Fisica Teorica della Materia, Fotonica & Nanostrutture

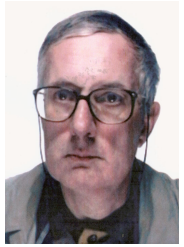
Dario Gerace

Dipartimento di Fisica, Università di Pavia

Giornata di orientamento L.M. in Scienze Fisiche - 19 Maggio 2015

Groups and People

- **Computational Statistical Mechanics**



Prof. S. Romano

- **Photonics & Nanostructures**

Prof. L. C. Andreani

Prof. D. Gerace

Prof. M. Liscidini

Post-Docs: A. Bozzola, P. Kowalczewski, S. W. Flores

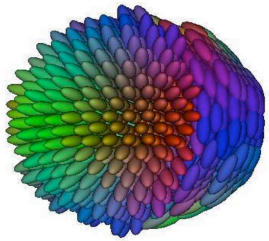
PhD students: F. Alpeggiani, S. Del Sorbo, M. Menotti, S. Rafizadeh

Master students: V. Introini, D. Kos, M. Passoni, L. Redorici

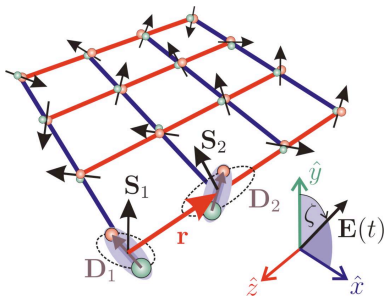
COMPUTATIONAL STATISTICAL MECHANICS

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

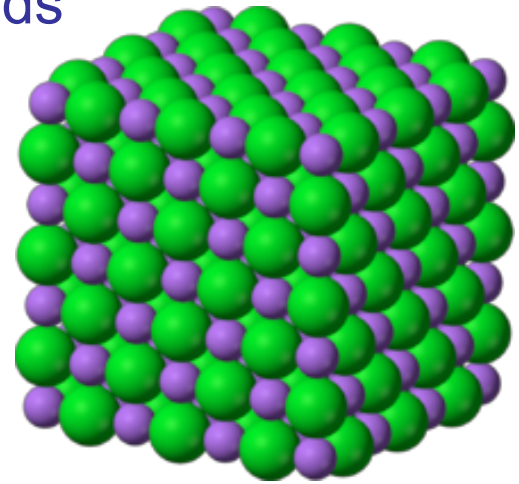
RELATED COURSES (L.M. Chimica):
Statistical Thermodynamics
Theoretical and Computational Chemistry

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

PHOTONICS

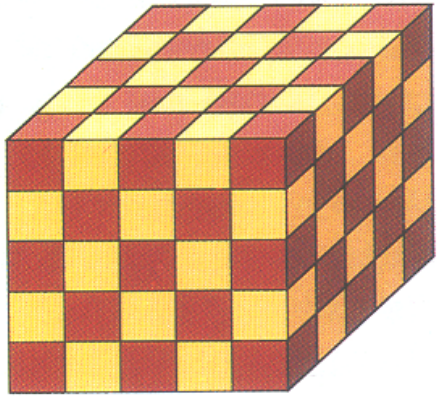
Photonic crystals

electrons in crystalline solids



Schrödinger equation

photons in periodic dielectric media



2nd-order Maxwell eqs. for harmonic fields

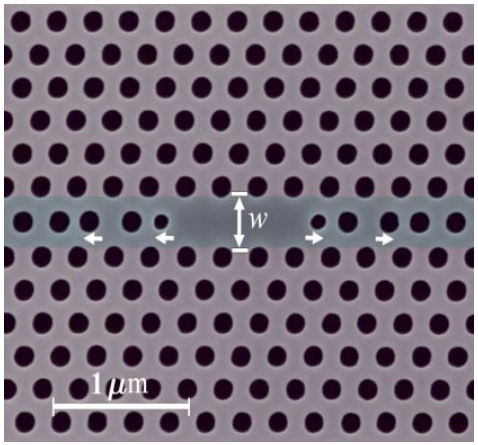
$$H\Psi = (-\frac{\hbar^2}{2m}\nabla^2 + U(\mathbf{r}))\Psi = E\Psi \quad \longleftrightarrow \quad \nabla \times \left(\frac{1}{\epsilon(\mathbf{r})}\nabla \times \mathbf{H}(\mathbf{r})\right) = \frac{\omega^2}{c^2}\mathbf{H}(\mathbf{r})$$

“Photonic bands” and energy gaps, as in solids!

