Bubbleformer

Forecasting Boiling with Transformers

Presented by
Sheikh Md Shakeel Hassan

Collaborators

Sheikh Md Shakeel Hassan

Xianwei Zou

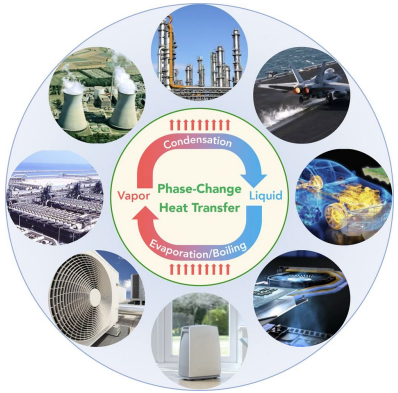
Aparna Chandramowlishwaran

Akash Dhruv

Vishwanath Ganesan

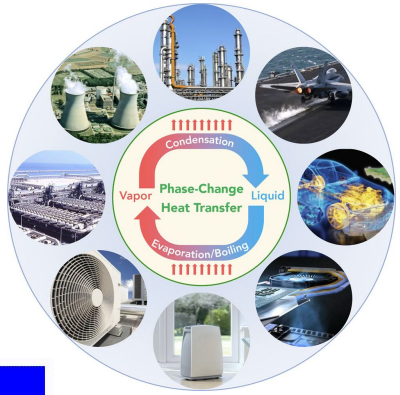
Boiling and its Applications

- Ubiquitous form of heat transfer
- Complex multiphase-multi physics phenomena
- Understanding crucial for thermal management



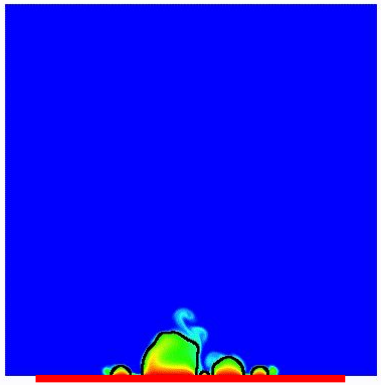
Boiling and its Applications

- Ubiquitous form of heat transfer
- Complex multiphase-multi physics phenomena
- Understanding crucial for thermal management



Pool Boiling

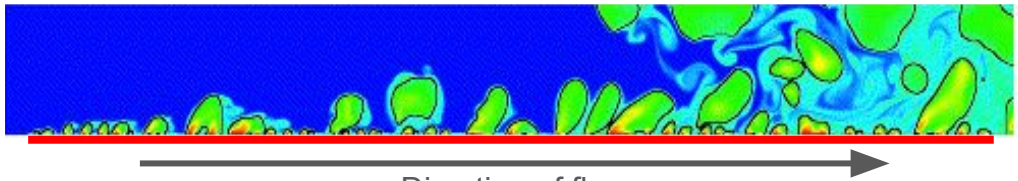
A **pool of liquid** sitting on a **heated surface**, can model the cooling of **nuclear reactors**



Constant Heater Temperature

Flow Boiling

A liquid ***flowing*** across a **heated surface**, can be used to model **liquid cooling** in data centers



Direction of flow

BubbleML 2.0

Hugging Face

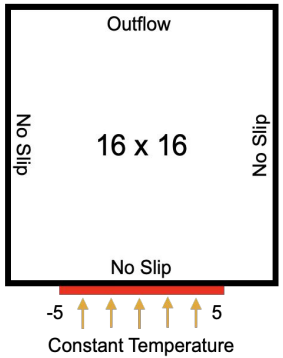
- Extended version of BubbleML[1]
- **160** high fidelity simulations for **Pool and Flow Boiling**
  - **Liquids:** Dielectric, Refrigerant, Dielectric
  - **Flow Regimes:** Bubbly, Slug and Annular flow
- Open source and extensible
- Ground truths for liquid & vapor **phases, temperature, pressure, and velocity**
- Additional physical fields: **mass flux** and **interface normals**

BubbleML 2.0

https://bit.ly/bubbleml_2

[1]BubbleML: A Multiphase Multiphysics Dataset and Benchmarks for Machine Learning, NeurIPS 2023

