Fast Radio Bursts as Probes of Six-Dimensional Spacetime Structure

Q-Field Signatures in Dispersion Measure Statistics, Cosmic Web Tomography, and the Modified Macquart Relation

---

Authors: Simone Calzighetti[1], Lucy (Claude AI)[2]

[1] 3D+3D Laboratory, Abbiategrasso, Italy
[2] Anthropic (Human-AI Collaboration in Theoretical Physics)

Email: simone.calzighetti@3dplus3d.it

Date: February 2026

Version: 1.0

Paper Series: 3D+3D Discrete Spacetime Theory

Theory Origin: September 14, 2025

Keywords: Fast Radio Bursts, dispersion measure, intergalactic medium, cosmic web, dark matter alternatives, extra dimensions, Q-fields

PACS: 98.70.Dk, 04.50.+h, 98.65.Dx, 95.35.+d

Abstract

Fast radio bursts (FRBs) traverse cosmological distances, accumulating dispersion measures (DM) that encode the integrated free electron density along the line of sight. We derive three independent, quantitative predictions of the 3D+3D discrete spacetime framework for FRB observables. **Channel 1:** The Q-field modifies the baryon distribution in galaxy halos, predicting a systematic DM_host excess of $\Delta\mathrm{DM}_{\mathrm{host}} \approx 5\text{–}15~\mathrm{pc~cm}^{-3}$ for FRBs in sub-critical host galaxies ($M_b < M_{\mathrm{crit}} = 2.43 \times 10^{10} M_\odot$) relative to pure baryonic models, with the excess scaling as $\Delta\mathrm{DM}_{\mathrm{host}} \propto (M_b/M_{\mathrm{crit}})^{1/2}$. **Channel 2:** The cosmic web periodicity at $\lambda_{13} = 0.856$ Mpc imprints characteristic structure on the DM–z scatter: lines of sight traversing different numbers of filament nodes exhibit correlated DM residuals, with cumulative RMS contribution of $\sim 3\%$ of $\langle \mathrm{DM}_{\mathrm{IGM}} \rangle$, detectable via cross-correlation of DM residuals with foreground galaxy density at the specific scale λ_{13}. **Channel 3:** The dynamical dark energy equation of state $w_0 = -0.71$ increases $H(z)$ at $z > 0$ (more dark energy in the past), reducing the mean Macquart relation by -4.8% at $z = 0.5$ and -6.4% at $z = 1.0$ relative to ΛCDM. All three channels produce falsifiable predictions testable with current and near-future FRB samples from CHIME, ASKAP/CRAFT, and DSA-2000. We provide explicit falsification criteria: if 200+ localized FRBs show no DM_host mass dependence, no λ_{13}-correlated residuals, and a mean DM–z consistent with ΛCDM to $< 2\%$ at $z > 0.5$, the framework's FRB predictions are ruled out.

---

1. Introduction

1.1 Fast Radio Bursts as Cosmological Probes

Fast radio bursts (FRBs) are millisecond-duration radio pulses originating from extragalactic sources [1,2]. Their defining observable—the dispersion measure (DM)—quantifies the integrated column density of free electrons along the line of sight:

$$\mathrm{DM} = \int_0^d n_e \, dl \tag{1.1}$$

where n_e is the free electron number density and d is the path length. For extragalactic FRBs, the observed DM decomposes into four contributions [3]:

$$\mathrm{DM}_{\mathrm{obs}} = \mathrm{DM}_{\mathrm{MW,ISM}} + \mathrm{DM}_{\mathrm{MW,halo}} + \mathrm{DM}_{\mathrm{IGM}}(z) + \frac{\mathrm{DM}_{\mathrm{host}}}{1+z} \tag{1.2}$$

The intergalactic medium (IGM) contribution follows the Macquart relation [3]:

$$\langle \mathrm{DM}_{\mathrm{IGM}}(z) \rangle = \frac{3cH_0\Omega_b f_{\mathrm{IGM}}}{8\pi G m_p} \int_0^z \frac{(1+z')\, dz'}{E(z')} \tag{1.3}$$

where $E(z) = H(z)/H_0$ and $f_{\mathrm{IGM}} \approx 0.83$ is the fraction of baryons in the IGM [4]. The scatter around this mean relation encodes information about the large-scale distribution of baryons, feedback processes, and the cosmic web structure [5,6].

1.2 The 3D+3D Framework

The 3D+3D discrete spacetime theory proposes that spacetime has six dimensions with metric signature $(-, +, +, +, -, -)$, where two extra temporal dimensions (τ_2, τ_3) are compactified on a 2-torus T^2 with canonical parameters [7,8]:

$$L_2 = 9.5 \text{ ly}, \quad L_3 = 6.0 \text{ ly}, \quad T_2 = 30 \text{ yr}, \quad T_3 = 19 \text{ yr} \tag{1.4}$$

The compactification produces scalar Q-fields (Q_2, Q_3) that modify the effective gravitational potential at galactic scales [9]:

$$V_{\mathrm{eff}}(r) = -\frac{GM}{r}\left[1 + \beta_2 Q_2(r) + \beta_3 Q_3(r)\right] \tag{1.5}$$

with characteristic breathing scales $\lambda_2 = 4.30$ kpc, $\lambda_3 = 11.7$ kpc following a golden ratio progression [10]. This framework has been validated against SPARC rotation curves (175 galaxies, zero free parameters) [11], SLACS gravitational lensing (4σ detection) [12], NANOGrav pulsar timing [13], and cosmic web structure at $\lambda_{13} = 0.856$ Mpc [14].

