Drilling Into Mars PLD

Keck Institute for Space Studies:
Unlocking the Climate Record Stored within Mars' Polar Layered Deposits

August 10, 2017

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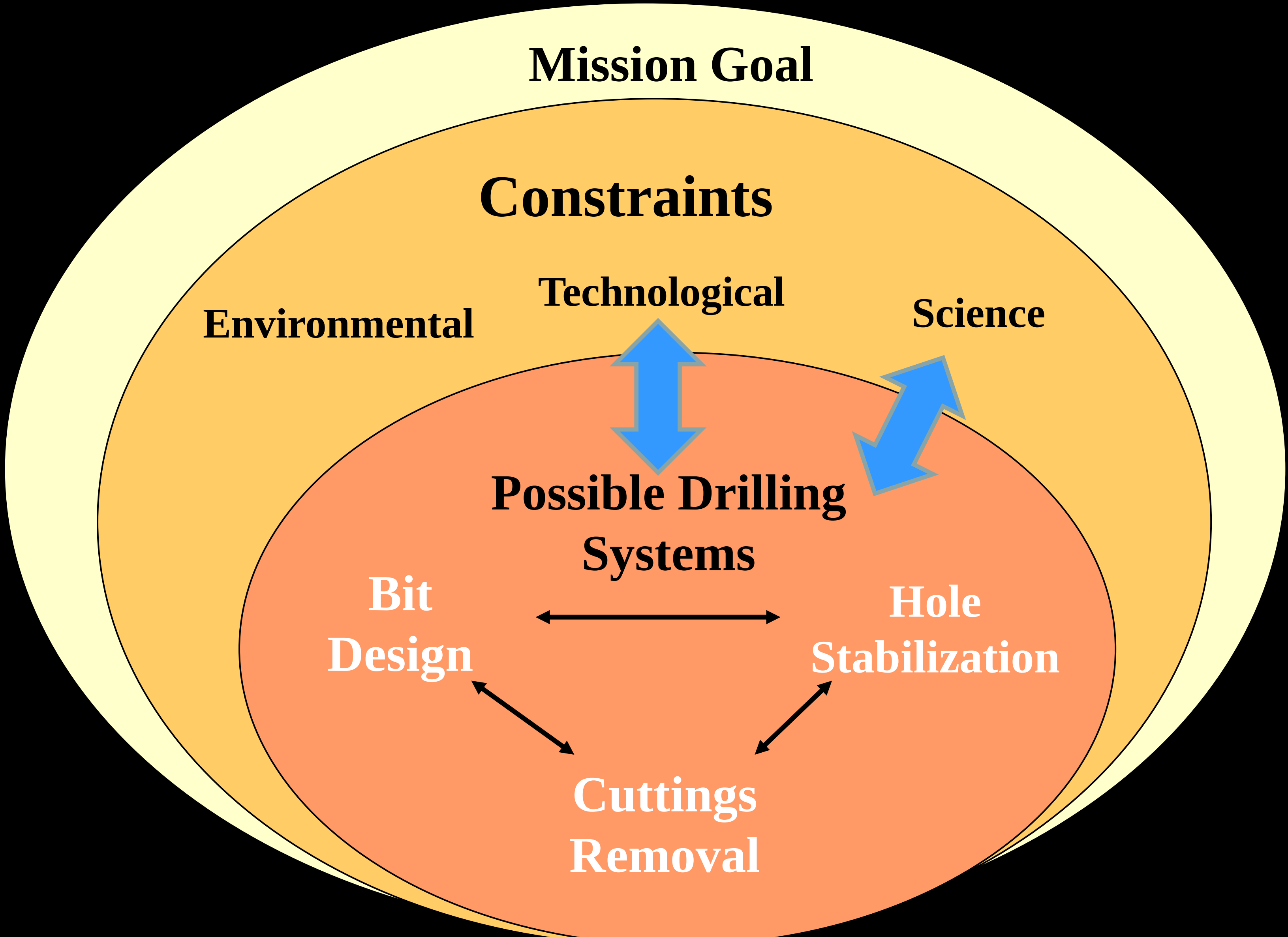
HONEYBEE ROBOTICS Engineering the Future

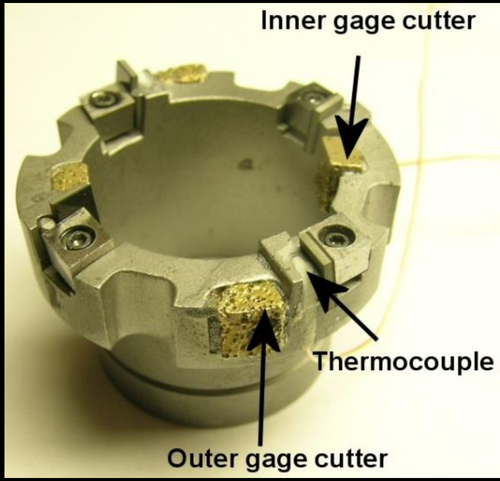
Drilling 101

Drilling Architecture Development Process



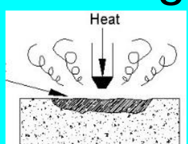
Drilling Steps

1. Drilling + 2. Cuttings Removal

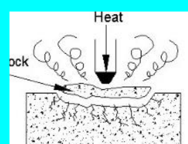


Selection of Drilling Method

- **Drilling Methods**
  - Thermal
    - Melting



    - Spalling

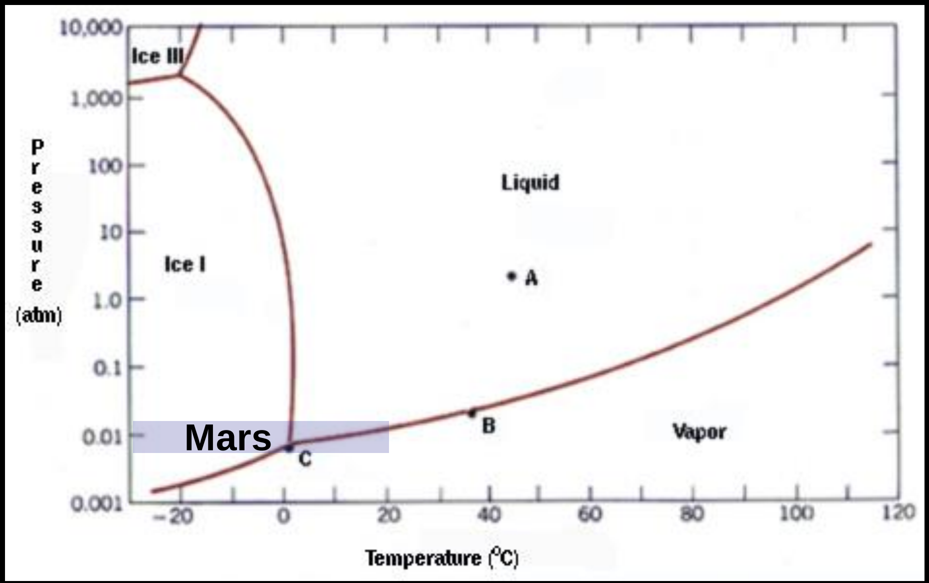


  - Chemical
  - Mechanical
    - Rotary
      - Drag Bits
        Tool Motion: Parallel
        - DI, SSD
        - PDC, TSP
      - Roller cone
        Tool Motion: Normal
        MT, TCI
    - Percussive
      Pneumatic,
      U-Sonic,
      Churn
    - R-P

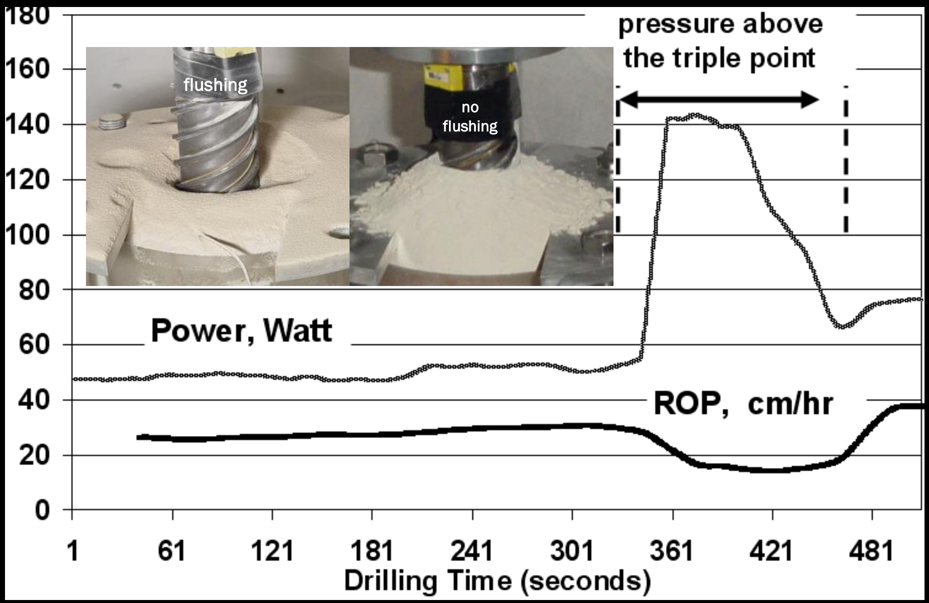
Selection of Cuttings Removal

- Cuttings Removal
  - Mechanica
    - Auger
    - Bailer
  - Liquid
    - Water, Mud
  - Gas
    - Continuous
    - Blasts

Drilling on Mars in Ice

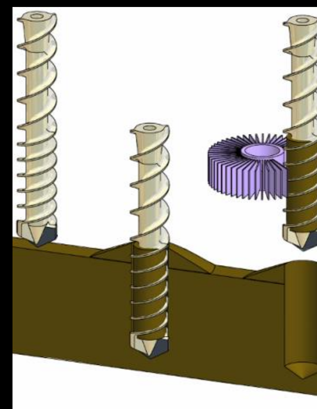


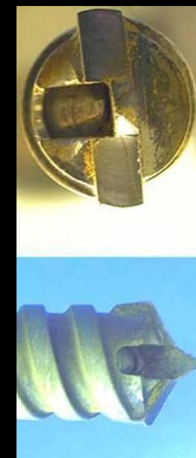
- Drilling power --> heat --> latent heat --> sublimation
- Volumetric expansion of ice → vapor 1000's x



Sampling Approaches

Complexity





1. Embedded Sensor
Step 1: Drill
Step 2: Analyze

2. Sniffer
Step 1: Drill
Step 2: Acquire Sample
Step 3: Analyze

3. Sampling Auger
Step 1: Drill
Step 2: Transfer Cuttings
Step 3: Analyze

4. Bit Sampler
Step 1: Drill
Step 2: Pull Out
Step 3: Transfer Cuttings
Step 4: Analyze

5. Core
Step 1: Drill
Step 2: Break-off core
Step 3: Capture Core
Step 4: Pull out
Step 5: Eject core
Step 6: Process core
Step 7: Transfer powder
Step 8: Analyze

Science Payoff

History of Planetary Drilling

Planetary "Deep" Drilling

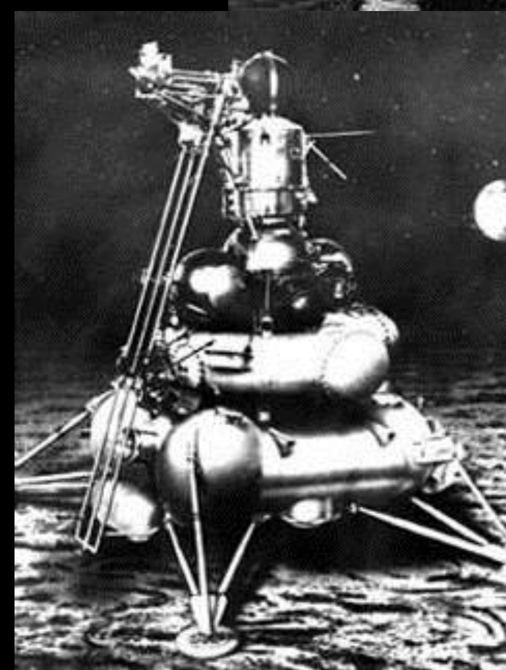
Apollo Lunar Surface Drill (1971, 1972)

- ~500 Watt, Battery Powered, and Human Operated
- 3 m coring depth and 2.4 m HFP depth
- A15: *The drill was hard to remove from the hole…it took both astronauts working at the limit of their combined strengths to pull up the drill …this caused a severe shoulder sprain in Scott.*

http://www.hq.nasa.gov/alsj/tools/judy20.jpg

Luna 16 (1970), 20 (1972), 24 (1976)

- Sample return missions
- Rotary-percussive
- Coring drill
- Supervised autonomy
- Depths of 35 cm, 25cm, & 2 m



http://www.zarya.info/Diaries/Luna/Luna16.htm

Mars Drilling

MER: Rock Abrasion Tool

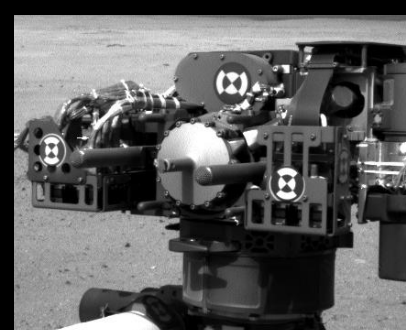
- Grinds 4.5cm diameter, <5mm deep hole in rocks
- Removes dust and rock crust

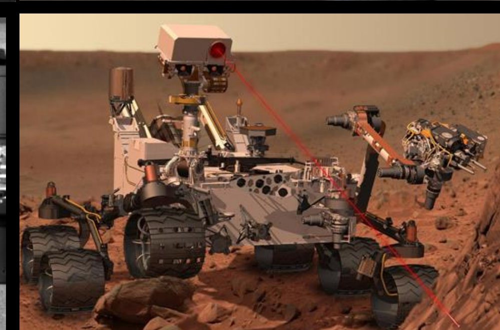
Phoenix: Scoop and RASP

- First human-made hardware that touched extraterrestrial ice
- Scoop removes loose layer
- RASP acquired soil/ice from mm below the surface

