Primary Dendrite Arm Spacing and Trunk Diameter in Al-7wt% Si Alloy Directionally Solidified Aboard the International Space Station.

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David Poirier – The University of Arizona
Richard Grugel – Marshall Space Flight Center

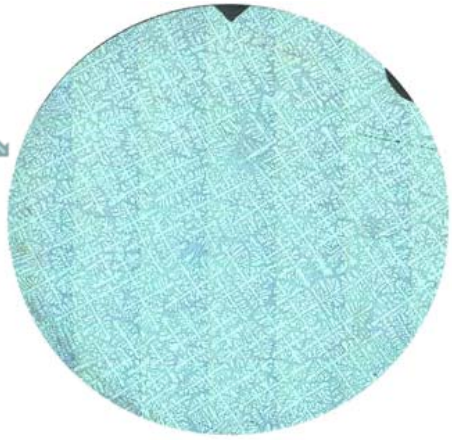
NASA and European Space Agency Collaborative Research Project : MICAST
(*Microstructure Formation in Castings of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions)*
MICAST6, MICAST7, MICAST2-12

Purpose

- Minimize Thermo-Solutal Convection by DS in Microgravity
- Produce Segregation Free Samples Grown Under Diffusion-Controlled Conditions
- Better Understand the Relationship between Processing and Microstructure-Development

Microgravity processing : Partially remelt and then DS from terrestrially grown dendritic mono-crystal in μg.

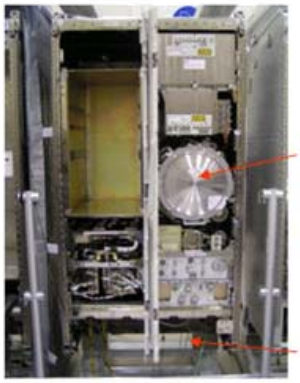
(Al-7%Si Single Crystal Dendritic)



