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Additive Manufacturing of Satellite Telescope Mirrors

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CEOI Conference 19th and 20th March 2024

Session 3: LIDAR AND ADVANCED OPTICS

Contents

- Benefits of Additive Manufacturing (AM)
- Applications of AM at UKATC
- General AM design process
- Metal AM process and applications brief overview
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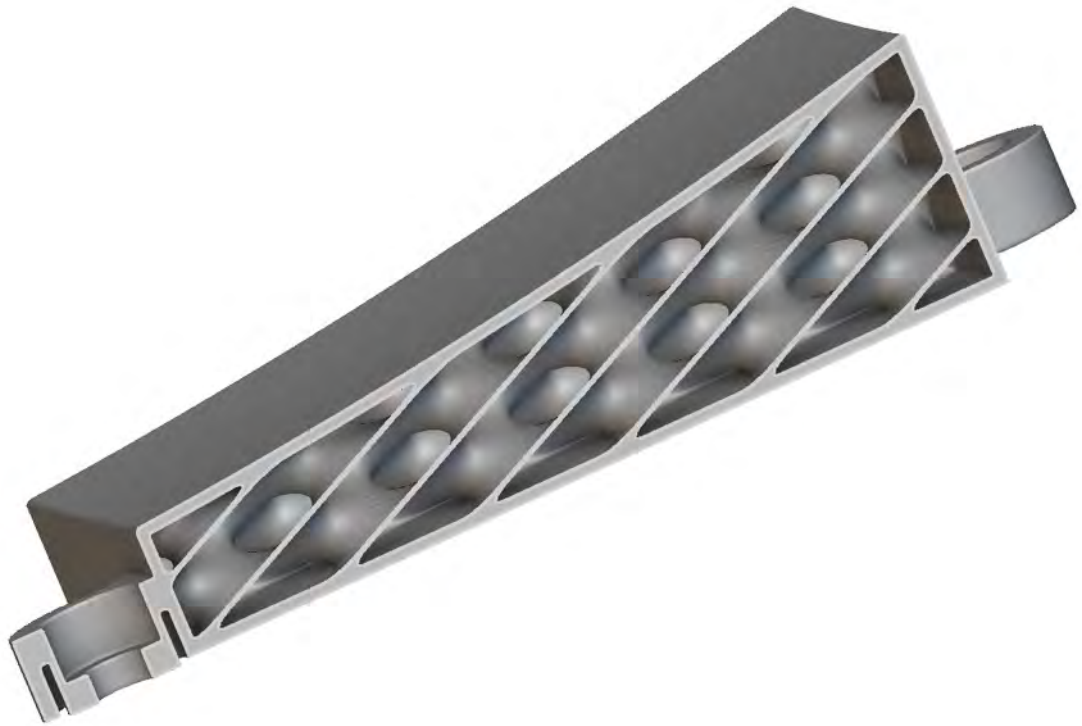
Additive Manufacturing Benefits

- Lighter mirror and component design using hollow lattice structures
- Lower mission costs
- Safer deorbit at end of life
- Unique mirror design lends well to AM
- Allow new science, mission and commercial ventures



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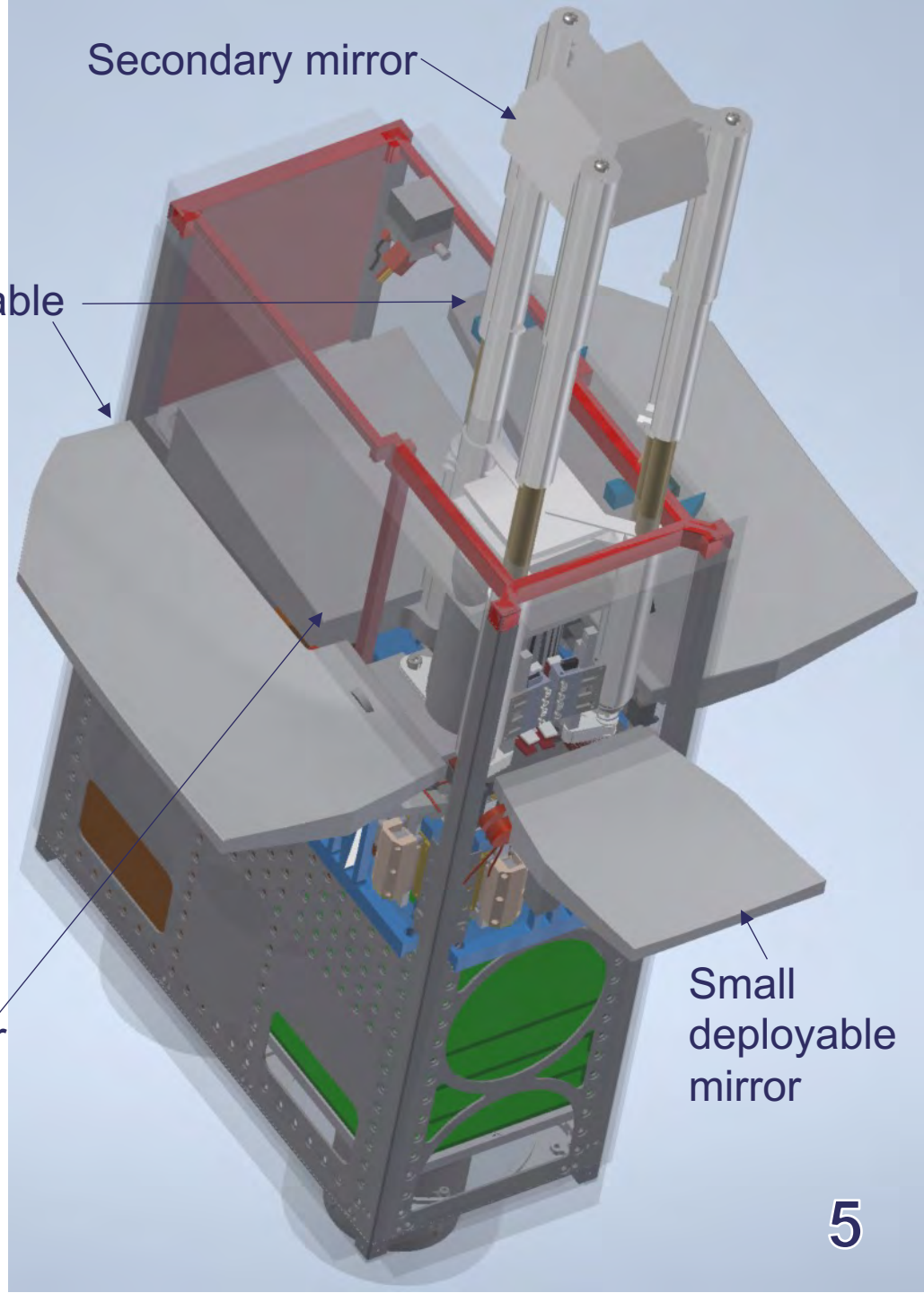
AM Applications: A-DOT