MSL: Rotary-Percussive Drill

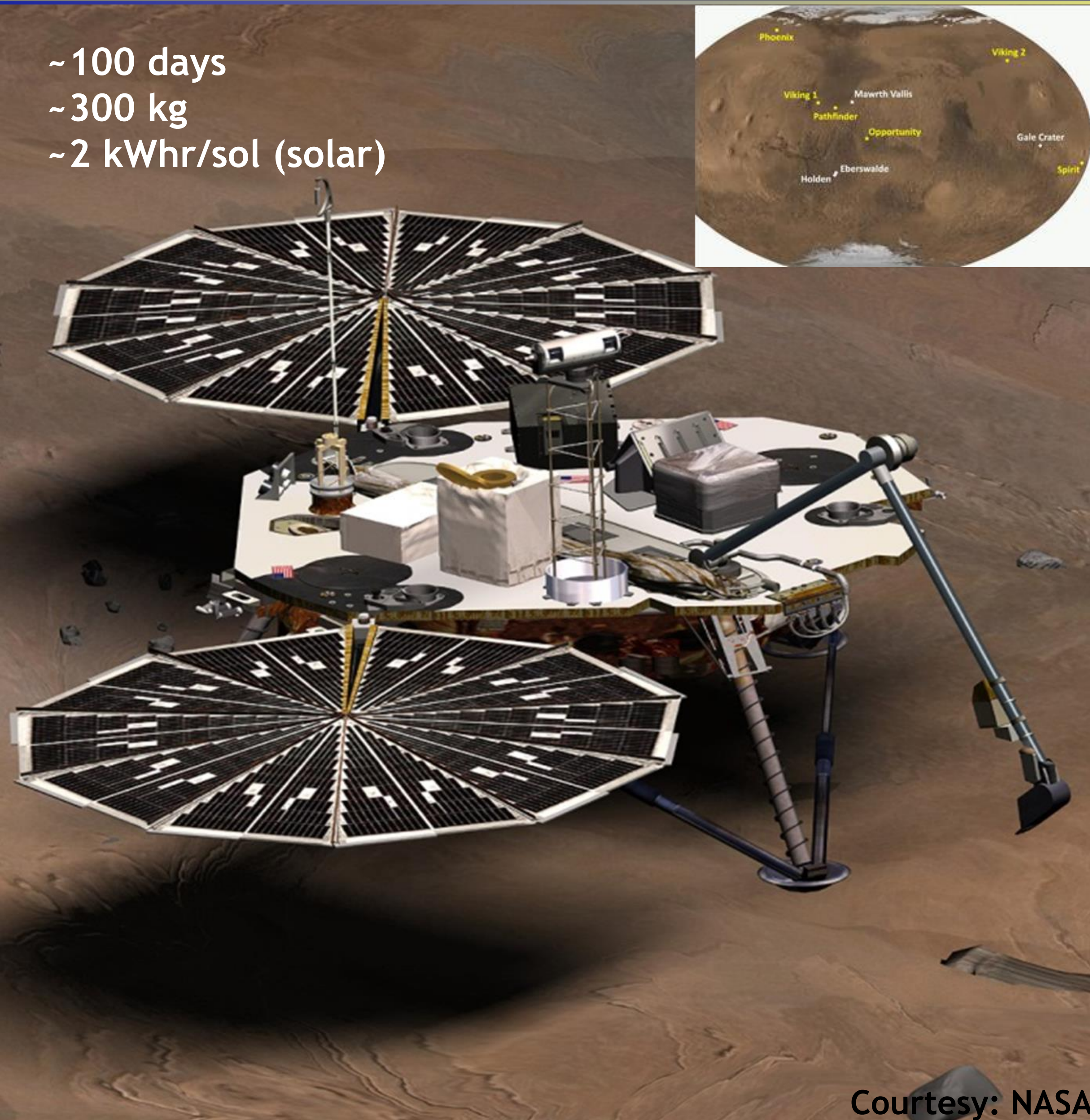
- 100 Watt, Rotary-Percussive
- Acquires powdered sample from ~ 5 cm depth.

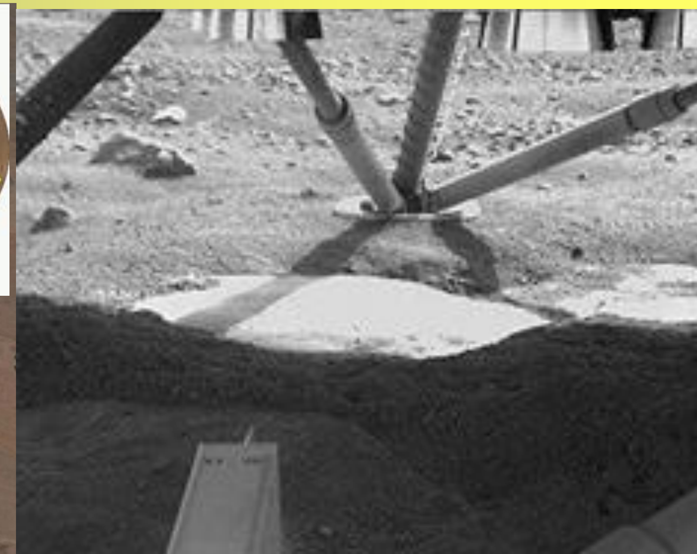


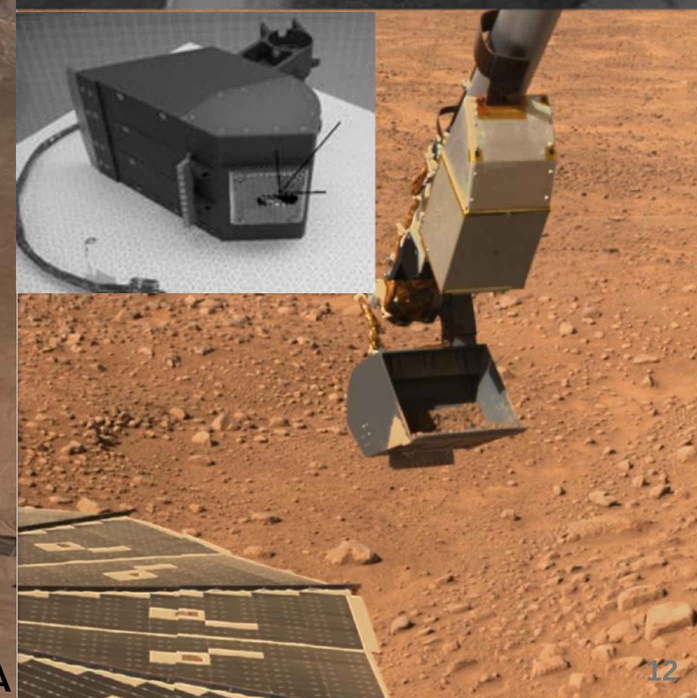


2008 Mars Phoenix

~100 days
~300 kg
~2 kWhr/sol (solar)

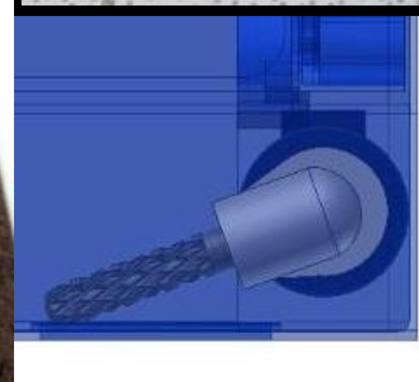






Courtesy: NASA

Mars Phoenix - RASP

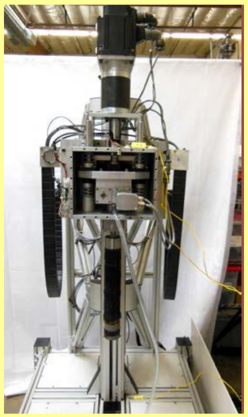


HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation

1 m class drill

Drilling Approaches

SONIC



ULTRA SONIC

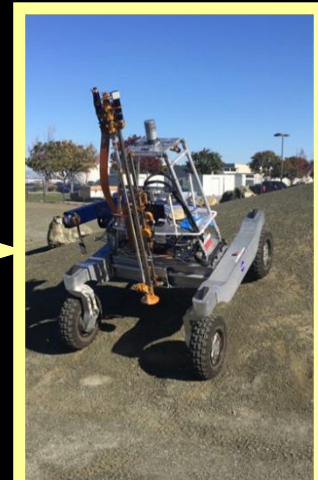
PERCUSSIVE

ROTARY

TRL 4 (Rot Perc)

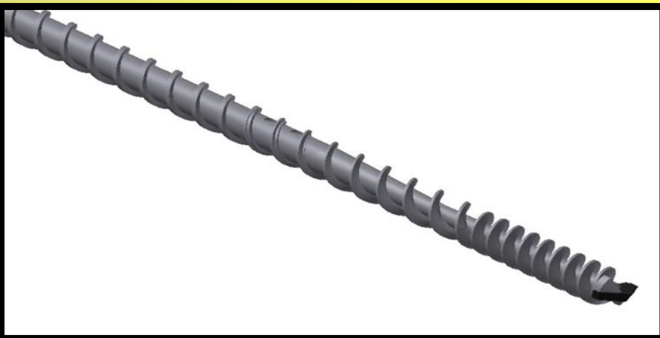
TRL 5 (Rot Perc)

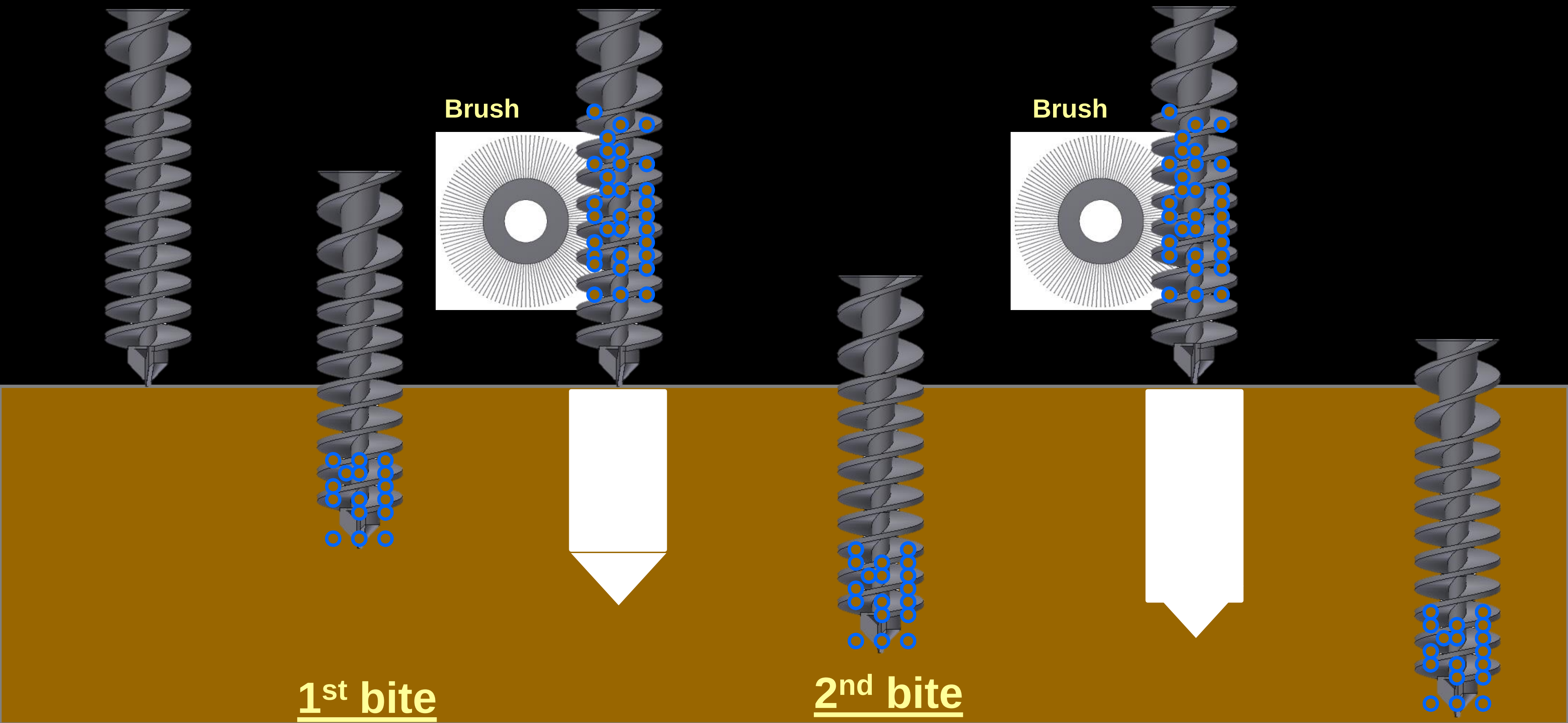
TRL 6 (Rot Perc)