Pool Boiling



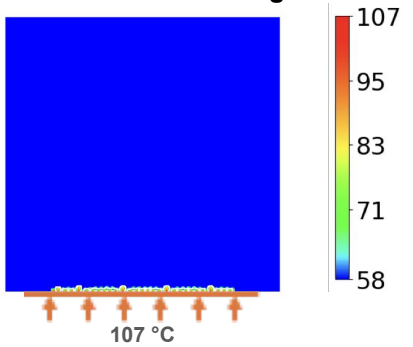
FC-72
Dielectric

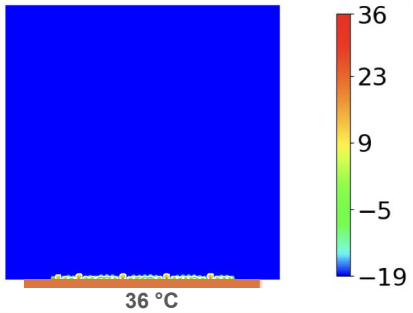
R515B
Refrigerant

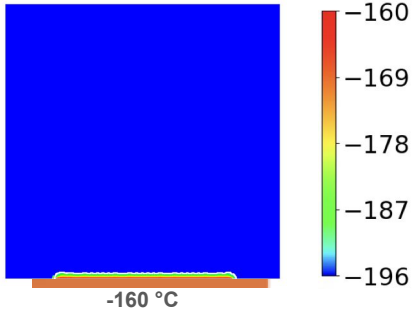
LN_2
Cryogen

Increasing Boiling Point

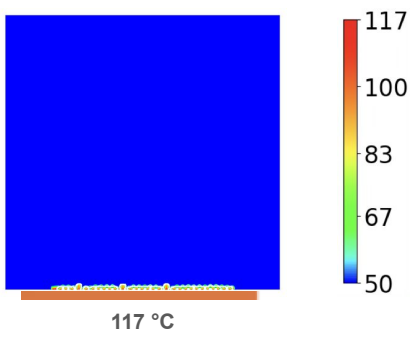
Saturated Pool Boiling

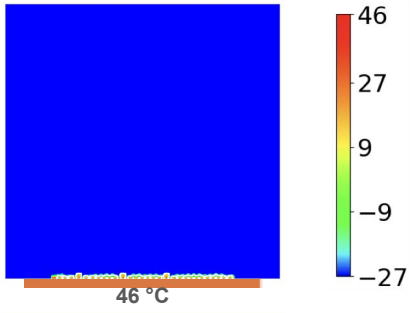


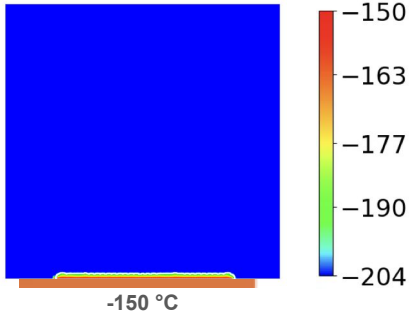




Subcooled Pool Boiling

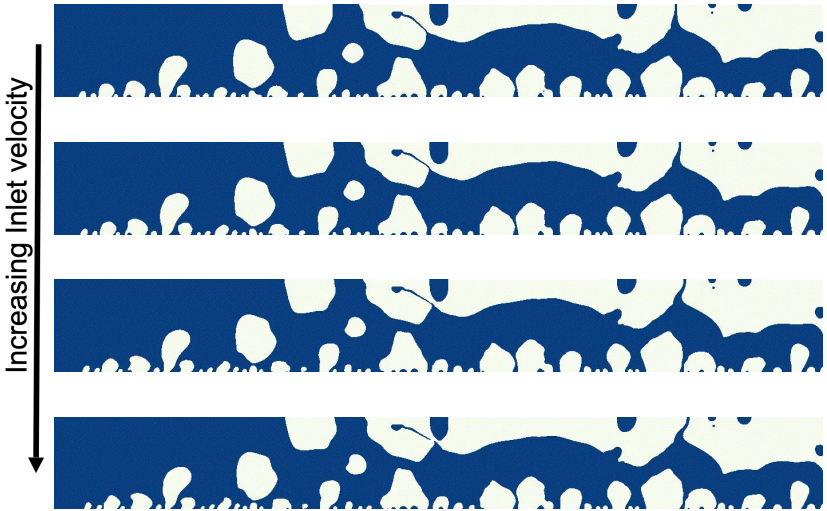


