



NASA Break the Ice Challenge Outpost Digger System

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COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT



Lunar Outpost™

What are Space Resources?



Photons

Minerals

Volatiles

Regolith

Volatiles
Water, Carbon Dioxide

Location

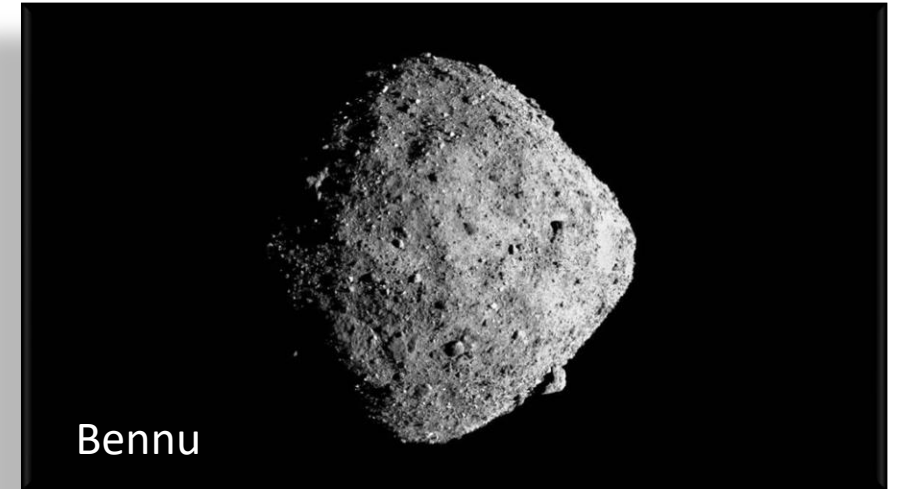
Microgravity
Vacuum
Location

Hydrated Minerals
Metals
Minerals
Ices

Water Ice
Carbon Dioxide
Regolith
Hydrated Minerals

Water Resources of the Inner Solar System

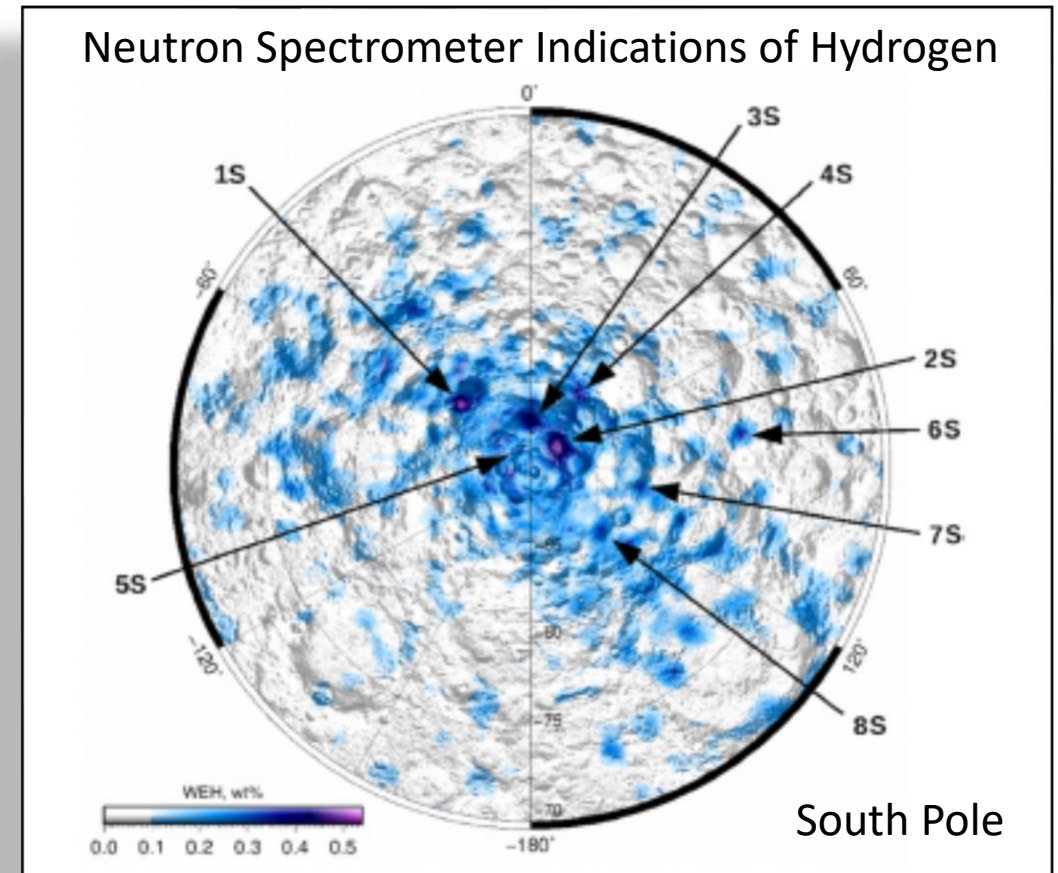
- Water is ubiquitous in the inner solar system
 - Poles of Mercury, Mars, Near Earth Asteroids (NEAs)
 - Poles of the Moon
- Water is essential for life, contains O_2 for breathing air and is excellent radiation shielding
- Water can be split into O_2 and H_2 then liquified into LO_2/LH_2 propellants
- Water can be used directly as propellant
 - Steam ($I_{sp} \sim 200s$)
 - Plasma ($I_{sp} \sim 1000s$)



