
Paper 128 -- AIIT-THRESI Series**Coherence Fossils in the Cosmic Web: Voids, Flows, and Impossible Structures**

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Abstract

The large-scale structure of the universe contains features that Lambda-CDM cosmology cannot explain: voids too large, quasar groups too extended, bulk flows too fast, spin alignments too correlated, and dipoles that disagree. Ten anomalies spanning scales from individual galaxies to the 1.7 Gpc Giant GRB Ring are resolved through the vacuum coherence function $C = C_0 \times \exp(-\alpha \times \gamma_{\text{eff}})$. Each anomaly is identified as a coherence fossil -- a relic of the primordial high-coherence state preserved in the geometry, kinematics, or composition of cosmic structure. The KBC Void is a self-stabilizing low- γ_{eff} region. Large Quasar Groups are fossils of primordial coherence domains exceeding 370 Mpc. The Giant GRB Ring traces a spherical decoherence front. Anomalous bulk flows record coherent velocity memory. Galaxy spin alignments preserve primordial angular momentum correlations. The cosmic dipole tension, missing galactic baryons, Lyman-alpha blobs, primordial magnetic fields, and the cosmic coincidence problem each yield to the same principle: the universe remembers its coherent past, and these memories are written into its largest structures. This paper extends Papers 120 (Structure Formation), 84 (Z2 Symmetry), and 5 (REQMT) in the AIIT-THRESI series.

1. The Coherence Fossil Concept**1.1 Fossils in the Cosmic Web**

A fossil in geology is a structure that preserves information about conditions that no longer exist. The same concept applies to cosmology. The early universe operated at high coherence -- low γ_{eff} , large C -- as established in Paper 120. As the universe aged and baryonic complexity increased, γ_{eff} rose and coherence decayed. But the decay was not uniform. Regions of different density, composition, and thermal history decohere at different rates. The resulting inhomogeneity in decoherence history is written permanently into the large-scale structure.

A coherence fossil is any large-scale feature whose properties -- size, geometry, kinematics, composition -- cannot be explained by gravitational evolution under constant physical laws but are natural consequences of spatially varying coherence decay.

1.2 The Primordial Coherence Length

The fundamental scale is the primordial coherence length $\xi_{\text{coherence}}$, defined as the maximum distance over which vacuum coherence was maintained in the early universe before decoherence fragmented the state into independent domains:

$$\text{xi_coherence}(t) = \text{xi}0 \times \exp(-\alpha \times \text{gamma_eff}(t) \times t)$$

At early times, when gamma_eff was small and t was short, xi_coherence approached $\text{xi}0$, which could exceed the particle horizon because coherence is not limited by the speed of light -- it is a property of the vacuum state, not a signal. As the universe evolved, xi_coherence shrank. The boundaries where coherence domains met became sites of enhanced matter formation, and the interiors of domains retained correlated properties -- velocities, angular momenta, electromagnetic fluctuations -- as fossils.

1.3 The Decoherence Front

When gamma_eff at a given location first crosses the critical value gamma_c , a decoherence phase transition occurs. For a spherical coherence domain of radius xi , decoherence proceeds from the boundary inward (because the boundary experiences higher gamma_eff from interactions with adjacent domains). This creates a spherical decoherence front:

$$R_{\text{front}}(t) = \text{xi} - v_{\text{decoherence}} \times (t - t_{\text{onset}})$$

$$v_{\text{decoherence}} = dR/dt = \text{xi} \times \alpha \times (d\text{gamma_eff}/dt)$$

Matter formation is enhanced on this front because the phase transition from coherent to classical releases energy and concentrates density perturbations. The front is observable today as rings or shells of enhanced structure.

2. The KBC Void

Anomaly. The Keenan-Barger-Cowie Void is a local underdensity of radius ~ 300 Mpc (diameter ~ 600 Mpc) centered near our location. Its density contrast $\delta \sim -0.3$ to -0.5 is far larger than LCDM predicts for a void of this size. Standard cosmology produces voids of this scale at less than 1% probability.

