

# State-of-the-art in surface metrology for metal additive manufacturing

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Manufacturing Metrology Team, Faculty of Engineering

# Review paper



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## **Surface texture metrology for additive manufacturing: a review (2016),**

*A. Townsend, N. Senin, L. Blunt, R. Leach, J. Taylor,*

Precision Engineering, 46. pp. 34-47.  
ISSN 0141-6359

# Metal AM



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Material	EBM	Laser	DED
Nickel alloys	0	100%	0
Aluminium alloys	0	100%	0
Stainless steels	0	87%	13%
Other steels	0	83%	17%
Titanium alloys	35%	50%	15%
Others	0	100%	0

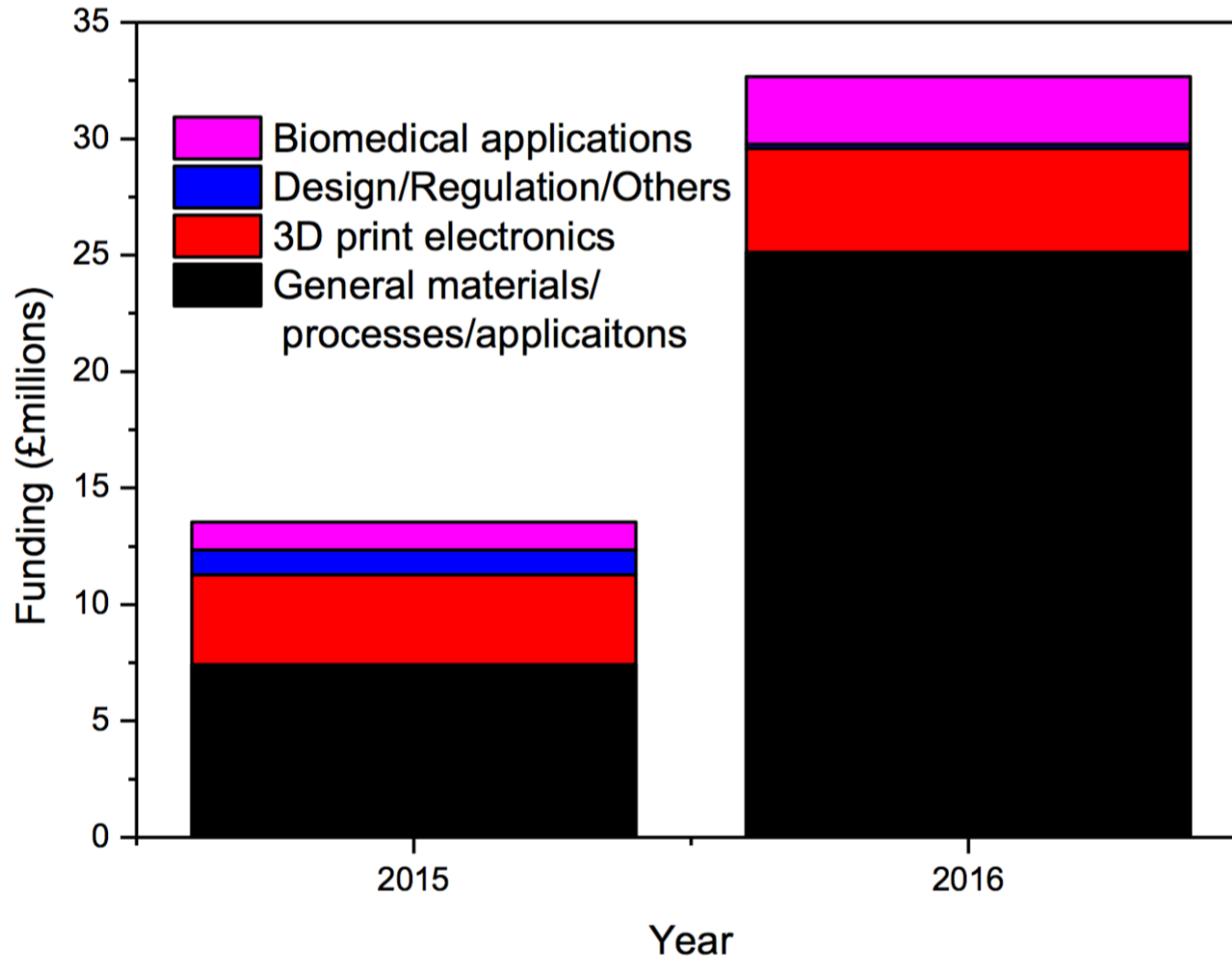
Material	%papers	
Nickel alloys	5%	(75% Inconel 625):
Aluminum alloys (e.g. AlSi10Mg)	5%	
Stainless steels	39%	(70% 316L)
Other steels	10%	
Titanium alloys (in particular: Ti6Al4V)	34%	(95% Ti6Al4V)
Others	7%	

Source: PE review paper

# Part I

## Role of surface metrology in AM research

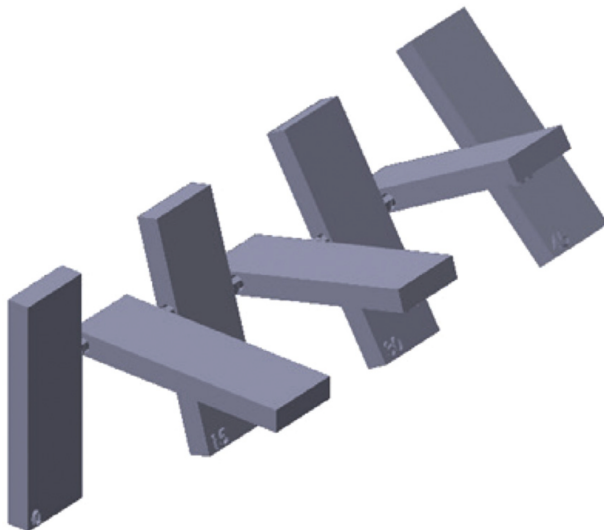
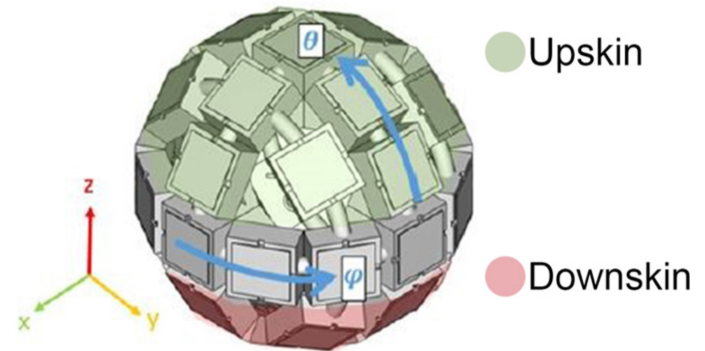
# Active AM projects 2015-2016 (RCUK)



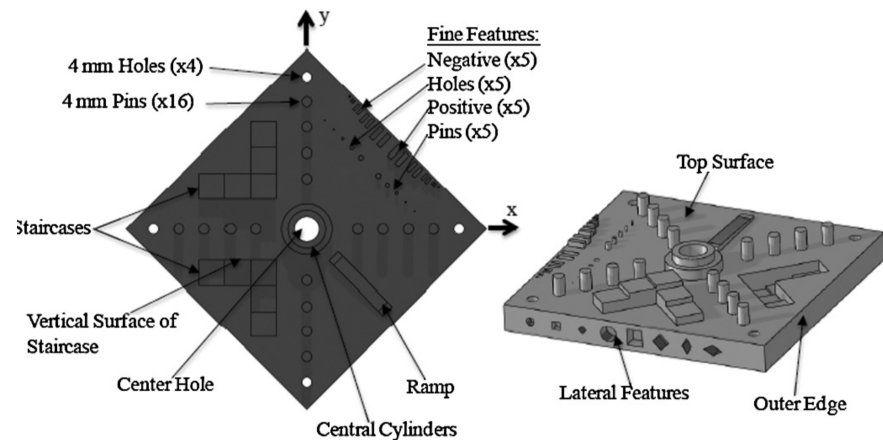
# Process capability assessment



90% literature on metal AM uses artifacts



ASTM F42 / ISO TC 261 (2015)



NIST (2012)

Source: PE review paper

# Application-specific / product-specific research?

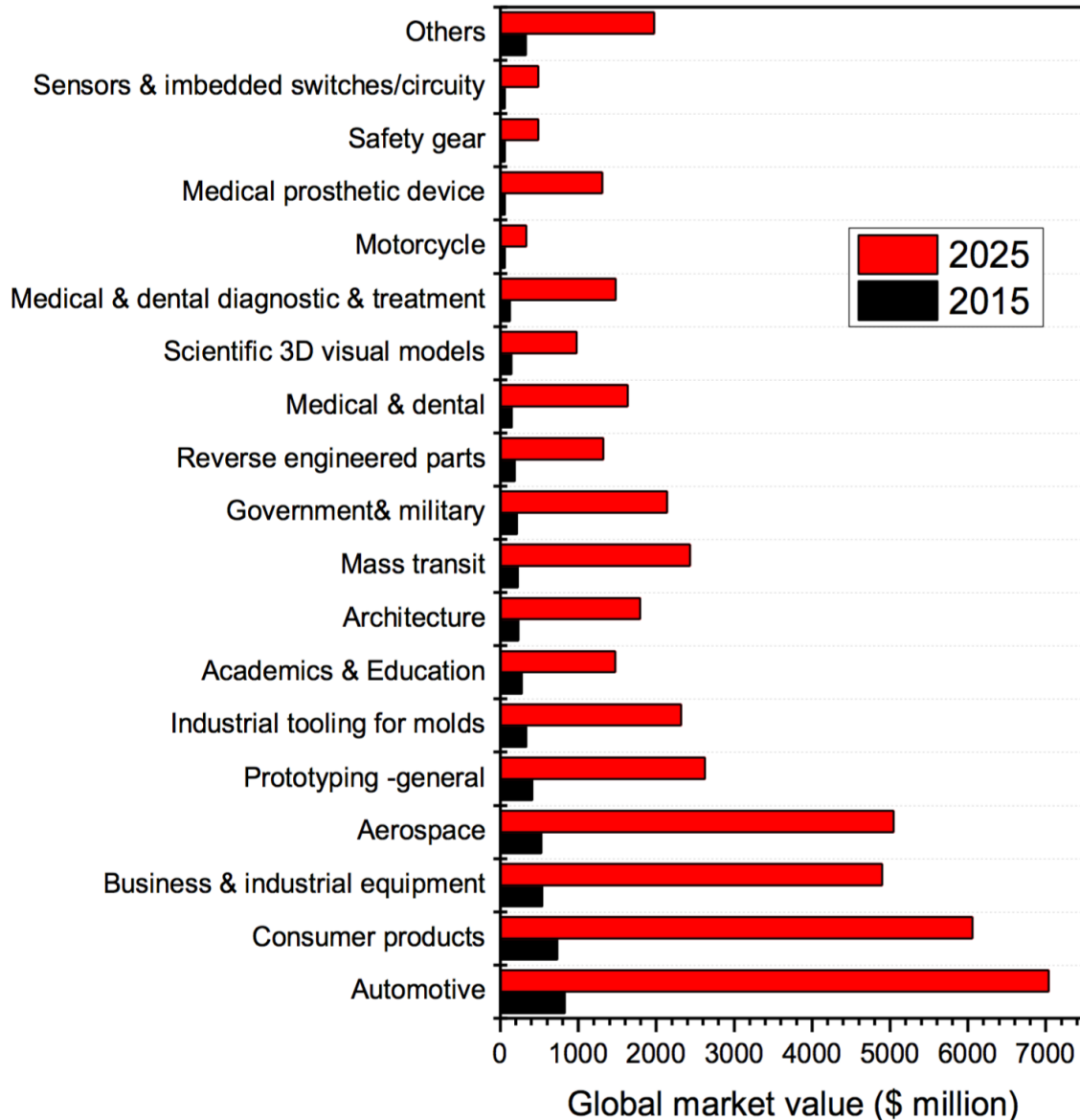


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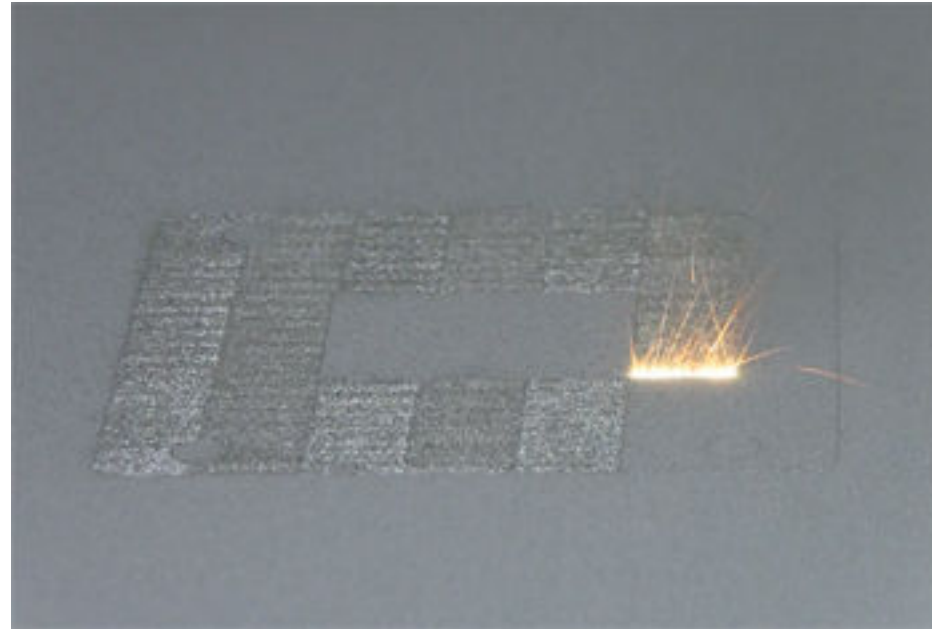
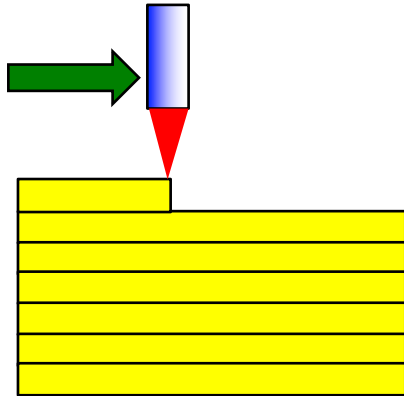
# AM markets by application



*The current landscape of AM research -  
2016 ICL AMN report*



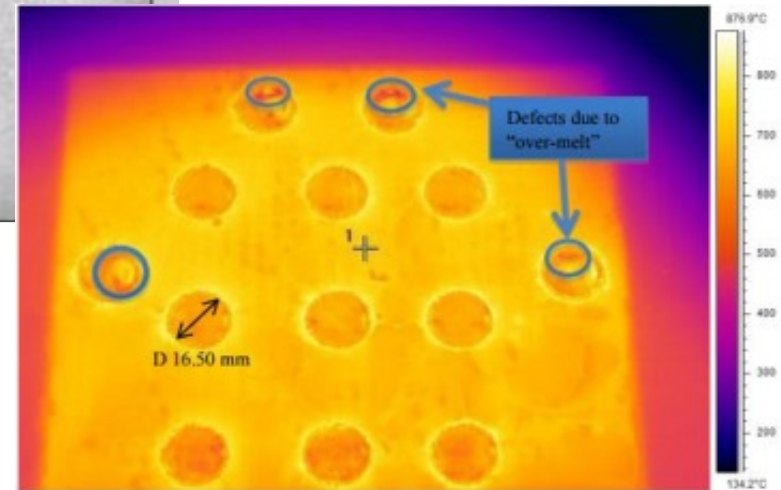
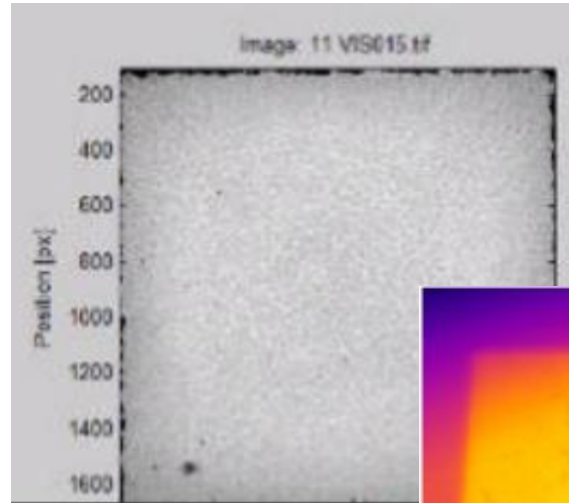
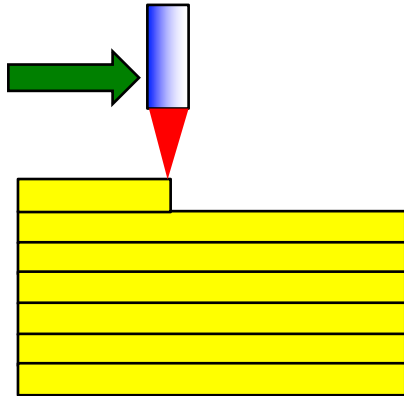
# In-process surface metrology