Water is the oil of space

Water on the Moon

- Water exists in the Permanently Shadowed Regions (PSRs) near the Poles of the Moon
 - Low obliquity of the Moon results in constant grazing sunlight at the poles
 - Water vapor (& other volatiles) from comet and asteroid impacts becomes cold trapped in the PSRs
- Confirmed by many remote sensing data sets
- Directly confirmed by 2009 LCROSS mission
 - Impact within Cabeus Crater
 - 5.6 ± 1.9 wt% ice in ejecta plume



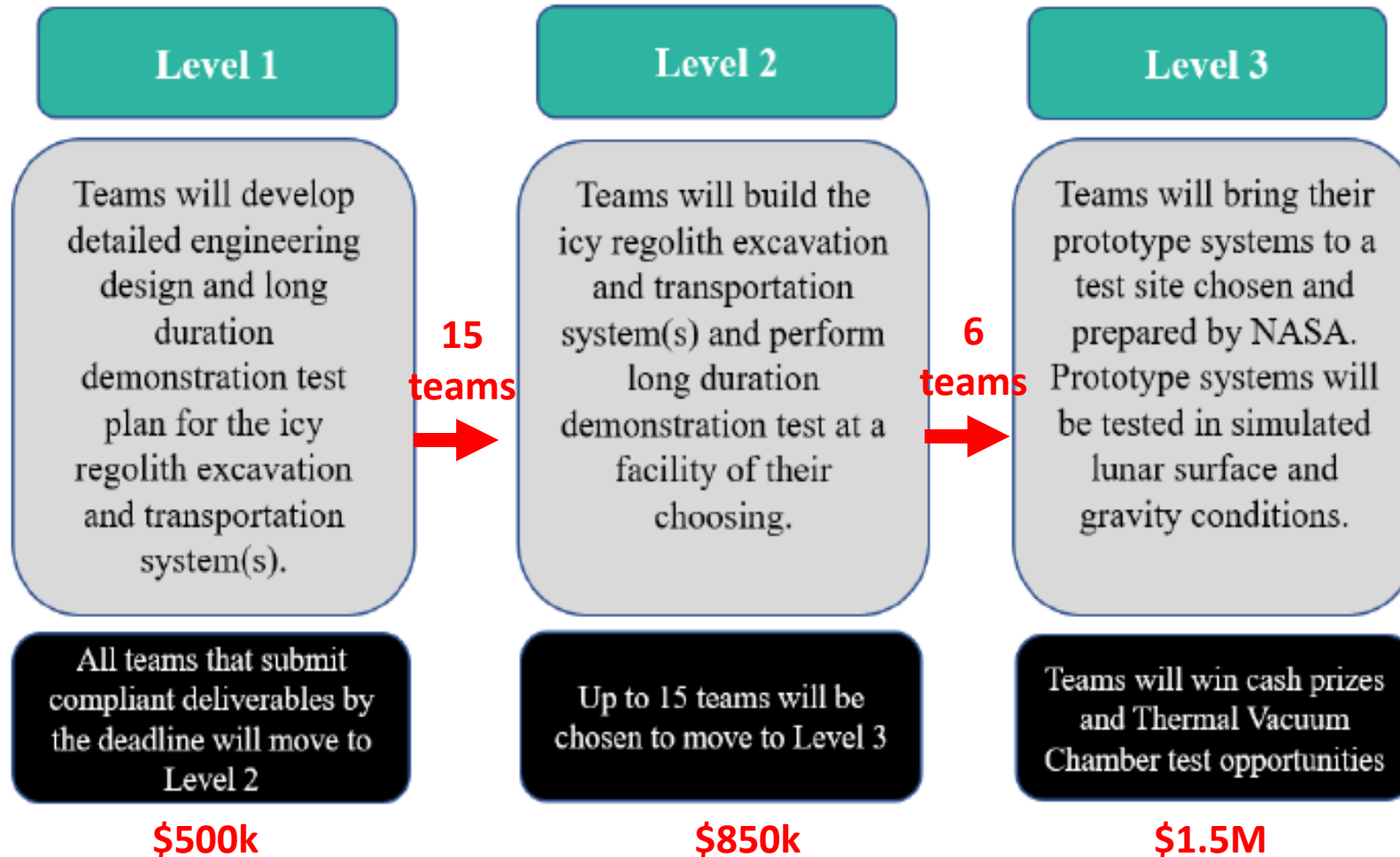
Sanin AB, et al. (2017) Hydrogen distribution in the lunar polar regions. *Icarus* 283:20-30.

NASA's Break the Ice Challenge

- Develop technologies to excavate icy regolith and deliver water in lunar environmental conditions
- Phase 1 Completed August 2021
 - Mines team awarded 2nd place (\$75k)
- Phase 2 began June 2022, Divided into 3 “levels”
 - Level 1 completed November 2022
 - 15 teams selected to move to level 2, including Mines/Lunar Outpost (\$38k)
 - Level 2 completed October 2023
 - 6 teams selected to move to level 3, Mines/Lunar Outpost 3rd place (\$125k)
- [Home - NASA's Break the Ice Lunar Challenge \(breaktheicechallenge.com\)](https://breaktheicechallenge.com)

