QUANTUM-NEST SUMMER SCHOOL 2025

QUANTUM NETWORK FOR EDUCATION AND SCIENTIFIC TRAINING

JUNE 23-27, 2025

UNIVERSITY OF PALERMO - PALERMO, ITALY

EVENT BOOKLET

https://quantum-saclay.fr/quantum-nest-2025

SISTEQ · QUANTUM SACLAY · DigiQ · QUARMEN Erasmus Mundus Joint Master

Università degli Studi di Palermo · université PARIS-SACLAY · FRANCE 2030 · QuanTEdu FRANCE · Co-funded by the European Union

Presentation of the school

The goal of the **Quantum-NEST School (Quantum Network for Education and Scientific Training)** is to provide an overview of the most recent and exciting evolutions and developments in the **quantum science and technology** field. The school offers lectures of high-profile scholars in quantum technology: this will provide the participants with a clear vision of the main topics and challenges in the field. It will be also a precious networking opportunity to meet established researchers in the field. It is primarily aimed at **master's and PhD students**.

Topics Edition 2025

Quantum optics and communication, quantum sensors, quantum materials and out-of-equilibrium dynamics, quantum information, quantum cryptography, quantum computing, quantum machine learning, superconducting qubits.

Organizers

Marino Marsi (University Paris-Saclay)
Massimo Palma (University of Palermo)
Rinaldo Trotta (Sapienza University of Rome)
SISTEQ – Società Italiana di Scienze e Tecnologie Quantistiche

PRACTICAL INFORMATION

Event dates: 23-27 June 2025

Event venue:
Department of Physics and Chemistry
University of Palermo
Via Archirafi, 36
90123 Palermo, Italy
https://maps.app.goo.gl/62iejNxzBGEvgqN68

The Department is located near the city center and is easily accessible by public transport (10-minute walk from Palermo Centrale Train Station).

How to reach the city center from Palermo Airport?

- By Train: Take the train to Palermo Centrale (approx. 1 hour – 6,80€)
- By bus (approx. 50 min. – 6€): https://www.prestiaecomande.it/orari-e-linee/
  Bus stops : *Politeama* for Hotel Ibis Crystal ; *Via Roma* for Gran Hotel Piazza Borsa and B&B Quattro Canti.
- You can also share a taxi at the airport (about 8€/person).

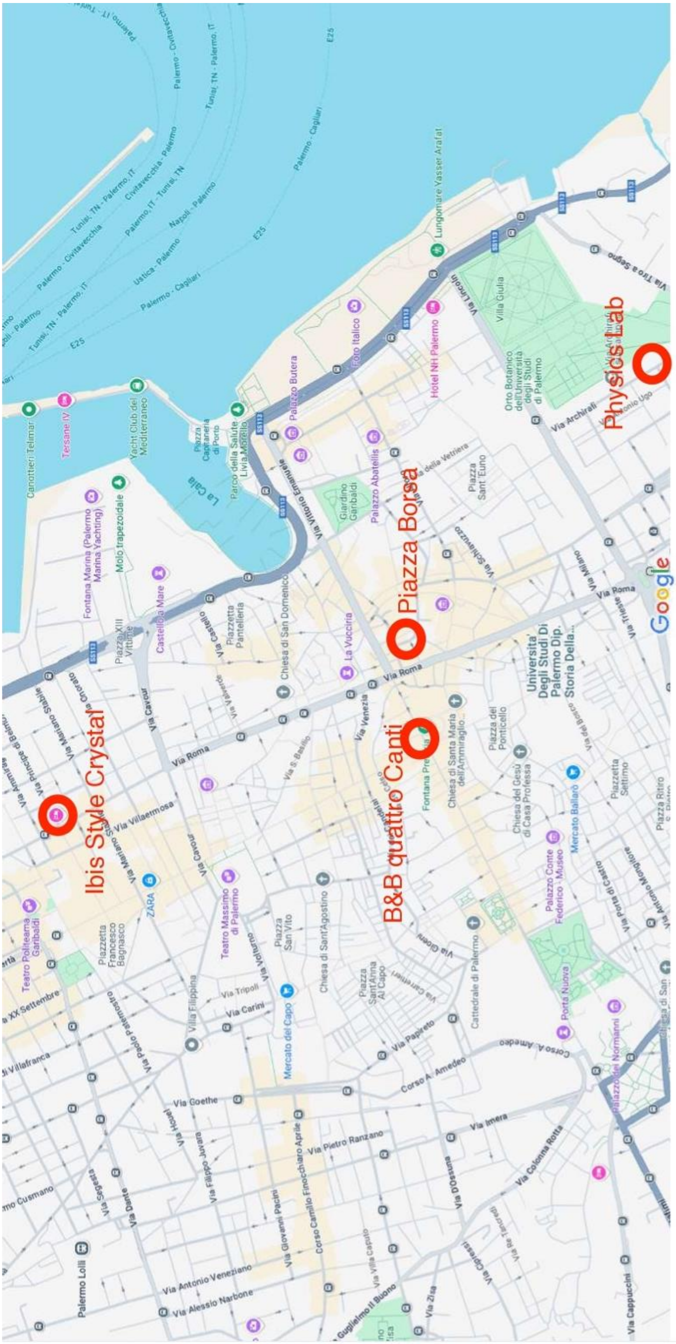
Hotels:

