# Sample Handling and Drilling Technologies for Mars and Ocean Worlds

KISS workshop

*Targeting Microhabitats for Life Detection*

Dr. Kris Zacny,
*Vice President, Exploration Systems*
*Honeybee Robotics*

19-24 September 2022

HONEYBEE ROBOTICS

ISO 9001 CERTIFIED

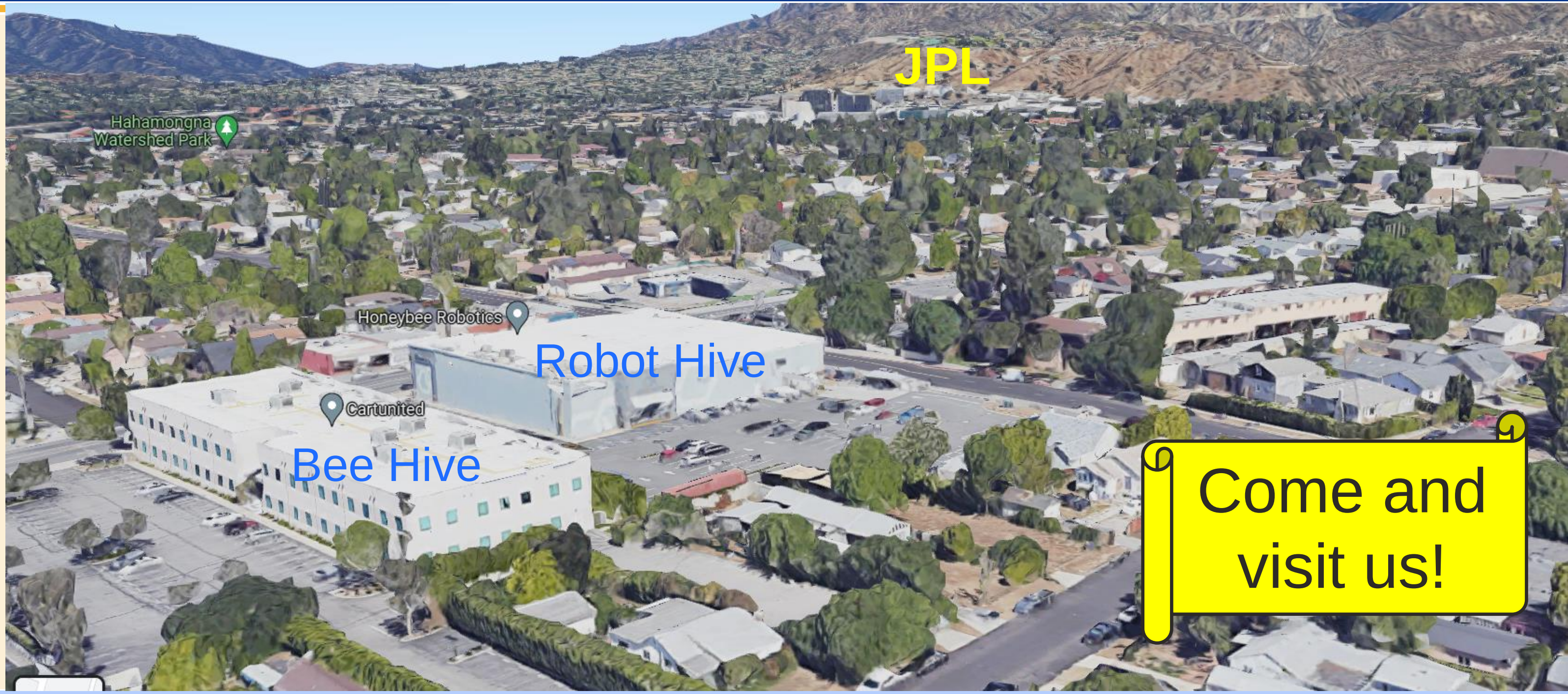
AS9100 CERTIFIED

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

# Introduction to Honeybee

# Honeybee Robotics – Altadena CA

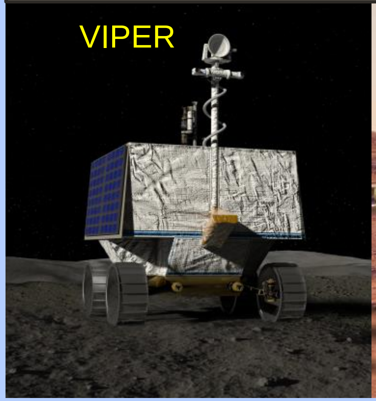
- Subsidiary of Blue Origin
- 400 employees and growing
- Two divisions:
  - Motion Control, Longmont CO
    - Actuators, SADAs, Sliprings
  - Exploration Systems, Altadena CA
    - Space Robots to find life, mine resources and explore our universe
    - We build systems (mechanical, avionics, software, mission operations)
    - We do Mission Operations (MSL, Dragonfly, VIPER) and Field experience (e.g., Antarctica, Greenland, Arctic, Atacama)




## Touch Life



## Mine the Sky

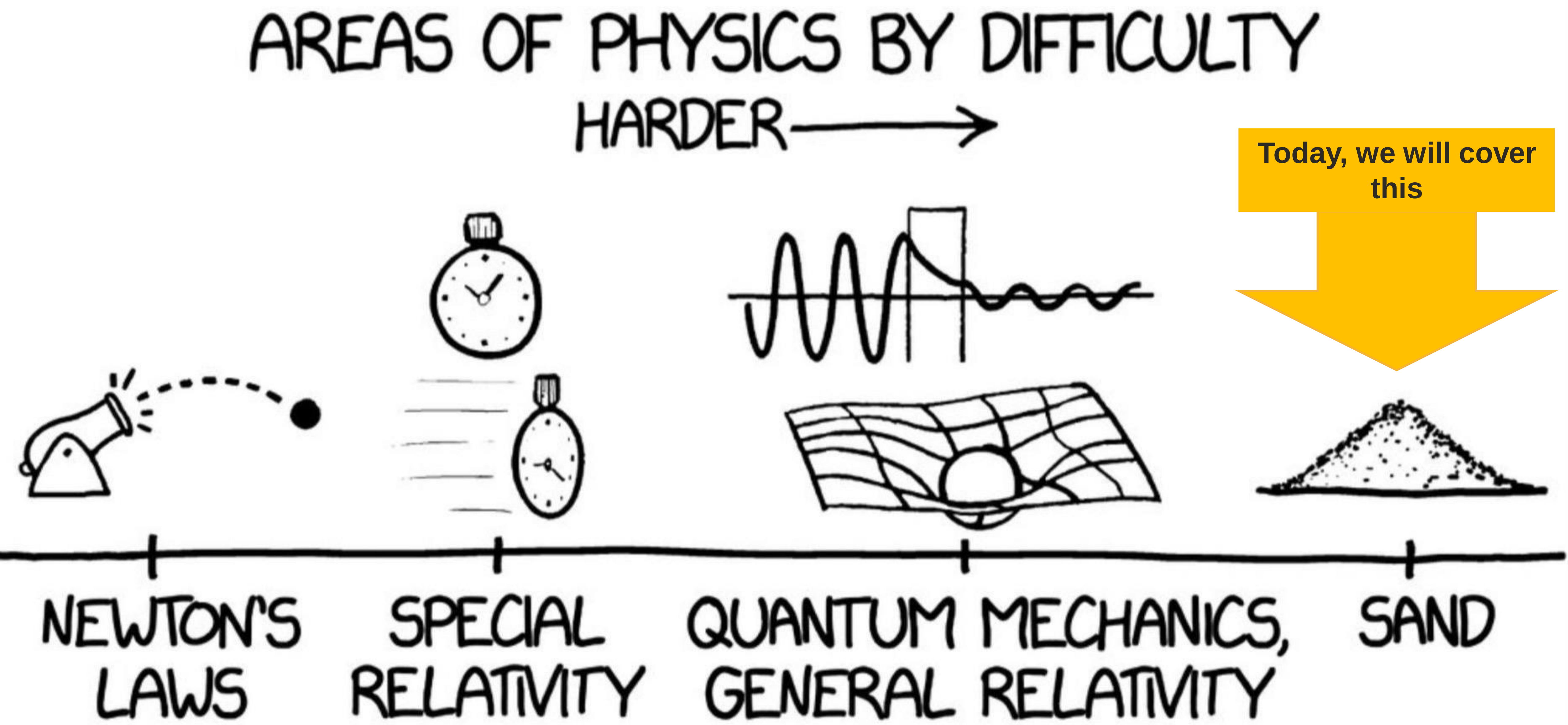




## Explore


HONEYBEE ROBOTICS
Exploration Technology

# Introduction to Sample Acquisition and Handling



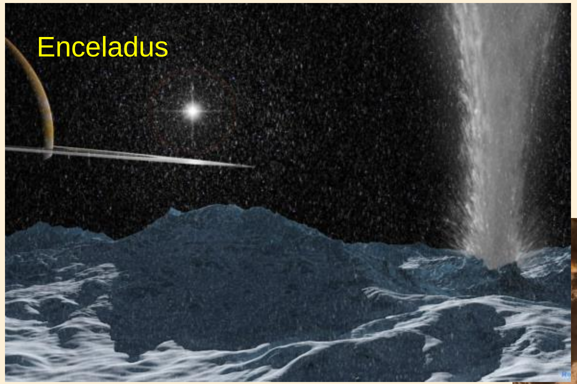

**Today, we will cover this**

# Challenges of drilling and sample handling

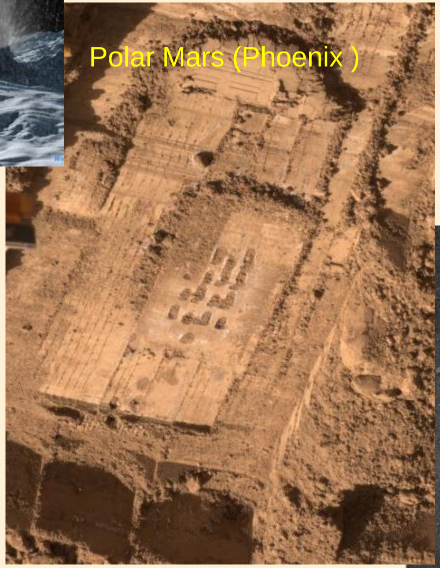
## Drilling / Sample Acquisition

- Drilling system needs to deal with "**geological uncertainty**" we won't know how sub-surface behaves until we get there. Stratigraphy changes on mm scale.
- Drilling system has to work with material strength spanning 100 Pa to >100 MPa (across **10^6** range), in addition to a range of depths.

100 Pa "snow"




50 MPa (icy-soil)




100 MPa (rock)


## Sample Handling

- Sample handling system has to do what **humans have hard time doing**: collect sample with various particle sizes and cohesion and put it inside a tiny cup or a tray
- Relying on gravity does not always works
- If sample is not presented in an optimal manner, the data will be compromised.

Sampling system and instrument is like **hand in glove** – there has to be a perfect fit

Imagine putting sand inside the straw

# Drilling / Sample Acquisition

# Past, Present and Future sampling missions to Mars and Ocean Worlds

HONEYBEE ROBOTICS
Exploration Technology

Timeline (Decades)

2000s 2010s 2020s

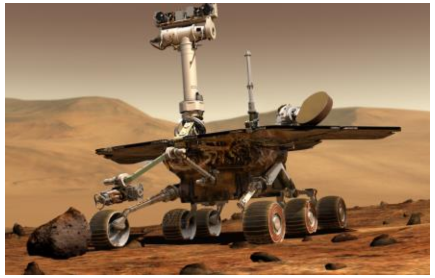
Depth regime (log-scale)

mm

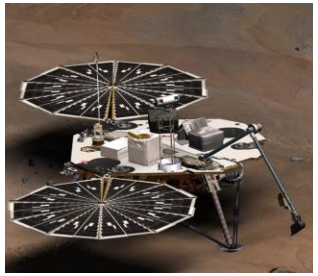
cm

m

MER (2003)

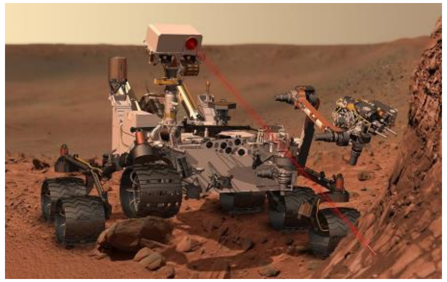


Phoenix (2007)



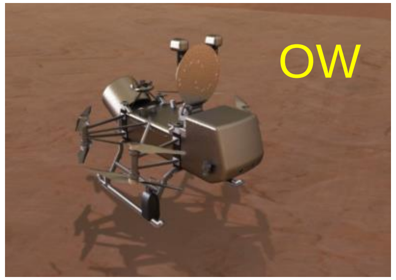
Viking 1 and 2 in 1976

Curiosity (2011)

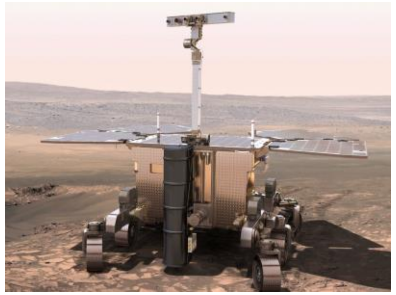


Perseverance (2020)

Dragonfly (2027)



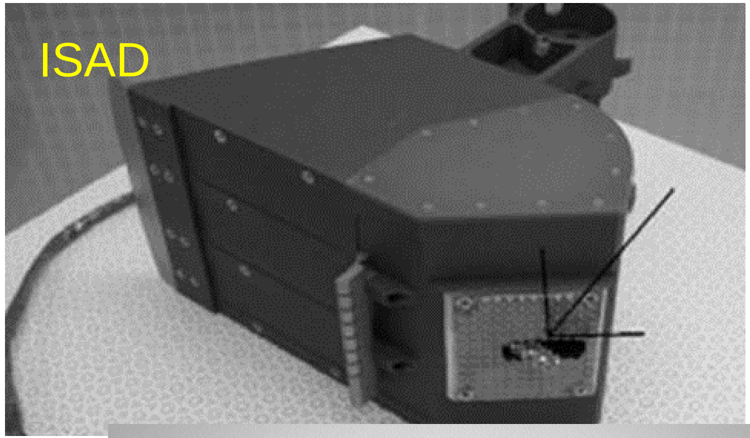

Rosalind Franklin (202?)



# Shallow (centimeters) drilling: many options exist

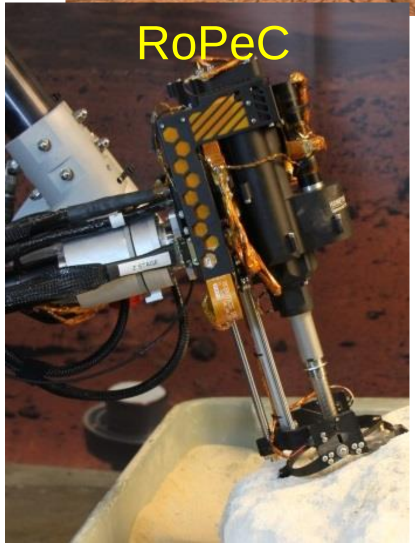
HONEYBEE ROBOTICS
Exploration Technology

- Shallow drilling has seen significant technology development efforts as well as implementation in flight missions
- Europa lander program helped to develop numerous sampling options at JPL and Honeybee
- Numerous approaches have also been developed for other Solar System bodies – these could be adapted to Mars and Ocean Worlds with some degree of modifications







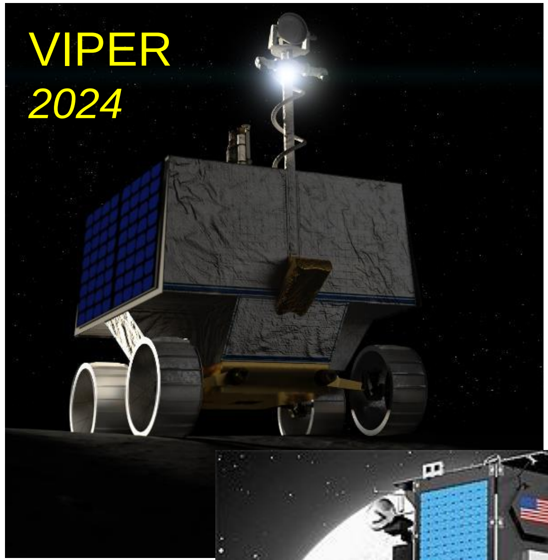




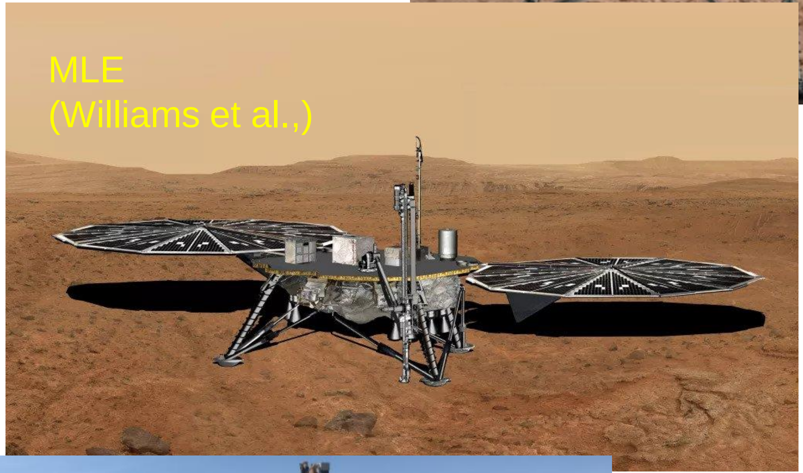
# MidRange (1+ meter) drilling: TRIDEN drill

