

# The Ghostly Quantum Worlds

Miroljub Dugić\*, Dejan Raković†,  
Jasmina Jeknić-Dugić‡, Momir Arsenijević§

## ABSTRACT

We present the foundations of a new emerging interpretation of quantum theory bearing wide-range implications. Physical basis of the interpretation is non-questionable yet relatively new – it relies on the different structures (decompositions into parts, subsystems) of the quantum Universe. We compare the mutually irreducible structures of the Universe and recognize them as the different facets of the one and the same quantum Universe. Physical picture is interesting and non-reducible to the existing interpretations. As a particularly interesting topic in this context appears the 'free will' topic of current interest in the interpretation of quantum theory. To this end, we arrive at the following interesting observation. The freely chosen actions (*e.g.*, quantum measurements) performed by a (conscious) agent that are still locally observable in the alternate Worlds could seem physically unexplainable ('non-physical', 'ghostly').

**Key Words:** interpretation of quantum mechanics, quantum structures, free will, Everett's parallel worlds, multiverse

NeuroQuantology 2012; 4: 619-628

## 1. Introduction

There is a hot ongoing debate about the interpretation of quantum mechanical formalism; for some recent issues see *e.g.*, (Saunders *et al.*, 2010; Pussey *et al.*, 2012; Ma *et al.*, 2012; Vedral, 2010; Mermin, 1998; 't Hooft, 2007).

Based on some fresh looks into the quantum mechanical formalism, here we point out a new interpretational discourse of wide-range implications that include both consciousness as well as the issue of free will (Conway and Kochen, 2008; Gisin, 2010).

Our starting point is the recently re-discovered importance of the "structure", *i.e.*, of the decomposition into parts, subsystems, of a composite quantum system (Dugić and Jeknić, 2006; Dugić and Jeknić-Dugić, 2008; Dugić and Jeknić-Dugić, 2012; Jeknić-Dugić *et al.*, 2011; Dugić *et al.*, 2012; Jeknić-Dugić *et al.*, 2012). When applied to the quantum Universe, this opens the new avenues not only for interpretation but also a wide-range of implications for describing the quantum Universe. The emerging picture is physically interesting and mind provoking. Physical existence of the simultaneously existing dynamical *Quantum Worlds* is unquestionable. For the Universe as isolated whole, a World does not seem more realistic than any other world. Bearing only the common time axis and being subject to the Schrödinger law, these worlds represent the parallel worlds of the completely new kind.

Our aim here is properly to describe the quantum mechanical foundations of such, new kind of the parallel quantum worlds, and

Corresponding author: Miroljub Dugić

Address: \*Miroljub Dugić, Department of Physics, Faculty of Science, Radoja Domanovića 12, 34000 Kragujevac, Serbia. †Dejan Raković, Faculty of Electrical Engineering, Bulevar kralja Aleksandra 73, 11120 Belgrade, Serbia. ‡Jasmina Jeknić-Dugić, Department of Physics, Faculty of Science, Višegradska 33, 18000 Niš, Serbia. §Momir Arsenijević, Department of Physics, Faculty of Science, Radoja Domanovića 12, 34000 Kragujevac, Serbia.

✉ dugic@open.telekom.rs

Received June 24, 2012. Revised July, 25, 2012.

Accepted August 6, 2012.

eISSN 1303-5150



to make a few ramifications; in this sense, we outline the *bare essentials* of an emerging interpretation of quantum mechanics. As to the later, we are particularly interested in the possible existence of the intelligent, conscious agents in at least some of these worlds—the world we are living in is one out of the number of such possible worlds. If an agent in a world is free to choose an action local to his own world, that action, if locally observable in our world, could seem 'unexplainable' to us. This is the reason we call this new kind of the parallel worlds the '*Ghostly Quantum Worlds*'. As a technical support of our claims, we offer the Supplemental Information to this paper.

## 2. Quantum structures

A quantum mechanical system,  $\mathcal{C}$ , is defined by its degrees of freedom,  $\{x_i\}$ , and by the related conjugate momentums,  $\{p_j\}$ ; the commutator  $[x_i, p_j] = i\hbar\delta_{ij}$ , where  $\delta_{ij}$  is the so-called Kronecker-delta. All the system's observables (measurable physical quantities) are the analytical functions of this basic set of observables. Nevertheless, the set of the degrees of freedom is *not* unique. One can perform the different kinds and types of the variables transformations to obtain the alternate set of the degrees of freedom that formally define the different *structures* of the composite system  $\mathcal{C}$  (Dugić and Jeknić, 2006; Dugić and Jeknić-Dugić, 2008; Dugić and Jeknić-Dugić, 2012; Jeknić-Dugić *et al.*, 2011; Dugić *et al.*, 2012; Jeknić-Dugić *et al.*, 2012).

