**TRNS: Physics-Inspired Stochastic Damping for Gravitational Wave Signal Denoising Demonstration on Real LIGO GW150914 Data**

**1. Executive Summary** TRNS delivers exceptional preservation of the critical gravitational wave chirp and merger signal while providing meaningful noise reduction. On the real LIGO GW150914 event (L1 detector), TRNS achieves **0.9852 signal-region correlation** and **+7.34 dB SNR improvement** with near-perfect trend preservation.

This high-fidelity result demonstrates TRNS's ability to respect the underlying physics of transient gravitational wave signals — a capability highly relevant to current LIGO operations and future LISA mission requirements.

**2. Data Provenance**

- **Event:** GW150914 (first confirmed binary black hole merger)
- **Detector:** LIGO Livingston (L1)
- **Dataset:** Public GWOSC archive
- **Segment:** 32 seconds centered on the merger (GPS 1126259462)
- **Sample Rate:** 4096 Hz

**3. Methods** TRNS is a lightweight, physics-inspired stochastic damping operator derived from temperature-regularized Navier-Stokes principles. It applies gradient-directed stochastic updates, advection, and coherence flux to suppress noise while strongly preserving transient signal features essential for gravitational wave detection.

The approach is completely training-free and computationally efficient, making it suitable for both ground-based processing and future space-based applications.

**4. Results – Quantitative Performance**

| Metric | Value |
|---|---|
| RMS Noise Reduction | 1.38× |
| Trend Error | 0.00% |
| Full Waveform Correlation | 0.9862 |
| **Signal Region Correlation** | **0.9852** |
| **SNR Improvement** | **+7.34 dB** |
| Runtime | 7.1 ms per 1000 samples |

**5. Visual Results Caption:** LIGO GW150914 Denoising with TRNS (High-Fidelity Mode) Top: Full 32-second waveform with merger time marked (red dashed line) Bottom: Zoom on the merger event showing excellent preservation of the chirp and ringdown structure.

TRNS maintains outstanding fidelity to the raw signal shape in the critical merger region while reducing noise.

**6. Relevance to NASA Missions**

- **LIGO / Ground-based GW Detection:** Improves data quality with minimal distortion of astrophysical transients.
- **LISA (Laser Interferometer Space Antenna):** Particularly promising for space-based gravitational wave detection where low-compute, radiation-hardened, physics-based methods are highly advantageous.
- **Broader Applications:** Transferable to vibration isolation, propulsion system monitoring, and other NASA time-series analysis needs.

**7. Key Advantages**

- Exceptional signal preservation (critical for weak transient detection)
- Extremely low computational footprint — ideal for edge and onboard processing
- Training-free and physics-based (interpretable and robust)
- No reliance on large training datasets

**8. Patent Status** TRNS is protected under pending U.S. Non-Provisional Patent Application No. 19/671,179 (filed May 7, 2026, Track One prioritized examination). The invention is in the process of assignment to Meadows McKnight LLC.

**Citation:**

LIGO Scientific Collaboration and Virgo Collaboration, "Observation of Gravitational Waves from a Binary Black Hole Merger," Phys. Rev. Lett. 116, 061102 (2016)