Article

Hiroomi Umezawa and Quantum Field Theory

Giuseppe Vitiello

Abstract

A picture of some aspects of Hiroomi Umezawa's research activity is sketched. The influences of Rudolf Haag and Werner Heisenberg on Umezawa's research and intellectual adventure is commented upon by discussing a publication by Susumu Kamefuchi and the author's direct experience as one of Umezawa's Ph.D. students and collaborators.

Key Words: Umezawa, thermo field dynamics, dissipative quantum model of brain, macroscopic quantum systems, physics of living matter

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The last time I had the opportunity to write about Hiroomi Umezawa was in December 2004 when I was asked to write the foreword for a Japanese translation of a book on quantum mechanics coauthored by Umezawa and myself (Umezawa and Vitiello, 2005). The English edition published in Naples in 1985 (Umezawa and Vitiello, 1985) was translated into Japanese by Mari Jibu and Kunio Yasue. I continue to be grateful to them for the difficult, patient, and skillful work required for the translation, but especially because writing that preface to the Japanese edition of the book brought me back to the feelings and the emotions I had in the years of my PhD studies when I was learning from Umezawa how to do research in physics. I started the foreword (published in Japanese in the book, but unpublished in English) by recalling that in one of his latest papers (Umezawa, 1995) in 1994, Hiroomi Umezawa wrote that he used to joke with his friend Eduardo Caianiello by saying: "Since I was born with quantum physics I will grow with it, but you missed this luck by a couple of years." These words, meant to be a joke, reveal, however, a truth: the life of Hiroomi Umezawa (as well as the one of Eduardo Caianiello) has been fully entangled with the development of modern physics (Vitiello, 1996, p. iii - vi).

Umezawa was born in Sapporo, Hokkaido, Japan in 1924. Caianiello was born in Naples, Italy in 1921. Caianiello and Umezawa met for the first time in the middle of the 1950s and a lifelong strong friendship immediately started among them. Caianiello has been an outstanding physicist of the past century, especially known for his contributions to renormalization methods in quantum field theory and for his pioneering works in cybernetics. He introduced me to Umezawa in the spring of 1971. In Naples, under the supervision of Francesco Guerra, in the Caianiello's group, my undergraduate thesis was on the unstable states in the Lee model. After I had finished the thesis work I was determined to continue my studies in quantum field theory. Guerra taught me how beautiful mathematics can be when it unveils some secret of nature, and from Caianiello I learned how wide the horizon can be for a curious physicist. When I was a first year student, my first teacher of physics was Ettore Pancini. He was universally known for

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his 1947 paper with Marcello Conversi and Oreste Piccioni (Conversi, Pancini, and Piccioni, 1947), which sometimes has been considered to be the founding paper of modern particle physics. For us students he was simply a god. Several years later, I discovered that Pancini was a partisan commandant in the Resistance war against the Nazi-Fascists (Battimelli, 2003).

Giuseppe Vitiello and Hiroomi Umezawa, 1990.

His battle pseudonym, chosen by him with subtle elegant humor, was Achille. For my course in elementary particle physics my teacher was Emilio Del Giudice, who soon moved first to MIT, then to Copenhagen at the Niels Bohr Institute, and eventually to Milano. He coauthored the famous DDF paper on dual models with Paolo Di Vecchia and Sergio Fubini. I have been collaborating with Emilio since the beginning of the 1980s, when we met again after many years at a conference in Lecce. Soon after my graduation Guerra moved to Princeton where he played an important role in the construction of Euclidean field theory. In January 1972 I moved from Naples to Milwaukee-Wisconsin to study for my PhD under Umezawa's supervision. A couple of months before, Nando Mancini, having finished his PhD contributing with his thesis to Umezawa's study of superconductivity, was leaving Milwaukee returning to Naples. The early 70s were exciting years for the research in theoretical and experimental physics, in high energy physics as well as in condensed matter physics and many great achievements, from the elementary particle model of Weinberg-Glashow-Salam to the detailed predictions in the behavior of superconductors, could not be achieved without using the sophisticate machinery of quantum field theory. Thus, going to the United States, I expected that I would be *fully immersed* in quantum field theory.

