# Advances in Sample Handling and Shallow/Deep Drilling Technologies

Planetary Science Decadal Survey 2022-2032
Panel on Mars

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ISO 9001 CERTIFIED
AS9100 CERTIFIED

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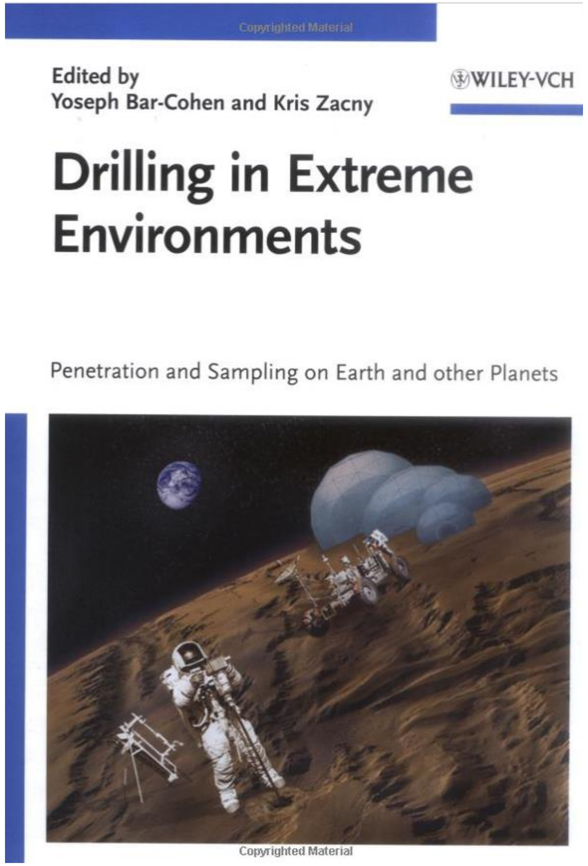
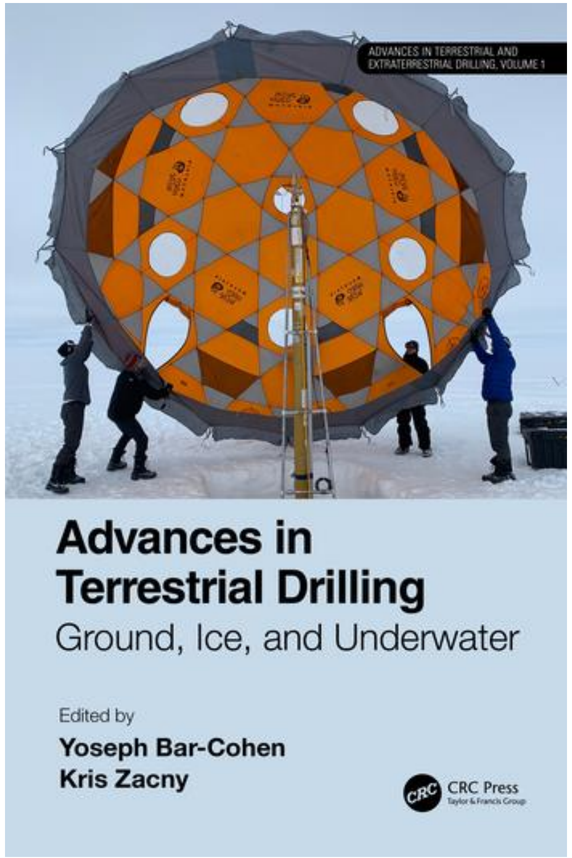
# Good reference for Planetary sampling

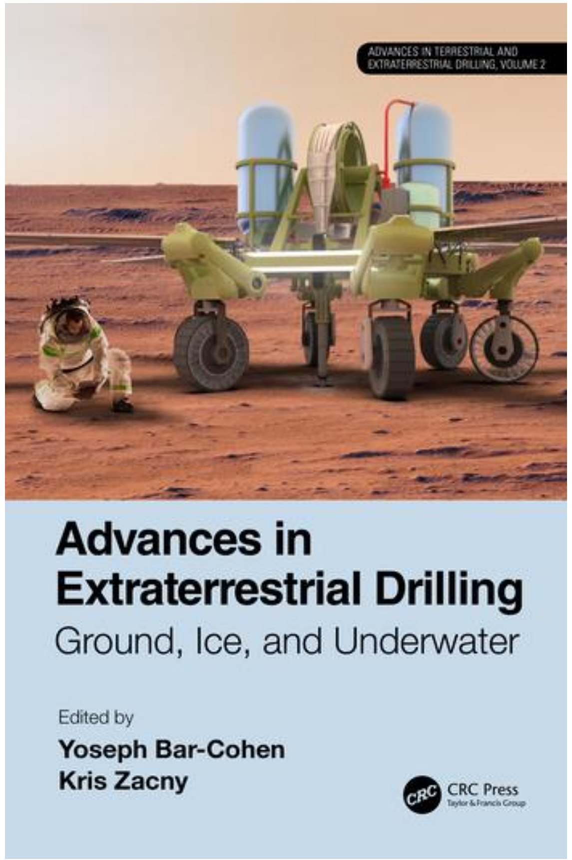
**2009**




**Topics covered:**
- Extraterrestrial drilling
- Ice drilling
- Sample handling
- Instruments
- Planetary protection

**2020**



# Agenda

1. Background to drilling, sampling, sample handling
2. Drilling technology status
    1. Shallow (centimeters)
    2. Mid-range (meters)
    3. Deep (10s of meters and more)
3. Sample handling technology status
4. Other considerations: Planetary Protection and Analog Tests
5. Conclusions

The work presented in these slides, have been funded by NASA, unless otherwise noted.

# Drilling is a final step in exploration

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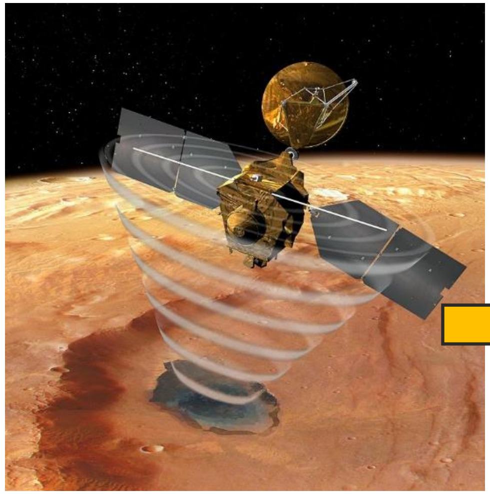
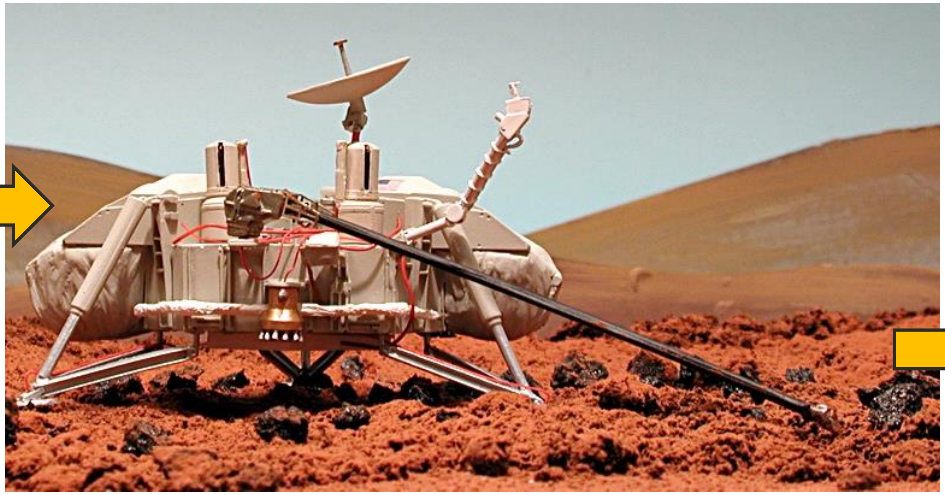
- **We are reaching a point, where to keep exploring, we need to go below the ground.**
- **Drilling: Exploration in 3D + Time. Going down is going back in time.**

Explore from above

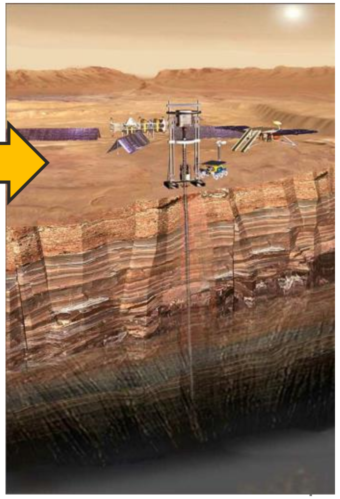


Surface: 1D



Surface: 2D

Subsurface: 4D



# Past, Present and "known" Future of drilling on Mars

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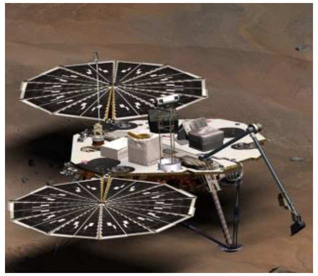
Timeline (Decades)

