

Towards trapped ions coupled to a running-wave optical cavity

N. Mizukami^{1,2}, G. Gatta^{2,3}, A. K. Parameswaran^{1,2,4}, M. S. Caracas², L. Duca^{1,2}, C. Sias^{1,2}

1. INRiM, Strada delle Cacce 91, 10135 Torino, Italy

2. LENS, Via Nello Carrara 1, 50019 Sesto Fiorentino FI, Italy

3. Università degli Studi di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino FI, Italy

4. Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Italy

Abstract: Trapped ions form shell structures in two-dimensional confinement, providing a suitable platform for simulating mesoscopic systems. We are working toward coupling this system to a running-wave optical cavity.

Trapped ions are an ideal platform for simulating both classical and quantum phenomena at the mesoscopic scale, owing to their precise controllability and single-particle-level detection. Under strong confinement along one axis, ions self-organize into a two-dimensional configuration, which is particularly notable due to its shell structure resembling the Thomson model of an atom.

To realize two-dimensional confinement, we have developed a linear Paul trap with a special design in which endcap electrodes are oriented differently from those in conventional designs [1]. Using the resulting two-dimensional Coulomb crystals, we have previously observed orientational melting, where the shell structure melts in the rotational degrees of freedom while remaining crystalline in the radial direction [2]. Furthermore, we have demonstrated structural transitions between distinct stable configurations analogous to molecular isomerization [3].

We are currently working to extend these experiments into the quantum regime by further reducing the ion temperature. To this end, we plan to employ an optical potential instead of an RF field in order to eliminate excess micromotion. To generate strong optical field, we have developed a running-wave optical cavity with a finesse exceeding 10,000. In addition, we are developing a laser source which will be coupled to this optical cavity to characterize the interaction between trapped ions and the cavity.

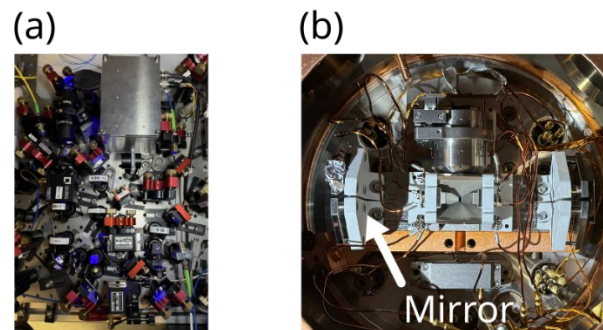


Fig. (a) Laser source and (b) an optical cavity for coupling ions.

References

- [1] E. Perego, L. Duca, and C. Sias, "Electro-Optical Ion Trap for Experiments with Atom-Ion Quantum Hybrid Systems," *Appl. Sci.* **10**, 2222 (2020).
- [2] L. Duca, N. Mizukami, E. Perego, M. Inguscio and C. Sias, "Orientational Melting in a Mesoscopic System of Charged Particles," *Phys. Rev. Lett.* **131**, 083602 (2023).
- [3] N. Mizukami, G. Gatta, L. Duca, and C. Sias, "Emulating isomerization with two-dimensional Coulomb crystals," arXiv:2508.05902 (2025).