Data: 5/06/2024

Curriculum Vitae
Vincenzo Macrí

Nationality: Italian

Present institutional address: vincenzo.macri@unipv.it

Second address: macrivince1978@gmail.com

Google Scholar, **ORCID Profile**

Research Positions

Research assistant RTDA 04/2024 - current

- **Institution:** University of Pavia
  Physics department, via bassi 6, 27100, Pavia (Italy)
  Project: National Quantum Science and Technology Institute (NQSTI)
  (PI: Prof. Marco Liscidini).
  Research topics: Integrated quantum nonlinear photonics.

Postdoctoral Research Scientist 04/2023 - 04/2024

- **Institution:** Universidad Autònoma de Madrid
  Ciudad Universitaria de Cantoblanco, 28049 Madrid, Spain.
  Group: IFIMAC & Departamento de Fisica Teòrica de la Materia Condensada
  (PI: Prof. Johannes Feist).
  Research topics: Theoretical study of strong light-matter interactions
  between organic molecules and nanophotonic structured environments.

Research grant type A 06/2022 - 04/2024

- **Institution:** Dipartimento di Ingegneria, Unipa, Italy.
  Group: Quantum Things
  Research topics: Open quantum systems ultra-strongly coupled in
  cavity-QED, cavity-Optomechanics, and Quantum Information

Postdoctoral Research Scientist 01/2018 - 03/2023

- **Institution:** RIKEN Theoretical Quantum Physics Laboratory
  Wako-shi (Tokyo area), Japan.
  Group: Theoretical Quantum Physics Laboratory (PI: Prof. Franco Nori).
  Research topics: Open quantum manybody systems ultra-strongly coupled:
  cavity-QED, circuit-QED, and cavity-Optomechanics.

Doctoral Researcher 11/2014 - 12/2017

- **Institution:** MIFT Department of Physics, University of Messina, Italy.
  Group: Theoretical Quantum Physics Laboratory (PI: Prof. Salvatore Savasta).

Academic Qualifications and Education

National Scientific Qualification 14/04/2021

- **ASN** (Abilitazione Scientifica Nazionle 02/A2)
  for the functions of second level university professor

PhD in Theoretical Physics with excellence 11/2014 -11/2017

- **Institution:** MIFT Department of Physics, University of Messina, Messina Italy.
  Thesis Title: Coherent resonant coupling of states with different excitations numbers in Hybrid quantum systems.
  Supervisor: Prof. Salvatore Savasta.
  Referees: Prof. S. De Liberato (Univ. of Southampton, UK) and Prof. V. Savona (EPFL, Switzerland).

Laurea Degree in Theoretical Physics (110/110 cum laude) 10/2003-07/2014

- **Institution:** MIFT Department of Physics, University of Messina, Messina Italy.
  Thesis Title: Optomechanical systems in ultrastrong coupling regime.
  Supervisor: Prof. Salvatore Savasta.

Computer programmer: post-graduate course 03/2001

- **Institution:** Assessorato Regionale del Lavoro ECAP-CGIL, Messina Italy.

High School-Technical electrical and electronic industries (60/60) 07/1998

- **Institution:** Istituto Professionale ETTORE MAIORANA, Messina Italy.

Awards

FY 2021 Incentive Research Projects 08/2021

- **Institution:** Theoretical Quantum Physics Laboratory, Riken, Japan

Teaching

Co-supervisor of the PhD thesis entitled "Cavity QED in electron systems" by Alberto Mercurio, student of XXXVI cycle of PhD Course in Physics 04/2021

· **Institution:** MIFT Department of Physics, University of Messina

Tutorials and Lectures for the class Quantum Optics (level M1) 2015 and 2016

· **Institution:** MIFT Department of Physics, University of Messina

Other Skills

Languages	Italian (Mother Tongue), English (Fluent), Japanese (Beginner)
Programming languages	Python, Julia, Wolfram Mathematica, Matlab, QuTiP, LaTeX.

Bibliometrics

23 peer-reviewed articles in the following journals: 1 in **Nature Physics**, 1 in **Physical Review X** (as first author), 4 in **Physical Review Letters** (one as first author), 12 in **Physical Review A** (4 as first author), 1 in **Scientific Reports**, and 4 in **Physical Review Research** (one as last author).

As of June 2024, **1466 citations** and a **h-index of 17** (Source: **Google Scholar**).

