Università di Pavia, Dipartimento di Fisica

Laurea Magistrale in Scienze Fisiche:

Curriculum di Fisica della Materia

Ricerche in Fisica della Materia Teorica

Lucio C. Andreani

Giornata di orientamento, Pavia, 17 maggio 2017

http://fisica.unipv.it

http://fisica.unipv.it/dida/Orientamento.htm

Fisica della Materia

- Fisica dei Solidi (semiconduttori, isolanti, metalli, materiali magnetici, superconduttori, transizioni di fase, …)
- Nanostrutture e nanotecnologie
- Ottica e fotonica
- Ottica quantistica, quantum information, quantum technologies
- Atomi e molecole
- Liquidi e "soft matter"

Gli enti nazionali:

CNR (Consiglio Nazionale delle Ricerche), dal 2004 comprendente l'ex INFM (Istituto Nazionale di Fisica della Materia)

CNISM (Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia)

IIT (Istituto Italiano di Tecnologia)

Piano di studi del curriculum (1)

36 CFU di insegnamenti obbligatori:

- Meccanica statistica* — *M. Guagnelli*
- Complementi di struttura della materia — *P. Carretta*
- Fisica dello Stato Solido I — *L.C. Andreani*
- Fisica dello Stato Solido II — *L.C. Andreani*
- Laboratorio di strumentazioni fisiche — *F. Marabelli*
- Laboratorio di fisica quantistica I — *M. Galli*

•*Se già seguito nella triennale, sostituire con corso affine*

Memento: la fisica è una scienza sperimentale

Piano di studi del curriculum (2)

12 CFU di insegnamenti "di area":

Fisica dei dispositivi elettronici a stato solido	*V. Bellani*
Nanostrutture di semiconduttori	*D. Gerace*
Spettroscopia dello stato solido	*M. Patrini, P. Galinetto*
Fotonica	*M. Liscidini*
Fisica quantistica della computazione	*C. Macchiavello*
Ottica quantistica	*L. Maccone*
Teoria fisica dell'informazione	*P. Perinotti*

