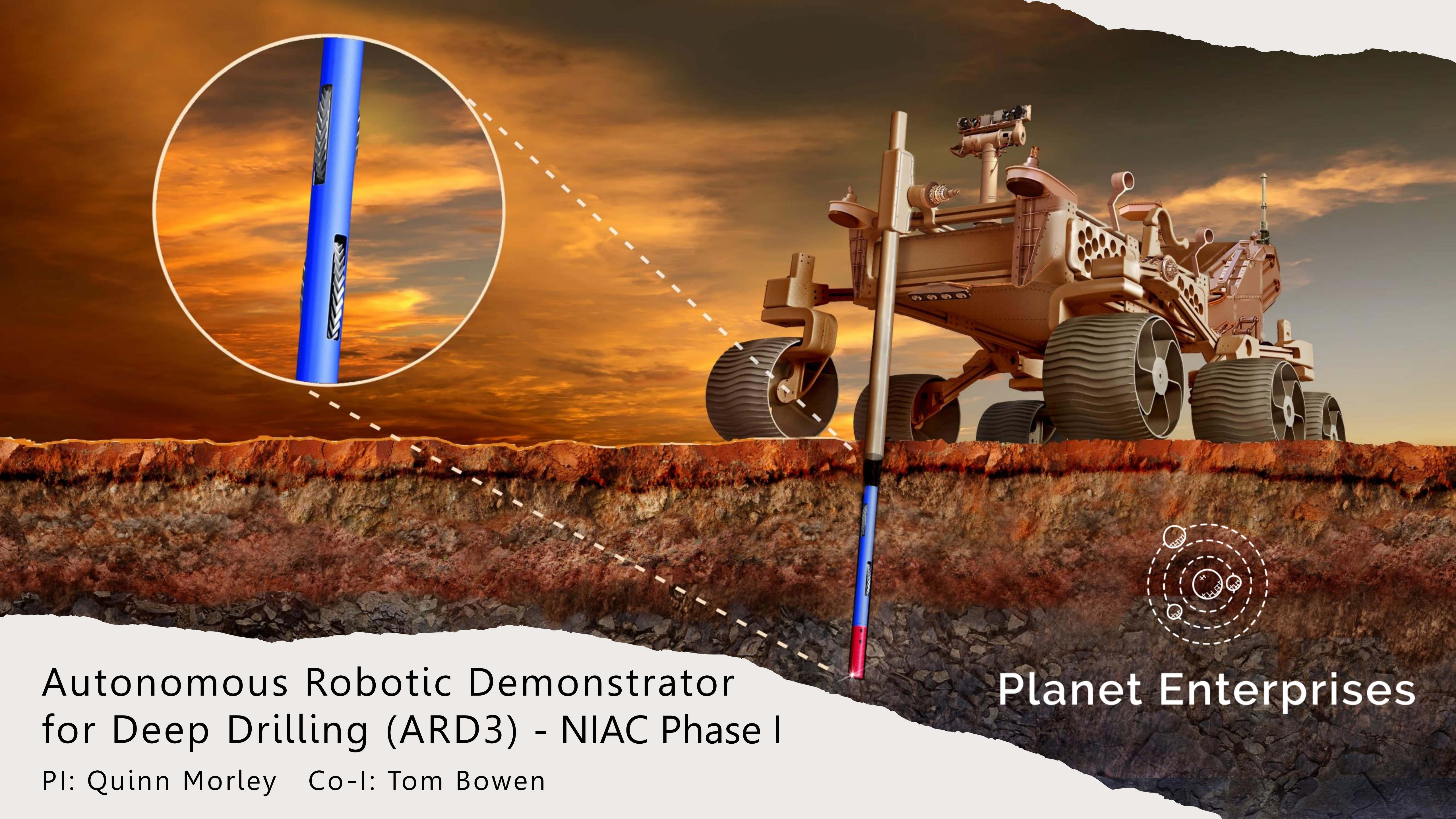

Autonomous Robotic Demonstrator for Deep Drilling (ARD3) - NIAC Phase I

PI: Quinn Morley   Co-I: Tom Bowen

Planet Enterprises

What are we trying to do?

- Drill 50 meters deep into the South Polar Layered Deposits (SPLD), an ice cap of Mars
- Analyze and cache ice cores
- Extended Mission: drill 1.5 kilometers deep
- Self-driving robots (borebots) “drive” up and down the hole, and take turns drilling

Why is it important?

- Mars’ polar caps can help us learn about the past climate of Mars, as well as the history of the solar system (including Earth)
- There may be liquid water under the cap

Autonomous Robotic Demonstrator for Deep Drilling (ARD3) - NIAC Phase I

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SPLD Characterization Summary

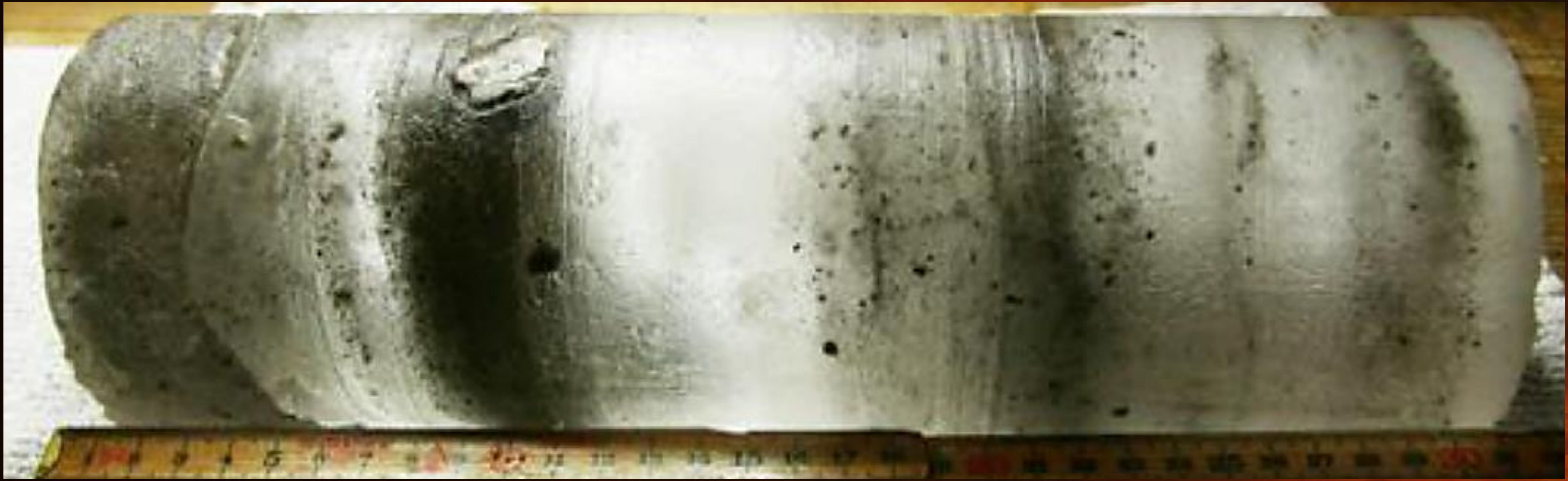
- A thick ice-cemented sublimation lag layer (on the order of 30 m) is one possible explanation for the fog effect that the SHARAD ground-penetrating radar instrument on the Mars Reconnaissance Orbiter (MRO) sees in the SPLD

- Zuber et. al claim the SPLD are "clean" water ice with 15% dust; Li et. al showed that this is indeed the case, but that large density variations exist

- No CO2 layers are expected in the stratigraphy below the top seasonal layer

To Summarize: the surface is likely hard, consolidated ice-bound dust/regolith that transitions to a hard and dense water ice with 5-25% dust content, which varies by layer. This result is <u>very favorable</u> in our context.