2000s | 2010s | 2020s

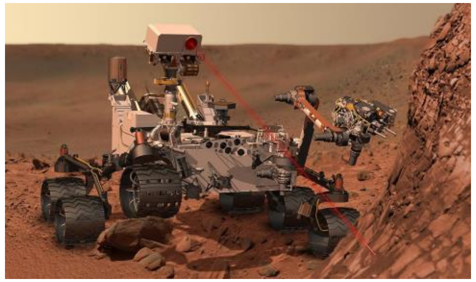
Depth regime (log-scale): mm, cm, m

MER (2003)

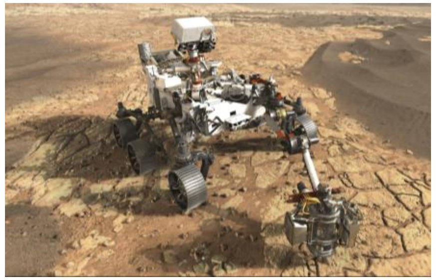
Phoenix (2007)



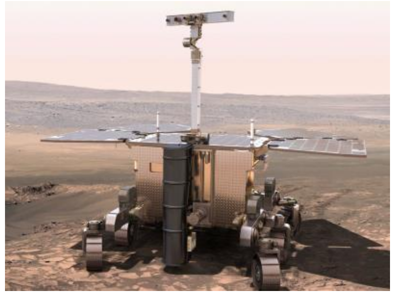
Curiosity (2011)



Perseverance (2020)



Rosalind Franklin (2022)



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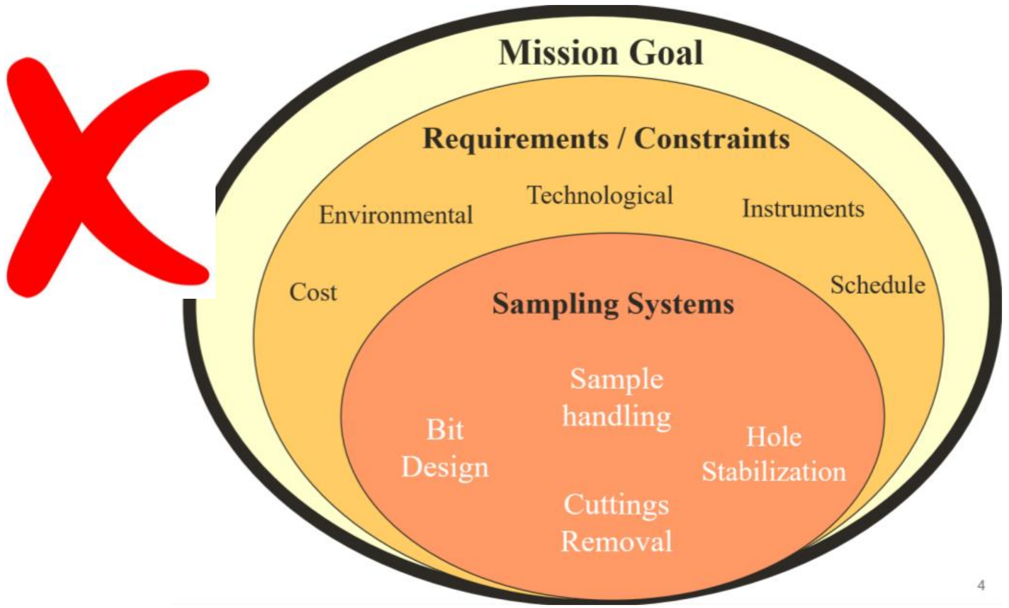
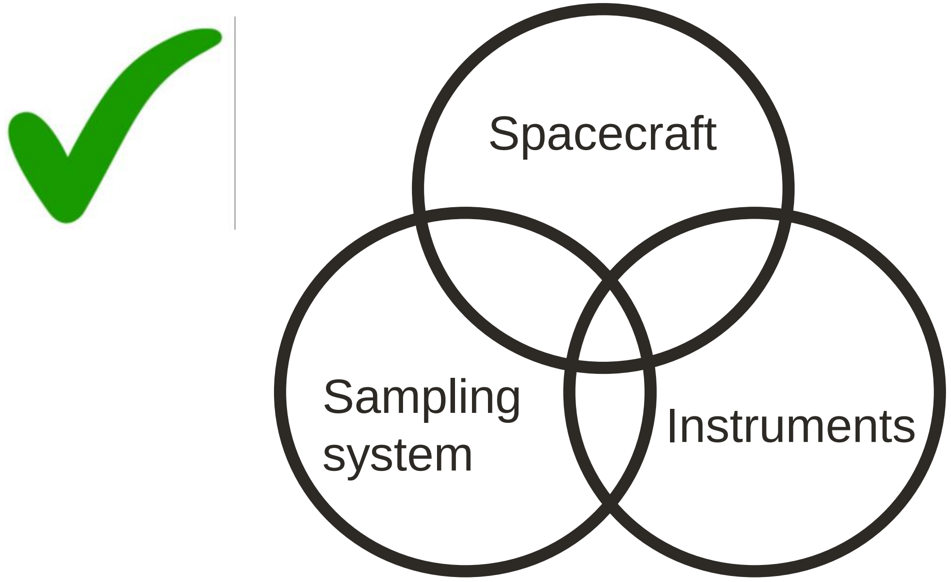
# General thoughts and considerations

- Development of a sampling system is a highly iterative process that needs to start very early on in the mission formulation. If there is no sample, there is no mission.
- Poorly designed sampling system that does not provide a sample in optimal state/position will affect science outcome.
- No two missions are alike. Only few sampling technologies can be 'built-to print' for other missions. We need to focus on identifying common approaches that can be adapted across many missions.
- There is no substitute for testing under relevant conditions (Mars chambers and in the field). Analysis or modelling does not have needed geological uncertainties to stress the system.
- Planetary Protection impacts the sampling system more than it impacts other systems (in some missions, sampling system is the only system that touches a sample).
- Beware of requirements! Very often 'nice to have' requirements are considered 'must haves' – these need to be identified and de or re-scoped otherwise sampling system gets too complex.



# Challenges of drilling and sample handling

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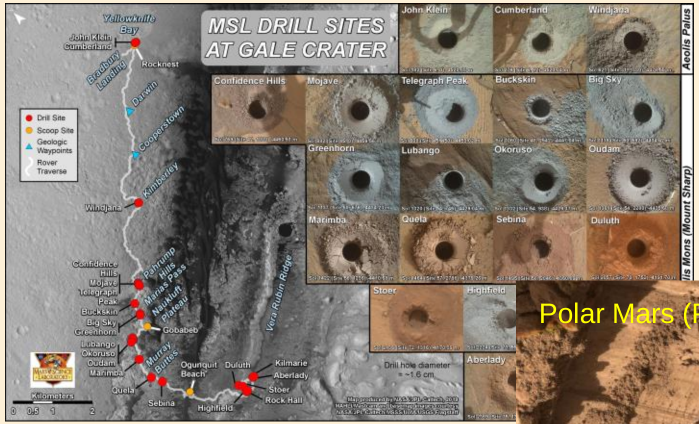
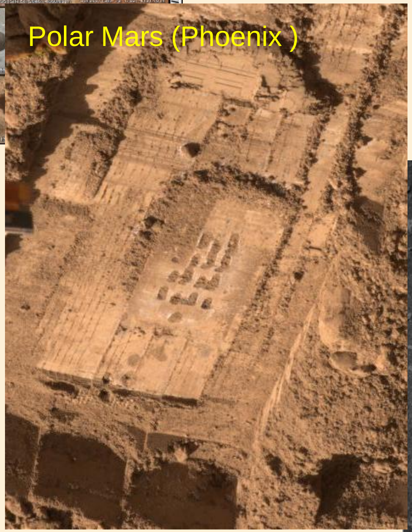
## Drilling

- 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 <1 MPa to >150 MPa (across 10^3 range), in addition to a range of depths.

10 MPa




50 MPa




100 MPa


## 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.

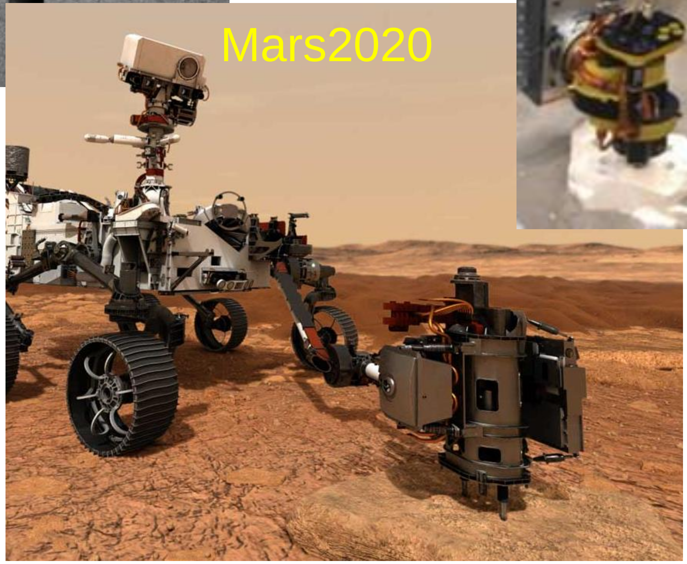
Sampling system and instrument is like hand in a glove – there has to be a perfect fit

