John Mitchell
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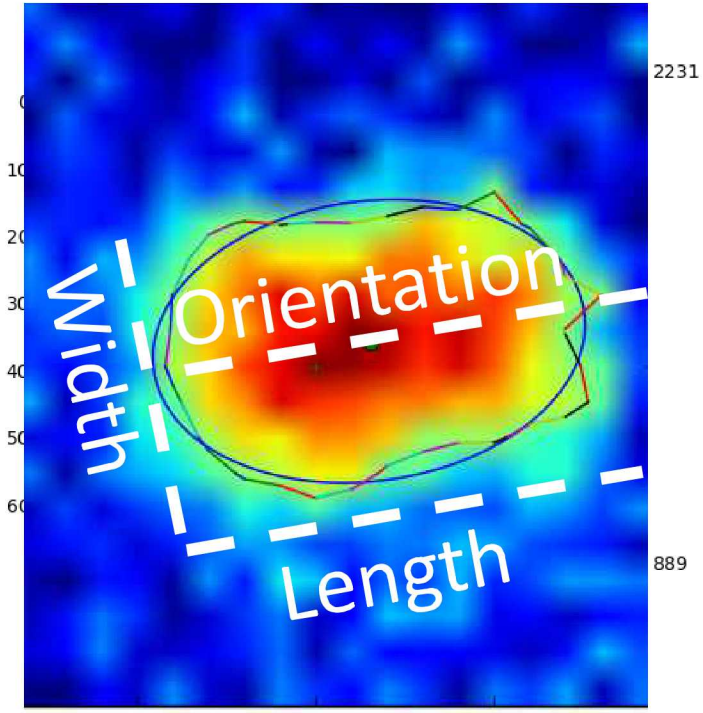
Linking pyrometry to porosity in additive manufactured metals

Thomas Ivanoff, Jon Madison, Daryl Dagel, Bradley Jared, Joshua Koepke, David Saiz, Laura Swiler

Thermal image



ANNUAL INTERNATIONAL SOLID FREEFORM FABRICATION SYMPOSIUM
August 12-14, 2019, Austin, Texas

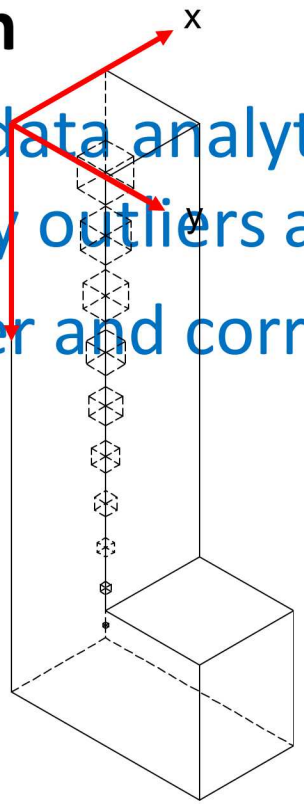
Linking in-situ pyrometry to pores

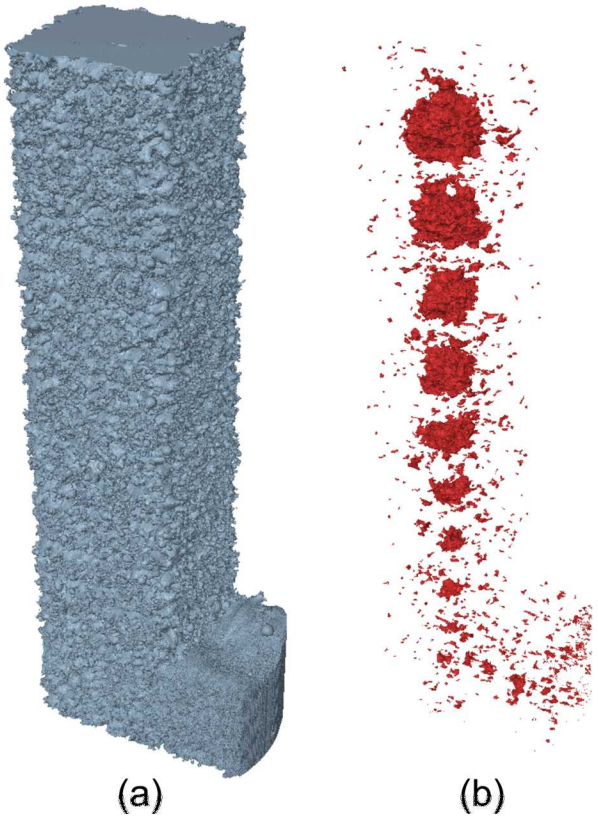
Challenge and Importance

- Pore formation in the AM process reduces material strength and quality and is difficult to predict

Approach

- Apply data analytics t ata to identify outliers and p l built parts
- Register and correlate micro-ct





