From Chaos To Corotating Hierarchies

Angular Momentum Inheritance
Across Seven Scales Of Magnitude

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ABSTRACT

The observational record of the universe displays a statistically robust co-rotation hierarchy spanning more than seven orders of magnitude in physical scale: whenever astrophysical objects share a coherent geometric configuration, they also share a preferred sense of rotation or a common spin axis. This co-rotation hierarchy has been independently confirmed across five observational sectors using optical polarimetry, radio interferometry, HI 21-cm kinematics, X-ray cluster morphology, Hubble Space Telescope and Gaia proper motions, and large spectroscopic redshift surveys. At satellite-galaxy scales, co-rotation is detected in every system where sufficient kinematic data exist (six systems; joint ΛCDM probability $< 10^{-12}$). At cluster scales, BCG–cluster alignment is established at one-in-a-million significance and is fully in place at $z > 1.3$, prior to the epoch when gradual tidal reorientation could have operated. Cluster–cluster orientation coherence extends to 200–300 Mpc, roughly ten times the ΛCDM tidal coherence limit.

At filament scales, Tudorache et al. (2025) directly detected coherent bulk rotation at ~110 km/s in a 1.7 Mpc HI chain embedded within a ~15 Mpc cosmic filament, at an amplitude exceeding IllustrisTNG predictions beyond parameter uncertainty. At the largest scales, radio-loud quasars exhibit coherent jet and polarization-vector alignments over 400–1,000 Mpc baselines, 20–30 times beyond the maximum reach of tidal torque theory. We argue that these observations are consistent with the framework of Successive Collision Theory (SCT), in which each large-scale collision imprints an orbital angular momentum $J = \mu(b \times v_{rel})$ as a boundary condition on the resulting debris field, propagating a preferred rotation axis through a conservation chain from quasar-scale alignments down to satellite planes. The central failure of ΛCDM in this domain is structural, not numerical: Gaussian random initial conditions contain no preferred large-scale angular-momentum axis, and no increase in simulation resolution can reproduce the observed coherence lengths. We present six falsifiable predictions — several testable with existing MeerKAT data — that discriminate between collision-driven angular-momentum inheritance and stochastic tidal-torque assembly.

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

1. INTRODUCTION

The ΛCDM cosmological model commands broad empirical support across a wide range of observations. Its six-parameter fit to the Planck CMB temperature and polarization power spectra is precise to better than 1% across more than two thousand multipoles (Planck Collaboration 2020). Baryon acoustic oscillations measured in galaxy surveys constrain the distance–redshift relation from z ~ 0.1 to z ~ 2.5 in quantitative agreement with ΛCDM predictions. The statistical properties of large-scale structure — the matter power spectrum, the abundance of galaxy clusters as a function of mass and redshift, and the topology of voids — are all reproduced by N-body simulations initialized with Gaussian random perturbations and evolved under cold dark matter gravity. These are genuine successes, and any alternative cosmological framework must account for them. The companion paper to this work (Nipok 2026) addresses specifically how Successive Collision Theory reproduces the CMB power spectrum at Planck precision through a Plasma Equivalence Theorem that is independent of plasma origin. The present paper focuses on a distinct and more specific domain: the angular momentum and rotational orientation of gravitationally bound structures, from dwarf satellite galaxies to radio-loud quasars, across seven orders of magnitude in physical scale.

It is in this domain that the ΛCDM framework faces a class of observational tensions that are qualitatively different from better-known challenges such as the Hubble tension or the S8 discrepancy. Those tensions are quantitative — they concern the precise values of parameters within an otherwise functioning framework. The angular momentum alignment problem is structural: the observed co-rotation and orientation coherence of astrophysical structures at multiple scales cannot be reproduced by any ΛCDM-based simulation, regardless of resolution or baryonic physics treatment, because the failure lies not in the dynamics but in the initial conditions. ΛCDM begins with Gaussian random density perturbations in which the phases of different Fourier modes are statistically independent. A consequence of statistical isotropy is that there is no preferred angular-momentum axis at any scale: the spins of structures at widely separated locations are uncorrelated beyond the reach of local tidal fields, which quantitative estimates place at roughly 15–50 Mpc depending on the observable (Schäfer 2009). At scales substantially larger than this, ΛCDM predicts that rotational orientations should be effectively random. This is not a failure of the simulations — it is a prediction of the theory's initial conditions. No increase in computational resolution will insert angular-momentum correlations that the initial conditions do not contain.

The observational record at every scale above a few megaparsecs contradicts this prediction. Satellite galaxies of the Milky Way, Andromeda, and Centaurus A are distributed in thin, coherently rotating planes; the statistical significance of the co-rotation in M31 reaches 99.998% (Ibata et al. 2013), yet such configurations arise in fewer than 0.5% of ΛCDM simulations. Brightest cluster galaxies (BCGs) are preferentially aligned with their host cluster major axes at better than one-in-a-million significance, and this alignment is fully established at redshifts $z > 1.3$ — when the universe was less than 4.5 Gyr old — making gradual tidal reorientation an implausible mechanism (West et al. 2017). Galaxy clusters exhibit coherent bulk rotation whose spin axes orient perpendicular to the nearest cosmic filament, with cluster–cluster orientation coherence measured out to 200–300 Mpc (Tang et al. 2025; Binggeli 1982), an order of magnitude beyond the ΛCDM coherence limit. At the largest probed scales, radio-loud quasars exhibit coherent jet and polarization-vector alignments over ~1 Gpc baselines (Hutsemékers et al. 1998, 2014; Mandarakas et al. 2021), 30–50 times larger than tidal-torque theory can reach.

Bridging these extremes, Tudorache et al. (2025) recently reported the first direct detection of bulk angular momentum in an individual cosmic filament, using MeerKAT 21-cm HI spectroscopy to measure a coherent velocity gradient consistent with solid-body rotation at ~110 km/s in a chain of 14 galaxies spanning ~1.7 Mpc, embedded within a much larger ~15 Mpc optical filament containing over 280 galaxies. The galaxy spin axes within this structure are aligned with the filament spine more strongly than IllustrisTNG reproduces for comparable configurations. This result reframes the statistical tendency for galaxies within filaments to share spin orientations from a population correlation into a physically grounded picture in which the filament itself carries coherent angular momentum that is then inherited by objects condensing within it.

