Subsurface Water Extraction From Extreme Environments

Jack Schultz[1] , Joey Palmowski[1], Kris Zacny[1], Bolek Mellerowicz[1], Leo Stolov[1], Bernice Yen[1], Dara Sabahi[1], Paul van Susante[2], Than Putzig[3], Michael Hecht[4]

Presented by: Jack Schultz

[1]Honeybee Robotics
[2]Michigan Technological Institute
[3]Planetary Science Institute
[4]MIT Haystack Observatory

ISO 9001 CERTIFIED
AS9100 CERTIFIED

Honeybee Robotics
2408 Lincoln Ave
Altadena, CA 91001
www.HoneybeeRobotics.com

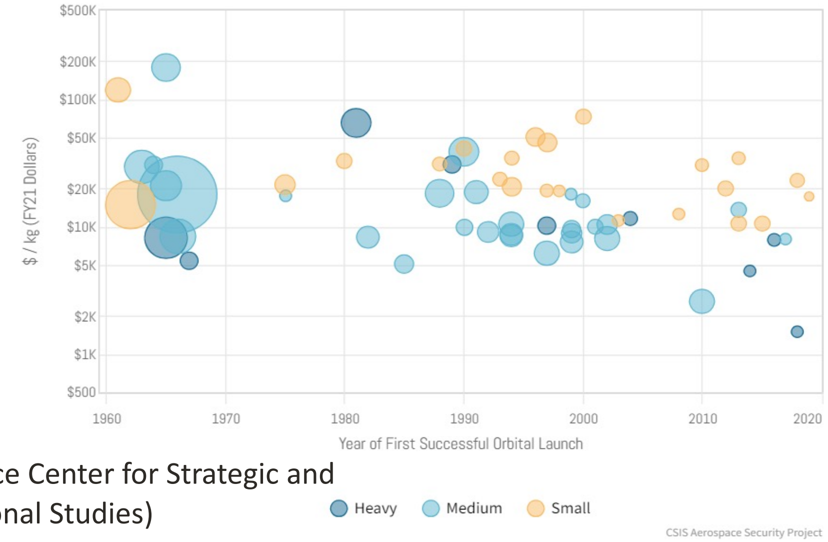
Relevance to the Field of ISRU

HONEYBEE ROBOTICS
Exploration Technology

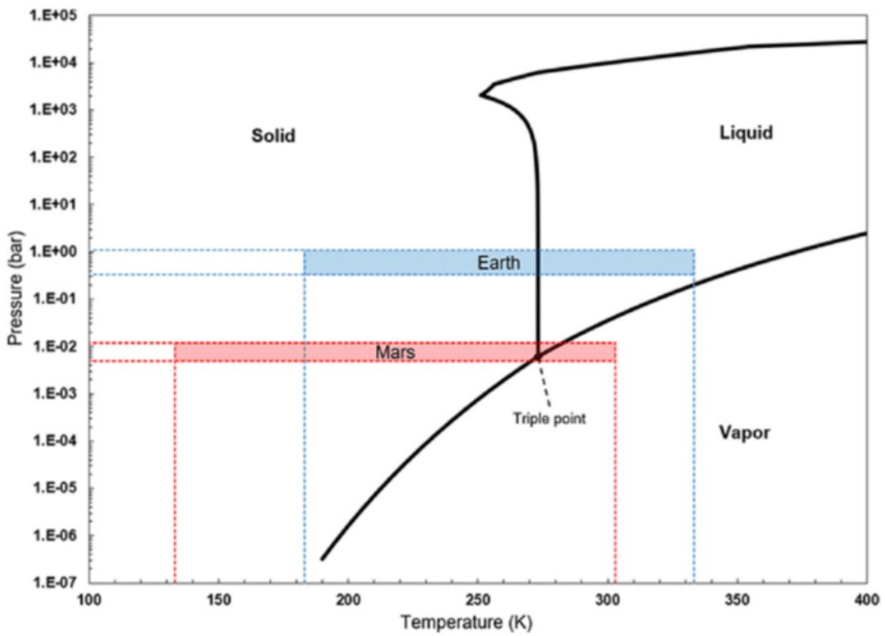
- ISRU is defined as the collection, processing, storing and use of materials encountered during space exploration.

- Cost of Launch
  - Present day launch costs are very high
  - 1kg of propellant on Mars costs roughly 225kg of propellant from Earth
  - Refilling Starship will require roughly 600 metric tons of water (Heldman et al. 2021)

- Evolution of the field to harness resources in site to reduce mission cost.
- Complications of presence of water in the target environment.



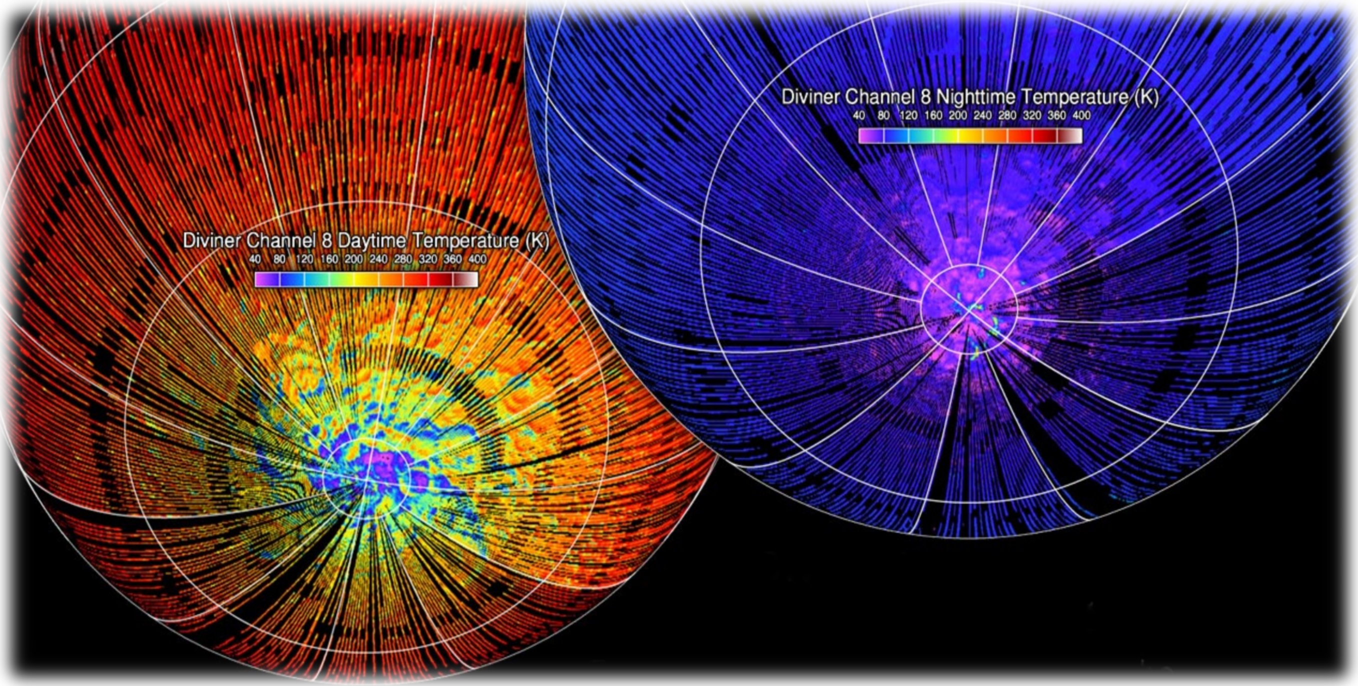
(Aerospace Center for Strategic and International Studies)



