



A Physical Philosophy for Approaching the True and Then the Beautiful: Principled Review on the Progress of Contemporary Physics

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Abstract

Physics demands not only the beautiful but also the true. The true is the first, and the beautiful is the second. The philosophy of physics should emphasize the true and then the beautiful. After reviewing three kind of main hypotheses beyond standard model, and based on experimental and observational evidences, three physical principles and three philosophical rules are suggested, namely P1-action principle, P2-duality principle, P3-equivalence principle, and R1-logic harmony, R2-minimum hypotheses, R3-maximum hopes. It is revealed that there are no supersymmetry and dark sectors because the space and time for the existence of unknown particles resemble impossible.

Keywords: Physical philosophy; The true; The beautiful; Standard model; Dark matter; Dark energy; Physical principles.



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1. Introduction

When we emphasize that the beautiful is an important spirit in physics, we must not forget that the true is the first pursuit of physics. We have a lot historical lessons, and we briefly mention three examples.

The first example is Ptolemy's model. Claudius Ptolemy (100-170) suggested his scientific cosmology, where our universe was described by perfect cycles and the Earth was located at the center of the universe, which looks beautiful. However, when we knew that some planets could reverse their steady eastward motions among the stars, i.e. phenomenon retrograde motion, the Ptolemaic model required the planets not only to move in circles around Earth but also to move along smaller circles, called epicycles, around imaginary points along the main circular orbits. Their epicycle centers must lie on the line connecting the Earth and Sun. Later, as the observed phenomenology developed more and more exactly, the world image became more and more complex by adding epicycles on epicycles, and then no one thought that was the true. Then it was well known that the beautiful had to give way to the true, while Nicolaus Copernicus (1473-1543) introduced his heliocentric model as known as Copernicus revolution.

The second example is Kepler's harmonic world model. In his book *Harmonices Mundi* (The Harmony of the World, 1619), Johannes Kepler (1571-1630) proposed the celestial-harmonic relationships. The text relates his findings about the concept of congruence with respect to diverse categories of the physical domain, including regularities in three-dimensional geometry, the relationships among different species of magnitude, the principles of consonance in music, and the organization of the Solar System. Kepler considered the *Harmonices Mundi* his greatest work. However, excepting the organization of the Solar System remained as the Kepler's third law, we abandon his all beautiful thoughts that the semi-regular Archimedean Solids determines the spacing between the planetary orbits in three dimensional geometric shapes and that there were "music of the spheres", though all of the planets would sing together in "perfect concord". Therefore, only three Kepler's laws[†] (the first two laws were proposed in his previous book, *Astronomia nova*) remained in science. We forgot the beautiful and kept the true.

The third example is GUT (Grand Unification Theory) models such as SU(5) and SO(10). As the present standard model is characterized by $SU_C(3) \times SU_L(2) \times U_Y(1)$ gauge field based on quantum field theory [1], logically, the minimum beautiful extension of the standard model is SU(5) grand unification, which could include symmetry $SU(3) \times SU(2) \times U(1)$ in it (without considering gravity), since the standard model had the greatest success, including the prediction of the W and Z bosons, the gluon, and the top and the charm quarks, before they were observed, as well as the prediction of the Higgs boson, which had been experimentally discovered in 2012 and verified in 2013 by LHC at energy 125.6 GeV/c² [2, 3]. However, as the standard model predicts neutrinos to be massless while the observed evidence of neutrino oscillations implies that neutrinos have tiny mass [4], it is strongly suggested that there exists new physics beyond the standard model. Now GUT looks beautiful. Unfortunately, the prediction from GUT indicates that proton would decay at the time level of 10³¹ years, but the experiment evidences give strong sign that is larger than 10³² years. We have to give up the beautiful, for seeking the true.

Therefore, not all mathematical/physical beautiful hypotheses were true. We need to recall the historical experiences, and let present physics pay more attention to the true, and then beautiful.

[†] 1. The orbit of a planet is an ellipse with the Sun at one of the two foci. 2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time. 3. The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

Meanwhile, in the 21st century, the dark sectors, dark matter and dark energy [5, 6], became the biggest issues in contemporary physics. The presence of dark matter is implied in a variety of astrophysical observations, including gravitational effects that cannot be explained unless more matter is present than can be seen. However, dark matter is only a hypothetical form of matter. It is never verified. It is thought to be non-baryonic in nature, possibly being composed of some undiscovered subatomic particles, or being nothing with considering modified gravity in modeling. Also, dark energy is an unknown form of energy, which is hypothesized to permeate all of space, tending to accelerate the expansion of the universe. The density of dark energy is very low, about $7 \times 10^{-30} \text{ g/cm}^3$, much less than the density of ordinary matter or dark matter within galaxies. However, it dominates the mass–energy of the universe because it is uniform across all the space. According to Planck satellite’s newest observation report [7, 8], and based on the standard cosmological model, the total mass–energy of the universe contains 4.9% ordinary matter and energy, 26.8% dark matter and 68.3% dark energy (negative pressure). The phenomena look beyond standard model. However, we lack of complete theory for interpreting and understanding.

In this article, by reviewing representative new models beyond standard model and based on progress of experimental and observational evidences, we try to discuss a physical philosophy, for approaching the true at first, and then beautiful, with considering three physical principles and three philosophical rules.