HONEYBEE ROBOTICS
Exploration Technology

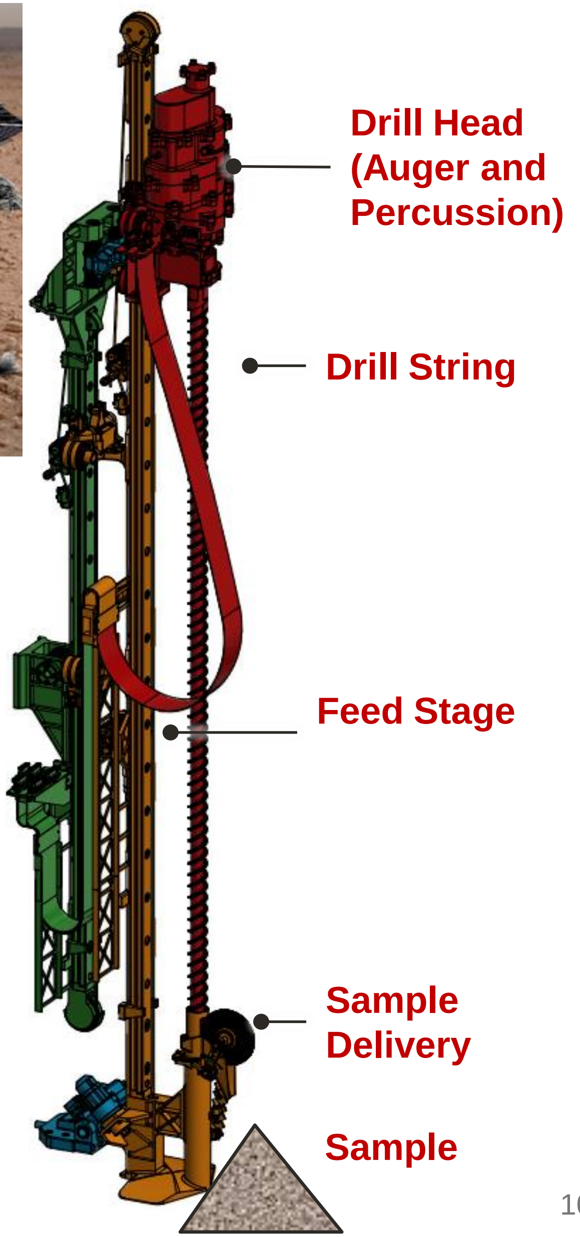
- Flying to the Moon with Polar Resources Ice Mining Experiment-1 (PRIME-1) and Volatiles Investigating Polar Exploration Rover (VIPER).
- Mars Icebreaker (PI McKay), Mars Polar Later Deposits (Byrne/Hayne/Smith) and Mars Life Explorer (Williams).





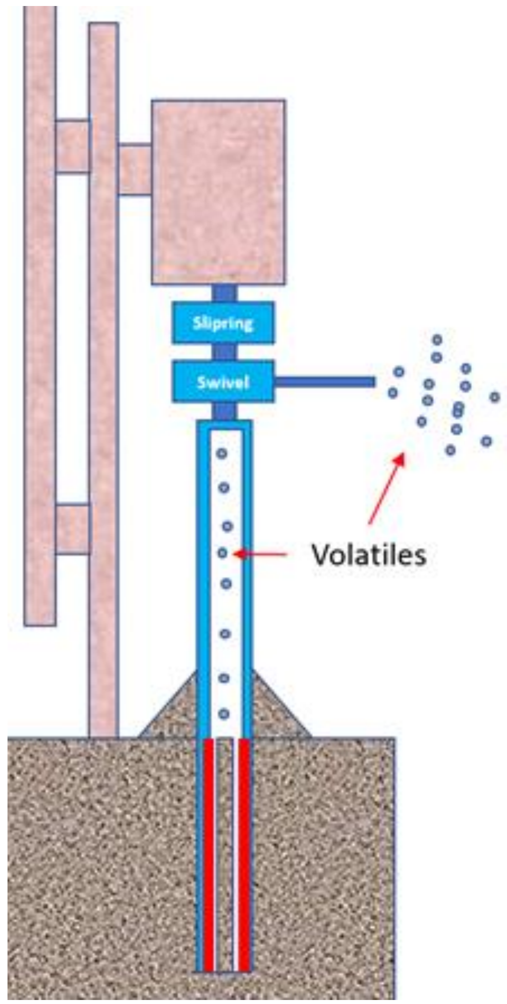



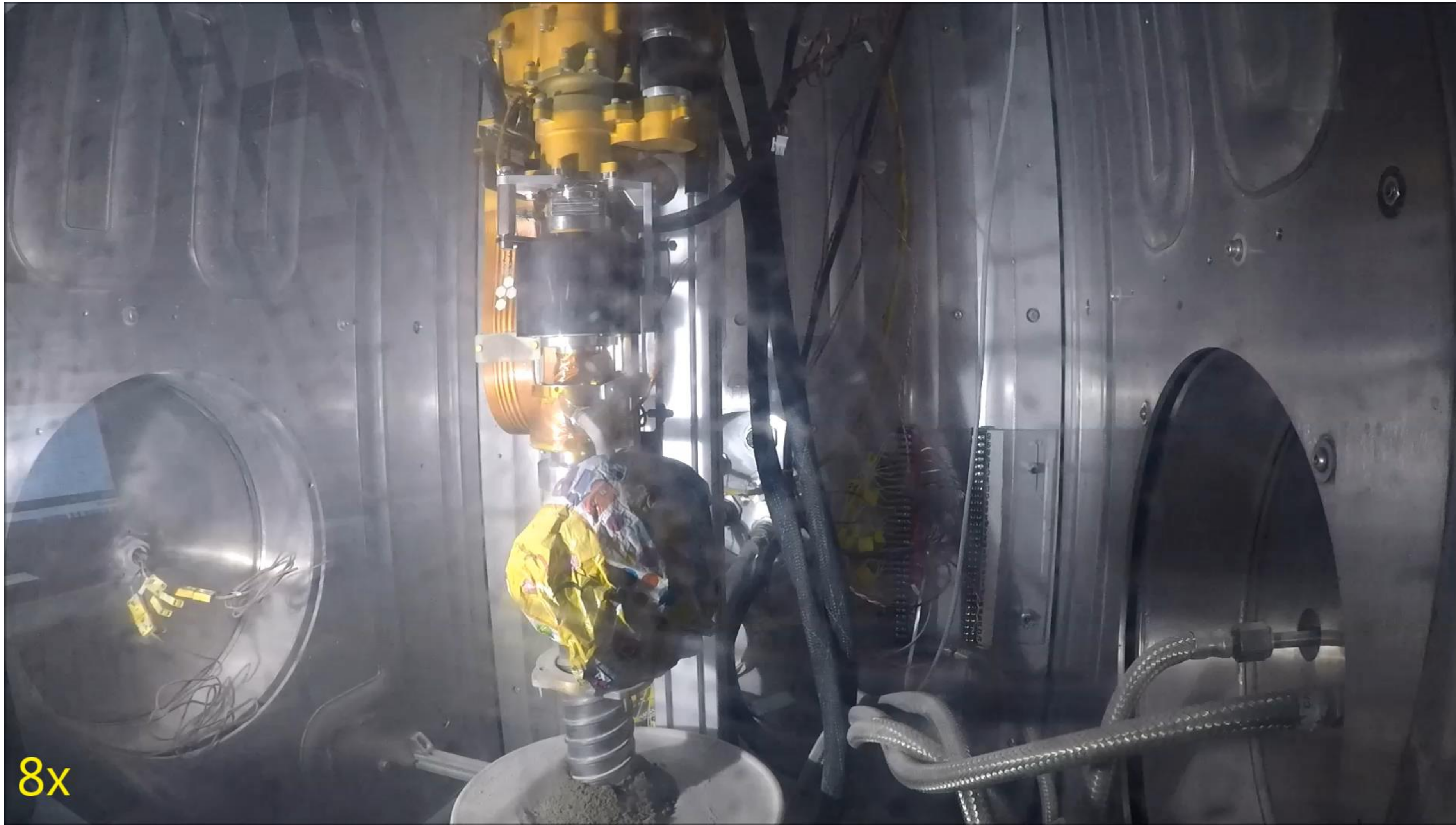




# MidRange (1+ meter) drilling: Planetary Volatiles Extractor (PVEx)

- Alternative means of delivering volatiles eliminates sample handling
- Volatiles flow into a capture system (cold trap, gas tank) or directly into an instrument. Need to consider mass flow
- Developed for Mars and lunar ISRU (TRL5/6)



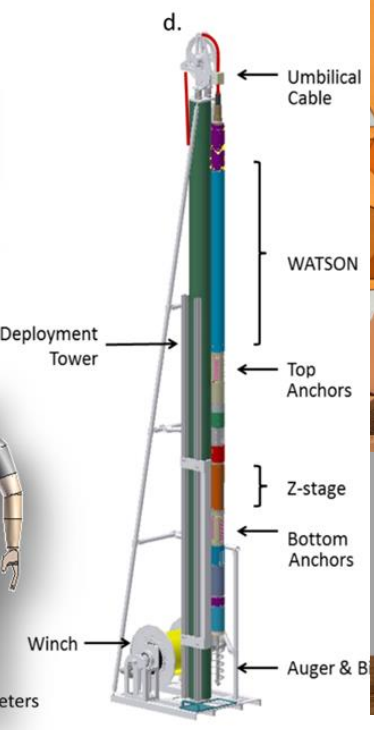



# Deep (10s-100s of meters) drilling

## Cable Suspended Drill

**Pros/Cons**
- Low mass/power
- Need stable borehole

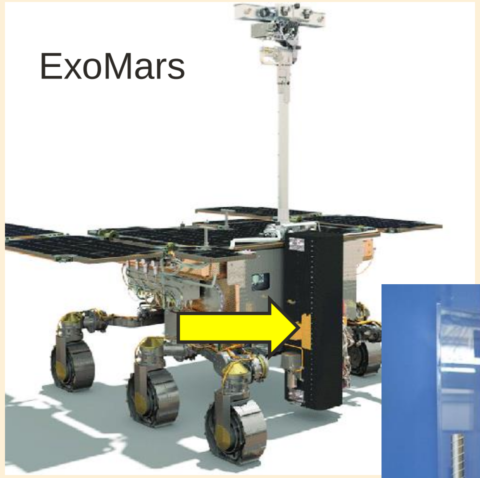
**Example:**
- Used in Antarctic ice coring
- AutoGopher, WATSON

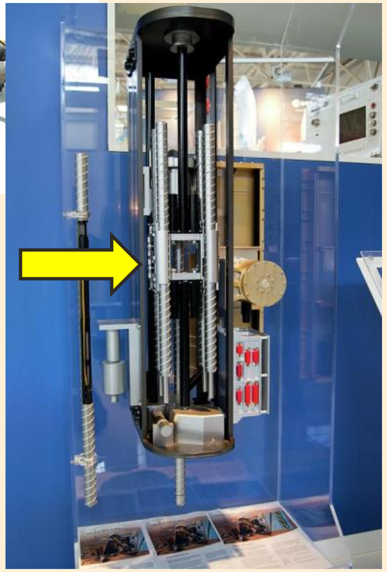



## Drill string with drill pipes

**Pros/Cons**
- Drilling system above the hole
- Mass/power/complex robotics

**Example:**
- Used in Oil and Gas
- ExoMars drill

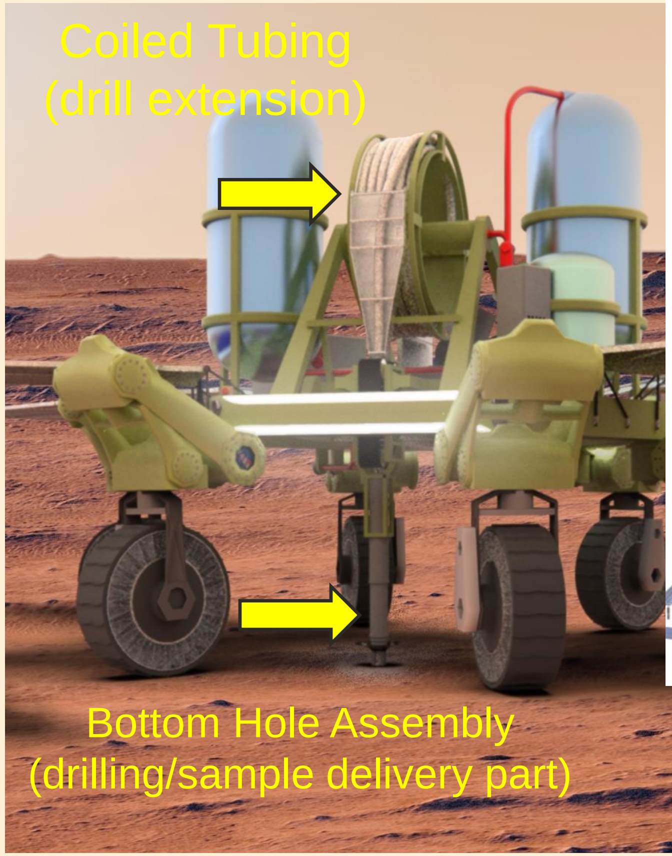


## Coiled Tubing Drilling

**Pros/Cons**
- Continuous drill pipe
- Mass/power/complex robotics

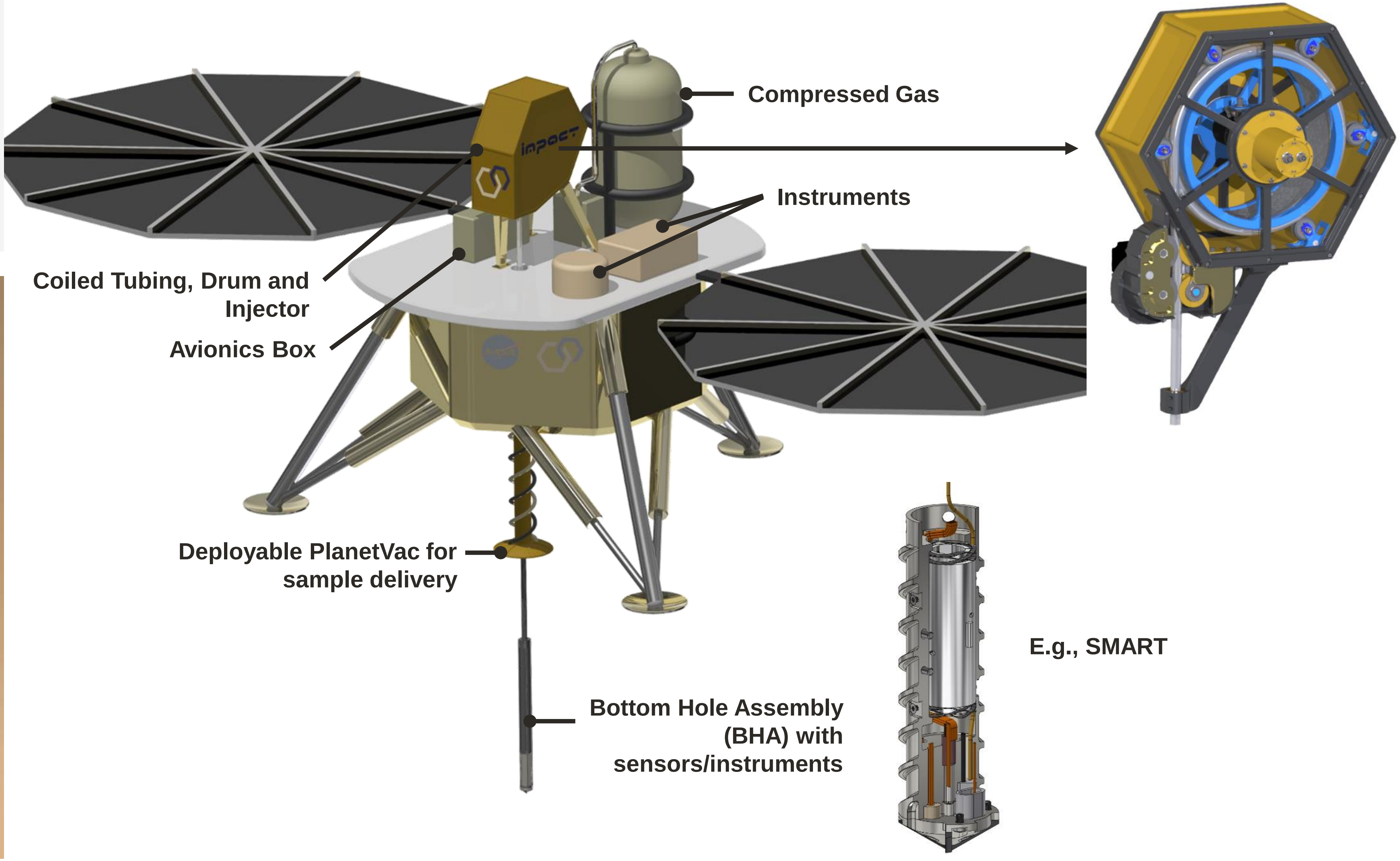
**Example:**
- Used in Oil and Gas
- RedWater drill, LISTER (the Moon, 2023)



