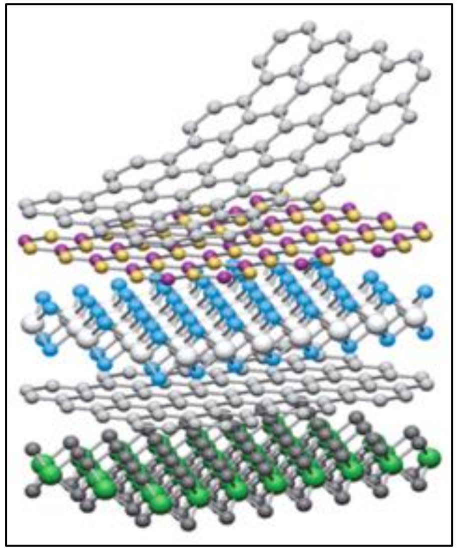
TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Corso di Laurea Magistrale in Fisica

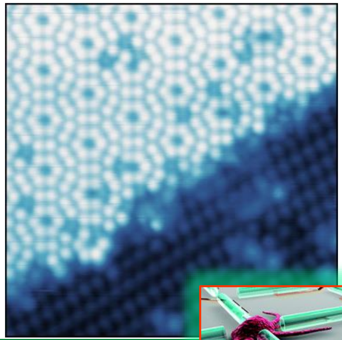
Fisica della Materia

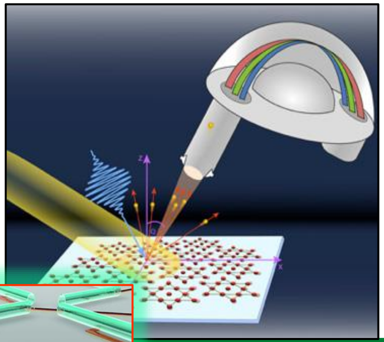
Welcome
to the
nanoworld!!

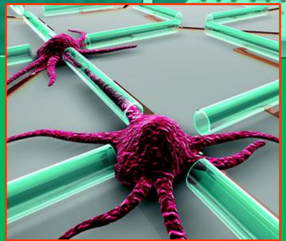


Prof.ssa Olivia Pulci

Prof. Fabrizio Arciprete





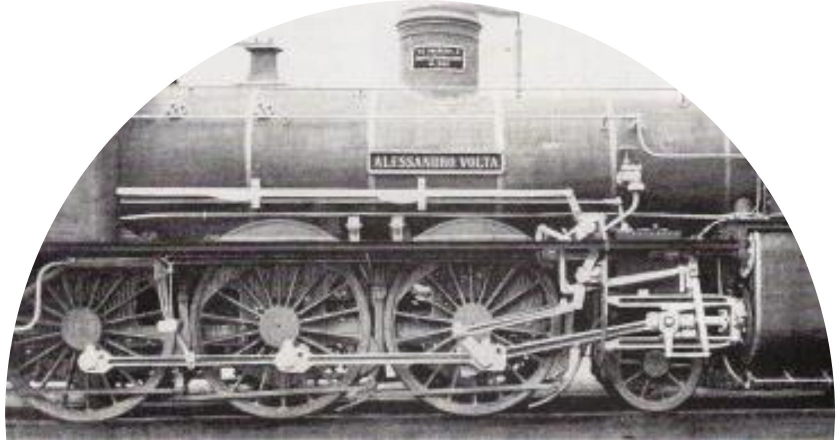


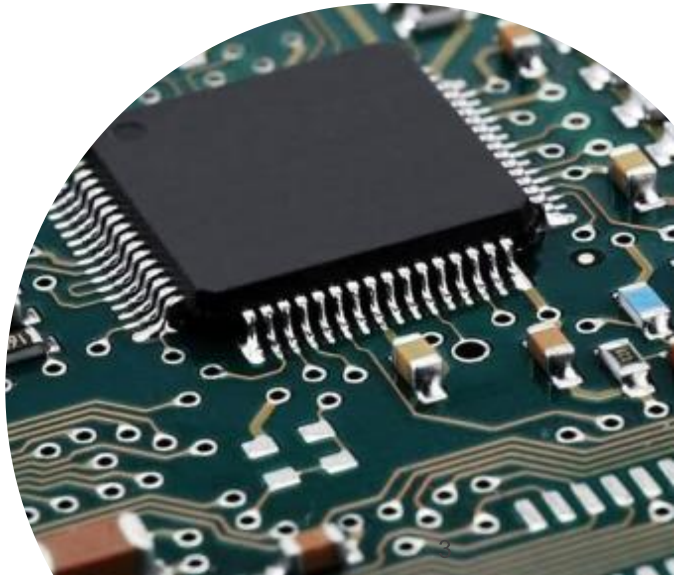
https://www.youtube.com/watch?v=DWouwx3Hxmk

I MATERIALI E LO SVILUPPO DELLA SOCIETA‘

- **Età della pietra**
- **Età del bronzo**
- **Età del ferro**
- **Età dell‘acciaio**
- **Età del silicio**
- **(e della plastica)**

- **…….eta‘ dei nuovi materiali**



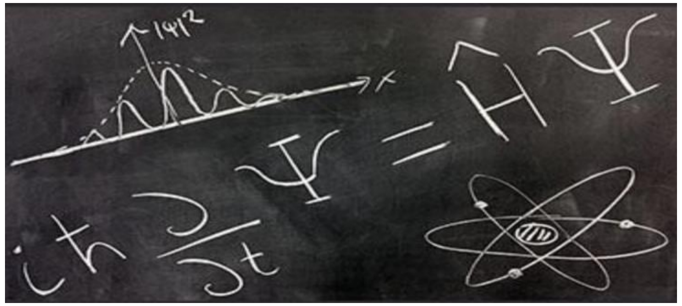


Fisica della Materia e nuovi materiali emergenti

Permette di spiegare molte delle proprietà macroscopiche della materia a partire da quelle microscopiche ma ancora tanti fenomeni vanno compresi

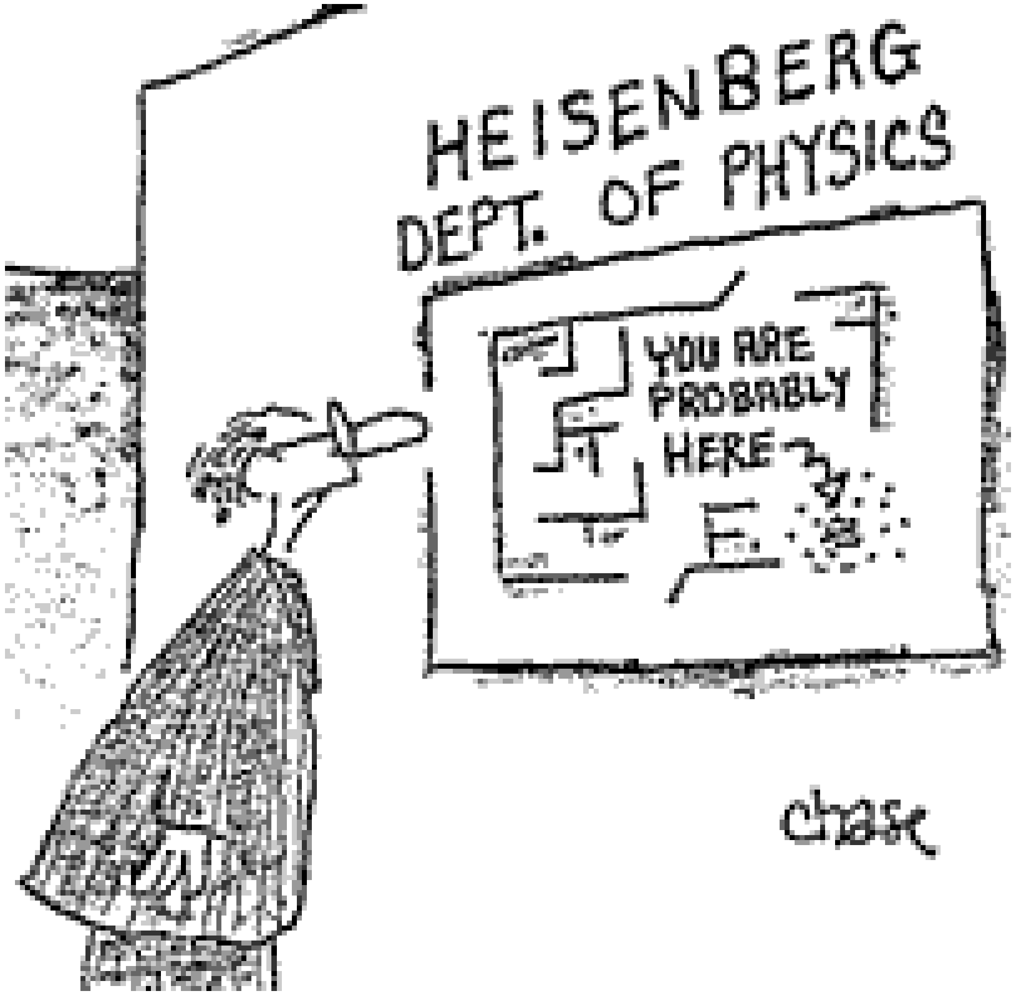
Le proprietà dei materiali sono alla base della maggioranza delle tecnologie moderne (attuali e future) e a molto del progresso delle altre branche della fisica

Forte interdisciplinarità
Legame con altre branche della scienza dalla chimica alla biologia all'ingegneria alla moderna Scienza dei Materiali

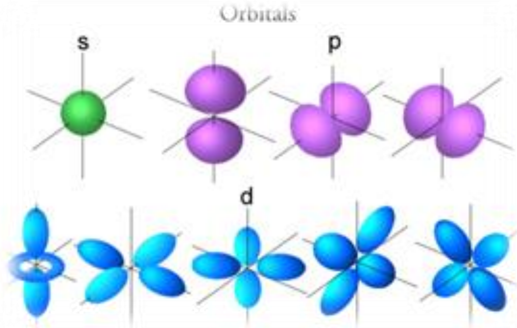


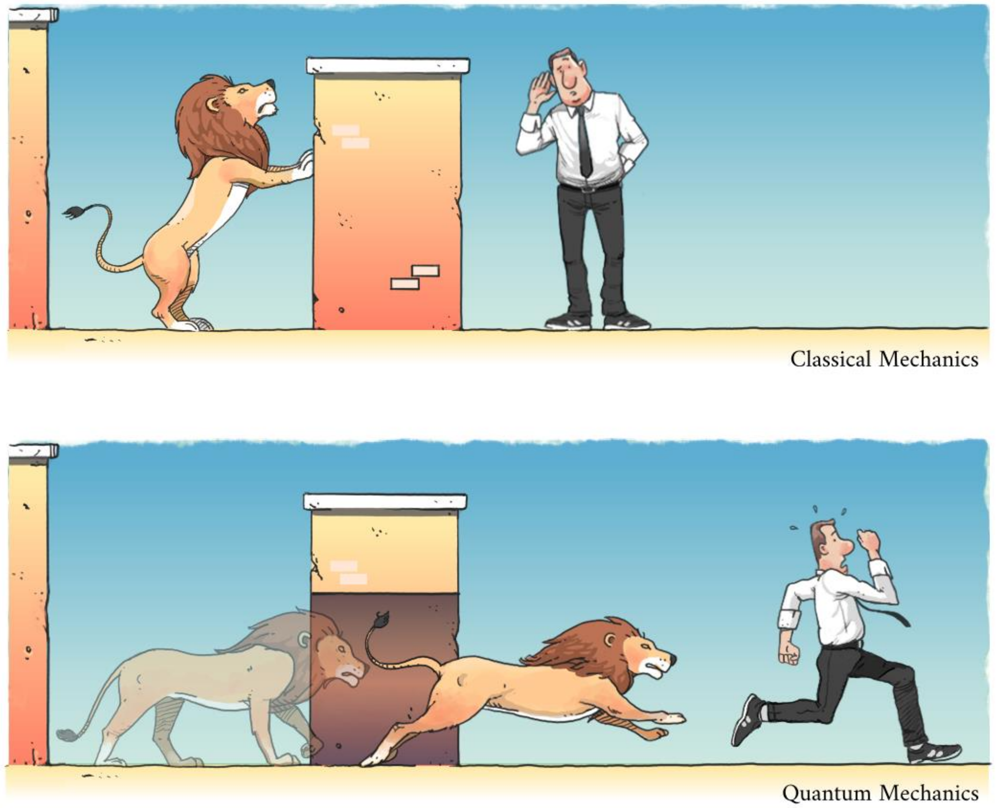
Perfetto campo di gioco per vedere applicate le leggi della meccanica quantistica

Nel nano-mondo impera la meccanica quantistica



Elettrone

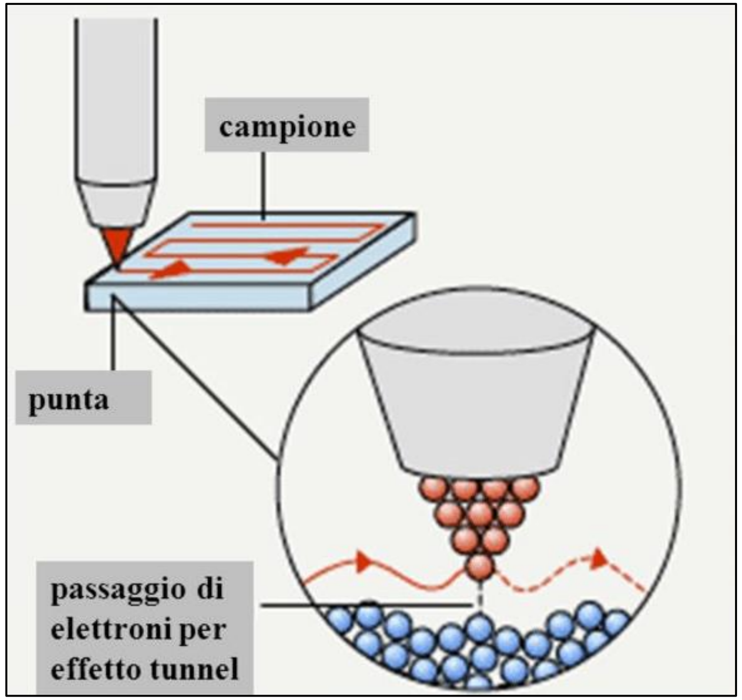




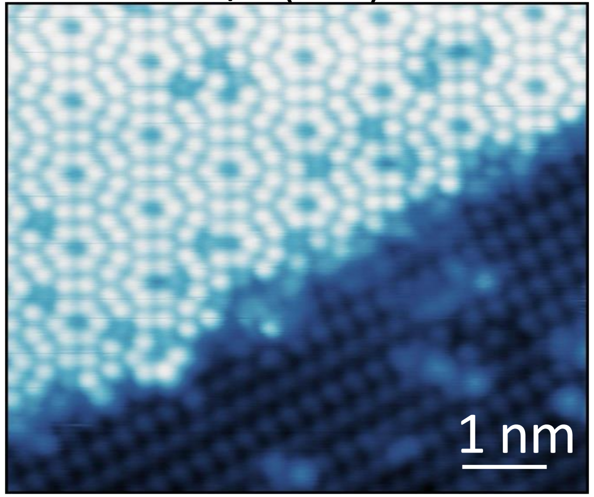
Effetto tunnel

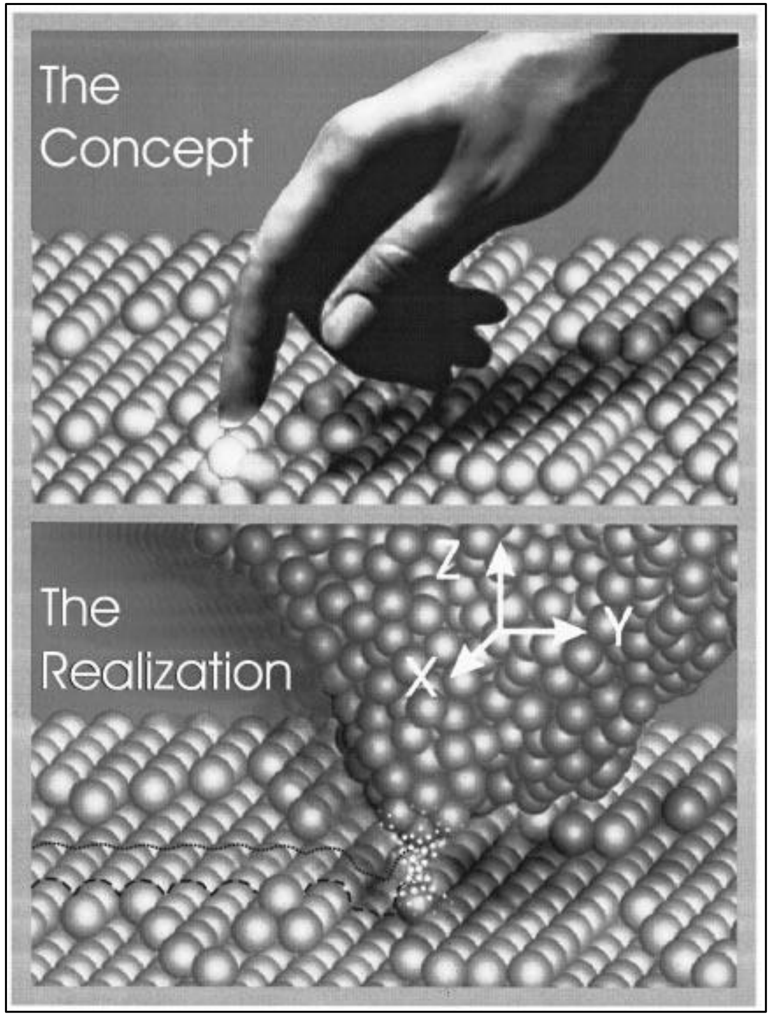
Microscopio ad Effetto tunnel

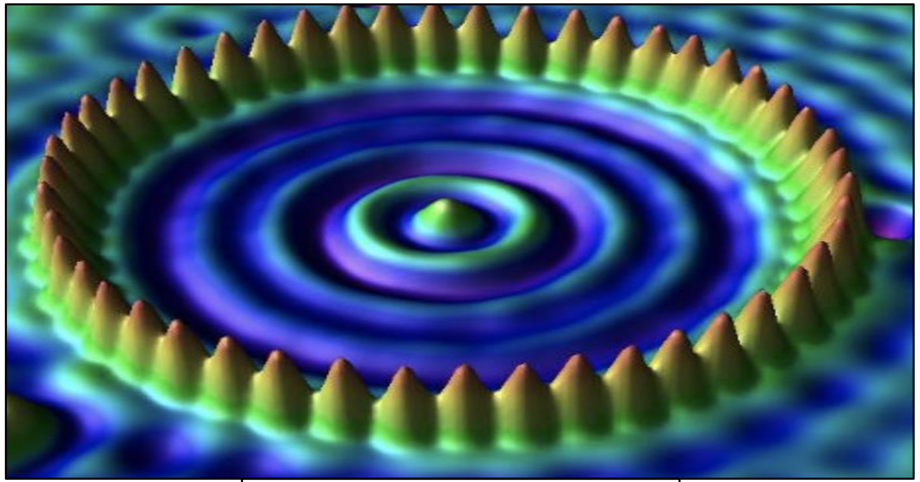
(Nobel prize 1986)



Ca/Si(111) 7x7







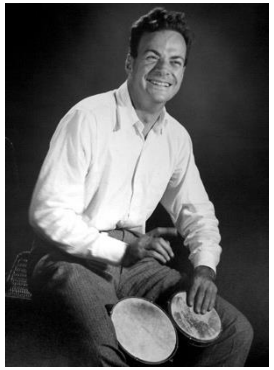
Fe atoms on Cu (IBM)

New functionalities

New materials

New Physics

"There's Plenty of Room at the Bottom (R.Feynman)"



ALLA BASE DELLE NUOVE TECNOLOGIE
C'E' LA RICERCA DI BASE
IN FISICA DELLA MATERIA

Quasi il 50% dei Nobel in Fisica assegnato negli ultimi 50 anni a scoperte collegate a questa branca della Fisica

