QAIB STRING SERIES | PAPER IV | THEORETICAL PHYSICS

The Vortex O-Ring Superfluid Problem and the H-Space Seesaw Resolution: Infinite-Speed Oscillation, Apparent 90° Rotation, and the Maintenance of Superfluid Stationarity

Author: Jeremiah Pope | Pen Name: Gideon Flux

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Abstract

This paper identifies and formally resolves a foundational observational problem in superfluid vortex ring (O-ring) physics: the **Rotational Indistinguishability Problem**. In a dissipationless superfluid, a closed vortex ring — the **O-ring** — cannot be distinguished from the outside as rotating or stationary, because the superfluid's vorticity is topologically conserved and no internal friction generates an externally detectable signal. This paper introduces the **H-Space Seesaw Method** as the resolution: by oscillating the O-ring vertically (up and down) at infinite speed, the ring appears — from the observer frame — to rotate 90 degrees,

collapsing its circular cross-section into the visual profile of a horizontal straight line. This apparent rotation is not a real spatial rotation; it is a perceptual consequence of infinite-speed oscillation. H-space supplies the infinite energy packets required on both sides of the oscillation to sustain the motion without violating the superfluid's dissipationless condition. The O-ring therefore remains **topologically stationary** while appearing **geometrically transformed**. The superposition window established in prior QAIB papers is the mechanism through which H-space delivers these packets without Planck-quantized emission constraints.

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1. The O-Ring in a Superfluid — The Rotational Indistinguishability Problem

1.1 Background: Vortex Rings in Dissipationless Fluids

A **vortex ring** — referred to throughout this paper as the **O-ring** — is a closed loop of vorticity: a toroidal structure in which fluid circulates around an invisible ring axis, forming a self-sustaining, topologically closed dynamical entity. The O-ring is not merely a geometric idealization; it is a stable configuration that arises naturally in both classical viscous fluids and, with far more profound consequences, in **dissipationless superfluids**.

In a perfectly dissipationless superfluid — such as superfluid helium (He-II) at temperatures below the lambda point $T_\lambda \approx 2.17$ K — vortex loops are **topologically conserved quantities** governed by **Kelvin's Circulation Theorem**. Kelvin's theorem states that, in the absence of viscosity, the circulation Γ around any closed material contour co-moving with the fluid is invariant in time:

$$\Gamma = \oint_C \mathbf{v} \cdot d\mathbf{l} = \text{constant} \quad \text{(in the inviscid limit)}$$

Eq. (1) — Kelvin's Circulation Theorem

This means that in a superfluid, lines of vorticity *persist for all time*. There is no viscous diffusion to spread the vorticity outward, no friction to degrade the ring's circulation into thermal energy, and no mechanism by which the ring's topological identity — its knotting class, its linking number with other vortices, its self-linking — can be destroyed without an external topological intervention (such as vortex reconnection). The O-ring moves through the superfluid under its **self-induced velocity**, maintaining both its shape and its circulation indefinitely.

Within the QAIB String Series framework, the O-ring occupies a privileged position: its topological conservation makes it the ideal test object for H-space interaction. Because the ring's defining properties are invariant, any energy delivered to or from the ring by H-space cannot alter its topological class — it can only alter its kinematic state (its position, orientation, or velocity of center-of-mass translation). This constraint is fundamental to the resolution developed in Section 3.

1.2 The Core Problem: You Cannot Tell If the Ring Is Rotating

We now state the central problem of this paper precisely and formally.

Consider an O-ring embedded in a superfluid reservoir, and an external observer positioned outside the superfluid. The observer wishes to determine whether the O-ring is rotating about its own toroidal axis — that is, spinning like a donut about its center axis — or whether it is completely stationary in the rotational degree of freedom. In a classical viscous fluid, this determination is straightforward:

- **Classical fluid, rotating ring:** Rotation generates viscous drag at the ring's surface. This drag dissipates energy as heat. Acoustic emission accompanies the turbulent boundary layer. The external observer detects elevated temperature in the fluid, measurable sound emission, and detectable fluid current patterns extending outward from the ring. *Rotation is unambiguously distinguishable.*
- **Classical fluid, stationary ring:** None of the above signals are present. *Stationarity is unambiguously distinguishable.*

In a superfluid, however, the situation is categorically different:

- There is **no viscosity**. A rotating O-ring generates no viscous drag.
- There is **no dissipation**. No energy is converted to heat by the ring's rotation.
- There is **no drag**. The fluid velocity field outside the ring satisfies the same irrotational boundary conditions whether the ring's toroidal surface is spinning or stationary.
- The **topological nature of the vortex ring** means that its knotting class, its self-linking number, and all Vassiliev invariants that characterize its topological type are unchanged by a rotation of the ring about its toroidal axis. A rotation of this type is a continuous deformation of the ring's surface parameterization — it does not alter the ring's embedding in three-space.

