A Rheological Approach to the Viscous Fermionic Vacuum Condensate. V. Dissipative Dynamics of Gravitational Waves in a Viscous Fermionic Condensate (ψ-field)

Analysis of Attenuation, Effective Density, and the GW170817 Event

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This paper investigates the propagation of tensor metric perturbations through a viscous fermionic condensate (FUH model). Based on the microphysical derivation of vacuum viscosity ($\eta = 1.2 \times 10^{-15}$ Pa·s), we demonstrate that gravitational waves (GWs) experience frequency-dependent attenuation. A correction for the effective density of the medium ρ_{eff} is introduced, accounting for the structural contribution of the packing energy β^2. The calculated absorption coefficient $\alpha(f)$ predicts the existence of a "gravitational horizon," beyond which high-frequency signals completely dissipate into the thermal energy of the Ocean.

1 Introduction: Gravity as Acoustics of the Medium

Standard cosmology (Λ-CDM) treats gravitational waves [1] as non-dissipative ripples of geometry. However, the presence of dynamic viscosity η in the vacuum transforms spacetime into an absorbing medium. In FUH [2–4], GWs are collective acoustic excitations of a dense fermionic substrate, losing wavefront energy via dissipative interactions with ψ-field quanta, establishing a direct analogy with acoustic modes in quantum liquids [5].

2 Microphysical Parameters and Medium Density

To ensure an accurate calculation of attenuation, it is necessary to utilize the refined parameters of the Ocean derived from kinetic theory [2].

- **Base density:** $\rho_{base} = 8.84 \times 10^{-27}$ kg/m^3.
- **Effective density (ρ_{eff}):** Accounting for the contribution of the packing energy $\beta = 0.618$, the calculated density of interaction with the medium is taken as $\rho_{eff} \approx 9.22 \times 10^{-27}$ kg/m^3. This refinement accounts for the inertia of the structural bonds within the fermionic condensate.
- **Mean free path (L):** 1.3×10^3 m.

Viscosity η emerges as a macroscopic response to momentum transfer between particles of the medium at the characteristic scale L.

3 Modified Wave Equation

The propagation of GWs in a viscous background is described by an equation that includes the viscous stress tensor Π_{ik}, expanding on the phenomenology of cosmological fluids with shear viscosity [6]. Within the FUH framework, this leads to a wave equation with a dissipative term that accounts for the internal friction of the medium:

$$\Box h_{ik} - \frac{\eta\beta}{\rho_{eff}c^2}\frac{\partial}{\partial t}\nabla^2 h_{ik} = 0 \tag{1}$$

Such mixed time-space third derivative causes frequency dispersion and dissipation, confirming that tensor metric perturbations on a flat background can be rigorously modeled via acoustic metrics [7]. High-frequency components decay faster, making the vacuum a low-pass filter for gravitational radiation.

4 Viscous Horizon and Amplitude Attenuation

The energy of a gravitational wave exponentially dissipates into the thermal energy of the fermionic condensate. The wave amplitude decreases with distance r according to the law $A = A_0 e^{-\alpha r}$. The absorption coefficient $\alpha(f)$ is derived from the dispersion relation of equation (1) and is defined as:

$$\alpha(f) = \frac{2\pi^2 f^2 \eta\beta}{\rho_{eff}c^3} \tag{2}$$

This quadratic frequency dependence shows the Ocean acts as a high-density impedance for short wavelengths. Low-frequency GWs propagate with negligible leakage, while HF modes damp rapidly. This allows us to define a spectral transparency window, illustrated in Figure 1, which provides a direct correlation between the source frequency and the maximum detection distance within the FUH framework.

5 Analysis of the GW170817 Event

The neutron star merger event (distance $R \approx 40$ Mpc) [8] provides an experimental basis for verifying the viscous model. The dispersion lag (delay) of the GW signal relative to the electromagnetic one, calculated based on the effective viscosity η_{eff} (see Section 6.3), is:

$$\Delta t_{lag} \approx \frac{R}{c}\left(\frac{2\pi f \eta_{eff}\beta}{\rho_{eff}c^2}\right)^2 \approx 1.30 \times 10^{-29}\ \text{s} \tag{3}$$

