G4t- X83 Report.

Theoretical Investigations of Trapped Interacting Bose-Einstein Condensates

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Grant #: N00014-97-1-0633

ONR program officer: Peter Reynolds

Subcontractors:
None.

Long-term Research Objective:
This program supports theoretical investigations of the quantum degenerate systems of trapped and interacting atomic gas. Primary topics being addressed are:

(1) To understand the properties of atomic Bose-Einstein condensates, in particular, the low energy excitations, dynamics of Bose-Einstein condensation, vortex states creation and detection.

(2) Theoretical prospects for quantum degeneracy and the realization of BCS states for interacting fermionic atoms, and the understanding their properties.

(3) Theoretical proposals for realizing practical coherent matter wave creation and output devices, the physics of atom lasers.

S&T Objectives:
Theoretical understanding of the quantum statistical behavior of trapped low temperature atom cloud and the development of atom laser theory.

Approach:
The theoretical studies require us to combine theoretical tools developed in the area of atomic physics, many-body statistical physics, and quantum optics. Numerical methods are developed for the solution of the low energy atomic scattering in the presence of an anisotropic interaction potential.

S&T Completed:
We have completed the calculation of the low energy scattering properties for alkali fermionic isotopes ^{6}Li, ^{38,40}K, and ^{82,84,86}Rb. This allowed for the prediction of p-wave paired BCS superfluid states for trapped atoms inside an electric field.
We have performed studies for evaporative cooling of a two trapped specie/state fermi gas in an attempt to model the JILA evaporation experiment.

Impact/Navy Relevance:
Theoretical studies of low temperature atomic gases provides support for the Navy funded experimental efforts along the same direction. As a subject of fundamental interests, these studies could also lead to better atomic clocks and atom interferometers for better rotational sensing.

Planned Research Efforts:
We proposed a new approach for creating Cooper pairs of fermionic atoms based a p-wave attractive interaction inside an electric field. This new phase has a relatively higher transition temperature T_c, and is analogous to the ^{3}He A_1 phase. We intend to continue this study by inclusion of the atomic hyperfine structures.
We studied kinetics of evaporation on trapped fermionic atoms, and addressed the issue of p-wave suppression in the one species case. We compared the slowing down behavior with the results calculated for the JILA (D. Jin) experiment where a two species gas (for ^{40}K in two distinct hyperfine states) was trapped.
We will mainly focus on the following two topics for the coming year:

(1) The Bose-Einstein condensation dynamics and the modeling of an amplified spontaneous emission atom laser.
(2) The properties of anisotropically interacting Bose gas.

Other Sponsored Science & Technology:
NSF Award, "Quantum Optical Studies of Degenerate Atomic Gas", $60k/year, 7/1/97 - 7/1/2002.

The above project from NSF mainly invovles the study of sigatures of atomic quantum degeneracy with near resonant light using quantum optical techniques. It's predictive powers are based on the properties of the qauntum degernate gases investigated in our group, e.g the condensate wave function, quasi-particle mode functions, and excitation spectra, etc.

A joint NSA/ARO award, "Quantum Logic with Trapped Atoms in Optical Cavity QED", U.S. Army Research Office, co-PI with M. S. Chapman and T. A. B. Kennedy, 5/1/98-4/30/2001, $1,055,079. My share is at the level of half support for a theoretical postdoc.

We proposed to carry out both theoretical and experimental investigations of a novel quantum computing system based on arrays of optical lattice trapped atoms inside a high Q cavity QED system. Our research results from studies of the macroscopic coherent atomic Bose-Einstein condensates will allow us to explore interesting connections of matter wave coherences with the coherence/decoherence properties for physics processes used for quantum entanglment and quantum logic.

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None.

Productivity:
Theoretical investigations of the quantum statistical behavior of trapped low temperature atom cloud and the development of atom laser theory. We have obtained several new results as listed below in the publication and presentation sections.

Technology Transfer:
The theoretical studies require us to combine tools developed in the area of atomic physics, many-body statistical physics, and quantum optics. The results of our research will be helpful to guide and explain the ongoing experimental efforts, eventually aiding advances in technologically relevant area. Numerical methods were also developed for the solution of the low energy atomic scattering in the presence of an anisotropic interaction.