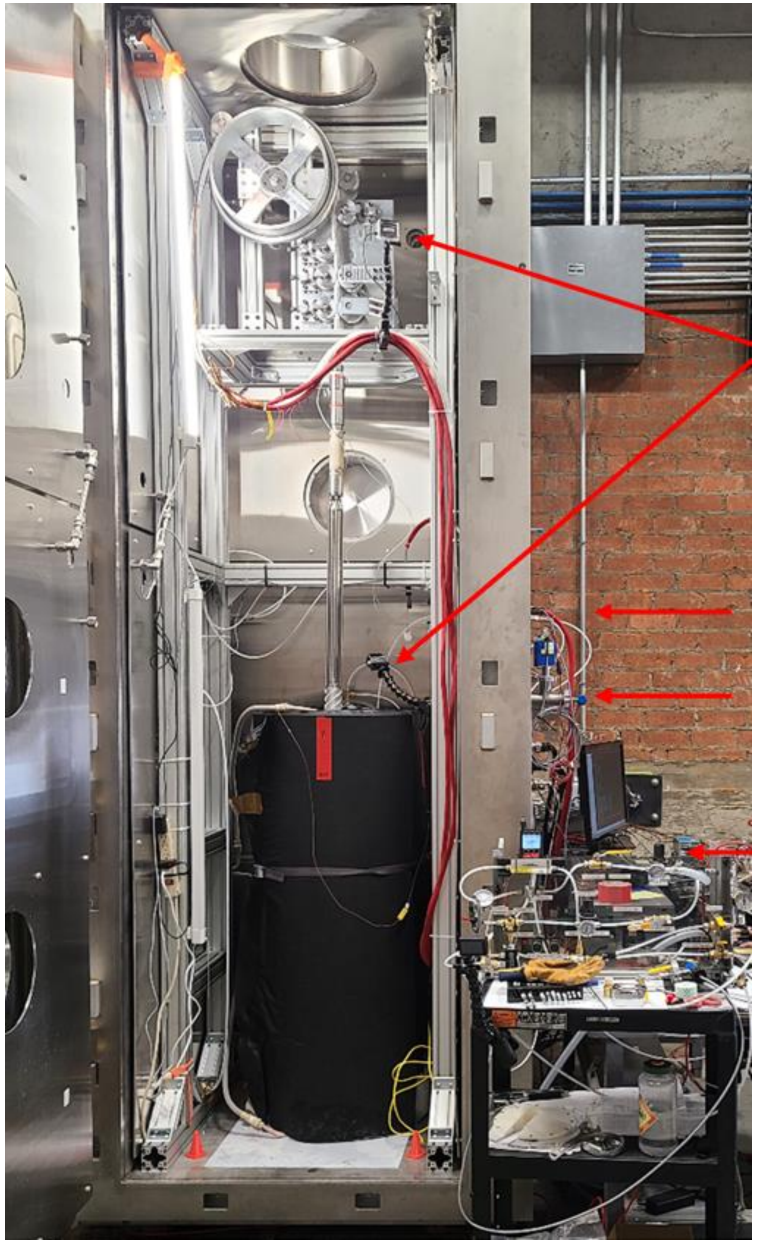

# IMPACT

**Investigating Mars via Penetration and Analysis with Coiled Tubing**

- Coiled Tubing based drilling system
- Downhole sensors/instruments
- Ability to deliver samples for in-situ analysis
- Depth is a function of available mass



# IMPACT / RedWater testing

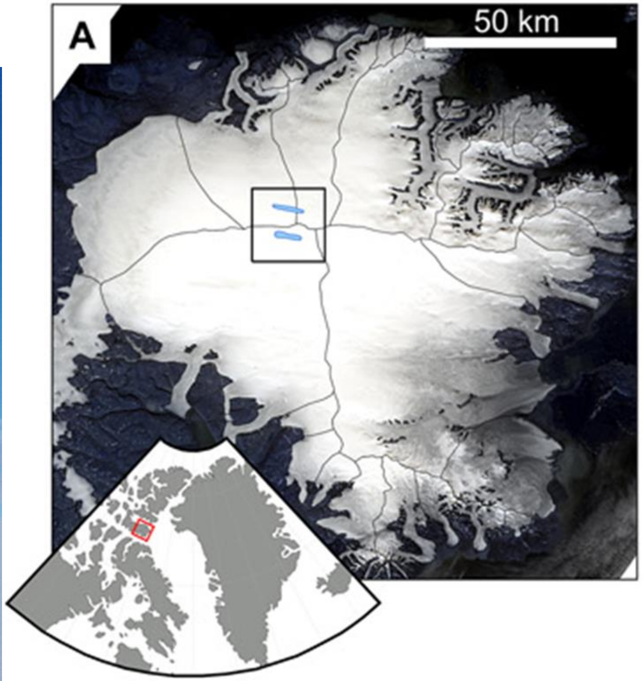


| Parameter | TVAC Test Data (−60°C ice, 5 Torr | Freezer Test Data (−5°C ice, 760 Torr) |
|---|---|---|
| Drilled depth, cm | 100 to 110 | 140 |
| Ice temperature, °C | −70 to −47 | −5.8 |
| Ambient pressure, Torr | 1 to 8 | 760 |
| Torque, Nm | 2.8 | 1.3 |
| WOB, N | 197 | 203 |
| ROP, mm/s | 0.54 | 0.59 |
| Mechanical power, W | 131 | 173 |
| Specific energy, Whr/cc | 0.017 | 0.021 |
| Thermal power, W | 860[b] | 1100 |
| Melting efficiency, % | 27 | 48 |
| Max well size, L | 6.6 | 90.5[c] |
| Gas mass flow rate, g/s | 0.55 | 18.5 |
| Gas to cuttings mass ratio[d] | 1:3.6 | 1:0.16 |
| Total gas, kg | 1 | 35 |

# UltraDeep (kilometers) drilling

HONEYBEE ROBOTICS
Exploration Technology

- Self enclosed robot with power system and comm to the surface (wired or wireless)
- Uses heat and mechanical cutting (when needed) to melt through ice
- Examples: SLUSH (Honeybee), Cryobot (JPL/Honeybee), IceDiver (UofW), VALKYRIE (Stone)

# Sample Handling

# Sample handling: Fines



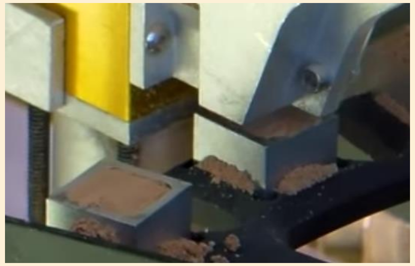
**Problem:**

Fines (incl. ice) pose difficulties related to: Cohesion, Adhesion, Particle Sizes, Metering, Cross-Contamination etc.

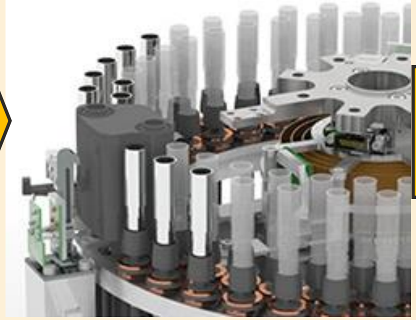
Clumps and fines

Fines

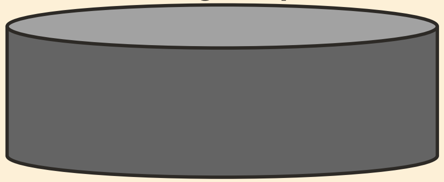
Tray



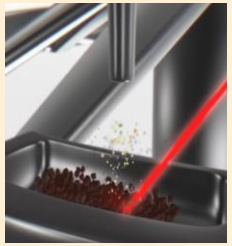
Small cup



Large cup



Look at

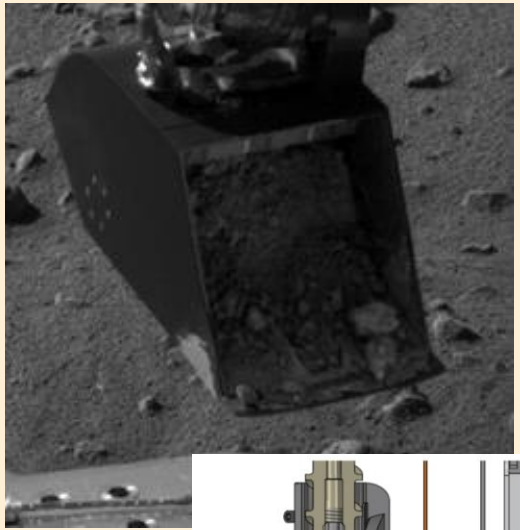


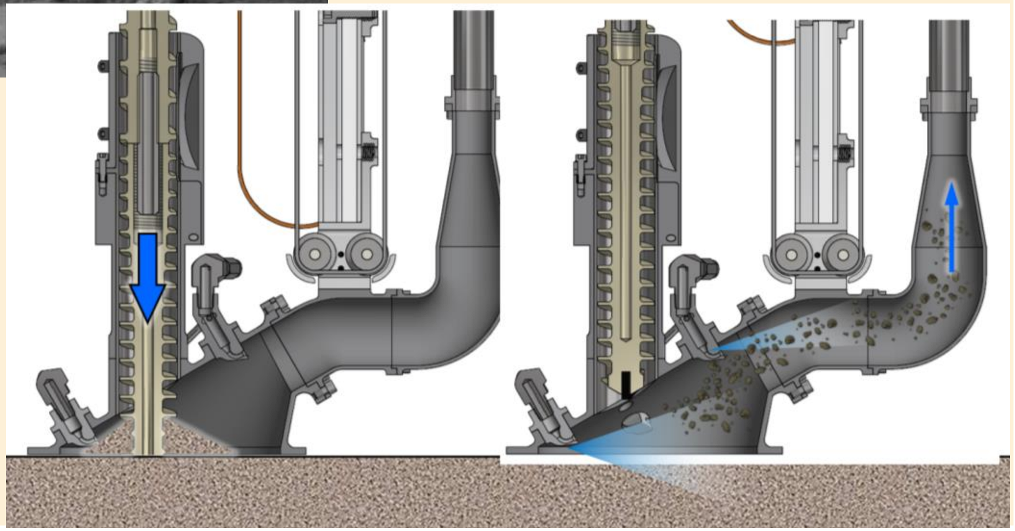
Heat up

Dissolve

**Options:**

1. Scoops for surface regolith
2. Pneumatics for powder movement
3. Several other options





# Pneumatic approach can be used in numerous missions

HONEYBEE ROBOTICS
Exploration Technology

**How this works:**

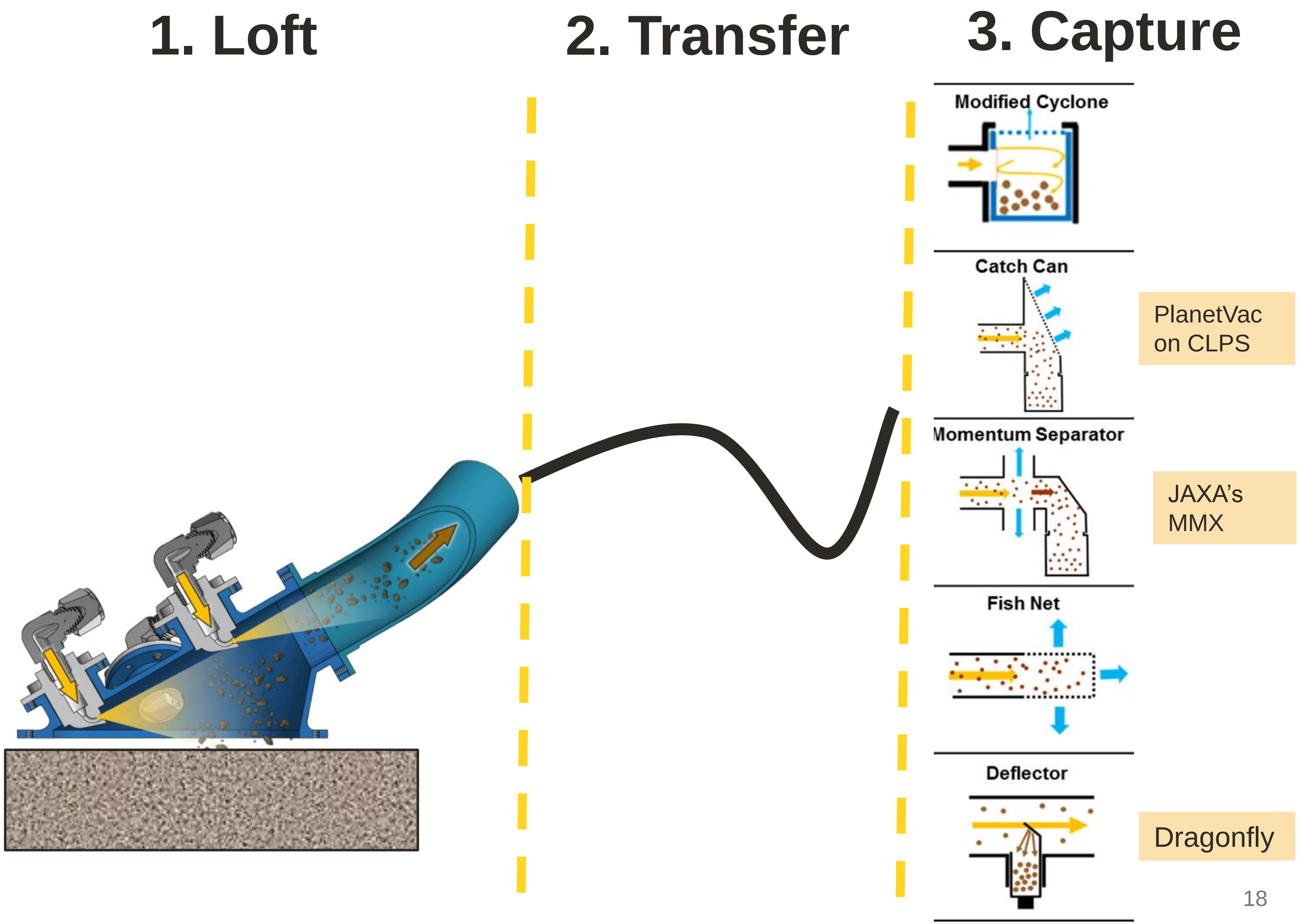
- Gas is used as a broom to sweep (loft) material via momentum exchange
- In vacuum, gas is like an explosive making pneumatic systems very efficient (1 g of gas lofts 100s grams of powder)

**Heritage**

- Uses cold gas propulsion components with flight proven components
- Sampling head and delivery is mission dependent TRL low to high

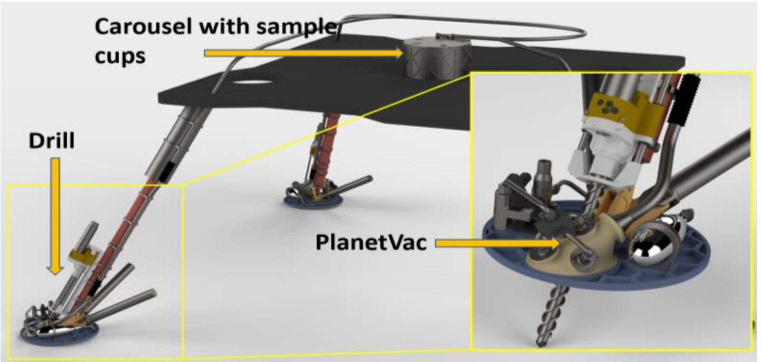
**Benefits:**

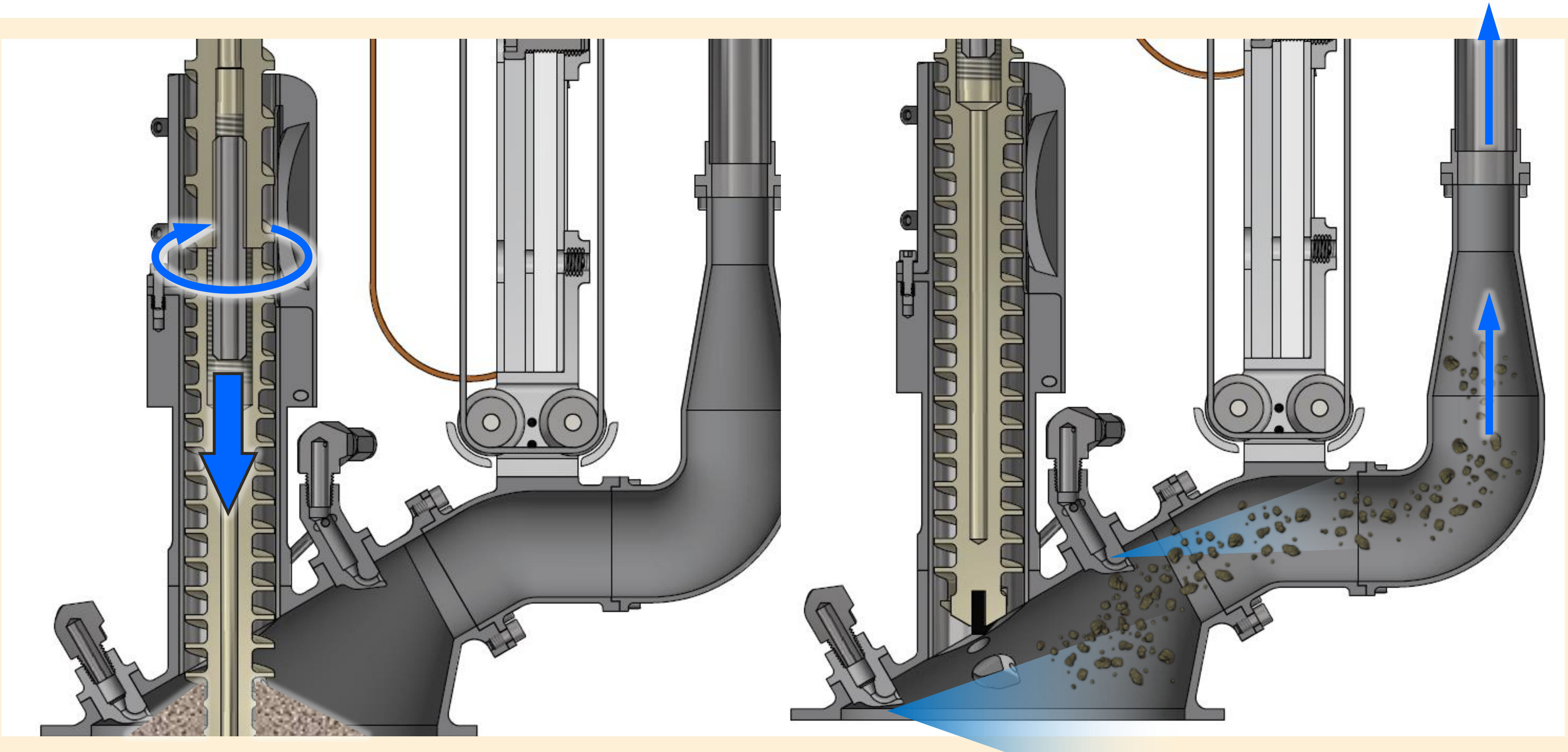
- Simple operation (actuator opens valve)
- Short sampling time
- No ground-in-the-loop needed
- Gravity agnostic – works with somewhat cohesive samples
- Sample delivery location independent from sample acquisition location
- Clean transfer lines between sampling to reduce cross contamination
- Works with a range of particle sizes

