EELS

Exobiology Extant Life Surveyor

Athabasca Glacier as an Icy Moon Analog Environment

The EELS Team
Presented by Richard Rieber

March 6, 2024

Jet Propulsion Laboratory, California Institute of Technology

Agenda

1. EELS Project Overview
2. Meet the Robots
3. Athabasca Glacier and the Field Test
4. Terramechanics
5. Surface Mobility
6. Vertical Mobility
7. Science

EELS Project Overview

JPL Dares Mighty Things

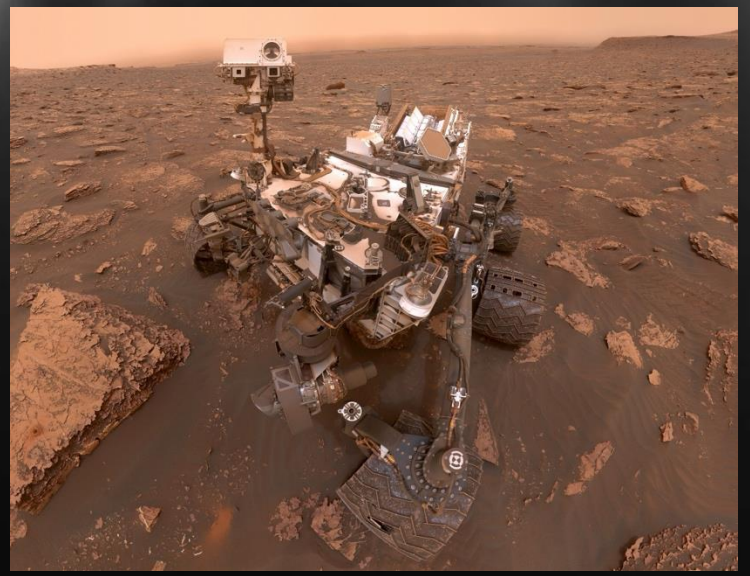
Robotic Exploration 1.0

Pre-Apollo Lunar exploration

High-cadence trial-and-error
e.g. Ranger, Surveyor, and Mariner missions

Robotic Exploration 2.0

Mars



Incremental sophistication in a multi-mission campaign
e.g. Mariner, Viking, Mars Observer, MGS, Pathfinder, Odyssey, MRO

Robotic Exploration 3.0

Subsurface, icy moons, & beyond

One-shot mission with adaptive, intelligent robot(s)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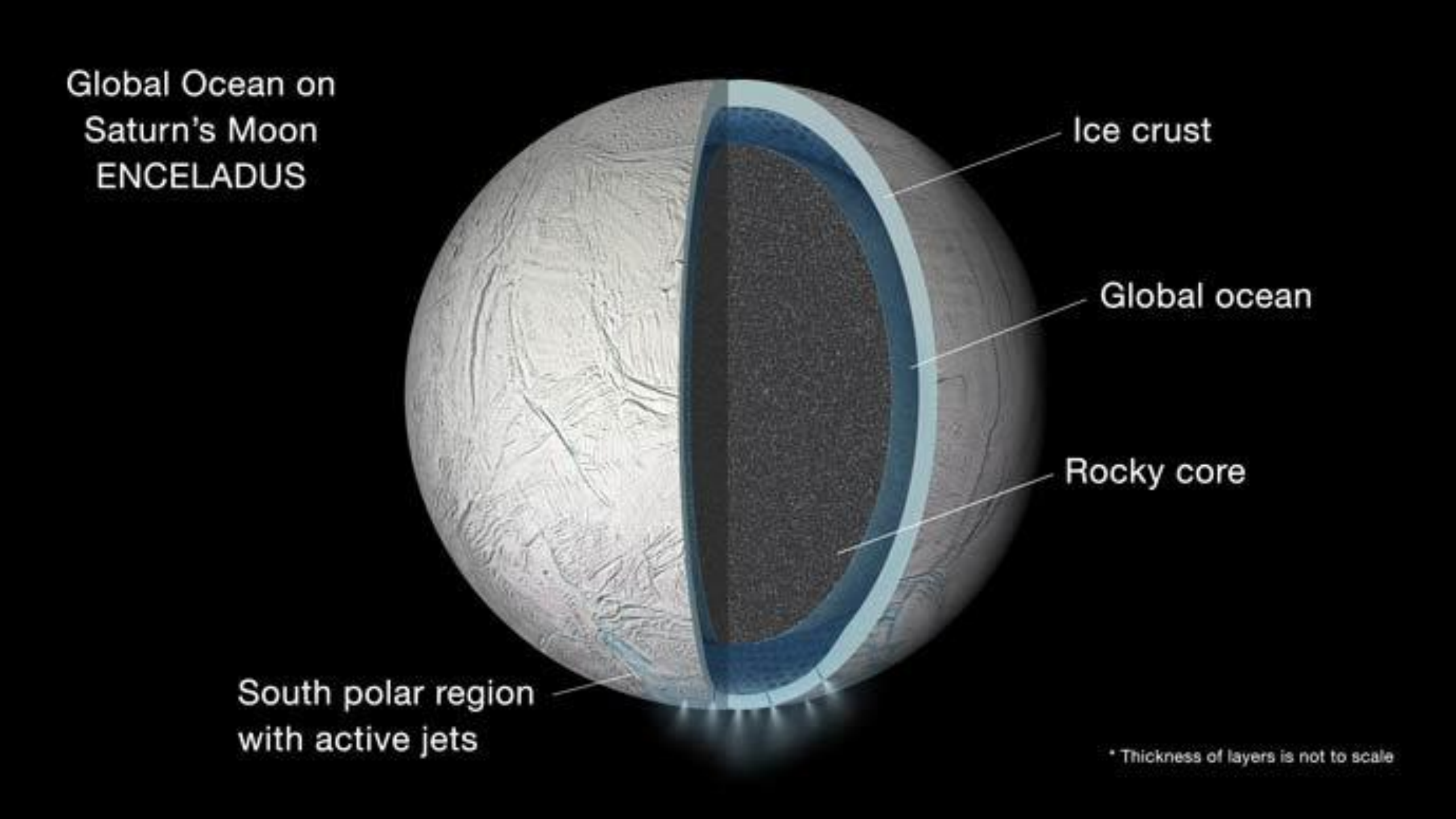
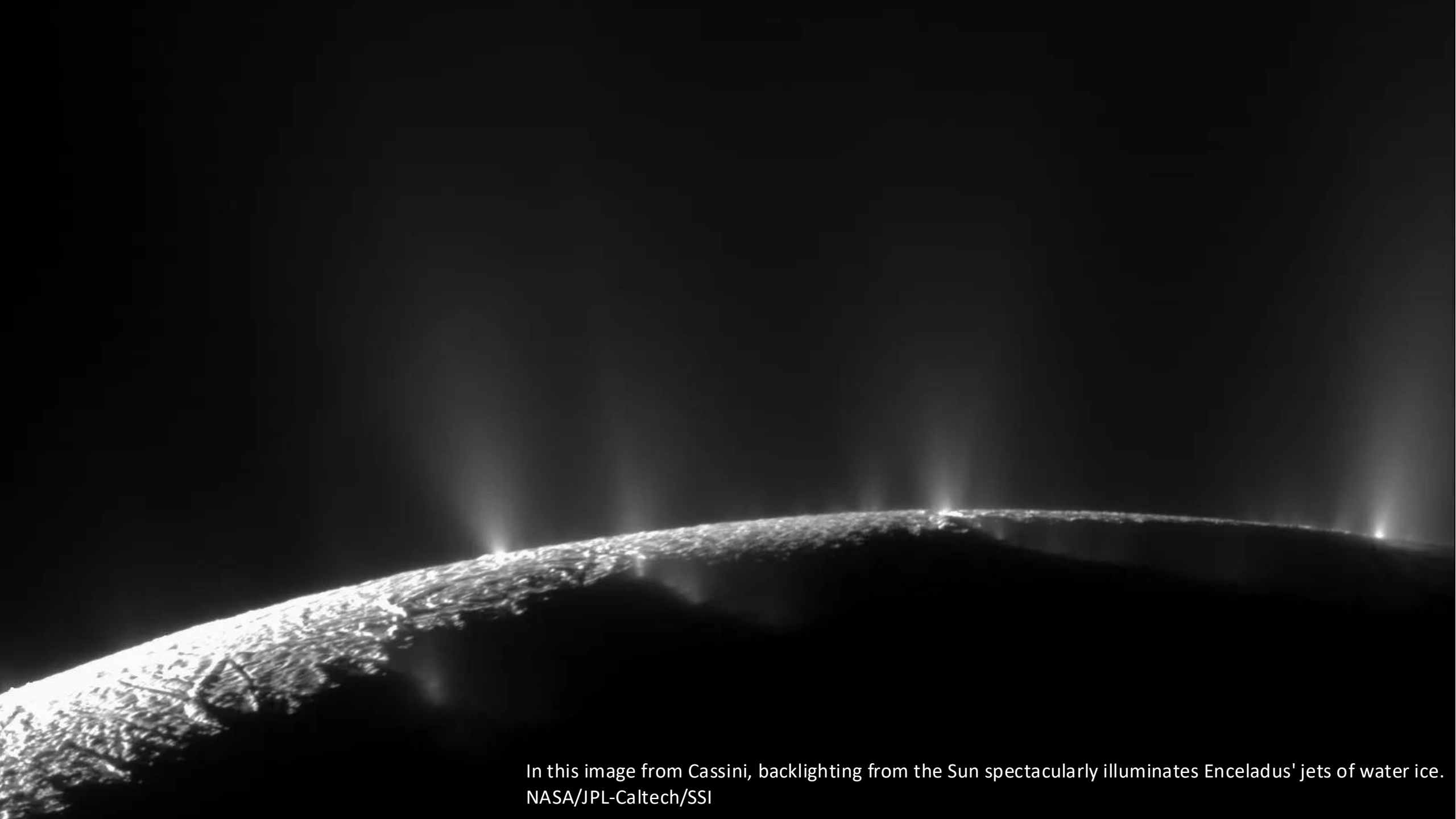
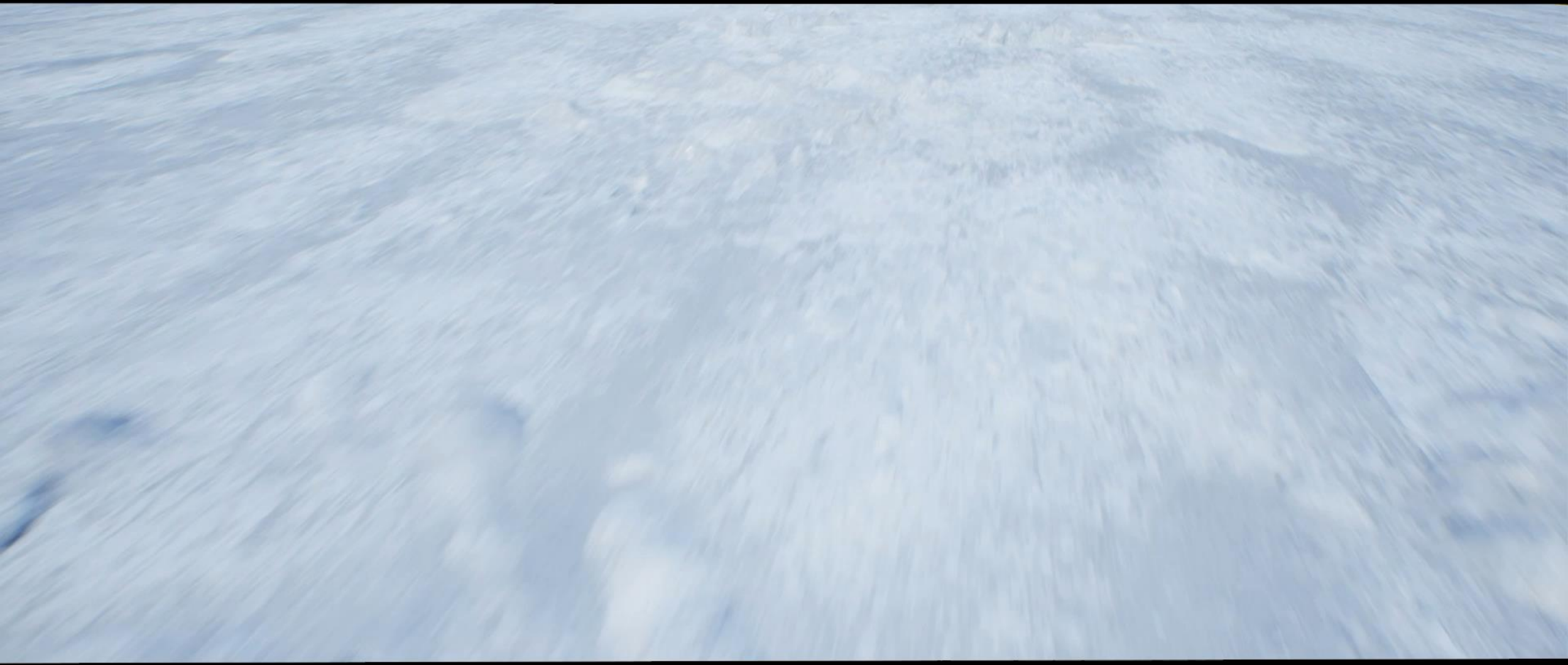

