Electrons on helium surface: a platform for studying disorder-free many-body physics

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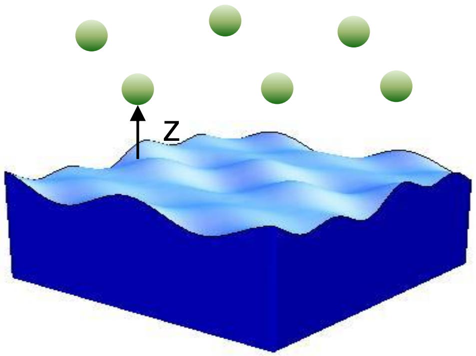
A strongly correlated electron system: $\Gamma = \frac{\text{Coulomb energy}}{\text{Kinetic energy}} \quad \frac{e^2(\pi n)^{1/2}}{k_B T} > 20$

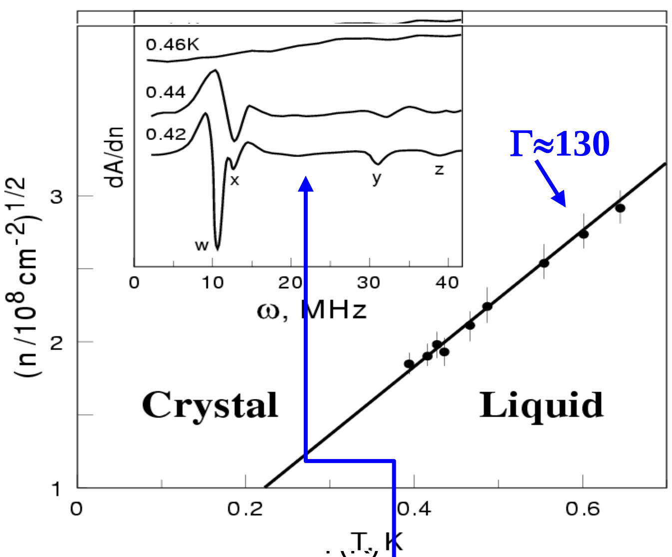


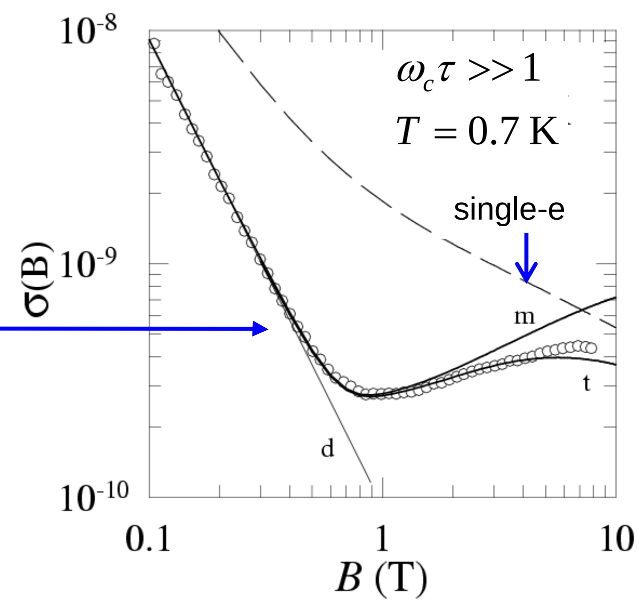
- States of individual electrons can be quantized
- Wave functions of different electrons do not overlap but the ***electron dynamics is affected by the strong e-e interaction***
- Coupling to the quantum field of surface vibrations. The coupling strength can be controlled. Polaronic effects, scattering, etc. are strongly affected by the electron correlations – new physics

$$\Gamma = \frac{\text{Coulomb energy}}{\text{Kinetic energy}} = \frac{e^2(\pi n_s)^{1/2}}{kT} > 20$$

Wigner crystallization

Correlated electron liquid





Grimes & Adams (1979); Fisher, Halperin, & Platzman (1979).

MD et al. (1993); Lea &MD (1998)

Resonances at the frequencies of capillary waves with **q=G,** reciprocal lattice vectors

Short-wavelength scattering by capillary waves with the momentum transferred to the electron liquid. **Instead of quantum Hall!**