Imagine putting sand inside the straw

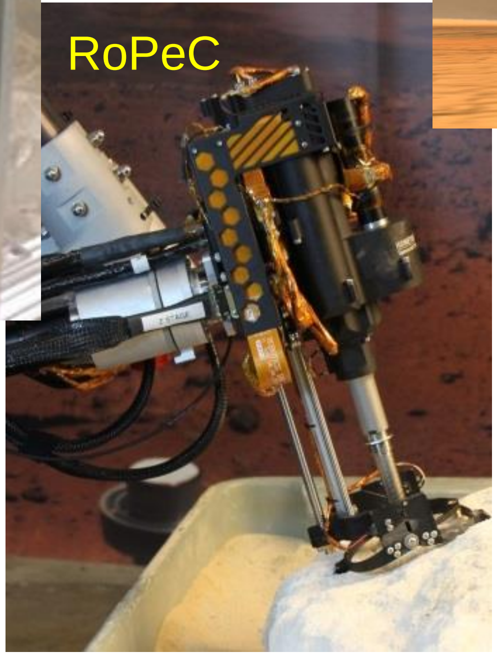
# Drilling

# Shallow (centimeters) drilling: many options exist

- Shallow drilling has seen significant technology development efforts as well as implementation in flight missions
- Numerous approaches have also been developed for other Solar System bodies – these could be adapted to Mars with some degree of modifications

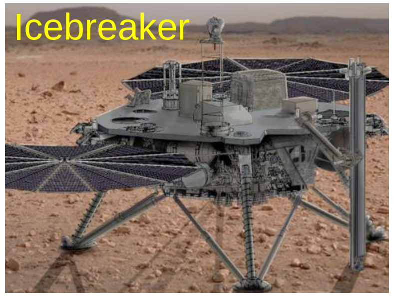




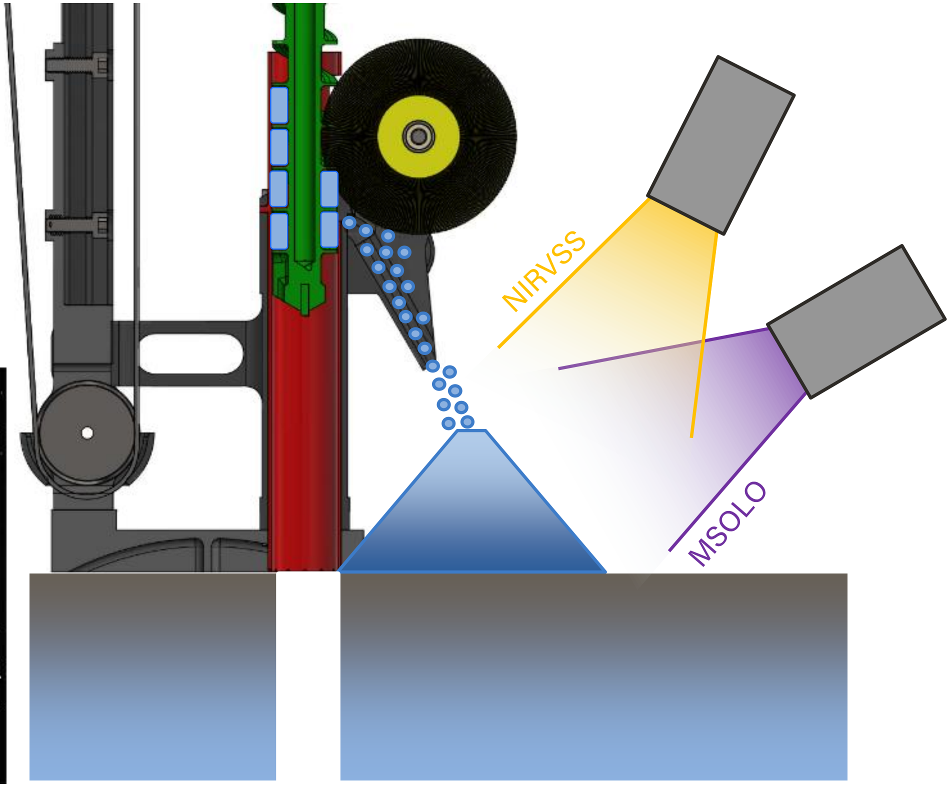


# MidRange (1+ meter) drilling: TRIDEN drill

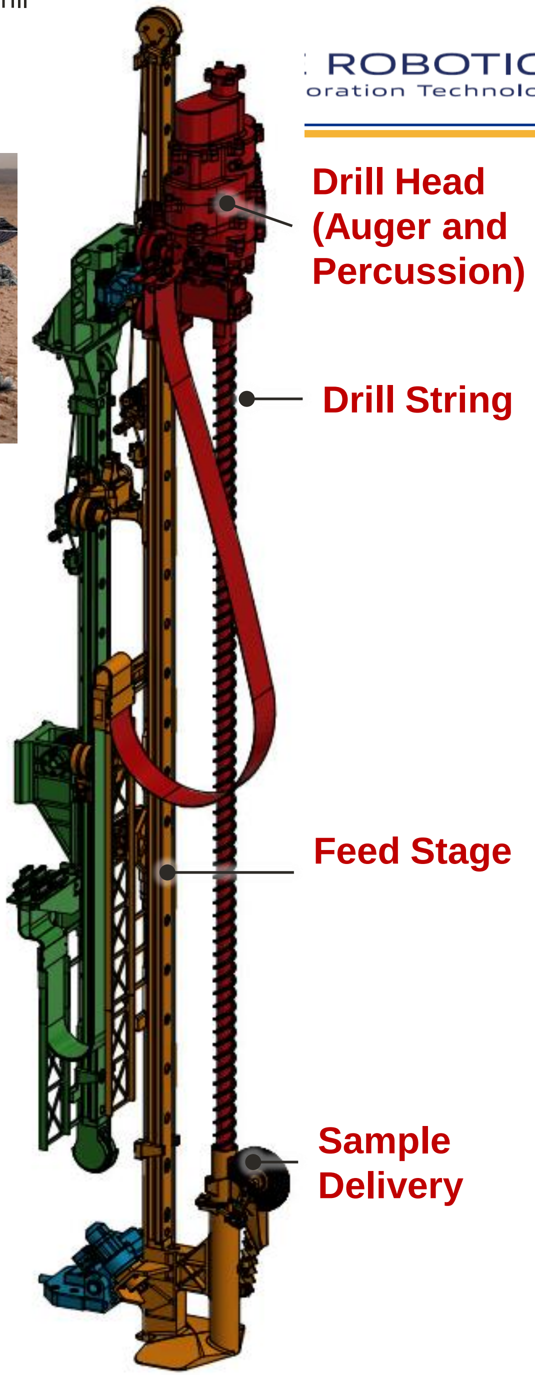
- Originally for Mars Icebreaker mission (PI McKay). Considered for Mars Polar Science (Byrne/Hayne/Smith) and other missions.
- Delivers volatile rich regolith to the surface in 10 cm ‘bites’ for analysis by the Mass Spectrometer observing lunar operations - MSolo (PI Captain) and the Near Infrared Volatile Spectrometer Subsystem- NIRVSS (PI Colaprete).
- Part of Polar Resources Ice Mining Experiment-1 (PRIME-1) and Volatiles Investigating Polar Exploration Rover (VIPER).
- Could be used on Mars missions.





