

From Chaos to Co-rotation: Angular Momentum Inheritance from Satellite Planes to Cosmic Filaments Under Successive Collision Theory

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Abstract

Across more than seven orders of magnitude in physical scale — from satellite galaxies orbiting their hosts at kiloparsec separations to radio-loud quasars separated by gigaparsecs — the universe displays a persistent and statistically robust pattern: whenever astrophysical objects share a coherent geometric configuration, they also tend to share a common sense of rotation or a preferred spin axis. Satellite galaxies in thin planes around the Milky Way, Andromeda, and Centaurus A co-rotate about their hosts at statistical significances exceeding 99.9%, yet such configurations arise in fewer than 0.5% of Λ CDM simulations. Galaxy clusters and their brightest cluster galaxies are mutually aligned over scales of 200–300 Mpc, roughly an order of magnitude beyond what simulations reproduce, and these alignments were already fully established when the universe was less than one-third its present age (West et al. 2017). The statistical detection of coherent bulk rotation in galaxy clusters (Tang et al. 2025) confirms that cluster spin axes align with their brightest central galaxy and orient perpendicular to the nearest cosmic filament. Radio-loud quasars exhibit coherent jet and polarization-vector alignments over ~ 1 Gpc baselines, 30–50 times larger than tidal-torque theory predicts. At the intermediate scale bridging these extremes, Tudorache, Jung et al. (2025) directly detected a rotating cosmic filament carrying coherent bulk angular momentum at ~ 110 km/s across a 14-galaxy, ~ 1.7 Mpc HI-selected chain, at an amplitude exceeding IllustrisTNG predictions beyond parameter uncertainty. Together, these results close a continuous chain of co-rotation inheritance running from the largest accessible scales down to individual satellite systems.

We argue that this hierarchy is not a collection of independent anomalies but a single, scale-invariant signature of angular-momentum inheritance set by discrete large-scale collision events. Within the proposed framework of Successive Collision Theory (SCT), each major collision is characterized by an orbital angular momentum $J = \mu(\mathbf{b} \times \mathbf{v}_{\text{rel}})$ that simultaneously defines both the geometric plane in which debris is distributed and the rotational sense inherited by all descendant structures. We develop this unified narrative across five observational sectors, contrast each with Λ CDM predictions, and present six falsifiable predictions that can discriminate between collision-driven and tidal-torque origins for cosmic co-rotation. The companion paper (Nipok

2026) demonstrates that SCT reproduces the Planck CMB power spectrum via the Plasma Equivalence Theorem, removing the most natural objection to any Λ CDM alternative. Three theoretical priorities for future development — quantitative angular momentum budget derivation, modified stress-energy tensor formulation, and collision-generation sequence determination — are identified explicitly.

Keywords: satellite planes · co-rotation · cosmic filaments · filament spin · cluster alignments · galaxy spin · quasar polarization · tidal torque theory · Successive Collision Theory · large-scale structure · angular momentum · Λ CDM tensions · MeerKAT · large quasar groups · BCG alignment · falsifiable predictions

1. Introduction

The Λ CDM cosmological model has earned its status as the prevailing paradigm by successfully reproducing a wide range of observations: the angular power spectrum of the cosmic microwave background, the statistical properties of large-scale structure, and the expansion history inferred from type Ia supernovae and baryon acoustic oscillations. In this framework, cold dark matter drives hierarchical structure formation while a cosmological constant accelerates the late-time expansion, all embedded in a statistically homogeneous and isotropic background spacetime. Angular momentum in Λ CDM arises primarily through stochastic tidal torques (Hoyle 1949; Peebles 1969; White 1984): as proto-halos collapse within the evolving cosmic web, misalignments between their inertia tensors and the surrounding tidal field generate spins whose directions and magnitudes reflect a complex, non-linear accretion history with no preferred global orientation.

A key implication of this picture is that, beyond modest correlations with the immediate tidal environment, the spins and orientations of gravitationally bound structures should be effectively random on large scales. While tidal torque theory (TTT) does allow spin–filament correlations at modest scales — typically up to ~ 30 – 50 Mpc under optimistic estimates (Schäfer 2009) — the default expectation is that strong, coherent spin alignments should be rare and progressively erased by non-linear evolution. Critically, in Λ CDM there is no mechanism by which the geometric arrangement of objects in a shared structure — a satellite plane, a filament, a cluster wall — should systematically predict the sense of their rotation. Co-planarity and co-rotation are, in this framework, independent properties.

The observational record increasingly contradicts this independence. Over the past two decades, every sufficiently sampled system in which objects share a common geometric configuration has been found to exhibit shared rotation as well. At the smallest scales, satellite galaxies of the Milky Way, Andromeda, and Centaurus A are distributed in strikingly thin planes — and in every case where radial velocities or proper motions have been measured for enough

members, those satellites co-rotate within the plane at significances that reach 99.998% in the case of M31 (Ibata et al. 2013), yet arise in fewer than 0.5% of Λ CDM simulations. Moving up in scale, brightest cluster galaxies are preferentially aligned with their host cluster's major axis at one-in-a-million significance or better (Smith et al. 2023), and cluster major axes themselves remain correlated with neighboring clusters over separations of 200–300 Mpc — roughly ten times the coherence length that simulations produce. Tang et al. (2025) have now statistically confirmed that galaxy clusters carry coherent bulk rotation, with spin axes that align with the spin of the central BCG and orient perpendicular to the nearest cosmic filament. At the largest probed scales, radio-loud quasars exhibit coherent jet and polarization-vector alignments over ~ 1 Gpc, 30–50 times beyond the maximum scale that TTT can reach.

The intermediate scale — cosmic filaments and the galaxies and clusters they contain — is where the hierarchy becomes most directly testable. Tudorache, Jung et al. (2025) have provided direct evidence that filaments are not merely passive scaffolding: using MeerKAT HI observations, they detected a cosmic filament carrying coherent bulk angular momentum consistent with solid-body rotation at approximately 110 km/s. The spin axes of member galaxies are aligned with the filament spine more strongly than any current cosmological simulation reproduces. This result reframes what was previously a statistical observation about galaxy populations into a physical picture: filaments are rotating structures whose bulk angular momentum is actively inherited by the objects condensing within them.

Successive Collision Theory (SCT) provides the common cause that Λ CDM lacks. In SCT, our visible universe exists within an infinite, eternal reality populated by nested comoving structures — spacetime pockets, each with its own inherited perception of space and time — that occasionally intersect at superluminal relative velocities (see Section 5.2 for the precise statement and motivation of this postulate). When two such structures collide, the encounter is governed by an orbital angular momentum $J = \mu(\mathbf{b} \times \mathbf{v}_{\text{rel}})$, where μ is the reduced mass, \mathbf{b} is the impact-parameter vector, and \mathbf{v}_{rel} is their relative velocity. This vector simultaneously fixes the plane in which pulverized matter is distributed and the rotational sense inherited by all structures that subsequently condense from that plasma. Because this axis is established at the moment of collision — as a boundary condition, not as a late-time emergent property — the resulting coplanarity and co-rotation of descendant structures are inseparably linked.

The present paper develops this unified angular-momentum narrative across five observational sectors. Section 2 examines co-rotating satellite planes around the Milky Way, Andromeda, Centaurus A, and a growing census of more distant hosts. Section 3 addresses galaxy cluster orientation, BCG alignment, and the recently confirmed coherent cluster spin. Section 4 covers quasar polarization and radio-axis alignments over gigaparsec baselines. Section 5 presents the filament scale in full. Section 6 develops the unified SCT collision-geometry mechanism. Section 7 presents six falsifiable predictions testable with MeerKAT, SKA, Euclid, and LSST. Sections 8 and 9 provide Discussion and Conclusions. Section 10 lists all references.

2. Co-rotating Satellite Planes: The Observational Census

The satellite plane problem has long been framed primarily as a geometric puzzle: why do the dwarf galaxy companions of large spirals distribute themselves in thin, flattened configurations rather than the roughly isotropic swarms predicted by Λ CDM? The deeper and more damaging challenge, however, is kinematic. In every system where a sufficient number of satellite velocities have been measured, the satellites do not merely inhabit a common plane — they orbit within it in the same direction. Co-planarity without co-rotation could, in principle, arise from chance alignments of subhalo orbits or from transient filamentary infall. Co-planarity combined with co-rotation cannot.

2.1 *The Milky Way — The Vast Polar Structure*

The eleven classical satellite galaxies of the Milky Way are concentrated in a thin plane oriented roughly perpendicular to the Galactic disc — the Vast Polar Structure (VPOS). Gaia proper motion measurements reveal that 7 to 9 of the 11 classical satellites share coherent orbital poles clustered within a narrow range on the sky. The frequency of such configurations in Λ CDM simulations — requiring the correct geometry, thickness, diameter, and co-rotation fraction simultaneously — is at or below 0.1% (Pawlowski & Kroupa 2020).

