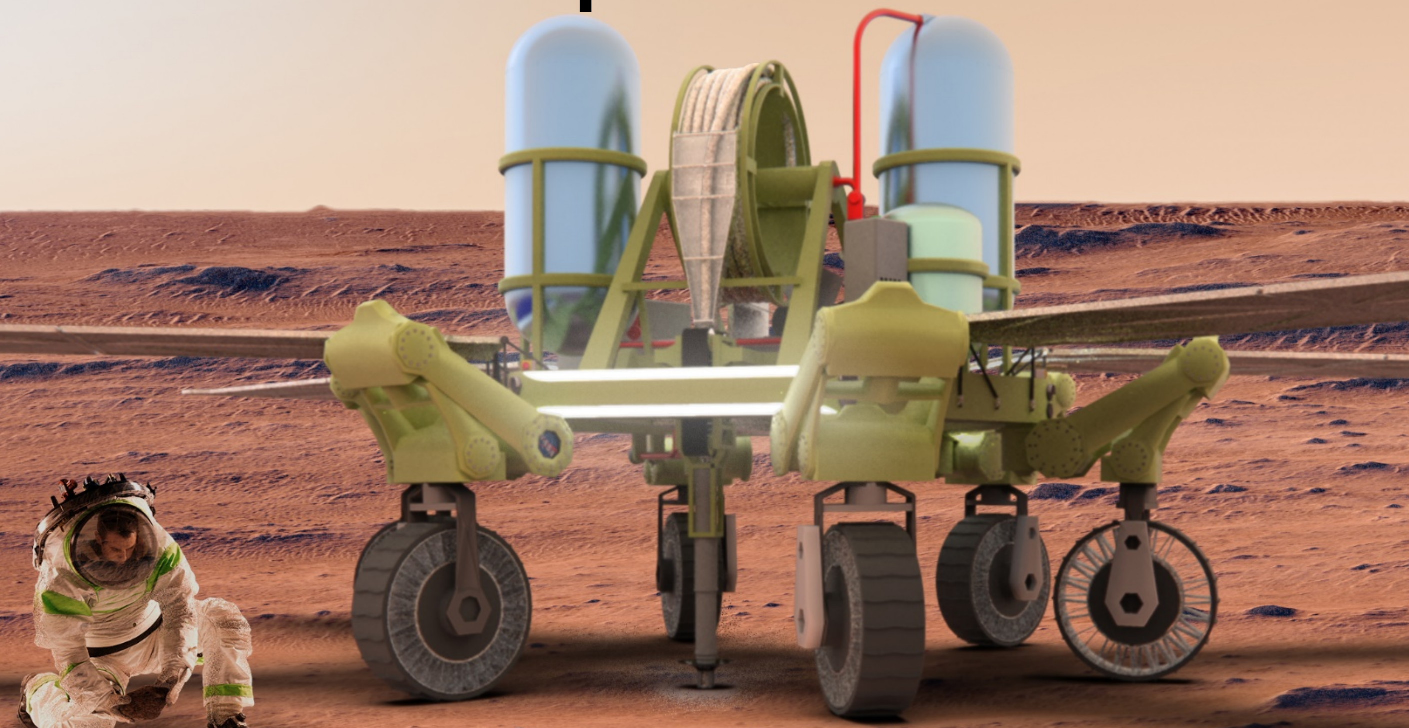
RedWater: Extraction of Water from Mars' Ice Deposits



SRR/PTMSS
12-15 June 2018

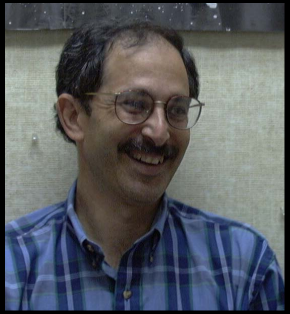
Kris Zacny - Honeybee Robotics
Mike Hecht - Haystack Observatory, Massachusetts Institute of Technology
Nathaniel Putzig - Planetary Science Institute
Dara Sabahi - NASA JPL -retired
Paul van Susante - Michigan Technological University

The RedWater Team

Water Team (Engineering team):

- Kris Zacny, Honeybee Robotics, PI
- Gale Paulsen, Honeybee Robotics, Systems Engineer
- Phil Morrison, Honeybee Robotics, Water extraction/engineering lead
- Bolek Mellerowicz, Honeybee Robotics, Lead Electrical/Controls
- Kristian Mueller, Honeybee Robotics, Project Manager



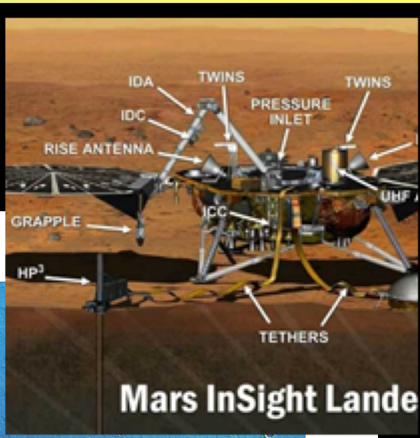
Red Team (Review team)

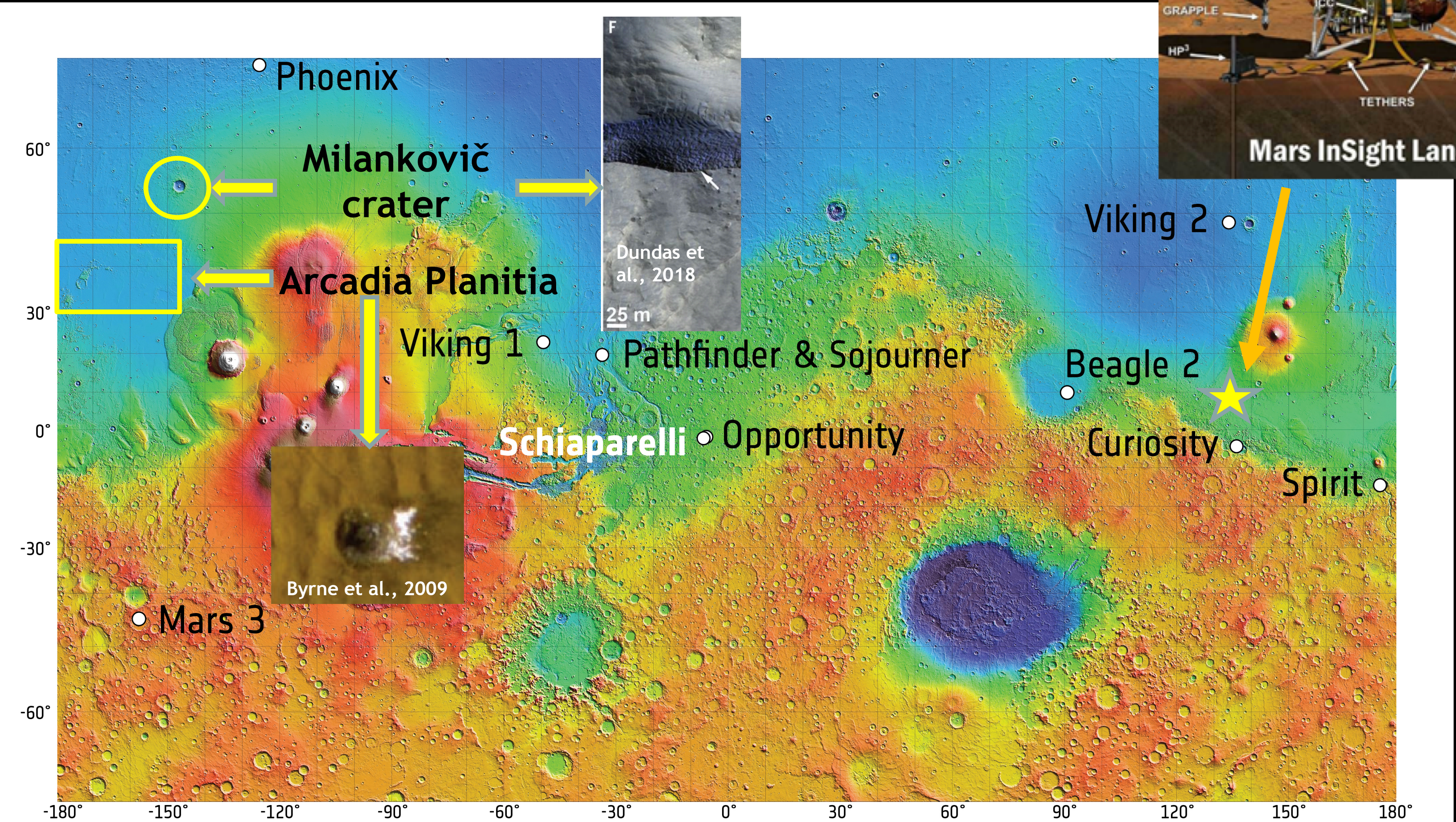
- Michael Hecht, Massachusetts Institute of Tech., Mars melt probes, ISRU (MECA, MOXI, Chronos)
- Nathaniel Putzig, Planetary Science Institute, Mars ice deposits (SHARAD, TES, THEMIS)
- Fredrik Rehnmark, Honeybee, drilling/engineering
- Dara Sabahi, NASA Jet Propulsion Lab (retired), Systems Eng. and Mars Ops. (MSL, MER, Phoenix, Pathfinder)
- Paul van Susante, Michigan Technological University, Mars excavation and ISRU



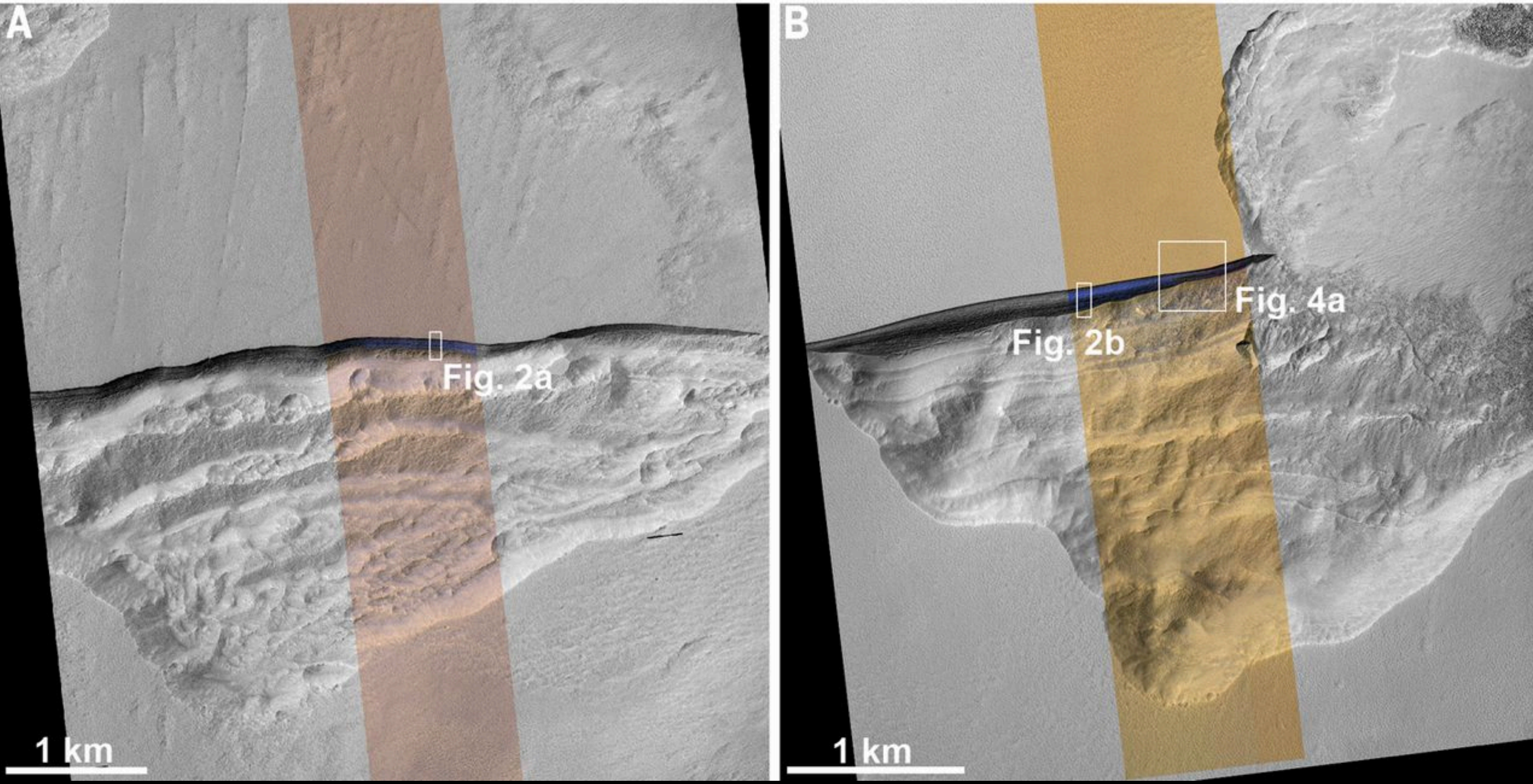

Our target: mid-latitude ice

- <20 m of regolith
- 10s of meters thick ice layer (down to 37N)
- Mars InSight will provide geotechnical properties of Mars regolith to 5m





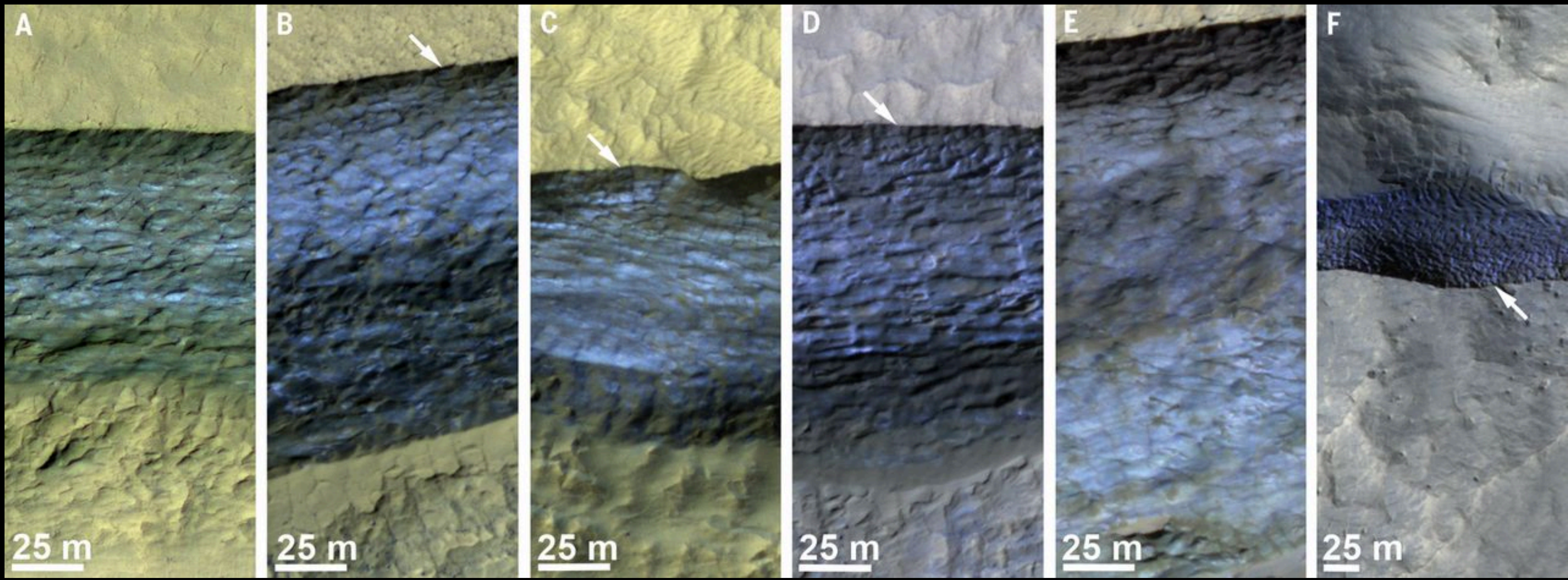
Pure Ice!