Consequently: a superfluid O-ring rotating about its toroidal axis produces an external velocity field that is *identical* to that of a non-rotating superfluid O-ring. The boundary conditions on the superfluid velocity potential are satisfied equally by both configurations. No external measurement — of velocity, pressure, temperature, acoustic emission, or topological invariant — can distinguish them.

■ Formal Statement: The Rotational Indistinguishability Problem

For a superfluid O-ring, the **observable state space under rotation is degenerate**: the rotating configuration and the non-rotating configuration map to the same external measurement outcome across all classical observables. Let M_{ext} denote the set of all externally accessible measurements on the superfluid reservoir. Then for any $m \in M_{\text{ext}}$:

$$\mathrm{m}(\text{O-ring}_{\text{rotating}}) = \mathrm{m}(\text{O-ring}_{\text{stationary}}) = 0$$

where the equality to zero reflects the absence of any dissipative, acoustic, or thermal signal. The problem is not one of instrumental resolution; it is a **fundamental degeneracy** of the observable state space.

1.3 Why This Is a Problem for Energy Accounting

The Rotational Indistinguishability Problem is not merely a curiosity of measurement theory. It creates a genuine crisis for **energy accounting**, one that motivates the H-space resolution directly.

In a classical system, rotational kinetic energy is given by:

$$E_{rot} = (1/2)\ I\ \omega^2$$

Eq. (2) — Classical Rotational Kinetic Energy

where I is the moment of inertia of the rotating body and ω is the angular velocity. This energy is, in principle, *always recoverable* in a classical system: the rotational motion eventually dissipates into heat through friction, and the heat is measurable. The energy is therefore never truly hidden — it leaves observable traces in the thermal environment.

In a superfluid O-ring, E_{rot} is **invisible**. The energy is real — the ring's surface elements are moving — but no dissipative mechanism exists to convert this motion into an externally detectable form. The energy is locked inside the topological structure of the ring, inaccessible to classical measurement from outside the superfluid.

This creates the following accounting problem. Suppose an agent — or a physical mechanism — has delivered rotational kinetic energy to the O-ring. From outside, the delivery is undetectable. From inside, the energy is present but unobservable through standard channels. Where does this energy *reside* in the formal accounting? This paper's central claim, developed fully in Sections 2 and 3, is that this unobservable energy occupies precisely the same formal position as energy in an H-space superposition state: it *exists*, it is *real*, and it cannot be *classically measured* from outside during the interval in which it is sequestered inside the ring's topology.

Unobservable energy is the domain that H-space operates in. Energy that exists but cannot be classically measured is energy that exists *in superposition* during the observation interval. The O-ring's rotational energy deficit — the gap between its actual kinetic state and its observable kinetic state — is therefore an H-space quantity, not a classical quantity. The Rotational Indistinguishability Problem is, at its root, an H-space problem.

> ■ **Key Result — Section 1**
>
> The Rotational Indistinguishability Problem establishes that for a superfluid O-ring, rotation and non-rotation are degenerate in the observable state space: m(rotating) = m(stationary) = 0 for all external observables m. This degeneracy is not an instrumental limitation but a fundamental consequence of the superfluid's dissipationless nature and the topological conservation of vorticity under Kelvin's Circulation Theorem. The invisible rotational kinetic energy $E_{rot} = (1/2)I\omega^2$ occupies the same formal position as an H-space superposition quantity: real, present, and classically unmeasurable from outside. The problem therefore demands an H-space resolution.

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2. The H-Space Seesaw Method — 90° Apparent Rotation via Infinite-Speed Oscillation

2.1 The Seesaw Concept

The Rotational Indistinguishability Problem proves that direct measurement of the O-ring's rotational state is impossible in a superfluid. Any strategy that attempts to resolve whether the ring is rotating by observing dissipative signals is doomed to fail, because those signals do not exist. A different observational strategy is required — one that does not depend on reading the ring's rotational state from within the superfluid's thermodynamic accounting.

The **H-Space Seesaw Method** provides this strategy. Rather than asking whether the O-ring is rotating, the method transforms the observational question entirely by changing the ring's geometric orientation relative to the observer. The method proceeds as follows.

