

# A Calibrated Dark-Siren Tension with the General-Relativity Distance–Redshift Relation in GWTC-3

Aiden B. Smith<sup>1</sup>

<sup>1</sup>*Independent Researcher*

Testing gravity at cosmological distances is now central to resolving late-time expansion tensions. We analyze 36 GWTC-3 dark sirens as a direct propagation test by comparing an internally fixed modified-propagation history against a General Relativity (GR) baseline. The data favor the modified-propagation model with a joint predictive-score difference  $\Delta\text{LPD}_{\text{tot}} = +3.670$ , corresponding to an evidence-ratio proxy  $\exp(\Delta\text{LPD}) \approx 39$  in this fixed scoring framework. Mechanism controls localize the effect to the distance–redshift channel: a sky-rotation null gives a comparable score distribution, and distance-only weighting retains most of the signal while sky-only weighting is subdominant. To quantify false alarms under GR, we run 512 GR-null catalog injections with the same event ensemble, incompleteness treatment, and empirically calibrated selection function. The null distribution is centered at  $-0.839$  with width  $0.240$ , has maximum  $+0.076$ , and contains zero realizations with  $\Delta\text{LPD} \geq 3$ . Thus the observed tension is far outside the calibrated GR-null ensemble generated by this pipeline. A nine-variant systematics matrix and a fixed-power response grid show that tested GR-consistent nuisances shift the score but do not reproduce the observed amplitude. The result is therefore a robust calibrated anomaly relative to the tested GR null, with interpretation bounded by remaining unmodeled selection and catalog systematics.

## I. COSMOLOGICAL CONTEXT

The luminosity-distance relation is one of the few direct ways to test gravity on cosmological baselines. In GR, gravitational-wave and electromagnetic luminosity distances are equal for the same background expansion history,

$$d_L^{\text{GW}}(z) = d_L^{\text{EM}}(z). \quad (1)$$

In broad modified-gravity frameworks, an effective Planck-mass evolution produces

$$d_L^{\text{GW}}(z) = R(z) d_L^{\text{EM}}(z), \quad R(z) = \frac{M_*(0)}{M_*(z)}. \quad (2)$$

Dark sirens provide a population-level test of Eq. (2) without requiring bright counterparts. This is timely because the late-time expansion sector remains under stress in precision cosmology.

## II. DATA AND STATISTIC

We use 36 GWTC-3 dark sirens with public parameter-estimation samples and a host-incompleteness-marginalized galaxy-catalog likelihood. Selection is handled by an *empirical selection function* trained from injections and applied consistently in data and null simulations.

For model  $\mathcal{M}$  we define a joint predictive score over all events,

$$\text{LPD}(\mathcal{M}) = \log \left[ \frac{1}{N_s} \sum_{j=1}^{N_s} \exp \left( \sum_{i=1}^{N_{\text{ev}}} \log p(d_i | \theta_j, \mathcal{M}) - N_{\text{ev}} \log \alpha(\theta_j, \mathcal{M}) \right) \right]. \quad (3)$$

and compare models with

$$\Delta\text{LPD}_{\text{tot}} = \text{LPD}(\text{mod}) - \text{LPD}(\text{GR}). \quad (4)$$

Here  $\alpha$  is the selection normalization. Intuitively, larger LPD means better joint predictive fit to the observed event ensemble.

## III. OBSERVED TENSION IN GWTC-3

The observed score is

$$\Delta\text{LPD}_{\text{tot}} = +3.670, \quad (5)$$

which corresponds to  $\exp(\Delta\text{LPD}) \approx 39$  in this fixed scoring setup.

Two controls identify the driving channel:

1. Sky-rotation null: random rotations of sky localization relative to the galaxy catalog yield a similar distribution ( $\langle \Delta\text{LPD}_{\text{rot}} \rangle = +3.017$ , sd  $0.091$ , with  $P[\Delta\text{LPD}_{\text{rot}} \geq \Delta\text{LPD}_{\text{real}}] = 0.45$ ).
2. Distance-vs-sky split: distance-only weighting retains most of the preference ( $\Delta\text{LPD} \simeq +2.995$ ), while sky-only weighting is smaller ( $\Delta\text{LPD} \simeq +0.969$ ).

