# Curriculum Vitae

Sergio Ciuchi

## Personal data

Name: Sergio Ciuchi
Born: July 29 1960
Nationality: Italian
Residence: Rome (Italy)

## Present position

Associate Professor in Theoretical Physics
University: University of L'Aquila
Department: Department of Physical and Chemical Sciences

Sergio Ciuchi is also member of CNR center "Insitute for Complex Sytems"

## Contacts

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## Education and Career

03/2019—04/2019 CPTGA Visiting Scientist at Centre de Physique Théorique Grenoble-Alpes, Grenoble, France

05/2016—06/2016 CPTGA Visiting Scientist at Centre de Physique Théorique Grenoble-Alpes, Grenoble, France

06/2015—07/2015 Visiting Professor at Institute for Theoretical Physics and Astrophysics, University of Würzburg, Germany

04/2014—06/2014 Visiting Professor at Institut Néel - CNRS, Grenoble, France

04/2011—09/2011 Visiting Professor at Instituto de Ciencia de Materiales de Madrid, Madrid, Spain.

03/2009—06/2009 Visiting scientist at Instituto de Ciencia de Materiales de Madrid, Madrid, Spain.

01/2005—Present Associate professor in condensed matter/theoretical physics.

02/2000—03/2000 Assistant professor (Maitre de conference) Université Joseph Fourier, Grenoble, France.

05/1996—07/1996 Assistant professor (Maitre de conference) Université Joseph Fourier, Grenoble, France.

12/1995—01/2005 Researcher in the Department of Physics, University of L'Aquila.

06/1995—11/1995 EU-Fellowship (Human Capital Mobility) Universitat de les Illes Balears on *"Fluctuation phenomena in laser light statistics"*.

04/1992—12/1995 Researcher in the Department of Chemistry, University of Basilicata.

10/1991 PhD degree in Applied Electromagnetism and Solid State Physics, University of Rome "La Sapienza", thesis entitled *"Non Linear Fluctuations in Transition Phenomena"*.

11/1990—04/1992 Permanent position (researcher) in ENEA (National Agency for Energy and Environment) Department of Robotics.

11/1986—12/1987 Military service.

02/1986—09/1986 Fellowship at Fondazione Ugo Bordoni, Italian Post Office Research Laboratory, Rome, concerning the experimental characterization of the partition noise in a semiconductor lasers.

12/1985 First degree in Physics *cum laude*, University of Rome "La Sapienza", thesis entitled *"Non Linear Relaxation in Disordered Magnetic Systems"*.

## Teaching

### Courses

1998-present - Course of Statistical Mechanics (Master degree in Physics, University of L'Aquila)

2007 2009-present - Course of Quantum Mechanics (degree in Physics, University of L'Aquila)

2008 - Course of Quantum Mechanics (Master degree in Mathematics, University of L'Aquila)

2005-2007 - Course of Electromagnetism (degree in Mathematics, University of L'Aquila)

2005 - Course of Physics (degree in Biotechnology, University of L'Aquila)

1998 - Course of strongly interacting electron-phonon systems (PhD in physics, University of Cagliari)

1997 - Course of strongly interacting electron systems (PhD in physics, University of L'Aquila)

### Lectures

2019 - "Introduction to open classical and quantum system", LLPMC and Institut Néel, Grenoble

2015 - "Introduction to open classical and quantum system:a short course on the blackboard", University of Würzburg

2013 - A short course on disordered systems (PhD in physics, University of L'Aquila)

2007 - Introductory lectures course of quantum dynamics (PhD in physics, University of L'Aquila)

2006 - Introductory lectures course of Superconductivity (PhD in physics, University of L'Aquila)

2005 - "Dynamical mean field approach in interacting electron-electron and electron-phonon systems: an introduction with some selected applications", International School of Physics "Enrico Fermi" "Polarons in Bulk Materials and System with Reduced Dimensionality", Varenna, Italy

1994 - "Polarons and superconductivity", introductory lectures to the International Conference *Euroconference on Physics of Unconventional Superconducting Materials* Pisa, Italy

