Suppression of phase separation in warm condensate mixtures

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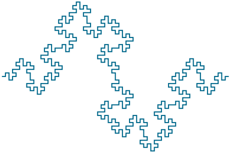


April 30, 2015

AR and D. Angom, arXiv:1502.00473 [cond-mat.quant-gas]

Plan of the talk

Gross-Pitaevskii equation (GPE)

- Equation of motion of the condensate wavefunction is given by Gross-Pitaevskii equation(GPE), strictly valid at $T = 0$K.

$$i\hbar\frac{\partial\psi}{\partial t} = \left[-\frac{\hbar^2}{2m}\nabla^2 + V_{\rm trap}(\mathbf{r}) + gN|\psi|^2\right]\psi,$$

  - $\psi \equiv \psi(\mathbf{r}, t)$: condensate wave function
  - $g = \dfrac{4\pi\hbar^2 a}{m}$
  - a: atomic scattering length > 0 : repulsive
  - N: Number of atoms in the condensate

$$V_{\rm trap} = \frac{m}{2}\left(\omega_x^2 x^2 + \omega_y^2 y^2 + \omega_z^2 z^2\right)$$

Ė. P. Gross, *Il Nuovo Cimento Series 10* **20**, (1961),
L. P. Pitaevskii, *Soviet Physics JETP-USSR* **13**, (1961),
C. Pethick & H. Smith, *Bose-Einstein Condensation in Dilute Gases*, (2008)

Finite Temperature models

Stationary Case:

- Hartree-Fock-Bogoliubov-Popov approximation
- Modified Popov approximation

Dynamical Case:

- Stochastic Gross-Pitaevskii equation (SGPE)
- Projected Gross-Pitaevskii equation
- Self-consistent Gross-Pitaevskii-Boltzmann (ZNG formalism)
- Dissipative Gross-Pitaevskii equation

AR, S. Gautam, and D. Angom, *Phys. Rev. A* **89**, 013617 (2014),
AR and D. Angom *Phys. Rev. A* **90**, 023612 (2014),
S. Gautam, AR, and Subroto Mukerjee, *Phys. Rev. A* **89**, 013612 (2014),
Blakie *et. al*, *Adv. Phys.* **57**, 363 (2008),
A. J. Allen, Ph.D. Thesis (2010),
N. P. Proukakis and B. Jackson, *J. Phys. B* **41**, 203002 (2008).

Many-body Hamiltonian

$$\hat{H} = \int \underbrace{d\mathbf{r}\,\hat{\psi}^\dagger(\mathbf{r},t)\left[\hat{h}(\mathbf{r})-\mu\right]\hat{\psi}(\mathbf{r},t)}_{\text{single-particle part}}$$
$$+\frac{1}{2}\iint \underbrace{d\mathbf{r}d\mathbf{r}'\,\hat{\psi}^\dagger(\mathbf{r},t)\hat{\psi}^\dagger(\mathbf{r}',t)U(\mathbf{r}-\mathbf{r}')\hat{\psi}(\mathbf{r}',t)\hat{\psi}(\mathbf{r},t)}_{\text{two-particle interaction term}}$$

where $\hat{h} = K.E + V_{\mathrm{trap}}$

$$U(\mathbf{r}-\mathbf{r}') = g\delta(\mathbf{r}-\mathbf{r}'), \left\langle \int d\mathbf{r}\,\hat{\psi}^\dagger(\mathbf{r},t)\hat{\psi}(\mathbf{r},t)\right\rangle = N$$

U:: Repulsive contact interaction; N:: Total number of atoms

$$\left[\hat{\psi}(\mathbf{r}),\hat{\psi}(\mathbf{r}')\right] = \left[\hat{\psi}^\dagger(\mathbf{r}),\hat{\psi}^\dagger(\mathbf{r}')\right] = 0; \left[\hat{\psi}(\mathbf{r}),\hat{\psi}^\dagger(\mathbf{r}')\right] = \delta(\mathbf{r}-\mathbf{r}')$$

A.Griffin, *Phys. Rev. B* **53**, 9341 (1996)

Hartree-Fock-Bogoliubov(HFB) approximation

The Bose field operator is

$$\hat{\psi}(\mathbf{r},t) = \sum_{i=0} \hat{\alpha}_i(t)\psi_i(\mathbf{r}) = \hat{\alpha}_0(t)\psi_0(\mathbf{r}) + \sum_{i=1} \hat{\alpha}_i(t)\psi_i(\mathbf{r}),$$

$$\hat{\alpha}_i^\dagger|n_0 n_1,\cdots,n_i,\cdots\rangle = \sqrt{(n_i+1)}|n_0 n_1,\cdots,n_i+1,\cdots\rangle,$$

$$\hat{\alpha}_i|n_0 n_1,\cdots,n_i,\cdots\rangle = \sqrt{n_i}|n_0 n_1,\cdots,n_i-1,\cdots\rangle.$$