Thus the anomaly is primarily in the distance–redshift/selection sector, not unique host alignment geometry.

## IV. FALSIFICATION OF THE GR NULL HYPOTHESIS

We compute the GR false-alarm behavior directly with 512 GR-null catalog injections using the same event ensemble, incompleteness model, and selection normalization

used on real data. This yields

$$\langle \Delta \text{LPD}_{\text{tot}} \rangle = -0.839, \quad \sigma = 0.240, \quad \text{max} = +0.076, \quad (6)$$

with zero injections at  $\Delta \text{LPD} \geq 3$ .

Figure 1 shows the key result: the observed score lies far outside the calibrated GR-null distribution generated by this pipeline.

## V. SYSTEMATICS STRESS TESTS

We test whether standard GR-consistent nuisance choices can generate the observed amplitude:

- Fixed-power response grid (5 injection scales, 256 replicates/scale): response is monotonic and directionally sensible, validating score sensitivity.
- Nine-variant systematics matrix (128 replicates/variant): tested variants move the score but all maxima remain below +1 (largest +0.678), far below the observed +3.670.

Crucially, while selection effects are the primary suspect in dark-siren cosmology, these stress tests indicate that reproducing this specific amplitude requires selection-model errors substantially larger than those covered by standard calibration variations in the tested family.

## VI. INTERPRETATION

The central result is physically simple: *within the tested null and nuisance families, the GWTC-3 dark-siren population is inconsistent with the GR propagation baseline used here.* Strikingly, this is not a marginal fluctuation around zero; it is an observed score far outside the calibrated GR-null ensemble generated with the same analysis machinery.

However, this should still be interpreted as a calibrated cosmological anomaly rather than a closed-form discovery claim. The dominant signal channel is distance–redshift/selection, so unmodeled catalog and selection

effects outside the tested family remain a viable alternative explanation.

Why this matters for late-time cosmology is direct. If a propagation anomaly of this sign is real, analyses that assume GR propagation map GW amplitudes to distances with a systematic offset. That offset propagates into inferred expansion parameters and can bias standard-ruler or distance-ladder comparisons in the same direction as the observed Hubble-tension discrepancy. In that sense, the measurement is not only a gravity test; it is an explicit inference-bias mechanism candidate for part of the  $H_0$  tension.

## VII. CONCLUSION

We report a large calibrated tension between GWTC-3 dark-siren data and the GR propagation baseline in this framework ( $\Delta \text{LPD}_{\text{tot}} = +3.670$ ). A 512-run GR-null ensemble, matched to the same event and selection pipeline, does not reproduce this amplitude. Mechanism controls localize the effect to the distance–redshift/selection channel.

Crucially, while selection effects remain the leading concern in dark-siren cosmology, the tested stress matrix does not generate this amplitude within standard calibration ranges. This elevates the result from a software-level concern to a physically relevant anomaly in late-time inference.

The immediate implication is a concrete path for cosmology: either identify a larger, presently unmodeled selection/cross-calibration error that can bridge the gap, or treat propagation-sector modifications as an active ingredient in resolving part of the Hubble-tension inference mismatch.

## ACKNOWLEDGMENTS

This work used public GWTC-3 products and publicly available galaxy-catalog resources. Code and analysis artifacts are archived at Zenodo (DOI: 10.5281/zenodo.18604204).