12 CFU di insegnamenti di altre aree:

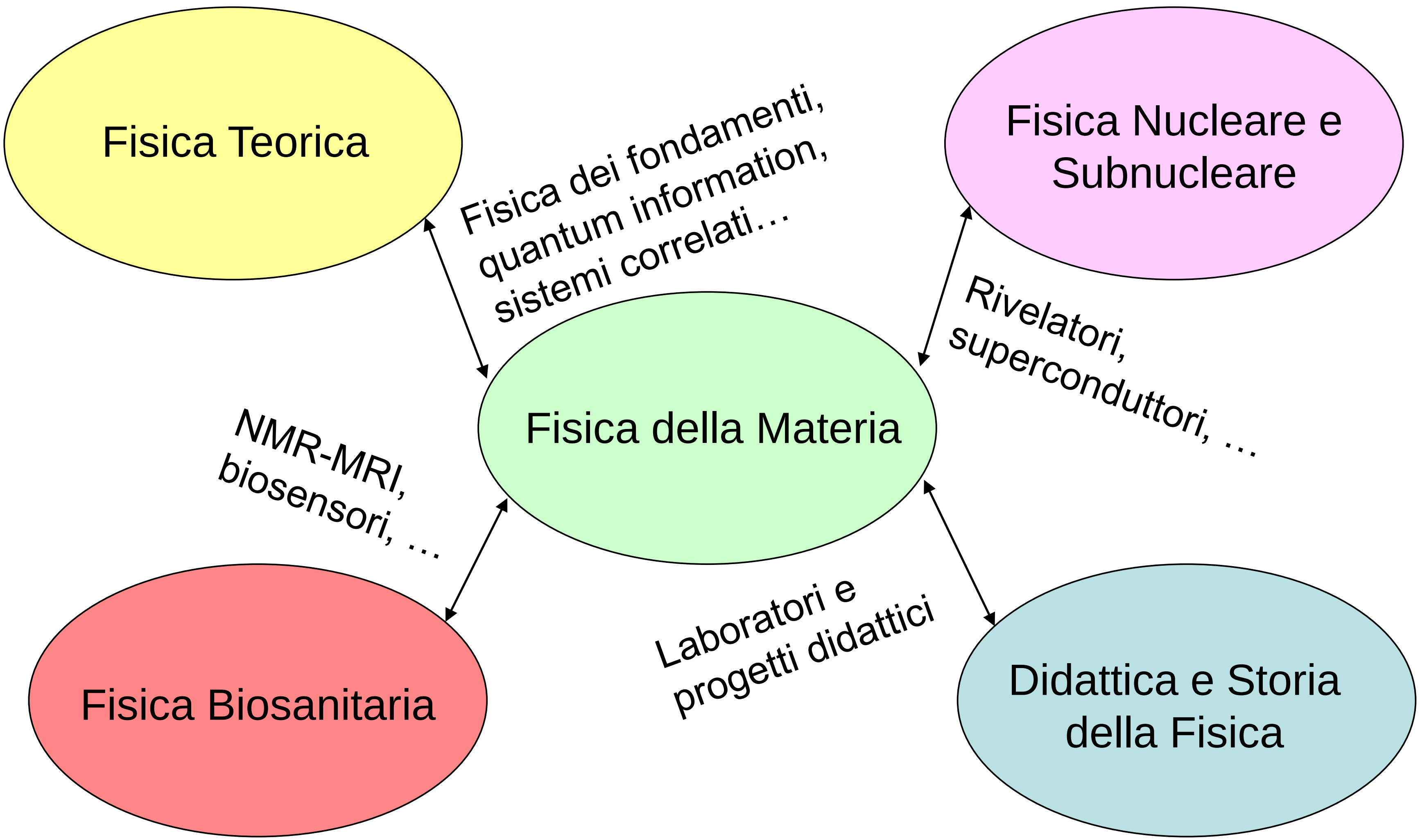
BIO, CHIM, FIS/05,06, GEO, INF, MAT, ING-IND, ING-INF, MED, M-STO (*controllare il settore scientifico-disciplinare*)

fra cui Termodinamica Statistica con Simulazioni *S. Romano*

12 CFU a scelta libera

48 CFU tesi di laurea magistrale

I curricula della laurea magistrale



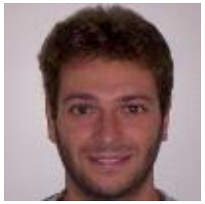
Ricerche in Fisica Teorica della Materia, Fotonica e Nanostrutture

- **Computational Statistical Mechanics**

S. Romano

- **Photonics & Nanostructures**

L.C. Andreani



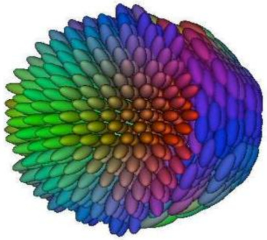
D. Gerace

M. Liscidini

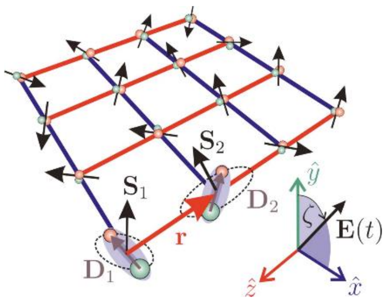
PhD students: D. Aurelio, M. Menotti, M. Passoni, S. Rafizadeh, F. Tacchino, G. Timò

Statistical Mechanics

- Computational research on liquid phases of matter (nematic phases of liquid crystals)



- Statistical mechanics of spin lattices (also exact demonstrations)



