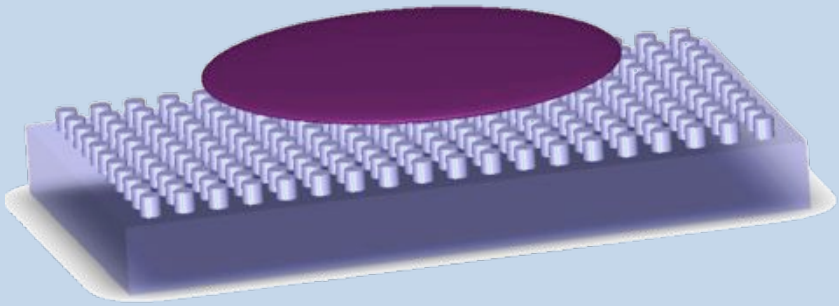
Probing and Understanding Exotic Superconductors and Superfluids
Trieste, 27-31 October 2014

Ultra-cold atoms in sub-wavelength lattice potentials



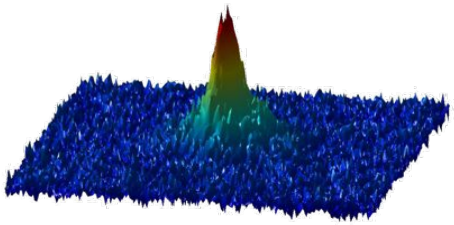
Simon Bernon
Laboratoire de photonique, numérique et nanosciences
Talence

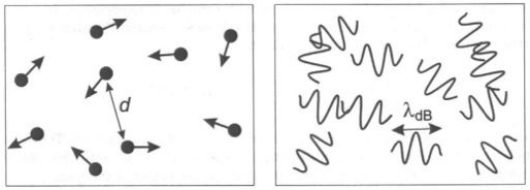
Model systems for condensed matter

Quantum Gas

Bose Einstein Condensation

Fermi Sea

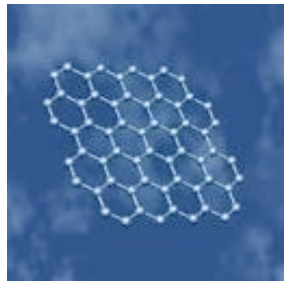


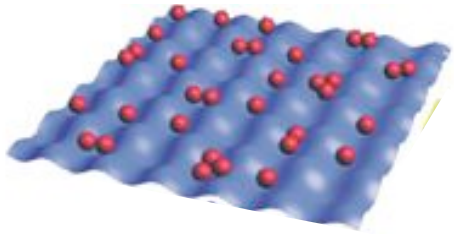


Protected

Controlled

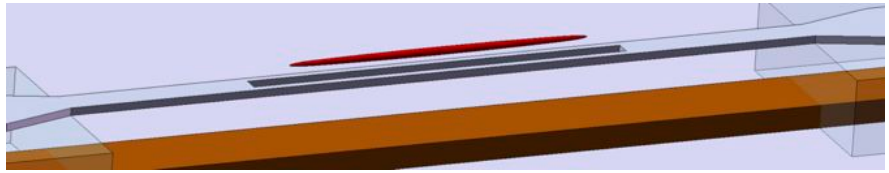
Quantum Simulator





From electrons in graphene to fermions in optical lattices

Hybrid quantum systems



Controlling the potential landscape

Atoms in far-off resonance laser fields

$$U = -\vec{d}.\vec{E} = -Re[\alpha(\omega)]\vec{E}.\vec{E} \propto -I(\vec{r})/\Delta$$

Potential energy

$$\Gamma \propto I(\vec{r})/\Delta^2$$

Scattering rate

Laser

Atom
(^{87}Rb / ^{40}K)

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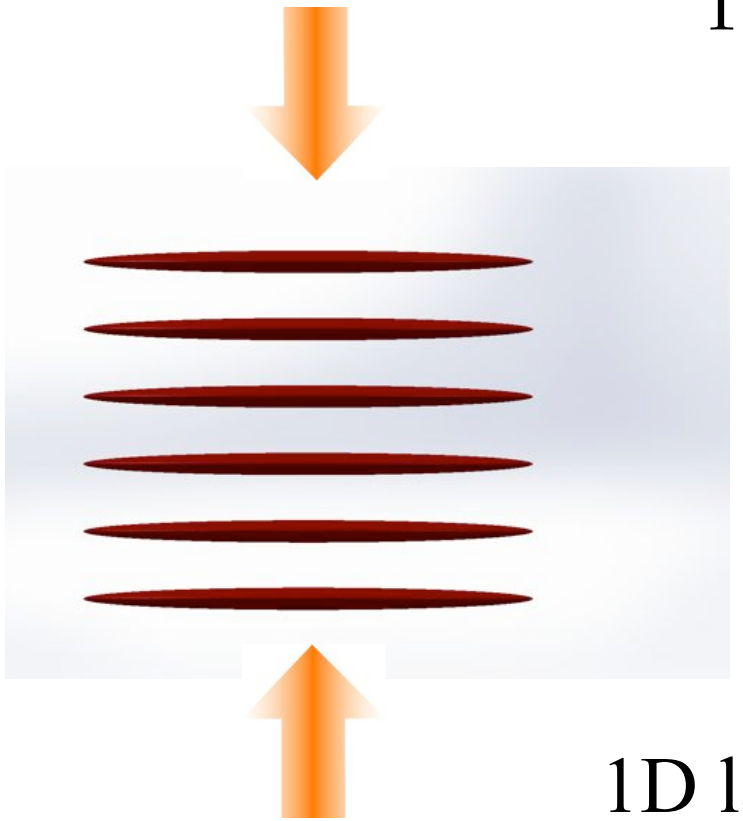

