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On the melting behaviour of metals extracted from LHS-1 regolith simulant by electrolysis in molten salt

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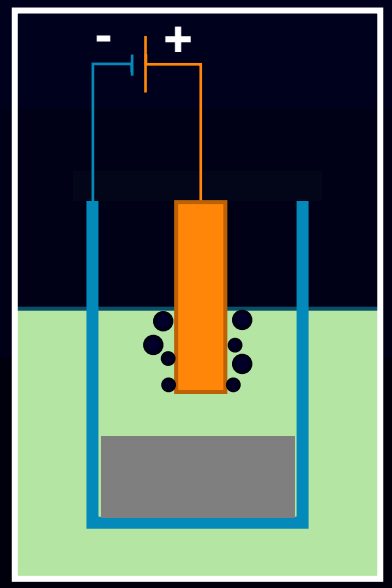
Context

FFC process is studied for metal production on the Moon

Regolith simulant



FFC process

Oxygen gas

Metal rich solid products

1. Characteristics
2. Melting behaviour
3. Laser interaction

Metal 3D process

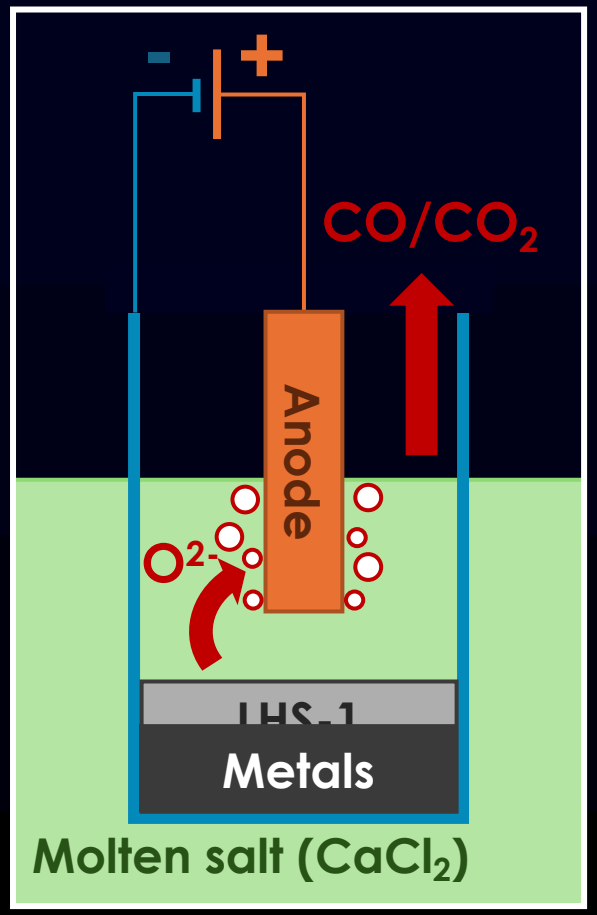
1

FFC electrolysis process

Previous results

Previous work

FFC process is applied to LHS-1 regolith simulant



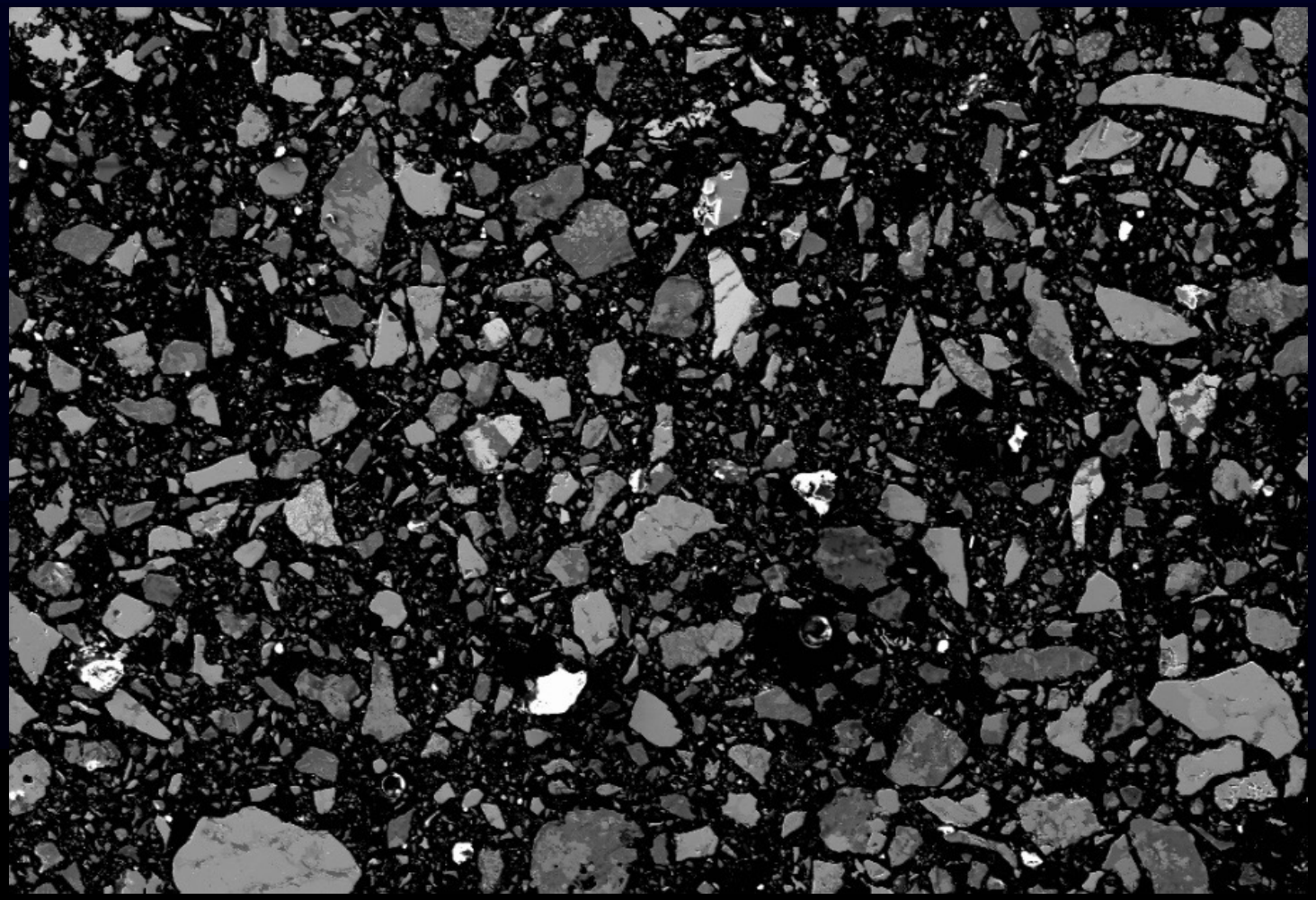
Electrolysis in molten $CaCl_2$

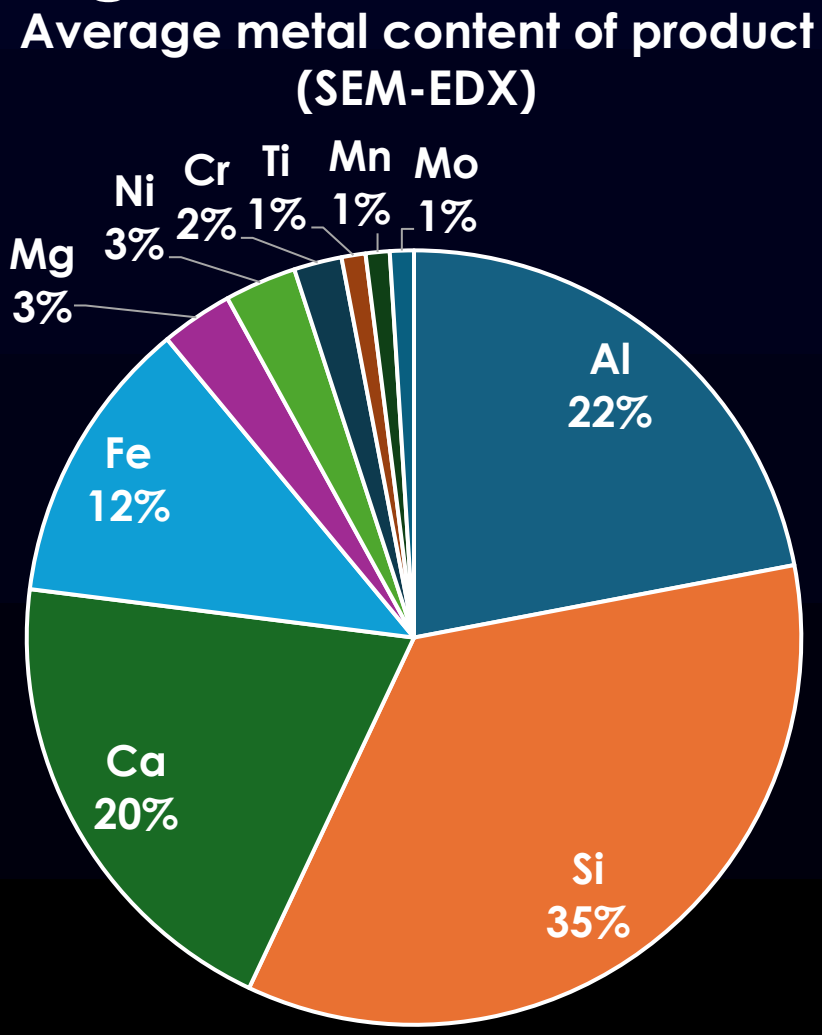
950 °C
