Lunar Surface Innovation

C O N S O R T I U M

LSIC Surface Power Focus Group August Meeting

August 27, 2020

We will start at 3 minutes after the hour

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Wes Fuhrman

Wesley.Fuhrman@jhuapl.edu

Today’s Agenda

- LSIC community announcements
  - CONFLUENCE IS HERE
  - ISRU Workshop – supply & demand
    - September 17
  - Conference on Advanced Power Systems for Deep Space Exploration
    - October 27-29

- Lightning Talks
  - Koki Ho
    - **ISRU** Trade study
  - AJ Gremer
    - **Extreme Access** -- rovers by Lunar Outpost
  - Craig Peterson
    - **Extreme Environments** (illumination)

- Fall Meeting/Open Discussion
  - Power as the unifying contextual theme
  - Structure
  - Breakouts/workshopping

Lunar Surface Innovation CONSORTIUM

LSIC Community

1. Harness the creativity, energy and resources of academia, industry and government in order for NASA to keep the United States at the forefront of lunar exploration
2. Identify lunar surface technology developments most in need of sponsor support and communicate those to NASA
3. **Provide a central resource for gathering and disseminating information, results, and documentation**

Confluence

- License provided -- 2000 available
- Contact Andrea Harman for access
    - ams573@alumni.psu.edu
- Tutorial sessions available
- Content can include
    - Calendar of LSIC and related events
    - Wiki content, including a capabilities survey of LSIC members
    - Information about telecons, etc.
    - Discussion area
    - Your ideas!

ISRU Supply & Demand Workshop

- September 17, 12-1700, EST
  - No registration required for LSIC members
- Objective: to bring potential ISRU consumers and potential producers together to discuss ISRU needs and supply issues
- Format
  - 5-10 minutes per talk.
  - Focused on quantities, e.g. mass, purity, timeline, locations
  - Two sessions. Supply and Demand, with questions/networking sessions between
- http://lsic.jhuapl.edu/Events/103.php?id=103

Conference on Advanced Power Systems for Deep Space Exploration

- October 27-29

- Advanced mission concepts … all depend on more capable power systems in the coming decades. The 2020 APS^{4}DS will pick up where the 2018 conference left off and look again to the future of deep space power systems.

- Virtual Format over 3 days
  - shortened days, increased number of parallel sessions
  - anticipate over 75 technical session talks
  - Detailed Agenda available as of this morning!

- https://www.usasymposium.com/deepspace/

Georgia Tech Daniel Guggenheim School of Aerospace Engineering
College of Engineering

