A Virtual Testbed Infrastructure for Cryo-robotic Subsurface Exploration

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Objective

- Develop a digital infrastructure to foster crossdisciplinary development of cryo-exploration technology
- Facilitate the systematic and reproducible virtual testing of candidate cryo-robot designs in different cryoenvironments complementary to lab and field tests
- Provide a Python interface to **integrate and process** mission data, and to conduct optimal data acquisition and UQ

Building blocks of the virtual testbed [2]

The cryo-robot's engineering design + payload module determine its dynamic behavior (physics-engine) and can be optimized accordingly (two-way coupling). The

cryo-robot's performance depends on the cryoenvironment. The payload module comprises sensors that inform about the cryoenvironment.



Physics-engine: Modelling the cryorobot's dynamic

Cryo-environment: Characterization of the ambient environmental conditions

Engineering design: specification of the cryobot's structure & geometry

Payload module: specification of the cryobot's sensors & science playload



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Physics-engine

Cryo-robot dynamics is a multi-physics process:

- A contact melting
- **B** nucleate boiling
- **C** lateral melting **D** heat conduction





E melt water convection Design optimization requires high-fidelity models, i.e. considering A – E; mission relevant metrics, such as transit time and power consumption can be approximated based on idealized efficiency & trajectory models A+D(+B) [1,3].

Cryo-environment [2]

- Ice Data Hub provided as Python module
- *.yaml files contain property data on vertical ice profiles
- Brokerage-type functional layer provides access, e.g. to temperature sensitive material parameters

Cryo-robot design [2,3]

- *.yaml files contain data on engineering design as relevant for the physics-engine
- Extendible Python / Jupyter workflow hosted on git

[1] Schüller K., Kowalski J. (2019. Icarus, 317, 1–9.

[2] Boxberg M. S. et al. (2020) EGU. Abstract # EGU21-13052

[3] Boxberg M. S. et al., 2021, submitted

[4] Plesa A.-C. et al. EPSC. Vol.14, Abstract # EPSC2020-1038, 2020

[5] Heinen D. et al., 2021, submitted



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Results:

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EnEx-RANGE-APU:	32 d
(2,88 kW,; 0,08 m radius)
TRIPLE-IceCraft:	29 d
(20 kW,; 0,20 m radius)	
RECAS:	54 d
(5 kW,; 0,15 m radius)	
Valkyrie:	140 d
(5 kW; 0,25 m radius)	

- Mission analysis based on a measured temperature profile at Dome C Antarctica [3]:
- Comparative study of different existing cryo-robot designs



Mission analysis based on a simulated Europa cryo-environment following [4]: ice shell thickness 40km / salt content 23 kg/m⁻³ for the TRIPLE IceCraft [5] Detailed results incl. sensitivity analysis and UQ in [3]: Reach out, if interested!

