FUNDAMENTAL QUESTIONS IN THEORETICAL PHYSICS: TOWARDS THE ULTIMATE UNIFICATION

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`"The World, with or without strings and branes, is a Chaosmos"`

Abstract

The fundamental issues beyond every frequently asked question in physics are presented. A truly unified field theory should be built based taking into account the different proposals and trials, putting them together in a global view. These previous theories are very briefly classified and explained. Finally, I describe how a unified field theory should be found according to these thoughts.

1 Introduction: the frequently asked questions and the *big question*

In the 20th century there has been three revolutions in physical sciences:

1. The relativity theory, a revolutionary and highly predictive theory about the space-time, inertia and gravitation, which includes the large scale structure of the Universe.
2. The quantum theory, a revolutionary and highly predictive theory about the matter fields, atoms and fundamental particles, which includes the small scale structure of the Universe.
3. The chaos and complexity, in fact, information theory, a revolutionary and highly predictive(this chaos is determinist) theory about the non-linear physics, fractal geometry, dimension theory, dynamical systems and life sciences, which are everywhere in physics and related applied sciences like computing, engineering, medicine, etc.

The last challenge which we have as physicists in the 21st century is to build a complete and consistent theory about the whole Universe (or Multiverse, depending on your taste). Some questions we wish to answer are:

- What are the space-time, the matter-energy and the movement?
- What are light, gravity and the other fields?
- What is the origin of the Universe?
- Why is the cosmological constant so small?

- How many fundamental constants ...?

Some more complete lists were reviewed in several meetings around the world, so let me add them here those selected from the conference Strings 2000:

1. Are all the (measurable) dimensionless parameters that characterize the physical universe calculable in principle or are some merely determined by historical or quantum mechanical accident and uncalculable?
2. How can quantum gravity help us to bridge and understand together quantum mechanics and general relativity as the final step into the formulation of a ultimate omplete theory which allow explain the origin of the universe (or multiverse)?
3. What is the lifetime of the proton and how do we understand it?
4. Is Nature supersymmetric, and if so, how is supersymmetry broken?
5. Why does the universe appear to have one time and three space dimensions?
6. Why does the cosmological constant have the value that it has, is it zero and is it really constant?
7. What are the fundamental degrees of freedom of M-theory (the theory whose low-energy limit is eleven-dimensional supergravity and which subsumes the five consistent superstring theories) and does the theory describe Nature?
8. What is the resolution of the black hole information paradox?
9. What physics explains the enormous disparity between the gravitational scale and the typical mass scale of the elementary particles?
10. Can we quantitatively understand quark and gluon confinement in Quantum Chromodynamics and the existence of a mass gap?

But also there are many others:

- Condensed matter and nonlinear physics. We have:

    1. What causes sonoluminescence? Sonoluminescence is the generation of small light bursts in liquids caused by sound. Bubbles form in the liquid at low pressure points of the sound wave, then collapse again as a high pressure wave passes. At the point of collapse a small flash of light is produced. The exact cause has been the subject of intense speculation and research.
    2. What causes high temperature superconductivity? Is it possible to make a material that is a superconductor at room temperature? Superconductivity at very low temperatures has been understood since 1957 in terms of the BCS theory, but high temperature superconductors discovered in 1986 are still unexplained. Should it requires anyons and/or fractional and/or projective statistics?
    3. How can turbulence be understood and its effects calculated? One of the oldest problems of them all. A vast amount is known about turbulence, and we can simulate it on a computer, but much about it remains mysterious.

    4. The Navier-Stokes equations are the basic equations describing fluid flow. Do these equations have solutions that last for all time, given arbitrary sufficiently nice initial data? Or do singularities develop in the fluid flow, which prevent the solution from continuing?

- Quantum mechanics. Here we have:

    1. How should we think about quantum mechanics? For example, what is meant by a "measurement" in quantum mechanics? Does "wavefunction collapse" actually happen as a physical process? If so, how, and under what conditions? If not, what happens instead?Scale relativity?
    2. Can we build a working quantum computer big enough to do things ordinary computers can't easily do? This question is to some extent impacted by the previous one, but it also has a strong engineering aspect to it. Some physicists think quantum computers are impossible in principle; more think they are possible in principle, but are still unsure if they will ever be practical.

