Accessing Mars' Climate Record through Deep-Subsurface Pulsed Plasma Discharge Drilling

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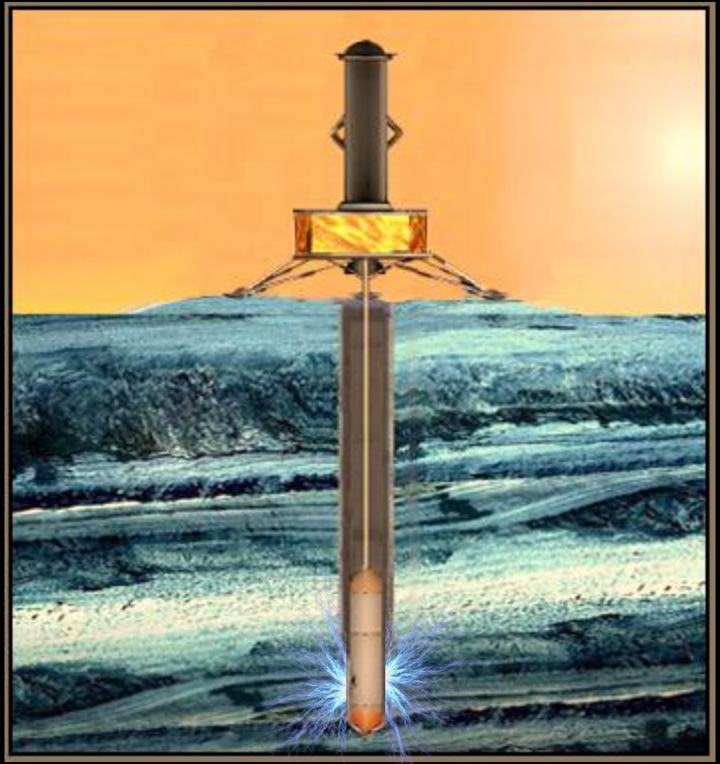
Abstract

Progress on the characterization of plasma discharges as an aid to more efficient subglacial access. Plasma discharges reduce ice thermal conductivity resulting in higher penetration efficiency for a thermal probe. Results on theoretical models and experimental validation are presented.



"Artist's Concept"
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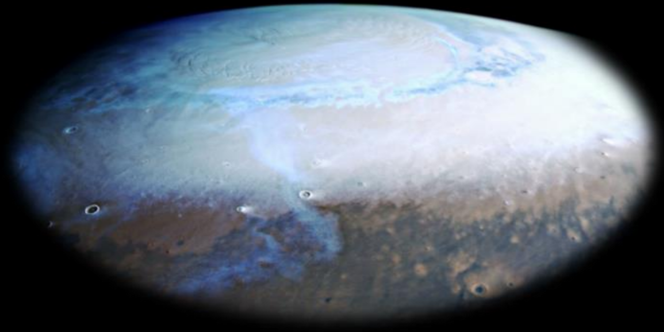
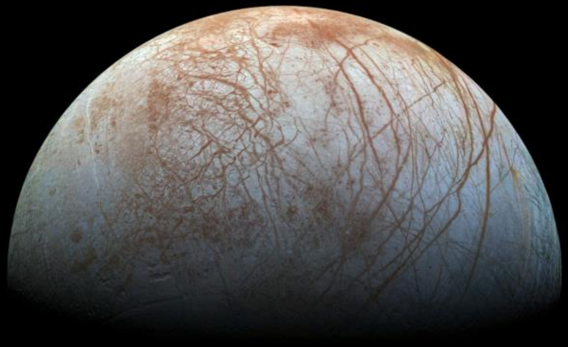
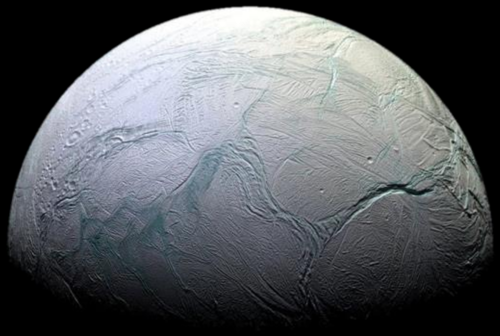
Sub-glacial environments in the solar system



