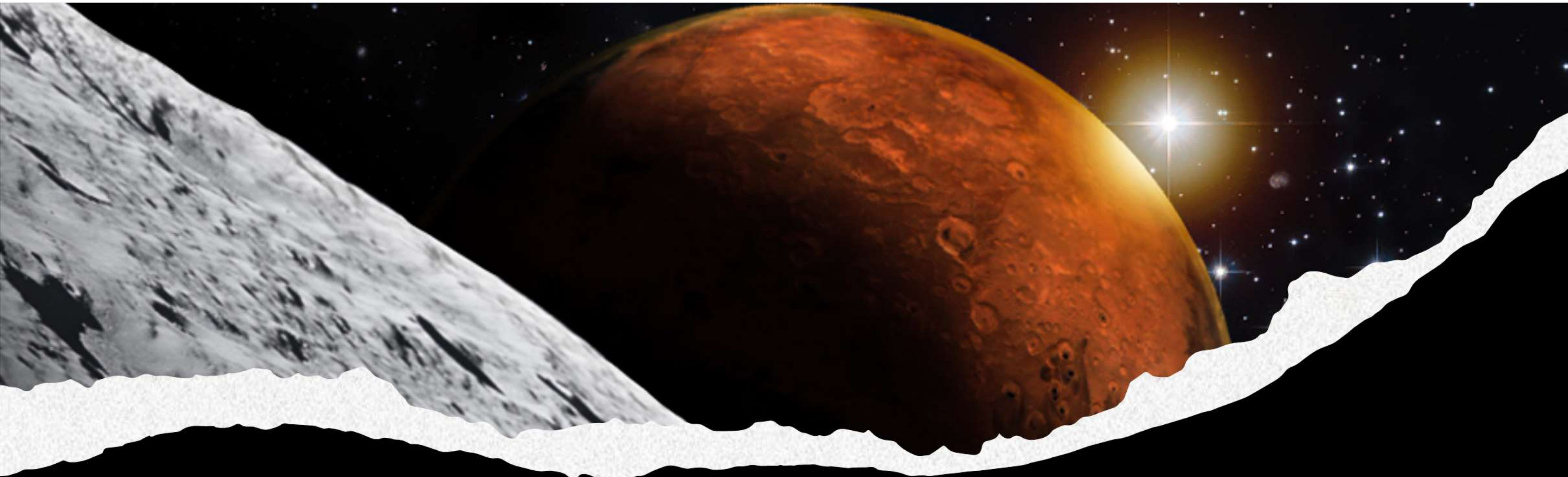

Powering Moon, Mars, and Beyond

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Enabling NASA's Moon to Mars Architecture

- Advancements in power technologies will be needed to return humans to the Moon, take our first steps on the surface of Mars, and explore locations to the outer planets and beyond
- Areas of energy generation, storage, management and control, and transmission will evolve to meet the mission needs of these locations
- Fission Surface Power systems will be key energy generation elements in these future ecosystems and enable steady scientific and industrial growth within

HUMAN LUNAR RETURN

Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (e.g., science) on and around the Moon.

FOUNDATIONAL EXPLORATION

Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (e.g., science) and Mars-forward precursor missions.

SUSTAINED LUNAR EVOLUTION

Enabling capabilities, systems, and operations to support regional and global utilization (e.g., science), economic opportunity, and a steady cadence of human presence on and around the Moon.

HUMANS TO MARS

Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (e.g., science) on Mars and continued exploration.

Human Lunar Return

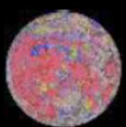
- Near term missions include returning humans to the lunar surface and exploration by landers and rovers for science and ISRU prospecting
- Power is expected to be localized to each element with the potential for some wired or wireless transmission
- Power ranges from 100s Watts to <10 kW
- Relatively short mission durations for crewed missions to long-durations* for some landers (night/cold survival may drive power needs)
- Mission locations may be selected to optimize the use of solar power generation
- A fission surface power system unlikely to be required for these mission cases but could be demonstrated