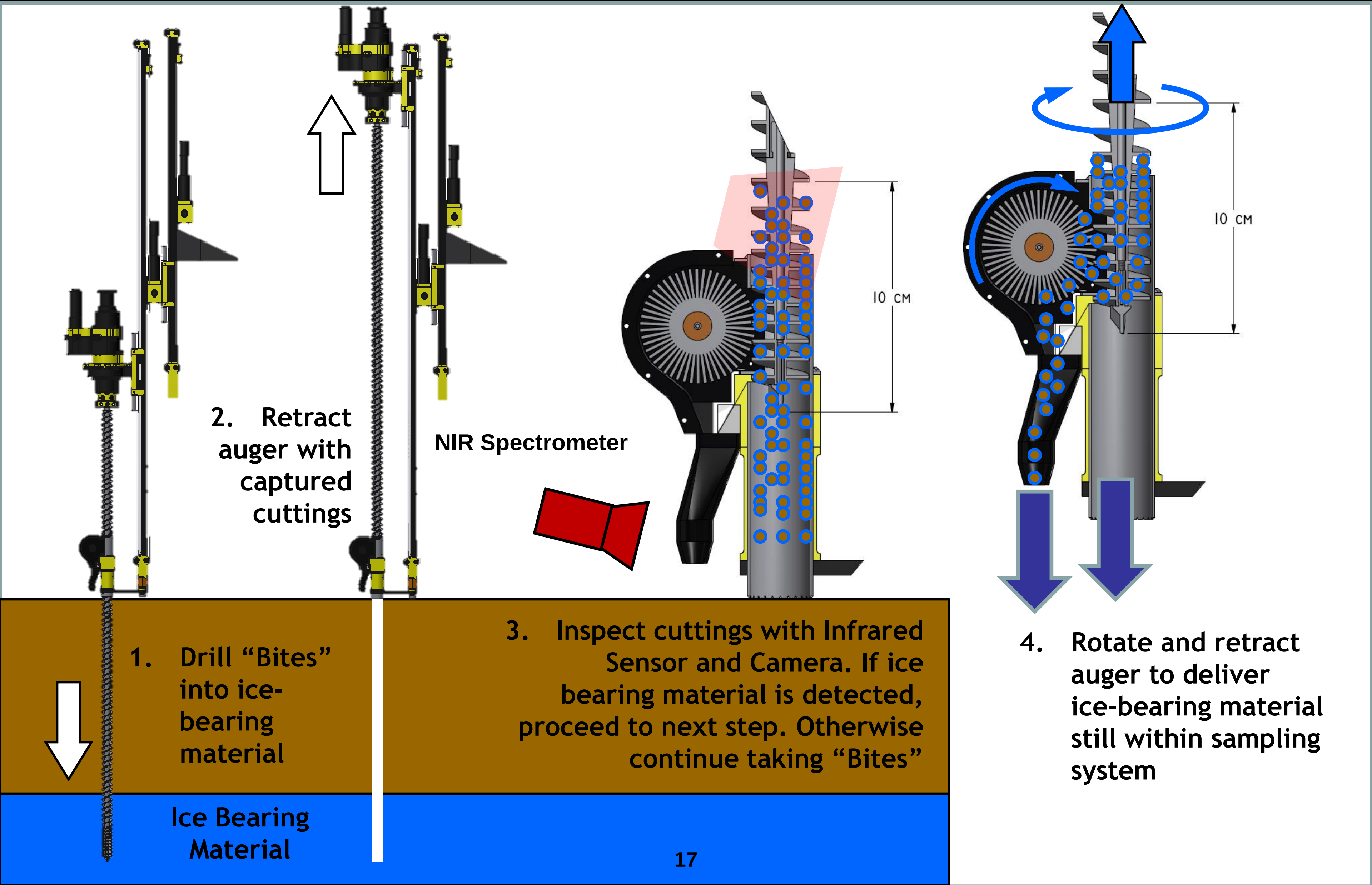
"Bite" Sampling Concept

- Drill to 1 meter in short (~ 10 cm) "bites"
- Preserve stratigraphy in "bites"
- More accurate strength measurement of subsurface
- Lower risk ("graceful failure") – if stuck at 60 cm, 5 bites done
- Time for analysis while drill in 'safe' place (above the hole)
- Time for subsurface to cool down





Implementation of “Bite” Sampling



LITA drill

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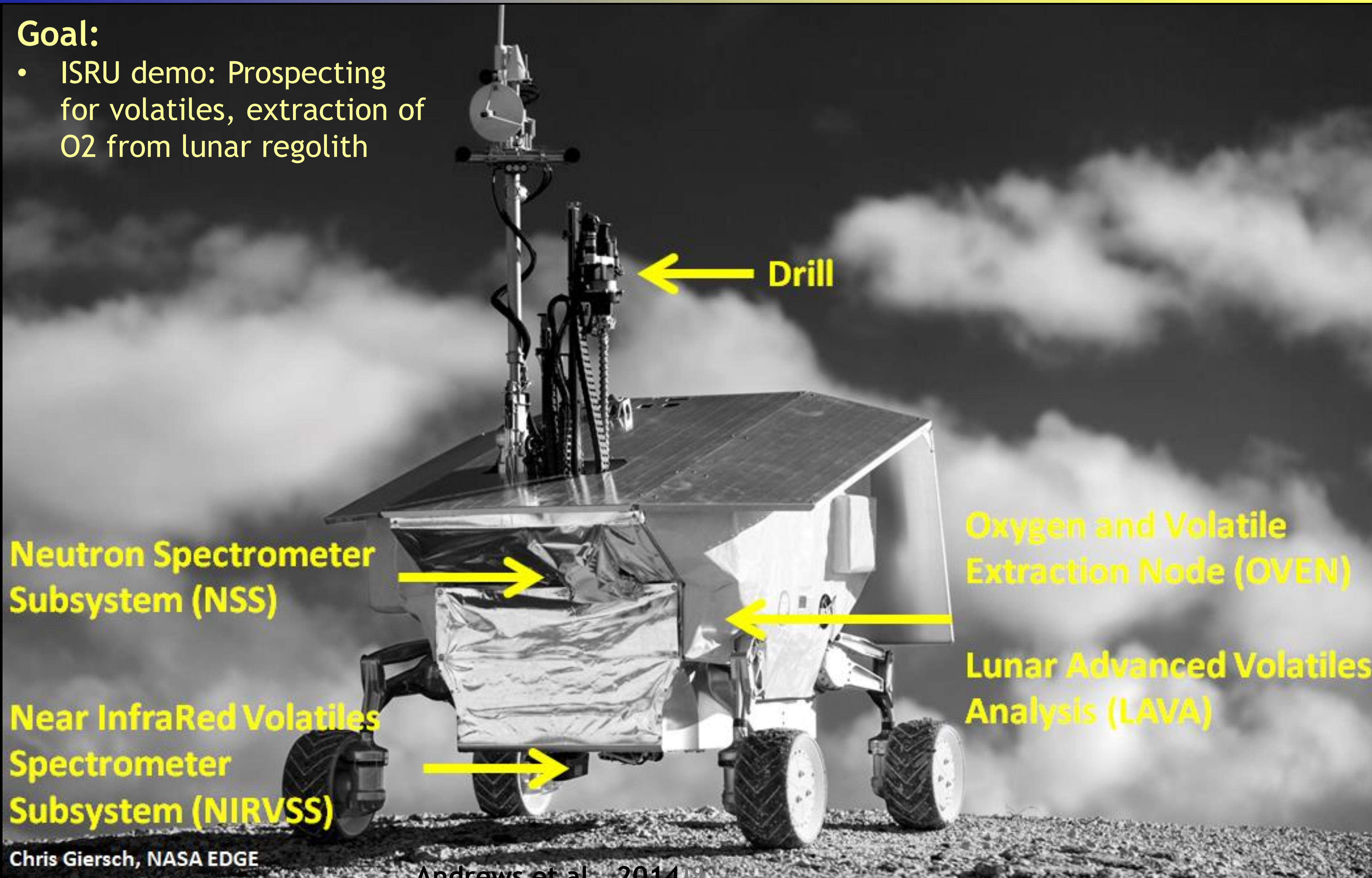
Resource Prospector (RP)

Goal:

- ISRU demo: Prospecting for volatiles, extraction of O2 from lunar regolith



Andrews et al., 2014

Mars IceBreaker

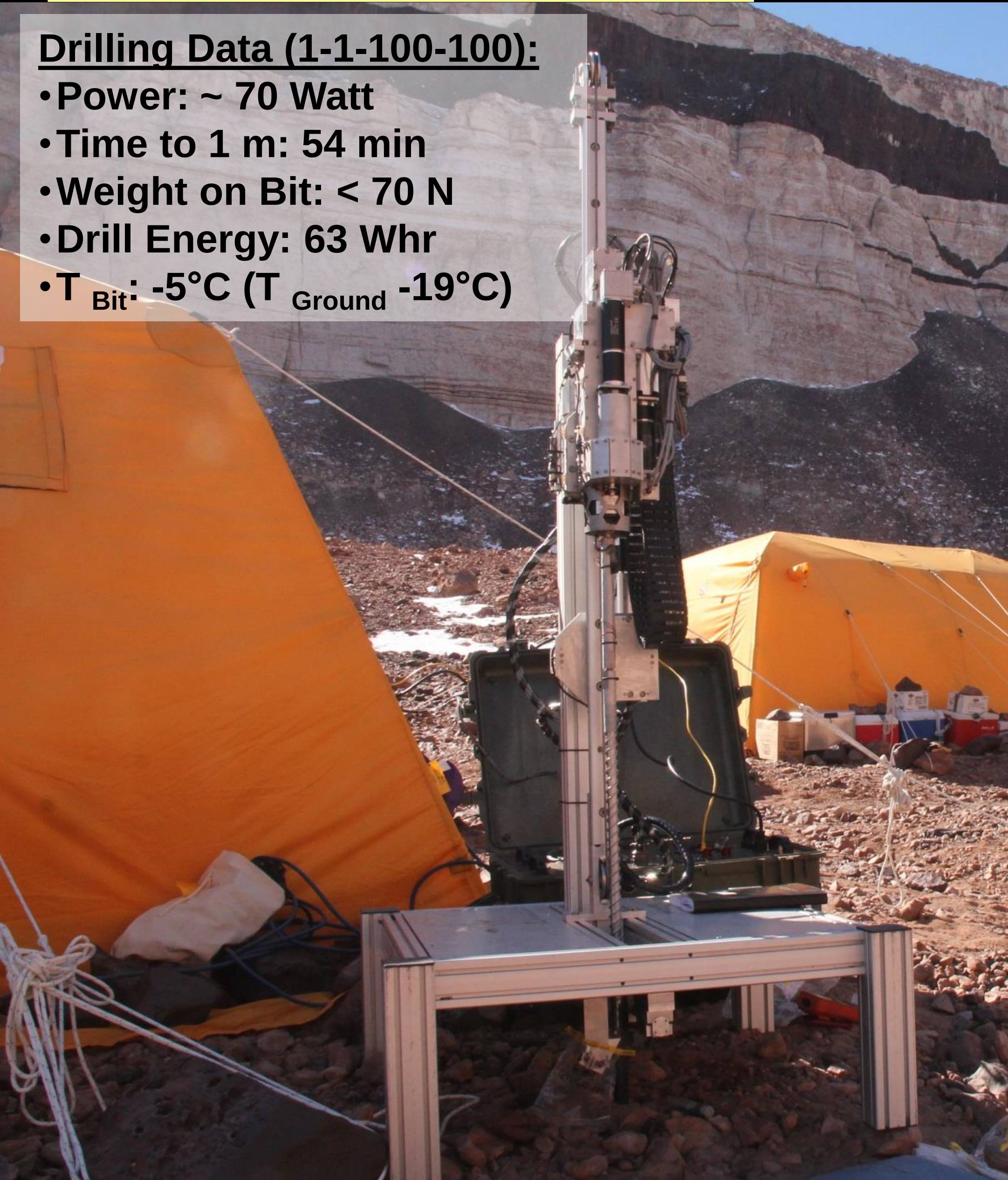
- Tested in Antarctica, Arctic, Greenland
- Design with PP in mind
- Tested in Mars Chamber

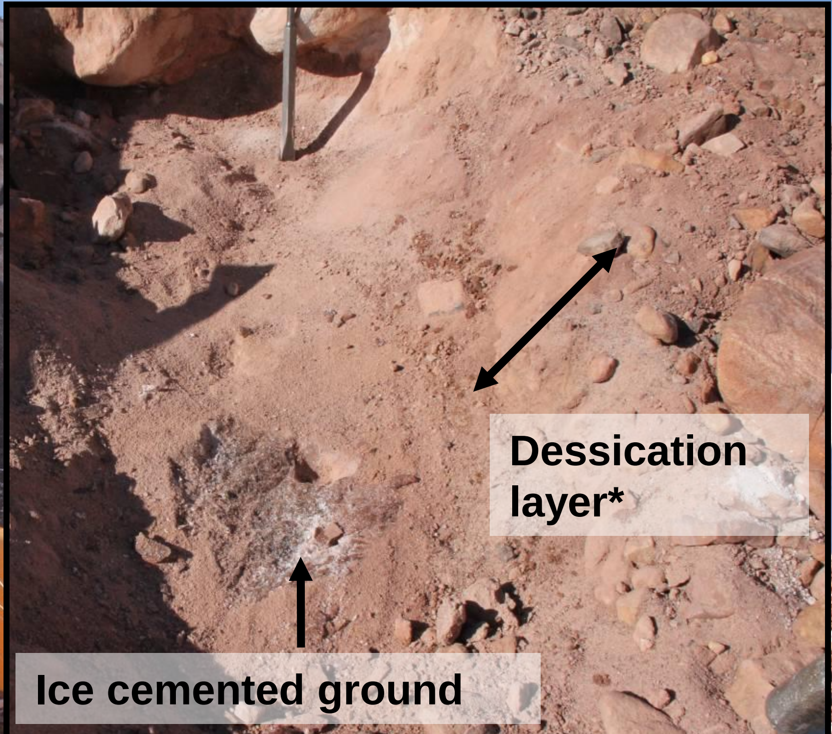
Testing in University Valley, Antarctica

