X-RAY TOMOGRAPHY FOR ADVANCEMENT OF **LASER POWDER BED FUSION ADDITIVE MANUFACTURING**

ANTON DU PLESSIS

ASSOCIATE PROFESSOR, STELLENBOSCH UNIVERSITY, SOUTH AFRICA

13 Sept 2019
TOSCA2019, Southampton, UK

UNIVERSITEIT iYUNIVESITHI STELLENBOSCH UNIVERSITY 100 1918-2018

Research group
3D INNOVATION

CPAM

CT FACILITY
STELLENBOSCH

Background

→2-time Tosca presenter
→Manager of Stellenbosch CT facility
→ Editorial board of journals

- Additive Manufacturing
- Scientific African
- Gigabyte (new data journal)

(GIGA)byte
Publishing at the Speed of Research

Publish your microCT models with *GigaByte*

- New “updatable” data journal coming in 2020 from *GigaScience*
- Get credit for peer reviewed datasets
- Includes integrated data hosting in GigaDB repository
- Curation and integration of models in sketchfab

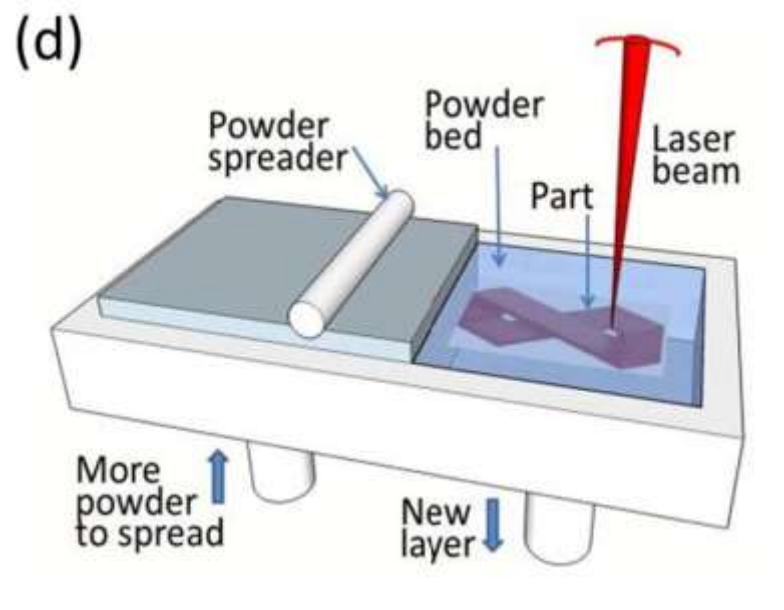
http://gigabytejournal.com/

Outline

→Additive manufacturing
→X-ray CT for additive manufacturing
→Standardization in CT for AM: round robin test 1
→CT round robin test 2
→Image quality quantification
→Conclusions and future of CT in AM

Additive manufacturing

→ **Additive manufacturing (AM) / 3D printing has grown over the last decade, way past the original "prototyping" use**
→ **Today it is possible (and proven) to manufacture mission-critical parts**
→ **Various materials are possible, the most well studied metals for AM are Ti6Al4V, AlSi10Mg, and various steels**
→ **Laser powder bed fusion is the most widely used and best developed AM method, with the highest complexity possible in produced parts**



From: DebRoy, T., et al. 2018. Additive manufacturing of metallic components–process, structure and properties. Progress in Materials Science, 92, pp.112-224.

X-ray tomography for additive manufacturing

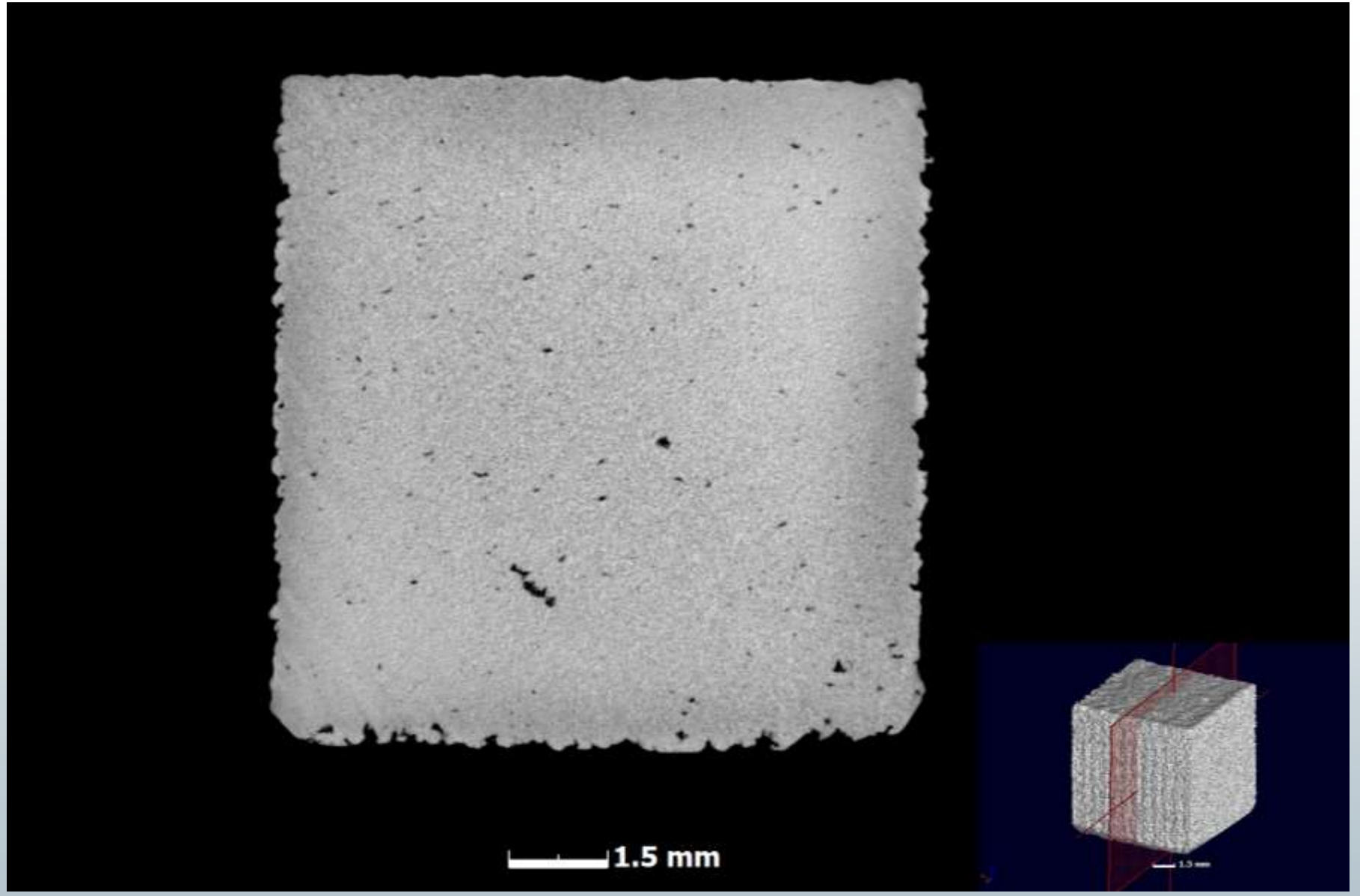
→ Widely known already for non-destructive and quantitative analysis of AM parts for:

- **Porosity**
- **Dimensional measurement**

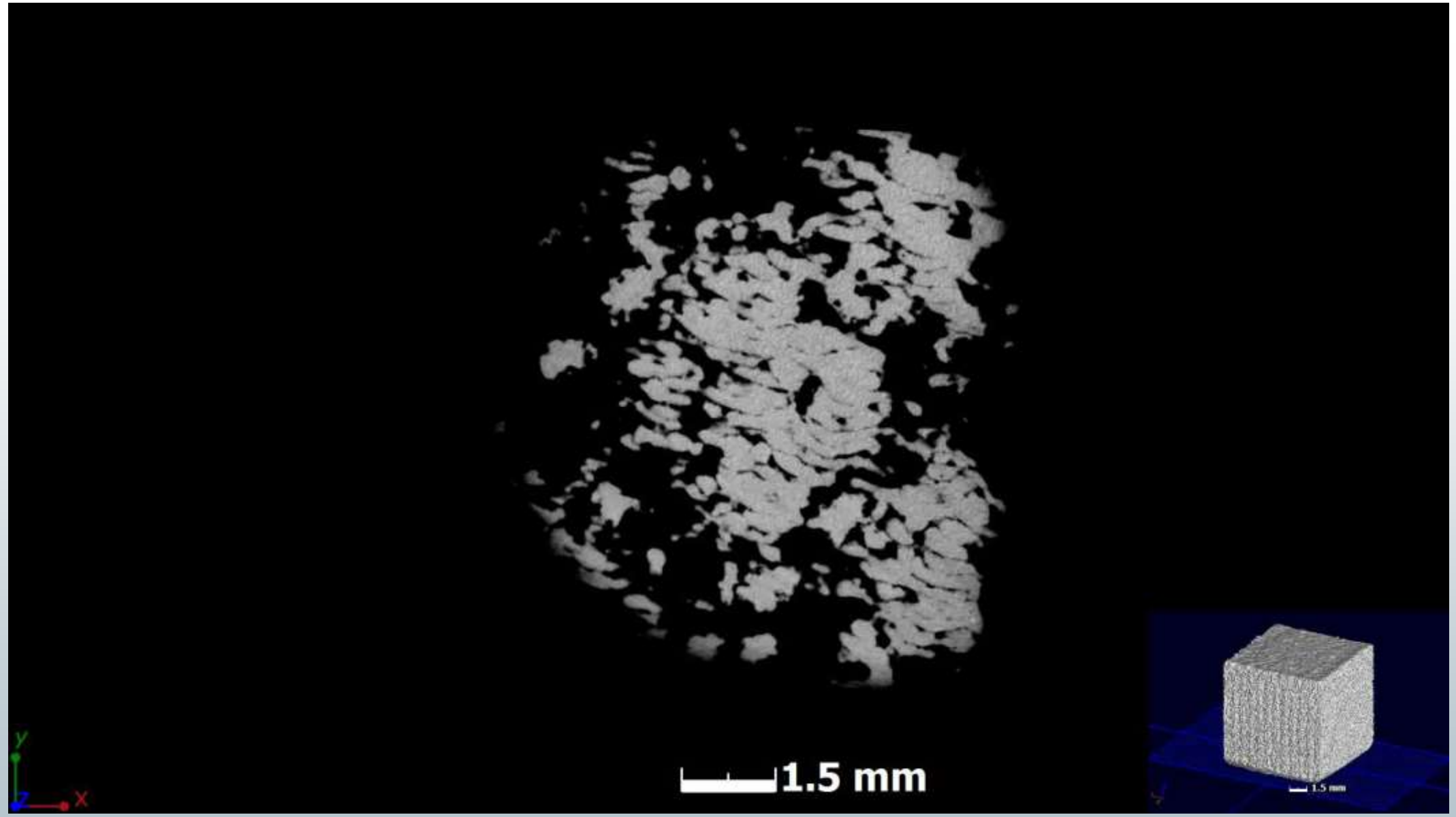
→ Other newer uses are:

- **Analysis of powder feedstock for quality – size, shape and porosity**
- **Density**
- **Time-lapse or 4D CT**
- **Surface roughness/topography**
- **Simulations – FEM**
- **Multiscale CT, etc.**

*** X-ray microcomputed tomography in additive manufacturing: a review of the current technology and applications. *3D Printing and Additive Manufacturing*, *5*(3), pp.227-247. Du Plessis, A., Yadroitsev, I., Yadroitsava, I. and Le Roux, S.G., 2018. https://www.liebertpub.com/doi/full/10.1089/3dp.2018.0060**