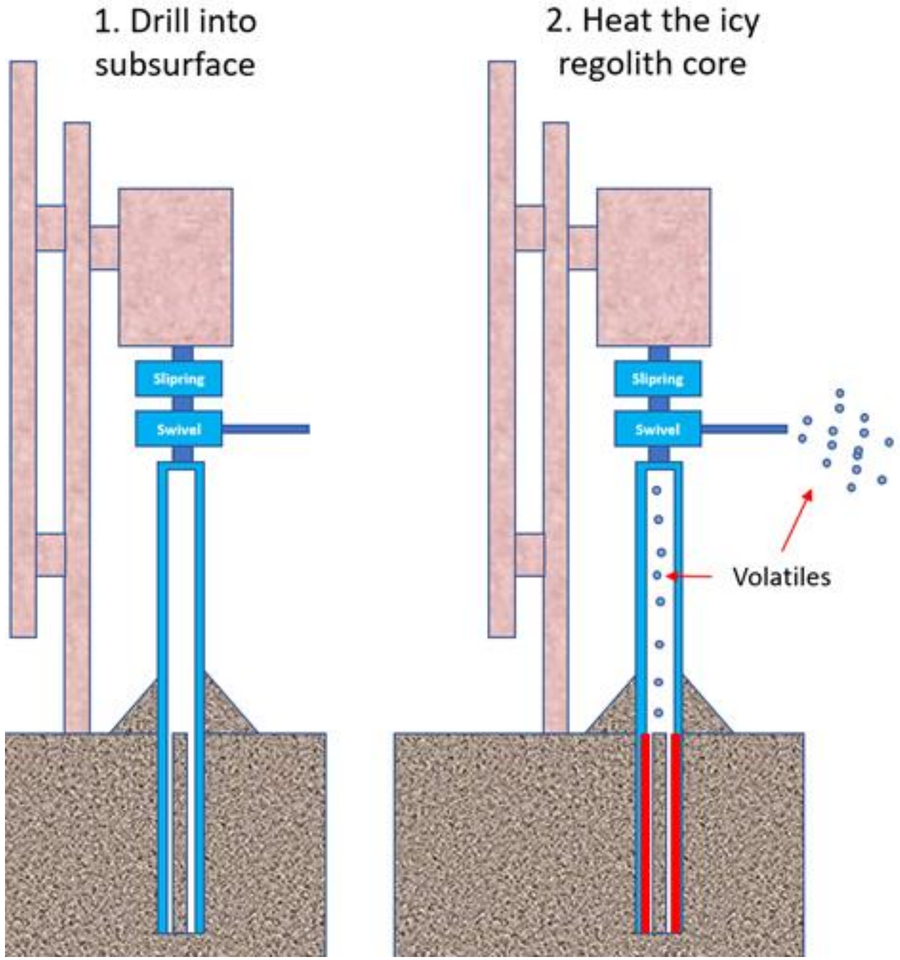



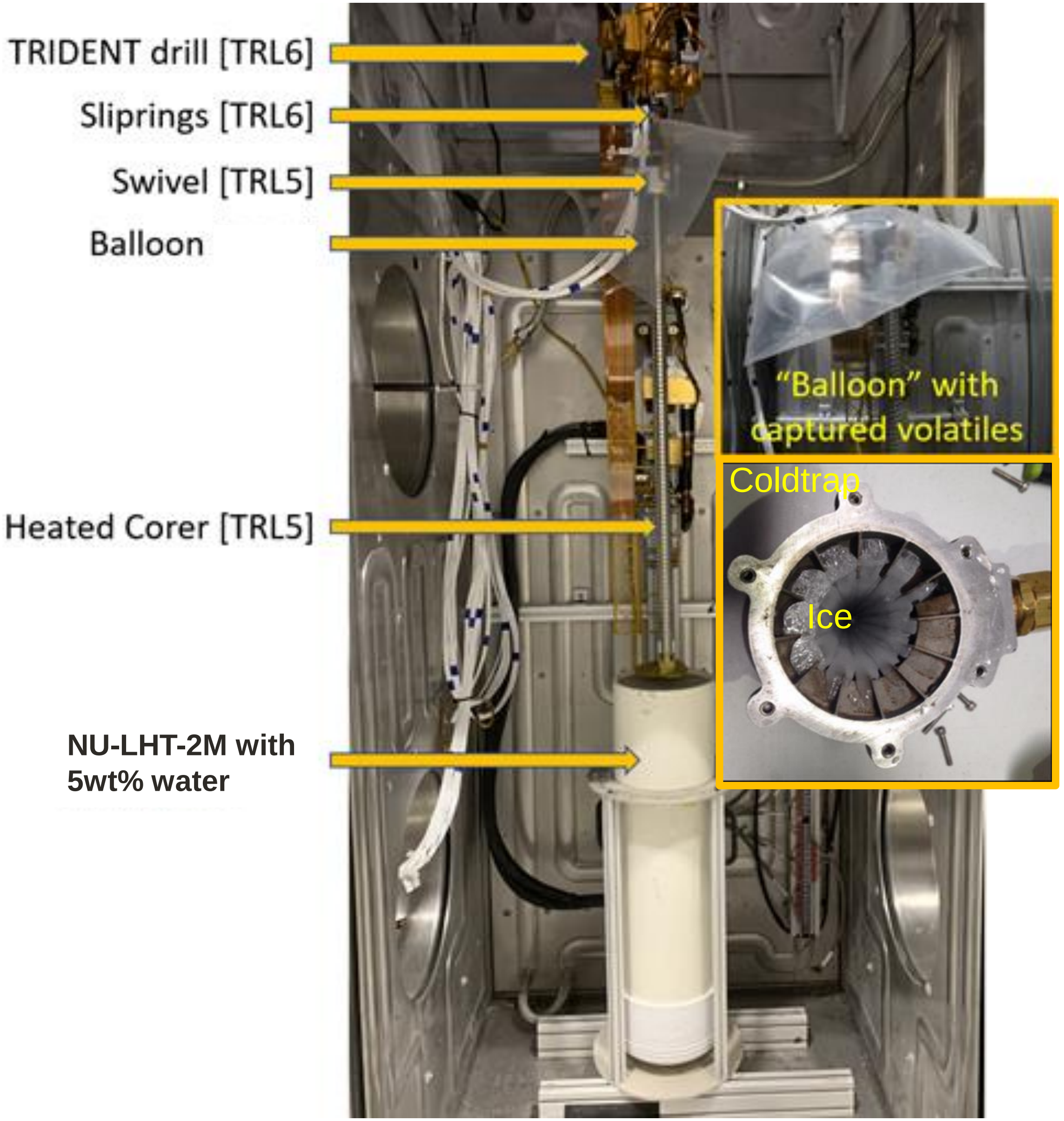

The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT)



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

- Alternative means of delivering volatiles eliminates sample handling
- Ice melts in the core before boiling off offers opportunity for additional in-situ science
- Volatiles flow into a capture system (cold trap, gas tank, instrument).
- Developed for Mars and lunar ISRU.



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

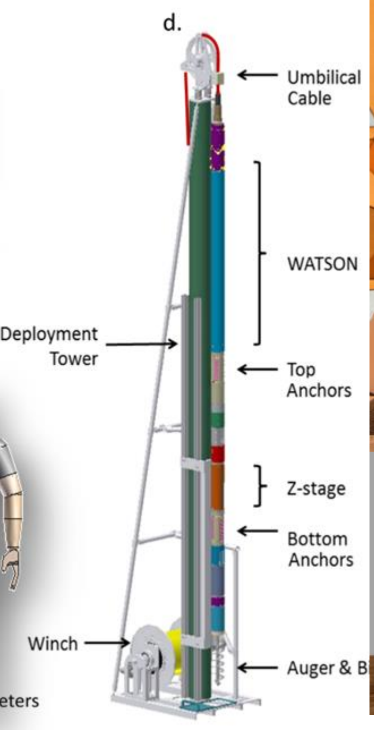
## Cable Suspended Drill

**Pros/Cons**

- Low mass/power
- Need stable borehole

**Example:**

- Used in Antarctic ice coring
- AutoGopher, WATSON



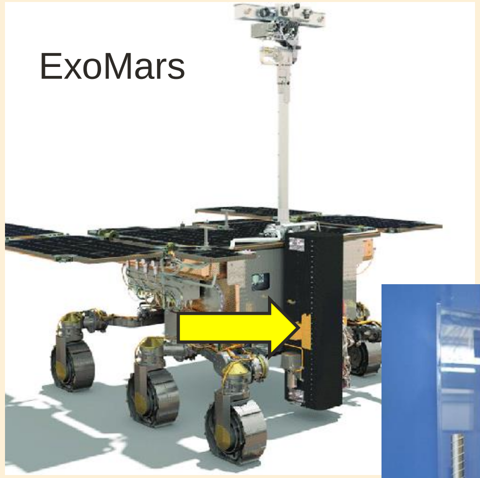

## Drill string with drill pipes

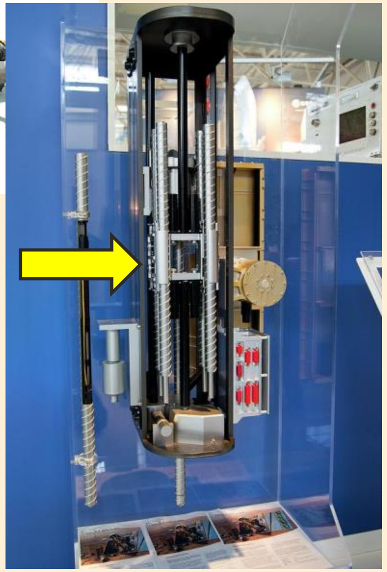
**Pros/Cons**

- Drilling system above the hole
- Mass/power/complex robotics

**Example:**

- Used in Oil and Gas
- ExoMars drill



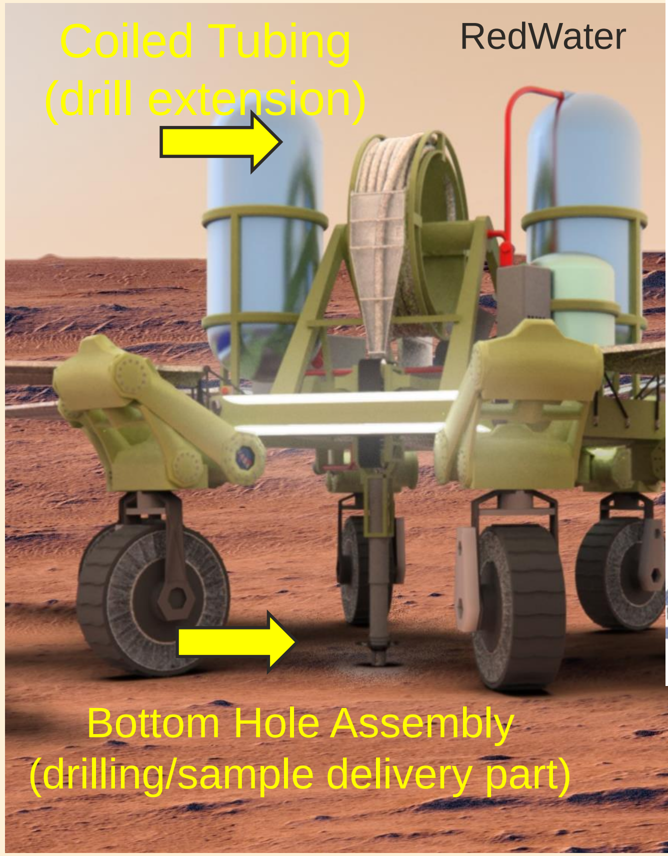
## Coiled Tubing Drilling

**Pros/Cons**

- Continuous drill pipe
- Mass/power/complex robotics

**Example:**

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




# Drill integrated instruments

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- “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