Need to be quick, need access, need to operate in challenging conditions

**Most 2.5D and 3D measurement techniques don't work**

# In-process surface metrology



## Often: 2D "imaging"

- Vision
- Thermal

## Other: (acoustic emissions, laser ultrasonics. Etc)

Defect "detection" (Y/N)

# Part II

# Measurement of AM topography

# Surface measurement pipeline

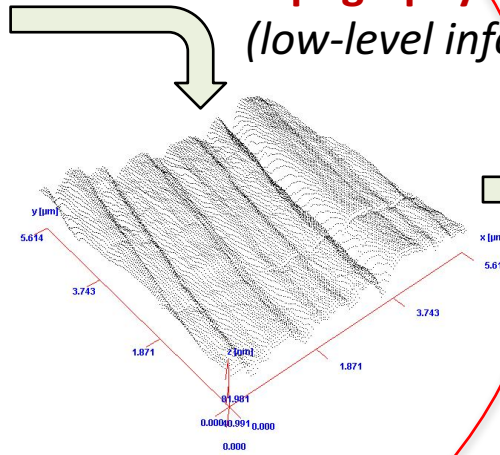


## Topography Acquisition

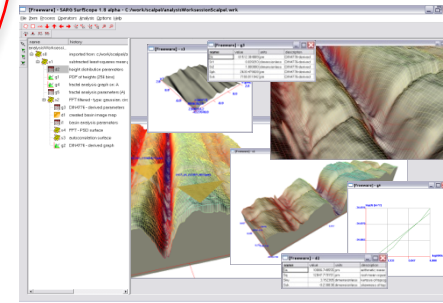


Hardware + software

## Topography data (low-level information)



## Topography Characterisation



Software

## Indicators (high-level information)

# Part II

## Measurement of AM topography

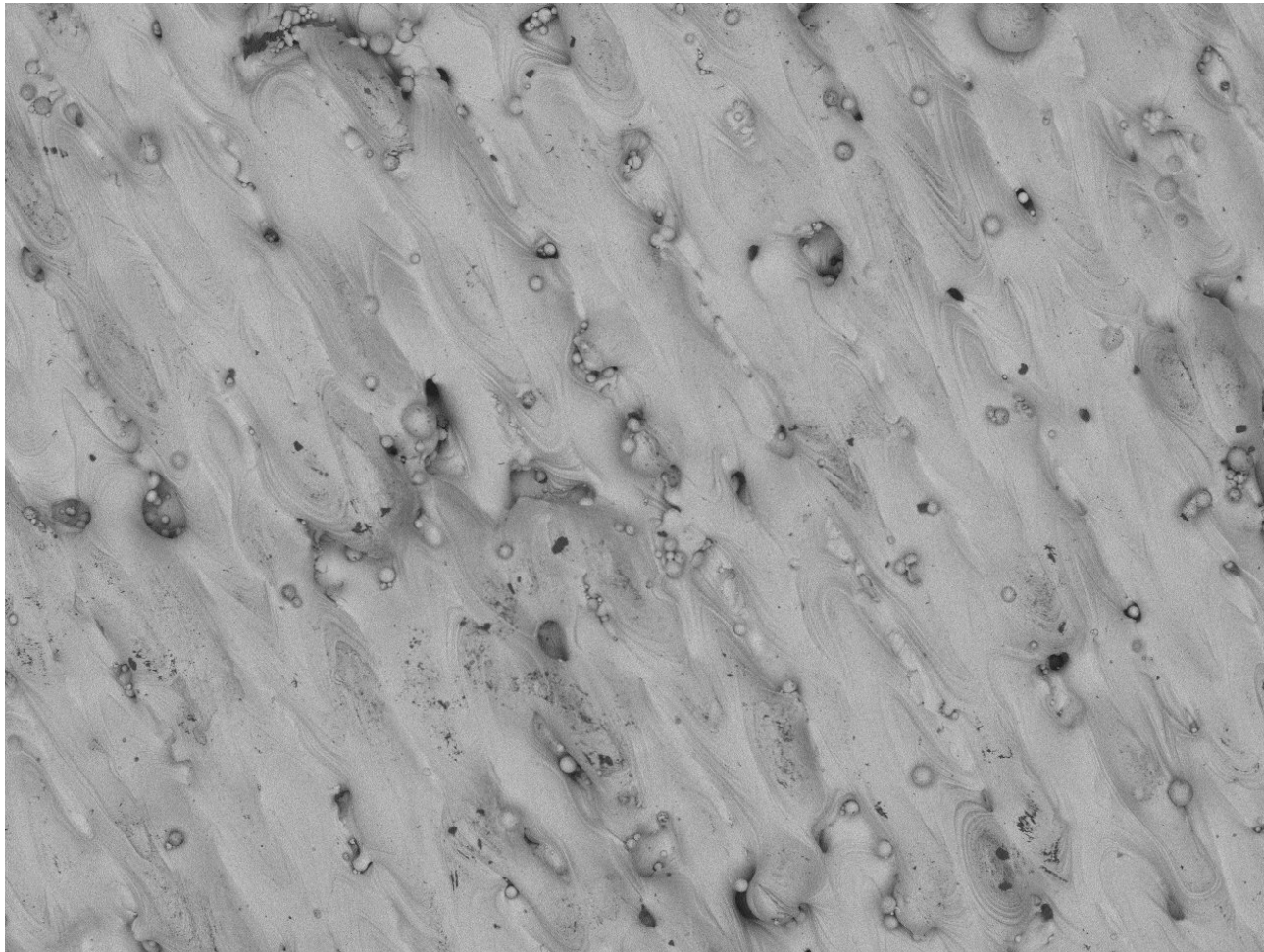
### What do AM surfaces look like?

