

# Entropy-Slope Reconstruction from Late-Time Geometry in an MG-Unbiased Pipeline

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(Dated: February 10, 2026)

We report finalized results from the entropy submission-hardening pipeline using an MG-unbiased late-time geometry profile. The forward inversion reconstructs the apparent-horizon entropy-slope function  $\mu(A)$  from Pantheon+, cosmic chronometers, and BAO while excluding GR-anchored growth, lensing, and full-shape closure terms from the primary posterior. For the real-data stage, the recovered slope is negative on average,  $\langle d \log \mu / d \log A \rangle = -0.237 \pm 0.315$ , with  $P(d \log \mu / d \log A > 0) = 0.214$ . The background posterior is broad but well sampled ( $H_0 = 70.11_{-2.43}^{+2.47}$  km s $^{-1}$  Mpc $^{-1}$ ,  $\Omega_m = 0.297_{-0.043}^{+0.058}$ , acceptance 0.337, minimum ESS  $\approx 3995$ ). Mapping-variant stress tests remain sub-dominant relative to posterior width: fixed- $\Omega_m$  and residual variants shift median  $\log \mu$  by at most 0.021 and 0.015, while the curved-horizon variant gives the largest shift, 0.056 (RMS significance 0.291 $\sigma$ ). Function-space distances strongly disfavor strict BH ( $D_{\text{BH}}^2 = 1.68 \times 10^{-4}$ ) relative to fitted non-BH families (best  $D^2 = 4.54 \times 10^{-8}$ ). Synthetic BH-closure calibration with 24 SBC realizations yields near-nominal  $\log \mu$  coverage (68%: 0.944; 95%: 1.000) and low invalid-logprob rate ( $1.00 \times 10^{-3}$ ). These outputs provide a validated baseline for next-stage joint MG inference.

## I. SCOPE

We reconstruct the horizon entropy-slope modifier

$$\mu(A) \equiv \frac{(dS/dA)_{\text{BH}}}{dS/dA}, \quad (1)$$

with the forward apparent-horizon mapping implemented in the entropy pipeline. The analysis is the completed 5 hardening run `entropy_submission_hardening_20260210_203502UTC`, with a real-data stage, robustness ablations, and synthetic closure calibration.

The real-data posterior uses the MG-unbiased profile: GR-anchored growth, lensing, and full-shape constraints 10 are excluded from primary inference to reduce cross-sector GR-closure bias. Results therefore quantify the entropy slope required by late-time geometry channels under this mapping.

## II. REAL-DATA RESULTS

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### A. Primary posterior

The real-data stage reports

$$H_0 = 70.11_{-2.43}^{+2.47} \text{ km s}^{-1} \text{Mpc}^{-1}, \quad (2)$$

$$\Omega_m = 0.297_{-0.043}^{+0.058}, \quad (3)$$

with acceptance fraction 0.337 and minimum effective sample size  $\text{ESS}_{\min} \approx 3995$ .

The entropy-slope summaries are

$$\left\langle \frac{d \log \mu}{d \log A} \right\rangle = -0.23697 \pm 0.31483, \quad (4)$$

$$P\left(\frac{d \log \mu}{d \log A} > 0\right) = 0.2143, \quad (5)$$

20 so  $\sim 78.6\%$  posterior weight lies at negative slope. The

area-averaged offset statistic is consistent with small net displacement,

$$\langle m \rangle = -0.0035 \pm 0.1523. \quad (6)$$

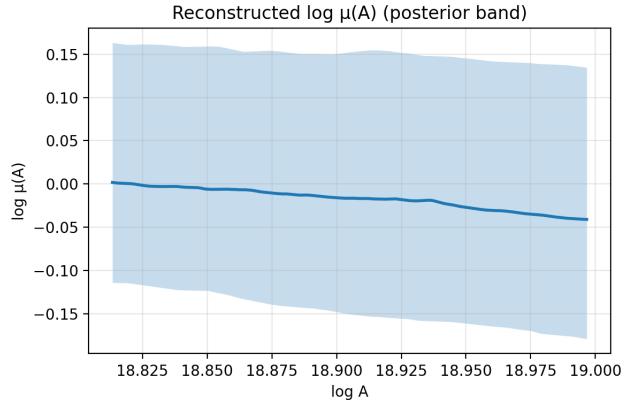


FIG. 1. Posterior band for  $\log \mu(\log A)$  from the finalized MG-unbiased real-data stage.

