

COMPLEXITY AT THE FUNDAMENTAL LEVEL OF OUR KNOWLEDGE

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COMPLEXITY AT THE FUNDAMENTAL LEVEL OF OUR KNOWLEDGE

1 THE FIRST REMARK

People speak of 'Complexity' as a source of new insights in physics, biology, geology, cosmology, social sciences and in all intellectual activities which look at the world through the lens of a standard analysis in terms of either Simplicity or Complexity. But 'Complexity' is ill-defined, as shown by the existence of at least seven definitions of Complexity.

2 SEVEN DEFINITIONS OF COMPLEXITY

Here are the seven definitions of Complexity.

DEFINITION NUMBER 1

Complexity is a property of systems that are somewhere in between a completely random and a completely regular state, often described by a highly non linear set of equations but sometimes not describable by equations at all.

DEFINITION NUMBER 2 (Gerardus 't Hooft)

Bad ones:

- 1) Chaos.
- 2) The need for lengthy calculations.
- 3) The need for many distinct variables.

Better ones:

- 4) Unexpected difficulty when attempting to describe something in a precisely formulated theory.
- 5) What is left over after all systematic approaches failed.

But it could also be that: Complexity is an excuse for sloppy thinking.

DEFINITION NUMBER 3 (Richard Kenway)

The Complexity of a theory (problem) is the minimum amount of computer time and storage required to simulate (solve) it to a specified level of precision.

DEFINITION NUMBER 4 (Constantino Tsallis)

If we admit that biological or linguistic evolution, or financial dynamics are complex phenomena, then their typical dynamics is somehow between strong chaos (i.e. positive Lyapunov exponents) and simple orbits (i.e. negative Lyapunov exponents). In other words, Complexity (or at least some form of it) is deeply related to the edge of chaos (i.e. vanishing maximal Lyapunov exponent). Since the edge of chaos appears to be related paradigmatically to an entropy index 'q' different from unity, there must be some deep connection between Complexity and generalized entropies such as 'S_q'.

DEFINITION NUMBER 5 (Leonard Suskind)

From the mathematical point of view:

- A problem can be polynomial, which means that it is not too hard to predict surprises.
- A problem can be NP or NP-complete, which represent different degrees of difficulty in predicting surprises.
- Surprises means: UEEC event (see later).
- That degree of difficulty can be associated with the level of Complexity.

DEFINITION NUMBER 6

A system is 'complex' when it is no longer useful to describe it in terms of its fundamental constituents.

DEFINITION NUMBER 7

The simplest definition of Complexity: '*Complexity is the opposite of Simplicity*'. This is why we have studied the Platonic Grand Unification (Addendum 1) and its extension to the Platonic Superworld (Addendum 2).

These seven definitions of Complexity must be compared with the whole of our knowledge (see Addendum 3) in order to focus our attention on the key features needed to study our real world.

3 COMPLEXITY EXISTS AT ALL SCALES

The Logic of Nature allows the existence of a large variety of structures with their regularities and laws which appear to be independent from the basic constituents and fundamental laws of Nature which govern their interactions.

But, without these laws it would be impossible to have the real world which is in front of us and of which we are part of.

A series of complex systems is shown in figure 1.

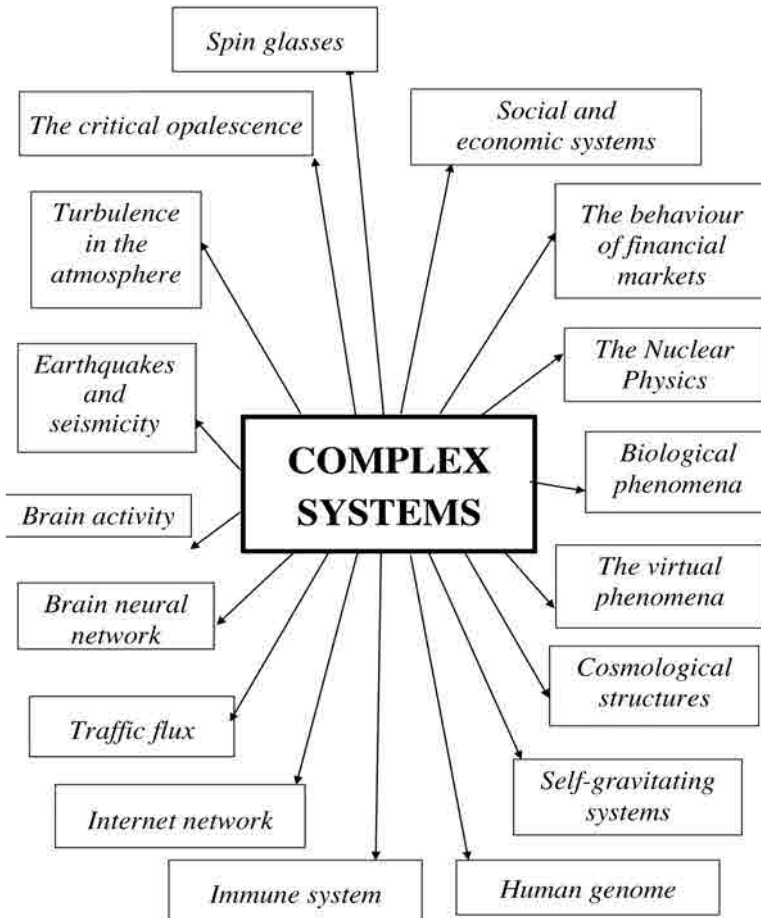


Figure 1

As you can see, we go from traffic flux, to the internet network, to earthquakes and seismicity, to social and economic systems, to the behaviour of financial markets, to the study of cosmological structures, and so on. A recent study proves that Complexity exists at the fundamental level of our knowledge: i.e. Science. Since the queen of all Sciences is Physics (Enrico Fermi) we will discuss the great achievement of the most advanced frontiers in Physics in order to prove that Complexity exists at the fundamental level of our knowledge.

Since History is granted to be the best example of Complexity, the conclusion is that Complexity exists at all scales, as illustrated in figure 2.

