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Metal Optics Technologies for Earth Observation

Emerging Technology for Earth Observation
19 March 2024

Centre for Advanced Instrumentation
Cyril Bourgenot

The University Of Sheffield. AMRC Advanced Manufacturing Research Centre

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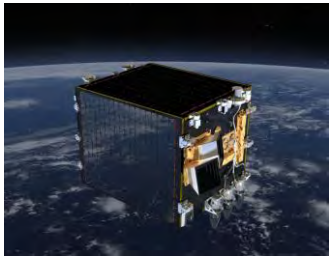
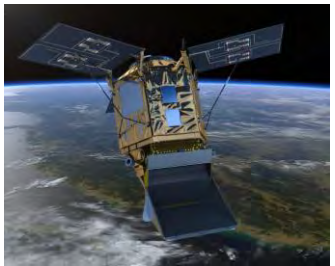
UK SPACE AGENCY

Metal Optics in ‘High End’ Earth Observation Payloads

- TROPOMI (Tropospheric Monitoring Instrument)
- ALTIUS (Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere)
- CHIME (Copernicus Hyperspectral Imaging Mission for the Environment)
- Proba-V (Project for On-Board Autonomy)





Nanosatellites / CubeSat

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Metal Optics Technologies for Space

TRL

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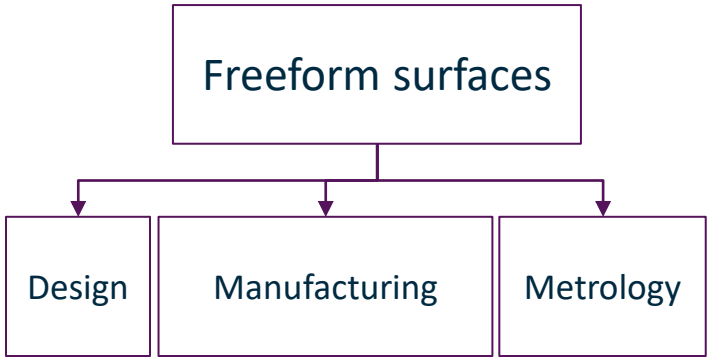

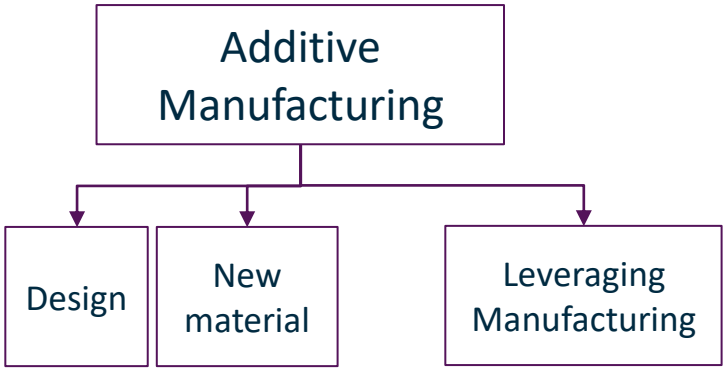

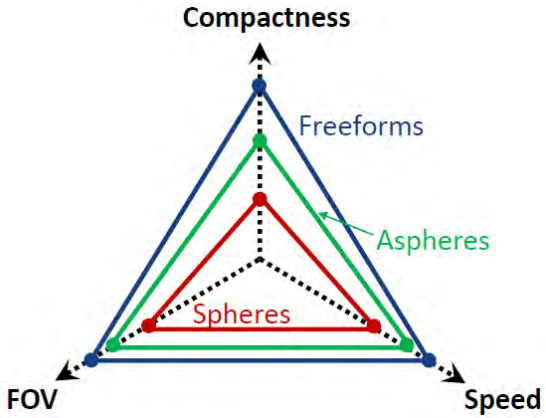

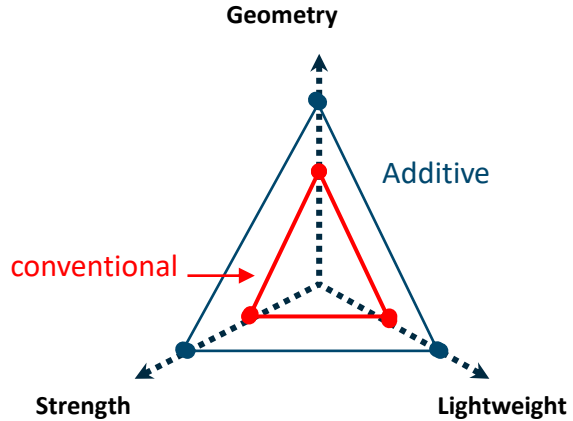

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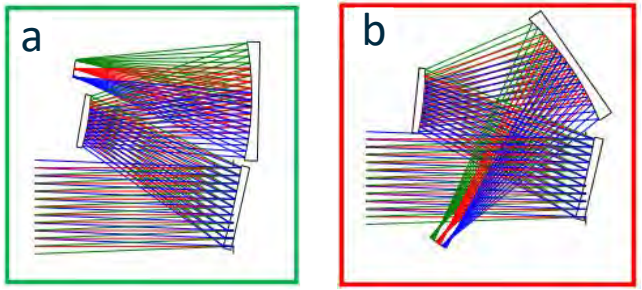
Plan

Advancing Metal Optics for Space Systems
ETP01-040

- Focus on freeform technologies
  - Freeform Design
  - Freeform Manufacturing
  - Freeform Metrology
- Focus on Additive Manufacturing
  - Design & Manufacturing of the telescope housing
  - New material
- Conclusion

Freeform Design



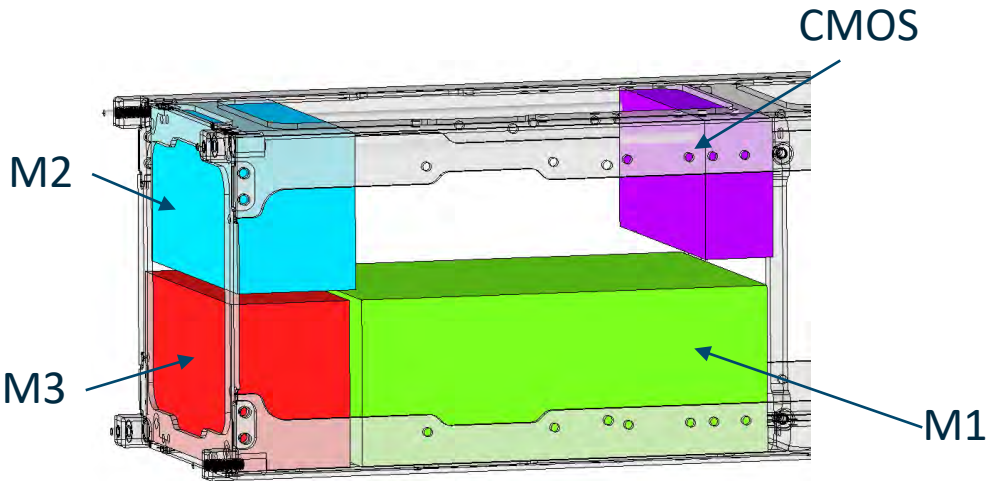
*Bauer, A., Schiesser, E.M. & Rolland, J.P. Starting geometry creation and design method for freeform optics. Nat Commun **9**, 1756 (2018).*

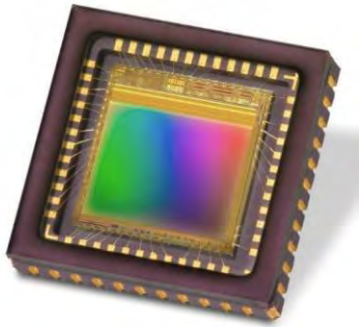
- Various folded configurations for an unobscured three-mirror imager
- Design (a) has the greatest potential to be corrected using freeform surfaces
- Design (b) has a better folding efficiency, and more potential for adding an instrument at the focus.

