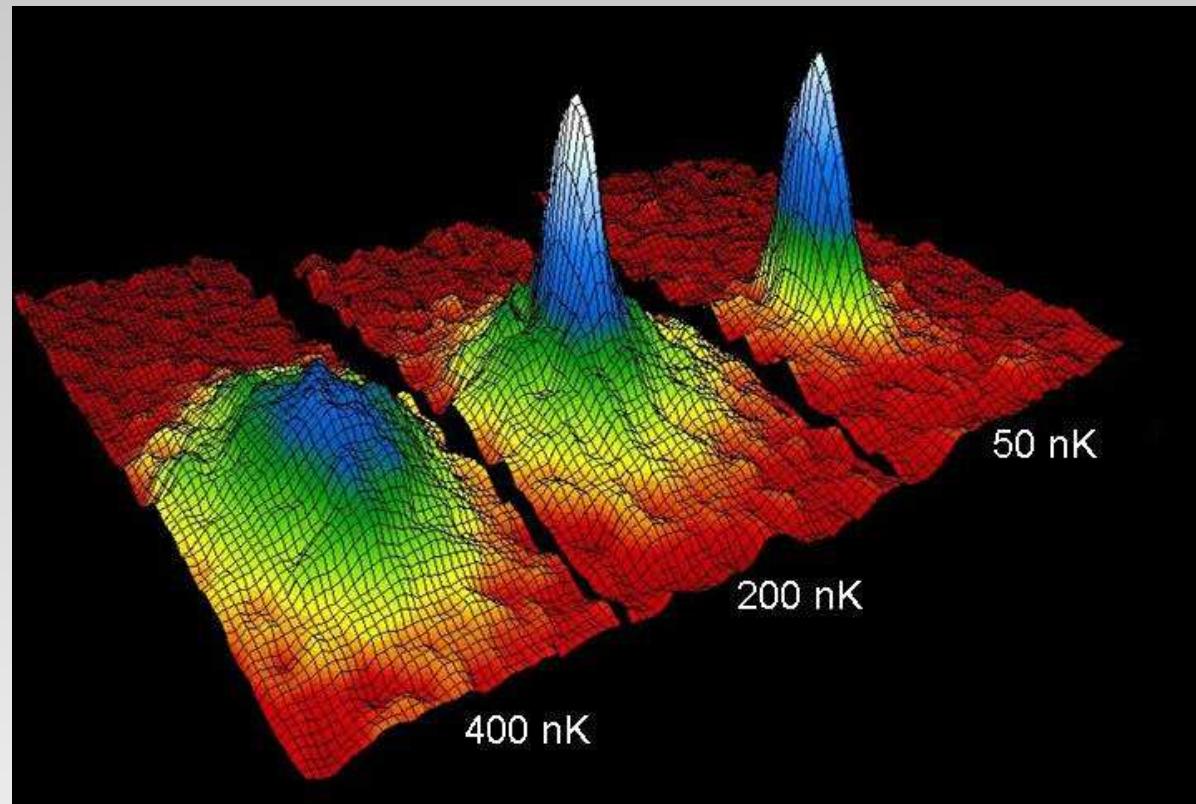


# Ultracold Quantum Gases



Aristeu Lima

Free University of Berlin

# Outline of the talk

- Brief historic remarks

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- Bose-Einstein condensation (BEC)

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# Historical remarks

- 1924: S. N. Bose and the bosons

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# Historical remarks

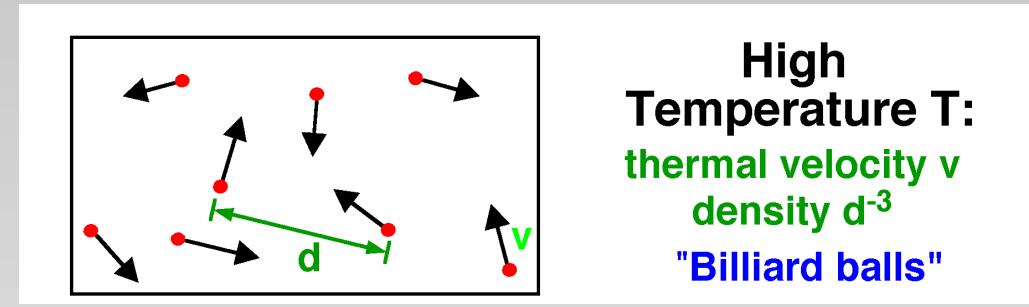
- 1924: S. N. Bose and the bosons
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- 1957: J. Bardeen, L. N. Cooper, and J. R. Schrieffer

**Microscopic Theory of  
Superconductivity**

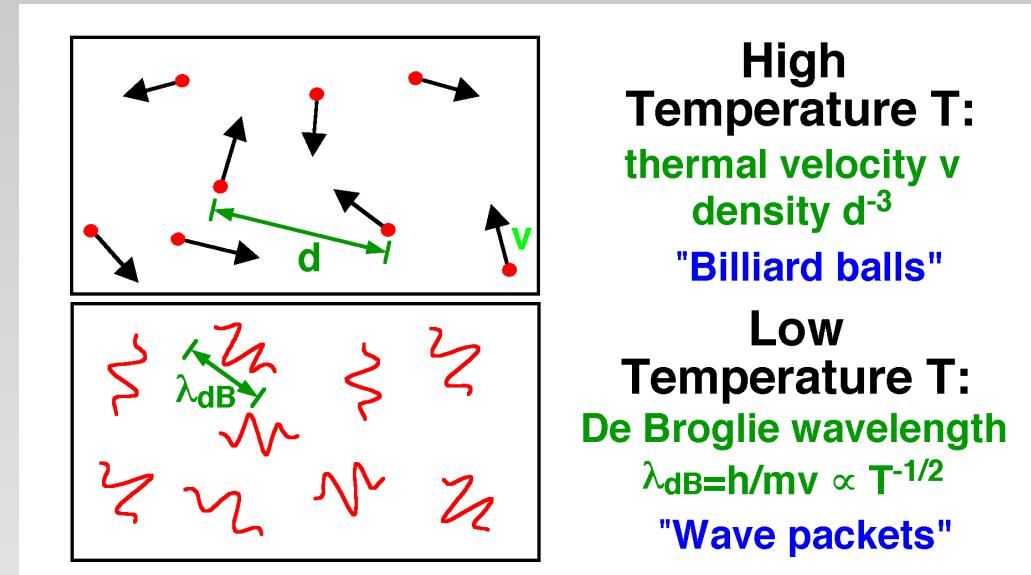
# Historical remarks

- 1924: S. N. Bose and the bosons
- 1924: A. Einstein
- 1926: E. Fermi and the fermions
- 1957: J. Bardeen, L. N. Cooper, and J. R. Schrieffer
- 1995: E. A. Cornell, C. E. Wieman, and W. Ketterle