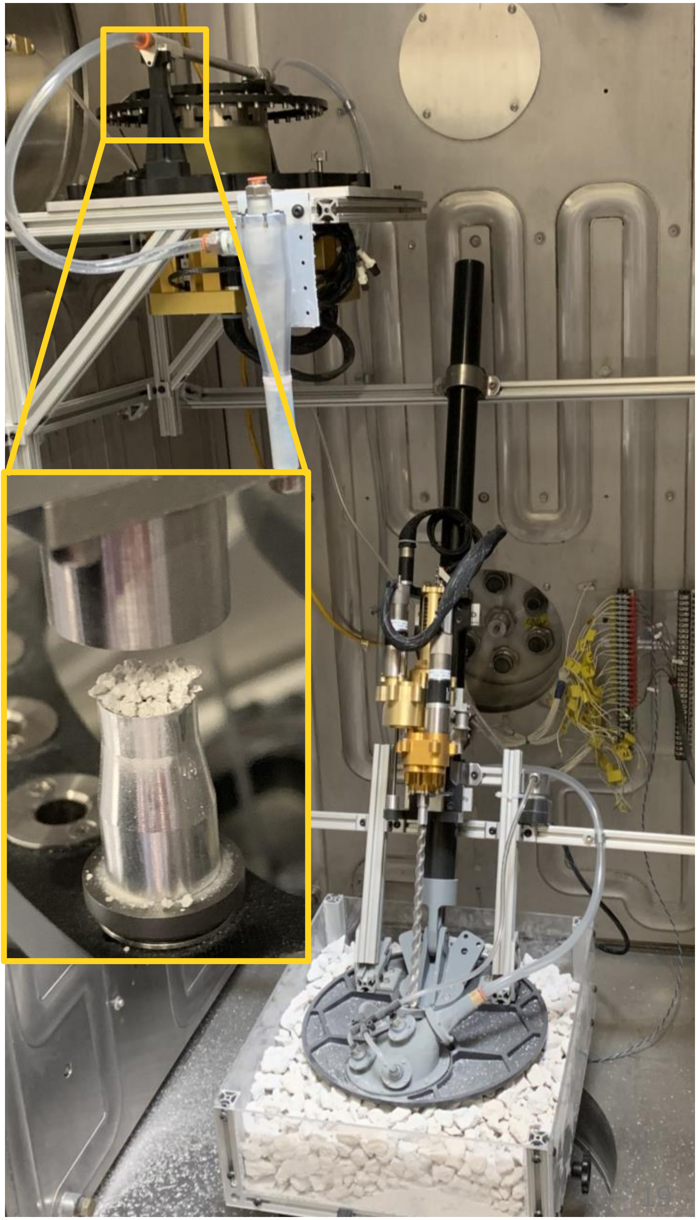


# Pneumatic approach can be coupled with a drill

- Drill brings sample to a surface – stratigraphy can be preserved
- PlanetVac delivers sample to an instrument or instrument suites
- Gas: dedicated supply (e.g., MMX) or compressed $CO_2$ atmosphere (e.g., M2020 MOXI)



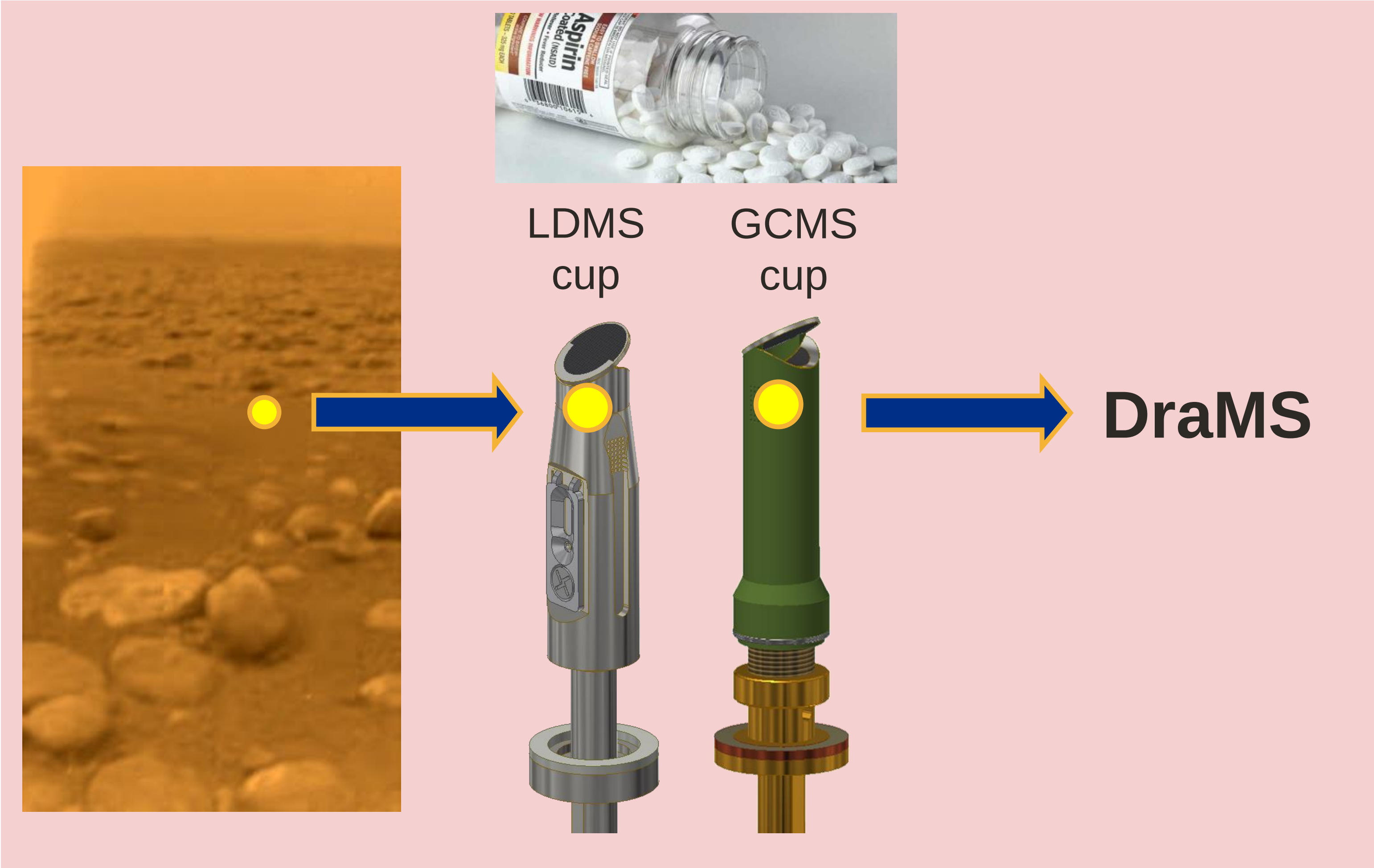



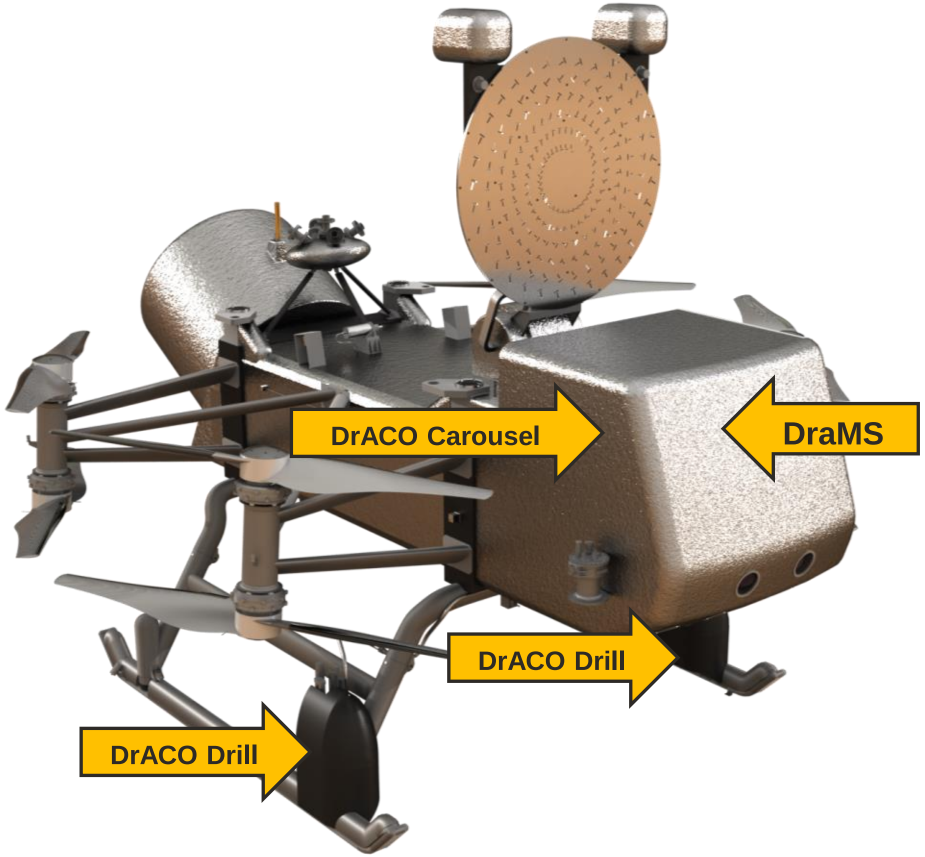


# Case study: DrACO Sampler on Dragonfly mission

HONEYBEE ROBOTICS
Exploration Technology

## Deliver samples of known quantity to DraMS – Dragonfly Mass Spectrometer



# DrACO architecture takes advantage of Titan thick atmosphere



**Hammer drill (x2)**

- *Breaks hard and soft material*

**40 LDMS cups and 18 GCMS cups**

- *Reduce cross contamination*
- *Metering*

**Vacuum cleaners (x2)**

- *Works well with dirt*
- *Transfer tube can be easily routed*
- *Minimal temp alteration*
- *Can clean tubes with air*

**Titan Surface**

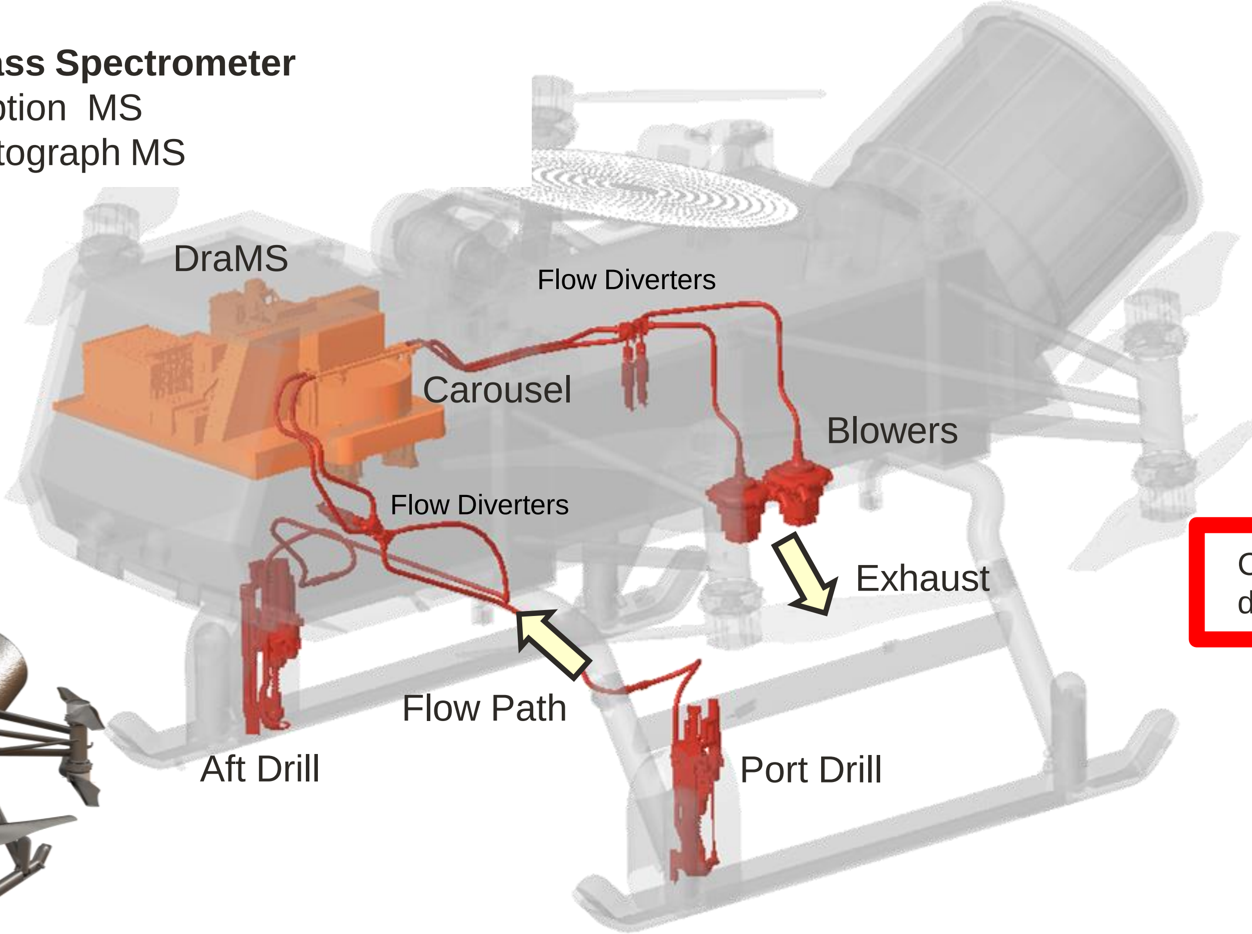
# DrACO System Overview

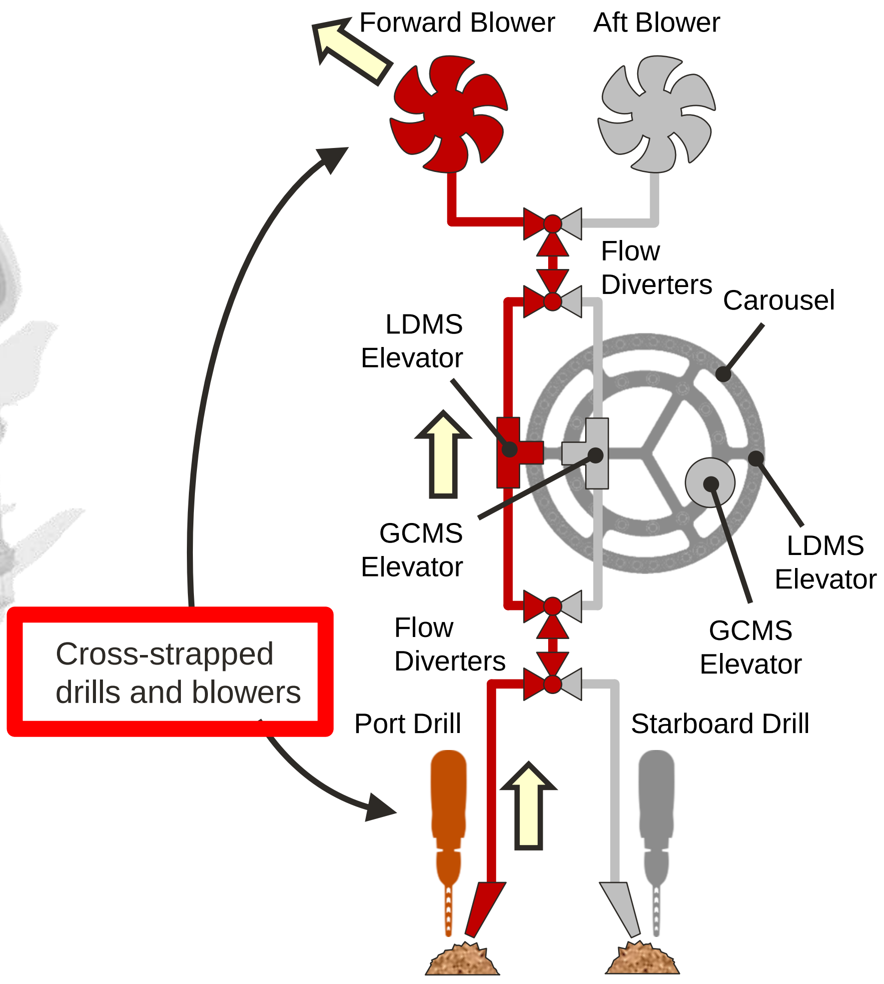
**DrACO: Drill for Acquisition of Complex Organics**

