XXIst Century Perspectives on the Micro & Macro Worlds

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Abstract. We present a broad perspective on our (Early) XXIt century understanding of both the macro and micro worlds, and whether the dream embodied in the symbolism of Glashow’s snake (Ouroboro) has been implemented to some degree or recessed away. Do we have a unified vision of the world at those extreme scales? What about the status of that «21st century» theory «that fell accidentally into the 20th century.” aka superstrings to quote E.Witten, and which is the «ideological» cement of very powerful aspiring-to-be paradigms like Cosmic Inflation, Multiverses, extra dimensions (ED) … as well as the inspiration of most pre-Big Bang theories. We will discuss along the way the fine tuning curse, the Cosmic Inflation and Multiverse’s Pandora box, and other big mysteries perhaps of our own making, and propose that in our search for «truth», and to keep our sanity in the actual jungle of bold «new ideas» and puzzles, we be guided by the voice of reason which goes by the unpretentious name of under- determinacy of theories.

Keywords: Theoretical physics, multiverse, GRB, CMB, under- determinacy

1. Hadrons versus Bisons

1.1. Introduction

Before plunging into the intricacies of today’s big physics puzzles, let us take a wider perspective, so much so that it may even be seen as a provocation. Here we acknowledge the clear inspiration from the wandering bison within the Tevatron’s ring at Fermilab, surviving specimens of what used to be freely roaming big herds of those animals in the American prairies. Let us thus take the bull (Or the bison) by its horns. It has long been held by the scientific community, and in any case by the physicists, that there are some most fundamental simple entities in the material world and today it is the quark (or sometimes the string...). On the other end, at the largest scale, the most relevant basic entity is the galaxy or perhaps the galactic clusters moving within an elastic space-time of flat geometry but unknown topology. If one is a strict reductionist, it is certainly so and a properly led bottom up approach from the smallest to the largest scale should ultimately fill the gaps. Yet we know that things are more complicated than that as there are indeed big uncrossing gaps in the great length scale of things as we will be discussing at some length later, and even if the concept of emerging reality could mitigate the gap problem, searching for the smallest material entities may not be the most relevant primary endeavor.
Now squeezed between those two extremes scales lurks the living, a propriety of matter of incredible complexity that stands beyond the realm of physics, indeed a kind of hyper-physics. Physics has been held to be the paradigmatic science, the discipline that all the other sciences take as an ideal to be molded after, imitate it, submit itself to its drastic standards … but most often fail. Didn’t Auguste Comte coin the name of social-physics for sociology out of consideration of the high esteem he held physics? Yet physics itself is now facing an existential challenge from biology to the point that some have predicted that if physics was the science of XXth century par excellence, biology might well be the science of the XXIth century. This is sometimes watered down somewhat by stating that to happen, biology will have opportunistically ally itself to computer science, AI, microelectronics. It may have to go through creating chimera from both worlds, some of which already exist at some extent today in the form of DNA chips.

At the heart of the fundamental division among the natural sciences today, although seldom if ever presented this way, is the sciences of the «inert» matter in contradistinction with those of the living. To put it more dramatically, we deal in physics with «dead» entities dictated ultimately by some QFT, while biologists manipulate living entities involving complicated self-reproducing biochemical processes, which can ultimately develop a higher level of activity, namely sentience and sapience. This is basically what correspond to consciousness and self awareness. There is indeed those big essential and uncrossable jumps we mentioned earlier when going from the hadrons to the bison. Now we could certainly imagine a functional World without living organisms, where life would be an option on matter, and which would impact minimally on its physical properties. This is in some way similar to the effect of Dark Matter (DM) and Dark Energy (DE) on the local properties of the hadronic World: All the laboratory experiments can be carried out without seen any of their effects, although it constitutes some 95% of the mass content of the Universe. Yet, we can’t easily brush aside the implications that the World is «gros du vivant», and that sentient beings are needed to merely imagine it.

