NTNU

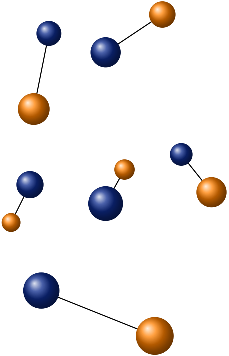
Innovation and Creativity

Computer simulations of effective lattice theories for strongly correlated systems

Steinar Kragset

NTNU, Trondheim November 10, 2006

List of papers



Paper I:
S. Kragset, A. Sudbø, and F. S. Nogueira,
Metal-insulator transition in two- and three-dimensional logarithmic plasmas,
Physical Review Letters **92**, 186403 (2004)

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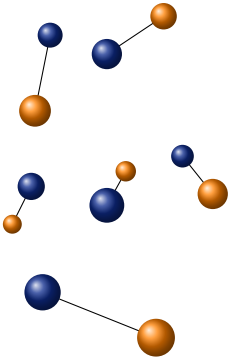

Paper I:
Metal-insulator transition in two- and three-dimensional logarithmic plasmas

Paper II:
K. Børkje, S. Kragset, and A. Sudbø,
Instanton correlators and phase transitions in two- and three-dimensional logarithmic plasmas,
Physical Review B **71**, 085112 (2005)

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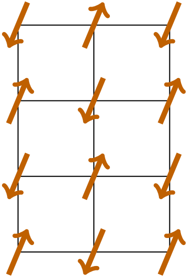

Paper III:
S. Kragset, E. Smørgrav, J. Hove,
F. S. Nogueira and A. Sudbø,
First order phase transition in a gauge theory of $S = 1/2$ quantum antiferromagnets,
cond-mat/0609336 (accepted for publication in Physical Review Letters)

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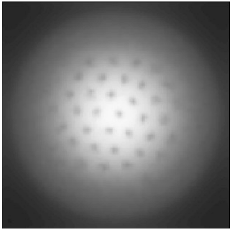

Paper IV:
S. Kragset, E. Babaev, and A. Sudbø,
Thermal fluctuations of vortex matter in trapped Bose–Einstein condensates,
Physical Review Letters **97**, 170403 (2006)

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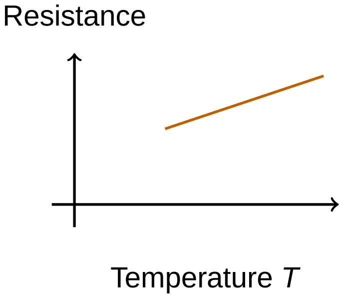
Strongly correlated systems



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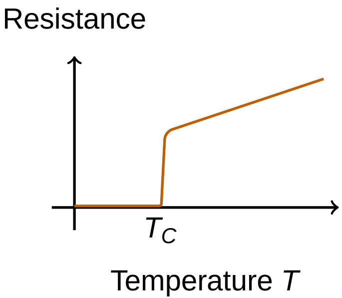
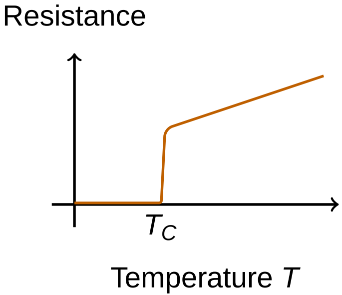


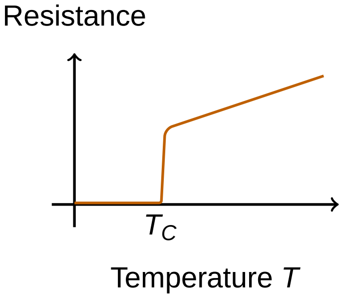
— 1911: Superconductivity discovered

Strongly correlated systems



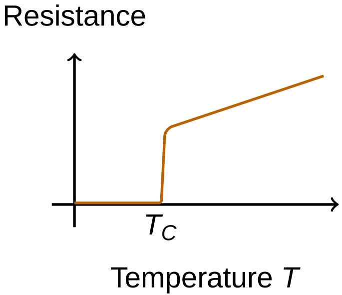
- 1911: Superconductivity discovered
- Theory explaining the mechanism in 1957

Strongly correlated systems



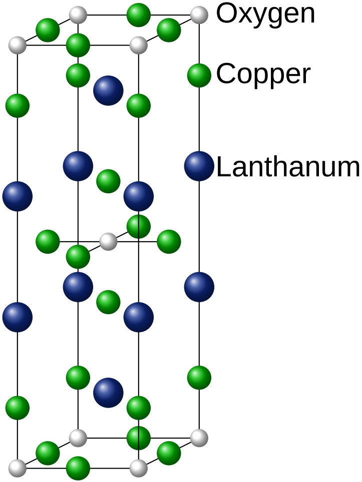
- 1911: Superconductivity discovered
- Theory explaining the mechanism in 1957
- 1986: Discovery of high-temperature superconductors

