A Virtual Testbed Infrastructure for Cryo-robotic Subsurface Exploration

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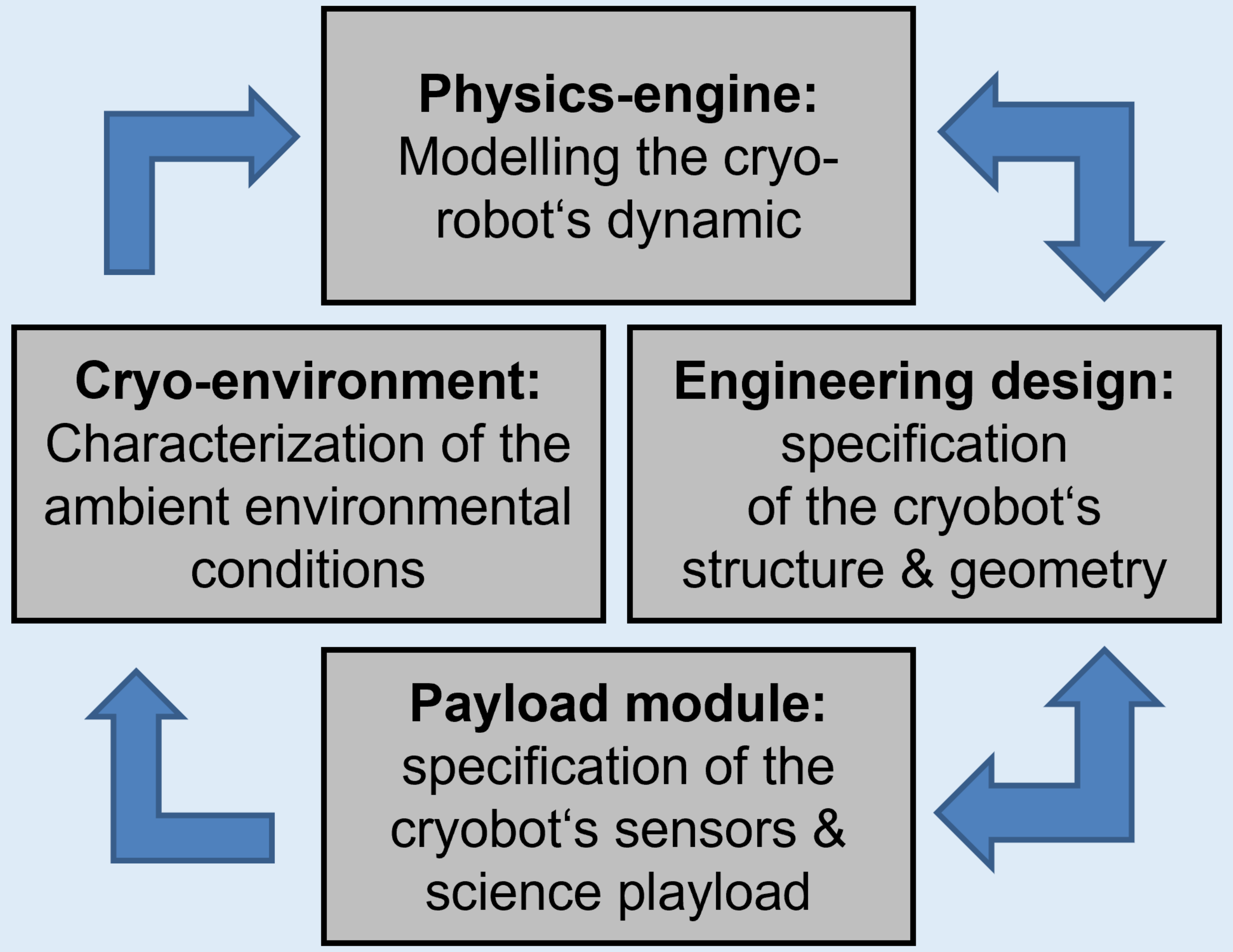
Objective

- Develop a **digital infrastructure** to foster cross-disciplinary development of cryo-exploration technology
- Facilitate the **systematic and reproducible virtual testing** of candidate cryo-robot designs in different cryo-environments 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]

