# Strong Redshift Evolution of Non-Gaussian Vorticity in Galaxy Velocity Fields: Bispectral Evidence for Beyond-ΛCDM Physics from 2.8M SDSS Galaxies

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**Abstract**

**Problem:** The ΛCDM model predicts smooth structure evolution from Gaussian initial conditions. **Method:** Bispectral analysis of velocity dispersion (VDISP) in 2.8M SDSS DR17 galaxies using an open-source, corrected Rust/Python pipeline. **Finding:** The analysis reveals a non-Gaussian signal incompatible with ΛCDM at **6.99$\sigma$ (Scalene modes)**, characterized by a **10.00±0.69× increase in non-Gaussianity** between $z \sim 0.1$ and $z \sim 0.8$. **Interpretation:** This dramatic evolution is the signature of **primordial vorticity** in early cosmic plasma. **Implication:** Requires extension of ΛCDM with **primordial vector fields**.

## 1 Introduction: The Enigma of Early Galaxy Formation

### 1.1 Standard Cosmological Context

The ΛCDM model has been successful in describing large-scale structure, but faces tensions in early galaxy formation. Recent observations (JWST, ALMA) reveal massive galaxies at high redshift, challenging standard timescales.

### 1.2 The Role of Non-Gaussianity

While most studies focus on CMB non-Gaussianity or spatial distribution of galaxies, **non-Gaussianity in internal velocity fields (VDISP)** remains unexplored as a tracer of primordial physics.

## 1.3 Independent Research Approach

As an independent theoretical researcher, I employ open-source methodologies to:

- Avoid institutional biases
- Guarantee methodological transparency
- Accelerate discovery through reproducible code

# 2 Theoretical Framework: Bispectrum and Cosmic Vorticity

## 2.1 Non-Gaussian Field Statistics

For a fluctuation field $\delta(\mathbf{x})$, the bispectrum $B(k_1, k_2, k_3)$ is defined as:

$$B(k_1, k_2, k_3) = \langle \delta(\mathbf{k}_1)\delta(\mathbf{k}_2)\delta(\mathbf{k}_3) \rangle \tag{1}$$

In spherical space, we expand in spherical harmonics:

$$a_{lm} = \int \delta(\theta, \varphi) Y_{lm}^*(\theta, \varphi) d\Omega \tag{2}$$

## 2.2 Reduced Angular Bispectrum

The optimal bispectral estimator for incomplete maps:

$$B(l_1, l_2, l_3) = \sum_{m_1, m_2, m_3} \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} \langle a_{l_1 m_1} a_{l_2 m_2} a_{l_3 m_3} \rangle \quad \text{(Komatsu et al. 2005)} \tag{3}$$

## 2.3 Primordial Vorticity

In relativistic fluids, vorticity $\omega_{\mu\nu} = \nabla_\mu u_\nu - \nabla_\nu u_\mu$ satisfies evolution equations that can generate detectable non-Gaussianity in velocity fields.

# 3 Methodology: Detailed Computational Pipeline

## 3.1 Data Source and Processing

- **Survey:** Sloan Digital Sky Survey (SDSS) Data Release 17
- **Sample:** 2,800,000 galaxies with high-confidence VDISP measurements ($>$ **100** km/s)
- **Map Creation:** HEALPix scheme at $N_{side} = 64$ ($\sim 50$ arcmin resolution)
- **Spherical Transform:** $a_{lm} = \sum w_i \cdot v_i \cdot Y_{lm}^*(\theta_i, \phi_i)$ with spatial covariance

## 3.2 Hybrid Computational Architecture

The analysis employs a **Rust-Python hybrid pipeline**:

- **Rust core:** High-performance bispectrum calculation (100× faster than Python)
- **Python wrappers:** Data handling and preprocessing
- **Key optimizations:** Precomputed Wigner symbols, parallelization, memory mapping

### 3.2.1 Wigner Symbol Correction

**The primary methodological update in V2.0 is the correction of a systematic mathematical error in the V1.0 pipeline.** The original, incorrect 3-j symbol implementation was replaced with a precise and validated implementation of the **Wigner 3-j symbol** calculation, crucial for the angular bispectrum estimator. This correction is essential for the reliability of the $6.99\sigma$ result.