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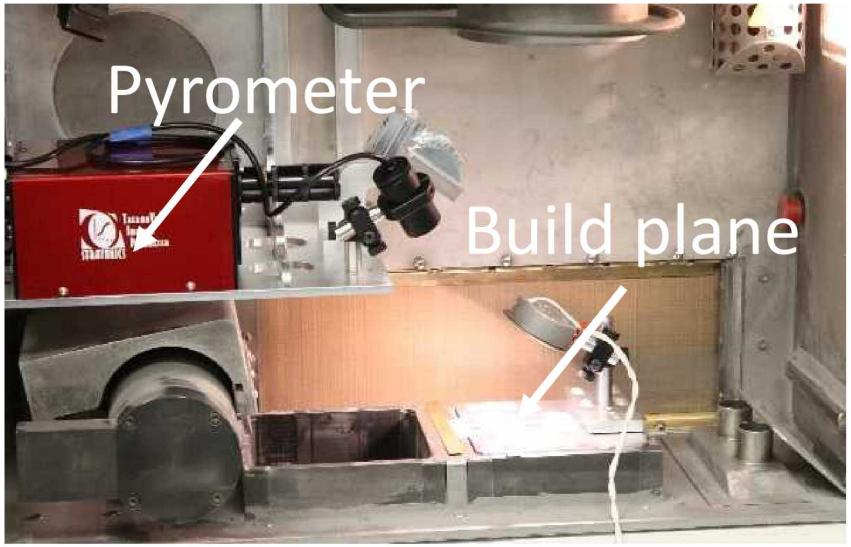
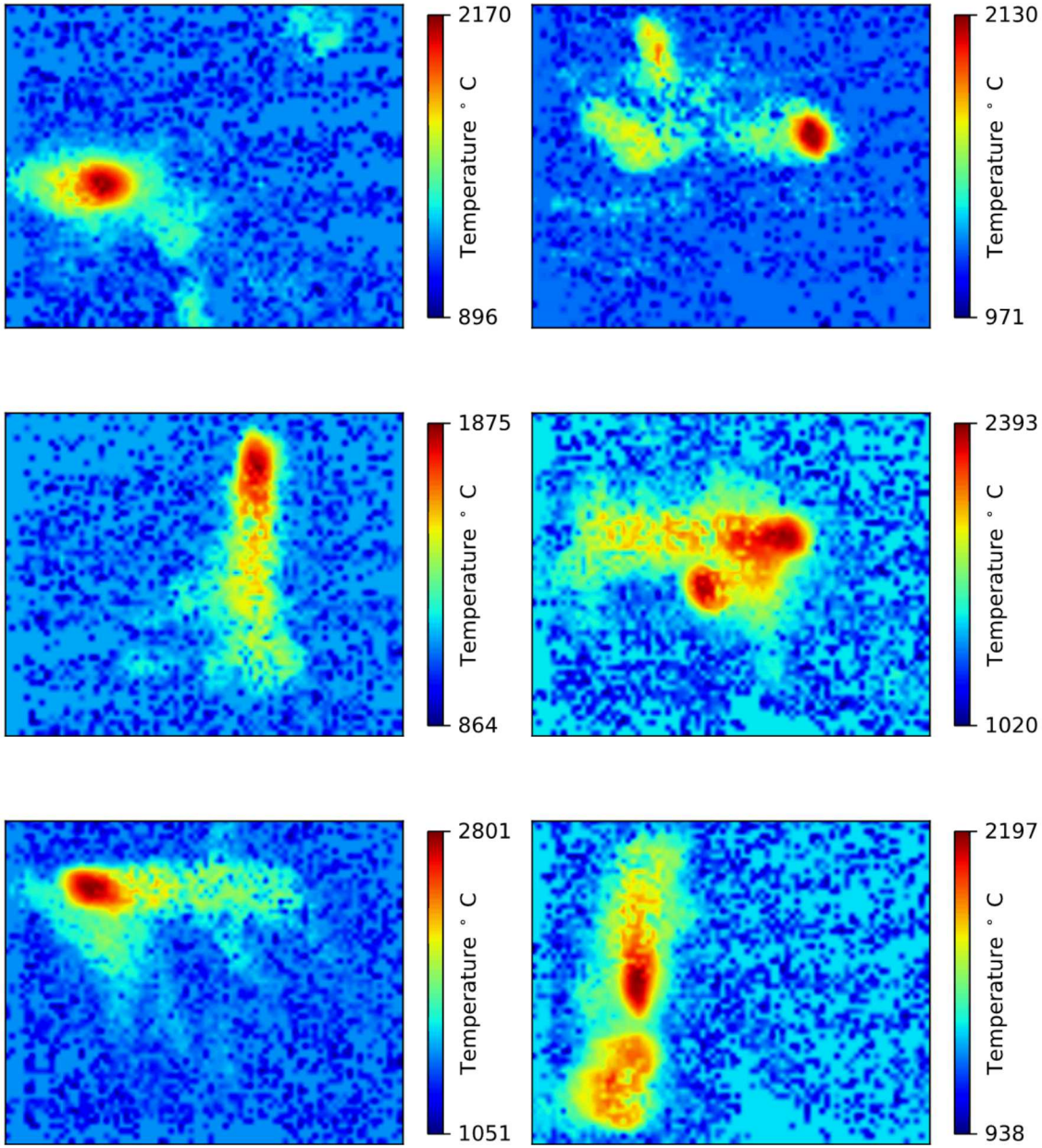
Pyrometry monitoring

- Stratonics Therma-Viz two-color pyrometer
  - CMOS, ~20µm/pixel
  - 750 & 900nm filters
- Fixed field, angled side viewing
  - FOV: 80 x 65 pixel (1.6 x 1.3mm)
  - frame rate: 6-7kHz
  - exposure: 90µsec
- Challenges
  - image resolution & registration with micro-ct data
  - emissivity variation – temperature estimation



Classifying outliers (right column)