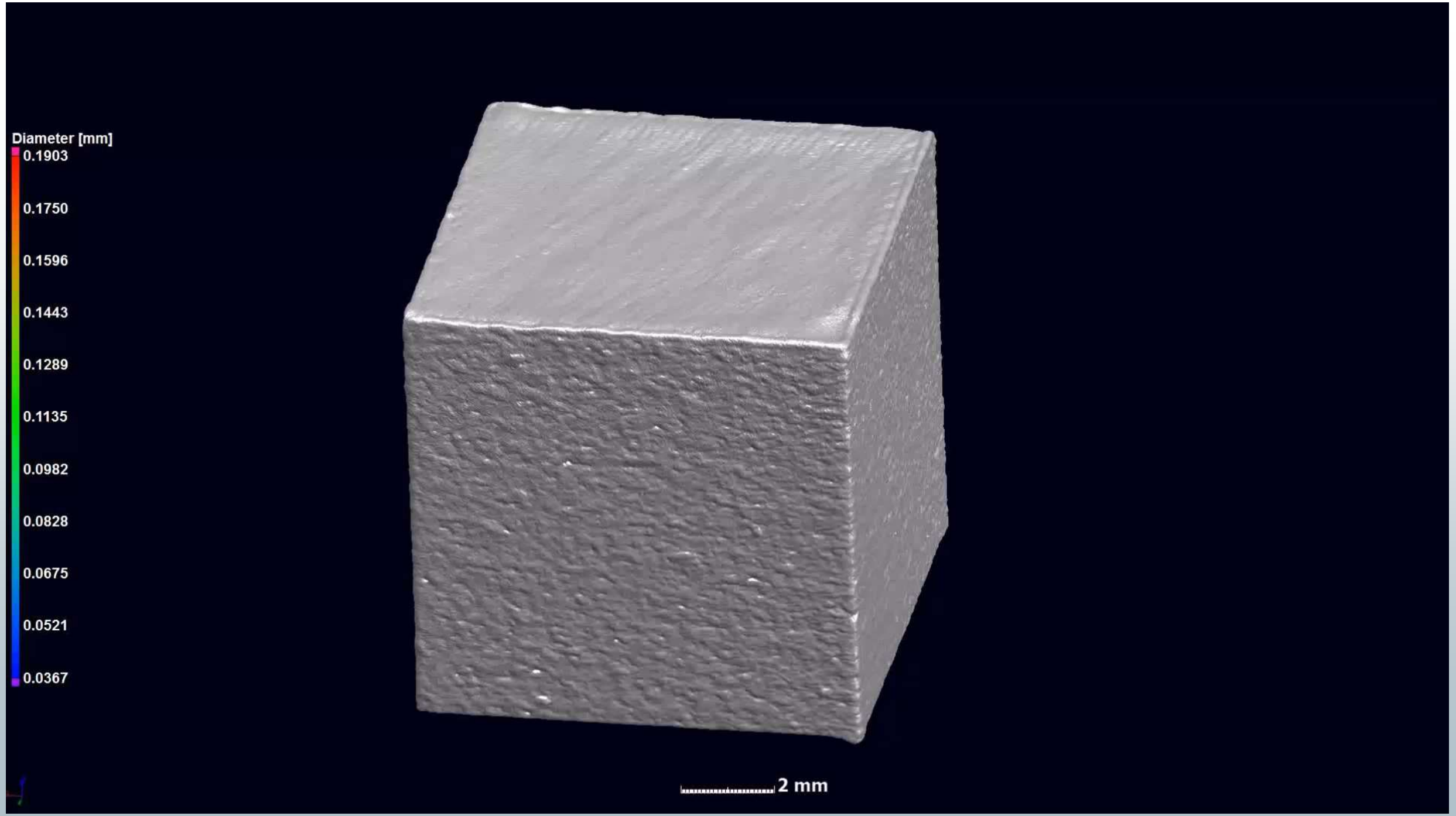


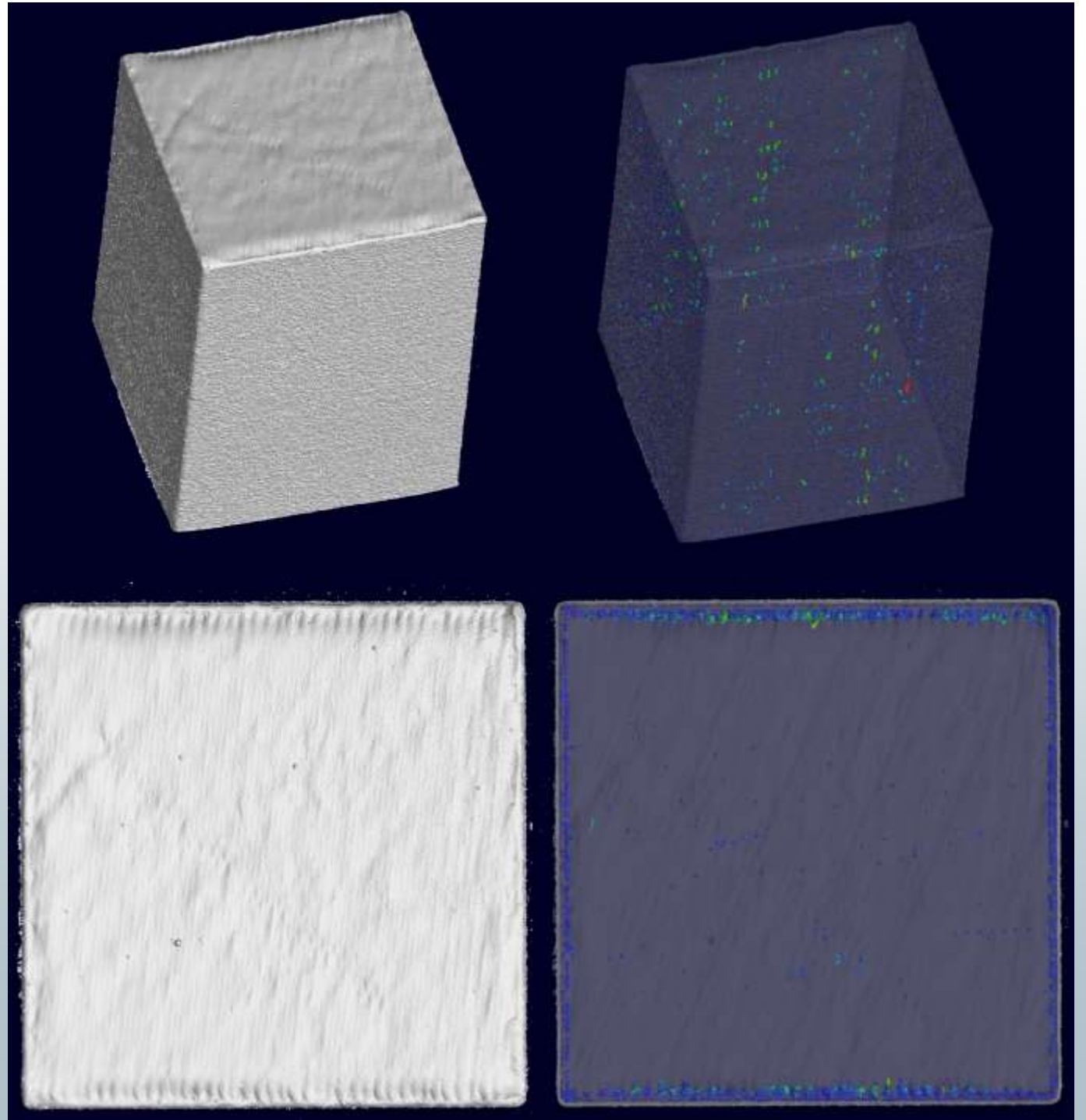
* du Plessis, A. and le Roux, S.G., 2018. Standardized X-ray tomography testing of additively manufactured parts: A round robin test. *Additive Manufacturing*, *24*, pp.125-136. https://doi.org/10.1016/j.addma.2018.09.014

