

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/275017249>

# Quantum Modeling of the Mental State: the Concept of a Cyclic Mental Workspace.

Article · January 2013

---

CITATIONS

10

READS

130

2 authors, including:



**Dirk K F Meijer**

University of Groningen

574 PUBLICATIONS 14,428 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Radiant Consciousness [View project](#)



Electronic music as a way to explore xenolinguistics [View project](#)

# Quantum modeling of the mental state: *the concept of a cyclic mental workspace*

Dirk K. F. Meijer<sup>1</sup> and Jakob Korf<sup>2</sup>

## **Abstract**

Taking into account the constituting elements of the human brain, such as neuronal networks, individual neurons, trans-membrane ion-fluxes and energy producing cellular metabolism as well as other molecules that promote neural activity, there is clear consensus that the present knowledge of the brain, collectively, is insufficient to explain higher mental processes such as (self)consciousness, qualia, intuition, meditative states, transpersonal experiences as well as functional binding between distant parts of the brain.

We argue that super-causal mechanisms are required to optimally integrate the above mentioned building blocks of brain function, also enabling the brain to amplify minimal perturbations for proper anticipation and action. We propose that such a super-causal structure may function as an interface between molecular transitions and the particular higher mental functions. As attractive bridging principles, the isoenergetic brain model and the physical-mathematical hypotheses denoted as quantum brain theories are treated.

It is acknowledged that elementary quantum processes are likely to be essential for higher brain functions, as well as behavior and cognitive processing, since our central nervous system forms an integral part of a dynamic universe as a non-local information processing modality. In addition we conclude that quantum concepts may, at least, serve as a useful probability model and/or metaphor for human cognition.

Yet, versatile brain function may require *complementary* information processing mechanisms at the classical and quantum (macro- and micro-) levels, both enabling bottom up and top down information processing. Concerted action of isoenergetic and quantum physics-based cognitive mechanisms in the human brain, requires a nested organization of fine-tuned neural micro-sites that enable decoherence-protected information transfer. For a rapid and causally effective flux of information, as well as a continuous updating of meaningful information, a super-causal field model is required. This neural structure is conceived by us as a “bi-cyclic” mental workspace, housing interacting and entangled wave/particle modalities that are integral parts of an a-temporal and universal knowledge domain.

---

<sup>1</sup> Professor of Pharmacology and Therapeutics, University of Groningen, The Netherlands, Email: [meij6076@planet.nl](mailto:meij6076@planet.nl)

*Corresponding address:* Dirk K. F. Meijer, Parklaan, 17, 9724AN Groningen, The Netherlands, Email: [meij6076@planet.nl](mailto:meij6076@planet.nl), Tel. nr.: 31-50-3180593

<sup>2</sup> Professor of Biological Psychiatry, University of Groningen, The Netherlands. Email: [j-korf@home.nl](mailto:j-korf@home.nl)

## Sections

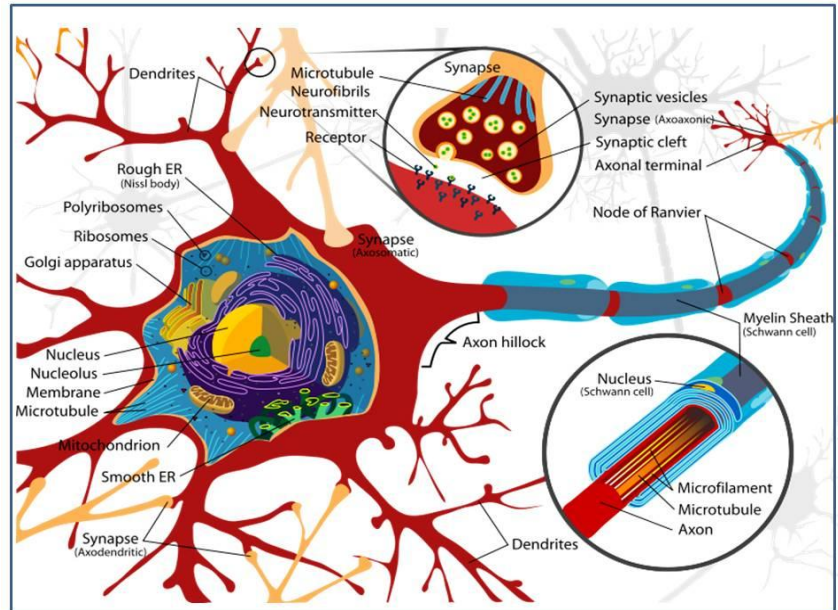
<i>1. Introduction</i>	2
<i>2. Philosophical premises in matter/mind considerations</i>	4
<i>3. Brain metabolism and mental function</i>	5
<i>4. Quantum physics and psychology</i>	9
<i>5. QM approaches in neurobiology: the state of art</i>	12
<i>6. QM and higher brain functions</i>	15
<i>7. Space/time dimensions and universal consciousness</i>	20
<i>8. An attempt to integrate the two supercausal brain models</i>	25
<i>9. Final considerations and discussion</i>	31
<i>Acknowledgements</i>	34
<i>References</i>	34