## Exercises

1999-2006 - Exercises of Quantum Mechanics (first degree in Physics, University of L'Aquila))

1995-1999 2002 - Laboratory exercises, laboratory of physics (degree in Biology, University of L'Aquila))

1993-1995 - Exercises of classical physics (degree in Mathematics, University of Basilicata))

1992-1993 - Exercises of electromagnetism (degree in Chemistry, University of Basilicata))

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## PhD thesis

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| 2005 | dr. G. Rastelli, Universitá de L'Aquila, *Wigner crystallization in polarizable and anisotropic systems* |
| 2006 | dr. S. Paganelli, Universitá di Bologna, *Coherent dynamics of quantum systems in a many body environment* |
| 2007 | dr. Giulia De Masi (co-tutor), Universitá de L'Aquila, *"Statistical Properties and Dynamical Evolution of Complex Networks"* |
| 2012 | dr. D. Di Sante (co-tutor), Universitá Universitá de L'Aquila, *Modeling cross coupling interactions in advanced materials* |

## Organization

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| 2000-present | Member of the PhD council, Dept. of Physics University/Dept. of Physical and Chemical Sciences of L'Aquila |
| 2003-2004 | Member of the Department fellowships panel, Department of Physics University of L'Aquila |
| 2000-2005 | P.I. INFM sect. C "Electron-phonon interaction in intermediate coupling regime" |
| 1997-2009 | Member in charge of the group of Statistical Mechanics, Department of Physics University of L'Aquila |
| 2018-present | Member of the Department resarch panel, Dept. of Physical and Chemical Sciences of L'Aquila |

## Congress Organization

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| 2016 | MiniWorkshop Strongly disordered systems in condensed matter and cold atoms, LLPMC, Grenoble, France |
| 2016 | Giornata in ricordo di Giovanni Paladin, DSFC, L'Aquila, Italy |

## Research projects and funding

2018 - Funding of Base Research Projects (Finanziamento delle attività base di ricerca) .

2007-2009 - Investigator in the L'Aquila unit of the national research project PRIN MIUR *"Strong correlation effects in non conventional materials and/or under extreme physical conditions: models and methods."* .

2005-2007 - Investigator in the L'Aquila unit of the national research project PRIN MIUR *"Ionic effects in metal-insulating transitions."* .

2003-2005 - Principal investigator of L'Aquila unit of the national research project PRIN MIUR *"Theoretical physics, models and mathematical methods"* .

2002-2004 - Investigator INFM Unit Roma "La Sapienza" of the PRA project *"UMBRA - Understanding MgB2: Research and Applications"* .

2001-2003 - Principal investigator of L'Aquila unit of the national research project PRIN MIUR *"Statistical physics of complex quantum and classical systems"* .

1997-2003 - Principal investigator of the National Institute of Matter Physics (INFM) research line *"Electron-phonon interaction at intermediate/large couplings"* INFM L'Aquila.

1999-2001 - Principal investigator of L'Aquila unit of the national research project PRIN MURST *Statistical physics and condensed matter theory* .

1999-2001 - Research advisor of the INFM (PAIS) fellowship *"Strongly coupled electron-phonon system"*, INFM L'Aquila.

1997-1999 - Principal investigator of L'Aquila unit of the national research project PRIN MURST *"Statistical mechanical models and strongly correlated systems"* .

## Current Research Topics

### Transport in organic systems and at organic/inorganic interfaces

In a strict collaboration with Simone Fratini (CNRS Grenoble), we develop along the last decade a formalism which is able to explain and predict the intrinsic mobility of crystalline organic semiconductors. The charge mobility of molecular semiconductors is limited by the large fluctuation of intermolecular transfer integrals, often referred to as off-diagonal dynamic disorder, which causes transient localization of the carriers' eigenstates. We develop a *transient* localization theory which recently evolves in *dynamical* localization correction (DLC) theory which interpolates from the standard Bloch-Boltzmann theory to the Anderson localization state. This research has significant impact for the optimization of organic semiconductor characteristics.