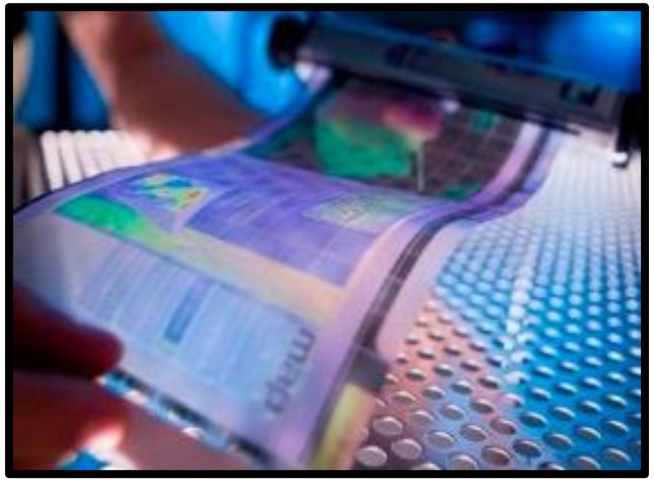
Riducendo la dimensione dei materiali a scale ridottissime (nm = miliardesimo di metro) le loro proprietà cambiano e nuovi fenomeni vengono osservati

New functionalities ⟷ New materials ⟷ New Physics

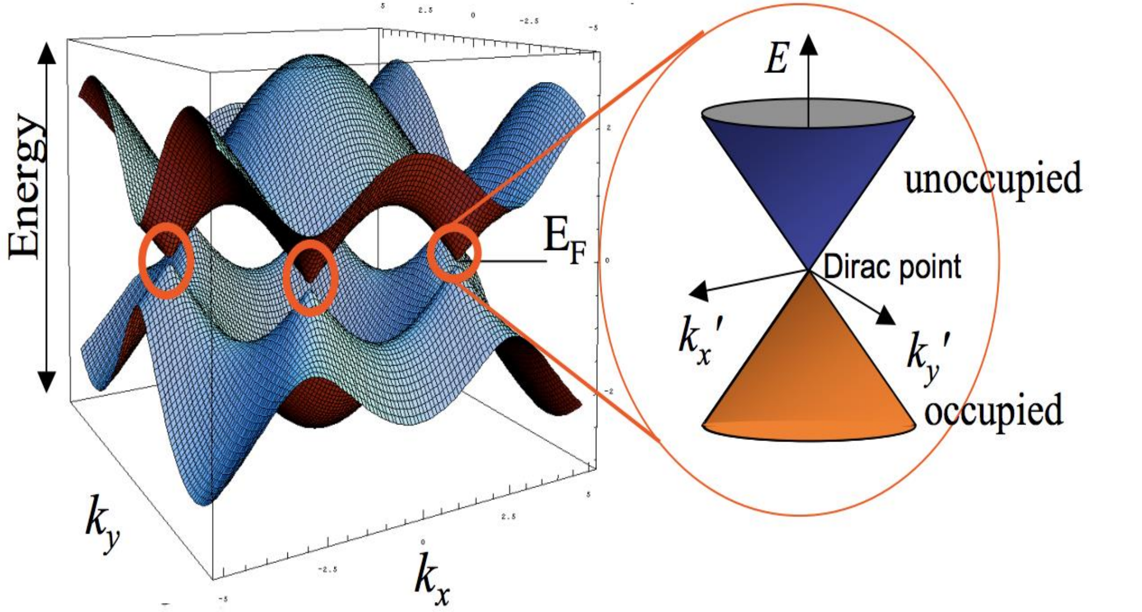
Graphene

Resistente,
Leggerissimo,
Flessibile,
Conduttore elettrico e termico
Assorbe luce ad ogni frequenza
Opacita'
Elettroni ultrarelativistici

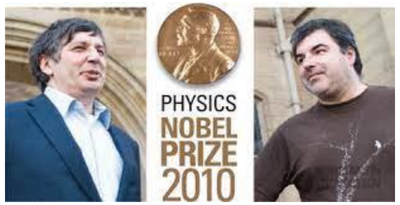
Resistenza del diamante,
Flessibilità della plastica

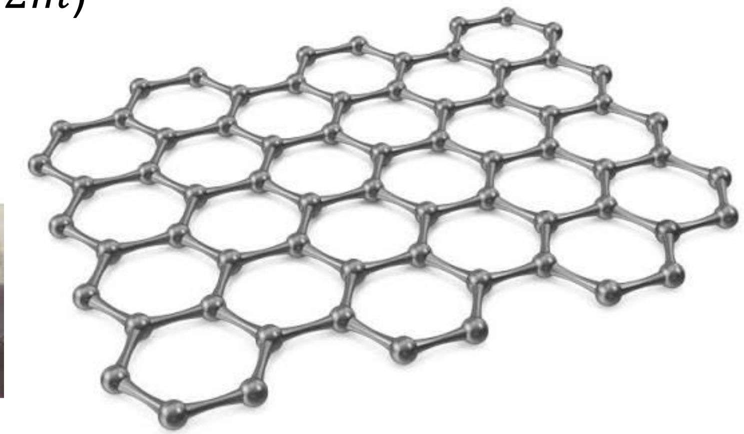


Elettronica flessibile/indossabile

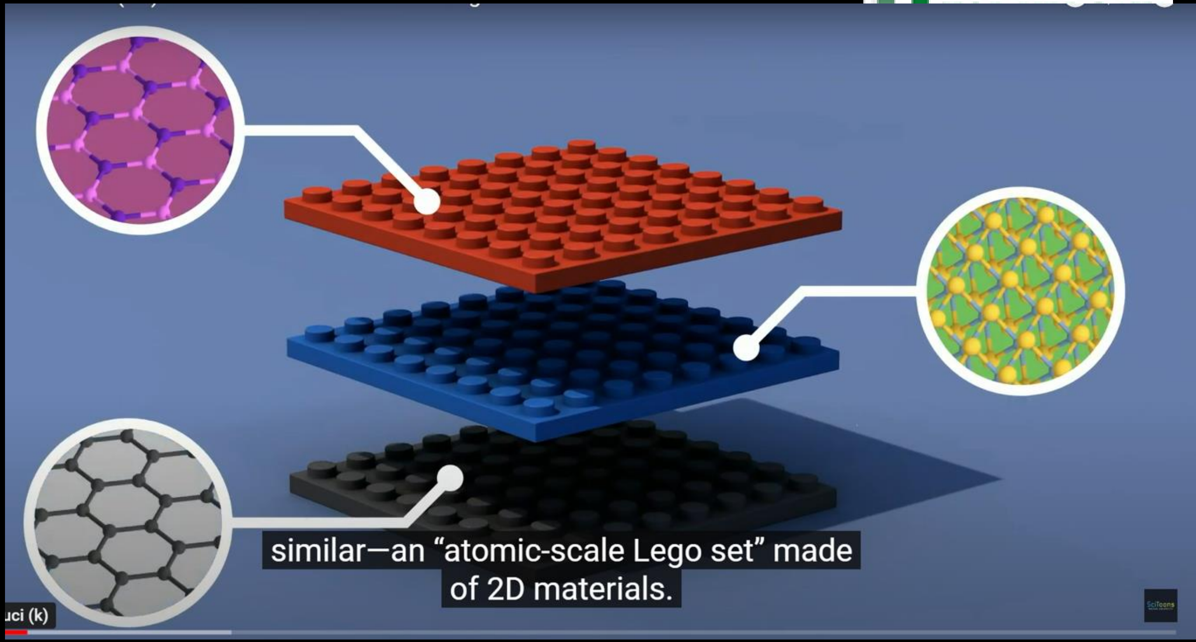


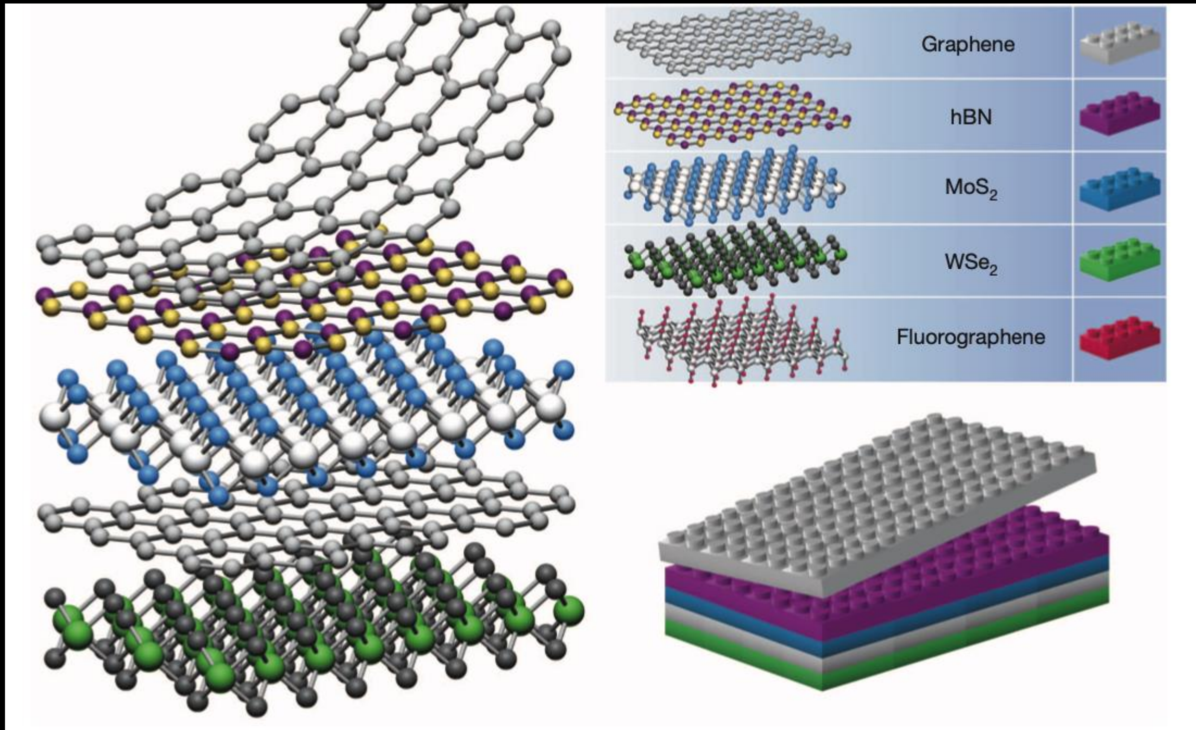
ECCELLENTE CONDUTTORE $\boldsymbol{E = v_d p}$, $v_d = c/300$.
Dispersione lineare energia-impulso, come le particelle ultra-relativistiche a massa nulla (elettroni nei materiali «normali» $E = p^2/2m$)

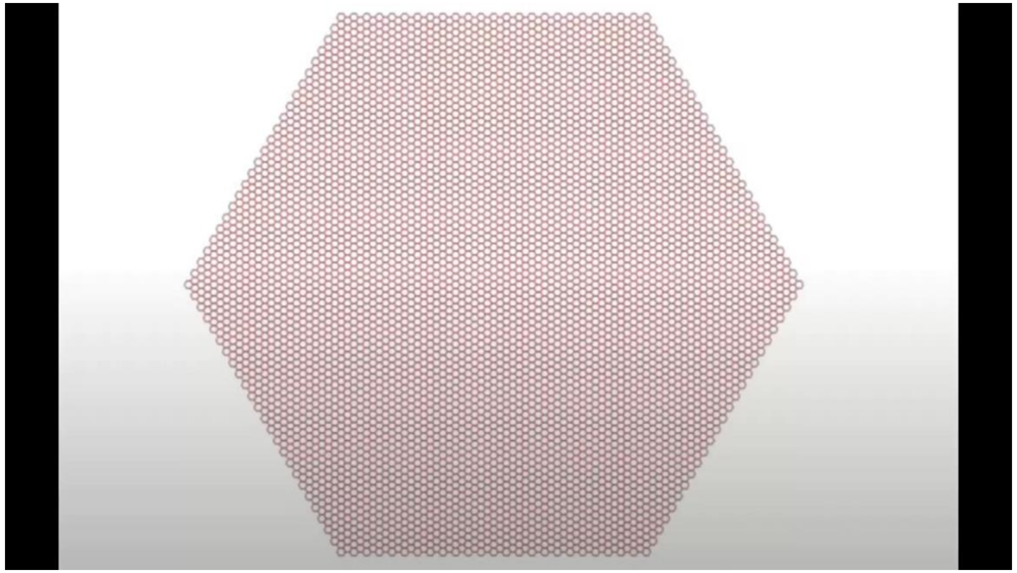


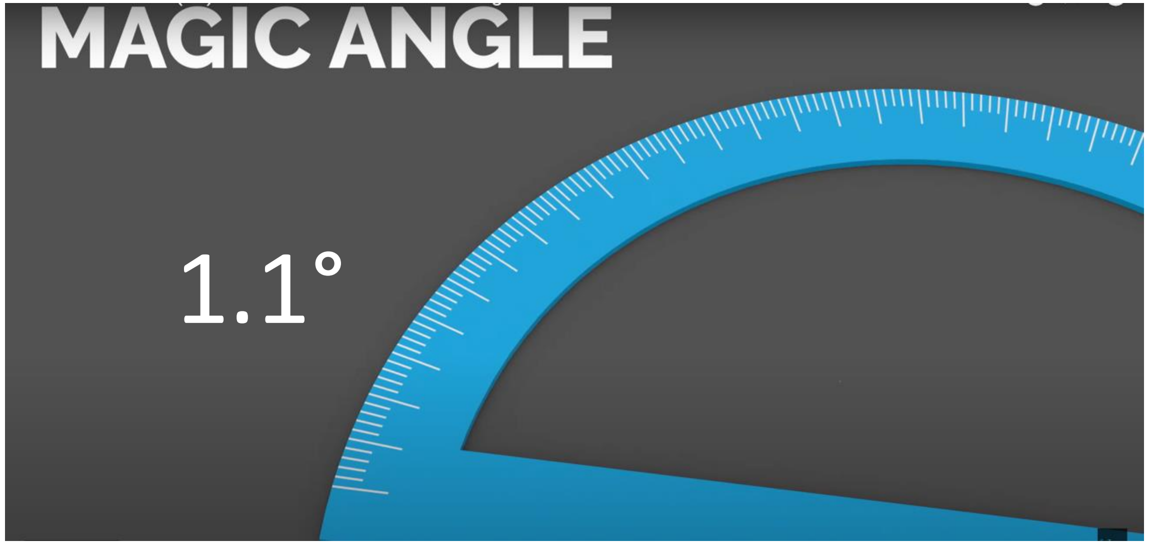


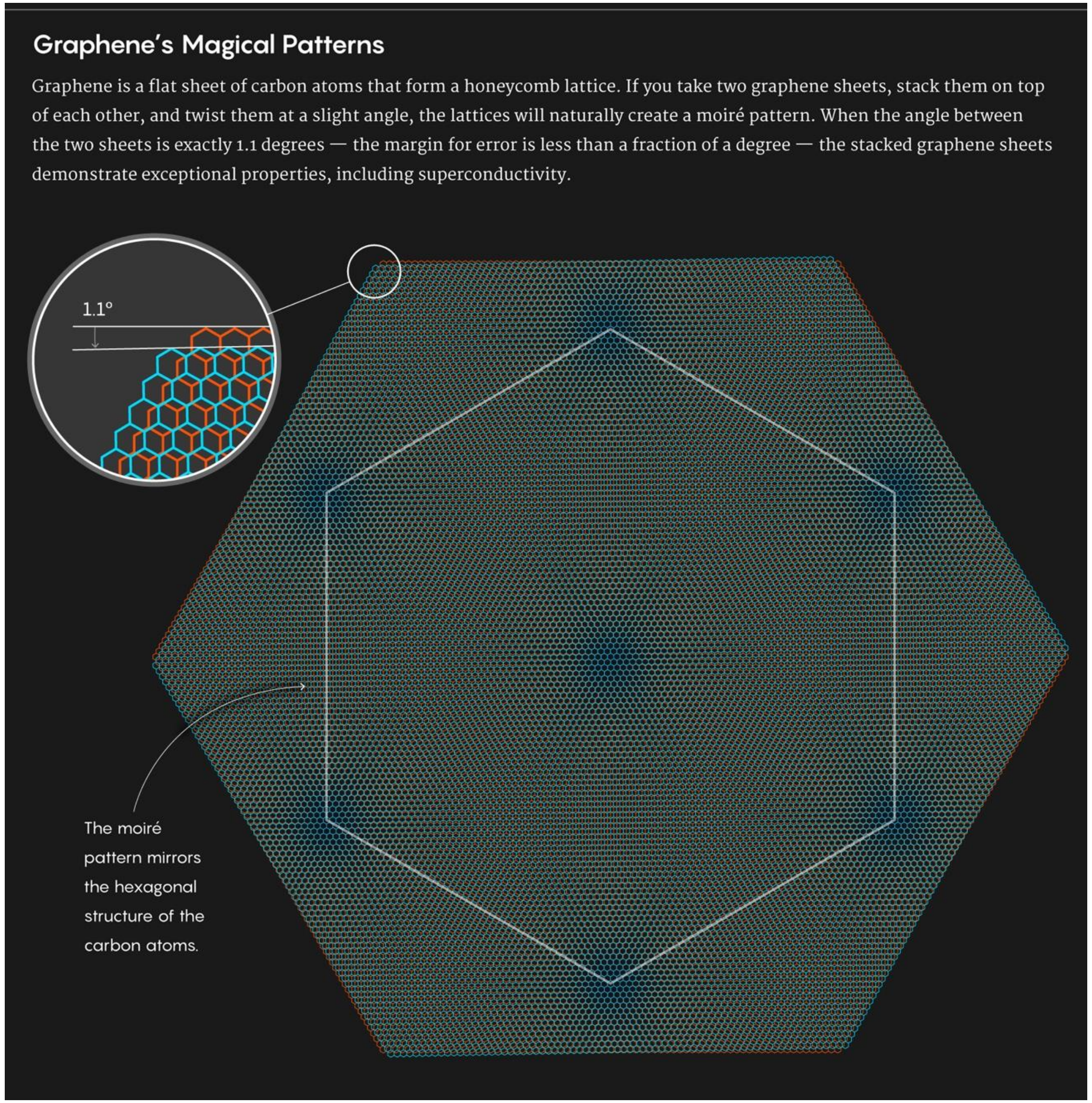
- Sequenza (ABB BAB CBCA…….)
- Deformazione (compressione/estensione)
- Campo elettrico/magnetico
- Drogaggio
- …….





