

# Quantum Vortices & Black Hole Superradiance



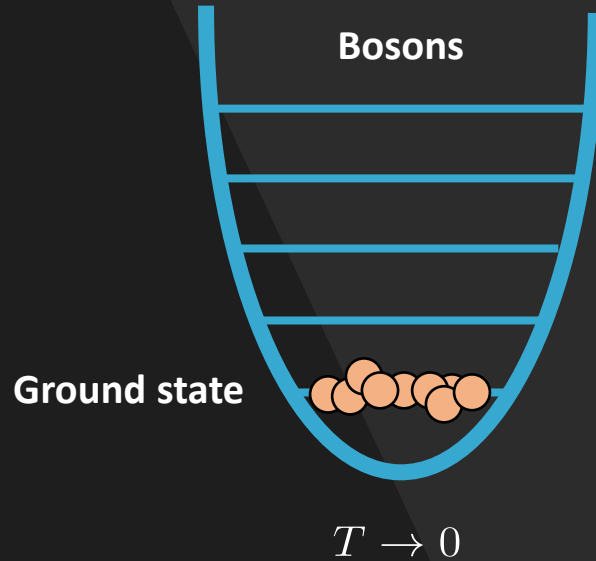
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# Quantum vortices

A quantum fluid shows quantum properties at the macroscopic level

Bose-Einstein condensate



$$\Psi(\mathbf{r}_1, \mathbf{r}_2, \dots, \mathbf{r}_N, t)$$

↓

$$\Psi(\mathbf{r}, t) = \sqrt{n(\mathbf{r}, t)} e^{iS(\mathbf{r}, t)}$$

↑                      ↑  
amplitude                      phase

Madelung representation

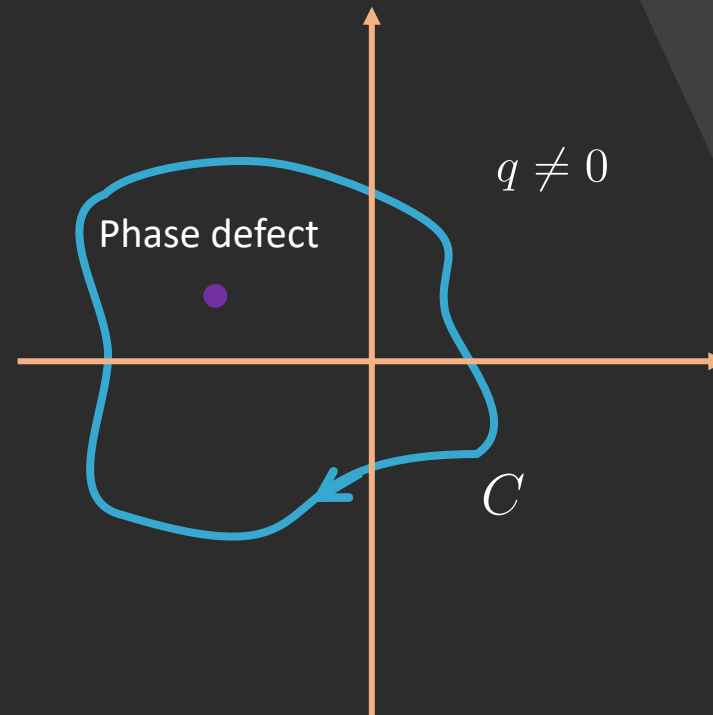
$$\Psi(\mathbf{r}, t) = \sqrt{n(\mathbf{r}, t)} e^{iS(\mathbf{r}, t)}$$

Change in phase around a closed path  $C$

$$\Delta S = \oint_C \nabla S \cdot d\mathbf{l} = 2\pi q, \quad q = 0, \pm 1, \pm 2, \dots$$