Strongly correlated systems

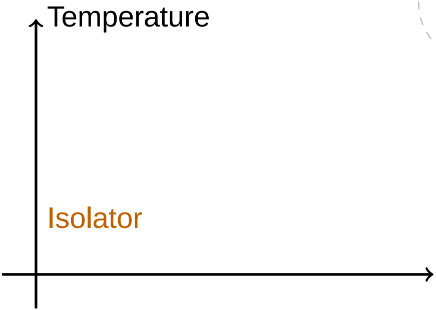


- 1911: Superconductivity discovered
- Theory explaining the mechanism in 1957
- 1986: Discovery of high-temperature superconductors
  - theory still missing

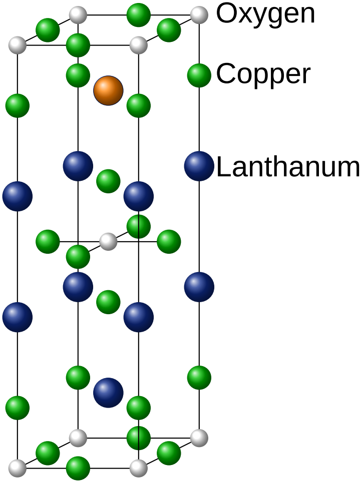
High-temperature superconductors



— Complex structures: La_2CuO_4

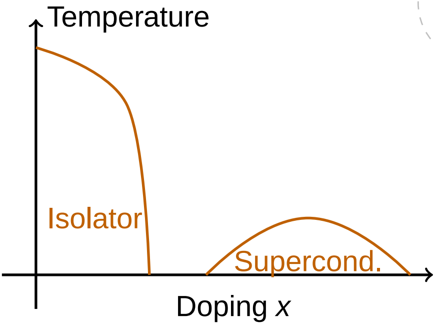


High-temperature superconductors

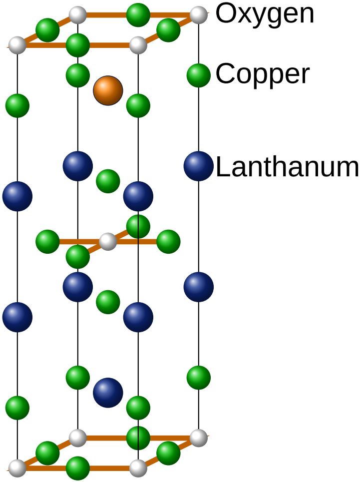


— Complex structures: La_2CuO_4

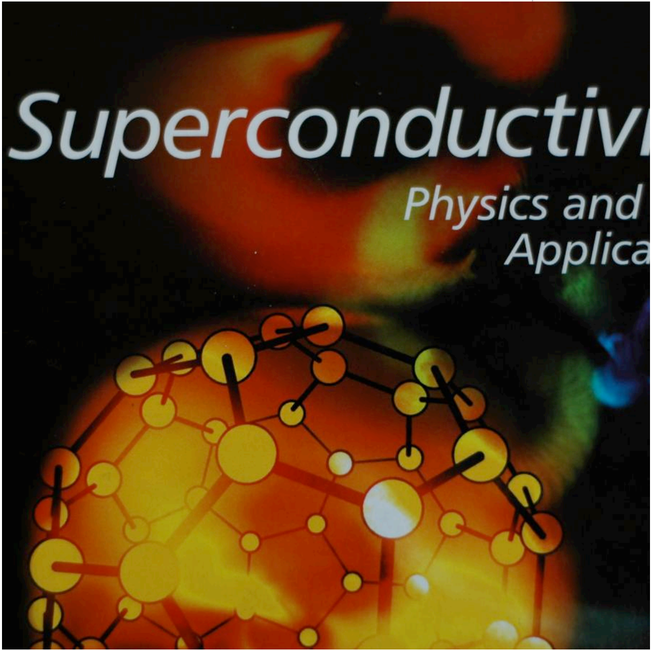
— Doping: $La_{2-x}Sr_xCuO_4$

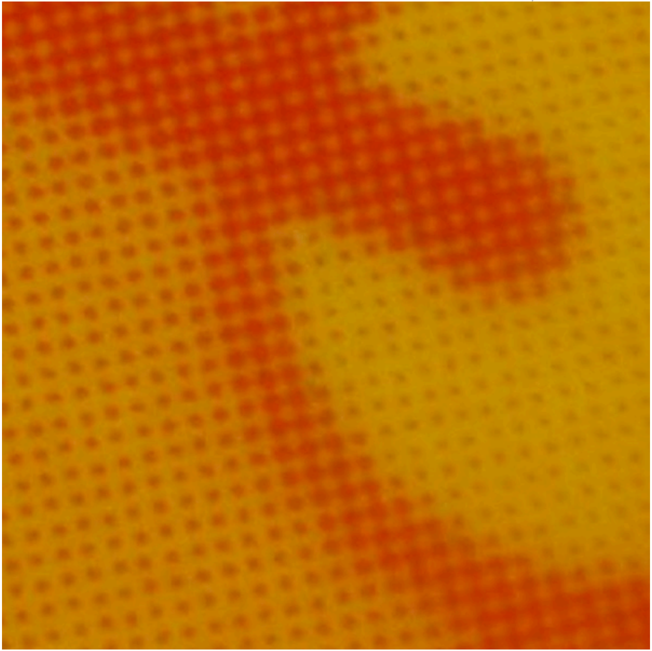


High-temperature superconductors



- Almost independent 2D planes
- Construct effective lattice models

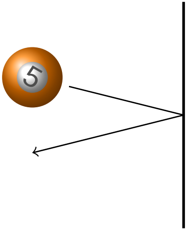

Superconductivi
Physics and
Applica



Effective lattice models

— Superconductivity is a macroscopic property

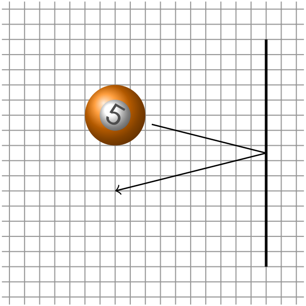
Effective lattice models



Example: Particle description of light

- Superconductivity is a macroscopic property
- Simplify microscopic model

Effective lattice models



Example: Particle description of light