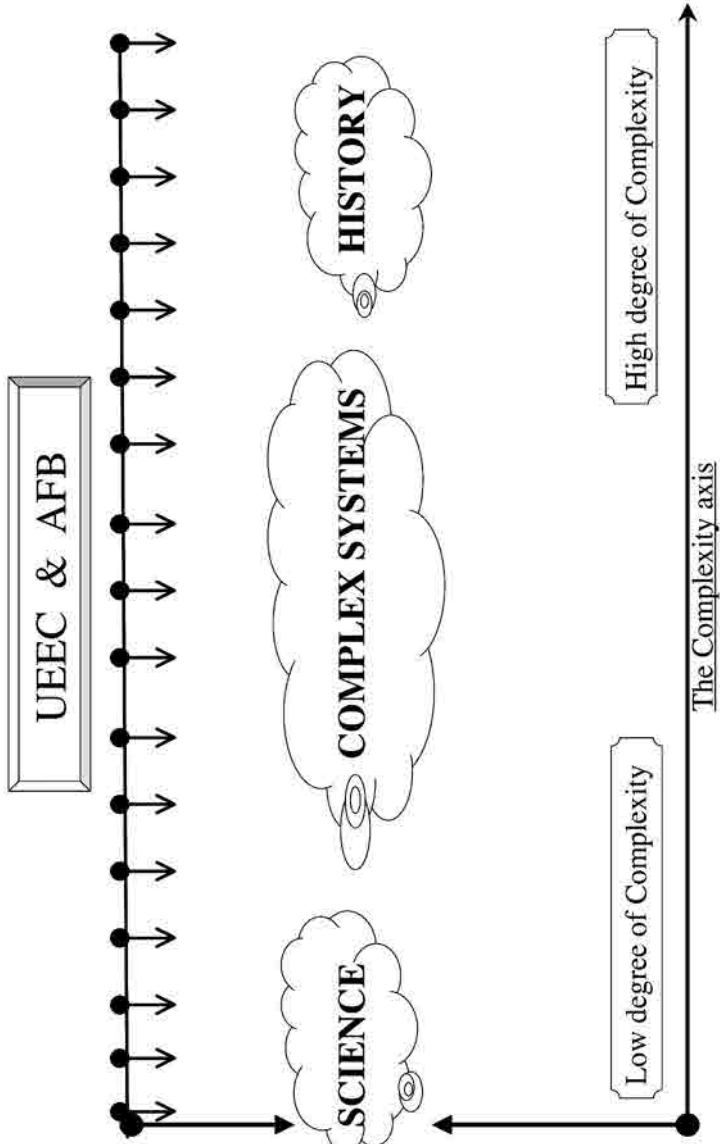


Figure 2

In this figure we have Science and History as the two extreme limits of Complexity. Science is the lowest limit in the degree of Complexity, while History is the highest degree of Complexity. The real world consists of systems with different degree of Complexity. The degree of Complexity of the sample shown in figure 1 is reported in figure 2 as being in between Science and History.

This enormous variety of real structures has in common the same experimental evidence for the property called Complexity.

4 THE EXPERIMENTAL EVIDENCE FOR THE EXISTENCE OF COMPLEXITY

The experimental evidences for the **existence of Complexity** are two:

- 1) The **Anderson-Feynman-Beethoven-type phenomena (AFB)** i.e. phenomena whose laws and regularities ignore the existence of the Fundamental Laws of Nature from which they originate;
- 2) The Sarajevo-type effects, i.e. **Unexpected Events** of quasi irrelevant magnitude which produce **Enormous Consequences (UEEC)**.

The only certainty about Complexity is the existence of these two experimentally observable effects. The **AFB** will be discussed in chapter 4.1 and the **UEEC** in chapter 4.2. These effects exist at all scales.

4.1 AFB PHENOMENA FROM BEETHOVEN TO THE SUPERWORLD

Beethoven and the laws of acoustics.

Beethoven could compose superb masterpieces of music without any knowledge of the laws governing acoustic phenomena. But these masterpieces could not exist if the laws of acoustics were not there.

The living cell and QED.

To study the mechanisms governing a living cell, we do not need to know the laws of electromagnetic phenomena whose advanced formulation is QED. All mechanisms needed for life are, to a great extent, examples of electromagnetic processes. If QED was not there, Life could not exist.

Nuclear physics and QCD.

Proton and neutron interactions appear as if a fundamental force of nature is at work: the nuclear force, with its rules and its regularities. These interactions ignore that protons and neutrons are made with quarks and gluons.

Nuclear physics does not appear to care about the existence of Quantum Chromodynamics (QCD), the fundamental force acting between quarks and gluons at the heart of the subnuclear world.

Nuclear physics ignores QCD but all phenomena occurring in nuclear physics have their roots in the interactions of quarks and gluons. In other words, protons and neutrons behave like Beethoven: they interact and build up nuclear physics without ‘knowing’ the laws governing QCD.

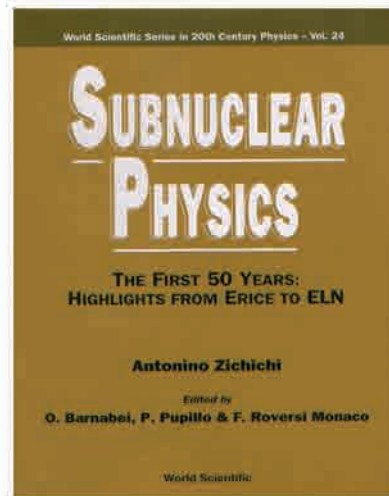
The most recent example of Anderson-Feynman-Beethoven-type phenomenon: **the World could apparently not care less about the existence of the Superworld.**

4.2 UEEC EVENTS, FROM GALILEI UP TO SM&B

In figure 3 there is a sequence of UEEC events from Galilei to Fermi-Dirac and the ‘strange particles’. The series of UEEC events goes on in figures 4, 5, 6 for the construction of the Standard Model. In figure 7 there is the most recent synthesis of UEEC events in what we now call the **SM&B**: the Standard Model and Beyond. In order to discuss, even in a very short way, the contents of all these figures (3, 4, 5, 6, 7) the time needed would exceed by many orders of magnitudes the one allocated to my Lecture. Purpose of these figures is to provide a list of some scientific achievements I have chosen in order to prove that all scientific steps come from totally unexpected events. The contents of all figures (3–7) are far from being complete. The figures (4, 5, 6) cover the first fifty years of Subnuclear Physics, whose detailed description can be found in my book whose front page is reproduced below. In the same volume I discuss the details of figure 7, the **SM&B**, which is the greatest synthesis of all times in the study of the fundamental phenomena governing the Universe in all its structures.

What about Platonic Simplicity? The definition n. 7 of Complexity (reported in chapter 2) forces us to check if Platonic Simplicity plays a role in the Logic of the Fundamental Constituents of matter. An example of Platonic Simplicity is the Platonic Grand Unification (Addendum 1), whose natural extension is in the existence of the Platonic Superworld (Addendum 2). Platonic Simplicity is totally violated in the Unification of all Fundamental Forces and in the construction of the Superworld.

The conclusion is that at the frontier of our scientific knowledge what is needed is not Platonic Simplicity but its opposite. Complexity exists at the fundamental level. In fact, starting from Platonic Simplicity, the **SM&B** needs a series of ‘ad hoc’ inputs [1] in order to be as it has to be.



'UEEC' TOTALLY UNEXPECTED DISCOVERIES FROM GALILEI TO FERMI-DIRAC AND THE 'STRANGE' PARTICLES	
<i>I</i>	Galileo Galilei discovery of $F = mg$.
<i>II</i>	Newton discovery of $F = G \frac{m_1 \cdot m_2}{R_{12}^2}$
<i>III</i>	Maxwell discovers the unification of electricity, magnetism and optical phenomena, which allows him to conclude that light is a vibration of the EM field.
<i>IV</i>	Planck discovery of $h \neq 0$.
<i>V</i>	Lorentz discovers that space and time cannot be both real.
<i>VI</i>	Einstein discovers the existence of time-like and space-like worlds. Only in the time-like world, simultaneity does not change, with changing observer.
<i>VII</i>	Rutherford discovers the nucleus.
<i>VIII</i>	Hess discovers the cosmic rays.
<i>IX</i>	Dirac discovers his equation, which opens new horizons, including the existence of the antiworld.
<i>X</i>	Fermi discovers the weak forces.
<i>XI</i>	Fermi and Dirac discover the Fermi–Dirac statistics.
<i>XII</i>	The 'strange particles' are discovered in the Blackett Lab.

