SMART: Instrumented Drill for ISRU Investigations on the Moon

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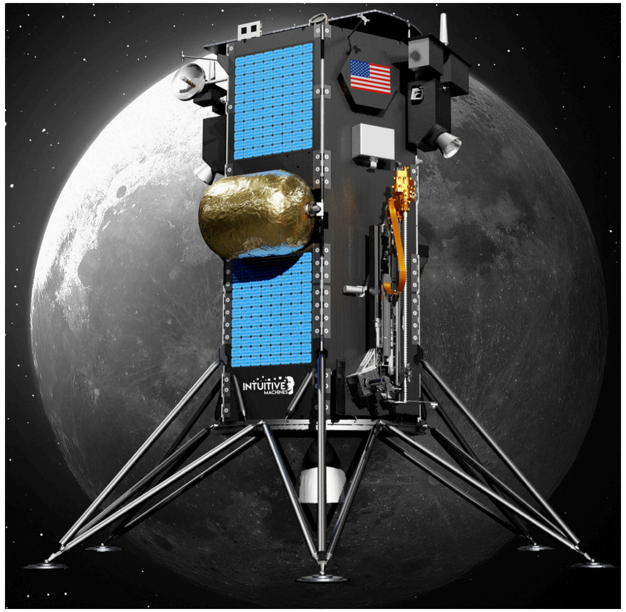
What is SMART?

SMART: Sensing, Measurement, Analysis, and Reconnaissance Tool: A next generation drilling system for ISRU

Current generation: TRIDENT Drill

- Rotary percussive drill flying to the Moon on the Prime-1 and VIPER missions
- TRIDENT is used to auger lunar regolith from 1 meter depth up to the surface for instrument analysis

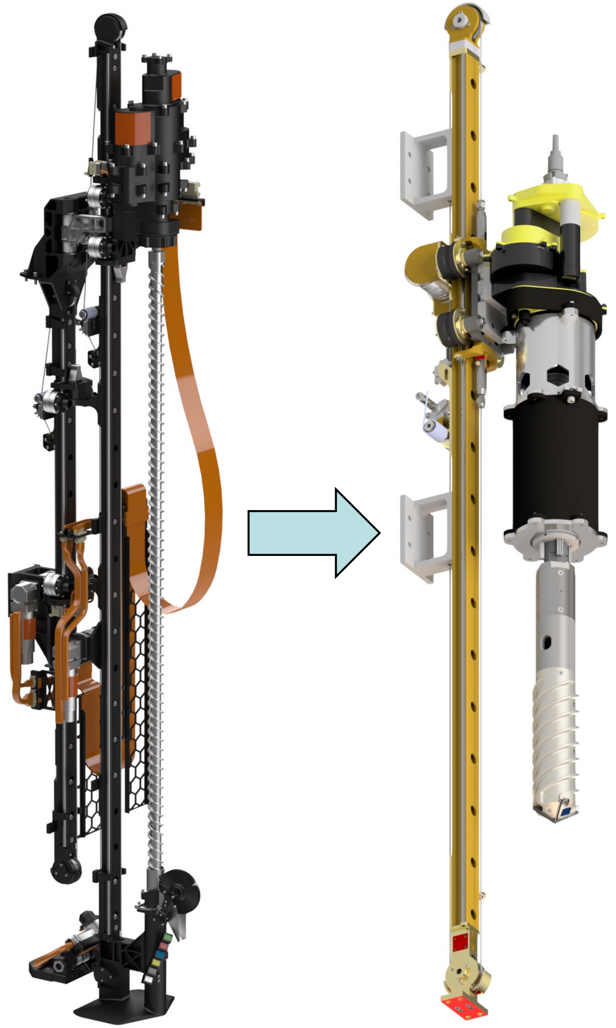


PRIME-1 Lander

P. Chu et al. (2020) "TRIDENT Drill for VIPER and PRIME1 Missions. LSIC 2020 Fall Meeting"

VIPER Rover

A. Colaprete et al. (2020). "Volatiles Investigating Polar Exploration Rover. NASA Technical Report"

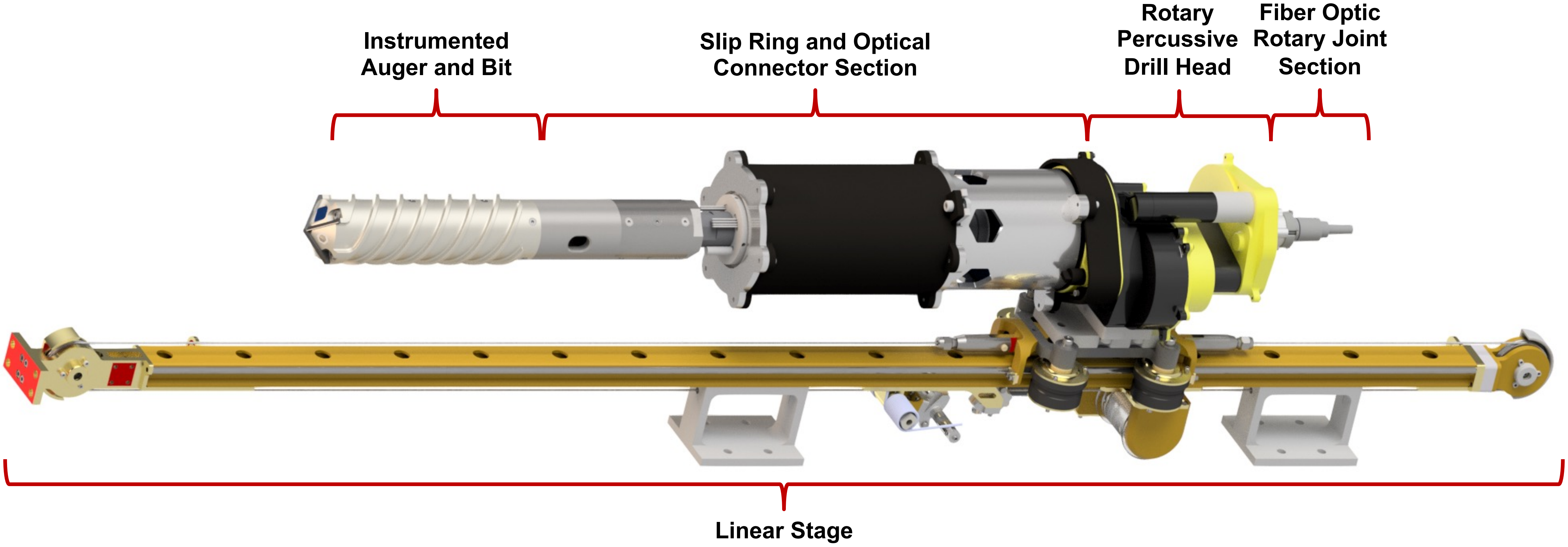


TRIDENT Flight Design

SMART Prototype Design

SMART Prototype Design Overview

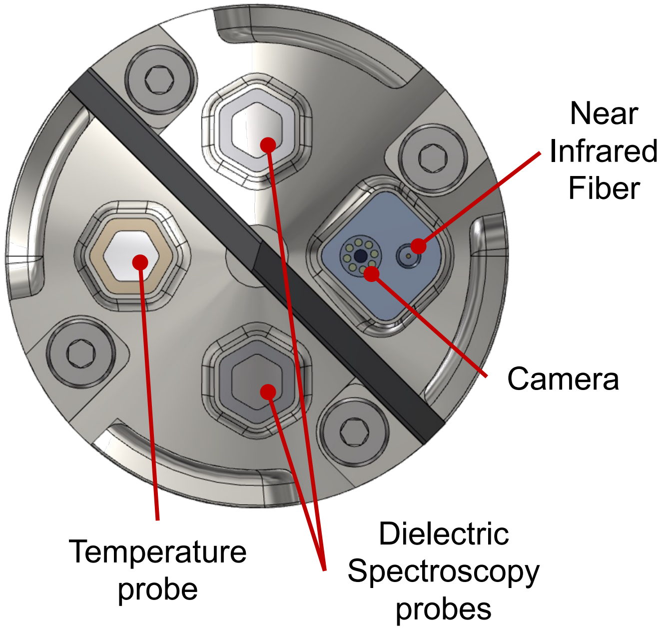
SMART packages sensors into the auger to bring the instruments to the sample, as opposed to bringing the sample to the instruments