Verseux (2018).

Inferred Ice Reserves on the Moon

- ❑ Daytime and Nighttime Temperatures of the lunar south pole have been recorded by the Diviner Radiometer Experiment on NASA's LRO.
- ❑ Peak Temperature: ~400K
- ❑ Minimum Temperature: ~25K
  - ❖ Lowest recorded temperature in the solar system
- ❑ Water presence on the surface of the moon.
- ❑ Inferred ice presence in the subsurface of the moon. (~3 billion metric tons) (LRO).



Nasa.gov

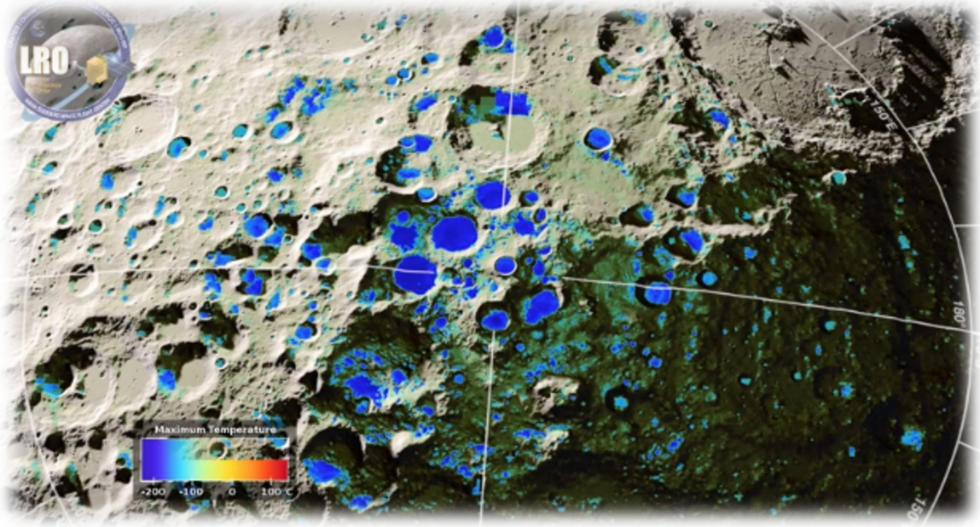


Image courtesy of NASA's Goddard Space Flight Center/Scientific Visualization Studio.

Potential Locations of Interest on Mars

- ❑ In 2020, Starship landing sites down-selected to four primary and three secondary (Golombek et al. 2021 LPSC)
- ❑ Main criteria:

- Elevation (below -2km wrt MOLA geoid)
- Lower latitude (<40° for solar power and thermal management)
- Surface slope (<5° over 10m length)
- Load bearing surface
- Close to significant ice deposits

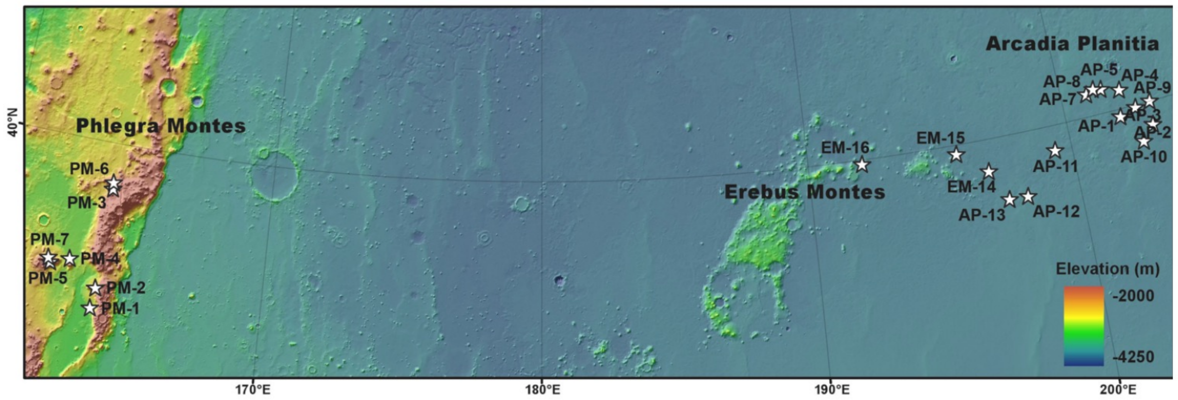


Fig. 1. Topographic map of Arcadia Planitia, Erebus and Phlegra Montes show landing sites considered for SpaceX Starship. Topography with respect to the MOLA geoid.

Table 1. Downselected prime (first 4) and secondary (last 3) landing sites

Landing Site	Latitude °N	Longitude °E	Elevation* km
PM-1	35.23	163.95	-3.2
AP-1	39.8	202.1	-3.9
AP-9	40.02	203.35	-3.9
EM-16	39.89	192.03	-3.9
AP-8	40.75	201.3	-3.9
EM-15	39.75	195.62	-3.9
PM-7	36.43	162.16	-2.3

*with respect to the MOLA geoid.