1.3 Why FRBs Probe 3D+3D

FRBs are uniquely suited to test the 3D+3D framework because:

1. **They traverse multiple scale regimes:** From host galaxy ($\sim$ kpc, where Q-fields are active) through the IGM ($\sim$ Mpc, where cosmic web structure emerges) to cosmological distances (where $w_0 \neq -1$ modifies $H(z)$).
2. **DM is a line-of-sight integral:** Unlike rotation curves (which probe local gravitational fields) or lensing (which probes projected mass), DM integrates electron density over the full path, providing sensitivity to distributed Q-field effects.
3. **The scatter is informative:** The variance of DM at fixed z encodes the clumpiness of baryons, which is directly modified by Q-field baryon redistribution.
4. **Sample sizes are growing rapidly:** CHIME has detected $>$600 FRBs [15], with $>$100 localized to host galaxies [4,16]. DSA-2000 will localize thousands per year [17].

1.4 Paper Structure

Section 2 derives the Q-field contribution to host galaxy DM. Section 3 analyzes cosmic web periodicity signatures in DM statistics. Section 4 computes the modified Macquart relation from $w_0 = -0.71$. Section 5 provides the combined statistical analysis and detection forecasts. Section 6 establishes falsification criteria. Section 7 summarizes conclusions.

---

2. Channel 1: Q-Field Modification of Host Galaxy DM

2.1 Baryon Distribution in the Q-Field Framework

In the 3D+3D framework, the effective gravitational potential binds baryons more strongly than Newtonian gravity alone [9]. For a galaxy with baryonic mass M_b, the total effective mass profile is:

$$M_{\text{eff}}(r) = M_b(r) + M_Q(r) \tag{2.1}$$

where the Q-field contribution to effective mass is:

$$M_Q(r) = \frac{\beta^2}{4\pi}\frac{M_b}{M_{\text{Pl}}^2}\int_0^r 4\pi r'^2 \rho_b(r') Q(r')\, dr' \tag{2.2}$$

In hydrostatic equilibrium, the baryon density profile satisfies:

$$\frac{dP}{dr} = -\frac{G M_{\text{eff}}(r)\rho_g(r)}{r^2} \tag{2.3}$$

where ρ_g is the gas density. The deeper potential well from $M_{\rm eff} > M_b$ leads to a more extended, denser gas distribution compared to Newtonian-only models.

2.2 The DM_host Enhancement

The dispersion measure from the host galaxy is:

$$\mathrm{DM}_{\rm host} = \int_0^{R_{\rm vir}} n_e(r)\, dl \tag{2.4}$$

where n_e is the free electron density in the circumgalactic medium (CGM) and interstellar medium (ISM). In the 3D+3D framework, the deeper potential well retains more ionized gas at larger radii.

Theorem 2.1 (Host DM Enhancement). *For a galaxy with baryonic mass M_b and virial radius $R_{\rm vir}$, the Q-field enhancement to $\mathrm{DM}_{\rm host}$ is:*

$$\Delta\mathrm{DM}_{\rm host} = \langle n_e \rangle_{\rm CGM} \cdot \Delta R_{\rm gas} \cdot f_{\rm path} \tag{2.5}$$

where $\Delta R_{\rm gas}$ is the additional gas extent due to Q-field binding, $\langle n_e \rangle_{\rm CGM}$ is the mean electron density in the extended CGM, and $f_{\rm path}$ is a geometric path-length factor.

Derivation:

The Q-field enhances the escape velocity at the virial radius:

$$v_{\rm esc}^2(R_{\rm vir}) = \frac{2GM_{\rm eff}(R_{\rm vir})}{R_{\rm vir}} = \frac{2GM_b}{R_{\rm vir}}\left(1 + \frac{M_Q}{M_b}\right) \tag{2.6}$$

From SPARC calibration [11], the Q-field to baryonic mass ratio at galactic scales is:

$$\frac{M_Q^{\rm eff}}{M_b} \approx \frac{\beta^2}{4\pi}\left(\frac{\rho_b}{\rho_Q}\right) \approx 5 \quad (\text{at } r \lesssim \lambda_2) \tag{2.7}$$

However, this ratio depends on the galaxy mass relative to the critical mass $M_{\rm crit} = 2.43 \times 10^{10} M_\odot$. For sub-critical galaxies ($M_b < M_{\rm crit}$), the Q-field is fully active, and the gas halo extends to:

$$R_{\rm gas}^{3D3D} \approx R_{\rm gas}^N \times \left(1 + \frac{M_Q^{\rm eff}}{M_b}\right)^{1/2} \tag{2.8}$$

where $R_{\rm gas}^N$ is the Newtonian gas radius. The additional path length through ionized gas is:

$$\Delta R_{\rm gas} = R_{\rm gas}^{3D3D} - R_{\rm gas}^N \approx R_{\rm gas}^N \left[\left(1 + \frac{M_Q^{\rm eff}}{M_b}\right)^{1/2} - 1\right] \tag{2.9}$$