# SLM of metals



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SLM\_Cube\_Z0000

2016-03-08

14:07 h

D7.8

x50

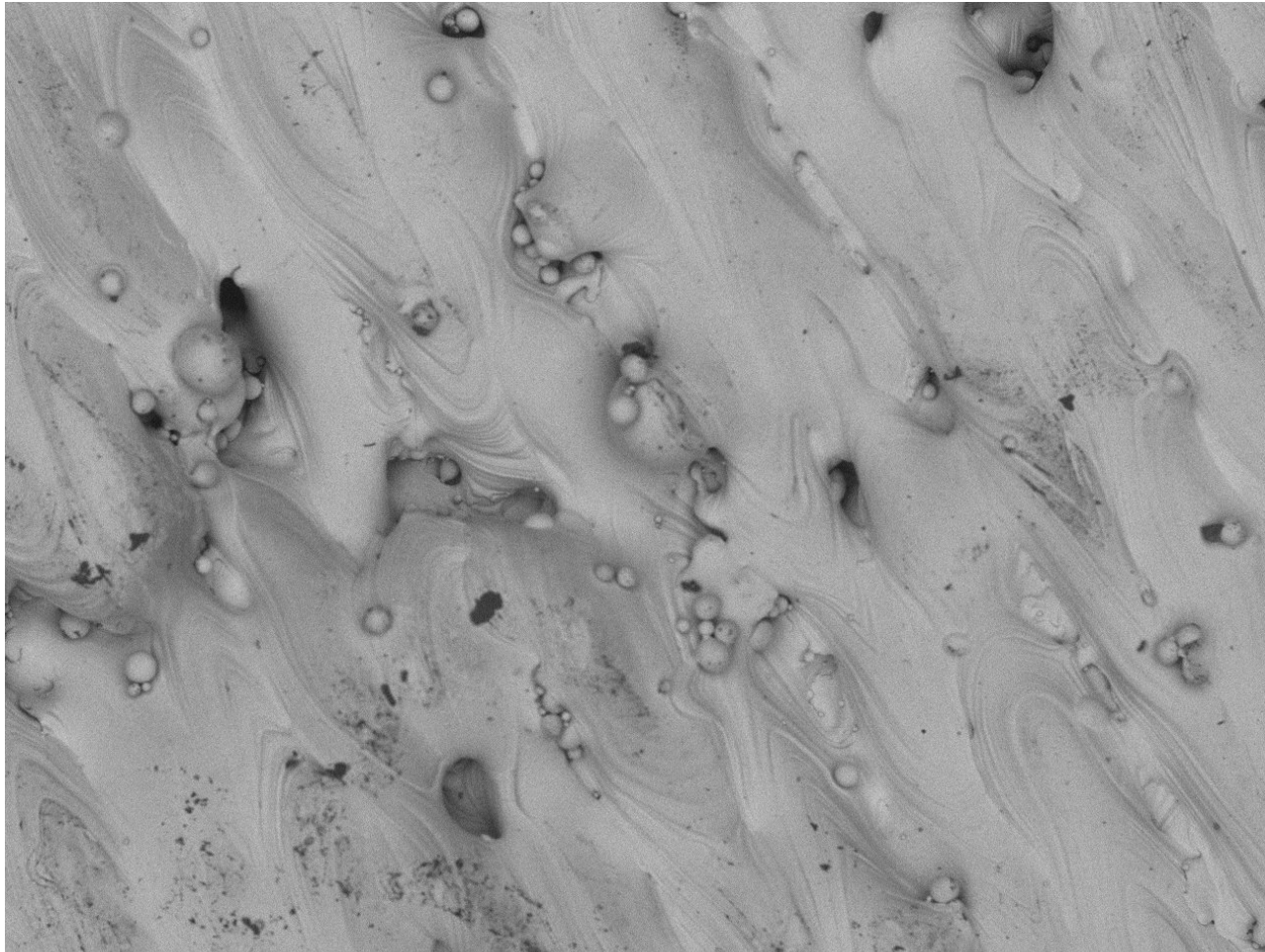
2 mm

# SLM of metals



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2016-03-08

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D7.8 x100

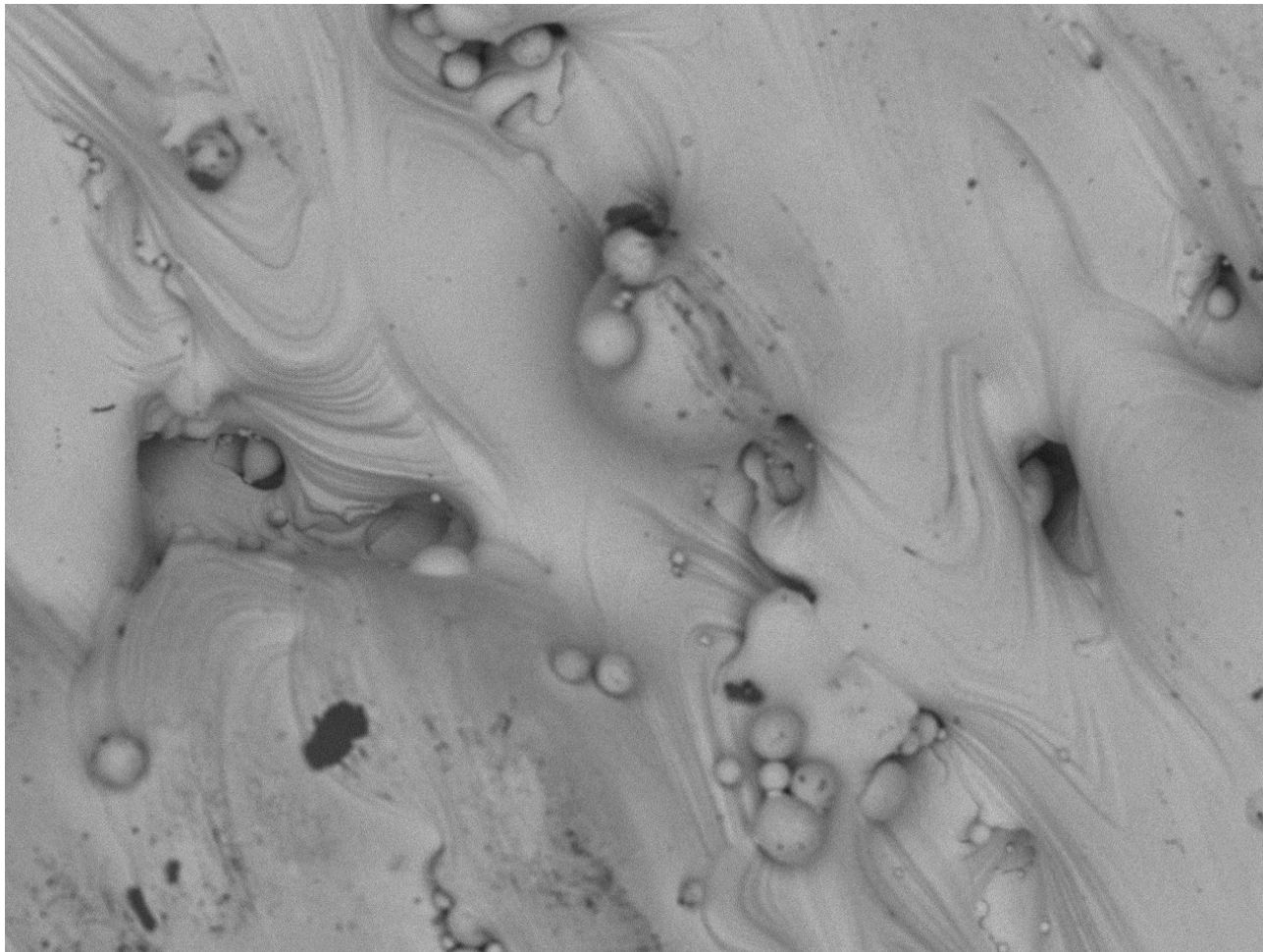
1 mm

# SLM of metals



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SLM\_Cube\_Z0002

2016-03-08

14:10 h

D7.8

x200

500  $\mu$ m

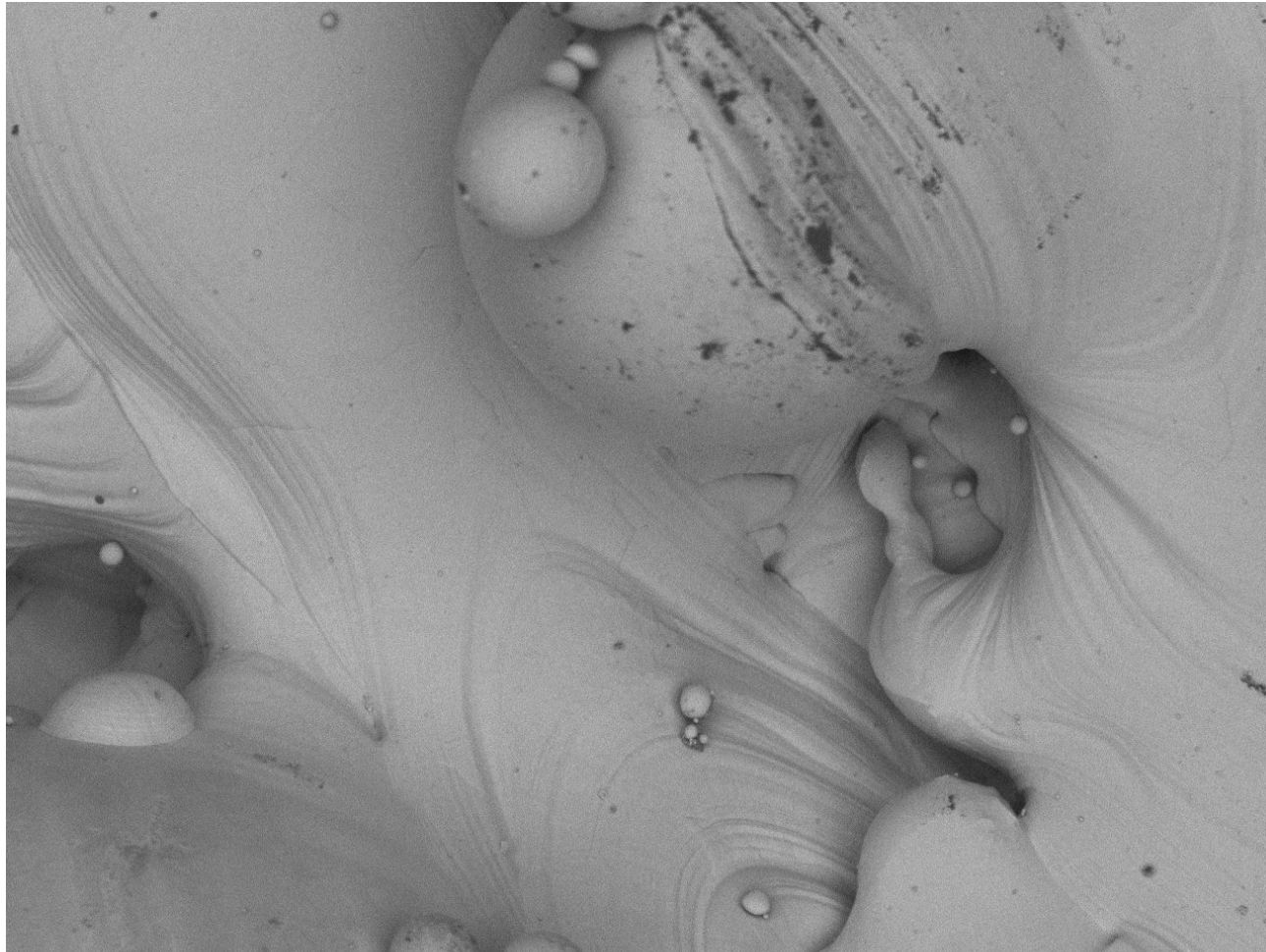


# SLM of metals



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SLM\_Cube\_Z0003

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14:12 h

D7.5 x500

200  $\mu$ m

# SLM of metals



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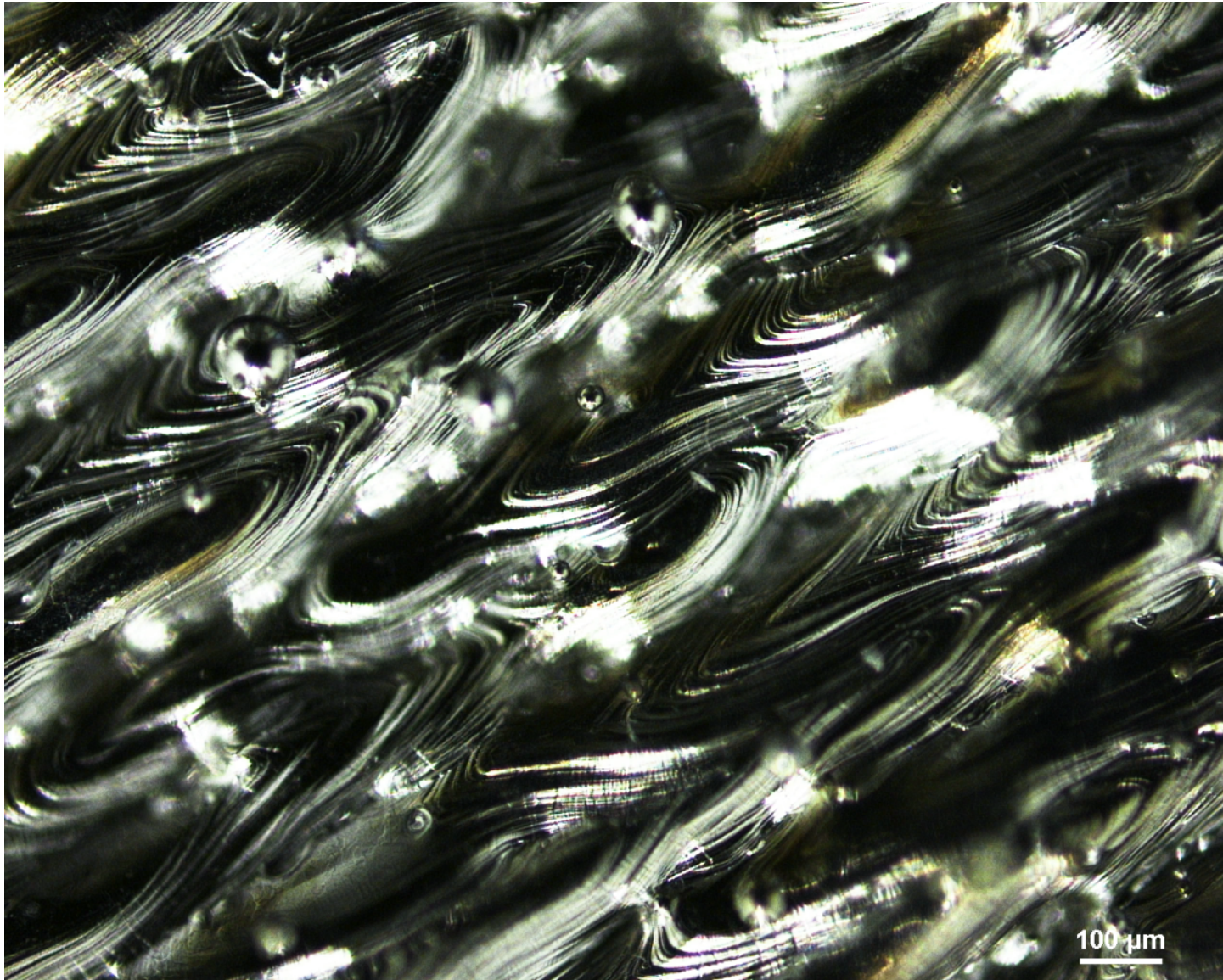


# SLM of metals



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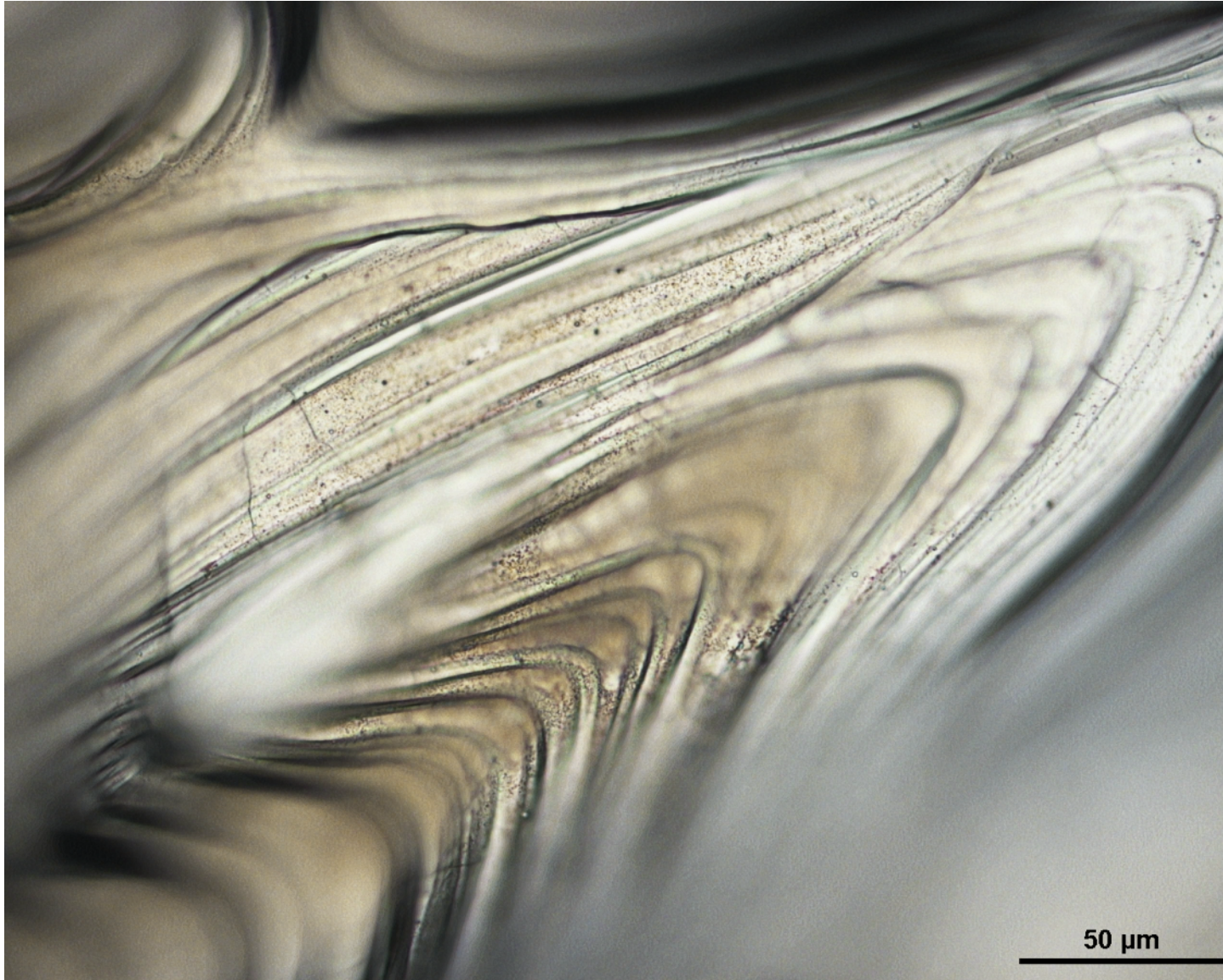


# SLM of metals



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# SLM of metals



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# Part II

# Measurement of AM topography

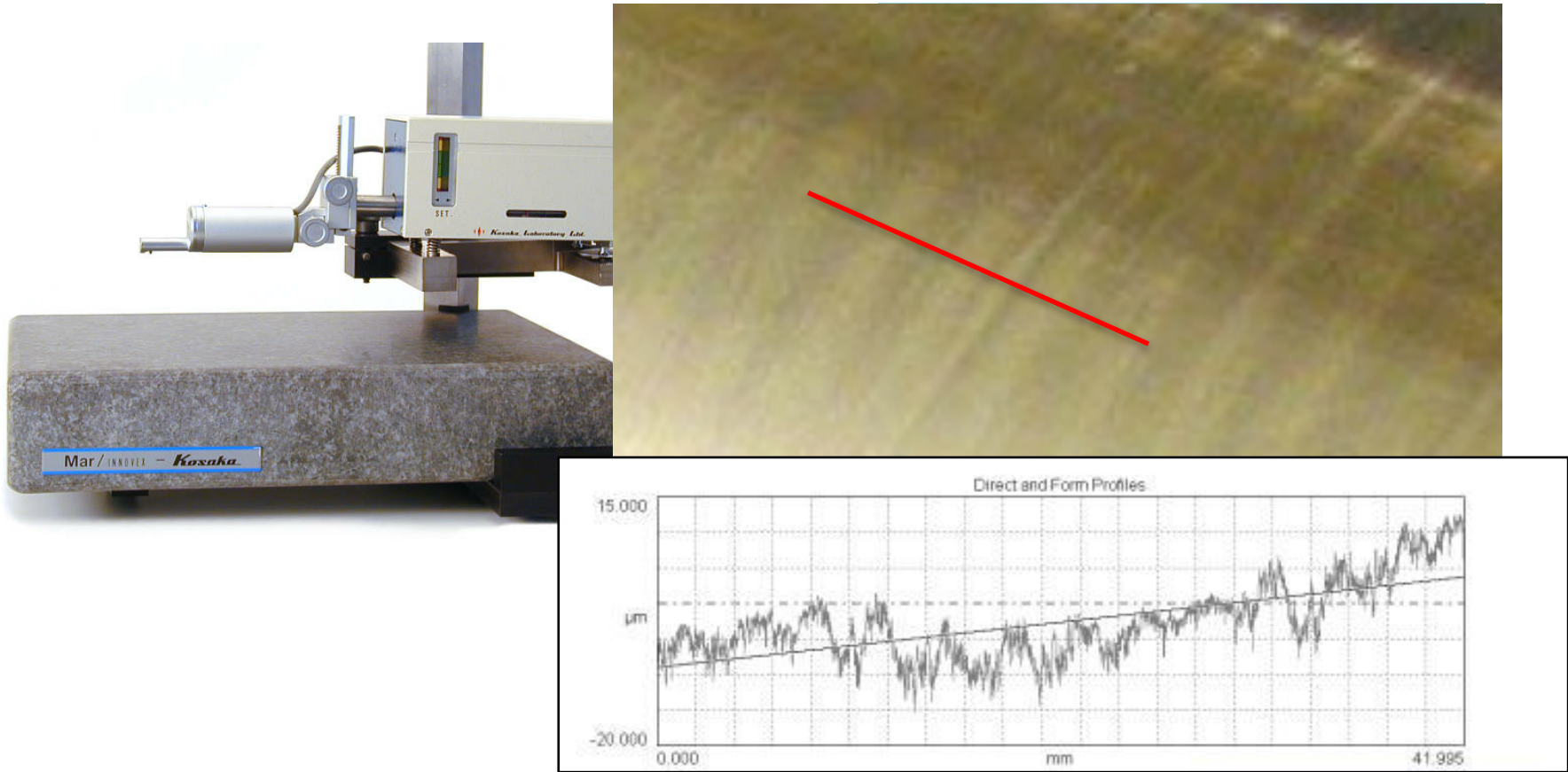
## Technologies

# Stylus profilometer



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**40% of metal AM literature**

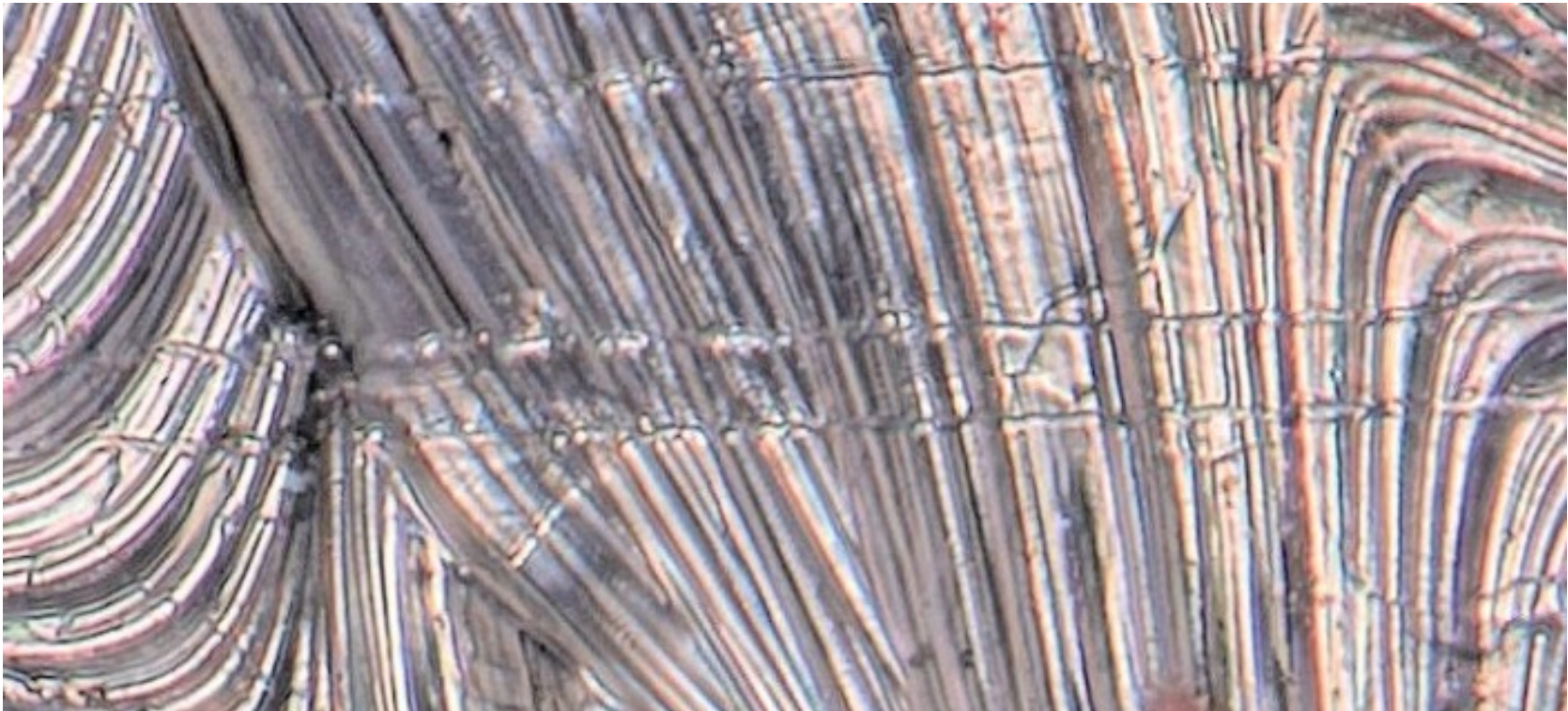
# Stylus problems



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- Representativeness
- Traversal problems
- Damage





# Optical areal measurement



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- Confocal Microscopy (%11)
- Focus Variation (%11)
- Coherence Scanning Interferometry (%7)

