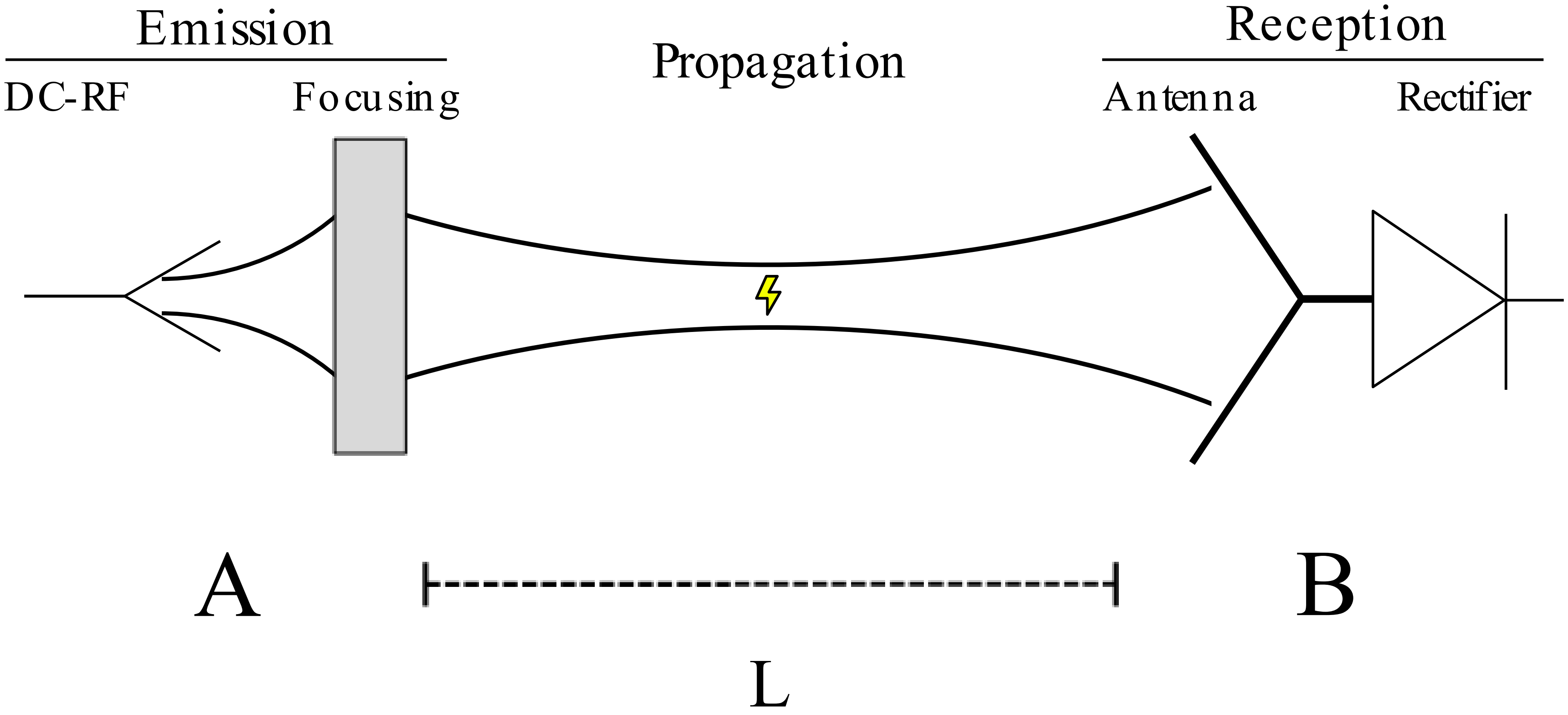
Our approach

QUASIOPTICAL APPROACH



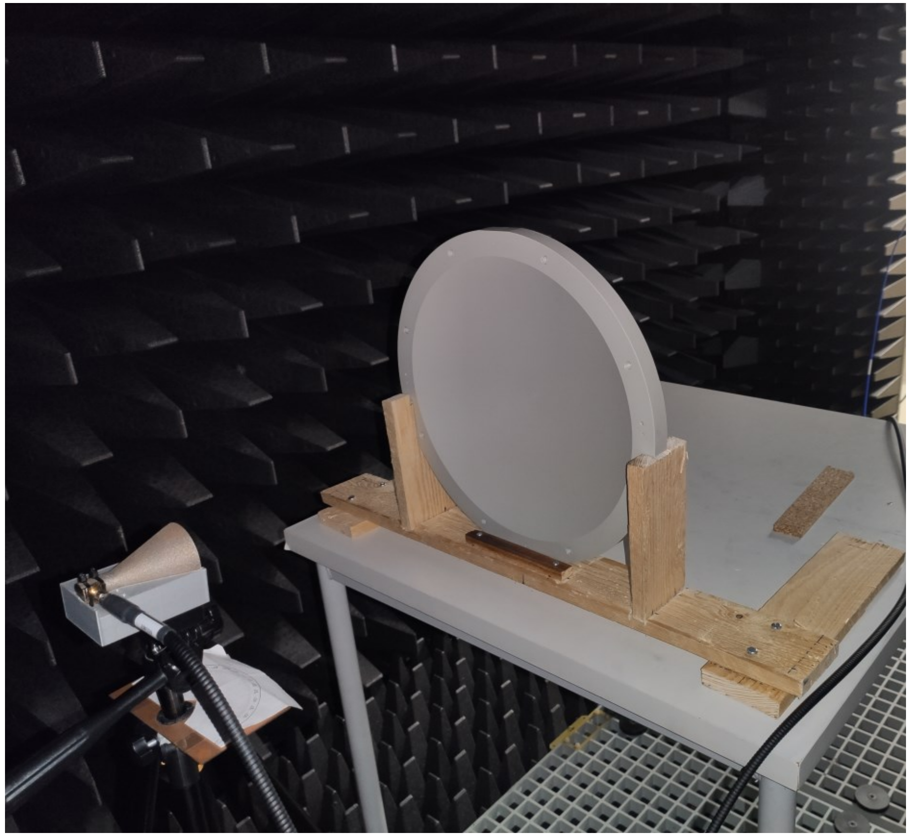
Frequency of operation	28 GHz
WPT distance	20 km
Beam radius at emission and reception	8.26 m

WIRELESS POWER TRANSFER SUBSYSTEM



QUASIOPTICAL APPROACH

- Higher efficiency
- More compact
- Cost saving
- More complex to design and setup



