TRIDENT

THE REGOLITH AND ICE DRILL FOR EXPLORATION OF NEW TERRAINS

SRR/PTMSS
12-15 June 2018

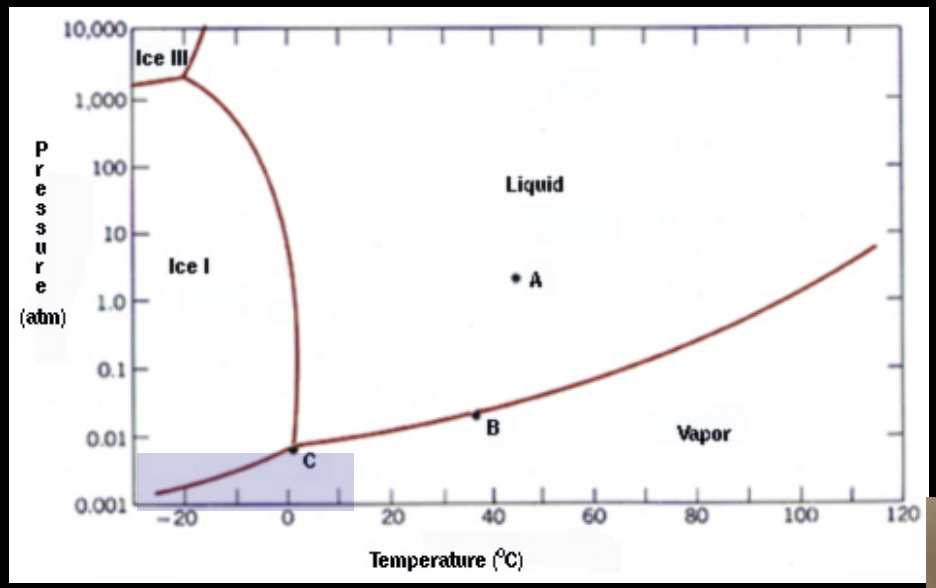
Presenter:
Kris Zacny, PhD
VP, Honeybee Robotics

G. Paulsen[1], K. Zacny[1], D. Kim[1], Z. Mank[1], A. Wang[1], T. Thomas[1], C. Hyman[1], B. Mellerowicz[1], B. Yaggi[1], Z. Fitzgerald[1], A. Ridilla[1], J. Atkinson[1], J. Quinn[2], J. Smith[2], J. Kleinhenz[3],

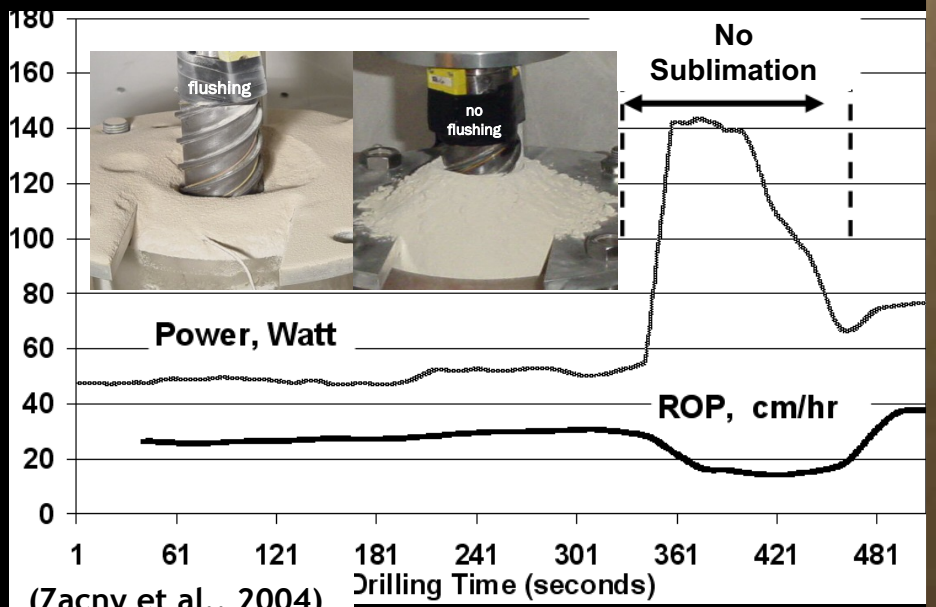
[1]Honeybee Robotics
[2]NASA Kennedy Space Center, FL,
[3]NASA Glenn Research Center, Cleveland, OH.

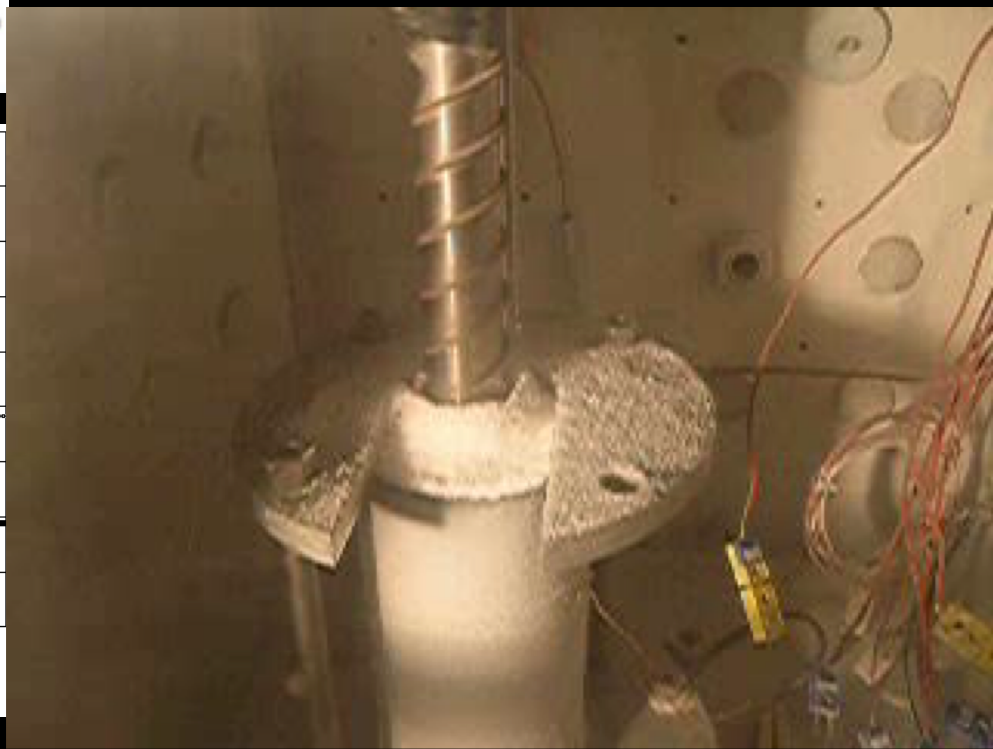
HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation

2002: Drilling in vacuum



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

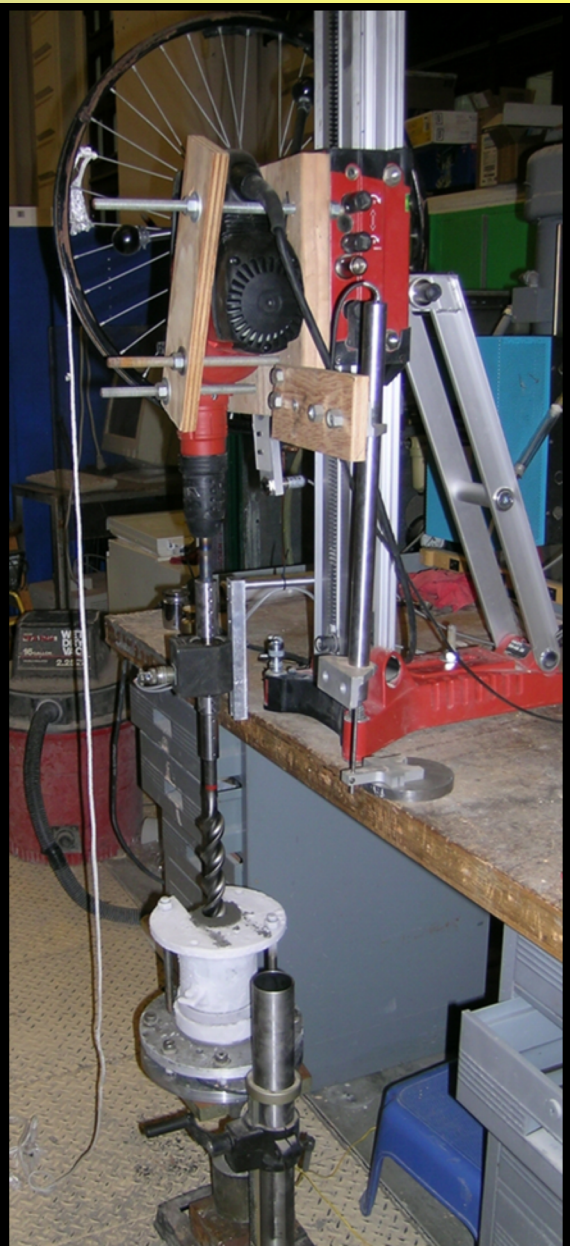




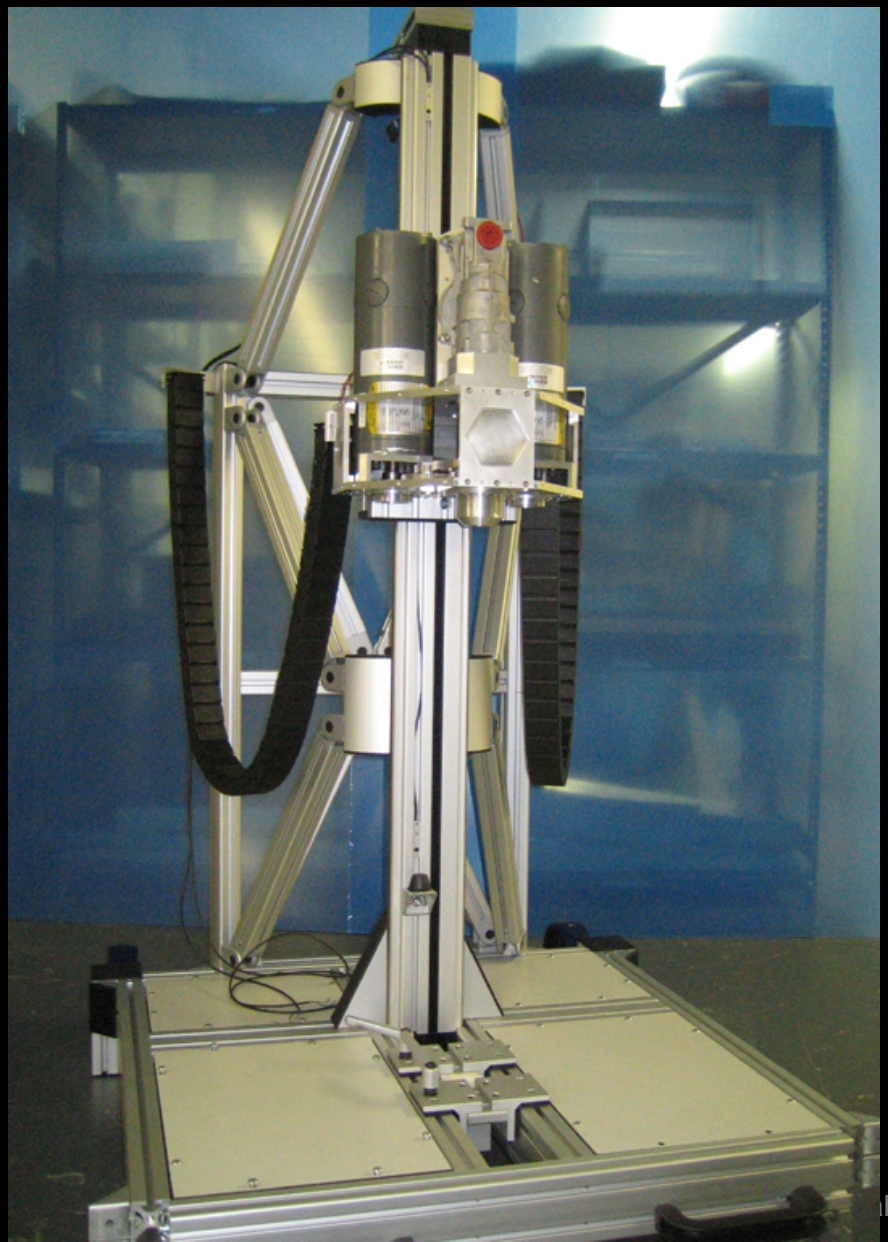
2005: TRL2 CRUX Drill

Strength value from Unconfined Compressive Strength tests

- UCS=43 MPa,
- std=11 MPa



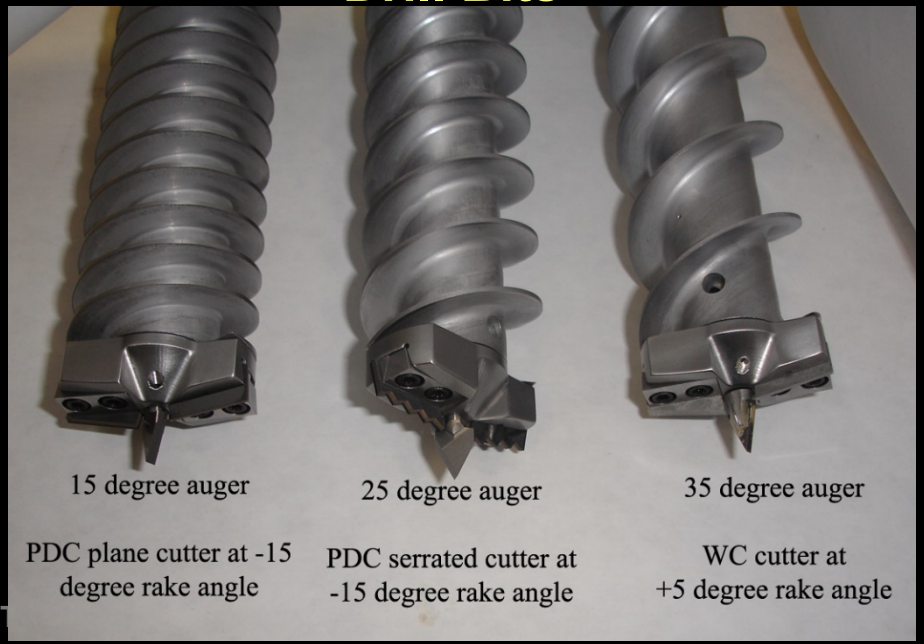
2005: TRL3 CRUX Lunar Drill



Drilling Methods:

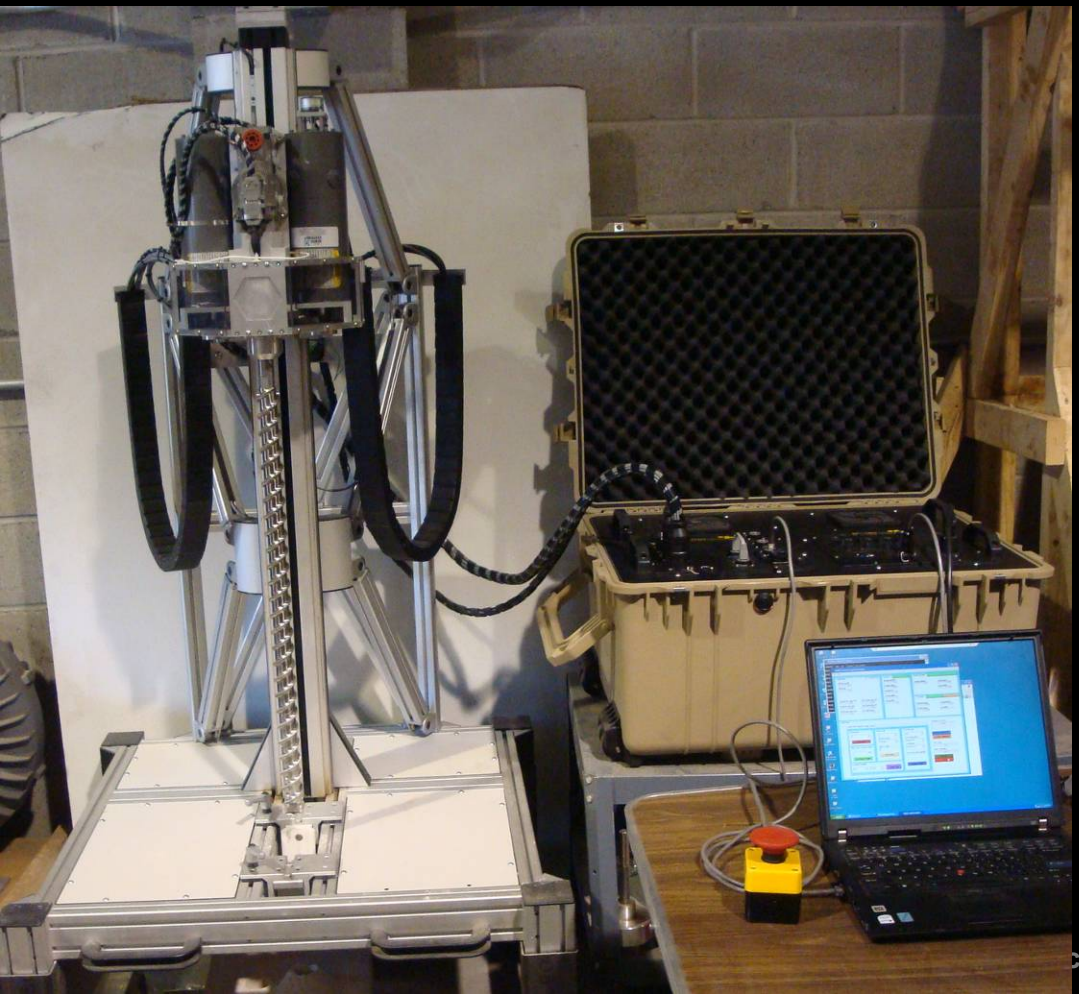
1. **Rotary,**
2. **Percussive,**
3. **Rot.-Perc.**

