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Surface Geometry and Heat Flux Effect on Thin Wire Nucleate Pool Boiling of Subcooled Water in Microgravity

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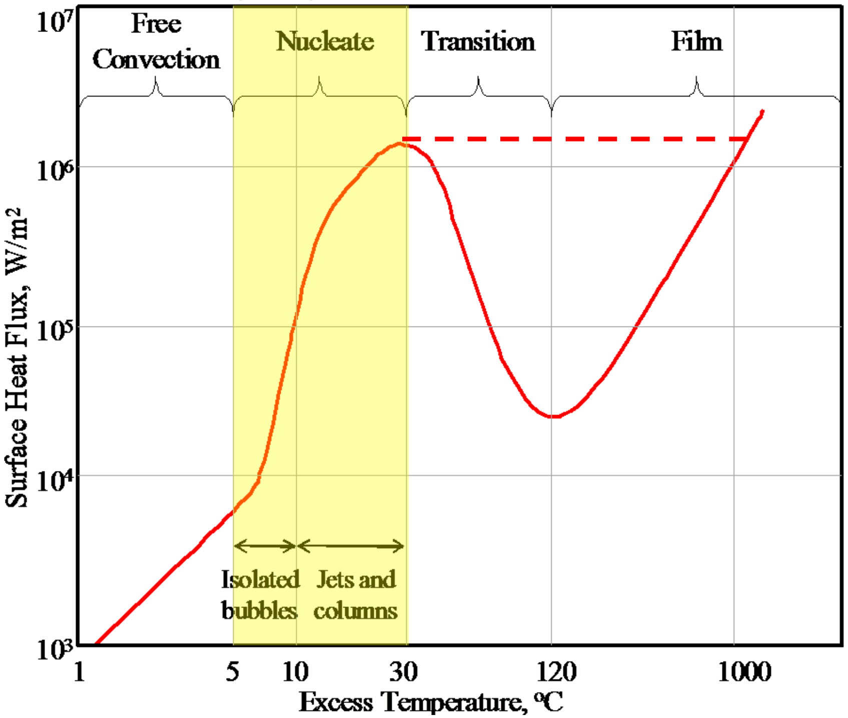
NUCLEATE BOILING

- Characterized by presence of bubbles
- High heat transfer rates
- Governed by Newton's law of cooling
- Wide range of terrestrial and possible space applications

Boiling regimes for water at 1 atm



Pool Boiling

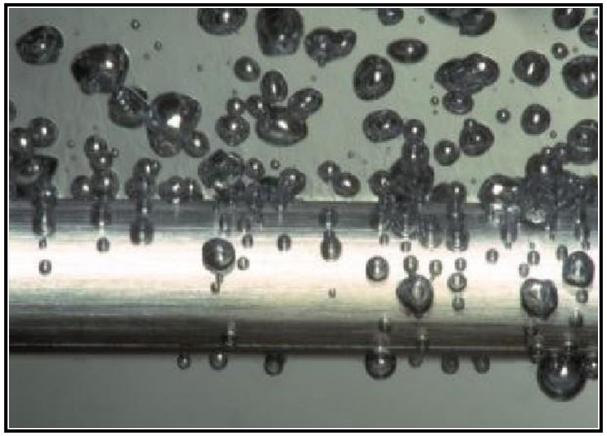
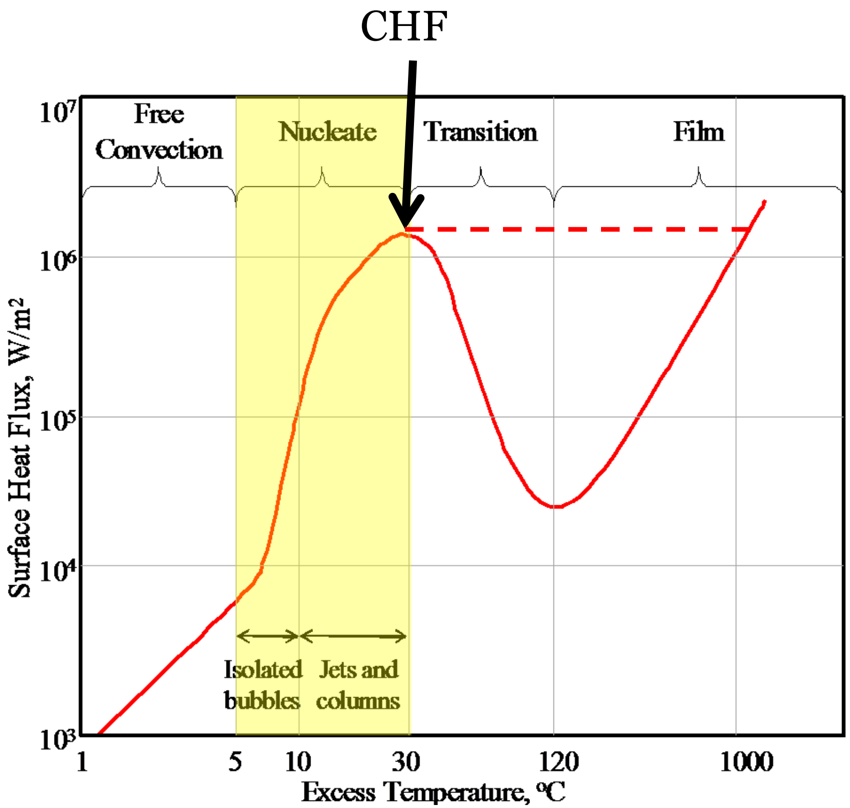


Photo courtesy of Incropera

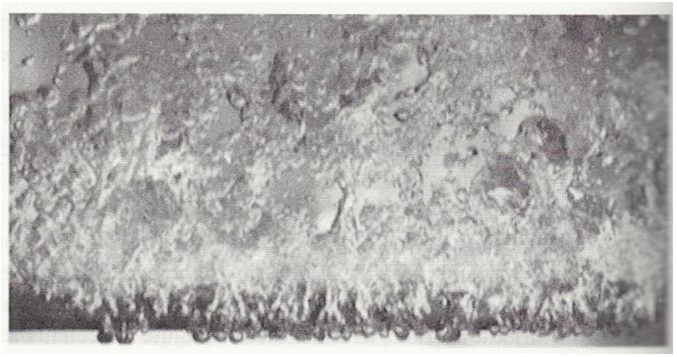
$$q'' = h(T_s - T_\infty)$$

q" - *heat flux*
h – *heat transfer coefficient*
T_s – *temperature of surface*
T_∞ – *bulk temperature of fluid*

