Proton Radiography Peers into Metal Solidification

A.J. Clarke, J.W. Gibbs, S.D. Imhoff, P.J. Gibbs,
D. Tourret, F.E. Merrill, pRad team

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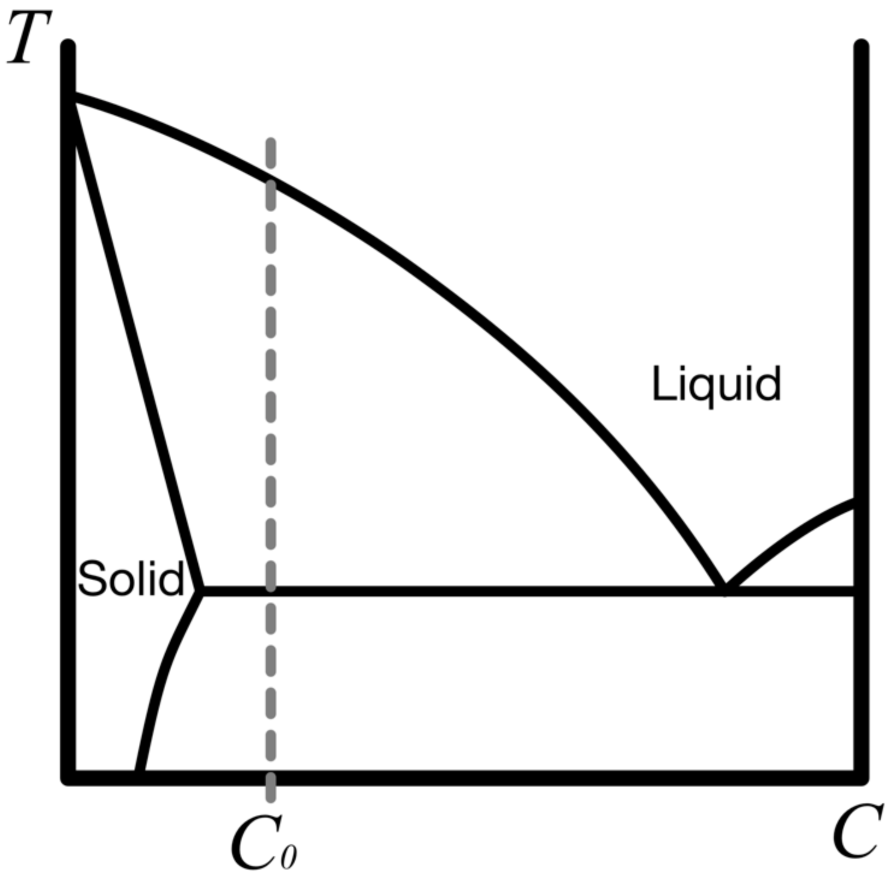
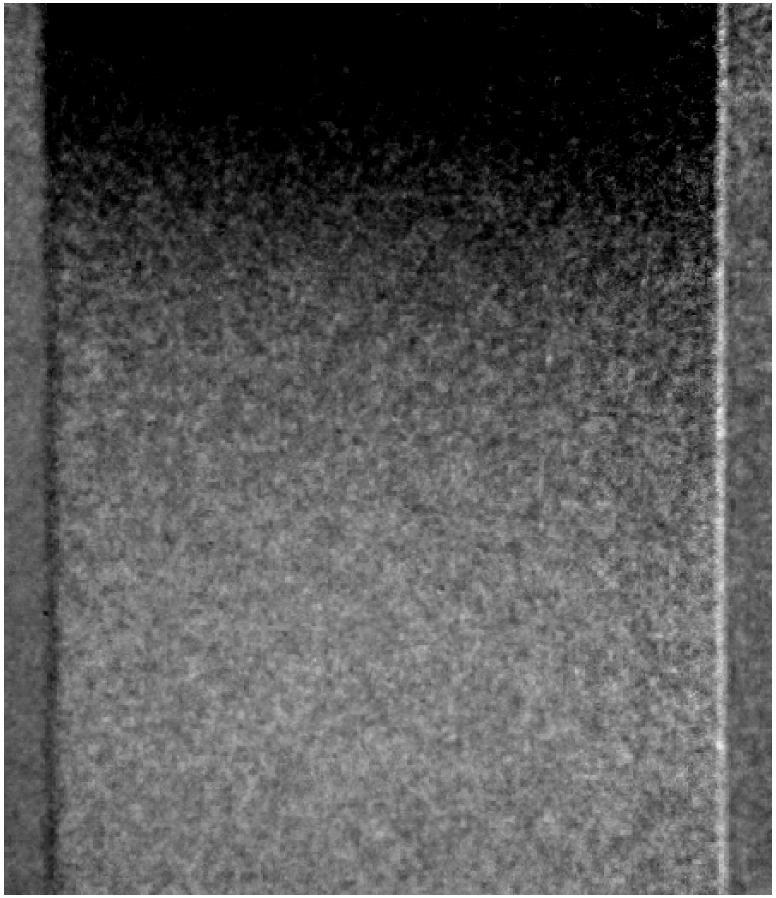
Solidification: chemical inhomogeniety





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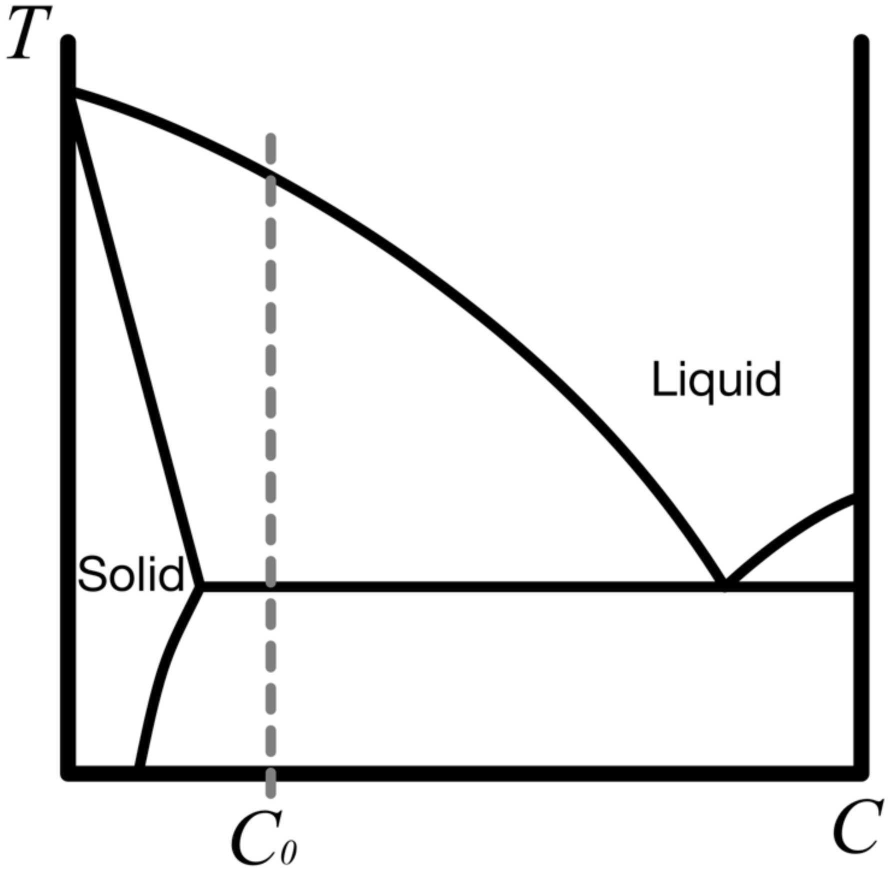
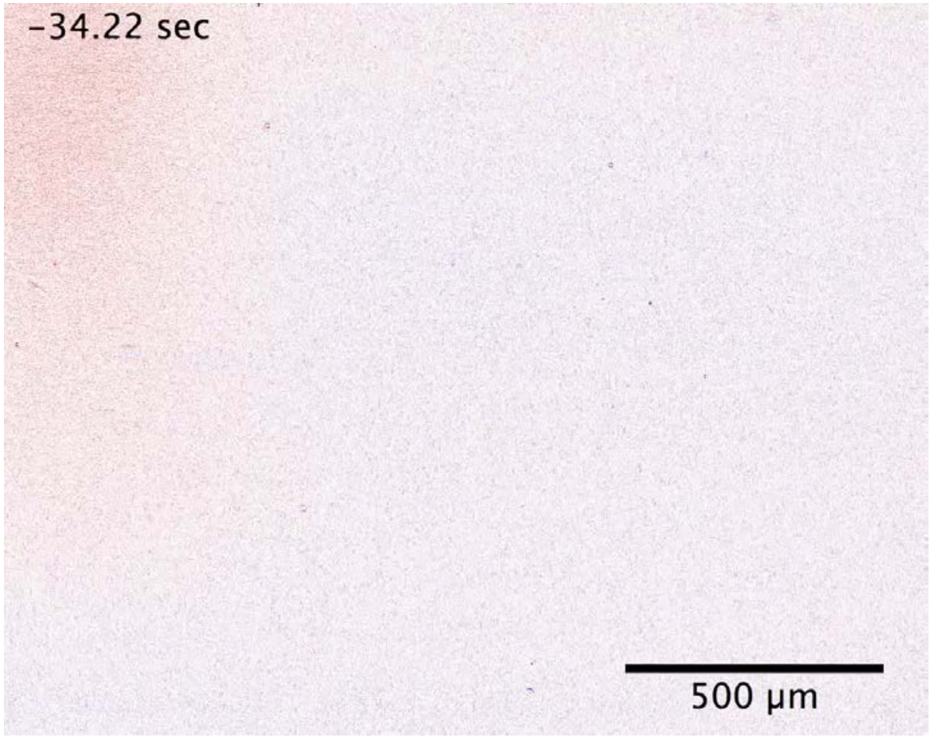
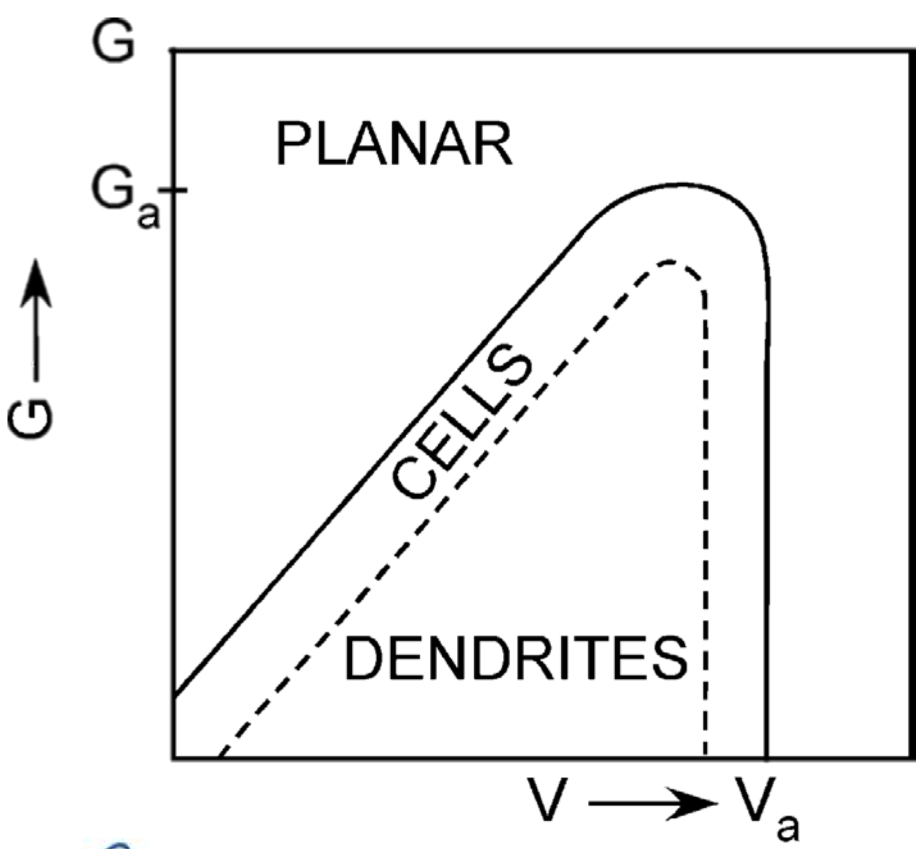
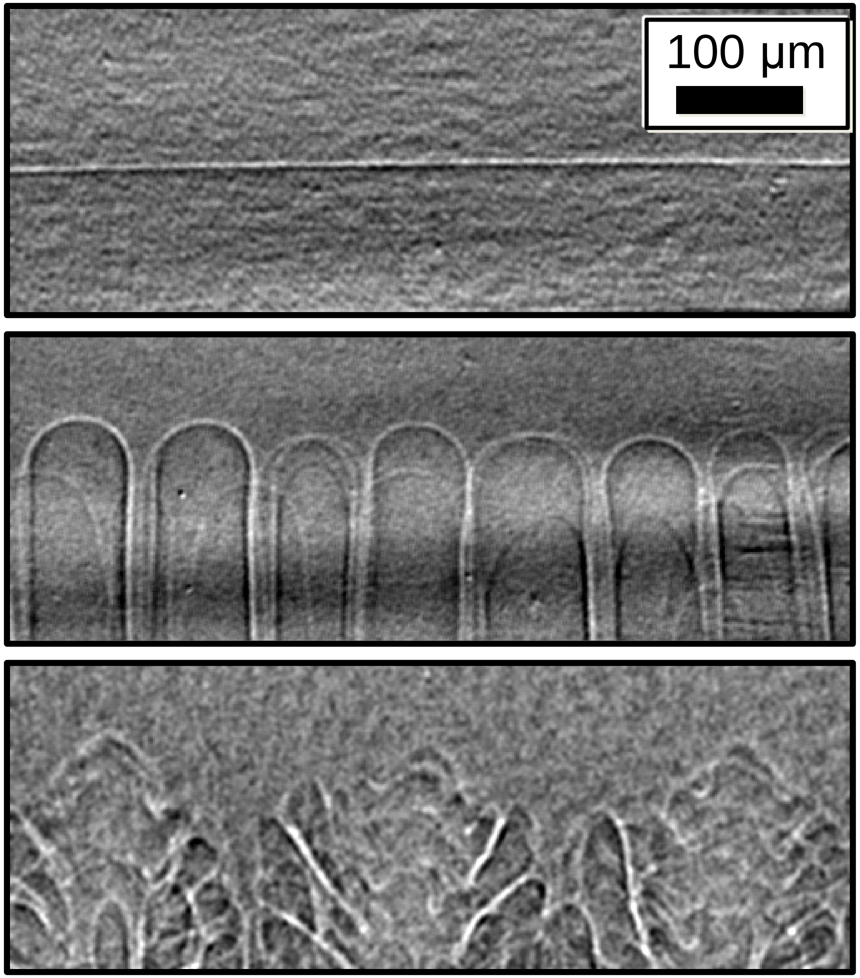