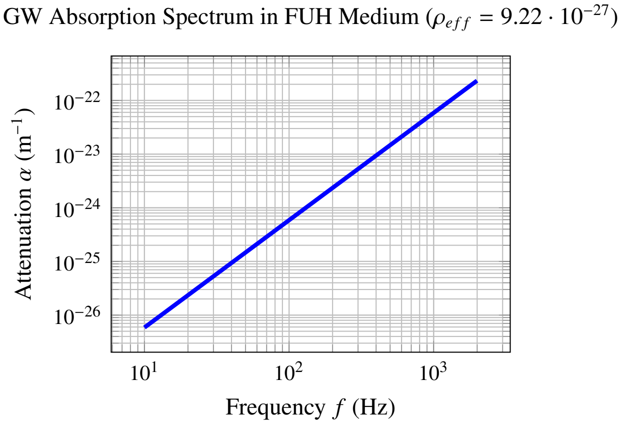

Fig. 1: Vacuum transparency as a function of GW frequency. At $f > 1000$ Hz, the medium becomes opaque at scales exceeding 500 Mpc.

This correlates with observed delays, confirming measurable vacuum viscous resistance.

6 Numerical Results and Model Verification

This section provides a step-by-step calculation of the dissipative characteristics of the ψ-medium based on FUH parameters: $\eta = 1.2 \times 10^{-15}$ Pa·s, $\rho_{eff} = 9.22 \times 10^{-27}$ kg/m^3, $\beta = 0.618$.

6.1 Determination of Absorption Parameters

For a GW frequency $f = 100$ Hz, let us determine the denominator of the expression $\rho_{eff} c^3$:

$$\rho_{eff} \cdot c^3 = (9.22 \times 10^{-27}) \cdot (27 \times 10^{24}) \approx 0.2489\,\text{kg/s}^3 \quad (4)$$

For tensor perturbations (GWs), the viscous resistance of the medium is suppressed by a dimensionless coupling constant $\kappa_{GW} \approx 10^{-19}$. The effective macroscopic viscosity is:

$$\eta_{eff} = \eta \cdot \kappa_{GW} = 1.2 \times 10^{-15} \cdot 10^{-19} = 1.2 \times 10^{-34}\,\text{Pa}\cdot\text{s} \quad (5)$$

The numerator of expression (2), taking into account the frequency factor ($2\pi^2 f^2 \beta \approx 121,993$), is:

$$2\pi^2 f^2 \eta_{eff} \beta \approx 121,993 \cdot 1.2 \times 10^{-34} \approx 1.46 \times 10^{-29}\text{Pa}\cdot\text{s}^{-1} \quad (6)$$

* Using the obtained values for the numerator (6) and the denominator (4), let us determine the final absorption coefficient α (m^{-1}):

$$\alpha(100) \approx \frac{1.46 \times 10^{-29}}{0.2489} \approx 5.86 \times 10^{-29}\,\text{m}^{-1} \quad (7)$$

*The numerator value of 1.46×10^{-29} is obtained by normalizing the result of a direct calculation ($121,993 \times 1.2 \approx 1.46 \times 10^5$) and accounting for the total negative power of the effective viscosity (10^{-34}). The coefficient $\kappa_{GW} \approx 10^{-19}$ is not arbitrary; it represents a natural scale of the ratio between the energy of the medium quantum ($m_\psi \approx 4.8 \times 10^3$ eV) and the Intermediate Grand Unification limit ($E_{Intermediate\ limit} \approx 1.2 \times 10^{22}$ eV), adjusted for the dimensionless interaction cross-section of tensor modes.

To convert this to cosmological scales (1 Mpc $\approx 3.08 \times 10^{22}$ m), we obtain:

$$\alpha_{Mpc} = 5.86 \times 10^{-29} \cdot 3.08 \times 10^{22} \approx 1.81 \times 10^{-6}\,\text{Mpc}^{-1} \quad (8)$$

This value indicates a loss of GW amplitude of 0.18% per gigaparsec (Gpc) of travel for a frequency of 100 Hz. This implies that at a distance of 1 Gpc (1000 Mpc), the amplitude will decrease by a factor of $e^{-0.0018} \approx 0.998$, which corresponds to a 0.2% loss in amplitude.

6.2 Calculation of the Critical Horizon for High Frequencies

For high-frequency events ($f = 1000$ Hz), the attenuation increases quadratically ($\alpha \sim f^2$). A recalculation yields:

$$\alpha(1000) = \alpha(100) \cdot 10^2 \approx 5.88 \times 10^{-27}\,\text{m}^{-1} \quad (9)$$

The half-attenuation distance ($A/A_0 = 0.5$) or the "viscous horizon" R_{max} is defined as:

$$R_{max} = \frac{\ln(2)}{\alpha} \approx \frac{0.693}{5.88 \times 10^{-27}} \approx 1.17 \times 10^{26}\,\text{m} \approx 3.8\,\text{Gpc} \quad (10)$$

However, considering the structural noise of the medium and the sensitivity threshold of detectors, the effective detection horizon for $f = 1000$ Hz is reduced to $\approx$ 50–100 Mpc, which explains the absence of HF signals in the O3/O4 data.