- Superconductivity is a macroscopic property
- Simplify microscopic model
- Put everything on a lattice

Computer simulations

— Model systems are not physical

Computer simulations

— Model systems are not physical

— Models are simplified, but not that simple

$$\langle O \rangle = \frac{1}{Z} \sum_{\{\psi\}} O_\psi \mathrm{e}^{-H_\psi / T}$$

Computer simulations

— Model systems are not physical

— Models are simplified, but not that simple

$$\langle O \rangle = \frac{1}{Z} \sum_{\{\psi\}} O_\psi \mathrm{e}^{-H_\psi/T}$$

— Use computers for experiments

Computer simulations
— Monte Carlo

$$\langle O \rangle = \frac{1}{Z} \sum_{\{\psi\}} O_\psi \mathrm{e}^{-H_\psi/T}$$

— Statistical methods

Computer simulations — Monte Carlo

$$\langle O \rangle = \frac{1}{Z} \sum_{\{\psi\}} O_\psi \mathrm{e}^{-H_\psi / T}$$

— Statistical methods

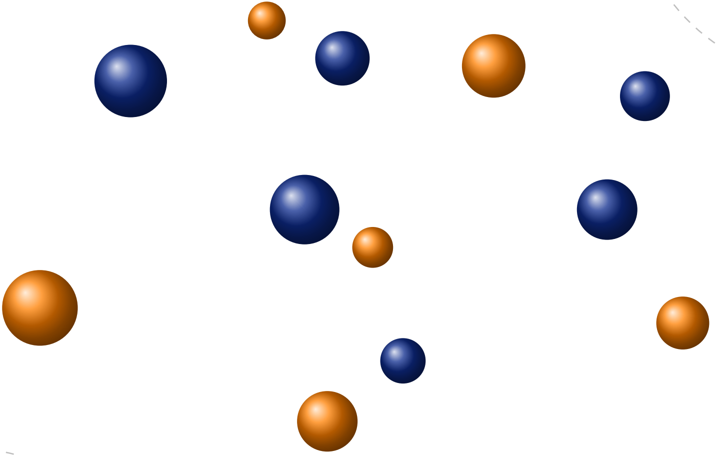
— Temperature enhances fluctuations

Computer simulations — Monte Carlo

$$\langle O \rangle = \frac{1}{Z} \sum_{\{\psi\}} O_\psi \mathrm{e}^{-H_\psi/T}$$

— Statistical methods
— Temperature enhances fluctuations
— Monte Carlo simulations imitate nature's randomness

