In the application to participate in the competitive examination, the candidate must elaborate a short project on one of the research topics listed below (only the topic indicated as first choice in the application).

1. Specific Inactivation of SARS-CoV2 Using Photoactive False Target

The lack of effective and specific therapeutic means against the current SARS-CoV2 epidemics is urgently calling for the development of new therapeutics for treating the viral infections.

Photodynamic viral inactivation is a technology used to reduce the viral load of blood derivatives. One of the biggest challenges for the application of this therapeutic approach is the development of constructs that can selectively target aggressive viruses such as SARS-CoV2. The main objective of the present proposal is to address this challenge by developing a nanostructure formed by conjugating a photosensitizer to a selective protein vector for the spike protein of the viral coating of SARS-CoV2. Two selective nanocarriers will be developed. The first exploits angiotensin-converting enzyme 2 (ACE2), which is the cellular receptor targeted by SARS-CoV2 to bind and infect host cells. The second is based on IgG antibodies developed by the body in response to the infection and isolated from recovered COVID-19 donors plasma.

This novel nanostructured photosensitizer will provide an effective and groundbreaking therapeutics, capable of selectively targeting the viral particles both in the upper respiratory tract, where entry genes (ACE2) are most highly expressed (nasal goblet and ciliated cells), and in the lungs, where the phototoxic action should be carefully directed in order not to worsen the severe inflammation condition found in the SARS-CoV2 patients. It is foreseen that all these aerial traits are efficiently reachable with optical fiber illumination.

References:

Contact: Prof.ssa Stefania Abbruzzetti, Email: stefania.abbruzzetti@unipr.it

2. Correlative multimodal bioimaging

Any single imaging modality is not adequate to systematically elucidate the fundamental physical processes of a cell, cellular networks or organisms. A correlative approach allows biophysical challenges to be studied within their overall spatio-temporal context, and application to pathologies and diseases can be targeted...
down to an individual cell and underlying molecular events. Moreover, the application of a multimodal approach to the same region of interest allows conclusions from a technique to be validated since each method can provide distinctive insights based on physically different contrast mechanisms.

We are interested in the study of the crowded environment of a cell and its nucleus with a molecular resolution. Atomic force microscopy and electron microscopy are excellent candidates for the investigation of biological material, but they also have some limitations like the lack of chemical specificity. At the same time, optical advanced and super-resolution microscopy is highly specific and allows investigating molecular systems in living samples. The coupling between these techniques will pave the way to a new class of experimental analysis. To realise this multimodal approach particular care will be dedicated to the selection and development of molecular label and processes that could enable a contrast mechanism in a different class of microscopy techniques. For instance, the use of functionalised photosensitiser molecules that can be super-resolved by optical nanoscopy, but also generate the condition for diaminobenzidine (DAB) oxidation and precipitation, would enable correlative light-electron microscopy (CLEM).

The candidate will work with highly skilled scientists and physicists in the dynamic environments of Istituto Italiano di Tecnologia in Genova. The candidate will acquire highly valued skills in the applications of advanced and super-resolution microscopy and with prototype instruments for biophysical research. The PhD student will take a main role in the development of the protocol that enables the correlative approach: from the preparation of the sample and the optimisation of the labelling strategy to the imaging aspects concerning instruments fine-tuning and image registration. He or she will coordinate the local research efforts together with input from the other project partners. In consultation with the supervisors, the PhD student will design and perform relevant experiments, analyse and interpret the results, write scientific articles and disseminate the results in international conferences.

References:


Contact: Prof. Cristiano Viappiani, Dr. Paolo Bianchini, Email: cristiano.viappiani@unipr.it, paolo.bianchini@iit.it

Quantum technologies exploit quantum mechanics to build devices that are impossible in a classical context. Within this field, molecular nanomagnets (MNMs) provide interesting opportunities and they are emerging as a promising platform for quantum computation and simulation [1]. MNMs are molecules with a core of 3d or 4f ions whose magnetic moments are coupled by exchange interactions. Their Hamiltonian can be
Chemically engineered to a large extent, to optimally target specific fundamental phenomena or technological applications. In particular, the magnetic states of some MNMs can encode qubits, the basic units of quantum computers.