Phase 2

- Phase 2 contains three levels

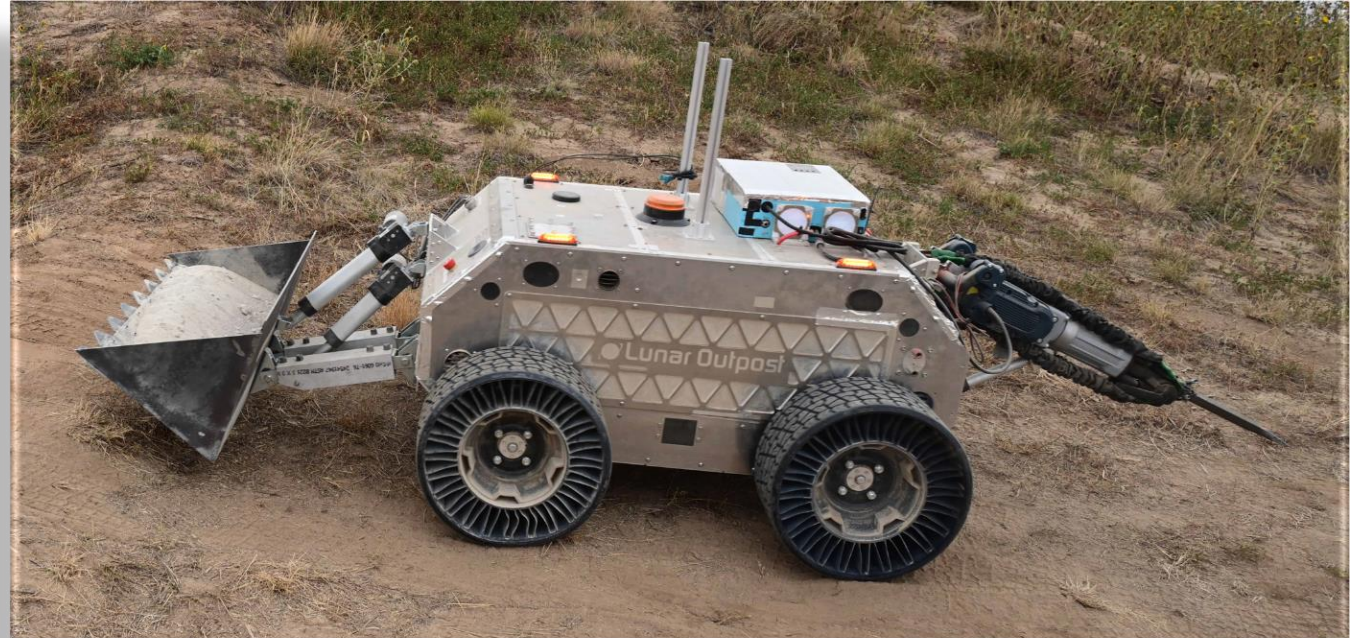


Phase 2, Level 2

- \$850k total prize money
- Culminated in a Durability Demonstration Test
 - 15 days continuous operations
 - Excavate and deliver 12,000kg simulated regolith
 - 800kg per day
 - 500m travel between excavation site and delivery site
 - Live video feed to judges
 - Judges site visit

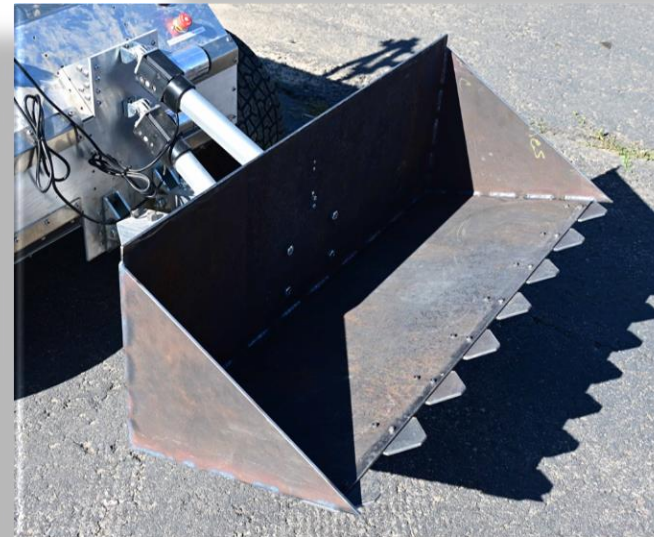
Outpost Digger System, Design Overview

- Two identical excavating rovers
 - Lunar Outpost design & build
 - “Hound” Rover platform
- Teleoperated
- Rechargeable batteries
- Excavation Subsystem (CSM design)
 - Scoop at one end
 - Impact hammer at other end
- Regolith transport via the scoop