This paper develops the observational case for this multi-scale hierarchy and examines whether a single physical mechanism can account for it. We propose and evaluate Successive Collision Theory (SCT) as a collision-based alternative framework in which large-scale structure forms not from the gravitational amplification of Gaussian random perturbations but from the debris of successive collisions between nested comoving structures. In SCT, each collision is characterized by an orbital angular momentum $J = \mu(b \times v_{rel})$, where μ is the reduced mass of the colliding system, b is the impact-parameter vector, and v_{rel} is their relative velocity. This single vector simultaneously fixes the geometric plane into which collision debris is distributed and the rotational sense of all structures that subsequently condense from that plasma. Because J is established at the moment of collision as a boundary condition on the initial conditions of structure formation — not as a late-time emergent property — the co-planarity and co-rotation of descendant structures are inseparably linked from the outset. We argue that this mechanism provides a physically motivated common cause for the observed multi-scale alignment hierarchy.

The paper is organized as follows. Section 2 surveys co-rotating satellite planes around the Milky Way, Andromeda, Centaurus A, and a growing census of more distant hosts. Section 3 examines galaxy cluster orientation, BCG alignment, and recently confirmed coherent bulk cluster rotation (Tang et al. 2025). Section 4 reviews quasar polarization and radio-jet alignments over gigaparsec baselines. Section 5 presents the filament scale, including the direct detection of bulk filament rotation (Tudorache et al. 2025). Section 6 develops the unified SCT mechanism. Section 7 presents six falsifiable predictions. Sections 8 and 9 provide discussion and conclusions.

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2. CO-ROTATING SATELLITE PLANES: THE OBSERVATIONAL CENSUS

The satellite plane problem has been framed, in much of the literature, primarily as a geometric puzzle: why do dwarf companions of large spiral galaxies distribute themselves in thin, flattened configurations rather than the roughly isotropic swarms predicted by ΛCDM subhalo populations? The more fundamental challenge, however, is kinematic. In every system where sufficient satellite velocities have been measured, the satellites do not merely inhabit a common plane — they orbit within it in the same rotational sense. 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. A rotationally coherent satellite plane requires that the angular momenta of its members be correlated — that they share not merely a geometric locus but a dynamical history. This is the constraint that ΛCDM has no mechanism to satisfy at the observed frequency. SCT predicts exactly this outcome: when a host and its companions condense from the same rotating debris field, inheriting the same collision-defined angular-momentum axis, co-planarity and co-rotation are linked from the outset as two expressions of the same initial condition.

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 disk — the Vast Polar Structure (VPOS; Pawlowski, Pflamm-Altenburg & Kroupa 2012). The plane is remarkable for its thinness: a root-mean-square height of roughly 20 kpc against a diameter exceeding 250 kpc. Proper motion measurements — first with the Hubble Space Telescope and subsequently refined with Gaia DR2 (Helmi et al. 2018) — 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 ΛCDM simulations — requiring simultaneously the correct geometry, thickness, diameter, and co-rotation fraction — is at or below 0.1% (Pawlowski & Kroupa 2020).

An important challenge to this picture was raised by Sawala et al. (2023), who applied Gaia proper motions to a reanalysis of the VPOS and argued that orbital pole clustering of the observed degree is more common in ΛCDM simulations than previously reported. Pawlowski & Kroupa (2020) and Pawlowski (2021) have demonstrated that the tension is substantially stronger when the full set of observational constraints — plane geometry, membership fraction, and kinematic coherence — is applied simultaneously. When these simultaneous constraints are applied to large simulation suites, the frequency of VPOS-like configurations remains at or below 0.1%. We conclude that the VPOS tension remains statistically significant under the most conservative analyses, though its precise magnitude is debated.

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 — approximately 15 of 27 satellites with available radial velocities — and reported a co-rotation signal significant at the 99.998% level, corresponding to a chance-occurrence probability 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, fewer than 0.04% of host galaxies display comparably extreme configurations. Two independent co-rotating satellite planes in the same galaxy group reduces the probability that ΛCDM stochastic processes are responsible, multiplicatively.

2.3 Centaurus A (NGC 5128)

Müller et al. (2018), publishing in Science, demonstrated that 14 of 16 Centaurus A satellites with available radial velocities follow a coherent velocity pattern consistent with co-rotation — a signal that, in ΛCDM simulations, arises in fewer than 0.5% of cases. Subsequent membership analysis by Kanehisa et al. (2023) extended the census to find that up to 21 of 28 potential satellites may be co-rotating. The Centaurus A result rules out the possibility that co-rotating satellite planes are a peculiarity of the Local Group environment.

2.4 Beyond the Local Volume

Pawlowski, Ibata & Bullock (2017), using photometric and spectroscopic data from the SDSS and the Subaru Hyper Suprime-Cam survey, identified kinematically coherent velocity patterns consistent with co-rotation in the satellite systems of two interacting galaxy pairs at approximately 40 Mpc: NGC 4490/NGC 4485 and NGC 2750. Most recently, Jerjen et al. (2025) reported that the interacting pair NGC 5713/5719 hosts a satellite system in which 12 of 14 members with measured line-of-sight velocities follow a coherent pattern consistent with co-rotation. The Jerjen et al. analysis finds the most consistent explanation to be the infall of two satellite systems following their host galaxies along the Boötes Strip filament — a mechanism that SCT treats as the small-scale expression of the same collision-defined angular-momentum inheritance operating at all larger scales. This is the first case in which a kinematically coherent satellite system is directly observed in formation during an ongoing galaxy merger.

2.5 Detection Rate and Combined Significance

Co-rotation is confirmed in every system where sufficient kinematic data exist for a meaningful test. The honest characterization is that the literature contains no published counter-example in which co-rotation was specifically tested with adequate sample size and rejected. With this caveat stated, the combined statistical weight is extremely large. Taking each system individually at a ΛCDM probability of approximately 0.5% and assuming independence, the joint probability is $P\_joint = (0.005)^6 \approx 2 \times 10^{-14}$. Even applying a generous look-elsewhere correction of a factor of ten, the corrected joint probability remains below 10^{-12}.

Table 1. Co-rotating satellite plane census as of early 2026.

System	Co-rotating / Total	Significance	ΛCDM Probability	Instrument	Reference
Milky Way (VPOS)	7–9 of 11	High; debated	≤ 0.1%	HST, Gaia DR2	Pawlowski & Kroupa (2020); Sawala et al. (2023)
M31 (GPoA)	~15 of 27	99.998% (1 in 50,000)	< 0.04%	WHT/ISIS, Keck/DEIMOS	Ibata et al. (2013)
Centaurus A	14–21 of 16–28	High (≥ 99.5%)	< 0.5%	VLT/MUSE, ESO/2.2m	Müller et al. (2018); Kanehisa et al. (2023)

System	Co-rotating / Total	Significance	ΛCDM Probability	Instrument	Reference
NGC 4490/4485	Detected	First extragalactic case	< 0.5%	SDSS, Subaru HSC	Pawlowski, Ibata & Bullock (2017)
NGC 2750	Detected	Confirmed	< 0.5%	SDSS, Subaru HSC	Pawlowski, Ibata & Bullock (2017)
NGC 5713/5719	12 of 14	Caught forming	< 0.5%	VLT, AAT	Jerjen et al. (2025)

ΛCDM probabilities reflect co-rotation alone; simultaneous geometric constraints (plane thinness, diameter, membership fraction) reduce the probability further in multi-constraint analyses. The VPOS kinematic significance is debated — see Section 2.1.

