FOR 2247

DFG FWF

From few to many-body physics with dipolar quantum gases

T3 Superfluidity in strong dipolar quantum gases

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Summary

In the near future ultracold quantum gases with stronger dipole-dipole interaction (DDI) will be realized experimentally. Therefore, this project is dedicated to study theoretically the emergence of superfluidity in strong dipolar quantum gases. On the one hand we will analyse how dipolar fermionic superfluidity arising from Cooper pairing is affected by a deformation of the Fermi surface. On the other hand we will improve the description of quantum droplets concerning condensate depletion, thermal fluctuations, and finite-size corrections.

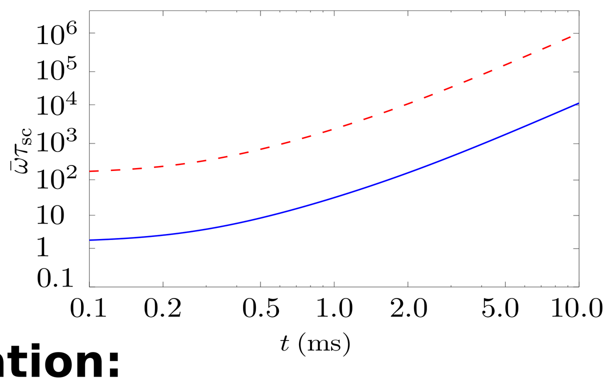
Preliminary work

Dipolar Fermions

1) HF BV at T = 0: dipolar orientation parallel to trap axis

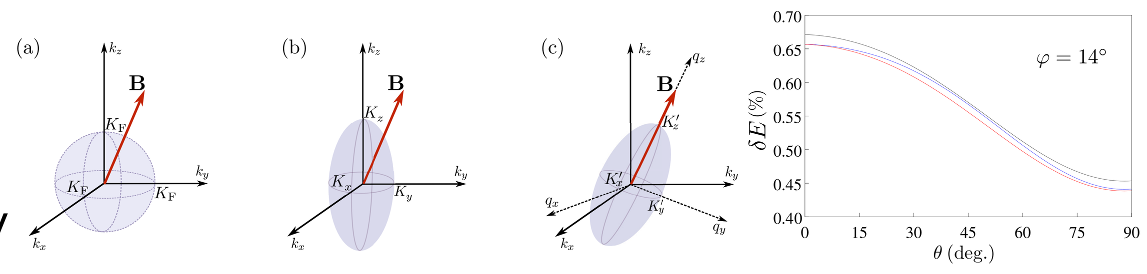
a) Collective excitations and TOF
b) From collective to hydrodynamic regime
c) Self-consistently determined relaxation time

A.R.P. Lima and A. Pelster, PRA **81**, 021606(R) (2010)
A.R.P. Lima and A. Pelster, PRA **81**, 063629 (2010)
V. Veljić, A. Balaz, and A. Pelster, PRA **95**, 053635 (2017)
F. Wächtler, A.R.P. Lima, and A. Pelster, PRA **96**, 043608 (2017)



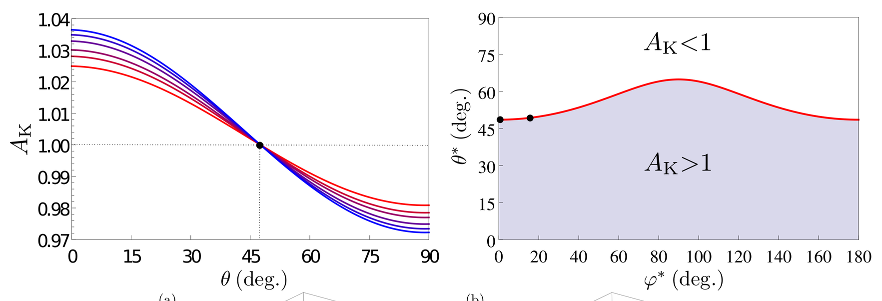
2) Elongated trap, arbitrary dipolar orientation:

a) Minimisation of HF energy yields Fermi surface deformation from sphere to ellipsoid due to Fock energy



b) Fermi surface deformation follows from momentum-space aspect ratio, which is identified with long-time limit of real-space aspect ratio within ballistic approximation