*(Usage percentages form the PE review)*

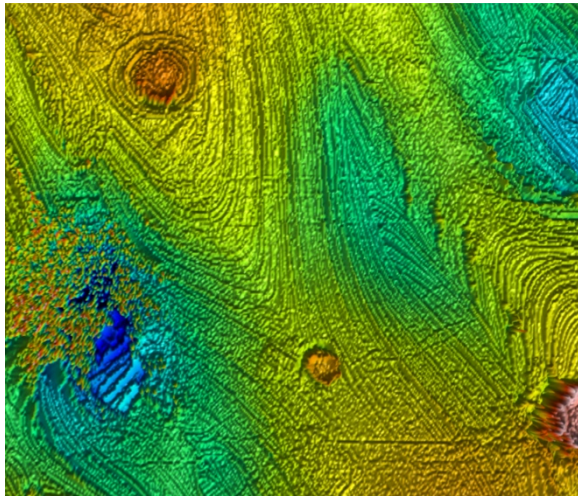
# Optical area measurement



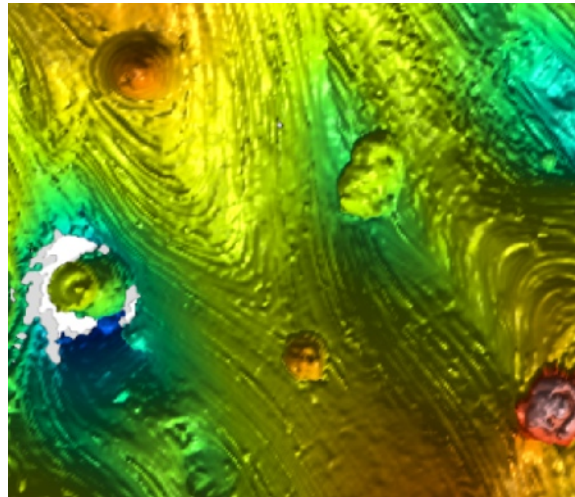
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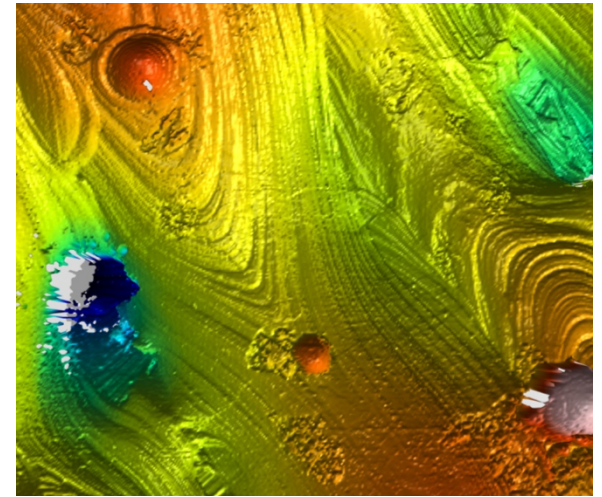
**CM**



**FV**



**CSI**

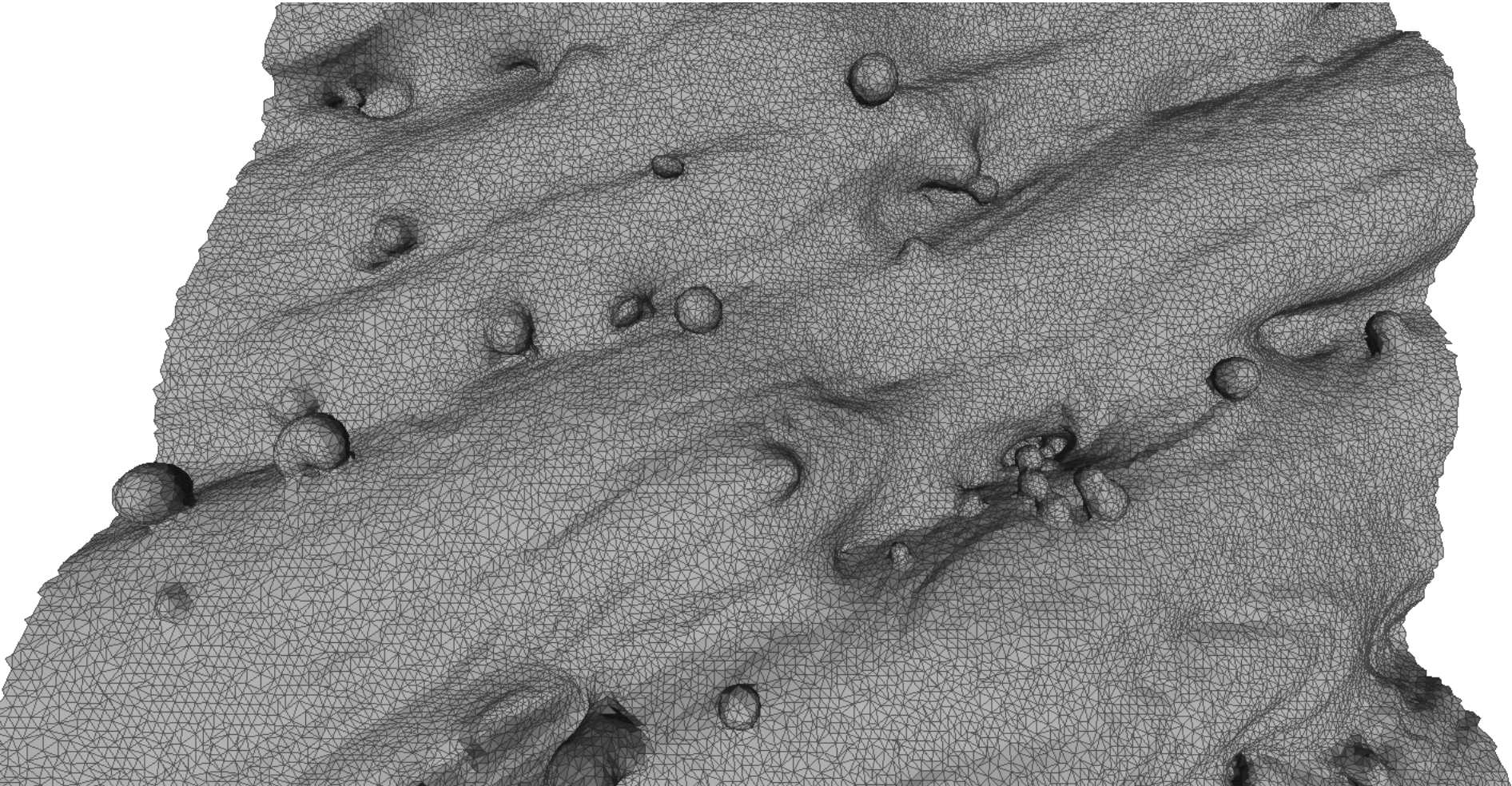


# X-ray Computed Tomography



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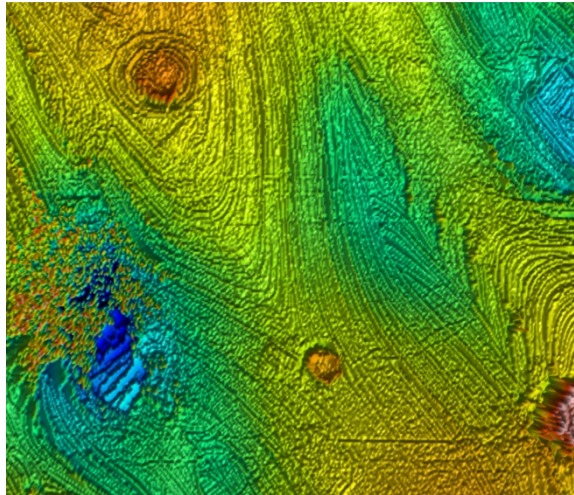
# Areal Measurement



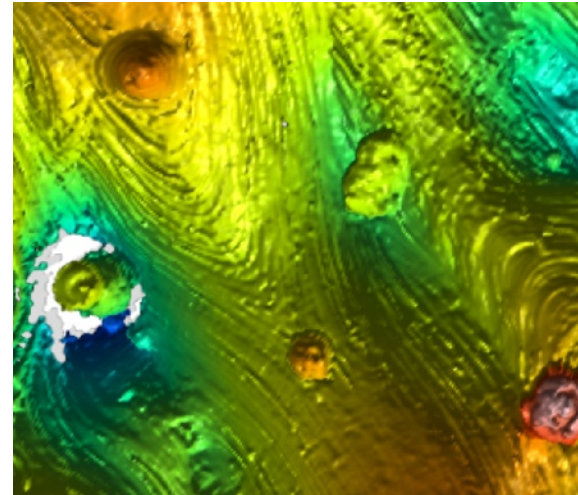
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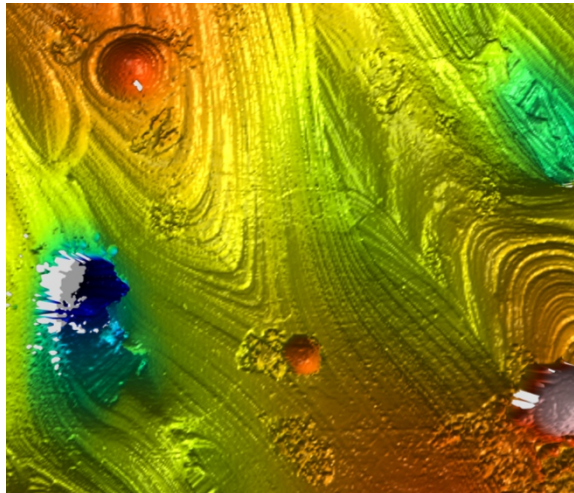
**CM**



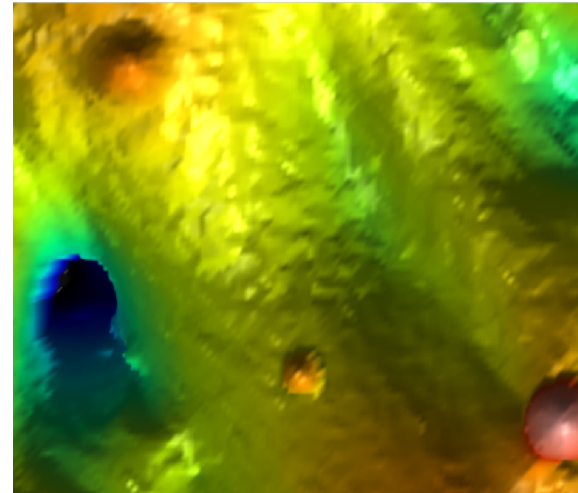
**FV**



**CSI**



**XCT**



# Part III

## Characterisation of AM topography

# Surface metrology pipeline

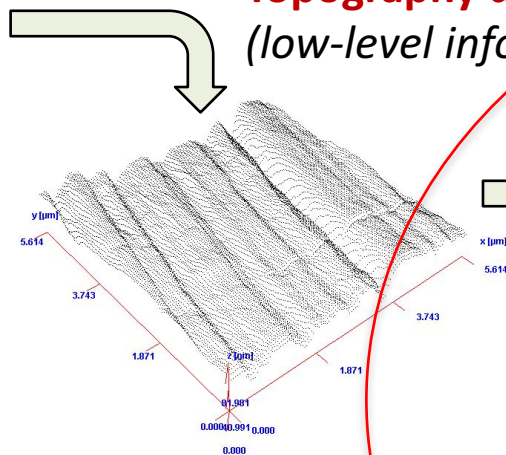


## Topography Acquisition

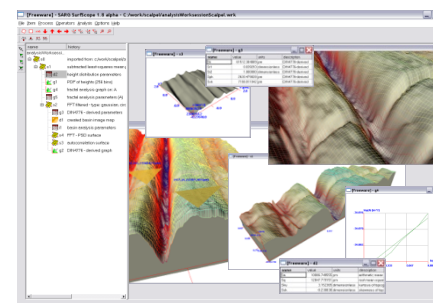


Hardware + software

## Topography data (low-level information)



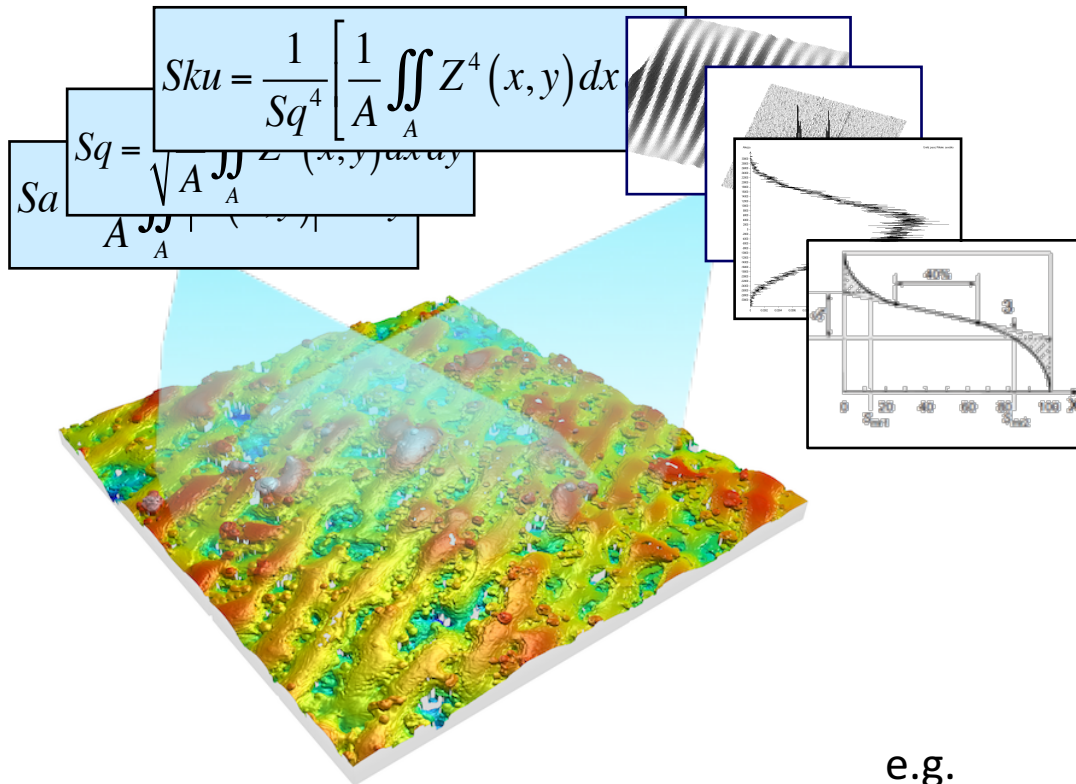
## Topography Characterisation



Software

## Indicators (high-level information)

# So many possibilities!



e.g.  
ISO 25178-2

# Texture parameters in AM surface metrology



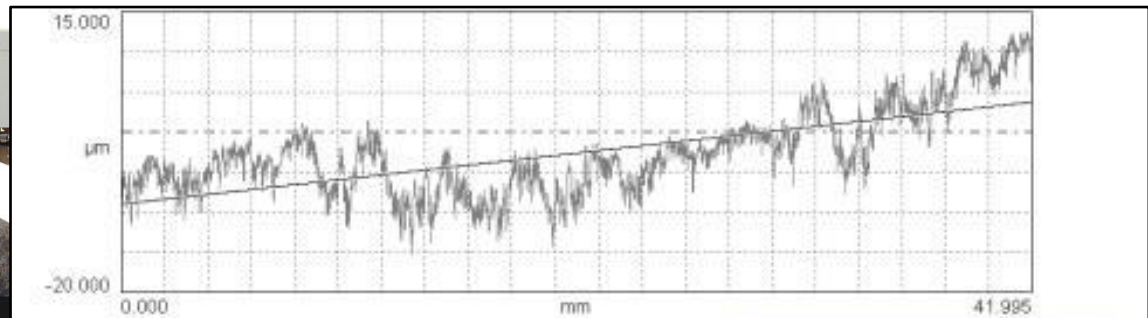
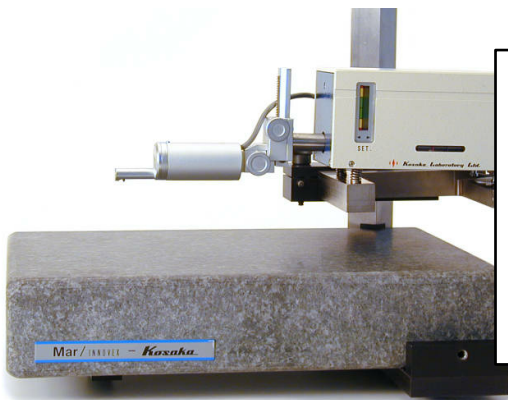
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*From the PE review:*