Journal publications appearing in print:
"Casimir-Polder Long-Range Interaction Potentials Between Alkali-Metal Atoms",
M. Marinescu and L. You, Phys. Rev. A 59, 1936 (1999).
"Controlling atom-atom interactions at ultralow temperatures by dc electric fields",
Marinescu and L. You, Phys. Rev. Lett. 81, 4596 (1998).
"Topological phases and vortex states of Bose-Einstein condensates",
K. G. Petrosyan and L. You, Phys. Rev. A 59, 639 (1999).
"Sympathetic cooling of an atomic Bose-Fermi gas mixture",
W. Geist, L. You, and T. A. B. Kennedy, Phys. Rev. A 59, 1500 (1999).

Formal technical reports released by your institution:
None:

Presentations (indicate invited presentations):

invited:
"Electric field modified atom-atom interactions and the prospects for P-wave BCS states",

Workshop on BEC and Degenerate Fermi Gases, JILA, Boulder, CO, organized by M. Holland and M. Edwards, Feb 10-12, 1999.
"Quantum computing with atoms and photons",
Argonne National Lab, March 1st, 1999.
"Electric field modified atom-atom interactions and the prospects for P-wave BCS states",
University of Chicago, March 1st, 1999.
"Controlling Atom-Atom Interactions: Implications for Bose and Fermi Systems",
Shanghai Institute of Optics and Fine Mechanics, Sept. 3rd, 1998.
"Atomic Bose-Einstein Condensation",
Nanjing University, Sept. 15th, 1998.
"Introduction to quantum information and computing",
two lectures at the Aspen Center for Physics, June 18th, 21st, 1999.
"Kinetics of BEC condensation inside magnetic traps",
Conference on 'Macroscopic Quantum Coherence Phenomena', organized by S. Fantoni, A. Leggett, and A. Smerzi, Trieste, July 5-9, 1999.

contributed:

"Ultra cold atomic collisions in the presence of an off-resonant laser field; Prospects for controlling the atomic BEC",
M. Marinescu and L. You, 1999 DAMOP.
"Initiation of Bose condensation of atoms confined in magnetic traps",
W. Geist, T. A. B. Kennedy, and L. You, 1999 DAMOP.
"Atomic condensates with anisotropic interactions",
S. Yi and L. You, 1999 DAMOP.
"Prospects for p-wave paired BCS states of fermionic atoms",
L. You and M. Marinescu, 1999 DAMOP.

Books or book chapters published:
None.

Patents (indicate status, e.g., filed, issued):
None.

Honors, awards or prizes received during the reporting year:
None.