- 6U CubeSat satellite for astronomy observation (approx 585 x 325 x 300 mm deployed)
- Current mirror designs from solid aluminium
- Noah Schwartz talk to provide more detail.
- Design for AM mirrors with 50-70% mass reduction



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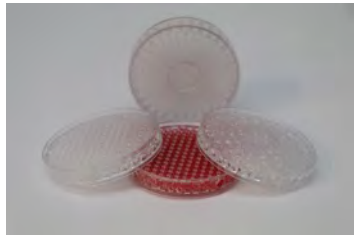
AM Design Process



Design specification

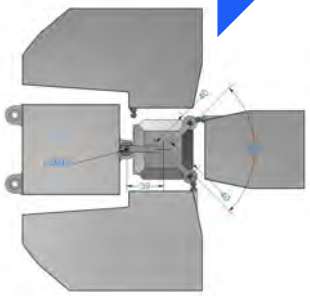
AM requirements: Material/process

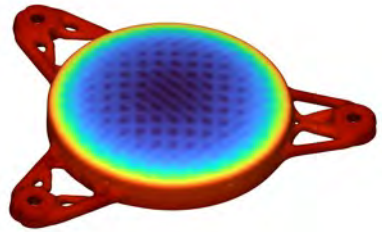
Lattice down selection - FEA

Prototype design - validation

Design for printing & post processing

Print!





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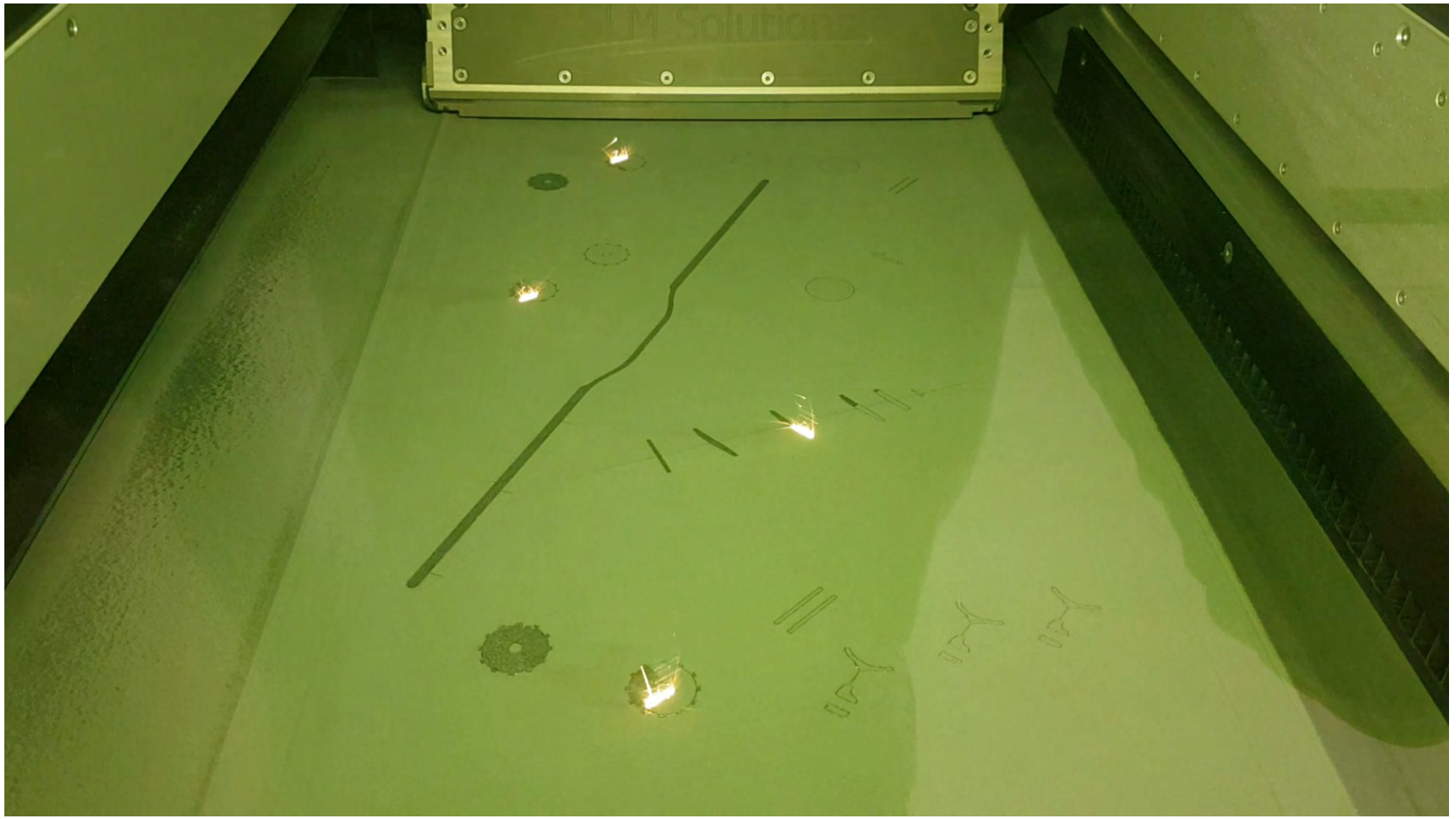
Aluminium AM Printing Process

- Thin layer of metal powder melted by a laser
- New layer of powder applied over the top
- Laser fuses new layer to previous layer
- Repeated until a solid part can be extracted from the powder bed