Golombek et al., (2021) LPSC

Inferred Ice Reserves on Mars

- The 30-65deg N latitude range is of interest based on its morphologic, infrared and radar observations.
- Presence of Ice hypothesized from data received on the SHARAD sounding Radar on the Mars Reconnaissance Orbiter mission and the High Resolution Imaging Science Experiment. (Image to the right)
- Martian Phoenix confirmed ice in the northern polar regions of Mars is covered by a few inches of soil.
- Studying the morphology of craters also indicates the potential reserve of ice in the Martian sub-surface.

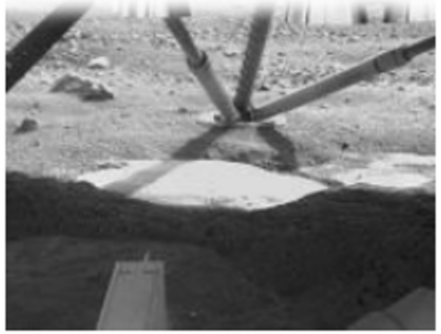


Figure 1. Phoenix thrusters removed top soil to expose ice on Mars. Photo: NASA

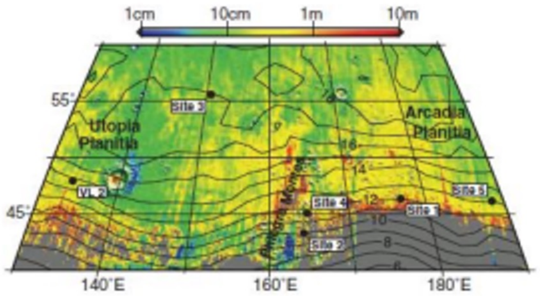
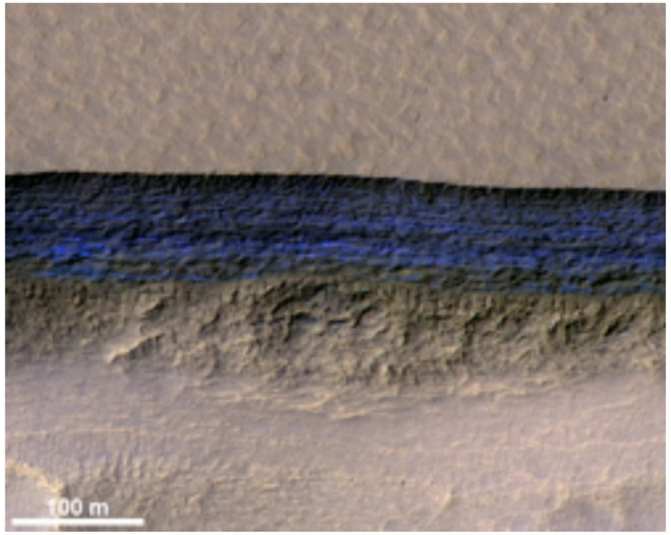
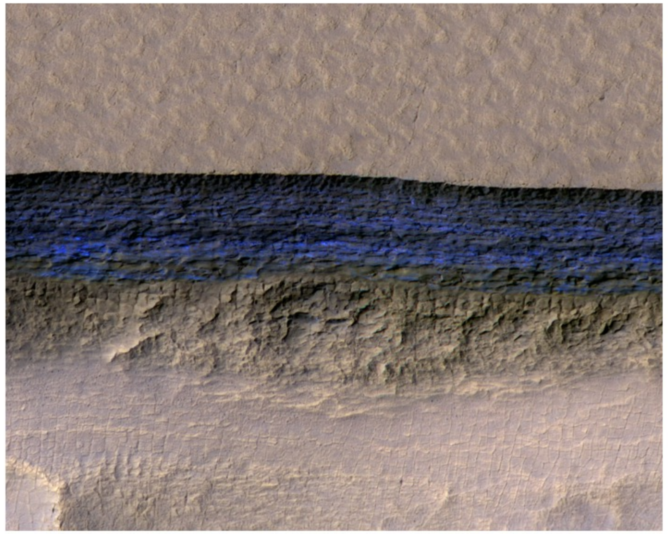


Figure 2. Viking 2 (VL 2) and locations of crater-excavated near-surface ice (1-5) are labeled and expected ice depths shown[10].

Figure 3. Regolith at Curiosity landing site has 1.5-3 wt% water.