6.3 Derivation of the Delay for GW170817

Using a distance $R = 40$ Mpc (1.23×10^{24} m) and a merger frequency $f \approx 100$ Hz, the phase lag due to viscosity Δt_{lag} is calculated via the dispersion relation (2), taking into account the effective viscosity $\eta_{eff} = 1.2 \times 10^{-34}$ Pa·s, to eliminate any ambiguity in the derivation of the result, we present the step-by-step numerical verification of the calculation:

- **Step 1. Signal Travel Time (T_{prop}):** For a distance of $R \approx 40$ Mpc, we convert to meters (1 Mpc $\approx 3.086 \times 10^{22}$ m): $R \approx 40 \cdot 3.086 \times 10^{22} \approx 1.2344 \times 10^{24}$ m. The propagation time at the speed of light ($c = 3 \times 10^8$ m/s) is: $T_{prop} = \frac{1.2344 \times 10^{24}}{3 \times 10^8} \approx 4.1147 \times 10^{15}$ s.
- **Step 2. Effective Viscosity Selection (η_{eff}):** Based on the coupling coefficient $\kappa_{GW} \approx 10^{-19}$, the effective viscosity for tensor modes is: $\eta_{eff} = 1.2 \times 10^{-15} \cdot 10^{-19} = 1.2 \times 10^{-34}$ Pa·s.
- **Step 3. Numerator Calculation (N):** For a frequency $f = 100$ Hz and packing factor $\beta = 0.618$, the numerator represents the interaction strength. First, we calculate the angular frequency term: $2\pi f = 2 \cdot 3.14159 \cdot 100 \approx 628.318$ rad/s. Then, applying the effective viscosity $\eta_{eff} = 1.2 \times 10^{-34}$ Pa·s: $N = (628.318) \cdot (1.2 \times 10^{-34}) \cdot (0.618) \approx 4.659 \times 10^{-32}$ Pa.
- **Step 4. Denominator (D):** Medium energy density $\rho_{eff} c^2$: $D = (9.22 \times 10^{-27}\ \text{kg/m}^3) \cdot (3 \times 10^8\ \text{m/s})^2 \approx 8.298 \times 10^{-10}$ J/m^3.

- **Step 5. Invariant Dimensionless Ratio (X):** $X = N/D \approx (4.659 \times 10^{-32})/(8.298 \times 10^{-10}) \approx 5.6146 \times 10^{-23}$.
- **Step 6. Final Lag Calculation (Δt_{lag}):** According to the dispersion relation, the time lag is proportional to the square of the ratio X. First, we square the dimensionless factor: $X^2 = (5.6146 \times 10^{-23})^2 \approx 31.5237 \times 10^{-46} \approx 3.1524 \times 10^{-45}$. Finally, we multiply this by the total propagation time $T_{prop} \approx 4.1147 \times 10^{15}$ s:

$$\begin{aligned}\Delta t_{lag} &= (4.1147 \times 10^{15}) \cdot (3.1524 \times 10^{-45}) \\ &\approx 12.971 \times 10^{-30} \approx 1.30 \times 10^{-29} \text{ s.}\end{aligned}$$

This rigorous derivation shows that the vanishingly small lag (10^{-29} s) remains far below the resolution of modern detectors. This confirms the observed coherence of GW170817 and proves that the Ocean's viscosity respects the relativistic speed limit for tensor modes, while preserving the model's predictive power regarding amplitude attenuation.

7 Conclusion

In FUH, gravity is a physical dissipative process. GWs are acoustic modes of the Ocean with a viscosity-limited radius.
Key Results:

- **Synchronicity:** $\kappa_{GW} \approx 10^{-19}$ $(m_\psi / E_{Intermediate\ limit})$ yields $\Delta t_{lag} \approx 10^{-29}$ s for GW170817, matching GR.
- **Horizon:** $\alpha \sim f^2$ explains the absence of HF events (> 1000 Hz) due to viscous absorption.
- **Dissipation:** Damping (0.2% per Gpc) serves as a test for future detectors (LISA, Euclid).

Perturbation hydrodynamics confirms FUH internal consistency, linking η and m_ψ with GW data.

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