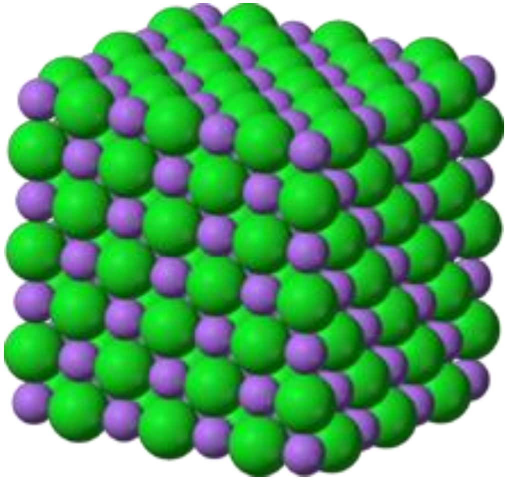
- Study of thermodynamic and structural properties of systems of interacting many particles

RELATED COURSES (L.M. Chimica):
Termodinamica Statistica
Chimica Teorica e Computazionale

WEBSITE: http://www2.pv.infn.it/~romano/

Crystalline solids

periodic lattices for electrons

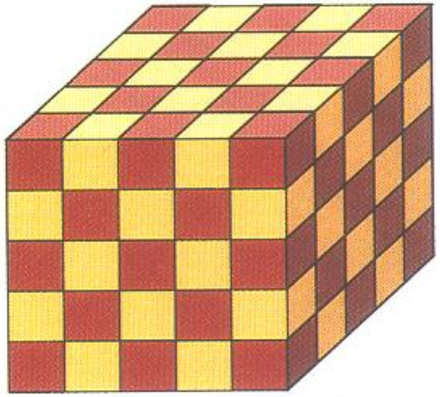


Schrödinger equation

$$H\Psi = (-\frac{\hbar^2}{2m}\nabla^2 + U(\mathbf{r}))\Psi = E\Psi$$

Photonic crystals

periodic dielectric media for photons



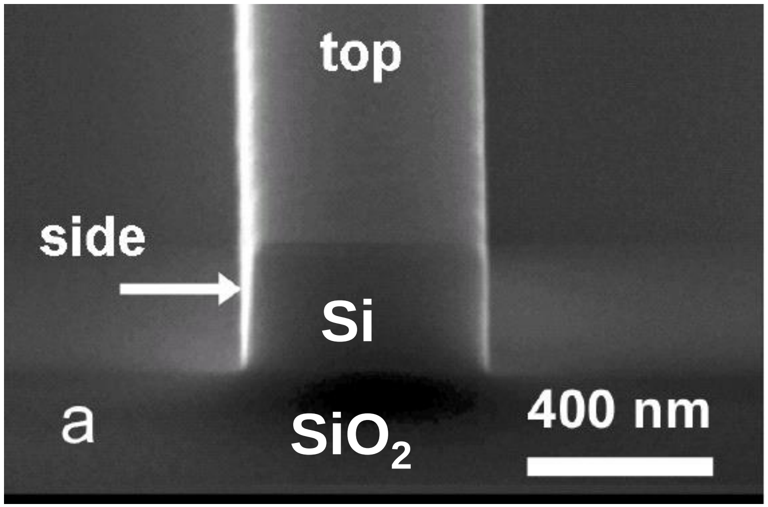
2nd-order Maxwell eqs. for harmonic fields

$$\nabla \times \left(\frac{1}{\epsilon(\mathbf{r})}\nabla \times \mathbf{H}(\mathbf{r})\right) = \frac{\omega^2}{c^2}\mathbf{H}(\mathbf{r})$$

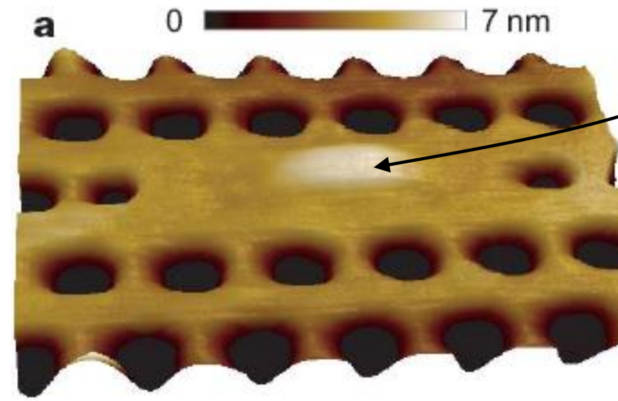
Allowed bands, energy gaps… reducing the dimensionality to control propagation and radiation-matter interaction in ***nanostructures***

