Prof. Dr. Fabrizio Carbone

Personal data: Fabrizio Carbone, born in Novi Ligure, Italy, 20/April/1976.

Education:

• **January the 8th 2007: PhD** in condensed matter physics, University of Geneva, Switzerland. PhD thesis title: *"Spectroscopic signatures of electronic correlations in superconductors and magnets."*

• **September 2001: Master degree** in quantum electronics, University of Pavia, Italy. Master thesis title: *"Study of all optical wavelength converters for telecommunication systems applications".*

Employment:

• **Since July 2018**: Associate professor, EPFL, CH.
• **2011-2018**: Tenure-track assistant professor at the EPFL, CH.
• **September 2010**: SNF professorship, EPFL, CH.
• **April 2009-September 2010**: Research assistant, group of prof. Majed Chergui, EPFL, CH.
• **April 2007-April 2009:** Post-doc, group of prof. Ahmed Zewail, Caltech, USA.
• **July 2003-March 2007:** PhD in prof. Dirk van der Marel`s group, University of Geneva, CH.
• **November 2002-June 2003:** PhD in prof. Dirk van der Marel`s group, University of Groningen, NL.
• **August 2002-November 2002:** Consultant for the Laboratorio Nazionale TASC under the supervision of prof. Fulvio Parmigiani, Trieste, Italy.
• **September 2000-August 2002:** Industrial researcher at the Advanced Photonics research Laboratory of Pirelli, Milan, Italy.

Publications and oral presentations at international conferences and workshops:

Dr Carbone's bibliographic information can be found on Google schoolar:
https://scholar.google.ch/citations?user=SUaa- BgAAAAJ&hl=de
His total number of citations (google scholar) is 4070 and the h-index is 32.
Since 2010, prof. Carbone's group international activity is testified by over 70 presentations of which more than 50 were invited talks. Our group has been also active in organizing the first international conference on ultrafast electron microscopy (bi-annual event, first edition in Lausanne, second in Trieste, third in Strasbourg) and other workshops and schools. The details of the organized events as well as several department colloquia organized by collaborators are not listed here for brevity and can be found on the group web-page under the voices News and Workshops:
https://www.epfl.ch/labs/lumes/

Peer review:

Peer reviewer for: Science, Science Advances, Nature, Nature Materials, Nature Communications, Phys. Rev. Lett., Phys. Rev. B, Physica B, European J. of Phys., Chem Phys., Chem. Phys. Lett., Carbon, JACS, PNAS, Appl. Phys. Lett.

Teaching experience:

- Undergraduate student instructor, Pirelli Labs (year 2002).
- Undergraduate student instructor, University of Geneva (year 2005).
- "Advanced experimental physics" undergraduate students, University of Geneva (year 2004).

- “Basic experimental physics” undergraduate students, University of Geneva (2005, 2006). (TP 1,2).
- “General Physics II” 1st year undergraduate students, EPFL, 2012-2018, (division of civil engineering), average 200 students per year.
- “The structure of condensed matter”, second year physics undergraduate students, EPFL since the spring semester (2014), average 50 students per year.
- “Solid State Physics 1”, 2014-2018, 3rd year bachelor, EPFL, average 70 students per year.
- “Solid State Physics IV”, since the spring 2019, master level course, average 12 students per year.
- “General Physics I”, since the spring 2019, first year students in geology (Univeristé de Lausanne), on average 110 students per year.

Language skills: Italian: mother tongue, English and French: fluent, written and spoken.

Grants awarded:

1. Bourse for perspective researcher of the Suisse National Science Foundation. Awarded in February 2007 (55000 Suisse francs).
2. Veni funding scheme of the NWO, Holland. Awarded in September 2008 (200000 Euro), application withdrawn after winning.
3. Ambizione grant, Suisse National Science Foundation. Awarded in September `09 (430000 CHF).
4. Prof. Boursier funding scheme of the Suisse National Science Foundation, awarded in February 2010 (1600000 Suisse francs).
5. ERC starting grant, awarded in June 2010, (1500000 €). Awarded in 2011
6. PI within the NCCR MUST (430000 CHF in the second phase). Currently active.
7. 3 SNF projects, 200000 CHF, 200000 CHF, 320000 CHF
8. Ambizione grant for Dr Rajeswari Jayaraman (postdoc in our group, 430000 CHF) awarded in 2016. Concluded
9. Participant to the Sinergia grant NanoSkyrmionics (to begin in October 2018)
10. Awarded an ERC Consolidator grant (2M CHF), to start in July 2018.
11. Awarded an unrestricted gift for research activities from Google (100000$) followed by a 250000$ grant.
12. FET open grant of the European Union (650000 EUR), SmartElectrons, starting in May 2021.