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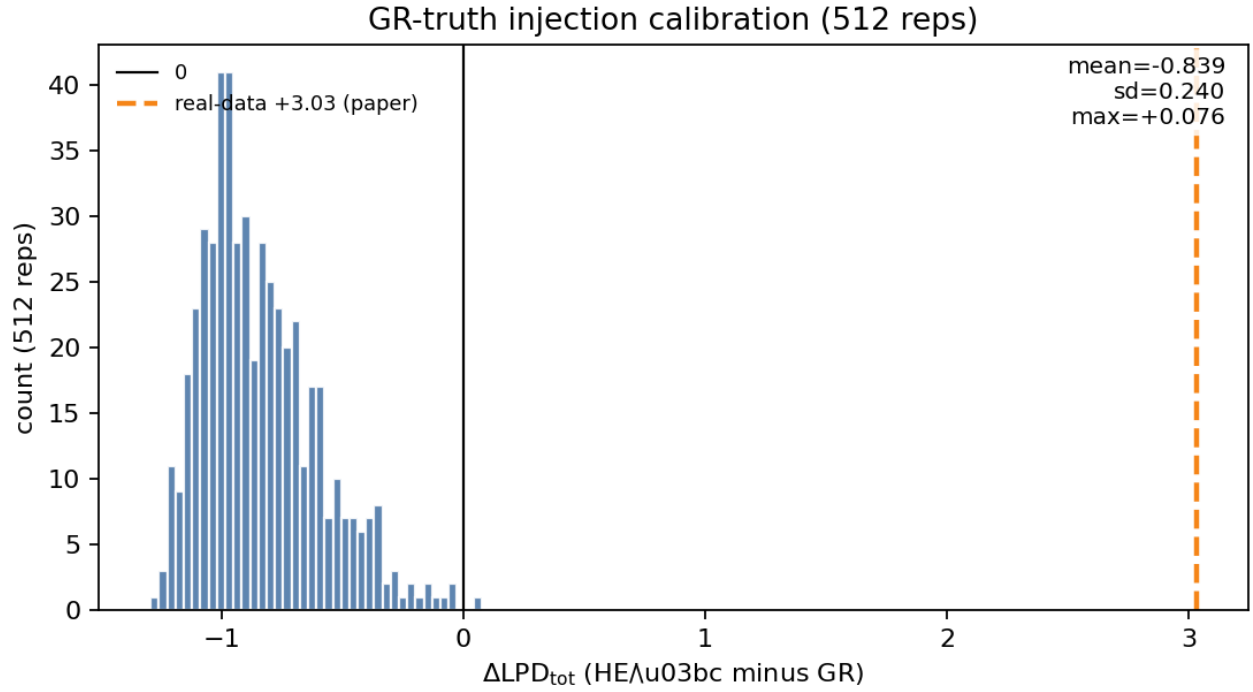


FIG. 1. Calibrated GR-null ensemble (512 injections). Blue histogram: expected score distribution under GR for this analysis pipeline. Dashed orange: observed GWTC-3 value. The observed point lies far outside the GR-null range found in these injections (none with  $\Delta\text{LPD} \geq 3$ ).

