Drilling: How do we access subsurface on Mars

Keck Institute for Space Studies (KISS)
MarsX

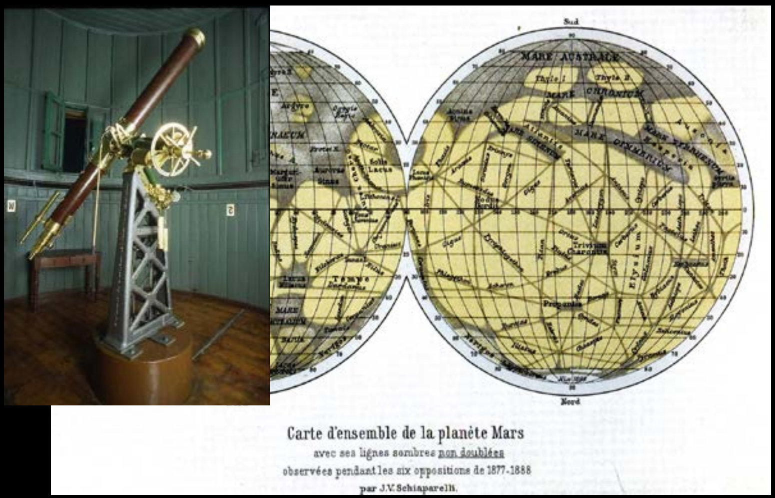
January 12, 2018

Dr. Kris Zacny

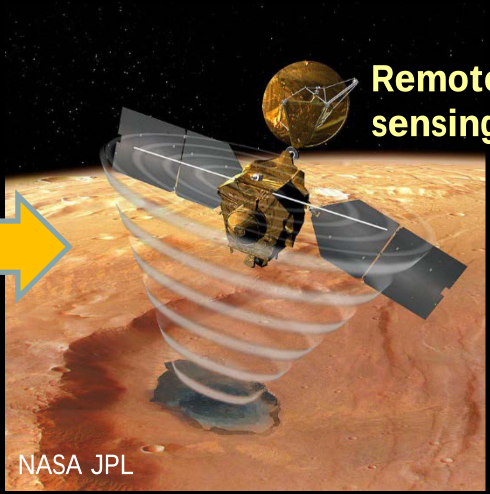
Director of Exploration Technology Group
Honeybee Robotics
zacny@honeybeerobotics.com

HONEYBEE ROBOTICS Engineering the Future

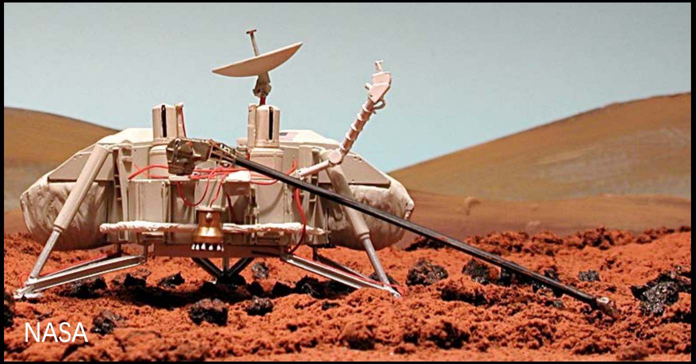
Why Drilling?!



Remote sensing

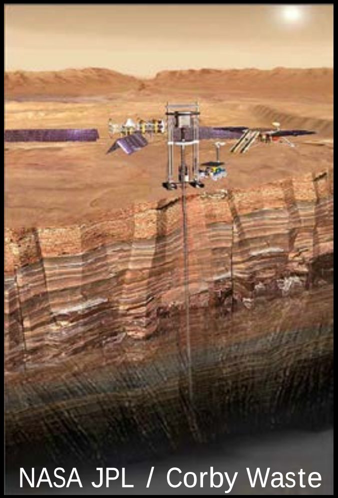


Groundtruth



2D

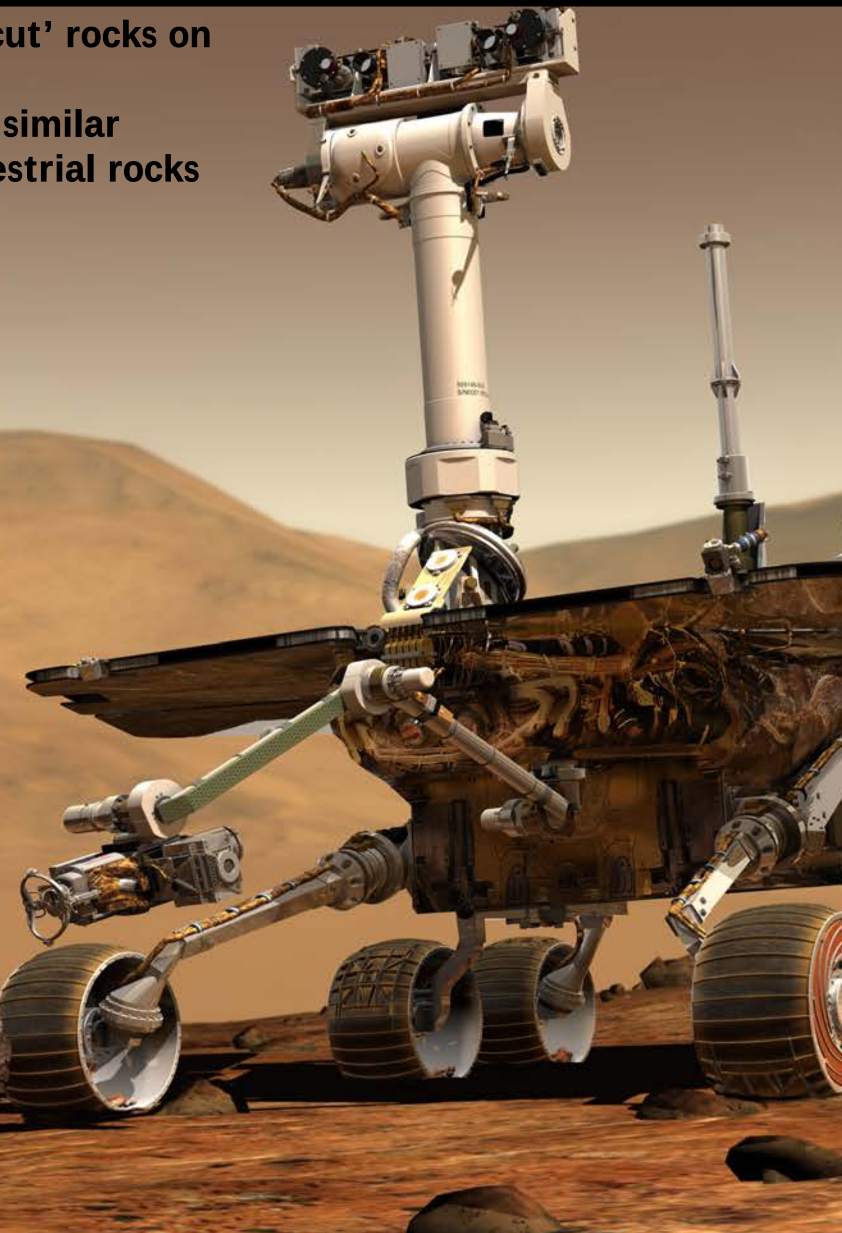
4D

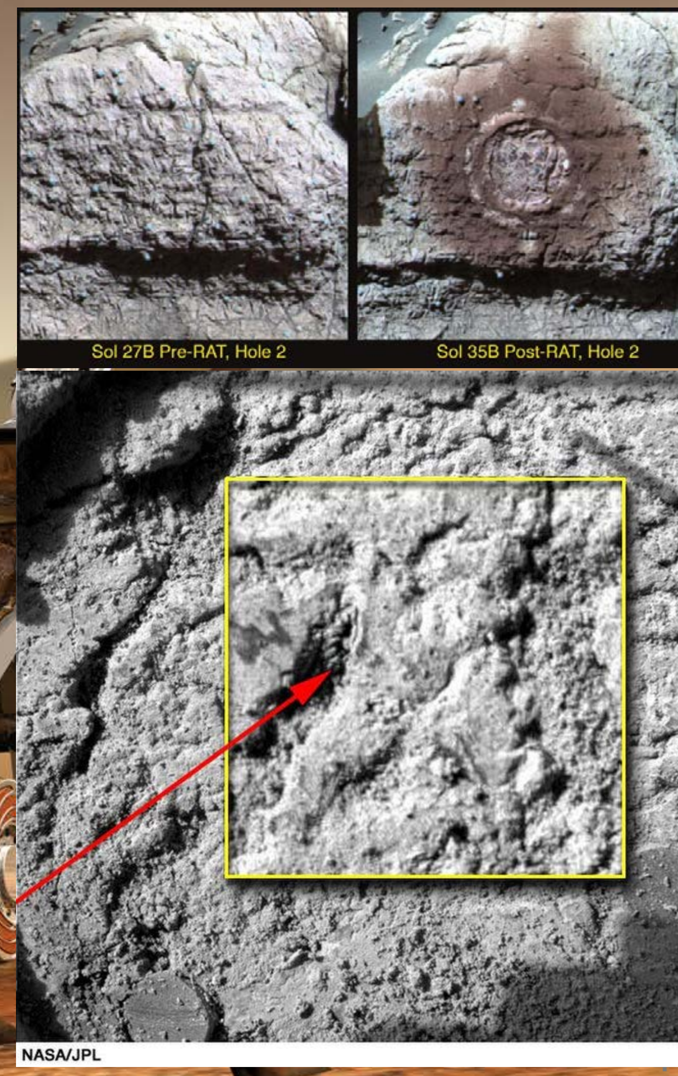


(Short) History of Mars (Shallow) Drilling

2003 MER Rock Abrasion Tool [5 mm]

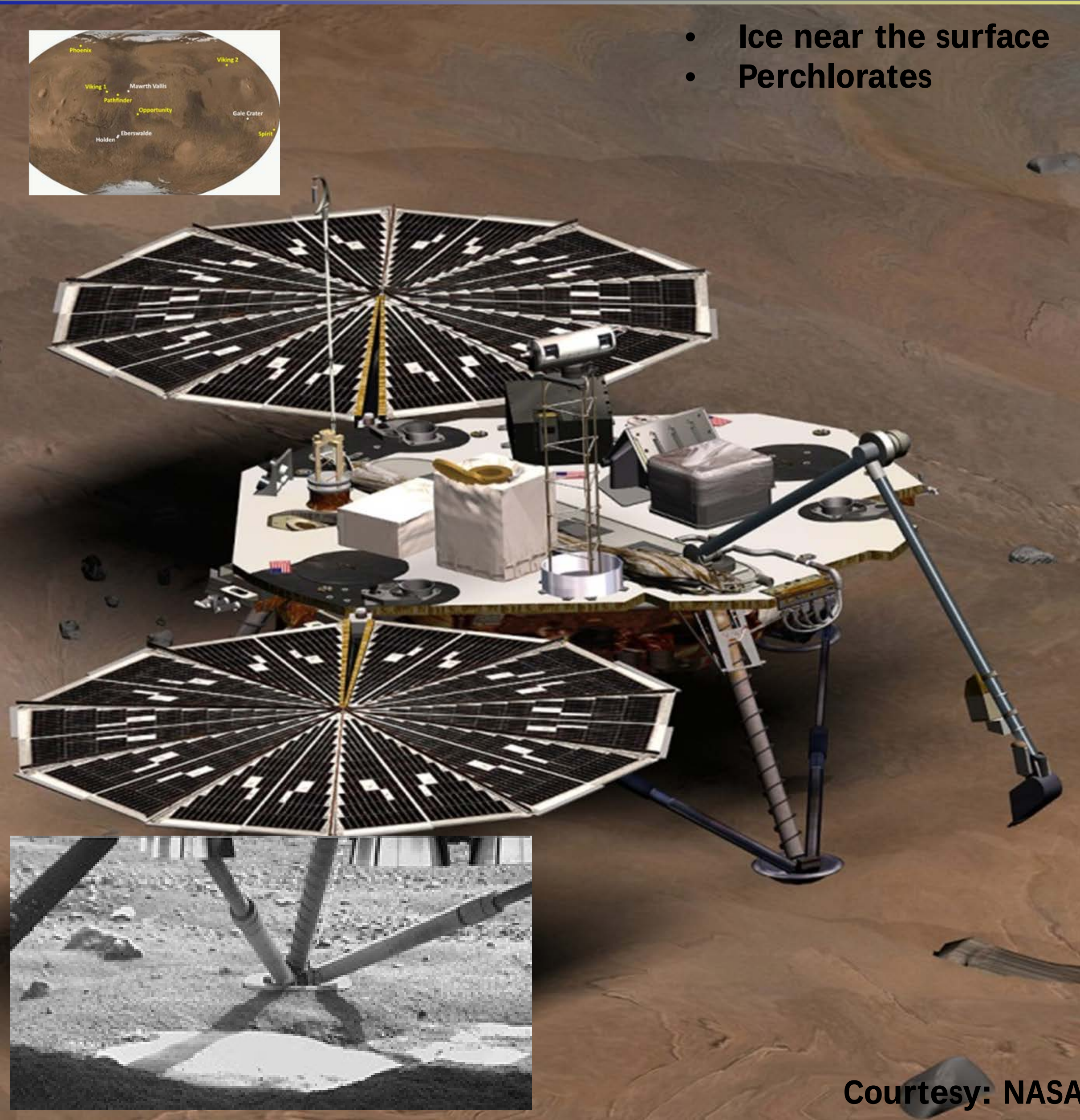
- It's feasible to 'cut' rocks on Mars (remotely)
- Mars rocks have similar strength to terrestrial rocks



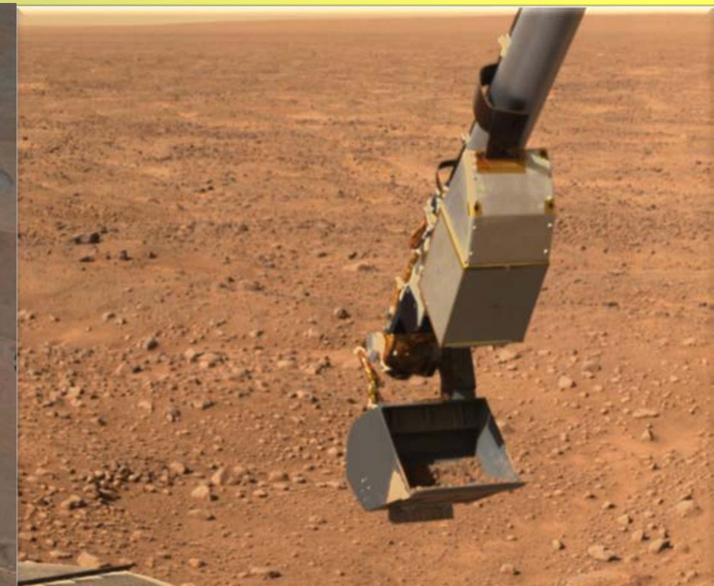


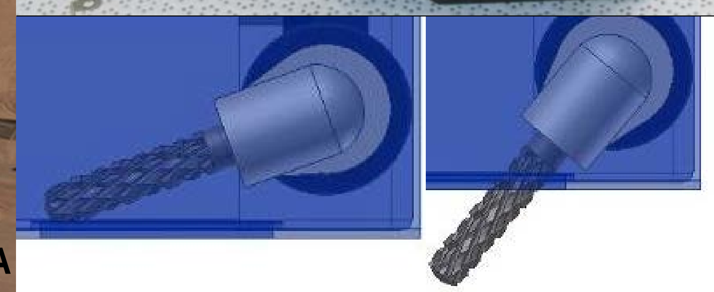
2008 Mars Phoenix Rasp [1 cm]

