Max-Planck-Institut für
Struktur und Dynamik der Materie

Max Planck Institute for the Structure and Dynamics of Matter

IMPRS UFAST Call for PhD applications 2026/2027

MM - Light-matter hybrids: Engineering correlated matter with quantum electromagnetic fluctuations

Title of PhD Project	**Light-matter hybrids: Engineering correlated matter with quantum electromagnetic fluctuations**
Type	Theory
Supervisor(s)	Dr. Marios Michael
Affiliation(s):	UHH
Number of positions:	1
Abstract:	This PhD project will explore how quantum electromagnetic fluctuations can be harnessed to control correlated phases of matter. Strong confinement of electromagnetic fields in cavities and nanophotonic structures can substantially modify vacuum fluctuations experienced by a material, opening possibilities for manipulating superconductivity, magnetism, ferroelectricity, and other collective phases. Existing theoretical descriptions, however, often rely on effective single-mode models and therefore cannot reliably predict the effects of realistic photonic environments. The student will develop a **field theoretical multi-mode** framework **of cavity–matter hybrids**, combining quantum electrodynamics with many-body physics. Starting from idealized cavity geometries, the project will quantify changes in electromagnetic vacuum fluctuations relative to free space and determine their influence on electronic and collective degrees of freedom. The framework will subsequently be extended to realistic nanophotonic and plasmonic structures, including surface-polaritonic platforms and metamaterials, where deep-subwavelength confinement can produce ultrastrong light–matter coupling. Ultimately, these methods will be applied to correlated and two-dimensional materials to identify photonic environments capable of stabilizing, suppressing, or enhancing many-body phases, with particular emphasis on superconductivity. The project aims to establish predictive principles for designing cavity–matter hybrids and guiding future experiments. Cavity-altered superconductivity, Nature volume 650, 864–868 (2026) Surface-Mediated Ultrastrong Cavity Coupling of Two-Dimensional Itinerant Electrons, Phys. Rev. Lett. 135, 156902 (2025) Equilibrium nonlinear phononics by electric field fluctuations of terahertz cavities, Phys. Rev. Research 7, 033163 (2025)
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