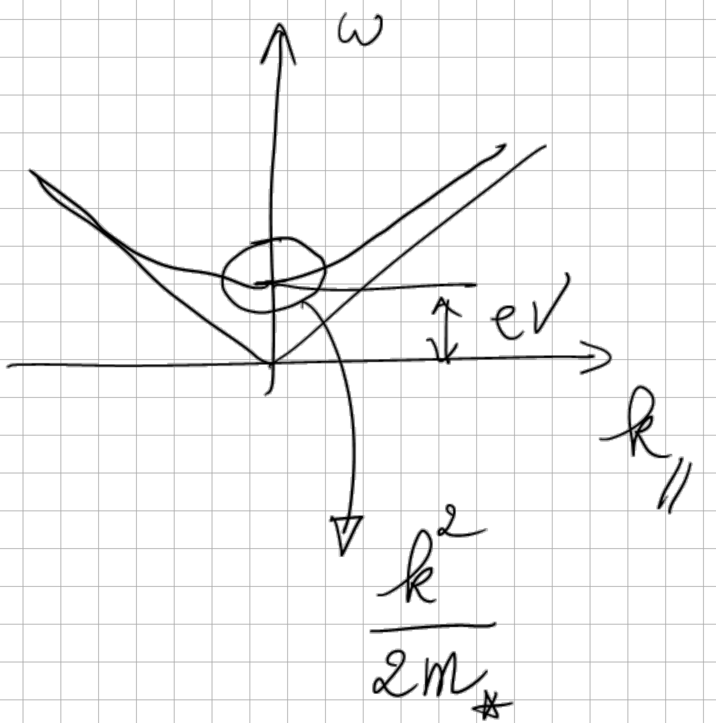
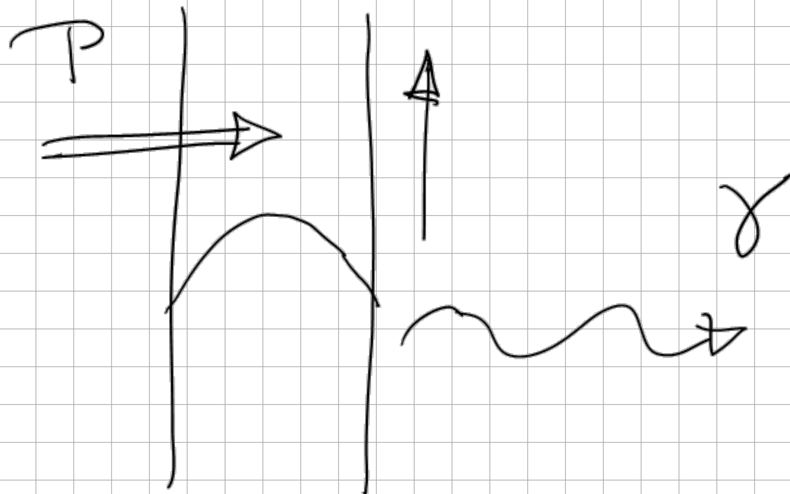
Vortices in Nonequilibrium BECs

