Source: Bernd Dachwald / FH Aachen

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Development and Antarctic Field Deployment of a Maneuverable Subsurface Probe for Solar System Ices

12th International Planetary Probe Workshop
Cologne, Germany, 15 – 19 July 2015

Subsurface Icecraft

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Methods of Deep Ice Research

Ice Core Drilling, Melting Probes, and the IceMole

IceMole in deployment rack on the Swiss Morteratsch glacier (2013)

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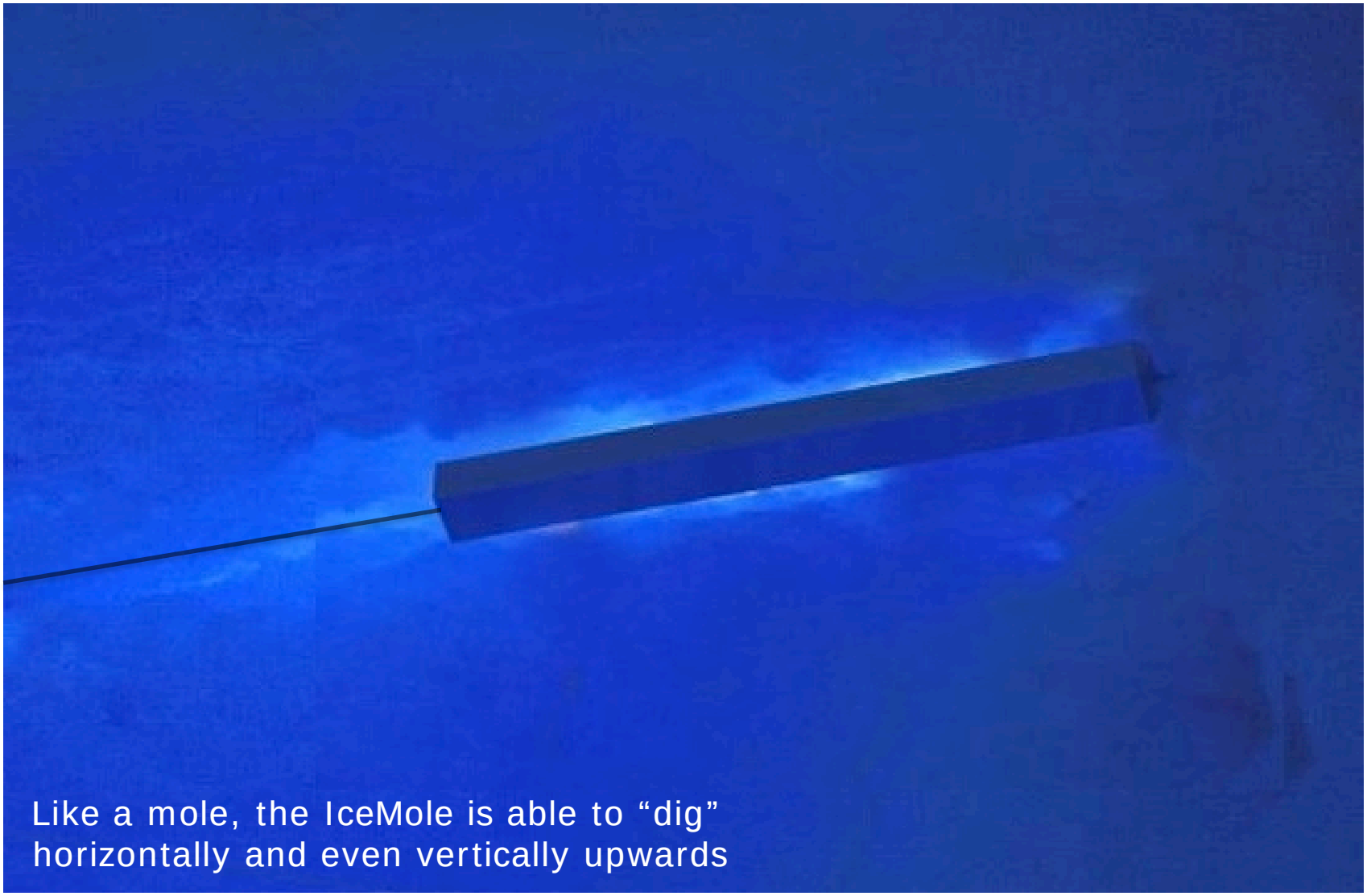
IceMole
Principle of Operations



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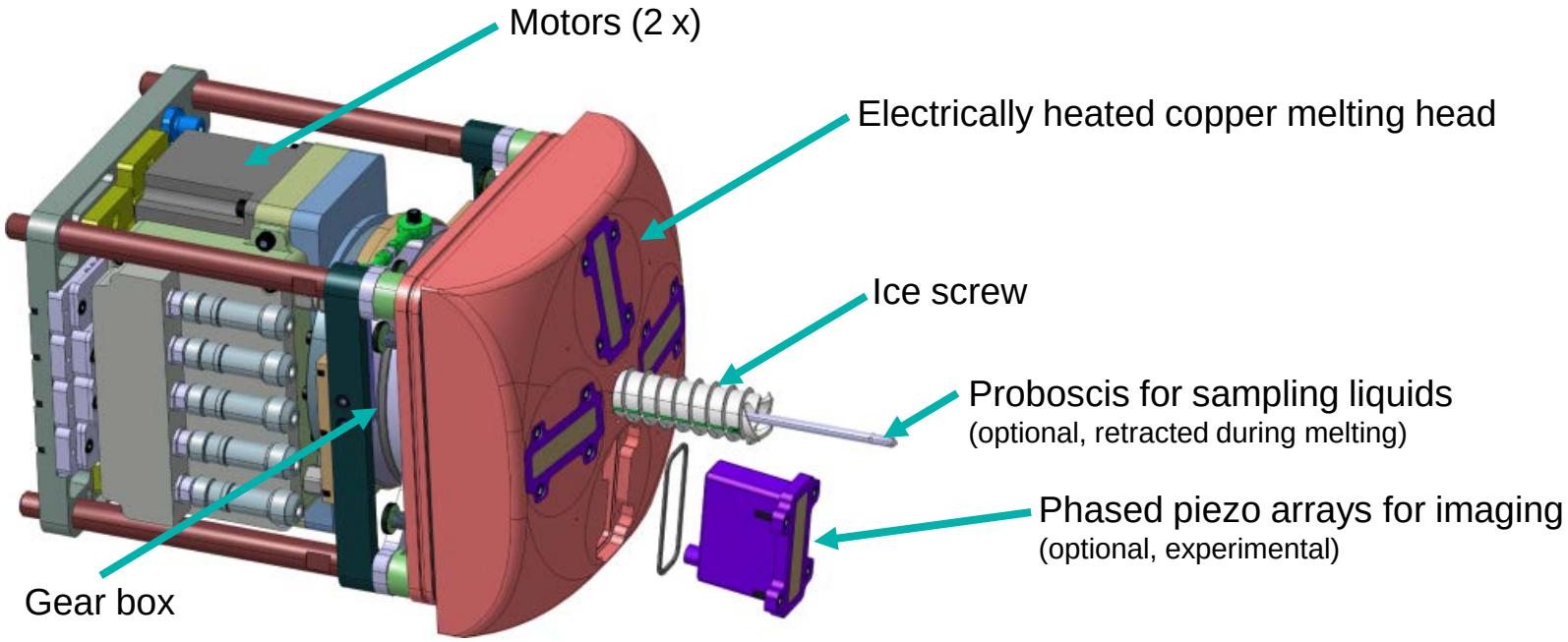
IceMole
Principle of Operations

> Forward motion ("digging") with combined melting head and continuously rotating ice screw at the tip