### 1. Introduction

The mind-brain issue has a long history of discussion with a strong multidisciplinary character. First of all theology and philosophy have a long tradition in these discussions, but more recently physics, mathematics, biology and medicine have largely contributed to this item. Philosophers and neurobiologists have often regarded their disciplines and approaches to be mutually exclusive. The long history of the mind-matter discussion, at least, highlights two aspects. Firstly, the fascination about the quest of the origin of the mind: how closely and in what manner is it associated with the physical world? Secondly, as yet there seems to be no convincing answer whether mind is an independent (mental) modality of the universe, in spite of the fact that the experience of self-consciousness, flow of thoughts and inner projections of our future are phenomena that we feel as a reality. It is clear that the brain does not simply process inputs and merge them at higher levels, but at the same time also does the opposite: it predicts what comes next. This is how it can recognize events, situations and people, and understand what is going on. Memory therefore is bidirectional: memory interprets the present while it is absorbing it and anticipates future events. Memory therefore becomes also a reservoir for possible solutions to problems.

Several frameworks have been proposed to reconcile the mental and the physical states. Most of these attempts start with relatively mono-disciplinary assumptions to tackle the mind-brain or mind-body problem. This essay analyzes some general concepts on brain functioning based on recent neurobiological investigations and discusses these with those originating primarily in quantum mechanical approaches. More precisely: we stress the importance of both quantum and classical molecular states for higher cerebral and, by implication, mental processes.

Firstly, various mind/brain concepts are discussed including emergent materialism, i.e. the idea that the interaction of the constituting components of the brain (i.e., neuronal networks or molecular communication networks in cells) creates emergent and largely unpredictable properties, that ultimately produce our experience of mind. We examine the relationship between brain energy-metabolism and general brain functions, and argue that they are, by and large, unrelated. We propose that brain metabolism serves to maintain a high energy state (“potential energy”) and isoenergeticity to ensure future activities. High energy molecular perturbations are supposed to be easily amplified to become meaningful signals for the organism. Together with the stored information, acquired during life, a “personal universe” is created.



*Fig. 1: Diagram of a typical neuronal structure, including synaptic transmission*