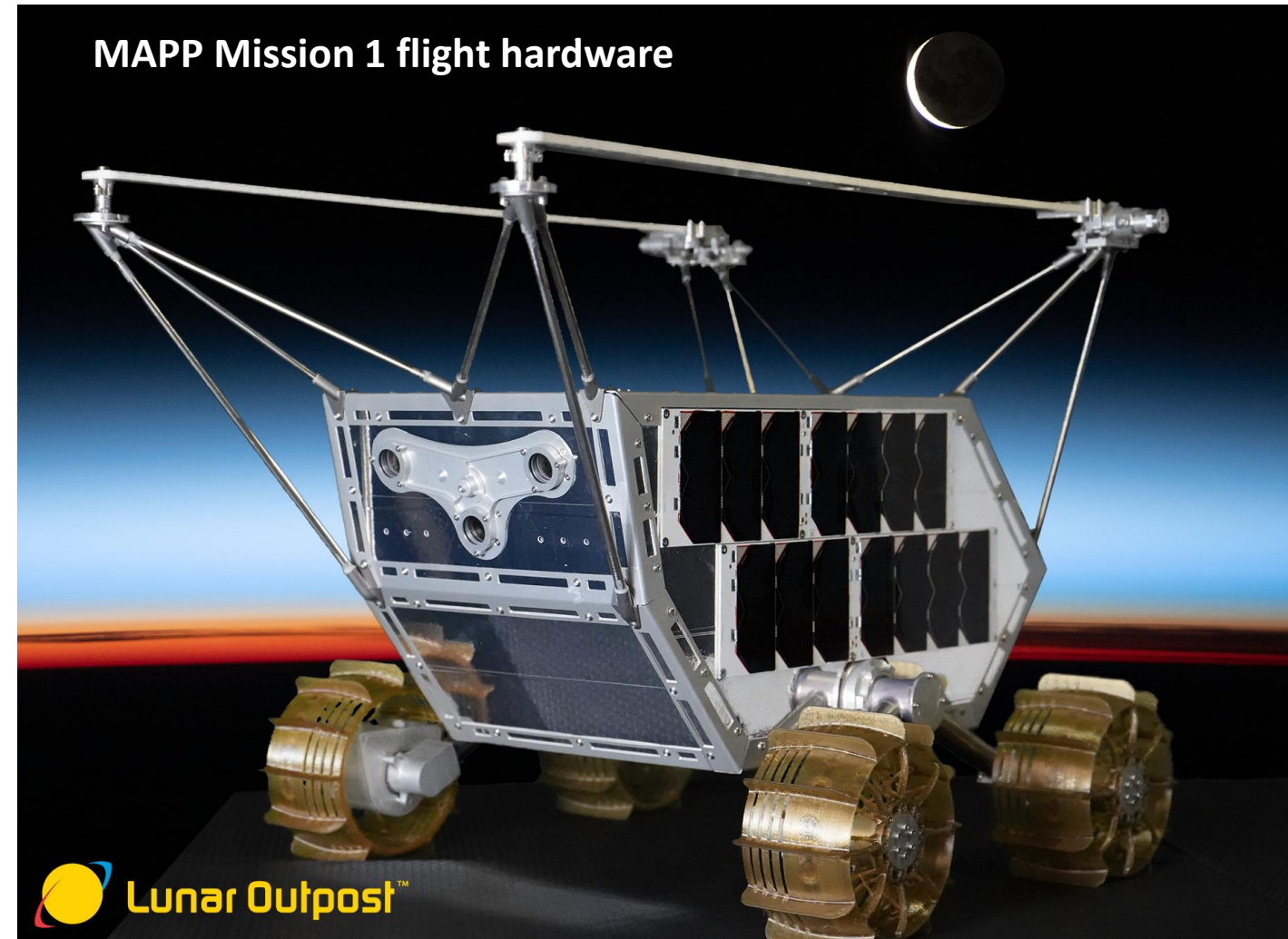
Excavation System

- Impact Hammer
 - Commercial impact hammer (Bosch brand)
 - Rewired to be remotely controllable (on/off)
 - Positioned via a commercial electro-mechanical actuator (raise/lower)
- Scoop
 - Built by Mines machine shop
 - Welded steel
 - Positioned via two commercial electro-mechanical actuators (raise/lower/tilt)



Rover Design Heritage

- Rover design leverages Lunar Outpost Mobile Autonomous Prospecting Platform (MAPP) rover technology
- Two missions scheduled to deploy on the Lunar surface in 2024