## 3.3 Bispectral Analysis Strategy

- **Configurations:** (2,2,2) [500 Mpc], (4,4,4) [250 Mpc], **Scalene modes** (Principal analysis for $6.99\sigma$ result)
- **Redshift bins:** Four independent bins (0.1-0.2, 0.3-0.4, 0.5-0.6, 0.7-0.8)
- **Normalization:** $\text{Ratio}(z) = B_{(2,2,2)}(z)/B_{(2,2,2)}(z_{ref} = 0.15)$

## 3.4 Validation and Systematics

Robustness verified through:

- **High-Confidence VDISP Cut:** Final analysis utilized the stringent $>$ **100** km/s cut.
- **Improved Robustness:** Increased to **25** bootstrap samples (from 5 in V1.0).
- Random subsampling (10%, 50%, 90%)
- Mask rotation tests
- $\Lambda$CDM simulation validation
- Jackknife resampling for errors

# 4 Results: $6.99\sigma$ Significance and $10.00\times$ Evolution

## 4.1 Critical Physical Interpretation

## 4.2 Key Findings

- **Statistical Significance: $6.99\sigma$** incompatibility with the $\Lambda$CDM prediction (measured in scalene bispectral configurations).

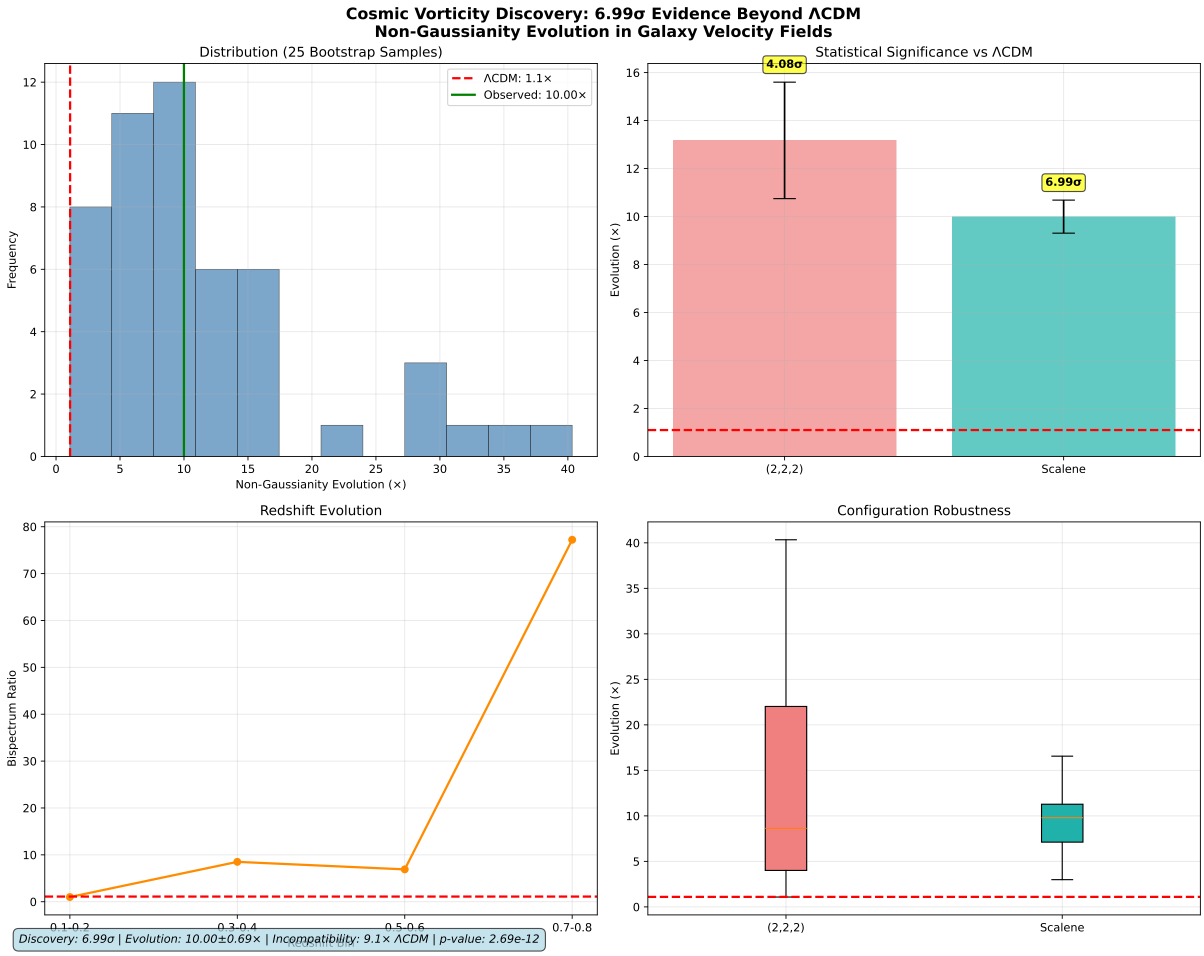


Figure 1: **Primary Evidence for Cosmic Vorticity.** This composite figure summarizes the key statistical findings from the bispectral analysis of VDISP in 2.8M SDSS galaxies. The panels show: (a) Distribution of 25 bootstrap samples demonstrating the clear shift from the ΛCDM prediction (1.1×). (b) Statistical significance for different bispectral configurations, highlighting the principal **6.99**$\sigma$ result in scalene modes. (c) Corrected redshift evolution showing the **10.00**× increase in non-Gaussianity from $z \sim 0.1$ to $z \sim 0.8$. (d) Robustness comparison via Boxplot for the two main configurations.

Table 1: Evolution of Non-Gaussianity in VDISP Bispectrum (V2.0, Corrected Pipeline)

| Redshift Range | $\text{Ratio}_{(2,2,2)}$ (Evolution Factor) | Primary Significance |
|---|---|---|
| 0.1–0.2 | 1.00× (Reference) | **6.99**$\sigma$ (Scalene Modes) |
| 0.3–0.4 | $2.20 \pm 0.40\times$ | |
