High Frontier: The First Asteroid Excavation Mission

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Presented by: Daynan Crull
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Colorado School of Mines: Space Resources Roundtable June 2024

Image credit: NASA

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Denver-based

18 engineers, scientists, analysts, builders, tinkerers, and of course…space nerds.

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Karman+: To mine Near-Earth Asteroids (NEAs) to provide abundant, sustainable energy and resources for the space economy.

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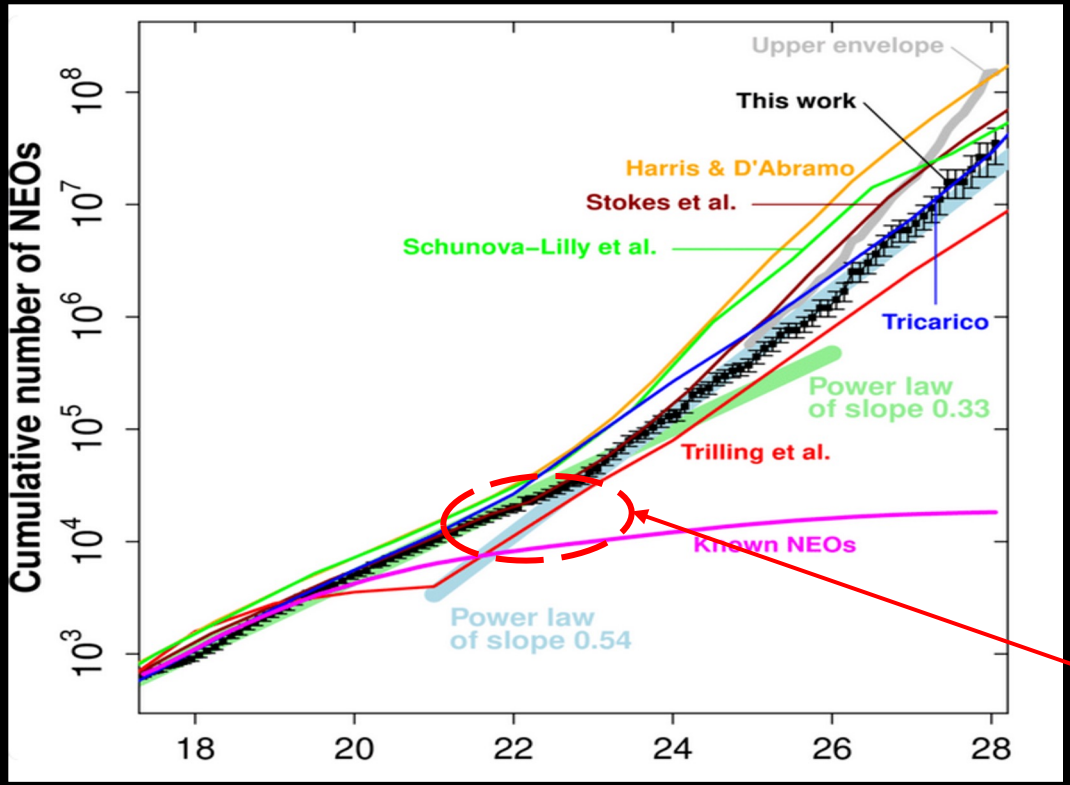
Asteroid regolith will enable economic activity in orbit with accessible resources at **scale**.



Many thousands of NEAs in our sweet spot of ~200m diameter yet to be discovered.

Source: [1]

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Asteroid regolith will enable economic activity in orbit with **accessible** resources at scale.

Population	Total number	Estimated number of Ch asteroids in population
NEOs >1 km	886 (known)	53 ± 27
NEOs >1 km, Δv < Moon	270 (S-H)	16 ± 8 (S-H)
	310 (TB)	19 ± 9 (TB)
NEOs >100 m, Δv < Moon	4487 (S-H)	269 ± 135 (S-H)
	~6000 (TB)	~360 ± 180 (TB)
All NEOs with Δv < Moon	11,785 (S-H)	700 ± 350 (S-H)
NEOs >100 m, $\Delta v \leq$ Bennu	78 (S-H)	~5–6 (S-H)
	58 (TB)	~2–5 (TB)

Source: [16]