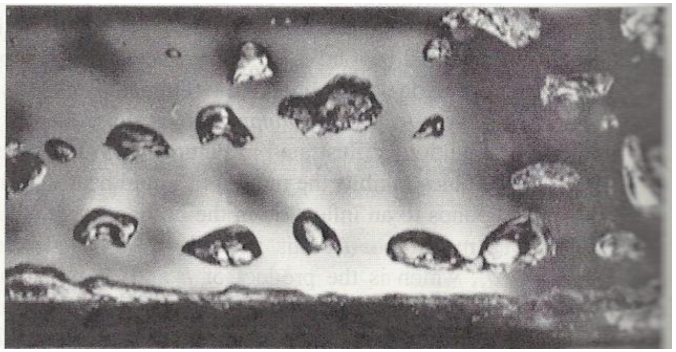
Heat Flux Effects



Photos courtesy of Incropera



Nucleate boiling



Film boiling

Surface Geometry Effects

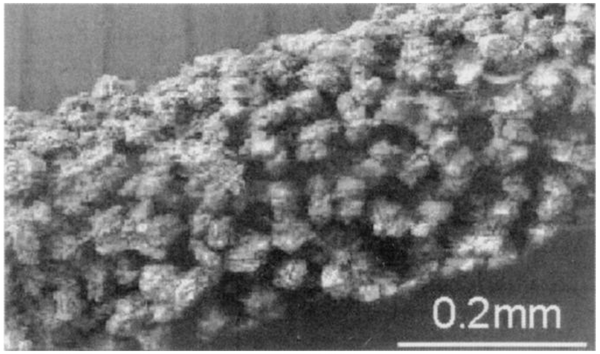


Photo courtesy of Fukada

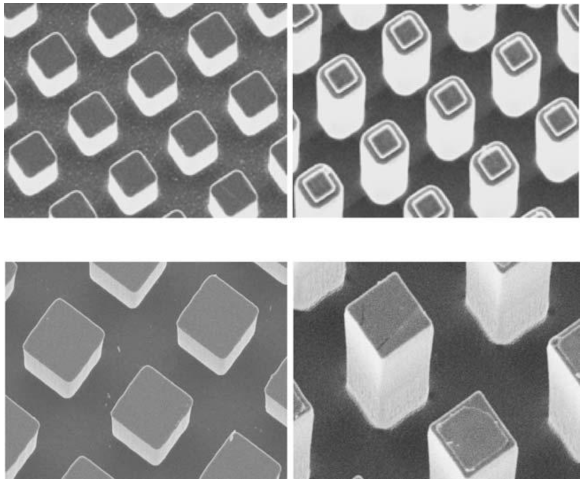


Photo courtesy of Zhao

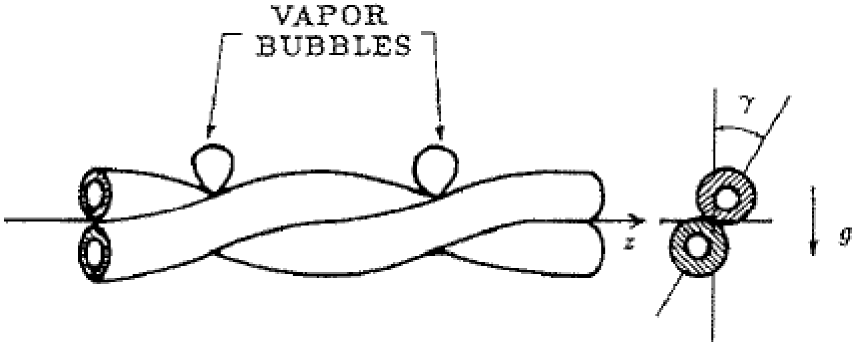
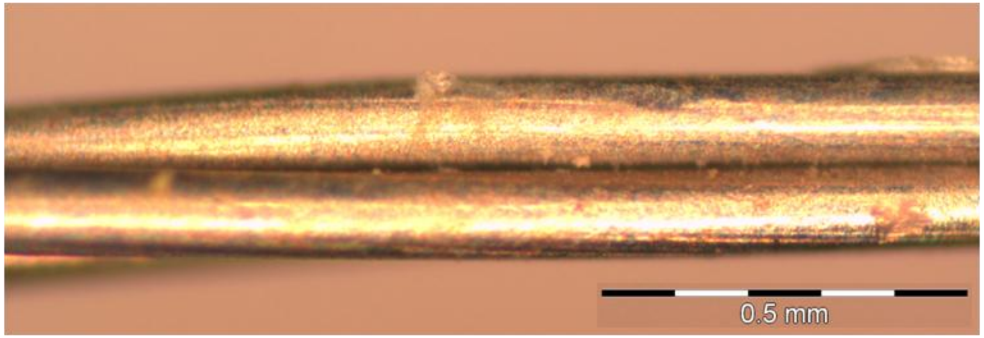