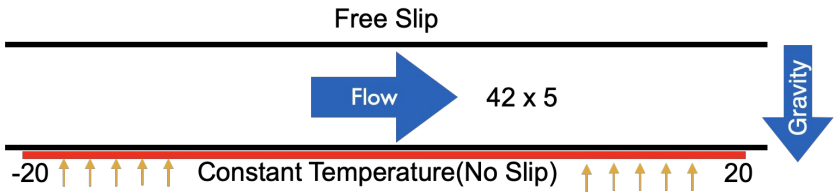


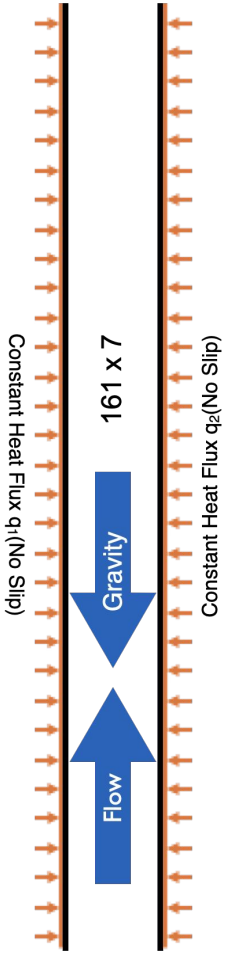


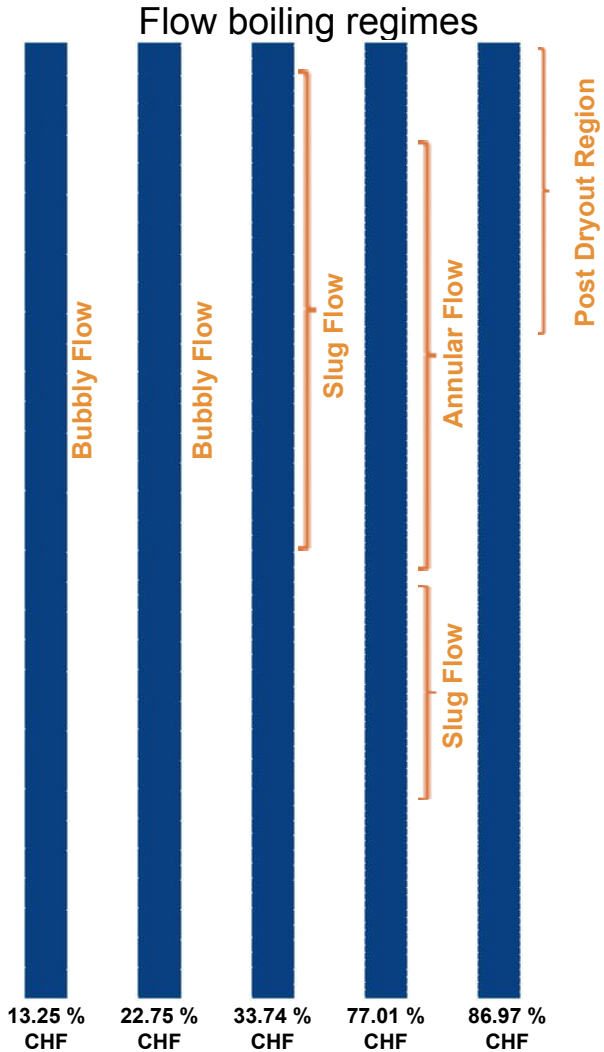
Flow Boiling

Flow boiling at different inlet velocities





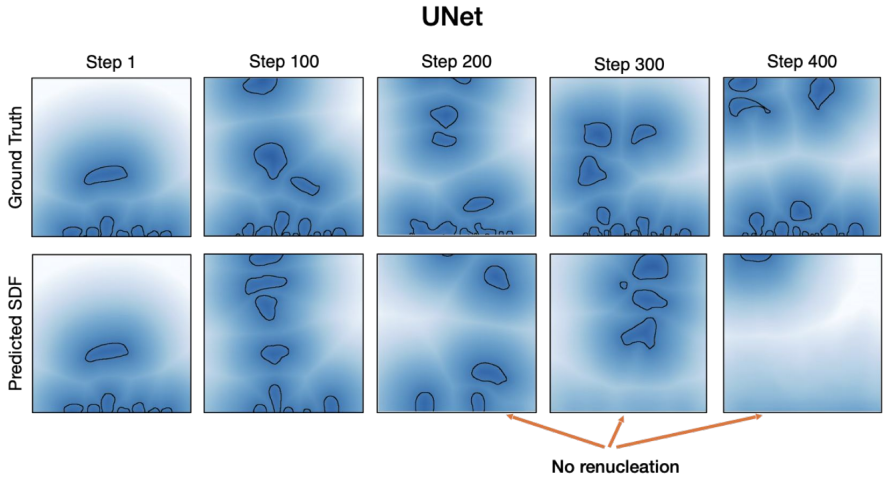




Failure Modes of Boiling ML Surrogates

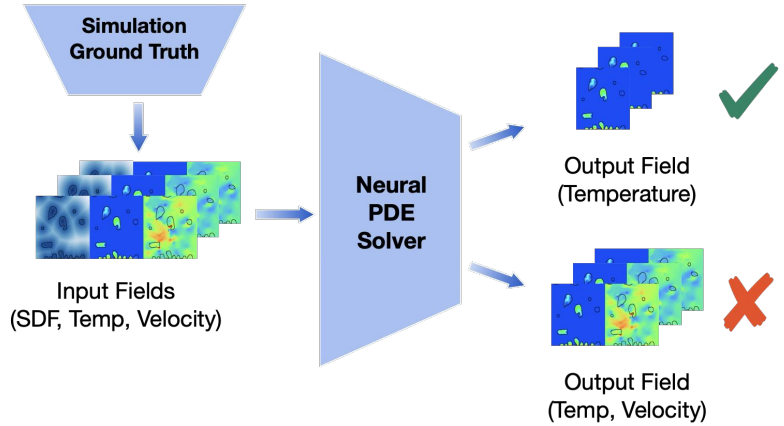
Simulation independent forecasting

- **Model input** → Past state (bubble position, temperature and velocity)