Figure 3

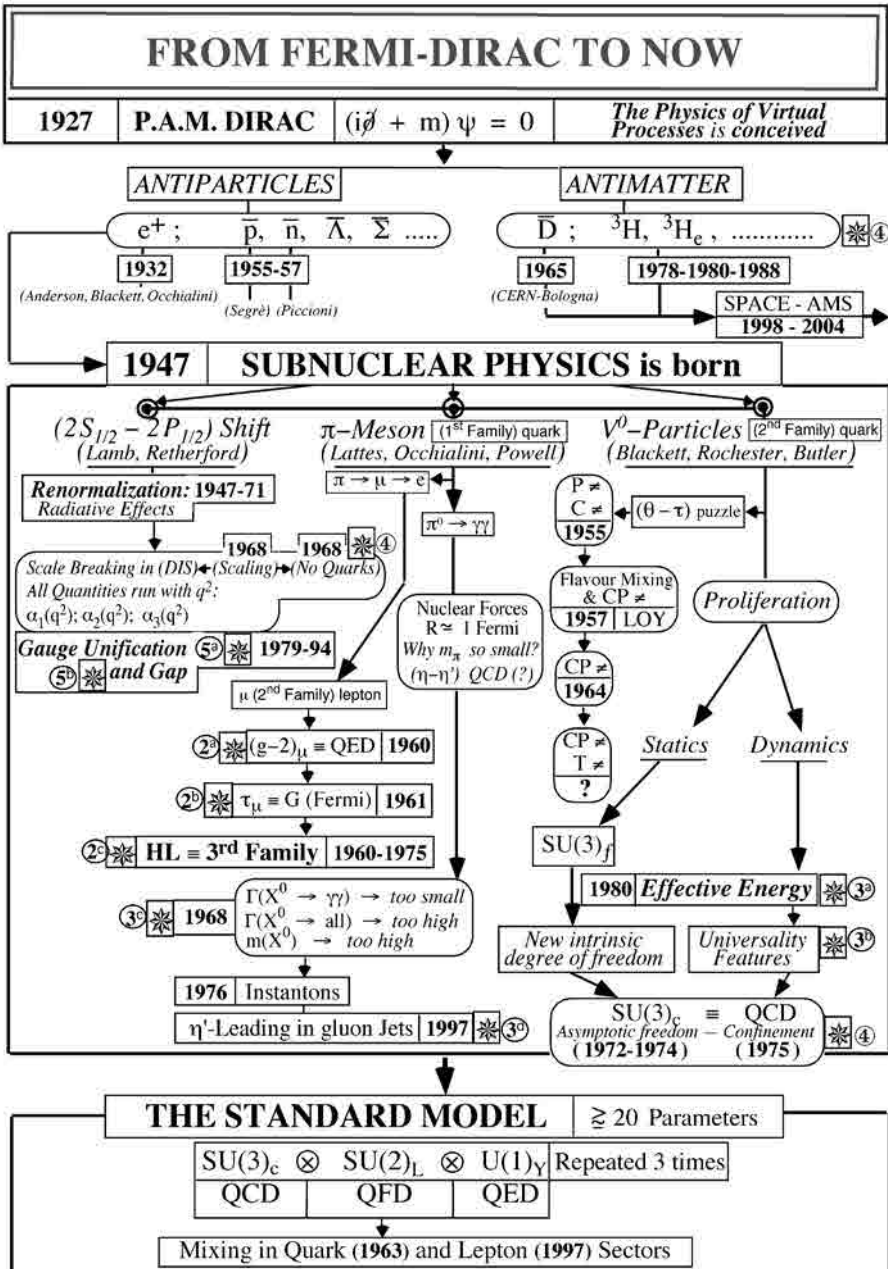


Figure 4

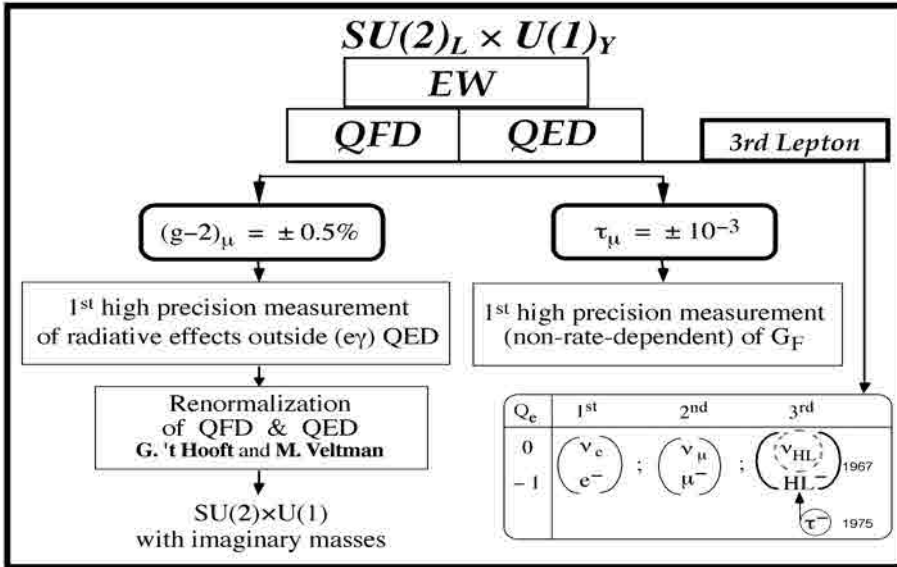


Figure 5: Details from figure 4, concerning $SU(2)_L$ and $U(1)_Y$.

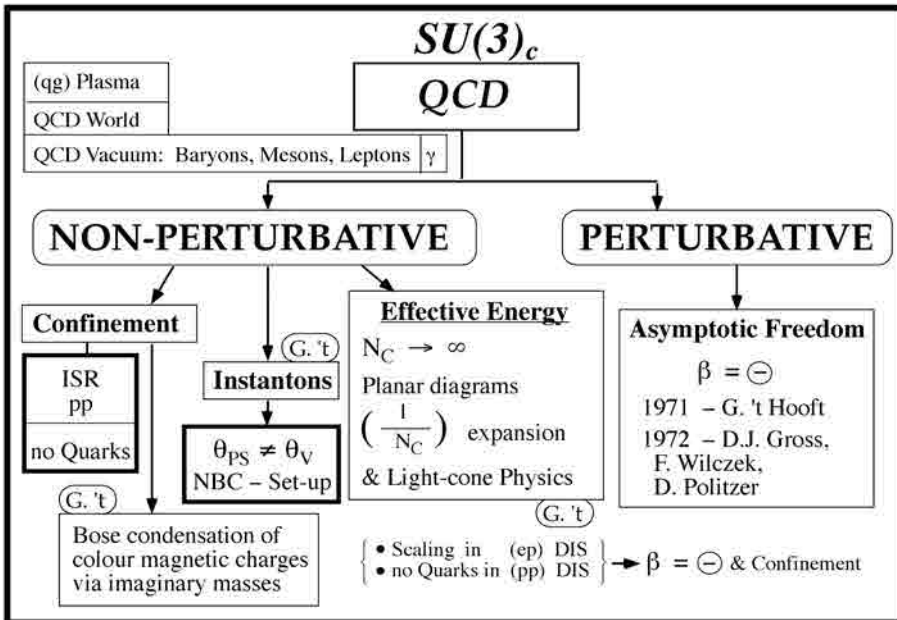


Figure 6: Details from figure 4, concerning $SU(3)_c$.

SM&B

THE STANDARD MODEL AND BEYOND

- ① RGEs (α_i ($i = 1, 2, 3$); m_j ($j = q, l, G, H$)): $f(k^2)$.
 - GUT ($\alpha_{\text{GUT}} \cong 1/24$) & GAP ($10^{16} - 10^{18}$) GeV.
 - SUSY (to stabilize $m_F/m_P \cong 10^{-17}$).
 - RQST (to quantize Gravity).
- ② Gauge Principle (hidden and expanded dimensions).
 - How a Fundamental Force is generated: SU(3); SU(2); U(1) and Gravity.
- ③ The Physics of Imaginary Masses: SSB.
 - The Imaginary Mass in SU(2) \times U(1) produces masses (m_{W^\pm} ; m_{Z^0} ; m_q ; m_l), including $m_\nu = 0$.
 - The Imaginary Mass in SU(5) \Rightarrow SU(3) \times SU(2) \times U(1) or in any higher (not containing U(1)) Symmetry Group \Rightarrow SU(3) \times SU(2) \times U(1) produces Monopoles.
 - The Imaginary Mass in SU(3)_c generates Confinement.
- ④ Flavour Mixings & CP \neq , T \neq .
 - No need for it but it is there.
- ⑤ Anomalies & Instantons.
 - Basic Features of all Non-Abelian Forces.

