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Two-dimensional Coulomb crystals: from structural transitions to quantum interfacesTBA

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The self-organization of strongly interacting particles in confined geometries gives rise to a variety of structural phenomena that are relevant both to fundamental physics and to the advancement of controllable quantum systems. Two-dimensional Coulomb crystals of trapped ions provide an ideal platform to explore these effects and represent one of the most promising routes toward scalable ion-based quantum processors.

We report on two structural phenomena in such crystals that highlight the complex interplay between trapping geometry and interactions. First, we investigate orientational melting, a transition specific to mesoscopic two-dimensional systems in which ions lose angular order while remaining radially localized [1]. Second, we explore structural bistability and demonstrate how configuration changes can emulate molecular isomerization [2]. Using Monte Carlo simulations, we map the potential energy surface of a six-ion crystal and identify a double-well structure supporting two coexisting metastable isomers. Experimentally, we resolve the occupation dynamics between these isomers with sub-millisecond resolution.

Finally, I will discuss the perspective of integrating two-dimensional Coulomb crystals into a bow-tie optical cavity. In contrast to conventional Fabry–Perot resonators, the bow-tie geometry provides uniform coupling between the entire ion crystal and the optical mode, offering a promising route toward distributed quantum computing architectures. Moreover, this configuration enables the generation of deep optical potentials for micromotion-free optical trapping of two-dimensional crystals [3], with the prospect of reaching lower temperatures and exploring the role of quantum fluctuations in structural transitions.

[1] N. Mizukami et al. arXiv2508.05902
[2] L. Duca et al. Phys. Rev. Lett. 131, 083602 (2023)
[3] E. Perego et al. Appl. Sci. 10, 2222 (2020)

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