2.6 SCT Interpretation

SCT predicts all three layers of the satellite co-rotation problem from a single mechanism. A collision imprints a preferred angular-momentum axis $J = \mu(b \times v_{rel})$ on the debris field from which the host and its companions form. The geometry of the collision determines both the plane of debris distribution and the rotational sense within it. Objects condensing from this debris share the plane because they formed from a common sheet of material, and share the rotational sense because that material carried a common angular momentum. The universality of the phenomenon across host types is consistent with the universality of the collision mechanism, which depends on collision geometry, not host morphology.

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3. GALAXY CLUSTER ORIENTATION, BCG ALIGNMENT, AND COHERENT CLUSTER SPIN

3.1 The Binggeli Effect: Cluster–Cluster Orientation Alignment

The tendency for galaxy clusters to align their major axes with the direction toward neighboring clusters was first reported by Binggeli (1982) and has been confirmed in every subsequent large-scale study. The signal has been confirmed across multiple observational channels, appearing in both optically selected cluster catalogs and X-ray morphology analyses (Chambers, Melott & Miller 2002; Paz et al. 2011). The coherence scale is the decisive point of tension with ΛCDM: N-body simulations produce statistically significant cluster–cluster shape alignments only out to separations of roughly 15–30 h^{-1} Mpc, whereas the observed signal extends to 200–300 Mpc — roughly an order of magnitude beyond the ΛCDM coherence length. The persistence of the signal to $z \sim 1$ — where clusters were already preferentially oriented relative to their neighbors — is the opposite of what late-time tidal assembly predicts.

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

Smith et al. (2023) reported BCG alignment significances of one-in-a-million or better when BCG position angles are compared simultaneously with the cluster member distribution and the orientation of the nearest large-scale structure filament segment, using a sample of more than 200 clusters. Multi-wavelength confirmation is provided by Hashimoto et al. (2008), who paired Chandra X-ray cluster morphologies with Subaru optical BCG position angles and found consistent alignment.

The temporal dimension of the BCG–cluster alignment is the most constraining single datum in this section. West et al. (2017) used Hubble Space Telescope imaging of 65 distant galaxy clusters to measure BCG alignment at redshifts exceeding $z = 1.3$. At this epoch the universe was approximately 4.3 Gyr old — less than one-third its present age. The BCG alignments at $z > 1.3$ are as strong as, and in some subsamples stronger than, the local alignments measured in low-redshift surveys. Tidal reorientation of a massive galaxy within its cluster potential operates on dynamical friction timescales of many gigayears; at $z > 1.3$ there is simply insufficient time for a gradual tidal mechanism to have produced the observed full alignment. The alignment must have been set very early, as an initial condition rather than as a dynamically assembled outcome.

3.3 Coherent Cluster Spin

Tang et al. (2025) analyzed samples of 2,170 and 1,329 spectroscopically confirmed galaxy clusters with masses $M > 10^{14}$ solar masses, drawn from SDSS and BOSS redshift surveys. The technique exploits the statistical distribution of maximum line-of-sight velocity differences between galaxy subsets on opposite sides of a projected rotation axis. The aggregate significance exceeds 100σ across the stacked sample. Detected rotation velocities show a clear mass dependence: clusters at 10^{14} solar masses rotate at approximately 360 km/s, rising to roughly 693 km/s at 10^{15} solar masses. Cluster spin axes are preferentially parallel to the spin of the central BCG, with the correlation strengthening in richer clusters, and are preferentially perpendicular to the orientation of the nearest cosmic filament. Manolopoulou & Plionis (2017) found statistically significant rotation in approximately 23% of Abell clusters, with detection rate and significance both correlating with dynamically younger, less-relaxed systems — the opposite of what tidal-torque assembly predicts.

3.4 A Theoretical Complication: Component Spin Misalignment

Barnes et al. (2017), using hydrodynamic simulations of massive clusters, demonstrated that the spin vectors of the dark matter halo, the galaxy population, and the intracluster medium can be mutually misaligned within the same cluster. This complication does not invalidate the Tang et al. (2025) or Manolopoulou & Plionis (2017) results, which aggregate over large samples. It does caution against interpreting any single-cluster rotation measurement as a clean recovery of the inherited J-vector.

Table 2. Cluster-scale alignment and co-rotation observations compared with ΛCDM tidal-torque predictions.

Phenomenon	What Is Observed	ΛCDM Prediction	Tension Level
Cluster–cluster orientation (Binggeli effect)	Correlated to 200–300 Mpc; confirmed in X-ray and optical; signal as strong at z~1 as z~0	Significant only to ~15–30 h^{-1} Mpc; signal should weaken at high z	**STRONG — coherence length exceeded by ~10×; wrong redshift trend**
BCG–cluster shape alignment	< 1-in-1,000,000 significance; fully established at z > 1.3; multi-wavelength confirmed	Gradual tidal reorientation over many Gyr; should be weaker at high z	**STRONG — alignment in place before tidal mechanism can operate**
BCG–cluster spin alignment	Statistically confirmed; strengthens with cluster richness; parallels shape result	Qualitatively expected from TTT; amplitude and richness dependence not reproduced	**STRONG — richness scaling and amplitude not reproduced by TTT**
Cluster spin ⊥ filament	Confirmed statistically; ~2,000 clusters (Tang et al. 2025)	Qualitatively consistent with TTT; amplitude underpredicted	**MODERATE–STRONG — links cluster spin to filament J-axis**
Cluster rotation speed vs. mass	360–693 km/s over 10^{14}–10^{15} solar masses; statistical proxy (Tang et al. 2025)	No quantitative ΛCDM mass–rotation scaling predicted	**MODERATE — mass scaling implies J proportional to collision energy**
Rotation in dynamically young clusters	~23% of Abell clusters; signal	TTT predicts stronger signal in older, more relaxed systems	**MODERATE — environment dependence**

Phenomenon	What Is Observed	ΛCDM Prediction	Tension Level
	stronger in less-relaxed systems		**reversed relative to TTT prediction**

TTT = tidal torque theory; BCG = brightest cluster galaxy. The most severe tensions are the 200–300 Mpc coherence of the Binggeli effect and the full establishment of BCG–cluster alignment at z > 1.3, both of which require angular momentum set as an initial condition rather than assembled by late-time tidal torques.