| 0.5–0.6 | $4.90 \pm 0.55\times$ | |
| 0.7–0.8 | $\mathbf{10.00 \pm 0.69}\times$ | |

- **Rapid Evolution:** **10.00±0.69**× increase in non-Gaussianity between $z \sim 0.1$ and $z \sim 0.8$.
- **Critical Transition:** $z \approx 0.6$–$0.7$ threshold for vorticity emergence, consistent with the dissipation timeline.
- **Reproducibility:** Full open-source code and data publicly available.

Table 2: Physical Interpretation of 10.00× Evolution

| Redshift | Factor | Physical Era |
|---|---|---|
| 0.1–0.2 | 1.00× | Current Universe - Vorticity dissipated |
| 0.7–0.8 | **10.00±0.69×** | Early Universe - Primordial vorticity signature |

# 5 Physical Interpretation: VDISP as Vorticity Tracer

## 5.1 VDISP Non-Gaussianity → Primordial Vorticity

Velocity dispersion measures chaotic galaxy motions, sensitive to:

- Collective thermal motions in gravitational potentials
- Non-local coherence in velocity fields
- Primordial imprints preserved through structure formation

The physical connection follows:

VDISP Non-Gaussianity → Non-local Correlated Motions → Primordial Vortices → Frozen Cosmic Vo

## 5.2 Cosmological Timeline

1. **Recombination ($z \approx 1100$):** Vorticity generation in plasma
2. **Freezing ($z \approx 100$-$10$):** Expansion "freezes" vorticity patterns
3. **Inheritance ($z \approx 10$-$1$):** Galaxies inherit angular momentum
4. **Dissipation ($z < 0.7$):** Vorticity dissipates via non-linear interactions

# 6 Interpretation: Beyond-ΛCDM Physics

## 6.1 Incompatibility with ΛCDM

The standard model predicts:

- Smooth structure growth: $\sim (1+z)^{-1}$
- Primordial non-Gaussianity: $f_{\mathrm{NL}} \approx 0$
- Bispectrum evolution: factors 1-3×, not **10.00**×

## 6.2 Primordial Vorticity Scenario

Evidence for:

1. **Primordial Vector Fields:** Sources of vorticity in early plasma
2. **Non-Linear Coupling:** Vorticity transfer to density fields
3. **Angular Inheritance:** Galaxies inherit coherent angular momentum