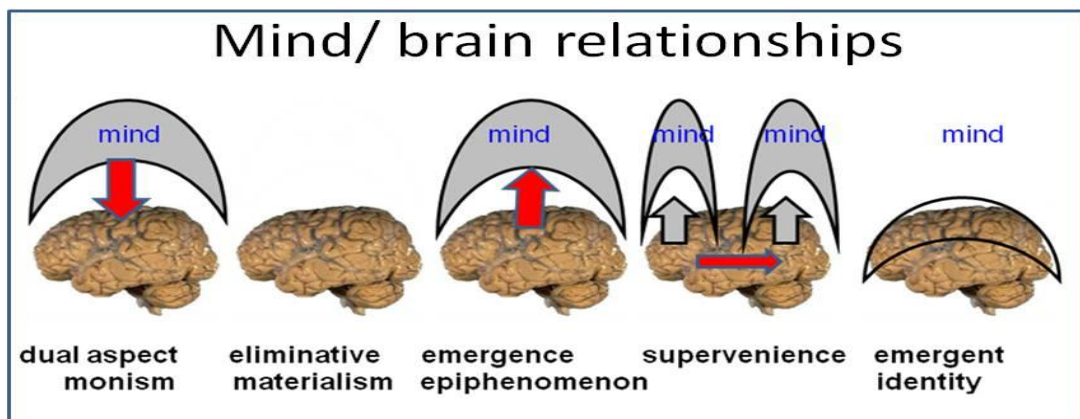
Secondly some recent physical-mathematical theories of mind are examined, denoted here as quantum mechanical (QM) theories, because they are largely based on quantum physics. The attractiveness of a quantum theory has been justified by its basic elements of: 1<sup>st</sup> uncertainty, that means that mental phenomena are not governed by classical physical laws of determinism and causation, so that there is room for intuition and free will; 2<sup>nd</sup> a universal consciousness with the individual consciousness as participating agents; 3<sup>rd</sup> consciousness, even seen as a non-physical entity, finally acts in the physical domain and may exert causal power; 4<sup>th</sup> explaining mental transitions from apparently non-conscious thoughts and processes to conscious ones and *vice versa*; 5<sup>th</sup> a potential difference between internal time perception and external physical time; 6<sup>th</sup> the possible non-temporality of the so called past, present and future, that would enable backward causation in which future events may affect present (and perhaps past) processes.

The particular quantum mechanisms are treated on the basis of two alternative stances. The first, takes quantum theories as a metaphor for probability-based brain processing, i.e. quantum theory inspired mathematical models are used to describe cognitive processes such as decision making. The other stance takes QM more literally: here the mind is seen as a QM-defined property of most, if not all, matter/energy or assumes extra space/time dimensions to describe and understand mental aspects of reality (see reviews of **Atmanspacher, 2011; Vannini and Di Corpo, 2008; Hu and Wu, 2010 and Tarlaci, 2010**).

Finally an attempt is made to integrate the two supercausal concepts, postulating a cyclic operating workspace housing complementary but interacting supercausal mechanisms in the form of classical neurobiological and quantum mechanical defined information flow. The scientific feasibility and testability of this model, as well as its respective implications for understanding mind/matter relations, are then discussed.

## 2. Philosophical premises in matter/mind considerations

This section summarizes and discusses some prominent philosophical stances on the mind-brain relationship as indicated in Figure 1. This choice is not exhaustive but serves to introduce preferable concepts. *Substance dualism* attributes mind and brain to belong to non-overlapping domains (of the universe).



**Fig. 2: Various Mind/ Brain theories.** Red arrows indicate presumed causative power that is either mind-down (on the left, dual aspect monism) or brain-up (theories assuming emergence, epiphenomenon, and supervenience). The mind is a non-existing entity in eliminative materialism. Gray arrows indicate the emergence of some physical or non-physical mind. Emergent identity theory assumes that some brain configuration is identical with the mind. More details are discussed in the main text.

The presumed advantage of dualism is that mind has many degrees of freedom because it is neither directly limited by physical systems, nor associated with deterministic laws. Others have proposed that the mind is a non-physical entity that either emerges from the brain or has to be considered as an epiphenomenon. Neither of the above concepts accommodates the power of the mind as an agent capable to affect the physical brain. According to *eliminative materialism* a concept such as mind cannot be described by the natural sciences, and consequently should be seen as a construction of "folk-psychology", instead (**Churchland, 1988**). All four theories fail to acknowledge the importance of mind in the evolution and the functioning and survival of organisms. One (monistic) answer to the afore mentioned brain-mind theories is a materialistic framework, that assumes that the mind (the subjective, qualitative, conscious mind) is fully identical to objective phenomena such as neurobiological behavioral or functional brain states. Jeagwon Kim (2007) is the major proponent of the supervenience theory, stating "..... that what happens in our mental life is wholly dependent on, and determined by, what happens with our bodily processes" (**Kim, 2005**). In other words: the mind must be equated to a brain state and in order to go to another state of the mind, the brain has to change its physical state. Yet, a tacit and implicit assumption of supervenience is that the emerging mind is irreducible to any or to all the underlying neurobiological components or processes. This seems to contrast systems biology theory, stating that emerging new properties arise as a consequence of the interaction of its constituting components (**Von Bertalanffy, 1950; Plessner, 1928**). In neurobiological terms, neither of the latter theories has to explain (or reduce) the mind as (to) a property of a collection of any of the constituents of the brain (e.g. proteins, genes, cells, aggregates of cells or neuronal networks). Yet, the mind can also be viewed upon as an emerging property that cannot be understood by or reduced to the properties of the underlying brain

constituents. In John Searle's terms: there exist emerging properties of the brain (depicted in **Fig.3**), that both have physical and mental aspects (**Vicari 2009; Searle 1992, 2000, 2007**).