> Sampling of uncontaminated ice core or liquids for in-situ analysis

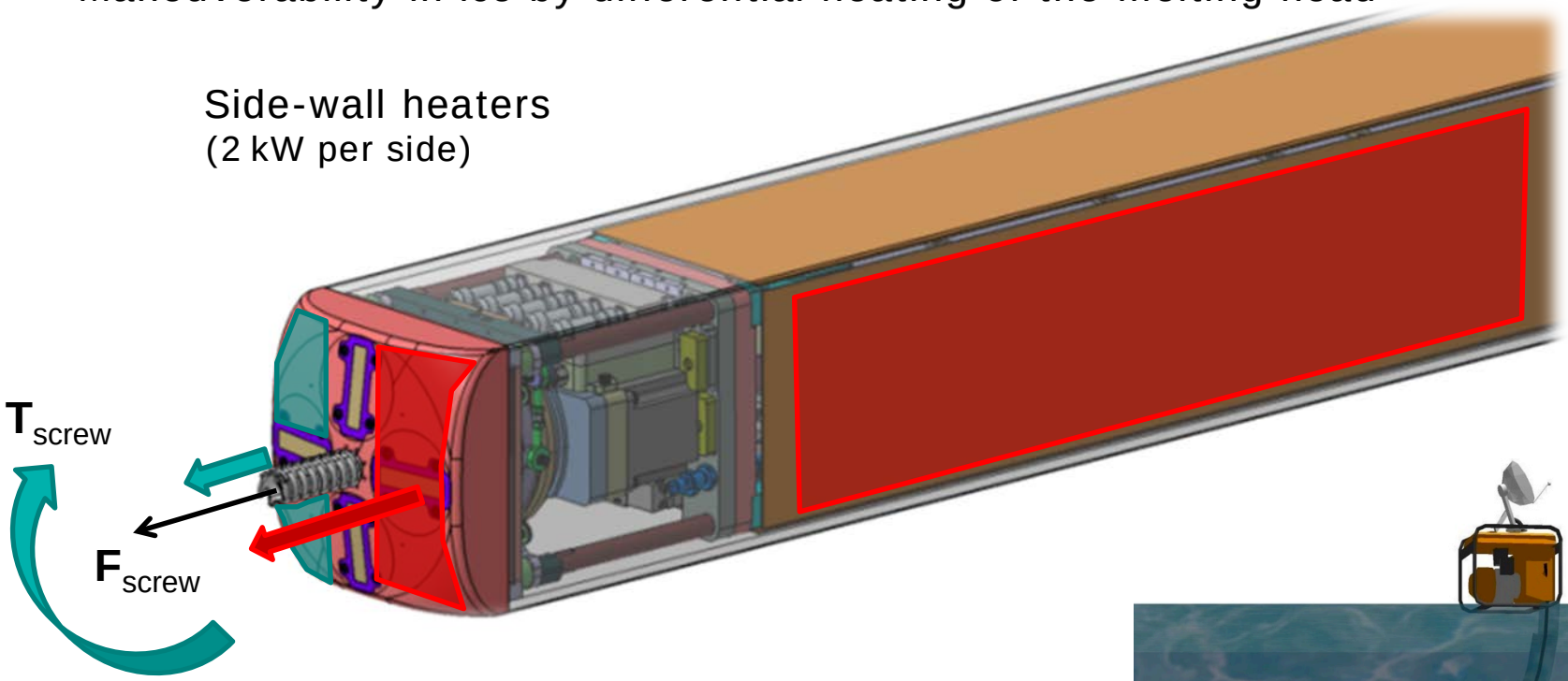
> Variety of of instrumentation options

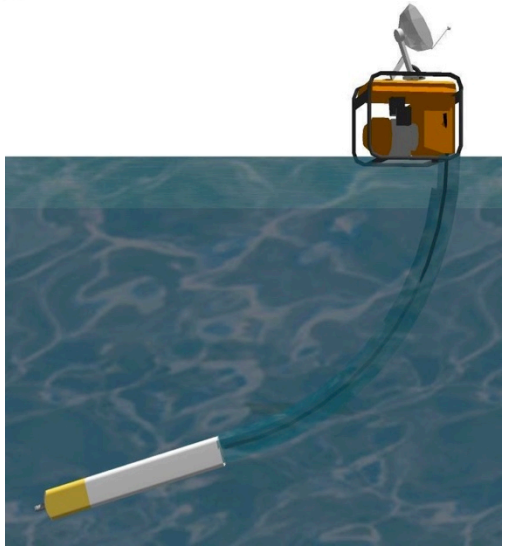


Equipped with 8 x 200 W and 8 x 160 W heating cartridges

IceMole
Principle of Operations

> Maneuverability in ice by differential heating of the melting head





> Power supply with generator on the surface
> Cable transmits power and data between the IceMole and the ground station

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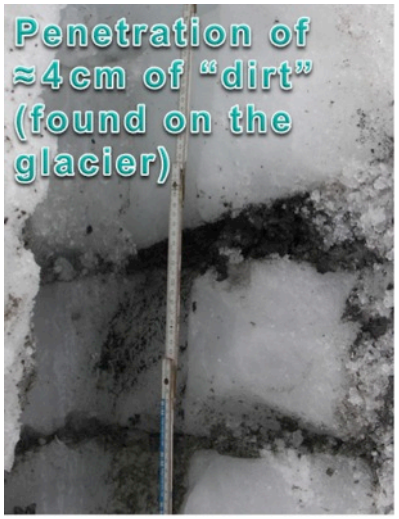
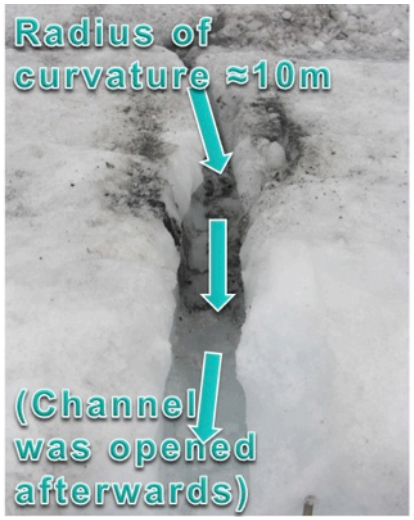
IceMole

Results from First Field Experiments

Digging upward (Switzerland 2010)

Digging sideward (Switzerland 2010)





Driving a curve and penetrating dirt (Switzerland 2010)

Penetrating a crevasse (Iceland 2012)

IceMole

Advantages with Respect to Existing Methods

	Drill	Melting Probe	IceMole
Controllability (incl. obstacle avoidance)	↓	↓	↑
Feasibility of space-resolved in-situ profile measurements	→	→	↑
Penetration of “dirt” layers	↑	↓	↑
Recoverability	↑	→	↑
Contamination	↓	↑	↑
Autonomy (incl. weather independency)	↓	↑	↑
Feasibility for space applications	↓	↑	↑