- Cosmology and astrophysics. Frequently asked questions are:

    1. What happened at or before the Big Bang? Was there really an initial singularity? Does the history of the Universe go back in time forever, or only a finite amount? Of course, these questions might not make sense, but they might.
    2. Are there really three dimensionporques of space and one of time? If so, why? Or is spacetime higher-dimensional, or perhaps not really a manifold at all when examined on a short enough distance scale? If so, why does it appear to have three dimensions of space and one of time? Or are these unanswerable questions?
    3. Is the Universe infinite in spatial extent? More generally: what is the topology of space?
    4. Why is there an arrow of time; that is, why is the future so much different from the past?
    5. Will the future of the Universe go on forever or not? Will there be a "big crunch" at some future time, will the Universe keep on expanding forever, or what?
    6. Is the universe really full of "dark energy"? If so, what causes it?
    7. Why does it seem like the gravitational mass of galaxies exceeds the mass of all the stuff we can see, even taking into account our best bets about invisible stuff like brown dwarfs, "Jupiters", and so on? Is there some missing "dark matter"? If so, is it ordinary matter, neutrinos, or something more exotic? If not, is there some problem with our understanding of gravity, or what?
    8. The Horizon Problem: why is the Universe almost, but not quite, homogeneous on the very largest distance scales? Is this the result of an "inflationary epoch"–a period of rapid expansion in very early history of the universe, which could flatten out inhomogeneities? If so, what caused this inflation?

   9. Why are the galaxies distributed in clumps and filaments?
   10. When were the first stars formed, and what were they like? What are Gamma Ray Bursters? What is the origin and nature of ultra-high-energy cosmic rays?
   11. Do black holes really exist? (It sure seems like it.) Do they really radiate energy and evaporate the way Hawking predicts? If so, what happens when, after a finite amount of time, they radiate completely away? What's left? Do black holes really violate all conservation laws except conservation of energy, momentum, angular momentum and electric charge? What happens to the information contained in an object that falls into a black hole? Is it lost when the black hole evaporates? Does this require a modification of quantum mechanics?
   12. Is the Cosmic Censorship Hypothesis true? Roughly, for generic collapsing isolated gravitational systems are the singularities that might develop guaranteed to be hidden beyond a smooth event horizon? If Cosmic Censorship fails, what are these naked singularities like? That is, what weird physical consequences would they have?
   13. Do gravitational waves really exist? If so, can we detect them? If so, what will they teach us about the universe? Will they mainly come from expected sources, or will they surprise us?

- Particle physics.And now:

   1. Why are the laws of physics not symmetrical between left and right, future and past, and between matter and antimatter? I.e., what is the mechanism of CP violation, and what is the origin of parity violation in Weak interactions? Are there right-handed Weak currents too weak to have been detected so far? If so, what broke the symmetry? Is CP violation explicable entirely within the Standard Model, or is some new force or mechanism required?
   2. Why is there more matter than antimatter, at least around here? Is there really more matter than antimatter throughout the universe? This seems related to the previous question, since most attempts at explaining the prevalence of matter over antimatter make use of CP violation.
   3. Are there really just three generations of leptons and quarks? If so, why? For example, the muon is a particle almost exactly like the electron except much heavier, and the tau particle is also almost the same, but heavier still. Why do these three exist and no more? Or, are these unanswerable questions?
   4. Why does each generation of particles have precisely this structure: two leptons and two quarks?
   5. Do the quarks or leptons have any substructure, or are they truly elementary particles?
   6. Is there really a fundamental Higgs boson, as predicted by the Standard Model of particle physics? If so, what is its mass? Is it composite? Note: in 2012 a Higgs-like particle was unveiled by LHC data.
   7. What is the correct theory of neutrinos? Why are they almost but not quite massless? Do all three known neutrinos–electron,

muon, and tau–all have a mass? Could any neutrinos be Majorana spinors? Is there a fourth kind of neutrino, such as a "sterile" neutrino?