Foundational Exploration

- Exploration of locations deeper within permanently shadowed regions and to location beyond the lunar poles
- Increasing the distance between energy generation location and use site (trade between mobile and stationary systems)
- Increasing mission durations
- Power needs continue to grow. Long periods of darkness will tax energy storage systems. Fission surface power systems can meet this need
- Expanding ISRU capability, producing feedstocks and commodities for a variety of uses.
- Demonstrations for Mars campaigns
- Increase in commercial campaigns, possibly providing power augmentation to NASA missions

In-Situ Resource Utilization (ISRU) Opportunities

Commercial Scale Water, Oxygen, Metals & Commodity Production



- Lunar resources mapped at meter scale for commercial mining
- 10's of metric tons of commodities per year for initial goal commercial usage
- Scalable to 100's to 1000's metric tons per year

Commodities for Habitats & Food Production

- Water, fertilizers, carbon dioxide, and other crop growth support
- Crop production habitats and processing systems
- Consumables for life support , EVAs, and crew rovers/habitats for growing human space activities

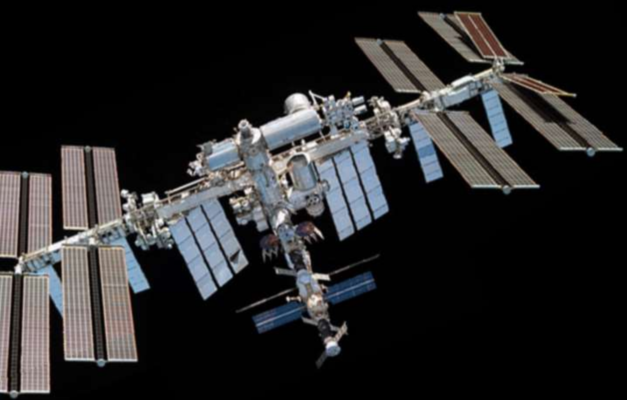
In Situ Derived Feedstock for Construction, Manufacturing, & Energy

- Initial goal of simple landing pads and protective structures
- 100's to 1000's metric tons of regolith-based feedstock for construction projects
- 10's to 100's metric tons of metals, plastics, and binders
- Elements and materials for multi-megawatts of energy generation and storage
- Recycle, repurpose, and reuse manufacturing and construction materials & waste

Commodities for Commercial Reusable In-Space and Surface Transportation and Depots

- 30 to 60 metric tons per lander mission
- 100's to 1000's metric tons per year of for Cis-lunar Space
- 100's metric tons per year for human Mars transportation

Evolution of Power Transmission from LEO Systems to a Future Lunar Grid

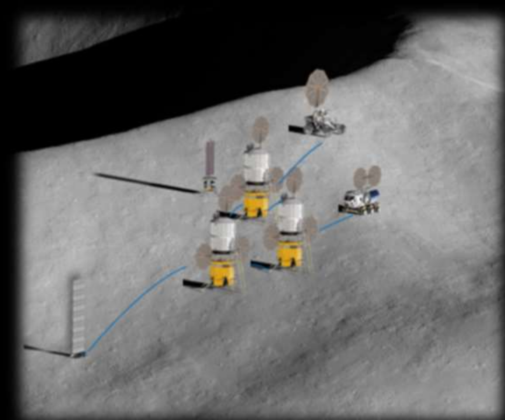


Low Earth Orbit and Early Artemis Elements

- Multi-kW_e-scale, mostly unidirectional systems <150 VDC
- Experience base in LEO radiation environment
- Most loads considered “critical”
- Reliability guaranteed by redundancy for critical loads

Artemis Campaign Lunar Surface Elements

- Multi-kW_e-scale, unidirectional systems <150 VDC for most projected end states of base architecture
- Higher voltage transmission (up to ~1kV)
- Artemis flight element reliability management scheme to be extended to surface elements where appropriate