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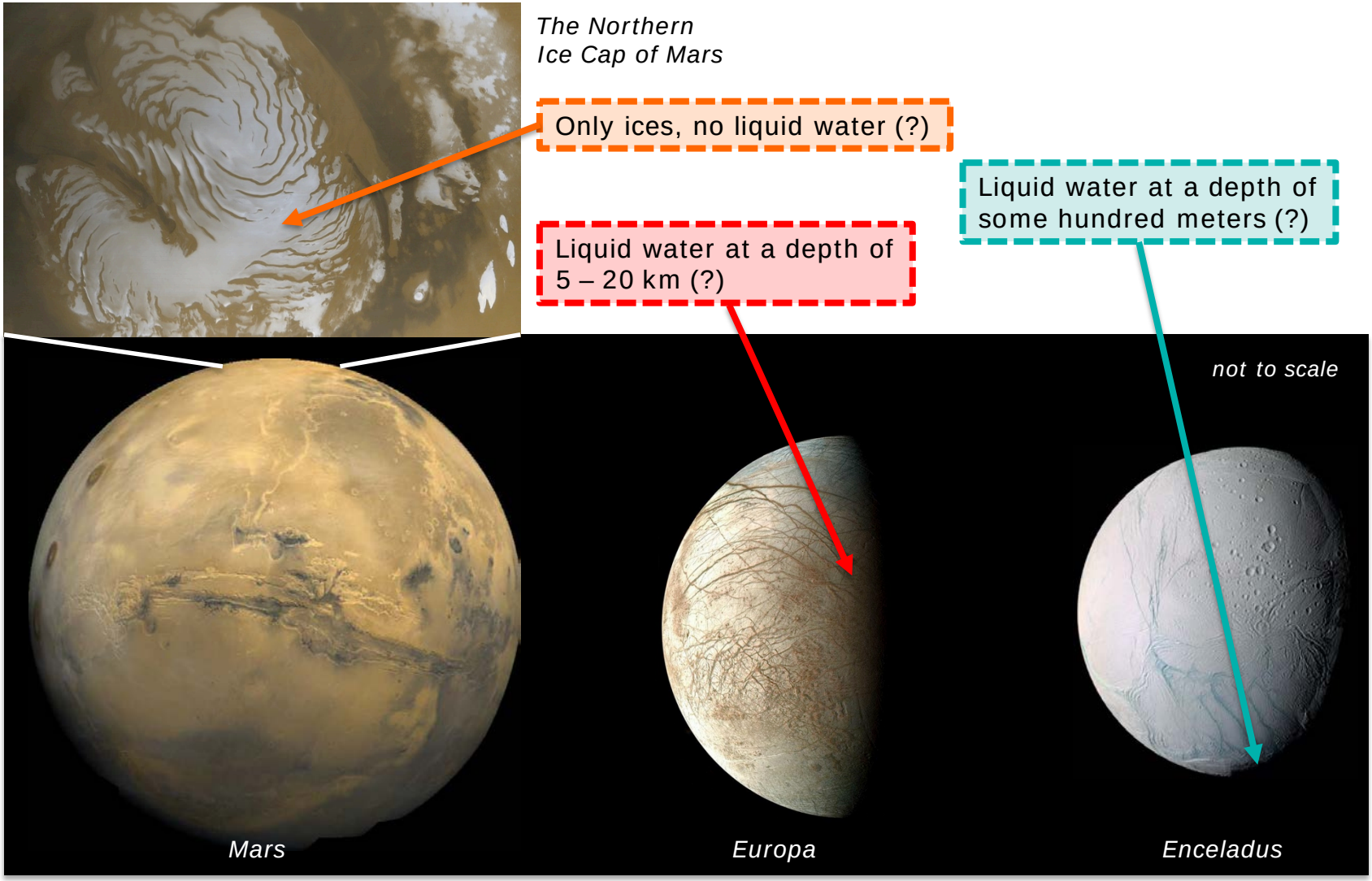
IceMole

Icy Targets of High Astrobiological Priority



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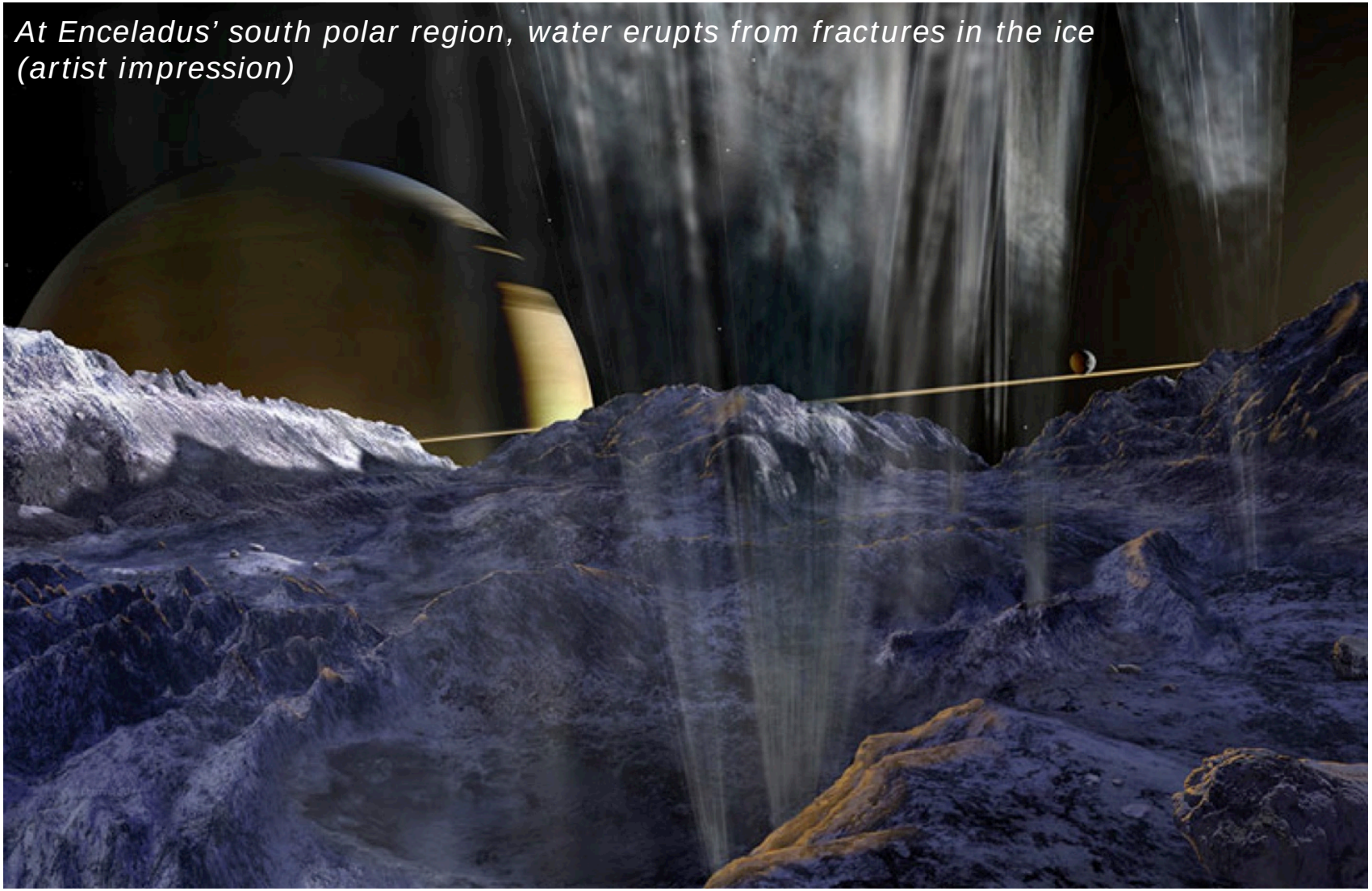
Enceladus Explorer (EnEx)

Goal: In-Situ Subsurface Analysis of Plume Material



At Enceladus' south polar region, water erupts from fractures in the ice (artist impression)