3.5 SCT Interpretation

The collision forming the parent filament set a preferred J-vector as a boundary condition for the entire structure at the formation epoch. Clusters condensing at nodes along this structure inherited the J-vector, spinning up perpendicular to the filament spine and aligning their elongated mass distributions with the filament axis. Their BCGs grew at the potential minima of those clusters, inheriting the same J-vector and aligning in both shape and spin. The high-redshift persistence of BCG alignment reflects the fact that the alignment was established at formation and has been progressively degraded, not assembled, over the subsequent ten billion years.

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4. QUASAR POLARIZATION AND RADIO AXIS ALIGNMENTS

4.1 Discovery and Statistical Foundation: The Hutsemékers Effect

Hutsemékers (1998) first reported that the optical linear polarization vectors of quasars in a defined sky region are not isotropically distributed but cluster around preferred orientations on coherence scales of order 1 Gpc. The initial sample of 170 quasars yielded a statistically significant signal that was subsequently strengthened as the sample grew to 355 objects in Hutsemékers et al. (2005), with the probability of the alignment arising by chance falling below 0.1% under two independent statistical tests applied both with and without parallel-transport corrections. The signal grows with sample size rather than diluting, ruling out domination by a small number of outliers.

Several properties of the Hutsemékers effect rule out mundane contamination explanations. Instrumental polarization at the telescopes used is measured below 0.1%. Interstellar polarization from Galactic dust cannot produce the redshift-dependent pattern: if Galactic dust were responsible, every redshift slice would exhibit the same polarization pattern. The observations show instead that the alignment pattern varies with redshift, with the mean polarization angle rotating at a rate of roughly 30° per Gpc. The signal is therefore intrinsic to the quasar population.

4.2 Quasar Spin Axes Aligned with Host Large-Scale Structure

Hutsemékers et al. (2014) measured polarization of 93 quasars belonging to Gpc-scale large quasar groups (LQGs) at redshifts near z ~ 1.3, finding that polarization vectors are preferentially either parallel or perpendicular to the major axes of their host structures at a probability of random occurrence of approximately 1%. Interpreting both cases through the inclination geometry of the quasar accretion disk, the consistent implication is that the spin axes of the central supermassive black holes are preferentially parallel to the major axes of their host LQGs. Pelgrims & Hutsemékers (2016) provided independent radio-wavelength confirmation: for LQGs with more than 20 members, radio polarization vectors are preferentially perpendicular to the LQG major axis at confidence exceeding 99%.

4.3 Direct Radio Jet Alignments

Radio jet morphology provides a more direct measurement of AGN spin-axis orientation than polarization-based inference. Multiple surveys have now established coherent jet alignment across a range of angular scales: Taylor & Jagannathan (2016) at ~30 Mpc using the GMRT; Contigiani et al. (2017) confirming two-dimensional alignments at ~30 Mpc and three-dimensional alignments extending to 640 Mpc using FIRST; Osinga et al. (2020) detecting alignments at ~100 Mpc in the LoTSS low-frequency survey; and, most significantly, VLBI observations by Blinov et al. (2020) and Mandarakas et al. (2021) establishing three-dimensional jet alignments at separations of 400–900 Mpc with no projection ambiguity.

Table 3. Radio jet and polarization alignment surveys establishing coherent quasar spin-axis orientations from ~30 Mpc to ~900 Mpc.

Survey	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 — no projection ambiguity	400–900 Mpc	> 99.5%	Blinov et al. (2020); Mandarakas et al. (2021)

Survey	Method	Scale	Significance	Reference
JVAS/CLASS (VLA), 8.4 GHz	Radio polarization vs. LQG major axis	Gpc-scale LQGs	> 99% (LQGs with > 20 members)	Pelgrims & Hutsemékers (2016)
Optical surveys (multiple), V/R band	Quasar optical polarization coherence	~1 Gpc coherence	< 0.1% chance of being random	Hutsemékers et al. (1998, 2005)

VLBI measurements are particularly constraining as they deliver three-dimensional jet orientations with no projection ambiguity and no polarization-mechanism assumptions.

4.4 Alternative Explanations and Why They Fall Short

The scale of the quasar alignment signal substantially exceeds what tidal torque theory can reach. Quantitative estimates place the maximum coherence length of TTT-driven spin alignments at approximately 30–50 Mpc (Schäfer 2009); the VLBI detections exceed this by a factor of 10–20. Photon–pseudoscalar mixing is largely ruled out by the absence of the predicted circular polarization signal. Primordial large-scale magnetic fields require field coherence lengths and amplitudes not well motivated by early-universe physics. Cosmological birefringence predicts a polarization rotation uniform across the sky at fixed redshift — the Hutsemékers effect is sky-position-dependent, not uniform, so birefringence does not constitute a complete explanation. None of these alternatives simultaneously accounts for the ~1 Gpc optical polarization coherence, the 400–900 Mpc VLBI jet alignments, the redshift dependence of the alignment angle, and the richness dependence of the LQG-alignment signal.

4.5 SCT Interpretation

Within the SCT framework, the quasar alignment signal represents the largest-scale manifestation of the same angular momentum inheritance mechanism responsible for satellite co-rotation planes and cluster orientation alignments. The J-vector of the most energetically dominant large-scale collision in our observable region is deposited as a preferred axis across the full spatial extent of the resulting debris field. Every filament, cluster, galaxy, and supermassive black hole that subsequently condenses within this field inherits — through the step-by-step conservation chain — a spin-axis orientation that reflects the original collision's J. The richness dependence of the alignment signal — stronger in more populated LQGs — is consistent with this picture: larger, more populated structures formed from more energetic and better-geometrically-defined collision events, whose J-vectors are larger in magnitude and more precisely defined.

5. THE FILAMENT SCALE

The cosmic filament occupies the pivotal position in the angular momentum hierarchy developed in this paper. It is the structural link between the gigaparsec-scale anomalies of Section 4 and the cluster- and satellite-scale co-rotation phenomena of Sections 2 and 3. If filaments themselves carry coherent bulk angular momentum — set at their formation epoch and inherited by every structure condensing within them — then the contents of any given filament are siblings in the same sense as satellite galaxies around a host: they share a common rotational history, and their aligned spins are a downstream consequence of the filament's own angular-momentum budget.

5.1 Kinematic Predictions: Filament Morphology from Collision Parameters

Within the SCT framework, every cosmic filament is the structural relic of a collision between two large-scale nested comoving structures. SCT makes the following kinematic prediction: 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 debris distributions. In the limit of a grazing encounter with large impact parameter, most of the kinetic energy is retained as angular momentum, and the resulting structure is a rotating sheet or wall rather than a thin strand. In the limit of a nearly head-on collision, the kinetic energy is converted primarily to heat and the result is an isotropic, roughly spherical node.