BEC occurs when: $n_0 \equiv N_0 \gg 1 \rightarrow N_0, N_0 \pm 1 \approx N_0$
where $N_0 \rightarrow$ Number of **condensate** atoms

HFB approximation: $\hat{\alpha}_0 = \hat{\alpha}_0^\dagger = \sqrt{N_0}$, then

$$\hat{\psi}(\mathbf{r},t) = \sqrt{N_0}\psi_0(\mathbf{r})e^{-i\mu t/\hbar} + \tilde{\psi}(\mathbf{r},t),$$

such that, $\langle\tilde{\psi}(\mathbf{r},t)\rangle = \langle\tilde{\psi}^\dagger(\mathbf{r},t)\rangle = 0.$

Dalfovo et al, *Rev. Mod. Phys.* **71**, 463 (1999)

Generalized GP equation

Equation of motion of the Bose field operator

$$i\hbar\frac{\partial\hat{\psi}(\mathbf{r},t)}{\partial t} = (\hat{h}-\mu)\hat{\psi}(\mathbf{r},t) + g\hat{\psi}^{\dagger}(\mathbf{r},t)\hat{\psi}(\mathbf{r},t)\hat{\psi}(\mathbf{r},t)$$

where, $\hat{\psi}(\mathbf{r},t) = \phi(\mathbf{r}) + \tilde{\psi}(\mathbf{r},t)$, and $\phi(\mathbf{r}) = \sqrt{N_0}\psi_0(\mathbf{r})$. $\phi/\tilde{\psi}$ is the condensate/non-condensate part.

$$\tilde{\psi}^{\dagger}(\mathbf{r},t)\tilde{\psi}(\mathbf{r},t)\tilde{\psi}(\mathbf{r},t) \simeq 2\underbrace{\langle\tilde{\psi}^{\dagger}(\mathbf{r})\tilde{\psi}(\mathbf{r})\rangle}_{\tilde{n}}\tilde{\psi}(\mathbf{r},t) + \underbrace{\langle\tilde{\psi}(\mathbf{r})\tilde{\psi}(\mathbf{r})\rangle}_{\tilde{m}}\tilde{\psi}^{\dagger}(\mathbf{r},t)$$

$\tilde{n} \rightarrow$ Non-condensate density; $\tilde{m} \rightarrow$ Anomalous average

Generalized GPE

Including the thermal component and anomalous term, the generalized GP equation is

$$(\hat{h}-\mu)\phi(\mathbf{r})+g|\phi(\mathbf{r})|^2\phi(\mathbf{r})+\underbrace{2g\tilde{n}(\mathbf{r})\phi(\mathbf{r})+g\tilde{m}(\mathbf{r})\phi^*(\mathbf{r})}_{T-dependent}=0$$

- $\hat{h}=K.E.+V_{\rm trap}$
- $\int|\phi(\mathbf{r})|^2\,d\mathbf{r}=1$

A.Griffin, *Phys. Rev. B* **53**, 9341 (1996);
Hutchinson *et. al Phys. Rev. Lett.* **78**, 1842 (1997)

Bogoliubov de-Gennes equations

Equation of motion of the thermal component

$$
\begin{aligned}
i\hbar\frac{\partial\tilde{\psi}}{\partial t} &= i\hbar\frac{\partial}{\partial t}(\hat{\psi}-\phi), \\
&= (\hat{h}-\mu)\tilde{\psi} + 2gn(\mathbf{r})\tilde{\psi} + gm(\mathbf{r})\tilde{\psi}^{\dagger},
\end{aligned}
$$

where, $n(\mathbf{r}) = |\phi(\mathbf{r})|^2 + \tilde{n}(\mathbf{r})$; $m(\mathbf{r}) = \phi^2(\mathbf{r}) + \tilde{m}(\mathbf{r})$;
$\tilde{\psi} = \sum_j \left[u_j\hat{\alpha}_j e^{-iE_jt} - v_j^*\hat{\alpha}_j^{\dagger}e^{iE_jt}\right]$;
$u_j, v_j \Rightarrow$ quasiparticle amplitudes
Bogoliubov de-Gennes equations:

$$
\begin{aligned}
\mathcal{L}u_j &- gmv_j = E_ju_j \\
\mathcal{L}v_j &- gm^*u_j = -E_jv_j
\end{aligned}
$$

where $\mathcal{L} = \hat{h} - \mu + 2gn(\mathbf{r})$

Non-condensate density

Density of the thermal component:

$$\langle\tilde{\psi}^\dagger(\mathbf{r})\tilde{\psi}(\mathbf{r})\rangle = \tilde{n} = \sum_j \left\{ \left[|u_j|^2 + |v_j|^2\right] \langle\hat{\alpha}_j^\dagger\hat{\alpha}_j\rangle + |v_j|^2 \right\}.$$

and multiplying factor

$$\langle\hat{\alpha}_j^\dagger\hat{\alpha}_j\rangle = \frac{1}{e^{\beta E_j} - 1} \equiv N_0(E_j).$$

is the Bose-Einstein distribution.