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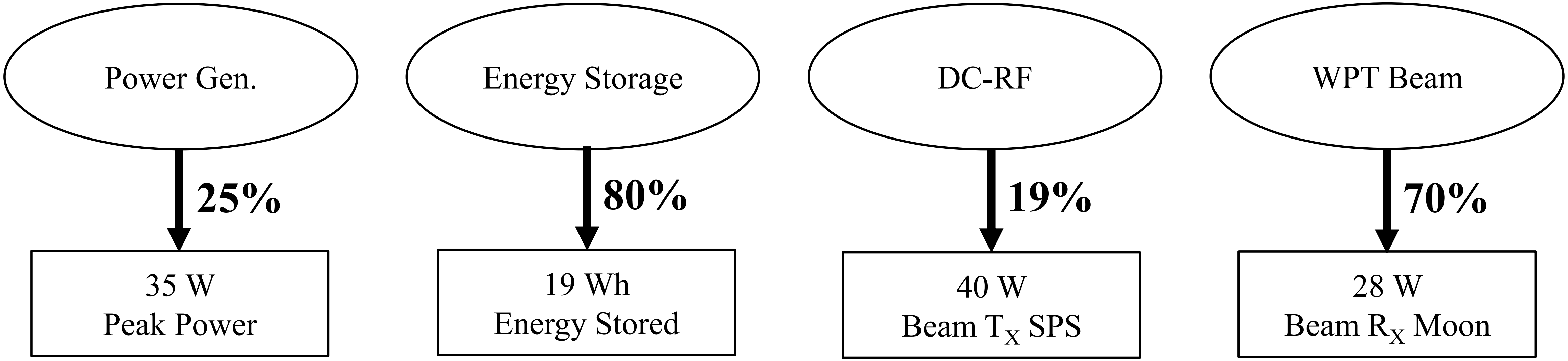
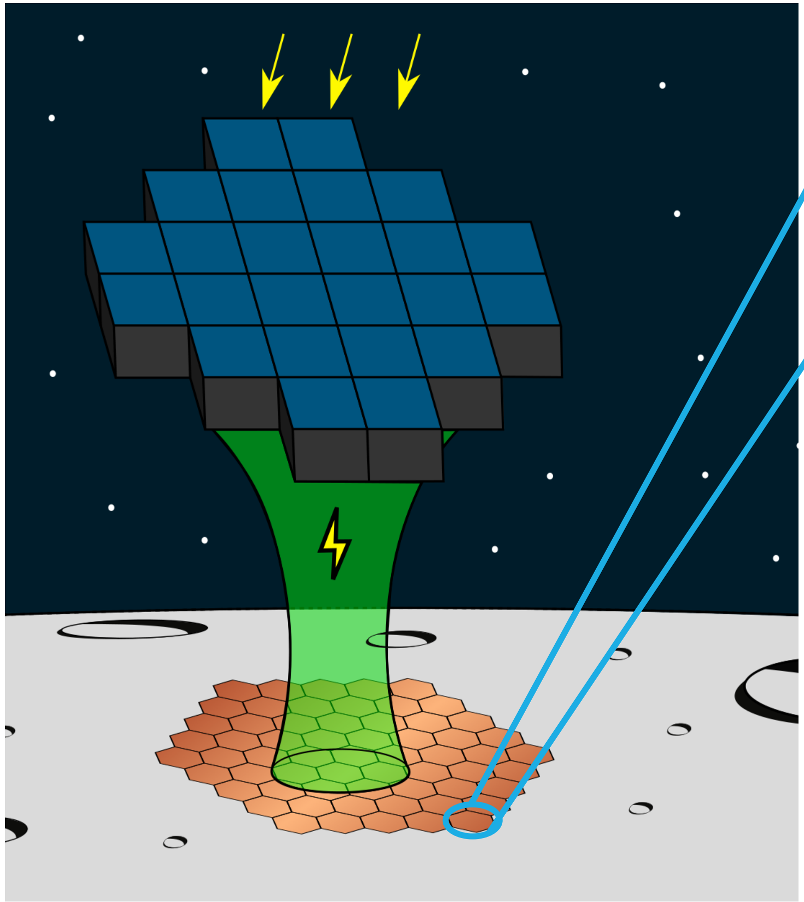
POWER BUDGET



