**Vortices in quantum fluids**

- Classical vortices (e.g., whirlpool, tornado): When the liquid rotates, one giant vortex forms.
- Quantum vortices (e.g., Bose-Einstein condensates): Large vortices are energetically unstable - many small vortices form. The form a triangular lattice or crystal.

Therefore in a quantum liquid:

- These many small vortices interact and act like particles, forming vortex states of matter - not possible in classical liquids.

Our work concerns the theory and experiments of creating ensembles of quantized vortices in polariton condensates towards new states of quantum vortex matter.

Ensembles can most successfully be created by rotation or spontaneous excitation.

**Observation of spontaneous vortex pairs**

Single vortex-antivortex pair in an exciton-polariton condensate

- Experimental optical vortices - Laguerre-Gauss modes
- Vortex velocity profile: vortex-antivortex pair less destructive than co-rotating vortices

Berezinskii-Kosterlitz-Thouless (BKT) superfluid

- Pairs of oppositely circulating vortices with energy proportional to separation
  \[ E_v \propto \frac{\mu^2}{2\pi m \xi} \ln \frac{\Delta}{\xi} \]
- Lower energy than interacting single vortices
- Usually form in 2D systems by thermal fluctuations
- Represnt microscopic nature of the BKT phase transition - phase distortions confined to vortex pairs

**Polariton condensate is strongly dissipative**

- Features of the excited polariton system:
  - Strong coupling of exciton and cavity photon modes in a semiconductor microcavity
  - Resulting lower polaritons can be generally treated as a dilute gas of very light repulsively interacting bosons.
  - Low mass \( \rightarrow \) high transition temperature
  - In plane momentum is conserved in photon mode
  - Condensates form by stimulated scattering of polaritons from a thermal reservoir - reservoir plays a strong role in condensate dynamics

**Rotating a polariton condensate**

- O: How do you rotate a liquid at a rate of \( 10^{11} \) times a second?
  - A: Stir the liquid with an optical vortex

Because light has no interactions, we can make any size or number of vortices

- Experimental optical vortices - Laguerre-Gauss modes
- Physically rotating laser beam at \( 10^{11} \)Hz

**What does a polariton condensate contribute to new states of quantum vortex matter?**

Vortices are unique in the polariton condensate than in other quantum liquids

- Multiquantized vortices can be stable
- Abrikosov lattices can be formed - density and size easily controlled

Creating quantum vortex states of matter with polariton condensates:

- BKT superfluid phase:
  - First experimental observation of vortex-antivortex pairs
  - Possible to study of the onset of BKT phase as vortex number is increased
- Fractional Quantum Hall phase:
  - Strong potential to observe and manipulate anyonic particles
  - Adjustable mass and density parameters \( \rightarrow \) easier to observe
  - Current experiments: rotation with an optical vortex

**Fractional Quantum Hall states**

Under very rapid rotation the vortex number becomes comparable to the polariton number:

- Polariotons and vortices combine to form a new composite fermion quasi-particle
- A new state emerges with similar physics to the electronic fractional quantum Hall liquid

**Vortices in a polariton condensate**

Multiquantized vortices can be uniquely observed in polariton condensates with a structure stabilized by the dissipative nature.

- [Vortex velocity profile](#): vortex-antivortex pair less destructive than co-rotating vortices
- [Berezinskii-Kosterlitz-Thouless (BKT) superfluid](#): Pairs of oppositely circulating vortices with energy proportional to separation
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