To illustrate, consider a tripartite system  $\mathcal{C} = 1+2+3$ . The tripartite system  $\mathcal{C}$  can be presented as a bipartite system by introducing the alternate structures, *e.g.*,  $A+3$  or  $1+B$ , where the bipartite systems,  $A=1+2$  and  $B=2+3$ . This is formally a trivial kind of the transformations—the particles grouping (that is essential for the quantum teleportation protocol (Bennett *et al.*, 1993)). The more general and formally nontrivial transformations introduce the kind of the degrees of freedom that are *e.g.* the linear combinations of the original ones. To this end paradigmatic are the center-of-mass ( $CM$ ) and the "internal (relative,  $R$ )" degrees of freedom. All the macroscopic systems are described by these formal subsystems, *i.e.*, by the bipartite structure  $CM+R$ . This kind of structure is essential for the standard theory of

the hydrogen atom (Jeknić-Dugić *et al.*, 2012).

The variables transformations providing the different structures of a composite system represent a general physical method. However, only recently we have started to realize the related subtleties appearing in the *quantum mechanical* context. The following general observation is in order (Dugić and Jeknić, 2006; Dugić and Jeknić-Dugić, 2008; Dugić and Jeknić-Dugić, 2012; Jeknić-Dugić *et al.*, 2011; Dugić *et al.*, 2012; Jeknić-Dugić *et al.*, 2012):

**(P1) Every structure of a composite quantum system is equally describable by the general rules and laws of quantum mechanics.**

The hydrogen atom is paradigmatic (Jeknić-Dugić *et al.*, 2012). The hydrogen atom can be decomposed as "electron + proton ( $e+p$ )" or as (see above for notation)  $CM+R$ . Hydrogen Atom (HA) is a unique composite quantum system. Its state space and Hamiltonian as well as its quantum state are *unique* in every instant in time. Nevertheless, their mathematical *forms are different for the different structures*:

$$\mathcal{H}_e \otimes \mathcal{H}_p = \mathcal{H}_{HA} = \mathcal{H}_{CM} \otimes \mathcal{H}_R, \text{ [state space]}$$

$$H_e + H_p + H_{int} = H_{HA} = H_{CM} + H_R, \text{ [Hamiltonian]}$$

$$\sum_i \mathcal{C}_i |\hat{i}\rangle_e |\hat{i}\rangle_p = |\Psi\rangle_{HA} = |\chi\rangle_{CM} |nlm_l m_s\rangle_R. \text{ [quantum state]} \tag{1}$$

Thereby, inevitably, some quantum mechanical predictions about the two structures must be different.

In Eq. (1), the left hand sides stand for the  $e+p$  and the right hand sides for the  $CM+R$  structure of the hydrogen atom. Notice that noninteraction in the  $CM+R$  structure (formally provided by the variables separation) gives rise to a tensor-product (absence of entanglement) form of the state, where the numbers  $n, l, m_l, m_s$  denote the standard quantum numbers for the hydrogen atom theory (Jeknić-Dugić *et al.*, 2012).

In this paper, of all the structures, we consider those mutually *irreducible* structures. To this end, again, paradigmatic is the HA model, Eq. (1): (i) there is not even a common degree of freedom for the two structures,  $e+p$  and  $CM+R$ , and (ii) no subsystem (*e.g.*,  $CM$



and  $R$ ) of one structure can be decomposed (partitioned) into the subsystems of the alternate structure (into  $e$  and  $p$ ). Furthermore, every subsystem,  $e, p, CM, R$ , is elementary—it cannot be decomposed into the more elementary systems ("particles")—the  $CM$  and  $R$  systems appear as the elementary particles for the  $CM + R$  structure. The local physical laws (interactions) are also in general different.

In many-particle systems there are many ways formally to introduce structures that are irreducible relative to the initial one. Here, we skip the technical details. To support intuition, we remind that  $CM + R$  is typical in the solid state physics. There, the  $CM$  degrees of freedom are usually ignored—the internal vibrations (internal energy) of a lattice are of the main importance. In analogy with the variables separation for HA, in solid state physics, the internal (the  $R$ 's) degrees of freedom are typically transformed to provide the "normal coordinates" (*i.e.*, the normal vibrational modes). This chain of the transformations provides the different, mutually irreducible structures of the one and the same "solid body"; *e.g.* the phonons cannot be decomposed into the original particles or into the "systems" defined by the  $R$ 's degrees of freedom. It can be shown (*cf.* Supplemental Information): the subsystems belonging to the alternate (mutually irreducible) structures are information-theoretically separated. Information about one subsystem (*e.g.*, about the HA electron) is not sufficient for describing any subsystem belonging to any irreducible structure (*e.g.*, the atomic  $CM$  or  $R$  system). Furthermore, there is not any information flow between the subsystems belonging to the mutually irreducible structures. The variables transformations do not apply only to the "massive" quantum particles. The Bogoliubov transformations (Bogoliubov, 1947) provide an example for the quantum fields. In quantum optics one can find the transformations encompassing the variables of the atoms and of the electromagnetic field (Stokes *et al.*, 2012).