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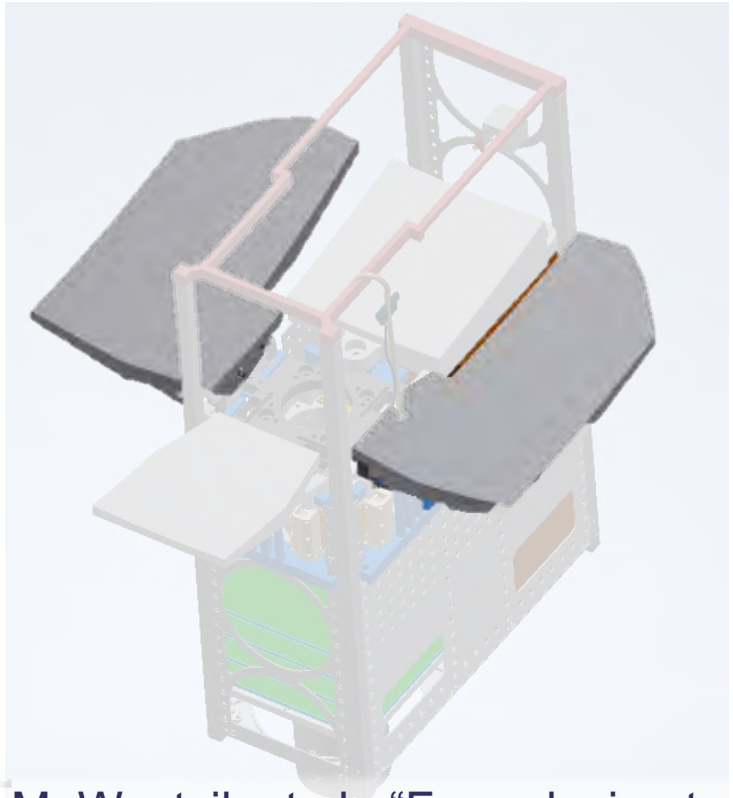
Printing Design Constraints & Application



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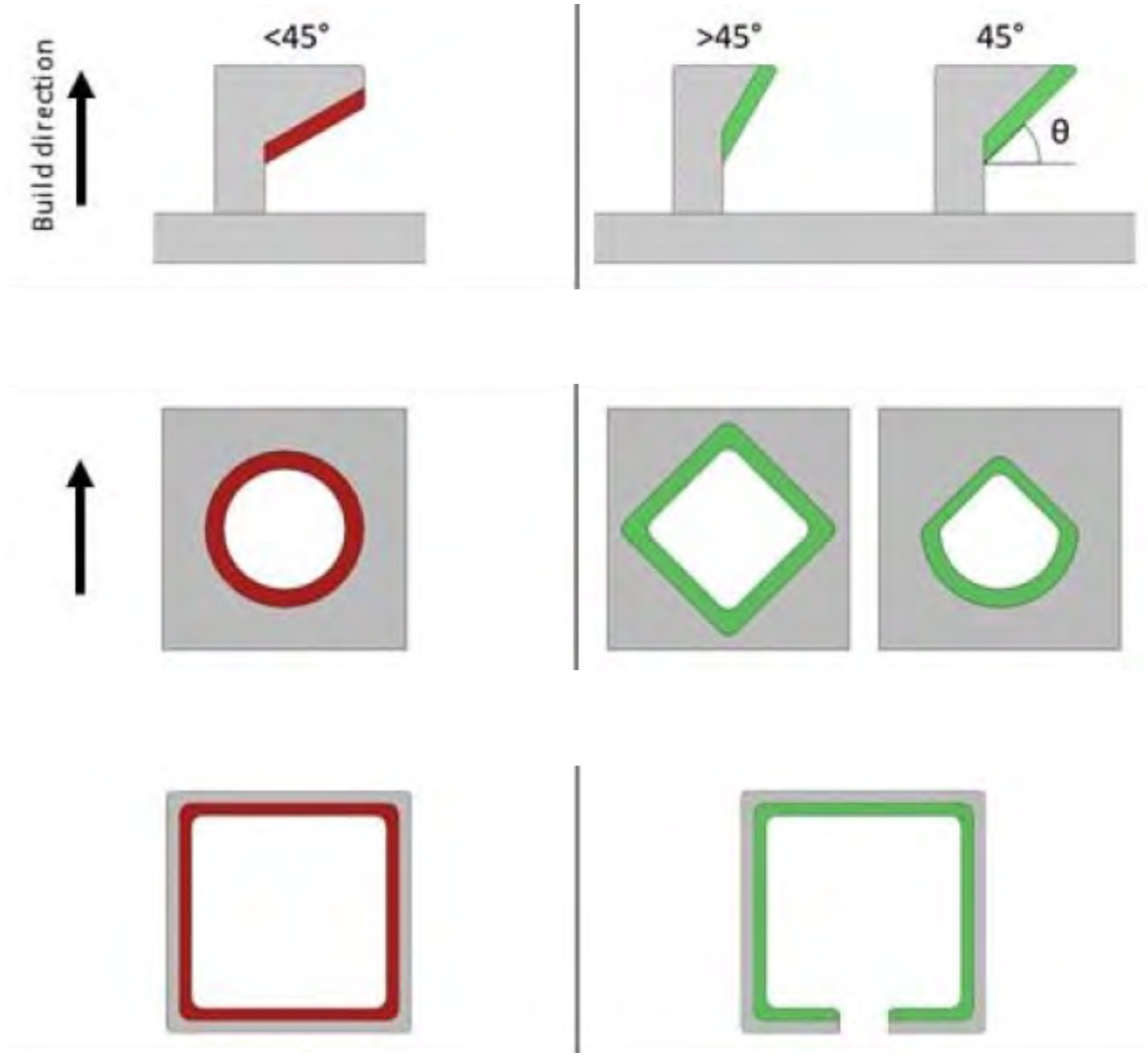
M. Westsik et al., “From design to evaluation of an additively manufactured, lightweight, deployable mirror for Earth observation”, (2023) 12677 – 41



