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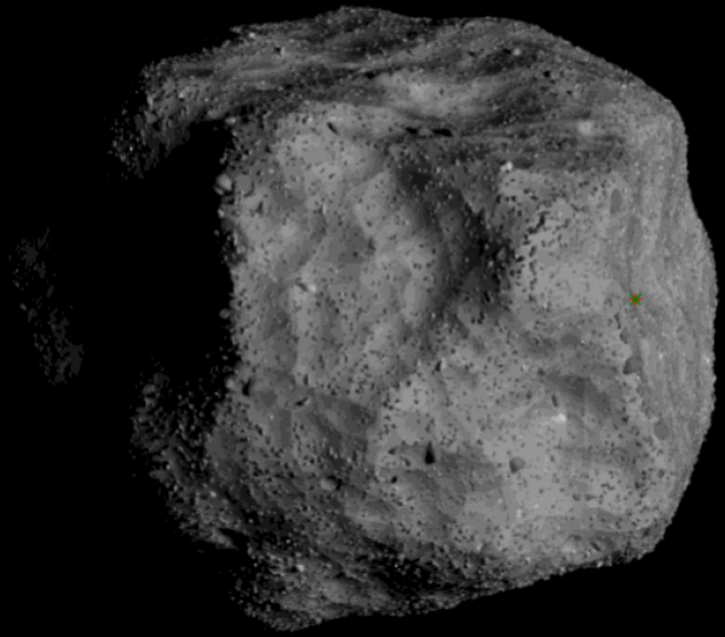
High Frontier: Roadmap to the Regolith Age



CO Mines SRR XXV
June 5, 2025
Daynan Crull, Cofounder and mission architect

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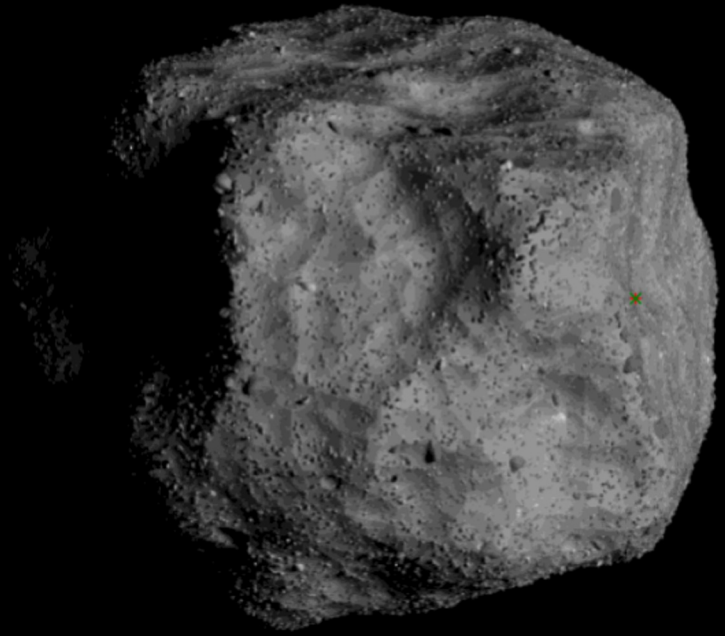
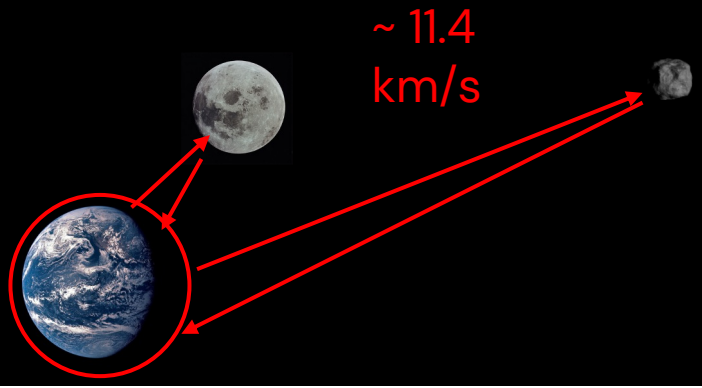
To mine Near-Earth Asteroids (NEAs) to provide abundant, sustainable energy and resources for the space economy.



https://www.karmanplus.com/about/

Asteroids for abundant, accessible water in space

2019 study: ~6000 of 100m diam+ NEAs requiring less delta-V than lunar surface. [1]



1. Rivkin, Andrew S., and Francesca E. DeMeo. "How many hydrated NEOs are there?." Journal of Geophysical Research: Planets 124, no. 1 (2019): 128-142.

