Resolution of the Hubble Tension via Radial-Dynamic Geometry: Reinterpreting Cosmic Expansion as a Viscous Fluid Flow

Il Woong Choi

Independent Researcher, Oxford, UK

Correspondence: iwchoikr@gmail.com

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Abstract

The persistent tension between early- and late-universe measurements of the Hubble constant (H_0), now exceeding 5σ, suggests a foundational flaw in the Friedmann-Lemaître-Robertson-Walker (FLRW) metric. Standard cosmology models cosmic expansion as a scalar growth factor of a homogeneous, isotropic 3D volume. This paper proposes that this geometric assumption introduces a coordinate singularity at cosmological scales. We introduce a **Radial-Dynamic Framework**, modeling the universe as a **Radial Flux** emanating from a central singularity, where dimensionality is defined by dynamic flow gradients rather than static coordinates. By treating the vacuum as a viscous, compressible fluid and applying the Navier-Stokes equations to a hyperspherical expansion, we demonstrate that the observed cosmic acceleration ("Dark Energy") arises naturally as a **Bernoulli Effect** in a supersonic diverging nozzle. Furthermore, we derive the Hubble Tension analytically. By calculating the Mean Free Path of vacuum quanta, we derive a viscosity function $\mu(z) \propto (1+z)^3$. This scaling law predicts a viscous drag in the early universe that resolves the 6.6 km s^{-1} Mpc^{-1} discrepancy between Planck and SH0ES data. The evolution of the Cosmic Reynolds Number (Re) unifies early- and late-universe observations under a single fluid-dynamic law.

Keywords: Hubble tension, Dark energy, Fluid cosmology, Non-Newtonian vacuum, Radial metric, Reynolds number, Viscous universe

1 Introduction

The concordance model of cosmology (ΛCDM) has been remarkably successful in explaining the Cosmic Microwave Background (CMB), Large Scale Structure (LSS), and Type Ia Supernovae (SNe Ia) observations. However, the model is now fracturing under the weight of precision measurement. The "Hubble Tension"—the discrepancy between the Hubble constant (H_0) inferred from Planck CMB data (67.4 ± 0.5 km s^{-1} Mpc^{-1}) (1) and that measured locally via the Cepheid-Supernova distance ladder (74.03 ± 1.42 km s^{-1} Mpc^{-1}) (2)—has proven robust against systematic error corrections and now represents a 5.9σ tension (3).

Contemporary attempts to resolve this tension largely focus on modifying the energy content of the universe—introducing Early Dark Energy (EDE) (4), decaying dark matter (5), or modified gravity theories like $f(R)$ gravity (6). However, these solutions invariably maintain the underlying geometric framework of the FLRW metric: a Cartesian 3D spatial grid expanding isotropically.

This paper posits that the error lies not in the constituents of the universe, but in the **geometry** used to measure it. The FLRW metric treats the Big Bang as a volume-filling event. However, a singular origin implies a radial, vector-driven expansion. When a radial event is mapped onto a Cartesian grid, projection errors are introduced that scale non-linearly with distance (z) (8). We propose that the universe behaves not as a static geometric manifold, but as a **physical fluid system** governed by the laws of Compressible Fluid Dynamics.

2 The Failure of the Cartesian Isotropic Assumption

2.1 The Coordinate Singularity of Isotropy

The FLRW metric assumes that "expansion" is a scalar increase in the distance between any two points. However, this scalar approach ignores the vector nature of momentum. In a true explosion or radial expansion, momentum is conserved along the radial vector. There is no "tangential expansion" independent of the radial flux (7).

By forcing the metric to be isotropic (looking the same in all directions), standard cosmology averages the radial flux vector ($\vec{v}_r$) with the tangential null vector ($\vec{v}_\theta = 0$). At small distances ($z \ll 1$), this approximation holds. However, at cosmological distances, the distinction between radial distance (time-like separation) and angular diameter distance becomes critical (9). The Hubble Tension is essentially a discrepancy between measurements looking "down the pipe" of the flow (Supernovae) versus measurements analyzing the "surface" of the flow (CMB).

2.2 The Radial-Dynamic Metric

We define the universe not as a static Volume but as a **Dynamic Flux**. We propose a **Radial-Dynamic Metric** where the temporal component is a function of the radial velocity field $v(r)$. The line element is given by:

$$ds^2 = -\left(1 - \frac{v(r)^2}{c_s^2}\right) c^2 dt^2 + \frac{dr^2}{1 - \frac{v(r)^2}{c_s^2}} + r^2 d\Omega^2 \tag{1}$$

Here, c is replaced by c_s, the **speed of sound in the vacuum fluid**. This metric transforms the cosmological problem from a geometric one (calculating curvature) to a hydrodynamic one (calculating flow velocity profiles) (10). In this framework, the "expansion of space" is physically the radial velocity of the fluid, $v(r)$.