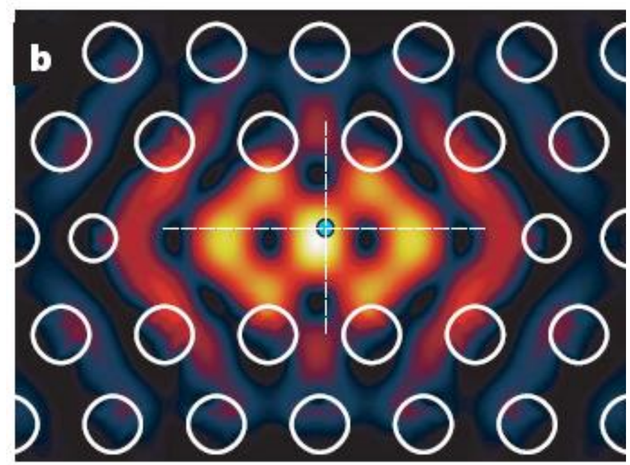
Spatial confinement: reducing the dimensionality… for both photons and electrons

Silicon wire for photonic integration

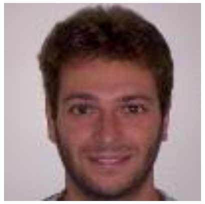


Photonic cavity with semiconductor quantum dot



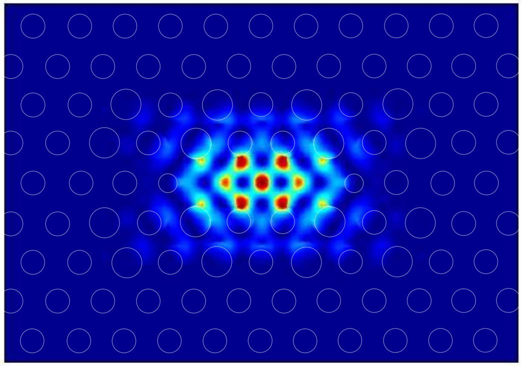


Photonic crystal nanocavities



- Confining photons to 0D → trapping light at the nanoscale

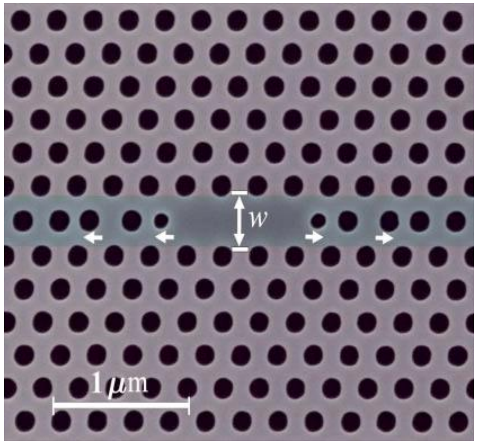
Theoretical modeling