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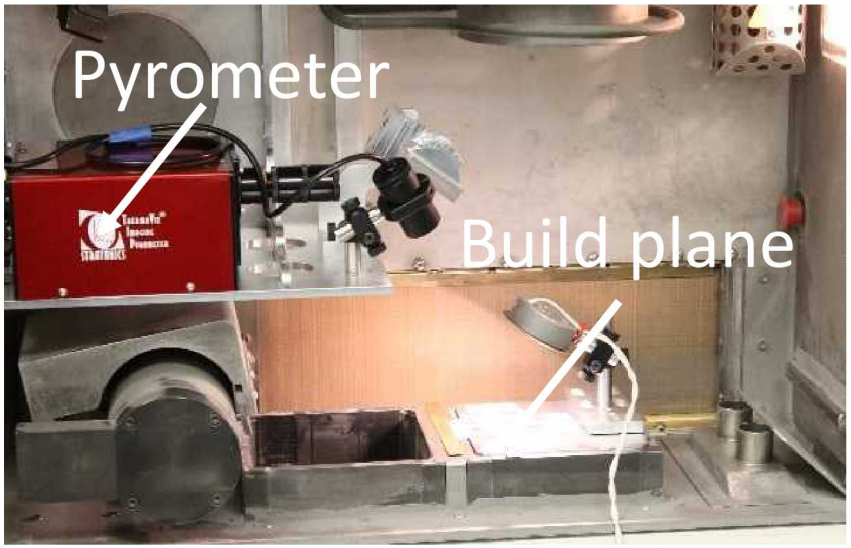
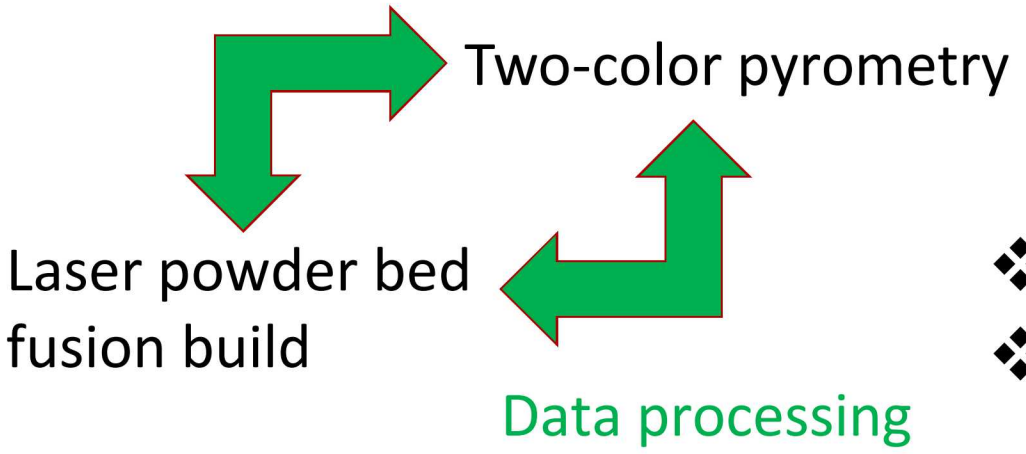
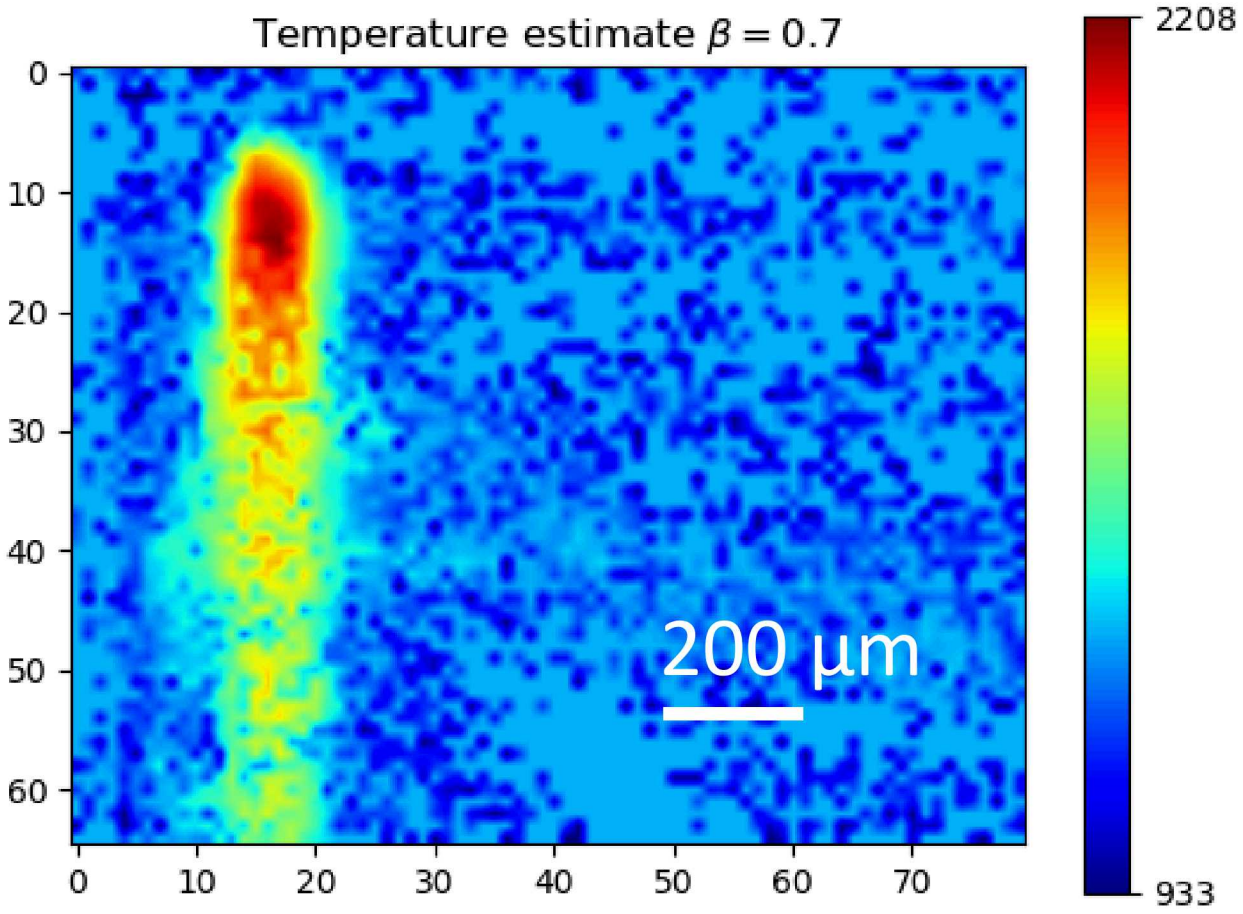
Processing steps





- Tens of thousands of files
- Multiple passes
- Remove images
  - Weak signal
  - Laser at image edge
- Process smaller set
  - Estimate temperatures
  - Contouring
  - Ellipse fit
- Process plots
- Classify images