Dundas et al., Science 359, 199–201 (2018

Fig. 1. Pits with scarps exposing ice. (A and B) Scarps 1 and 2. Both (A) and (B) show HiRISE red-filter data merged with the center color strip in early-summer observations. Parallel ridges indicate retreat of scarps. North is up and light is from the left in all figures.

Pure Ice!

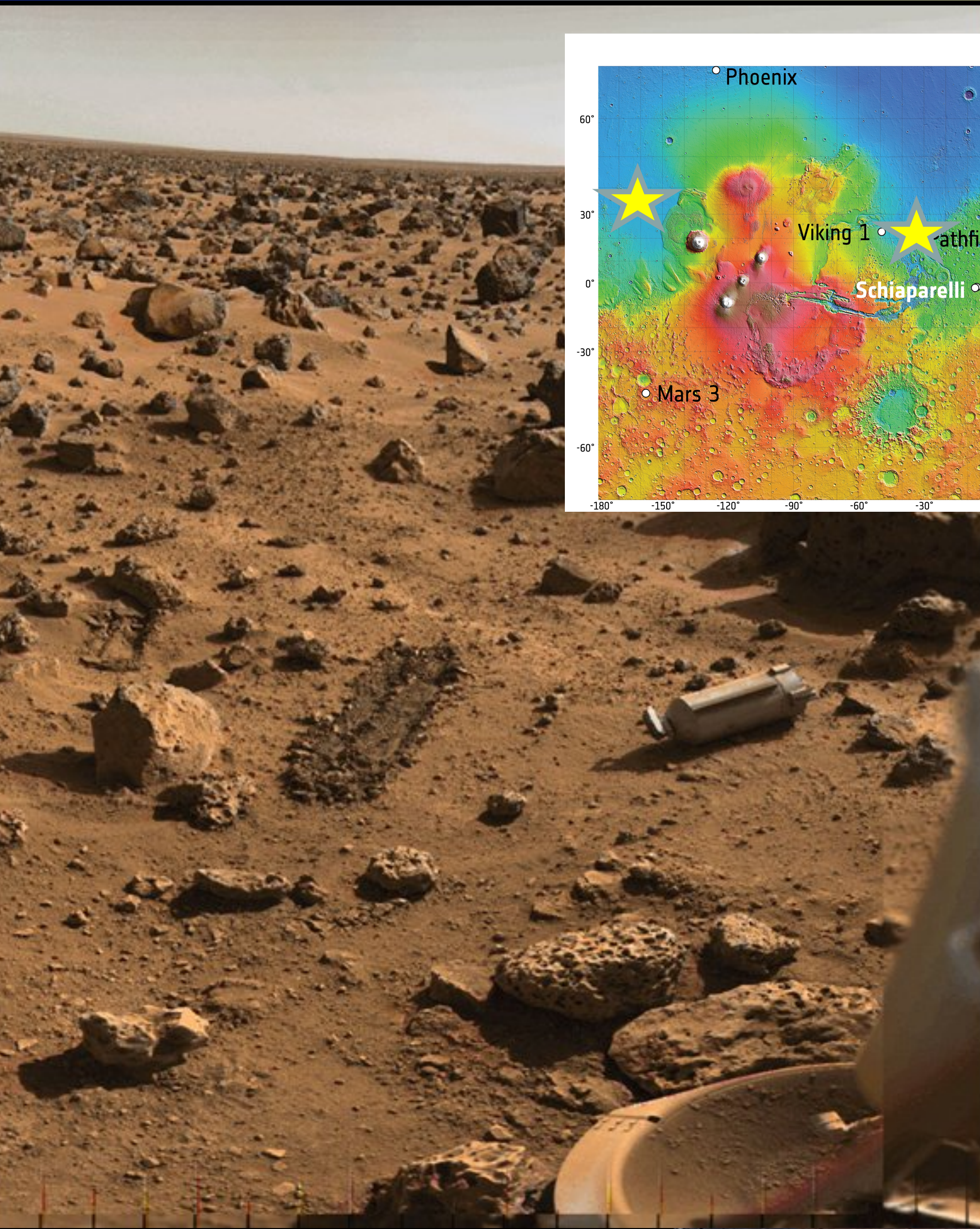


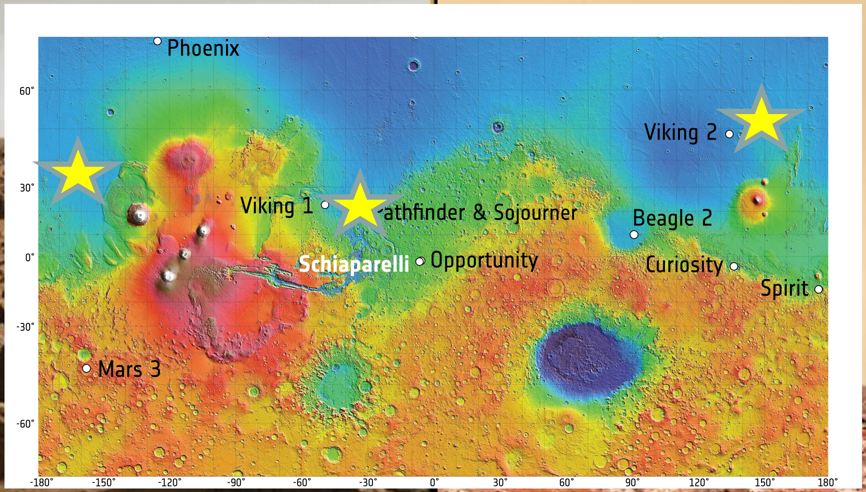
Dundas et al., Science 359, 199-201 (2018)

Fig. 2. Enhanced-color transverse sections of icy scarps in late spring/early summer. (A to F) Arrows indicate locations where relatively blue material is particularly close to the surface. Downhill is to the bottom in (A) to (E) (Scarps 1 to 5, respectively) and to the top in (F) (Milankovič Crater).

Banding or layering is visible in several scarps, and (E) shows a distinct change in color as well as multiple fractures cutting the ice.

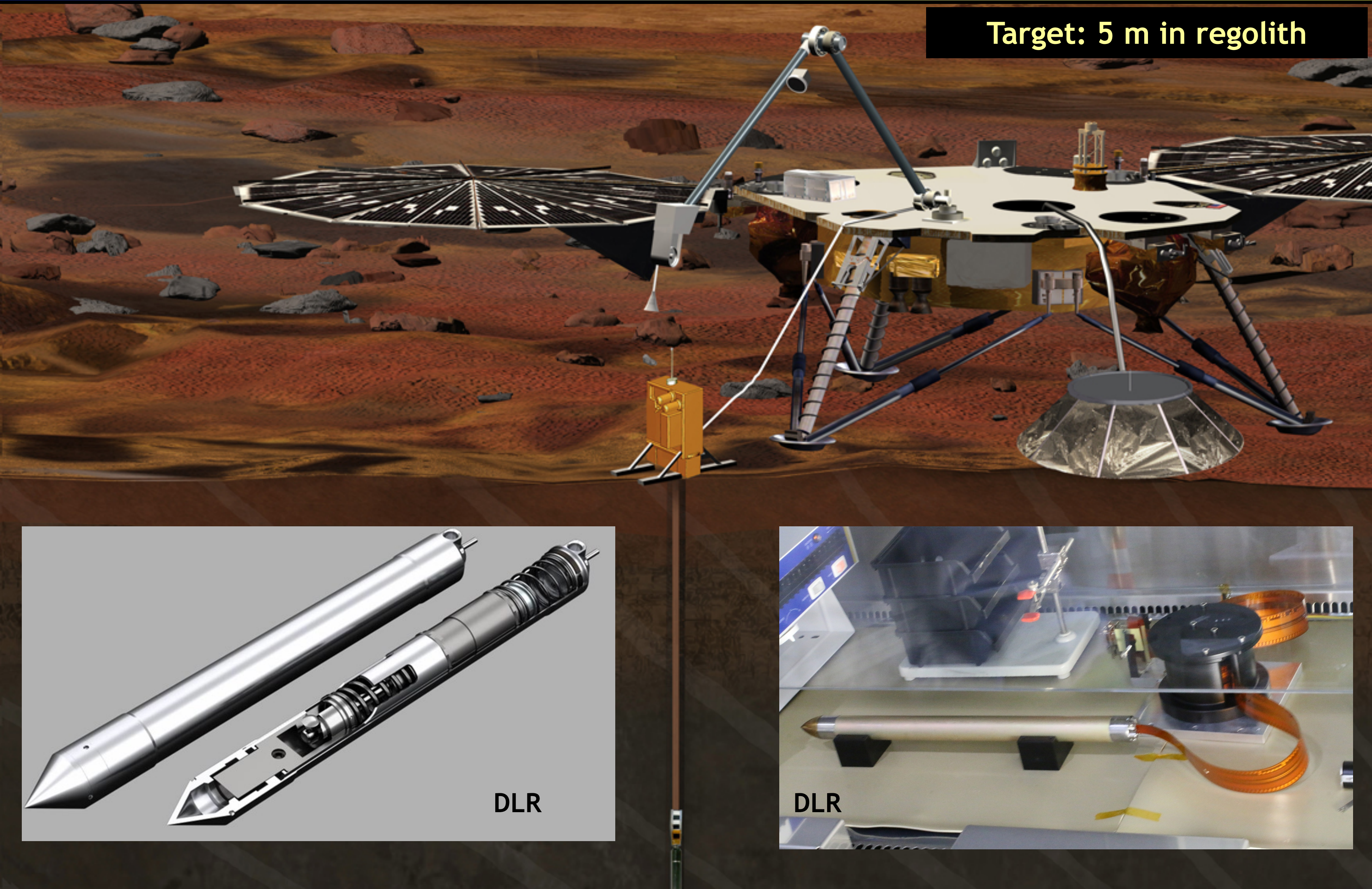
Viking1 (22N) and Viking2 (47N)





Frost at the Viking 2 site

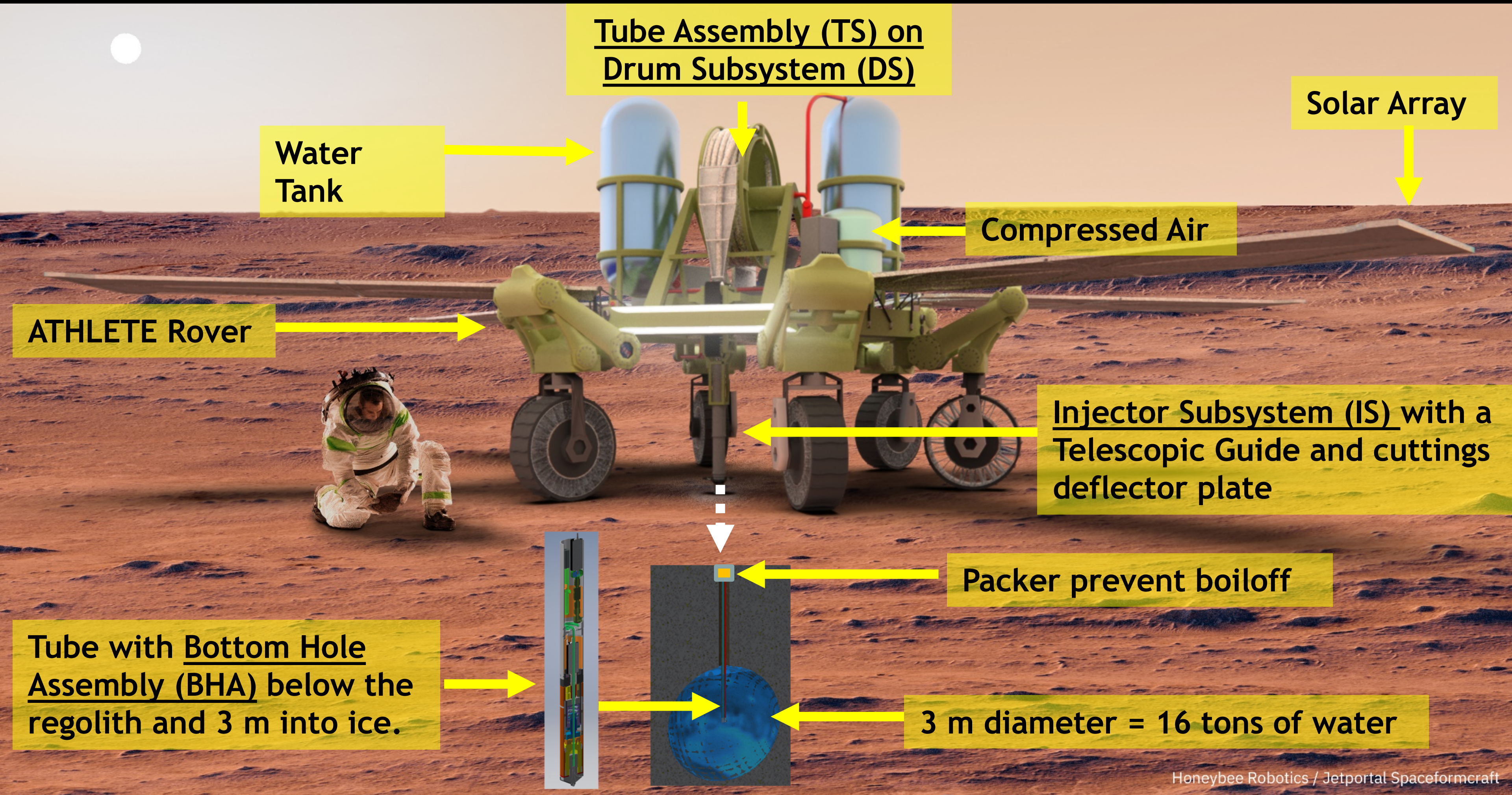
2018 InSight Mole



RedWater: Major Subsystems

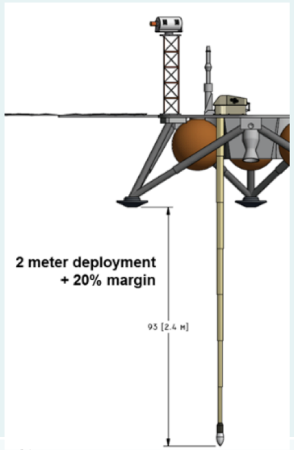
Using terrestrial technologies:

1. Coiled Tubing: Create a hole
2. RodWell: Melt and extract water

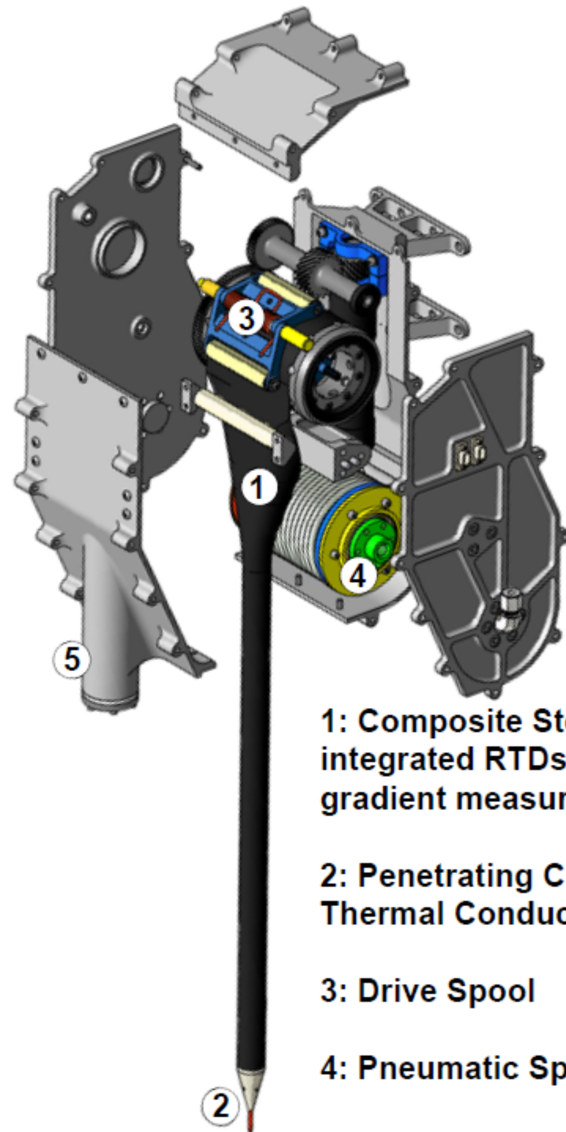


How to make 20+ m hole?

Drilling ~20m regolith and ~3m ice

	Coiled Tubing	Telescopic	Jointed Pipe	Wireline
				
Robotic complexity	Low	Medium	High	Medium
Borehole diameter	Small	Large	Small	Small
System mass	Low	Medium	High	Low
Chips transport	Compressed air	Compressed air	Compressed air	Bailer
Borehole stability	Not a problem	Not a problem	Not a problem	Casing
Weigh on Bit	Limited by lander mass	Limited by lander mass	Limited by lander mass	Via anchors and Z-stage
Antitorque	Need stiff tube	Square tubing	Need stiff tube	Not an issue
Instrumentation	Easy	Easy	Difficult	Easy
Can leave in a ground to form Rodwell	Yes	Yes	Yes	No
Maturity or TRL	Used in oil field. TRL5 (Honeybee)	Used in mining as raise borers	Used in oil field, geotechnical drilling. TRL 5 (Honeybee)	Used in Antarctica, Greenland. TRL5 (Honeybee)
Depth of planetary drill, if applicable	2 m in 2 minutes in compacted (1.9 g/cc) JSC-1A (Honeybee)	Under development for SMD	8 m in rock (Honeybee)	13.5 m and 10.5 m in rock (Honeybee)
Downselect?	Y	Maybe	N	N

Prior “Coiled Tubing” Development



1: Composite Stem with ~10 integrated RTDs for thermal gradient measurement

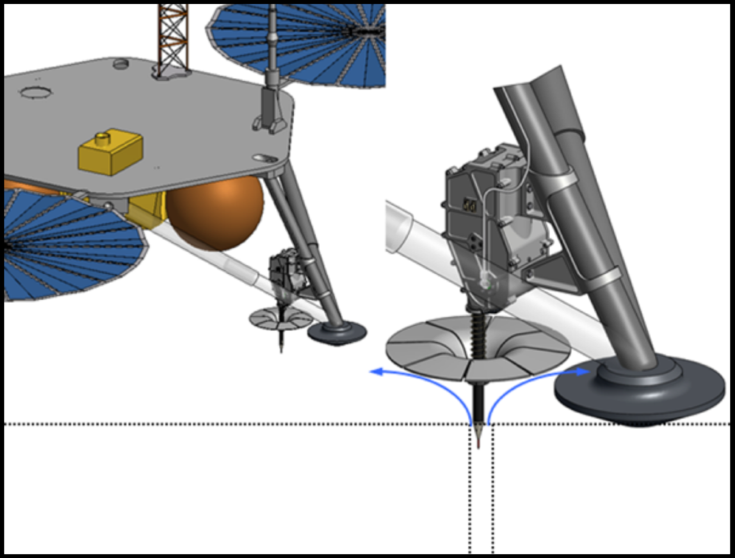
2: Penetrating Cone with Thermal Conductivity Needle

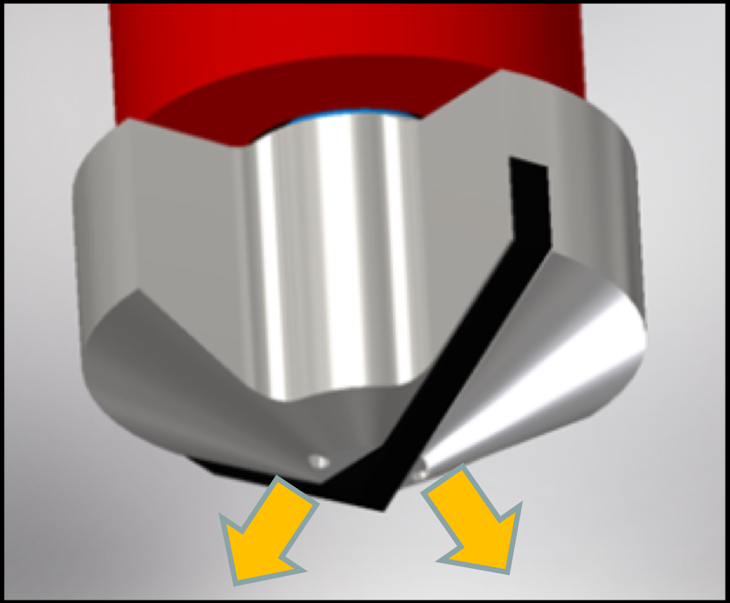
3: Drive Spool

4: Pneumatic Spool

5: Guide Bushing and Brushes

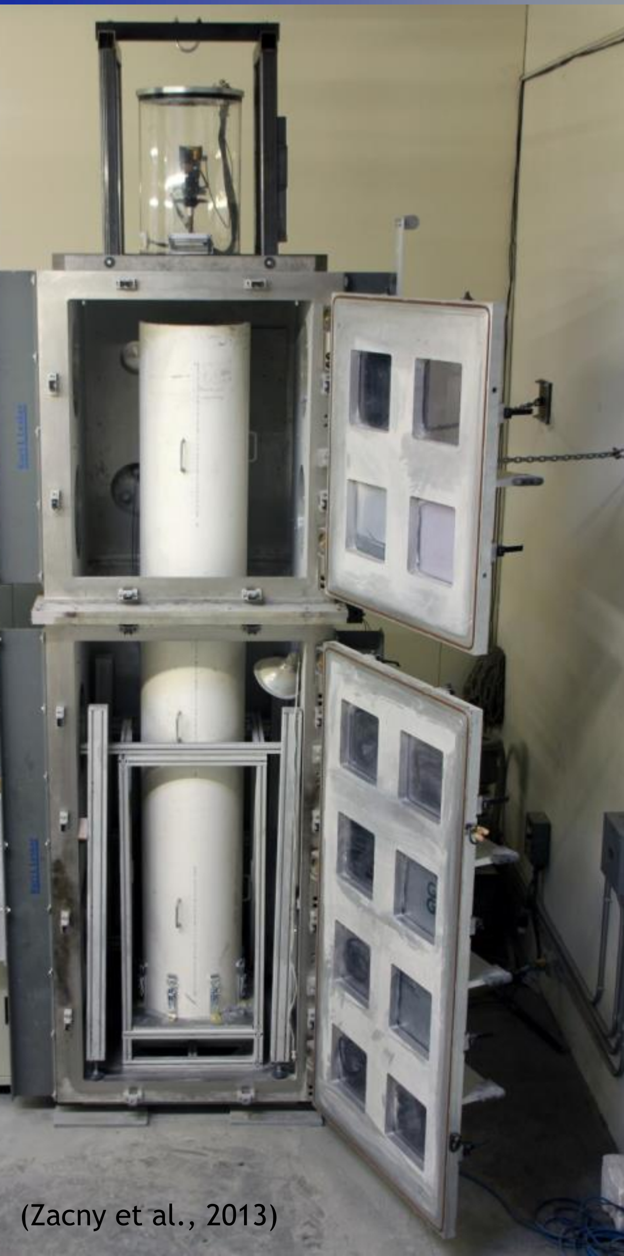
Proof of Concept



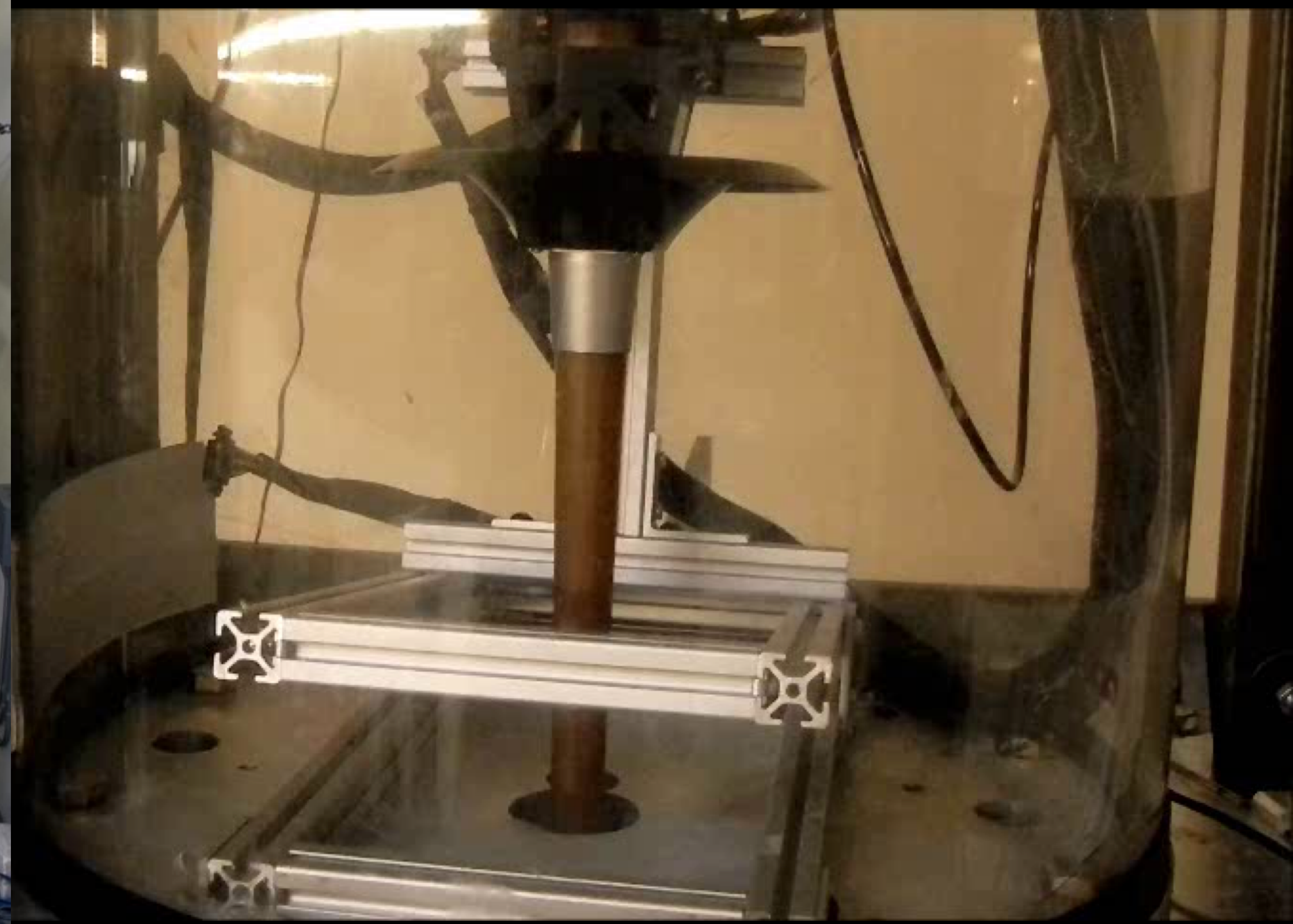


Pneumatic Drill Testing using "CT"