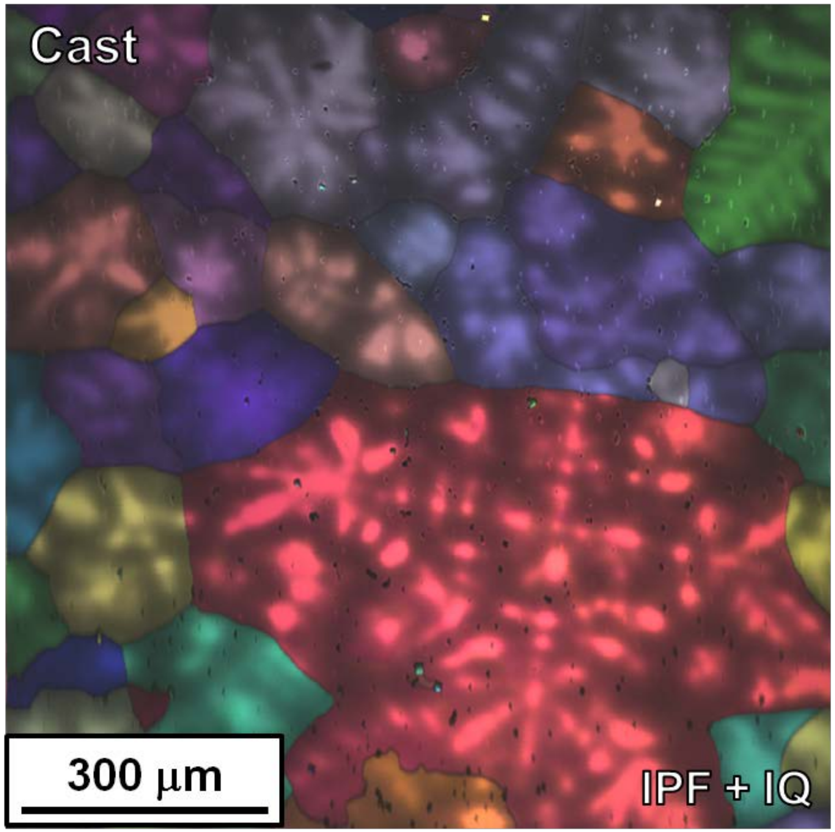


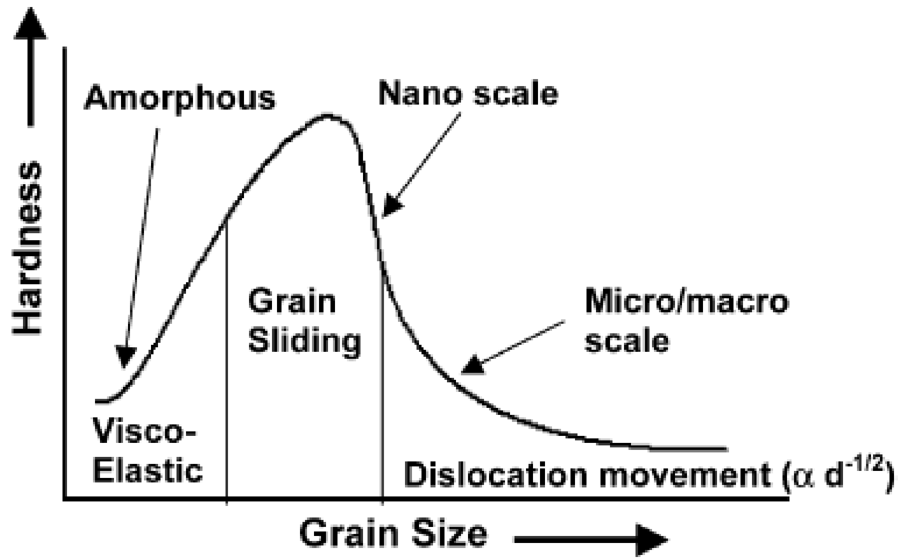
Solidification: pattern formation



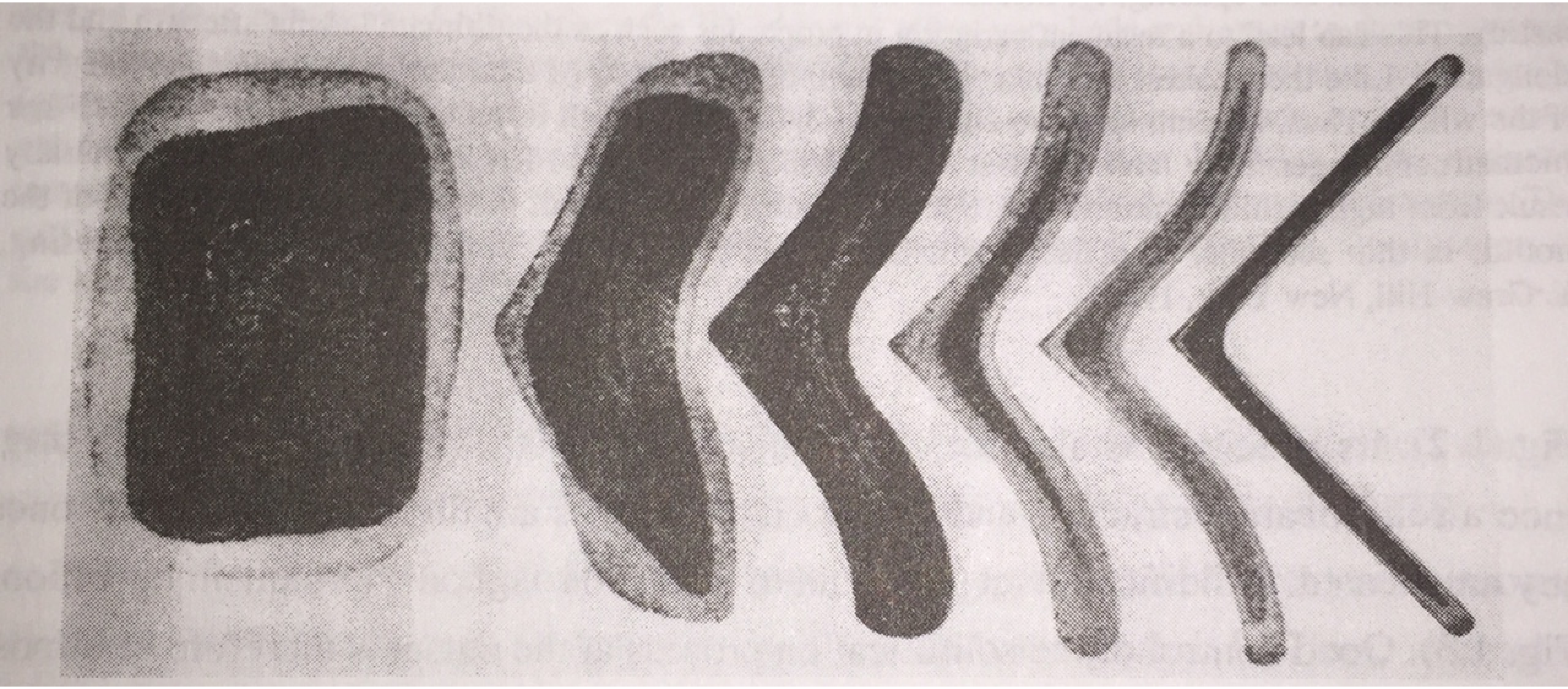


Solidification: relationship to properties





Solidification: persistence

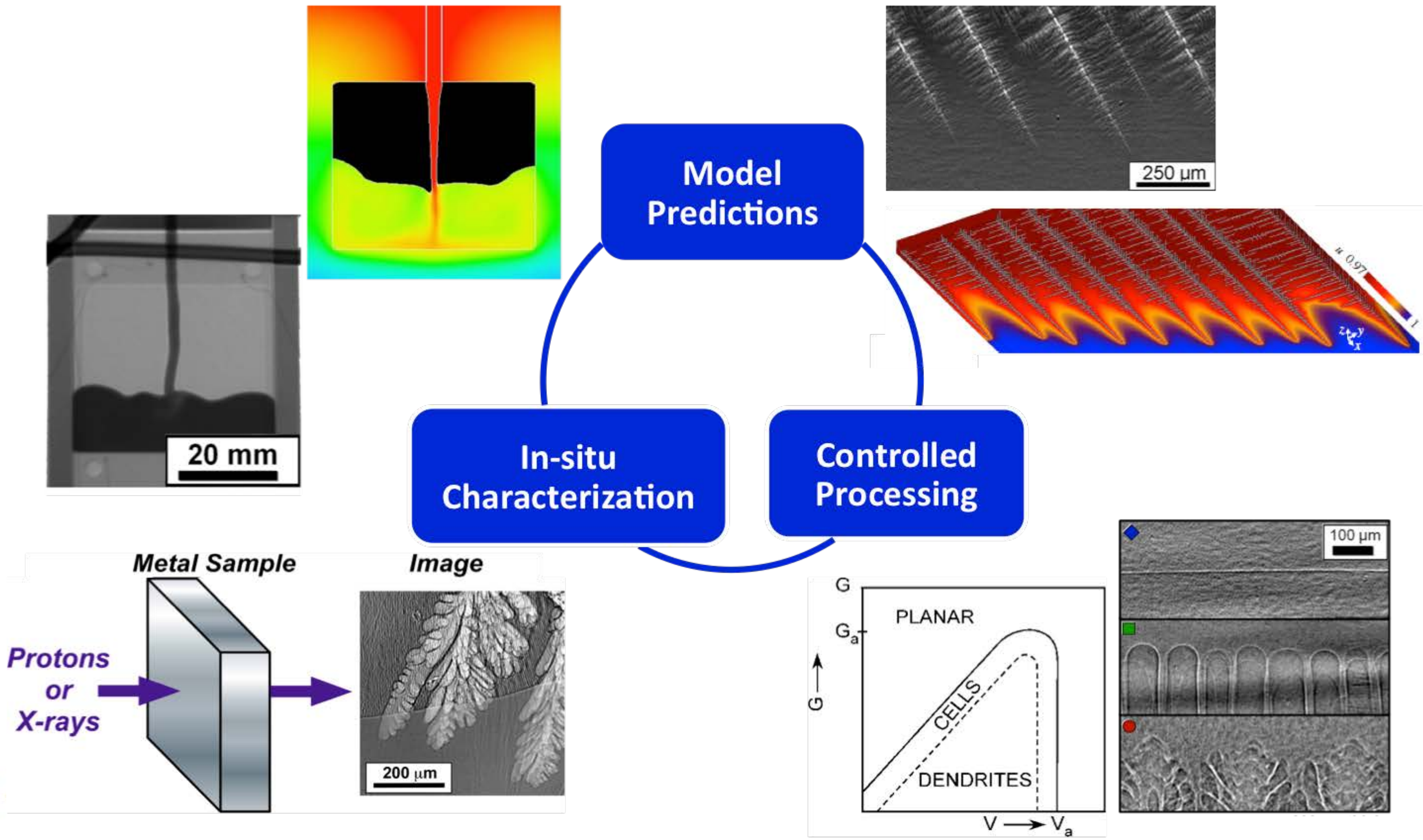


Kurz & Fisher. *Fundamentals of Solidification.* (1998)

Solidification

- Experienced by almost all metals and alloys
- Influences:
  - Grain size and shape
  - Chemical homogeneity
  - Defect type and density
  - Residual stresses