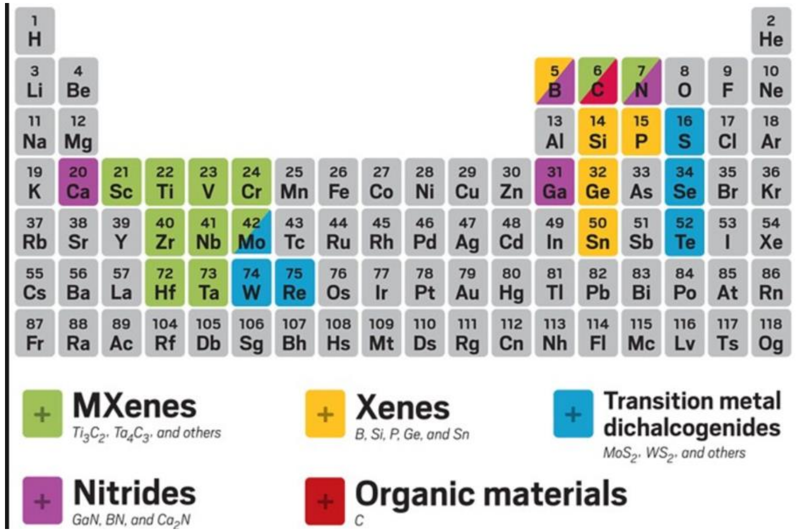


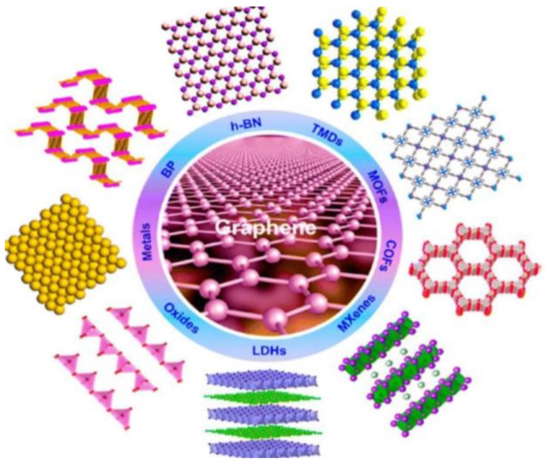


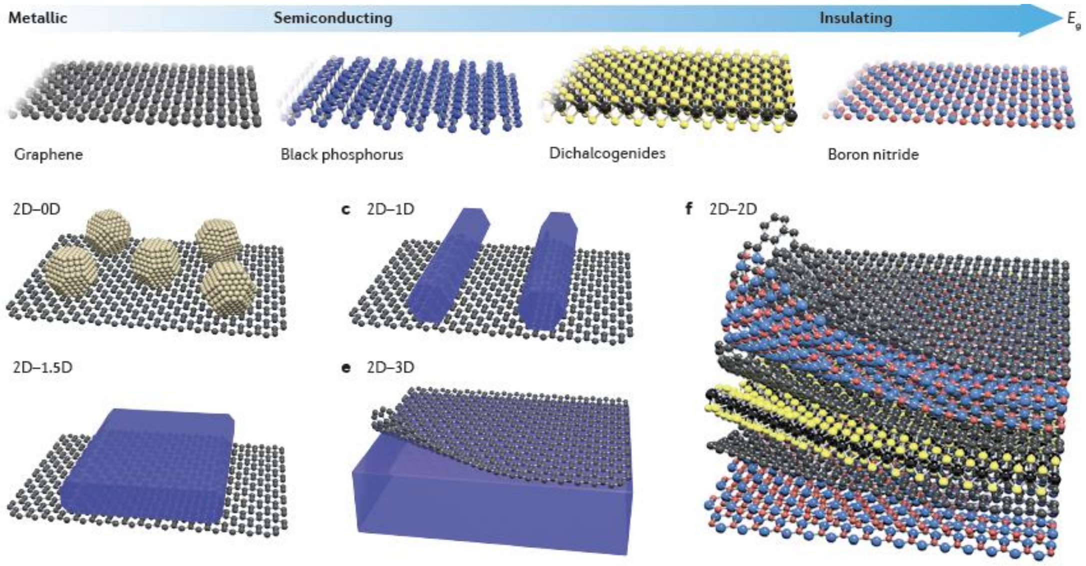


SUPERCONDUTTORE!!!!

Nuovi materiali 2D oltre al grafene







van der Waals heterostructures

In questo Dipartimento si studiano:

Graphene, Silicene, Germanene
Transition Metal Dichalcogenides
Phase Change Materials
Monochalcogenides
Hybrid layered Perovskites

Sono interessanti sia per studiare problemi fondamentali di fisica della materia condensata sia come componenti di nano-dispositivi di nuova concezione.

Fisica fondamentale: effetto Hall quantistico, superconduttività, ecc.

Molte applicazioni possibili: nanoelettronica, celle solari, LED, Sensori,

SUSTAINABLE DEVELOPMENT GOALS

https://www.un.org/sustainabledevelopment/

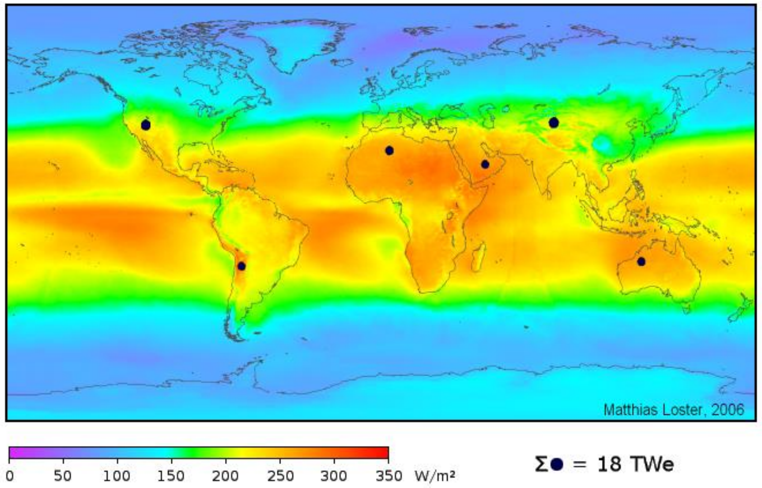
«The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including poverty, inequality, climate change, environmental degradation, peace and justice.»

17 Goals to Transform Our World

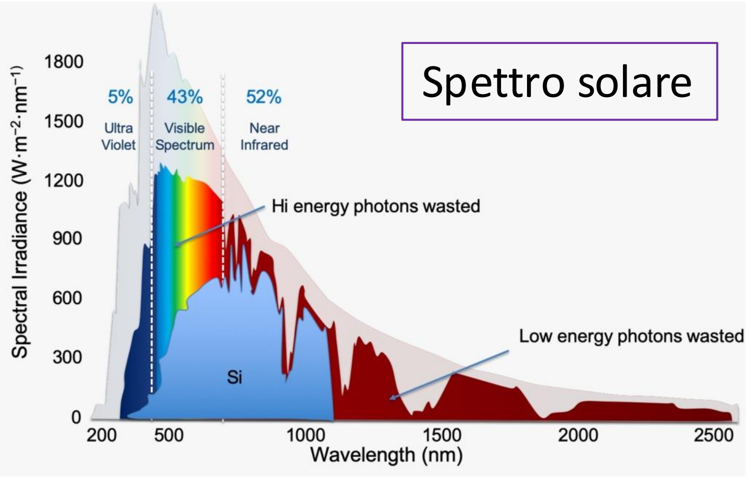
7. **Energia pulita e accessibile**
9. **Industria, Innovazione e Infrastrutture**
11. **Citta' e Comunita' sostenibili**
12. **Consumo e produzione responsabile**

ONU

Uno sguardo al fotovoltaico……

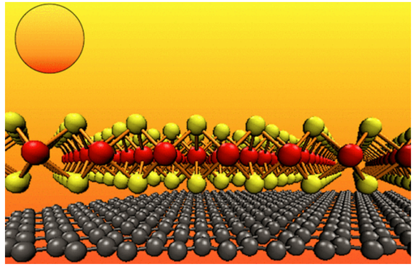


With a conversion efficiency of only 8 %, sunlight hitting the dark discs could power the whole world. The colors show a three-year average of solar irradiance, including nights and cloud coverage



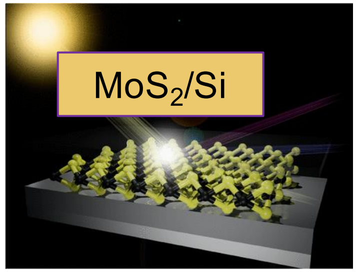
2D Materials for optoelectronics and photovoltaics

Many Transition Metal Dichalcogenides (MoS_2, $MoSe_2$,…) show a crossover from indirect to direct gap when going from bilayer to monolayer exhibiting an enhanced monolayer photo-luminescence



Extraordinary Sunlight Absorption in One Nanometer Thick Photovoltaics with 2D Materials

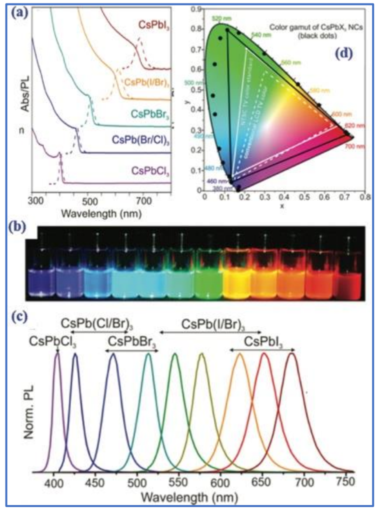
M.Bernardi, M.Palummo, J.C.Grossman, Nano Lett. 2013, **13**, 3664

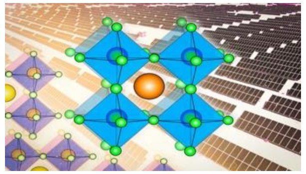


Monolayer MoS_2 Heterojunction Solar Cells

Tsai *et al. ACS Nano* 2014, **8**, 8317

Perovskites: $CsPbX_3$, (X=Cl, Br, I)

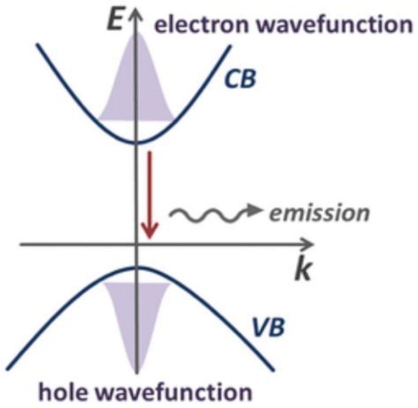


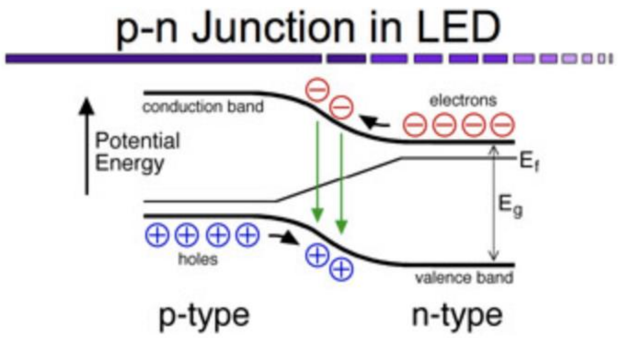


Defects tolerance → high absorption of sunlight, good conduction properties perovskite is an excellent material for solar cells and LED

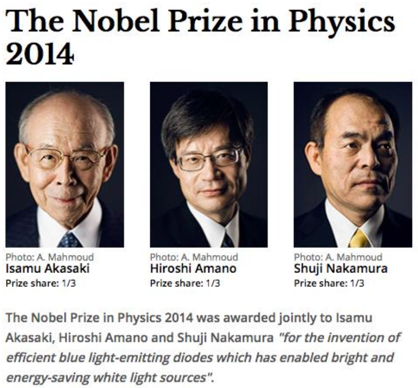
Sustainable Development

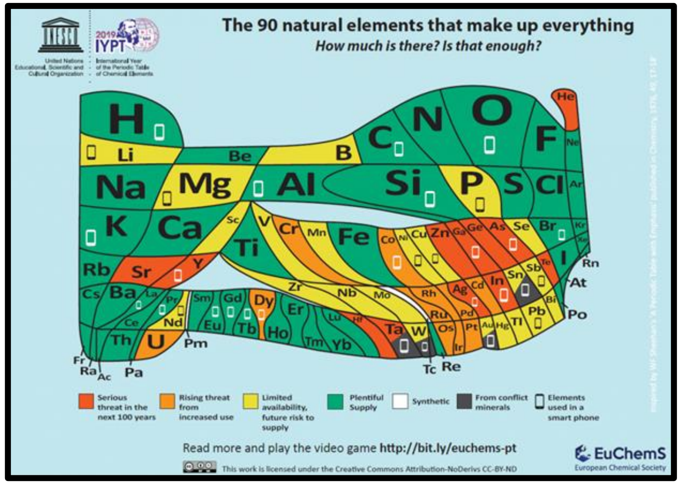
LED a luce blu basato su seminconduttore a gap diretta GaN:

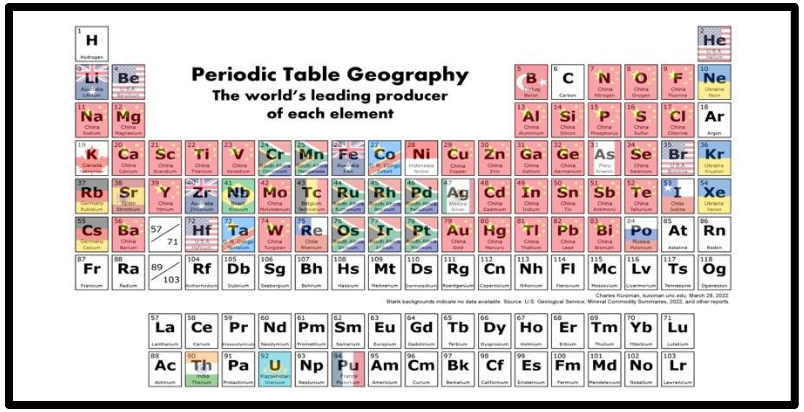




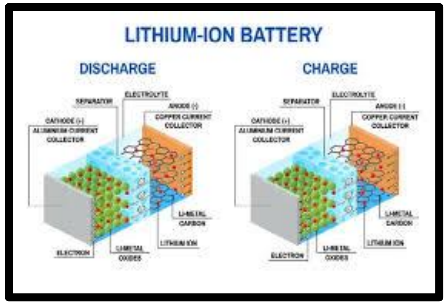
Light Emitting Diode







Novel materials for energy harvesting and storage



- Electronic Properties
- Ionic mobility in complex crystal lattices
- Thermodynamic stability of phases
- Formation of interfacial layers with liquid and solid electrolytes


Uno sguardo al futuro

A.I. NELLA FISICA DELLA MATERIA

- **Machine learning**
- **Deep learning**
- **High Throughputs**
- **AI**
- **…………**

REVIEW ARTICLE | INSIGHT
https://doi.org/10.1038/s41563-020-0777-6
nature materials
Check for updates

Machine-learned potentials for next-generation matter simulations

Pascal Friederich[1,2,3,7], Florian Häse[1,2,4,5], Jonny Proppe[1,2,8] and Alán Aspuru-Guzik[1,2,4,5,6]

"Milioni di nuovi materiali scoperti con l'intelligenza artificiale
Un salto in avanti di 800 anni"

AI tool GNoME finds 2.2 million new crystals, including 380,000 stable materials that could power future technologies

https://deepmind.google/discover/blog/millions-of-new-materials-discovered-with-deep-learning/

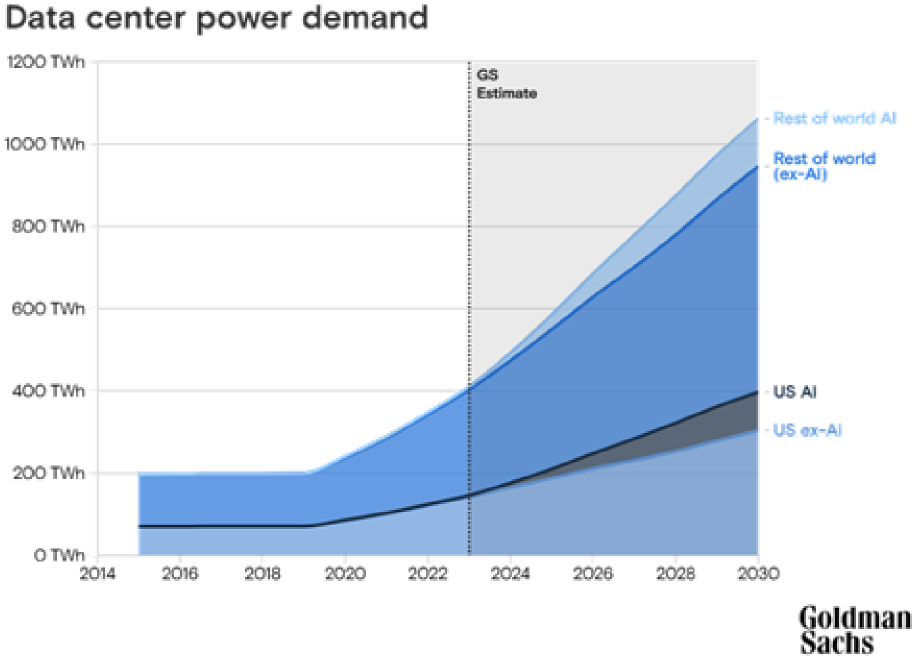
https://www.futuroprossimo.it/2023/12/lai-di-deepmind-un-salto-in-avanti-di-800-anni-nella-scienza-dei-materiali/

La (in)sostenibilita’ dell’intelligenza artificiale

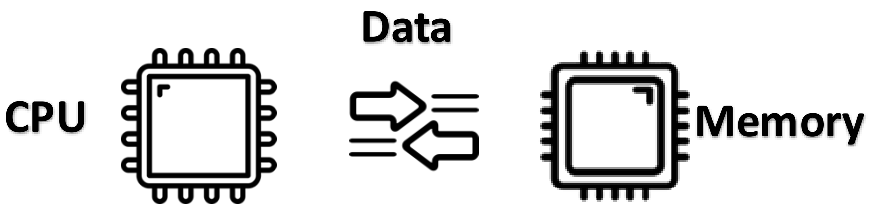
Microsoft amazon Google OpenAI

Goldman Sachs Research:
Data centres set to consume 3-4% worldwide electricity by 2030 (currently 1-2%)

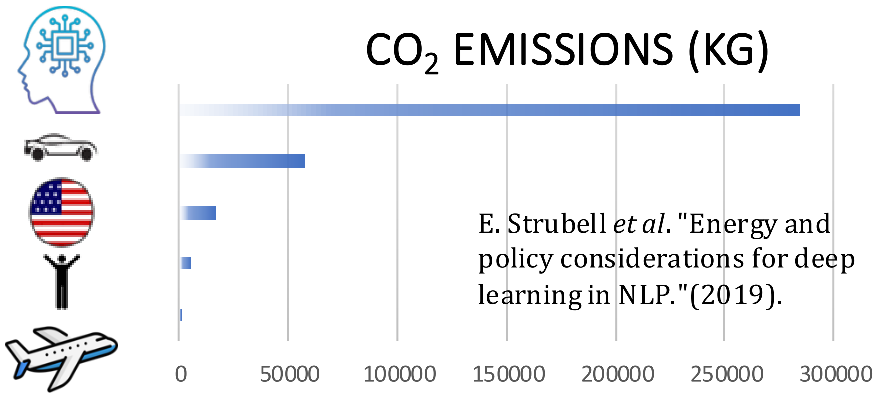
+160 %



Conventional computing



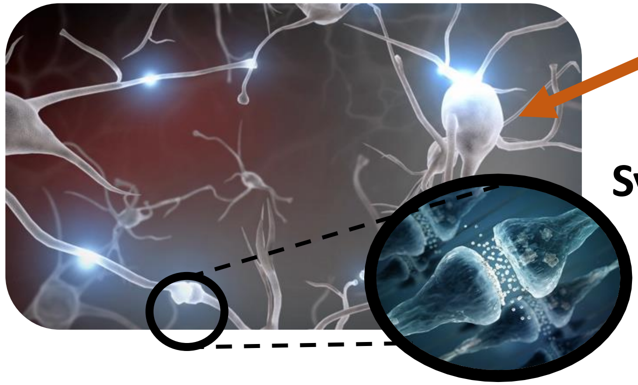
Computation and data storage in **two distinct places**

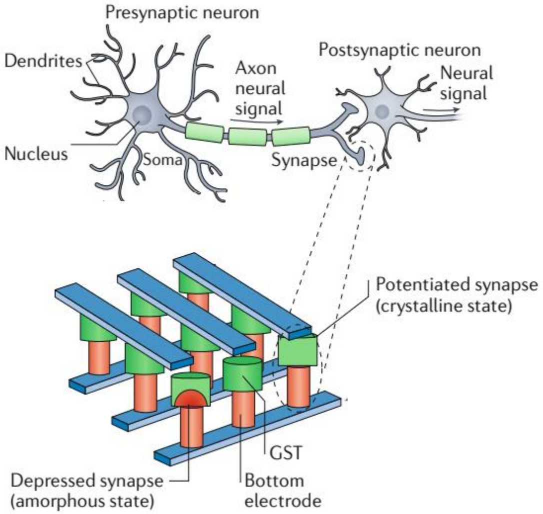


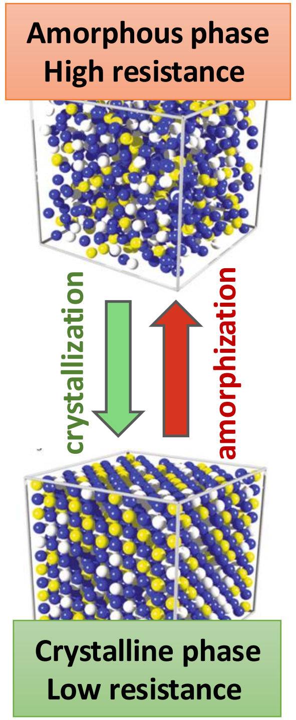
	Air travel NY SF	Human life (1p, 1 y)	American life (1 p, 1 y)	Car lifetime	State of art AI training
Emissions (Kg)	900	5000	16400	57153	284019