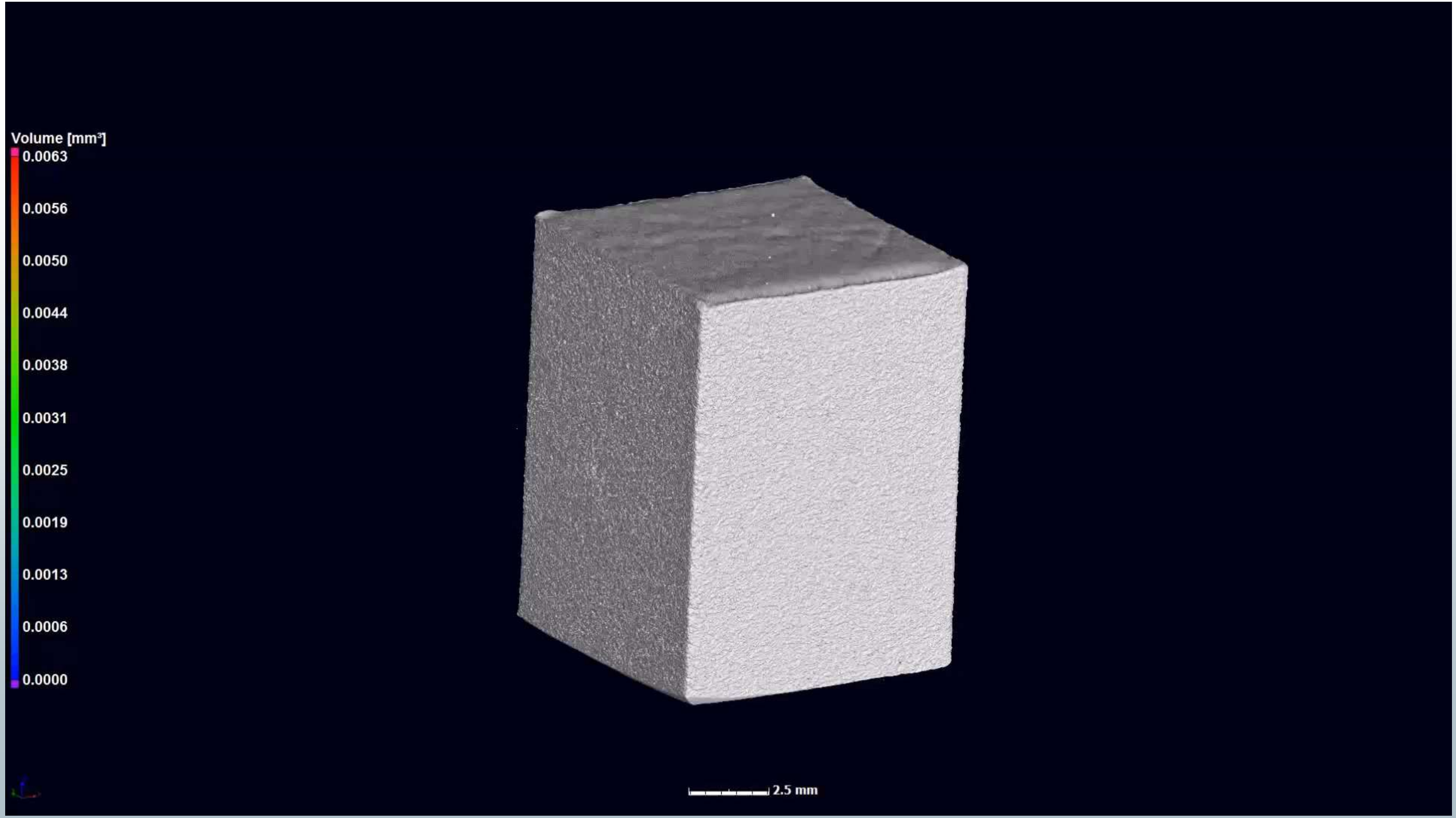


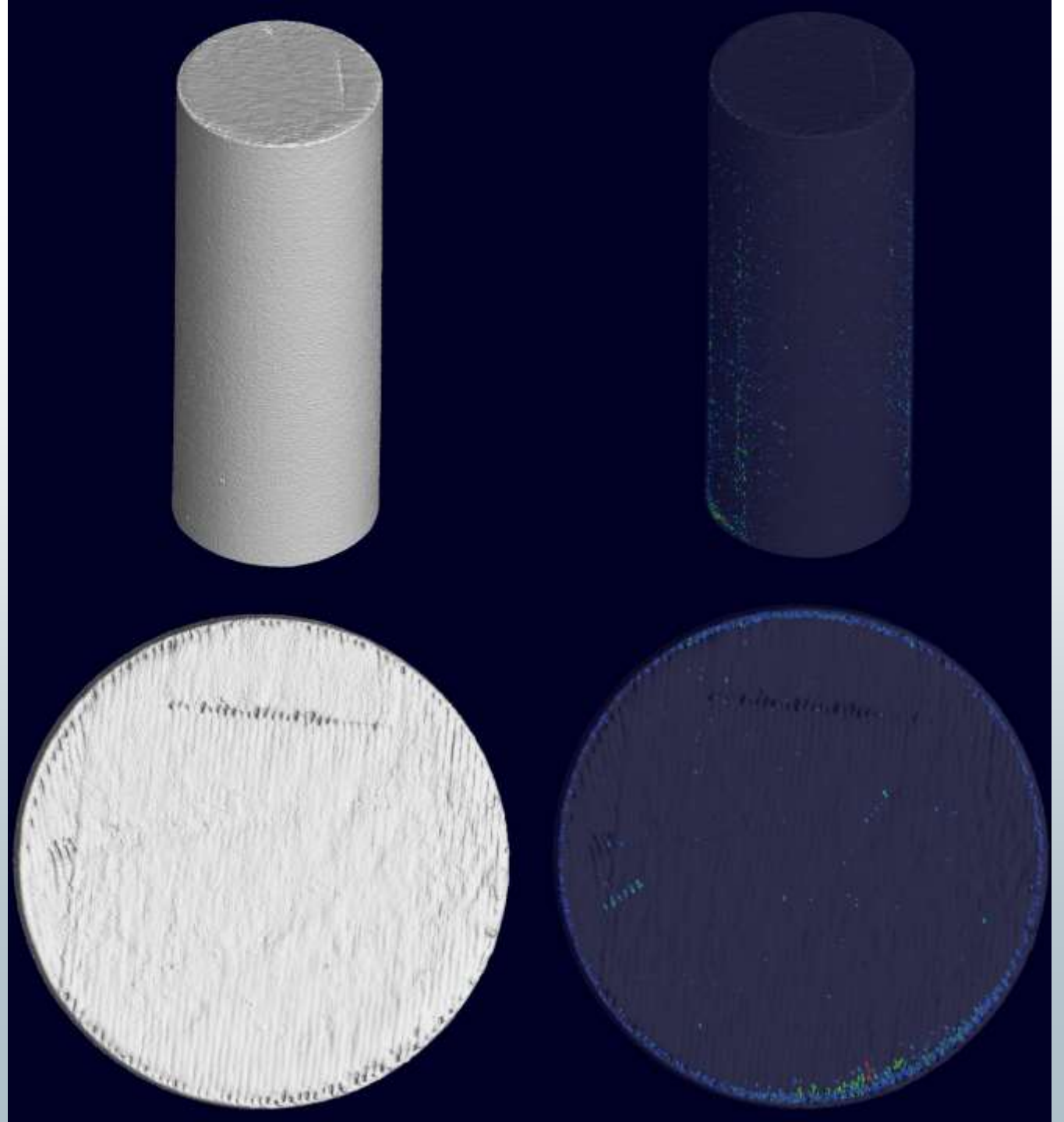
0.13%

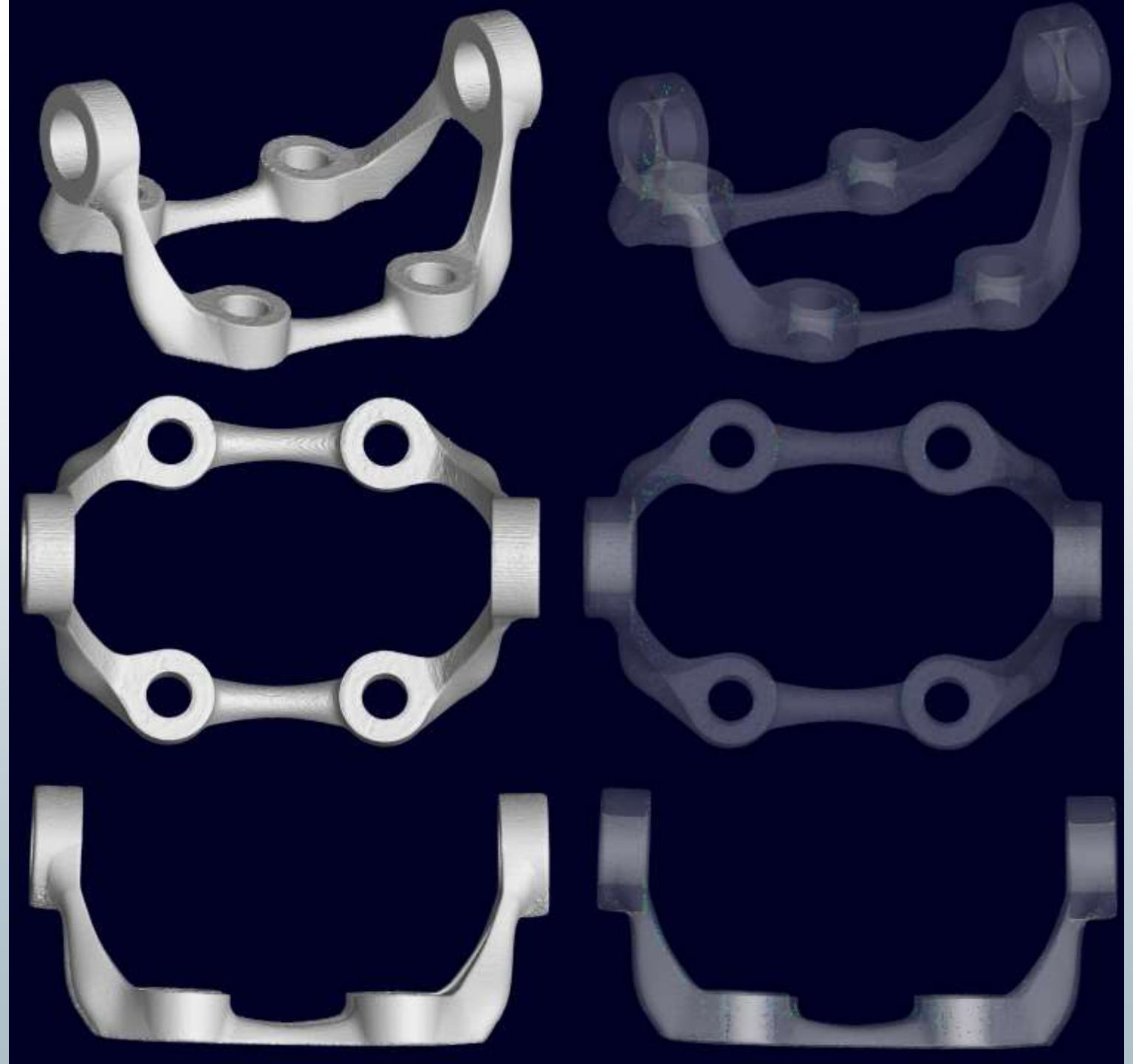
* du Plessis, A. and le Roux, S.G., 2018. Standardized X-ray tomography testing of additively manufactured parts: A round robin test. *Additive Manufacturing*, *24*, pp.125-136. https://doi.org/10.1016/j.addma.2018.09.014

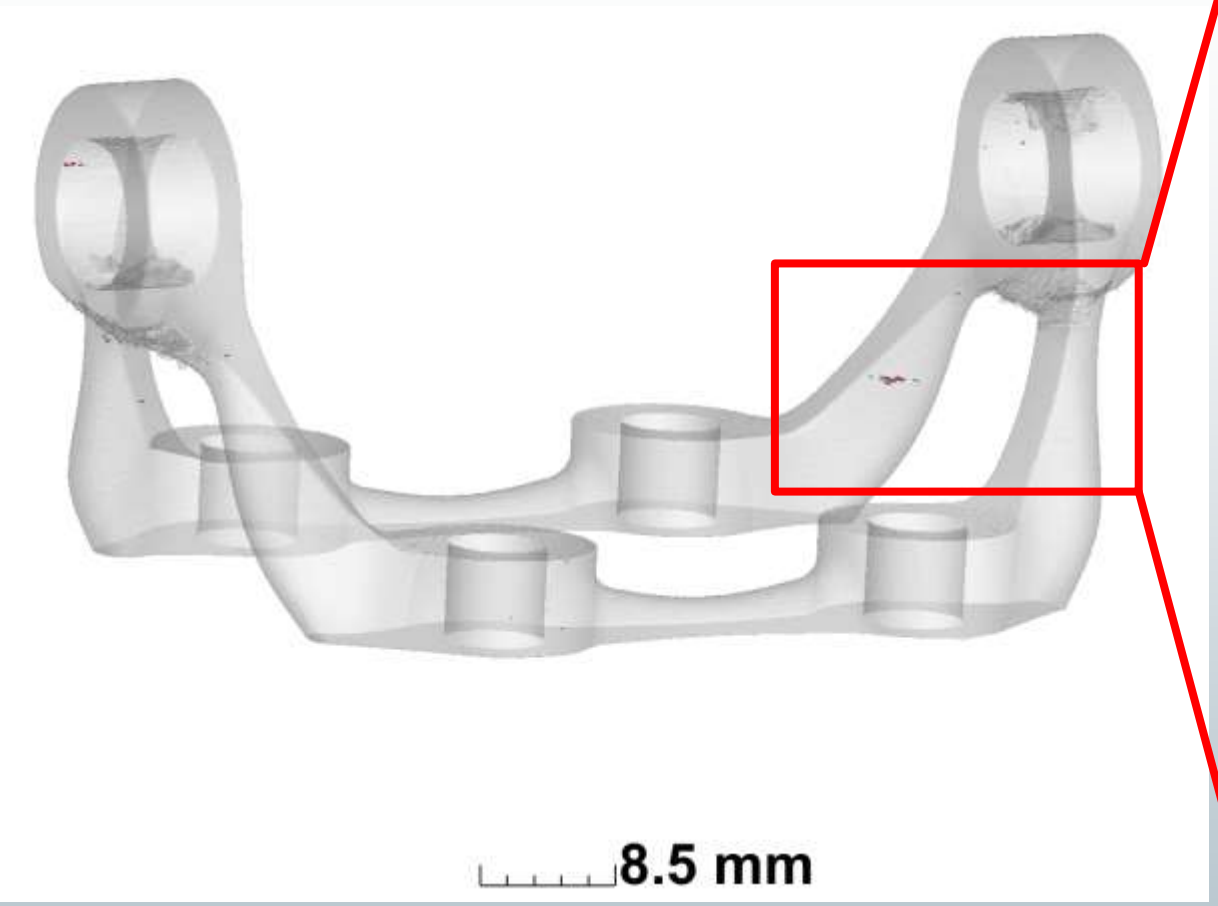

Diameter [mm]
0.1903
0.1750
0.1596
0.1443
0.1289
0.1135
0.0982
0.0828
0.0675
0.0521
0.0367
2 mm