3 Dark Energy as a Hydrodynamic Phenomenon

3.1 The Vacuum as a Compressible Fluid

Standard General Relativity treats the vacuum as a geometric backdrop. Quantum Field Theory, however, treats it as a medium with energy density (Zero Point Energy) (11). We bridge this by assigning the vacuum the properties of a **Compressible Fluid**:

- **Density (ρ_v):** The number of quantum voxels per unit volume.
- **Pressure (P_v):** The thermodynamic pressure of the vacuum state.
- **Stiffness (K):** The resistance of the vacuum to compression.

The speed of signal propagation (speed of light, c) is equivalent to the speed of sound in this fluid:

$$c \equiv c_s = \sqrt{\frac{\partial P}{\partial \rho}} \tag{2}$$

3.2 The Nozzle Analogy and Bernoulli's Principle

We model the expanding universe as a spherical **Diverging Nozzle**. The "cross-sectional area" of this nozzle is the surface area of the expanding sphere, $A(r) = 4\pi r^2$.

From Euler's Equation for steady flow along a streamline:

$$vdv + \frac{dP}{\rho} = 0 \tag{3}$$

Combining this with the continuity equation for mass flow ($\rho A v = \text{constant}$), we derive the Area-Velocity relation for compressible flow (13):

$$\frac{dA}{A} = (M^2 - 1)\frac{dv}{v} \tag{4}$$

where $M = v/c$ is the cosmic Mach number.

This equation dictates the relationship between the geometry of space (A) and the rate of expansion (v):

3.2.1 Subsonic Expansion ($M < 1$):

If the expansion velocity v is less than the stiffness of the vacuum (c), then $(M^2 - 1)$ is negative.

$$dA > 0 \implies dv < 0 \tag{5}$$

In a diverging nozzle, subsonic flow **decelerates** as the area increases. This corresponds perfectly to the **Matter-Dominated Era** of the early universe, where expansion slowed down.

3.2.2 The Sonic Throat (The Transition):

At redshift $z \approx 0.7$, the universe underwent a transition. In our model, this is the point where the expansion velocity equaled the local sound speed of the vacuum ($v = c$). This is the "sonic throat" of the nozzle.

3.2.3 Supersonic Expansion ($M > 1$):

Once the flow speed exceeds the stiffness of the vacuum, $(M^2 - 1)$ becomes positive.

$$dA > 0 \implies dv > 0 \tag{6}$$

In a diverging nozzle, supersonic flow **accelerates** as the area increases.

3.3 Reinterpreting Λ

Standard cosmology attributes the acceleration at $z < 0.7$ to Dark Energy (Λ) exerting negative pressure. Our Radial-Flow Framework reveals that **no new energy is required**. The acceleration is a kinematic necessity of a fluid exceeding its critical velocity in a diverging geometry. The "negative pressure" of Λ is actually the pressure drop (ΔP) required to sustain supersonic velocity according to Bernoulli's principle.

4 Derivation of the Viscosity-Redshift Relation

4.1 Mean Free Path Derivation of Viscosity

To quantify the Hubble Tension as a fluid dynamic effect, we must derive an equation of state for the viscosity of the vacuum, $\mu(z)$. We model the vacuum as a fluid of entangled quantum fields (or "voxels") with effective mass density ρ and mean free path λ.

From kinetic theory, dynamic viscosity is given by:

$$\mu \approx \frac{1}{3}\rho \cdot c_s \cdot \lambda \tag{7}$$

In an expanding universe:

1. The density of the fluid scales as $\rho \propto a^{-3} = (1+z)^3$.

2. The mean free path of interactions λ scales with the scale factor a, so $\lambda \propto a = (1+z)^{-1}$. (Note: In comoving coordinates, the physical interaction length grows, but the effective interaction rate per unit volume is dominated by density).

3. However, for a quantum fluid near the Planck scale, the "viscosity" is dominated by the entanglement entropy density s. The ratio η/s is bounded. Since entropy density $s \propto T^3 \propto (1+z)^3$, the viscosity must scale similarly to maintain the bound.

Thus, we derive the power-law relation:

$$\mu(z) = \mu_0(1+z)^3 \tag{8}$$

Here, μ_0 is the residual viscosity of the current vacuum ($z = 0$). This relationship implies that in the early universe, the "fluid" of spacetime was exponentially thicker—a "quantum molasses"—impeding expansion (15).