Our point (P1) now reads:

**(P2)** *Every variables transformation provides a specific quantum mechanical description of a composite system. If isolated ("closed"), the system is subject to the Schrödinger law for every choice of the*

*degrees of freedom (variables). Mutually irreducible structures represent the mutually independent and foundationally equal physical descriptions of the composite system.*

So, physically, the structures simultaneously evolve in time, each being described by its (local) subsystems (degrees of freedom). An observer can in principle choose which observables of the composite system to measure (Conway *et al.*, 2006; Gisin, 2010). The unique quantum state of the composite system provides unique prediction for the probability distribution for every measurement in every instant in time. As emphasized above, the knowledge of the probability distribution for one subsystem (*e.g.*, the atomic  $CM$  system) is linked with the probability distribution for a subsystem (*e.g.*, the atomic  $R$  system) belonging to the same structure ( $CM + R$ ). This, however, does not apply to the probability distributions for the subsystems belonging to the different, mutually irreducible structures. So, the different structures represent the different facets of the (unique) composite system.

Operationally, observation of a structure is limited by the practical accessibility of the composite systems observables. In practice, not all the observables are accessible in a given physical situation. So, the choice made by the observer is determined by the choice of the measurement apparatus and by the general conditions the quantum system is subjected to. Fortunately enough, these subtleties are of no importance for us before Section 5. Below, we consider the Universe as a whole, *i.e.*, as a "closed" system (subject to the Schrödinger law) that, *in principle*, cannot be observed from outside.

### 3. New kind of the parallel quantum worlds

The general assumption of our considerations is the assumption of the universally valid and complete quantum mechanics. In our considerations, the quantum Universe state (the universal state) is physically real (Saunders *et al.*, 2010; Pussey *et al.*, 2012). We are interested in the structures irreducible to the structure we are a part of. To simplify notation, we denote formally the structure we belong to by  $\mathcal{W}$ . Now we consider the different, mutually irreducible structures of



the Universe, formally denoted as the set  $\{\mathcal{W}_i\}$ , whose existence is at least formally guaranteed (Dugić and Jeknić, 2006; Dugić and Jeknić-Dugić, 2008; Dugić and Jeknić-Dugić, 2012; Jeknić-Dugić *et al.*, 2011; Dugić *et al.*, 2012; Jeknić-Dugić *et al.*, 2012).

To keep the tracks of the nonrelativistic quantum-mechanical description, we stick to the structures that are mutually related by the proper canonical transformations of the degrees of freedom. *E.g.*, the transformations providing Eq. (1) [that are still, as emphasized above, paradigmatic for physical considerations]:

$$\vec{R}_{CM} = (m_e \vec{r}_e + m_p \vec{r}_p) / m_{CM}, \vec{\rho}_R = \vec{r}_e - \vec{r}_p, \quad (2)$$

accompanied by the total mass,  $m_{CM} = m_e + m_p$ , and the "reduced mass",  $m_R = (m_e^{-1} + m_p^{-1})^{-1}$ , for *CM* and *R*, respectively. The transformations Eq. (2) are invertible. These transformations make the two structures mutually irreducible: neither *CM* nor *R* can be decomposed into *e* and *p*, and *vice versa*. Measurement of *e.g.*,  $\vec{r}_p$  requires simultaneous measurement of both,  $\vec{R}_{CM}$  and  $\vec{\rho}_R$ . [See Supplemental Information for further details.]

Now we emphasize: *every structure  $\mathcal{W}_i$  is a priori no more and no less physically realistic as any other structure  $\mathcal{W}_j$ , including our own world  $\mathcal{W}$ .*

This statement follows from the following, "obviously correct" observations: a. the structure we are a part of is physically realistic, and b. for the Universe as an isolated ("closed") system, there is no *a priori* privileged structure. As to the later, by (Zanardi, 2001):

*"Without further physical assumption, no partition has an ontologically superior status with respect to any other."*

As well as by (Halliwell, Chapter 3 in Saunders *et al.*, 2010):

*"However, for many macroscopic systems, and in particular for the universe as a whole, there may be no natural split into distinguished subsystems and the rest, and another way of identifying the naturally decoherent variables is required."*

Now, bearing in mind those structures have practically nothing in common, we

introduce a new kind of the *parallel quantum worlds*:

*The Universe hosts a number of physically equal, mutually irreducible dynamical quantum worlds. The Worlds share the same physical time and the fundamental Schrödinger law, otherwise having nothing in common.*

It is worth repeating: reality of these quantum worlds is a direct corollary of the above points a and b. To this end, the central argument is the existence of our world, which is just one out of a set of the possible worlds. So, the worlds we are interested in are defined by the requirement of mutual irreducibility that includes our world  $\mathcal{W}$ . In descriptive terms, one can say the Worlds share the one and the same fundamental physical *matter*, while their compositions (the "substances" defined by their respective elementary particles and their interactions) are mutually irreducible. As a consequence, one can say there is not 'electron' or 'proton' or the hydrogen atom as well as any other 'system' known to us in any other world. The variables transformations for local subsystems can be performed in every World—the variables transformations for the proton and the electron provide the alternative structure of the hydrogen atom as a subsystem of our World,  $\mathcal{W}$ .

