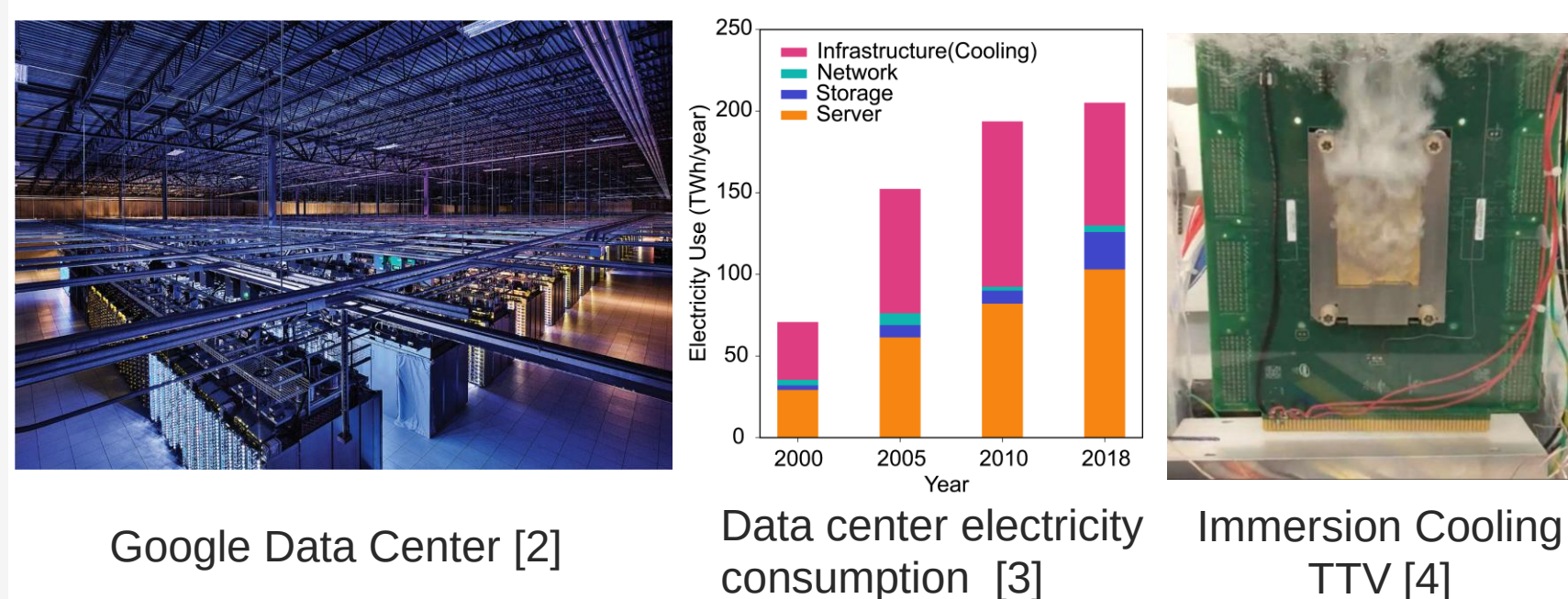


Prediction of Fin Array Heat Sink Performance Under Two-Phase Immersion Cooling

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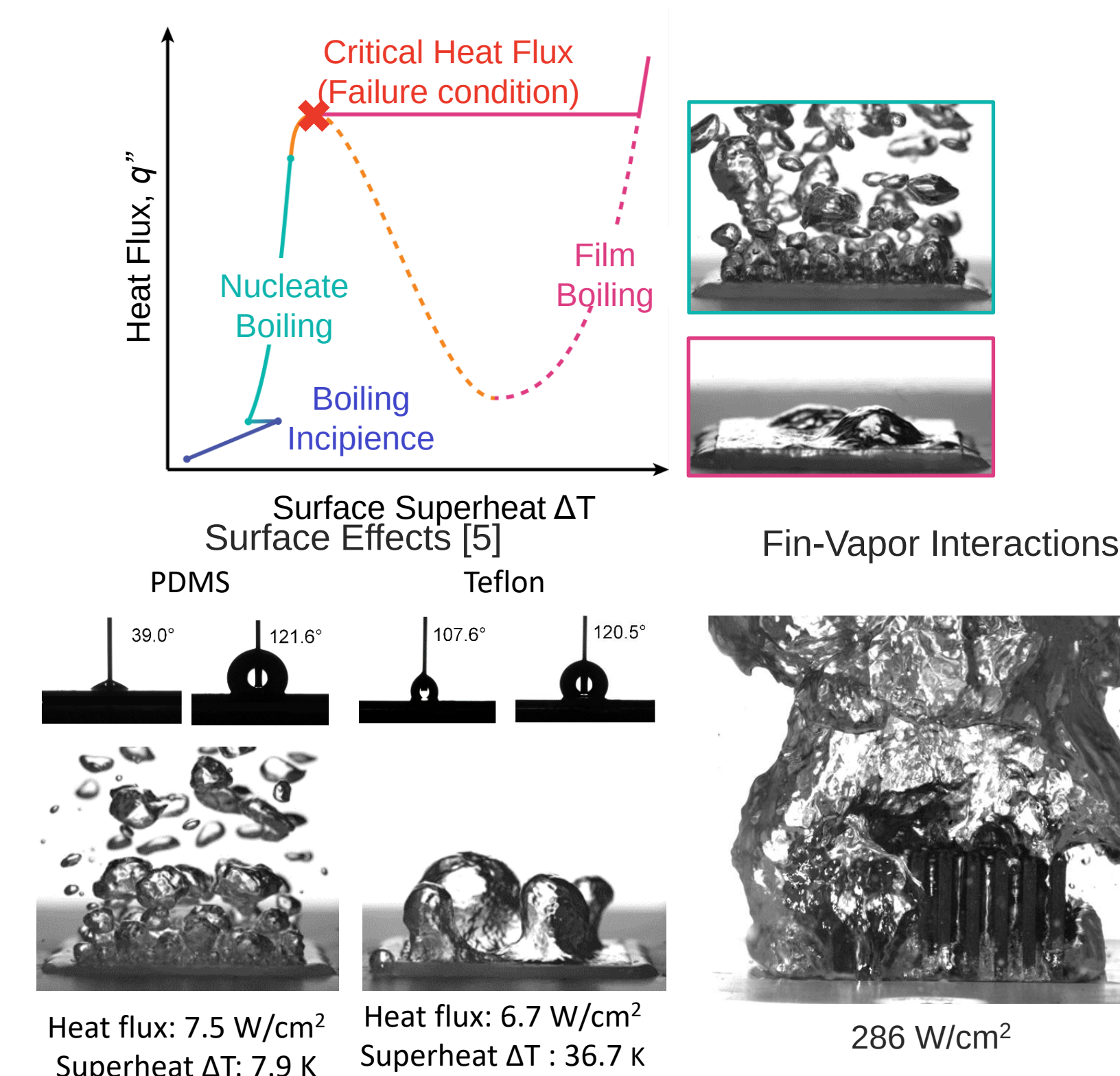
Motivation

- Cooling can account for up to 40% of overall data center energy usage [1]
- Two-phase immersion cooling can significantly reduce the energy cost for large, high-power systems
- Two-phase immersion cooling performance can be improved by utilizing extended surface heat sinks