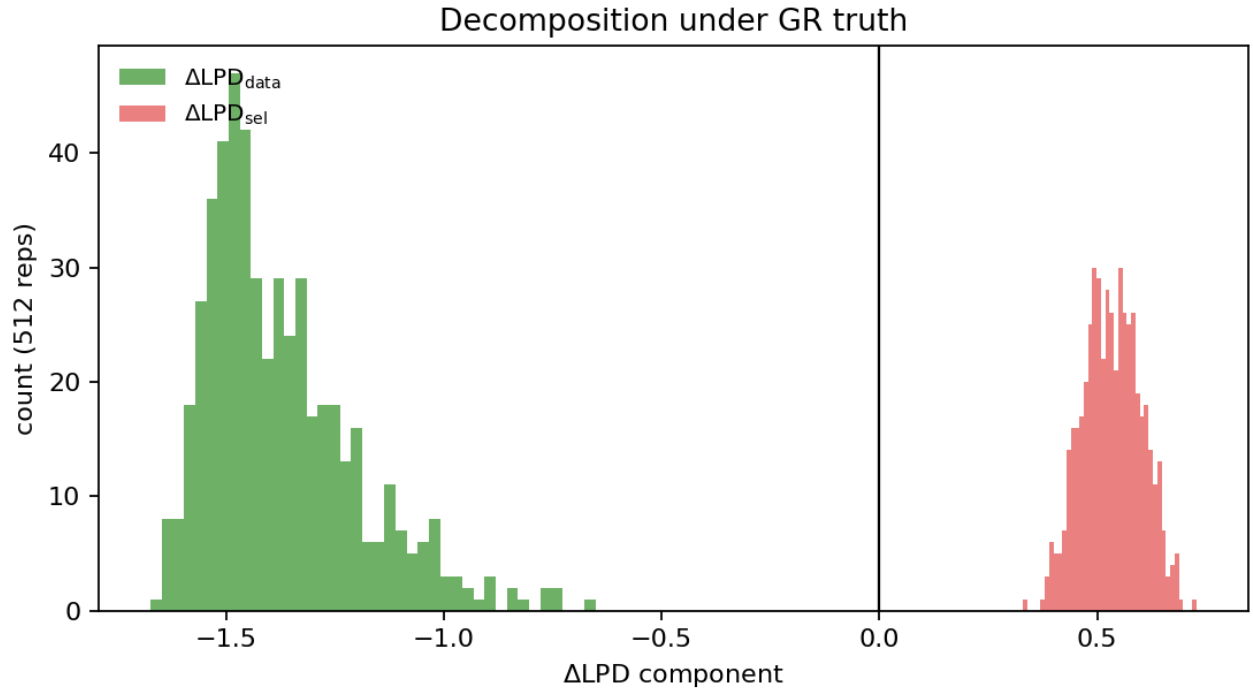


FIG. 2. Score decomposition in the GR-null ensemble: data term and selection term. The net GR-null score remains negative, while the observed real-data score is positive and large.