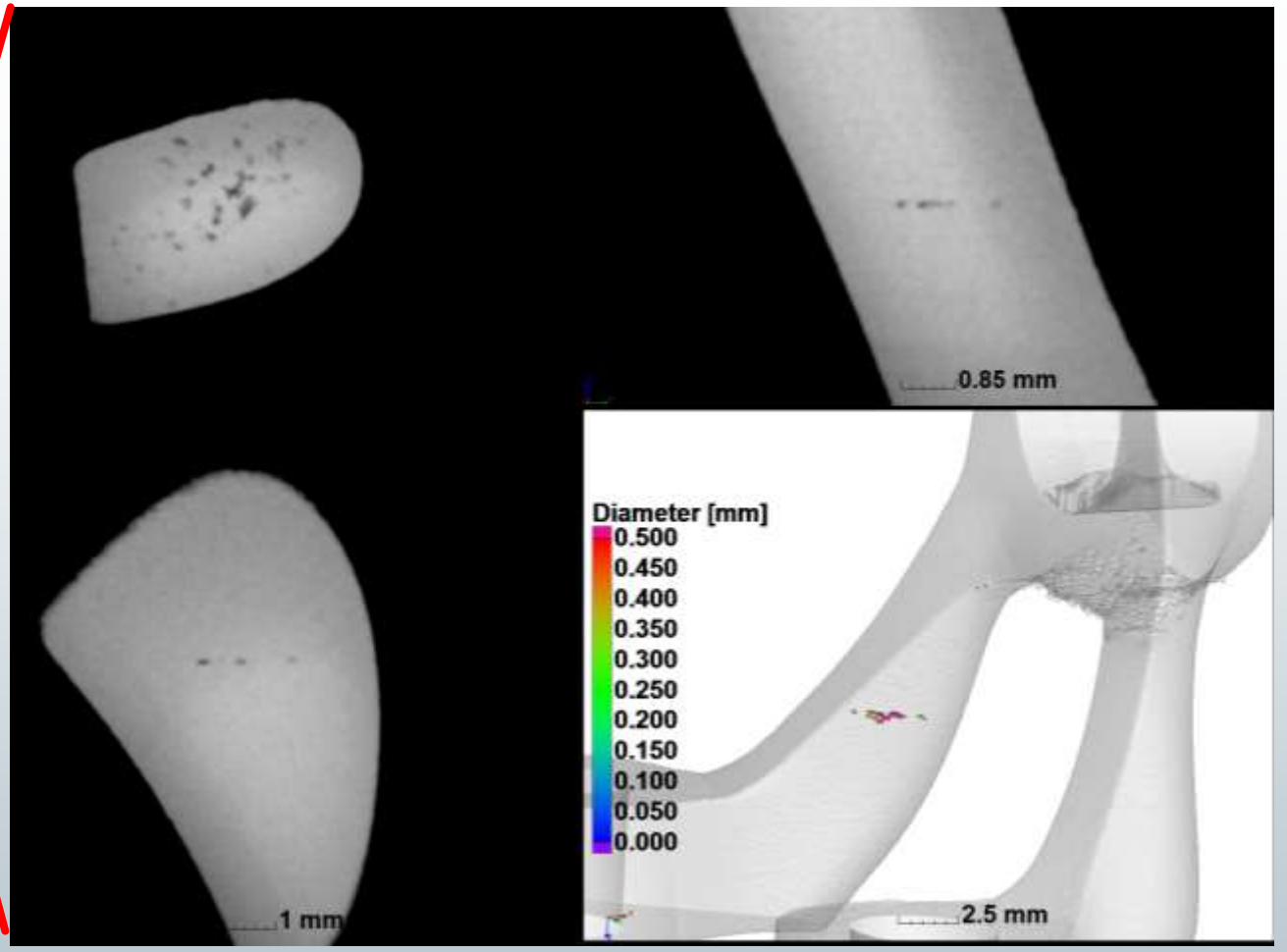


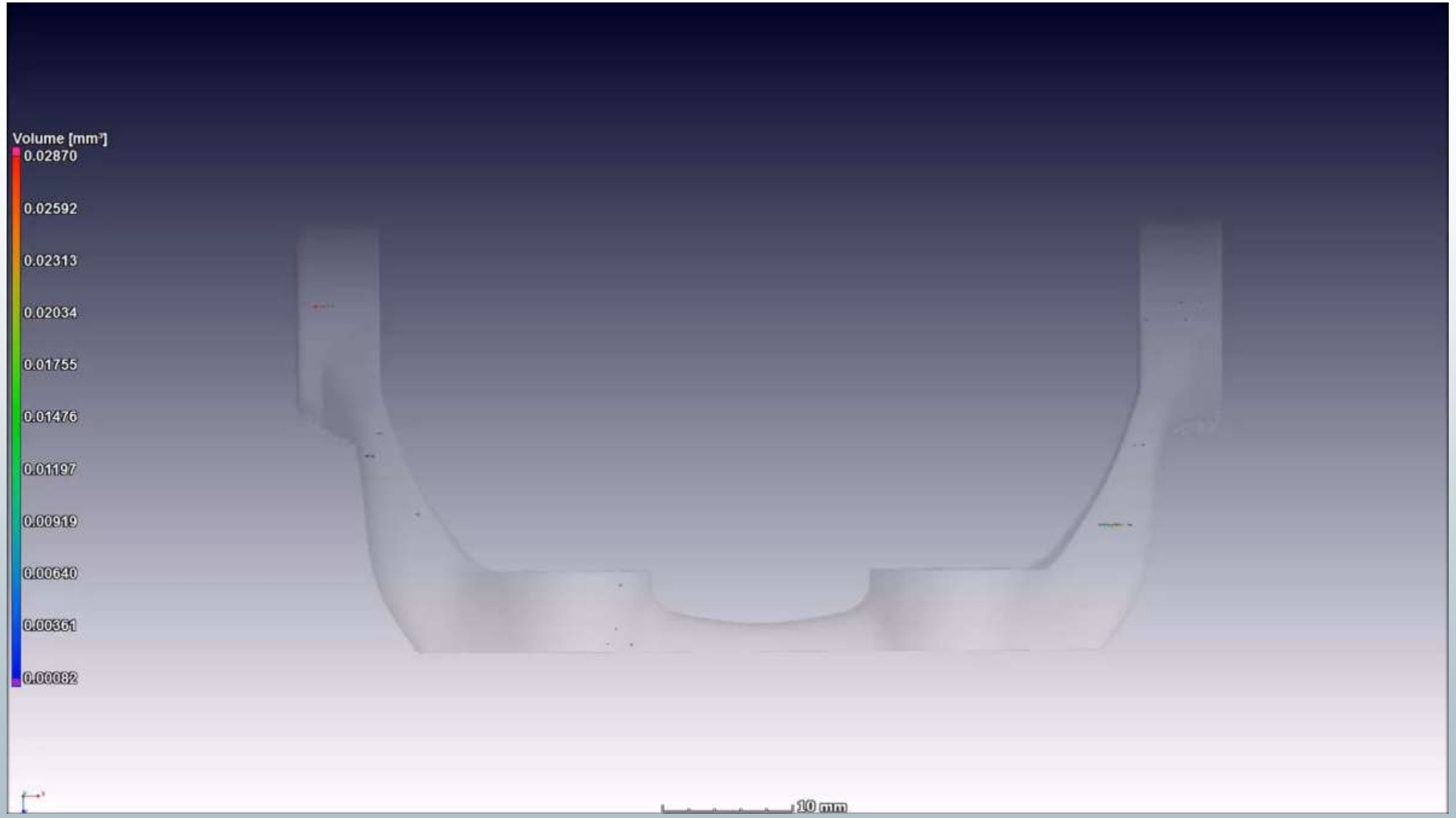

Volume [mm³]
0.0063
0.0056
0.0050
0.0044
0.0038
0.0031
0.0025
0.0019
0.0013
0.0006
0.0000
2.5 mm