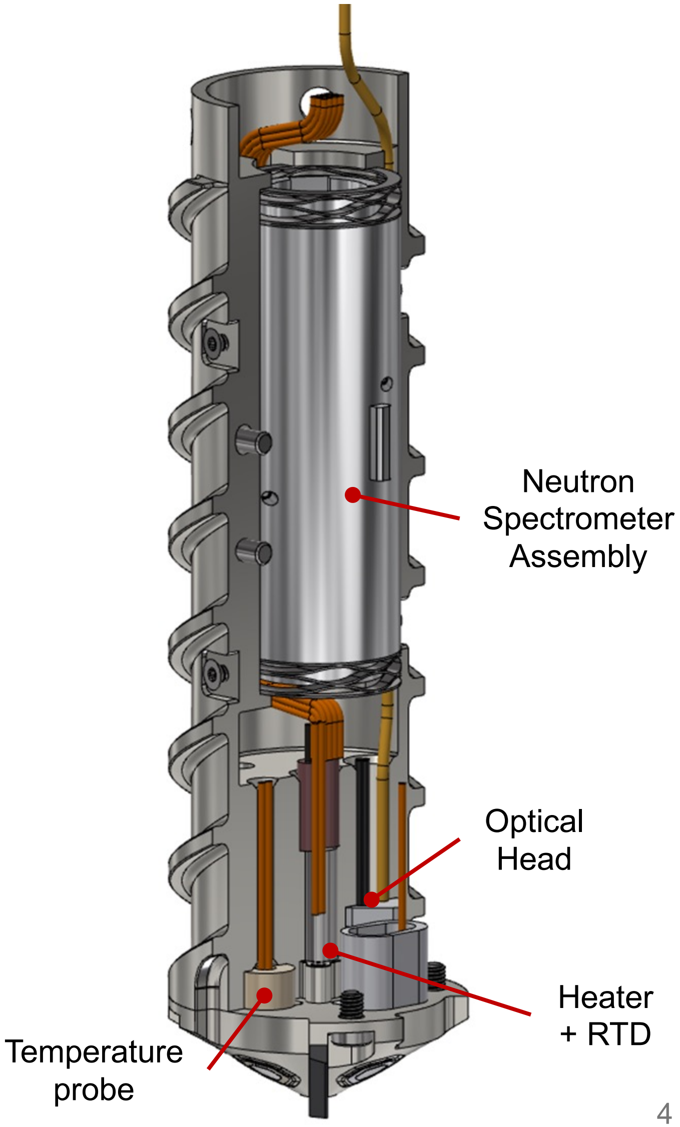


Instrument Suite

2-inch (~5 cm) diameter auger and drill bit instrumented with:

- **Near infrared spectrometer** for volatiles and mineralogical information
- **Neutron spectrometer** for hydrogen detection
- **Dielectric spectroscopy** probe for electrical properties
- **Temperature sensor and heater** for thermal gradient and thermal conductivity measurements
- **Camera** for visible light images and surface texture

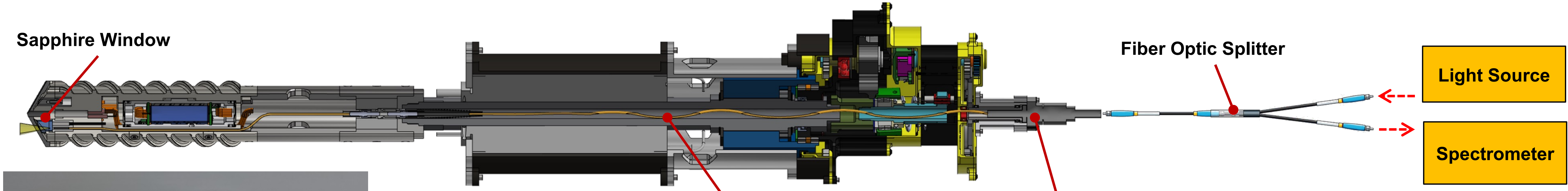


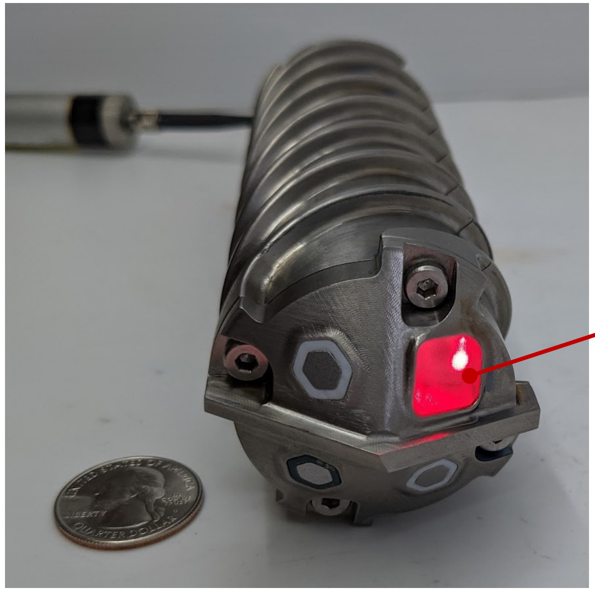


Instrument – Near Infrared Spectrometer (NIR)

How it works:

- 1x multimode fiber optic cable passes through entire drill axis
- Near infrared light (800-2,500 nm) bounces off regolith and signal transmits through same fiber to spectrometer
- Spectral scan identifies composition of minerals and ices in the regolith



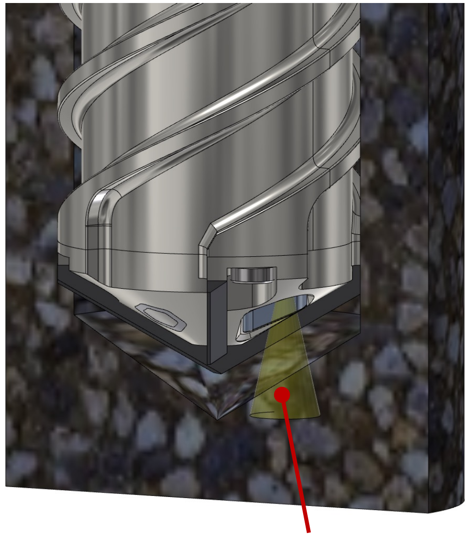


Instrument – Near Infrared Spectrometer (NIR)

HONEYBEE ROBOTICS
Exploration Technology

Not the first drill-integrated NIR spectrometer.

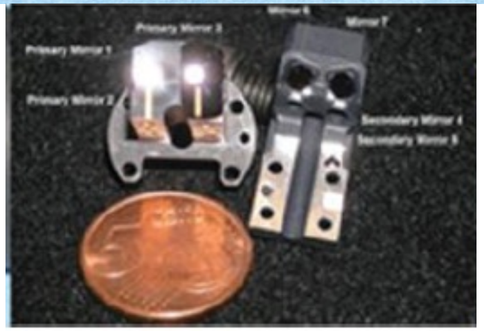
- Ma_MISS on ExoMars Rover also uses fiber optics and FORJ for NIR measurements
  - Independent fibers for illumination and collection
  - Collimator with window pointing sideways