- **Model output** → Future state (bubble position, temperature and velocity)
- Autoregressive forecasting models **fail to re-nucleate** new bubbles



Flow Boiling velocity prediction

- Lack of **directional inductive bias**
- Insufficient **spatiotemporal integration**



Bubbleformer Goals

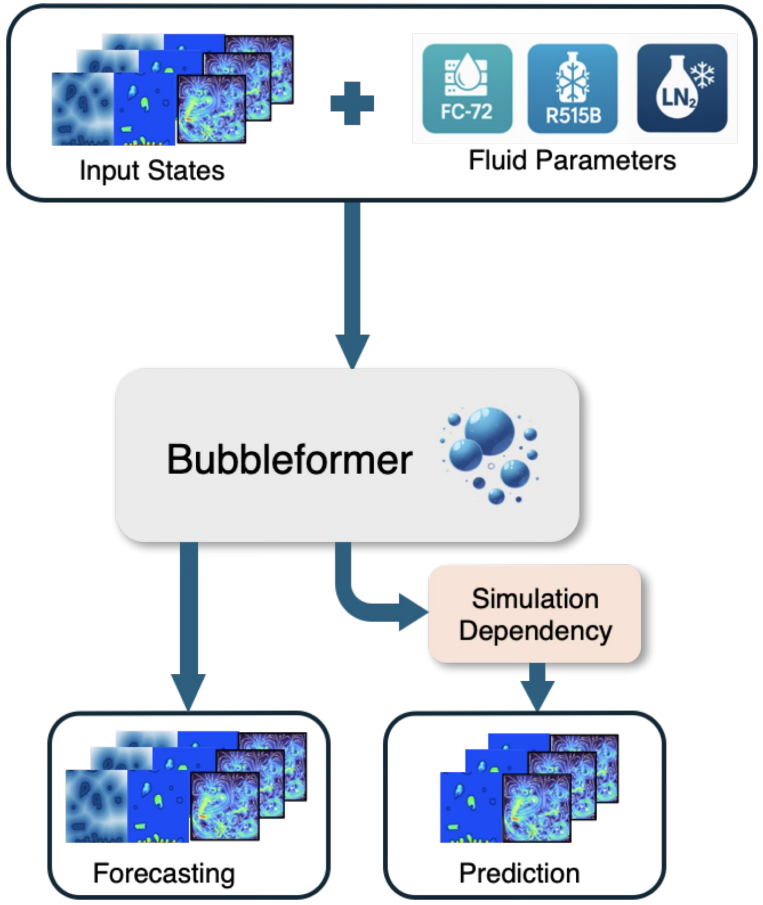
Microscopic hydrodynamic response
- Velocity and temperature fields
- Bubble dynamics and nucleation

