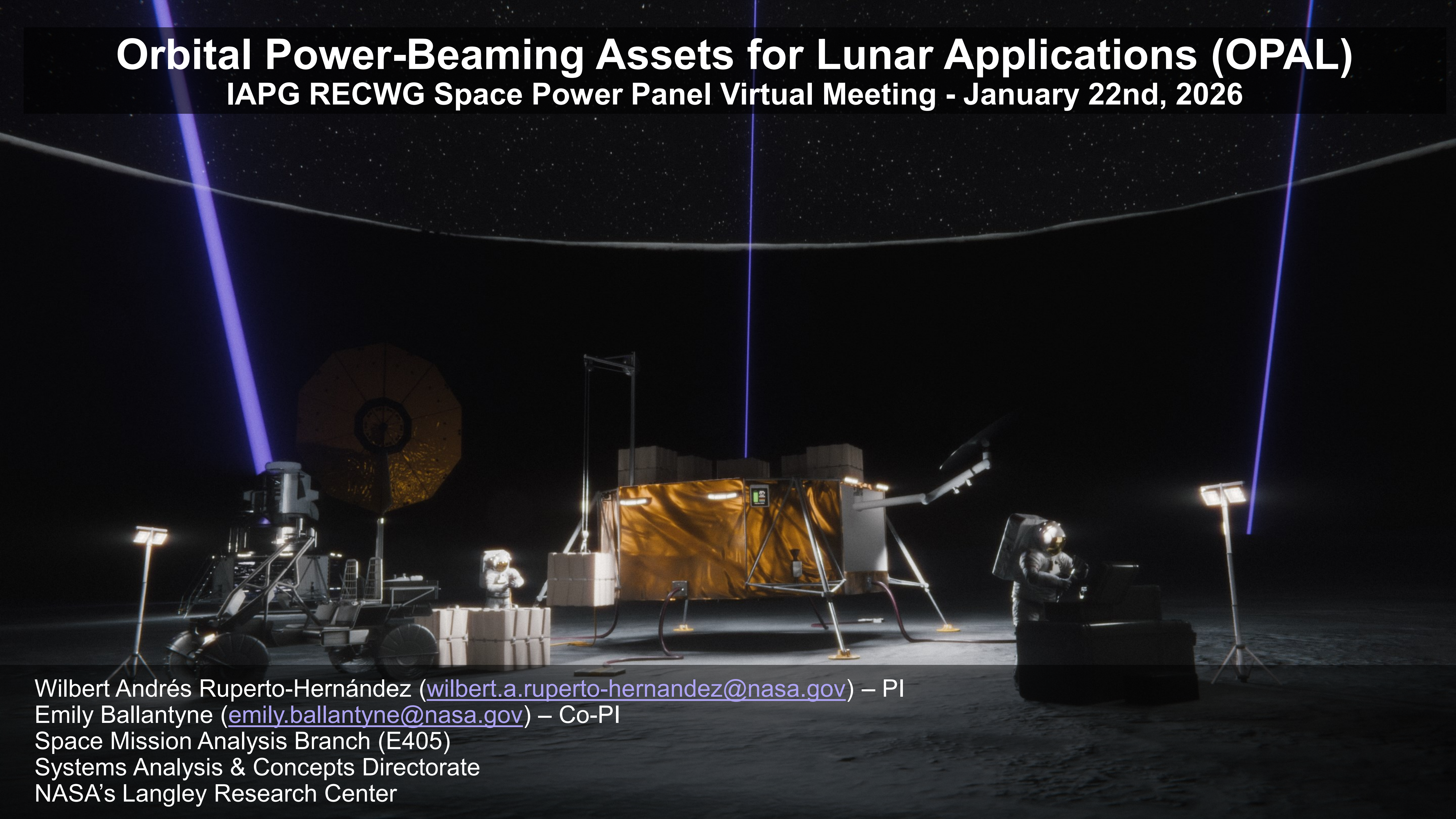

Orbital Power-Beaming Assets for Lunar Applications (OPAL)

IAPG RECWG Space Power Panel Virtual Meeting - January 22nd, 2026

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BLUF – Orbital Power-Beaming Assets for Lunar Applications

Why are we doing this?