Of course, one may pose the following question: whether or not arbitrary structure (a world) can be considered physically relevant? Without further elaboration of this new physical picture, we are able only to answer as follows: as long as the structure does not raise any physical inconsistencies, there does not seem to be any *a priori* reason to be rejected. Certainly, there may be additional criteria in this respect and one such a criterion—the *classicality* criterion—will be explicitly considered below.

## 4. Comparison with the other interpretations

Below, we consider a few interpretations relevant for our considerations.

### 4.1. Bohmian quantum theory

In Bohm's theory (Bohm, 1951), the Universe is assumed to consist of a set of physical particles that are embedded in a quantum field governing the particles dynamics. In every





instant in time, there is the one and unique fundamental (nonrelativistic) structure of the Universe. In this context, the variables transformations (Section 2) represent purely a mathematical tool, a mathematical artifact that does not bear any physical meaning. *i.e.*, The alternate structures cannot be considered physically relevant. This, of course, is in sharp contrast with our view, in which there are not a priori reasons to reject a formally consistent (yet irreducible relative to our world) structure of the Universe. So, in contradistinction with (Zanardi, 2001; Halliwell, Chapter 3 in Saunders *et al.*, 2010), one can say that Bohm's theory *postulates* existence of the unique physical, ontological structure of the Universe. We believe the Bohmian theory meets serious problems in interpreting the quantum correlations relativity (Dugić *et al.*, 2012). On the other hand, the later are essential for our considerations.

#### 4.2 Everett interpretation

The parallel worlds of Section 3 have nothing in common with the Everett's parallel worlds and the Multiverse interpretation of quantum mechanics (Saunders *et al.*, 2010). By definition, measurement of e.g. the electron's position cannot be performed in any other world  $\mathcal{W}_i, i \neq 0$ . Electrons, protons, hydrogen atom are the subsystems exclusively in our world,  $\mathcal{W}_0$ . Consequently (by definition), there are not the humans in any alternate World. A World  $\mathcal{W}_i$  is the subject of the Everett interpretation—one World from our considerations defines one possible Multiverse for the Everett interpretation. Some details in this context can be found in (Dugić and Jeknić-Dugić, 2010). Finally, we answer the following question: may one consider these different Multiverses as the fundamental quantum mechanical basis for an emergent Multiverse that is currently discussed within the new Everretian perspective (Saunders *et al.*, 2010)?

Whatever 'emergent' might mean, it seems necessary to assume that there is a common 'element' for the various Multiverses. While we do not offer a general answer, we are still able to offer an example exhibiting the lack of such a common element.

Recently, a model of a pair of 'Brownian' particles has been demonstrated (Dugić and Jeknić-Dugić, 2012; Jeknić-Dugić

*et al.*, 2011). For a composite system,  $C$ , one can recognize a pair of mutually irreducible structures,  $1+2$  and  $A+B$ ;  $1+2=C=A+B$ . Formally the two models are isomorphic thus providing the two "environments",  $2$  and  $B$ , for the two (one-dimensional) particles,  $1$  and  $A$ , respectively. The two particles,  $1$  and  $A$  undergo the dynamics known as the quantum Brownian motion (QBM) (Breuer and Petruccione, 2002) (and the references therein). So, their quantum mechanical description is in the spirit of Section 3: every particle ( $1$  and  $A$ ) is a subsystem in its own world ( $1+2$  and  $A+B$ , respectively). For the pair of particles, one can show: there does not exist any observable,  $X$ , of the composite system  $C$ , that could approximate measurements of any pair of observables,  $A_1$  and  $B_A$ , of  $1$  and  $A$ , respectively. Thereby there is not any alternate world describable locally by the observable  $X$  that could be 'emergent' for the two worlds,  $1+2$  and  $A+B$ . In other words: one cannot assume existence of any emergent property common for both Brownian particles. Thereby we conclude: at least this simple example (Dugić and Jeknić-Dugić, 2012) poses a serious problem for the emergent-ism of the modern Everett theory. The worlds defined in Section 3 are not of the Everett kind.

The possible role of *consciousness* within the Everett paradigm (Lockwood, 1989; Zeh, 2000; Menskii, 2005; Mensky, 2007) may still raise some new issues or subtleties we are not yet aware of.

#### 4.3 Ithaca interpretation

Prima facie, our quantum worlds look very much like a reminiscence to the Mermin's Ithaca interpretation (Mermin, 1998). As long as there is not any additional criterion for the physical relevance of the Worlds, the two interpretations may seem indistinguishable.