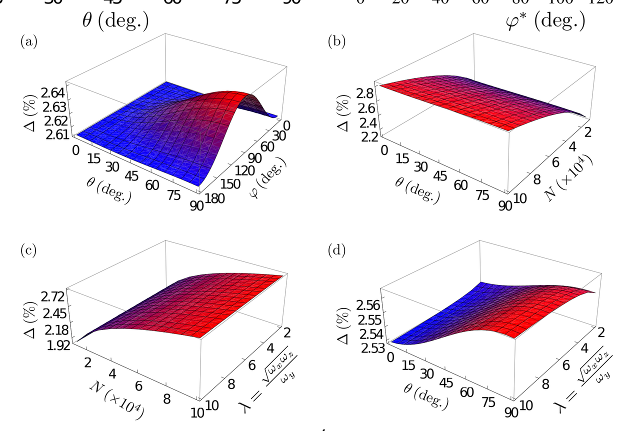
c) Despite of non-trivial Fermi surface deformation momentum-space aspect ratio can be equal to unity irrespective of trap geometry and particle number



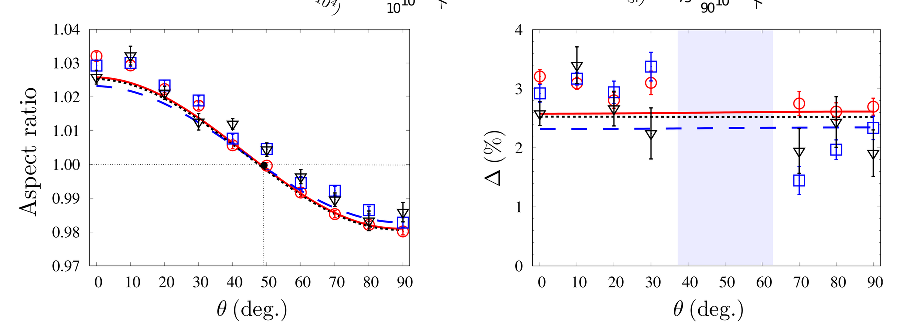
d) Dependence of Fermi surface deformation for erbium on different system parameters

V. Veljić et al., NJP **20**, 093016 (2018)

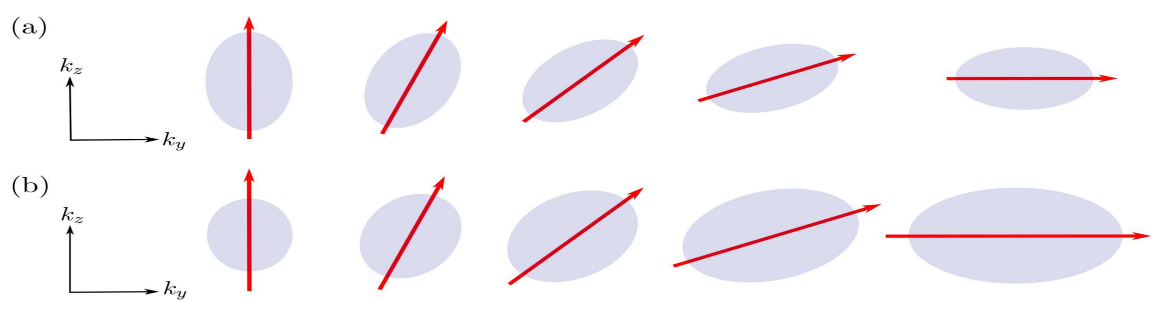
Chomaz E2 Ferlaino



e) Theoretical analysis of experimental TOF data for erbium Fermi gas reveals rotation of rigid Fermi ellipsoid



f) Schematic angular dependence of Fermi surface deformation for (a) atoms, (b) molecules

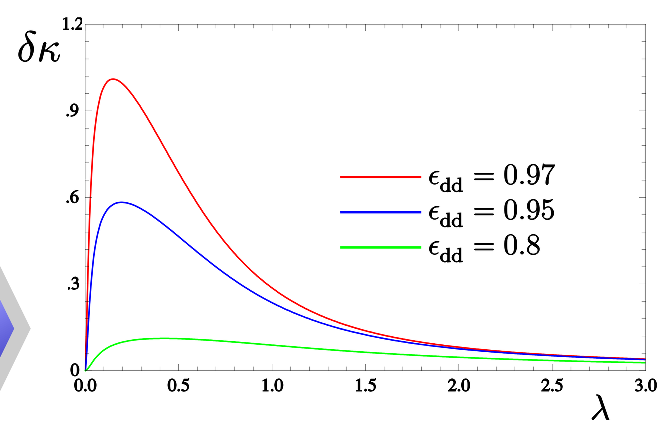


Dipolar Bosons

1) Dipolar LHY correction of chemical potential:

a) Quantum fluctuations reduce MF cloud stretching along dipolar axis: positive change of aspect ratio
b) Prework for extended GP of quantum droplets