- To remove the **burden of landed power system mass**.
- To enable an increase in **operating power** and **longer and more flexible missions**.
- To **improve the end-to-end efficiency** of current power beaming technology and concepts.

What is OPAL?

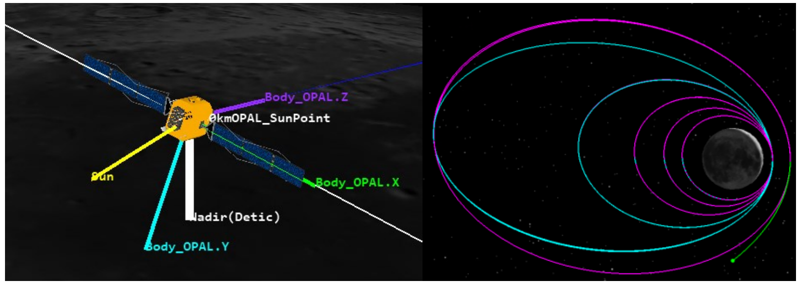
- Concept development study (March 2024 – today).
- OPAL is focused on optical power beaming from lunar orbit to power assets on the **lunar surface** through **lunar night** and in **low-illumination** regions.
- OPAL is exploring the **concept of a focusable and power-tunable optical power beaming system.**

Why now and why us?

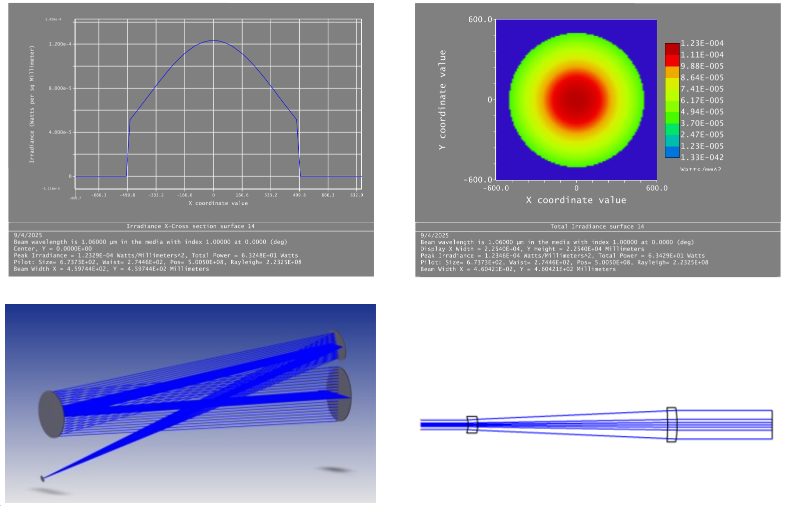
- Optical power beaming is gaining momentum with development activities happening across government, industry, and academia.
- This is a complex **<u>systems-of-systems problem.</u>**

Optical power beaming is a large and complex trade space. OPAL has developed a unique Integrated Optical Power Beaming Analysis Capability to study this new concept.

