The Analyticity Parameter of Neutron Star Post-Merger Oscillations

Is 3 Unique to Black Holes?

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Scaffold

Abstract

For black hole ringdown, the analyticity parameter = / 3 is universal — independent of mass, spin, and multipole [Paper I]. This universality originates from the topological structure of the photon sphere via the WKB approximation. Neutron star post-merger oscillations lack a photon sphere; their oscillation spectra depend on the nuclear equation of state (EOS). We compute _NS from numerical relativity simulations of binary neutron star mergers across multiple EOS models and show that _NS is EOS-dependent, ranging from [TBD] to [TBD]. This makes _NS a novel EOS discriminant, complementing the tidal deformability Λ and the dominant post-merger frequency f .

1. Introduction

[Paper I established 3 for BH QNMs. Key question: does this extend to NS?]

1.1 Why _NS Should Differ

- No light ring → WKB argument fails
- Oscillation modes (f, p, w, g) have EOS-dependent structure
- The damping rates depend on the compactness, the crust, viscosity
- _NS encodes structural information about the remnant

1.2 NS Post-Merger Spectrum

- Dominant f mode (~2-4 kHz)
- Secondary peaks: f , f , spiral-arm frequencies
- w-modes (spacetime modes) at higher frequencies
- The ratio of damping rates between these → _NS

2. Method

2.1 NR Waveforms

- Source: CoRe database (Dietrich et al.)
- Select 4-6 simulations spanning soft/stiff EOS: SLy, APR4, H4, MS1, DD2
- Extract post-merger GW signal (after merger, t > t_merger)
- Focus on the dominant (2,2) mode

2.2 Mode Extraction

- Prony/matrix pencil method for multi-frequency extraction
- Identify f (fundamental) and overtones/secondary frequencies
- Compute _n for each identified mode
- Define _NS = / (ratio of first secondary to dominant damping rate)

2.3 Comparison Framework

- BH control: compute _BH from same-mass BH QNMs
- Plot _NS(EOS) vs _BH = 3

3. Results

3.1 _NS by EOS

[Table: EOS | f (kHz) | | | _NS] [Prediction: _NS varies with EOS, potentially 1.5-5]

3.2 _NS as EOS Discriminant

- Correlation with compactness C = M/R
- Correlation with tidal deformability Λ
- Information content: does _NS add to Λ?

3.3 Comparison with BH Universality

- _BH 3 (universal)
- _NS ? (EOS-dependent)
- The difference fingerprints the object: BH vs NS from alone

4. Discussion

4.1 Observational Prospects

- Post-merger signal detectable with ET/CE at ~10 Mpc
- _NS measurable if SNR > ~20 in post-merger band
- Complementary to pre-merger tidal constraints

4.2 BH Mimickers

- If a compact object has 3 in ringdown → strong evidence for BH
- If 3 → evidence for exotic compact object or NS remnant

5. Conclusion

[_NS is EOS-dependent, making it a new observable. Combined with f and Λ, it provides a three-pronged constraint on the nuclear EOS.]

References

[TBD — key refs: Dietrich et al. CoRe database, Bauswein et al. f universal relations, Paper I]