An important counterpoint was raised by Sawala et al. (2023), who argued that orbital pole clustering of the observed degree is more common in simulations than previously reported, and that the VPOS may be a transient structure. This interpretation remains actively debated. Pawlowski and collaborators have demonstrated that when the full set of observational constraints — plane geometry, membership fraction, and kinematic coherence simultaneously — is applied to large simulation suites, the tension does not dissolve (Pawlowski 2021).

2.2 *Andromeda (M31) — The Great Plane of Andromeda*

Ibata et al. (2013) identified a planar subgroup comprising roughly half of M31's known satellite population and reported a co-rotation signal significant at the 99.998% level — a probability of chance occurrence of approximately 1 in 50,000. The structure is geometrically extreme: at least 400 kpc in diameter yet with a perpendicular root-mean-square scatter of fewer than 14.1 kpc. When the full set of observational constraints is applied simultaneously to the Millennium-II simulation (Boylan-Kolchin et al. 2009), fewer than 0.04% of host galaxies display comparably extreme configurations.

2.3 *Centaurus A (NGC 5128)*

Müller et al. (2018), publishing in *Science*, demonstrated that 14 of 16 Centaurus A satellites follow a coherent velocity pattern aligned with their spatial distribution — a co-rotation signal arising in fewer than 0.5% of Λ CDM simulations. Subsequent analysis by Kanehisa et al. (2023) found that up to 21 of 28 potential satellites may be co-rotating.

2.4 *Beyond the Local Volume*

NGC 4490/NGC 4485 and NGC 2750 host satellite distributions with kinematically coherent velocity patterns at ~ 40 Mpc (Pawlowski, Ibata & Bullock 2017), using SDSS and Subaru HSC imaging. Most recently, Jerjen et al. (2025) reported that NGC 5713 and NGC 5719 hosts a system in which 12 of 14 satellites follow a coherent velocity pattern — the first co-rotating satellite system caught in the act of formation during an ongoing merger.

2.5 Methodological Note on the 100% Detection Rate

The observed co-rotation frequency of 100% across all adequately sampled systems requires a methodological caveat. The criterion 'adequately sampled' was applied post-hoc to select systems with sufficient kinematic data. A joint probability calculation for six independent systems each falling in the $\sim 0.5\%$ Λ CDM tail yields approximately $(0.005)^6 \approx 2 \times 10^{-14}$. Applying a generous look-elsewhere correction factor of 10 for the number of galaxy systems examined in the literature leaves a corrected probability below 10^{-12} . This is not a marginal tension.

Table 1: Co-rotating Satellite Plane Census

System	Co-rot./Total	Significance	Λ CDM Prob.	Survey / Instrument	Year	Reference(s)
Milky Way (VPOS)	7–9 / 11	High; debated [†]	$\leq 0.1\%$	HST (PM); Gaia DR2	2018	Pawlowski & Kroupa (2020); Sawala et al. (2023)
M31 (GPoA)	$\sim 15 / 27$	99.998%	0.04%	WHT/ISIS; Keck/DEIMOS	2013	Ibata et al. (2013)
Centaurus A	14–21 / 16–28	$\geq 99.5\%$	$< 0.5\%$	VLT/MUSE; ESO/2.2m	2018; 2023	Müller et al. (2018); Kanehisa et al. (2023)
NGC 4490/4485	Detected	First extragalactic	$< 0.5\%$	SDSS; Subaru HSC	2017	Pawlowski, Ibata & Bullock (2017)
NGC 2750	Detected	Confirmed	$< 0.5\%$	SDSS; Subaru HSC	2017	Pawlowski, Ibata & Bullock (2017)
NGC 5713/5719	12 / 14	Caught forming	$< 0.5\%$	VLT spectroscopy; DSS	2025	Jerjen et al. (2025)

Table 1. Complete census of co-rotating satellite plane detections as of early 2026. In every system with sufficient kinematic data, co-rotation is confirmed. The observed frequency of 100% stands against a Λ CDM expectation of approximately 0.5%, a tension that compounds multiplicatively across six independent systems. [†] The VPOS significance is debated; see Section 2.1 and Sawala et al. (2023). Λ CDM probability of 0.5% refers to the frequency with which Λ CDM N-body simulations produce a system matching observed geometry, co-rotation fraction, and kinematic coherence simultaneously (Boylan-Kolchin et al. 2009).

3. Galaxy Cluster Orientation, BCG Alignment, and Coherent Cluster Spin

One scale above the satellite-plane phenomena, the rotational alignment signal reappears in a structurally analogous but observationally independent form. Galaxy clusters are not randomly oriented with respect to one another, their surrounding large-scale environment, or the central galaxies at their gravitational cores. The observed alignments are strong, multi-wavelength confirmed, coherent over scales that exceed Λ CDM predictions by an order of magnitude, and fully established at epochs when the universe was less than one-third its present age.

3.1 The Binggeli Effect: Cluster–Cluster Orientation Alignment

Binggeli (1982) first reported that galaxy clusters tend to align their major axes with the direction toward neighboring clusters. Every subsequent large-scale survey has confirmed and extended this result. The signal has been confirmed independently in X-ray cluster shape analyses (Chambers, Melott & Miller 2002) and in optical photometric catalogues (Paz et al. 2011), demonstrating it is not an optical selection artefact. The coherence extends to 200–300 comoving Mpc — roughly ten times the Λ CDM tidal coherence limit of $\sim 15\text{--}30 h^{-1}$ Mpc. Tidal torque theory has no mechanism for generating orientation correlations across causally disconnected regions on structure-formation timescales.

3.2 BCG–Cluster Alignment: Signal Strength and the High-Redshift Constraint

Smith et al. (2023) reported alignment significances of one-in-a-million or better when BCG position angles are compared simultaneously with the cluster member distribution and the nearest filament orientation. X-ray confirmation using Chandra-derived shapes paired with Subaru optical BCG morphologies (Hashimoto et al. 2008) demonstrates the alignment reflects the true three-dimensional mass distribution.

The temporal constraint is the most demanding single datum in this section. West et al. (2017) used HST imaging of 65 distant clusters to show BCG alignments fully established at $z > 1.3$, when the universe was approximately 4.3 Gyr old — less than one-third its present age. The alignment at $z > 1.3$ is as strong as at $z \sim 0$, the direct opposite of what gradual tidal reorientation predicts. Any mechanism assembling the alignment through tidal forces over many Gyr cannot have produced a full signal when only 4.3 Gyr had elapsed. This result almost certainly rules out gradual assembly as the cause and requires the alignment to have been set near the epoch of cluster formation.

3.3 Coherent Cluster Spin

Tang et al. (2025) analyzed samples of 2,170 and 1,329 spectroscopically confirmed clusters with masses $M > 10^{14} M_{\odot}$, using the statistical distribution of maximum line-of-sight velocity differences between member galaxies on opposite sides of a projected rotation axis. This is a statistical proxy for bulk rotation — measured in aggregate over thousands of clusters, not a direct per-cluster detection. The aggregate significance exceeds $\sim 100\sigma$. Rotation velocities show a clear mass dependence: ~ 360 km/s at $10^{14} M_{\odot}$ rising to ~ 693 km/s at $10^{15} M_{\odot}$. Cluster spin axes

are preferentially parallel to their BCG spin axis and perpendicular to the nearest filament — a geometry linking cluster spin to filament angular momentum (see Section 5).

Barnes et al. (2017), using the MACSIS hydrodynamic simulations, demonstrated that dark matter, galaxy, and ICM spin vectors can be mutually misaligned within the same cluster, complicating the extraction of clean rotation signals from individual systems. This does not invalidate the Tang et al. aggregate result but cautions against per-cluster rotation interpretations without accounting for component misalignment.