- Ice near the surface
- Perchlorates



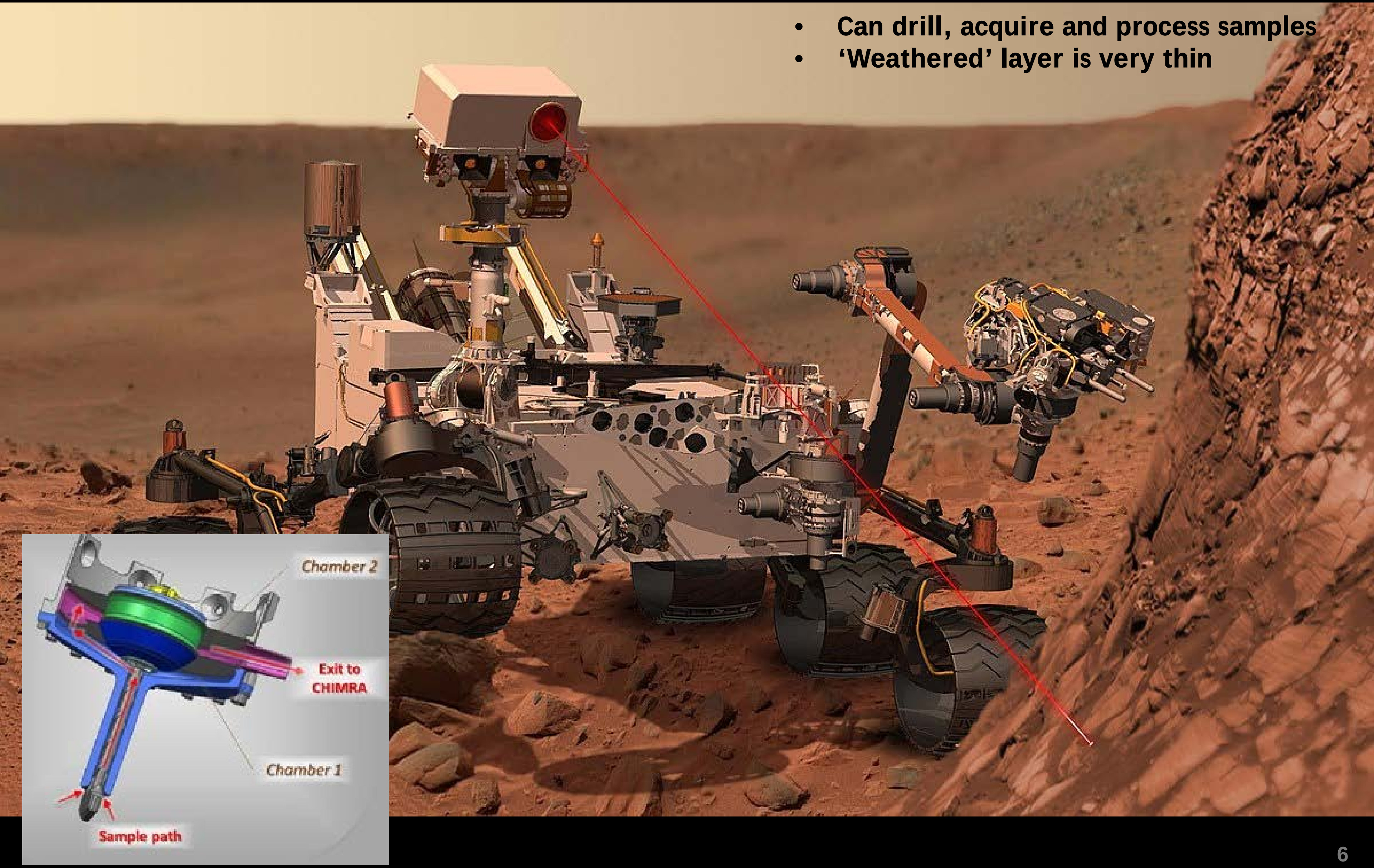
Courtesy: NASA





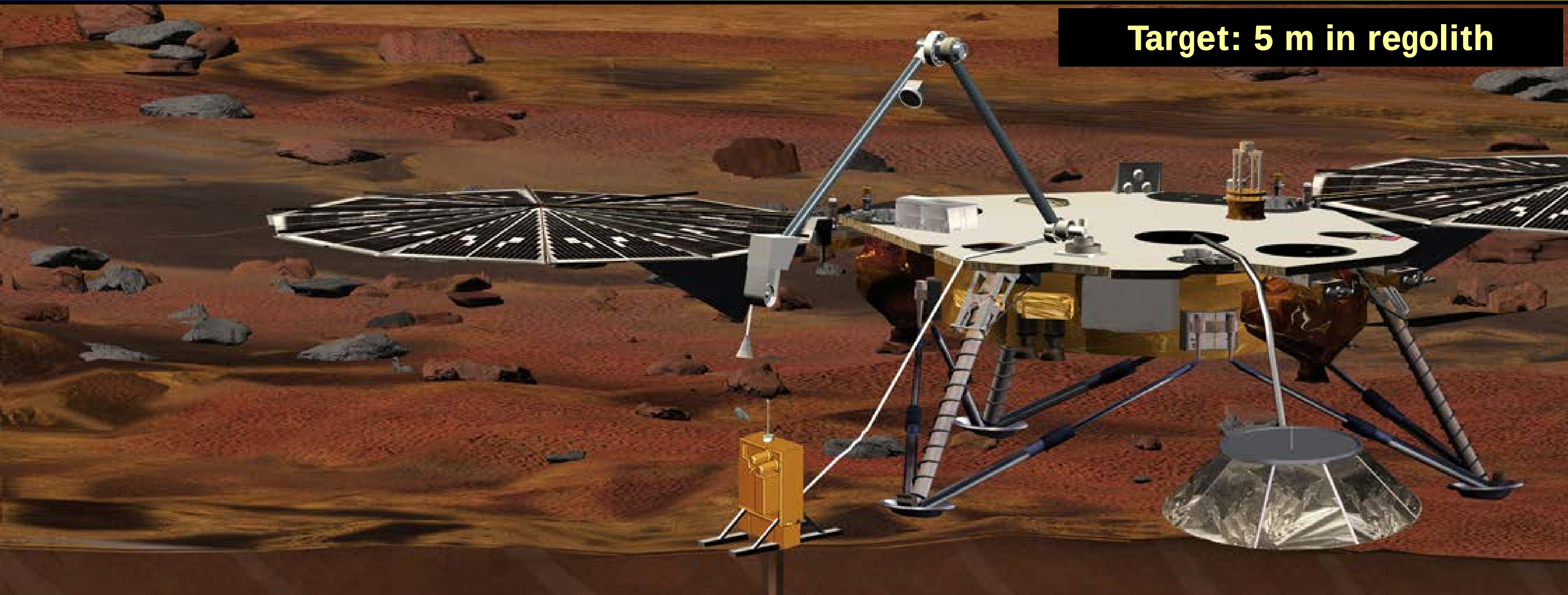
2011 MSL Powder Acquisition Drill [5 cm]

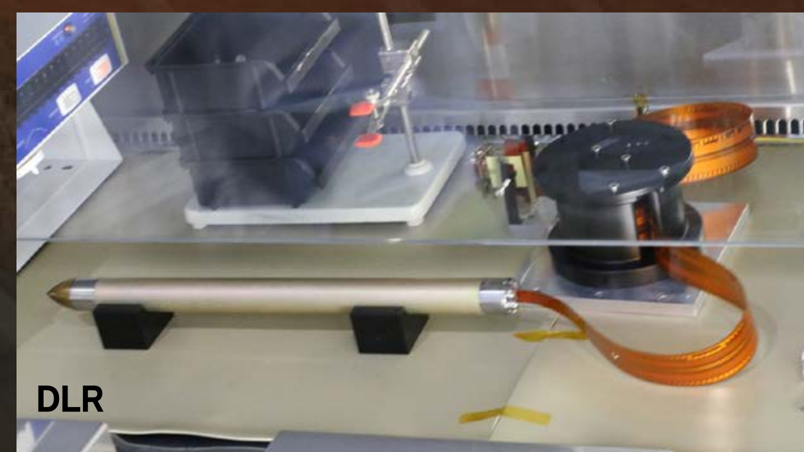
- **Can drill, acquire and process samples**
- **'Weathered' layer is very thin**



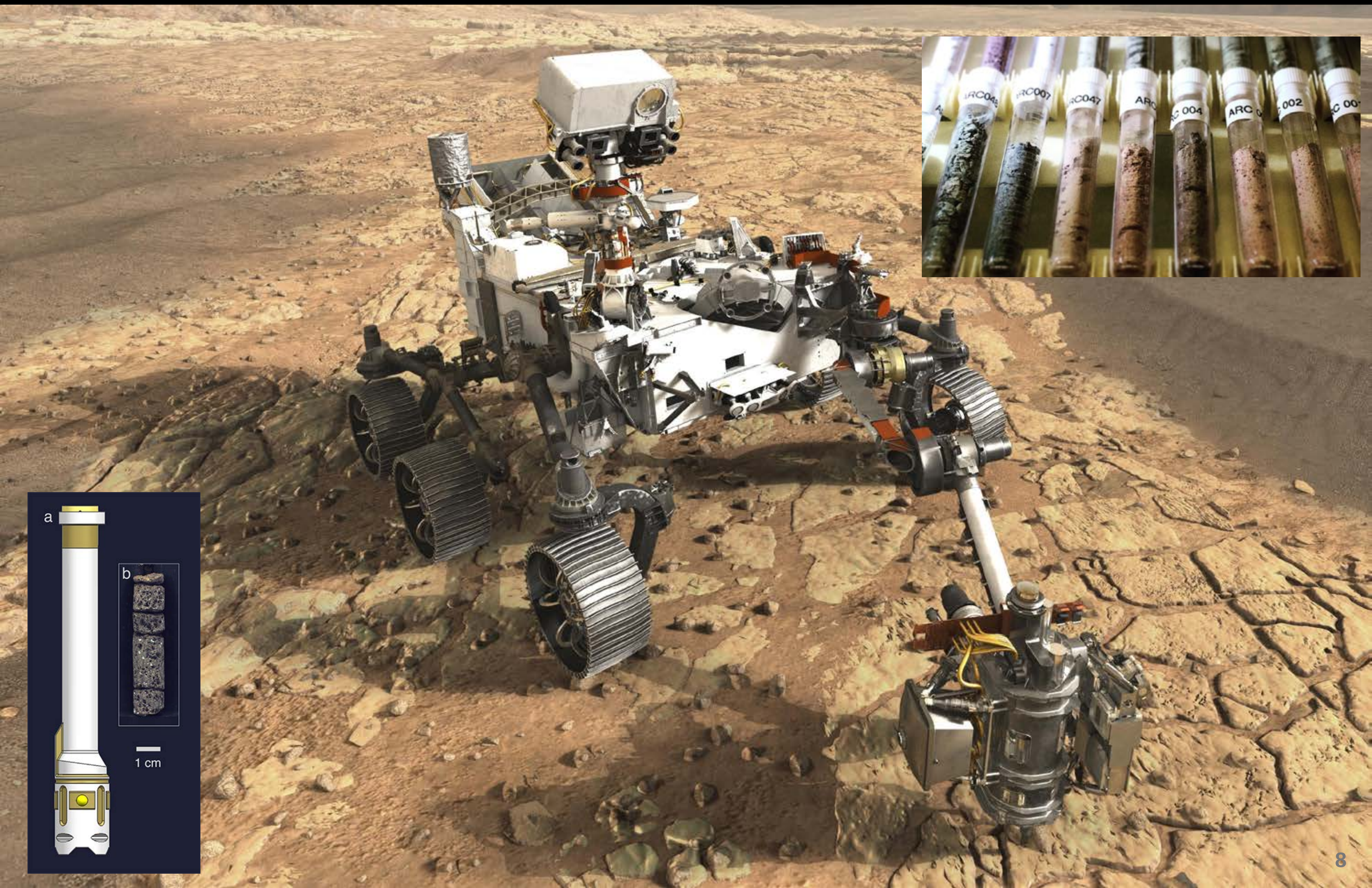
Upcoming: 2018 InSight Mole [5 m]

Target: 5 m in regolith

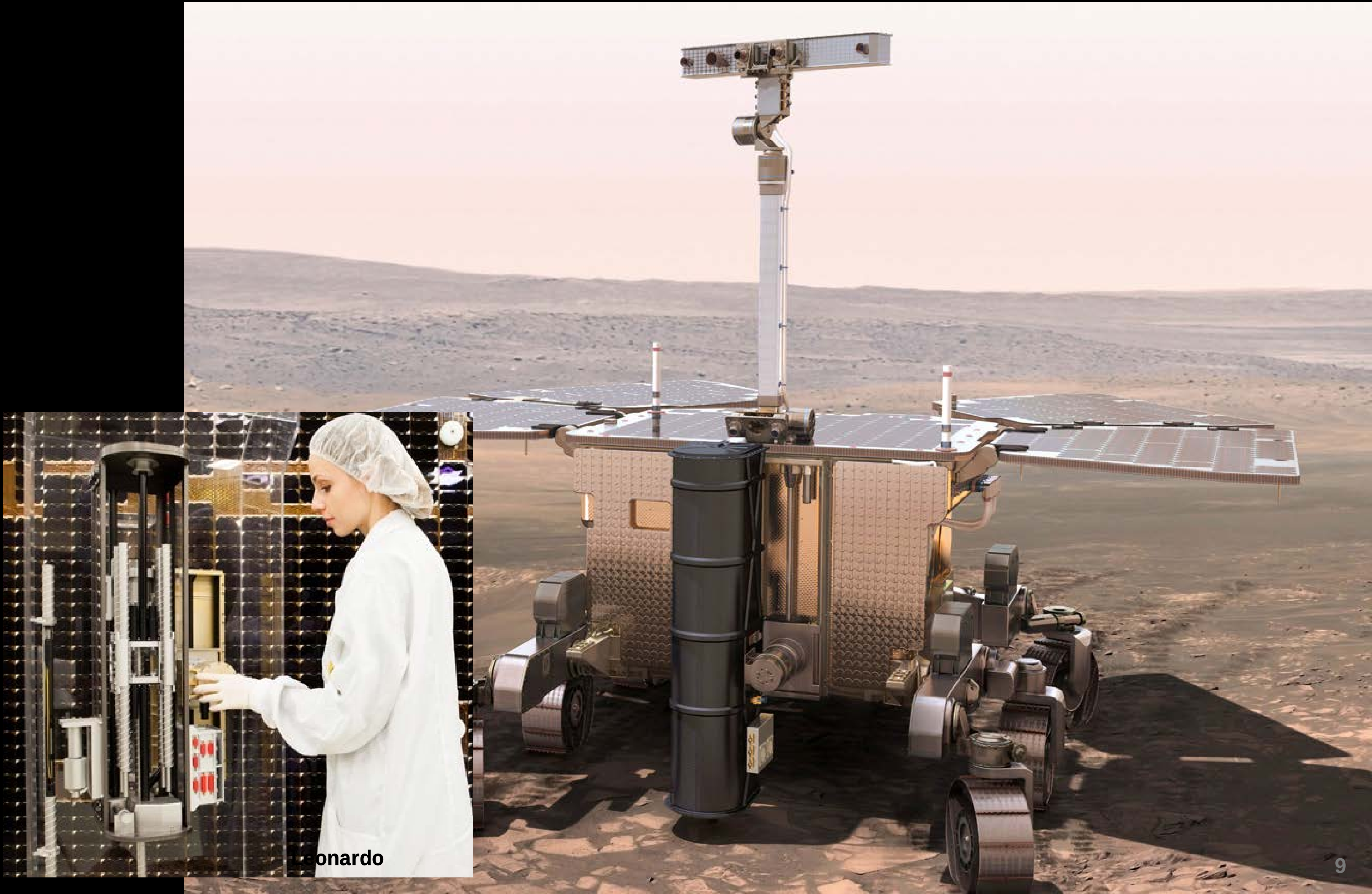




Upcoming: Mars2020 Coring Drill [6 cm]

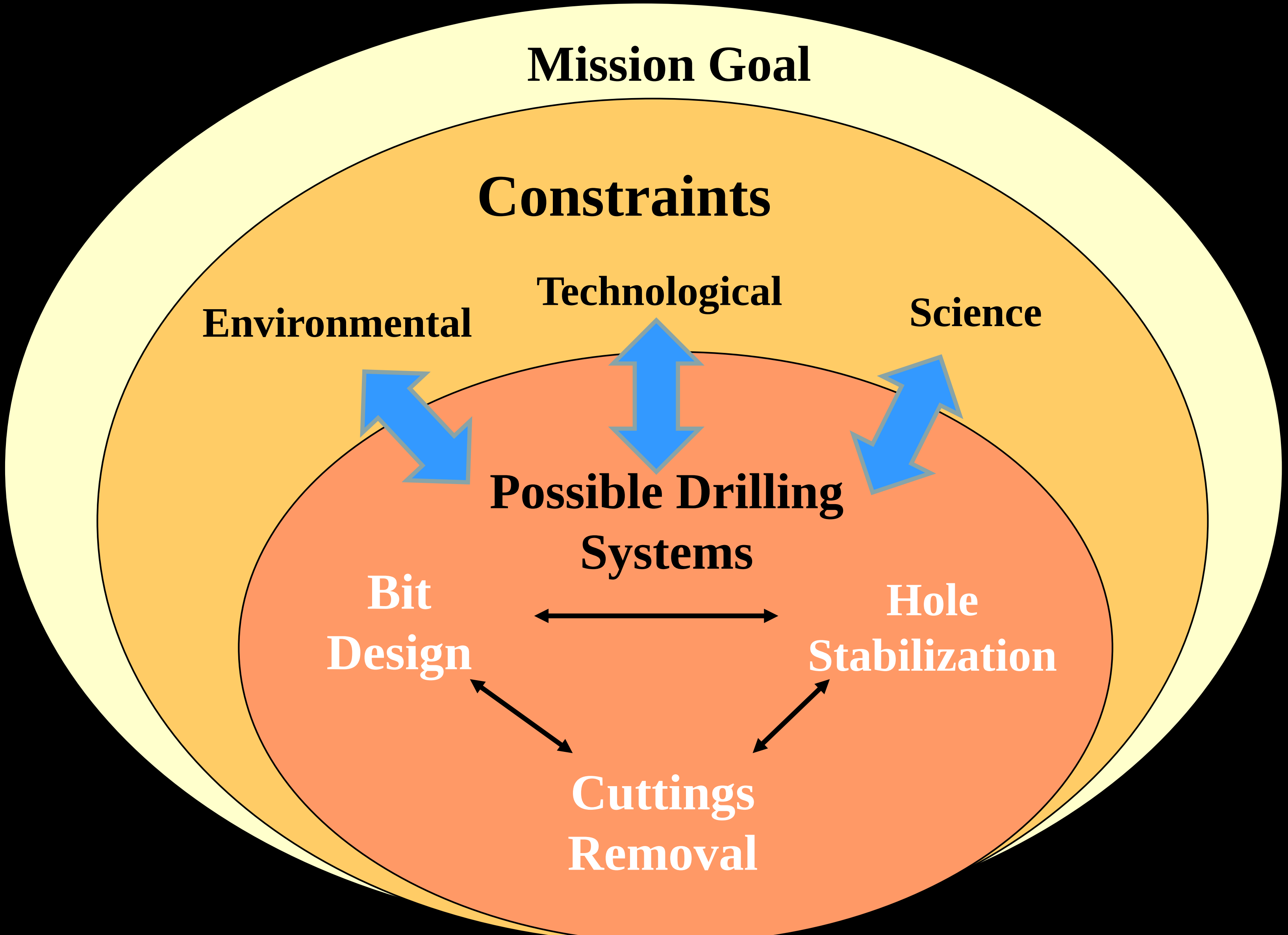


Upcoming: 2020 ExoMars Drill [2 m]



