Università degli Studi di Parma
Dottorato di Ricerca in Fisica – XXXIV ciclo – PhD in Physics

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. **Muon site and couplings in superconductors, magnets, and molecular nanomagnets**

Muon spin spectroscopy (MuSR) is a powerful experimental technique. The muon spin evolution over the microsecond time scale probes the static and dynamic spin properties of magnetic materials, superconductors and molecular nanomagnets. Conventional studies are performed without the a priori knowledge of the interstitial muon implantation site and couplings, which may be obtained by ab-initio calculations (DFT and molecular dynamics). A much greater wealth of information can be extracted from experiments when both are known.

The candidate will be offered the opportunity to learn the experimental technique by participating to collaborative experiments at international large scale facilities (ISIS, U.K. and PSI, CH). He/she will be also taking part in the ongoing effort, funded by a European H2020 project, in developing ab-initio calculations to assist MuSR data analysis. Both aspects will be applied to advanced condensed matter topics.

References

1. P. Bonfà R. De Renzi Towards the computational prediction of muon implantation sites and interaction parameters for μSR experiments Full text J. Phys. Soc. Jpn , 85 091014, green access arXiv:1604.03281
2. I. J. Onuorah, P. Bonfà, R. De Renzi, Muon contact hyperfine field in metals: A DFT calculation, Phys. Rev. B 97, 174414
3. For a general reference on MuSR see https://arxiv.org/abs/cond-mat/0207699

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2. **Epitaxial growth and study of wide bandgap oxide semiconductors**

The preparation and investigation of new semiconductors is an exciting field of research, both from physical and technological point of view.

Since 2014, the semiconductor team at the Dept. of Mathematical, Physical and Computer Sciences has been working on semiconducting oxides, in close cooperation with IMEM-CNR institute and many other research groups in Italy and abroad. In the last times, research has been focused on the orthorhombic phase of Ga_2O_3 (so called epsilon phase). It is in principle suitable for fabrication of power transistors and deep UV-sensors.

In the frame of the doctoral thesis, the student will be engaged in epitaxial deposition of ε-Ga_2O_3 on foreign substrates as well on the investigation of the physical characteristics of the material by Hall effect, optical absorption, photo-conductivity, X-ray diffraction. Further measurements will be carried out with external partners. In the course of the PhD work, it should also be possible to start preparing and studying ternary epilayers such as $(InGa)_2O_3$ or $(AlGa_2)_2O_3$, which paves the way to new physics and to new application fields.

References

1. F.Boschi, M.Bosi, T.Berzina, E.Buffagni, C.Ferrari, R.Fornari: " Hetero-epitaxy of ε-Ga2O3 layers by MOCVD and ALD", J. Crystal Growth 443 (2016) 25–30; DOI 10.1016/j.jcrysgro.2016.03.013
2. R. Fornari, M. Pavesi, V. Montedoro, D. Klimm, F. Mezzadri, I. Cora, B. Pecz,, F. Boschi, A. Parisini, A. Baraldi, C. Ferrari, E. Gombia, M. Bosi: "Thermal stability of ε-Ga2O3 polymorph", Acta Mater. 140 (2017) 411-416, http://dx.doi.org/10.1016/j.actamat.2017.08.062

3. M. Pavesi, F. Fabbri, F. Boschi, G. Piacentini, A. Baraldi, M. Bosi, E. Gombia, A. Parisini and R. Fornari: “e-Ga2O3 epilayers as a material for solar-blind UV photodetectors”, Mater. Chem. Phys. 205 (2018) 502-507 https://doi.org/10.1016/j.matchemphys.2017.11.023

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3. Carbon based nanostructured materials for energy storage