Dry Valleys: 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

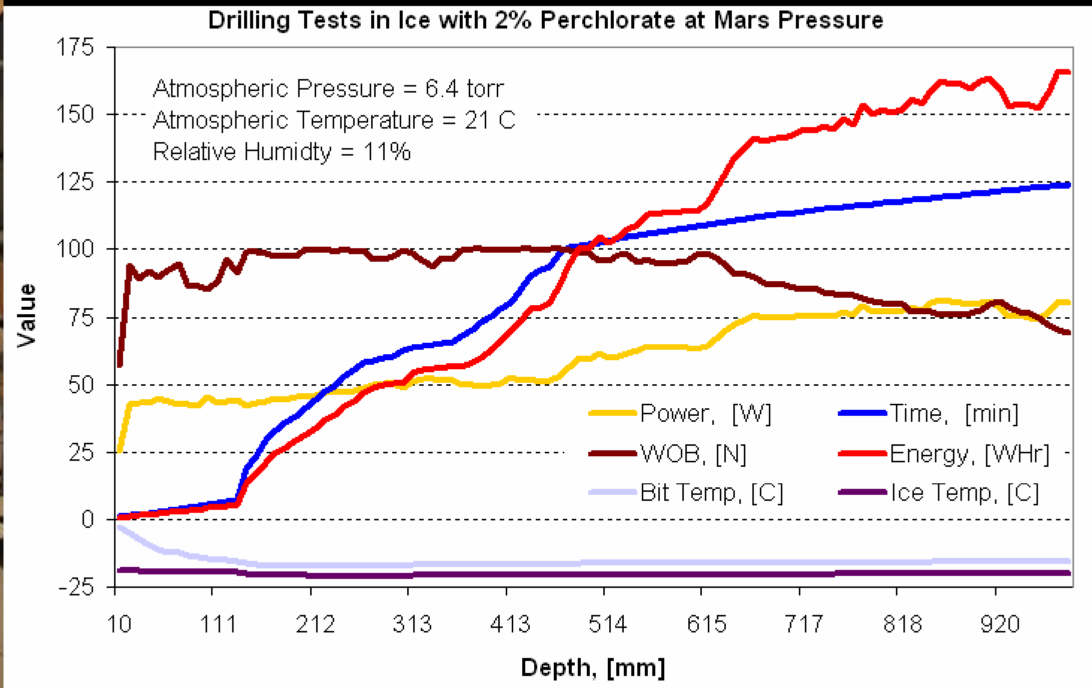
Drilling Data:

- **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



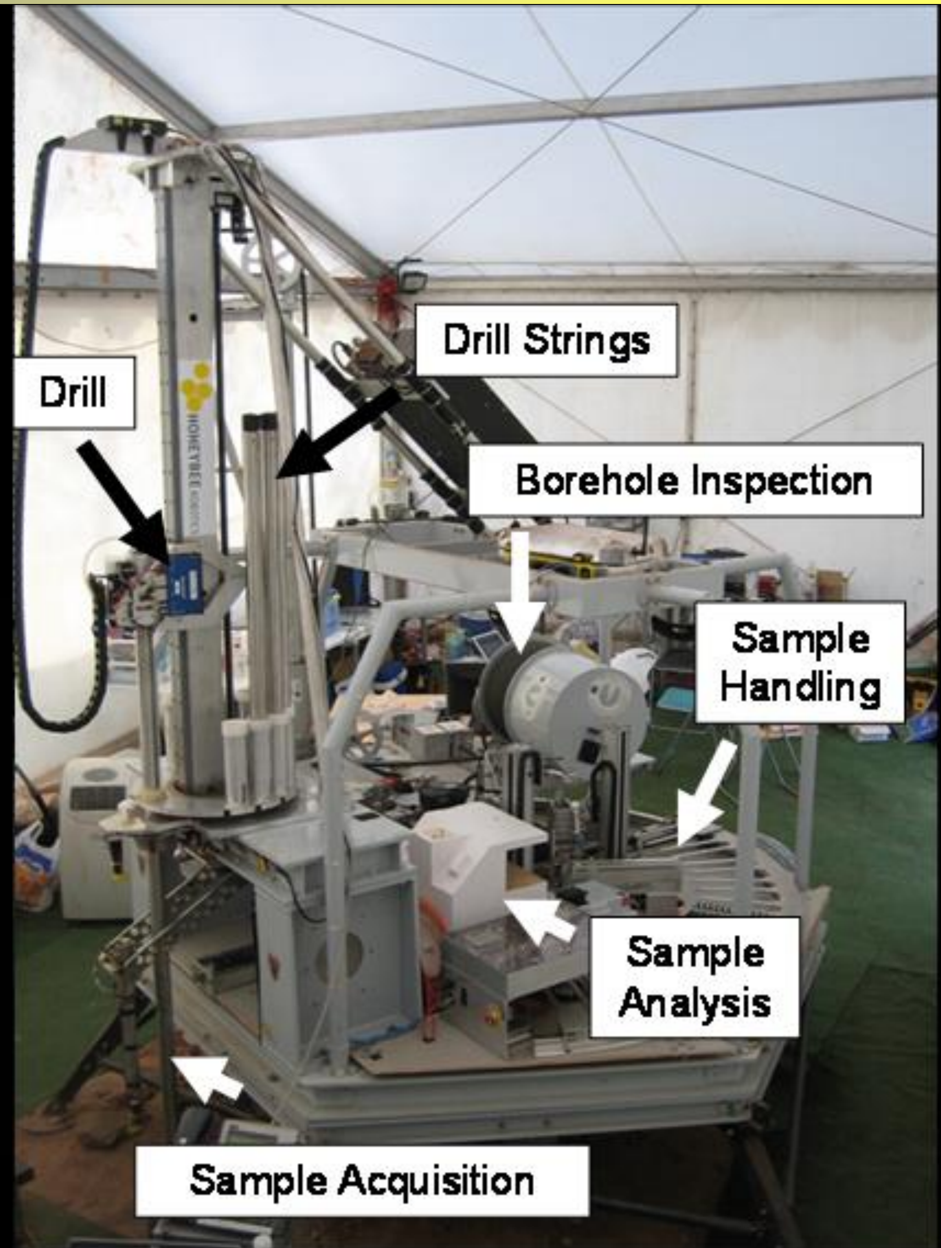
10 m class drills

MARTE

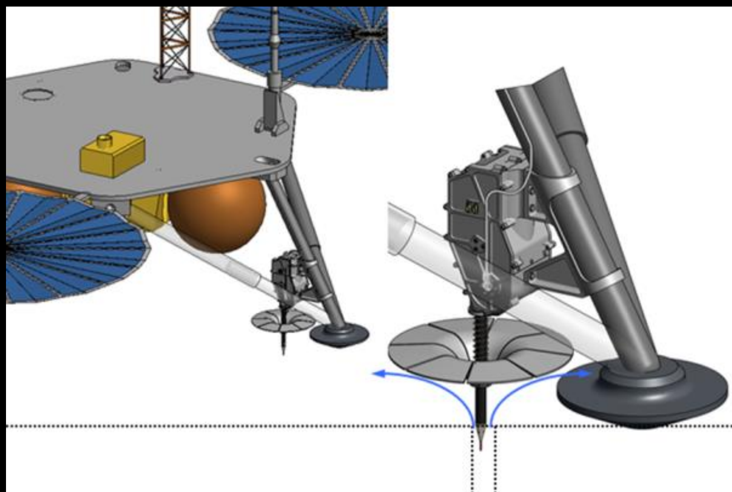
- 10 m coring drill
- Core processing
- Instruments for core analysis
- ASTEP funded (PI. Carol Stoker)

MARTE
Limestone Drilling Test
NASA Ames Research Center
May 2005

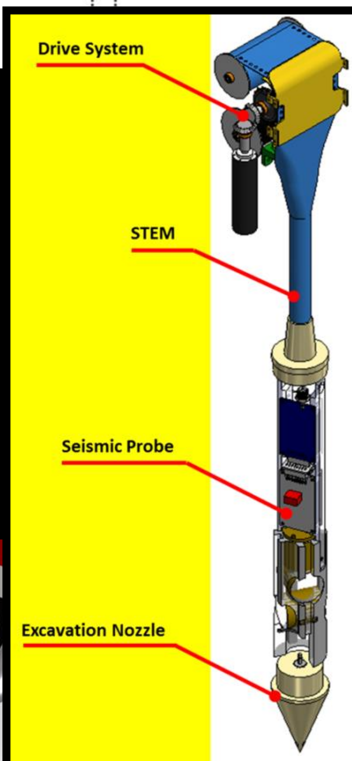
Honeybee Robotics



STEM Drill

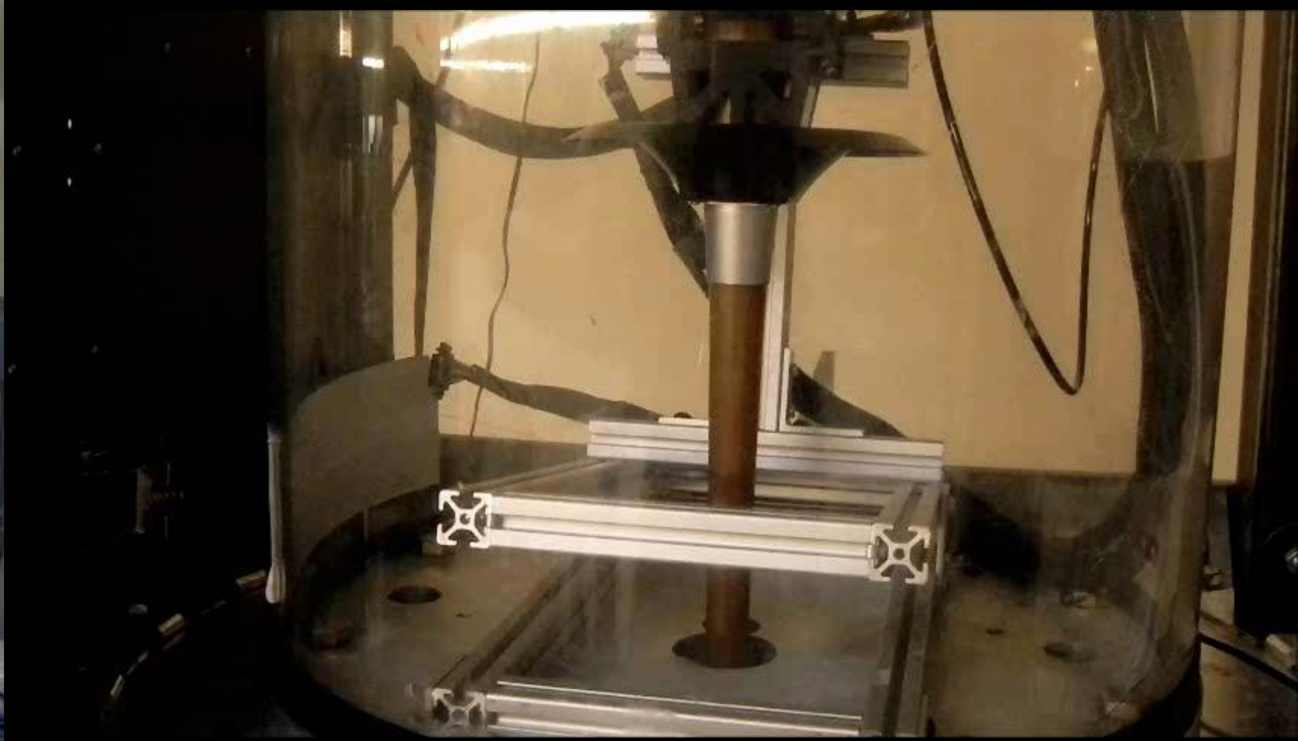


- Coiled up stem with a drill bit at the end
- Gas used to blow cuttings out
- Small form factor – large depth
- Designed for heat flow probe (S. Nagihara)
- Designed for seismic sensor (M. Siegler)



STEM Drill Testing

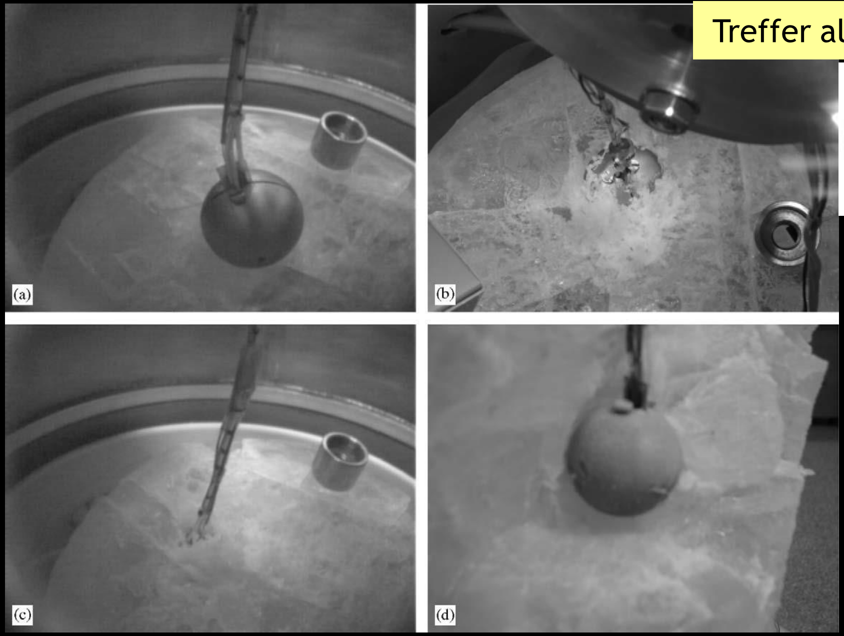
- Testing in compacted lunar soil simulant
- Tests done at Mars pressures
- ‘drilled’ 2 m in 2 mine
- Can stop-start