1D lattice structure

Controlling the potential landscape

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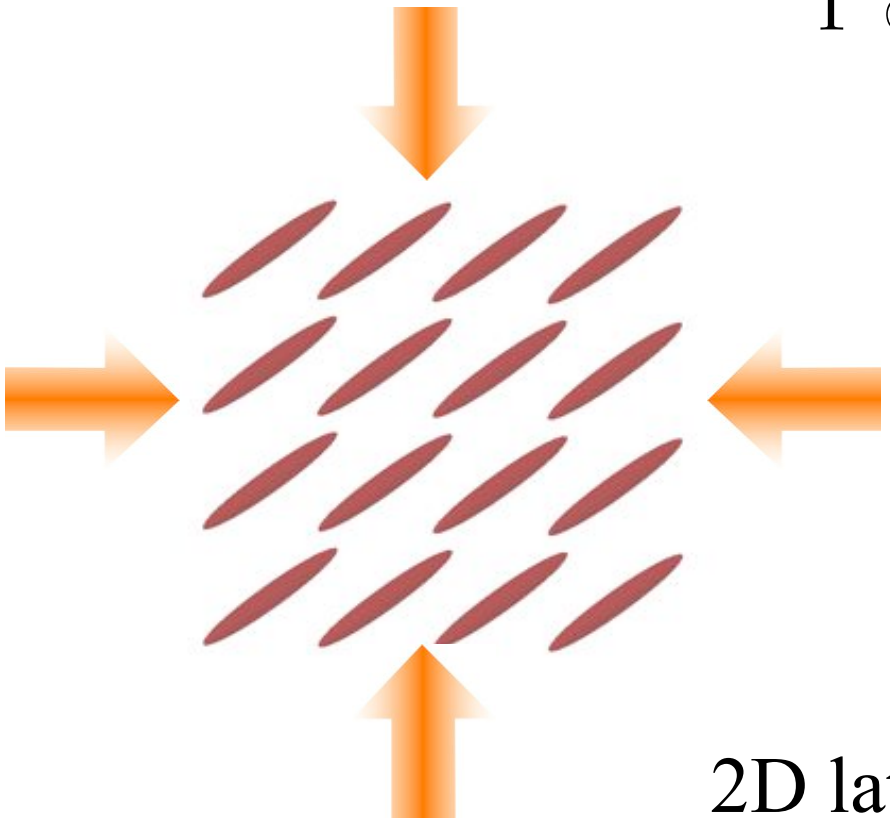