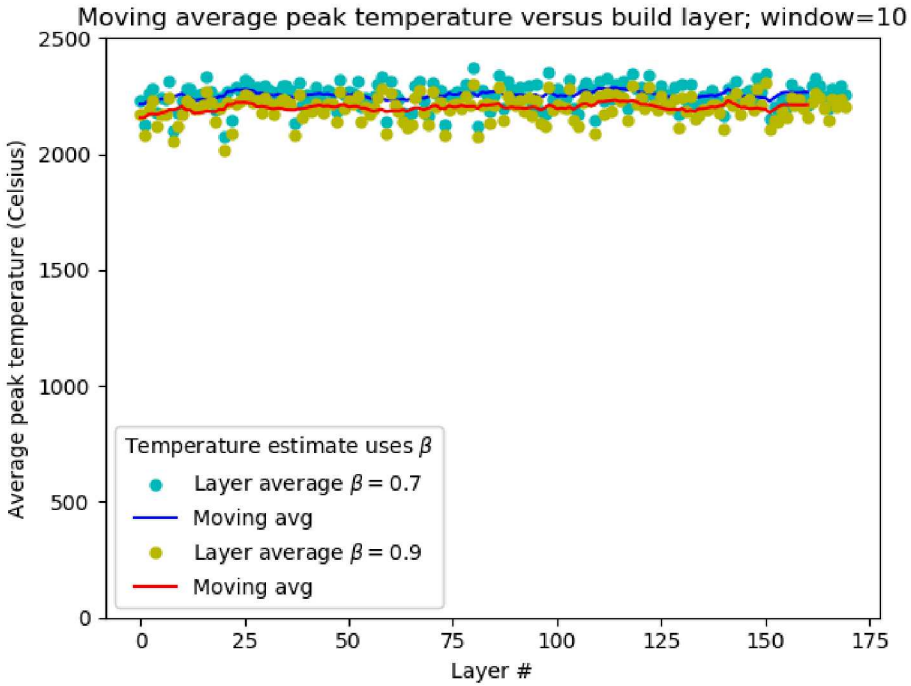
Estimate temperatures*

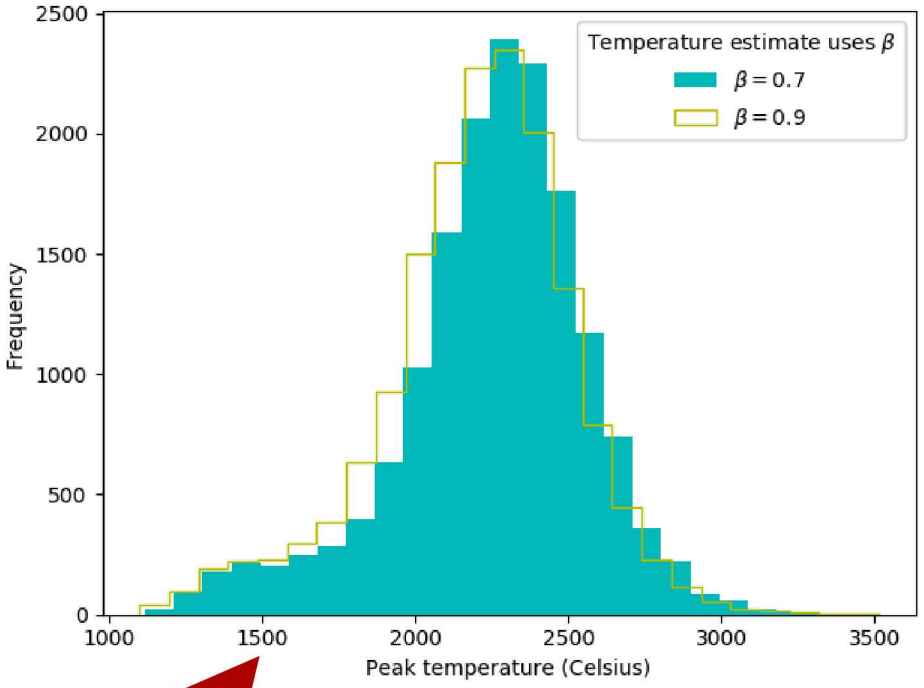


*Dagel, Daryl, J, et al., *Four-color imaging pyrometer for mapping temperatures of laser-based metal processes*, Sandia National Laboratories report SAND2016-3453C.

Pyrometer data processing

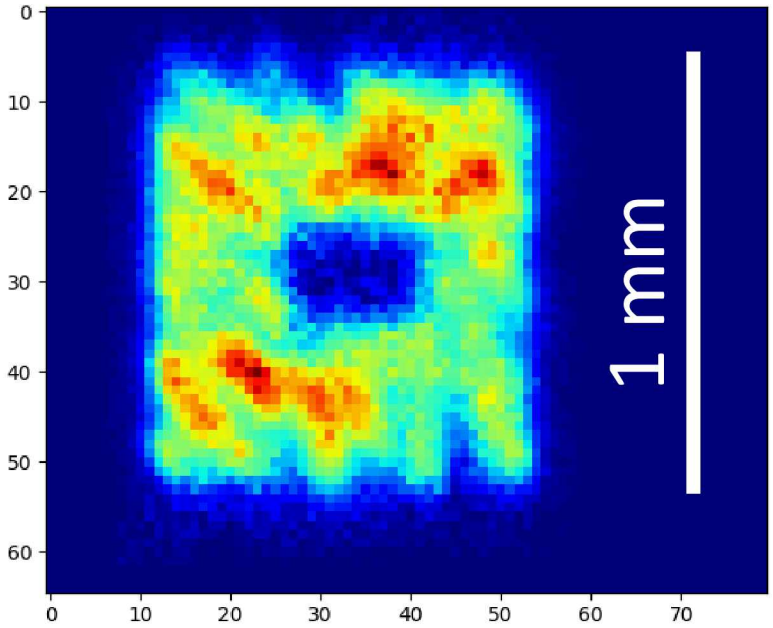
Moving average temperature history by layer

