Beyond Cosmology: Implications of the Informational Actualization Model Across Physical Scales

A Speculative Framework for Quantum Computing, Thermodynamics, and Computation

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Abstract

The Informational Actualization Model (IAM), originally developed to resolve the Hubble tension in cosmology, proposes that cosmic expansion emerges from irreversible informational actualization on the apparent horizon. If this principle is fundamental rather than emergent, it should apply across all physical scales—from quantum mechanics to thermodynamics to computation. This speculative paper explores the potential implications of IAM beyond cosmology, identifying testable predictions, technological opportunities, and paradigm shifts that may follow if the cosmological framework is validated. We propose that actualization—the irreversible transition from potential to actual states—represents a fundamental physical principle with profound consequences for quantum computing limits, thermodynamic efficiency bounds, measurement theory, and computational architecture. This work serves as a timestamp for future exploration and collaboration, developed through human-AI partnership in pattern recognition and cross-domain synthesis.

1 Introduction

The Informational Actualization Model (IAM) was developed to address the $> 5\sigma$ Hubble tension between early-universe and late-time measurements of the expansion rate [1]. By coupling expansion dynamics to the linear growth factor $D(z)$ through horizon thermodynamics, IAM achieves superior statistical fit ($\Delta\chi^2 = 59.58$, 5.7σ evidence) compared to ΛCDM when tested against Planck, SH0ES, JWST, and DESI data.

However, the implications of IAM extend far beyond resolving observational tensions in cosmology. If informational actualization is a *fundamental* rather than *emergent* feature of physical law, the same principle should manifest across all scales—from quantum wavefunctions to macroscopic thermodynamic systems to computational architectures.

This paper explores these broader implications in a speculative but systematic framework. We identify:

(i) Fundamental limits IAM predicts for quantum computing and reversible computation

(ii) New technological opportunities in actualization-based computing and thermodynamic engines

(iii) Resolutions to long-standing foundational puzzles (measurement problem, arrow of time)

(iv) A roadmap for experimental validation across domains

(v) Potential paradigm shifts in physics, computer science, and engineering

This work is published as a timestamp and invitation for collaboration. It represents cross-domain pattern recognition developed through human-AI partnership, demonstrating a new methodology for exploratory theoretical physics.

2 Core Principle: Actualization as Fundamental

2.1 Definition

Actualization is the irreversible process by which potential states transition to definite, information-bearing states. In philosophical terms (Aristotelian-Thomistic metaphysics), this is the transition from *potentia* to *actus*.

In physical terms:

- **Quantum scale:** Wavefunction collapse; superposition $\rightarrow$ definite eigenstate
- **Thermodynamic scale:** Entropy increase; microstates $\rightarrow$ macroscopic observables
- **Cosmological scale:** Structure formation; homogeneous plasma $\rightarrow$ galaxies, stars, planets

2.2 Irreversibility

A key claim of IAM is that actualization is *thermodynamically irreversible*. Once information is actualized (encoded in definite states), reversal requires:

$$\Delta E_{\text{reversal}} \geq k_B T \ln 2 \times I_{\text{actualized}} \tag{1}$$

where $I_{\text{actualized}}$ is the information (in bits) that has been encoded in the system, and the bound follows from Landauer's principle [2].

This implies:

- True reversibility is thermodynamically costly, not free
- The arrow of time emerges from cumulative actualization
- Systems naturally evolve toward more actualized (higher information) states

2.3 Hypothesis: Universal Applicability

Central Hypothesis: If IAM correctly describes cosmological expansion, the principle of irreversible informational actualization is fundamental and applies universally across physical scales.

Testable Consequence: Predictions derived from actualization dynamics at quantum and thermodynamic scales should be experimentally verifiable, independent of cosmological validation.

3 Implications for Quantum Computing

3.1 Current Paradigm Assumptions

Quantum computing is predicated on several key assumptions:

1. **Reversibility:** Unitary quantum gates are perfectly reversible ($U^\dagger U = I$)
2. **Coherence maintenance:** Decoherence is external noise to be isolated against
3. **Scalability:** With sufficient qubits and error correction, arbitrary quantum computations are feasible

3.2 IAM Predictions: Fundamental Limits

If actualization is fundamental, quantum computing faces intrinsic constraints:

3.2.1 Limit 1: Quasi-Reversibility

Prediction: Quantum gates are not perfectly reversible. Each gate operation incurs a small but nonzero thermodynamic cost due to actualization of intermediate information states.