SPLD Ice Core Analog

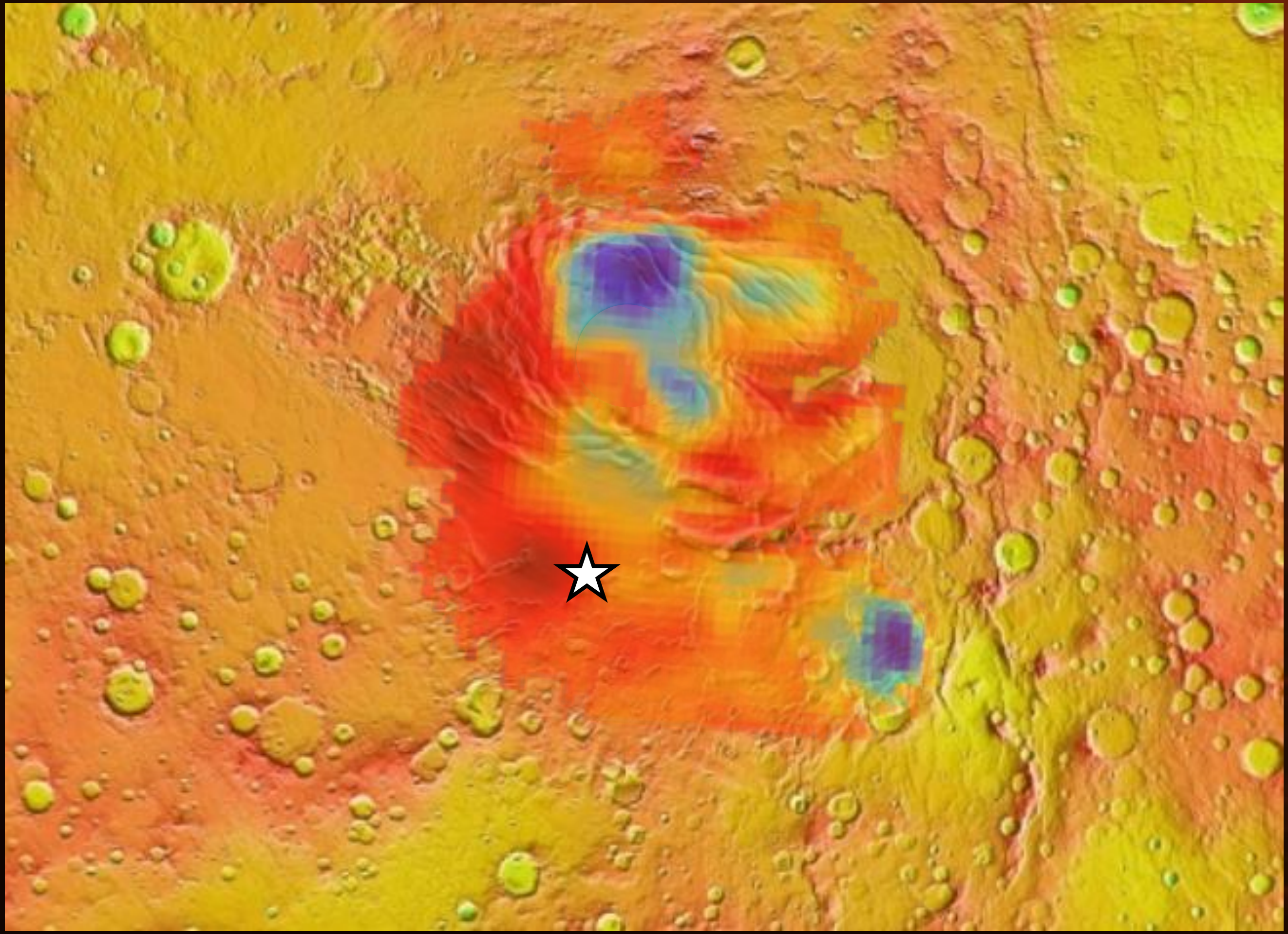


Ice core taken from the bottom of the NEEM borehole in Greenland

SPLD cores may be very similar (with more admixed dust) and are very likely to come up in pieces as seen here.

From: Smith, I. et al, “The Holy Grail: A road map for unlocking the climate record stored within the Mars [PLD]”

