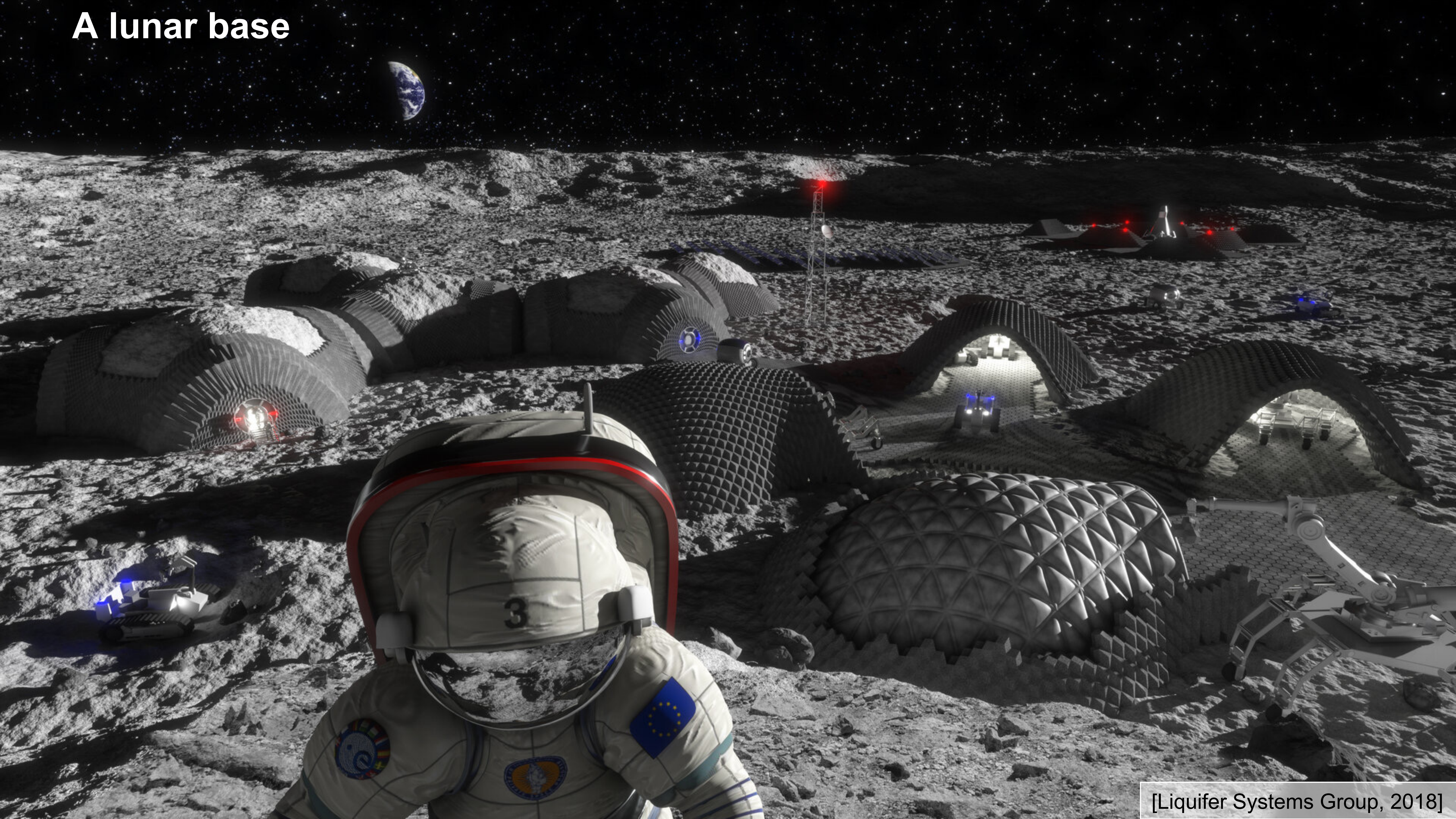
Molten Regolith Extrusion (MREx): Additive Manufacturing Experiments in Vacuum

Simon Stapperfend

Chair of Space Technology, Technische Universität Berlin

A lunar base



[Liquifer Systems Group, 2018]

Project: 3D-LAVA

Additive Manufacturing using

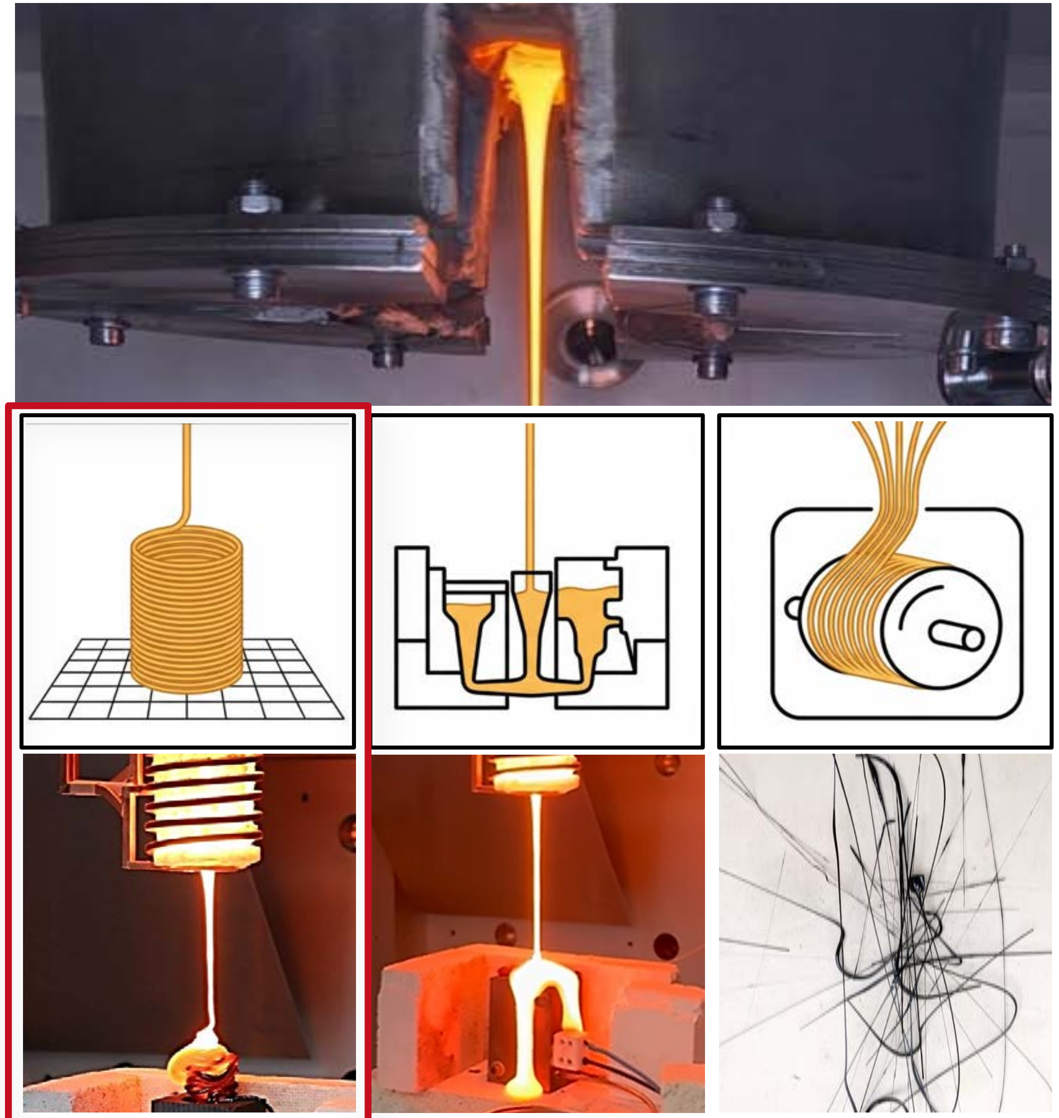
Molten Regolith Extrusion (MREx)

Advantages

+ Construction without binder

+ Only electrical energy and regolith needed

+ Little powder handling required



Additive Manufacturing

Casting

Fibre Drawing

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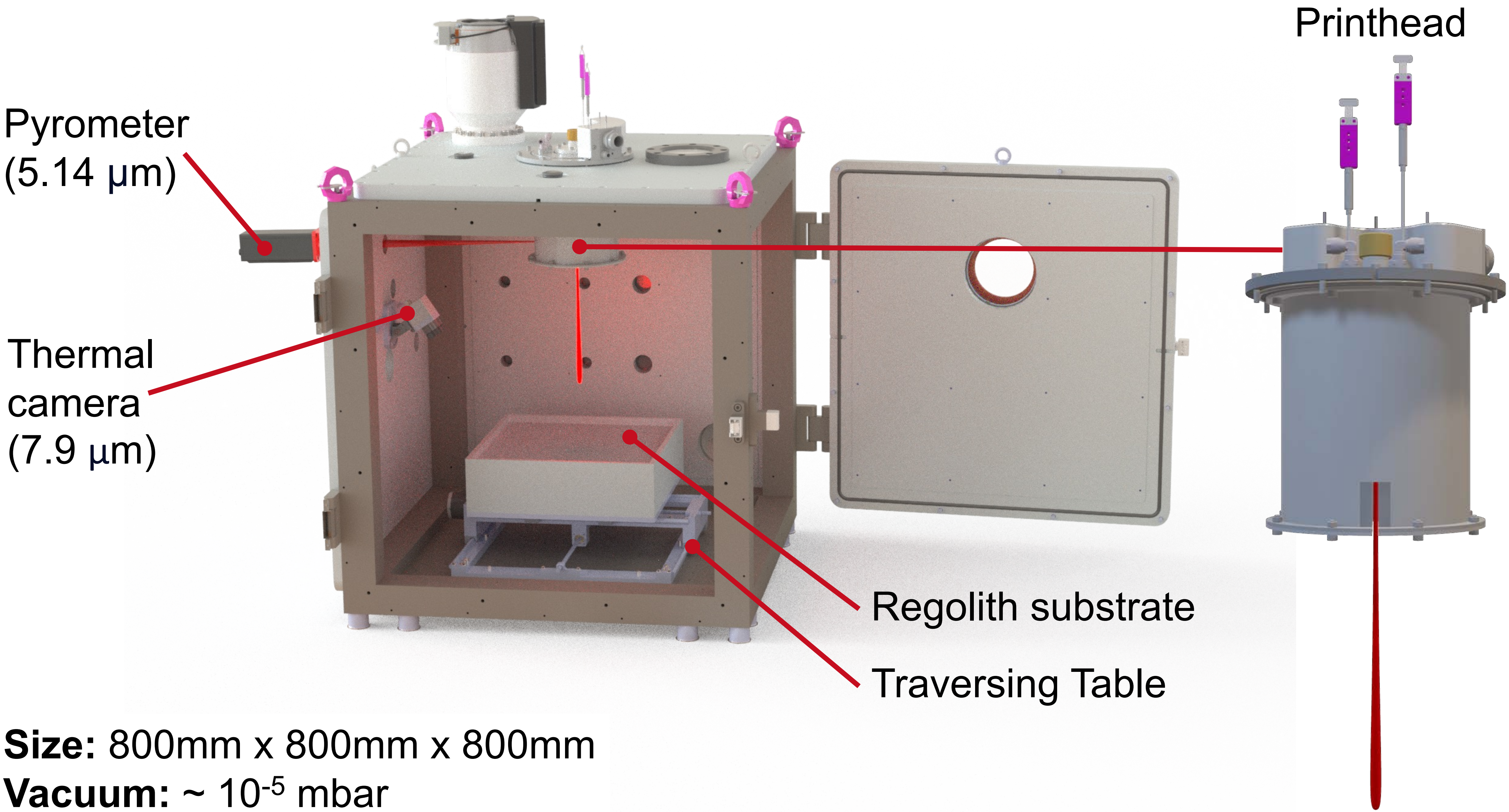
Experimental Setup