Drill Bits



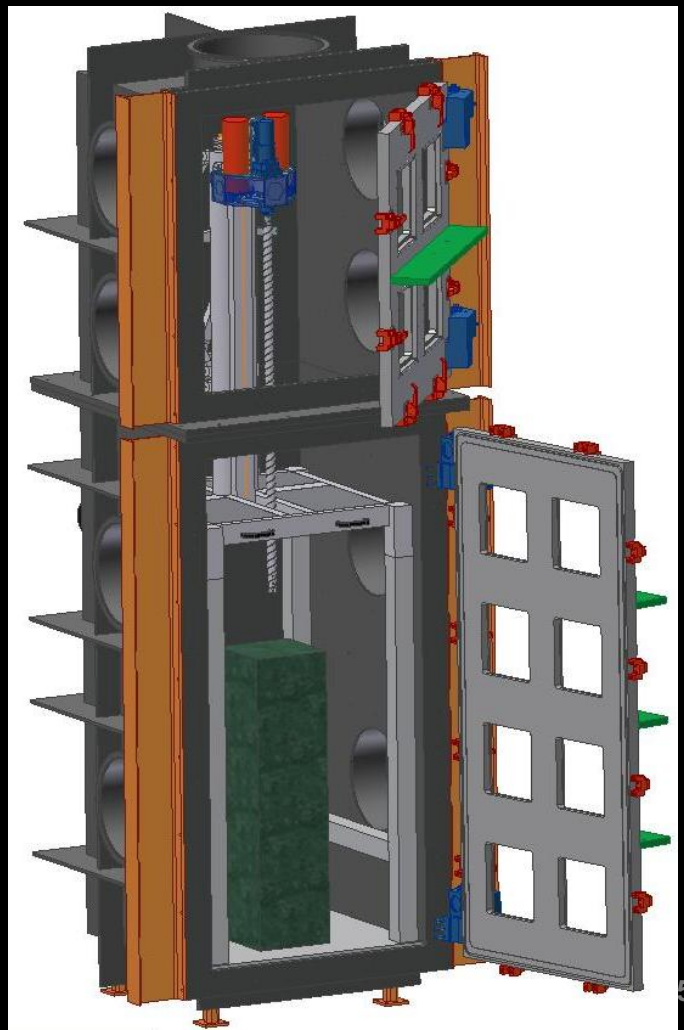
2008: TRL3 Crux drill and chamber

- 1 kW Rotary-Percussive drill
- WOB: 1000 N
- 1 meter stroke

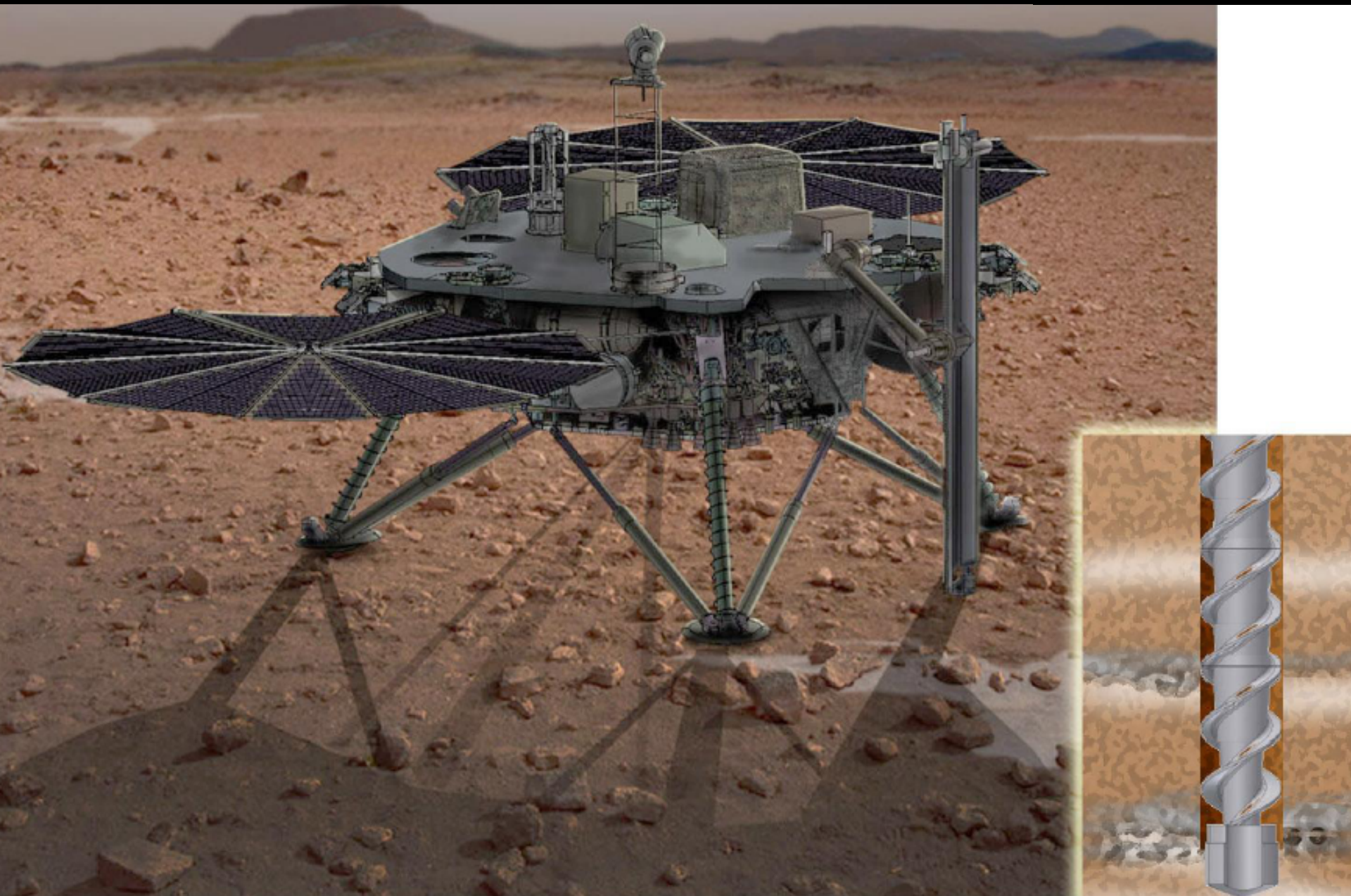


Vacuum chamber:

- 1 m x 1 m x 3.5 m
- 1 torr vacuum

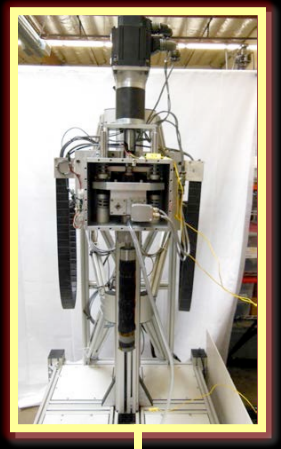


2010: TRL4 Mars IceBreaker Drill



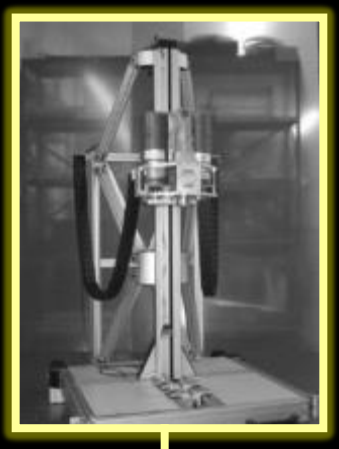
2010: Drilling Trades

SONIC



ULTRA SONIC

PERCUSSIVE



ROTARY

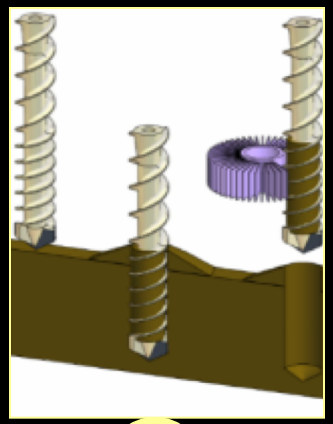
TRL 4 (Rot Perc)

2010: Sampling Trades

Complexity

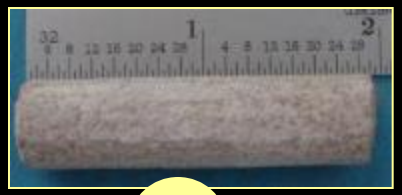
1. Embedded Sensor
Step 1: Drill
Step 2: Analyze

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

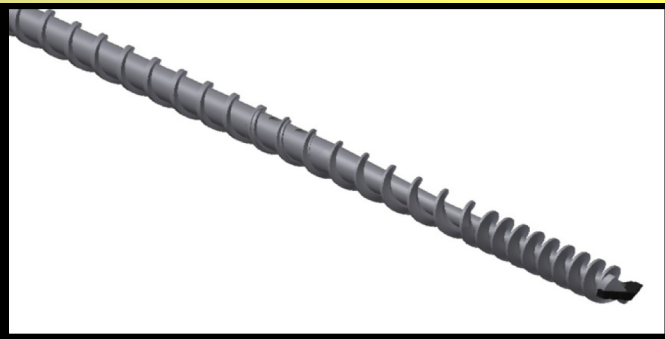


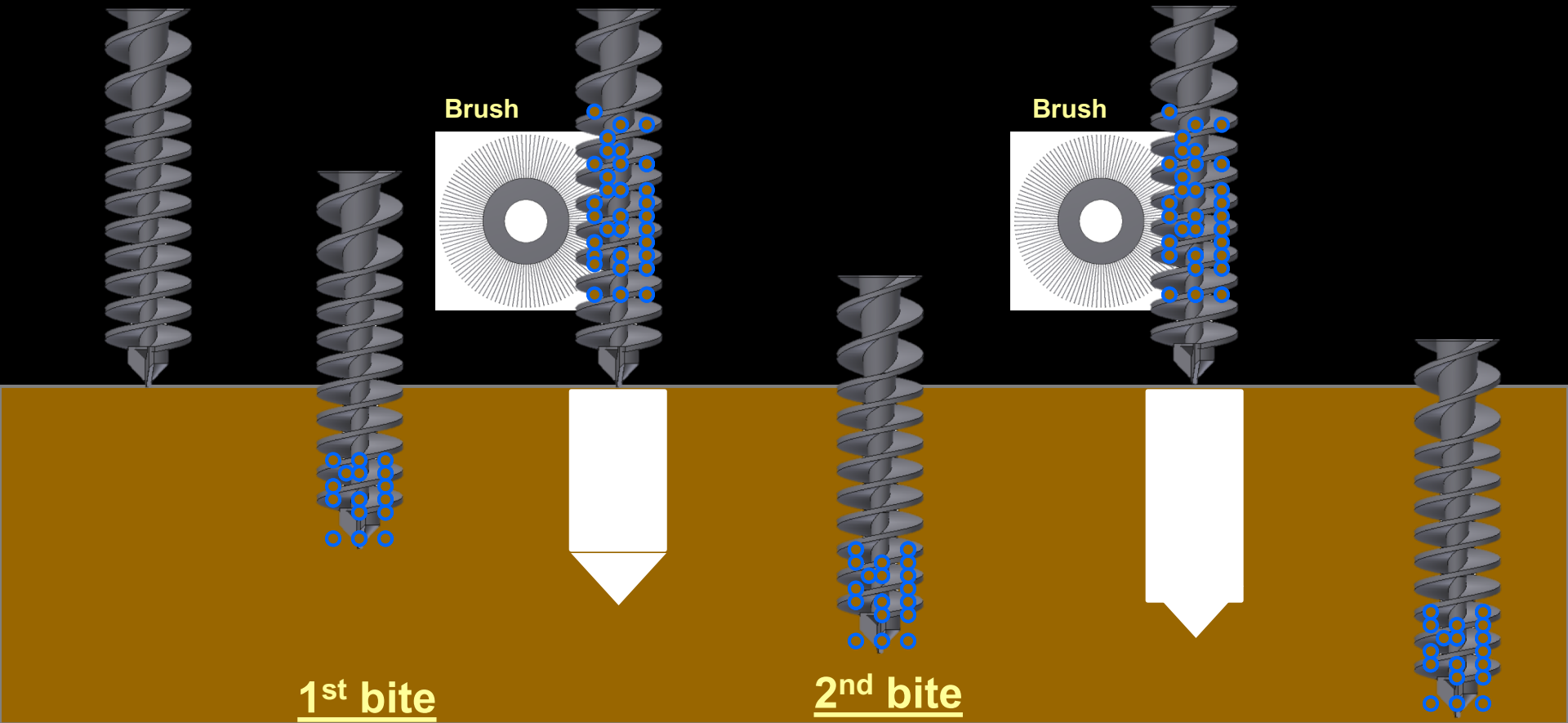
5. Core
Step 1: Drill
Step 2: Break-off core
Step 3: Capture Core
Step 4: Pull out
Step 5: Eject core
Step 6: Process core
Step 7: Analyze

Science Payoff

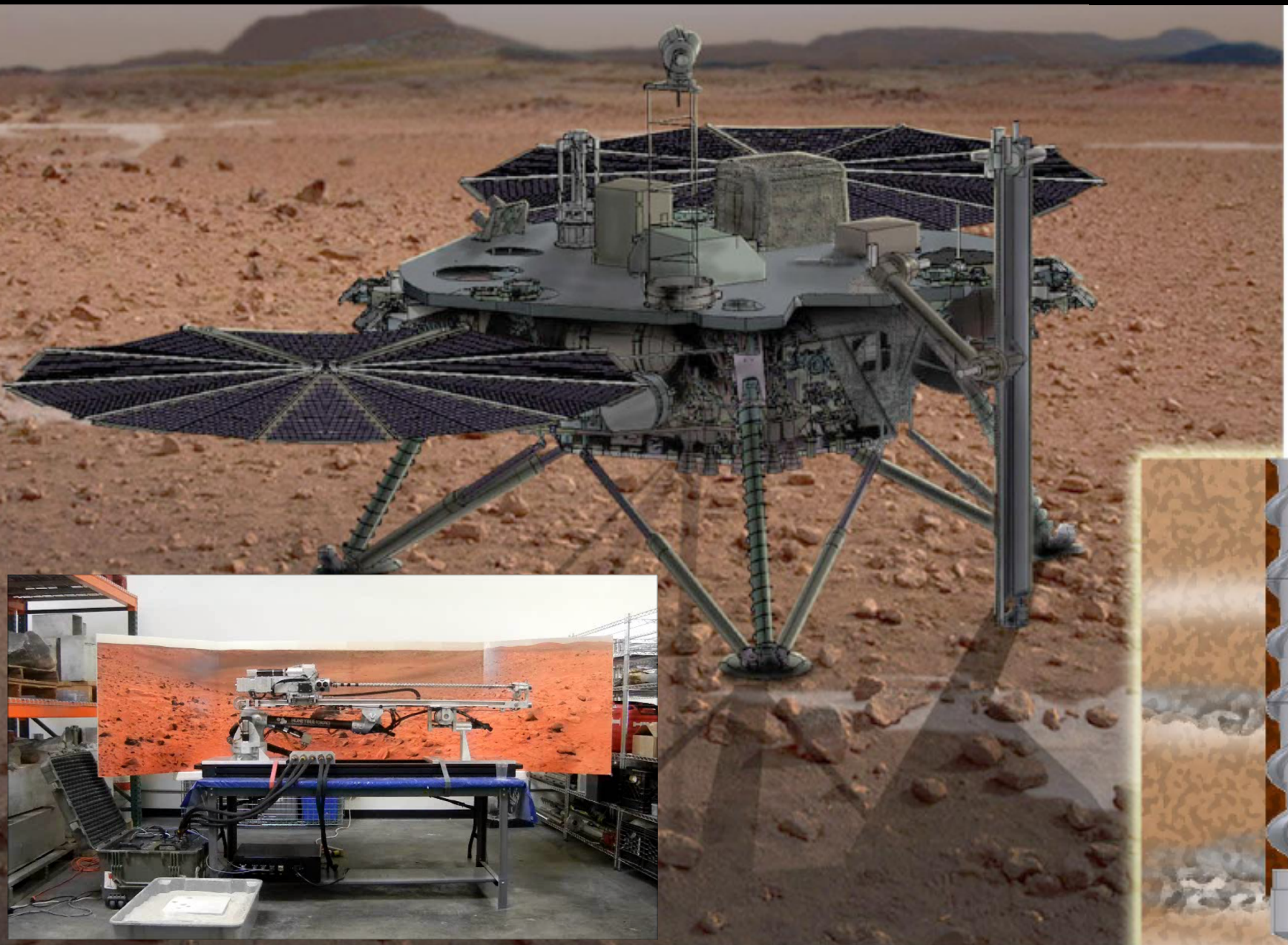
2010: "Bite" Sampling Concept

- 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
- Lower torque and power since less cuttings conveyed to surface

