Quantum fluctuations in dipolar Bose-Einstein condensates and Bose-Bose mixtures

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Recap: Mean field theory

+ contact term: $g\,n = \dfrac{4\pi\hbar^2}{m} a\,n$
+ dipole term: $\int \mathrm{d}^3 r'\, U_{\mathrm{dd}}(\mathbf{r'} - \mathbf{r}) n(\mathbf{r'})$

⇒ Gross–Pitaevskii equation:

$$\mathrm{i}\hbar \frac{\partial \psi(\mathbf{r})}{\partial t} = \left[-\frac{\hbar^2 \nabla^2}{2m} + V_{\mathrm{ext}}(\mathbf{r}) + g n(\mathbf{r}) + \int \mathrm{d}^3 r'\, U_{\mathrm{dd}}(\mathbf{r'} - \mathbf{r}) n(\mathbf{r'}) \right] \psi(\mathbf{r})$$

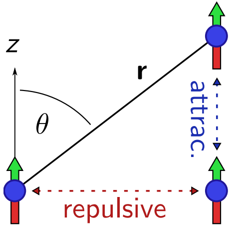
with $n(\mathbf{r}) = |\psi(\mathbf{r})|^2$

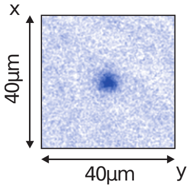
When do we care about quantum fluctuations?

[1] Lee et al., Phys. Rev. **106**, 1135
[2] Lima and Pelster, Phys. Rev. A 89, **84**, 041604
[3] Schmitt et al., Nature **539**, 259–262

When do we care about quantum fluctuations?

- $U_{dd} = C_{dd}(1 - 3\cos^2\theta)r^{-3}$ is anisotropic
  - ⇝ Mean field (MF) part can be decreased by changing the trapping aspect ratios
  - ⇒ Quantum fluctuations (QF) get important
- MF competes with QF
  - $\mu_{MF} \propto -n$
  - $\Delta\mu_{LHY} \propto n^{3/2}$. [1,2]
- Experiments with Cr, Dy[3] and Er





[1] Lee et al., Phys. Rev. **106**, 1135
[2] Lima and Pelster, Phys. Rev. A 89, **84**, 041604
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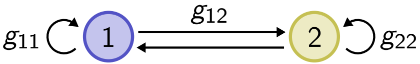
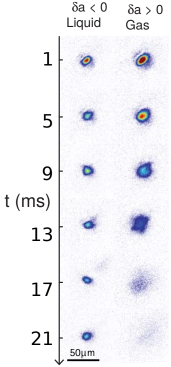
Bose Bose mixture



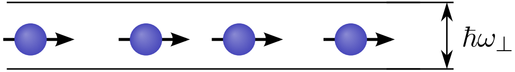
- $g_{11}, g_{22} > 0$ and $g_{12} < 0$ with $g_{12}^2 \gtrsim g_{11} g_{22}$.
- MF competes with QF
  - $\mu_{\mathrm{MF}}^{(1)} \propto -n^{1/2}$
  - $\Delta\mu_{\mathrm{LHY}}^{(1)} \propto n_1^{3/2}$. [4]
- Experiments with ^{39}K [5]
  and Na-K mixture in near future

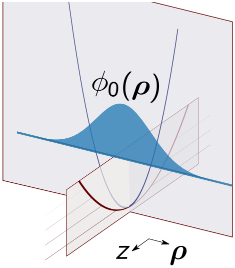


[4] D. S. Petrov, Phys. Rev. Lett. **115**, 155302

[5] Cabrera et al., Science **359**, 301-304

Quasi one-dimensional system



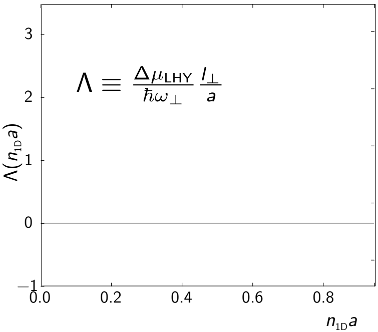


- $\mu \ll \hbar\omega_\perp$
- BEC is 1D
- Ground state wavefunction:

$$\Psi(\mathbf{r}) = \phi_0(\boldsymbol{\rho})\psi(z)$$

- $\phi_0(\boldsymbol{\rho})$ is Gaussian
- $g_{1D} = \frac{g}{2\pi l_\perp^2}, \qquad l_\perp = \sqrt{\frac{\hbar}{m\omega_\perp}}$ = radial oscillator length
- MF competes with QF
  - $\mu_{MF} \propto n$
  - $\Delta\mu_{LHY} \propto -n$