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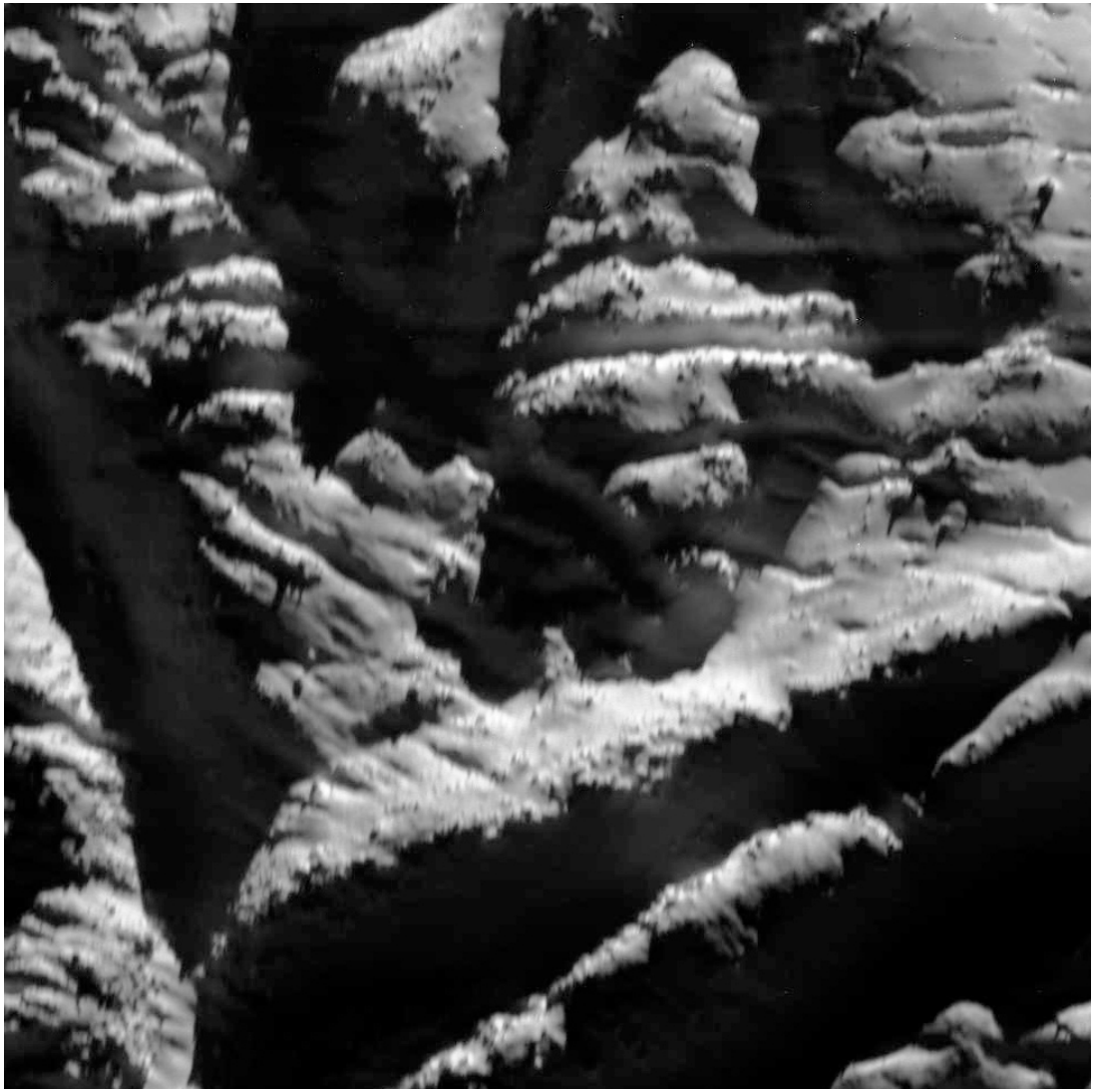
Enceladus Explorer (EnEx)

Goal: In-Situ Subsurface Analysis of Plume Material



Rough terrain at Enceladus' south pole with boulders resting along the tops of high frozen ridges *(edited from the original raw image to enhance detail) (Image credits: NASA/JPL/Space Science Institute, Universe Today)*

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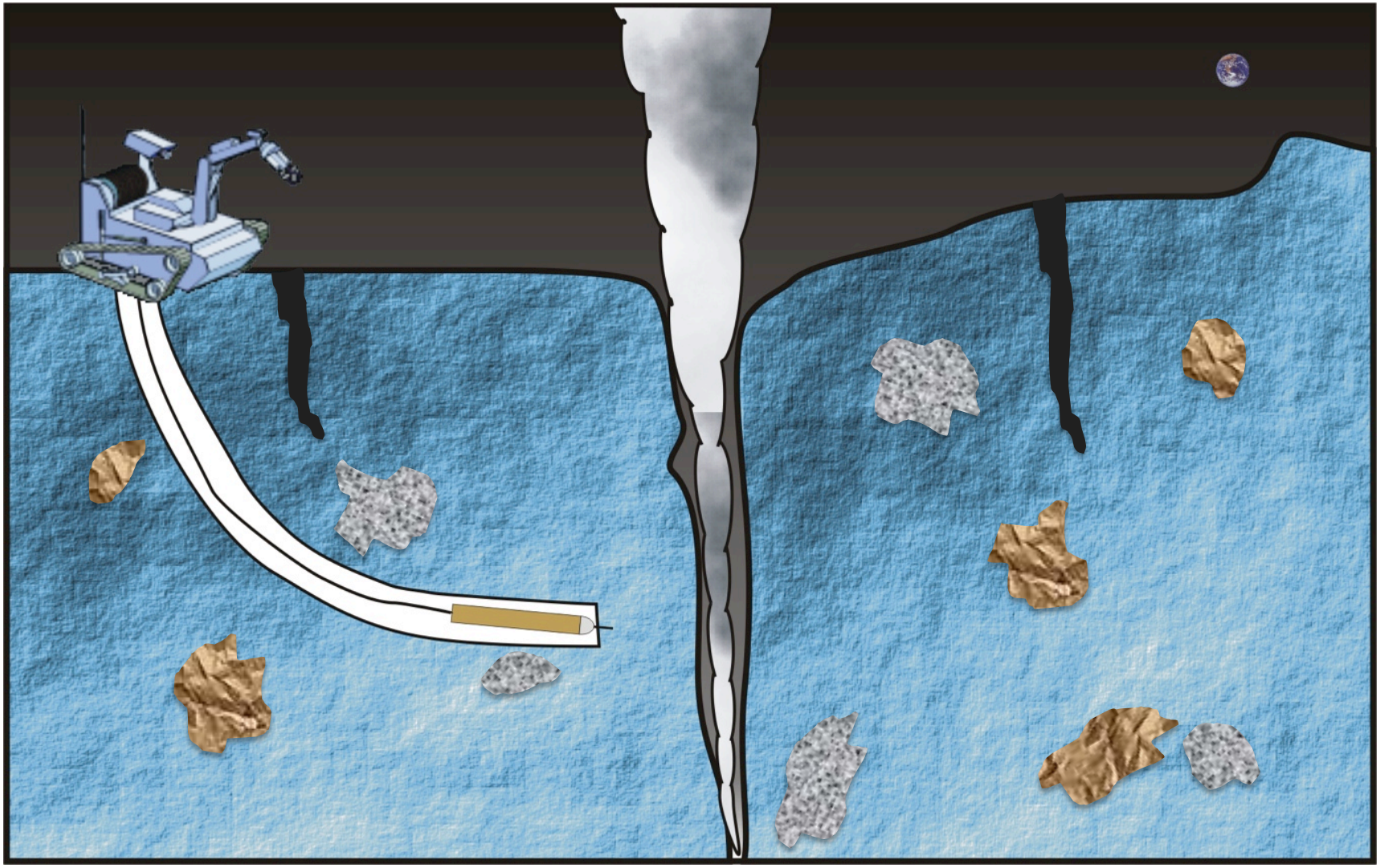
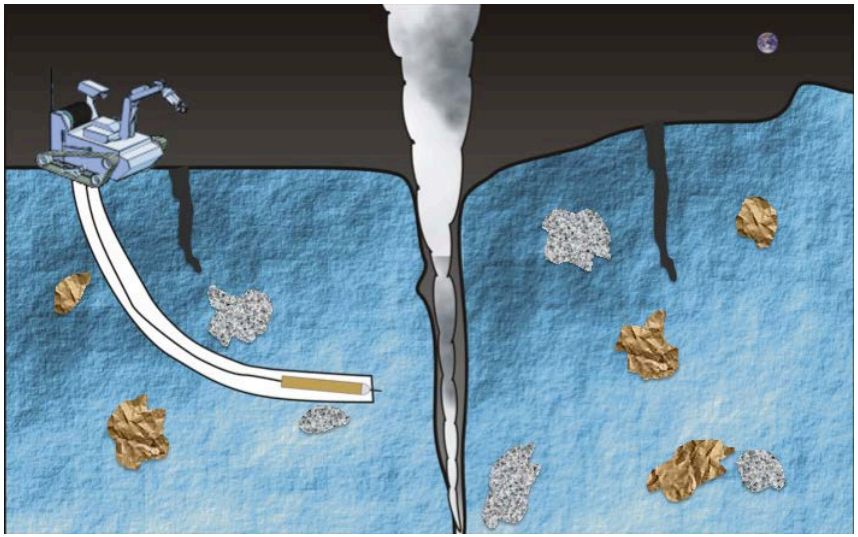
Enceladus Explorer (EnEx)
Mission Scenario and Objective