80% papers on metal AM use **profile parameters**

**$Ra$**  >>>>  **$Rq$**  >>  **$Rz$ ,  $Rt$**  >> ... (others)...



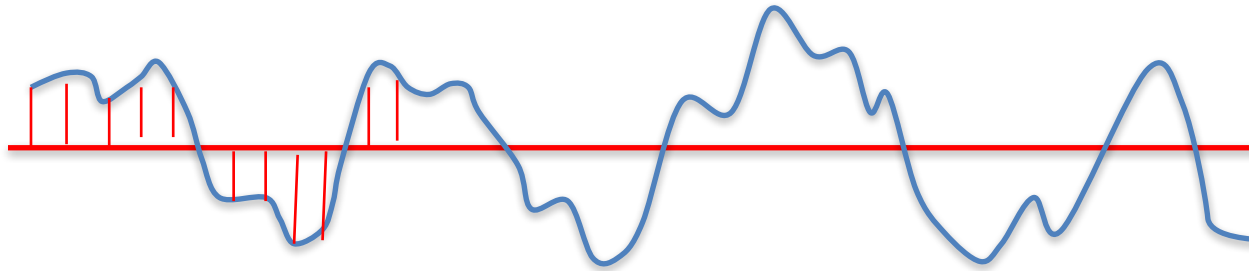


# The good old $Ra$



ISO 4287:1997

$Ra$  – Arithmetical mean deviation of surface heights (on the roughness profile)



$$Ra = \frac{1}{l} \int_0^l |z| dx$$

# Texture parameters in AM surface metrology



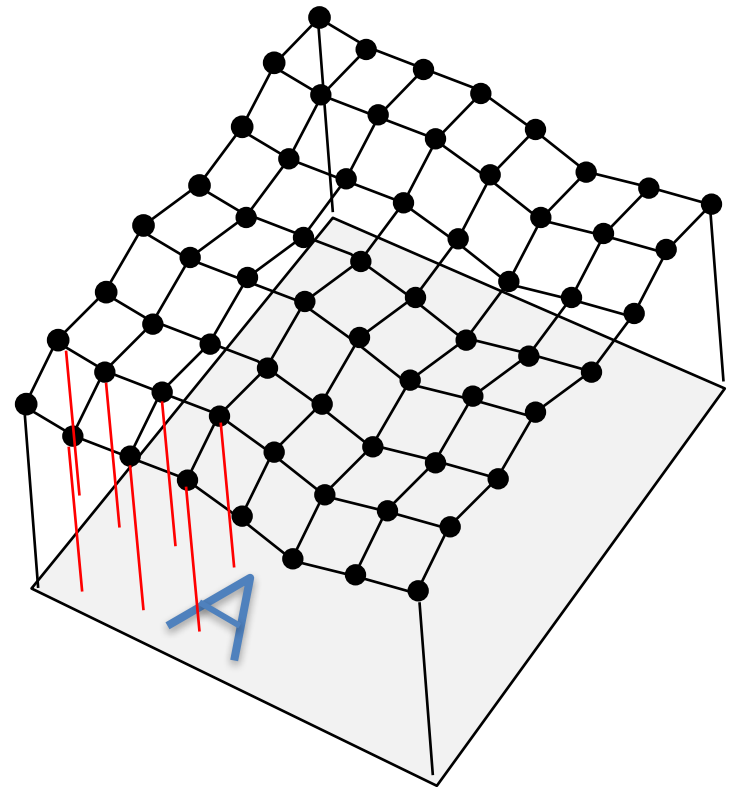
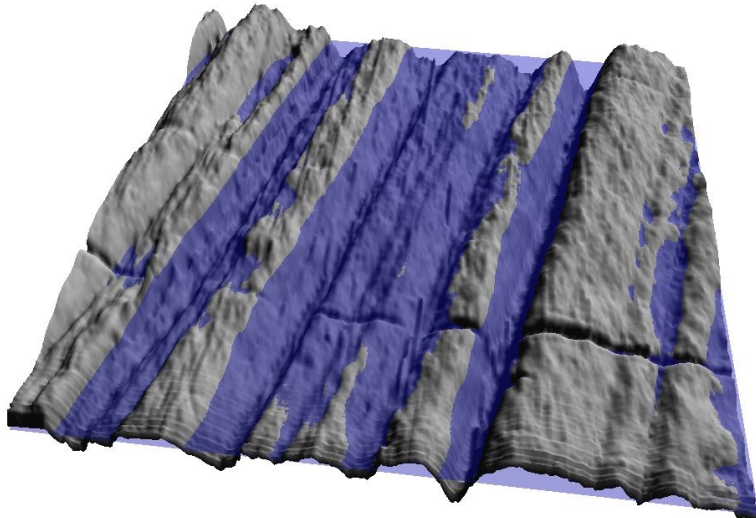
*From the PE review:*

20% papers on metal AM use **areal parameters**

(90% of which cite  $Sa$ )

ISO 25178-2 arithmetic mean height -  $Sa$

$$Sa = \frac{1}{A} \iint_A |z(x, y)| dx dy$$



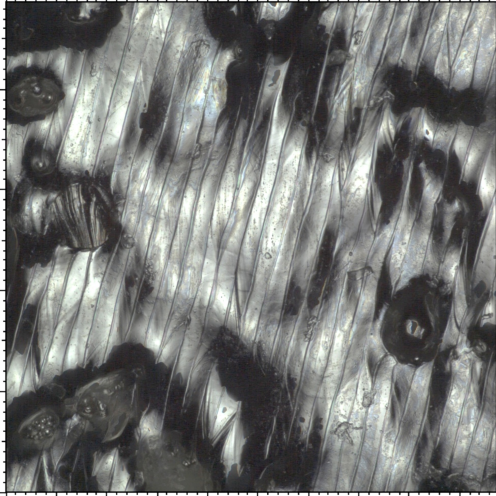
# Scale-limited characterisation



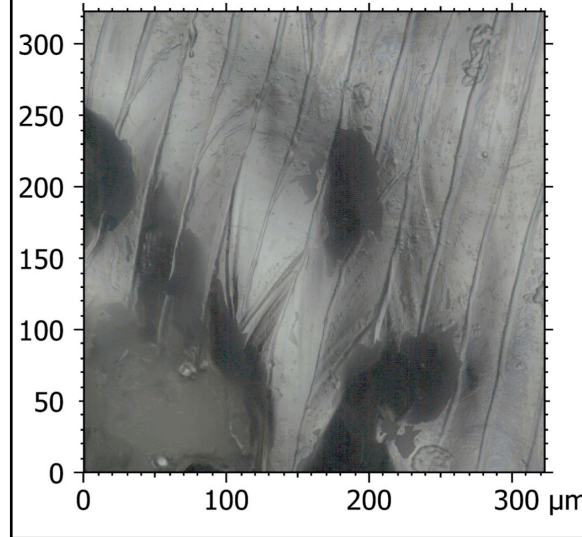
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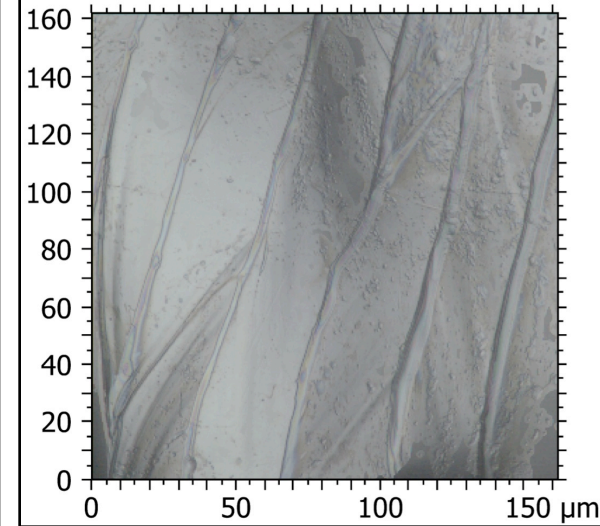
20x



50x



100x



## Choice criteria

- Study application/function
- Study mfg. process
- Study measurement
- Parallel with profiles?
- Intrinsic properties of the dataset

From the PE review:

90% papers using profile parameters indicate cut-offs

70% papers using areal parameters indicate cut-offs

# Feature-based characterisation

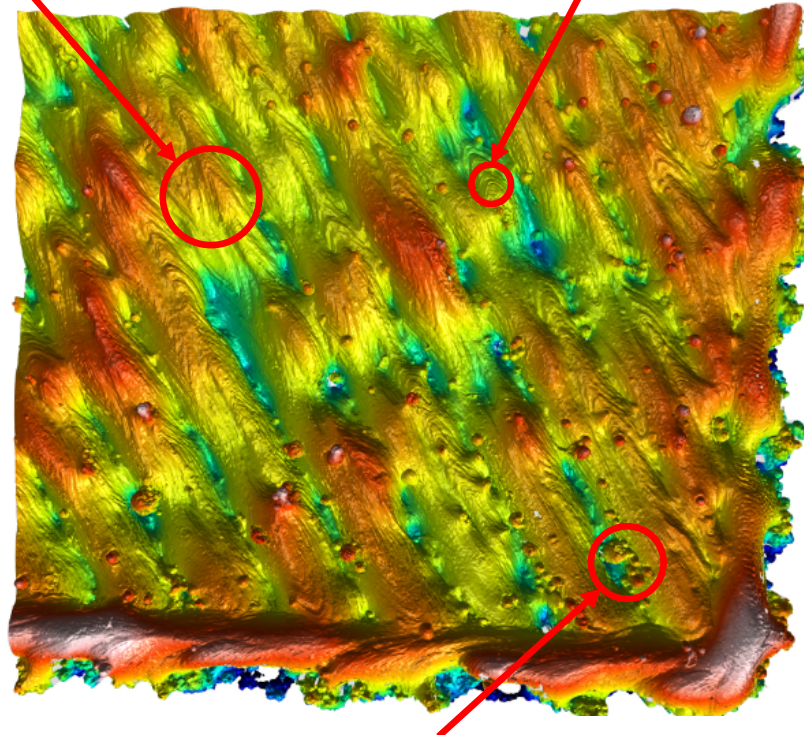


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Weld track width?

Weld ripple spacing?



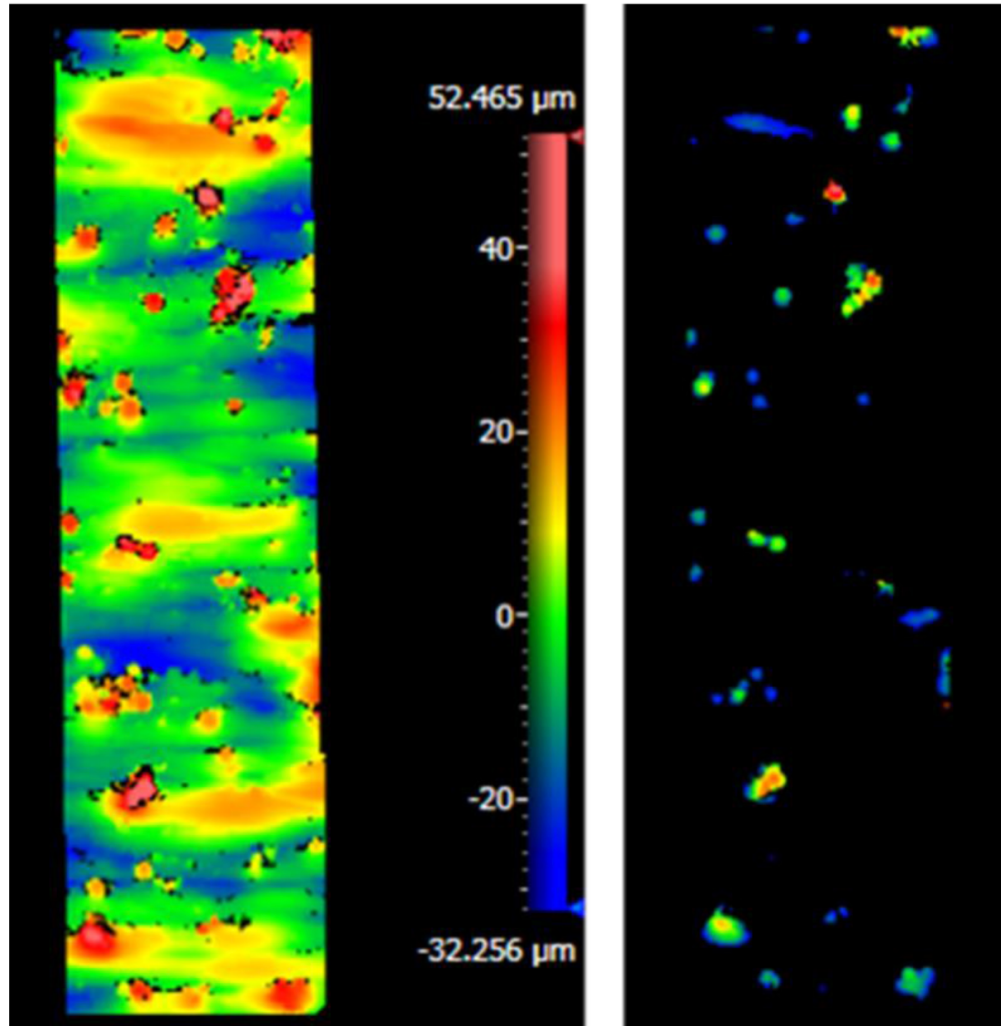
Diameter of attached particles?