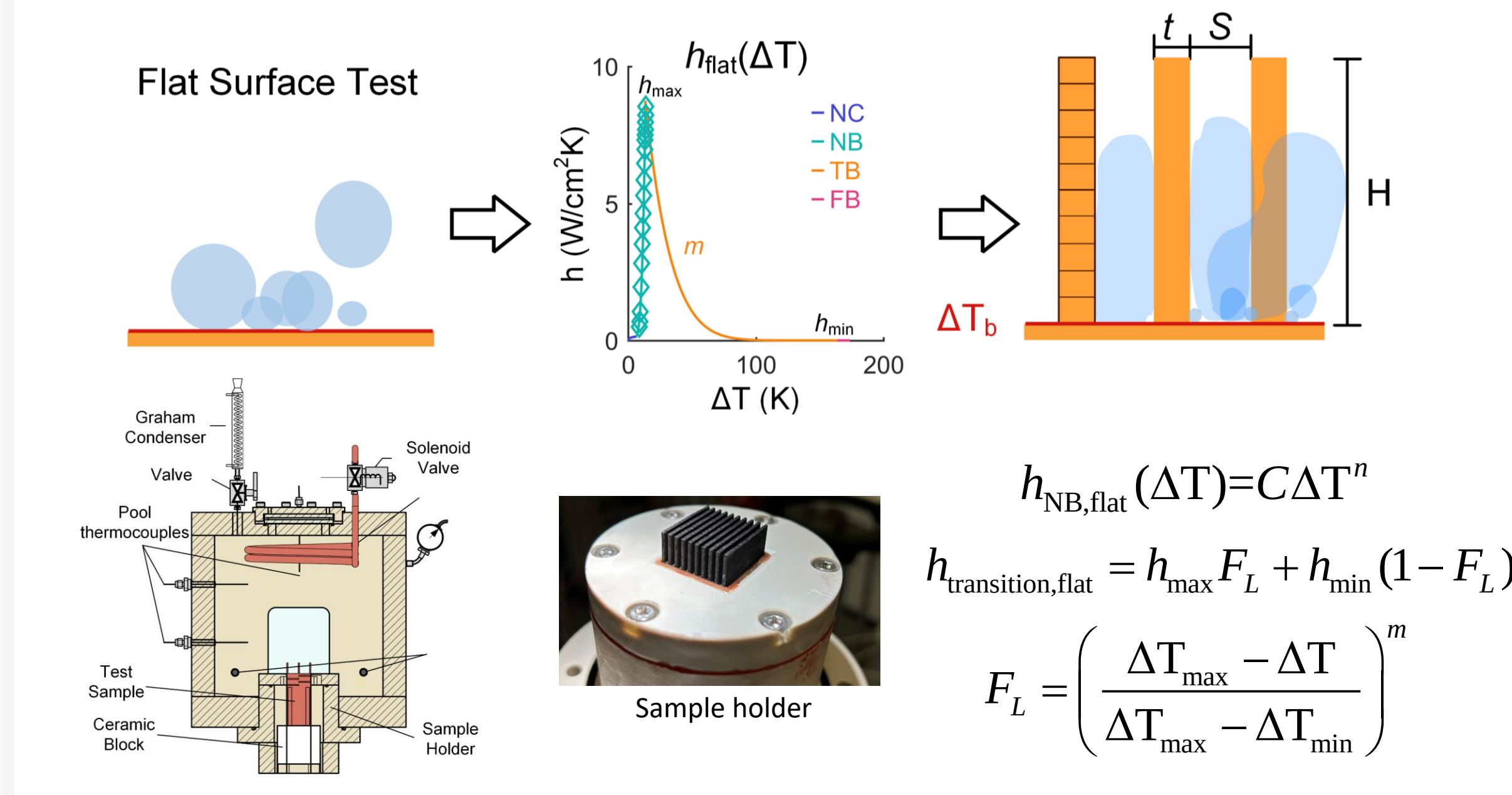
Background

- Boiling heat transfer rate changes drastically with surface superheat
- Quantifying the influence of surface properties on boiling can be challenging
- Fin-vapor interactions influence the boiling behavior and performance on heat sinks, but no predictive model is available