Global Ocean on
Saturn's Moon
ENCELADUS
Ice crust
Global ocean
Rocky core
South polar region
with active jets
* Thickness of layers is not to scale



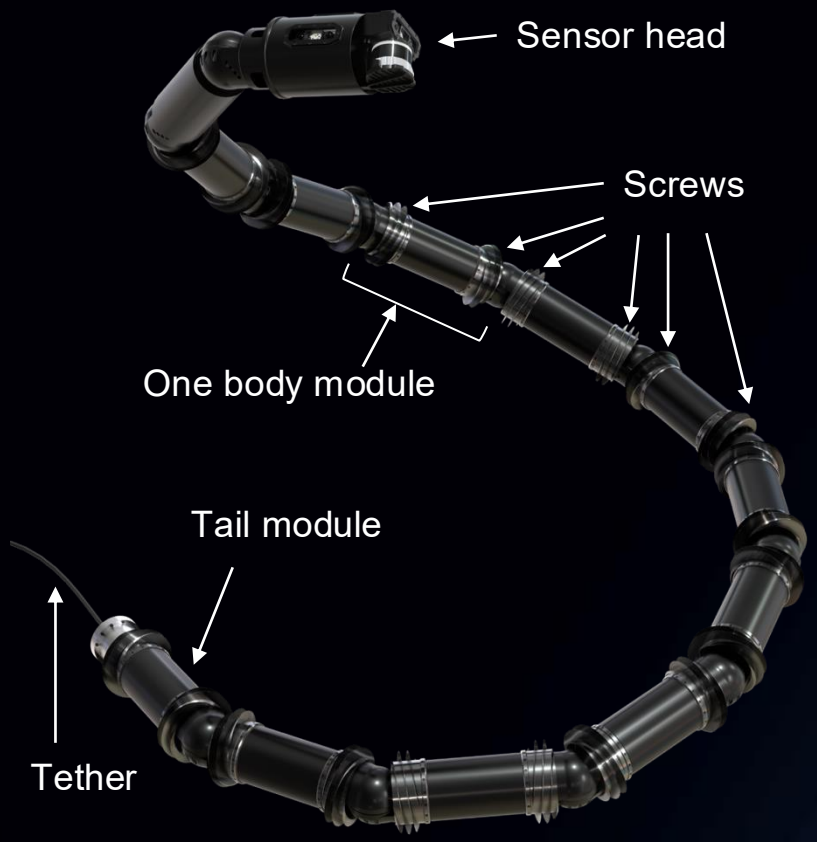
In this image from Cassini, backlighting from the Sun spectacularly illuminates Enceladus' jets of water ice.
NASA/JPL-Caltech/SSI