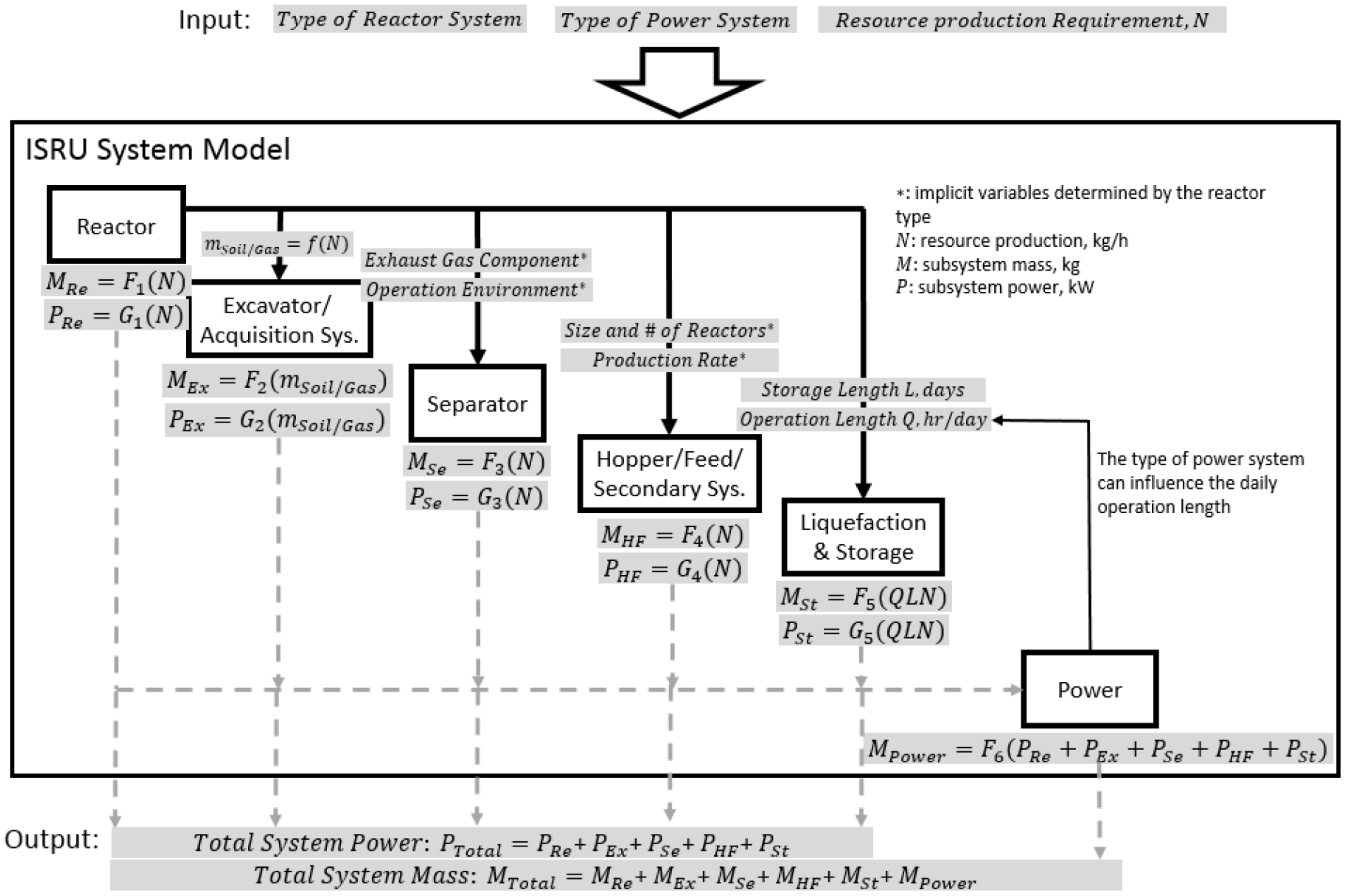
Georgia Tech

Summary of ISRU Trade Study

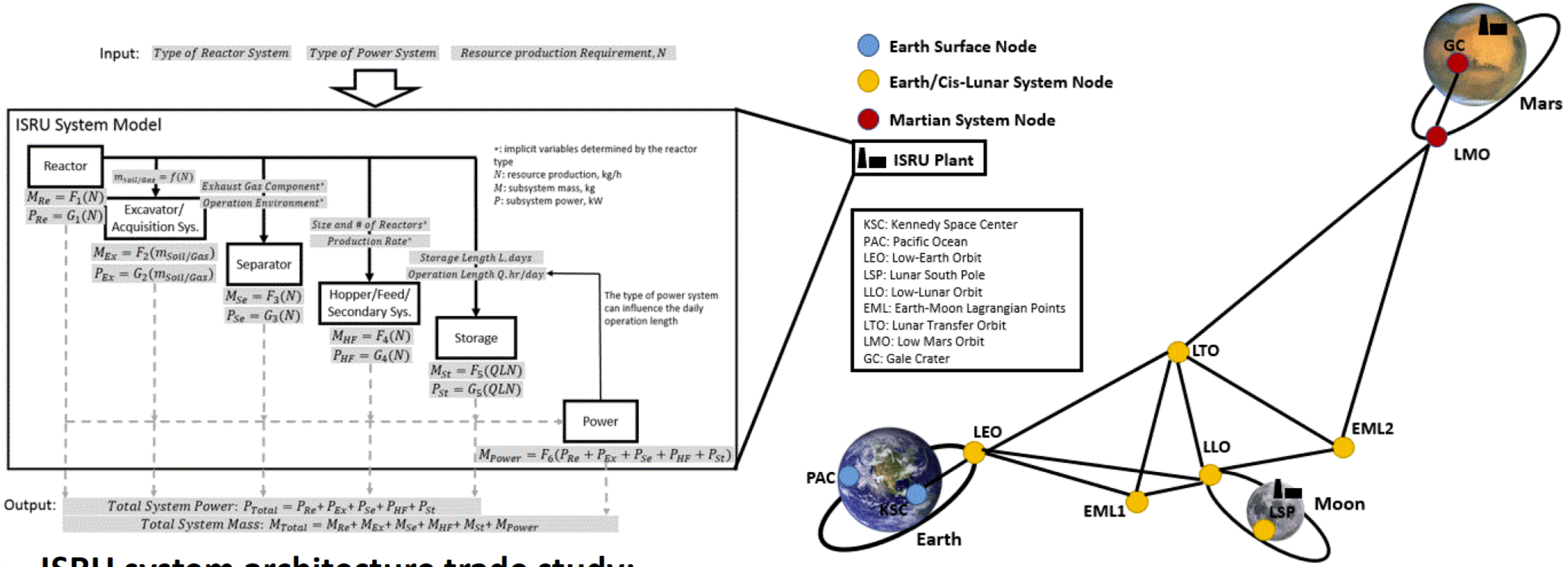
Prof. Koki Ho
Director, Space Systems Optimization Group
Georgia Institute of Technology
Formerly at Univ. of Illinois