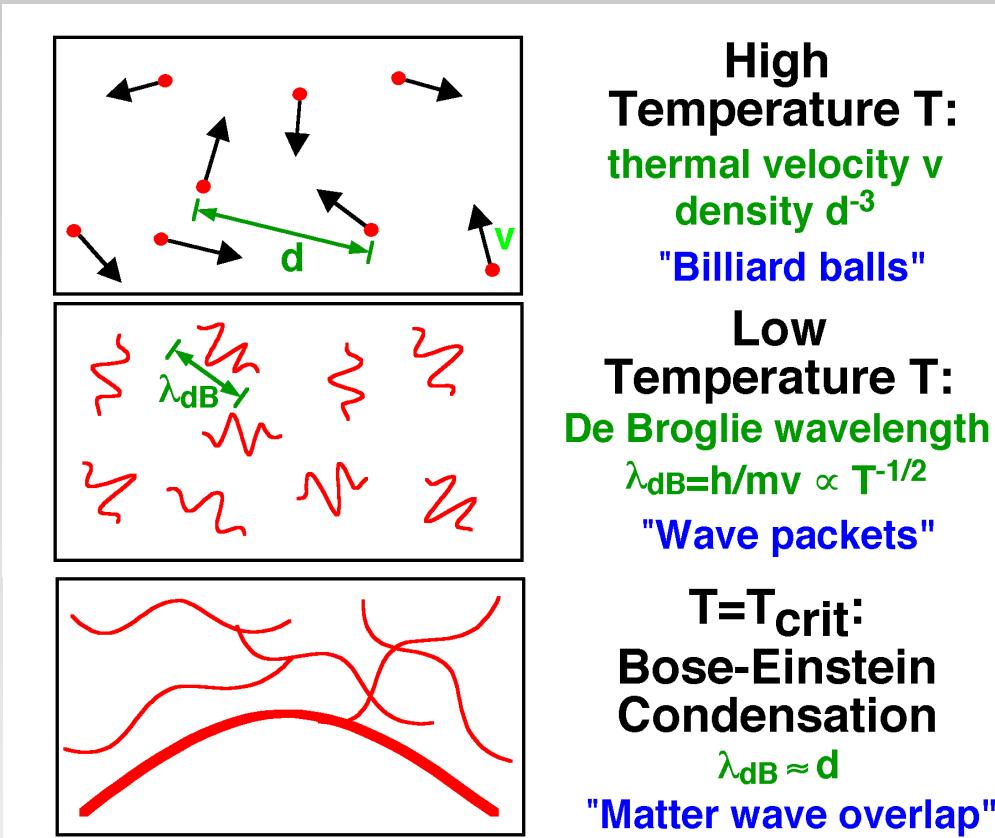
# Bose-Einstein Condensation



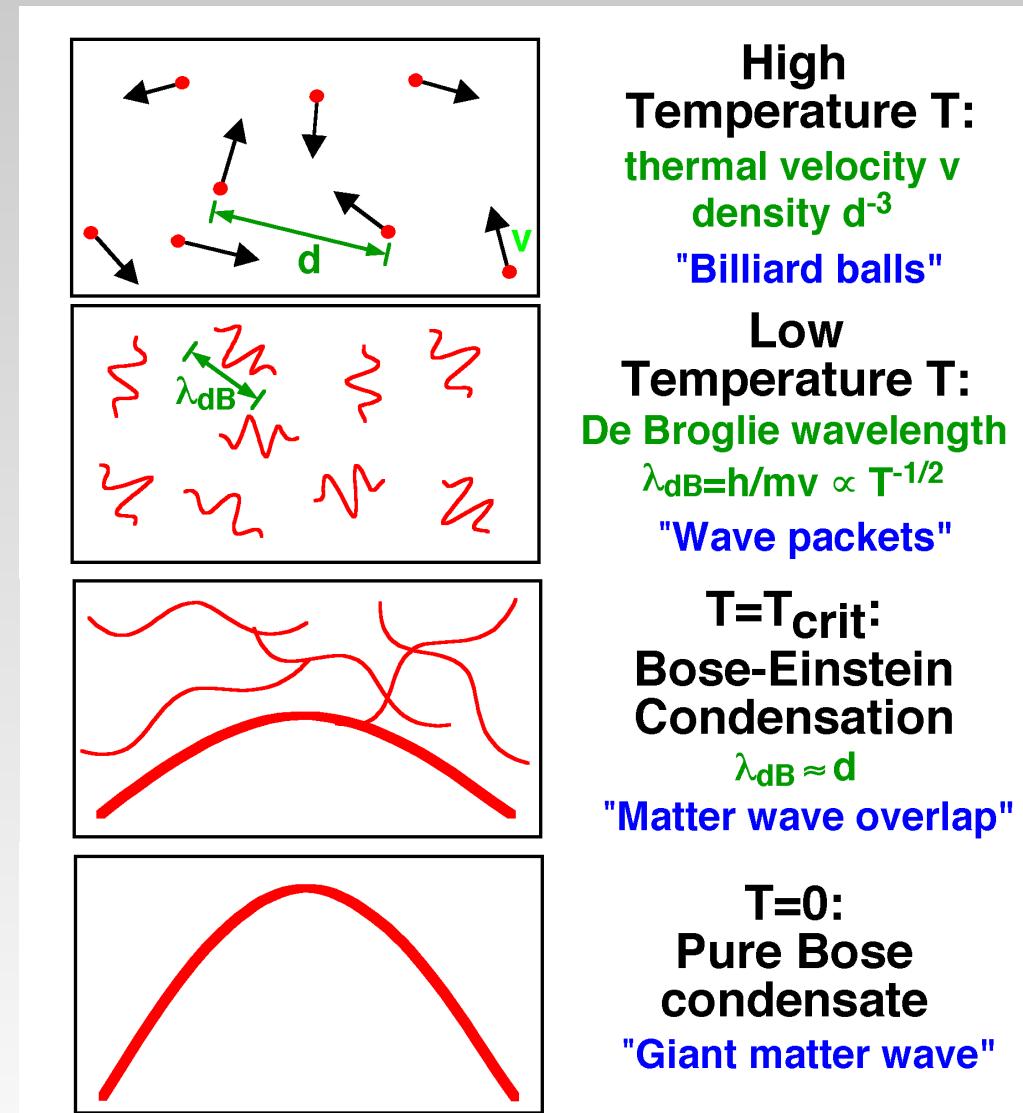
# Bose-Einstein Condensation



# Bose-Einstein Condensation



# Bose-Einstein Condensation



# Bose-Einstein Condensation

- Laser cooling and Trapping (Nobel 1997)

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# Bose-Einstein Condensation

- Laser cooling and Trapping (Nobel 1997)
- Evaporative cooling (Nobel 2002)
- Condensed elements

		Periode				□ = Hauptgruppen		□ = Nebengruppen		□ = Edelgase		Schale					
I	II	IIIa	IVa	Va	VIIa	VIIIa	Ia	Ib	III	IV	V	VI	VII	VIII			
1.008 1 H Wasserstoff									10.811 5 Bor	12.011 6 Kohlenstoff	14.007 7 Stickstoff	15.999 8 Sauerstoff	18.998 9 Fluor	20.180 10 Neon			
6.941 2 Li Lithium	9.012 3 Be Beryllium													K			
22.990 3 Na Natrum	24.305 12 Mg Magnesium								26.982 13 Al Aluminium	28.086 14 Si Silicium	30.974 15 P Phosphor	32.066 16 S Sulfid	35.453 17 Cl Chlor	39.948 18 Ar Argon			
39.098 19 K Kalium	40.078 20 Ca Calcium	44.956 21 Sc Scandium	47.88 22 Ti Titan	50.942 23 V Vanadin	51.996 24 Cr Chrom	54.938 25 Mn Mangan	55.847 26 Fe Eisen	58.933 27 Co Kobalt	58.89 28 Ni Nickel	63.546 29 Cu Kupfer	65.39 30 Zn Zink	69.723 31 Ga Gallium	72.61 32 Ge Germanium	74.922 33 As Arsen	78.904 34 Se Selen	83.8 35 Br Brom	83.8 36 Kr Krypton
85.468 37 Rb Rubidium	87.62 38 Sr Strontium	88.906 39 Y Yttrium	91.224 40 Zr Zirkonium	92.906 41 Nb Niob	95.94 42 Mo Molybdän	98.906 43 Tc Technetium	101.07 44 Ru Ruthenium	102.906 45 Rh Rhodium	106.42 46 Pd Palladium	107.868 47 Ag Silber	112.411 48 Cd Cadmium	114.82 49 In Indium	118.71 50 Sn Antimon	121.75 51 Sb Tellur	127.6 52 Te Iod	126.904 53 I Xenon	O
132.905 55 Cs Cäsium	137.327 56 Ba Barium	138.906 56 La Lanthan	178.49 72 Hf Hafnium	180.948 73 Ta Tantal	183.85 74 W Wolfram	186.207 75 Re Rhenium	190.2 77 Os Osmium	192.22 78 Ir Iridium	195.08 79 Pt Platin	196.967 80 Au Gold	200.59 81 Hg Quecksilber	205.24 82 Tl Thallium	207.2 83 Pb Blei	208.98 84 Bi Bismut	209.987 85 Po Polonium	222.018 86 At Astat	P
223.02 87 Fr Francium	226.025 88 Ra Radium	227.028 89 Ac Actinium	261.103 104 Rf Rutherfordium	262.114 105 Ha Hahnium	263.118 106 Sg Seaborgium	262.123 107 Ns Neidoborium	ca. 265 108 Hs Hassium	ca. 268 109 Mt Meitnerium	ca. 269 110 Ds Darmstadium	ca. 272 111 Rg Roentgenium	?	ca. 277 112 ?	ca. 289 114 ?	ca. 289 116 ?	ca. 293 118 ?	Q	
<b>Lanthanide</b> Aggregatzustand unter Normalbedingungen: Fe fest Hg flüssig He gasförmig * = radioaktives Element																	
<b>Actinide</b> 140.12 58 Ce Cer Praseodym 140.91 59 Pr Praseodym 144.24 60 Nd Neodym 150.35 61 Pm Promethium 151.96 62 Sm Samarium 157.25 63 Eu Europium 158.92 64 Gd Gadolinium 162.50 65 Tb Terbium 164.93 66 Dy Dysprosium 167.26 67 Ho Holmium 168.93 68 Er Erbium 173.04 69 Tm Thulium 174.97 70 Yb Ytterbium 174.97 71 Lu Lutetium																	
232.04 80 Th Thorium 231 91 Pa Protactinium U Uranium 238.03 92 Np Neptunium 237 93 Pu Plutonium 244 94 Am Americium 243 95 Cm Curium 247 96 Bk Berkelium 251 97 Cf Californium 254 99 Es Einsteinium 257 100 Fm Fermium 258 101 Md Mendelevium 259 102 No Nobelium 260 103 Lr Lawrencium																	