System level response
- Heat flux, flow regime

Physics-based evaluation metrics
- **KL divergence:** Heat flux distribution
- **Eikonal loss:** Bubble dynamics
- **Relative vapor volume error:** Mass conservation

Generalize across fluids and geometries

Long and stable autoregressive rollouts

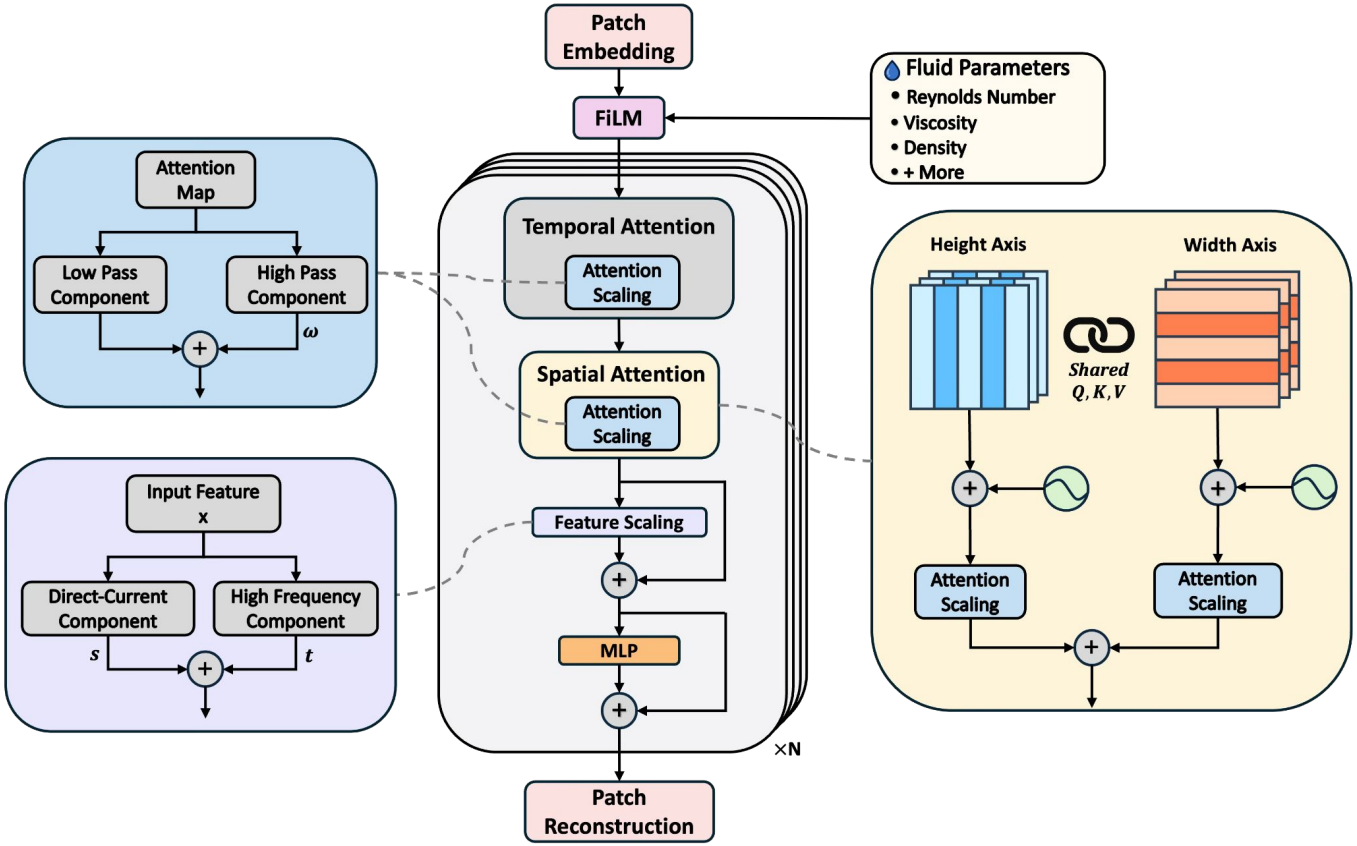


Bubbleformer Architecture

Spatiotemporal transformer blocks with **temporal attention** & **axial attention** across space