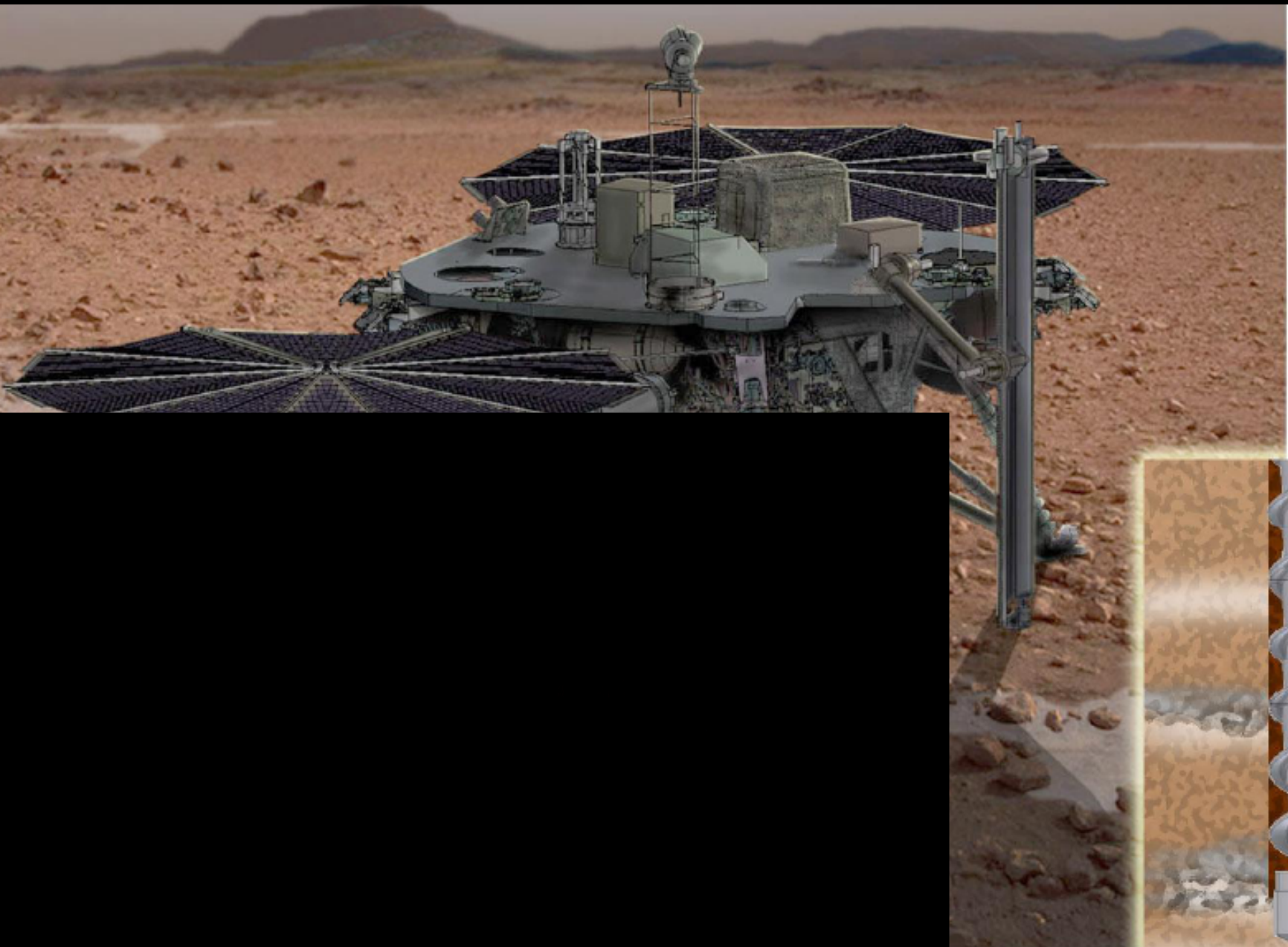




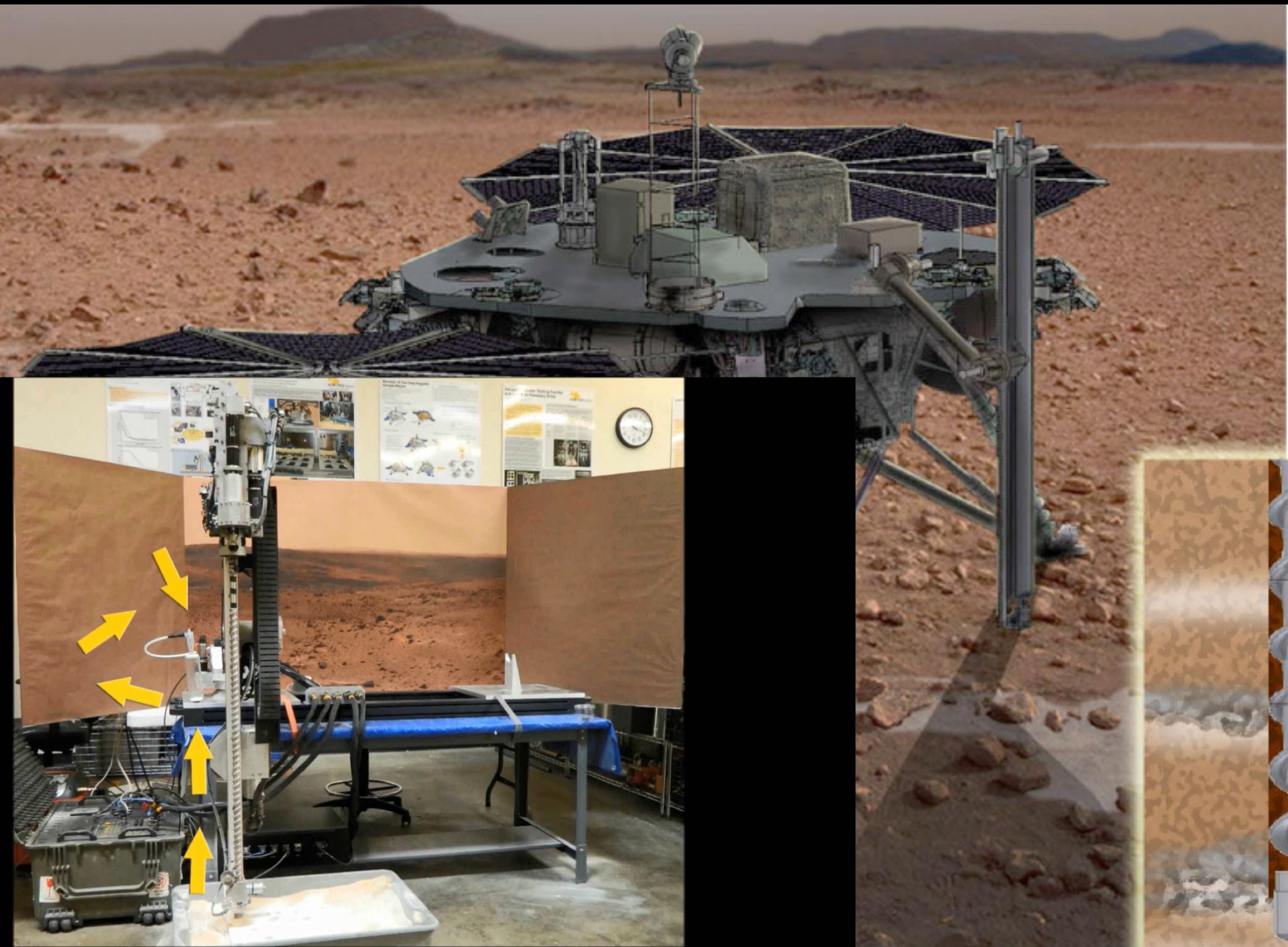
2010: TRL4 Mars IceBreaker Drill



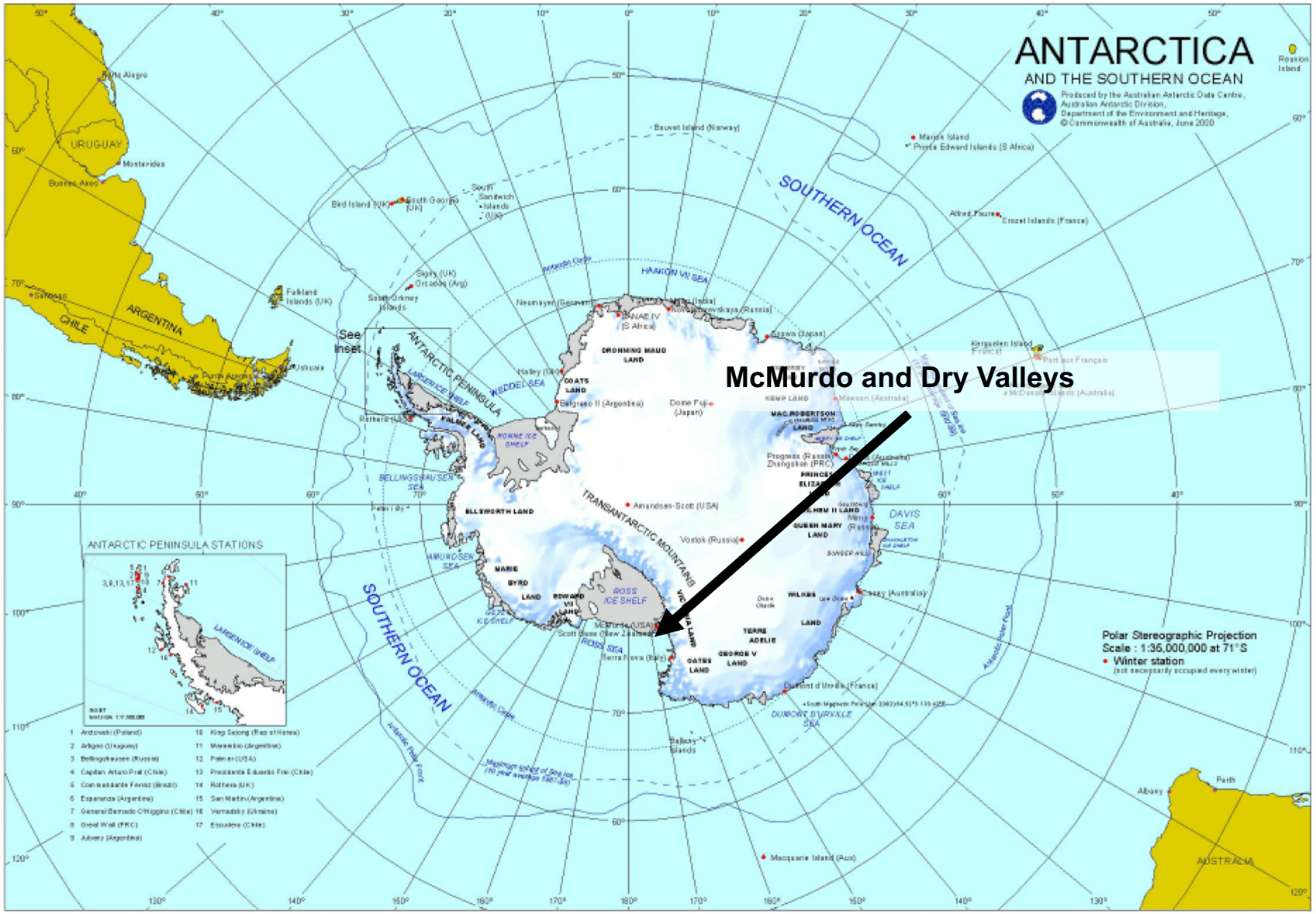
Sample Delivery using Drill



Sample Delivery using Gas



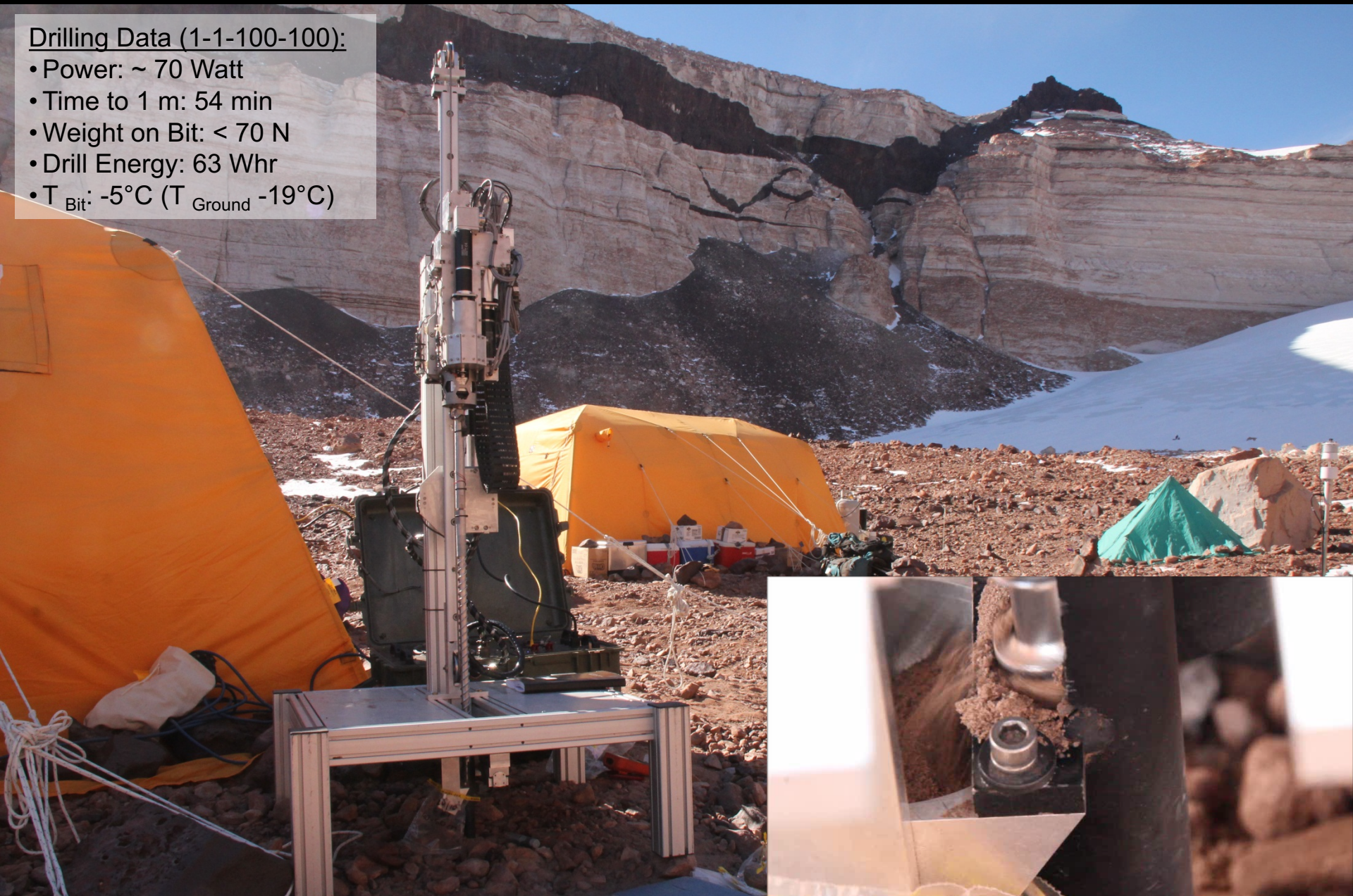
Testing in Cold Regions



McMurdo Station, Antarctica