- This material is partially based upon work supported by the funding from NASA NextSTEP program (80NSSC18P3418) awarded to the University of Illinois, where this work was initiated.
- H. Chen, T. Sarton du Jonchay, L. Hou, and K. Ho, "Integrated In-Situ Resource Utilization System Design and Logistics for Mars Exploration," *Acta Astronautica*, Vol. 170, pp. 80-92, 2020.

Integrated ISRU Models

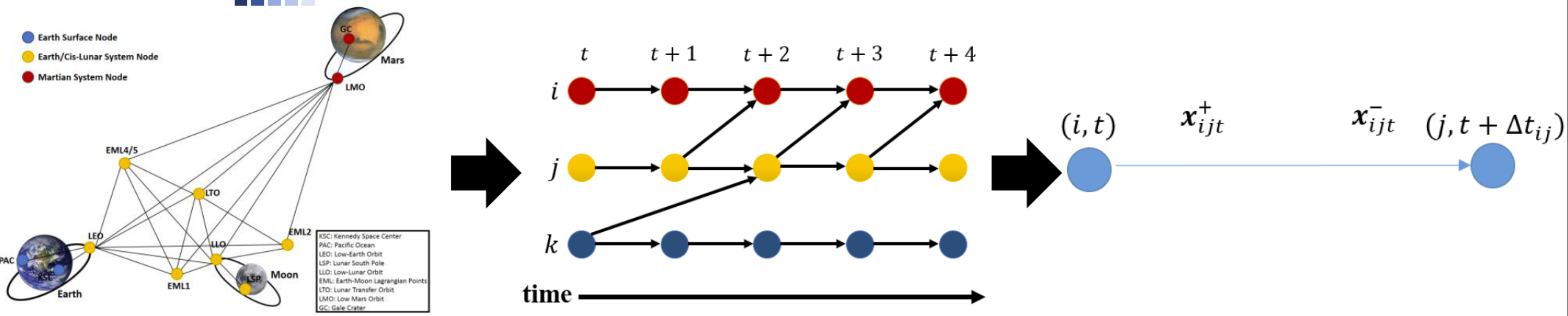


ISRU Trade Studies



- **ISRU system architecture trade study:**
  - Reactor type(s) selection for demands
  - Power subsystem selection: PV vs nuclear
- **ISRU operational trade study**:
  - Daytime-only operation or deploy additional batteries/fuel cells for night
  - Frequency of logistics missions and its impact on storage size
- **ISRU deployment timeline/location trade study:**
  - Deploy ISRU in 1 stage or multiple stages? If multiple stages, how many?
  - Could lunar ISRU be beneficial to Mars mission?
  - What if there is a space station, such as Deep Space Gateway?

Space Logistics Optimization



Minimize: $\mathcal{J} = \sum_{(v,i,j,t)\in\mathcal{G}} \mathbf{c}_{vijt}{}^T \mathbf{x}_{vijt}$

Subject to:

$$\sum_{(v,j):(v,i,j,t)\in\mathcal{G}} \mathbf{x}_{vijt} - \sum_{(v,j):(v,j,i,t)\in\mathcal{G}} F_{vji}\mathbf{x}_{vji(t-\Delta t_{ji})} \leq \mathbf{d}_{it} \quad \forall i \in \mathcal{N} \;\; \forall t \in \mathcal{T}$$

Flow Transformation

Mass balance

$$H_{vij}\mathbf{x}_{vijt} \leq \mathbf{0}_{l\times 1} \quad \forall (v,i,j,t) \in \mathcal{A}$$