NIR field of view inside borehole

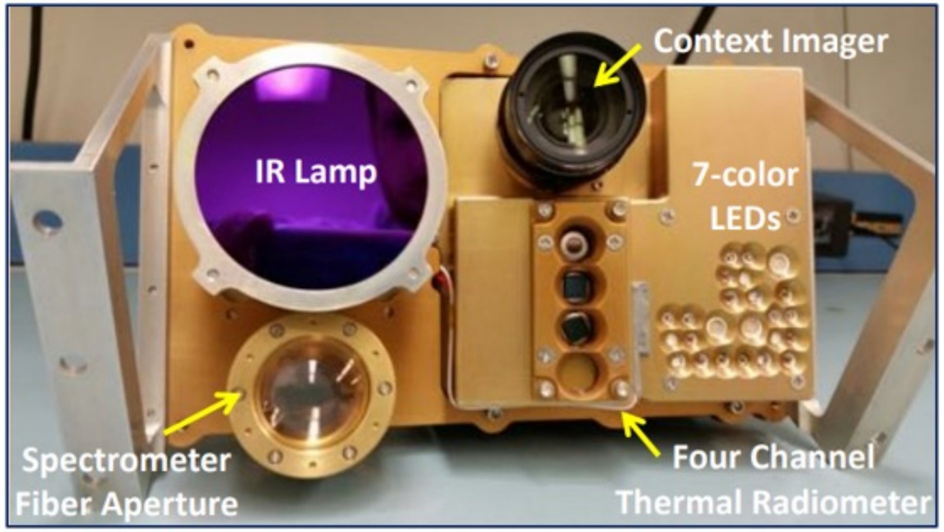
Heritage

Mars Multispectral Imager for Subsurface Studies (Ma_MISS) on the ExoMars rover



De Sanctis, M. C. et al. (2017). “Ma_MISS on ExoMars: Mineralogical Characterization of the Martian Subsurface”. Astrobiology, 17(6–7), 612–620.

Near InfraRed Volatiles Spectrometer System (NIRVSS) that will fly on the VIPER rover to the Moon

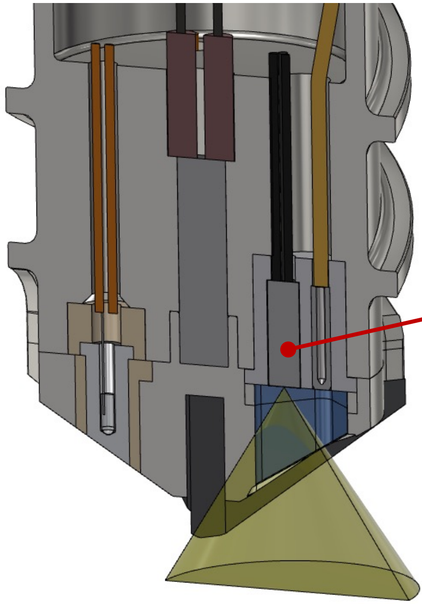


K. Ennico Smith et al. (2020) “The Volatiles Investigating Polar Exploration Rover Payload”. In LPSC 2020

Instrument - Camera

How it works:

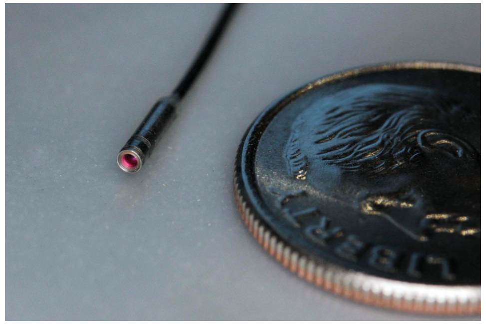
- Miniature CMOS camera head and LEDs collect visible light images through the sapphire window
- Signals are passed through slip ring to computer
- Images used for surface texture and scientific context



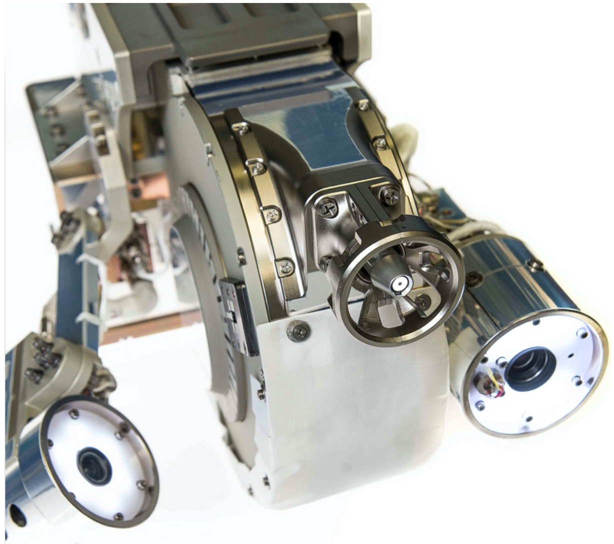
Visible Light CMOS Camera (4.2 mm OD)

Heritage

Miniature CMOS camera head used in orbit on NASA's Robotic Refueling Mission



https://nexis.gsfc.nasa.gov/rrm_phase2.html



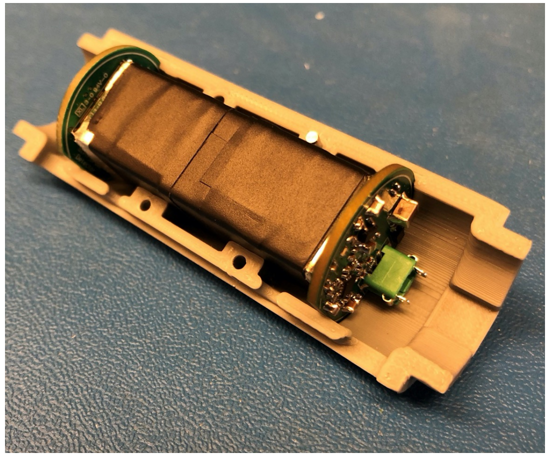
Instrument – Neutron Spectrometer

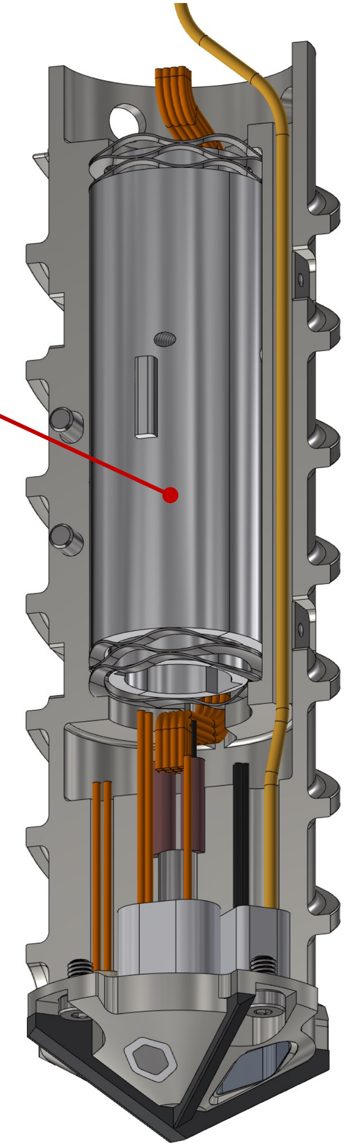
How it works:

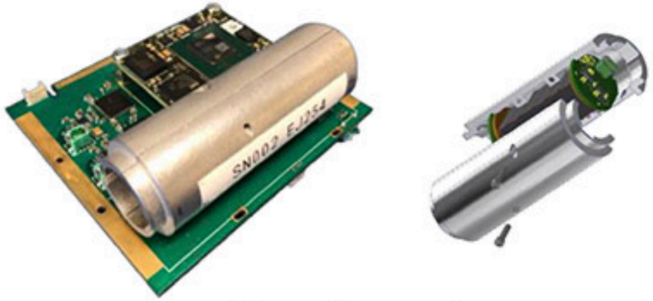
- Galactic cosmic rays hit hydrogen atoms in the lunar regolith to produce neutrons
- Neutrons hit the scintillator which releases photons
- Photo array on either side of scintillator detect photons and transmit signal to DAQ

Intrepid, the compact neutron spectrometer initially designed to fit in a drill auger at NASA Ames (PI: Dayne Kemp)