Multi-scale Prediction and Control of Metal Alloy Solidification Dynamics



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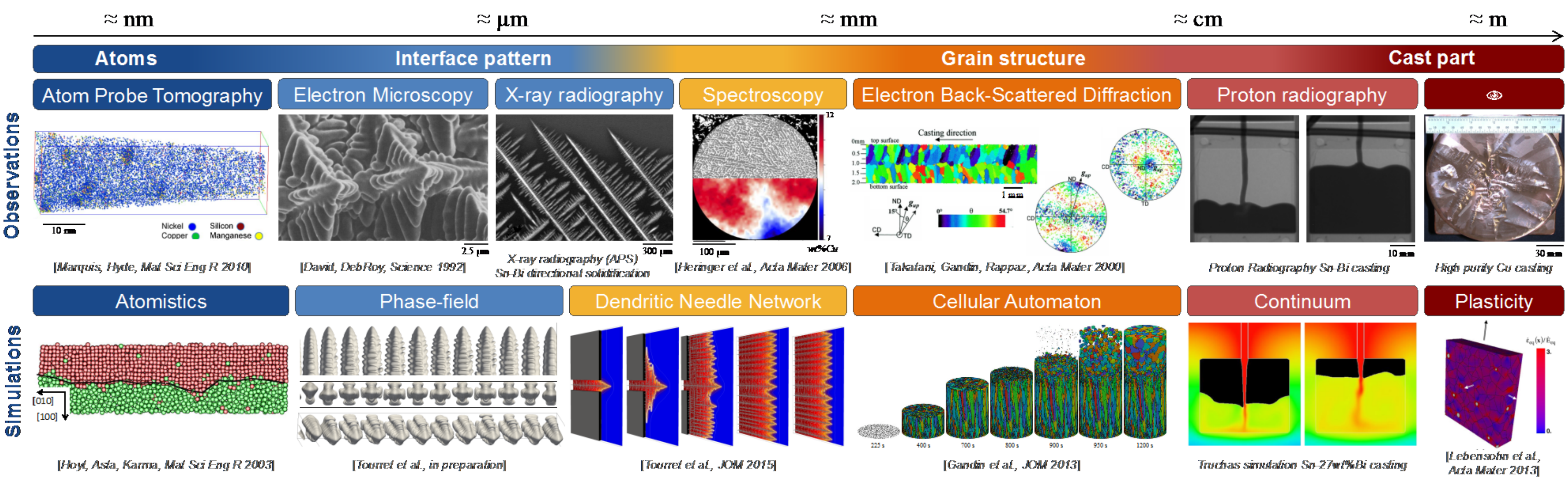
Solidification: multi-scale

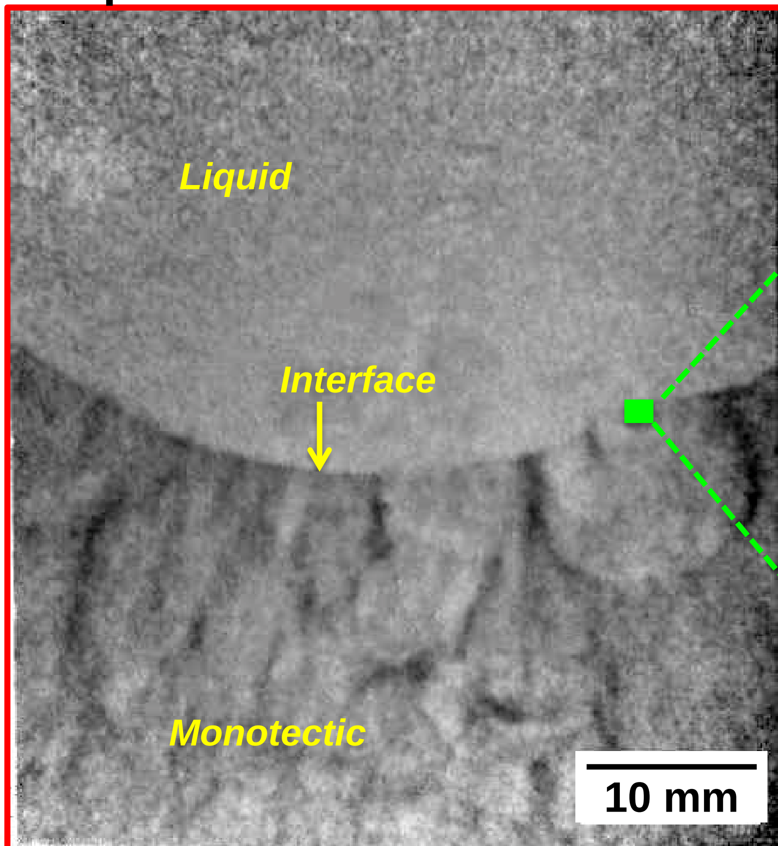


pRad: overview

	X-rays	Protons
Contrast dependence	(Atomic number)^4	Mass density
Sample thickness	~100 µm	µm to cm
Spatial resolution	0.5 to 2 µm	25 to 280 µm
Field of view	1 to 5 mm	17 to 120 mm
Exposure time	ms to s	ns to µs
Frame rate	0.1 to 1000 Hz	20 Hz (for statics)

