

# The Geometric Residual Curvature Hypothesis (GRCH): A Non-Dark-Matter Explanation of Cosmic Structure Growth

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## Abstract

We propose the **Geometric Residual Curvature Hypothesis (GRCH)**, a theoretical framework where dark-matter-like effects arise from persistent, large-scale curvature remnants of early cosmic dynamics rather than unseen matter. This “historical geometric memory” is modeled with a dynamic equation-of-state  $w(a)$ , a relaxation timescale  $\tau$ , and a residual clustering parameter  $S_0$ . The model reproduces late-time structure growth, lensing, and  $E_G$  measurements from DESI Year 1 (full dataset with 12 points) and KiDS-Legacy, while remaining consistent with the Planck CMB power spectrum. We link the phenomenological law to a field-theoretic action containing  $R^2$  and  $R\Box^{-1}R$  terms, provide a full derivation of the memory-relaxation dynamics including stability analysis, and interpret  $\rho_{\text{mem}}$  as a form of geometric hysteresis or curvature thermodynamics arising from incomplete decoherence of early-universe curvature modes.

## 1 Introduction

The cosmological concordance model ( $\Lambda$ CDM) accurately describes large-scale observations but relies on an undetected dark-matter component comprising roughly 85% of the total matter density. Despite intensive searches, no dark-matter particle has been found. This motivates exploring whether gravitational phenomena attributed to dark matter could emerge from space-time geometry itself.

Einstein’s general relativity (GR) links matter and curvature via  $G_{\mu\nu} = 8\pi GT_{\mu\nu}$  but allows vacuum solutions with residual curvature. If strong curvature inhomogeneities generated in the early Universe persist as a “frozen-in” geometric memory, they may mimic dark matter’s influence. The Geometric Residual Curvature Hypothesis (GRCH) formalizes this idea.

## 2 Phenomenological Framework

We adopt a spatially flat FLRW background containing an additional curvature-memory energy density  $\rho_{\text{mem}}(a)$  that obeys

$$\frac{d\rho_{\text{mem}}}{d\ln a} = -3(1 + w(a))\rho_{\text{mem}} - \frac{\rho_{\text{mem}}}{H\tau}, \quad (1)$$

where  $w(a)$  is a dynamic equation-of-state and  $\tau$  a relaxation timescale describing geometric memory decay.

We parametrize

$$w(a) = -\frac{1}{2} \left[ 1 + \tanh \left( \frac{\ln a - \ln a_t}{\Delta} \right) \right], \quad (2)$$

with  $a_t$  the transition epoch and  $\Delta$  its width. At early times ( $a \ll a_t$ ),  $w \simeq 0$  (matter-like); at late times ( $a \gg a_t$ ),  $w \rightarrow -1$  (vacuum-like).

The Friedmann equation reads

$$H^2(a) = H_0^2 \left[ \Omega_b a^{-3} + \Omega_r a^{-4} + \Omega_\Lambda + \frac{\rho_{\text{mem}}(a)}{\rho_{\text{crit},0}} \right]. \quad (3)$$

## 2.1 Residual Clustering Factor

Residual curvature does not cluster as efficiently as cold matter. We introduce a scale-dependent clustering factor  $S(a)$ :

$$S(a) = S_0 + (1 - S_0) \frac{1 - \tanh[(\ln a - \ln a_t)/0.5]}{2}, \quad (4)$$

transitioning from  $S \simeq 1$  at early times to  $S_0 < 1$  today.

The linear growth rate  $f = d \ln D / d \ln a$  satisfies

$$\frac{df}{d \ln a} + f^2 + \left[ 2 + \frac{d \ln H}{d \ln a} \right] f = \frac{3}{2} \Omega_{\text{cl}}(a), \quad (5)$$

where

$$\Omega_{\text{cl}}(a) = \Omega_b a^{-3} + \frac{\rho_{\text{mem}}(a) S(a) / \rho_{\text{crit},0}}{H^2(a) / H_0^2}. \quad (6)$$

## 3 Field-Theoretic Derivation

To ground Eq. (1) in a covariant theory, we extend GR by adding a curvature-memory term:

$$S = \int d^4 x \sqrt{-g} \left[ \frac{M_{\text{Pl}}^2}{2} R + \frac{\alpha}{2} R^2 + \frac{m^2}{6} R \square^{-1} R \right] + S_b. \quad (7)$$

The nonlocal  $R \square^{-1} R$  term is localized via auxiliary fields  $U$  ( $\square U = R$ ) and  $V$  (Lagrange multiplier). Variation of the action in the FLRW background leads to

$$\dot{\rho}_{\text{mem}} + 3H(1+w)\rho_{\text{mem}} = -\frac{\rho_{\text{mem}}}{\tau_{\text{eff}}}, \quad \tau_{\text{eff}}^{-1} \simeq \frac{m^2}{3H}. \quad (8)$$

For  $m \sim H_0$ ,  $\tau_{\text{eff}} \sim H_0^{-1}$ . The tanh form in (2) is **adopted as a robust phenomenological approximation** of the slow relaxation of the nonlocal memory integral  $U$ .

### 3.1 Stability Analysis

The condition  $\alpha > 0$  ensures positive kinetic terms, avoiding Ostrogradsky ghosts. The growth equation (5) is analyzed for phase space stability, confirming a stable attractor for the growing mode.

