Sample Capture

14 June 2021
Keck Institute for Space Studies

Planetary Science of Venus
and the
Promise of In Situ Sampling Techniques

Honeybee Robotics:
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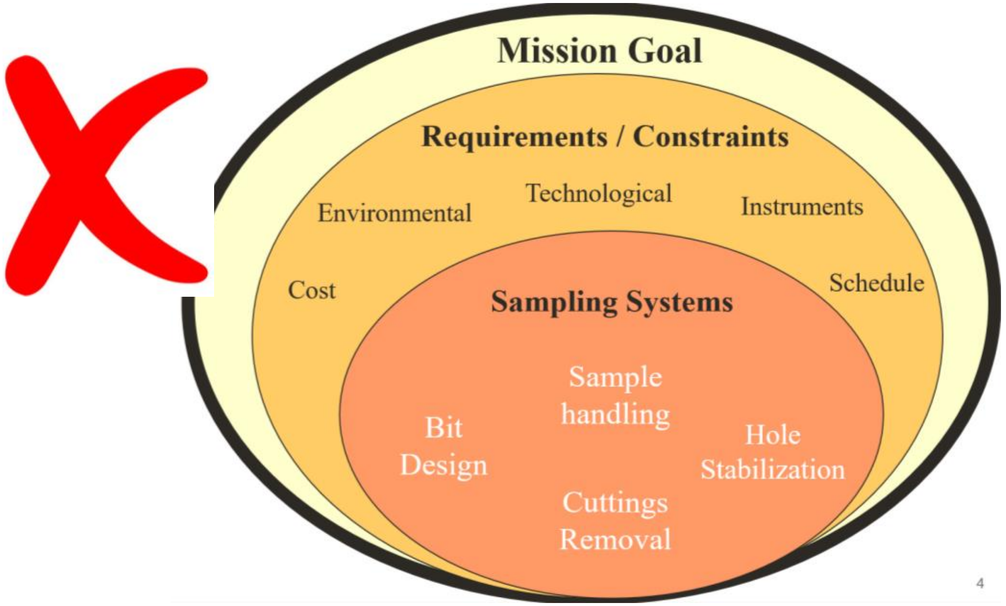
Agenda

- ☐ Sample collection
  - Drilling
  - Sample handling
  - Considerations

- ☐ Sample collection examples
  - MMX
  - Mars Sample Return
  - Venus
    - Past
    - Future

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.



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Mission Goal

Requirements / Constraints

Environmental

Technological

Instruments

Cost

Schedule

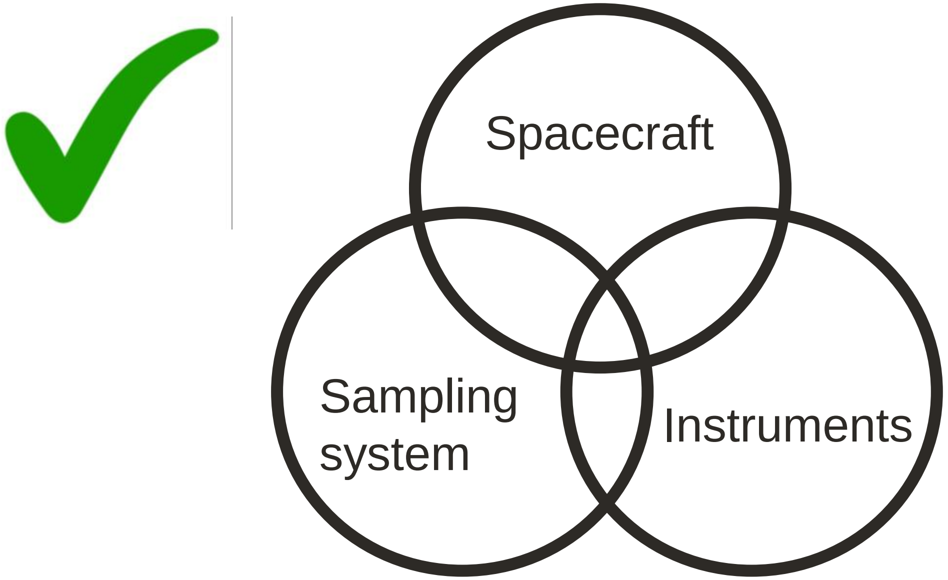
Sampling Systems

Bit Design

Sample handling

Hole Stabilization

Cuttings Removal



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Spacecraft

Sampling system

Instruments

Challenges of drilling and sample handling

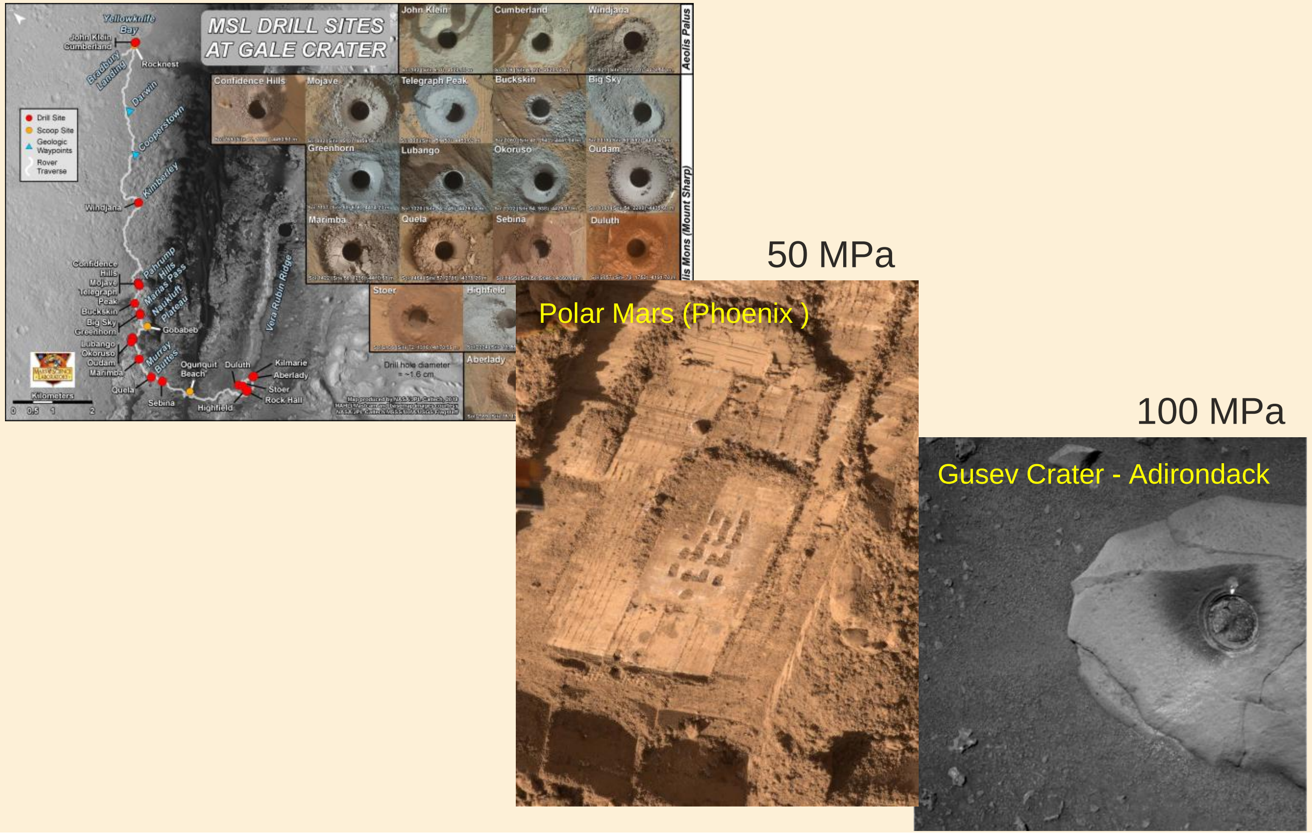
Drilling

- ❑ 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.

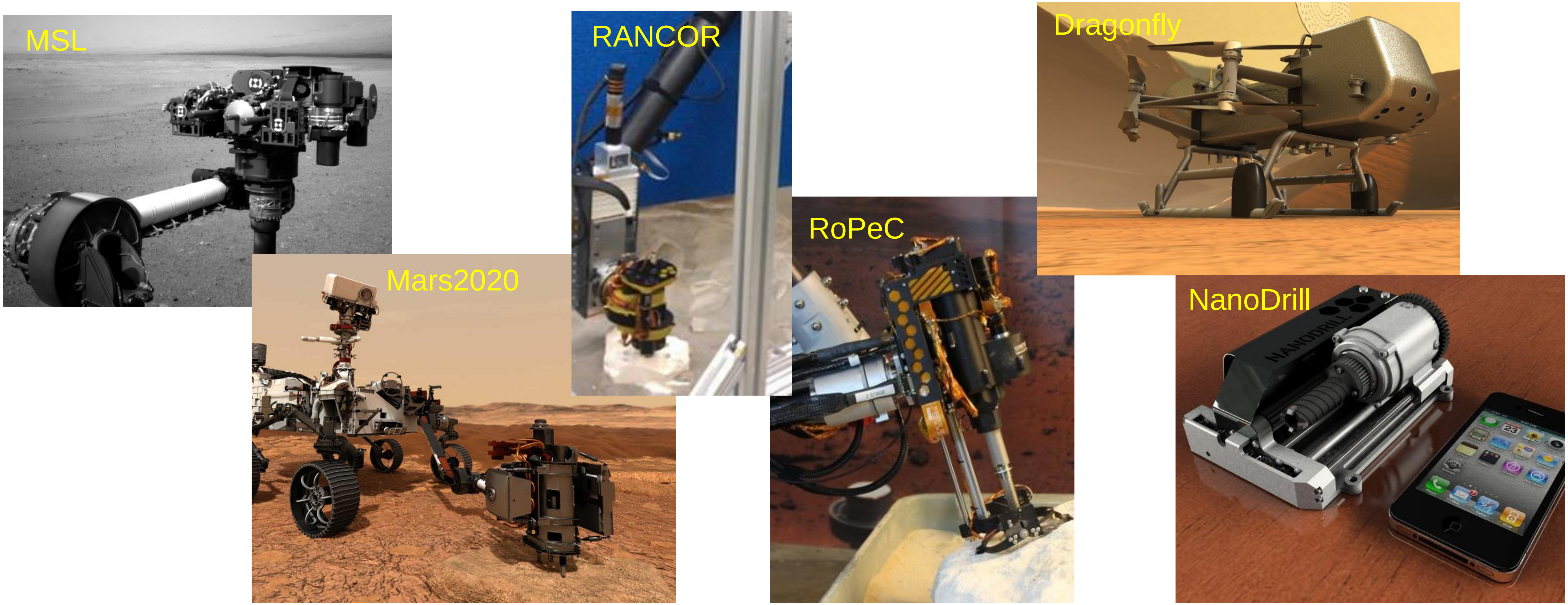
Sampling system and instrument is like hand in a glove – there has to be a perfect fit

Imagine putting sand inside the straw

Drilling

Shallow (centimeters) drilling: many options exist

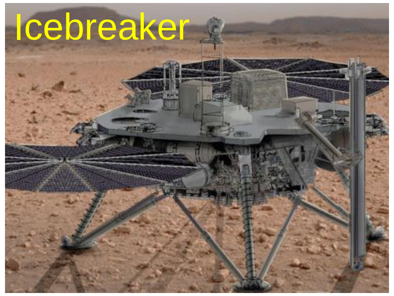
- Shallow drilling has seen significant technology development efforts as well as implementation in flight missions
- Numerous approaches have also been developed for other Solar System bodies – these could be adapted to Mars with some degree of modifications