100 m class drills

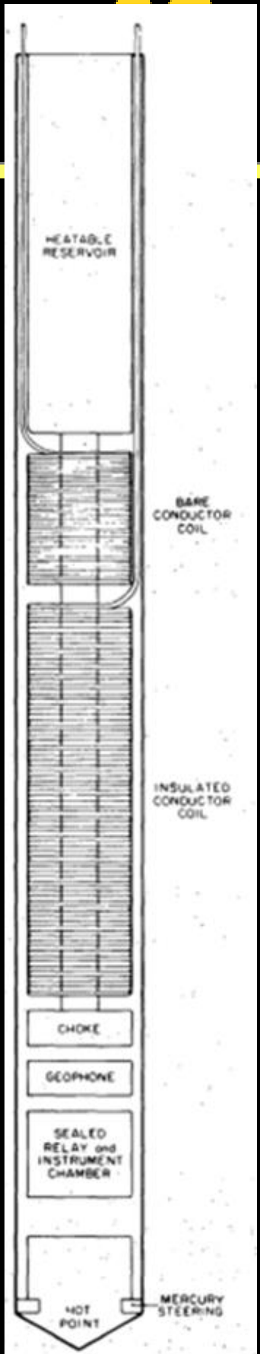
Melt probes

- Developed in 1960s and tested in Antarctica and Greenland
- Simple but slow, power hungry, mostly one way (down), inefficient, doesn't work well in sediments and non-icy formations
- k of cryogenic ice is 4x higher (difficult to warm up ice)
- Need integrated heat (e.g. Pu=238) or wires and power on the surface
- Examples:
  - Philbert probe (CRREL)
  - Cryobot (CalTech/JPL)
  - Ice Diver (Univ. of Washington)
  - VALKYRIE (Stone Aerospace)



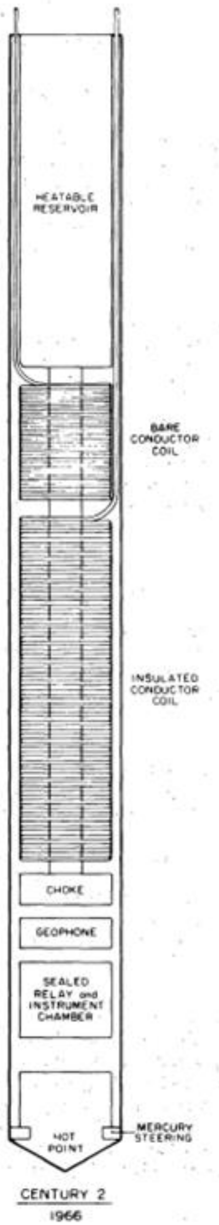
Treffer al., 2003

Hecht et al., 2003

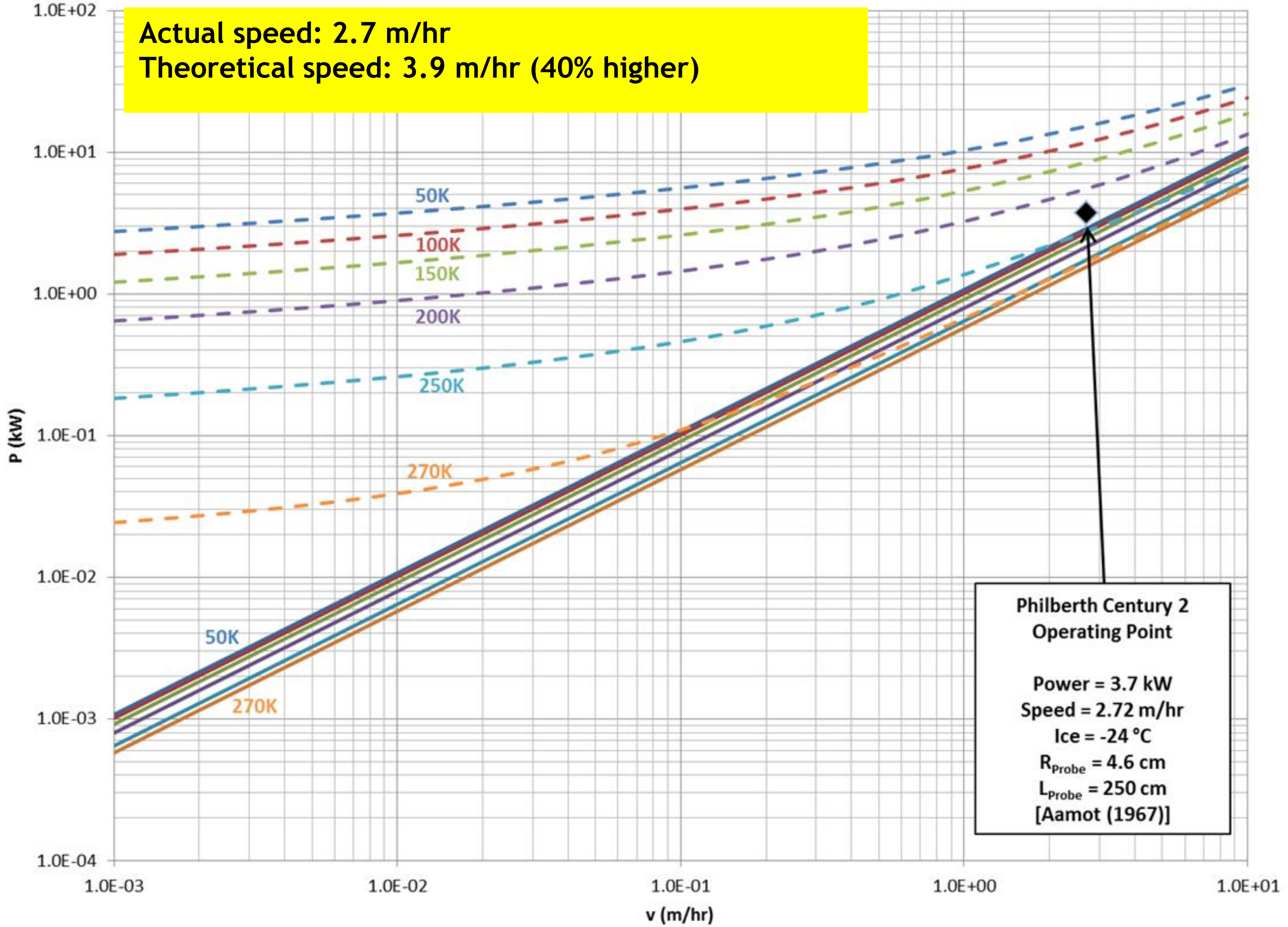


Philbert, 1966

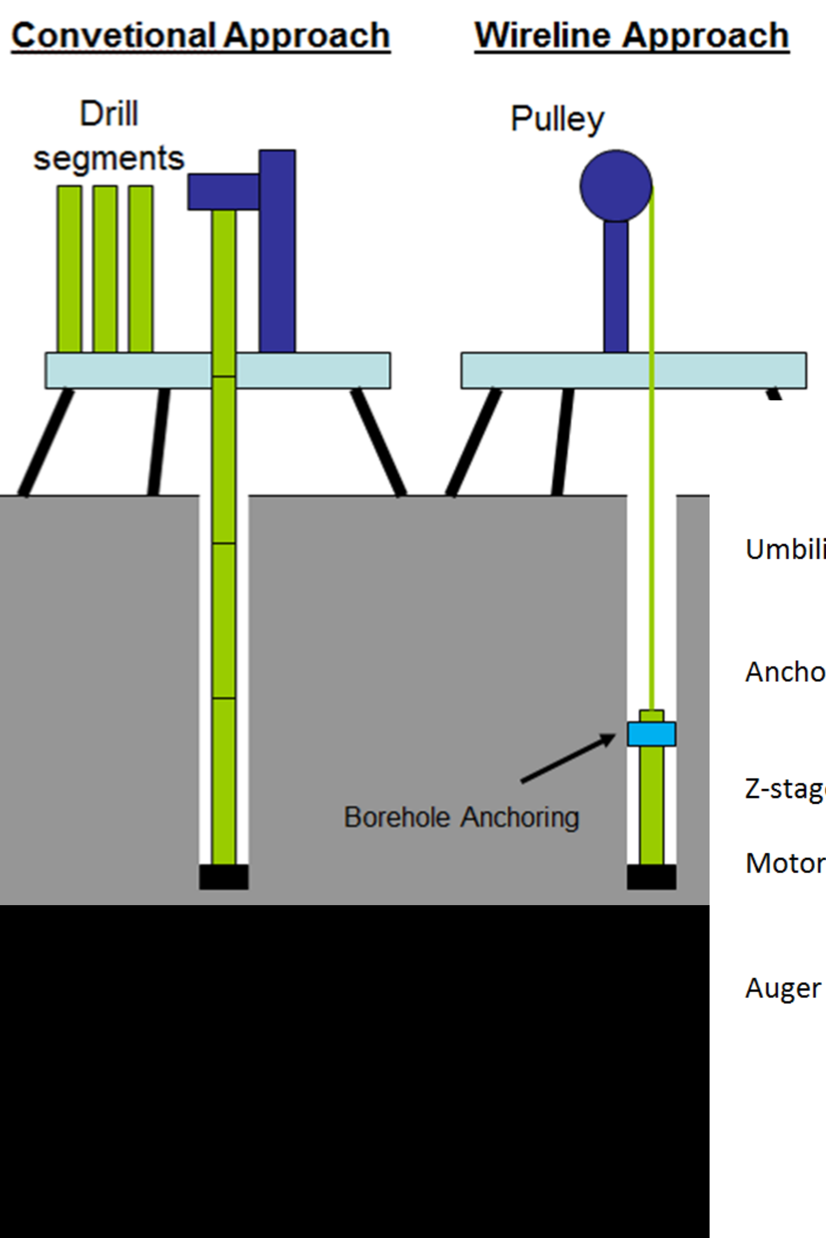
Philberth Probe at Century 2
L = 2.5 m, R = 4.6 cm, Ice=-24C, P=3.7 kW



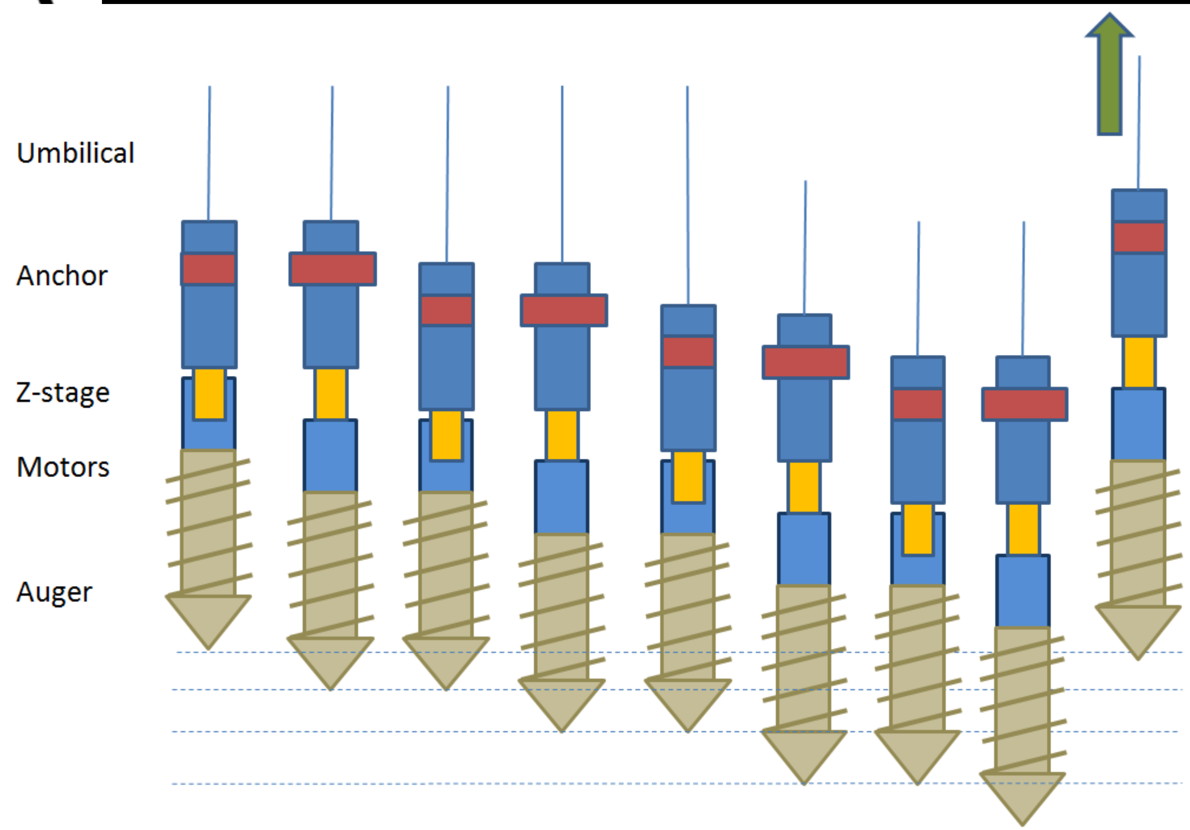
Actual speed: 2.7 m/hr
Theoretical speed: 3.9 m/hr (40% higher)



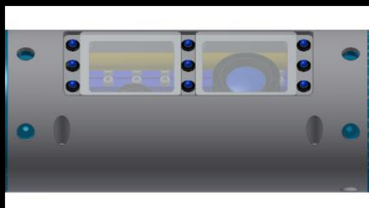
Inchworm/Wireline/Cable Suspended



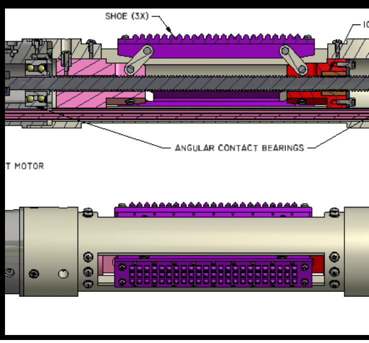
- Used in Antarctica and Greenland
- Works only when borehole is stable
  - Would need expandable casing and bi-center bit to deal with a hole collapse
- Delivers sample and can deploy instrument downhole