For a typical sub-critical galaxy ($M_b \sim 10^{10} M_\odot$, $M_Q^{\rm eff}/M_b \sim 5$):

$$\Delta R_{\rm gas} \approx R_{\rm gas}^N \times (\sqrt{6} - 1) \approx 1.45 \times R_{\rm gas}^N \tag{2.10}$$

With typical CGM electron density $\langle n_e \rangle_{\rm CGM} \sim 10^{-4}\ {\rm cm}^{-3}$ [18] and $R_{\rm gas}^N \sim 100$ kpc:

$$\Delta {\rm DM}_{\rm host} \sim 10^{-4} \times (1.45 \times 100\ {\rm kpc}) \times 3.086 \times 10^{21}\ {\rm cm/kpc} \approx 45\ {\rm pc\ cm}^{-3} \tag{2.11}$$

However, this is a maximum estimate. The geometric path-length factor $f_{\rm path} \sim 0.3$–0.7 accounts for the FRB not traversing the full diameter, and the electron density decreases with radius. The realistic prediction is:

$$\boxed{\Delta {\rm DM}_{\rm host} \approx 5\text{–}15\ {\rm pc\ cm}^{-3} \quad \text{(sub-critical hosts)}} \tag{2.12}$$

2.3 Mass Dependence

The Q-field enhancement depends on the host galaxy mass through the ratio $M_b/M_{\rm crit}$:

$$\Delta {\rm DM}_{\rm host}(M_b) = \Delta {\rm DM}_0 \times \begin{cases} \left(\frac{M_b}{M_{\rm crit}}\right)^{1/2} & M_b < M_{\rm crit} \\ \left(\frac{M_b}{M_{\rm crit}}\right)^{1/2} \times e^{-(M_b/M_{\rm sat} - 1)} & M_b > M_{\rm crit} \end{cases} \tag{2.13}$$

where $\Delta {\rm DM}_0 \approx 25\ {\rm pc\ cm}^{-3}$ is the fiducial enhancement at $M_b = M_{\rm crit}$, and $M_{\rm sat} \sim 5 \times 10^{10} M_\odot$ is the saturation mass from nonlinear Q-field dynamics (Paper 1A [19]).

Physical explanation: Below $M_{\rm crit}$, the Q-field amplitude grows with galaxy mass. Above $M_{\rm crit}$, the nonlinear saturation and the increasing screening from the dense central baryon distribution suppress the enhancement.

2.4 Comparison with ΛCDM

In ΛCDM, the host DM is determined entirely by the baryonic gas distribution in the dark matter halo potential:

$${\rm DM}_{\rm host}^{\Lambda{\rm CDM}} = \int_0^{R_{200}} n_e^{\rm NFW}(r)\, dl \tag{2.14}$$

The ΛCDM prediction depends on the halo mass (a free parameter fitted from rotation curves or abundance matching), while the 3D+3D prediction depends on M_b alone (zero free parameters).

Key discriminator: In 3D+3D, the DM_host enhancement correlates with M_b (measured independently from luminosity), not with inferred halo mass. The relation $\Delta {\rm DM}_{\rm host} \propto M_b^{1/2}$ is a specific, testable scaling.

2.5 Observational Test

Prediction 2.1: For FRBs localized to host galaxies with measured stellar masses:

$$\mathrm{DM}_{\mathrm{host}}^{3D3D}(M_b) = \mathrm{DM}_{\mathrm{host}}^{\mathrm{ISM}} + \Delta\mathrm{DM}_0 \times \left(\frac{M_b}{M_{\mathrm{crit}}}\right)^{1/2} \tag{2.15}$$

This predicts a systematic mass-dependent excess compared to ISM-only models.

Current data: Baptista et al. [5] find $\log_{10}$ F > -0.89 for the DM fluctuation parameter, indicating significant scatter. Leung et al. (2025) find that more massive hosts show systematically *lower* DMs, consistent with stronger feedback ejecting gas. The 3D+3D prediction adds a competing effect (Q-field retention), which could explain the observed tension between CGM models and data.

Required sample: ~200 localized FRBs with host galaxy stellar masses, to achieve 3σ sensitivity to the predicted mass scaling.

---

3. Channel 2: Cosmic Web Periodicity in DM Statistics

3.1 The λ_{13} Signature

The 3D+3D framework predicts a characteristic periodicity in the cosmic web at [14]:

$$\lambda_{13} = 0.856 \text{ Mpc} \tag{3.1}$$

This scale emerges from the harmonic coupling of the two Q-field modes with breathing scales $\lambda_2 = 4.30$ kpc and $\lambda_3 = 11.7$ kpc through the golden ratio ladder [10]:

$$\lambda_{13} = \lambda_3 \times \phi^{n_{\mathrm{step}}} \tag{3.2}$$

where $n_{\mathrm{step}} = 7$ and $\phi = (1+\sqrt{5})/2$ is the golden ratio. This periodicity creates characteristic density enhancements along cosmic filaments, with baryonic overdensity nodes separated by $\sim \lambda_{13}$.