Attention and feature scaling for **high frequency** features

Feature-wise Linear Modulation (FiLM) to **condition** on **fluid parameters**

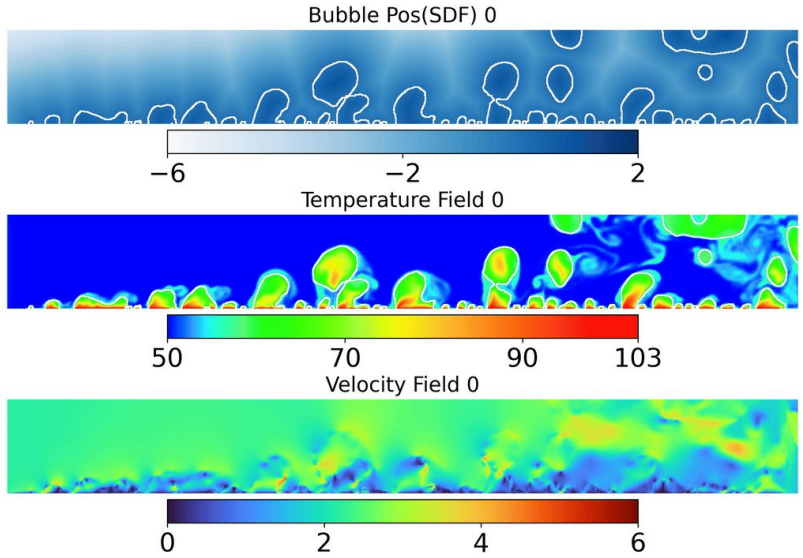


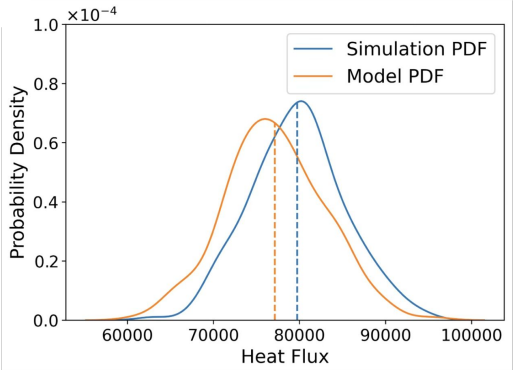
Forecasting: Flow Boiling

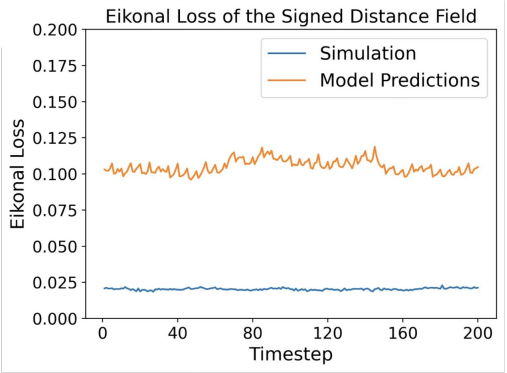
Can perform **Flow Boiling** downstream tasks

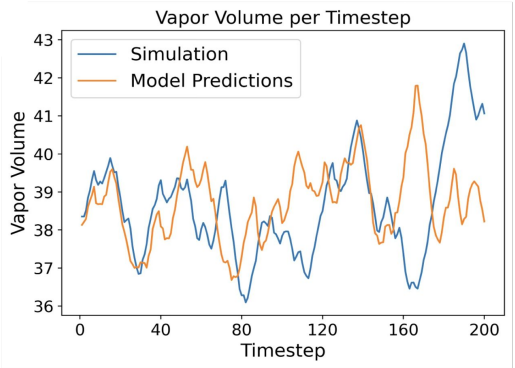
Stable forecasts for upto **200 timesteps**