### Strongly correlated systems: Divergent Precursors of the Mott-Hubbard Transition at the Two-Particle Level

Is the normal phase close to the Metal to Insulator Transition really *normal*? We address this question using Dynamical Mean Field Theory as well as analytical calculations in the Hubbard model. In a joint collaboration with several researches from European institutions we where able to detect, for the first time, an hidden divergence of the local Bethe-Salpeter equation in the charge and particle-particle channel which sets a precise boundary *within* the normal metallic phase. We provide a comprehensive understanding of this elusive phenomenon by describing the local two-particles correlators in different channels (spin,charge,pairing) in terms of a suitably defined correlation functions. This analys lead recently to unveil unexpected "attraction-from-repulsion" mechanism which can occur in the vicinity of a metal-insulator transition driven by short range electronic repulsion. This mechanism could be of relevance in explaining the high temperature superconductivity in oxides which remains an open problem since its discovery in the eighties.

### Strongly disordered metallic systems

In collaboration with S. Fratini (CNRS, Grenoble), V. Dobrosavljević (SMFL and Florida State University Tallahassee, FL, USA) and D. Di Sante (University of Würzburg, Germany) we developed a local theory which is able to explain the large temperature behaviour of strongly disordered metals beyond the so-called Mott-Ioffe-Regel limit, solving the unsettled question of universality of the correlations between the temperature coefficient of the resistivity and its residual ($T = 0$) value. The disorder-driven metal-insulator transition is fundamentally changed (e.g. in its critical exponents) with respect to the non-interacting (Anderson) scenario. The formalism developed here is able to be generalised in the presence of long-range electron-electron interaction and we are currently working in this direction.

## Referee

Referee for Physical Review Letters, Nature Communications, Physical Review B, and E, J. Chem. Phys., Europhysics Letters, European Journal of Physics B, J. Phys.: Condens. Matter, Physica C

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## Editorial Board

Editorial Board of Condensed Matter

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## Selected publications

- M. Reitner, P. Chalupa, L. Del Re, D. Springer, **S. Ciuchi**, G. Sangiovanni, and A. Toschi
  *"Attractive effect of a strong electronic repulsion – the physics of vertex divergences"*
  Phys. Rev. Lett. **125**, 196403 (2020).
  In this paper we finally identify an important physical consequence of the divergences found in the analysis of the two-particle correlations in ref. Phys. Rev. Lett. **110**, 246405 (2013). These divergences signal the onset of effective attraction in short-range repulsive electronic systems near a metal to insulator transition. However as *effective* attraction this phenomena could not simply trigger a superconducting state via usual $s$-wave pairing, neither a charge ordering. On the other hand it this unexpected "attraction-from-repulsion" mechanism could be of relevance in explaining the high temperature superconductivity in oxides which remains an open problem since its discovery in the eighties. Press release

- S. Ciuchi, D. Di Sante, V. Dobrosavljević and S. Fratini
  *"The origin of Mooij correlations in disordered metals"*
  npj Quantum Materials **3**, 44 (2018).
  In this paper we re-interpret a large series of experiments on transport measurements in strongly disordered metals which dates back to the 70's. A collection of these experiments appeared in C.C. Tsuei Phys. Rev. Lett. **57**, 1943 (1986). We here criticize the traditional "weak localization" scenario supported by Tsuei. Instead we formulate a strong-coupling approach which is able to explain both the typical values of resistivity and its apparent spread in much different samples. More specifically we formulate a strong-coupling approach to tackle the interplay of strong disorder and lattice deformations (phonons) in bulk three-dimensional metals at high temperatures. We identify a polaronic mechanism of strong disorder renormalization, which describes how a lattice locally responds to the relevant impurity potential. This mechanism is physically distinct and unrelated to Anderson localization, but realizes early seminal ideas of Anderson himself (P. W. Anderson, Nature, 235, 163 (1972)), concerning the interplay of disorder and lattice deformations.

