Critical velocity for superfluidity of a generalized Gross-Pitaevskii flow past a localized obstacle in one dimension

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1. Critical velocity for superfluidity

Michel *et al.*, 2018; Eloy *et al.*, 2021

Landau: $v_c = \min \epsilon_p/p$

Beyond Landau: $v_c = ?$

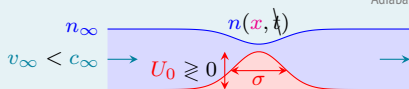No scattering off a localized obstacle when $v_\infty < v_c$

$\longrightarrow$ Analytical and numerical results in 1D

2. Generalized Gross-Pitaevskii equation

Ultracold atoms, microcavity polaritons, paraxial or guided photons, etc.:

$$i\psi_t = -\frac{1}{2m}\psi_{xx} + (U(x) + g(n = |\psi|^2) - \underbrace{i\gamma}_{\text{Adiabatic}})\psi$$

$n_\infty \qquad n(x,t)$

$v_\infty < c_\infty \qquad U_0 \gtrless 0 \qquad \sigma$

3. Narrow then wide obstacle

Narrow: $v_c = \begin{cases} F(U_0, \sigma), & \text{Repulsive} \\ c_\infty, & \text{Attractive} \end{cases}$

Wide: $v_c = \begin{cases} G(U_0) + H(U_0, U_{xx}(0))/\sigma^{4/3} \\ c_\infty \end{cases}$

$g(n) \propto n$ Hakim, 1997; Leboeuf and Pavloff, 2001; Pavloff, 2002

4. Obstacle of arbitrary width

$U(x) = U_0 \exp(-x^2/\sigma^2), \ U_0/(mc_\infty^2) = 0.7$

- $g(n) \propto n$
- $g(n) \propto n/(n + n_s), \ n_s/n_\infty = 1$
- Narrow
- Wide

(axes: v_c/c_∞ versus σ/ξ_∞, from 0 to 8)