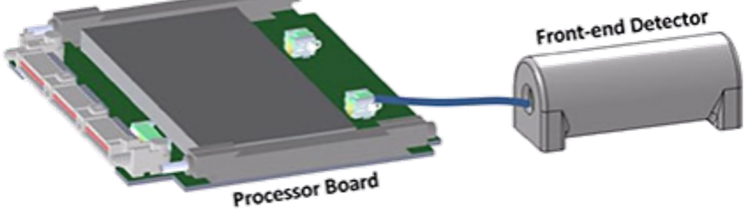
- Picks up neutrons in <u>thermal</u> and epithermal range
- The technology has been advanced for flights on a NASA CubeSat program
- Tested w/ neutron source surrounded by lunar regolith w/ different wt% water







Drill-based Intrepid v1.0



Space-based Intrepid v2.0

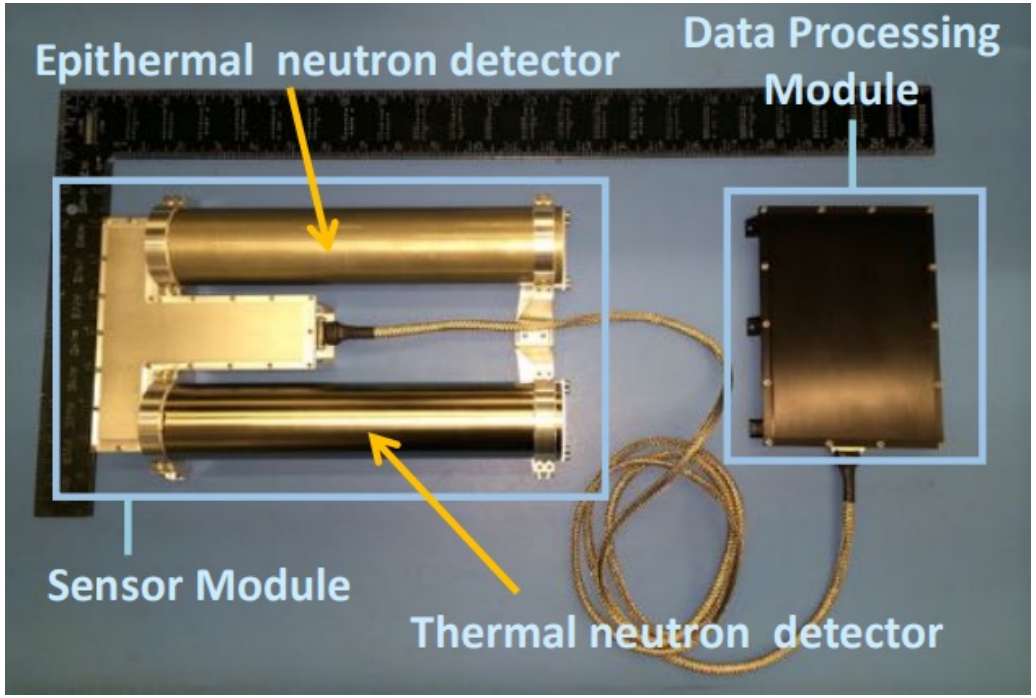
D. Kemp, A. N. Nguyen. (2020) "Intrepid Particle Detector". Available at: https://flightopportunities.ndc.nasa.gov/media/technology/260/257-summary-chart.pdf [Accessed 9 Nov. 2021]

Instrument – Neutron Spectrometer

Neutron spectrometers are not new to the Moon.

Heritage

Neutron Spectrometer System (NSS) flying on VIPER rover to the Moon



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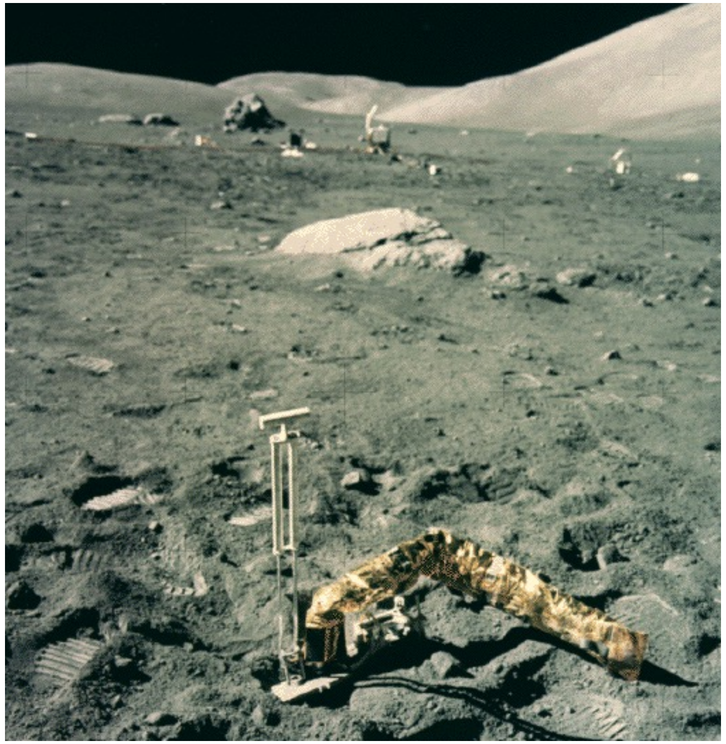
Lunar Neutron Probe deployed on Apollo 17

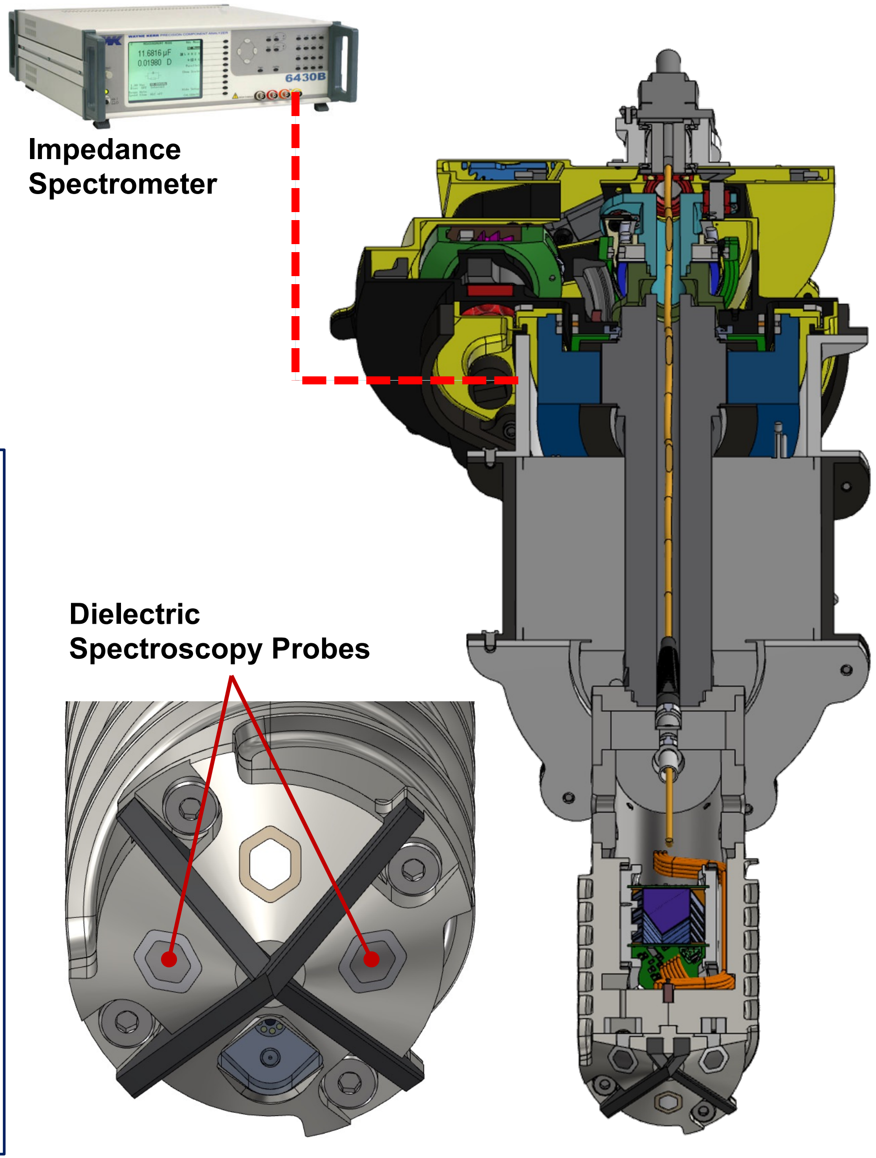


https://www.lpi.usra.edu/lunar/missions/apollo/apollo_17/experiments/lnp/

Instrument – Dielectric Spectroscopy

How it works:

- Two nearby conductive probes apply small electric field to measure relative permittivity and conductivity over a frequency range
- Measurements can be used to estimate water ice content in regolith



Heritage

Dielectric Spectroscopy (DS) probes tested in Mojave Desert on the AXEL Rover

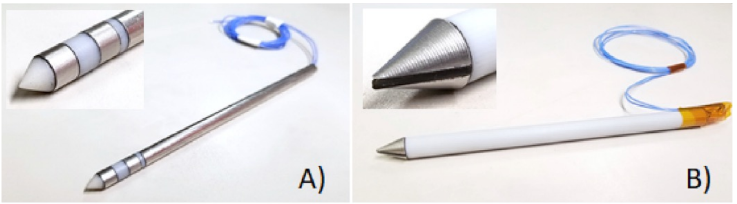
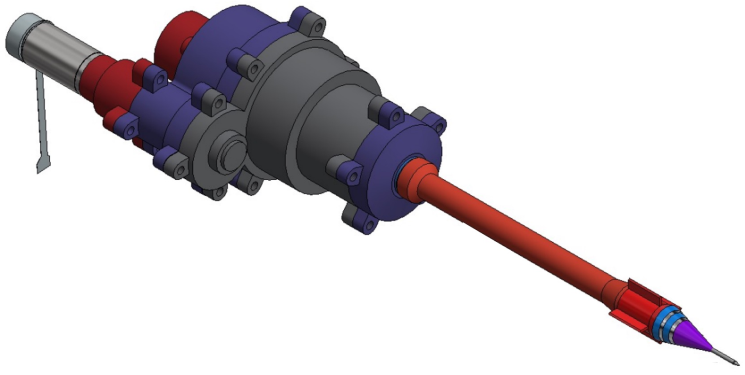


Fig. 12. A) DS probe 'Donut' prototype. B) DS probe 'Sandwich' prototype.

Chin, K. B., et al. (2020). Planetary and Space Science, 187, 104948. https://doi.org/10.1016/j.pss.2020.104948

Soil Properties Assessment, Resistance, and Thermal Analysis (SPARTA) multi-tool under development

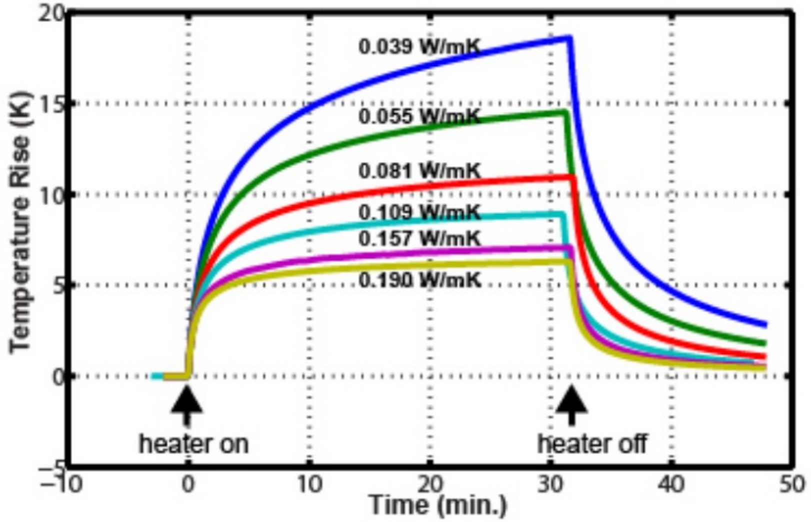


R. C. Anderson et al. (2022). LPSC, 2398, https://www.hou.usra.edu/meetings/lpsc2022/pdf/2398.pdf

Instrument – Temperature Sensor and Heater

How it works:

- Temperature measurement: RTD measures regolith temperature
  - Also provides thermal correction for NIR measurements
- Thermal conductivity: heater supplies known power while temperature change over time is monitored (needs calibration)
  - Provide heat flow measurements of the Moon
- Heater can also be used to help free auger if stuck in icy regolith



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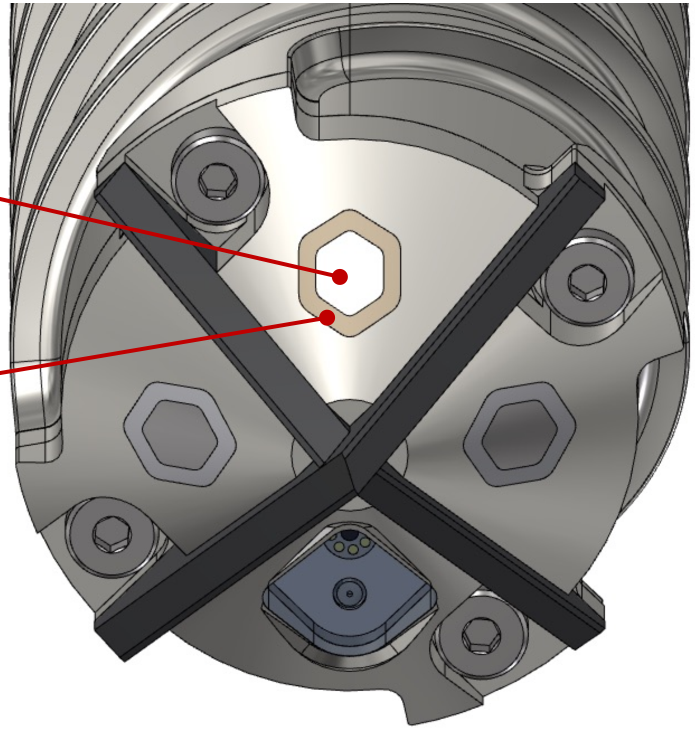
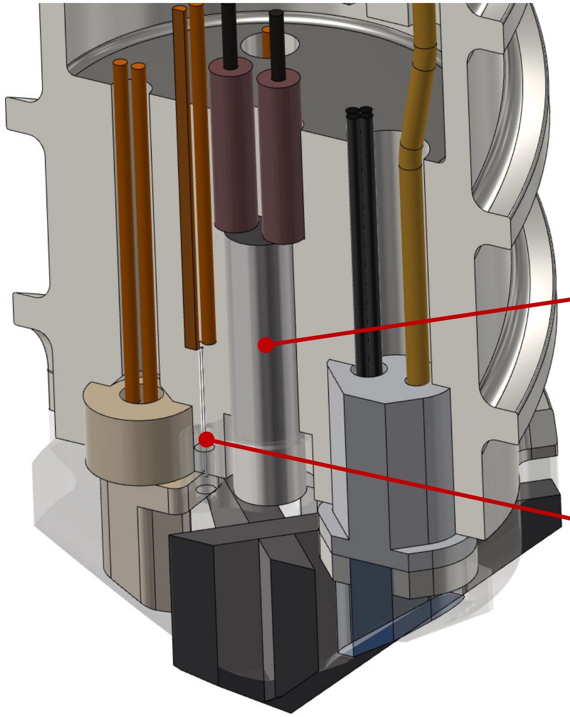


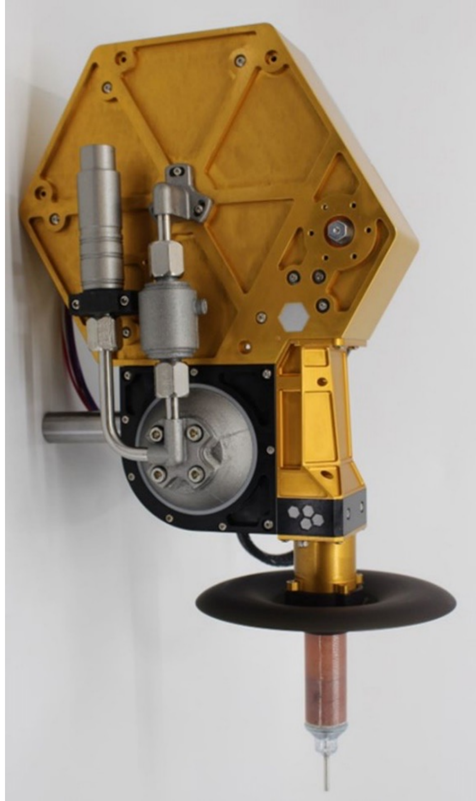


Instrument – Temperature Sensor and Heater

Building off legacy of lunar heat flow science.