Asteroids for abundant, accessible water in space

2018 (study data):

- **18,000** NEOs
- **6000** >100m, **Δv** < moon
  - **360 Ch***

*Based on 6% observed Ch type, but solar system rate is 17%, which suggest observation bias and actual Ch could be closer to 17%

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Asteroids for abundant, accessible water in space

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- 18,000 NEOs
- 6000 >100m, Δv < moon
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2025 projection (2x):
- **38,000** NEOs
- ***12000*** >100m, **Δv** < moon ?
  - ***720 Ch?***

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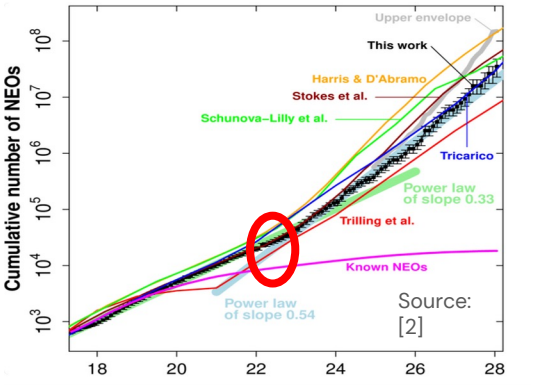
Asteroids for abundant, accessible water in space

2018 (study data):
- 18,000 NEOs
- 6000 >100m, Δv < moon
- 360 Ch*

2025 projection (2x):
- 38,000 NEOs
- *12000* >100m, Δv < moon ?
  - *720 Ch?*

2035 (10x):
- 380,000? NEOs
- 120,000? >100m, Δv < moon
- 7200 Ch?



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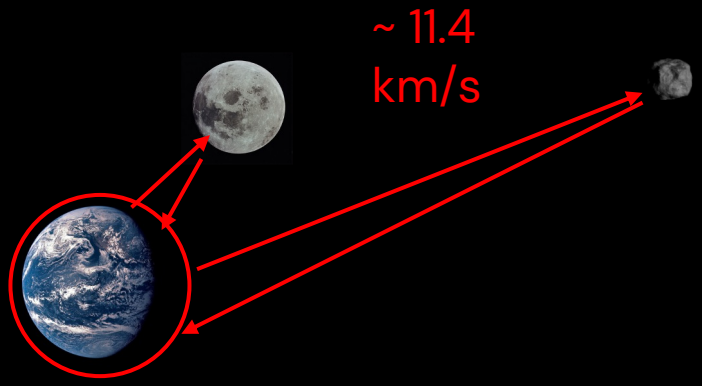
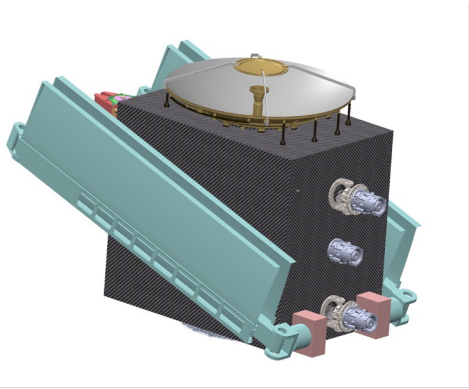
2. Heinze, A. N., Larry Denneau, John L. Tonry, Steven J. Smartt, Nicolas Erasmus, Alan Fitzsimmons, James E. Robinson et al. "NEO population, velocity bias, and impact risk from an ATLAS analysis." The Planetary Science Journal 2, no. 1 (2021): 12.

Asteroids for abundant, accessible water in space

Reachable hydrated asteroids:

- 720 Ch asteroids (current catalog)
- 7,200 in next 10 yrs?