Optimisation of design (b) to fit into a 3U CubeSat frame maximising the aperture

Freeform Design constraints

- Dimension : fit within 1.5U => allocated space for mirrors
- EFFL : 450mm, so in LEO should give a **GSD of 5m** with 4.5 microns pixel
- F/5 => Unobscured aperture of Φ90mm
- System optical quality : diffraction limited in the visible
- FOV set by e2V 1/1.8’ CMOS sensor format => ~0.9° x 0.7°





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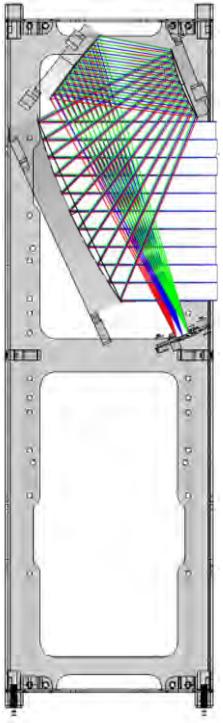
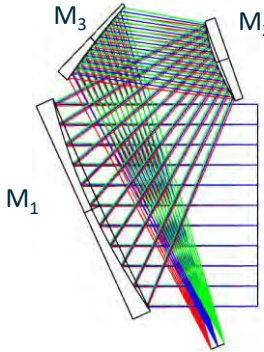
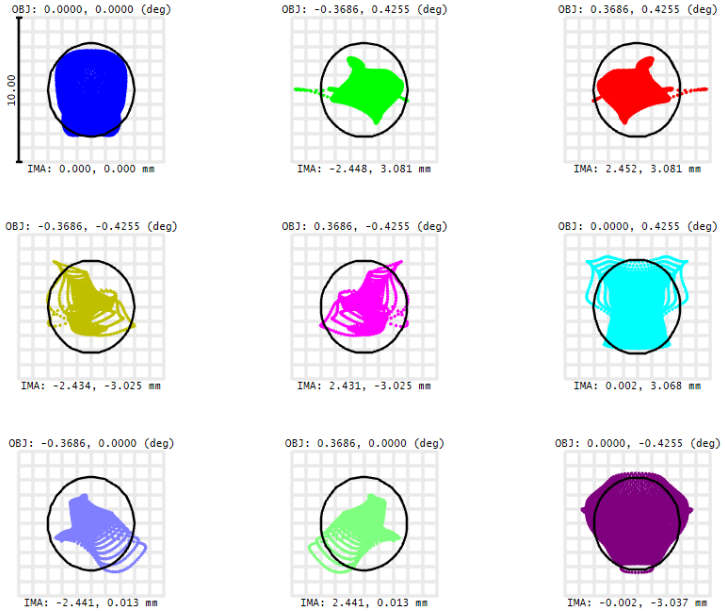
Freeform Design

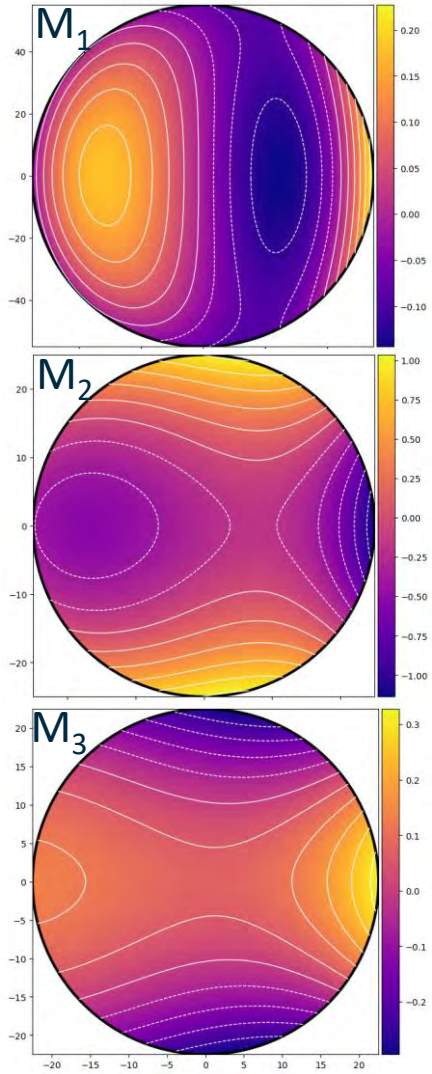




aperture

90mm





- Optimisation based on optics position within a defined volume, with EFFL & Aperture set
- Freeform optimisation on minimising spot radius RMS
- Starting from spherical design then adding relevant Zernike term step by step up to term 60

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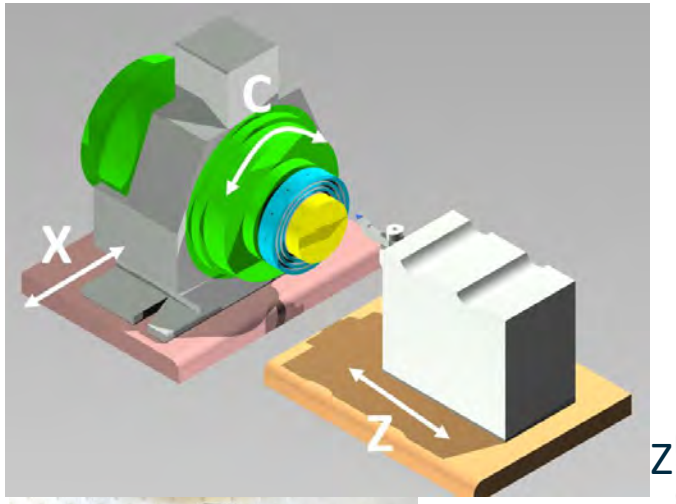
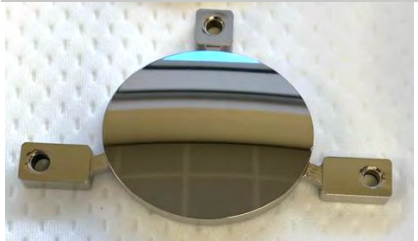
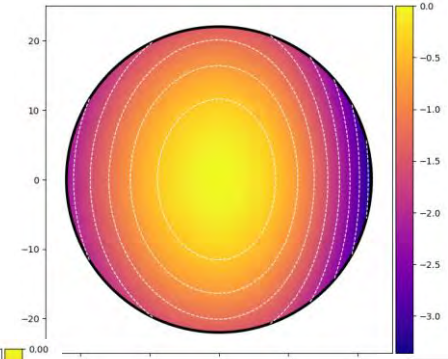
Freeform Manufacturing

- 3 axis machining + a Fast Tool servo
- Sag of the surface is more that the FTS stroke
- AlSi40 + NiP mirrors

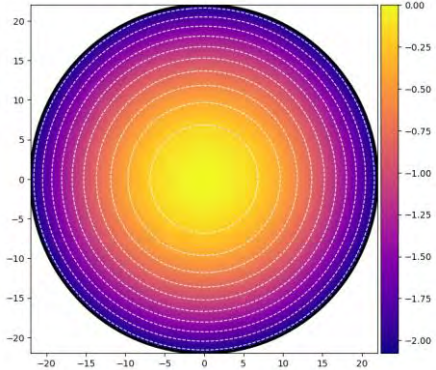




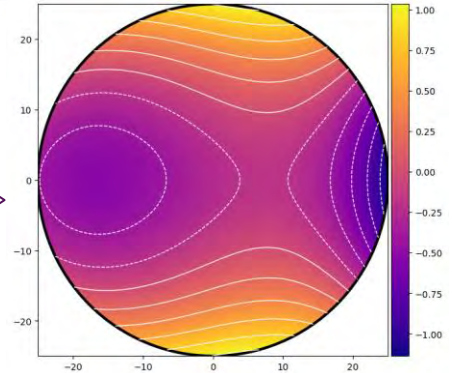


M2
freeform

Z axis



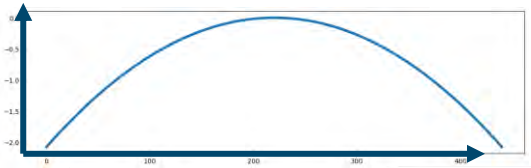
FTS Z axis



Rotationally symmetrical component

Freeform component

Z



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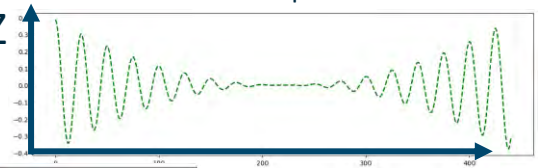
FTS Z



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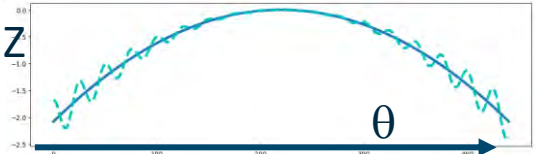
Z +FTS Z