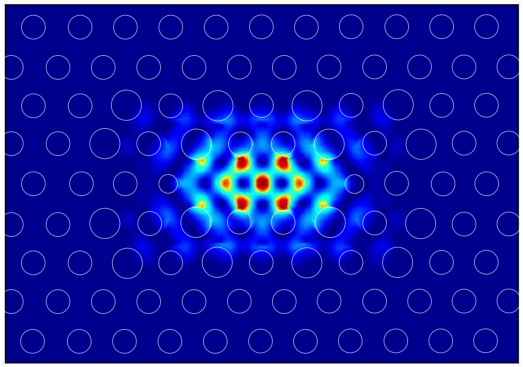
Photonic crystal nanocavities


- Trapping light at the nanoscale

SEM of a fabricated device



Theoretical modeling

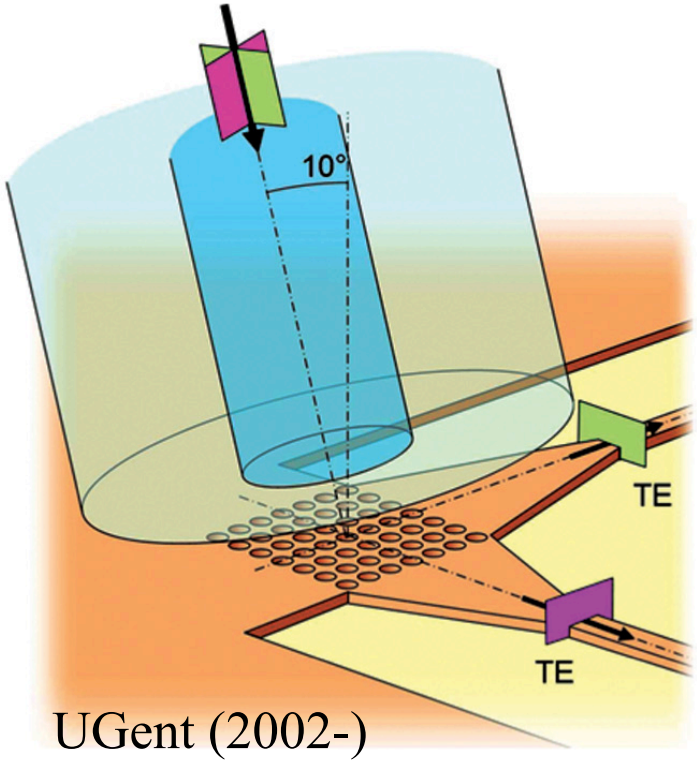


$Q \sim 10^6 \rightarrow \tau \sim 1$ ns

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

- Several applied and fundamental works on enhanced optical nonlinearities in collaboration with optical spectroscopy group (see Guizzetti)

Photonic crystals in silicon photonics: grating couplers for telecom applications



UGent (2002-)

EU project Fabulous

SEVENTH FRAMEWORK PROGRAMME

Fabulous

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

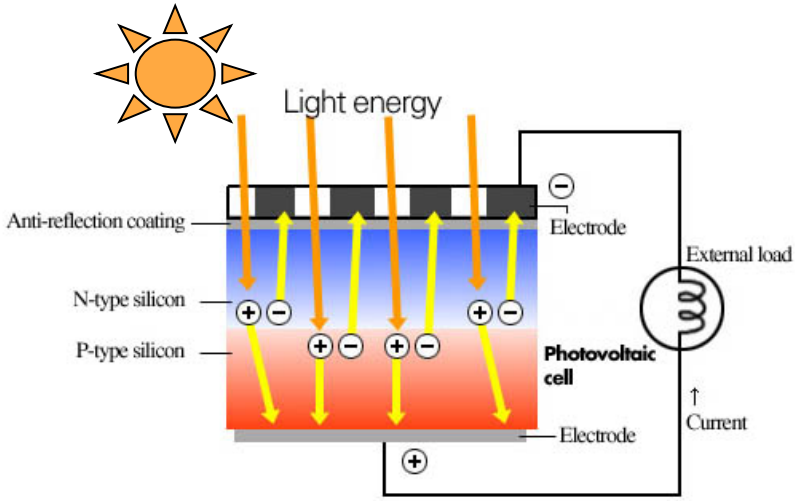
Project goal: realizing an Optical Network Unit in silicon photonics → optical modem on a silicon chip!