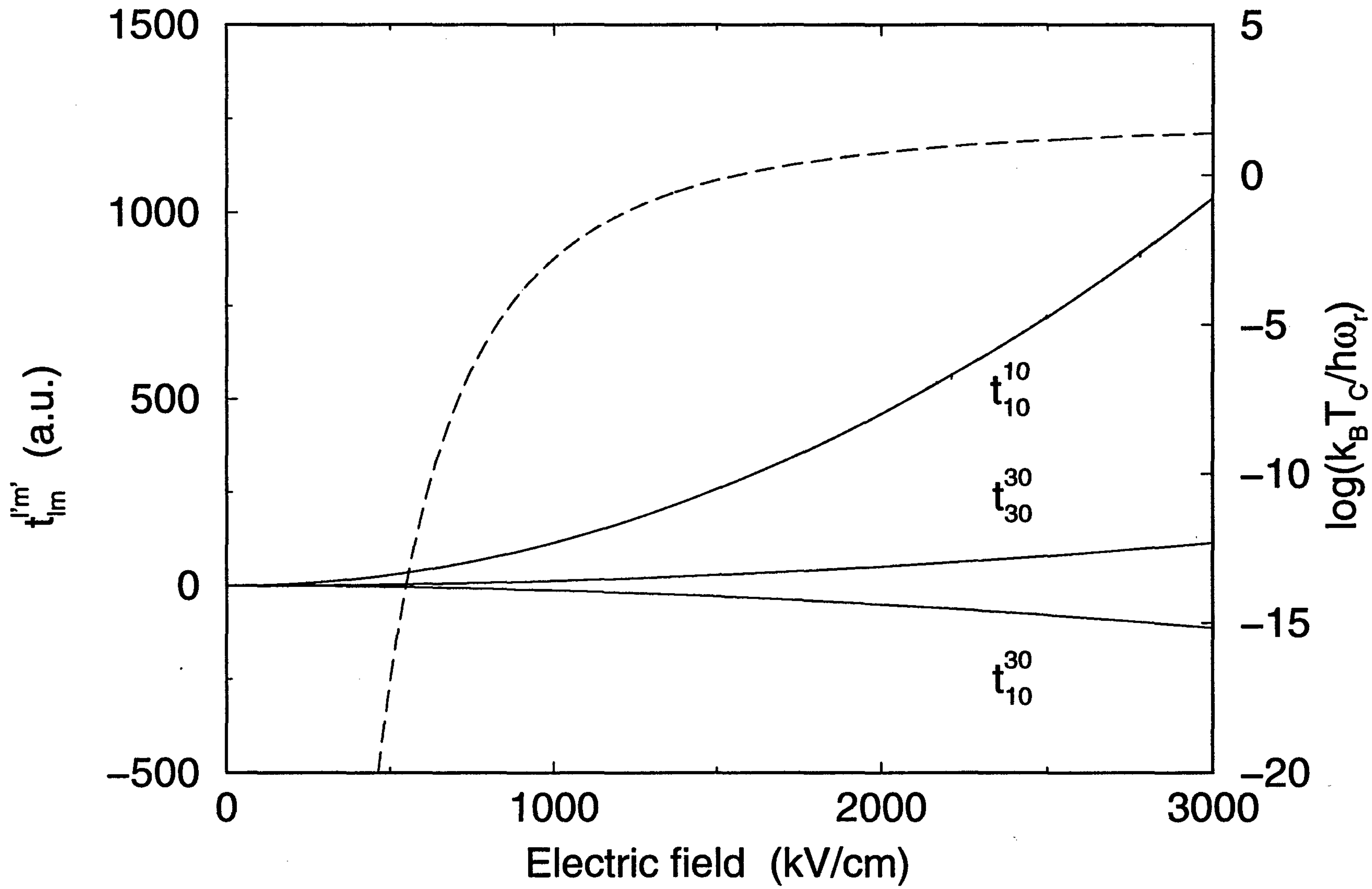
Number of Students Supported (minimum of 1/4 of their support):

Post Doctoral: 1 **Doctoral:** 0.5 **Masters:** 0.5 **Undergraduate:** 0

Of these students, the number who were:

Females: 0.5

Under-represented Ethnic groups: 0



1500
1000
500
0
−500
0
1000
2000
3000
Electric field (kV/cm)
5
0
−5
−10
−15
−20
$t_{lm}^{l'm'}$ (a.u.)
$\log(k_B T_c/h\omega_r)$
t_{10}^{10}
t_{30}^{30}
t_{10}^{30}

The effective scattering lengths in the p-wave channel for fermioni
c isotope ^{82,84,86}Rb.
The ground state width of the sperhically symmetric magnetic trap i
s $a_r\sim 0.39$ (μm)
and the trap cneter density is $n(\vec r=0)\sim 2.1\times 10^{14}$/
cm^3.
All three isotopes give similar results since hyperfine structures
are not included here.
The half lifetimes of the three isotopes are 1.25 minute, 32.9, and
 18.8 days respectively.
The relevant fermi degeneracy parameters are the fermi energy $\eps
ilon_F\approx 181.7$ ($\hbar\omega_r$),
and fermi momentum $k_F\approx 13.5/a_r$, The solid lines denote el
ectric field dependence of the effective
scattering lengths t_{lm}^{lm} in (a.u.) and refer to the left ve
rtical scale, while the dashed line denotes
k_BT_c (for pairing with t_{10}^{10}) in units of $\hbar\omega_
{r}$ and refers to the (10 based) logarithmic
right vertical scale.

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The subject report is forwarded in conformance with the contract/grant specifications.

Should you have any questions or comments regarding this report(s), please contact the Project Director or the undersigned at 404-894-4763.

/tw

Sincerely,

Thelma Woods

Thelma Woods
Customer Service Representative

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