Maxwell's Equations with a Measurement-Dependent Collapsible Field

Classical electrodynamics assumes that electromagnetic fields are fully observable and that measurement plays no dynamical role in their evolution. However, recent advances in quantum measurement theory have demonstrated that measurement strength itself can drive dynamical transitions, separating coherent and suppressed regimes in physical systems[1,2]. These findings motivate the exploration of whether analogous, measurement dependent effects can arise within classical field theories while remaining experimentally accessible. A longstanding challenge is to determine whether transient, coherence dependent phenomena can be incorporated into Maxwell's theory without introducing new fundamental forces or modifying spacetime geometry. It remains unclear whether collapse like suppression can be formulated consistently at the level of electromagnetic fields, rather than being imposed externally. Here we show that introducing a hidden, collapsible field into Maxwell's equations yields transient modifications of electromagnetic propagation, energy redistribution, and effective force like dynamics that vanish smoothly under measurement-controlled collapse. Numerical simulations reveal a clear source–mediator–sink paradigm governed by the collapse rate, defining whether hidden coherence temporarily amplifies, redistributes, or suppresses observable effects. Unlike theories of modified gravity, the present framework does not source spacetime curvature but is consistent with analogue approaches in which effective forces emerge from internal field structure rather than geometry[3]. Related studies have shown that internal electromagnetic mode coupling can produce zitterbewegung like motion and momentum exchange in structured photonic systems, confirming that subtle, force like dynamics can arise without new interactions[4,5]. Importantly, the predicted effects can be probed using existing high coherence platforms operating in weak or dispersive measurement regimes, such as phase only interferometric and cavity based techniques, enabling experimental tests that preserve coherence while remaining sensitive to transient hidden field influence[6].

References

1. Noel, C. et al. Measurement-induced quantum phases realized in a trapped-ion quantum computer. Nat. Phys. 18, 760–764 (2022).

2. Agrawal, U., Lopez-Piqueres, J., Vasseur, R., Gopalakrishnan, S. & Potter, A. C. Observing quantum measurement collapse as a learnability phase transition. Phys. Rev. X 14, 041012 (2024).

3. Almeida, C. R. & Jacquet, M. J. Analogue gravity and the Hawking effect: historical perspective and literature review. Eur. Phys. J. H 48, 15 (2023).

4. Lovett, S. et al. Observation of zitterbewegung in photonic microcavities. Light: Sci. Appl. 12, 126 (2023).

5. Cahaya, A. B. Zitterbewegung, momentum and spin dynamics of electromagnetic waves in a linear dielectric medium. Phys. Rev. A 112, 033721 (2025).

6. Lee, J. et al. Real-time observation of the spin Hall effect of light using metasurface-enabled single-shot weak measurements. Nat. Commun. 16, 2699 (2025).