There is no question that the failure of physics to solve those big puzzles left over from late XXth century physics is really stemming from the limitations of experimental particle physics as it stumble on the «not high enough» energy limit of present day colliders which has put every «beyond the Standard Model» theory basically on hold. The hints we get from experiments are too feeble as we can’t probe a high enough mass region where are possibly lurking other non-standard gauge bosons and Higgs, not talking about the SUSY zoo, ED particles and other exotic brands. Thus, the great hope pinned on the UHE Cosmic Rays for their capability to cross the many orders of magnitude energy gap and reach for the physics of cosmic accelerators and whatever they might be spitting out of new exotic massive particles.
Now, unlike the 19th century physics whose two dark clouds as described by Lord Kelvin were pregnant of an amazing new synthesis around which much of the XXth century physics gravitated around, the big black clouds (Dark Matter, Dark Energy,….) of the twentieth century have not given way to any fertile synthesis but have rather become enshrouded into a thicker mystery. If physicists from Lord Kelvin to S.Hawking were thinking that physics might be brought to completion within their lifetime, we are now stuck with an uncompleted grand unification scheme bearing the frustrations of the past forty or so years. This frustration cannot better brought to the fore by the new trend of thought entertaining the idea that physics built on unambiguous facts and rock solid univocal explanations is foregone. That this physics, and here we mean «frontier» physics, stands to be replaced by one with flouted contours made of ever competing though incommensurate «explanations» (Mere unsubstantiated speculations for others), or worse, that we are entering an era of computer simulated physics to palliate the sparsity of data or from the mere technical impossibility of carrying out some crucial experiments [1].

2. The Particle Physics Connection to the Universe

One of the most significant advance in modern physics is certainly its successful drive to uncover the intimate structure of the microscopic world. We can say in this early part of the XXIst century that we believe we know the fundamental constituents of matter and their various modes of interaction. So much so that this knowledge has found its way to High School textbooks.

2.1. The intimate structure of matter

Our world is one of fermionic matter, conveniently classified in two kinds: the hadronic one and the leptonic one. The hadronic component which constitutes the bulk of matter and forms all the structures we see around including our bodies is made ultimately of quarks, with the two common ones bring the "u" and the "d" quarks, and with four more found during fleeting instants in high energy processes like at colliders or when cosmic rays slam into matter. The leptonic matter is basically made of the electron, the only stable lepton and two more massive ones namely the muon and the taon. Beside this, three chargeless and almost massless leptons exist, the neutrinos, but they are so weekly interacting that they are of no consequence in everyday life.

![Fig 2: The basic components of matter: six quarks and six leptons. The four stables are: The "u" and "d" quarks forming the hadronic matter while the electron a non nuclear particle reestablish the overall electrical neutrality of matter, and the neutrino which is an almost non interacting particle of no direct significance in daily life.](image)

All these matter particles interact through exchange of other particles of spin one and two, this time called bosons, namely the photon, the W- and Z bosons, gluons and gravitons. This historical achievement has at the same time slashed out most extensions of the SM, including SUSY, strings, most technicolor models. Ultimately the results of the Large Hadron Collider (LHC) at CERN in Geneva may have killed many beautiful theories. It is in some sense the particle physics version of the biological Cretaceous–Paleogene “great extinction”. At the other hand of the spectrum, towards the infinitely large, lay stupendous objects and structures that no physicist, say early 20th century one, could have imagined: hierarchized clusters of galaxies,
galaxies in fury going by the name of Active Galactic Nuclei or AGNs including the quasars and its cousins the blazars and magnetars, galactic black holes, millisecond pulsars...

Should we be concerned as physicists with those cosmic structures and all this queer world? Certainly, the Universe is that large laboratory where all kinds of processes are taking place in conditions no earthly laboratory can provide. It is indeed the largest laboratory we can think of but even the ultimate one. As such, all the forms of matter under all the possible conditions are there, and all the imaginable processes are taking place and more. So if we, as physicists, are true to our vocation as the matter experts, the Universe should be our domain of predilection par excellence. It is also necessary multidisciplinary in view of the extreme conditions which prevail and thus the array of lengths and energy scales covered, which is indeed one of the characteristics of today's astrophysics.

![Fig 3: Left. The Eagle nebula in far IR and X-Rays. The challenges of interpreting this complex scene is at the heart of the astrophysical enterprise.](image)

![Fig 4: Right. The last cosmic information billboard. Anything which has occurred before that had to have left its imprint on the electromagnetic wall some 380,000 years after the Big Bang. At the top is the map of temperature anisotropies of the CMB at the time when the Universe became transparent to photons as obtained by the Planck telescope (ESA and the Planck Collaboration). The various spots are the cosmic seeds that would evolve into structure like galaxy clusters. At the bottom is a suggestive illustration on the role of CMB maps in understanding the early Universe.](image)

The various "electromagnetic" telescopes (Optical, IR, X and Gamma rays) enable one to see the Universe even in the distant past as the light which reaches us now from faraway places informs us of the state of matter long ago. Yet, what is available to see is only the Universe when the first stars started to ignite and the first galaxies shaped themselves some few hundred millions years after the Big Bang. Could we see before that period, namely after the reionisation era? The answer is yes and in an astonishing way. In 1965 was discovered the Cosmic Microwave Background (CMB) [2], which was interpreted as a distant echo of the Big Bang and a truly electromagnetic wall. Nothing before that era could ever be seen. All we could hope for is that whatever event which took place before that fatidic instant has left its mark on that CMB background. All the rich physics prior to that time is hidden for eternity, including the C(Nu)B of free streaming neutrinos some one second after the Big Bang itself and has to be inferred from particle theory.

