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Backreaction of Quantum Fields on Moving Atoms, Black Holes and the Early Universe

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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. They are combined into a set of **generalized FDR** by Hsiang *et al* [6][7] recently. This matrix relation ensures the self-consistency in the backreaction of quantum field processes on the detectors. In the open quantum system perspective these relations provide deeper physical insights into the backreaction problems of quantum field processes in moving atoms, radiating black holes and the early universe. For latest results on FDRs in the context of **quantum thermodynamics**, see, e.g., [8].

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

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

[3] E. Mottola, Phys. Rev. D33, 2136 (1986). [4] P. Candelas and D. W. Sciama, Phys. Rev. Lett. 38, 1372 (1977)

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[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 Phys. Rev. D*100, *025019* (2019)

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[8] J.-T. Hsiang and B. L. Hu, *Fluctuation-Dissipation Relation for a Quantum Brownian Oscillator in a Parametrically Squeezed Thermal Field*, Ann. Phys. 433, (2021) 168594
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