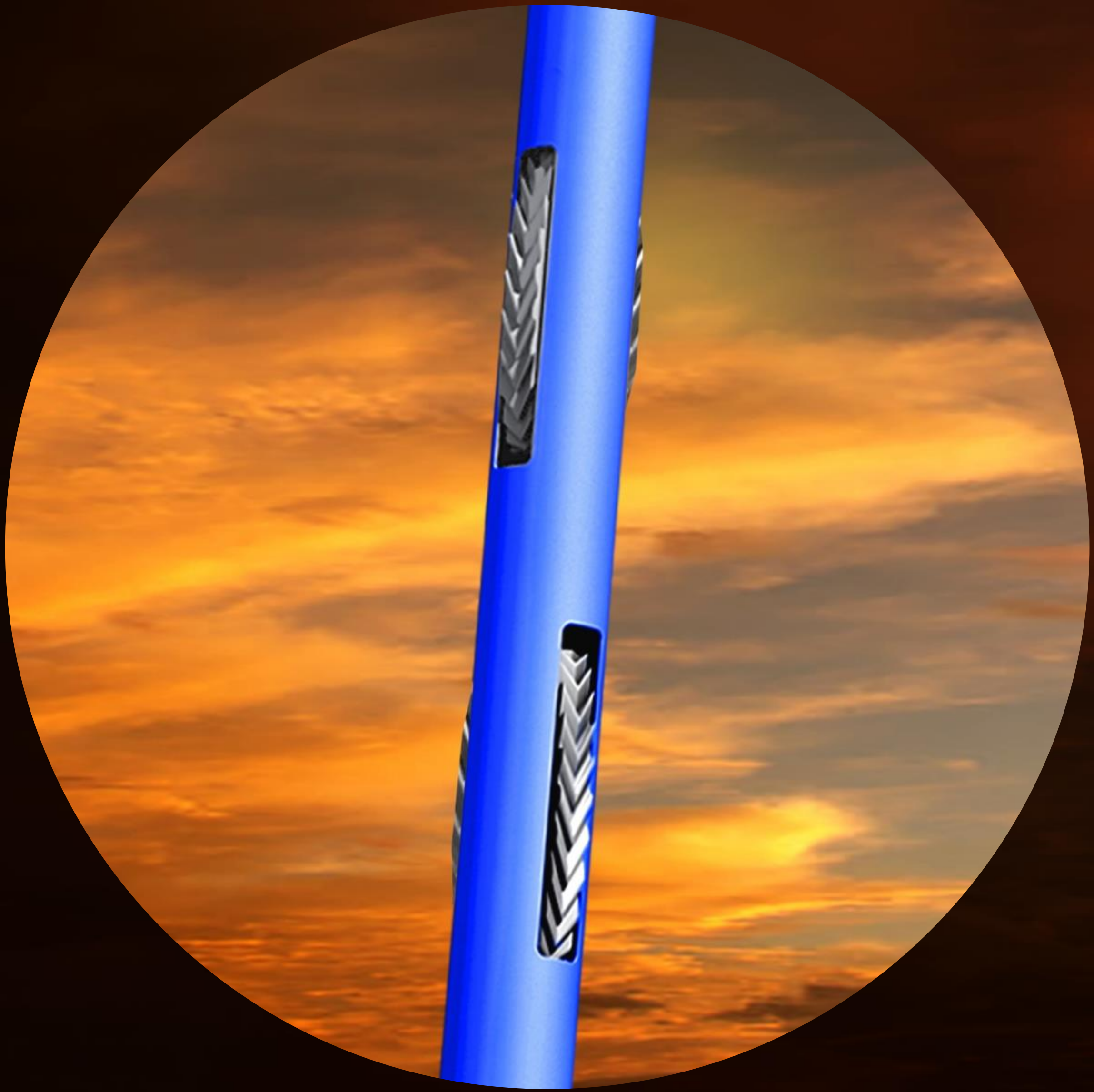
Potential Landing Site: -81.00° 193.00°



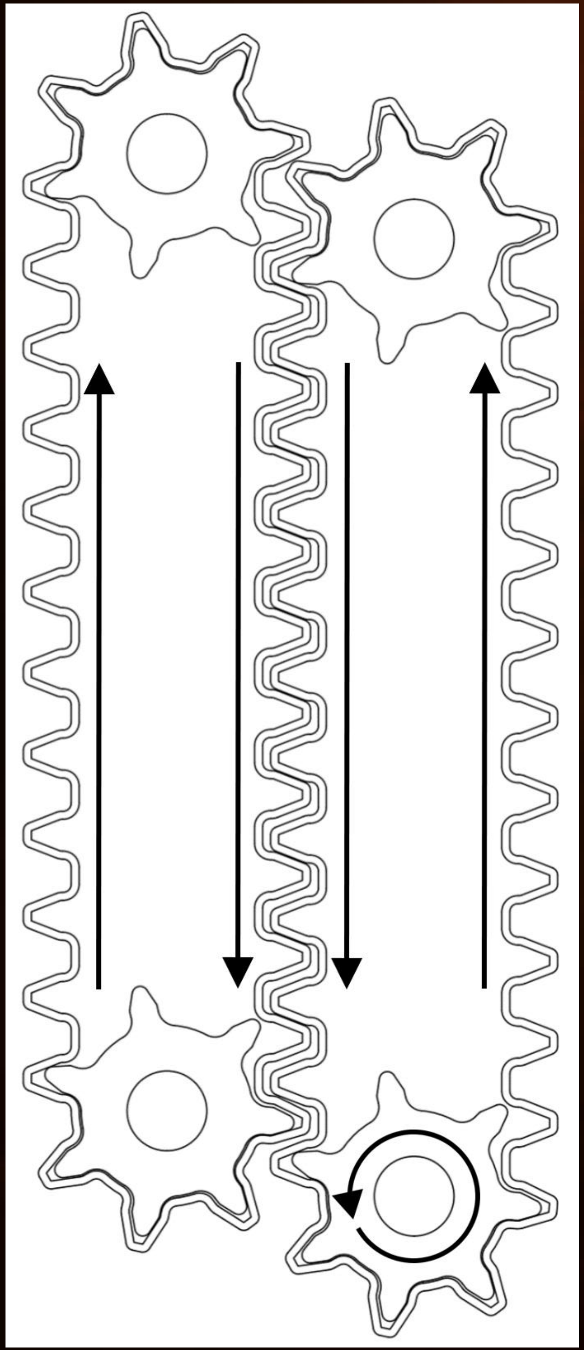
Density at potential landing site: 1200 kg/m^3 ± 100 kg/m^3
(Density overlay is figure 6-d, Li et. al 2012)

uahirise.org/ESP_066074_0990

Borebot Drivetrain



- Tank tracks shown are actually flexible ring gears
- As prototyped, the entire drive system is made of flexible components: small chunks of ice or rock could pass through without causing binding or failure
- This NIAC study is mainly focused on the feasibility of self-driving drilling robots *in the context of* SPLD deep drilling from a rover



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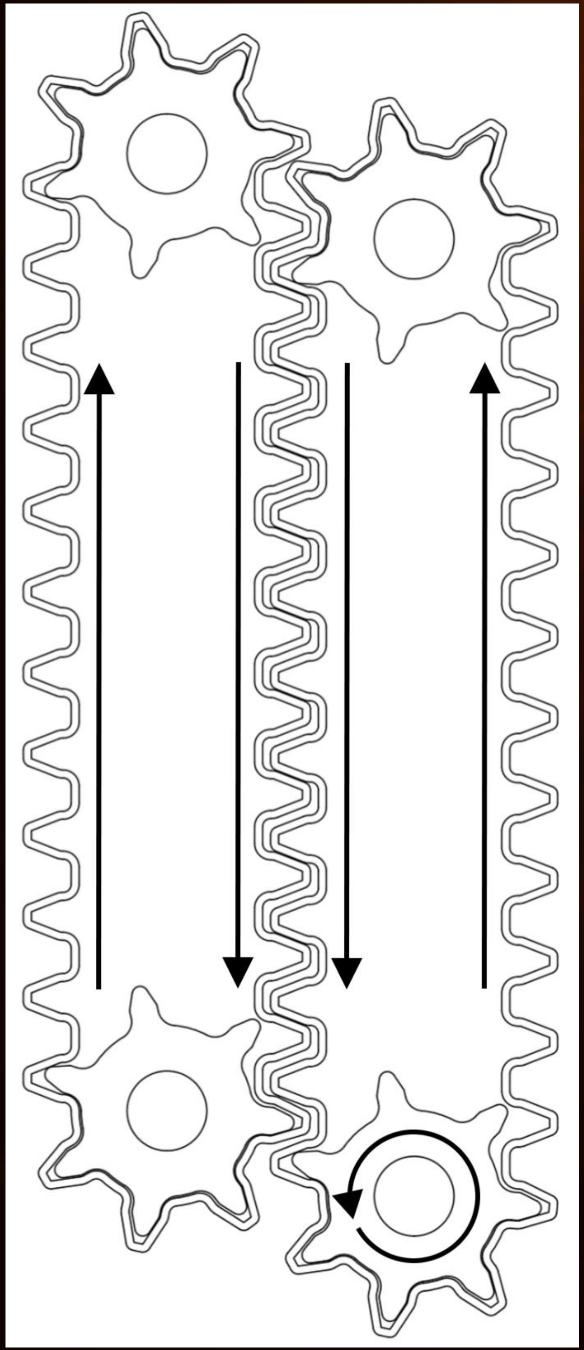