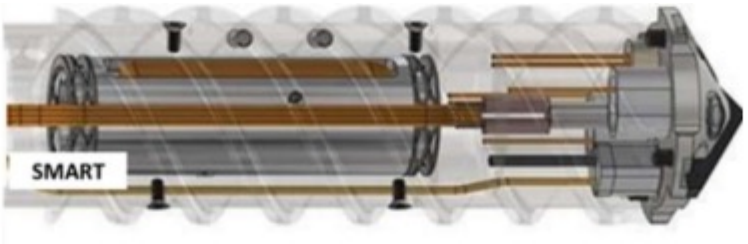
January 11, 2018

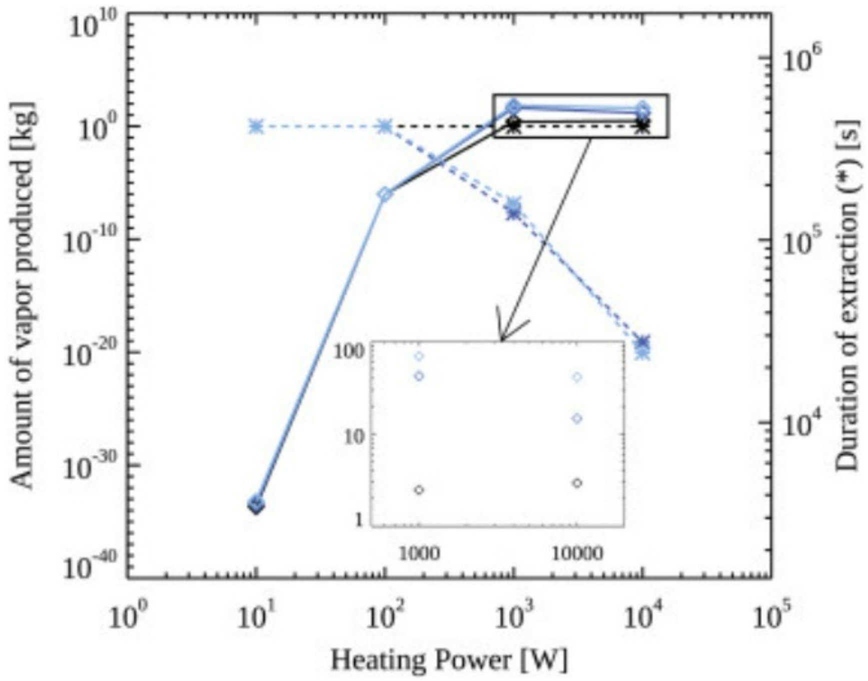


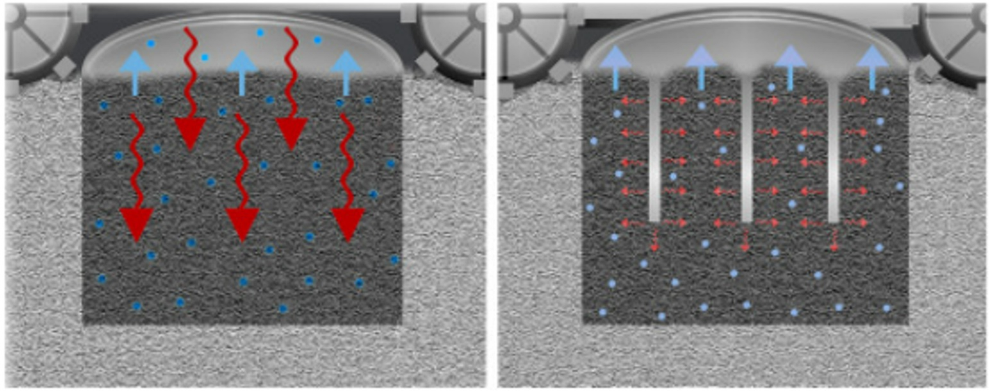


Extraction Methods for subsurface water from the Moon

- Sublimation can be beneficial but does have its limitations
- Improper meshing of the drill geometry.
  - Tests from Honeybee Robotics show that f the geometry of the mining device does not contain the vapor appropriately, it can result in leakage through the regolith and be re-frozen somewhere else.
- SMART Instrumented Auger
  - Near Infrared Spectrometer (NIR):
    - Volatiles, Mineralogy
  - Neutron Spectrometer (NS):
    - Presence of Hydrogen
  - Temperature Sensor and Heater
    - Thermal conductivity as a function of depth
    - Induce sublimation for volatile capture
  - Dielectric Spectroscopy Probe (DSP):
    - Electrical Properties
  - Camera
    - Regolith Texture properties







Phil Metzger and Julie Brisset (Planetary and Space Science)

Honeybee's PVEx

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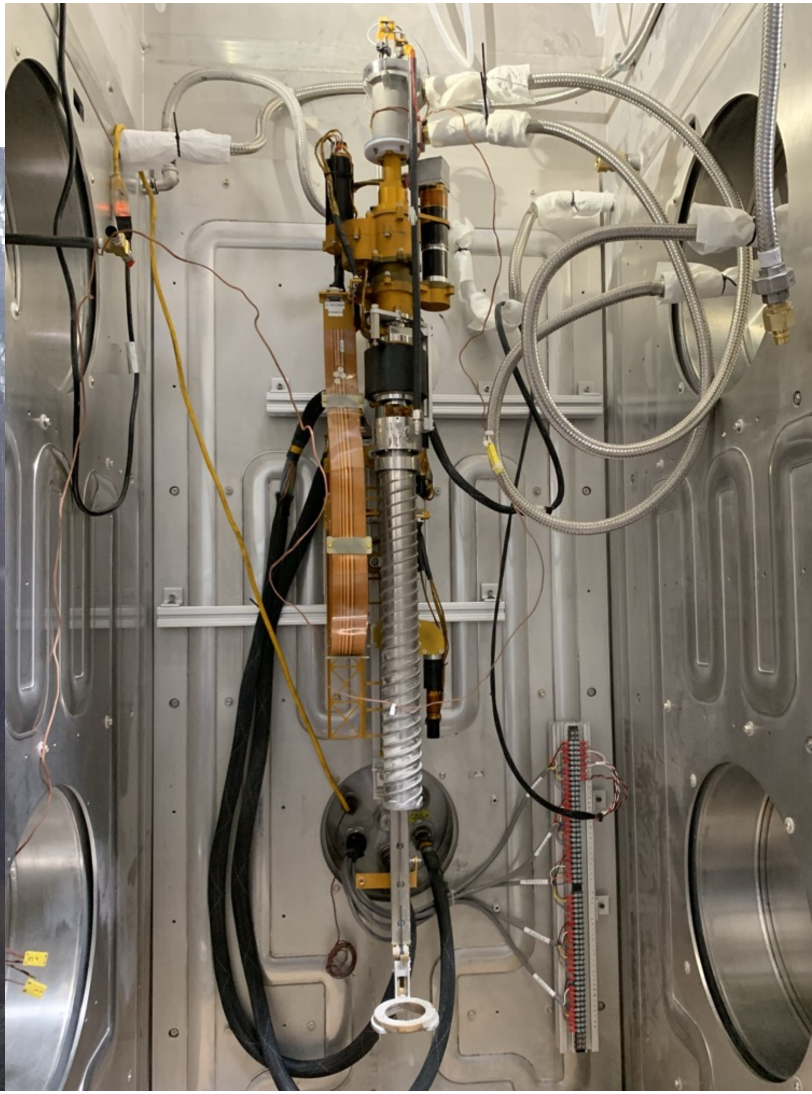
Exploration Technology