Transverse View

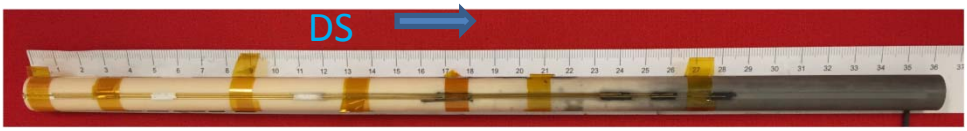
ESA- Sample Cartridge Assembly

ESA_MSL Low Gradient Furnace



ESA: Material Science Laboratory

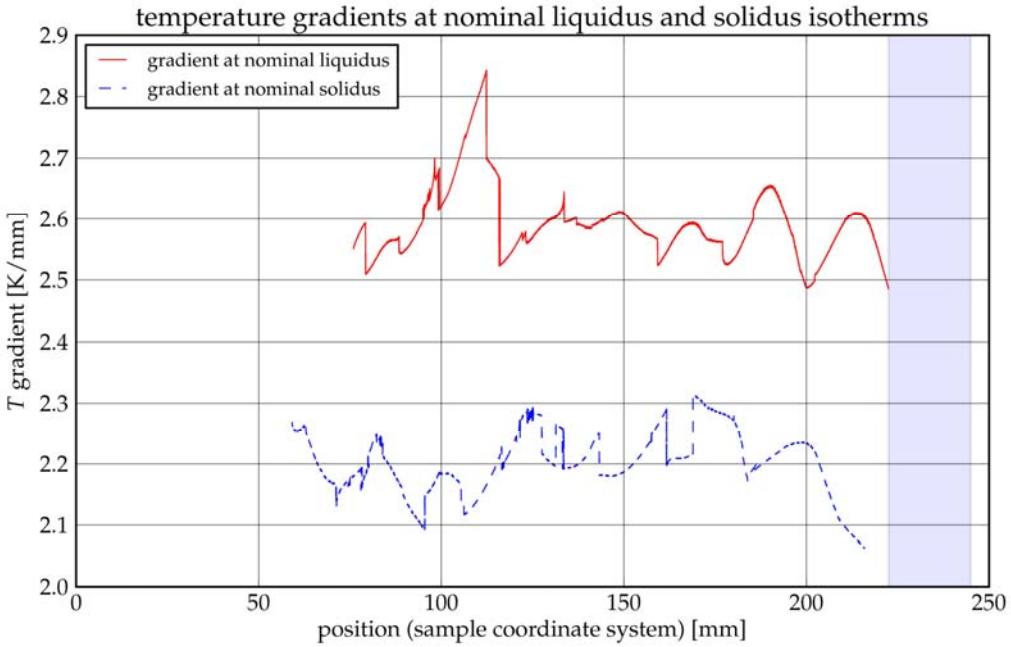
NASA_MSSR-1 Flight Rack

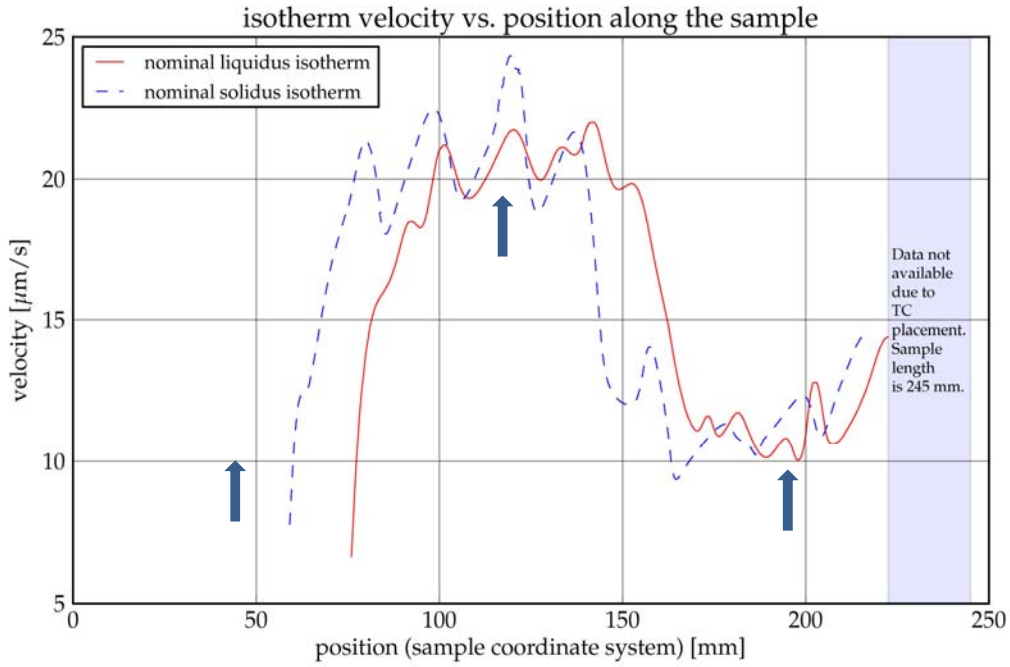


Alumina crucible and 12 thermocouples

TYPICAL THERMAL GRADIENTS AND GROWTH RATE DATA

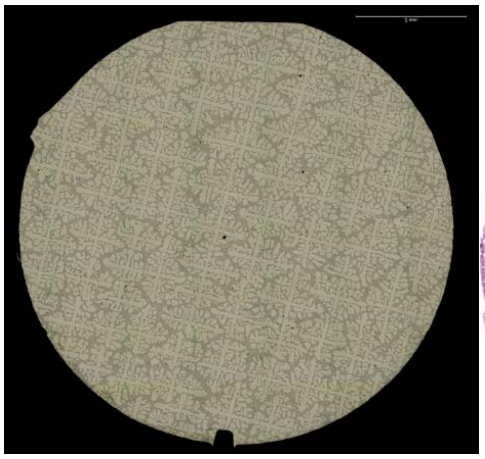
MICAST7: ESA-SQF (1-hr heat-up, 1-hr hold (G_l ~ 26 K cm^{-1}): 8.4 cm at 20 μm s^{-1}, 6.5 cm at 11 μm s^{-1}





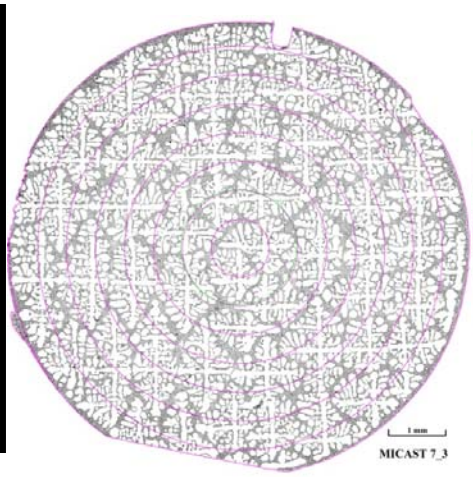
Typical Microstructures (MICAST7)
Directionally solidified on ground and on ISS

SEED
41 K cm^{-1}, 22 μm s^{-1}



MICAST7: 26 K cm^{-1}

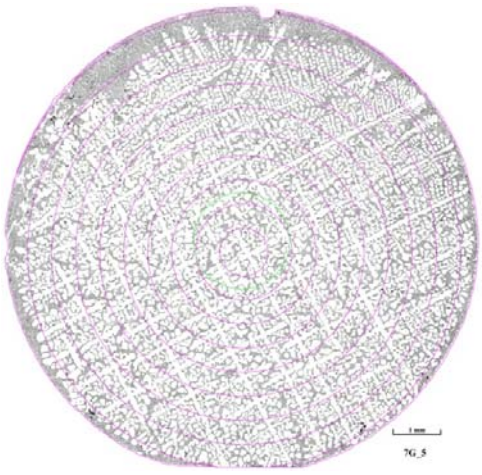
21 μm s^{-1}



11 μm s^{-1}

Terrestrial DS: 24 K cm^{-1} ➔

23 μm s^{-1}



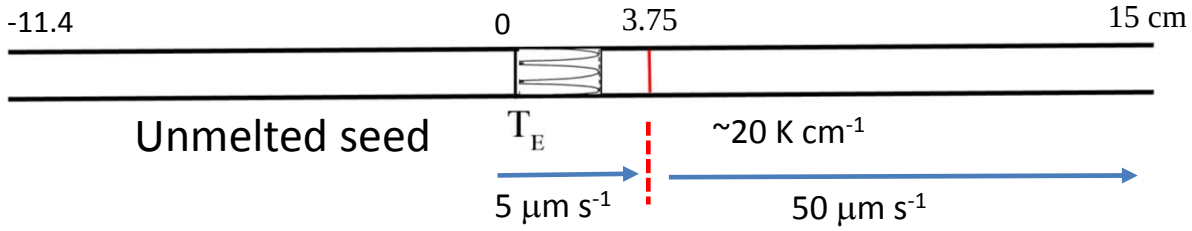
10 μm s^{-1}

1. Primary dendrite (Nearest-Neighbor) spacing (J.D. Hunt and S.Z. Lu, MMT, 1996)
2. Primary dendrite trunk diameter (Tewari, Grugel, Poirier, MMT, 2014)
3. Radial macrosegregation (Ghods, Johnson, Lauer, Tewari, Grugel, Poirier, *JCG: 2016)*