List of Publications

1. **Quantum field heat engine powered by phonon-photon interactions**
   A. Ferreri, **V. Macrí**, F. K. Wilhelm, F. Nori, D. E. Bruschi
   Phys. Rev. Res. **5**, 043274 (2023)

2. **Optomechanical Two-Photon Hopping**
   E. Russo, A. Mercurio, F. Mauceri, R. Lo Franco, F. Nori, S. Savasta, **V. Macrí**
   Phys. Rev. Res. **5**, 013221 (2023)

3. **Pure Dephasing of Light-Matter Systems in the Ultrastrong and Deep-Strong Coupling Regimes**
   A. Mercurio, S. Abo, F. Mauceri, E. Russo, **V. Macrí**, A. Miranowicz, S. Savasta, O. Di Stefano
   Phys. Rev. Lett. **130**, 12360 (2023)

4. **Coherent resonant coupling between atoms and a mechanical oscillator mediated by cavity-vacuum fluctuations**
   B. Wang, J. M. Hu, **V. Macrí**, Z. L. Xiang, F. Nori
   Phys. Rev. Res. **5**, 013075 (2023)

5. **Spontaneous Scattering of Raman Photons from Cavity-QED Systems in the Ultrastrong Coupling Regime**
   V. Macrí, A. Mercurio, F. Nori, S. Savasta, C. S. Muñoz
   Phys. Rev. Lett. **129**, 273602 (2022)

6. **Regimes of cavity QED under incoherent excitation: From weak to deep strong coupling**
   A. Mercurio, **V. Macrí**, C. Gustin, S. Hughes, S. Savasta, F. Nori
   Phys. Rev. Res. **4**, 023048 (2022)

7. **Revealing higher-order light and matter energy exchanges using quantum trajectories in ultrastrong coupling**
   V. Macrí, F. Minganti, A. F. Kockum, A. Ridolfo, S. Savasta and F. Nori
   Phys. Rev. A, **105**, 023720 (2021)

8. **Dissipative state transfer and Maxwell's demon in single quantum trajectories: Excitation transfer between two noninteracting qubits via unbalanced dissipation rates**
   F. Minganti, **V. Macrí**, A. Settineri, S. Savasta and F. Nori
   Phys. Rev. A **103**, 052201 (2021)

9. **Spin squeezing by one-photon-two-atom excitation processes in atomic ensembles**
   V. Macrí, F. Nori, S. Savasta and D. Zueco
   Phys. Rev. A. **101**, 053818 (2020)

10. **Conversion of Mechanical Noise into Correlated Photon Pairs: Dynamical Casimir effect from an incoherent mechanical drive**
    A. Settineri, **V. Macrí**, L. Garziano, O. Di Stefano, F. Nori and S. Savasta
    Phys. Rev. A. **100**, 022501 (2019)

11. **Emission of photon pairs by mechanical stimulation of the squeezed vacuum**
    W. Qin, **V. Macrí**, A. Miranowicz, S. Savasta and F. Nori
    Phys. Rev. A. **100**, 062501 (2019)

12. **Resolution of gauge ambiguities in ultrastrong-coupling cavity QED**
    O. Di Stefano, A. Settineri, **V. Macrí**, L. Garziano, R. Stassi, S. Savasta and F. Nori
    Nat. Phys. **15**, 803 (2019)

13. **Interaction of Mechanical Oscillators Mediated by the Exchange of Virtual Photon Pairs**
    O. Di Stefano, **V. Macrí**, A. Ridolfo, R. Stassi, A. F. Kockum, S. Savasta and F. Nori
    Phys. Rev. Lett. **122**, 030402 (2019)

14. **Simple preparation of Bell and Greenberger-Horne-Zeilinger states using ultrastrong-coupling circuit QED**
    V. Macrí, F. Nori and A. F. Kockum
    Phys. Rev. A. **98**, 062327 (2018)

15. **Dissipation and thermal noise in hybrid quantum systems in the ultrastrong-coupling regime**
    A. Settineri, **V. Macrí**, A. Ridolfo, O. Di Stefano, A. F. Kockum, F. Nori and S. Savasta
    Phys. Rev. A. **98**, 053834 (2018)

16. **Nonperturbative Dynamical Casimir Effect in Optomechanical Systems: Vacuum Casimir-Rabi Splittings**
    V. Macrí, A. Ridolfo, O. Di Stefano, A. F. Kockum, F. Nori and S. Savasta
    Phys. Rev. X **8**, 011031 (2018)

17. **Quantum Nonlinear Optics without Photons**
    R. Stassi, **V. Macrí**, A. F. Kockum, O. Di Stefano, A. Miranowicz, S. Savasta and F. Nori
    Phys. Rev. A. **96**, 023818 (2017)

18. **Deterministic quantum nonlinear optics with single atoms and virtual photons**
    A. F. Kockum, A. Miranowicz, **V. Macrí**, S. Savasta and Franco Nori
    Phys. Rev. A. **95**, 063849 (2017)