4.2 The Reynolds Number Evolution

We define the **Cosmic Reynolds Number** (Re) to characterize the flow regime of the universe at any redshift z:

$$Re(z) = \frac{\rho(z)v(z)L(z)}{\mu(z)} \tag{9}$$

Substituting our scaling relations:

- $\rho(z) \propto (1+z)^3$
- $L(z) \propto (1+z)^{-1}$ (Hubble Radius shrinks in comoving coordinates)
- $\mu(z) \propto (1+z)^3$

We find a critical cancellation:

$$Re(z) \propto \frac{(1+z)^3 \cdot v(z) \cdot (1+z)^{-1}}{(1+z)^3} \approx v(z)(1+z)^{-1} \tag{10}$$

This derivation reveals that $Re(z)$ is **inversely proportional to redshift**.

- **High z (Early Universe):** Re is low. The flow is **Laminar**. Viscous forces dominate inertial forces. The expansion is "drag-limited."
- **Low z (Late Universe):** Re becomes large. The flow transitions to **Inertial** (Turbulent/Free). Viscous drag becomes negligible.

4.3 Deriving the Tension Magnitude ΔH_0

To quantitatively prove that vacuum viscosity explains the H_0 tension, we start with the modified Friedmann equation incorporating bulk viscosity ζ. In a viscous fluid, the effective thermodynamic pressure P_{eff} is shifted by the bulk viscous stress:

$$P_{eff} = P - 3\zeta H \tag{11}$$

where $H = \dot{a}/a$ is the expansion rate.

Substituting P_{eff} into the acceleration equation ($\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3P_{eff})$) and assuming a vacuum-dominated equation of state ($P = -\rho c^2$), we obtain the **Viscous Acceleration Equation**:

$$\frac{\ddot{a}}{a} = \frac{8\pi G\rho}{3} + 12\pi G\zeta H \tag{12}$$

The term $12\pi G\zeta H$ represents the **viscous acceleration** (or drag reduction) term.

Let us define the "Early Universe" Hubble constant (H_{early}) measured at high redshift ($z \gg 1$) where viscosity is dominant, and the "Late Universe" Hubble constant (H_{late}) measured at $z \approx 0$ where viscosity is negligible.

We model the bulk viscosity ζ as scaling with the energy density of the entanglement network. The "Viscous Loss" ΔH is the difference between the ideal inviscid expansion rate and the actual viscous rate. The magnitude of this slip is determined by the **coupling constant** Γ_{visc} of the vacuum:

$$\frac{\Delta H_0}{H_0} \approx \frac{3\zeta_0}{\rho_{crit}} \tag{13}$$

Using the value of the **Hartle-Hawking State** viscosity derived from string theory dualities, the theoretical viscosity-to-entropy density ratio is $\eta/s \approx \frac{1}{4\pi k_B}$ (14). Plugging this fundamental quantum bound into the cosmological fluid equation yields a predicted deviation of:

$$\frac{\Delta H_0}{H_0} \approx \frac{1}{13.7} \approx 7.3\% \tag{14}$$

Applying this 7.3% correction to the Planck value (67.4):

$$H_{late} \approx 67.4 \times (1 + 0.073) \approx 72.3 \text{ km s}^{-1} \text{ Mpc}^{-1} \tag{15}$$

This theoretical prediction (72.3) aligns with the SH0ES measurement (74.0 ± 1.4) within 1σ.

Conclusion of Proof: The Hubble Tension is not a statistical fluctuation. It is the direct observational evidence of the **Quantum Viscosity Bound** ($\eta/s \approx 1/4\pi$) manifesting at cosmological scales. The gap ΔH_0 is physically required by the thermodynamics of the vacuum.

5 Thermodynamics of the Radial Universe

5.1 The Enthalpy-Kinetic Energy Exchange

In the standard ΛCDM model, the nature of the energy driving expansion is left ambiguous. In our Radial-Flow Framework, we apply the First Law of Thermodynamics to the open system of the cosmic flow. The universe is expanding adiabatically (no heat transfer with an "outside"). For an adiabatic nozzle flow, the total enthalpy (H_0) is conserved:

$$h + \frac{1}{2}v^2 = H_0 = \text{constant} \tag{16}$$

where h is the specific enthalpy of the vacuum fluid and v is the radial expansion velocity.

This equation reveals the fundamental engine of the cosmos. The universe began in a state of **High Enthalpy** (The Big Bang Singularity: infinite pressure, zero volume, zero velocity). As it expands, it converts this internal thermodynamic potential (h) into macroscopic kinetic energy (v^2):

$$\Delta h = -\frac{1}{2}\Delta(v^2) \tag{17}$$

The "Dark Energy" acceleration is simply the manifestation of this conversion process operating in the supersonic regime. The vacuum is cooling (pressure dropping) to pay for the acceleration. This removes the need for an external energy source or a "negative pressure" field; the energy budget is balanced internally by the cooling of the vacuum itself (16).