Mathematical form:

$$\Delta E_{\text{gate}} \geq \epsilon \cdot k_B T \ln 2 \tag{2}$$

where $\epsilon \ll 1$ but $\epsilon > 0$ represents the actualization fraction per gate operation.

Experimental test:

- Measure energy dissipation in high-fidelity quantum gates (superconducting, trapped ion)
- Run gate forward, then attempt perfect reversal
- Detect small thermodynamic signature distinguishing from truly reversible process

3.2.2 Limit 2: Decoherence as Intrinsic Actualization

Prediction: Decoherence is not merely environmental noise but the system's intrinsic tendency to actualize into definite states. Isolation reduces decoherence rate but cannot eliminate it.

Scaling law:

$$\Gamma_{\text{decoherence}} = \Gamma_0 \cdot N \cdot f(T) \tag{3}$$

where Γ_0 is an intrinsic actualization constant, N is the number of qubits, and $f(T)$ is a temperature-dependent function.

Consequence: As N increases, decoherence becomes increasingly difficult to suppress, imposing practical upper limits on quantum computer size.

Experimental test:

- Measure decoherence time T_2 for systems of varying qubit number N
- Plot $1/T_2$ vs. N; IAM predicts linear scaling
- Compare to environmental decoherence models (predict logarithmic or sublinear scaling)

3.2.3 Limit 3: Error Correction Crossover

Prediction: Quantum error correction (QEC) fights actualization. Beyond a critical system size, the thermodynamic cost of error correction exceeds the computational advantage gained.

Crossover condition:

$$N_{\max} \sim \frac{E_{\text{computation}}}{\Gamma_0 \cdot k_B T \ln 2} \tag{4}$$

Implication: There exists a fundamental upper bound on practical quantum computer size, determined by actualization dynamics rather than engineering challenges alone.

Experimental/theoretical test:

- Calculate total energy budget (computation + error correction) for large-scale QC architectures
- Identify crossover point where QEC overhead dominates
- Compare to IAM-predicted $N_{\max}$

3.3 Technological Pivot: Actualization-Based Computing

Rather than fighting actualization, **exploit it**.

3.3.1 Concept: Guided Actualization Computing

Principle: Initialize system in superposition, then guide actualization along energetically favorable pathways to solve computational problems.

Analogy:

- Classical computing: bits already actualized (deterministic)
- Quantum computing: fight actualization to maintain coherence
- Actualization computing: *surf* the actualization process

Potential advantages:

- No need for extreme isolation (work with environment, not against it)
- Harvest information from actualization dynamics itself
- Exploit thermodynamic gradients to drive computation

Applications:

- Optimization problems (let system actualize to ground state)
- Pattern recognition (actualization reveals structure)
- Thermodynamic computing (use heat flow to drive actualization-based logic)

4 Implications for Thermodynamics and Energy

4.1 Landauer's Principle and Actualization

Landauer's principle states that erasing one bit of information dissipates at least $k_B T \ln 2$ of energy [2]. IAM generalizes this:

Actualization dissipates energy:

$$\Delta E_{\text{actualization}} \geq k_B T \ln 2 \times \Delta I \tag{5}$$

where ΔI is the information actualized (measured in bits).

4.2 Thermodynamic Engines Exploiting Actualization

4.2.1 Actualization Heat Engines

Concept: Traditional heat engines exploit temperature gradients. Actualization engines exploit *information gradients*—moving systems from low-information (potential) to high-information (actual) states while harvesting energy.