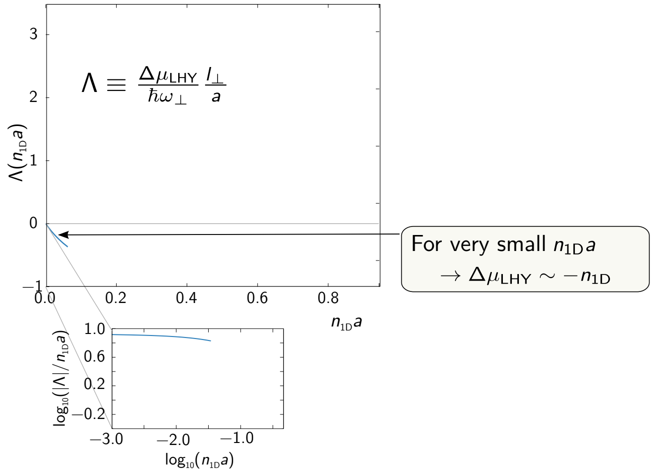
Dimensional crossover



[6] Edler et al, Phys. Rev. Lett. **119**, 050403

Dimensional crossover

- Consider large densities i.e. $g_{1D} n_{1D} \gtrsim \hbar\omega_\perp$.[6]



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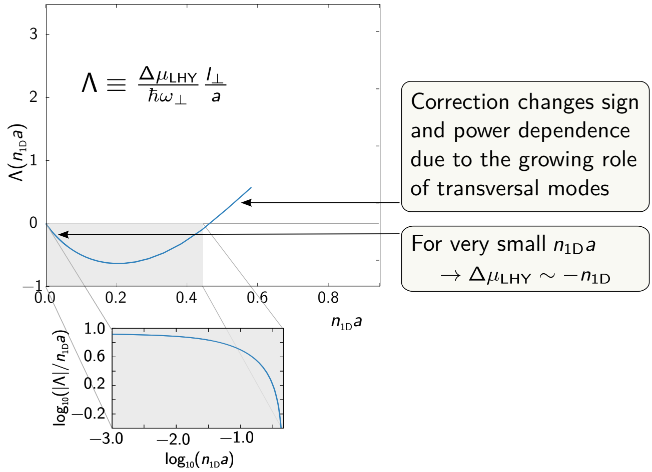

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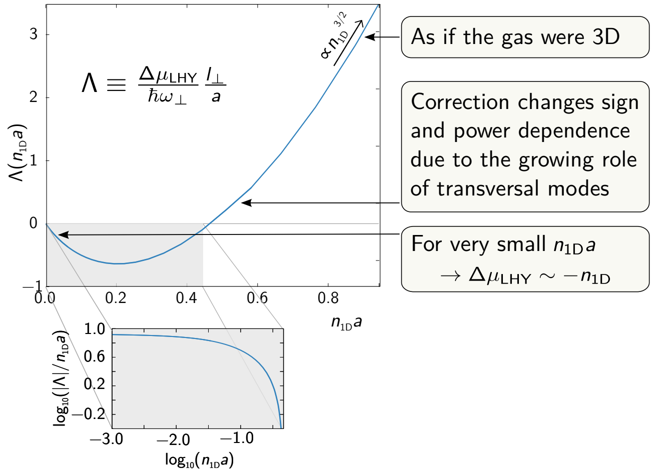


[6]Edler et al, Phys. Rev. Lett. **119**, 050403

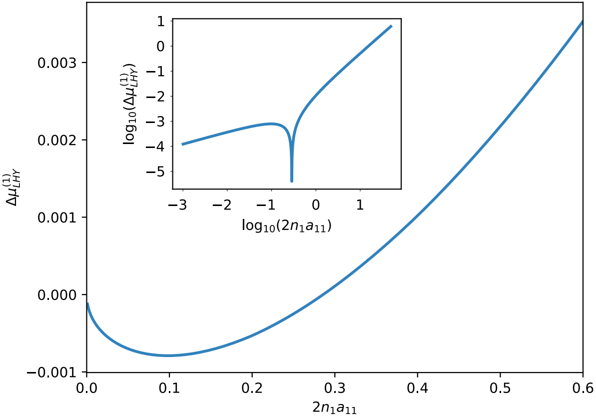
Bose Bose mixture in (fully) quasi one-dimension

- MF competes with QF
  - $\mu^{(1)}_{\text{MF}} \propto +n$
  - $\Delta\mu^{(1)}_{\text{LHY, 1D}} \propto -n_1^{1/2}$. [7]

[7] Petrov and Astrakharchik, PRL, **117**, 100401

Dimensional crossover

- For specific set of parameters g_{11}, g_{22}, g_{12}:



Summary

- Weakly interacting systems exists where the QF are not negligible because of small MF
- MF and QF competes with each other which leads to a stable and trap free solution
- In "1D" systems the LHY corrections have a crossover to a 3D behaviour

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Thank you for your attention

Merci pour votre attention