Michiel Wouters

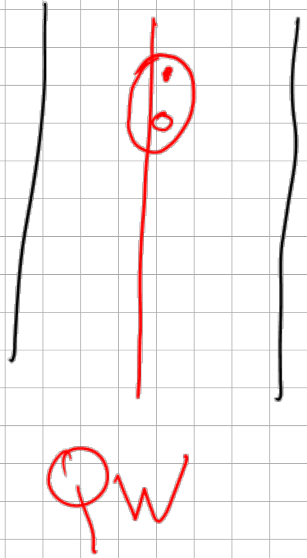
University of Antwerp

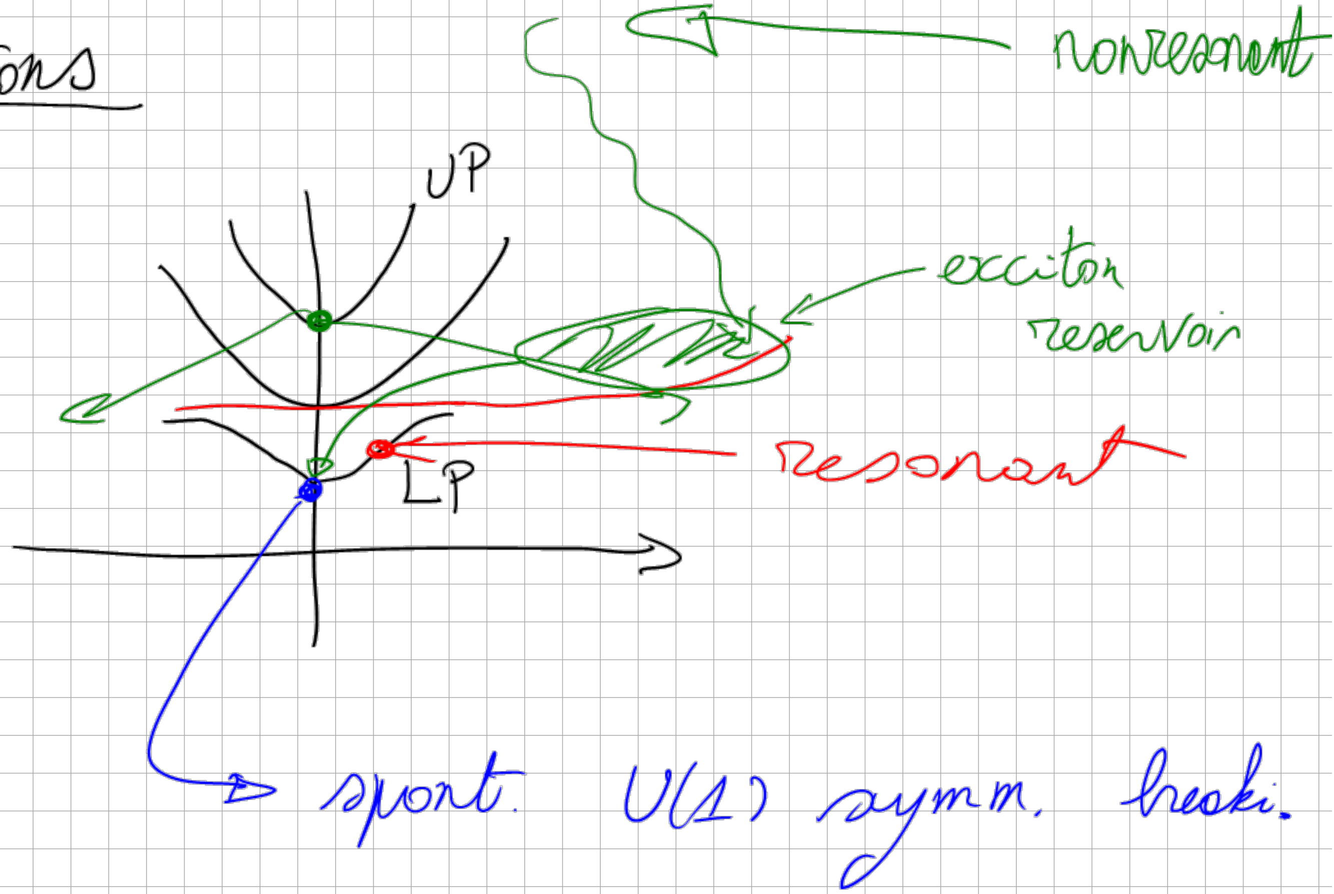




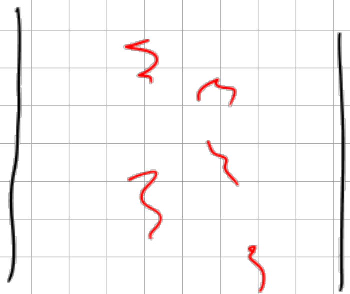
$$T_{\text{phot BEC}} \sim \frac{1}{m^{\wedge}} \gg T_{\text{at BEC}}$$

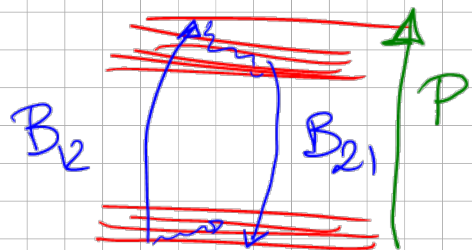
Exciton - polaritons





Photon BEC





$$\frac{B_{21}(\omega)}{B_{12}(\omega)} = e^{-(\omega-\omega_0)/k_BT}$$

generalized Gross-Pitaevskii equation

$$i\frac{\partial}{\partial t}\psi = \left(-\frac{\nabla^2}{2m} + g|\psi|^2 + V(x)\right)\psi - i\frac{\gamma}{2}\psi$$