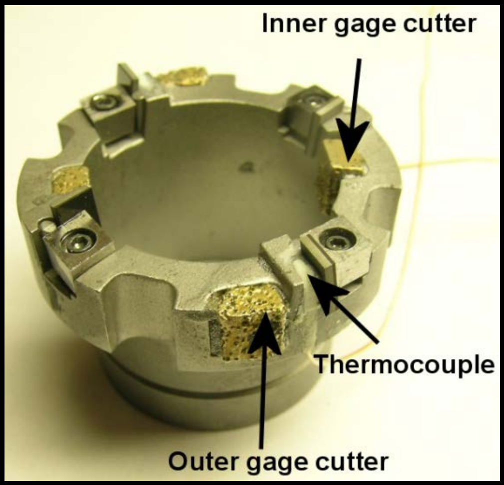
Drilling 101

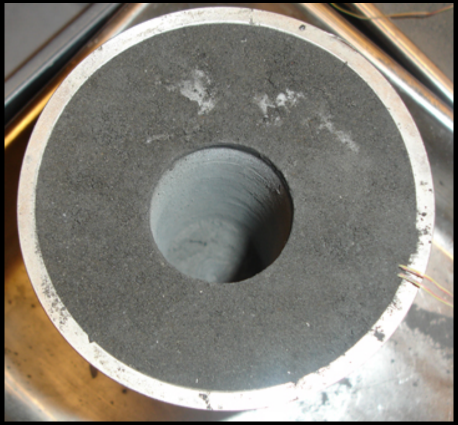
Drilling Architecture Development Process



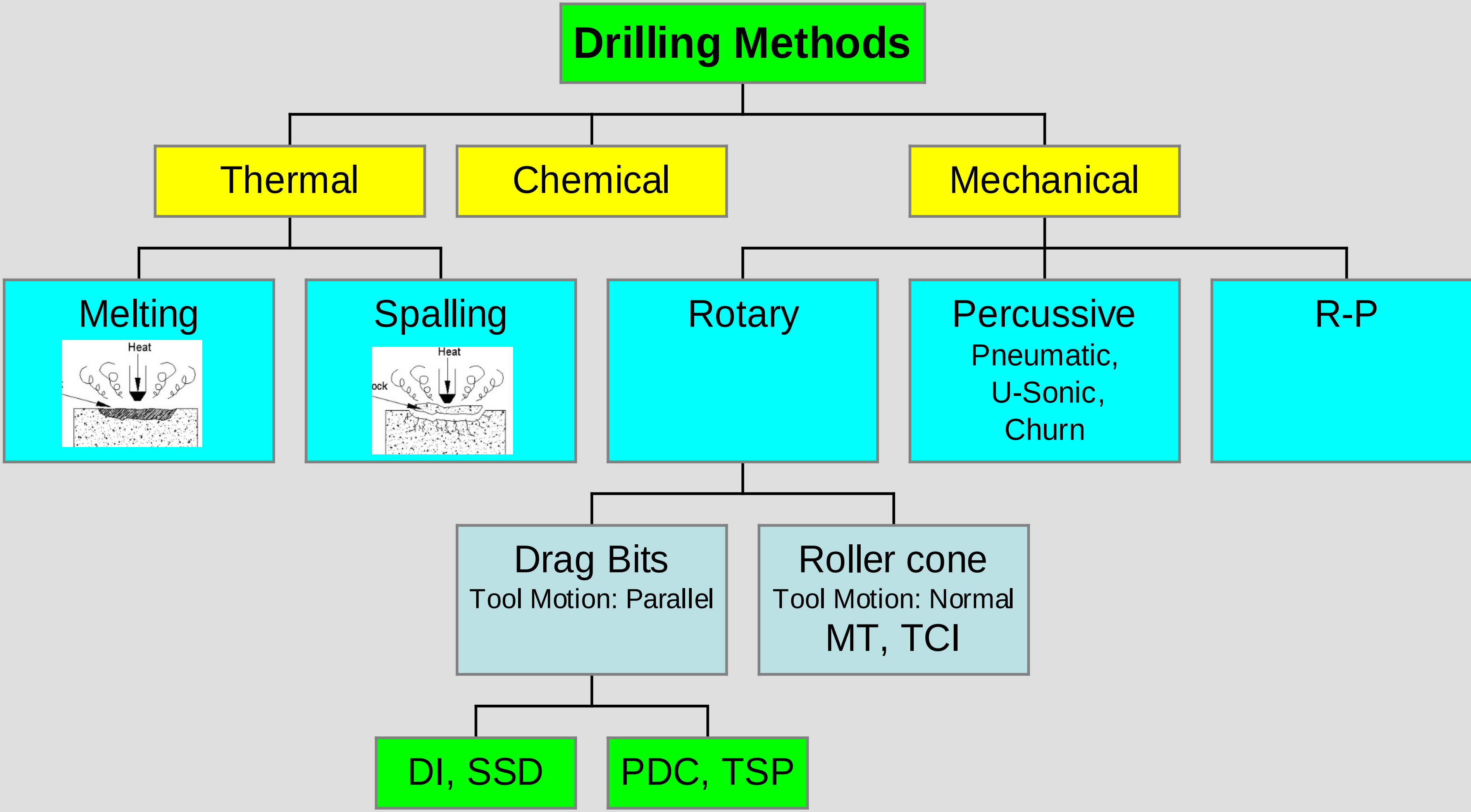
Drilling Steps

1. Drilling + 2. Cuttings Removal





Selection of Drilling Method



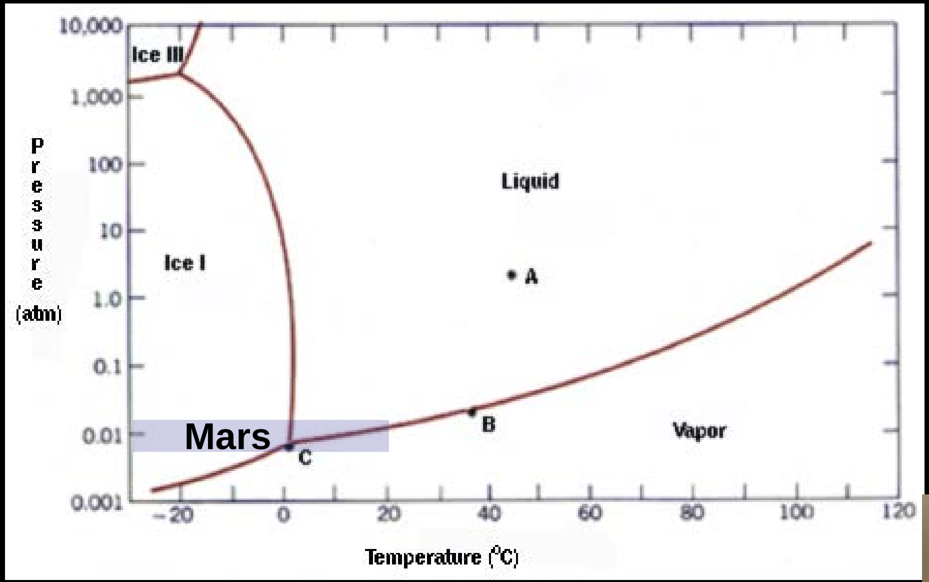
Selection of Cuttings Removal

Cuttings Removal

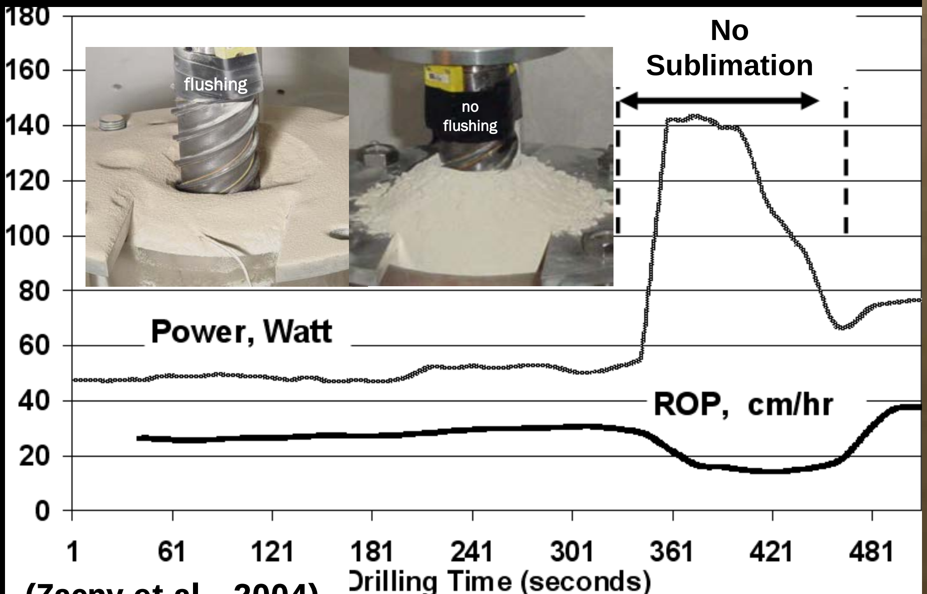
- **Mechanical**
  - **Auger**
  - **Bailer**
- **Fluid**
  - **Water, Mud**
- **Gas**
  - **Continuous**
  - **Blasts**

Dedicated tank
Mars air
Fuel / He pressurant

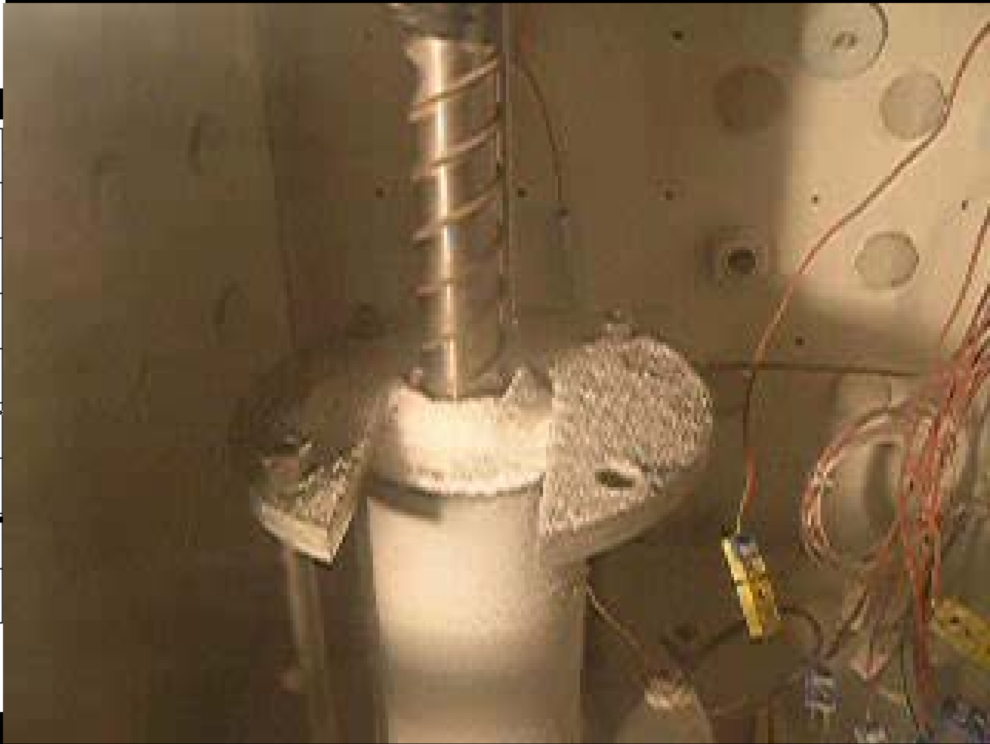
Generating drilling fluid on Mars



- Drilling power --> heat --> latent heat --> sublimation
- Volumetric expansion of ice → vapor 1000's x



(Zacny et al., 2004)

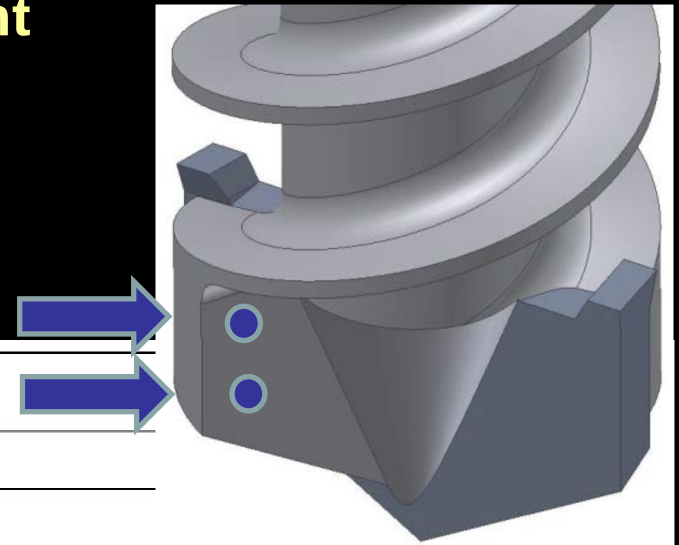


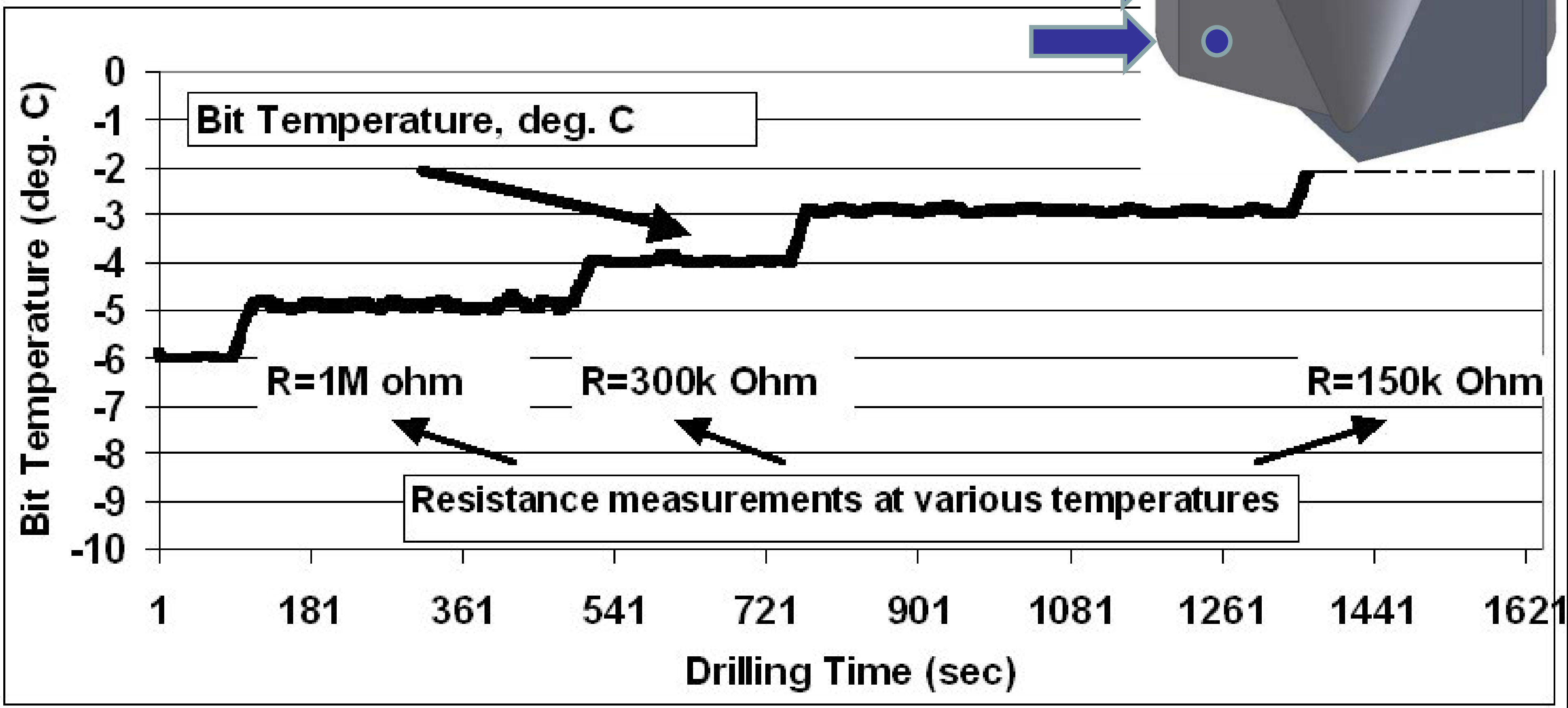
But problems can happen in icy soil (even on Mars)!

Recovered (after a lot of work!)

What options do we have?