2. A Brief Review of Representative Hypotheses Beyond Standard Model

There are many hypotheses for approaching physical unification beyond standard models, in which we mention and review three kinds of representative ones. These hypotheses can be classified as string theory and M-theory [9, 10]; LQG and CDT [11-13]; as well as MOND and TeSeV [14-16].

For each kind of the hypothesis, we conclude its advantages and costs for reaching its physical image.

2.1. String Theory and M-Theory

Among all hypotheses beyond the standard model, string theory and M-theory are the most famous ones. Although this kind of models have been called as theories, they still belong to hypotheses, as they never been verified by physical experiments and never forecast verifiable physics. Originated from string theory and developed to become M-theory even F-theory, this kind of hypotheses focused on and characterized by supersymmetry and duality as shown as Figure 1.

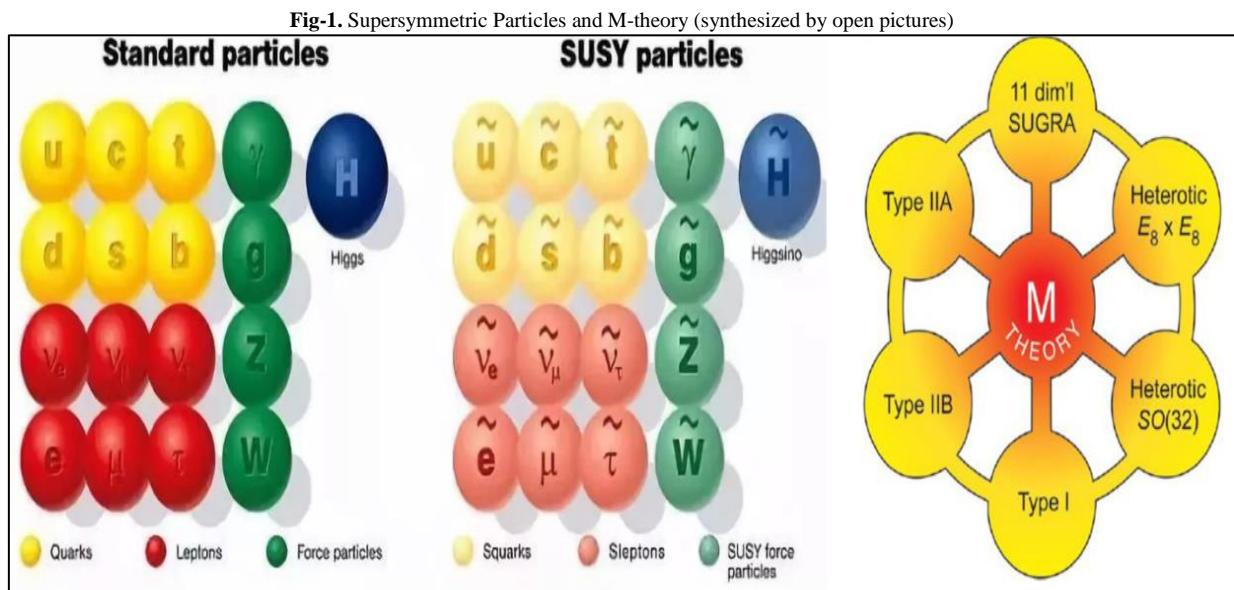


Figure 1 means that present particles (left) should be doubled to exist their supersymmetric partners (middle) and all types of “theories” are duality each other (right). For those representative scientists, we may mention American physicists Edward Witten, Leonard Susskind and Cumrun Vafa.

We can characterize two typical properties of M-theory. 1) The ‘theory’ contains strings and branes (membranes) as structural bases in 11 dimensions of spacetime, with using compactification to explain how the extra dimensions reduce to the four spacetime dimensions we observe. 2) There are dualities and identifications within the ‘theory’ that allow it to reduce to special cases of the string theories known, and ultimately into the physics we observe in our universe. Roughly speaking, fermions are the constituents of matter, while bosons mediate interactions between particles. In hypotheses with supersymmetry, each boson has a counterpart which is a fermion, and vice versa. When supersymmetry is imposed as a local symmetry, one automatically obtains a quantum mechanical hypothesis that includes gravity. Such a hypothesis is called a supergravity, while a hypothesis of strings that incorporates the idea of supersymmetry is called a superstring. There are several different versions of superstring ‘theories’ which are all subsumed within the M-theory framework. At low energies, the superstring hypotheses are approximated by supergravity in ten space-time dimensions. Similarly, M-theory is approximated at low energies by supergravity in eleven dimensions.

Theoretically, the advantages of M-theory include 1) mathematical harmony and 2) logical concordance. However, for reaching its bright image, we have to pay following costs: 1) we need supersymmetric particles with duality between bosons and fermions, and 2) we need 11-12 dimensions. Over the past nearly 30 years of research, superstring or M-theory has developed greatly. There are six superstring versions: type I, type IIA, type IIB, Supergravity, Heterotic-O and Heterotic-E. These belong to a unified framework of 11 dimensions called M-theory. As the main stream of contemporary physical philosophy, M-theory is an overall hypothesis embracing not only quantum gravity but also matter and forces. It is based on the idea that present particles and hypothetical supersymmetric partners are vibrating strings. We may say that string theory and M-theory resemble beautiful, but we cannot say that they are true. The biggest issue of M-theory focuses on its verification, where it forecasts billions ways to real world, leading to unknown reality. Even there is no any mastered equations, though there were mathematical Seiberg-Witten equations based on Yang-Mills theory. We do not believe that the string theory and M-theory characterize reality, and we don't know any real physics beyond 4 dimension space-time. Therefore, M-theory, or its 12 dimensional F-theory, remains only a tantalizing conjecture.