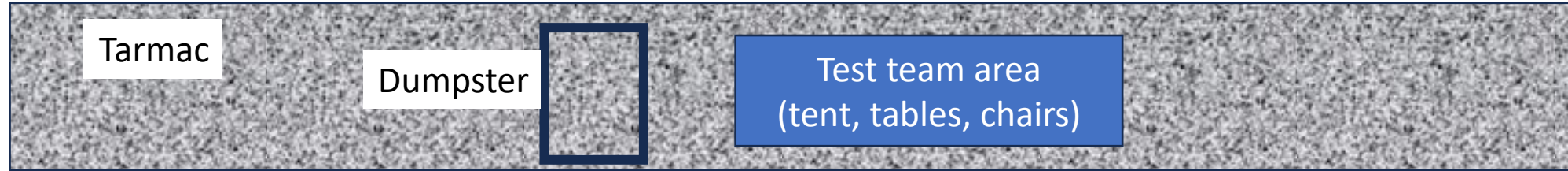


Durability Test Overview

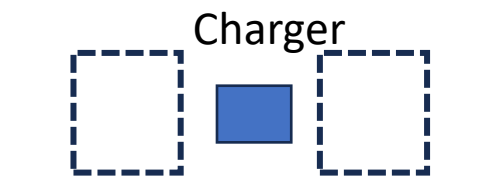
- Conducted at Colorado Air & Space Port
- 6 acre field next to tarmac
- Power augmented
- WiFi installed by Eastern Slope Technologies
- Concrete slab (lunar regolith simulant) poured August 12 by Brannan Concrete
- Testing began September 9, completed September 23