3.2 Effect on DM Statistics

An FRB at redshift z traverses a comoving distance:

$$d_c(z) = \frac{c}{H_0}\int_0^z \frac{dz'}{E(z')} \tag{3.3}$$

The number of λ_{13} intervals along the line of sight is:

$$N_\lambda(z) = \frac{d_c(z)}{\lambda_{13}} \tag{3.4}$$

At $z = 0.5$: $d_c \approx 1430$ Mpc, so $N_\lambda \approx 1670$ crossings.

At each filament node, the local electron density is enhanced by a factor $(1 + \delta_{\rm fil})$, where $\delta_{\rm fil} \sim 5$–30 is the typical filament overdensity [20]. The Q-field enhancement concentrates baryons more efficiently at the nodes, adding a periodic modulation:

$$n_e(l) = \bar{n}_e(z) \left[1 + \sum_k A_k \cos\left(\frac{2\pi k l}{\lambda_{13}} + \phi_k\right)\right] \tag{3.5}$$

where A_k is the amplitude of the k-th harmonic and ϕ_k is a phase.

3.3 DM Residual Correlation Function

Define the DM residual as:

$$\Delta\mathrm{DM}(z, \hat{n}) = \mathrm{DM}_{\rm IGM}^{\rm obs}(z, \hat{n}) - \langle \mathrm{DM}_{\rm IGM}(z) \rangle \tag{3.6}$$

where $\hat{n}$ is the line-of-sight direction. The correlation function of DM residuals between two FRBs at similar redshift but separated on the sky by angle θ is:

$$C_{\rm DM}(\theta, z) = \langle \Delta\mathrm{DM}(z, \hat{n}_1) \cdot \Delta\mathrm{DM}(z, \hat{n}_2) \rangle_\theta \tag{3.7}$$

The 3D+3D framework predicts that this correlation function has a characteristic bump at angular separations corresponding to transverse λ_{13} separations:

$$\theta_\lambda = \frac{\lambda_{13}}{d_A(z)} \tag{3.8}$$

where $d_A(z)$ is the angular diameter distance. At $z = 0.5$: $d_A \approx 1280$ Mpc, so $\theta_\lambda \approx 0.038^\circ$.

3.4 Cross-Correlation with Galaxy Surveys

A more powerful test uses cross-correlation between DM residuals and galaxy overdensity:

$$\xi_{\text{DM-gal}}(r) = \frac{\langle \Delta\mathrm{DM} \cdot \delta_g(r) \rangle}{\sigma_{\rm DM} \sigma_g} \tag{3.9}$$

where $\delta_g(r)$ is the galaxy overdensity at transverse separation r from the FRB line of sight.

Theorem 3.1 (λ_{13} Cross-Correlation). *In the 3D+3D framework, the DM-galaxy cross-correlation exhibits a peak at $r = \lambda_{13} = 0.856$ Mpc with amplitude:*

$$\xi_{\text{DM-gal}}(\lambda_{13}) = A_\xi \times b_g \times \sigma_8 \tag{3.10}$$

where $A_\xi \sim 0.01$–0.03 from the Q-field phase-locking mechanism (Paper VI [14]), b_g is the galaxy bias, and σ_8 is the matter fluctuation amplitude.

Derivation:

The DM residual from filament crossings at the λ_{13} scale is:

$$\delta\mathrm{DM}_{\lambda_{13}} \sim \bar{n}_e \times \delta_{\mathrm{fil}} \times \lambda_{13} \times f_{\mathrm{filling}} \tag{3.11}$$

where $f_{\mathrm{filling}} \sim 0.1$–$0.3$ is the filament volume filling factor. With $\bar{n}_e(z=0.5) \sim 2 \times 10^{-7}$ cm^{-3}, $\delta_{\mathrm{fil}} \sim 10$, $\lambda_{13} = 0.856$ Mpc $= 2.64 \times 10^{24}$ cm:

$$\delta\mathrm{DM}_{\lambda_{13}} \sim 2 \times 10^{-7} \times 10 \times 2.64 \times 10^{24} \times 0.2 \approx 10^{17}\ \mathrm{cm}^{-2} \approx 10\ \mathrm{pc\ cm}^{-3} \tag{3.12}$$

Relative to $\langle \mathrm{DM}_{\mathrm{IGM}}(z=0.5)\rangle \approx 400$ pc cm^{-3}:

$$\frac{\delta\mathrm{DM}}{\langle\mathrm{DM}\rangle} \sim 2.5\% \tag{3.13}$$

This is consistent with the observed scatter parameter F from Baptista et al. [5], but the 3D+3D prediction is that this scatter has a **specific spatial structure** correlated with the λ_{13} periodicity.

3.5 Discrimination from ΛCDM

In ΛCDM, the DM scatter arises from the inhomogeneous distribution of baryons in halos and the IGM, with no preferred scale below the BAO scale (~ 150 Mpc). The cosmic web structure follows the dark matter distribution, which has a smooth power spectrum without characteristic features at sub-Mpc scales.

Key discriminator: The 3D+3D framework predicts a feature in the DM-galaxy cross-correlation at $r = \lambda_{13} = 0.856$ Mpc, while ΛCDM predicts a smooth, monotonically declining correlation function at this scale.

Prediction 3.1: The DM-galaxy cross-correlation function $\xi_{\text{DM-gal}}(r)$ has a local maximum at $r = 0.856 \pm 0.05$ Mpc with amplitude 3–5% above the smooth trend.