Enceladus Explorer (EnEx)
Mission Scenario and Objective

"Development of an Autonomous Steerable Subsurface Ice Probe to Demonstrate Autonomous Navigation in Deep Ice"
(not yet in space)



Enceladus Explorer Collaboration:

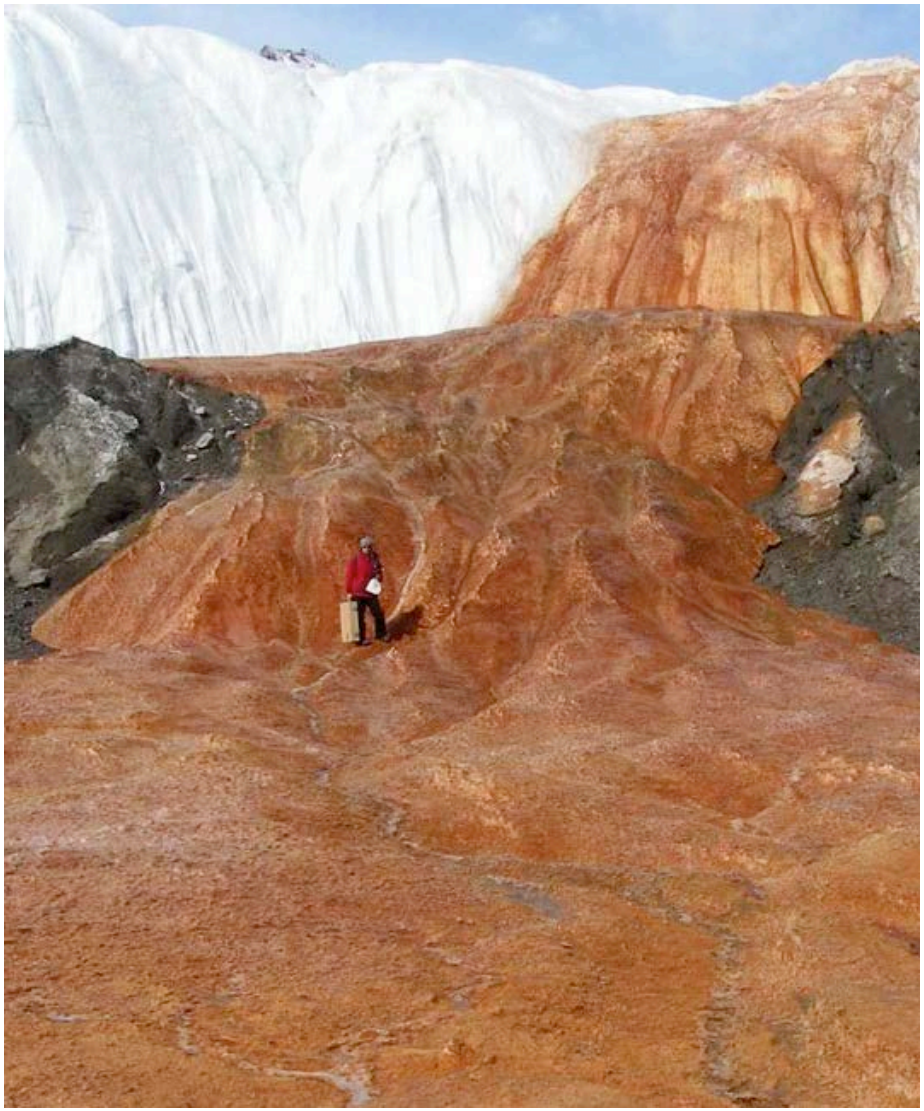
- **Prof. Dr. Bernd Dachwald** (PI) and Team
  Prof. Dr. Gerhard Artmann and Team
  FH Aachen University of Applied Sciences
- **Prof. Dr. Bernd Eissfeller** and Team
  Prof. Dr. Roger Förstner and Team
  Univ. of the Armed Forces, Munich
- **Prof. Dr. Kerstin Schill** and Team
  Uni Bremen
- **Prof. Dr. Peter Hecker** and Team
  Technical University Braunschweig
- **Prof. Dr. Christopher Wiebusch** and Team
  RWTH Aachen University
- **Prof. Dr. Klaus Helbing** and Team
  Bergische Univ. Wuppertal

EnEx ENCELADUS EXPLORER
an Initiative of DLR Space Administration

Gefördert durch:
Bundesministerium für Wirtschaft und Technologie
aufgrund eines Beschlusses des Deutschen Bundestages

The project Enceladus Explorer is based on an idea and initiative of the DLR Space Administration.

Blood Falls, Taylor Glacier, Antarctica
Sampling Subglacial Life and the US MIDGE Project



MIDGE: Minimally Invasive Direct Glacial Exploration
US sub-project with NSF funding
PIs: Jill Mikucki, Slawek Tulaczyk, Berry Lions, Erin Pettit

Objective: Clean sample return of subglacial water from a crevasse for life detection and analysis

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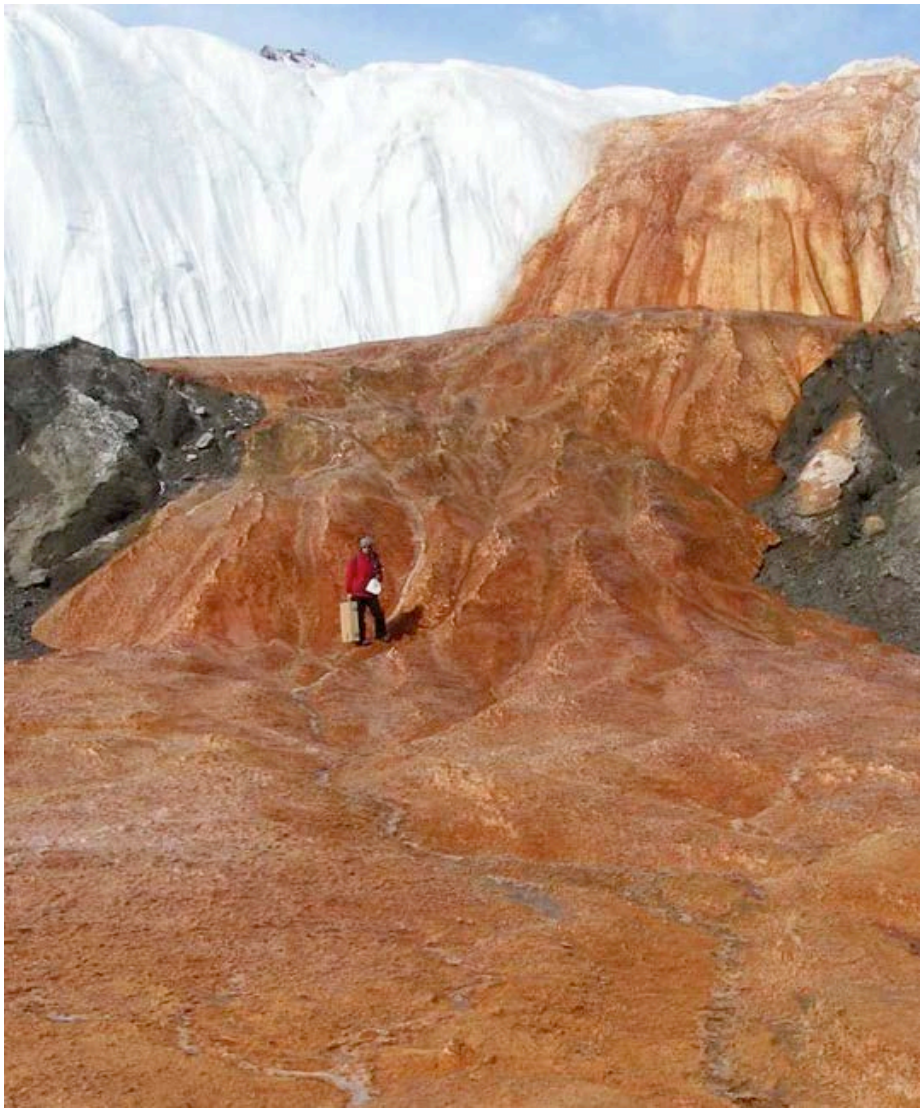
Blood Falls, Taylor Glacier, Antarctica