E. Strubell *et al.* "Energy and policy considerations for deep learning in NLP."(2019).

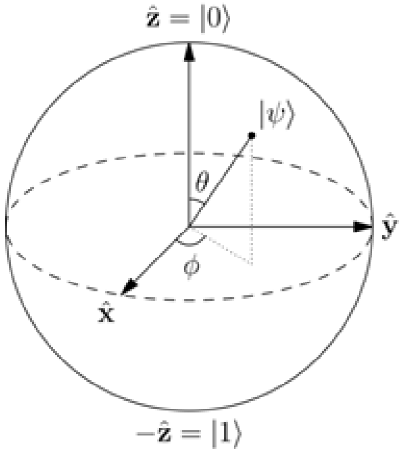
Neuromorphic computing





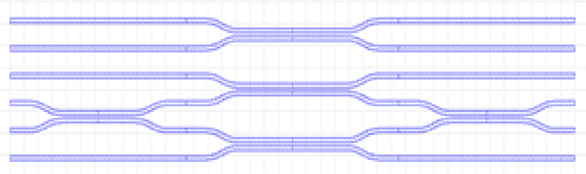


Quantum computing

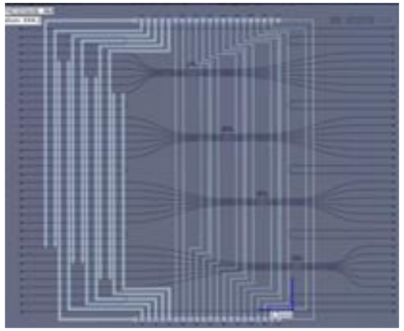


$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i\phi}\sin\frac{\theta}{2}|1\rangle$$

$$\mathrm{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$



Controlled NOT

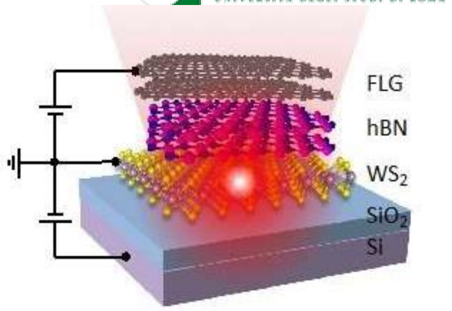


chip ottico con quattro porte CNOT

Come si articola il Curriculum

CURRICULUM IN FISICA

PIANO DI STUDI IN FISICA DELLA MATERIA *(GIÀ STRUTTURA DELLA MATERIA)*



Curriculum in Fisica – Fisica della Materia					
I Anno - I Semestre	FIS/02 - Metodi Matematici della Fisica 2	9 CFU	II Anno - I Semestre	FIS/03 - Fisica Teorica della Materia	6 CFU
	FIS/02 - Meccanica Quantistica 2	9 CFU		Esame a scelta da Elenco 1	6 CFU
	FIS/03 - Fisica Quantistica della Materia 2 *(già Struttura della Materia 2)*	6 CFU		1 Esame a scelta libera	6 CFU
Gruppo opzionale	1 Esame a scelta da Elenco 2 (FIS/05 o FIS/06)	6 CFU		Tesi	10 CFU
I Anno - II Semestre	FIS/03 - Fisica dei Solidi	6 CFU	II Anno - II Semestre	FIS/01 - Laboratorio di Fisica della Materia	8 CFU
	FIS/03 - Teoria Quantistica della Materia e Tecniche Computazionali *(già Teoria Quantistica della Materia)*	6 CFU		Tesi+Prova finale	28 CFU
	L-LIN/12 - Lingua Inglese (corso avanzato – C1)	2 CFU			
Gruppo opzionale	1 Esami a scelta - Elenco 1	6 CFU			
Gruppo opzionale	1 Esame a scelta libera	6 CFU			

INSEGNAMENTI OBBLIGATORI: 52 CFU - INSEGNAMENTI A SCELTA: 18 CFU DA ELENCO 1 E 2 - TESI: 38 CFU

INSEGNAMENTI A SCELTA LIBERA: 12 CFU (DI CUI 6 CFU POSSONO ESSERE CONSEGUITI CON UNO STAGE)

Come si articola il Curriculum

Elenco degli insegnamenti a scelta:

Elenco 1

FIS/01 - Fisica Computazionale (8 cfu)
FIS/01 - Machine Learning Methods for Physics (6 cfu)
FIS/07 - Teoria e Tecn. Computazionali per la Fisica Biologica (6 cfu)
FIS/02 - Meccanica Statistica 2 (6 cfu)
FIS/01 - Cibernetica (6 cfu)
FIS/03 - Fisica dei Dispositivi a Stato Solido (6 cfu)
FIS/03 - Fisica dei Liquidi e dei Sistemi Disordinati (6 cfu)
FIS/03 - Introduzione alla Crescita dei Cristalli (6 cfu)
FIS/03 - Materiali e Fenomeni a Bassa Temperatura (6 cfu)
FIS/03 - Microscopia e Nanoscopia (6 cfu)
BIO/10 - Biochimica (6 cfu)
FIS/03 - Fisica dei Sistemi a Bassa Dimensionalità (6 cfu)
FIS/03 - Complementi di Ottica (6 cfu)
FIS/07 - Fisica del Neutrone e Applicazioni (6 cfu)
FIS/03 - Ottica Quantistica (6 cfu)
FIS/01 – Introduzione alle Tecnologie Quantistiche (6 cfu)
FIS/04 – Nuclear Sciences and Applications (6 cfu)
FIS/01 – Elettronica Digitale (6 cfu)
FIS/02 – Meccanica Statistica ed Ottimizzazione (6 cfu)
FIS/02 - Teoria dei campi e particelle 1 (6 cfu)
FIS/03 – Materiali 2D (6 cfu)
…e altri, vedi guida dello studente

Elenco 2

FIS/05 - Modern Astrophysics (6 cfu)
FIS/05 - Relativity and Cosmology (6 cfu)
FIS/06 - Fisica dei Sistemi Dinamici (6 cfu)
FIS/05 - Big Data, Machine Learning and Astrophysical Data (6 cfu)
FIS/06 - Oceanografia Fisica (6 cfu)
FIS/06 - Chemodinamica dell'Atmosfera (6 cfu)
FIS/06 - Space Science (6 cfu)
FIS/06 - Space Weather (6 cfu)
FIS/05 - Astrobiology and Habitability (6 cfu)
FIS/05 - Planetary Sciences and Space Missions (6 cfu)
FIS/05 - Digital Data Analysis (8 cfu)
…e altri, vedi guida dello studente

Insegnamenti a Scelta Libera: consultare anche l'offerta formativa del Corso di Laurea in Scienza e Tecnologia dei Materiali (*e.g.*: Materiali Nanostrutturati per l'elettronica, Biomateriali, Elettronica organica e biologica, …)

Attività di Indirizzo

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

STAGE DI 150 ORE (attività a scelta, può sostituire l'esame a scelta libera) – 6 cfu:

- presso docenti e laboratori dell'Ateneo
- presso un laboratorio di ricerca esterno o azienda italiana
- istituzione estera

- Joint Study Agreement with IBM Research Lab (Zurich)
- Queensland University of Technology (Brisbane, Australia)

Prova finale 38 cfu: discussione di una Tesi originale su un'attività di ricerca presso gruppi di ricerca di Tor Vergata o esterni

GreenNano
Nanomaterials for Green and Digital Transitions
(Erasmus Mundus JMD)
(https://www.greenanomaster.eu/)

SBOCCHI PROFESSIONALI

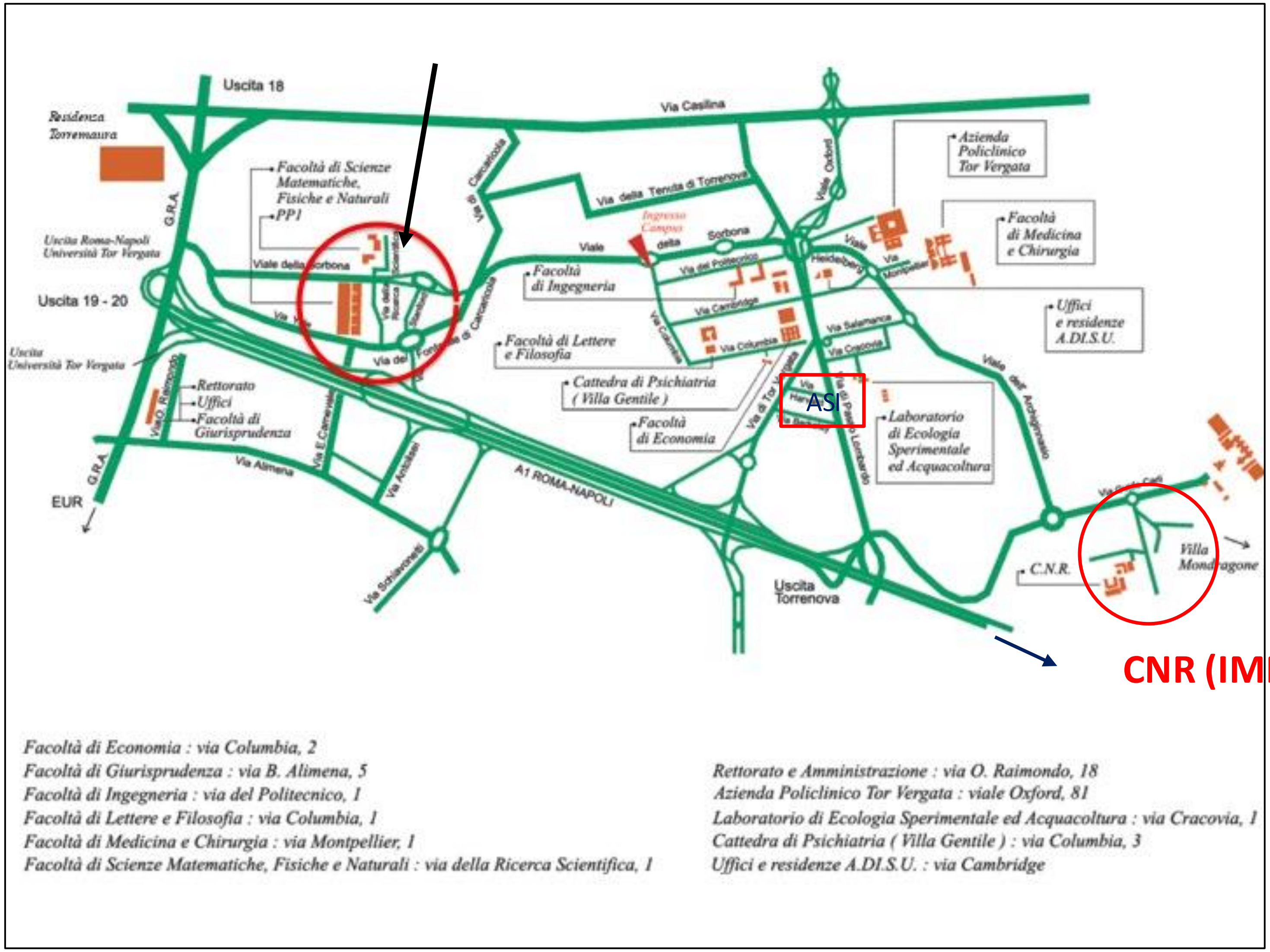
- Settore Industriale e **Mondo del Lavoro**:

- elettronica	- sviluppo di materiali
- informatica	- econofisica
- telecomunicazioni	- analisi dati
- alta tecnologia	- scuola
- energetica	

IBM Research Lab (Zurich), SIEMENS, PHILIPS, OSRAM, LEONARDO, STMicroelectronics, CICCIresearch, MICRON, LFOUNDRY, …….

Perché Tor Vergata ?

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA



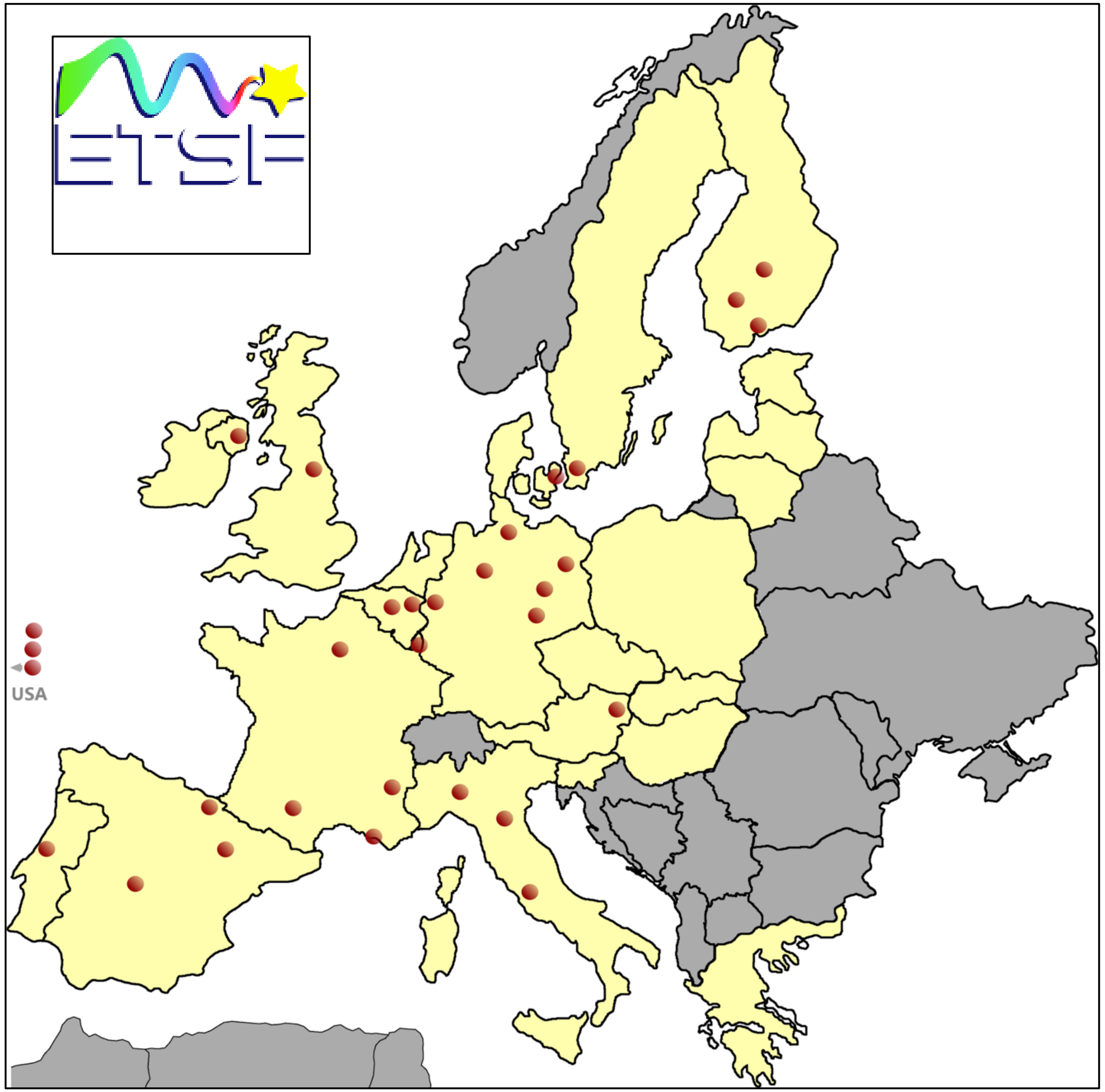
Frascati National Laboratories (INFN, ENEA)
ESA

CNR (IMM, ISM)

Stages, collaborazioni, internships,……

http://www.beforehand.eu/
2019-22

http://nano.bsu.by/disetcom/
2019-23



European Research Council
Starting Grant 2026-2031

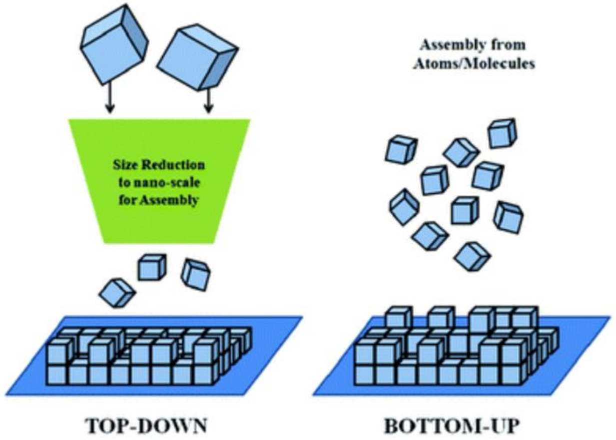
European Doctorate Network
https://times.uv.es/
2024-2027

STILES
(https://pnrr.inaf.it/progetto-stiles/stiles-programma/)

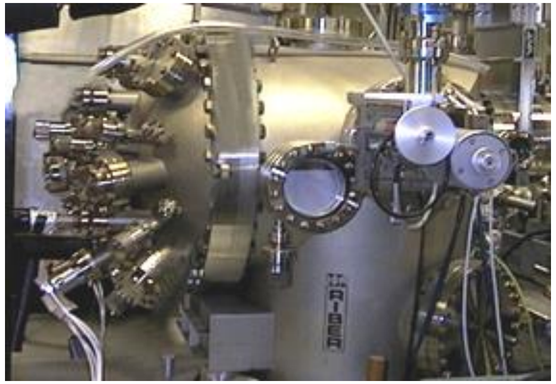
www.etsf.eu

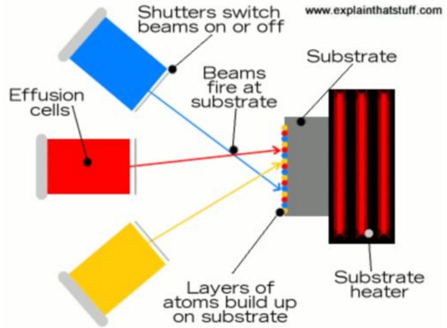
www.cecam.org

Cosa impara uno studente di fisica della materia? @esperimenti



Metodi di Crescita dei materiali



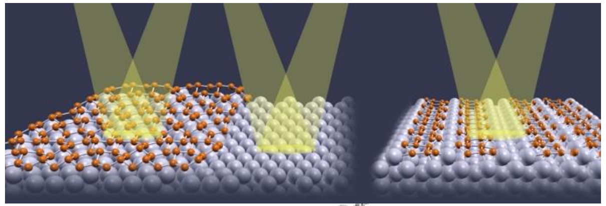


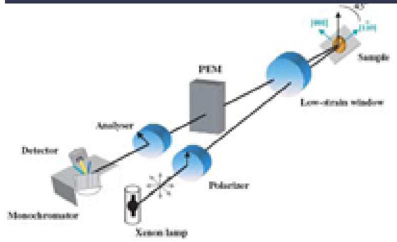
Molecular Beam Epitaxy (MBE)

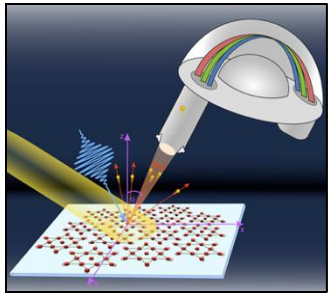
Chemical Vapor Deposition (CVD)

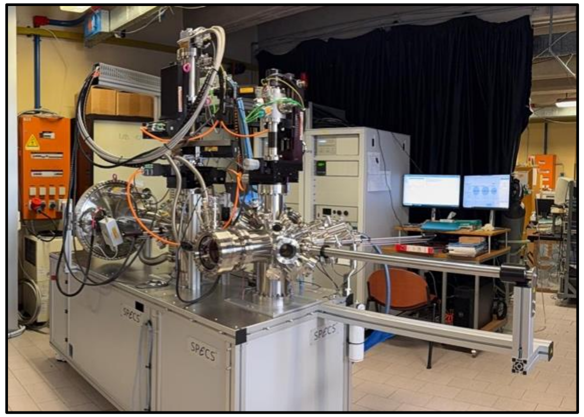
Vapor Solid Deposition (VSD)

Spettroscopie Ottiche ed Elettroniche







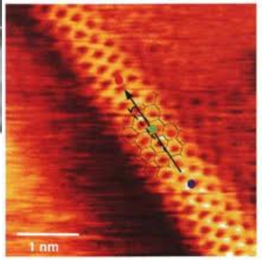


X-ray Photoemission Spectroscopy (XPS)

