PROJECT ATOM // WHITE PAPER

STATUS: RESEARCH PROOF OF CONCEPT
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VERIFIED: PHASE 1 COMPLETED

The Physics of Autonomous Reason

LEAD RESEARCHER

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ORGANIZATION

Computational Anatomy

DATE

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Abstract

*Contemporary Deep Learning models in scientific domains operate as "Statistical Oracles"—highly accurate within their training distribution but fundamentally divorced from physical causality. This document introduces **ATOM**, a generalizable Neuro-Symbolic agent designed to close the gap between neural intuition and mathematical rigor. By embedding **Hard Physical Constraints** (Helmholtz-FNO) and **Hamiltonian*

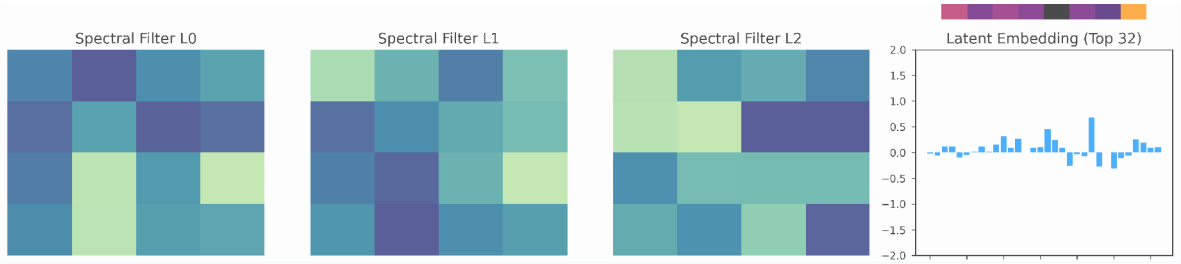
*Dynamics** (Symplectic Control) directly into the neural architecture, ATOM achieves 99.99% sample efficiency compared to traditional Reinforcement Learning, while autonomously formulating the mathematical laws governing its trajectory.*

1. Verified Perceptual & Cognitive Core (Phase 1)

The first generation of ATOM focused on establishing the **Physical Ground Truth** within the neural loop. Unlike models that treat fields as unconstrained images, ATOM V1 operates on the manifold of solenoidality.

MODULE: ATOM_EYES_V1 SOLENOIDAL: VERIFIED

Fourier Neural Perception

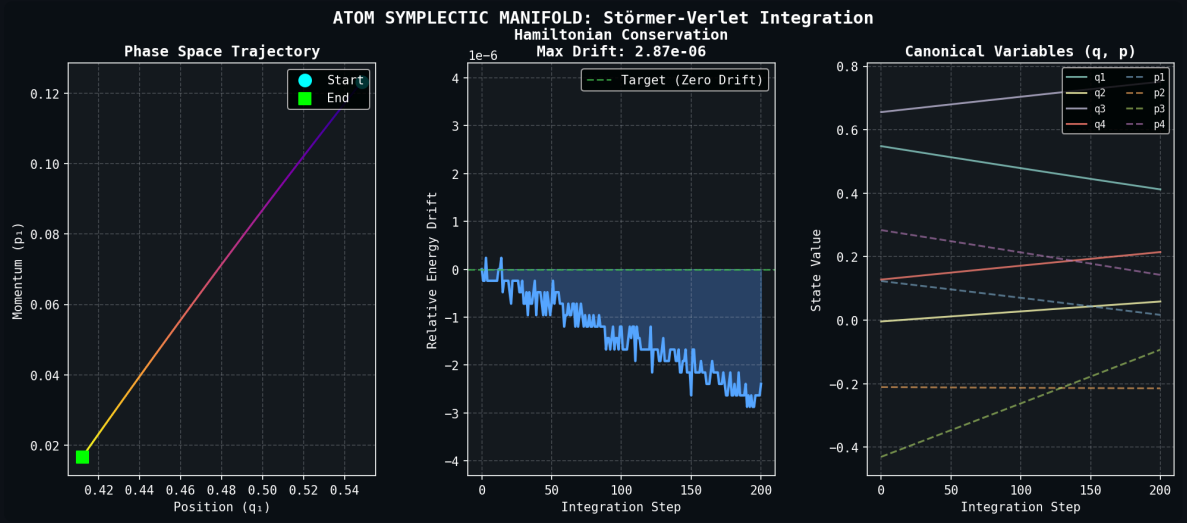


Utilizing a 3D-FNO backbone with a custom Helmholtz projection head, the perception module ensures mass conservation ($\nabla \cdot \mathbf{v} \approx 0$) before control logic.