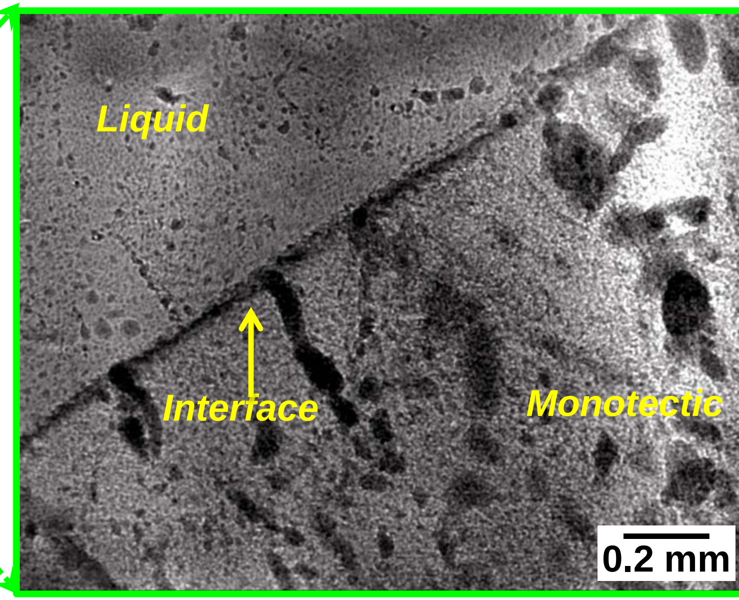
pRad results: microstructure formation

Proton Imaging
pRad at LANSCE at LANL



6 mm thick;
> 10,000 mm^3 volume imaged

X-ray Imaging
APS at ANL

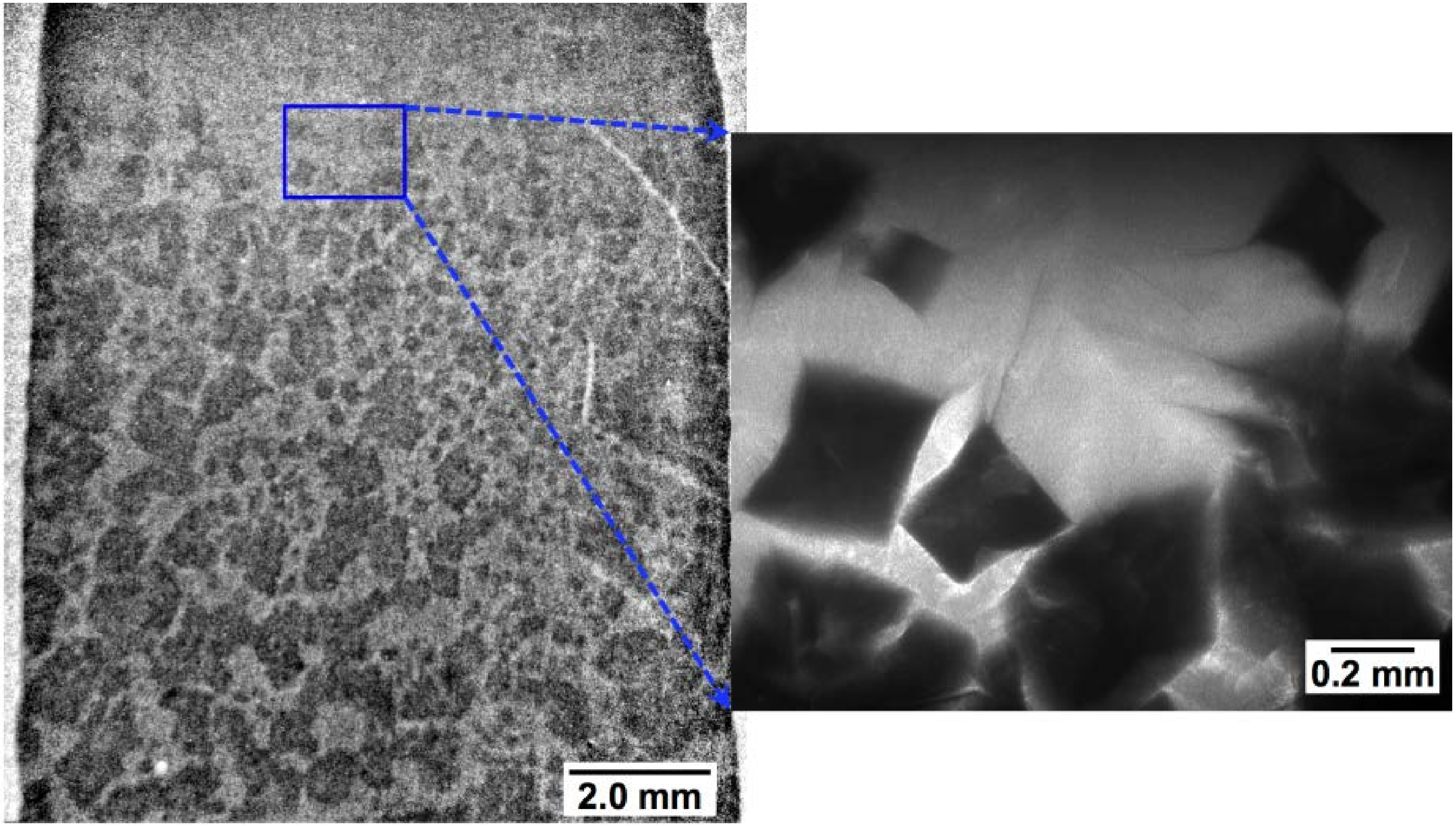


200 μm thick; < 1 mm^3 volume imaged

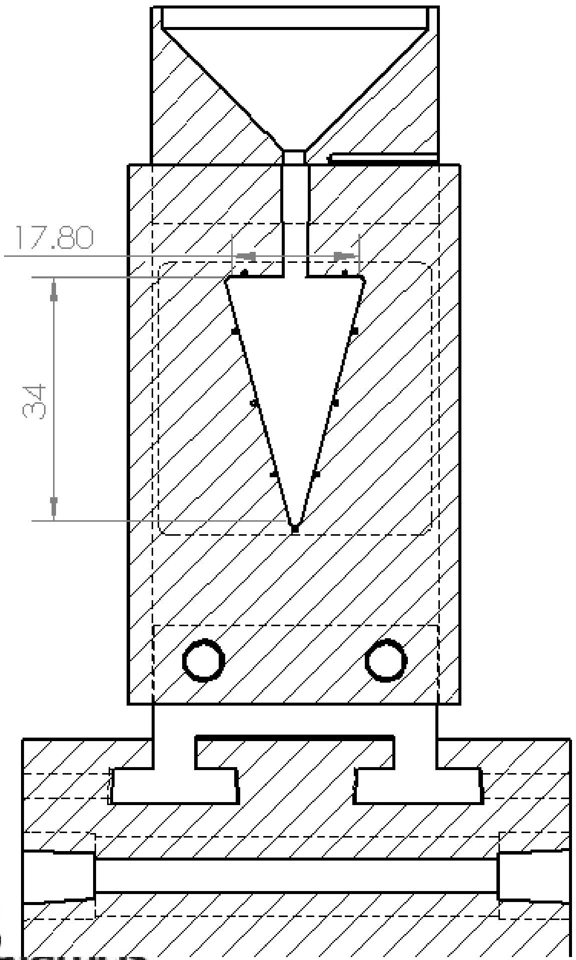
A. Clarke *et al.*, Proton Radiography Peers into Metal Solidification. Scientific Reports 2013; 3:2020

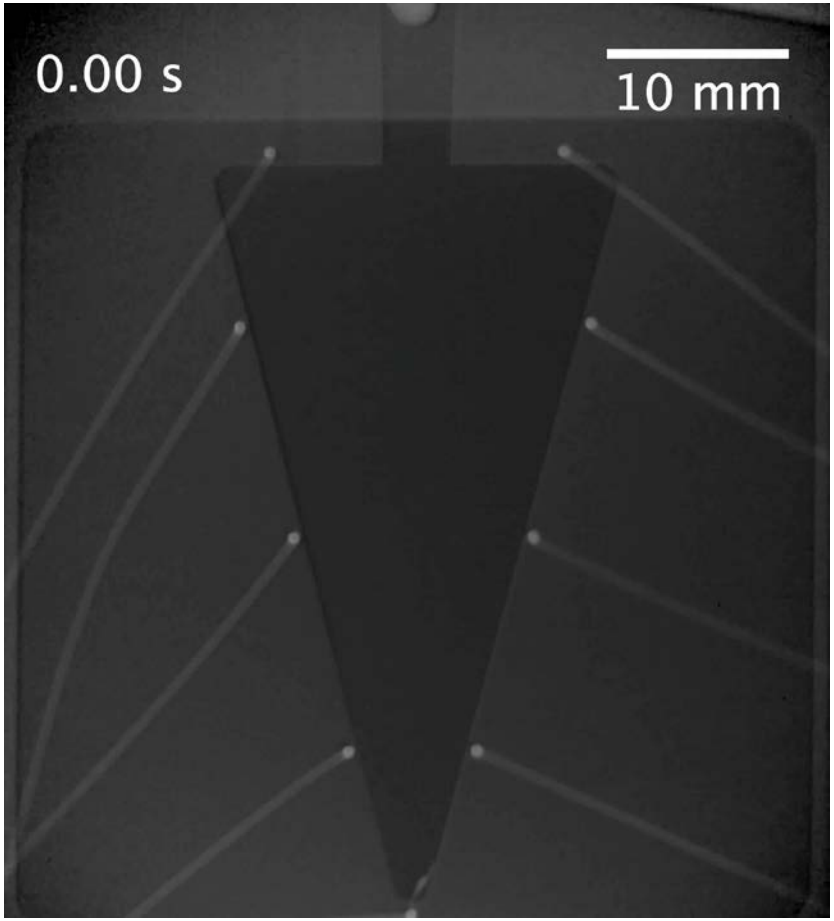
http://www.nature.com/srep/2013/130619/srep02020/full/srep02020.html