8.5 mm


0.85 mm
Diameter [mm]
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1 mm
2.5 mm


Volume [mm³]
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0.02592
0.02313
0.02034
0.01755
0.01476
0.01197
0.00919
0.00640
0.00361
0.00082
10 mm

ROUND ROBIN TEST 1

- **Parts produced in variety of L-PBF systems – attempt to make good parts: cube, bracket + cylinder**
- **All parts scanned according to standard/prescribed parameters and image analysis steps**
- **Demonstrated two things**
  1. **Various distinct error types are present even in parts with >99.87% density**
  2. **All these errors can be clearly identified using the standard "recipe"**

ROUND ROBIN TEST 2

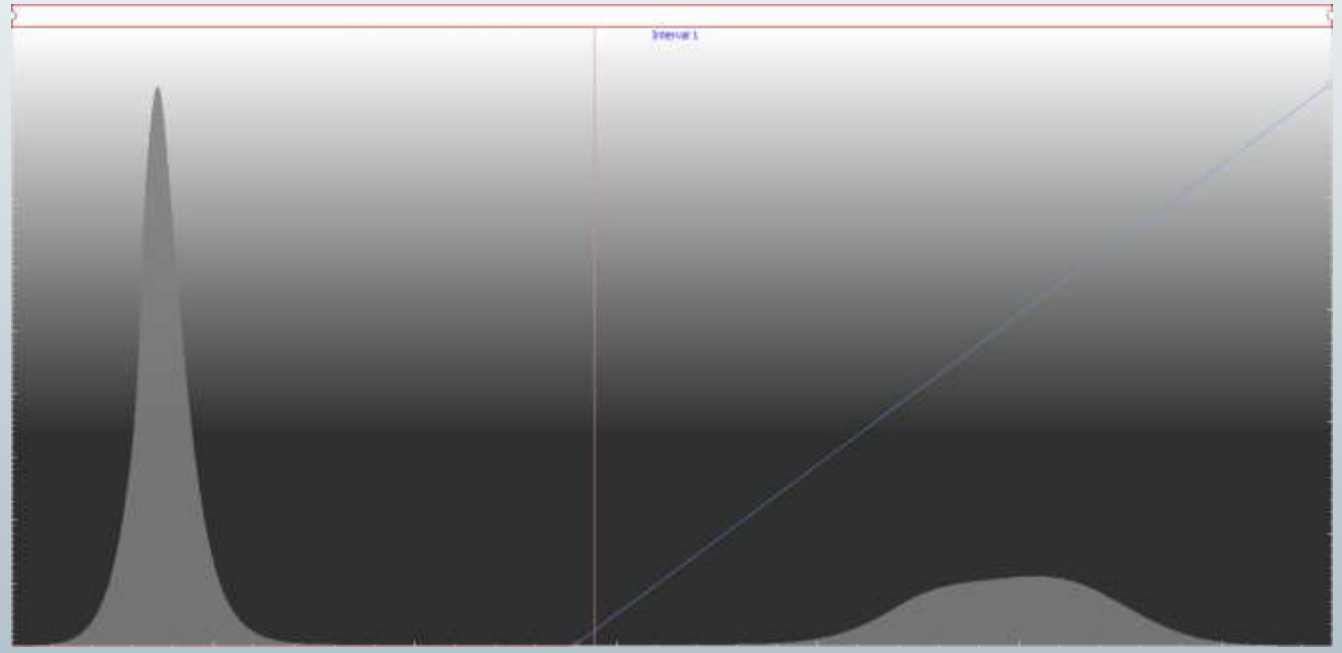
- One set of bracket, cube and cylinder was selected from previous work with different pore types
- Sent to total of 10 different micro-CT labs, and asked to analyse according to the "recipe"
- What was learned
  - Major porosity distributions correctly identified by all
  - Quantification was OK but not perfect
  - Image analysis workflow requires some simplifications
  - Image quality varies in different scans – affecting the workflow

* du Plessis, A. et al 2019. Laboratory X-ray tomography for metal additive manufacturing: round robin test. *Additive Manufacturing, accepted for publication.* https://doi.org/10.1016/j.addma.2019.100837

IMAGE QUALITY QUANTIFICATION

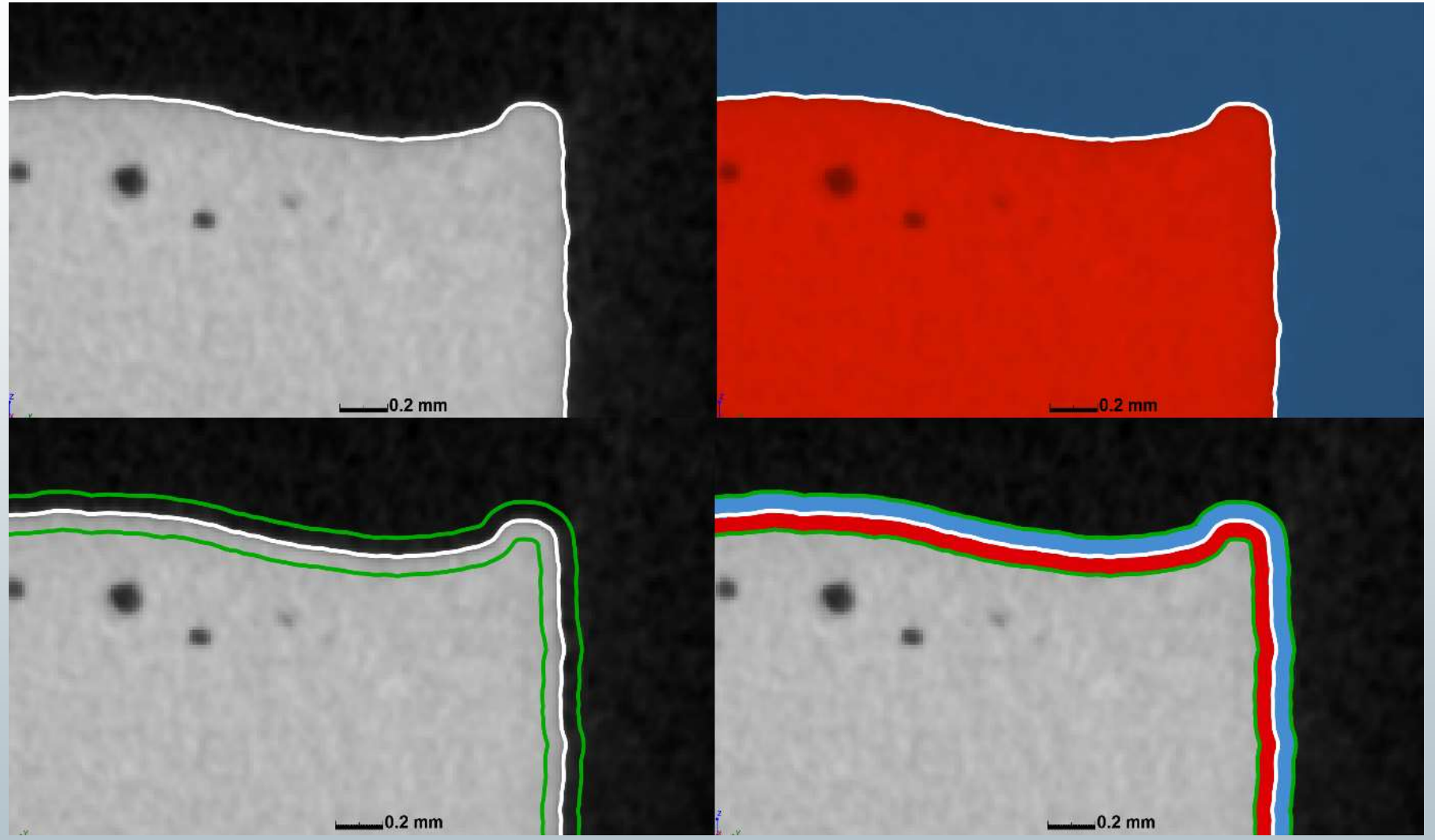
- **THE 10 MM CUBE WAS USED AGAIN AND SCANNED ON DIFFERENT SYSTEMS, WITH VARIED SCAN PARAMETERS INDUCING DIFFERENT ARTIFACTS**
- **IMAGE QUALITY WAS QUANTIFIED ACCORDING TO A SIMPLE METHOD:**

$$Q = \frac{|\mu_2 - \mu_1|}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$