5.2 The Superluminal Velocity Postulate

The SCT picture of large-scale structure formation rests on a foundational postulate: the nested comoving reference frames of SCT are permitted to move relative to one another, in the global parent frame, at velocities exceeding c. This is a foundational postulate of the theory, not a derivable consequence of General Relativity as currently formulated, and is stated explicitly as such. Its motivation draws from a well-established feature of relativistic cosmology: metric expansion already permits recession velocities exceeding c between causally disconnected regions of our own universe (Davis & Lineweaver 2004). SCT extends this accepted reasoning to collisions between independently formed pockets. A rigorous mathematical derivation from an appropriate extension of the Einstein field equations is identified in Section 6.7 as the first priority for future theoretical development.

5.3 The Collision Medium and Large-Scale Angular Momentum Coherence

A critical property of the SCT collision that directly explains the observed angular momentum coherence scales is the spatial extent of the interpenetrating plasma. When two large-scale nested comoving frames collide, their constituent matter interacts across the entire overlap region of the two colliding structures. Every parcel of plasma within this region acquires a velocity component consistent with the net J-vector of the encounter. The result is that the angular momentum axis established by the collision is coherent across the full spatial extent of the collision debris, which may extend over hundreds of megaparsecs or more. It is this global spatial coherence of the J-vector — established at the collision epoch as a boundary condition — that explains why filaments, and the galaxies and clusters within them, share coherent angular momentum over the scales observed in Sections 3 and 4, scales that no tidal torque mechanism can reproduce.

5.4 Multi-Generation Collisions and the Dominant J-Vector

The cosmic web is the product of a hierarchy of nested collision events. Each subsequent collision resets the J-vector locally, imprinting a new preferred axis on the subregion within which it operates, while the larger-scale angular momentum inherited from the parent collision persists across the entire original debris field. The result is a nested hierarchy of J-vectors: a dominant, large-scale J-vector set by the most energetically significant collision in the formation history of a given large-scale structure, plus a series of progressively smaller, local J-vectors set by subsequent collisions within subregions. The dominant J-vector is readable across the largest observable scales, in the filament orientations, cluster alignment patterns, and quasar axis preferences documented in Sections 2–4.

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

In the SCT picture, the angular momentum of a cosmic filament shows a hierarchical structure that mirrors the hierarchy of collision events from which the filament formed. Where a sub-dominant secondary collision deposited material along a branch direction — producing a secondary filament or 'tentacle' departing from the main strand — the angular momentum axis of that sub-filament reflects the J-vector of the secondary collision, which is generically misaligned with the dominant J-vector of the parent strand. At the branch point, the angular momentum field is expected to show a rapid transition — an 'eddy' — between the two competing J-vectors, with elevated scatter in galaxy spin orientations relative to the smooth regions of the parent strand. This prediction is stated formally as Prediction 2 in Section 7.

5.6 Galaxy Spin–Filament Alignment: Observations and Discriminating Power

Statistical surveys using SDSS, COSMOS, and related catalogs have established a robust, mass-dependent pattern in the alignment of galaxy spin axes with their host filament spines. Low-mass, late-type galaxies preferentially align their spin axes parallel to the filament spine. More massive, earlier-type galaxies tend toward perpendicular alignment, with the transition occurring at a characteristic mass scale of approximately $10^{10.5}$ solar masses (Codis et al. 2018; Welker et al. 2020). The IllustrisTNG cosmological simulation suite reproduces this spin-flip qualitatively. 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 with the standard model.

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

Tudorache et al. (2025) provided the first direct detection of coherent bulk angular momentum in an individual cosmic filament. Using MeerKAT HI 21-cm observations from the MIGHTEE survey combined with optical data from DESI and SDSS, they resolved the kinematic structure of a filament consisting of 14 HI-selected galaxies in a chain spanning approximately 1.7 Mpc, embedded within a much larger cosmic filament of ~15 Mpc traced by optical galaxies. The velocity gradient across the HI chain is consistent with solid-body rotation at approximately 110 km/s. The spin axes of the member galaxies are aligned with the filament spine ($\langle|\cos\psi|\rangle = 0.64 \pm 0.05$) at a strength that exceeds the predictions of IllustrisTNG by an amplitude that cannot be accounted for by resolution uncertainty or sub-grid physics variations within reasonable parameter ranges. This result demonstrates that an individual filament is a rotating dynamical object whose bulk angular momentum is coherent over megaparsec scales and is actively transmitted to the galaxies condensing within it.

Table 4. Filament-scale observations and SCT predictions compared with ΛCDM and IllustrisTNG.

#	Observation	ΛCDM / IllustrisTNG	SCT Prediction	Status
1	Galaxy spin parallel to filament (low-mass, late-type)	Qualitative match; amplitude underpredicted	Parallel alignment from J inheritance	**Confirmed tension (amplitude)**
2	Galaxy spin perpendicular to	Qualitative match; amplitude underpredicted	Perpendicular for massive siblings with high J-transfer	**Confirmed tension (amplitude)**

#	Observation	ΛCDM / IllustrisTNG	SCT Prediction	Status
	filament (high-mass, early-type)			
3	Mass-dependent spin-flip at ~$10^{10.5}$ solar masses	Reproduced qualitatively by IllustrisTNG	Predicted from mass-dependent J partitioning	Not discriminating — both frameworks match qualitatively
4	Vortical velocity excess around filaments (Wang et al. 2021)	Not reproduced at observed amplitude	Natural consequence of filament bulk J	**Confirmed tension**
5	Direct bulk rotation at ~110 km/s in 1.7 Mpc HI chain; full filament ~15 Mpc; spin alignment exceeds IllustrisTNG (Tudorache et al. 2025)	Not reproduced; IllustrisTNG amplitude exceeded beyond parameter uncertainty	Direct prediction: filament carries bulk J from formative collision	**Confirmed tension (single detection; population-level confirmation needed)**
6	Filament length/width diversity correlates with collision parameters	Not specifically predicted	Relative velocity governs length; mass ratio governs width	SCT prediction only — untested
7	Branch-point spin disorder; sub-filament spin diverges from main strand	Not predicted	Eddy instability at competing J-vectors (Prediction 2, Sec. 7)	SCT prediction only — speculative
8	Alignment strength decreases from main strand to sub-filaments	Not predicted	Hierarchical J inheritance	SCT prediction only — speculative

Rows 1–5 represent confirmed observational results for which a statistically significant tension with the standard model exists. Rows 6–8 are SCT theoretical predictions that have not yet been systematically tested against observational data and should not be read as evidence for SCT.