Photo courtesy of Chyu



MICROGRAVITY OBSERVATIONS

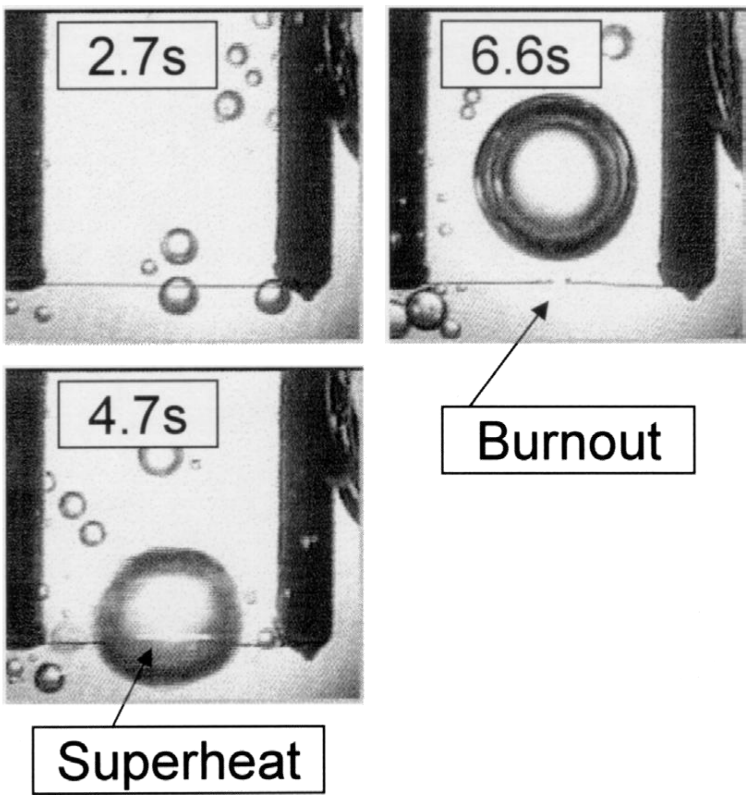
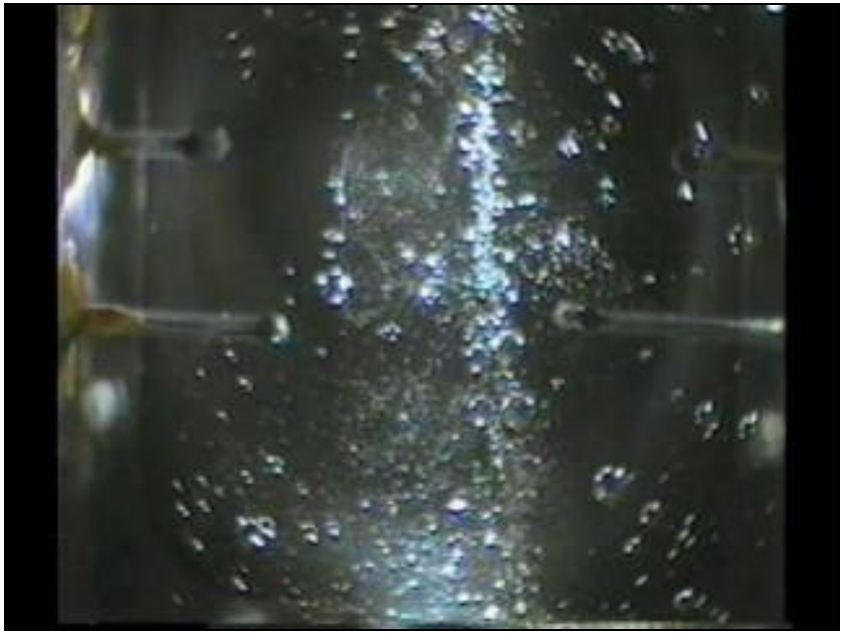


Photo courtesy of Fukada

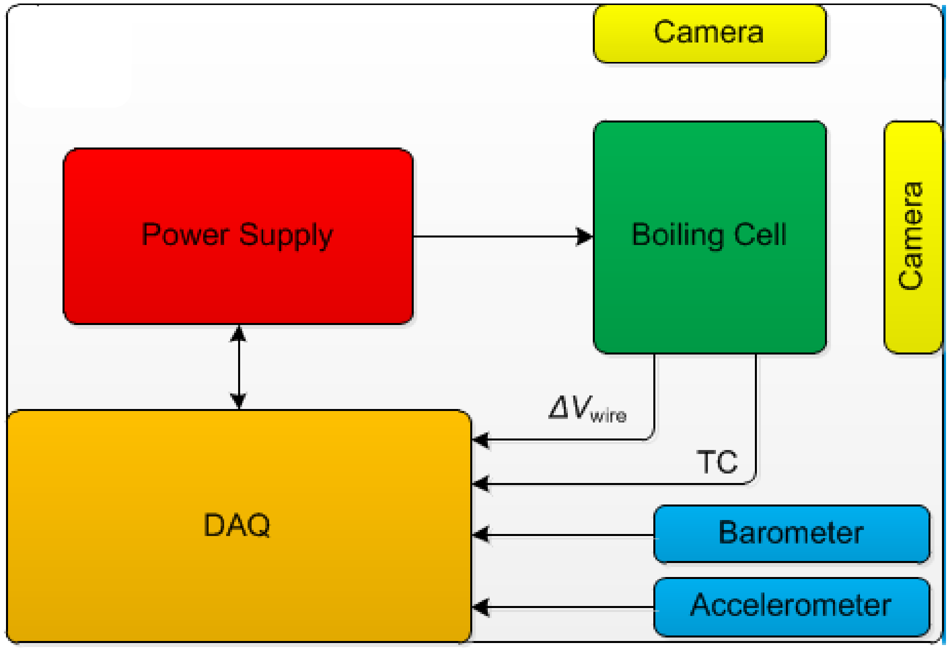


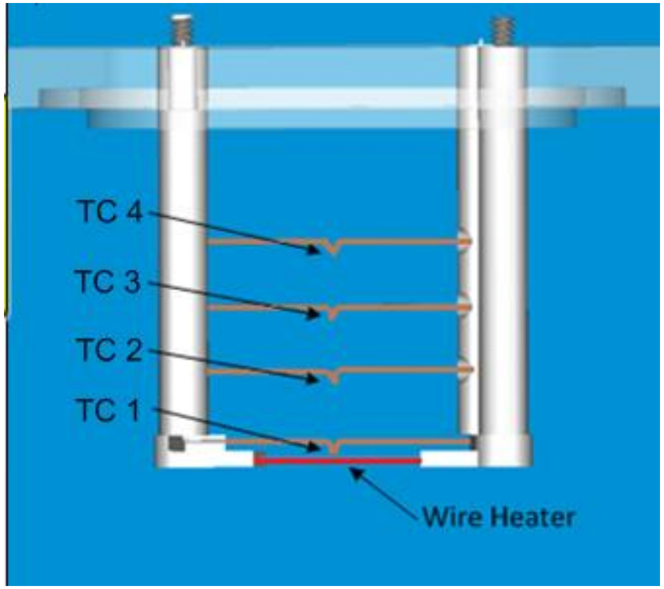
Objectives

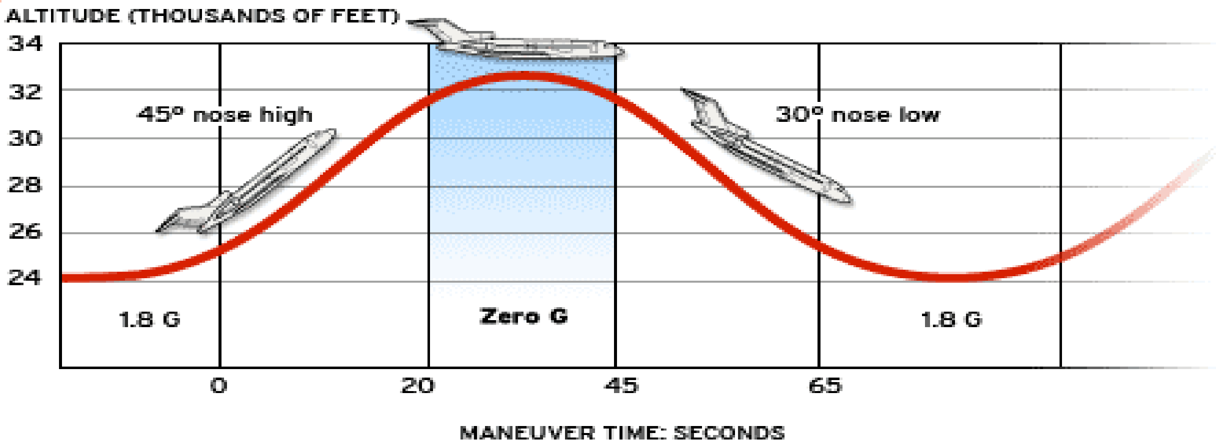
Investigate the effects of surface geometry, heat flux, and gravity on nucleate boiling by observing:

- Onset of nucleate boiling characteristics
- Steady state heat transfer characteristics
- Bubble dynamics

Experimental Setup



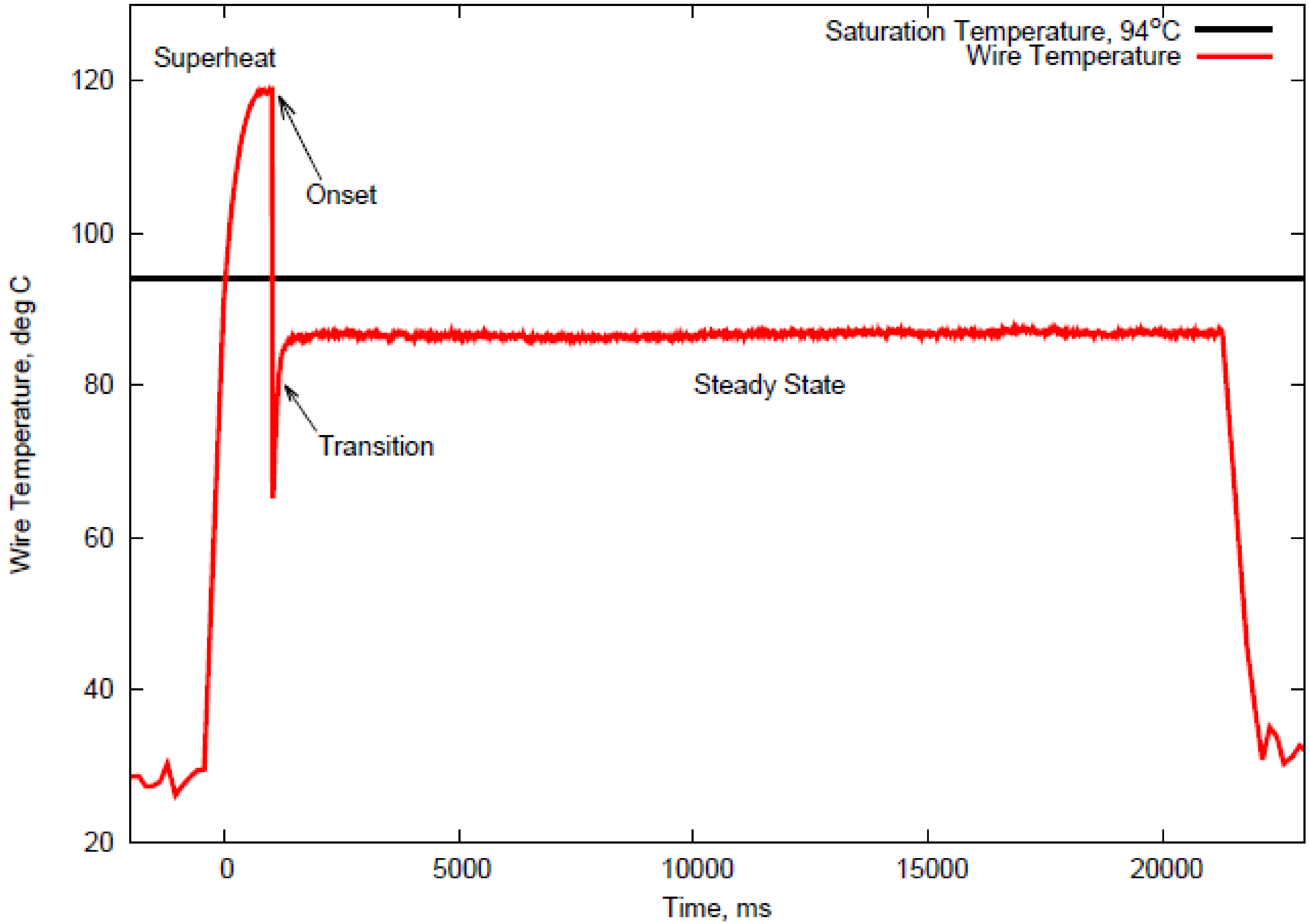




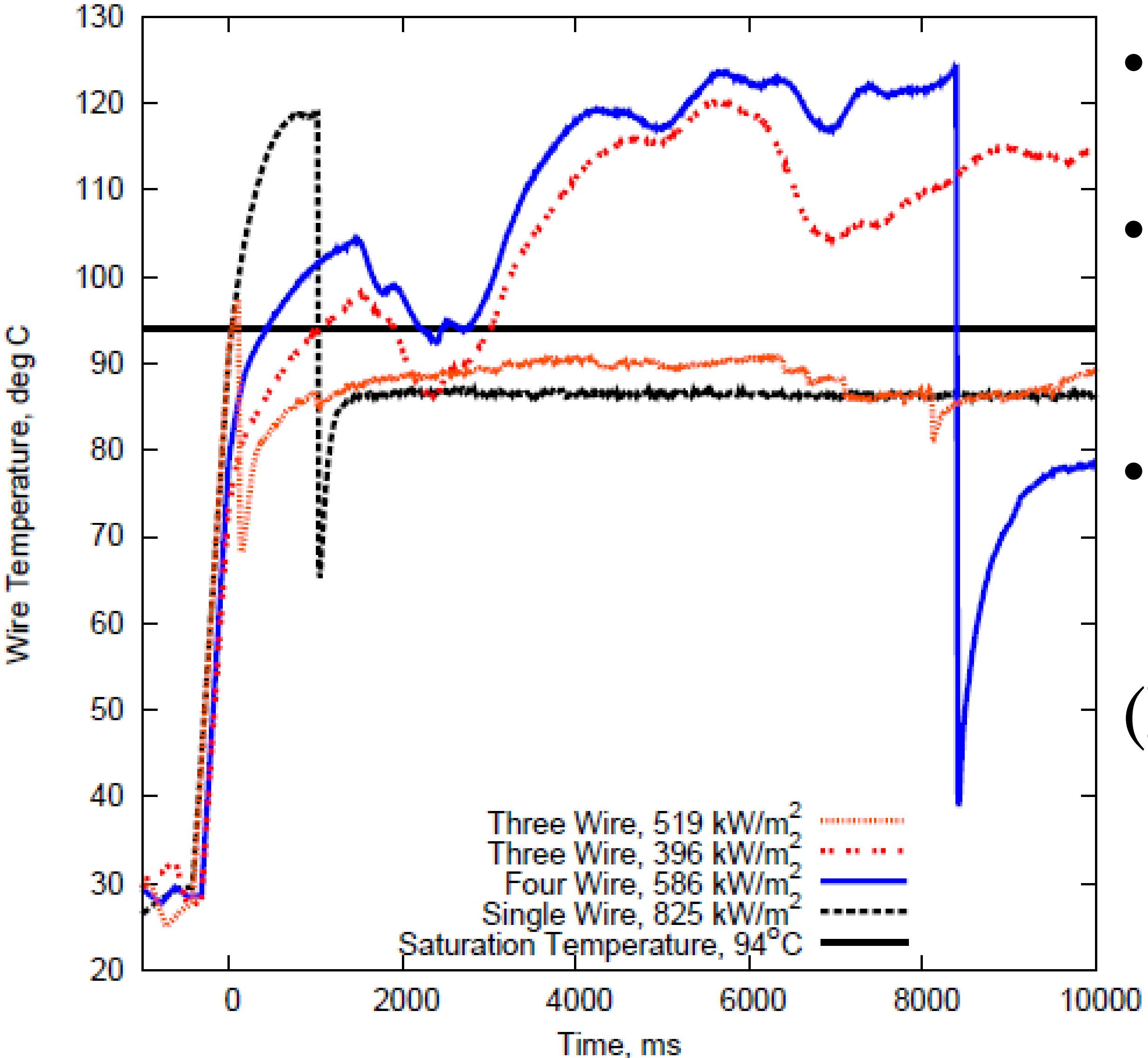
SOURCE: The Zero Gravity Corporation

MSNBC

Transient Wire Behavior



Onset of Nucleate Boiling

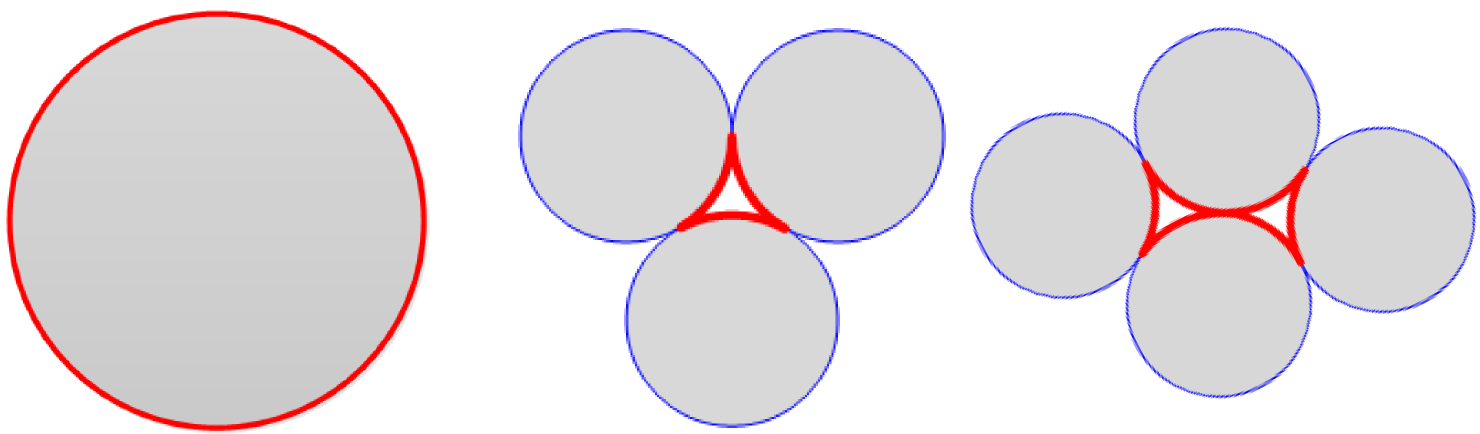


- Steady condition before boiling
- Range of three wire onset heat flux
- Average wire temperature below saturation

(Bubble dynamic effects on wire temperature)

Effects of Surface Geometry

	Single-wire	Three-wire	Four-wire
Minimum Onset Heat Flux	825 kW/m^2	Between 396 and 519 kW/m^2	586 kW/m^2
Concentrated Surface Area to Total Surface Area	1:1	1:6	1:4