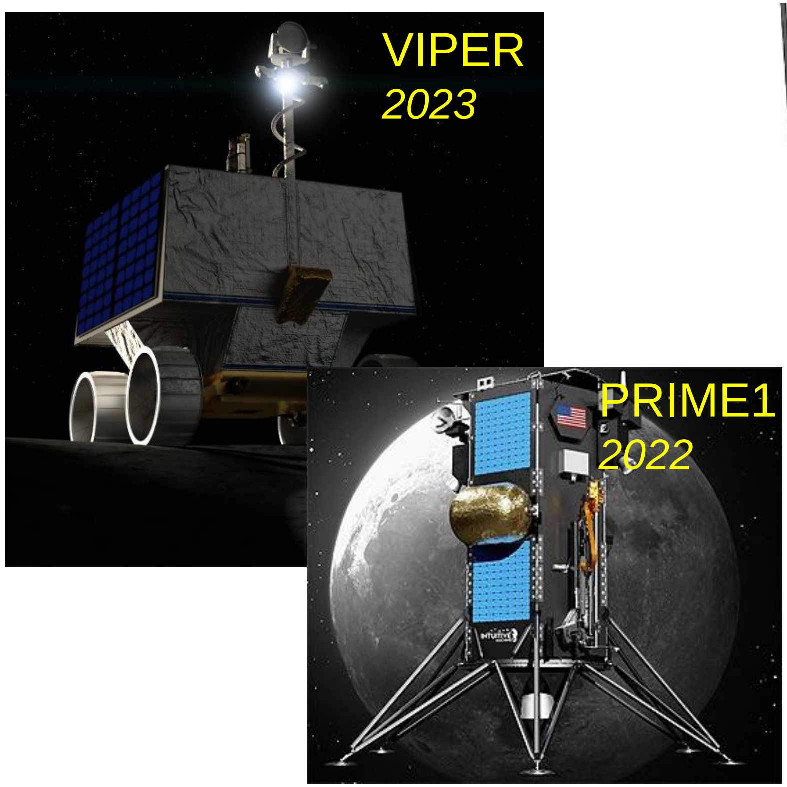


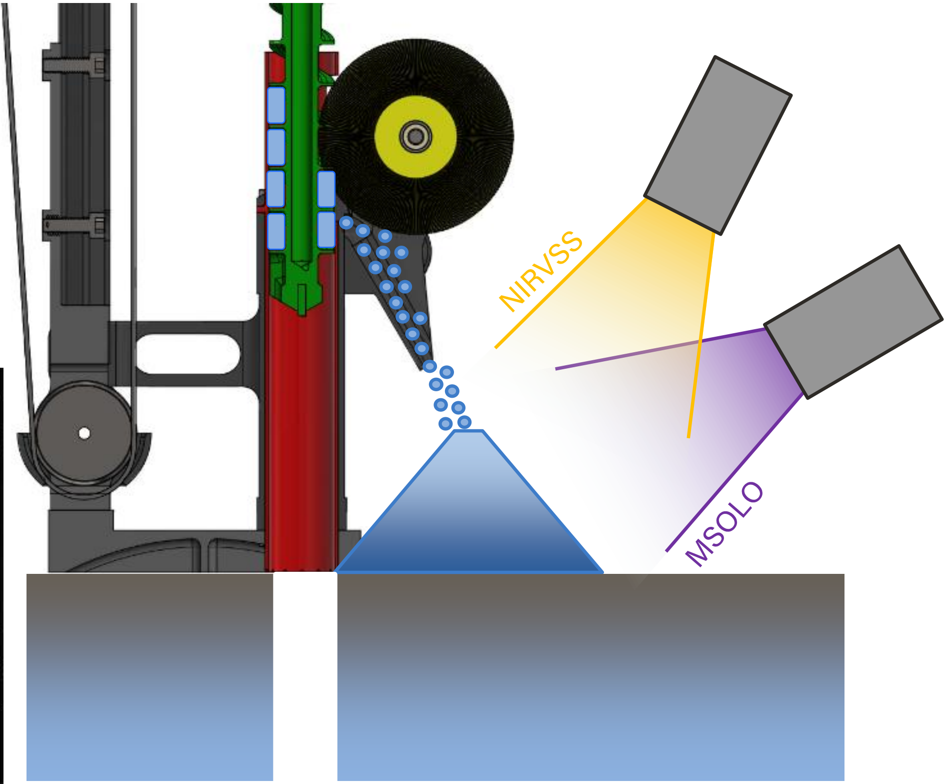
MidRange (1+ meter) drilling: TRIDEN drill

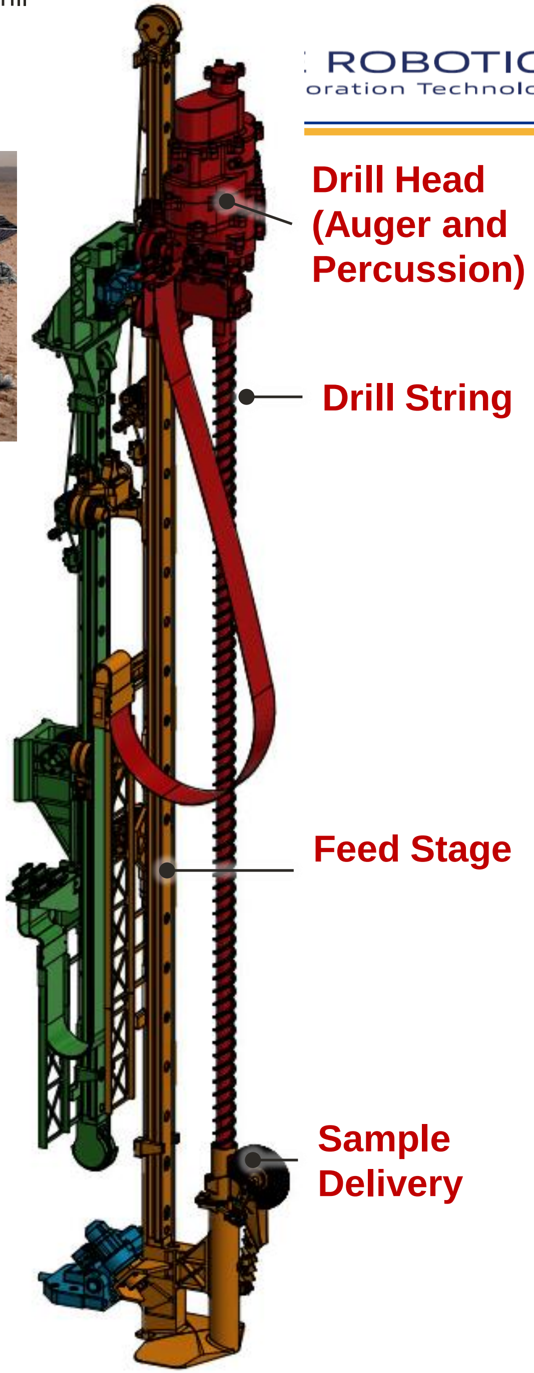
The Regolith and Ice Drill
for Exploration of New
Terrains (TRIDENT)

- 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).



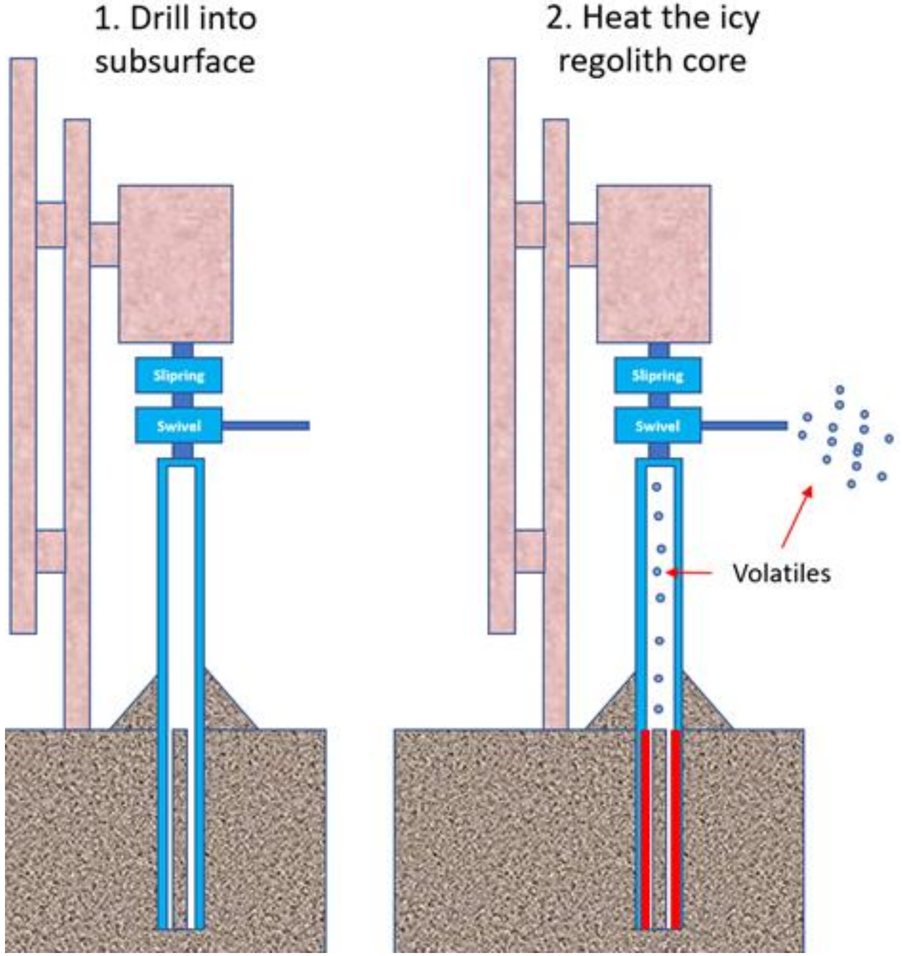


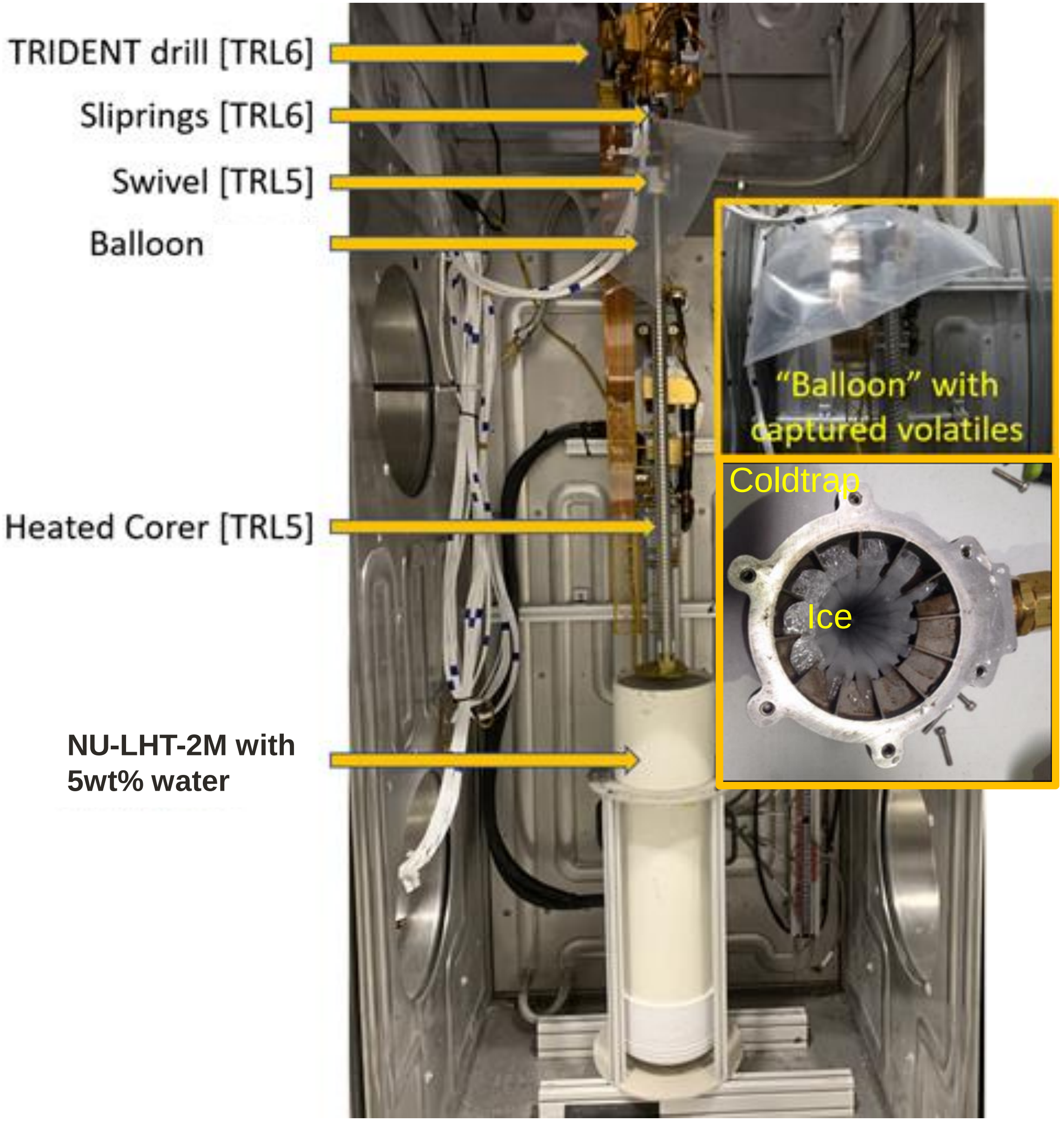




MidRange (1+ meter) drilling: Planetary Volatiles Extractor (PVEx)

- 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.