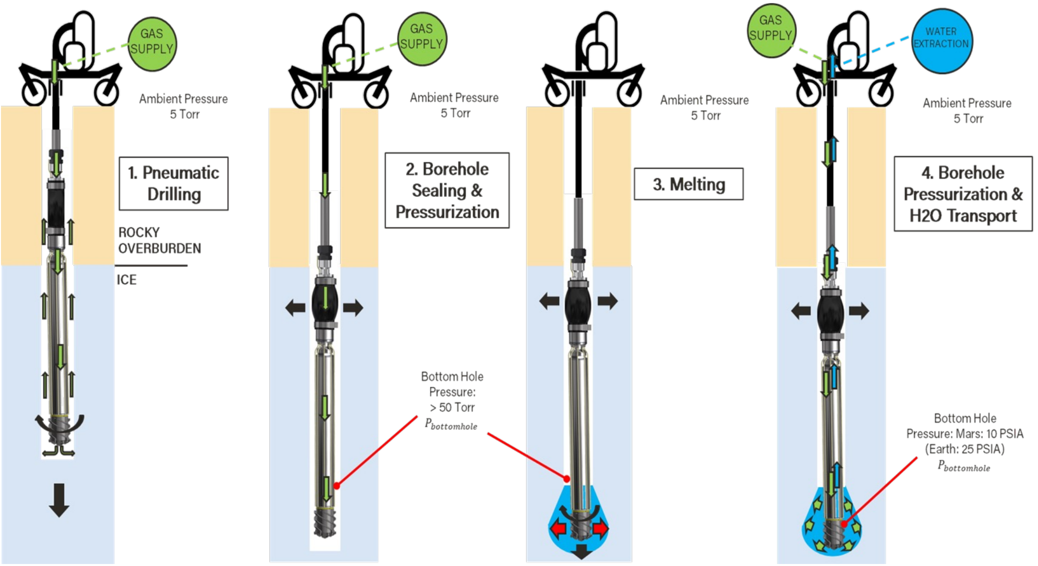
- ~6 grams of water per hour
- 192 Whr to capture 7 grams
- Maintained at -30C
- Heating as primary means of extraction results in a power-hungry process.

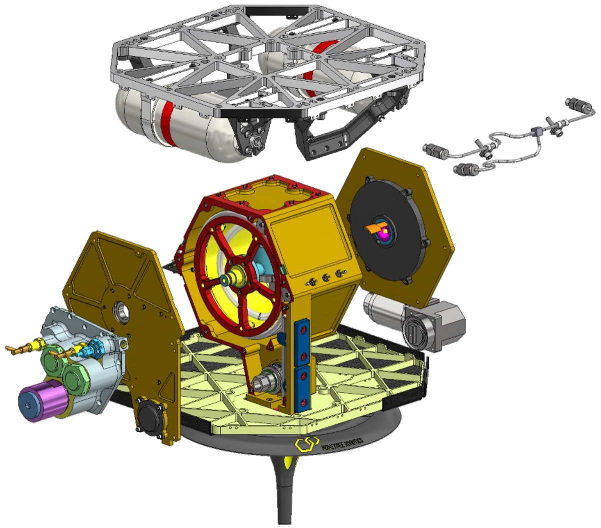
Test #	Test Setup	Test Configuration	Collection Efficiency
4.14.1	12% Water by Wt.	100W @ 1.5 hrs	12%
4.14.2	5% Water by Wt., Vent Cold Trap	100W @ 1.5 hrs	5.8%
4.14.3	5% Water by Wt.	100W @ 2 hrs	7.4%
4.14.4	4% Water by Wt., Slow Heat	50W @ 12 hrs	35%
4.14.5	6% Water by Wt., CT thawed mid-test	50W @ 12 hrs	43%

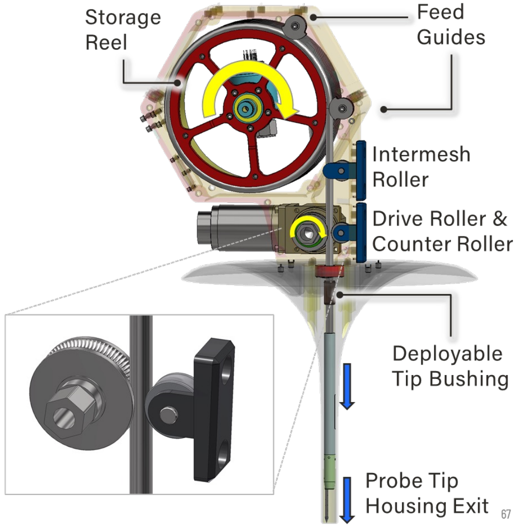


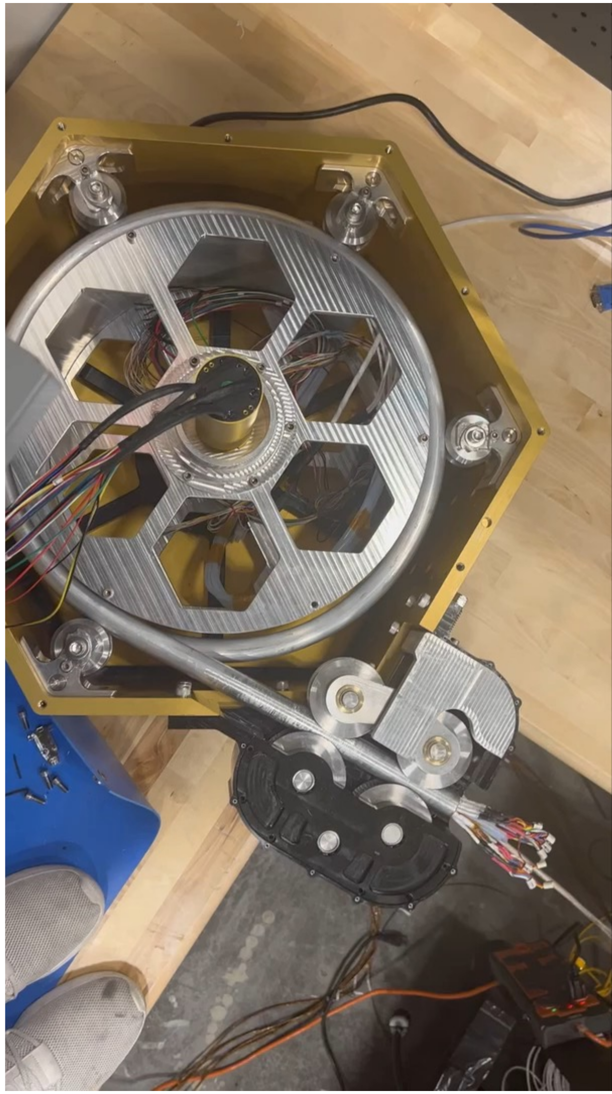
Coiled Tube Drilling

- Uses "injector" to unspool coiled-tubing providing the necessary weight-on-bit for downhole penetration
- Extensive history in oil/gas industry
- Some terrestrial systems can drill as deep as 5000 meters!
- Extra-terrestrial heritage with **Honeybee's LISTER**, selected to go to the moon in 2024 on NASA CLPS mission.
- Rodriguez Well (RodWell)
  - First developed by Raul Rodriguez
  - Primary means of capturing subsurface oil