3.2 V
24 hours

Methods adapted from A. Meurisse, et al., 2022, *Planetary and Space Science*

Previous work

Metals obtained are granular and heterogeneous

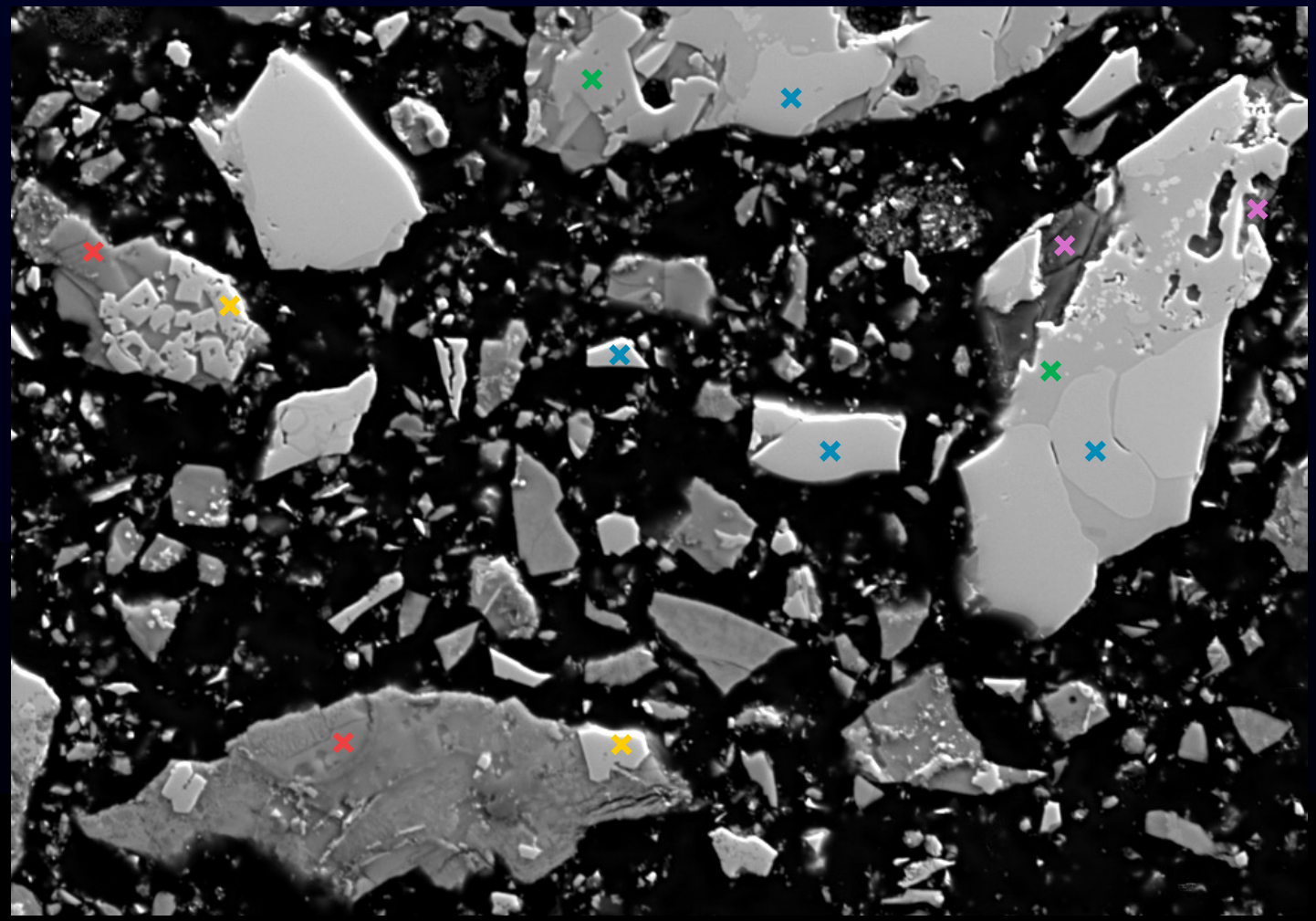




Detailed results published in T. Schild, et al., 2025, *Acta Astronautica*

Previous work

Complex mix of phases cannot be separated mechanically



Si-Fe

Al-Si-Fe

Si

Al_2Si_2Ca

Al-Si-Fe-Ti

Detailed results published in T. Schild, et al., 2025, *Acta Astronautica*

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Thermal post-processing

Melting behaviour of metallic products

Thermal post-processing

Metal mixture is expected to melt above 1000 °C

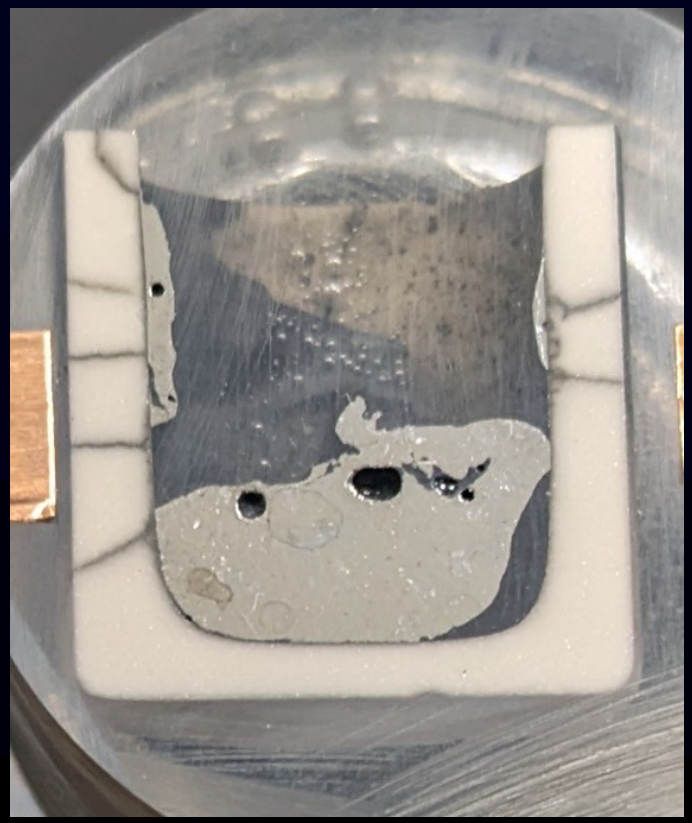
Al	Si	Ca	Fe
25%	39%	23%	13%

1 cm