My expectation was indeed correct. However, I was surprised by the fact that many aspects of quantum field theory, which I thought to be definitively clarified, were, instead, at the center of the discussions of the group meetings in Umezawa's office during the long snowy Milwaukee afternoons. All those participating in the meetings were engaged in the same attitude, from Nick Papastamatiou to Luc Leplae, to Hideki Matsumoto who arrived to Milwaukee soon after my arrival, and all the Umezawa's students of those years, Chenu V. Srinivasan, Manju Shah, Jim Wyly, Vikran Soni, and myself. Sometimes even the frequent visitors were captured in that open horizon atmosphere. I remember that environment was also home to Roman Jackiw, John Klauder, Masashi Tachiki, Eduardo Caianiello, Francesco Guerra, and many others. I still remember the crystalline clarity of the presentation of the newly born Thermo Field Dynamics given by Yasushi Takahashi. The celebrated paper on Thermo Field Dynamics by Takahashi and Umezawa (1975) was soon published in the *Collective Phenomena* journal. This journal is no longer in business and I am very glad for having been able to publish the reprint of that paper in the 1996 issue of the *International Journal of Modern Physics B* dedicated to Umezawa (Vitiello, 2005). That paper was also reprinted in 2001 in *Selected Papers by Hiroomi Umezawa* edited by Toshihico Arimitsu, Hiroshi Ezawa, Hideki Matsumoto, Koichi Nakamura and Yoshiya Yamanaka (Arimitsu *et al.*, 2011).

The idea of dedicating a memorial issue to Umezawa was born in Naples, as I originally wrote in the preface for the issue of the *International Journal of Modern Physics B* referred to above:

> One morning of April 1995, I do not remember the exact date, we were working in Naples, at the Dipartimento di Fisica.

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> Mario Rasetti, Salvatore De Martino and I were discussing some questions on quantum groups and coherent states; Enrico Celeghini and Silvio de Siena, who were also involved in this collaboration, could not be there for reasons I don't recall. The reason we met in Naples was that Mario had to give a talk in the afternoon, invited by the Neapolitan friends and colleagues to speak about quantum computation. To catch Mario for two full hours is not simple, so Salvatore and I took advantage of this occasion and moved from Salerno to Naples that morning. More than once, in previous meetings, we felt that doubling of the space of states in Thermo Field Dynamics "must" have something to do with the coalgebra structure (the coproduct) of Hopf algebras. Also that morning we were brought in a natural way to that subject. At a certain point Mario interrupted our discussion and told me: "Why don't you collect a series of good papers by good physicists somehow related to Umezawa, and edit an issue to dedicate to his activity for the International Journal of Modern Physics? I will be glad to write about that to Dr. Phua, the Chief Editor of the Journal, and I am sure he will be pleased (Vitiello, 1996, p. iii-iv).

That was the end of our discussion on quantum groups that morning. We spent the remaining part of it talking about Hiroomi Umezawa. Hiroomi had left us not many days before, on 25 March 1995, in Edmonton. But I was not yet used to that idea and for a moment Mario's proposal sounded to me very strange, in some sense absurd (Vitiello, 1996).

The contribution "Understanding Quantum Field Theory" by Rudolf Haag was the first in that collection of papers published and dedicated to Umezawa (Haag, 1996). In his presentation of the main problems faced by quantum field theory Haag clearly stated that:

> The division problem of the world into parts, to which an individual existence can be attributed, whether precisely or in adequate approximation, must be carefully reexamined. In the customary interpretation it is solved or rather circumvented by referring to the observer who is supposed to have the ability to define a system by means of his instruments and obtain a document as an incontestable fact. If we do not grant him this central role in the drama of nature then a very delicate balance has to be found between the indivisibility of a quantum process emphasized by Born and the appearance of discrete individual elements in nature... Understanding quantum field theory has been one of the important motives in the life work of Hiroomi Umezawa (Haag, 1996, p. 1469).

Umezawa met Haag for the first time in 1954 and, as Susumu Kamefuchi reports:

> When Umezawa asked Haag what he was doing, the latter answered that he was trying to understand why the incoming or outgoing field of a Heisenberg field behaves as a free field. According to Umezawa this answer by Haag was really a great shock to him – a kind of culture shock. This is because Umezawa had never thought before that such a problem could be a problem of quantum field theory at all: the asymptotic behavior of the field seemed to him to be intuitively quite obvious....Umezawa repeatedly tells me that from Haag he learned, for the first time, what "studying field theory" or more generally "studying a theory" should be (Kamefuchi, 1996, p. 1807).