Closely related to Searle's conceptualization is the idea of creative evolution as advanced by **Kauffman, 2012 and Vattay et al., 2012**. Both evolution of species and individual ontology have a common principle: relatively simple entities evolve to more complicated organisms. However, the Darwinian type of evolution does not solely lead to biological structures with higher complexity, but also to entirely new structures that cannot be predicted or deduced from the properties of precursor components. The properties of the constituting elements, somehow, enable an integrated and interacting network that is largely unpredictable from the properties of these precursor elements. In other words, a cell is more than a collection of molecules such as proteins, lipids and nucleic acids. Rather, it is a well-organized entity that, for instance, entertains a correct replication process and gains survival based on an adequate adaptive response to environmental challenges. From a classical ontological point of view, the higher complexity is supposed to be an emergent (bottom up) property of the lower levels, but cannot be fully predicted from these lower level properties: in this sense it is a creative, hence non-ergodic transition. This principle of emergent materialism is close to Atmanspacher's concept of contextual emergence (**Atmanspacher 2007; Atmanspacher and Rotter, 2008**). Yet, the supposed emergent processes often seem to take the form of explanations in retrospect and exhibit limited explanatory power. Alternatively, the underlying functional levels may possess an intrinsic dynamic character, being, to some extent subject to top-down causation ("enslavement" **Kelso, 1995**) or in QM terms: influenced by backward causation (**Auletta et al., 2008, Murphy, 2011**).

In short, it is proposed that the brain should be regarded as a "personal universe" formed during life, through permanent actual realizations of dynamic brain states that are the product of sensory as well as stored information that contains memorized and anticipatory elements. A central question is: what does the mind do that the brain does not?, as nicely discussed by **Burns, (2000)**.

The classical model depicts the brain as a complex network system of components, including atoms, molecules, cellular energy, protein perturbations, trans-membrane ion fluxes, synaptic transmission and electric signaling through nerve action potentials. By internal interaction of these constituting elements and also through recurrent interaction with external (environmental) information, it is supposed to produce a versatile workspace: the mind. *However, in spite of such an integrated functional network concept, in our opinion, some higher mental brain functions cannot be simply explained or predicted from the properties of these building blocks, that is, without integrating additional bridging theories.*

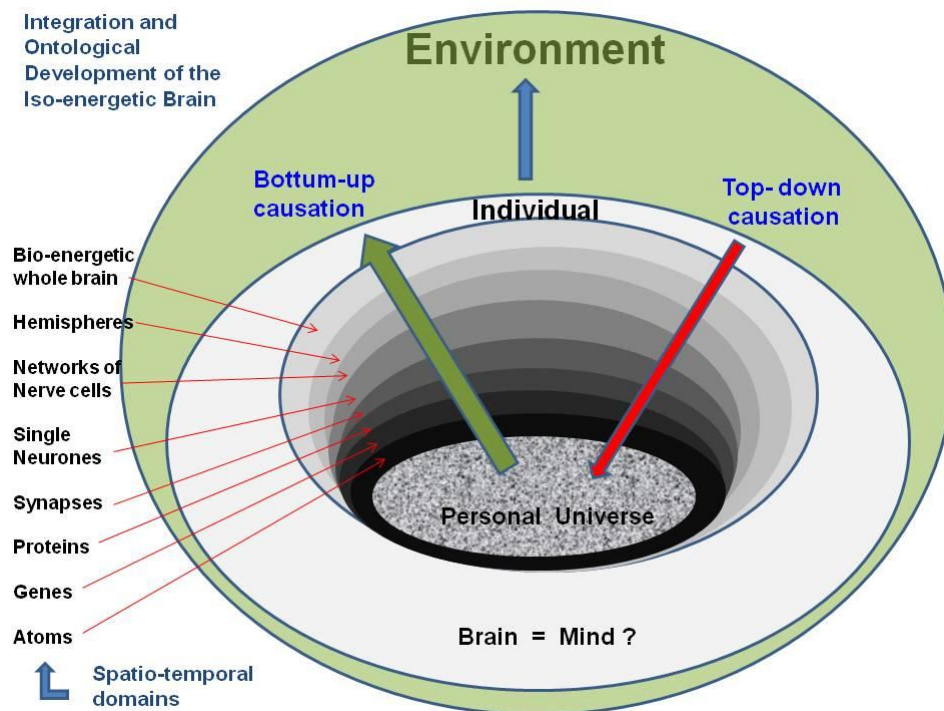
### **3. Brain metabolism and mental function.**