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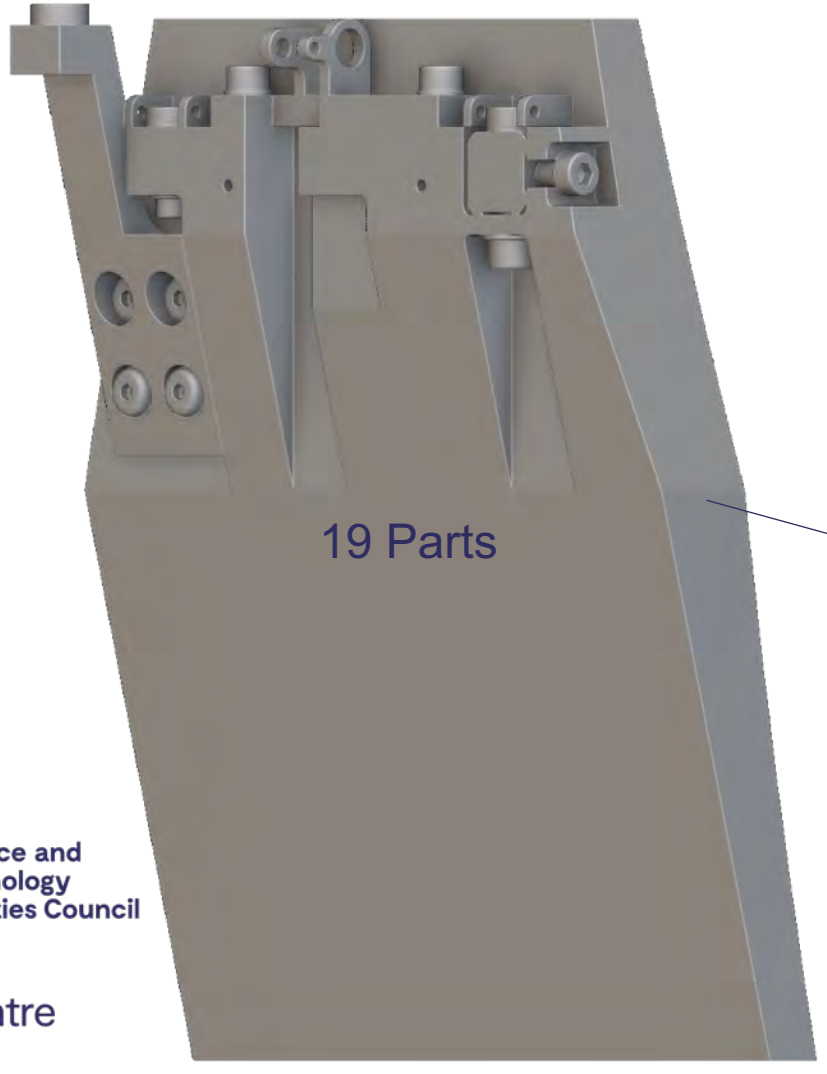
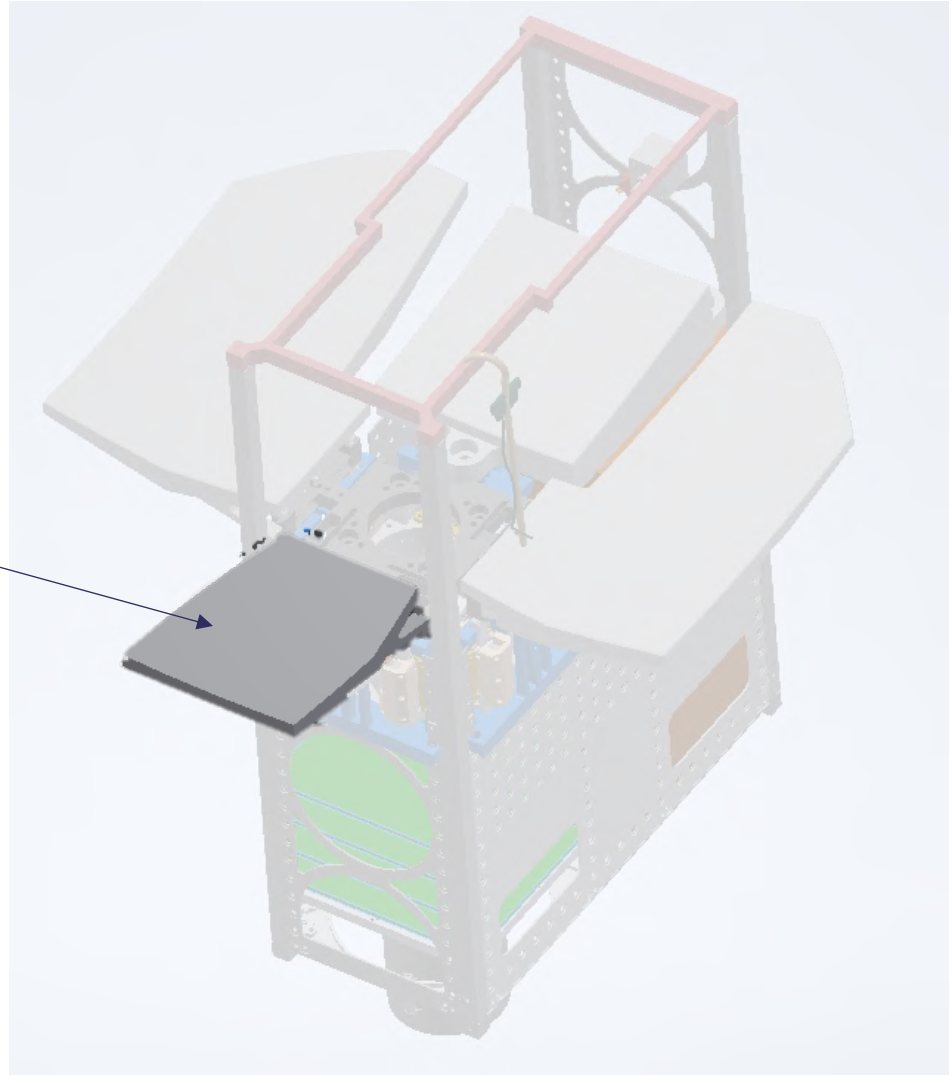
Small Deployable Mirror Design Features