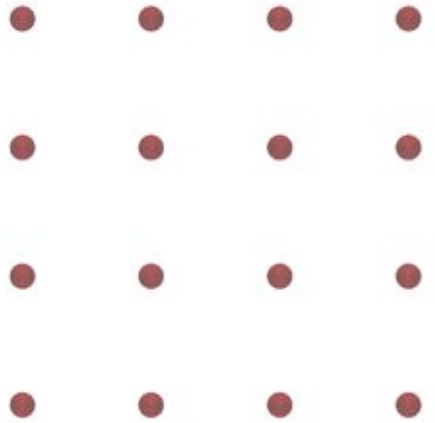

2D lattice structure

Controlling the potential landscape

Atoms in far-off resonance laser fields

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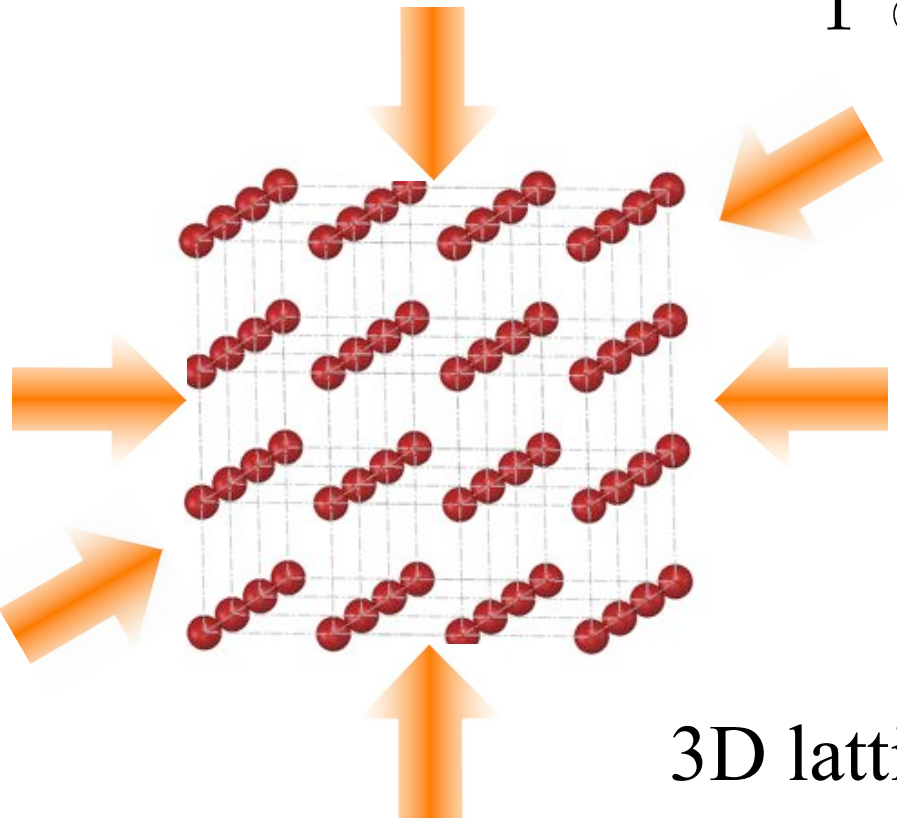
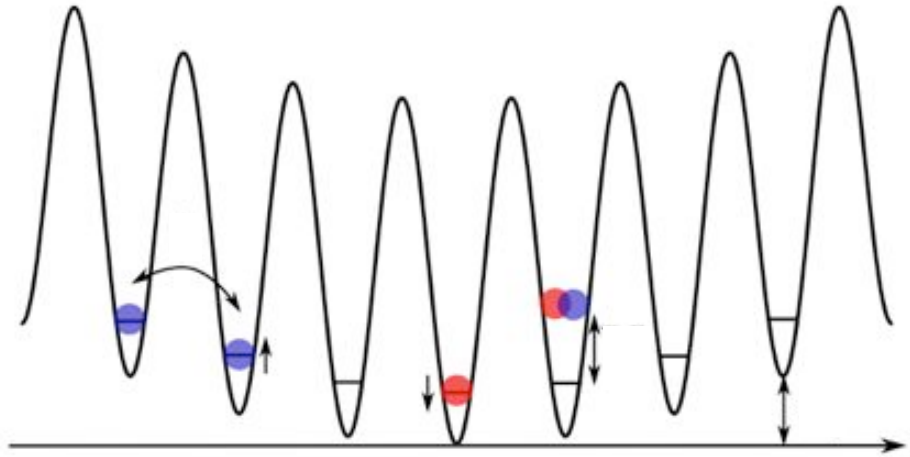
Potential energy

$$\Gamma \propto I(\vec{r})/\Delta^2$$

Scattering rate





Spin mixture of fermionic gas

3D lattice structure

Energies at play in the lattice

Atoms in far-off resonance laser fields

$$U = -\vec{d}.\vec{E} = -Re[\alpha(\omega)]\vec{E}.\vec{E} \propto -I(\vec{r})/\Delta$$ Potential energy

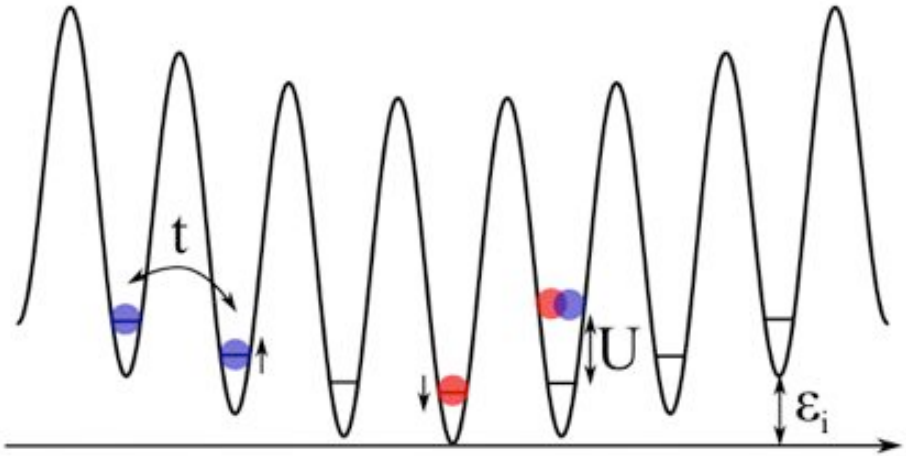
$$\Gamma \propto I(\vec{r})/\Delta^2$$ Scattering rate