θ

Freeform Manufacturing - SPDT

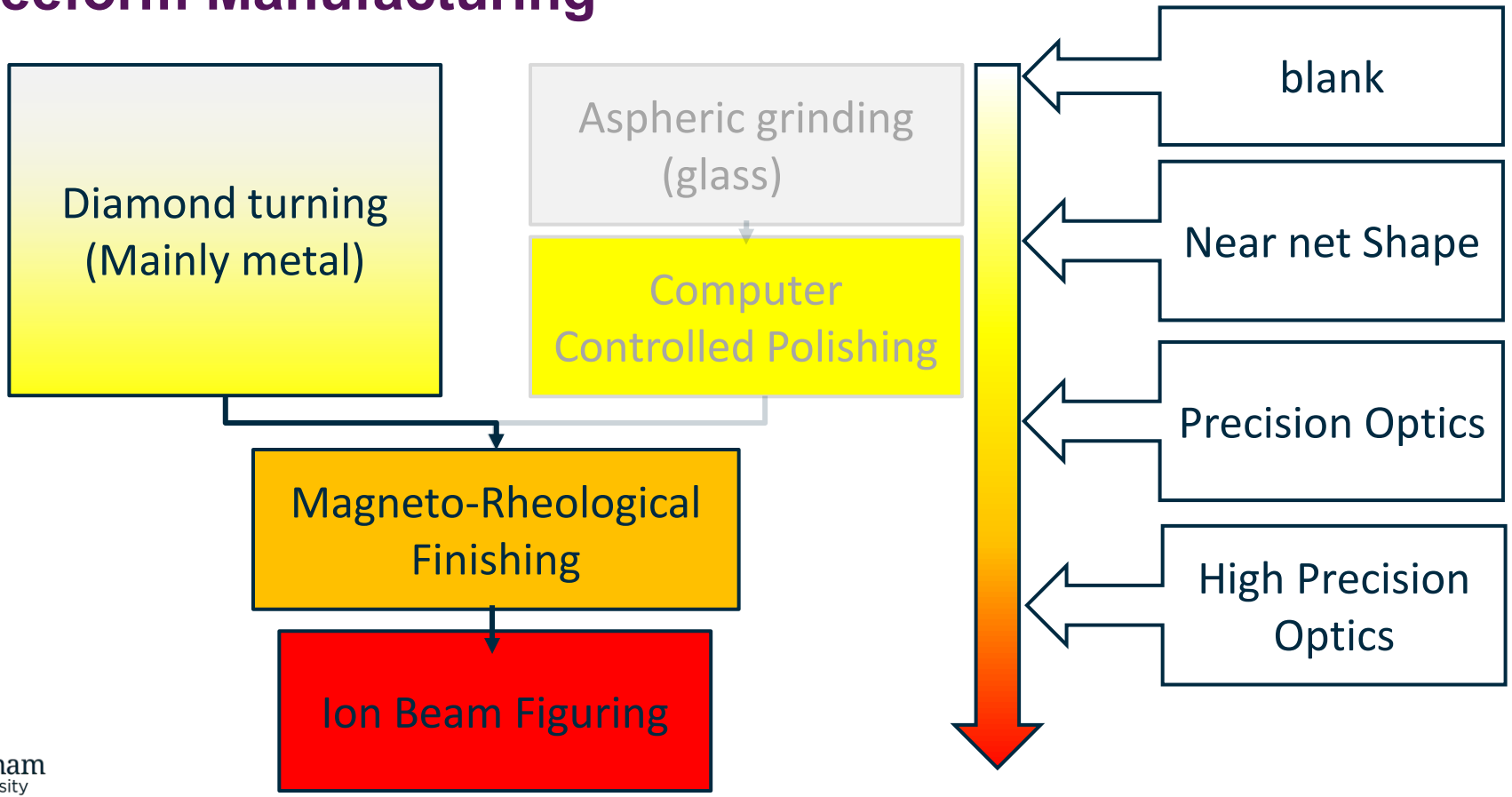
Fast tool servo machining

- piezo electric head added to the machine as an axis
- Stroke of +/- 3mm
- High bandwidth synchronised with spindle at 200RPM

Tool path programming :

- Custom tool path
- FTS reduces the machining time by more than a factor 2 – (2 hours finishing)
- Less form error because of less axis inertia

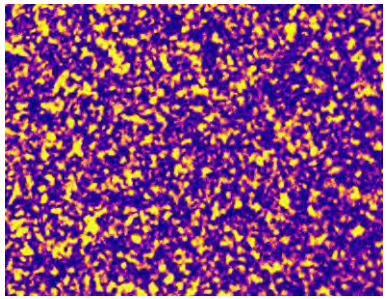
Freeform Manufacturing



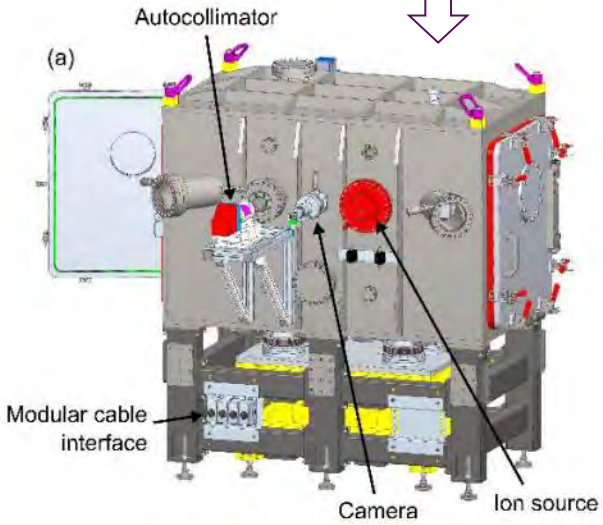
Freeform Manufacturing – X-ray technologies

The Optics and Metrology group at DLS is involved in research and development in the field of X-ray optics.

- Beamline optics manufacturing : Ion Beam Figuring (IBF)
- Optical Metrology of x-ray optics : Speckle Angular Measurement (SAM)



Nano-precision metrology of X-ray mirrors with laser speckle angular measurement
doi: 10.1038/s41377-021-00632-4



Ion Beam Figuring and Optical Metrology System for Synchrotron X-ray Optics
doi: 10.1117/12.2528463

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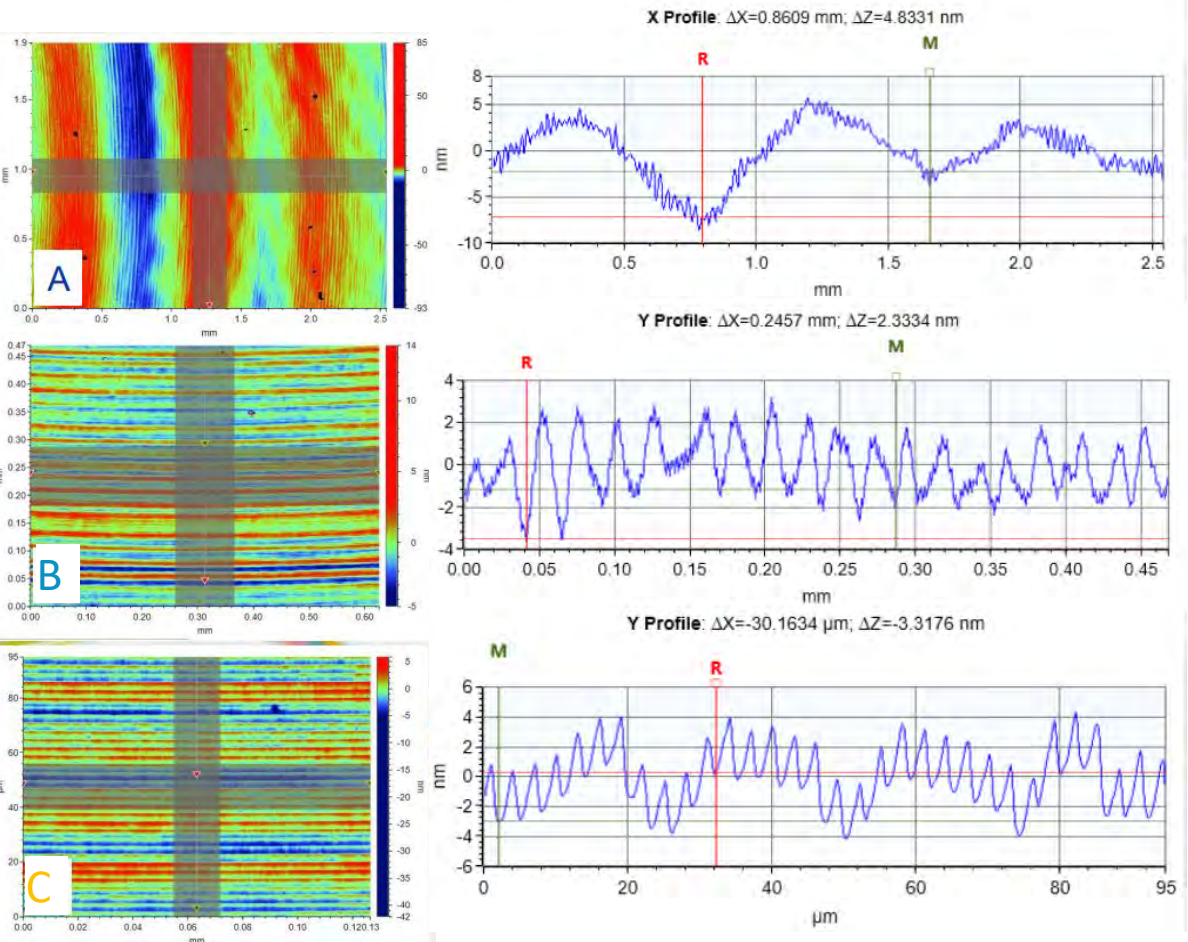
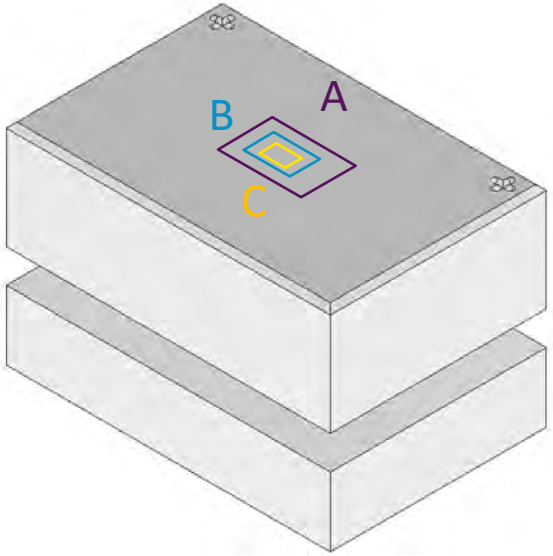
Roughness measurement