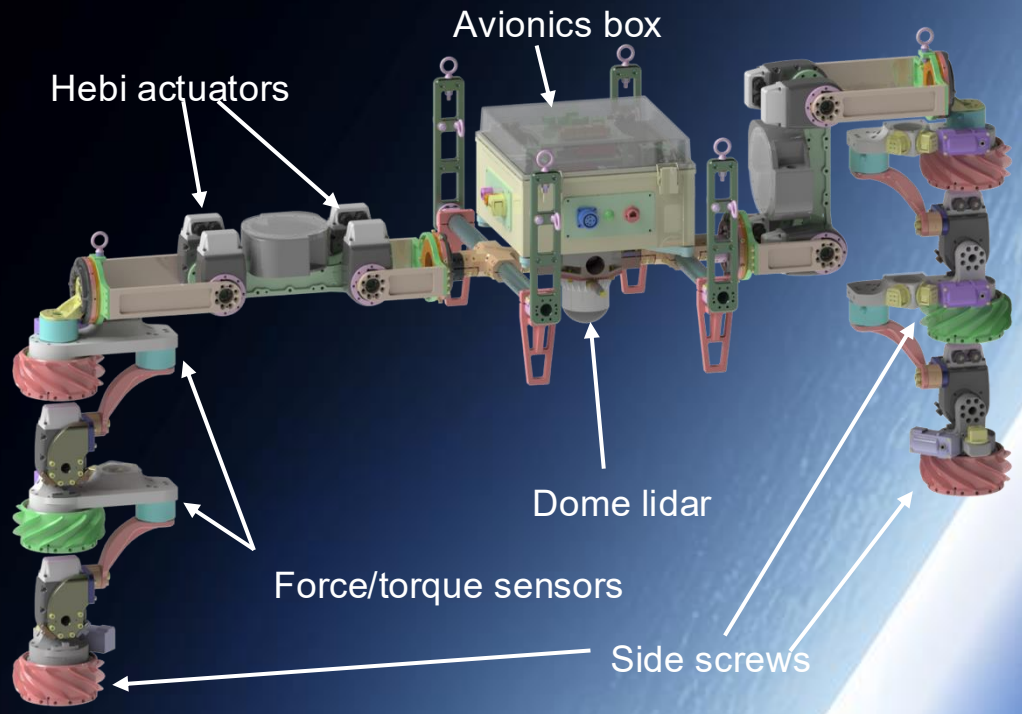
Meet the Robots

EELS Hardware

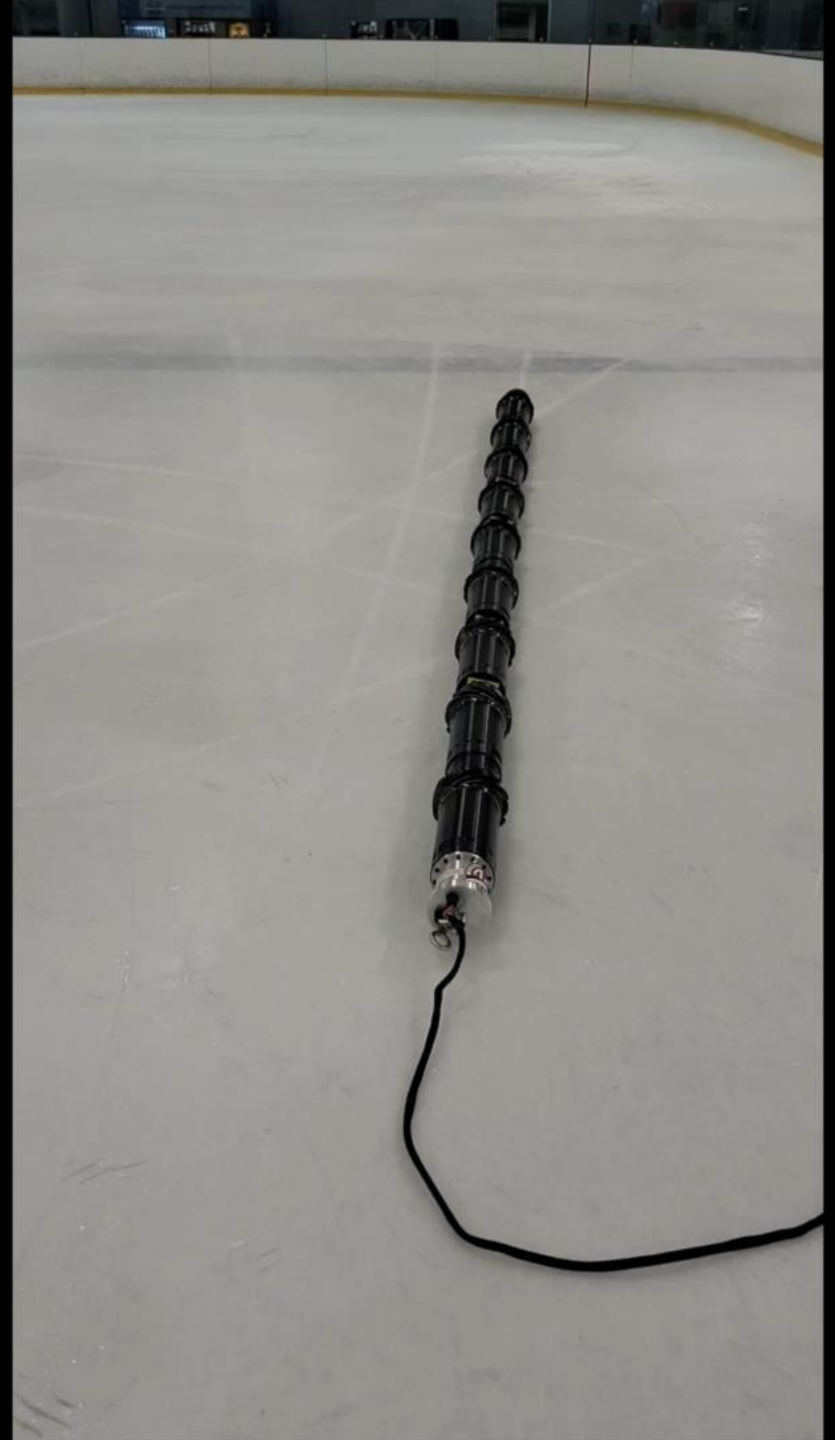
EELS 1.0



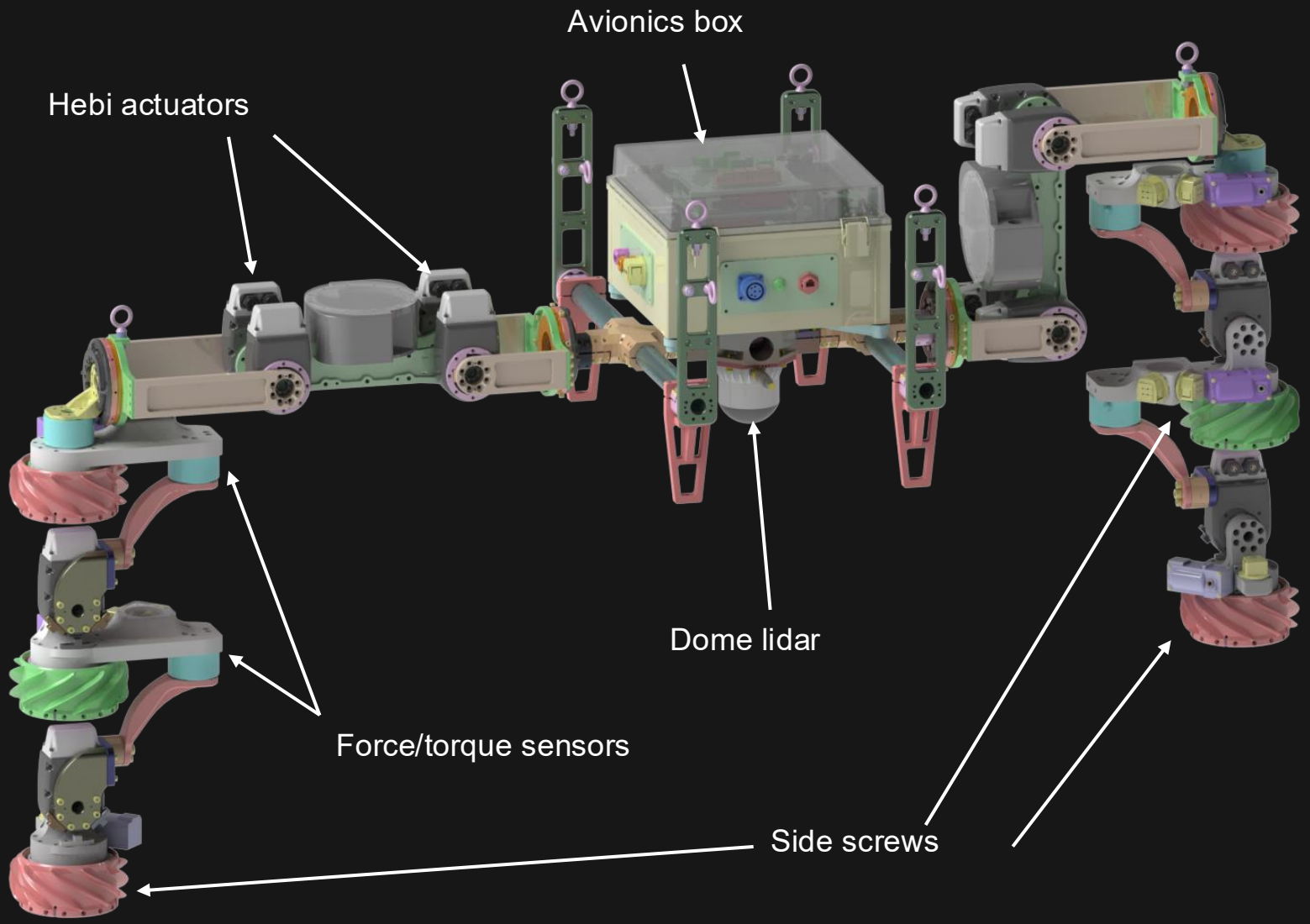
EELS 1.5

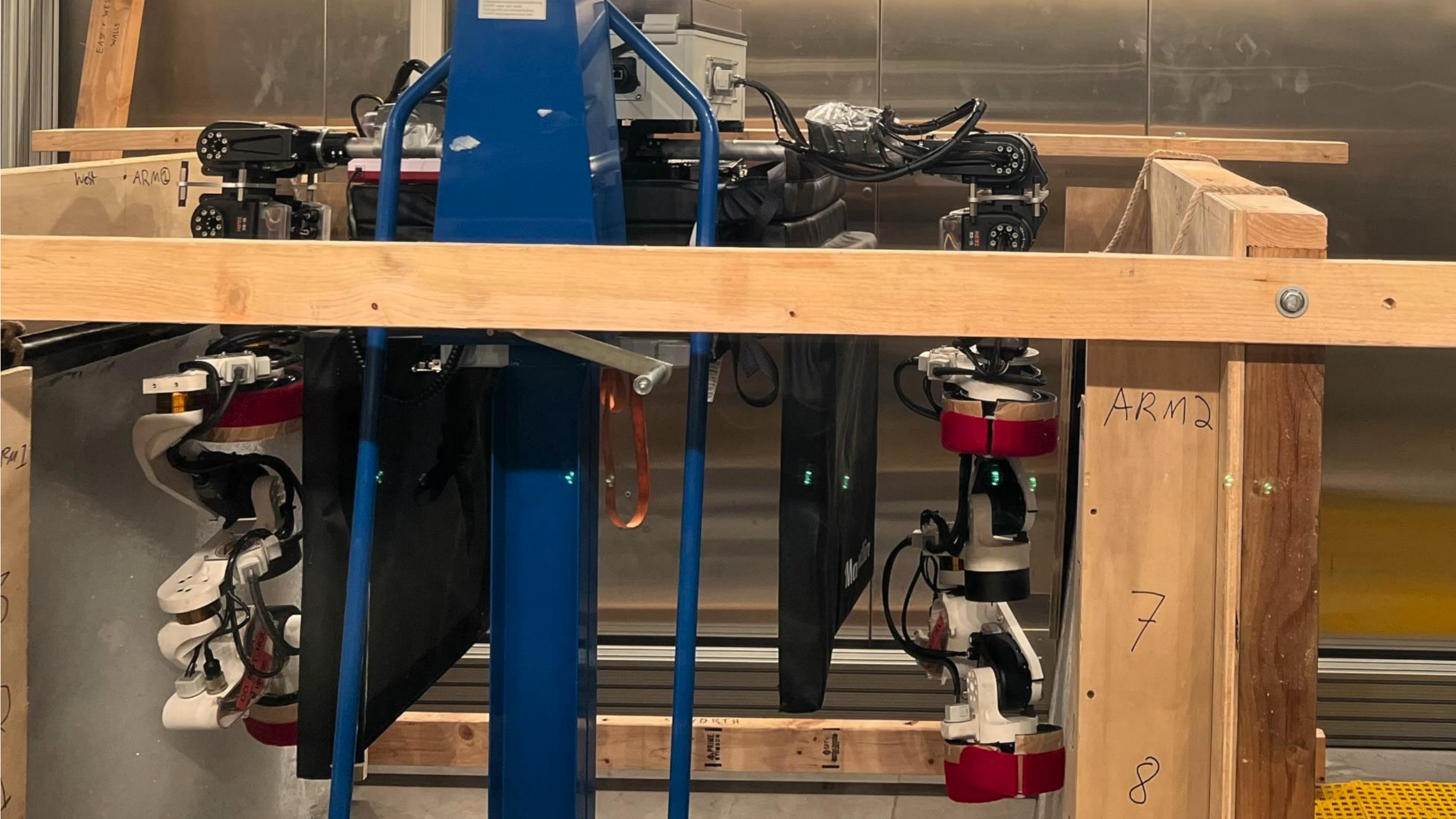


Garden-EELS



EELS1.5


Avionics box
Hebi actuators
Dome lidar
Force/torque sensors
Side screws


ARM2
7
8

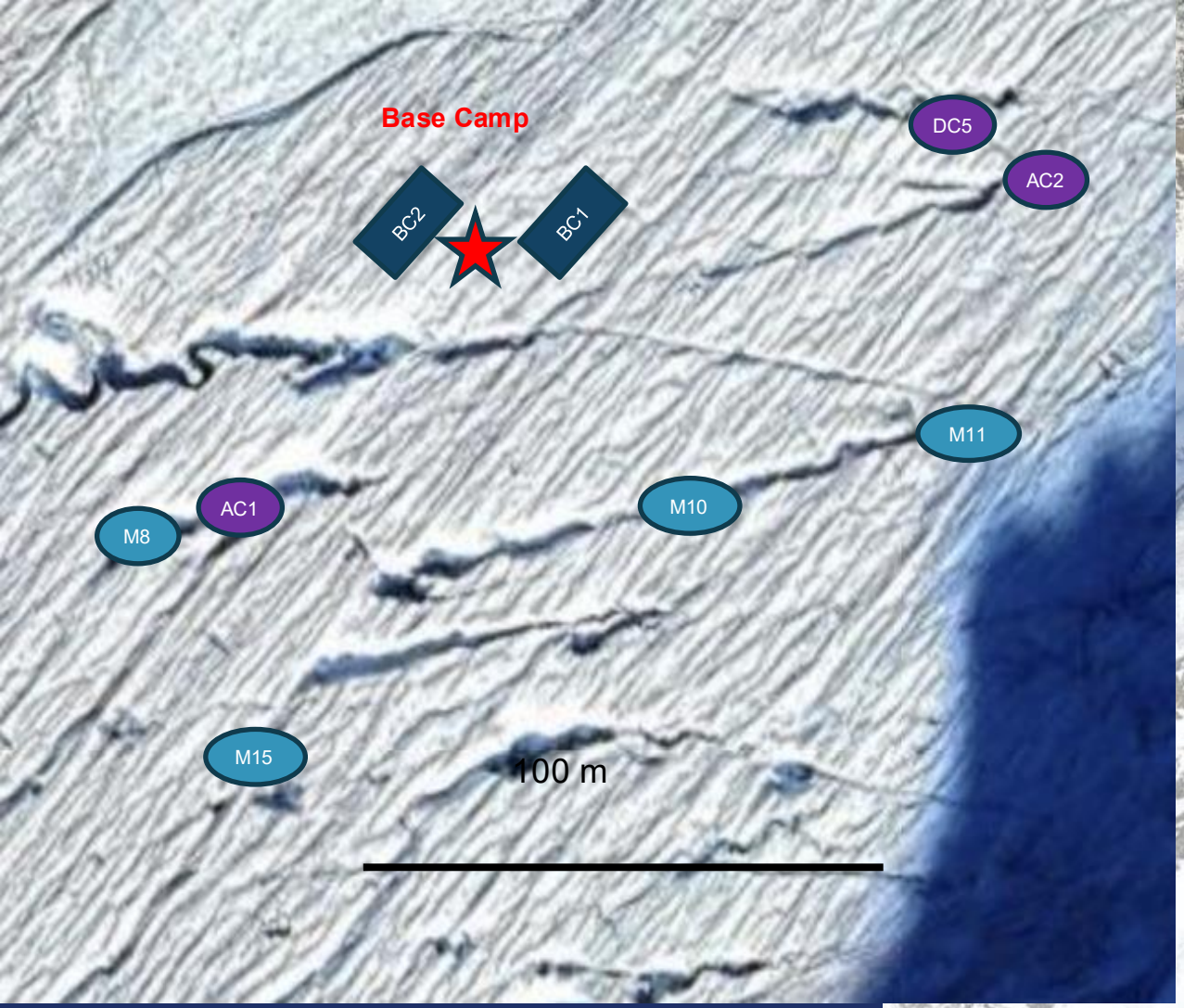
Athabasca Glacier

Athabasca Glacier


93
Hamber
Provincial
Park
Mt Clemenceau
Mt Columbia
93
White Goat
Cummins
Lakes
Provincial
Park
Kinbasket Lake


Athabasca Glacier
Alberta, Canada

The best analog for cryo-vents on icy moons


Base Camp
DC5
AC2
BC2
BC1
M11
M10
AC1
M8
M15
100 m


Columbia Icefield Glacier Adventure
Temporarily closed
Glacier View Lodge
Temporarily closed
Icefields Pkwy
Columbia Icefield Campground
93
gate
Road Access
Toe of the Athabasca Glacier Trailhead
Snow coach transfer area.
Base Camp / Heli LZ


Base camp

Day	Activities
1	Advanced team left JPL and arrived in Calgary. The shipment truck arrived in Athabasca.
2	The advanced team arrived in Athabasca and started unloading, while the 15-person main team left JPL and arrived in Calgary.
3	The advanced team conducted initial scouting of the glacier to identify suitable test sites. The main team and the safety guides arrived in Athabasca.
4	Robots and gear were transported to the Base Camp on the glacier by a helicopter.
5	**Vertical**: Test rig was set up over the “M8” moulin while the shake-out test at the Base Camp of the EELS 1.5 robot was conducted on site. **Science**: LiDAR scan of M8 was performed. **Screw**: Conducted first screw mobility tests.