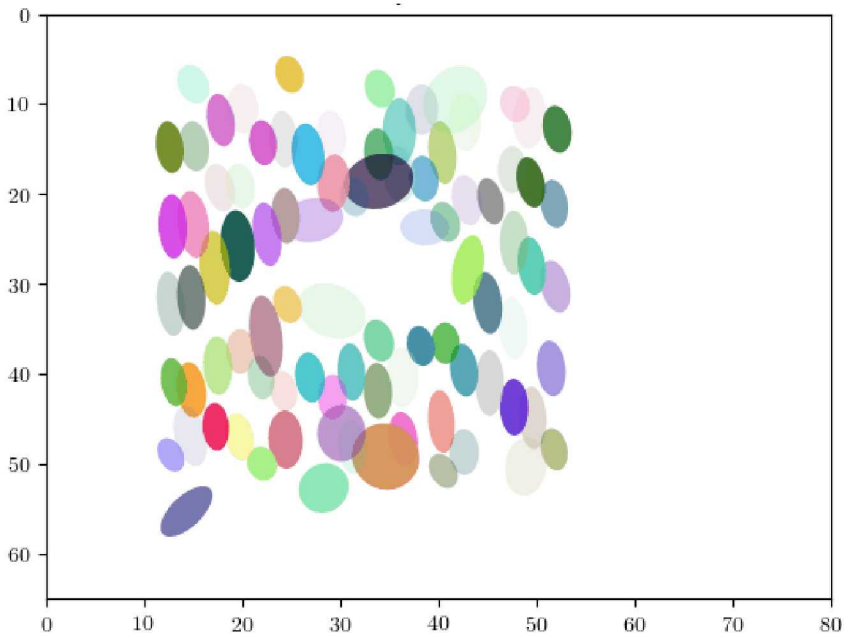




melt temperature

Raster path observation
Layer 119



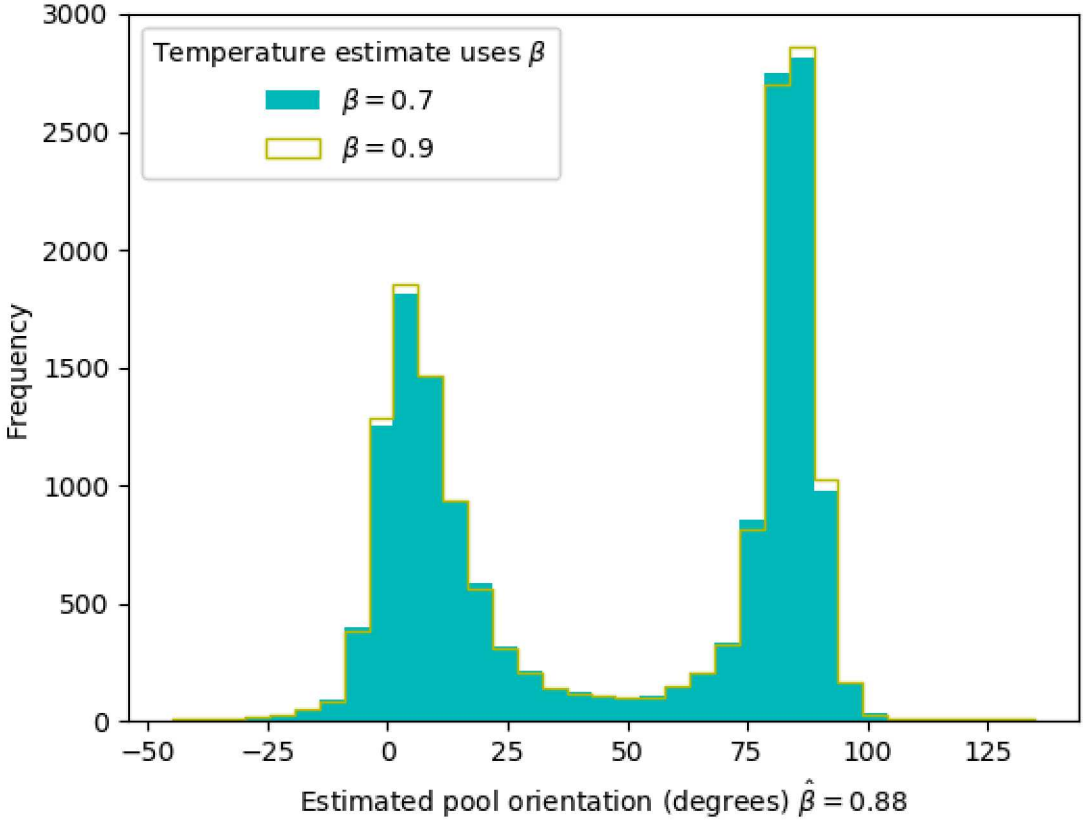


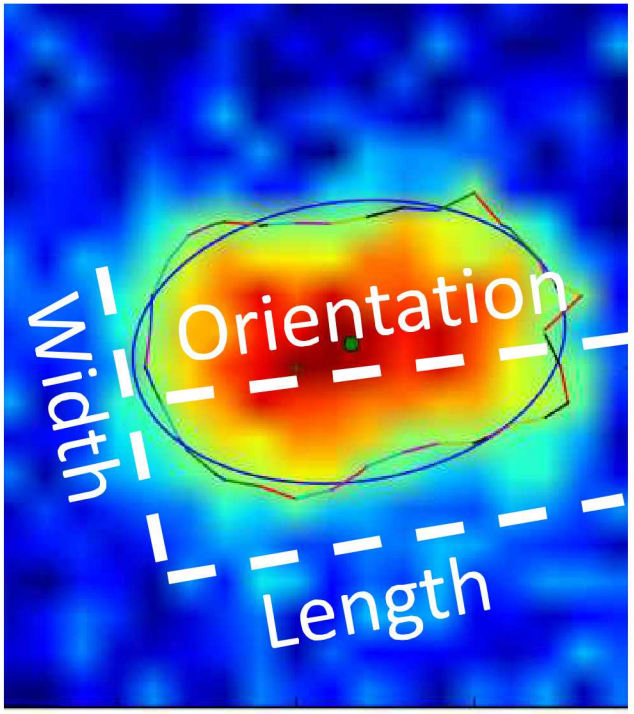
History of thermal
Input at each pixel

Best fit ellipse

- Size
- orientation

Pyrometer data processing
Pool orientation (best fitting ellipse)