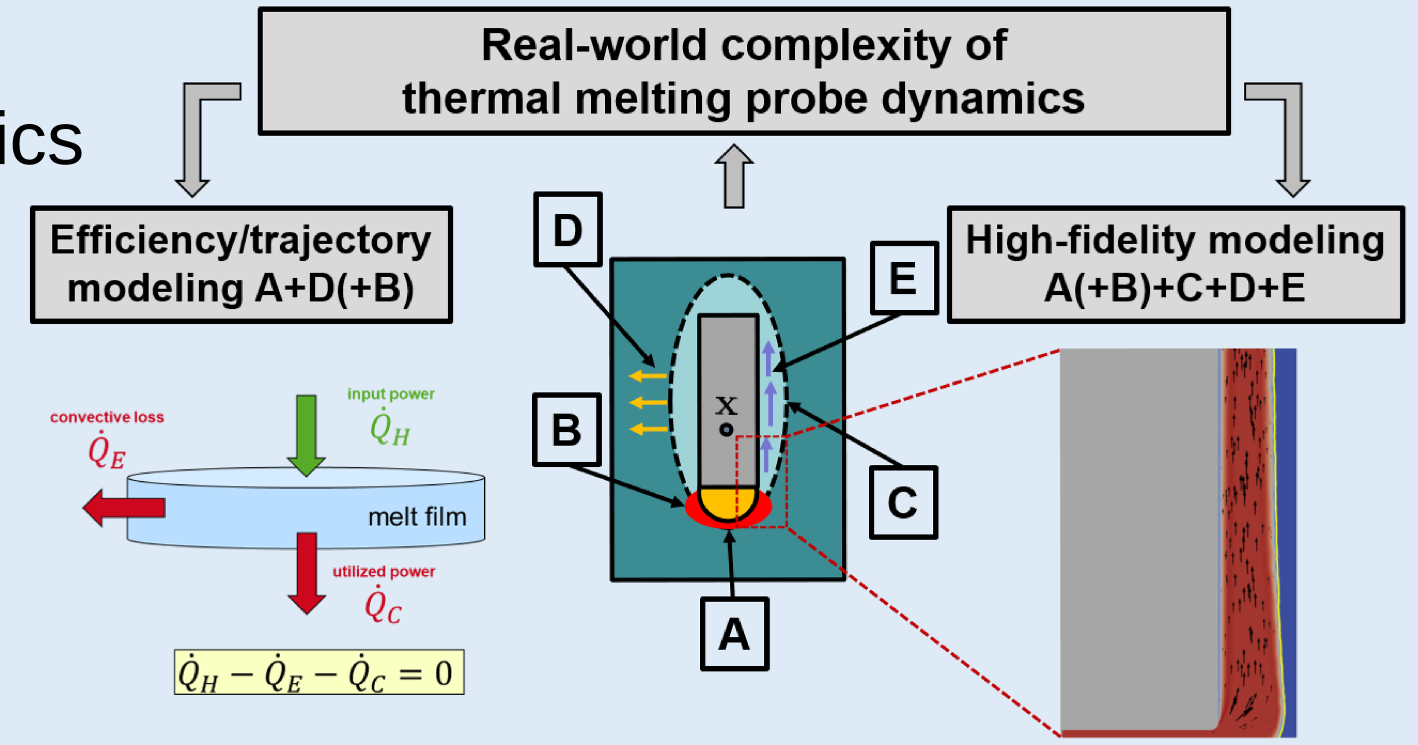
The cryo-robot's **engineering design** + **payload module** determine its dynamic behavior (**physics-engine**) and can be optimized accordingly (two-way coupling). The cryo-robot's performance depends on the **cryo-environment**. The payload module comprises sensors that inform about the **cryo-environment**.



Physics-engine

Cryo-robot dynamics is a multi-physics process:

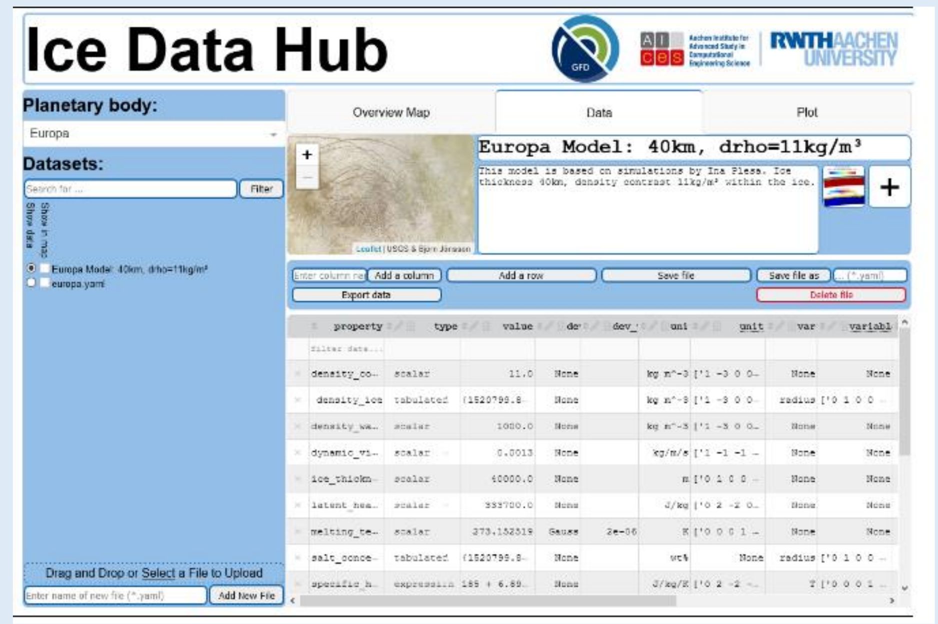
A contact melting
B nucleate boiling
C lateral melting
D heat conduction
E melt water convection