6	**Vertical**: Dress rehearsal of vertical position hold test was performed in M8. **Science**: The DC5 dry channel was mapped with LiDAR. Screw: Three different screws were tested on ice at the Base Camp.
7	**Surface**: Shake-out test of EELS 1.0 and open-loop surface mobility test in BC1. **Vertical**: Successful vertical position hold was achieved in M8. **Science**: The M8 moulin was re-mapped with LiDAR, and preliminary scans were collected of M11. Conductivity measurements were performed with a handheld probe at DC5 and M8, as well as various supraglacial streams, to identify suitable test sites for the CE instrument. **Screw**: Surface screw tests were performed at the Base Camp.
8	Unfavorable weather. A small group conducted scouting and Base Camp maintenance activities.
9	**Surface**: Demonstrations of screw- and shape-based gaits at BC1 were performed. **Vertical**: Test rig was set up over the “M11” moulin. **Science**: Performed LiDAR mapping of AC1 and inspected M15. Screw: Additional screw tests were performed at the Base Camp.
10	**Surface**: The sensor head was attached to EELS 1.0; the team successfully completed the check out of the sensor head. **Science**: Initial check-out of the CE instrument was conducted.
11	**Vertical**: EELS 1.5 successfully held the vertical position using force feedback control and climbed up the M11 moulin a few cm. Science: 3D scans were taken in M15 with Scaniverse; water samples were collected at a supraglacial stream and analyzed with the CE instrument on the ice at Base Camp.
12	**Vertical**: EELS 1.5 successfully held the vertical position using force feedback control and climbed up the M11 moulin a few cm. **Science**: Performed a spiked blank measurement with the CE instrument; mapped more of M15 using Scaniverse.