Microscopie a sonda (AFM, STM)

Scanning Tunneling Microscopy (STM)

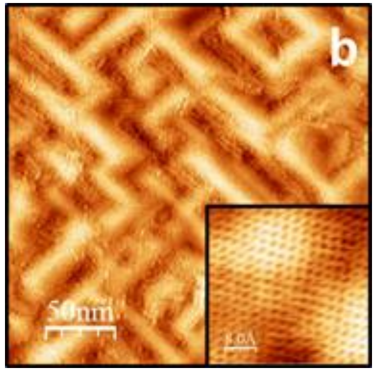
Nanotubo di Carbonio



La ricerca sperimentale @UNITOV

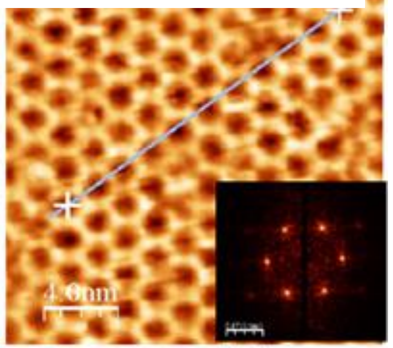
TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Growth & characterization of 2D materials & semiconductor nanostrctures



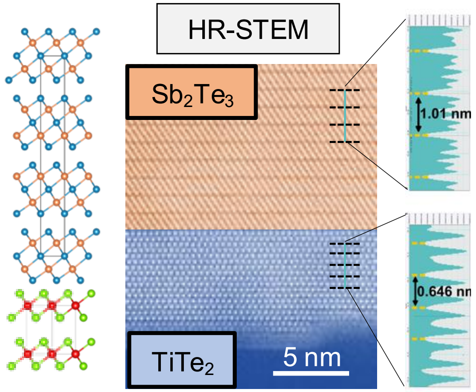
GRAPHENE /Ge(001)

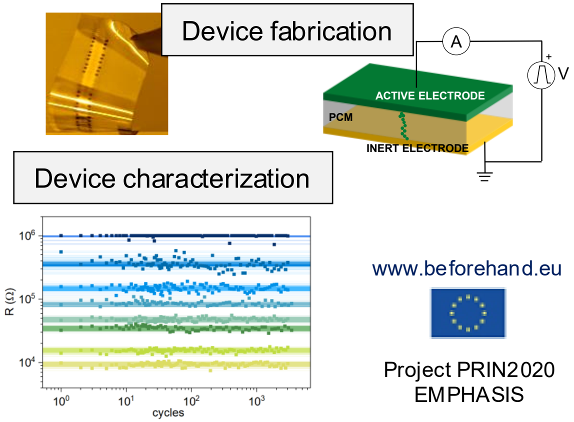
Project P2DAME 2020



Polymer of P2TANG/Au(111)

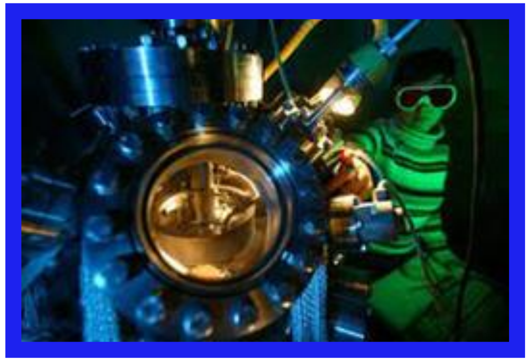
Growth, Characterization and Properties of Phase Change Material Alloys and Heterostructures for Data Storage and Neuromorphic Applications





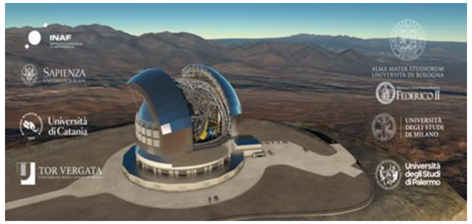
www.beforehand.eu

Project PRIN2020
EMPHASIS



A surface science approach to astrobiology:

Life on Early Earth.



Finanziato dall'Unione europea
NextGenerationEU
STILES

https://pnrr.inaf.it/progetto-stiles/

The UHV system for X ray photoemission @LHe T.

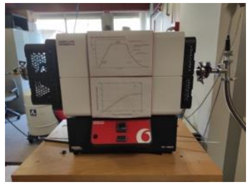
Contacts:

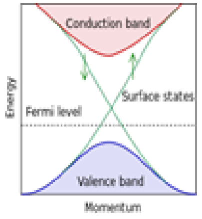
Prof. Fabrizio Arciprete
Dott.ssa Beatrice Bonanni
Dott.ssa Sabrina Calvi
Prof. Massimo Fanfoni
Dott.ssa Alessandra Filabozzi
Prof. Claudio Goletti
Prof.ssa Anna Sgarlata

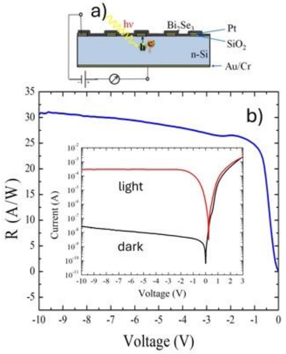
La ricerca sperimentale @UNITOV

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

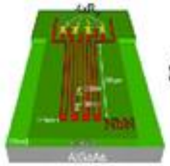
Growth, characterization & applications of topological insulators and van der Waals materials

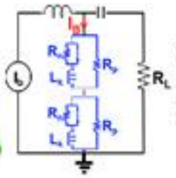


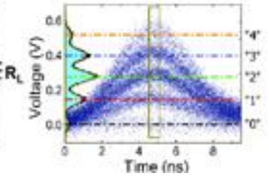




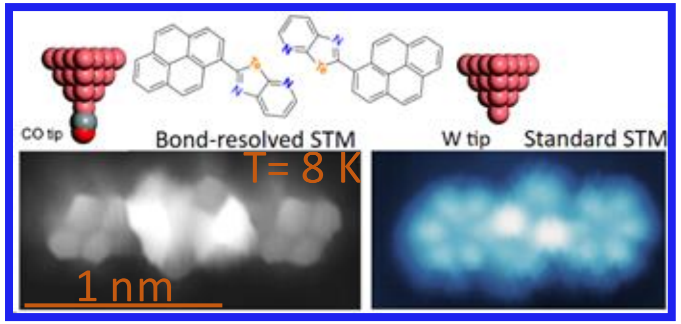
Superconductive Photon Number Resolving Detectors



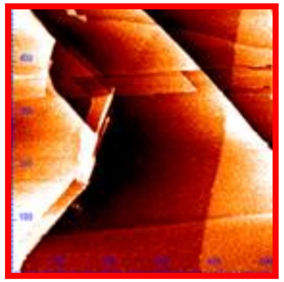




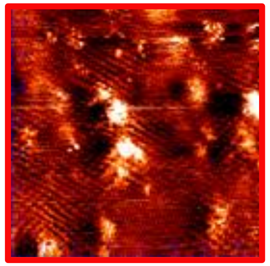
Bottom-up synthesis & electronic characterization of organic architectures by low-temperature scanning probe microscopy



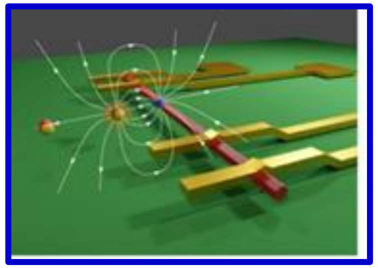
Growth and applications of 2D borophene



Project
PRIN2022
HYBORON



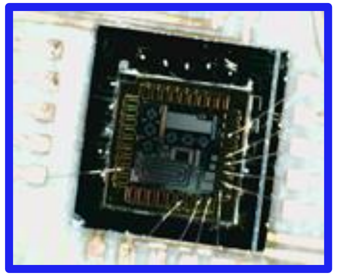
Nanodevice architectures for low-perturbation single-ion detection



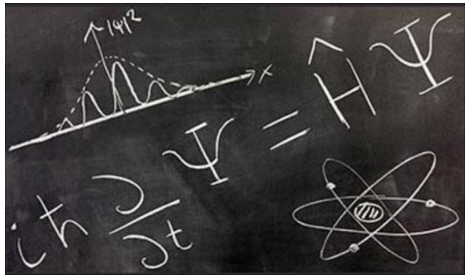
Contacts:

Prof. Luca Camilli
Prof.ssa Paola Castrucci
Prof. Matteo Cirillo
Prof. Luca Persichetti
Dott. Andrea Salamon
Prof. Matteo Salvato
Prof.ssa Manuela Scarselli

Superconductivity: topological properties of Josephson junctions, Bose-Einstein condensates



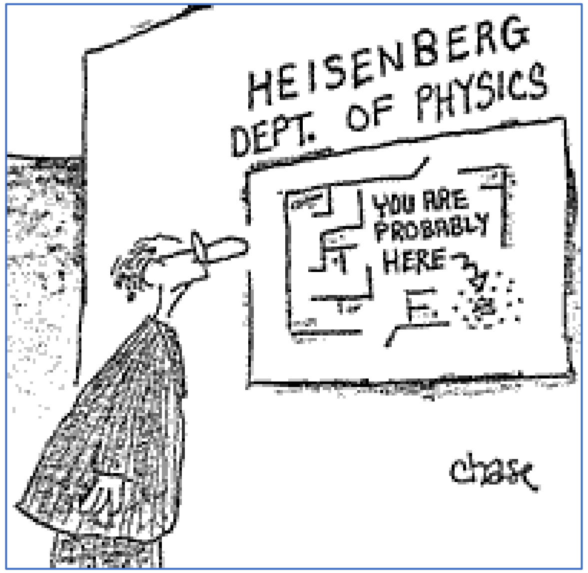
Cosa impara uno studente di fisica della materia?



$$H\Psi = E\Psi$$

@Teoria Many Body e Simulazioni

$$H = \sum_{i}^{N} \frac{\vec{p}_i^{\,2}}{2m} + \sum_{I}^{N} \frac{\vec{P}_I^{\,2}}{2M_I} - \sum_{i,I}^{N} \frac{Ze^2}{|\vec{r}_i - \vec{R}_I|} + \frac{1}{2} \sum_{i,j\, i\neq j}^{N} \frac{e^2}{|\vec{r}_i - \vec{r}_j|} + \frac{1}{2} \sum_{I,J\, I\neq J}^{N} \frac{Z_I Z_J e^2}{|\vec{R}_i - \vec{R}_j|}$$

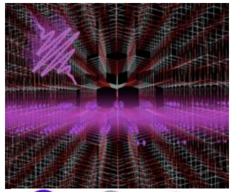


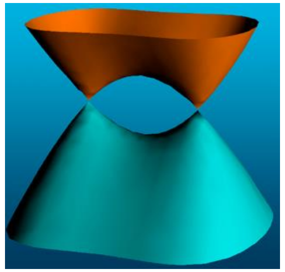
MICROSCOPIC UNDERSTANDING OF FUNDAMENTAL PROPERTIES

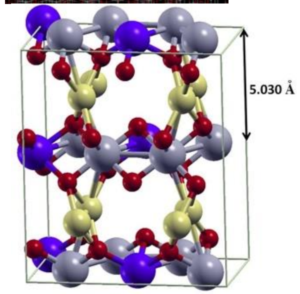
INTERPRET EXPERIMENTAL DATA

PREDICT New PROPERTIES and NEW FUNCTIONALITIES

3D Materials for electronics and optoelectronics



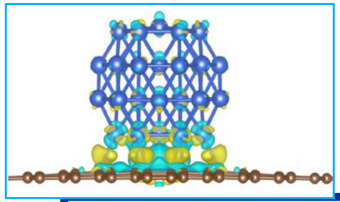




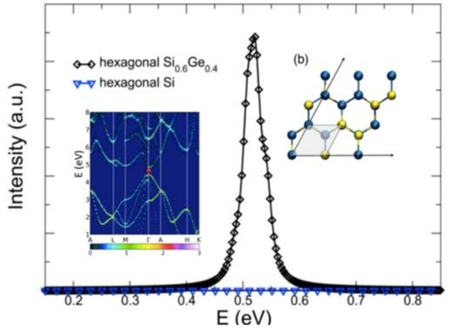
3D Dirac Materials

New generation batteries

0D:clusters, nanodots

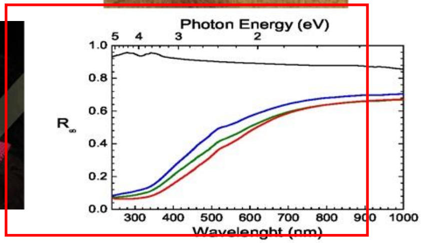


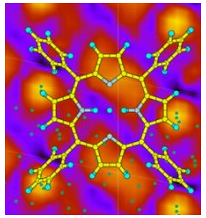
1D-materials: wires, tubes



Computational Research of new materials

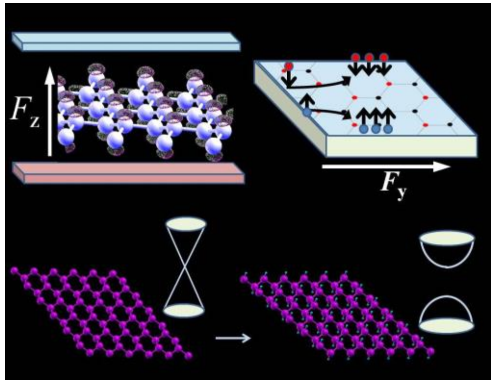
CULTURAL HERITAGE





Water, organic and biological systems

$$H\Psi = E\Psi$$

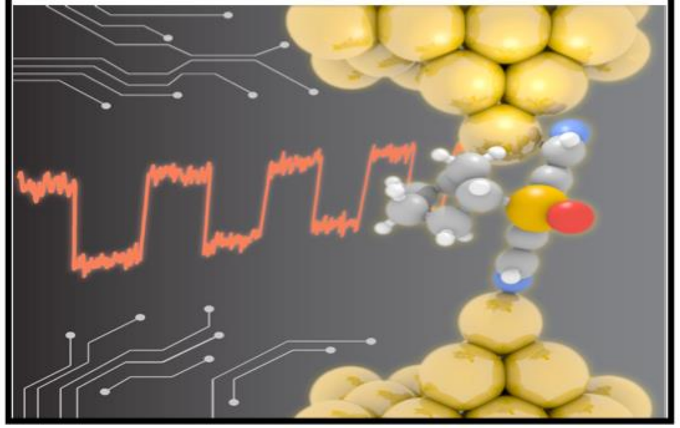


2D MATERIALS: graphene and beyond

Ab-initio theory and simulation group (Prof.ssa. O. Pulci, Prof.ssa M. Palummo, Dott. Tommaso Giovannini)

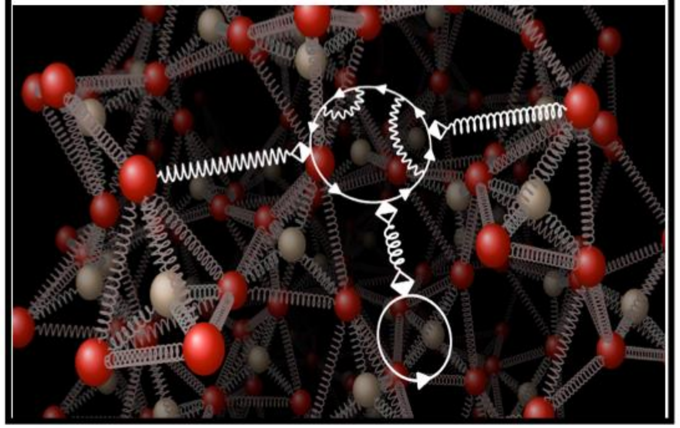
Nonequilibrium Theory and Simulations of Many-Body Quantum Systems

Molecular Electronics

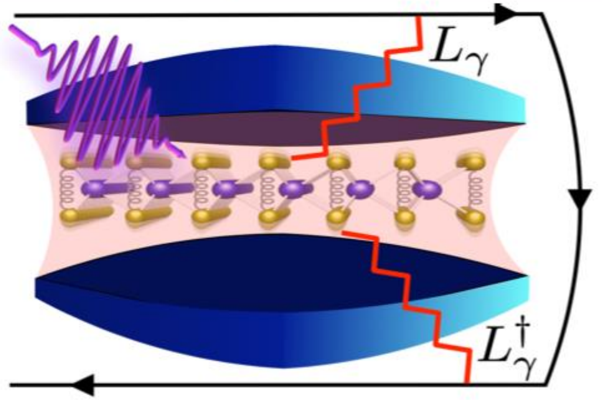


$$i\hbar \frac{d}{dt}\Psi = H\Psi$$

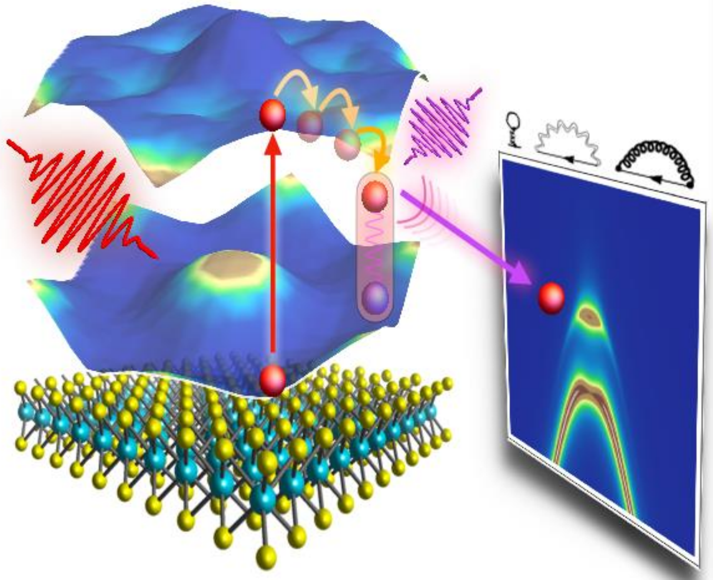
Nonequilibrium phonons



Dissipative Quantum Systems



Dynamics of Carriers and Excitons



Research on ultrafast quantum particles and their mutual interactions

Many-Body Theory Group

Contacts
Prof. Gianluca Stefanucci
Prof. Enrico Perfetto

Gruppo di Fisica della Materia
Dipartimento di Fisica
Università di Roma “Tor Vergata”

Fabrizio Arciprete – fabrizio.arciprete@roma2.infn.it
Beatrice Bonanni - beatrice.bonanni@roma2.infn.it
Sabrina Calvi - sabrina.calvi@roma2.infn.it
Luca Camilli - luca.camilli@roma2.infn.it
Paola Castrucci – paola.castrucci@roma2.infn.it
Matteo Cirillo - cirillo@uniroma2.it
Massimo Fanfoni - massimo.fanfoni@roma2.infn.it
Alessandra Filabozzi - alessandra.filabozzi@roma2.infn.it
Tommaso Giovannini – tommaso.giovannini@roma2.infn.it
Claudio Goletti – claudio.goletti@roma2.infn.it
Maurizia Palummo – maurizia.palummo@roma2.infn.it
Enrico Perfetto - enrico.perfetto@roma2.infn.it
Luca Persichetti - luca.persichetti@roma2.infn.it
Olivia Pulci - olivia.pulci@roma2.infn.it
Matteo Salvato - matteo.salvato@roma2.infn.it
Manuela Scarselli - manuela.scarselli@roma2.infn.it
Anna Sgarlata - anna.sgarlata@roma2.infn.it
Gianluca Stefanucci - gianluca.stefanucci@roma2.infn.it

WELCOME INTO
THE FUTURE!