Mars' Poles

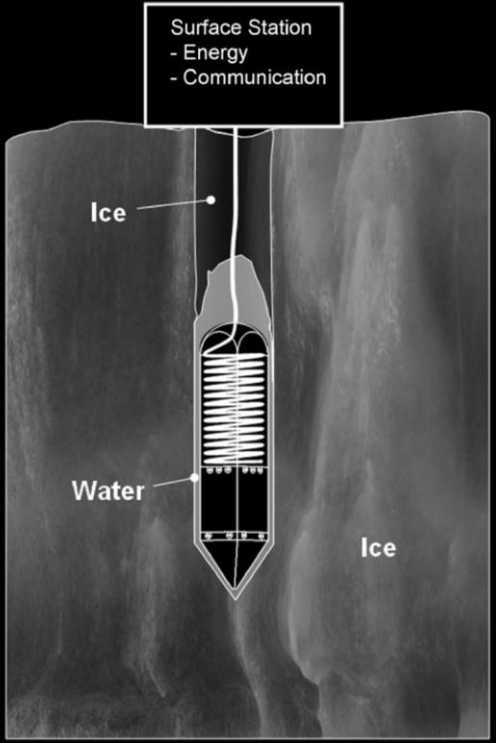


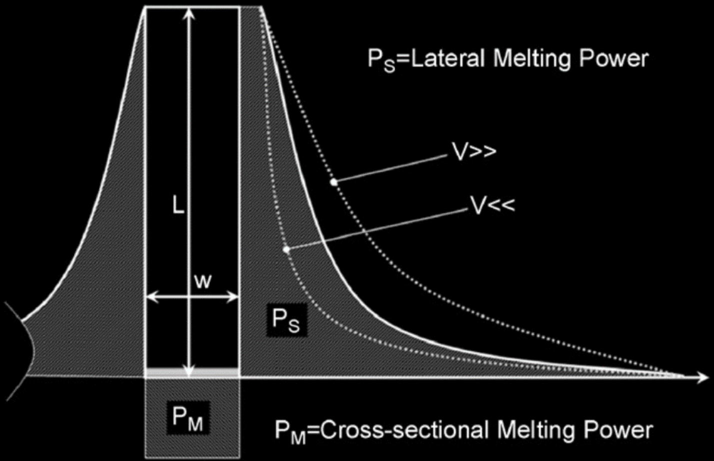
Europa

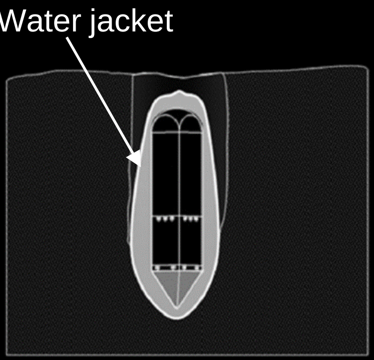


Enceladus

Melt probe theory

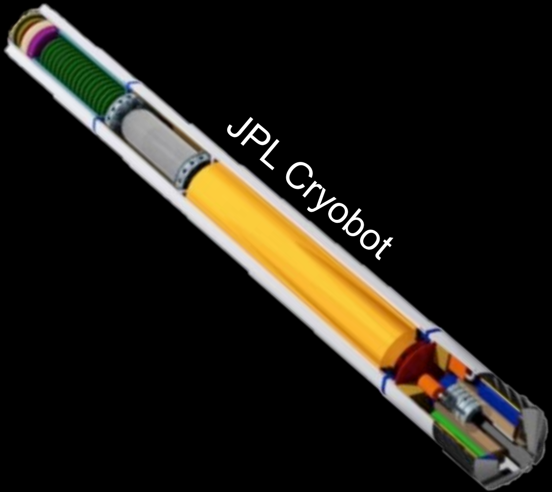


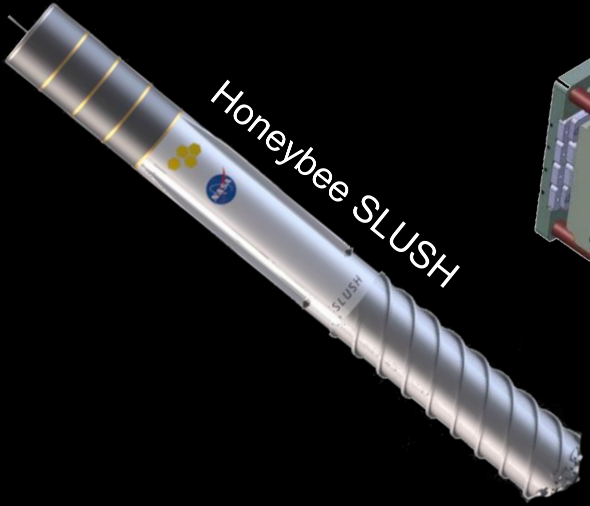


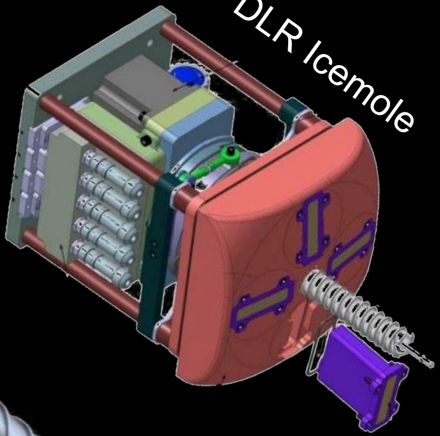


Melt probe – improvements

*Planetary probes combine **different penetration techniques** to address melt probe limitations.*