Mars Analog: University Valley, Antarctica

Ice Cemented Ground – Soil Did Not Stick!



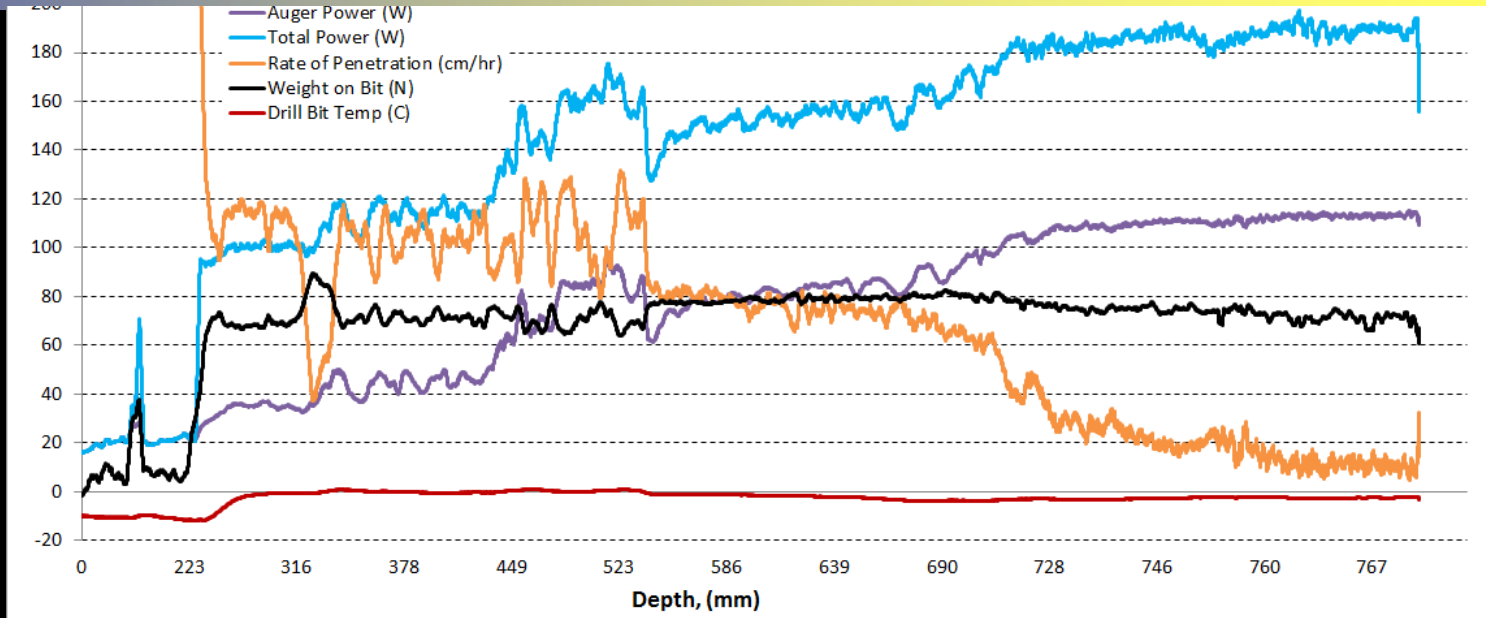
Drilling Data (1-1-100-100):

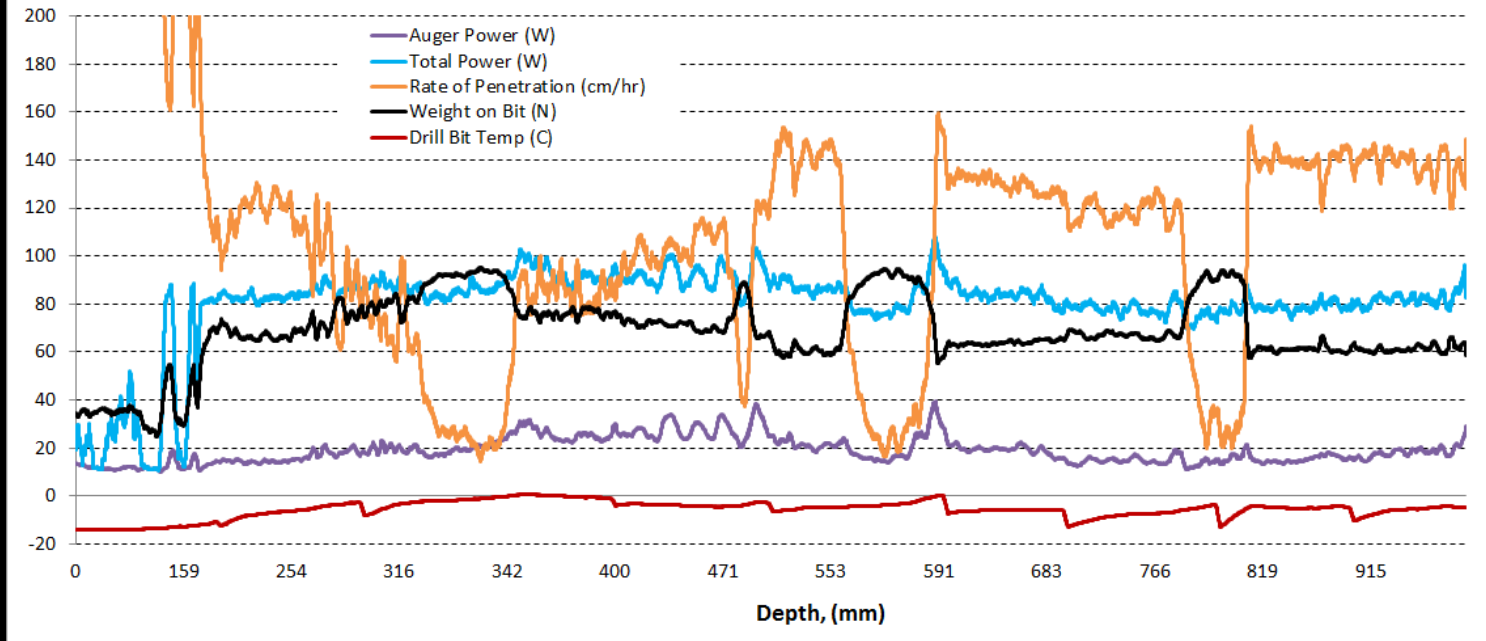
- Power: ~ 70 Watt
- Time to 1 m: 54 min
- Weight on Bit: < 70 N
- Drill Energy: 63 Whr
- T_{Bit}: -5°C (T_{Ground} -19°C)