2.2. The LQG and CDT

Merging quantum mechanics into general relativity, loop quantum gravity (LQG) and causal dynamical triangulations (CDT) are hypotheses of quantum gravity, making them to be possible candidates as theory of everything. Its goal is to unify gravity in a common theoretical framework with the other three fundamental forces of nature, beginning with relativity and adding quantum features, leading to two main versions, LQG and CDT.

The proponents of LQG are Ashtekar, Rovelli and Smolin, whose works are based on Ashtekar's discovery that general relativity could be expressed in language like that of a gauge field. LQG is a mathematical formalism that defines a tentative quantum hypothesis of space-time, which can be defined as a Schrödinger quantization of a canonical formalism. The space of quantum states is defined as a Hilbert space K of complex-valued Schrödinger wave functional $\Psi[A]$ on gravitational connection. The quantum dynamics of space-time is governed by the Wheeler-De Witt equation, or the Einstein-Schrödinger equation

$$F_{ab}^{ij}(\vec{\tau}) \frac{\delta}{\delta A_a^i(\vec{\tau})} \frac{\delta}{\delta A_b^j(\vec{\tau})} \Psi[A] = 0 \quad (1)$$

If we write the Wheeler-De Witt equation as $C\Psi=0$, there is a linear operator $P \sim \delta(C)$, called the projector, on the space of the solution of the equation. Matrix elements of P are interpreted as transition amplitudes between quantum states of space. Now, LQG developed a complete system, including quantization kinematics and quantum dynamics based on quantum geometry. LQG is a background independent unified hypothesis, in which gravity will arise from quantum space-time and space is divided into discrete "atoms" of volume. Recent developments of LQG reveal that preons are described by ribbon graphs, which show their activation. As a main alternative to string-theory, LQG invokes a new technique for applying quantum rules to Einstein's general relativity, with using discretized actions and path integrals, but a systematic technique for computing physical transition amplitudes from the background-independent and nonperturbative formalism of LQG has not yet been developed. A recent research revealed that the LQG might link with M-theory via H-duality [17], so they could be induced into similar type.

The CDT originates from Euclidean quantum gravity, proposed by physicist Stephen Hawking and developed systematically by J. Ambjorn, J. Jurkiewicz, and R. Loll. Its basic idea is that space-time geometry is made by piling up a large number of blocks, each of which represents a simple causal process. The causality means that the space-time geometry contains information about which events cause which other events. CDT approximates space-time as a mosaic of triangles, which have a built-in distinction between space and time. On a small scale, space-time takes on a fractal shape. There are a few simple rules that govern how the blocks can be piled up and a simple formula that gives the quantum-mechanical probability of quantum space-time. Using $P(\sigma)$ to measure the probability of a random walk to have returned to its origin after diffusion time σ (or σ evolution steps if the diffusion is implemented discretely), for diffusion on a flat d -dimensional manifold, CDT has the exact relation $P(\sigma)=1/(4\pi\sigma)^{d/2}$. For general spaces, the spectral dimension $D_s(\sigma)$ can be defined as the logarithmic derivative:

$$D_s(\sigma) = -2 \frac{d \log P(\sigma)}{d \log \sigma} \quad (2)$$

where the dimension will depend on σ ; small values of σ probe the small-distance properties of the underlying space, and large values its large-distance geometry. But we were not sure whether CDT could unify various interactions.

Figure 2 shows total features with combining related hypotheses. It competes with string and M-theory that begins with quantum field and adds gravity.



In MOND, violation of Newton's laws occurs at extremely small accelerations, characteristic of galaxies yet far below anything typically encountered in the Solar System or on Earth. Since Milgrom's original proposal, MOND has successfully predicted a variety of galactic phenomena that are difficult to understand from a dark matter perspective. However, MOND and its generalisations do not adequately account for observed properties of galaxy clusters, and no satisfactory cosmological model has been constructed from the hypothesis.

In its relativistic version TeVeS, according to [Bekenstein \[14\]](#), important physical principles, such as action principle, equivalence principle etc., are kept in MOND. An important alternative is that gravitational metric $g_{\mu\nu}$ is replaced by physical metric $\tilde{g}_{\mu\nu}$:

$$\tilde{g}_{\mu\nu} = e^{-2\phi} (g_{\mu\nu} + A_\alpha A_\beta) - e^{2\phi} A_\alpha A_\beta \quad (3)$$

where gravity is carried by a vector field A_α and a scalar field ϕ , with their own free actions.

Theoretically, the advantages of MOND and TeVeS include 1) ruling out dark sectors, and 2) keep concordance to GR. However, for reaching the bright image, we also have to pay following costs: 1) we have to modify GR, and 2) we must explain all astronomical findings. The MOND and TeVeS resemble near true.