Gran Hotel Piazza Borsa
Via dei Cartari, 18
https://maps.app.goo.gl/6hJ5nX171J7G7jKD6
The guests can check in from 14:00.
Check-out time is 12:00.

B&B Hotel Palermo Quattro Canti
Via Vittorio Emanuele, 291
https://maps.app.goo.gl/kWmUr1ypm4Wcm1aUA
The guests can check in from 14:00
Check-out time is 12:00

Ibis Styles Palermo Crystal
Via Roma, 477 A
https://maps.app.goo.gl/WfxXghfzZwqvMKP59
The guests can check in from 14:00.
Check-out time is 12:00.

No parties or loud gatherings should take place at the hotel. Please note that SISTEQ, as the organizer, holds responsibility (including financial responsibility) for ensuring that these rules are respected. As there are other clients, we ask for your cooperation to maintain a peaceful environment.


Ibis Style Crystal
B&B quattro Canti
Piazza Borsa
Physics Lab

SPEAKERS & LECTURES

Giulio Crognaletti, University of Trieste, Italy
“Noisy Quantum Computation”

Marcelo Goffman, CEA Saclay, France
“Introduction to superconducting quantum circuits”

Michele Grossi, CERN, Switzerland
“Quantum machine learning”

Mauro Paternostro, University of Palermo, Italy
“Three brief discussions on the thermodynamics of quantum processes”

Jean-François Roch, ENS Paris-Saclay, France
“Point defects in diamond as atomic-like systems for quantum technologies”

Fabio Sciarrino, University of Rome La Sapienza, Italy
“Integrated photonics for quantum information processing”

Ana Silva, University of Porto, Porto
“Ultrafast Spectroscopy for Probing and Controlling Quantum Materials: From Principles to Applications”

Vladyslav Usenko, Palacky University Olomouc, Czech Republic
“Quantum cryptography with discrete and continuous variables of light”

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PROGRAMME

Attendance at all lectures is mandatory. You will be required to sign an attendance sheet during both the morning and afternoon sessions each day. Please note that no attendance certificate will be issued to students who miss any part of the scheduled classes.

ALL LECTURES IN LECTURE HALL A (1ST FLOOR)

	Monday June 23th
17:00	Welcome presentation and cocktail at the Physics Department. Lecture hall A.

	Tuesday June 24th
9:15-10:15	G. Crognaletti *"Noisy Quantum Computation"*
10:15 - 11:15	J-F. Roch *"Point defects in diamond as atomic-like systems for quantum technologies"*
11:15 - 11:30	**Coffee break**
11:30 - 12:30	M. Goffman "Introduction to superconducting quantum circuits"
12:30 - 14:00	**Lunch**
14:00 - 15:00	J-F. Roch *"Point defects in diamond as atomic-like systems for quantum technologies"*
15:00 - 16:00	M. Grossi *"Quantum machine learning"*
16:00 - 16:20	**Coffee break**
16:20 - 17:20	A. Silva *"Ultrafast Spectroscopy for Probing and Controlling Quantum Materials: From Principles to Applications"*
17:30 - 19:00	**Poster session (by Arteq students for all participants)**