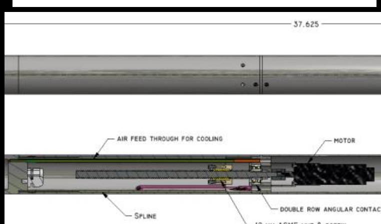
AMNH/AutoGopher Drill



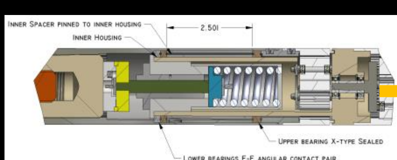
Microscope



Anchor

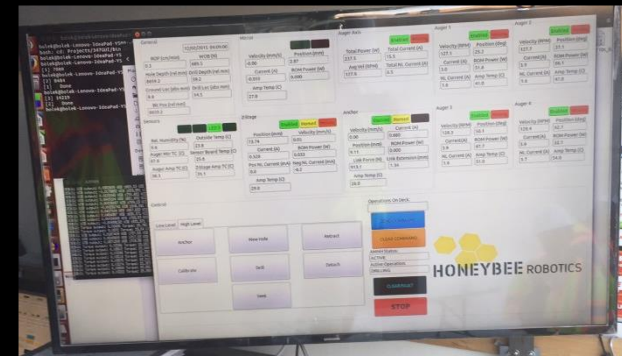


Z-stage

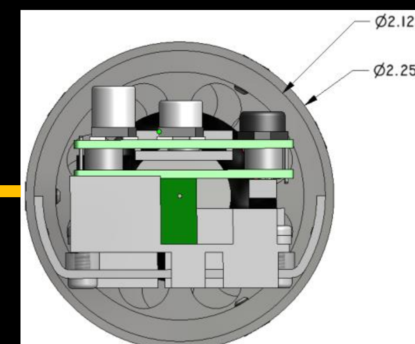


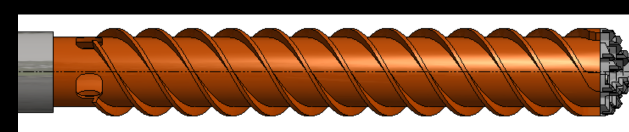
Hammer

Drill Controller



Electronics



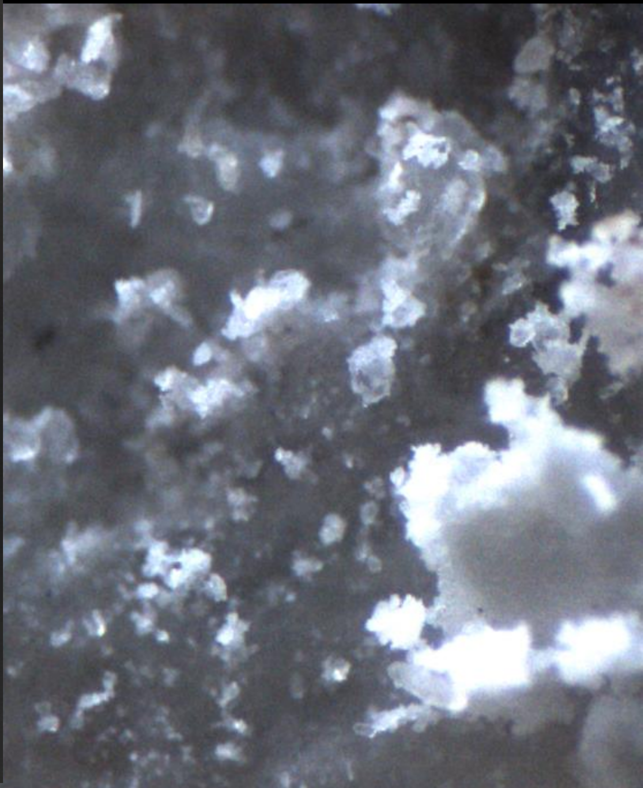


Auger and Bit

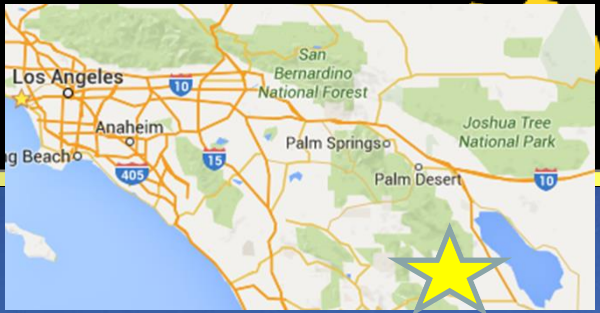
Microscope 0.5 micron / pixel

UV LED

White LED



AMNH/AutoGopher Drill

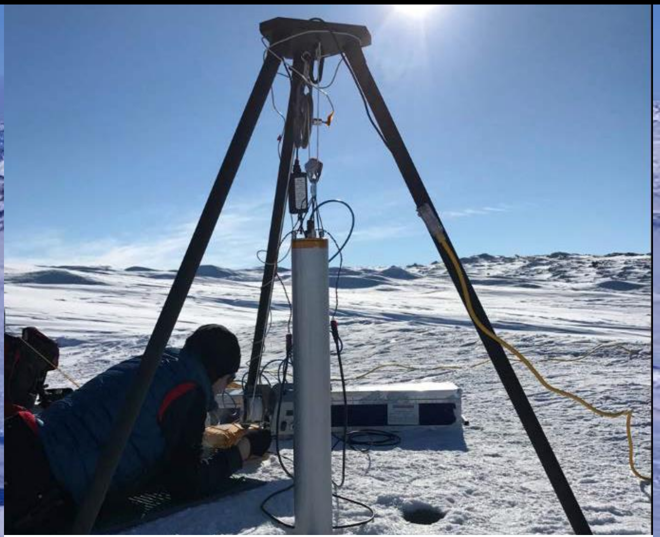


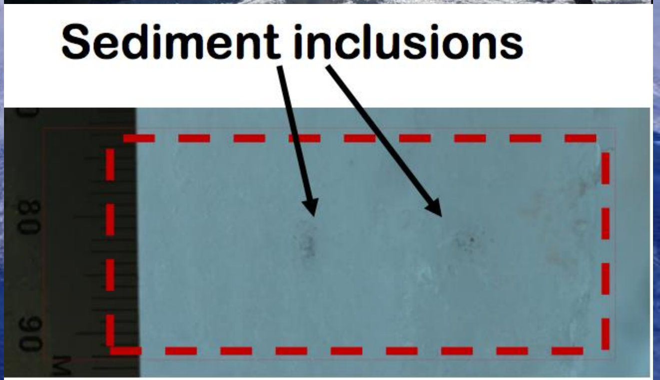
Drilled two holes
- 10.5 m
- 13.5 m

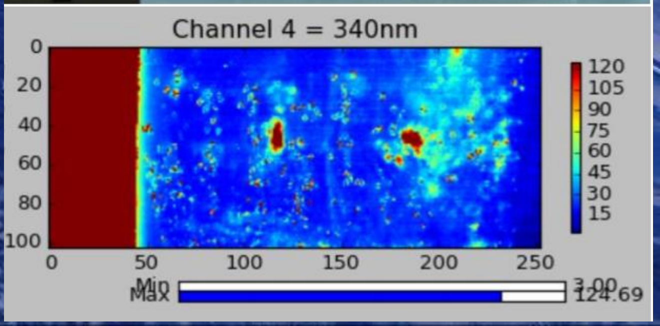
Next step: AutoGopher2, MatiSSE, Zacny (PI)

WATSON – Deep UV/Raman in a Drill

PSTAR, Roh Bhartia (PI)