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

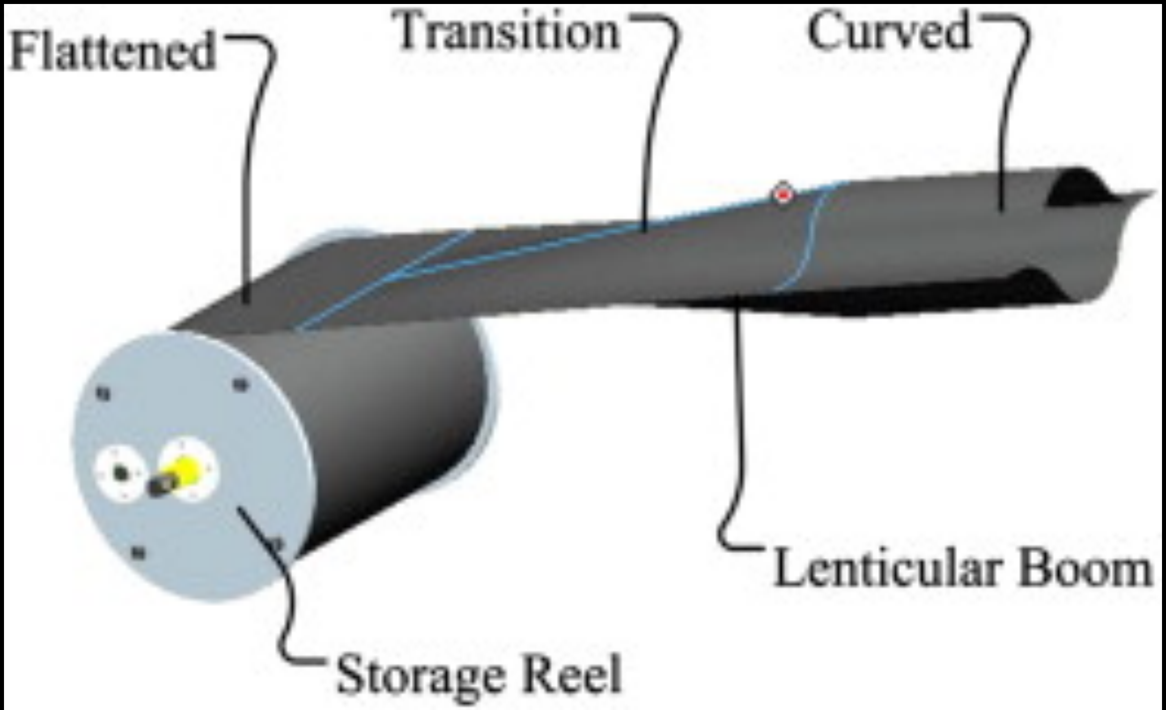


(Zacny et al., 2013)



Good Option: Collapsible Tubular Mast

Viking Arm

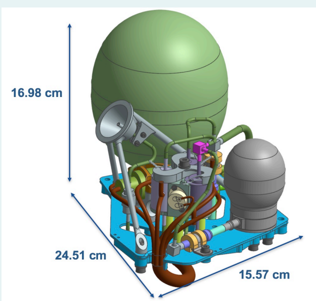
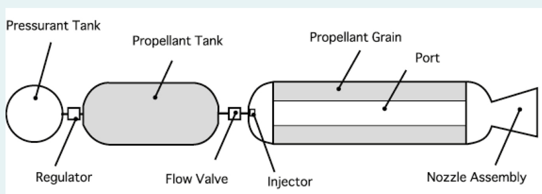
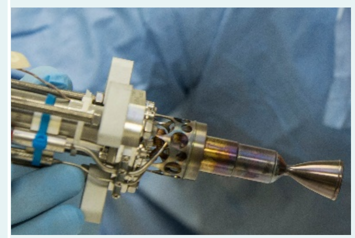


Terrestrial CT Rig: RoXplorer

- RoXplorer: 15 tons, drills to 500 m at 1 m/min in hard rock
- What would it weigh if the target was 25 m (20x less)?

Gas Source?

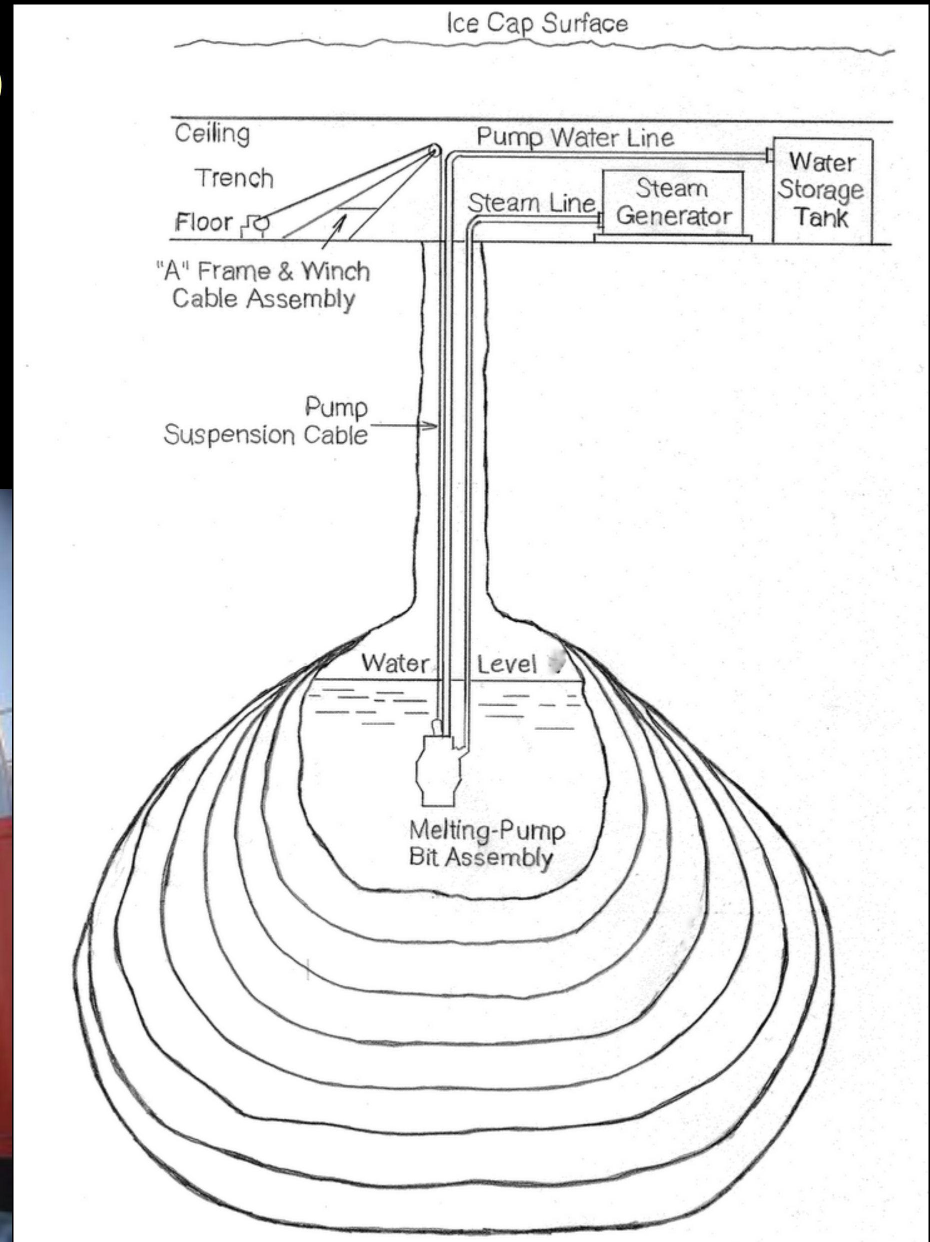
- Based on tests, need 1 gram of gas for each 500 grams of soil
- Assuming 5 cm diameter and 25 m deep hole, need 10 kg of gas
- 5 options – all feasible!

	Gas tank from earth.	Helium pressurant	Burn fuel reserves	ISRU gas	Compressed Martian air
					
TRL	9	9	9	5	7
Pros	Ready to be used	Could come 'free' if not required for takeoff.	Need a thruster and either capture gas in a tank or use it when needed.	It's already there!	On demand. Compressor is being developed for Mars2020 MOXI. The PI is member of RedWater.
Cons	Consumable. Ti tank with 10 kg He at 14 MPa is 30kg.	Need to access the tank.	Need dedicated thruster	Need tanks.	Requires electrical power. Compressor has limited life span.

Is RodWell Feasible for Mars?

RodWell at the South Pole

RodWell (Now)

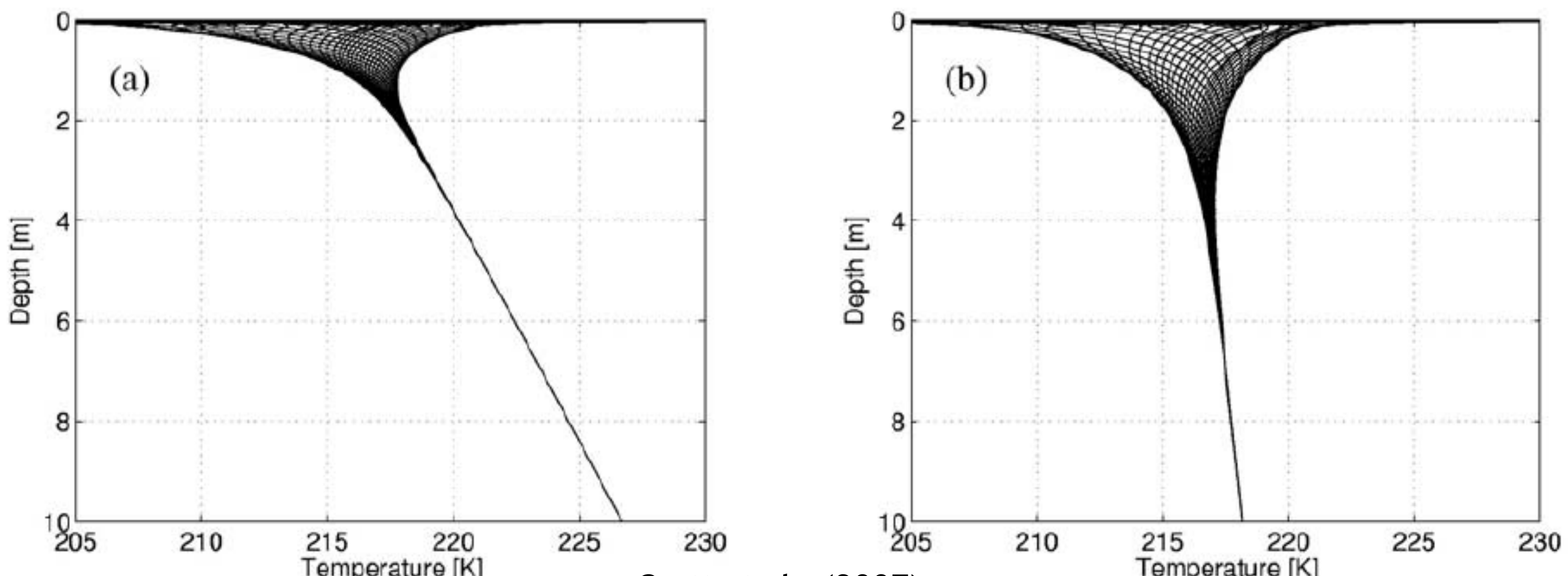


Snow melter (Before)

Ice Temperature

- South Pole ice at 8 m depth is –50°C, irrespective of season (temperature fluctuates within top 2 m, only). As such, RodWell works well in -50 °C ice.
- The annual temperature at the Viking2 site (~higher than Arcadia Planitia) is -110°C to -5°C.
- Extrapolating along thermal gradient we expect the ice at ~20 m depth to be at -60 °C
- Expecting similar temperatures of ice!
- Mars InSight mission will validate the models in 2018

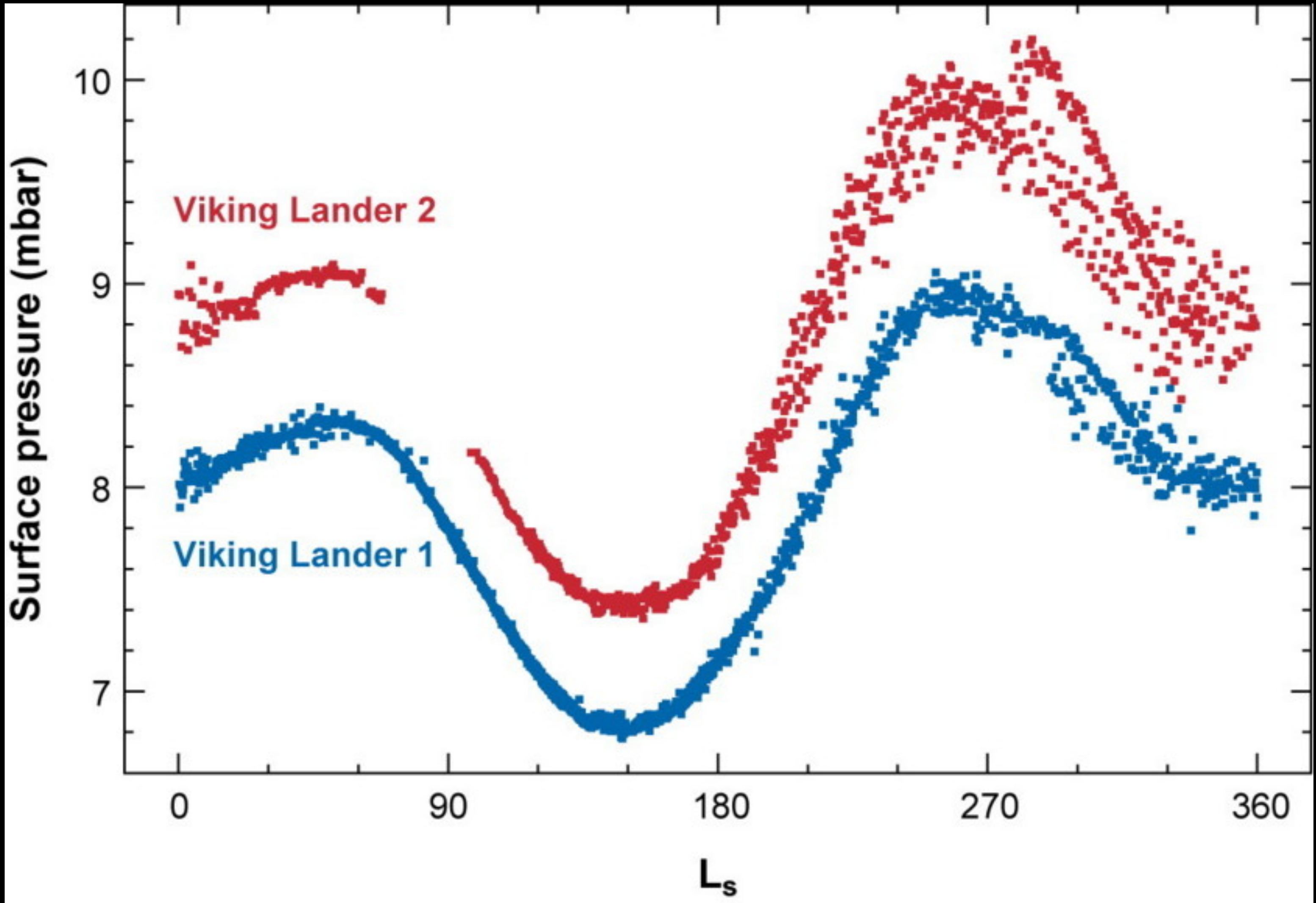
Depth penetration of the annual temperature wave at 120E, 20N, using data from the NASA/MSFC Mars GRAM as the surface boundary condition and assuming a planetary heat flow of 20mW/m2.