2.2. The Two Dark Horses of Cosmology: DM & DE
Modern astrophysics and cosmology have to their credit some great achievements, yet it is confronted with great puzzles. Let us mention few of these mysteries. There is first the hyper energetic Gamma Ray Bursts or GRB's which are by far the most powerful explosions in the Universe. Then the existence of the GZK limit [3] which may enable us to probe the high energy limit of the Lorentz transformation or in other words the domain of validity of special relativity. Could one succeed one day in detecting the C\textsubscript{Nu}B, that is the cosmic background in neutrinos instead of photons? It is actually unthinkable experimentally wise due to the extreme weakness of the neutrino's interaction with any form of matter, but perhaps through some unknown process at present time which would enable us to peek much farther in the history of the Universe.

Indeed this neutrino background, which is a strong prediction of the hot standard Big Bang model, appeared few seconds after the Big Bang when the Universe was at a temperature of some ten billion kelvins (~1MeV) and would allow one to probe the physics of the Universe much earlier than what allows us the CMB which is right now the ultimate looking back limit time wise.

The existence of Dark Matter (DM) and Dark Energy (DE) [4] are perhaps the most baffling discovery of all and has left perplexed the scientific community. What is this shadow matter which is everywhere but that we couldn't till now detect in any direct way? This is not as trivial as finding some traces of substance of unknown origin in some material object; we are talking about forms of matter making up some 95% of the energy content of the Cosmos! Even in the context of the standard Big Bang cosmology (Friedmann - Lemaître models), it is game changing as the geometry and the
Universe’s fate have become disentangled. Indeed, the Universe is flat only because of the DE density contribution and its negative, … but then as we don’t know the future evolution of the DE energy density, the Universe’s ultimate fate is unknown; is it an indefinite expansion, a Big Rip or a Big Crunch? They are even higher level theoretical speculations that one may leave one in some disarray: Visions where our Universe would be like a giant computer, or a Black Hole whose Schwarzschild radius is the Hubble's horizon, or even a hologram. Even if we could determine the Universe geometry, which at present time looks flat that is Euclidian, what is its topology or connectivity? When looking at it globally, is it a simply connected space or a multiply connected one and thus its spatial extent? Does its structure has holes, handles, or is it crumpled? Recall that geometries with negative curvature can have a finite volume according to its topology. Then the most baffling speculation of all: Is the Universe single or multiple? In the latter case, it would be forming a so-called Multiverse [5] with causally disconnected bubble Universes, each one with its own specific set of laws, our own Universe within its Hubble horizon constituting one single bubble.

So one may describe cosmology today as Trotsky’s physicist version of permanent revolution, with indeed a fundamental conceptual revolution every decade or so.

3. The Grand Connections

Late XXth century physics has been able to unravel deep connections between the microscopic (Laboratory) physics and the large scale Universe. Let us review some of those connections. The first one might be the chemical evolution of the Universe starting from the Big Bang. This non trivial fact constitutes one of the greatest triumphs of modern science. Starting basically from two elements produced in the primordial nucleo-synthesis, stellar evolution punctuated by Supernovae explosions has literally filled out the Periodic Table of Mendeleev. That table would have otherwise stayed empty and a mere virtuality the way we are talking today about stable super-heavy elements in some islands of stability beyond element 115. The various chemical elements dispersed throughout the Cosmos are thus the fiery products of titanesque stellar explosions. In addition this stellar nucleo-synthesis occurred also as the result of neutron stars merging which produced some heavy elements like gold, platinum uranium and the like as it was discovered through the detection of time correlated gravitational waves and GRB’s in 2017 [6], although this scenario for producing most of these heavy elements this way has recently been disputed [7].

Fig 7: How large should be a world (Or a bubble) for our cosmos and its underpinnings including us to exist and behave the way we experience it?