Other hypotheses, we may mention spinor and twistor theory (STT), as well as HUFT especially. STT is a hypothesis developed by [Penrose \[22\]](#). Spinor mathematics, invented by mathematician E. Cartan, originated from the root of a vector. Penrose (and Rindler) introduced it as a calculus in four-dimensional Lorentzian space-time. Twistor hypothesis arose from a desire to unify and account for the various occurrences of complex numbers, holomorphic functions, and conformally invariant calculus in general relativity and space-time geometry. Similar to superstring-theory, STT had its unique value primarily in mathematics rather than in physics. And its predictions or suggestions of the space curvature $K < 0$ and the cosmos constant $\Lambda = 0$ seem troublesome, as astronomical observation suggests strongly that $K \sim 0$ and $\Lambda > 0$. HUFT [\[23\]](#) extended GR with including both GR and QT, which is also an independent hypothesis covering universe. However, HUFT needs spin-force and scalar-force as basic interactions and forecasts 26 dimensions and more vector-bosons than standard model, which have no present experimental supports.

3. Observational Evidences as Foundations of Physics

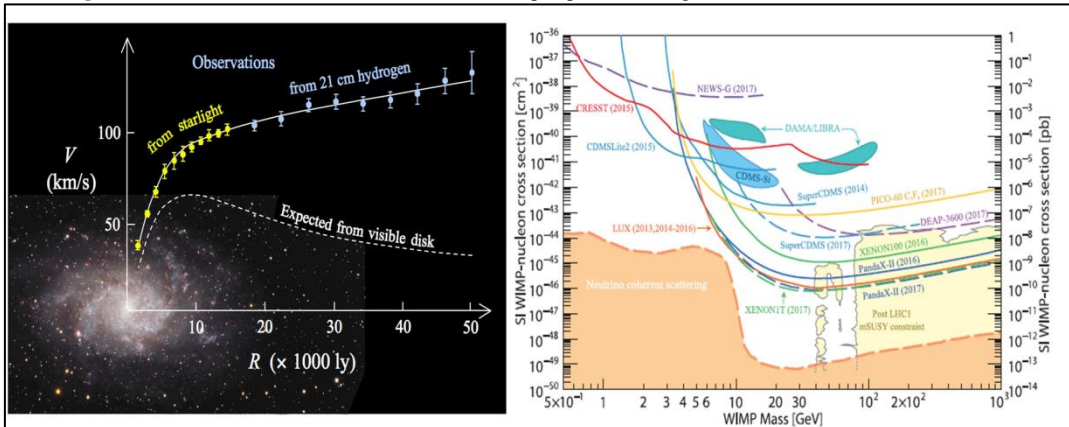
The standard model is a harmonic successful model that predicts the Higgs boson, which had been experimentally discovered in 2012 and verified in 2013 by LHC at energy 125.6 GeV/c² [\[2, 3\]](#). It is well known that the Higgs mechanism describes how the weak SU(2) gauge symmetry is broken and how fundamental particles obtain mass, which was also the last particle predicted by the micro-particle standard model to be observed, although efforts to confirm that it has all of the properties predicted by the standard model are ongoing. Other great successes of the micro-particle standard model included the prediction of the W and Z bosons, the gluon, and the top and the charm quarks, before they had been observed. However, the worst disadvantage in the micro-particle standard model is the complete absence of gravity, and it predicts neutrinos to be massless while the observed evidence of neutrino oscillations implies that neutrinos have tiny mass.

The standard model is also the simplest successful model that provides a reasonably good account of the following observational evidences of the universe, i.e. 1). The existence of the cosmic microwave background and the large-scale structural distribution of galaxies; 2). The abundances of hydrogen (including deuterium), helium, and lithium, as famous BBN hypothesis of elements synthesis; and 3). The accelerating expansion of the universe observed in the light from distant galaxies and supernovas [\[24\]](#).

There are strong observational and phenomenological evidences for supporting that we need new hypothesis beyond standard models, in which Dark Matter (DM) and Dark Energy (DE) are observational evidences, while the Cosmic Microwave Background (CMB) and the Big Bang Nucleosynthesis (BBN) belong to the phenomenological evidences.

On the matter distributed in the universe, ones' observation showed that there must be dark matter, as shown as [Figure 4](#), while the Weak Interaction Macro-Particles (WIMP) hypothesis is verified.

Fig-4. Dark matter and WIMP in the universe (left is open picture and right from RPP [Olive and Peacock \[25\]](#))



In Figure 4, the left diagram gives strong sign that there exists dark matter according to present physical hypotheses, and the right diagram came from reconstructed gravitational lensing observation on Abell 1689 which revealed substructure of dark matter. However, both directed detection and indirect detection of dark matter find nothing [26-28].