8. Is quantum chromodynamics (QCD) a precise description of the behavior of quarks and gluons? Can we prove using QCD that quarks and gluons are confined at low temperatures? Is it possible to calculate masses of hadrons (such as the proton, neutron, pion, etc.) correctly from the Standard Model, with the help of QCD? Does QCD predict that quarks and gluons become deconfined and form plasma at high temperature? If so, what is the nature of the deconfinement phase transition? Does this really happen in Nature?
9. Is there a mathematically rigorous formulation of a relativistic quantum field theory describing interacting (not free) fields in four spacetime dimensions? For example, is the Standard Model mathematically consistent? How about Quantum Electrodynamics? Even the classical electrodynamics of point particles does not yet have a satisfactory mathematically rigorous formulation. Does one exist or is this theory inconsistent?
10. Is the proton really stable, or does it eventually decay?
11. Why do the particles have the precise masses they do? Or is this an unanswerable question?
12. Why are the strengths of the fundamental forces (electromagnetism, weak and strong forces, and gravity) what they are? For example, why is the fine structure constant, that measures the strength of electromagnetism, about 1/137.036? Where do such dimensionless constants come from? Or is this an unanswerable question?
13. Are there important aspects of the Universe that can only be understood using the Anthropic Principle? Or is this principle unnecessary, or perhaps inherently unscientific?
14. Do the forces really become unified at sufficiently high energy?
15. Does some version of string theory or M-theory give specific predictions about the behavior of elementary particles? If so, what are these predictions? Can we test these predictions in the near future? And: are they correct?

Anyway, probably every answer to these questions can be deduced from the one involving the *big question*, **the primordial question**, the one which guides all our quest :

How can we merge quantum theory and general relativity to create a quantum theory of gravity as the link to the ultimate theory and how can we test this theory?

It has been suggested that perhaps we are wrong in several aspects. General relativity consider gravity as a continuum geometry, quantum field theory consider matter as a discrete and chaos theory has not been applied too much into these extremal worlds. How can we put all together? The so called quantum gravity is probably a misconception or misnomer to something that has not completely emerged yet, but it should be some kind of nexus towards the building of a global theory.

2 A classification of the different approaches and roads to quantum gravity

We describe briefly different approaches proposed to this date. There are non vacuum intersections between different topics, but it serves as guide or map:

2.1 Quantization of Geometry

Idea: Take a manifold-like structure, deform it a bit, and try to mimic general relativity. There are several recipes:

2.1.1 Discretization of ordinary manifolds

Idea: discretizate a smooth ordinary manifold with structures like simplices, finite sets?This approach has a fundamental gap between the topology of the macrophysics and the topology of the microphysics, i.e., at Planck level.

Example 1. Critical point analysis: spikes in quantum Regge theory, fractals, thermodynamics of geometric structures.

Example 2. Finite sets: replace the continuum with a finite substratum. This idea is related to lattice theories.

Example 3. Cantorial fractal transfinite spaces. M.El Naschie's approach. A little crackpottery.

Example 4. Prequantum and subquantum theories like the work of P. LaViolette or preon and technicolor physics.

2.1.2 Non-commutative approach

Idea: Change the continuum space-time to a discrete algebra of operators. The best example: Connes' description of the Standard Model.

2.1.3 Scale relativity

Idea: The universe is a fractal and scales are relative.
Example 1. Nottale's pioneer proposal, now also his main line of research.

Example 2. Today, scale relativity has been generalised in C. Castro's approach based on the geometry of C-spaces (Clifford spaces) and extended scale relativity. Fascinating feature: Energy = Entropy= Area = Information= Dimension = …

2.1.4 Clifford algebraic approaches

Idea: It from bit, more properly from algebraic bits. Related to C-spaces. Principal work of D.Finkelstein and collaborators. Also, we can remark the proposed derivation of masses and coupling constans from Clifford algebras and set theory, by Tony Smith.

2.1.5 Traditional Quantum Classical Field Theories

Idea: Matter is quantized, i.e., discrete. The continuum limit is classical field theory.

Example 1: semiclassiclal gravitation. Bekenstein-Hawking radiation and information loss. Gravity is classical field, matter is quantum.