Next in the list is the mystery of missing anti-matter in the Universe. In a World coming out of a Big Bang, we would expect from standard particle physics, an equal amount of matter and anti-matter. Particle physicists exploiting some leeway in the Standard Model were able to bring forth a mechanism which goes by the name of primordial lepto-genesis based on CP violation which could have generated a baryon excess over anti-baryons (baryogenesis) needed to obtain a tiny excess of matter over anti-matter that we observe. Then in an epic annihilation battle between those two material components, they both annihilated each other save for a tiny amount of the stuff the ordinary matter is made of. Not only are there intricacies involved to make the mechanism work, but there is also much arbitrariness in choosing the values of the various parameters. Ultimately, in the absence of any good
enough handle on the CP violation parameters, it is a fitting game, although there is basically no other game in town to save the World of being but tiny smears of matter and not a «Great Nothingness».

We will conclude this grand connections short list with a puzzling fact of why is the Universe so huge and basically empty? In other words, why is the Universe scale incommensurately larger than the human scale? Could we live in a smaller and possibly denser one? A rather similar issue arises when we ask ourselves why do we need a whole planet to live a life as we know it (Value of g so that we stay grounded, retention of the atmosphere, vast oceans, early volcanism... and be able to cultivate our garden) [8]. It is clear that in order to live our lives we need a huge planet which resulted itself from events at the scale of a stellar system ... and a star like our Sun. At a larger scale, the Universe has to come to age through out of scale events (Big Bang, the ensuing phase transitions, matter radiation decoupling...) which enabled its expansion, and stellar nucleo-synthesis to occur. This naturally resulted in an almost empty space with scattered tiny balls of plasma gaz and condensed matter we call stars and planets.

4. Integrating all the levels and Multivocity

As we saw going through the various topics related to what a new comprehension and puzzles brought to us, it is clear that theoretical physics, or frontier physics is not close to come to an end. On the contrary, as a new comprehension expands, new puzzles keep popping up requiring new thinking, new concepts, and certainly to be ready to put some issues thought previously to be understood into question. The biggest puzzles have to do with the concept of matter itself, or at least the dominant form of it in the Universe. That Dark Matter and Dark Energy, entities of utterly unknown properties, form some 95% of the material content of the whole is deeply disturbing. Although there is no consequence on everyday physics, this fact itself should be quite disturbing by itself. It is also going through a mild crisis on the conceptual front as some of its pet theories it has laboriously invested in for the last few decades, namely, superstrings, ED, LQG and the like, didn't get any experimental confirmation nor even any hint of it. DM is still a deep mystery and the SUSY particles haven’t been found at the LHC putting into question the relevancy of SUSY itself.

May be the problem lays in the fact that not having found alternative theories, we tend to assume that only the first groundbreaking theory on a given topic, especially if well crafted, can explain the data. There is also built-in the fact that nobody wants to challenge the dominant story unless you have a much better one to offer and preferably well endowed with wholehearted supporters. Now this dominant theory has often become so because people have invested time, grants, smart graduate students in refining it and thus pathfinding it a way to success. Another hint is the fact that cosmology is renewing its main paradigm every decade or so. We have also seen instances where appendages to a theory even if felt vital at some point are highly susceptible to be gotten rid of later to then completely forget the claim about their crucial character. The new situation can still be at the mercy of a maverick who may enable a fallen theory to be kept alive beyond its natural death point. Thus Fred Hoyle has kept almost single-handedly the Steady State theory alive as an alternative to the Big Bang for close to two decades, even when their original proponents have given up on it! He even could explain within his theory the 3K temperature of the CMB radiation better than standard BB cosmology at that time...A similar situation happened quite prominently earlier with the Bootstrap theory in particle physics. In other word, a well assisted theory may never die! This is where the concept of underdeterminacy of theories may come to the rescue. This is a concept in epistemology popularized by W.V.Quine which states:

«Physical theories can be at odds with each other and yet compatible with all possible data even in the broadest sense. In a word, they can be logically incompatible and empirically equivalent.» [9]

Yet we are so little used to this pluriocity aspect of theories that it may sound like heresy. That should temper the ardor of those who may believe in the irrevocability of some pet theories, even when the phase space of equivalent ones has not been probed or may never be probed for reasons underlined above.
5. Conclusions
Theoretical Physics stands in this early XXIst century in a state of bewilderment. It is indeed a sobering moment of unaccomplished dreams left over from the late XXth century, but if the history is of any guide, physics is crisis-prone and there was no time in the past when the theoretical landscape was unobstructed. May be the Einstein-like of physics program based on an ever going simplification and unification will have to come to an halt till more fundamental bricks and new concepts are found and brought to bear. For this to happen, experimental data and new theories will have to tally. The debate is on within the particle physics community for building a beyond the LHC «Next Collider» and whether we could afford it [9]. Other big projects are popping up which should probe further the mysteries of the material world at various scales. This cautiously hopeful vision allows me to conclude in saying that frontier physics should have a challenging but shinning future.

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