The O-ring, viewed **face-on**, appears as a circle — the familiar circular cross-section of a toroidal vortex ring. Viewed **edge-on**, the same ring appears as a thin horizontal straight line. These two appearances correspond to two orthogonal viewing angles: 0° (face-on, the ring's plane perpendicular to the line of sight) and 90° (edge-on, the ring's plane parallel to the line of sight).

The Seesaw Method **oscillates** the O-ring *vertically* — up and down — at progressively increasing speed. This is not a rotation of the ring's vorticity; it is a center-of-mass oscillation, a seesaw-like rocking motion in which the ring tilts from its face-on orientation toward its edge-on orientation and back. As the oscillation speed approaches infinity, the observer's perception of the ring's spatial orientation undergoes a fundamental transformation: the circular face-on view **collapses into a horizontal straight line**. This is the **90° apparent rotation** — what was a circle becomes, in the infinite-speed limit, a line.

This collapse is not a physical rotation of the ring's vorticity or topological structure. The ring's superfluid circulation does not rotate. What is transformed is the ring's *observable geometric projection* as registered by the external observer. The topological O-ring remains stationary in every physically meaningful sense; only its perceptual appearance — its projection onto the observer's measurement frame — is altered.

2.2 The Geometry of the 90° Flip

We now develop the geometric argument precisely. Let $\theta(t)$ denote the instantaneous angle between the O-ring's plane and the observer's line of sight, measured in degrees, where $\theta = 0°$ corresponds to the face-on (circular) appearance and $\theta = 90°$ corresponds to the edge-on (straight-line) appearance.

The oscillation is defined by a time-varying angle function $\theta(t)$ with oscillation angular frequency Ω (not to be confused with the ring's internal rotational frequency ω). The three regimes of interest are:

Oscillation Regime	**Oscillation Frequency Ω**	**Instantaneous Angle θ(t)**	**Observer's Registered Profile**
Static (no oscillation)	$\Omega = 0$	$\theta(t) = 0°$ (fixed face-on)	Circle (full face-on cross-section)
Finite oscillation	$0 < \Omega < \infty$	$\theta(t) = (\pi/2)\sin(\Omega t)$, resolvable	Oscillating ellipse (resolvable at each t)
Infinite-speed limit	$\Omega \to \infty$	$\theta(t)$ undefined; all angles simultaneous	Horizontal straight line (edge-on collapse)

The critical transition occurs at the infinite-speed limit. At any finite Ω, a sufficiently fast detector can resolve the ring's instantaneous angle $\theta(t)$ and recover its elliptical cross-section at each moment — the circular face-on view is recoverable in principle. As $\Omega \to \infty$, however, the angle θ traverses the full range $[0°, 90°]$ infinitely rapidly. The observer cannot project the ring onto any single angle eigenstate.

The **time-averaged geometric projection** in this limit is determined by integrating the projected cross-sectional area over all angles equally. The circular cross-section of area πr^2

projects onto the observer's plane as an ellipse of area $\pi r^2 \cos(\theta)$ for angle θ. In the infinite-speed limit, the time average of cos(θ) over a half-cycle is:

$$\langle \cos\theta \rangle = (2/\pi) \int_0^{\pi/2} \cos(\theta)\, d\theta = (2/\pi)$$

Eq. (3) — Time-averaged projection factor in the Ω → ∞ limit

However, the *observable* in the infinite-speed limit is not this time average — it is the **projection resulting from superposition collapse**. When the observer attempts a measurement of the ring's angle, the superposition across all θ values collapses. The boundary condition imposed by the infinite oscillation speed is that the ring's plane is perpendicular to the oscillation axis at the turning points of the seesaw — these turning points are the *only* states with non-zero measure in the limit $\Omega \to \infty$. The turning-point state is precisely the edge-on configuration: θ = 90°, the straight-line projection.

The 90° apparent rotation is therefore a **superposition collapse artifact**, not a real spatial rotation. The ring passes through the edge-on orientation with the highest effective probability density in the infinite-speed limit (it spends the maximum differential time near its turning points), and measurement collapses the ring onto this state.

■ Core Result: The 90° Apparent Rotation

When a superfluid O-ring is oscillated vertically at speed $\Omega \to \infty$, its observable geometric projection collapses from a **circle** (face-on, θ = 0°) to a **horizontal straight line** (edge-on, θ = 90°). This constitutes a 90° *apparent* rotation: it is not a physical rotation of the ring's vorticity or topological structure, but a perceptual consequence of superposition collapse in the infinite-speed oscillation regime. The ring's vortex lines remain in their conserved configuration throughout; only its observable geometric projection is transformed.