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Karman+ technical focus

Deep Space Missions

Robotic, low-cost and reliable

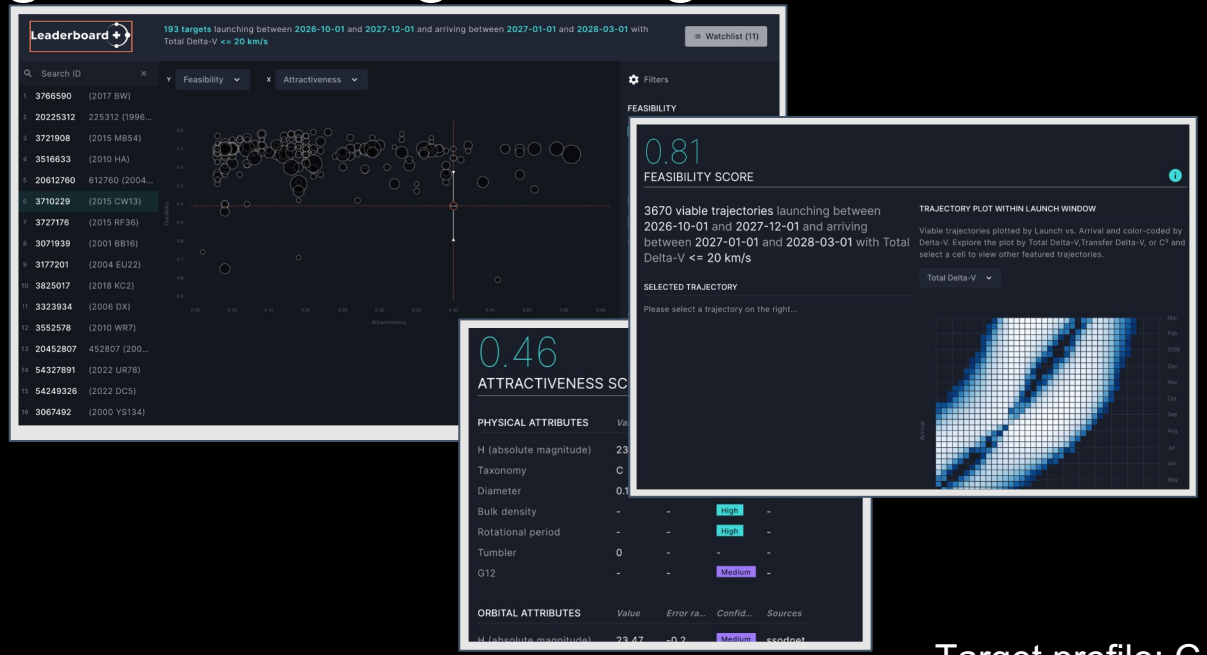
Mining in Microgravity

Excavating regolith

Asteroid ISRU

Extracting and processing regolith at the asteroid

Building a bridge to the Regolith Age



0. Exploration

Establish company, team, technical focus, approach, feasibility analysis

Exit criteria: Critical path established, K+1 Mission defined (High Frontier)

Target profile: C-type rubble pile NEAs

Building a bridge to the Regolith Age

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Establish company, team, technical focus, approach, feasibility

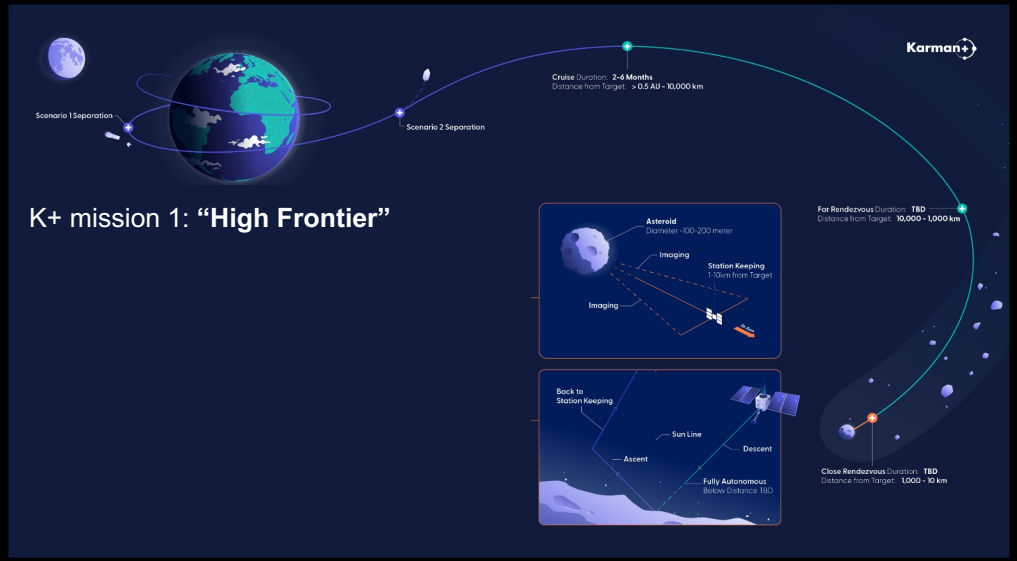
COMPLETED

Exit criteria: Critical path established, K+1 Mission defined (High Frontier)

1. TAG

Multiple small s/c missions for mass return to cislunar.

Exit criteria:
Master/scale (1) Deep Space and (2) Mining in zero-G
$/kg trend to $10,000



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Building a bridge to the Regolith Age

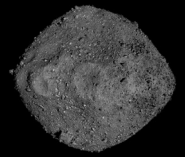

Image credit: NASA

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IN PROGRESS

Master/scale (1) Deep Space and (2) Mining in zero-G

$/kg trend to $10,000

2. Mine & Tug

Processing at asteroid, including s/c components.

Exit criteria:
Master/scale (3) ISRU w/ advanced regolith products.
$/kg trend to $100

Building a bridge to the Regolith Age

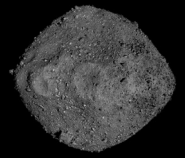

Image credit: NASA

SBSP Image credit: Karman+

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Exit criteria: Master/scale (3) ISRU w/ advanced regolith products. **$/kg trend to $100**

3. Whole buffalo

Use and move entire asteroids to build massive structures.