Metal granulate
2 g sample

1070 °C
1 bar He

1 cm

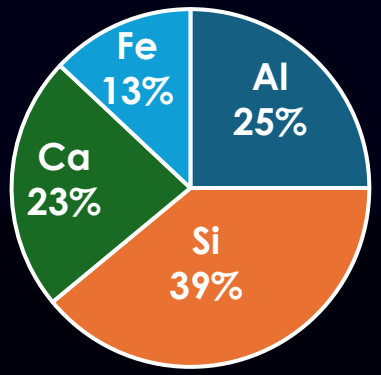


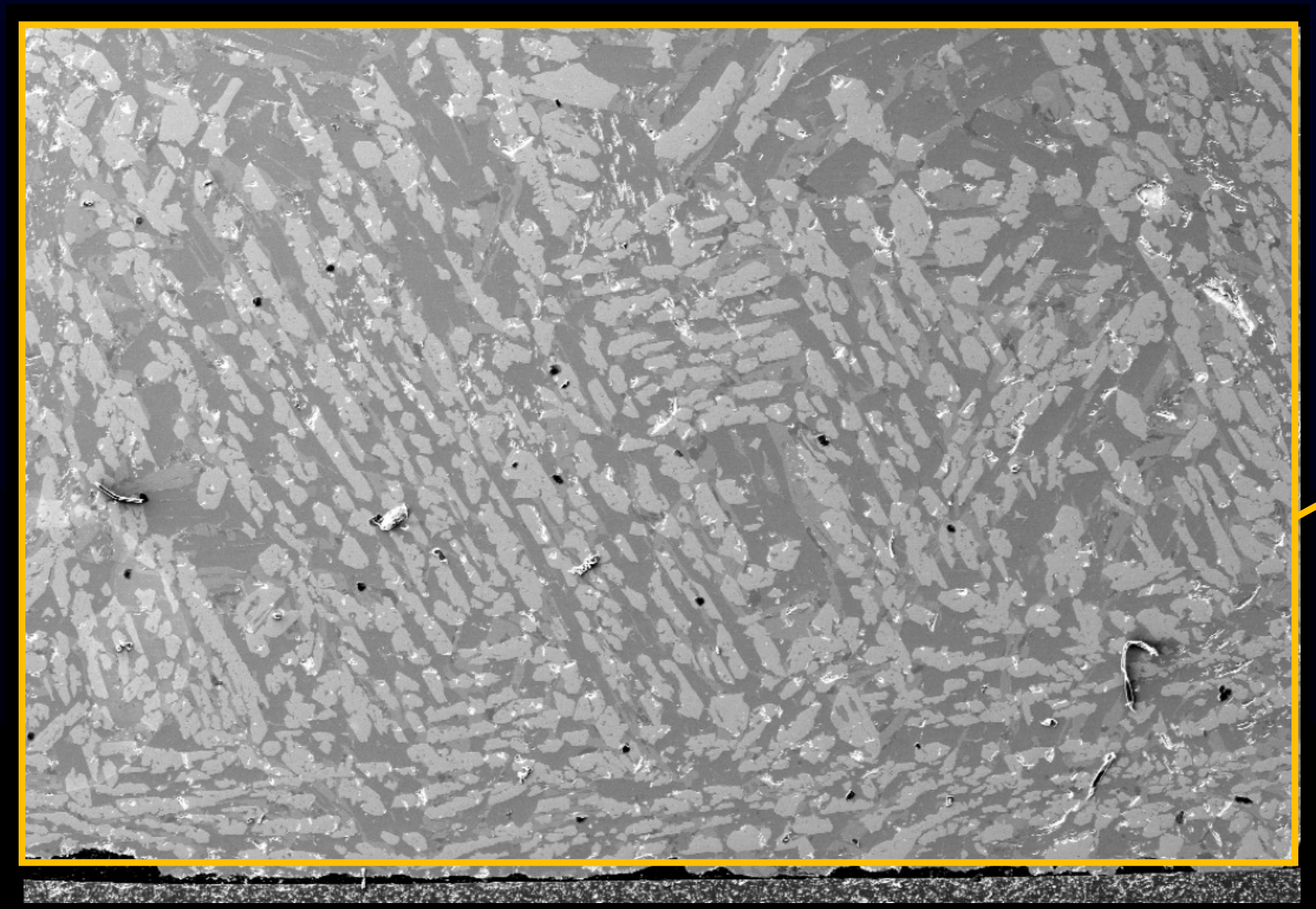
1 cm

Thermal post-processing

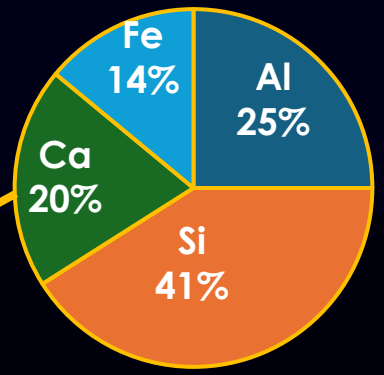
Resulting ingot is dense and isotropic

Starting metal content



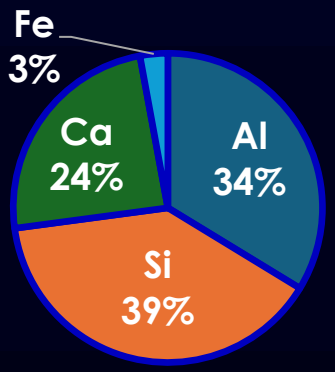


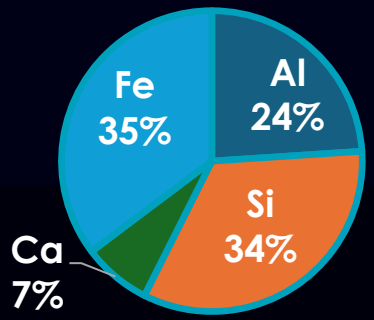
Final metal content

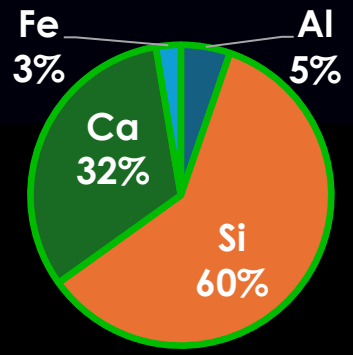


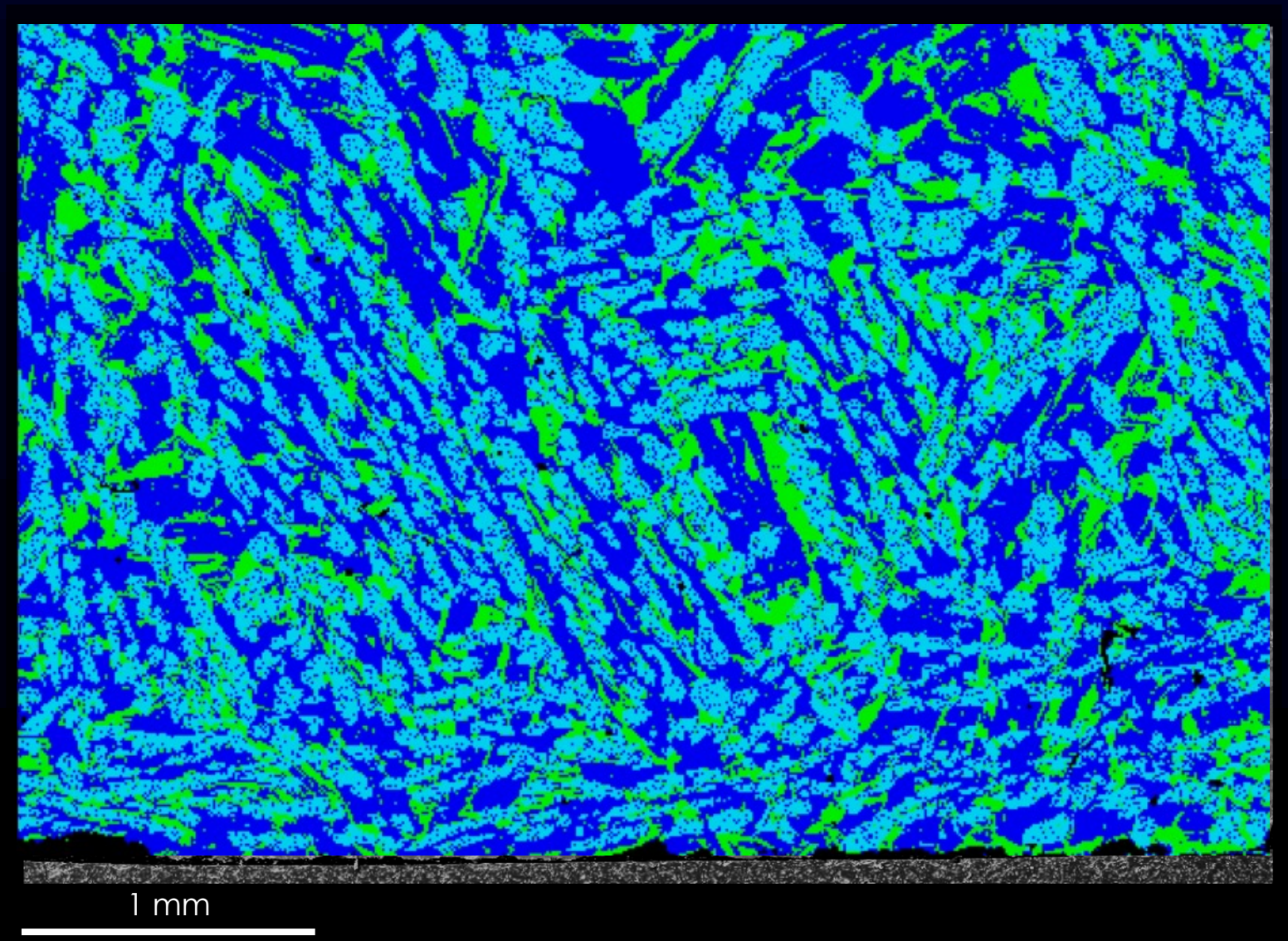
Thermal post-processing

Metals are distributed in 3 main compositional clusters









Al_2Si_2Ca

$Si_8Al_6Fe_4Ca$

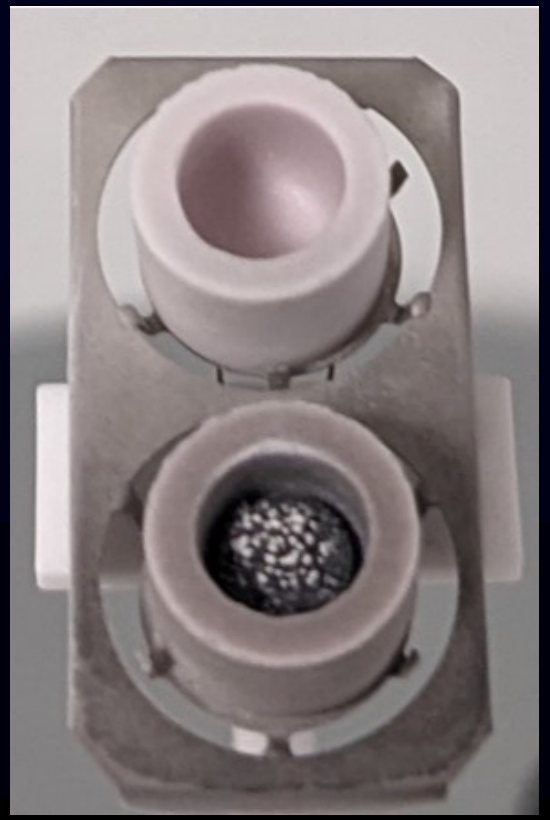
Si_2Ca

Thermal post-processing

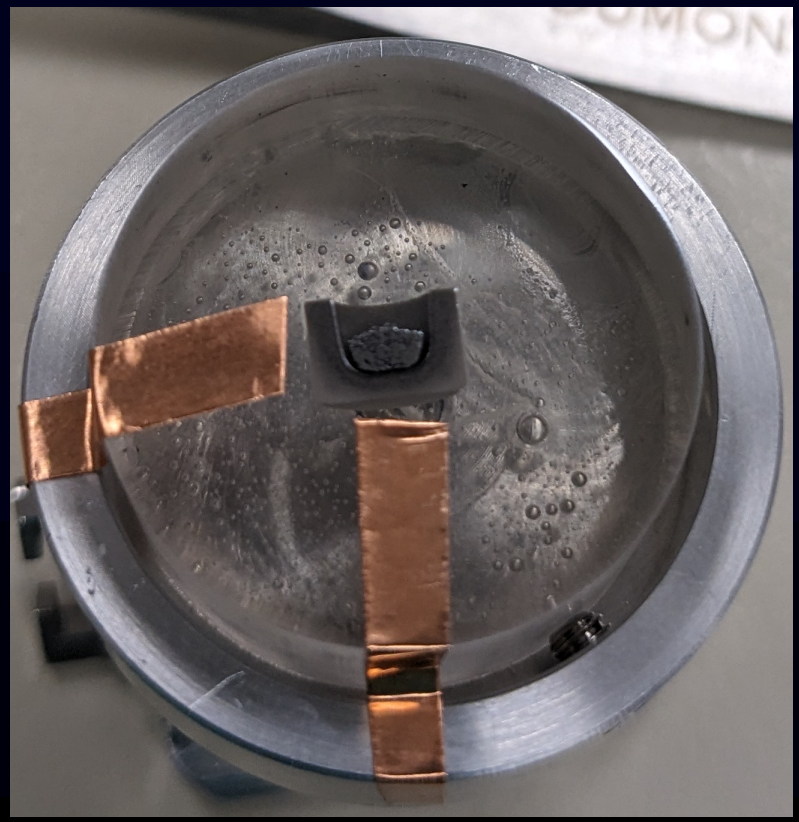
FFC products do not fully melt during thermal cycle