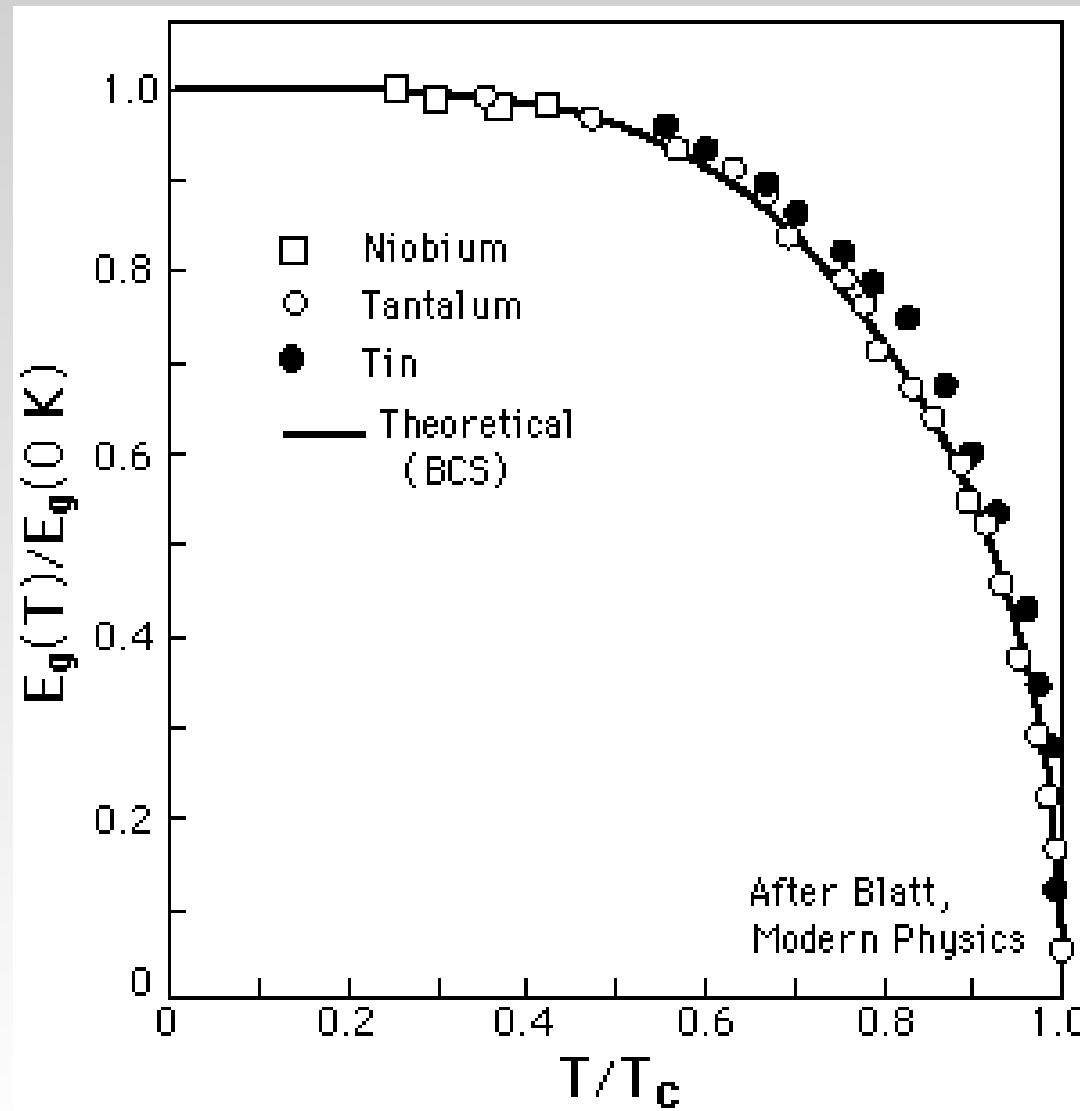
# BCS superconductivity

- Bardeen, Cooper and Schrieffer: Nobel Prize 1972



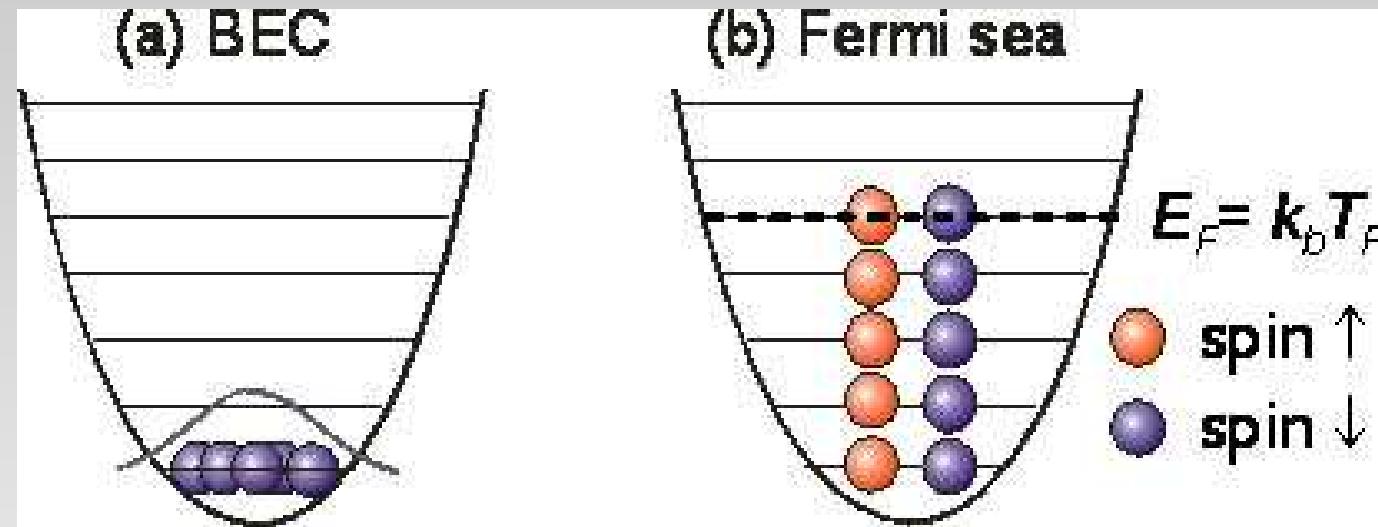