Exit criteria: Transformative, including heavy manufacturing and energy (SBSP). **$/kg trend to $0.01**

Building a bridge to the Regolith Age

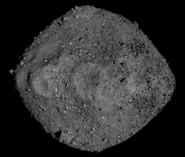

Image credit: NASA

SBSP Image credit: Karman+

Image credit: Amazon Studios

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Use and move entire asteroids to build massive structures.

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4. Expanse

Move Earth-centric operations to asteroids, including main belt.

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Cruise Duration: **2-6 Months**
Distance from Target: **> 0.5 AU - 10,000 km**

Far Rendezvous Duration: **TBD**
Distance from Target: **10,000 - 1,000 km**

Close Rendezvous Duration: **TBD**
Distance from Target: **1,000 - 10 km**

K+ mission 1: **“High Frontier”**

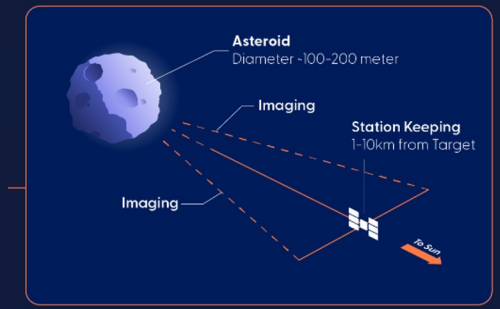
~~Tech~~ Capability demo mission

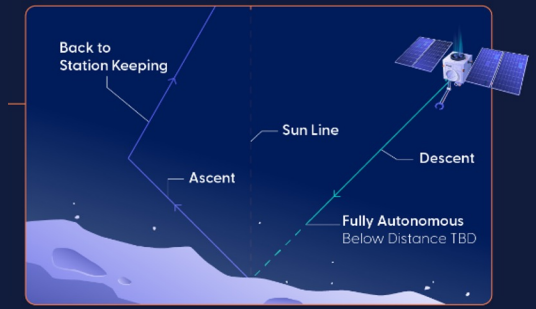
4Q 2026 launch → Mission complete in 2027
$20-30 million

Mission objectives:

1. Rendezvous with near-Earth Asteroid
2. Capture sample from surface at kg-scale
3. Transmit data confirm sample capture

Extended mission objective:
Multiple attempts to land on surface and test excavation and performance and autonomous operations





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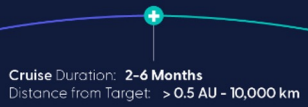

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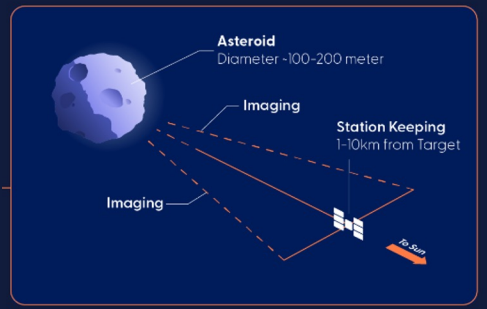
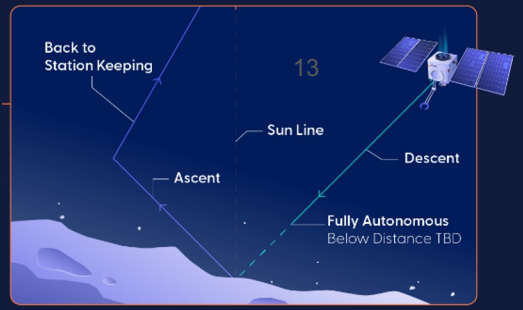
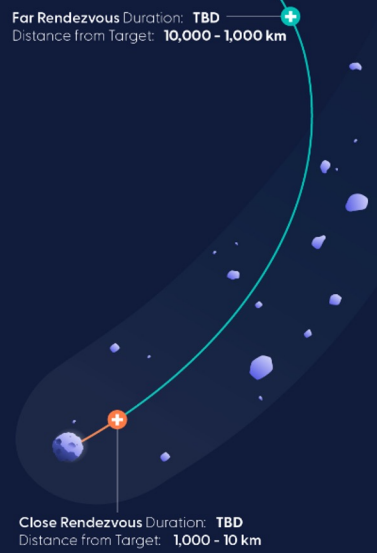
Deep Space Missions

Future state: TAG at scale:

- Fully Autonomous Missions
- Little/no reliance on ground
- Minimal pre-mission asteroid data
- Low-cost missions







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Deep Space Missions

High Frontier:

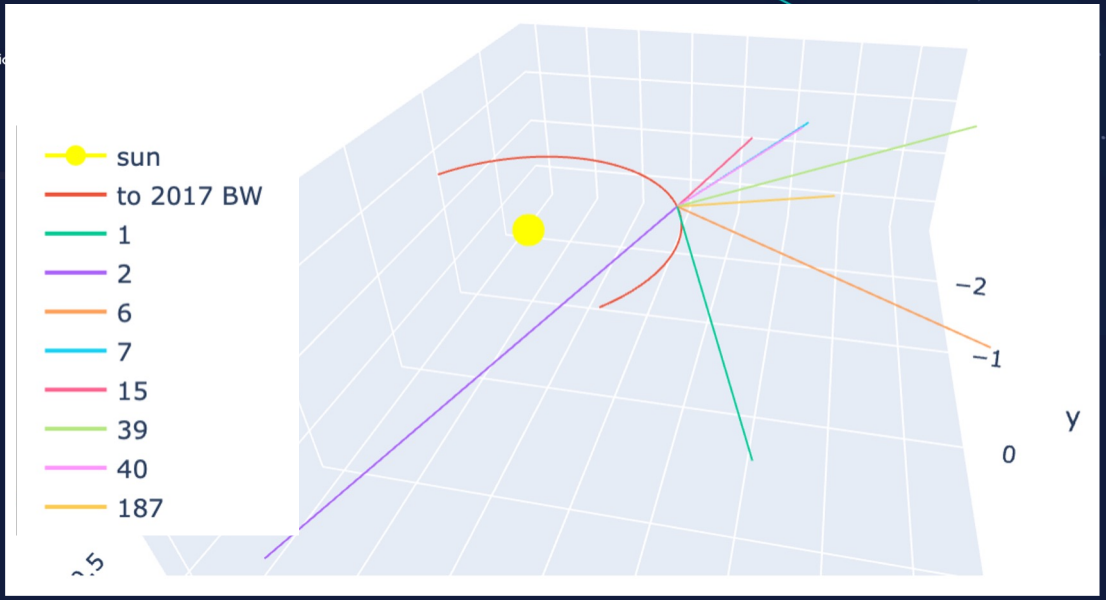
Mission design and target selection: probabilistic thinking and custom decision engine (“compono”).

- More options -> less risk
- Iterate through design quickly
- Can develop generalizable mission architecture

Deep Space Missions

High Frontier:

Beacon nav [7,11] during cruise: reduce reliance on ground/radiometric tracking



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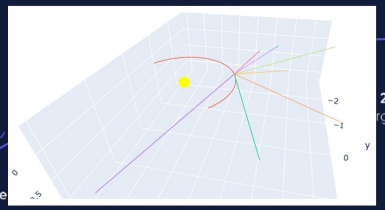
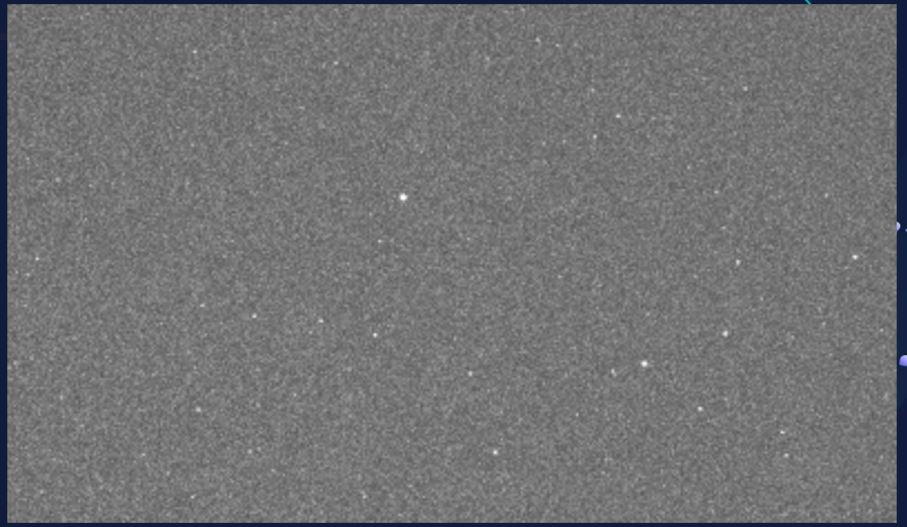


2-6 Months
rget: > 0.5 AU - 10,000 km

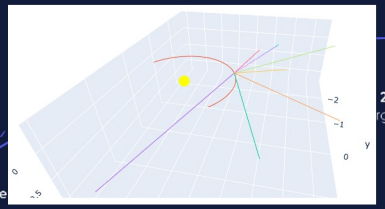
Deep Space Missions



High Frontier:

COTS + approach:

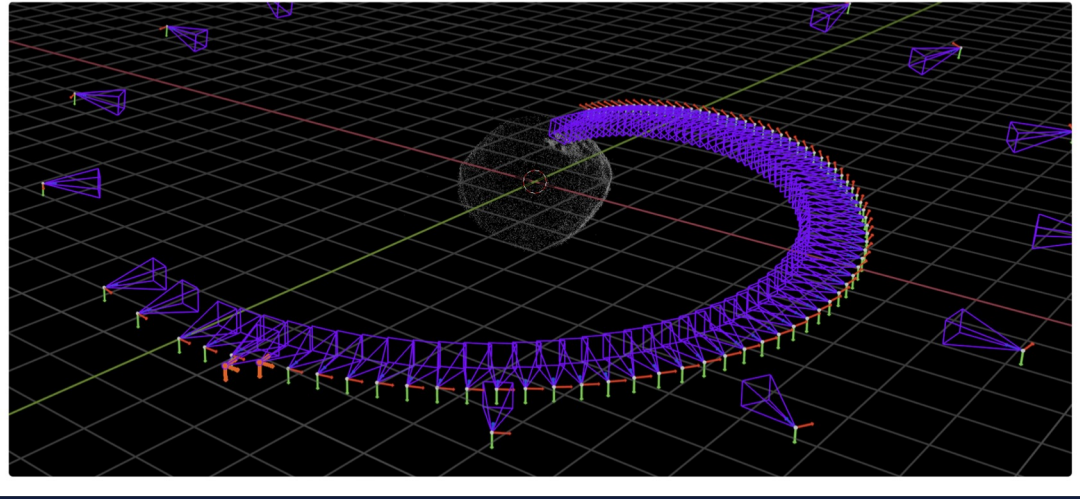
- Radical diligence (test everything mindset)
- Identify performance capability and all paths to t
  (e.g. beacon sig processing at right)