5.8 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. At the filament scale, Tudorache et al. (2025) have closed this 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, and where the chain connecting satellite co-rotation at kiloparsec scales to quasar axis coherence at gigaparsec scales can be identified as a single physical process.

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6. THE UNIFIED SCT COLLISION-GEOMETRY MECHANISM

6.1 The Organizing Equation: J = μ(b × v_rel)

The fundamental equation of the SCT collision mechanism is:

$$J = \mu(b \times v_{rel})$$

where μ is the reduced mass of the two colliding comoving structures, b is the impact-parameter vector between their centers of mass, and v_rel is their relative velocity in the global parent frame at the moment of contact. This equation simultaneously determines three properties of the resulting debris field: its magnitude (set by the product |μ||b||v_rel|), its direction (the axis about which the debris rotates, perpendicular to the plane containing b and v_rel), and the sense of rotation (determined by the sign of b × v_rel).

For an order-of-magnitude estimate: a collision producing a filament of ~100 Mpc length, with colliding structures each of mass ~10^{17} solar masses, a reduced mass of ~5×10^{16} solar masses, an impact parameter of ~10 Mpc, and a relative velocity of ~3c, yields $|J| \sim 3 \times 10^{79}$ kg m^2 s^{-1}. For comparison, the angular momentum of a galaxy cluster is roughly 10^{73}–10^{75} kg m^2 s^{-1}, and a filament of ~100 Mpc length containing thousands of clusters requires a total angular momentum budget of order 10^{76}–10^{78} kg m^2 s^{-1}. This order-of-magnitude consistency demonstrates that the equation can, in principle, account for the angular momentum budgets required by the observations.

6.2 Why ΛCDM Cannot Replicate the Signal: A Structural Failure

In ΛCDM, angular momentum arises through tidal torques: as proto-halos collapse, misalignments between their inertia tensors and the local tidal field generate spins. This mechanism is stochastic by construction. The tidal field at any point is sourced by the density field within the local causal horizon, and the resulting spin directions are effectively random beyond the tidal coherence length. The observations do not merely show a stronger-than-expected signal; they show a signal of a fundamentally different character. Co-planarity and co-rotation that are entangled — where the geometric arrangement of objects predicts their rotational sense — cannot arise from an ensemble of independently torqued halos, regardless of the strength of the tidal field. The failure is in the initial conditions themselves, and no perturbative modification to ΛCDM can remedy it without changing the character of those conditions fundamentally.

6.3 Scale-by-Scale Application of J = μ(b × v_rel)

SATELLITE PLANES: At the satellite scale, the collision involved structures of order 10^{12} solar masses with impact parameters of order tens to hundreds of kpc and infall velocities of order hundreds to thousands of km/s. The resulting J-vector fixed the orbital plane and rotational sense of the debris from which the satellite galaxy population formed. ΛCDM tidal torques produce co-rotating satellite planes in fewer than 0.5% of simulated hosts — roughly 200 times less frequently than observed.

GALAXY CLUSTERS: At the cluster scale, the formative collision involved structures of order 10^{14}–10^{15} solar masses with impact parameters of order Mpc. ΛCDM produces BCG–cluster alignment at comparable angular scales, but only through gradual tidal reorientation over several Gyr — a timescale inconsistent with the full alignment observed at $z > 1.3$. The ΛCDM tidal coherence length for cluster shape alignments is ~15–30 h^{-1} Mpc; the observed alignment persists to 200–300 Mpc, a factor of ~10 beyond this limit.

COSMIC FILAMENTS: At the filament scale, the resulting J-vector defines both the filament's elongation axis and its bulk angular momentum, inherited by every galaxy and cluster condensing within it. ΛCDM tidal torques generate spin–filament correlations up to scales of ~30–50 Mpc; the observed signal in Wang et al. (2021) and Tudorache et al. (2025) exceeds IllustrisTNG predictions in amplitude at all scales tested.

QUASAR AXES: At the largest scale, the formative collision set the preferred axis for supermassive black hole spin orientations across the full spatial extent of the collision debris — observed as the ~1 Gpc Hutsemékers polarization coherence and the 400–900 Mpc VLBI jet alignments. ΛCDM tidal torques predict no coherence on these scales.

6.4 The Conservation Chain: Angular Momentum Inheritance Without Long-Range Forces

The scale-by-scale application raises an immediate question: how does angular momentum set at the filament or quasar scale propagate down to the satellite plane scale? The answer in SCT does not require any long-range force or exotic communication. It requires only local conservation of angular momentum acting through a chain of physically connected formation events. The formative collision sets J_filament for the entire debris volume. As the filament collapses and fragments, each proto-cluster condensing at a density node inherits a fraction of J_filament through the angular momentum of the rotating matter that accretes onto it. Within the cluster, the BCG forms at the potential minimum, accreting the highest-specific-angular-momentum material first. At no point is action at a distance required. The hierarchy is maintained by local angular momentum conservation at each generational handoff, exactly as angular momentum is conserved in the collapse of a molecular cloud into a stellar system.

6.5 Dark Matter and Dark Energy: Qualitative Reinterpretations

SCT offers qualitative reinterpretations of both dark energy and dark matter within its nested-comoving-frame picture. Dark energy, in this view, is a manifestation of the gradual dissipation of the overlapping gravitational wells of a nested succession of parent comoving frames — a process that observers at our scale would interpret as an accelerating metric expansion. Dark matter reflects cooperative gravitational effects among coherently moving baryonic structures within a comoving frame, rather than a new particle species. Both reinterpretations require formal modifications to the Einstein field equations — specifically, a modified stress-energy tensor that accommodates nested comoving frame contributions — that have not yet been derived. These are identified as priority directions for future theoretical development.

6.6 The Complete Hierarchy and the Scale-Invariant Follow-the-Leader Principle

The four-sector application of J = μ(b × v_rel) establishes that the same equation, with physically appropriate parameters at each scale, accounts for the full observational record from satellite planes at sub-Mpc scales to quasar axes at Gpc scales. The equation does not change between scales, only its inputs. Every rung of the hierarchy from quasar to satellite is playing follow-the-leader to the rung above it, with the J-vector of each level set by the collision at that level and constrained by the J-vector inherited from the level above. The entire observational record — across seven orders of magnitude in spatial scale — is the multi-scale fossil record of this nested collision hierarchy.

Table 5. The angular momentum inheritance hierarchy: SCT vs. ΛCDM across all scales.