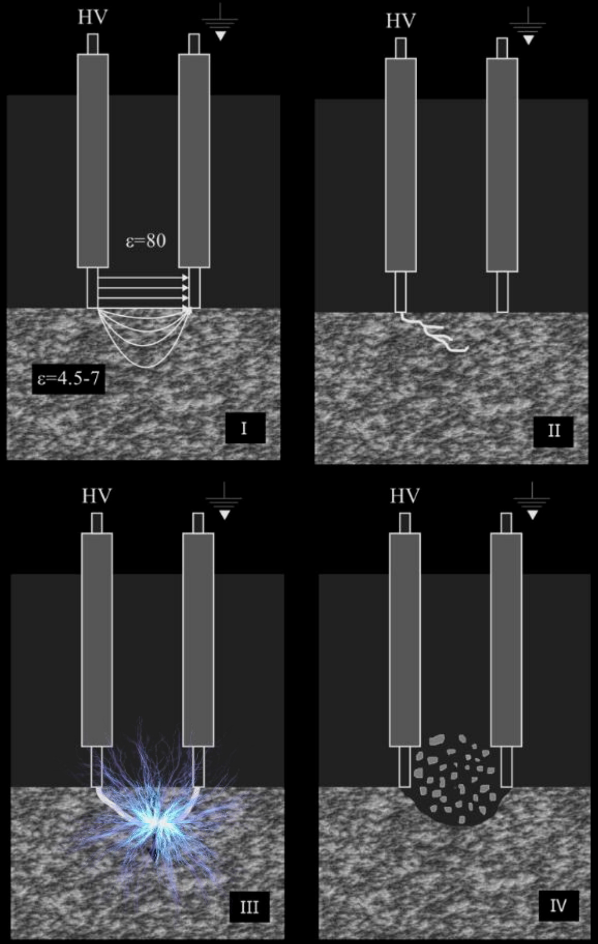


Thermal + Water Jetting

Thermal + Mechanical

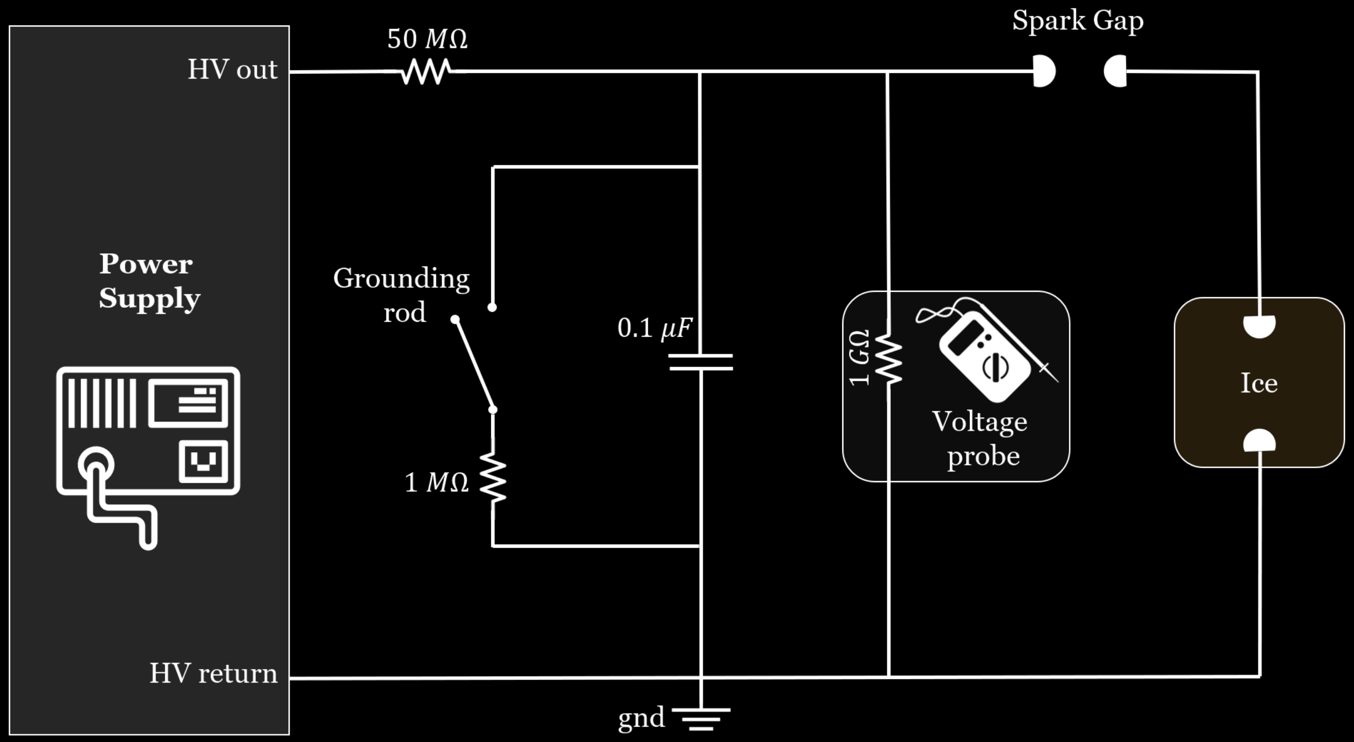
Plasma drilling

- Deep drilling technology. Used to create bore-holes in rock.
- ***Dielectric breakdown and energy deposition in a material leads to an overpressure event which fractures the surrounding material.***
- The technological solutions investigated on Earth for plasma drilling are ill-suited for planetary exploration
  - High power consumption
  - Use of a drilling fluid (incompressible) that serves as a medium through which the shock wave can move.
- Possibly a thermal probe performance enhancer?



[Timoshkin, et al 2004]