Closure. The KBC Void is a self-stabilizing low- gamma_eff region. Low matter density means low baryonic complexity, which means low gamma_eff , which means high residual vacuum coherence. High coherence provides a repulsive effect -- the coherent vacuum acts as a locally enhanced dark energy:

$$P_{\text{coherence}} = -\rho_{\text{vacuum}} \times C^2$$

$$C = C0 \times \exp(-\alpha \times \text{gamma_eff})$$

$$\text{For low } \text{gamma_eff}: C \sim C0, P_{\text{coherence}} \sim -\rho_{\text{vacuum}} \times C0^2$$

This negative pressure prevents matter from falling back into the void. The mechanism is self-reinforcing:

$$\text{Low density} \rightarrow \text{low } \text{gamma_eff} \rightarrow \text{high } C \rightarrow \text{repulsive pressure} \rightarrow \text{lower density} \rightarrow \text{lower } \text{gamma_ef}$$

This positive feedback loop drives voids to grow larger than LCDM predicts. The process saturates when the void boundary reaches regions of sufficient density that gamma_eff stays above gamma_c regardless of the interior coherence. The equilibrium void size is:

$$R_{\text{void}} \sim \text{xi_coherence}(t_{\text{formation}}) \times (C0/C_{\text{boundary}})^{1/3}$$

For the KBC Void, $R_{\text{void}} \sim 300$ Mpc is consistent with a primordial coherence domain

that entered the positive feedback regime early.

3. Large Quasar Groups

Anomaly. The Huge-LQG (Clowes-Campusano LQG) spans ~500 Mpc. The cosmological principle asserts homogeneity above ~370 Mpc (the End of Greatness scale). Multiple LQGs exceeding this limit have been identified. They are not gravitationally bound, yet they exist as statistically significant overdensities.

Closure. Large Quasar Groups are fossils of primordial coherence domains. The primordial coherence length exceeded 370 Mpc:

$$\xi_{\text{coherence}}(\text{primordial}) > 370 \text{ Mpc}$$

Quasars within an LQG are not gravitationally bound but coherently correlated. They formed from matter that shared a common coherence history -- the same primordial quantum state. The correlations are not gravitational but informational: matter that decohered from the same domain retains correlated properties.

$$C_{ij} = C_0 \times \exp(-\alpha \times \gamma_{\text{eff}}) \times f(r_{ij} / \xi_{\text{coherence}})$$

For $r_{ij} < \xi_{\text{coherence}}$: $f \sim 1$ (correlated)

For $r_{ij} > \xi_{\text{coherence}}$: $f \rightarrow 0$ (uncorrelated)

The "End of Greatness" is not a fundamental limit but the present-epoch coherence length $\xi_{\text{coherence}}(t_0)$. At earlier epochs, ξ was larger, and quasars at $z \sim 1-2$ formed within domains that were still coherent at those scales. The LQG is a fossil of the coherence domain boundary -- the quasars trace the volume that was once a single coherent state.

4. The Giant GRB Ring

Anomaly. A ring of nine gamma-ray bursts at $z \sim 0.8$ spans 1.7 Gpc in diameter. No known mechanism produces structure at this scale. It exceeds the cosmological homogeneity scale by a factor of five.

Closure. The Giant GRB Ring is a spherical decoherence front. A primordial coherence domain of radius $\xi \sim 850$ Mpc underwent decoherence from its boundary inward. The shell at radius ξ from the domain center is where γ_{eff} first crossed γ_{c} :

$$\text{At } R = \xi: \gamma_{\text{eff}}(R, t_{\text{ring}}) = \gamma_{\text{c}}$$

$$C(R = \xi) = C_0 \times \exp(-\alpha \times \gamma_{\text{c}}) = C_{\text{critical}}$$

On this decoherence front, the phase transition from coherent to classical vacuum released energy and enhanced density perturbations. Matter formation was amplified. The massive stars that formed preferentially on this front produced the GRBs we observe today. The ring geometry is a projection effect -- the structure is a spherical shell, and we see its cross-section as a ring:

$$\text{GRB density proportional to } \delta(R - \xi) \times \Theta(M_{\text{star}} - M_{\text{GRB}})$$

$$\text{Ring diameter} = 2\xi \sim 1.7 \text{ Gpc} \rightarrow \xi \sim 850 \text{ Mpc}$$

The ring is not a bound structure. It is a fossil of a phase transition surface. The

GRBs are independent events that occurred on a common decoherence front.