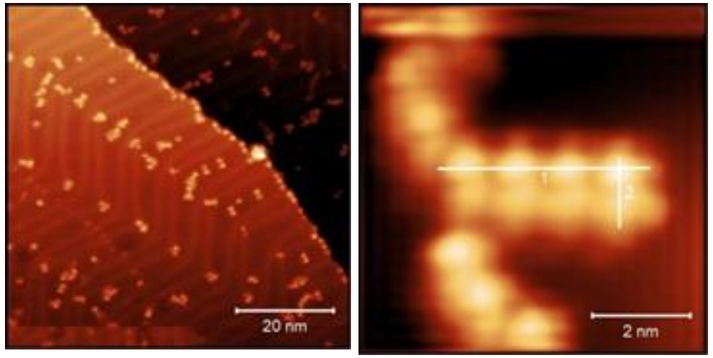
THANKS
for Coming

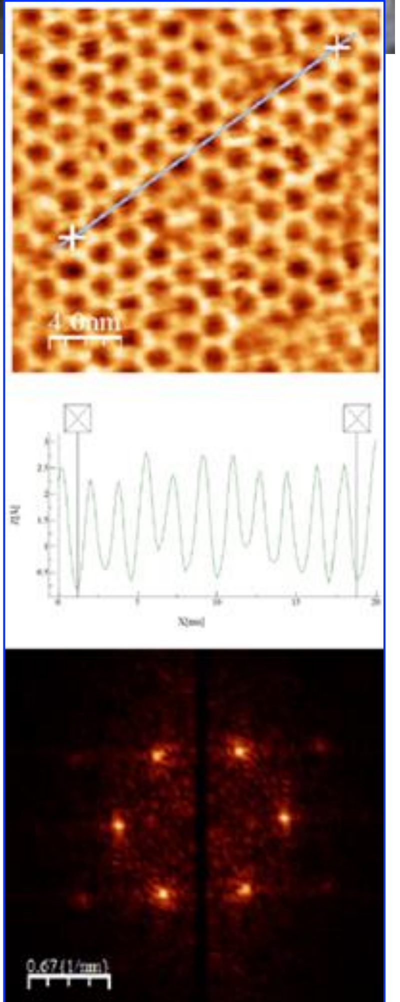
Io continuo a stupirmi.
È la sola cosa che renda la
vita degna di essere vissuta.
(Oscar Wilde)

Laboratorio NanoLab VT STM

3. PROGETTO GREEN - Growth of coRrole layErs: from propErty tuning to applicatioNs (Bando di Ateneo 2022-24) *Primissimi stadi di crescita di molecole di TioAcetilCorrolo* su Au(111)

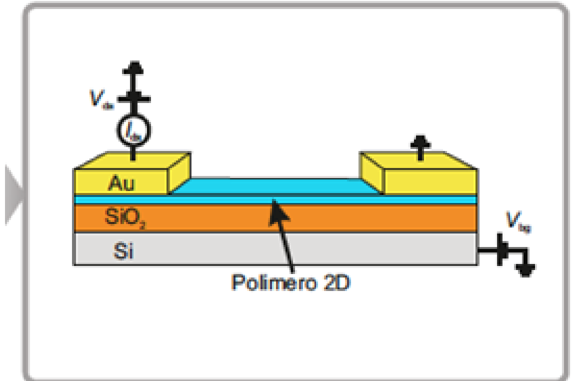
Scarselli, Sgarlata, Bonanni





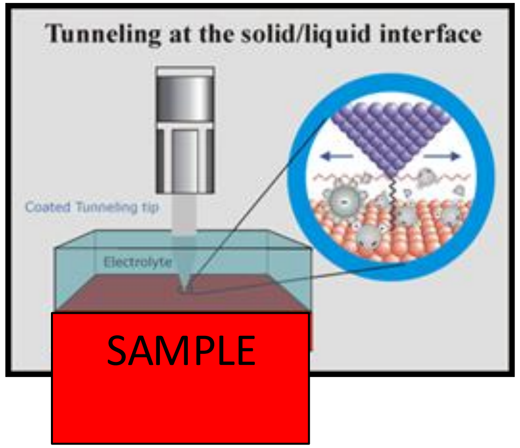
4. PROGETTO P2DAME (Bando REGIONE LAZIO) Sgarlata, Palummo Studio di un nuovo polimero semiconduttore ad alta mobilità per la realizzazione di un transistor a effetto di campo (FET). Future possibili applicazioni nel campo delle trasmissioni satellitari ed in ambito aerospaziale.

Progetto con quattro Imprese (OHB Italia, S2G-Technologies, Conser e CADMOS microsystem) del Lazio

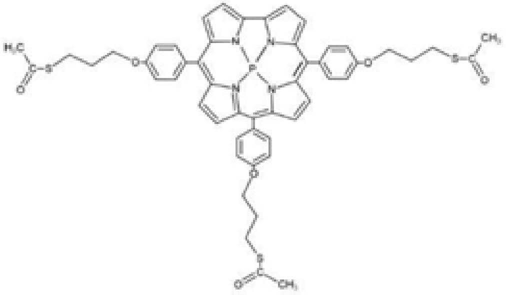


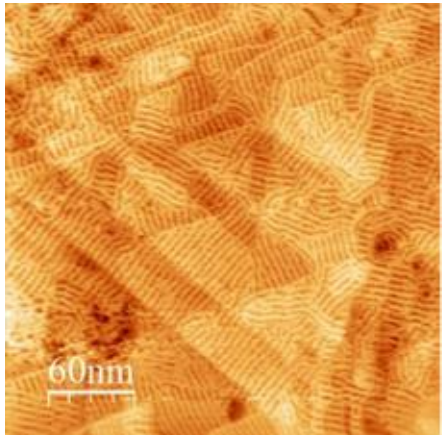
Laboratorio NanoLabSTM
Alcuni risultati recenti

(Bonanni, Goletti, Sgarlata, Fanfoni)

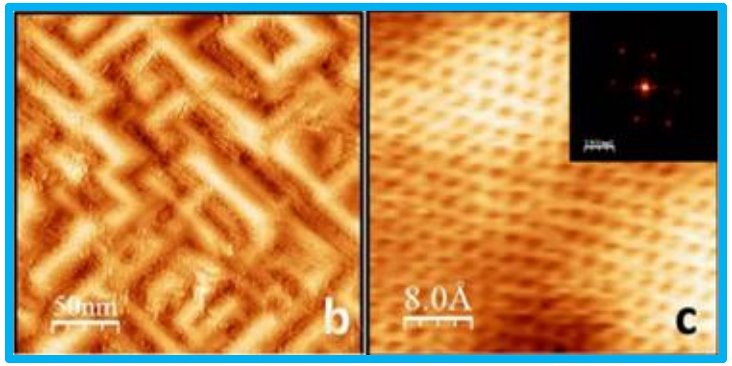


1. Studio in situ, in soluzione ed in tempo reale, della formazione di film molecolari con tecniche sperimentali di crescita e analisi statistiche (es. frattali) in figura immagine di una superficie di Au(111) dopo la deposizione di un film di corroli





2. *NanoSpettroscopia e Caratterizzazione Morfologica con Risoluzione Atomica di Materiali Bidimensionali:*
GRAFENE SU GERMANIO

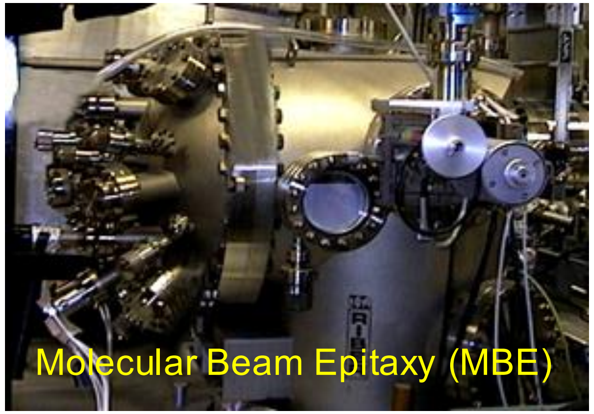


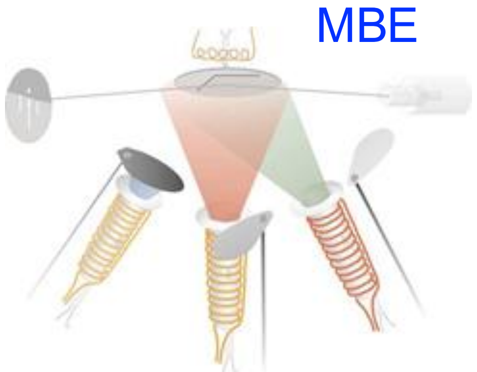
Laboratorio MBE

Molecular Beam Epitaxy Group

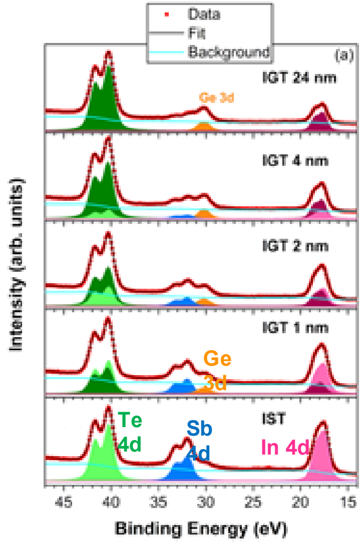
Prof. F.Arciprete, Dott.ssa S. Calvi, Dott. S. Prili, MSc. A. Diaz Fattorini, MSc. C. Petrucci

Epitaxial growth and characterization of semiconductor: engineering new materials





HREELS
UPS-XPS
LEED

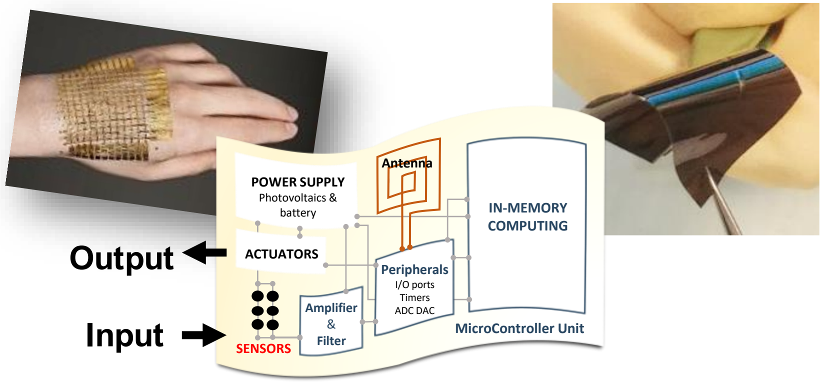


Growth of Phase Change Material: *GeTe-Sb_2Te_3* (GST) alloys and heterostructures on rigid and flexible substrates

Characterization by:

- *in situ* XPS and UPS photoemission
- Atomic Force Microscopy
- X-ray Diffraction, Raman (c/o CNR-IMM)
- Device fabrication (c/o CNR-IMM)

PCM for memory devices on flexible substrates



Selected papers:

- Scientific Reports **6**, 23843 (2016)
- Advanced Functional Materials **29**, 1805184 (2019)
- Science **374**, 1321-1322 (2021)
- Advanced Materials Interfaces **9**, 2101556 (2022)
- Advanced Science **11**, 2304785 (2024);
- ACS Applied Electronic Materials, **7**, 9320 (2025)

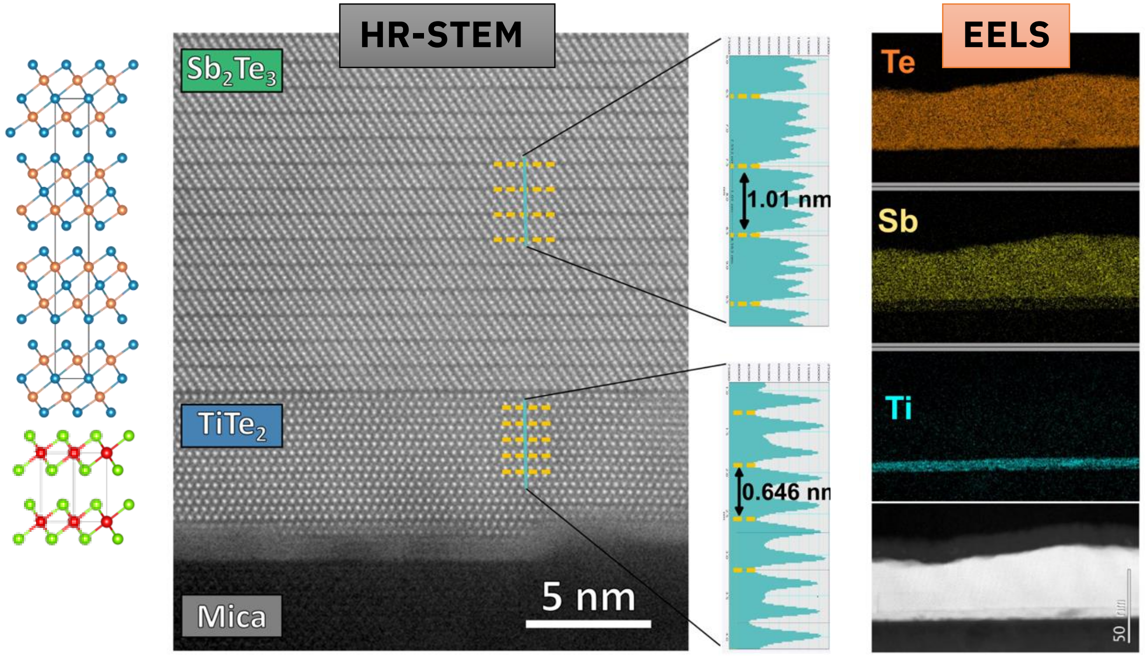
Laboratorio MBE

Prof. F.Arciprete, Dott.ssa S. Calvi, Dott. S. Prili, MSc. A. Diaz Fattorini, MSc. C. Petrucci

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

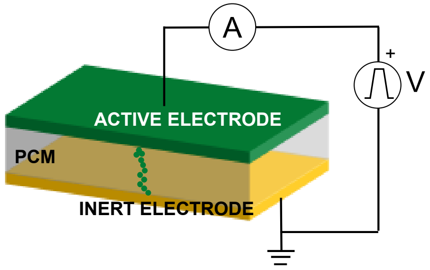
Amorphous-to-crystalline transition for Data storage and Neuromorphic applications

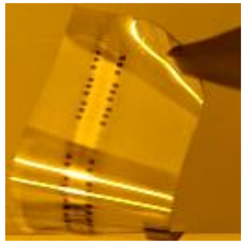
Epitaxy and investigation of interfaces in heterostructures



S. Prili *et al.* In preparation (2026)

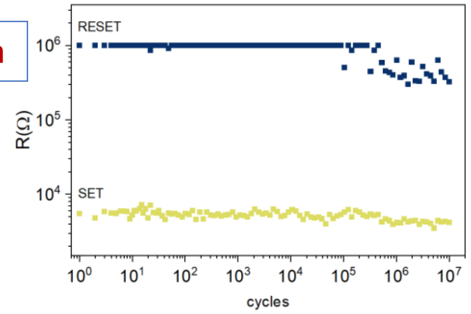
Conductive Bridge Memory Cell

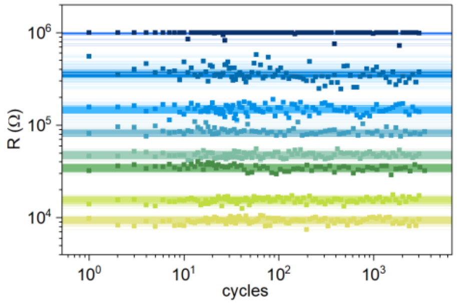




Device fabrication

Device characterization





S. Calvi *et al.*, in preparation (2026)

Exploitation of PCM analog storage capability for Neuromorphic applications (Artificial Synapses):

Project PRIN2020 – EMPHASIS - ***NE**uro**M**or**PH**ic devices b**AS**ed on chalcogen**I**de hetero**S**tructures* - funded by the Italian Ministry of University and Research **(https://sites.google.com/uniroma1.it/emphasis)**

Collaborations: IBM Research Laboratories in Zurich, Istituto di Microelettronica e Microsistemi - CNR in Rome, STMicroelectronics in Agrate Brianza (MI), Corning Research & Development Corporation in NY, USA

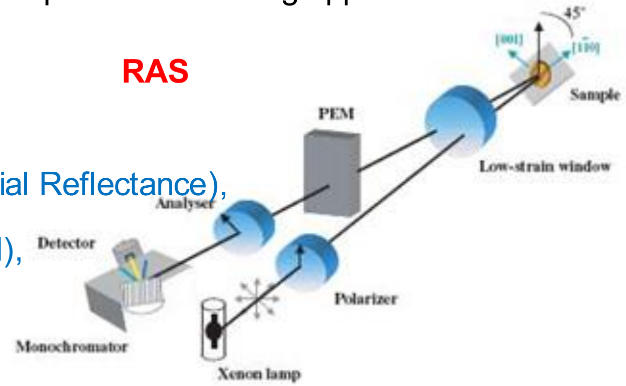
Laboratorio Fisica delle superfici

- ***SURF* Group**: ***SU**rface and inte**RF**ace in liquid and UHV*
- **MEMBERS:** Prof. C. Goletti, Dr.ssa B. Bonanni, MSc. I. Tomei

XPS chamber with
EC pre-chamber

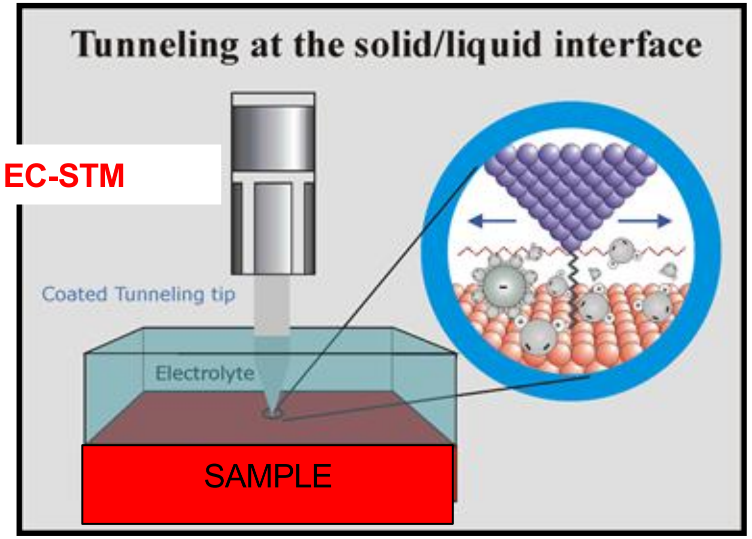
- **RESEARCH TOPICS**:
- Optical properties of surfaces in UHV and in solution
- In-situ and real-time characterization of organic layer grown by Organic Molecular Beam Epitaxy
- Scanning tunneling microscopy in solution of thin layers adsorbed/deposited on conductive substrates
- Interaction of organic layers with analytes by optical spectroscopy and Kelvin probe for sensing applications

RAS



- **TECHNIQUES**:
- Optical spectroscopy (Reflectance Anisotropy Spectroscopy, Surface Differential Reflectance),
- Scanning tunneling microscopy in UHV and in solution (ElectroChemical-STM),
- X-ray Photoemission Spectroscopy (XPS)
- LHe cryostat

EC-STM



- **Running research projects:**
- *Surfaces of ice*
- *Growth of GaAsBi alloys and of topological materials*
- *Optical and electronic properties of thin layers of corroles and porphyrins on metal surfaces in UHV*
- *Chiral organic layers for sensing applications*

Finanziato dall'Unione europea
NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

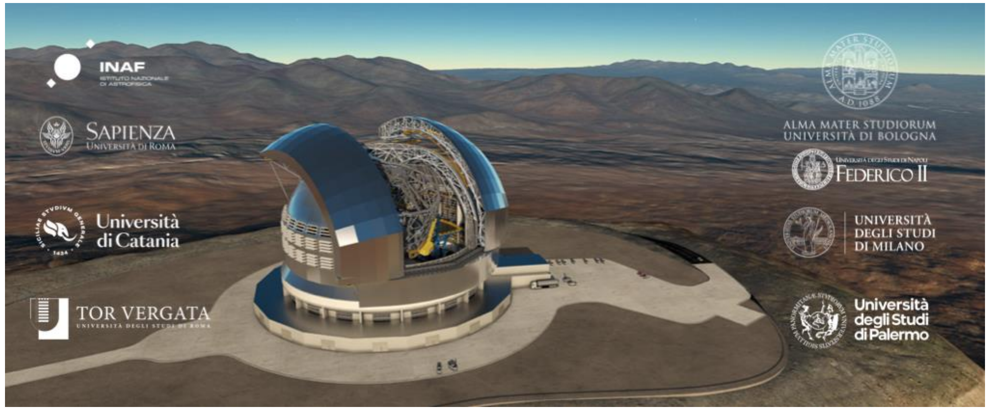
Prebiotic lab@TV

Con un finanziamento di 1.2 milioni di euro è stato attrezzato un nuovo laboratorio per l'avvio di una linea di ricerca di interesse astrobiologico: studiare (con metodi propri della Fisica delle superfici) l'evoluzione di film ultrasottili (un solo strato molecolare) di aminoacidi deposti su substrati solidi, scelti tra i minerali presenti sulla terra primordiale (3.5-4 miliardi di anni fa). Lo scopo: studiare le condizioni per le quali potrebbe essersi sviluppata la vita sulla terra.