pRad results: microstructure formation



pRad to visualize casting process





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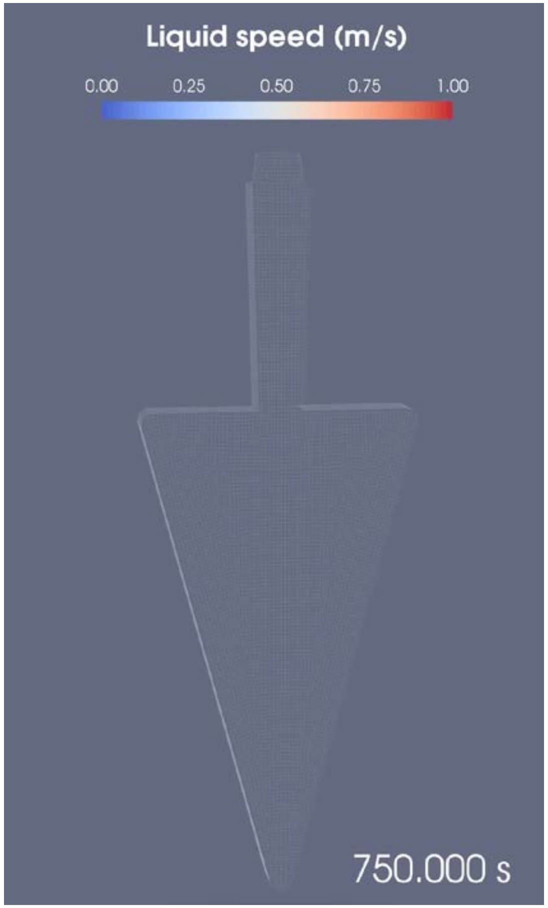

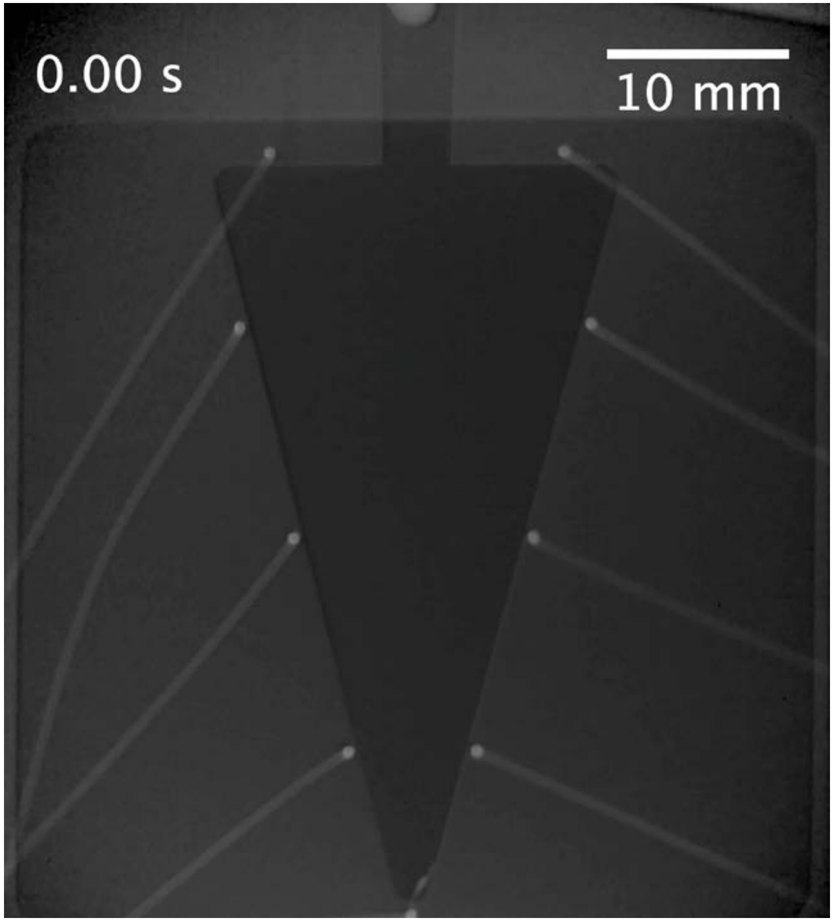

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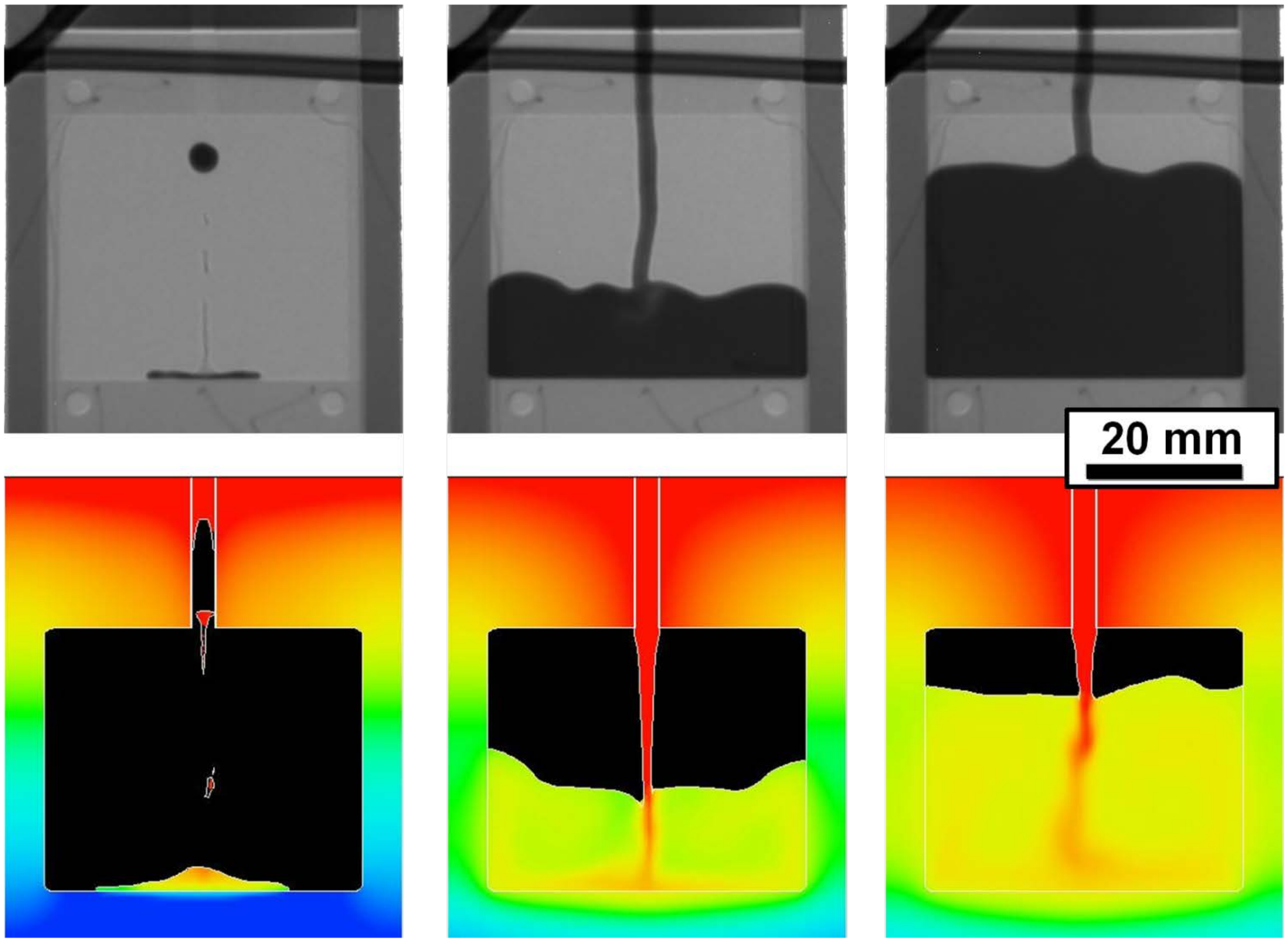