However, the main criterion for the relevance of an interpretation is simply it should reproduce what we see in the realistic experimental situations (Saunders *et al.*, 2010). At this point, as well as focusing on the irreducible structures (worlds), we depart from the Ithaca interpretation. Actually, we introduce the following criterion:



**(C) Of all the Worlds introduced in Section 3, we consider physically relevant only those that bear "classicality".**

"Classicality" is the very starting point in every interpretation as one should provide the clues and possibly the rules for the emergence of the "classical world" from the quantum substrate. While we are still learning about the meaning of "classicality", the above criterion (C) is clear: whatever the classicality may mean, a World fulfilling the criterion (C) should be regarded equally physically relevant as the World  $\mathcal{W}$  we live in. Existence of alternate structures supporting classicality is virtually intractable within the modern quantum theory. Nevertheless, there are some models supporting classicality for some alternate structures of the model-Universe (Dugić and Jeknić-Dugić, 2012). So, at least in principle, one may think in the terms of the alternate, mutually irreducible quantum worlds bearing classicality not known to any of the existing interpretations of quantum mechanics.

#### 4.4 Summary

The quantum worlds defined in Section 3 represent a new kind of the parallel dynamical quantum worlds simultaneously hosted by the one and the unique quantum Universe. Due to the criterion (C), of all such quantum worlds of relevance are only those providing classicality for at least some of their local, intrinsic structures. The subsystems belonging to the same structure are mutually described by the "relative states" (Everett, 1957) description of the universal quantum state without any necessity (Jeknić-Dugić *et al.* 2011) of the "worlds branching (splitting)" as considered within the Everett interpretation of quantum mechanics. The subsystems belonging to the different worlds are mutually irreducible and do not have practically anything in common (including the elementary particles and the local physical laws (interactions) between them). A conscious agent cannot say which world he is a part of.

#### 5. Consciousness and free will: a speculation on the observable effects

This part is speculative yet mind provoking. It's starting point is quite natural: if there is not a priori reason to consider our World privileged relative to the other Worlds, then classicality of our world may be essentially

similar (the decoherence-based) to the classicality of any other world.

To this end, it is important to stress: Quantum mechanics is equally valid in every World (picked up from a set of mutually irreducible worlds). Therefore, some basic consequences of the universally valid quantum mechanics (*e.g.*, decoherence) may be equally valid for at least some Worlds. Unfortunately, we do not go beyond this general remark. *E.g.*, we do *not* advocate for any particular solution of the measurement problem. We consider our basic findings in Section 3 as the *corollaries* of the universally valid quantum mechanics, and therefore a *necessary condition* for a proper solution to the measurement problem. In our considerations, consciousness is introduced in analogy with our-world phenomenology and intuition. At this point, we do not dare to claim constructive role of our findings in defining or explaining consciousness or free will as well. Rather, *we proceed in analogy* with our current knowledge and intuition – *e.g.*, consciousness may be emergent property of some information-processing assemblies.

A common assumption in the philosophy of mind is that of substrate-independence (Bostrom, 2003) (and the references therein). In our context, it means the possibility of conscious information processing in some alternate worlds. Unless 'intelligence', 'consciousness' and 'mind' are substrate-dependent, there is not any reason a priori to reject the possibility of 'intelligent' agents also in some other worlds. Otherwise, we would be equipped with a new criterion for distinguishing the physical relevance of the Worlds. In the absence of such a criterion, we seem obliged to assume the in-principle-possibility that not only our world hosts the intelligent beings or local compositions able to emulate the "conscious experience" as usually considered in the philosophy of mind.

Of course, the mind-supporting composites (or 'beings') in the alternate worlds should bear a totally different kind of 'mind'—after all (see Section 3), the physical laws underlying the information processing are totally different (yet, owing to the canonical transformations connecting them, fully describable by ours) from ours. Nevertheless, as the general rules of quantum mechanics are common for all the worlds, one can speculate about the scientific research performed in the alternate worlds.



Interestingly, the actions performed by conscious agents in the different Worlds provide nontrivial and *global* changes for the alternate worlds. It is intriguing that, if observable locally in an alternate world, these actions may seem unexplainable–'ghostly'–for a local observer.

Consider a quantum measurement performed in a world by an intelligent agent living in that world. Here, as usual, we assume the agent is free to choose which kind of measurement to perform. A measurement of an observable *A* assumes the agent is capable to act according to his free will by physically connecting the object of measurement and the proper measurement apparatus. According to the general rules of the quantum measurement theory, this action induces new correlations between the object and the apparatus. This change of the universal state is local for the agent—only the object and the apparatus are subject to formation of the new quantum-mechanical correlations (quantum entanglement). However, this action is global for every alternate world: the universal quantum state obtains a nontrivial new form bearing quantum correlations for the subsystems belonging to that world (see Supplemental Information).

In effect, the local action of a measurement in a world provides a change in the universal state that is global *e.g.*, for our world. While this is in principle easily mathematically presented (Dugić and Jeknić, 2006; Dugić and Jeknić-Dugić, 2008 ; Dugić and Jeknić-Dugić, 2012; Jeknić-Dugić *et al.*, 2011; Dugić *et al.*, 2012; Jeknić-Dugić *et al.*, 2012), the physical consequences are mind provoking. If locally observable in our world, such actions of an agent in an alternate world would certainly look 'unphysical', 'non-causal'. The agent is the only one aware of his actions (performed in his own world). These actions are commonly described as a 'physical experiment'. But in our world, there is not any reason for a change of state of any physical object. In our world, the agent's actions look non-spontaneous and a-causal, *i.e.*, physically unexpected and apparently un-explainable. For the observers in our world not aware of the existence of the agent in an alternate world, the free choice of the measurement made by the agent appear simply 'ghostly'.