Electrical schematic



In-ice discharges

- Unconstrained ice
  - ***Excavation***
  - ***Chipping***

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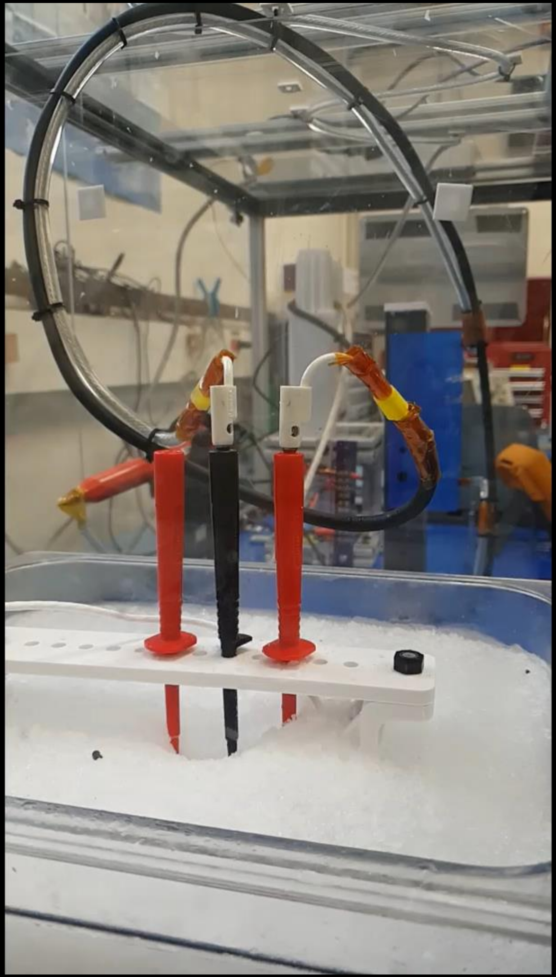
Sediment removal
Melting less ice

- Constrained ice
  - ***Cracking***

↓

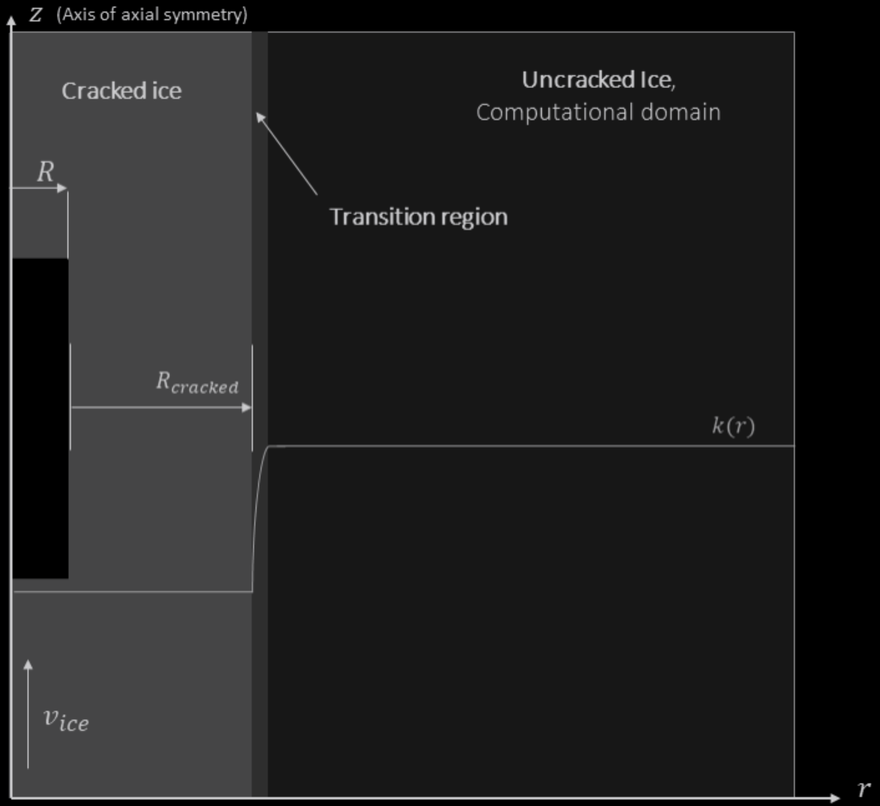
Thermal conductivity reduction
Fewer conductive losses



Model

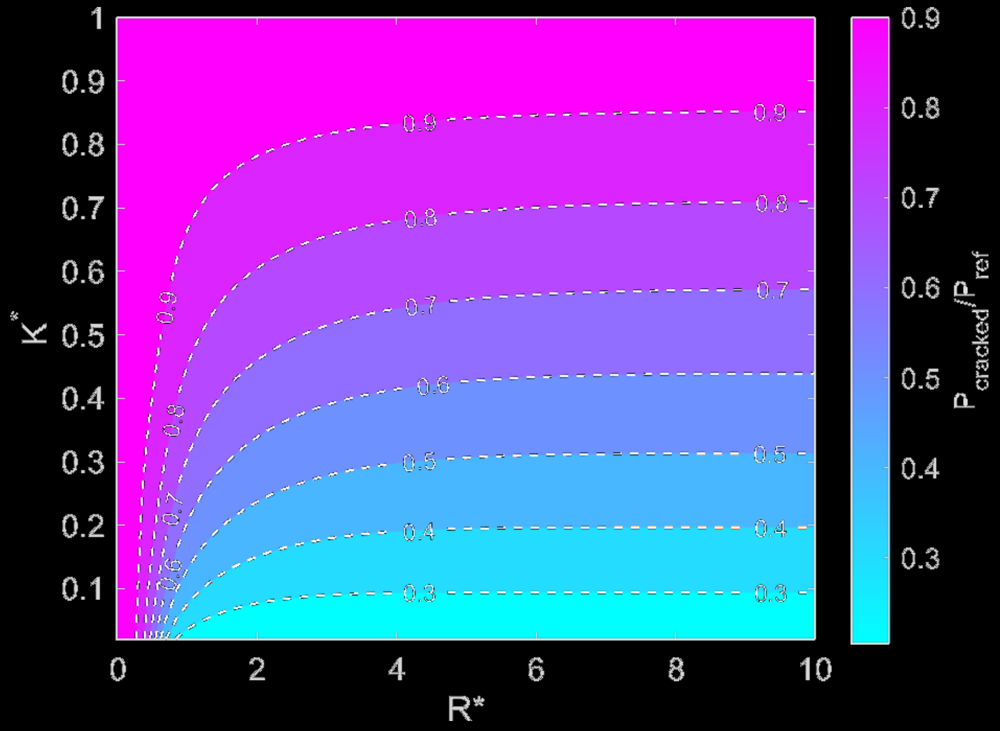
- FEA Simulation pipeline courtesy of PRIME, written in MATLAB.
- Cracked ice mimicked as a thermal conductivity scaling factor $k(r)$, with sigmoid shape.
- Parameters:
  - K^* → T/C reduction factor (k/k_{ref})
  - R^* → cracked region extent (R_{crck}/R)
  - m → transition region extent
- $0 < k(r) < 1$