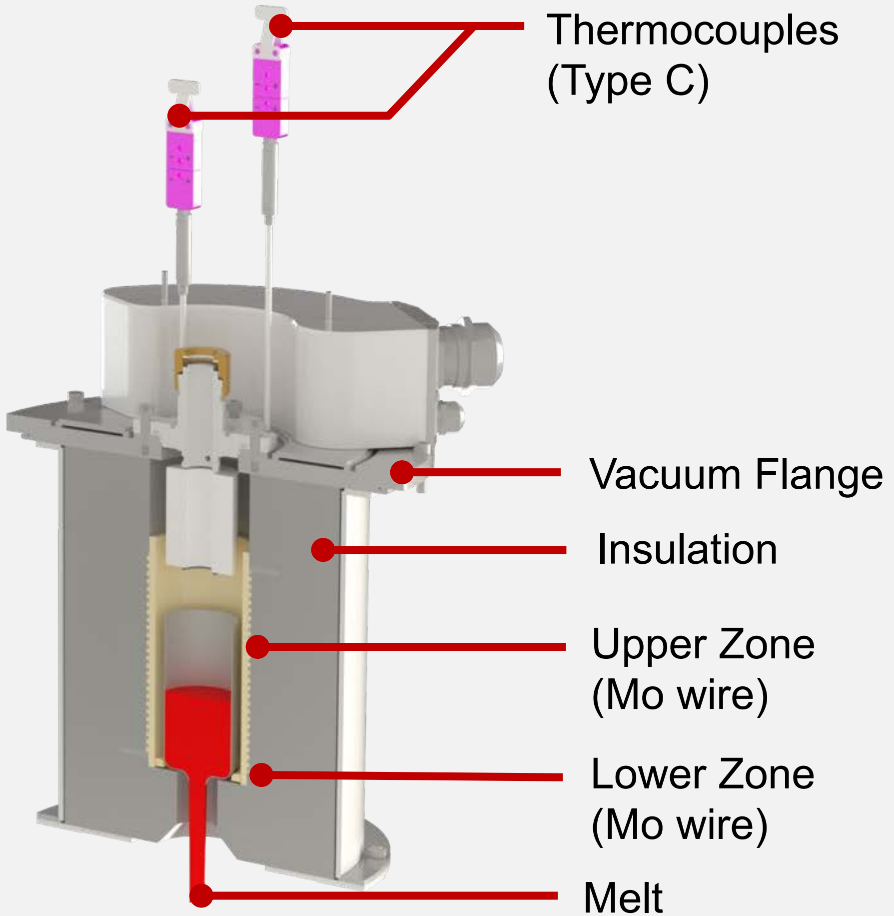
Size: 800mm x 800mm x 800mm
Vacuum: ~ 10^{-5} mbar

(Old) Printhead

- Custom vertical tube furnace
- Hot zone in vacuum
- Temperatures: up to 1,600 °C
- Two heating zones (crucible and nozzle)
- $Pt_{90}Rh_{10}$ crucible filled with mare simulant

→ Currenty being replaced by induction heater

RESISTIVE FURNACE



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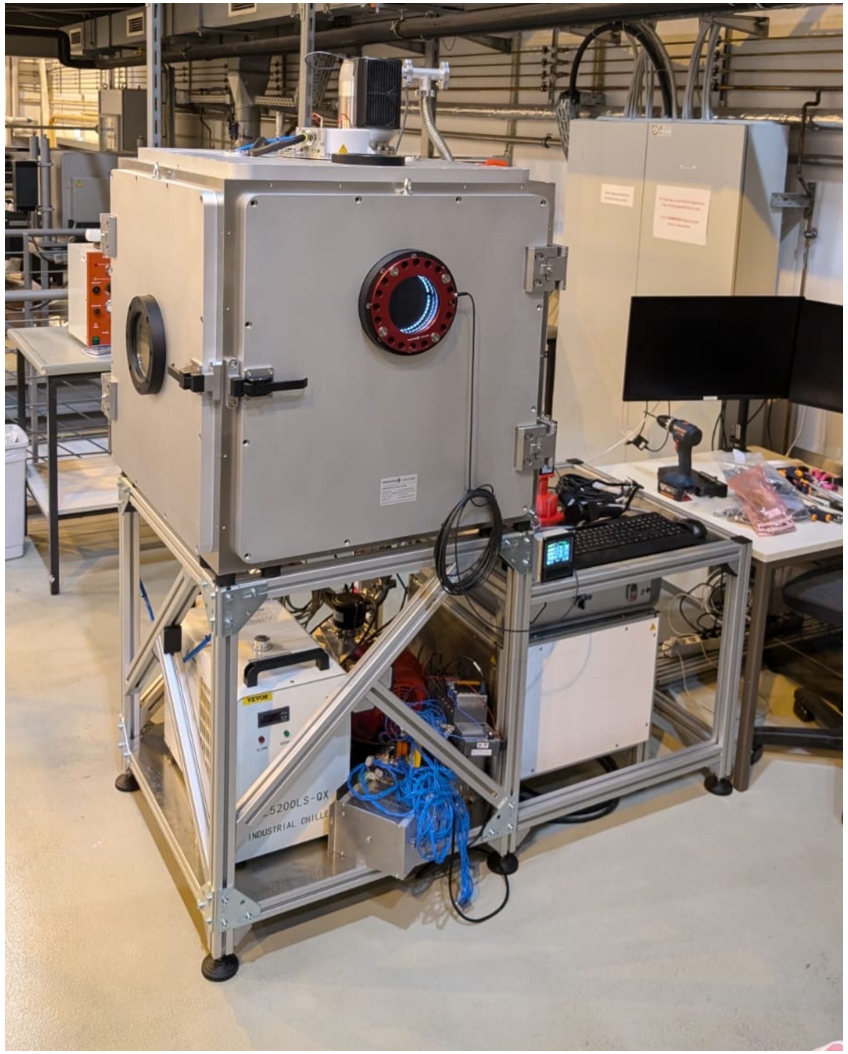
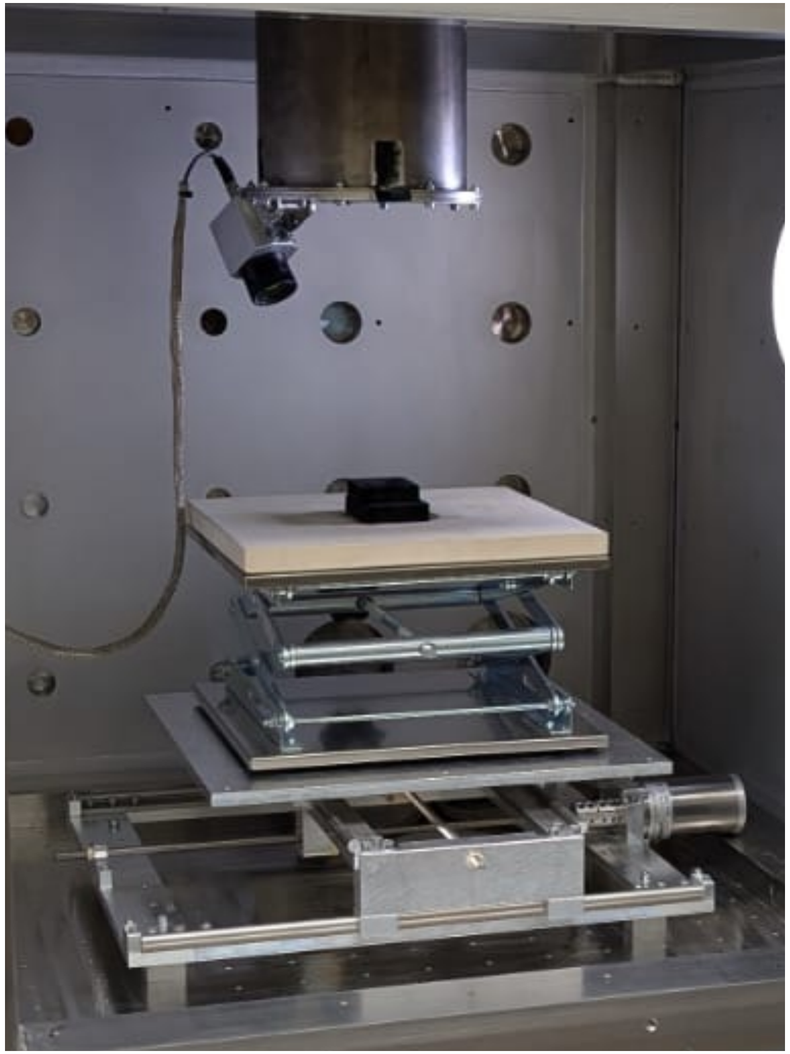