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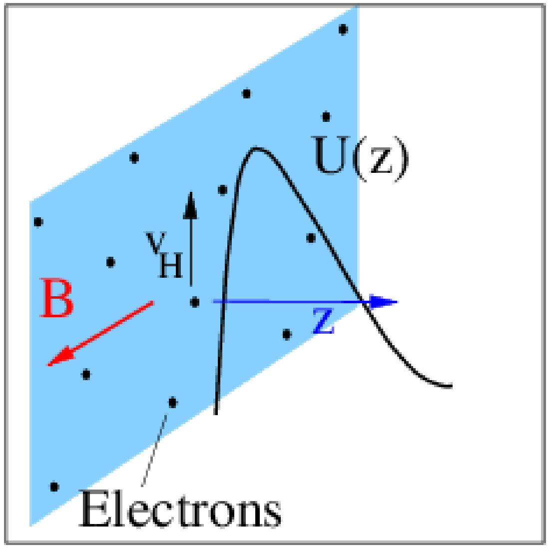
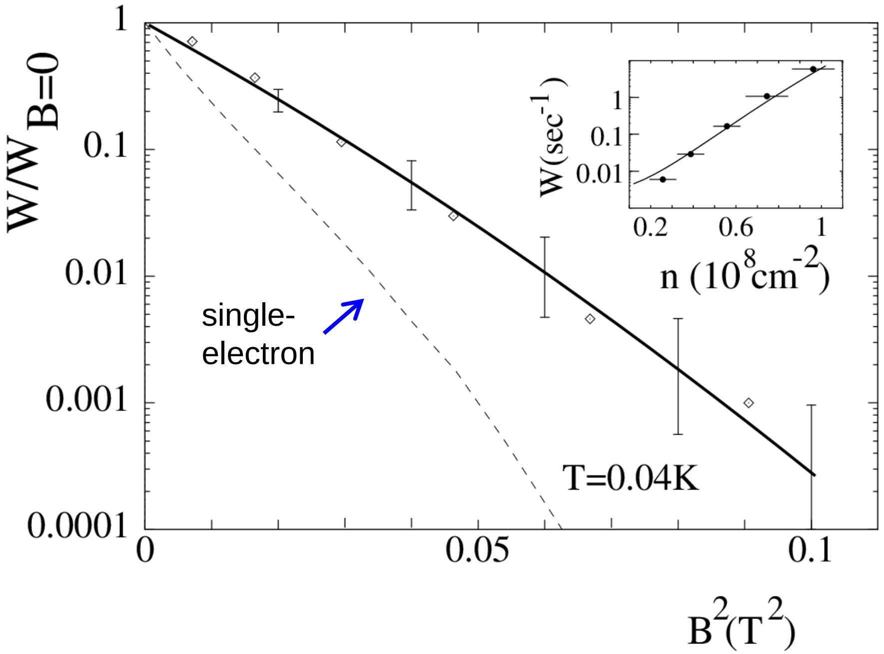
Many-electron tunneling from the 2D layer transverse to a magnetic field

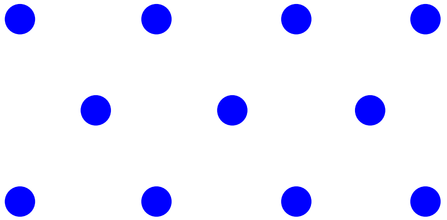




Experiment: Menna et al. (1993); theory MD, Sharpee, & Platzman (2001

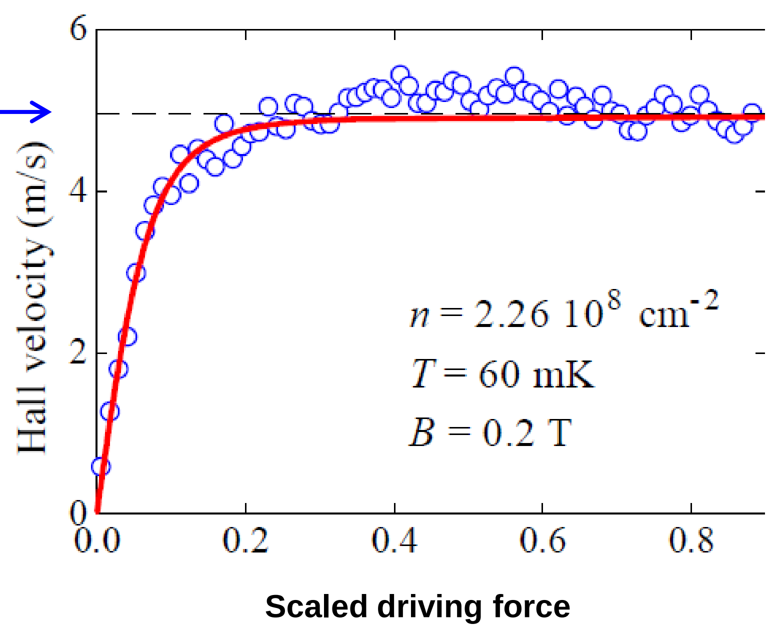
Mössbauer-type momentum transfer from the tunneling electron to the correlated electron system

Many-electron „sound barrier“ and stick-slip transitions

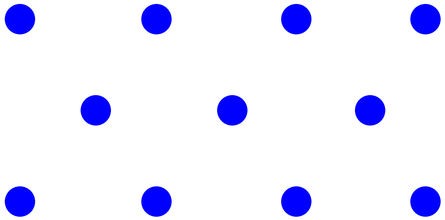


Bragg-Cherenkov many-electron friction: where the ripplon frequency $\boldsymbol{\omega}(\mathbf{G}) = \mathbf{v}\cdot\mathbf{G}$, all ripplons are emitted in phase **The force on the Wigner crystal** $\propto N^2 \Longrightarrow$ **“many-electron sound barrier”**