$$k(r) = K^* - (1 - K^*)\frac{e^{m(r-R_{crack})}}{e^{m(r-R_{cracked})} + R_{crack}}$$



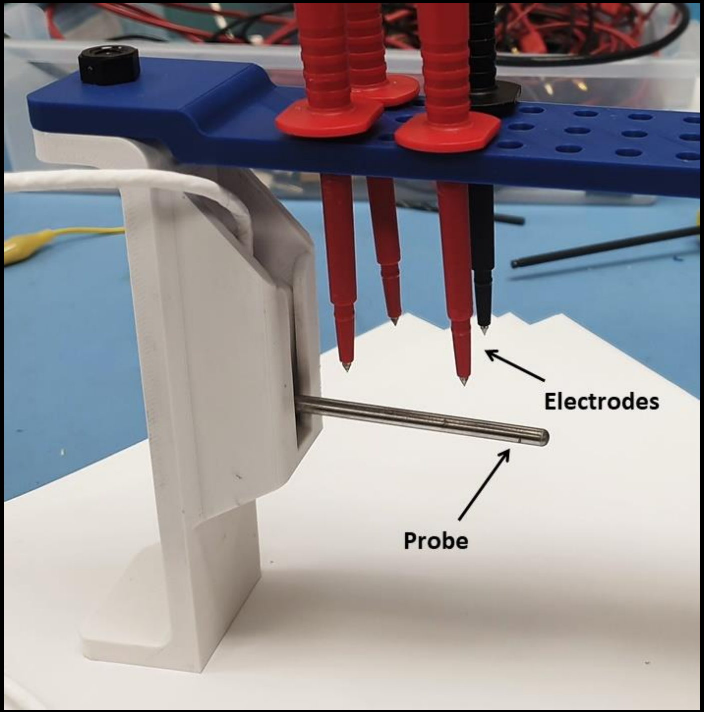
Results

- Simple tool that allows to estimate power savings, provided that K^* and R^* are known.
- P_{crack}/P_{ref} exhibits little sensitivity to variations in:
  - Temperature
  - Velocity
  - Probe geometry
- The tool allows to optimize the power output in multi sidewall heater probes.