Grott et al., (2007)

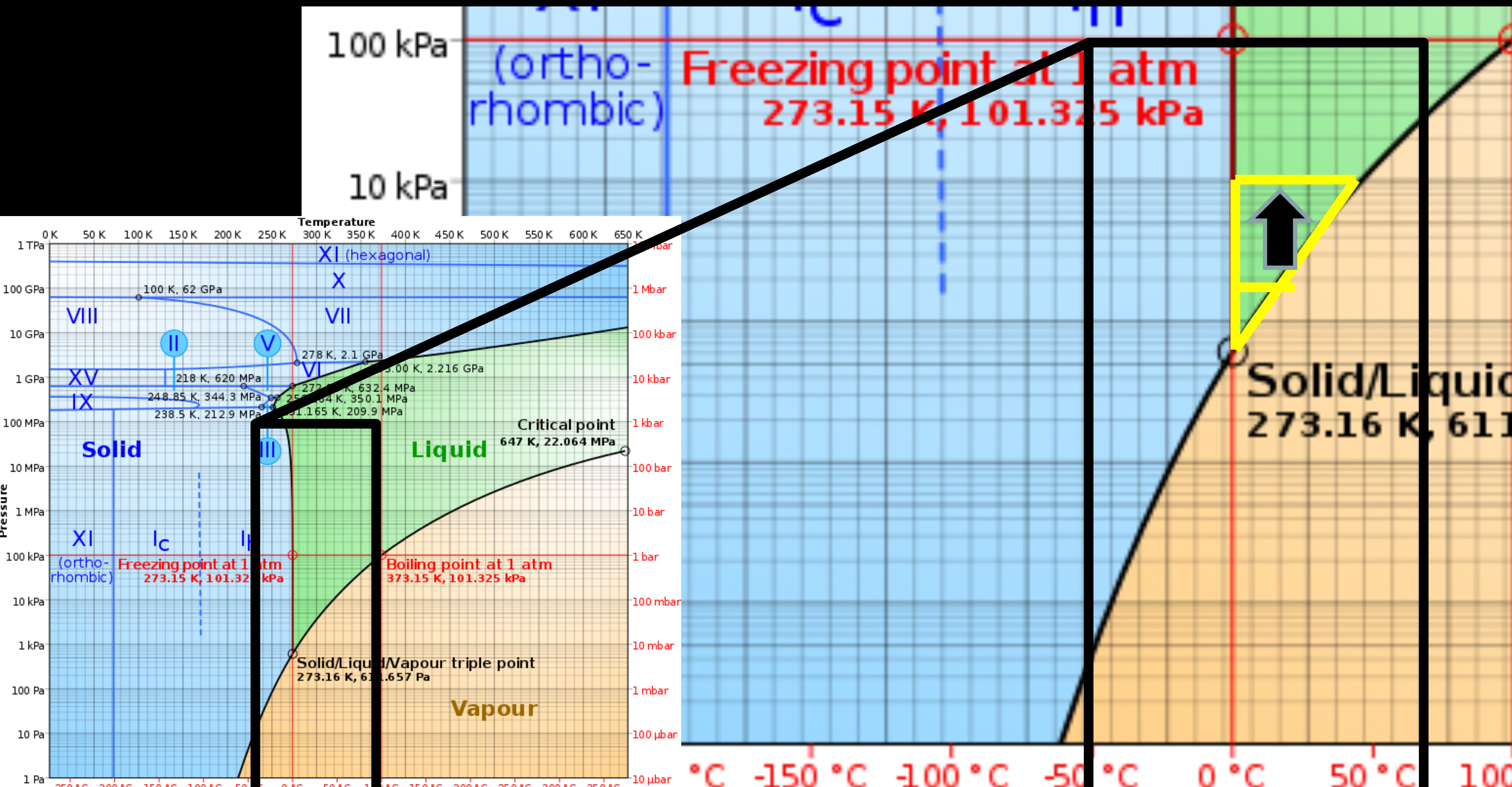
Liquid water is possible

- Atmospheric pressure is always above triple point.
- When atmosphere reaches Rh of 100%, liquid water can form.



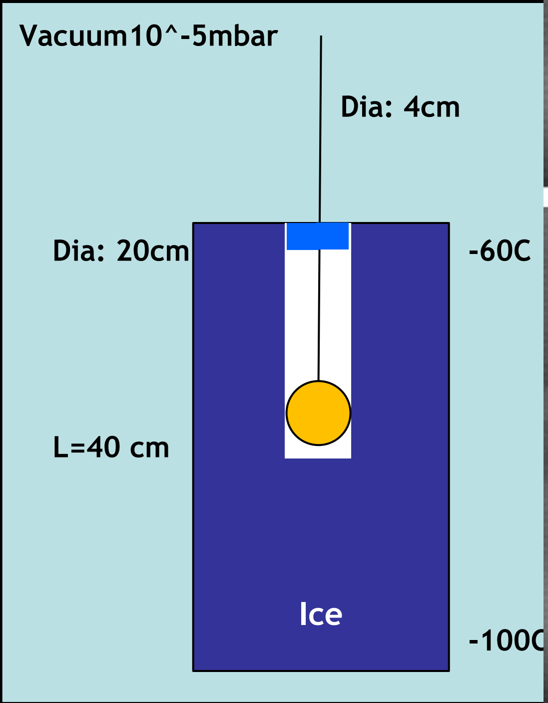
Liquid water is unstable...

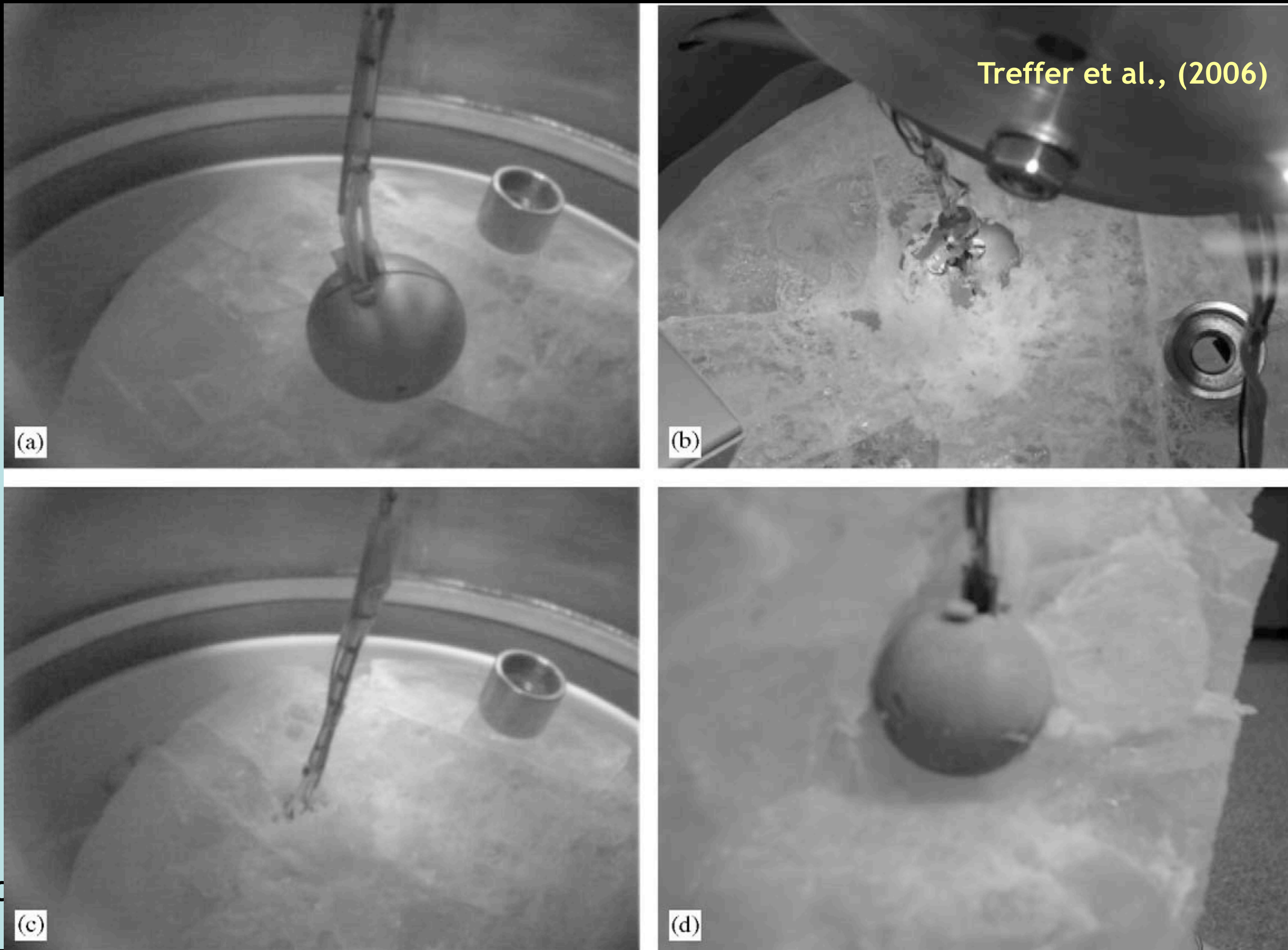
- Keep water liquid (not vapor) to reduce energy (334 kJ/kg vs 2260 kJ/kg)
- Rodwell needs to be pressurized to allow liquid water to be stable over larger temperature range (otherwise it will boil off).
- Use a packer (active approach) or plug it via water vapor re-condensation.



Borehole closure during melting

- Refreezing around the cable caused the probe to lose contact with the ice and hang from the cable
- Mars borehole will self seal



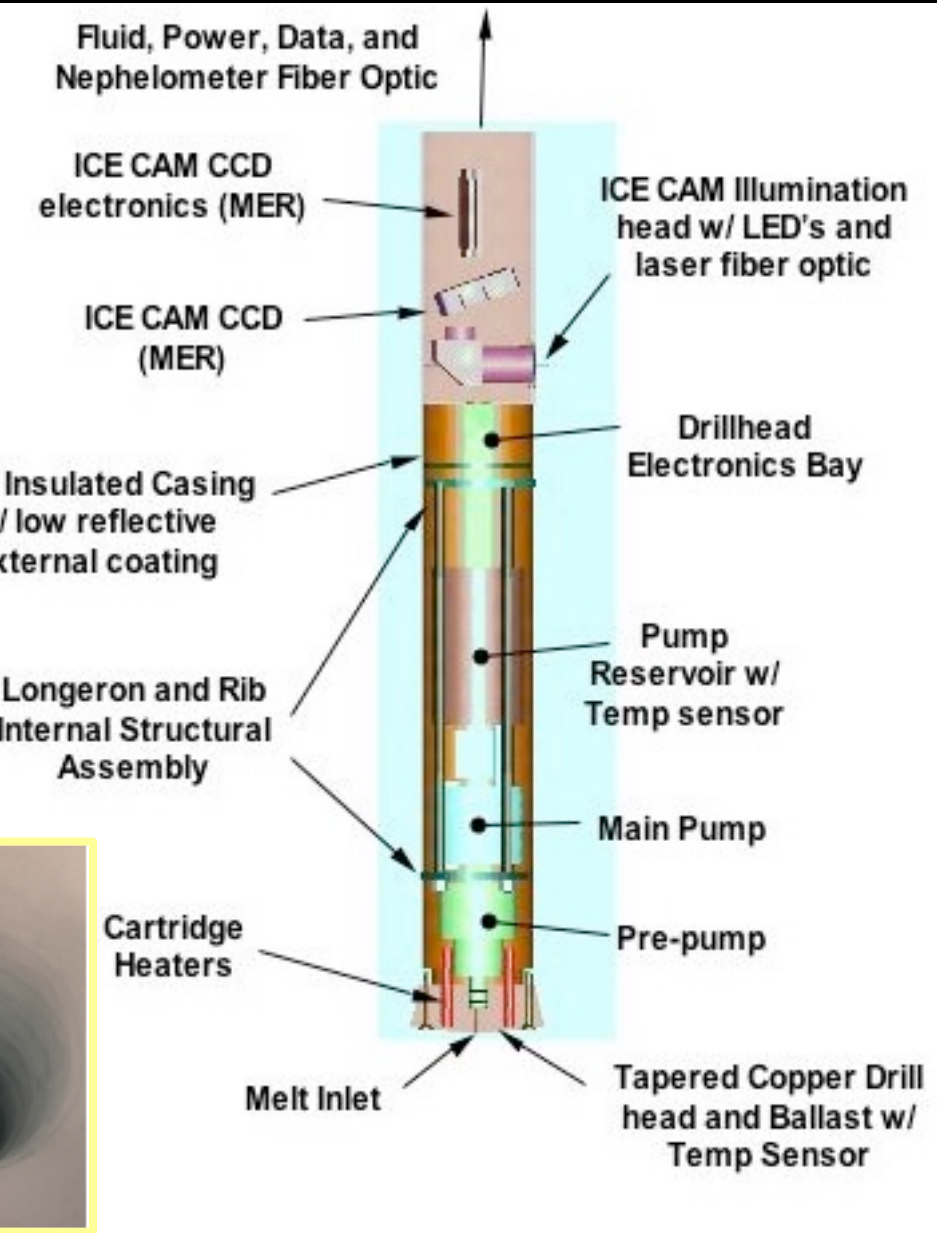


Treffer et al., (2006)