- S. Fratini, S. Ciuchi, D. Mayou, G. Trambly de Laissardiére and A. Troisi
  *"A map of high-mobility molecular semiconductors"*

Nature Materials **16**, 998 (2017).
In this paper we rationalize, using the " transient localization" scenario, the transport properties of many cristalline molecular semiconductors where both band and hopping transport theories fails. This paper is important because it provides a unified theory by which it is possible to screen many, still non existing, compounds and design new ones with optimal transport characteristics. A Nature *News & Views* describe this work.

- Domenico Di Sante, Simone Fratini, Vladimir Dobrosavljević, and Sergio Ciuchi
  *"Disorder-driven metal-insulator transitions in deformable lattices"*
  Phys. Rev. Lett **118** 036602 (2017).
  In this paper we address the problem of Anderson Metal-Insulator transition in the presence of non negligible interactions between the carriers and the host lattice. This paper is important because it provides a first microscopic model calculation to the early intuition by Anderson (P. W. Anderson, Nature, 235, 163 (1972)), that a positive correlation between disorder trapping potential and self-localization effects may take place in a deformable lattice. Explicit calculations show that for strong disorder, even a modest electron-phonon interaction is found to dramatically renormalize the random potential, opening a mobility gap at the Fermi energy, however the transition still remains continuous in nature.

- T. Schäfer, G. Rohringer, O. Gunnarsson, S. Ciuchi, G. Sangiovanni, A. Toschi
  *"Divergent Precursors of the Mott-Hubbard Transition at the Two-Particle Level."*
  Phys. Rev. Lett. **110**, 246405 (2013).
  Is the normal phase close to the Metal to Insulator Transition really *normal*? We address this question using Dynamical Mean Field Theory as well as analytical calculations in the Hubbard model. We where able to detect a divergence of the local Bethe-Salpeter equation in the charge channel which sets a precise boundary *within* the normal metallic phase. Beyond this limit the use of perturbation theory-derived approaches could be questionable (see e.g. E. Kozik et al., Phys. Rev. Lett. 114, 156402 (2015)). Recent results seems to indicate that this result is more general and similiar features are present also in continuum models (see A. Stan et al. New. J. Phys. 17, 093045 (2015)).

- S. Ciuchi S. Fratini
  *"Band dispersion and electronic lifetimes in crystalline organic semiconductors"*
  Phys. Rev. Lett. **106**, 166403 (2011).
  In organic semiconductors (OSC) the polaronic nature of carriers is often taken as paradigm to understand their transport properties. However standard polaronic theories relies on the dominant molecular character of the materials which can be not so clear in the case of the compounds with wider bands. In this paper we simulate the output of an angular resolved photoemission spectroscopy (ARPES) experiment using an OSC model which takes into account several sources of interactions affecting the carriers such as disorder and electron-lattice with intramolecular and in-

termolecular displacements. The temperature dependence of the features of the ARPES spectra allows to rule out the polaronic scenario for OSC such as Pentacene or Rubrene.

- S. Fratini and S. Ciuchi
  *"Band-like motion and mobility saturation in organic molecular semiconductors"*
  Phys. Rev. Lett. **103**, 266601 (2009).
  This paper represent an important step to understand the disputed nature of transport in intrinsic organic single crystal semiconductors (see e.g. A. Troisi Chem. Soc. Rev. 40, 2347 (2011)). Using the Kubo formula for electrical conductivity, we show that the large thermal lattice fluctuations associated to the weak van der Waals inter-molecular bonding induce a crossover in mobility from a band-like behaviour to a "resistivity-saturated" regime in which the transport is non coherent but with no sign of thermally activated hopping characteristic of carrier self-localization. As a consequence this crossover can be understood from the simultaneous presence of band carriers and incoherent states that are dynamically localized by the thermal lattice disorder.