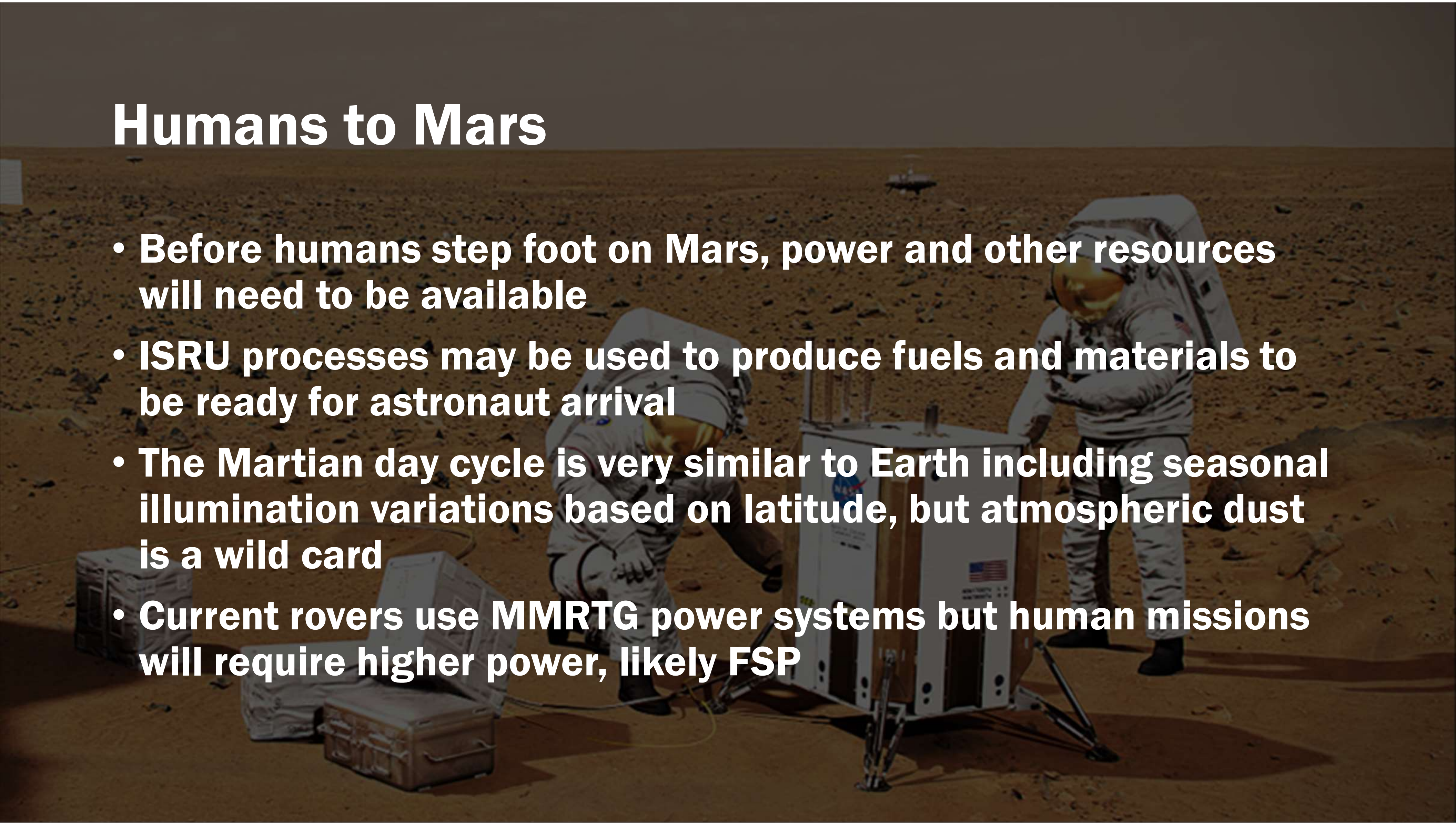


Lunar Power Grid

- MW_e-scale, uni- and bi-directional systems ranging from 150V to 1kV levels
- Higher voltage transmission for long distances
- Multiple users/interfaces, interoperability needed
- May include ISRU derived elements