High Frontier:

- 13+ km/s with SEP system
- < $20 million per mission
- Future mission kick stage: GTO -> NEA -> LEO (more delta-V allocated to cruise)

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High Frontier: asteroid excavation mission

Mission objectives:

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

$20 million budget (s/c development, ops, launch)

Img: SpaceX

High Frontier: asteroid excavation mission

Launch (booked)**:**

- **Feb/Mar 2027**
- **SpaceX Transporter-19** (SSO rideshare)

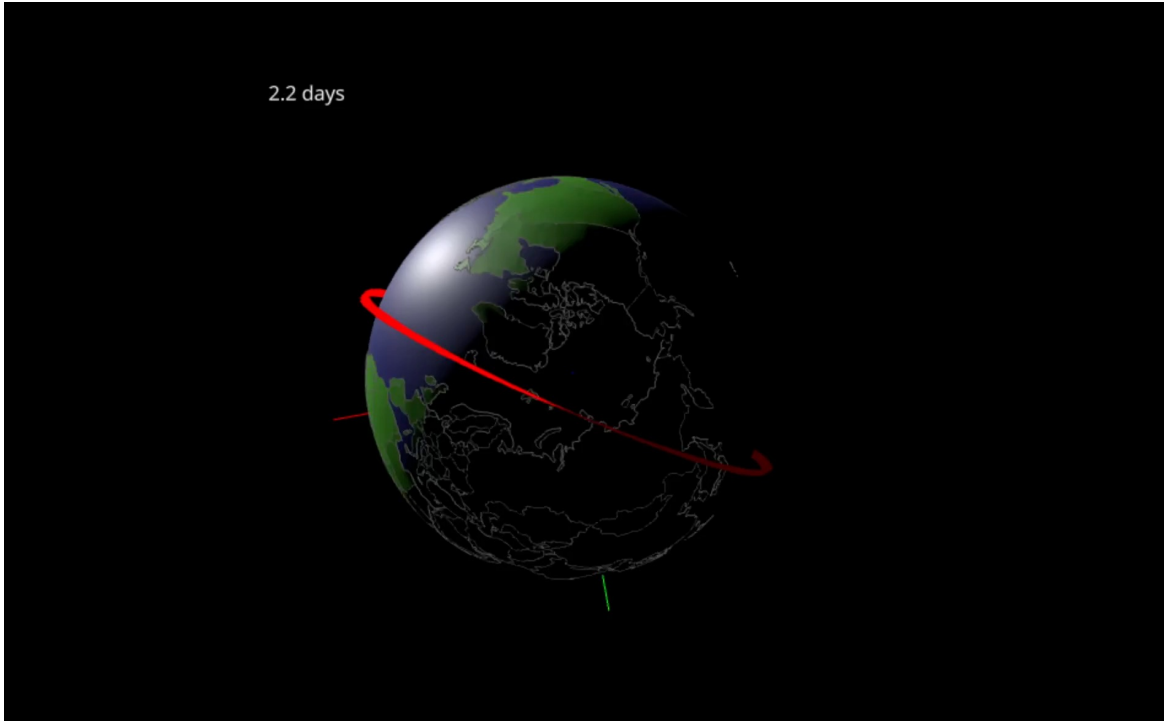
Earth Phase:

- **SSO to heliocentric** (i.e. Earth escape, c3=0)
- **7.5 months** (80% duty cycle w/ 3 SEP thrusters)

Interplanetary Cruise:

- Several months based on target
- Thrust + Coast (beacon nav, comms point)

Target Acquisition / Rendezvous (days)



Above: Simulation of s/c “spiral out” orbit raise to Earth escape. (K. Anderson/K+)

High Frontier: asteroid excavation mission

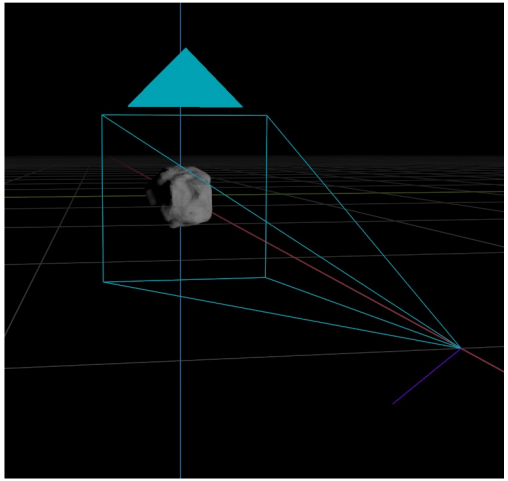
Asteroid survey:
- A few weeks
- Stationkeeping (range of ~ 1km)
- Choose TAG site

Descent
- Simultaneous Localization and Mapping (SLAM)

