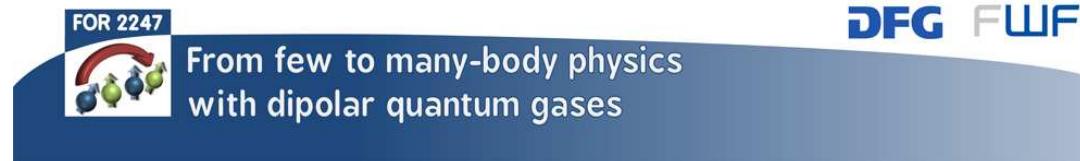
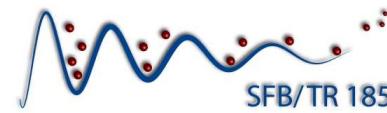


Ultracold Quantum Gases: A Fascinating Playground for Basic Research

Axel Pelster



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1. Introduction
2. Theses Topics
3. Outlook



1.1 Identical Quantum Particles

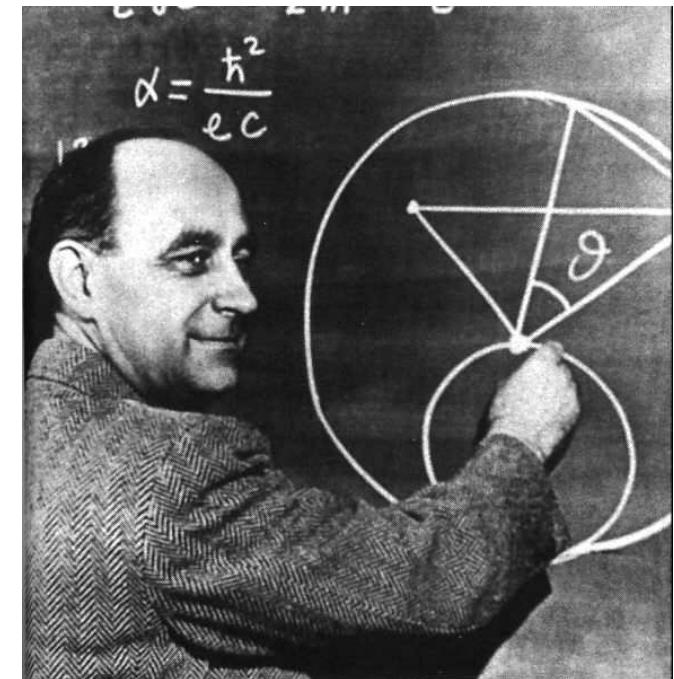
Bosons:

- Symmetric wave function
- Integer spin

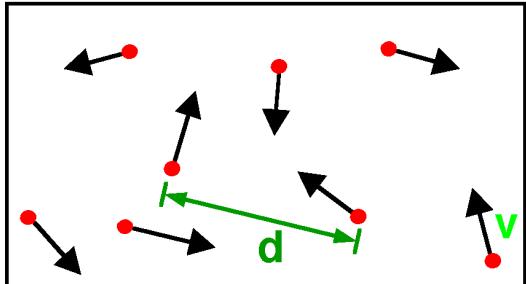


Fermions:

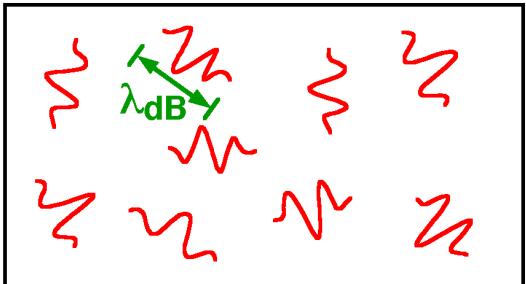
- Anti-symmetric wave function
- Half-integer spin



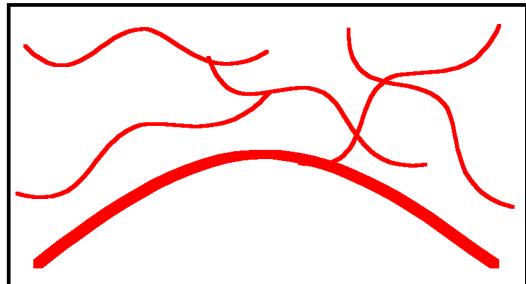
1.2 What is Bose-Einstein Condensation?



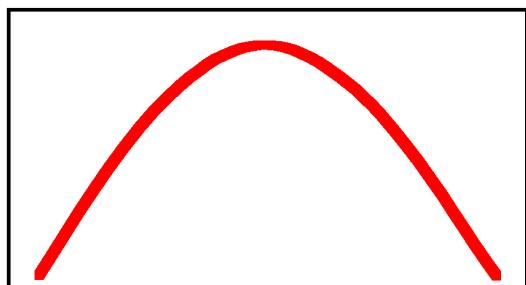
High Temperature T:
thermal velocity v
density d^{-3}
"Billiard balls"



Low Temperature T:
De Broglie wavelength
 $\lambda_{dB} = \hbar/mv \propto T^{-1/2}$
"Wave packets"



T=T_{crit}:
Bose-Einstein
Condensation
 $\lambda_{dB} \approx d$
"Matter wave overlap"



T=0:
Pure Bose
condensate
"Giant matter wave"