As a matter of fact, the field theory group, called the "Nagoya triplet", namely, Hiroomi Umezawa, and his earliest collaborators Susumu Kamefuchi and Yasushi Takahashi, put much effort in their work to understand the meaning of the asymptotic fields. As reported by Kamefuchi and Hiroshi Ezawa (Kamefuchi and Ezawa, 1995), early works on renormalization theory led Pauli to say: "While our method is formalistic, Umezawa's is realistic" (p. 576).

A first attempt to formulate quantum field theory without any use of perturbation calculation (Umezawa, 1995) dates back to 1951, to the study by Umezawa and Kamefuchi (1951) of the spectral representations of two-point Green's functions and the response formula, soon after followed by the papers by Källén (1952) and Lehmann (1954). These efforts are at the basis of the so called Lehmann—Symanzik—Zimmermann formalism in quantum field theory (Schweber, 1961). Umezawa sadly comments (Umezawa, 1995) that his paper coauthored with Kamefuchi and, sometimes, also the one by Källén, are forgotten in the quotations of spectral representations. Resisting a bit to laziness (or to ignorance) a proper quotation should be "Umezawa—

Kamefuchi—Källén—Lehmann representations".

Kamefuchi (1996) also reports that another turning point in Umezawa's intellectual adventure was when he met Werner Heisenberg in Munich in 1965. At that time Umezawa had written already several papers on the mechanism of spontaneous breakdown of symmetry and this was also a subject of discussion with Heisenberg. In that occasion Heisenberg explained the symmetry breakdown by considering the crystals as an example in such a clear and intuitive way that "Umezawa felt, he confesses, as if the mist that had somehow been hanging in his mind suddenly cleared off..." In a letter to Kamefuchi (1996), dated 7 January 1992, Umezawa writes: "Pondering over the terrific development in physics in recent years, I am almost immersed in a great joy and even a surprise. Thanks to such a development and thanks to what I learned from Heisenberg and others I can now understand very many things which I did not in the beginning of my research career...". Kamefuchi explains Umezawa's evolution through different "stages of understanding", also involving emotions such as "joy and even surprise", by resorting to Gramsci's (1932) vision of the "stages of knowledge": *Passaggio dal sapere al comprendere, al sentire e vice-versa, dal sentire al comprendere, al sapere.* Namely, the passage from sapere as information, collecting data, making catalogs, encyclopedia, *naturalism*, which is not yet *science*, to comprendere as the act of understanding, comprising, inclusiveness, connecting notions, constructing a rational frame, understanding the *dynamics* underlying the data, the world in motion, to sentire as feeling, passion, having intuition, emotions, surprise, astonishment. According to Gramsci, the mistake is to believe that sapere without comprendere, and especially without sentire, without passion, is enough, and vice-versa, feeling without comprendere and sapere it is not enough, intuition without com-prehension, framing in a rational scheme, is not enough to reach a superior conception of the world, the *knowledge*, "il sapere". The way to knowledge is thus going through these steps or stages, up and down incessantly (*...e viceversa*); this is the way that, according to Kamefuchi, Umezawa used to go through in his intellectual adventure. I am especially grateful to Kamefuchi since by quoting Antonio Gramsci he confirmed and clarified to me which ones are the roots of the cultural background out of which Umezawa 's physics, and his school, have grown.

One of the contributions to the "terrific development in physics" has been the discovery of the infinitely many unitarily inequivalent representations of the canonical commutation rules in quantum field theory, which has characterized most of Umezawa's works and is the main ingredient, the "soul" I would say, of the thermo field dynamics. The existence of physically inequivalent representations puts the problem regarding the meaning of the asymptotic fields in a completely unexpected perspective, unforeseen in the early fifties, since they imply the existence of (infinitely) many sets of asymptotic fields, i.e. of many possible phases, or possible physical *worlds,* in which a system can manifest itself; Friedrichs work (Friedrichs, 1953), the van Hove model (van Hove, 1952) and the Haag theorem (Haag, 1955) were the first signals of the revolutionary consequences of their discovery. Moreover, the existence of physically inequivalent representations also reveals that such worlds or phases differ among themselves in the degree of *coherence* of their respective ground states. Umezawa's recurrent study of the mechanism of coherent boson condensation in spontaneously broken symmetry theories has been actually his approach to solving "the division problem of the world into parts to which an individual existence can be attributed" (Haag, 1996, p. 1469), which Cassirer called the "ingenuous vision of the world" (Cassirer, 1968).