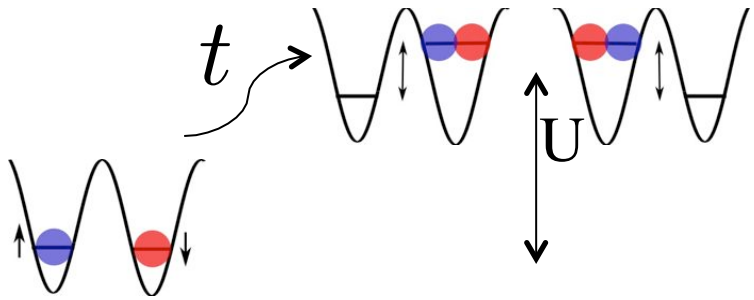
Energies

t Tunneling rate

U Interaction energy

ϵ_i Residual external trapping





Fermi-Hubbard Hamiltonian

$$H = -t \sum_{\langle i,j\rangle,\sigma} (\hat{c}^{\dagger}_{i,\sigma}\hat{c}_{j,\sigma} + \text{h.c.}) + U \sum_i \hat{n}_{i,\uparrow}\hat{n}_{i,\downarrow} + \sum_i \varepsilon_i \hat{n}_i.$$

Energies at play in the lattice

Atoms in far-off resonance laser fields

$$U = -\vec{d}.\vec{E} = -Re[\alpha(\omega)]\vec{E}.\vec{E} \propto -I(\vec{r})/\Delta$$ Potential energy

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Energies

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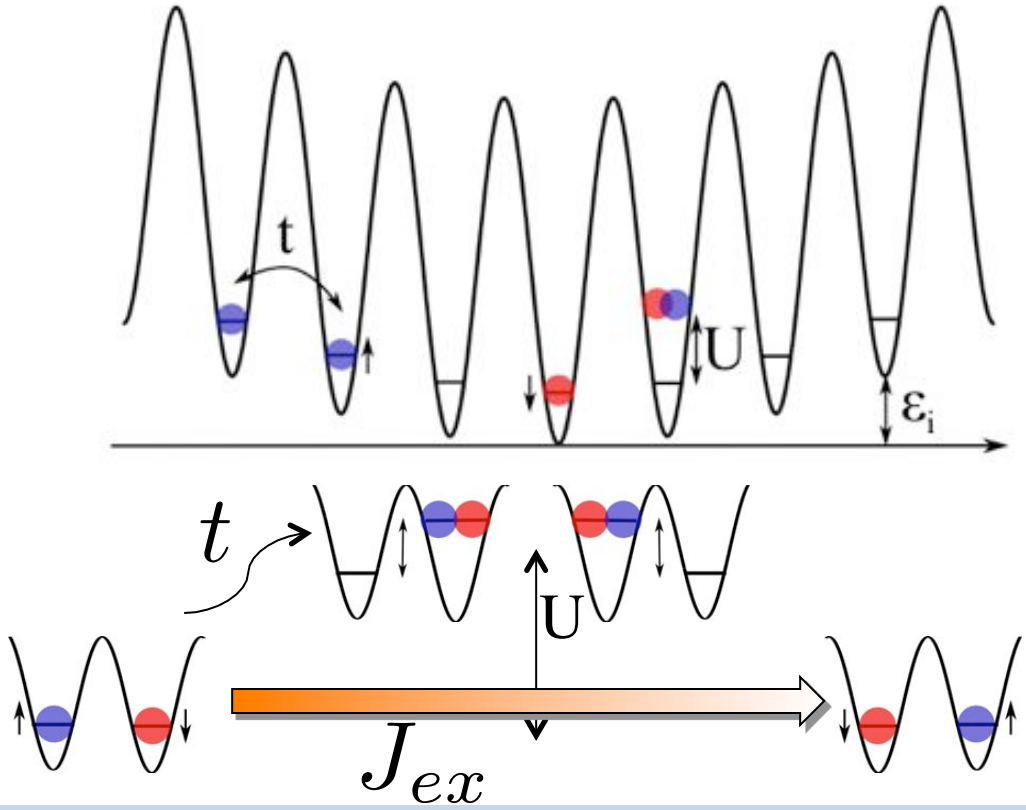
U Interaction energy