(Not-so) Novel Approaches to Extracting Water from Martian subsurface

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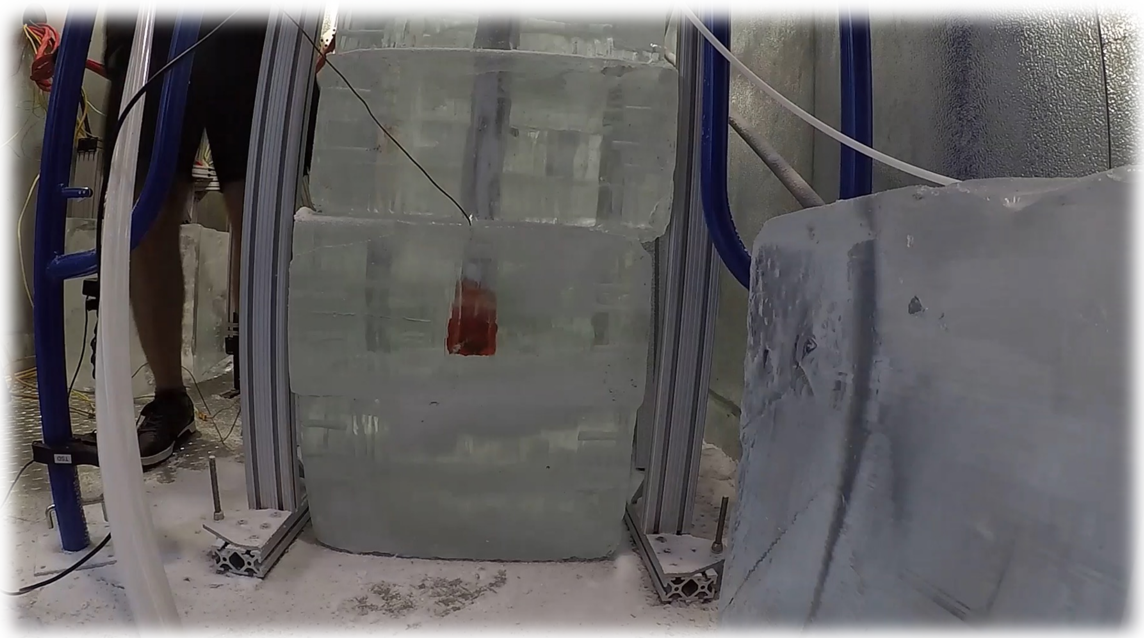
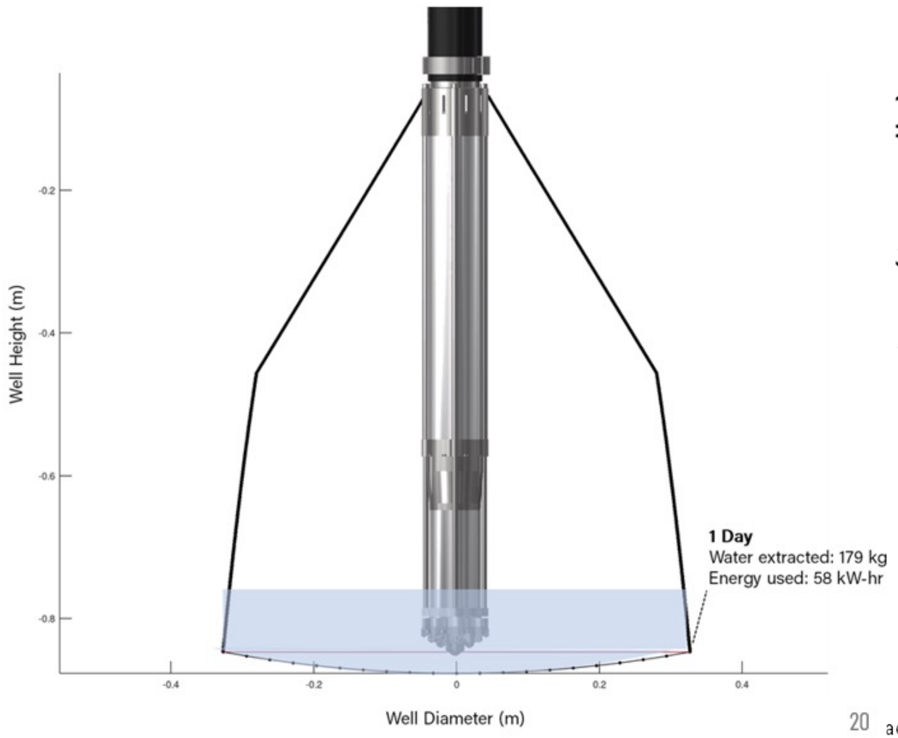
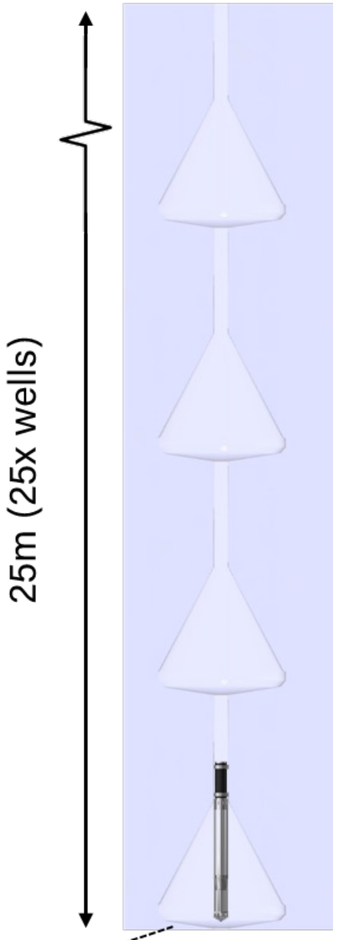
Exploration Technology

- Honeybee Robotics' RedWater system employs the use of RodWell technology to create the wells downstream in the borehole.
- Small Internal volume of coiled tube to deploy deep into the Martian subsurface.

- Convective Currents in the well to improve thermal conductivity.