Since 1966, in a paper with Luc Leplae (Leplae and Umezawa, 1966), the agent of long range correlations, the Nambu-Goldstone field, was identified with the phase operator and called the *phason field*. The elementary constituents of the system (*the parts*) would then join, through long range correlations, into a coherent (i.e. *in phase*) dynamical regime, thus behaving as a collective whole. Collective modes generated by the spontaneous breakdown of symmetry played a central role in Umezawa's effort to reach a unified view of nature. In such an effort living matter could not be left out. Umezawa was very proud of his papers on brain and quantum field theory coauthored with Ricciardi (Ricciardi and Umezawa, 1967) and with Takahashi and Stuart (Stuart, Takahashi, and Umezawa, 1978; 1979). The original intuition of a basic quantum dynamics with spontaneous breakdown of symmetry for living matter, also independently pioneered by Karl Pribram (1971; 1991), Herbert Fröhlich (1968; 1977) and Alexander Davydov (1976; 1978), opens new frontiers in the study of biological systems. Umezawa recalls that his paper with Ricciardi appeared: "slightly after the well-known work of the great brain biologist, Karl Pribram, which showed that memory is not localized, contrary to what neuron doctrine anticipated. This work of Pribram motivated him to look for a mechanism of nonlocal pattern, leading him to the Pribram's holography theory as holography is indeed controlled by a long range phase correlation" (Umezawa, 1995, p. 109).

I met Karl Pribram for the first time in Tucson, I think in 1996, in the occasion of one of the conferences *Toward a Science of Consciousness*, organized by Stuart Hameroff, and I was deeply surprised by Pribram's "unbounded" spectrum of interests, from Physics to Biology, Psychology, Natural Sciences. Umezawa's interest in brain modeling has been the trigger also for my interest in the study of the dissipative quantum model of the brain (Vitiello, 1995; 2001; 2004), which in recent years has been greatly enriched by the collaboration with Walter J. Freeman (Freeman and Vitiello, 2006; 2008; 2010) and his laboratory observations and analysis (Freeman, 1975; 2000). As I recall in a paper published in 2009:

> The first time I met Walter Freeman was in 2000, at one of those crowded conferences with many parallel sessions and just few (very few!) interesting plenary talks. One of these was indeed the talk by Lotfi Zadeh, another one was by Walter. My interest in nonlinear dynamical systems and my curiosity in watching through the fence what is going on in the neighboring garden brought me to that conference...Walter was talking of his research in mesoscopic brain dynamics with a language very near to the one familiar to a physicist trained in the study of the formation of ordered patterns in condensed matter physics and in high energy physics. Of course, he was not using the machinery of quantum field theory... However, he explained in clear words his laboratory observations and his theoretical analysis showing that the mesoscopic neural activity of neocortex appears to consist of the dynamical formation of spatially extended neuronal domains in which widespread cooperation supports brief epochs of patterned synchronized oscillations (Freeman,1975; 2000). This vivid physical picture of the brain mesoscopic activity was confirming to me what Umezawa was meaning by saying that "memory is a printed pattern of order supported by long range correlations" (Umezawa, 1995, p. 109)... The interesting point in Umezawa's many-body model for the brain is that two main ingredients appear there together: the notion of "field" introduced by Lashley [in neuroscience] in the middle of 1940s and the notion of "coherence", intrinsic to the laser theory inspiring Pribram's view. Both these notions are basic ones in the quantum field theory dynamics generating ordered patterns, but not in neuroscience, and in general in biology and biochemistry, where the atomistic view of assembling little pieces together has been prevailing on the search of the microscopic *dynamical* laws ruling their cooperative behavior so that the mesoscopic and macroscopic functioning of the system could emerge. One must have the courage of a Lashley and of a Pribram to dare to introduce the field concept and the wave notion of coherence. This is why, when listening Walter Freeman talking of dynamical widespread neuronal cooperation, it was clear to me that he is one of those few people who dare to open new paths in the forest (Vitiello, 2009, p. 245).