Advantage of Bite Approach

Continuous Auger

Bite Approach





Antarctic Dry Valleys: Massive Ice

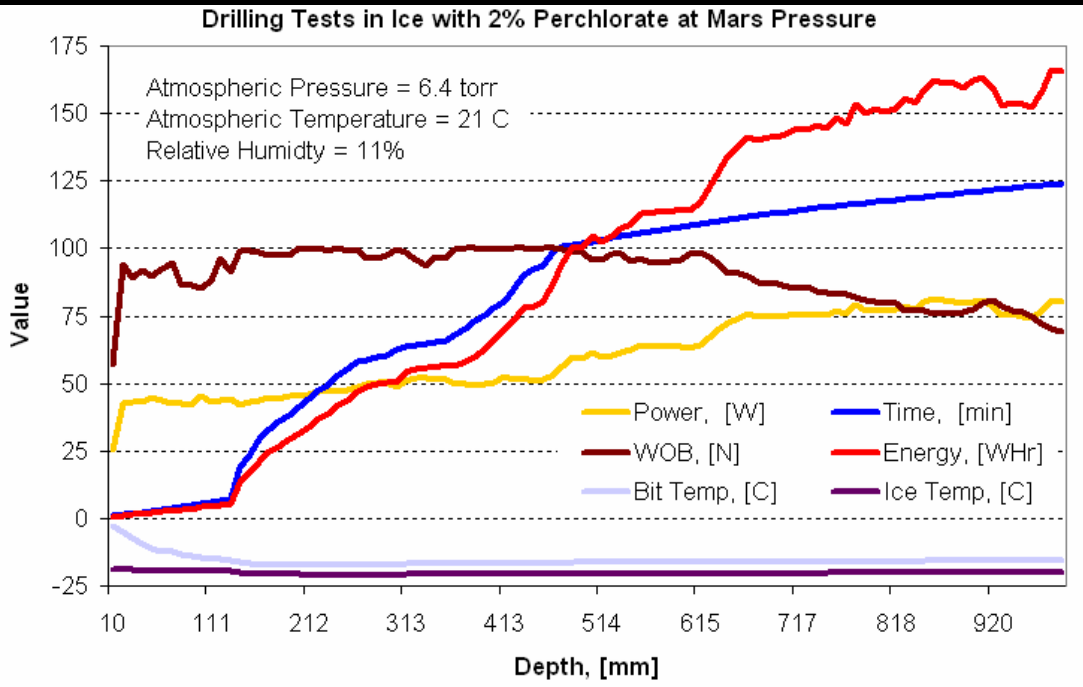
Drilling Data:

- 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)

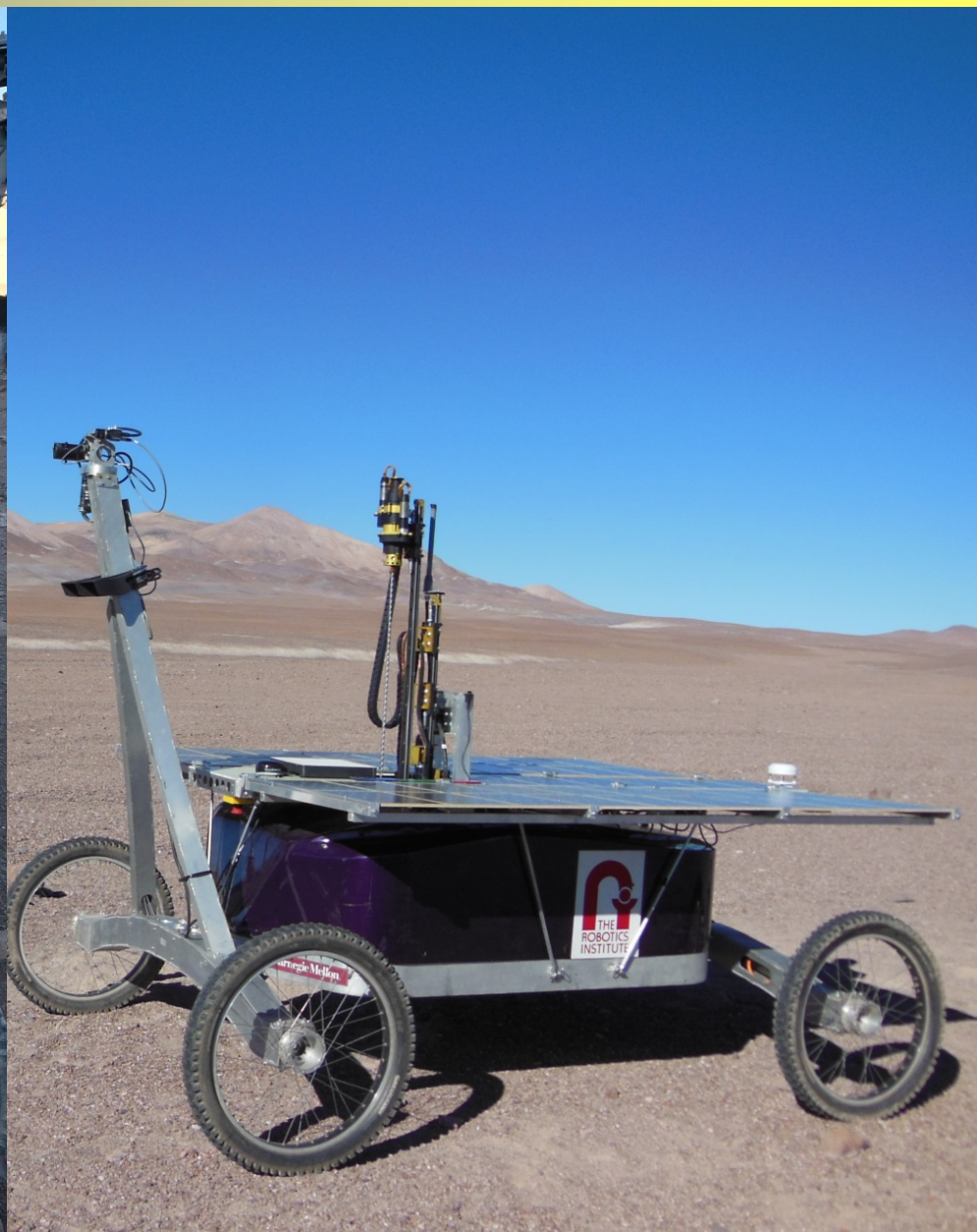
Ice cuttings include many single ice chucks as large as 6 mm long