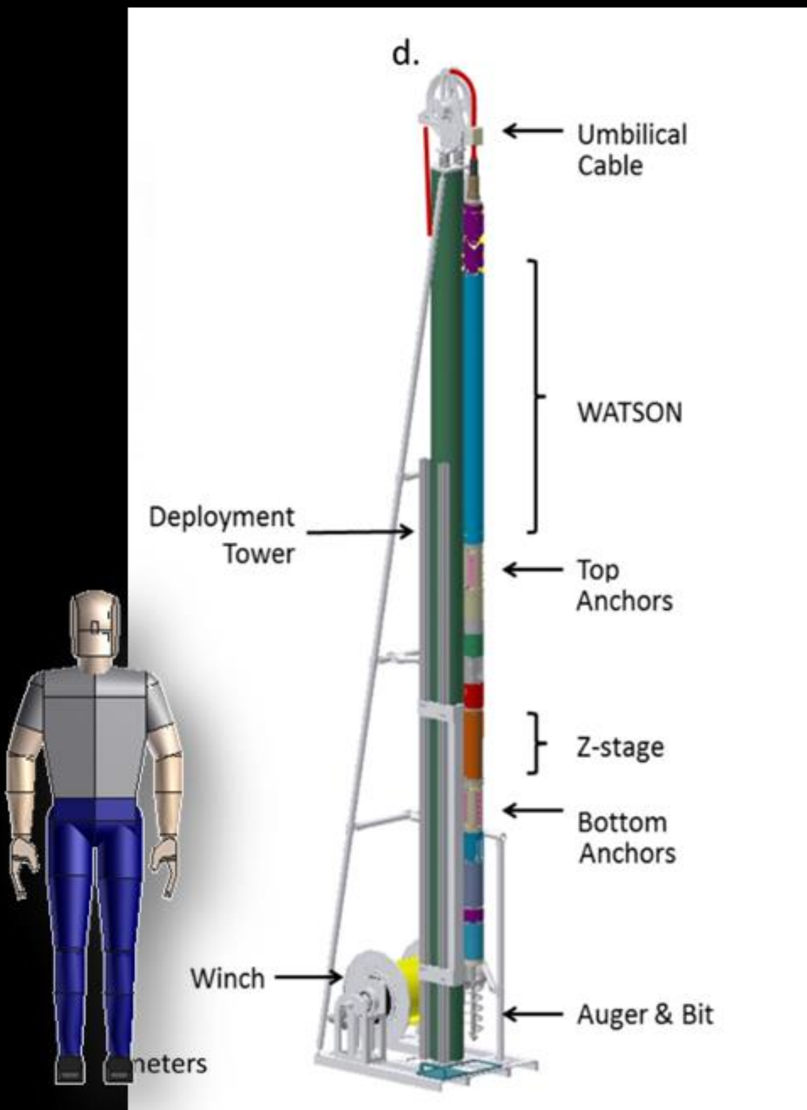




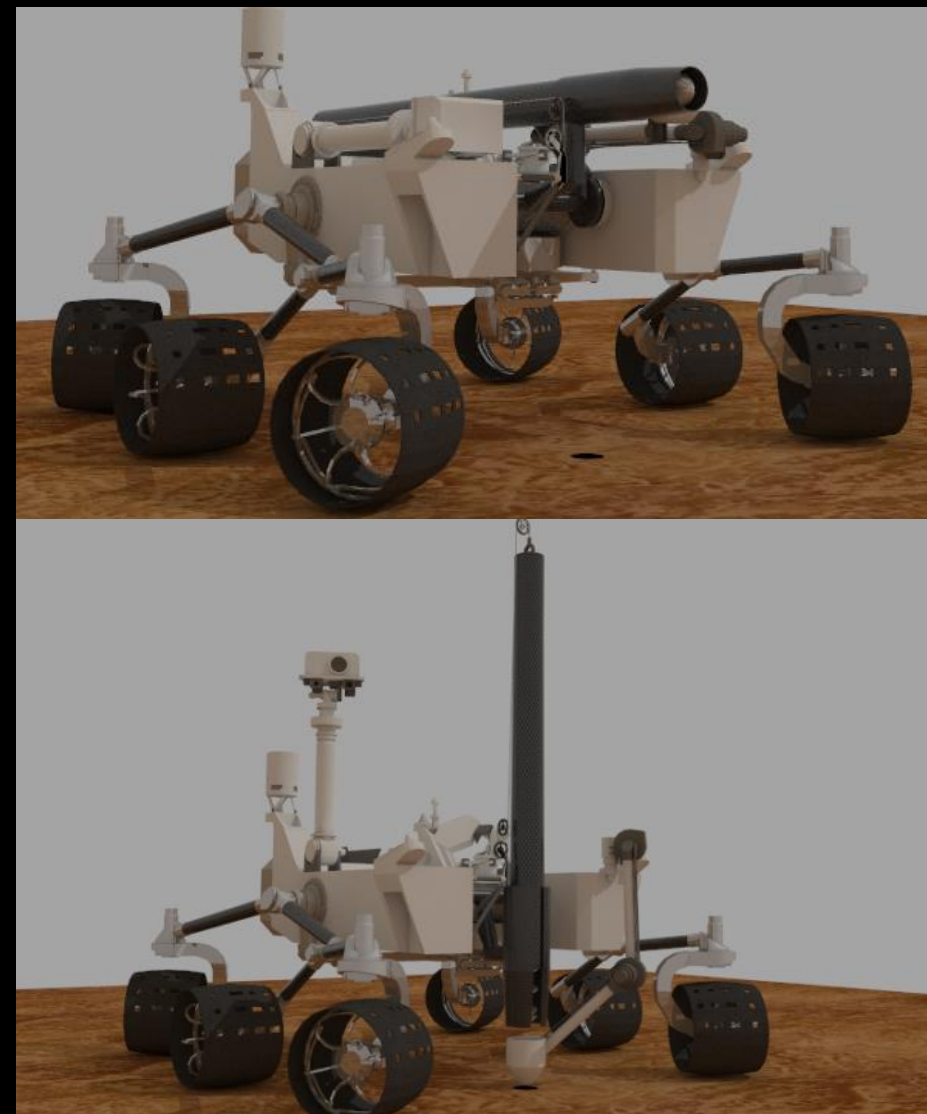


WATSON – next steps

Greenland 2018



Mars PLD 2028

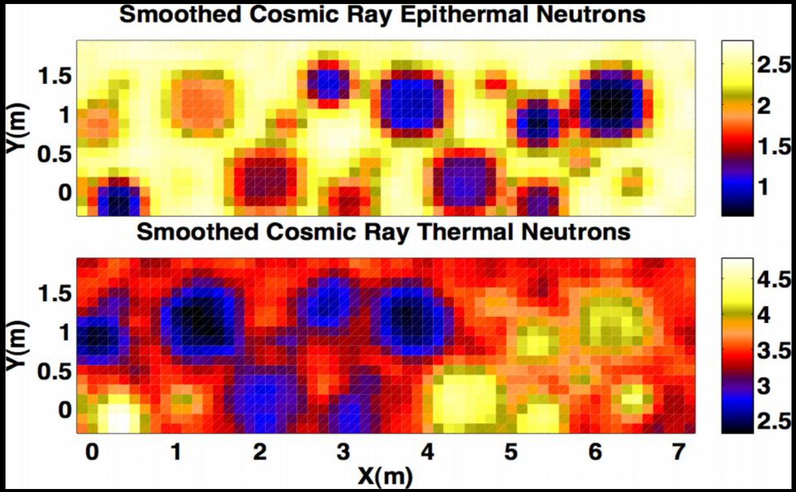


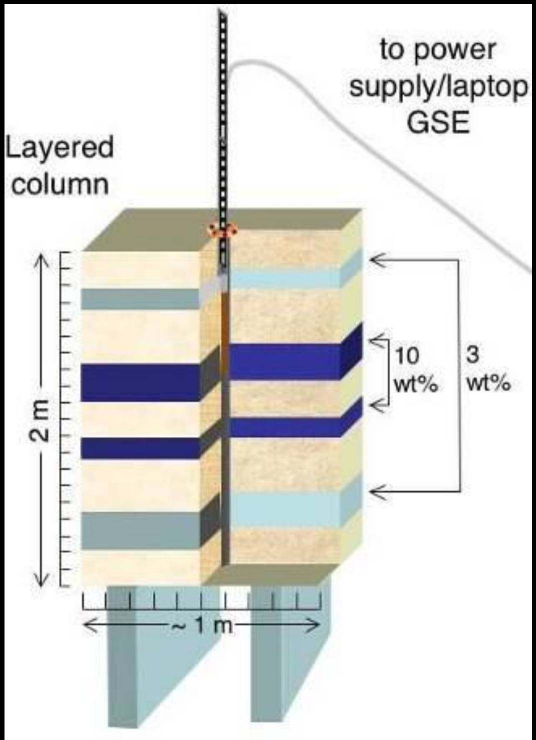
Smart Drills

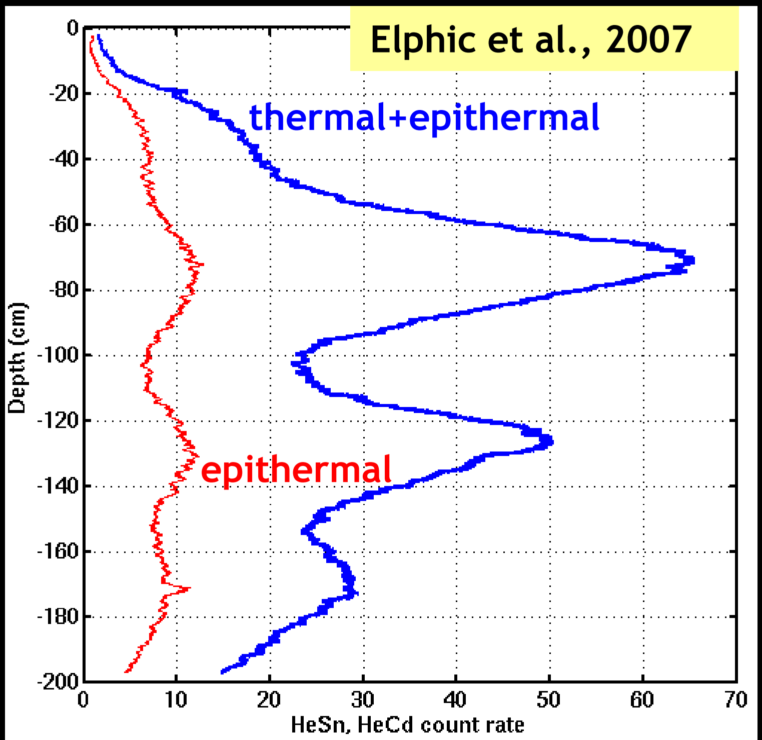
Downhole Neutron Spectrometer

Neutron Spectrometer

- Hydrogen → Water
- Rover Based: H2-rich regions
- Drill based: Groundtruthing

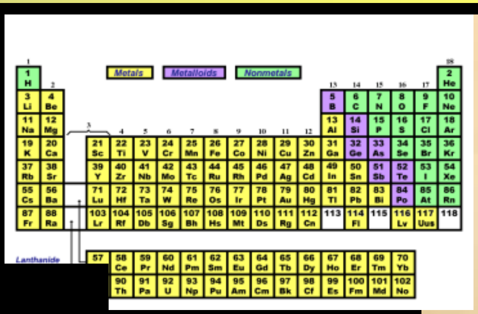






LIBSLog

- Laser Induced Breakdown Spectroscopy
  - Elements
- Logging tool (deployed in an existing hole)

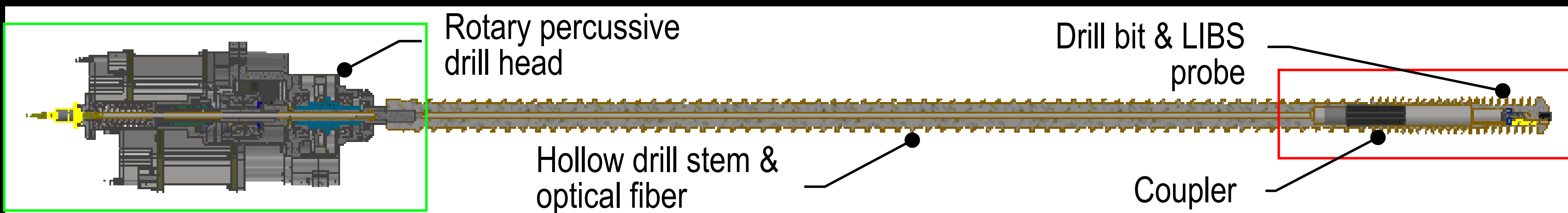


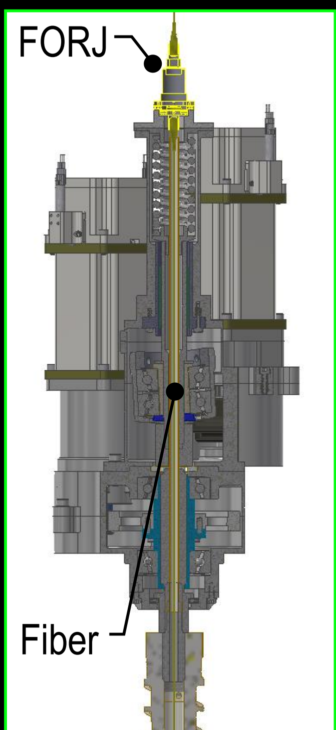
SBIR project with Pablo Sobron

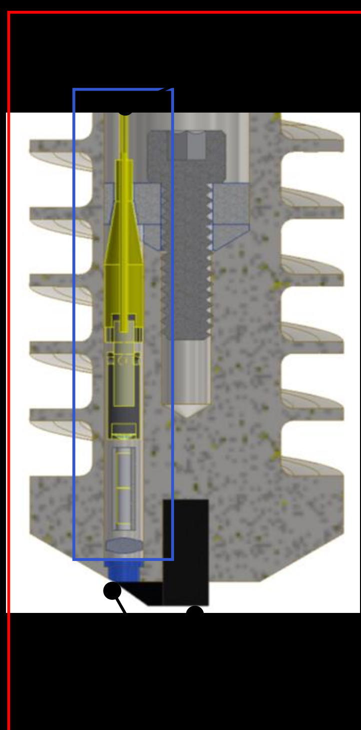
Instrumented Bit for In-Situ Spectroscopy (IBISS)

STTR project with Pablo Sobron

- LIBS and Raman*
- Deployed inside a drill





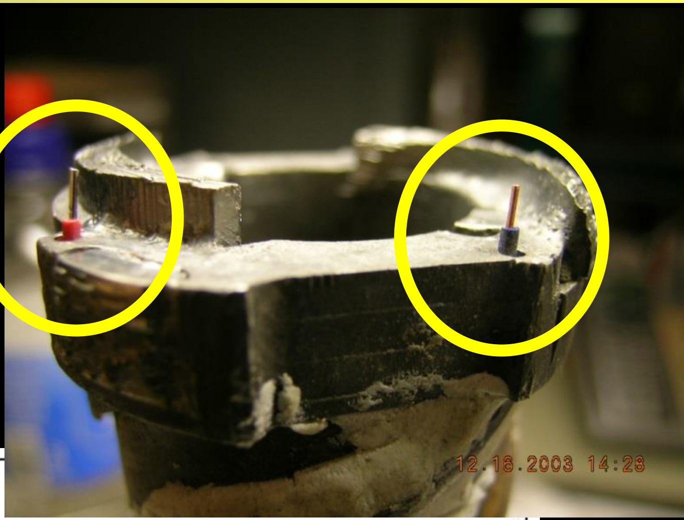


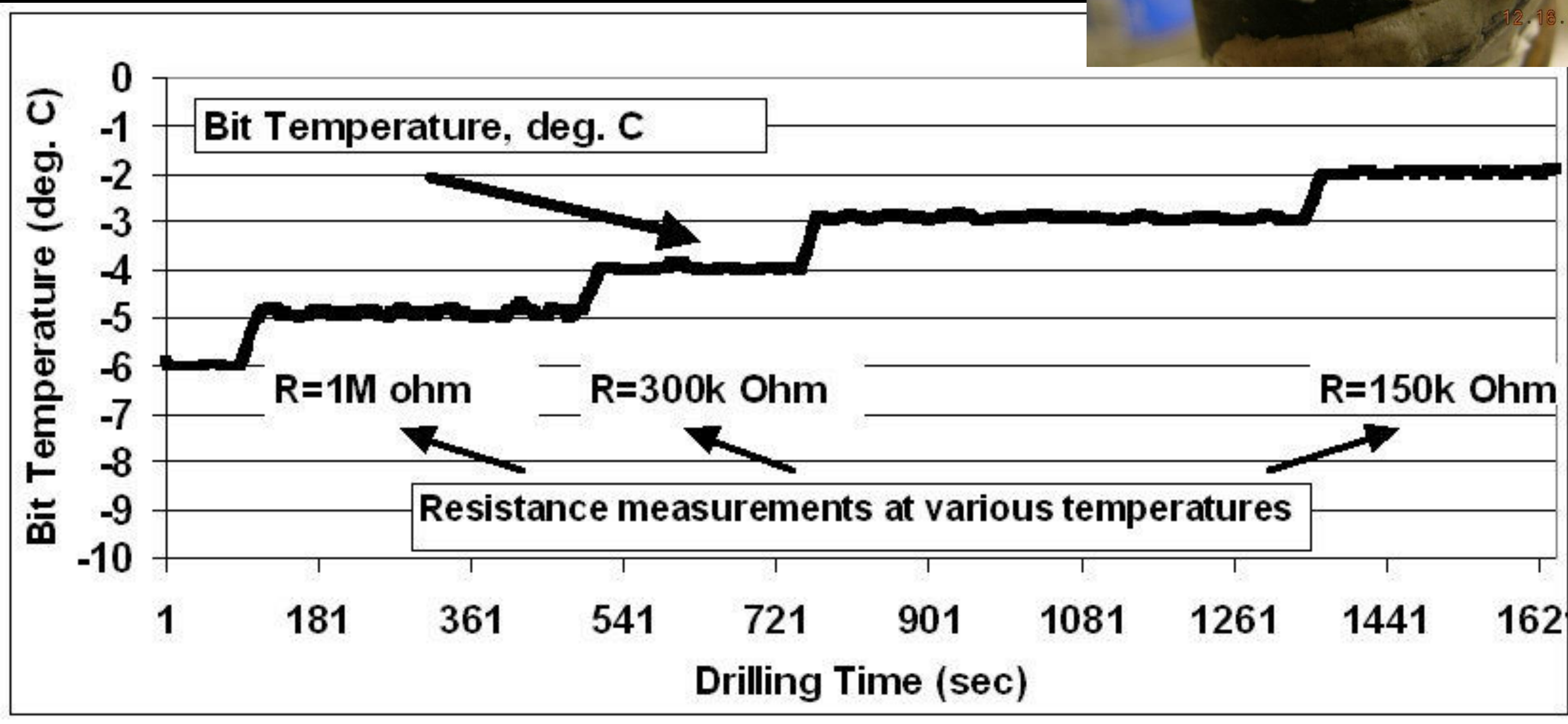
- Raman can be used as a temperature probe for ice (Sobron and Wang, JRS 2011)
- Raman can observe salts (including halides) in ice in near real time (*Sobron et al, LPSC 2013)*
- Raman can measure ice crystallinity (*Rull et al, SAA 2011)*
- Raman is sensitive to Ih, II, III, IX, V, and VI forms of ice (*Sukarova et al, J. Phys. C: Solid State Phys, 1984)*

Zacny et al., 2007

Electrical Conductivity

- Ways to determine icy-soil thawing and prevent thaw-refreeze conditions.
- Critical in 'salty' and clay rich formations
- Look for a large ΔR/ Δ T
  - ΔR/ Δ T = 700 kΩ/ °C vs. 75 kΩ/ °C

