

Project Report: Graph-O-Foam: ActiveScan Copilot (Lite) — Foam Stability Forecasting

1. Executive Summary

The *Graph-O-Foam* project delivers a complete pipeline to predict and visualize foam stability from experimental datasheets. By converting standard lab spreadsheets (BD + HD in XLSX format) into synthetic microscopy frames, our workflow generates measurable bubble metrics (count, radius, circularity, coarsening) and links them to foam half-life or stability labels. Eleven machine learning architectures were benchmarked, ranging from standard deep learning (MLP) to explainable and physics-informed models (EBM, KAN, TITANS/PIEBT).

2. Workflow and Methods

2.1 Data Processing

- BD Sheet (Bubble Dynamics):** Generates synthetic microscopy frames representing bubble evolution over time.
- HD Sheet (Foam Stability):** Supplies target labels (half-life if reached; otherwise “not reached within window”).
- Feature Extraction:** OpenCV-based segmentation extracts bubble metrics per frame:
 - Radius distributions
 - Bubble count and coarsening behavior
 - Circularity and shape descriptors

2.2 Model Evolution

The project followed a four-stage development path:

Stage	Model	Approach	Outcome
I	Multi-Layer Perceptron (MLP)	Baseline deep learning	RMSE 24.03, poor physics capture
II	KAN, EBM	Interpretability + tabular learning	EBM RMSE 3.97; KAN improved transparency
III	PIEBT/TITANS	Physics-informed, neural memory	RMSE 6.42; respects Plateau’s laws, Young-Laplace, Marangoni effects
IV	PINN, RL	Experimental physics embedding	Explicit constraints often less effective; RL showed moderate correction

3. Tools and Frameworks

- **Python 3.11, Streamlit** (dashboard & interactive visualization)
 - **Pandas + OpenPyXL** (data ingestion and preparation)
 - **NumPy + OpenCV** (synthetic frame generation, segmentation, and analysis)
 - **Matplotlib / Streamlit charts** (plots and overlays)
 - **Git + GitHub** (versioning and collaboration)
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4. Results and Comparative Analysis

Rank	Model	Class	RMSE	Key Strength
1	EBM	Ensemble	3.97	Highest accuracy, robust tabular performance
2	SVR	Ensemble	4.50	Strong tabular performance
3	TITANS (PIEBT)	Physics-informed	6.42	Best physics-accuracy balance
4	KAN	Physics-informed	6.55	High transparency
5	MLP	Baseline	24.03	Standard baseline
6	PINN	Experimental	25.49	Explicit physics constraints, less flexible

5. Key Findings and Demo Impact

- Synthetic frames allow “no-image” labs to generate visually realistic bubble evolution.
 - Feature-to-stability linkage is fully explainable: users can see both metrics and predictions evolve.
 - One-click condition comparisons (GO vs NGO, nanoparticle size) produce instant visual and quantitative insights, making it highly hackathon-ready.
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6. Conclusion

Graph-O-Foam demonstrates a hybrid, explainable, and physically-informed approach for foam stability prediction. By integrating synthetic visualization, computer vision, and ML modeling, it bridges the gap between raw experimental data and actionable stability insights. This workflow provides a powerful platform for researchers, enabling interactive comparisons, reproducible forecasts, and interpretable analytics in foam science.