▲Whole test setup



▲Inside chamber with Traversing Table

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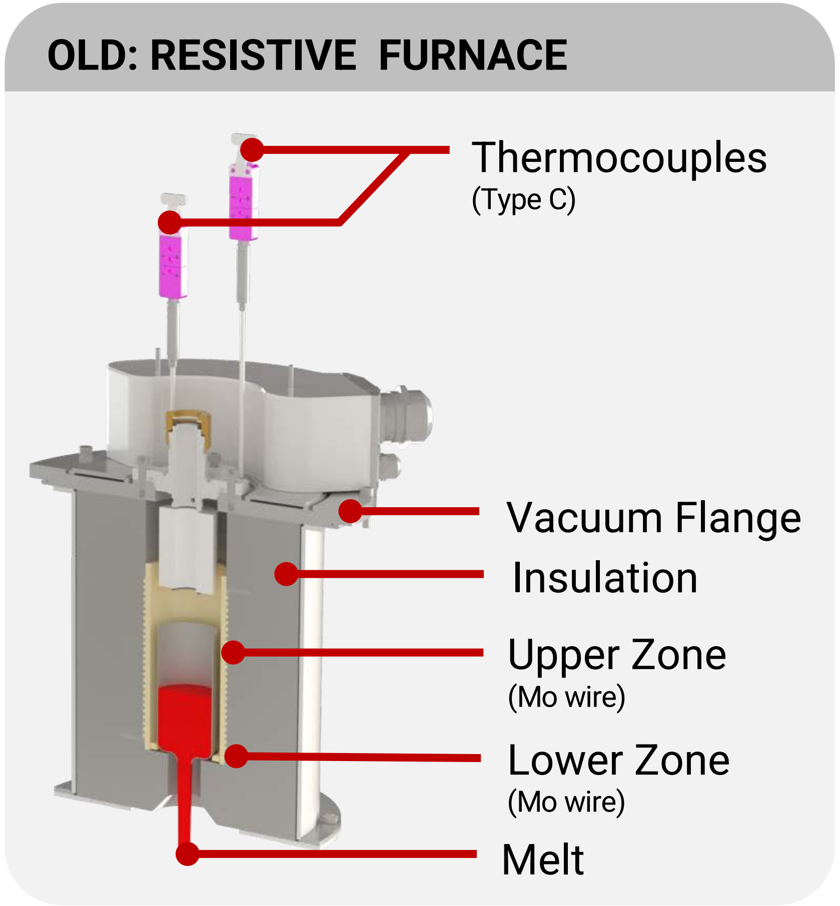
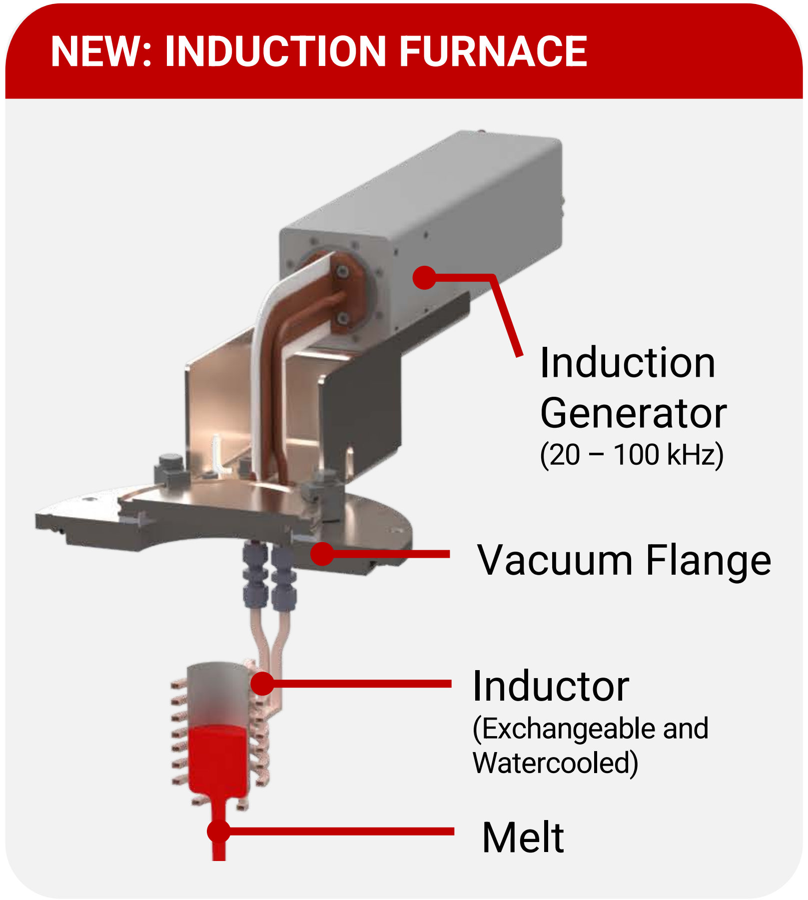
New furnace design



- ✓ Shorter cycle times
- ✓ Better process control
- ✓ Optimized geometry
- ✓ Expandable design
- ✓ Easy maintenance
- ✓ Modular system
- ✓ Higher efficiency
- ✓ Flexible operation

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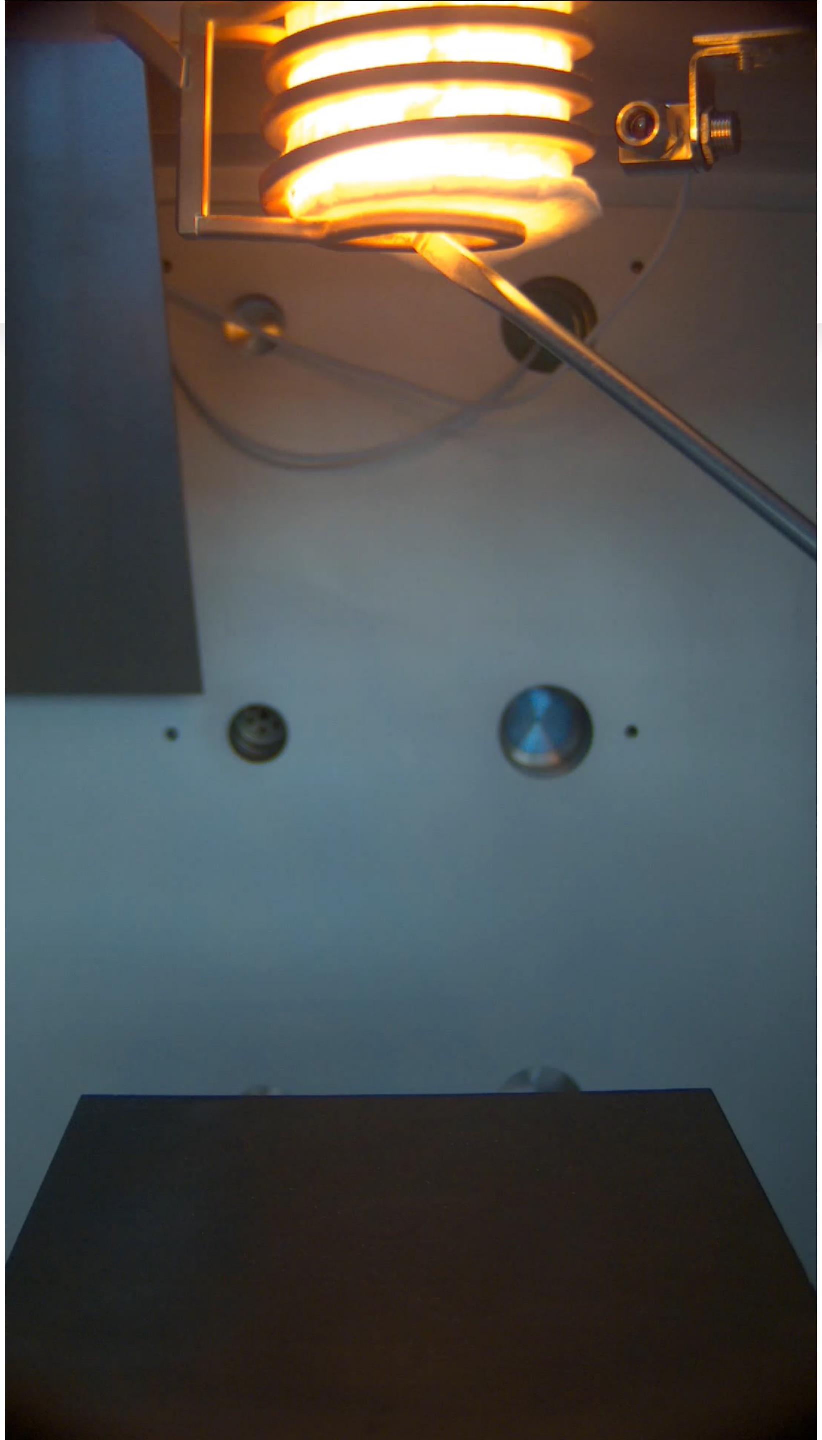
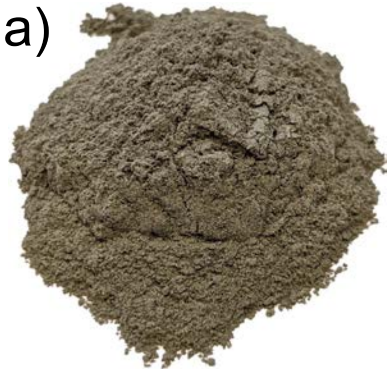


Experimental overview

Several experiments were performed:

- Material (LX-M100): regolith (a), coarse particles, sintered particles (b), vacuum sintered (c), glass shards (d)
- Substrates: regolith powder, cordierite, graphite
- Different table movement patterns

a)



b)

c)

d)