Paper I and II:
A logarithmically interacting plasma



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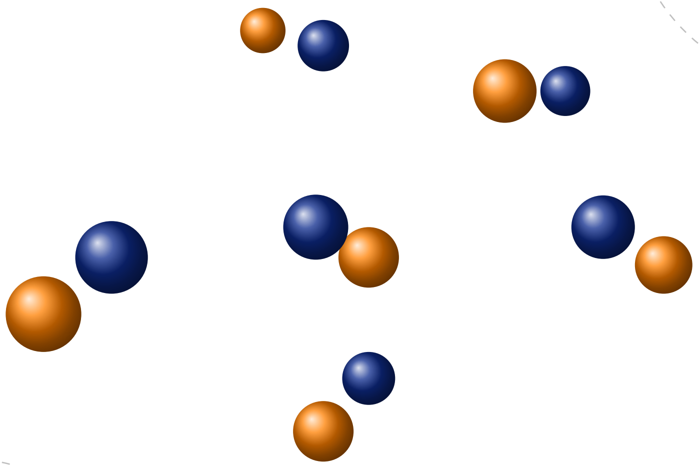
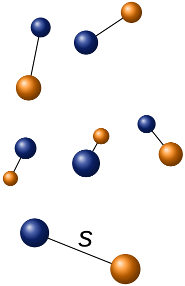
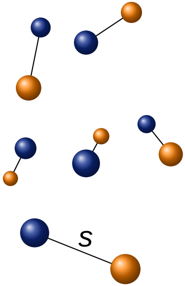


Dipole moment



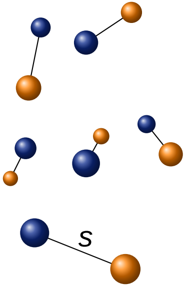
— Polarizability proportional to $\langle s^2 \rangle$

Dipole moment

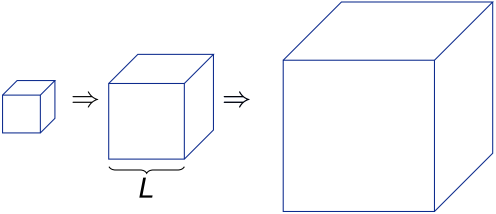


- Polarizability proportional to $\langle s^2 \rangle$
- Measure $\langle s^2 \rangle$ as a function of temperature

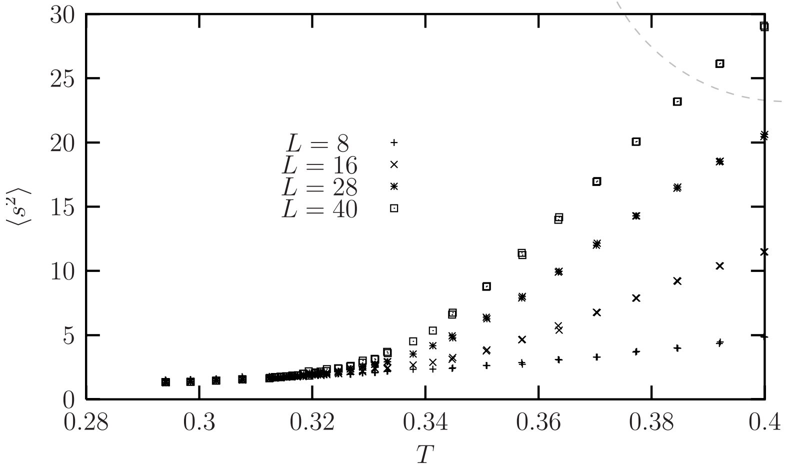
Dipole moment



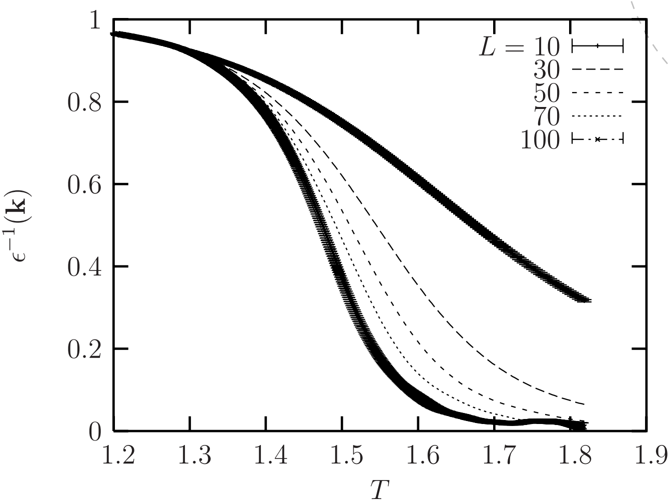
- Polarizability proportional to $\langle s^2 \rangle$
- Measure $\langle s^2 \rangle$ as a function of temperature
- System size upper limit