Heritage

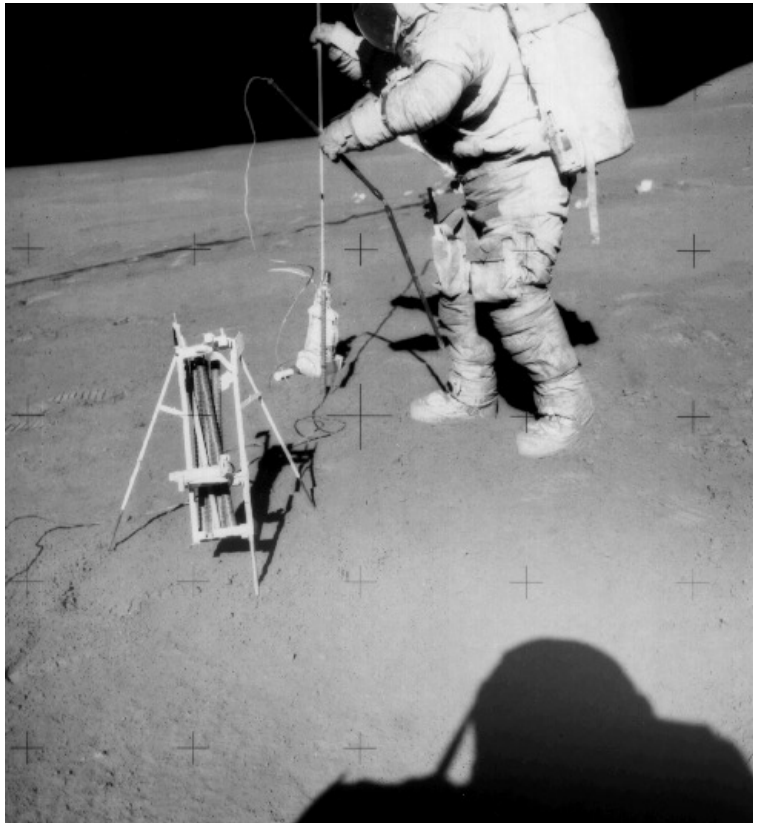
Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity (LISTER) heat flow probe flying to the Moon



S. Nagihara et al. (2020) “The Heat Flow Probe for the Commercial Lunar Payload Services Program Of NASA.” In LPSC 2020,

TRIDENT instrumented with heaters and temperature sensors passing through a slip ring

Heat Flow Experiment on Apollo 15 and 17



https://www.lpi.usra.edu/lunar/missions/apollo/apollo_15/experiments/hf/

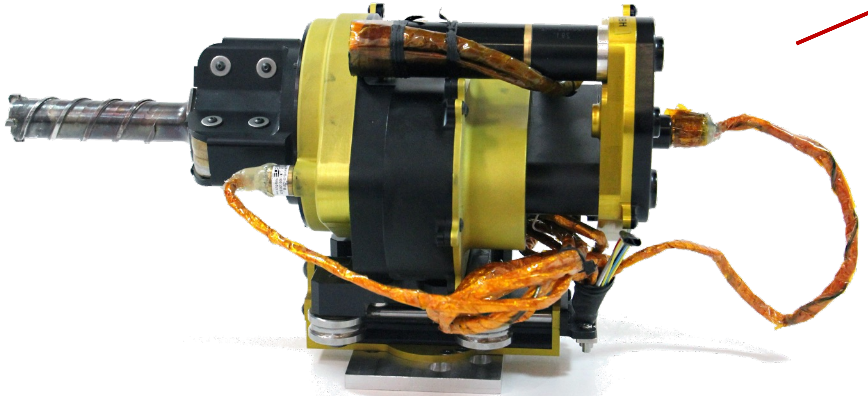
Instrument – Drill and Linear Stage

The drill is also an instrument.

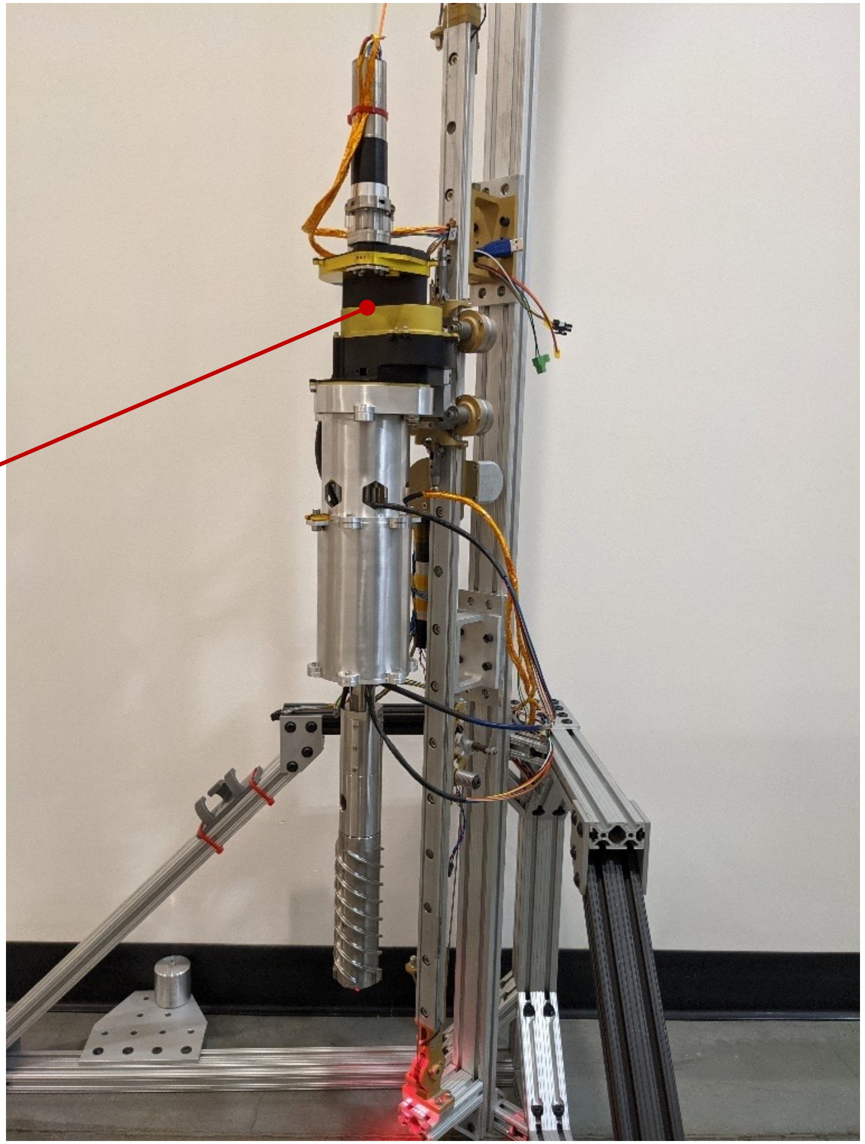
- Feedback from the linear stage and auger motors can be used to determine regolith strength
  (ice cemented lunar regolith much harder to drill through than dry powder)

SMART prototype uses an older Honeybee drill named RANCOR (one of the precursors to Mars 2020 drill)