TRIDENT drill [TRL6]
Sliprings [TRL6]
Swivel [TRL5]
Balloon
Heated Corer [TRL5]
NU-LHT-2M with 5wt% water

Deep (10s-100s of meters) drilling

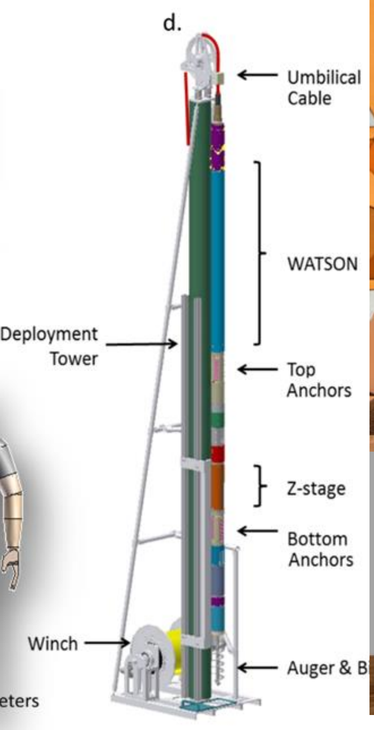
Cable Suspended Drill

Pros/Cons

- Low mass/power
- Need stable borehole

Example:

- Used in Antarctic ice coring
- AutoGopher, WATSON



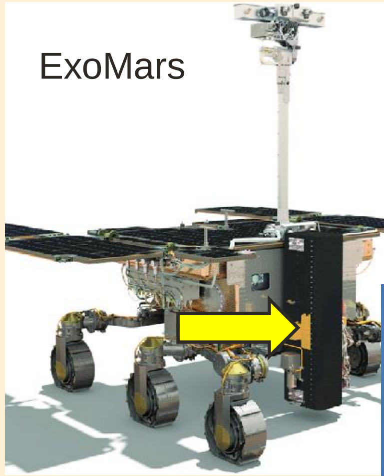
Drill string with drill pipes

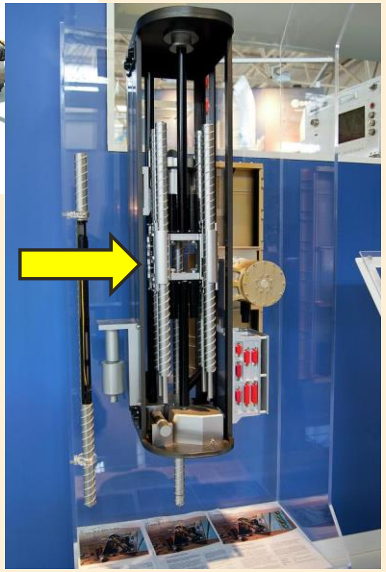
Pros/Cons

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

Example:

- Used in Oil and Gas
- ExoMars drill





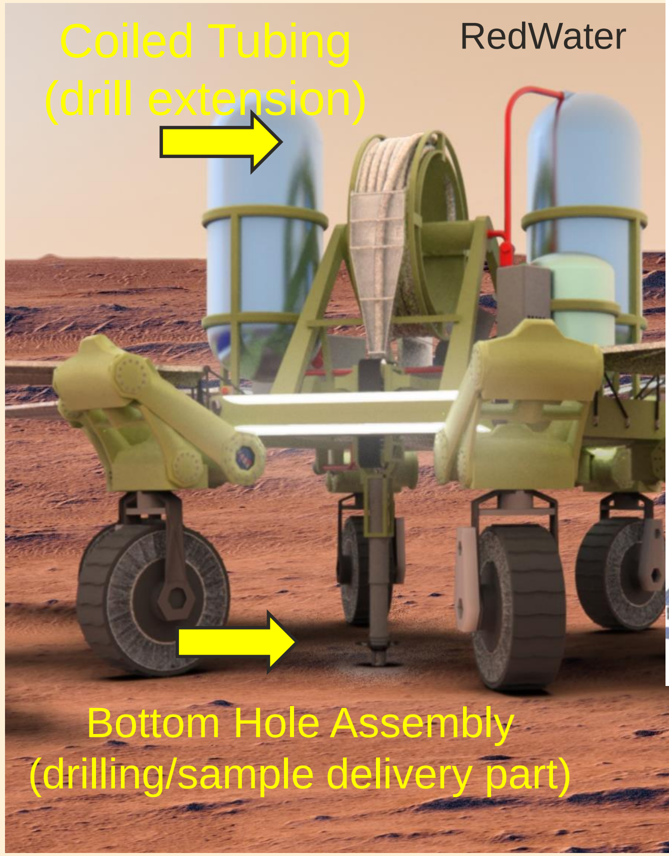
Coiled Tubing Drilling

Pros/Cons

- Continuous drill pipe
- Mass/power/complex robotics

Example:

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



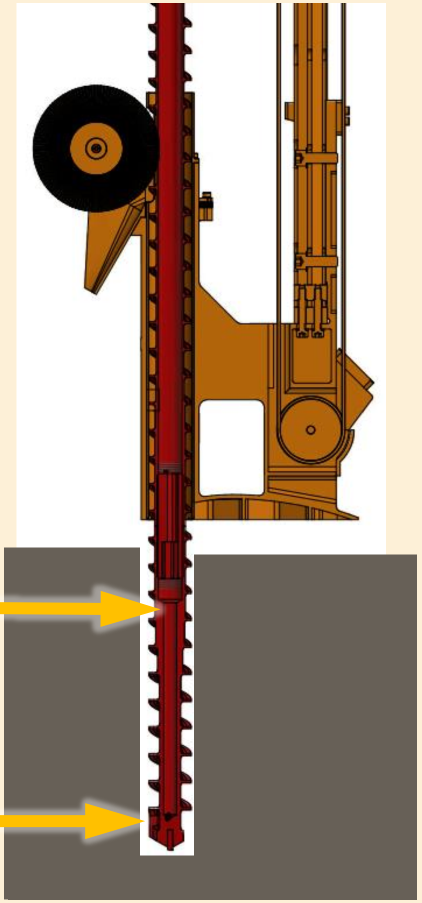
Drill integrated instruments

- “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:

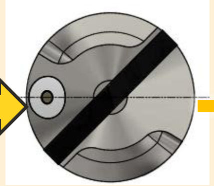
- Geotechnical properties of regolith
  - *Ice concentration and physical state of ice*
- Thermal properties of regolith: thermal gradient, thermal conductivity, heat flow



Heater and Temp Sensor

Material strength from drilling energy

Bit Temperature Sensor

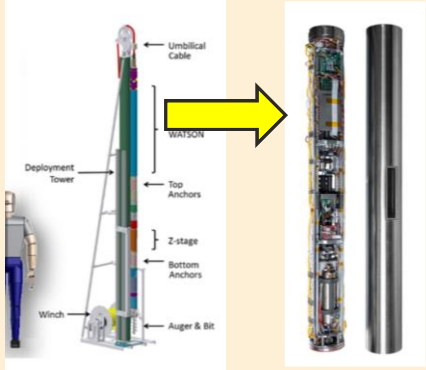


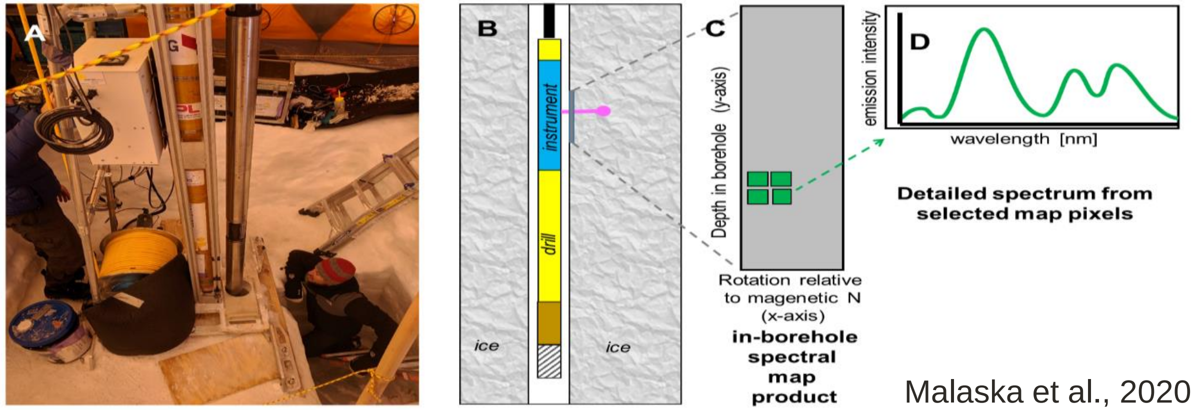
WATSON life detection drill

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:

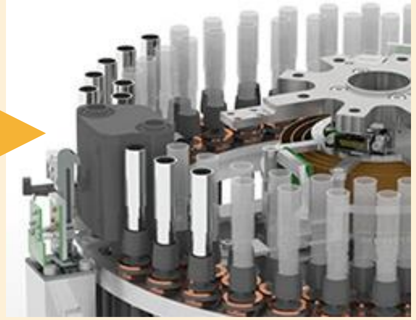
Fines pose difficulties related to: Cohesion, Adhesion, Particle Sizes, Metering, Cross-Contamination etc.

