A Realist Interpretation of the Quantum Measurement Problem

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Abstract. A new, realist interpretation of the quantum measurement processes is given. In this scenario a quantum measurement is a non-equilibrium phase transition in a “resonant cavity” formed by the entire physical universe including all its material and energy content. Both the amplitude and the phase of the quantum mechanical wavefunction acquire substantial meaning in this picture, and the probabilistic element is removed from the foundations of quantum mechanics, its apparent presence in the quantum measurement process is viewed as a result of the sensitive dependence on initial/boundary conditions of the non-equilibrium phase transitions in a many degree-of-freedom system. The implications of adopting this realist ontology to the clarification and resolution of lingering issues in the foundations of quantum mechanics, such as wave-particle duality, Heisenberg’s uncertainty relation, Schrödinger’s Cat paradox, first and higher order coherence of photons and atoms, virtual particles, the existence of commutation relations and quantized behavior, etc., are also presented.

INTRODUCTION

Since its very inception, quantum mechanics was plagued at its foundation with the so-called “interpretation problem”. Unlike a classical measurement, the result of a quantum measurement in general can only be predicted in a probabilistic sense. The quantum mechanical wavefunction is the most quantitative result from a quantum calculation, and one can hope for a definitive answer only if the measurement is towards an eigenvalue of a system already settled onto its corresponding eigenstate. If this is not so, the underlying system is assumed to subsequently “collapse” onto an eigenstate of the measurement operator, with the probability for the choice of eigenstate given by the absolute square of the wavefunction projected onto the the eigenstate being measured.

Debates over the past 80 years over the underlying reality/or the lack thereof of the wavefunction collapse had resulted in a wide spectrum of possible explanations, from the earliest orthodox Copenhagen Interpretation[1, 2, 3], to the “Many Worlds Interpretation[4, 5], and onward to the different versions of the so-called “Decoherence Theories”[6, 7, 8] which advocate a two-stage wavefunction collapse, with the second stage involving the intervention of a conscious observer. In a previous article[9], we had shown that all of these previous proposals amounted to giving up realism at certain stages of the interpretation, which often lead to pathological cases such as the infamous “Schrödinger’s Cat paradox”[10]. Other candidate interpretations such as deBroglie and Bohm’s pilot wave theories[11, 12] are contradicted by the image provided by modern quantum field theories on the nature of fundamental particles as non-local field resonances[13].

In this article, we argue that the resolution of the quantum measurement problem lies in its analogy to a class of nonequilibrium phase transitions in the classical world and the resulting formation of the so-called “dissipative structures”[14, 15, 9].

THE NEW ONTOLOGICAL VIEW

The universe is an open and evolving system. If we insist on a realist interpretation of the quantum processes, and insist also a classical-type ontology for quantum phenomena which connects with our intuition, we need to seek the origin of the quantized behavior in some forms of resonance interaction as well. Since physical constants such as Planck’s constant and the speed of light are universal, and different types of interaction processes in vastly different
environments give the same elementary-particle properties, these universal characteristics are expected to be produced through the actions of the entire matter and energy content of the universe. Such a view is closely related to Mach’s principle for explaining the origin of mass and inertia [16], and forms the starting point of the new ontological view of quantum mechanics we are presenting in this paper.

We now summarize the main hypotheses of this work:

- It is assumed that a generalized “Mach’s Principle” governs the operation of the physical universe. Features of the local physical interactions, including the values of fundamental constants and the forms of physical laws, are determined by the global distribution of all the matter and energy content in the universe. Such a view is shared by many contemporary working physicists [17, 18].
- The quantized nature of fundamental processes originates from nonequilibrium phase transitions in the universe resonant cavity. The usual quantization procedure by enforcing the commutation relation is equivalent to establishing modal closure relation in the universe resonant cavity. Uncertainty relations are the phenomenological derivatives of the corresponding commutation relations and thus have no independent fundamental significance.
- Due to the successive nature of phase transitions the physical universe is organized into hierarchies in both its laws and its phenomena. The hierarchy in the physical laws is reflected in the spontaneous breaking of gauge symmetry in the formation of physical laws, as well as in the division of the domains of validity of laws governing different branches of physics and chemistry. Similar hierarchy in the physical phenomena is responsible for forming the quantum and classical division, as well as the micro- and macroscopic division. Macroscopic structures, being stable resonance features in the large scale, are capable of resisting the diffusion/smearing tendency of pure quantum states governed by Schrödinger-type wave equations.
- A quantum measurement process happens under appropriate boundary conditions such that an irreversible nonequilibrium phase transition is induced in the joint system of the object being measured, the measuring instrument and the rest of the universe.
- A quantum mechanical wavefunction describes the substantial distribution of the underlying matter of a specific modal type in the configuration space. Its absolute square gives the probability for obtaining a particular result in the measurement phase transition. Its phase encodes the influence of the environment including the different types of force fields, and the gradient of the phase determines the subsequent evolution of the wavefunction. The probabilistic element is thus removed from the ontology of quantum mechanics.
- In this picture the vacuum fluctuations are the “residuals” after forming the “whole” numbers of quasi-stationary modes in the open, nonequilibrium universe cavity. The fluctuations in the vacuum reflect the continuous energy exchange with the “whole” modes needed to sustain these modes.