$Q \sim 10^6$ → $\tau \sim 1$ ns

$V \sim (\lambda/n)^3$ → $|E|^2 \sim 1/V$

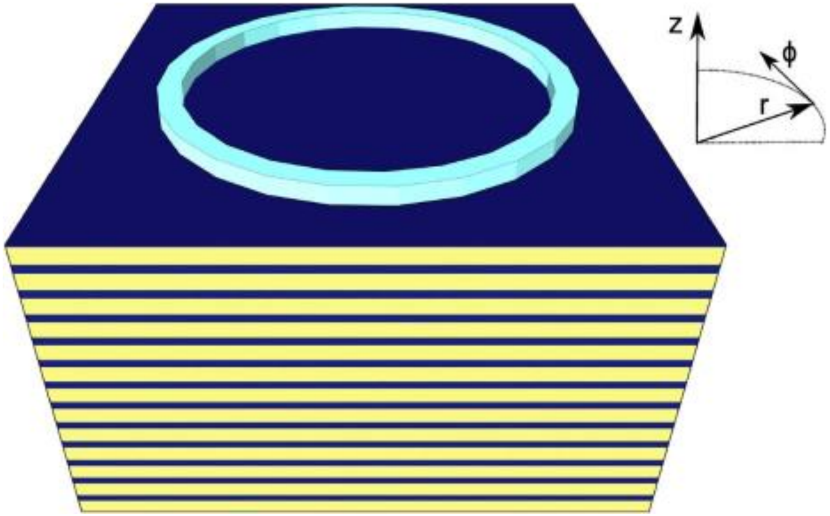
SEM of a fabricated device

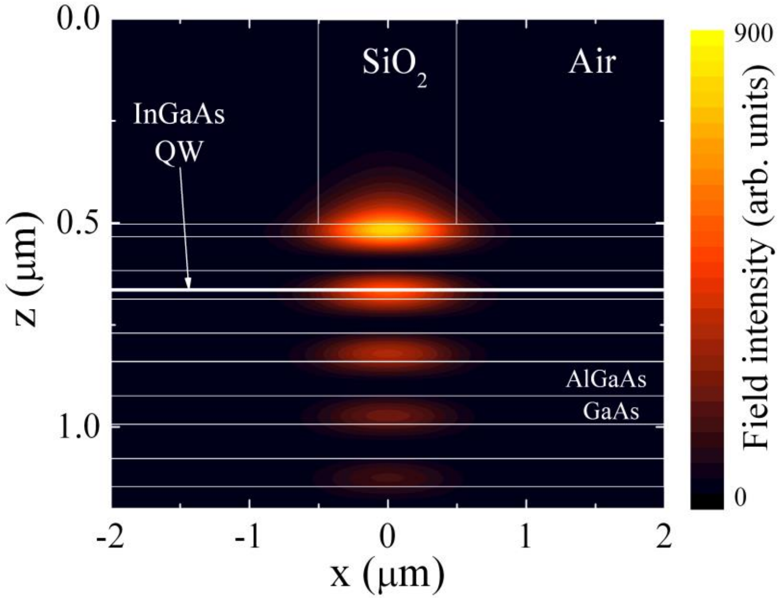


- Control of spontaneous emission, strong light-matter coupling, single-photon sources… also in collaboration with optical spectroscopy group (see Marabelli)

Bloch surface waves

- Theoretical study of optical surface waves in periodic media, control of light propagation and confinement…