# BCS superconductivity

- Universality of the energy gap



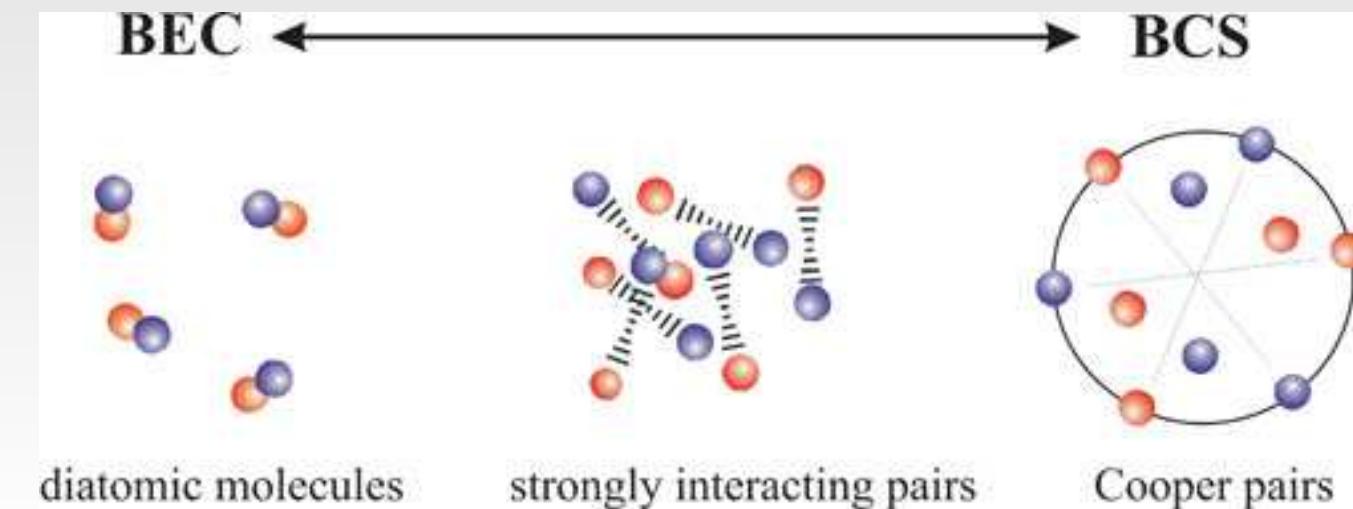
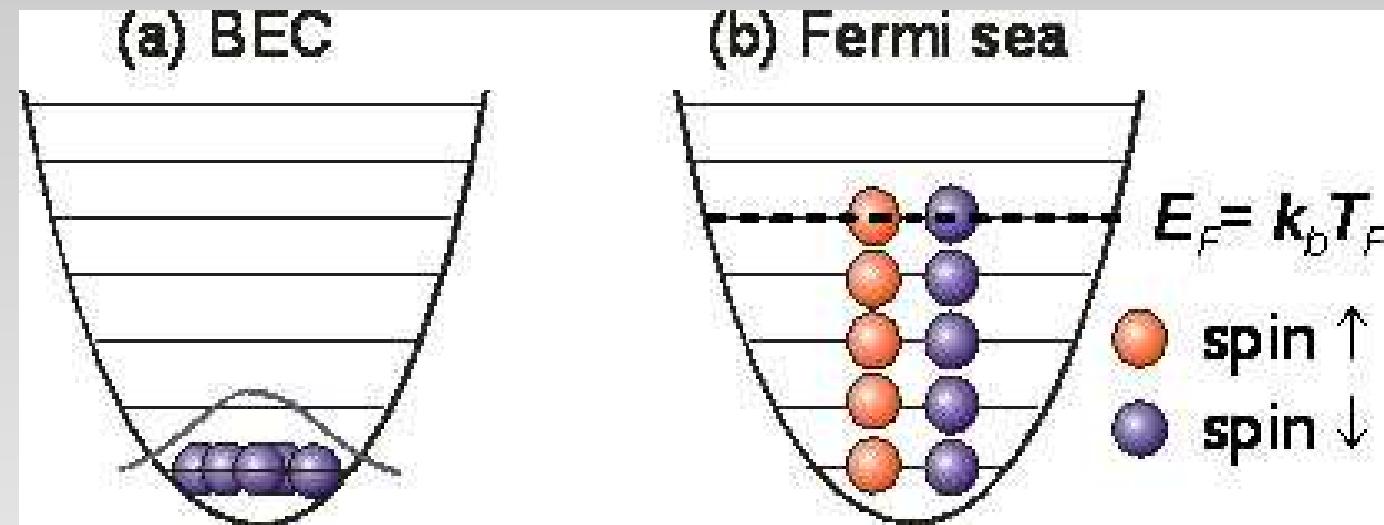
# BCS-BEC crossover