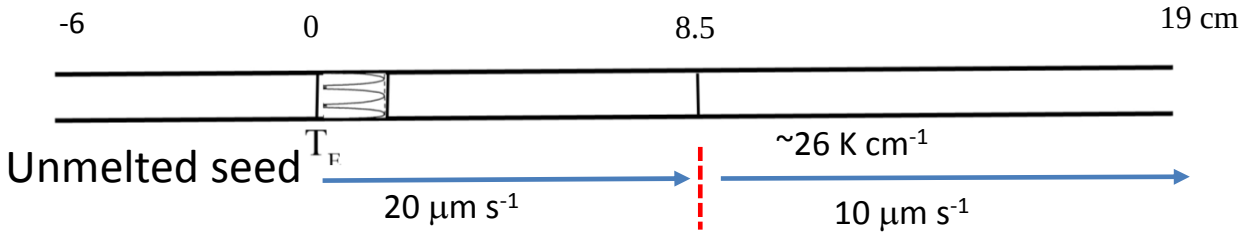
MICAST SAMPLE PROCESSING CONDITIONS

7.8-mm dia, 25 cm long samples

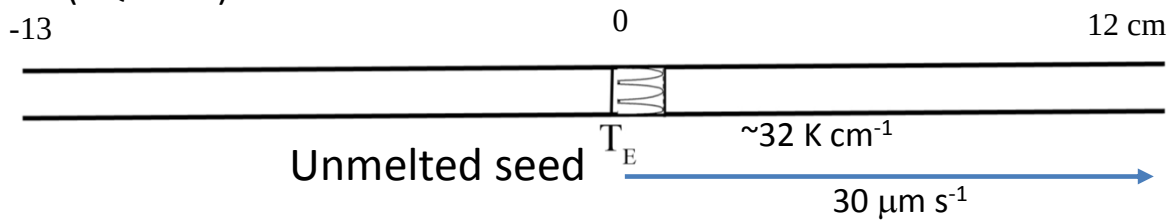
MICAST-6 (LGF-SCA)



MICAST-7 (LGF-SCA)

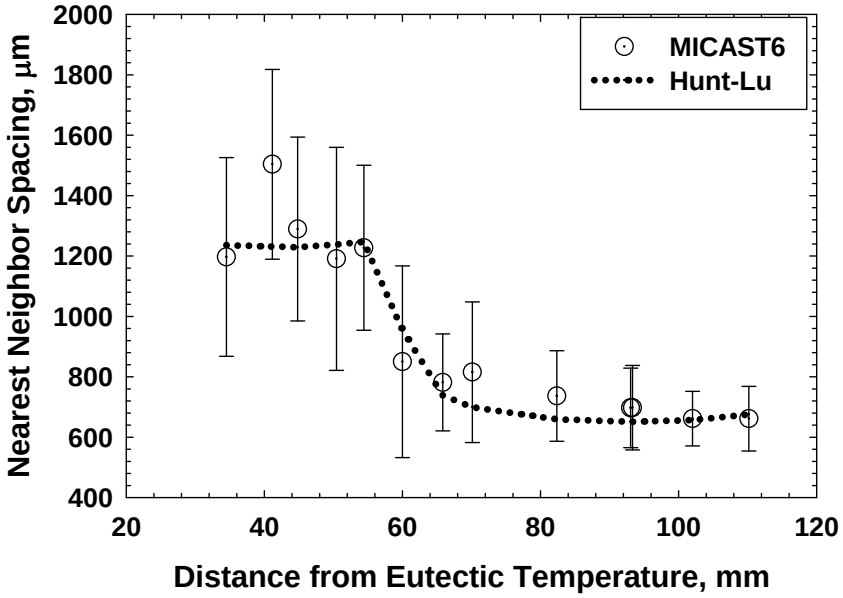


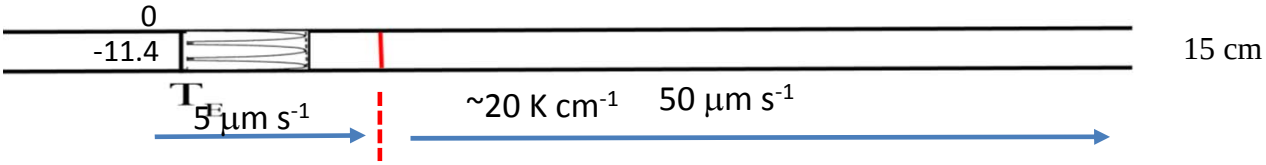
MICAST2-12 (SQF-SCA)

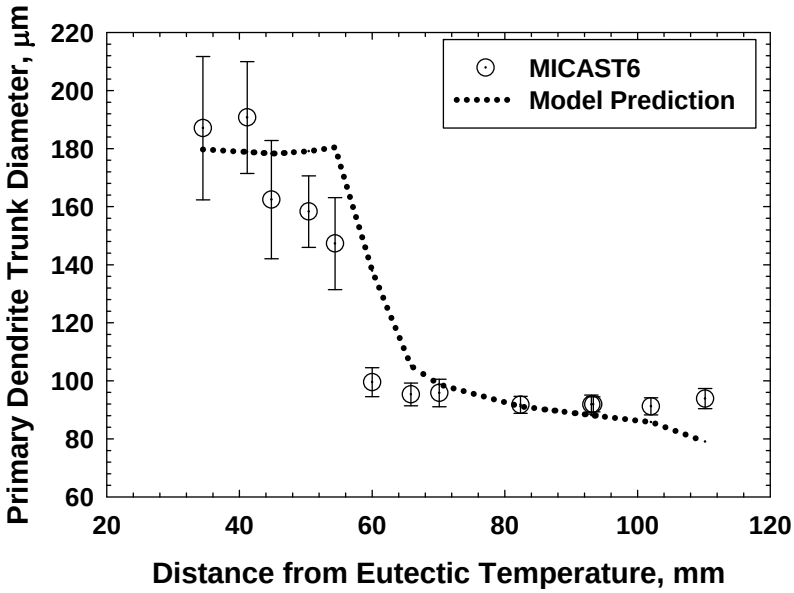


NEXT: COMPARE NEAREST NEIGHBOR SPACING AND PRIMARY DENDRITE TRUNK DIAMETER WITH PREDICTIONS FROM DIFFUSIVE TRANSPORT MODELS