Touch-And-Go
- 30 seconds of contact
- Selected excavation head (1 of 2) deployed (testing of "pokeball" pictured right)
- kgs of regolith captured and contained aboard

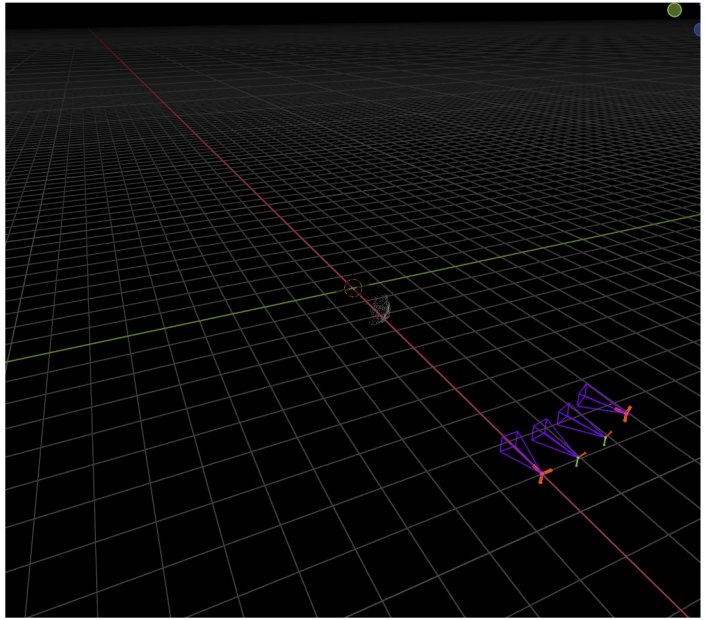
Sample analysis / data downlink
- Mass + science data (U Tokyo dielectric analyzer)

Extended mission / end of life:
- Repeated TAG attempts until loss (at asteroid)

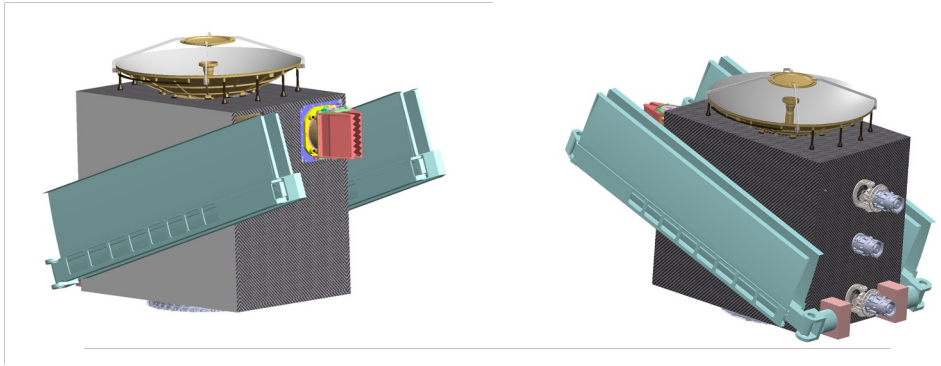


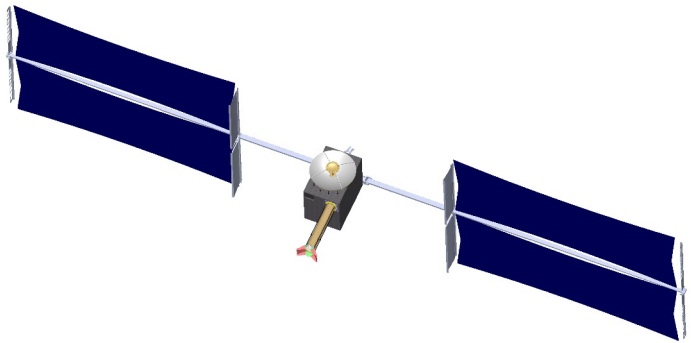
Above: Simulation of asteroid survey from stand-off orbit (K. Anderson/K+)

Below: Simulation of s/c descent using Simultaneous Location And Mapping method (K. Anderson/K+)