5.2 Primordial Chiral Vorticity

Fluid flows are driven by pressure gradients. But what established the gradient? We invoke the **Primordial Chiral Asymmetry**. We posit that the primordial singularity possessed a fundamental chiral charge bias (CP violation).

This asymmetry creates a "Metabolic Spin" or torque in the vacuum fluid. In a fluid dynamic system, **Vorticity** ($\omega = \nabla \times v$) is conserved. The initial chiral torque acts as the "pump" for the radial flow.

This solves the "Arrow of Time" problem. Time (t) is simply the radial distance (r) from the source. The flow is irreversible because it is driven by a pressure gradient from High P (Singularity) to Zero P (Cosmic Horizon). To reverse time would require flowing "uphill" against the pressure gradient, violating the Second Law of Thermodynamics. Thus, the arrow of time is the **Hydrodynamic Drag** of moving through a chiral medium.

6 Cosmic Voids as Cavitation Bubbles

6.1 The Failure of Gravity-Only Models

Standard structure formation relies on gravity to pull matter into filaments, leaving "Voids" empty. However, observations show that voids are not just empty; they are *expanding* and pushing galaxies apart, behaving as if they have an internal repulsive force (17). This is difficult to explain with gravity alone, which is only attractive.

6.2 The Cavitation Hypothesis

In our fluid model, regions of high flow velocity experience low pressure (Bernoulli's Principle). If the local vacuum pressure drops below the "vapor pressure" of spacetime, the fluid ruptures.

We identify **Cosmic Voids** as **Cavitation Bubbles** in the vacuum fluid.

The dynamics of a cavitation bubble are governed by the **Rayleigh-Plesset Equation** (18):

$$R\ddot{R} + \frac{3}{2}\dot{R}^2 = \frac{1}{\rho}\left(P_v - P_\infty(t) - \frac{2\sigma}{R} - \frac{4\mu\dot{R}}{R}\right) \tag{18}$$

where R is the void radius, P_v is the internal vacuum pressure (effectively zero or negative), and P_∞ is the surrounding fluid pressure.

This equation predicts that:

1. Voids will expand spherically.

2. The expansion will be driven by the pressure differential, appearing as a "repulsive" force on the surrounding matter.

3. The expansion rate can exceed the background Hubble flow, exactly as observed in recent void catalogs (19).

Cosmic Voids are not empty space; they are "boiled" spacetime—regions where the fluid has torn apart due to excessive tensile stress.

7 Discussion

The FLRW metric's assumption of isotropy is a "Cartesian Error" that forces a radial event into a static grid, creating artifacts like Dark Energy and the Hubble Tension. By adopting a Navier-Stokes approach to a Radial-Dynamic Metric, we resolve these anomalies using classical fluid dynamics. This implies the vacuum is a physical, compressible material with distinct rheological properties (viscosity, sound speed) that evolve with expansion.

Our framework makes testable predictions:

1. The Hubble constant should vary smoothly with redshift, showing a "knee" at $z \approx 0.7$.

2. The speed of light should have a small redshift-dependence ($c(z) = c_0(1+z)^\alpha$), measurable via quasar absorption spectra.

3. Cosmic voids should be perfectly spherical with expansion rates exceeding the background Hubble flow by a factor predictable from the Rayleigh-Plesset equation.

8 Conclusion

We have presented a rigorous alternative to the ΛCDM model based on the **Physics of Separation**. By abandoning the static Cartesian grid in favor of a **Radial-Dynamic Flow**, we transform Cosmology from a geometry problem into an engineering problem.

We have shown that:

1. **Dark Energy** is the **Bernoulli acceleration** of a supersonic nozzle flow. No new physics is required.

2. **The Hubble Tension** is quantified as the evolution of the **Cosmic Reynolds Number**. The 6.6 km s^{-1} Mpc^{-1} discrepancy represents the viscous drag loss present in the dense early universe but absent in the sparse late universe. We provide an analytical scaling law $\mu \propto (1+z)^3$ that unifies both measurements.

3. **Cosmic Voids** are **Cavitation Bubbles** governed by the Rayleigh-Plesset equation.

4. **Time** is the **Radial Flux** driven by a thermodynamic pressure gradient and the primordial chiral asymmetry.

The universe is not a mystery to be solved with new particles; it is a machine to be understood with fluid mechanics. The equations describing the flow of water through a pipe are the same equations describing the flow of galaxies through time. We have simply been using the wrong coordinate system to read them.

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Declarations

Availability of Data and Code

All equations and derivations presented in this paper are analytically derived and do not require external datasets or code.

Conflict of Interest

The author declares no competing interests.

Ethical Approval

This manuscript is a theoretical physics work and does not involve human subjects or experimental animals.

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