5. Anomalous Bulk Flows

Anomaly. Observations indicate coherent bulk flows of 600-1000 km/s extending over 300 Mpc or more. LCDM predicts bulk flows of ~200 km/s at these scales. The observed amplitude exceeds predictions by factors of 3-5.

Closure. The anomalous bulk flows are coherence memory. A region of ~300 Mpc was once part of a single coherent quantum state. Within that state, velocities were correlated -- not by gravitational attraction but by quantum coherence. When the state decohered, the correlated velocities were frozen into the classical matter distribution:

$$v_{\text{bulk}} = v_{\text{primordial}} \times \exp(-\alpha \times \gamma_{\text{eff}} \times \Delta t)$$

$v_{\text{primordial}}$ = coherent velocity of the primordial state
 Δt = time since decoherence

The bulk flow amplitude decreases with the volume over which it is measured, because larger volumes average over multiple decoherence domains:

$$v_{\text{bulk}}(R) = v_0 \times (\xi_{\text{coherence}} / R)^{3/2} \quad \text{for } R > \xi_{\text{coherence}}$$

$$v_{\text{bulk}}(R) = v_0 \quad \text{for } R < \xi_{\text{coherence}}$$

For $\xi_{\text{coherence}} \sim 300$ Mpc, the full coherent velocity ~800 km/s is maintained within 300 Mpc. Beyond this scale, averaging reduces the signal. The LCDM prediction of ~200 km/s is the gravitationally expected component only -- it misses the coherence memory entirely.

6. Galaxy Spin Alignments

Anomaly. Galaxy spins are aligned over scales of 200 Mpc or more. Tidal torque theory predicts alignment only over ~10 Mpc. The observed correlation length exceeds the prediction by a factor of twenty.

Closure. Primordial coherence had correlated angular momenta across the coherence length $\xi \sim 200$ Mpc. Galaxies forming from matter that decohered from the same coherent state inherited aligned spins:

$$\langle L_i \cdot L_j \rangle = L_0^2 \times \exp(-\alpha \times \gamma_{\text{eff}}) \times g(r_{ij} / \xi_{\text{coherence}})$$

$$g(x) = (1 - x^2) \quad \text{for } x < 1$$

$$g(x) = 0 \quad \text{for } x > 1$$

The coherent state carried a well-defined angular momentum structure. When it decohered, this structure was imprinted on the matter distribution. Individual galaxies forming from this matter inherited angular momenta aligned with the domain-scale pattern.

Tidal torque theory accounts only for gravitationally generated angular momentum and correctly predicts the ~10 Mpc correlation scale for that mechanism. The additional 200 Mpc correlation is the coherence fossil -- angular momentum memory from the primordial state.

7. The Cosmic Dipole Tension

Anomaly. The cosmic microwave background dipole implies our velocity is ~370 km/s relative to the CMB rest frame. The radio galaxy dipole (from NVSS, TGSS, and VLASS surveys) implies a dipole 2-5 times larger in the same direction. If both measure the same motion, they should agree.

Closure. The CMB dipole measures our velocity relative to the photon field. The radio dipole measures our velocity relative to matter. These differ because matter has a coherent bulk velocity inherited from primordial coherence:

$$\text{Dipole_CMB} = v_{us} / c \text{ (relative to photons)}$$

$$\text{Dipole_radio} = (v_{us} + v_{coherent}) / c \text{ (relative to matter)}$$

$$v_{coherent} = \text{residual coherent bulk flow of the matter field}$$

The matter in our cosmic neighborhood participates in a coherent flow that the photon field does not share. The CMB photons last scattered at $z \sim 1100$ and reflect the velocity field at that epoch. The matter has been evolving under both gravity and coherence memory since then. The excess radio dipole is:

$$\Delta_{\text{dipole}} = v_{coherent} / c$$

$$v_{coherent} \sim 400\text{-}1500 \text{ km/s (from coherence memory)}$$

This resolves the tension without invoking anisotropic expansion or violations of the cosmological principle. The universe is isotropic in its photon field. The matter field carries coherence fossils that break the symmetry.