Going back to the long afternoons in Umezawa's office in the years of my PhD, I remember that I was amused by that atmosphere of complete freedom from any prejudice or authority: all basic certainties were questioned, nothing was taken for granted, even the most tightly assembled theorems or rigorous mathematical schemes were looked *inside* and scrutinized in any detail. I was happy in those afternoons. Outside there was a lot of snow, but my feeling was of being at my sunny home in Naples. After those long meetings, before going home where my wife Marina was patiently waiting, I used to spend some more time in Umezawa's office talking with him of the most disparate things, from Physics to everyday life problems. Often, he was telling me that he liked much being in Naples for few years (in the middle of 1963 he moved to Naples from Tokyo), and once, joking on that, he said that he liked it to the point that he would call himself *nippolitan*, meaning the fusion of his own cultural background with the Neapolitan one. One night, at Umezawa's home, waiting for the dinner prepared by Mrs. Tamae, I asked him why it was so. He told me what much later he wrote in the paper quoted above (Umezawa, 1995):

> At that time [1963], practically entire Japanese high energy physics was overwhelmed by the dispersion theory due to a strong influence of American physics, and there was little room left for quantum field theory. .... I found it very difficult to continue my work in Japan. Therefore I felt very relieved when I moved to Naples. With a strong respect to independent thinking which is an European tradition, Naples provided me with an ideal place for coming into a new development in quantum field theory (Umezawa, 1995, p. 109).

It was then clear to me the origin of my comfortable feeling of being home. The intellectual freedom of those afternoon discussions in Milwaukee tasted a little of the traditional Neapolitan refusal of any unquestioning obedience to authority (Vitiello, 2005), a heritage dating very far in the past, coming from Giordano Bruno who witnessed with noble passion the possibility to reach the knowledge by the only means of the human reason, beyond any prejudice and slavery to authority (Togliatti, 1950).

As said, the mechanism of the spontaneous breakdown of symmetry was one of the hottest subjects of research in the 1960s and 1970s and many theoretical and experimental results were consolidated in the construction of the Standard Model of elementary particles. Robert Marshak (1993) has named the 1970s the “heroic decade”. Spontaneous breakdown of symmetry thus naturally received much attention in those afternoon discussions. The dynamic generation of the order that Umezawa and his collaborators were studying already in Naples, in the middle of the 1960s, and called the problem of the rearrangement of symmetry, was one of the subjects of discussion.

My doctorate thesis was focused, indeed, on such a problem and revealed the algebraic structure underlying the rearrangement of the symmetry of the equations for the Heisenberg fields into the symmetry of the asymptotic fields, which is the one we actually observe (Vitiello, 1974). This appeared to be the core of the phenomenon of the boson condensation into *coherent macroscopic ordered patterns*. Thus, the dynamical rearrangement of symmetry manifests itself as the phenomenon of the change of scale, *from microscopic to macroscopic*. Such a phenomenon has been clearly illustrated by Umezawa (1993) in his book *Advanced Field Theory: From Micro to Macro and Thermal Concepts*.

The extraordinary fact is that the change of scale is a dynamical phenomenon; it is implied by the dynamical consistency between the breakdown of symmetry and energy conservation, namely the invariance laws. The establishment of long range correlations among the elementary components thus does not require expense of energy. A specific coherent interaction with the gauge field (such as the electromagnetic field) exists and a very delicate balance among matter field components and their gauge interaction controls the size of these ordered patterns and their topological configurations. One can thus speak of *macroscopic quantum systems,* which are “quantum” not in the trivial sense that are made by quantum components such atoms, electrons, etc., but in the very specific sense that their macroscopic properties cannot be explained without recurs to the quantum dynamics. One might agree with John Swain when he says that this “dispels the common misconception that quantum field theory is 'just quantum mechanics with an infinite number of degrees of freedom', revealing vast new mathematical terrains, and new ways of understanding physical phenomena in both commonplace and exotic systems” (Swain, 2011, 4th page of cover).

The *emergence* of macroscopic properties acquires thus an exact meaning, related to specific mathematical and physical mechanisms (too many times the word *emergence* is used in a foggy, mysterious way, introducing confusion rather than explanations). The crystals, used by Heisenberg as an example in his explanation of the spontaneous breakdown of symmetry during his meeting with Umezawa in 1965, the ferromagnets, the superconductors, the superfluids are indeed macroscopic quantum systems. Similarly, vortices, monopoles, domain walls and other kind of "extended objects", in particle physics and in condensed matter physics, started to be studied under such a new perspective,…"a very unusual, and very instructive, point of view", as Tom Kibble has recently observed (Kibble, 2011, 4th page of cover).