Spatial periods:

A: 0.5 – 0.8 mm

B: 25 um

C: 3 um

Peak to valley:

A: 5 - 11 nm

B: 4 - 8 nm

C: 3 - 4 nm

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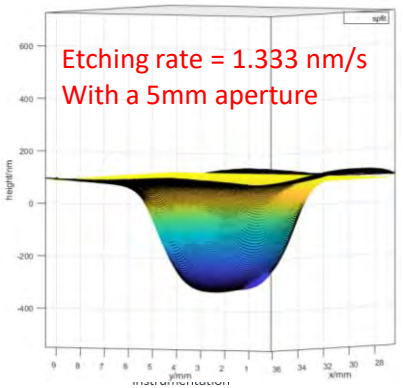
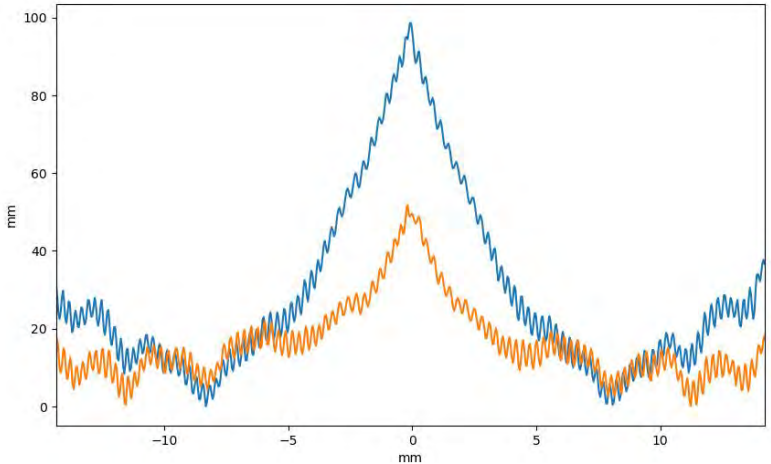
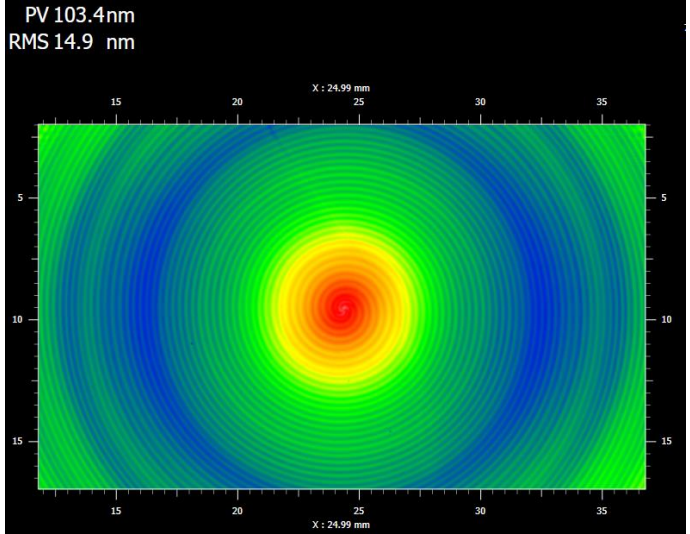
Freeform Manufacturing - IBF

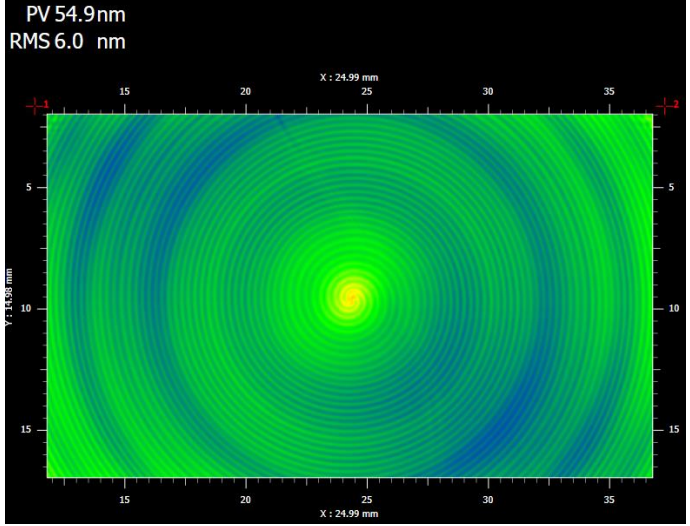
- IBF is a contactless process.
- A small beam of positive charged Argon ions, is targeted at the substrate surface.
- excellent stability of the removal rate.
- no sub-surface damages on the substrate.
- high precision down to single nanometres.

Beam removal function (BRF):