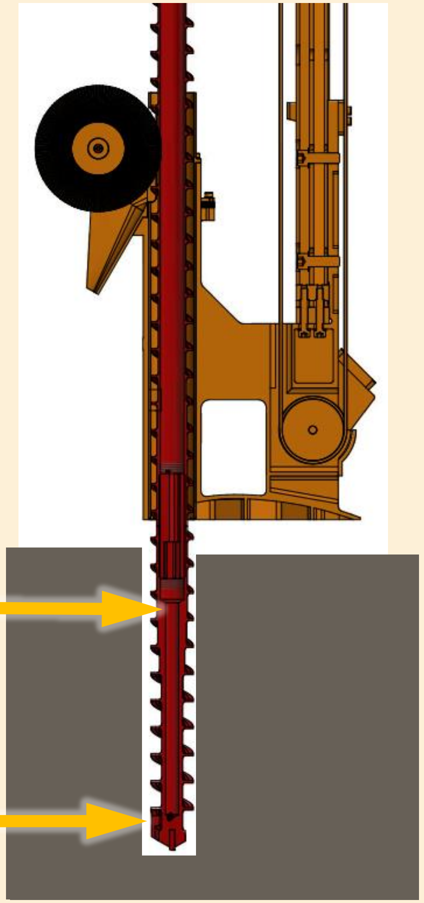
**TRIDENT data:**

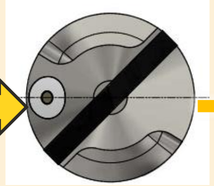
- Geotechnical properties of regolith
    - *Ice concentration and physical state of ice*
- Thermal properties of regolith: thermal gradient, thermal conductivity, heat flow

Heater and Temp Sensor

Material strength from drilling energy

Bit Temperature Sensor

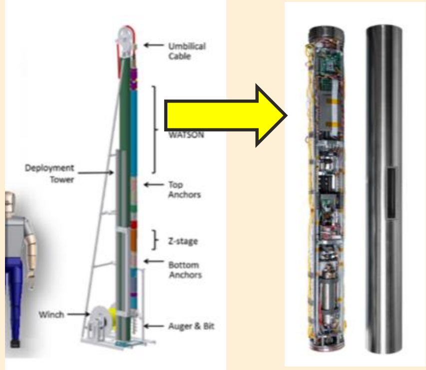




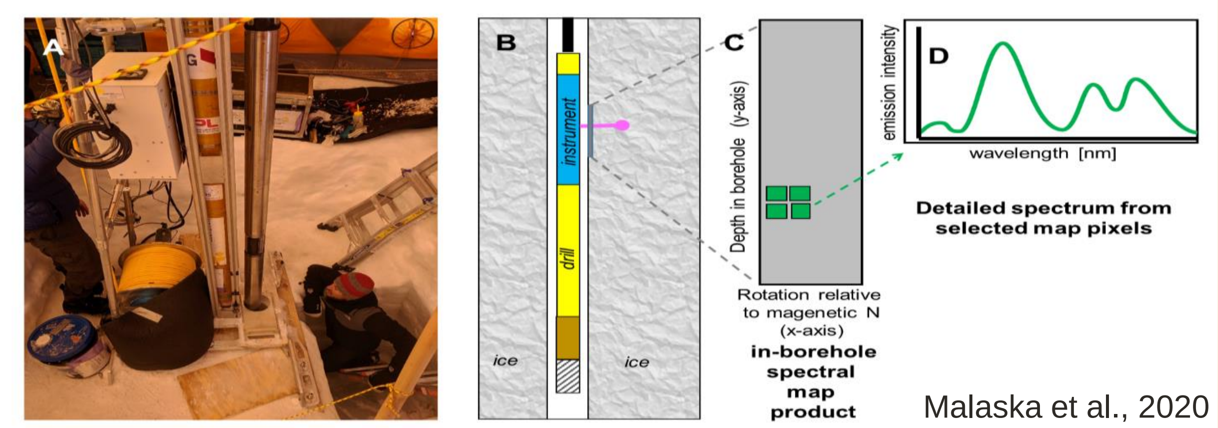
## WATSON life detection drill

**WATSON data:**

- Deep UV Raman/fluorescence (M2020 SHERLOC, PI Beegle)
- 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

# Sample Handling

# Sample handling: Fines



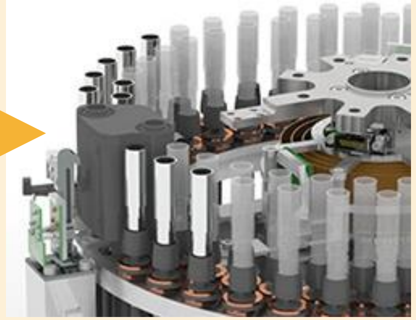
**Problem:**
Fines pose difficulties related to: Cohesion, Adhesion, Particle Sizes, Metering, Cross-Contamination etc.