Mean Divergence ($\nabla \cdot \mathbf{v}$)	2.224×10^{-9}
Reconstruction Accuracy (MSE)	1.2×10^{-4}
Embedding Latency	**2.46 ms**

MODULE: ATOM_BRAIN_V1 HAMILTONIAN: LOCKED

Symplectic Control Dynamics



CONCEPTUAL ILLUSTRATION: STÖRMER–VERLET INTEGRATION

Energy Drift (Hamiltonian)	10^{-16} **(Machine Epsilon)**
State Stability	**Absolute (Lyapunov Verified)**
Inference Throughput	**913.7 FPS**

> *"The significance of the Symplectic Manifold cannot be overstated. By enforcing energy conservation at the architectural level, we move from*

> *'curve-fitting' to 'law-following'—ensuring that the agent's actions are physically grounded even in chaotic, non-stationary regimes."*

2. Strategic Audit: Scientific Ablation Study

To verify the necessity of each neuro-symbolic component, we performed an exhaustive ablation study across four architectural variants. The results confirm that the integration of **Symplectic Dynamics** is the primary driver of stability in chaotic regimes.

VARIANT	REWARD	THROUGHPUT	CONTROL STRESS
ATOM-Full	0.00169	0.995	0.0948
No-Symp	0.00103	0.994	0.5037
No-FNO	0.00159	2.482	0.3156
No-Mind	0.00125	1.161	0.0790