mp4 video https://git.io/JBbJ1

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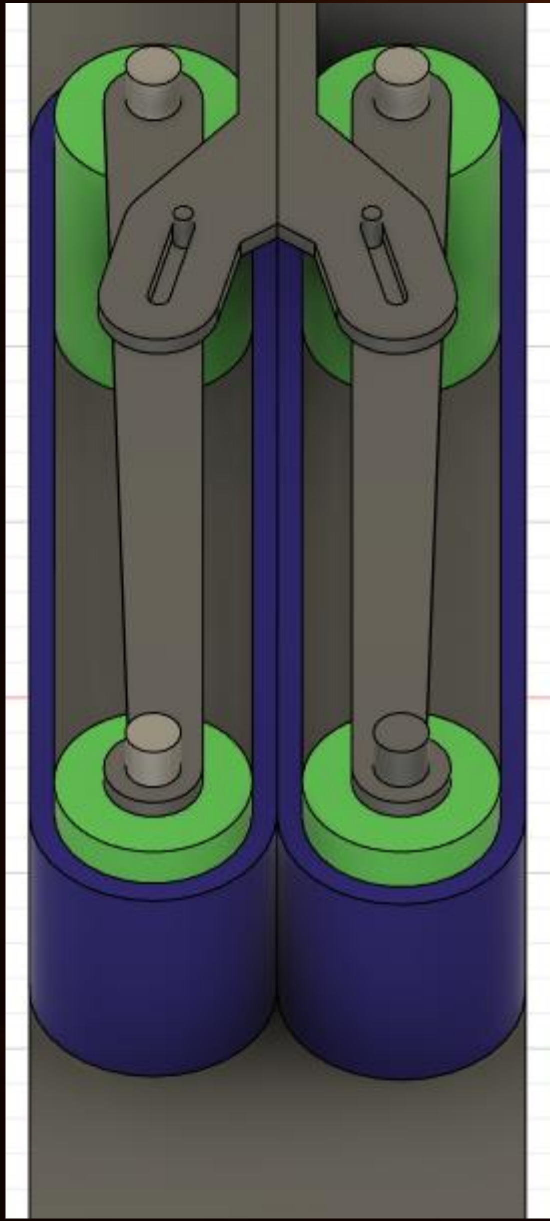
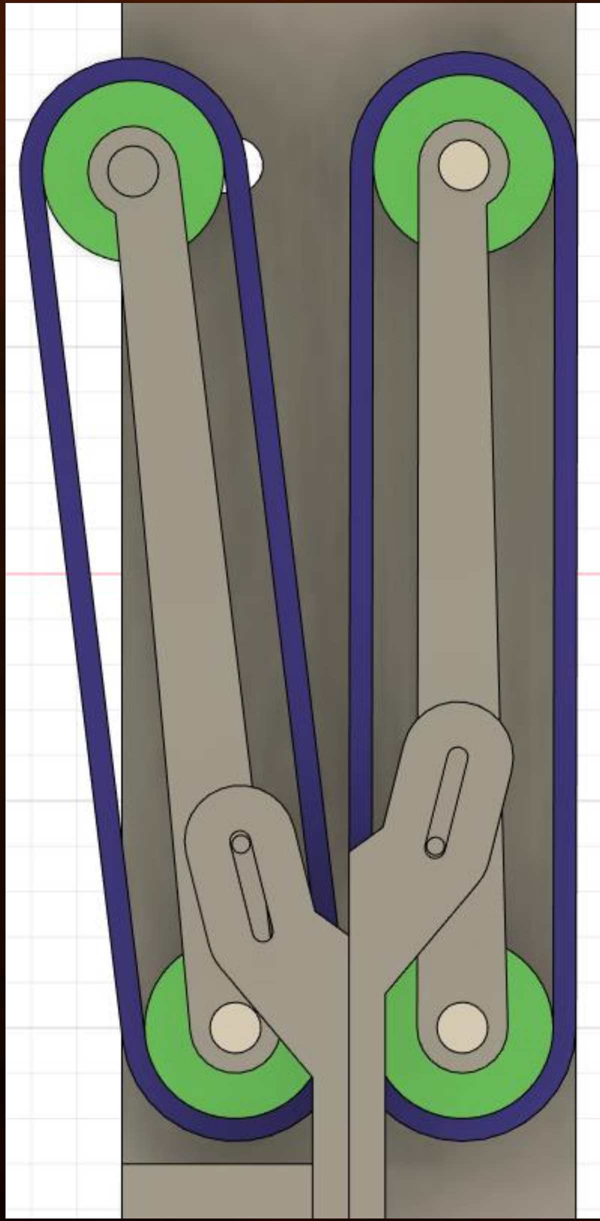
Borebot Drivetrain: Directional Drilling





- Kicking one end of a tread out can provide a slight drivetrain angle (on the order of 1 deg.) for steering the direction of the drilling operation

- Onboard accelerometers can be used to ensure the borehole is heading in the right direction, within set limits

- Greater kick-out can possibly allow entering/exiting branch boreholes if drilling around an obstruction or taking additional cores

Borebot Drivetrain: Directional Drilling

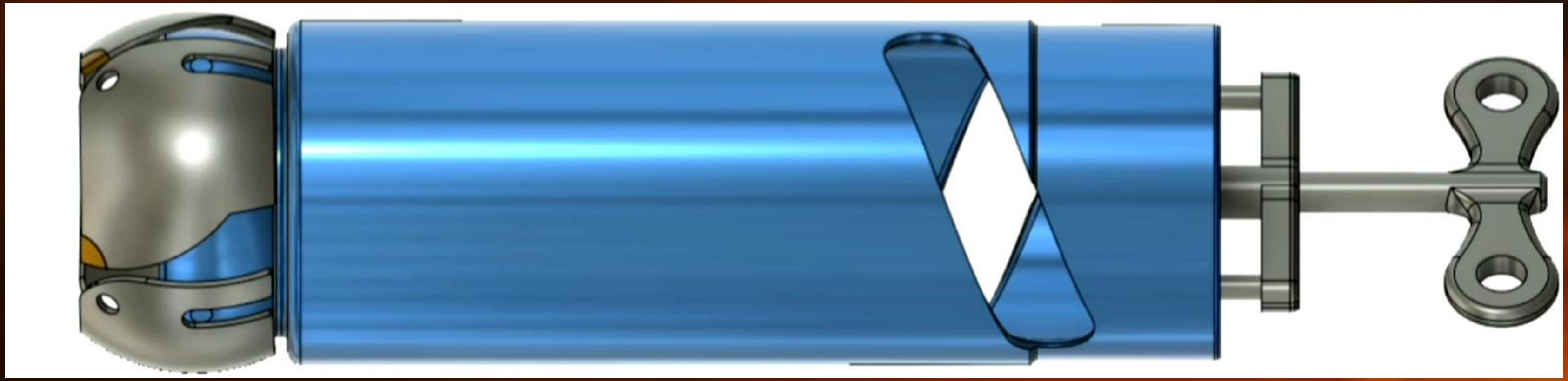
- Two borebot drivetrains could be joined together with an articulated joint, and use jackscrews for adjustment
- This concept could enable reliable, frequent branch borehole use and may have terrestrial applications, i.e., Earth science deep drilling in Antarctica
- On Mars, this could be used to mitigate a stuck borebot by creating a branch bore in order to bypass the blocked part of the bore

Mitigating Drilling Challenges – Crumbly Ice

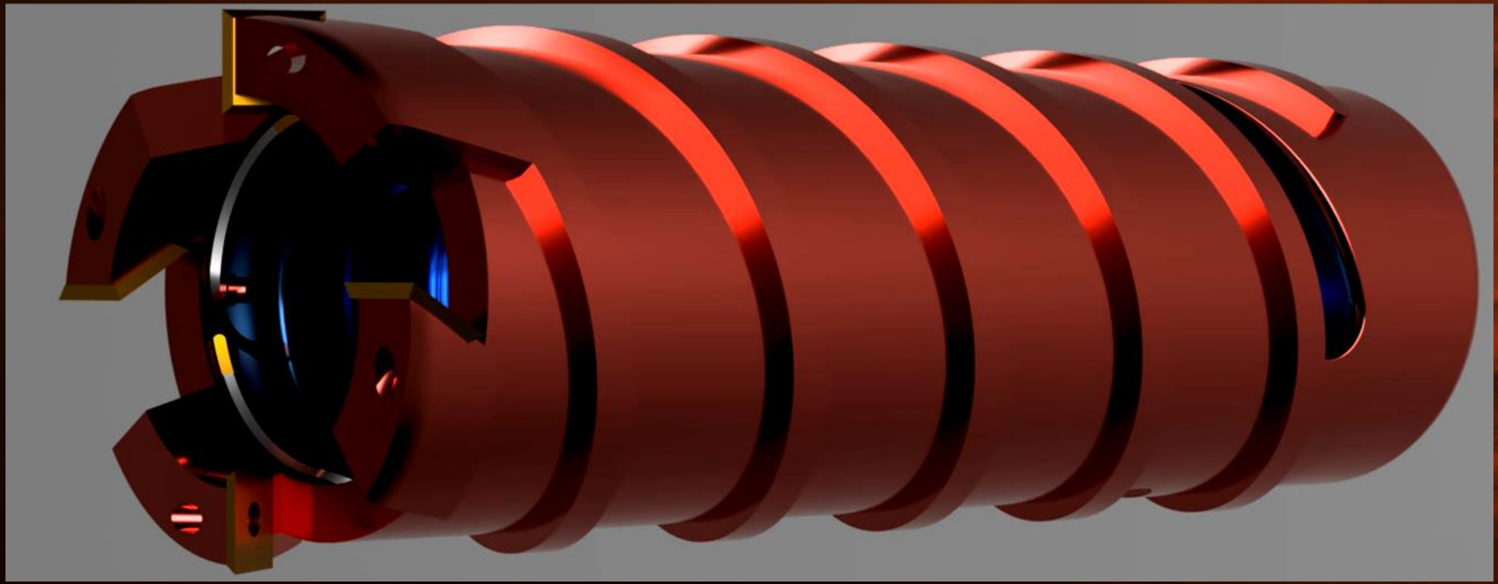
- This innovation enables reliable capture of crumbly/non-cohesive ice cores
- Carbide teeth are brazed onto a steel-bladed spherical iris
  - Low annular profile, can take a 40 mm dia. core
  - Larger diameter after throat (room for chips)
- The main drill motor is used to actuate the iris via a clever pin-puller strategy
  - Full drilling torque available to close iris
- A ratchet mechanism could hold the aperture while rotating the drill in order to cut hard/consolidated cores