**IMPLICATIONS ON THE FOUNDATION OF QUANTUM MECHANICS**

**The Quantum Mechanical Wavefunction**

In the current ontology, the quantum mechanical wavefunction or the so-called probability wave becomes a physical entity. The fact that the wavefunction exists in the 3n-dimensional configuration space does not pose a problem, since this signifies only the interchange and interrelation of the parts and parcels of the modal content among a multi-particle quantum state. The dispersion of the position-eigenstate wavepacket [19] is here seen as a natural tendency for a localized “particle” to evolve towards plane-wave-like momentum eigenstate [9].

Whereas the amplitude of the wavefunction is connect to the modal density in the configuration space, and thus leads to the probability of a particular measurement outcome, the spatial variation of the phase of the wavefunction characterizes the probability flux, and thus determines its subsequent evolution. The phase of the quantum mechanical wavefunction also carries imprints of various kinds interaction fields, and is the medium through which the force fields apply their influence to the wavefunction.

**Evolution of the Quantum States**

The wavefunction of a quantum observable usually spreads out in infinite space, and the interaction between the different quantum modes are global in nature. Therefore quantum mechanics is formulated in the Hilbert space which
is a natural domain to describe global modal relations.

Traditionally, a general quantum evolution involves the two-stage process of a continuous unitary evolution which is covariant and energy conserving, followed by a discontinuous “wavefunction collapse”, represented by the reduction of the wavefunction into an eigenstate of an observable. It was the second step, i.e., the wavefunction collapse process, which acquired a more substantial meaning in the new ontology.

Even in the unitary evolution phase, certain features of the global interaction can already be discerned. For a state which is not an eigenstate of the energy operator, expand it in terms of the eigenstates of an observable \( \alpha \) that commutes with the Hamiltonian \( H \), we have

\[
\Psi(\vec{x}, t) = \int d^3x' K(\vec{x}, t; \vec{x}', t_0) \Psi(\vec{x}', t_0),
\]

where

\[
K(\vec{x}, t; \vec{x}', t_0) = \sum_\alpha <\vec{x}| \alpha > <\alpha | \vec{x}' > \exp \left(-\frac{i E_\alpha (t-t_0)}{\hbar}\right),
\]

which represents the transition amplitude between the relevant eigenstates. We see that as the unitary evolution proceeds the relative weights of the constituent energy eigenstates vary with time, i.e., there is a kind of transition process happening continuously between the constituent eigenstates. The main difference between the transitions during the unitary evolution, and the transitions during a true quantum measurement, is whether the transition is controlled by a continuous and predictable evolution of the complex probability amplitude, or else a discontinuous settling onto a definitive eigenstate of the measurement operator with certain probability (equal to square of the probability amplitude).

Even though an eigenvalue of a stationary state is a constant (call it \( \alpha \)), the eigenfunction is in general time dependent (the particular form of the evolution of the eigenfunction, if it is a simultaneous eigenstate of the Hamiltonian, is \( |\alpha > \exp(-\frac{i E_\alpha t}{\hbar}) \)). Therefore a quantum mechanical stationary state is a kind of dynamical equilibrium in constant evolution (including a constant exchange with the quantum vacuum), consistent with the nonequilibrium stationary state picture we have proposed.