$$\psi \to e^{i\theta}\psi \qquad + \frac{i}{2}R(n_R)\psi + \sqrt{\frac{\gamma + R(n_R)}{2}}\,\xi + F_L e^{-i\omega_L t}$$

$$\frac{d}{dt}|\psi|^2 = -\gamma|\psi|^2 + R(n_R)\left(|\psi|^2 + 1\right)$$

$$\frac{\partial}{\partial t}\rho = -i[H,\rho] + L(\rho)$$

$$\hookrightarrow \frac{\gamma}{2}\left(2a\rho a^\dagger - a^\dagger a\rho - \rho a^\dagger a\right)$$

$$0 \leftarrow \frac{d}{dt} n_R = -\gamma_R n_R + P - R\, n_R |\psi|^2$$

$$n_R = \frac{P}{\gamma_R + R|\psi|^2}$$

$$i\frac{\partial \psi}{\partial t} = \dots + \frac{i}{2}\left(\frac{RP}{\gamma_R + R|\psi|^2}\psi - i\frac{\gamma}{2}\psi\right) \overset{0}{=}$$

$$\hookrightarrow \sim i(\alpha' - \beta|\psi|^2)\psi$$

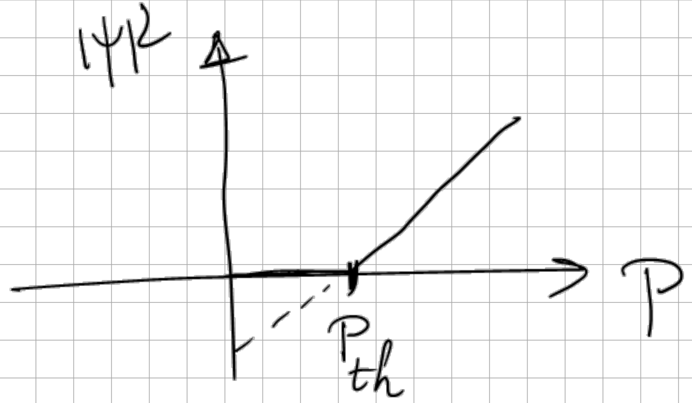
$$i\frac{\partial}{\partial t}\psi = \left(-\frac{\nabla^2}{2m} + g|\psi|^2 + V\right)\psi + \frac{i}{2}(a - \beta|\psi|^2)\psi$$

complex Ginzburg - Landau

study excitations : $\psi = e^{-i\omega_0 t}(\sqrt{n_0} + \delta\psi)$

diffusive Goldstone

$$|\psi|^2 = \frac{P - \gamma_R \gamma}{R\gamma}$$



$$\Psi = \sqrt{n}\; e^{i\Theta}$$

$$\frac{d}{dt} n(x,t) = -\nabla\left(n \frac{\nabla\theta}{m}\right) + \left(R \frac{n(x,t)}{R} - \gamma\right) n(x,t)$$