- Per tile & Per orbit

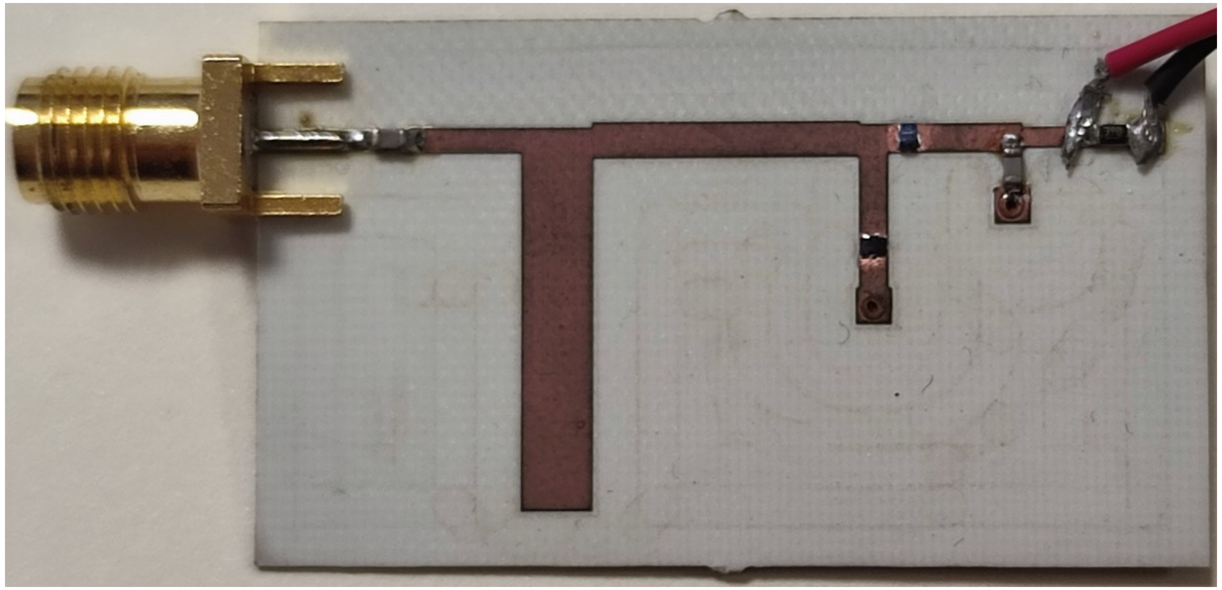
POWER RECEPTION



Antenna Array

RF-DC Converters

30 dBm of RF were converted to DC with 50% efficiency
Achieved experimentally



POWER BUDGET

$$T_{X_{duration}} = \frac{E_{available}\,(Wh)}{T_{X_{consumption}}\,(W)} = \frac{11}{215} \times 60 = 3\ \text{min}$$

	Per tile (W)	Total system (kW)
Peak Power generated	35	91.4
Beam power T_X	40	104
Beam power R_X	28	73.1