19. **Frequency conversion in ultrastrong cavity QED**
    A. F. Kockum, **V. Macrí**, L. Garziano, S. Savasta and F. Nori
    Sci. Rep. **7**, 5313 (2017)

20. **One Photon Can Simultaneously Excite Two or More Atoms**
    L. Garziano, **V. Macrí**, R. Stassi, O. Di Stefano, F. Nori and S. Savasta
    Phys. Rev. Lett. **117**, 043601 (2016)
    APS Physics Focus **9**, 83 (2016)

21. **Deterministic synthesis of mechanical *NOON* states in ultrastrong optomechanics**
    V. Macrí, L. Garziano, A. Ridolfo, O. Di Stefano and S. Savasta
    Phys. Rev. A. **94**, 013817 (2016)

22. **Multiphoton quantum Rabi oscillations in ultrastrong cavity QED**
    L. Garziano, R. Stassi, **V. Macrí**, A. F. Kockum, S. Savasta and F. Nori
    Phys. Rev. A. **92**, 063830 (2015)

23. **Single-step arbitrary control of mechanical quantum states in ultrastrong optomechanics**
    L. Garziano, R. Stassi, **V. Macrí**, S. Savasta, and O. Di Stefano
    Phys. Rev. A. **91**, 023809 (2015)

Conferences and seminars

FQMT'24 Frontiers of Quantum and Mesoscopic Thermodynamics July 2024
Invited Speaker *Prague, Czech Republic*

· Spontaneous scattering of Raman photons from cavity-QED systems in the ultrastrong coupling regime
https://fqmt.fzu.cz/24/index.php?active=invs

IQIS2022 Italian Quantum Information Science September 2022
Invited Speaker
Local Organising Committee *Palermo, Italy*

· Mechanical-Electromagnetic Energy conversion in optomechanical systems
https://iqis2022.unipa.it/program/
https://iqis2022.unipa.it/committees/

FQMT'22 Frontiers of Quantum and Mesoscopic Thermodynamics August 2022
Invited Speaker
Chairman of session four *Prague, Czech Republic*

· Virtual and real dynamical Casimir effect in optomechanical systems
https://fqmt.fzu.cz/22/index.php?active=talks
https://fqmt.fzu.cz/22/index.php?active=table&densel=0&chair=1

APS March Meeting March 2021
oral contribution *Online conference USA*

· Dynamical Casimir effect in optomechanical systems
https://meetings.aps.org/Meeting/MAR21/Session/R28.12

20th Anniversary of Superconducting Qubits SO20 May 2019
Poster Presentations *Tsukuba, Japan*

· Non-perturbative Dynamical Casimir Effect in Optomechanical Systems:
Vacuum Casimir-Rabi Splittings
https://cems.riken.jp/sq20th/program.html

APS March Meeting March 2018
oral contribution *Los Angeles, USA*

· Non-perturbative Dynamical Casimir Effect in Optomechanical Systems:
Vacuum Casimir-Rabi Splittings
http://meetings.aps.org/Meeting/MAR18/Session/R26.8

APS March Meeting March 2017
oral contribution *New Orleans, USA*

· Quantum Nonlinear Optics without Photons
https://meetings.aps.org/Meeting/MAR17/Session/Y27.8

Workshops RIKEN Center for Emergent Matter Science January 2017
Invited Speaker *Tokyo, Japan*

· Ultra-strongly coupled systems with strong dissipation
https://wakoshi.wixsite.com/riken/copy-of-ultra-strongly-coupled-syst-1

APS March Meeting March 2016
oral contribution *Baltimore, USA*

· Multiphoton Quantum Rabi Oscillations in Ultrastrong Cavity QED
https://meetings.aps.org/Meeting/MAR16/Session/C48.6

FisMat Italian National Conference on Condensed Matter Physics October 2015
oral contribution *Palermo, Italy*

· Synthesizing Quantum States in Ultrastrong Optomechanics
http://eventi.cnism.it/fismat2015/submission/view/1061dar

SUMMARY OF RESEARCH EXPERIENCE

I am a highly motivated theoretical physicist working in the quantum optics field. I am investigating novel quantum optics problems in the ultrastrong coupling regime. It is a remarkable light-matter interaction regime where a large number of exotic nonlinear optical processes can be realized. I am familiar with advanced tools in quantum optics, including master equations (even in the ultrastrong coupling regime, where the standard approaches fail), many-body correlation functions, input-output theory for resonators, among many others. During my career, I employed a wide range of techniques including analytical approaches (e.g., generalized perturbative transformation) as well as state-of-the-art numerical approaches, exact-diagonalization, Monte Carlo quantum trajectory. Some of the key results of my work, developed during the PhD in Italy and postdoctoral research at Riken research center in Japan, include:

Gauge ambiguities in ultrastrong coupling cavity quantum electrodynamics.
In this work, published in Nature Physics, I contributed with analytical calculations to identify the source of gauge violation providing a general method for the derivation of the gauge-invariant Hamiltonians in arbitrary light-matter quantum systems. This is achieved by compensating the non-localities introduced in the construction of the effective Hamiltonians. The resulting quantum Rabi Hamiltonian in the Coulomb gauge differs significantly in form from the standard one, but provides the same physical results obtained by using the dipole gauge. These results shed light on gauge invariance in the non-perturbative and extreme-interaction regimes for the quantum Rabi and Dicke models. This results are also relevant for the study of open quantum systems. Indeed, it turns out that when the light-matter interaction is very strong the correct gauge dependence of the subsystem operators, appearing in the master equation, cannot be neglected as usual. Moreover, if the coupling between a subsystem and the environment is described by a gauge interaction and the system-bath coupling strength is not weak, the preservation of the gauge principle should be ensured despite any truncation procedure. By using all this tools, it is possible to investigate the photon flux emission rate of this system under the incoherent excitation of the two-level atom for any light-matter interaction strength and consider different effective temperatures. These results have been published in Physical Review Research. Following the same path, spontaneous Raman scattering of incident radiation can be observed when cavity-QED systems approaches the ultrastrong coupling regime, without coupling to any vibrational degree of freedom. This effect, and its strong sensitivity to the system parameters, opens new avenues for the characterization of cavity QED setups and the generation of quantum states of light.

High-frequency mirror in ultrastrong coupling cavity-optomechanics allows to observe dynamical Casimir effect.
I have demostrated for the first time that in cavity-optomechanical system, describing quantum-mechanically both the cavity field and the vibrating mirror, dyinamical Casimir effect can be observed. This result was published in the journal Physical Review X with me as the first author. The full quantum approach developed describes the dinamical Casimir effect without introducing a time-dependent light-matter interaction. Vacuum emission can originate from the free evolution of an initial pure mechanical excited state, in analogy with the spontaneous emission from excited atoms. In this work the nonperturbative regime provides direct access to the level structure determining the dynamical Casimir effect and can display Rabi-like oscillations of the cavity-field and oscillating-mirror signals. A different configuration can be study to demonstrate a phonon-hopping mechanism, namely, two spatially separated moveable mirrors (constituting a cavity-optomechanical system) can exchange energy coherently and reversibly, by exchanging virtual photon pairs. This result has been published in the journal Physical Review Letters. Finally, a combination of two 1D-electromagnetic boxes separate by a vibrating two-sided perfect mirror displays photon-pair hopping between the two electromagnetic resonators. In particular, the two-photon hopping is not due to tunneling, but rather to higher-order resonant processes due to virtual mechanical-energy conversion mechanism.

Quantum exotic nonlinear optical effects in ultrastrong coupling cavity-QED.
Regarding cavity-QED, I explored the possibility of generating multiphoton quantum Rabi oscillations in the ultrastrong regime. I have shown that a system consisting of a single two-level system coupled ultrastrongly to a resonator can exhibit anomalous vacuum Rabi oscillations, where two or three photons can be jointly emitted by the two-level system into the resonator and reabsorbed by the two-level system in a reversible and coherent process. With this work I expanded my collaborations to an international level. This work marks the beginning of my collaboration with Prof. Nori's group at the Theoretical Quantum Physics Laboratory CPR in RIKEN. In another work, I have contributed to the discovery of an exciting new effect in cavity-QED: considering two separate atoms interacting with a single optical mode, when the frequency of the resonator field is twice the atomic transition frequency, it is possible to show that there exists a resonant coupling between one photon and two atoms, via intermediate virtual states connected by counter-rotating processes. If the resonator is prepared in its one-photon state, the photon can be jointly absorbed by the two atoms in their ground state which will both reach their excited state with a probability close to one. This work was selected as Editors' Suggestion for Physics Review Letter. It was also featured in the APS 'Physics Focus' and widely covered by the popular media all over the world. I contributed to the realization

of a new method for frequency conversion of photons, which is both versatile and deterministic. We have shown that a system with two resonators ultrastrongly coupled to a single two-level system can be used to realize both single and multiphoton frequency conversion processes. The conversion can be exquisitely controlled by tuning the two-level system frequency to bring the desired frequency-conversion transitions on or off resonance. Moreover, I worked to generalize a nonlinear optical processes with two-level systems, where only virtual photons are involved. The results presented there show that N spatially-separated and nondegenerate two-level systems can coherently exchange energy in analogy with light modes in nonlinear optics.