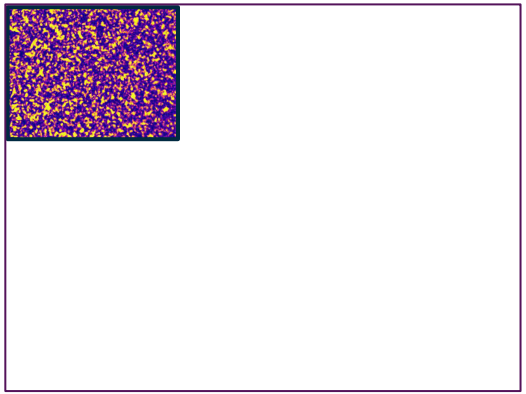




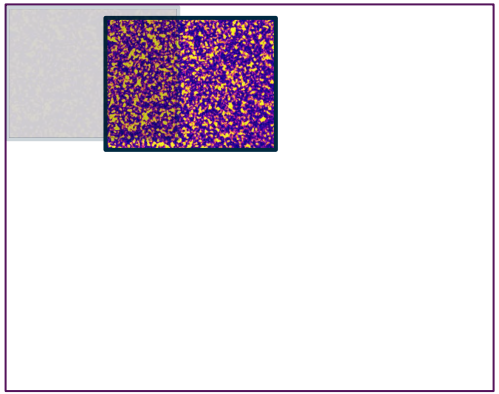


Freeform Metrology - SAM

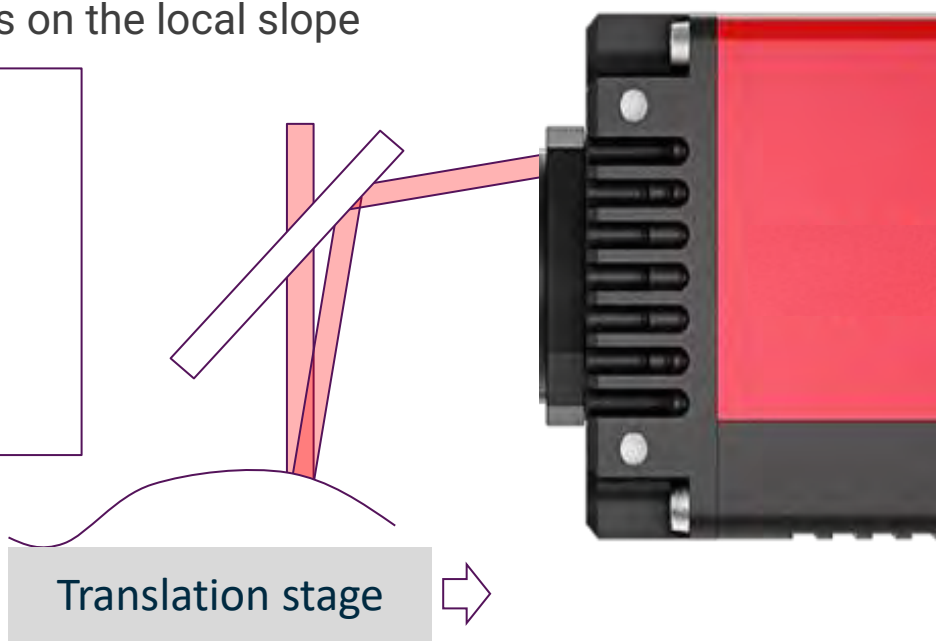
- The Speckle Angular Measurement is a slope measurement method similar to a Shark-Hartmann WFS
- SAM uses a speckle pattern reflected on a surface under test and directed onto a camera. The deflection of the speckle informs on the local slope



instructed



Measured



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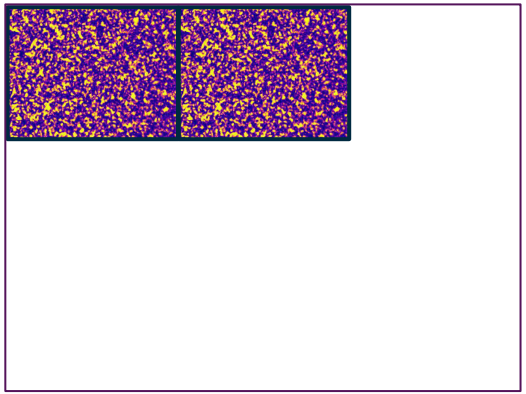

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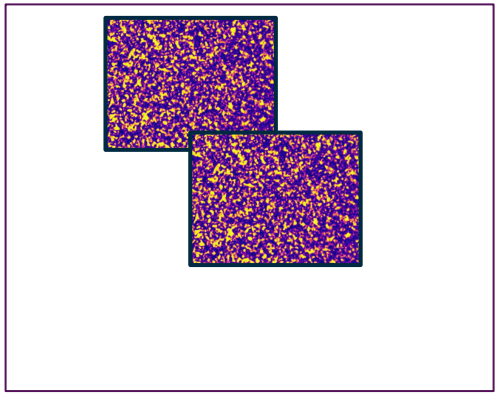
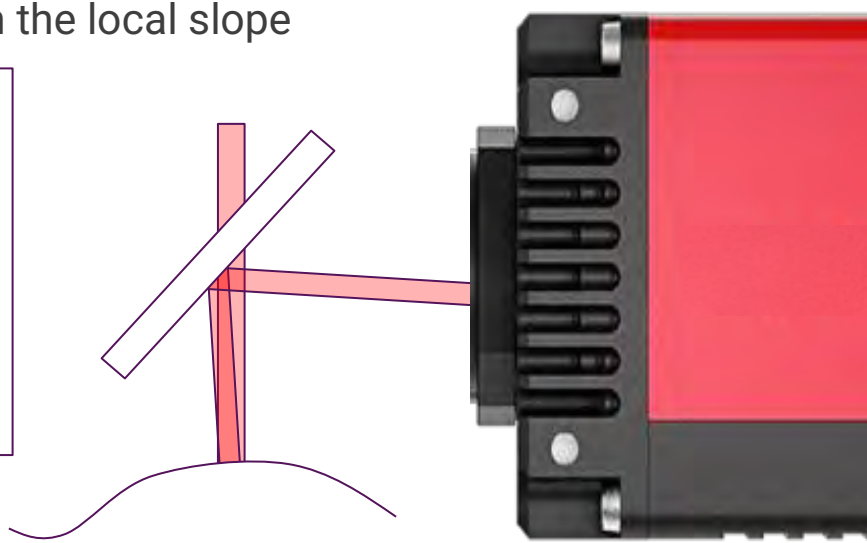


Measured



Translation stage

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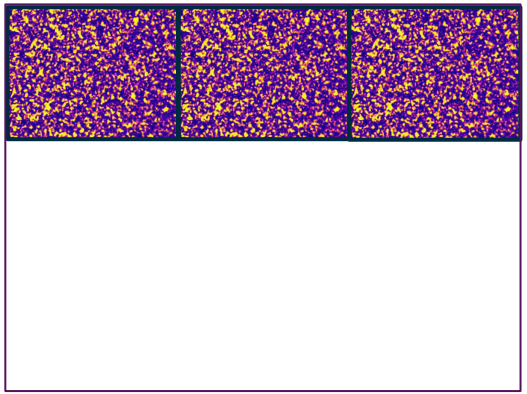

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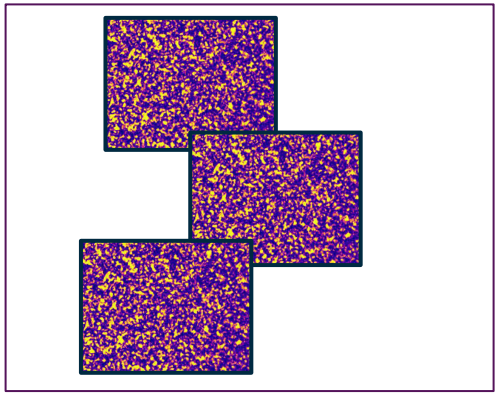
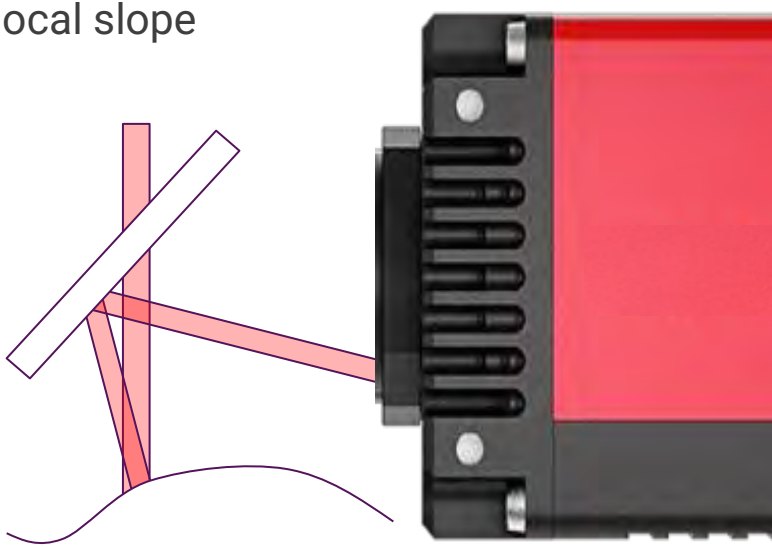