### B. Mapping-variant robustness

Mapping stress tests are stable relative to posterior width. Relative to the baseline variant (V1\_free), median-shape shifts are:

- V0\_fixedOm:  $\text{RMS}(\Delta \mu / \sigma) = 0.080$ ,  $\max |\Delta \log \mu| = 0.0214$ .
- V2\_residual:  $\text{RMS}(\Delta \mu / \sigma) = 0.062$ ,  $\max |\Delta \log \mu| = 0.0153$ .
- V1\_curved:  $\text{RMS}(\Delta \mu / \sigma) = 0.291$ ,  $\max |\Delta \log \mu| = 0.0562$ .

The curved-horizon nuisance is the dominant mapping perturbation but remains sub-1 $\sigma$  in RMS significance.

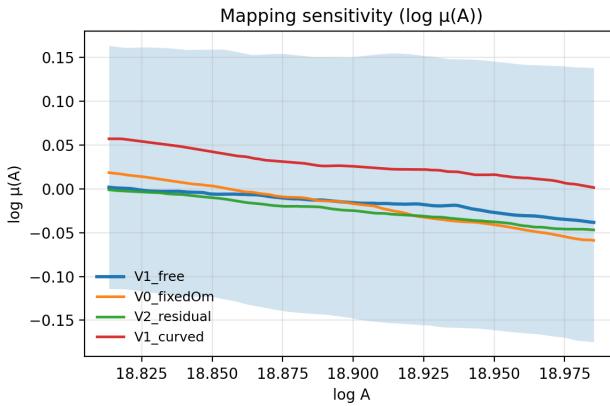


FIG. 2. Mapping-variant comparison of reconstructed  $\log \mu(\log A)$ .

### C. Function-space proximity

Weighted function-space distances to parametric families (fit to posterior mean) are

$$\begin{aligned} D_{\text{BH}}^2 &= 1.68 \times 10^{-4}, \\ D_{\text{Tsallis}}^2 &= 4.54 \times 10^{-8}, \quad D_{\text{Barrow}}^2 = 4.54 \times 10^{-8}, \\ D_{\text{Kaniadakis}}^2 &= 1.12 \times 10^{-7}. \end{aligned} \quad (7)$$

In this run, non-BH families track the reconstructed shape much better than strict BH. Best-fit summary parameters are  $\delta_{\text{Tsallis}} = 1.23697$ ,  $\Delta_{\text{Barrow}} = 0.47393$ , and  $\tilde{\beta}_{\text{Kaniadakis}} = 0.50660$ .

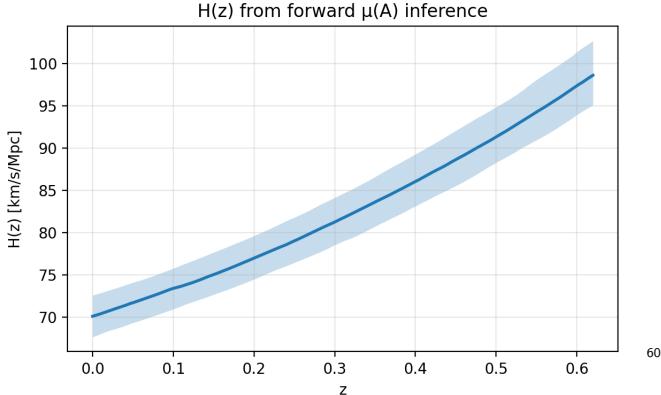


FIG. 3. Forward-reconstructed  $H(z)$  band for the same posterior draws.

## III. ABLATION AND SYNTHETIC CLOSURE

### A. Ablation suite

Seven ablation cases were executed (kernel, covariance, and smoothing variations). Across cases,

$$D_{\text{BH}}^2 \in [0.117, 0.553], \quad \min D_{\text{Kaniadakis}}^2 = 4.37 \times 10^{-3}. \quad (8)$$

The qualitative ordering is consistent with the real-data stage: non-BH families remain much closer than BH across tested settings.