Carbon nanostructures, thanks to their excellent mechanical, electronic and thermal properties, high specific surface and a "hierarchical" porosity, are very promising materials for energy storage. They can be used either as solid state gas absorbers, for the development of more efficient hydrogen tanks in the automotive field, or as active materials (electrodes, solid electrolytes) in innovative ionic batteries or in supercapacitors. Recent studies have shown that alkali cluster intercalated fullerides and graphene, also decorated with metallic nanoparticles, reversibly absorb hydrogen, with an optimal binding energy for applications. In addition, graphene, obtained by thermal exfoliation of graphite oxide (TEGO), or by laser conversion of suitable precursors (LIG), is an excellent candidate as an active material in innovative N-ion batteries, or in symmetrical and flexible supercapacitors. The candidate will deal with the synthesis and characterization of new derivatives of fullerenes, graphene and vegetable charcoal (bio-char) for energy storage applications. The new materials will be studied with structural and transport characterization techniques, both in-situ and ex-situ, even at large sources (neutron spectroscopy, synchrotron light diffraction and polarized muon spectroscopy (μSR)).

References

1. M. Gaboardi, N. Sarzi Amadè, M. Aramini, C. Milanese, G. Magnani, S. Sanna, M. Riccò, D. Pontiroli, “Extending the hydrogen storage limit in fullerene”, Carbon 120, 77-82 (2017)
2. J. C. Pramudita, A. Rawal, M. Choucair, D. Pontiroli, G. Magnani, M. Gaboardi, M. Riccò, N. Sharma, Mechanism of sodium insertion/extraction on the surface of defective graphenes, ACS Appl. Mater. Interfaces 9 (1), 431-438 (2017)
3. M. Gaboardi, A. Bliersbach, G. Bertoni, M. Aramini, G. Vlahopoulou, D. Pontiroli, P. Mauron, G. Magnani, G. Salviati, A. Züttel and M. Riccò, Decoration of graphene with nickel nanoparticles: study of the interaction with hydrogen, J. Mat. Chem. A 2 1039-1046 (2014)

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4. Synthesis and characterization of nanostructures for medicine

This Project focuses on the production and characterization of nanostructures for medicine. Remotely activated, stimuli-responsive nanostructures will be developed to devise new therapeutic strategies following these two lines:

i) Self-Lighted Photodynamic Therapy (SLPDT), is an approach to cancer therapy based on the ability of certain nanostructures to generate cytotoxic species (e.g. singlet oxygen) under X-ray irradiation, increasing the effectiveness of radiotherapy sessions.

ii) Magnetic Hyperthermia (MH) capsules, containing superparamagnetic nanoparticles which are able to generate a local temperature increase that kills cancer cells when irradiated by radiofrequency magnetic fields. These activities are part of the COST network TD1402 “Radiomag” of which dr. Davide Orsi is a member This project has a strong interdisciplinary character. It will rely on collaborations in progress with the Laboratory of Toxicology of the Department of Medicine, with IMEM-CNR and with the Department of Chemical Sciences, Life and Environmental Sustainability of UNIPR.

References

1. T. Rimoldi, JoMS: Materials in Medicine 27 10 (2016)] [D. Orsi et al. accepted in Nanomedicine (2017)
2. L. Cristofoliniet al. ACS Applied Materials & Interfaces, 8 25043 (2016)

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5. Development of molecular systems for the delivery of photosensitizers and for applications in super-resolution microscopy

(*Fellowship funded by Istituto Italiano di Tecnologia*)

The project intends to develop delivery systems for photosensitizers based on recombinant human proteins bearing (in the same genetic construct) selective peptide functionalities, able to target specific receptors overexpressed on the plasma membrane of tumor cells. The carrier protein binds a photosensitizer. The systems will be further functionalized with fluorescent molecules that allow to achieve sub-diffractive resolution in fluorescence microscopes. Some of these photosensitizers show direct fluorescence emission properties. The study comprises an extensive spectroscopic characterization of the developed compounds, also with high temporal resolution, and advanced optical microscopy.