ϵ_i Residual external trapping

$$J_{ex} = t^2/U$$

Superexchange energy



Energies at play in the lattice

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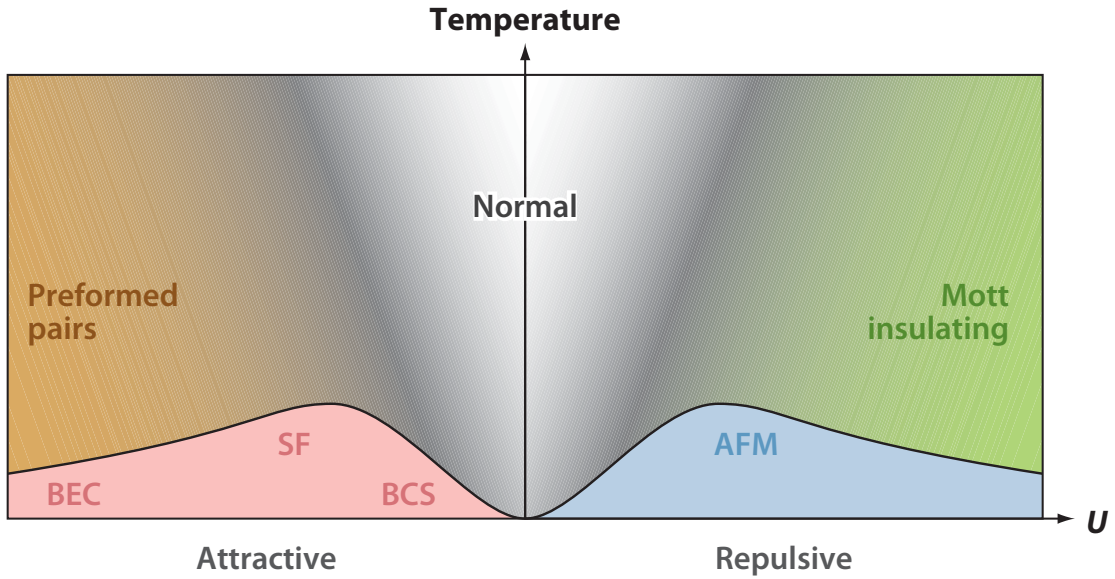
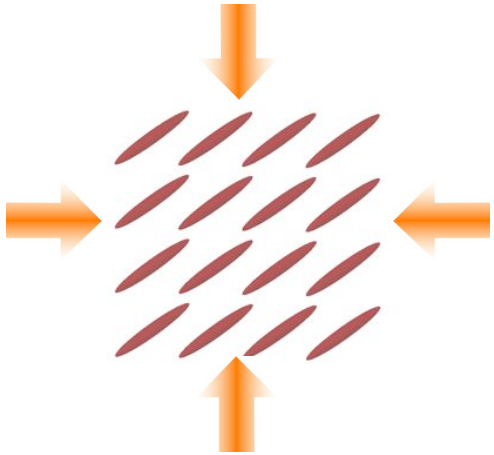
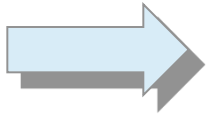
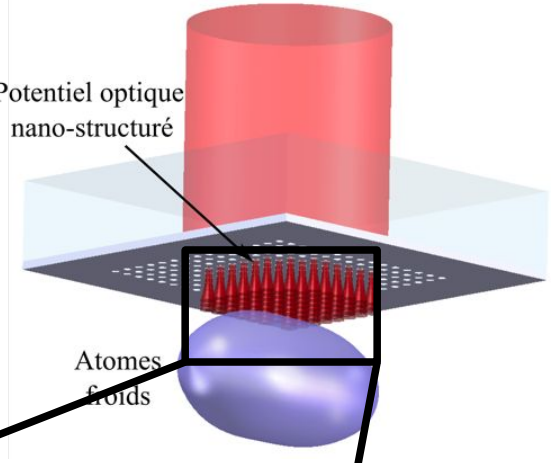