Con spettroscopia di fotoemissione X (XPS) saranno investigate in Ultra Alto Vuoto (UHV) le reazioni tra molecole organiche su superfici di minerali (aventi proprietà catalitiche e chirali) per la formazione di composti, con evidente connessione al campo della farmaceutica e della sensoristica.

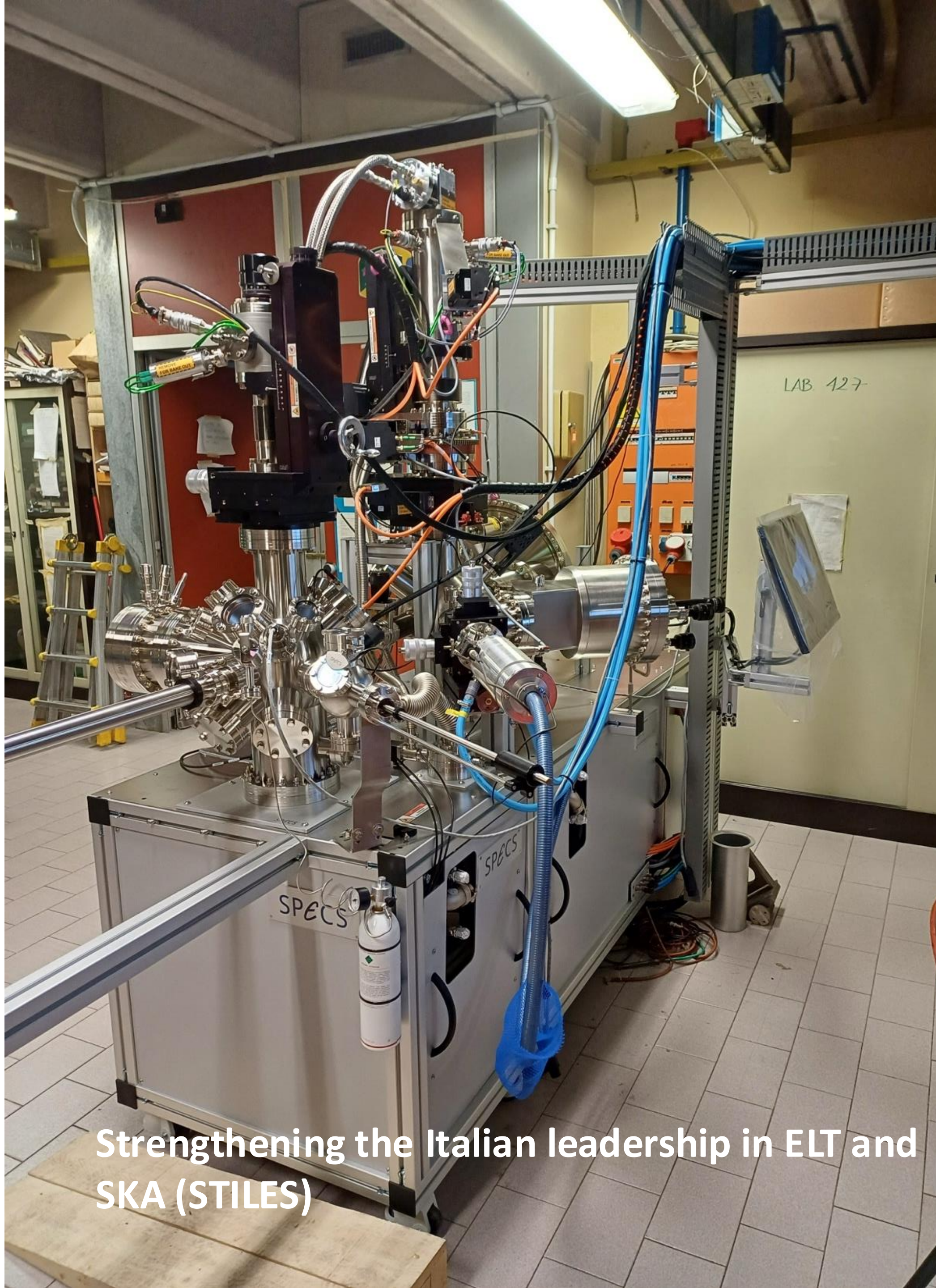
Il sistema UHV è formato da tre camere da vuoto, attrezzate con:

- Tecniche LEED, XPS, RAS, flood gun, ion sputtering, spettrometria di massa
- XPS con sorgente a doppio anodo Al/Ag e monocromatore
- Manipolatori: a 4 assi @LNT (90 K) e a 5 assi @LHe (3.5 K sul criostato)
- Sorgenti di Knudsen per evaporazione di materiali organici e biologici



<u>Progetto STILES</u>

goletti@roma2.infn.it



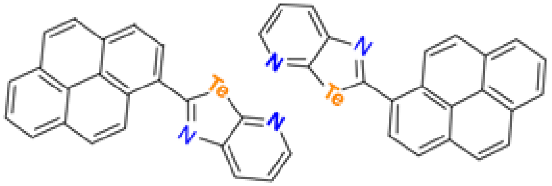
Molecules & Chemical Reactions on surfaces

Associate Prof. Luca Camilli, Prof. Luca Persichetti

Cryogen-free Low-Temperature STM, nc-AFM (T< 9K) with closed-loop helium expansion cycle

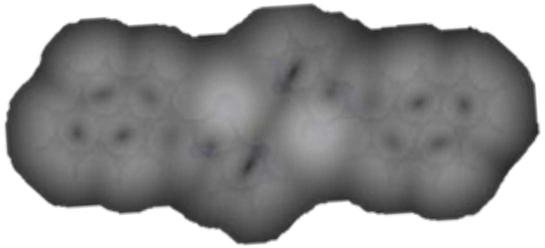
On-surface chalcogen bonds chemistry (collaboration Un. Wien)

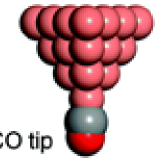
Molecular structure



DFT simulations

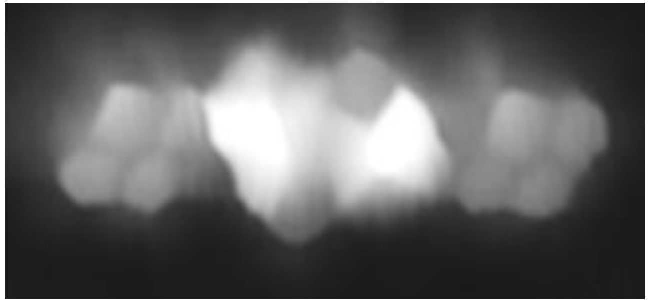
(C. Hogan, M. Palummo)





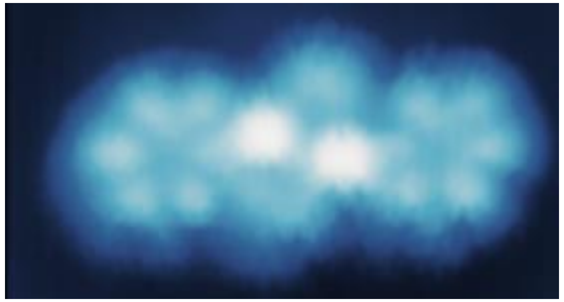
CO tip

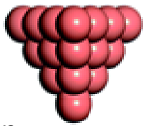
Bond-resolved STM



W tip

Standard STM



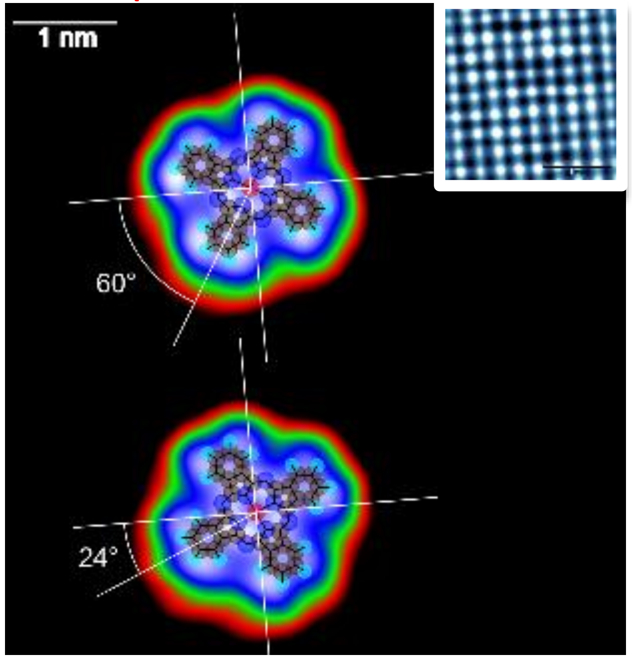


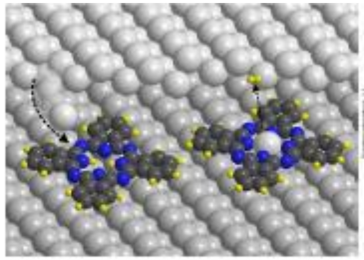
1 nm

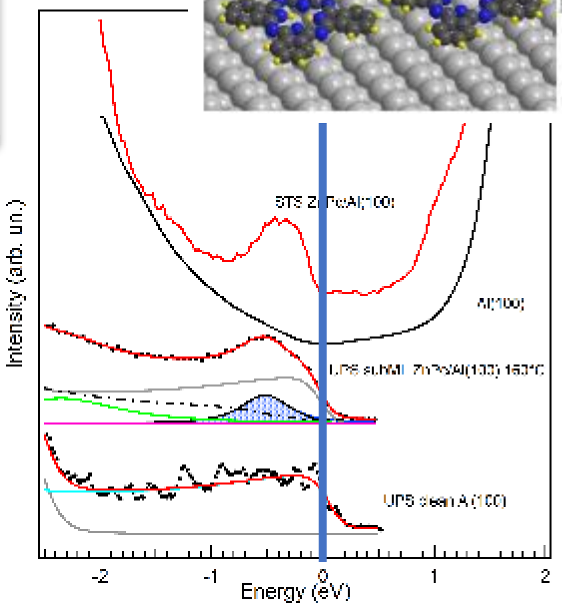
@-263 °C

Cross-metalation of ZnPc on Al(100)

(collaboration Roma Tre University)





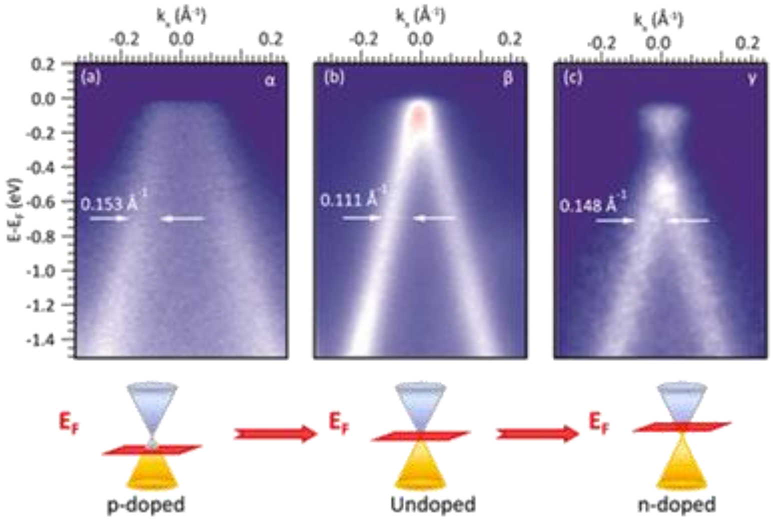


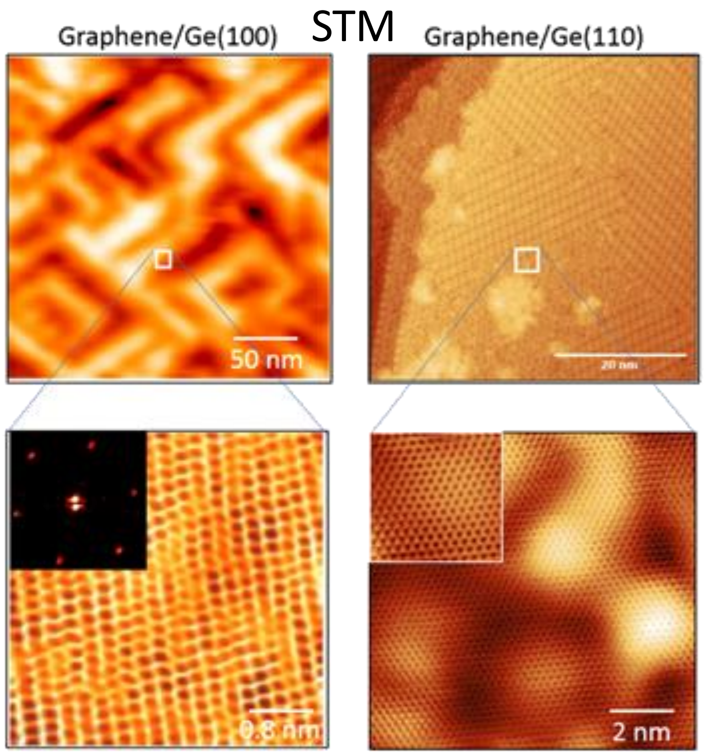
Graphene on Germanium surfaces

Associate Prof. Luca Camilli, Associate Prof. Manuela Scarselli, Prof. Luca Persichetti

(collaboration Roma Tre University & IFN-CNR)

ARPES@ ASTRID2 light source (Denmark)





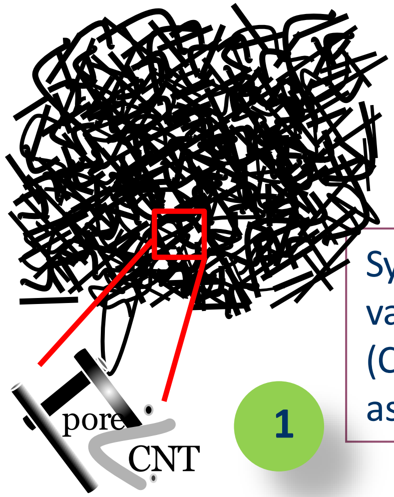
Applied Surface Science 602, 154291 (2022)
J. Phys. Chem. Letters 12, 1262 (2021)

Progetto LifePlastSens (coordinatore Luca Persichetti)
finanziato attraverso il FESR Fondo Europeo di Sviluppo Regionale – Programma Operativo regionale del Lazio, Programmazione 2014-2020, Progetti Gruppi di Ricerca 2020 – protocollo GeCoWEB n. A0375-2020-36566, CUP F85F21001660009.

Laboratorio materiali nanostrutturati e sistemi 2D

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Growth and applications of carbon nanotube (CNT) sponges



CNT-sponge

1

Synthesis from chemical vapour deposition (CVD) direct self-assembly

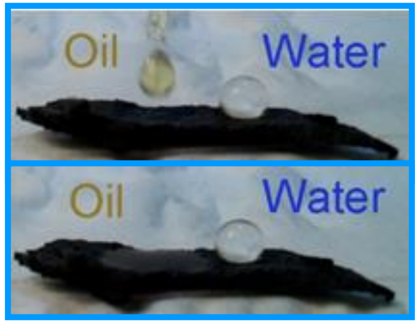
2

Mechanical response

3D ?

4

Biocompatible material



3

Hydrophobicity ⇔ olephilicity

NANOSPES= Synthetic NANOsponges vs. natural SPonges: biomimicry for sustainable management of Emerging pollutantS in water

5

e-mail: manuela.scarselli@roma2.infn.it
web page □
http://people.roma2.infn.it/~scarsel

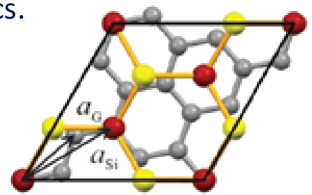
Laboratorio materiali nanostrutturati e sistemi 2D

Growth and atomic resolution characterization of 2D materials (like silicene, the Si equivalent of graphene) and topological insulators (Bi_2Se_3, Bi,…)

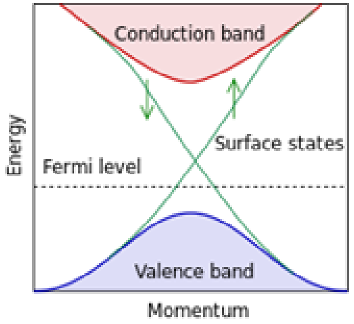
Silicene does not exist in nature, due to Si atom tendency to hybridize in the sp^3 configuration.

In our lab, we obtained silicene growth on graphite and we are studying the growth conditions to have silicene on graphene/SiC substrates.

To have silicene grown on insulating substrate is the first step for its use in electronics.



Graphene atoms (gray), silicene atoms in yellow and red

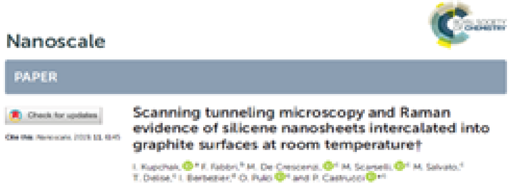


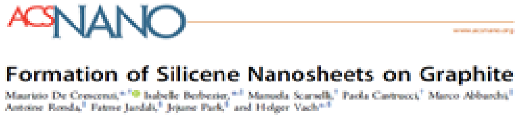
TI (Bi_2Se_3, Sb_2Te_3, Bi_2Te_3,…) represent a state of matter in which the material bulk has insulating properties while the surface hosts highly conducting states, where electrons are characterized by a Dirac-like dispersion energy.