Linking in-situ pyrometry to pores

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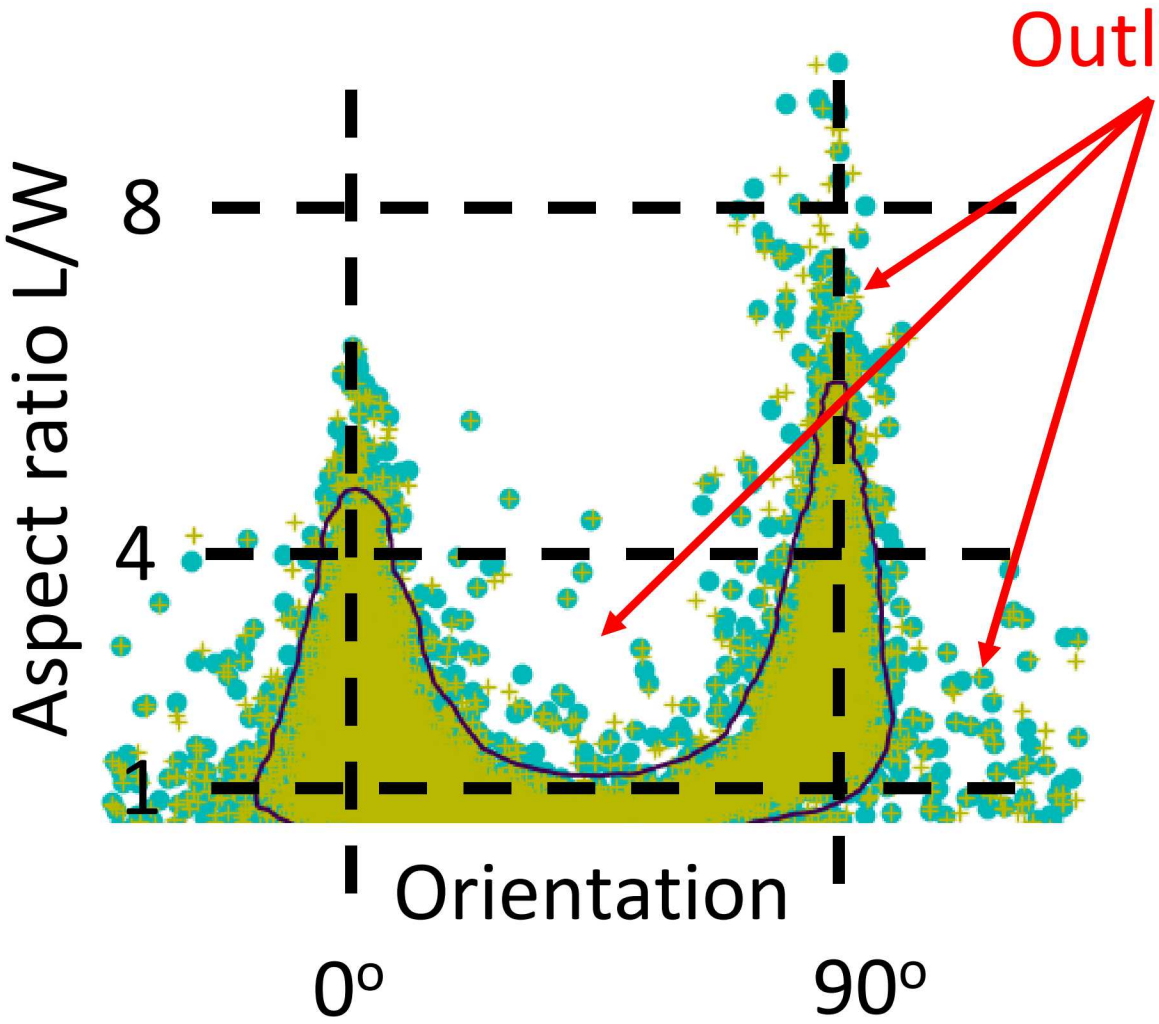