- SAD: Sample Acquisition Drill (x2)
- PTS: Pneumatic Transport System (x2)
- SDC: Sample Delivery Carousel
- Avionics

**DraMS: Dragonfly Mass Spectrometer**

- Laser Desorption MS
- Gas Chromatograph MS



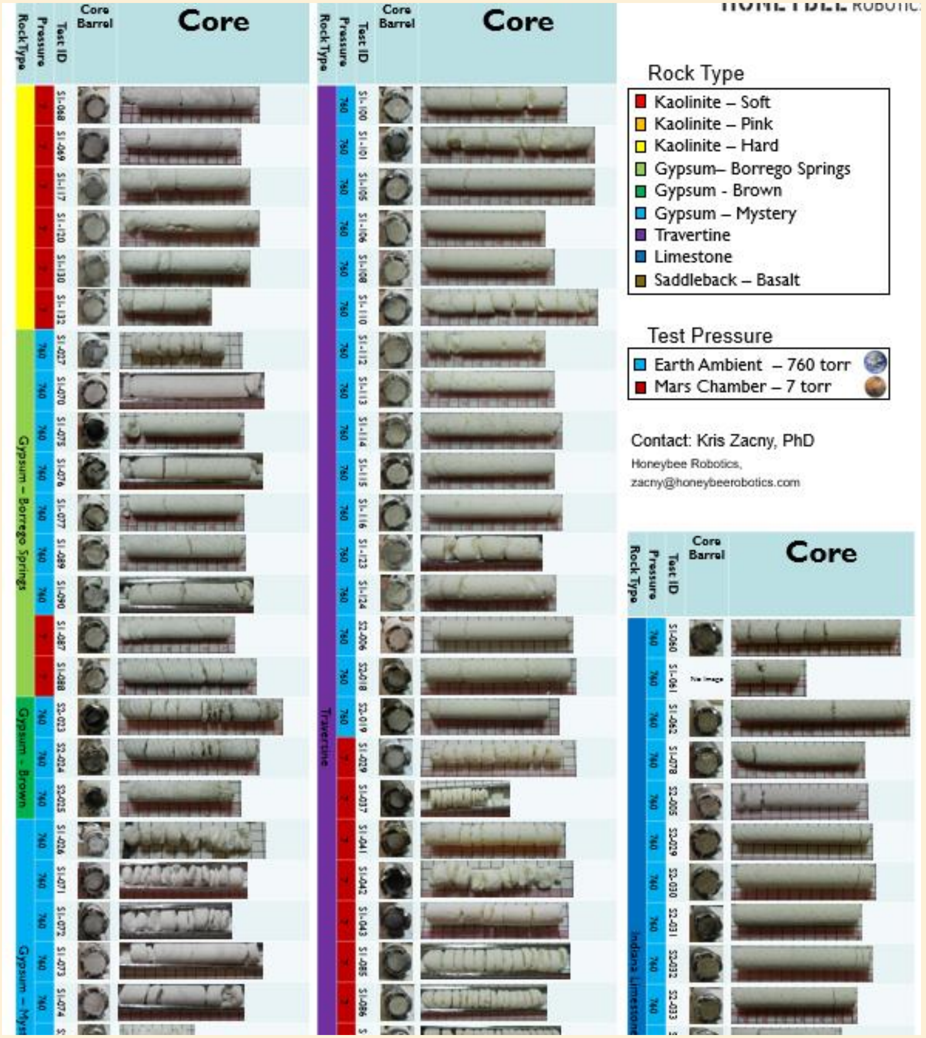
See Dragonfly video showing sampling system

https://youtu.be/XbglDa3rzBk

# Sample handling: Cores

**Problem:**

Cores are unpredictable: Intact vs. Several pieces vs. Mostly Broken up

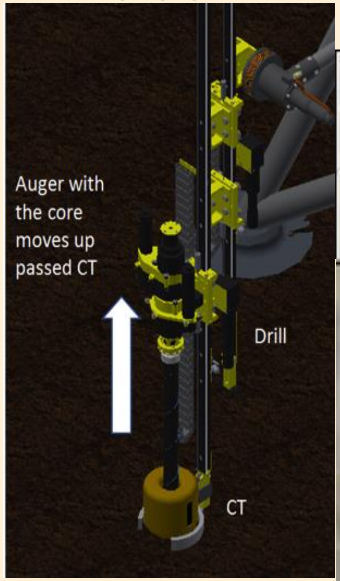



**Options:**

1. Seal and return to Earth (Mars2020, Apollo, Luna24)
2. Analyze in-situ (e.g., X-ray micro computed tomography)
3. Crush into powder for further distribution (ExoMars)
4. Use PreView or SLOT bits to examine in-situ
5. Manipulate the core (after triaging) for subsampling, thin section etc.

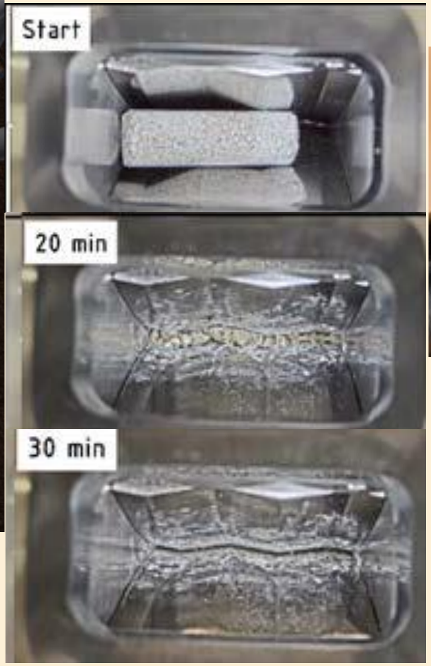
Mars2020


MicroCT




PI Obbard

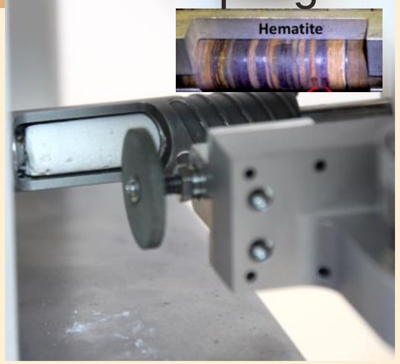
ExoMars




Redlich et al., 2018

PreView Bit

SubSampling




PI Brinckerhoff

HONEYBEE ROBOTICS
Exploration Technology

# Drill Integrated Instruments

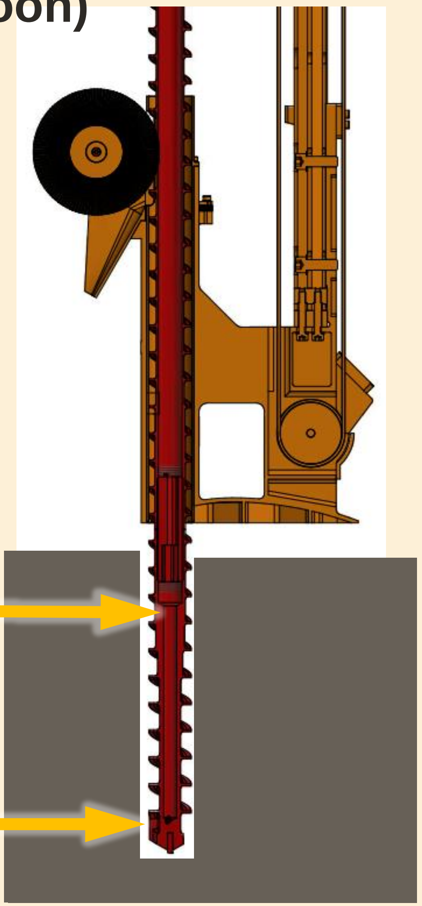
# Drill integrated instruments

- “Bringing an instrument to a sample vs a sample to an instrument” could significantly simplify a mission and enhance scientific data and in some cases (deep probes) will be the only plausible approach to meet science goals.
- Measurement is done in-situ, stratigraphy can be preserved on a sub-mm scale.
- Examples: Raman, deep UV fluorescence, IR, LIBS, Neutron Spectrometer, Heaters, Temp Sensors

## TRIDENT drill (flying to the Moon)

**TRIDENT data:**

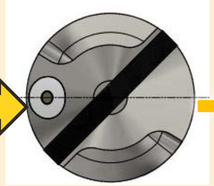
- Geotechnical properties of regolith
    - *Ice concentration and physical state of ice*
- Thermal properties of regolith: thermal gradient, thermal conductivity, heat flow



Heater and Temp Sensor

Material strength from drilling energy

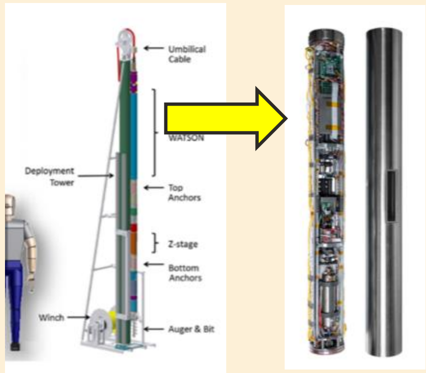
Bit Temperature Sensor



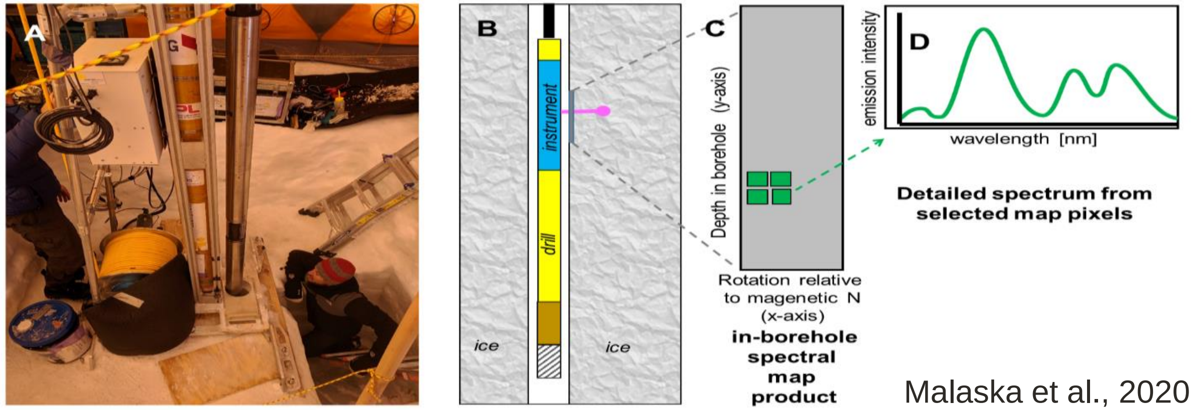
## WATSON life detection drill

**WATSON data:**

- Deep UV Raman/fluorescence based on M2020 SHERLOC
- Spectral signatures were consistent with organic matter fluorescence from microbes, lignins, fused-ring aromatic molecules, including polycyclic aromatic hydrocarbons, and biologically derived materials such as fulvic acids




Bhartia et al. 2018



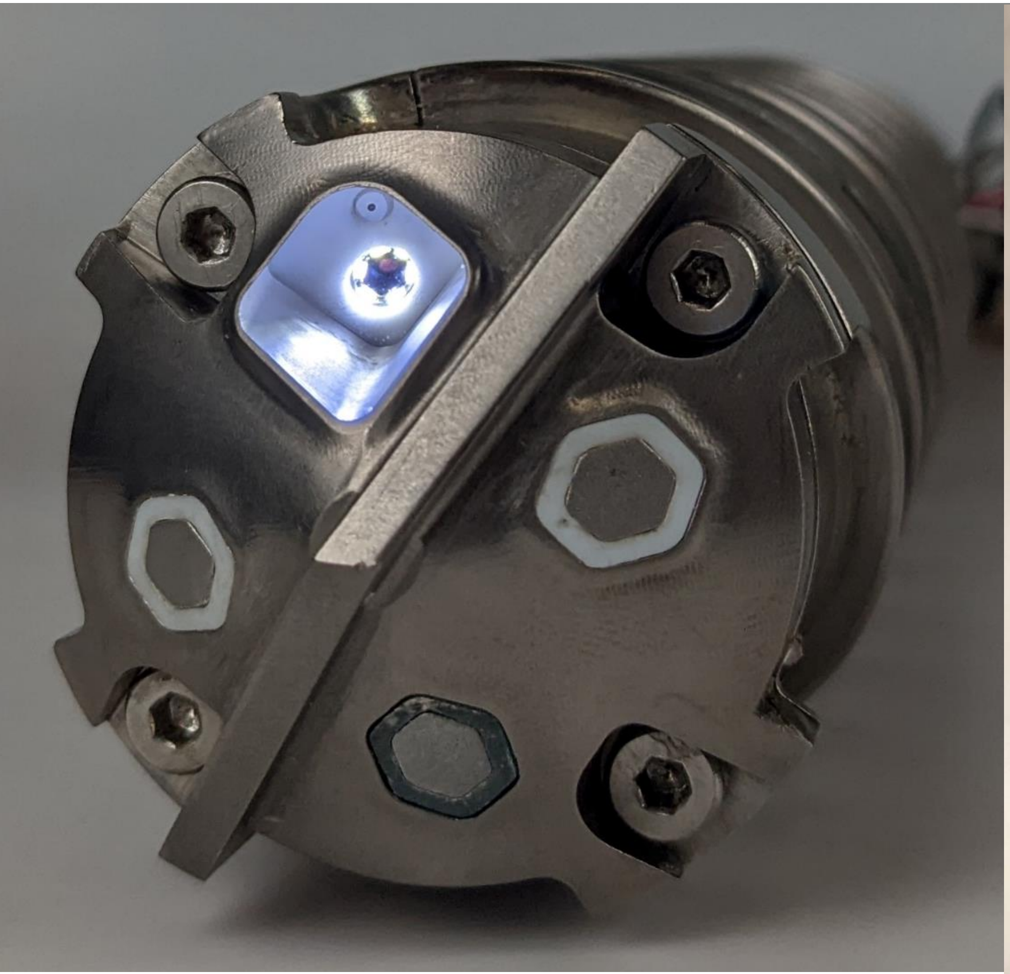

Malaska et al., 2020

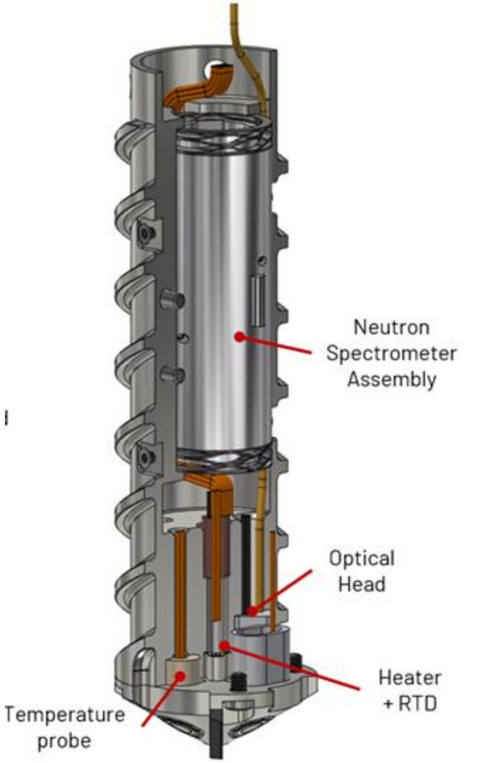
# SMART Drill

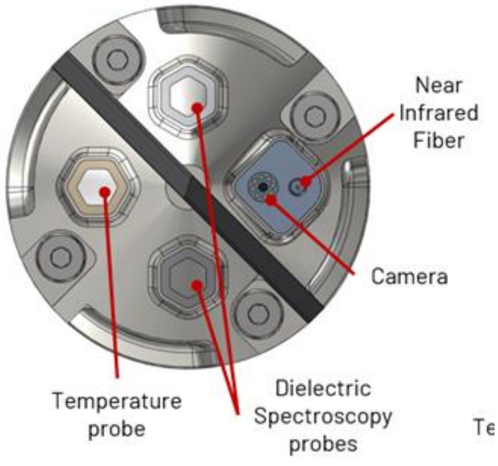
## Sensing, Measurement, Analysis, and Reconnaissance Tool