MICAST-6 (LGF-SCA)

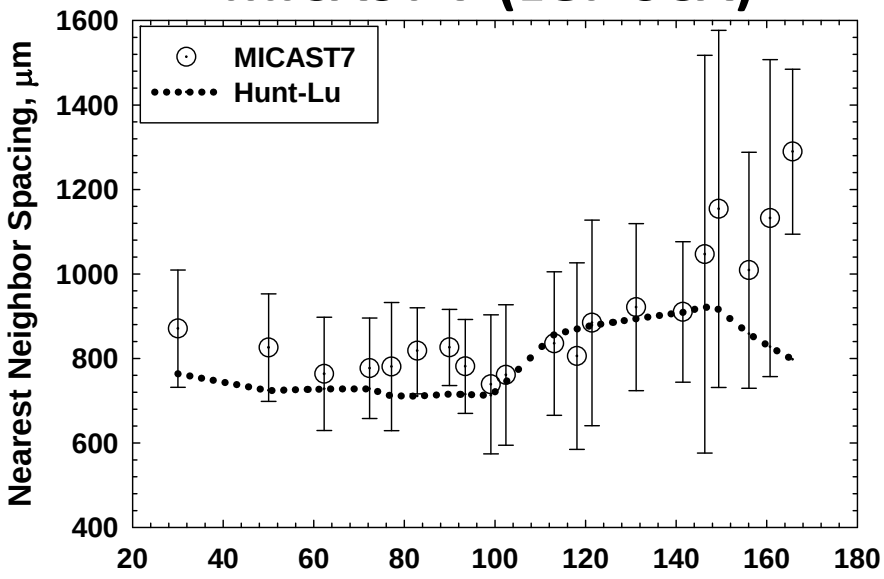


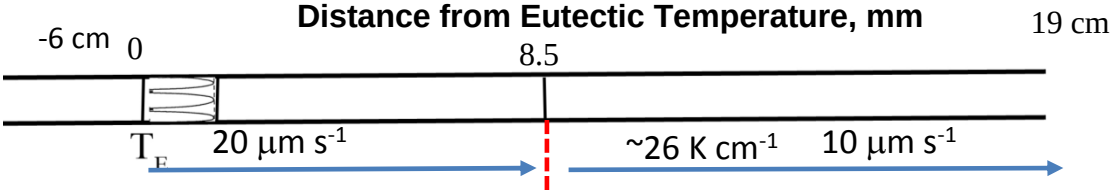


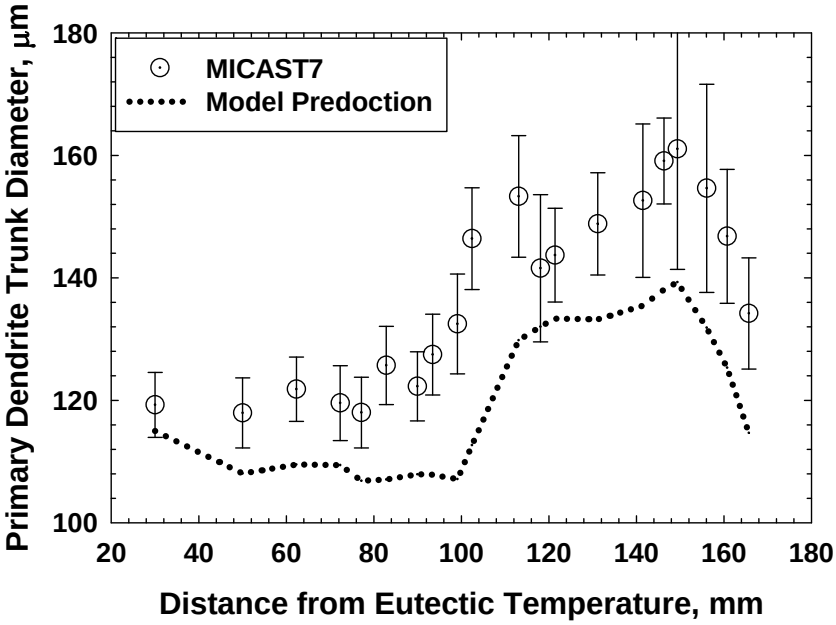


MICAST 6 DATA SHOW GOOD FIT WITH MODEL PREDICTIONS

MICAST-7 (LGF-SCA)