Bose agglomerate versus Fermi sea



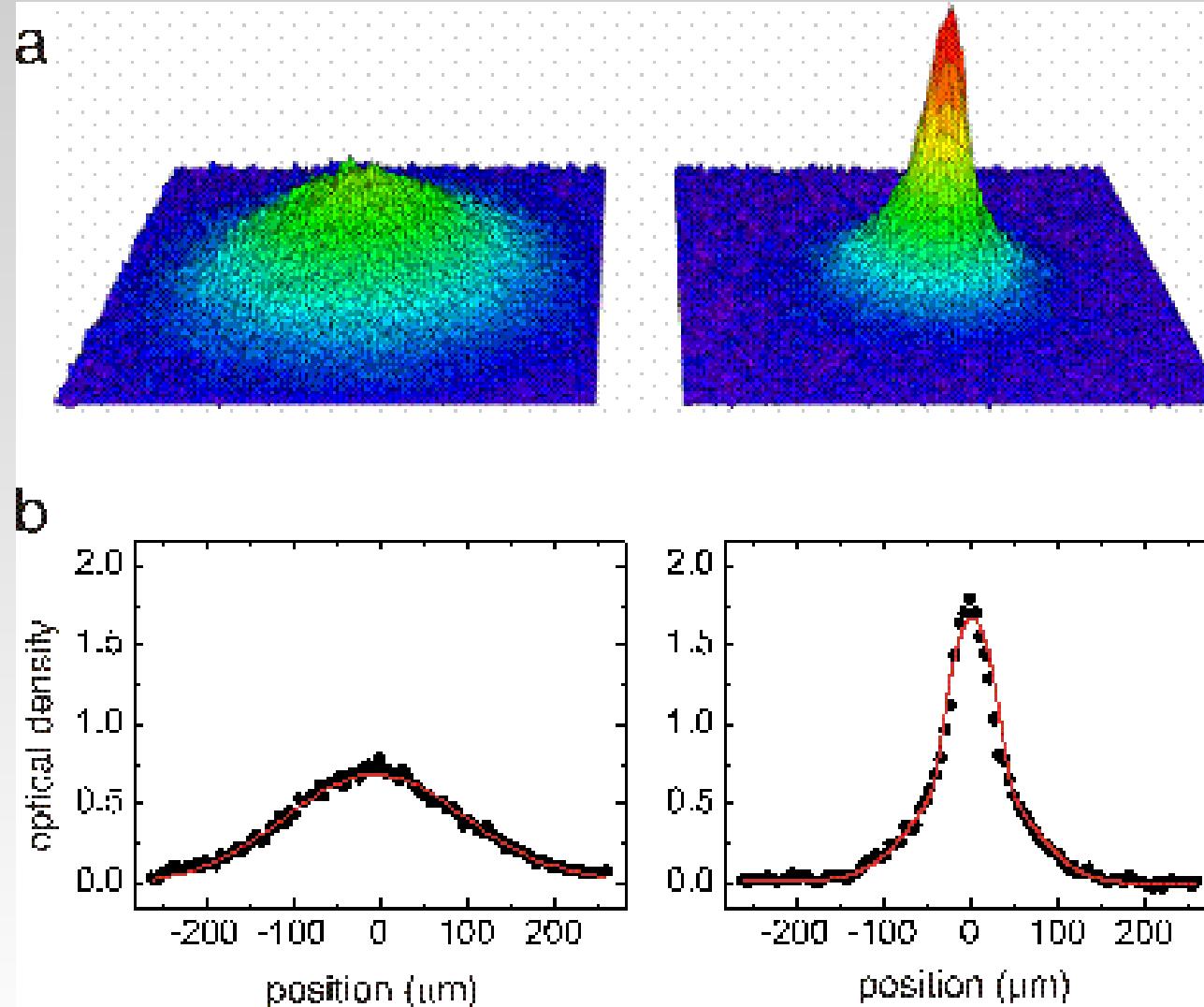
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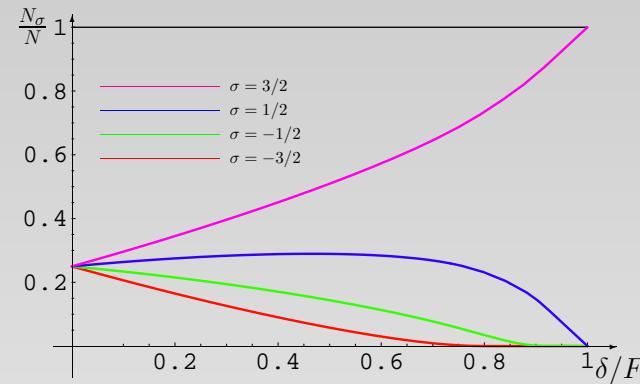
# BCS-BEC crossover