Consistent physics

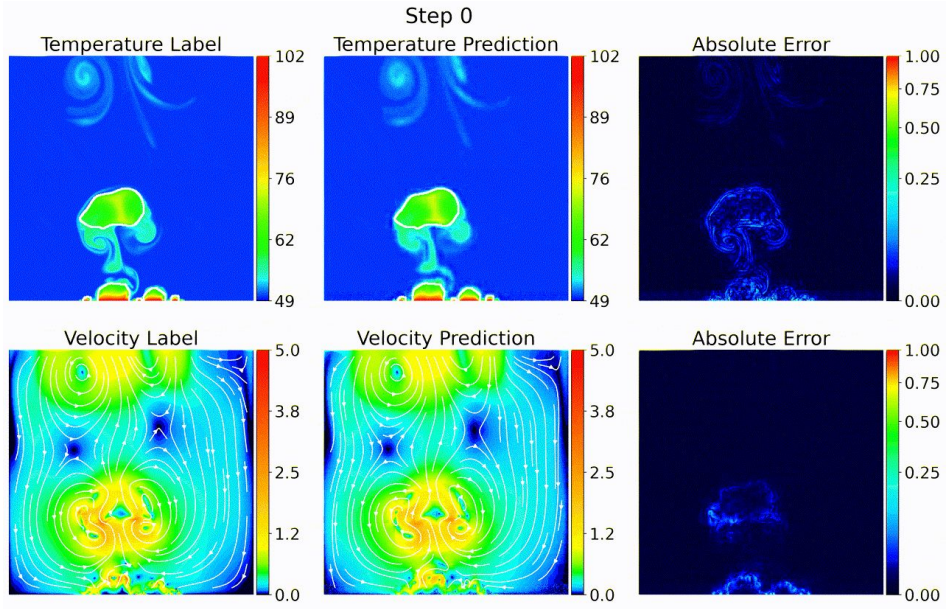




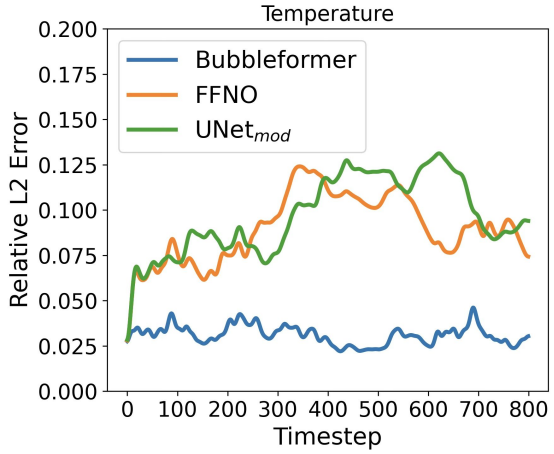


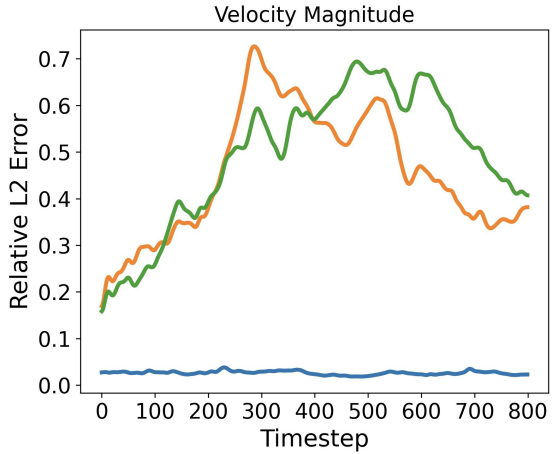


Subcooled Pool Boiling: BubbleML Benchmark



FC-72





Pool Boiling predictions are improved**. Longer rollouts** are made possible.

Thank you!

BubbleML 2.0

https://bit.ly/bubbleml_2

Bubbleformer

https://bit.ly/bubbleformer