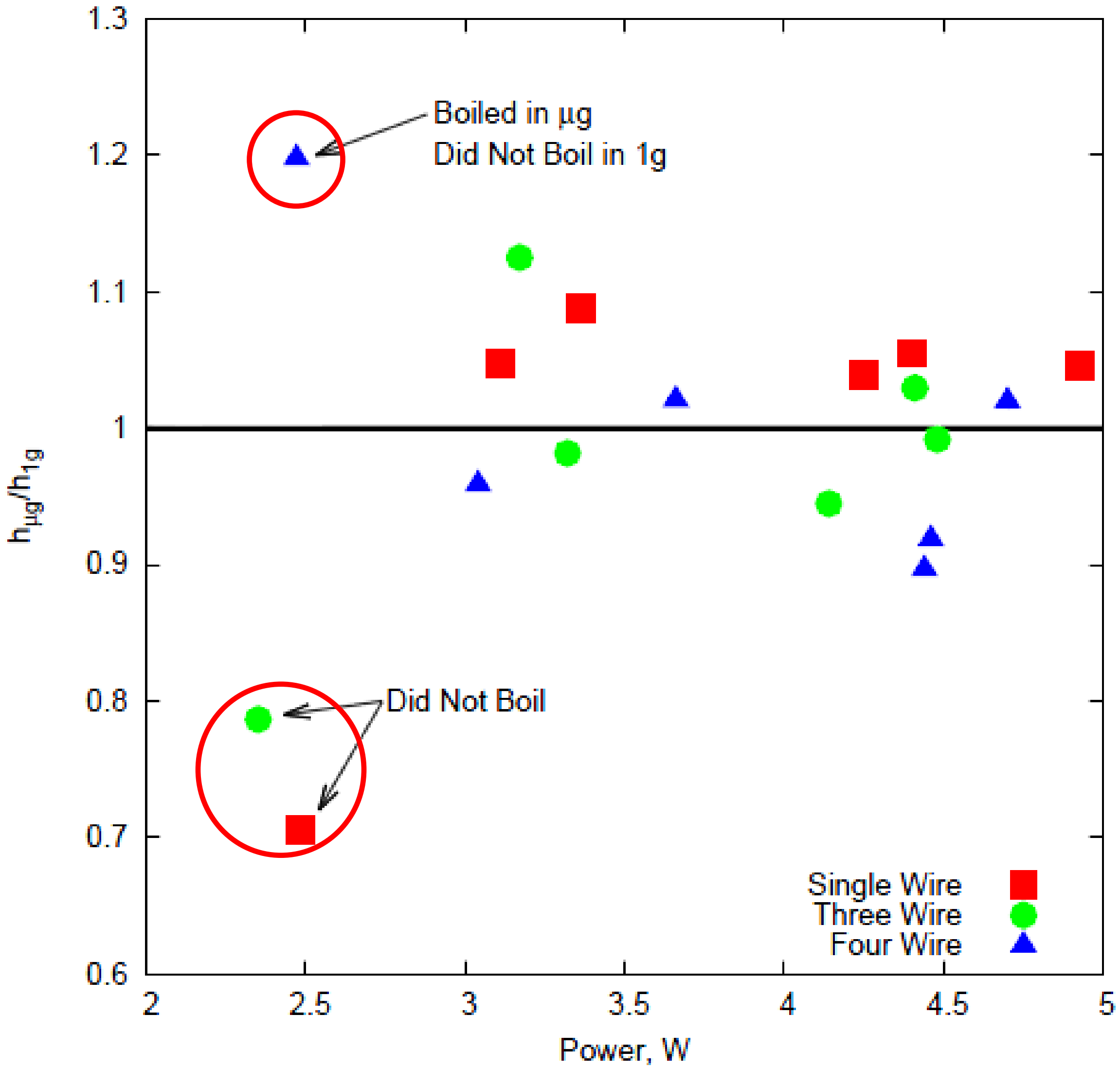


$$\frac{Red\ Area}{Blue\ Area} = \frac{1}{1}$$

$$\frac{Red\ Area}{Blue\ Area} = \frac{1}{6}$$

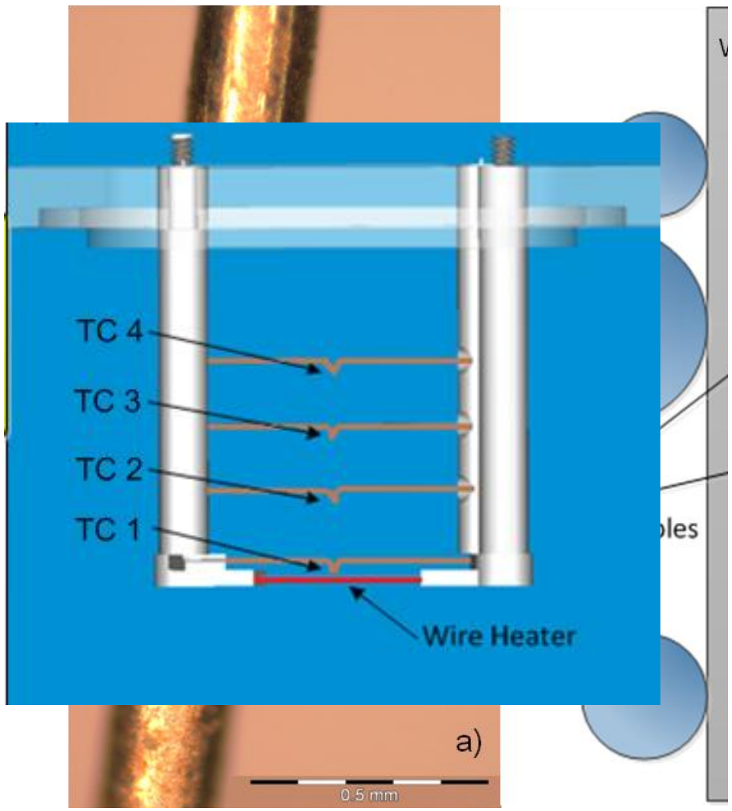
$$\frac{Red\ Area}{Blue\ Area} = \frac{1}{4}$$

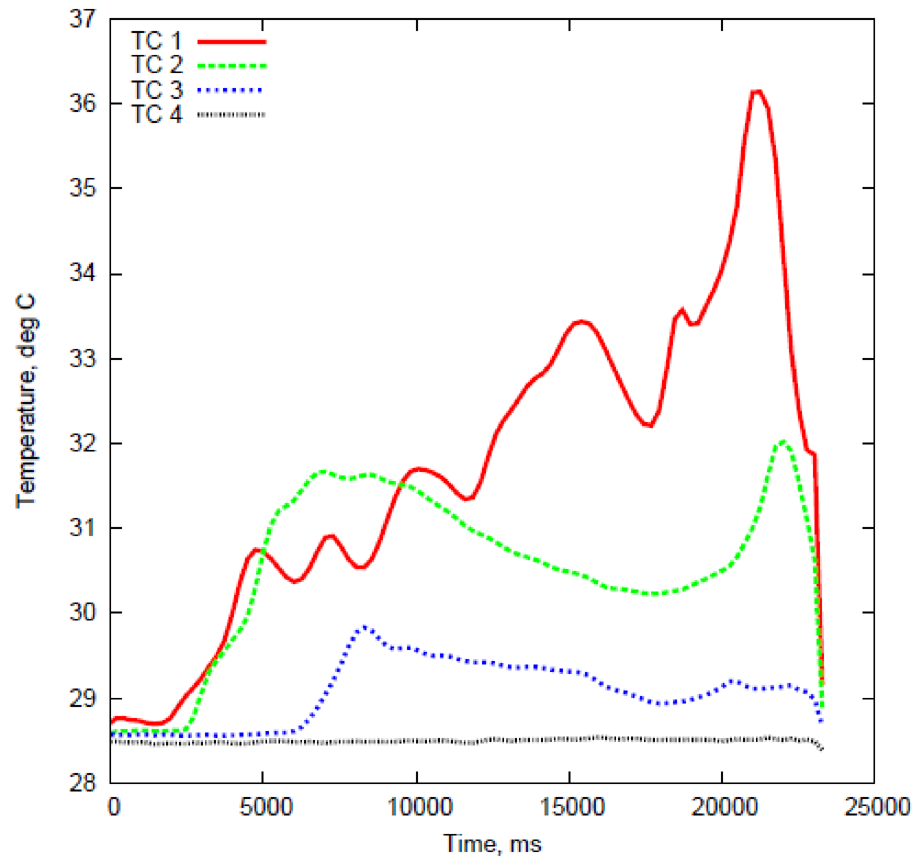
Steady State Heat Transfer



- Efficiency of boiling heat transfer in 1g and 0g are similar
- More effective area (more active nucleation sites) in microgravity