Table 2: Cluster-Scale Alignment and Co-rotation Observations

Phenomenon	Observation	Λ CDM Prediction	Tension	Key Reference(s)
Cluster–cluster orientation (Binggeli effect)	Correlated to 200–300 Mpc; X-ray & optical confirmed; strong at $z \sim 1$	Significant only to $\sim 15\text{--}30 h^{-1}$ Mpc; signal should weaken with time	Strong ($\sim 10\times$ coherence length exceeded; wrong redshift trend)	Binggeli (1982); Chambers et al. (2002); Paz et al. (2011)
BCG–cluster shape alignment	$< 1\text{-in-}10^6$ significance; fully established at $z > 1.3$; multi-wavelength confirmed	Gradual tidal reorientation over many Gyr; weaker at high z	Strong (alignment in place before tidal mechanism operates)	Hashimoto et al. (2008); West et al. (2017); Smith et al. (2023)
BCG–cluster spin alignment	Confirmed; strengthens with cluster richness; parallels 1-in- 10^6 shape result	Qualitatively expected from TTT; amplitude not reproduced	Strong (1-in- 10^6 significance; richness scaling not reproduced)	Tang et al. (2025); Manolopoulou & Plionis (2017)
Cluster spin \perp filament (BCG–filament angle)	Confirmed statistically; Tang et al. (2025), $n \sim 2000$ clusters	Qualitatively consistent with TTT; amplitude underpredicted	Moderate–Strong (links cluster spin to filament J-axis)	Tang et al. (2025)
Cluster rotation speed vs. mass	360–693 km/s over $10^{14}\text{--}10^{15} M_{\odot}$; statistical proxy measurement	No quantitative mass–rotation scaling predicted	Moderate ($J \propto$ collision energy implied)	Tang et al. (2025)
Rotation in dynamically young clusters	$\sim 23\%$ of Abell clusters; signal stronger in less-relaxed systems	TTT predicts stronger signal in older, relaxed systems	Moderate (environment dependence reversed relative to TTT)	Manolopoulou & Plionis (2017)

Table 2. Cluster-scale alignment and co-rotation observations compared with Λ CDM tidal-torque predictions. BCG–cluster spin alignment is rated Strong to reflect the 1-in-a-million shape alignment significance and the failure

of TTT to reproduce the amplitude and richness scaling. The most severe tensions are the 200–300 Mpc coherence of the Binggeli effect and the full BCG alignment at $z > 1.3$.

4. Quasar Polarization and Radio Axis Alignments

4.1 *The Hutsemékers Effect*

Hutsemékers (1998) first reported that optical linear polarization vectors of quasars cluster around preferred orientations on coherence scales of order 1 Gpc. The sample grew to 355 objects in Hutsemékers et al. (2005), with the probability of the alignment arising by chance falling below 0.1%. The signal grows with sample size rather than diluting. Instrumental polarization ($< 0.1\%$) and Galactic interstellar polarization (0.2–0.3% at high latitudes) cannot explain the redshift-dependent pattern: the mean polarization angle rotates at roughly 30° per Gpc and coherent and random regions alternate along the line of sight with a comoving scale of approximately 1.5 Gpc. A Galactic foreground cannot rotate with redshift.

The preferred alignment axis is consistent with the direction of the CMB quadrupole and octupole alignment — the so-called 'Axis of Evil' (Land & Magueijo 2005) — within approximately 20° . The a posteriori probability of this angular coincidence is estimated at a few percent or smaller. We note, however, that the CMB multipole alignments are themselves debated: several analyses have argued they may partly reflect residual foreground contamination (Schwarz et al. 2016), and the statistical significance weakens under some foreground-correction prescriptions. We therefore treat the directional coincidence as suggestive but not conclusive.

4.2 *Quasar Spin Axes Aligned with Host Large-Scale Structure*

Hutsemékers et al. (2014) measured polarization of 93 quasars in Gpc-scale Large Quasar Groups at $z \sim 1.3$, finding polarization vectors preferentially parallel or perpendicular to host LQG major axes at $\sim 1\%$ probability of chance occurrence — implying supermassive black hole spin axes are preferentially parallel to the LQG elongation. Pelgrims & Hutsemékers (2016) confirmed this at 8.4 GHz using the JVAS/CLASS survey, with radio polarization vectors perpendicular to LQG major axes at $> 99\%$ confidence in groups with more than 20 members.

4.3 *The LQG Orientation Question: An Open Question*

Friday, Clowes & Williger (2022) reported that LQG position angles are inconsistent with uniform distribution, with median modes consistent with mean quasar radio polarization angles. However, Park (2024) revisited this analysis using Sobolev tests in redshift space and found no statistically significant departure from uniformity, also questioning whether LQGs constitute physically coherent structures rather than projection artefacts. We treat the Friday et al. (2022) LQG orientation result as suggestive but unconfirmed. The quasar polarization and VLBI jet alignment evidence rests on considerably firmer ground and does not depend on LQGs being physically real structures.

4.4 Alternative Explanations

Photon–pseudoscalar mixing is largely ruled out by the absence of predicted circular polarization. Primordial large-scale magnetic fields require coherence lengths and amplitudes not well motivated and are constrained by CMB Faraday rotation. Cosmological birefringence — a CPT-violating rotation of photon polarization planes — was detected at $\sim 3\sigma$ by Minami & Komatsu (2020). However, birefringence predicts a uniform rotation at fixed redshift regardless of sky position or large-scale structure membership. The Hutsemékers effect shows sky-position-dependent coherence that varies with redshift: birefringence cannot produce spatially structured alignment of this kind and is therefore not a complete explanation. Global anisotropy is constrained by Planck polarization data to an unlikely dominant contribution.

Table 3: Radio Jet and Polarization Alignment Surveys

Survey	Freq. Band	Method	Scale	Significance	Reference
GMRT (ELAIS-N1)	612 MHz	Mutual 2D jet orientation	~ 30 Mpc	$> 99.9\%$	Taylor & Jagannathan (2016)
FIRST (VLA)	1.4 GHz	Mutual 2D jet orientation	~ 30 Mpc	$> 99\%$	Contigiani et al. (2017)
FIRST (VLA)	1.4 GHz	Mutual 3D jet orientation	~ 640 Mpc	$> 99\%$	Panwar et al. (2020)
LoTSS (LOFAR)	120–168 MHz	Mutual 2D jet orientation	~ 100 Mpc	$> 99.7\%$	Osinga et al. (2020)
VLBI (multi-array)	2–43 GHz	Mutual 3D jet orientation	400–900 Mpc	$> 99.5\%$	Blinov et al. (2020); Mandarakas et al. (2021)
JVAS/CLASS (VLA)	8.4 GHz	Radio polarization vs. LQG axis	Gpc-scale LQGs	$> 99\%$ (LQGs > 20 members)	Pelgrims & Hutsemékers (2016)
Optical (multiple)	Optical V/R band	Quasar optical polarization coherence	~ 1 Gpc coherence	$< 0.1\%$ (random)	Hutsemékers (1998); Hutsemékers et al. (2005)

Table 3. Radio jet and polarization alignment surveys. Significance values are as reported by the respective studies; $>$ indicates a lower bound where exact figures require interpolation. VLBI measurements are the most physically direct, delivering 3D jet orientations at parsec resolution with no projection or polarization-mechanism assumptions.

5. The Filament Scale

The cosmic filament occupies the pivotal position in the angular momentum hierarchy. It is the structural link between the gigaparsec-scale quasar anomalies and the cluster- and satellite-scale co-rotation phenomena. If filaments carry coherent bulk angular momentum set at their

formation epoch, then every structure condensing within them shares a common rotational history — and the contents of any given filament are siblings in exactly the same sense as satellite galaxies around a host.

Part A: Filament Formation Physics

5.1 Kinematic Predictions: Filament Morphology from Collision Parameters

SCT makes the following kinematic prediction, stated explicitly as a testable proposition rather than an established result: the length-to-width ratio of a cosmic filament should correlate with the relative velocity and mass ratio of its parent collision. Higher relative velocities produce more elongated debris fields; more comparable mass ratios produce wider, more symmetric distributions. This is Kinematic Prediction 1 of SCT, stated formally in Section 7, and testable through correlations between filament aspect ratios and estimated relative velocities — accessible with DESI and 4MOST spectroscopic samples.

5.2 The Superluminal Velocity Postulate

SCT postulates the existence of nested comoving reference frames whose relative velocities in the global parent frame may exceed c . This is a foundational postulate of the theory, not a derivable consequence of General Relativity as currently formulated. Metric expansion already permits recession velocities $> c$ between causally disconnected regions — no local Lorentz invariance is violated in such scenarios, as Davis & Lineweaver (2004) demonstrated in detail. The generalization to colliding frames in an infinite universe is speculative but internally consistent. A rigorous derivation from a modified Einstein field equation is identified in Section 6.8 as the first priority for future theoretical development of SCT.

5.3 Speculative Extension: Exotic Matter

[Speculative theoretical extension — outside the observational scope of this paper.] At frame boundaries, SCT proposes that extreme collision conditions may produce exotic matter states not present in the standard model. This is not required by the observational case developed in Sections 2–4 and is not invoked in any prediction of Section 7.

5.4 Speculative Extension: Net Mass Creation

[Speculative theoretical extension — outside the observational scope of this paper.] SCT proposes that net mass-energy creation may occur at frame boundaries under superluminal-frame conditions. This lies substantially outside the observational scope of this paper and is not a prerequisite for the angular momentum inheritance arguments in Sections 2 through 6.

5.5 The Collision Medium and Large-Scale Angular Momentum Coherence

When two large-scale nested comoving frames collide, the interpenetrating plasma of each frame is distributed across the entire spatial extent of both frames at the moment of contact. The \mathbf{J} -vector of the encounter is therefore coherent across the full overlap volume — potentially

hundreds of megaparsecs for sufficiently large parent structures. This global spatial coherence, established instantaneously at the collision epoch as a boundary condition, explains why filaments and their contents share coherent angular momentum over the scales observed in Sections 3 and 4, scales that no tidal torque mechanism operating locally and growing gradually can reproduce.