	Per tile (Wh)	Total system (kWh)
Energy stored in batteries	19	49.6
Energy available to transmit	11	28.7
Energy received on Moon	1.4	3.7

$$E_{Moon} = 2611 \times 28 \times \frac{3}{60} = 3.7\ \text{kWh}$$

SYSTEM'S EFFICIENCY

	Solar Panel	Energy storage	Transmitter	Beam	Total
η [%]	25	80	19	70	**2.6**

3.7 kWh each 2h!

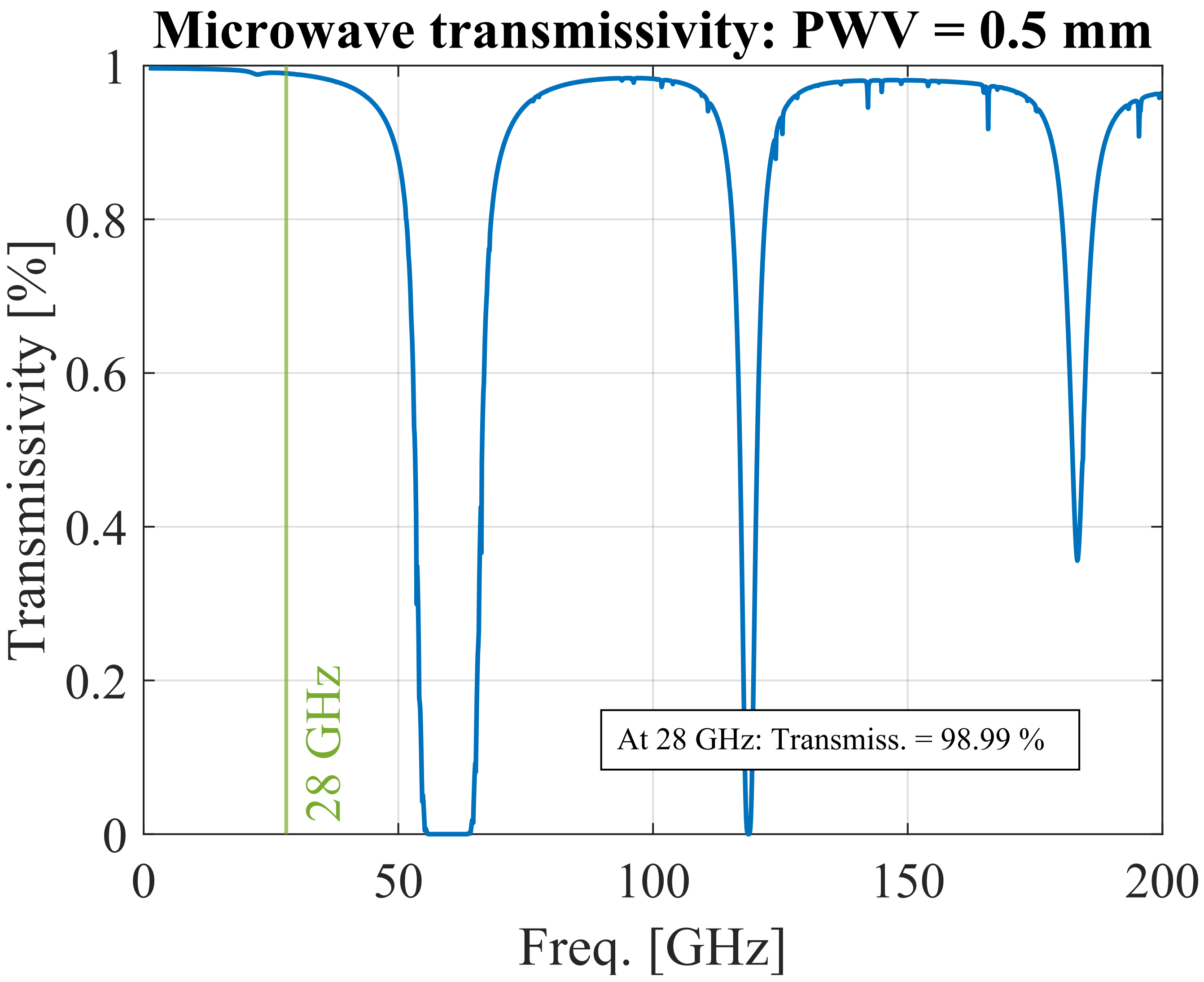
Can be increased by adding tiles or constellations