In practice, apart from stationary states and freely-evolving wavefunctions, the density matrix formalism had also been employed to describe quantum systems that are thought to be statistical mixtures. In the current ontology, no physical system is actually in a statistical mixture state. The apparent success of the density matrix approach is understood as the intrinsic harmonic nature of the evolution of the parts and parcels of constituent quasi-stationary states – thus the effect of time averaging mimics the effect of ensemble averaging.

### Extent of Quantum Measurement

A quantum measurement is in general a non-local process. Quantum measurements involve not only the objects being measured, the measuring apparatus, but also involve the “give and take” with the rest of the universe. This “give and take” with the rest of the universe accounts for the apparent violation of energy conservation in many quantum measurement processes (including the position-momentum measurement pair). It also provides a natural explanation to the paradoxical fact that the accelerated electrons radiate in certain cases (as when they travel freely in straight lines) and not in other cases (as when they circulate an atomic nuclei in bound states).

A pure quantum mechanical resonance (such as a photon) remains a modal resonance spread out in space until the moment of detection. Detection shows quantum behavior because the “remainder” of the stuff in the universe cavity shows quantum behavior. The detected particle is in general no longer the same particle during propagation because of the exchange with the universal background.

The strongest support for the involvement of the universe resonant cavity during the quantum measurement process is actually the consistency of emerging elementary-particles’ characteristics throughout different types physical processes (such as the constancy of electron charge and mass whether it is created out of neutron decay, or else out of the electron/positron pair production from energetic photons). Without a global resonant cavity to determine the modal characteristics, we would not have such things as elementary particles, or fundamental constants themselves. The identity of particles is the result of their being the same mode, and the properties of the fundamental particles are created at the moment of phase transition, since before this transition an electron, say, does not already exist inside a neutron.
Wave-Particle Duality

The wave-particle duality is manifest most clearly in the de Broglie relation $p = h/\lambda$, and Planck relation $E = h\nu$, each equation on one side indicates a pure wave characteristic ($\nu$ and $\lambda$) and on the other side a pure particle characteristic ($E$ and $p$). The seeming contradictory characteristics is easily clarified in the new ontology: A particle is more of a pure resonance when it is a wave mode and is is spread out. When it is a localized particle, it is in a mixed resonant state, or the superposition of pure states.

In fact, in quantum field theories, only the fields are localized, but field quanta are spatially extended. These spatially distributed field quanta arrive from the first approximation of the solution of field equations in the non-interacting limit, which simplifies analysis and is the source of the name “particle”[13].

Uncertainty Principle and Commutation Relations

In general, the uncertainty relations can be shown to originate from the corresponding equality relations linking the commutators and anticommutators of the quantum observables $A$ and $B$ as[20]

$$|\langle \Delta A \Delta B \rangle|^2 = \frac{1}{4} |\langle [A,B] \rangle|^2 + \frac{1}{4} |\langle \{\Delta A,\Delta B\} \rangle|^2,$$

(3)

Furthermore, from Schwarz inequality $\langle \Delta A \rangle^2 \langle \Delta B \rangle^2 \geq |\langle \Delta A \Delta B \rangle|^2$, the usual uncertainty relation can be arrived at:

$$\langle \Delta A^2 \rangle \langle \Delta B^2 \rangle \geq \frac{1}{4} |\langle [A,B] \rangle|^2.$$

(4)

The uncertainty principle is thus just another way of writing the commutation relations, which themselves are deterministic. The uncertainty principle itself seemed to later acquire more prominence in the discussions of quantum phenomena only because of its intimate relation to the probabilistic outcome of quantum measurements.

Quantum Vacuum

After quantizing space with a set of modes using the commutation or anticommutation relations, we expect to end up with some leftovers, as is typical for the formation of nonequilibrium quasi-stationary modes[15]. We proposed that these leftover fractional modal content in the quantization process is the constituents of vacuum fluctuations.

The vacuum field fluctuates because the resonant components keep evolving in the nonequilibrium universe cavity, just as in another example of such a nonequilibrium dissipative structure, that of the spiral structure in galaxies[13], where the individual star’s trajectory keeps evolving and moving in and out of the spiral pattern even though total energy is conserved and the spiral density wave is meta-stable.