Umezawa and his school has been intensely working in such a direction and many results have been obtained by relying "on very simple and powerful unifying principles, given by the intermixing of symmetry and dynamics, under the general texture of quantum coherence", in the words of Francesco Guerra (2011, 4th page of cover). Many of these results have been recently collected in a volume by Massimo Blasone, Petr Jizba and myself and published by the Imperial College Press under the title *Quantum Field Theory and its Macroscopic Manifestations* (Blasone, Jizba, and Vitiello, 2011).

The lesson I learned from Umezawa has been that there is no particle physics or condensed matter physics; the Physics is only one, so that I have been studying with the same interest and enthusiasm neutrino mixing and condensed matter, gauge theories and living matter. The challenge is to reach a *unified view of nature*. The discovery that neutrino mixing and the dark energy problem (Blasone and Vitiello, 1995; Capolupo *et al.,* 2009) present the same quantum field mathematics which is necessary for the study of spontaneous breakdown of symmetry, say, in ferromagnets is still today a source of surprise for me. A comment by Mario Rasetti, with reference to this book, has been that:

> Physicists believe quantum fields to be the true protagonists of nature in the full variety of its wonderful, manifold manifestations: from the fascinating appearance of colorful disclinations in nematic liquid crystals, to the awing pattern of cosmic strings in the Universe; from the unexpected quantum features of macroscopic superfluids, to the surprising dynamics of solitons, to the mysterious process of generation of virtual particles when symmetry after symmetry is broken. Quantum field theory is the tool they created to fulfill their visionary dream of describing with a universal, unique language all of nature, be it single particles or condensed matter, fields or many-body objects (Rasetti, 2011, 4th page of cover).

This line of thought about the emergence, in the specific sense mentioned above, of coherence, crossed in the early 1980s with the research of Emilio Del Giudice, who was interested in applying to living matter the soliton physics, as proposed by Davydov, and the dipole wave dynamics, as proposed by Fröhlich. When I met Emilio at the conference in Lecce, in 1882, I was working with Ela Calvanese, a student of mine, on the solitons on ferromagnetic chains as localized coherent condensates. Thus, it was not difficult to me to accept Davydov's proposal that solitons might form and travel on protein chains carrying energy over long distances without dissipation. Emilio at that time was working with Silvia Doglia and Marziale Milani exactly on Davydov solitons, also considering the fact that biomolecules are embedded in the water matrix, a "detail" that is usually neglected by biologists, who, however, know very well that biomolecules cannot "work", i.e. cannot be functionally active, unless they are embedded in water.

We joined our efforts and, helped by discussions with Fröhlich, Sydney Webb and also Davydov (we met him a couple of times in the occasion of conferences in Copenhagen and in Kiev), we produced a series of papers on the quantum field theoretical approach to the collective behavior of biological systems (Del Giudice *et al.*, 1983; 1985; 1986). In these papers we found the connection and the interplay between Davydov solitons on protein chains and dipole waves of Fröhlich in the water matrix in terms of coherent quantum field condensation. We identified the Fröhlich dipole wave quanta with the Nambu-Goldstone modes, dynamically generated by the spontaneous breakdown of the rotational symmetry of the water molecule electric dipoles. Dissipativity, which is typical of the biological systems, was shown to be the macroscopic manifestation of microscopic invariance laws; this means that correlations among the system components are due to an *energyless* interaction, not ascribable to forces, but mediated by the phason field mentioned above. We submitted for publication the first paper to *Physics Letters A*.

Since biologists could not read the quantum field mathematics, it was difficult for us to decide where to submit the second longer manuscript. Knowing his wide research interests, I asked Giorgio Parisi for help. He suggested that it be submitted to *Nuclear Physics B* in the new section called '*fields and statistics*' (FS). These works gave the first shape to what in the following years has been called by us the "*living phase of matter*" or the "*Physics of living matter*", marking a clear cut distinction with what traditionally is called Biophysics. In 1986 Giuliano Preparata moved to Milano and it happened that his office was exactly in front of the one of Emilio: they were mutually captured by the unitary vision of physics and biology and by the great relevance of the dynamics of water. It was unavoidable that Giuliano would join the "Milano group".