Clumps and fines

Fines

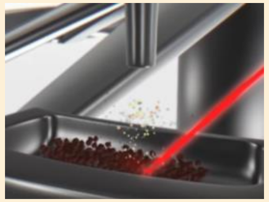
Tray

Small cup

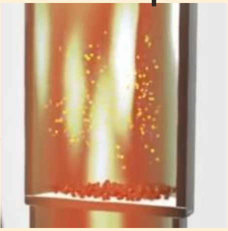


Large cup

Look at



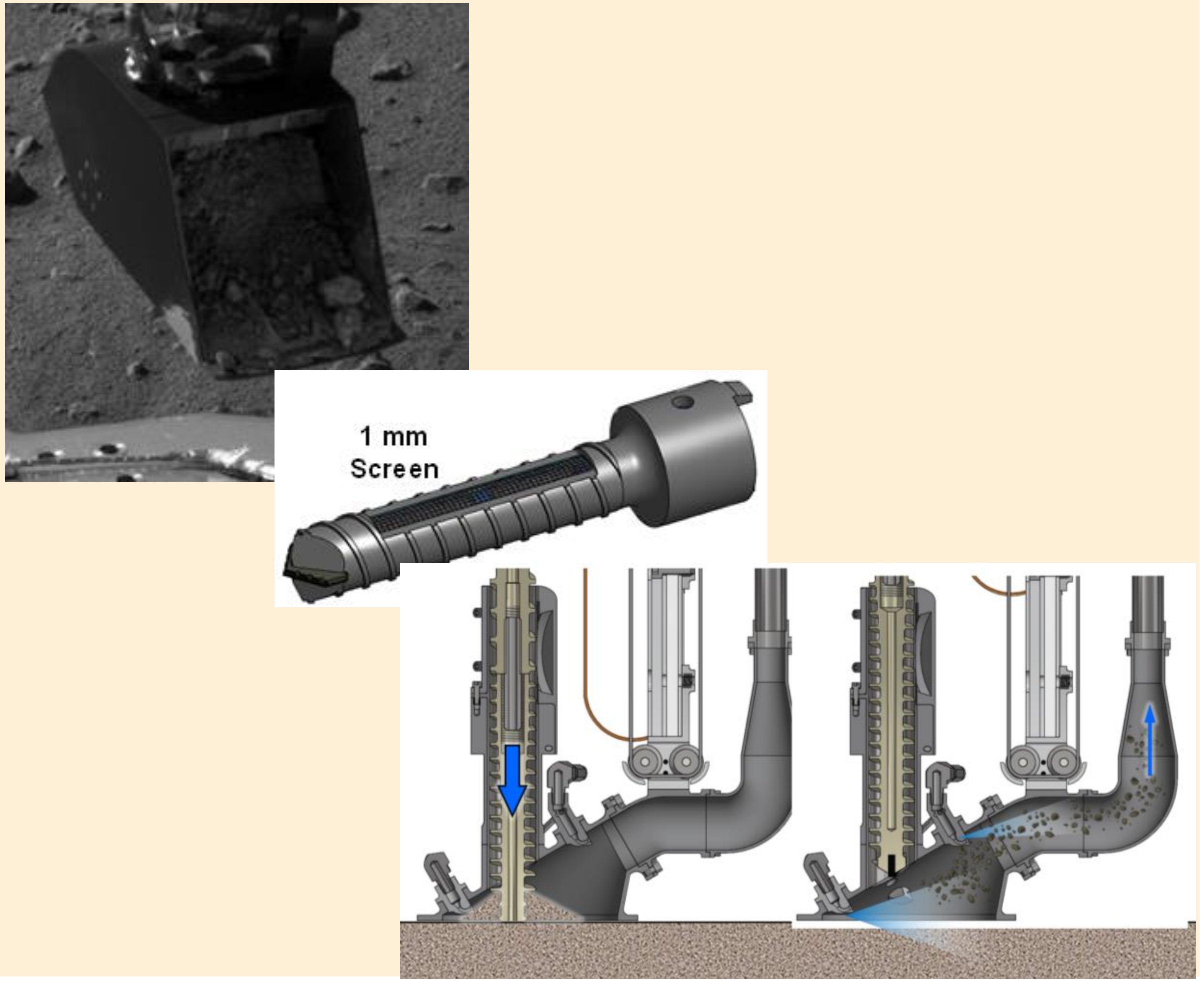
Heat up



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

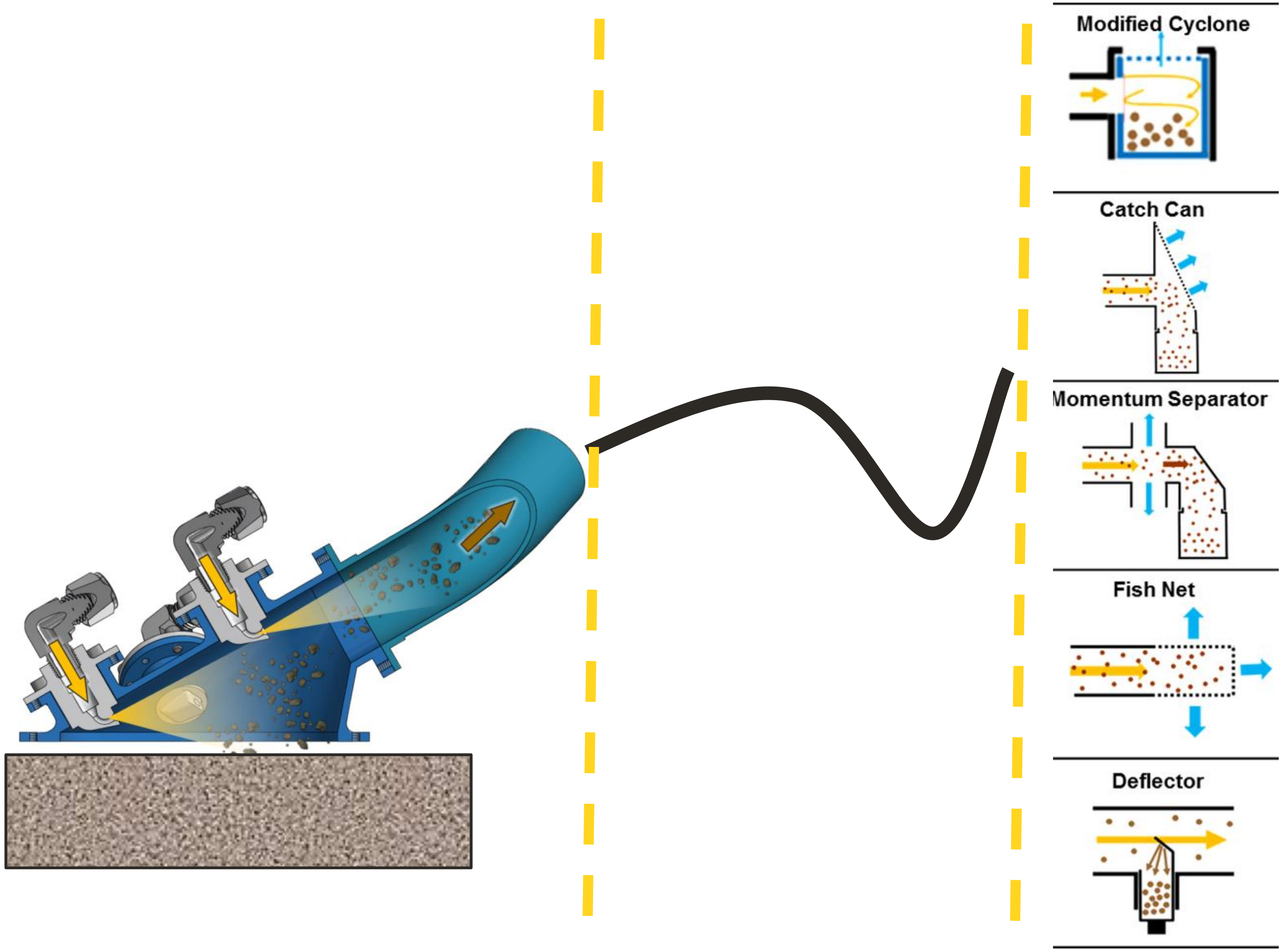
Benefits:

- 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

1. Loft

2. Transfer

3. Capture



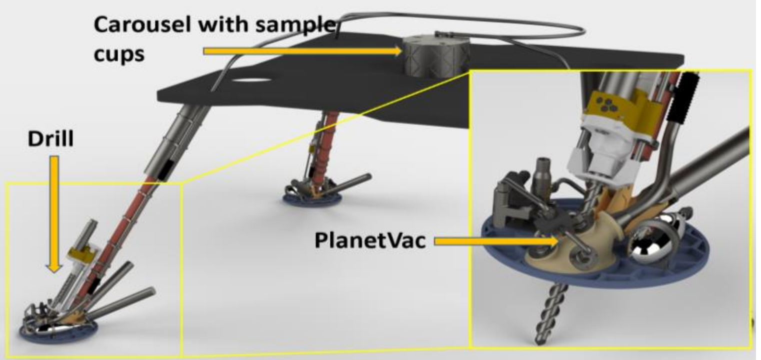
PlanetVac on CLPS

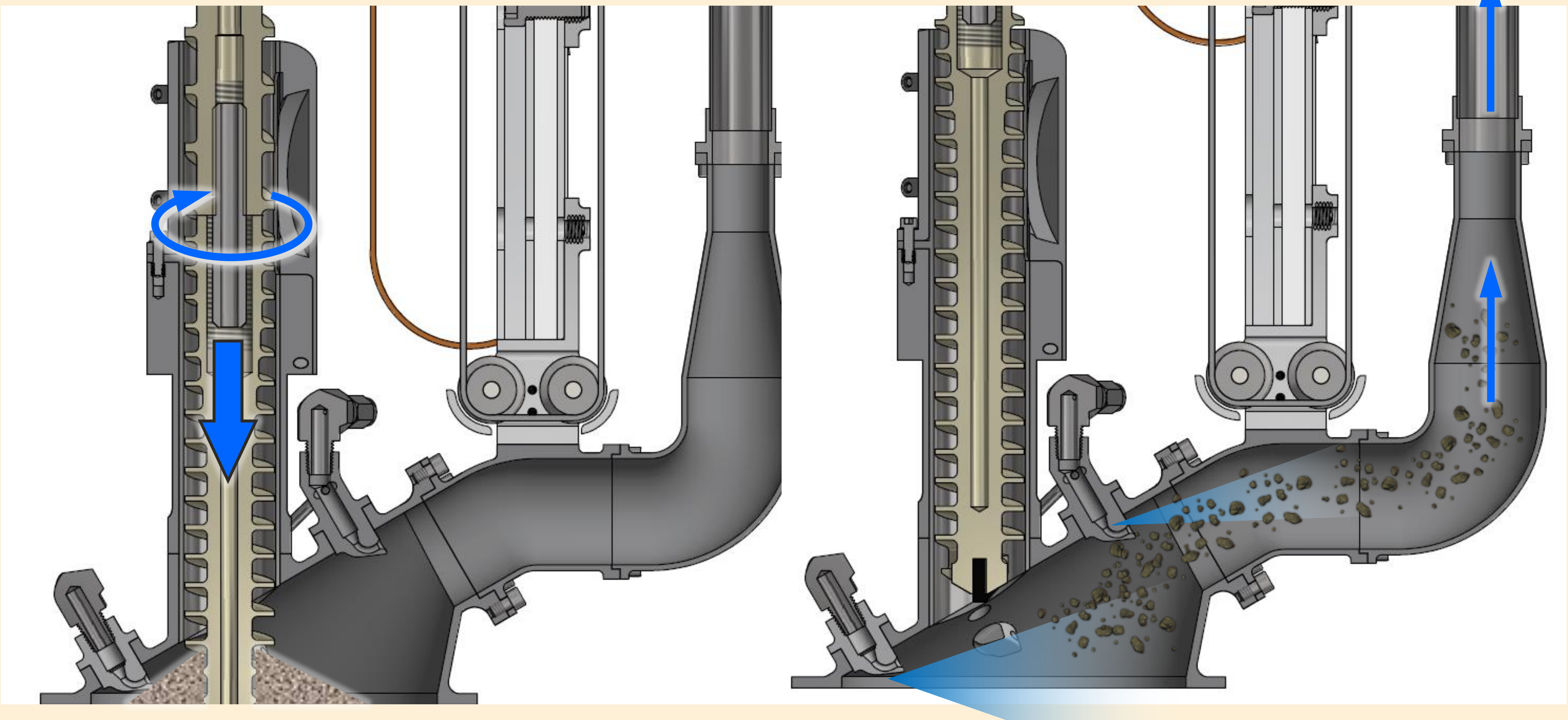
JAXA's MMX

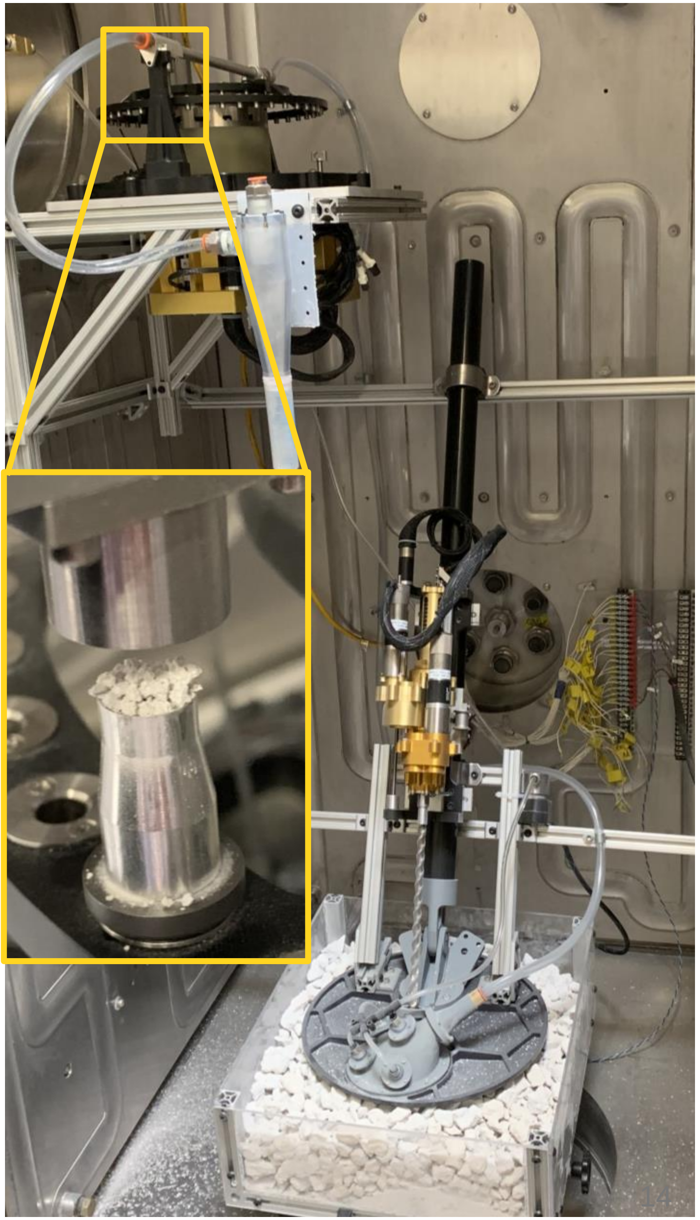
Dragonfly

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 CO2 atmosphere (e.g., M2020 MOXI)



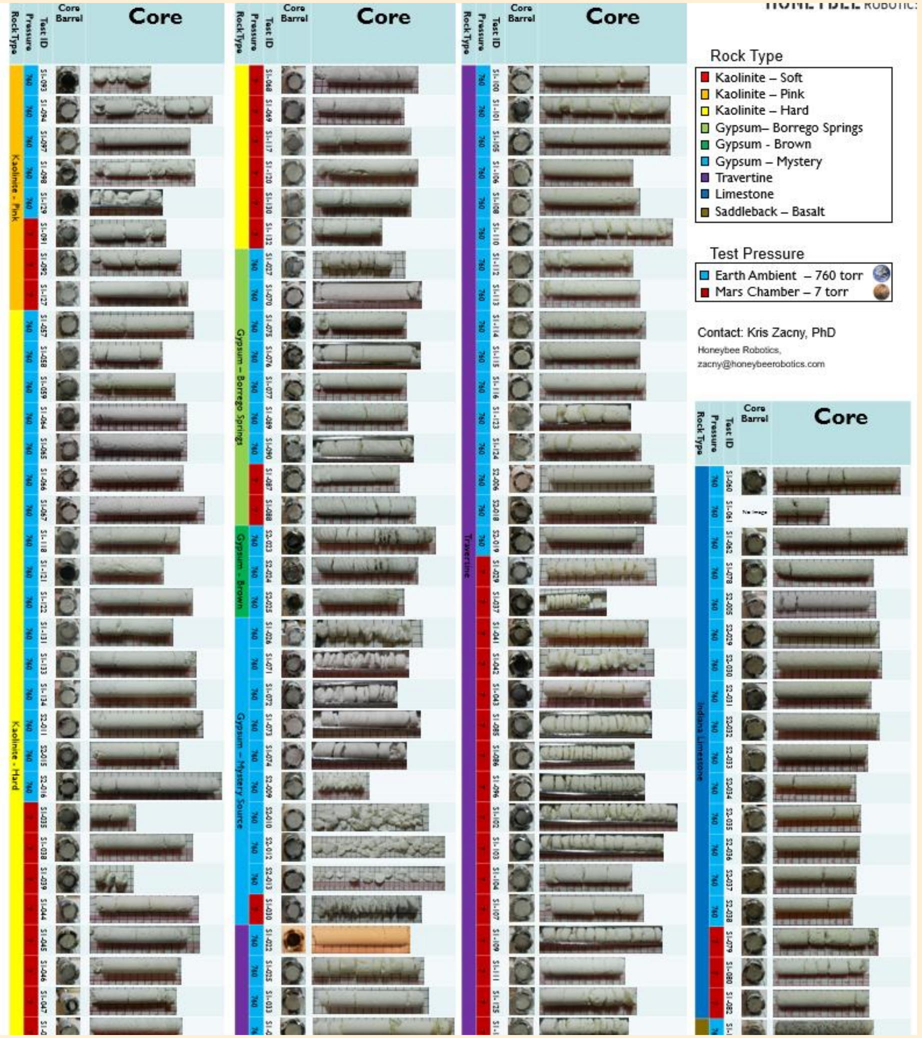




Sample handling: Cores

Problem:

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

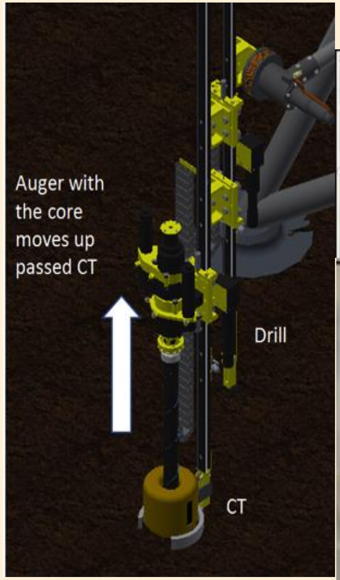


Options:

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.

