Relativistic frame-dragging and the Hong-Ou-Mandel dip

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Anthony J. Brady

General relativity and quantum mechanics constitute the foundation of modern physics, yet at seemingly disparate scales. On the one hand, general relativity predicts deviations from the Newtonian concepts of absolute space and time — due to the mass-energy distribution of nearby matter and by way of the equivalence principle — which appear observable only at large-distance scales or with high-precision measurement devices. On the other hand, quantum mechanics predicts deviations from Newtonian concepts of deterministic reality and locality and appears to dominate in regimes in which general relativistic effects are typically and safely ignored. This dichotomous paradigm of modern physics is, however, rapidly changing due to a) the ever-increasing improvement of quantum measurement strategies and precise control of quantum technologies and b) current efforts to extend quantum mechanical demonstrations to large-distance scales — like, e.g., bringing the quantum to space [1,2].

These technological developments complement the theoretical developments of quantum fields in curved space — a formal description of quantum fields propagating on a (classical) background curved space-time — which has matured over the last fifty-odd years. Alas, even with such progression, there has not yet been a single observation concurrently requiring the principles of general relativity and quantum mechanics for its explanation. The present thus seems a ripe time to furnish proof-of-principle demonstrations capable of probing these fundamental theories, in tandem. Such is the aim of our work.

In this report, we investigate the Hong-Ou-Mandel (HOM) effect — a two-photon quantum-interference effect — in the space-time of a rotating spherical mass (the earth), for various interferometric configurations. We show that, in principle, general relativistic frame-dragging — due to the mass current of the earth — induces observable changes in HOM interference signatures. For completeness and correspondence with current literature, we also analyze the emergence of gravitational time-dilation effects in HOM interference, for a dual-arm configuration. The formalism thus presented is quite extensive and allows for easy encoding of general relativistic effects into local, multi-photon, quantum-interference phenomena. The landscape of proof-of-principle demonstrations (like these) is quite fruitful [1,3,4], with great potentiality for near-term manifestation in space [2,5] or in a terrestrial setting [6]. Further, demonstration of such instances would signify genuine observations of quantum and general relativistic effects, in tandem, and would also extend the domain of validity of general relativity, to the arena of quantum electromagnetic fields.

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