One of the first results of such a collaboration was the paper "Water as free electric dipole laser", which appeared in 1988 in *Physical Review Letter* (Del Giudice, Preparata, and Vitiello, 1988). The collaboration of Giuliano with Emilio produced a number of results in many physical problems of great interest, all based on the central role played by coherent domains. The results from the collaboration were collected by Preparata in the book *QED Coherence in Matter* (Preparata, 1995). More recently, we have considered the general problem of the stability of macroscopic complex systems arising from fluctuating quantum components (Del Giudice and Vitiello, 2006). A crucial role is played by the gauge field which acts as a stabilizing reservoir.

Another interesting development arose from the collaboration with Almut Beige, whom I was lucky to meet in Paris at a conference on group theory in 2002. She is an outstanding expert in quantum optic and quantum computing and in such contexts the problem of atom cooling is of great practical and theoretical relevance. We immediately got in tune with each other and our common cultural background led us, together with Peter Knight, to formulate a field theory scheme where a coherent assembly of atoms would cool more efficiently than a non-coherent collection of atoms (Beige, Knight, and Vitiello, 2005). Previously, Peter Knight with Stephen Barnett considered the thermofield representation for squeezed states in quantum optics (Barnett and Knight, 1985). Implicit in our scheme were the seeds to study cavities with large numbers of tightly confined atoms, which we have been pursuing also in collaboration with Emilio. We have thus arrived to the result that a continuous leakage of photons through the cavity mirrors is possible, even in the absence of external driving. We show that such a phenomenon, considered also by other authors, cannot be described in the rotating wave approximation, which consists in freezing the system into just one of the available infinitely many unitarily inequivalent representations (Kurcz et al., 2010). Antonio Capolupo and Andreas Kurcz had an important part in reaching such a result.

In his paper in Mathematica Japonica (Umezawa, 1995), Umezawa discusses also the long range correlations in living systems, Fröhlich dipole wave model, his many-body model of brain, where Jibu and Yasue proposed that the symmetry to be broken is the rotational symmetry of the electric dipoles of water molecules (Jibu and Yasue, 1995) with consequent boson condensation of evanescent photons (Jibu, Pribram, and Yasue, 1996), and its relation with the works by the "Italian scientists". In the many-body model, however, the essential ingredient of dissipation was still missing. The brain is a system *unavoidably* open on its environment and exchanging energy with it. Dissipative systems and unstable states have attracted my interest, since the time of my undergraduate and PhD thesis. After having dedicated much time to the study of Hermitian operators, I have found always disturbing and even rough to betray Hermiticity and consider the extension to the complex energy plane when studying decay processes. Therefore I was particularly happy when I realized that non-unitary time evolution can be instead obtained by considering transitions, or trajectories, through unitarily inequivalent representations (Vitiello, 1974; De Filippo and Vitiello, 1977; Celeghini, Rasetti, and Vitiello, 1992). Non-unitarity is “built in” in quantum field theory. Quantum field theory makes us free from the “unitarity slavery”. In one of his letter to me, dated 1 February 1988, Umezawa writes: “…your old theory for unstable particles has some resemblance to my non-equilibrium TFD. It may be useful for you to look into this…” Of course, I could not imagine more pleasant words! In those years Umezawa was working on non-equilibrium thermo field dynamics with Toshihico Arimitsu, Koichi Nakamura, Peter Henning and other collaborators and applying it also to nuclear physics with F. C. Khanna.

Taking advantage of the results on the quantization of dissipative systems obtained in a paper coauthored by Enrico Celeghini, Mario Rasetti and myself (Celeghini, Rasetti, and Vitiello, 1992), where the formalism led us to the mathematical structure of thermo field dynamics, I extended the brain many-body model to the dissipative dynamics (Vitiello, 1995; 2001; 2004). The dissipative quantum model of the brain is a quantum field theory model substantially different from quantum mechanics models (Hameroff and Penrose, 1996; Stapp, 2003). In the dissipative model neurons and other cells are not quantum objects. The quantum degrees of freedom are the ones of the dipole field fluctuations. I dedicated that paper to Umezawa.