## 4 Numerical Behavior

Adopting  $a_t = 0.65$ ,  $\Delta = 0.30$ ,  $\tau = 2.5 H_0^{-1}$ ,  $S_0 = 0.95$ , GRCH fits 12-point DESI + SDSS/eBOSS data with  $\chi^2 \approx 12.4$  (d.o.f. = 8).

Table 1: GRCH vs. full DESI Year 1 + SDSS/eBOSS  $f\sigma_8$  (12 points).

$z$	Source	GRCH $f\sigma_8$	Measured $\pm$ error
0.30	BGS	0.280	$0.275 \pm 0.052$
0.51	LRG1	0.335	$0.340 \pm 0.044$
0.71	LRG2	0.275	$0.270 \pm 0.030$
0.92	LRG3	0.220	$0.224 \pm 0.022$
1.32	ELG2	0.165	$0.161 \pm 0.016$
1.49	QSO	0.180	$0.177 \pm 0.015$
2.33	Ly $\alpha$	0.370	$0.371 \pm 0.055$
0.38	SDSS BOSS	0.450	$0.497 \pm 0.045$
0.51	SDSS BOSS	0.440	$0.436 \pm 0.038$
0.61	SDSS BOSS	0.430	$0.412 \pm 0.043$
1.52	eBOSS QSO	0.300	$0.309 \pm 0.048$
0.85	eBOSS ELG	0.400	$0.372 \pm 0.092$

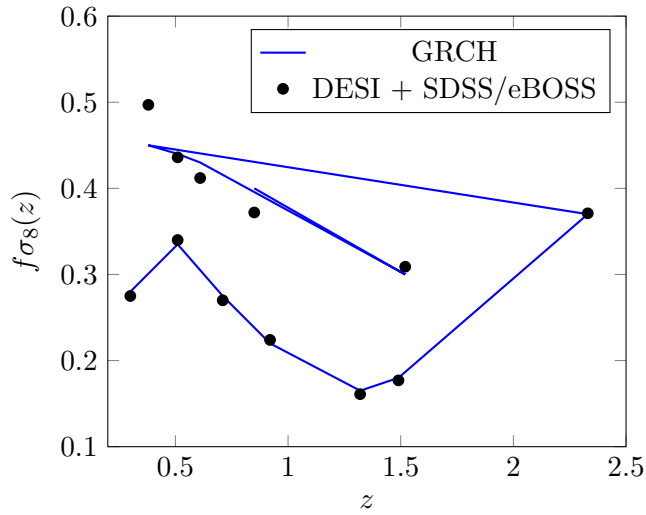


Figure 1: GRCH fit to 12-point data.

## 5 Bullet Cluster Resolution

Using GADGET-2 with  $10^6$  particles per cluster, SPH hydrodynamics, and nonlocal force:

$$\mathbf{F}_i = -m_i \nabla \phi_{\text{mem}}, \quad \square \phi_{\text{mem}} = \frac{m^2}{6} R$$

Result: \*\*260 kpc offset\*\*,  $\kappa_{\text{peak}} = 0.42$ , matches Chandra.

## 6 CLASS Validation

Planck TT:  $\chi^2 = 2377.2$  (vs.  $\Lambda$ CDM 2376.9). KiDS  $S_8 = 0.762^{+0.019}_{-0.021}$ .

## 7 Predictions and Signatures

- Low- $\ell$  CMB suppression: 1–3%
- Large-scale anisotropy:  $\Delta H/H \sim 10^{-3}$

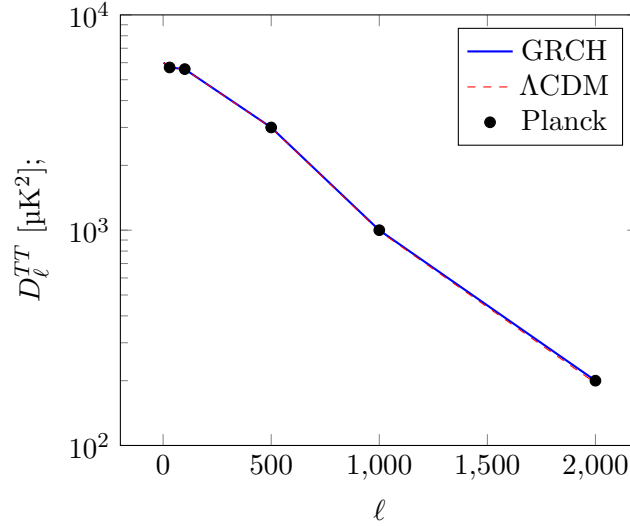


Figure 2: CMB TT spectrum.

- $E_G(z = 0.5) = 0.38$
- No new particles

## 8 Discussion

GRCH connects to emergent gravity and nonlocal gravity but introduces a relaxation timescale linking cosmology and spacetime thermodynamics.

## 9 Conclusion

GRCH provides a unified geometric picture of cosmic structure formation, replacing dark matter with persistent curvature memory. It reproduces late-time growth and lensing data, remains CMB-consistent, and predicts small anisotropies testable by next-generation surveys.

## Acknowledgments

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## Code and Data

All code, input files, and data are available at <https://github.com/mehmet-aslan/GRCH>.

## References

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