Example 2: SUSY and SUGRA. Try to relate bosons and fermions.

2.1.6 Stochastic manifolds

Idea: the name says it all.

Example 1. Quantum geometrodynamics. Essentially, the work of Prugovecki, Namsrai,...

Example 2. Stochastic quantization. C. Beck has derived Standard Model parameters using this method and a chaotic string theory.

Example 3. Gravity in stochastic metrics. Linked to semiclassical approaches.

Example 4. Nelson's approach, nonlinear quantum mechanics stuff,etc.

2.1.7 Canonical quantum gravity

Idea: the general relativity is OK. The problem is to choose other variables. The quantization procedure is done in those new variables.

Examples: loop representation, Ashtekar's approach, quantum spin dynamics, weaves, loop quantum gravity,. . . Problem is that everything is geometry. It seems that there are no matter fields.

Related topic: interpretation of time.

2.1.8 Quantum cosmology

Idea: quantum mechanics of the Universe as a whole.

Related topics: black hole thermodynamics and related quantum gravity effects, like particle creation, Hawking stuff, cosmic strings, singularities, Unruh effect,. . .

2.1.9 Topological quantum field theory

Idea: topology as the key to quantum theory.

Related topics: knots, categorical approach, twisted and q-algebras, Donaldson and Witten theory, 4-manifold topology.

Examples: BF theory, CS theory.

2.1.10 Phenomenology of quantum gravity

John Ellis' favourite stuff, experimental conjectures, what is the significance of strings in the context of the standard model. Also, this is the main research of G. Amelino-Camelia. Recently, it has been reported two amazing discoverings:

- The Universe seems to be accelerating on cosmologic scales. It claims cosmological constant that is not zero as usually considered.
- The Blach Hole information paradox and the black hole entropy origin.

In my opinion, these are the first two experimental hints claiming for a quantum gravity theory and a bigger symmetry in Nature. Of course, anyone can advocate standard physics, but this force us to create dark matter, dark energy, and some more tricky things as time accelarating, hidden masses,...Perhaps they can account part of the reported anomalies, but I believe that a more exciting scenario is to consider the problem of unification. Future experiments can probably test these proposals.

2.2 Revolutionary totally different view of quantum gravity

Idea: the QFT and General Relativity are not adequate in the Planck regime.

2.2.1 String theory

Idea: instead of a point particle, take a little string. Different modes of the string represent different particles. Supersymmetry relates fermionic and bosonic states. But what is the background space of a string? Is it a meaningful question? A string theory should reproduce the low energy theories(i.e. gravity and QFT).
Example 0. Kaluza-Klein theories. Gravity(D- dimensions)=Gravity(4D)+ Matter Fields after compactification.

Example 1. 2D quantum gravity. Completely solved model? No, Liouville gravity as example. It is related to conformal field theory.

Example 2. Matrix models. Cloin reseallly related to discretization of strings and other extendons (extended objects).

Example 3. Duality, mirror symmetry.

Example 4. Batalin-Vilkovisky topics: almost any gauge theory can be handled with this framework. Has anyone got a nice regularization in addition? Choose the one you like: zeta function, lattice, dimensional, ...

Example 5. W-algebras. A nice generalization of the Lie algebras which include higher orders on the right hand side of the commutator.

Example 6. K-theory. Powerful tool of algebra used in string theory.

Example 7. M-theory. Old 5 string theories and 11D SUGRA unified in parameter space. M stands for mistery, magics, membranes,... according to the taste.

2.2.2 Membranes and other extendons(p-branes)

Idea: from points to strings, membranes, hypermembranes, hypersuperextramembranes, ad libidum.

2.2.3 p-adic structures and other ways to count

Idea: close to number theory, let's assume that Nature prefers primes. Maybe she's really weird. It has been applied in string theory and to simple quantum mechanical models. Very much of it elaborated in Eastern Europe.

Example: p-adic quantum mechanics applied to the Universe, adelic cosmology and field theory,...

2.2.4 Cellular automata

Idea: Wolfram's favourite, the Universe is like a human body, completely filled with little machines processing bytes and bytes.