19 Parts



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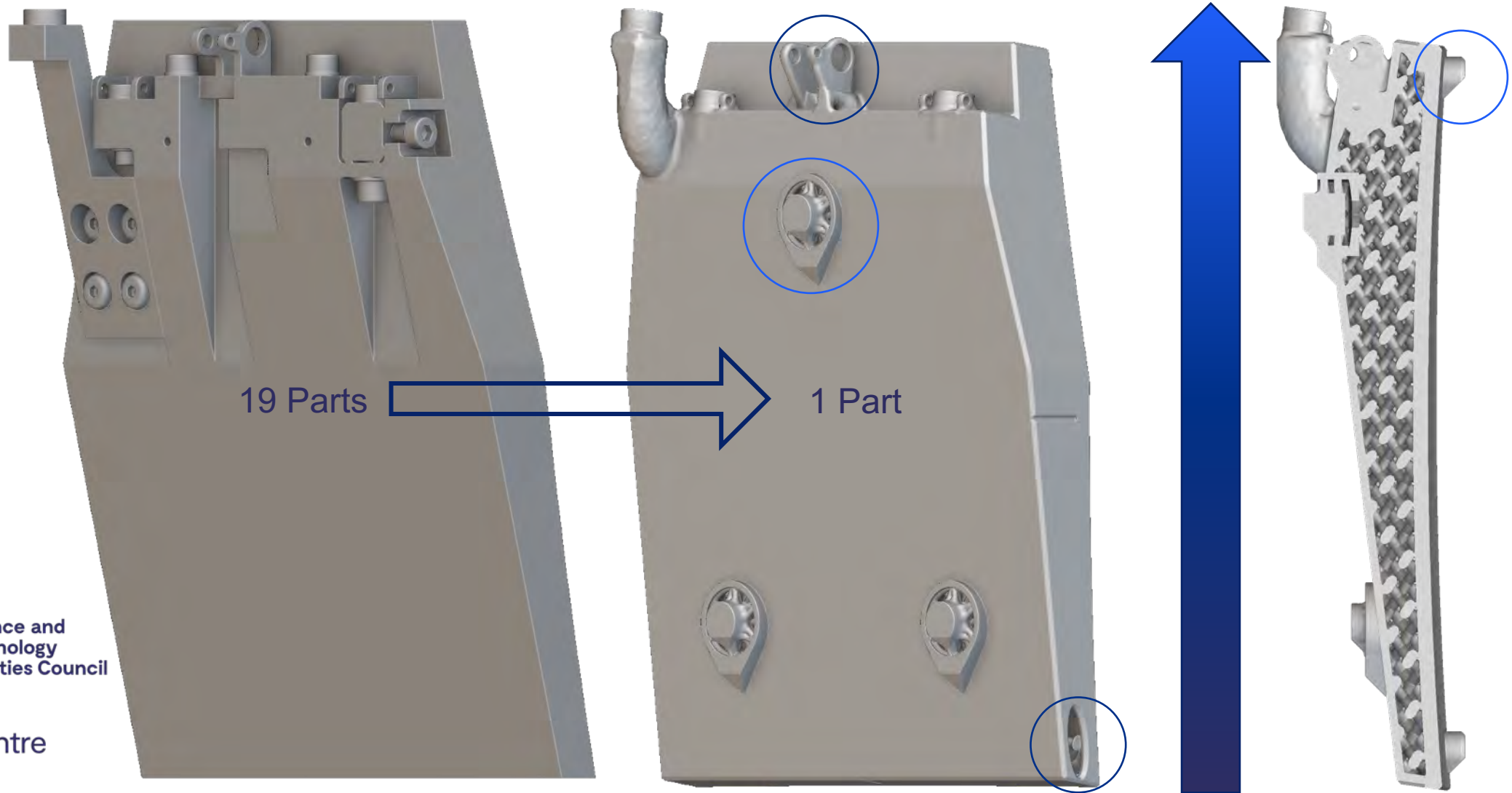

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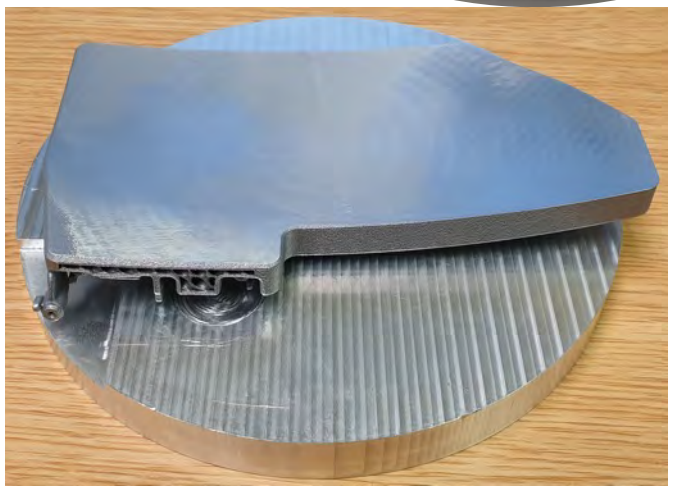
Conventional Manufacturing

Levelling Surfaces → Drilling and Tapping → Mounting → CNC & rough machining mirror surface → Single Point Diamond Turning the mirror surface



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AM in Ceramics

Why print in ceramics?

- Targeting shorter wavelength EO missions (Visible → UV)
- Ceramics are typically harder materials, so achievable surface roughness is usually lower
- Ceramics have significantly lower coefficients of thermal expansion (CTE)
- Current investigation is small scale – Have to start somewhere!

Image credit: Ebbets et al, Optical Engineering 52(9), 091808 (2013).

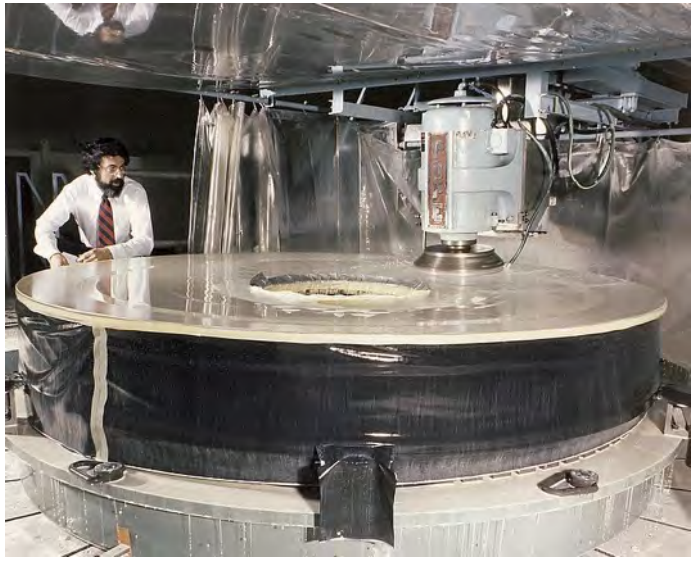

Image credit: NASA Hubble Space Telescope's photostream

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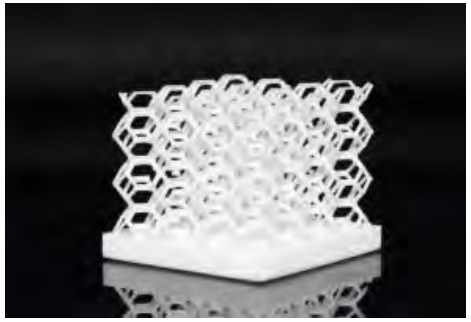
AM in Ceramics

