Continued Presentation Space Solar Power Developments at Boeing

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The Boeing Company

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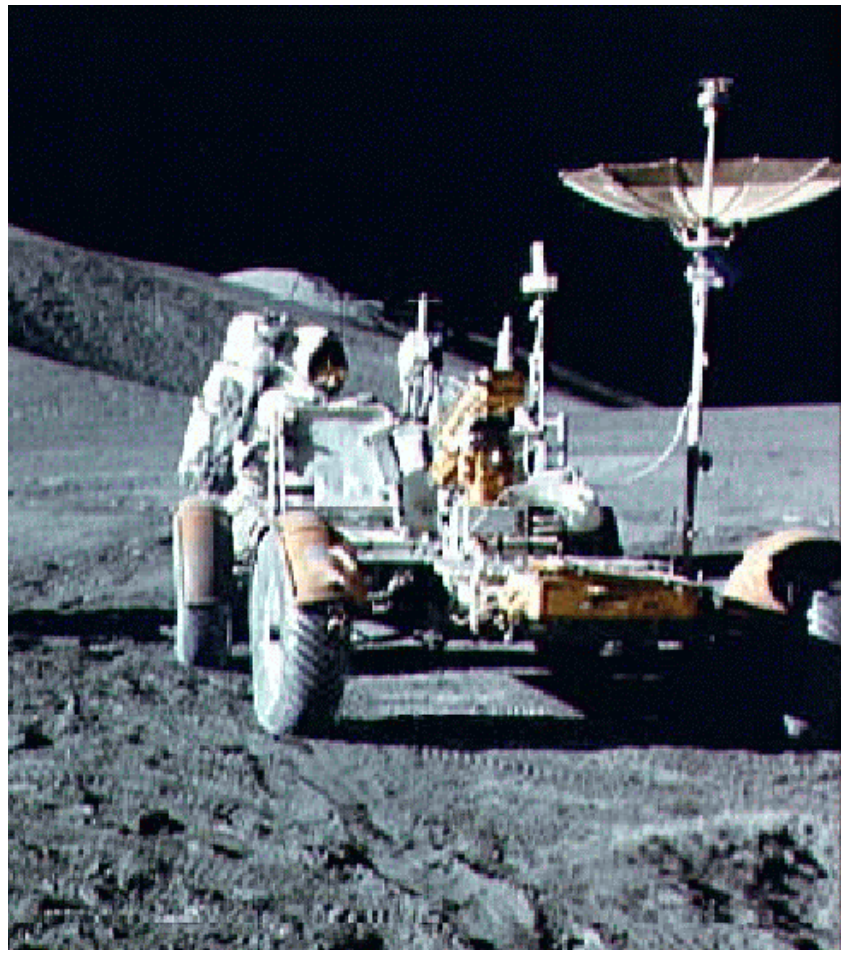
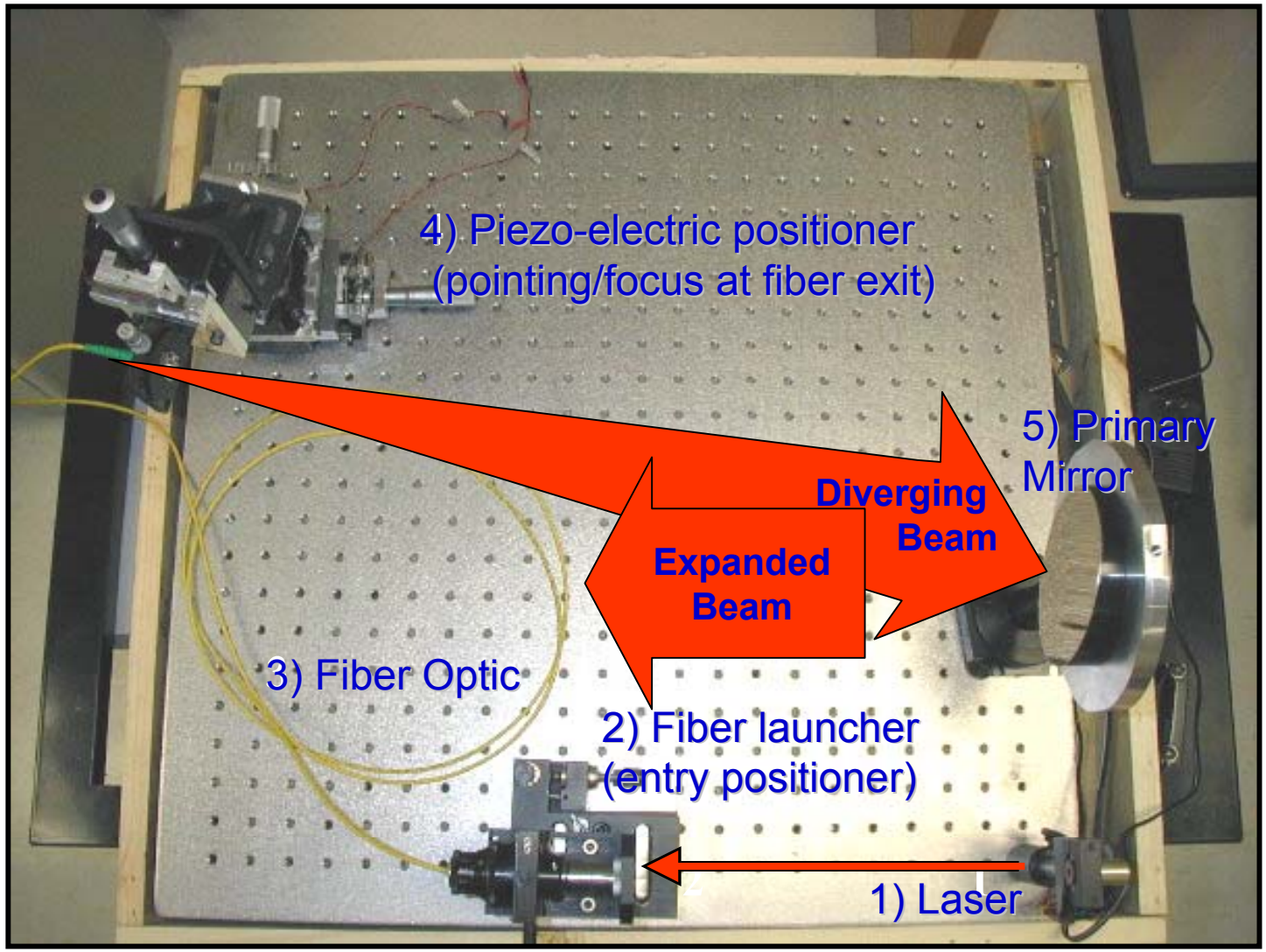
Apollo Lunar Roving Vehicle (LRV): Candidate for Lunar Laser-PV WPT Mission