13	The team scouted moulins to identify the next site for vertical tests. Activities interrupted due to heavy rain.
14	**Surface**: EELS 1.0 was tested in AC2; it crawled into and out of the channel by itself. **Vertical**: Test rig was set up at M10. EELS 1.5 was winched down into the moulin and tried position hold with force control but did not succeed. **Science**: The CE instrument was placed in a water stream at the bottom of AC2 and successfully sampled the water and performed an analysis in situ. **Screw**: The screw testbed was placed vertically on the ice wall of M8 and tested the new screw with a 10 degree pitch angle.
15	**Surface**: EELS 1.0 obstacle avoidance tests were performed at BC2 with the sensor head. **Vertical**: The EELS 1.5 robot made a controlled descent in the M10 moulin over ~1.5 m using a shape-based control. **Science**: The CE instrument was submerged in a pool of glacier water near M11 and successfully performed in-situ analysis.
16	**Surface**: EELS 1.0 obstacle avoidance tests were performed at BC2 with the sensor head. **Vertical**: The EELS 1.5 robot made a controlled descent in the M10 moulin over ~1.5 m using a force feedback control. **Science**: The CE instrument was deployed in both the 4th and 7th active surface channels west of base camp and performed successful sampling and sample conductivity measurements.
17	**Science**: CE was deployed deep in M8 moulin and performed successful sampling and conductivity measurements. The base camp was demobilized. Robots and gear were transported to a nearby parking lot by a helicopter.
18	Robots and gear were loaded on the truck.
19	Additional shipping logistics were handled. The team moved to Calgary.
20	The team left Calgary.