At $T = 0$**,** $\tilde{n} = \sum_j |v_j|^2 \rightarrow$ **Quantum depletion**

The anomalous average:

$$\langle\tilde{\psi}(\mathbf{r})\tilde{\psi}(\mathbf{r})\rangle = \tilde{m} = -\sum_j u_j v_j^* \left[2\langle\hat{\alpha}_j^\dagger\hat{\alpha}_j\rangle + 1\right],$$

AR and D. Angom, *Phys. Rev. A* **90**, 023612 (2014)

A.Griffin, *Phys. Rev. B* **53**, 9341 (1996)

Problems in HFB

- HFB theory is not *gapless*. Violates Hugenholtz-Pines theorem.

Gapless finite temperature approximation

$\Downarrow$

Neglect $\tilde{m}$.

$\Downarrow$

HFB-Popov approximation

Valid in $0 < T \lesssim 0.65\, T_c$

N. P. Proukakis and B. Jackson, *J. Phys. B* **41**, 203002 (2008)

Two-component fluid motivations

- Transition from miscible to immiscible phase.
  Example – Temperature driven phase-separation in cyclohexane-aniline mixture.
- Dynamical instabilities related to two-component fluid, namely Rayleigh-Taylor instability.
- Are there any similarities and differences in binary mixtures of quantum fluids ?

H. Stanley, *Introduction to Phase Transitions and Critical Phenomena*, (1971)

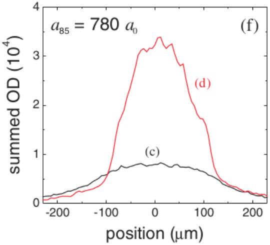
Unique feature of binary BEC

Role of interactions

Phase Separation

$U_{11} U_{22} - (U_{12})^2 > 0$

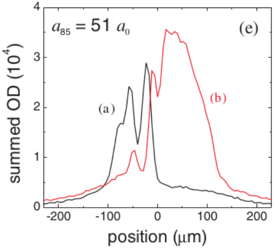
Miscible regime



^{85}Rb–^{87}Rb

$U_{11} U_{22} - (U_{12})^2 < 0$

Immiscible regime



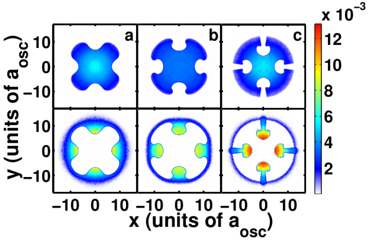
Papp et. al, *Phys. Rev. Lett.* **101**, 040402 (2008);
Inouye et. al, *Nature* **392** 151, (1998);
Chin et. al, *Rev. Mod. Phys.* **82**, 1225 (2010).

Unique feature of binary BEC

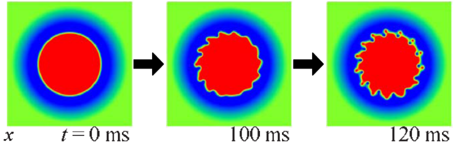
Dynamical Evolution

Instabilities

Rayleigh-Taylor Instability



Kelvin-Helmholtz Instability



AR, S. Gautam, D. Angom, arXiv:1210.0381, (2012),
Takeuchi et. al, *Phys. Rev. B.* **81**, 094517 (2010),
Sasaki et al. , *Phys. Rev. A* **80**, 063611 (2009),
S. Gautam and D. Angom *Phys. Rev. A* **81**, 053616 (2010).