**Clumps and fines**

**Fines**

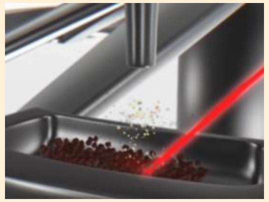
**Tray**

**Small cup**



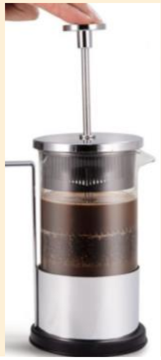
**Large cup**

**Look at**



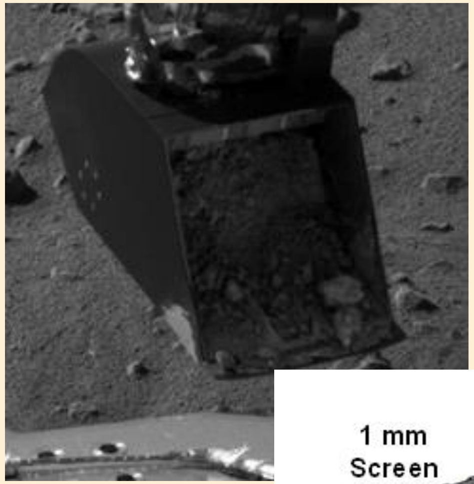
**Heat up**

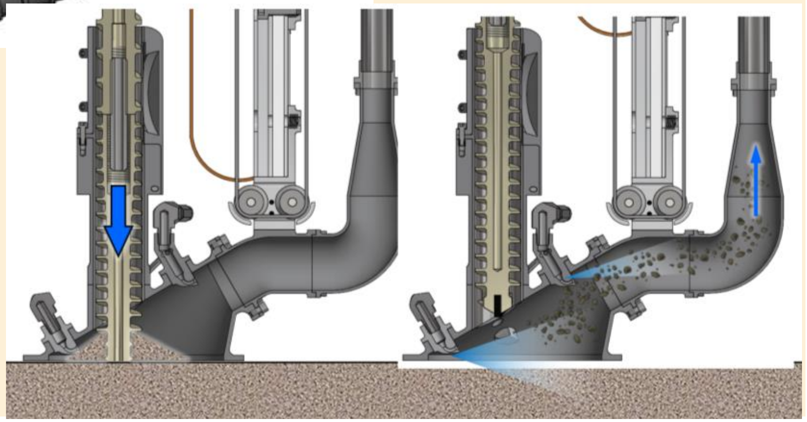
**Dissolve**



**Options:**

1. Scoops for surface regolith
2. Powder Bit for drill cuttings
3. Pneumatics for powder movement



# Pneumatic approach can be used in numerous missions

**How this works:**

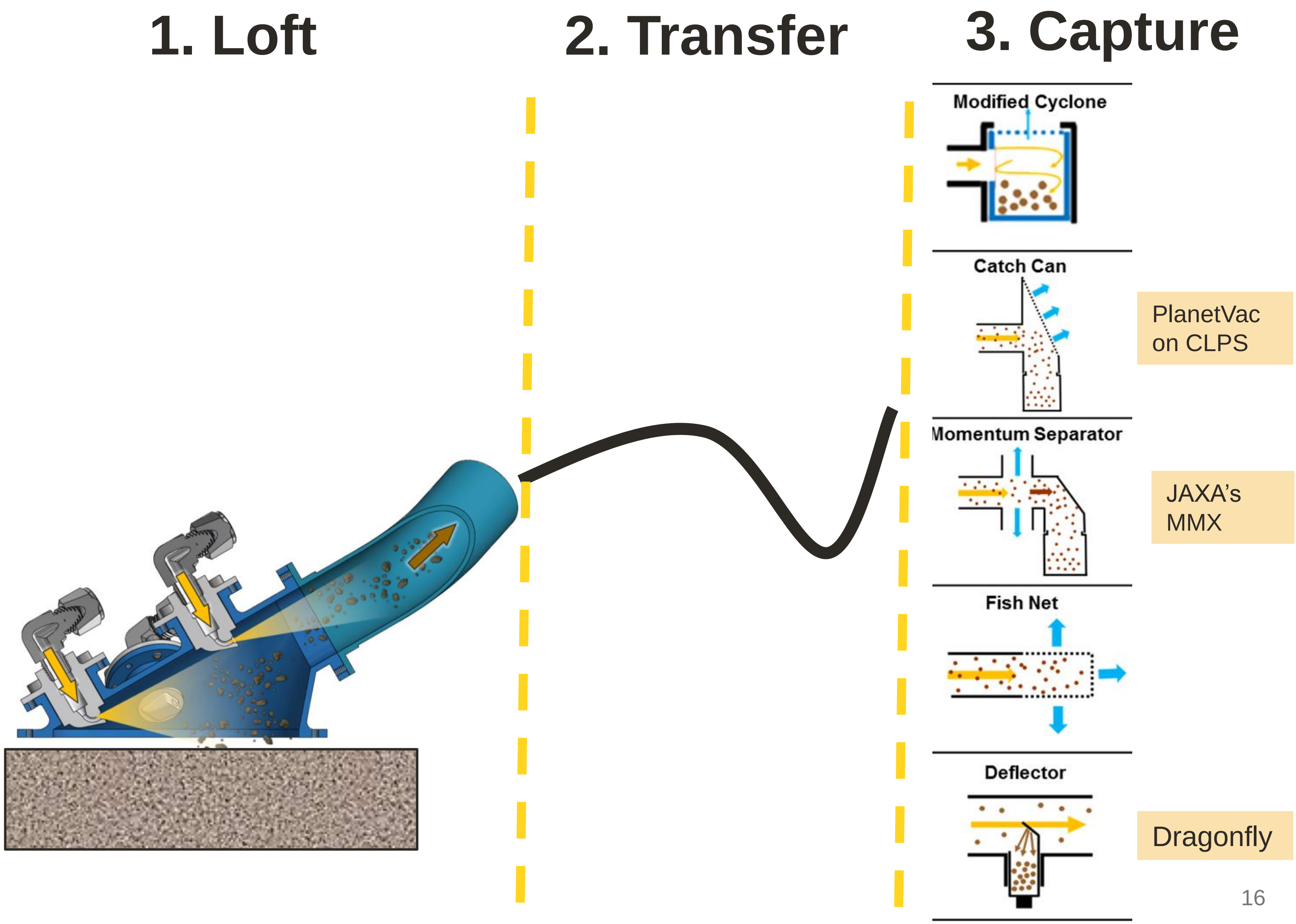
- Gas is used as a broom to sweep (loft) material via momentum exchange
- In vacuum, gas is like an explosive making pneumatic systems very efficient (1 g of gas lofts 100s grams of powder)

**Heritage**

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

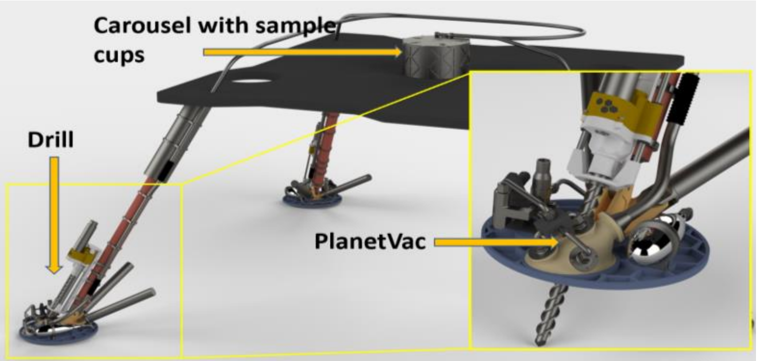
**Benefits:**

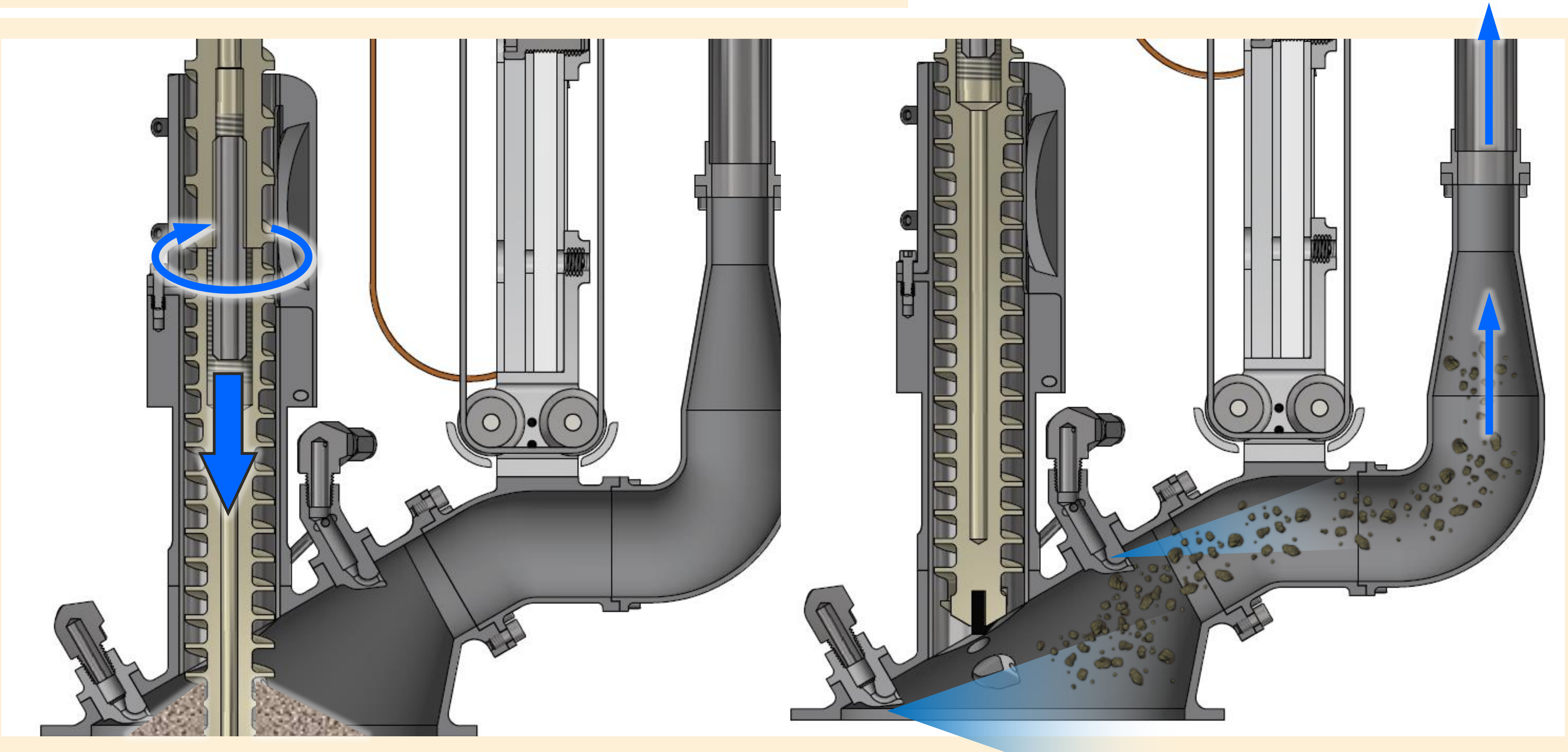
- Simple operation (actuator opens valve)
- Short sampling time
- No ground-in-the-loop needed
- Gravity agnostic – works with somewhat cohesive samples
- Sample delivery location independent from sample acquisition location
- Clean transfer lines between sampling to reduce cross contamination
- Works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

