Enrico Onofri

Curriculum Vitae et Studiorum

Parma - May 2017

1. Academic profile

- Chairman of "Gruppo Collegato INFN di Parma", Sez. Milano-Bicocca, 2007–2013.
- Deputy Vice-Rector of the University of Parma, with responsibility over the organization of Doctoral Courses, 2004-2012.
- Member of the National Steering group for the reform of Academic curricula, responsible for the *Mathematics, Physics and Computer Science* sector, leading to the present law about University Classes (1998-99).
- Dean of the Faculty of Science, Univ. of Parma, 1995–1999
- Full Professor in Theoretical Physics, Univ. of Parma, 1990-2016 (date of retirement)
- Full Professor in Theoretical Physics, Univ. of Trento, 1986–1989
- Summer visitor at CERN (1986, 2003), Fermi Nat'l Accel. Lab. (1987, 1992, 1995, 2003), Brookhaven Nat'l Lab. (1989, 1995), Université de Montpellier II, LPTA (2001–2002, 2004–2008)
- Associate Professor, University of Parma, 1983–1986
- Fellow at CERN, Theory Division (1981–1982)
- Visiting Fellow, Dept. of Physics, Princeton University (Nov.1975–Sept.1976)
- Assistant Professor, University of Parma, (1970–1980)
- Degree in Physics cum laude, University of Parma, Italy (1968).

2. Scientific Research

The dominant theme in E.O.'s research has been the application of modern mathematical methods (Differential Geometry, Group Theory, Topology, Functional Analysis, Numerical Analysis, Discrete Mathematics) to various branches of Theoretical Physics. For the most part his scientific production is a result of collaboration with other scientists, notably **V. Fateev, J. R. Klauder, G. Marchesini, P. Menotti, G. Veneziano, M. Virasoro** and many others, among whom some of his former students, **C. Destri, F. Di Renzo, G. Burgio, R. De Pietri, L. Scorzato** and recently with his close colleagues **G. Cicuta** and **M. Bonini**. The following is a sketchy presentation of topics and results, with the most relevant papers.

2.1. **Coherent States and Geometric Quantization.** E.O. has presented in a simple way the connection between Geometrical Quantization and the existence of a Coherent States basis; his main contribution ([72]) is cited in the literature among the papers of Perelomov and Kirillov (see Klauder and Skagerstam, "Coherent States", World Sci. 1985). In a subsequent paper with J. Klauder [47] it was shown how *Geometric Quantization is deeply connected to the Path Integral formulation of quantum mechanics in phase space*, through a mechanism very similar to the emergence of Landau levels in two dimensional electron films in a magnetic field. The main idea behind the 1989 paper is that the whole machinery of Geometric Quantization (the construction of a line bundle over phase space) can be reduced to the standard approach of quantization of gauge theories when one realizes the path integral in phase space by a *Wiener regularization* as suggested by Klauder. Coherent state techniques have been applied to the problem of Berry's phase, both Abelian and non-Abelian [46, 45]. In the paper [22] EO addresses the question of defining canonical operators starting from a compact phase space: the way out of the apparent difficulty *(a finite dimensional Hilbert space cannot host canonical operators)* is found in a rather surprising result: the $U(1)^2$ symmetry of the torus at the classical level is broken to $Z_N \times Z_N$ by quantum effects, where N^2 is the volume of phase space in $\hbar$ units, which is quantized in units $\hbar$, a result similar to Dirac's monopole quantization condition. In a subsequent paper [9] a spectral algorithm adapted to the quantum monopole problem has been used to demostrate the invariance of the degeneracy spectrum of Landau levels on the torus under perturbations respecting the anomalous $Z_N \times Z_N$ symmetry.

