Open Quantum Dynamics and Dissipative State Selection in Nanoplasmonic Cavities

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Nanoplasmonic cavities realise an extreme regime of cavity quantum electrodynamics in which strong light-matter coupling emerges at the few-nanometre, few-femtosecond scale under intrinsically open, lossy, and dispersive conditions [1-4]. In contrast to conventional high-Q cavities, these systems operate far from the closed, Hermitian limit, raising fundamental questions on the role of dissipation, mode non-orthogonality, and the quantum description of radiative leakage. Here we develop a unified framework that connects experimentally accessible nanoplasmonic architectures [5,6] with a rigorous open-system quantization. In waveguide-coupled configurations, quantum nanoplasmonic coherent perfect absorption (qnCPA) [7] enables selective excitation and stabilization of dressed states through impedance matching, illustrating how dissipation and driving can be coherently balanced to control quantum states in non-Hermitian environments. On the theoretical side, a quantum quasinormal-mode (QNM) approach [8], rooted in macroscopic QED, provides a consistent quantization of open resonators via complex mode expansions and perfectly matched layers. This yields a modal Fock-space formulation and a microscopically derived Lindblad dynamics that captures both coherent and dissipative inter-mode coupling. These results establish nanoplasmonic cavities as a model platform for exploring quantum dynamics in open, non-Hermitian systems, where loss is not merely detrimental but can be harnessed as a resource for state preparation and control.

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[1] R. Chikkaraddy, B. de Nijs, F. Benz, S. J. Barrow, O. A. Scherman, E. Rosta, A. Demetriadou, P. Fox, O. Hess, and J. J. Baumberg, Nature 535 (2016) 127.

[2] N. Kongsuwan, A. Demetriadou, R. Chikkaraddy, F. Benz, V. A. Turek, U. F. Keyser, J. J. Baumberg, and O. Hess, ACS Photonics 5 (2018) 186.

[3] H. Groß, J. M. Hamm, T. Tufarelli, O. Hess, and B. Hecht, Sci. Adv. 4 (2018) eaar4906.

[4] X. Xiong, N. Kongsuwan, Y. Lai, C. E. Png, L. Wu, and O. Hess, Appl. Phys. Lett. 118 (2021) 130501.

[5] D. D. A. Clarke and O. Hess, PhotoniX 5 (2024) 33.

[6] O. Hess, Eur. Phys. J. Spec. Top. (2025).

[7] Y. Lai, D. D. A. Clarke, P. Grimm, A. Devi, D. Wigger, T. Helbig, T. Hofmann, R. Thomale, J.-S. Huang, B. Hecht, O. Hess, Nat. Commun. 15 (2024) 6324.

[8] L. Meschede, D. D. A. Clarke, and O. Hess, APL Quantum 3 (2026) 016103.