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	Wednesday June 25th
9:15-10:15	J-F. Roch *“Point defects in diamond as atomic-like systems for quantum technologies”*
10:15 - 11:15	M. Paternostro *“Three brief discussions on the thermodynamics of quantum processes”*
11:15 - 11:30	**Coffee break**
11:30 - 12:30	M. Goffman *“Introduction to superconducting quantum circuits”*
12:30 - 14:00	**Lunch**
14:00 - 15:00	V. Usenko *“Quantum cryptography with discrete and continuous variables of light”*
15:00 - 16:00	A. Silva *“Ultrafast Spectroscopy for Probing and Controlling Quantum Materials: From Principles to Applications”*
16:00 - 16:20	**Coffee break**
16:20 - 17:20	M. Grossi *“Quantum machine learning”*
17:30 – 18:30	**For Quarmen students only: information meeting about the semester 3 at UPSaclay**

	Thursday June 26th
9:15-10:15	G. Crognaletti *"Noisy Quantum Computation"*
10:15 - 11:15	M. Paternostro *"Three brief discussions on the thermodynamics of quantum processes"*
11:15 - 11:30	**Coffee break**
11:30 - 12:30	M. Goffman *"Introduction to superconducting quantum circuits"*
12:30 - 14:00	**Lunch**
14:00 - 15:00	V. Usenko *"Quantum cryptography with discrete and continuous variables of light"*
15:00 - 16:00	M. Grossi *"Quantum machine learning"*
16:00 - 16:20	**Coffee break**
16:20 - 17:20	A. Silva *"Ultrafast Spectroscopy for Probing and Controlling Quantum Materials: From Principles to Applications"*

	Friday June 27th
9:15-10:15	V. Usenko *“Quantum cryptography with discrete and continuous variables of light”*
10:15 - 11:15	F. Sciarrino *“Integrated photonics for quantum information processing”*
11:15 - 11:30	**Coffee break**
11:30 - 12:30	M. Paternostro *“Three brief discussions on the thermodynamics of quantum processes”*
12:30 - 14:00	**Lunch**
Afternoon	**Social activity – Visit.**

Noisy Quantum Computation

Giulio Crognaletti
University of Trieste, Italy /INFN sez. Trieste, Italy

This lecture provides a comprehensive introduction to noisy quantum computation, focusing on the effects of noise as a fundamental limitation in current quantum devices. We model noisy quantum computers as open quantum systems, where interactions with the environment induce decoherence and dissipation. The resulting reduced dynamics of the quantum computer are described by completely positive (CP) maps. We introduce key examples of these maps—such as depolarizing, dephasing, and amplitude damping channels—and analyze their properties, including unitality, non-unitality, and the contractivity of CP maps under various metrics. These features critically affect the evolution of quantum states and the mean values of observables, with direct consequences for the reliability and expressiveness of quantum computations and quantum machine learning models. We explore how noise degrades the performance of parameterized quantum circuits (PQCs), especially through the emergence of noise- induced Barren Plateaus, where gradients vanish due to concentration phenomena, rendering optimization intractable. The lecture includes examples and hands-on exercises to build both theoretical insight and practical intuition into the challenges posed by noise in quantum computing.

M.A. Nielsen and I.L. Chuang, Quantum Computation and Quantum Information, 10th Anniversary Edition, Cambridge University Press, 2010.
S. Wang et al., "Noise-induced barren plateaus in variational quantum algorithms," Nature Communications 12, 6961 (2021).
G.Crognaletti et al. "Estimates of loss function concentration in noisy parametrized quantum circuits", arXiv:2410.01893

Introduction to superconducting quantum circuits

Marcelo Goffman
Quantronics group / CEA Saclay

In this series of lectures, I will introduce the fundamental principles and practical aspects of superconducting quantum circuits. I will start by describing how superconducting electrical circuits are analyzed within a quantum mechanical framework, focusing on the construction of Lagrangians and Hamiltonians and the process of canonical quantization. I will explain how superconducting artificial atoms are engineered and present methods for controlling and reading out their quantum states, particularly within the framework of circuit quantum electrodynamics (circuit-QED). I will discuss key experimental realizations such as Transmon and Fluxonium qubits, and describe how one can characterize their performance through measurements of relaxation and dephasing times. In addition, I will address the origins and effects of noise and decoherence in superconducting circuits, discuss modeling strategies, and identify common noise sources. My goal is to provide a clear overview of the use of superconducting circuits in quantum information experiments and to highlight the main challenges in the field.