Mission Design & ConOps Assessment

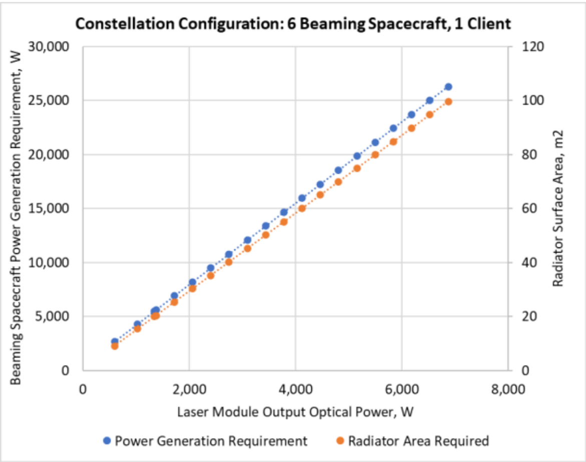


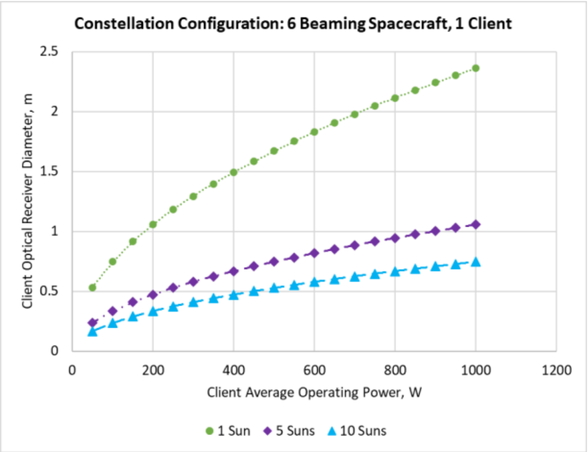
Optical Physical Beam Propagation Simulation & Optical Design