Experimental realization of binary BEC

2 different **atoms**

- ^{87}Rb–^{41}K
  Thalhammer et. al, PRL, **100**, (2008)
- ^{84}Sr–^{87}Rb
  Pasquiou et. al, PRA, **88**, (2013)
- ^{23}Na–^{87}Rb
  Xiong et. al, arXiv:1305.7091, (2013)
- ^{133}Cs–^{87}Rb
  McCarron et. al, PRA(R), **84**, (2011)

2 different **isotopes**

- ^{85}Rb–^{87}Rb
  Papp et. al, PRL, **101**, (2008)

2 different **hyperfine states**

- $|F=1, m_F=+1\rangle$, $|F=2, m_F=-1\rangle$ of ^{87}Rb
  $|F=2, m=2\rangle, |F=2, m=-1\rangle$
  Tojo et. al, PRA, **82**, (2010)

Coupled Generalized GP equation

From **HFB-Popov** approximation

$$\begin{pmatrix}\Psi_1\\ \Psi_2\end{pmatrix} = \begin{pmatrix}\phi_1\\ \phi_2\end{pmatrix} + \begin{pmatrix}\tilde{\psi}_1\\ \tilde{\psi}_2\end{pmatrix},$$

$$\hat{h}_1\phi_1 + U_{11}\left[n_{1c} + 2\tilde{n}_1\right]\phi_1 + U_{12}[n_{2c} + \tilde{n}_2]\phi_1 = 0,$$

$$\hat{h}_2\phi_2 + U_{22}\left[n_{2c} + 2\tilde{n}_2\right]\phi_2 + U_{12}[n_{1c} + \tilde{n}_1]\phi_2 = 0.$$

- $n_{kc} = |\phi_k|^2$: Condensate density of k^{th} species
- $\tilde{n}_k$: Non-condensate density of k^{th} species

where, $\hat{h}_k = -\frac{\hbar^2\nabla^2}{2m_k} + V_k(\mathbf{r}) - \mu_k$

BdG Equations

$$
\begin{aligned}
\hat{\mathcal{L}}_1 u_{1j} - U_{11}\phi_1^2 v_{1j} + U_{12}\phi_1(\phi_2^* u_{2j} - \phi_2 v_{2j}) &= \hbar E_j u_{1j}, \\
-\hat{\mathcal{L}}_1 v_{1j} + U_{11}\phi_1^{*2} u_{1j} - U_{12}\phi_1^*(\phi_2 v_{2j} - \phi_2^* u_{2j}) &= \hbar E_j v_{1j}, \\
\hat{\mathcal{L}}_2 u_{2j} - U_{22}\phi_2^2 v_{2j} + U_{12}\phi_2(\phi_1^* u_{1j} - \phi_1 v_{1j}) &= \hbar E_j u_{2j}, \\
-\hat{\mathcal{L}}_2 v_{2j} + U_{22}\phi_2^{*2} u_{2j} - U_{12}\phi_2^*(\phi_1 v_{1j} - \phi_1^* u_{1j}) &= \hbar E_j v_{2j},
\end{aligned}
$$

$$
\begin{aligned}
\text{where, } \hat{\mathcal{L}}_1 &= \left(\hat{h}_1 + 2U_{11}n_1 + U_{12}n_2\right), \\
\hat{\mathcal{L}}_2 &= \left(\hat{h}_2 + 2U_{22}n_2 + U_{12}n_1\right), \\
n_1 &= n_{1c} + \tilde{n}_1, n_2 = n_{2c} + \tilde{n}_2.
\end{aligned}
$$

Non-Condensate density:

$$
\tilde{n}_k = \sum_j \left\{ \left[|u_{kj}|^2 + |v_{kj}|^2\right] N_0(E_j) + |v_{kj}|^2 \right\}
$$

AR, S. Gautam, D. Angom, *Phys. Rev. A.* **89**, 013617 (2014)

Phase-separation in binary BEC
$T = 0$

Density profiles

from miscible to immiscible(phase-separated)

$^{133}\mathrm{Cs} - ^{87}\mathrm{Rb}$ mixture in quasi-1D trap

$\omega_{z(\mathrm{Rb})} = 2\pi \times 3.89\mathrm{Hz}, \omega_{z(\mathrm{Cs})} = 2\pi \times 4.55\mathrm{Hz},$

$\omega_{\perp(\mathrm{Cs})} = 8.835\omega_{z(\mathrm{Cs})}; \omega_{\perp(\mathrm{Rb})} = 8.277\omega_{z(\mathrm{Rb})}$

$\omega_\perp \gg \omega_z$, $\hbar\omega_\perp \gg \mu$

$a_{\mathrm{CsCs}} = 280a_0, a_{\mathrm{RbRb}} = 100a_0$

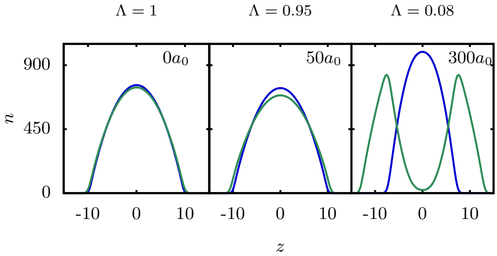
Measure of phase separation

$$\Lambda = \frac{\left[\int n_1(z)n_2(z)dz\right]^2}{\left[\int n_1^2(z)dz\right]\left[\int n_2^2(z)dz\right]}.$$

$\Lambda = 1 \rightarrow$ Miscible and signifies complete overlap of the two species,

$\Lambda = 0 \rightarrow$ the binary condensate is completely phase-separated.