### B. Synthetic BH closure (SBC)

The synthetic closure stage completed  $N = 24$  SBC realizations with BH truth. Coverage metrics are

$$\log \mu(x) : C_{68} = 0.944, C_{95} = 1.000, \quad (9)$$

$$\log \mu(\log A) : C_{68} = 0.940, C_{95} = 1.000, \quad (10)$$

$$H(z) \text{ pointwise} : C_{68} = 0.739, C_{95} = 0.981, \quad (11)$$

$$H(z) \text{ simultaneous} : C_{68} = 0.917, C_{95} = 0.958. \quad (12)$$

Sampler health remained stable. SBC acceptance was 0.3628 on average ( $p10/p50/p90 = 0.3589/0.3625/0.3693$ ). The invalid-logprob rate was  $1.00 \times 10^{-3}$  ( $p90 1.53 \times 10^{-3}$ ; max  $1.80 \times 10^{-3}$ ), dominated by prior-bound hits on  $\log \sigma_{d2}$ .

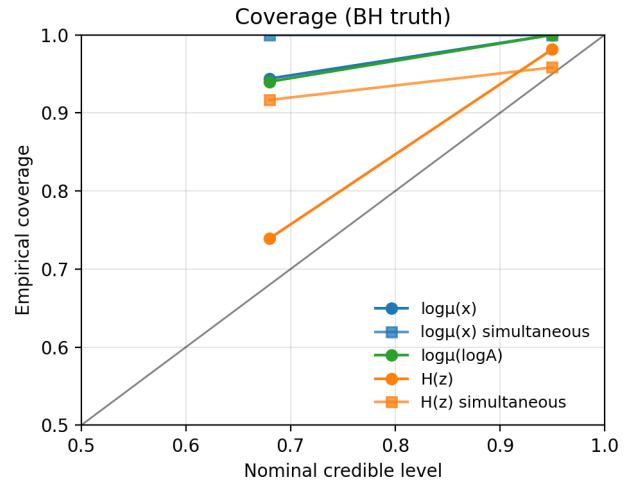


Figure: Synthetic-closure coverage summary from the BH-truth SBC stage.

## IV. CONCLUSION

The hardening pipeline completed end-to-end and returns a consistent result: under the MG-unbiased geometry profile, the recovered entropy slope is mildly-to-moderately negative in posterior mean, with broad uncertainty but clear sign preference toward negative values. Mapping-variant shifts are limited, ablation behavior is qualitatively stable, and synthetic closure calibration is healthy enough to support next-stage joint analyses.

## ACKNOWLEDGMENTS

This work used A.I. tools extensively, including ChatGPT 5.3.

## DATA AVAILABILITY AND DOIS

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- O3 modified-gravity tension anomaly repository (Zenodo): <https://doi.org/10.5281/zenodo.18585598>.  
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- O3 search-sensitivity injection data (Zenodo): <https://doi.org/10.5281/zenodo.7890437>.  
90
- GWTC-3 catalog: <https://doi.org/10.1103/PhysRevX.13.041039>.
- Pantheon+ constraints: <https://doi.org/10.347/1538-4357/ac8e04>.  
95
- Planck 2018 parameters: <https://doi.org/10.1051/0004-6361/201833910>.

- Planck 2018 lensing: <https://doi.org/10.1051/0004-6361/201833886>.
- SDSS DR12 BAO: <https://doi.org/10.1093/mnras/stx721>.
- eBOSS DR16 constraints: <https://doi.org/10.1103/PhysRevD.103.083533>.
- DESI 2024 BAO constraints: <https://doi.org/10.1088/1475-7516/2025/02/021>.
- Cosmic-chronometer component DOI: <https://doi.org/10.1088/1475-7516/2012/08/006>.
- Cosmic-chronometer component DOI: <https://doi.org/10.1103/PhysRevD.71.123001>.
- Cosmic-chronometer component DOI: <https://doi.org/10.1088/1475-7516/2010/02/008>.