Applications in optoelectronics, spintronics, superconductivity

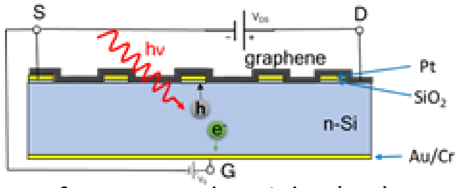

Nano Research
Research Article
Raman investigation of air-stable silicene nanosheets on an inert graphite surface


Nanoscale
ROYAL SOCIETY OF CHEMISTRY
PAPER
Stoichiometric Bi_2Se_3 topological insulator ultra-thin films obtained through a new fabrication process for optoelectronic applications


Nanoscale
ROYAL SOCIETY OF CHEMISTRY
PAPER
Scanning tunneling microscopy and Raman evidence of silicene nanosheets intercalated into graphite surfaces at room temperature


ACS NANO
Formation of Silicene Nanosheets on Graphite

Broad-band, ultra-fast photodetectors (PD) based on Grafene/Si and Bi2Se3/Si heterojunctions



PD operating at low voltages from near ultraviolet (UV) to near infrared (IR), ultra-fast (~10ns) and highly sensitive, find applications in many strategic fields from Aerospace to Security, Cultural Heritage, Medical Diagnostics. However, on the market these PDs, obtained by superimposing a PD on the Si and one on the InGaAs, are much slower, expensive and not "green" due to the presence of the As. In our lab, we change the paradigm and aim to create and optimize a PD based on the ultra-fast Graphene/Si and Bi2Se3/Si heterojunction, operating at low voltage from UV to IR, sensitivity ≥1A / W, non-toxic and cheaper


Nanoscale
ROYAL SOCIETY OF CHEMISTRY
PAPER
Stoichiometric Bi_2Se_3 topological insulator ultra-thin films obtained through a new fabrication process for optoelectronic applications

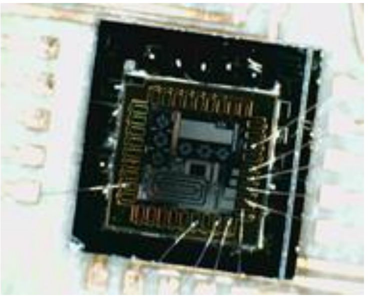

Large-area, high-responsivity, fast and broadband graphene/n-Si photodetector


Carbon
Femtosecond light pulse response of photodetectors based on Graphene/n-Si heterojunctions

Email: paola.castrucci@roma2.infn.it
matteo.salvato@roma2.infn.it

Laboratorio Superconduttività

La ricerca sulla superconduttività @UNITOV
Realization and characterization of thin films and superconductors for coatings, photovoltaics, sensors, CNT's and superconductor based devices in the field of energy efficiency, energy production, detectors and Bose Einstein Condensation



(Superconductivity lab: Prof. M. Cirillo, Dott. V. Merlo)

Es. Interferometri Josephson: studio dell'andamento della corrente in funzione del flusso applicato in un parallelo di un certo numero di giunzioni Josephson

APPLIED PHYSICS LETTERS 113, 192601 (2018)

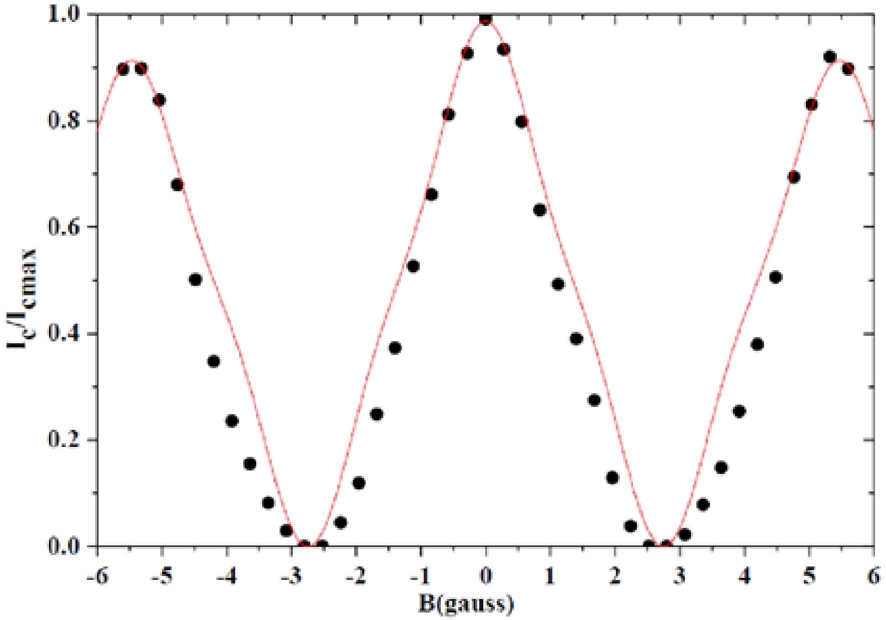
Engineering quantum interference

M. Lucci,[1] V. Merlo,[1] I. Ottaviani,[1] M. Cirillo,[1,a)] D. Badoni,[2] V. Campanari,[2] G. Salina,[2] J. G. Caputo,[3] and L. Loukitch[3]
[1]*Dipartimento di Fisica and MINAS Lab Università di Roma "Tor Vergata," 00133 Roma, Italy*
[2]*Istituto Nazionale di Fisica Nucleare, Sezione di Roma "Tor Vergata" Via della Ricerca Scientifica 1, 00133 Roma, Italy*
[3]*Laboratoire de Mathématiques, INSA de Rouen, Avenue de l'Université, F-76801 Saint-Etienne du Rouvray, France*

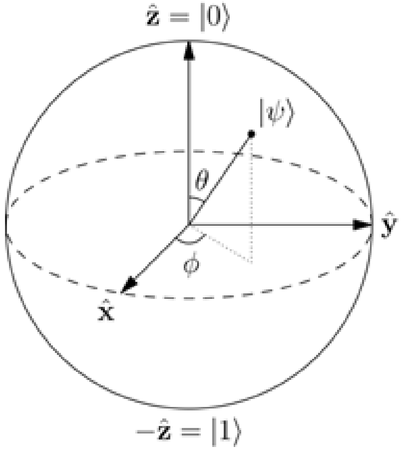
(Received 15 September 2018; accepted 25 October 2018; published online 8 November 2018)

A model for describing the interference and diffraction of wave functions of one-dimensional Josephson array interferometers is presented. The derived expression for critical current modulations accounts for an arbitrary number of square junctions, the variable distance between these, and the variable size of their area. Predictions are tested on real arrays containing up to 20 equally spaced and identical junctions and on arrays shaped with peculiar geometries. A very good agreement with the modulations predicted by the model and the experimental results is obtained for all the tested configurations. It is shown that specific designs of the arrays generate significant differences in their static and dynamical (non-zero voltage) properties. The results demonstrate that the magnetic field dependence of Josephson supercurrents shows how interference and diffraction of macroscopic quantum wavefunctions can be manipulated and controlled. *Published by AIP Publishing.*
https://doi.org/10.1063/1.5057767

http://superlab.roma2.infn.it



TECNOLOGIE QUANTISTICHE: QUANTUM INFORMATION WITH PHOTONS

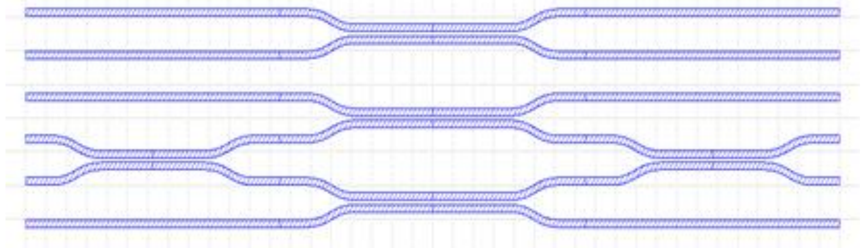


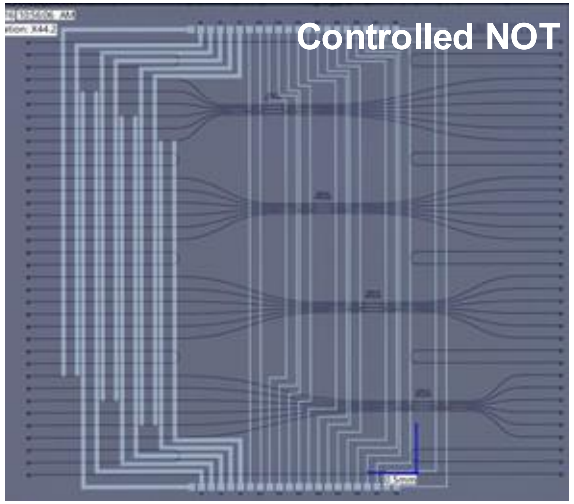
$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i\phi}\sin\frac{\theta}{2}|1\rangle$$

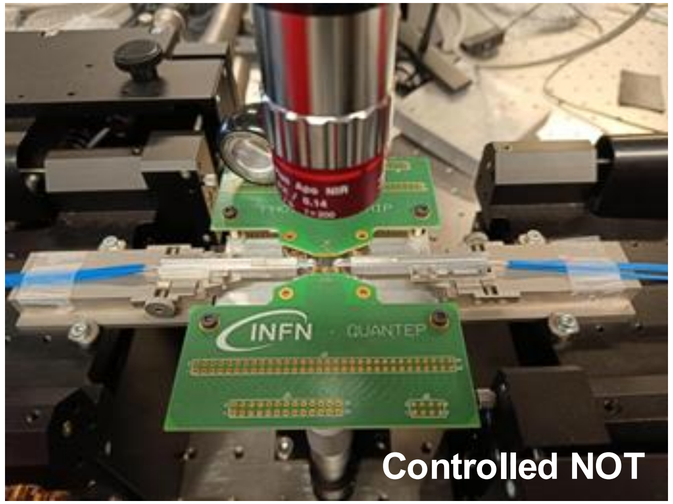
$$\mathrm{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

- Fotonica integrata (SOI, SiN, $LiNbO_3$)
- Quantum Computing (with Linear Optics)
- Quantum Key Distribution
- Single Photon Detector (Bi_2Se_3)
- Photon Number Resolving Detector (NbN)

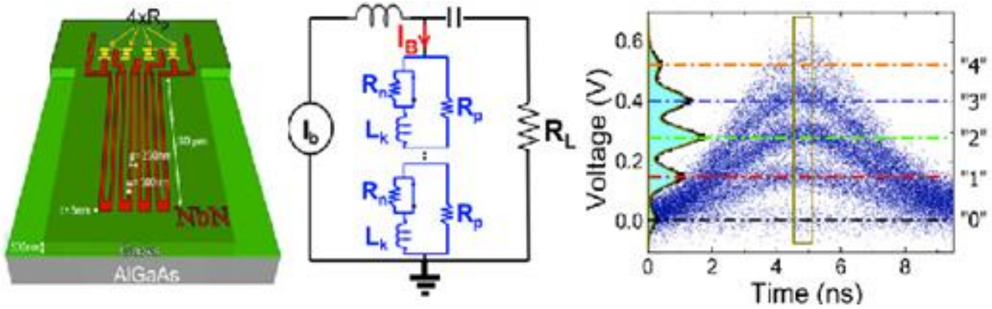
Controlled NOT







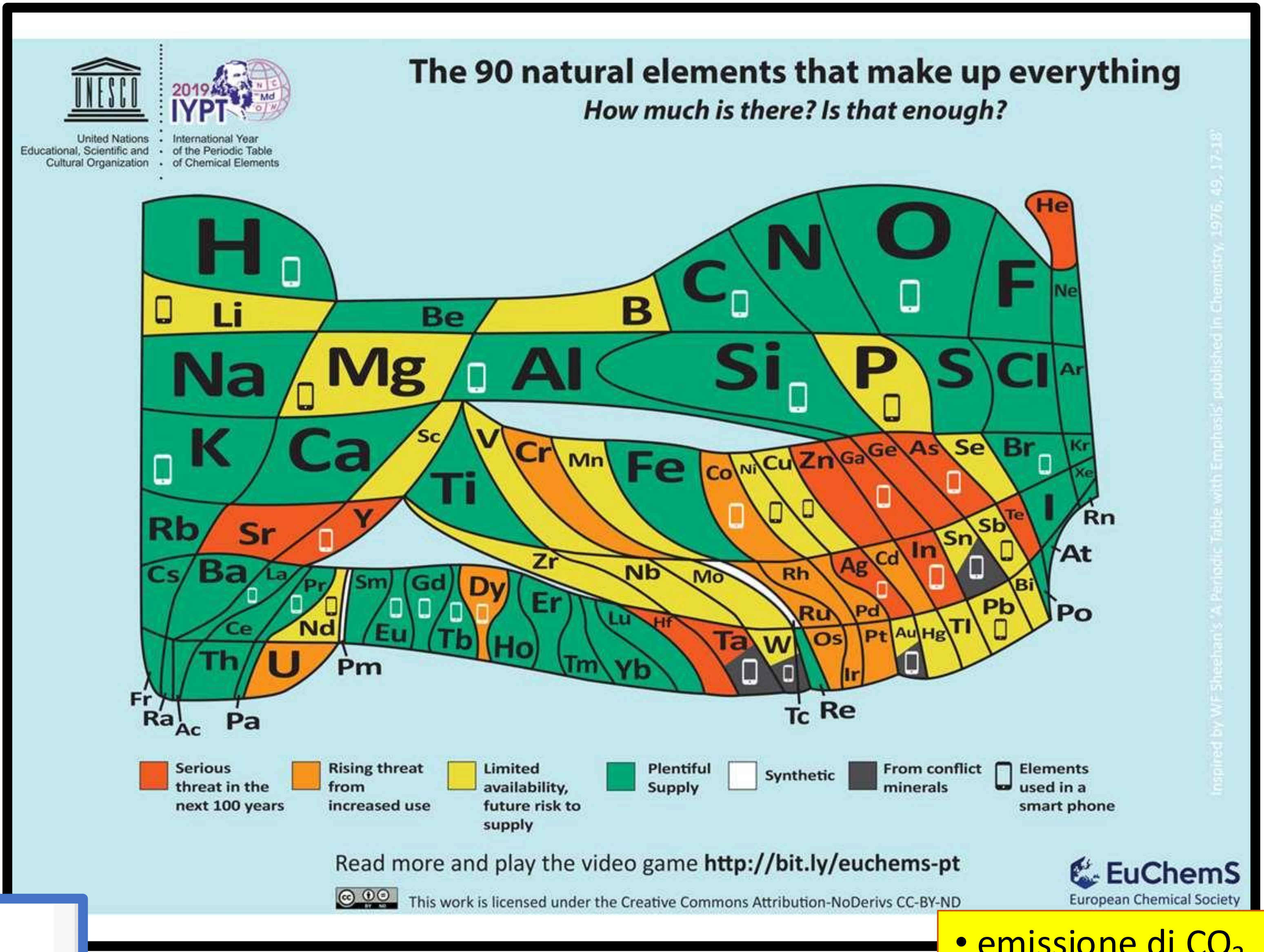
Superconductive Photon Number Resolving Detectors



Contatti

andrea.salamon@roma2.infn.it
fabio.dematteis@roma2.infn.it
matteo.salvato@roma2.infn.it

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

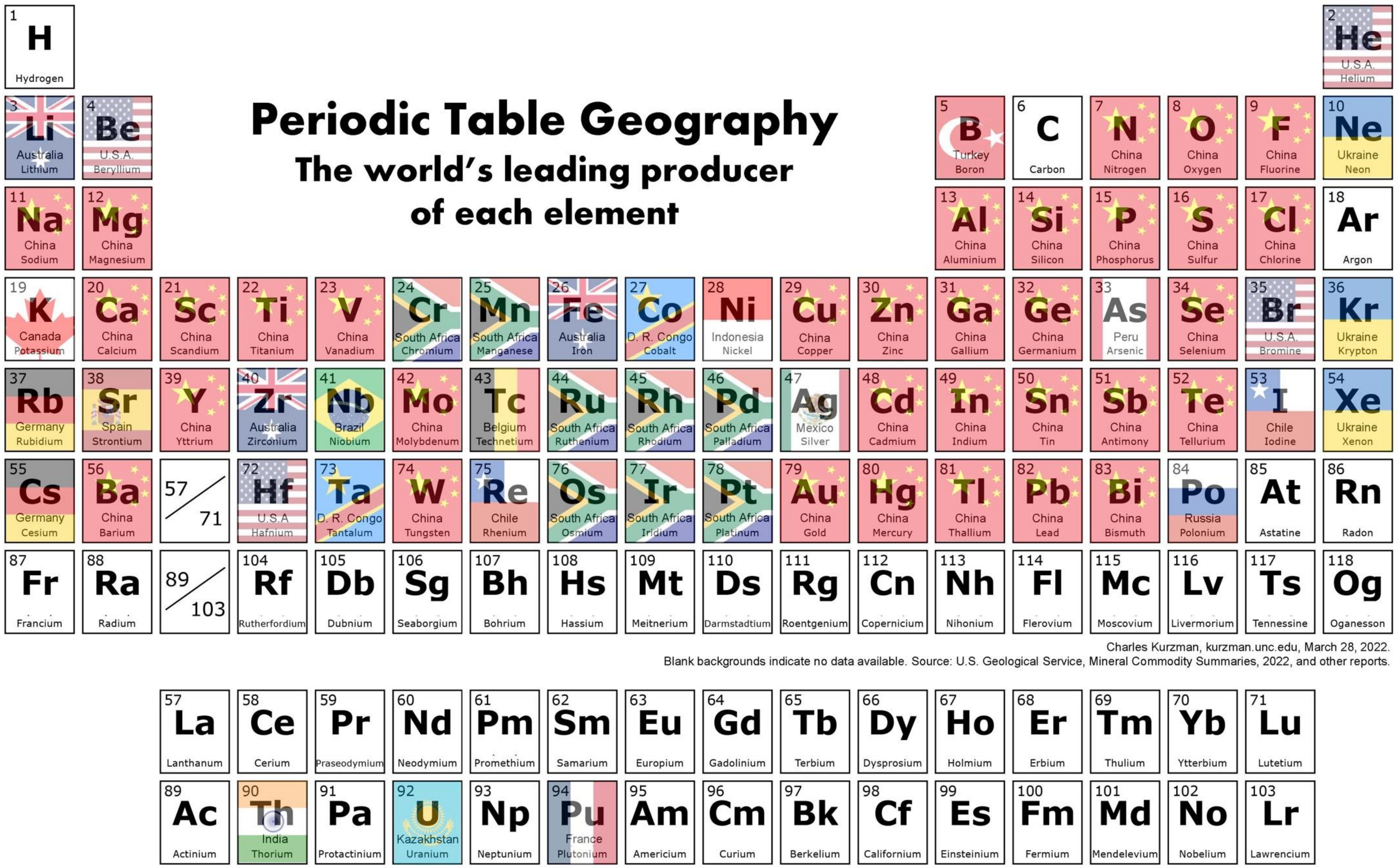


Time remaining before resource exhaustion*

Cobalt	Nickel	Aluminium
20 years	*70 years*	*15 000 years*

**By taking the 2021 production, we will have exhausted the reserves of an element within n years*

- emissione di CO_2
- consumo di H_2O
- pericolosita‘
- provenienza (rischio geopolitico)
- ….


Periodic Table Geography
The world's leading producer of each element
1 H Hydrogen
2 He U.S.A. Helium
3 Li Australia Lithium
4 Be U.S.A. Beryllium
5 B Turkey Boron
6 C Carbon
7 N China Nitrogen
8 O China Oxygen
9 F China Fluorine
10 Ne Ukraine Neon
11 Na China Sodium
12 Mg China Magnesium
13 Al China Aluminium
14 Si China Silicon
15 P China Phosphorus
16 S China Sulfur
17 Cl China Chlorine
18 Ar Argon
19 K Canada Potassium
20 Ca China Calcium
21 Sc China Scandium
22 Ti China Titanium
23 V China Vanadium
24 Cr South Africa Chromium
25 Mn South Africa Manganese
26 Fe Australia Iron
27 Co D. R. Congo Cobalt
28 Ni Indonesia Nickel
29 Cu China Copper
30 Zn China Zinc
31 Ga China Gallium
32 Ge China Germanium
33 As Peru Arsenic
34 Se China Selenium
35 Br U.S.A. Bromine
36 Kr Ukraine Krypton
37 Rb Germany Rubidium
38 Sr Spain Strontium
39 Y China Yttrium
40 Zr Australia Zirconium
41 Nb Brazil Niobium
42 Mo China Molybdenum
43 Tc Belgium Technetium
44 Ru South Africa Ruthenium
45 Rh South Africa Rhodium
46 Pd South Africa Palladium
47 Ag Mexico Silver
48 Cd China Cadmium
49 In China Indium
50 Sn China Tin
51 Sb China Antimony
52 Te China Tellurium
53 I Chile Iodine
54 Xe Ukraine Xenon
55 Cs Germany Cesium
56 Ba China Barium
57 / 71
72 Hf U.S.A. Hafnium
73 Ta D. R. Congo Tantalum
74 W China Tungsten
75 Re Chile Rhenium
76 Os South Africa Osmium
77 Ir South Africa Iridium
78 Pt South Africa Platinum
79 Au China Gold
80 Hg China Mercury
81 Tl China Thallium
82 Pb China Lead
83 Bi China Bismuth
84 Po Russia Polonium
85 At Astatine
86 Rn Radon
87 Fr Francium
88 Ra Radium
89 / 103
104 Rf Rutherfordium
105 Db Dubnium
106 Sg Seaborgium
107 Bh Bohrium
108 Hs Hassium
109 Mt Meitnerium
110 Ds Darmstadtium
111 Rg Roentgenium
112 Cn Copernicium
113 Nh Nihonium
114 Fl Flerovium
115 Mc Moscovium
116 Lv Livermorium
117 Ts Tennessine
118 Og Oganesson
57 La Lanthanum
58 Ce Cerium
59 Pr Praseodymium
60 Nd Neodymium
61 Pm Promethium
62 Sm Samarium
63 Eu Europium
64 Gd Gadolinium
65 Tb Terbium
66 Dy Dysprosium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium
89 Ac Actinium
90 Th India Thorium
91 Pa Protactinium
92 U Kazakhstan Uranium
93 Np Neptunium
94 Pu France Plutonium
95 Am Americium
96 Cm Curium
97 Bk Berkelium
98 Cf Californium
99 Es Einsteinium
100 Fm Fermium
101 Md Mendelevium
102 No Nobelium
103 Lr Lawrencium
Charles Kurzman, kurzman.unc.edu, March 28, 2022.
Blank backgrounds indicate no data available. Source: U.S. Geological Service, Mineral Commodity Summaries, 2022, and other reports.