Mitigating Drilling Challenges – Crumbly Ice

Use URLs to download .mp4 animations if viewing a PDF



https://git.io/JsPov



https://git.io/JsKah

Mitigating Drilling Challenges – Automation

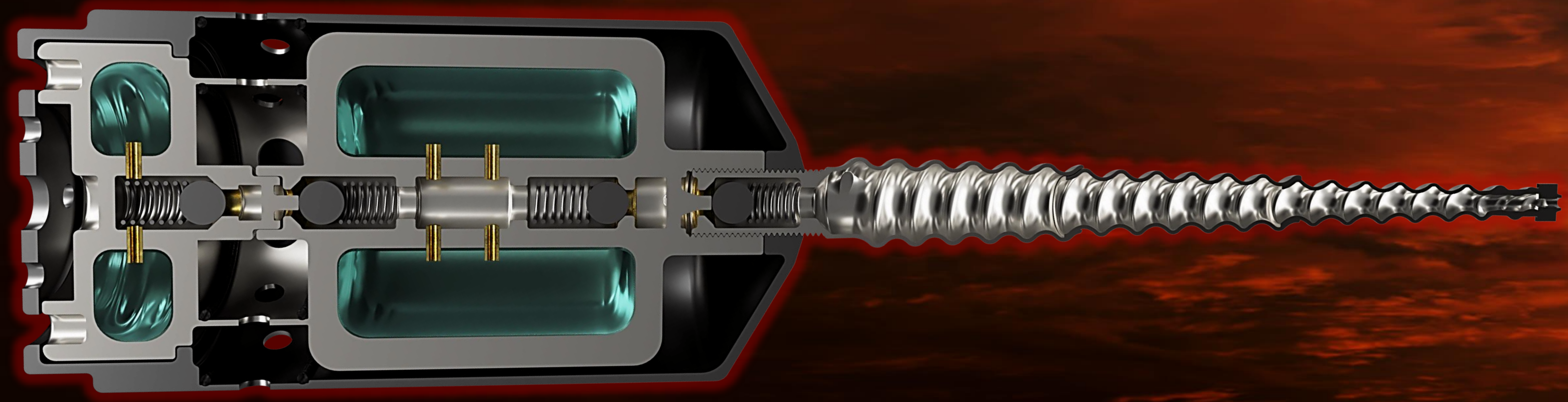
Continuous autonomous core drilling with a dozen robots operating sequentially completely changes the trade space:

- Time for core/chip removal, drill cleaning, and servicing is low-impact and can take place in dedicated bays
- Removal rates are less important, efficiency more so
  - Penetration rates as low as 15 cm/hr, targeted power < 15 W
- Trips to the surface are a science goal, not an inconvenience
- Max round trip time at 1.5 km depth, including drilling: 3.5 hrs.
  - This low speed still allows for a 4-year nominal extended mission, culminating in subglacial lake access
  - Target component lifespans to support 10,000 cycles / 10 years

Sampling Liquid Water on Another World

"Breakthrough" is a notorious phase of subglacial lake access, and is a major challenge for our extended mission goal.

As a mitigation measure, we calculated the thickness required of an ice "plug" in order to prevent breakthrough (see next slide) and developed a penetrator probe instrument to perform the final subglacial access and extract a liquid water sample. The required ice thickness to prevent breakthrough is about 4 cm.



Sampling Liquid Water on Another World

Ref. Arnold, N.S. et. al (2019), "Modeled Subglacial Water Flow …" Methods section for $\kappa = 1$.

Ref. K.F. Voitkovskii (1960), "Mechanical Properties of Ice," for shear strength estimate.

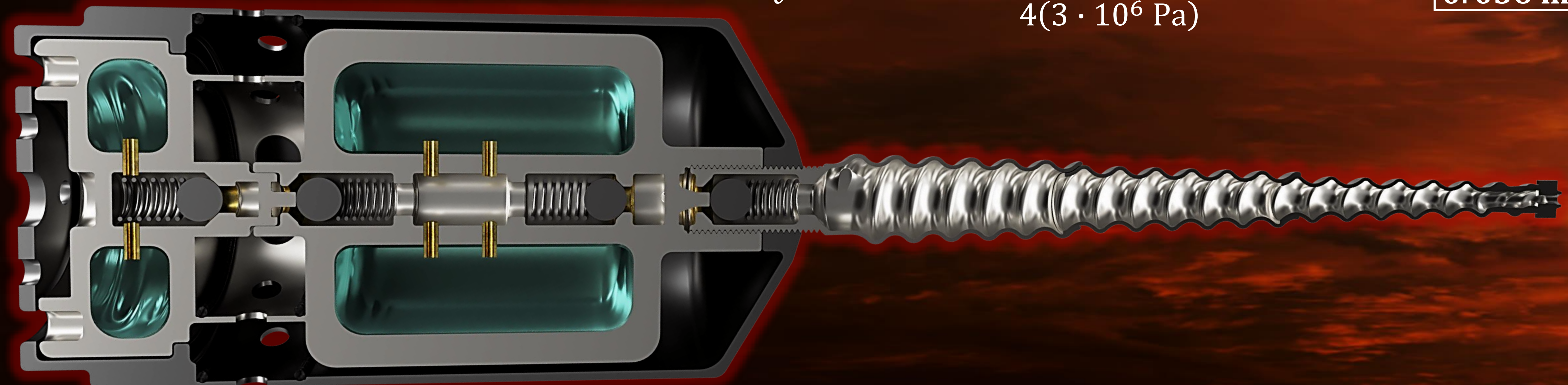
$\Delta P = P_{H_2O} - P_{atm} \quad \rightarrow \quad \Delta P \approx P_{H_2O}$

Shear strength S for water ice at 200 K: **3.0 MPa** (conservative)