$$\bullet n = \frac{1}{d^3}$$

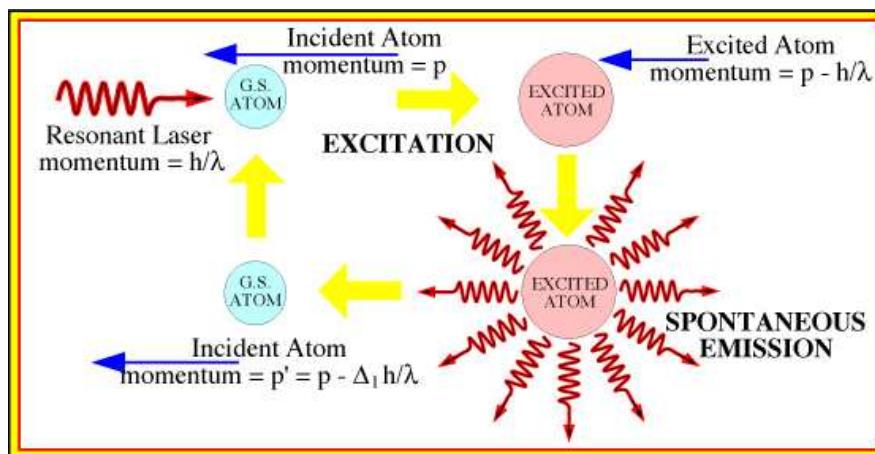
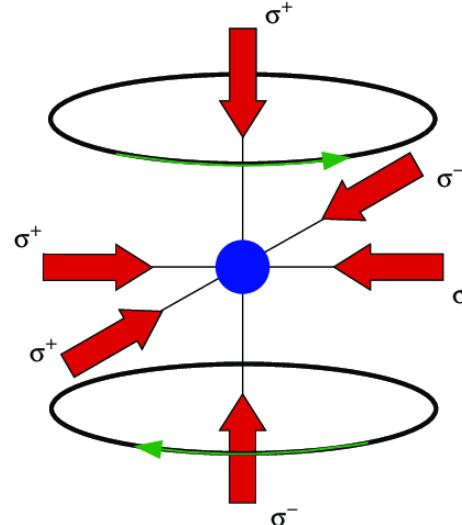
$$\bullet \lambda_{dB} = \frac{\hbar}{\sqrt{2Mk_B T}}$$