COMPLETE STRUCTURE

N_{tiles}	Total Area	Orbital Period	Total Efficiency	Energy Supply
2611	305 m^2	117 min	2.6 %	3.7 kWh

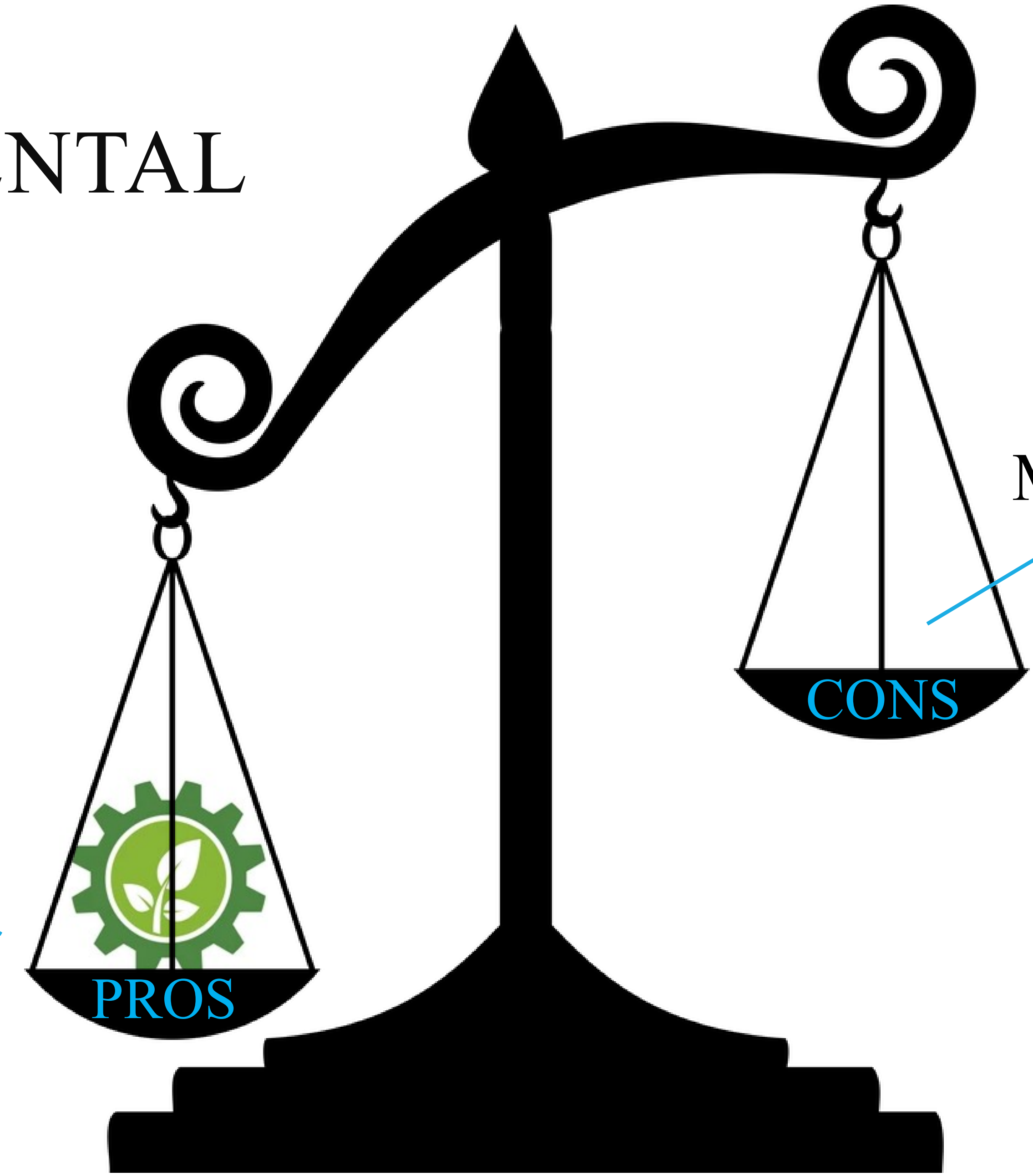
FLEXIBILITY

- Adequate for other missions and celestial bodies
- Including Earth's atmosphere



ENVIRONMENTAL IMPACT

Clean energy
Reduced size
Increased Efficiency



More complexity