Phase-separation in binary BEC
$T = 0$
through a_{12}



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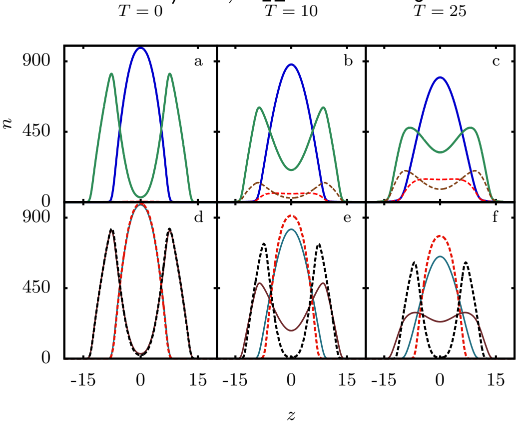
Suppression of phase-separation

$T \neq 0$, $a_{12} = 300a_0$

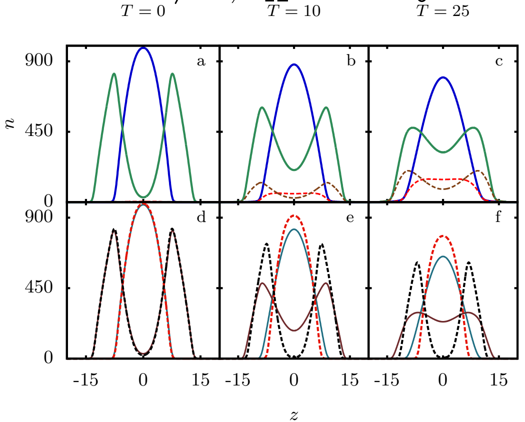


(a)-(c)The solid blue (green) lines represent $n_{\rm Cs}(n_{\rm Rb})$. The dashed red(brown) lines represent $\tilde{n}_{\rm Cs}(\tilde{n}_{\rm Rb})$ at $T = 0, 10, 25$nK respectively.

Λ increases.

Suppression of phase-separation

$T \neq 0, a_{12} = 300a_0$

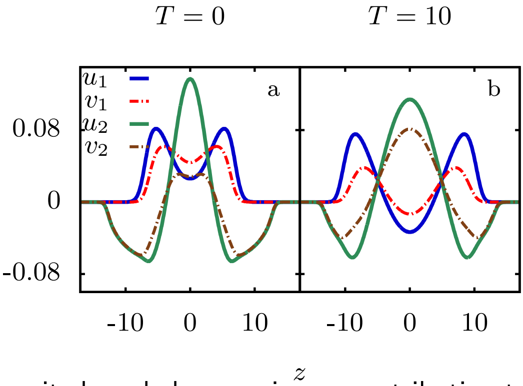


(d)-(f) The solid dark cyan (maroon) lines represent $n_{c\mathrm{Cs}}(n_{c\mathrm{Rb}})$. The dashed crimson(black) lines $n_{c\mathrm{Cs}}(n_{c\mathrm{Rb}})$ at $T = 0$ with the same number of condensate atoms at $T = 0, 10, 25$nK respectively.

Effect of $\tilde{n}$ on miscibility-immiscibility transition

Suppression of phase-separation

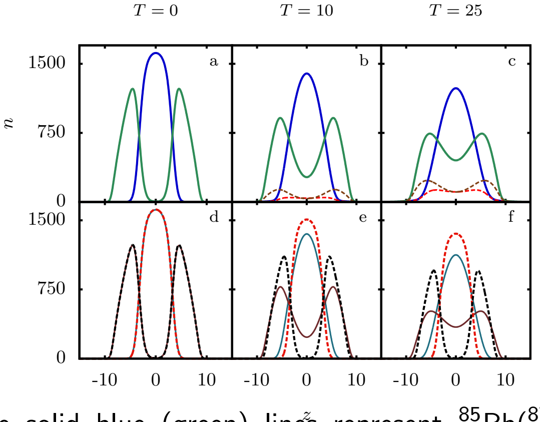
origin



The fourth excited mode has maximum contribution to the thermal cloud.

Suppression of phase-separation

$T \neq 0, a_{11} = 115a_0$



(a)-(c) The solid blue (green) lines represent ^{85}Rb(^{87}Rb). The dashed red(brown) lines represent $\tilde{n}_1(\tilde{n}_2)$.

Λ increases.