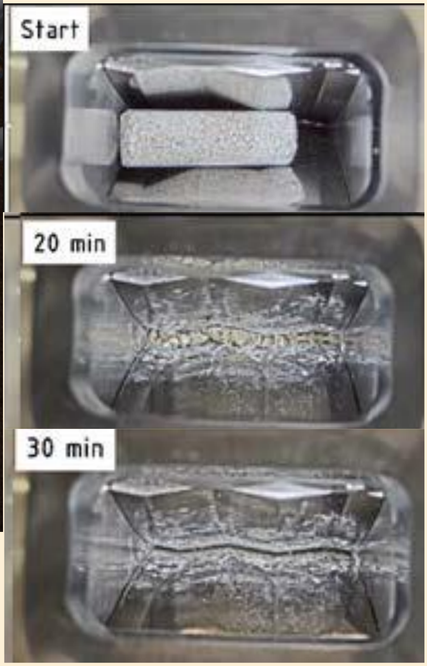
Mars2020

MicroCT



PI Obbard

ExoMars



Redlich et al., 2018

PreView Bit

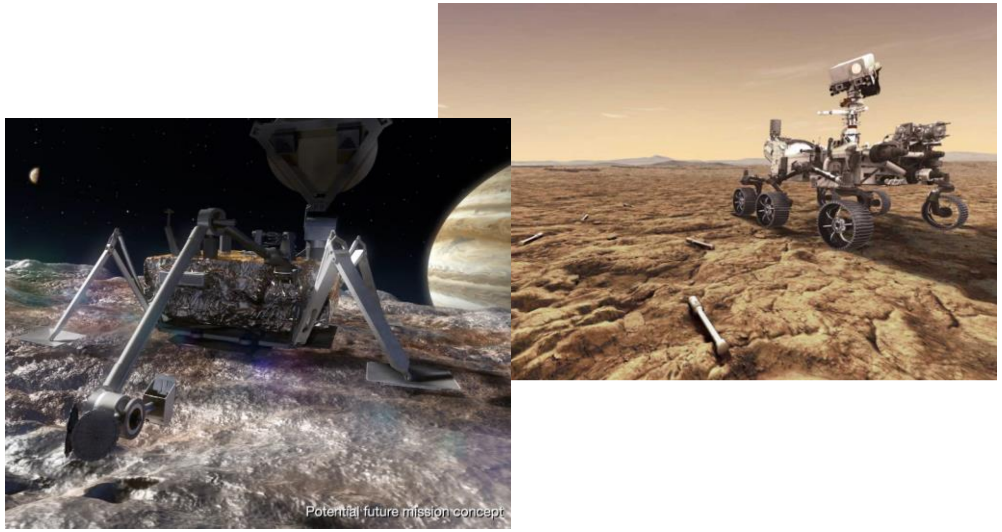
SubSampling

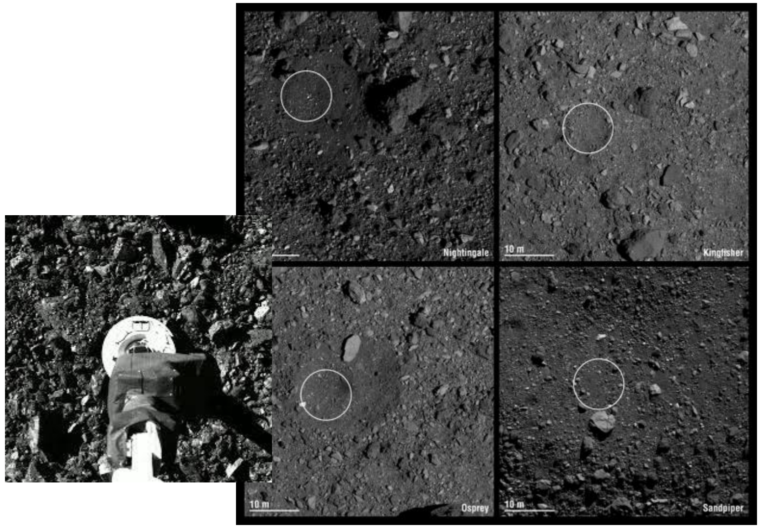
PI Brinckerhoff

Other considerations

Important Considerations

- Location
  - Mars, asteroid, Europa, Venus
- What analysis are going to be done
  - Geological, biological, volatiles, etc.
- Selected analysis places restrictions on:
  - Material selection
  - Collection strategy
  - Sample processing
  - Storage conditions
- Packaged samples must meet stringent science-driven contamination control requirements
  - Drives the physical architecture and hardware implementation

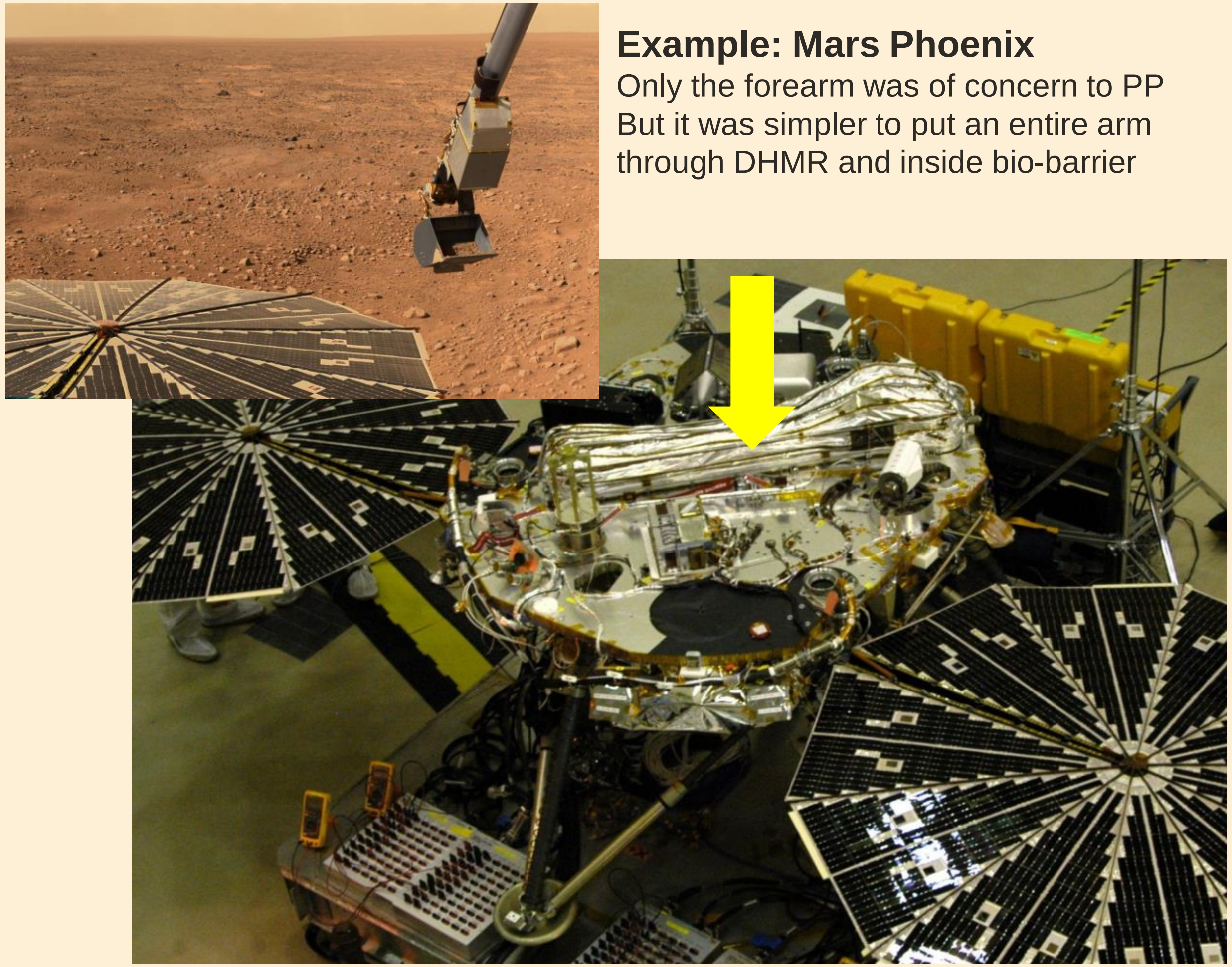




Planetary Protection

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

Current Status: send clean hardware



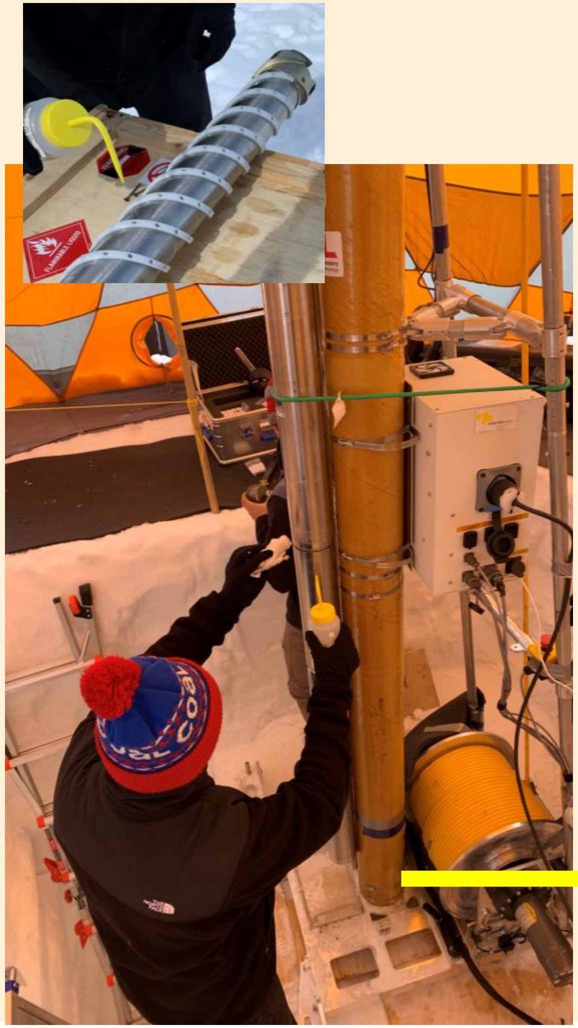
Example: Mars Phoenix

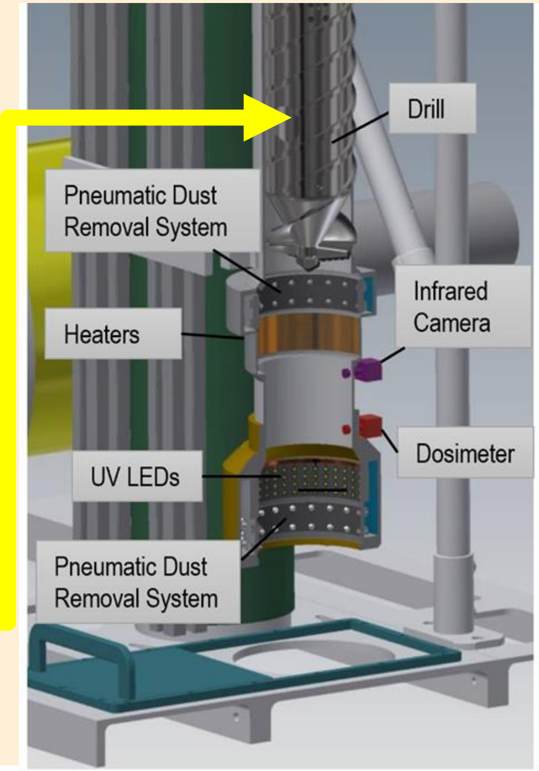
Only the forearm was of concern to PP
But it was simpler to put an entire arm through DHMR and inside bio-barrier

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



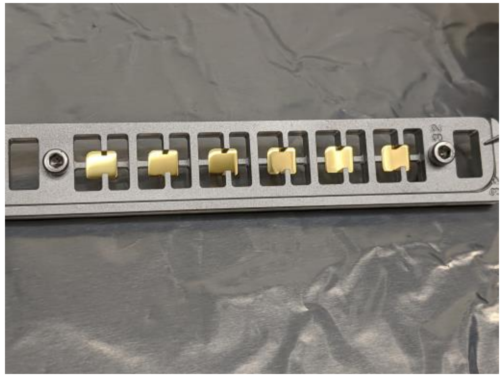


Witness Plates: Various Passive Getters

- Volatiles/Organics
  - Fired aluminum foil
  - Si wafer
  - Ultra-low density silica aerogel
- Particles
  - TiN
  - 3M No. 480 polyethylene tape with an acrylic pressure-sensitive backing/Kapton tape
  - Polished gold (ideal for electron microscopy)