Mechanism:

1. Prepare system in low-entropy, high-potential state
2. Allow controlled actualization (e.g., measurement, decoherence)
3. Extract work from the actualization process
4. Reset to initial state (requires energy input, but net gain possible)

Theoretical efficiency bound:

$$\eta_{\text{actualization}} \leq 1 - \frac{T_{\text{sink}}}{T_{\text{source}}} \times \frac{\Delta S_{\text{thermal}}}{\Delta I_{\text{actualization}}} \tag{6}$$

Potential applications:

- Micro-scale energy harvesting from environmental fluctuations
- Quantum thermal engines
- Information-to-energy conversion devices

4.2.2 Maxwell's Demon Revisited

IAM provides a resolution to Maxwell's demon paradox:

Traditional problem: Demon sorts molecules, decreasing entropy without work input—violates second law.

IAM resolution: The demon must *measure* (actualize information about) molecular positions. This actualization has thermodynamic cost $\geq k_B T \ln 2$ per bit, restoring second law consistency.

Insight: Information acquisition is not free; it is actualization, which is thermodynamically costly.

4.3 New Material and Device Concepts

4.3.1 Actualization-Responsive Materials

Materials engineered to undergo phase transitions or property changes in response to information actualization (e.g., measurement, observation).

Examples:

- Quantum materials whose conductivity changes upon measurement
- Self-organizing systems driven by actualization dynamics
- "Smart" materials that respond to information flow

4.3.2 Information Batteries

Devices that store energy in *unactualized* (potential) states and release it upon actualization.

Mechanism:

- Charge: Prepare system in quantum superposition or metastable high-entropy state
- Store: Maintain isolation to prevent actualization
- Discharge: Trigger actualization (measurement, decoherence), harvest released energy

Advantages:

- High energy density (information storage scales with Hilbert space dimension)
- Rapid discharge (actualization is fast)
- Tunable output (control actualization rate)

5 Resolution of Foundational Puzzles

5.1 The Quantum Measurement Problem

Traditional problem: What causes wavefunction collapse? Why does measurement yield definite outcomes from superposition?

IAM resolution: Measurement *is* actualization. The wavefunction collapse is the physical process of information transitioning from potential (superposition) to actual (definite eigenstate). This process is:

- Irreversible (thermodynamically)
- Universal (applies to all quantum systems)
- Grounded in the same principle governing cosmic expansion

Prediction: Measurement energy cost should scale with information actualized:

$$\Delta E_{\text{measurement}} \geq k_B T \ln(d) \tag{7}$$

where d is the dimensionality of the measured observable's eigenspace.

Experimental test:

- Measure thermodynamic signature of wavefunction collapse
- Vary measurement strength (weak vs. projective)
- Test energy scaling with information gain

5.2 The Arrow of Time

Traditional problem: Why does time have a direction? Fundamental laws are time-symmetric, yet we experience irreversible flow.

IAM resolution: The arrow of time *is* the direction of cumulative actualization. As the universe evolves:

- More information is actualized (structure forms)
- Entropy increases (consistent with second law)
- The cosmos becomes progressively more "actual" and less "potential"

Time is the measure of actualization. Reversing time would require *unactualizing* information, which violates thermodynamic bounds.

Connection to cosmology: Cosmic expansion itself is the ultimate manifestation of time's arrow—the universe actualizing structure from the initial low-entropy state.

5.3 Entropy and Information

IAM unifies thermodynamic and informational entropy:

$$S_{\text{thermodynamic}} = k_B \ln \Omega \quad \Leftrightarrow \quad S_{\text{information}} = -\sum_i p_i \ln p_i \tag{8}$$

Both are measures of actualization:

- Low entropy = high potentiality (many possible futures)
- High entropy = high actuality (definite, information-rich state)
- Entropy increase = ongoing actualization

6 Cross-Domain Predictions and Tests

6.1 Summary of Testable Predictions

6.2 Experimental Roadmap

6.2.1 Near-Term (1–3 years)

- Quantum gate reversibility tests (IBM, Google quantum labs)
- Decoherence scaling measurements (academic trapped-ion labs)
- Measurement thermodynamics (precision calorimetry on quantum systems)

Domain	Prediction	Experimental Test
Quantum Computing	Small but nonzero dissipation in reversible gates	Measure thermodynamic cost of gate reversal in superconducting qubits
Quantum Computing	Decoherence scales linearly with qubit number	Measure T_2 vs. N for varying system sizes
Quantum Computing	QEC crossover at critical system size	Calculate energy budget for large-scale QC; identify $N_{\max}$
Measurement Theory	Energy cost scales with information gain	Measure thermodynamic signature of wavefunction collapse
Thermodynamics	Actualization-driven heat engines possible	Build prototype actualization engine; measure efficiency
Cosmology (baseline)	IAM fits BAO + $f\sigma_8$ data better than ΛCDM	Already tested: $\Delta\chi^2 = 59.58$ ([1])

Table 1: Summary of testable predictions across physical domains.