Fig-5. Accelerating expanding cosmos relies dark sectors (from RPP Olive and Peacock [25])

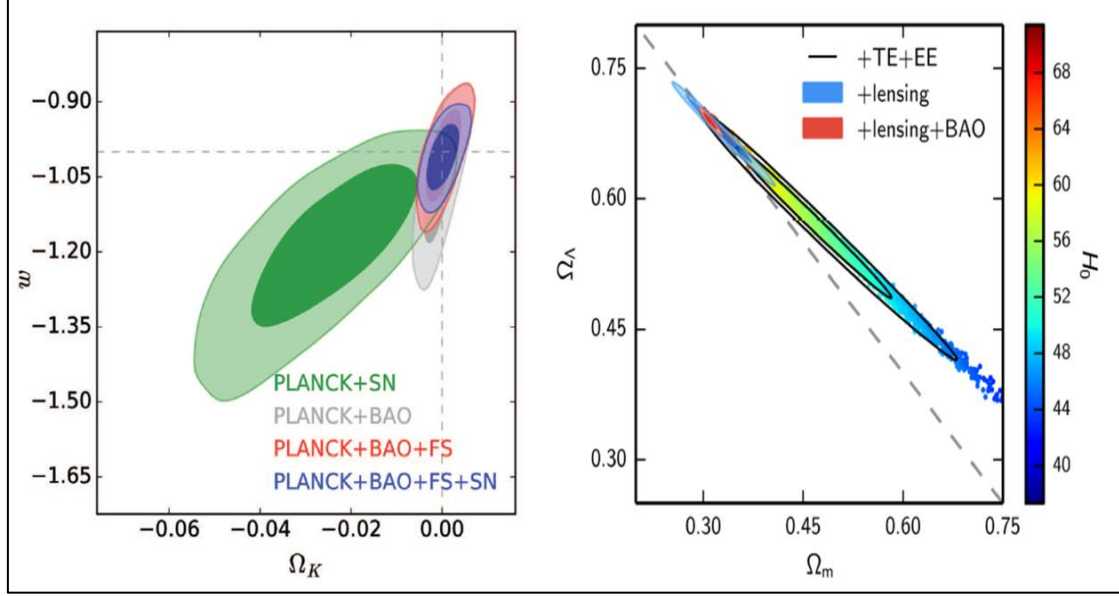
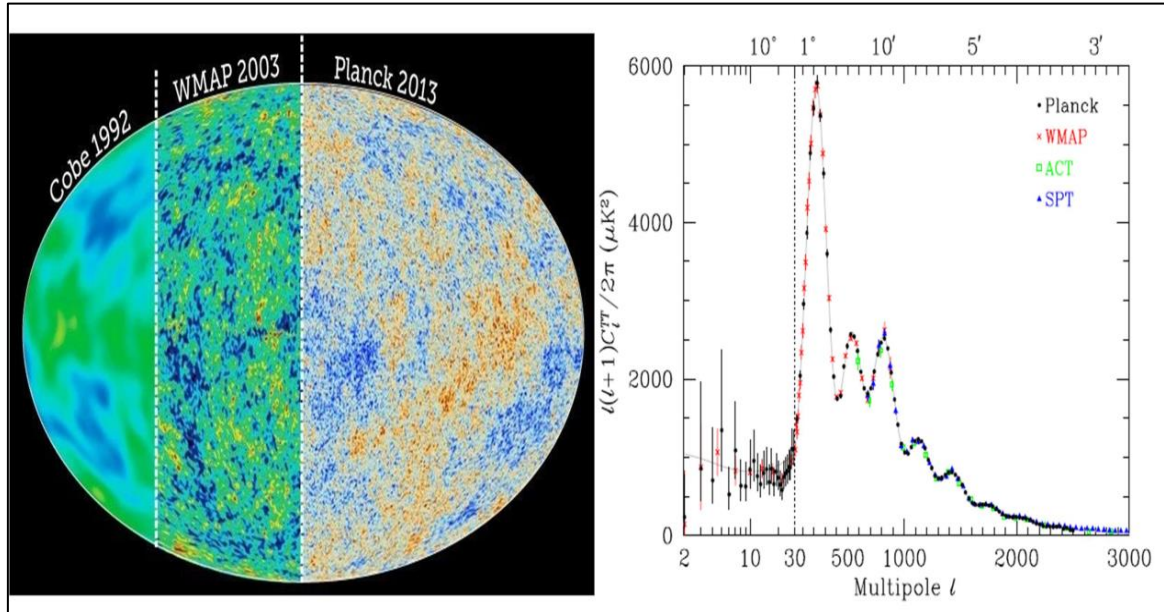


Figure 5 illustrates that both dark matter and dark energy are necessary components for explaining galaxy rotation curves and accelerating expansive universe, which are observed and verified, particularly the observations of accelerating expansion since 1998.

According to the cosmological principle (the universe is homogeneous and isotropic), the spatial distribution of matter in the universe never produces observable irregularities in the large-scale structure. Although the universe is inhomogeneous at smaller scales, it is statistically homogeneous on the large-scale scope. The cosmic microwave background is isotropic, which was verified by Cobe 1992, WMAP 2005 and Planck 2013, as shown as Figure 6, in which the left diagram describes the CMB from Cobe, WMAP and Planck, supporting that CMB was isotropic, though there was inhomogeneous at smaller scales. And the right diagram in Figure 6 illustrates that the plotted curve is the best-fit Λ CDM (Lambda Cold Dark Matter) model.

Fig-6. The homogeneous and isotropic universe (left is open picture and right from RPP Olive and Peacock [25])



Historically, as a key prediction of the standard cosmological model, CMB was discovered in 1965. From that point on, big bang cosmology was generally accepted, where the universe started in a hot, dense state and had been expanding over time. The rate of expansion depends on the types of matter and energy present in the universe, and in particular, whether the total density is above or below the so-called critical density.