A.R.P. Lima and A. Pelster, PRA **84**, 041604 (R) (2011)
A.R.P. Lima and A. Pelster, PRA **86**, 063609 (2012)



E1 Pfau
Chomaz E2 Ferlaino
T1 Santos
T2 Büchler

2) Anisotropic superfluidity:

a) Linear response theory:

$$p_i = VM\left(n_{nij}v_{nj} + n_{sij}v_{sj}\right) + \ldots$$

M. Ueda, Fundamentals and New Frontiers of Bose-Einstein Condensation (World Scientific, 2010)

b) Directional dependence of sound velocities

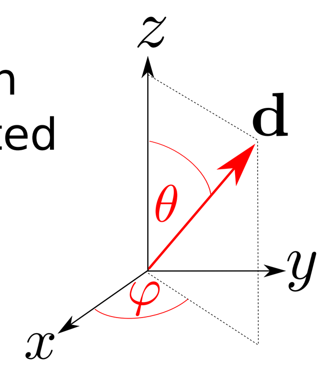
$$c_e = \sqrt{\frac{1}{m}\frac{\partial \mu}{\partial n}\mathbf{e}^T n_s \mathbf{e}}$$

C. Krumnow and A. Pelster, PRA **84**, 021608(R) (2011)
B. Nikolić, A. Balaz, and A. Pelster, PRA **88**, 013624 (2013)
M. Ghabour and A. Pelster, PRA **90**, 063636 (2014)

Objectives

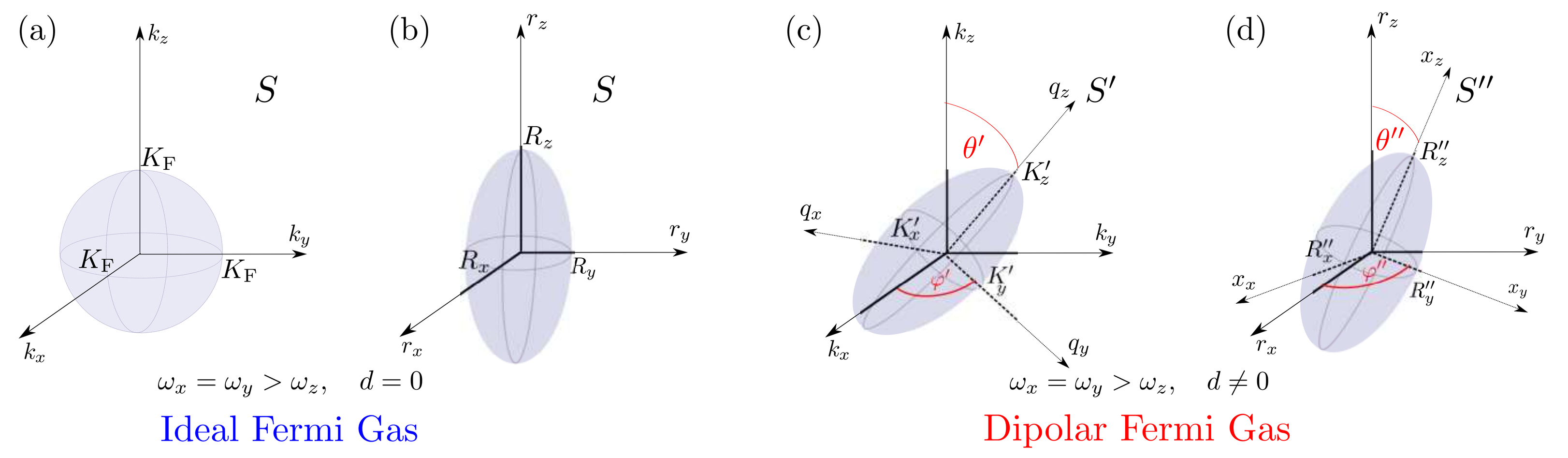
Dipolar Fermionic Superfluidity

1) HF BV at T=0: general trap and dipolar orientation



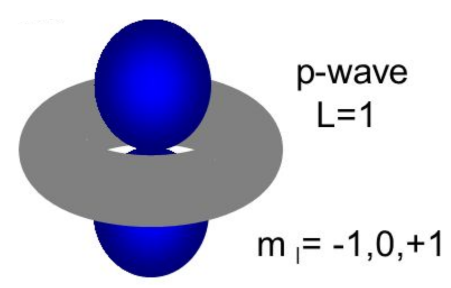
a) Rotation of spatial ellipsoid affects Fermi surface deformation
- Elongated trap: recovery of V. Veljić et al., NJP **20**, 093016 (2018) expected
- Isotropic trap: both spatial and momentum ellipsoid should be rotated in direction of dipolar axis due to symmetry reasons

b) Statics: stability diagram, reduced stability region expected
c) Dynamics: non-ballistic TOF, self-consistent relaxation time