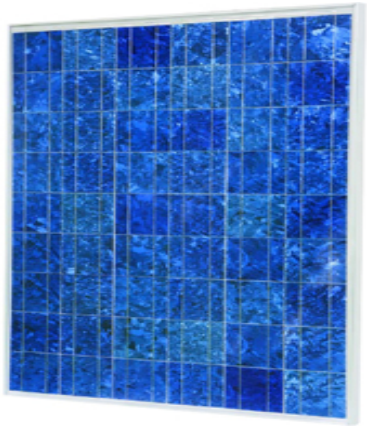
Photovoltaics


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

⇒ both fundamental aspects (efficiency limits) and applied ones

⇒ ***cultural*** opportunities, as well as ***funding*** and ***career*** ones





- Projects: public + industrial

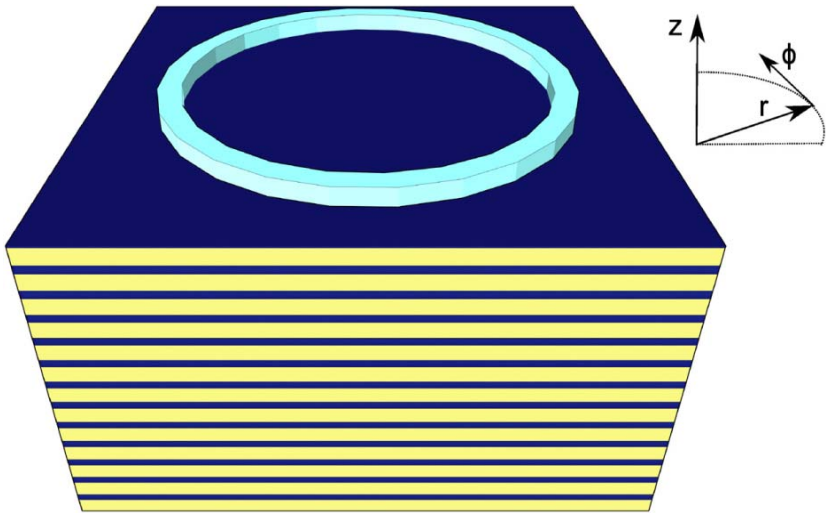
EU FP7 Marie Curie ITN Network "PROPHET"

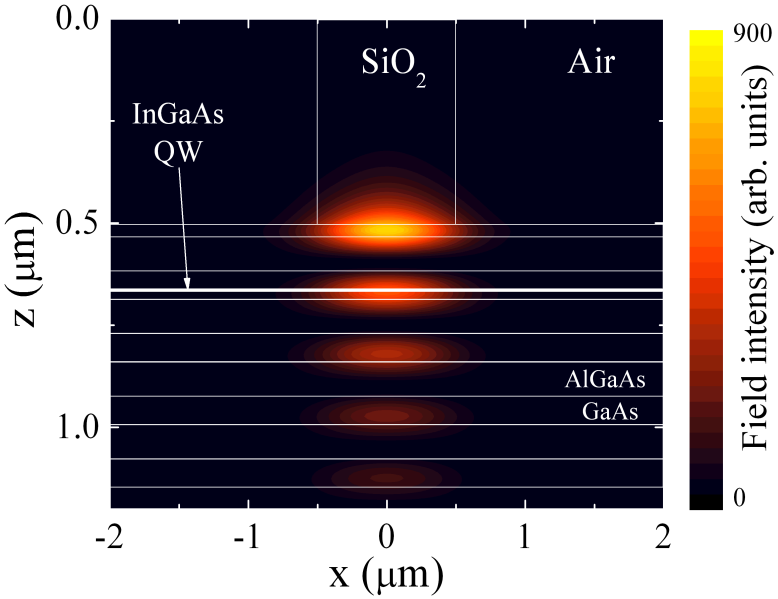
ENI S.p.A. "*Photonics for PV systems based on fluorescent concentrators*"

Nanophotonics meets Photovoltaics !