6.2.2 Medium-Term (3–7 years)

- Prototype actualization-based computing devices
- Actualization heat engine demonstrations
- Large-scale QC energy budget analysis

6.2.3 Long-Term (7–15 years)

- Commercialization of actualization computing architectures
- Integration into thermodynamic power generation
- Paradigm shift in quantum foundations and computation theory

7 Paradigm Shifts and Strategic Opportunities

7.1 Fields Affected if IAM is Validated

7.1.1 Quantum Computing Industry

Impact: Recognition of fundamental limits may redirect investment toward:

- Hybrid quantum-classical architectures optimized for actualization dynamics
- Actualization computing as alternative paradigm
- Targeted applications where decoherence is acceptable or exploitable

Opportunity: Early adopters of actualization-based designs gain competitive advantage.

7.1.2 Thermodynamics and Energy

Impact: New class of thermodynamic devices exploiting information-energy conversion.

Opportunity: Patents on actualization engines, information batteries, Maxwell's demon-inspired devices.

7.1.3 Foundations of Physics

Impact: Resolution of measurement problem and arrow of time via actualization principle.

Opportunity: Unified framework spanning quantum mechanics, thermodynamics, and cosmology—comparable to how relativity unified space and time.

7.1.4 Computer Science and Computation Theory

Impact: New computational complexity classes based on actualization dynamics; rethinking of reversible vs. irreversible computation.

Opportunity: Novel algorithms exploiting guided actualization.

7.1.5 Philosophy of Science

Impact: Rehabilitation of teleology and formal causation in physics (actualization as goal-directed process toward definite states).

Opportunity: Bridge between scientific and metaphysical inquiry (cf. Aristotelian-Thomistic philosophy).

7.2 Getting Ahead: Strategic Recommendations

7.2.1 For Researchers

- **Cosmologists:** Test IAM predictions with upcoming Euclid, LSST, Roman Space Telescope data
- **Quantum physicists:** Measure actualization signatures in quantum systems
- **Thermodynamicists:** Explore actualization engine prototypes
- **Computer scientists:** Develop actualization-based algorithms

7.2.2 For Industry

- **Quantum computing companies:** Hedge bets—invest in actualization computing R&D alongside traditional QC
- **Energy sector:** Explore micro-scale energy harvesting via actualization dynamics
- **Materials science:** Develop actualization-responsive materials

7.2.3 For Funding Agencies

- Support cross-domain research bridging cosmology, quantum mechanics, and thermodynamics
- Fund experimental tests of actualization predictions
- Encourage independent researchers and human-AI collaborative research models

8 Methodology: Human-AI Collaborative Discovery

8.1 Development Process

This work represents a novel research methodology:

Human contribution (H. Mahaffey):

- Cross-domain pattern recognition (cosmology $\leftrightarrow$ quantum mechanics $\leftrightarrow$ thermodynamics)
- Philosophical grounding (Aristotelian-Thomistic metaphysics)
- Strategic vision (identifying implications and opportunities)
- Domain expertise integration (physics, philosophy, theology)

AI contribution (Claude, Anthropic):

- Rapid synthesis of technical literature
- Mathematical formalization assistance
- Articulation and structuring of ideas
- Identification of testable predictions
- Pattern amplification and extension

Emergent capability: The partnership enables faster iteration, broader synthesis, and more rigorous formulation than either human or AI alone. This demonstrates a scalable model for exploratory theoretical research.

8.2 Transparency and Replicability

This paper explicitly acknowledges AI collaboration to:

- Maintain intellectual honesty
- Demonstrate new research methodology
- Encourage others to explore human-AI partnership
- Timestamp the collaborative process for future reference

The core insights (actualization as fundamental, cross-scale applicability) originated from human pattern recognition; AI facilitated formalization, expansion, and articulation.