Deep Space Missions

High Frontier:

Simultaneous Location And Mapping (SLAM)
for surface descent, TAG maneuver and method development w/ open source tools like Blender [12,13,14]



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Mining in Microgravity

Future state: TAG at scale:

- Scalable (1000s kgs)
- Robust to varied and unknown surface conditions
- Extreme field conditions (temp, micrograv)
- Rapid TRL advancement

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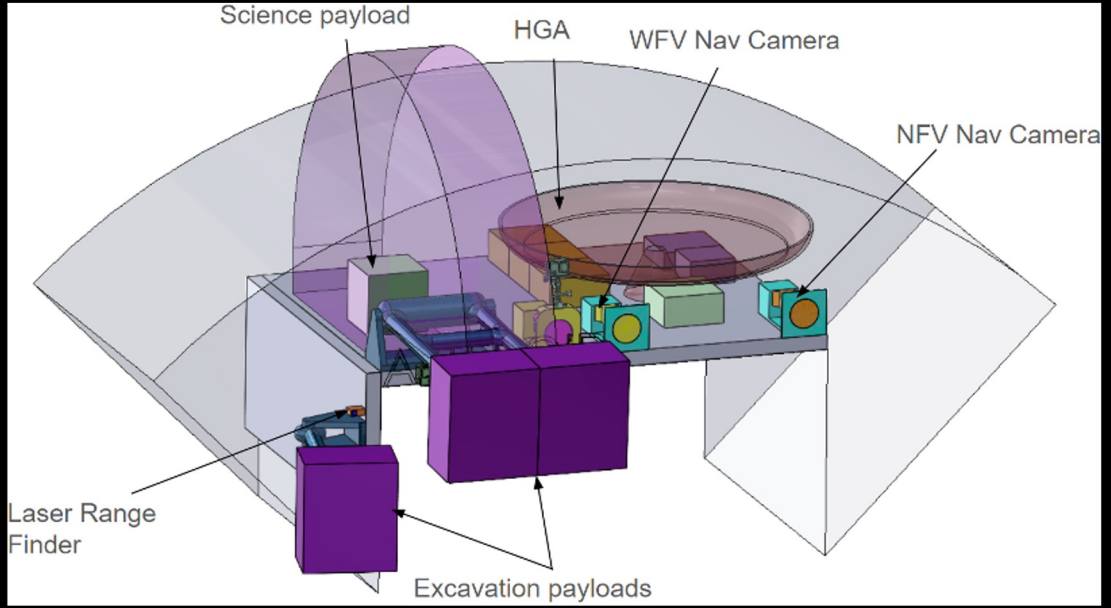
Mining in Microgravity

High Frontier:

Isolating our R&D: working w/ bus provider for integrated platform, our focus is the deployable excavation assemble.



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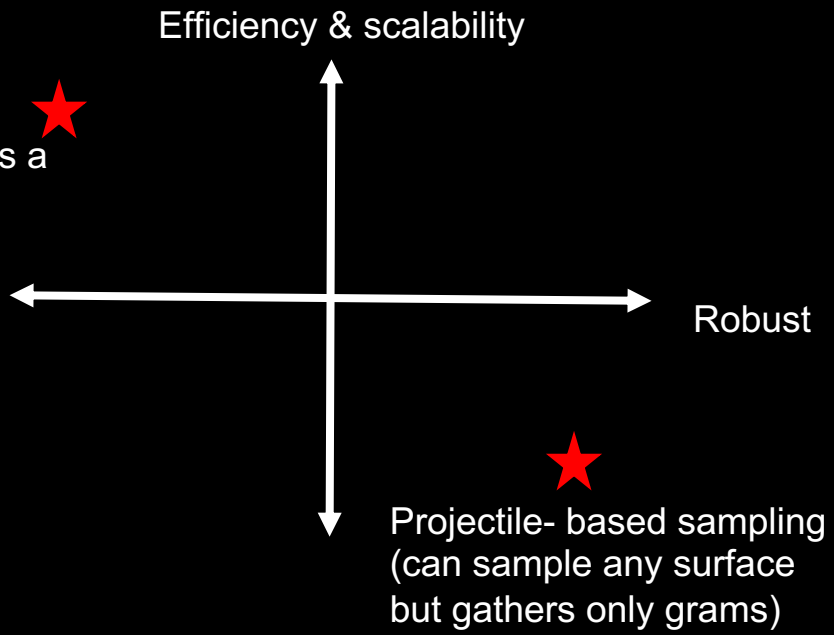
Mining in Microgravity

High Frontier:

Balance of robustness vs efficiency/scalability.