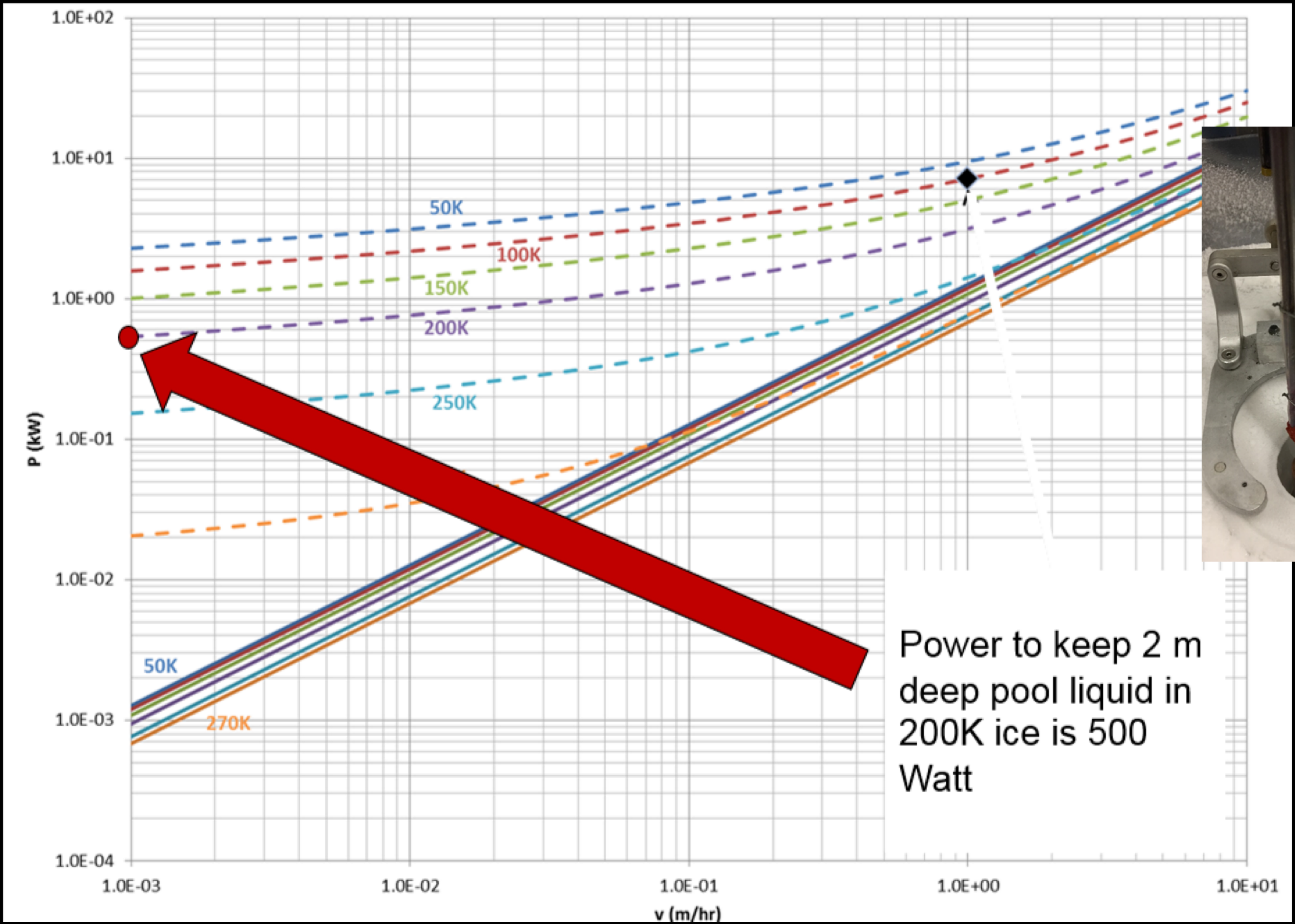
Chronos: Melting and Pumping

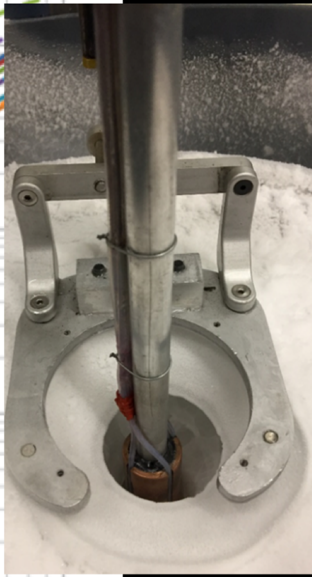
- Discovery class mission to Mars Polar Layer Deposits
- The drill is suspended from a tether, which provides down-hole power and data transfer and keeps the meltwater liquid all the way to the surface.
- A 7.5 cm diameter drill, with ~200–400 W, can descend at 20–45 cm/hr in 163K ice.

Hecht and Saunders (2003)



Melt Probe Tests



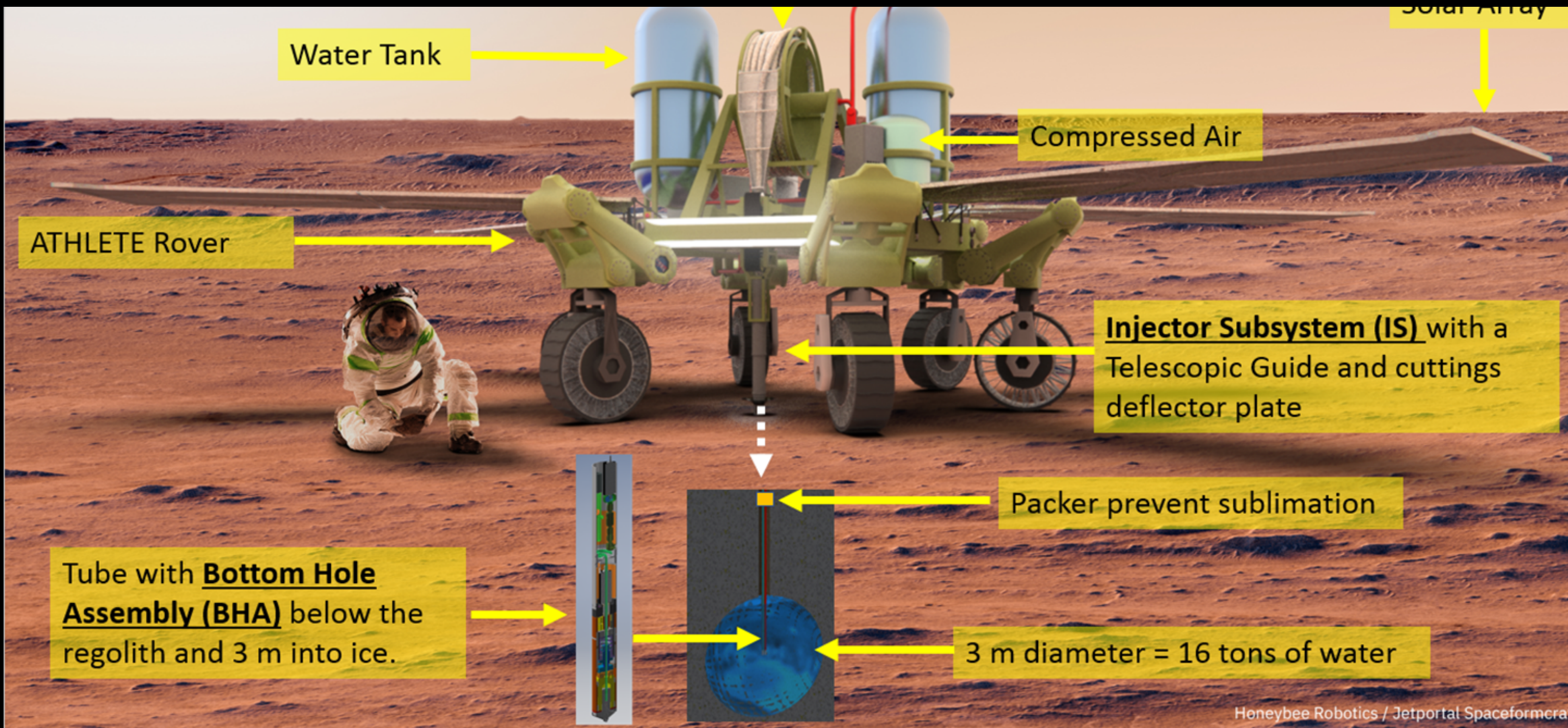


Power to keep 2 m deep pool liquid in 200K ice is 500 Watt

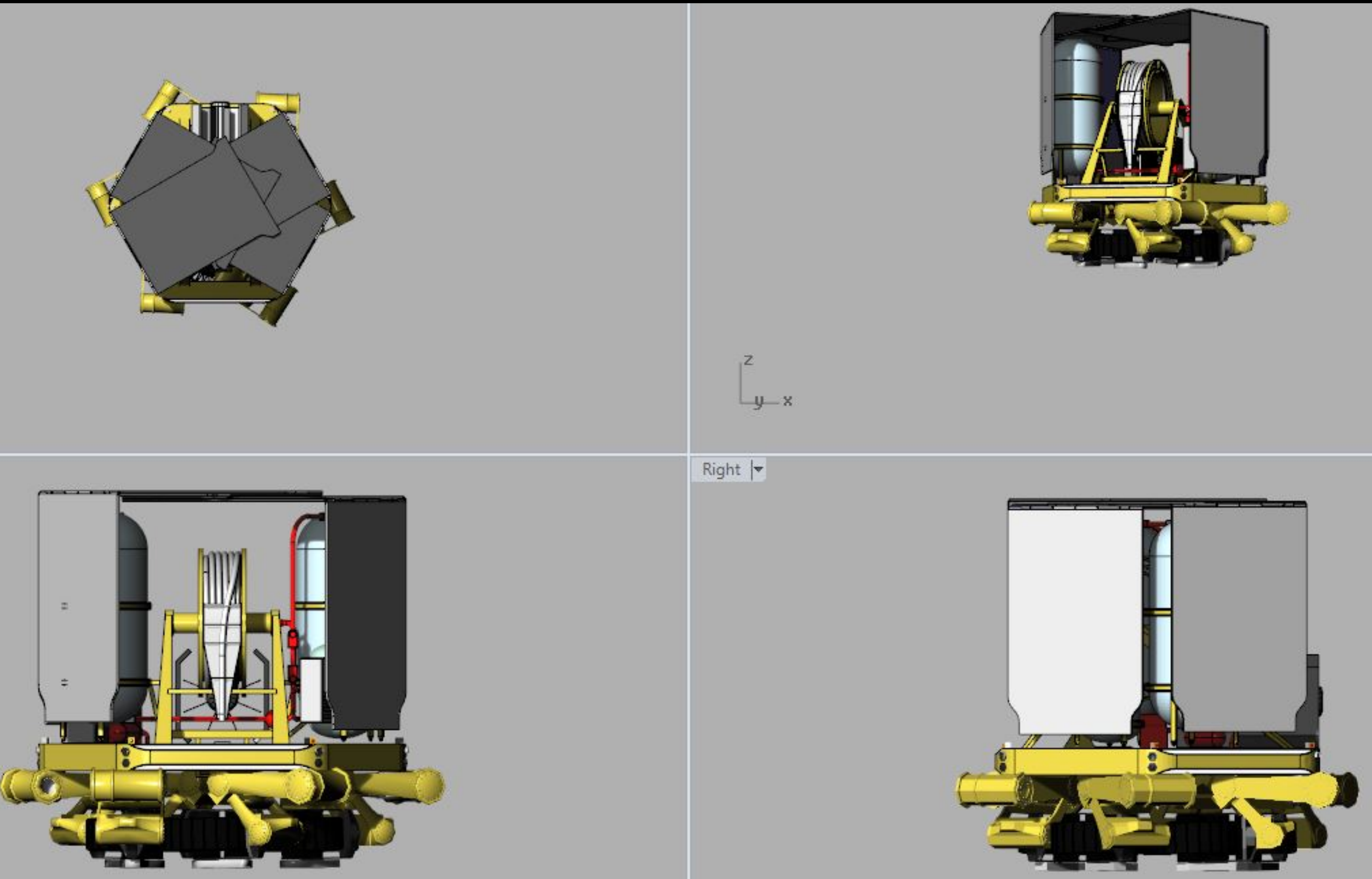
RedWater Details

How many RedWaters are needed?

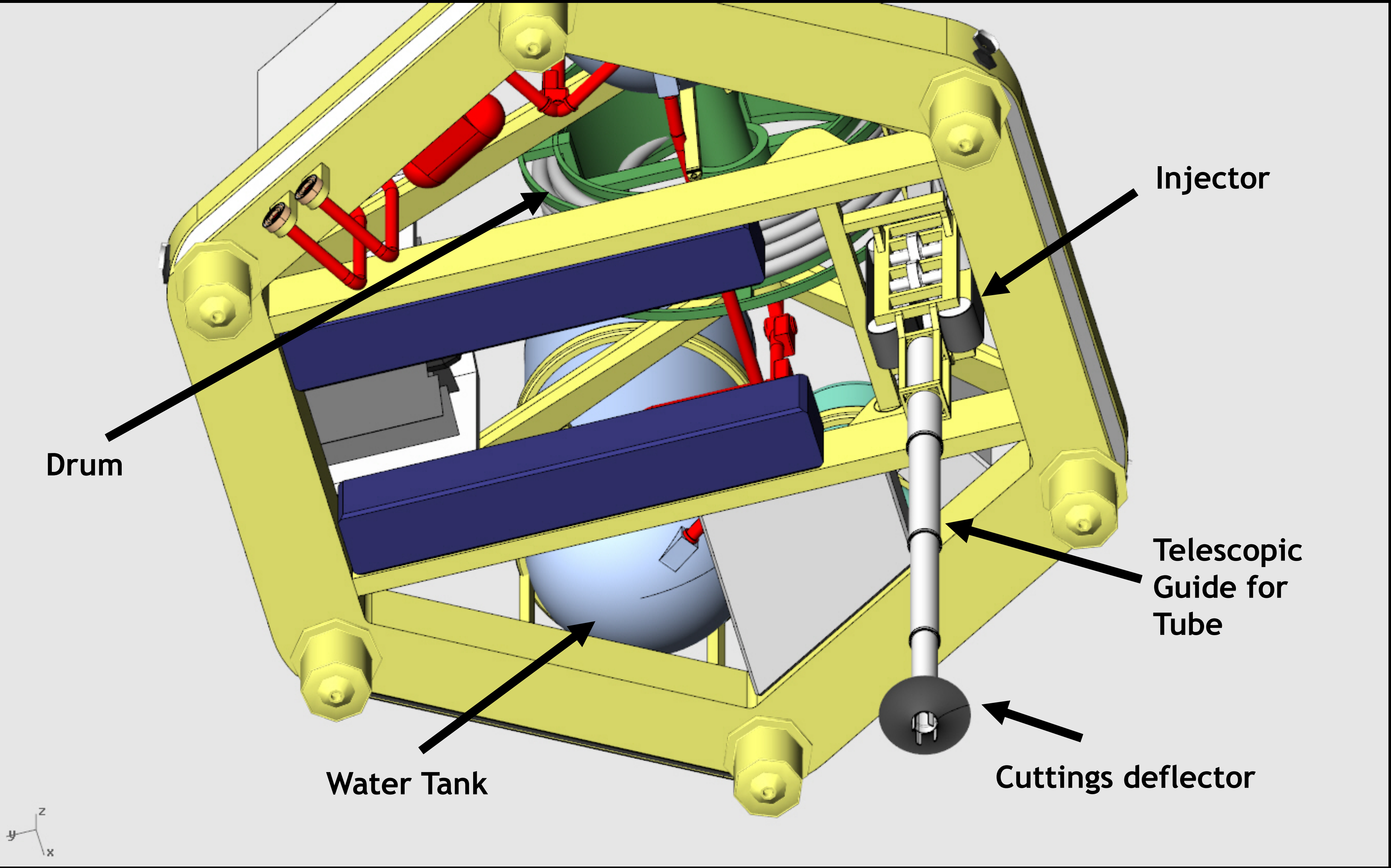
- Goal: 16 tons (per solicitation).
- 16 tons fits a sphere (for simplicity a sphere rather than a bulb) of ~3 m in diameter.
- Need approx. 3 m of ice above the melt hole to support overburden regolith
- Hence the ice needs to be 3 m + 3 m = 6 m thick (less than the thickness of ice layers observed by SHARAD)
- Need 1 RedWater