Correlation function

measure of coherence

The normalized first order correlation function is given by

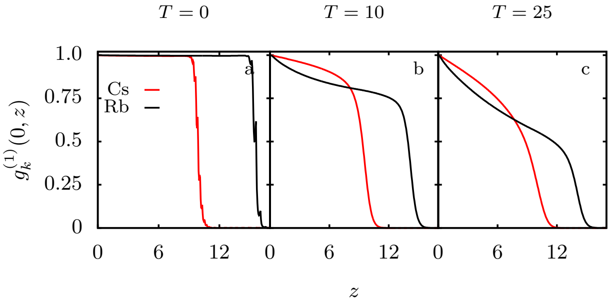
$$
\begin{aligned}
g_k^{(1)}(z,z') &= \frac{\langle \hat{\Psi}_k^\dagger(z)\hat{\Psi}_k(z')\rangle}{\sqrt{\langle \hat{\Psi}_k^\dagger(z)\hat{\Psi}_k(z)\rangle\langle \hat{\Psi}_k^\dagger(z')\hat{\Psi}_k(z')\rangle}}.\\
&= \frac{n_{ck}(z,z') + \tilde{n}_k(z,z')}{\sqrt{n_k(z)n_k(z')}},
\end{aligned}
$$

where,

$$
\begin{aligned}
n_{ck}(z,z') &= \phi_k^*(z)\phi_k(z')\\
\tilde{n}_k(z,z') &= \sum_j \{[u_{kj}^*(z)u_{kj}(z') + v_{kj}^*(z)v_{kj}(z')]N_0(E_j)\\
&\quad + v_{kj}^*(z)v_{kj}(z')\}.
\end{aligned}
$$

Correlation function

measure of coherence



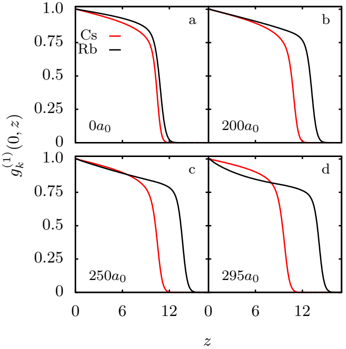
At $T = 0$, $g^{(1)}_{\mathrm{Cs/Rb}}(0, z) = 1$ for $a_{12} = 300a_0$.

When $T \neq 0$, the $g^{(1)}_{\mathrm{Cs/Rb}}(0, z)$ is maximum at $z = 0$ and decays to zero with increasing z.

The rate of decay of the $g^{(1)}_{\mathrm{Cs/Rb}}(0, z)$ increases with temperature.

Correlation function

distinct variation at $T = 25$nK



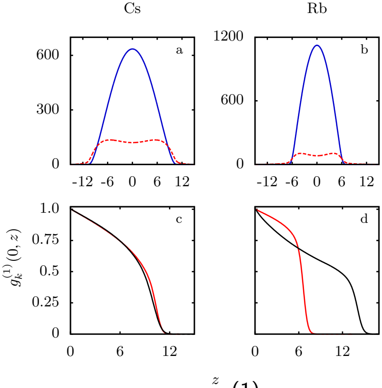
The $g_k^{(1)}(0, z)$ of the individual species cross each other at a certain z_0. Two species have equal $g^{(1)}_{\mathrm{Cs/Rb}}(0, z_0)$.

With increase in a_{12}, z_0 increases, and $g^{(1)}_{\mathrm{Cs/Rb}}(0, z_0)$ decreases.

Difference in the decay rates of $g^{(1)}_{\mathrm{Cs/Rb}}(0, z_0)$; it is much faster in Cs.

Correlation function

distinct variation at $T = 25\text{nK}$

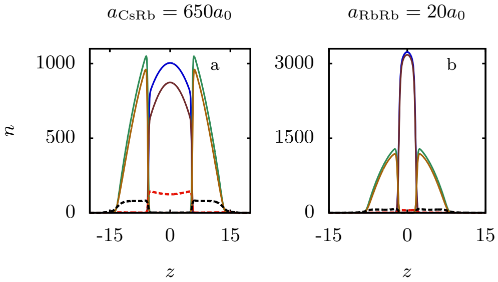


The solid red(black) line represents $g^{(1)}_{\mathrm{Cs}}(0,z)$ in Cs BEC(Cs-Rb TBEC).
The solid red(black) line represents $g^{(1)}_{\mathrm{Rb}}(0,z)$ in Rb BEC(Cs-Rb TBEC).

Phase-segregation

independent of temperature

$$U_{12} \gg \sqrt{U_{11} U_{22}}$$



Phase-separation in ^{87}Rb-^{133}Cs TBEC for $a_{12} = 650a_0$.
The solid blue (green) lines represent $n_{c\rm Cs}(n_{c\rm Rb})$ at $T = 0$.
The solid maroon (yellowish brown) lines represent $n_{c\rm Cs}(n_{c\rm Rb})$, and the dashed crimson (black) lines represent $\tilde{n}_{c\rm Cs}(\tilde{n}_{c\rm Rb})$ at $T = 25$nK.