- S. Paganelli S. Ciuchi
  *"Tunnelling system coupled to an harmonic oscillator: an analytical treatment"*
  J. Phys.: Condens. Matter **18** 7669-7685 ( 2006).
  In this paper we give an analytical formula in term of a continued fraction expansions for the spectral function of a tunnelling electron, coupled to a local lattice oscillation at non-zero temperature. This allows us to revise critically universally accepted analytical approaches valid in the non-adiabatic limit. This paper has triggered later research on the coherence and entanglement evolution of coupled tunneling-vibron systems (see e.g. H. Hossein-Nejad et al. New. J. Phys. 12, 065045 (2010))

- I. N. Hulea , S. Fratini, H. Xie, C.L. Mulder, N.N. Iossad, G. Rastelli, S. Ciuchi, and A. F. Morpurgo
  *"Tunable Fröhlich Polarons in Organic Single-Crystal Transistors"*
  Nature Materials **5**, 982 (2006).
  This paper results as a fruitful collaboration with the experimental group of A. Morpurgo. We were able to explain in therm of purely interface-induced interaction of polaronic origin the characteristics of several Organic Field Effects Transistors (OFET) made with different gate materials. A *News & Views* describe this work. This work represent one of the most succesful attempt to study the high polarizability gate effects on to the carrier motion (see the review A. Troisi Chem. Soc. Rev. 40, 2347 (2011)). The physics of the polar interactions at interfaces has also been relevant in different fields such as graphene (S. Fratini and F. Guinea Phys. Rev. B 77, 195415 (2008)). The collaboration with A. Morpurgo has continued with further publications (see eg. N. Minder at al. Adv. Mater. 26, 1254 (2014)]) as well as with the publication of a general form for the theory of interacting polarons activation (S. Ciuchi et al. Phys. Rev. B **79** 035113 (2009)).

- S. Fratini, S. Ciuchi
  *"Dynamical Mean-Field Theory of Transport of Small Polarons"*
  Phys. Rev. Lett. **91**, 256403 ( 2003).
  In this paper the low density transport properties for charges interacting with phononic degree of freedom are analyzed as a function of the temperature and of the coupling with phonon using Dynamical Mean Field Theory. An analytic scaling law for resistivity is also provided. This paper is important because it shows that a single theory is able to span continuously across the polaron crossover describing both the weak scattering as well as the activated regimes. Later has been recognized that this theory is of high relevance in the case of organic semiconductors (see the review by V. Coropceanu, J. Cornil,D.A. da Silva, et al. Chem. Rev., 107 (4), 926 (2007)).

- M. Capone, S. Ciuchi
  *"Polaron Crossover and Bipolaronic Metal-Insulator Transition in the half-filled Holstein model."*
  Phys. Rev. Lett. **91**, 186405 ( 2003).
  In this paper we compare and disentangle the polaron formation mechanism and the metal insulator transition which can have a bi-polaronic origin in polaronic system. This paper is important from both methodological and technical reasons. From a general point of view it clearly states that the conditions for polaron formation is not generally equivalent to those that guarantee the bi-polaronic metal to insulator transition. These two concept were often confused in the literature. From a technical point of view we devise a method based on exact diagonalization by Lanczos technique which allow to attack non perturbatively the many-polaron system. This method is crucial to analyze correctly the polaronic region of the system in the presence of Hubbard repulsion as was done later on (see a series of publications and among all G. Sangiovanni et al. Phys. Rev. Lett. 94, 026401 (2005)).

- S. Ciuchi F. de Pasquale
  *"Charge ordered state from weak to strong coupling"*
  Phys. Rev. B **59**, 5431 ( 1999).
  This paper presents a study of the Charge Ordered State spanning from the weak to the strong coupling using Dynamical Mean Field Theory. The importance of this paper is that it qualitatively and quantitatively identify the difference between weak and strong coupling charge ordered state. It can be proved that the the charge ordering scenario spanning from weak to strong coupling is qualitatively similar to that of the Bose-Einstein to BCS crossover for the superconducting transitions. The strong coupling scenario proposed here is of relevance for the case of rare earth manganates (see e.g. the review paper by C. N. R. Rao et al J. Phys.: Cond. Mat. 12 R83-R106 (2000)). The approach presented here has been extended successively by Millis and coworkers to include quantum phonons (S. Blawid and A. J. Millis Phys. Rev. B 63 115114 (2001)).