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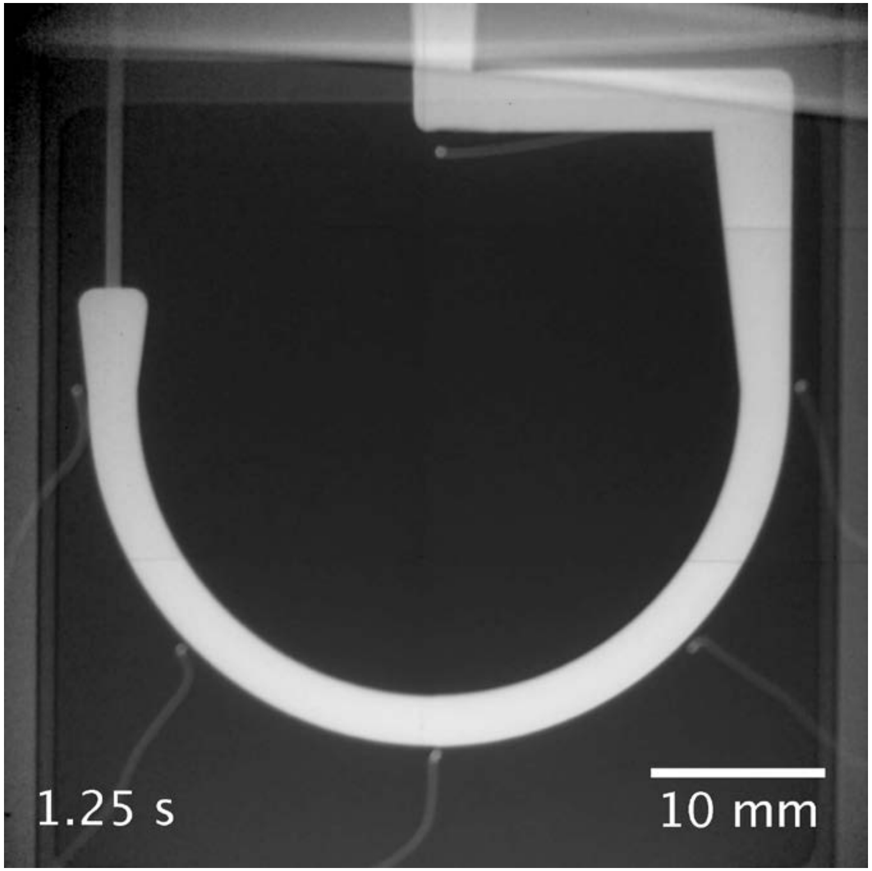
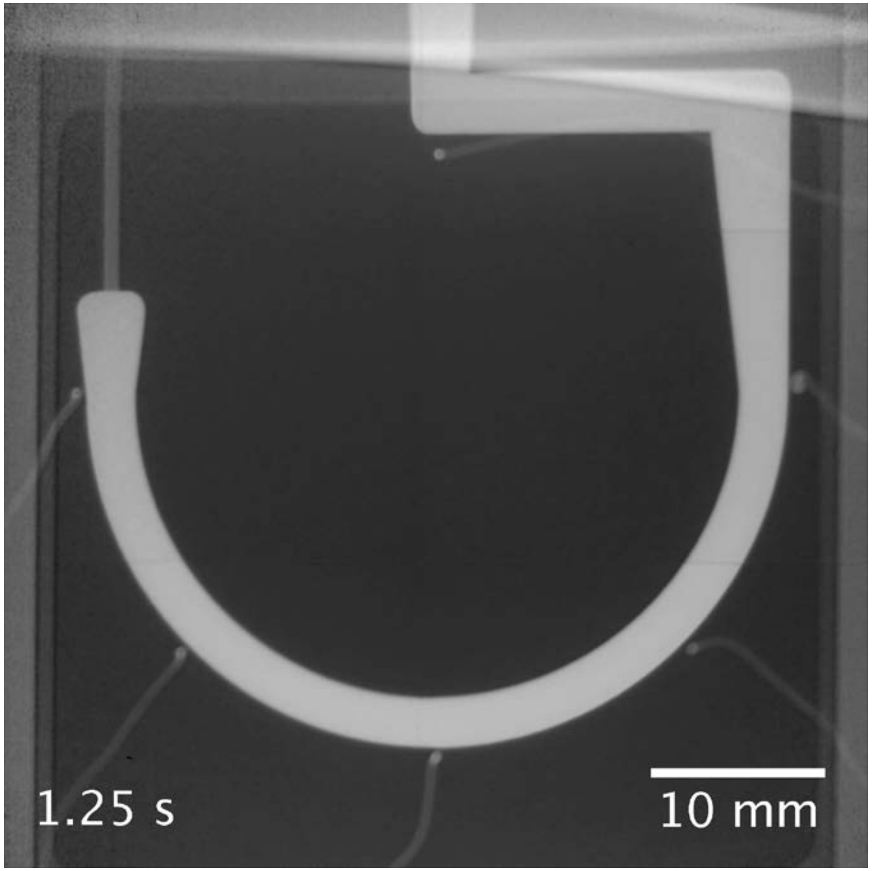
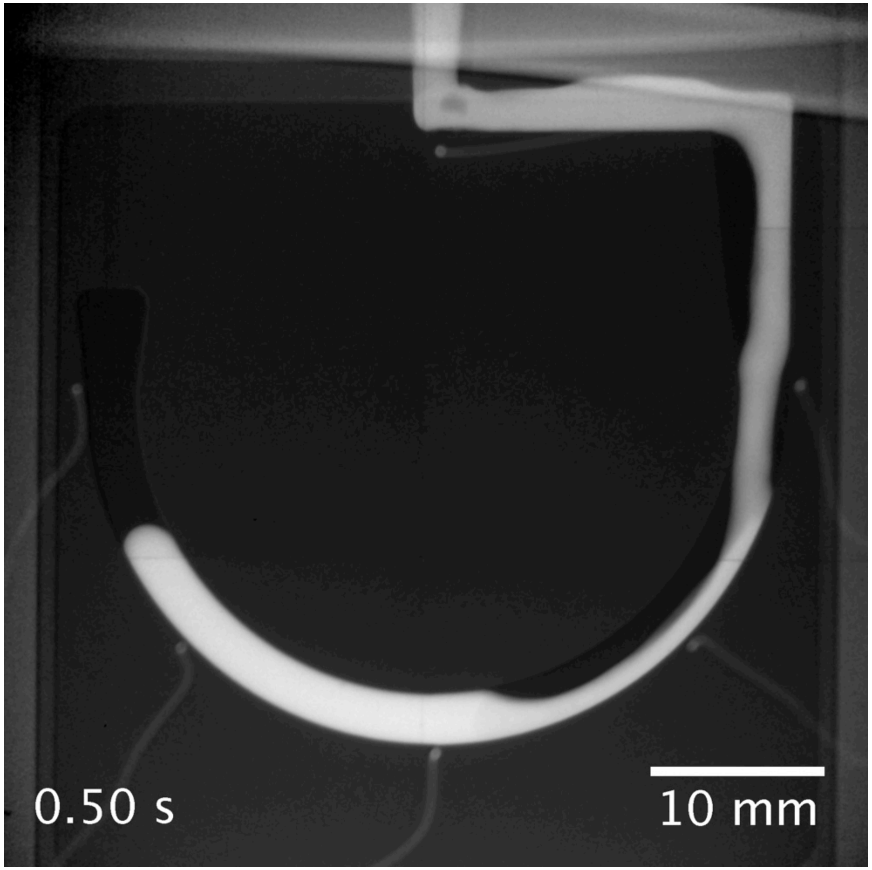


80wt% Bi – 20wt% Sn
(low viscosity)



20wt% Bi – 80wt% Sn
(high viscosity)

pRad to visualize casting process



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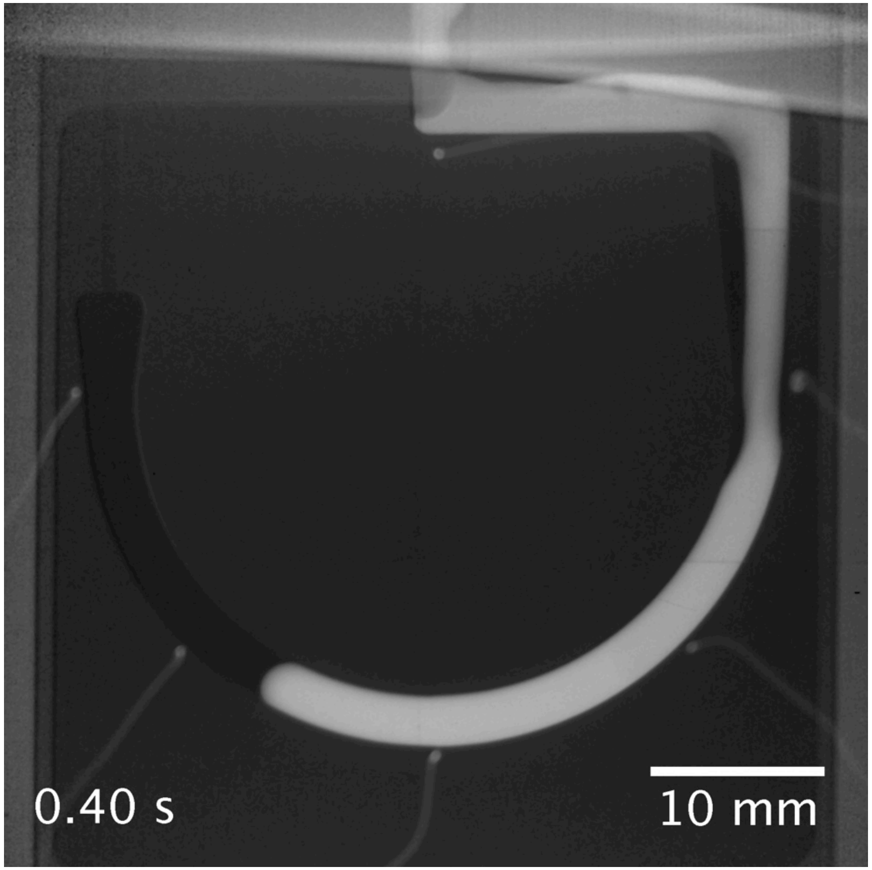

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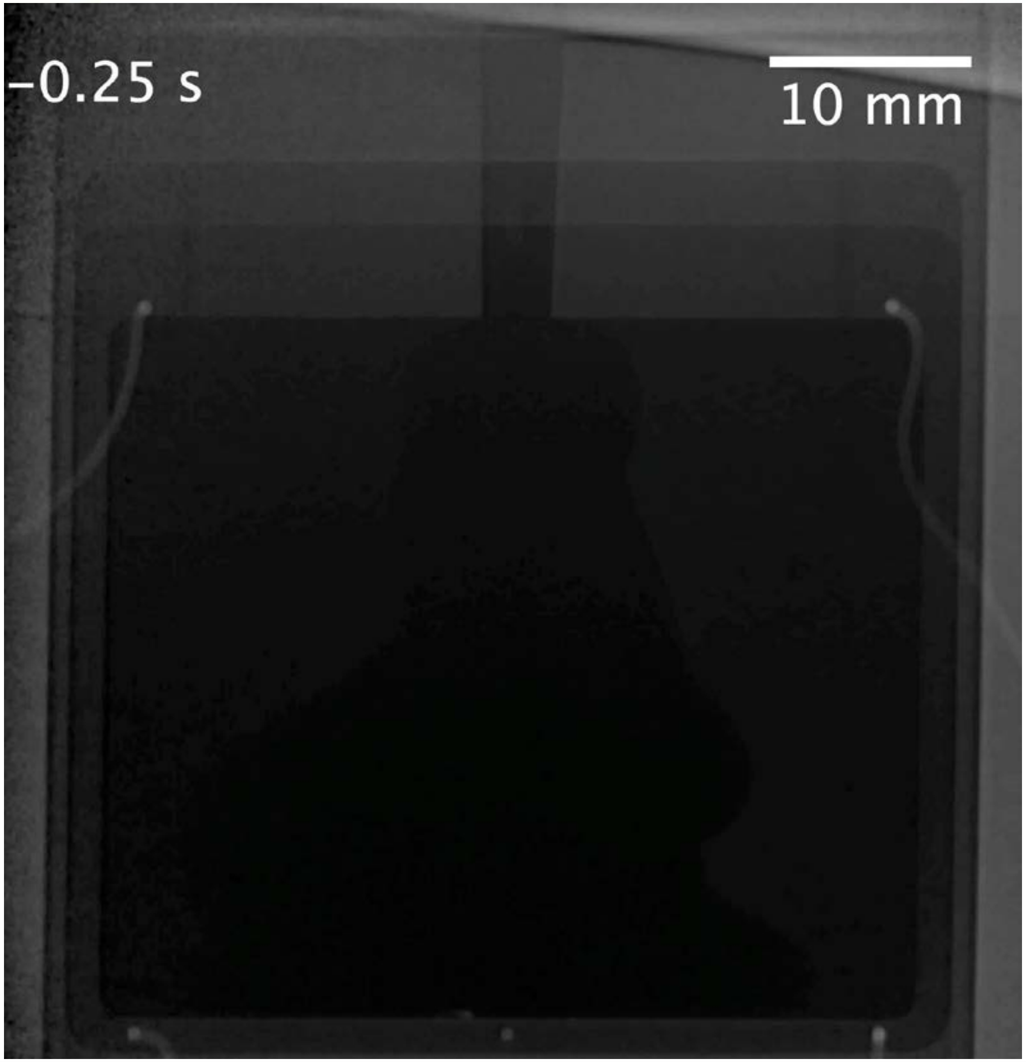