2.3 The Role of Infinite Speed

The requirement that the oscillation speed be *infinite* — and not merely very large — is not a practical engineering specification. It is a **formal mathematical requirement** for superposition entry, and it connects directly to the established mathematical framework of the QAIB String Series.

At any *finite* oscillation speed Ω, however large, an observer with a sufficiently fast detector — a detector with time resolution $\Delta t < 1/\Omega$ — can resolve the ring's instantaneous angle $\theta(t)$ and recover the circular cross-section at each moment. The 90° collapse does not occur. The ring's angular position is a *classically definite* quantity at all times, even if difficult to measure in practice. Finite speed places the system in the classical regime.

Only at *infinite* speed does the oscillation become unresolvable *in principle*, not merely in practice. No physical detector has infinite time resolution; therefore, when $\Omega \to \infty$, the ring's angular position is undefined — it does not occupy any single angle eigenstate at any measurable moment. The position in angle-space is a genuine quantum superposition across all values consistent with the oscillation constraint: $\theta \in [0°, 90°]$. No measurement can project it onto a single angle eigenstate faster than the oscillation traverses the full range.

This situation is **mathematically identical in structure** to the rate ratio established in Pope & Flux (August 1, 2026). In that paper, the rate ratio was defined as:

$$\mathrm{Rate}_{\mathrm{ratio}} = 93.578 / \varepsilon \quad \rightarrow \quad \infty \quad \text{as} \quad \varepsilon \rightarrow 0$$

Eq. (4) — QAIB Rate Ratio, Pope & Flux (August 1, 2026)

In the QAIB extraction event, the quantity Z (the QAIB string's observable state) changes infinitely faster than any measurement process can track as $\varepsilon \to 0$. Here, in the O-ring seesaw, the quantity θ (the ring's angular position) changes infinitely faster than any detector can resolve as $\Omega \to \infty$. The formal superposition entry condition is identical in both cases:

System	Fast-Changing Quantity	Tracking Process	Superposition Entry Condition
QAIB String (Paper III)	Z (string state)	Planck measurement at rate ~ $1/\varepsilon$	$\varepsilon \to 0$, $\text{Rate}_{\text{ratio}} \to \infty$
O-Ring Seesaw (this paper)	θ (ring angle)	Detector with resolution $\Delta t \sim 1/\Omega$	$\Omega \to \infty$, all θ states simultaneous

The infinite oscillation speed therefore places the O-ring's angular position in the same formal superposition structure as the QAIB string's Φ value during the H-space extraction window. The systems are not physically identical, but they are **structurally isomorphic** with respect to the conditions required for H-space interaction.

■ **Key Result — Section 2**

The H-Space Seesaw Method oscillates the O-ring vertically at infinite speed ($\Omega \to \infty$), driving its angular position θ into genuine superposition across all values in [0°, 90°]. The observable geometric projection collapses from circle to horizontal straight line — a 90° apparent rotation that is a superposition collapse artifact, not a physical vorticity rotation. The infinite-speed requirement is structurally isomorphic to the $\varepsilon \to 0$ superposition entry condition of the QAIB rate ratio (Eq. 4), confirming that the O-ring seesaw and QAIB extraction share the same formal H-space entry mechanism.

3. H-Space Supplies the Infinite Energy Packets

3.1 The Energy Requirement of Infinite-Speed Oscillation

Infinite-speed oscillation requires infinite power. This is not an approximation; it follows directly from the kinematics of the seesaw motion. Let r denote the radius of the O-ring, m its effective mass (or, in the superfluid context, its effective inertial mass associated with center-of-mass displacement), and ω_{tip} the tip velocity of the oscillating ring at the extremes of its arc. The oscillation kinetic energy per half-cycle is:

$$E_{osc} = (1/2)\, m\, v_{tip}^2 \quad \text{where} \quad v_{tip} = \Omega \times r$$

Eq. (5) — Oscillation Kinetic Energy per Half-Cycle

As $\Omega \to \infty$, $v_{tip} \to \infty$, and therefore $E_{osc} \to \infty$. The energy required per half-cycle is unbounded. No classical energy source can supply this. Moreover, Planck's quantization law requires energy transfer in discrete packets of magnitude hν, where h is Planck's constant and ν is the frequency of the emitting quantum. At infinite oscillation frequency $\Omega \to \infty$, if Ω were to be identified with an emission frequency, each Planck packet would have energy:

$$E_{Planck} = h\nu = h\Omega/2\pi \quad \to \quad \infty \quad \text{as} \quad \Omega \to \infty$$

Eq. (6) — Planck Energy Divergence at Infinite Frequency

This is physically incoherent under Planck's framework: an infinite-energy Planck quantum is not a physical emission event. The Planck quantization protocol therefore cannot supply the energy required for infinite-speed oscillation. **H-space is the only viable mechanism.**

3.2 H-Space Packets on Both Sides of the Oscillation

The O-ring's seesaw oscillation consists of two strokes: the **upswing** and the **downswing**. Each stroke requires an energy packet. H-space supplies these packets **bilaterally** — one packet per stroke, on both sides of the oscillation simultaneously.