<u>Key Features</u>:
Flight-proven on the Moon
2 flight-qualified units still exist
Long Distance Roving Capability
Large Platform for WPT Receiver

<u>LRV Modifications for MSC-2 Use</u>
Add Large Photo-Voltaic Panel
Revise Batteries (rechargeable)
Revise Deployment System
Revise Data / Comm. Interfaces
Delete Crew Interfaces (optional)
Add Teleoperation Capability
Extend Range of Ops (TBD x 100 km)
Requalify for Low T Ops (~100 Kelvin)
Add Scientific Payload Interfaces



Experimental Laser Transmitter (Harvey Mudd College)



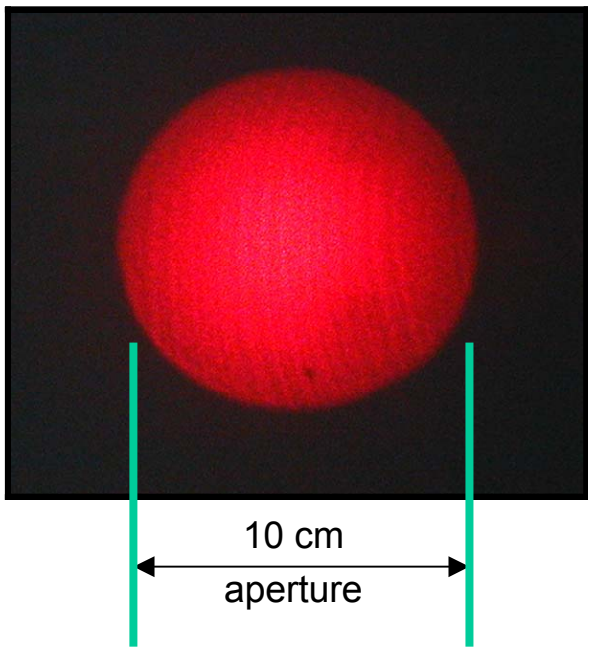
Initial Transmission of Expanded Beam

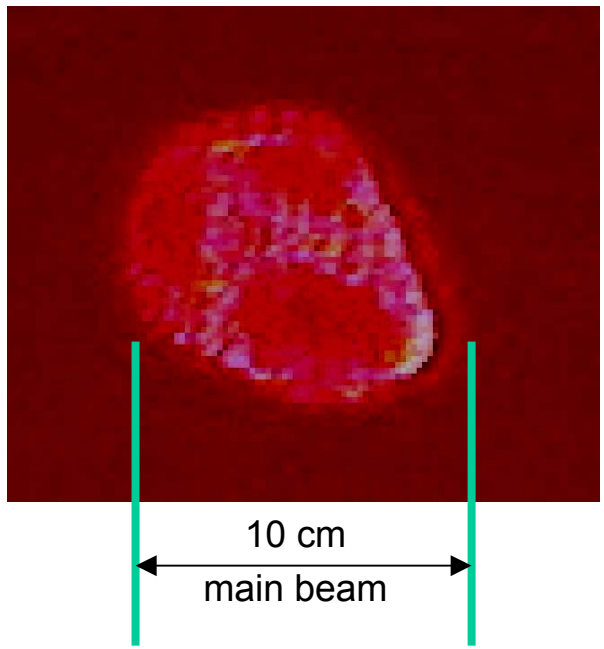
Short-Range (~ 1 meter)

- Minor imperfections from diamond-cut primary mirror (corrected by replacing mirror)

Mid-Range (~ 1 kilometer)

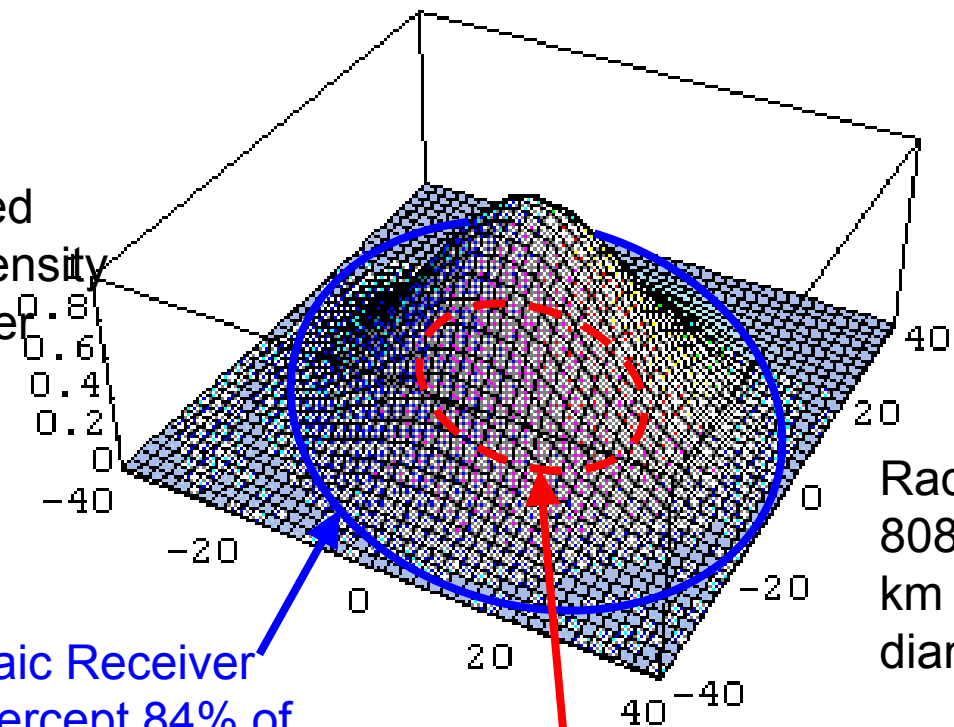
- Image distortion due to 3 hole mounting of primary mirror (corrected by replacing mirror)