▲Extrusion onto cordierite plate

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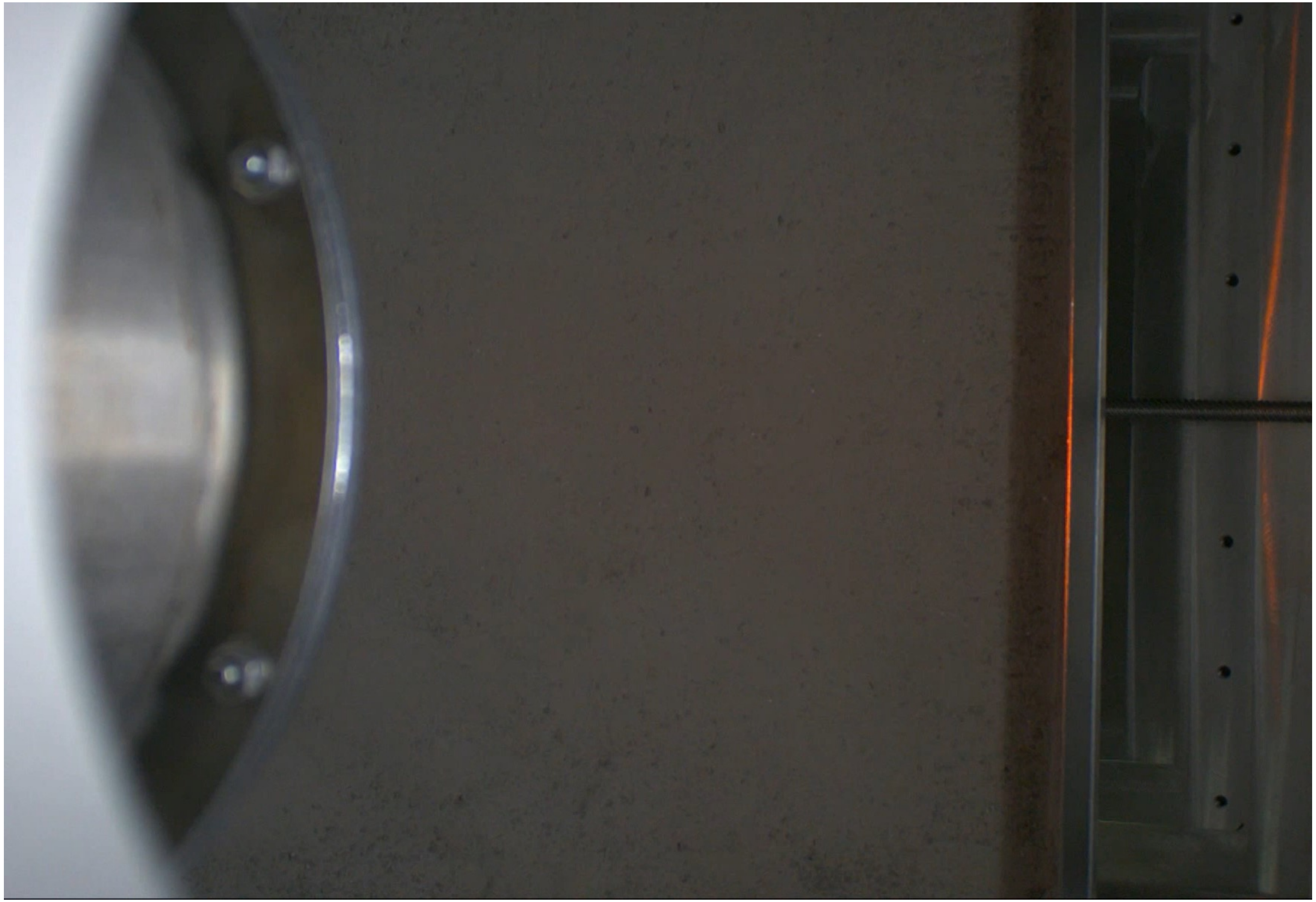
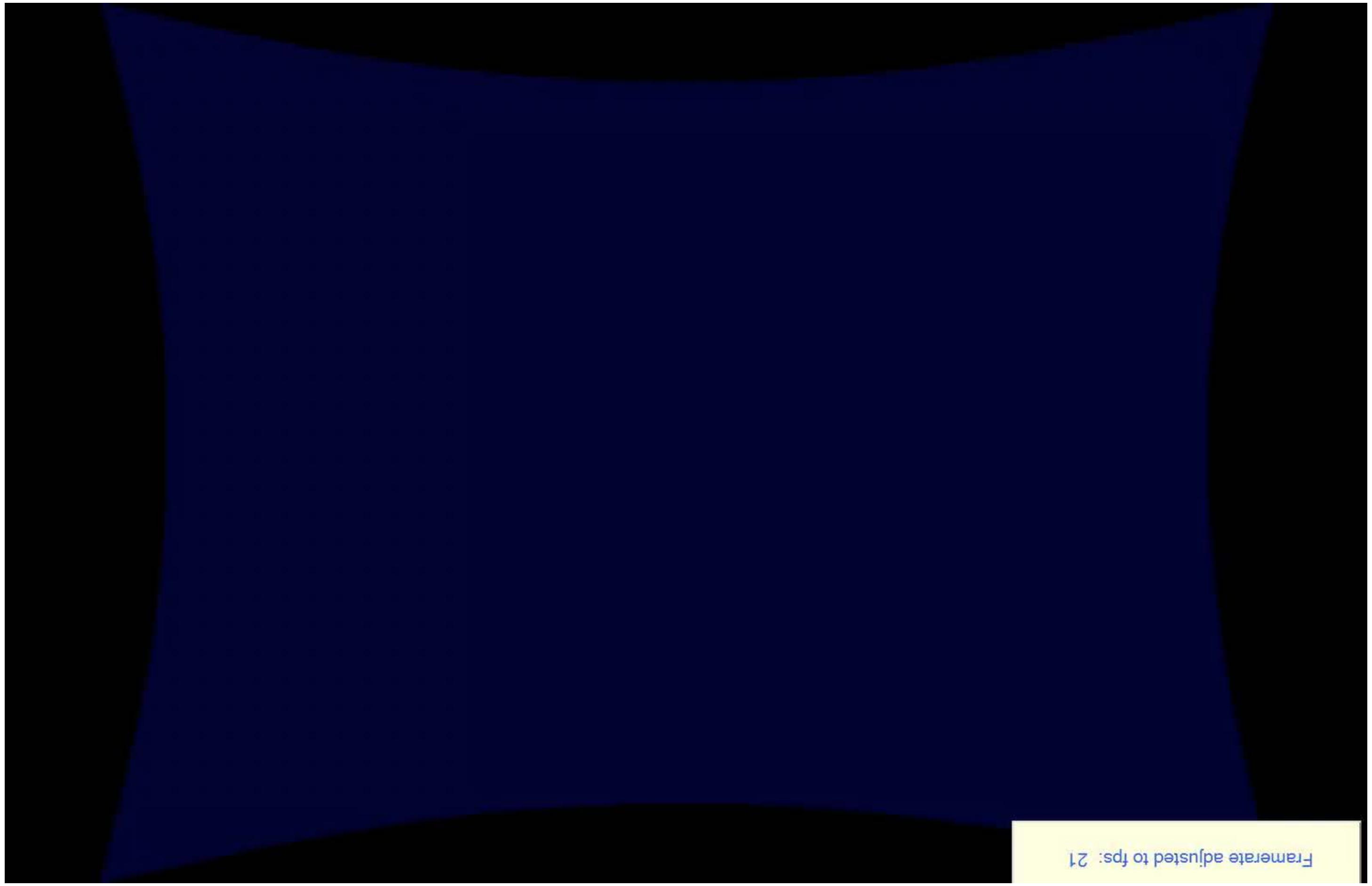
First Experiment



▲Curved part

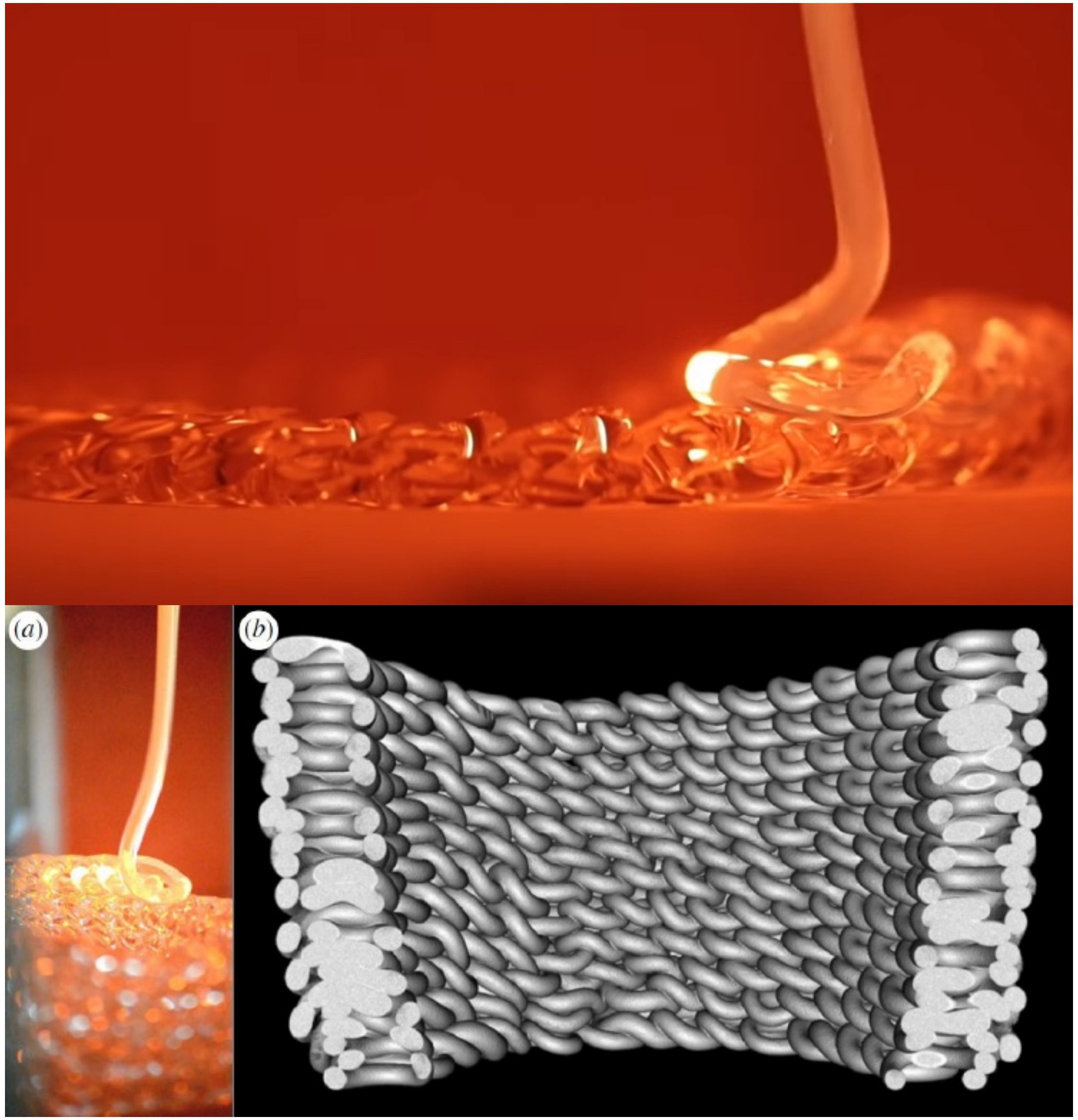
More Experiments

Thermal camera




Fracture edge with pore
Intact line of glass with glass fibers
Coiling of fine glass fibers
„Plug“ from the previous batch
Glass bead with fibre
Crucible after outflow: ~6 g remain in crucible

Current Status and Goal

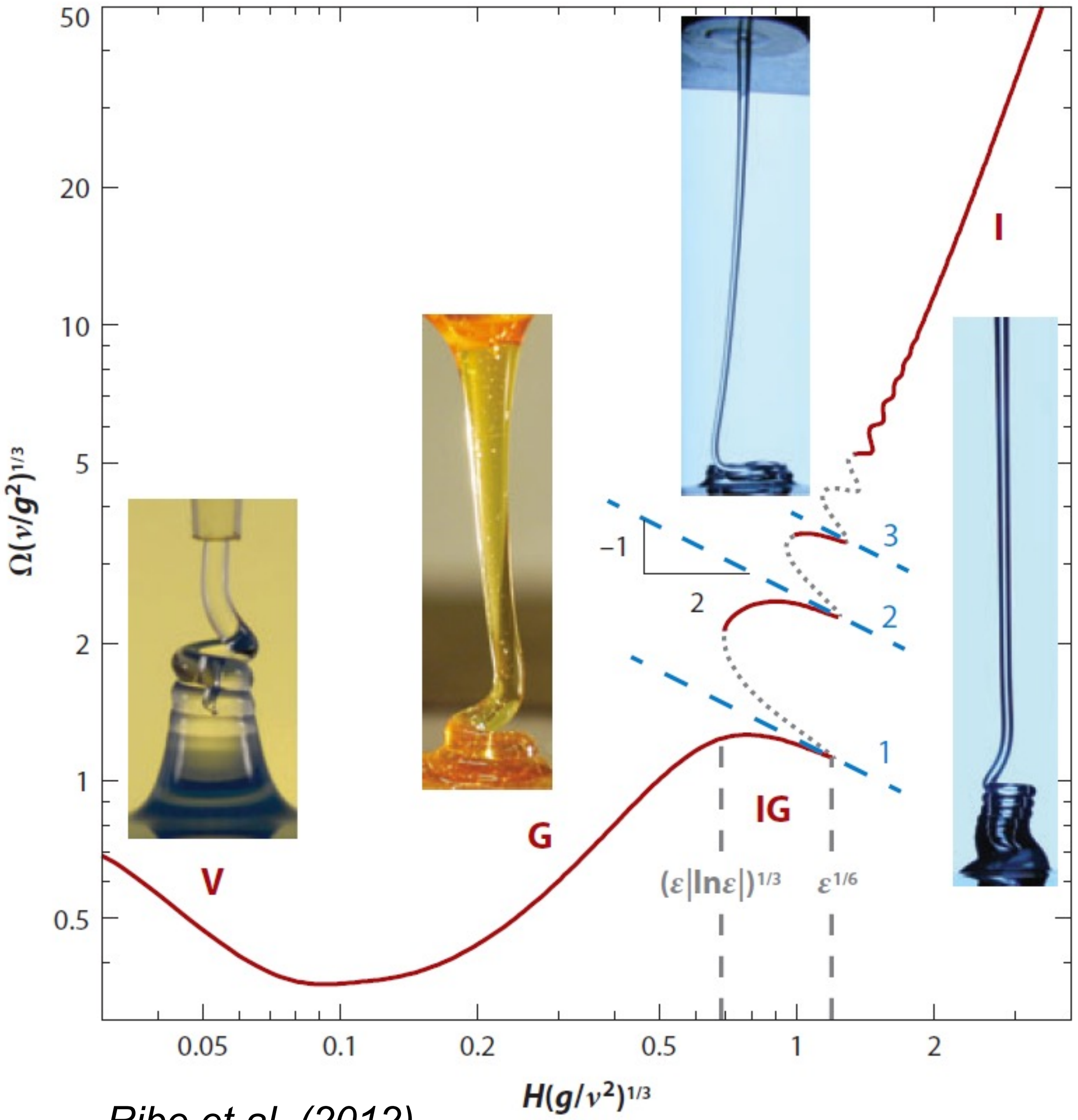


Brun, P.-T. ; Inamura, C. ; Lizardo, D. ; Franchin, G. ; Stern, M. ; Houk, P. ; Oxman, N. : The molten glass sewing machine. In: *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences* 375 (2017), Nr. 2093. http://dx.doi.org/10.1098/rsta.2016.0156. – DOI 10.1098/rsta.2016.0156. – ISSN 1364-503X

Coiling can be divided into four regimes.