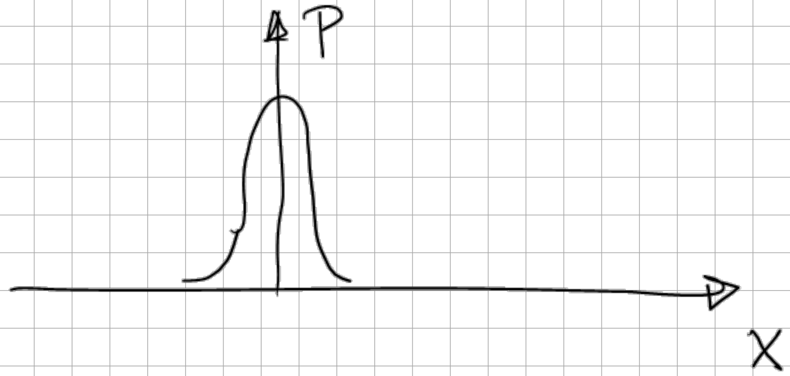
linear + adiabatic det δn

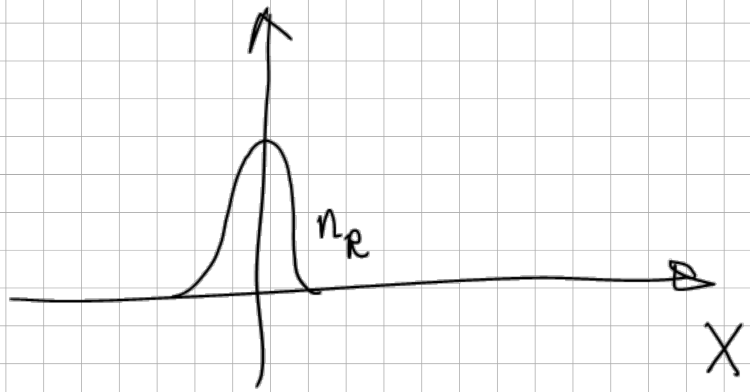
$$\frac{d}{dt}\theta = -\left[-\frac{\hbar^2}{2m\sqrt{n}}\nabla^2\sqrt{n} + gn + \frac{1}{2}(\nabla\theta)^2\right] + \xi$$

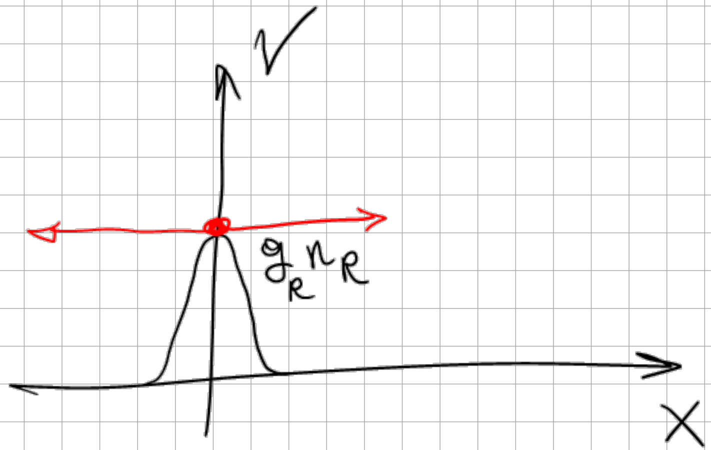
hom. system: $\frac{d\theta}{dt} = -gn \longrightarrow \psi \sim e^{-ignt}$ (μ)

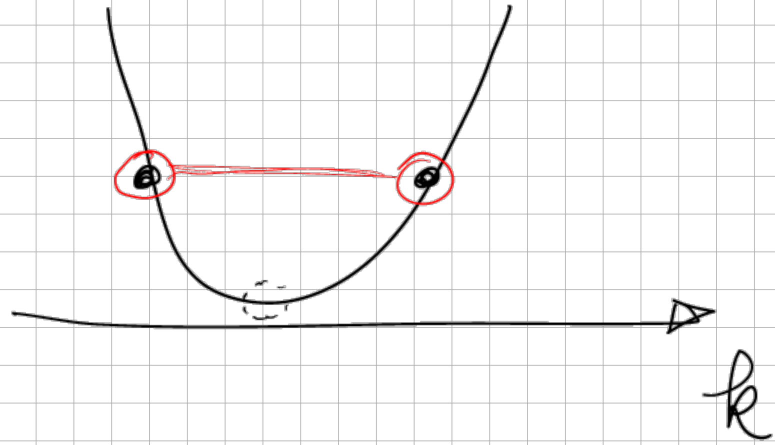
$n(x,t) = n_0 + \delta n$

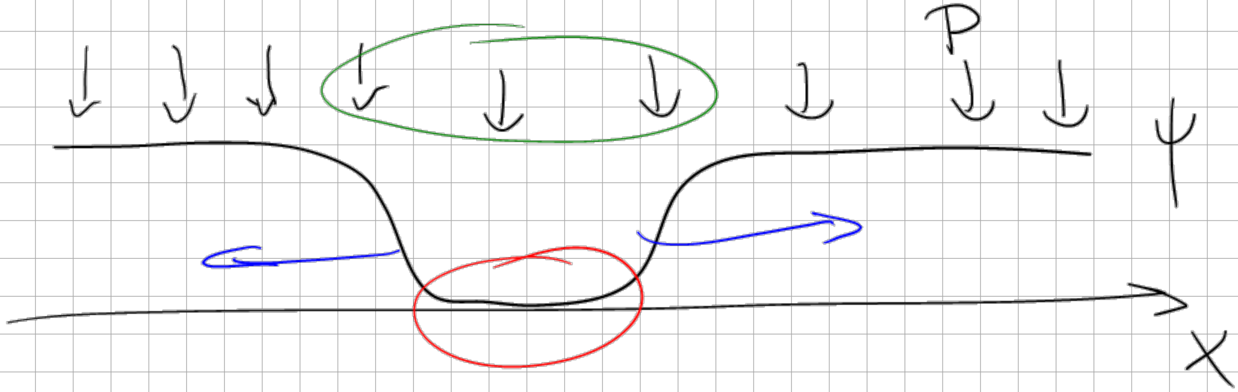
$\rightsquigarrow$ eq. for phase $\longrightarrow$ compare to Kardar–Parisi–Zhang