Around CMB, dark matter and dark energy could be discussed in unified framework [29]. During the 1980s, most researches focused on cold dark matter with critical density in matter, around 95% CDM (Cold Dark Matter)

and 5% baryons, as these showed success at forming galaxies and clusters of galaxies, but problems remained. Notably, the model required a Hubble constant lower than preferred by observations, and the model under-predicted observed large-scale galaxy clustering. These difficulties sharpened with the discovery of CMB anisotropy by COBE in 1992, and several alternatives including Λ CDM (Lambda Cold Dark Matter) and mixed cold + hot dark matter came under active consideration. The Λ CDM model can be extended by adding cosmological inflation, quintessence and other elements that are current areas of speculation and research in cosmology. If the Hubble constant is not too high, the CMB alone requires an almost flat universe with $\Omega_m + \Omega_v \sim 1$.

The effects of universal rotation may or may not explain all dark sectors. Actually, early in 1946, Gamow started the issue of rotating universe [30], and then the rotating angular velocity had been estimated about 10^{-13} rad yr⁻¹ [31] or less than 10^{-9} rad yr⁻¹ [32]. However, the newest CMB analysis seems to deny the evidence of cosmic rotation, for which a UK group claimed that the Universe is isotropic on large scales, without traces of rotations, and anisotropic expansion of the Universe is strongly disfavored [33]. Therefore, we need to explore new physics with considering physical principles and philosophical rules.

4. The Physical Principles and Philosophical Rules for New Physics

Philosophically, physicists do always to find simple, natural and symmetry hypothesis as a correct physical theory, so that a good hypothesis, beyond standard model, should abide some physical principles and philosophical rules for approaching the true and then the beautiful.

The principled construction of physics is an elegant theoretical pursuit. Here, three physical principles (3P: ADE or HHE) are suggested to keep in unified physics.

P1. Action principle (Hamilton principle). This principle keeps least action in physical system, which determines the dynamic mechanism of physical processes, on which the dynamic equation can be derived by Lagrangian of the system with using variation methodology.

When we define scalar energy E and vector momenta p_μ with linking Hamilton function H and Lagrangian function L , we may obtain math-physical equations following Hamilton principle as follows

$$L = p_\mu x_\mu - H; \quad \delta \int_s d^4 x L = 0 \quad (4)$$

where Greek subscripts μ, ν denote 1, 2, 3, 4 and Latin subscripts i, j do 1, 2, 3.

P2. Duality principle (Heisenberg principle). This principle produces quantum effects, which fits duality of particle and wave in quantum theory, as well as combination of maximum and minimum dualities, which may connect micro- and macro-world.

$$[\psi, A] = \psi A - A\psi = i\hbar \quad (5)$$

where ψ is scalar and A is a vector, in any real number system. As time and space are scalar and vector, physical measures combining with space-time, as if energy E (linking to ψ) and momentum \mathbf{p} (linking to A), construct canonical commutation relations similarly to Eq. (5) as

$$[t, E] = tE - Et = i\hbar \quad (6)$$

$$[x, p] = xp - px = i\hbar \quad (7)$$

This is just the origin of Heisenberg's uncertainty principle.

P3. Equivalence principle (Einstein principle). This principle balances mathematical structure and physical essence, which matches the equivalence of space-time curvature and matter-energy distribution in Einstein general relativity.

$$G_{\mu\nu} = kT_{\mu\nu} \quad (8)$$

P1 originated from analytical mechanics, which is a foundation of physics, linking with all physical theories. P2 came from quantum mechanics, which is a basic consideration in micro-physics. P3 proposed by Einstein in his general relativity, which contributes a key to macro-physics.

Physicists should also abide following three philosophical rules (3R or 3H: LMM) for reaching both truth and beauty.

R1. Logic harmony: It is better to invent new mathematics, and the mathematical structure approaches the physical essence.

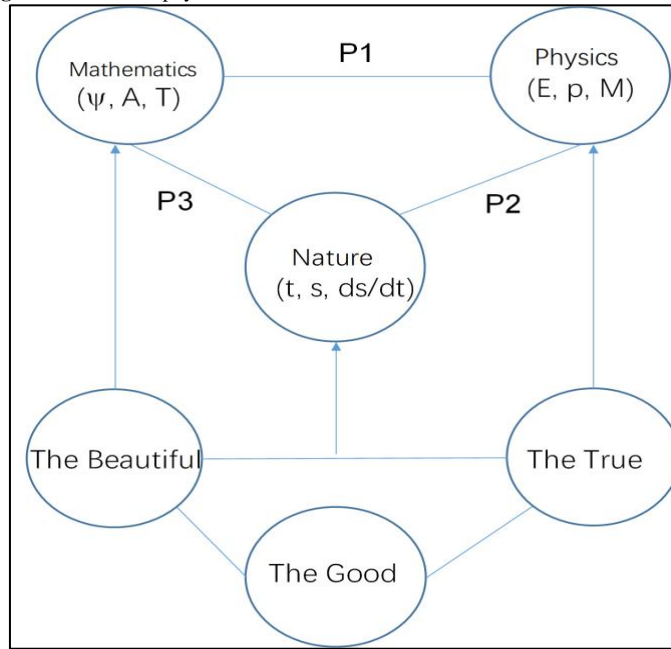
R2. Minimum hypotheses: it needs minimum basic facts (particles/fields). It is expected to introduce the least particles and forces.