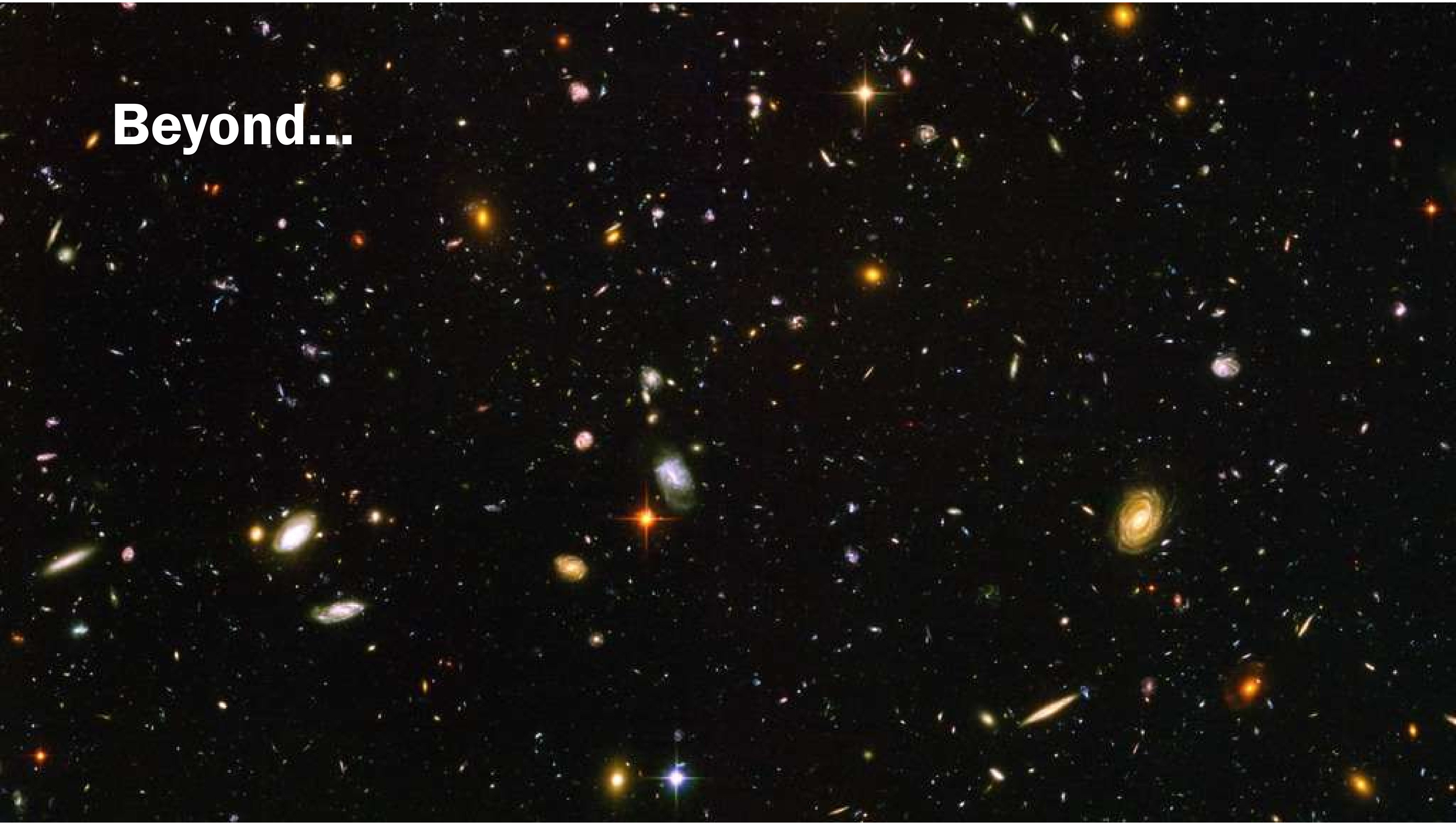
Sustained Lunar Evolution

- A state of regional and global utilization of the Moon by multiple organizations
- Potential for a MW scale power grid supplying power to a variety of users, powering habitats, science platforms, industrial scale ISRU plants
- Production of propellants and resources for future Mars missions
- Up to 1000 km transmission segments produced from ISRU components
- Such a state would require multiple fission surface power systems located across the surface



Humans to Mars

- Before humans step foot on Mars, power and other resources will need to be available
- ISRU processes may be used to produce fuels and materials to be ready for astronaut arrival
- The Martian day cycle is very similar to Earth including seasonal illumination variations based on latitude, but atmospheric dust is a wild card
- Current rovers use MMRTG power systems but human missions will require higher power, likely FSP


Beyond...