Note: q = quark and squark; l = lepton and slepton; G = Gauge boson and Gaugino; H = Higgs and Shiggs; RGEs = Renormalization Group Equations; GUT = Grand Unified Theory; SUSY = Supersymmetry; RQST = Relativistic Quantum String Theory; SSB = Spontaneous Symmetry Breaking.	m_F = Fermi mass scale; m_P = Planck mass scale; k = quadrimomentum; C = Charge Conjugation; P = Parity; T = Time Reversal; \neq = Breakdown of Symmetry Operators.
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The five basic steps in our understanding of nature. ① The renormalization group equations (RGEs) imply that the gauge couplings (α_i) and the masses (m_j) all run with k^2 . It is this running which allows GUT, suggests SUSY and produces the need for a non point-like description (RQST) of physics processes, thus opening the way to quantize gravity. ② All forces originate in the same way: the gauge principle. ③ Imaginary masses play a central role in describing nature. ④ The mass-eigenstates are mixed when the Fermi forces come in. ⑤ The Abelian force QED has lost its role of being the guide for all fundamental forces. The non-Abelian gauge forces dominate and have features which are not present in QED.

Figure 7

5 THE TWO ASYMPTOTIC LIMITS: HISTORY AND SCIENCE

A key feature in our search to understand Complexity is to compare the two asymptotic limits which characterize the world where we live and of which we are part of: History and Science.

The real world seems to be characterized by two basic features, which are one on the opposite side of the other: *Simplicity* and *Complexity*.

It is generally accepted that *Simplicity* is the outcome of *Reductionism*, while *Complexity* is the result of *Holism*.

The most celebrated example of *Simplicity* is *Science* while the most celebrated example of *Complexity* is *History*.

Talking about asymptotic limits, the general trend is to consider **History** as the asymptotic limit of *Holism* and of *Complexity*; **Science** as the asymptotic limit of *Reductionism* and of *Simplicity*, as illustrated in figure 8.

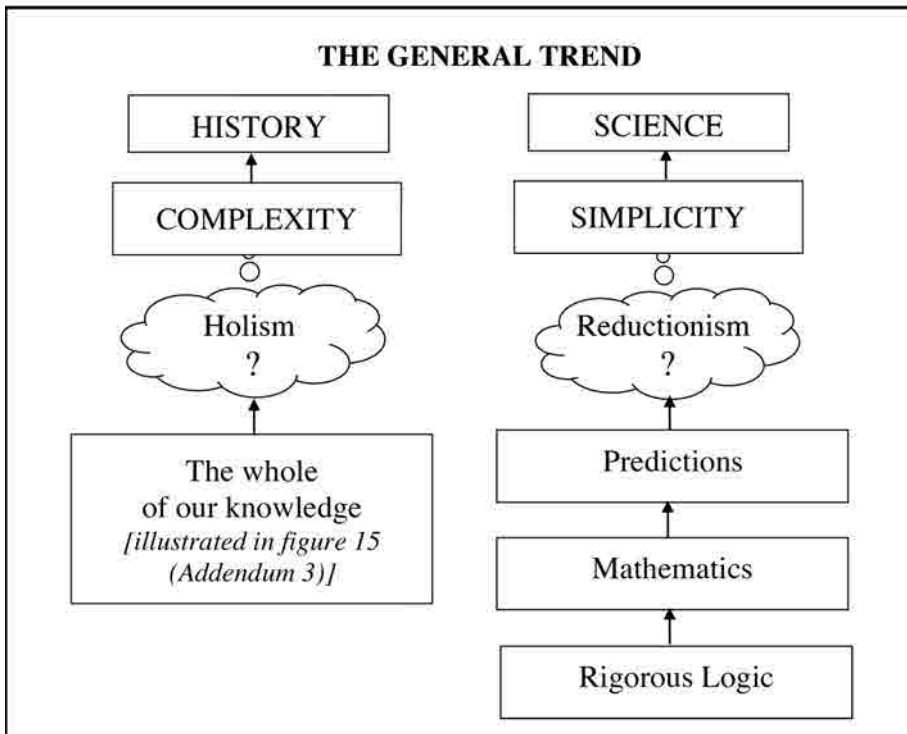


Figure 8

The Logic of Nature allows the existence of *Science* (the asymptotic limit of Simplicity) and of *History* (the asymptotic limit of Complexity), which **share a property, common to both of them.**

It is interesting to define *Science* and *History* in terms of this property, **probably the only one**, which they share; i.e. **Evolution.**

- Science is the Evolution of our Basic Understanding of the laws governing the world in its Structure \equiv **EBUS.**
- History is the Evolution of the World in its Real Life \equiv **EWRL.**

In Table 1 we compare these two supposedly asymptotic limits — History and Science — on the basis of ‘What if?’; a condition elaborated by the specialists in what is now known as ‘virtual history’ [2].

On the basis of ‘What if?’ these specialists conclude [2] that the world would not be as it is, if one, or few, or any number of ‘What if?’ had not been as History tells us. This is not the case for Science.

The world would have exactly the same laws and regularities, whether Galileo Galilei or somebody else had discovered

$$F = mg \text{ (} F \equiv \text{force; } m \equiv \text{mass; } g \equiv \text{acceleration due to gravity),}$$

and so on for all the other scientific discoveries.

It is in the consequences of ‘What if?’ that the two asymptotic limits of Simplicity and Complexity seem to diverge, despite the fact that the sequence of ‘What if?’ in Science belongs to the ‘totally unexpected events’ (UEEC) exactly like the others listed in the column of History.

TABLE I

‘WHAT IF?’			
	In History = EWRL		In Science = EBUS
I	What if Julius Caesar had been assassinated many years before?	I	What if Galileo Galilei had not discovered that $F = mg$?
II	What if Napoleon had not been born?	II	What if Newton had not discovered that $F = G \frac{m_1 \cdot m_2}{R_{12}^2} ?$
III	What if America had been discovered few centuries later?	III	What if Maxwell had not discovered the unification of electricity, magnetism and optical phenomena, which allowed him to conclude that light is a vibration of the EM field?
IV	What if Louis XVI had been able to win against the ‘Storming of the Bastille’?	IV	What if Planck had not discovered that $h \neq 0 ?$
V	What if the 1908 Tunguska Comet had fallen somewhere in Europe instead of Tunguska in Siberia?	V	What if Lorentz had not discovered that space and time cannot be both real?
VI	What if the killer of the Austrian Archduke Francisco Ferdinand had been arrested the day before the Sarajevo event?	VI	What if Einstein had not discovered the existence of time-like and space-like real worlds? Only in the time-like world, simultaneity does not change, with changing observer.
VII	What if Lenin had been killed during his travelling through Germany?	VII	What if Rutherford had not discovered the nucleus?
VIII	What if Hitler had not been appointed Chancellor by the President of the Republic of Weimar Paul von Hindenburg?	VIII	What if Hess had not discovered the cosmic rays?
IX	What if the first nuclear weapon had been built either by Japan before Pearl Arbour (1941) or by Hitler in 1942 or by Stalin in 1943?	IX	What if Dirac had not discovered his equation, which opens new horizons, including the existence of the antiworld?
X	What if Nazi Germany had defeated the Soviet Union?	X	What if Fermi had not discovered the weak forces?
XI	What if Karol Wojtyla had not been elected Pope, thus becoming John Paul II?	XI	What if Fermi and Dirac had not discovered the Fermi–Dirac statistics?
XII	What if the USSR had not collapsed?	XII	What if the ‘strange particles’ had not been discovered in the Blackett Lab?