Durability Test Site



● Camera 2



Rover overnight parking

Scale

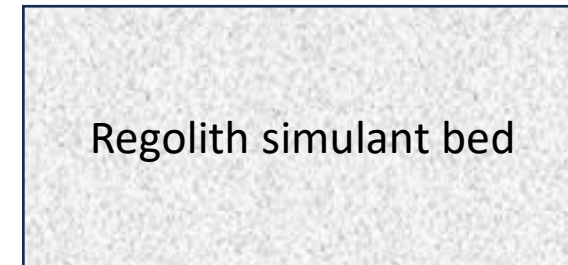


Dump pit & cart



Ramp

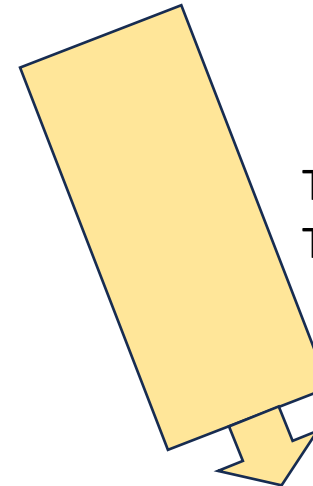
● Camera 1



Transportation Track

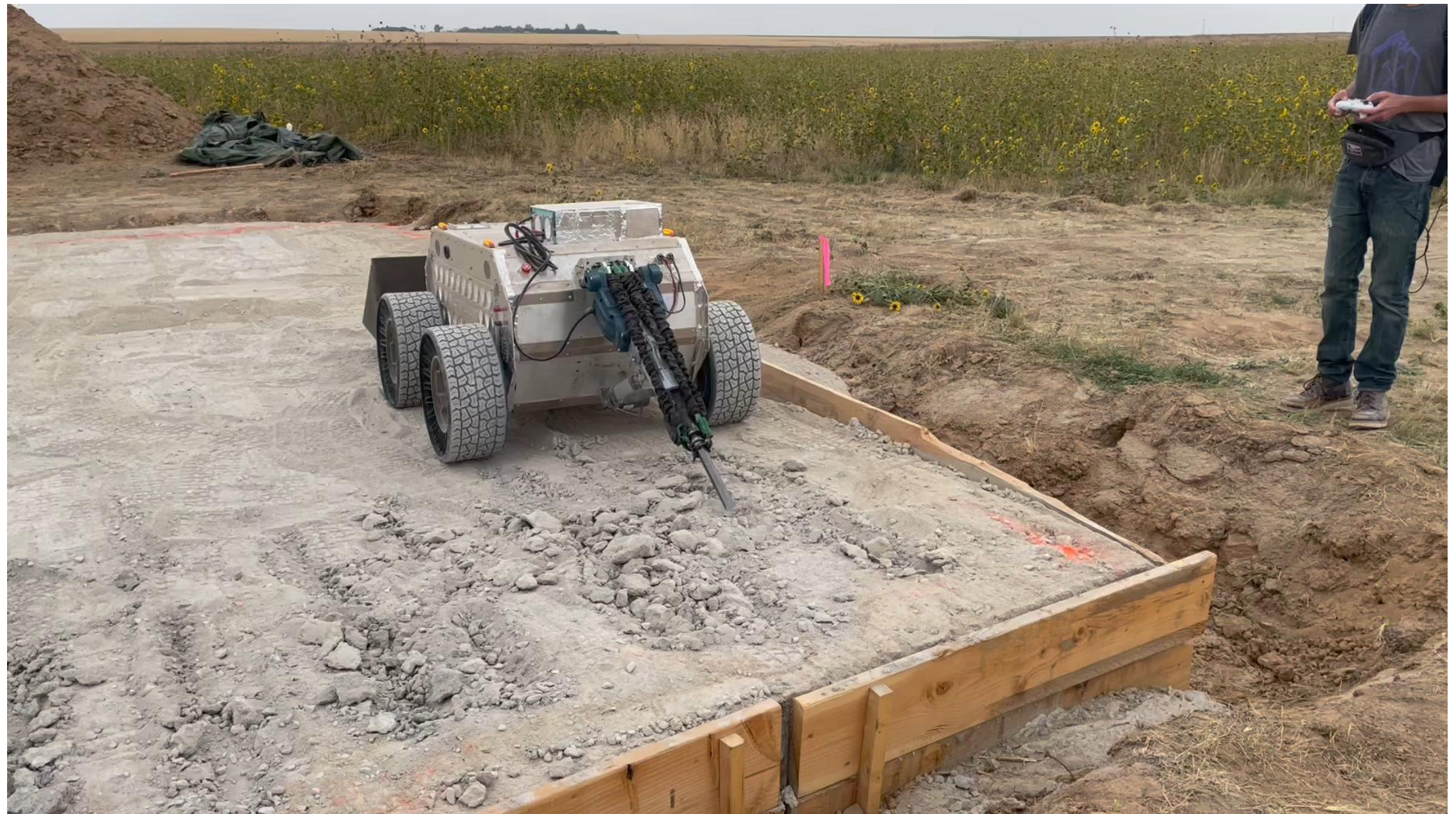


Transportation Track



















Break the Ice Challenge
Ice Diggers Team
Durability Demonstration Test
9/21/2023

Media Coverage

- We held a media day September 11
- Congressional and Senate staffers
 - House: Crow & Caraveo offices
 - Senate: Bennett office
- TV: 9 News and Fox 31
 - <https://www.youtube.com/watch?v=gtD00MURJxo>
 - https://www.dropbox.com/scl/fi/cz4huqp9dkmssc0g09wyy/BHDN_1_AIRCHECK-KDVR-5PM2023-09-11-CODENOF1ENC002.mpg_KDVR89f4_132-compressftpverylight.mov?rlkey=rn6laey485xbtuv48fut91yu5&dl=0
- Radio: CPR
 - <https://www.cpr.org/2023/09/11/colorado-school-of-mines-ice-lunar-challenge-lunar-outpost/>
- Print: Denver Post

Summary

- The Outpost digger system performed well in the 15 day test at CASP
 - 12,583kg of regolith simulant delivered averaging 839kg/day
- Mines/Lunar Outpost finished in 3rd place and are one of 6 teams moving on to the Level 3 competition
- Level 3 will be an in person competition at a NASA facility
 - Early June 2024
 - Judging based on Excavation and Mobility
 - 1st place award \$1M, second place award \$0.5M