References

1. Delcanale, P.; Pennacchietti, F.; Maestrini, G.; Rodríguez-Amigo, B.; Bianchini, P.; Diaspro, A.; Iagatti, A.; Patrizi, B.; Foggi, P.; Agut, M.; Nonell, S.; Abbruzzetti, S.; Viappiani, C. Subdiffraction localization of a nanostructured photosensitizer in bacterial cells *Scientific Reports* **2015**, *5*, 15564.
2. Rodríguez-Amigo, B.; Delcanale, P.; Rotger, G.; Juárez-Jiménez, J.; Abbruzzetti, S.; Summer, A.; Agut, M.; Luque, F. J.; Nonell, S.; Viappiani, C. The complex of hypericin with β-lactoglobulin has antimicrobial activity with perspective applications in dairy industry *Journal of Dairy Science* **2015**, *98*, 89–94.

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6. Molecular probes for photoacoustic microscopy

(*Fellowship funded by Istituto Italiano di Tecnologia*)

The project intends to develop molecular systems to be used as contrast agents for photoacoustic microscopy. Sensor systems of chemical-physical parameters will be developed based on non-radiative relaxation of molecular probes. Fluorescent and non-fluorescent proteins will be used to devise sensors, possibly based on FRET, in which acceptors are non-fluorescent. Particular attention will be paid to the use of photochromic proteins with absorption in the spectral region of the red and the near IR. We intend to develop systems for the monitoring of pH, oxygen, CO, and others.

References

1. Eric M. Strohm, Michael J. Moore, and Michael C. Kolios Photoacoustic Microscopy: A Review IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 22, NO. 3, MAY/JUNE 2016 6801215 Single Cell
2. Lihong V. Wang and Liang Gao Photoacoustic Microscopy and Computed Tomography: From Bench to Bedside, Annu. Rev. Biomed. Eng. 2014. 16:155–85

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7. Fluorescent proteins as biosensors for single cell nitric oxide imaging

Over the years, numerous intracellular monitoring systems have been proposed for nitric oxide (NO), one of the most important signal molecules in biology. Most of the sensors developed suffer however from the disadvantage of providing values of NO concentrations mediated on a population of cells. The imaging of the NO concentration at the single cell level allows to obtain information on signal transmission events with high spatio-temporal resolution able to detect differences between the different cells. This information can only be obtained through the use of high-resolution microscopy on fluorescent probes genetically encoded within cells.

This project aims to develop fluorescent probes for FLIM (Fluorescence Lifetime IMaging) microscopy applications from fluorescent proteins of different colors. Chimeric constructs will be prepared for FRET (Förster Resonance Energy Transfer) in which the acceptor is able to bind NO with a concomitant spectral change. Preliminary results have shown an appreciable sensitivity to NO of some different fluorescent protein variants, similar to Green Fluorescent Protein.

The study is being carried out in collaboration with the ICS4 institute of the Forschungszentrum Juelich in Germany.

References

1. Eroglu, E. et al. Development of novel FP-based probes for live-cell imaging of nitric oxide dynamics. Nat Commun 7, 10623 (2015).
2. Eroglu, E. et al. Genetic biosensors for imaging nitric oxide in single cells. Free Radic. Biol. Med. doi:https://doi.org/10.1016/j.freeradbiomed.2018.01.027 (2018)

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8. The gauge/gravity correspondence and its QFT realizations

This project revolves around the fundamental concepts of holography and duality, which in the last 20 years have developed as powerful tools to formulate non-perturbative Quantum Field Theory, thanks to the picture-changing paradigm encoded in the AdS/CFT or gauge/gravity correspondence. This duality allows to model strongly interacting systems by the use of a dual weakly coupled string/gravitational theory, and at the same time it has unveiled new routes to address fundamental questions in black hole physics and suggestive connections between quantum gravity, field theories and quantum information. Striking realization of gauge/gravity correspondence are provided by: 1) the duality between superstring theory on AdS5xS5 and N=4 superconformal Yang-Mills theory in D=4 with gauge group U(n) and matter in the adjoint representation 2) the duality between M-theory on AdS4xS7/Zk and N=6 superconformal ABJM model, a 3d Chern-Simons (CS) theory based on U(n)_k x U(m)_{-k} gauge group with matter in the bifundamental representation. The study of 3d CS-matter models may also have interesting implications for the description of condensed matter systems and non-susy dualities. The project will focus on different aspects the correspondence, by studying a particularly rich class of observables represented by supersymmetric Wilson Loops (WLs) and related physical quantities like cusp anomalous dimensions, Bremsstrahlung functions describing the energy emitted by slowly moving massive particles, quark-antiquark potentials, entanglement entropy and their non supersymmetric avatars. WLs can be used also to explore the relations between supersymmetric localization and quantum integrability. One can also define one-dimensional defect conformal theories through WLs: far-reaching consequences on the one-dimensional bootstrap program, on the realization of an AdS2 x CFT1 correspondence and on the related Mellin amplitudes/Witten diagrams computations will be investigated.