MIDGE and EnEx Objectives “in Harmony”



EnEx: Enceladus Explorer
German sub-project with DLR funding
PI: Bernd Dachwald

Objective: Development of an Autonomous Steerable Subsurface Ice Probe to Demonstrate Autonomous Navigation in Deep Ice” (not yet in space)

MIDGE: Minimally Invasive Direct Glacial Exploration
US sub-project with NSF funding
PIs: Jill Mikucki, Slawek Tulaczyk, Berry Lions, Erin Pettit

Objective: Clean sample return of subglacial water from a crevasse for life detection and analysis

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EnEx-IceMole
Interior View

- Length: 2.0 m
- Mass: ≈ 60 kg
- Advanced attitude and position determination system
- Clean sampling system for liquids
- Max. power for melting head: 8 x 200 W + 8 x 160 W
- Max. power for side wall heaters: 8 x 1000 W
- Melting velocity: ≈ 1 m/h
- Min. curve radius: ≈ 10 – 15 m

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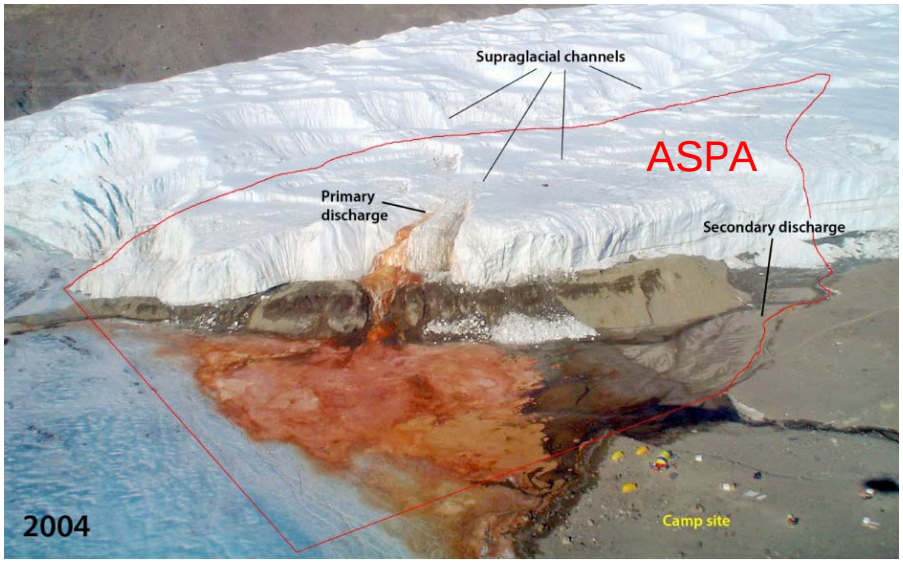
Clean Access

Field-Based Monitoring, Microbiological Control, and Decontamination



NRC Code of Conduct Recommendation 7:

Drilling in conjunction with sampling procedures will inevitably introduce microorganism into the subglacial aquatic environment. **The number of microbial cells contained in or on the volume of any material or instrument added to or placed in these environments should not exceed the minimum concentration of microbes in the basal glacial ice being passed through**

- Lower Taylor Glacier is an ASPA (Antarctic Specially Protected Area)
- Microbiological tests according to ECSS-Standard Q-ST-70-55C
- Probe and instrument cleaning
- Clean access monitoring according to Planetary Protection Standards
- Field testing of IceMole and instrumentation and clean access strategies
- Clean access documentation and reporting

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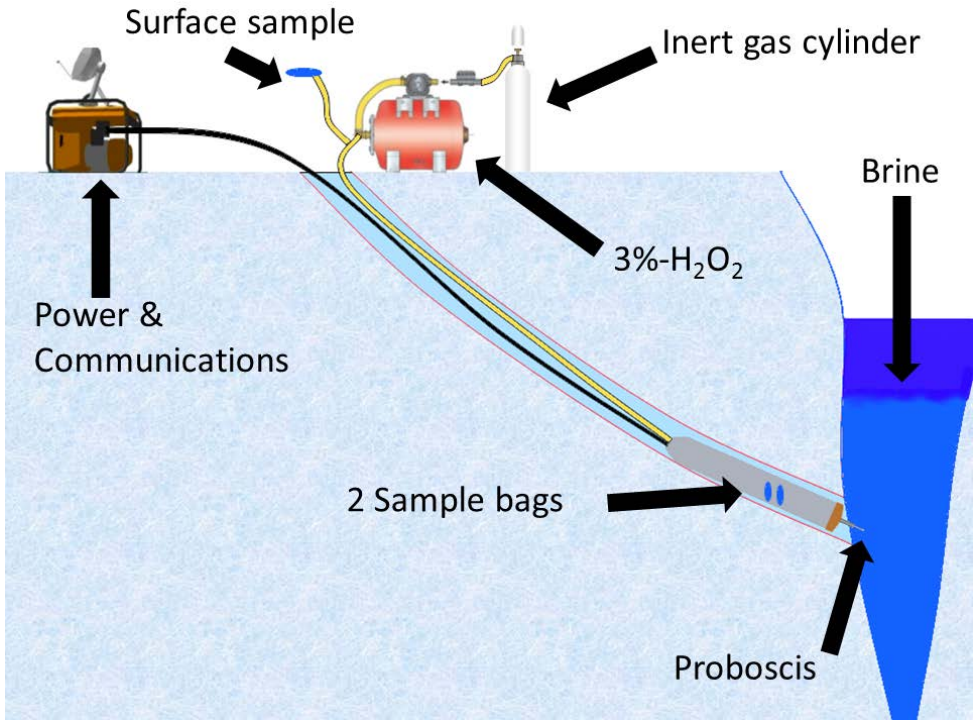
Canada Glacier, Antarctica, 2013