2.2.5 Brans-Dycke theories

Idea: gravitational field = metric tensor + scalar field

2.2.6 Non-symmetric gravity

Idea: non symmetric metric tensor.

2.2.7 Higher order derivative theories

Idea: The name says it all. Take higher order lagrangians and hamiltonians in a jet-bundle.
Related topic: equivalent lagrangians and hamiltonians.

2.2.8 Quantum geometrodynamics

Idea: Wheeler's approach. Physics is about information. Now it also involves the holographic principle. Related methods include:

- Path integral methods.
- Wheeler-de Witt approach.
- Superspace and minisuperspaces (in the sense of Wheeler)
- Spinorial and twistorial methods.
- Topological geometrodynamics. By the finnish physicist Matti Pitkanen.

2.2.9 Non standard/ deformed QFT approach

Idea: the name says it all. Deform QFT to avoid infinities and try take into account gravity. Related to noncommutative field theories.
Examples: rigorous methods and algebraic approaches to QFT with a jump to gravitation, noncommutative field theory, Connes' approach,...

3 Towards the unified theory: beyond present tested theories

Since Isaac Newton's primer work on gravitation, joining together terrestral and celestial gravity, physics has advanced a lot. However, also the pioneer works of Faraday and Maxwell have advocated the unification of the fundamental forces(he joined together electricity and magnetism in the same fashion Newton did with gravitation, however two centuries later) and, moreover, a picture of physical universe as a whole. Nowadays, we have the Standard Model (although, as Gerard 'Hooft and others have remarked, the best name should be Standard Theory) which describes three interactions (weak, electromagnetic, strong) but no the gravitational field , this one described by General Relativity. Einstein himself also tried to unify physics in his lifetime, when he finished the General Theory of Relativity.

By the other hand, the question of unification and the building of a ultimate theory bring us a lot of other questions that, as far as I know, has not been considered, seriously, until its last consequences:

-What are the effects of that theory on the known physics? That is, for example, is superconduction possible at ambient temperature? What about the origin of life? In fact, what is life? Quantum mechanics does NOT answer this simple question -the origin and definition of live beings. Is possible the time travel? What about the nuclear and atomic structure, like the existence of superheavy nuclei?And what about the high energy phenomena in the Universe? And the hyperluminical trip and communication towards everywhere at the universe? I think the ultimate theory must be able to answer these kind of questions, in spite they can seem to be science-fiction. Reason: reality surpasses and is more amazing than fiction. In fact, the ultimate theory should be able to answer every question a priori. A posteriori, of course, it could be harder because of the complexity of equations or structures involving the solutions. Here, I do not agree completely with Feynmann(something pesimist) vision in his book *The character of the physical law.* Besides these questions, there are another ones. Specially, is the ultimate theory complete and consistent? If one applies the Gödel's incompleteness theorem the answer should be no. But, does the ultimate theory avoid this known result in mathematical logic? I think the ultimate theory is not only a naive single theory and should provide a scheme which avoids it in some way, as supersymmetry and Grassmann variables provided an alternative to the Coleman-Mandula theorem in the S-matrix approach. A theory based on category theory should be able to answer every question, although we could find contradictions 'a la Gödel'?.

The structure of a final theory has not been considered so much in the literature. Here, it seems the road to it is being guided by intuition and induction about certain properties. A list: holography, absence of anomalies, regularization, renormalization, duality, finiteness in perturbation theory, diffeomorphism invariance, dicreteness,etc. However, we need a unifying scheme(and, what is more important, PHYSICAL PRINCIPLES, like relativity) too. As far as I know, the more fascinating ideas(and perhaps the best) belong to topos theory and the extended relativity approach launched some years ago by Laurent Nottale and, nowadays, the main research topic of people working on doubly and triply special relativities (Magueijo, Amelino-Camelia,. . .) and extended scale relativity. Ironically, we only need a suitable generalization of known theories. However, as shown by the work of C. Tsallis on non-extensive entropy, the question and quest of a generalization scheme is often no trivial. This is not a surprise. It has always been so. Another example about this problem is quantum (particle)mechanics. Often it is not stress than QM and its relativistic counterpart, Quantum Field Theory, are about points, puntual particles. However, in the picture of General Relativity, based upon the diffeomorphism group, the notion of point is incomplete. Like another authors had remarked long ago: we need a pointless geometry. Then, QM, QFT need a consistent generalization, probably Nambu Mechanics or some deformed mechanics. However, this kind of mechanics is yet not completely developed and needs also further investigation. Probably, we can understand the dynamics of p-branes better so...Recently, there has been exciting advances about quantization of Nambu Mechanics...