# Feature-based characterisation



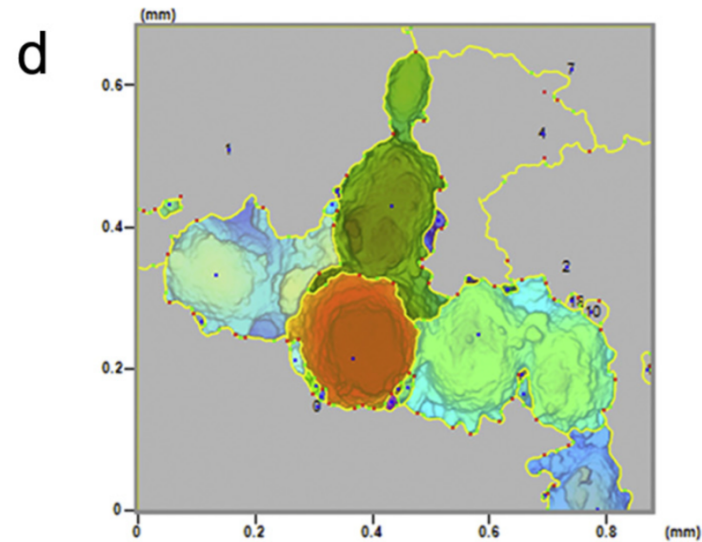
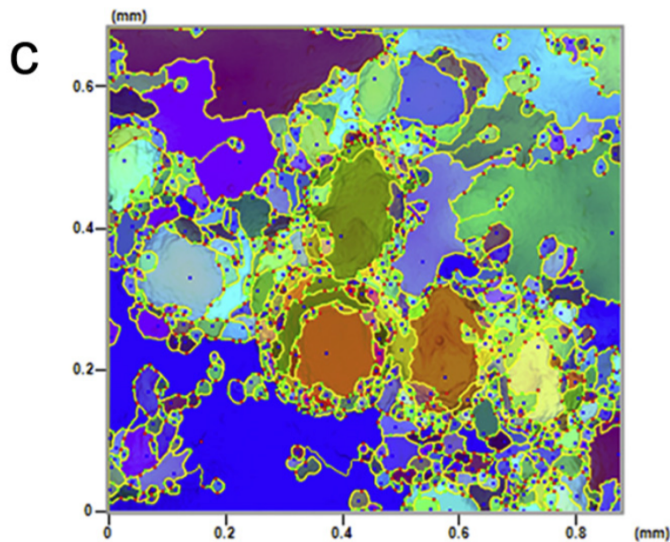
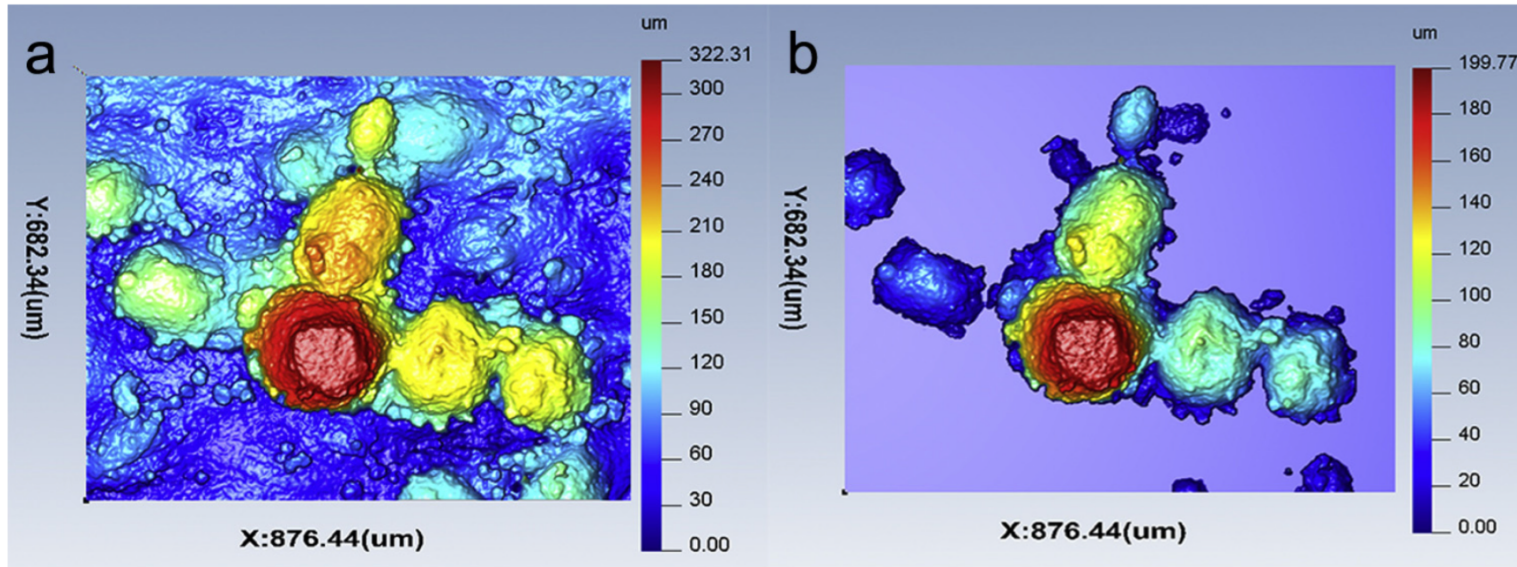
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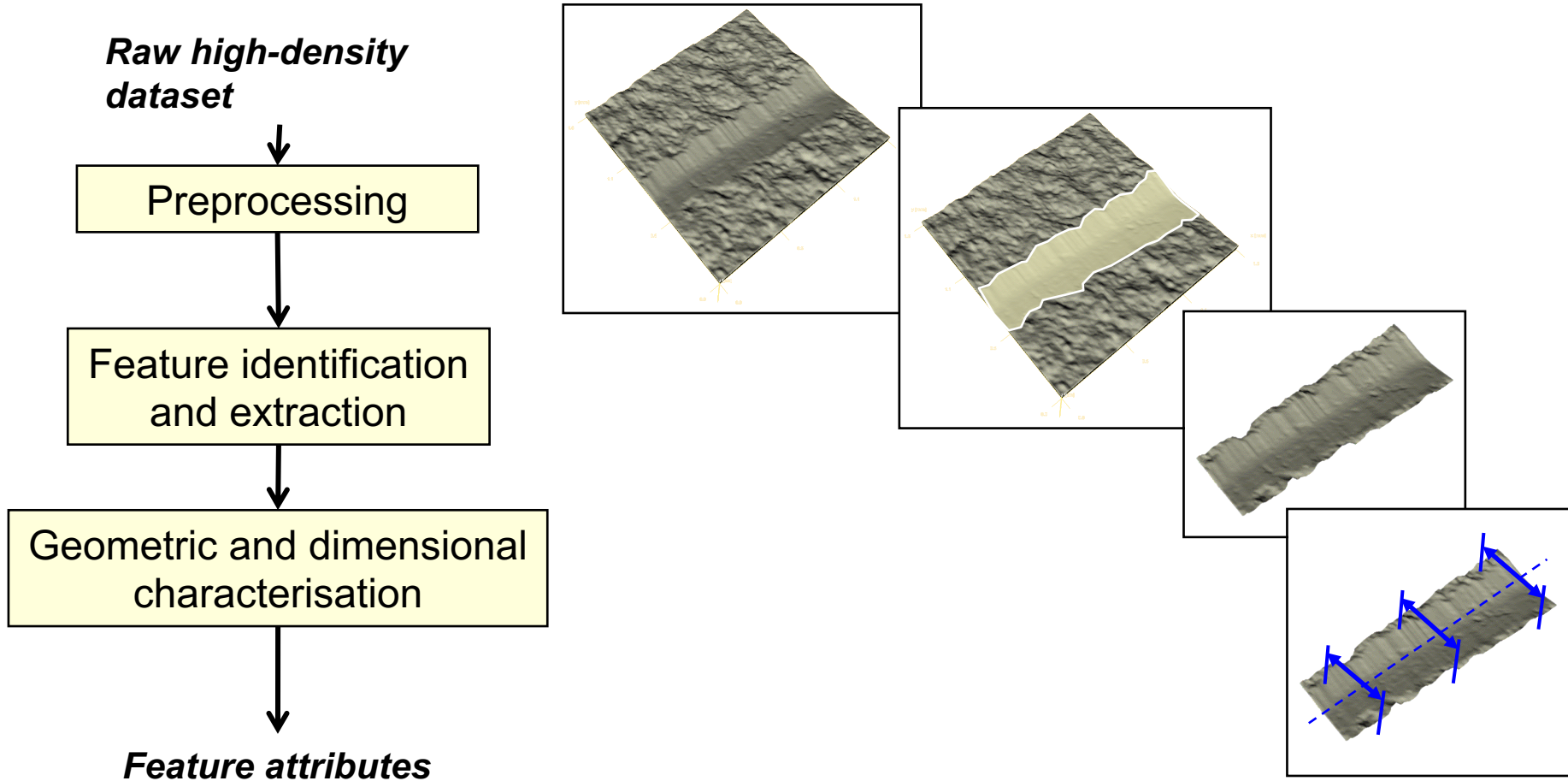
*Z. Reese, J. Taylor, C. Evans*  
ASPE 2016

# Feature-based characterisation



A. Townsend, L. Blunt, PE review, 2016

# Feature-based characterisation

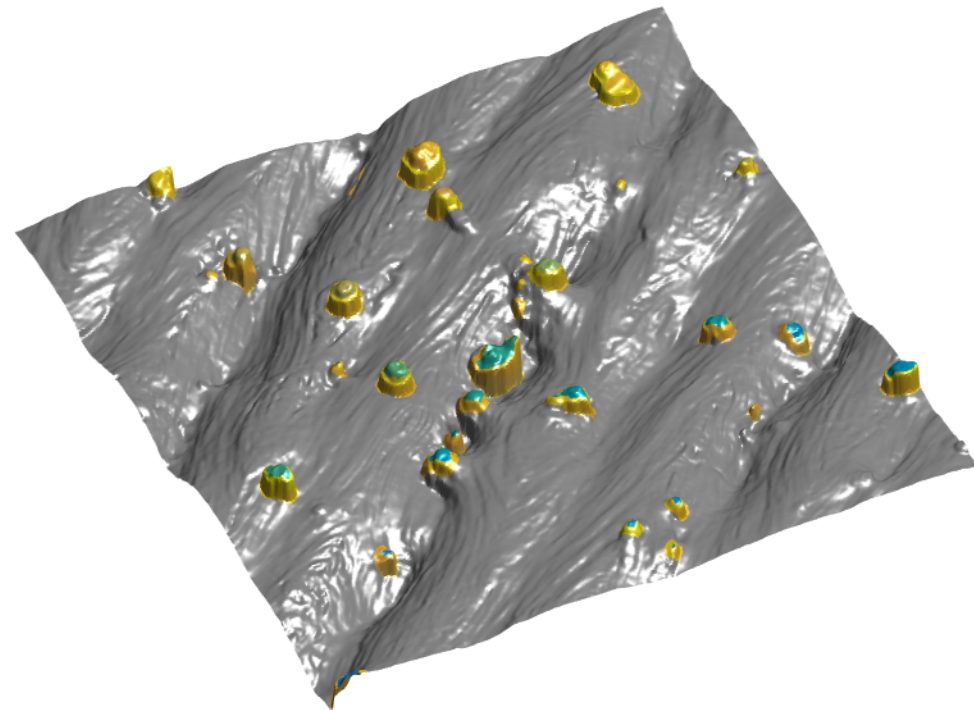
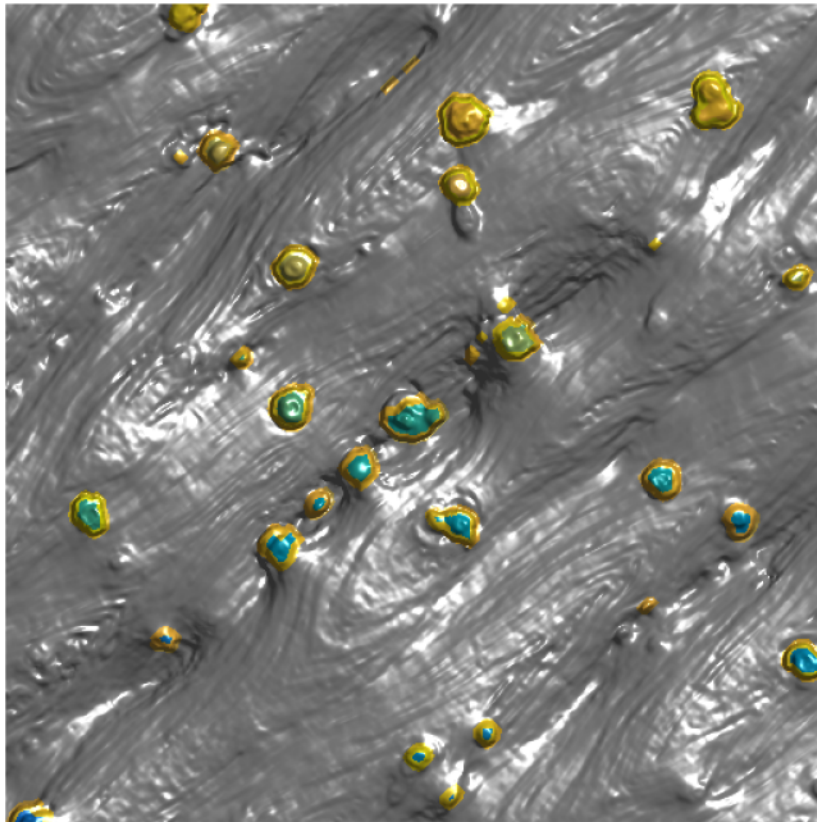


# Feature-based characterisation



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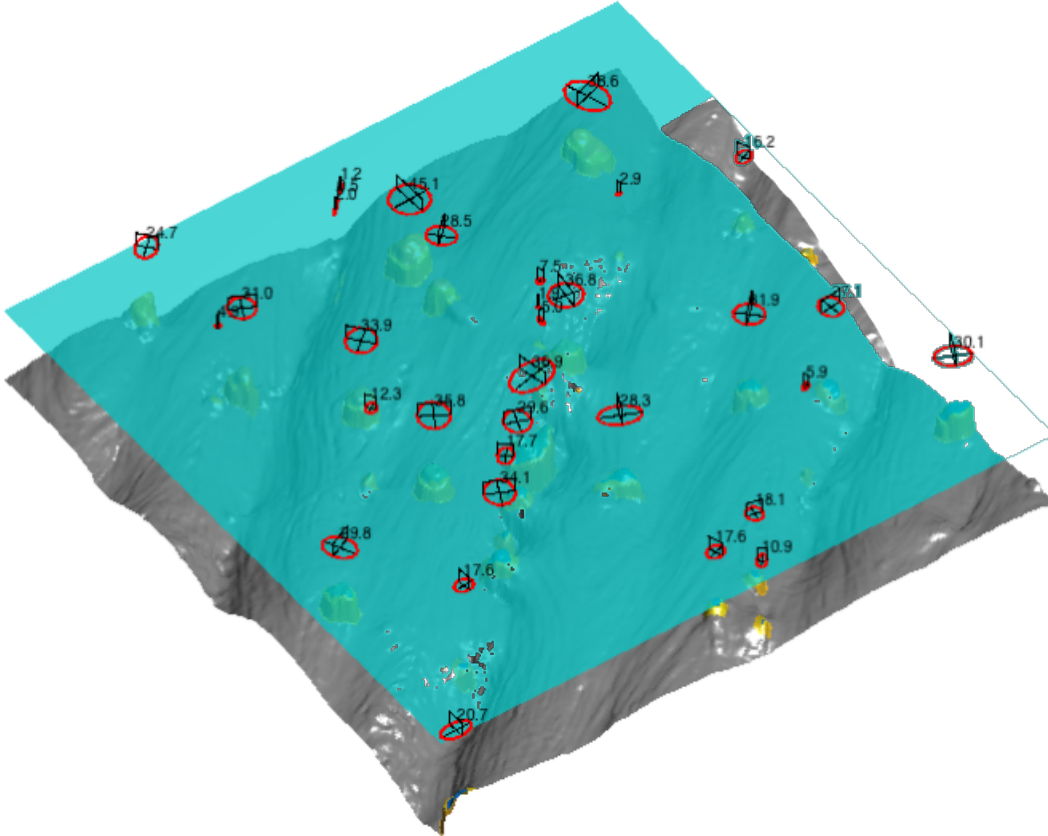
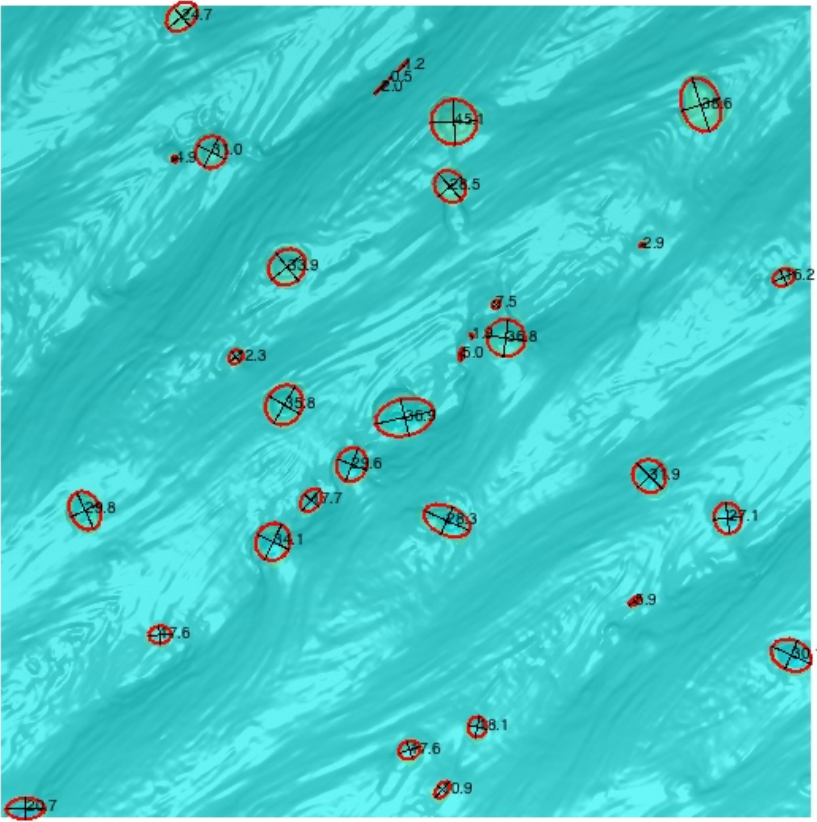
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*N. Senin, R.K. Leach  
ASPE 2016*



# Feature-based characterisation

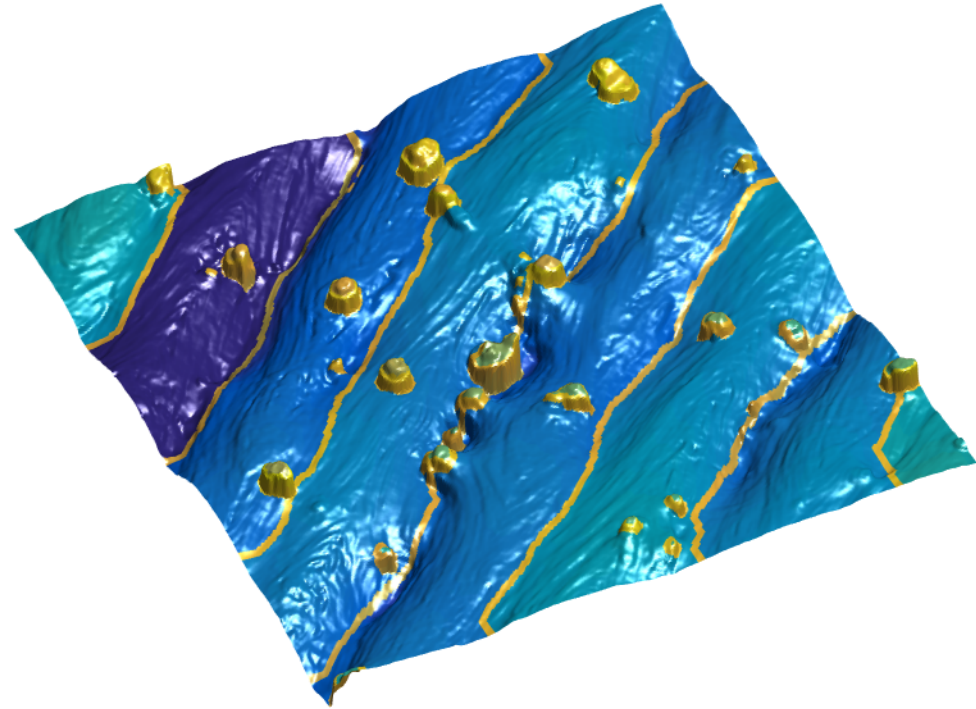
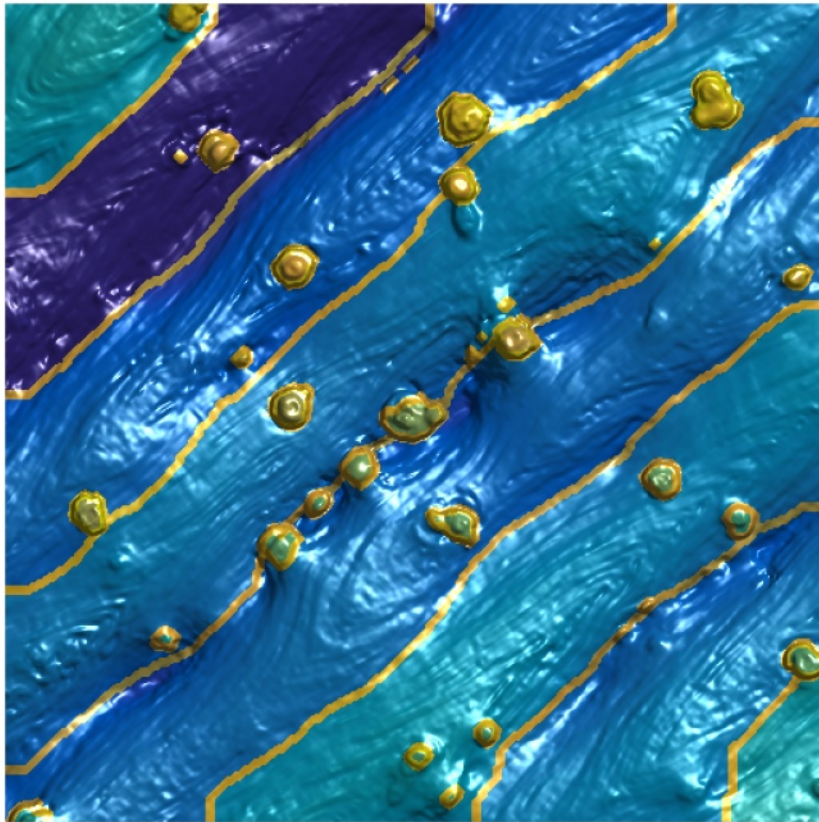