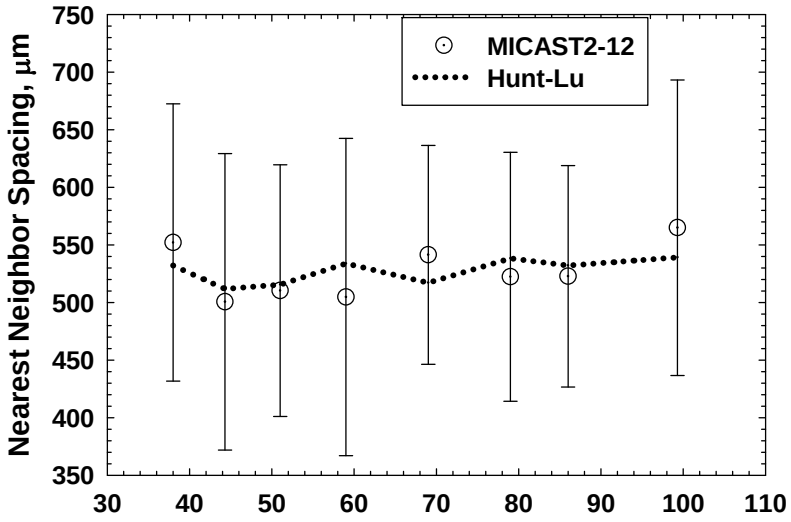






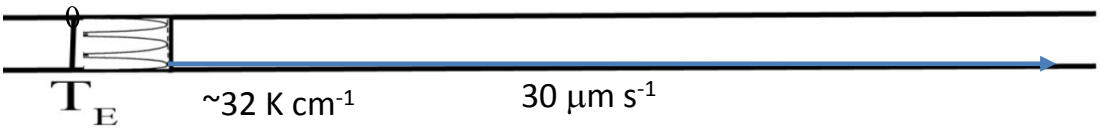
MICAST 7 DATA SHOW GOOD FIT WITH MODEL PREDICTIONS

MICAST2-12 (SQF-SCA)