Options for materials

Alumina

Deformable mirror

Zirconia

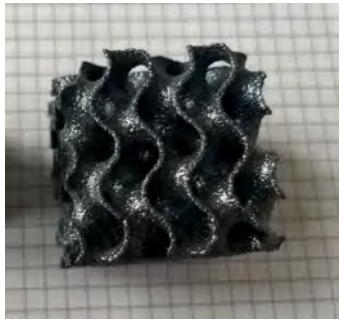


Kelvin cell lattice

Silicon nitride

Impeller

Silicon carbide



Gyroid lattice

Fused silica

Polishing test

- Ceramics are increasingly available on a commercial level
  - Through specialised printing bureaux
  - Or purchasing the printer and material

Image credits, left to right: M Roulet et al. Proceedings of SPIE, vol. 11349 (2020): 113490D. 3Dmatters. Altun et al. (2020). Applied Sciences. 10. 996. 10.3390/app10030996. Jason Cowan

AM in Ceramics

Options for materials

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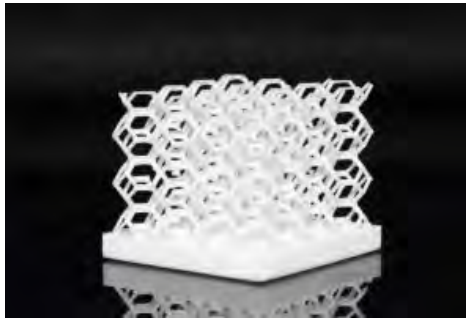
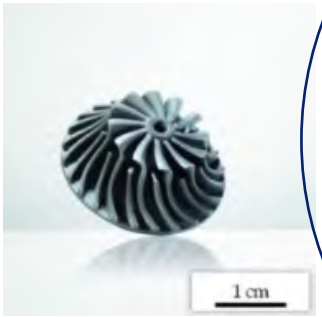


Kelvin cell lattice

Silicon nitride



Impeller

Silicon carbide

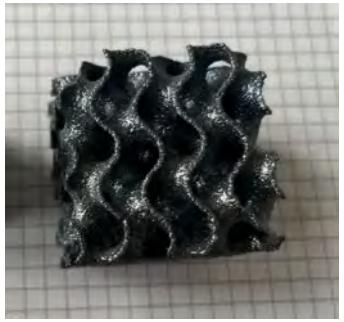


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Image credits, left to right: M Roulet et al. “Use of 3D printing in astronomical mirror fabrication.”Proceedings of SPIE, vol. 11349 (2020): 113490D. 3Dmatters. Altun et al. (2020). Dense, Strong, and Precise Silicon Nitride-Based Ceramic Parts by Lithography-Based Ceramic Manufacturing. Applied Sciences. 10. 996. 10.3390/app10030996. Jason Cowan

AM in Ceramics

Fused Silica

- Glass powder held in a prepolymer makes up a resin
- Layers of this resin are cured by a UV light source
- After printing, ‘green’ parts are baked at 600C to debind prepolymer, then 1300C to sinter into a homogeneous solid.

Image credit: Glassomer

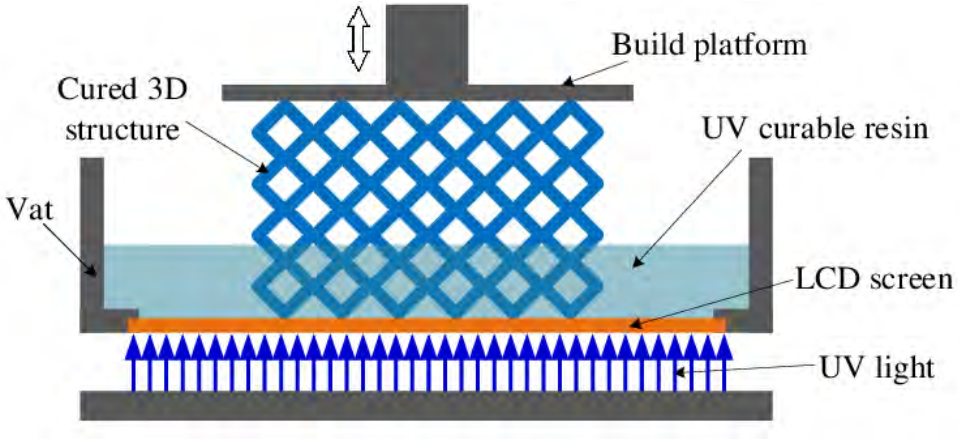


Image credit: Zhu, Z. IEEE Photonics Journal PP, 1–8 (08 2023).

AM in Ceramics

- Solid test samples are a proof of concept for the printed material
- Currently undergoing polishing trials to assess feasibility for mirror applications

AM in Ceramics

Silicon Carbide

- Thin layers of powder are glued together with droplets of binder
- Parts are baked to debind, then liquid silicon is infiltrated into the porous structure
- Final part is a Silicon carbide and silicon matrix
- Loose powder can act as support – no additional supports needed*