5.6 Multi-Generation Collisions and the Dominant J-Vector

The cosmic web results from a hierarchy of nested collision events. Each region of the observable universe shows the co-rotation signal of its most recent energetically dominant collision; the hierarchy of earlier collisions contributes as scatter but does not alter the directional character of the dominant signal. All six falsifiable predictions of Section 7 are formulated in terms of this dominant J-vector, regardless of generation number.

Part B: Observational Evidence and Λ CDM Comparison

5.7 Eddies, Tentacles, and Branch Points: A Testable SCT Prediction

The following represents a physically motivated but as yet unconfirmed prediction of the SCT framework. Where a secondary collision deposits material along a branch direction, the galaxy spins within the sub-filament should reflect the J-vector of the secondary collision, generically misaligned with the dominant J-vector of the parent strand. The key testable prediction: galaxy spin coherence should be strongest in the main strand, weaker in secondary branches, and most disordered at branch points. This is stated formally as Section 7, Prediction 2, and is testable with MeerKAT over filament volumes of $\sim 10\text{--}50$ Mpc extent.

5.8 Galaxy Spin–Filament Alignment: Discriminating Power

Statistical surveys using SDSS, COSMOS, and related catalogues establish a robust, mass-dependent pattern: low-mass, late-type galaxies preferentially align spin axes parallel to the filament spine, while more massive systems tend toward perpendicular alignment (Codis et al. 2018; Welker et al. 2020). Importantly, this mass-dependent spin-flip is also reproduced qualitatively by IllustrisTNG within the Λ CDM framework. The spin-flip pattern does not, by itself, strongly discriminate SCT from Λ CDM. The discriminating observable is the amplitude: IllustrisTNG consistently underpredicts the strength of the alignment signal at both ends of the mass distribution. The amplitude discrepancy — not the qualitative pattern — is the genuine tension.

5.9 Bulk Filament Rotation: The Tudorache et al. (2025) Detection

Wang et al. (2021) demonstrated, using stacked SDSS data over thousands of filament segments, a statistical excess in the vortical velocity field consistent with large-scale filament rotation. This establishes rotation as a population-level property but is indirect — measuring an aggregate over many structures.

Tudorache, Jung et al. (2025) provided the first direct detection of coherent bulk angular momentum in an individual cosmic filament. Using MeerKAT HI 21-cm observations, they resolved the kinematic structure of a filament consisting of 14 HI-selected galaxies spanning approximately 1.7 Mpc, embedded within a broader ~ 15 Mpc structure. The velocity gradient across the filament is consistent with solid-body rotation at approximately 110 km/s. The spin axes of member galaxies are aligned with the filament spine at a strength that exceeds IllustrisTNG predictions by an amplitude that cannot be accounted for by resolution uncertainty or sub-grid physics variations within reasonable parameter ranges. This is not a statistical tendency — it is a directly detected, resolved, rotating dynamical structure actively transmitting angular momentum to its member galaxies.

Table 4: Filament-Scale Observations vs. Λ CDM and SCT Predictions

#	Observation	Λ CDM / IllustrisTNG	SCT Prediction	Status	Key Ref.
1	Galaxy spin \parallel filament (low-mass, late-type)	Qualitative match; amplitude underpredicted	Parallel alignment from J inheritance	Confirmed obs. tension (amplitude discrepancy)	Tempel & Libeskind (2013); Dubois et al. (2014)
2	Galaxy spin \perp filament (high-mass, early-type)	Qualitative match; amplitude underpredicted	Perpendicular for massive siblings with high J-transfer	Confirmed obs. tension (amplitude discrepancy)	Codis et al. (2018); Ganeshiah Veena et al. (2019)
3	Mass-dependent spin-flip at $\sim 10^{10.5} M_{\odot}$	Reproduced qualitatively by IllustrisTNG	Predicted from mass-dependent J partitioning	Not discriminating (SCT and Λ CDM both match)	Welker et al. (2020); Codis et al. (2018)
4	Wang et al. (2021): vortical velocity excess around filaments	Not reproduced at observed amplitude	Natural consequence of filament bulk J	Confirmed obs. tension	Wang et al. (2021)
5	Tudorache et al. (2025): bulk rotation 110 km/s, 14 galaxies, 1.7 Mpc; spin alignment exceeds IllustrisTNG	Not reproduced; amplitude exceeded beyond parameter uncertainty	Direct prediction: filament carries bulk J from formative collision	Confirmed obs. tension (single detection; confirmation required) [†]	Tudorache et al. (2025)
6	Filament length/width diversity correlates with collision parameters	Not specifically predicted	Kinematic prediction: v_{rel} governs length, mass ratio governs width	SCT prediction (interpretive; untested)	—

#	Observation	Λ CDM / IllustrisTNG	SCT Prediction	Status	Key Ref.
7	Branch-point spin disorder; tentacle spin divergence from main strand	Not predicted	Eddy instability at competing J-vectors; Prediction 2 (Sec. 7)	SCT prediction (speculative; no data)	—
8	Alignment strength decreases from main strand to sub-filaments	Not predicted	Hierarchical J inheritance; Prediction 2 (Sec. 7)	SCT prediction (speculative; no data)	—

Table 4. Filament-scale observations and SCT predictions. Rows 1–5 represent confirmed observational results with statistically significant tensions with the standard model. Rows 6–8 are SCT theoretical predictions awaiting systematic testing and should not be read as evidence for SCT. † Row 5 is based on a single detected filament; population-level confirmation is required.

5.11 The Filament Scale as Keystone

The filament is the keystone of the angular momentum hierarchy because it is the only scale at which angular momentum inheritance can be directly observed in a structural object, cross-validated in its contents, and compared to a physical mechanism — bulk rotation — that explains why the inheritance occurs. Tudorache et al. (2025) have closed the explanatory gap: a filament rotates, its galaxies inherit that rotation, the amplitude exceeds what tidal torques produce, and every cluster threading such a filament shows a perpendicular spin axis consistent with having accreted rotating filament material. The filament is the rung where the physical mechanism of inheritance is directly visible, connecting satellite co-rotation at kiloparsec scales to quasar axis coherence at gigaparsec scales as a single physical process.

6. The Unified SCT Collision-Geometry Mechanism

6.1 The Organizing Equation: $J = \mu(\mathbf{b} \times \mathbf{v}_{rel})$

The fundamental equation of the SCT collision mechanism is $J = \mu(\mathbf{b} \times \mathbf{v}_{rel})$, where μ is the reduced mass of the two colliding comoving structures, \mathbf{b} is the impact-parameter vector between their centers of mass, and \mathbf{v}_{rel} is their relative velocity in the global parent frame. This vector simultaneously determines: the magnitude of angular momentum deposited, the direction of the preferred axis (perpendicular to the plane containing \mathbf{b} and \mathbf{v}_{rel}), and the sense of rotation (right- or left-handed from the sign of $\mathbf{b} \times \mathbf{v}_{rel}$).

For a collision producing a ~ 100 Mpc filament, taking $\mu \approx 5 \times 10^{16} M_{\odot}$, $\mathbf{b} \sim 10$ Mpc = 3×10^{23} m, and $\mathbf{v}_{rel} \sim 3c = 9 \times 10^8$ m/s gives $|J| \sim \mu \cdot \mathbf{b} \cdot \mathbf{v}_{rel} \sim 3 \times 10^{79}$ kg m² s⁻¹. A 100 Mpc filament containing thousands of clusters requires a total angular momentum budget of order 10^{76} – 10^{78} kg m² s⁻¹. The estimate of 10^{79} kg m² s⁻¹ is physically reasonable for seeding filament-scale

angular momentum. This order-of-magnitude consistency does not constitute a derivation, but demonstrates the equation is not purely symbolic.

6.2 Why Λ CDM Cannot Replicate the Signal: A Structural Failure

The Λ CDM framework fails to reproduce the co-rotation hierarchy not because simulations lack resolution or sub-grid physics are miscalibrated, but because its initial conditions — Gaussian random fluctuations with no preferred large-scale angular momentum — cannot by construction produce the observed entanglement of geometry and rotation. The entanglement of co-planarity and co-rotation is the signature of a common-origin formation event, not of correlated but independent tidal histories. No perturbative modification to Λ CDM can remedy a failure of initial conditions without fundamentally changing the character of those conditions.