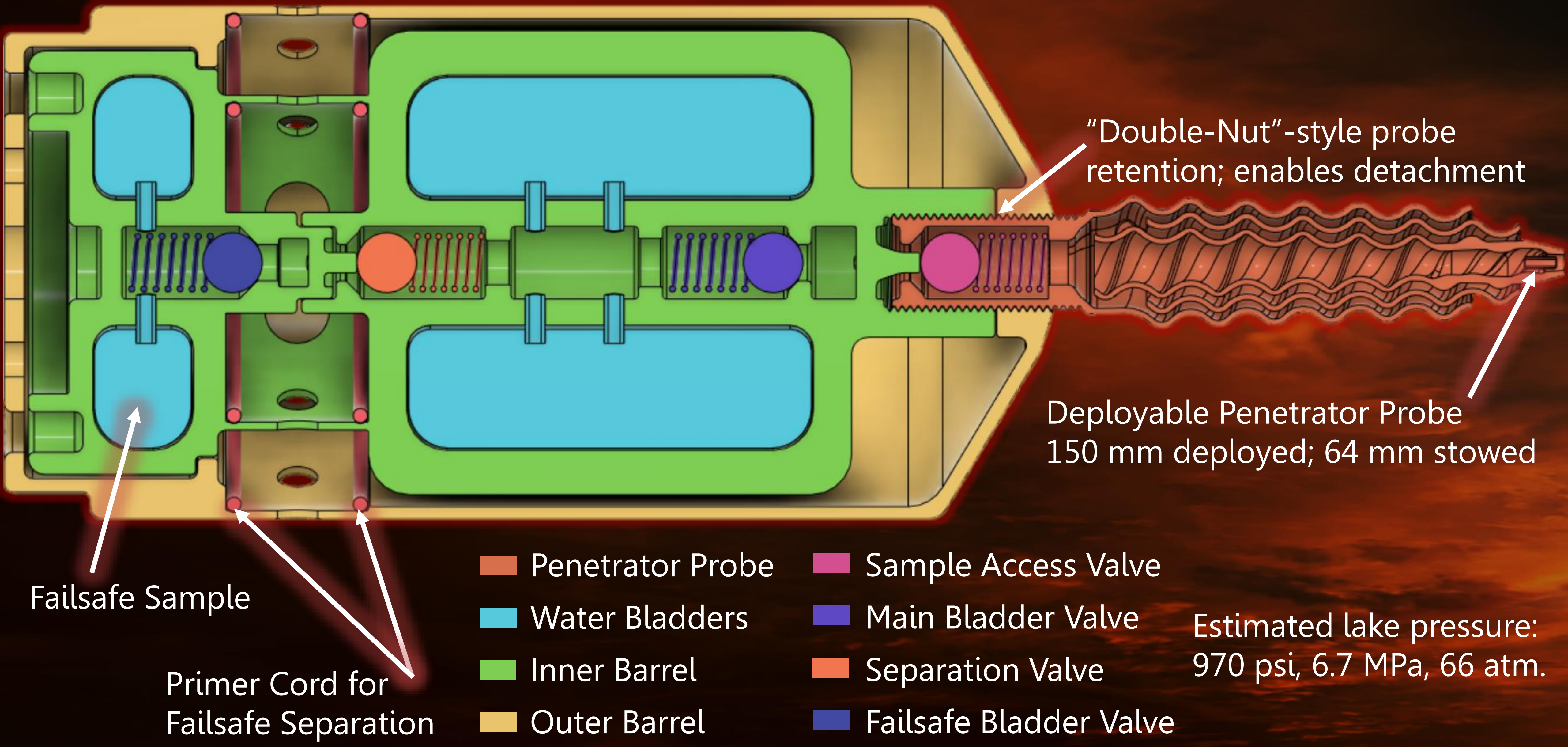
$F = L \cdot t \cdot S$ (Punching force equation), L is perimeter of shape

$$t = \frac{F}{LS} = \frac{P_{H_2O} \cdot A}{\pi \cdot D \cdot S} = \frac{P_{H_2O} \cdot \frac{\pi}{4} D^2}{\pi \cdot D \cdot S} = \frac{P_{H_2O} D}{4S} = \frac{\kappa \rho_{ice} g h D}{4S} = \frac{\boldsymbol{\rho_{ice} g h D}}{\boldsymbol{4S}}$$

$$t = \frac{\left(1200 \frac{\text{kg}}{\text{m}^3} \cdot 3.71 \frac{\text{m}}{\text{s}^2} \cdot 1{,}500 \text{ m}\right)(0.064 \text{ m})}{4(3 \cdot 10^6 \text{ Pa})} = \boxed{\mathbf{0.036\ m}}$$

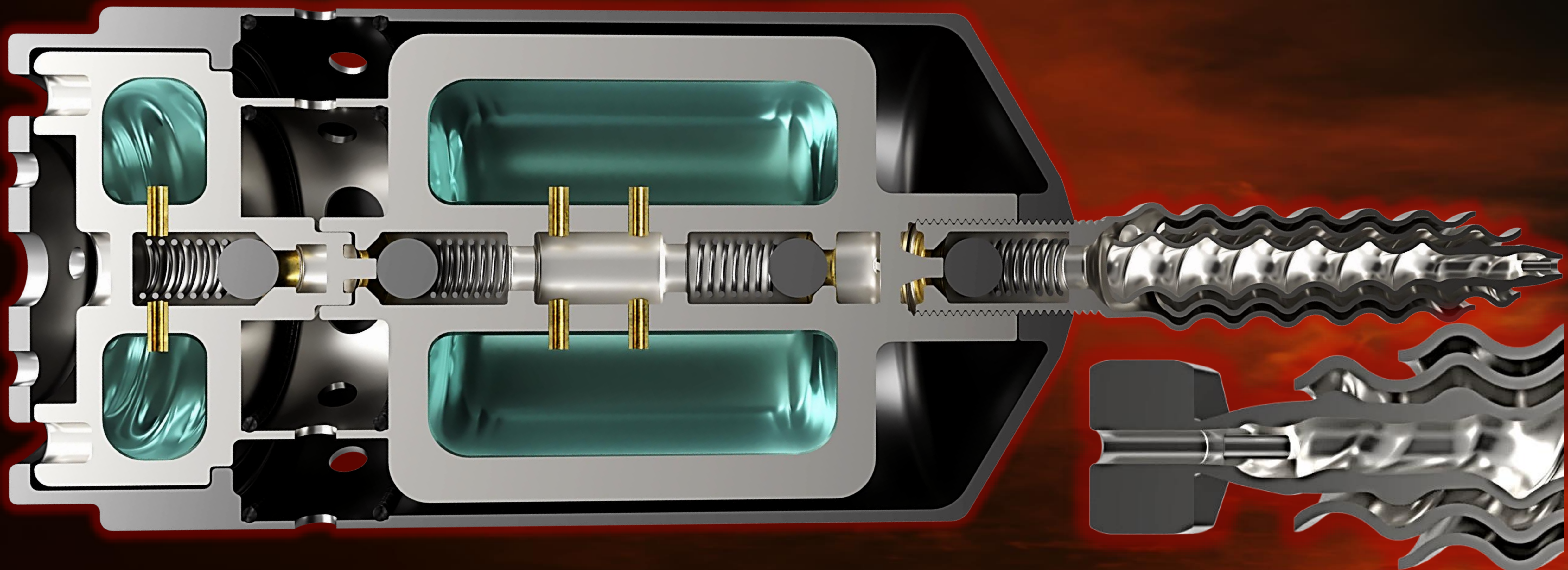


Sampling Liquid Water on Another World



Estimated lake pressure: 970 psi, 6.7 MPa, 66 atm.