Many effects which so far have been attributed to the quantum vacuum, such as the scale dependence in the renormalization group approach, the Casimir force, the virtual particles and the lifetime of atomic levels, as well as the spontaneous emission of radiation, can equally be thought of as due to the influence of the rest of the matter distribution in the universe. For example, the addition of metal plates as in the Casimir effect changes the boundary condition of the entire vacuum, force is thus needed to put the plates in. Virtual particles are those which appear in a quantum electrodynamic calculation and do not satisfy energy and angular momentum conservation; They are “not on the mass shell” and are represented by the internal lines in Feynman diagrams. Their existence is another indication that a quantum phase transition involves the rest of the universe to “close the loop”, and the conservation relation is restored for resonant interactions only when the phase transition is complete (this last condition is in fact not yet met by the current pertubative QED, in the strong coupling case or in higher order calculations, likely indicating the inherent failure for a local field theory to become self-consistent).

This view of the vacuum also provides a possible explanation of why some of these very same effects (including Lamb shifts, Casimir effects, spontaneous emission, van der Waals forces, and the fundamental linewidth of a laser) can be explained equally successfully by adopting either the vacuum-fluctuation point of view or the source-field point of view[22].

The relation of field quantization and vacuum fluctuation may also be related to the “fluctuation-dissipation theorem”. The dissipative leak into the vacuum is needed to maintain the stability of the nonequilibrium modes. The environment needs to be constantly evolving in order for the fundamental resonances to be stable. So the un-saturatedness...
and the constant evolving nature of the universe maybe a prerequisite for setting up the fundamental laws as we observe today.

First and Higher Order Coherence of Photons and Atoms. Identical Particles

When Dirac commented that “A photon interferes only with itself”[23], he referred to the first order coherence property of the photons. Subsequent intensity interferometry experiments[24] had revealed that photons do interfere with one another, which are the higher order coherence properties of photons. Such first and higher order coherence properties were also observed for atoms in the atom interferometry experiments[25].

In the current ontology, the first order coherence of the atoms and photons reveals their underlying wave and modal nature, whereas the higher order correlation is a manifestation of the finite-Q nature of the universe resonant cavity, resulting in “non-pure” spatial modes which entangles the different field resonances. Due to this entanglement (as reflected in the Bose-Einstein or Fermi-Dirac statistics, for example), after emission a photon has a tendency to merge back to the universal “soup” of the background photon flux during propagation, unless the photon flux is so low that it can be described as spatially and temporally separated monophotonic states, in which case its degree of second order coherence \( g^2(0) < 1 \) as is appropriate for photons in the non-classical photon number states. The analytical expressions for the degree of second order coherence for bosons and fermions show different expressions according to their respective wavefunction symmetries[26], and these statistics are only meaningful when the particle flux is high enough.

Resolution of the “Schrodinger’s Cat Paradox”

Under the new ontology there is no longer a dichotomy between the classical and the quantum world. The classical systems consist of subunits where “wavefunction collapse” have already been induced by nature, through naturally occurring boundary conditions. After a spontaneous phase transition, the overall system will be in a quasi-stationary state and thus is stable, though its constituent parts may still evolve in a harmonic fashion as shown before for the energy eigenstate. A macroscopic object in general does not possess an overall quantum mechanical wavefunction that freely evolves.

The spontaneous nature of the phase transitions in natural systems helps to resolve “Schrodinger’s Cat” type of paradoxes since a naturally occurring "quantum measurement" does not have to involve a conscious observer. The cat in question was already in a definitive Live or Dead state before the observer opened the box, and not in a linear superposition state of the kind: \( a \cdot \text{Live} + b \cdot \text{Dead} \). The phase transition view also explains the stability and reproducibility of these natural orders, i.e., the result of the non-equilibrium phase transitions is insensitive to the details of the initial-boundary conditions, and depends only on the gross nature of these conditions[14, 15].

THE HIERARCHICAL ORDERING OF QUANTUM AND CLASSICAL MECHANICS

Origin of Physical Laws

The idea that matter throughtout the universe collectively determines the local inertial frames is known as Mach’s principle. A generalized version of Mach’s principle demand all physical interactions to be relational. This characteristic is reflected in Feynman’s formulation of a significant fraction of dynamical laws (both quantum and classical) as sum of the classical action integral over all possible paths and histories[27] i.e.,

\[
<x_N, t_N|x_1, t_1> = \int_{x_1}^{x_N} \mathcal{D}[x(t)] \exp[i \int_{t_1}^{t_N} dt \frac{L_{\text{classical}}(x, \dot{x})}{\hbar}].
\]

The above space-time formulation explicitly demonstrated that the quantum mechanical amplitude at any given location and time is the sum of all past influences of all the amplitudes distributed throughout space. Classical trajectory and causal influence are realized only because the influence of the rest of the paths sum over to zero due to the rapid phase fluctuations.
Other evidence that physical laws, both classical and quantum, are globally and resonantly selected include the fact that most laws are deriveable from the least action or variational principles. This otherwise mysterious characteristic can now be understood as that for every physical process, the energy content of concern is always distributed globally, and the process samples the environmental/boundary conditions of the entire space of relevance to filter out the surviving resonant component.