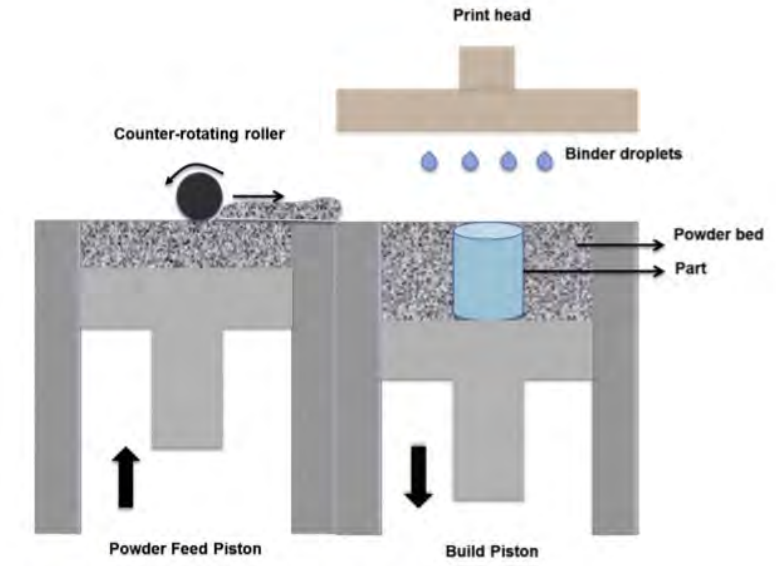
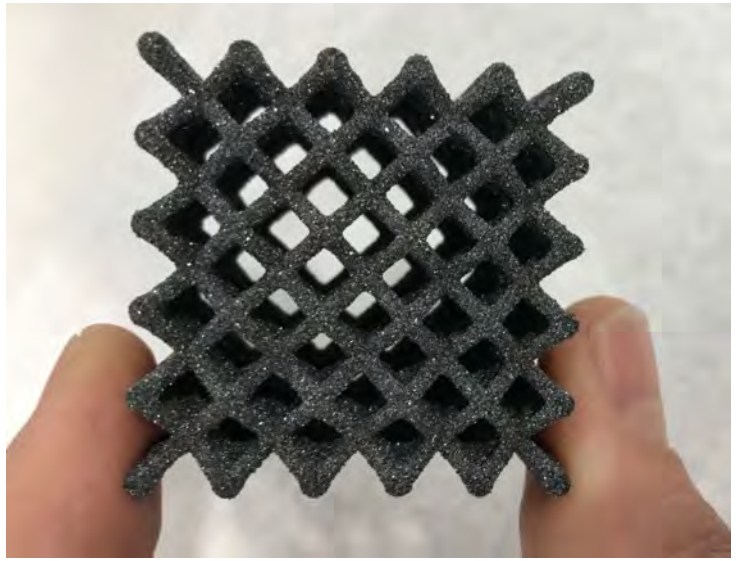
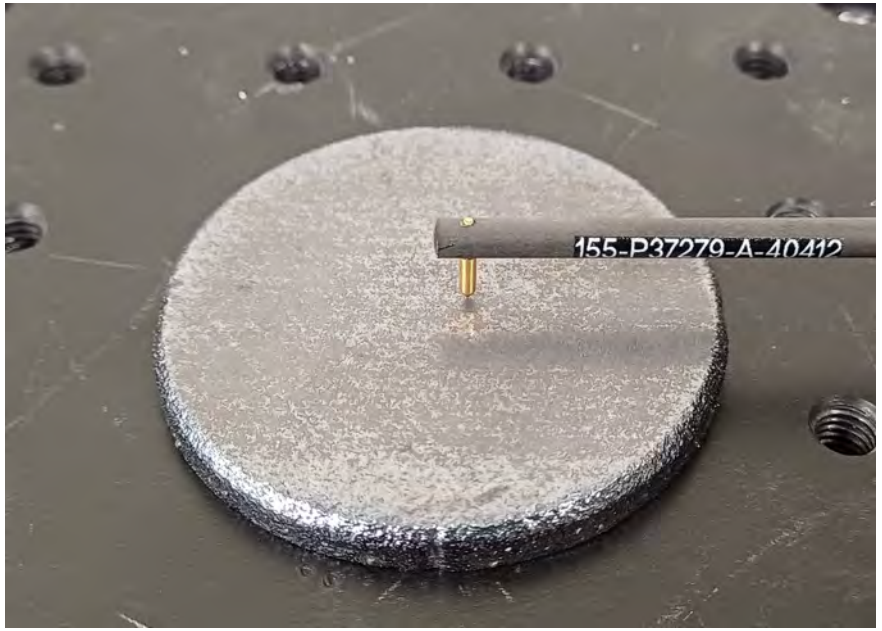
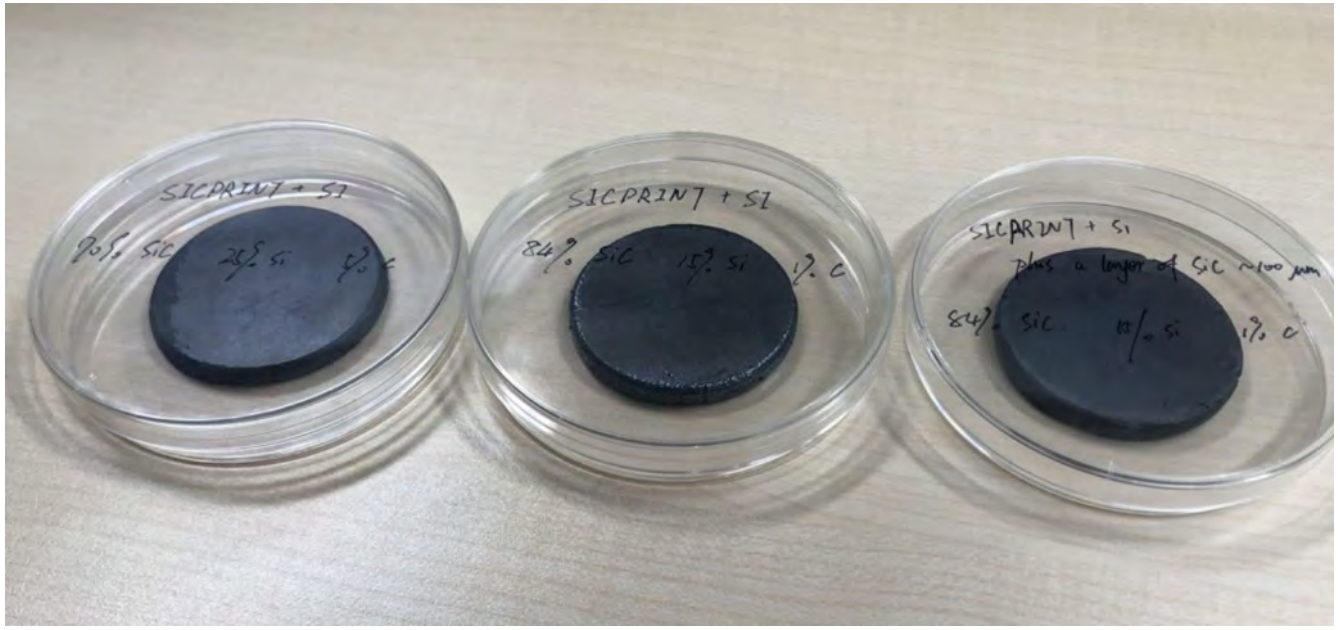