Prizes:

Winner of the University Latsis prize in 2016.

Supervisor activity:

Graduated PhD students: Mathieu Cottet, Giulia Mancini, Luca Piazza, Andreas Mann, Francesco Pennacchio, Edoardo Baldini, Simone Borroni, Gabriele Berruto.

Present associations: member of the American Physical Society, member of the American Crystallographic Association

Grants reviewer for: ERC starting and consolidator grants (EU), career grants (USA), DOE research grants (USA), former member of the committee for the perspective researcher fellowships of the FNS (Suisse), Royal academy of Sweeden, Hellenic minister of education, Deutsche forschungsgemeinschaft (DFG), international expert, Germany, Netherlands Organisation for Scientific Research (NWO), international expert, NL. PALM, "Laboratory of Excellence", French Ministry of Research, international expert, FR. Belgian Academy of Science, international referee, BE. Canadian Academy of Science, international referee, CA

Major scientific achievements:

Prof. Fabrizio Carbone is an associate professor at the EPFL, Faculty of Basic Sciences, where he founded the Laboratory for Ultrafast Microscopy and Electron Scattering (LUMES) in 2011. The applicant's research over the last years has been focused on the static and dynamical investigation of strongly correlated electron materials and nanostructures. Some of his most notable contributions to the research fields have been:
As an **independent researcher**, prof. Carbone founded the Laboratory for Ultrafast Microscopy and Electron Scattering, where fs optical spectroscopy, electron diffraction and electron microscopy were combined to investigate the out of equilibrium properties of materials and nanostructures.
Few recent results obtained by the LUMES laboratory, relevant for this proposal, are:

i) **The Attosecond coherent control of both the longitudinal and transverse component of the electron wavefunction was demonstrated by our group in these two papers:**

"Attosecond coherent control of free-electron wave functions using semi-infinite light fields" **Nature Comm.** 9 1 (2018) and

"Ultrafast generation and control of an electron vortex beam via chiral plasmonic near fields" **Nature Materials** 18 573 (2019), highlighted in "Vorticity induced by chiral plasmonic fields" **News and Views in Nature Materials** (2019).

In quantum mechanics, Schrödinger equation dictates the faith of a quantum system described by a wave-function that can be subjected to a certain potential. The aim of wavefunction engineering is to re-shape the initial wavefunction of such a quantum system in a way to obtain a specific behaviour as a result of its interaction with a specific potential. The simplest particle to manipulate has been historically the photon, thanks to its massless nature and the large availability of coherent beams and optical tools such as gratings and lenses. Later, the manipulation of matter waves has been proven, patterning the wavefunction of massive particles such as electrons and neutrons. **In the first of these two papers**, we manipulate the longitudinal component of the electron wavefunction and show that this can yield ultrashort electron bunches in the attosecond and potentially even zeptosecond regime. In this article, we also discuss the potential interest of such shaped-electrons for nuclear physics experiments.