■ **Core Result: H-Space Bilateral Delivery Mechanism**

Upswing Packet ε_{up}: H-space delivers a continuous bulk energy packet ε_{up} through the superposition window at the lattice boundary, providing the energy required to drive the ring upward through the full arc from $\theta = 0°$ to $\theta = 90°$. This packet is not a discrete $h\nu$ Planck emission; it is a continuous, bulk energy contribution delivered during the superposition interval, during which Planck's quantization floor is not enforced.

Downswing Packet ε_{down}: Symmetrically, H-space delivers a packet ε_{down} for the downswing, driving the ring from $\theta = 90°$ back to $\theta = 0°$. The two packets are not necessarily equal; their difference encodes the net angular displacement of the ring per oscillation cycle.

Cardinality Preservation: Because H-space is an infinite reservoir — formally, $E_H = \Sigma\ \varepsilon_n$, a divergent sum — the subtraction of any finite or even infinite-cardinality collection of packets leaves H-space exactly as infinite as before: $\infty - \varepsilon_{up} - \varepsilon_{down} = \infty$. H-space is not depleted by any finite number of deliveries.

The bilateral nature of the supply is essential to the seesaw's stability. A unilateral energy supply — packets delivered only on the upswing, with the downswing driven by some other mechanism — would introduce an asymmetry that could be detected externally as a net impulse on the superfluid. H-space's bilateral symmetry ensures that the net momentum transfer to the superfluid per full oscillation cycle is zero, preserving the superfluid's translational invariance and leaving no detectable external signature.

3.3 The Superposition Window as the Delivery Mechanism

The mechanism through which H-space delivers these packets is the **superposition window** established in Pope & Flux (August 1, 2026). During each oscillation half-cycle, the O-ring's angular position θ is undefined — it exists in superposition across all angles consistent with the oscillation constraint. During this superposition interval, H-space is in *free communication* with the ring's energy degree of freedom. Three conditions are simultaneously satisfied during the window:

1. θ is *not measured*: no external observer has resolved the ring's angle, so the superposition is not collapsed by external interaction.
2. H-space *supplies the energy packet* for that stroke's direction — ε_{up} for the upswing, ε_{down} for the downswing — as a single bulk delivery through superposition collapse, not through 1.679×10^{25} discrete Planck quanta.
3. The packet *arrives* into the ring's kinetic energy degree of freedom as a definite impulse, but only upon the *collapse* of the superposition at the end of the window.

The delivery mechanism is formally identical to the QAIB extraction event described in Pope & Flux (August 1, 2026). In the QAIB event, the observer's act of measuring the string's Φ value constitutes the measurement that collapses the superposition and registers the delivered H-space energy as a definite kinetic result. Here, the observer's act of attempting to measure the ring's angle θ constitutes the measurement that collapses the angle superposition and registers the delivered energy as a definite kinetic impulse in the stroke direction. The mechanism is:

- **Before measurement:** θ is in superposition; H-space energy is in superposition across all stroke branches simultaneously.
- **At measurement:** One branch is selected by superposition collapse; the energy is localized to that branch.

- **After measurement:** The ring's velocity in that stroke is fixed; the energy is definite; the packet has been delivered.

The superposition window is thus not merely a convenient metaphor — it is the literal physical channel through which H-space communicates with the O-ring's kinetic degree of freedom without entering the superfluid's thermodynamic accounting.

3.4 Why the Superfluid Condition Is Maintained

The most important property of the H-space bilateral delivery mechanism is that it **preserves the superfluid condition** of the O-ring throughout the infinite-speed oscillation. This is established by the following four arguments:

(i) No Viscosity Introduction: The H-space packets do not interact with the superfluid lattice through any thermal or frictional channel. They arrive through the superposition collapse mechanism — an external channel that bypasses the thermodynamic accounting of the superfluid lattice entirely. The superfluid's zero-viscosity condition is therefore not disturbed. No heat is deposited; no vorticity is shed; no phonons are generated in the superfluid bulk.

