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Emergence of fluid behaviour, atom by atom

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As an effective theory, hydrodynamics provides a successful framework to effectively describe the dynamics of many-body systems by introducing macroscopic quantities such as particle densities and fluid velocities. It requires coarse graining over microscopic constituents to define a macroscopic fluid cell, which is large compared to the interparticle spacing and the mean free path. In addition, the entire system must consist of many such fluid cells.

The requirement on the system size has been challenged by experiments with high-energy heavy-ion collisions, where collective particle emission - typically associated with the formation of a hydrodynamic medium - has been observed with few tens of final-state particles . In our experiments we find emergergence of hydrodynamics in a system with significantly less constituents by observing the inversion of the aspect ratio of an initially elliptic cloud.

Our observation challenges the requirements for a hydrodynamic description, as in our system all relevant length scales, i.e. the system size, the inter-particle spacing, and the mean free path are comparable. The single particle resolution and deterministic control over particle number and interaction strength in our experiment allow us to explore the boundaries between a microscopic description and a hydrodynamic framework in unprecedented detail. In particular, we are also able to quantitatively study fluid properties in our tiny systems by exciting collective modes such as a quadrupole or a compression mode.

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