T. Esslinger. ARCMPhys 1:129 (2010)

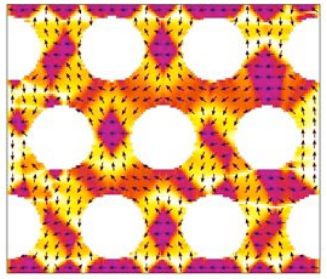
From far to near field



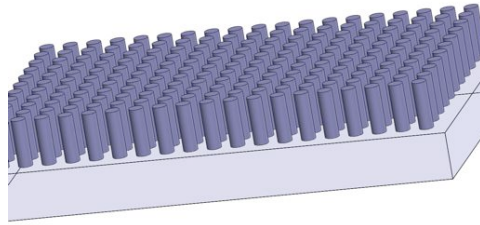




Metallic Plasmons



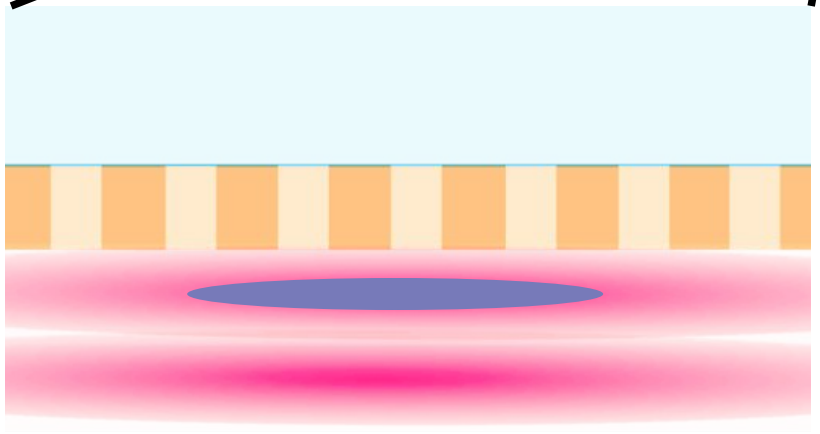
Dielectric



Far-field approach

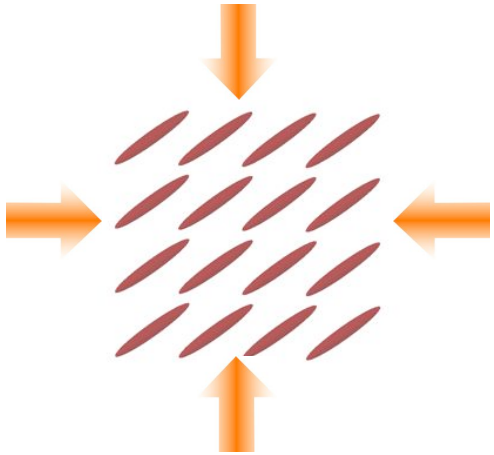
Near field of surfaces

Nano-holes array in a gold layer

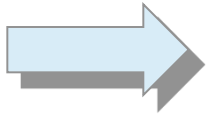


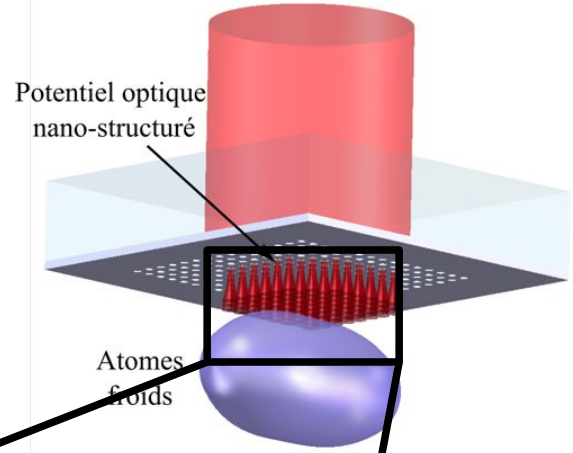
Retro-reflected laser

From far to near field



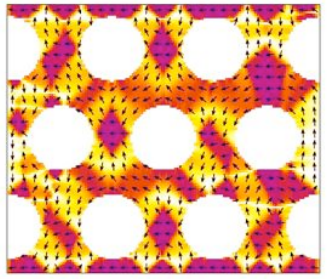
Far-field approach



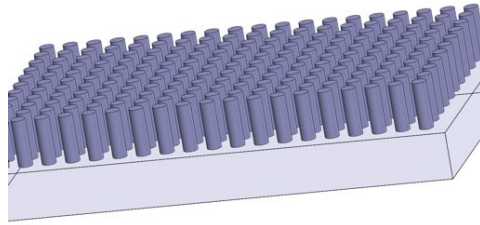