Measured



Translation stage

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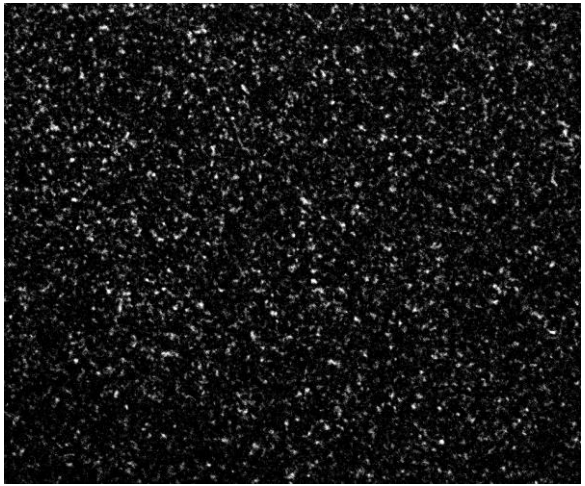
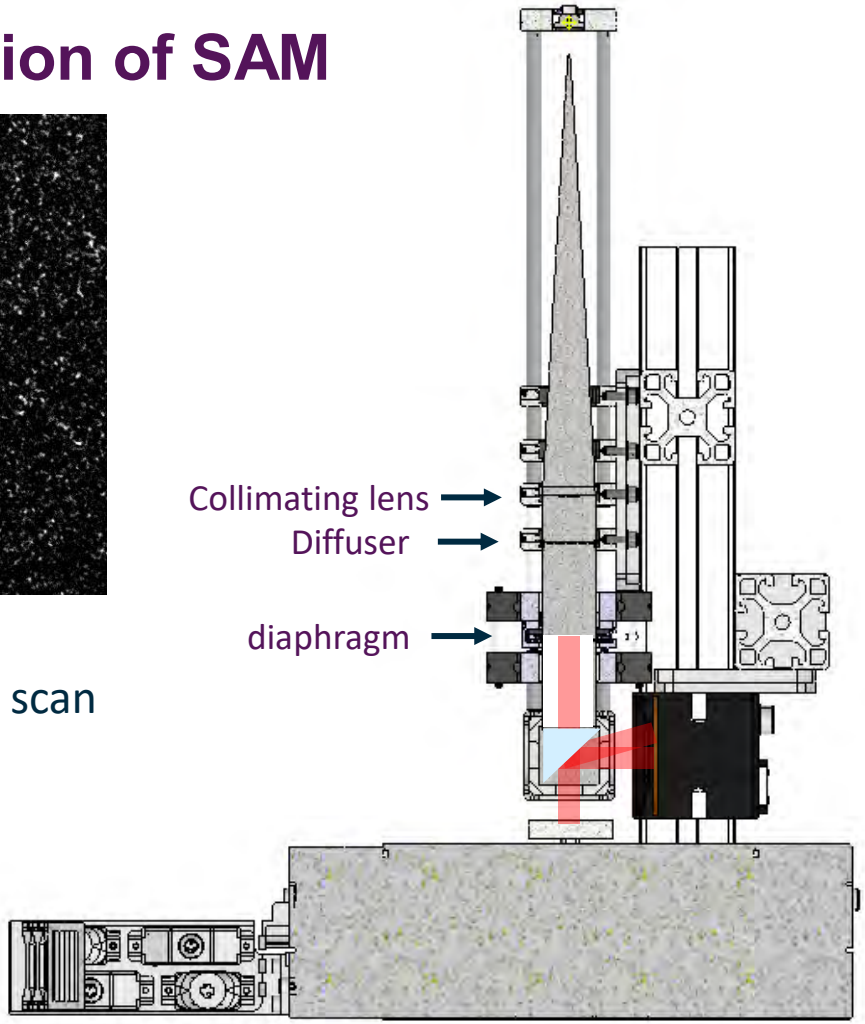
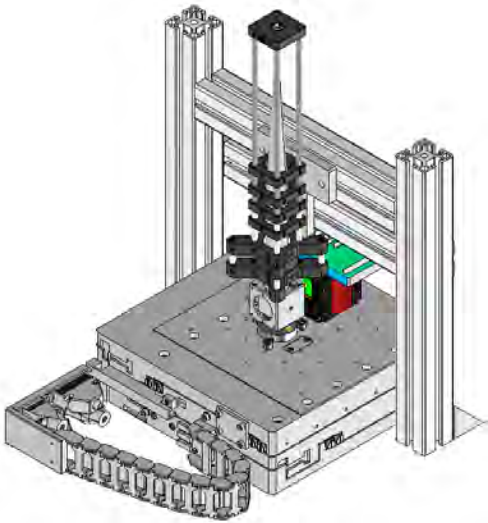
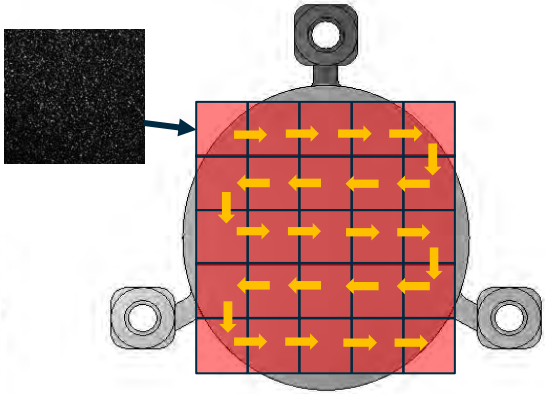
Implementation of SAM



Speckle variation during scan







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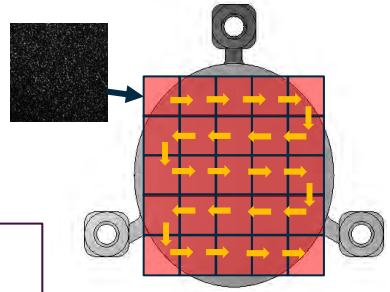
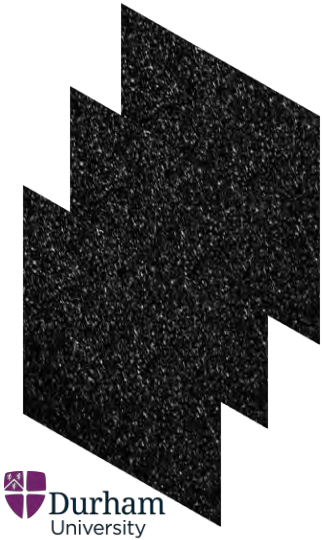
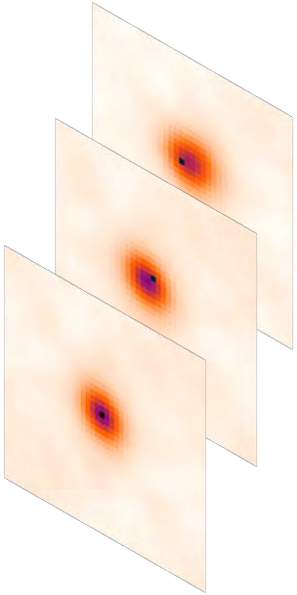
SAM Algorithm

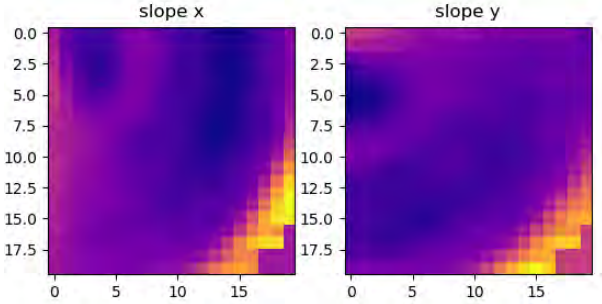


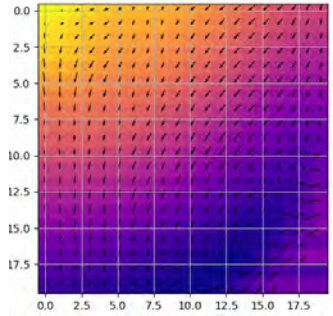
Sequence of speckle images → Sequence of cross correlation → Slopes → Integration





Slope x	Slope y
0	0
3.2 pixels	-4.3 pixels
5.1 pixels	5.1 pixels
9.7 pixels	-6.2 pixels
-8.6 pixels	-2.7 pixels
...	
3.3 pixels	-2.2 pixels