# Feature-based characterisation



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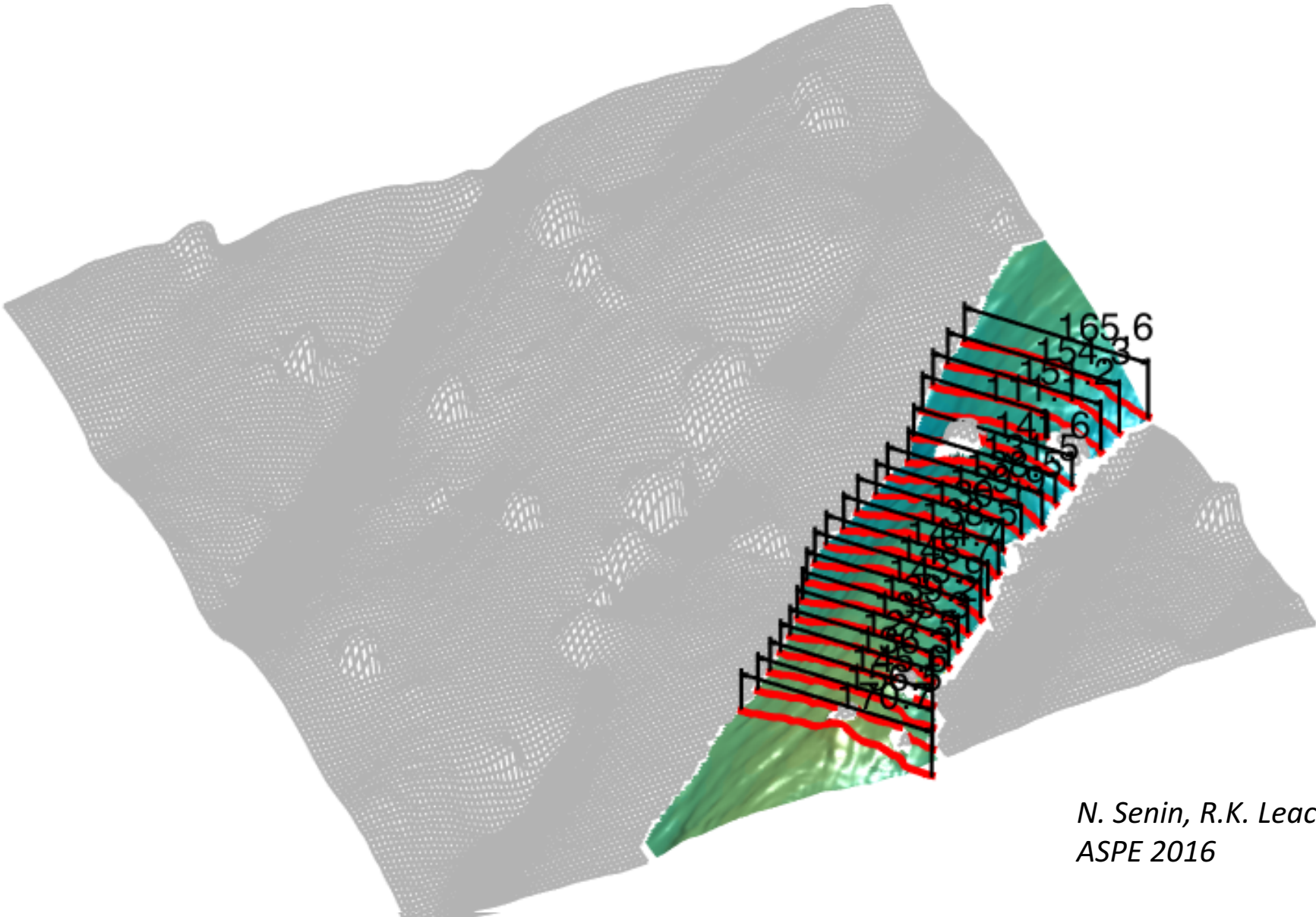
*N. Senin, R.K. Leach  
ASPE 2016*

# Feature-based characterisation



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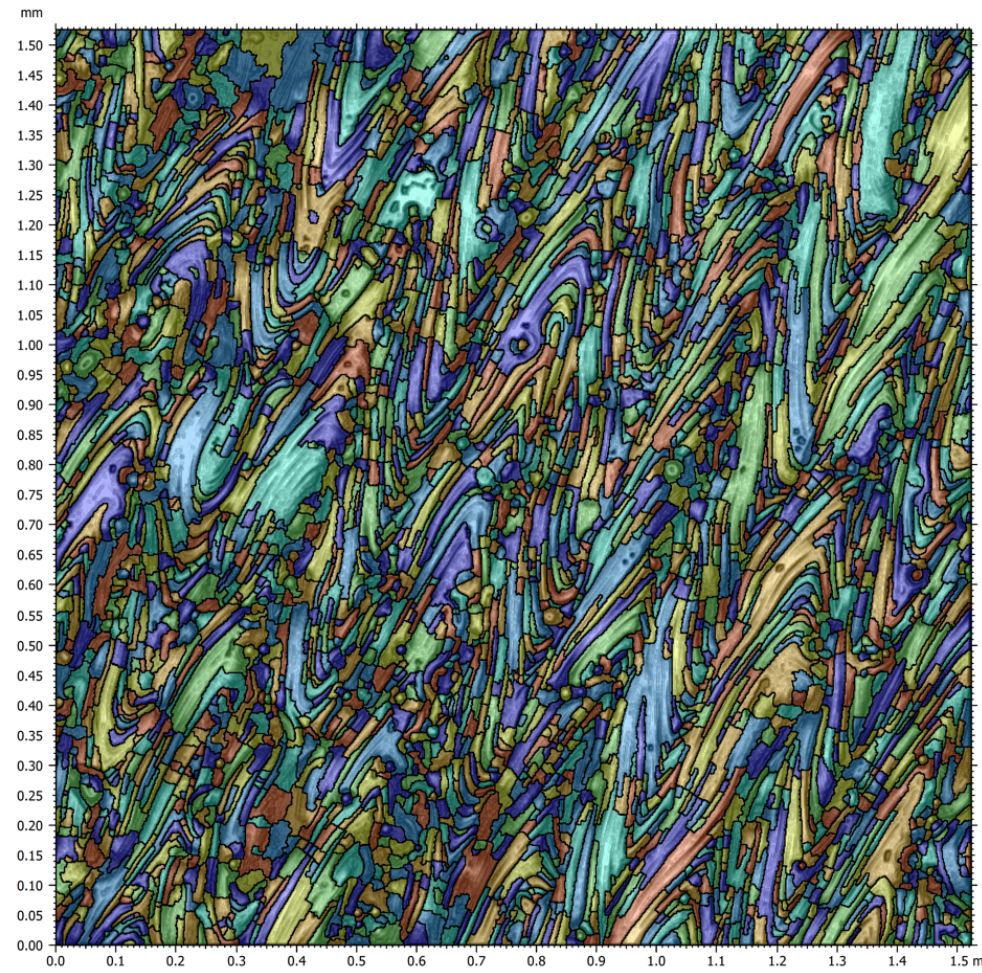
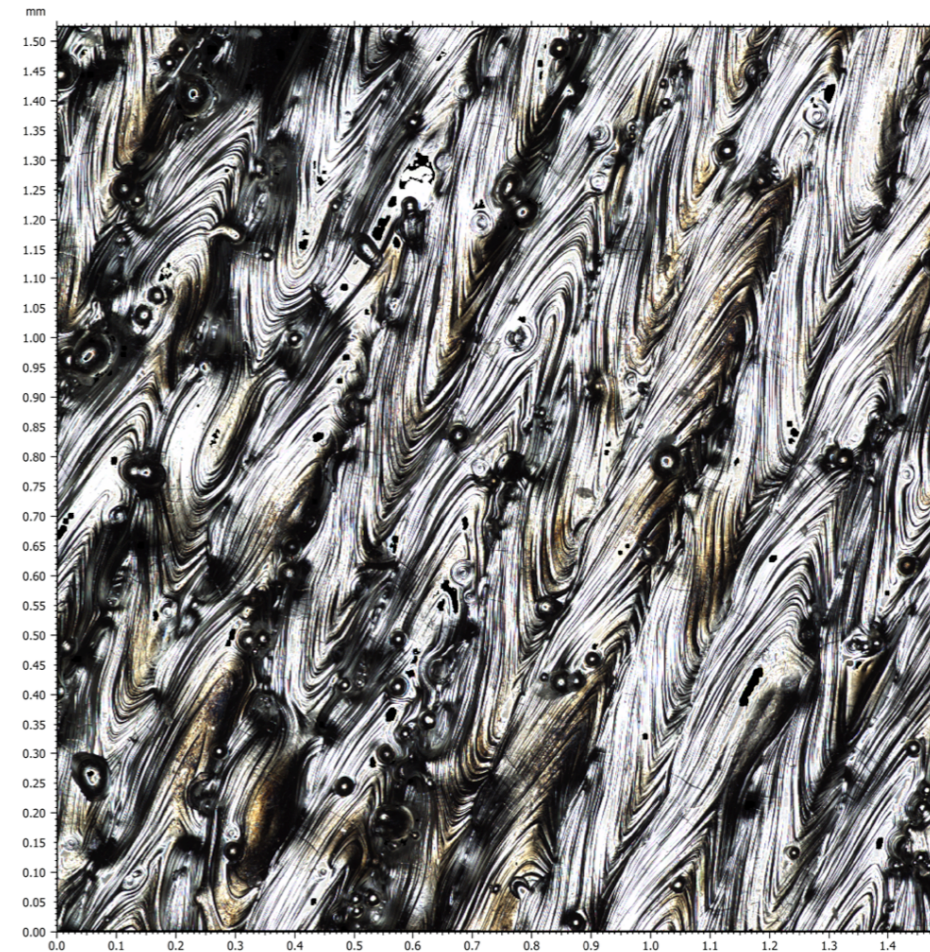
*N. Senin, R.K. Leach  
ASPE 2016*

# Feature-based characterisation



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*N. Senin, R.K. Leach  
ASPE 2016*

# Part IV

## Open challenges

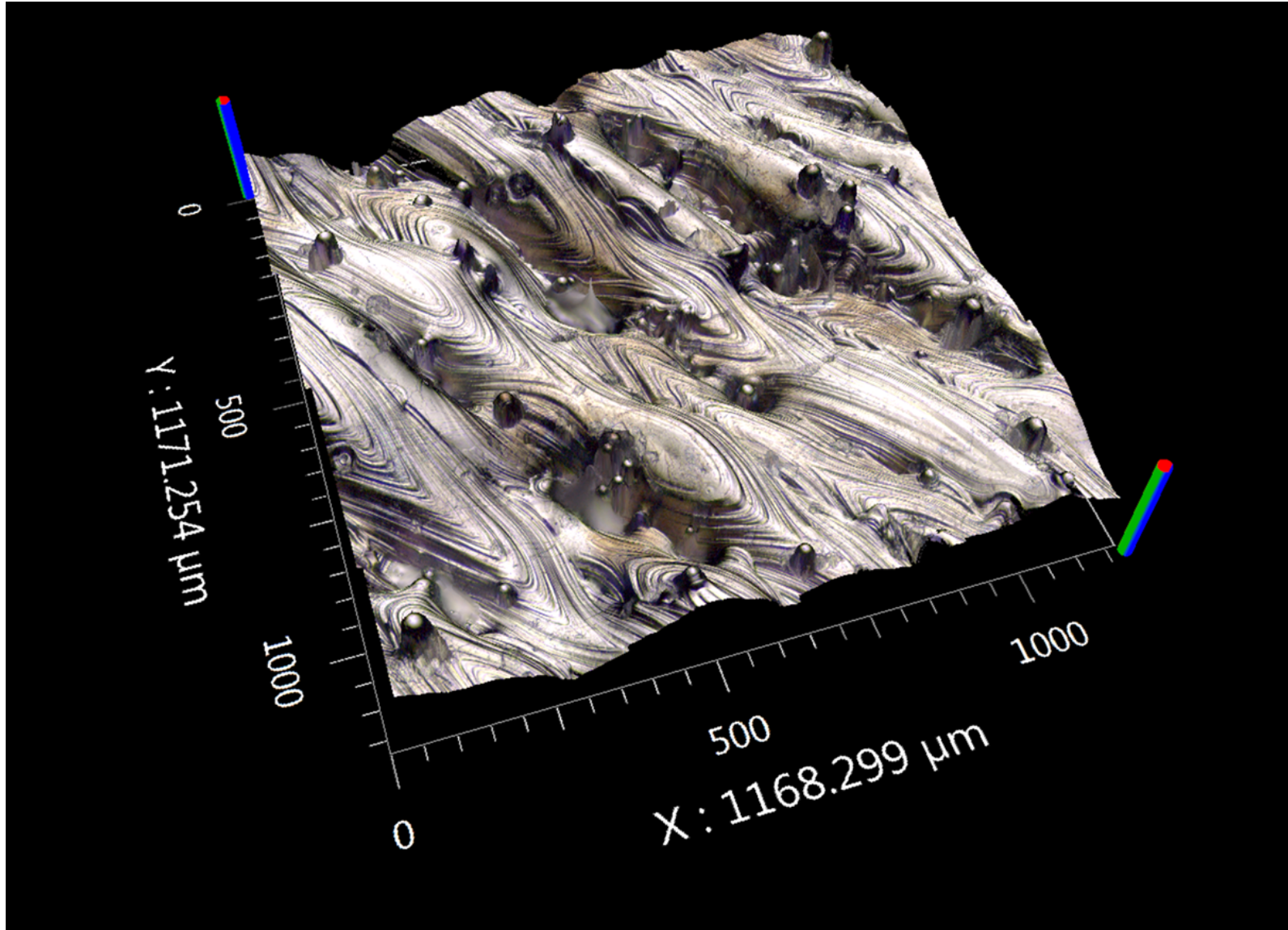
### Quality of acquired topography?

# It does indeed look beautiful...



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# Part IV

## Open challenges

### What's relevant in topography?

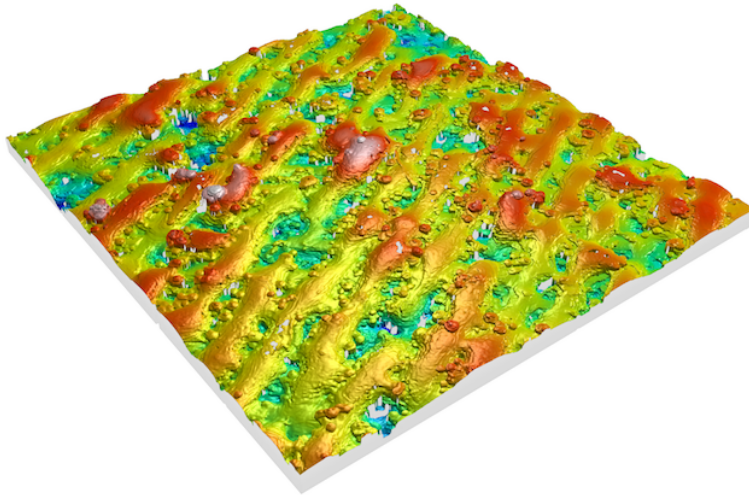
# What is relevant?