- Future iterations will use a more customized design



Honeybee Robotics
RANCOR drill

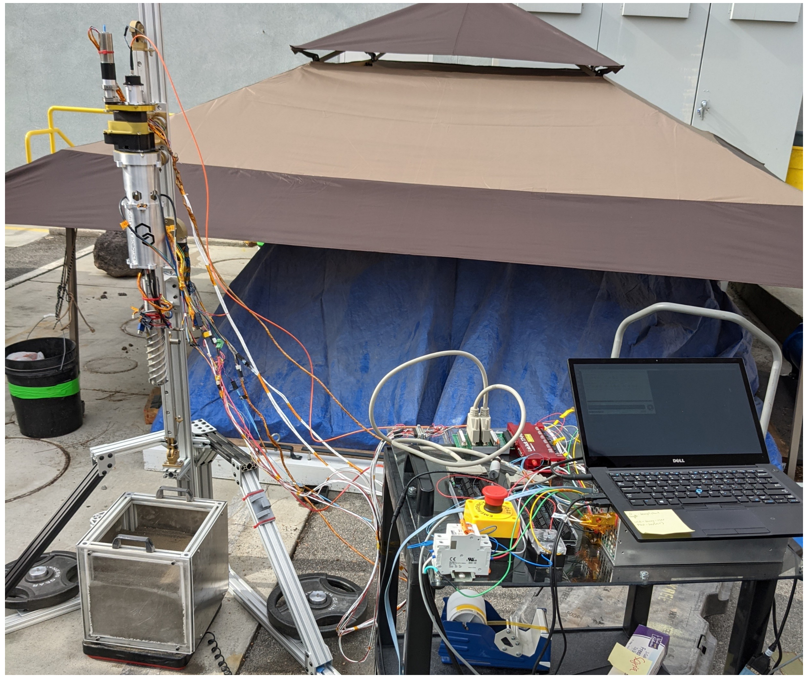


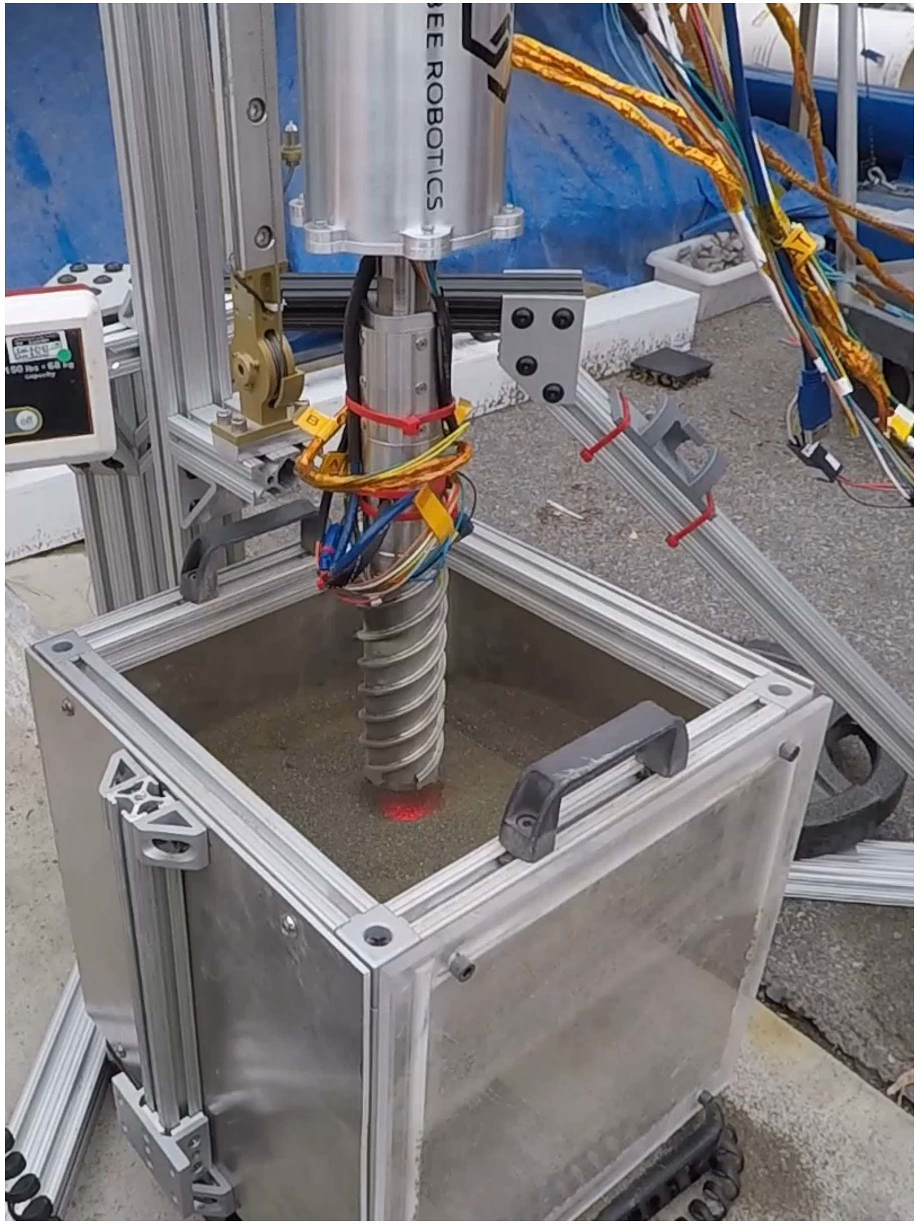
RESOURCE

Assembly and Testing to Date

HONEYBEE ROBOTICS
Exploration Technology

A majority of the hardware has been assembled and a functional drilling test has been completed in loosely compacted JSC-1a.





What's next:

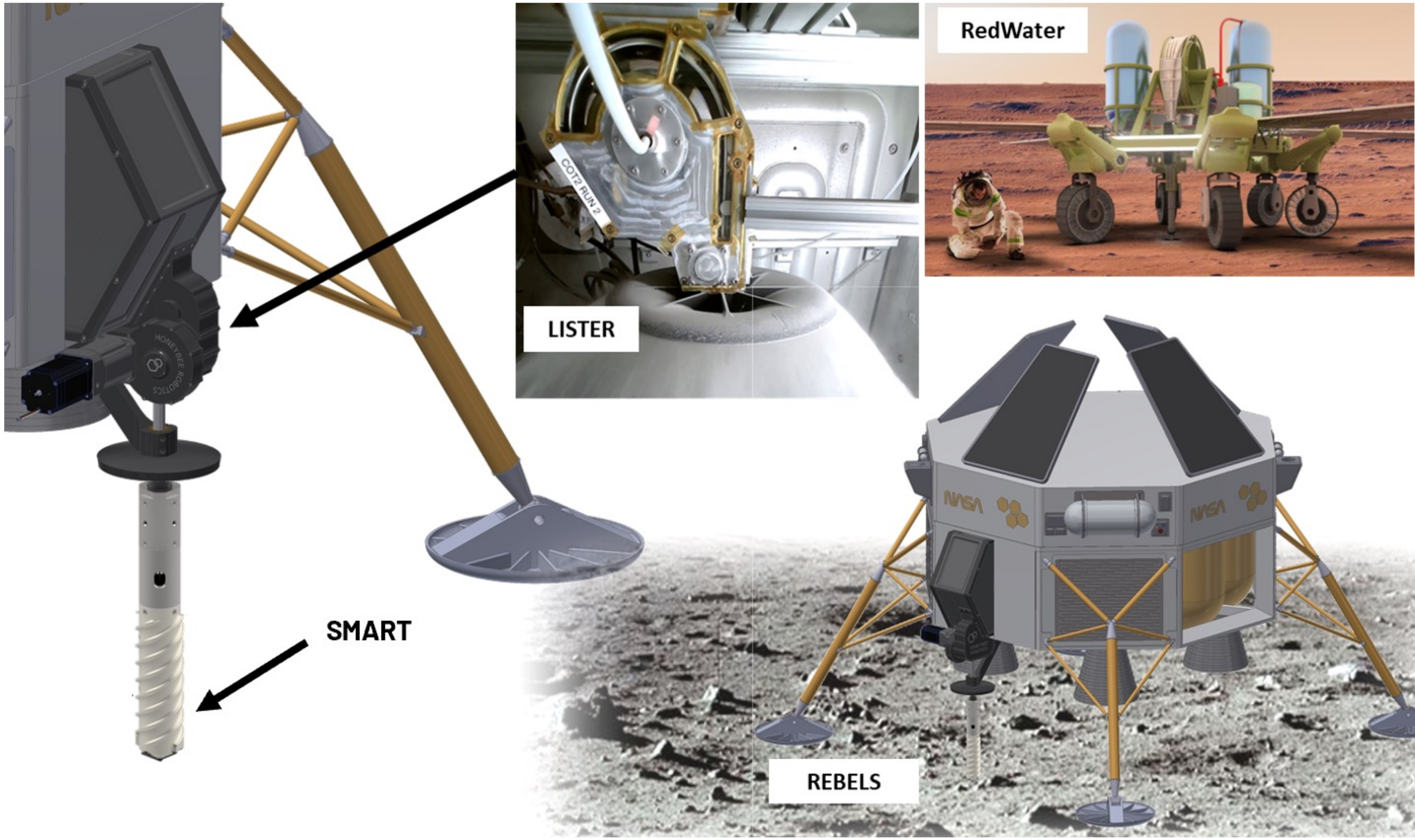
- Instrument integration
- Testing in lunar environments