Conclusions

- To examine the properties of TBECs in the neighbourhood of phase separation, it is essential to incorporate the thermal component.
- There is a delay or suppression of phase-separation due to the thermal component generic to any binary BEC mixture.
- Different from the classical binary fluids which undergo miscible-immiscible transition with temperature as control parameter.
- Each species has two sub-components, the condensate and non-condensate atoms. The condensate components are coherent, but the non-condensate components are incoherent and like the normal gas.

Conclusions

- Spatial density variations of all the components due to the nature of the confining potential.
- The transition to the phase separated domain at finite temperatures is associated with a distinct change in the profile of the correlation function.
- In the strongly phase separated domain, temperature does not alter the density profiles.

Conclusions

- Spatial density variations of all the components due to the nature of the confining potential.
- The transition to the phase separated domain at finite temperatures is associated with a distinct change in the profile of the correlation function.
- In the strongly phase separated domain, temperature does not alter the density profiles.

...and finally

THANK YOU

the group

Prof. Dilip Angom

Dr. Brajesh K. Mani

Dr. Sandeep Gautam

Dr. S. Chattopadhyay

Mr. Kuldeep Suthar

THANK YOU

the group

Prof. Dilip Angom

Dr. Brajesh K. Mani | Dr. Sandeep Gautam

Dr. S. Chattopadhyay | Mr. Kuldeep Suthar

Backup Slides

Phase-separation in binary BEC
$T = 0$

Density profiles

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$^{133}\mathrm{Cs} -^{87}\mathrm{Rb}$ mixture in quasi-1D trap

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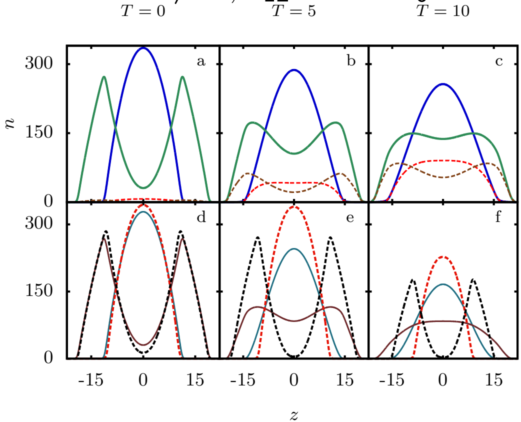
$\omega_{\perp(\mathrm{Cs})} = 50.0\omega_{z(\mathrm{Cs})}; \omega_{\perp(\mathrm{Rb})} = 50.0\omega_{z(\mathrm{Rb})}$

$\omega_\perp \gg \omega_z$, $\hbar\omega_\perp \gg \mu$

$a_{\mathrm{CsCs}} = 280a_0, a_{\mathrm{RbRb}} = 100a_0$

Suppression of phase-separation

$T \neq 0, a_{12} = 295a_0$



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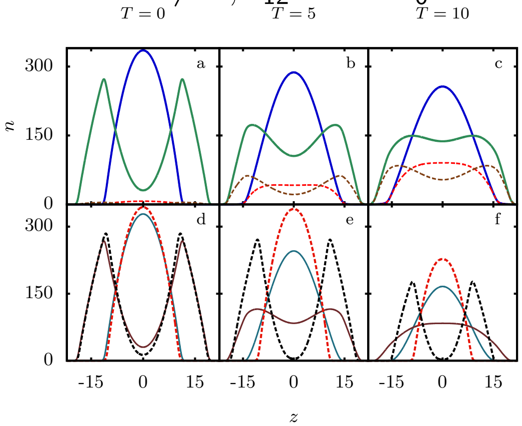
Λ increases.

Suppression of phase-separation

$T \neq 0$, $a_{12} = 295a_0$

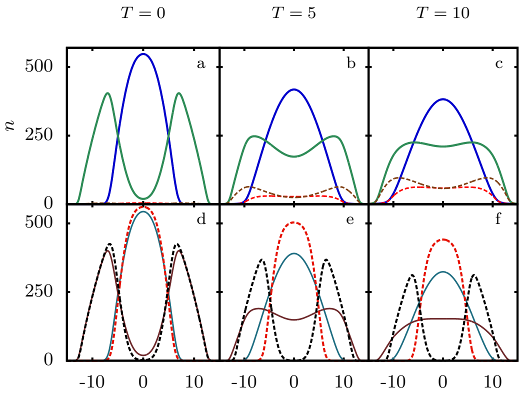


(d)-(f) The solid dark cyan (maroon) lines represent $n_{c\mathrm{Cs}}(n_{c\mathrm{Rb}})$. The dashed crimson(black) lines $n_{c\mathrm{Cs}}(n_{c\mathrm{Rb}})$ at $T = 0$ with the same number of condensate atoms at $T = 0, 5, 10$nK respectively.