Gaussian Laser Beam Intensity Distribution

- Smaller receiver, allowing beam spill-over, may be advantageous for lunar polar applications (<1/5 the PV area for >1/2 the power output)
- More even illumination of photo-voltaic array improves efficiency

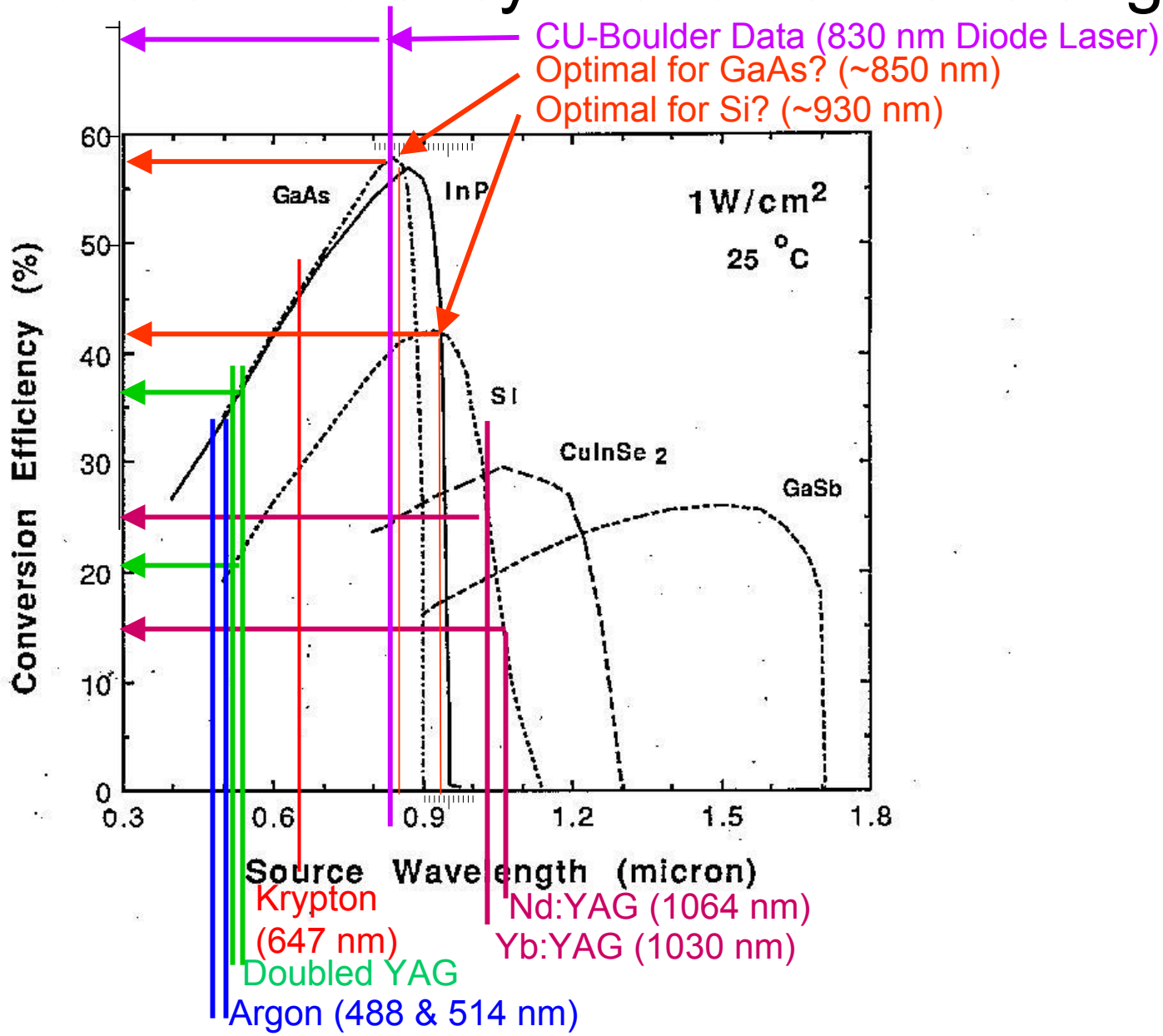


Radius (cm) from center of 808 nm laser beam at 100 km distance from 25 cm diameter aperture transmitter

Photo-Voltaic Receiver sized to intercept 84% of total incident power (100% of beam's main lobe)

Smaller Photo-Voltaic Receiver intercepts 19% of main beam lobe, to collects 50% of total power (60% of power in main lobe)

Photo-Voltaic Efficiency Trend vs Wavelength



Gallium Arsenide Photo-Voltaic Cell Efficiency vs. Laser Wavelength (U. Colorado-Boulder)