## Molecules and Cooper Pairs

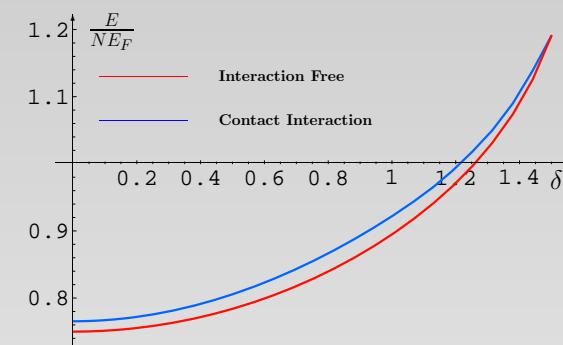


# Spinor Fermi gases

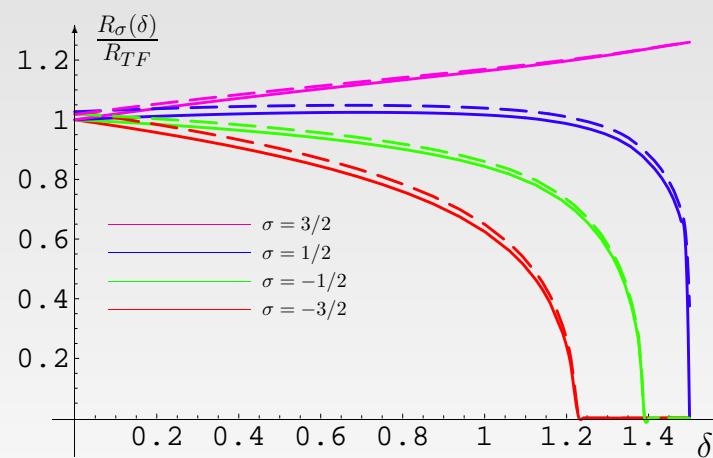
## Zeeman Populations



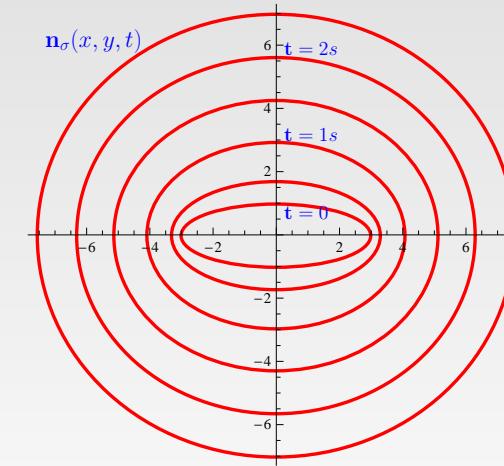
## Internal Energy



## Thomas-Fermi Radii

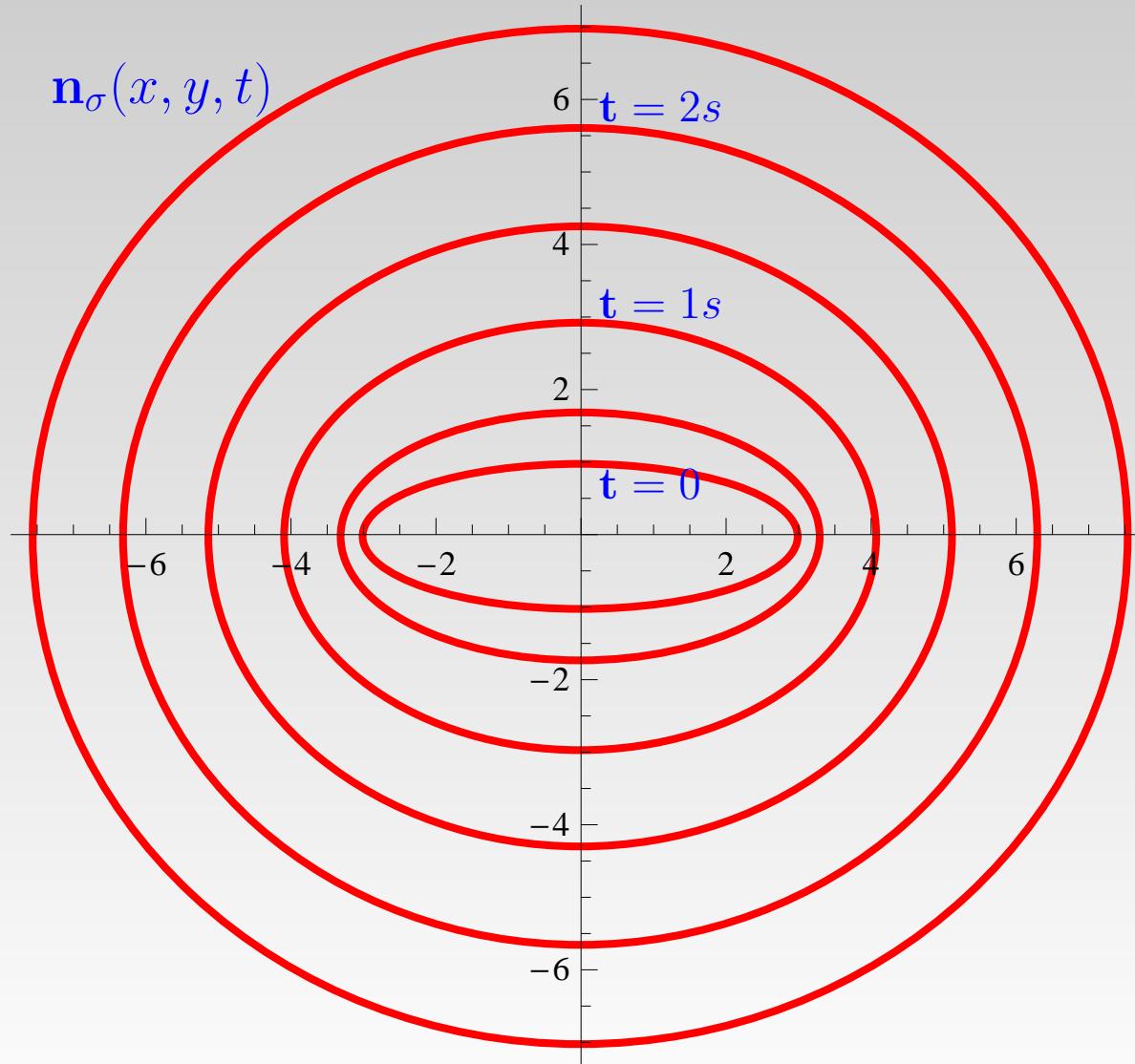