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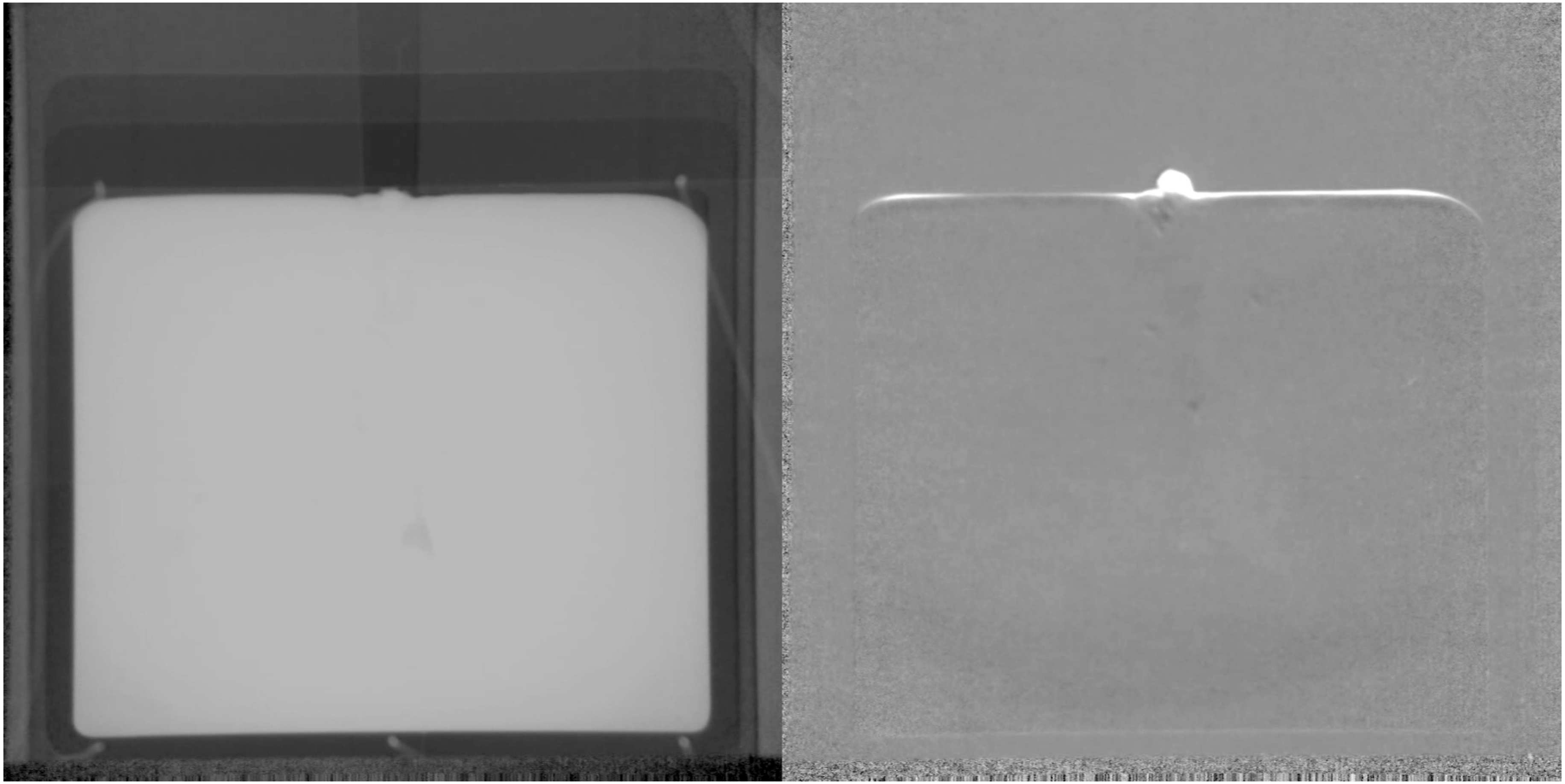
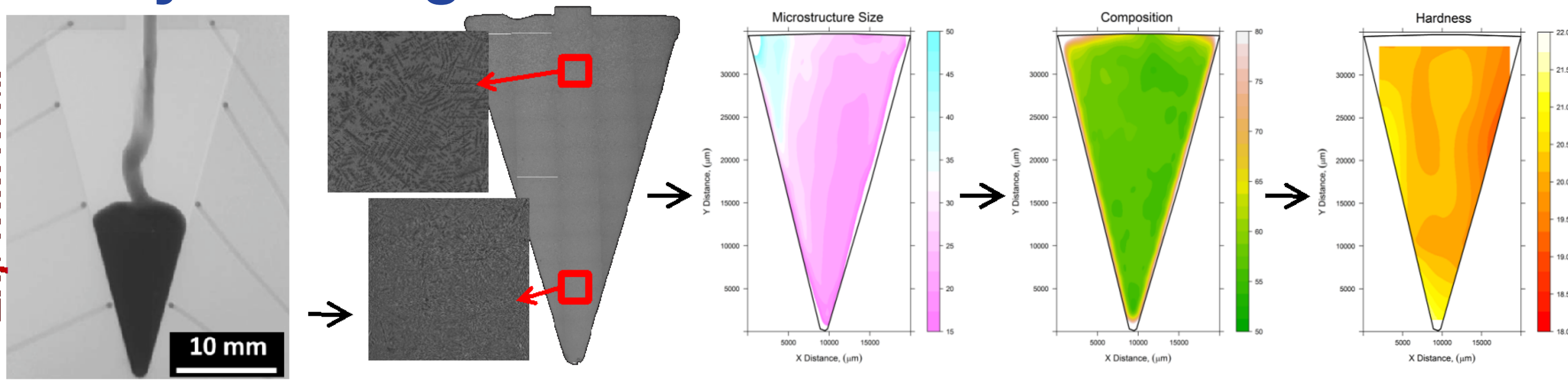
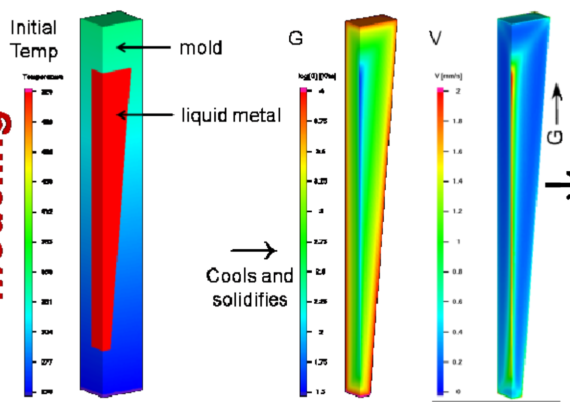


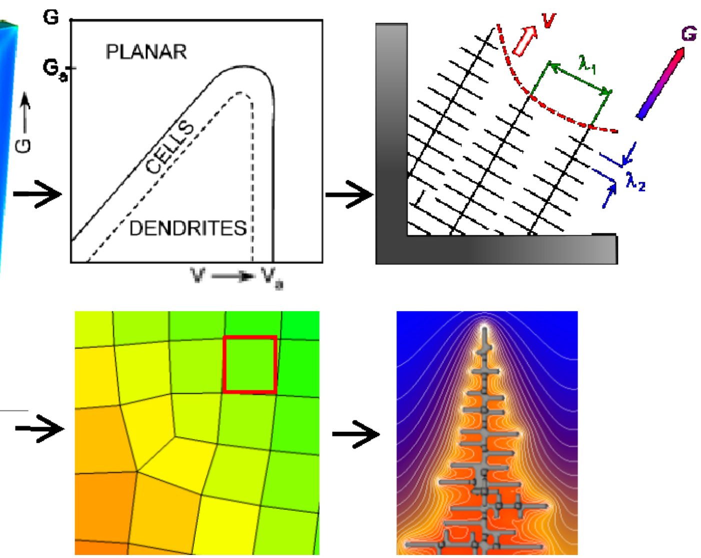
From μm to m: Bridging Length Scales in Metal Alloy Casting Simulations

Experimental



Modeling





<u>Goal</u>: Add and validate a microstructural model into Truchas (an ASC code for finite volume modeling of metal casting)

- pRad gives the fluid flow and macroscopic solidification behavior to constrain Truchas
- Truchas predicts the thermal history and microstructural variations
- Dendritic needle network modeling predicts local microstructural evolution, informed by Truchas temperatures
- Ex-situ characterization is used to validate the microstructural models
- Microstructural characteristics are compared to mechanical properties