Aluminum Witness Plate Mars 2020

TiN-coated Particle Sieve Mars 2020



Gold Witness Plates Mars 2020

Analog field testing is critical

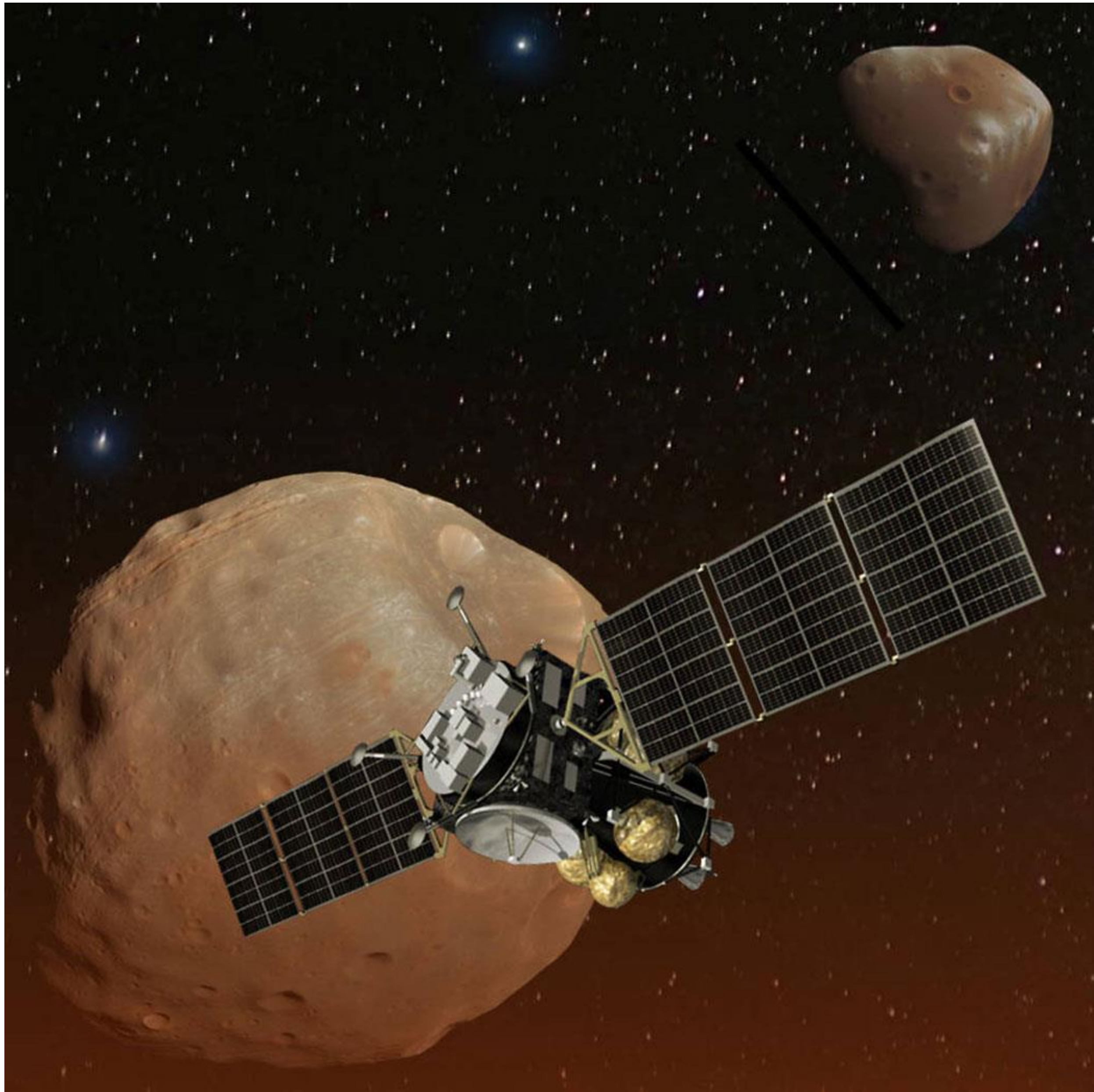
- From a geotechnical perspective, Mars is very similar to Earth (e.g. Peters et al., 2017, Thomson et al., 2013)
- There are numerous locations on Earth that are very good analogues for Mars: Dry Valleys, Atacama etc.
- It’s imperative to test drilling hardware in analog locations and subject it to ‘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

MARTIAN MOONS EXPLORATION

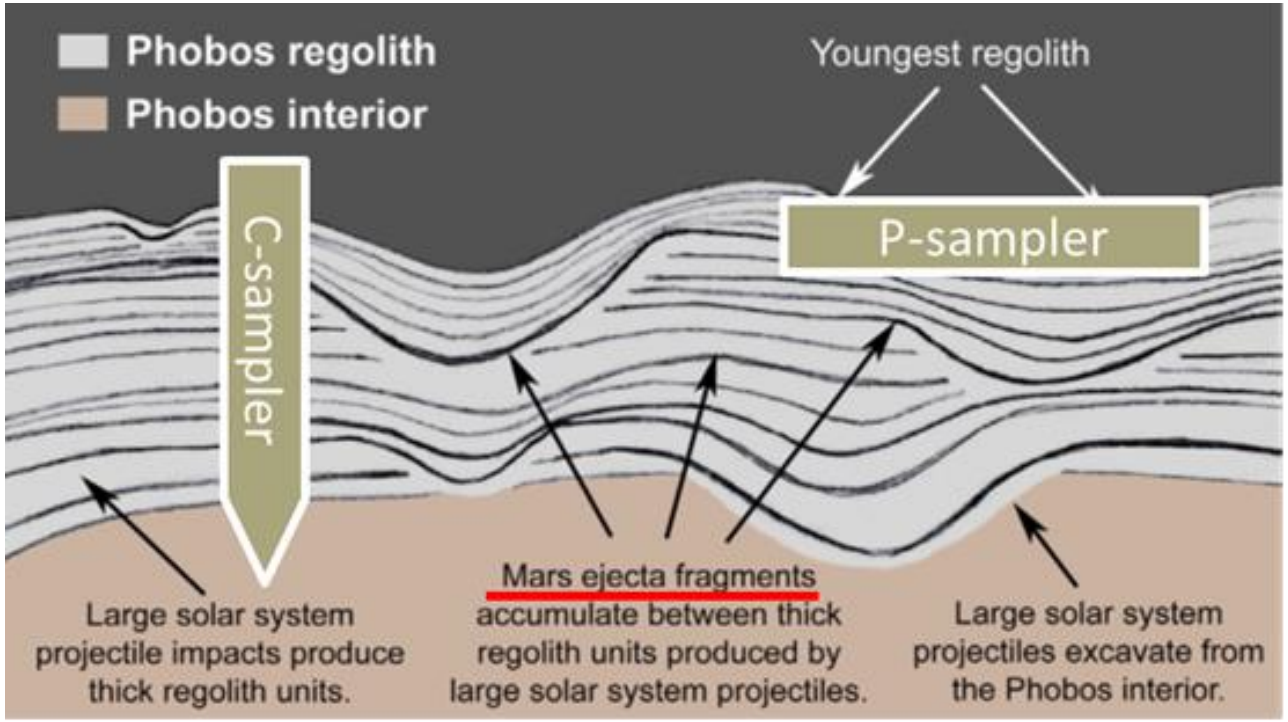
Martian Moons eXploration (MMX) mission

- JAXA mission with contributed payloads from NASA and ESA
- Goals:
  - Sample return from Phobos
  - Flyby of Deimos
  - Monitoring Mars climate
- MMX will try to determine whether the Martian moons are captured asteroids or the result of a larger body hitting Mars.
- Payload:
  - Gamma rays and Neutrons Spectrometer (MEGANE) – NASA (APL)
  - Wide Angle Multiband Camera (WAM)
  - Near-Infrared Spectrometer (MacrOmega) - CNES
  - Optical Radiometer composed of Chromatic Imagers (OROCHI)
  - Telescopic Nadir Imager for Geomorphology (TENGOO)
  - Light Detection and Ranging (LIDAR)
  - Circum-Martian Dust Monitor (CMDM)
  - Mass Spectrum Analyzer (MSA)
- Sampling systems:
  - Core Sampler - JAXA
  - Pneumatic Sampler – NASA/Honeybee

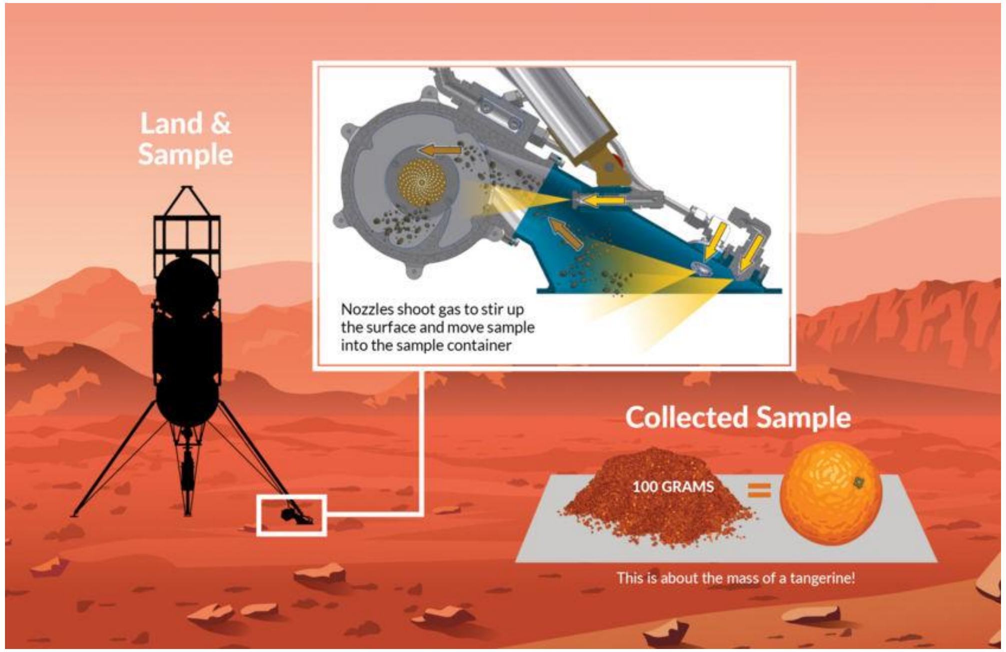


Dual Sampling Approach

- MMX has two samplers:
  - Core Sampler (C-Sampler) – “push tube” deployed using robotic arm during the 2-3 hr period on Phobos surface
  - Pneumatic Sampler (P-Sampler) – compressed gas sampling system activated either just after touch down or before take off
- C-Sampler captures deeper material while P-Sampler captures surface material
- Since C-sampler and P-Sampler use different sampling techniques, this provides mission redundancy



Footpad Sampler

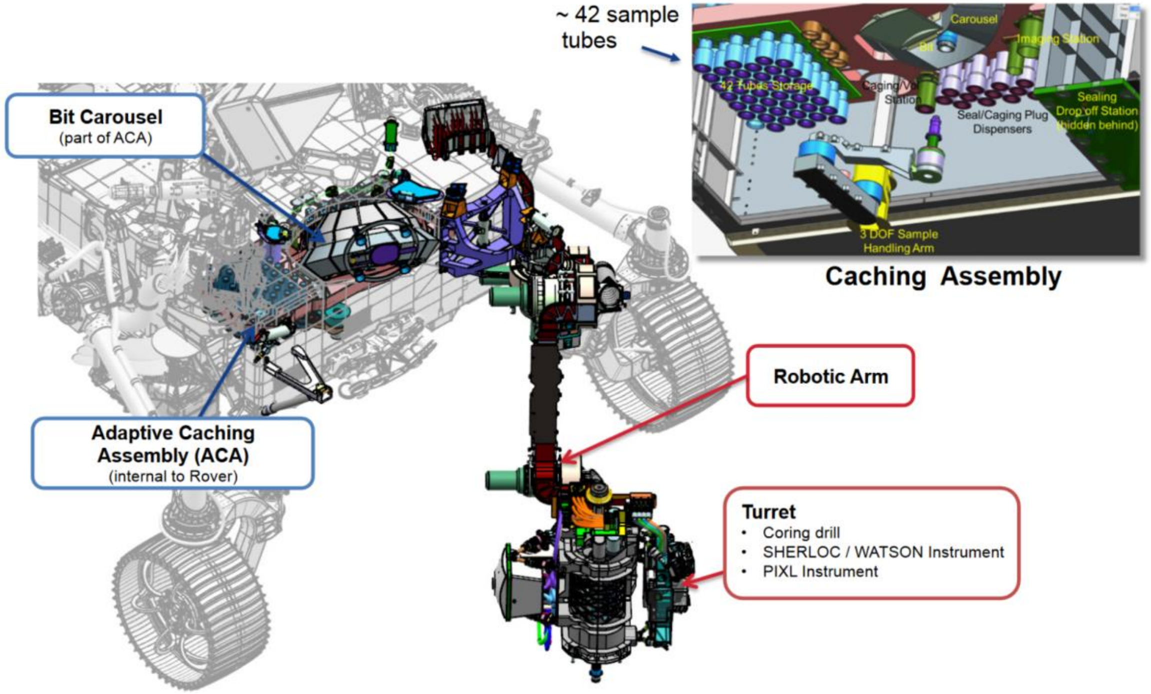


Video and details at:
https://www.honeybeerobotics.com/planetvac-xodiac-test/
http://www.planetary.org/explore/projects/planetvac/

MARS 2020

Mars 2020

- Collects rock cores and regolith samples
- Packages these materials into hermetically sealed sample tubes
- Deposits them on the Martian surface for potential return to Earth
- Sampling and Caching System's consists of two robotic systems
  - outside of the Rover consisting of a Robotic Arm and Turret
  - inside of the Rover called the Adaptive Caching Assembly (ACA)
- Turret assembly contains a new rotary-percussive drill (also referred to as the Corer)



~ 42 sample tubes

Caching Assembly

Bit Carousel
(part of ACA)

Adaptive Caching Assembly (ACA)
(internal to Rover)

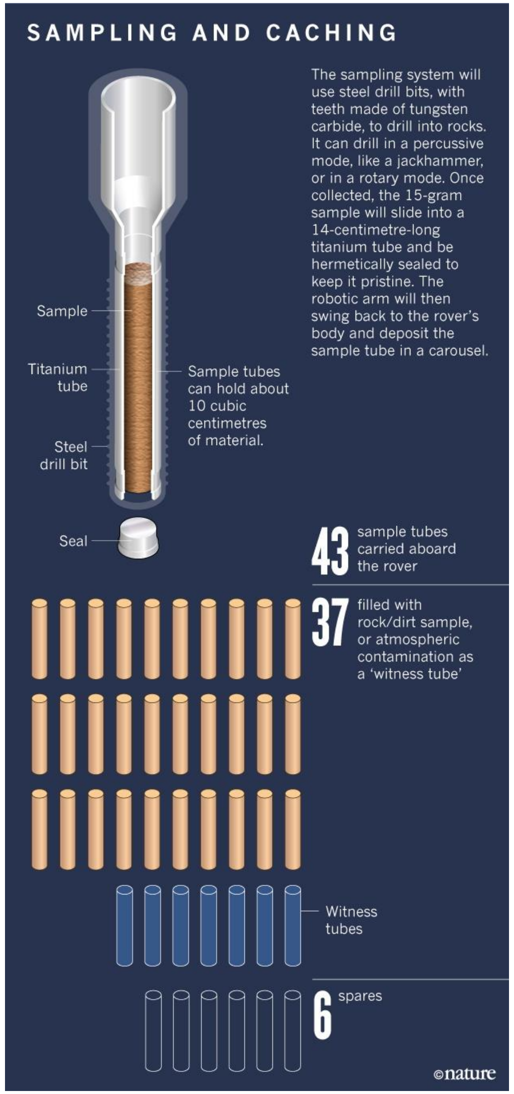
Robotic Arm

Turret
- Coring drill
- SHERLOC / WATSON Instrument
- PIXL Instrument

Mars 2020 Cont.