- It depends on:
  - Drop height
  - Gravity
  - Viscosity (and therefore temperature)

→ Desired: Gravitational Regime (G)



Ribe et al. (2012)
DOI: 10.1146/annurev-fluid-120710-101244

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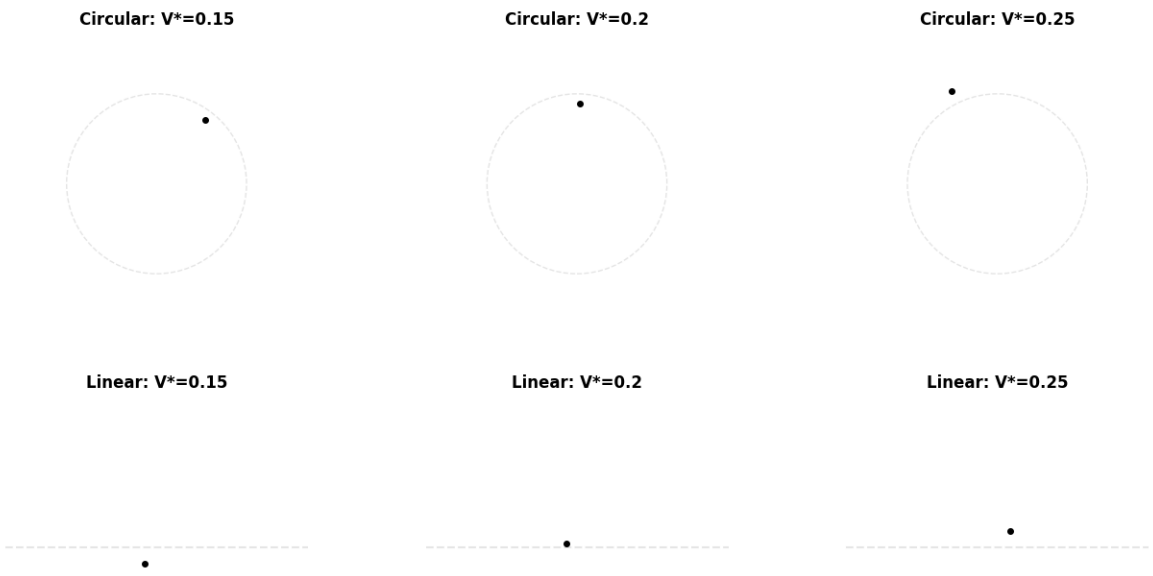
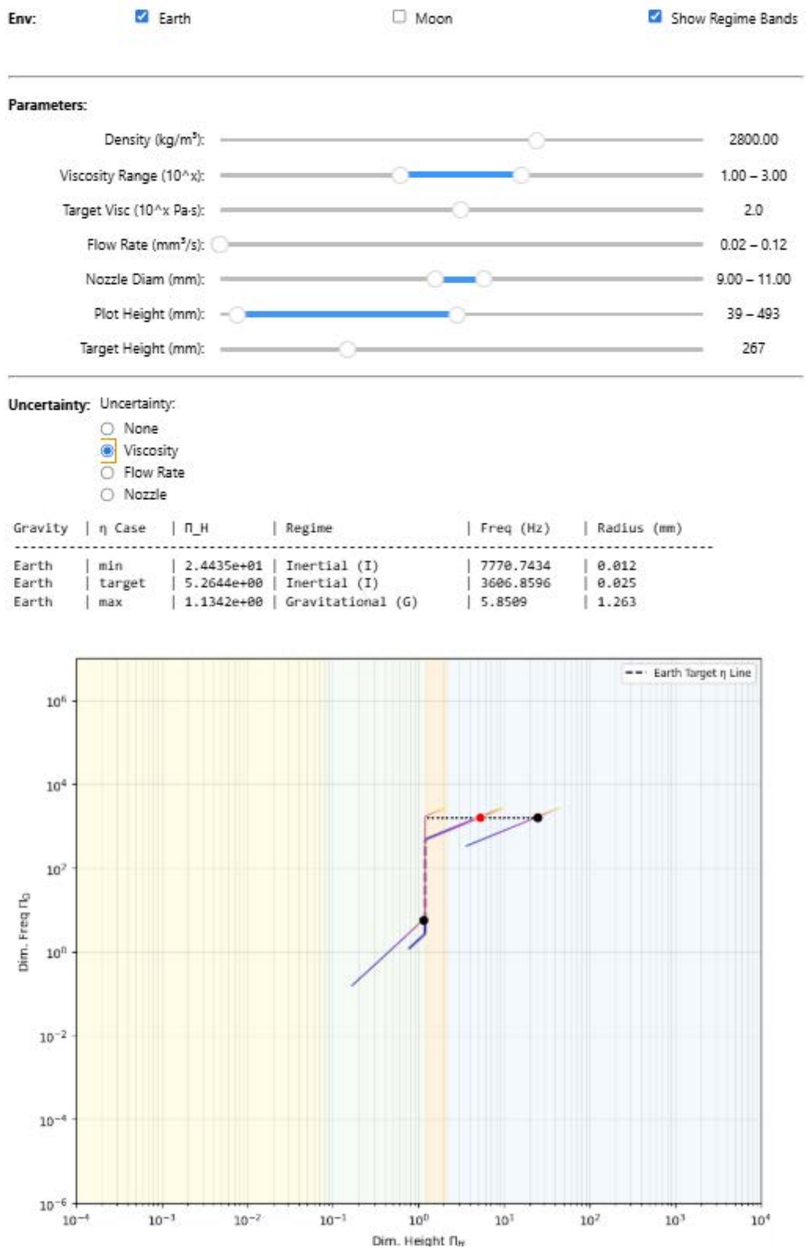
Modelling the Process





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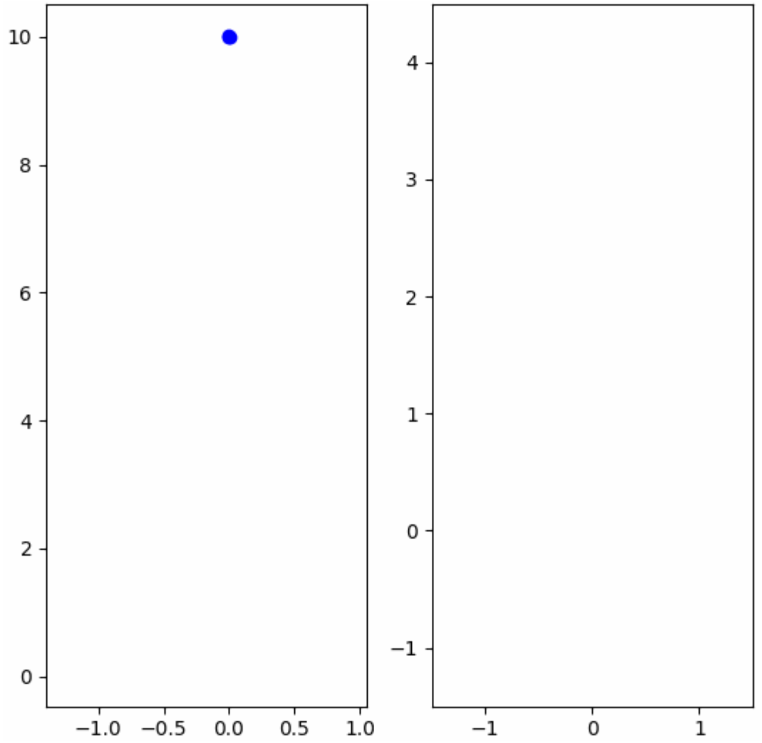
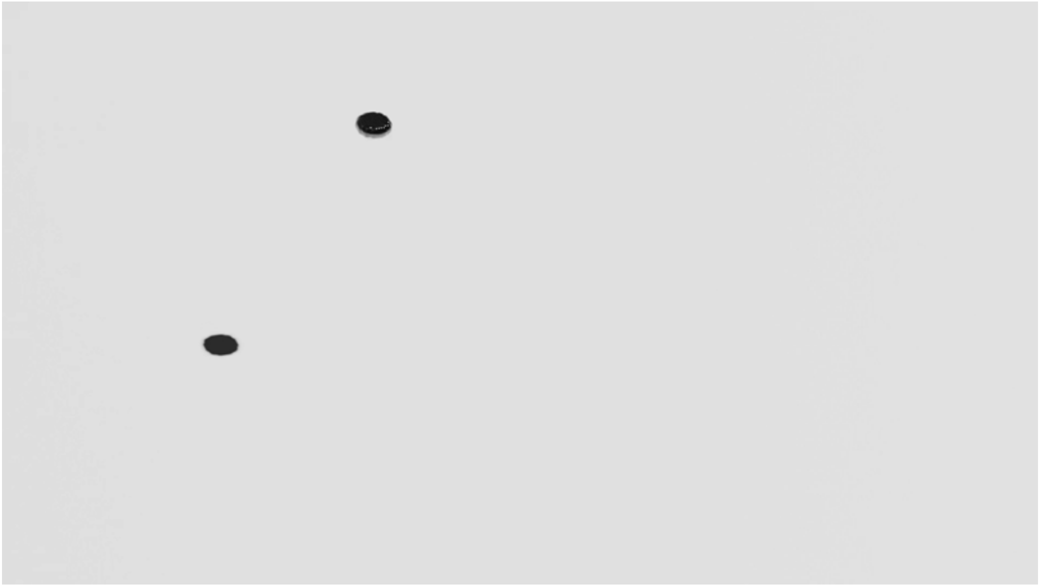
- Development of a simple slicer
- Implementation of the rope-coiling effect
- Use of open-source solutions
  (SPlisHSPlasH from RWTH Aachen)





▲Current implementation

▲Rope-Coiling Effect in SPlisHSPlasH [Promo Video]