- Temperature measurement alone not sufficient
- Measure Temperature AND Resistivity
- Look for a large ΔR/ Δ T
  - ΔR/ Δ T = 700 kΩ/ °C vs. 75 kΩ/ °C

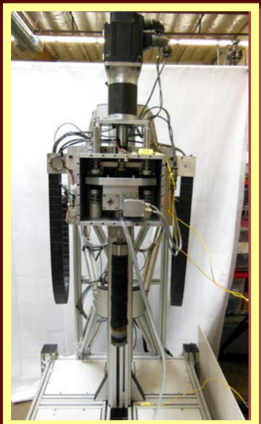




1 m class drill

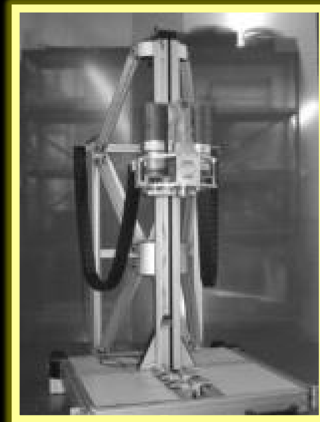
Drilling Approaches

SONIC

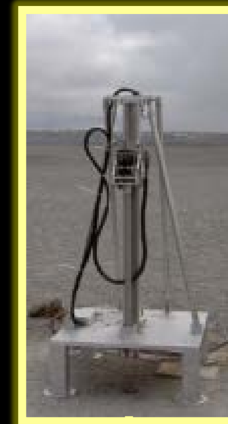


ULTRA SONIC

PERCUSSIVE



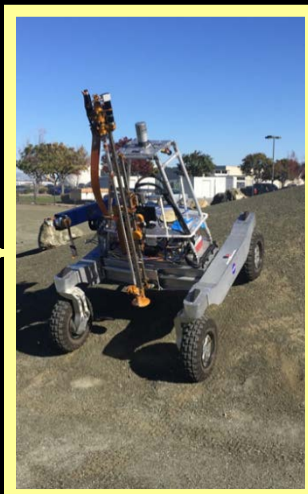
ROTARY



TRL 4 (Rot Perc)

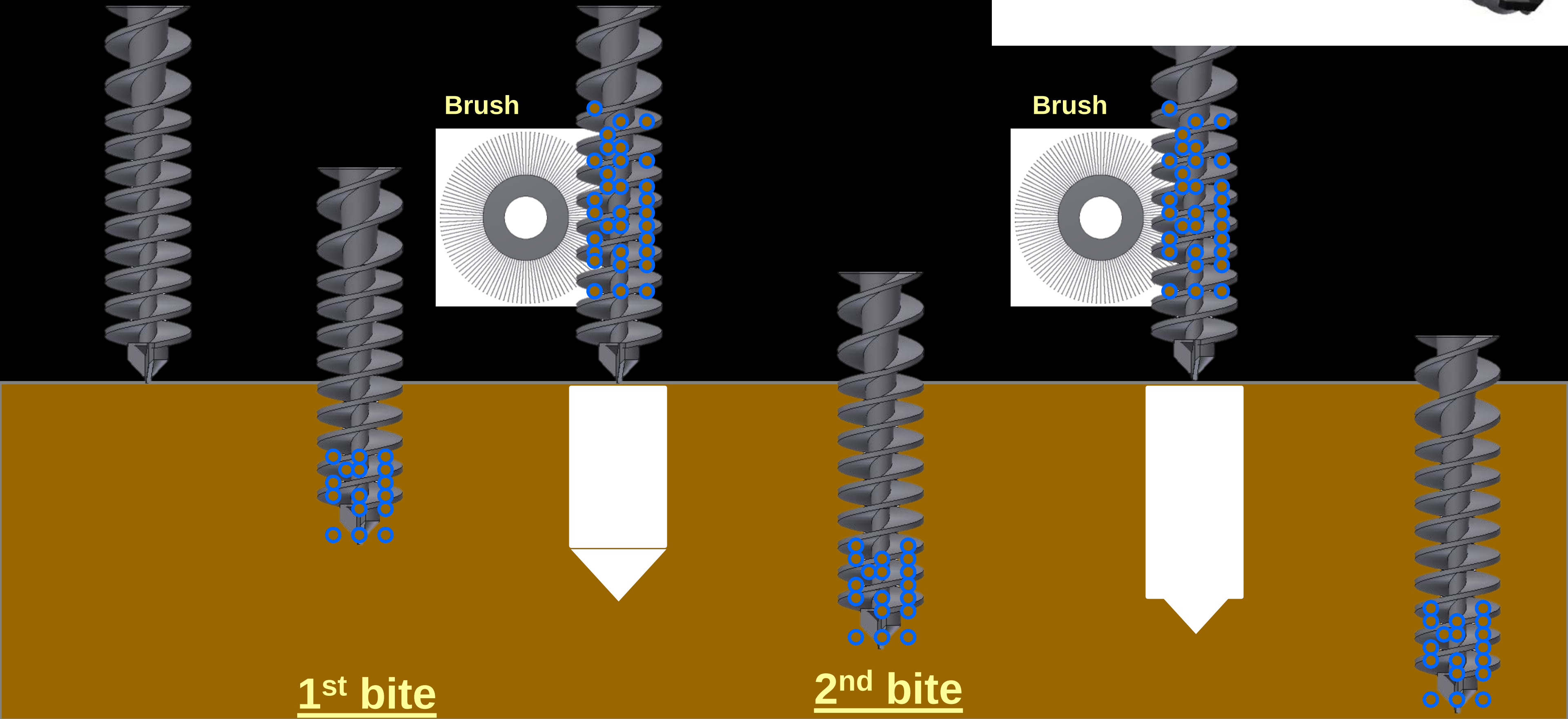
TRL 5 (Rot Perc)

TRL 6 (Rot Perc)



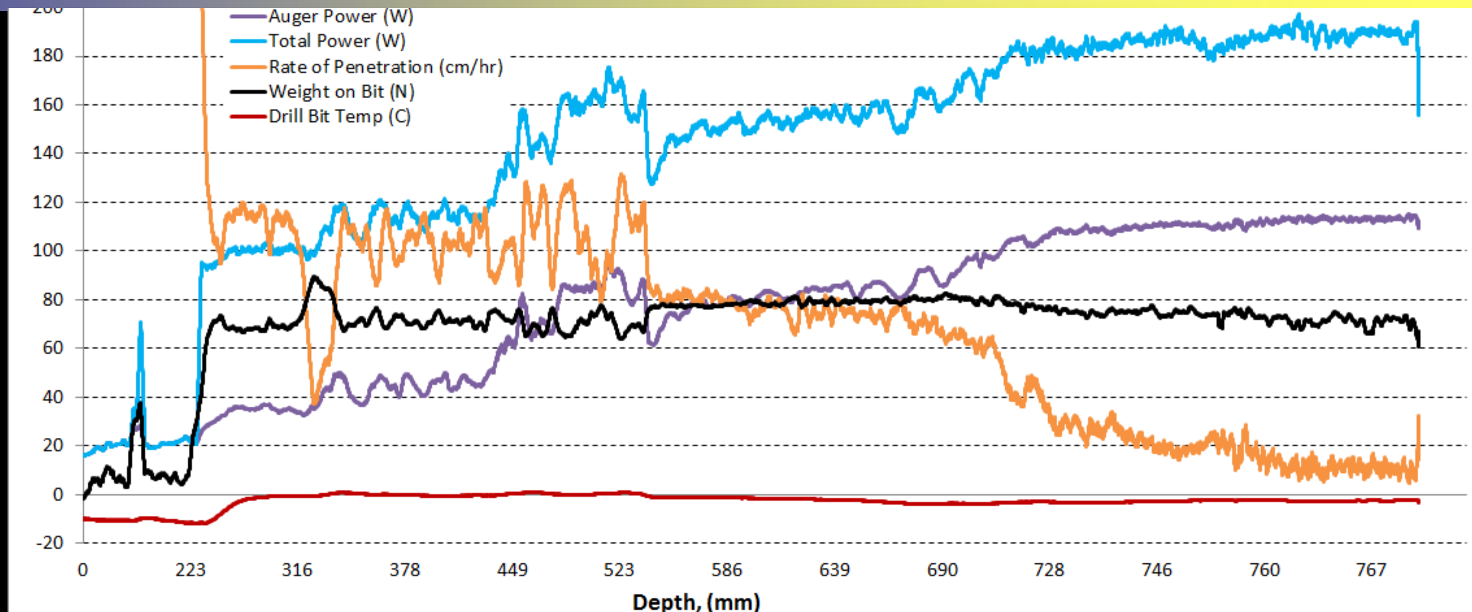
“Bite” Sampling Concept

- Drill in short (~ 10 cm) “bites”
- Preserve stratigraphy in “bites”
- More accurate strength measurement of subsurface
- Lower power and torque (see next slides)
- Drill in safe place during sample analysis
- Extra time for subsurface to cool down

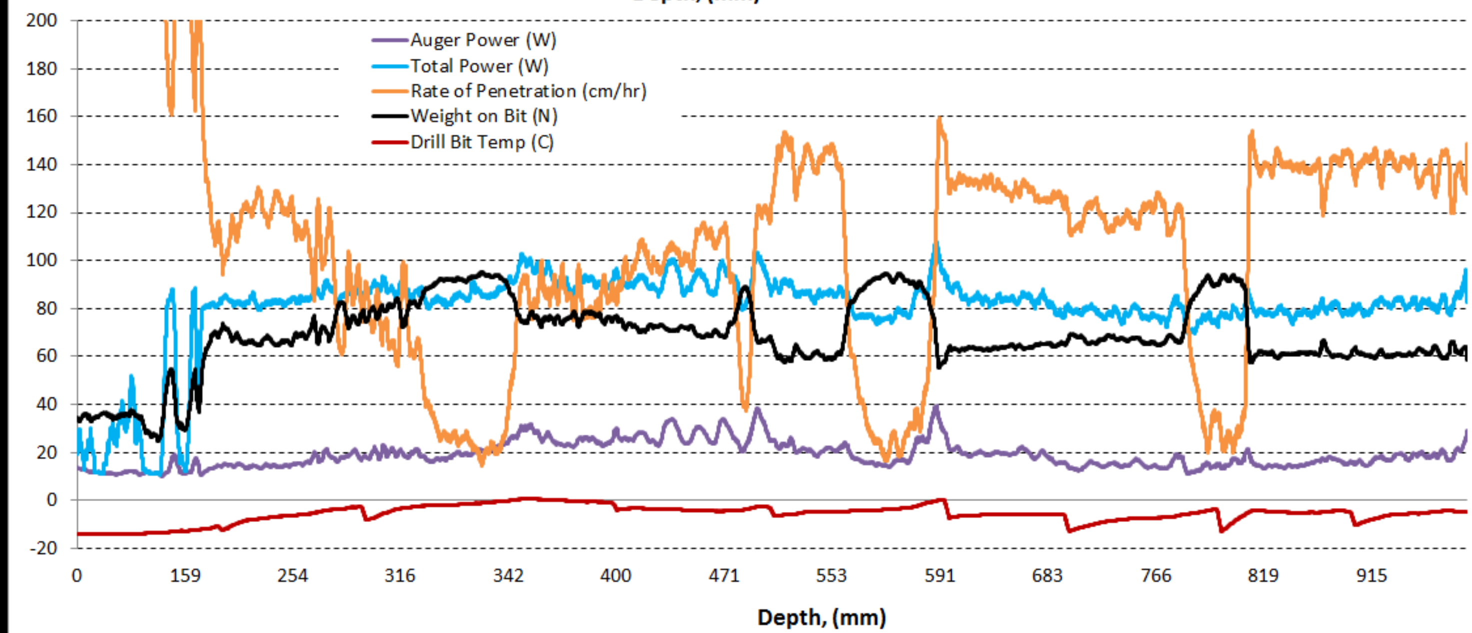


Advantage of Bite Approach

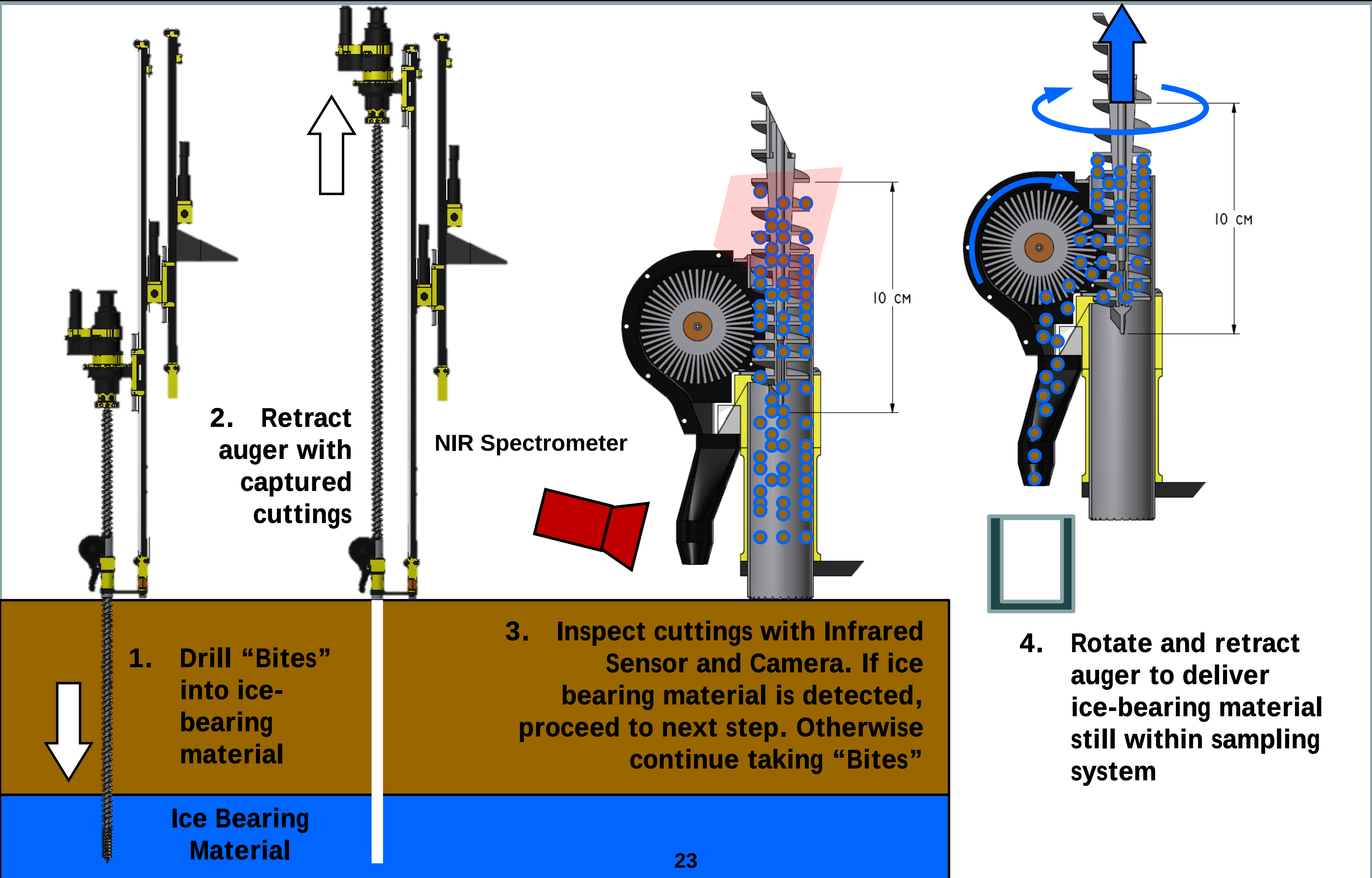
Continuous Auger



Bite Approach



Implementation of “Bite” Sampling

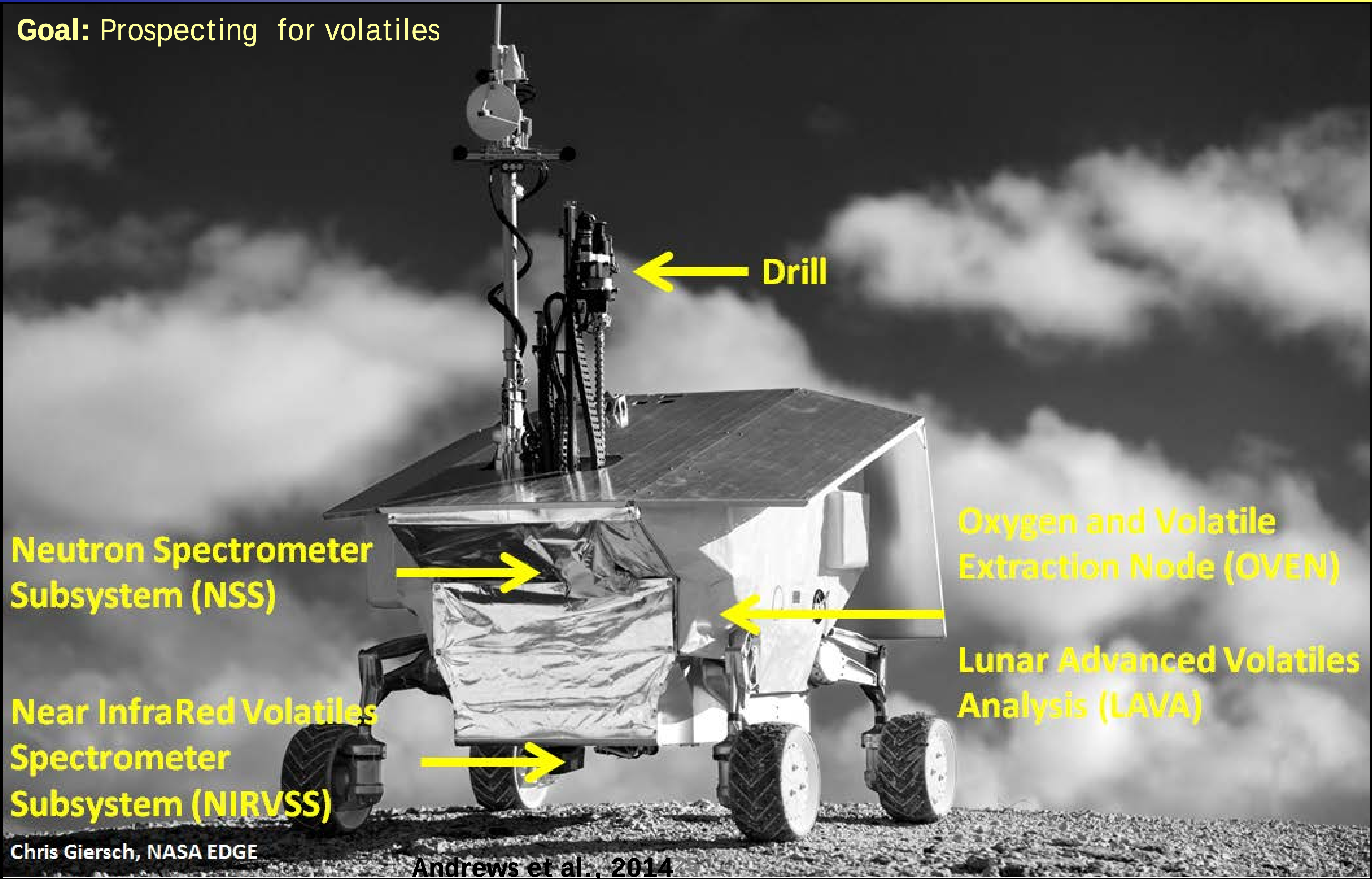


1. Drill “Bites” into ice-bearing material
2. Retract auger with captured cuttings
3. Inspect cuttings with Infrared Sensor and Camera. If ice bearing material is detected, proceed to next step. Otherwise continue taking “Bites”
4. Rotate and retract auger to deliver ice-bearing material still within sampling system