**Symmetry and Conservation Relations**

The well-known relation between the symmetry of a dynamical system and the corresponding conservation law that holds for such a system is the celebrated Noether’s theorem. The existence of Noether’s theorem is another reflection that physical laws and the matter contents have mutual dependence. This mutual dependence is ingrained in the form of dynamical equations (which is the reason Noether’s theorem can be proven by using these equations) since the laws/equations and the matter distribution are co-selected out of the the universe resonant cavity.

For the large-scale distribution of matter in the universe, we have the approximate time invariance (which leads to energy conservation) and isotropy (which leads to momentum and angular momentum conservation). However, if we look more closely, both symmetry and conservation on the large scale are indeed only approximate.

First of all, the expansion of the universe violates the time invariance of the matter distribution. This could have several consequences. If the values of the fundamental constants are determined by the characteristics of the universe resonant cavity, depending on the fashion of this determination the expansion could lead to the variation of the values of these “constants” with time, though the case is not settled yet of whether we have actually observed any such changes. Another consequence is that over the long time span of the cosmic time energy conservation is no longer guaranteed, since the matter distribution changes with time as a result of the expansion of the universe. This could very well be the origin of dark energy and the accelerated expansion of the universe.

Secondly, as revealed by the work of Lee and Yang, as well as Wu, in weak interactions parity conservation is violated, i.e., the laws of physics has a preference for “handedness”. If there is indeed the interrelation between laws and matter distribution, this handedness in the laws reveals that large-scale matter distribution in the universe has a helical component in it. This would be natural to expect for a matter distribution originating from the Big Bang or other initial condition for the cosmos. The fact that the parity nonconservation only manifests in weak interactions perhaps has to do with the fact that weak interaction is the shortest in range of all the fundamental forces, thus is less sensitive to the asymmetries in its immediate environment, so other longer range influences which reflect the asymmetries of the universe is more obviously manifest. Furthermore, the proven conservation of CPT, and the demonstration of CP violation in certain sub-class of weak interactions shows that time-reversal symmetry is violated in these interactions as well. Therefore, even at the microscopic level we have the evidence of time’s arrow manifest, which is another indication that irreversible evolution and phase transitions had played a role in the formation and selection of microscopic laws.

**Structures of S-Matrix Theory and Quantum Field Theories**

S-matrix theory was invented to circumvent certain problems of quantum field theories. The motivation comes partly from the observation that in many scattering experiments light quanta come in and go off as approximate plane waves. In this theory the dynamics was not specified by a detailed model of interaction in spacetime, but was determined by the singularity structure of the scattering amplitudes, subject to the requirement of maximal analyticity. The success of the S-matrix approach is likely to be due to the fact that the underlying physics obeys global, modal characteristics. The result of the calculations is expressed through particles on the mass shell, which is equated in our ontology to the outcome of phase transitions. Other features of the applications of S-matrix, such as boot-strapping and “nuclear democracy” in hadron theory also reveal a distinctive modal characteristic.

Quantum field theories describe local interactions between particles and fields. However, certain global elements are implicit in its formulation for processes such as scattering, just as the S-matrix theories. Some of the common practices in quantum field calculations, such as Feynman’s diagrammatic approach are integral representations of the entire phase transition process, described in terms of input and output states only, and omitting (or “integrating out”) any detailed description of the “on-location” behavior of the interaction and particle creation/annihilation.
The need for renormalization (or for the manual incorporation of the experimentally observed values of parameters into perturbative quantum field theories to cancel certain infinities) is a reflection of the insufficiency and non-self-consistency of the quantum field theories. The cause of this is partly because the theory is local (and the renormalization allows the incorporation of certain environmental screening effect), and partly because it attempts to synthesize quantum theory with special relativity (spontaneous quantum measurement phase transitions implicit in the phenomena that quantum field theories attempt to describe necessarily violate Lorentz invariance required by special relativity, see further the discussion in the next section). Empirical input is thus needed to construct a self-consistent field theory due to the singular nature of phase transitions whose details cannot be modeled in a top-down deductive type of analysis.