Bloch surface waves

- Theoretical study of optical surface waves in periodic media.



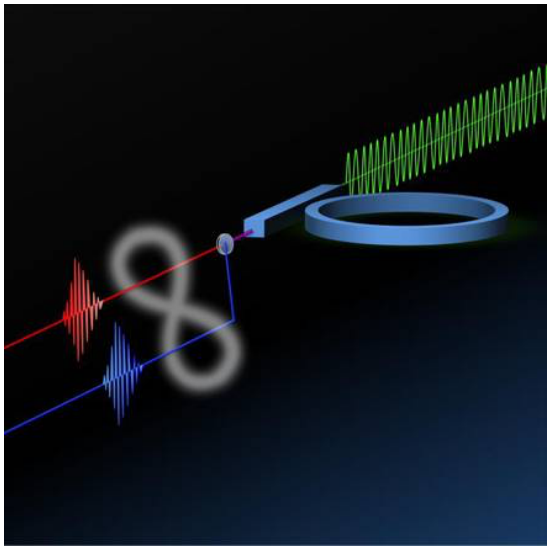


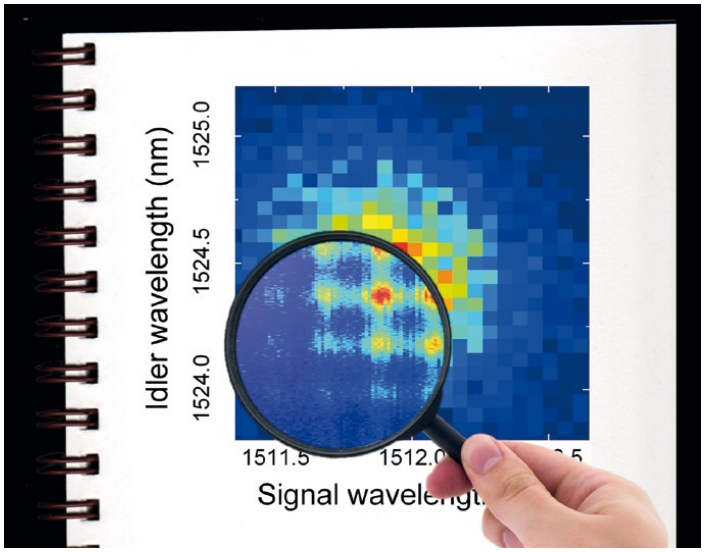
⇒ e.g., Biosensing applications

Quantum Nonlinear Photonics

- Theorertical studies on the generation and characterization of nonclassical states of light (i.e., entangled, squeezed …), in connection with experiments (see Guizzetti)

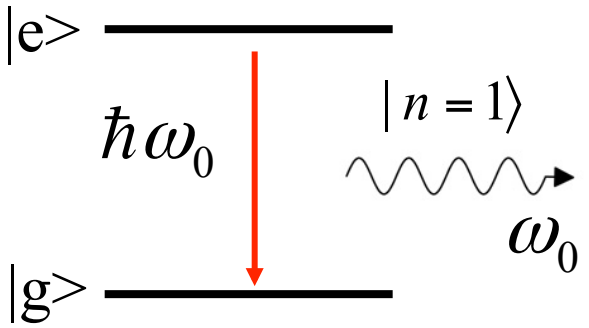
- Connections to Quantum Mechanics, Quantum Computation and Quantum Information (see D'Ariano)