Rover Architecture: Atacama

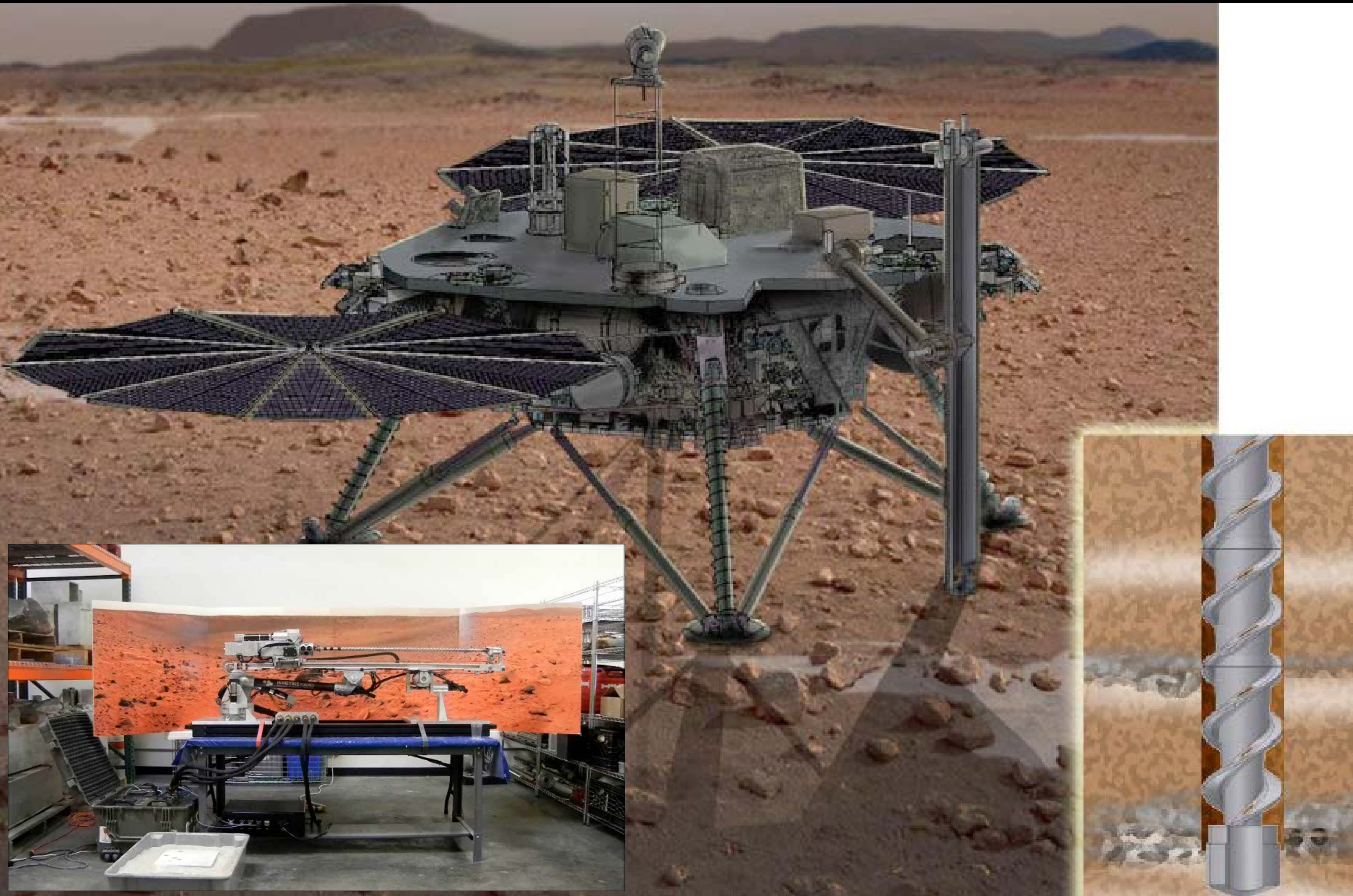
Rover Architecture: Resource Prospector

Goal: Prospecting for volatiles

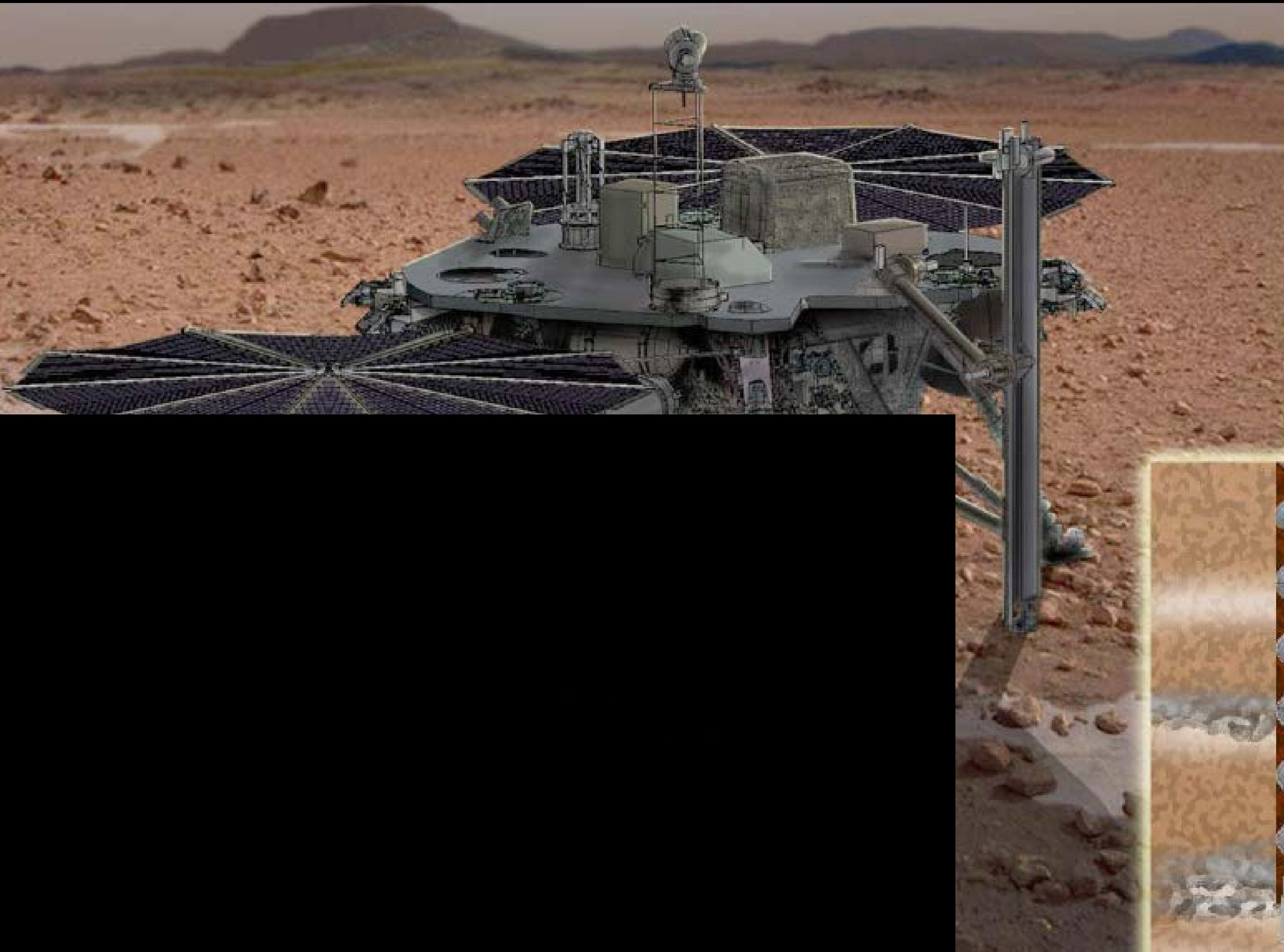


Andrews et al., 2014

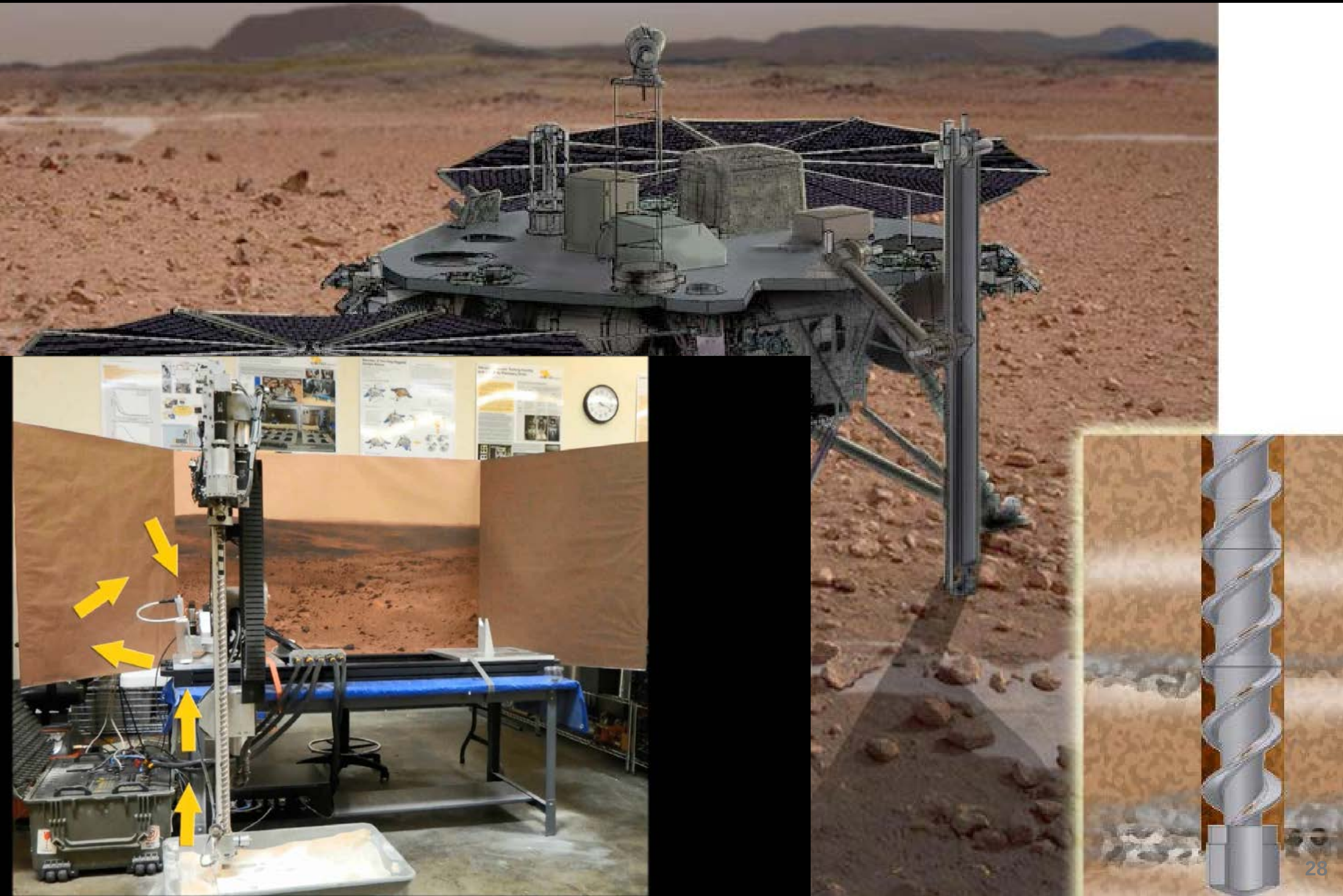
Lander Architecture: Mars IceBreaker



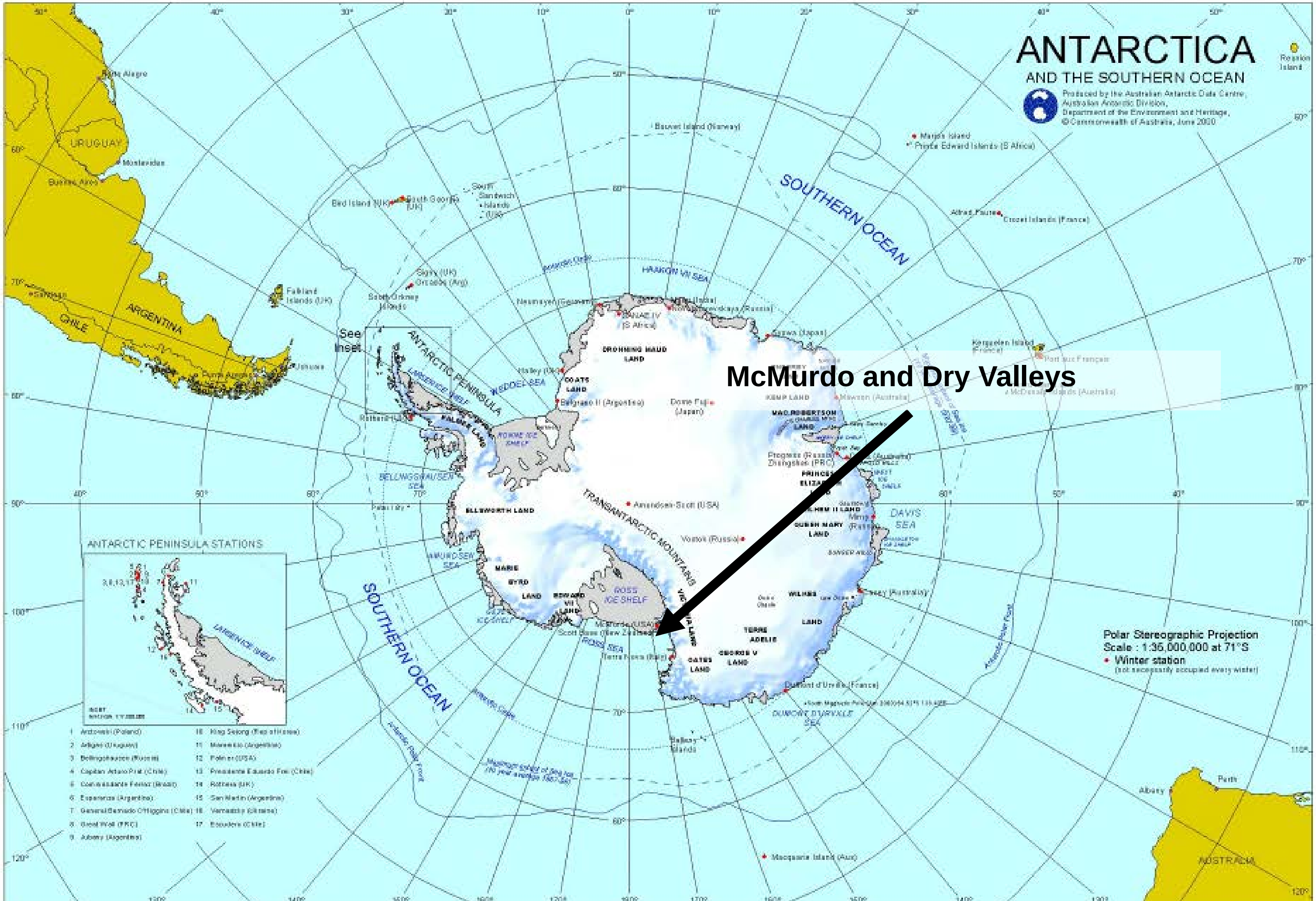
Sample Delivery using Drill



Sample Delivery using Gas



Testing in Cold Regions



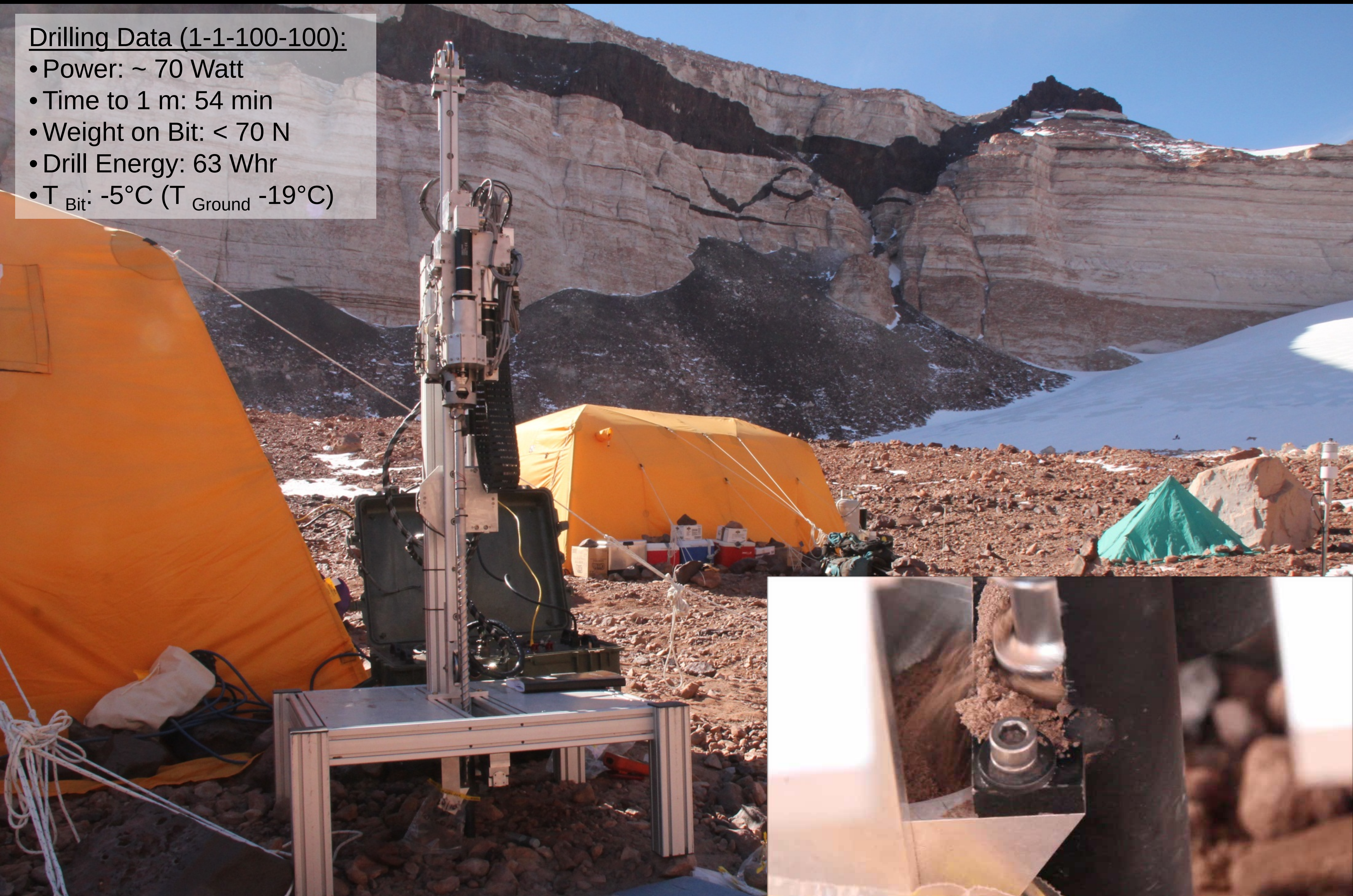
McMurdo Station, Antarctica

Mars Analog: University Valley, Antarctica

Ice Cemented Ground – Soil Did Not Stick!

Drilling Data (1-1-100-100):

- Power: ~ 70 Watt
- Time to 1 m: 54 min
- Weight on Bit: < 70 N
- Drill Energy: 63 Whr
- T_{Bit}: -5°C (T_{Ground} -19°C)



Antarctic Dry Valleys: Massive Ice

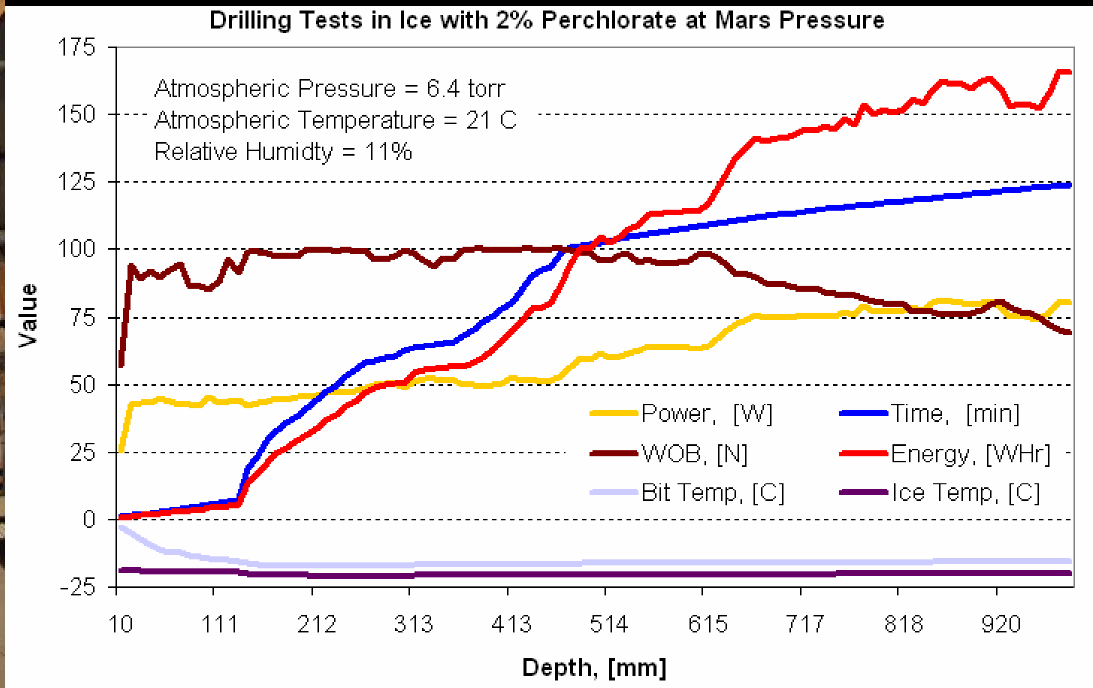
Drilling Data:

- Power ~ 150 Watt (at 2.5 m depth)