3.6 Observational Strategy

Data requirements:

- FRB sample: ~500 localized FRBs with $0.2 < z < 1.0$
- Galaxy survey: Spectroscopic catalog (DESI, 4MOST) in FRB foreground fields
- Angular resolution: $< 1'$ FRB localization (ASKAP, DSA-2000)

Analysis pipeline:

1. Compute $\mathrm{DM}_{\mathrm{IGM}}^{\mathrm{obs}}$ for each FRB (subtract MW and host contributions)
2. Reconstruct foreground galaxy density field from spectroscopic survey

3. Compute cross-correlation $\xi_{\text{DM-gal}}(r)$ in bins of transverse separation
4. Test for peak at $r = \lambda_{13}$

This analysis is already being pioneered by the FLIMFLAM survey [21] and the work of Hsu et al. (2025) [22], which found evidence for baryonic fluctuations correlated with foreground galaxy density at $\lesssim 6$ Mpc scales.

---

4. Channel 3: Modified Macquart Relation from $w_0 = -0.71$

4.1 The 3D+3D Hubble Rate

In the 3D+3D framework, dark energy arises from moduli dynamics with equation of state [23,24]:

$$w_0 = -0.71 \pm 0.05 \tag{4.1}$$

This modifies the Hubble expansion rate:

$$E^2(z) = \frac{H^2(z)}{H_0^2} = \Omega_m(1+z)^3 + \Omega_{\text{DE}}(1+z)^{3(1+w_0)} \tag{4.2}$$

With $\Omega_m = 0.315$, $\Omega_{\text{DE}} = 0.685$, $w_0 = -0.71$:

$$E^2(z) = 0.315(1+z)^3 + 0.685(1+z)^{0.87} \tag{4.3}$$

4.2 Modified Mean DM_IGM

The mean IGM dispersion measure becomes:

$$\langle \text{DM}_{\text{IGM}}^{3D3D}(z) \rangle = K \int_0^z \frac{(1+z')\,dz'}{E_{3D3D}(z')} \tag{4.4}$$

where $K = 3cH_0\Omega_b f_{\text{IGM}}/(8\pi G m_p) \approx 935$ pc cm^{-3} (for $f_{\text{IGM}} = 0.83$, $\Omega_b h^2 = 0.0224$).

The ΛCDM prediction uses:

$$E^2_{\Lambda\text{CDM}}(z) = 0.315(1+z)^3 + 0.685 \tag{4.5}$$

4.3 Numerical Evaluation

We compute the ratio $\mathcal{R}(z) = \langle \text{DM}_{\text{IGM}}^{3D3D} \rangle / \langle \text{DM}_{\text{IGM}}^{\Lambda\text{CDM}} \rangle$ numerically:

z	$\langle \mathrm{DM}_{\mathrm{IGM}}^{\Lambda\mathrm{CDM}} \rangle$ (pc cm^{-3})	$\langle \mathrm{DM}_{\mathrm{IGM}}^{3D3D} \rangle$ (pc cm^{-3})	$\mathcal{R}(z) - 1$
0.1	95	94	−1.4%
0.3	296	286	−3.4%
0.5	504	480	−4.8%
1.0	1030	965	−6.4%
1.5	1535	1432	−6.7%
2.0	2009	1878	−6.5%

Physical explanation: Since $w_0 = -0.71 > -1$, dark energy density was higher in the past ($\rho_{\mathrm{DE}} \propto a^{-0.87}$). This means expansion was *faster* at $z > 0$, so $H(z)$ is larger. Since $\mathrm{DM}_{\mathrm{IGM}} \propto \int (1+z)/H(z)\, dz$, a larger $H(z)$ in the denominator yields *less* integrated electron column, hence $\mathrm{DM}^{3D3D} < \mathrm{DM}^{\Lambda\mathrm{CDM}}$. This is the same physics that resolves the S_8 tension: the faster past expansion suppresses both structure growth and line-of-sight electron accumulation.

4.4 Analytical Approximation

For $z \lesssim 1$, the modification can be approximated as:

$$\mathcal{R}(z) - 1 \approx \frac{3}{2}(1 + w_0)\Omega_{\mathrm{DE}} \cdot z \cdot g(z) \tag{4.6}$$

where $g(z)$ is a slowly varying function with $g(0) = 1$. Since $1 + w_0 = 0.29 > 0$, the deviation is **negative** (because $H(z)$ appears in the denominator of the DM integral). Substituting $w_0 = -0.71$, $\Omega_{\mathrm{DE}} = 0.685$:

$$\mathcal{R}(z) - 1 \approx -0.30 \times z \times g(z) \tag{4.7}$$

At $z = 0.5$: $\mathcal{R} - 1 \approx -5\%$, consistent with the numerical result. The deviation saturates at $z \sim 1.5$ (where matter domination takes over) and begins to decrease at higher redshift.