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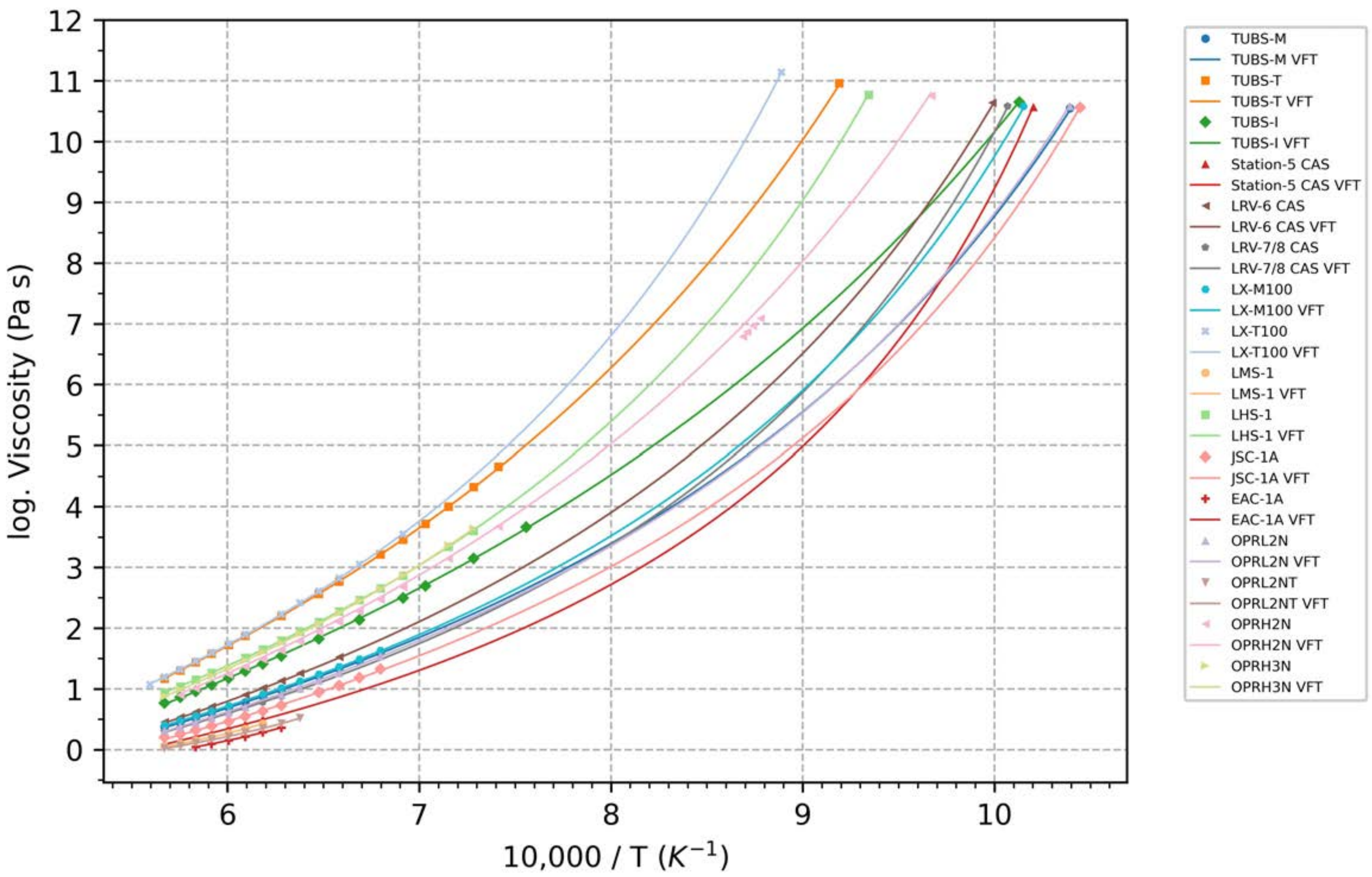
Measuring High-temperature Properties ongoing

- Viscosity *(@LMU)*
- Spectral Emissivity (@CNRS)
- Enthalpies *(@LMU)*
- Surface Tension *(@DLR)*
- Density *(@DLR)*
- Cooling Rates *(@OU)*
- Crystallization *(@OU)*
- Wetting *(@TUB)*
- …



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and Climate Action
on the basis of a decision
by the German Bundestag

Thank you for your attention

Questions?

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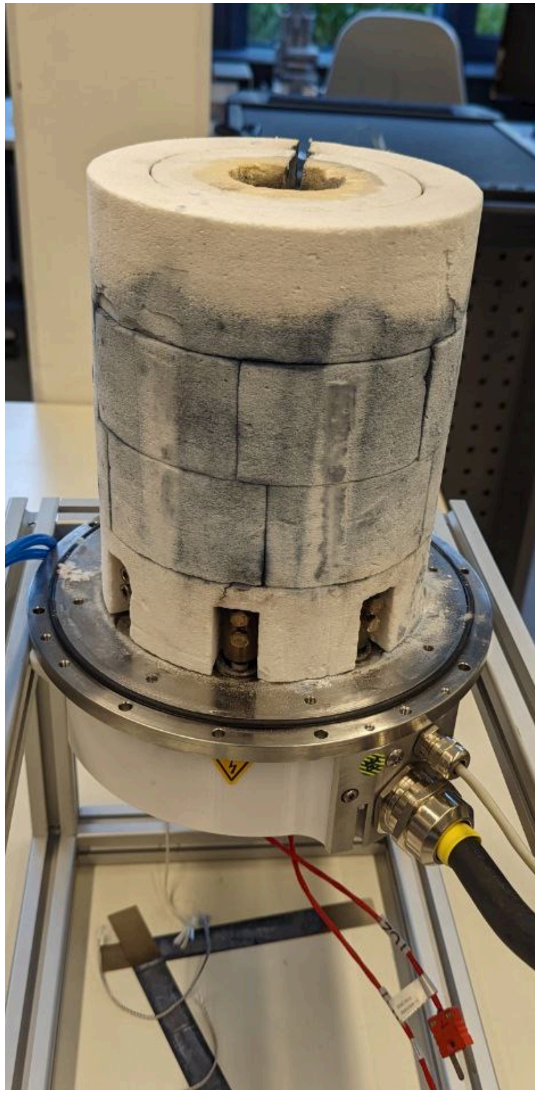
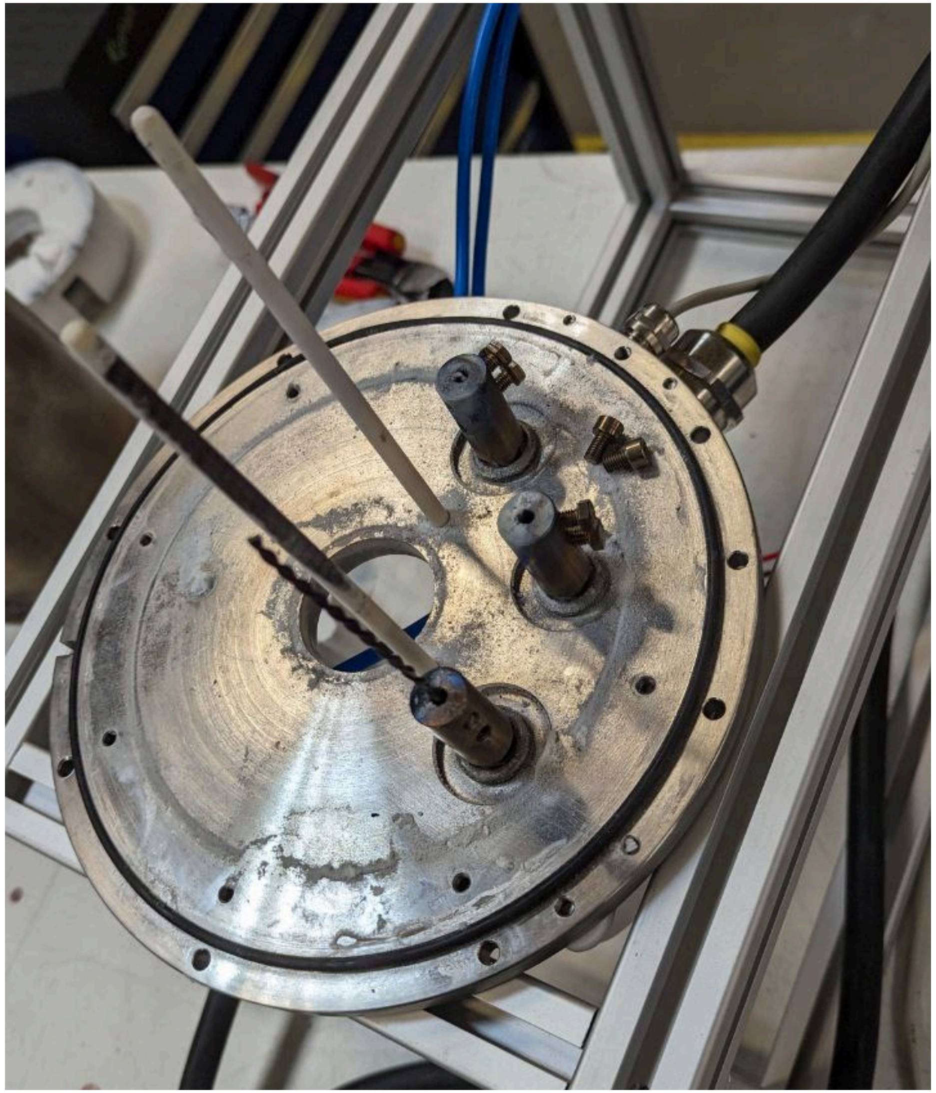
berlin

Printhead (inside)

a) Druckkopf zusammengebaut



b) Isolierung



c) Druckkopf-Deckel

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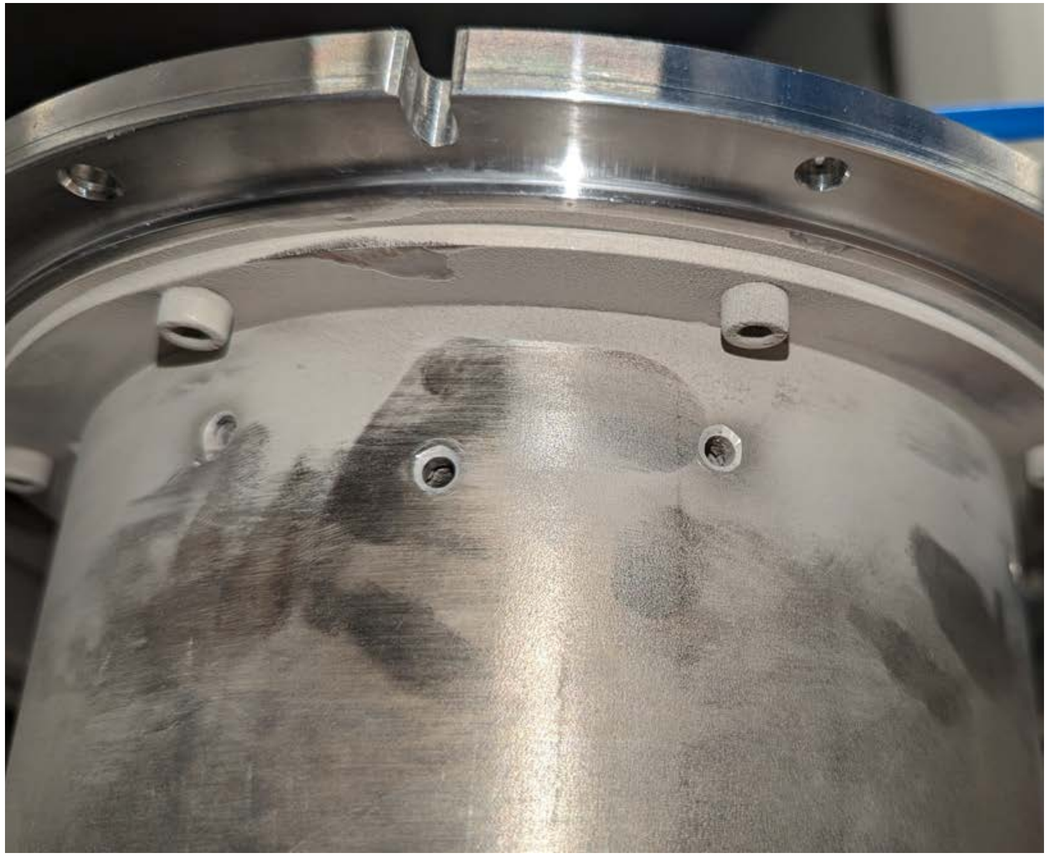
Regolith Issues