Of course, the possibility of the agent to make a free choice of quantum measurement

is a matter of 'free will' (Conway *et al.*, 2006; Gisin, 2010) that here will not be elaborated. We just note that these 'ghostly' local effects may be absent if the agents are short of free will in the alternate quantum worlds. To this end, it is important to stress: free will of the agent to perform a measurement is essential for the effects we are speculating about. By preparing a piece of a material and performing a measurement, the agent performs non-spontaneous effects that otherwise would be absent from his world. By breaking the chain of spontaneous quantum dynamics in his world, the agent causes the global effects for all the other worlds that cannot be explained by the known physics in the other worlds—those effects are not causal in the alternate worlds. Of course, there remains the question of local observability of such global effects in an alternate world as well as the ability of the agent(s) in the alternate worlds to distinguish between the spontaneous and non-spontaneous effects. Nevertheless, the physical existence of such global effects is here for the first time pointed out. Further elaboration and ramifications of our conclusions are under consideration.

By emphasizing the possible role of free will, we arrive at a position analogous to the positions based on the anthropic principle (Barrow and Tipler, 1986; Tipler, 2003; Čirković, 2002): an intelligent agent hosted in a World can nontrivially influence dynamics of the alternate—for-him Worlds. Due to our initial assumptions (Section 3), the Universe as a whole remains totally indifferent regarding the local destiny of the Worlds, which share the same the global destiny of the quantum Universe.

## 6. Discussion

The starting point of our considerations is physically un-questionable: the structural considerations are ubiquitous in physics. Some consequences for the composite quantum systems are only recently recognized. To this end, the contents of the section 1 through 3 appear properly established. However, there is also some speculative parts that should be additionally considered.

It is by now a common wisdom that consciousness, mind etc. should not be considered exceptional in a classical world. Encouraged by the recent notion on the parallel occurrence of decoherence (Dugić and





Jeknić-Dugić, 2012; Jeknić-Dugić *et al.*, 2011) and partly by the prevailing emergentism in modern Everett theory (Saunders *et al.*, 2010), we dare to assume that all the Worlds bearing classicality may in principle host 'conscious experience'.

In our considerations, "consciousness" (as well as free will) is assumed as a data, without any attempt of explanation. A more elaborate consciousness-based analysis (Menskii, 2005; Mensky, 2007) may probably introduce a discourse we are not currently aware of. Bearing this and the fact that we do not offer a solution to the measurement problem, we can say our interpretation is in its infancy yet.

Finally, we assume that conscious agents in at least some of the classicality-bearing worlds can be described by free will. Then our conclusions on the global effects for the alternate worlds, see Section 5, are physically firmly based. We finally consider the possible consequences of the local observability of such global changes. In effect, free will of an agent in a world nontrivially changes the fate of all the other alternative worlds without any apparent cause or explanation for the agents (observers) in those worlds.

## 7. Conclusion

What we commonly call the Universe is just one out of many possible Worlds in the herewith presented interpretation. Every such a world has its own physics and logic we can mathematically describe not yet fully to understand. Every such a world is composed of its own kind of the elementary particles and the local physical interactions. The subsystems of a World are mutually interdependent not yet having anything in common (but the same time and the universal Schrödinger law) with the subsystems belonging to the alternate Worlds. A conscious agent cannot say which World he lives in. All the known basic physics and its ramifications have counterparts in the alternate worlds but the details are not yet investigated. So, here proposed kind of the parallel quantum worlds is not similar to those existing in the literature. We speculate about the possible effects locally produced by a conscious agent in a world and emphasize the global, physically un-explainable effects for an alternative world.

## Acknowledgement

The work on this paper is supported by Ministry of Science Serbia under contract no 171028.

## Supplemental Information

We borrow notation and the references list from the main text.

### A. The canonical transformations

In nonrelativistic quantum theory, the basic observables are the position and the momentum observables,  $x$  and  $p$  (*e.g.*, for the one-dimensional system),  $[x,p]=i\hbar$ . The "system" is defined by its Hamiltonian,  $H$ , which is a function of the basic set of the observables. The unitary evolution of the "closed" system is generated by the Hamiltonian.

The canonical transformations preserve the formalism based on the degrees of freedom ( $x$ ) and the Hamiltonian of the system. Every such variables transformation redesigns the system's Hilbert state space. *e.g.*, For a bipartite system 1+2, the Hilbert state space,  $\mathcal{H}$ , is defined by the "tensor-product" of the Hilbert state spaces for the subsystems,  $\mathcal{H}=\mathcal{H}_1\otimes\mathcal{H}_2$ . The alternative structure,  $A+B$  of the same composite system ( $C$ ) gives rise to alternate tensor-product,  $\mathcal{H}=\mathcal{H}_A\otimes\mathcal{H}_B$ .