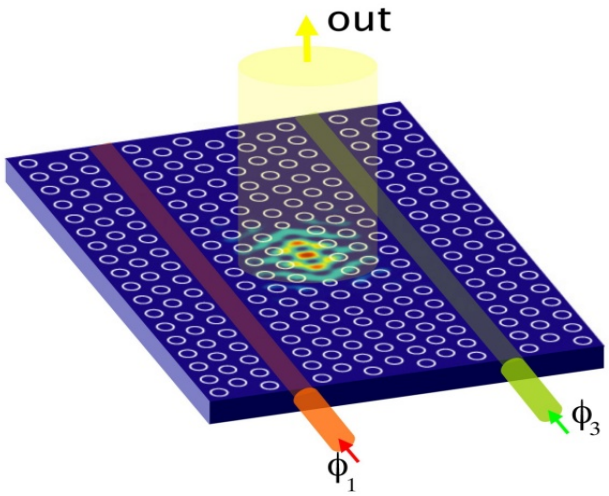


Single-photon sources

- An ideal single-photon source →



- Our interest: realizing single-photon sources integrated in silicon chips



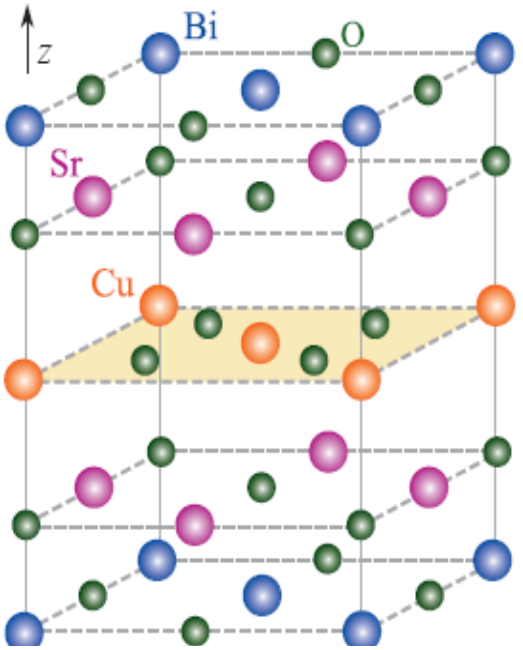
Ultimately: single-photon devices (transitors, diodes…)

Fundamental physics today…applications tomorrow ?

ELEMENTARY MATERIAL EXCITATIONS

Elementary excitations as quasi-particles

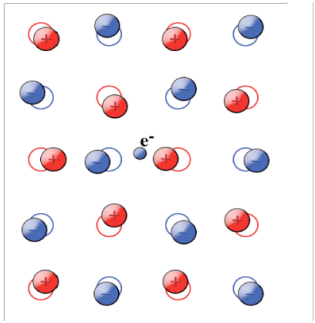
- Solids are complex systems…but their low-energy excitations can be described in terms of collective degrees of freedom, which can be considered actual particles

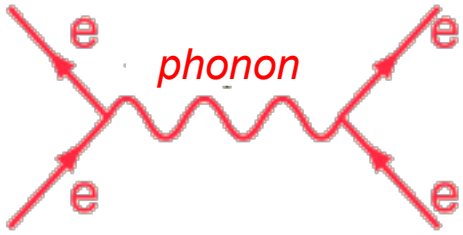


phonons, excitons, polaritons, plasmons, magnons, …

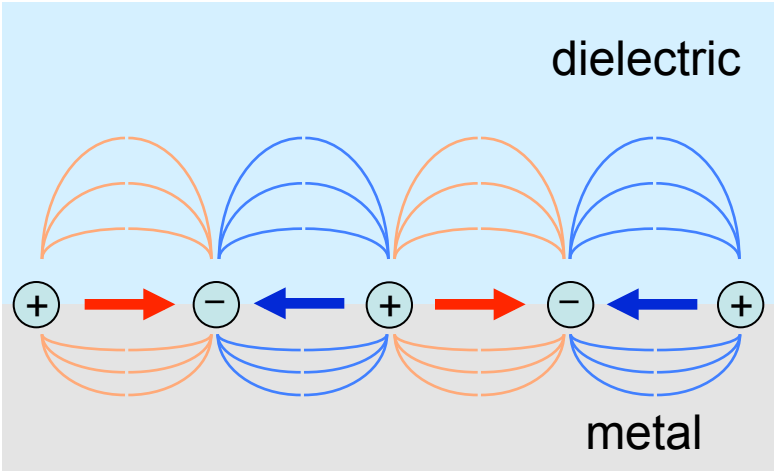
- Quantum theories of elementary excitations → QFT