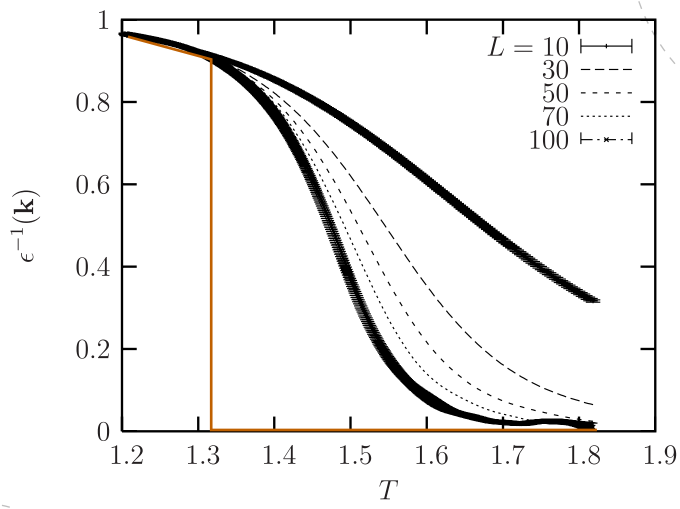
Polarizability



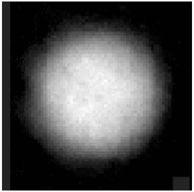
Inverse dielectric constant



Inverse dielectric constant



Paper IV:
Thermal fluctuations of vortex matter in trapped Bose–Einstein condensates



J. Dalibard

— Some atomic gases condense into superfluids at extremely low temperatures

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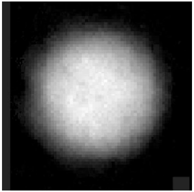

J. Dalibard

— Some atomic gases condense into superfluids at extremely low temperatures
— Does not respond to rotation

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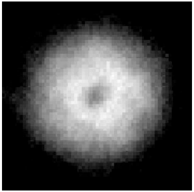

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- Some atomic gases condense into superfluids at extremely low temperatures
- Does not respond to rotation
- Not until a certain rotation rate

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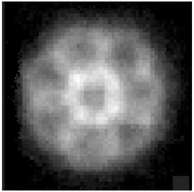


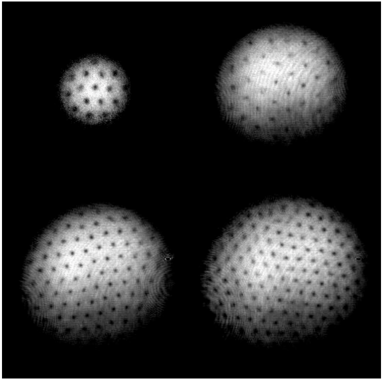
J. Dalibard

- Some atomic gases condense into superfluids at extremely low temperatures
- Does not respond to rotation
- Not until a certain rotation rate
- Faster rotation

Vortices

— Dynamics of neutron stars
— Type-II superconductors
— Rotating Bose condensates and other superfluids

Vortex lattices

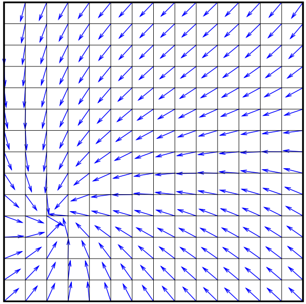


W. Ketterle

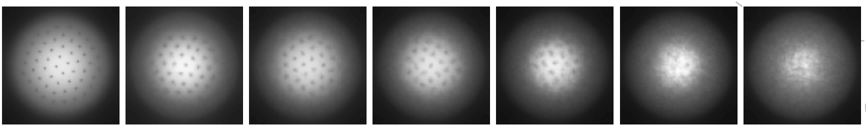
- Difficult to control temperature in experiments
- What are the temperature effects?
- Convenient to use Monte Carlo simulations

Modelling vortex systems

— Simple model of phase fluctuations



Simulated trapped vortex lattices



$T = 0.50$ $T = 1.00$ $T = 1.11$ $T = 1.25$ $T = 1.43$ $T = 1.67$ $T = 2.00$

- Condensate density depletes in outer regions with increasing temperature
- High stability in the lattices

Conclusions

With Monte Carlo simulations I have studied:

- Phase transitions in effective lattice models for strongly correlated systems
- Thermal fluctuations in trapped Bose–Einstein condensates

The results have been published in four research articles