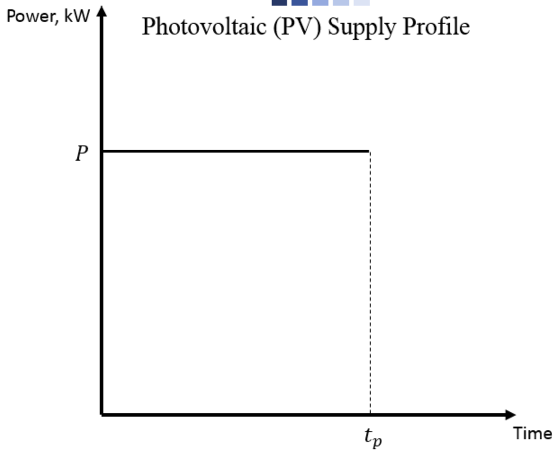
Flow Concurrency

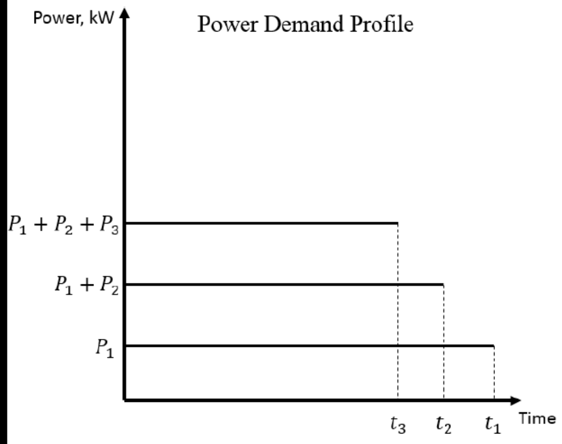
$$\begin{cases} \mathbf{x}_{vijt} \geq \mathbf{0}_{p\times 1} & \text{if } t \in W_{ij} \\ \mathbf{x}_{vijt} = \mathbf{0}_{p\times 1} & \text{otherwise} \end{cases} \quad \forall (v,i,j,t) \in \mathcal{A}$$

Flow bound

$$\mathbf{x}_{vijt} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_p \end{bmatrix}_{vijt}, x_n \in \mathbb{Z}_+ \; or \; \mathbb{R}_+ \quad \forall n \in \{1, \dots, p\} \quad \forall (v,i,j,t) \in \mathcal{A}$$

Power System Analysis Example





Define the commodity flow variables as,

$$\boldsymbol{x}_{vijt} = \begin{bmatrix} x^{I_1}\text{: infrastructure system 1, kg} \\ x^{I_2}\text{: infrastructure system 2, kg} \\ x^{I_3}\text{: infrastructure system 3, kg} \\ x^{P}\text{: power generation system, kg} \\ x^{E}\text{: energy storage system, kg} \end{bmatrix}_{vijt}$$

Power generation capacity constraint can be written as,

$$\begin{bmatrix} P_{I_1}\left(1 + \frac{Q_{I_1} - Q_p}{\varepsilon Q_p}\right) & P_{I_2}\left(1 + \frac{Q_{I_2} - Q_p}{\varepsilon Q_p}\right) & P_{I_3}\left(1 + \frac{Q_{I_3} - Q_p}{\varepsilon Q_p}\right) & -P_0 \end{bmatrix}_{vij} \begin{bmatrix} x^{I_1} \\ x^{I_2} \\ x^{I_3} \\ x^{P} \end{bmatrix}_{vijt} \leq 0$$

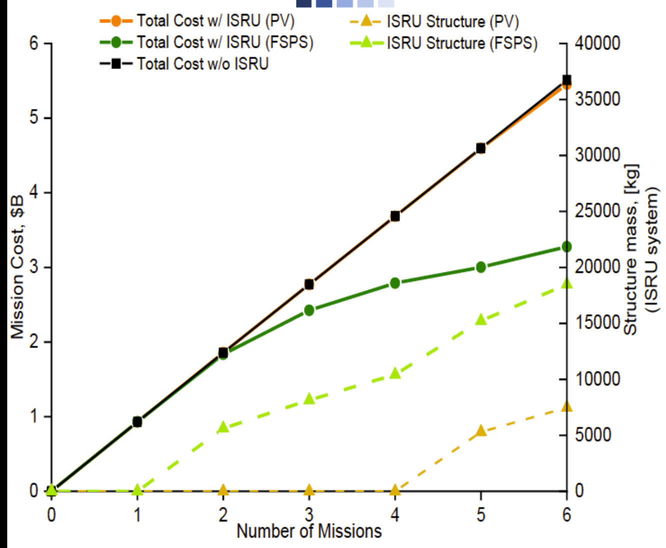
where Q is the system operation time per solar day.