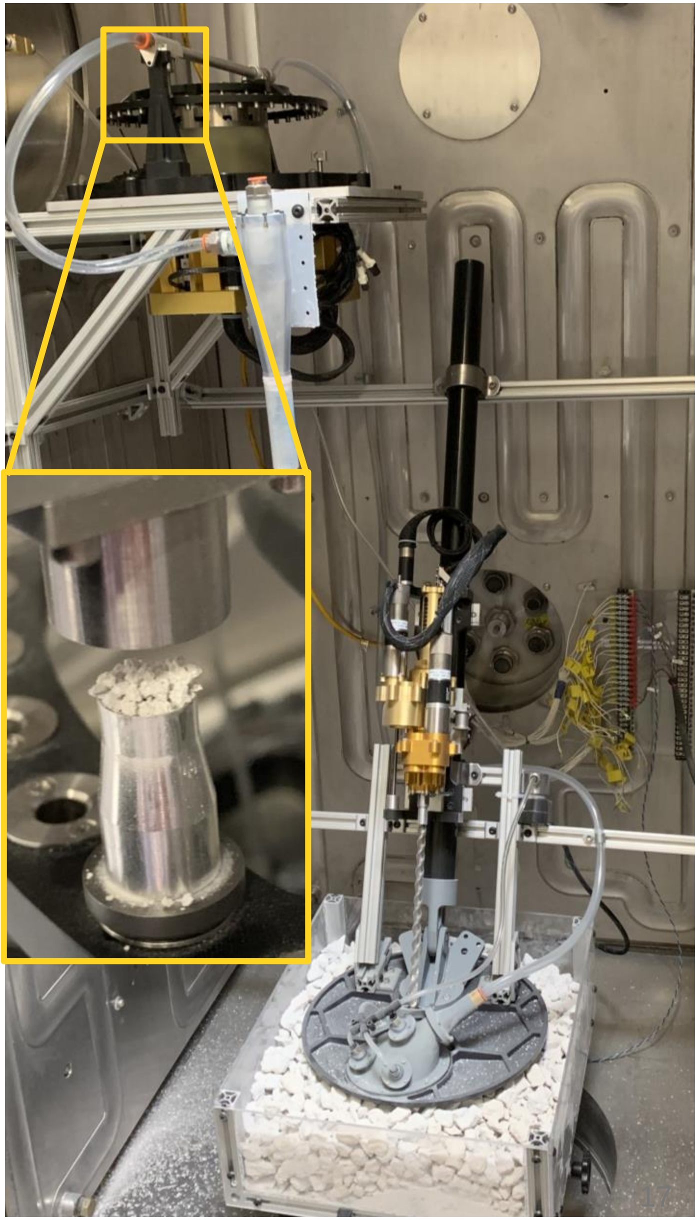


# Pneumatic approach can be coupled with a drill

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





# Sample handling: Cores

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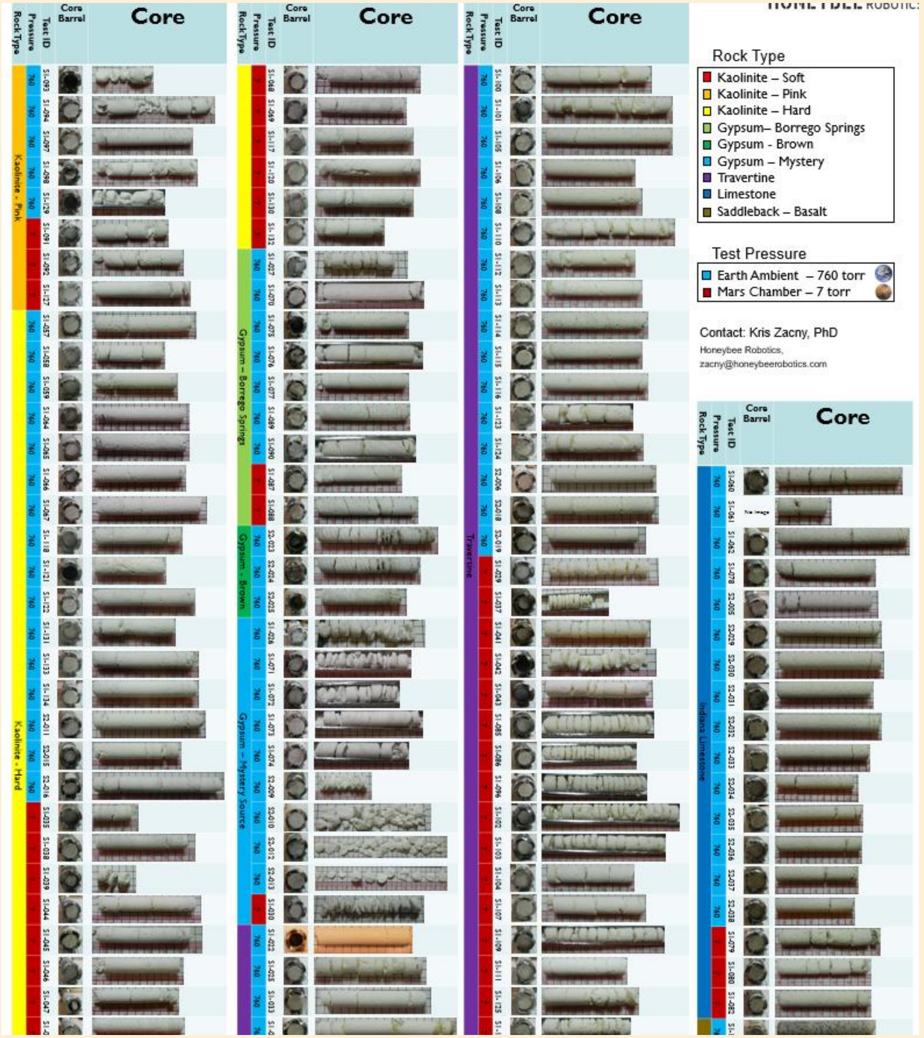
**Problem:**

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

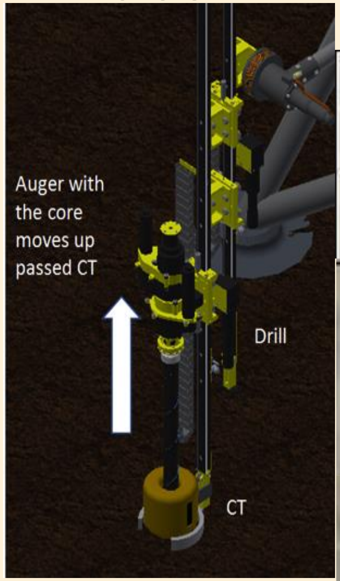



**Options:**

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.

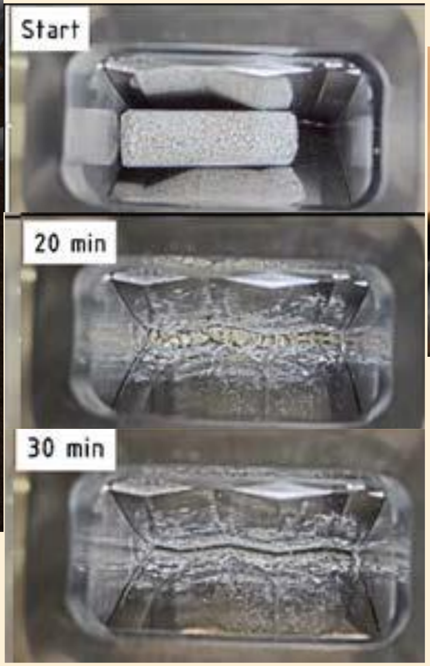
Mars2020


MicroCT




PI Obbard

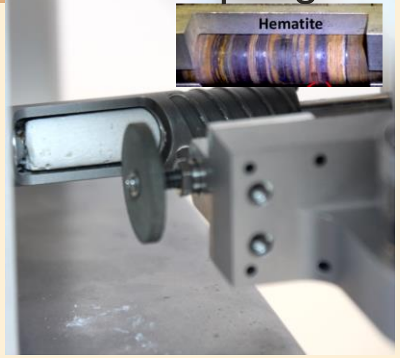
ExoMars




Redlich et al., 2018

PreView Bit

SubSampling




PI Brinckerhoff

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# Other considerations

# Planetary Protection

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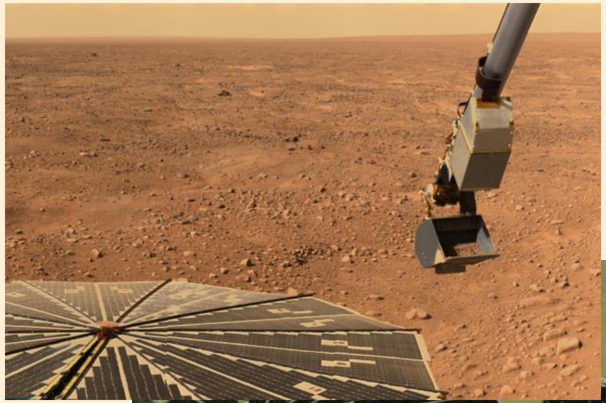
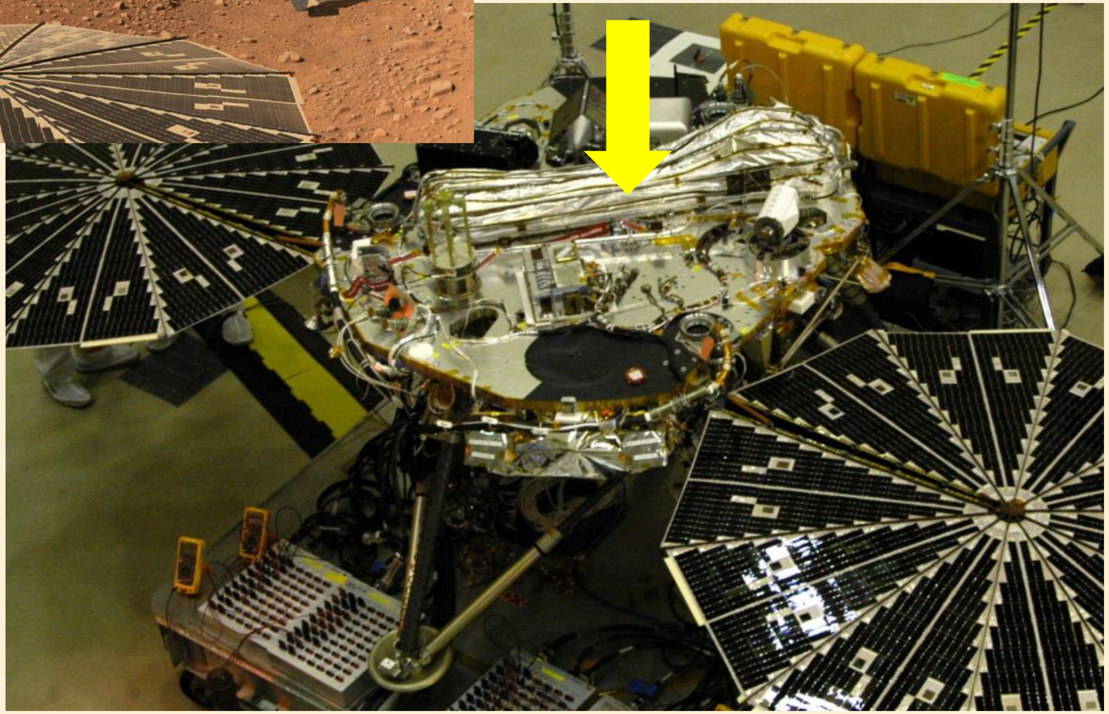
**In most cases, sampling system is the only system that touches Special Regions**