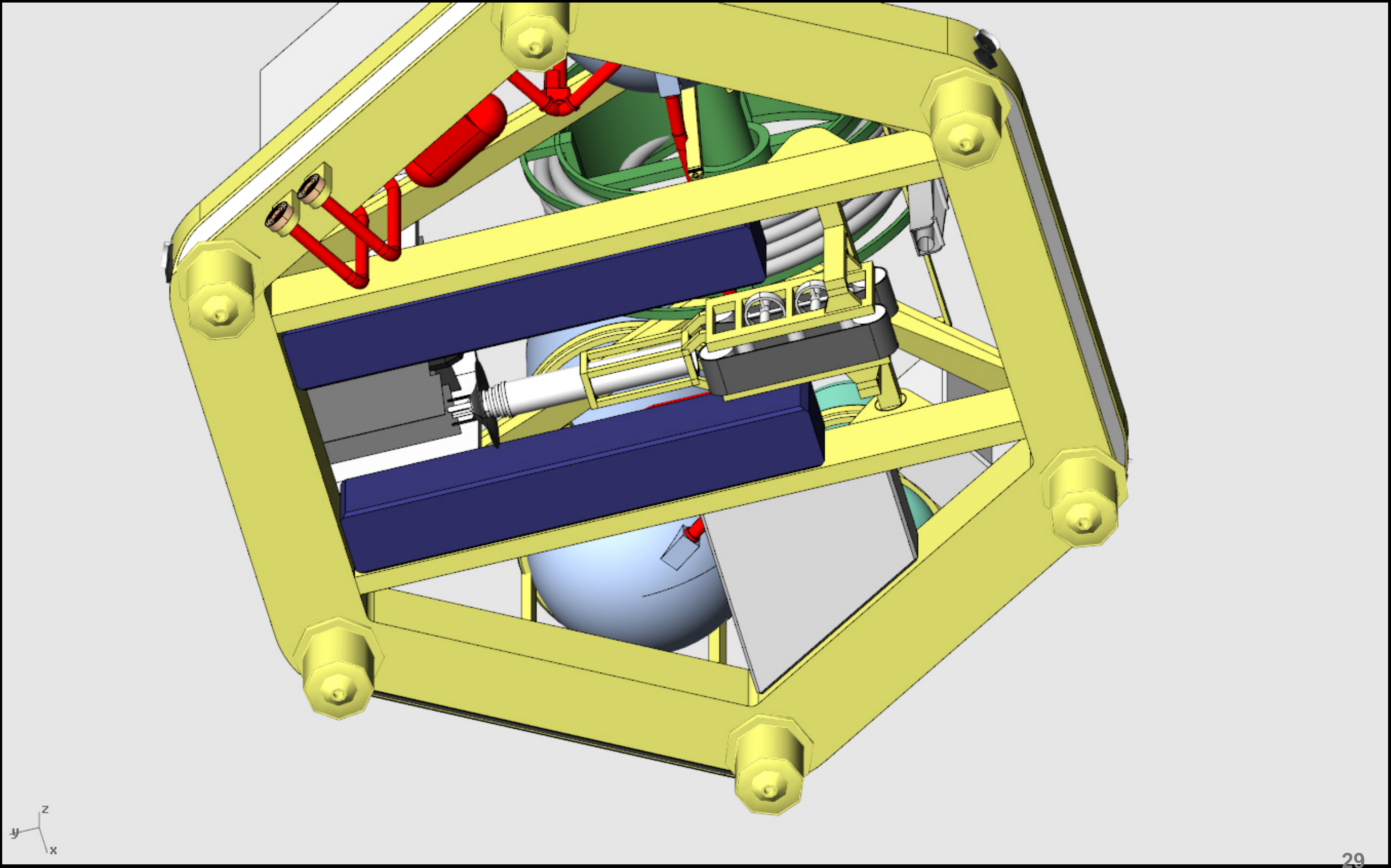
RedWater: Stowed



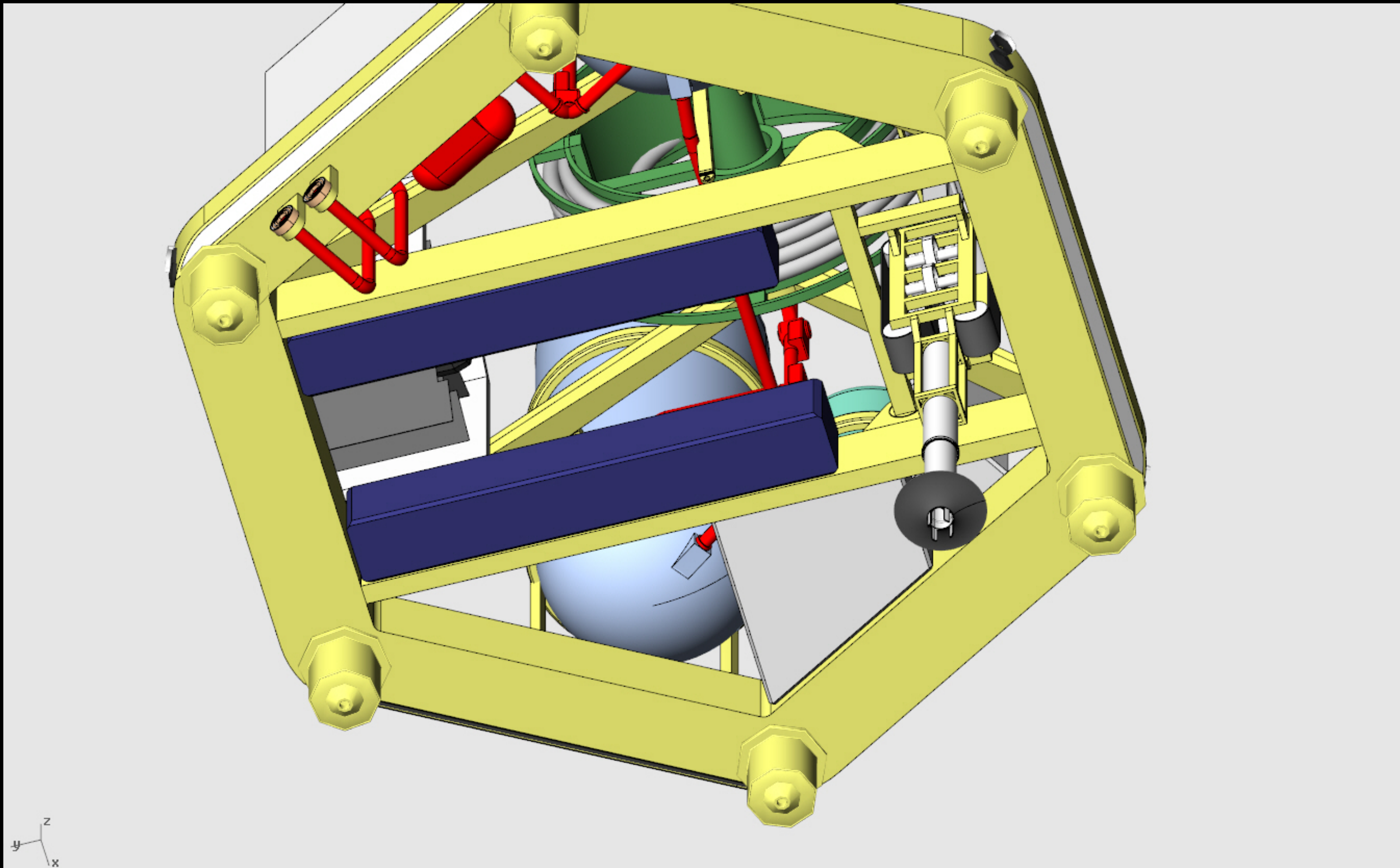
RedWater: Bottom view



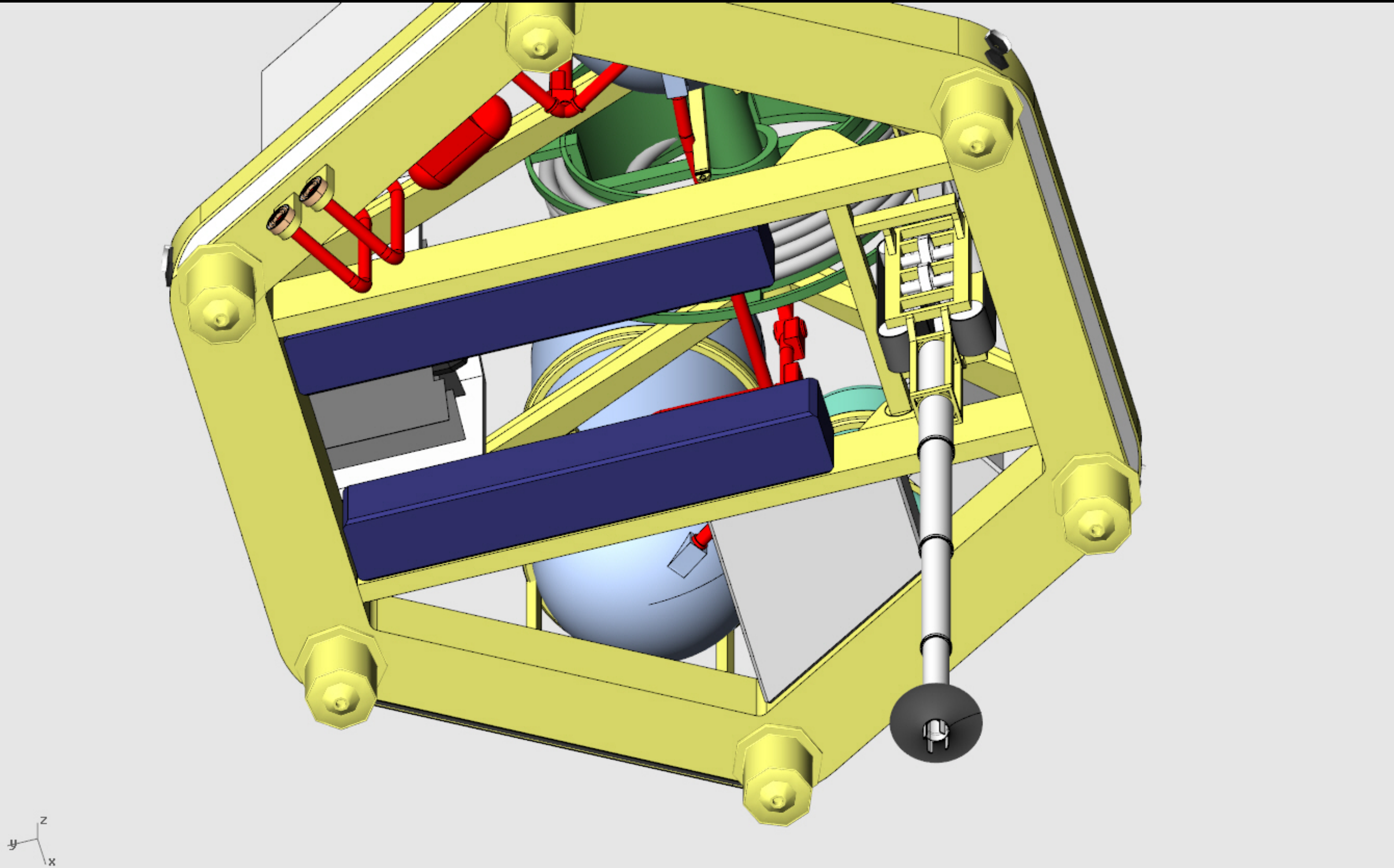
Injector Deployment 1/3



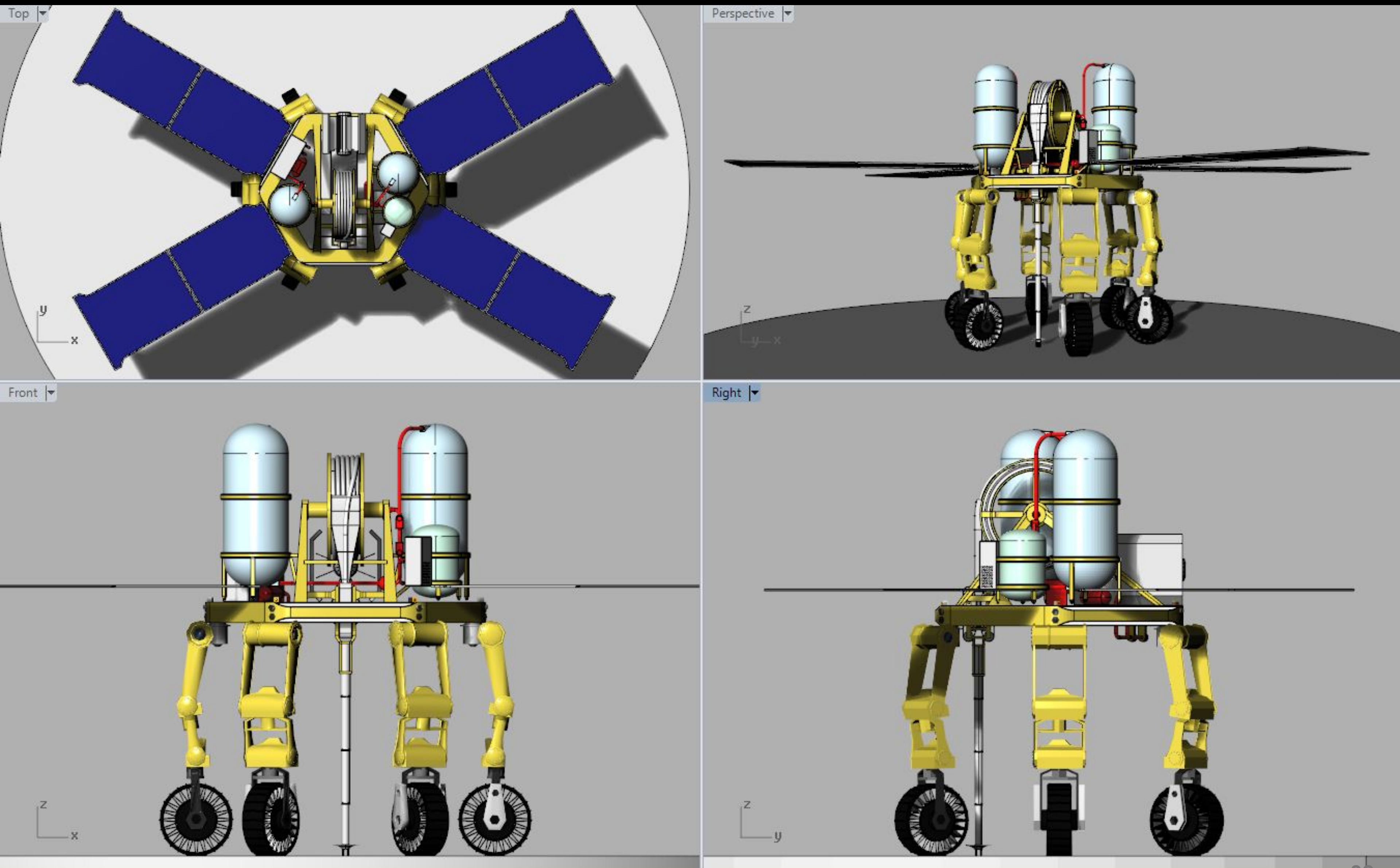
Injector Deployment 2/3



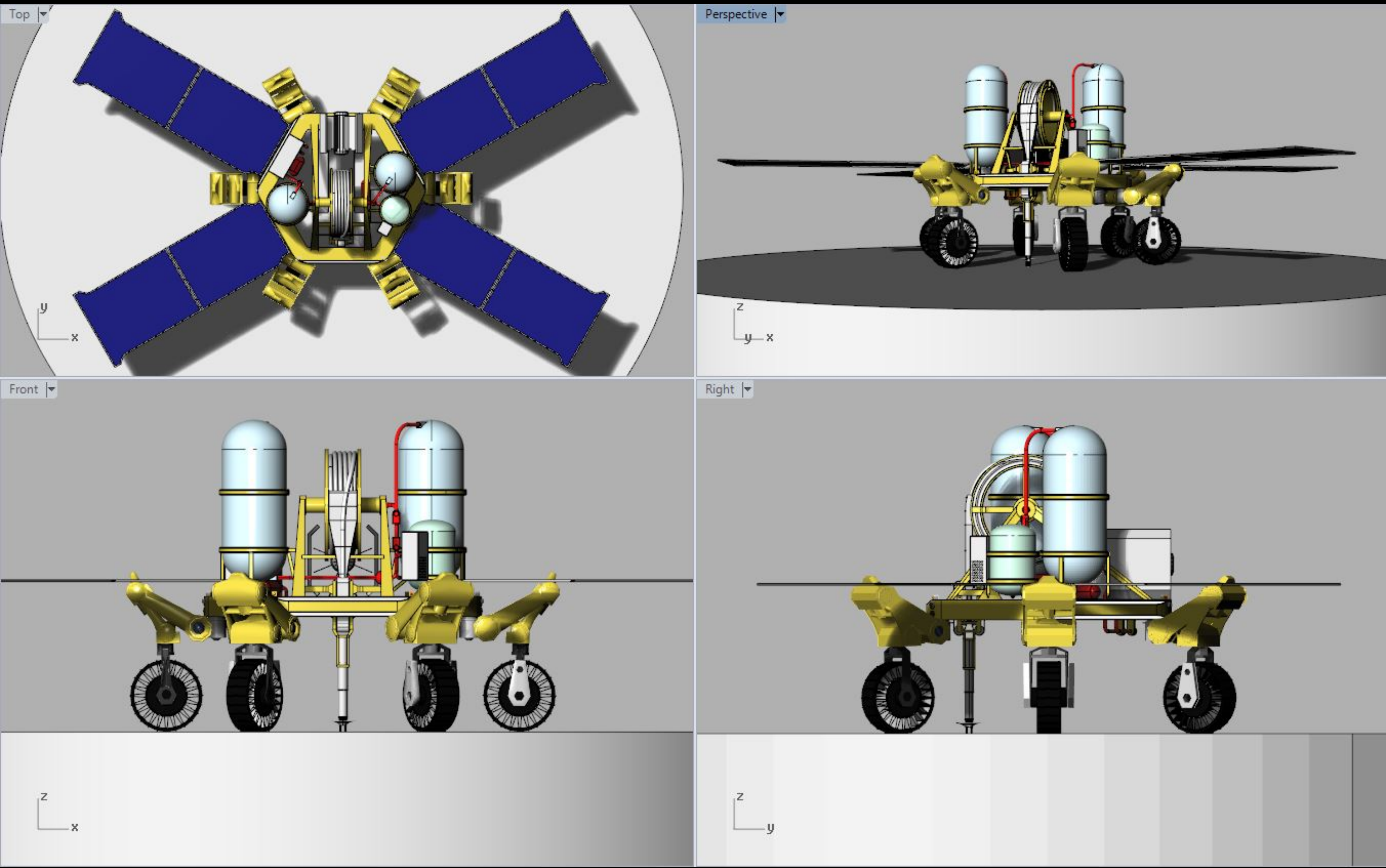
Injector Deployment 3/3



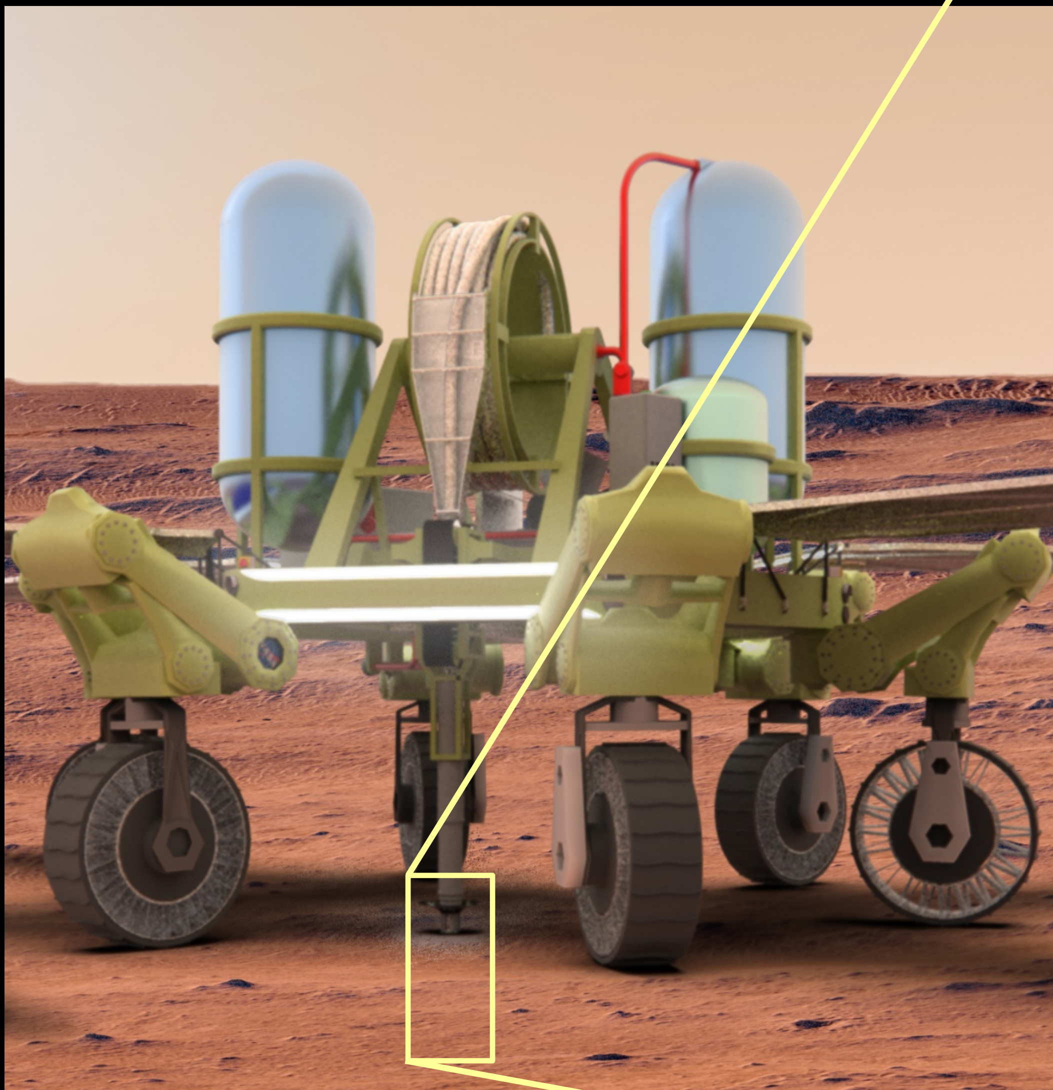
Squatting to drill 1 / 2 (eliminates injector)

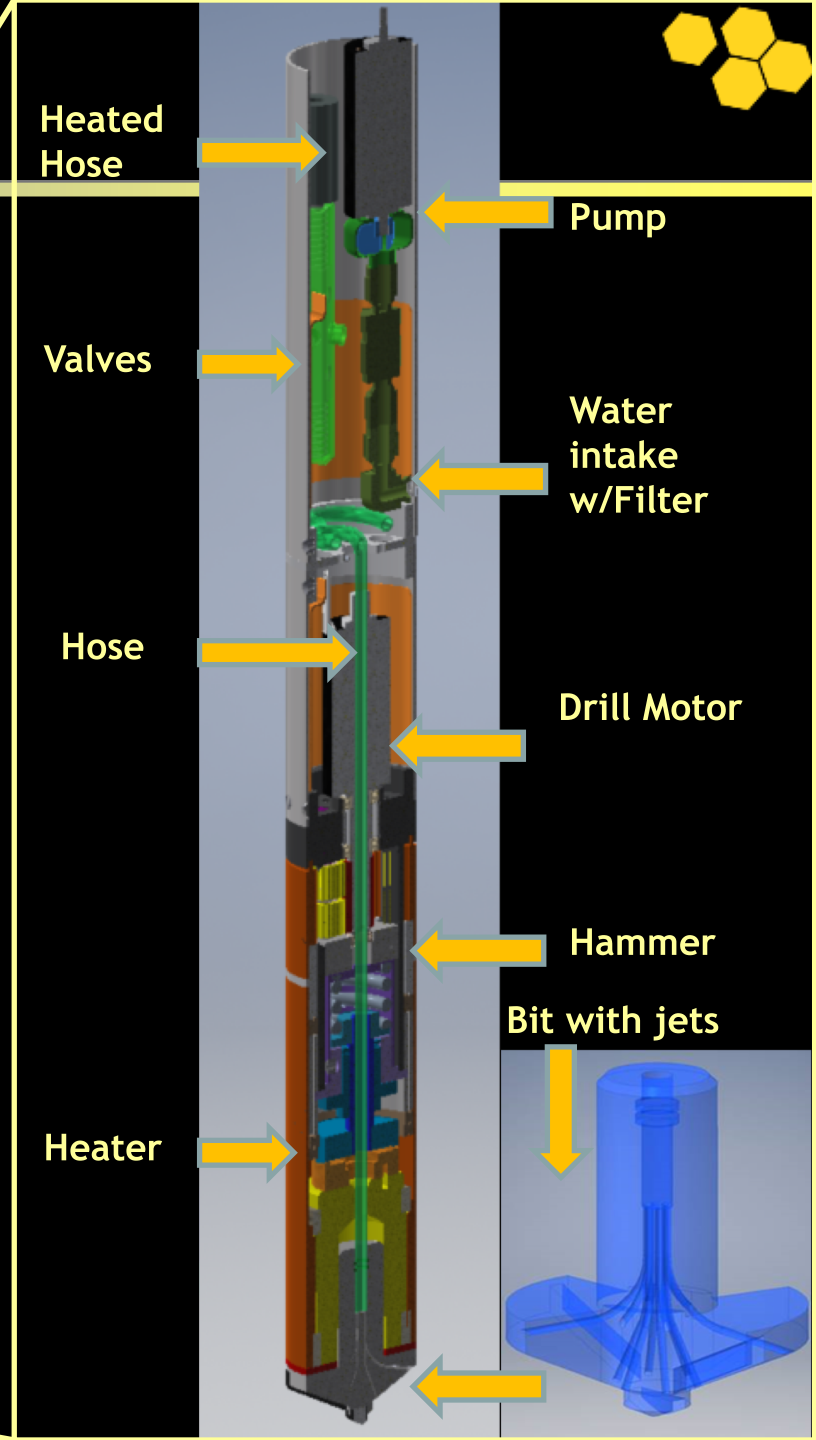


Squatting to drill 2 / 2 (eliminates injector)

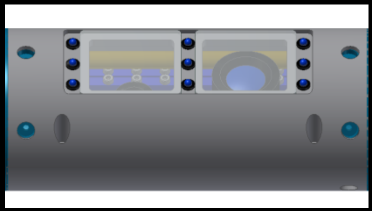


