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Backreaction Problems in Moving Atoms, Radiating Black Holes and the Early Universe via Generalized Fluctuation-Dissipation Relations

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“Backreaction” in gravitation and cosmology is a difficult yet important class of problems imbued with many challenging issues of theoretical physics. It studies how quantum field processes like cosmological particle creation affect the dynamics of the early universe, how Hawking radiation back-reacts and changes the fate of a black hole. Research in this field began in the late 70’s, with tools from quantum field theory in curved spacetime and its higher level extensions, semiclassical gravity of the 80’s and stochastic gravity of the 90’s [1]. New insights were added since then from nonequilibrium quantum field theory [2] using open quantum system ideas and techniques. An interesting theme is the use of fluctuation-dissipation relations (FDR) to capture the backreaction of quantum fields and their fluctuations on the dynamics of the background spacetime and its fluctuations, known as metric fluctuations or spacetime foams. In this talk I first mention samples of important work on this topic, exposing the insufficiency of linear response theory [3] and the mismatches in earlier proposals [4], then summarize the results of Raval, Hu and Anglin [5] based on stochastic field theory methods. While studying N moving Unruh-DeWitt detectors or harmonic atoms in a quantum field, these authors showed the existence of FDR between any one detector and the quantum field. They also discovered a new set of relations called the correlation-propagation relations (CPR) between two moving detectors via the quantum field. We then describe recent results by J. T. Hsiang et al [6][7] in the derivation of the FDR-CPR combination for moving detectors. This matrix relation, called the generalized FDR, ensures self-consistency in the backreaction of quantum field processes on the detectors. Interpreting these results in the open quantum system perspective, with the detectors playing the role of atoms, or quantum black holes as atoms, these relations provide rare physical insights into the backreaction problems of quantum processes in moving atoms, radiating black holes and the early universe.

[1] See, e.g., B. L. Hu and E. Verdaguer, *Semiclassical and Stochastic Gravity* (Cambridge UP 2020)

[2] See, e.g., E. Calzetta and B. L. Hu, *Nonequilibrium Quantum Field Theory* (Cambridge UP 2008)

[3] E. Mottola, *Phys. Rev. D* 33, 2136 (1986)

[4] P. Candelas and D. W. Sciama, *Phys. Rev. Lett.* 38, 1372 (1977)

[5] A. Raval, B. L. Hu and J. Anglin, *Phys. Rev. D* 53, 7003 (1996).

[6] J.-T. Hsiang, B. L. Hu, and S.-Y. Lin, *Fluctuation-Dissipation and Correlation-Propagation Relations from the Nonequilibrium Dynamics of Detector-Quantum Field Systems* arXiv:1905.08596 (submitted to PRD)

[7] J.-T. Hsiang, B. L. Hu, S.-Y. Lin and K. Yamamoto, *Fluctuation-Dissipation and Correlation-Propagation Relations in 4D for Uniformly-Accelerated Detectors in a Quantum Field* (prepared for PLB)

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