Parametric Vehicle Sizing

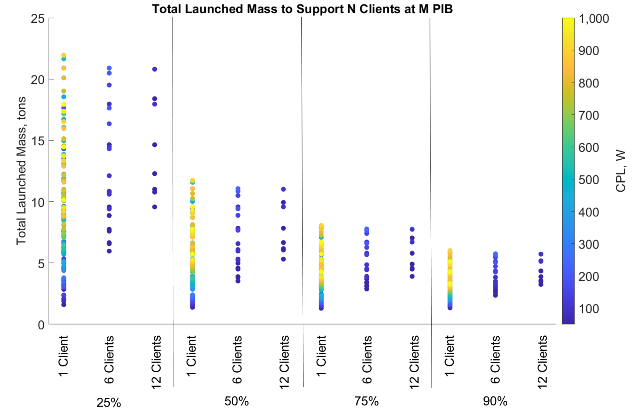
Beaming Spacecraft Systems Sizing





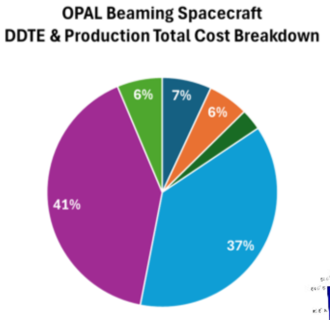
Client Systems Sizing

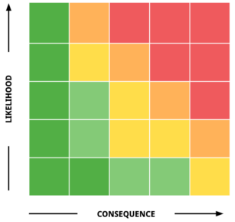
Systems-of-Systems Analysis



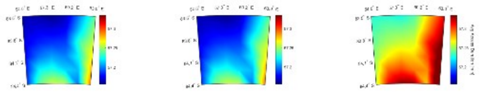
Power-in-the-Bucket, PIB

Architecture Impact Analysis





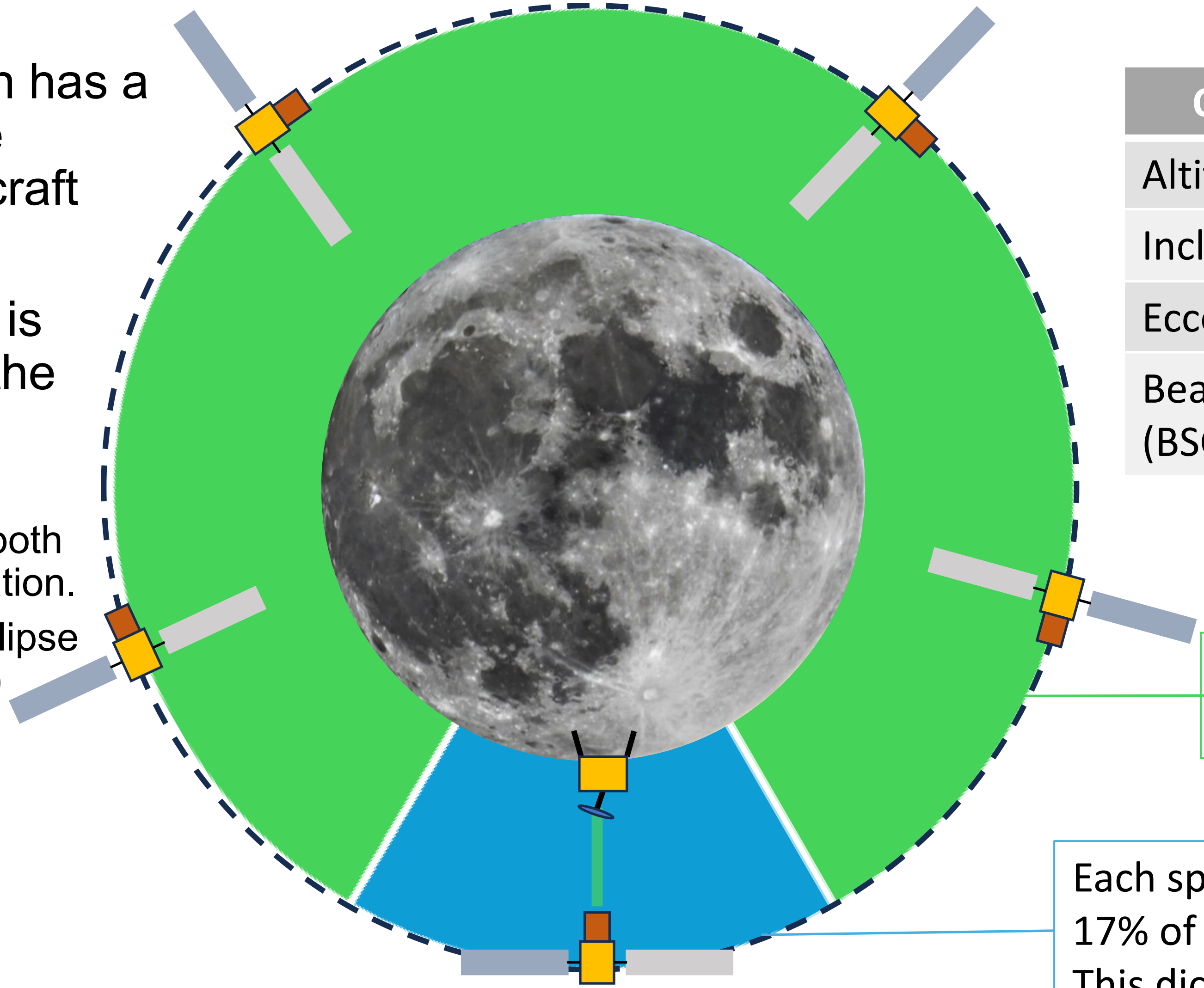
Risk Analysis