- S.Ciuchi F.de Pasquale S. Fratini and D.Feinberg
  *"Dynamical mean-field theory of the small polaron"*
  Phys. Rev. B **56**, 4494 ( 1997).

This paper presents for the first time the full semi-analytical solution to the single particle spectral properties of the small polaron. The method presentd in this paper is also at the basis of our subsequent research on the t-J Holstein model. Several modern approaches, among all the Momentum Average Approximation by M. Berciu and co-workers, are based on this non perturbative treatment (M. Berciu Phys. Rev. Lett. 97 036402 (2006)). As our results were preliminary presented at conferences and in letter format they were also acknowledged in the most-cited review on Dynamical Mean Field Theory by A. Georges et. al (A. Georges, G. Kotliar, W. Krauth and M. Rozenberg, Reviews of Modern Physics 68, 13-125 (1996)).

- D.Feinberg, S.Ciuchi, F.de Pasquale
  *"Squeezing phenomena in interacting electron-phonon systems"*
  International Journal of Modern Physics B **4**, 1317 ( 1990)
  This review paper approach the problem of polaron formation as a function of the coupling of the charge carrier to the lattice with analytical and numerical techniques. An unified discussion of the phase diagram of the single polaron is carried on and non-gaussian fluctuation regime, reminiscent of squeezing phenomena occurring in quantum optics, was found at the crossover . Renewed interest in this approach arose in the context of mesoscopic quantum physics (see A. Zazunov et al. Phys. Rev. Lett. 97, 196801 (2006)).

- S.Ciuchi, F.de Pasquale
  *"Non linear relaxation and ergodicity breakdown in random anisotropy spin glasses"*
  Nucl. Phys. **B300** [FS22)] ( 1988).
  This paper presents for the first time the full analytical time-dependent solution of the spherical p=2 spin model for spin glasses starting from different initial condition. The non-linear relaxation regime is analyzed looking at different single or two spin properties. This paper acquired renewed attention in connection of the dynamical properties of models for the glass transition (see e.g. the review Crisanti, A., Ritort, F. Journal of Physics A: Math. Gen. 36 (21), pp. R181-R290 (2003)). In our subsequent research we studied the finite size corrections leading to a long time regime in which ergodicity is finally restored as well as we generalize this dynamical study to the p=2+n models which can be relevant models for the study of glassy relaxation.

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## Invited talks and lectures

- "Disorder-induced polarons in strongly disordered metals"
  CECAM Workshop "Polarons in the 21st Century" Wien, Austria 2019

- "Dynamics of Electrons at Organic/Dielectric Interface"
  6th Workshop on Molecular Theories and Simulations, Gaeta, Italy 2007

- "Dynamical mean field approach in interacting electron-electron and electron-phonon systems: an introduction with some selected applications" (lec-

tures)
"Polaron Crossover vs Bipolaronic Metal-Insulator Transition in the Holstein model at half-filling" (seminar)
International School of Physics "Enrico Fermi" "Polarons in Bulk Materials and System with Reduced Dimensionality", Varenna, Italy 2005

- "Dynamical Mean Field Theory of small polarons"
  Electronic Properties of Organic Semiconductors, Leiden 7 - 11 Luglio 2003.

- "Dynamical Mean Field Theory of charge ordered systems"
  VII Natl. congress on statistical physics and complex systems, Universita' degli Studi di Parma 3 - 5 Giugno 2002.

- "Optical conductivity of small polarons",
  Polaron Effects in Cuprates and Manganites, Villa Orlandi - Anacapri, Italy 2000

- "Polarons and superconductivity",
  introductory lectures to the Intnl. Conf. Euroconference on Physics of Unconventional Superconducting Materials, Pisa, Italy 1994

- "Electron-phonon interaction in high dimensions",
  XIII National Congress on Theoretical Physics and Condensed Matter Fai della Paganella, Italy 1994

- "Superconductivity and density waves in high dimensions",
  Intl. Conference Superconductivity and Strongly Correlated Electron Systems, Amalfi, Italy 1993