NEAR TERM DEMONSTRATOR

Proof of concept

- Demonstration of a complete system tile (28 GHz)
- 100-m wireless power transfer experiment
- Array of 4 horn antennas
- Lens with 1.3 m of diameter

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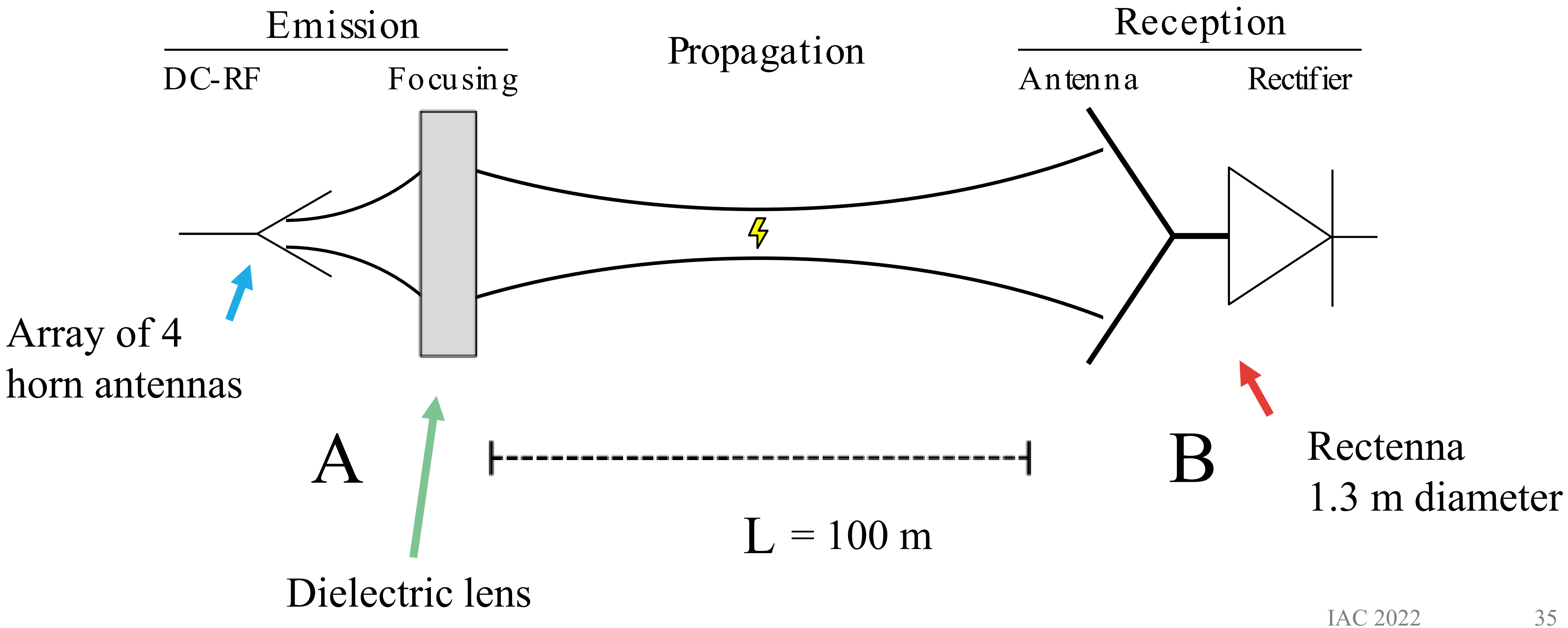
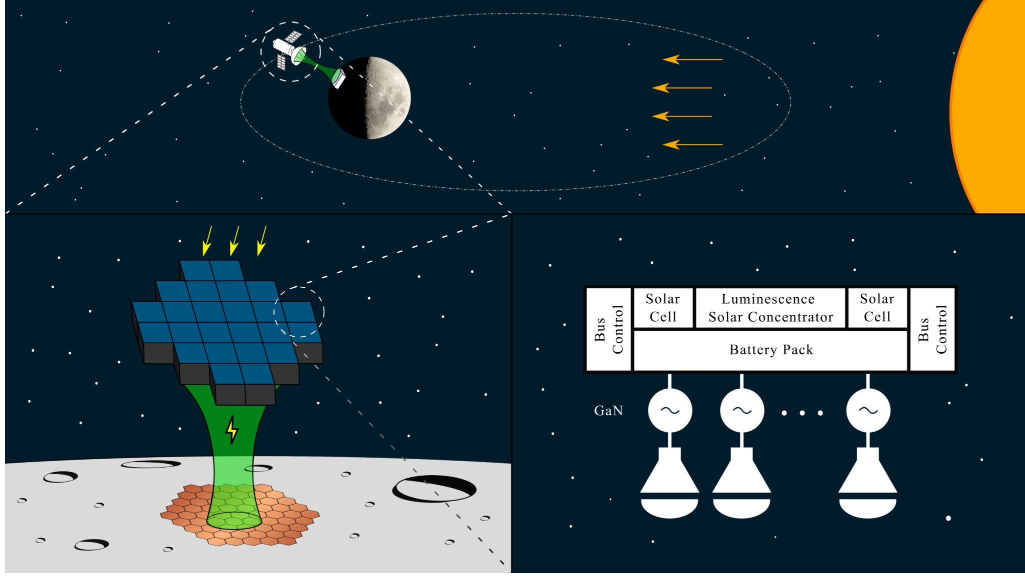
NEAR TERM DEMONSTRATOR