6.3 Scale-by-Scale Application

The same equation applies at every level of the angular momentum hierarchy, with μ , b , and v_{rel} taking values appropriate to each scale. For satellite planes ($\mu \sim 10^{12} M_{\odot}$, $b \sim$ tens to hundreds kpc), the collision defines the plane and rotational sense of the satellite debris: Λ CDM tidal torques operate at the same spatial scale but produce co-rotating planes 200 times less frequently. For galaxy clusters ($\mu \sim 10^{14}\text{--}10^{15} M_{\odot}$, $b \sim$ Mpc), the collision simultaneously defines cluster elongation, BCG orientation, and cluster spin: the Λ CDM tidal coherence limit is $\sim 15\text{--}30 h^{-1}$ Mpc while alignments extend to 200–300 Mpc, a factor of ~ 10 . For filaments ($\mu \sim 10^{17} M_{\odot}$, $b \sim$ tens Mpc, $v_{\text{rel}} \sim \text{few} \times c$), the collision defines bulk filament angular momentum: observations exceed IllustrisTNG amplitude predictions at all tested scales. For quasar axes ($\mu \sim 10^{18}\text{--}10^{20} M_{\odot}$, $b \sim$ hundreds Mpc, $v_{\text{rel}} \gg c$), the J-vector defines preferred black hole spin orientations across ~ 1 Gpc: observations exceed TTT maximum coherence by a factor of 20–30.

6.4 The Conservation Chain

The downward inheritance of angular momentum requires no long-range forces — only local conservation of J acting through a chain of physically connected formation events. The formative collision sets J_{filament} for the entire debris volume. Each proto-cluster condensing at a density node inherits a fraction through the angular momentum of accreting rotating matter; conservation is maintained locally at each step. The BCG forms at the potential minimum, accreting highest-specific-angular-momentum material first; its orientation is set by the same J-vector. This is the same local conservation operating in molecular cloud collapse into stellar systems — the novelty in SCT is only that the top-level boundary condition is set by a collision rather than by stochastic tidal torques.

6.5 Dark Matter and Dark Energy: Qualitative Reinterpretations

SCT offers qualitative reinterpretations of both dark energy (as a manifestation of gravitational-well dissipation across nested comoving frames) and dark matter (as cooperative gravitational effects among coherently moving baryonic structures). Both reinterpretations require

formal modifications to the Einstein field equations that have not yet been derived, and neither is within the observational scope of this paper. These are identified as priority directions for future theoretical development.

Table 5: The Angular Momentum Hierarchy — SCT vs. Λ CDM Across All Scales

Scale	$\mathbf{J} = \mu(\mathbf{b} \times \mathbf{v}_{\text{rel}})$ params	Observed coherence	Λ CDM limit	Ratio	Tension	Key Observation(s)
Satellite planes	$\mu \sim 10^{12} M_{\odot}$; $b \sim \text{tens kpc}$; $v_{\text{rel}} \sim \text{sub-}c$	~ 0.25 Mpc diameter; co-rotation frequency 100% observed	0.5–1 Mpc tidal reach; co-rotation freq. $\sim 0.5\%$	$\sim 200\times$ more frequent than Λ CDM	Strong (frequency)	Ibata et al. (2013); Müller et al. (2018)
Galaxy cluster orientation	$\mu \sim 10^{14} - 10^{15} M_{\odot}$; $b \sim \text{Mpc}$; $v_{\text{rel}} \sim \text{sub-}c$	200–300 Mpc (Binggeli effect); BCG alignment at $z > 1.3$	$\sim 15 - 30 h^{-1}$ Mpc; alignment grows with time	$\sim 10\times$ beyond Λ CDM limit	Strong (scale & epoch)	Binggeli (1982); West et al. (2017)
Filament rotation	$\mu \sim 10^{17} M_{\odot}$; $b \sim \text{tens Mpc}$; $v_{\text{rel}} \sim \text{few} \times c$	$\sim 10 - 100$ Mpc (Wang et al. 2021; Tudorache et al. 2025)	$\sim 30 - 50$ Mpc TTT spin–filament correlation	Amplitude exceeds IllustrisTNG [†]	Strong (amplitude; single detection)	Wang et al. (2021); Tudorache et al. (2025)
Quasar axis alignment	$\mu \sim 10^{18} - 10^{20} M_{\odot}$; $b \sim \text{hundreds Mpc}$; $v_{\text{rel}} \gg c$	$\sim 400 - 1000$ Mpc (VLBI jets; Hutsemékers polarization)	No TTT prediction; maximum $\sim 30 - 50$ Mpc	$\sim 20 - 30\times$ beyond TTT maximum	Strong (scale; no Λ CDM mechanism)	Hutsemékers et al. (2005); Mandarakas et al. (2021)

Table 5. The angular momentum inheritance hierarchy across all five observational sectors. The consistent pattern of observed coherence exceeding Λ CDM predictions by $10 - 200\times$ reflects the coherence of the SCT collision \mathbf{J} -vector across the spatial extent of the debris field. [†] Amplitude exceeds IllustrisTNG beyond parameter uncertainty; single-system detection requires population-level confirmation.

6.6 The Scale-Invariant Follow-the-Leader Principle

The four-sector application of $\mathbf{J} = \mu(\mathbf{b} \times \mathbf{v}_{\text{rel}})$ establishes that the same equation with physically appropriate parameters accounts for the full observational record from satellite planes at sub-Mpc scales to quasar axes at Gpc scales. Every rung of the hierarchy from quasar to satellite is playing follow-the-leader to the rung above it, with the \mathbf{J} -vector of each level set by the collision at that level and constrained by the \mathbf{J} -vector inherited from above. The entire observational record — across seven orders of magnitude in scale, across galaxy types, cluster morphologies, redshifts, and survey techniques — is the multi-scale fossil record of this nested collision hierarchy.

6.8 Open Questions and Theoretical Priorities

Priority 1: Quantitative angular momentum budget derivation. A rigorous derivation requires solving the full collision dynamics for two interpenetrating comoving frames at superluminal relative velocities — specifically the angular momentum partition function (retained J vs. heat) as a function of grazing angle and mass ratio, the radial profile of angular momentum density in the debris field, and the propagation of the J budget through the condensation hierarchy. Until this derivation is available, the predictions of Section 7 are stated as directional rather than precise.

Priority 2: Modified stress-energy tensor for cooperative gravitational effects. The dark matter reinterpretation requires a formal modification to the right-hand side of the Einstein field equations — a stress-energy tensor extended to account for the collective gravitational contribution of objects sharing a comoving frame. Deriving this and demonstrating it reproduces observed rotation curves and lensing signals is the second theoretical priority.

Priority 3: Observational strategy for determining collision generation number. An observational strategy for determining the generation number — from the nested J -vector structure of the cosmic web, searching for systematic misalignments between filament-scale and quasar-scale J -vectors that would indicate two distinct collision generations — is the third theoretical priority and a target for DESI and SKA data.

7. Six Falsifiable Predictions

Predictions 1–3 are primary tests: if confirmed, they would provide strong positive evidence for collision-driven angular momentum inheritance over tidal-torque assembly. Predictions 4–6 are secondary tests: their confirmation would be consistent with SCT but harder to uniquely attribute to it, while their disconfirmation would constrain specific parameters of the SCT framework. All six predictions specify the Λ CDM null hypothesis in semi-quantitative or quantitative terms.

Prediction 1: Filament Morphology and Rotation Amplitude Correlate with Collision Geometry

SCT prediction — Category A (two-node filaments): Bulk rotation amplitude should correlate with endpoint mass ratio; nearer-to-unity mass ratios correspond to higher retained angular momentum and higher rotation amplitude. Detecting this correlation at 3σ requires approximately 50–100 filaments spanning a factor of 10 in endpoint mass ratio, accessible with the forthcoming MeerKAT Large Survey Programme and DESI Bright Galaxy Survey at $0 < z < 0.3$.

Category B (fading-endpoint filaments): Where a filament has one well-defined cluster anchor and fades diffusely into a void at the other end, SCT predicts this as the expected majority case reflecting highly asymmetric collisions. Fading-endpoint filaments should show lower mean rotation amplitudes than symmetric two-node filaments of comparable length. SCT therefore

predicts fading-endpoint filaments are more common than two-node filaments, consistent with observed filament catalogues.

Λ CDM null: No systematic correlation is predicted between rotation amplitude and endpoint configuration, because rotation arises from the local tidal field rather than collision geometry. A statistically significant difference in mean rotation amplitude between two-node and fading-endpoint filaments at $> 2\sigma$, after controlling for filament length and environment, would not be expected.

Sample definition note: For Category A, the minimum requirement is two spectroscopically confirmed clusters or rich groups ($M > 10^{13.5} M_{\odot}$) within 5 Mpc of each identified endpoint. For Category B, the fading end is operationally defined as the end at which galaxy number density falls below the mean field density within the final 10 Mpc of the filament spine. These criteria must be fixed before sample selection to avoid post-hoc classification bias.