6 COMPLEXITY AND PREDICTIONS

It is now necessary to establish the relation which exist between Complexity and Predictions.

In the previous chapters 4.1 and 4.2 we have discussed the experimental basis for the existence of Complexity, i.e., AFB and UEEC events.

We will now discuss the experimental evidence for the existence of Predictions and the sequence which correlates UEEC and Predictions.

We will see that Predictions depends on UEEC. The experimental evidences for the **existence of Predictions are** the very many results of scientific reproducible experiments.

Quantum Electro-Dynamics, QED, is the best example. The anomalous magnetic moments, in symbols $(g-2)$, of the electron (e) and of the muon (μ):

$$(g-2)_{e, \mu}$$

are theoretically computed at an extraordinary level of precision (few parts in ten billion parts for the electron) and are experimentally verified to be correct. Could the

$$(g-2)_{e, \mu}$$

be theoretically predicted before the discovery of the Maxwell equations and the existence of Quantum Electro-Dynamics (QED)? The answer is obviously no.

The sequence which correlates UEEC events and Predictions is very clear.

Predictions at the fundamental level of scientific knowledge depend on UEEC events.

For example: it is the discovery of the laws governing electric, magnetic and optical phenomena (all totally unpredicted) which produced the mathematical structure called QED.

The mathematical structure was not discovered before the innumerable series of UEEC events found in electricity, magnetism and optics. This series of UEEC events allowed Maxwell to express 200 years of experimental discoveries in a set of 4 equations.

The mathematical formalism comes **after** a totally unexpected discovery: an **UEEC event** which no one was able to **predict**.

In the whole of our knowledge rigorous predictions exist only in Science. These predictions are based on the mathematical description of a single UEEC event or a series of UEEC events. This description can either be the result of new mathematics (example the Dirac δ -function) or the use of existing mathematical formalism (example: the Einstein use of the Ricci tensor calculus). The UEEC event at the origin of the Dirac equation [3] is the fact that the electron was not a 'scalar' particle but a spin $\frac{1}{2}$ object.

The UEEC events at the origin of Einstein mathematical formulation of the gravitational forces are the discoveries of

$$\text{Galilei (F = mg),}$$

of

$$\text{Newton (F = G } \frac{m_1 \cdot m_2}{R_{12}^2} \text{),}$$

and of Lorentz that Space and Time could not be both real and that all electromagnetic phenomena obeyed a new invariance law, now called Lorentz-invariance. These are just two examples of the fact that the greatest steps in the **progress of Science** come from totally unpredicted discoveries. It is the mathematical formulation of these discoveries which allow Predictions to be made. Once made, these Predictions need experimental checks, since they extend our knowledge much further away from the original UEEC event.

Even when we have a mathematical formalism coming from a series of UEEC events, if this formalism opens a new frontier, as it is the case for the Superworld, the experimental proof is needed to verify the validity of the new theoretical frontier.

Today we have a reasonable mathematical formalism to describe the **Superworld**, but in order to know if the Superworld exists we need the experimentally reproducible proof for its existence. And it could be that, while searching for the Superworld a totally unexpected discovery (UEEC) comes in. This is the reason why we need to perform experiments, as Galileo Galilei realized 400 years ago.

7 CHAOS, EVOLUTION AND HISTORY

Two topics in this review devoted to Complexity have not been mentioned: the modern theory of Chaos and the theory of Evolution of living matter.

7.1 CHAOS

One of the most interesting problems in the modern theory of Chaos is the study of the transition to Chaos of dynamical systems.

With my friend and colleague André Petermann, we have published [4] a paper where we prove that the existence of chaos, in a rigorous mathematical language, is still lacking. In this paper [4] we point out that a rigorous Chaos would exist, for example, if a set of strongly coupled non linear differential equations produced all sort of results, inspite of the fact that the initial conditions are exactly the same.

Another possibility for the existence of chaos would be the existence of a finite systems of Axioms followed by Rules.

If the same system brought to different and contradictory conclusions, once again, this would be the proof that Chaos exists in a rigorous logical mathematical structure.

The conclusion is that modern theory of chaos depends on the lack of rigorous knowledge of some parameters in the initial conditions; but this has little to do with chaos [4].

7.2 EVOLUTION OF LIVING MATTER

And now a few remarks on the so called theory of Evolution and origin of our species. Such a theory has never been formulated in terms of a rigorous logic, using the mathematical language.

In order to have an idea of the degree of Complexity in the mathematics needed to describe the evolution of living matter let us see what is needed to describe in a rigorous mathematical language the evolution of the simplest piece of “electricity”, discovered in 1897 by J.J. Thomson and called “electron”.

After more than a century this particle is established to be “elementary”, i.e. without any structure and therefore without Complexity inside its structure since this structure does not exist.

In order to describe the evolution of this “elementary” particle we need a system of four differential equations coupled. This was discovered by P.A.M. Dirac in 1928 [3].

When we go from an elementary particle to the simplest form of “living

matter” the interaction with the environment must be taken into account as shown in Figure 9.

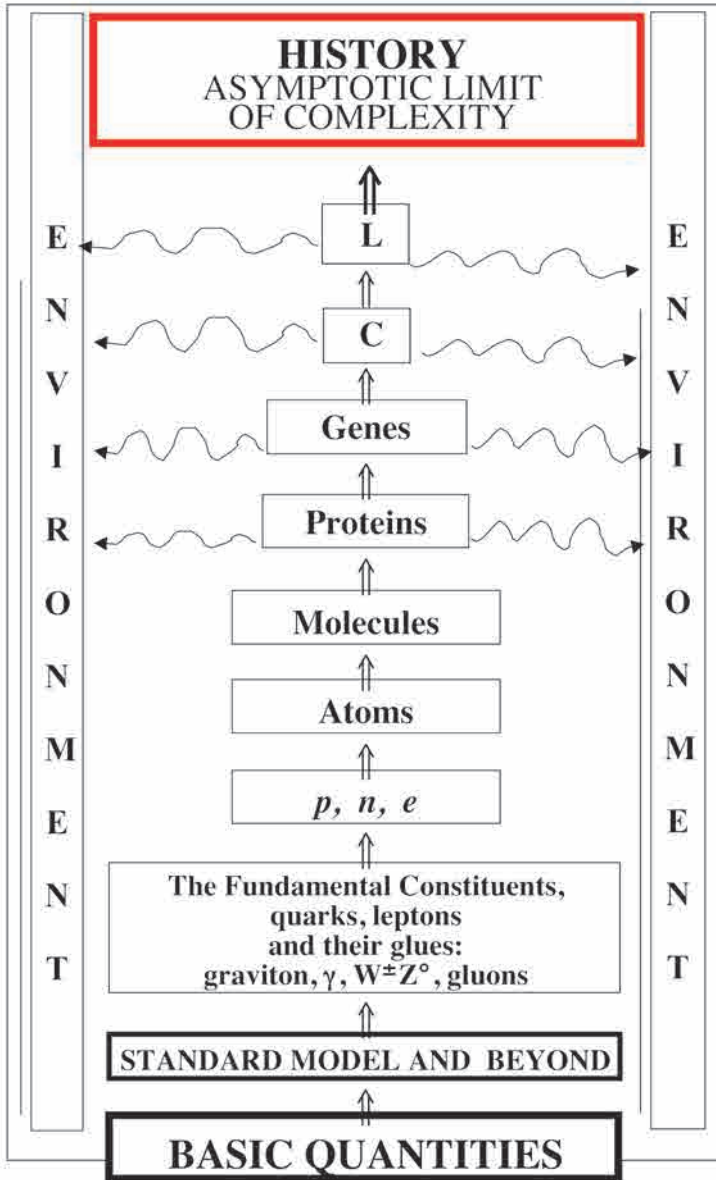


Figure 9

This interaction is a source of a high degree of Complexity. Furthermore the number of “pieces” of inert matter must be at least 10^{11} . This is the maximum limit dictated by Quantum Entanglement. There is no general agreement on this number, the problem being that its value could be much larger. This problem is called “the problem of minimal life” still far from being solved. Notice that hundreds of researchers are at present engaged to study the problem of “minimal life” in many Labs, some of them being secret.