U. Vool and M. Devoret, International Journal of Circuit theory and applications 45, 897 (2017)
Ciani, D. P. Di Vicenzo and B. M. Terhal, Lecture Notes on Quantum Electrical Circuits. DOI: https://doi.org/10.59490/tb.85
P. Krantz et al., A quantum engineer's guide to superconducting qubits, Appl. Phys. Rev. 6, 021318 (2019);

Quantum Machine Learning

Michele Grossi
CERN

This lecture offers an introduction to quantum machine learning (QML), with a focus on variational approaches using parameterized quantum circuits (PQCs). We begin by reviewing the basic structure of PQCs, highlighting their role as trainable ansätze for supervised and unsupervised learning tasks. The concept of data reuploading is introduced as a key technique to enhance the expressivity of quantum models, enabling them to represent more complex decision boundaries. We then explore the expressivity of PQCs through the lens of function classes and their capacity to approximate classical and quantum functions. Building on this, we introduce quantum kernel methods, which leverage quantum feature maps and the Hilbert space structure of quantum states to define implicit models. We contrast these with explicit models, such as quantum neural networks (QNNs), discussing their respective advantages, limitations, and relationships. Throughout the lecture, we emphasize the theoretical foundations as well as practical aspects of model design, and we include examples and exercises to develop a clear understanding of how QML models operate and generalize.

M. Schuld and N. Killoran, "Quantum machine learning in feature Hilbert spaces," Phys. Rev. Lett. 122, 040504 (2019).
P. Pérez-Salinas et al., "Data re-uploading for a universal quantum classifier," Quantum 4, 226 (2020).

Three brief discussions on the thermodynamics of quantum processes

Mauro Paternostro
Quantum Theory Group, Department of Physics and Chemistry E. Segrè, University of Palermo

Thermodynamics underpins all areas of natural sciences: chemical, biological and physical processes are possible only in virtue of a delicate energetic balance that is effectively described through the framework and toolbox provided by thermodynamics.
In this context, the energetics of quantum systems and processes is a fundamental problem to investigate: how quantum matter exchange energy with its surroundings, how macroscopic thermodynamic laws emerge from microscopic quantum fluctuations, and whether the development of quantum technologies will help designing new, more sustainable devices are all interesting questions of current interest.
In these three lectures we will investigate the fundamental interplay between quantum theory and thermodynamics : I will address the question of whether a 'resource theory of quantum thermodynamics' can be established, where genuinely quantum resources can be identified and exploited for energetic advantages. I will then move to illustrate processes where energy is extracted efficiently from a quantum battery. Finally, I will discuss the fundamental role that 'measuring' has on the thermodynamics of a quantum process.

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Point defects in diamond as atomic-like systems for quantum technologies

Jean-François ROCH
ENS Paris-Saclay & Institut Universitaire de France

It is often said that crystals are like people: it is often their flaws that make them interesting... For example, the color of diamond gems is linked to the existence of impurities within the crystal. These defects give the material specific optical, electrical and magnetic properties.

Th lectures will describe how these defects behave like artificial atoms nestled within the diamond crystalline matrix. We will apply first-principles quantum mechanics to the most studied point defect in diamond, the nitrogen-vacancy center, in order to construct its energy levels and understand its luminescence and spin properties.

We will then describe techniques that have been developed to fabricate the NV center and address it down to the individual level.

We will finally describe how the unique quantum properties of the NV center can be used for quantum sensing, leading today to a myriad of applications.

Integrated photonics for quantum information processing

Fabio Sciarrino
Sapienza Università di Roma, Dipartimento di Fisica

Photonic quantum technologies represent a promising platform for several applications, ranging from long-distance communications to quantum computing and simulatuib. Indeed, the advantages offered by single photons do make them the candidate of choice for carrying quantum information in a broad variety of areas with a versatile approach. Furthermore, recent technological advances are now enabling first concrete applications of photonic quantum information processing. The goal of this lecture is to provide the audience with an overview of the state of the art in this active field, with a due balance between theoretical, experimental and technological results.