2023 Athabasca Field Team

Mike Paton

Alex Gardner
Ben Hockman
Eloise Marteau
Guglielmo Daddi
Hiro Ono
Marcel Veismann
Martin Peticco
Matt Robinson
Michael Swan
Phillipe Tosi
Rich Rieber
Rohan Thakker
Sina Aghli
Tomas Drevinskas
Avak Archanian
Bryson Jones
Eric Ambrose
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Lori Shiraishi
Marlin Strub
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Rachel Etheredge
Rob Royce
Sarah Yearicks
Tiago Vaquero
Tony Tran

Eddie Cartaya

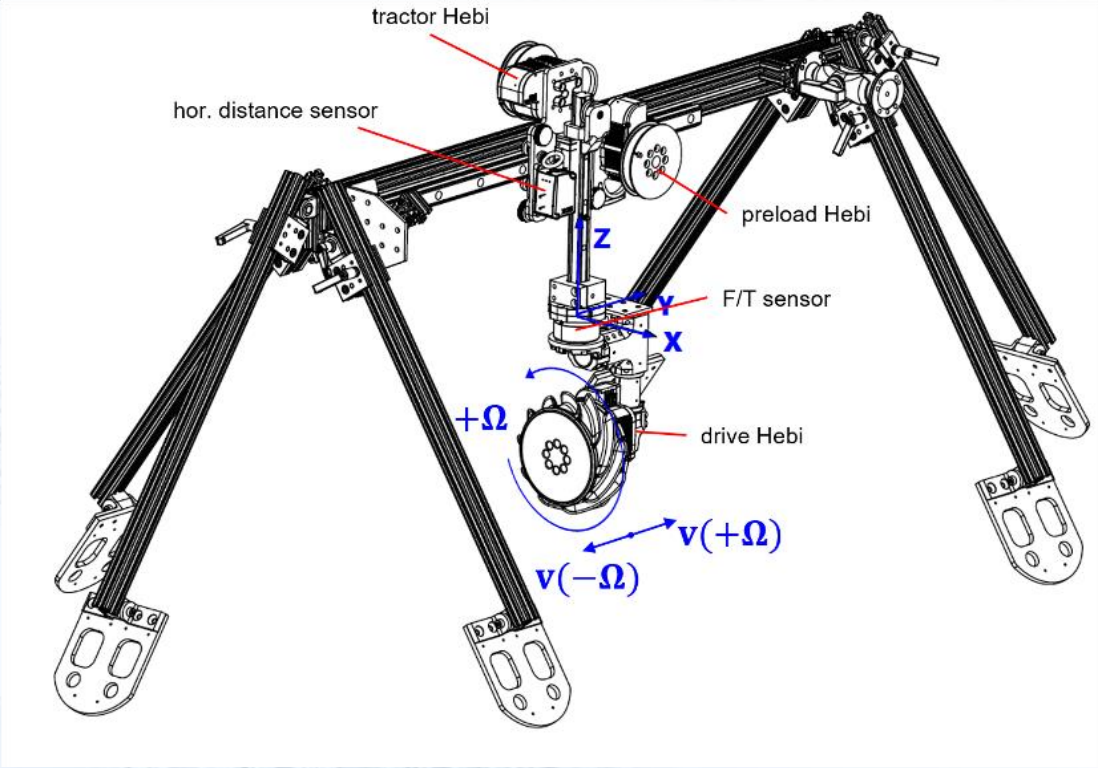
Andrew Blackstock
Cathy Baroco
Christian Stenner
Kevin Amba
Mike Pazini
Scott Linn
Tom Wood
Ben Swerdlow
Chantelle Amba
Katie Graham
Mary Ryan
Nick Maslen
Tom Gall