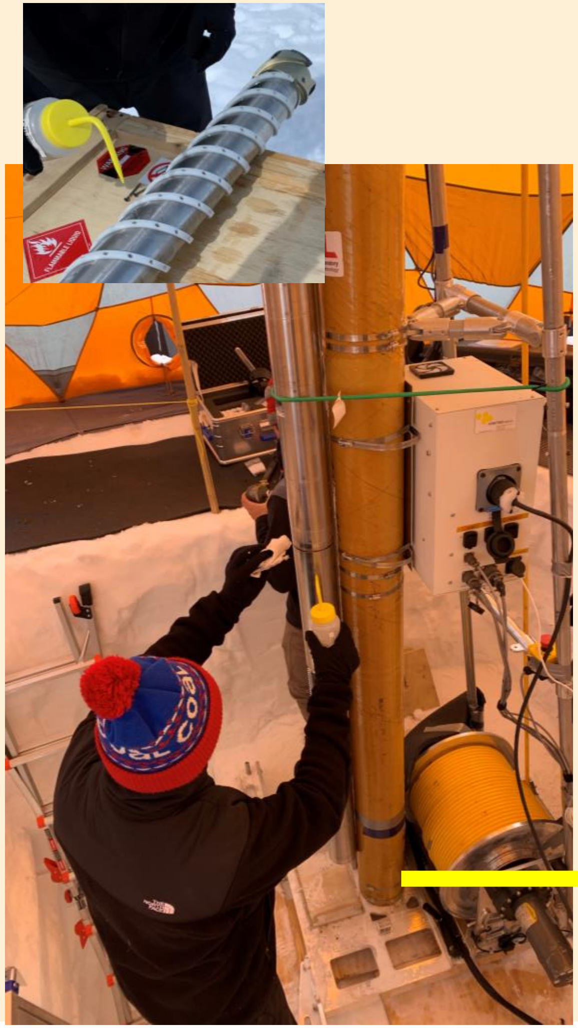
## Current Status: send clean hardware



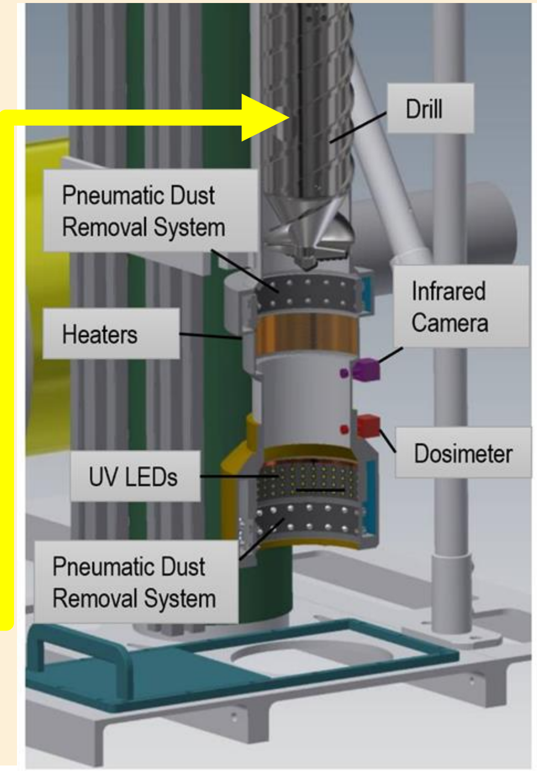
**Example: Mars Phoenix**
Only the forearm was of concern to PP
But it was simpler to put an entire arm through DHMR and inside bio-barrier



## Future status: in-situ sterilization/cleaning

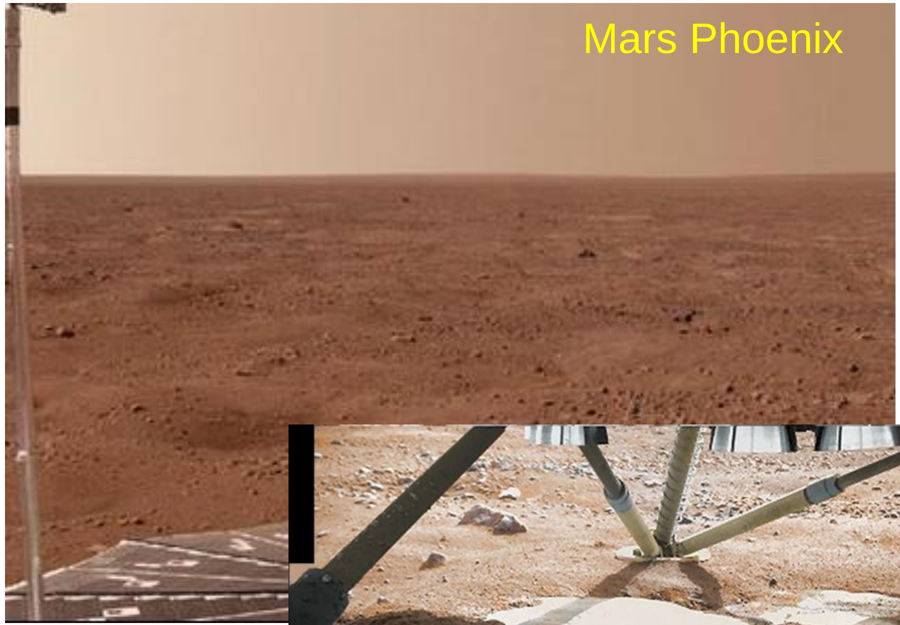


**Example: WATSON life detection drill**
Adding cleaning station to clean the drill prior to entering subsurface would simplify Integration and Test and cut the development cost and complexity

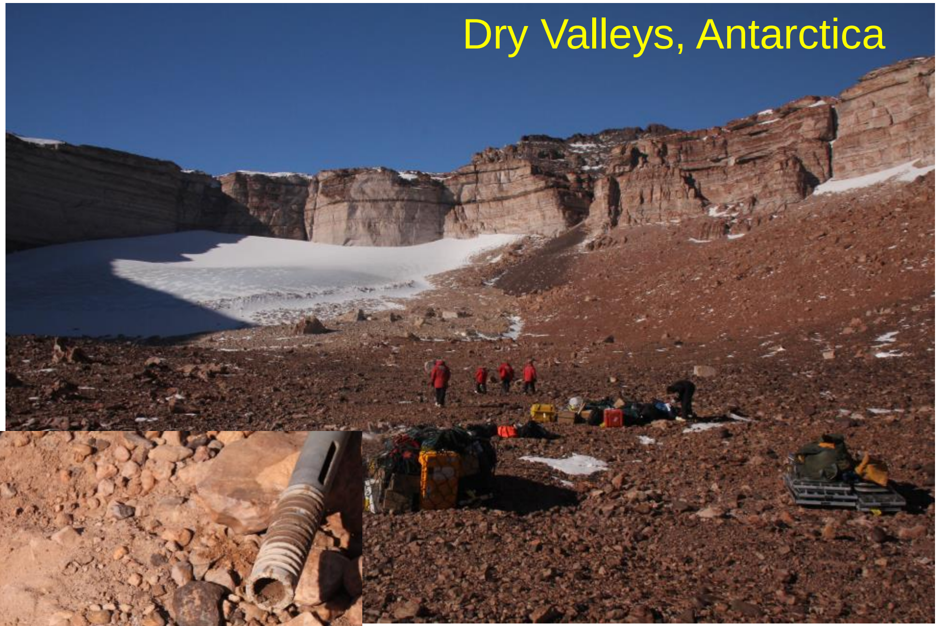


# Analog field testing is critical

- From a geotechnical perspective, Mars is very similar to Earth (e.g. Peters et al., 2017, Thomson et al., 2013)
- There are numerous locations on Earth that are very good analogues for Mars: Dry Valleys, Atacama etc.
- It’s imperative to test drilling hardware in analog locations and subject it to ‘geological uncertainty’ that nature can offer; we cannot come up with all the test scenarios in a lab.
- If we fail on Earth, we are bound to fail on Mars.




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




# Conclusions

- Depth regimes:
  - Shallow drilling is relatively mature. There are many ‘tools in the toolbox’ to choose from to meet mission requirements.
    - Suitable for Discovery, New Frontiers, and Flagship mission class
  - Mid Range drilling regime is mature for lunar drilling. Some modifications needed to adapt “Moon” drill to “Mars” drill. PP/CC requirements would need to be considered for some Mars missions.
    - Suitable for  Discovery, New Frontiers, and Flagship mission class
  - Deep drilling regime requires significant technology development.
    - Suitable for New Frontiers, and Flagship mission class
- Sample handling is very challenging and requires significant technology development. Focus on technologies that can be applied to more than one mission.
- Planetary Protection significantly affects sampling system. Technology for in-situ sterilization or en-route sterilization should also be considered and developed.