$$\bullet \frac{\lambda_{dB}}{d} \approx 1$$

$$\bullet T_c \approx \frac{\hbar^2 n^{3/2}}{2Mk_B}$$

1.3 Cooling Techniques

Magneto-optical trap

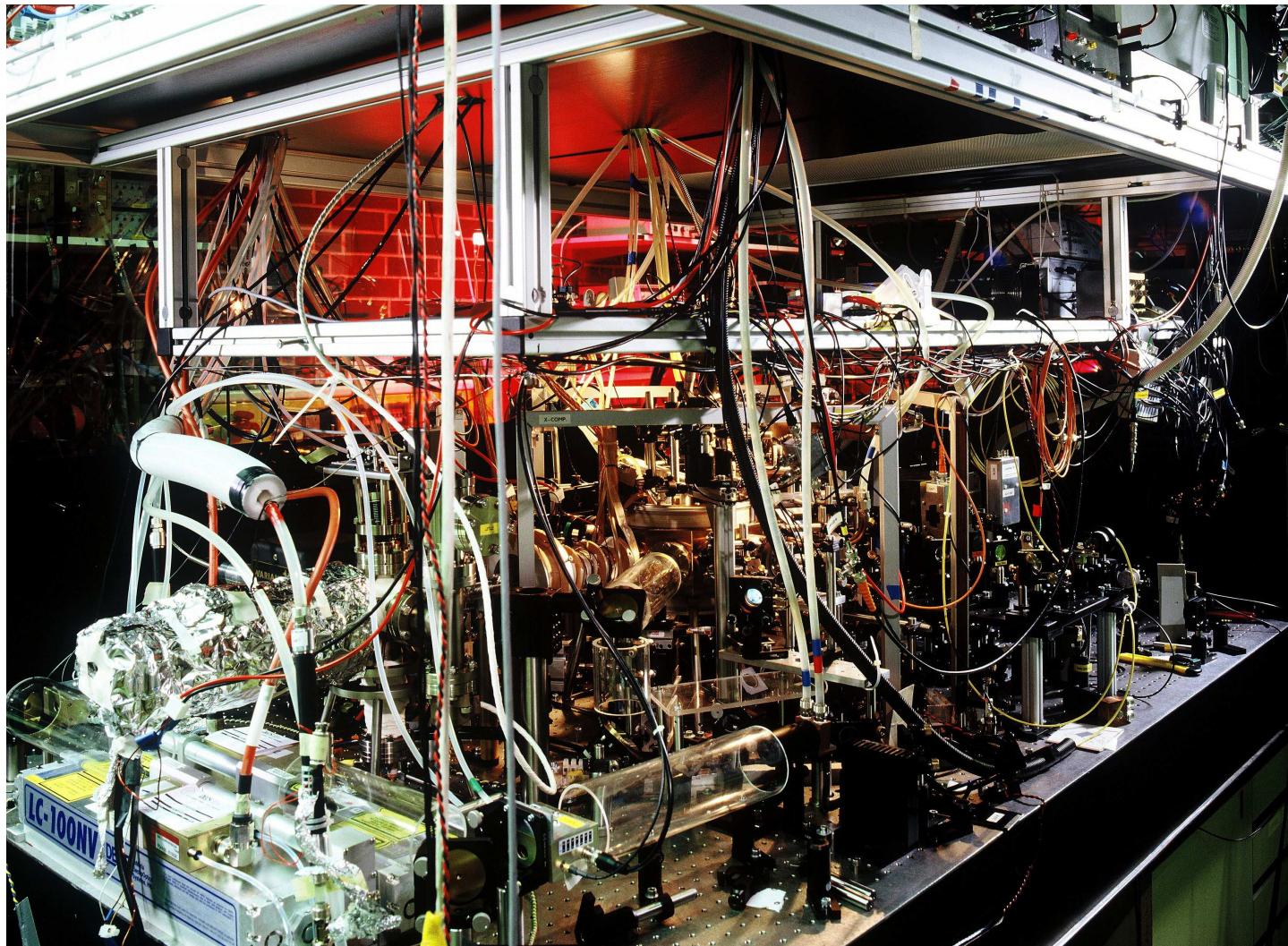


Laser cooling

Evaporative cooling

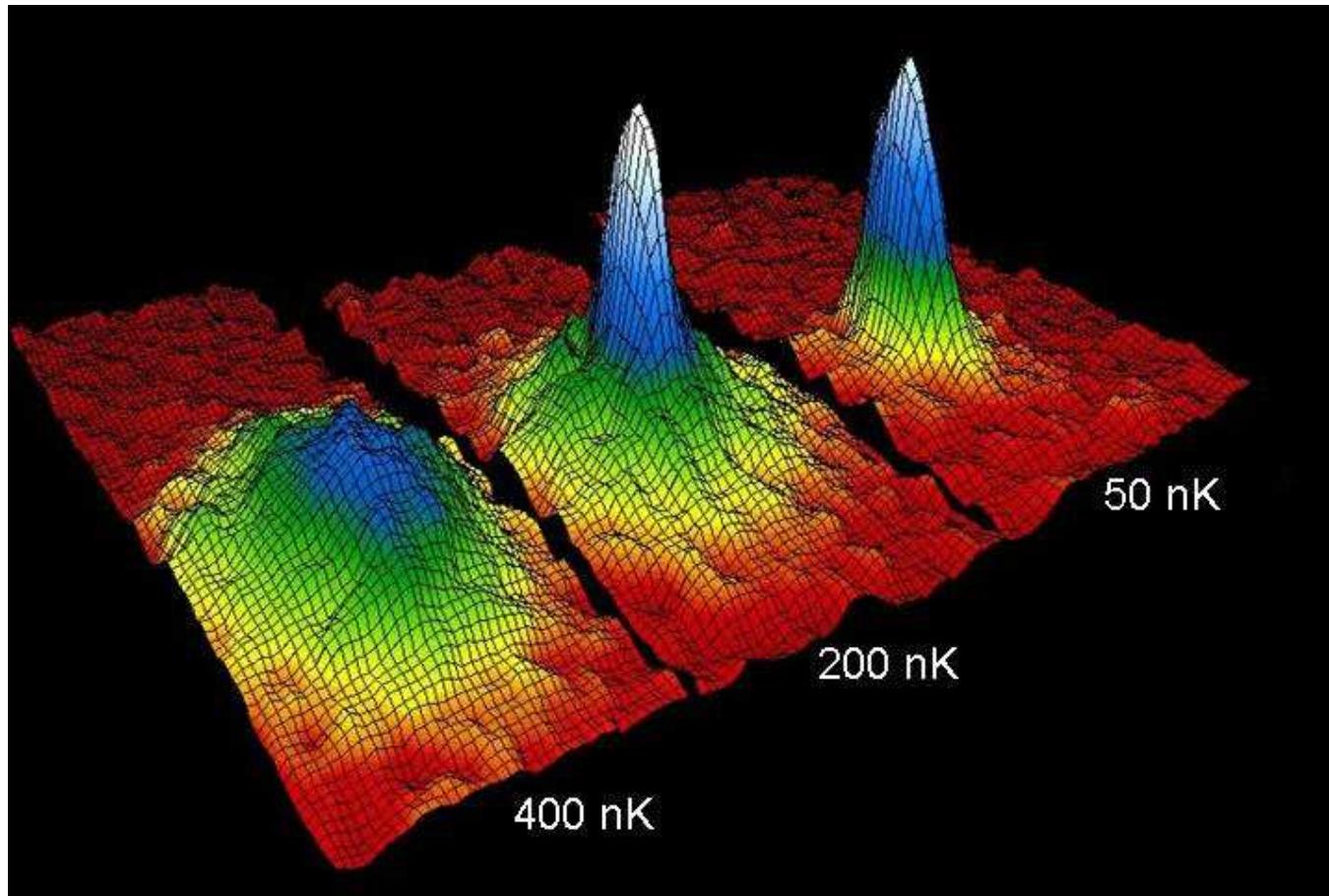


1.4 Experimental Apparatus



Costs about 1.000.000 EUR

1.5 Time-of-Flight Absorption Pictures



JILA (1995): ^{87}Rb , $N=20\,000$, $\omega_1 = \omega_2 = \omega_3/\sqrt{8} = 2\pi \times 120 \text{ Hz}$