The **energy storage capacity constraint** can be written as,

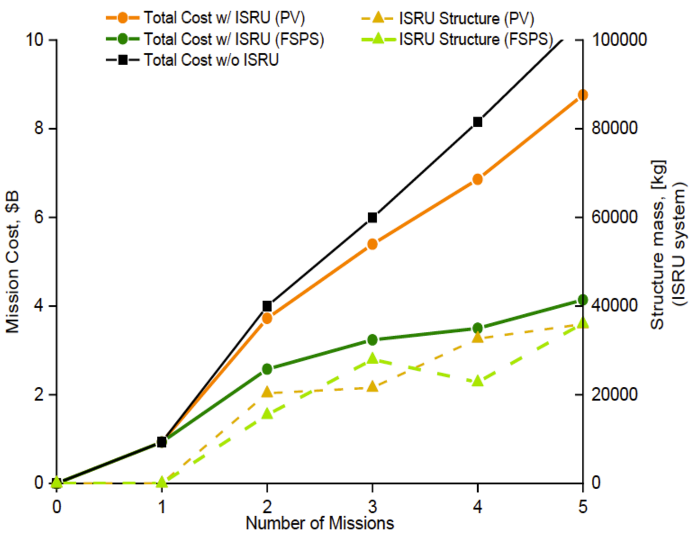
$$\begin{bmatrix} -P_{I_1} & -P_{I_2} & -P_{I_3} & P_0 & -\frac{\gamma}{\varepsilon Q_p} \end{bmatrix}_{vij} \begin{bmatrix} x^{I_1} \\ x^{I_2} \\ x^{I_3} \\ x^{P} \\ x^{E} \end{bmatrix}_{vijt} \leq 0$$

where P is the system power demand or supply.

Example Results



Cargo transportation mission (One-way)



Human exploration mission (Round-trip)

- ISRU is more effective for round-trip missions than one-way cargo missions;
- FSPS (Fission Surface Power Systems) has a better performance than the PV (Photovoltaic) power system (i.e., solar panels) in this case.

- **Developed optimization framework can be used for**
  - ➢ Design of large-scale <u>space exploration campaign</u> considering the <u>interaction</u> between space infrastructure design and space transportation planning.
  - ➢ Fast evaluation of <u>potential performances</u> of space architectures and spacecraft in large-scale campaign

Lunar Outpost

The Next Leap

LUNAR OUTPOST MISSION:

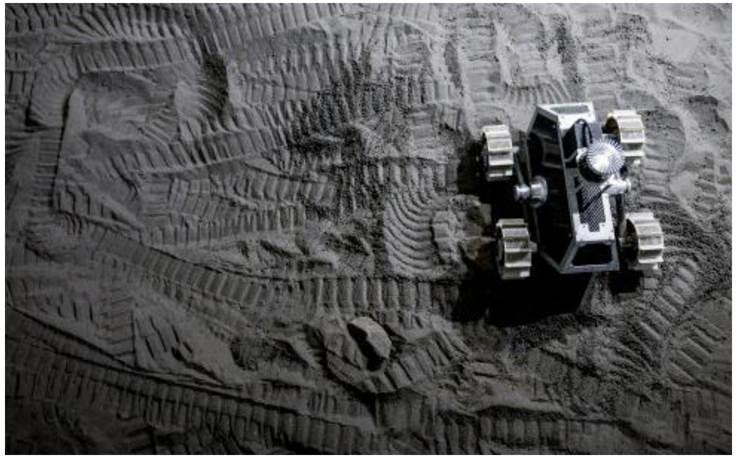
Develop technology that enables a presence on the Lunar surface, while creating Earth analogs that drive innovation and have positive impact.