- SMART (SSERVI: PI Heldmann): NIR (NIRVSS), Neutron Spectrometer, Camera, Dielectric Spectroscopy Probe, Heater, Temp Sensor

- OptiDrill (PICASSO, PI Bywaters) – drill with multispectral imager



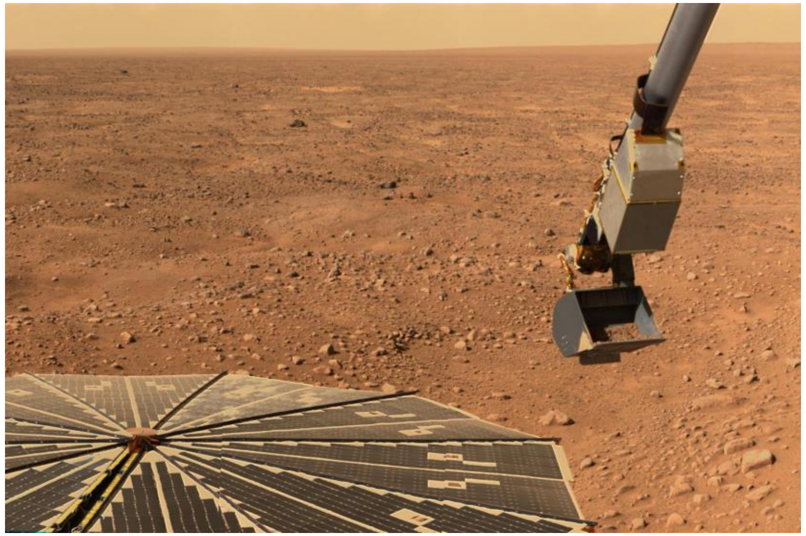



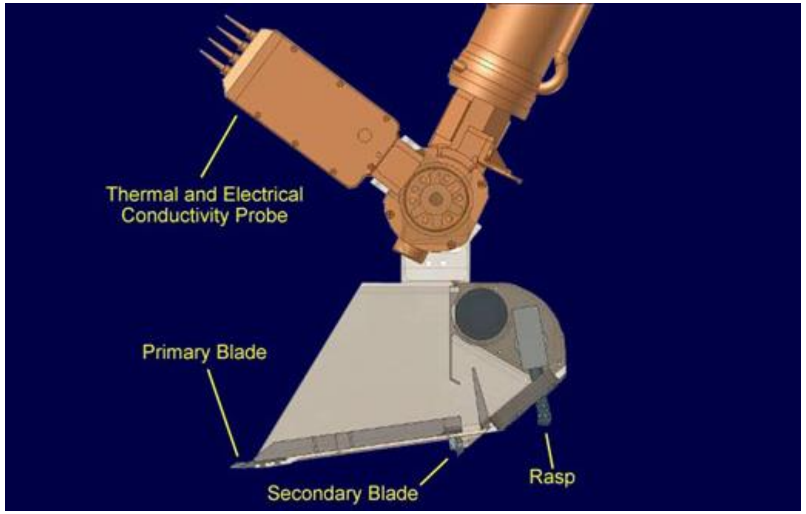



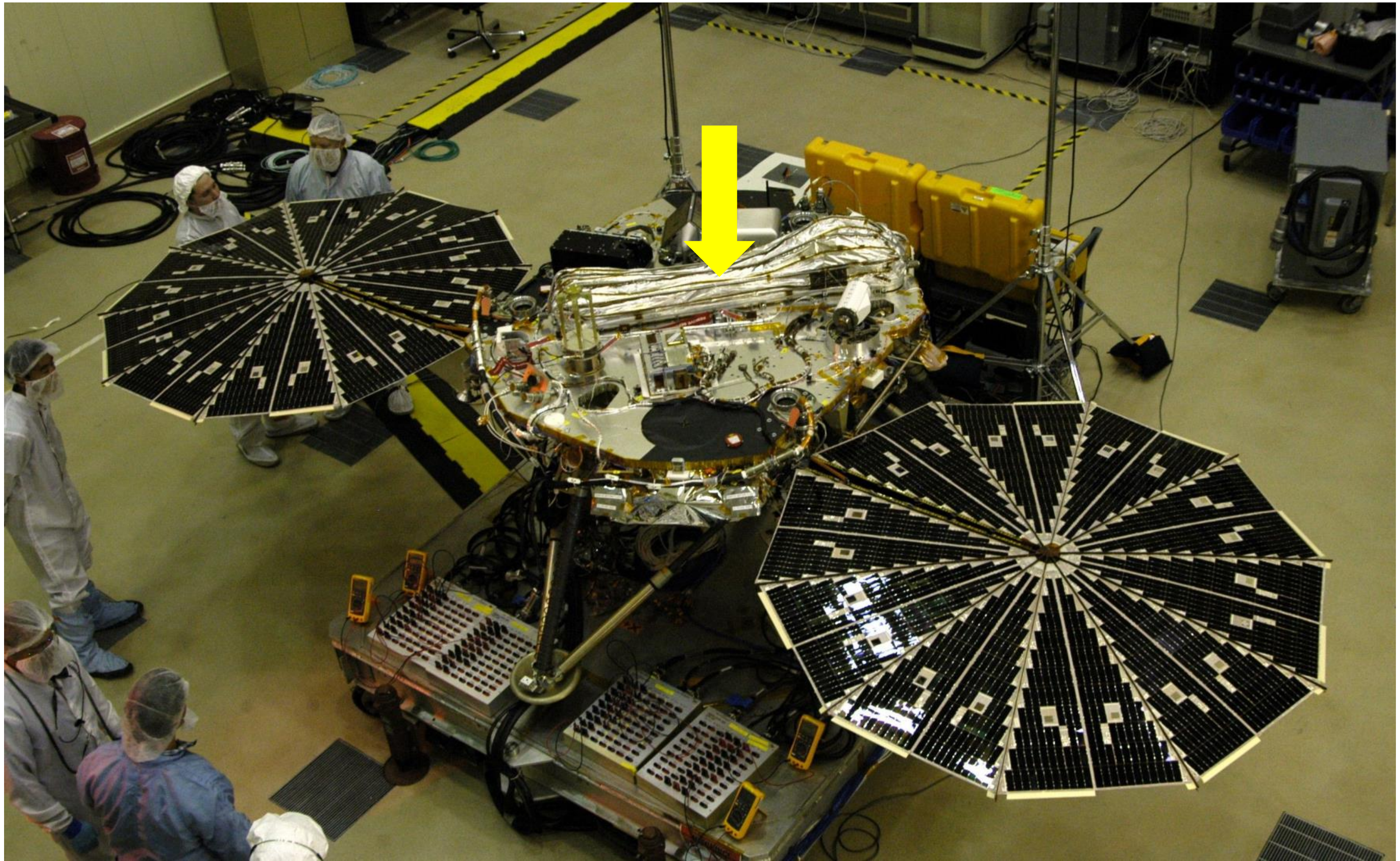
# Planetary Protection ("Kill bugs") and Contamination Control ("Remove bugs")

# Lesson from Mars Phoenix

- Only the forearm was of concern to PP…but
- It was simpler to put an entire arm (including end of the arm instrument) through DHMR and inside bio-barrier



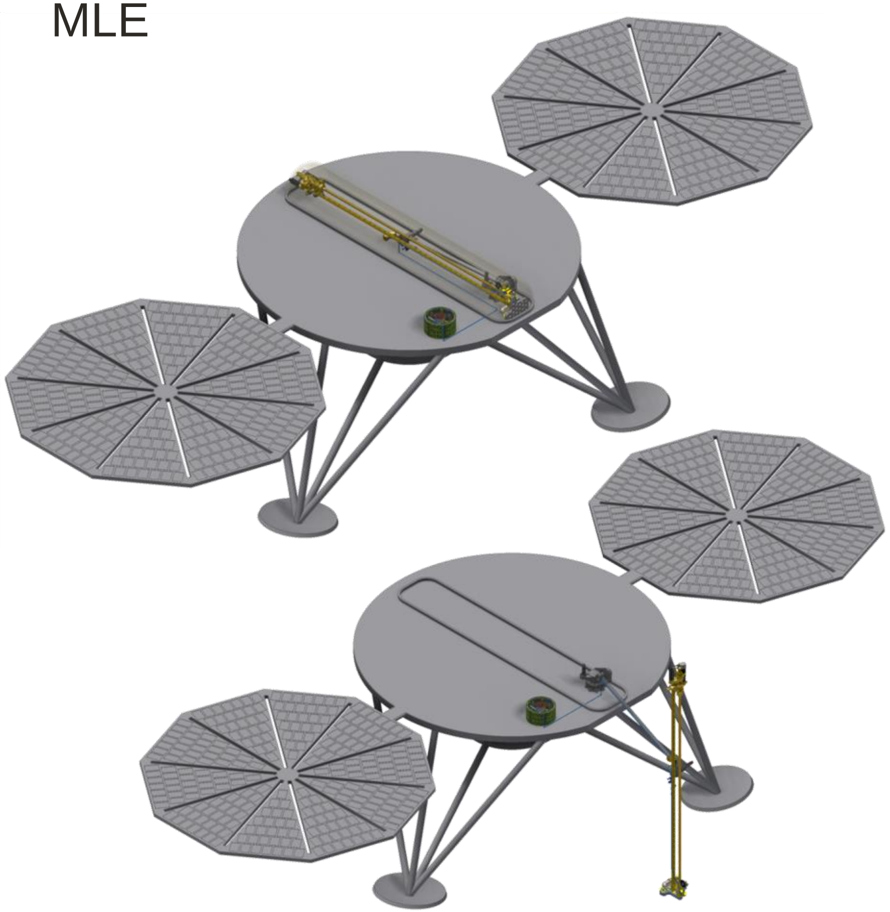


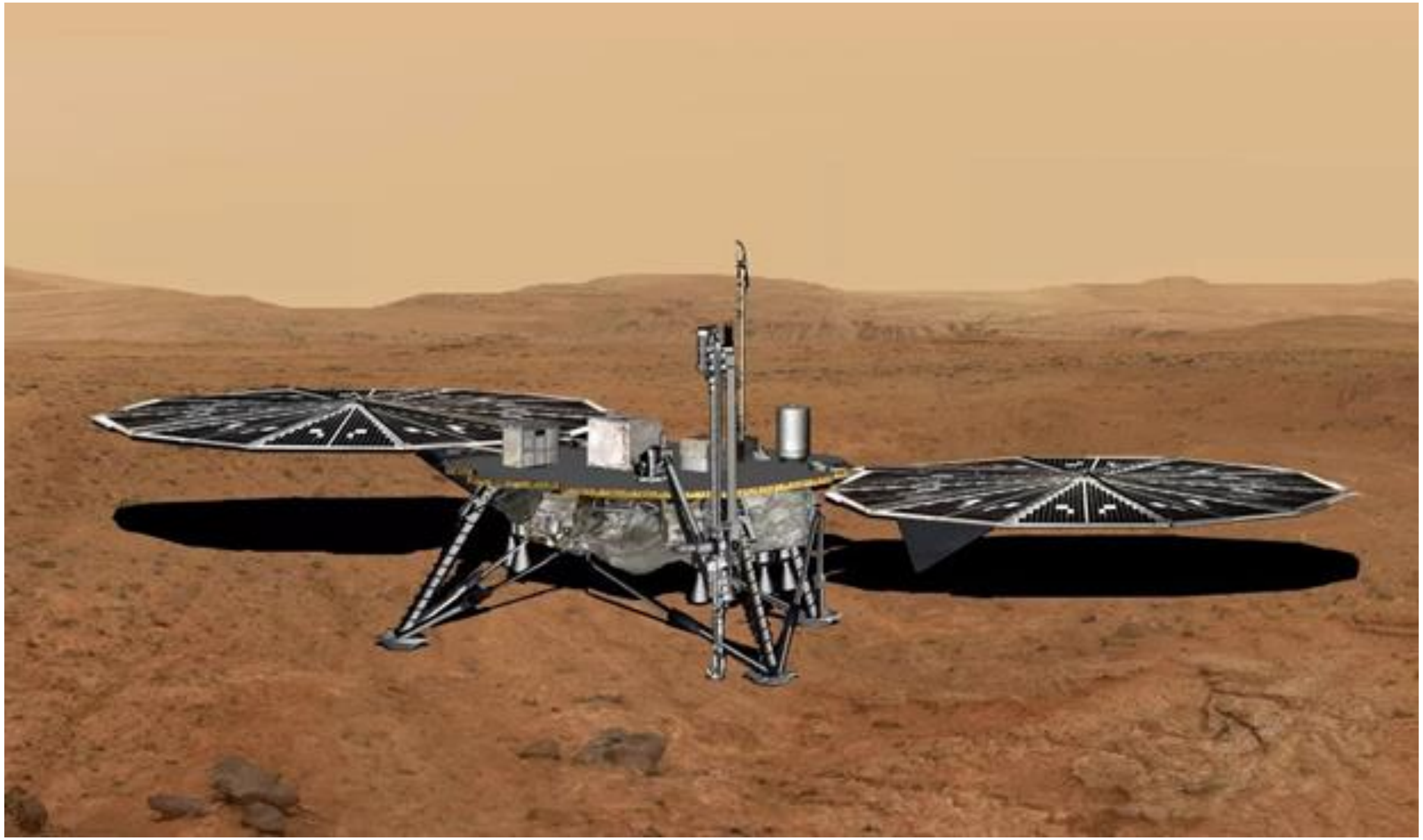



# For Small Drills: Phoenix-like Bio-Barrier could work

- A drill could potentially fit inside a bio-barrier (Phoenix-style)
- Example: Icebreaker (McKay et al., 2013) and Mars Life Explorer (Williams et al., 2021)
- Bio-barrier takes up significant deck volume and may complicate sample transfer