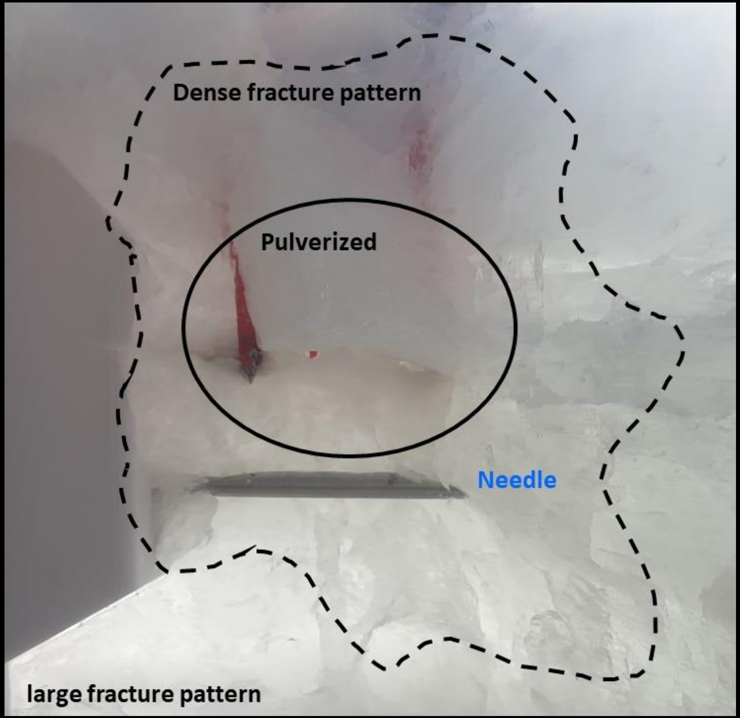


Thermal conductivity readings

- Measure with COTS instrument

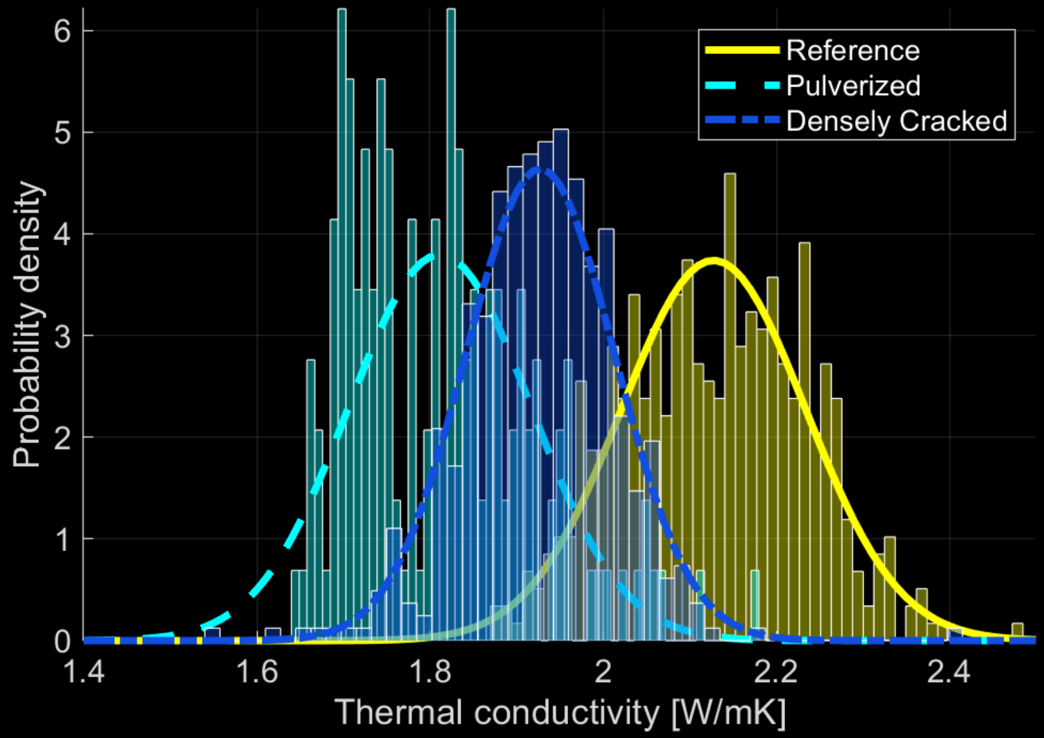


- 3 main cracked regions



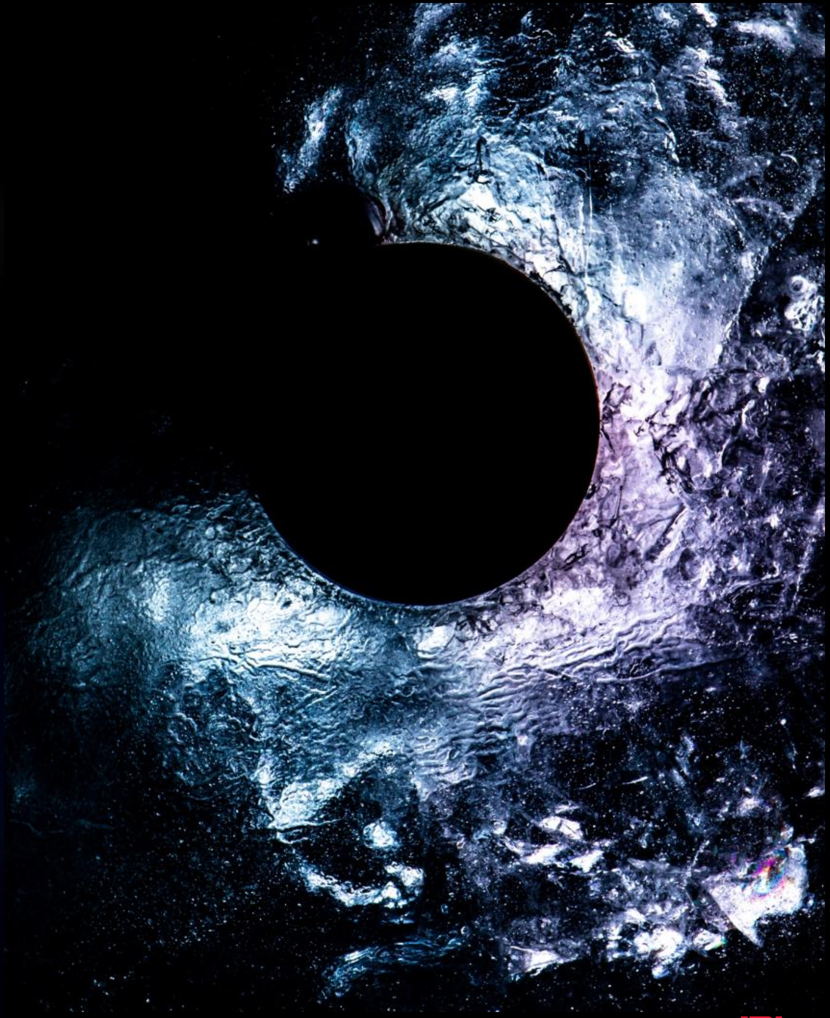
Results

- Shown region dependent thermal conductivity reduction (up to 25% in some experiments)
- $\sim 10\%$ power saving according to thermal model (depends on R^*)
- Experiments not fully concluded due to SARS-CoV-2
  - Incomplete data from pulverized region (only two experiments)
  - R^* was not investigated
  - E, V dependence not investigated