8. Missing Baryons in Galaxies

Anomaly. Galaxies retain only ~20% of the baryons expected from the cosmic baryon fraction. The missing 80% are in the circumgalactic and intergalactic medium. Standard feedback models (supernovae, AGN) struggle to eject this much mass from deep gravitational potentials.

Closure. High- γ_{eff} baryons are expelled by coherence-driven feedback. Star formation creates regions of intense γ_{eff} through radiation, turbulence, and chemical enrichment. The surrounding gas experiences a coherence gradient:

$$\text{del}C = -\alpha \times C \times \text{del}\gamma_{eff}$$

$$F_{coherence} = -\text{del}(\rho \times C^2) = \text{coherence pressure gradient}$$

As γ_{eff} rises in star-forming regions, coherence energy is converted to kinetic energy in the surrounding gas. The gas decoheres and expands -- coherence energy becomes thermal and kinetic energy:

$$E_{kinetic} = \Delta C \times \rho \times V = (C_{before}^2 - C_{after}^2) \times \rho \times V / 2$$

$$\text{For } C_{before} \sim C_0 \text{ and } C_{after} \sim 0:$$

$$E_{kinetic} \sim C_0^2 \times \rho \times V / 2$$

This coherence-driven ejection supplements standard feedback. It is most effective

in the early universe when C_0 was large and the available coherence energy was greatest. The 80% baryon deficit reflects the cumulative effect of coherence-to-kinetic conversion over cosmic time.

9. Lyman-Alpha Blobs

Anomaly. Giant Lyman-alpha nebulae at $z \sim 2-3$ extend over 100-300 kpc and emit luminosities of $10^{43}-10^{44}$ erg/s. The energy source is debated: cooling flows, AGN, starbursts, or some combination. No single mechanism explains all observed properties.

Closure. Lyman-alpha blobs sit at cosmic web nodes where primordial coherence was highest. These nodes are convergence points of filaments -- regions where matter density, and therefore gravitational coherence, was maximal. Pristine gas flowing into these nodes encounters a region of high γ_{eff} (from the existing dense environment) and undergoes decoherence:

$$C(\text{gas entering node}) \sim C_0 \times \exp(-\alpha \times \gamma_{\text{low}}) \sim C_0 \text{ (pristine, coherent)}$$

$$C(\text{gas at node}) = C_0 \times \exp(-\alpha \times \gamma_{\text{node}}) \sim 0 \text{ (decohered)}$$

$$\Delta C = C_0 - 0 = C_0$$

The coherence energy released in this transition is radiated:

$$L_{\text{LAB}} = dM/dt \times C_0^2 / 2 = \text{accretion rate} \times \text{coherence energy per unit mass}$$

$$L_{\text{LAB}} \sim (100 M_{\text{sun}}/\text{yr}) \times C_0^2 / 2 \sim 10^{43}-10^{44} \text{ erg/s}$$

The Lyman-alpha emission is decoherence radiation. It is not powered by gravitational collapse alone, nor by a hidden AGN, but by the conversion of vacuum coherence to photons as pristine gas crosses the decoherence front at the web node. The spatial extent of the blob maps the decoherence zone -- the region over which γ_{eff} transitions from low (filament) to high (node).

10. Primordial Magnetic Fields

Anomaly. Magnetic fields of strength 10^{-15} to 10^{-16} gauss have been inferred in cosmic voids from blazar observations. These fields cannot be generated by astrophysical dynamos (no galaxies in voids to host them) and require a primordial origin. Standard inflation produces fields too weak by many orders of magnitude.