e.g. → a Cooper pair





Plasmonics

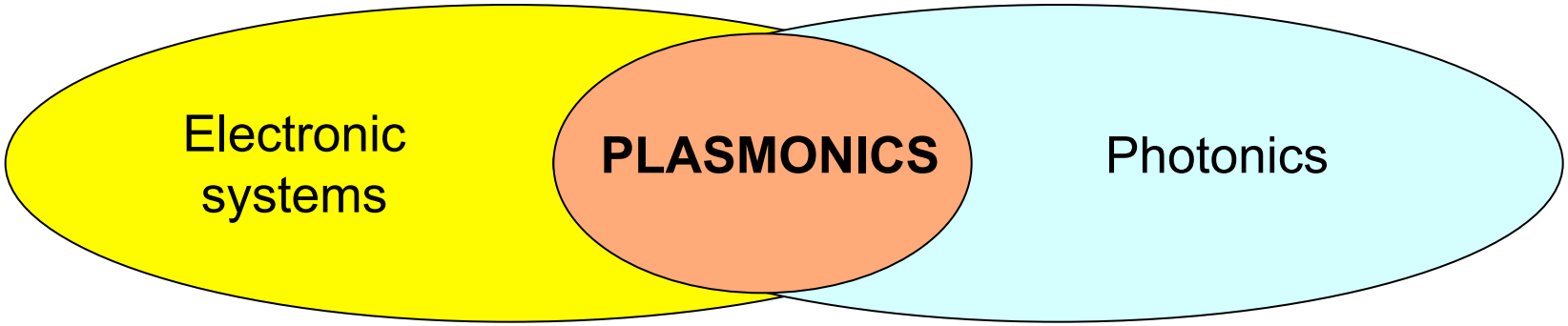


PLASMONS: collective excitations of free electrons in a metal

They can LOCALIZE → surface plasmons

They can COUPLE TO RADIATION (surface plasmon polaritons)

Vibrant field of research, with many fundamental aspects (control of radiative processes, sub-wavelength optics, classical and quantum phenomena) and applied ones (biosensors…)

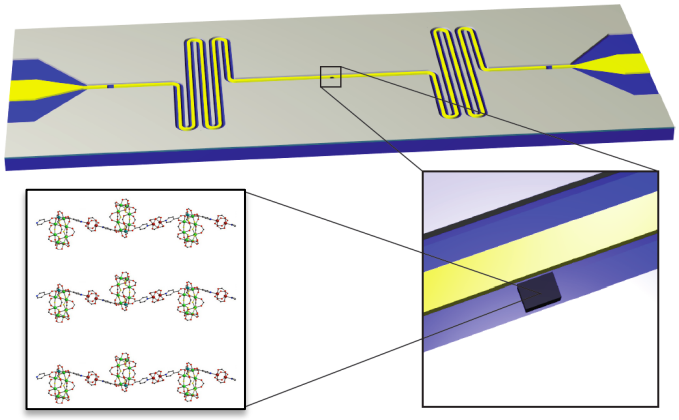


Quantum simulators

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

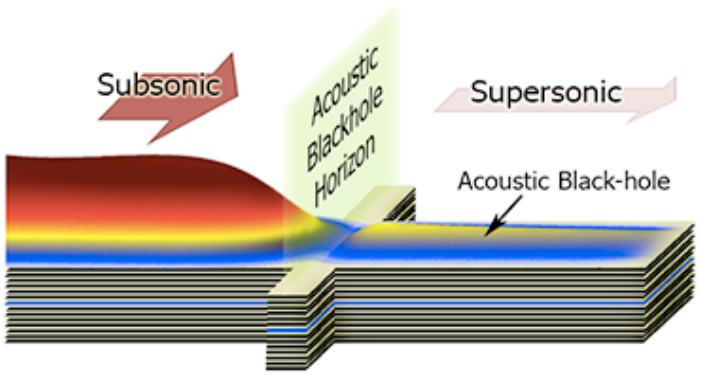
  Elementary unit (qubit): collective spin ensemble in a microwave resonator →