The conclusion is that in order to describe the evolution of the simplest form of living matter we need a (so far unknown) number of differential non linear equations strongly coupled. When this will be attempted, the degree of Complexity will surely be extremely high.

Despite the Complexity of all problems mentioned above, people speak as if not only the evolution but even the origin of the living matter, which we humans are made of, have been scientifically understood.

Let me hope that this telegraphic note will call your attention on the problems which must be taken into account when we go from the elementary form of inert matter to living matter, up to History.

7.3 A FEW WORDS ON HISTORY

No one has ever attempted to describe in a rigorous mathematical language History. If this would be possible “predictions” could be made (as explained in chapter 6), despite the enormous degree of Complexity which characterizes History. Notice that what we call the Queen of all Sciences (Physics) deals with problems where the interaction with the environment is zero.

8 THE LESSON FOR THE FUTURE

We have proved that AFB and UEEC – which are at the origin of Complexity, with its consequences permeating all our existence, from molecular biology to life in all its innumerable forms up to our own, including History – do exist at the fundamental level [5–8] and [1].

It turns out that Complexity in the real world exists, no matter the mass-energy and space-time scales considered.

Therefore the only possible prediction is that:

- **Totally Unexpected Effects** should **show up**.
- **Effects**, which are impossible to be predicted on the basis of **present knowledge**.

We should be prepared with powerful experimental instruments, technologically at the frontier of our knowledge, to discover Totally Unexpected Events in all laboratories, the world over (including CERN in Europe, Gran Sasso in Italy, and other facilities in Japan, USA, China and Russia). All the pieces of the Yukawa gold mine [9] could not have been discovered if the experimental technology was not at the frontier of our knowledge.

Example: the cloud-chambers (Anderson, Blackett, Neddermeyer), the photographic emulsions (Lattes, Occhialini, Powell), the high power magnetic fields (Conversi, Pancini, Piccioni) and the powerful particle accelerators and associated detectors for the discovery – the world over – of the **SM&B** as synthetically reported in chapter 4.2. This means that we must be prepared with the most advanced technology for the discovery of totally unexpected events like the ones found in the Yukawa gold mine.

The mathematical descriptions, and therefore the predictions – for new phenomena to be discovered in the field opened by the given UEEC event – come after the UEEC event, never before.

Recall:

- The **discoveries in Electricity, Magnetism and Optics** (UEEC).
- **Radioactivity** (UEEC).
- The **Cosmic Rays** (UEEC).
- The **Weak Forces** (UEEC).
- The **Nuclear Physics** (UEEC).
- The **Strange Particles** (UEEC).
- The **3 Columns** (UEEC).
- The **origin of the Fundamental Forces** (UEEC).

The present status of Science is reported in figure 10.

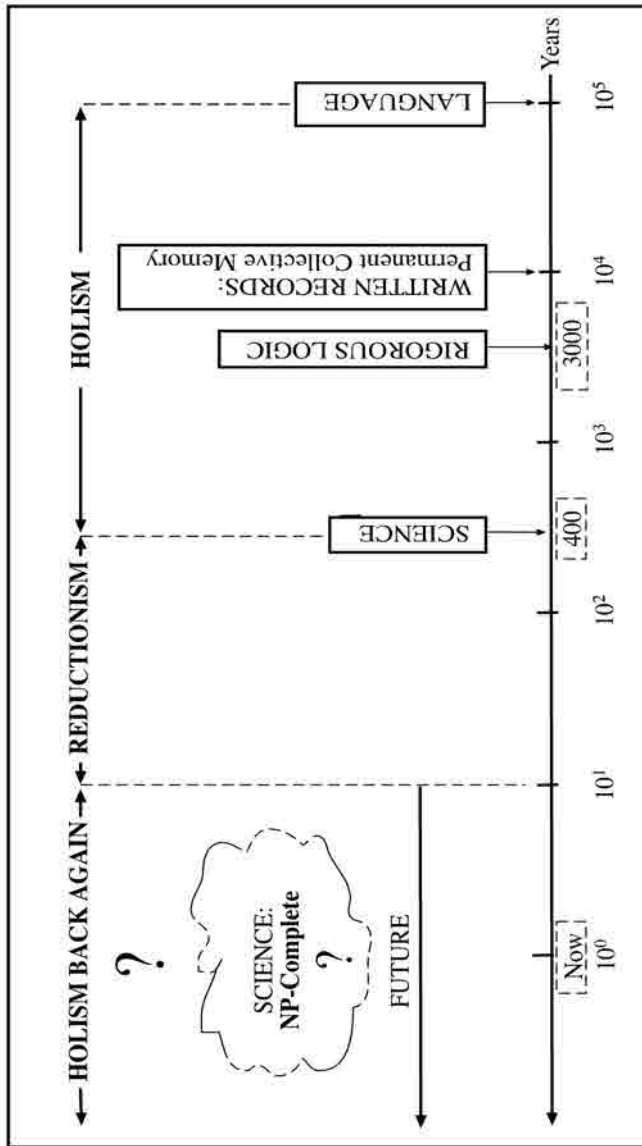


Figure 10

It could be that Science will be mathematically proved to be 'NP-complete'. This is the big question for the immediate future [10].

It is therefore instructive to see how Science fits in the whole of our knowledge as reported in Addendum 3.

Let me point out that Science is the consequence of us being the only form of leaving matter endowed with Reason, from where the sequence of Language–Logic–Science has been originated [11]. The time-sequence of Language–Logic–Science is shown in figure 11.

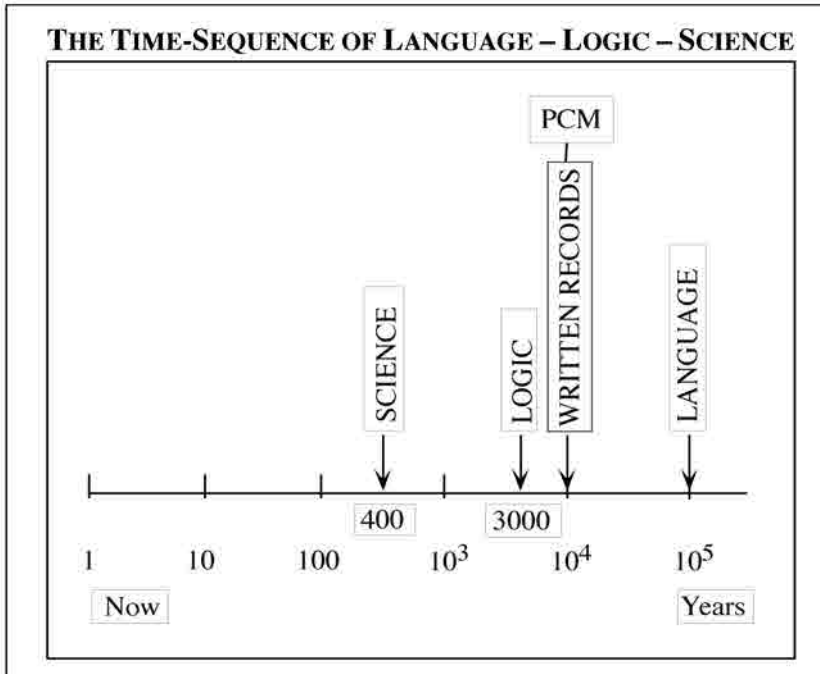


Figure 11

The experimental evidence is that UEEC events dominate our life as we have shown in chapter 5, Table-1, where the evolution of the world in its real life (EWRL = History) and the evolution of our basic understanding of the laws governing the world (EBUS = Science) have been compared.