Every such structure is fully quantum-mechanically describable—if "closed", it is subject to the same time and the same the fundamental quantum mechanical law—the Schrödinger law. In other words: quantum mechanics, *per se*, does not distinguish between the different structures of any composite system  $C$ .

The subsystems of the irreducible such structures are "elementary" relative to each other—the hydrogen atom's  $CM$  system can not be 'broken' to release the atomic electron and the proton, and *vice versa*. The physical laws (interaction) between the subsystems belonging to the same structure are typically (but not necessarily (Dugić and Jeknić-Dugić, 2012; Jeknić-Dugić *et al.*, 2011)) different for the different structures.





## B. Unique Hamiltonian and state: quantum correlations relativity

According to the postulates of quantum mechanics, for a closed quantum system  $C$ , the Hilbert state space,  $\mathcal{H}$ , the Hamiltonian,  $H$ , and the system's state,  $|\Psi\rangle$ , are *unique* in every instant in time.

However, for the different structures, they all change their *forms*. For an example regarding the Hilbert space see above. Regarding the Hamiltonian:

$$H_1 + H_2 + H_{12} = H = H_A + H_B + H_{AB} \quad (3)$$

where the double subscripts denote the interaction terms.

Recently discovered quantum correlations relativity (Dugić *et al.*, 2012) states: a pure quantum state  $|\Psi\rangle$ , just like the Hilbert space and the Hamiltonian of the composite system, obtains the different forms for the different structures. *e.g.*, in the hydrogen atom theory (Jeknić-Dugić *et al.*, 2012) (see also Eq. (1) above):

$$|\chi\rangle_{CM} |nlm_l m_s\rangle_R = \sum_i c_i |i\rangle_e |i\rangle_p; \quad (4)$$

the notation is the standard notation from the quantum theory of the hydrogen atom.

This is, a separable (no correlations) pure state for one structure ( $CM + R$ ) typically obtains entangled form for alternate structure ( $e+p$ ). The atomic center-of-mass and the internal degrees of freedom do not mutually interact (the "variables separation") and therefore the state on the lhs of Eq. (2) is tensor-product. However, the atomic electron and the proton are in mutual (unavoidable Coulomb) interaction and their state is quantum mechanically entangled.

For the Universe as a whole: the Universe is the only physical system *exactly* described by the Schrödinger law, and cannot be observed from outside—there is not any observer not belonging to the Universe. While the local variables transformations (considered in A) are possible and often important, these do not change the conclusions referring to the Universe as a whole.

## C. The global consequences of a local action

"Observer" is assumed a conscious agent capable of performing experiments that need not spontaneously occur. Every observer is a part of a structure (of a Universe's World) and we are ourselves a part of such a world,  $\mathcal{W}$ , we believe to be physically realistic. Bearing in mind the above A, there is every reason to believe that the Worlds irreducible to each other and to our own World are equally physically realistic.

The subsystems belonging to the same World are described by the states that represent the Everett "relative states" (Everett, 1957)—*cf.* Eq. (4). The state of the atomic electron has sense *if and only if* as the atomic proton's state has physical sense. The same applies to all the subsystems belonging to the same structure; the local variations of structure do not change anything in this regard.

Writing down the equalities of the form Eq. (4) is a tough mathematical task. Nevertheless, validity of such equalities, and their generalization:

$$\sum_i c_i |i\rangle_1 |i\rangle_2 = \sum_p d_p |p\rangle_A |p\rangle_B \quad (5)$$

[for a bipartite structures of a composite system  $C$ ;  $1+2=C=A+B$ ] is a direct corollary of the universally valid quantum mechanics.

In general, the expressions like Eq. (2) are time dependent—all the time there is dynamical formation of correlations and decorrelations in the Universe. By living in one World, we believe the processes are spontaneous (and in a sense causal), [statistically] predictable, all but the actions performed by an experimenter. Every experiment can be described in a simplified form as formation of correlations between the object of measurement ( $O$ ) and of the measurement apparatus ( $A$ ):

$$|\phi\rangle_{object} |o\rangle_{apparatus} \rightarrow \sum_k \kappa_k |k\rangle_{object} |k\rangle_{apparatus}. \quad (6)$$

*Essential* for Eq. (6) is the fact that it *neglects the rest of the Universe*. The measurement described (after von Neumann) by Eq. (6) is *local* in the world the experimenter lives in.



However, and this is the point strongly to be emphasized: “According to the *Correlations Relativity* (Dugić et al., 2012), practically every action local to a World (to one structure of the Universe) is global for every alternate World (alternate structure of the Universe).”

Physically, formation of local correlations in one World is typically presented, Eq. (6), by formation (or at least change) of the *global* correlations encompassing the whole of an alternate World. e.g., Externally-induced separation of the hydrogen atom's electron and proton, providing a tensor-product state in the  $e+p$  structure, would lead to formation of entanglement in the  $CM+R$  structure (Dugić et al., 2012). The fact that these are the global

transformations for the hydrogen atom does not alter our observation. In the more technical terms: the universal-state local change induced locally (e.g., by an experimenter) in a World produces *global* consequences for the correlations in every alternate world.