- Time to reach 1 m / 2.5 m: 1 hr / 2.5 hr
- Weight on Bit: < 70 Newton
- Energy: 120 Whr for 1 m / 300 Whr for 2.5 m
- T Bit-10 °C (T Ice -24 °C)

Ice cuttings include many single ice chucks as large as 6 mm long

Test in Mars chamber

- 1 m depth in 3.5 m chamber
- Tests in
  - ice (w and w/out perchlorate)
  - icy-soil
  - rock
- Drilling at 1-1-100-100 level: 1m in 1 hr with 100 Watt and 100 Newton WOB



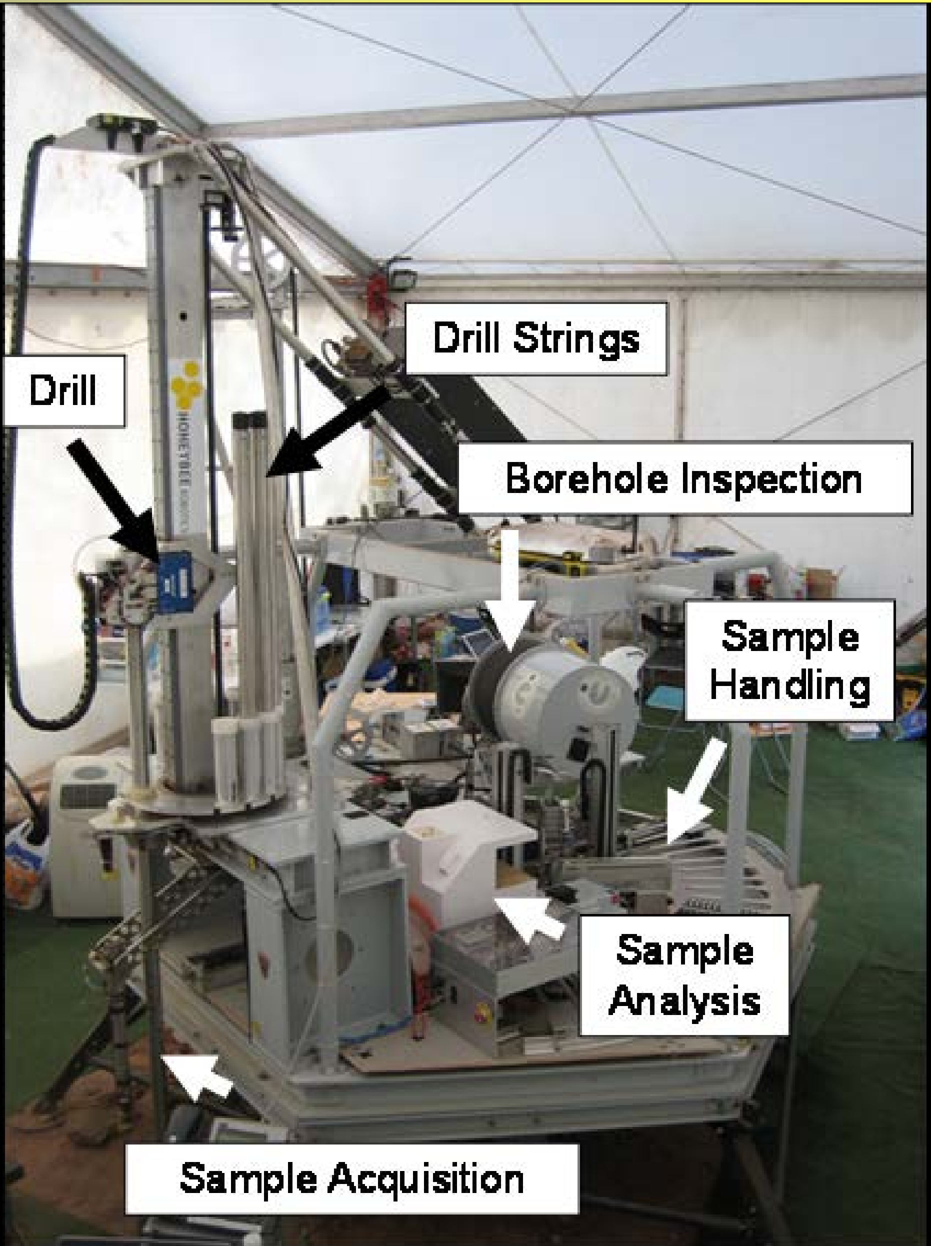
10 m class drills

MARTE

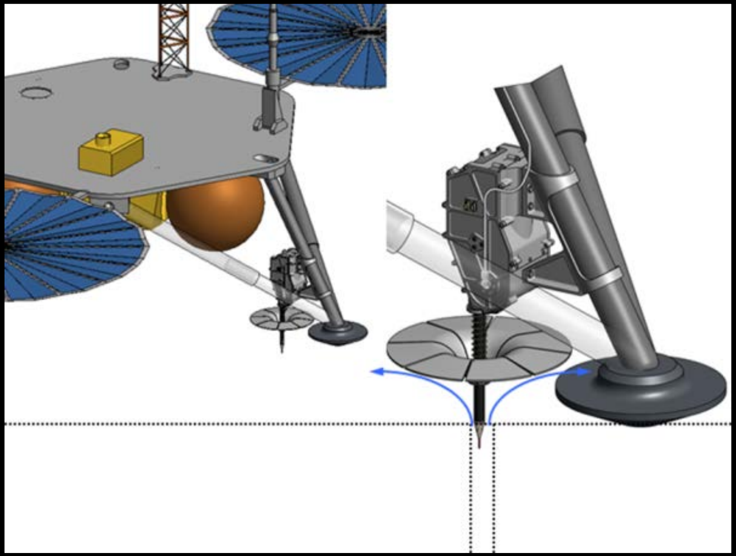
- 10 m coring drill
- Core processing
- Instruments for core analysis
- ASTEP funded (PI. Carol Stoker)

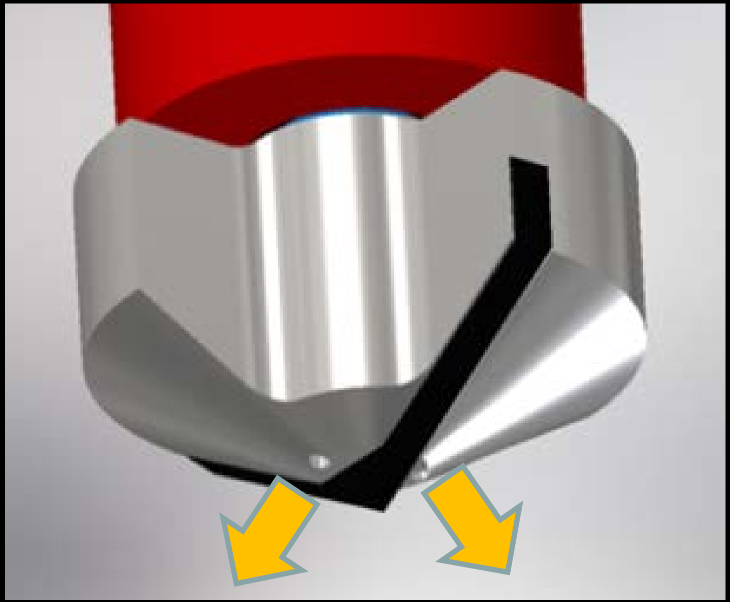
MARTE
Limestone Drilling Test
NASA Ames Research Center
May 2005

Honeybee Robotics



STEM-Pneumatic Drill

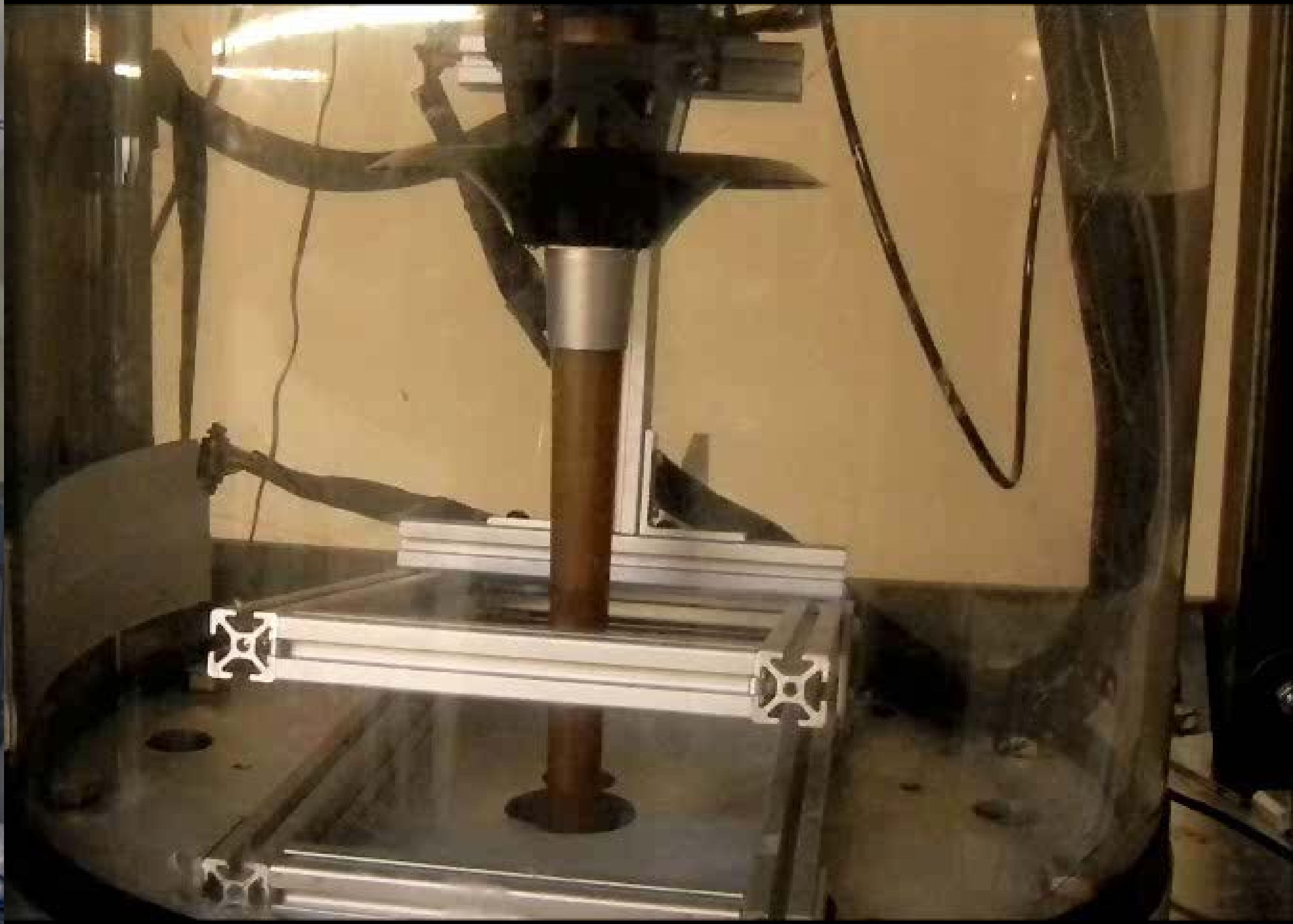




Pneumatic Drill Testing

(Zacny et al., 2013)