In the second article, we show how to imprint a spatial pattern onto the transverse phase profile of the electron wavefunction, for example a vortex. In a vortex beam, a circularly symmetric wavefunction presents a phase singularity in its central axis, causing an orbital angular momentum (OAM) of value $m\hbar$, where $\hbar$ is the reduced Planck constant and m an integer number dictated by the patterning profile. Electron vortex beams have been particularly promising for electron microscopy applications, due to their sensitivity to magnetic fields, but are being considered also for quantum information15 and radiotherapy applications. **The vast majority of previous wavefunction engineering experiments are carried out by passing a coherent stream of particles through a passive and massive element acting on their wave nature** to exploit quantum interference effects to modulate their wavefunction. **In our laboratory, we demonstrated the possibility to obtain twisted matter waves without using a massive, opaque, device but using nano-shaped electromagnetic fields**. This is a very important advance as the contact interaction with phase masks can result in huge losses in brightness of the beam and decoherence effects in the case of charged particles (**electrons, proton and even ions**). Furthermore, the possibility to use light as handle for changing the OAM of a charged particle allows its ultrafast manipulation, such as switching the sign of the topological charge of a vortex beam on a sub-fs scale. The ability to twist matter waves is a very recent achievement in experimental physics whose full potential has yet to be explored. We note that, in particular, manipulating the wavefunction of composed particles, such as atoms and ions for instance, would mean being able to fiddle with their internal structure and in return their nuclear and electronic energy levels. Some of these perspectives were discussed in a recent article from our group in **Applied Physics Letters** (Madan et al. **Appl Phys. Lett.** 116 230502 2020).

ii) **Nuclear excitations of out of equilibrium atoms and ions.**

Our group got interested in nuclear phenomena in 2018 when we proposed a possible way of coherently controlling nuclear excitations using ultrafast electron and light pulses (Vanacore et al, Nature Communications 9 2694 (2018), see above). Our proposition came out at the same time as the first experimental observation of Nuclear excitation by electron capture (NEEC) by Dr Chiara and Carroll (Chiara et al., Nature 554 217 (2018)). The combination of these ideas/observations sparkled some new interest in the interdisciplinary topic of using ultrafast lasers and electron technology (which is the core business of our group) for controlling nuclear phenomena. Google Inc. has been interested in the perspective of these experiments for energy harvesting applications and reached out to us providing financing for implementing them.

https://actu.epfl.ch/news/google-funds-epfl-research-on-nuclear-phenomena/

Ever since, a lively debate sparked around Chiara's first observation as the NEEC cross section implied by their experiments cannot be theoretically accounted for (Wu et al., Phys. Rev. Lett. 122, 212501 (2019)). Upon discussion with Dr Chiara and Dr Carroll, we pointed out that, in their experiments, NEEC can take place in an out-of-equilibrium environment whereas current theoretical estimates rely on the assumption that the capturing ion is in its electronic ground state during the NEEC process.

In arXiv:2102.05718 (in review with PRL), we reported a detailed theoretical analysis of the NEEC cross section in the presence of an electronically excited capturing ion. We found that NEEC can be enhanced be several orders of magnitude in these conditions. We also pointed out that with current ultrafast technologies, such out of equilibrium conditions may be tailored at will, leading to an active control of the energy release from nuclei. This work is especially important for seeding interdisciplinary interest among different communities such as those of out of equilibrium physics, ultrafast light and electron beams physics, ultrafast phenomena and nuclear physics.

In another article in preparation (draft available upon request) we investigate the problem of gamma emission from a target impinged by a fast moving external electron. The external electron energy loss provides possibly sufficient energy to excite the target nucleus and let it decay to undergo either a resonant radiative transition (γ-photon emission) or a nonradiative transition (internal conversion, photoelectric effect, etc.). We studied this problem theoretically by regarding the target nucleus in two pragmatical models: two and three level quantum systems. Interstingly, we found that under certain electron-irradiation conditions, a coherent and directional emission of gamma-rays can be stimulated. These results are relevant for the current proposal and for application in future high-energy radiation sources.

iii) **Laser-induced plasma spectro-microscopy**.

The possibility to excite nuclear transitions using laser-induced plasmas is very appealing for table-top nuclear experiments. However, despite a lot of effort, little is known about the microscopic properties of such light-induced plasmas. The main reason is the difficulty in obtaining direct experimental information on a plasma density and temperature. In our laboratory, we recently demonstrated the ability of our ultrafast Transmission Electron Microscope to records meV/femtosecond/nm resolved movies of a nano-confined plasma, yielding unique information on its microscopic properties and dynamical evolution. Such The results of this study have been reported as a CLEO conference proceeding paper *"Charge Dynamics Electron Microscopy"* to make them readily available to the community and will be submitted soon to an international journal. This method gives us the ability to engineer the ideal condition for laser-induced plasma generation from different targets, which are tested in our ultrafast TEM and then reproduced in our nuclear spectroscopy apparatus.