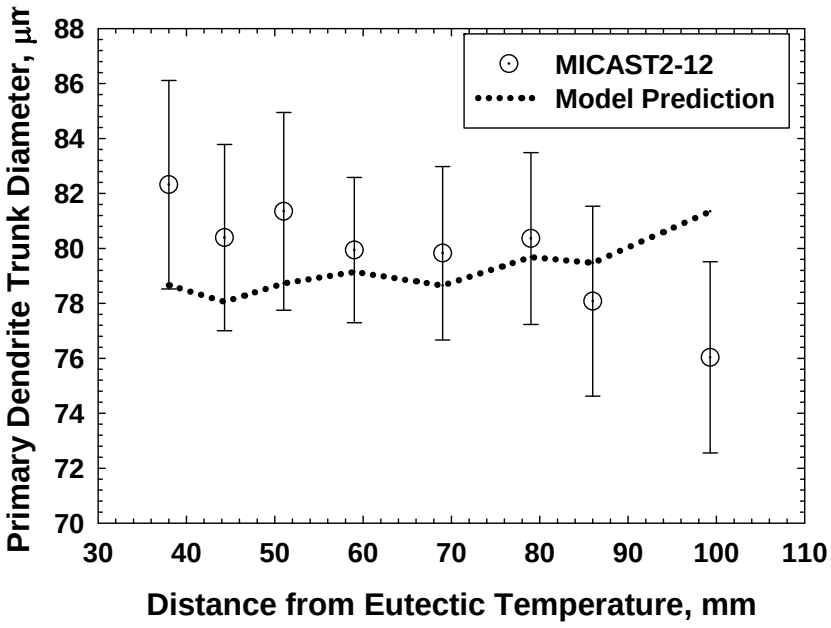
-13 cm

12 cm



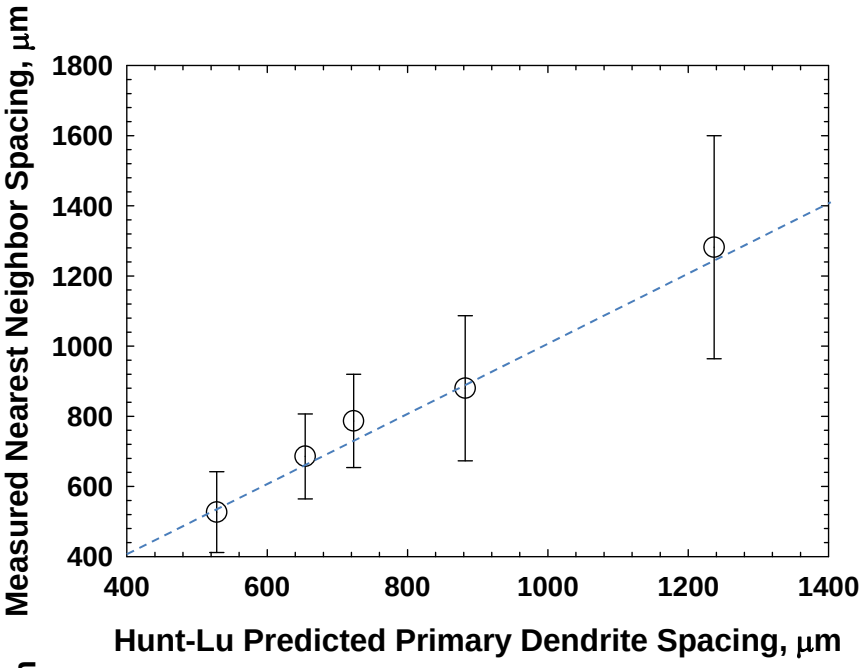
~32 K cm^{-1}

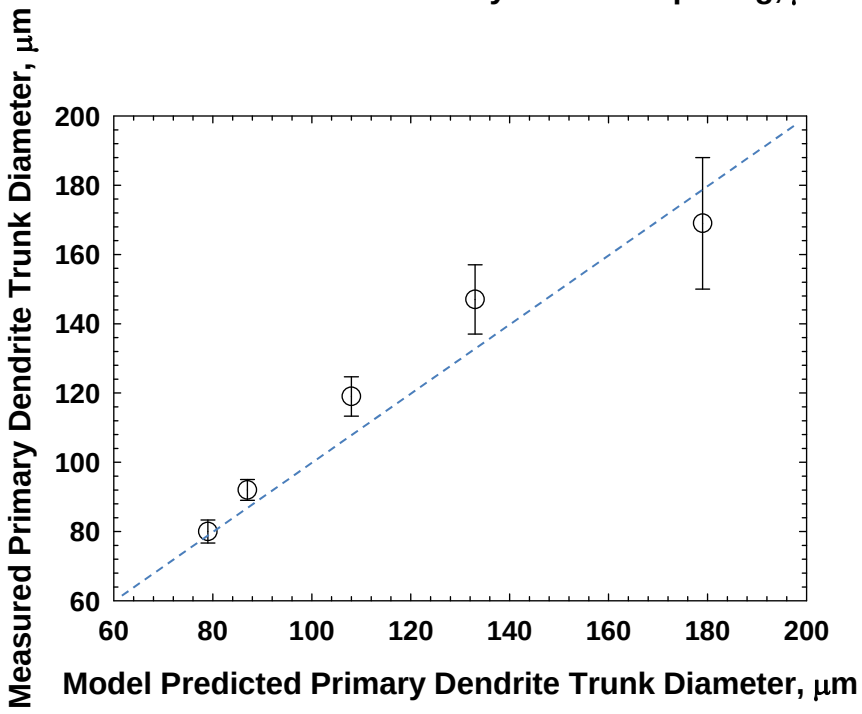
30 µm s^{-1}



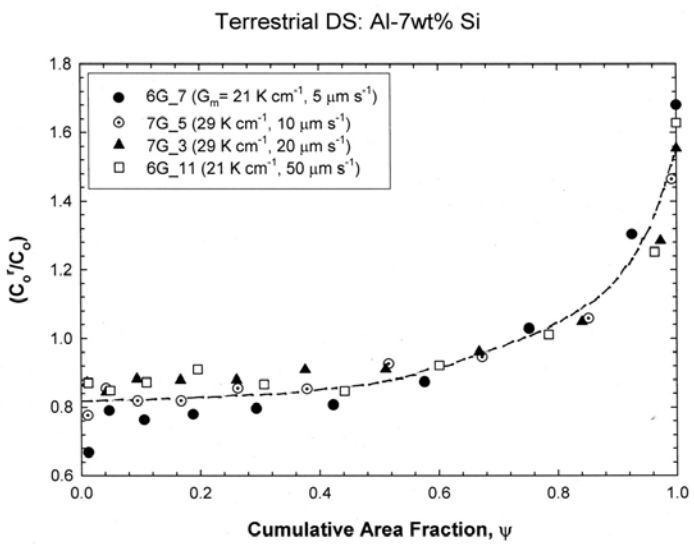
MICAST 2-12 DATA SHOW GOOD FIT WITH MODEL PREDICTIONS

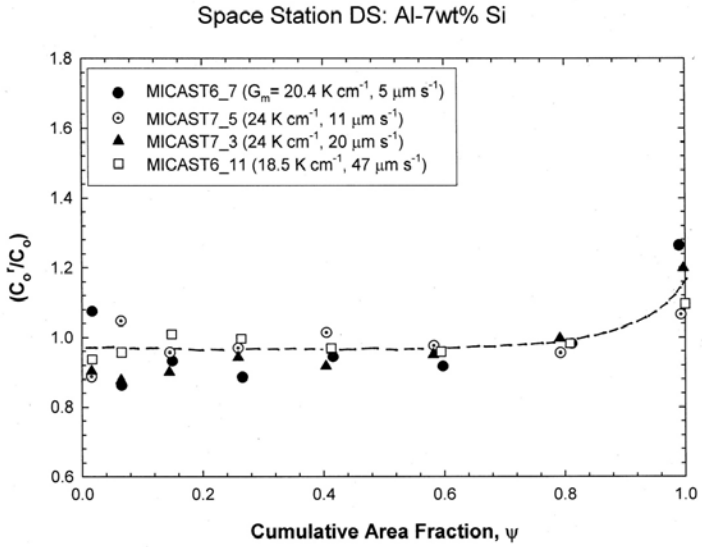
STEADY STATE DENDRITE-ARRAY MORPHOLOGY (Comparison with Diffusive Transport Models)

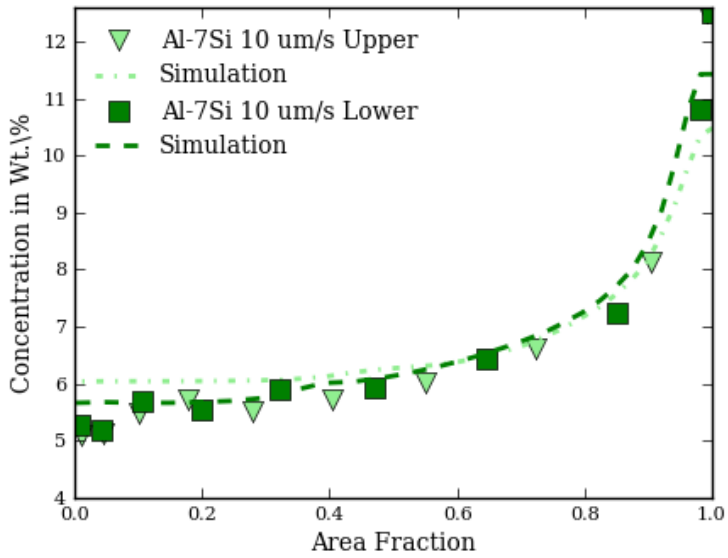


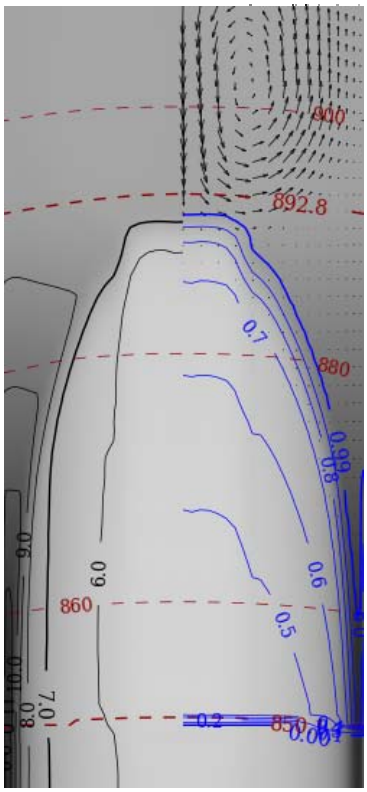


Comparison of radial macrosegregation: Al-7% Si directionally solidified on ground and on ISS









Extensive radial macrosegregation associated with "dendrite steepling" in terrestrial samples is nearly absent in ISS processed samples.