Prediction 2: Hierarchical Spin Alignment Along Filament Topology

SCT prediction: Galaxy spin coherence should be strongest along the main strand of a well-defined filament, measurably weaker in secondary branches, and most disordered at branch points. Λ CDM null: Tidal torques produce smooth variation with no specifically elevated disorder at topological branch points. Candidate systems: Perseus-Pisces supercluster filament and the Virgo infall region. MaNGA and SAMI IFU surveys already provide resolved spin measurements for thousands of galaxies within these volumes.

Prediction 3: Satellite Plane Orientation Traces Host Filament Angular Momentum

SCT prediction: The normal vector of a co-rotating satellite plane should be aligned with the angular momentum axis of the host filament. Λ CDM null: Satellite plane normals are determined by the host's local merger history with no systematic relationship to the host filament J-vector.

Preliminary Local Group test: The VPOS normal of the Milky Way is oriented broadly consistent with the angular momentum axis of the Local Group filament; the GPoA normal of Andromeda is similarly oriented. Their near-parallelism is consistent with both having inherited a common filament-level J-vector. Neither system alone provides statistical significance. Statistical requirement: ~ 200 or more hosts with confirmed co-rotating satellite planes and resolved filament membership — deliverable by LSST/Rubin's photometric satellite census within its first three years.

Prediction 4: Cluster Spin Coherence Stronger Within Filaments Than in Field

SCT prediction: Clusters within a common filament should show more strongly correlated spin orientations than field clusters or clusters from different filaments, with correlation strengthening with proximity to the filament spine and with filament mass. Λ CDM null: Cluster spin correlations decay approximately isotropically with separation — no filament-membership

dependence. A filament-membership dependence at $> 2\sigma$ after controlling for cluster separation and local density would not be expected under Λ CDM.

Prediction 5: Quasar Polarization Preferred Axis Aligns with BCG Spin Axis in Common Large-Scale Structures

SCT prediction: Quasars residing in the same large-scale wall or supercluster-scale structure as a population of clusters should have their polarization preferred axis consistent with the mean spin axis of the BCGs in those clusters — both set by the same large-scale collision J-vector. Λ CDM null: Quasar spin axes and BCG spin axes are determined by independent processes with no predicted correlation beyond what would arise from a weak shared tidal environment.

Prediction 6: Co-rotation Signal Strength Does Not Decrease at High Redshift

SCT prediction: (a) BCG–cluster shape and spin alignment at $z > 1.3$ should be at least as strong as at $z \sim 0$. (b) Within-filament galaxy spin coherence at $z \sim 1–1.5$ should be equal to or greater than the amplitude measured in local SDSS surveys. (c) The cluster–cluster orientation alignment coherence length at $z \sim 1$ should not be shorter than at $z \sim 0$.

Λ CDM null: All three signals arise through tidal torques that accumulate over cosmic time. The signals should be measurably weaker at high z — quantitatively, tidal alignment amplitude scales approximately as the linear growth factor $D(z)$, which falls by a factor of ~ 2 between $z = 0$ and $z = 1$, and by a factor of ~ 4 by $z = 2$. Any of the three signals measured at high- z amplitude comparable to or stronger than the low- z amplitude, after correcting for selection effects, would be inconsistent with Λ CDM tidal-torque assembly.

Instruments: Euclid cluster survey is expected to deliver well-characterized cluster shape and BCG morphology measurements to $z \sim 1.5–2$ for samples of 10^4 or more clusters. JWST and forthcoming optical IFU programs (BlueMUSE, HARMONI on the ELT) will provide the resolved galaxy kinematics for test (b) at $z \sim 1–1.5$.

8. Discussion

8.1 What the Observational Record Establishes

This paper has documented a continuous, multi-scale co-rotation hierarchy spanning more than seven orders of magnitude in physical scale, independently confirmed across five observational sectors using optical polarimetry, radio interferometry at parsec and kiloparsec scales, HI 21-cm kinematics, X-ray cluster morphology, HST and Gaia proper motions, and large spectroscopic redshift surveys. In every sector, the observed coherence length exceeds the maximum produced by Λ CDM tidal-torque mechanisms by a factor of 10 to 200. The individual sector probabilities are each small; their product under the assumption that the five sectors are independent anomalies is negligibly small even under conservative estimates that do not account for the look-elsewhere effect. The observational conclusion is unambiguous: co-planarity and co-

rotation are systematically entangled across the observable universe in a manner that Λ CDM's stochastic initial conditions cannot produce.

8.2 What SCT Explains and What It Does Not Yet Explain

SCT accounts for the co-rotation hierarchy, the full-strength persistence of BCG–cluster alignment at $z > 1.3$, the direct detection of bulk filament rotation at amplitudes exceeding IllustrisTNG predictions, and the ~ 1 Gpc coherence scale of quasar polarization and radio jet alignments — all through the single mechanism of $\mathbf{J} = \mu(\mathbf{b} \times \mathbf{v}_{\text{rel}})$ applied at each level of a nested collision hierarchy. What SCT does not yet provide is a quantitative account of the amplitude of these signals. Without the angular momentum budget calculation identified as Priority 1 in Section 6.8, the predicted alignment amplitudes at each scale cannot be derived from first principles. The qualitative predictions of Section 7 will become quantitatively falsifiable once this calculation is performed.

8.3 The Broader Λ CDM Tension Landscape

The co-rotation anomalies documented here do not stand alone. The persistent Hubble tension ($\sim 5\sigma$ discrepancy in H_0), the S8 tension in matter fluctuation amplitude, and the unexpected abundance of massive, morphologically mature galaxies at $z > 4$ revealed by JWST all challenge Λ CDM's initial conditions and structure formation history. An alternative framework whose initial conditions are set by discrete collision events — which naturally produce directional, non-Gaussian angular momentum fields coherent over the full spatial extent of the collision debris — is, at minimum, less surprised by these anomalies than Λ CDM. We do not claim that SCT resolves the Hubble tension or the S8 tension — those require dedicated analyses — but note that these independent tensions collectively motivate exploration of frameworks with fundamentally different initial conditions.

8.4 CMB Consistency

The most immediate objection to any alternative cosmological framework is whether it reproduces the CMB angular power spectrum. This is addressed directly in the companion paper (Nipok 2026), which derives the CMB power spectrum within the SCT framework using the Plasma Equivalence Theorem: the angular power spectrum of CMB temperature fluctuations is determined by the acoustic dynamics of the photon-baryon fluid at recombination, not by the mechanism that created that fluid. A superheated plasma produced by a succession of superluminal collisions, once it reaches local thermal equilibrium, is acoustically equivalent to a plasma produced by a Planck-temperature singularity. SCT therefore reproduces the observed CMB peak structure, peak ratios, and damping tail. This paper's observational claims do not depend on the companion paper but are consistent with it.

8.5 Limitations of This Analysis

Three limitations should be stated explicitly. First, the superluminal collision postulate of Section 5.2 is a founding postulate of SCT, not a derivable consequence of General Relativity as currently formulated. Until a modified Einstein field equation accommodating nested comoving frame collisions is formally derived, the postulate remains a physically motivated hypothesis rather than a theoretical result. This is the most significant theoretical gap in the SCT framework.

Second, the collision-generation sequence of our observable region is unknown. The generation number carries implications for the total energy budget, the properties of CMB residuals, and the expected variance in large-scale structure properties across different regions.

Third, while the amplitude discrepancies between observed alignment signals and Λ CDM or IllustrisTNG predictions are real and documented across all five sectors, SCT has not yet made quantitative amplitude predictions of its own. The angular momentum budget calculation of Section 6.8 Priority 1 is the prerequisite for that demonstration.

8.6 The Path Forward

The observational record assembled in this paper does not permit the conclusion that Λ CDM's anomalies in the angular momentum domain are statistical fluctuations. The co-rotation hierarchy is too consistent across too many independent sectors, too persistent to high redshift, and too coherent over scales too far beyond Λ CDM's tidal reach to be plausibly accommodated by parameter adjustment within the standard framework. Whether SCT, or a future framework that retains the collision-geometry insight while placing it on firmer mathematical foundations, ultimately provides the correct account, the data are clear. The six falsifiable predictions of Section 7 — testable with MeerKAT, DESI, Euclid, LSST, and VLBI survey programmes already underway or imminent — provide the empirical path to that determination.

9. Conclusions

This paper has presented observational evidence, a theoretical framework, and six falsifiable predictions bearing on a single question: why do astrophysical objects share a common sense of rotation whenever they share a common geometric configuration, across every scale at which the question has been asked? The following conclusions summarize what the evidence establishes, what the SCT framework proposes, and where the work that remains is most urgently needed.

1. A continuous co-rotation hierarchy spanning more than seven orders of magnitude in physical scale is documented across five independent observational sectors and is statistically robust. Satellite co-rotation is observed at 100% frequency across six independent systems against a Λ CDM expectation of $\sim 0.5\%$; BCG–cluster alignment is fully in place at $z > 1.3$; cluster–cluster orientation coherence extends to 200–300 Mpc against a Λ CDM limit of $\sim 15\text{--}30 h^{-1}$ Mpc; filament bulk rotation is directly detected at ~ 110 km/s in an individual 1.7 Mpc structure (Tudorache et al.

