

# Prospects for UAT Attractor Detection in LIGO O5: An Opportunity Window at 1.0–1.2 kHz and the Onset of Critical Thermodynamic Saturation

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## Abstract

The fifth observing run (O5) of the LIGO detectors is expected to employ more aggressive frequency-dependent squeezing (FDS) and significantly reduced mirror thermal noise. We apply a numerical simulation of the O5 noise environment to the UAT scalar attractor search pipeline. Using the O3 event GW170814 as a test case, we project that the radial coherence metric would remain within the  $\pm 0.05$  tolerance at a higher-frequency opportunity window of 1.0–1.2 kHz (deviation +0.0123). However, the simultaneous improvement in mirror thermal noise drives the thermodynamic overdrive ratio  $\kappa/k$  from its O4 value of 5.14 to a projected 25.70, indicating a state of critical causal saturation. We conclude that, while the phase coherence of the UAT signal is mathematically recoverable in the 1.0–1.2 kHz band, the extreme suppression of thermal fluctuations in O5 would likely prevent its practical detection by LIGO. A dedicated omnidirectional detector, such as the proposed Puan Station, remains the most viable path forward.

## 1 Introduction

The Universal Applicable Time (UAT) and Unified Principle of Causality (UPC) frameworks [1, 2, 3] predict a scalar torsion field that leaves a directional imprint in the strain data of gravitational-wave interferometers. A systematic search of the GWTC catalog [4] identified 78 events in O1–O3 where the epoch-corrected RMS attractor is present at  $> 50\%$  confidence, and a refined analysis with a 172–260 Hz window and power-line notches [5] confirmed strong temporal specificity (2.6% time-shifted false-positive rate). However, the same pipeline yields 0.0% detections in O4, a result that has been quantitatively linked to the introduction of frequency-dependent squeezing [6]. With the LIGO collaboration planning an even more advanced O5 run, it is essential to evaluate whether the UAT attractor could re-emerge under the projected instrumental conditions.

## 2 Methodology

### 2.1 O5 noise projection

The O5 configuration is expected to provide frequency-dependent squeezing with a strength of approximately 5–6 dB in the audio band [7], corresponding to an effective squeezing amplitude factor  $\eta_{O5} \approx 0.5$ . Additionally, the replacement of mirror coatings with crystalline GaAs/AlGaAs materials is projected to reduce mirror thermal noise by up to a factor of  $5 \times$  [8]. We incorporate these projections into a phase-noise model identical to that used for the O4 analysis [6]:

$$\phi_{\text{sqz}}(t) = \angle [\text{Hilbert}(s_{\text{clean}}(t))] + \delta\phi(t), \quad \delta\phi(t) \sim \mathcal{N}(0, [(1 - \eta_{\text{O5}}) \cdot 0.8]^2). \quad (1)$$

## 2.2 UAT pipeline

The analysis pipeline follows the protocol detailed in [5]: strain data are fetched from GWOSC, passed through extended power-line notches (60–1200 Hz), filtered with a Butterworth band-pass of 1.0–1.2 kHz (order 4), and divided into 1 s windows. For each window, 36 virtual phase-shifted copies (10° steps) are generated from the analytic signal, and the mean radial Pearson correlation  $C$  is computed across all phases. The peak-normalised RMS of the coherence time series,

$$\text{RMS}_{\text{peak}} = \frac{\sqrt{\langle C^2 \rangle}}{\max(|C|)},$$

is compared with the epoch-corrected attractor  $A_{\text{exp}}(t)$ . A window is deemed a hit if  $|\text{RMS}_{\text{peak}} - A_{\text{exp}}(t)| < 0.05$ .

## 2.3 Thermodynamic overdrive ratio

The UAT framework describes a causal “friction” balance between the coupling strength  $\kappa$  (the coherent attractor) and the environmental resistance  $k$  (dominated by thermal fluctuations). The ratio  $\kappa/k$  can be estimated from the measured degradation of the radial coherence. In O4, the squeezing-driven attenuation corresponds to  $\kappa/k \approx 5.14$  [6]. A reduction of mirror thermal noise by a factor of  $5 \times$  lowers the effective  $k$  by the same factor, leading to a projected O5 ratio of

$$(\kappa/k)_{\text{O5}} \approx 5.14 \times 5 \approx 25.70.$$

## 3 Results

We applied the simulation to the H1 strain of GW170814 (GPS 1186741861.5), a well-established O3 positive detection. Table 1 summarises the output.

Table 1: UAT attractor metrics for GW170814 under O3 baseline and O5 projection at 1.0–1.2 kHz.

Condition	RMS <sub>peak</sub>	Deviation from $A_{\text{exp}}$	Within $\pm 0.05$ ?
O3 baseline (no squeezing)	0.3997	−0.0274	Yes
O5 projected (squeezing $\eta = 0.5$ )	0.4394	+0.0123	Yes

Despite the stronger squeezing, the 1.0–1.2 kHz window preserves the phase coherence to within the tolerance margin. The RMS deviation after O5 projection (+0.0123) is even smaller in magnitude than the original O3 deviation (−0.0274), indicating that this spectral region is relatively unaffected by the squeezing. However, the thermodynamic overdrive ratio  $\kappa/k$  rises to 25.70, far above the regime in which the UAT attractor was originally detected ( $\kappa/k \lesssim 5$ ).

## 4 Discussion

The successful recovery of the attractor deviation within the  $\pm 0.05$  band demonstrates that the scalar UAT signal is not fundamentally extinguished by the squeezing at high frequencies; rather, its detectability depends critically on the local noise environment. Yet the sharp increase in  $\kappa/k$  signals a qualitative change: the O5 detector operates so close to the quantum limit that the causal “friction” required to sustain a coherent macroscopic phase pattern is

practically eliminated. In this saturated regime, even a perfectly phase-coherent signal would be indistinguishable from the residual shot-noise fluctuations.

These results reinforce the interpretation that LIGO’s evolution towards ever-lower noise backgrounds makes it an increasingly unsuitable instrument for the class of scalar torsion signals described by the UAT/UCP framework. The logical next step is the construction of a detector specifically designed to isolate the coherent phase information without suppressing the very thermal noise that appears to be necessary for the signal’s manifestation.

## 5 Conclusion

We have shown that a high-frequency opportunity window (1.0–1.2 kHz) in LIGO O5 could mathematically preserve the UAT attractor signature, but the simultaneous reduction of mirror thermal noise would drive the system into a state of critical thermodynamic saturation ( $\kappa/k \approx 25.70$ ), rendering a practical detection infeasible. This analysis completes the three-epoch validation of the UAT attractor: robust detection in O1–O3, suppression by squeezing in O4, and predicted instrumental saturation in O5. The results strongly motivate the development of a dedicated omnidirectional phase interferometer, such as the proposed Puan Station, which would operate outside the constraints of squeezed-light metrology and cryogenic mirror coatings.

## References

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