The human brain is an extremely complex organ that is able to adequately react to environmental challenges, by fast information processing. In our paper, this remarkable speed of information processing will be put into the context of some known psycho-physiological data that are presently available. In this respect, we take into account aspects of brain energy-metabolism and blood circulation as measured by functional MRI, in addition to some other aspects of basic neurophysiology. The human brain consumes approximately 25% of the energy of the whole body at physical rest, and approximately 70% of the brain energy supports and maintains neurotransmission processes and the generation of nerve action potentials (**Attwell and Iadecola, 2002; Mangia et al., 2009; Korf and Gramsbergen, 2007**).



Neuro-imaging, including functional MRI are generally thought to reflect brain function. It appeared however that brain functions are essentially disconnected from brain metabolism. The following examples illustrate this idea:

First: a) even subliminal stimulations of less than 50 milliseconds might inform the perceiver (in e.g. advertisements; for references see **Korf, 2010**). b) Linguistic studies illustrate the extreme speed of cognition: meaningful as opposed to nonsense words can already be distinguished within 50 milliseconds (**Turennout et al., 1998**). c) The time-lag of unconscious to conscious experience ranges from 0.3 - 0.5 sec. (**Libet, 2006**). These observations collectively show that complicated, culture-specific, information is recognized in our brain prior to reaching consciousness and also show that information processing by the brain is much faster than metabolism. Therefore a prime role for very fast changes of the protein conformation seems more likely. In neurophysiological terms: information can be retrieved from the environment and/or from memory by less than six consecutive action potentials and/or synaptic transmissions.



**Fig. 3.** Cartoon of the isoenergetic model of the brain and mind-brain relationships. The figure shows the levels of organization of the isoenergetic brain, largely based on the concepts of Searle and Kauffman (see text). The lowest levels of complexity are elementary particles (modalities of strings?), atoms and protein molecules, whereas the higher levels are formed by individual neurons, and neuronal networks. The spatio-temporal organization is created through bottom up processes. Although any of the underlying functional levels has its own dynamics, they are also subject to top-down causation (“enslavement”).

Second, the underlying assumption of fMRI is that psychological /mental tasks require an adequate supply of energy. Indeed, after a short sensory stimulation, the regional cerebral blood flow increases after a delay of 0.5 - 2.0 seconds and peaks over 4–6 seconds, before returning to baseline metabolism. This time course is far slower than the neural firing seen within 50 milliseconds, for example, after light flashes (**De Zwart et al., 2009**). Similar or even a faster electro-physiological response was reported during auditory stimuli: spotting the origin of noise with both ears is

performed subconsciously within 0.05 milliseconds. This is substantially faster than the time range of most neurotransmission events or action potentials (about 2 milliseconds). Such a fast discrimination may only be achieved by converging the particular information almost instantaneously, for instance by rapid conformational perturbations in brain proteins.

These and many other experiments support the idea that brain metabolism represents a delayed response to the neuronal activity. A “weak coupling” is also apparent at the cellular level. The generation of an action potential starts by a change of protein conformation, for example leading to in the opening of sodium and potassium channels and terminated by their closing. The signal to open the channels happens within less than 0.1 millisecond. The cycle of opening and closing of the channels lasts less than 2 milliseconds and the rest-potential is being restored after about 5 milliseconds. Opening and closing of the channels is achieved by protein conformational changes and require very little energy, whereas far more energy is required to restore the trans-membrane rest potential and the related ion gradients following activity (for more details, see **Korf, 2012**. For trans-membrane carrier mediated process that play a role in cellular transport of neurotransmitters and drug molecules, see **Meijer, 1989, 1998**).