1.6 Periodic Table of Chemical Elements

1	H Wasserstoff $[He]1s^1$ 1.007 229.14 229.14 229.14 -1.1 0.0899*	2	He Helium $[He]1s^2$ 0.0002 406.0 406.0 0.18*
3	Li Lithium $[He]2s^1$ 0.53 7.02 134.0 134.0 1.1 1.85	4	Be Beryllium $[He]2s^2$ 2.0 9.012 1287 2489 1.8
11	Na Natrium $[Ne]3s^1$ 0.97 22.99 22.99 22.99 22.99 22.99 22.99 -1.1 1.74	12	Mg Magnesium $[Ne]3s^2$ 2.3 24.365 450 1000 1.3
19	K Kalium $[Ar]3d^14s^1$ 0.86 39.09 75.9 75.9 75.9 75.9 75.9 -1.1 1.55	20	Ca Calcium $[Ar]3d^24s^2$ 1.4 41.98 3103 3287 3287 3287 3287 2.4 3.450
37	Rb Rubidium $[Kr]4d^15s^1$ 1.53 85.61 39.31 46.9 46.9 46.9 46.9 -1.0 2.63	38	Sr Strontium $[Kr]4d^25s^2$ 1.5 40 91.24 1867 4464 4464 4464 4464 4464 1.8 3.50 2.34
55	Cs Cäsium $[Xe]4d^16s^1$ 1.90 132.91 84.81 87.7 87.7 87.7 87.7 -0.8 3.62	56	Ba Barium $[Xe]4d^26s^2$ 2.0 137.33 727 1870 1870 1870 1870 0.9 3.62
[87]	Fr Francium $[Rn]5d^17s^1$ 1 223.03 67.07 0.7 0.7 0.7 0.7 -0.8 5.5	[88]	Ra Radium $[Rn]5d^27s^2$ 2 224.03 700 1777 1777 1777 1777 0.8 5.5
57	La Lanthan $[Xe]4f^15d^16s^2$ 6.17 138.91 347.0 347.0 347.0 347.0 347.0 -2.0 3	58	Ce Cer $[Xe]4f^15d^26s^2$ 6.77 140.12 3369 3369 3369 3369 3369 -1.1 3.4
[89]	Ac Actinium $[Rn]5f^66d^17s^2$ 10.07 227.0 1856 3360 3360 3360 3360 -2.0 3	[90]	Th Thorium $[Rn]5f^76d^17s^2$ 11.72 1755 1755 1755 1755 1755 1755 -1.1 2.34
59	Ce Cer $[Xe]4f^15d^26s^2$ 6.48 140.91 3369 3369 3369 3369 3369 -1.1 3.4	60	Pr Praseodym $[Xe]4f^25d^16s^2$ 7.00 144.28 3188 3188 3188 3188 3188 -1.1 3.4
[91]	Pa Protactinium $[Rn]5f^76d^17s^2$ 15.37 1755 1755 1755 1755 1755 1755 -1.1 5	[92]	U Uran $[Rn]5f^76d^17s^2$ 19.16 15.37 34.5,6 34.5,6 34.5,6 34.5,6 34.5,6 -1.1 5
61	Nd Neodym $[Xe]4f^35d^16s^2$ 7.00 144.91 3188 3188 3188 3188 3188 -1.1 3.4	62	Pm Promethium $[Xe]4f^35d^16s^2$ 7.54 146.92 3188 3188 3188 3188 3188 -1.1 2.3
[93]	Pa Protactinium $[Rn]5f^76d^17s^2$ 20.45 1755 1755 1755 1755 1755 1755 -1.1 5	[94]	U Uran $[Rn]5f^76d^17s^2$ 19.82 19.82 34.5,6,7 34.5,6,7 34.5,6,7 34.5,6,7 34.5,6,7 -1.1 5
63	Sm Samarium $[Xe]4f^55d^16s^2$ 7.2 146.92 3188 3188 3188 3188 3188 -1.1 2.3	64	Eu Europium $[Xe]4f^55d^16s^2$ 7.54 146.92 3188 3188 3188 3188 3188 -1.1 2.3
[95]	Pu Plutonium $[Rn]5f^76d^17s^2$ 13.67 19.82 34.5,6,7 34.5,6,7 34.5,6,7 34.5,6,7 34.5,6,7 -1.1 5	[96]	Gd Gadolinium $[Xe]4f^75d^16s^2$ 7.89 146.92 3188 3188 3188 3188 3188 -1.1 3.4
[97]	Am Americium $[Rn]5f^76d^17s^2$ 13.67 19.82 34.5,6,7 34.5,6,7 34.5,6,7 34.5,6,7 34.5,6,7 -1.1 5	[98]	Tb Terbium $[Xe]4f^95d^16s^2$ 8.25 157.25 3230 3230 3230 3230 3230 -1.2 3.4
[99]	Cf Berkelium $[Rn]5f^76d^17s^2$ 15.1 14.78 (2),3(4) 3.4 3.4 3.4 3.4 3.4 -1.1 5	[100]	Dy Dysprosium $[Xe]4f^{10}5d^16s^2$ 8.78 158.93 3230 3230 3230 3230 3230 -1.2 3.4
[101]	Es Einsteinium $[Rn]5f^106d^17s^2$ 8.84 164.93 3230 3230 3230 3230 3230 -1.2 3.4	[102]	Ho Holmium $[Xe]4f^{11}5d^16s^2$ 8.78 166.93 3230 3230 3230 3230 3230 -1.2 3.4
[103]	Fm Fermium $[Rn]5f^116d^17s^2$ 8.84 168.93 3230 3230 3230 3230 3230 -1.2 3.4	[104]	Er Erbium $[Xe]4f^{12}5d^16s^2$ 9.32 170.93 3230 3230 3230 3230 3230 -1.2 3.4
[105]	Db Dubnium $[Rn]5f^146d^17s^2$ 11.34 1755 1755 1755 1755 1755 1755 -1.1 5	[106]	Tm Thulium $[Xe]4f^{14}6d^17s^2$ 19.32 172.03 3230 3230 3230 3230 3230 -1.2 3.4
[107]	Sg Seaborgium $[Rn]5f^{14}6d^17s^2$ 22.56 1755 1755 1755 1755 1755 1755 -1.1 5	[108]	Cn Copernicium $[Rn]5f^{14}6d^17s^2$ 13.55 173.03 3230 3230 3230 3230 3230 -1.2 3.4
[109]	Mt Meitnerium $[Rn]5f^{14}6d^17s^2$ 21.45 1755 1755 1755 1755 1755 1755 -1.1 5	[110]	Ds Darmstadtium $[Rn]5f^{14}6d^17s^2$ 19.32 1755 1755 1755 1755 1755 1755 -1.1 5
[111]	Rg Roentgenium $[Rn]5f^{14}6d^17s^2$ 15.11 1755 1755 1755 1755 1755 1755 -1.1 5	[112]	Cn Copernicium $[Rn]5f^{14}6d^17s^2$ 13.55 173.03 3230 3230 3230 3230 3230 -1.2 3.4
[113]	Uut Ununtrium $[Rn]5f^{14}6d^17s^2$ 11.34 1755 1755 1755 1755 1755 1755 -1.1 5	[114]	Uuq Ununquadium $[Rn]5f^{14}6d^17s^2$ 11.34 1755 1755 1755 1755 1755 1755 -1.1 5
[115]	Uup Ununpentium $[Rn]5f^{14}6d^17s^2$ 11.34 1755 1755 1755 1755 1755 1755 -1.1 5	[116]	Uuh Ununhexium $[Rn]5f^{14}6d^17s^2$ 11.34 1755 1755 1755 1755 1755 1755 -1.1 5
[117]	Uus Ununseptium $[Rn]5f^{14}6d^17s^2$ 11.34 1755 1755 1755 1755 1755 1755 -1.1 5	[118]	Uuo Ununoctium $[Rn]5f^{14}6d^17s^2$ 11.34 1755 1755 1755 1755 1755 1755 -1.1 5

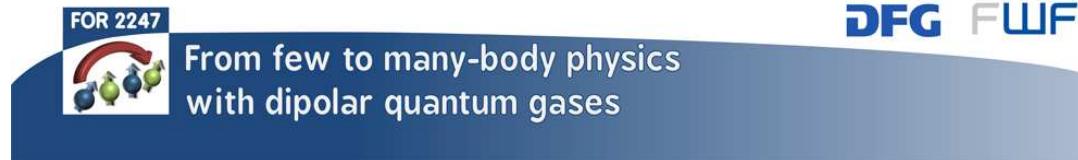
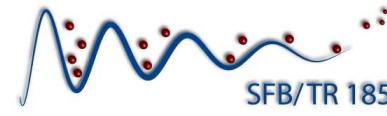
Quantum degenerate **bosons** and **fermions**