5 mm

1415 °C
in Helium



5 mm



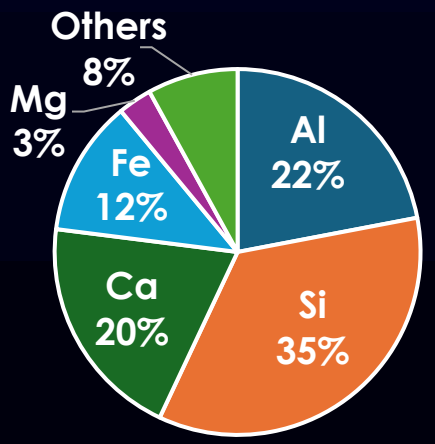
5 mm

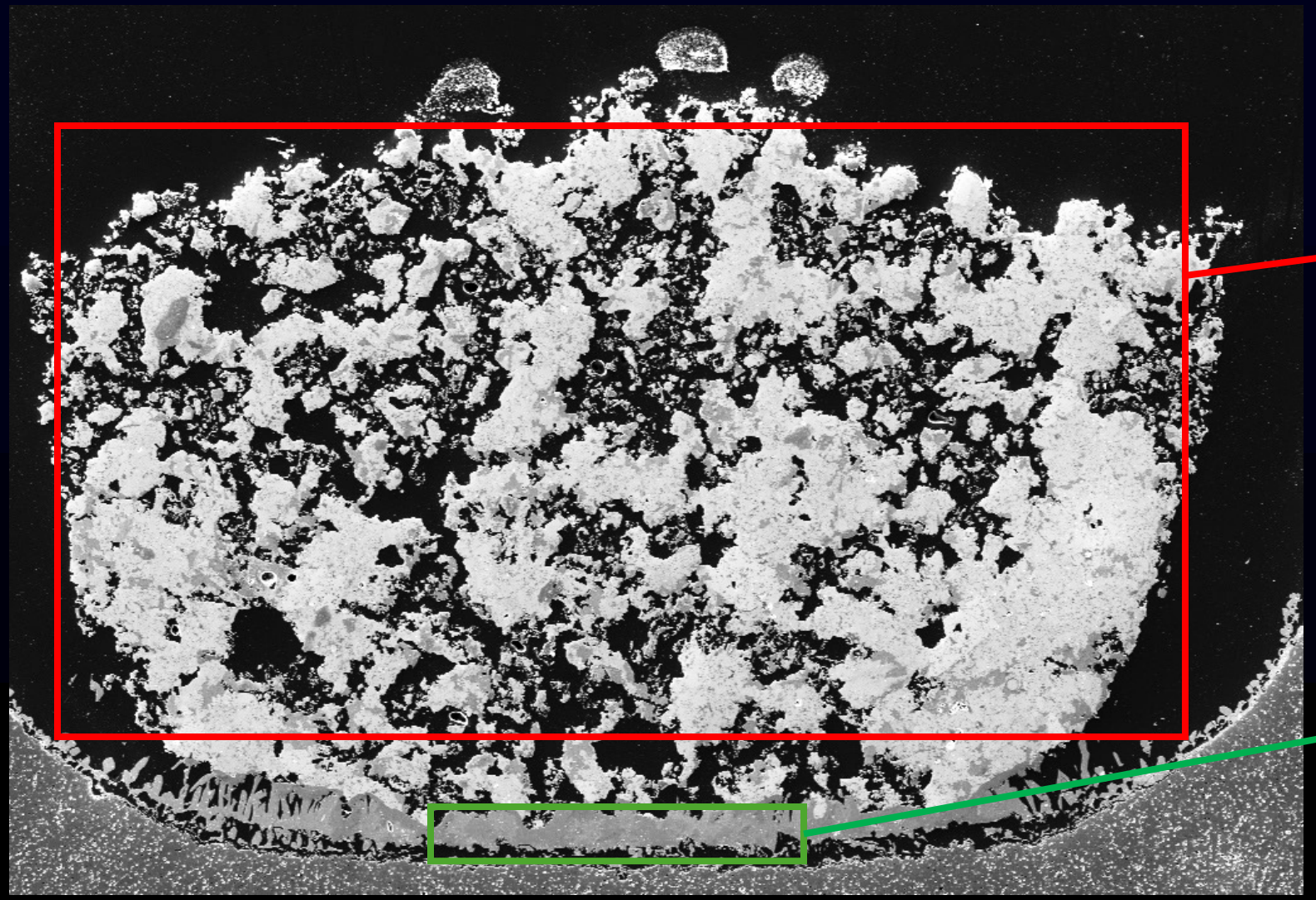
Reduced LHS-1
Sieved and ground
30 mg sample

Thermal post-processing

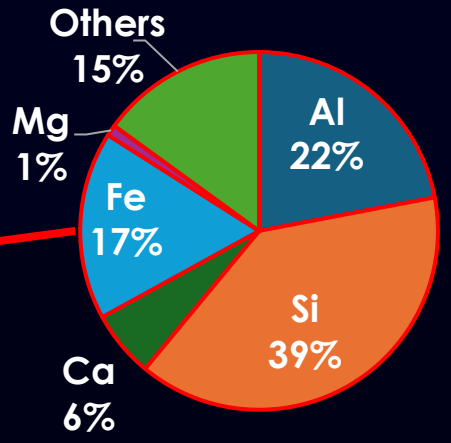
Ingot obtained at 1415 °C is porous and segregated

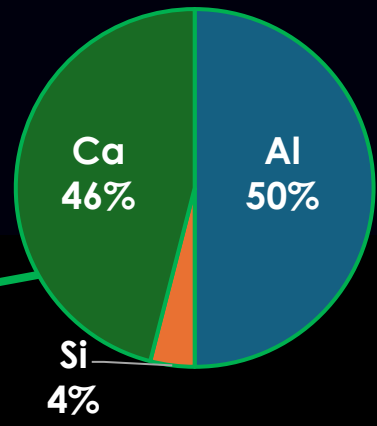
Starting metal content





Final metal content

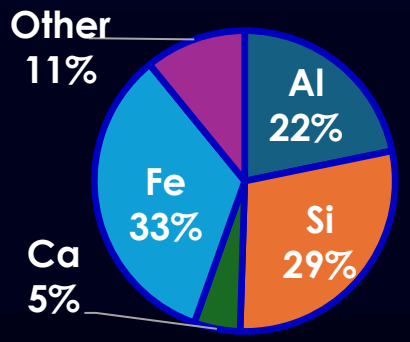


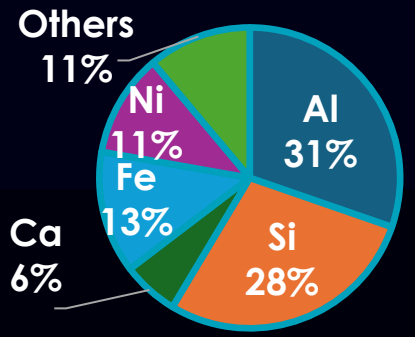


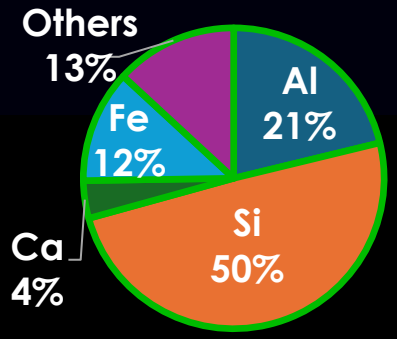
Thermal post-processing

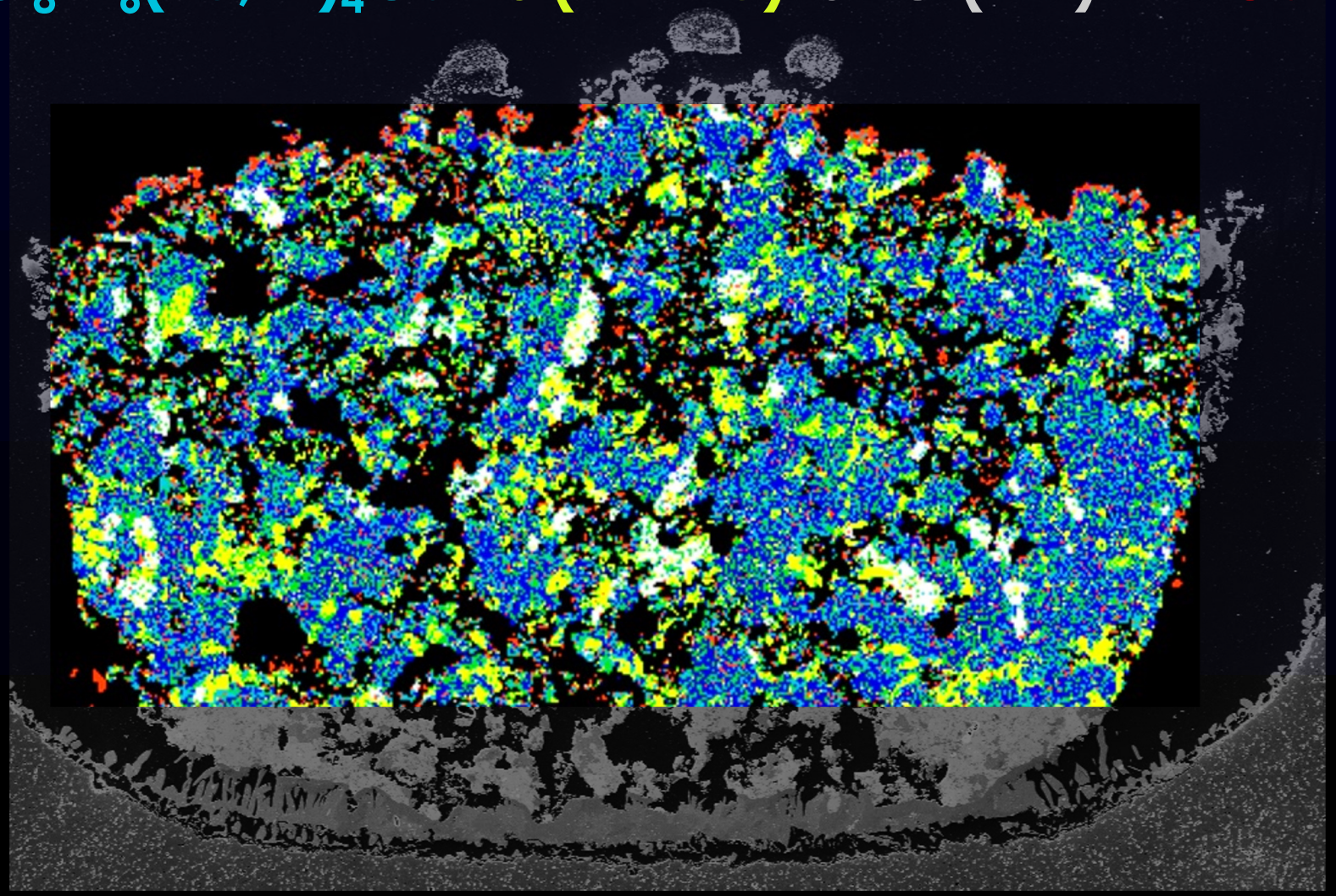
Local concentration of contaminants is observed