Gauge field programme emerges within the framework of quantum field program and incorporates certain global features of field theories. Fundamental interactions can now be characterized by gauge potentials and the phase of a wave function becomes the new local variable. In this formulation local gauge invariance is used to derive the forms of dynamical interactions, and just as the variational procedure for the derivation of physical laws the success of the gauge invariance procedure reflects the resonant origin of the relevant laws. Spontaneous symmetry breaking was developed as a mechanism to preserve gauge invariance when dealing with massive gauge quanta.

Since the late 1970s theorists gradually realized that the high-energy effects in gauge theories can be calculated without taking the cutoff in the normal renormalization procedure to infinity. The cutoffs in these Effective Field Theories serve as boundaries separating energy regions which are separately describable by different sets of parameters with different symmetries. This practice is also related to the so-called renormalization-group approach which explicitly deals with the scale-dependence of certain fundamental physical interactions. As commented by Cao, most of the physical theories we know are scale-independent within its range of validity, and the scale-dependence of parameters in field theories indicates the screening effect of the environment, as first suggested by Dirac, and also indicates the smoothness and homogeneity of the variation of these interactions with scale.

### Issues about Covariance and the Absolute Reference Frame

We expect that the establishment of fundamental laws and the selection of fundamental constants through the resonant interaction in the universe according to Mach’s principle are processes which are not constrained by the speed of light limit: For otherwise the mere size of the universe and the cycle of propagations needed to resonantly establish a fundamental constant would prevent these constants and laws to be universal. Similarly, the variational approach for the selection of physical laws only works if all possible paths are explored simultaneously/instantaneously.

The speed-of-light limit appears to hold strictly only for classical processes. In classical physics, the influences of the nonclassical paths, which involve superluminal signal propagation, cancel each other out, so the superluminal effect is not apparent.

For quantum physics, both the measurement and the non-measurement type, the effect of space-time paths requiring superluminal signal propagation can no longer be ignored. The quantum measurement processes, especially the Einstein-Podolsky-Rosen type or delayed-choice type of experiments, showed both the global extent of the wavefunction and the superluminal nature of the wavefunction collapse. That this is also true during most of the unitary evolution stages of a quantum state is less obvious, but is reflected nonetheless in the quantum mechanical rules of state evolution (equations), in Feynman’s path integral formulation of quantum mechanics (equation), which contains the integration over the classical paths at subluminal speed and over nonclassical paths at superluminal speed, as well as in Feynman diagrams for most of the virtual paths.

Covariance in relativistic quantum mechanics appears to hold only for the results of quantum measurements (local events), and not for the evolution of states themselves (global events in general), even though many of the formulations of QED are supposed to be “manifestly covariant” (such as Feynman’s path integral approach, which as we have just commented still contains the contributions from superluminal pathways). Especially for states which have not completed the phase transition, such as many quantum tunneling processes and certain optical evanescent-wave propagation, the speed-of-light limit is often found to be violated, and these processes appear to occur “on borrowed energy” from their environment.

Further more, there appears to be the need for a universal reference frame in order for the phase transitions to happen with respect to. The Aharonov-Bohm effect which shows the influence to the phase of the wavefunction in regions where the nominal field strength is absent demonstrates the substantiality of a global potential function. In fact, the reference frame established by the entire content of the universe is a convenient one, if the universe is finite. This reference frame obviously possesses the relational nature demanded by Mach’s principle.
CONCLUSIONS

The new ontological view on the quantum measurement problem based on the generalized Mach's principle and nonequilibrium phase transitions, is shown to lead to coherent interpretations of a wide spectrum of well-known phenomena in both the quantum and the classical world. Such global phase transitions are likely to be responsible for the structure and forms of physical laws, the values of fundamental constants, as well as the hierarchies of phenomena we observe in the microscopic and macroscopic world. If proven correct, the insight thus gained from this picture could provide intuitive guidance to the efforts of the attempted unification of fundamental interactions, as well as to the resolution of issues at the interface of physics and cosmology such as the accelerated expansion of the universe and the origin of dark energy.

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