Ultracold Quantum Gases: A Fascinating Playground for Basic Research

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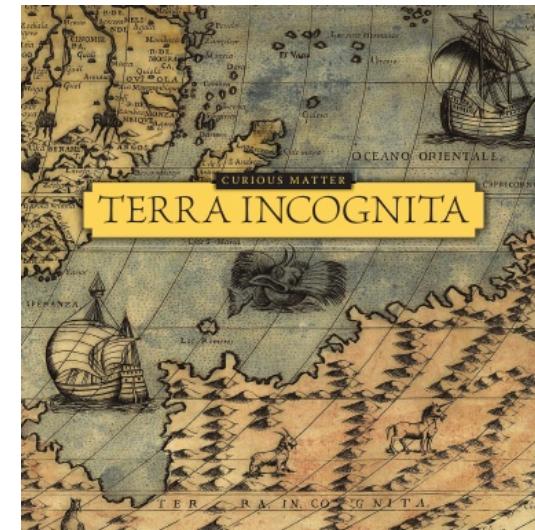


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- 1. Introduction**
- 2. Theses Topics**
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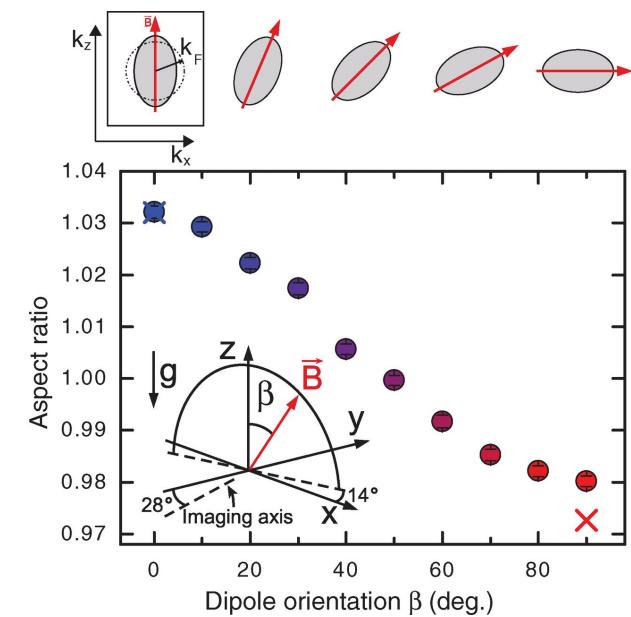
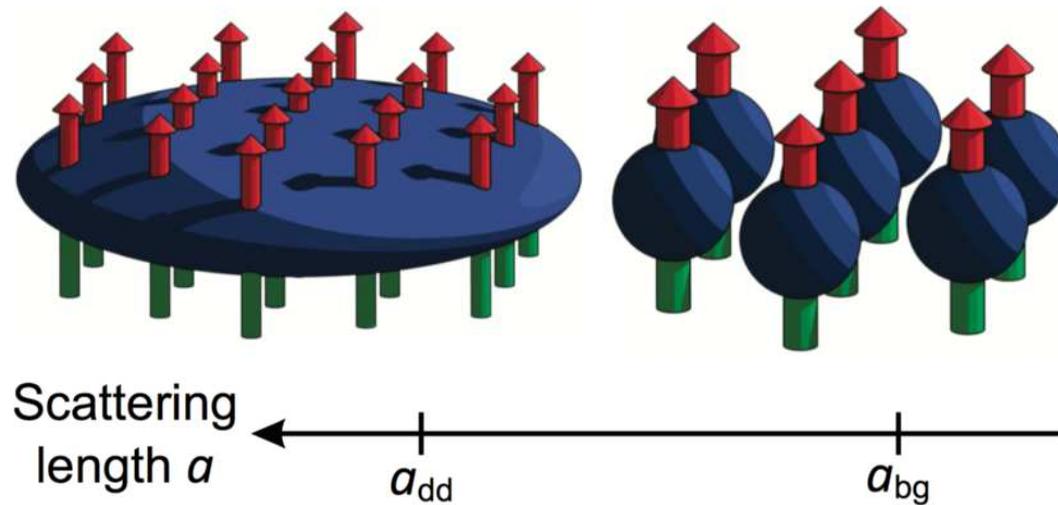
2.1 Strong Dipolar Quantum Gases



From few to many-body physics
with dipolar quantum gases

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Hanover, Innsbruck, Kaiserslautern, Munich, Stuttgart



Dipolar Bose gases:
Quantum droplets

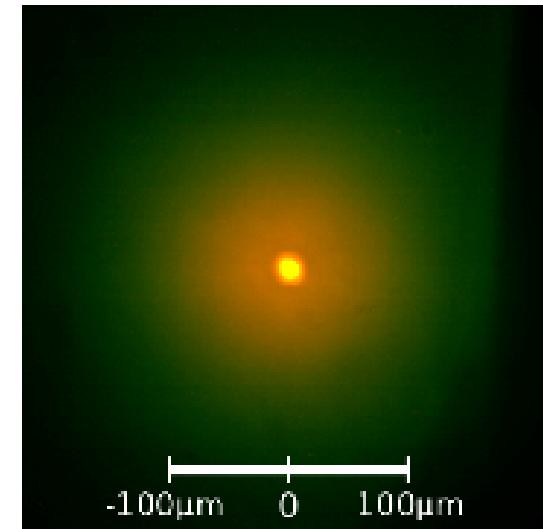
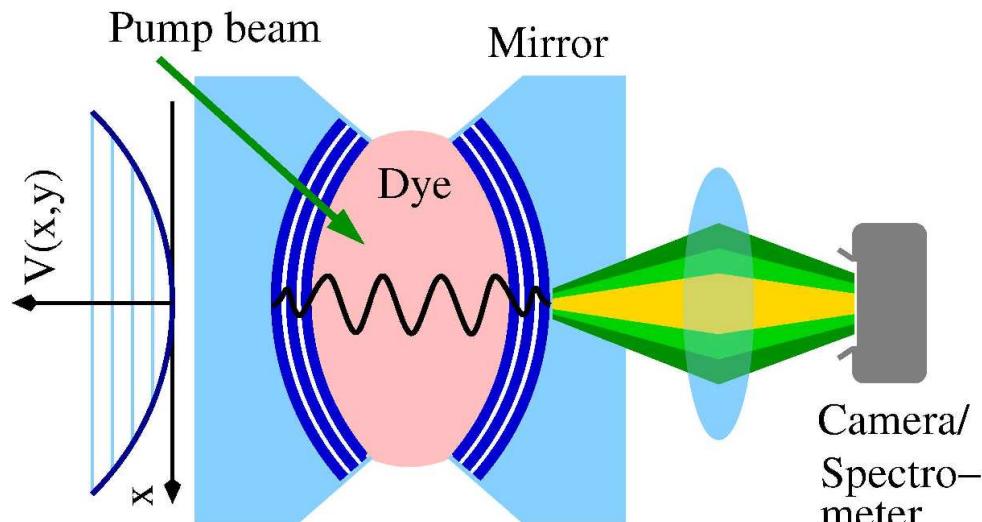
Pelster, Physik-Journal 18, Nr. 6, 20 (2019)