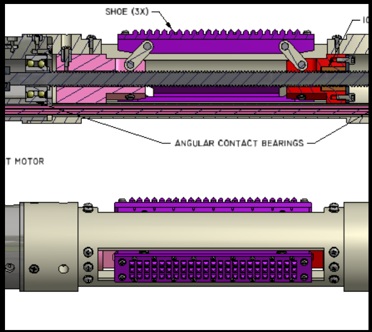
Bottom Hole Assembly



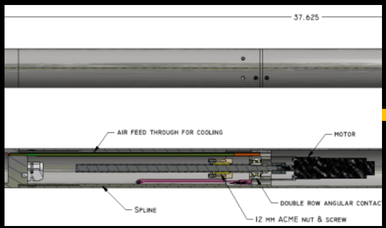


BHA Heritage: Wireline Drills

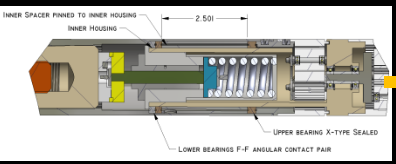




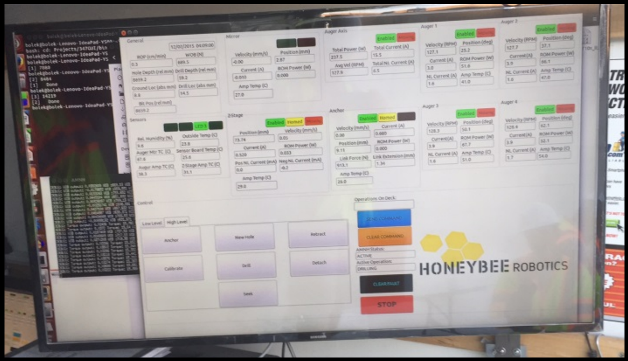
Anchor

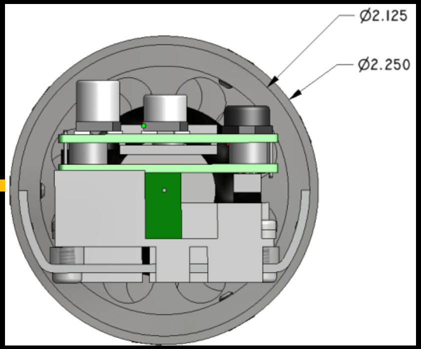


Z-stage

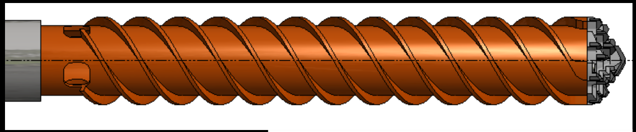


Hammer





Electronics



Auger and Bit


Two holes
• 10.5 m
• 13.5 m
U-HAUL
MISSISSIPPI
AMERICAN MUSEUM NATURAL HISTORY
USG
NASA

Acknowledgements

- HEOMD Advanced Exploration Systems
  - NextSTEP-2, ISRU Technology

RedWater