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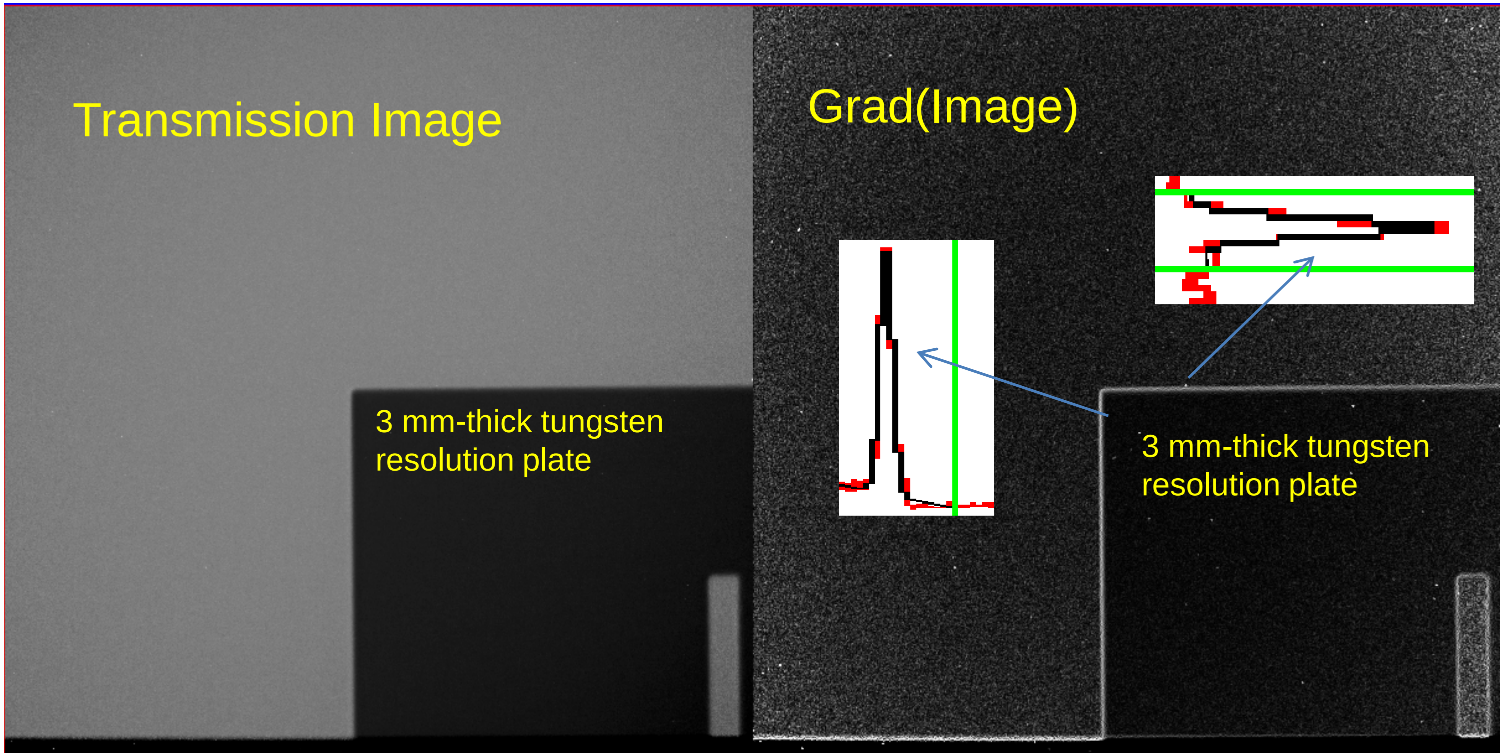
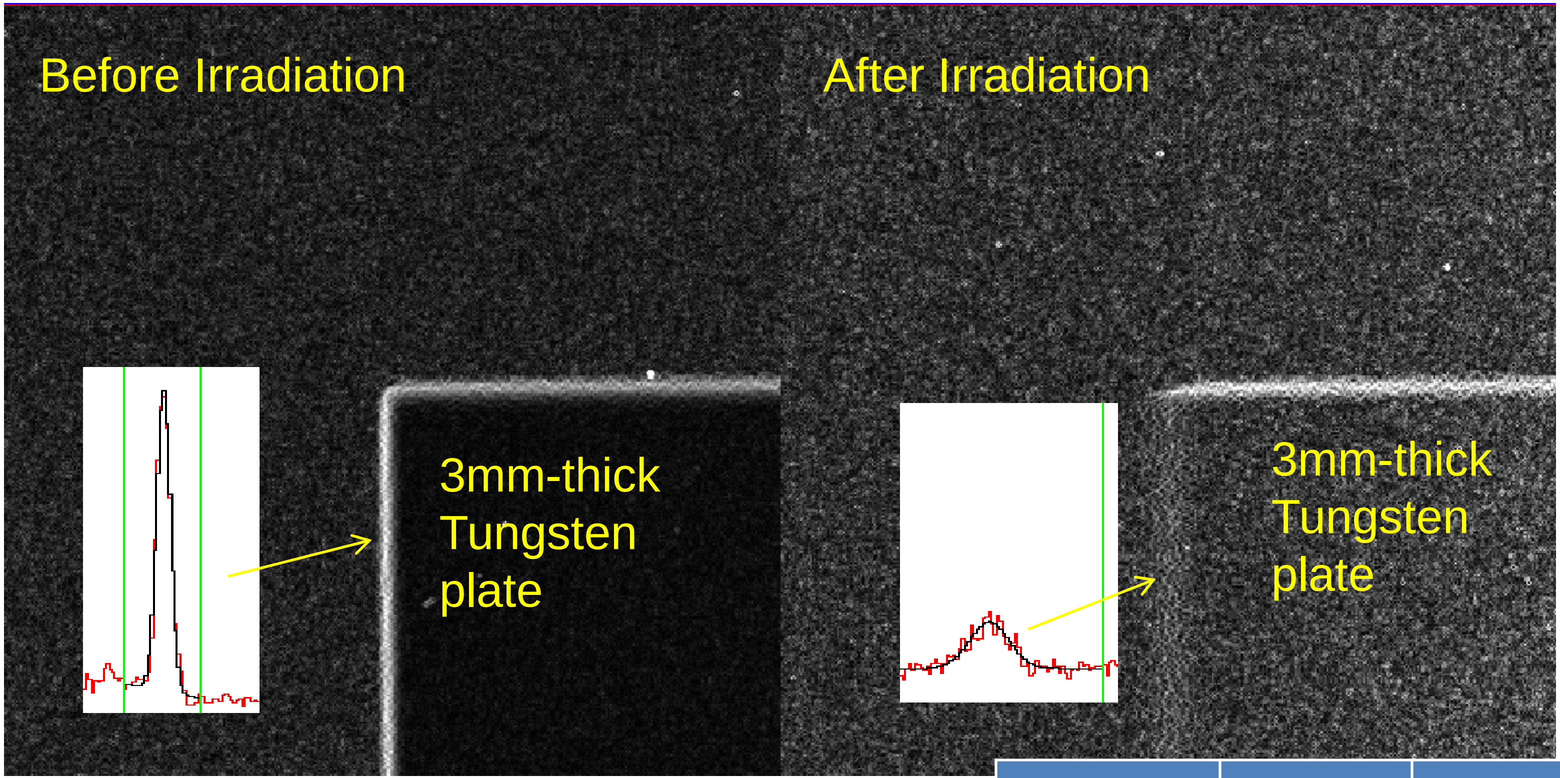
LDRD innovation for our nation

Future work: x7 magnification

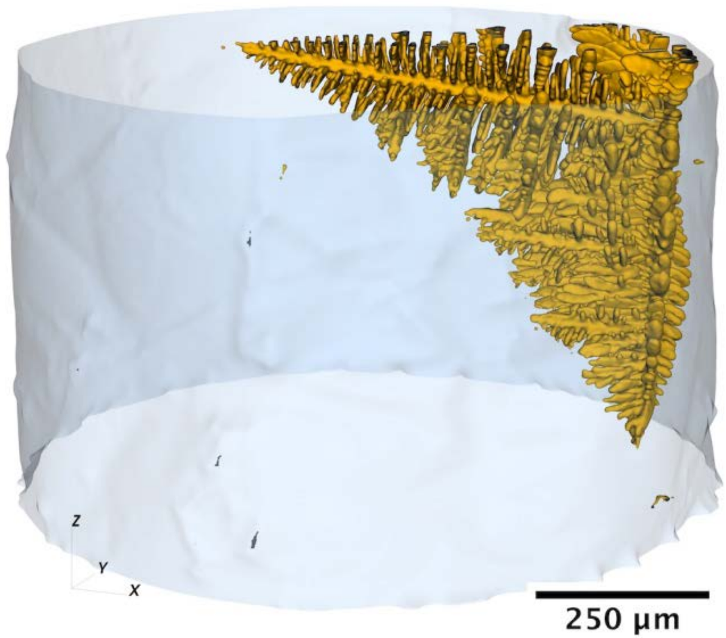


Future work: x7 magnification



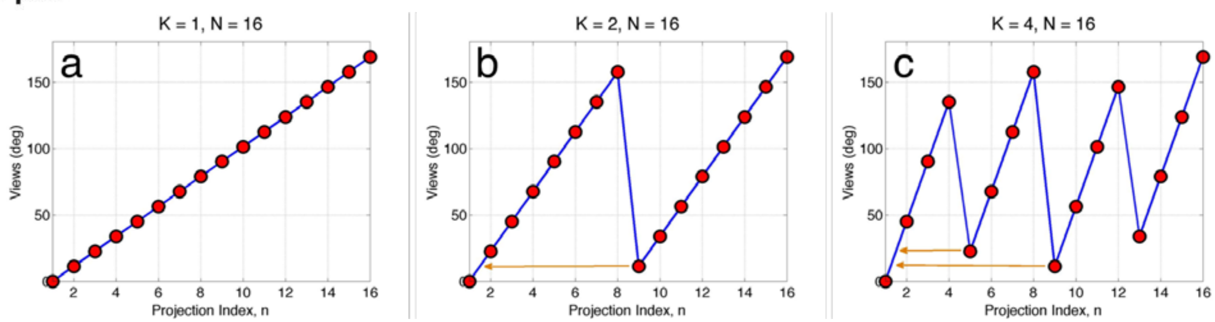
	Before	After
σx (μm)	23	66
σy (μm)	26	28

Future work: time resolved proton tomography



Example x-ray image of 3D dendritic growth

4-axis motion control Bridgman furnace



Tomographic reconstruction software (Time-Interlaced Model-Based Iterative Reconstruction (TIMBIR)

Acknowledgements

- This work was supported by AJC's Early Career award from the U.S. DOE, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering
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- pRad Team at LANL
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