Drilling on Canada Glacier

Taylor Glacier, Antarctica, 2014

Operational Scenario and the Challenge for 2014



Crevasse, a few years before

2014, no crevasse visible

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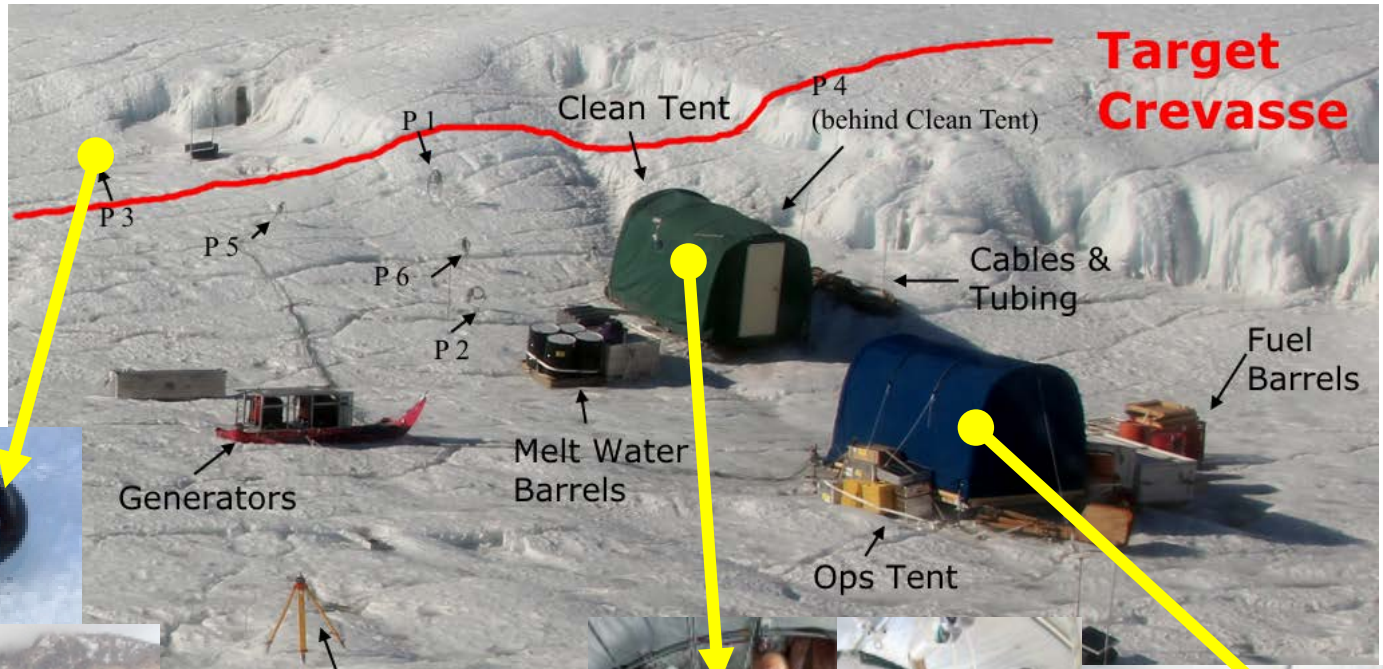
Taylor Glacier, Antarctica, 2014
Operations at Blood Falls



"Pinger Field"
Ultrasound Emitters for Navigation

Clean Tent

Ops Tent

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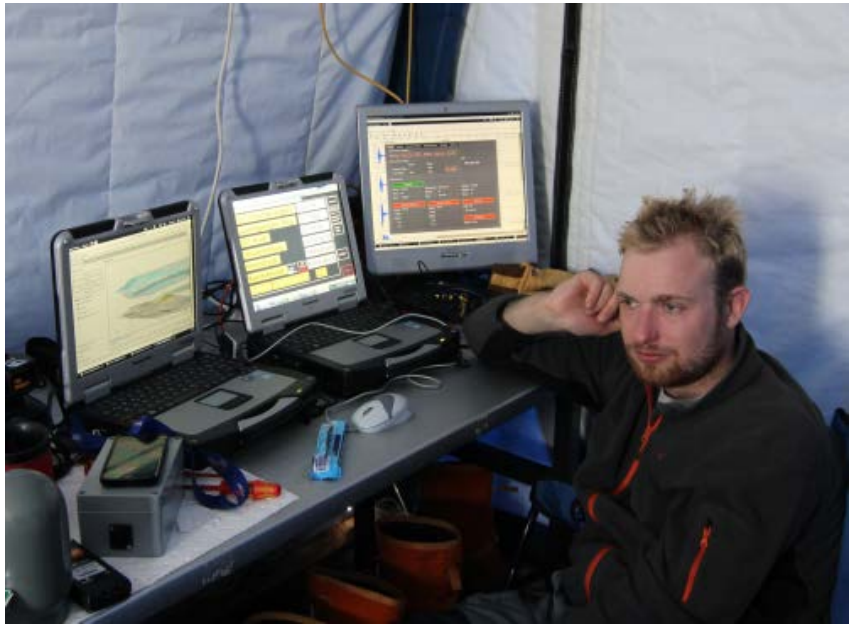
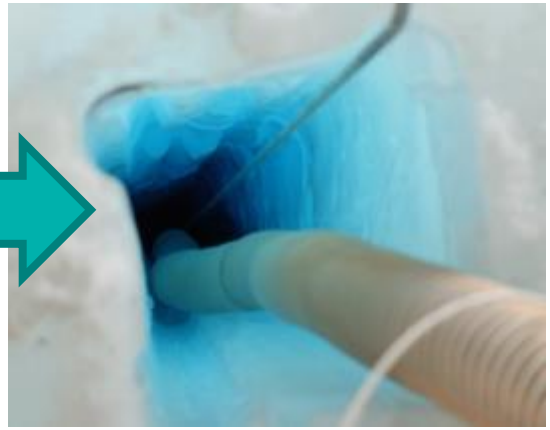
Taylor Glacier, Antarctica, 2014
Operations at Blood Falls





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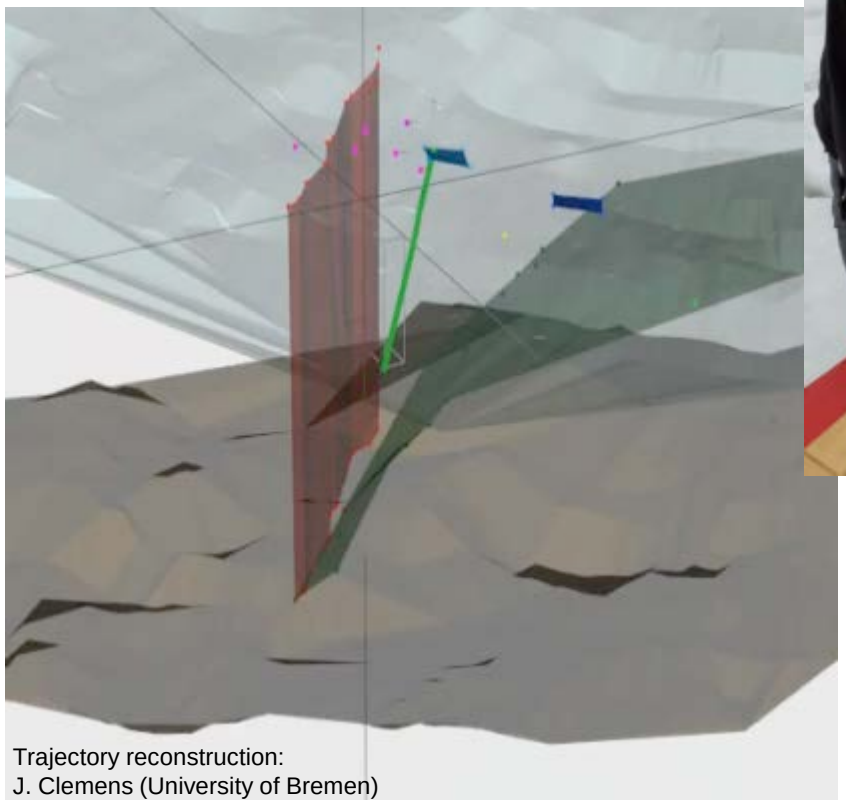
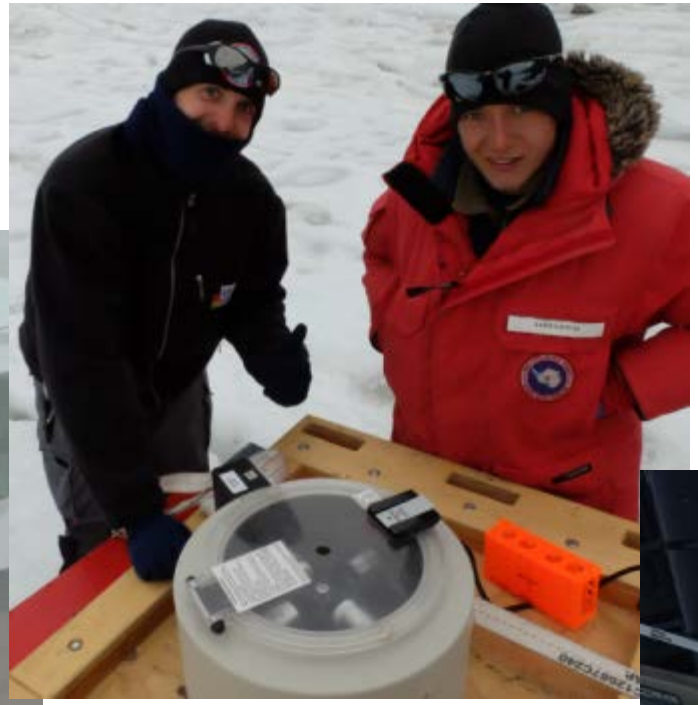
Taylor Glacier, Antarctica, 2014
Operations at Blood Falls