## Expansion

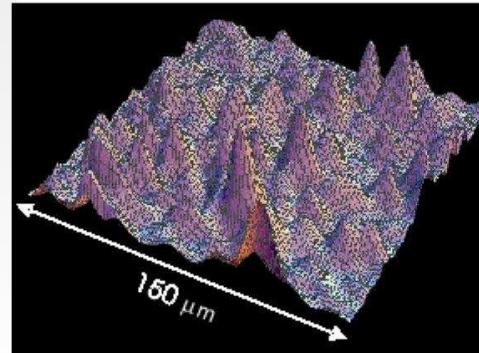
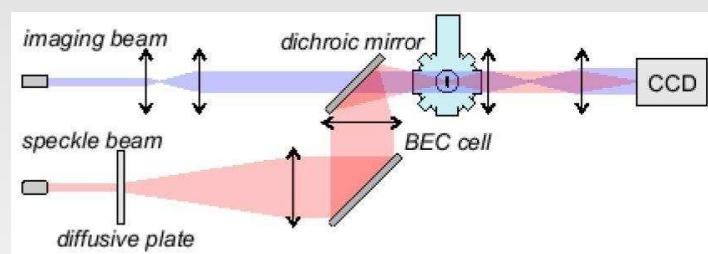
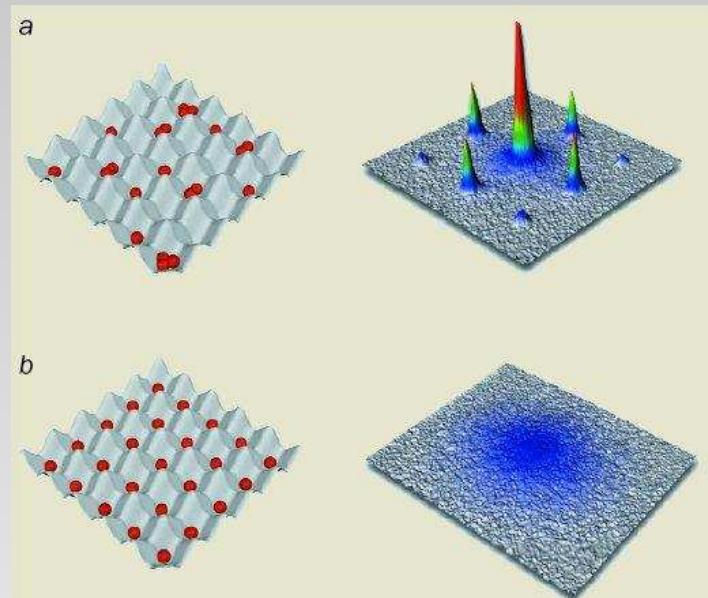
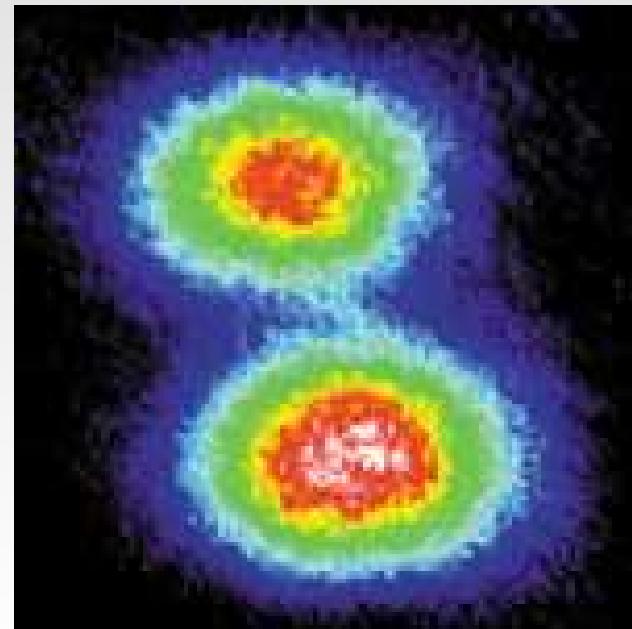
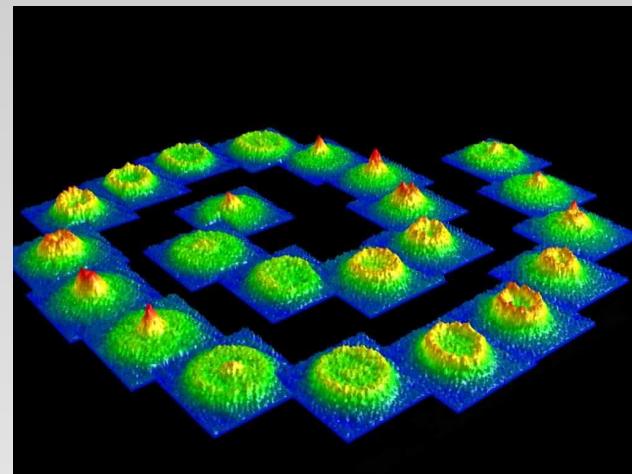