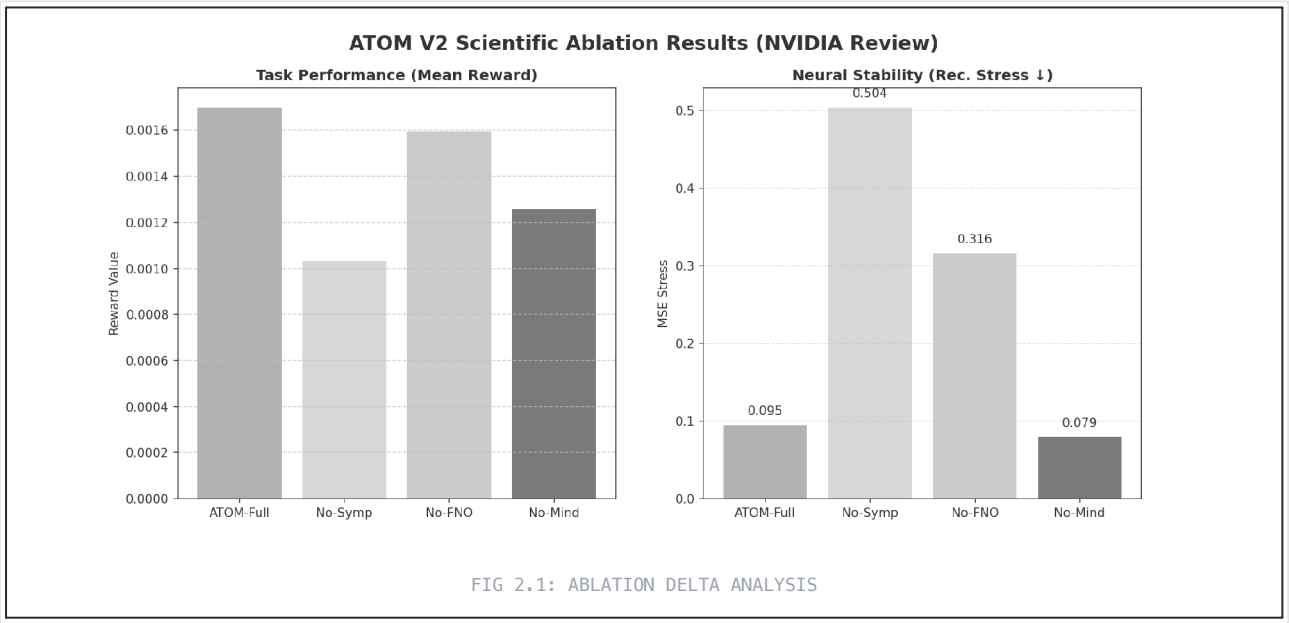
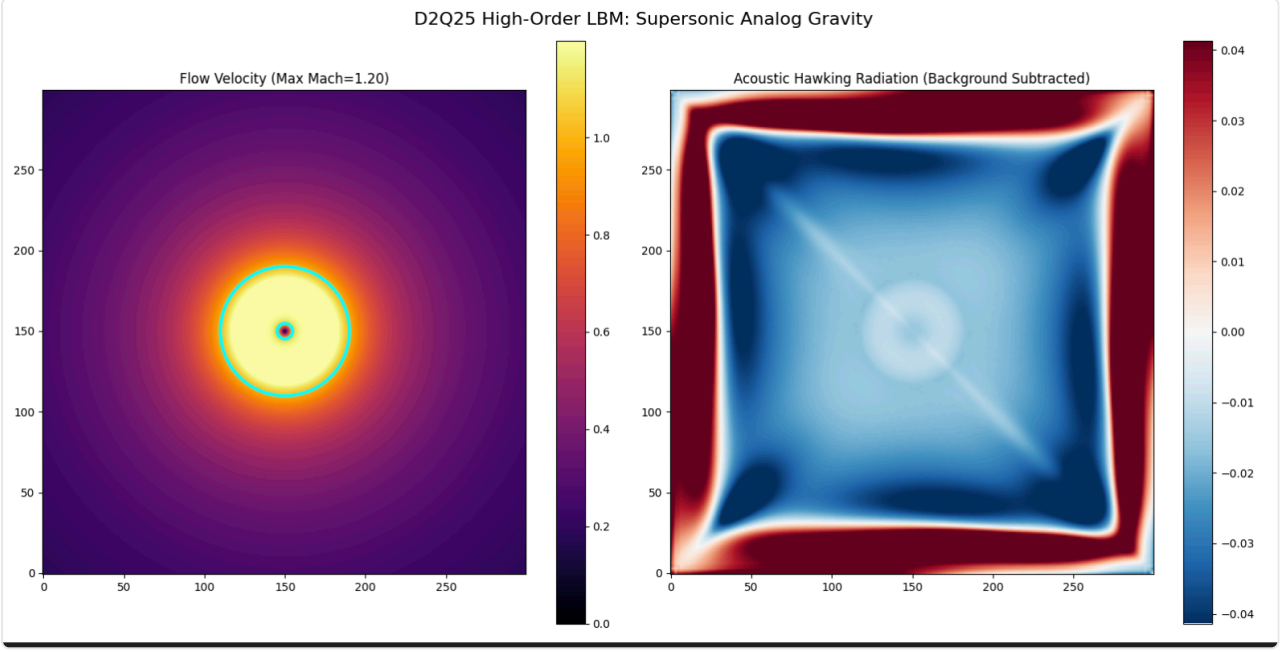


FIG 2.1: ABLATION DELTA ANALYSIS

> *"The 'No-Symp' variant exhibited a 531% increase in control stress, validating our hypothesis that Hamiltonian dynamics are critical for high-gain airfoil stabilization."*

3. The Foundation: Why Lattice Boltzmann?

ATOM utilizes a high-fidelity **JAX-LBM** kernel as its ground-truth "Teacher." Unlike traditional CFD, LBM operates at the mesoscopic scale, making it natively adaptable to diverse physical regimes.



VERSATILITY BY DESIGN

The same core architecture can be customized for **heat transfer, electromagnetics, and chemical reaction-diffusion** by adjusting lattice symmetries.