250 Hours
20 acted: 1645 kg
Energy used: 0.527 MW-hr

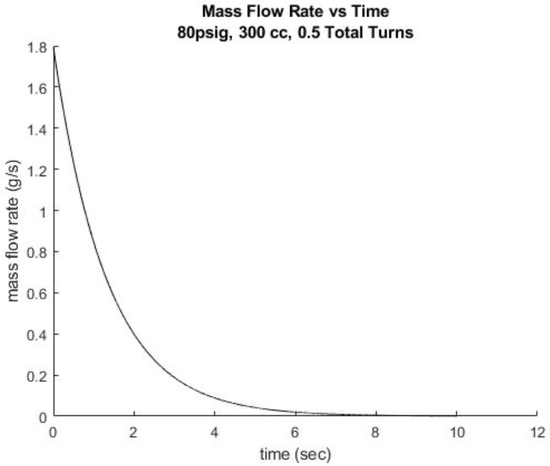
Pneumatic Excavation

LISTER
3-m depth lunar heat flow probe
TRL6
Currently being integrated onto Firefly Lander

RedWater

- 25-m deep drill for Martian water harvesting
- TRL5

- 1:3.6 mass of gas to mass of cuttings cleared in TVAC test



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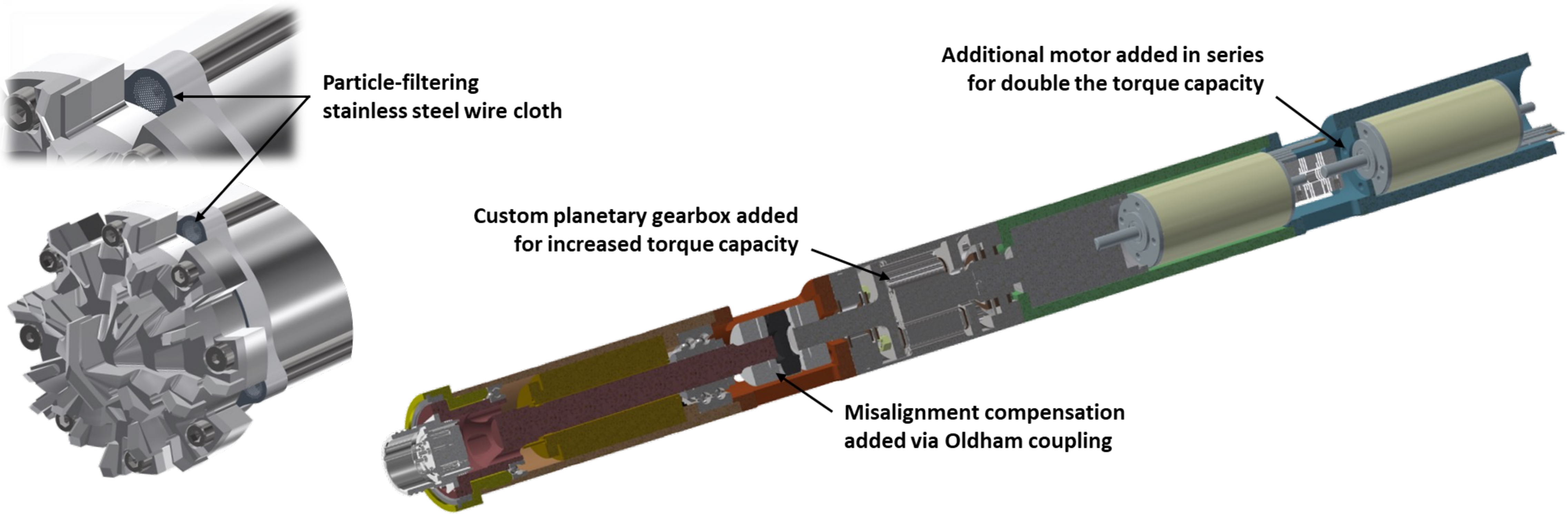
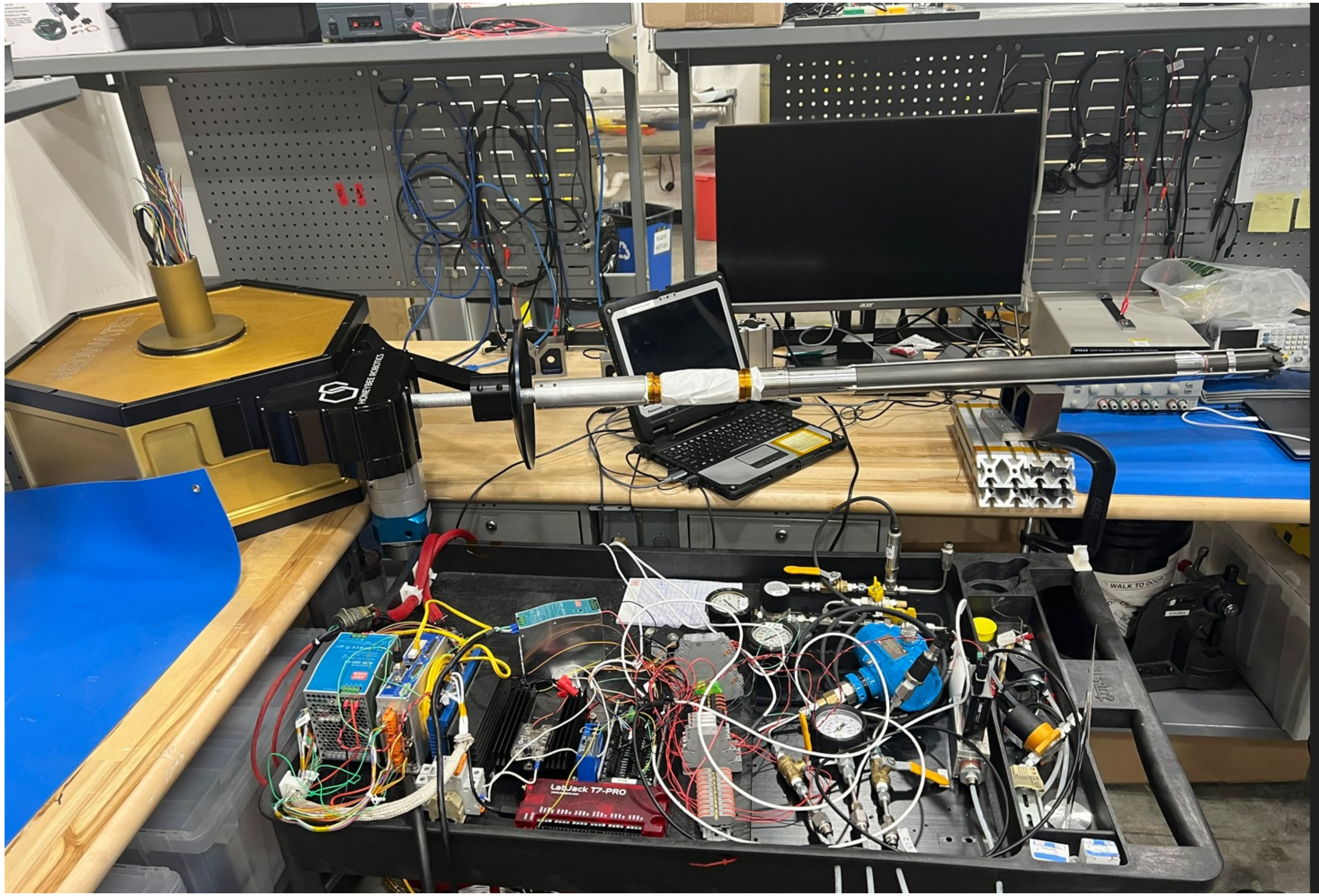
Thank you!
Questions?