Bragg-Cherenkov barrier

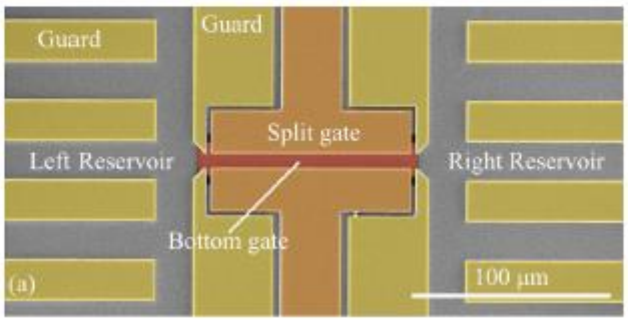


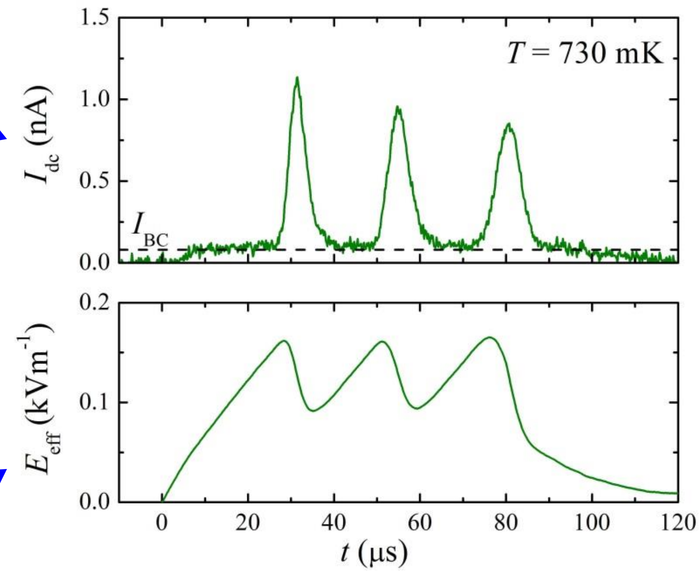
Many-electron stick-slip transitions



Bragg-Cherenkov many-electron friction: where the ripplon frequency $\boldsymbol{\omega}(\mathbf{G}) = \mathbf{v} \cdot \mathbf{G}$, all ripplons are emitted in phase**. The force on the Wigner crystal** $\propto N^2 \Longrightarrow$ **"many-electron sound barrier"**

"velocity" in the channel"





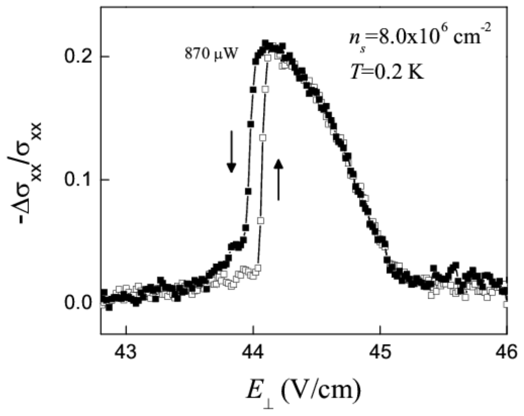
force on the electrons

Rees et al., QFS 2015

What is in common and what is different

Semiconductor heterostructures

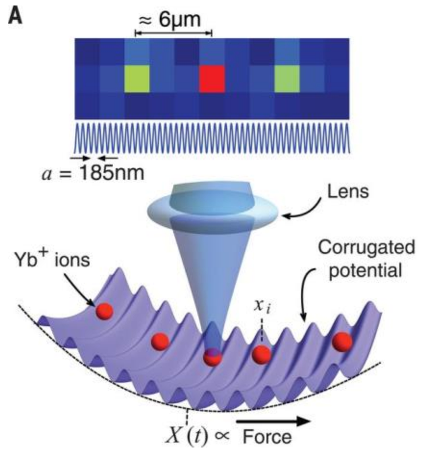
- No disorder, but can be hand-made
- Strong electron correlations
- Long relaxation times
- Exquisite control of
    - electron density
    - coupling to the bosonic field
    - lower-dimensional systems (wires and dots)
    - low-power nonequilibrium behavior



many-electron optical bistability – observed in the 2D world only for e-on-He, Konstantinov et al.

Cold atoms and ions

- Many-particle systems, $N \sim 10^6 - 10^8$
- Almost ideal “substrate”
- Versatile controllable geometry
- Long lifetime
- But
    - no access to individual particles
    - no quantum-coherence effects so far, but spins and CQED are promising and should be scalable



simulation of stick-slip with individually accessed cold ions , Bylinskii et al.

Challenges

- Interplay of strong electron correlations and strong coupling to a bosonic field
- Commensurate-incommensurate transitions in 2D. The interplay with topological defects
- Quantum and classical dynamics of correlated systems far away from thermal equilibrium, including
  - many-body resonant phenomena
  - nonequilibrium phase transitions
  - novel quantum phases of nonequilibrium electron matter in strong magnetic fields
- Spin physics of a correlated electron liquid, with extremely long coherence times
- Orbital and spin-based coherent quantum effects
- Localized modes and optomechanics of a Wigner crystal on a patterned substrate