(Ghods, Johnson, Lauer, Tewari, Grugel, Poirier, *JCG: 2016)*

SUMMARY

Space Station processed Al-7 Si samples (MICAST 6, 7 and 2-12) show that:

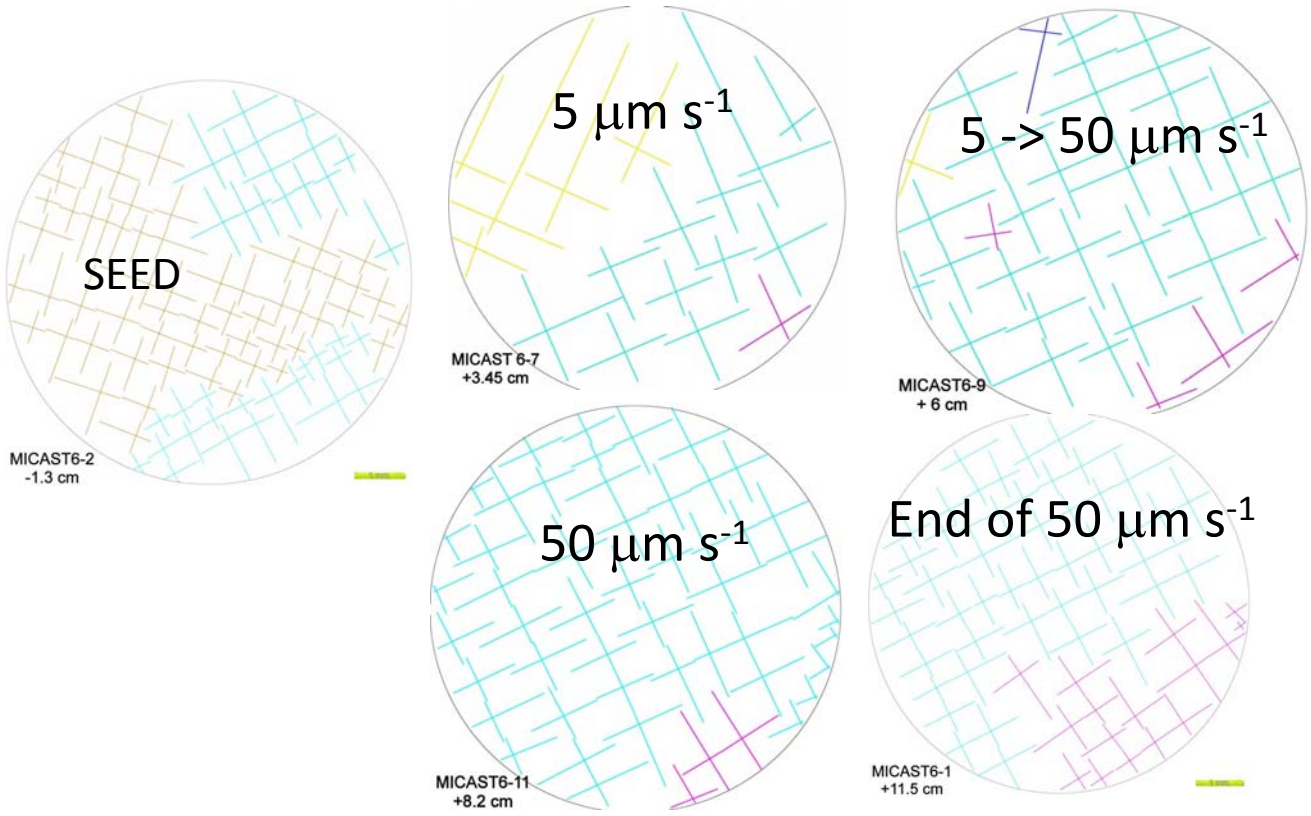
- Their steady state primary dendrite spacing (Nearest-Neighbor) shows a good agreement with predictions from Hunt-Lu Model (J.D. Hunt and S.Z. Lu, MMT, 1996)
- Their steady-state primary dendrite trunk diameter shows a good agreement with a coarsening based analytical model (Tewari, Grugel, Poirier, MMT, 2014)
- There is no radial macrosegregation; the terrestrial samples show radial macrosegregation caused by "steepling" thermosolutal convection (Ghods, Johnson, Lauer, Tewari, Grugel, Poirier, *JCG: 2016)*

There was no convection during DS on ISS?.

Spurious misoriented grain formation along the MICAST sample length suggests otherwise!!