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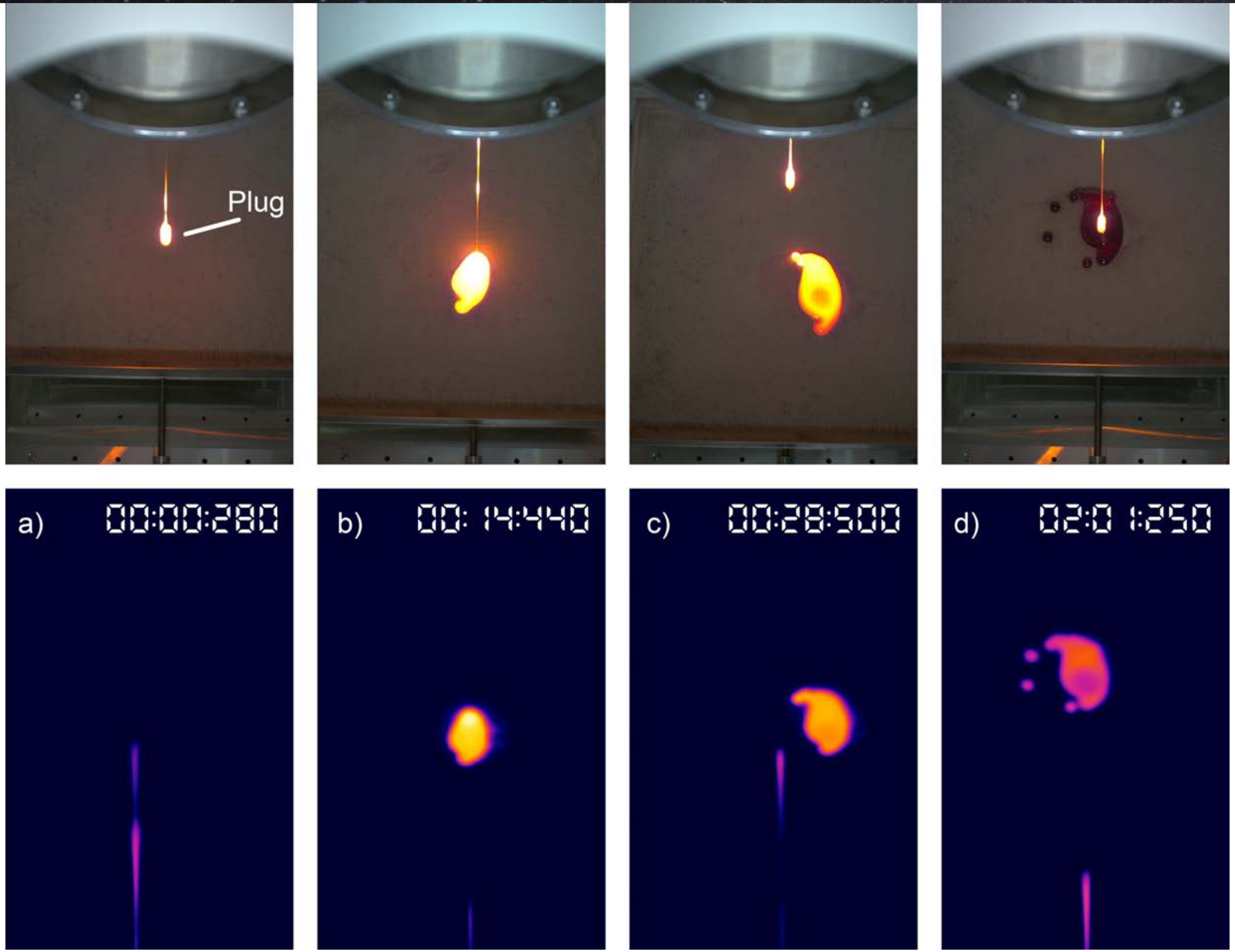
More Experiments



▲Curved part

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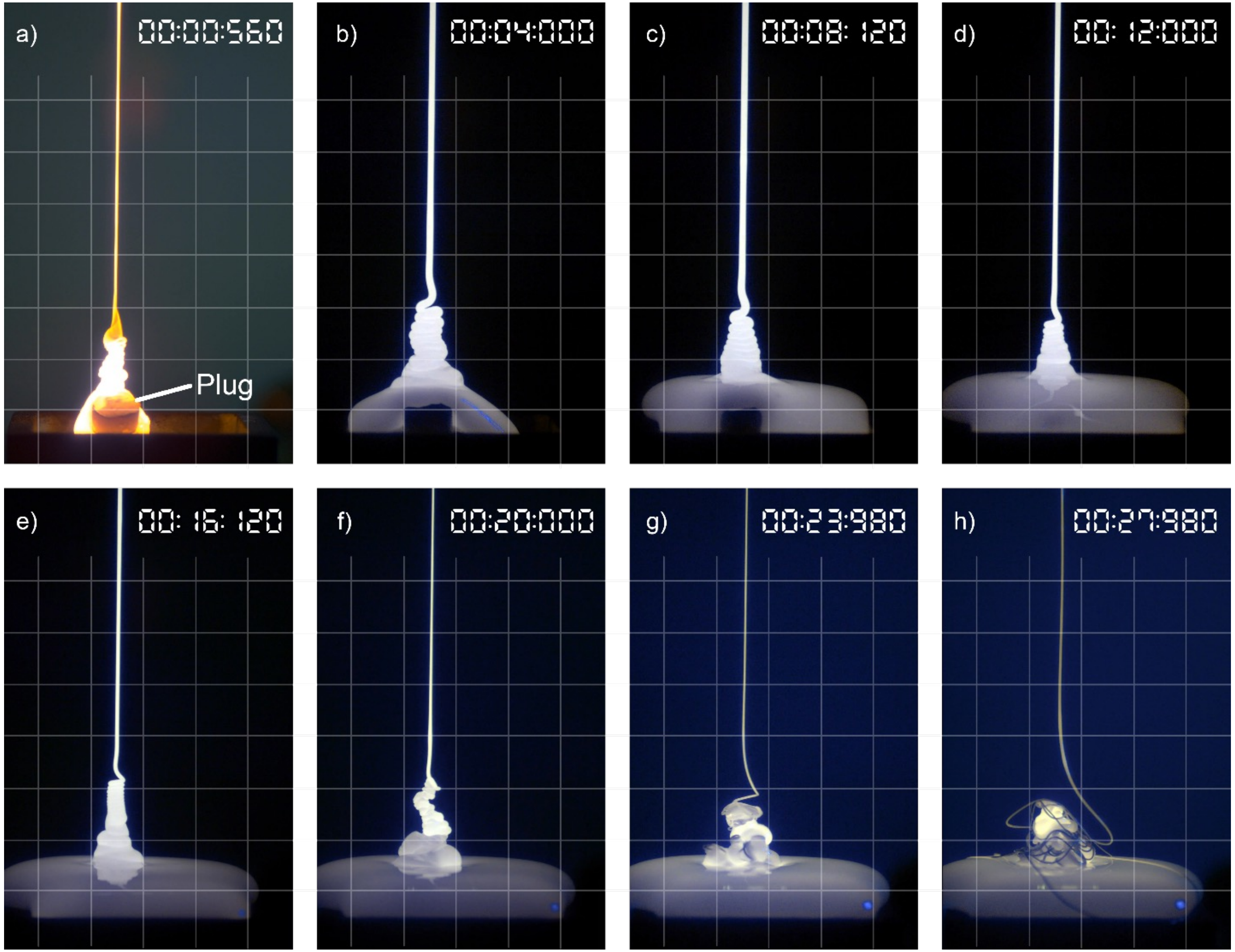
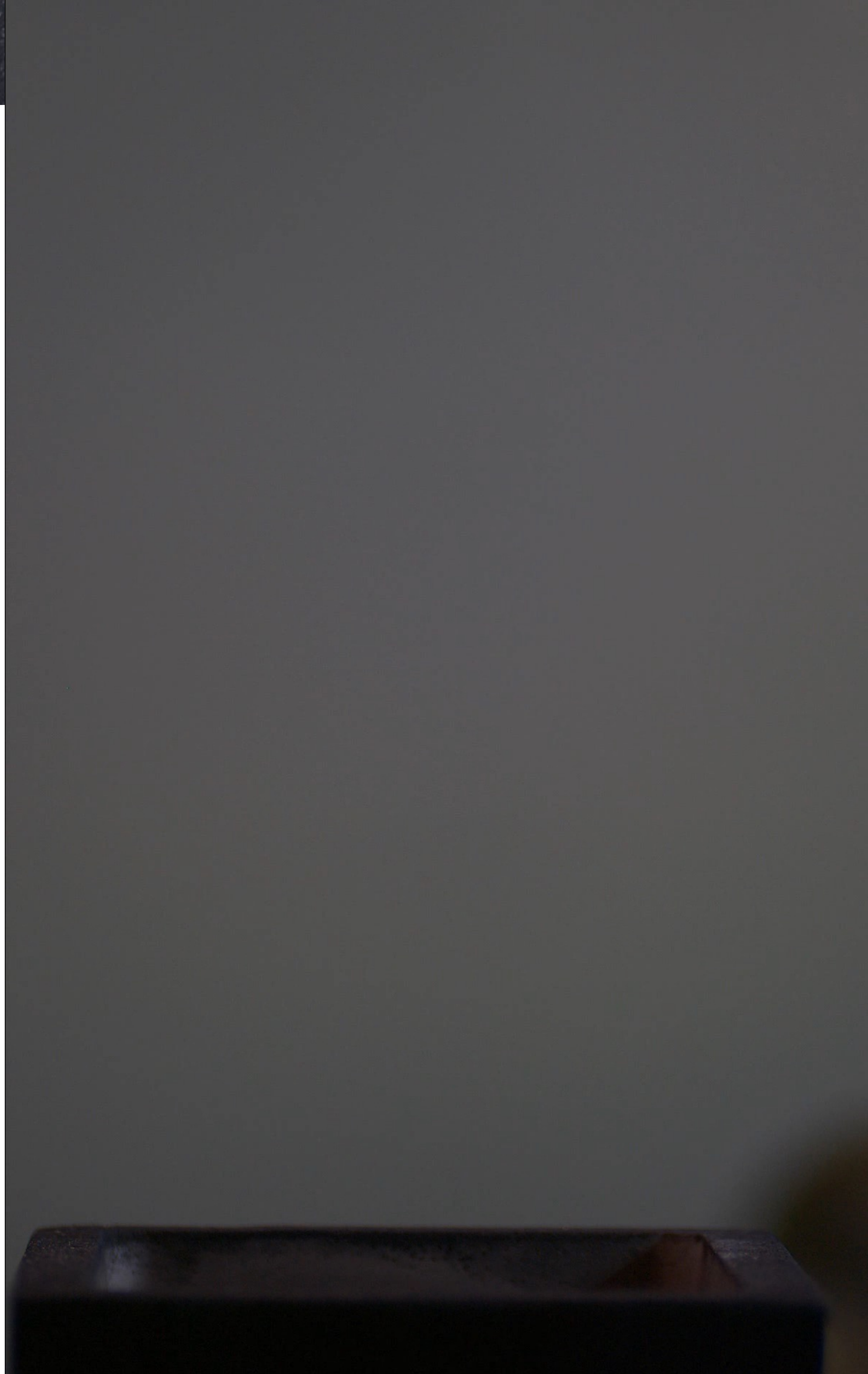
Coiling and Buckling