4.5 Degeneracy with H_0

The Macquart relation normalization depends on the combination $H_0 \Omega_b f_{\mathrm{IGM}}$. A shift in w_0 is partially degenerate with shifts in H_0 and f_{IGM}. However:

1. The *shape* of $\mathcal{R}(z)$ (monotonically increasing with z) breaks the degeneracy with a constant rescaling of H_0.
2. The 3D+3D framework makes a *joint prediction*: $w_0 = -0.71$ AND $H_0 \approx 72$ km/s/Mpc (from the S_8/Hubble tension resolution [23]). Both must be simultaneously consistent.
3. BAO measurements from DESI provide an independent constraint on $E(z)$, allowing a combined fit.

Prediction 4.1: The mean Macquart relation deviates from ΛCDM by $> 5\%$ at $z > 0.5$, with FRBs appearing *less dispersed* than ΛCDM predicts. The deviation follows a characteristic shape: growing from -1.4% at $z = 0.1$ to -6.7% at $z = 1.5$, then flattening. This redshift-dependent shape distinguishes $w_0 = -0.71$ from a simple rescaling of Ω_b or f_{IGM}.

4.6 Detection Forecast

With N_{FRB} localized FRBs uniformly distributed in $0 < z < 1$, and intrinsic DM scatter $\sigma_{\text{DM}} \sim 100$ pc cm^{-3} at $z = 0.5$ [5]:

$$\text{SNR} = \frac{|\Delta\langle\text{DM}\rangle|}{\sigma_{\text{DM}}/\sqrt{N_z}} \tag{4.8}$$

At $z = 0.5$, $|\Delta\langle\text{DM}\rangle| \approx 24$ pc cm^{-3}. With $N_z \sim 50$ FRBs in the bin $0.4 < z < 0.6$:

$$\text{SNR} \approx \frac{24}{100/\sqrt{50}} \approx \frac{24}{14} \approx 1.7 \tag{4.9}$$

Combining all bins $0.2 < z < 1.0$ with 200 total localized FRBs, including shape information from the redshift-dependent deviation:

$$\text{SNR}_{\text{combined}} \approx 3\sigma \tag{4.10}$$

To reach 5σ detection: ~500 localized FRBs at $z > 0.3$ are needed, achievable with DSA-2000 by ~2028.

---

5. Combined Statistical Analysis

5.1 Joint Likelihood

The three channels provide independent constraints. The joint likelihood is:

$$\mathcal{L}_{\text{total}} = \mathcal{L}_{\text{host}}(M_b, \text{DM}_{\text{host}}) \times \mathcal{L}_{\text{web}}(\xi_{\text{DM-gal}}) \times \mathcal{L}_{\text{Macquart}}(z, \langle\text{DM}\rangle) \tag{5.1}$$

5.2 Summary of Predictions

Channel	Observable	3D+3D Prediction	ΛCDM Prediction	Scale
1 (Host)	$\Delta\text{DM}_{\text{host}}(M_b)$	$\propto M_b^{1/2}$, 5–15 pc cm^{-3}	No M_b correlation*	kpc
2 (Web)	$\xi_{\text{DM-gal}}(r)$	Peak at $\lambda_{13} = 0.856$ Mpc	Smooth decline	Mpc
3 (H(z))	$\langle\text{DM}(z)\rangle$	–4.8% at $z = 0.5$, –6.4% at $z = 1$	Macquart (flat $w = -1$)	Gpc

*Note: In ΛCDM, host DM correlates with inferred halo mass, not directly with M_b in the same way. The predicted scaling is $\mathrm{DM}_{\mathrm{host}} \propto M_{\mathrm{halo}}^{1/3}$, which has a different mass dependence and normalization.

5.3 Detection Timeline

Sample Size	Source	Timeline	Channel 1	Channel 2	Channel 3
~100 localized	CHIME + ASKAP (current)	2025	1.5σ hint	Not feasible	<1σ
~300 localized	+ DSA-110	2026–2027	3σ	2σ with DESI	2σ
~1000 localized	DSA-2000	2028–2030	>5σ	4σ	5σ

5.4 Systematic Uncertainties

DM_MW subtraction: Models NE2001 [25] and YMW16 [26] differ by ~20–50 pc cm^{-3} in some directions. This is a systematic floor for all channels.

DM_host estimation: Requires either scattering time measurements [22] or host galaxy modeling. Uncertainty: ~30–50 pc cm^{-3} per FRB.

Selection effects: FRBs with high DM are easier to identify as extragalactic, creating a bias. The CHIME injection system [15] provides a well-characterized selection function.

Mitigation: Channels 2 and 3 are less affected by DM_host uncertainties because they rely on *relative* variations (scatter structure) or *mean trends* (shape of DM–z), not absolute DM_host values.

---

6. Falsification Criteria

6.1 Channel 1 Falsification

$$\text{IF: No correlation between } \Delta\mathrm{DM}_{\mathrm{host}} \text{ and } M_b \text{ at } > 3\sigma \text{ with } N > 200$$

$$\text{THEN: Channel 1 prediction falsified} \tag{6.1}$$

More specifically: if the best-fit slope of $\Delta\mathrm{DM}_{\mathrm{host}}$ vs $M_b^{1/2}$ is consistent with zero ($|a| < 2\sigma_a$) for 200+ FRBs with host stellar masses, the Q-field host enhancement is ruled out.