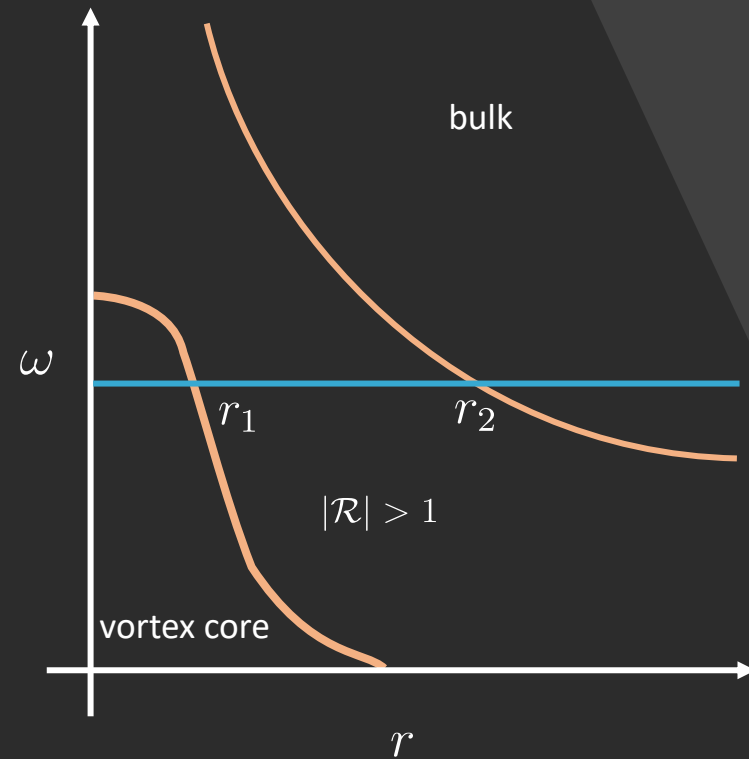
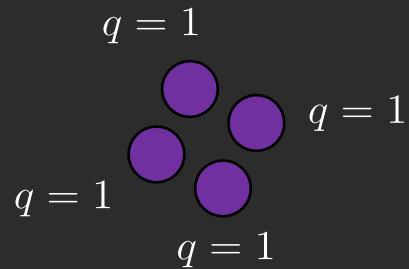
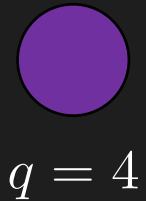
Circulation around a closed path  $C$

$$\Gamma = \oint_C \mathbf{v} \cdot d\mathbf{l} = q\kappa, \quad \kappa = \frac{h}{m}$$



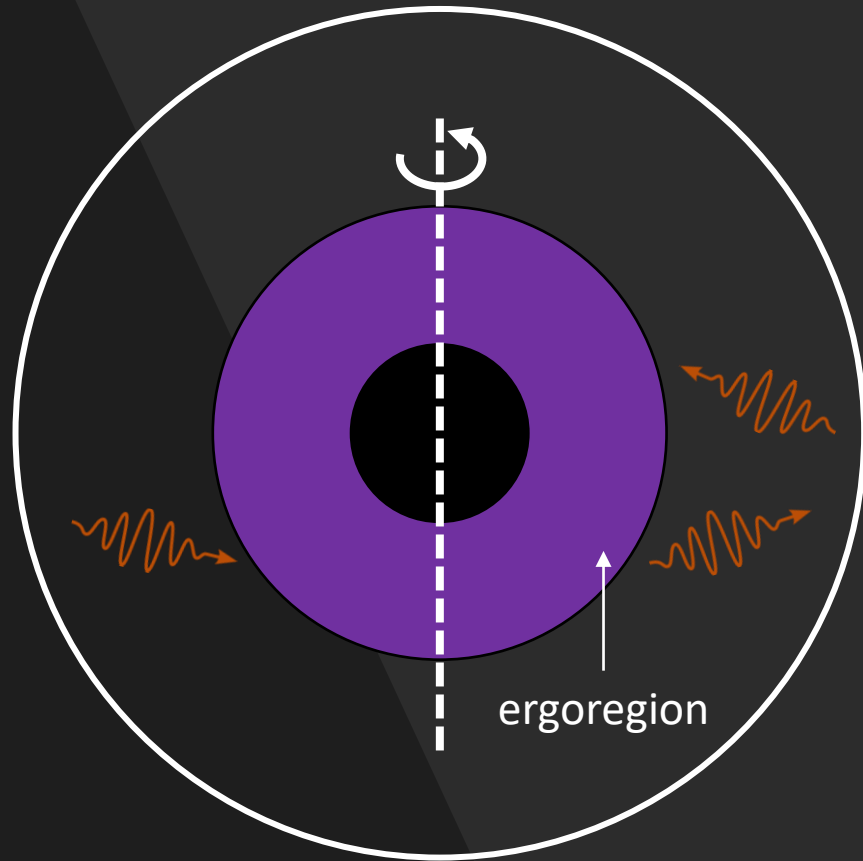
# Vortex instability

$|q| > 1$  Multiply-quantised vortex (MQV)



# Black hole superradiance

Rotating black hole



Repeated reflections and amplifications lead to  
Unbounded growth of the instability  
→ Black hole bomb instability

Thank you for listening