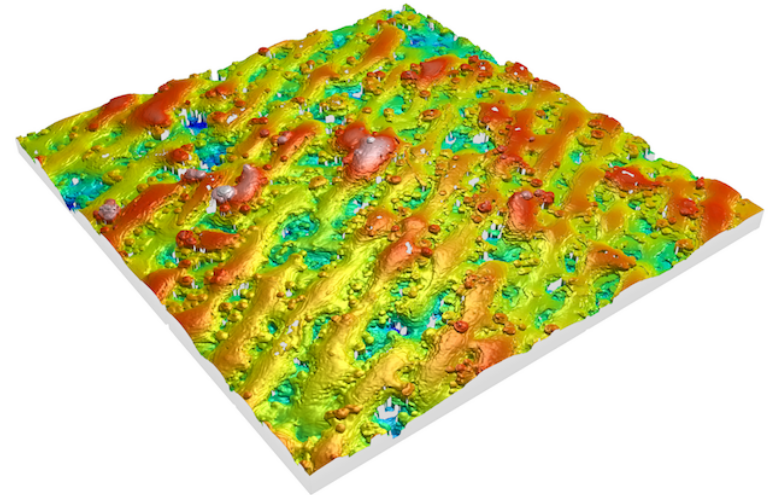
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**Global texture?**  
vs.  
**Local features?**



**What scales?**



Possibly, **no single answer**  
(Viewpoints are context dependent)

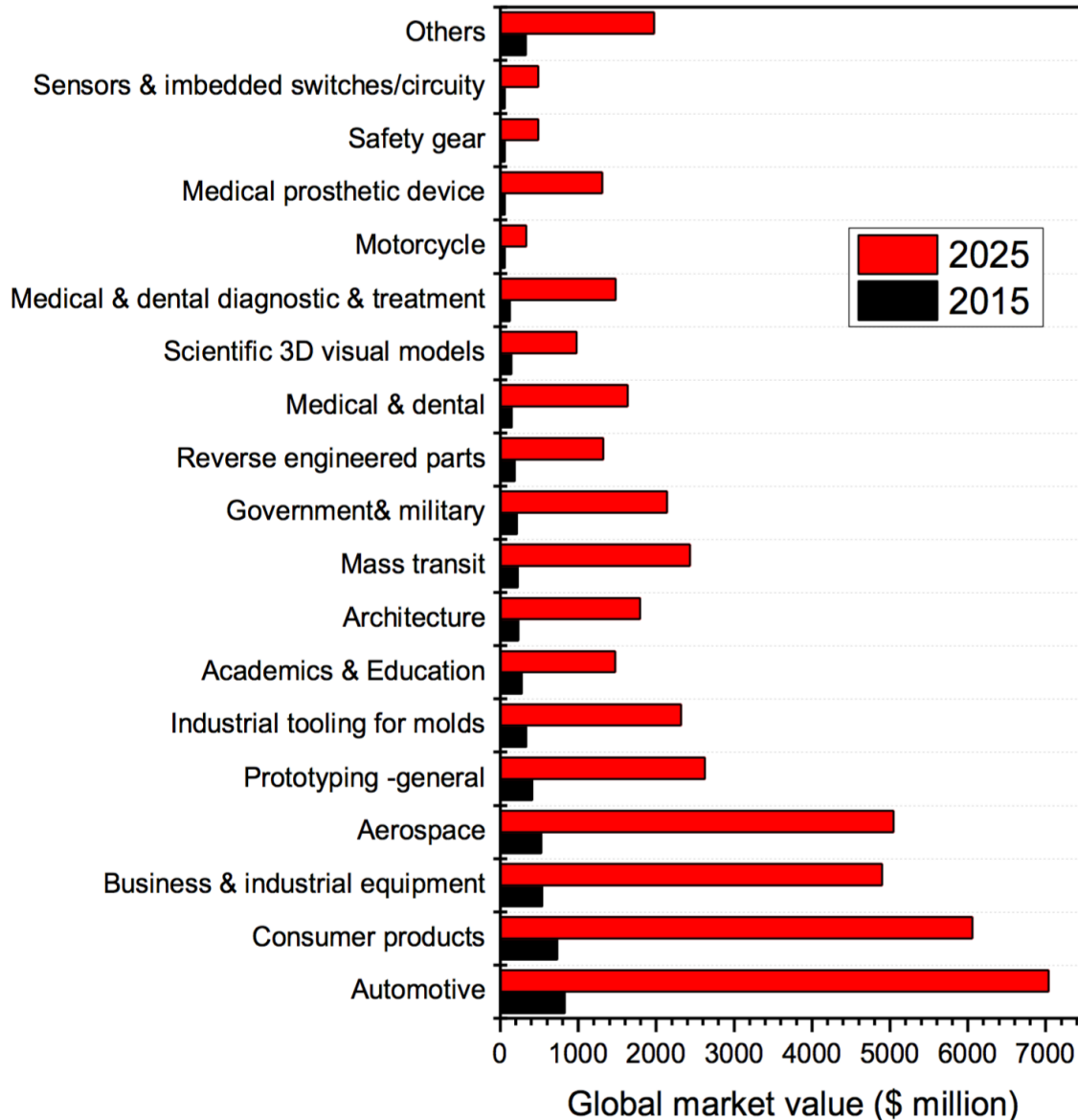


# Part IV

## Open challenges

### New scenarios for surface metrology

# AM markets by application



*The current landscape of AM research -  
2016 ICL AMN report*

# Do we know what to expect?



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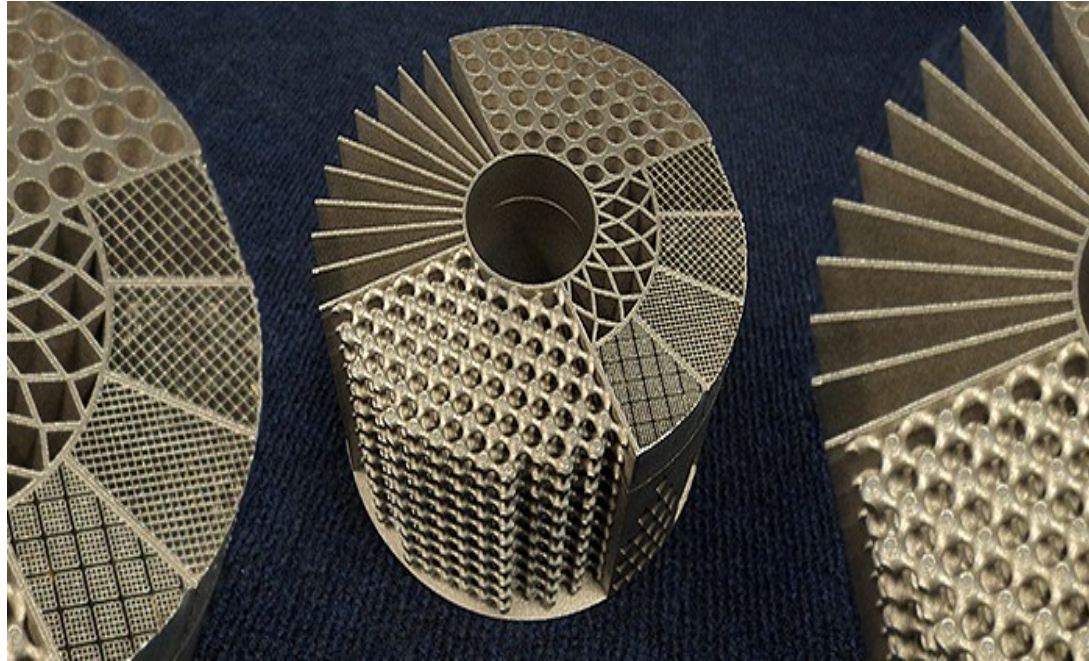
**AM technologies inspire the **creation of new designs****  
**... forcing metrology to deal with **unforeseen challenges****

# Lattice structures

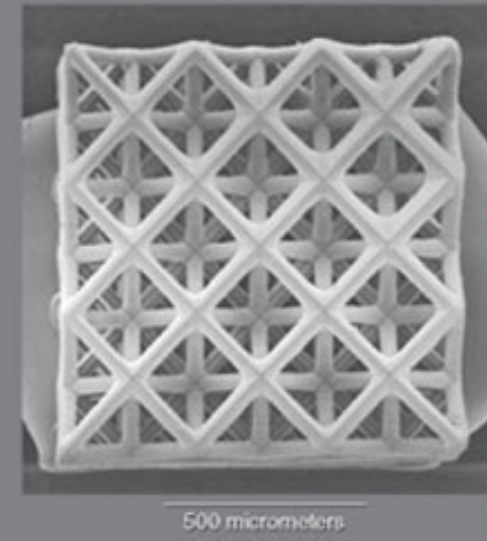
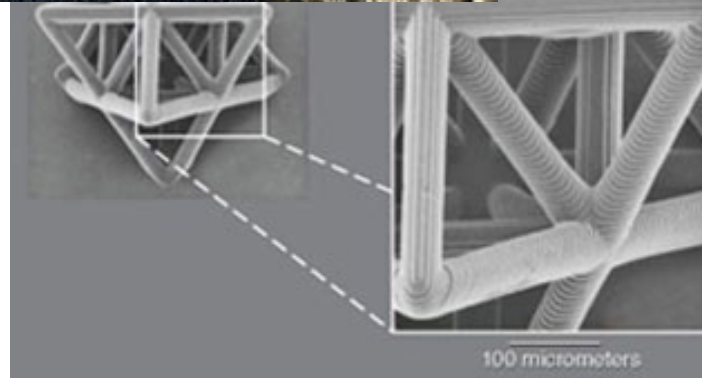


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**Where is the surface?**



# Freedom of form



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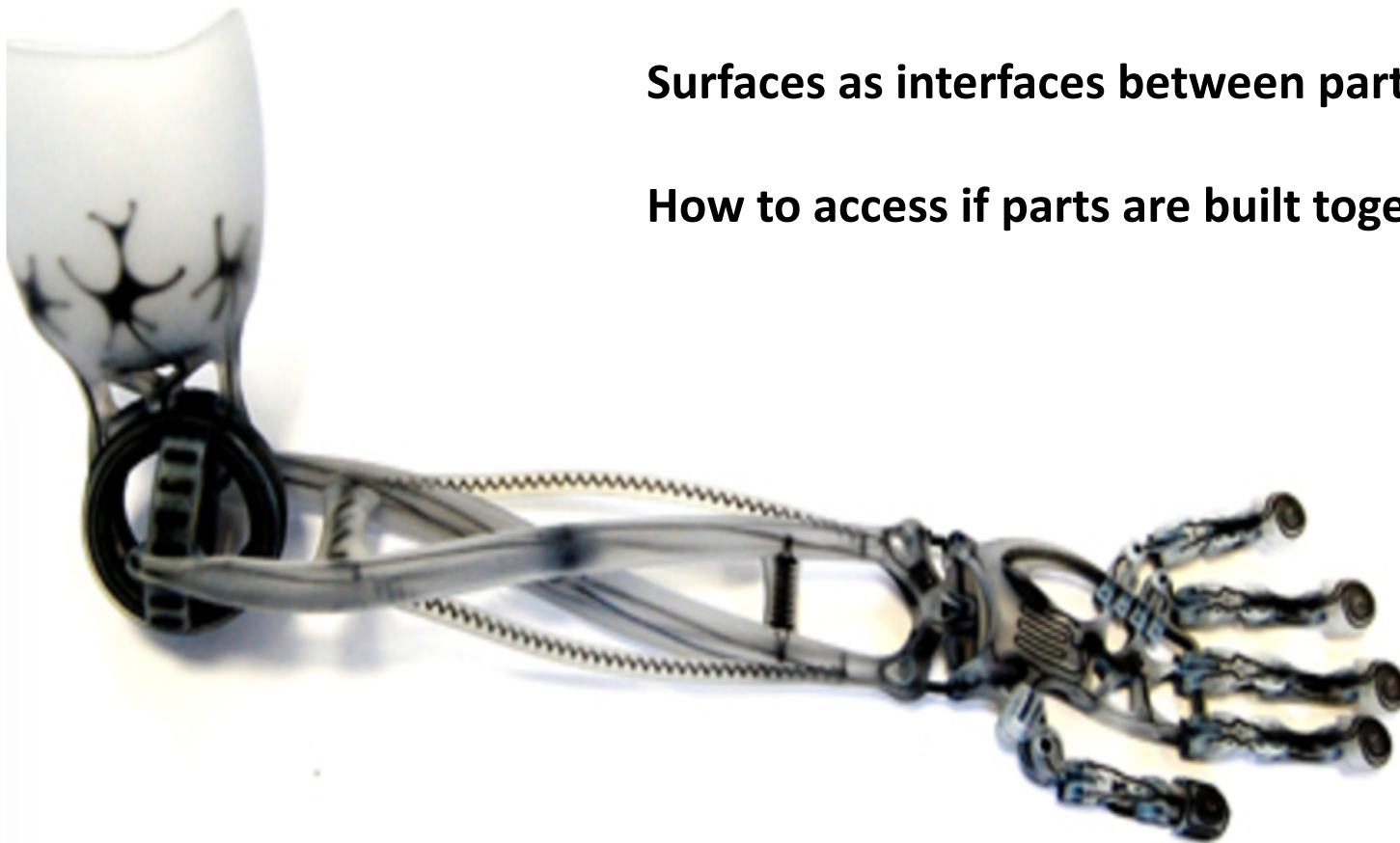
**No tool-access problems**

**Probe-access problems?**



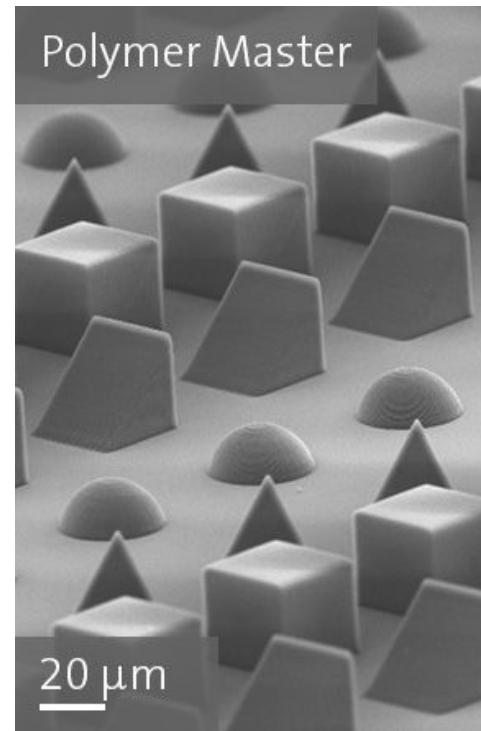
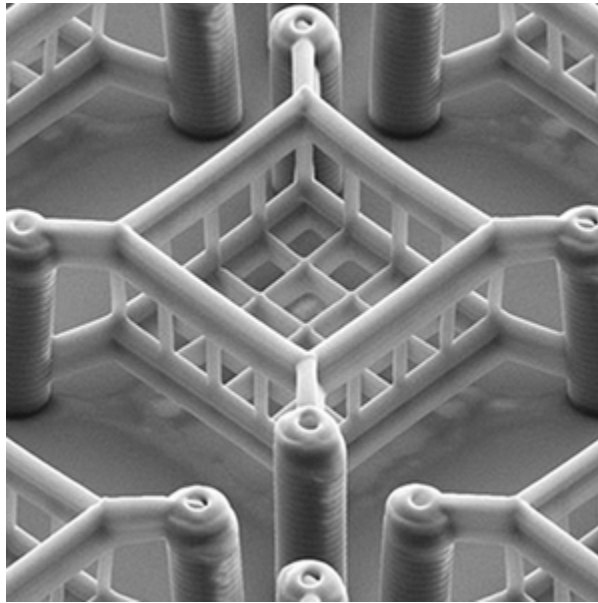
**Surfaces as interfaces between parts**

**How to access if parts are built together?**





# Dimensional micro-metrology



The Manufacturing Metrology Team



# Thank you

Centre for Precision Technologies @ Huddersfield



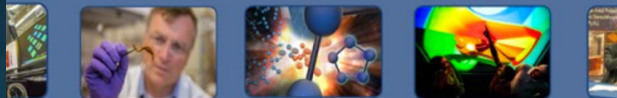
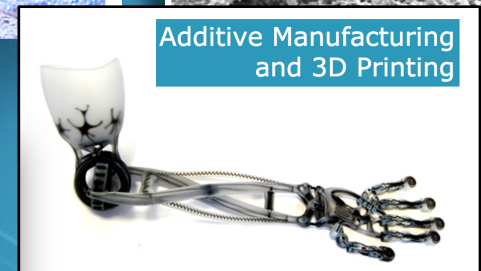
Advanced Manufacturing Technology Research Group



Advanced Materials Research Group



Additive Manufacturing and 3D Printing



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