Image credit: Muthuswamy, P. Lasers in Manufacturing and Materials Processing 7 (09 2020)



AM in Ceramics





- Similar test samples to investigate achievable surface roughness
- Purpose of disks is to determine suitability for future fabrication

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Image credit: Jason Cowan

AM in Ceramics

- Results of fused silica and silicon carbide tests will be presented at SPIE in Japan
- Atkins et al. ‘Additive manufacturing in ceramics: targeting lightweight mirror applications in the visible, ultraviolet and X-ray’
- Future works to include printing and polishing samples with lightweight structures and non-flat surfaces

AM Mirror Summary

- AM is a disruptive technology with the potential to provide cost effective, highly complex component
- Ideal for the unique, custom nature of astronomical hardware
- Lightweight AM mirrors can reduce launch costs, and decrease both manufacturing time and complexity
- Metal and ceramic materials are commercially available, increasing the access to AM
- Risk adverse field, change in design mindset, and print defects are barriers to wider adoption

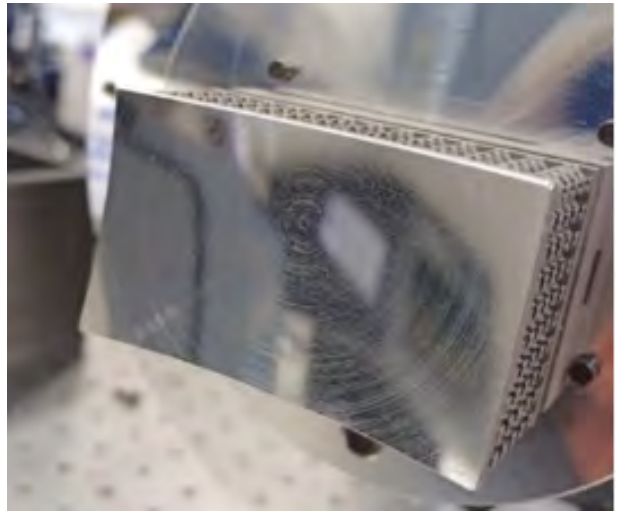
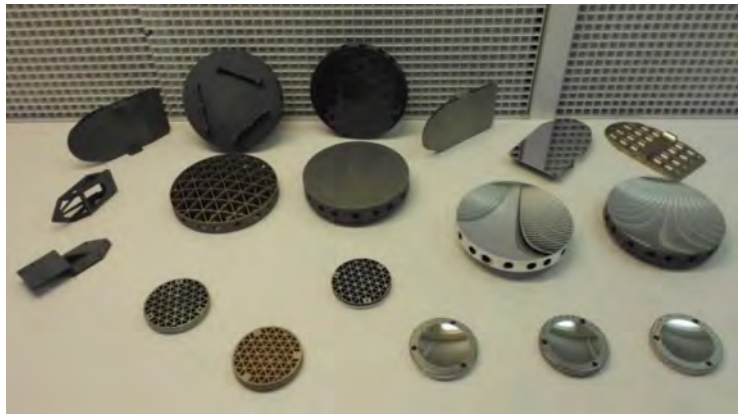


Image credit: Paenoi et al. Proc. SPIE 12188, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation V, 121880U (29 August 2022); https://doi.org/10.1117/12.2627757



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Thank you

Collaborators and thanks:

UKATC – Carolyn Atkins, Younes Chahid, Marcell Westsik

RAL Space – Matt Beardsley, Micheal Harris

Durham Uni.– Cyril Bourgenot

DLS – Simon G. Alcock, Ioana Theodora Nistea

INAF Brera - Marta Civitani, Gabriele Vecchi

Osaka Uni. – Rongyan Sun, Prof. Yamamura

Uni. Of Edinburgh – Nan Yu

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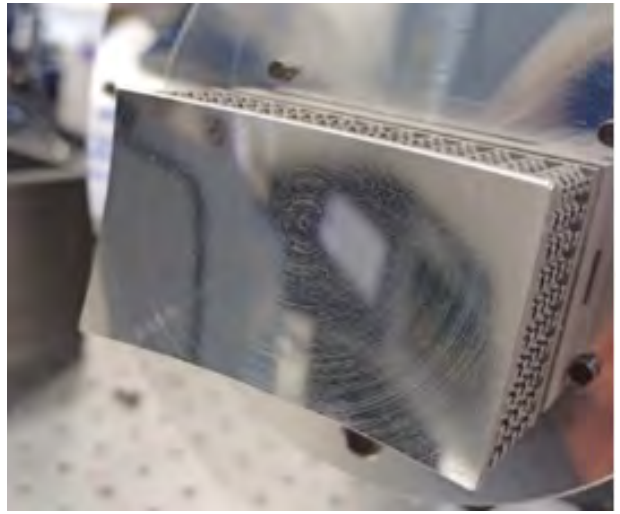

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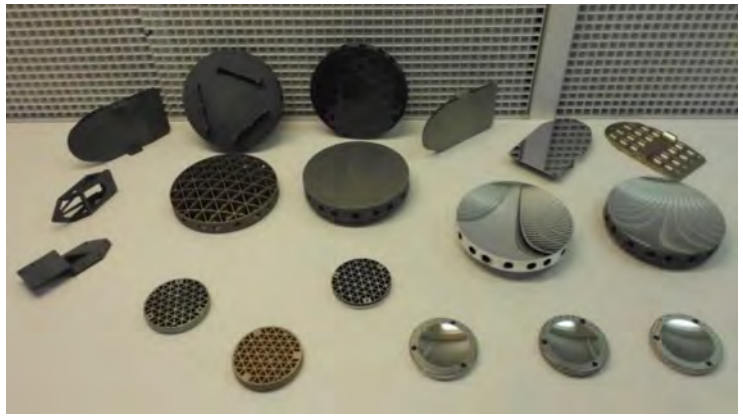

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