The human brain consumes approximately 25% of the energy of the whole body at physical rest, and approximately 70% of the brain energy supports and maintains neurotransmission processes as well as the generation of nerve action potentials (**Attwell and Iadecola, 2002; Mangia et al., 2009; Korf and Gramsbergen, 2007**).

The afore-mentioned experiments, show that brain energy metabolism is primarily restorative, rather than being required for starting and performing activity. Energy consumption follows neural activity and appears to prepare the neuron for future activity. A similar reasoning applies to other metabolic process. For instance, gene transcription, protein synthesis or neurotransmitter formation and degradation do not directly cause functional brain activity. We conclude therefore, that biochemical conversions do provide the conditions enabling fast processing and storing of information, but are not directly instrumental in the neurotransmission processes per se.

Often the mental (cognitive) state is seen as a short lasting event. Fast transitions from one state to another occur with little or no connections (or interference) with preceding states (e.g. **Allefeld et al., 2009**). This time frame might indeed apply to visual images (e.g. **Atmanspacher, 2011**) or during epileptic insults (**Allefeld et al., 2009**), but does not necessarily apply to a normal uninterrupted state of consciousness (**Spivey, 2012**). Apparently, the mental state is to some extent (life)time-independent and personal: within this context, while transitions of cognition, mood and other mental features may occur.

The neurophysiological processes may therefore be better positioned in a more general time frame (**Kiebel et al., 2008**). For the timing of behavior six sequential and functionally hierarchical time scales were distinguished: 1: for sensory processing (1-200 milliseconds; the same range as sublingual recognition, memory and speaking, see section 2); 2: preparing movement trajectories (0.01 - 1.5 seconds); 3: contextual influence on action prediction (10 seconds or longer); 4: ordering “cognitive control” system (>10 seconds and much longer); 5: representation of temporally most stable environmental states; 6: the latter can be extended to longer periods, ranging from minutes to years and even to life-time.

Specific brain regions are supposed to be associated with each of the first five time frames, according to the hierarchic rostro-caudal gradient of the brain, ranging from the sensory and



associative cortex to the orbito-frontal cortex (**Kiebel et al., 2008**). Such an hierarchical time frame may also be conceptualized as the time required to create a personal brain. We emphasize here also that processes, at the highest level of the brain complexity, have a direct hierarchical influence on the lower level processes. In other words, each lower level hierarchy might be considered as a sub-time-space or part of a higher level hierarchy (**Vicari, 2009**). Consequently, the lower level configurations may eventually emerge into an individual time-space configuration or - in the concluding words of the previous section- to a personal universe.

The foregoing section illustrates the weak relationship between cerebral metabolism and electrophysiological brain functioning, and stresses the potential key role of various proteins in the initiation and execution of neuronal and mental activity. During life, our organism seems to build up a personal brain: an inner personal universe. Most mental capabilities, learned during development and life, become manifest by subconscious processing of information, in a time frame that is in the sub-millisecond range and hence extremely fast as compared to classical neuronal communication and synaptic transmission. This, as yet non-comprehensible activity, is maintained after a variety of normal non-conscious brain states (sleep etcetera) and even after brain trauma, except perhaps the most severe experiences.

In some prominent quantum brain models (**Hameroff and Penrose 1996, Penrose and Hameroff, 2011, Kaivairainen, 2005, Bernroider, 2004, Yasue and Jibu, 1995**), it is proposed that clusters of structured water can undergo gel/sol conformational shifts, supporting tubular and/or channel proteins to display vibratory features that enable coherent signal transduction (see section 5). The main issue of the present essay is to evaluate the potential of wave information to exert such relatively rapid brain reactions and also if they are somehow coupled to manifest mental processes, including time symmetric forward and backward causation.