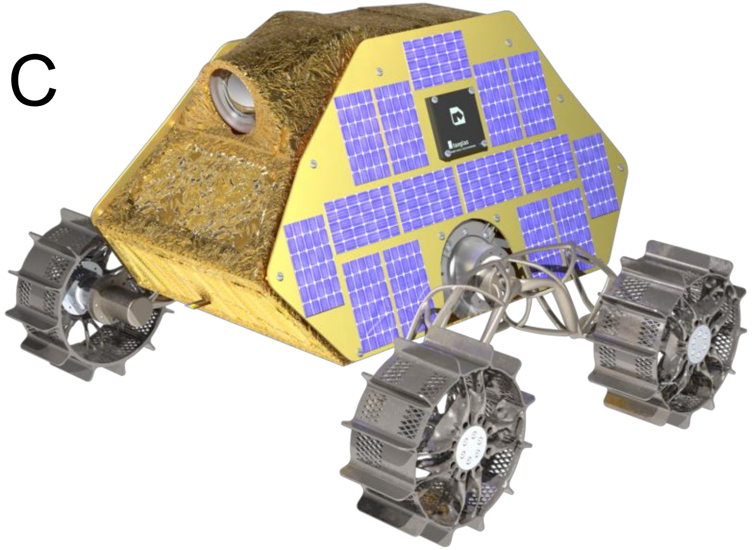
Company Overview

- Founded 2017, HQ in Golden, Colorado
- Planetary robotics contract with NASA
- Advanced instrumentation contract with USAF
- AFRL contract for robust space systems
- Life-support system on-board Gateway at KSC
- Provider Bloomberg Smart Cities Initiative

Mobile Autonomous Prospecting Platform

- M1 (Mission 1) MAPP
- Mobility services for high-TRL payloads
- CLPS lander as secondary payload
- Mission Duration: 7-14 days
- Thermal range: -60 C to +130 C
- Maximum Range: 8 km
- Flight-ready Q2 2021





