MICHELE SIMIONATO

C.V. - RESEARCH ACTIVITY AND PUBLICATIONS

1 Short CV

1.1 Personal data

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1.2 Experience

Laurea in Physics:	University of Padova, February 23, 1994 with highest grade and cum laude.
Thesis:	“Formulazione geometrica di teorie di supergravità in diverse dimensioni”
Advisor:	Prof. Mario Tonin.
Corso di Perfezionamento:	University of Padova, March-October 1994
Thesis:	“Invarianza BRST e quantizzazione delle teorie di Yang-Mills”
Ph. D. :	University of Parma, May 6, 1998
Thesis:	“Azione wilsoniana e risommazione della teoria delle perturbazioni”
Advisor:	Prof. G. Marchesini, Dr. M. Bonini
Post-Doc:	LPTHE Jussieu - Paris from March, 1998 up to September, 2001
Post-Doc:	University of Pittsburgh from October, 2001
At the moment working on:	Non-Equilibrium Quantum Field Theory and Early Universe Cosmology
Teaching:	Undergraduate lectures on Astrophysics at Pitt
Languages:	Italian, English, French

2 Scientific Activity

In the last years I have mostly worked on Out-of-Equilibrium Quantum Field Theory and its applications. Out-of-Equilibrium QFT is especially needed in the study of the Early Universe Physics and in Heavy Ion collisions since in these situations the time evolution of the system is so rapid that a local thermodynamical equilibrium assumption cannot hold; moreover a full relativistic treatment is needed. For sake of discussion, Out of Equilibrium QFT can be split into two different realms: the realm of systems strongly out of equilibrium and the realm of systems weakly of equilibrium. Both from the physical and the technical point of view, the two realms are very different and are studied with completely different tools. As it can be expected, strongly out of equilibrium systems are much more difficult to study and their analysis is at the very beginning. The systems where we have the most of information and understanding are simple systems containing scalar fields, like the $O(N)$ linear sigma-model which has been understood well enough in the large N limit, or in similar frameworks such as the Hartree-Fock approximation, where the theory is gaussian-like [1], at least for homogeneous systems. The non-homogeneous situation is numerically challenging but within the reach of present day computers [3]. The study of next-to-leading corrections has been started very recently and it looks very promising [2]; the same can be said for what concerns even the leading order in $1/N$ for more complicate systems like Yukawa systems or quantum electrodynamics.

On the other hand, much more has been understood in the case of weakly out of equilibrium systems, in which there are standardized methods to attack the problem. The fundamental tool to perform the study of weakly out of equilibrium systems is linear response theory. Consider a system near equilibrium, i.e. with a density matrix equal to a thermal density matrix except for a small disturbance, which can be imputed to the presence of a set of small external sources $J^i(x)$ coupled to the fundamental fields $\phi^i(x)$ of the system. The only non-equilibrium effects, neglecting quadratic effects in J, are in the evolution of one-point functions $< \phi^i(x) >_\rho$ and two-point functions $< \phi^i(x)\phi^j(y) >_\rho$. Since the density matrix is nearly thermal, methods of thermal field theory can be used and the evolution can be studied in principle by using perturbation theory, i.e. by computing thermal Feynman diagrams. The difficulties come from severe infrared divergences which invalidate naive perturbation theory and require resummation of infinite sets of diagrams. Eventually, under certain conditions, the effect of this resummation is believed to be equivalent to a phenomenological effective classical kinetic theory, based on a quantum-relativistic Boltzmann equation. However the precise correspondence within the classical theory and the underlying quantum field theory is not very well understood, except in the case of the ϕ^4 theory [4]. In my work, I was particularly interested in studying situations under which the kinetic approximation *fails*, the approach to thermalization is subtle and non-equilibrium effects are expected to play a major role.

2.1 Activity on Non-Equilibrium Quantum Field Theory and Cosmology

I focused my activity on Out-of-Equilibrium QFT on the analysis of electromagnetic signatures of non-equilibrium system. This has consequences not only in Heavy Ion physics but also in Cosmology, specifically on the problem of generation of magnetic fields during the first phases of the evolution of the Universe.

- **[SQED]** *Non-Equilibrium Quantum Plasmas in Scalar QED: Photon Production, Magnetic and Debye Masses and Conductivity*, D. Boyanovsky, H. J. De Vega, M. Simionato, hep-ph/9909259, 55pp. Published in Phys. Rev. D61: 085007, 2000.

  This was one of the first papers in the literature studying strongly out of equilibrium aspects of quantum electrodynamics. Here we studied possible signatures of strongly out of equilibrium processes, which eventually appear in Heavy Ions Collisions or in the Early Universe. Questions we have analized are the photo-production process, the dynamics of the electrical conductivity, and the generation of magnetic and electric mass for the photon in scalar QED, using the non-perturbative 1/N expansion.