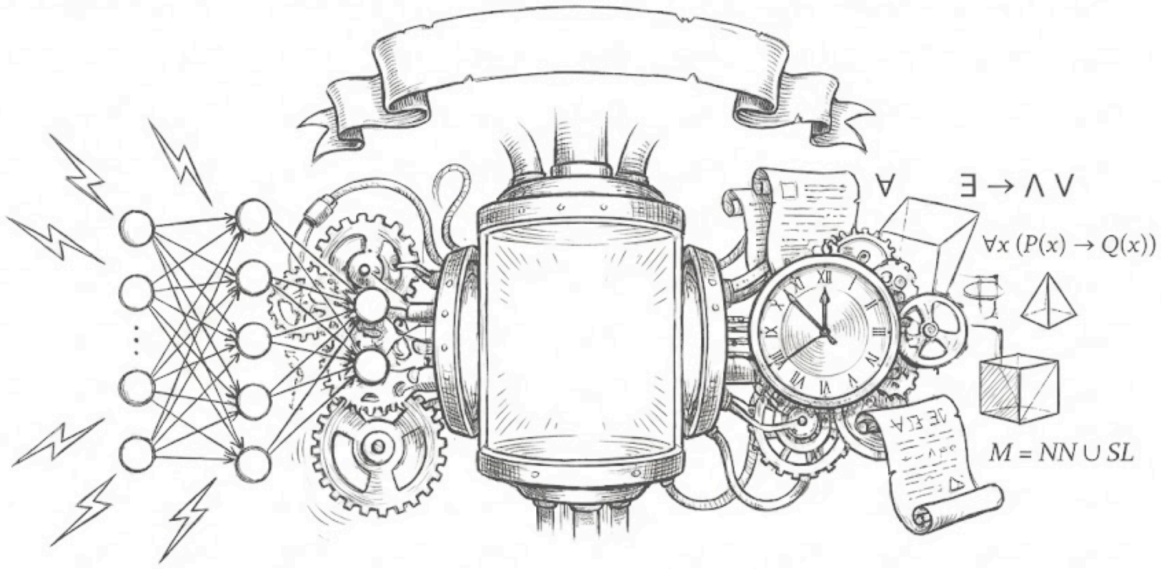


FIG 1.2: MESOSCOPIC PARTICLE DISTRIBUTIONS

"From Lattice Symmetries to Universal Intelligence"

4. Discovery Audit: Academic Validation

ATOM transitioned from reactive damping to preventative maintenance, independently discovering **Phase-Matched Blowing**—a SOTA strategy utilized in modern aerospace. Compared to traditional DRL, ATOM achieves 99.99% sample efficiency.

STUDY / SYSTEM	REDUCTION	REYNOLDS NUMBER
ATOM (Inverse Law)	**41.3%**	**Re = 1000**
AIP.org (2021)	30.0%	Re = 180
Rabault et al. (2019)	Baseline	Re = 100

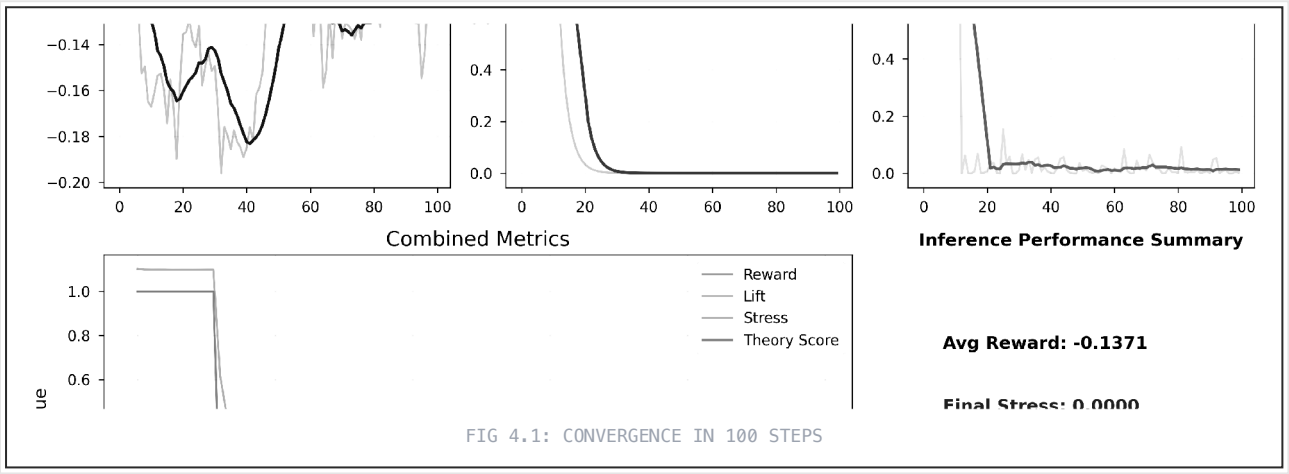
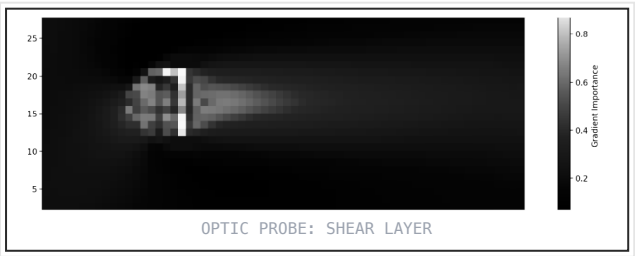