Photography

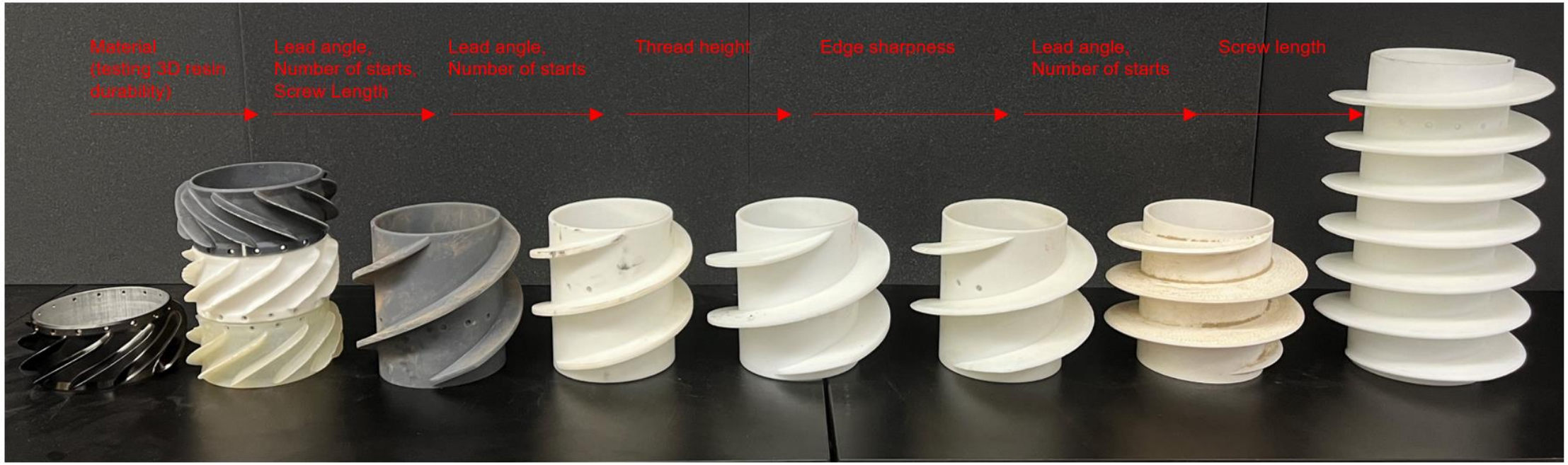
Jason Nelson

Terramechanics Testing

Terramechanics Characterization

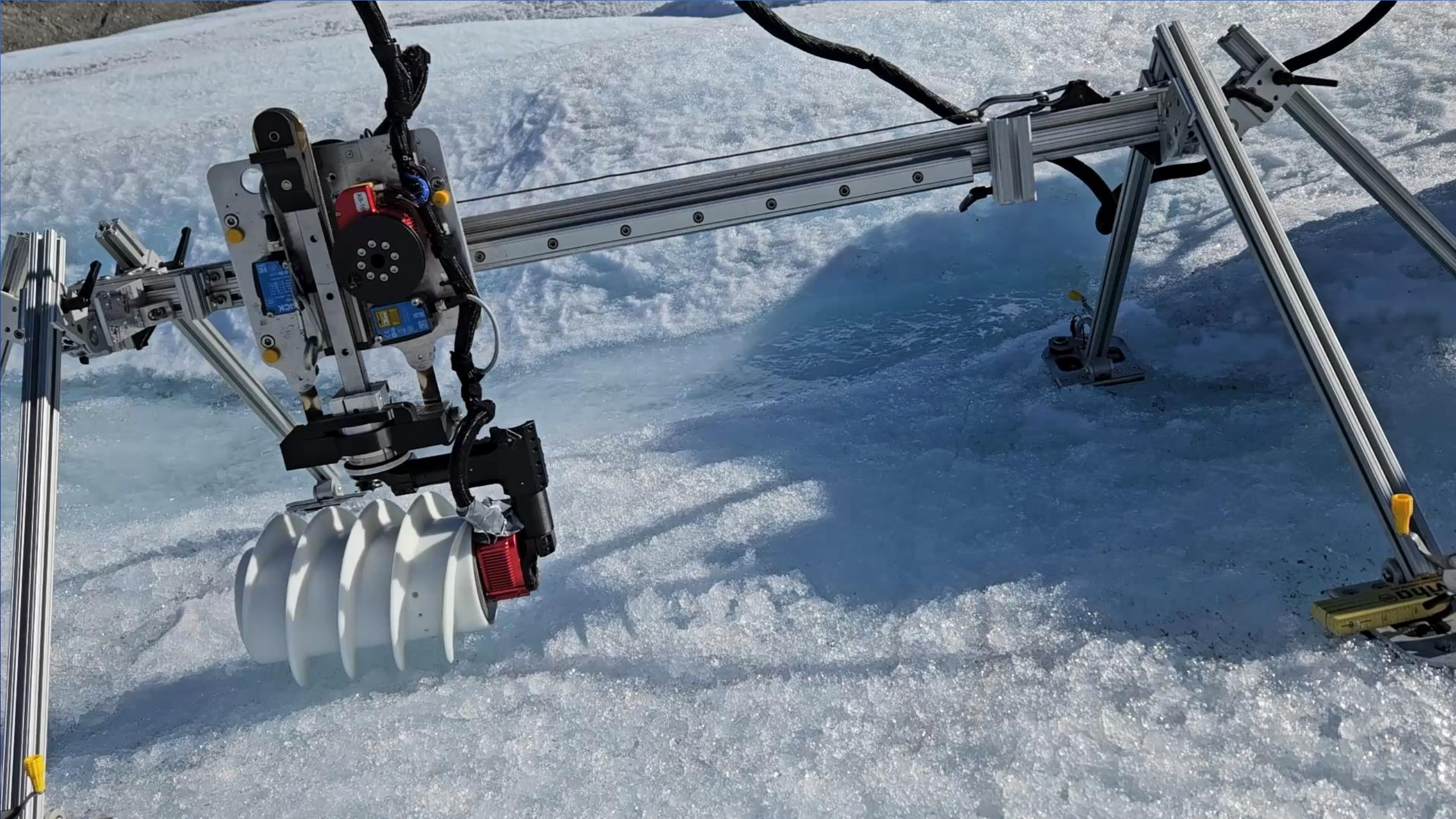


Screw family photo



$Material:$	AL	$Grey\ Pro, Flex, 4k$	$Grey\ Pro$	$4k$	$4k$	$4k$	$10k$	$4k$
$Lead\ angle, \psi$	$\psi = 30°$	$\psi = 30°$	$\psi = 30°$	$\psi = 15°$	$\psi = 15°$	$\psi = 15°$	$\psi = 7°$	$\psi = 7°$
$Number\ of\ starts, n_s$	$n_s = 10$	$n_s = 10$	$n_s = 3$	$n_s = 2$	$n_s = 2$	$n_s = 2$	$n_s = 1$	$n_s = 1$
$Thread\ height, h_t$	$h_t = 15mm$	$h_t = 15mm$	$h_t = 20mm$	$h_t = 20mm$	$h_t = 32.75mm$	$h_t = 32.75mm$	$h_t = 32.75mm$	$h_t = 32.75mm$
$Screw\ Length, L$	$L = 56mm$	$L = 56mm$	$L = 146mm\ (\frac{1}{2}M)$	$L = 146mm\ (\frac{1}{2}M)$	$L = 146mm\ (\frac{1}{2}M)$	$L = 146mm\ (\frac{1}{2}M)$	$L = 146mm\ (\frac{1}{2}M)$	$L = 313mm\ (1M)$
$Test\ location *:$	A, IR	MY	MY	MY	MY	MY, TM	MY	MY, TM
$System\ Integration **:$	$EELS, TB$	TB	TB	TB	TB	$EELS, TB$	TB	$EELS, TB$

$*: A = Athabasca, IR = Ice\ Ring, MY = Mars\ Yard, TM = Table\ Mountain$
$**: EELS = Robot, TB = Testbed$



Surface Testing

Sub-Surface Mobility List of Tests

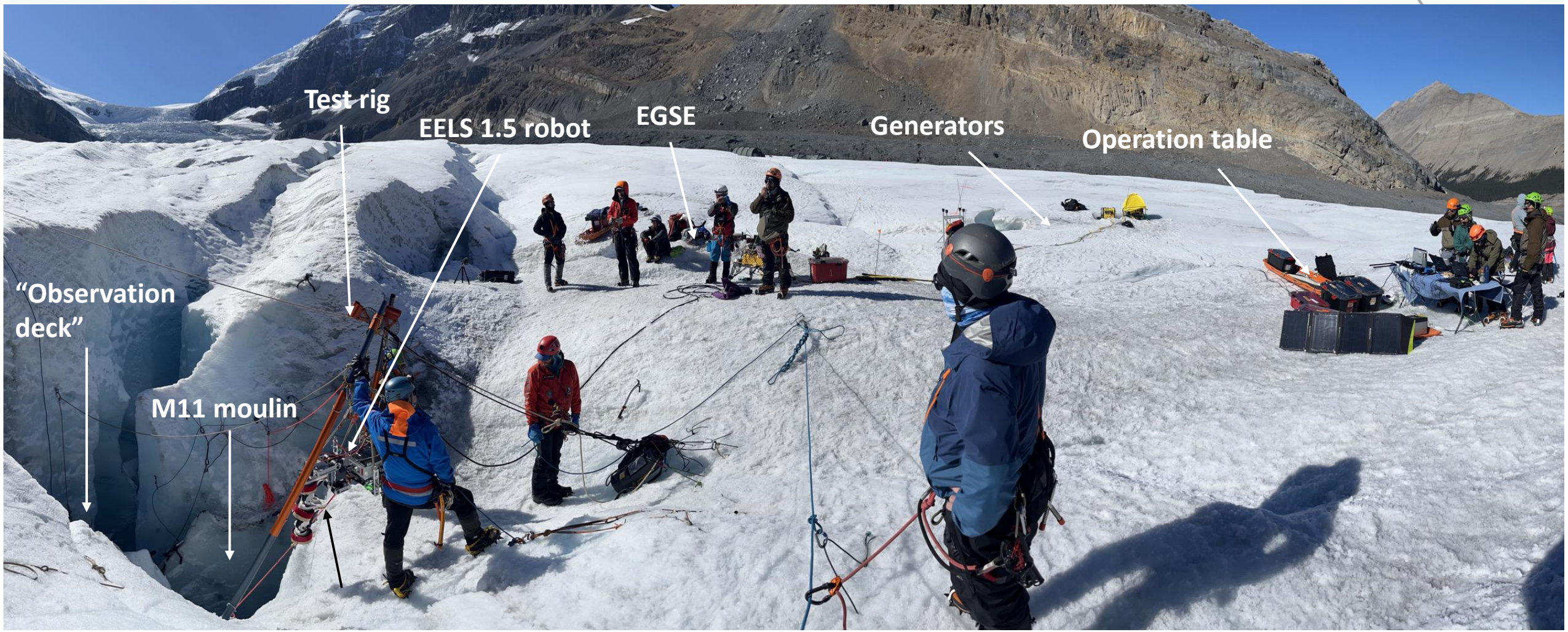
Day	Screw	Sensor head	Test site
7	Metal	No	BC1
9	Plastic	No	BC1
14	Plastic	Yes	AC2
15	Plastic	Yes	BC2
16	Plastic	Yes	BC2


DURABOOK
LIFETIME

Sub-Surface Testing

Sub-Surface Mobility List of Tests

Day	Site	Position hold	Vertical motion	Force control
6	M8	No	No	No
7	M8	Yes	No	No
11	M11	Yes	2 cm up	Yes
12	M11	Yes	5 cm up	Yes
14	M10	No	No	No
15	M10	Yes	1.5 m down	No
16	M10	Yes	1.5 m down	Yes

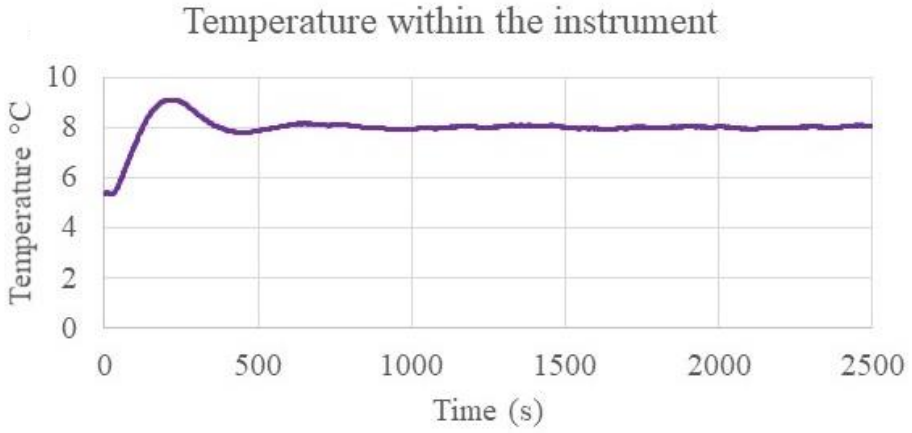

Test rig
EELS 1.5 robot
EGSE
Generators
Operation table
"Observation deck"
M11 moulin