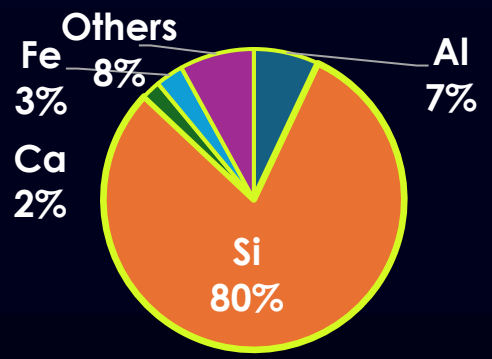
$Si_8Al_6(Fe,Ni)_4Ca$ Si(-Al-Fe) Si-Cr(-Al) Al-Ca

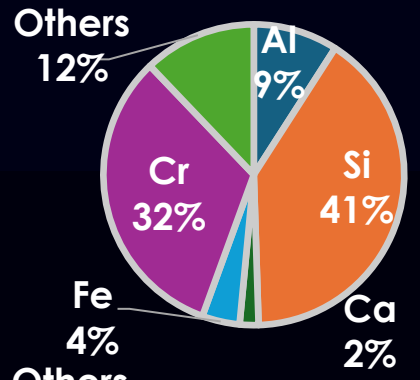


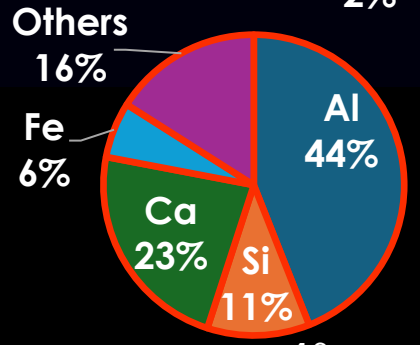












Reduced LHS-1 does not behave like pure metal mixture

Al-Si-Ca-Fe mixture

Consolidated to dense ingot after heating at 1070 °C

Isotropic distribution of metallic phases

Well equilibrated with 3 main intermetallic phases present

Reduced LHS-1

Consolidated but still porous after heating as high as 1415 °C

Separation and pooling of **Al-Ca rich phase & loss of Mg**

Multitude of phases with **local concentrations of contaminants**

Residual O content, **surface reoxidation**, or **presence of contaminants** affect melting

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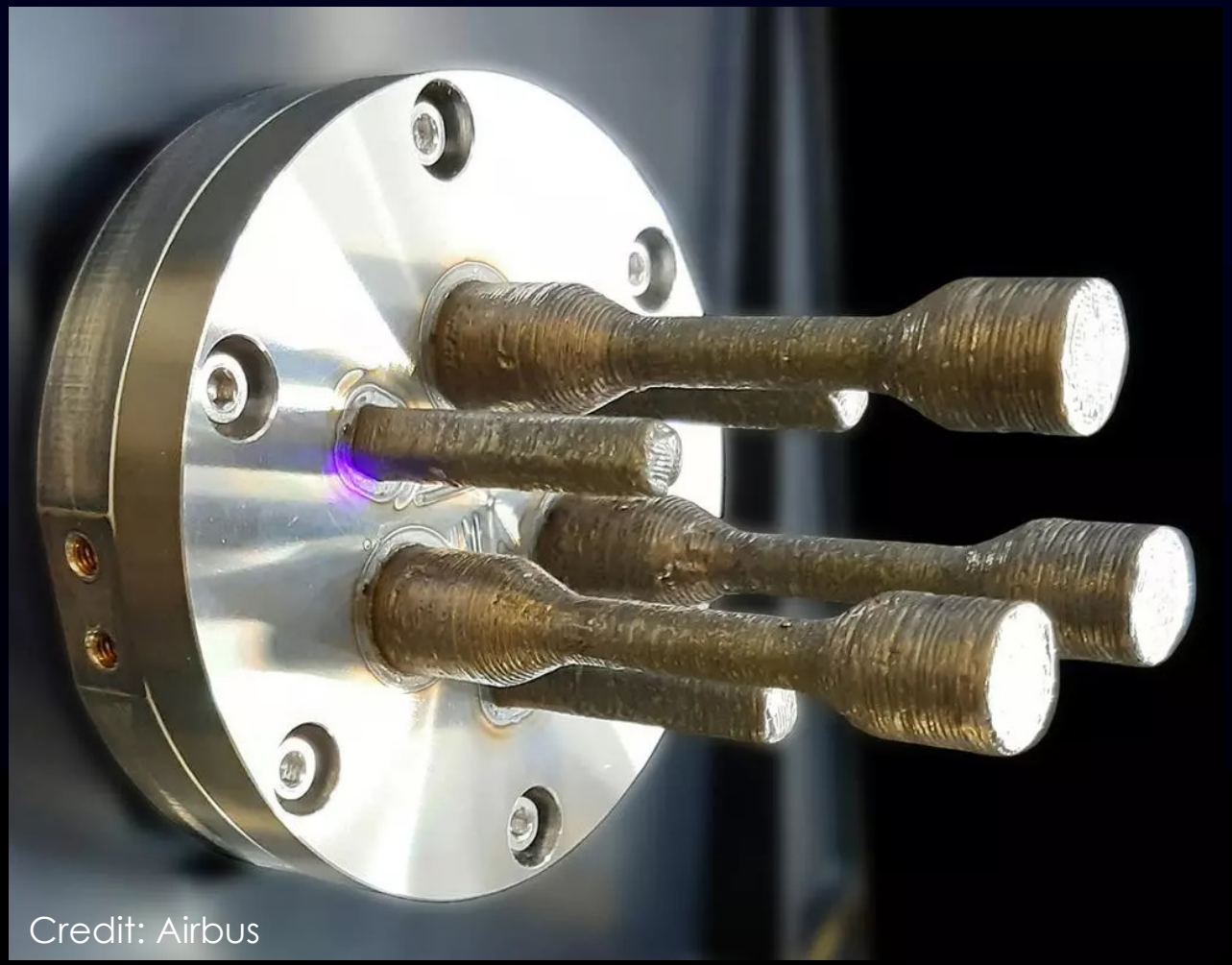
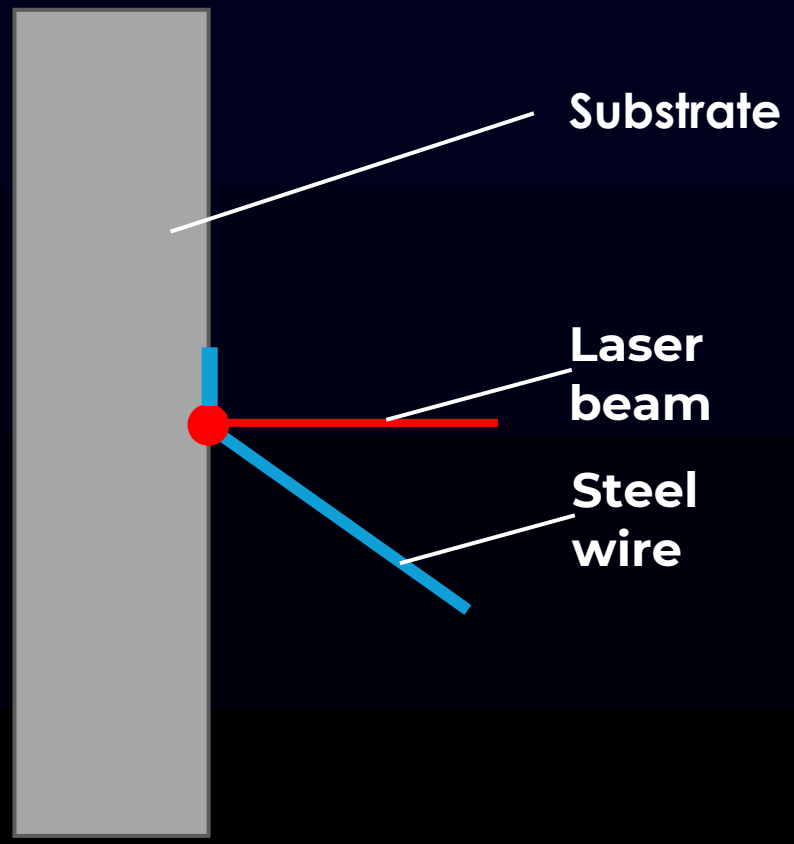
Towards additive manufacturing