R3. Maximum hopes: it can explain most present experiments/observations and forecast much more possible phenomena, particularly to explain dark sectors and main issues in contemporary physics, giving checkable forecasts or falsification mechanism.

When a new physics matched above 3P and 3R, it might reach a new milestone for approaching the true and the beautiful.

5. Discussion: Linkages between Mathematics and Physics

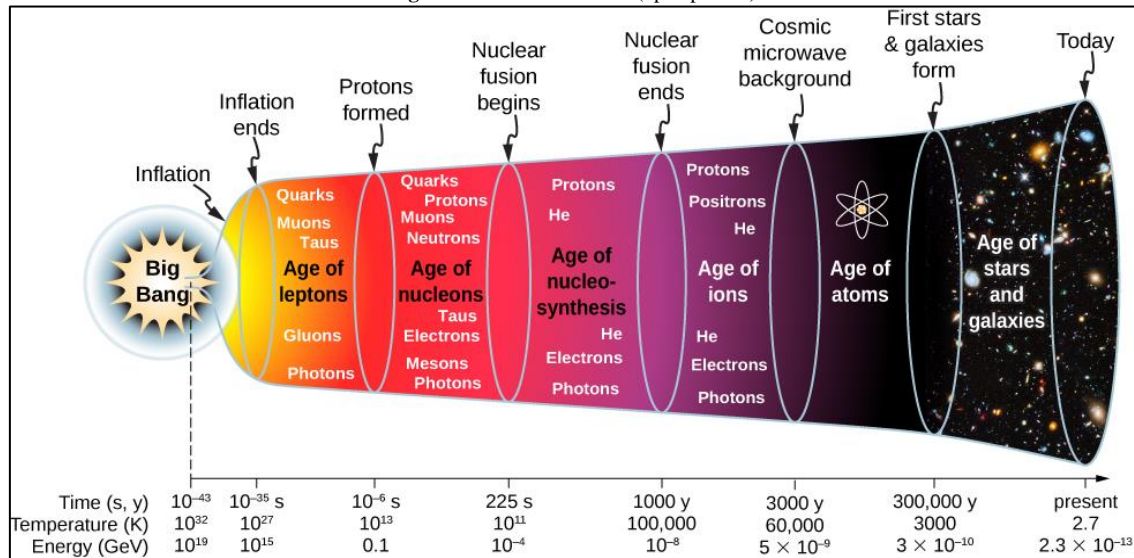
We always set up some equations for describing natural processes. These mean a good hypothesis should have good mathematical structure with matching physical essence [34, 35], for approaching the true and then the beautiful, as shown as Figure 7.

Fig-7. Mathematical physical relations based on the True, the Good and the Beautiful

The linkages between mathematics and physics focus on time. If there is space variable in equations only, the equations belong to mathematics. If there are both space and time in equations, the equations belong to physics. In other words, if an equation includes space variables only, it is mathematics; and if it contains time (t) meantime, it is physics.

Meanwhile, the mathematical structure demands to match physical essence. In any new theory, it is better to invent new mathematics. When the mathematical structure approaches the physical essence, we may find the true, as well as the beautiful.

Also, we have strong evidences to deny supersymmetry and dark sectors, because we have only one second timespan leaving for supersymmetric and dark particles in the known universe, as shown as [Figure 8](#).

Fig-8. The Known Universe (open picture)

This means that there are little space (inflation size) and time ($<1s$) for the existence of supersymmetry and dark sectors, according to present physical knowledge. However, the phenomena of both galaxies' rotation curves and gravitational lenses indicate the stability of dark sectors. Therefore, new theory beyond standard model resemble better to focus on the modified theories based on general relativity and quantum field theory [36, 37], rather than supersymmetric partners and dark sectors.

6. Conclusion

Conclusively, general relativity and quantum field theory still keep as the foundations to probe into new theory beyond the standard model. Although there are thousands and hundreds hypotheses trying to solve the physical problem of quantum gravity, there is no unique hypothesis which has absolute advantage to reach a brilliant stop with approaching both the true and the beautiful.

Following 3P physical principles (action principle, duality principle and equivalence principle), with abiding 3R philosophical rules, there is possible way to lead to a bright future. Since the true is first and the beautiful is second, TeVeS-type hypotheses may be feasible considerations near the true, without supersymmetry and dark sectors, in which models would be modified and new supersymmetric particles are not necessary. This review supplies a physical philosophy for further studies.