Nano-structured
laser field

Metallic
Plasmons



Dielectric



Near field of surfaces

Nano-holes array in
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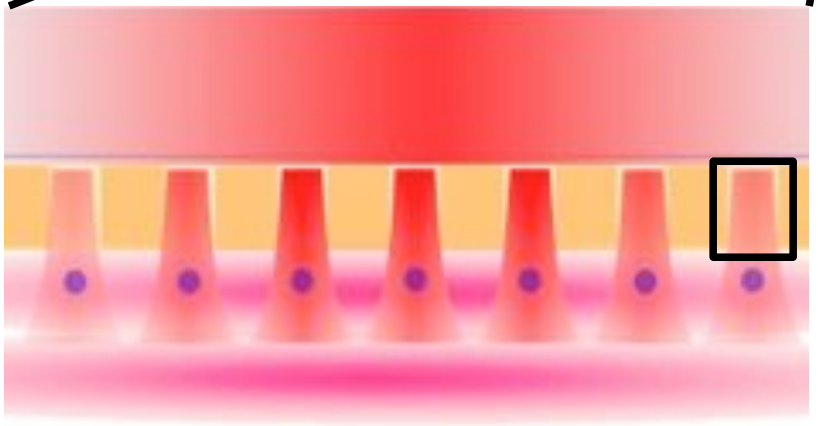
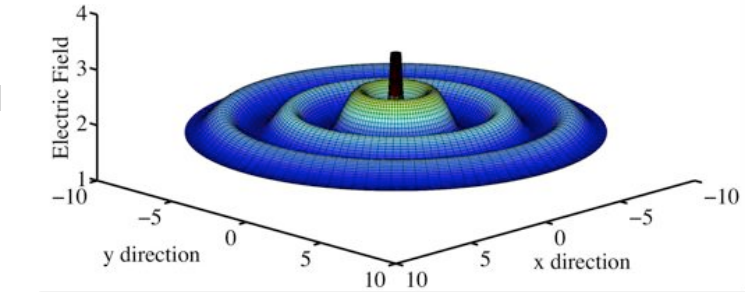
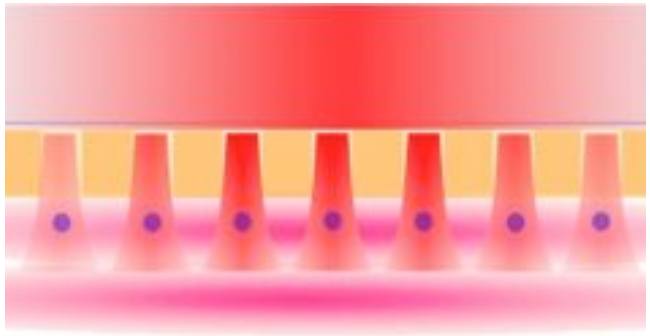




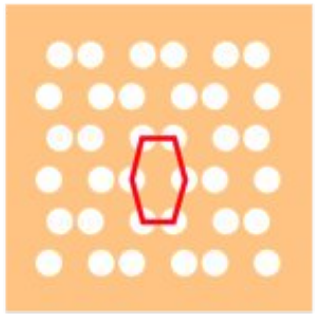
Retro-reflected laser

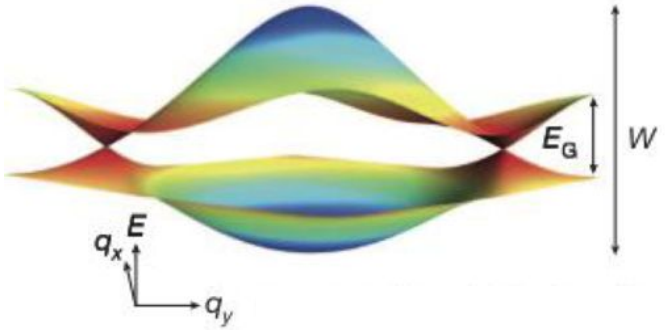
Sub-wavelength regimes

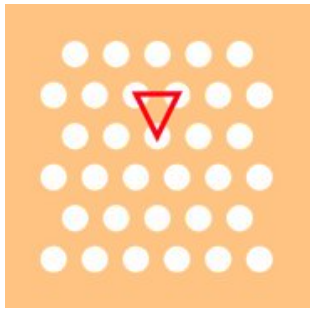


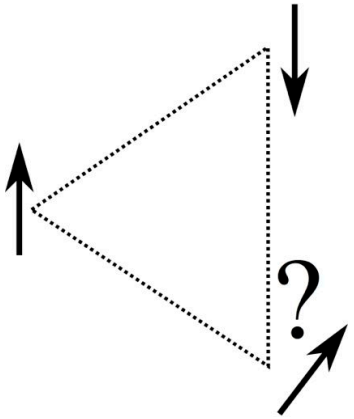
Exotic potential geometries
+ impurities