9 CLOSING REMARKS: FROM PLANCK TO COMPLEXITY

Four centuries of Galilean research work based on Reductionism, i.e. on the identification of the simplest elements in the study of Nature, has allowed us

to get the greatest achievements of Science, i.e. the so called **Standard Model** and its extension (**SM&B**), illustrated before in figure 7.

This extension predicts GUT (the Grand Unification Theory), the existence of the Superworld and the resolution of the quantum-gravity problem via the powerful theoretical structure of RQST (Relativistic Quantum String Theory).

These developments started thirty years ago when a great scientific novelty came; all experimental discoveries obtained with our powerful accelerators were to be considered only matters of extremely low energy.

The scale of energy on which to direct the attention to understand the Logic that rules the world, from the tiniest structures to the galactic ones, had to be shifted at a much higher level: to the mass-energy named after Planck, E_{Planck} , something like seventeen powers of ten above the Fermi scale, E_{Fermi} , that already seemed to be an extremely high level of energy.

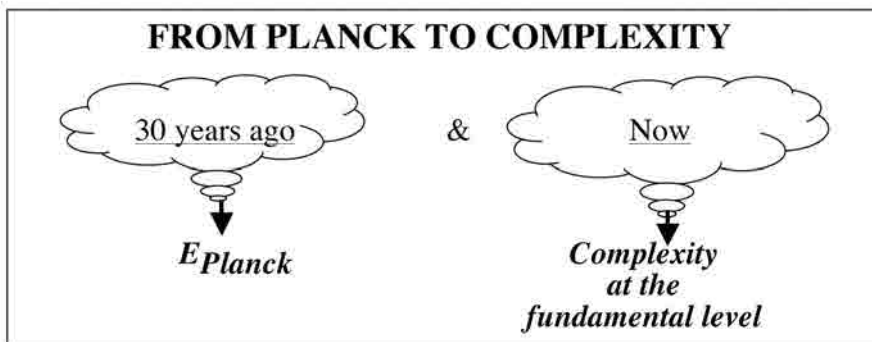


Figure 12

Now, after thirty years, it comes about the novelty of our time: Complexity exists at the fundamental level [1]. In fact, **AFB** and **UEEC** events exist at all scales, as reported all along this lecture.

This result is corroborated from the mathematical structure (the only one) to be in a position of describing all that happens at the Planck scale: the Relativistic Quantum String Theory (**RQST**).

This mathematical structure produces innumerable minima of energy, named **Landscape**.

The theoretical discovery of the **Landscape** (Leonard Susskind) [12], has been followed by another formidable discovery in mathematical physics: the

most rigorous model of RQST (Raphael Bousso and Joseph Polchinski) is **NP-complete** (Michael R. Douglas and Frederik Denef) [13].

This discovery corroborates all that we have put in evidence during the last five years [5–8]: **Complexity exists at the fundamental level** [1].

We do not know what will be the final outcome of String Theory.

What we know is that: *‘The world appears to be complex at every scale. Therefore we must expect a continued series of surprises that we cannot easily predict’*.

A detail of great interest to me: with the advent of the LHC it will be possible to study the properties of the Quark-Gluon-Coloured-World (QGCW), which is a world totally different from all we have been dealing with since the origin of Science.

10 THE FINAL QUESTION

The final question is: why the greatest achievements of Science have always been generated by UEEC, i.e. totally unexpected events?

ADDENDUM 1 THE PLATONIC GRAND UNIFICATION

In figure 13 is reported the best example of Platonic Grand Unification (the blue straight line). The points have a sequence of 100 GeV in energy. The last point where the 'ideal' platonic straight line intercepts the theoretical prediction is at the energy of the Grand Unification. This corresponds to $E_{GU} = 10^{16.2}$ GeV. Other detailed information on the theoretical inputs: the number of fermionic families, N_F , is 3; the number of Higgs particles, N_H , is 2. The input values of the gauge couplings at the Z^0 -mass is $\alpha_3(M_Z) = 0.118 \pm 0.008$; the other input is the ratio of weak and electromagnetic couplings also measured at the Z^0 -mass value: $\sin^2 \theta_W(M_Z) = 0.2334 \pm 0.0008$.

The Platonic Grand Unification should be along the straight line (in blue) but Nature seems to follow the red points.

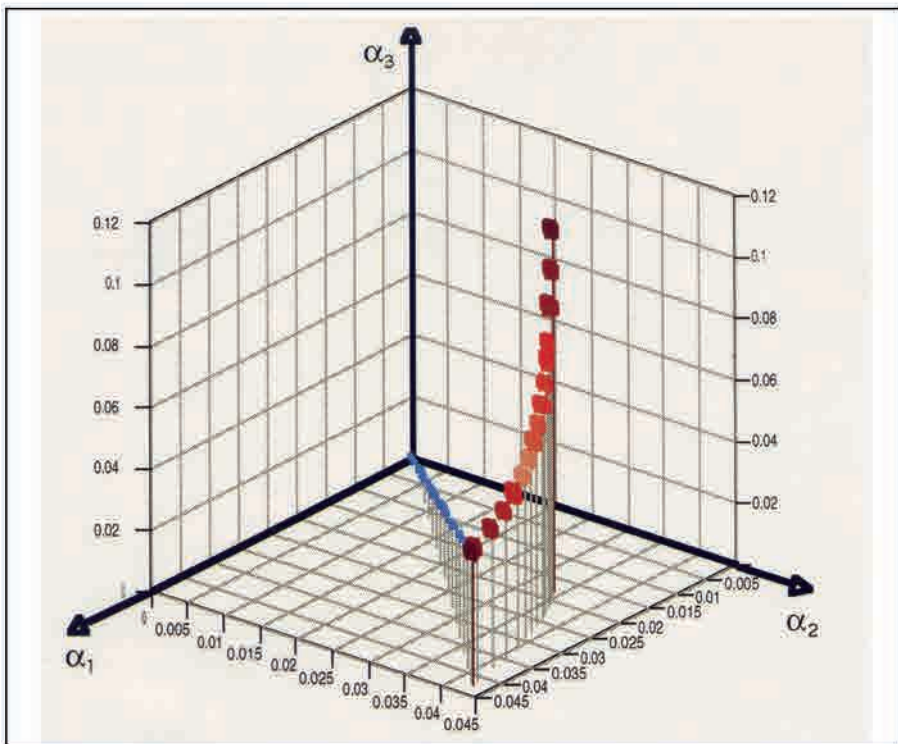


Figure 13

ADDENDUM 2
THE PLATONIC SUPERWORLD

THE PLATONIC CONCEPT OF SUPERSYMMETRY

The **Gauge Principle** should generate a
Gauge Force → **Gauge Bosons**
If *NATURE* was platonically *SUPERSYMMETRIC*
Supersymmetry Transformation should generate **Gauginos**

1st DEVIATION FROM PLATONIC SIMPLICITY
OUR FERMIONS ARE NOT THE GAUGINOS

2nd DEVIATION FROM PLATONIC SIMPLICITY
*THE FUNDAMENTAL FERMIONS ARE OF TWO
DIFFERENT CLASSES: LEPTONS AND QUARKS*

3rd DEVIATION FROM PLATONIC SIMPLICITY
*THERE IS NOT ONLY ONE BUT THREE FAMILIES
OF FUNDAMENTAL FERMIONS*

4th DEVIATION FROM PLATONIC SIMPLICITY
*THE FUNDAMENTAL FERMIONS BECOME MIXED WHEN THE
WEAK FORCES ARE SWITCHED ON: MIXINGS EXIST*