HF highlight #1: Pivot from payload to full s/c





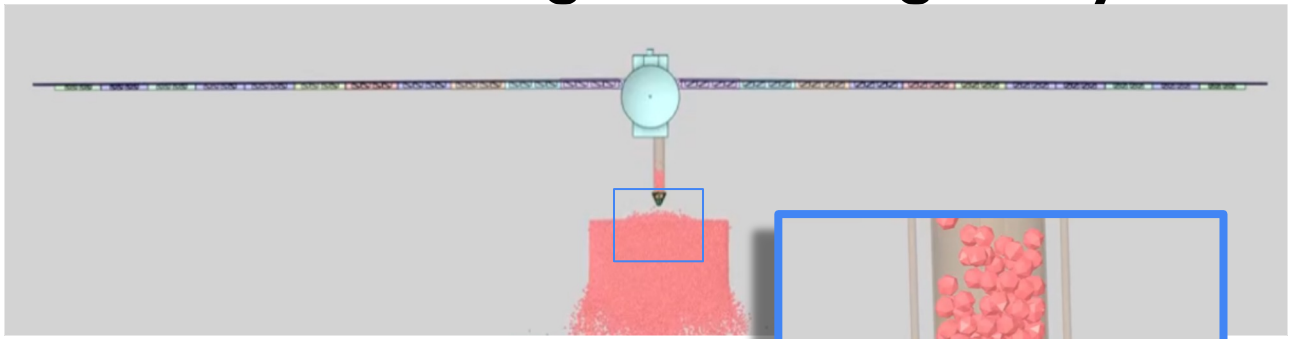
Above: S/C design concepts (K+)

80% of High Frontier is being designed, built, and tested in-house. Including:

- Thruster gimbals
- Deep Space comms system (co-developed)
- Nav cameras (COTS+)
- Flight computer (COTS+)
- Solar assembly
- < 650 kg wet mass, fits in F9 XL plate

HF highlight #2: Excavation testing for microgravity

Above: "Orbees" multi-media test bed (L. Bowersox, J. Daughtry/K+)



Above: Simulation of excavation in microgravity (J. Daughtry/K+)

Emphasize hardware: creative physical tests of granular dynamics (left)

Calibrate sims with physical tests (above/right)

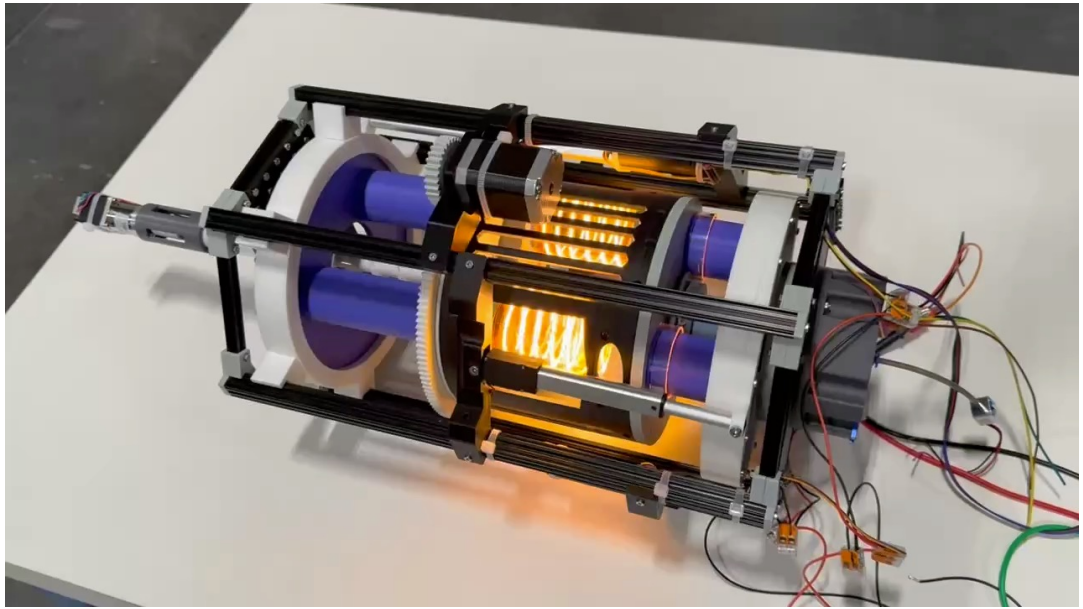
Extrapolate microgravity sim to explore: excavation velocity, boom compliance, s/c flex, etc.