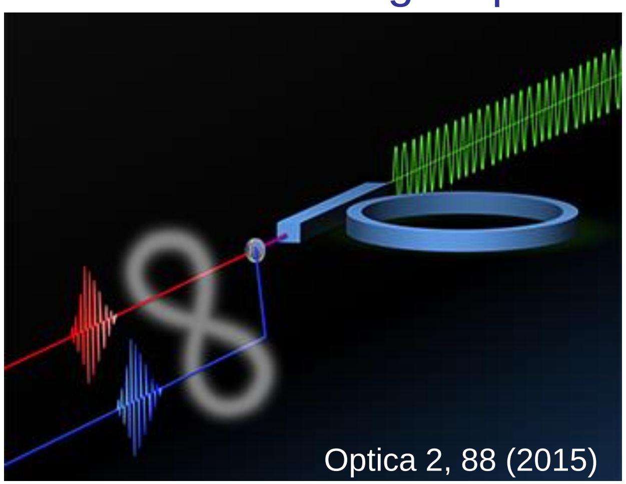
⇒ e.g., Biosensing applications

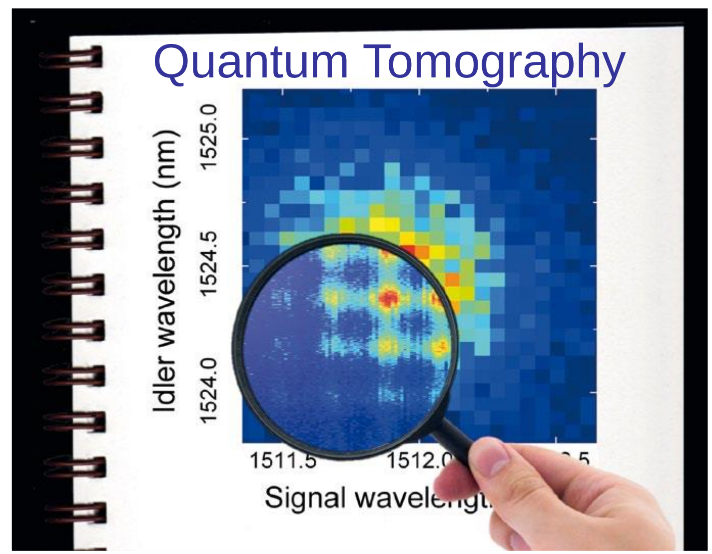
Quantum Nonlinear Photonics

- Theoretical studies on the generation and characterization of nonclassical states of light, e.g (i.e., entangled, squeezed …), in connection with experiments: M. Galli, D. Bajoni (see Marabelli)

- Connections to fundamental physics: Quantum Mechanics, Quantum Computation and Quantum Information (see D’Ariano)

Generation of entangled photons





Quantum Technologies

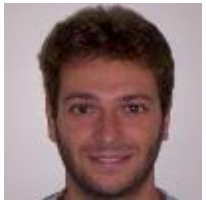
The European Commission is launching a € 1 billion Quantum Technologies Flagship

Examples of quantum technologies are:

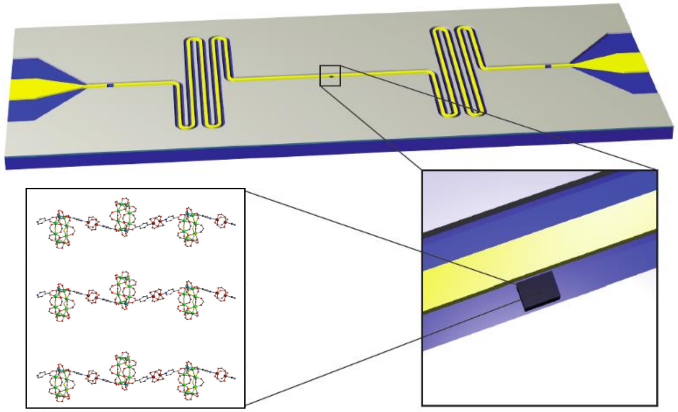
- *Quantum communication, quantum key distribution*
- *Quantum computing, quantum simulators*
- *Quantum sensors*
- *Quantum metrology*

These technologies may be implemented in solid-state and in photonic systems (superconducting qu-bits, silicon photonics…)

Quantum simulators



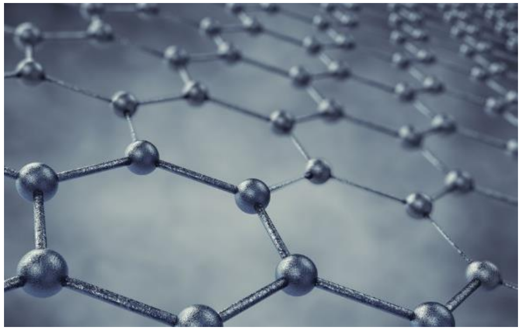
- Digital simulators: Directly computing the time evolution of complex manybody models

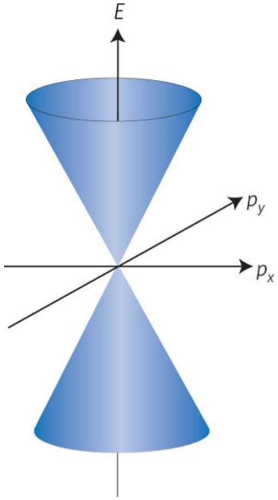


Elementary unit (qubit): collective spin ensemble in a microwave resonator →

MIUR – FIRB and PRIN project in collaboration with Univ. Parma

- Analog simulators: Studying systems with formal analogies with models in theoretical physics