P
X


n_R
X

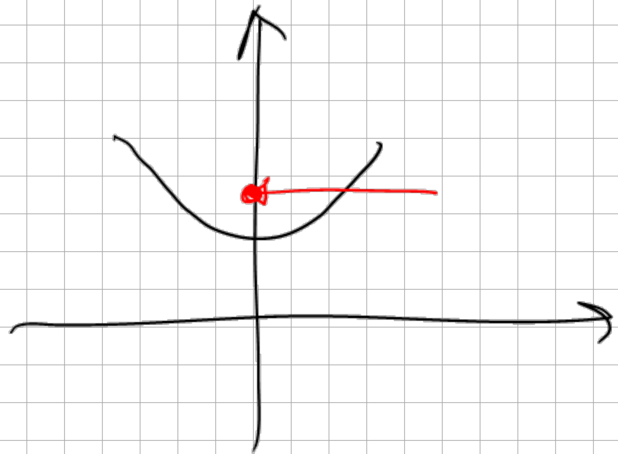

g_R n_R
X

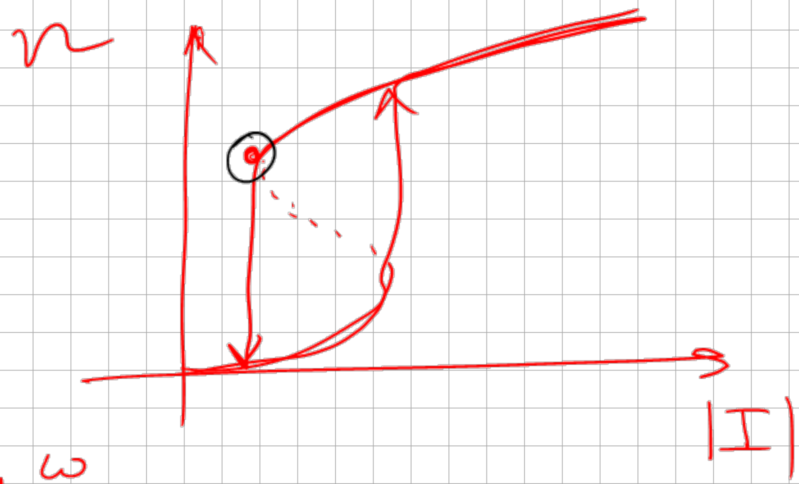

k

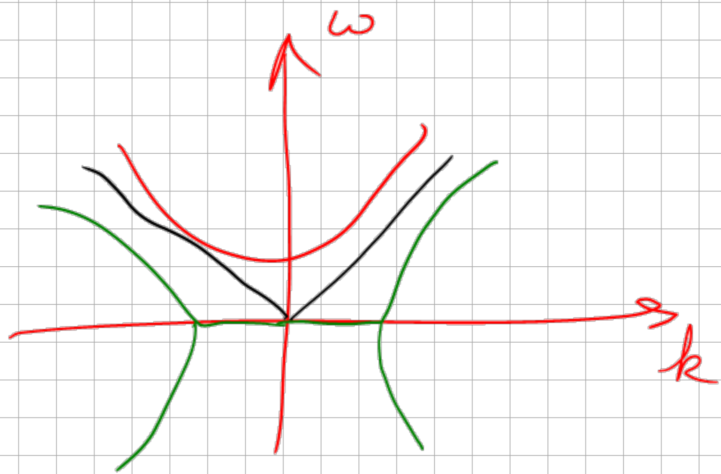


$$\frac{d}{dt} n = (R n_R - \gamma) n - \nabla\left(n \frac{\nabla \theta}{m} \right)$$

suppressed







Carusotto & Ciuti RMP 2013

Quantum fluids of light.