Dipolar Fermi gases:
Fermi surface deformed

2.2 Dimensional Crossover in Trapped Photon Gases



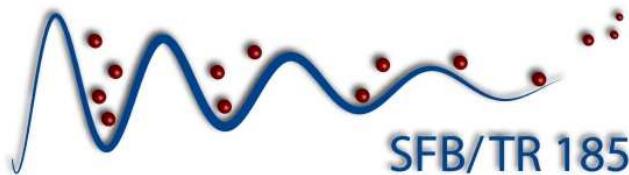
Bonn, Kaiserslautern



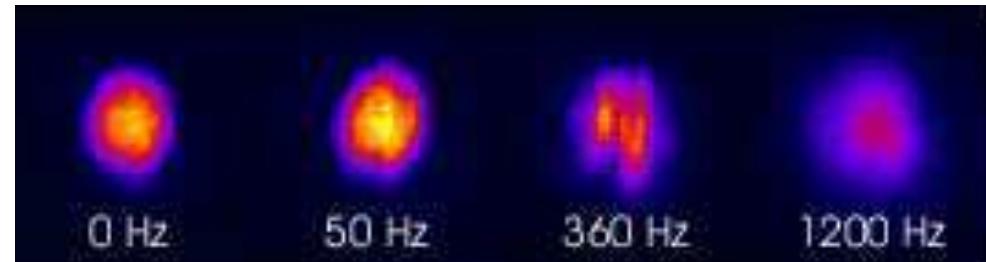
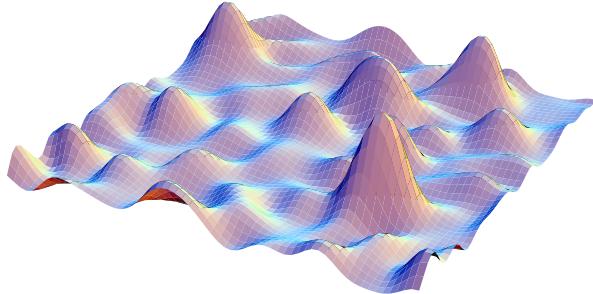
Pelster, Physik-Journal **10**, Nr. 1, 20 (2011); Physik-Journal **13**, Nr. 3, 20 (2014)

**Theory support for new photon BEC set up
in research group of Georg von Freymann**

2.3 Random Potentials

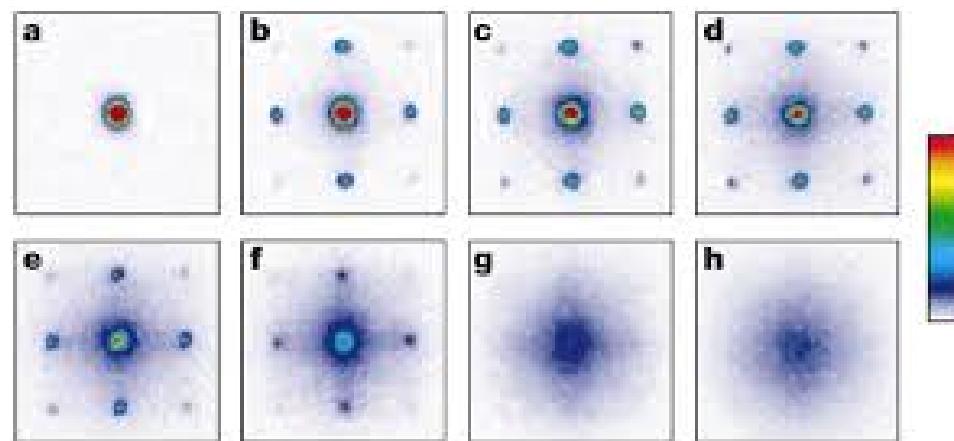
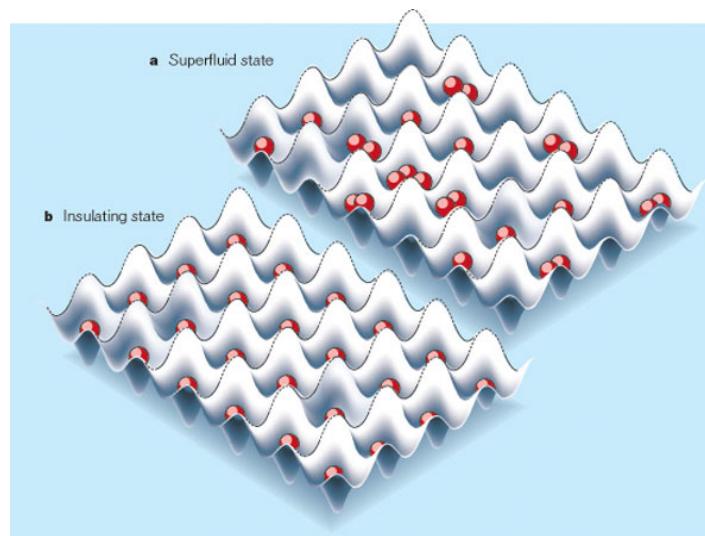