References:

1. Large N field theories, string theory and gravity
https://arxiv.org/pdf/hep-th/9905111.pdf
2. Localization techniques in quantum field theories
https://arxiv.org/pdf/1608.02952.pdf
3. Review of AdS/CFT Integrability: An Overview
https://arxiv.org/pdf/1012.3982.pdf

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9. Implications on the physics of fundamental interactions from cosmological observations
(*Fellowship funded by Istituto Nazionale di Fisica Nucleare, INFN*)

The cosmological and astroparticle signatures of various frameworks for Physics Beyond the Standard Model will be analyzed: massive neutrinos, Dark Matter, modifications of General Relativity. Computational tools for the computation of cosmological observables to be measured by future surveys will be developed. In particular, in collaboration with the Euclid consortium, computational techniques of cosmological perturbations beyond the linear order will be implemented, aiming at a precise extraction of cosmological parameters.

References

1. Cosmology and fundamental physics with the Euclid satellite Luca Amendola (U. Heidelberg, ITP) et al.. Jun 1, 2016. 345 pp. Published in Living Rev. Rel. 21 (2018) no.1, 2 DOI: 10.1007/s41114-017-0010-3, e-Print: arXiv:1606.00180 [astro-ph.CO]
2. The effect of massive neutrinos on the BAO peak Marco Peloso (Minnesota U.), Massimo Pietroni (INFN, Padua & Parma U.), Matteo Viel, Francisco Villaescusa-Navarro (Trieste Observ. & INFN, Trieste). May 27, 2015. 26 pp. Published in JCAP 1507 (2015) no.07, 001 DOI: 10.1088/1475-7516/2015/07/001 e-Print: arXiv:1505.07477 [astro-ph.CO]

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10. Dynamic processes on Time Evolving Networks

In several social, economic and technological systems interactions are described by networks whose connections evolves rapidly in time. Recently, a great interest have been devoted to these kind of systems, since the development of information technology have made available a great amount of data which can be studied and analyzed. In this framework, several models have been introduced taking into account of different aspects of real networks: inhomogeneous activity of the nodes, memory effects, and temporal fluctuations. The research will be focused on understanding how network dynamics influences the interaction dynamics in the system. Clearly, the case where the time scales of networks evolution and of system interaction are comparable is of particular interest. In socio-economical systems, where this framework naturally applies, the models of particular interest are diffusion, epidemic spreading and opinion dynamics. The final goal of the research will be the comparison with real data

References

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2. P. Holme and J. Saramäki Phys. Rep. 519, 97-125 (2012)
3. E. Ubaldi, A. Vezzani, M. Karsai, N. Perra and R. Burioni Scientific Reports 7, 46225 (2017).

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11. Quantum transport of ultracold atoms

Position reserved to fellowship holders of Albert-Ludwigs-Universität Freiburg (Germany)

The goal is to formulate a realistic proposal for the implementation of experiments which implement quantum transport of ultracold atoms. The main challenges, which at the the present state-of-the art are not solved, would be: (1) the definition of thermal baths for the control of temperature and the coherences of the reservoirs of cold atoms and (2) the theoretical and numerical description of a system composed of many interacting particles coupled to appropriate reservoirs of atoms. In addition to the fundamental interest in

many-body physics, possible applications of this work are neutral-atom circuits for atomtronics that work as or better than the most flexible coherent electronic devices.

References

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