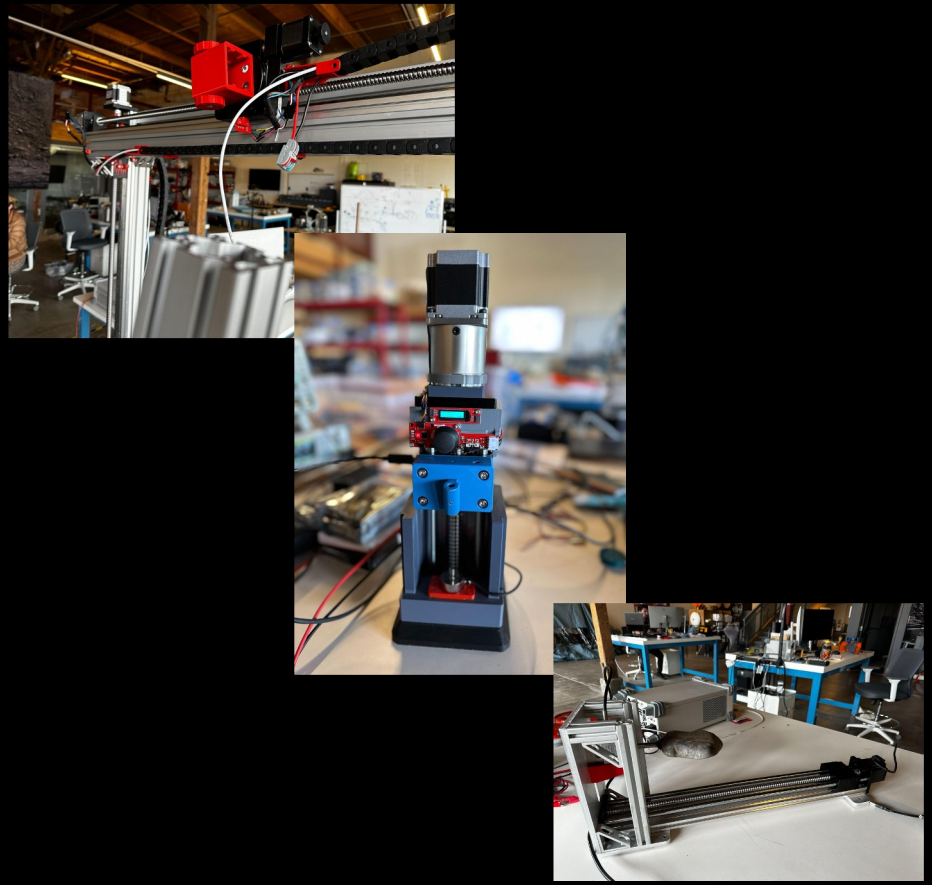


Mining in Microgravity

High Frontier:

Testing:

- Novel test suite
- Blend sims w/ physical tests
- Approx to microgravity
- Little known granular dynamics
- LIttle known regolith strength
- Little known regolith composition



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Asteroid ISRU

Future state: TAG at scale:

- Demo regolith product
- Early R&D on space-based extraction, refinement
- Simultaneous prospecting / excavation (emphasis on sample!)

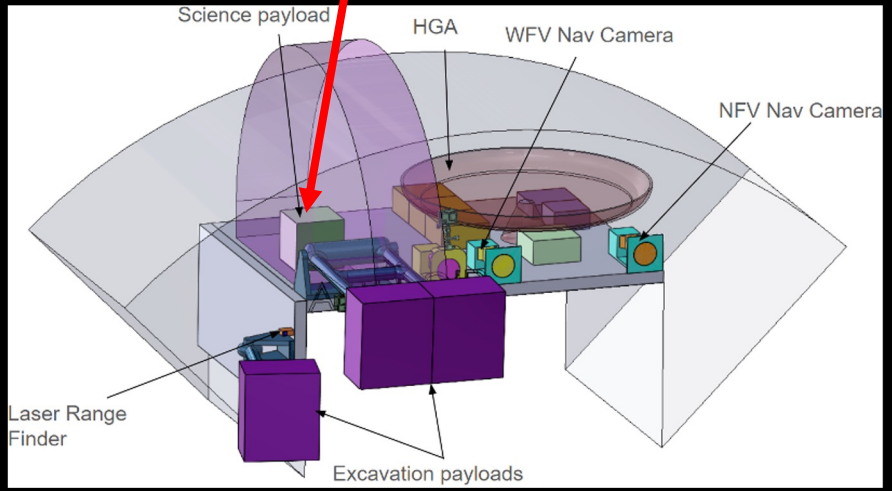
Asteroid ISRU

High Frontier:

Issued an RFP for science instrumentation.

HF science payload: Surface Dielectric Analyzer. (Pof. Hideaki Miyamoto)