CONCLUSION



Proposed a novel solar power satellite system architecture

- Capable of energy storage
- Modular
- Adaptable to various scenarios (moon, asteroids, Earth, etc)
- Solar power generation + energy storage + wireless power transfer
- Green energy
- Near term demonstrators

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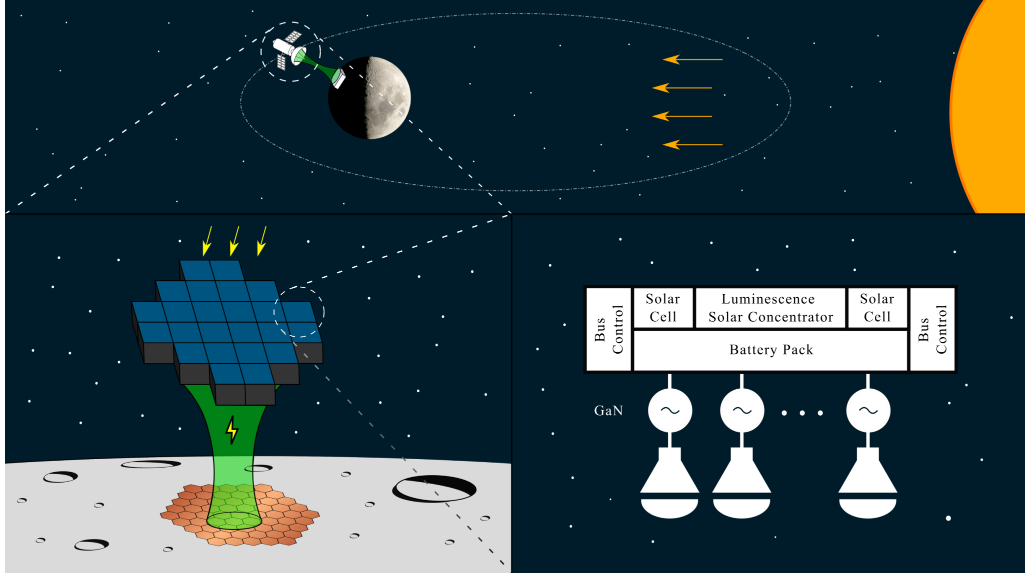
Q&A



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