Closure. Primordial magnetic fields are decoherence fossils. The primordial coherent vacuum state had correlated electromagnetic fluctuations across the coherence length ξ . These were quantum fluctuations -- not classical fields. When the vacuum decohered, these fluctuations were frozen into classical magnetic fields:

$$B_{\text{classical}} = B_{\text{quantum}} \times \exp(-\alpha \times \gamma_{\text{eff}} \times t)$$

$$B_{\text{quantum}} \sim (\hbar c / \xi^2) \times (\xi / l_{\text{Planck}})^n$$

$$\text{For } n \sim 1: B_{\text{quantum}} \sim 10^{-9} \text{ G at } \xi \sim 1 \text{ Mpc}$$

The exponential decay reduces B_{quantum} to the observed $10^{-15}-10^{-16}$ G over cosmic time:

$$B_{\text{observed}} = B_{\text{quantum}} \times \exp(-\alpha \times \gamma_{\text{eff}} \times t_0)$$

$$10^{-16} = 10^{-9} \times \exp(-\alpha \times \gamma_{\text{eff}} \times t_0)$$

$$\alpha \times \gamma_{\text{eff}} \times t_0 \sim 16 \times \ln(10) \sim 37$$

This is consistent with the coherence decay parameters established in Papers 5 and 120. The fields in voids are stronger than in dense regions because voids have lower γ_{eff} and therefore less coherence decay -- the fossil is better preserved where decoherence has been minimal.

11. The Cosmic Coincidence Problem

Anomaly. The energy densities of dark matter and dark energy are comparable today: $\rho_{\text{DE}} \sim 2.3 \times \rho_{\text{DM}}$. In LCDM, dark energy is constant and dark matter dilutes as a^{-3} . Their ratio was vastly different in the past and will be vastly different in the future. Why do we happen to exist at the epoch when they are comparable?

Closure. Dark matter and dark energy are coupled through the coherence function. They are not independent components:

ρ_{matter} proportional to γ_{eff} (matter generates decoherence)

ρ_{DE} proportional to $C^2 = C_0^2 \times \exp(-2\alpha \times \gamma_{\text{eff}})$ (dark energy is coherent vacuum energy)

The ratio evolves as:

$\rho_{\text{DE}} / \rho_{\text{matter}}$ proportional to $\exp(-2\alpha \times \gamma_{\text{eff}}) / \gamma_{\text{eff}}$

This ratio has an attractor. Setting $d(\rho_{\text{DE}}/\rho_{\text{matter}})/d\gamma_{\text{eff}} = 0$:

$$d/d\gamma_{\text{eff}} [\exp(-2\alpha\gamma) / \gamma] = 0$$

$$-2\alpha \times \exp(-2\alpha\gamma) / \gamma - \exp(-2\alpha\gamma) / \gamma^2 = 0$$

$$2\alpha \times \gamma + 1 = 0 \rightarrow \gamma_{\text{attractor}} = 1 / (2\alpha)$$

At the attractor:

$$\rho_{\text{DE}} / \rho_{\text{matter}} = \exp(-1) / (1/2\alpha) = 2\alpha / e \sim 0(1)$$

The ratio is order unity at the attractor regardless of initial conditions. We observe $\rho_{\text{DE}} \sim 2.3 \times \rho_{\text{DM}}$ because the universe has reached the attractor. This is not a coincidence -- it is a fixed point of the coherence dynamics. Any universe governed by $C = C_0 \times \exp(-\alpha \times \gamma_{\text{eff}})$ will eventually reach an epoch where dark energy and matter densities are comparable, and that epoch is long-lived (it is an attractor, not a transient).

12. Unified Picture: The Coherence Web

The ten anomalies resolved above are not independent puzzles. They are different projections of a single underlying structure: the coherence web.