- Stringent Planetary Protection and Contamination Control requirements were levied on the Adaptive Caching Assembly hardware
  - Drove design and material choices as well as assembly methods
  - Special hardware handling techniques

- Drive the physical architecture and hardware implementation
  - less than 10 ppb organic carbon
  - less than 1 terrestrial viable organism per sample[1]



SAMPLING AND CACHING

The sampling system will use steel drill bits, with teeth made of tungsten carbide, to drill into rocks. It can drill in a percussive mode, like a jackhammer, or in a rotary mode. Once collected, the 15-gram sample will slide into a 14-centimetre-long titanium tube and be hermetically sealed to keep it pristine. The robotic arm will then swing back to the rover's body and deposit the sample tube in a carousel.

Sample tubes can hold about 10 cubic centimetres of material.

43 sample tubes carried aboard the rover

37 filled with rock/dirt sample, or atmospheric contamination as a 'witness tube'

6 spares

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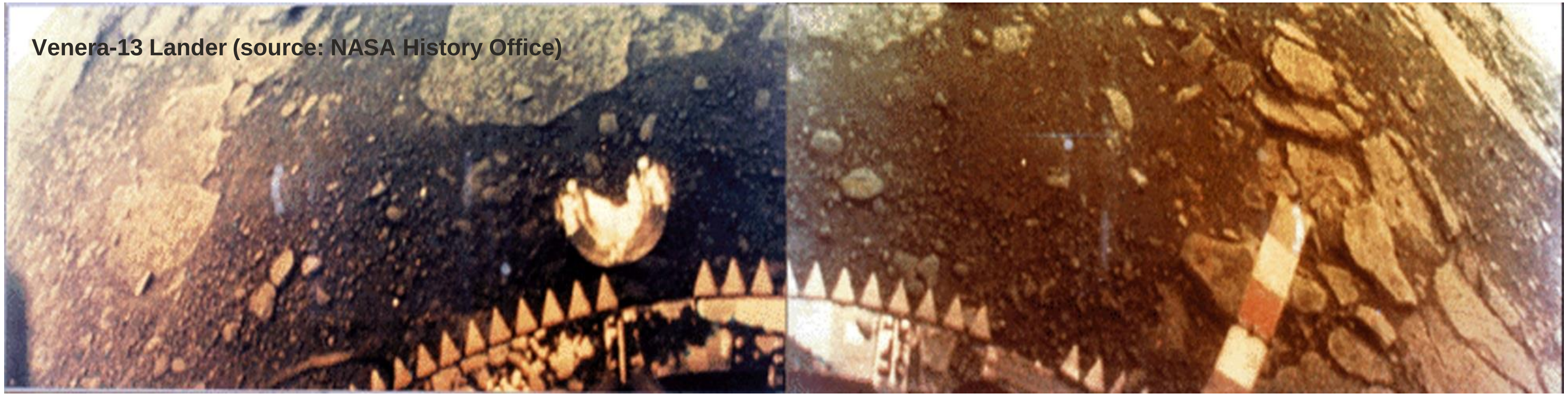
[1] Silverman & Lin, Proceedings of the 45th Aerospace Mechanisms Symposium, NASA Johnson Space Center, 2020

VENUS

Exploration of Venus

- Venus and Earth are similar in size, composition and distance from the sun but have dramatically different climates.
  - Venus atmosphere consists mostly of CO_2 gas, which traps heat in a runaway greenhouse effect. Surface conditions are inhospitable to life, as we know it.
  - On Earth, carbon in the atmosphere is regulated in a global cycle maintaining a balance that supports life.
- What past conditions or events could explain the different planetary evolution?
  - Surface samples are critical to investigating possible role of geochemistry
- Soviet Venera-13 & 14 landers both completed in-situ soil analysis experiments.[1-2]
  - GZU Soil Sampling Drill
    - Capable of drilling 3cm in 120 seconds
  - Pneumatic Sample Transport System
  - X-Ray Fluorescence Spectroscopy Instrument



Venera-13 Lander (source: NASA History Office)

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1. Mitchell, D. (2004). Drilling into the Surface of Venus. Online at http://mentallandscape.com/V_Venera11.htm (as of 17 June 2017).
2. Surkov, Y.A. et al. (1984) New Data on the Composition, Structure, and Properties of Venus Rock Obtained by Venera 13 and Venera 14, *Proc. of l4th Lunar and Planetary Science Conference, Part 2 in J. Geophys. Res. 89*, B393–B402.

Past Missions with Sampling Capabilities

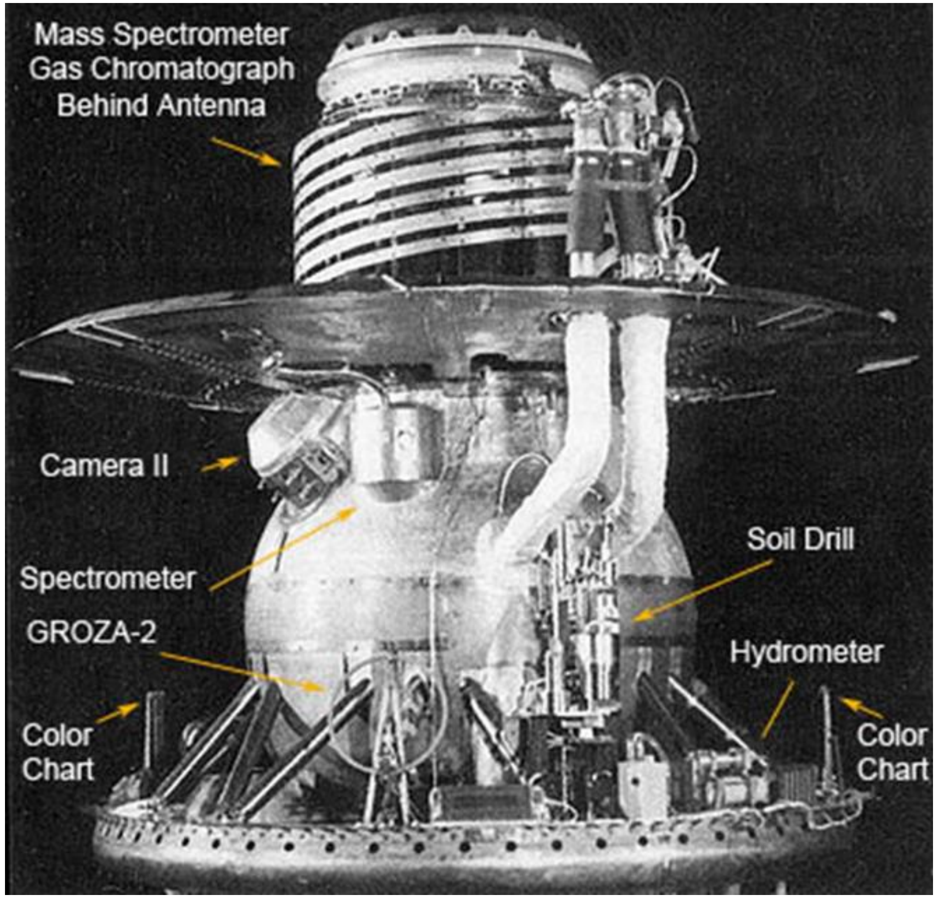
Missions	Year	Surface Survival Time* (min)	Did Sampler work?
Venera 11	1978	95	Loss of pressure seals on a drill (failure of the PROP-V)
Venera 12	1978	110	Failed to deposit sample (probably same cause as V11)
Venera 13	1981	127 (goal: 32)	Yes
Venera 14	1981	57 (goal: 32)	Yes
Vega 1	1984	56	Activated during descent by TBD shock that triggered touch down accelerometer
Vega 2	1984	57	Yes

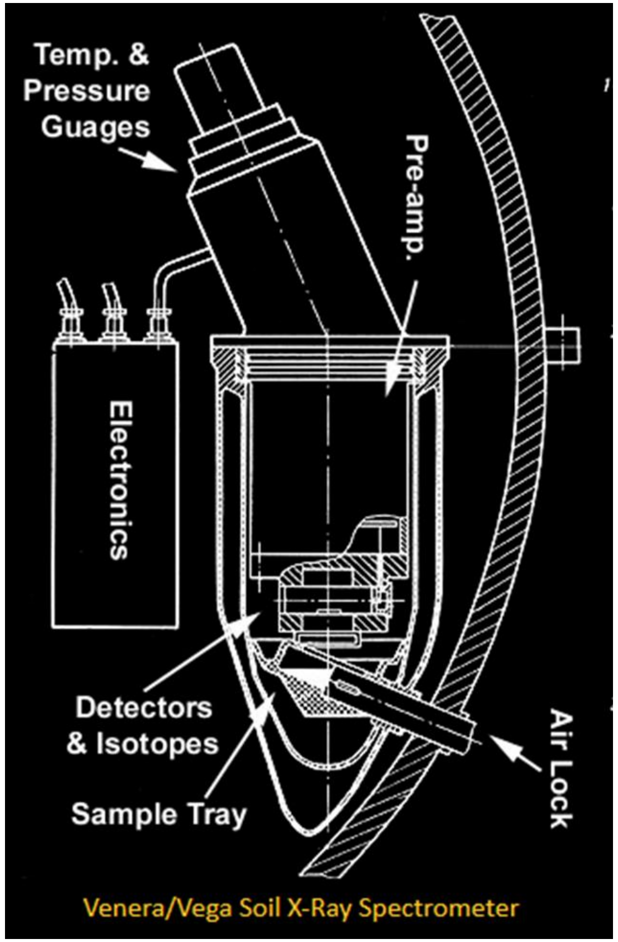
*Data was transmitted to flyby s/c which relayed data back to Earth. The ‘survival duration’ was linked to the time window for the relay flyby spacecraft:

- V11: Information was transmitted to the flight platform for re-transmittal to Earth until it moved out of range 95 minutes after touchdown
- V13/14: the collected spectra were transmitted to the flyby module and the telemetry channel, and the measurement cycles continued until loss of communications

Venera Drill Operation

1. Boring
    1. Electric motor starts, actuates ball detent, drill falls to the ground, starts drilling for 126 seconds
2. Loading of the Sample
    1. At 120 sec, 1st pyro is actuated, air is drawn in (initial P inside tubes is 100 kPa) and falls into soil receptacle
    2. At 128 sec, 2nd pyro is actuated, air lock on soil feeding mechanism closes
    3. At 188 sec, 3rd pyro is actuated, pierces membrane to vacuum tank, pressure drops from 9 MPa to 5 kPa
3. Transfer of Sample to XRF
    1. At 200 sec, 4th pyro fires, capsule with soil moves, hits hard stop, soil continues and is spray through windows