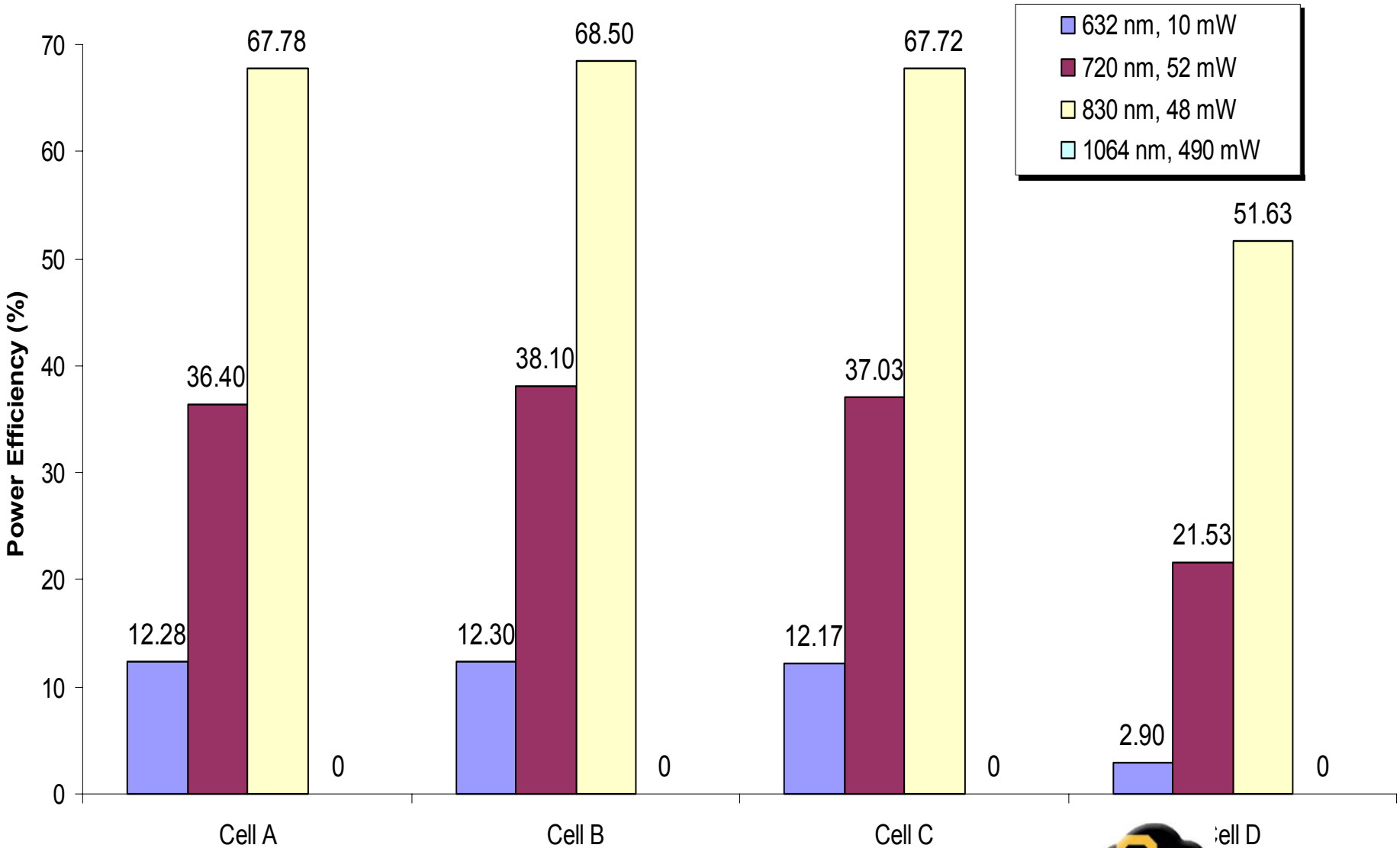


Photo-Voltaic Rover for Further Research (Carnegie Mellon University)

- Developed by the Robotics Institute at Carnegie Mellon University to demonstrate technology for a future Lunar Polar mission
- Circumnavigated Haughton Crater in the Canadian Arctic in Summer, 2001
  - Autonomous ops in constant sunlight
- Currently under study for potential near-term applications in ground demonstrations of Laser-Photovoltaic wireless power transmission
  - Large, cooperative target for long distances
  - Possible system revisions (e.g., PV receiver)

Key Points and Conclusions

- **SSP and WPT technology can enable space science and exploration in the near term**
  - **MSC-1: Power Plug or "LAMP" spacecraft**
  - **MSC-2: Lunar Polar Solar Power outpost**
  - **Near-term applications provide top-level traceability to commercial SSP**
- **Micro-wave WPT systems are efficient, and beam power through clouds / light rain, but require large sizes for long distance WPT**
  - **Need specialized ground asset: rectenna**
- **Laser-PV WPT systems allow smooth transition from conventional Solar power to SSP**
  - **Synergistic with terrestrial Solar PV arrays**
  - **Small aperture size allows for low cost to first power**

Key Points and Conclusions (Continued)

- **Laser-PV WPT systems open new architecture options**
  - **Lower efficiency of current / near-term technology would seem to indicate higher mass, but specific power may be competitive**
    - **Small apertures minimize WPT and PMAD system mass**
  - **Narrow beams can overlap to generate a "top hat" energy profile**
    - **Allows for better use of land at receiver site**
  - **Lower land use facilitates multiple receiver sites**
    - **May be needed to mitigate weather outages**
  - **Gravity gradient-stabilized Sun Tower-like architectures may make more sense for lasers than for microwave systems**
    - **Cosine loss at midday mitigated by ambient sunlight at receiver site**
    - **Rigid arrays, with both sides able to convert sunlight to electricity, may be preferable rotating (gimbaled) arrays**

NEXT STEPS

- **Develop high tech components for near-term end-to-end ground technology demonstrations**
  - **High Voltage Solar Power Supply**
  - **High Voltage power Management and Distribution**
- **Continue analyses of Large SSP satellites**
  - **Near-term, modest-scale systems (MSC-1)**
  - **Farther-term, larger-scale systems**
- **Continue technology development for lunar polar SSP system applications**
  - **Accessing and processing ice resources**