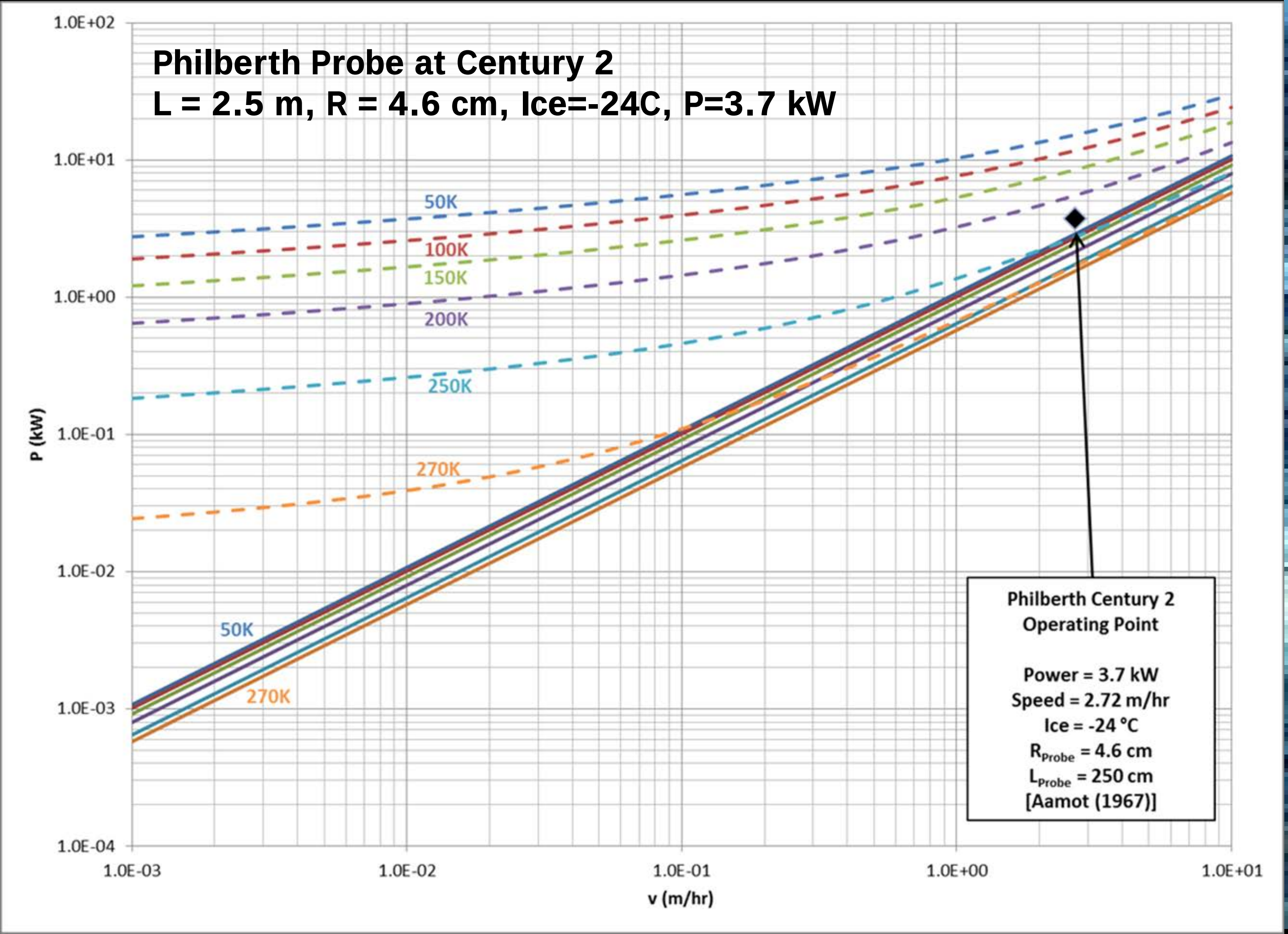
- Compacted soil simulant (1.9 g/cc)
- Mars pressures
- 2 m in 2 minutes
- Demonstrated Stop-Start

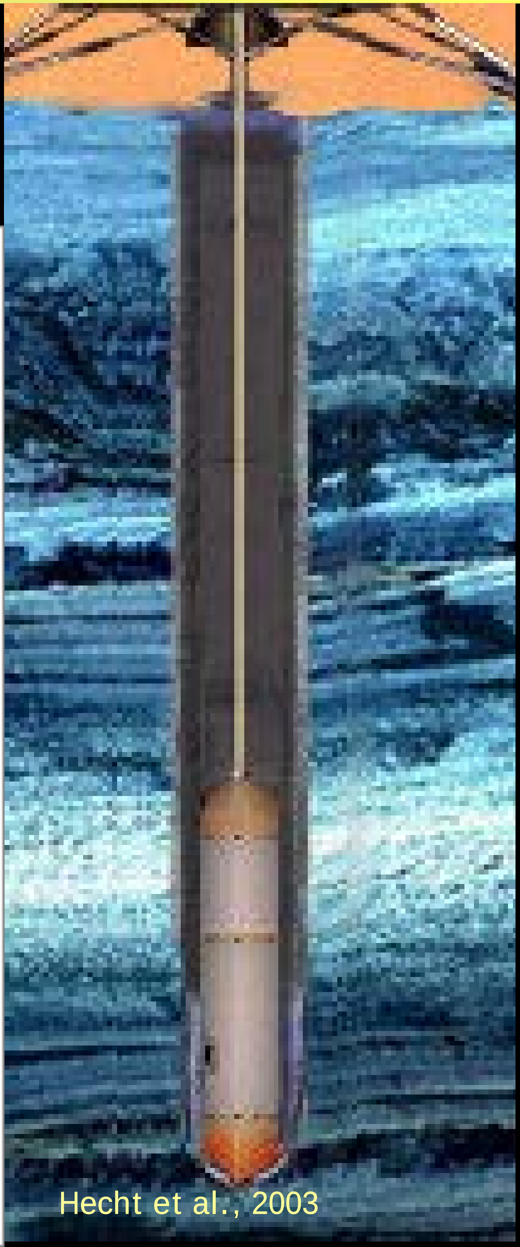


>100 m class drills

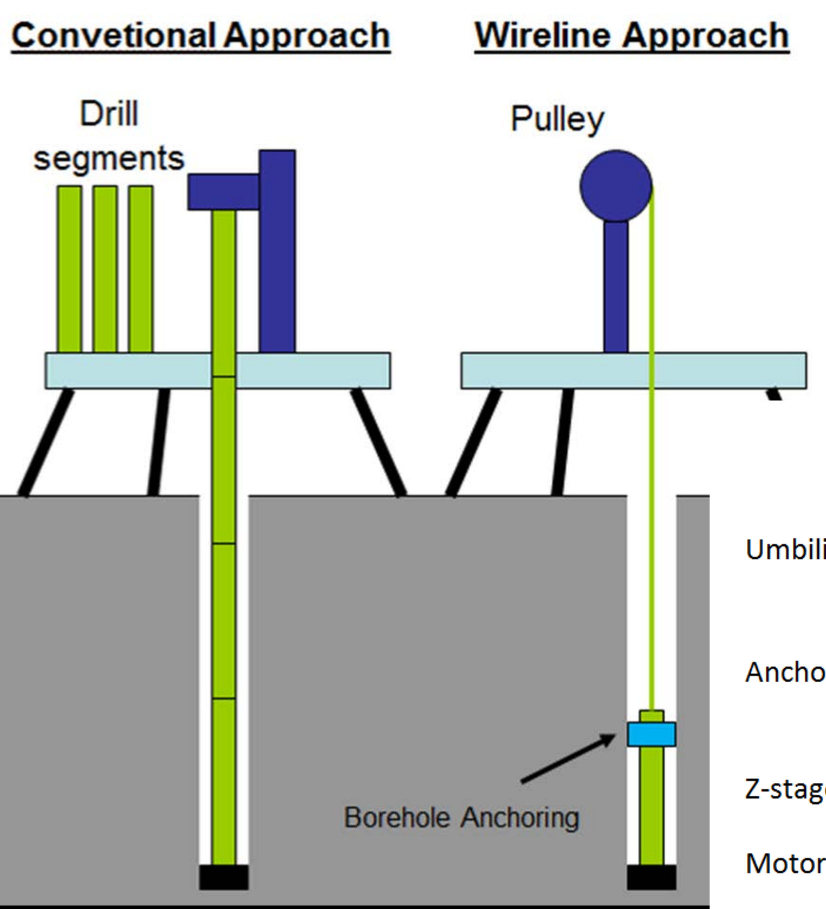
Melt probes

- Developed in 1960s by CRREL
- Simple but slow, power/energy hungry
- Work in ice only (or very limited wt% silt)

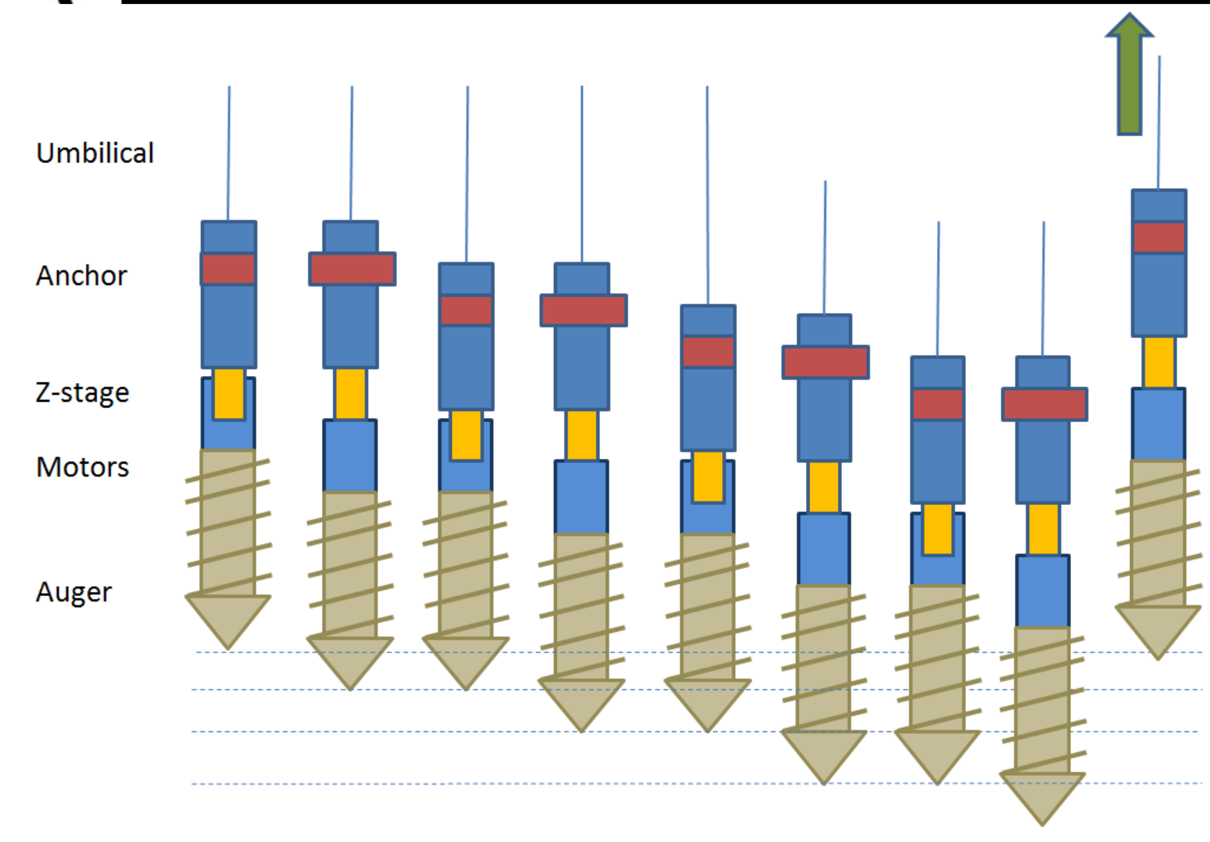




Inchworm / Wireline / Cable Suspended



- Used in Antarctica and Greenland
- In unstable boreholes, need expandable casing and bi-center bit
- Delivers sample and can deploy instrument downhole



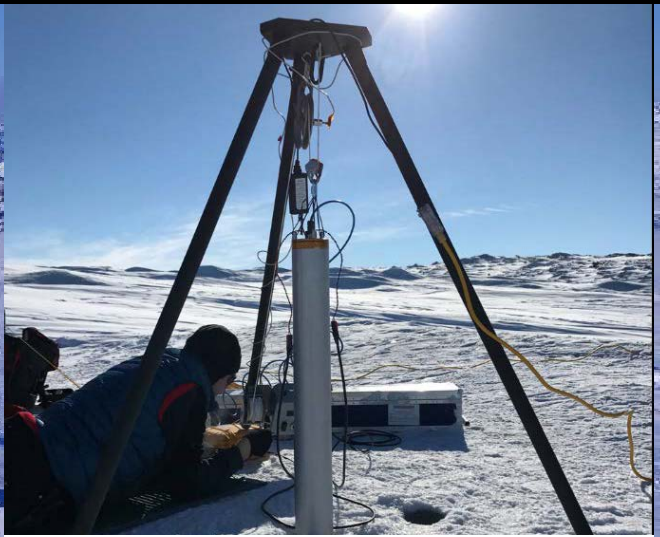
AMNH Deep Drill

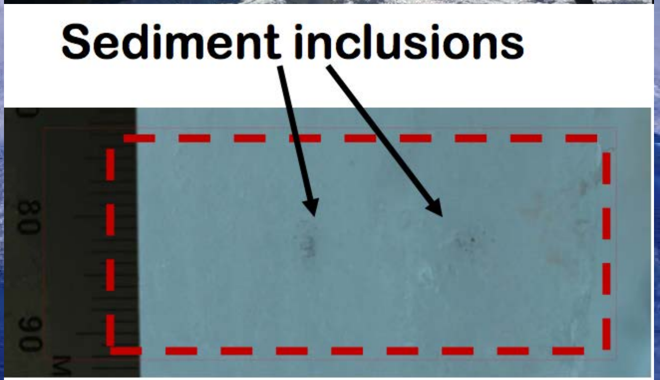
Drilled two holes

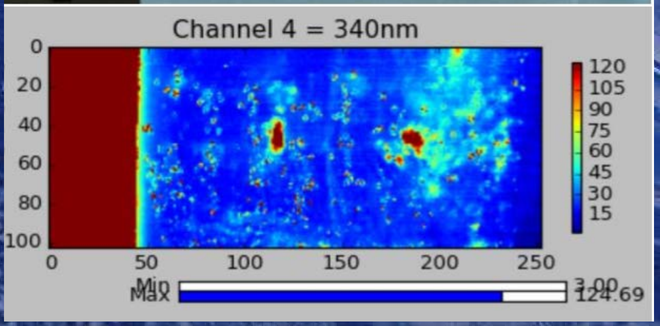
- **10.5 m**
- **13.5 m**

WATSON – Deep Drill with UV/Raman

PSTAR, Roh Bhartia (PI)