Towards additive manufacturing

Metal3D system has demonstrated metal printing in Space

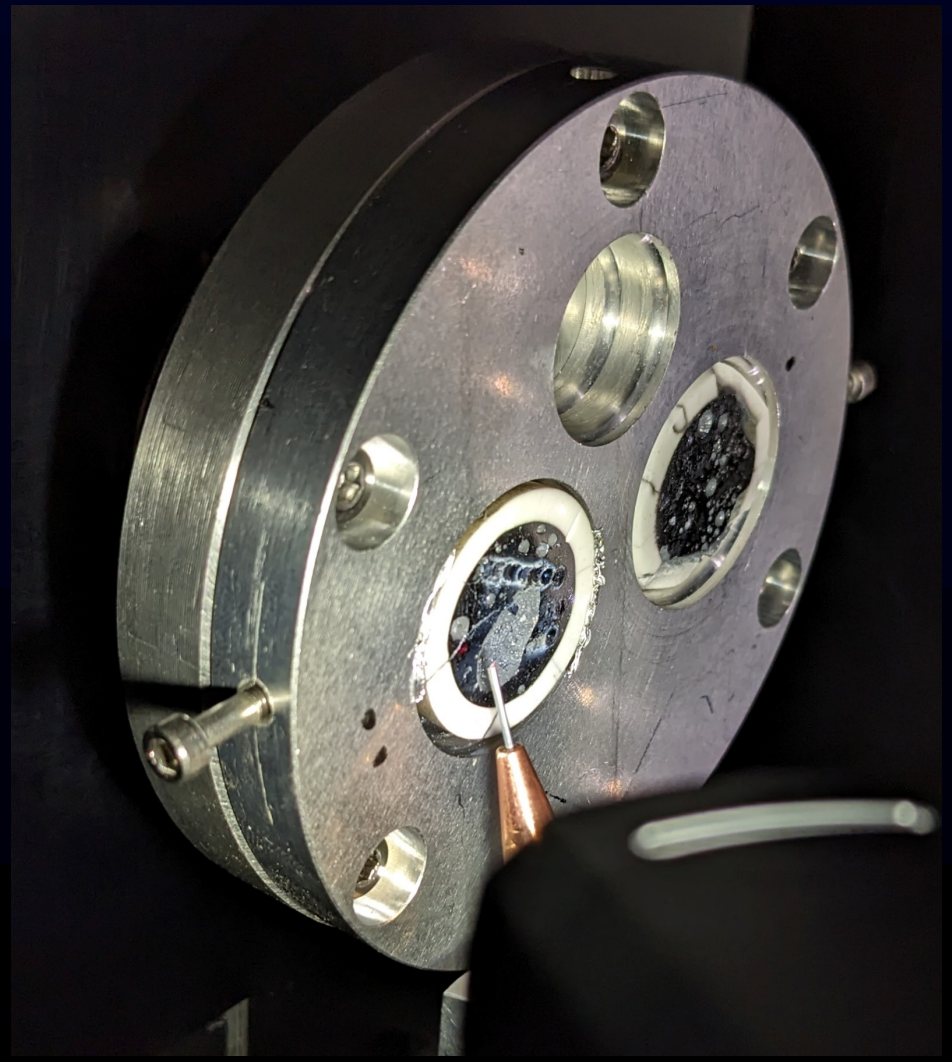


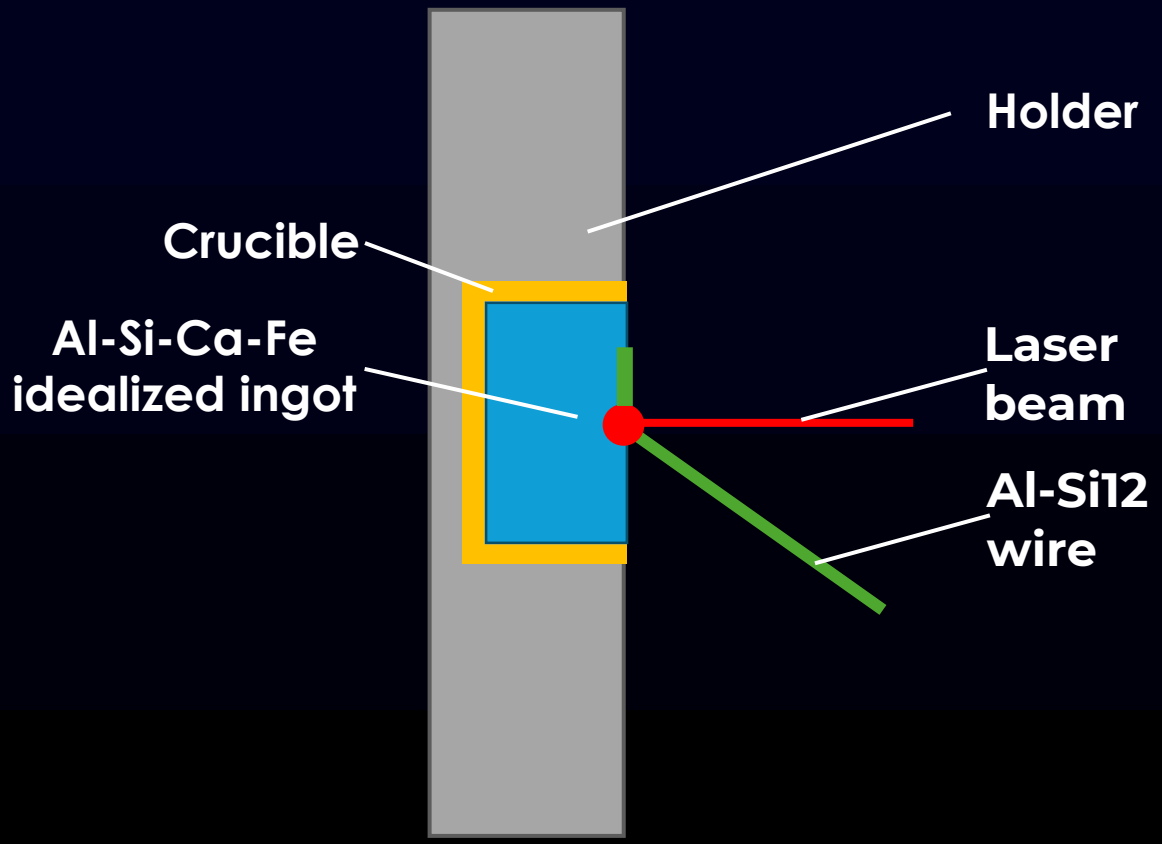
Credit: Airbus



Towards additive manufacturing

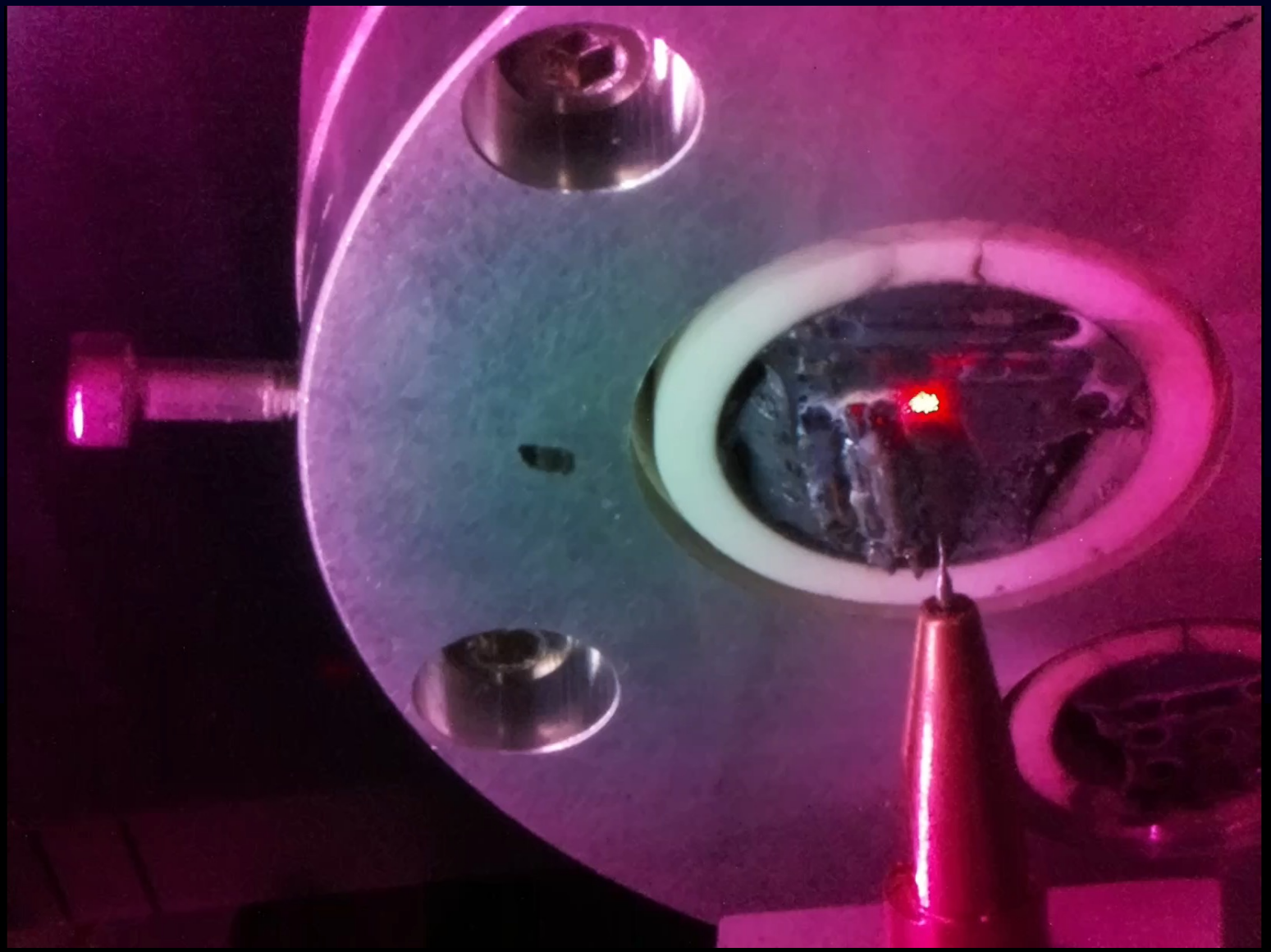
Metal3D system is used with Al-Si-Ca-Fe ingot substrate