High Frontier 2: water extraction in-situ, deliver to customer

HF2 mining ConOps:

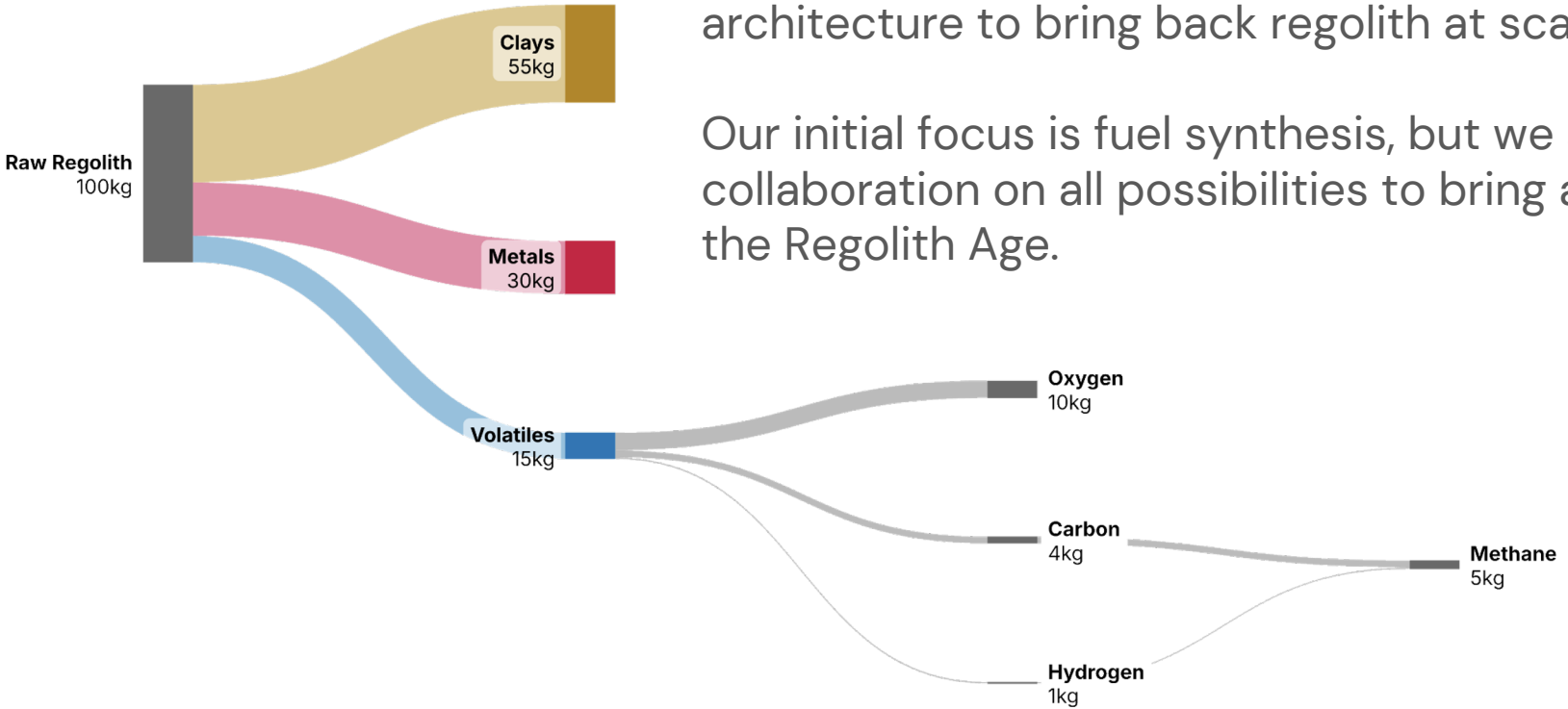
1. Extraction (100 kg)
2. Conveyance
3. Grinding
4. Sublimation (right)
5. Purification
6. Transport and delivery

See our booth tonight for actual hardware demo!



Above: Hardware prototype of water sublimation chamber (S. Hallam/K+)

High Frontier 3,4… “the whole buffalo”



We are developing a s/c + mission architecture to bring back regolith at scale.

Our initial focus is fuel synthesis, but we seek collaboration on all possibilities to bring about the Regolith Age.

Work with us

~ 25 full time engineers on-site in Broomfield, CO

karmanplus.com/jobs

Environmental testing? We're leasing equipment.

Regolith simulant? See our booth tonight.