Many-gaps

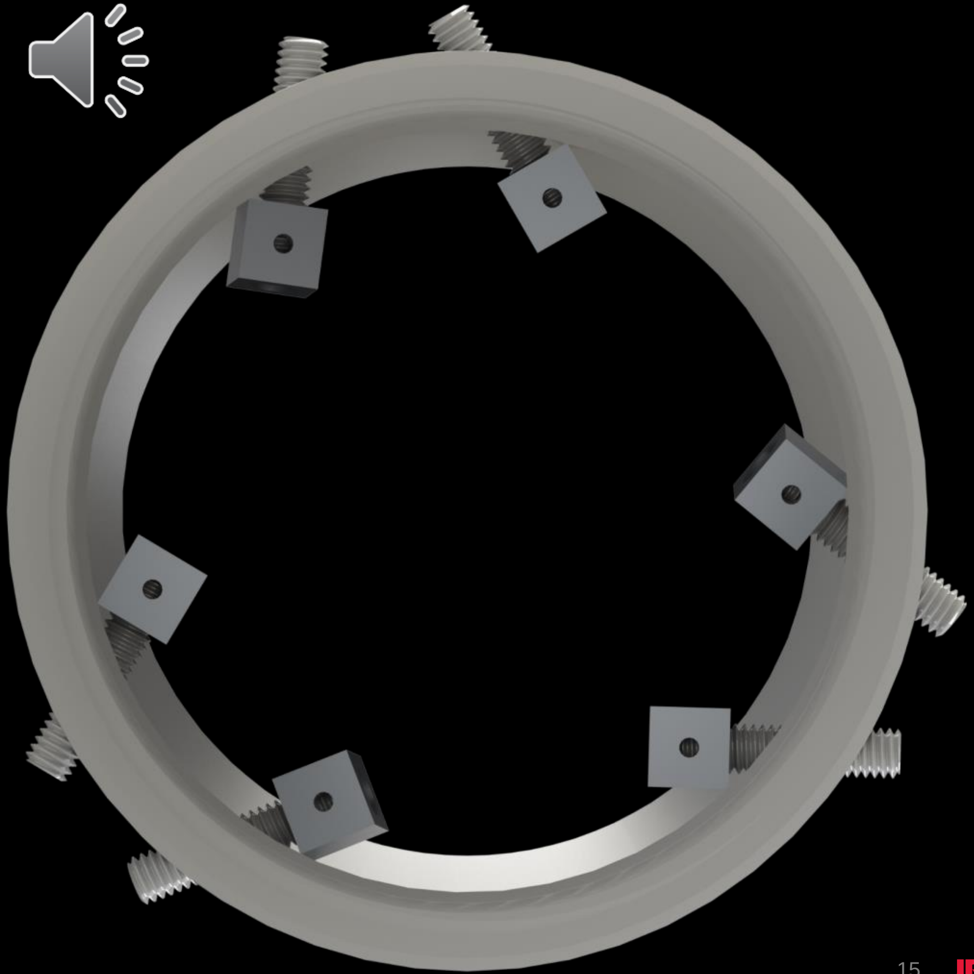
Many-gaps

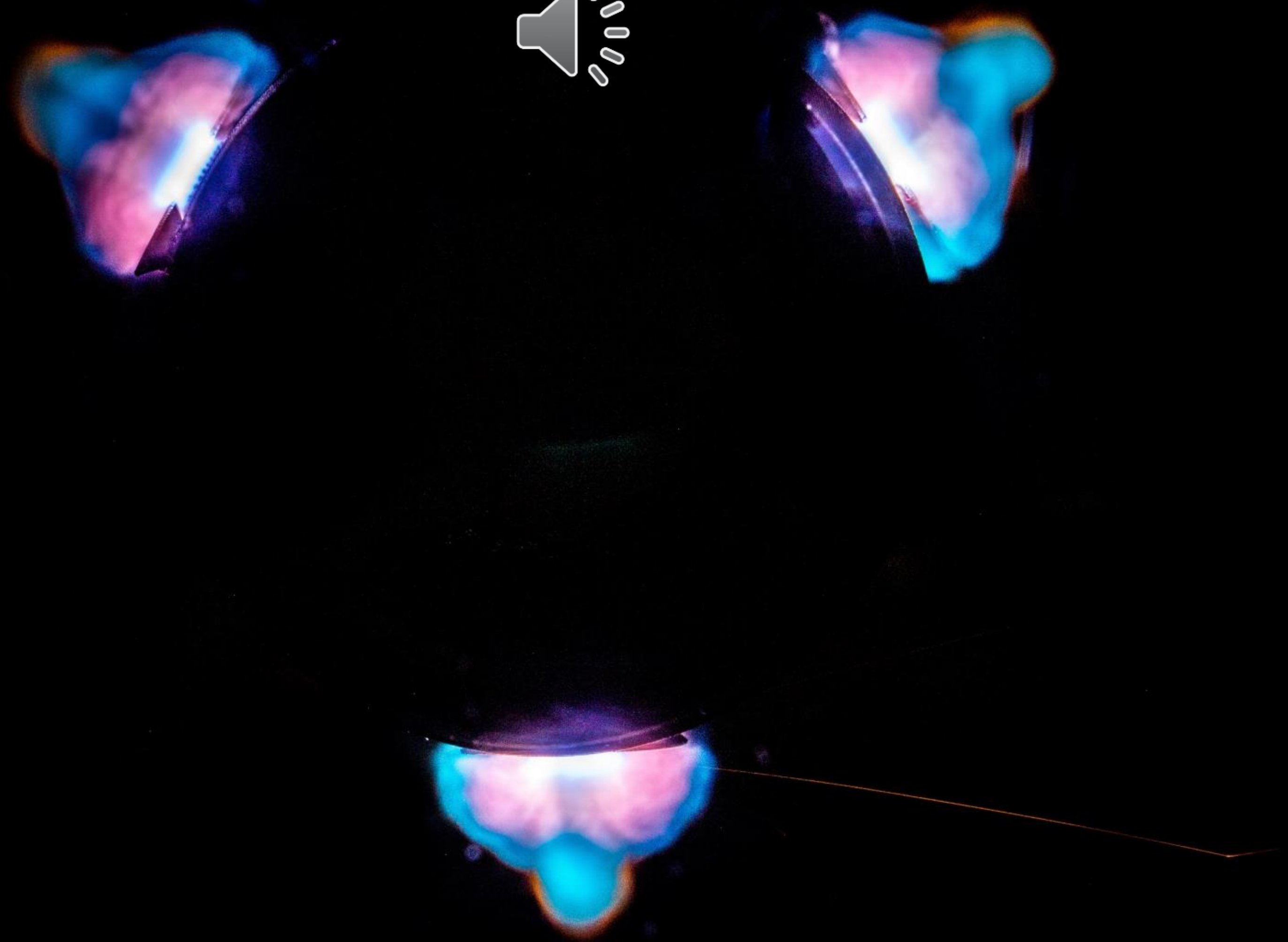


JPL

Internal arcing mitigation

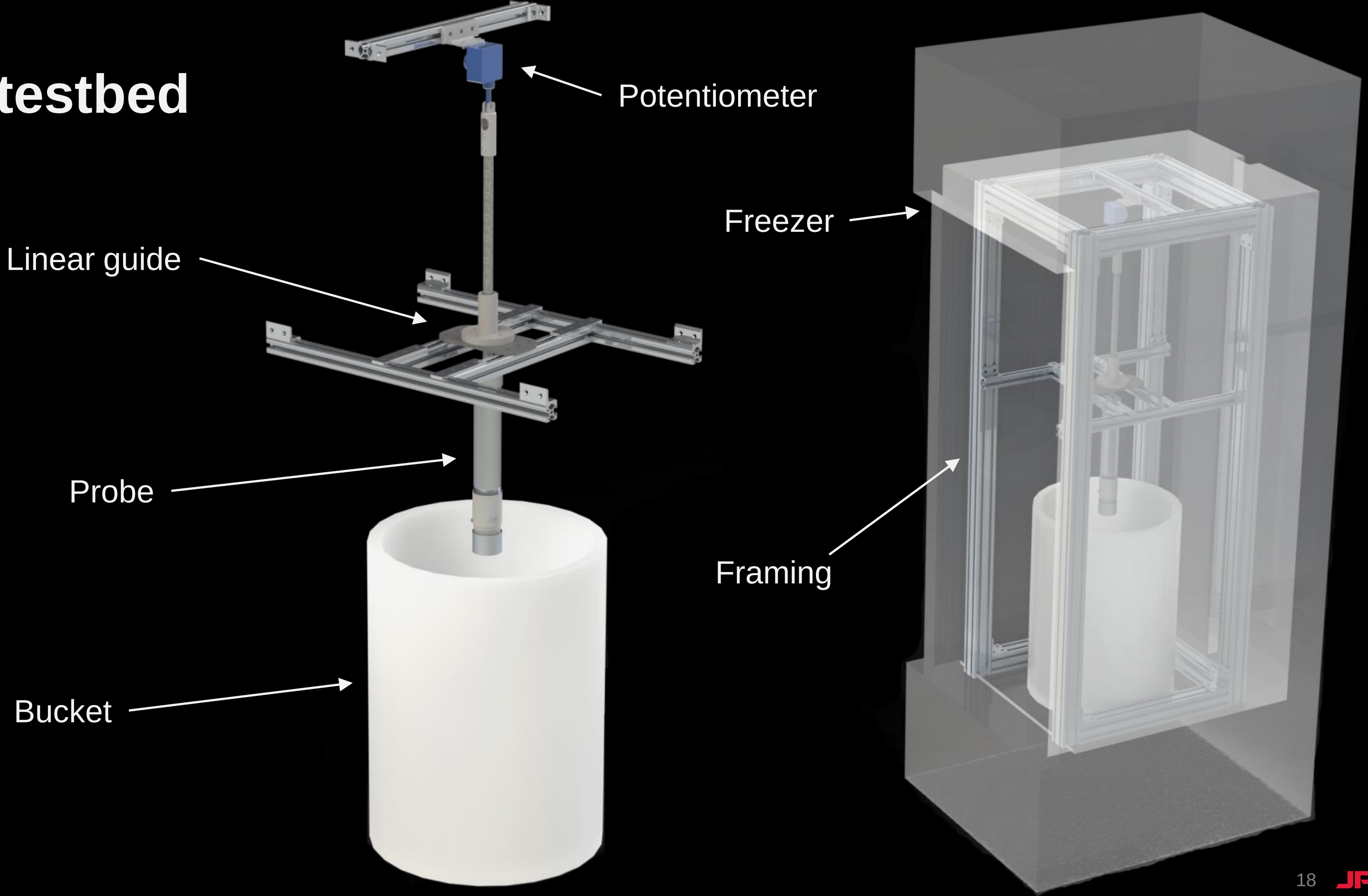
- Screw angling increases distance between connector and decreases distance between desired arc-path
- Potting the space between connectors with high-temp Silicone insulation (very high breakdown voltage $> 25\ kV/mm$)
- Rest of module is potted with thermally conductive epoxy to facilitate thermal transfer





3 gaps

Race testbed



Publications

-Guglielmo Daddi, “Thermal probe enhanced with pulsed plasma discharges for efficient ice penetration,” submitted to *Politecnico Di Torino as a Master Thesis. May 2020*

-Submission to ICARUS journal, in progress.

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