Dirac
Fermions



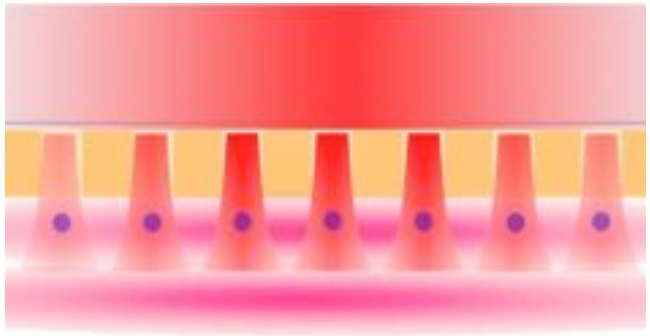






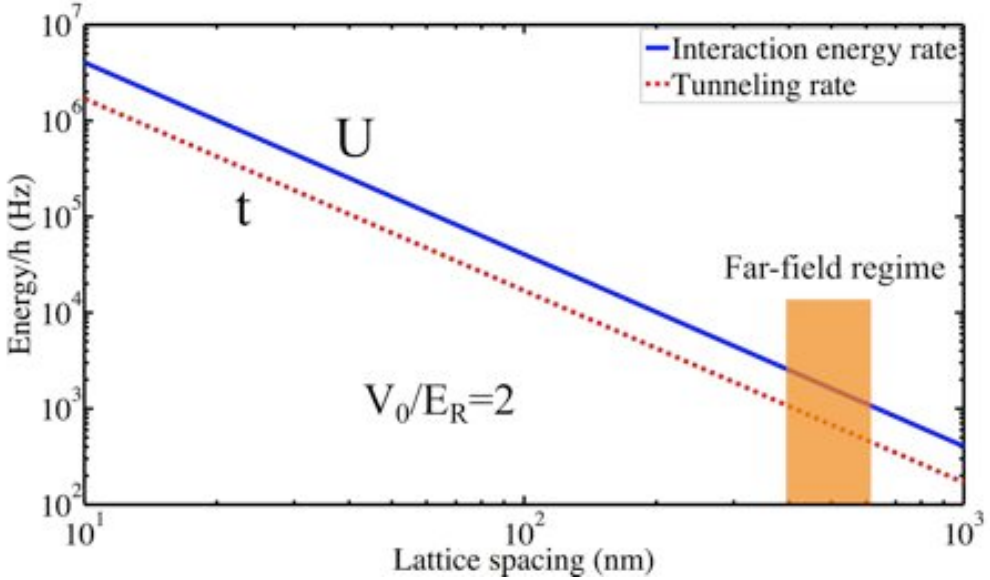
Magnetic frustration

Sub-wavelength regimes



High energy regimes

2D sub-wavelength lattice



M. Gullans, PRL 109, 235309 (2012)

Energy scaling

$$U \propto t \propto l_{per}^{-2}$$

Versus temperature

$$J_{ex} = t^2/U \propto l_{per}^{-2}$$

$$T \propto \bar{\omega} \propto l_{per}^{-4/3}$$

$$\boxed{\frac{J_{ex}}{T} \propto l_{per}^{-2/3}}$$

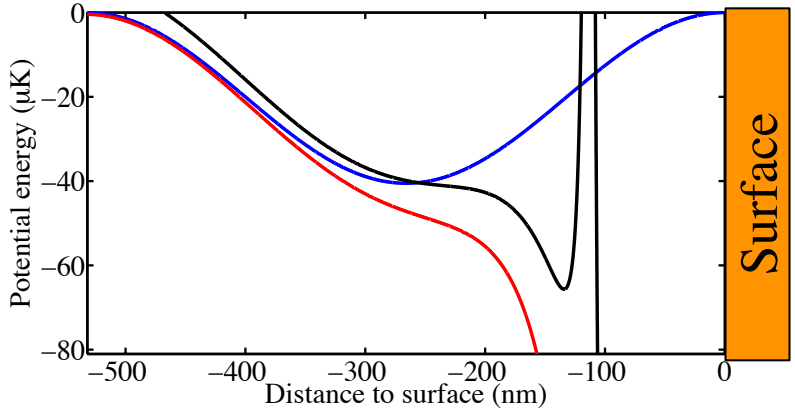
On going

3D MOT 2D MOT

Designing and mounting the dual species apparatus ^{40}K and ^{87}Rb

Loading and evaporation in an optical dipole trap ⇨ Transfer to the surface trap

Surface effect : Casimir-Polder potential, atomic absorption



⇒ Create steeper potential variation using differential light shift state engineering

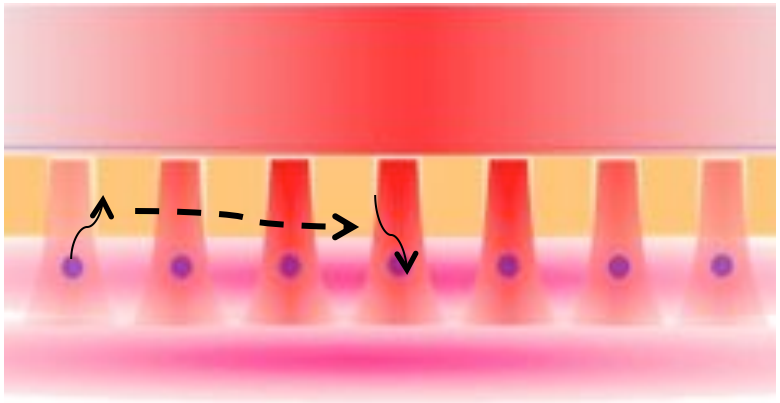
Conclusion

Quantum simulator

- Sub-wavelength regimes favorable to explore condensed matter physics
- A technically challenging system that will tackle a broad range of physical problem (Lamb shift, etc …)

Hybrid side

- Strong coupling to solid state systems
- Long range solid state mediated dipole-dipole interaction



M. Gullans, PRL 109, 235309 (2012)

People involved

Cold atoms group

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Artificial matter simulation team

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Philippe Lalanne

Fermions in lattices

Leticia Tarruel

Solid state theory

Jerome Cayssol