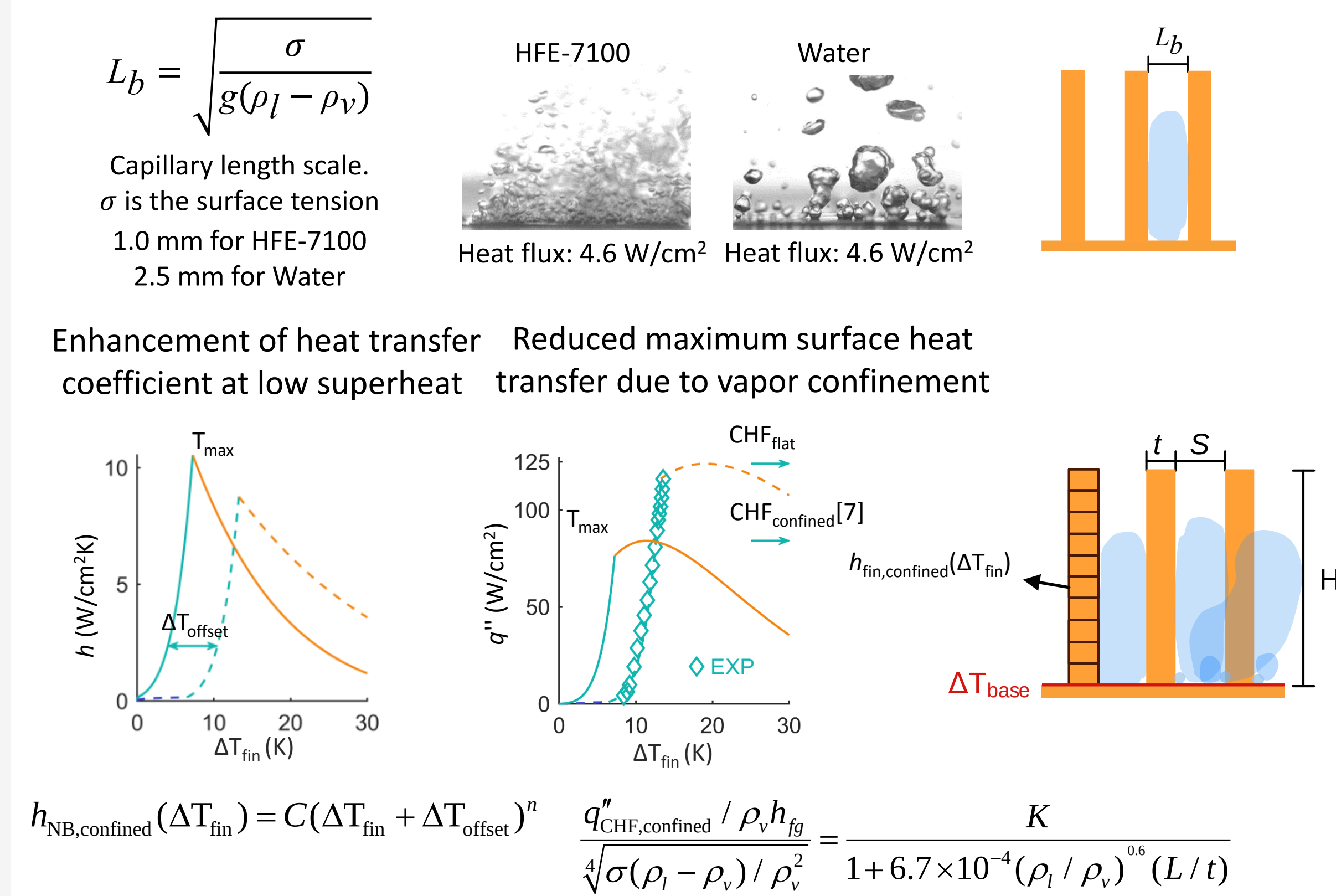
Our Approach for Predicting Heat Sink Performance