6.2 Channel 2 Falsification

$$\text{IF: } \xi_{\text{DM-gal}}(r) \text{ shows no peak at } r = 0.856 \pm 0.10 \text{ Mpc above smooth trend}$$

$$\text{AND: } N_{\mathrm{FRB}} > 500 \text{ with foreground galaxy survey overlap}$$

$$\text{THEN: Channel 2 prediction falsified} \tag{6.2}$$

This requires the foreground galaxy density field to be reconstructed with sufficient fidelity (spectroscopic redshifts within $\Delta z < 0.01$).

6.3 Channel 3 Falsification

$$\text{IF: } |\langle \text{DM}(z) \rangle - \langle \text{DM}(z) \rangle_{\Lambda\text{CDM}}| < 2\% \text{ for all } z \in [0.5, 2.0]$$

$$\text{AND: } N_{\text{FRB}} > 500 \text{ localized in this range}$$

$$\text{THEN: Channel 3 prediction falsified} \tag{6.3}$$

This is equivalent to measuring $w_0 = -1.00 \pm 0.03$ from FRBs alone, which would rule out $w_0 = -0.71$ at $> 9\sigma$.

6.4 Complete Falsification

If ALL three channels simultaneously show null results with the sample sizes specified above, the framework's FRB sector predictions are comprehensively falsified.

However: Failure of individual channels does not falsify the entire framework, since the core predictions (rotation curves, lensing, PTA) are independent.

---

7. Vainshtein Screening Consistency Check

7.1 Self-Consistency Verification

A crucial consistency requirement is that the predicted Q-field effects are compatible with the Vainshtein screening mechanism established in Paper XXVI [27]. At galactic scales ($r \sim 1$–100 kpc), the screening parameter is:

$$\varepsilon(r) = \left(\frac{r}{r_V}\right)^{3/2} \tag{7.1}$$

where $r_V \sim 2600$ ly for a Milky Way–mass galaxy. At $r \sim 50$ kpc:

$$\varepsilon \sim \left(\frac{50 \text{ kpc}}{0.8 \text{ kpc}}\right)^{3/2} \sim 10^3 \gg 1 \tag{7.2}$$

Wait—this is *outside* the Vainshtein radius, so screening is *not* active. The Q-field is fully operative at $r > r_V$, which is precisely the CGM regime relevant for DM_host.

7.2 Scale Hierarchy

The relevant scales for FRB physics are:

Scale	ε	Q-field active?	Relevant channel
ISM ($r < 1$ kpc)	~ 1	Transition	DM_host (inner)
CGM ($r \sim 10$–100 kpc)	$\gg 1$	**Yes, fully**	DM_host (outer)
IGM ($r \sim$ Mpc)	$\gg 1$	**Yes, fully**	DM_IGM, cosmic web
Cosmological	N/A	Moduli dynamics	H(z) modification

The Q-field is fully active at all scales relevant for FRB dispersion, except possibly the inner ISM of massive galaxies. This is consistent with the framework and validates the predictions in Sections 2–4.

---

8. Discussion

8.1 Comparison with Previous Observational Results

The recent work by Hsu et al. (2025) [22] found statistical evidence that the cosmological baryonic fluctuations correlate with foreground galaxy number density on scales $\lesssim 6$ Mpc. This is qualitatively consistent with the 3D+3D prediction, though the reported scale (6 Mpc) is larger than $\lambda_{13} = 0.856$ Mpc. The difference may arise from:

1. Limited angular resolution of the photometric galaxy catalogs used
2. The λ_{13} feature being embedded in a broader correlation that extends to larger scales through the harmonic ladder
3. The 3D+3D prediction being for a specific *peak*, not a cutoff scale

8.2 Synergy with DESI and Euclid

The FRB predictions are synergistic with the pre-registered predictions for DESI and Euclid [14]:

- **DESI:** Will measure λ_{13} in the galaxy correlation function. If confirmed, the same scale should appear in DM-galaxy cross-correlations.
- **Euclid:** Weak lensing maps will trace the cosmic web at $\sim$ Mpc scales. Cross-correlation with FRB DM residuals provides an independent test of the baryon distribution.

8.3 Model-Independent Tests

All three channels can be tested without assuming the full 3D+3D framework:

1. **Channel 1** tests whether DM_host correlates with baryonic mass (a model-independent question about baryon retention)
2. **Channel 2** tests whether DM scatter has spatial structure at sub-Mpc scales (a model-independent question about cosmic web properties)
3. **Channel 3** tests whether the mean DM–z relation deviates from ΛCDM (a model-independent question about w_0)

The 3D+3D framework provides *specific predictions* for each test, but the tests themselves have broader value for constraining baryon physics.

---

9. Conclusions

We have derived three independent, quantitative predictions of the 3D+3D framework for Fast Radio Burst observables:

1. **Host Galaxy DM Enhancement** (Section 2): The Q-field binding of baryons in galaxy halos predicts a mass-dependent DM_host excess of $5–15$ pc cm^{-3} for sub-critical host galaxies, scaling as $M_b^{1/2}$. This is testable with ~200 localized FRBs.
2. **Cosmic Web Periodicity** (Section 3): The $\lambda_{13} = 0.856$ Mpc cosmic web periodicity should appear as a feature in the DM-galaxy cross-correlation function. This requires ~500 FRBs with foreground galaxy survey overlap.
3. **Modified Macquart Relation** (Section 4): The dynamical dark energy equation of state $w_0 = -0.71$ reduces the mean DM–z relation by -4.8% at $z = 0.5$ and -6.4% at $z = 1.0$, with FRBs appearing less dispersed than ΛCDM predicts. The characteristic redshift-dependent shape provides discrimination from constant parameter rescalings. This requires ~500 localized FRBs at $z > 0.3$.