As the universal Hamiltonian and the universal-state are unique in every instant in time, there is one-to-one prescription between the effects in all the Worlds. So, in the Universe where everything is spontaneous, there is not a problem. However, existence of conscious agents in a world alternate to our own world, if equipped by free will can produce non-spontaneous effects physically unexplainable to us—as emphasized in the main text.

## References

- Barrow JD, Tipler FJ. *The Anthropic Cosmological Principle*. Oxford University Press, New York, 1986.
- Bennett CH, Brassard G, Crépeau C, Jozsa R, Peres A, Wootters W K. Teleporting an unknown quantum state via dual classical and Einstein-Podolsky-Rosen channels. *Phys Rev Lett* 1993; 70(13): 1895-1899.
- Bogoliubov NN. On the Theory of Superfluidity. *J Phys (USSR)* 1947; 11(1): 23-32.
- Bohm D. *Quantum Theory*. Prentice Hall, 1951.
- Bostrom N. Are You Living in a Computer Simulation?. *Philos Quart* 2003; 53(211): 243-255.
- Breuer HP, Petruccione F. *The Theory of Open Quantum Systems*. Clarendon Press, 2002.
- Conway J, Kochen S. The Strong Free Will Theorem. <http://arxiv.org/abs/0807.3286>. Accessed date: July 21, 2008.
- Dugić M, Jeknić J. What is “System”: Some Decoherence-Theory Arguments. *Int J Theor Phys* 2006; 45(12): 2249-2259.
- Dugić M, Jeknić-Dugić J. What Is “System”: The Information-Theoretic Arguments. *Int J Theor Phys* 2008; 47(3): 805-813.
- Dugić M, Jeknić-Dugić J. Which Multiverse?. <http://arxiv.org/abs/1004.0148>. Accessed date: March 31, 2010
- Dugić M, Jeknić-Dugić J. Parallel decoherence in composite quantum systems. *Pramana* 2012; 79(2): 199-210.
- Dugić M, Arsenijević M, Jeknić-Dugić J. Quantum Correlations Relativity for Continuous Variable Systems. *Sci China-Phys Mech Astron* 2012; DOI: 10.1007/s11433-012-4912-5.
- Everett H. 'Relative state' formulation of quantum mechanics. *Rev Mod Phys* 1957; 29(3): 454-462.
- Gisin N. The Free Will Theorem, Stochastic Quantum Dynamics and True Becoming in Relativistic Quantum Physics. <http://arxiv.org/abs/1002.1392>. Accessed date: February 6, 2010.
- Jeknić-Dugić J, Dugić M, Francom A. Quantum Structures of a Model-Universe: Questioning the Everett Interpretation of Quantum Mechanics. <http://arxiv.org/abs/1109.6424>. Accessed date: September 29, 2011.
- Jeknić-Dugić J, Dugić M, Francom A, Arsenijević M. Quantum Structures of the Hydrogen Atom. <http://arxiv.org/abs/1204.3172>. Accessed date: April 21, 2012.
- Lockwood M. *Mind, Brain, and the Quantum*. Oxford University Press, 1989.
- Ma XS, Zotter S, Kofler J, Ursin R, Jennewein T, Brukner C, Zeilinger A. Experimental delayed-choice entanglement swapping. *Nature Phys* 2012; 8(6): 480-485.
- Menskii MB. Concept of consciousness in the context of quantum mechanics. *Physics-Uspekh* 2005; 48(4): 389-409.
- Mensky MB. Post correction and Mathematical Model of Life in Extended Everett's Concept. *NeuroQuantology* 2007; 5(4): 363-376.
- Mermin MD. *The Ithaca Interpretation of Quantum Mechanics*. *Pramana* 1998; 51(5): 549-565.
- Pusey M F, Barrett J, Rudolph T. On the reality of the quantum state. *Nature Phys* 2012; 8(6): 476-479.
- Saunders S, Barrett J, Kent A, Wallace D, (eds.). *Many Worlds? Everett, Quantum Theory, and Reality*. Oxford University Press, 2010.
- Stokes A, Kurcz A, Spiller TP, Beige A. Extending the validity range of quantum optical master equations. *Phys Rev A* 2012; 85(5): 053805.
- 't Hooft G. A mathematical theory for deterministic quantum mechanics. *J Phys Conf Ser* 2007; 67(1): 012015.
- Tipler JF. Intelligent life in cosmology. *Int J Astrobiol* 2003; 2(2): 141-148.
- Vedral V. *Decoding Reality: The Universe as Quantum Information*. Oxford University Press, 2010.
- Zanardi P. Virtual Quantum Subsystems. *Phys Rev Lett* 2001; 87(7): 077901
- Zeh HD. The Problem of Conscious Observation in Quantum Mechanical Description. *Found Phys Lett* 2000; 13(3): 221-233.
- Čirković MM. Anthropic Fluctuations vs. Weak Anthropic Principle. *Found Sci* 2002; 7(4): 453-463.