- Conduct boiling test on flat surface to retrieve surface heat transfer coefficient function $h_{\text{flat}}(\Delta T)$ for different boiling regimes.
- Apply $h_{\text{flat}}(\Delta T)$ to fin array and solve fin equation at different base superheat to predict performance
- Compare the prediction with boiling test results



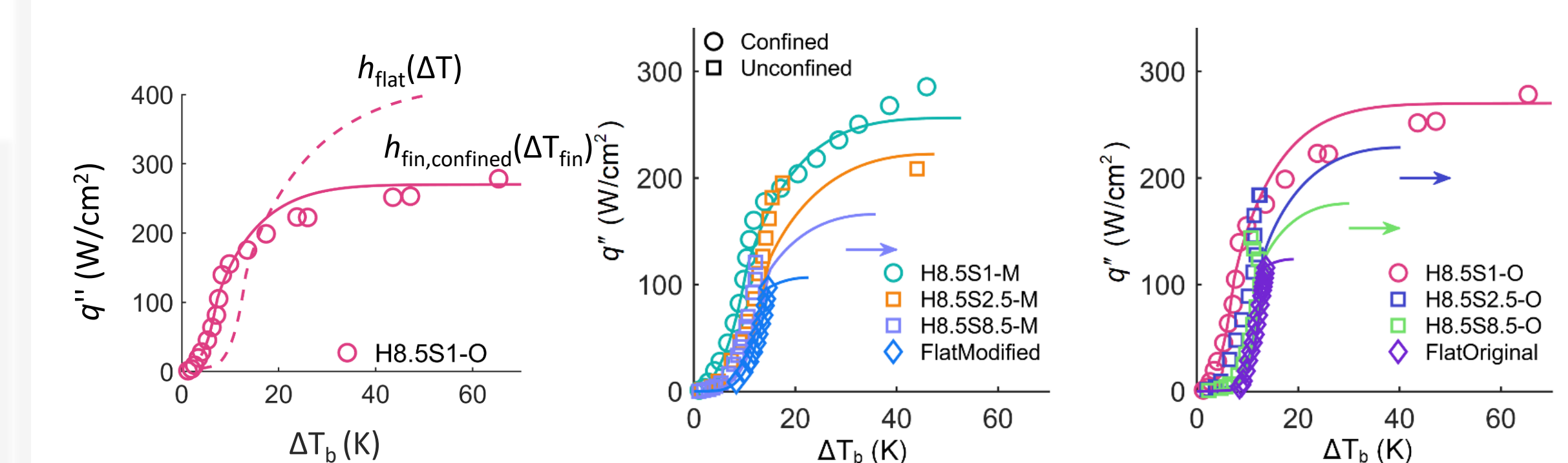
Capillary Length Governs the Fin-Vapor Interactions [6]

- Modify heat transfer coefficient function when spacing S is below the capillary length L_b [6]