HONEYBEE ROBOTICS

Back Up Slides

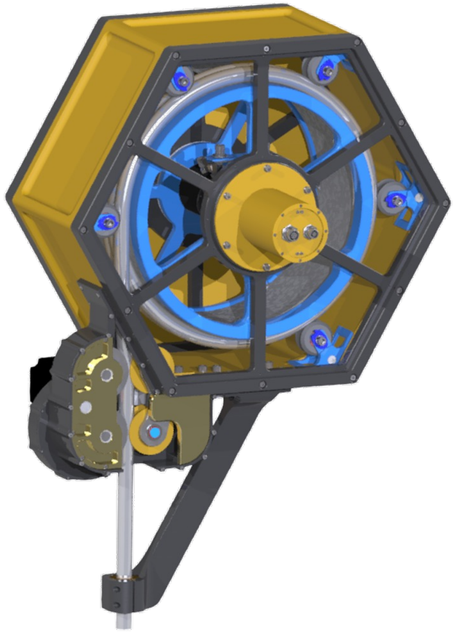

Particle-filtering
stainless steel wire cloth
Additional motor added in series
for double the torque capacity
Custom planetary gearbox added
for increased torque capacity
Misalignment compensation
added via Oldham coupling


LabJack T7-PRO

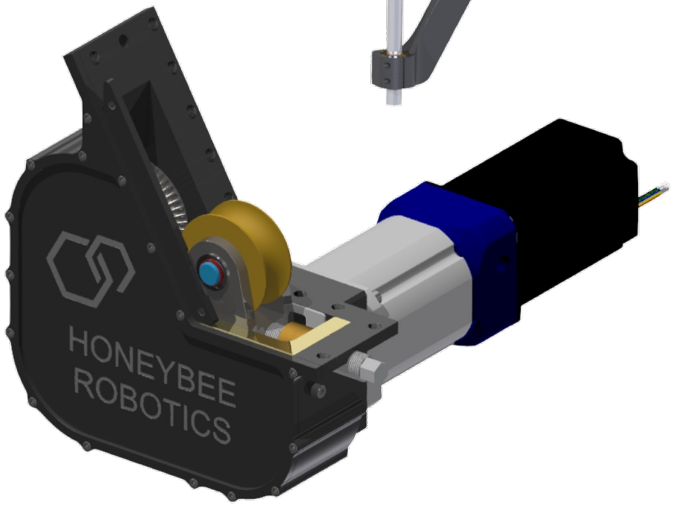
TRL6 Packer

- ❑ Flight Forward Configuration: Folded bilayer
  - ❖ Gas tight fluoropolymer bladder layer
  - ❖ Durable Vectran/Kevlar abrasion layer

CT Drum

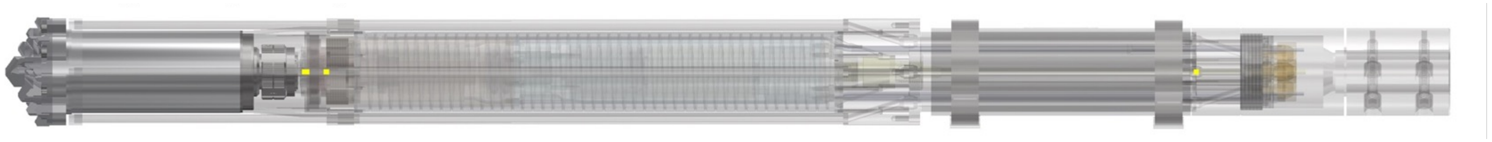


CT Injector

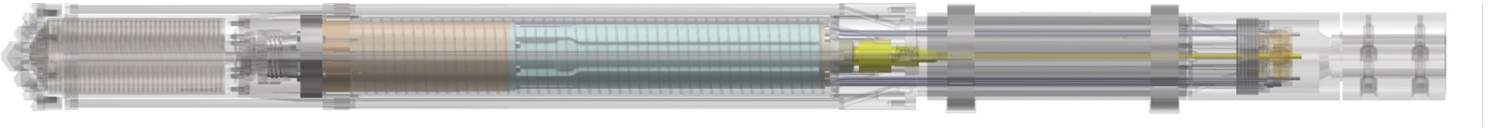


BHA

Heated Drill Bit

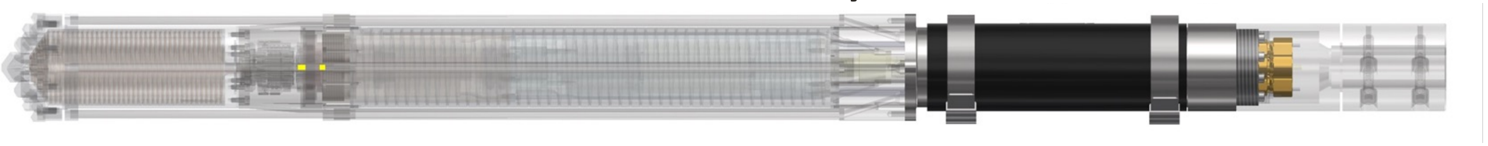


Slip-Ring + Drill Motor Assembly



Heated Fluid Transfer Lines

Packer Assembly



Bending Torque of 304 Stainless CT