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Manual Experiments

▲Molten and resolidified regolith simulant
(manual pouring experiments)

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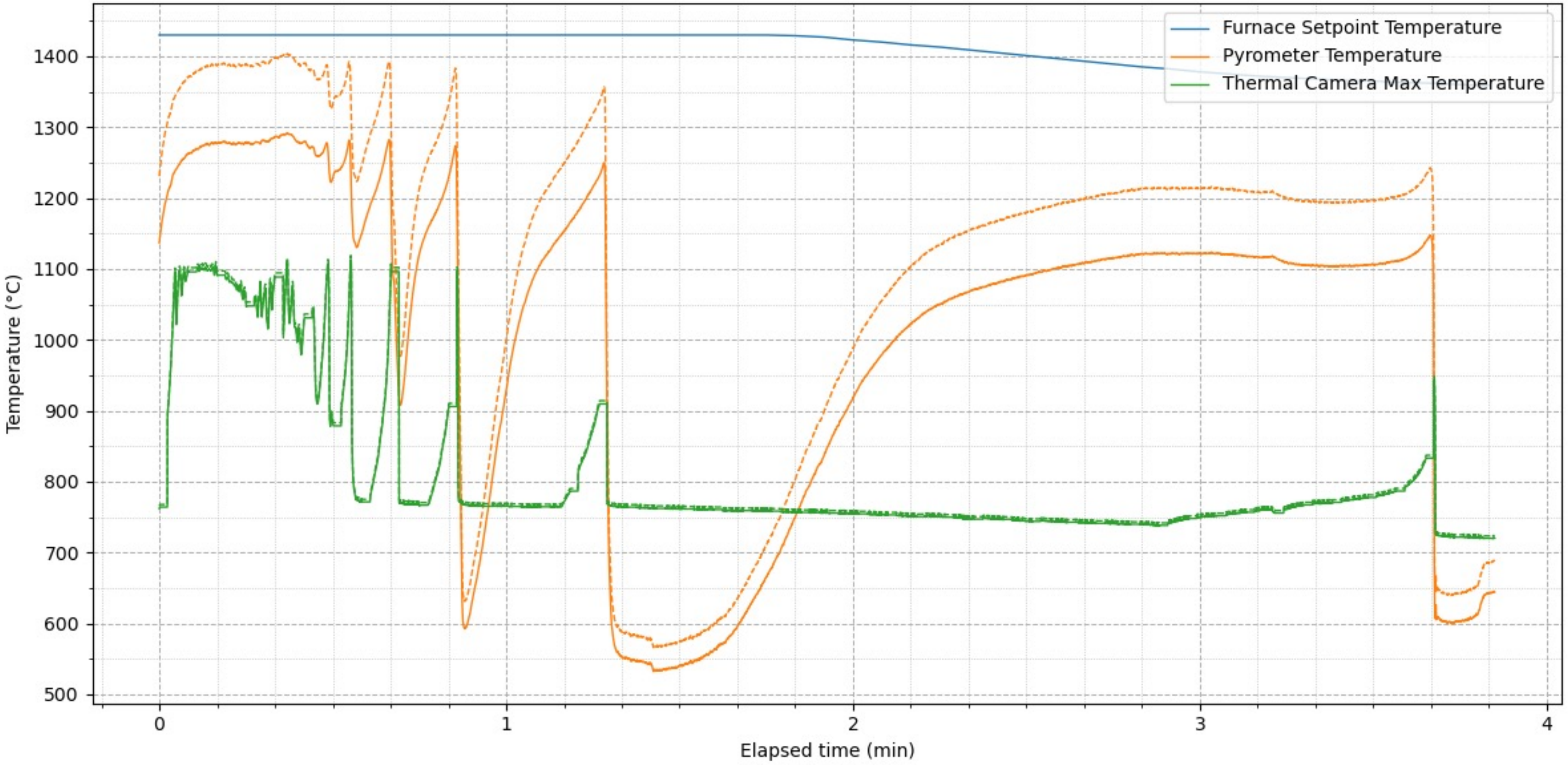
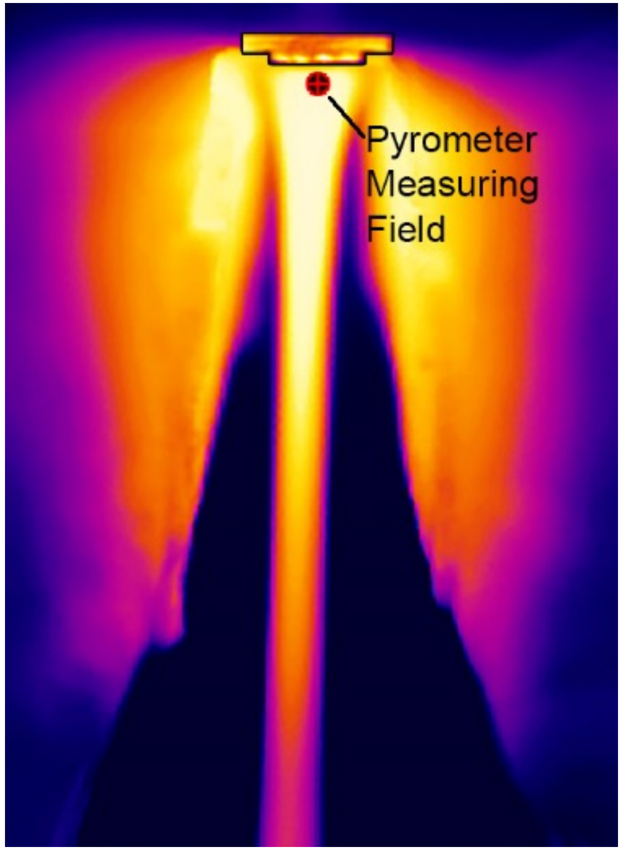
Temperature sensors used:

- Pyrometer (5,1 µm) → Emissivity ε = 0.865
- Thermal camera (7,9 µm) → Emissivity: ε = 0.99





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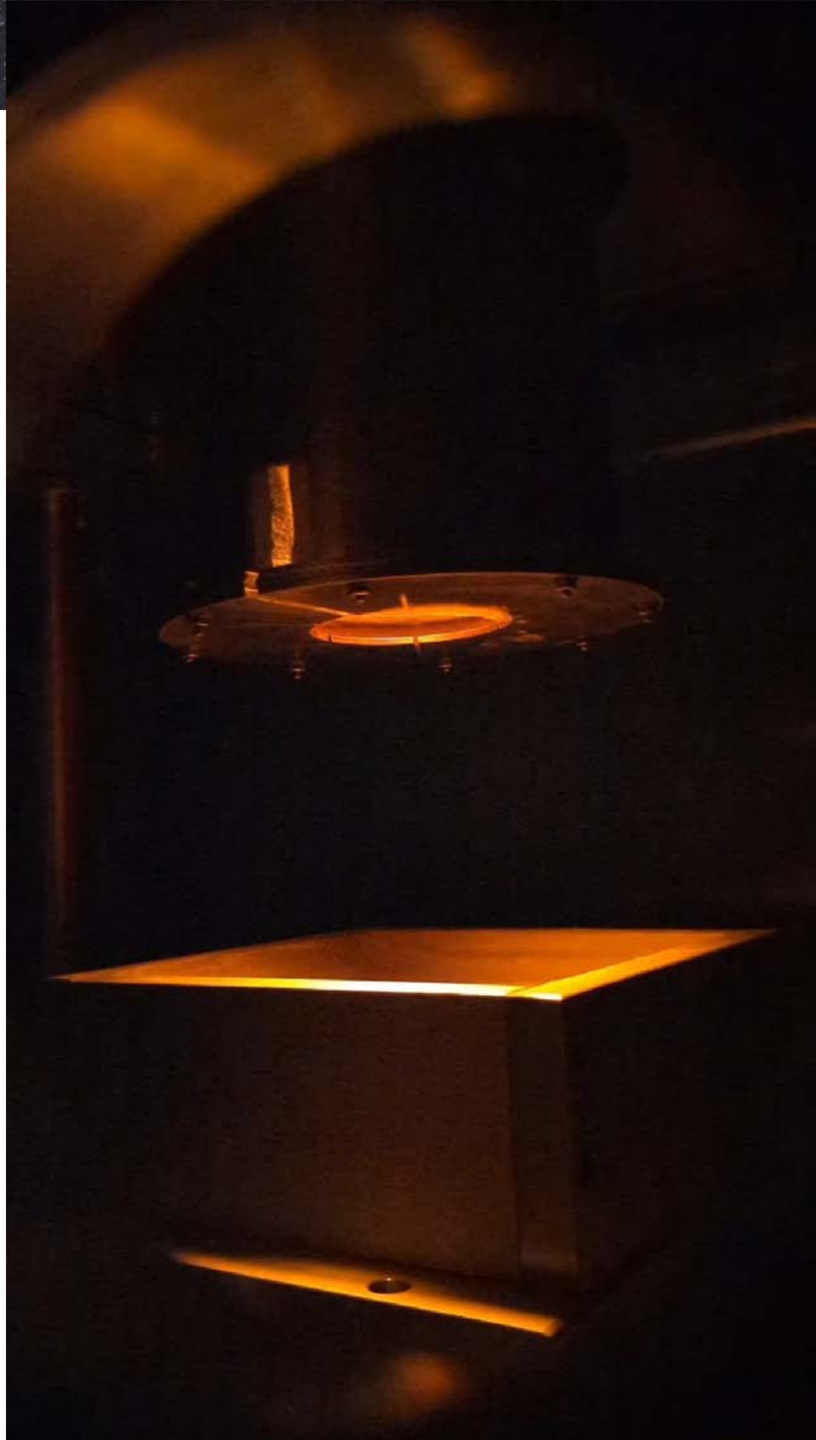
Extrusion process

1. Set printhead temperature to 1,400 °C

2. Regolith melt leaves printhead in a free fall

3. Homogenous flow starts

4. Homogenous flow ends, some more droplets fall



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