By the way, we have learnt a lot about gauge theories, quantization and other topics. Specially, about global questions like cohomology (e.g.: the work of J.A. de Azcarraga et al.). Between them, perhaps the best known example of a perturbative (in principle) gauge theory of gravity has been STRING THEORY; since the time it was created as a hadron model, string theory (or M-theory now) has been the leader approach to quantum gravity. I believe this is not a coincidence. String theory should be some kind of PERTURBATIVE quantum gravity. NON-PERTURBATIVE quantum gravity should be a form of LOOP QUANTUM GRAVITY (or GENERAL QUANTUM RELATIVITY, so frequently called by Thomas Thiemann, Abhay Ashtekar and others). Of course these claims are very speculative, but there have a lot of theoretical facts like the entropy calculation in these aproaches which support these ideas. The ultimate theory might prove these facts and others of more experimental (that is, it must be testable and falsable) character.

4 Towards unification

The ultimate theory is focused on the physical principles of quantum gravity and the formulation of a ultimate unified theory(physical and mathematically but, perhaps, not alone mathematically complete and consistent since it is posible mathematics need physics to merge and get the dream of a final theory). And my quest is mainly focused on the *big question* written before, and since its answer involve any question asked before, they are subjects to my study as well.

I would like to make a thesis, and work on, about the mathematical and physical developments of more general Relativiy principles and theories related to quantum gravity and unification of forces...and I will try to apply some new ideas I can be able to imagine. Then I will try to understand better present theories and their implications in a complete unification scenario.

Specially, I am very interested in ANY extension of Special and General Relativity from the idea of symmetry, and I

also love the algebraic issues involved with the answers. I think the algebraic and geometrical features of this approach are very stimulating and deserve further reliable research. Moreover, I find very attractive and suggestive the tools based on geometric algebra, polylogarithms, arithmetic phycis, number theory, information theory and other modern branches of pure and applied Mathematics. I follow closely the developments in certain subjects of Physics, Chemistry and Mathematics, three sciences I like to merge into Physchematics. Its connections with information theory, the comprehension of quantum mechanics and a lot of additional topics. . . are really very amazing. I consider it a line of research not-covered in the literature with many possibilities, potentialities, applications,. . . . Also, it fits my own ideas about the real question of unification in physics and maths. Having stressed this preference, I *do not avoid* any others related topics for researching.

I would like trying to join together the several hints and pieces provided by the different approaches have been launched into a unifying scheme based on physical principles and suitable mathematics. An important related idea is holography but there are many others from several areas of physics, like the non-additive property found in non-extensive thermodynamics. This is an ambitious program but it requires more investigation concerning, for example, if the theory should be complete and consistent(in the sense of physics), the low energy applications, the proper formalism and mathematical tools, etc. Recently, I have been interested in the relation of number theory and physics, in particular, as the gap which can be able to unify all the physics...It seems that another people is doing research about it now...However, no one has intended a multidisciplinary atack on these problems and questions. This is one of my tasks. The mathematical theory will be based on category theory (linking all physics), number theory will be essential(it will determine the invariants and numbers we see), and the universal symmetry principle which governs the ultimate theory will be a generalised or extended quantum/cosmic universal group (it will descompose into $Diff(M) * (SU(3) \times SU(2) \times U(1))$, not yet identified...)

Everything is relative and relational, this is a fundamental Principle of physics and Nature, like The Arkhe or Taiji principle of ancient Greek and Chinese civilizations, respectively, on which The Nature is based: The Principles of Relativity (i.e. relations and/or connections) and Reciprocity (i.e. duality) . Briefly, there is nothing more beyond of it, only structures (geometry) , relationships (links), chaos (universality) and complexity (numbers) . . .