Bonn, Kaiserslautern



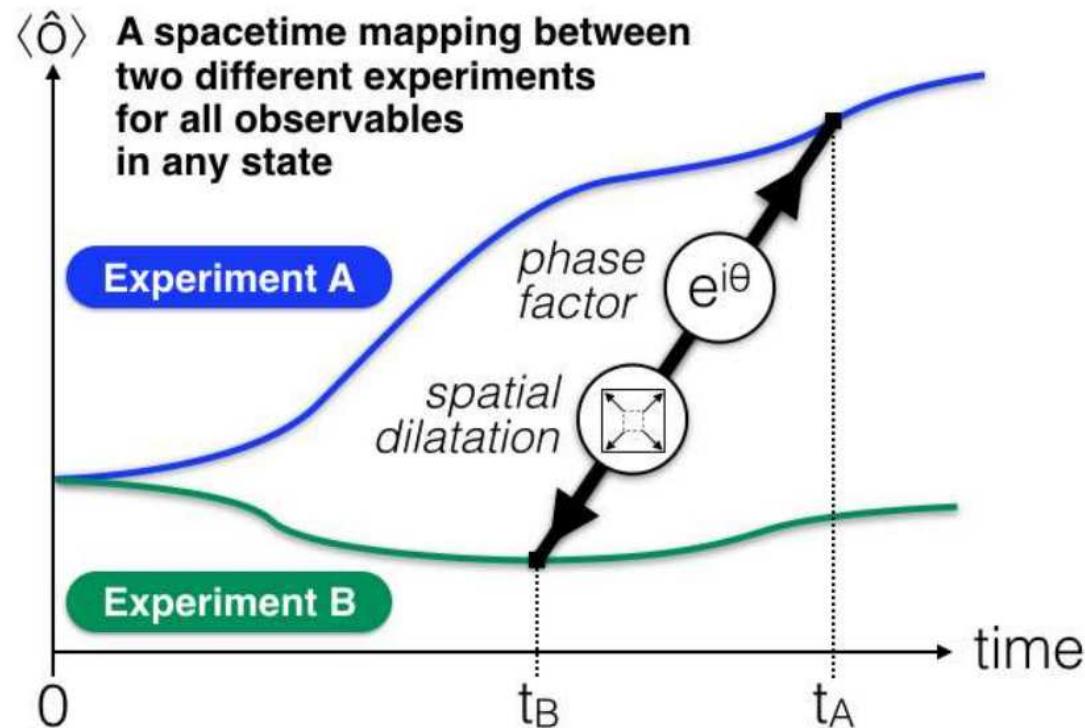
Theory support for ${}^6\text{Li}$ BEC-BCS crossover experiment in research group of Artur Widera

2.4 Bosons in Optical Lattices



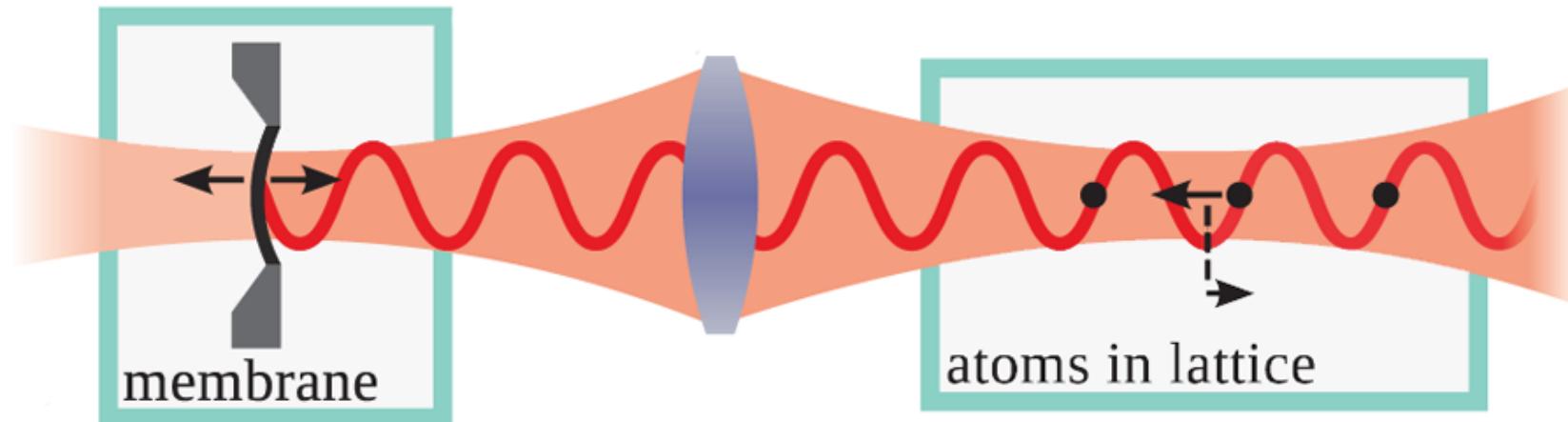
Superfluid-Mott quantum phase transition