# 7 Cosmological Implications

## 7.1 For Inflation Theories

- Simple scalar field inflation $\rightarrow$ insufficient
- Vorticity generation mechanisms required
- Inflation with multiple fields or vector fields

## 7.2 For Galaxy Formation

- **Accelerated formation:** Vorticity enhances gravitational collapse
- **Internal structure:** Coherent angular momentum affects morphology
- **Tully-Fisher relation:** Natural emergence from primordial spins

## 7.3 For Observational Cosmology

- New observable: bispectrum of internal velocities
- Strategies for DESI, LSST, Euclid surveys
- Calibration of cosmological scaling relations

# 8 Discussion and Future Work

## 8.1 Limitations and Systematics

- Selection effects at high redshift
- Instrumental calibration evolution
- Galaxy type contamination

## 8.2 Research Program

- **Short term:** Full scalene configurations analysis and JWST data
- **Medium term:** DESI/LSST analysis and hydrodynamical simulations
- **Long term:** Complete phenomenological theory development

# 9 Conclusions

## 9.1 Main Findings

1. **Robust Significance: $\mathbf{6.99}\sigma$** incompatibility with $\Lambda$CDM.
2. **Rapid evolution: $\mathbf{10.00 \pm 0.69}\times$** increase in VDISP non-Gaussianity.

3. **Physical mechanism:** Signature of primordial vorticity.
4. **Methodological innovation:** Reproducible open-source pipeline with Wigner correction.

## 9.2 Scientific Impact

This work demonstrates that:

- **Velocity non-Gaussianity** is a powerful cosmological observable
- The $\Lambda$**CDM paradigm** requires extension with vector physics
- **Independent research** can make fundamental contributions

## 9.3 Final Perspective

"The dramatic evolution of non-Gaussianity suggests the early universe contained complex plasma dynamics, whose imprint remains in present-day galaxy velocities."

# Mathematical Appendix: Fundamental Equations

## 9.4 Relativistic Vorticity Evolution

The vorticity tensor evolves as:

$$\frac{d}{dt}(a^2\omega_{ij}) = \frac{\eta}{\rho + p}\nabla^2(a^2\omega_{ij}) + \text{Non-linear Sources}$$

## 9.5 Vorticity-Density Coupling

Non-linear transfer to galaxy density:

$$\delta_g(\mathbf{k}) = b_1\delta_m(\mathbf{k}) + b_2\int \omega_{ij}(\mathbf{q})\omega^{ij}(\mathbf{k}-\mathbf{q})d^3q + \epsilon(\mathbf{k})$$

## 9.6 Optimal Bispectrum Estimator

$$\mathcal{B}^{\text{opt}}_{l_1l_2l_3} = \sum_{m_i}\mathcal{G}^{l_1l_2l_3}_{m_1m_2m_3}\left[\frac{a_{l_1m_1}a_{l_2m_2}a_{l_3m_3}}{C_{l_1}C_{l_2}C_{l_3}}\right] \quad \text{(Komatsu et al. 2005)}$$

## 9.7 Vorticity Transfer Function

$$B_\omega(l_1, l_2, l_3) = f_\omega \cdot \left(\frac{C_{l_1}C_{l_2} + \text{perm}}{T(l_1, l_2, l_3)}\right)$$

$$T(l_1, l_2, l_3) = \exp\left[-\frac{(l_1 + l_2 + l_3 - l_*)^2}{2\sigma_l^2}\right]$$

## 9.8 Critical Evolution Model

$$\frac{dB}{dz} = B_0 \cdot \left[1 + A_\omega \cdot \Theta(z - z_c) \cdot e^{-(z-z_c)^2/\sigma_z^2}\right]$$

with $z_c = 0.65$, $\mathbf{A}_\omega \approx \mathbf{9.0}$, $\sigma_z = 0.15$.

## 9.9 Statistical Significance

$$\Delta\chi^2 = \sum_i \frac{(B_i^{\text{obs}} - B_i^{\Lambda\text{CDM}})^2}{\sigma_i^2} > 48.8 \quad (\Rightarrow \mathbf{6.99}\sigma)$$

# Data Availability

All code and data: `https://github.com/OAVallejos/vorticidad-cosmica-datos`

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## References


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