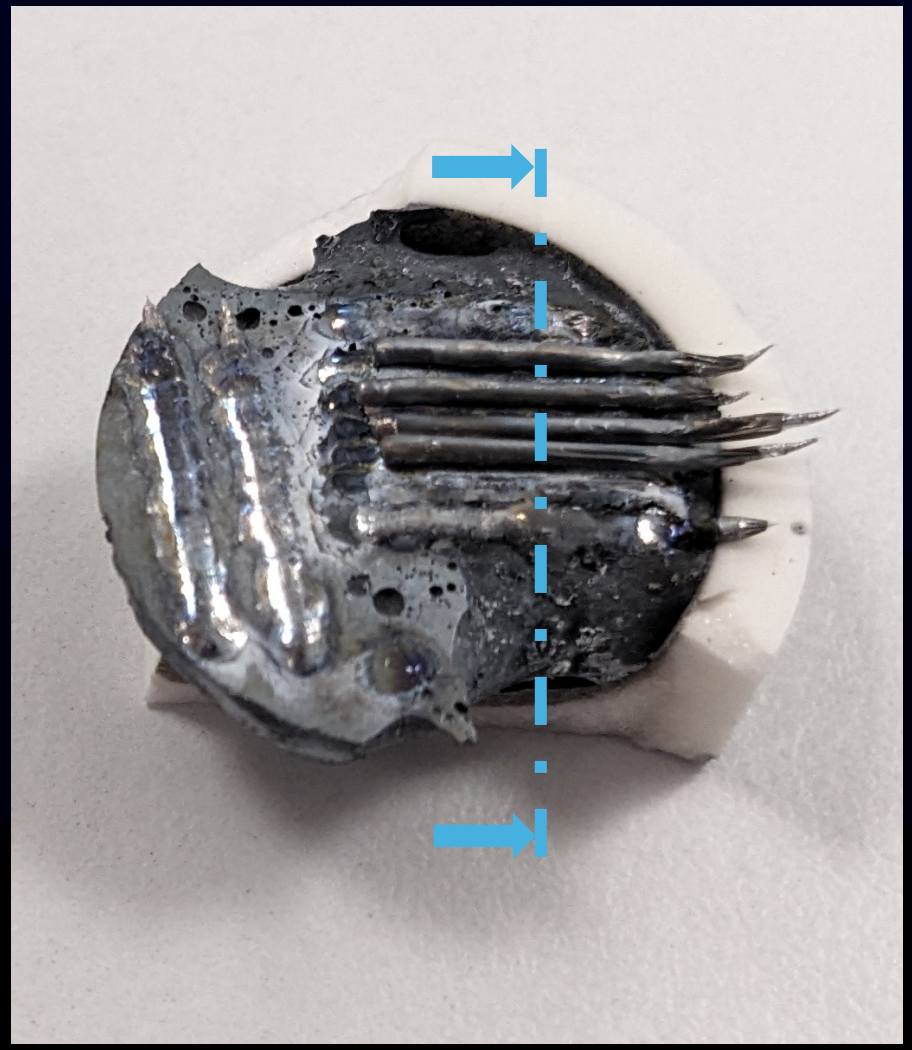
Towards additive manufacturing

Idealized ingot is used as substrate for Al-Si12 deposition

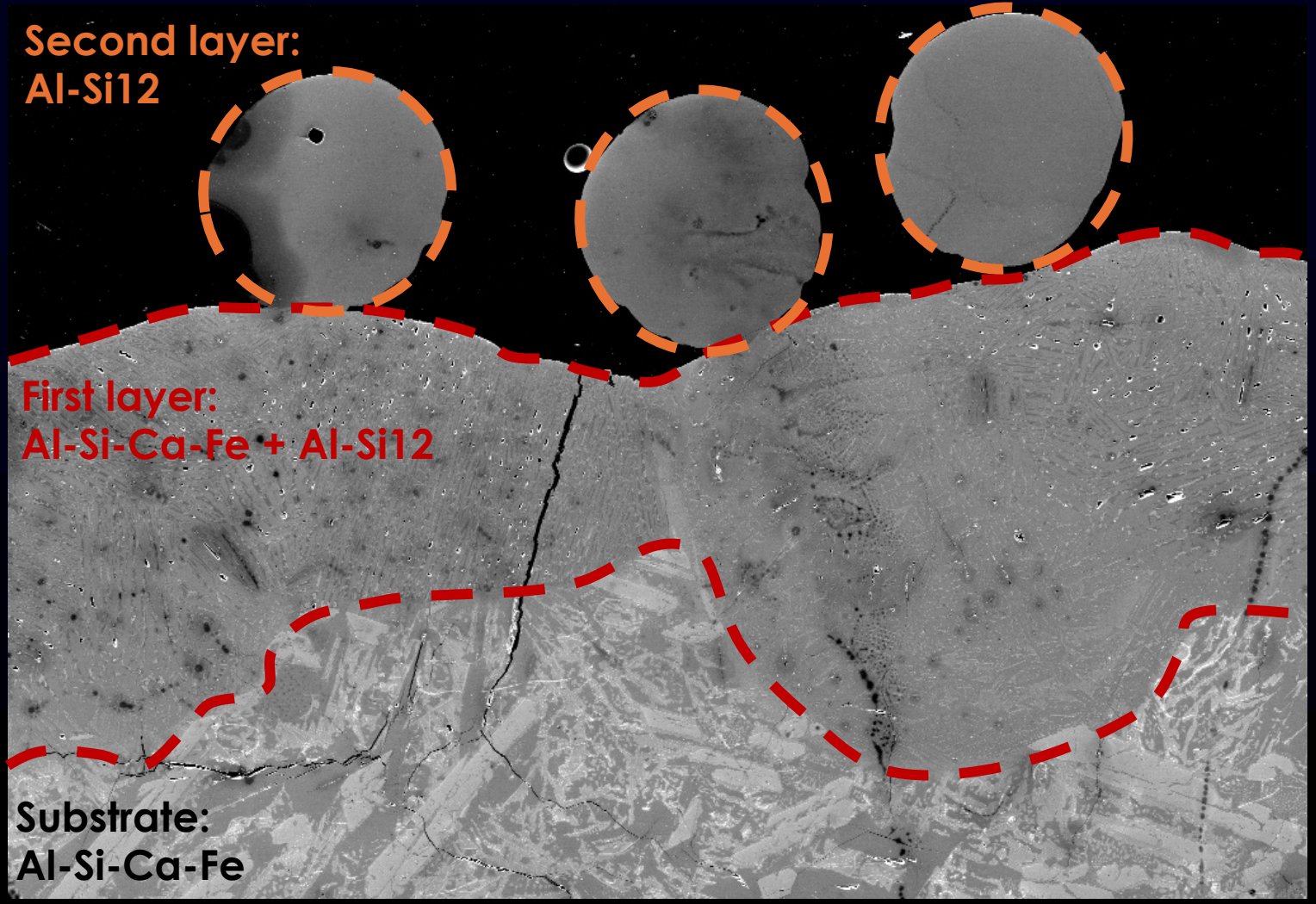


Towards additive manufacturing

Substrate melts and binds well with Al-Si12 wire



1 cm



1 mm

4

Conclusions

Conclusions

Casting of metals as obtained by FFC electrolysis of LHS-1 regolith simulant is challenging

Metals mixed in ratios typical of reduced regolith perform well in laser based additive manufacturing

Thank you!