** M. Reiter, D. Weiß, C. Gusenbauer, M. Erler, C. Kuhn, J. Kastner, Evaluation of a histogram-based image quality measure for X-ray computed tomography, ICT Conf. (2014) 273–282. www.3dct.at.*

IMAGE QUALITY QUANTIFICATION



Q1

Q2

https://www.researchgate.net/publication/335842062_Not_all_scans_are_equal_X-ray_tomography_image_quality_measurement

IMAGE QUALITY QUANTIFICATION – SCAN TIME

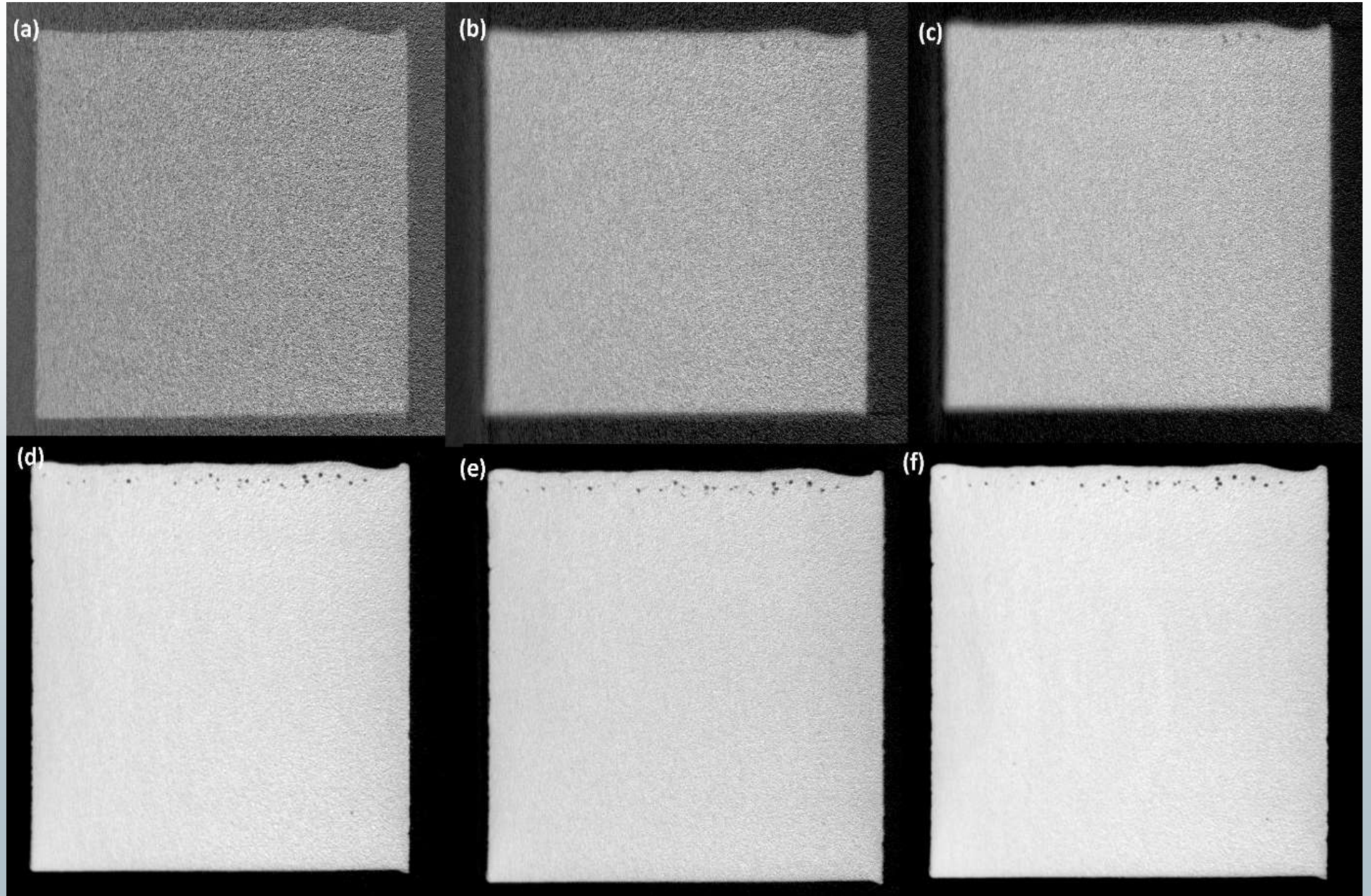


IMAGE QUALITY QUANTIFICATION – SCAN TIME

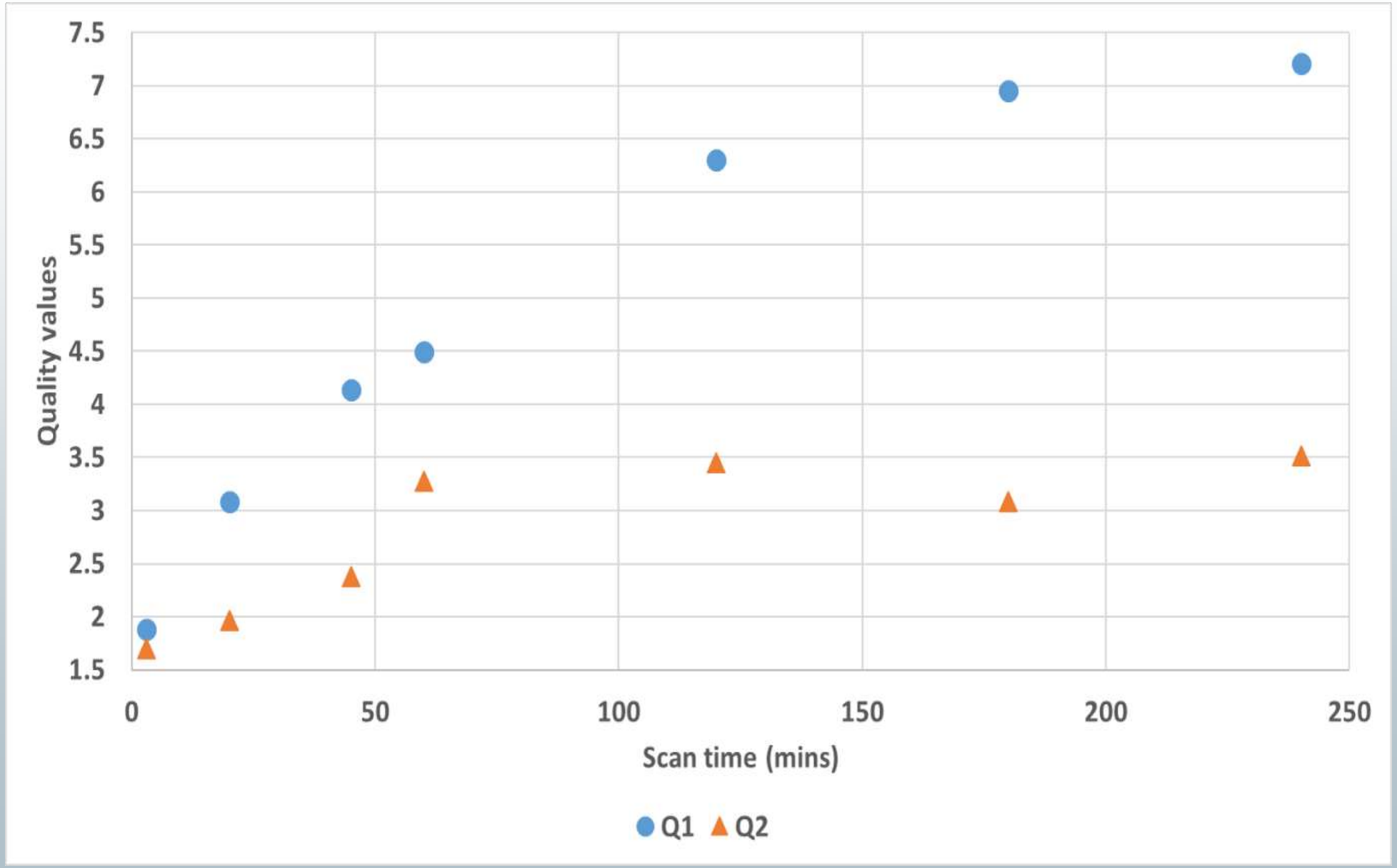


IMAGE QUALITY QUANTIFICATION – SCAN TIME

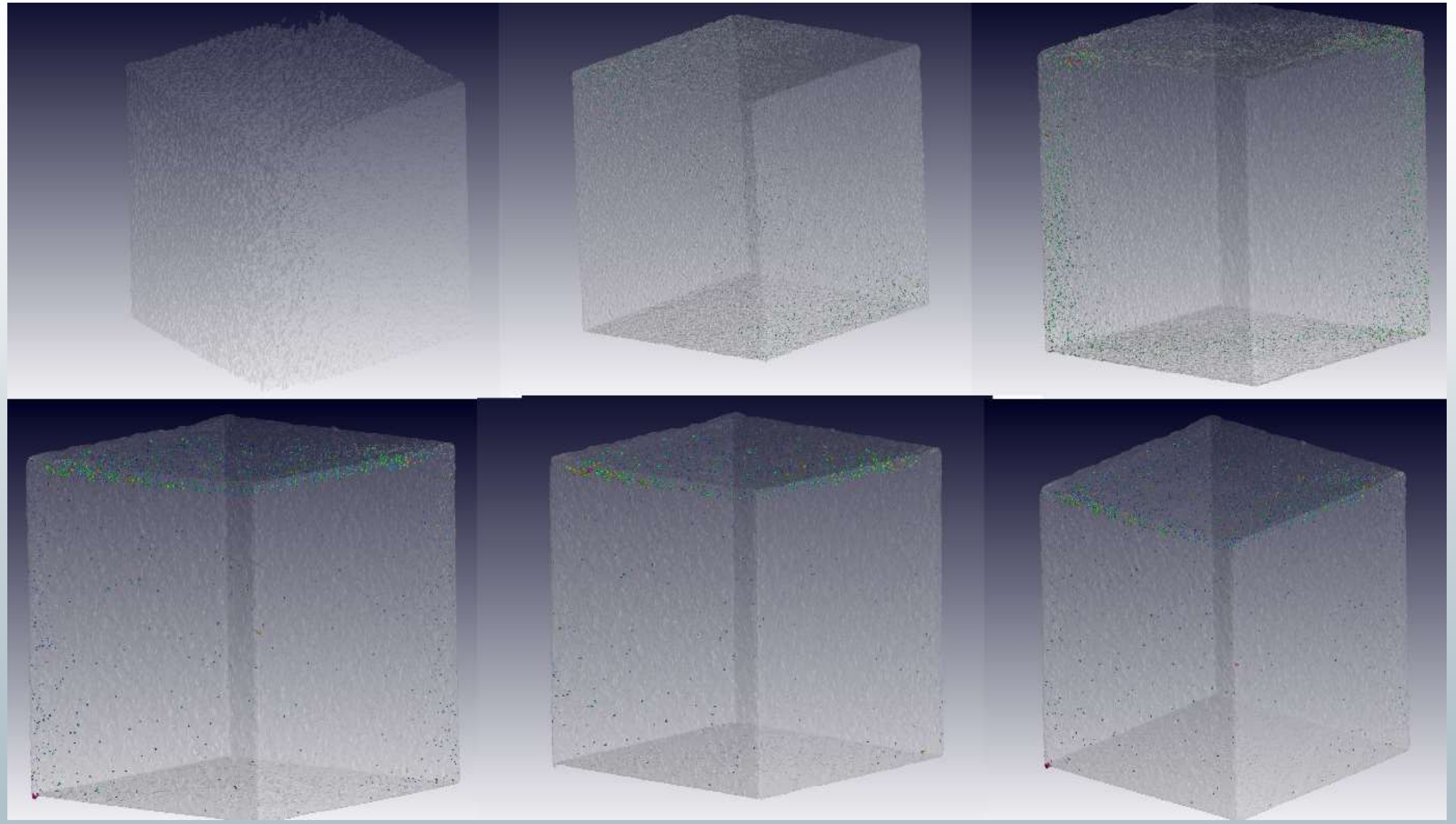
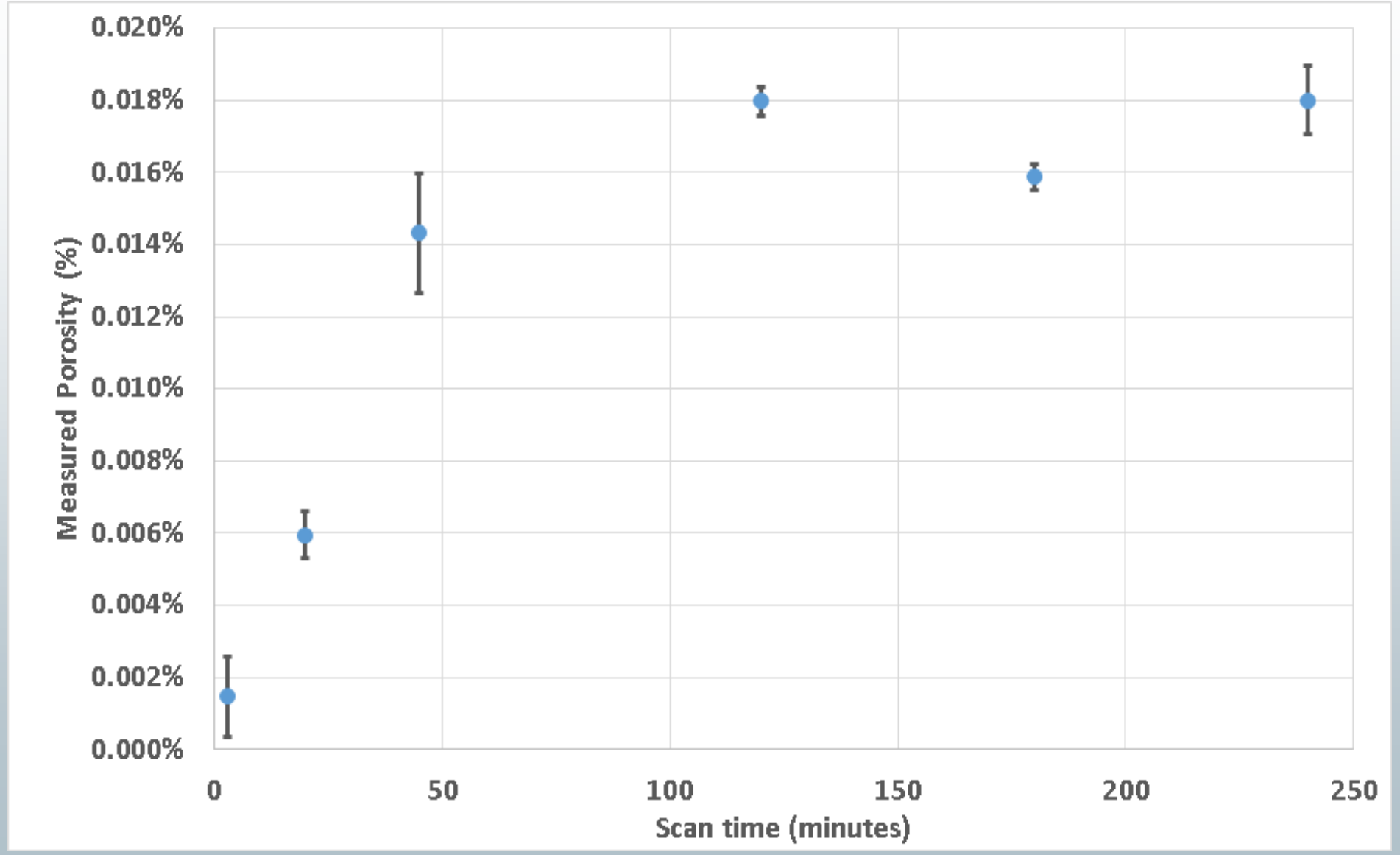


IMAGE QUALITY QUANTIFICATION – SCAN TIME



CONCLUSIONS

- An overview was given of Tomography for Scientific Advancement in the field of metal Additive manufacturing
- Huge potential to improve additive processes and assist in qualification of parts for high end applications
- Image quality quantification is now possible in CT scans (not only for AM cubes)

CONTACT

- For my research & publications:
  - Blogs.sun.ac.za/duplessis
  - Email anton2@sun.ac.za
  - Please connect with me on researchgate, linkedin and twitter
  - Facility: www.sun.ac.za/ctscanner

South African connections

Veno Naidoo, currently at zeiss uk

Acknowledgement for all collaborators, especially:

Prof Igor Yadroitsev

Dr Ina Yadroitsava

THANKS FOR LISTENING!