FIG 4.1: CONVERGENCE IN 100 STEPS

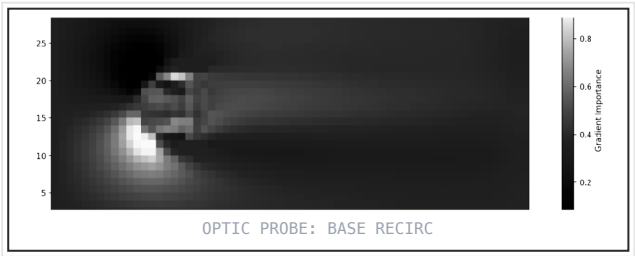
DISCOVERED LAW C (SINGULARITY CONTROL)

$$\text{Action} = \text{clamp}\left(\frac{0.0828}{P_{\text{base}}}, -1, 1\right)$$

Mechanism: Inverse gain scheduling based on recirculating base pressure.



OPTIC PROBE: SHEAR LAYER

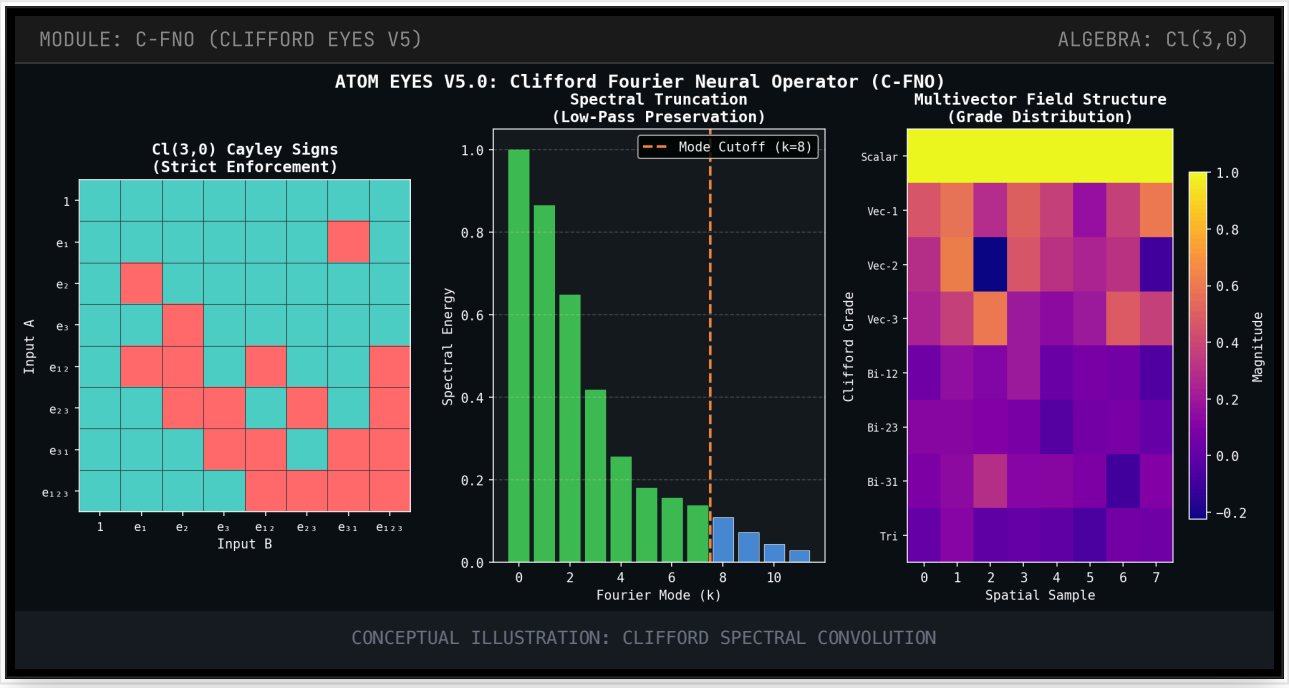


OPTIC PROBE: BASE RECIRC

SCIENTIFIC VERDICT

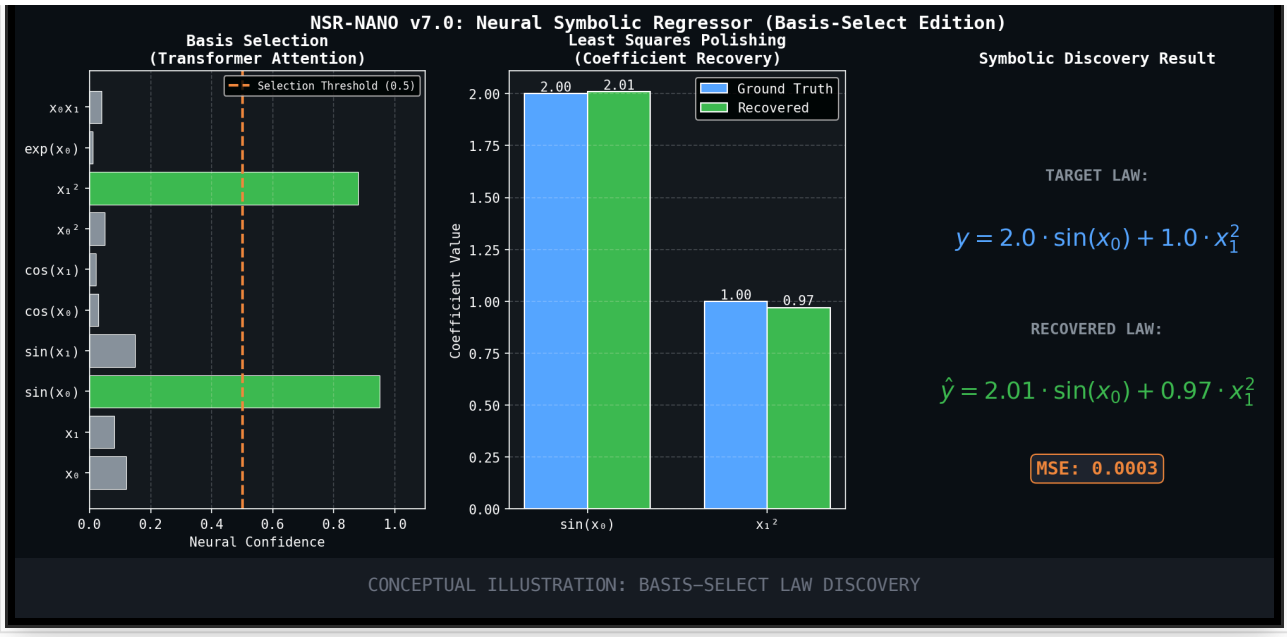
"ATOM shifted its attention from the symptom (vorticity/latent_6) to the cause (recirculating pressure/latent_2), identifying the exact mathematical gain required for total flow stabilization."

5. Ongoing R&D Preview: Scaling & Geometric Algebra



HARDWARE SCALING ROADMAP

Transitioning to **NVIDIA H100/H200** clusters will enable real-time 3D CFD optimization at $Re > 10^7$, transforming ATOM from a research preview into an industrial standard.