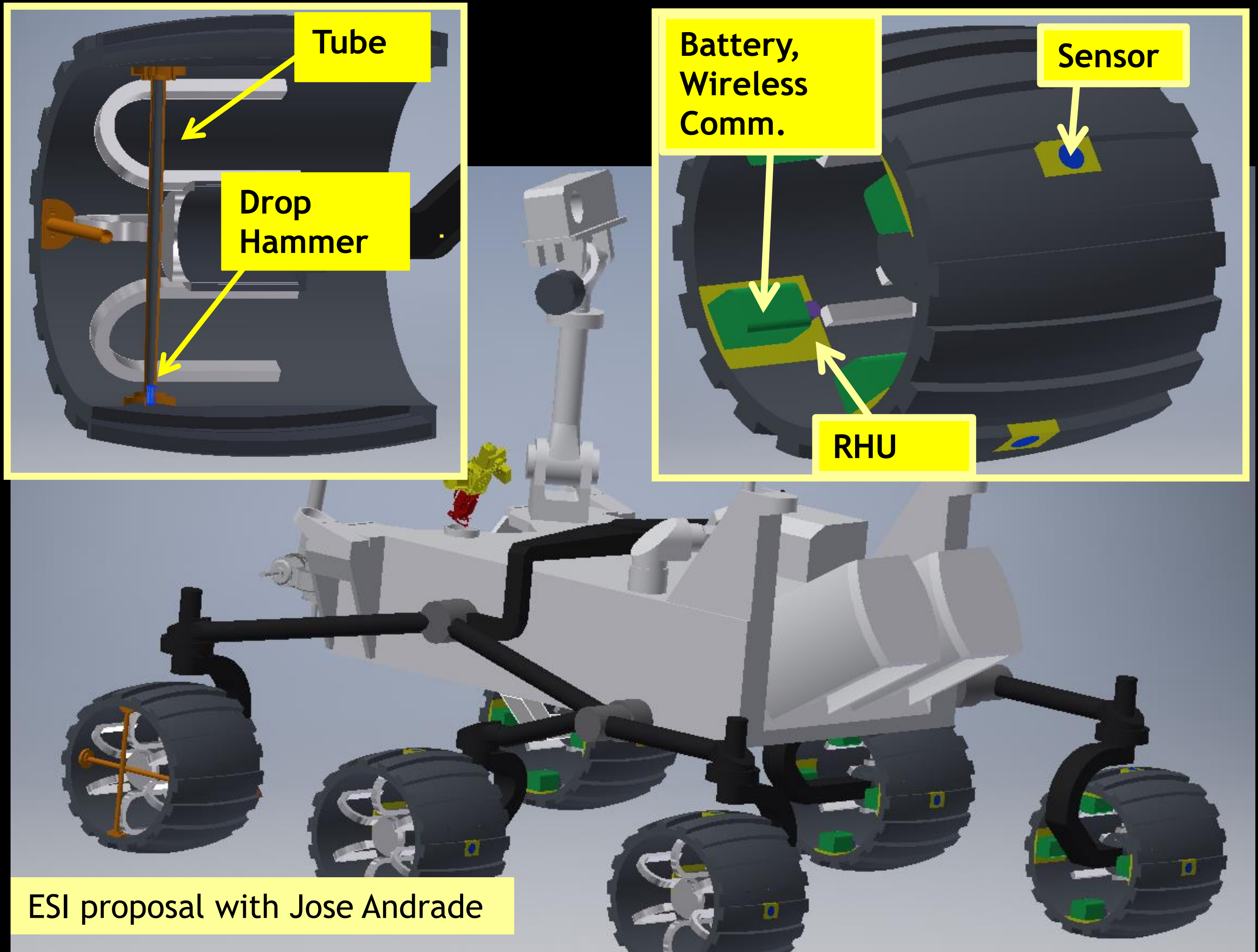




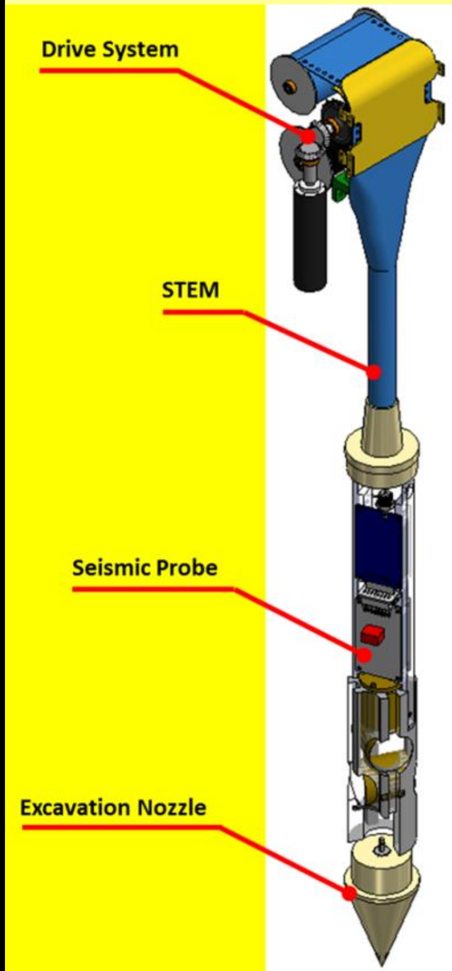
Seismic Systems

Rover based

Drill based



STTR with M. Siegler



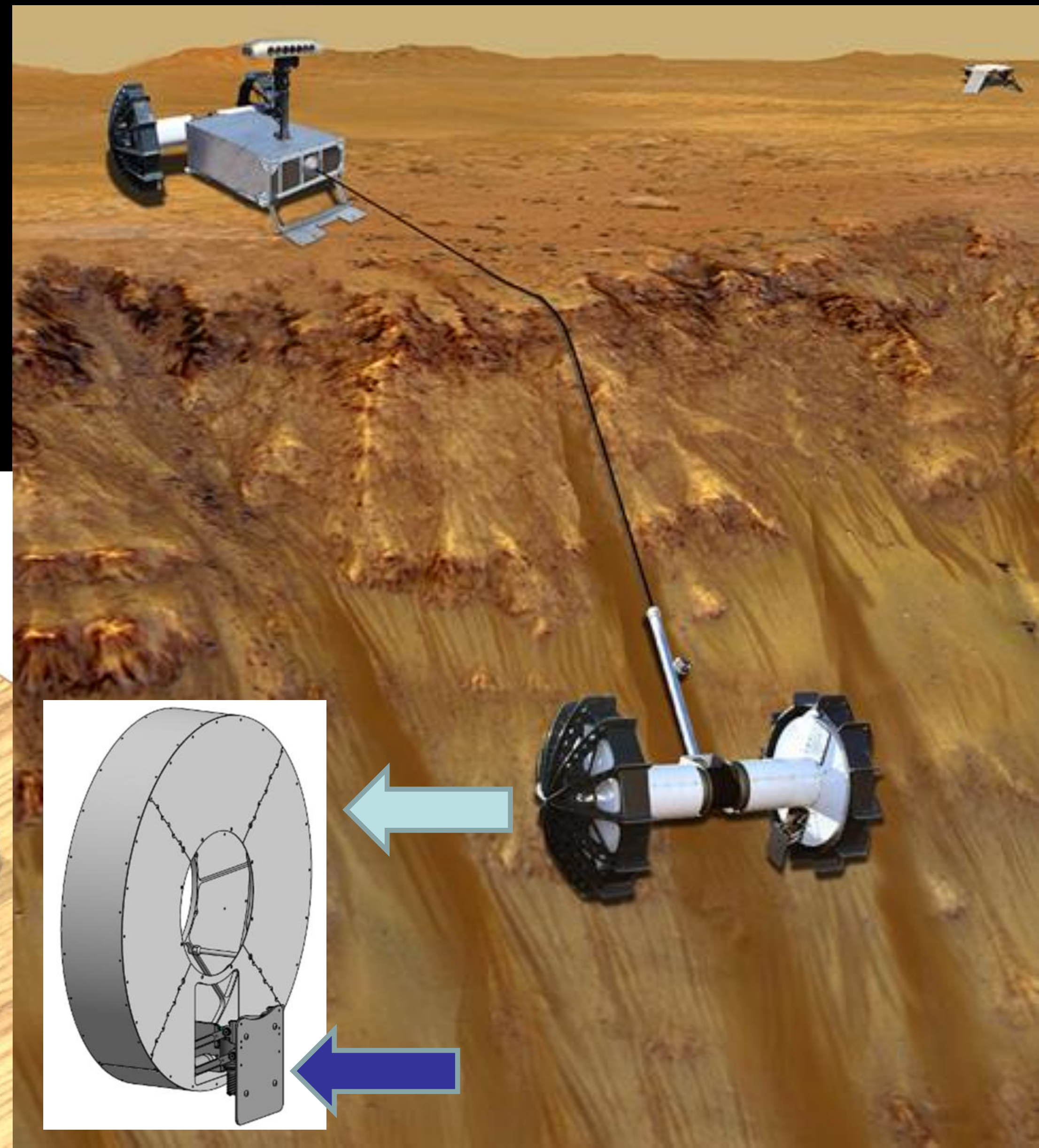
Extreme Access Systems

PI - Issa Nesnas (JPL)

Axel Rover

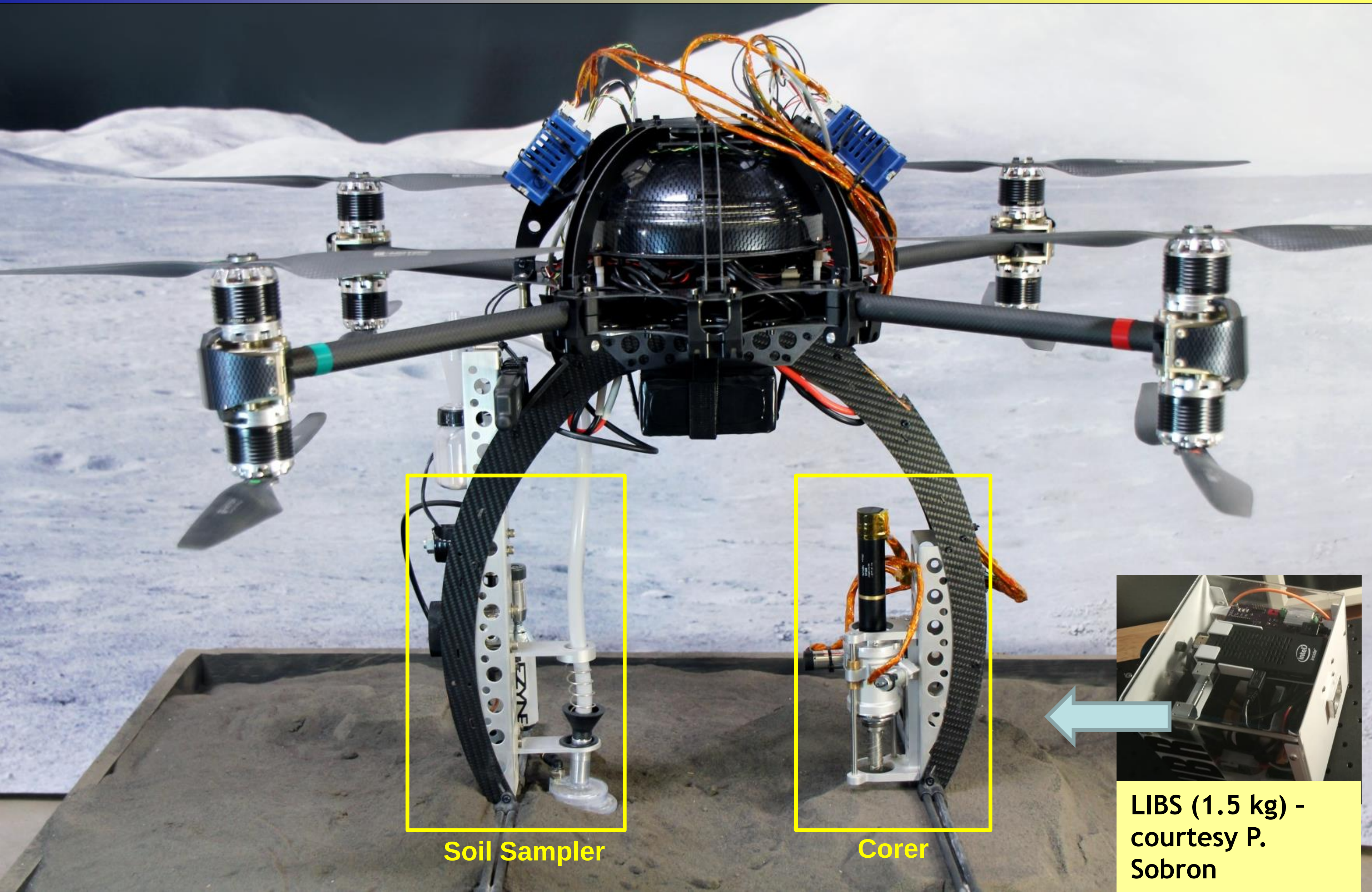
- "Axel" detaches from a rover
- Payload bay used for sampling systems and instruments
- Powder and Coring drills are at TRL 4

Zacny et al., (2013)



Drone with Samplers

Zacny et al., (2014)



LIBS (1.5 kg) - courtesy P. Sobron

Conclusions

- So far we penetrated mm's to cm's on Mars
- 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
  - Extreme access systems should also be considered
- Drills can bring sample to an instrument and can bring an instrument to a sample. Drill integrated instruments include:
  - Temperature profile and k, (heat flow probe)
  - Seismic
  - LIBS, UV, Raman
  - Microscope
  - Strength/density (comes "free" from drill telemetry)
- PP! – we are going to the "Mars Special Regions" (Cat IVc)