The purpose of the present thesis is the development of algorithms and schemes for using MNMs as qubits, and strategies for their protection from errors [2]. The focus will be mostly on platforms where MNMs are embedded in planar superconducting resonators [3].

Further research themes will be: i) the study of MNMs as sensors, in particular in connection with recent proposals for the detection of dark matter [4]. ii) the transport properties of chiral molecules where spin selectivity has been observed, thus offering new opportunities to control molecular qubits.

These activities require both the characterization of MNMs by advanced simulation techniques (e.g., DFT calculations, incoherent Lindblad-type evolution) and the development of digital quantum computation schemes.

Part of this research will be performed within the European FET Project “FAult Tolerant MOlecular Spin processor (FATMOLS)”, and will require collaboration with international partners and coworkers.

References:

Contact: Prof. Paolo Santini, Email: paolo.santini@unipr.it

4. Stimuli responsive nanostructures for biomedical applications

The investigation of stimuli responsive nanostructure as promising therapeutic agents focuses on their potential for localized non-invasive action with minimal side effects.

This project is centred on the development and characterization of nanostructures activated by high-penetration stimuli (infrared light, X-rays, magnetic fields) for the treatment of tumours in deep tissues.

Two approaches shall be explored: i) Self-Lighted Photodynamic Therapy (SLPDT), where a nanostructure releases reactive oxygen species when irradiated by X-rays from a Radiotherapy source, and ii) Magnetic Hyperthermia (MH), where superparamagnetic nanoparticles irradiated by radiofrequency magnetic fields induce a localized temperature increase that kills cancer cells.

The project shall investigate the encapsulation of stimuli responsive nanostructures by the Layer-by-Layer technique, aiming at a) combining them in a drug-delivery polymeric carrier, b) increasing their stability in physiologic conditions, or c) to achieve functionalization with targeting molecules such as folic acid.
Within this multidisciplinary project, the candidate shall interact with chemists, material scientists and medical doctors from the University of Parma and IMEM-CNR.

References:
- L. Cristofolini et al., ACS Appl. Mater. Interfaces. 8, 25043 (2016)

Contact: Prof. Davide Orsi, Email: davide.orsi@unipr.it

5. Dynamical processes and fluctuations on networks
Network theory provides a natural framework for the description of the topology of the interactions in many social, ecological and economic systems. It is well known that the dynamical properties of these systems are determined by the fluctuations in the connectivity and by the inhomogeneities of the network [1]. On the other hand, systems with non-Gaussian fluctuations are characterized by rare events which are not exponentially suppressed and they can be studied with the so called “Big Jump principle” [2]. In the research we will consider dynamical processes evolving on complex networks e.g. in epidemic or neural systems and we will focus on the presence of rare catastrophic events in the dynamical evolution. A theoretical and analytical issue will be to find the general principles that rule the interplay between the networks inhomogeneous topology and the dynamical fluctuations. A more applicative and numerical point should be an estimate of catastrophic extreme events that have a crucial role in epidemic, geological and neural systems.

References:

Contact: Dr. Alessandro Vezzani, Email: alessandro.vezzani@unipr.it

6. Properties of foams, emulsions and single molecular layers
Multi-phase systems, such as emulsions and foams, are ubiquitous: think just to food (mayonnaise, milk and dairy products, creams and pastes ...) and pharma (ointments, emulsions, systems for controlled drug release ...). Also, many industrial processes involve multiphase systems, such as paintings, coolants, lubricants, oil separators etc.

The properties of all these systems, and their functionality, are determined by phenomena happening at interfaces, such surface tension, interfacial absorption and the dynamical balance between formation and disintegration of supramolecular complexes.

Although based on some general principles, emulsion formulation still relies on semi-empirical approaches. We lack in fact quantitative models predicting accurately the features of emulsions from properties of the single interface, which would be beneficial for a sustainable use of resources and to mitigate environmental impact of goods production and waste disposal.
In the doctoral project we will investigate this issue, also in preparation for experiments to be conducted in microgravity onboard the International Space Station, using a suite of spectroscopy and microscopy techniques including:

- Dynamic Light Scattering and Diffusing Wave Spectroscopy
- Rheometry
- Micro fluorescence spectroscopies

Finally, for the interpretation of the results, we shall benefit from experiments on single drops conducted in laboratories at ICMATE-CNR in Genova.