Access Analysis

Concept of Operations

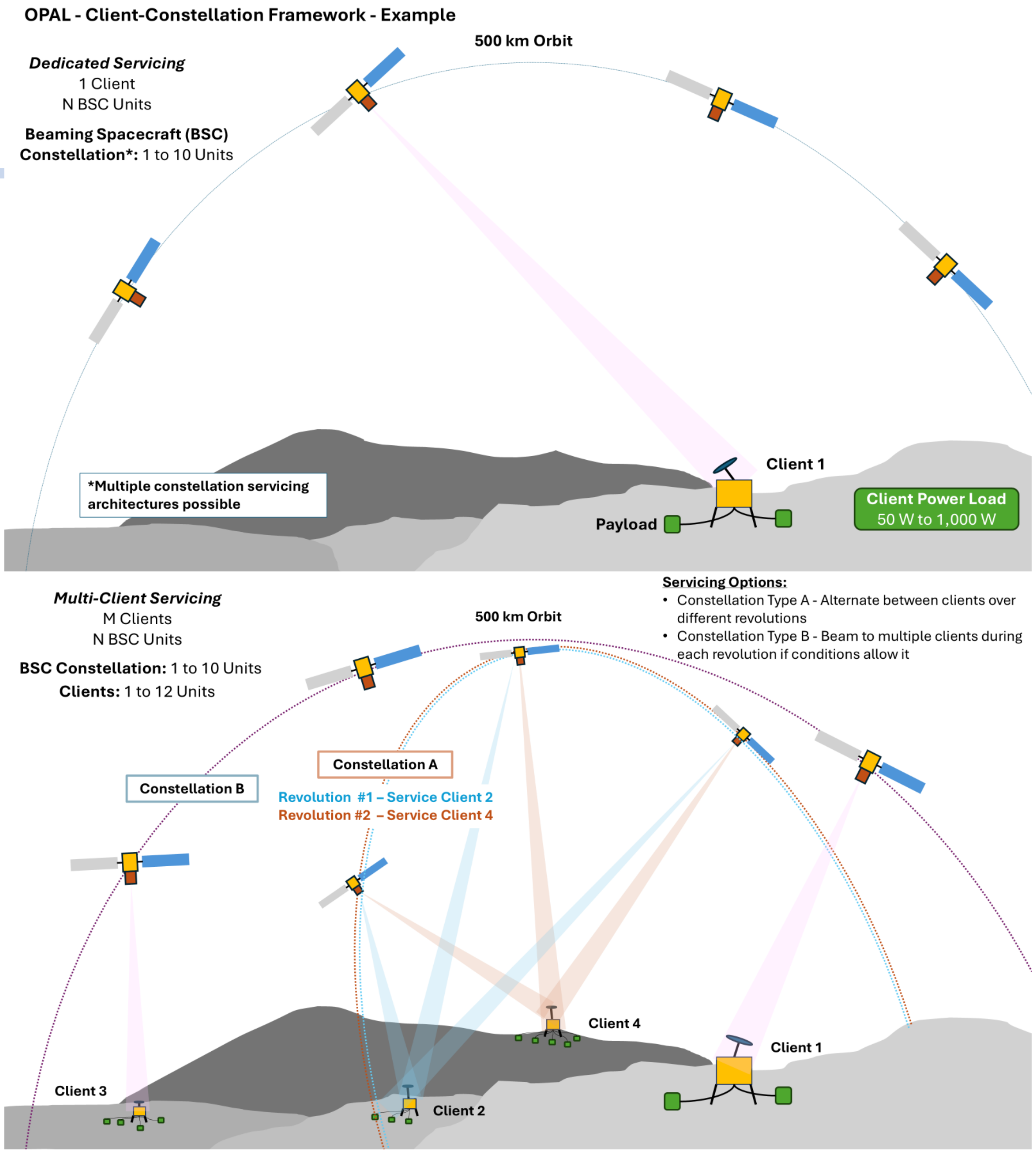
- The orbital selection has a direct impact on the mission and spacecraft designs.
- Preliminary altitude is selected based on the following traded parameters:
  - Orbital stability in both altitude and inclination.
  - Access times & eclipse time fraction (ETF) for the client.
  - Optical beam propagation