2.2. $1/N$ **expansion.** The interest in the "topological expansion" of Veneziano and 't Hooft brought to a series of papers where the quantum mechanical model introduced by Brezin et al was studied beyond the $U(N)$ invariant sector [67, 66]. The adjoint sector was solved in the limit of large N; the singular integral equation which was found in this study was subsequently useful in many other problems (see e.g. J.P. Rodrigues, JHEP, (2005), 0512, 043). The excited states problem in the large N limit was also studied in the collective field method introduced by Jevicki and Sakita (see [64]). A model similar to 't Hooft two dimensional QCD in the large N limit but dealing with baryons was studied in [65]. Only rather recently, E.O. came back to the study of the $1/N$ expansion following a paper of Veneziano and Wosiek where the large N limit was considered for supersymmetric quantum mechanics. The enumeration of independent strings of operators of the form $\mathrm{Tr}(a_1^\dagger\, a_2^\dagger \ldots a_n^\dagger)$ where a_i are $N \times N$ matrices with entries given by bosonic or fermionic operators, e.g. $\mathrm{Tr}(b^\dagger f^\dagger f^\dagger b^\dagger b^\dagger b^\dagger f^\dagger f^\dagger b^\dagger f^\dagger)$ was presented in [12]. The anticommutation properties of fermionic operators make the enumeration of non vanishing strings (words) a rather subtle combinatorial problem. Our solution gives an extension of Mac-Mahon and Polya formulae in a non commuting context. An extension of the results of Veneziano and Wosiek to the whole subspace of $U(N)$ invariant states for susy quantum mechanics was recently presented [11].

2.3. **CERN 1981–82.** As fellow at CERN, EO collaborated with several people *(M. Virasoro, V. Fateev, P. Menotti, G. Marchesini).* His interest was attracted by Lattice Gauge Theory and by the formulation of string theory introduced by Polyakov. The main achievement was the introduction of a special variation of the lattice action for any choice of gauge group, known as the "Heat kernel action" [62]. Following a study of Polyakov string theory with Virasoro [58], EO looked for an estimate which could prove the boundedness from below of Polyakov–Liouville action. The Moser–Trudinger inequality was indeed the right tool, but the result required to find the best constant in the inequality, which was not known: *the inequality with the best possible constant is now known as Moser–Trudinger–Onofri inequality in the mathematical literature* (see e.g. "google scholar: Moser Trudinger"). Other papers in this period cover some new results in the calculation of multidimensional integrals [63] and a variant of Villain's action in the non–abelian case [56] where algebraic identities were introduced which were subsequently rediscovered under various names, but essentially reduce to the modified ("defomed") canonical commutation relations $A\,A^\dagger - q^2 A^\dagger A = 1 - q^2$.

2.4. **Computational Physics.** Starting with the years spent at Trento University, EO shifted his main interest to problems requiring heavy use of numerical analysis and symbolic calculus on the computer. His main interest has been focused on Lattice Gauge Theory. The main achievement in this field has been the introduction of a numerical technique to compute lattice observables in weak coupling perturbation theory, which is well known to be rather hard in the more standard diagrammatic approach. The method is now applied by many other groups and it is known as *"Numerical stochastic perturbation theory"*. With this method, which is based on Parisi–Wu stochastic quantization, high orders in perturbation theory can be reached in realistic cases; it was also applied to the calculation of renormalization constants, and to beta function coefficients [36]-[36].

A numerical spectral approach has been applied to the Amati-Ciafaloni-Veneziano equation describing the high energy scattering of gravitons [8]. The study has identified the insurgence of a critical regime for small values of the quotient ρ/R, impact parameter over Schwartschild radius; the value is compatible with estimates derived in general relativity.

A personal interest in applying modern numerical routines to celestial mechanics led to the publication in Ref. [20] where the issue of the stability of the Lagrangian point L_3 is studied taking into account the full dynamics Earth-Moon-Sun-satellite.

The application of symbolic computation using Mathematica or `form` has been one of the recent interests of E.O. From one side, the study of large order perturbation expansions in Q.M. using `form` has led to an analysis of various relevant cases in conjunction with recent results by Zinn-Justin and Jentschura and Dunne and Ünsal, but no original results have emerged (F. Mignosa Thesis, 2016, U. di Parma). Studying matrix elements of Hydrogen bound states with Mathematica has led to some new results linked to the dynamical symmetry $\mathsf{SO}(4)$ [3].