Scale	Collision Parameters (J = μ(b × v_rel))	Observed Coherence	ΛCDM Limit	Factor Beyond ΛCDM	Tension
Satellite planes	μ ~10^{12} M⊙; b ~tens of kpc; sub-light velocity	~0.25 Mpc diameter; 100% co-	~0.5–1 Mpc; co-rotation	~200× more frequent	**STRONG**

Scale	Collision Parameters (J = μ(b × v_rel))	Observed Coherence	ΛCDM Limit	Factor Beyond ΛCDM	Tension
		rotation frequency in all tested systems	~0.5% in simulations		
Galaxy cluster orientation	μ ~10^{14}–10^{15} M⊙; b ~Mpc; sub-light velocity	200–300 Mpc (Binggeli effect); BCG alignment fully established at z > 1.3	~15–30 h^{-1} Mpc; alignment grows with time	~10× beyond limit	**STRONG**
Filament rotation	μ ~10^{17} M⊙; b ~tens of Mpc; ~few × light speed	~15 Mpc individual filament (Tudorache et al. 2025); 10–100 Mpc population (Wang et al. 2021)	~30–50 Mpc (TTT spin–filament correlation)	Amplitude exceeds IllustrisTNG beyond uncertainty	**STRONG**
Quasar axis alignment	μ ~10^{18}–10^{20} M⊙; b ~hundreds of Mpc; substantially above light speed	~400–1,000 Mpc (VLBI jets; Hutsemékers polarization)	No TTT prediction; TTT maximum ~30–50 Mpc	~20–30× beyond TTT maximum	**STRONG**

For each scale, the table lists the approximate collision parameters, the observed coherence scale, the maximum ΛCDM tidal coherence length, and the factor by which observations exceed the ΛCDM limit. The filament row now correctly reflects both the 1.7 Mpc HI chain and the 15 Mpc optical filament of Tudorache et al. (2025).

6.7 Open Questions and Theoretical Priorities

PRIORITY 1: QUANTITATIVE ANGULAR MOMENTUM BUDGET DERIVATION. A rigorous quantitative derivation requires solving the full collision dynamics for two interpenetrating comoving frames. This means: (a) deriving the angular momentum partition function — what fraction of |J|_total is retained as bulk angular momentum versus dissipated as heat — as a function of the collision's grazing angle and mass ratio; (b) computing the radial profile of angular momentum density in the resulting debris field; and (c) propagating the angular momentum budget through the condensation hierarchy to derive predicted alignment amplitudes at the satellite, cluster, filament, and quasar scales for direct comparison with the amplitude discrepancies documented in Table 5.

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. The stress-energy tensor must be extended to account for the collective gravitational contribution of a population of objects sharing a comoving frame. Deriving the mathematical form of this modification and demonstrating that it reproduces the observed rotation curves and lensing signals currently attributed to dark matter is the second priority for future theoretical development.

PRIORITY 3: OBSERVATIONAL STRATEGY FOR DETERMINING COLLISION GENERATION NUMBER. An observational strategy for determining the generation number — whether our observable region was shaped by the second, fifth, or tenth collision in a local sequence — carries implications for the overall energy budget and for the predicted properties of CMB residuals. Searching for systematic misalignments between filament-scale and quasar-scale J-vectors that would indicate the angular momentum record of two distinct collision generations is identified as the third theoretical priority and a target for dedicated analysis with DESI and SKA data.

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7. SIX FALSIFIABLE PREDICTIONS

The observational case developed in Sections 2–5 establishes a pattern; the theoretical mechanism of Section 6 provides a causal account of it. The following six predictions follow directly from the SCT collision-geometry mechanism and are stated with explicit ΛCDM null hypotheses so that each can be confirmed or disconfirmed by identifiable observations with foreseeable instruments.

Predictions 1–3 are primary tests: if confirmed, they would provide strong positive evidence for collision-driven angular momentum inheritance over tidal-torque assembly, because the specific signal character predicted has no natural account in ΛCDM. Predictions 4–6 are secondary tests: their confirmation would be consistent with SCT, while their disconfirmation would constrain specific parameters of the SCT framework.

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

SCT predicts that cosmic filaments will display two morphologically distinct endpoint configurations reflecting two broad categories of collision geometry, and that the rotation amplitude and aspect ratio should correlate with which category a filament belongs to. CATEGORY A (two-node filaments): where a filament connects two well-defined overdensities, the bulk rotation amplitude should correlate with the mass ratio of the two endpoints — nearer-to-unity mass ratios correspond to more symmetric encounters, higher retained angular momentum per unit debris mass, and therefore higher rotation amplitude. CATEGORY B (fading-endpoint filaments): where a filament has one well-defined cluster anchor and fades diffusely into a void at the other end, the rotation amplitude is predicted to be lower, consistent with a more asymmetric collision that converted more kinetic energy to heat.

ΛCDM NULL HYPOTHESIS: In ΛCDM, no systematic relationship is predicted between a filament's endpoint configuration and its bulk rotation amplitude. A statistically significant difference in mean rotation amplitude between two-node and fading-endpoint filaments — at $> 2\sigma$ after controlling for filament length and large-scale environment — would not be expected under ΛCDM.

Prediction 2: Hierarchical Spin Alignment Along Filament Spine

Galaxy spin-axis coherence should be strongest along the main strand of a well-defined filament, measurably weaker in secondary branches departing from that strand, and most disordered at branch points where two collision-defined J-vectors intersect. ΛCDM NULL HYPOTHESIS: In ΛCDM, galaxy spin alignments with filaments arise from the local tidal field, which varies smoothly along and across a filament with no mechanism for specifically elevated disorder at topological branch points. CANDIDATE SYSTEMS: The Perseus-Pisces supercluster filament (~70–80 Mpc) and the Virgo infall region (~10–20 Mpc) both have sufficient angular resolution, galaxy sampling density, and existing redshift coverage. A dedicated cross-match of MaNGA/SAMI spin vectors with the branching topology of these filament catalogs would constitute the first test of this prediction with existing data.

Prediction 3: Satellite Plane Orientation Traces Host Filament Angular Momentum

The normal vector of a co-rotating satellite plane should be aligned with — or at a consistent angular offset from — the angular momentum axis of the filament hosting the parent galaxy. ΛCDM NULL HYPOTHESIS: In ΛCDM, satellite plane normals are determined by the host's local merger history with no systematic relationship to the host filament's angular momentum axis. 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, and the near-parallelism of the VPOS and GPoA normals is consistent with both inheriting a common filament-level J-vector. A sample of ~200 or more host galaxies with confirmed co-rotating satellite planes and resolved filament membership is needed for a statistically significant test; LSST/Rubin Observatory is expected to deliver this within its first three years of full survey operations.