In the next sections, the various QM theories of mind are shortly discussed. It is important to note that the neurobiological and the QM concepts are not necessarily mutually exclusive and even may function in a complementary fashion (see section 8). One could envision also that the “inner or personal universe” as proposed by us, is mirrored in the outer universe and vice versa and that, in evolution, both aspect were essential for the creation of first life, along with mutations and selection (**Davies, 2004**). Nature, in this manner, fully employed its basic physical instruments to produce beings that would be able to understand the world both by observation and introspection. The classical neurological interpretation of the brain can therefore be seen as a bottom up (atomic/molecular to neuronal networks) flow of information (see **Fig. 3**), whereas quantum approaches are based on entangled states implying a non-local and unbroken reality. In both cases a multilayered organization of brain is at stake, although direction of the flow of information can occur in top-down and bottom up directions (see **Fig. 3**). Alternatively (see **Fig. 7**), personal mind can be envisioned as a non-local expression of a cosmic (universal) mind through interfacing individual and universal consciousness (quantum information field), consequently including a top-down aspect.

#### **4. Quantum physics and psychology**

Psychological observations and recent experiments have led to non-deterministic models of brain function based on quantum mechanics and chaos theory (**Freeman, 2006, 2008; King, 2003**). Atmanspacher makes a distinction between descriptive and explanatory models in mind/matter considerations, in which the term correlation is a relevant descriptive term, while causation is seen as an explanatory term related to theoretically understanding correlations between cause and effect. With regard to quantum models a distinction is made between QM models in which intentional conscious acts are correlated with physical state reductions including QM field models in which mental states are treated as vacuum states of quantum fields as opposed to QM metaphoric models.

With regard to the latter, Niels Bohr has already suggested that mutually excluding images (see below) have aided the formulation of the complementary hypothesis of quantum mechanics (**Busemeyer and Bruza 2012**). Many authors (references in **Atmanspacher, 2007, 2004; Busemeyer and Bruza 2012**), have recognized the potential of using a quantum probability approach in the psychology of cognition and decision making rather than more classical approaches. Quantum mechanics and its formalisms should be viewed upon here as a metaphors, **Atmanspacher et al. (2004)**, in that “particular features of the quantum theoretical formalism are realized in a non-physical context”. In this section we present examples of this stance.

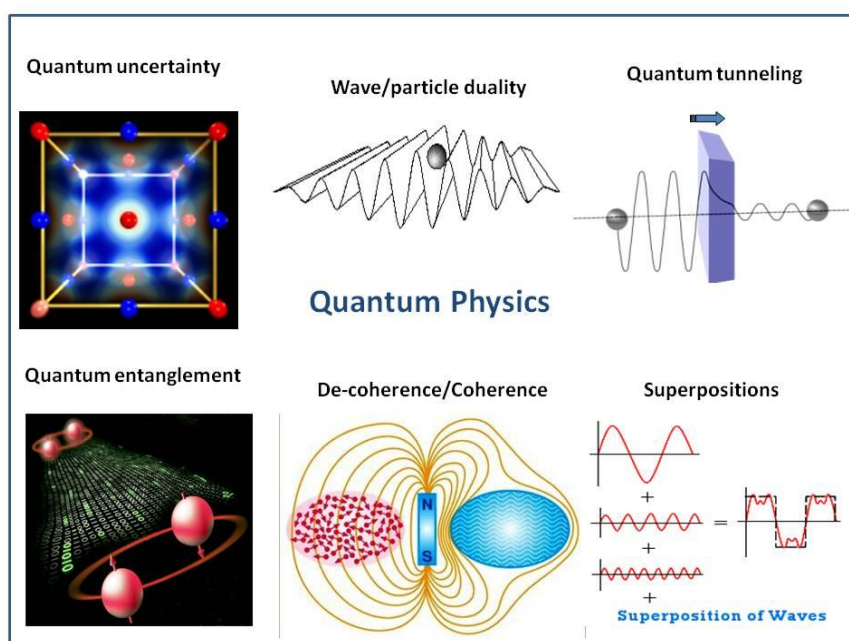
Recent research has been focused on modeling of decision making (**Busemeyer and Bruza, 2012; Pothos and Busemeyer, 2011**). In experimental settings subjects were asked to make easy choices with game cards between a few alternatives. These alternatives were best described with stochastic models, rather than as deterministic processes. Other research did focus on the idea of geometric sub-spaces, where the probability of choices became order- and context- dependent. This means that decisions are made not only by taking into account the grounds as independently contributing factors, but also by their order of exposure to the subject. Again, this has been related to the “real” quantum theory, where a wave function (in a superposition and without a distinct spatial location) becomes a well-localized particle after interference with a physical body, including an observer.