東京大学
THE UNIVERSITY OF TOKYO

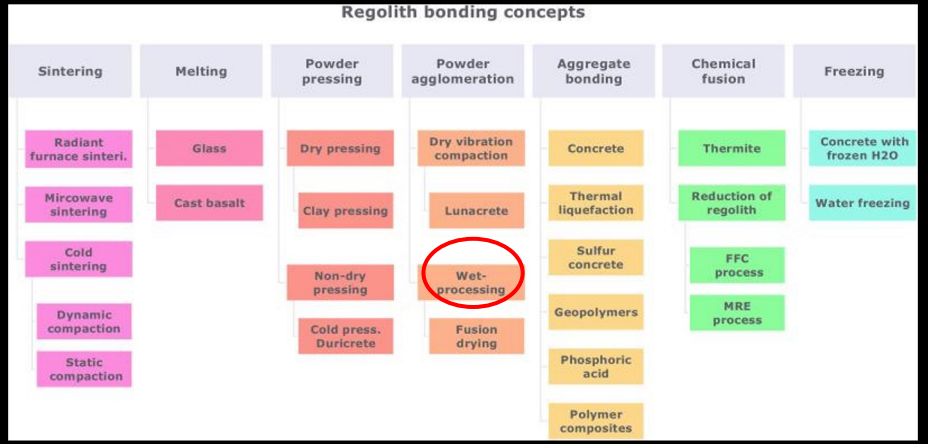


Asteroid ISRU

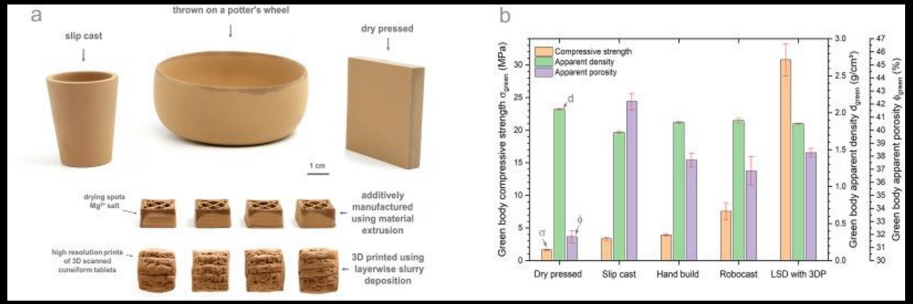
High Frontier:

Initial research: Wet processing using tempered smectite clay such as phyllosilicate material found in Ryugu sample:

- Water extraction
- Feedstock for Additive Manufacturing via methods such as material extrusion



Source: [15]

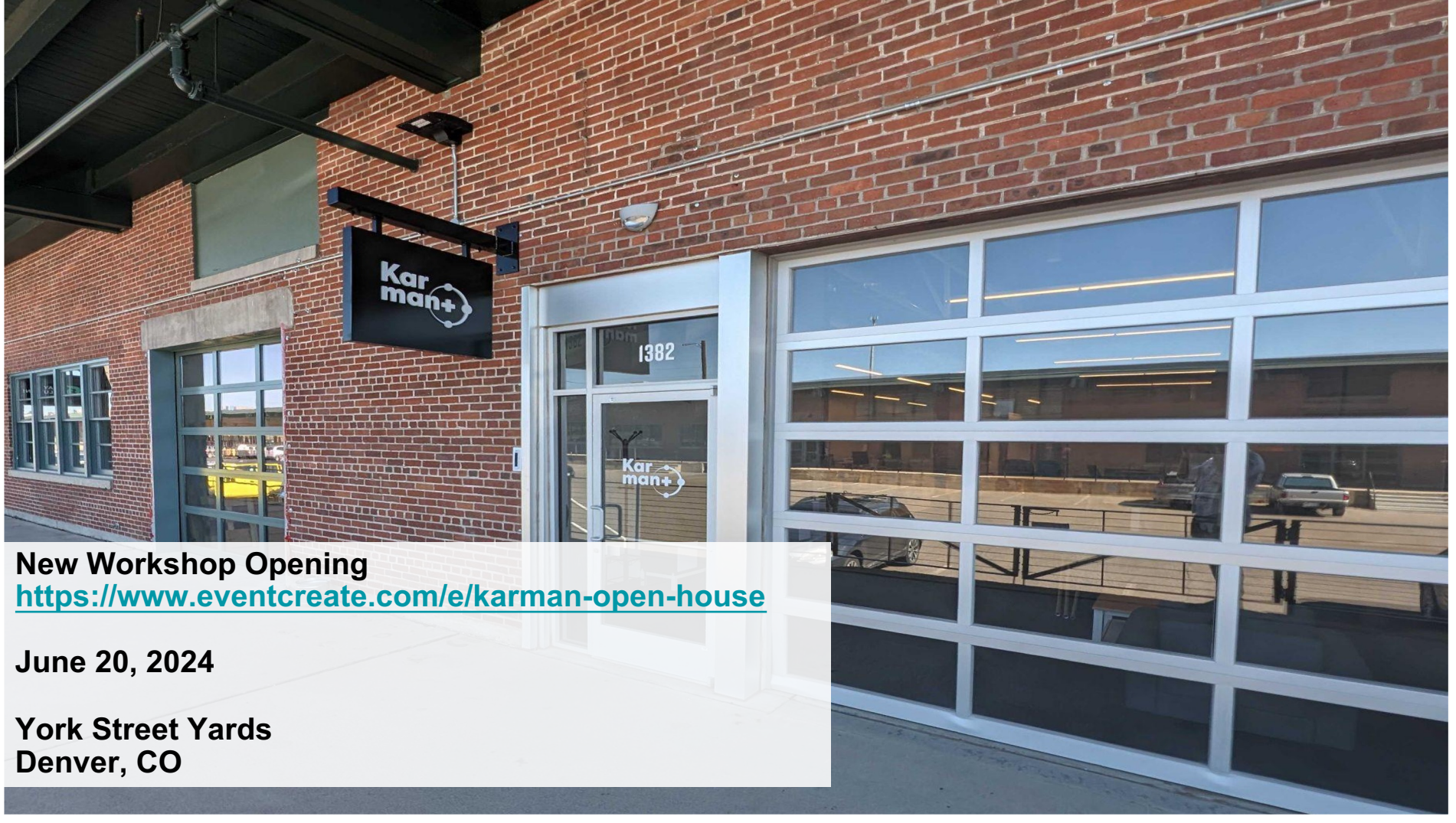


Source: [15]