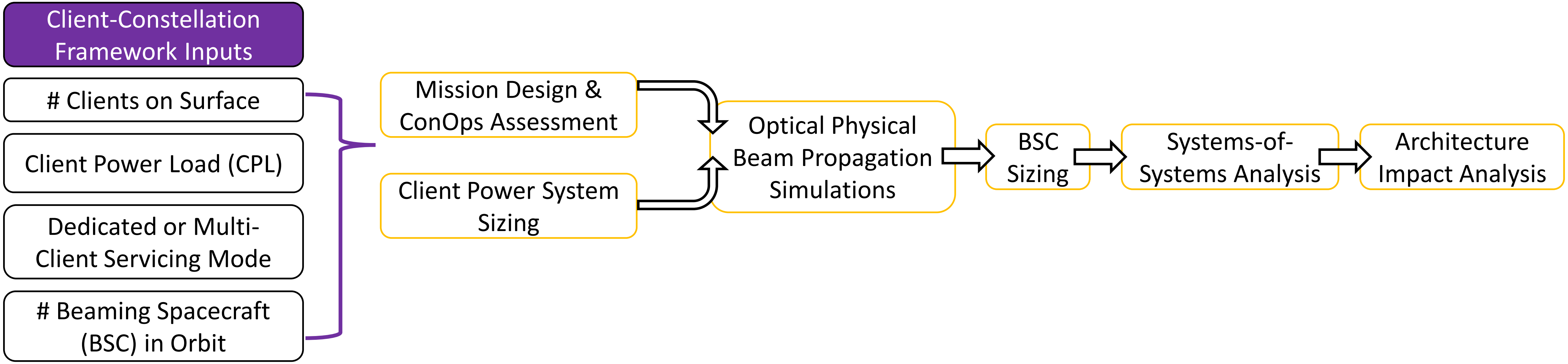
Orbital Mission Design Example	
Altitude (km)	500
Inclination (deg)	90
Eccentricity	0
Beaming Spacecraft (BSC) in Constellation	5

Analyzing the OPAL Architecture

- There are <u>three main elements</u> that compose the OPAL architecture:
  - **<u>The Client</u>** – A surface assets that receives the optical beam and turns it into electricity to operate itself and/or its payload.
  - **<u>The Optical Beam</u>** – A laser beam that is generated at and transmitted from the Beaming Spacecraft.
  - **<u>The Beaming Spacecraft (BSC)</u>** – An orbiting spacecraft that generates, conditions, shapes, and points the optical beam to each client.
- The relationships between these elements are intricate and result in a <u>complex and large trade space.</u>
- We have created a **Client-Constellation Framework** that enables analysis of thousands of potential mission configurations.



Integrated Optical Power Beaming Systems Analysis Workflow



- OPAL's approach enables an integrated systems analysis that can help evaluate component-level and system-level performance as well as broader impacts to lunar architecture and missions.
- Technology performance parameters (for both Client and BSC), mission design parameters, and assumptions are fed into parametric sizing tools.
- Optical beam propagation simulation data, which can help infer first-order performance of the **optical payload**, is also fed into the sizing tools, namely the **Power in the Bucket (PIB)**.