References:

Contact: Prof. Luigi Cristofolini, Email: luigi.cristofolini@unipr.it

7. Study of the Cu (In, Ga) (S, Se) system for thin film solar cells (TFSC)

The optimization of the gap of the Cu (In,Ga)(S,Se) system is fundamental in the study of materials for Tandem solar cells, with c-Si bottom cells and high band gap "CIGS" top cells. We will try to define and optimize the compositions, through a "band-gap engineering" process, varying the In/Ga and Se/S ratios, to increase the value of the gap up to values close to 2 eV. The project has two main scopes; the first is to bring the overall efficiency of the solar cell up to 30%. The second objective is spectroscopic. Innovative solutions for the study by micro-Raman spectroscopy of highly absorbing multi-layered semiconducting materials should be adopted. Raman spectroscopy is very effective in determining the various phases of chalcogenide systems; we would like to optimize the method to obtain information on microscopic scale about the thickness, composition, grading, and presence of spurious phases in the CIGS films, in a completely non-destructive way.

The work will be carried out in collaboration with the CNR-IMEM institute (Parma) who will supervise the synthesis part both through the vacuum deposition technique (PED, pulsed electron deposition) and by experimenting CIGS depositions using solution techniques.

References:
8. Research in Theoretical Physics in the framework of INFN activities: Astroparticles, Gravitational Waves and Quantum Field Theory

The Theoretical Physics Group in Parma is active in several different branches of research on fundamental physics. Our activities range from theoretical aspects of Quantum Field Theory and String Theory to applications of Lattice QCD and include Statistical Physics with particular attention to Complex Systems dynamics. Particularly relevant for this PhD project are the activities in Cosmology and Astroparticle physics, exploring the universe structure through the Standard Model and beyond-the-standard-model theories. The hidden nature of Dark Matter and Dark Energy will be studied in detail, thanks to new international collaborations as EUCLID. Moreover, the recent observations of gravitational waves have prompted new perspectives in these research fields, offering the opportunity to investigate novel phenomena in extreme regimes. Traditional Quantum Field Theory finds applications also in these contexts, providing frameworks (as axions, quintessence or massive gravitons) to improve our large ignorance on the fundamental constituents of our universe. Four Iniziative Specifiche of INFN will be present here (GAST, QCDLAT, DYNYSMATH and INDARK) providing support to researches and scientific activities.

References: more information at https://web.infn.it/www-pr/en/welcome-to-infn-parma-unit/

Contact: Prof. Luca Griguolo, Email: luca.griguolo@unipr.it

9. Metal-insulator transitions and Dirac insulators in strong spin-orbit interaction metal oxides

Simple band theory classifies metals and insulators by filled vs. partially filled tight binding bands. The picture is drastically altered by strong electron correlations, giving rise, e.g., to Mott-Hubbard insulators, often "decorated" by unconventional superconductivity.

Strong spin-orbit interactions (SOI) in metals can generate new types of insulators, decorated by other exotic ground states. For example in 4d and 5d compounds bandwidth, d-orbital crystal-field splitting and exchange constant J compete with SOI. Their ground state is also highly susceptible to external perturbations such as strain, doping and pressure. A smoking gun in this game is the onset of magnetic order, for which NMR and MuSR (PSI, Villigen and ISIS, UK) are techniques of election. DFT is the main tool for determining the ground state of the system [1,2], and predicting hyperfine and quadrupolar couplings, the interactions that are actually probed by the two complementary experimental techniques. Ongoing studies by us on NaOsO3 and AgF2.

Expected results

This project will shed light on the nature of the insulator-metal transition and on the novel quantum states emerging when different interactions, including the strong SOI of 5d metals, compete (mechanisms of criticality vs. quantum criticality).

Samples will be provided also by Dr. Kazunari Yamaura (National Institute for Materials Science, Japan), in collaboration with Profs. Sanna and Franchini, Bologna, Vienna. The candidate is asked to perform the NMR
and MuSR experiments, and to learn DFT coupling calculations. The weight of the second aspect depends on her/his preferences. Co-supervision by Prof. Allodi (NMR) and Dr. Bonfà (DFT).

References:


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