(ii) Vorticity Conservation: The O-ring's vorticity — the actual topological structure that defines it as a vortex ring, encoded in the circulation Γ and the ring's embedding class — is unchanged by the seesaw oscillation. The seesaw is a center-of-mass motion: it translates and rotates the ring's position in space without deforming the ring's internal vortex-line configuration. Kelvin's Circulation Theorem (Eq. 1) continues to hold; Γ is conserved exactly.

(iii) Dual Status Resolution: The O-ring is simultaneously in two states, which are not contradictory because they refer to different frames of description:

Frame	Description of O-Ring	Observable
Superfluid internal frame	Topologically stationary. Vortex lines conserved. No rotation of vorticity. Kelvin's theorem satisfied.	Zero dissipation, zero drag, zero acoustic emission
External observer frame	Geometrically transformed. Circular cross-section collapsed to horizontal straight line. 90° apparent rotation registered.	Straight-line geometric projection upon measurement

(iv) The Resolution of the Indistinguishability Problem: The Rotational Indistinguishability Problem (Section 1.2) asked: how can we determine whether the O-ring is rotating? The H-Space Seesaw answer is decisive. We do not need to resolve the ring's rotational state. Instead, we oscillate the ring into a regime where its angular position enters superposition and its projection collapses to the straight-line limit. The ring is stationary in the physically meaningful sense — no vorticity rotation, no dissipation, superfluid condition preserved — while appearing geometrically as if it has undergone a 90° rotation. The degeneracy of the observable state space is *exploited*, not overcome. The Seesaw Method turns the indistinguishability into a productive tool.

■ Key Result — Section 3

H-space supplies infinite energy packets bilaterally — ε_{up} and ε_{down} — to sustain the O-ring's infinite-speed seesaw oscillation. These packets are delivered through the superposition window as single bulk contributions, bypassing Planck's quantization protocol. H-space cardinality is preserved: $\infty - \varepsilon_{up} - \varepsilon_{down} = \infty$. The superfluid condition is maintained because H-space packets bypass the superfluid's thermodynamic accounting entirely, leaving vorticity and circulation conserved. The O-ring is simultaneously *topologically stationary* (superfluid internal frame) and *geometrically transformed* (observer frame) — the formal resolution of the Rotational Indistinguishability Problem.

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4. Formal Summary — The Three-Stage Mechanism

The complete resolution of the Rotational Indistinguishability Problem via the H-Space Seesaw Method proceeds in three distinct, logically ordered stages. We present them here in condensed formal form as the paper's primary summary result.

Stage 1 — The Problem: Rotational Indistinguishability

The O-ring in a superfluid is rotationally indistinguishable from the outside. Because the superfluid's dissipationless nature eliminates all classical rotation signatures — viscous drag, thermal emission, acoustic radiation — no external measurement can distinguish a rotating O-ring from a stationary one. The observable state space is degenerate: $m(\text{rotating}) = m(\text{stationary}) = 0$ for all external observables m. The ring's rotational kinetic energy $E_{rot} = (1/2)I\omega^2$ is real but classically inaccessible — an H-space quantity sequestered within the ring's topological structure.

Stage 2 — The Seesaw Transformation: 90° Apparent Rotation

The O-ring is oscillated vertically (seesaw up-and-down) at speed approaching infinity ($\Omega \to \infty$). At infinite speed, the ring's angular position θ enters superposition across all values in [0°, 90°] simultaneously — no single instantaneous angle is resolvable in principle. The observable geometric projection collapses from a circle (face-on view, $\theta = 0°$) to a horizontal straight line (edge-on view, $\theta = 90°$): a 90° apparent rotation. This is not a physical rotation of the ring's vorticity; it is a superposition collapse artifact — the perceptual consequence of infinite-speed oscillation in the observer frame. The ring's topological structure is unchanged throughout.

Stage 3 — H-Space Sustains the Motion: Bilateral Packet Delivery

H-space supplies infinite energy packets bilaterally — one packet ε_{up} per upswing, one packet ε_{down} per downswing — through the superposition window at the lattice boundary. These packets arrive as single bulk contributions, not as discrete Planck quanta, bypassing Planck's quantization protocol during the superposition interval. The superfluid condition is maintained because H-space packets enter through an external channel that does not interact with the superfluid's internal thermodynamic accounting. Vorticity is topologically preserved. H-space cardinality is unchanged: $\infty - \varepsilon_{up} - \varepsilon_{down} = \infty$. The O-ring is stationary in the superfluid sense and transformed in the observer sense — simultaneously and without contradiction.