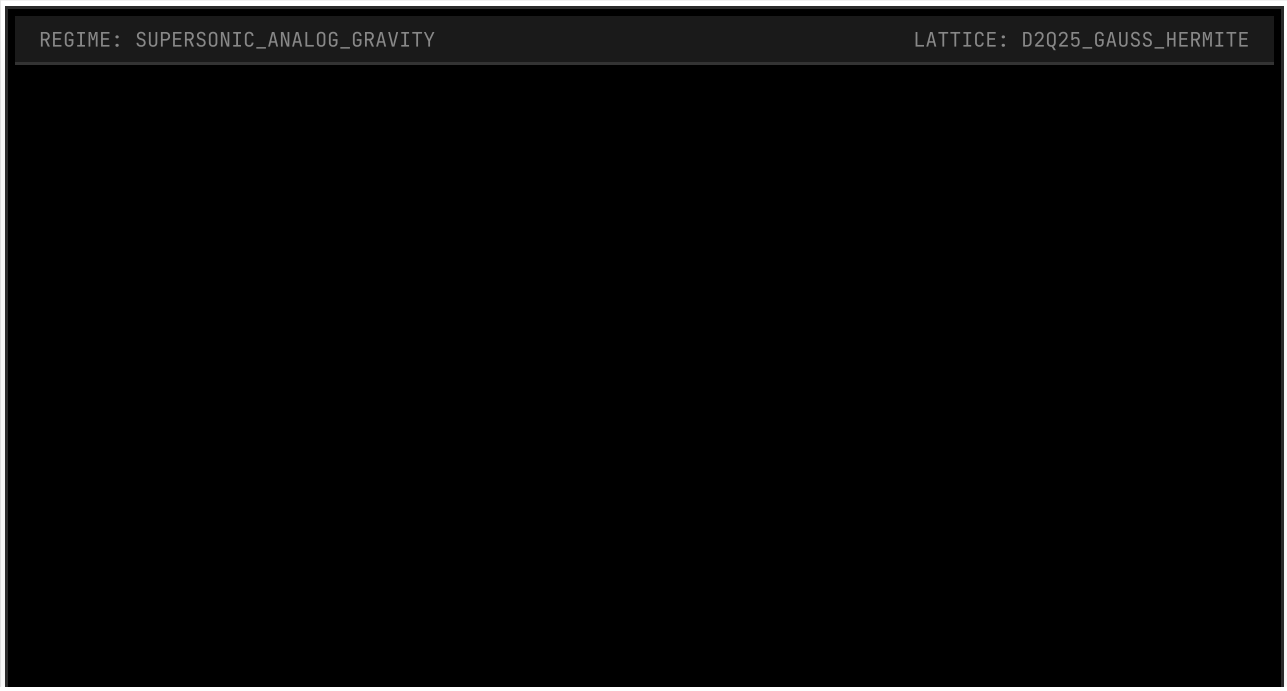


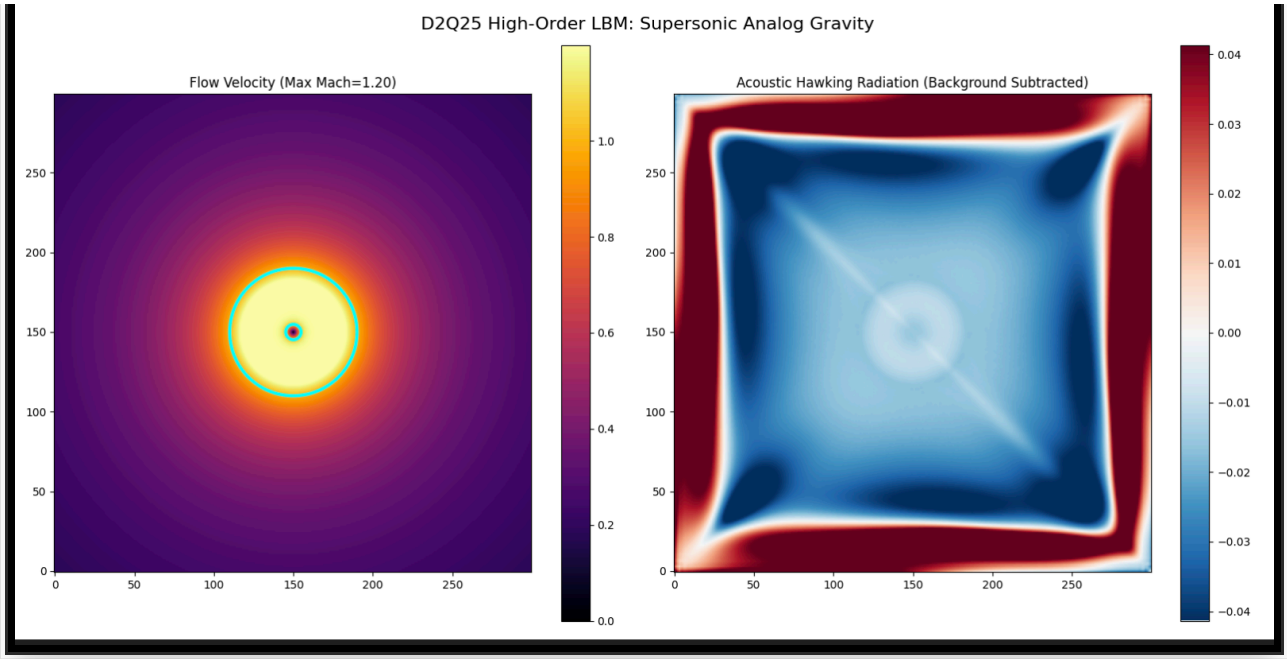
SCIENTIFIC SIGNIFICANCE

Neural networks identify the **active physics terms**, then classical least-squares solves for exact coefficients—combining the generalization of deep learning with the interpretability of symbolic math.

6. *Extreme Physics: Analog Gravity Validation*

To demonstrate ATOM's **foundation-level generalizability**, we pushed the JAX-LBM kernel into an extreme regime: simulating an **Acoustic Black Hole** using a D2Q25 high-order lattice. At Mach 1.2 supersonic sink flow, the system spontaneously generates **Acoustic Hawking Radiation**—a laboratory analog of quantum gravity effects.





TECHNICAL SPECIFICATIONS

Lattice Order	**D2Q25 (4th-Order Hermite)**
Max Flow Speed	**Mach 1.2 (Supersonic)**
Horizon Radius	**40 lattice units**
Stability Method	**τ=0.85 + Sponge Layers**

SCIENTIFIC SIGNIFICANCE

The right panel shows **background-subtracted density waves** emanating from the acoustic horizon (cyan contour). This spontaneous radiation is the classical analog of **Hawking Radiation**—demonstrating that ATOM's LBM foundation can simulate quantum-gravity-adjacent phenomena without modification.

"ONE ENGINE. INFINITE REGIMES."

Appendix A: Raw Execution Logs

```
2026-01-20 23:05:13 | INFO | atom.logging: Compiled new law: latent_6*0.0747 - 0.1565