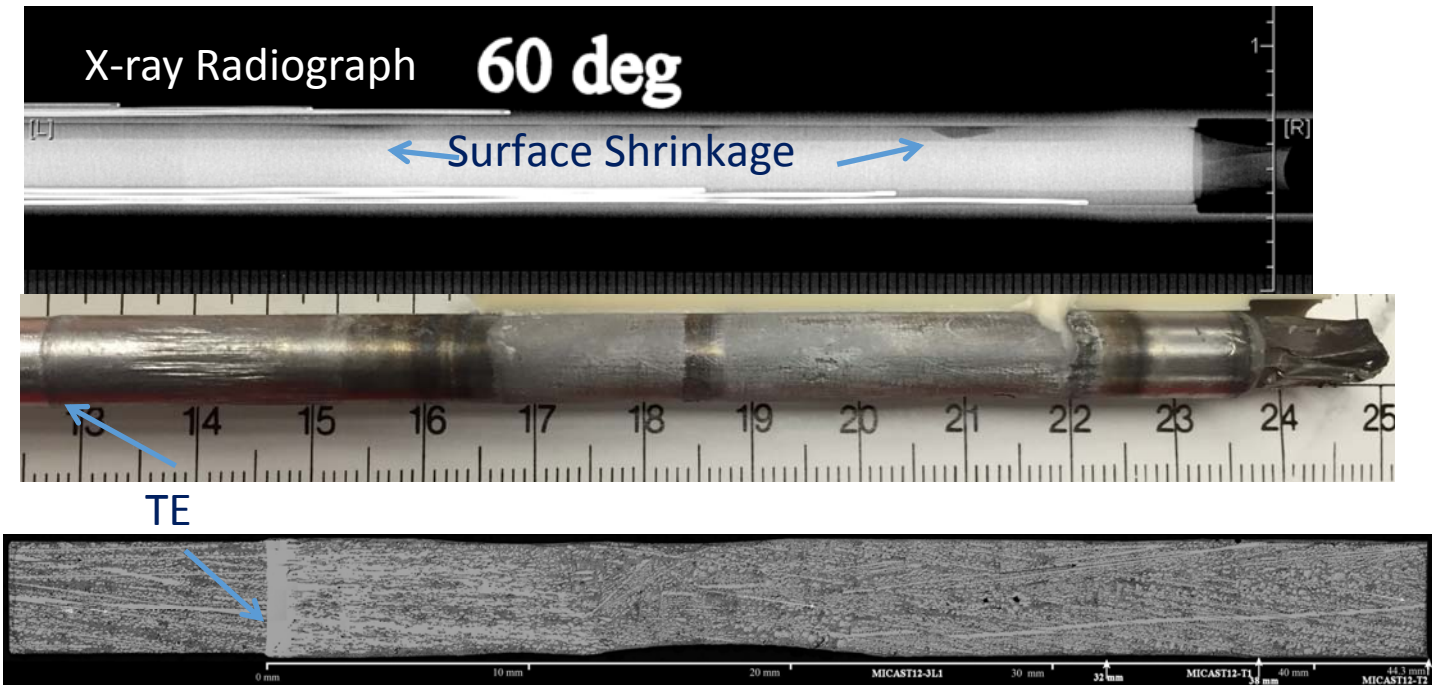
Surprises??

MICAST-6: Grains elimination and formation along DS length

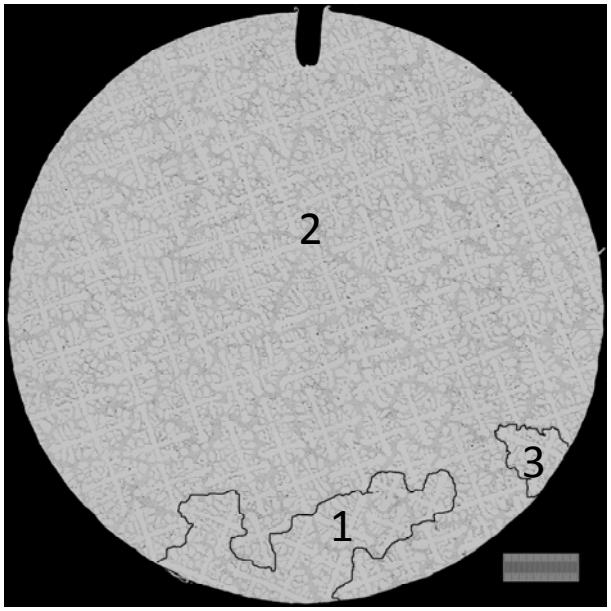


SPURIOUS GRAINS DURING DS IN THE ABSENCE OF CONVECTION ??

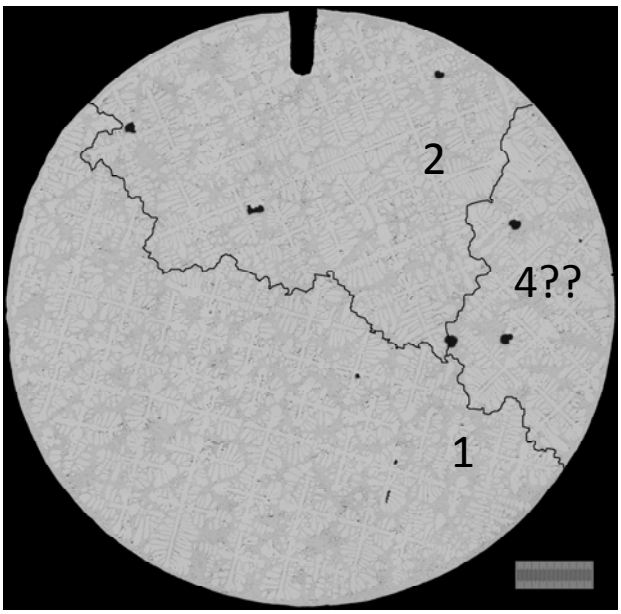
MICAST2-12:



MICAST12-1(-11mm)



MICAST12-2M (+99 mm)



"Is Marangoni Convection caused by surface pores responsible for dendrite fragmentation and spurious grain formation during DS in microgravity?"

Grateful for support from

- NASA
- ESA
- DLR-MUSC
- ALCOA