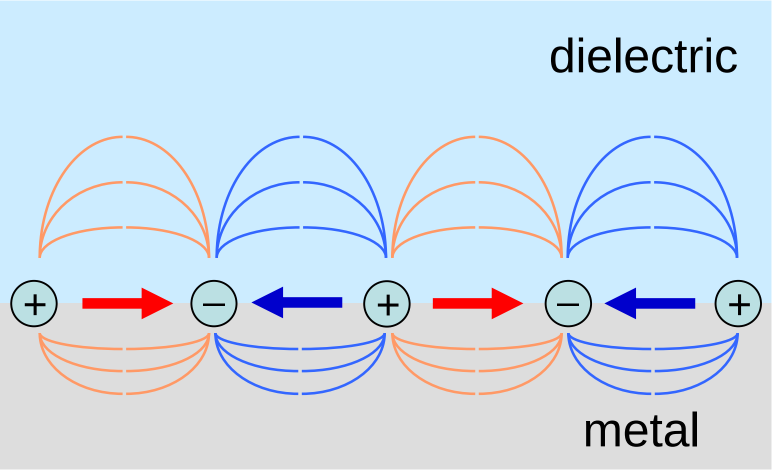




e.g.: relativistic electrons in graphene, analog dynamics in curved space-time (Hawking radiation)

Elementary excitations as quasi-particles

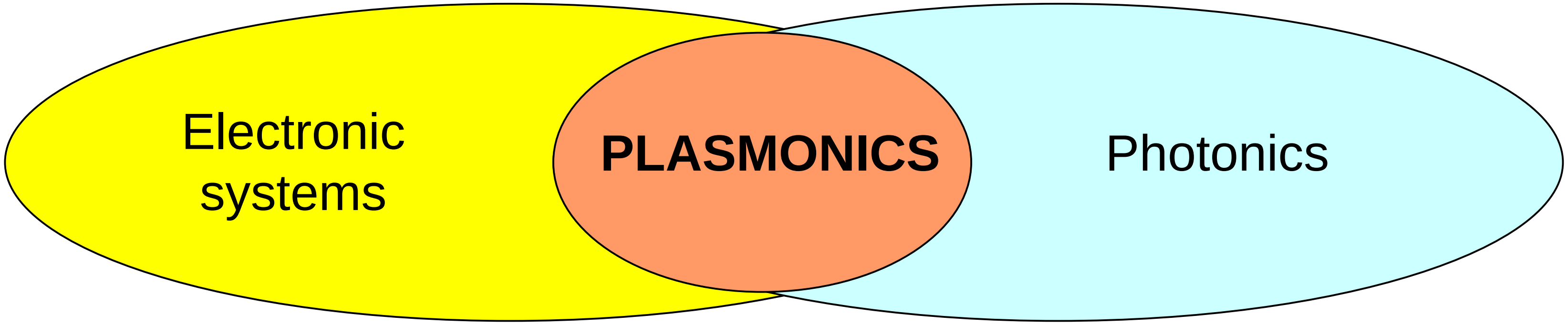
Excitations in solids can be described in terms of collective degrees of freedom, which can be considered as actual particles: phonons, excitons, polaritons, plasmons, magnons… and fractional charges *e*/3



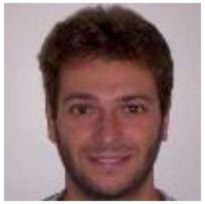
PLASMONS: collective excitations of free electrons in a metal