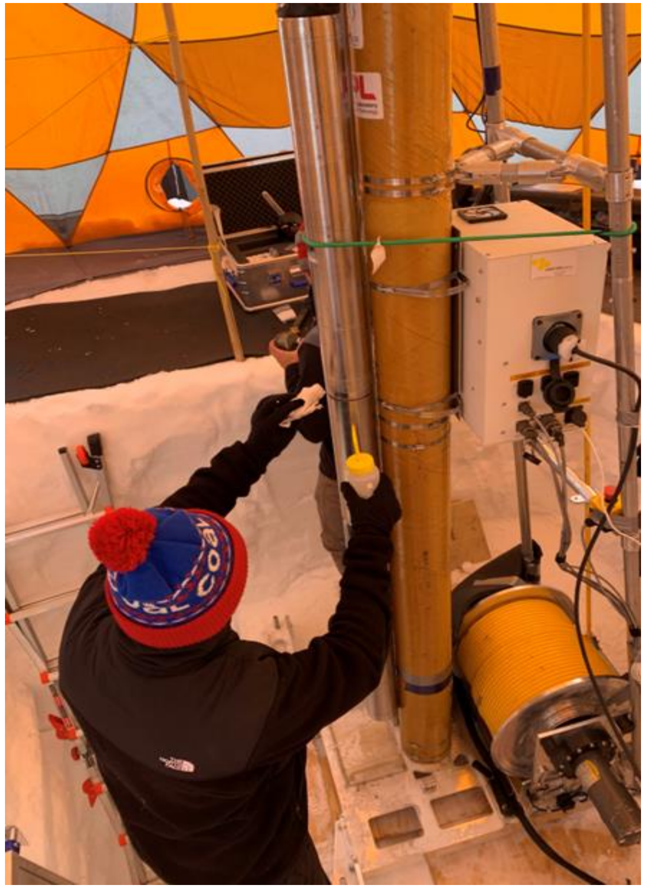
MLE

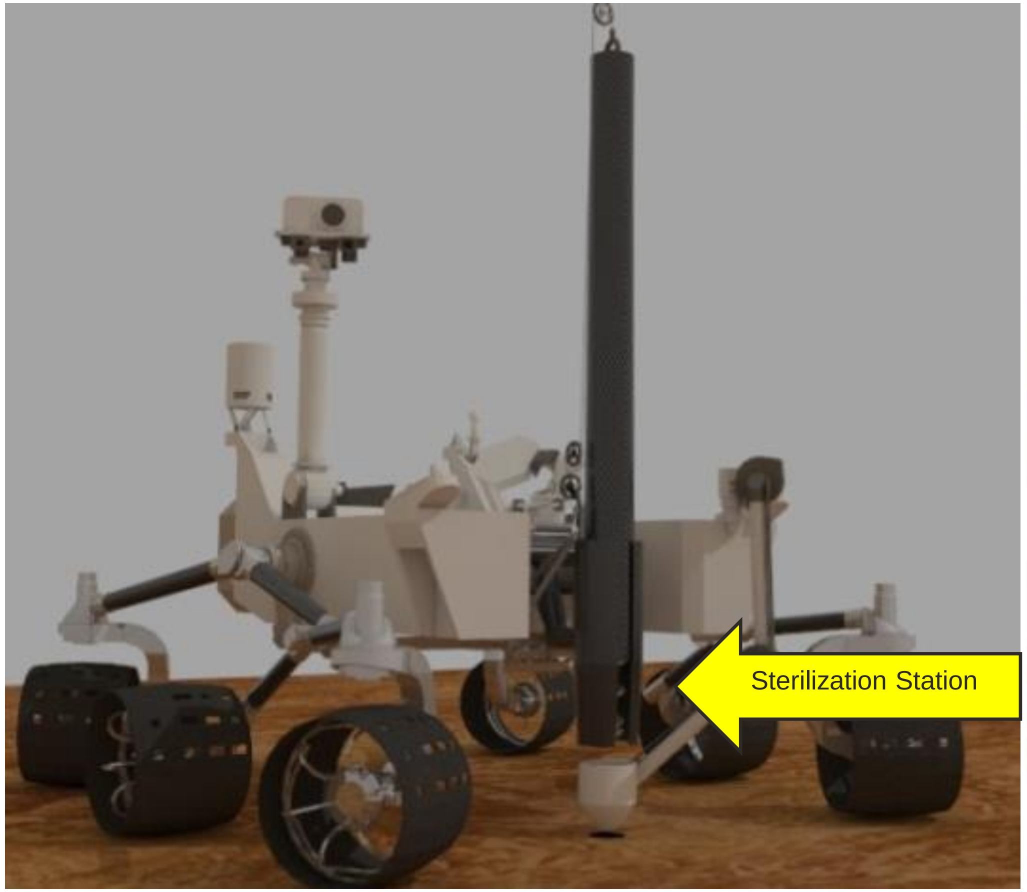


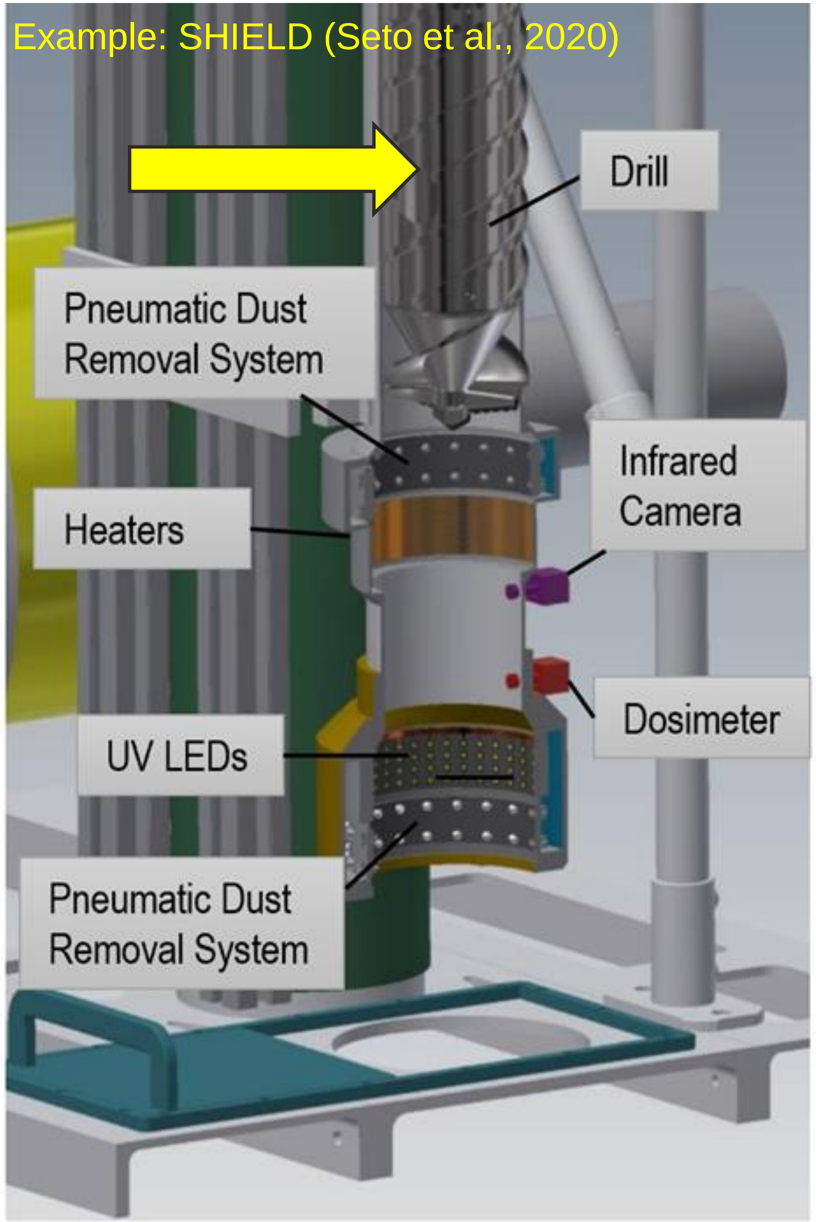


# For Large Drill: In-Situ Sterilization

- Difficult to put large drill into a bio-barrier
- Adding cleaning station to clean the drill prior to entering subsurface would
  - Simplify Integration and Test
  - Cut the development cost and complexity
  - Re-cleans after launch contamination
  - Minimizes cross contamination between each sampling event



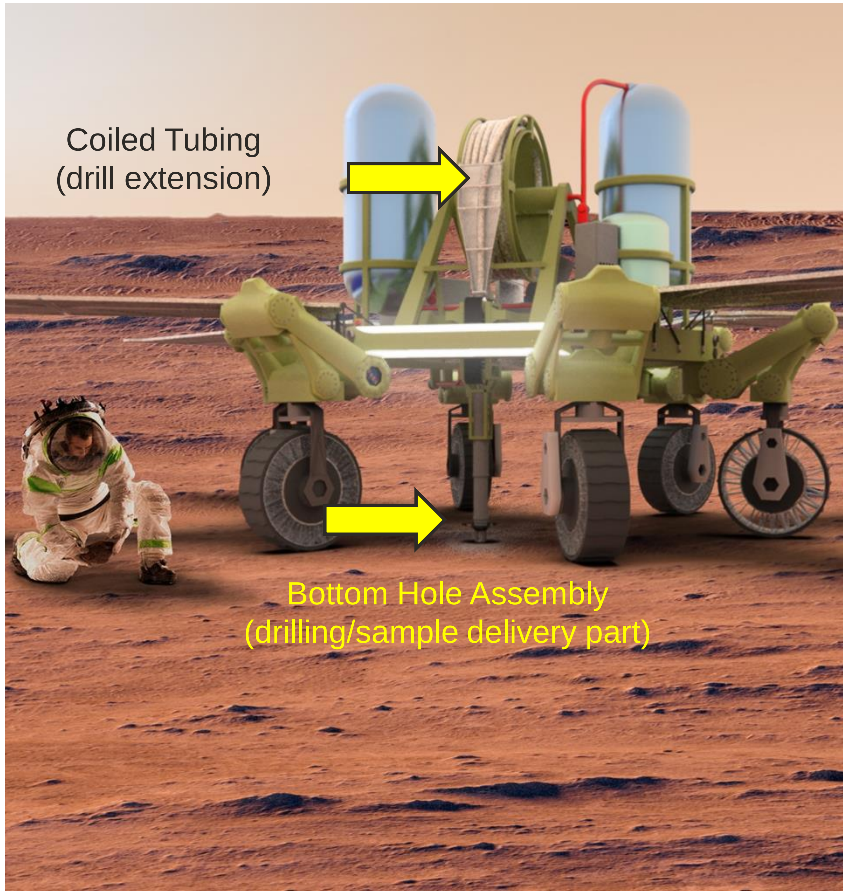


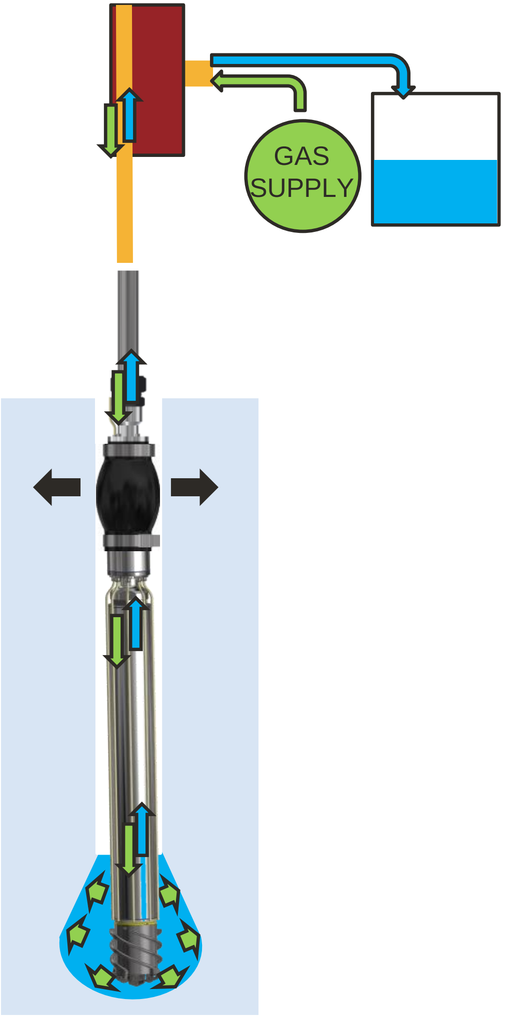



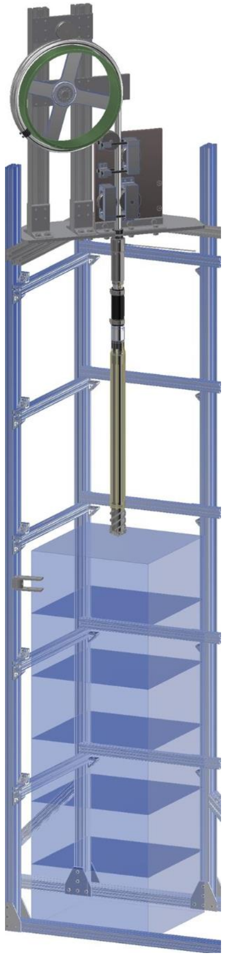
# For Large Drill: Self sterilization

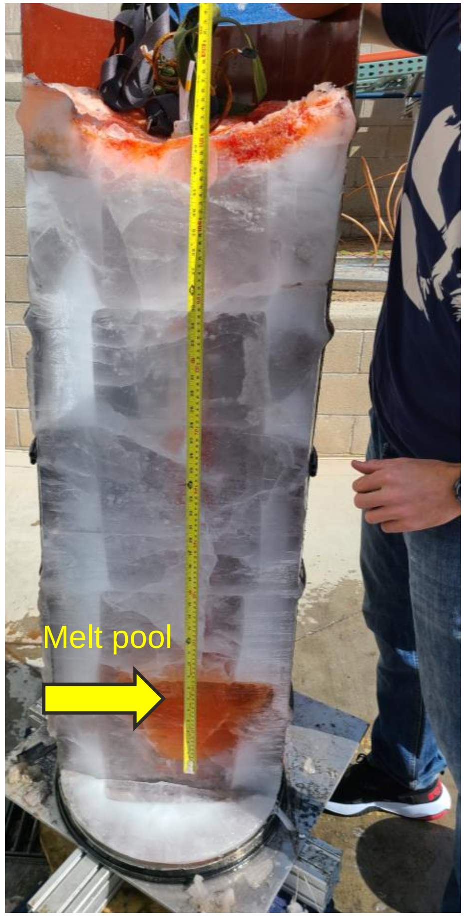
- Water mining concepts for Mars require access to ice (Special Regions)
- Many of these concepts use heated drills and in turn could be self-sterilized
- Mined water would need to be **analyzed** (we can look for microbes!) and treated

**RedWater** (Zacny et al., 2018)



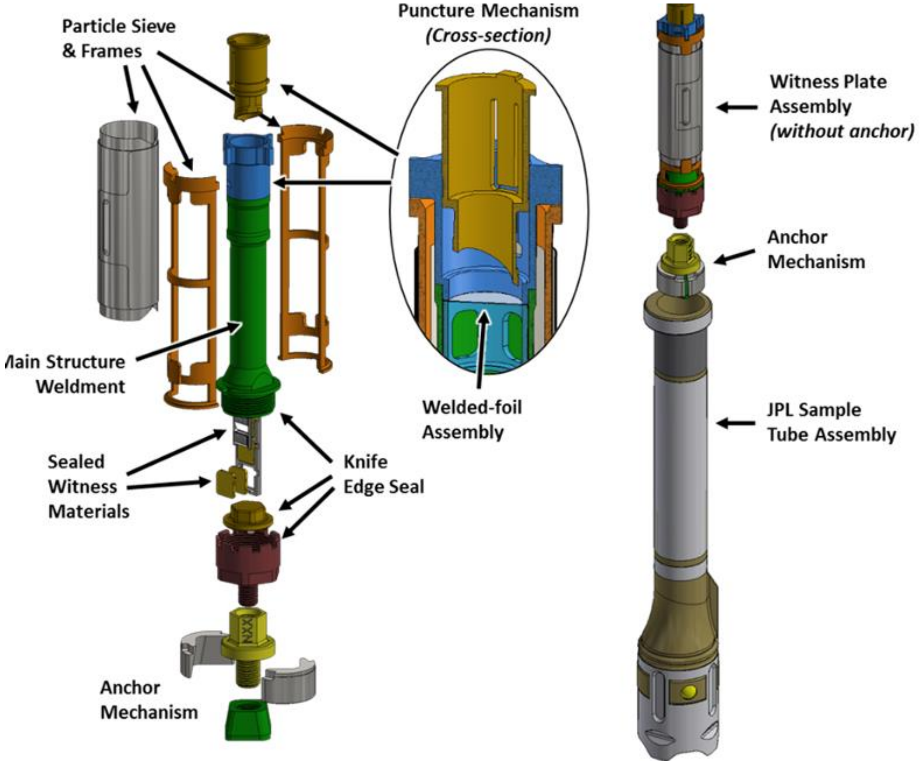



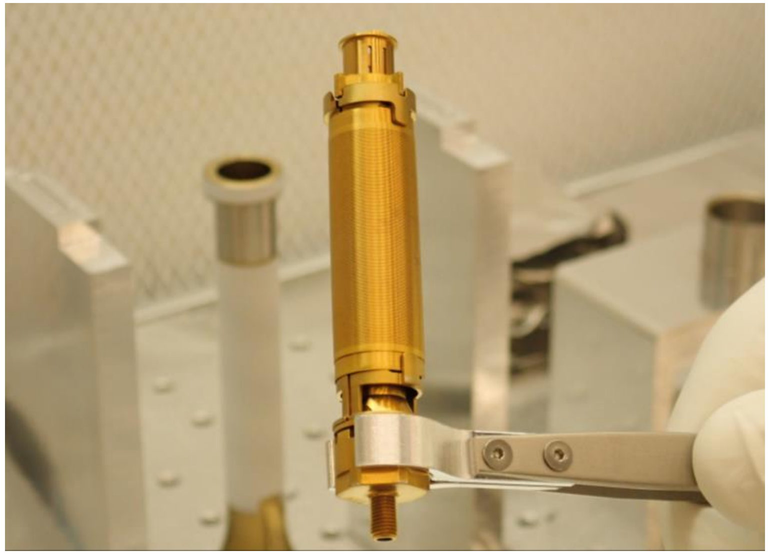


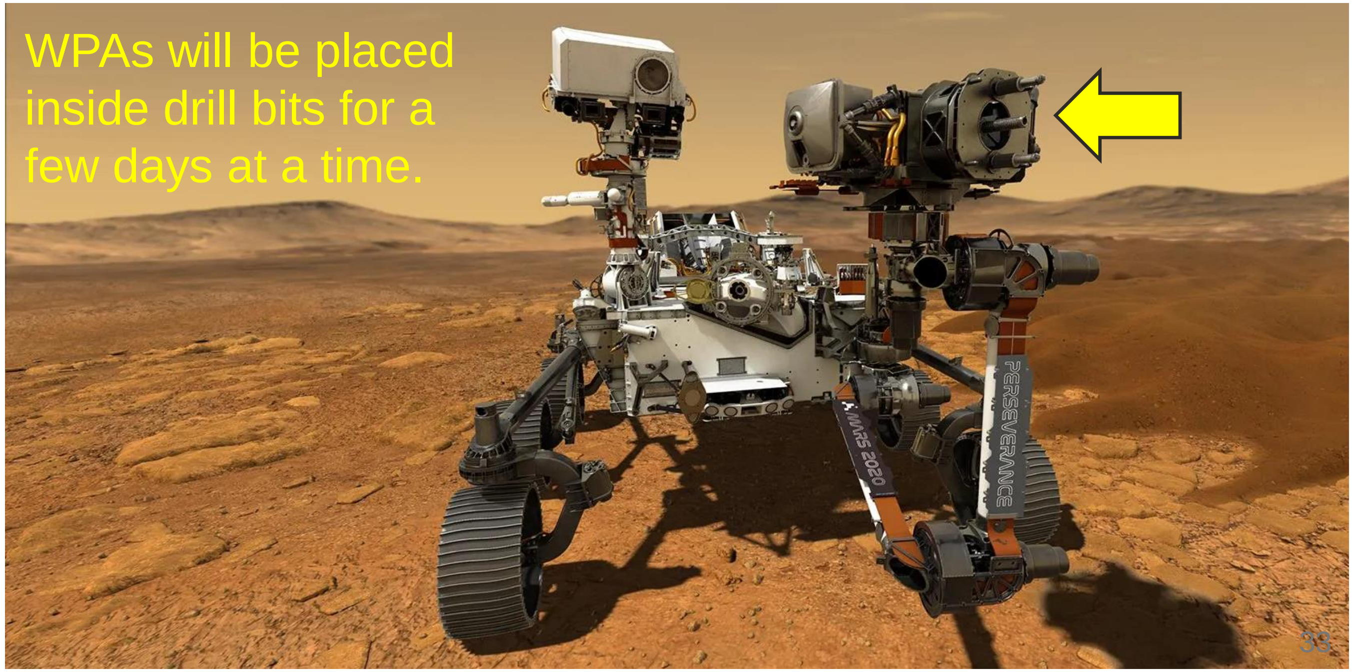
# State of the art in terms of cleaning? (Perseverance Rover)

**Witness Plate Assemblies (WPA) – 5 of them.**

- WPA provide contamination knowledge; will be earth returned along with Mars samples
- Fabricated custom vacuum-oven to allow baking at 350C prior to their assembly using sterilized tools.
- The entire process of fabricating and assembling WPAs has been extremely complex.