  MIUR – FIRB project in collaboration with Univ. Parma



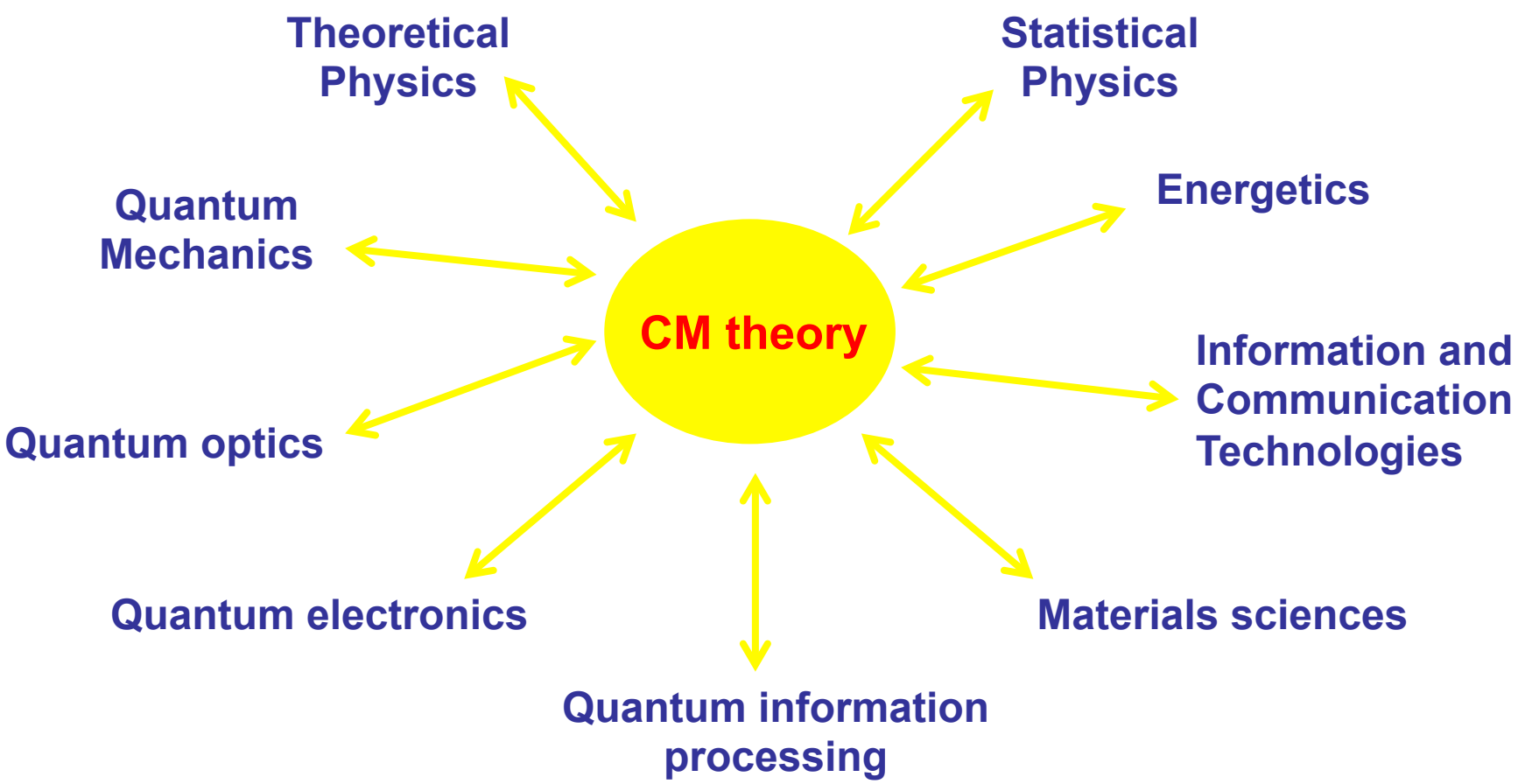
- Analog simulators: Studying systems with formal analogies with models in theoretical physics

  e.g.: relativistic electrons in graphene, strongly correlated photonic lattices, analog dynamics in curved space-time



Research in Condensed Matter Theory

APPLIED RESEARCH ⟷ **FUNDAMENTAL RESEARCH**



Research in Condensed Matter Theory

- Problem solving → trained at developing numerical and/or analytic skills

- Collaborative works, international environment