Proceedings of Path Integrals: Trends and Perspectives

# Spinor Fermi gases: Expansion



# Outlook



Unordnung

# Thanks

- DAAD German Academic Exchange Service

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- DFG-Priority Program SPP 1116: *Interactions in Ultra-Cold Atomic and Molecular Gases*

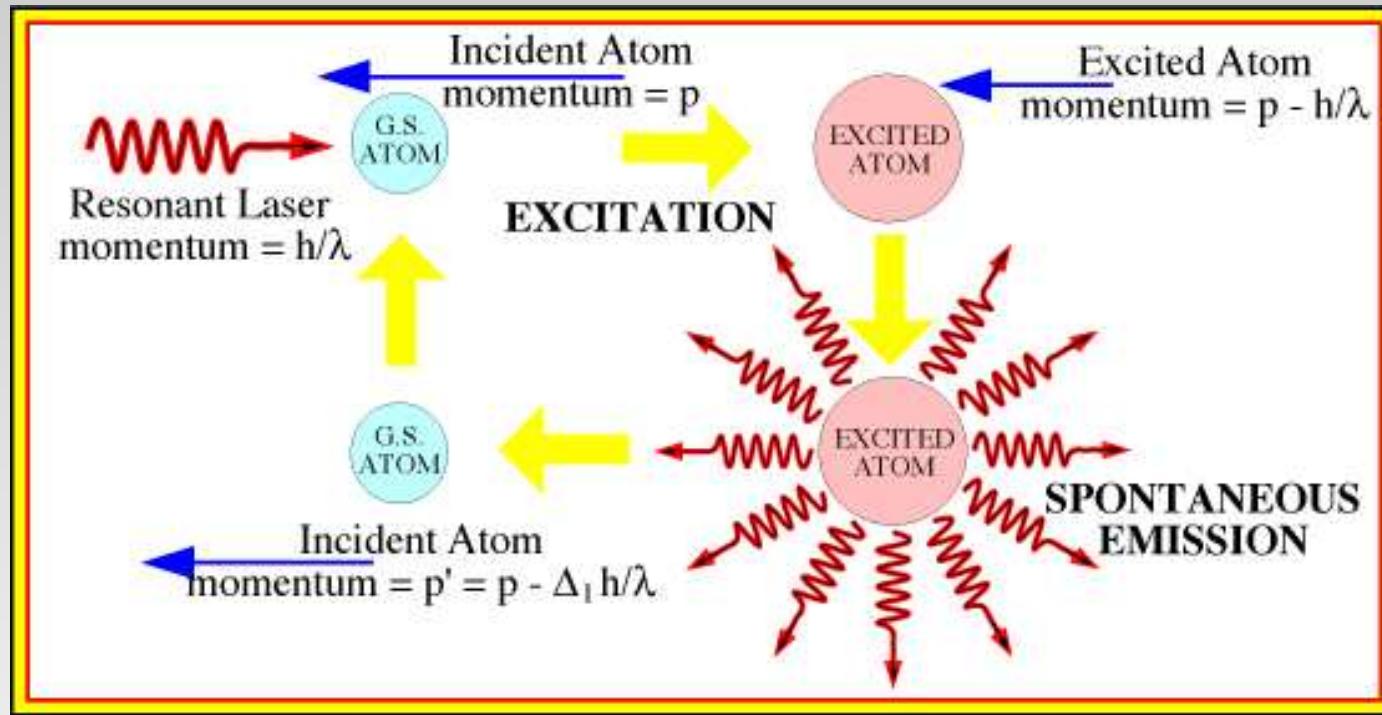
# Thanks

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- Cold atoms group FU-Berlin



# Laser Cooling

Back



# Evaporative cooling

Back