Effect of $\tilde{n}$ on miscibility-immiscibility transition

Suppression of phase-separation

$T \neq 0, a_{11} = 120a_0$

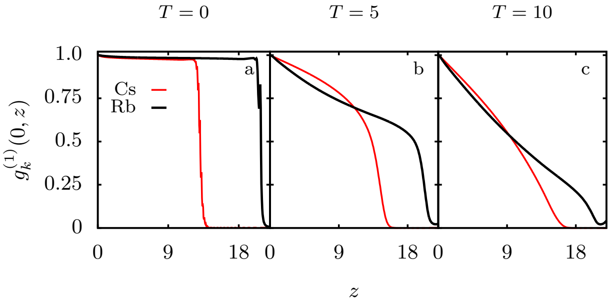


(a)-(c) The solid blue (green) lines represent ^{85}Rb(^{87}Rb). The dashed red(brown) lines represent $\tilde{n}_1(\tilde{n}_2)$.

Λ increases.

Correlation function

measure of coherence



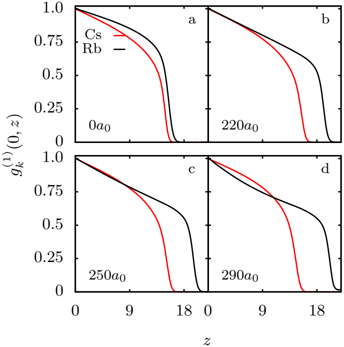
At $T = 0$, $g^{(1)}_{\mathrm{Cs/Rb}}(0, z) = 1$.

When $T \neq 0$, the $g^{(1)}_{\mathrm{Cs/Rb}}(0, z)$ is maximum at $z = 0$ and decays to zero with z.

The rate of decay of the $g^{(1)}_{\mathrm{Cs/Rb}}(0, z)$ increases with temperature.

Correlation function

distinct variation at $T \neq 0$



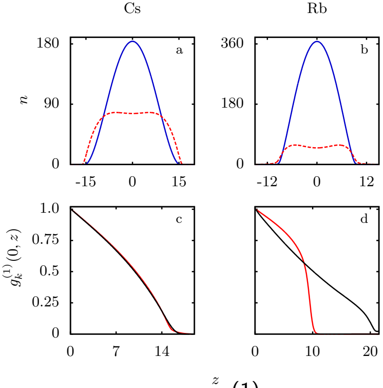
The $g_k^{(1)}(0, z)$ of the individual species cross each other at a certain z_0.
Two species have equal $g_{\mathrm{Cs/Rb}}^{(1)}(0, z_0)$.

With increase in a_{12}, z_0 increases, and $g_{\mathrm{Cs/Rb}}^{(1)}(0, z_0)$ decreases.

Difference in the decay rates of $g_{\mathrm{Cs/Rb}}^{(1)}(0, z_0)$; it is much faster in Cs.

Correlation function

distinct variation at $T = 10\text{nK}$



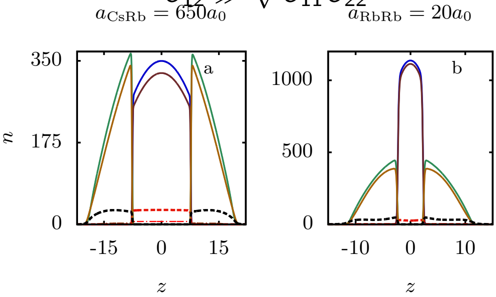
The solid red(black) line represents $g^{(1)}_{\rm Cs}(0, z)$ in Cs BEC(Cs-Rb TBEC).

The solid red(black) line represents $g^{(1)}_{\rm Rb}(0, z)$ in Rb BEC(Cs-Rb TBEC).

Phase-segregation

independent of temperature

$$U_{12} \gg \sqrt{U_{11} U_{22}}$$



Phase-separation in ^{87}Rb-^{133}Cs TBEC for $a_{12} = 650a_0$.
The solid blue (green) lines represent $n_{c\rm Cs}(n_{c\rm Rb})$ at $T = 0$.
The solid maroon (yellowish brown) lines represent $n_{c\rm Cs}(n_{c\rm Rb})$, and the dashed crimson (black) lines represent $\tilde{n}_{c\rm Cs}(\tilde{n}_{c\rm Rb})$ at $T = 10$nK.