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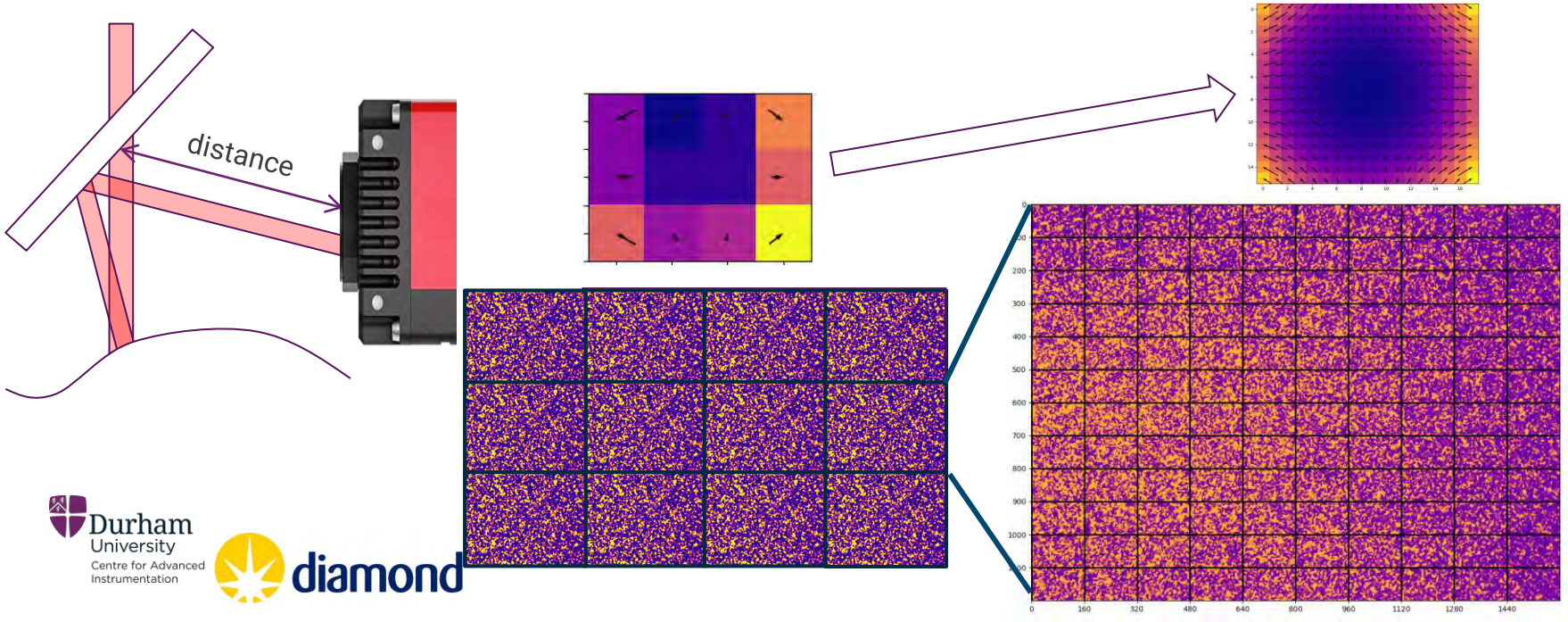
Freeform Metrology - SAM

- Analysis of the speckle spots motion for finer spatial resolution
- Compromise between sensitivity (longer distances) and camera size.
- developing a Python model to test the reconstruction (work in progress)



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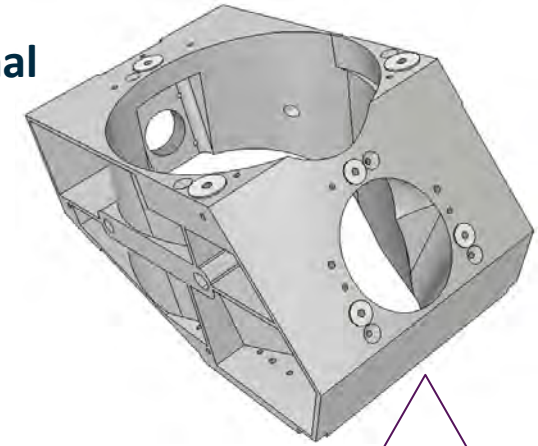
Additive Manufacturing - Design

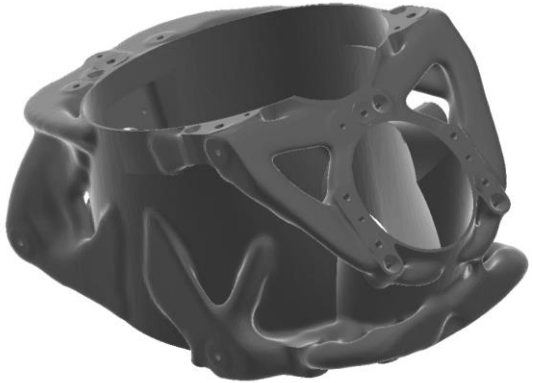
Additive Manufacturing

Design | **New material AlSi40** | Leveraging Manufacturing

Conventional design

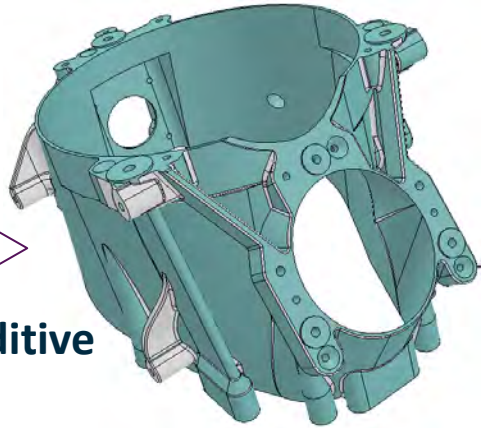


	mass (g)	First Mode frequency (Hz)	Von Mises Stress [N/mm²]
CM	379	1344Hz	2.3 (149)
DFAM	182	1023Hz	3.2 (149)



Generative design

Design for Additive Manufacturing



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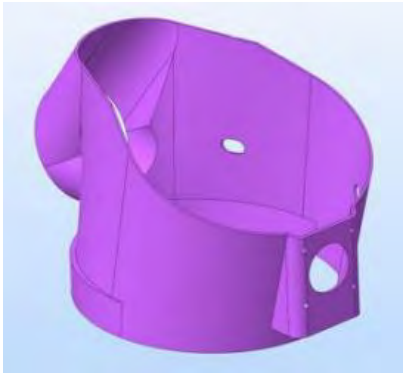
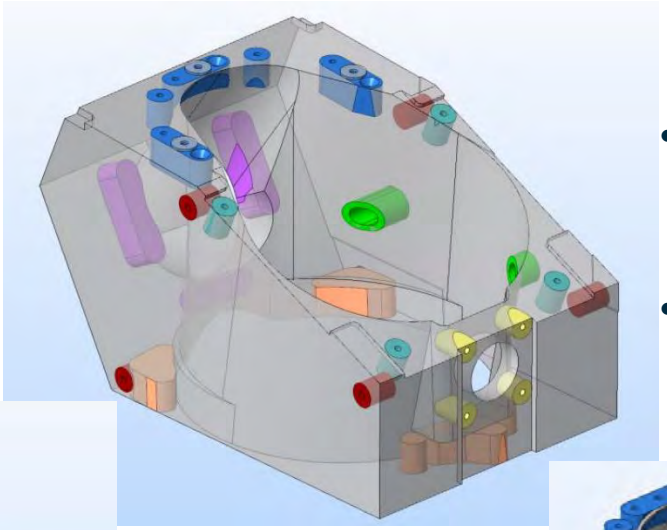
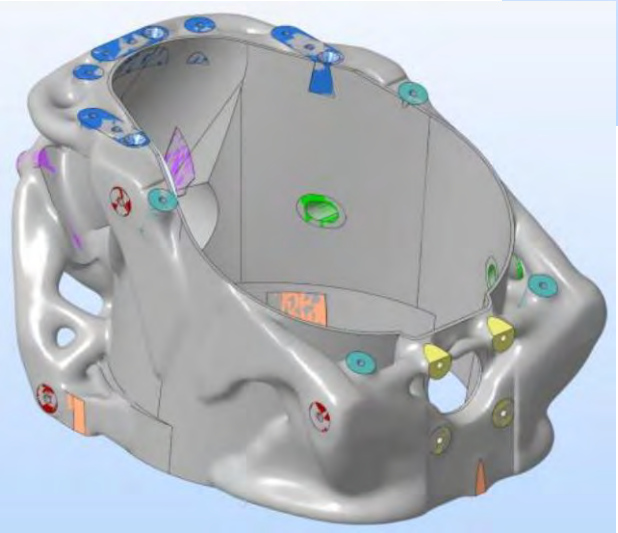
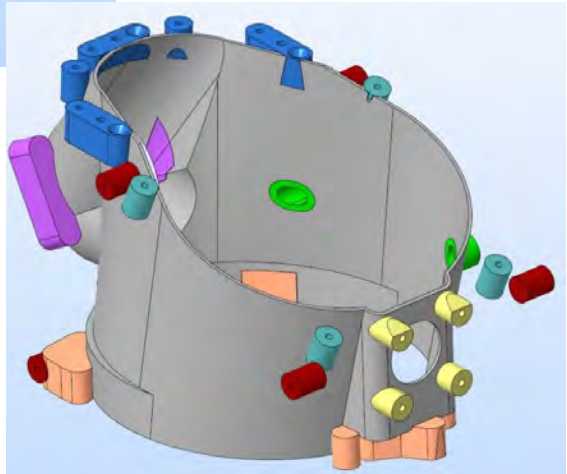
Additive Manufacturing - Design