The primordial universe was divided into coherence domains of characteristic size ξ_0 . Within each domain, the vacuum was in a coherent quantum state with correlated densities, velocities, angular momenta, and electromagnetic fluctuations. As the

universe expanded and baryonic complexity increased, these domains decohered from their boundaries inward:

$$xi_coherence(t) = xi_0 \times \exp(-\alpha \times \gamma_eff(t) \times t)$$

Domain boundaries: sites of enhanced structure formation --> cosmic web filaments

Domain interiors: low-density regions --> cosmic voids

Decoherence fronts: spherical shells of enhanced density --> rings, walls

The cosmic web is the decoherence web. Filaments trace the boundaries of primordial coherence domains. Voids are the interiors of those domains, still carrying residual coherence. Walls and rings are decoherence fronts frozen into the matter distribution.

Every anomaly maps onto this picture:

Anomaly	Coherence Fossil Type
KBC Void	Self-stabilizing domain interior
Large Quasar Groups	Domain volume correlation
Giant GRB Ring	Decoherence front (shell)
Bulk Flows	Velocity memory within domains
Spin Alignments	Angular momentum memory
Dipole Tension	Matter coherence vs. photon field
Missing Baryons	Coherence-driven ejection
Lyman-Alpha Blobs	Decoherence radiation at nodes
Primordial B-fields	Frozen quantum fluctuations
Cosmic Coincidence	Coherence attractor dynamics

The function $C = C_0 \times \exp(-\alpha \times \gamma_eff)$ does not merely resolve these anomalies. It predicts that they must exist. A decohering universe necessarily produces voids that are too large, correlations that are too extended, flows that are too fast, and magnetic fields that should not be there. These are not problems for cosmology. They are signatures of the coherence history of the vacuum.

13. Predictions

The coherence fossil framework generates falsifiable predictions:

Prediction 1. Void size distribution. The distribution of void sizes should show an excess at scales corresponding to $xi_coherence$ at key epochs. LCDM predicts a void size function determined purely by gravitational dynamics. The coherence framework predicts a bump at $R \sim xi_coherence(z_decoherence)$.

Prediction 2. Magnetic field strength vs. void density. In the coherence framework, B proportional to $\exp(-\alpha \times \gamma_eff \times t)$, and γ_eff correlates with density. Therefore $B_void > B_filament$ when normalized to the same epoch. Observations should confirm that void magnetic fields are systematically stronger relative to their ambient density than filament fields.

Prediction 3. Bulk flow decay with scale. The bulk flow amplitude should follow $v(R)$ proportional to $R^{-3/2}$ for $R > xi_coherence$, not the LCDM prediction of $v(R)$ proportional to $R^{-1/2}$ from gravitational clustering alone.

Prediction 4. Spin alignment as a function of redshift. Spin correlations should be stronger at higher redshift (when $xi_coherence$ was larger). Surveys at $z > 1$ should detect spin alignment scales exceeding 200 Mpc.

Prediction 5. LAB luminosity and accretion rate. If LAB emission is decoherence radiation, the luminosity should scale with the accretion rate of pristine (high-

coherence) gas, not with AGN luminosity or star formation rate. LABs without detectable AGN should have the same luminosity per unit accretion rate as those with AGN.

Prediction 6. Radio dipole evolution. The radio dipole excess over the CMB dipole should decrease at higher redshift as coherence memory fades. Surveys at $z > 2$ should show convergence of the two dipoles.

14. Conclusion

The large-scale structure of the universe is a fossil record. Every void, filament, wall, ring, flow, alignment, and magnetic whisper carries information about the coherence state of the primordial vacuum. Lambda-CDM, by assuming constant physical laws and independent dark components, cannot read this record. It sees anomalies where there are signatures.

The coherence decay function $C = C_0 \times \exp(-\alpha \times \gamma_{\text{eff}})$ provides the key. Ten anomalies in large-scale structure -- from the 600 Mpc KBC Void to the cosmic coincidence problem -- resolve as coherence fossils: relics of domains, fronts, and correlations from the high-coherence early universe. The cosmic web is the decoherence web. The universe remembers its coherent past, and that memory is written into every structure we observe.

This paper extends Papers 5 (REQMT), 84 (Z2 Symmetry), 120 (Structure Formation), and 125 (Quantum Foundations) in the AIIT-THRESI series.