Focusing the Beam to Maximize Power in the Bucket

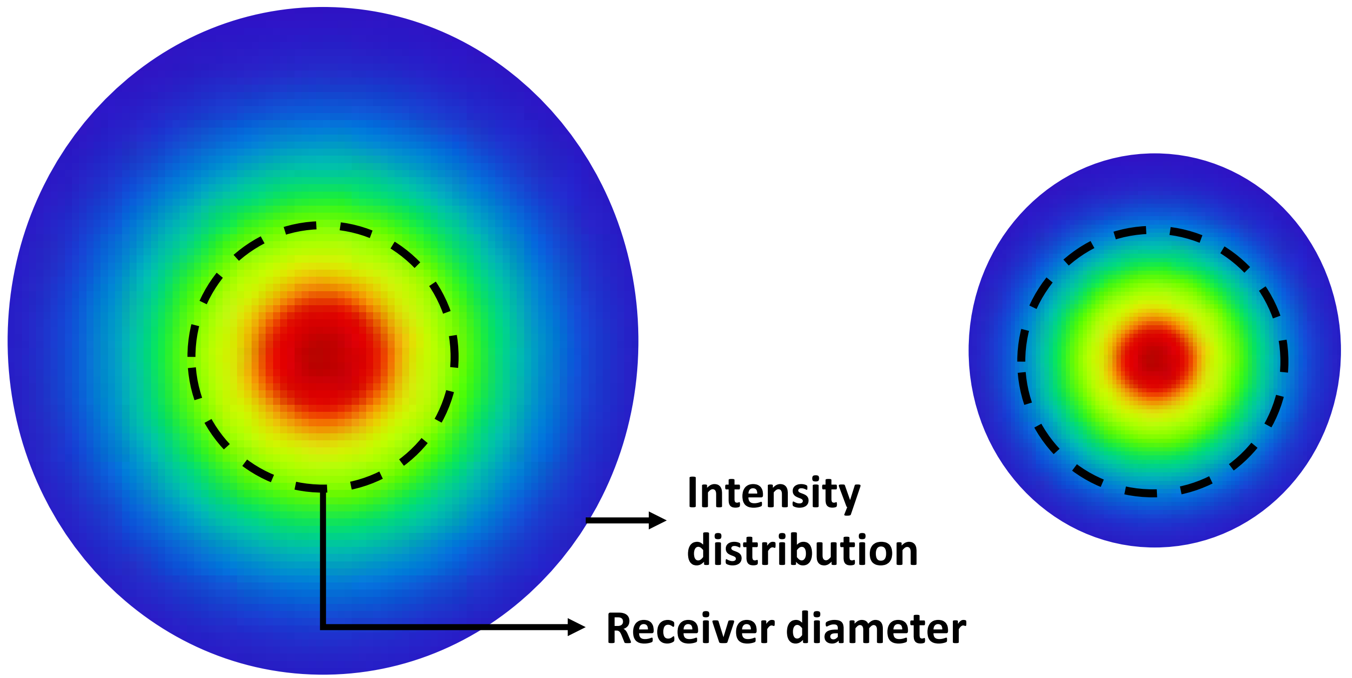
- Power in the bucket (PIB) is the percentage of total beamed power that illuminates the receiver.
- By focusing the beam, PIB can be maximized, which results in less power lost to receiver overflow.
- Minimizing this loss improves the end-to-end (E2E) efficiency of the system and reduces risk to the lunar surface.
  - Risks might include unintentional lunar surface volatization, health risks to astronauts, and risks to client systems

Without focusability:

- PIB is minimized to 25-75%.
- There is significant overflow of the beam outside the receiver.
- All overflow power increases risk to surface activities.

With focusability:

- PIB is maximized to 75-90%.
- There is minimal receiver overflow.
- Minimizes risk to surface activities.



Key Assumptions

Orbit Assumptions	
Altitude (km)	500
Inclination (deg)	90
Eccentricity	0
Orbital Period (s)	9,900
Client Access Time per spacecraft (s)	1,600