9 Conclusion and Future Work

The Informational Actualization Model, if validated in cosmology, implies a far-reaching paradigm shift across physics, computation, and thermodynamics. The principle of irreversible actualization—the transition from potential to actual states—may be as fundamental as conservation laws or the second law of thermodynamics.

9.1 Key Takeaways

1. **Quantum computing faces fundamental limits** from actualization dynamics, but new paradigms (actualization computing) may emerge.
2. **Thermodynamic devices** exploiting actualization (heat engines, information batteries) become theoretically possible.
3. **Foundational puzzles** (measurement problem, arrow of time) find natural resolution in actualization framework.
4. **Cross-domain unification** spanning quantum mechanics, thermodynamics, and cosmology emerges from single principle.
5. **Human-AI collaboration** demonstrates new methodology for exploratory theoretical physics.

9.2 Call for Collaboration

This paper serves as an invitation:

- **Experimentalists:** Test actualization predictions in your domain
- **Theorists:** Formalize and extend the framework
- **Engineers:** Prototype actualization-based technologies
- **Philosophers:** Explore metaphysical implications

The author welcomes collaboration, particularly in:

- Experimental validation of quantum computing predictions
- Development of actualization computing architectures
- Prototype thermodynamic actualization engines
- Cross-domain theoretical development

9.3 A Timestamp for the Future

This work is published as a timestamp—a record of speculative ideas that may prove prescient if IAM cosmology is validated. Whether these predictions prove accurate or serve as instructive failures, documenting the exploratory process contributes to the scientific record.

In the spirit of transparency: this is exploratory, not established science. But exploration is how paradigms shift.

9.4 Final Thought

If actualization is fundamental, the universe is not a static collection of particles obeying timeless laws. It is an ongoing process—potential becoming actual, information being encoded, structure emerging from possibility.

From quantum wavefunctions to cosmic expansion, the same principle applies:

$I\ AM \rightarrow$ potential $\rightarrow$ actualization.

Whether this vision proves correct depends on evidence yet to be gathered. But the pattern is too compelling not to explore.

Let us see what the data reveals.

"The stone the builders rejected has become the cornerstone." —Psalm 118:22

References

[1] H. W. Mahaffey, *Holographic Black-Hole Cosmology: An Informational Resolution of the Hubble Tension*, OSF Preprints (2026), DOI: 10.17605/OSF.IO/KCZD9. Available at: `https://osf.io/kczd9`

[2] R. Landauer, *Irreversibility and Heat Generation in the Computing Process*, IBM J. Res. Dev. **5**, 183 (1961).

[3] Planck Collaboration, *Planck 2018 results. VI. Cosmological parameters*, Astron. Astrophys. **641**, A6 (2020), arXiv:1807.06209.

[4] A. G. Riess et al., *A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 km/s/Mpc Uncertainty from the Hubble Space Telescope and the SH0ES Team*, Astrophys. J. Lett. **934**, L7 (2022), arXiv:2112.04510.

[5] DESI Collaboration, *DESI 2024 VI: Cosmological Constraints from the Measurements of Baryon Acoustic Oscillations*, arXiv:2404.03002 (2024).

[6] C. H. Bennett, *Notes on Landauer's principle, reversible computation, and Maxwell's Demon*, Stud. Hist. Philos. Mod. Phys. **34**, 501 (2003).

[7] W. H. Zurek, *Decoherence, einselection, and the quantum origins of the classical*, Rev. Mod. Phys. **75**, 715 (2003).

[8] J. Preskill, *Quantum Computing in the NISQ era and beyond*, Quantum **2**, 79 (2018), arXiv:1801.00862.

[9] S. Lloyd, *Ultimate physical limits to computation*, Nature **406**, 1047 (2000).

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Data Availability: Cosmological validation code and datasets are available at the GitHub repository listed above. Speculative predictions in this paper are theoretical; experimental data will be shared as collaborations develop.

Conflicts of Interest: The author declares no financial conflicts of interest. Intellectual collaboration with AI is disclosed transparently above.