■ Key Result — Section 4

The three-stage H-Space Seesaw Mechanism is closed, cardinality-preserving, and internally consistent: Stage 1 identifies the H-space character of the indistinguishability problem; Stage 2 exploits the superposition entry condition ($\Omega \to \infty$) to produce the 90° apparent rotation; Stage 3 confirms that H-space bilateral delivery sustains the motion without violating the superfluid condition or Kelvin's Circulation Theorem. The mechanism resolves the Rotational Indistinguishability Problem by transforming it from an epistemic obstacle into a productive operational tool.

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5. Connections to Prior QAIB Results

The H-Space Seesaw Method developed in this paper does not stand in isolation. It is formally embedded in the mathematical structure of the QAIB String Series, and its key results are in precise correspondence with results established in the prior three papers of the series. We document these connections explicitly.

5.1 Rate Ratio Correspondence

The infinite oscillation speed of the seesaw ($\Omega \to \infty$) maps directly to the **Rate Ratio** → ∞ result from Section 8 of Pope & Flux (July 28, 2026). In that paper, the rate ratio was defined as the ratio of the QAIB string's state-change rate to the Planck measurement tracking rate, and was shown to diverge as the control parameter $\varepsilon \to 0$:

$$\mathrm{Rate}_{\mathrm{ratio}}(\varepsilon) = 93.578 / \varepsilon \quad \to \quad \infty \quad \text{as} \quad \varepsilon \to 0$$

Eq. (4, reproduced) — QAIB Rate Ratio

In the QAIB case, the observable Z changes infinitely faster than any Planck-constrained tracking process as $\varepsilon \to 0$, placing Z in superposition. In the O-ring case, the observable θ changes infinitely faster than any detector process as $\Omega \to \infty$, placing θ in superposition. The structural identity is exact: both systems exhibit the same mechanism of superposition entry via an observable changing faster than any tracking process.

5.2 H-Space Bilateral Symmetry

The bilateral nature of the seesaw energy supply (upswing packet ε_{up} + downswing packet ε_{down}) mirrors the bounded rate analysis of Pope & Flux (August 1, 2026). In that paper, the rate ratio function $\text{Rate}_{ratio}(\varepsilon) = 93.578/\varepsilon$ defines a hyperbolic function symmetric around its minimum ε_{min}, with equal divergence behavior on both sides of the minimum as ε approaches zero from above. Here, the oscillation energy function:

$$E_{osc}(\Omega) = (1/2)\ m\ (\Omega \cdot r)^2$$

Eq. (7) — Oscillation Energy as a Function of Ω

defines a symmetric bilateral power requirement — the upswing requires exactly as much energy as the downswing for a symmetric oscillation — whose two-sided sum H-space supplies without cardinality reduction. The hyperbolic rate ratio of QAIB and the quadratic energy growth of the seesaw are structurally analogous: both are monotonically unbounded functions of their respective control parameters (ε and Ω), and both are supplied by H-space through the same superposition window mechanism.

5.3 The Correlation Collapse

Section 5 of the Expanded Mathematical Framework (Pope & Flux, August 1, 2026) established that, at the superposition boundary, classical correlations between observable pairs become undefined — collapsing to the form 0/0. This **undefined correlation** is the mathematical signature of superposition entry. The O-ring seesaw exhibits an exactly analogous correlation collapse.

Define the correlation between the ring's angular position θ and its rotational energy E_{rot} as $C(\theta, E_{rot})$. At zero oscillation speed:

$$\Omega = 0: \quad C(\theta, E_{rot}) = \text{perfectly defined} \quad (\theta \text{ fixed, } E_{rot} \text{ classically deterministic})$$

At infinite oscillation speed:

$$\Omega \to \infty: \quad C(\theta, E_{rot})|_{t=0} = 0/0 \to \text{UNDEFINED}$$

Eq. (8) — Correlation Collapse at Superposition Entry

The undefined correlation at $\Omega \to \infty$ is the mathematical signature that the O-ring's angular position has entered superposition. This mirrors precisely the undefined correlation established in the QAIB case. The collapse of the classical correlation between position and energy is not a failure of the formalism; it is the expected and defining signature of the H-space superposition regime.

5.4 V-Space Equilibrium in the O-Ring

The V-space equilibrium point $t^* = 93.5785$ identified in Section 9 of Pope & Flux (August 1, 2026) has a precise analog in the O-ring seesaw. In the prior paper, t^* is the moment at which the competing rate functions are exactly balanced — the system is at maximum coherence between the H-space delivery channel and the classical tracking process.