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

Galaxy clusters residing within a common cosmic filament should show more strongly correlated spin orientations than clusters drawn from field environments or different filaments, with the correlation strength increasing with proximity to the filament spine and with filament mass. ΛCDM NULL HYPOTHESIS: In ΛCDM, cluster spin correlations arise from the local tidal field and decay approximately isotropically with separation, with no specific enhancement predicted for clusters sharing a filament membership. The Tang et al. (2025) sample of ~2,000 clusters provides the starting point; the test requires filament membership assignments from a spectroscopic redshift survey of comparable volume.

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

Quasars residing within the same large-scale wall or supercluster-scale structure as a population of galaxy clusters should have their polarization preferred axis consistent with the mean spin axis of the BCGs in those clusters. Both quasar spin axes and BCG spin axes were set by the same large-scale collision J-vector. ΛCDM NULL HYPOTHESIS: In ΛCDM, quasar spin axes and BCG spin axes are determined by independent processes on very different mass and spatial scales, with no predicted correlation beyond what would arise from weak shared tidal environment.

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

The SCT mechanism sets alignment signals as boundary conditions at the collision epoch and predicts that those signals are degraded — not assembled — over cosmic time. A direct and unique prediction follows: (a) BCG–cluster shape and spin alignment should be at least as strong at $z > 1.3$ as at $z \sim 0$; (b) within-filament galaxy spin coherence at $z \sim 1–1.5$ should equal or exceed the amplitude measured in local SDSS surveys; (c) cluster–cluster orientation coherence at $z \sim 1$ should not be shorter than at $z \sim 0$.

ΛCDM NULL HYPOTHESIS: In ΛCDM, all three signals arise through tidal torques that accumulate over cosmic time and should therefore be measurably weaker at high z, scaling approximately as the linear growth factor D(z), which falls by a factor of ~2 between $z = 0$ and $z = 1$, and ~4 by $z = 2$. INSTRUMENT: Euclid's cluster survey is expected to deliver well-characterized cluster shape and BCG morphology measurements to z ~ 1.5–2 for samples of 10^4 or more clusters.

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. The hierarchy is 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 ΛCDM tidal-torque mechanisms by a factor of 10 to 200. The observational conclusion is unambiguous: co-planarity and co-rotation are systematically entangled across the observable universe in a manner that ΛCDM'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 J = μ(b × v_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 — specifically, the fraction of the collision's kinetic energy that is partitioned into retained bulk angular momentum rather than heat. Without the angular momentum budget calculation identified as Priority 1 in Section 6.7, the predicted alignment amplitudes at each scale cannot be derived from first principles.

8.3 The Broader ΛCDM Tension Landscape

The co-rotation anomalies documented in this paper do not stand alone in the observational challenge to ΛCDM. The persistent Hubble tension — a ~5σ discrepancy between the locally measured and CMB-inferred values of H_0 — the S8 tension in the amplitude of matter fluctuations, and the unexpected abundance of massive, morphologically mature galaxies at z > 4 revealed by JWST all point to difficulties with the model'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 the co-rotation hierarchy and the large-scale alignment anomalies than ΛCDM is.

8.4 CMB Consistency

The most immediate objection to any alternative cosmological framework is whether it reproduces the CMB angular power spectrum. This objection 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, and those dynamics depend on the thermodynamic properties of that fluid rather than on the specific mechanism that created it. 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. The SCT framework therefore reproduces the observed CMB peak structure, peak ratios, and damping tail without modification.

8.5 Limitations of This Analysis

Three limitations of the present paper 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 at superluminal relative velocities is formally derived, the postulate remains a physically motivated hypothesis. This is the most significant theoretical gap in the SCT framework.

Second, the collision-generation sequence of our observable region is unknown. The predictions of Section 7 are formulated in terms of the most recent energetically dominant collision and are independent of generation number, but the generation number carries implications for the total energy budget and the properties of CMB residuals.

Third, while the amplitude discrepancies between observed alignment signals and ΛCDM 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 6.7 Priority 1 is the prerequisite for that demonstration, and the predictions of Section 7 should be understood as directional rather than precise until it is completed.

8.6 The Path Forward

The observational record assembled in this paper does not permit the conclusion that ΛCDM'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 ΛCDM's tidal reach to be plausibly accommodated by parameter adjustment within the standard framework. The six falsifiable predictions of Section 7 — testable with MeerKAT, DESI, Euclid, LSST, and VLBI survey programs already underway or imminent — provide the empirical path to that determination.

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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 six 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 EXISTS AND IS STATISTICALLY ROBUST. Satellite co-rotation planes, galaxy cluster orientation alignments, cosmic filament bulk rotation, and quasar spin-axis coherence together form a continuous angular momentum hierarchy spanning more than seven orders of magnitude in physical scale. Each sector is independently confirmed across multiple surveys, wavelengths, and statistical methods. The hierarchy is not a collection of marginal signals: satellite co-rotation is observed in all six systems tested against a ΛCDM expectation of ~0.5%; BCG–cluster alignment is established at one-in-a-million significance and fully in place at $z > 1.3$; cluster–cluster orientation coherence extends to 200–300 Mpc against a ΛCDM tidal limit of ~15–30 h^{-1} Mpc; filament bulk rotation is directly detected at ~110 km/s in an individual 1.7 Mpc HI structure embedded in a ~15 Mpc optical filament (Tudorache et al. 2025); and quasar spin-axis coherence extends to ~1 Gpc, 20–30 times beyond the maximum reach of tidal torque theory.

2. THE ΛCDM FAILURE IS STRUCTURAL, NOT NUMERICAL. The standard model fails to reproduce the co-rotation hierarchy not because its 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. No increase in simulation volume or particle count can remedy a failure of initial conditions.

3. SCT PROVIDES A UNIFIED CAUSAL MECHANISM. The equation $J = \mu(b \times v_{rel})$, 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. The framework applies the same equation across all five observational sectors.

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.

5. THREE THEORETICAL GAPS REMAIN OPEN. SCT does not yet provide: (a) a quantitative derivation of the angular momentum partition function; (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.

6. SIX FALSIFIABLE PREDICTIONS DEFINE THE EMPIRICAL TEST. Prediction 1 (filament rotation amplitude correlates with endpoint mass ratio) 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. Prediction 3 (satellite plane normals trace host filament J-vectors) requires the LSST/Rubin satellite census. 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 $z \sim 1.5$–2.

If Euclid finds that BCG alignment strength, within-filament spin coherence, and cluster orientation correlations at $z \sim 1.5$–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.

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DATA AVAILABILITY

This paper contains no original observational data. All datasets cited are available through the publications referenced herein. Readers seeking access to the MeerKAT/MIGHTEE HI data underlying Tudorache et al. (2025) should consult the published paper at https://doi.org/10.1093/mnras/staf2005.

CONFLICT OF INTEREST

The author declares no conflicts of interest.

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