Looking Ahead

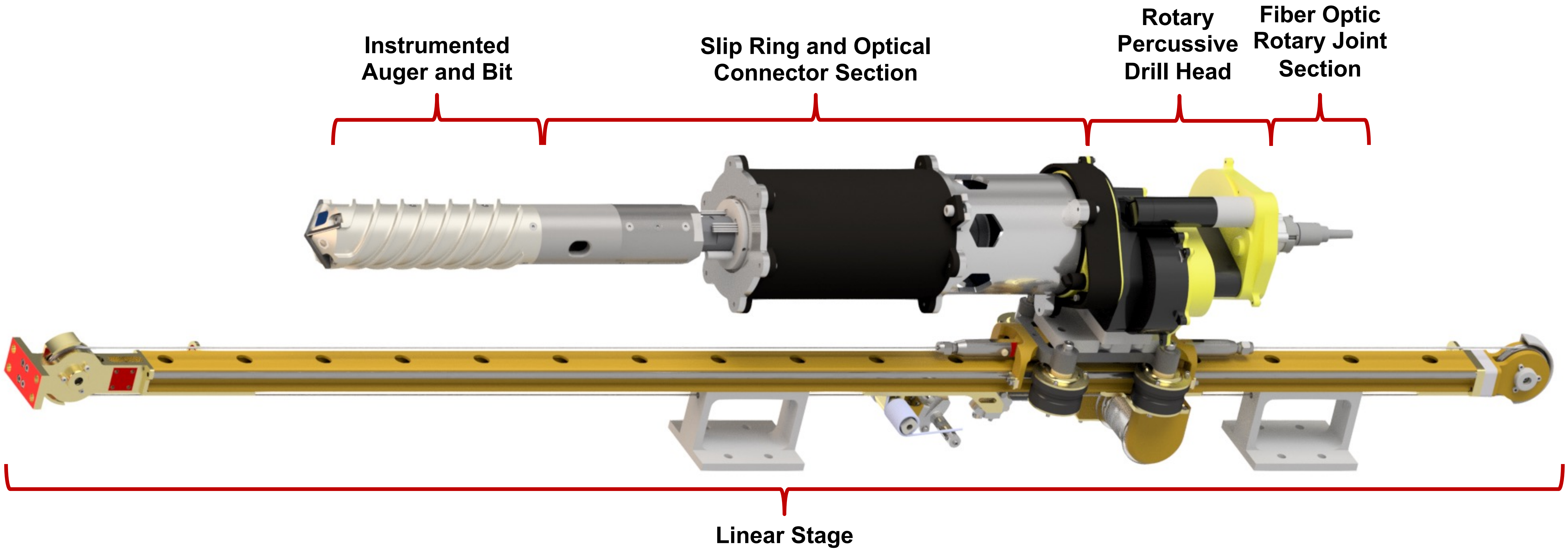
SMART can be mounted to a lander, rover, or even be adapted as a handheld system for the high grading on the lunar surface as part of the Artemis program

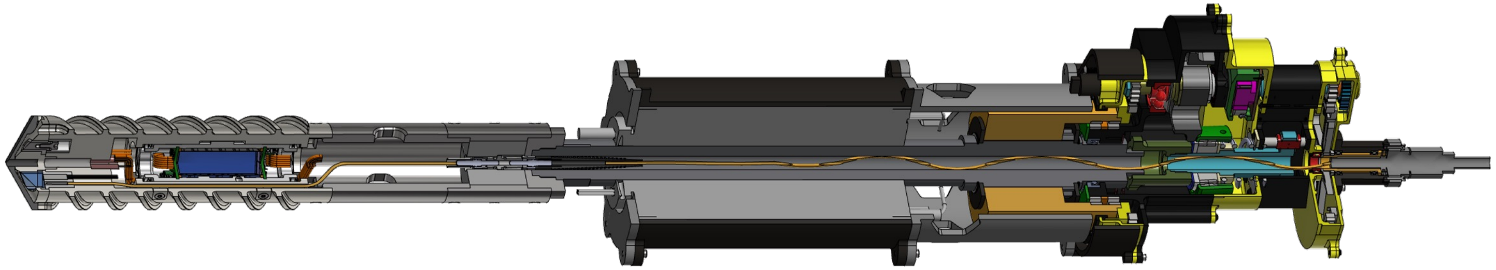
Sensor payload can also be repurposed for other missions such as: Rapidly Excavated Borehole for Exploring Lunar Sub-surface (REBELS)

- 10 m scale drilling system designed for in situ science below the lunar surface
- Combines technologies from existing Honeybee projects



SMART Prototype Design Overview





Collaborators and References

- Work funded by RESOURCE: Resource Exploration and Science of Our Cosmic Environment
  - Led by Jen Heldmann
- Collaboration between Honeybee Robotics, NASA Ames, NASA JPL

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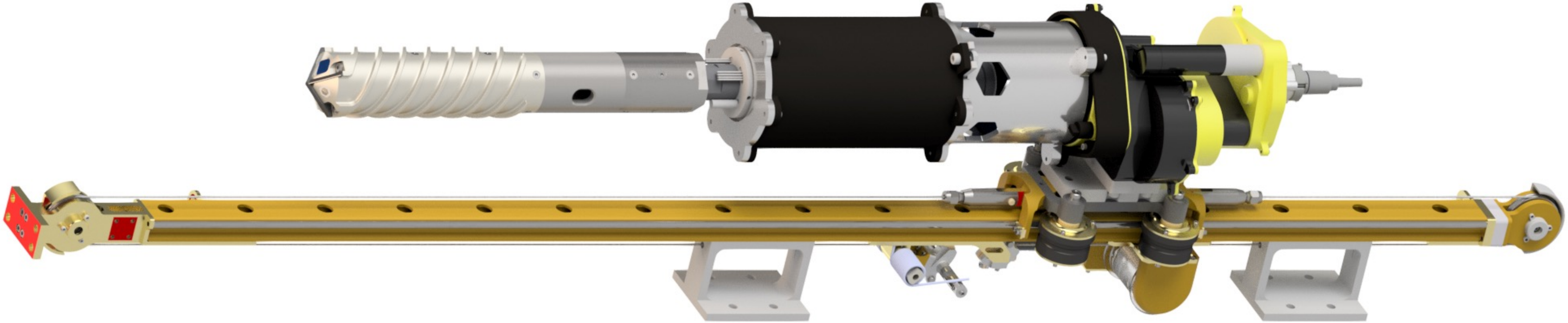
Questions?



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Thank you!