5th DEVIATION FROM PLATONIC SIMPLICITY
THERE ARE DIFFERENT MIXINGS

Figure 14

ADDENDUM 3 THE WHOLE OF OUR KNOWLEDGE

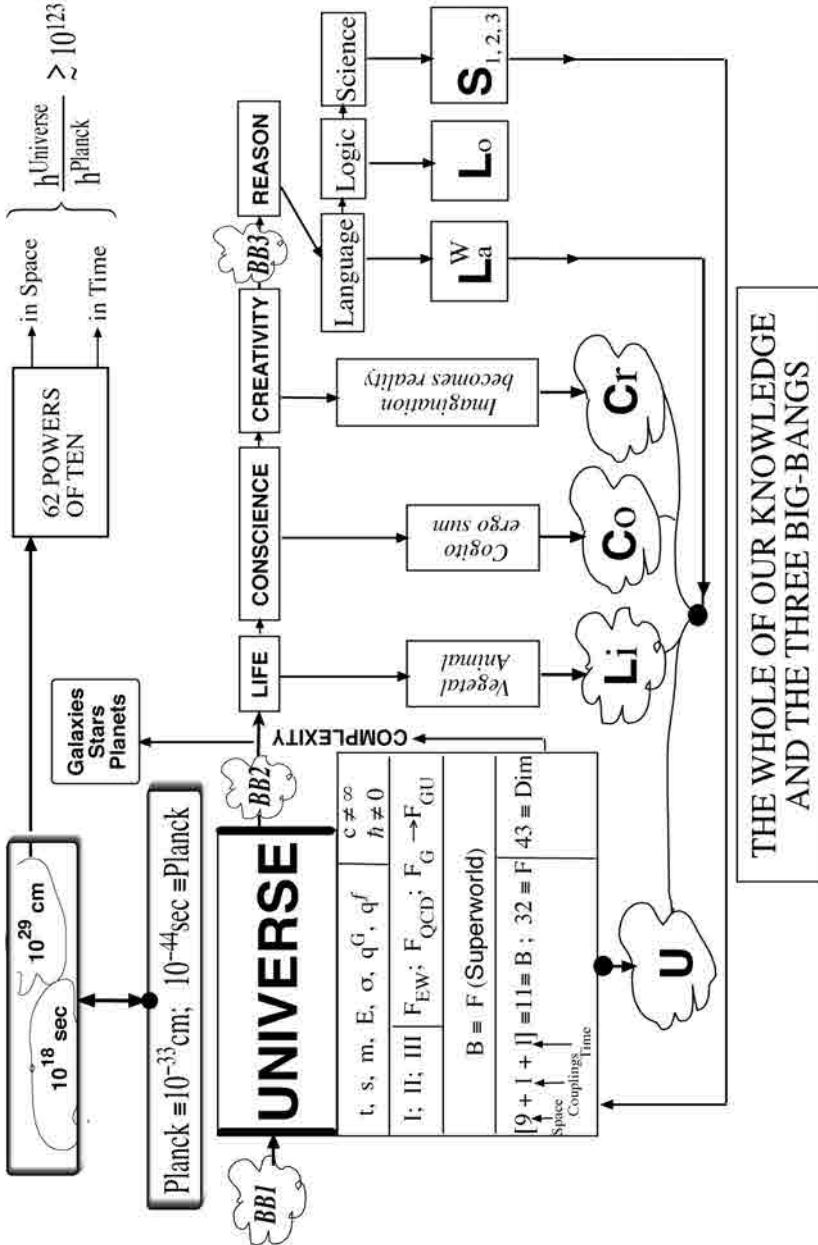


Figure 15

ADDENDUM 4

UEEC EVENTS IN NUCLEAR PHYSICS

Let me dedicate some attention to discuss UEEC events in nuclear physics. In fact in many books it is considered standard wisdom the fact that nuclear physics is based on perfectly sound theoretical predictions. People forget the impressive series of UEEC events discovered in what I have decided to call the ‘Yukawa gold mine’.

Let me quote just three of them:

- 1 The first experimental evidence for a cosmic ray particle believed to be the Yukawa meson was a lepton: the muon.
- 2 The decay-chain: $\pi \rightarrow \mu \rightarrow e$ was found to break the symmetry laws of Parity and Charge Conjugation.
- 3 The intrinsic structure of the Yukawa particle was found to be governed by a new fundamental force of Nature, Quantum ChromoDynamics: QCD.

As you know 2007 was the centenary of the birth of Hideki Yukawa, the father of theoretical nuclear physics. In 1935 the existence of a particle, with mass intermediate (this is the origin of ‘mesotron’ now ‘meson’) between the light electron, m_e , and the heavy nucleon (proton or neutron), m_N , was proposed by Yukawa [14].

This intermediate mass value was deduced by Yukawa from the range of the nuclear forces. Contrary to the general wisdom of the time, Yukawa was convinced that the particles known (electrons, protons, neutrons and photons), could not explain how protons and neutrons are bound into the extremely small dimensions of a nucleus.

In order to make this ‘prediction’, Yukawa needed the Heisenberg uncertainty principle: a totally unexpected theoretical discovery.

The origin of it was the totally unexpected discovery of the dual nature of the electron (wave and particle) and of the photon (wave and particle).

Heisenberg himself tried to explain the binding forces between the proton and the neutron, via the exchange of electrons, in order not to postulate

the existence of a new particle. The very light electron, m_e , could not stay in the very small dimension of the nucleus.

The author of the uncertainty principle and father, with Dirac and Pauli, of Quantum Mechanics, did not realise this contradiction. The need for a new 'particle' was the reason. What no-one was able to predict was the 'gold-mine' hidden in the production, the decay and the intrinsic structure of this new 'particle'.

This 'gold-mine' is still being explored nowadays and its present frontier is the Quark-Gluon-Coloured-World (QGCW) [15].

I have recently described [9] the unexpected conceptual developments coming from the study of the production, the decay and the intrinsic structure of the Yukawa particle.

Let me just quote the most relevant UEEC events: chirality-invariance, spontaneous symmetry breaking, symmetry breaking of fundamental invariance laws (P, C, T), anomalies, and 'anomaly-free condition', existence of a third family of fundamental fermions, gauge principle for non-Abelian forces, instantons and existence of a pseudoscalar particle made of the quanta of a new fundamental force of Nature acting between the constituents of the Yukawa particle.

ADDENDUM 5

UEEC EVENTS WHERE I HAVE BEEN DIRECTLY INVOLVED

A few cases (seven) where I have been directly involved are summarised in figure 16. Each **UEEC** event is coupled with a **despite**, in order to emphasize the reason why the event is unexpected.

*UEEC EVENTS
IN THE CONSTRUCTION OF THE SM&B
MY PERSONAL EXPERIENCE*

- ① *The 3rd lepton, HL (now called τ) with its own neutrino, ν_{HL} (now called ν_{τ}),
despite the abundance of neutrinos: ν_e and ν_{μ} .*
- ② *Antimatter
despite S-matrix and C, P, CP, T breakings.*
- ③ *Nucleon Time-like EM structure
despite S-matrix.*
- ④ *No quarks in violent (pp) collisions
despite scaling and Asymptotic Freedom.*
- ⑤ *Meson mixings
 $\theta_V \neq \theta_{PS} : (51^\circ) \neq (10^\circ) \neq 0$ **despite** $SU(3)_{uds}$.*
- ⑥ *Effective energy: the Gribov QCD-light
despite Platonic Simplicity and QCD-confinement not rigorously understood.*
- ⑦ *The running of $\alpha_1 \alpha_2 \alpha_3$ versus energy at a point E_{GU}
1979) (1991) **despite** straight line convergence.*

EGM

Figure 16

All these events have contributed to the construction of the **Standard Model and Beyond (SM&B)**.

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