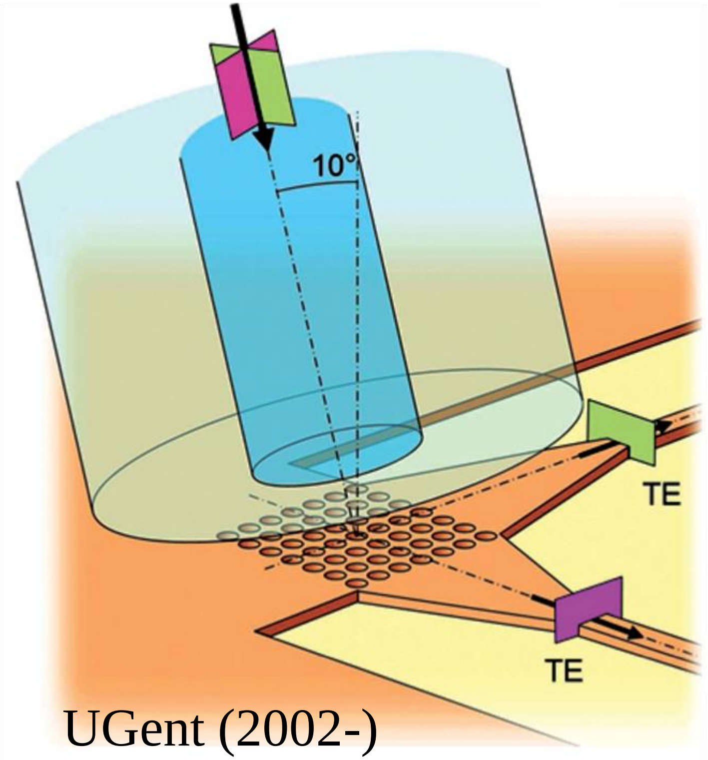
They can LOCALIZE → surface plasmons

They can COUPLE TO RADIATION (surface plasmon polaritons)



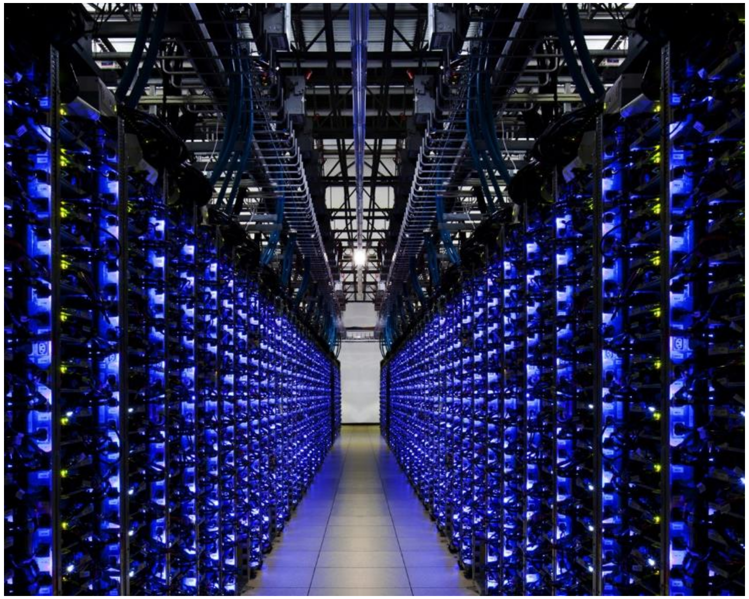
Photonic crystals in silicon photonics: the grating coupler





UGent (2002-)

The problem: optimizing the coupling efficiency from a *single-mode optical fiber* (long-distance communication) into a *silicon optical integrated circuit*



Applications:

- Optical modem on a silicon chip
- Optical transfer in data centers
- Slow light on a chip…

Photovoltaics


- Photovoltaic conversion in solar cells = **optical problem** (light trapping) + **electronic problem** (carrier collection)

$\Rightarrow$ both fundamental aspects (nanophotonics, efficiency limits) and applied ones

Silicon-based (ground)

III-V multijunctions (space)

- Projects: public, private, industrial (EU, Cariplo, ENI, RSE…)

Research in Condensed Matter Theory