[1] E Pelucchi et al., "The potential and global outlook of integrated photonics for quantum technologies", Nature Reviews Physics 4 (3), 194-208 (2022).
[2] T. Giordani, F. Hoch, G. Carvacho, N. Spagnolo and F. Sciarrino. Integrated photonics in quantum technologies. La Rivista del Nuovo Cimento 46, 71–103 (2023).
[3] J. Wang, F. Sciarrino, A. Laing, and M.G. Thompson, "Integrated photonic quantum technologies", Nature Photonics 14 (5), 273-284 (2020).
[4] F. Flamini, N. Spagnolo, and F. Sciarrino, "Photonic quantum information processing: a review", Rep. Progr. Phys. 82, 016001 (2019).
[5] D.J. Brod, E. F. Galvao, A. Crespi, R. Osellame, N. Spagnolo, and F. Sciarrino, "Photonic implementation of Boson Sampling: a review", Advanced Photonics 1, 034001 (2019).
[6] F. Hoch, T. Giordani, L. Castello, G. Carvacho, N. Spagnolo, F. Ceccarelli, C. Pentangelo, S. Piacentini, A. Crespi, R. Osellame, E. F. Galvão, F. Sciarrino. Modular quantum-to quantum Bernoulli factory in an integrated photonic processor, Nature Photonics 19, 12-19 (2025).
[7] F. Hoch, E. Caruccio, G. Rodari, T. Francalanci, A. Suprano, T. Giordani, G. Carvacho, N. Spagnolo, S. Koudia, M. Proietti, C. Liorni, F. Cerocchi, R. Albiero, N. Di Giano, M. Gardina, F. Ceccarelli, G. Corrielli, U. Chabaud, R. Osellame, M. Dispenza, F. Sciarrino. Quantum machine learning with Adaptive Boson Sampling via post-selection, Nature Communications 16, 902 (2025)

Ultrafast Spectroscopy for Probing and Controlling Quantum Materials: From Principles to Applications

Ana Silva
IFIMUP – Institute of Physics for Advanced Materials, Nanotechnology and Photonics and LaPMET – Laboratory for Physics of Materials and Emerging Technologies, Department of Physics and Astronomy, Faculty of Sciences of University of Porto

The advent of ultrafast laser technology and the generation of ultra-short light pulses—from femtoseconds to attoseconds—have opened new frontiers in the study of light–matter interactions on previously inaccessible timescales. These breakthroughs enable the observation and control of dynamic processes in quantum materials far from equilibrium, offering unique insights into transient electronic, structural, and magnetic phenomena.
These lectures will introduce the fundamental principles and experimental techniques of ultrafast and quantum optics, providing a pathway from basic concepts to cutting-edge applications in condensed matter physics. Topics will range from the generation and characterization of femtosecond and attosecond pulses and light–matter interactions on ultrafast timescales, to pump–probe spectroscopy across a broad spectral range (from THz to X-rays), aimed at probing and manipulating quantum materials.

[1] Weiner, Ultrafast Optics (Wiley, 2009)
[2] J Lloyd-Hughes et al., The 2021 ultrafast spectroscopic probes of condensed matter roadmap, J. Phys.: Condens. Matter, 33, 353001, 2021
[3] A. Zong, et al., Emerging ultrafast techniques for studying quantum materials. Nat Rev Mater 8, 224–240, 2023

Quantum cryptography with discrete and continuous variables of light

Vladyslav Usenko
Palacky University Olomouc

In these lectures we will explore the fascinating field of quantum cryptography, focusing on the motivation behind it, discussing the methods of quantum key distribution (QKD) and the ways to show and analyze the security of QKD. We will consider both discrete- and continuous-variable QKD protocols, based, respectively, on direct and coherent detection of quantum light, and analyze security, practical performance, limitations and advantages of both families of the protocols, considering both quantum and classical resources needed for the protocol implementations. We will also discuss the relevance of security assumptions in the analysis of the protocols and consider the ways to waive some of these in the fully or partially device-independent protocols, immune against quantum hacking attacks on QKD.

M. A. Nielsen, and I. L. Chuang, Quantum Computation and Quantum Information, 10th Anniversary Edition. (Cambridge University Press, 2010)
N. Gisin, G. Ribordy, W. Tittel, and H. Zbinden, Quantum Cryptography, Rev. Mod. Phys. 74, 145 (2002)
V. Scarani et al., The security of practical quantum key distribution, Rev. Mod. Phys. 81, 1301 (2009)
S. Pirandola, Advances in quantum cryptography, Advances in Optics and Photonics 12, 1012 (2020)