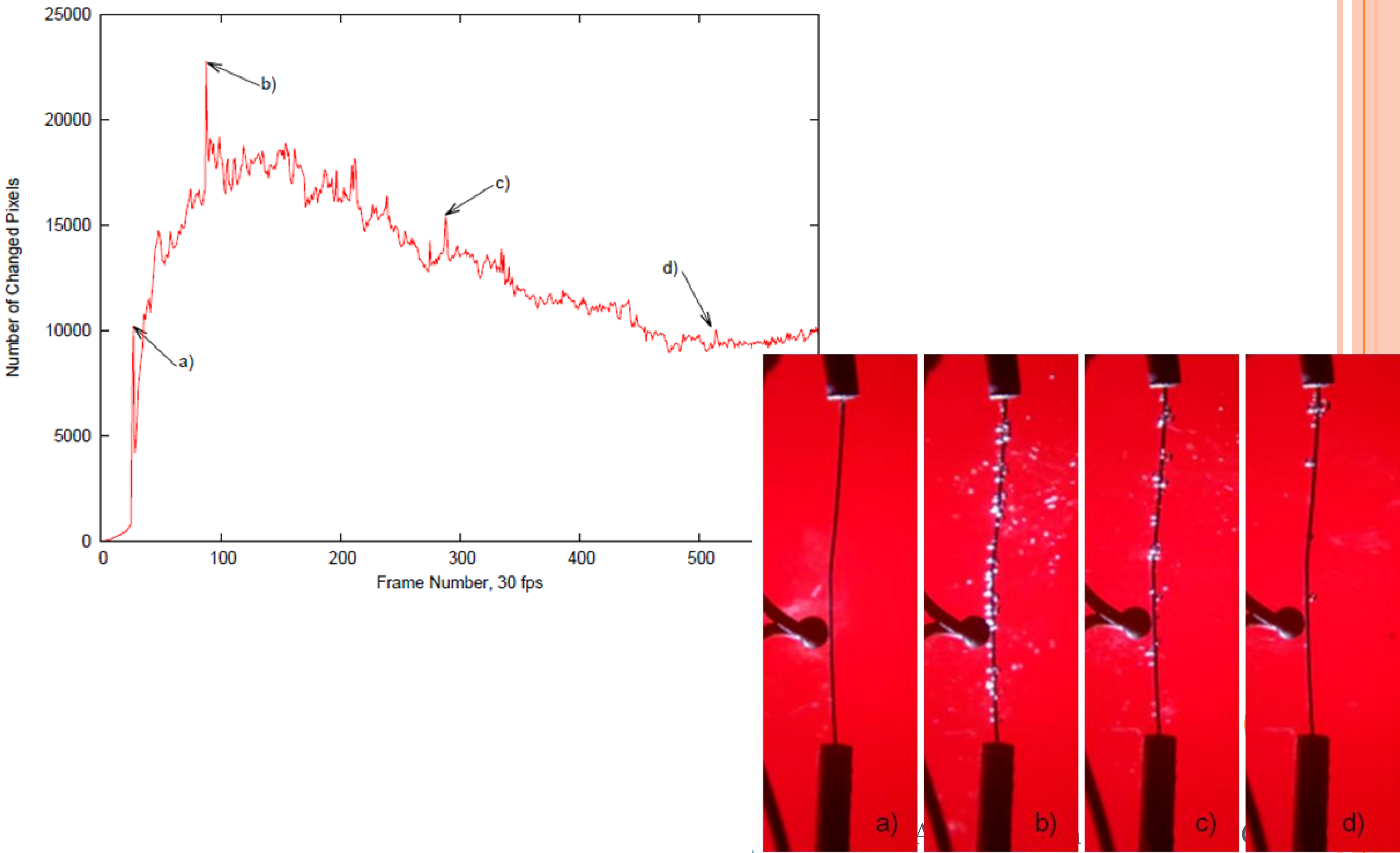
Bubble Dynamics - Jets



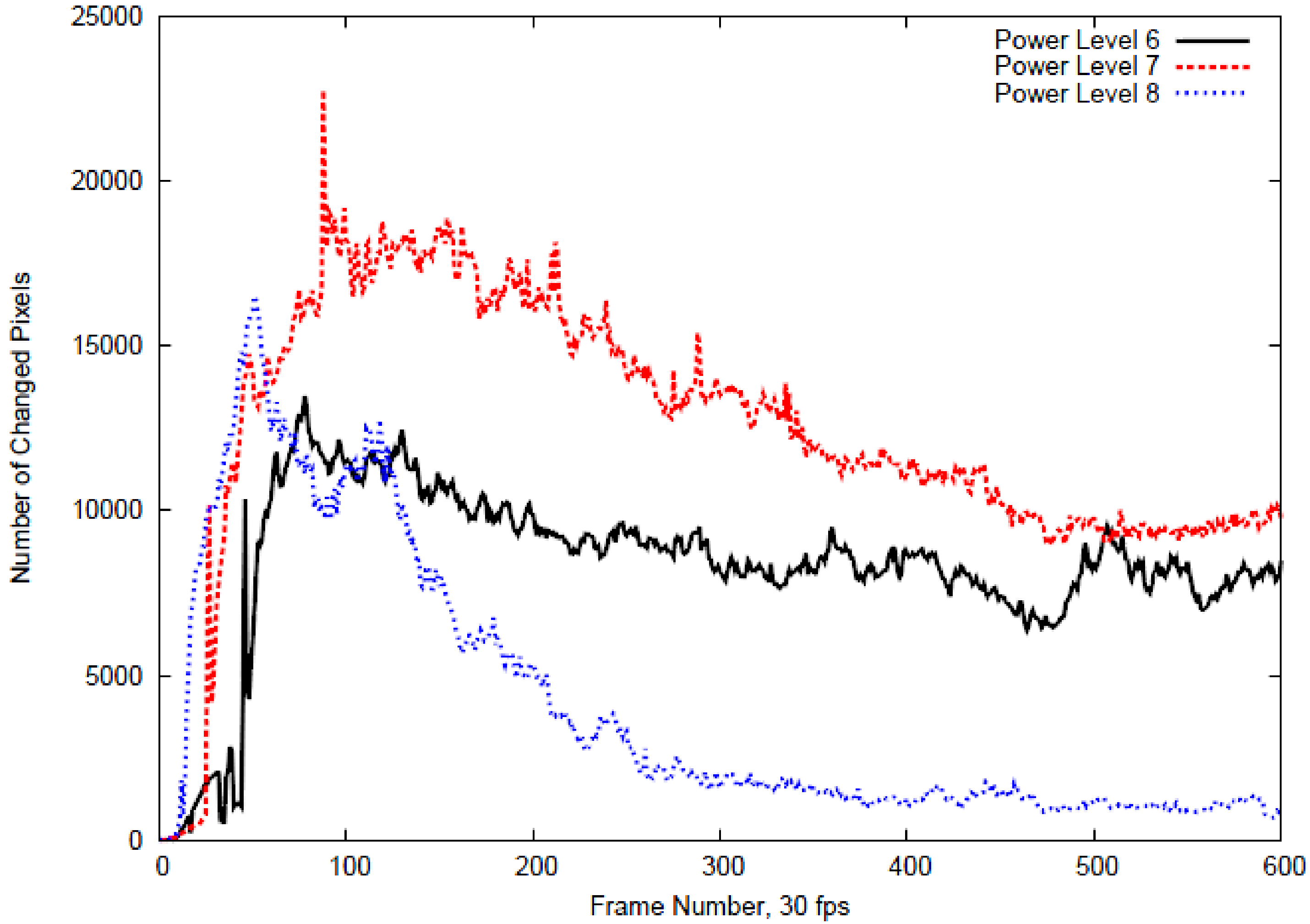


	TC 1	TC 2	TC 3	TC 4
Distance from wire	1 mm	6 mm	11 mm	16 mm

Relative Bubble Area Analysis (RBAA)



Heat Flux Effect - RBAA



Conclusions

- The unique twist of three-wires provides a surface geometry that reduces the required heat flux for onset boiling
- In many instances, steady state heat transfer is enhanced in microgravity in the range of 5-10%
- As heat flux increases, there is an increased tendency to form jets, which provide convective current normally absent in microgravity

Acknowledgements

- SpaceX
- Rocky Mountain NASA Space Grant Consortium
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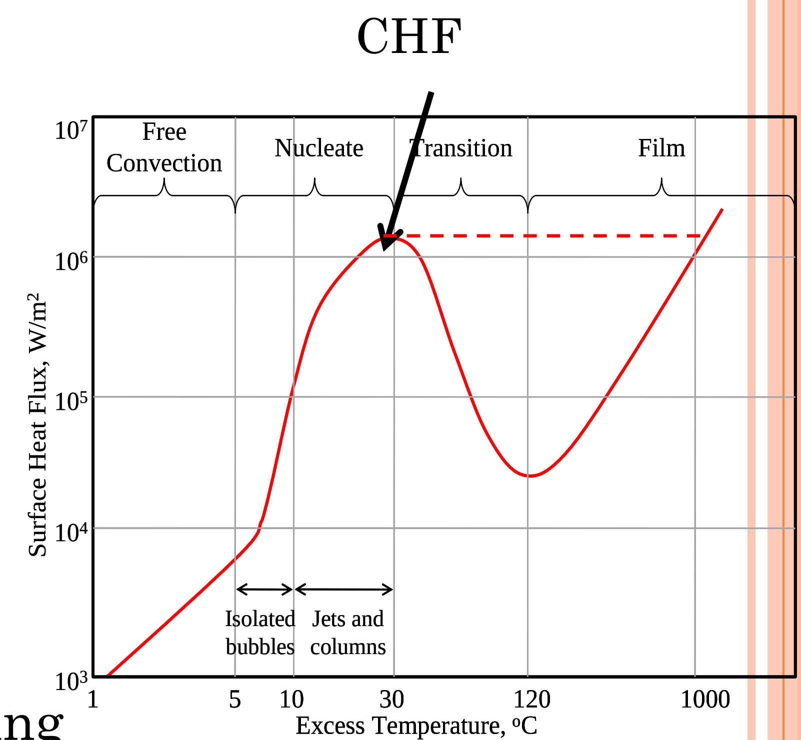
- USU Department of Physics
- USU Undergraduate Research