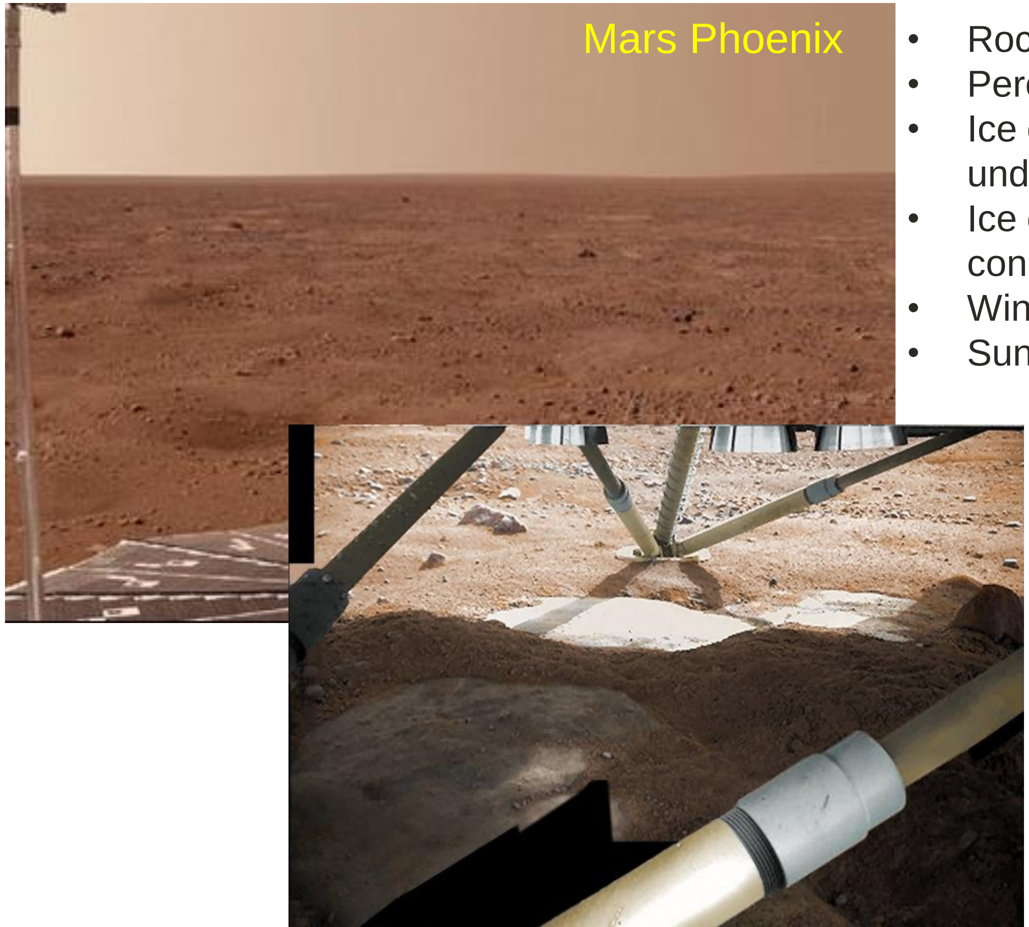





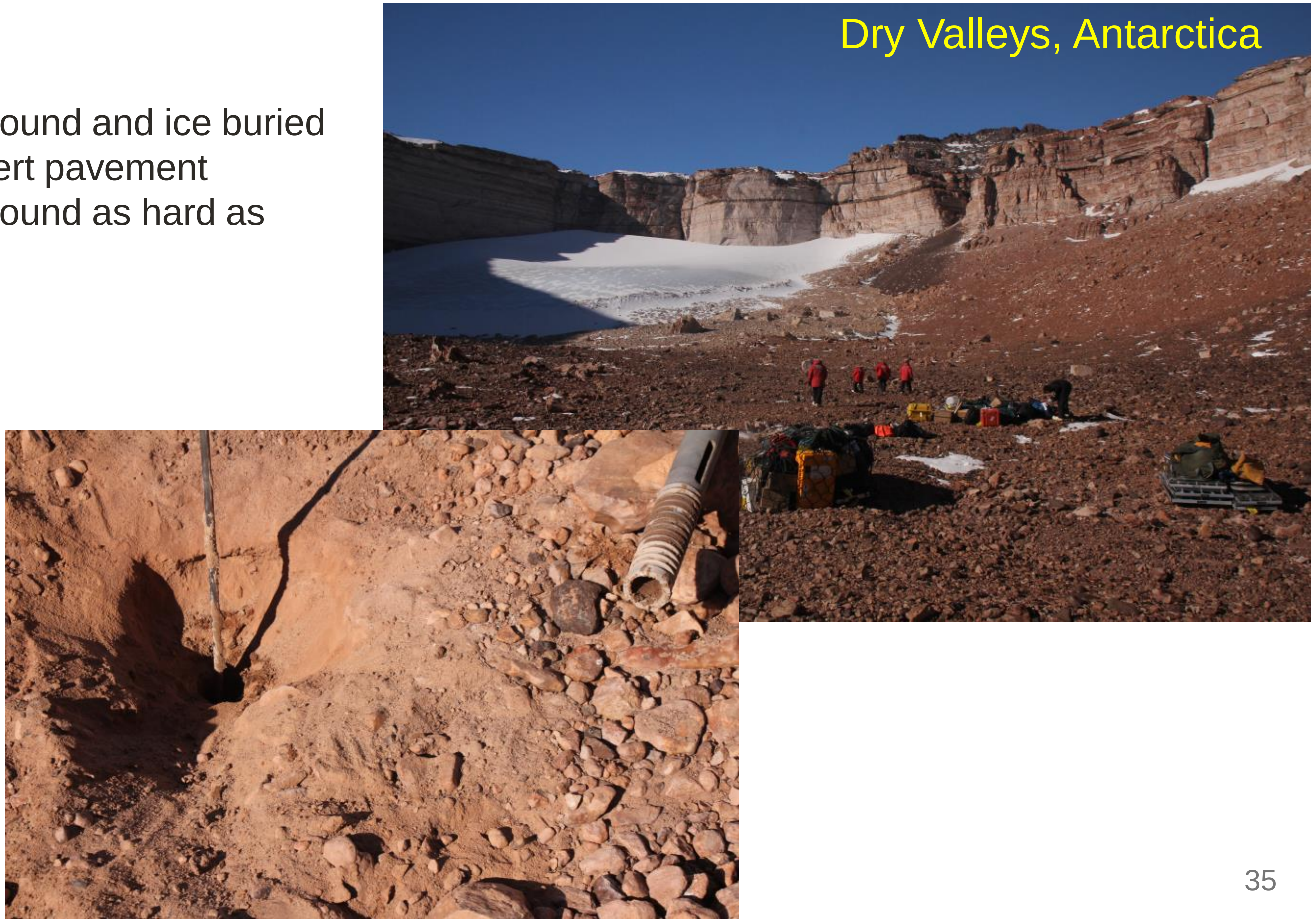
# Analog Field Testing

# Analog field testing is critical

- There are many locations on Earth that are very good analogues for Mars/Ocean Worlds: Antarctica, Greenland etc.
- It’s imperative to test drilling hardware and cleaning protocols in analog locations and subject it to ‘geological and environmental uncertainty’ that nature can offer (e.g., wind, brines).




- Rocks
- Perchlorates
- Ice cemented ground and ice buried underneath desert pavement
- Ice cemented ground as hard as concrete
- Wind
- Sun



# Field Testing: In-Situ Cleaning

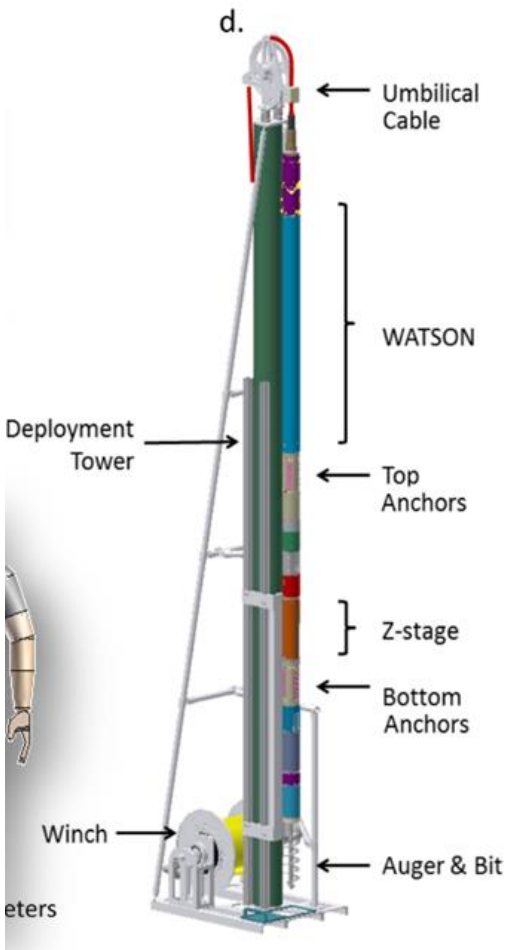
HONEYBEE ROBOTICS
Exploration Technology

## Example: WATSON life detection drill (Bhartia et al., 2018)

- Used IPA in Greenland to clean outer drill surface (this is NASA-approved method to reduce bio-burden)
- The drill was lowered 100 m below the surface and used integrated Deep UV/Raman to detect microbial colonies (Malaska et al., 2020)

## Example: ARADS system (Glass et al., 2018)

- Using IPA in Atacama was very effective in reducing bio-burden
- The samples, captured using 1 m drill, were transferred to a range of instruments for analysis

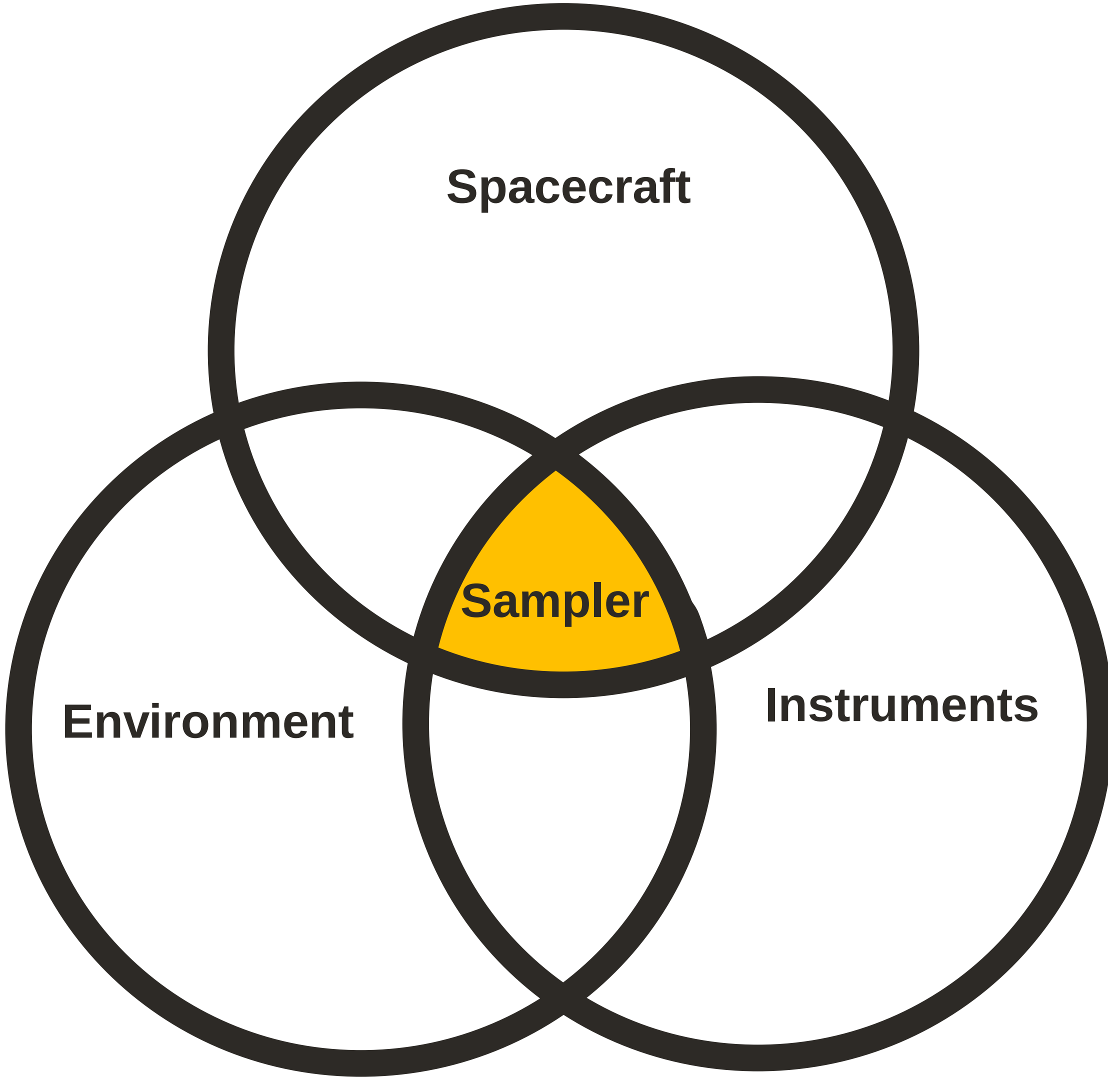




# Conclusions

# General thoughts and considerations

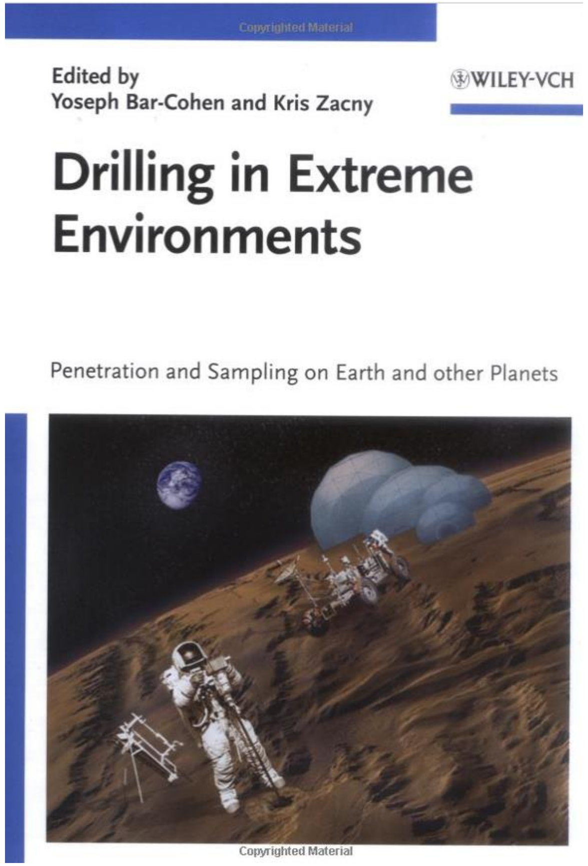
- Development of a sampling system is an iterative process that needs to start very early on in the mission formulation.
- If there is no sample, there is no mission. If sampling system is poorly designed, instrument will return poor data.
- Technology status for sample acquisition:
    - Shallow drilling is relatively mature.
    - Mid Range drilling regime is mature for lunar drilling. Some modifications needed to adapt to Mars and Ocean Worlds.
    - Deep drilling regime requires significant technology development.
    - Sample handling is challenging and needs significant development.
- Drill integrated instruments have potential to be game changer
- There is no substitute for testing under relevant conditions: TVACs and in the field (geological uncertainties stress the system).
- Planetary Protection (“killing bugs”) and Contamination Control (“removing bugs”) significantly affects sampling system (PP eliminates spores but does not remove all the organic contaminants). Technology for in-situ sterilization or en-route sterilization should also be considered and developed.



# Good reference for Planetary sampling

HONEYBEE ROBOTICS
Exploration Technology

**2009**




**Topics covered:**

- Extraterrestrial drilling
- Ice drilling
- Sample handling
- Instruments
- Planetary protection

**2020**