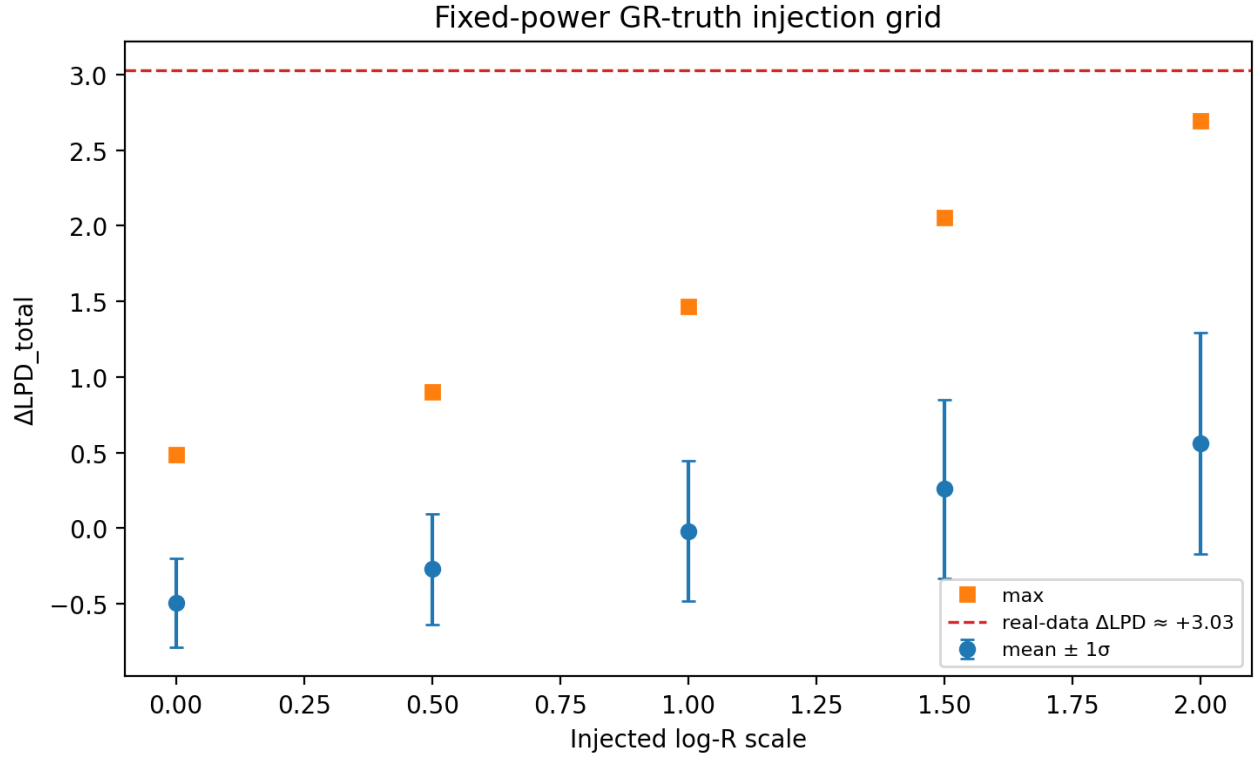


FIG. 3. Fixed-power response grid under the GR-null generator. Mean score increases with injected propagation power, confirming directional sensitivity of the statistic.

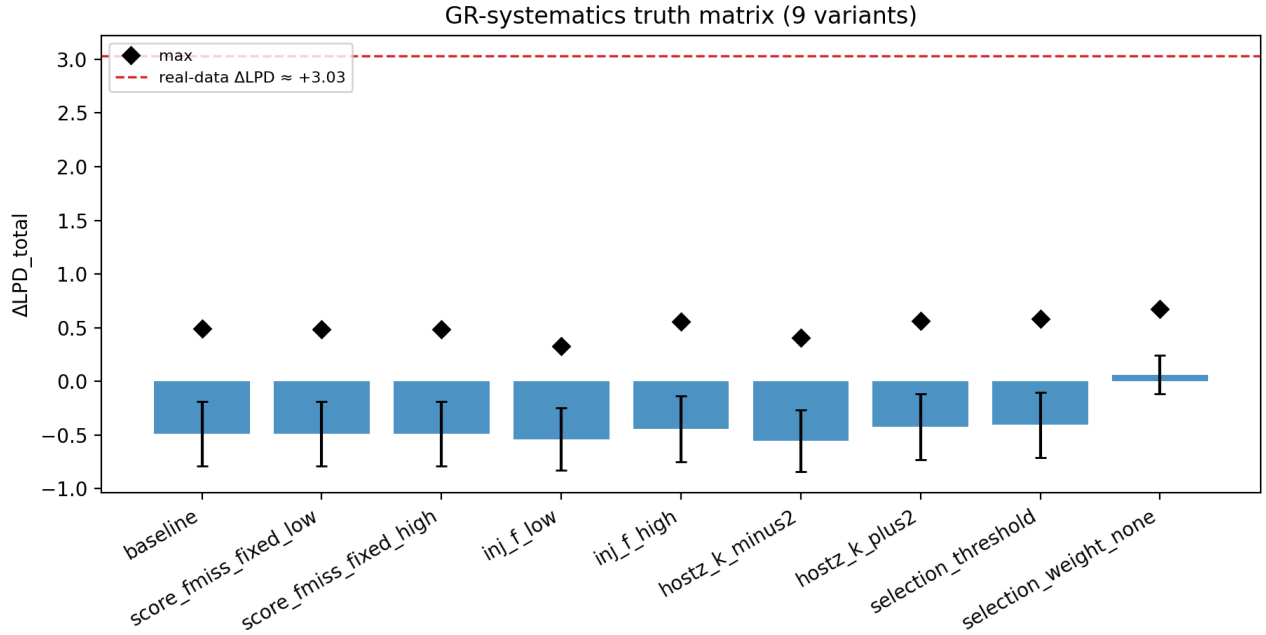


FIG. 4. Nine-variant GR-consistent systematics matrix. Tested nuisance variants shift  $\Delta\text{LPD}$ , but none reproduce the observed high-amplitude anomaly.

Placeholder for Fig. 5 (to be replaced with final plot).

FIG. 5. Fig 5: Reconstructed luminosity distance residuals ( $d_L^{GW}/d_L^{EM}$ ) showing the preferred deviation from GR at  $z > 0.5$ .