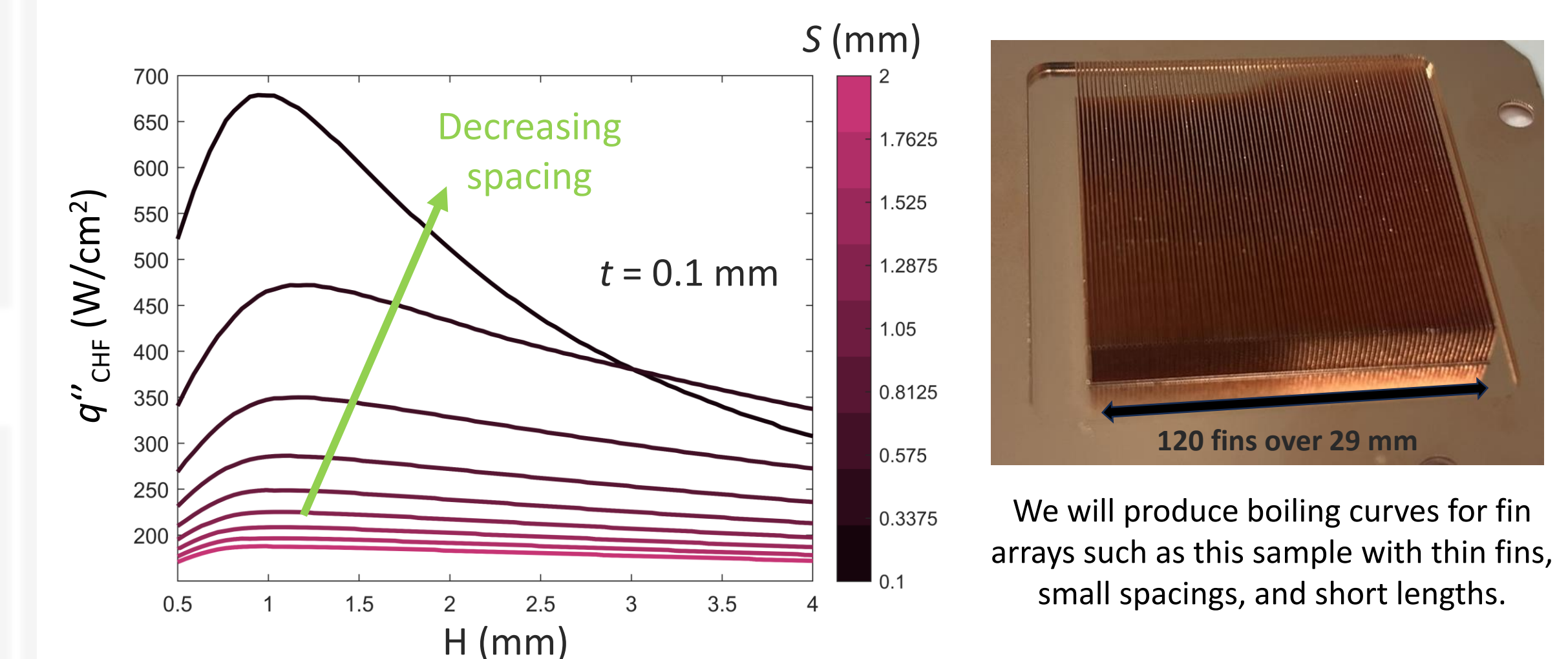
Predicting the Performance of Fin Arrays

- Accurate predictions of confined and unconfined fin arrays in water, at spacings as low as 1 mm



Optimization of Longitudinal Fin Array Parameters

- Goal: predict an ideal fin height and spacing to produce the highest heat flux



- Fin array with a thickness $t = 0.1$ mm, spacing $S = 0.1$ mm, and height $H = 1.2$ mm predicted to have $5 \times$ CHF of a flat surface (> 600 W/cm²)
- Increased surface area outweighs confinement effect (smaller spacings and thicknesses yield higher heat fluxes)

Conclusions

- ✓ A model was developed for predicting the vapor confinement effect on fin array performance under two-phase immersion
- ✓ This model is used to identify thin heat sink geometries that may be of interest for high heat flux cooling

[1] <https://www.energy.gov/articles/doe-announces-40-million-more-efficient-cooling-data-centers>

[2] <https://blog.google/inside-google/infrastructure/safety-first-ai-autonomous-data-center-cooling-and-industrial-control/>

[3] Lei, Nuoa, and Eric R. Masanet. In Data Center Handbook, 15–26. 2021.

[4] <https://www.intel.com/content/www/us/en/newsroom/news/intel-to-develop-data-center-cooling-tech.html#gs.776dt5>

[5] T. P. Allred, J. A. Weibel, and S. V. Garimella. Int. J. Heat Mass Transf., 2019,

[6] M. Winter and J. A. Weibel, International Journal of Heat and Mass Transfer 202, p. 123727, 2023

[7] M. Monde, H. Kusuda, and H. Uehara, Journal of Heat Transfer 104, pp. 300–303, 1982.