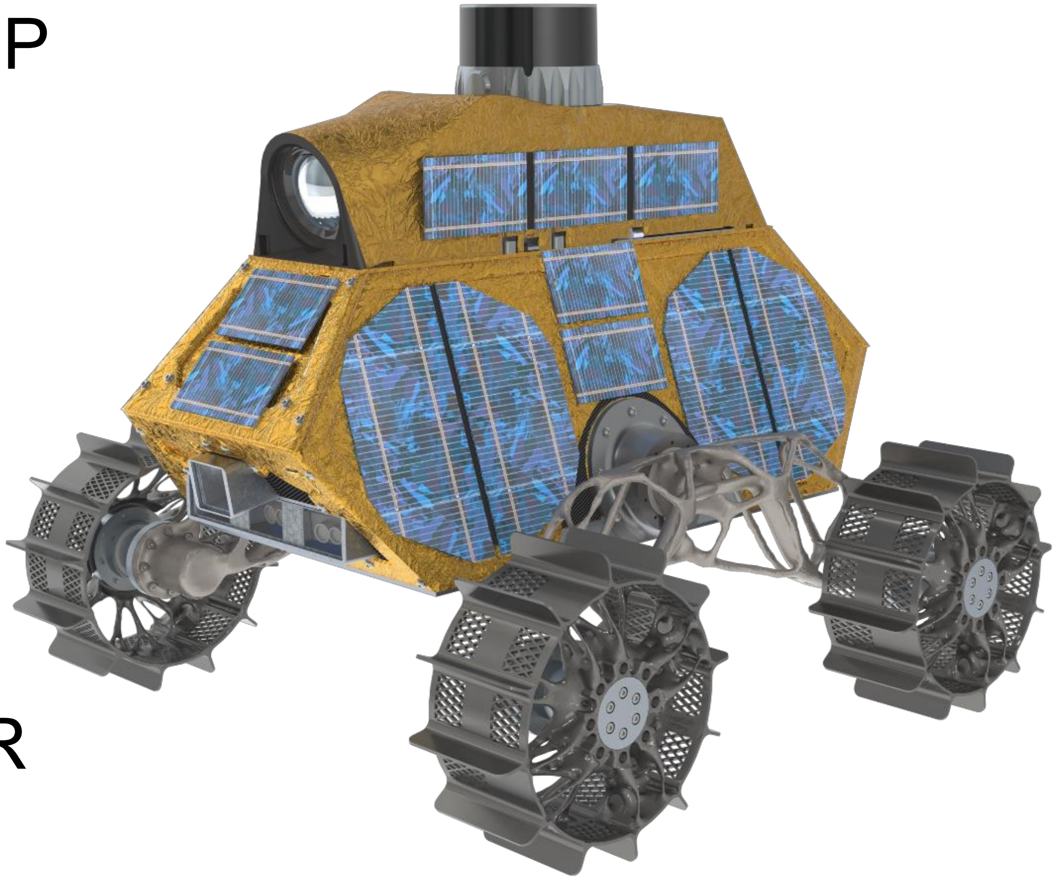
Lunar Outpost™

M1-MAPP Payload Volumes

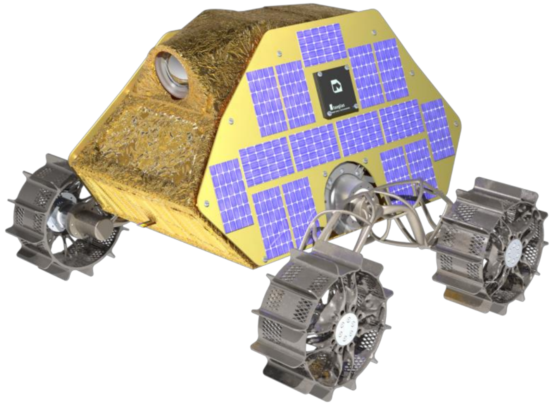
External Volume 1 (Orange)	426 cm^3
Internal/External Volume 2 (Purple)	1105 cm^3
Internal Volume 3 (Blue)	1443 cm^3
Internal Volume 4 (Red)	1215 cm^3
External Volume 5 (Green)	820 cm^3
Total Payload Volume	**5,009 cm^3**

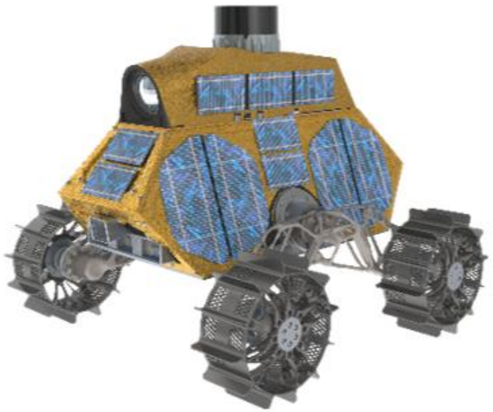
COLD-MAPP

- Cryogenic-Operation, Long-Duration MAPP
- Funded by NASA SBIR
- Lunar South Pole, 82-88˚
- Thermal Range: -230 C to +100 C
- Mission Duration: 75-100 days
- Maximum Range: 20 km, max 2 km from lander
- Staged approach: hibernate, operate, PSR
- Flight-ready Q3 2022



Current Rover Lineup





	M1-MAPP	COLD-MAPP	HL-MAPP
Bounding Envelope	44x48x35cm	44x48x35cm	1.5x1.3x1.3m
Chassis Mass	5kg	12kg	220kg
Payload Mass	5kg	3kg	80kg
Total Mass	10kg	15kg	300kg
Peak Payload Power	35W	35W	85W
Operational Lifespan	7-14 Earth Days	75-100 Earth Days	150 Earth Days
Lunar Night Survival	None	Yes	Optional
Maximum Surface Speed	10cm/s	10cm/s	20cm/s
Maximum Surface Range	8km	20km	50km

PSR MAPP

- COLD-MAPP survival: ~3 hrs
- Power Requirements:
  - Heater Power: ~13W continuous
  - Electrical Power: ~19W continuous
  - Payload Power: ?
    - Surface Measurements - Watts
    - Excavations – 10's-100's of Watts
- Of interest:
  - Lander docking/recharging
  - Beamed heat/power
  - Low-mass RHU/RTGs

Contact Us

Justin Cyrus – CEO
(908) 577–4014
Justin@LunarOutpost.com

Julian Cyrus – COO
(973) 738-3885
Julian@LunarOutpost.com

AJ Gemer – CTO
(720) 987– 4060
AJ@LunarOutpost.com

Lightning Talks

- Craig Peterson of Trans Astronautica Corporation

Fall Meeting/Open Discussion

- ASU as the virtual host/co-creators

- Theme is the interconnection between focus groups using power as the unifying context
  - Systems-engineering emphasis
  - Mix of high-level and technical talks

- Two days
  - Day 1 more plenary talks, virtual poster session
  - Day 2 more workshop/discussions
  - Abstract portal is open:
    - http://lsic.jhuapl.edu/Events/102.php?id=102

- Workshop topics/brainstorming
  - Many parallel topics for smaller group sizes