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

Results:

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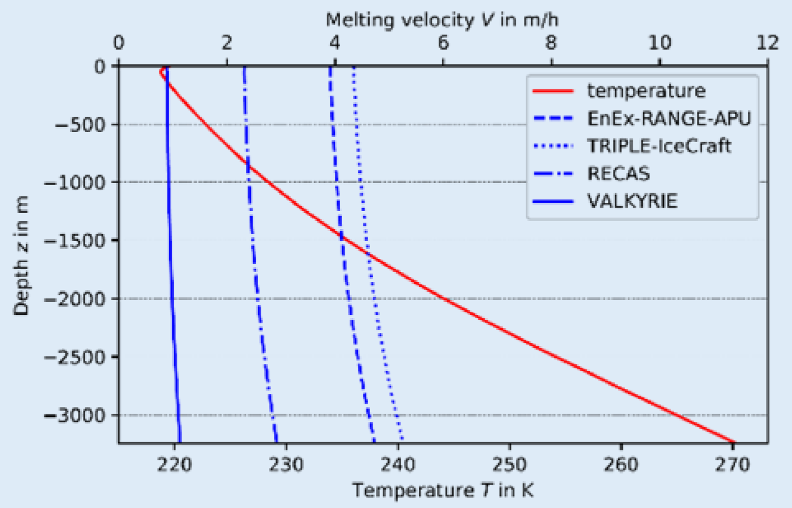

Transit time:

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

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

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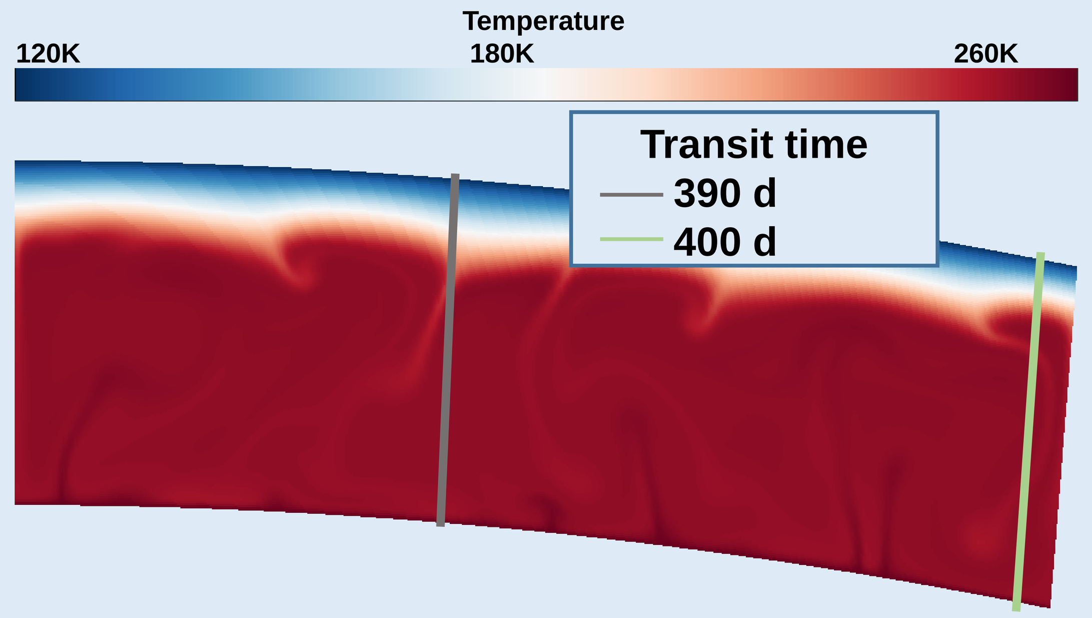

- Mission analysis based on a simulated Europa cryo-environment following [4]: ice shell thickness 40km / salt content 23 kg/m^{-3} for the TRIPLE IceCraft [5]
- Detailed results incl. sensitivity analysis and UQ in [3]: **Reach out, if interested!**

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[1] Schüller K., Kowalski J. (2019. Icarus, 317, 1–9.
[2] Boxberg M. S. et al. (2020) EGU. Abstract # EGU21-13052
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[4] Plesa A.-C. et al. EPSC. Vol.14, Abstract # EPSC2020-1038, 2020
[5] Heinen D. et al., 2021, submitted

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