- **[M1]** *Magnetic Field Generation From Nonequilibrium Phase Transitions*, D. Boyanovsky, M. Simionato, H.J. de Vega, hep-ph/0208272, 37pp. To be published in Phys. Rev. D

  In this paper we extend the analysis given in **[SQED]** focusing on the analysis of the magnetic field spectrum from strongly out of equilibrium phase transitions. The motivation is to apply this kind of analysis, here for semplicity developed in Minkowski space-time, to cosmological space-times, with the aim of understanding primordial magnetic fields generated during the early stages of evolution of the universe. With this in view, we study in detail the effect of the electrical conductivity on the generation of long wavelenghts magnetic field;

we prove that the amplitude of the magnetic field is strongly suppressed and that its correlation lenght is of order of the correlation lenght of the scalars.

- **[M2]** *Large scale magnetogenesis from a non-equilibrium phase transition in the radiation dominated era*, D. Boyanovsky, M. Simionato, H.J. de Vega, hep-ph/0211022, 25pp. Submitted to Phys. Rev. D.

  In this second paper we apply the framework developed in **[M1]** to the analysis of the magnetic spectrum generated by non-equilibrium effects during a second order phase transition at the beginning of the the radiation dominated era. The new effect is a very strong production during the scaling regime epoch of the phase transition which maybe enough to produce the seeds needed to explain the cosmic magnetic fields observed today on the Megaparsec scale, if the scaling regime endures until the electroweak phase transition.

2.2 Activity on Thermal Field Theory

I give now a short descriptions of my papers on (near) Equilibrium QFT, made in collaborations involving H.J. De Vega (LPTHE, Paris), D. Boyanovsky (University of Pittsburgh), R. Holman (Carnegie Mellon University).

- **[DRG]***Dynamical Renormalization Group Resummation of Finite Temperature Infrared Divergences*, D. Boyanovsky, H. J. De Vega, R. Holman, M. Simionato, LPTHE-98-08, PITT-98-08, hep-ph/9809346, 36pp. Published in Phys. Rev. D60, 065003, 1999.

  In this paper we studied the anomalous relaxation of scalar fluctuations in high temperature scalar QED,as a model for understanding the infrared singularities involved in the computation of the fermion damping rate. Consistently with previous work in the literature, [5] we show that the relaxation is non-exponential. The new point is that the infrared divergences are managed by using the Dynamical Renormalization Group approach (DRG). The DRG is a general method of solution for differential equations (initial value problems) which consists in a resummation of the secular terms appearing in the naive perturbative solution, and it is valid even for asymptotically large times. The same method has been successfully applied in a variety of situations [6].

- **[CSD]** *Relaxing near the critical point*, D. Boyanovsky, H. J. De Vega, M. Simionato, LPTHE-00-16, hep-ph/0004159 , 41pp. Published in Phys. Rev. D63:045007, 2001.

  Here we studied the thermalization rate for critical systems. By considering a scalar $O(N)$ model at the critical temperature and working non-perturbatively at next-to-leading order in the large N expansion, we found a critical slowing down behavior for long wavelengths. This means that the time needed to thermalize long wavelengths fluctuations (i.e. homogenous field configurations) increases up to infinity. This fact has phenomenological consequences, since it means that near a second order phase transition one should expect sensible deviation from equilibrium for the distribution functions of soft particles.

- **[LP]** *The Landau Pole at Finite Temperature*, H. J. de Vega and M. Simionato, hep-ph/0011268, 6 pp. Published in Phys. Rev. D64: 021703, 2001.

  This paper differs from the others since it addresses a purely equilibrium issue, i.e. how the position of the ultraviolet Landau pole changes for a trivial theory when the existence of a medium at temperature $T \neq 0$ is taken in account. We found analytically in the case of the $O(N)$ linear sigma model that the Landau pole position increases with the temperature, i.e. the range of validity of the theory increases when there are in-medium effects. As a consequence the theory behaves perfectly well even at temperatures well beyond the zero-temperature Landau pole (which I remind can be at low energies for strongly coupled theories, like for instance the pion $O(4)$ model).

2.3 Activity on Wilson Renormalization Group

My scientific activity during my Ph. D. years was about gauge theories in the Wilson Renormalization Group Approach. In particular I refer here to a recent formulation in which one studies the Exact Renormalization Group Equation (ERGE) of the Euclidean one-particle-irreducible effective action $\Gamma(\phi, \Lambda)$ where the Wilsonian scale Λ is interpreted as an infrared cutoff. This is a more elegant formulation of the Wilson's renormalization group equation (others well known forms of the evolution equation where given by Wegner and Houghton and by Polchinski) first introduced (independently) by Wetterich [7] and Bonini, D'Attanasio, Marchesini [8]. The equation for the Wilsonian effective action can be obtained from the equation for the 1PI effective action via a Legendre transformation and they are mathematically equivalent; however for many applications, both perturbative and non-perturbative, the equation on $\Gamma(\phi, \Lambda)$ is much more convenient.

While the nonperturbative analysis of the ERGE equation (with particular interest to the computation of critical exponents in three-dimensional scalar theories) have been extensively studied by many authors [9], the perturbative expansion has been the preferred subject of study of Bonini and Marchesini and collaborators, including myself, as well of others [10]. A great advantage of the perturbative studies, is that it is possible to have a clear understanding of the problems encountered in extending the Wilsonian formalism to gauge theories, i.e. the problems due to the breaking of gauge-invariance. In particular, in perturbation theory it is possible to solve the so-called fine-tuning equations which say how to fix the ultraviolet non-invariant action in terms of renormalized parameters in such a way than the physical action becomes consistent with the gauge-symmetry (i.e. with the Ward-Takahashi or Slavnov-Taylor identities).