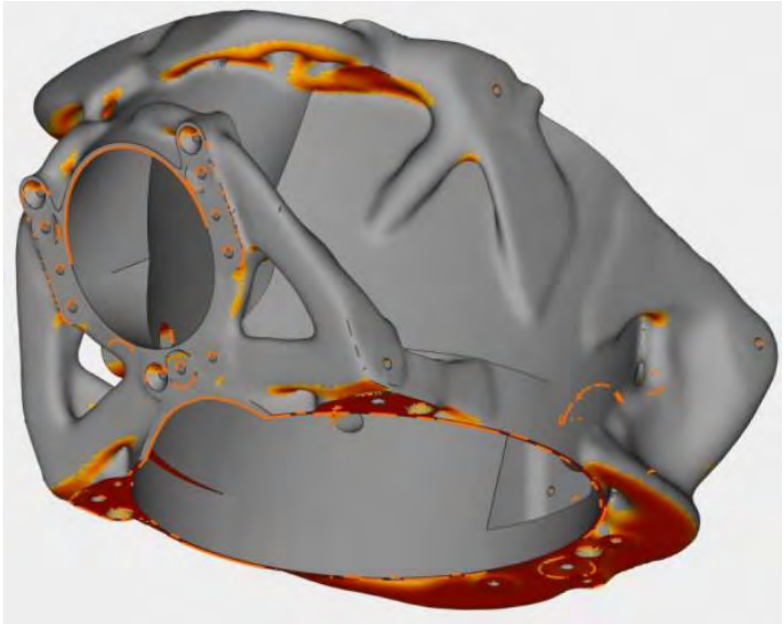


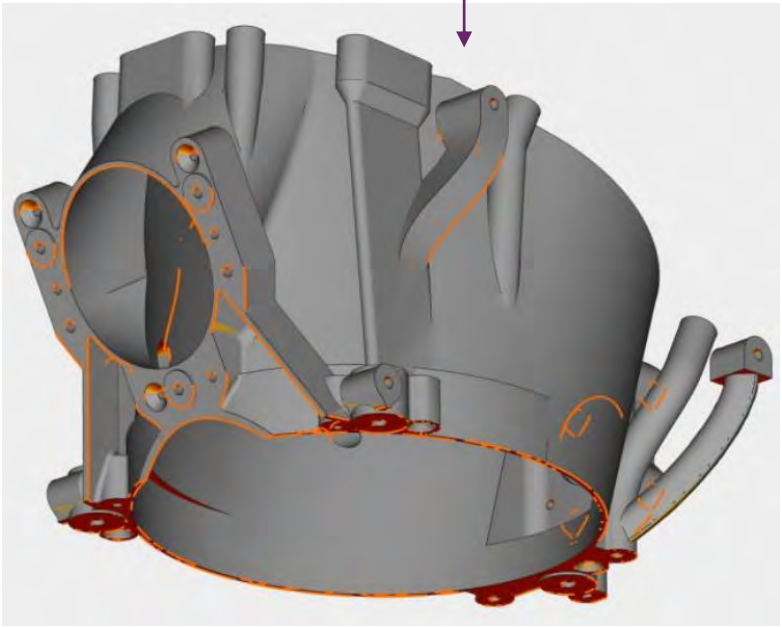


- **Non-design space** elements were separated from this geometry
- Thin internal skin as non-design space to clear the beam path
- One solution was topology optimised and the other was an informed design

Additive Manufacturing - Design

- The Generative design was done using Creo Parametric software
- critical 45° self-supporting angle for aluminium





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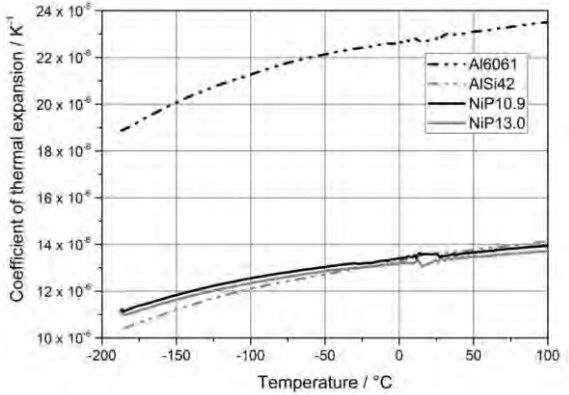
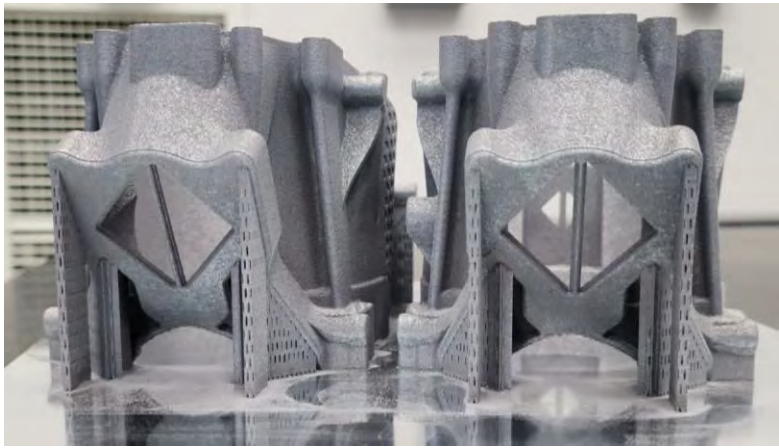
Additive Manufacturing

- Printed so far in AlSi10 with good results
- Currently being printed in AlSi40
- Delayed due to the elliptical shape of the particles affecting the flowability of the material in the AM machine.
- Previous reported work at Fraunhofer IOF





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https://doi.org/10.1117/12.2056271
https://doi.org/10.1117/12.2690312

Conclusion

- Design of a compact 3 freeform mirrors telescope suitable for Earth Observation - 1.5U
- Freeform manufacturing in AlSi40 + NiP
- Manufacturing by Fast Tool Servo
- Optimisation of IBF on representative samples
- Development/adaptation/assessment of SAM for freeform mirrors
- Design of the telescope housing compatible for Additive Manufacturing
- 3D printing of the housing in AlSi40
- Project to be fully tested and completed in October 2024

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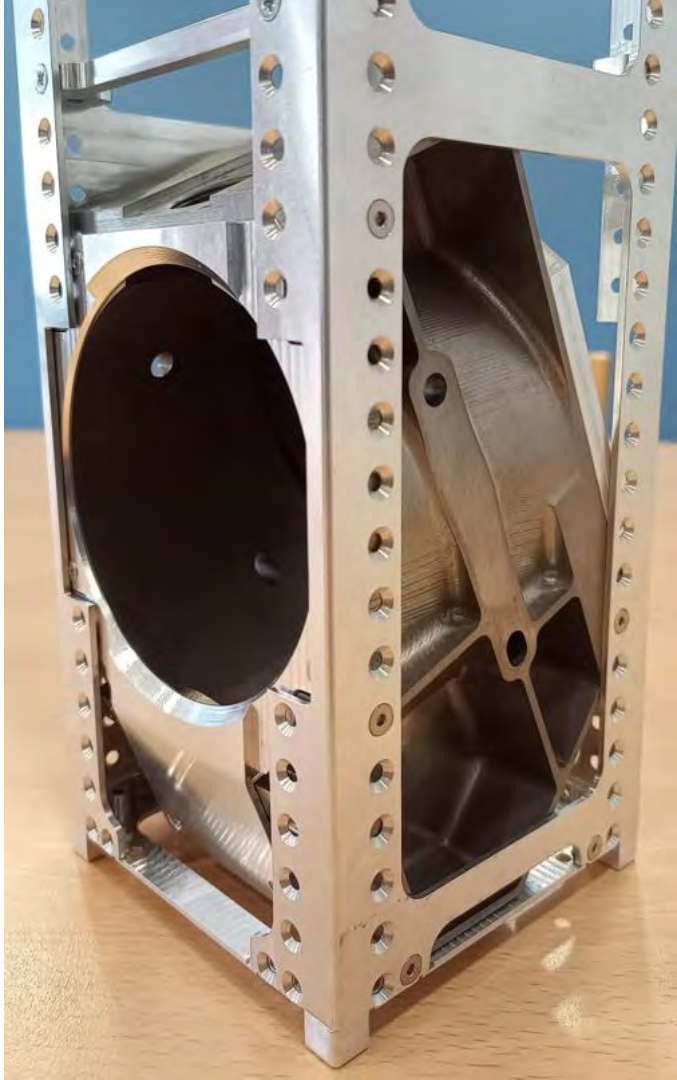
diamond

UK SPACE AGENCY



Space Optics Event in Durham

Christophe Buisset, ESA

Stephen Knox, SSTL

Ann Fitzpatrick, RAL Space

Carolyn Atkins, UK ATC

Rory Evans, Oxford University

Short and sharp technical talks

Hear from industry and academic experts

Find out about Durham University's cutting-edge R&D

Networking with industry and academia

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