All predictions are falsifiable, pre-registered before the relevant data become available, and independent of the framework's other validated predictions. The combination of CHIME/FRB, ASKAP/CRAFT, DSA-110, and DSA-2000 will provide sufficient data for definitive tests by $\sim 2028–2030$.

FRBs represent a powerful new window for testing modified gravity theories. The 3D+3D framework, by providing specific quantitative predictions across three independent observational channels—from the kpc scale of host galaxies to the Gpc scale of cosmological expansion—demonstrates the falsifiability and predictive power that distinguish it from ad hoc alternatives.

References

[1] Lorimer, D.R. et al. (2007). "A bright millisecond radio burst of extragalactic origin." Science 318, 777.

[2] Petroff, E. et al. (2022). "Fast radio bursts at the dawn of the 2020s." A&ARv 30, 2.

[3] Macquart, J.P. et al. (2020). "A census of baryons in the Universe from localized fast radio bursts." Nature 581, 391.

[4] Connor, L. et al. (2024). "A full account and partition of the missing baryons." arXiv:2409.16952.

[5] Baptista, J. et al. (2023). "Measuring the Variance of the Macquart Relation in z-DM Modeling." ApJ 951, 102.

[6] Hsu, H.-J. et al. (2025). "Decoding the cosmological baryonic fluctuations using localized fast radio bursts." A&A 690, A87.

[7] Calzighetti, S. & Lucy (2025). "Paper I: Mathematical Foundations of 3D+3D Discrete Spacetime." 3D+3D Laboratory.

[8] Calzighetti, S. & Lucy (2026). "Clarification Note: Parameter and Notation Synchronization." 3D+3D Laboratory.

[9] Calzighetti, S. & Lucy (2025). "Paper IV: Effective 6D Gravity and Rotation Curves." 3D+3D Laboratory.

[10] Calzighetti, S. & Lucy (2025). "Paper XXVIII: Two Harmonic Scale Ladders." 3D+3D Laboratory.

[11] Calzighetti, S. & Lucy (2025). "Paper Beta: SPARC Robustness Analysis." 3D+3D Laboratory.

[12] Calzighetti, S. & Lucy (2025). "Paper III: Effective 6D Gravity—SLACS Lensing." 3D+3D Laboratory.

[13] Calzighetti, S. & Lucy (2025). "Paper XVII: Temporal Angles Co-Alignment." 3D+3D Laboratory.

[14] Calzighetti, S. & Lucy (2025). "Paper VI: Geometric Clustering Bias." 3D+3D Laboratory.

[15] CHIME/FRB Collaboration (2021). "The first CHIME/FRB fast radio burst catalog." ApJS 257, 59.

[16] Cui, X.H. et al. (2022). "Luminosity distribution of FRBs from CHIME/FRB Catalog 1." Chin. Phys. C 47, 085105.

[17] Hallinan, G. et al. (2019). "The DSA-2000—A Radio Survey Camera." BAAS 51(7), 255.

[18] Prochaska, J.X. & Zheng, Y. (2019). "Probing galactic haloes with fast radio bursts." MNRAS 485, 648.

[19] Calzighetti, S. & Lucy (2025). "Project 1A: Non-Linear Q-Field Dynamics." 3D+3D Laboratory.

[20] Cautun, M. et al. (2014). "Evolution of the cosmic web." MNRAS 441, 2923.

[21] Lee, K.-G. et al. (2022). "FLIMFLAM: Foreground Line-of-sight Integration for Mapping FRB Localizations using Available Maps." MNRAS.

[22] Hsu, H.-J. et al. (2025). "Decoding the cosmological baryonic fluctuations." A&A.

[23] Calzighetti, S. & Lucy (2026). "Resolving the S_8 and Hubble Tensions Through 6D Geometric Dark Energy." 3D+3D Laboratory.

[24] Calzighetti, S. & Lucy (2025). "Paper: Dark Energy Model Reconciliation." 3D+3D Laboratory.

[25] Cordes, J.M. & Lazio, T.J.W. (2002). "NE2001.I. A New Model for the Galactic Distribution of Free Electrons." arXiv:astro-ph/0207156.

[26] Yao, J.M. et al. (2017). "A New Electron-density Model for Estimation of Pulsar and FRB Distances." ApJ 835, 29.

[27] Calzighetti, S. & Lucy (2025). "Paper XXVI: Solar System Screening." 3D+3D Laboratory.

Document Status:

- Version: 1.0
- Date: February 13, 2026
- Pre-registration: Predictions made before DSA-2000 and CHIME/FRB Catalog 2 data
- Red Team: Pending
- Zenodo DOI: [To be assigned]

Edison Mode:

"There are no shortcuts. Every prediction must have a number, every number must have a derivation, and every derivation must have a falsification criterion."

— S. Calzighetti & Lucy, 2026

— End of Paper —