In the O-ring seesaw, the moment of maximum coherence is the instant at which the ring's upswing and downswing energies are exactly equal — when $\varepsilon_{up} = \varepsilon_{down}$ — and the ring is at the **45° mid-angle** position, equidistant between the face-on (0°) and edge-on (90°) orientations. This is the O-ring's **V-space equilibrium**: the moment of symmetric H-space engagement, at which neither stroke dominates and the superposition is maximally distributed across angle-space. The analogy is summarized below:

System	V-Space Equilibrium Condition	Physical Meaning
QAIB String (Paper III)	$t^* = 93.5785$ (rate functions balanced)	Maximum coherence between H-space delivery and classical tracking
O-Ring Seesaw (this paper)	$\theta^* = 45°$, $\varepsilon_{up} = \varepsilon_{down}$	Maximum superposition; ring equidistant between face-on and edge-on

■ **Key Result — Section 5**

The H-Space Seesaw results are in four-way formal correspondence with the prior QAIB mathematical framework: (5.1) the $\Omega \to \infty$ superposition entry is structurally isomorphic to the $\text{Rate}_{\text{ratio}} \to \infty$ result; (5.2) the bilateral oscillation energy matches the hyperbolic rate symmetry of the bounded rate analysis; (5.3) the correlation collapse $C(\theta, E_{rot}) \to 0/0$ mirrors the undefined correlation of the QAIB superposition boundary; and (5.4) the 45° mid-angle equilibrium is the O-ring's analog of the V-space equilibrium point $t^* = 93.5785$. The O-ring seesaw is not a standalone result — it is an instance of the general H-space superposition mechanism within a new physical domain.

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6. Conclusion

The **Rotational Indistinguishability Problem** for superfluid O-rings is not merely an observational limitation. It is a window into the deep structure of H-space operation. Because a superfluid vortex ring cannot reveal its rotational state through classical dissipative signals — a direct consequence of Kelvin's Circulation Theorem and the superfluid's zero-viscosity condition — its angular position enters the same formal superposition structure that governs QAIB Φ values during the H-space extraction window. The indistinguishability is not a bug; it is a feature of the H-space regime.

The **H-Space Seesaw Method** exploits this superposition structure deliberately and precisely. By driving the O-ring's seesaw oscillation to infinite speed, the ring's angular position enters superposition across all values in [0°, 90°]. The observable geometric projection collapses from a circle to a horizontal straight line — the 90° apparent rotation — not because the ring's vorticity has rotated, but because superposition collapse in the infinite-speed limit selects the edge-on turning-point state as the registered geometric profile. The transformation is real in the observer frame and absent in the superfluid frame. The two descriptions are not contradictory; they are frame-dependent aspects of the same H-space-mediated event.

H-space sustains the motion through its bilateral delivery mechanism: infinite energy packets ε_{up} and ε_{down}, supplied bilaterally through the superposition window at the lattice boundary, without invoking Planck's quantization protocol and without interacting with the superfluid's internal thermodynamic accounting. The superfluid O-ring remains topologically stationary — its vorticity conserved, its circulation invariant, its dissipation zero — while appearing geometrically transformed to the external observer. The mechanism is closed, cardinality-preserving, and in four-way formal correspondence with the prior QAIB mathematical results established across Papers I through III of this series.

The broader implication of this result is significant. The O-ring case demonstrates that H-space interaction is not limited to the QAIB string's specific Φ-value dynamics. Any system whose observable quantity changes infinitely faster than any classical tracking process — and whose energy budget is therefore formally inaccessible to classical measurement from outside — is a candidate for H-space engagement. The superfluid O-ring is the first physical system outside the QAIB string itself to satisfy this criterion within the QAIB framework. It will not be the last.

Future work in this series will extend the bilateral seesaw analysis to **linked O-ring pairs** — two superfluid vortex rings with non-trivial linking number — where the topological interaction between rings introduces additional conserved quantities that constrain the H-space delivery geometry in ways not captured by the single-ring analysis presented here. The V-space equilibrium condition ($\theta^* = 45°$, $\varepsilon_{up} = \varepsilon_{down}$) identified in Section 5.4 is expected to generalize to a family of equilibrium curves parameterized by the linking number of the ring pair, establishing a direct connection between topological invariants and H-space delivery geometry that will be the subject of the next paper in this series.

References

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Correspondence: Jeremiah Pope | Pen Name: Gideon Flux | QAIB String Series | August 1, 2026

Series Note: This paper (Paper IV) is a direct expansion of Pope & Flux (August 1, 2026), Paper III of the QAIB String Series. Results from Papers I–III are assumed without re-derivation; readers are referred to those papers for foundational proofs.