Sampling Liquid Water on Another World



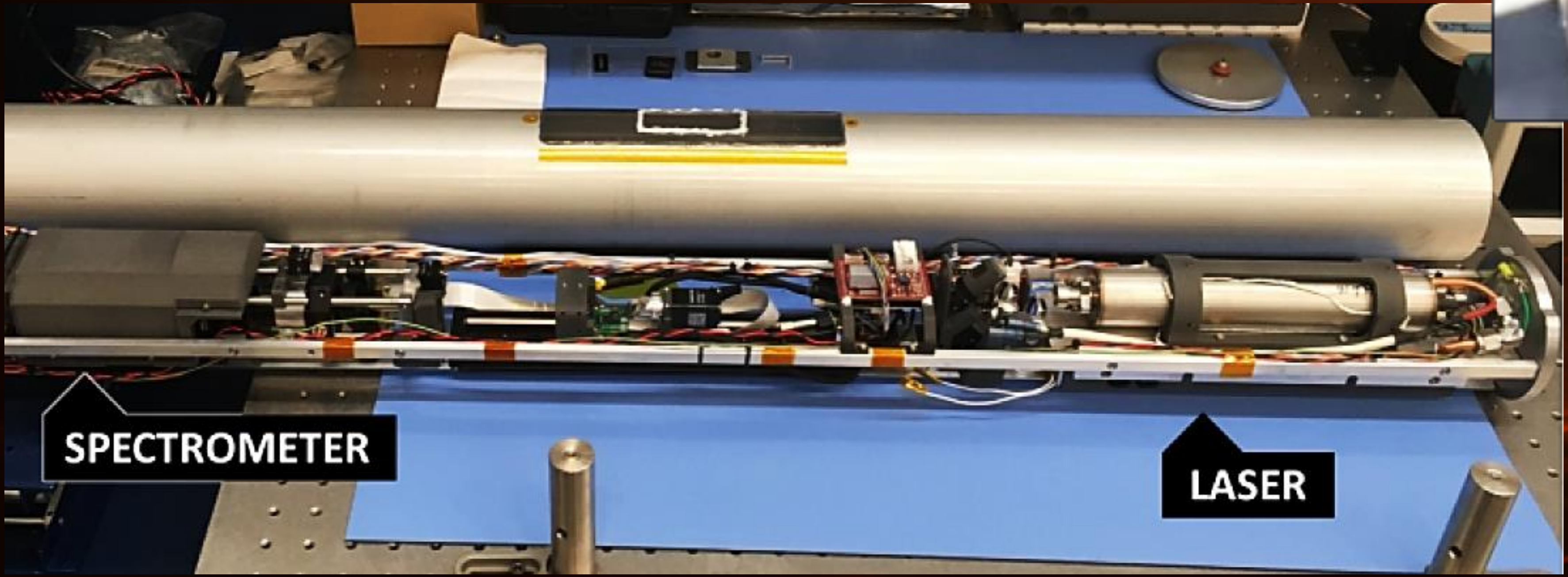
- The Penetrator Probe deploys in-situ via counter-rotation of the borebot drill motor
- 10 mm shear-nut ensures proper torque for deployment and "setting" of the telescoping sections of the probe (this friction fit is critical), the nut breaks off when torque is reached
- A "nut pocket" on the rover's arm/chassis can hold the nut during deployment

Science Instruments

Downhole Instruments

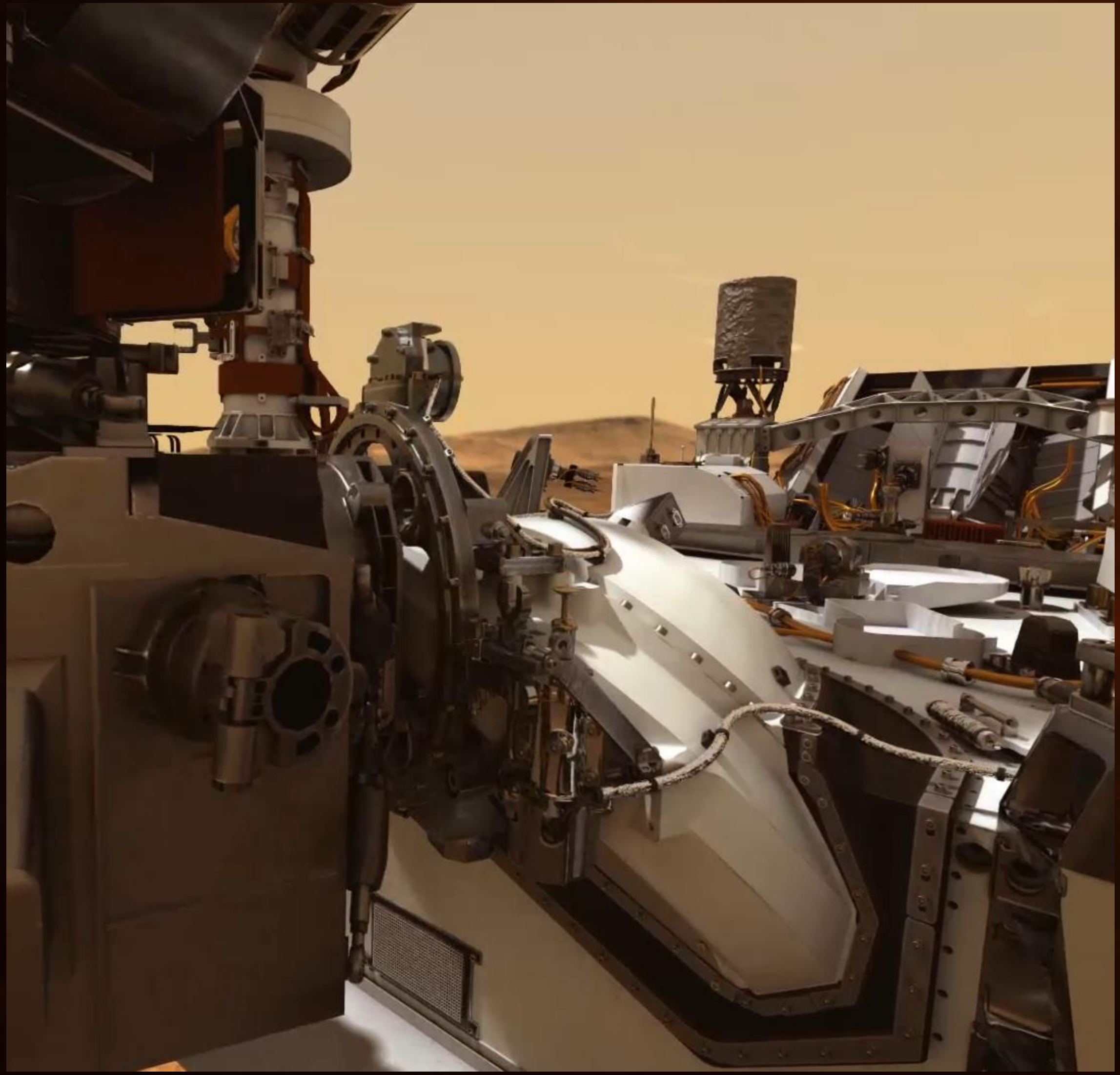
- Microscopic imager (white and UV light), seen right
- WATSON Deep UV Raman Spectrometer, seen below
- Ice conductivity measurement
- D/H hydrogen ratio measurement
- Sonar for ice thickness and density