Call to action

- Register for updates on the website: https://www.karmanplus.com/k-company-update-q1-2024/

- Open to partnerships / collaboration on the focus areas:
  - Deep space
  - Mining in microgravity
  - Asteroid-based ISRU



New Workshop Opening
https://www.eventcreate.com/e/karman-open-house

June 20, 2024

York Street Yards
Denver, CO

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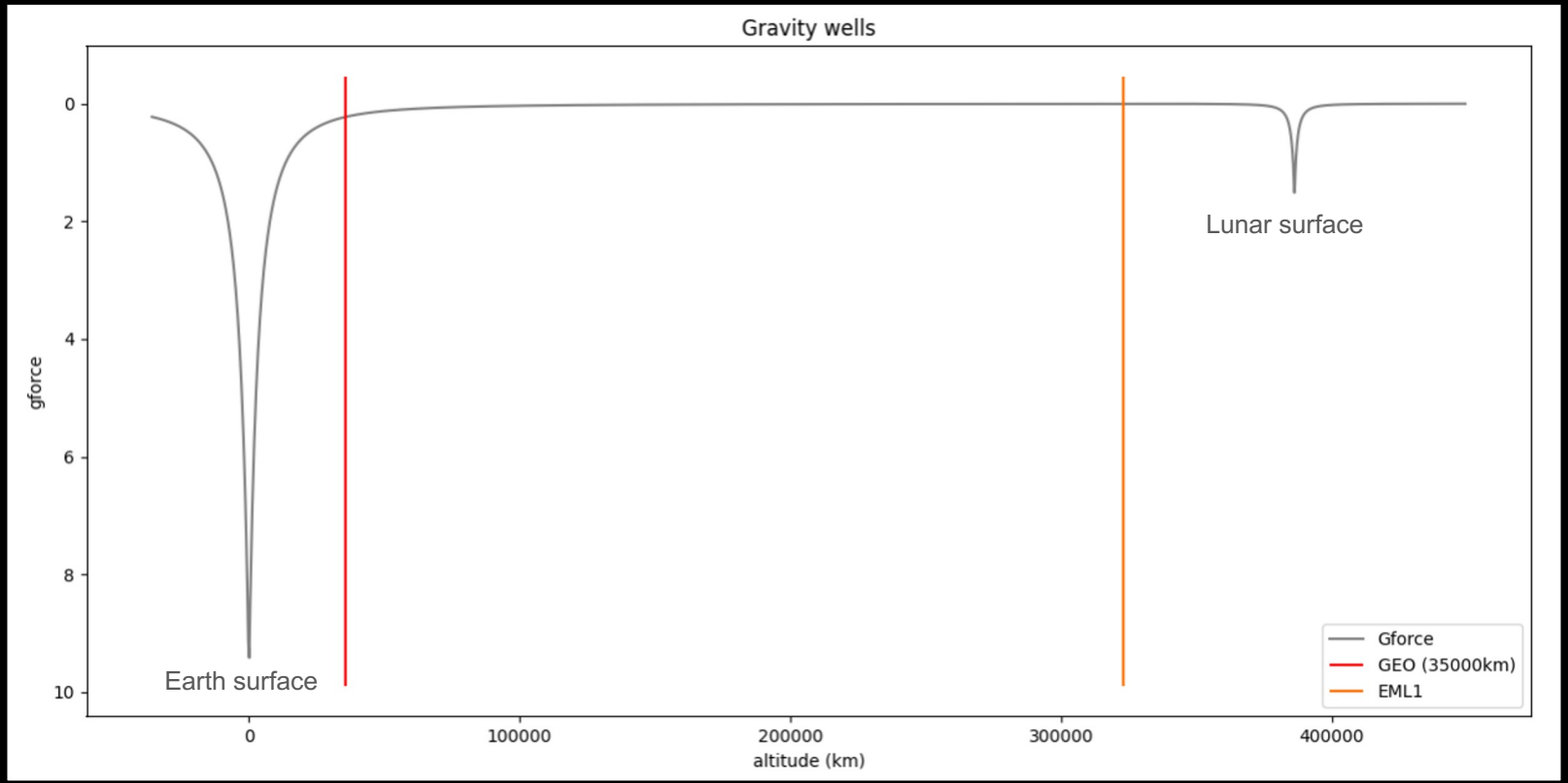

Missions that inspire and guide us

Asteroid missions:

- Hayabusa/Hayabusa2 (TAG sample) [2,3]
- OSIRIS-REx (OpNav, TAG sample) [4]
- Janus (survey + lessons learned) [5]
- DART (“interaction”) [6]

Deep Space Missions:

- Deep Space 1 (tech demo + autonomous nav) [7]
- SMART-1 (spiral out maneuver) [8]
- Psyche (SEP, Deep Space Op Comms) [9]

Low-Cost:

- Chandrayaan-3 [10]
- Many missions planned/ in progress

Hayabusa2 capsule returns to Earth w/ Ryugu sample.
Img credit: JAXA

Bennu capsule.
Img credit: NASA

DART debris field.
Img credit: NASA