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Previous work

FFC process is applied to LHS-1 regolith simulant

20 cm

Electrolysis in molten $CaCl_2$

950 °C
3.2 V
24 hours

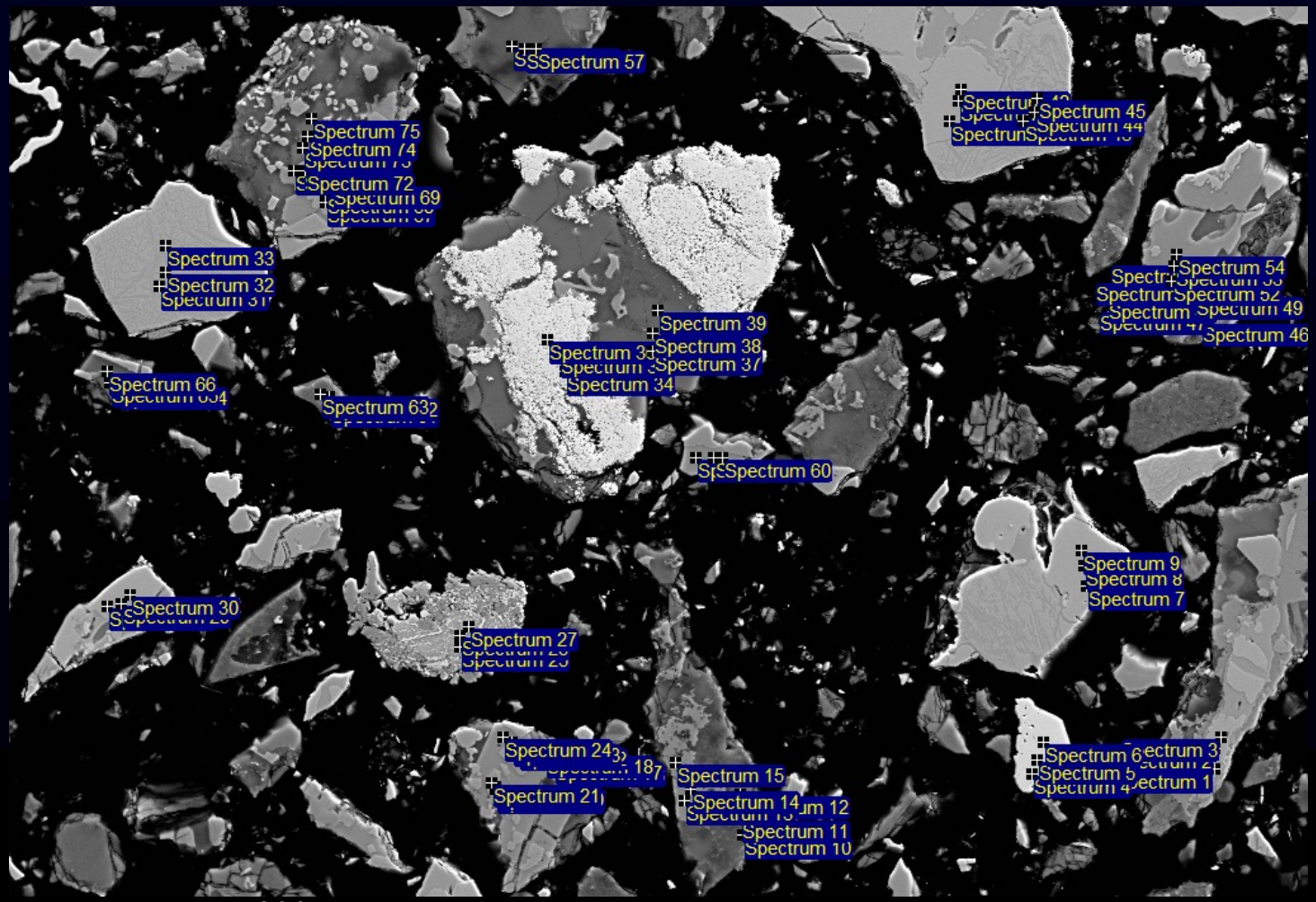
20 cm

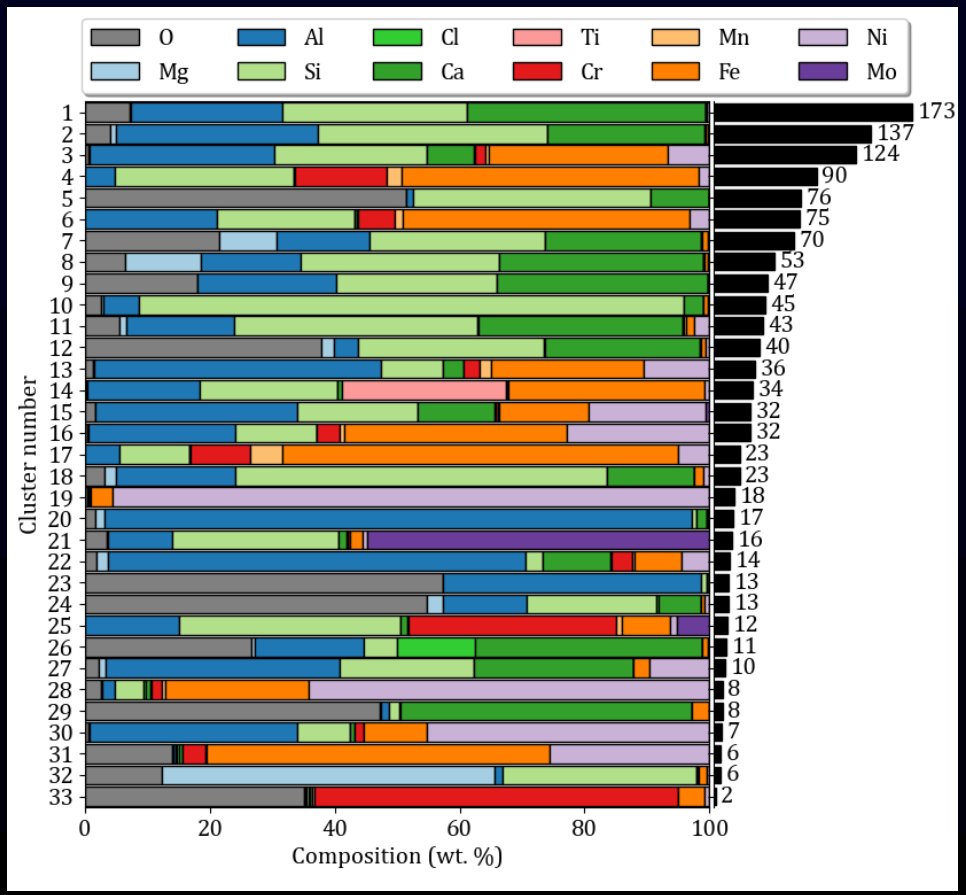
1 cm

Methods adapted from A. Meurisse, et al., 2022, *Planetary and Space Science*

Previous work

Complex mix of phases cannot be separated mechanically

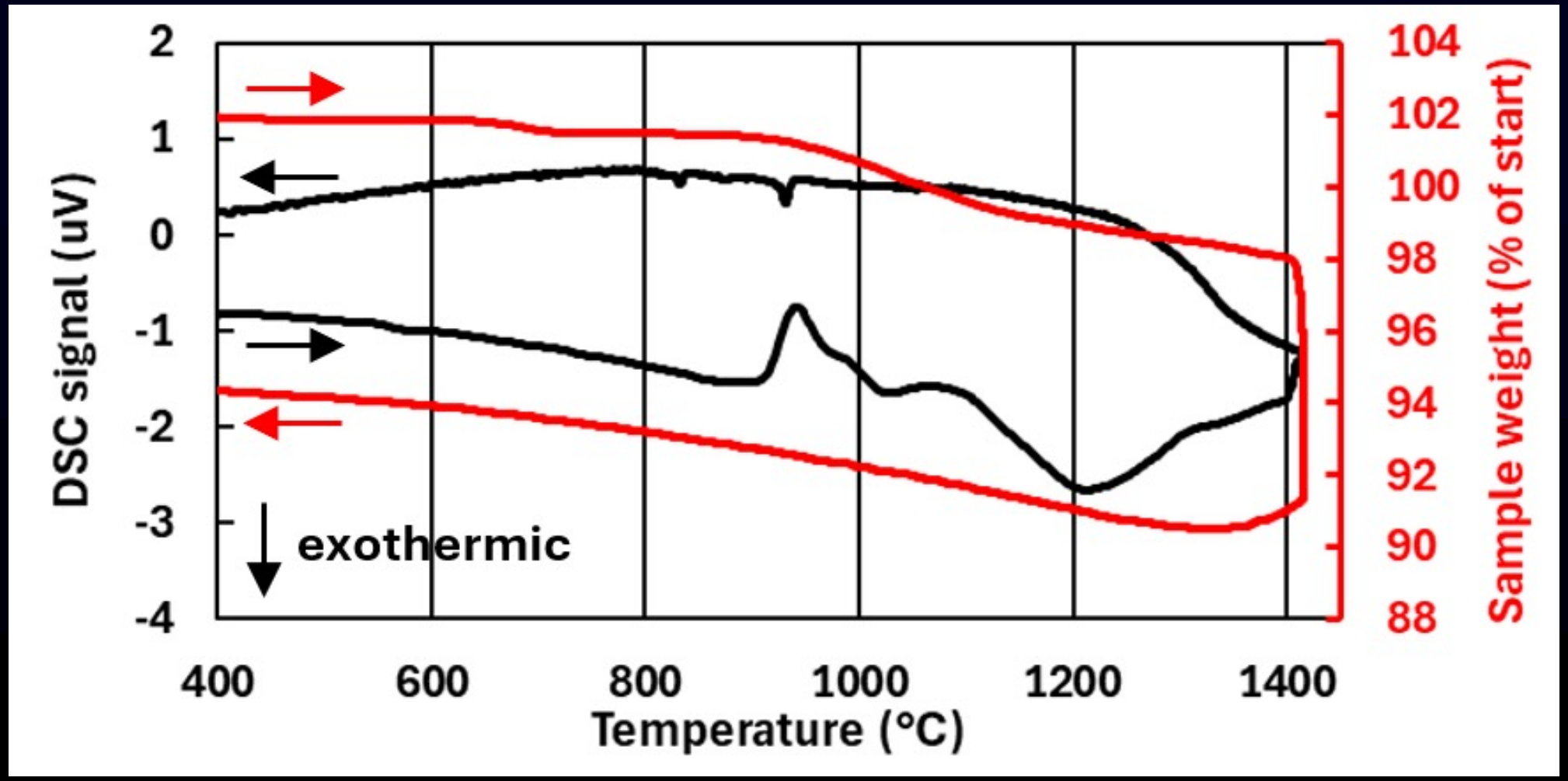




Detailed results published in T. Schild, et al., 2025, *Acta Astronautica*

Thermal post-processing

DSC shows melting main phase change at 900 – 1000 °C



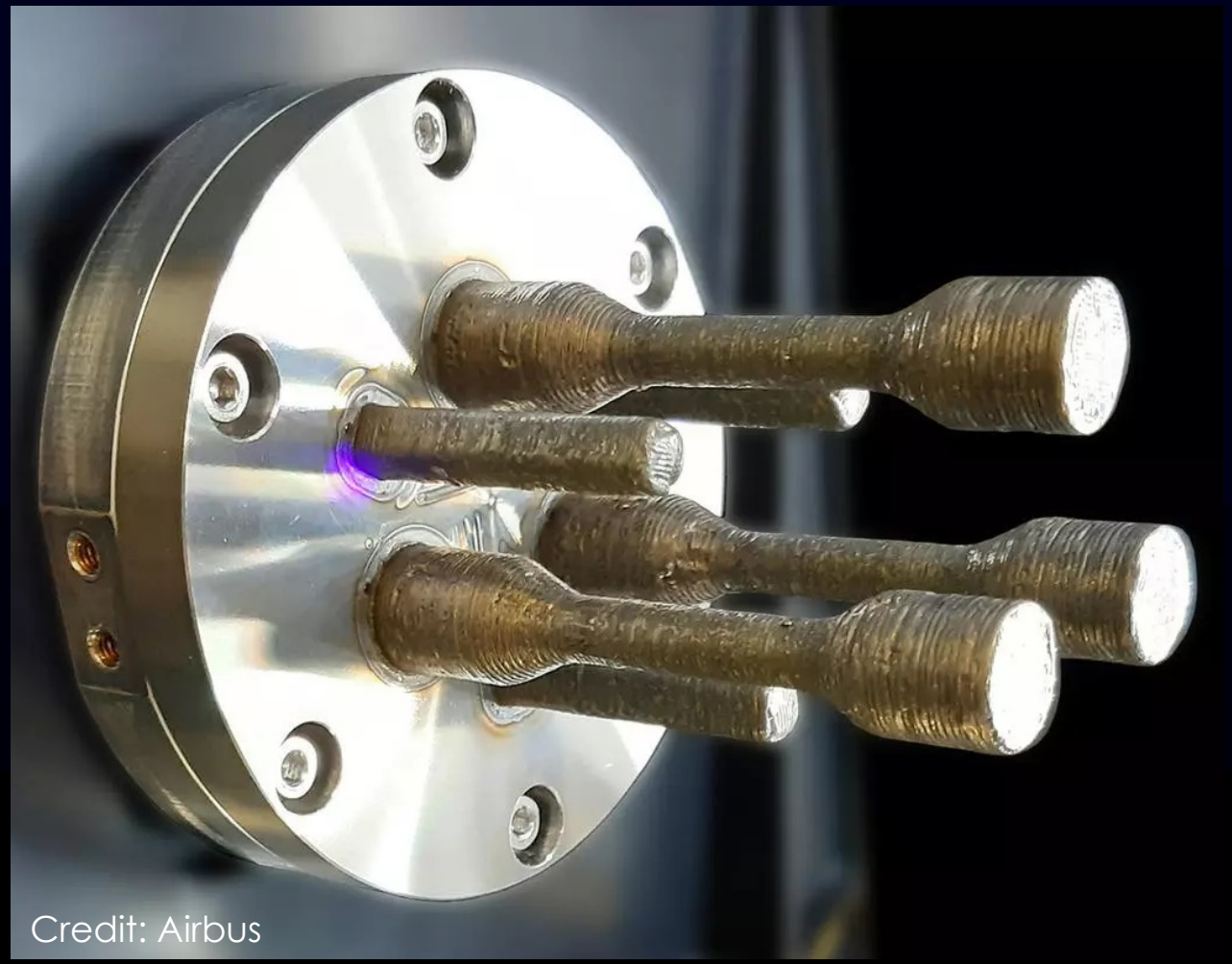
Towards additive manufacturing

Metal3D system is designed for manufacturing in space

Metal3D system installed onboard ISS

Credit: NASA

Test parts produced by Metal3D in orbit



Credit: Airbus