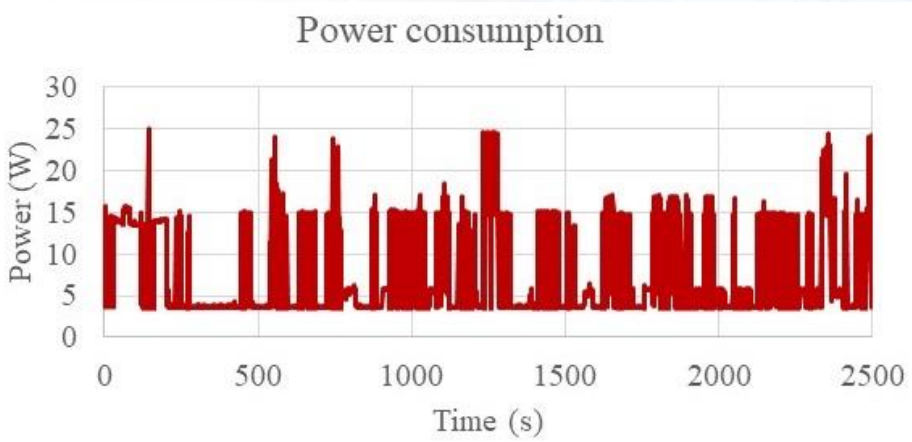

DURABOOK

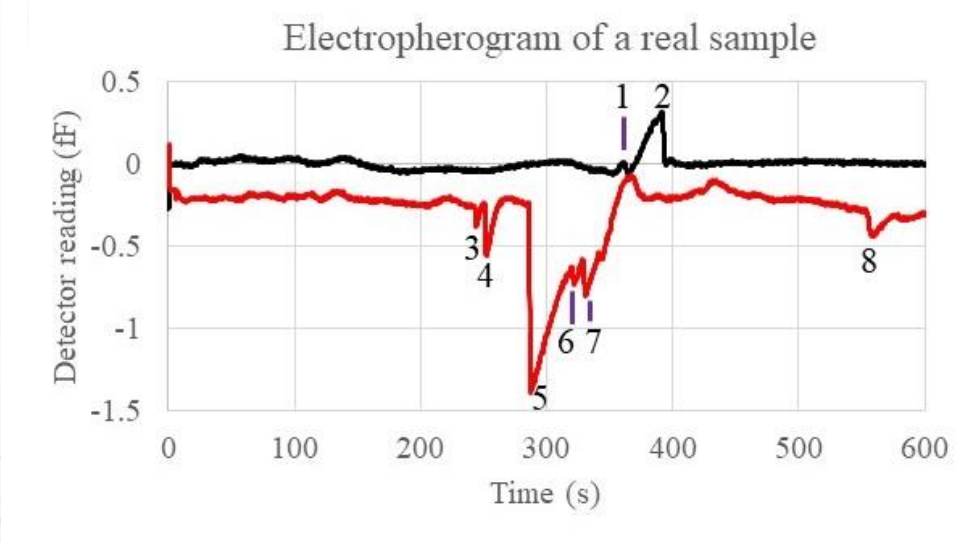
Science


HIGH
VOLTAGE

Capillary Electrophoresis Results







Electropherogram of a real sample during separation. Peaks:

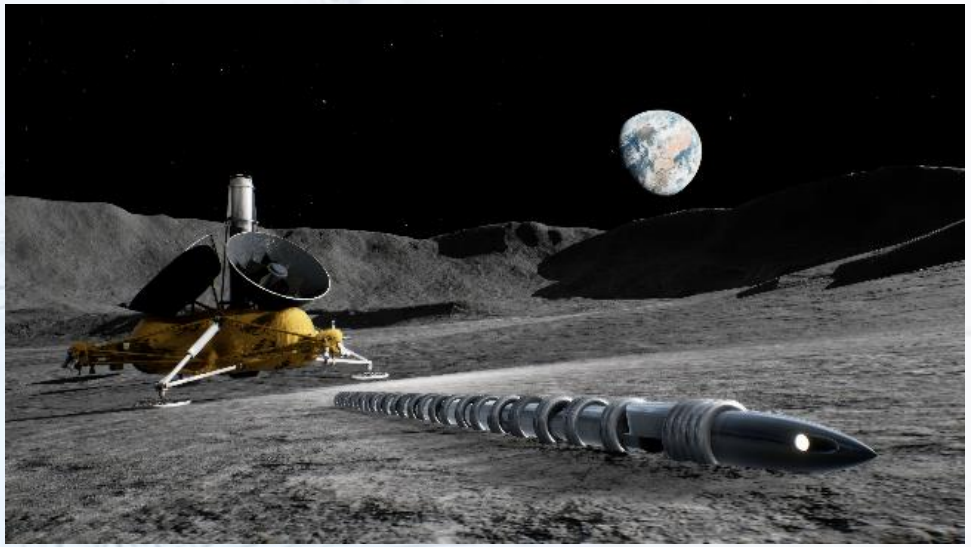
1. $SO4^{2-}$
2. Cl^{-}
3. Cs^{+}
4. K^{+}
5. Ca2+
6. Mg2+
7. Na+
8. unidentified

EELS

Conclusions and the Future

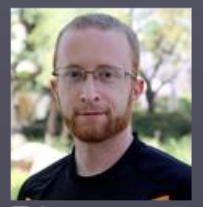
Conclusions

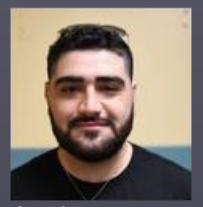
- This field test demonstrated subsurface mobility is technically feasible.
  - Lots of work to go to make it a reality
- Future studies:
  - Explore transition between gaits
  - Study transition between Surface and Sub-Surface mobility modes
  - Study payload accommodation and science cases
- Possible precursor mission: Lunar EELS
  - Visit permanently shadowed regions
  - Lava tubes?
  - Instruments?



The EELS Team


Sina Aghil


Eric Ambrose


Avak Archanian


Joseph Bowkett


Morgan Cable


Kalind Carpenter


Guglielmo Daddi


Hendrik Dreger


Tomas Drevinskas


EELS1.0


EELS1.5


Rachel Etheredge


Alex Gardner


Peter Gavrilov


Nikola Georgiev


Matt Gildner


Tristan Hasseler


Ben Hockman


Mitch Ingham


Abhi Jain


Levi Janssen


Harrison Jenkins


Curtis Jin


Bryson Jones


Chris Lopez


Daniel Loret

Mike Malaska


Eloise Marteau


Daniel McGann

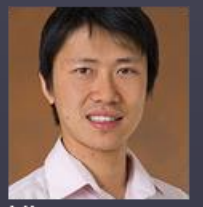

Hovhannes Melikyan


Paul Nadan


Jack Naish


Yashwanth Nakka


Benjamin Nuernberger


Hiro Ono


Melissa Pamer


Daniel Pastor


Mike Paton

Martin Peticco


Vedant Ranade

Rich Rieber

Matt Robinson

Jacob Rodriguez

Christiahn Roman

Rob Royce

Mirza Samnani

Lori Shiraishi

Santino Sini

Linda Spilker

Marlin Strub

Michael Swan

Marco Tempest

Rohan Thakker

Phillipe Tosi

Tony Tran

Tiago Vaquero

Marcel Veismann

Jessica Weber

Sarah Yearicks

Harshad Zade

Jenny Zhang


DIRECTACTIONVERTICAL
The *AMAZING* DAV Team