- Space Dynamics Lab
- American Aerospace Advisors
- National Instruments

Questions

Future Research

1) Extend input power range up to critical heat flux (wire burnout)



2) Further resolve onset conditions for boiling

3) 2-D Heater:
- Electric pulses to ‘seed’ the bubbles
- Bubbles grow as they accept heat
- Possibility to control amount of cooling

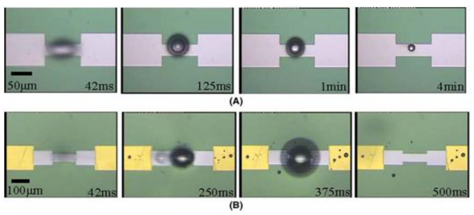
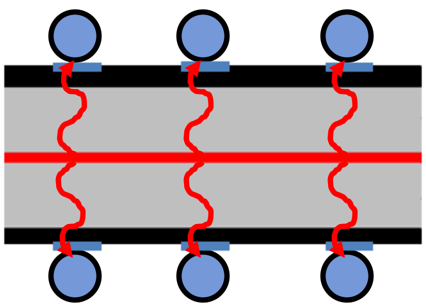


Photo courtesy of Deng



Geometry	"Power Level"	Input Current (A)	Average Power (W)	Average Heat Flux (kW/m²)
Single Wire	5	2.13	2.48	599
	6	2.37	3.11	750
	7	2.60	3.36	786
	8	2.81	4.40	1031
	9	3.01	4.93	1168
Three-Wire	5	2.20	2.35	397
	6	2.46	3.17	503
	7	2.71	3.32	559
	8	2.91	4.41	670
	9	3.12	4.48	777
Four-Wire	5	1.69	2.47	512
	6	1.91	3.04	639
	7	2.09	3.66	689
	8	2.26	4.44	930
	9	2.42	4.70	992