Penetration of brine-filled crevasse after "only" 18 m of drilling



Trajectory reconstruction:
J. Clemens (University of Bremen)



Collection of > 400 pints of brine

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Enceladus Explorer
The Mission Concept

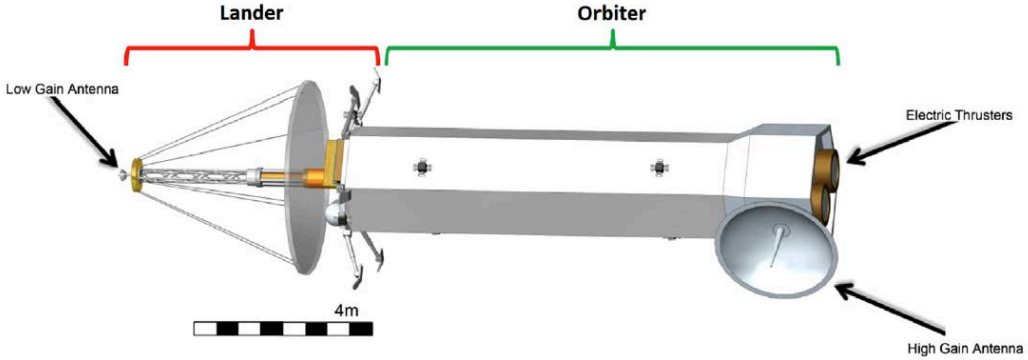
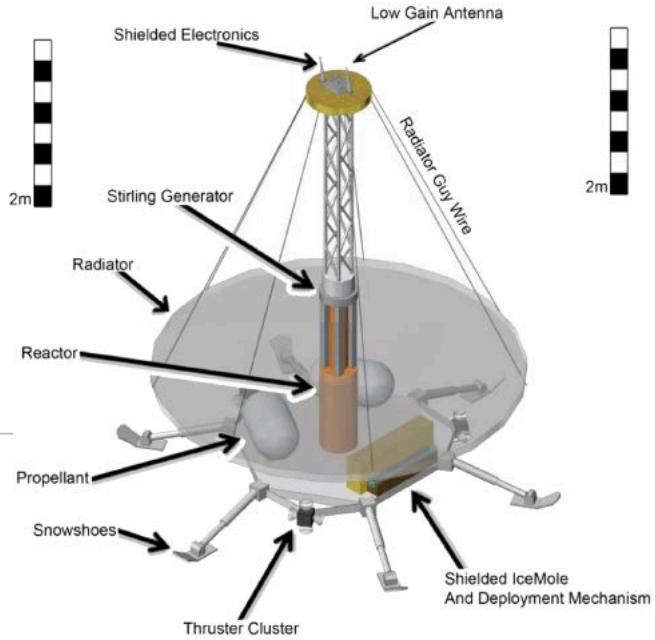


Fig. 8. Preliminary design of the Combined Spacecraft, comprised of the Orbiter and Lander, before Lander separation.



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journal homepage: www.elsevier.com/locate/actaastro

A lander mission to probe subglacial water on Saturn's moon Enceladus for life ☆

Konstantinos Konstantinidis [a,*], Claudio L. Flores Martinez [b], Bernd Dachwald [c], Andreas Ohndorf [d], Paul Dykta [a], Pascal Bowitz [a], Martin Rudolph [a], Ilya Digel [c], Julia Kowalski [c], Konstantin Voigt [a], Roger Förstner [a]

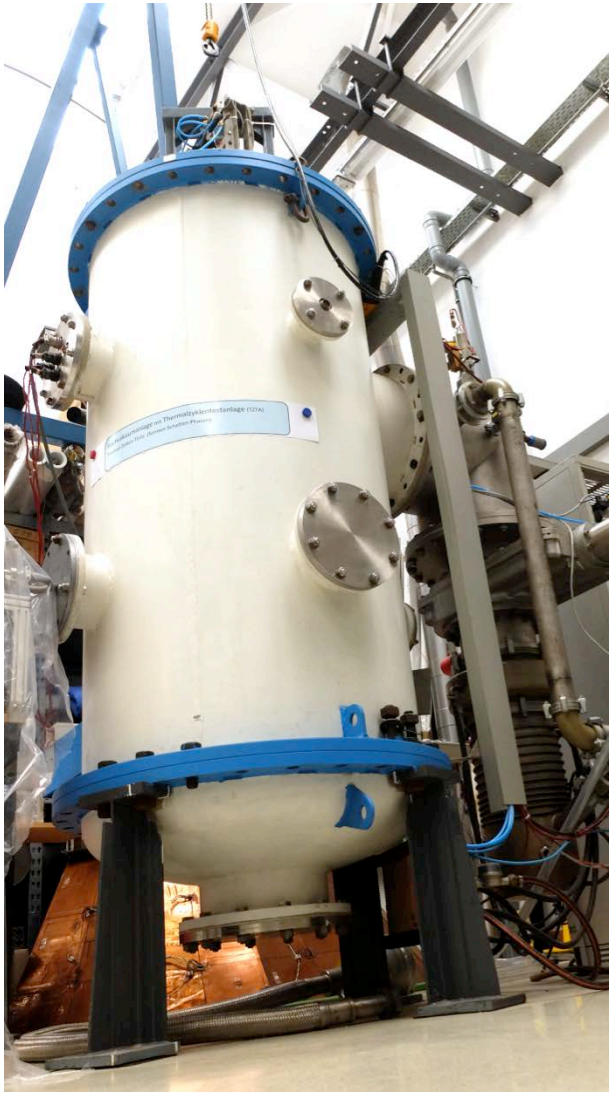
[a] Institute for Space Technology and Space Applications, Bundeswehr University Munich, Werner-Heisenberg-Weg 39, 85579 Neubiberg, Bavaria, Germany
[b] Centre for Organismal Studies,University of Heidelberg, Im Neuenheimer Feld 234, 69120 Heidelberg, Baden-Württemberg, Germany
[c] Faculty of Aerospace Engineering, FH Aachen University of Applied Sciences, Hohenstaufenallee 6, 52064 Aachen, Germany
[d] Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Oberpfaffenhoffen, Bavaria, Germany

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

EnEx-nExT (Environmental Experimental Testing)
Preparing the IceMole for Extraterrestrial Applications



> Traditional melting probes have difficulties with melting under low-pressure conditions (poor heat transfer at the melting head and sublimation)

> The IceMole for EnEx-nExT will be much smaller (≈ 8 x 8 x 50 cm, < 5 kg, ≈ 1000 W)

> It will be tested between 2016 and 2018 under simulated space conditions (pressure < 6 mbar, temperature < -180° C) with DLR funding to demonstrate the feasibility of the IceMole concept

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

Thank you for your attention!

ICE MOLE
Subsurface Icecraft

Blood Falls Field Test
EnEx & MIDGE