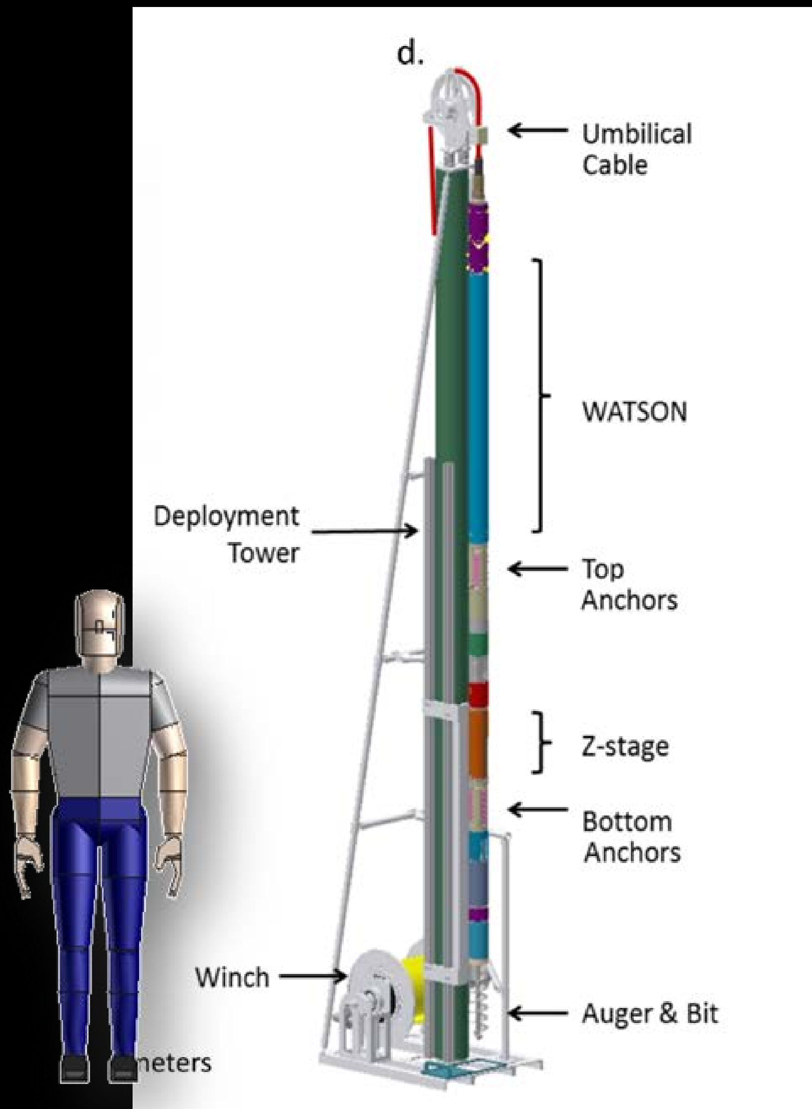




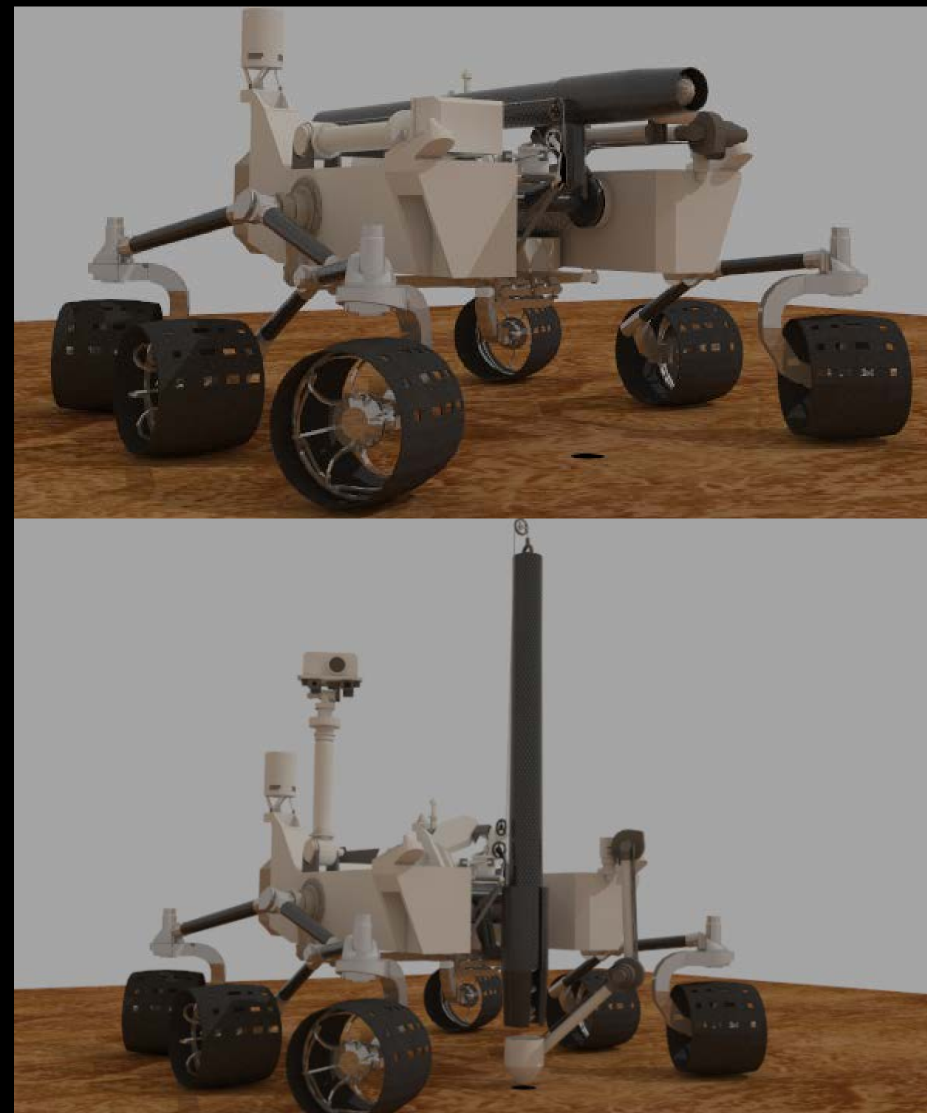


WATSON – next steps

Greenland 2019



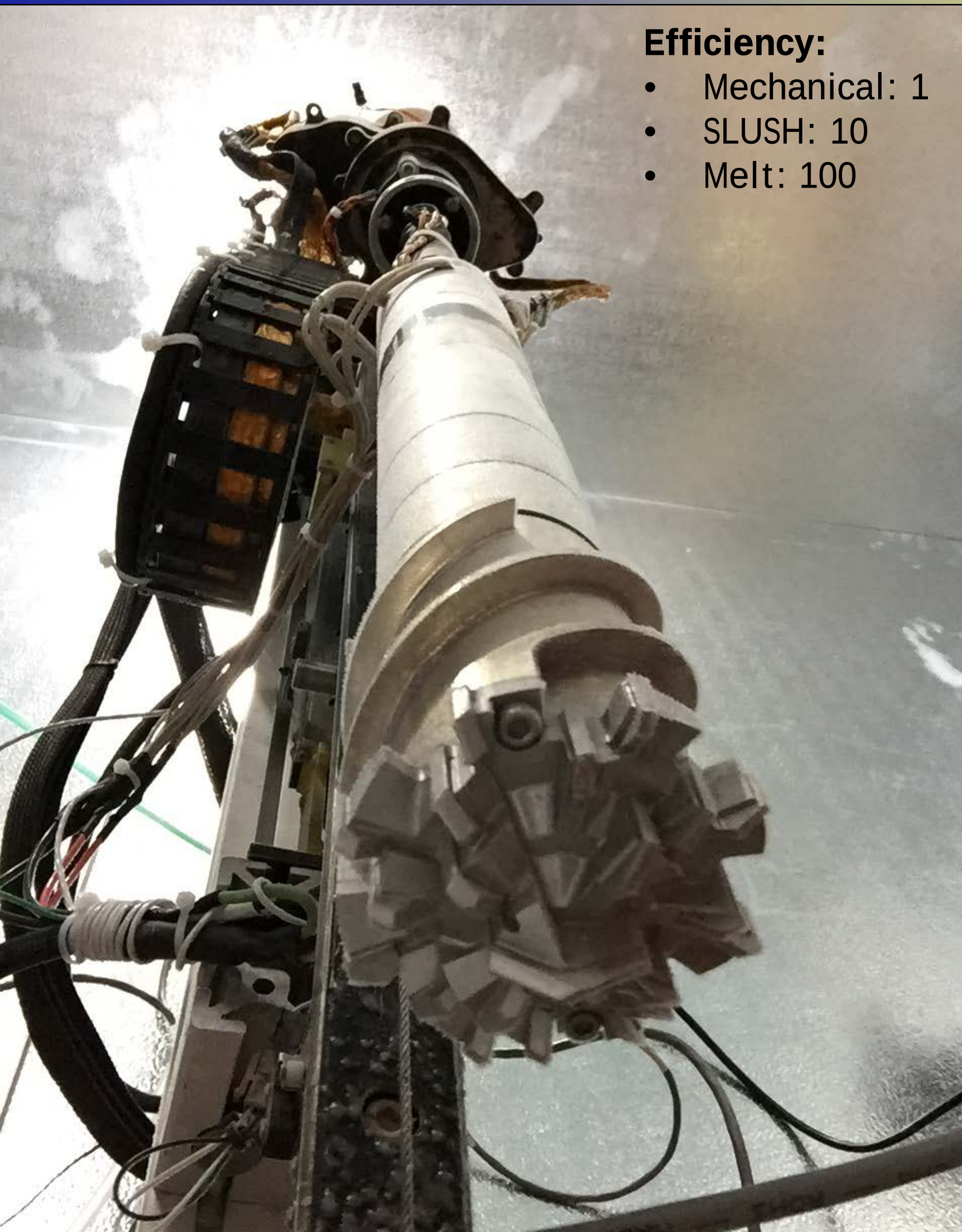
Mars (2029 ☺)

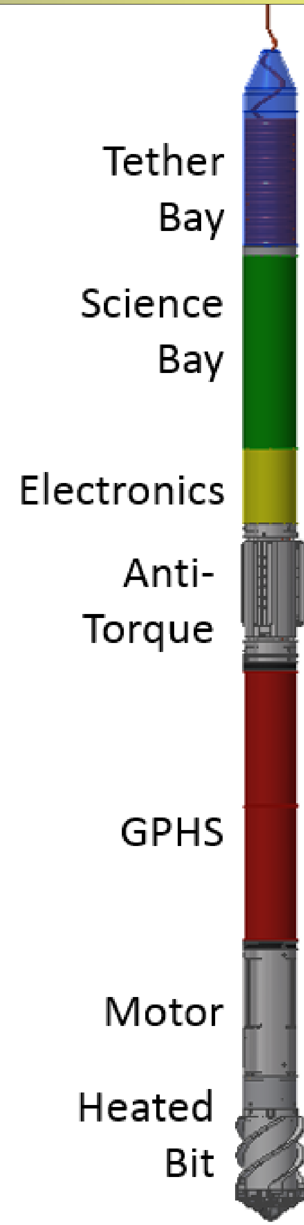


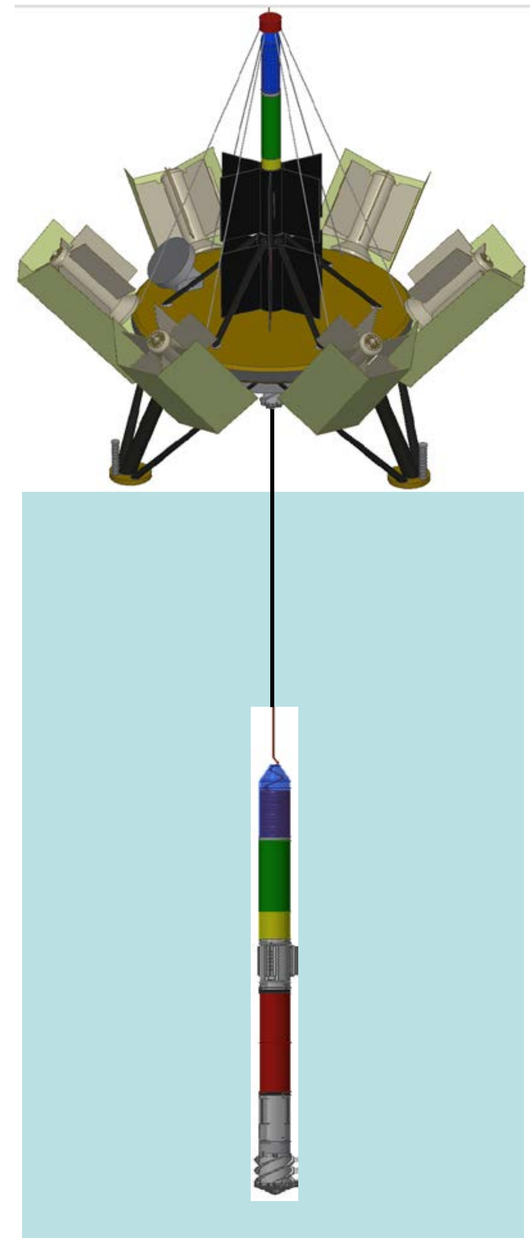
SLUSH Drill: Thermo-Mechanical

Search for Life Using Subsurface Heated Drill

Efficiency:
- Mechanical: 1
- SLUSH: 10
- Melt: 100



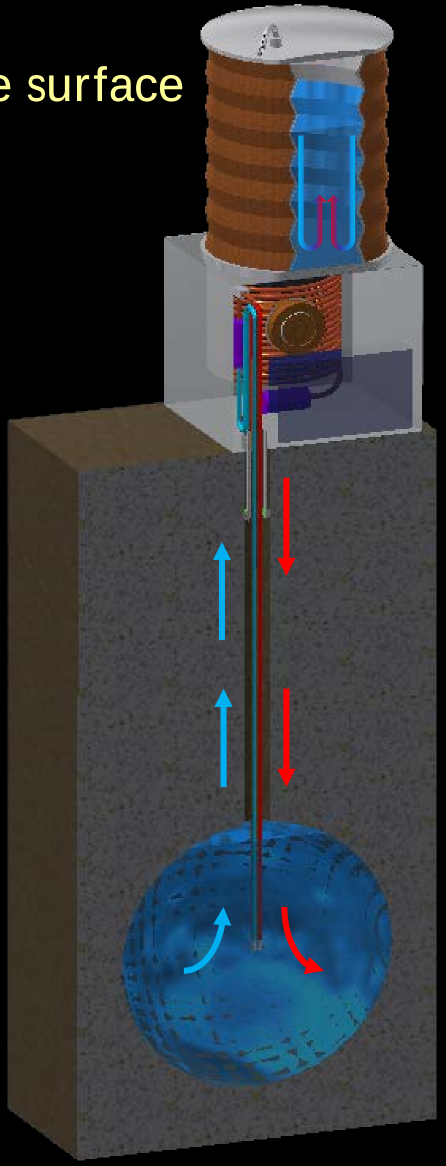




Drill based water extraction systems

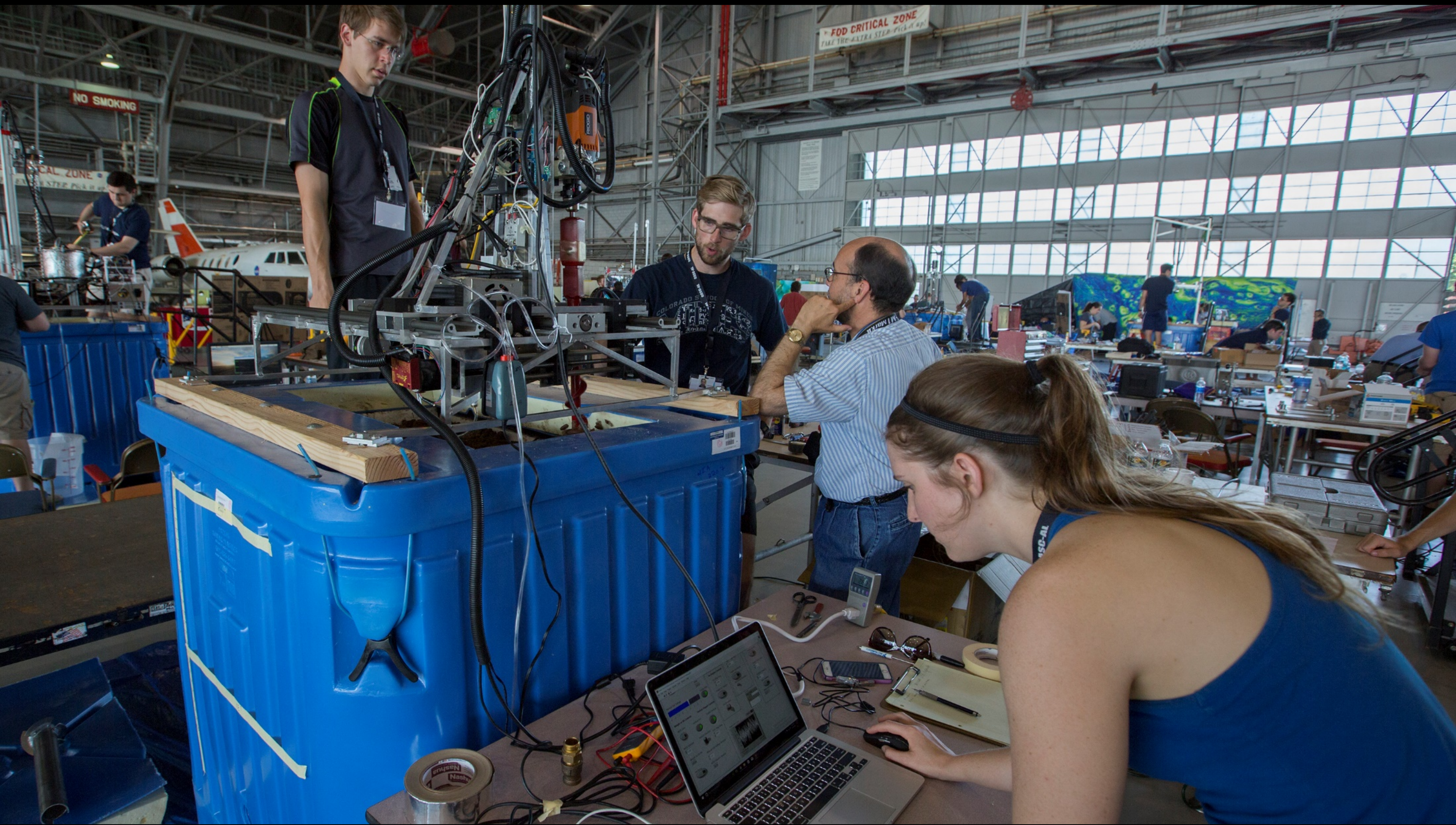
RedWater

- STEM drill with pneumatic cuttings transport makes a hole
- STEM based pumping system deploys and pumps water to the surface



2nd NASA's Mars Ice Challenge (RASC-AL)

- Dates: June 5-7, 2018
- NASA Langley



Conclusions

- Mars depth record climbed from 5 mm in 2003 to 5 cm in 2012
- Need technology to reach meters and possibly 100s of meters.
- Current Technology Readiness Level (TRL)
  - 1 m class systems are at TRL 6
  - 10 m class systems are at TRL 4
  - 100 m class systems are at TRL 4
- Drills can bring sample to an instrument AND can bring an instrument to a sample:
  - Temperature profile and k, (heat flow probe)
  - Resistivity, LIBS, UV, Raman, Microscope
  - Strength/density (comes “free” from drill telemetry)
- There is no substitute for tests in analogs on Earth (e.g. Dry Valleys)
- Numerous ISRU options exist for mining water on Mars

Acknowledgments

- NASA SBIR
- NASA ROSES Programs (PIDDP, ASTEP, ASTID)
- NASA HEOMD Advanced Exploration Systems
- NASA JPL

Thank You!