My Ph. D. thesis consisted in the analysis of the consistency of suitable approximation schemes for solving the evolution equation for gauge theories in the perturbative region, by implementing some kind of resummation, i.e. expanding in terms of a scale-dependent coupling constant.

- **[REN]** *Beta function and flowing coupling in the exact Wilson renormalization group in Yang-Mills theory*, M. Bonini, G. Marchesini and M. Simionato, UPRF-96-464, IFUM-525-FT, hep-th/9604114, 19pp. Published in Nucl. Phys. B483 (1997) 475.

  In this paper we introduced a general scheme to generate an improved (resummed) perturbative solution of the ERGE and we applied it to QCD. We shown that in this context the infrared Landau pole can be avoided, giving support to the view that it is only an artifact of the usual RG-improved perturbation theory. The philosophy is that it should be possible to define a kind of effective running constant well behaved in the infrared. This is indeed the case in the Wilsonian approach. However the problem of the approach as presented here was the consistency with gauge-invariance. To elucidate this problem we studied in detail the case of abelian gauge theories in the (unpublished) paper **[BS]** *Wilson renormalization group and improved perturbation theory*, M. Bonini, M. Simionato, UPRF-97-05, hep-th/9705146, 24pp. There we shown that the improved perturbation theory is indeed consistent with gauge-invariance, at the physical scale $\Lambda = 0$ even if in the loop computations one uses a Ward identities-breaking infrared cutoff.

- **[QED]** *Gauge Consistent Wilson Renormalization Group I: The Abelian Case*, M. Simionato, UPRF-98-08, LPTHE-98-08, hep-th/9809004, 34pp. Published in Int.J. Mod. Phys. A15:2121, 2000.

  Motivated by the need to improve the formulation in **[REN]**, which cannot be easily implemented in the non-abelian case beyond the one-loop level, in this paper I have reconsidered the abelian-case. The essential point was to recognize that the simplest way to introduce an infrared cutoff in a theory, i.e. by giving a mass to all massless fields, can be reinterpreted in a Wilsonian way (this is non-trivial, however, since the would-be ERGE requires an explicit ultraviolet regularization in order to be well defined). Then the ERGE can be immediately identified with the Callan-Symanzik equation. The big advantage of this formulation is that it is consistent with the Ward-Takahashi identities to all orders in perturbation theory.

- **[NC]** *Gauge Consistent Wilson Renormalization Group II: The Non-Abelian Case*, M. Simionato, UPRF-98-10, LPTHE-98-10, hep-th/9810117, 33pp. Published in Int.J. Mod. Phys. A15:2153, 2000.

  The other advantage of the formulation introduced in **[QED]** relies on the fact that it can be extended to the non-abelian case provided we work in algebraic noncovariant gauges. The crucial point is that the introduction of the Wilsonian infrared cutoff as a mass term for the gauge field minimize the problem of the gauge-symmetry breaking, which is harmless in the gauge of non-covariant gauge-fixing, in the sense that the Ward-Takahashi identities are preserved to all scales. Moreover renormalizability and unitarity are preserved, but not the Lorentz-covariance, which is broken, at $\Lambda \neq 0$, even for would be physical quantities. This is the reason why the infrared cutoff *must* be removed, at the very end, in order to recover the physical theory.

- **[ANC]** *On the Consistency of the Exact Renormalization Group Approach Applied to Gauge Theories in Algebraic Non-Covariant Gauges*, M. Simionato, LPTHE-00-18, hep-th/0005083, 48pp. Published in Int. J. Mod. Phys. A15:4811, 2000.

  Since algebraic noncovariant gauges are typically very subtle and very singular, at least in perturbative applications, I performed a careful study of the infrared limit $\Lambda \to 0$ in various gauges. In particular, I found that the perturbative expansion in the axial gauge is plagued by unphysical infrared divergences in the $\Lambda \to 0$ limit, which appears even in the computation of a would be physical quantity like the Wilson loop corresponding to the interquark potential. On the contrary, as expected, the light-cone gauge with the Mandelstan-Leibbrandt prescriprions, which comes *automatically* in the Wilsonian formalism, is perfectly consistent and well behaved with respect to the perturbative expansion. The the program of **[REN]** can be successfully implemented.

3 Teaching experience

In the spring 2002 I taught part of the undergraduate Astrophysics Course of the University of Pittsburgh, giving lectures on black holes, cosmology and dark matter.

4 Programming

I also have a pretty good expertise in programming and I am the author of two papers on Object Oriented Programming:

- *Metaclass programming in Python* in collaboration with David Mertz and published by IBM developerWorks:
  `http://www-106.ibm.com/developerworks/library/l-pymeta.html`

- *The Python 2.3 Method Resolution Order* available at the Python 2.3 official web-page:
  `http://www.python.org/2.3/mro.html`

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