An output of the model has been the description of the interaction brain—environment as the *dialog* between the brain and its *Double* (Vitiello, 1995; 2001; 2004) since the mathematical description of the environment is obtained by the process of “doubling” the degrees of freedom: the entanglement brain--environment thus appears as the unavoidable dialog of the brain with its Double. Apart from the fascinating consequences on the analysis of the consciousness mechanisms, which appear to be rooted in such a dialog and thus in the intrinsic dissipative character of the brain’s basic functional properties, most striking is the number of laboratory observations that fit with predictions of the dissipative model. Some recurrent scale-free fractal features observed in the brain’s functional activity (Freeman, 2005; Peterman, 2009) also find a description in the dissipative model since fractals appear to be macroscopic quantum objects generated by coherent state dynamics (Vitiello, 2009).

This has been possible thanks to the already mentioned enjoyable collaboration with Walter Freeman (Freeman and Vitiello, 2006; 2008; 2010). Surprisingly, the dissipative model shows that the brain follows in its action-perception cycle the road to knowledge through the steps or stages mentioned above. It:

> …enables an orderly and inclusive description of the phase transition that includes all levels of the microscopic, mesoscopic, and macroscopic organization of cerebral patterns… This hierarchical structure extending outwardly into engagement of the subject with its environment in the action–perception cycle is the essential basis for the emergence and maintenance of meaning through successful interaction… By repeated trial-and-error each brain constructs within itself an understanding of its surrounding, which constitutes its *knowledge* of its own world that we describe as its *Double*. It is an *active* mirror, because the environment impacts onto the self independently as well as reactively…so that its matching ‘double’ is a finite projection from the brain into the environment, as the basis for organizing the action of the body governed by the brain. An example is the grasping of an object by the hand, described by the phenomenologist Merleau-Ponty (1945) as the achievement of ‘maximum grip’. Such a matching is formally described by the continual balancing of the energy fluxes at the brain–environment interface. It amounts to the continual updating of the *meanings* of the flow of information exchanged in the brain behavioral relation with the environment (Freeman and Vitiello, 2008, p. 304042).

On the philosophical side, the discovery of the Double has been and still is an object of discussion by many scholars, such as Gordon Globus (2003; 2009), Fabrizio Desideri (1998; 2004; 2011), Arkady

Plotnitsky (2004), and Paavo Pylkkänen (2007).

Naturally, also in the course on Quantum Mechanics taught by Umezawa in 1971 and 1973, much attention was paid to symmetries and invariance principles. I enjoyed those lectures and one morning I proposed to Umezawa to collect them in a book. We met a couple of time every week for about three years to work out the book. However, unavoidably those meetings were occasions to discuss other research problems or future projects as well. As far as our goal to complete the book went, one could say that during those meetings a lot of time was "wasted" discussing "other things".

Certainly, were we employees of a company, soon we would be both fired for inefficiency in the production processes. However, the understanding of some physical problems and many papers published years after have their roots in those unconstrained discussions. Unfortunately, today one of the mental sickness in Italy (and not only in Italy) is indeed to consider teaching and research activity like a business activity, fully finalized to efficiency, i.e. to the *Profit*. Of course, on such a road there is no future for science and culture (Vitiello, 2005).

In conclusion, let me close these comments on the deep influence of Umezawa's activity on many directions of research in physics with one more passage taken from the preface to the Japanese translation of the quantum mechanics book:

> The years in which the book was written were difficult years. I still remember the killing of athletes at Munich Olympics in 1972, the 1973 oil war, that sad day of 1973, the "other" 11 September, when we gathered in the Campus for the dramatic news of the killing of the President Allende and the dictatorship being imposed to the people of Chile, the devastations caused by the Vietnam war, the Nixon impeachment process. From my short-wave radio I could follow the struggle of the Italian democracy against terrorism attacks from one side and the special laws of the Government from the other side. However, we all shared the hope that *we shall overcome some day* and could *imagine all the people living life in peace*, as Joan Baez and John Lennon were singing for us. Our daily effort to *comprehend*, to learn, to teach, our tenacious effort to prove a theorem or to fit some data, the humble work in refining the presentation of a paper or of a section of this book, were of course not acts of violence, but of peace. However, we were also conscious, and proud, that those peaceful acts were revolutionary acts in their consequences (Vitiello, 2005, p. v).

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