References

- [1] Patrignani, C., 2016. "Particle data group review of particle physics." *Chinese Physics C*, vol. 40, p. 100001.
- [2] The ATLAS Collaboration, 2012. "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC." *Physics Letters B*, vol. 716, pp. 1-29.
- [3] The CMS Collaboration, 2012. "Observation of a new boson at a mass of 125 GEV with the CMS experiment at the LHC." *Physics Letters B*, vol. 716, pp. 30-61.
- [4] Doršner, P. I., 2005. "Fileviez perez unification without supersymmetry: Neutrino mass, proton decay and light leptoquarks." *Nucl. Phys. B*, vol. 732, p. 53.
- [5] Matarrese, S., 2011. *Dark matter and dark energy: a challenge for modern cosmology*. Springer.
- [6] Planck Collaboration, 2014. "Planck 2013 results. I. Overview of products and scientific results." *Astronomy and Astrophysics*, vol. 571, p. 48.
- [7] Planck Collaboration, 2014. "Planck 2013 results. XVI. Cosmological parameters." *Astronomy and Astrophysics*, vol. 571, p. 66.
- [8] Witten, E., 1995. "String theory dynamics in various dimensions." *Nuclear Physics*, vol. B443, pp. 85-126.
- [9] Becker, K., Becker, M., and Schwarz, J. H., 2007. *String theory and m-theory: A modern introduction*. Cambridge: Cambridge University Press.
- [10] Rovelli, C., 2004. *Quantum gravity*. Cambridge: Cambridge University Press.
- [11] Ambjorn, J., 2002. "3d lorentzian, dynamically triangulated quantum gravity." *Nucl.Phys.Proc.Suppl.*, vol. 106, pp. 980-982.
- [12] Dupuis, M., Ryan, J. P., and Speziale, S., 2012. "Discrete gravity models and loop quantum gravity: a short review." *SIGMA*, vol. 8, p. 052.
- [13] Milgrom, M., 1983. "A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis." *The Astrophysical Journal*, vol. 270, pp. 365-370.
- [14] Bekenstein, J. D., 2004. "Relativistic gravitation hypothesis for the modified Newtonian dynamics paradigm." *Physical Review D*, vol. 70, p. 083509.
- [15] Bekenstein, J. D., 2011. "Tensor-vector-scalar-modified gravity: from small scale to cosmology." *Philosophical Transactions of the Royal Society, A*, vol. 369, pp. 5003-5017.
- [16] Milgrom, M., 2015. "MOND theory." *Canadian Journal of Physics*, vol. 93, pp. 107-118.
- [17] Addazi, A. and Marciano, A., 2018. "A new duality between topological M-theory and loop quantum gravity." *Science China - Physics, Mechanics and Astronomy*, vol. 61, p. 120421.
- [18] Mielczarek, J. and Trzesniewski, T., 2018. "Towards the map of quantum gravity." *General Relativity and Gravitation*, vol. 50, p. 68.
- [19] Sanders, R. H., 2005. "A tensor-vector-scalar framework for modified dynamics and cosmic dark matter." *Mon. Not. Royal Astron. Soc.*, vol. 363, pp. 459-468.
- [20] Sanders, R. H., 2009. "Modified Newtonian dynamics: a falsification of cold dark matter." *Advances in Astronomy*, vol. 2009, p. 9.
- [21] Ferreira, P., 2014. "Testing GR with cosmology." Available: http://bccp.berkeley.edu/beach_program/COTB14Ferreira.pdf
- [22] Penrose, R., 2004. *The Road to Reality: a complete guide to the laws of the universe*. London: Jonathan Cape.
- [23] Wu, Y. L., 2018. "Hyperunified field theory and gravitational gauge-geometry duality." *European Physical Journal C*, vol. 78, p. 28.
- [24] Riess, A. G., 1998. "Observational evidence from supernovae for an accelerating universe and a cosmological constant." *The Astronomical Journal*, vol. 116, pp. 1009-1038.
- [25] Olive, K. A. and Peacock, J. A., 2018. "Big-bang cosmology. In tanabashi, m. Et al. (particle data group)." *Review of Particle Physics (Rpp)*, *Physical Review*.
- [26] Baudis, L., 2016. "Dark matter detection." *Journal of Physics G: Nuclear and Particle Physics*, vol. 43, p. 044001.
- [27] Bertone, G., Hooper, D., and Silk, J., 2005. "Particle dark matter: Evidence, candidates and constraints." *Physics Reports*, vol. 405, pp. 279-390.
- [28] Davis, J. H., 2015. "The past and future of light dark matter direct detection." *International Journal of Modern Physics A*, vol. 30, p. 1530038.
- [29] Peebles, P. J. E. and Ratra, B., 2003. "The cosmological constant and dark energy." *Reviews of Modern Physics*, vol. 75, pp. 559-606.
- [30] Gamow, G., 1946. "Rotating universe?" *Nature*, vol. 157, p. 549.
- [31] Birch, P., 1982. "Is the Universe rotating?" *Nature*, vol. 298, pp. 451-454.
- [32] Su, S.-C. and Chu, M.-C., 2009. "Is the Universe rotating?" *The Astrophysical Journal*, vol. 703, pp. 354-361.

- [33] Saadeh, D., 2016. "How isotropic is the Universe?" *Physical Review Letters*, vol. 117, p. 131302.
- [34] Ye, 2009. "Clifford-Finslerian physical unification and fractal dynamics." *Chaos, Solitons and Fractals*, vol. 41, pp. 2301-2305.
- [35] Ye, 2017. *A vortex mechanism linking micro-particles to macro-galaxy without supersymmetry. Scientific Metrics: towards analytical and quantitative sciences*. Springer, pp. 57-72.
- [36] Einstein, A., 1916. "The foundation of the general theory of relativity." *Annalen der Physik*, vol. 49, p. 1916.
- [37] National Academy of Sciences, 2003. *Connecting quarks with the cosmos: Eleven science questions for the new century*. Washington, D.C.: The National Academies Press.