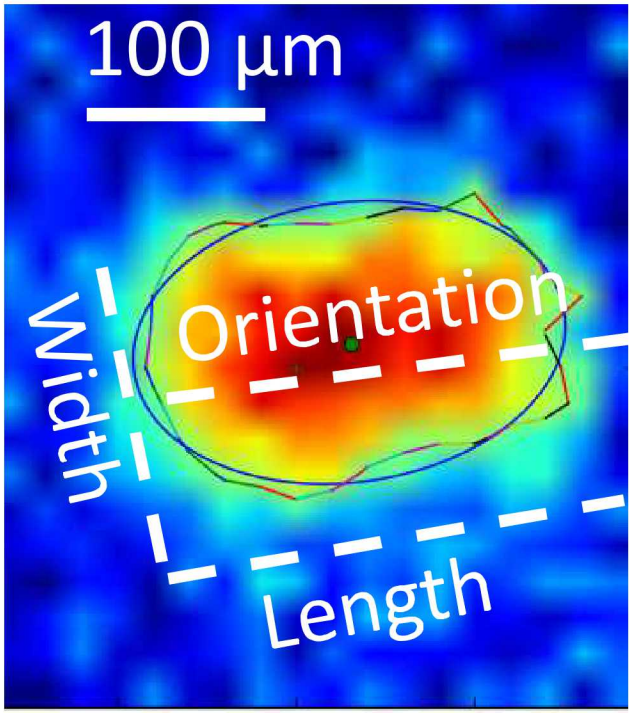

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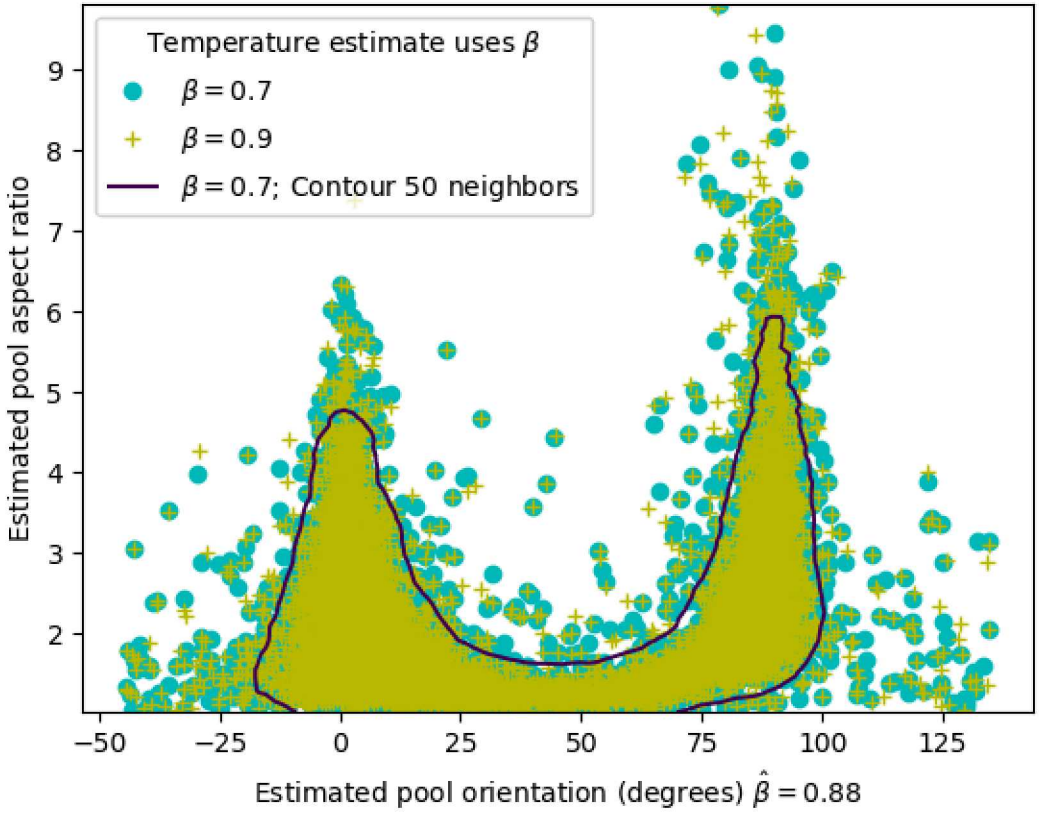
Linking in-situ pyrometry to pores

Data analytics: Identifying outliers

- Map feature space to unit dimensions
- Clustering via kdtree
- Threshold on number of neighbors



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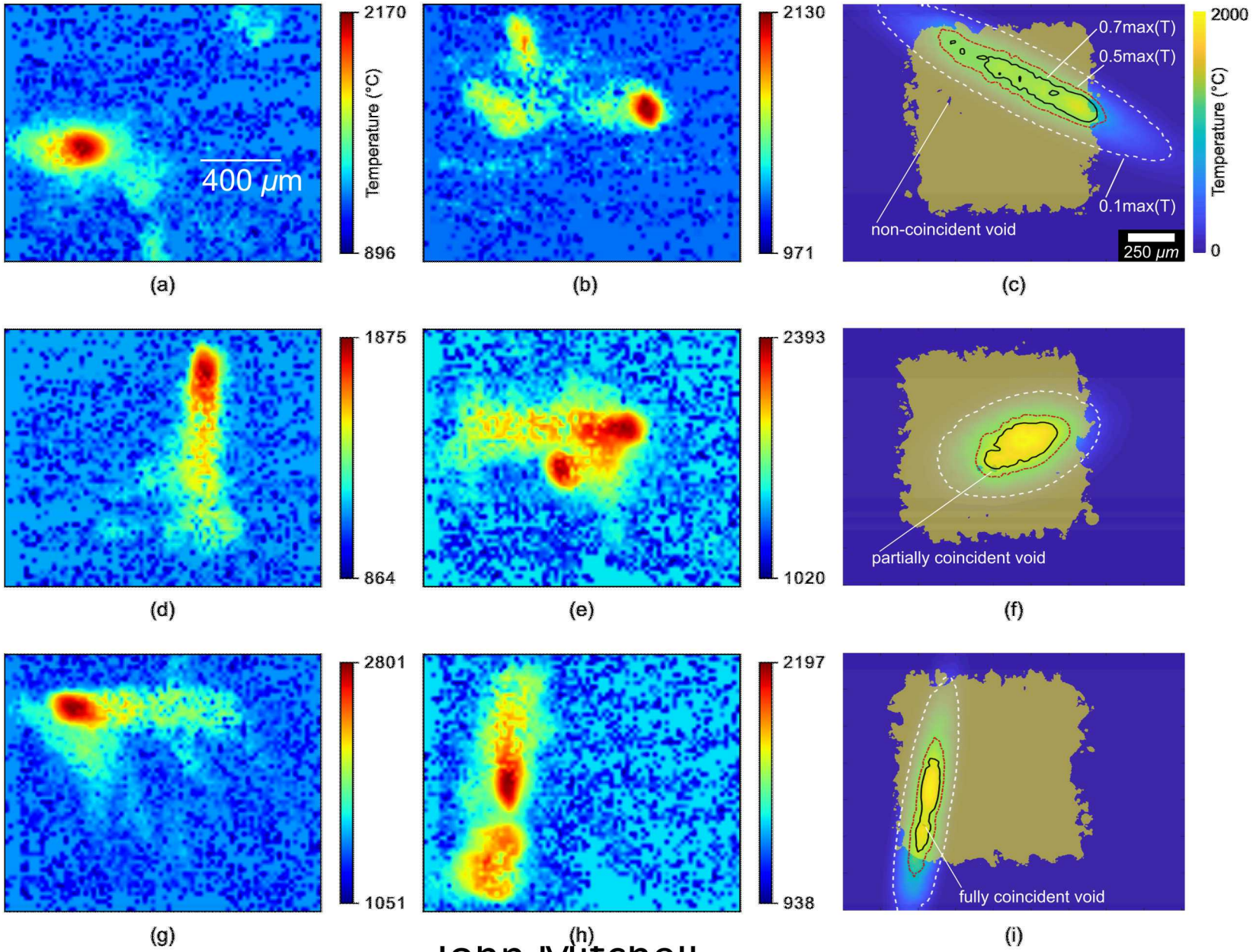
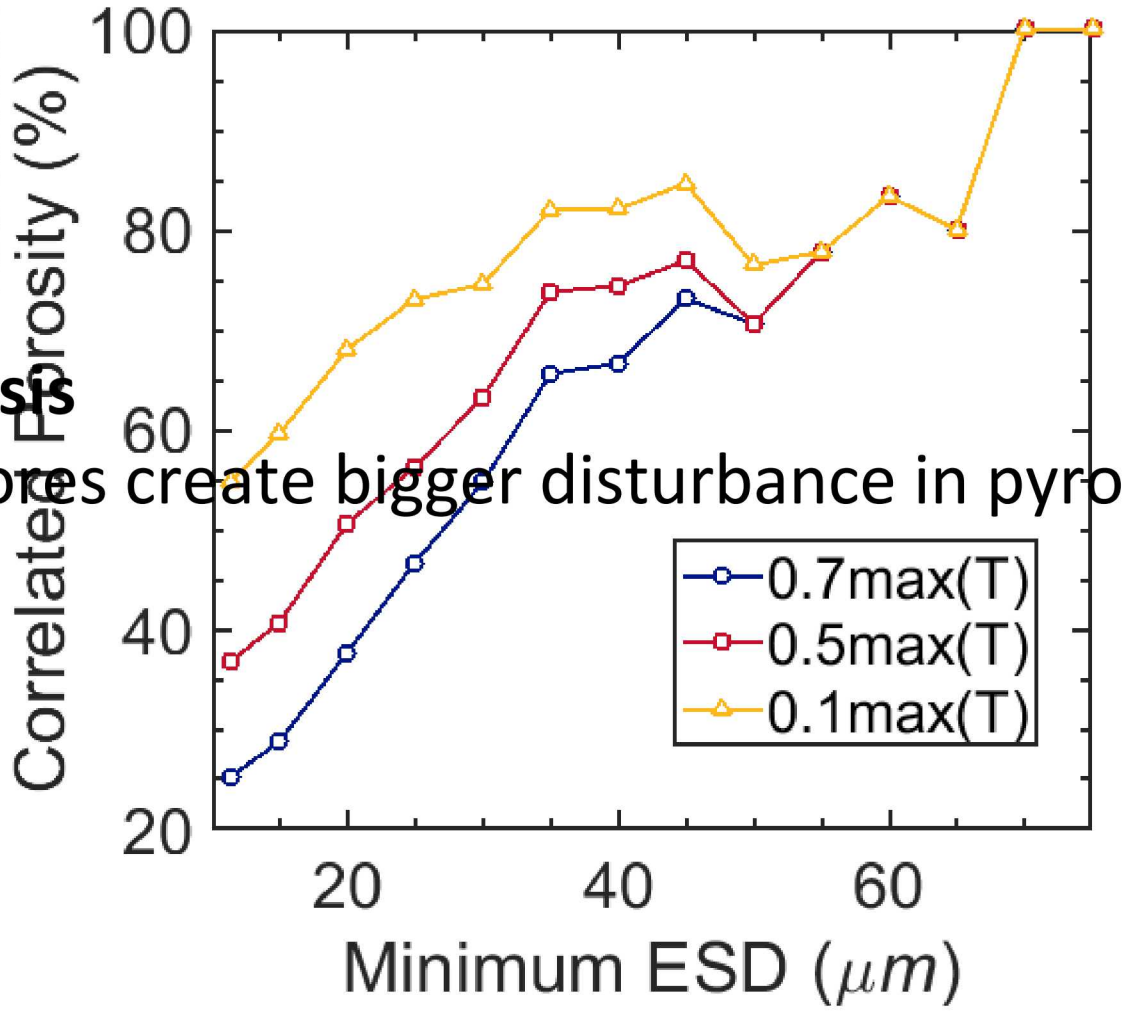
Linking in-situ pyrometry to pores