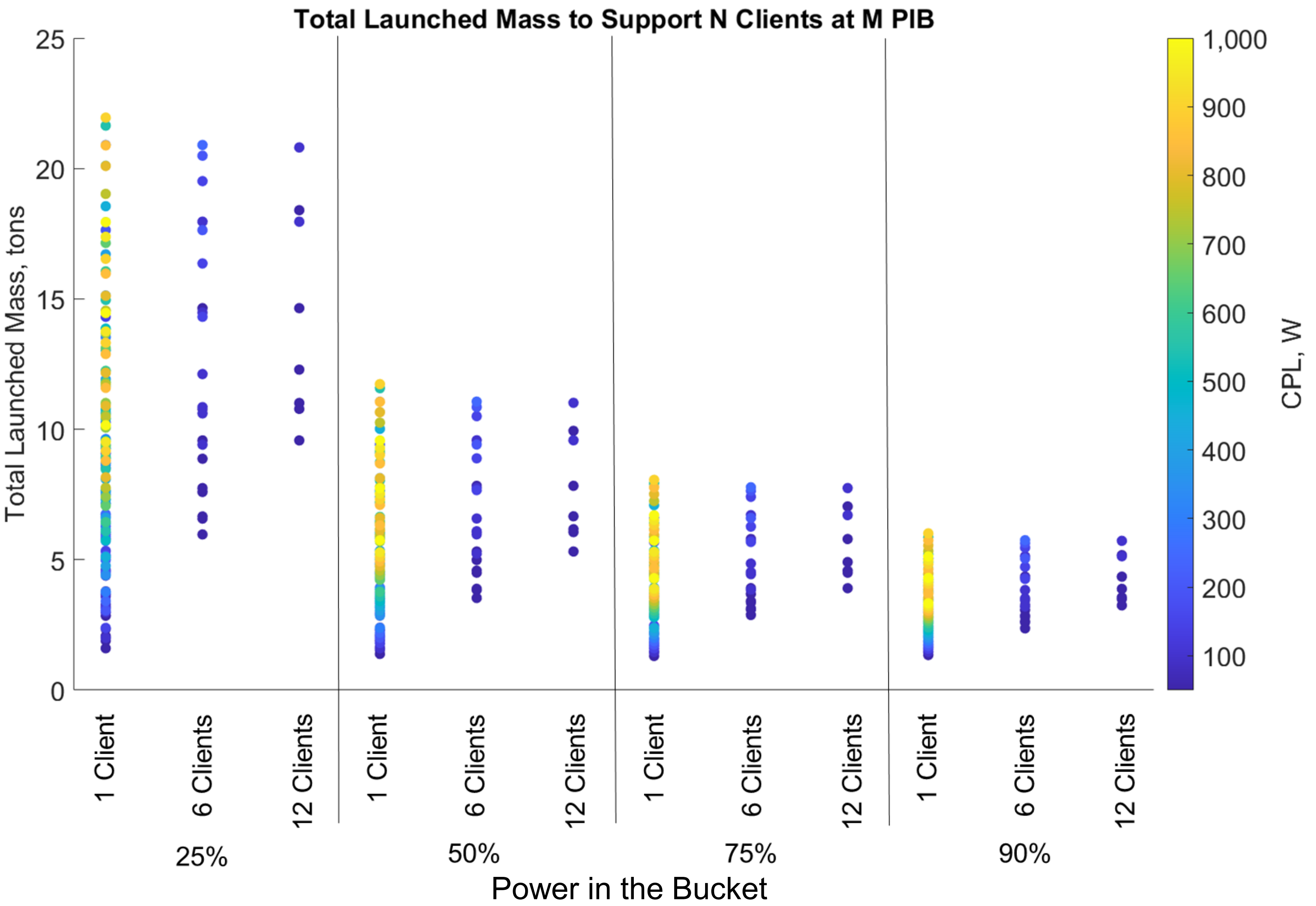
Client Assumptions	
Receiver Diameter (m)	≤ 1
Receiver O2DC Efficiency (%)	40
Receiver Tracking	Yes
Specific Battery Mass (Wh/kg)	200
Power in the Bucket (%)	90

Configuration Assumptions	
Number of spacecraft	1-6
Number of clients	1-12

Beaming Spacecraft Assumptions	
PV Cell Efficiency (%)	33
Mission Duration (yrs)	10
Propulsion Type	Monoprop
Laser DC2O Efficiency (%)	50

Impacts of Power in the Bucket on Systems Sizing

- PIB drives the laser power requirements and, therefore, the sizing of the beaming spacecraft (BSC).
- With higher PIB, there is a decrease in:
  - Overall BSC systems mass
  - Mass in lunar orbit to satisfy power demands on the surface
  - Laser power requirements and cost



Conclusions

- Incorporating focusability into the optical power beaming design will:

Increase Power in the Bucket (PIB)

Decrease losses due to receiver overflow

Improve end-to-end efficiency of the system

Decrease the total system mass

Decrease overall cost and risk

OPAL Literature

- LSIC Surface Power Workshop FY25 - https://ntrs.nasa.gov/citations/20250009404
- LaRC CIF/IRAD FY25 Executive Summary - https://ntrs.nasa.gov/citations/20250011709
- April 2025 White Paper - https://ntrs.nasa.gov/citations/20250003718
- ASCEND 2025 Manuscript - https://ntrs.nasa.gov/citations/20250006489