2025) at an amplitude exceeding IllustrisTNG predictions beyond parameter uncertainty; and quasar spin-axis coherence extends to ~ 1 Gpc, 20–30 times beyond the maximum reach of tidal torque theory.

2. The Λ CDM failure is structural, not numerical. The standard model fails not because simulations lack resolution or sub-grid physics are miscalibrated, but because its Gaussian random initial conditions cannot by construction produce the observed entanglement of geometry and rotation. No increase in simulation volume or particle count can remedy a failure of initial conditions.

3. SCT provides a unified causal mechanism. The equation $\mathbf{J} = \mu(\mathbf{b} \times \mathbf{v}_{\text{rel}})$ applied at each level of a nested collision hierarchy simultaneously fixes the geometric plane of debris distribution and the rotational sense inherited by all structures condensing within it. Angular momentum propagates downward through the hierarchy by local conservation at each generational handoff, requiring no long-range forces.

4. SCT is consistent with the CMB power spectrum. The companion paper (Nipok 2026) demonstrates via the Plasma Equivalence Theorem that the Planck CMB peak structure, peak ratios, and damping tail are reproduced within the SCT framework, because these observables are determined by the acoustic dynamics of the photon-baryon fluid after its creation, not by the creation mechanism. The most natural objection to any Λ CDM alternative is thereby answered.

5. Three theoretical gaps remain open: (a) a quantitative derivation of the angular momentum partition function — without which amplitude predictions cannot be made from first principles; (b) a formal derivation of the superluminal collision postulate from a modified Einstein field equation; and (c) an observational strategy capable of determining the collision-generation sequence of our observable region. These are identified as ranked priorities in Section 6.8.

6. Six falsifiable predictions define the empirical test program. Prediction 1 (filament rotation amplitude and morphology) is accessible with MeerKAT and DESI at $z < 0.3$. Prediction 2 (hierarchical spin alignment along filament topology) is testable with existing MaNGA/SAMI data cross-matched against Perseus-Pisces and Virgo filament catalogues. Prediction 3 (satellite plane normals trace host filament J-vectors) requires the LSST/Rubin satellite census over ~ 200 hosts. Predictions 4 and 5 are testable with the Tang et al. (2025) cluster sample combined with DESI filament membership. Prediction 6 requires Euclid cluster morphology at $z \sim 1.5\text{--}2$.

If Euclid finds that BCG alignment strength, within-filament spin coherence, and cluster orientation correlations at $z \sim 1.5\text{--}2$ are equal to or stronger than their local counterparts — the direct prediction of a formation-epoch boundary condition — it would constitute the most temporally precise evidence yet that the angular momentum structure of the universe was written once, early, by discrete events, and has been slowly fading ever since; a result that no refinement of Λ CDM's stochastic assembly picture could accommodate without changing the character of that picture entirely.

Conflict of Interest

The author declares no conflict of interest.

Data Availability

This study is a theoretical and observational review. No new data were generated. All cited datasets are publicly available through the referenced sources.

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10. References

- Barnes, D. J., Kay, S. T., Bahé, Y. M., et al. (2017). The Cluster-EAGLE project: global properties of simulated clusters with resolved galaxies. *Monthly Notices of the Royal Astronomical Society*, 471(1), 1088–1106. <https://doi.org/10.1093/mnras/stx1647>
- Binggeli, B. (1982). The shape and orientation of clusters of galaxies. *Astronomy & Astrophysics*, 107(2), 338–349.
- Blinov, D., Pavlidou, V., Papadakis, I., et al. (2020). Alignment of radio galaxy axes using combined NVSS and FIRST images. *Monthly Notices of the Royal Astronomical Society*, 492(1), 556–566. <https://doi.org/10.1093/mnras/stz3137> [details to verify]

- Boylan-Kolchin, M., Springel, V., White, S. D. M., Jenkins, A., & Lemson, G. (2009). Resolving cosmic structure formation with the Millennium-II Simulation. *Monthly Notices of the Royal Astronomical Society*, 398(3), 1150–1164. <https://doi.org/10.1111/j.1365-2966.2009.15191.x>
- Chambers, S. W., Melott, A. L., & Miller, C. J. (2002). Testing the Butcher-Oemler effect and cluster ellipticity as a function of cluster orientation. *The Astrophysical Journal*, 565(1), 17–22. <https://doi.org/10.1086/324177> [details to verify: confirm this is the intended reference for X-ray cluster shape alignment confirmation]
- Codis, S., Pogosyan, D., & Pichon, C. (2018). On the connectivity of the cosmic web: theory and implications for cosmic voids. *Monthly Notices of the Royal Astronomical Society*, 479(1), 973–993. <https://doi.org/10.1093/mnras/sty1643>
- Contigiani, O., de Gasperin, F., Miley, G. K., et al. (2017). Radio galaxy zoo: cosmological alignment of radio sources. *Monthly Notices of the Royal Astronomical Society*, 472(1), 636–646. <https://doi.org/10.1093/mnras/stx1977>
- Davis, T. M., & Lineweaver, C. H. (2004). Expanding confusion: common misconceptions of cosmological horizons and the superluminal expansion of the universe. *Publications of the Astronomical Society of Australia*, 21(1), 97–109. <https://doi.org/10.1071/AS03040>
- DESI Collaboration, Aghamousa, A., Aguilar, J., et al. (2016). The DESI Experiment Part I: Science, Targeting, and Survey Design. arXiv:1611.00036. <https://arxiv.org/abs/1611.00036>
- Dubois, Y., Pichon, C., Welker, C., et al. (2014). Dancing in the dark: galactic properties trace spin swings along the cosmic web. *Monthly Notices of the Royal Astronomical Society*, 444(2), 1453–1468. <https://doi.org/10.1093/mnras/stu1227>
- Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al. (2016). The Gaia mission. *Astronomy & Astrophysics*, 595, A1. <https://doi.org/10.1051/0004-6361/201629272>
- Ganeshaiyah Veena, P., Cautun, M., van de Weygaert, R., et al. (2019). The cosmic ballet II: spin alignment of galaxies and haloes with large-scale filaments in the EAGLE simulation. *Monthly Notices of the Royal Astronomical Society*, 487(2), 1607–1625. <https://doi.org/10.1093/mnras/stz1343>
- Gardner, J. P., Mather, J. C., Clampin, M., et al. (2006). The James Webb Space Telescope. *Space Science Reviews*, 123(4), 485–606. <https://doi.org/10.1007/s11214-006-8315-7>
- Hashimoto, Y., Henry, J. P., & Boehringer, H. (2008). Alignment of brightest cluster galaxies in X-ray clusters. *Monthly Notices of the Royal Astronomical Society*, 390(4), 1562–1568. <https://doi.org/10.1111/j.1365-2966.2008.13815.x>
- Helmi, A., Babusiaux, C., Koppelman, H. H., et al. (2018). The merger that led to the formation of the Milky Way's inner stellar halo and thick disk. *Nature*, 563(7729), 85–88. <https://doi.org/10.1038/s41586-018-0625-x>
- Hoyle, F. (1949). On the fragmentation of gas clouds into galaxies and stars. In *Problems of Cosmical Aerodynamics: Proceedings of a Symposium on the Motion of Gaseous Masses of Cosmical Dimensions* (pp. 195–197). Central Air Documents Office, Dayton, Ohio.
- Hutsemékers, D. (1998). Evidence for very large-scale coherent orientations of quasar polarization vectors. *Astronomy & Astrophysics*, 332, 410–428.
- Hutsemékers, D., & Lamy, H. (2001). Confirmation of the existence of coherent orientations of quasar polarization vectors on cosmological scales. *Astronomy & Astrophysics*, 367(2), 381–387. <https://doi.org/10.1051/0004-6361:20000443>
- Hutsemékers, D., Cabanac, R., Lamy, H., & Sluse, D. (2005). Mapping extreme-scale coherent orientations of quasar polarization vectors. *Astronomy & Astrophysics*, 441(3), 915–930. <https://doi.org/10.1051/0004-6361:20053067>
- Hutsemékers, D., Braibant, L., Pelgrims, V., & Sluse, D. (2014). Alignment of quasar polarizations with large-scale structures. *Astronomy & Astrophysics*, 572, A18. <https://doi.org/10.1051/0004-6361/201424631>
- Ibata, R. A., Lewis, G. F., Conn, A. R., et al. (2013). A vast, thin plane of corotating dwarf galaxies orbiting the Andromeda galaxy. *Nature*, 493(7432), 62–65. <https://doi.org/10.1038/nature11717>
- Jerjen, H., Müller, O., Pawlowski, M. S., et al. (2025). A co-rotating satellite system caught forming around an interacting galaxy pair. [details to verify: journal, volume, and pages pending final publication record]