Linking in-situ pyrometry to pores

Outliers correlated with pores by size

Minimum E	60	70
Thresh $0.1T_l$	83%	100%
Thresh $0.5T_l$	83%	100%
Thresh $0.7T_l$	83%	100%
Total # Pore	6	2



Hypothesis

Bigger pores create bigger disturbance in pyrometry

Linking in-situ pyrometry to pores

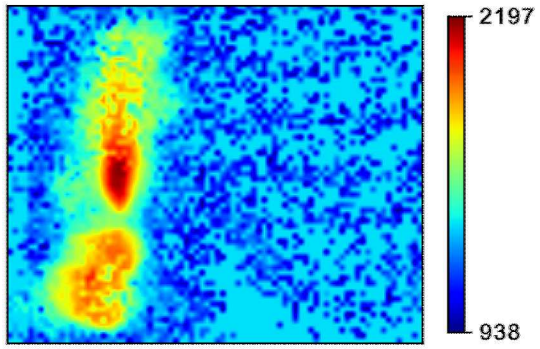
Pore detection rates with and without outlier qualifications

	All Melt Pools (10,598)		*Outlier* Melt Pools (458)	
	Correlated Pores	Detection Rate	Correlated Pores	Detection Rate
Thresh $0.1T_p$	580 (94%)	0.06	529 (55%)	1.20
Thresh $0.5T_p$	576 (93%)	0.05	356 (37%)	0.78
Thresh $0.7T_p$	560 (91%)	0.05	245 (25%)	0.53

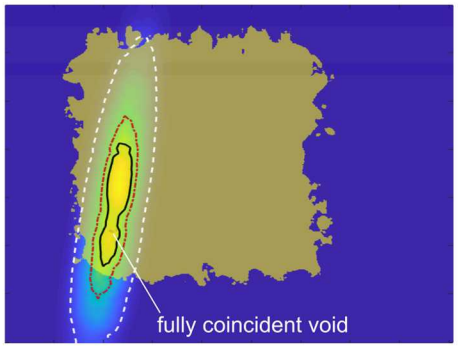
Pore detection rates for outliers is better than luck

Linking in-situ pyrometry to pores

Pyrometry



CT Overlay (pore) with pyrometry



Conclusions

Paper has been written and submitted (in review)

- Laser powder bed fusion in-situ pyrometry monitoring
- Processed large pyrometry datasets
- Computational strategy for identifying instantaneous anomalous conditions from pyrometry (*outliers*)
- Computer tomography of built parts (*pores*)
- Demonstrably linked *outliers* to *pores* in built parts (LPBF of stainless steel)