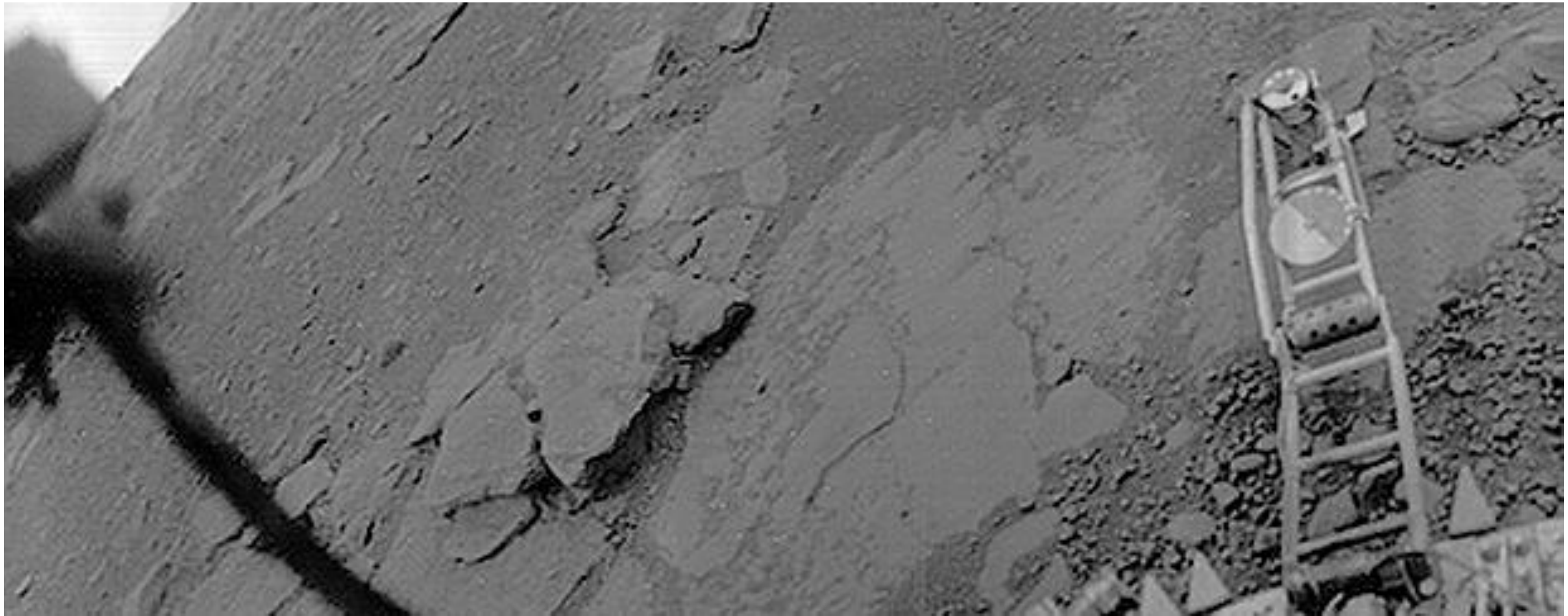
Venera/Vega Soil X-Ray Spectrometer

Terrain

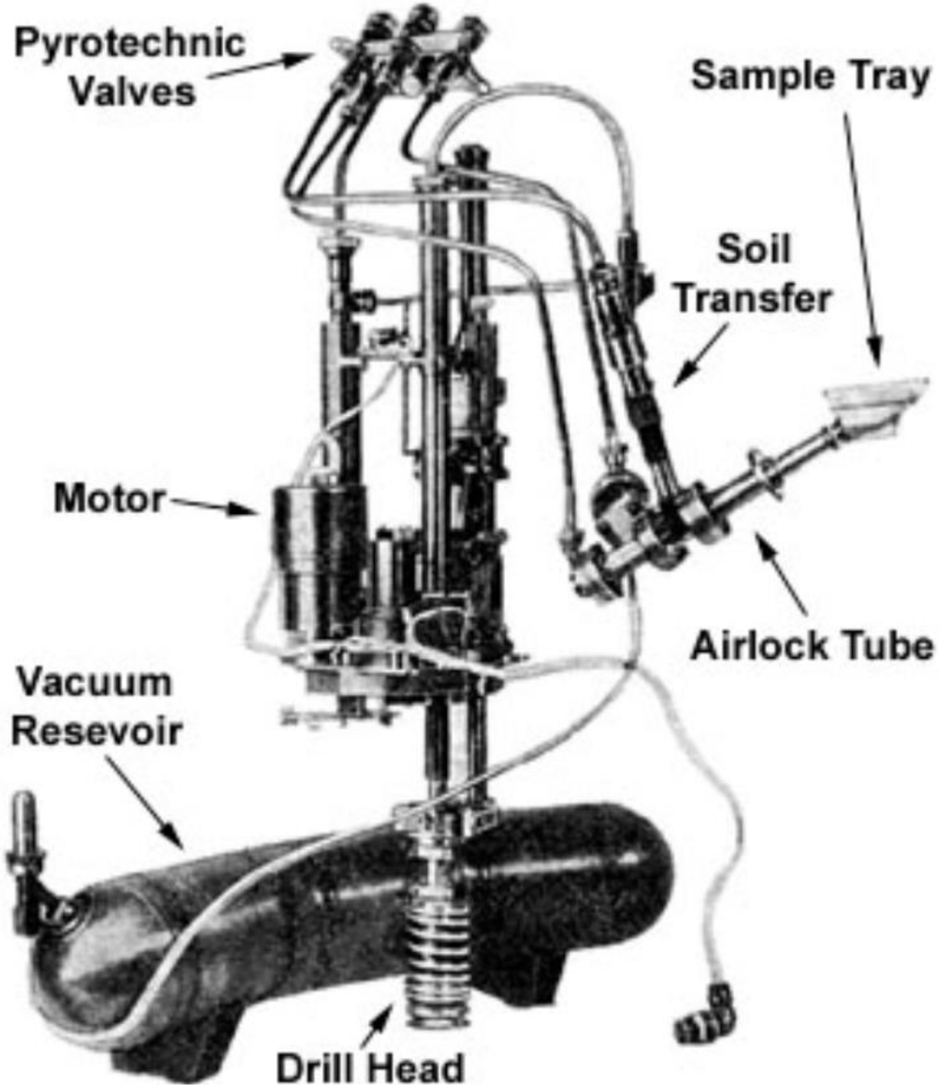
- V13: orange-brown **flat bedrock covered with loose regolith and small flat thin angular rocks**.
- V13: Rolling hills with **layered slabs of rock and soil**, unusual K-rich basalt.
- V14 **a flat expanse of rock with no soil** (geologically recent lava flow?)
- V14 Radar imaging: younger volcanic plain with lobate flows of lava, first considered to be solidified lava, is actually **layered and crunchy** (as determined by impact deceleration analysis).

What type of rocks?

- ☐ Drill (V13, 14): **weathered porous basalt or compacted ashy volcanic tuff-type**
- ☐ XRF V13: similar to **terrestrial leucitic basalt** with a high potassium content.
- ☐ XRF V14**: terrestrial oceanic tholeiitic basalts**
- ☐ V13 Prop-V: 260 - 1000 kPa, analogous to **heavy clays** or compacted dust-like
- ☐ Venera-7 parachute failed but lander survived. From Doppler shift at impact surface was **harder than sand but no harder than pumice**.



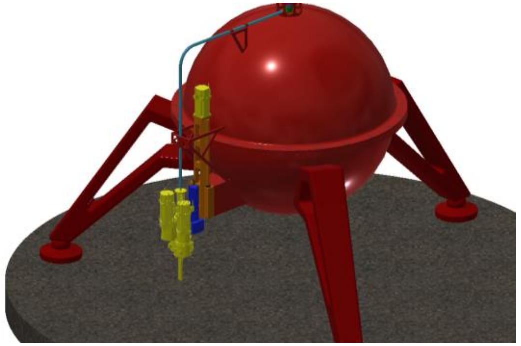
Venera



- ❑ High temperature devices
  - ❖ GZU soil sampling drill
- ❑ Developed new heat-resistant materials and electronics
- ❑ Exotic lubricants designed to function at high pressures and temperatures up to 1000° C
  - ❖ molybdenum disulphide
  - ❖ microscopic metal flakes
- ❑ Machine parts designed to fit and function properly only after thermal expansion to 500° C.

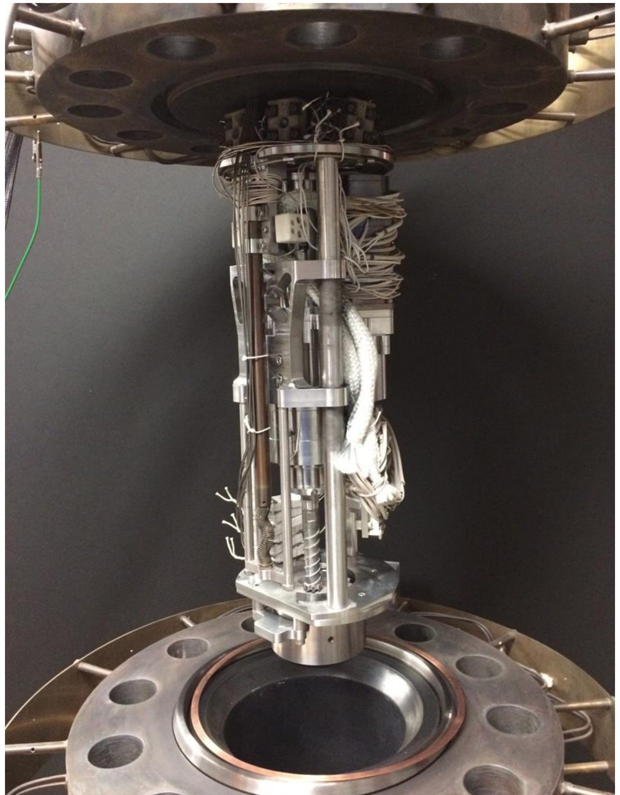
New - Venus drill and sample delivery system

- High temperature technology for Venus In Situ Explorer (VISE) NF mission
  - Rotary Percussive drill: 5 cm depth
    - 4 mm/min in 120 MPa basalt
  - Pneumatic transfer (suction based – similar to Venera)
- End to end testing performed in Venus chamber at JPL (P, T, CO2)



Actuator: Planetary gearbox, BLDC Motor, PIPS sensor

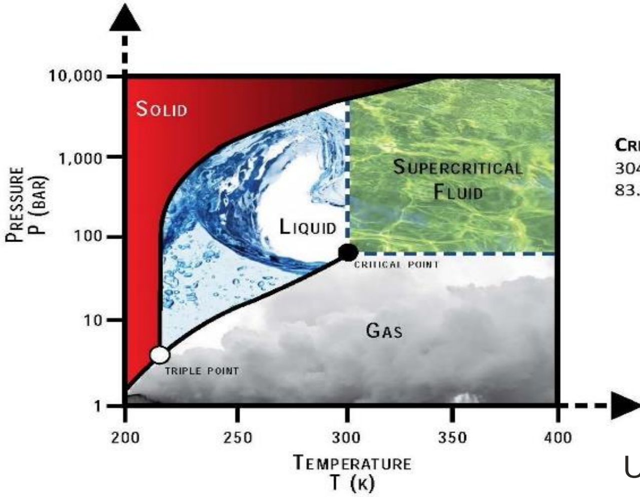
Rotary-Percussive Drill



Venus chamber

Drilling Trials in JPL’s Venus Chamber

- The drill is mounted to the lid of the chamber and wired to electrical feed-throughs.
- With lid in place and drill suspended inside, the chamber is filled with CO_2 to 600 psi at room temperature, the fill valve is closed and a leak check is performed.
- The chamber is then heated to 460°C, during which the pressure rises to 1340 psi (requires periodic venting to prevent overpressure). CO_2 reaches critical point.
- Drilling test is performed when chamber has reached Venus temperature and pressure.



Critical Point
304° K = 31° C = 88° F
83.8 bar = 8.38 Mpa
= 1,070 psi

US DOE

Lid w/ Drill

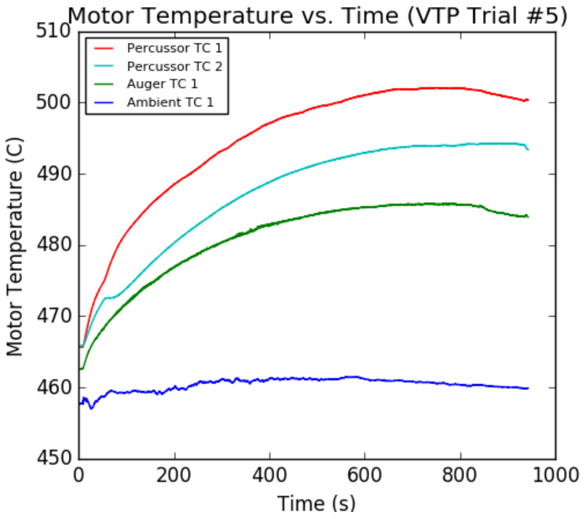
Chamber

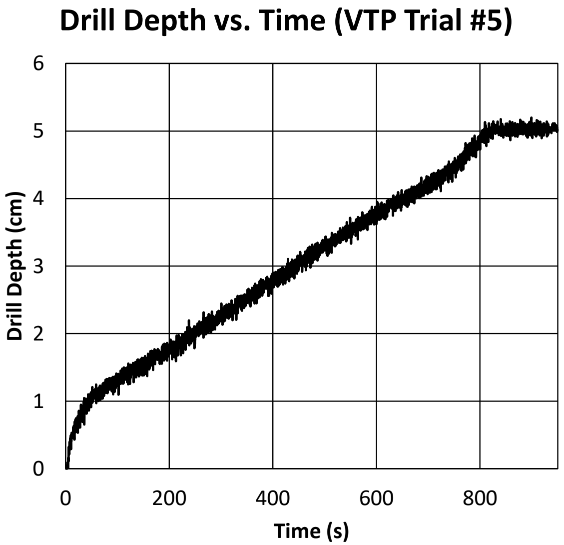
Torquing Bolts

Insulating Blankets

1 Atmosphere Drilling (RT)

New - Venus drill and sample delivery system


Motor Temperature vs. Time (VTP Trial #5)


Drill Depth vs. Time (VTP Trial #5)

Simulant fines generated by the drill

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. Modifications needed to adapt “Moon” drill to other enviornments.
    - 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.

QUESTIONS?