2.5 Quantum Gas Mappings



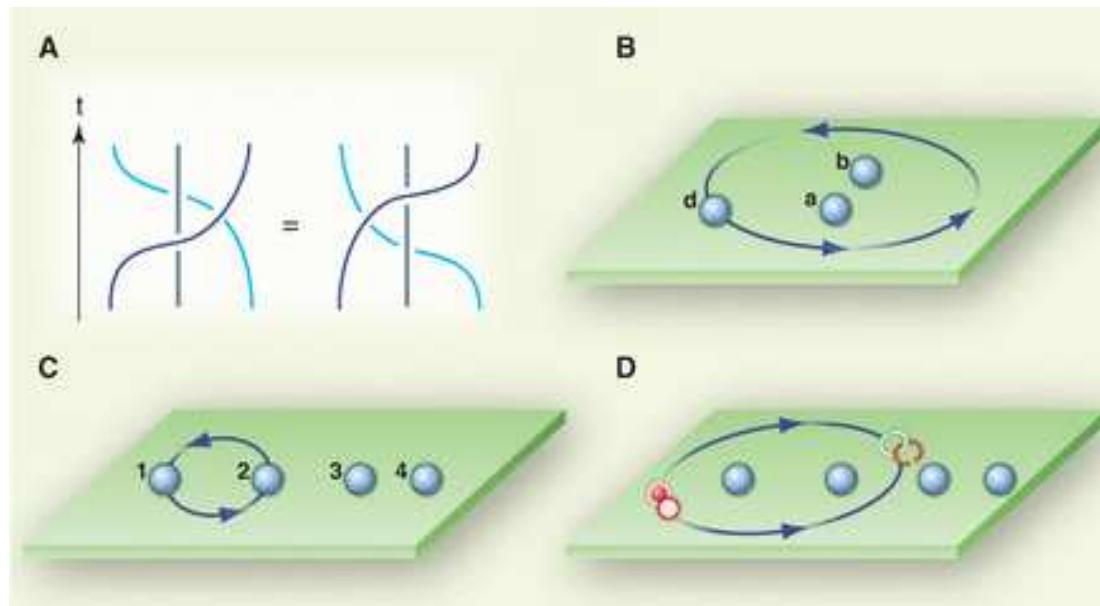
New solution strategy:
Map one quantum gas experiment to another

2.6 Hybrid Atom-Optomechanical Systems



- Cooling of nanomembrane
- Long-range interactions in atom gas mediated by cavity field
- Non-equilibrium phase transitions

2.7 Anyonic Statistics



How to interpolate between Bose-Einstein
and Fermi-Dirac statistics?

2.8 Quantum Gases on Manifolds



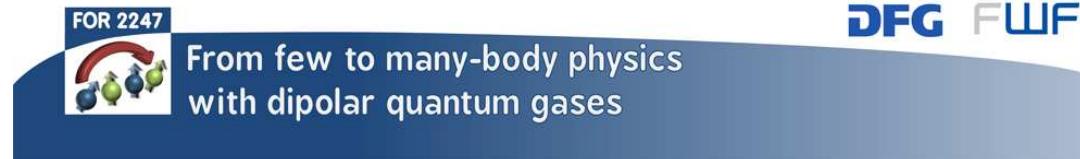
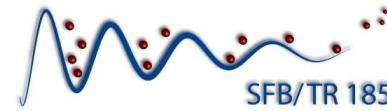
**Berezinskii-Kosterlitz-Thouless (BKT) phase transition:
unbinding of vortex/antivortex pairs**

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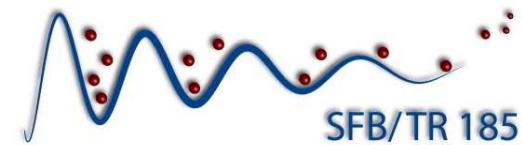
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3.1 Conferences and Schools

- International Winter School
on Open Quantum Many-Body Systems:
Tutzing, February 20 – 23, 2023



- Workshop on Low Dimensional Quantum Gases:
São Paulo, March 19 – 22, 2023



- DPG School on Ultracold Atoms and Molecules:
Bad Honnef, August 6 – 12, 2023

WILHELM UND ELSE
HERAEUS-STIFTUNG



3.2 Homepage

www-user.rhrk.uni-kl.de/~apelster/

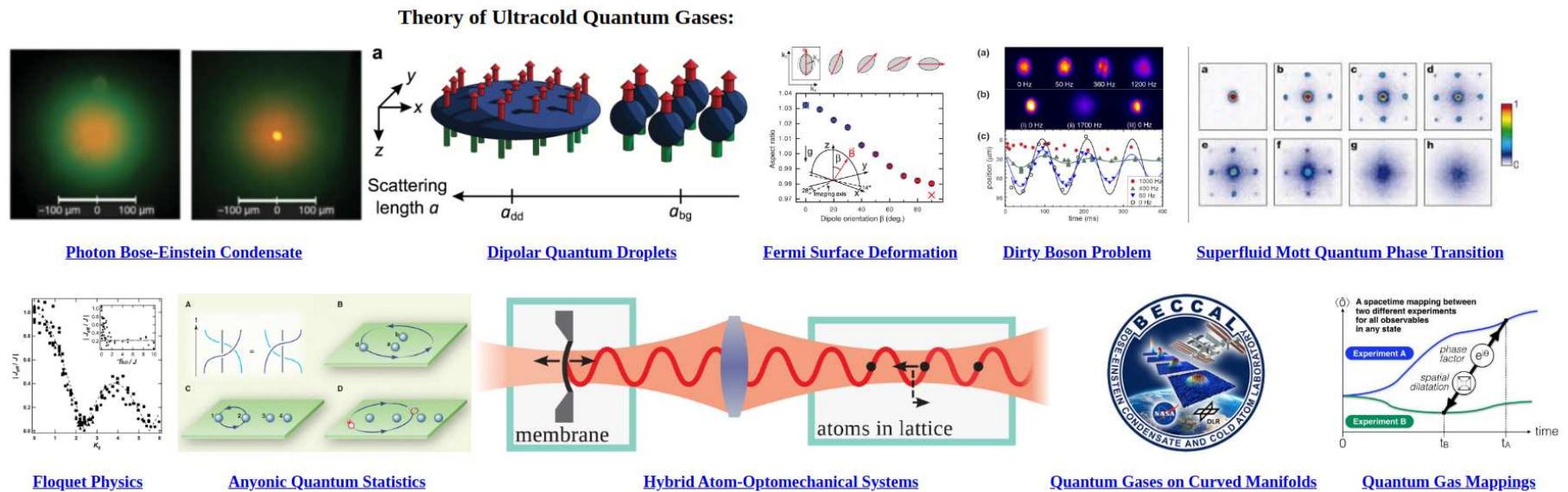


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Other Research Interests:

- Anholonomic Space and Time Transformations
- Gravitational Theories with Torsion

List of Publications:

- [Pupil Research Projects](#)

Tag der Physik 2019

[Gravitationswellen - Ein neues Fenster ins Universum](#)

<https://www-user.rhrk.uni-kl.de/~apelster>
axel.pelster@physik.uni-kl.de