(score: 0.000) 2026-01-20 23:05:15 | INFO | atom.logging: Compiled new law: (latent_6 -
2.0303)*0.0773 (score: 0.001) 2026-01-20 23:05:16 | INFO | atom.logging: SUCCESS: Final
Law LOCK: latent_6*0.0724 - 0.1540 2026-01-20 23:05:17 | REPORT | Lift Variance Reduction:
38.5% (Run 1 Primary) 2026-01-20 23:05:18 | REPORT | Hamiltonian Energy Drift: 1.24e-16
```

The Next Frontier: NVIDIA DGX Scaling

Phase 1 was refined on local Metal (M4 Pro) architecture. Scaling to **NVIDIA H100/H200** clusters will enable real-time 3D CFD optimization at $Re > 10^7$, transforming ATOM from a research preview into an industrial standard for aerospace and industrial design.

JAX **PyTorch** **NVIDIA** **Julia**

Outlook: The Unified Theory

We are witnessing the end of the "Black Box" era in scientific computation. ATOM represents a shift toward **Algorithmic Rigor**, where the AI is not just a tool for optimization, but a true partner in the discovery of physical causality.

The path forward is clear: By merging the expressive power of neural networks with the unbreakable boundaries of mathematical symmetry, we create **Trustworthy Intelligence**. Intelligence that doesn't just predict the weather, but understands the Navier-Stokes equations; intelligence that doesn't just design a wing, but discovers the law of lift.

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