2) Cooper pairing

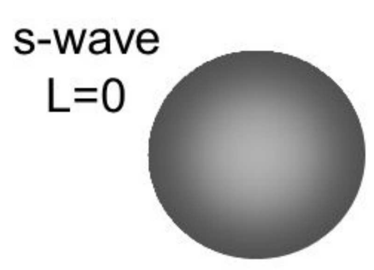
a) One component: p-wave superfluidity
- Anisotropic order parameter
- HFB: C. Zhao, L. Jiang, X. Liu, W.M. Liu, X. Zou, and H. Pu, PRA **81**, 063642 (2010)



Chomaz E2 Ferlaino

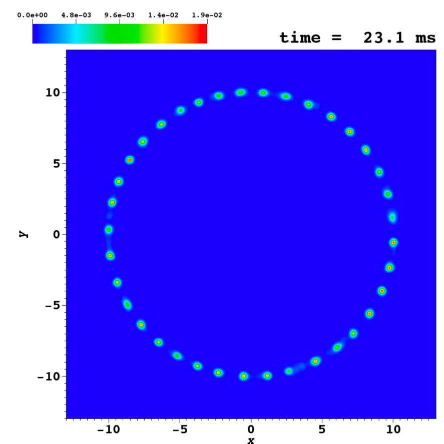
b) Two components: s-wave superfluidity
- Isotropic order parameter
- BCS: T. Shi, J.-N. Zhang, C.-P. Sun, and S. Yi, PRA **82**, 033623 (2010)

c) Anisotropic superfluidity:
- Extend uniform to trapped case
- Impact of Fermi surface deformation
- Tunability via trap geometry and dipolar orientation



Bloch E4 Luo

Description of Quantum Droplets



1) Condensate Depletion

a) Self-consistent quantum fluctuations: HF BP

B. Irsigler and A. Pelster, PRA **95**, 043610 (2017)

b) Application: achieve droplets with higher density due to tighter harmonic confinement or ring trap

2) Thermal fluctuations

a) Hugenholtz-Pines approach: avoid renormalization
b) Josephson sum rule: condensate and superfluid density
c) Application: temperature dependence of droplet properties
- Sound velocities from anisotropic two-fluid model
- Hybridization of first and second sound velocities?
- Tilting of dipoles' orientation initiates droplet formation

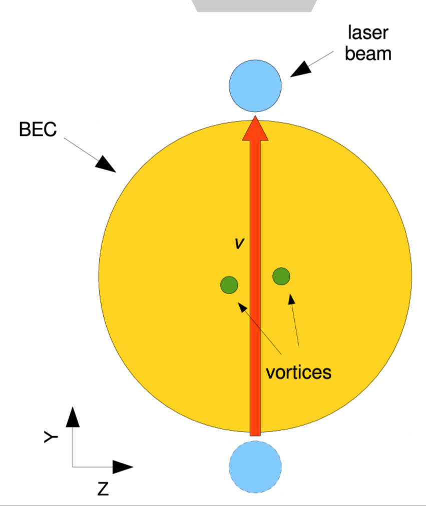
A. Boudjemaa, Ann. Phys. **381**, 68 (2017); E. Aybar and M.O. Oktel, arXiv:1805.06261

T2 Büchler

3) Finite-size corrections

a) Gradient expansion of quantum fluctuations
b) Anisotropic fluctuation correction of kinetic energy
c) Application: vortices as local probes of superfluidity
- Ellipsoidal deformation due to anisotropic DDI
- Vortex generation by a moving obstacle
- Do vortices enhance or hinder droplet formation?
- Does fast rotation lead to lattice of vortices or droplets?

T1 Santos



E1 Pfau
Chomaz E2 Ferlaino
Ospelkaus E5 Zenesini
E6 Nägerl

Collaborations within the Forschergruppe