Zacny, K. et. al, 2016.
doi:10.1061/9780784479971.027



Eshelman, M. et. al, 2019.
doi:10.1089/ast.2018.1925

Science Instruments

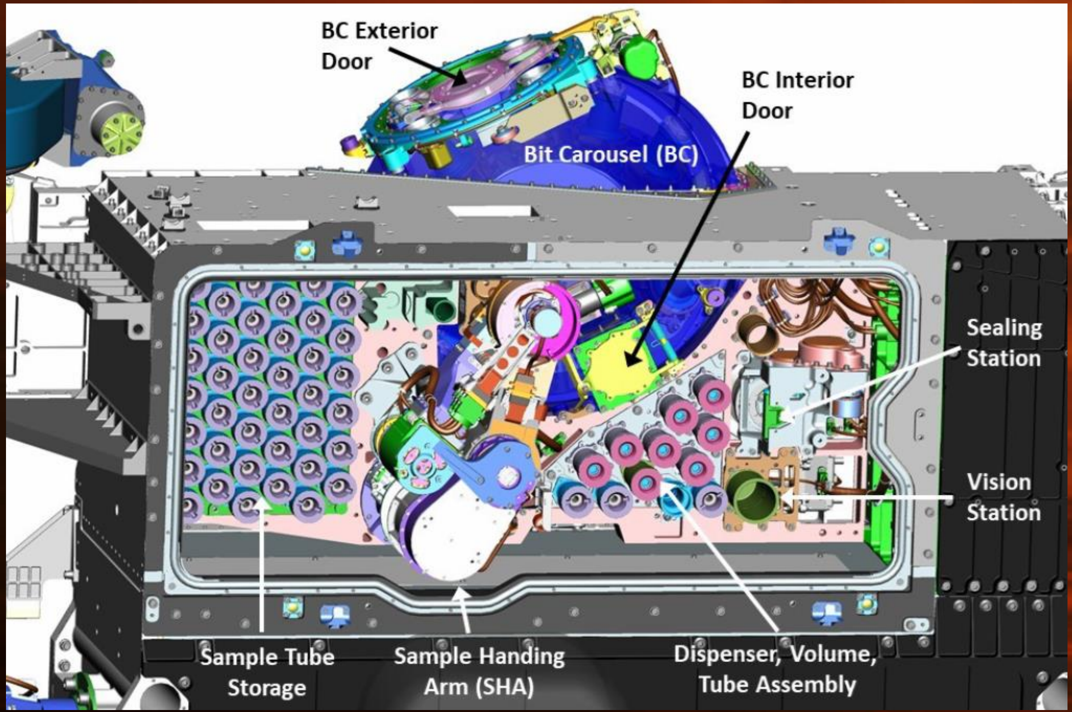


https://mars.nasa.gov/mars2020/multimedia/videos/?v=423

Rover Instruments

- The Perseverance Adaptive Caching Assembly (ACA) is used
  ↳ Handoff from ACA to internal rover science payload

- The "Turret Corer" is moved from robot arm to rover chassis
  ↳ Will now re-core ice cores to extract pristine core center

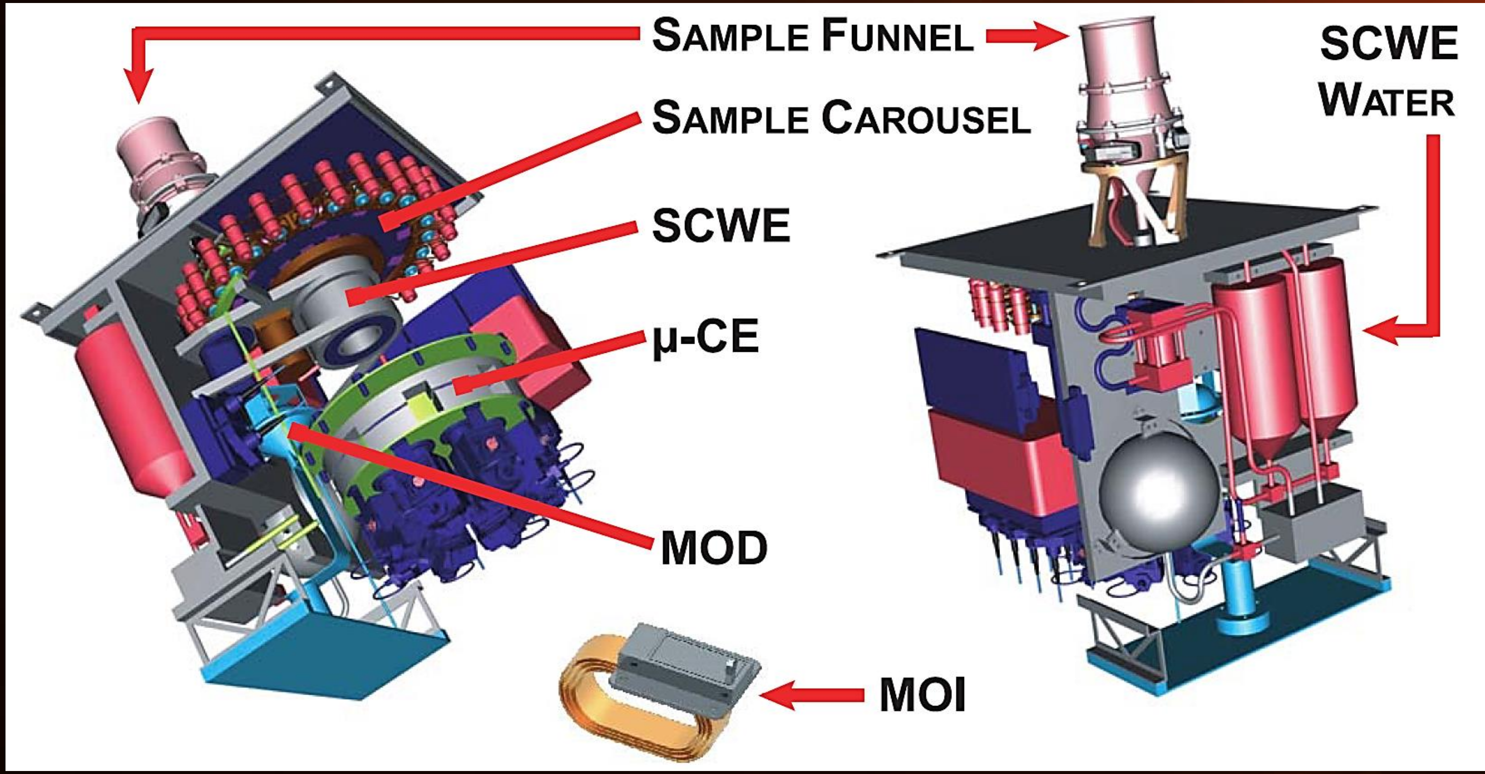


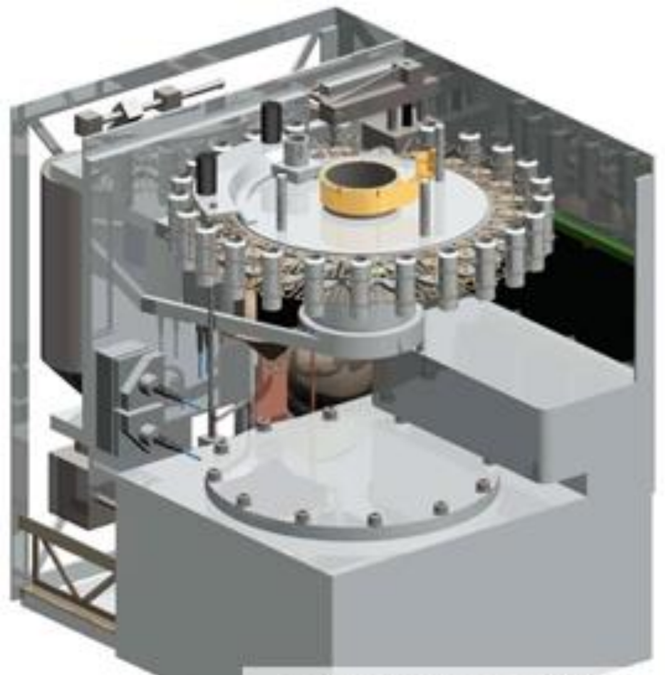
Boeder & Soares, 2020.
doi:10.1117/12.2569650

Science Instruments

Rover Instruments

- Urey life detection instrument (in the space used by MOXIE on Perseverance)
- Raman UV Spectrometer (added to ACA vision station, or external [SHERLOC])
- Ice core melting station, with mass spectrometer analysis of released gasses





Urey instrument for life detection

Aubrey, A., et. al. (2008). “The Urey Instrument: An Advanced In Situ Organic and Oxidant Detector for Mars Exploration.” doi:10.1089/ast.2007.0169

Thanks for Watching!

- Please reach out via email if you have any questions or comments

- Thanks to the NASA Space Technology Mission Directorate and the NIAC Program for this incredible opportunity

- Special thanks to Dr. Kris Zacny, Dr. Chris Dreyer, Dr. Mike Malaska, Dr. Peter Buhler, Dr. Than Putzig, and Laura Forczyk, MSc for their help and support

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