- Jonas, J., & MeerKAT Team. (2016). The MeerKAT radio telescope. *Proceedings of Science (MeerKAT2016)*, 001. <https://doi.org/10.22323/1.277.0001>
- Kanehisa, K. J., Pawlowski, M. S., & Müller, O. (2023). Satellite planes of the Centaurus A group. *Monthly Notices of the Royal Astronomical Society*, 524(1), 952–965. <https://doi.org/10.1093/mnras/stad1966>
- Land, K., & Magueijo, J. (2005). Examination of evidence for a preferred axis in the cosmic radiation anisotropy. *Physical Review Letters*, 95(7), 071301. <https://doi.org/10.1103/PhysRevLett.95.071301>
- Laureijs, R., Amiaux, J., Arduini, S., et al. (2011). Euclid Definition Study Report. arXiv:1110.3193. <https://arxiv.org/abs/1110.3193>
- LSST Science Collaboration, Abell, P. A., Allison, J., et al. (2009). LSST Science Book, Version 2.0. arXiv:0912.0201. <https://arxiv.org/abs/0912.0201>
- Mandarakas, N., Blinov, D., Casadio, C., et al. (2021). Intrinsic alignment of radio AGN. *Astronomy & Astrophysics*, 653, A123. <https://doi.org/10.1051/0004-6361/202141142>
- Manolopoulou, M., & Plionis, M. (2017). Galaxy cluster rotation. *Monthly Notices of the Royal Astronomical Society*, 465(3), 2616–2633. <https://doi.org/10.1093/mnras/stw2870>
- Minami, Y., & Komatsu, E. (2020). New extraction of the cosmic birefringence from the Planck 2018 polarization data. *Physical Review Letters*, 125(22), 221301. <https://doi.org/10.1103/PhysRevLett.125.221301>
- Müller, O., Pawlowski, M. S., Jerjen, H., & Lelli, F. (2018). A whirling plane of satellite galaxies around Centaurus A challenges cold dark matter cosmology. *Science*, 359(6375), 534–537. <https://doi.org/10.1126/science.aao1858>
- Myers, S. T., Jackson, N. J., Browne, I. W. A., et al. (2003). The Cosmic Lens All-Sky Survey — I. *Monthly Notices of the Royal Astronomical Society*, 341(1), 1–12. <https://doi.org/10.1046/j.1365-8711.2003.06256.x>
- Nipok, J. M. (2026). CMB Power Spectrum from Successive Collision Theory: A Quantitative Framework at Planck Precision. Preprint. <https://thenaturalstateofnature.org/PREPRINTS/2026/February/SCTCMBPowerSpectrumFromSCT.pdf> | <https://doi.org/10.13140/rg.2.2.20310.31042>
- Osinga, E., van Weeren, R. J., Boxelaar, J. M., et al. (2020). Alignment of radio source axes in the LoTSS survey. *Astronomy & Astrophysics*, 642, A70. <https://doi.org/10.1051/0004-6361/202038346>
- Panwar, M., Prabhakar, Singh, K., et al. (2020). Alignment of radio sources in the FIRST survey. *Monthly Notices of the Royal Astronomical Society*, 499(1), 1226–1233. <https://doi.org/10.1093/mnras/staa2916>
- Pawlowski, M. S., Ibata, R. A., & Bullock, J. S. (2017). Connected satellite plane structures are common in Λ CDM simulations. *The Astrophysical Journal*, 850(2), 132. <https://doi.org/10.3847/1538-4357/aa9307>
- Pawlowski, M. S., & Kroupa, P. (2020). The Milky Way's disc of classical satellite galaxies in light of Gaia DR2. *Monthly Notices of the Royal Astronomical Society*, 491(3), 3042–3059. <https://doi.org/10.1093/mnras/stz3163>
- Pawlowski, M. S. (2021). Planes of satellite galaxies: within the Λ CDM framework. *Galaxies*, 9(2), 66. <https://doi.org/10.3390/galaxies9020066>
- Paz, D. J., Sgró, M. A., Merín, M., & Padilla, N. (2011). Alignments of galaxies and clusters. *Monthly Notices of the Royal Astronomical Society*, 414(3), 2029–2039. <https://doi.org/10.1111/j.1365-2966.2011.18518.x>
- Peebles, P. J. E. (1969). Origin of the angular momentum of galaxies. *The Astrophysical Journal*, 155, 393–401. <https://doi.org/10.1086/149876>
- Pelgrims, V., & Hutsemékers, D. (2016). Evidence for the alignment of quasar radio polarizations with large quasar group axes. *Astronomy & Astrophysics*, 590, A53. <https://doi.org/10.1051/0004-6361/201526979>
- Pillepich, A., Springel, V., Nelson, D., et al. (2018). Simulating galaxy formation with the IllustrisTNG model. *Monthly Notices of the Royal Astronomical Society*, 473(3), 4077–4106. <https://doi.org/10.1093/mnras/stx2656>
- Planck Collaboration, Aghanim, N., Akrami, Y., et al. (2020). Planck 2018 results VI: Cosmological parameters. *Astronomy & Astrophysics*, 641, A6. <https://doi.org/10.1051/0004-6361/201833910>

- Sawala, T., Cautun, M., Frenk, C., et al. (2023). The Milky Way's plane of satellites is consistent with Λ CDM. *Nature Astronomy*, 7(4), 481–491. <https://doi.org/10.1038/s41550-022-01856-z>
- Schäfer, B. M. (2009). Galactic angular momenta and angular momentum correlations in the cosmological large-scale structure. *International Journal of Modern Physics D*, 18(2), 173–222. <https://doi.org/10.1142/S0218271809014388>
- Schaye, J., Crain, R. A., Bower, R. G., et al. (2015). The EAGLE simulations of galaxy formation. *Monthly Notices of the Royal Astronomical Society*, 446(1), 521–554. <https://doi.org/10.1093/mnras/stu2058>
- Schwarz, D. J., Copi, C. J., Huterer, D., & Starkman, G. D. (2016). CMB anomalies after Planck. *Classical and Quantum Gravity*, 33(18), 184001. <https://doi.org/10.1088/0264-9381/33/18/184001>
- Shimwell, T. W., Röttgering, H. J. A., Best, P. N., et al. (2017). The LOFAR Two-metre Sky Survey I. *Astronomy & Astrophysics*, 598, A104. <https://doi.org/10.1051/0004-6361/201629313>
- Smith, G. P., Bianconi, M., Jauzac, M., et al. (2023). Alignment of brightest cluster galaxies with host clusters and large-scale structure filaments. [details to verify: journal and volume pending full confirmation]
- Swarup, G., Ananthkrishnan, S., Kapahi, V. K., et al. (1991). The Giant Metrewave Radio Telescope. *Current Science*, 60(2), 95–105.
- Tang, L., Lin, W., Wang, Y., & Kang, X. (2025). Statistical detection of coherent rotation in galaxy clusters and alignment with BCG spin and cosmic filaments. [details to verify: journal, volume, and pages pending confirmation]
- Taylor, A. R., & Jagannathan, P. (2016). Alignments of radio galaxies in deep radio imaging of ELAIS-N1. *Monthly Notices of the Royal Astronomical Society Letters*, 459(1), L36–L40. <https://doi.org/10.1093/mnrasl/slw038>
- Tempel, E., & Libeskind, N. I. (2013). Galaxy spin alignment along filaments as a constraint on dark matter models. *The Astrophysical Journal Letters*, 775(2), L42. <https://doi.org/10.1088/2041-8205/775/2/L42>
- Tudorache, M. N., Jung, S. L., de Blok, W. J. G., et al. (2025). Detection of coherent bulk angular momentum in a MeerKAT HI-selected cosmic filament. [details to verify: journal, volume, and pages pending confirmation]
- Wang, P., Libeskind, N. I., Tempel, E., Kang, X., & Guo, Q. (2021). Possible observational evidence for cosmic filament spin. *Nature Astronomy*, 5(7), 839–845. <https://doi.org/10.1038/s41550-021-01380-6>
- Welker, C., Bland-Hawthorn, J., van de Sande, J., et al. (2020). The SAMI galaxy survey: first detection of a transition in spin alignment with respect to cosmic filaments. *Monthly Notices of the Royal Astronomical Society*, 491(2), 2864–2884. <https://doi.org/10.1093/mnras/stz2860>
- West, M. J., de Propris, R., Bremer, M. N., & Phillipps, S. (2017). The unchanging universe: BCG alignment in clusters at $z > 1$. *Nature Astronomy*, 1(3), 0157. <https://doi.org/10.1038/s41550-017-0157>
- White, S. D. M. (1984). Angular momentum growth in protogalaxies. *The Astrophysical Journal*, 286, 38–41. <https://doi.org/10.1086/162573>