Test in vacuum 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

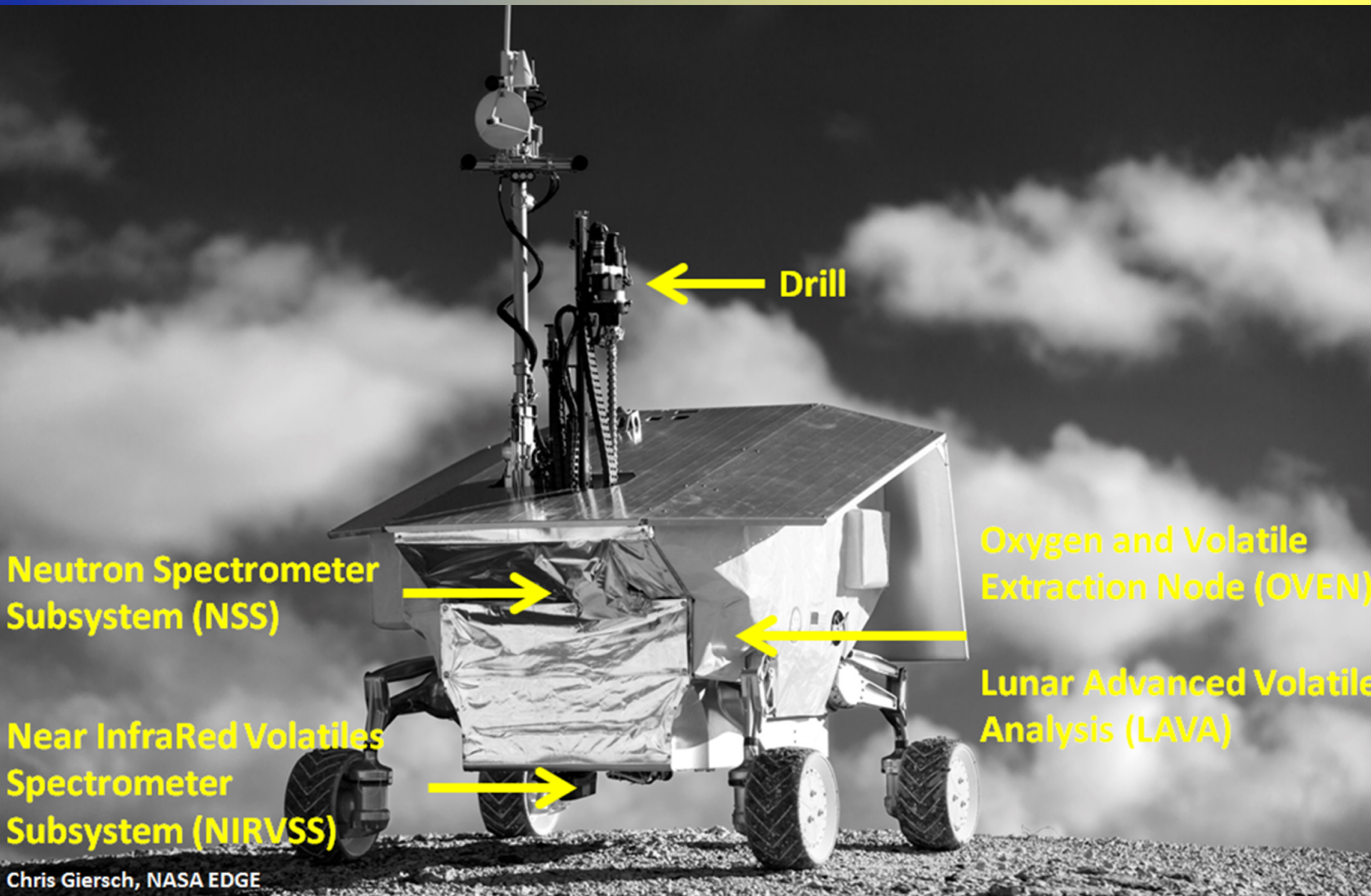


2012: LITA Drill



2012: TRL5 LITA Drill

2015: TRL5/6 RP Drill



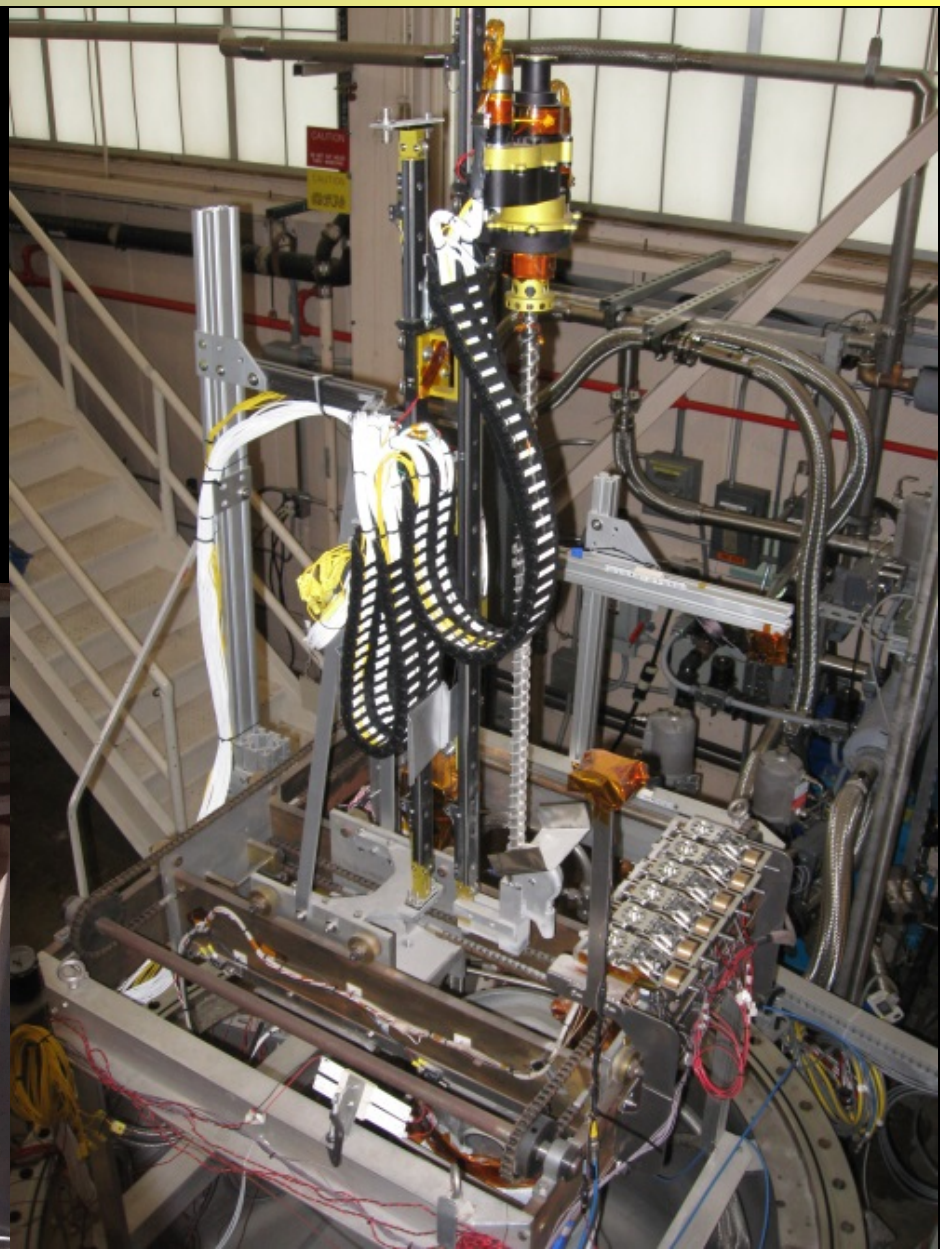
2015: TRL5 Drill Tests at GRC

Background:

- Soil:
  - NU-LHT-3M with 4-5 water wt%,
  - Vibratory compacted to ~1.5 g/cc
  - Temp: -140 C to - 90 C
- Chamber P: ~10^-6 torr
- Crucible T: -85 C to - 50 C (+10 C)

Goal:

1. Capture sample from 40 - 50 cm
2. Deliver to crucible
3. Seal

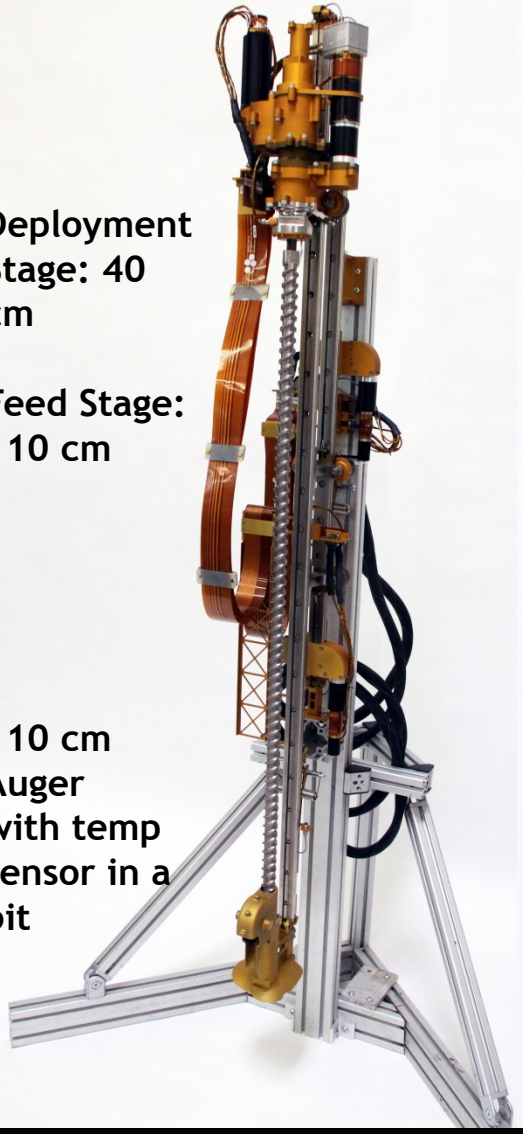


2017: TRL6 TRIDENT Drill

Deployment Stage: 40 cm

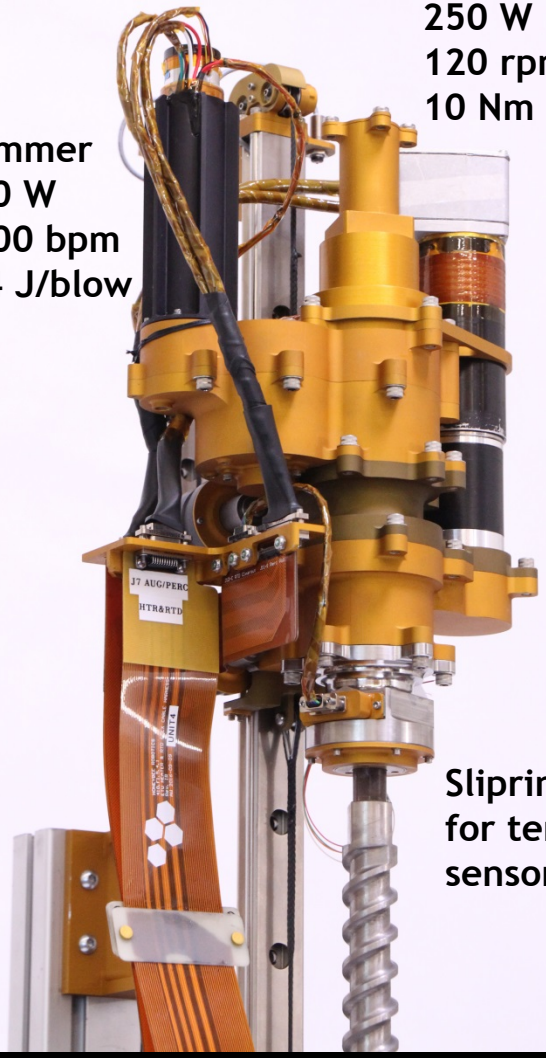
Feed Stage: 110 cm

110 cm Auger with temp sensor in a bit

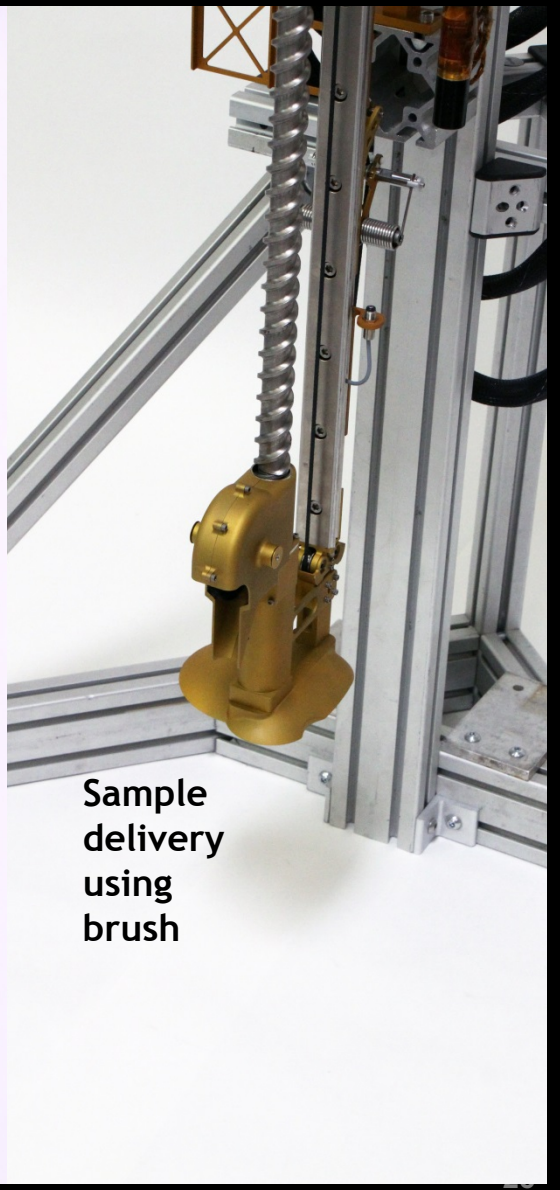


Hammer
250 W
1800 bpm
2-4 J/blow

Rotary
250 W
120 rpm
10 Nm



Sliprings for temp sensor

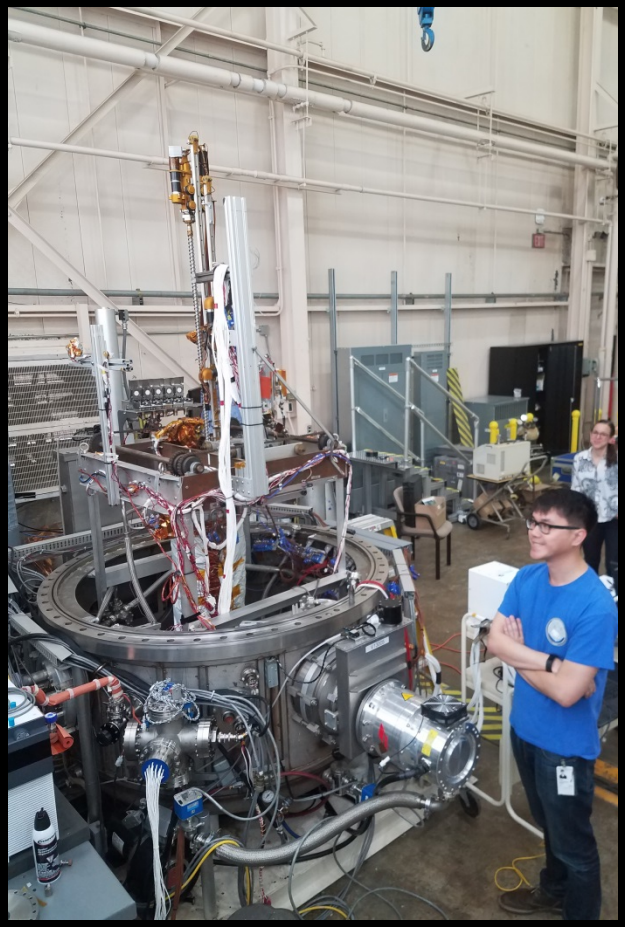


Sample delivery using brush

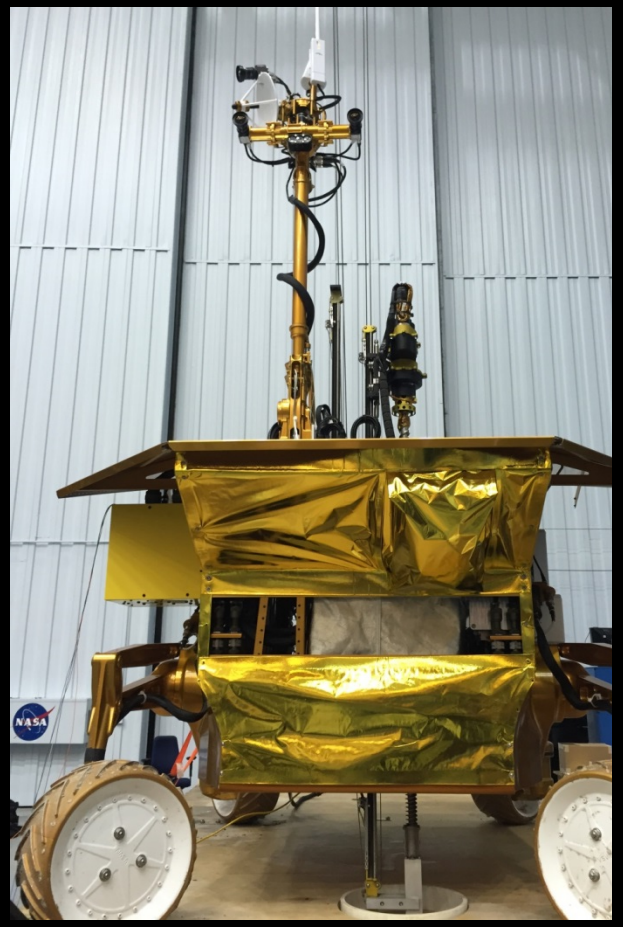
2017: TRIDENT (TRL6)

Vibration tests

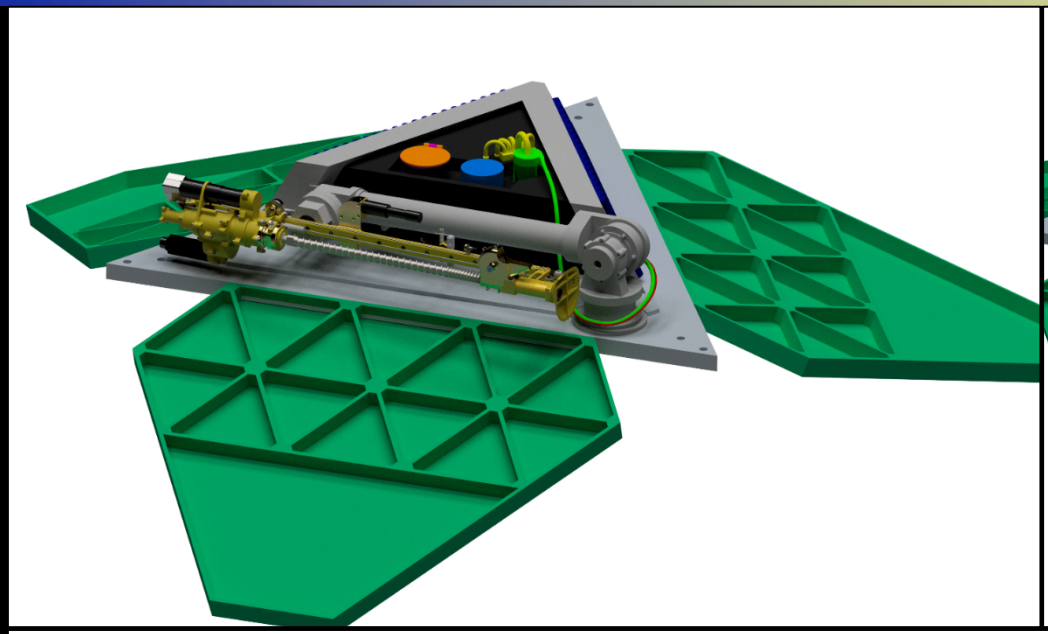
Thermal Vacuum Chamber tests

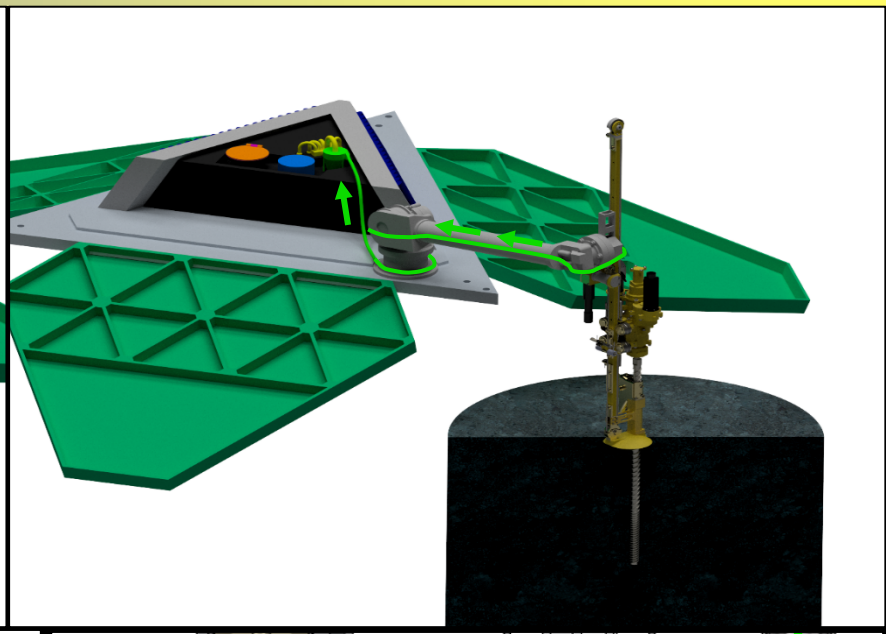


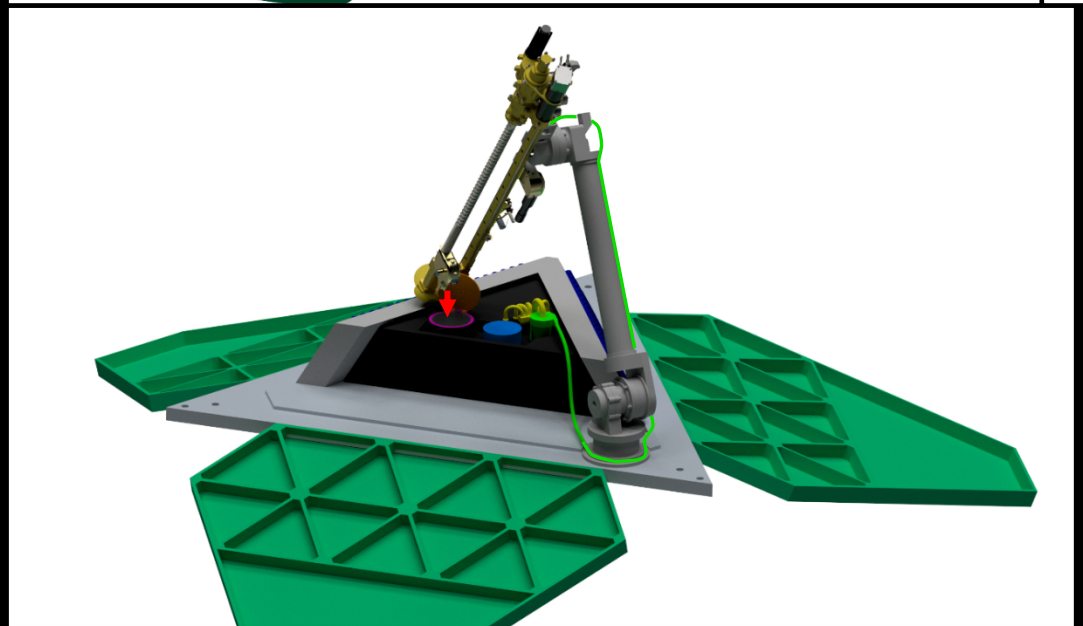
Remote Ops tests

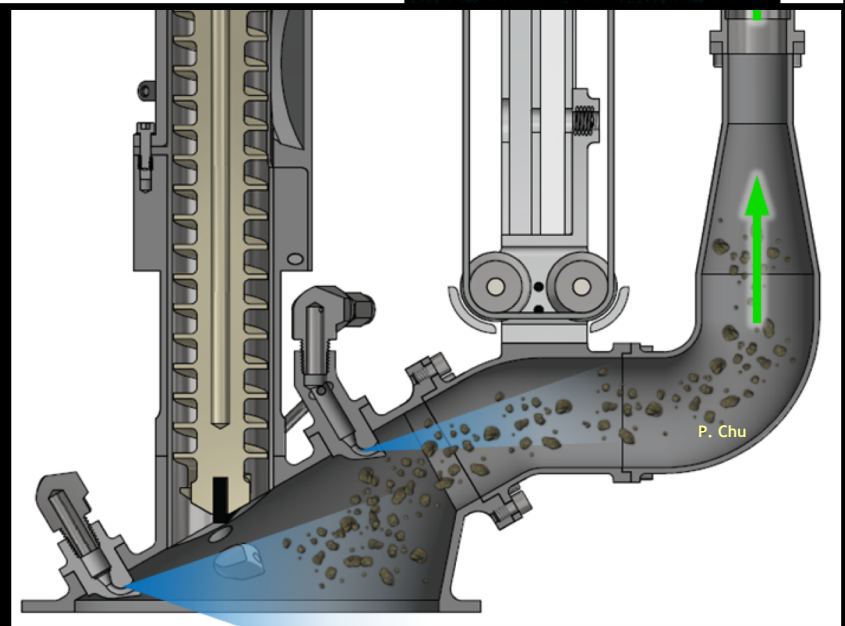


Small Landers









Conclusions

- Space is not a sprint – it's a marathon with occasional sprints.
- Technology development takes a very long time
  - Lower but consistent funding level provides more benefit than large and time constrained budgets
- Competition for funding is stiff – a lot of smart people have great ideas and great proposals. But there is always some funding!
- Never give up!

Acknowledgments

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

Thank You!

Kris Zacny
zacny@honeybeerobotics.com

http://utcjonesobservatory.tumblr.com/