His contribution to the recent paper devoted to the phenomenon of synchronization [4] regards the numerical study of the main evolution equation, leading to synchronization; the numerical technique requires capturing events during the evolution, which can easily performed using Matlab's routines for ordinary differential equations.

2.5. **Conformal field theory.** Starting in 1992, a fruitful collaboration with V. A. Fateev was born, which led to a series of papers dealing with exact results in the field of integrable systems. In this activity, EO's main task consists in providing computing support (both numerical and symbolic) while, admittedly, the physical ideas stem from the experience and original ideas and conjectures of V.A.F. [35, 32, 39, 18, 17, 16]. Highlights in this collaboration are given by the study of the renormalization flow of the non–linear sigma model, boundary one-point functions and classical solutions in Toda theories.

The paper [13] contains an exact solution of the so–called Marchesini–Muller equation, which was partly conjectured on the basis of a perturbative treatment in [14]. See also [15] where algorithmic details are reported.

In the most recent paper of the collaboration with Fateev, Litvinov and Neveu [6] a differential equation is derived for the four-point correlation functions of Liouville field theory on the sphere.

3. Planning and Deploying computing facilities

Prompted by requirements of computing facilities for his research, EO started to devote part of his time to the development of parallel computers at his home institution. Various achievements include 1) the installation of a prototype APE100 computer in Parma, following the suggestion of N. Cabibbo to extend the use of APE machines outside the Roma/Pisa group (1993) , 2) the collaboration of his group to the development of APE1000 and APE/next, 3) the acquisition of a first PC cluster devoted to numerical relativity (Albert100, 2002), and 4) its upgrade to a modern fast–communication cluster with 32 AMD Opteron processors (Albert2, 2004). In the years 2008-2011 he collaborated with the group of R. Tripiccione in the construction of a new parallel computer under the special INFN project "Aurora" [5].

In the last 20 years he collaborated with INFN's IVth commission (theoretical Physics) on the problem of optimizing the computer resources in the 20+ INFN sites. In 2008 four PC clusters have been installed in the INFN sites of Bari, Catania, Milano-Bicocca and Pisa according to a plan prepared by R. Tripiccione and E.O. The clusters have been shared under GRID by the community of INFN theoretical physicists.

4. Teaching

EO has taught several courses, both at graduate and undergraduate level, in Parma, Trento and Milano: *Mathematical methods for physicists, Introductory theoretical Physics, Advanced Quantum Mechanics, Computational methods for Physicists, Monte Carlo techniques, Analytical Mechanics, Computational physics laboratory, Probabilistic Methods for Physicists.*

From 1991 to 2015 he has served as Director of the "Parma School of Theoretical Physics" for post-graduate students, sponsored by INFN. Since 2007 the school has an international character and is attended by approximately fourty student coming from all European countries (*http://www.pr.infn.it/snft*).

He is co-author with C. Destri of a graduate-level book "Istituzioni di Fisica Teorica" adopted by many Italian Universities (3000 copies sold) [31]. Another book "Lezioni sulla Teoria degli Operatori Lineari" (now out of print) [52] has been adopted also at other Universities. A revised augmented edition is now available on line
(`http://www.pr.infn.it/~enrico.onofri/`). He wrote the article "Schrodinger equation" for the Treccani Encyclopedia (1986). Recent contributions, freely distributed to students at the University of Parma, "Lezioni sul Momento Angolare in Meccanica Quantistica", "Metodi Probabilistici della Fisica" (available on line *http://www.fis.unipr.it*). In the last three years he has supervised four students for the second level degree and four students for the first degree diploma. In the years 2013-14-15 he taught an introductory course in General Physics for Students in Engineering. He retired from his University job on Nov.1st, 2016,

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Enrico Onofri
I.N.F.N., Gruppo Collegato di Parma
c/o Dipartimento di Scienze Mat., Fis. e Inf.
Università degli Studi di Parma
Parco Area delle Scienze 7/a
43124 Parma
E-mail: enrico.onofri@unipr.it
Homepage: http://www.pr.infn.it/~enrico.onofri