The authors of the latter studies emphasized the quantum nature of their models, because they use terms such as superposition, entanglement and collapse as they are used in quantum physics to denote an undetermined state (a wave function), that after collapse behaves as a particle. Entanglement is used in QM to denote that, for instance, spin properties of a particle (entities) are correlated with a related particle, in the sense that. the orientation of the spin of one particle becomes determined after the collapse through observation of the related particle. Related to these QM ideas are rapidly alternating brain and mind states as, for example, illustrated with classical ambiguity pictures, picturing the brain in a state of superposition (**Atmanspacher et al., 2004**).

A quantum approach was also used to model bi-stable perceptions: figures such as the Necker cube, can be interpreted as either of the particular spatial configurations. The switch between these interpretations are assumed to be short as compared to observation time (“Zeno effect”, see **Schwartz et al., 2004; Stapp, 2009, 2012**), and, moreover, the two interpretations are mutually exclusive: the interwoven objects cannot simultaneously be conceptualized. During a short period of time only one configuration is recognized and alternating views are more or less subject to the will of the observer. Despite such persuading theorizing, **Busemeyer and Bruza (2012)** lay to heart the lesson that in the psychological experiment a superposition is merely a word that can be interpreted as representing a number of different senses, while an entangled cognitive state is highly

biased towards one subset of interpretive senses. Finally, collapse is merely the process “by which a subject decides upon a particular interpretation in the context of a set of cues and stimuli.” The question remains how and when such subconscious thoughts or arguments become manifest prior to the very moment that the subject definitely chooses or decides.

The related time course of the cerebral electrophysiological activity was described during the initiation and execution of voluntarily behavior (e.g. movement of the fingers) by the classical experiments of Libet and later by others. This approach (**Libet 2006; Haggard 2005; Haggard and Eimer, 1999; Soon et al., 2008; Bode et al., 2011**) might be regarded as a decision making experiment and the readiness potential can be seen as to reflect the superposition state of the brain. Following regional brain activity using fMRI technology (see **Bode et al., 2011**) showed that the preparation phase in the anterior frontopolar cortex might precede the decision as much as 6 seconds.



**Fig 4:** Central elements of Quantum Physics theory, such as uncertainty, wave/particle duality, entanglement, coherence/de-coherence, quantum tunneling and superposition of wave functions.

Once in the superposition state, decisions in a laboratory context are made in a very short period of time (already within 50 milliseconds; as in the **Turennout, 1998** study) as compared to the preparation time.

**Spivey and coworkers, 2007**, have emphasized the continuity of mind, rather than sequential states, as opposed to the quantum approach. They illustrate their ideas with decision-making experiments, showing that the subjects in an, apparently indecisive, state, stay longer indecisive when the decisions are more ambivalent, once the choice as been made, the decision is realized faster (**Pezzulo et al., 2011; Spivey 2007; 2012**). These studies show that decisions are anticipated far before the overt behavior (**Bode et al., 2011**). These laboratory experiments are compatible with the idea that the central nervous system (the subject) develops a kind of superposition state before making the choice (the “collapse”). For the subject, the significance of artificial problem solving, is evidently modest and requires little “mind-space.” More important decisions might require a “larger space of the personal universe”, and more processing time.

**Trueblood and Busemeyer (2012)** summarize four reasons for considering a quantum approach to human judgments: (1) human judgment is not a simple readout from pre-existing or recorded state, it is rather the process of imposing measurements that forces the resolution of the indeterminacy; (2) before measurement cognition behaves more like a wave than a particle allowing the individual to feel a sense of ambiguity about different belief states simultaneously, as if beliefs remain in a superimposed state until a final decision must be reached; (3) changes in the context produced by one judgment can affect later judgments: quantum probability theory captures this phenomenon through the notion of incompatibility about another; (4) cognitive logic does not necessarily obey the rules of classic logic such as the commutative and distributive axioms. Quantum logic is more generalized than classic logic and can model human judgments that do not obey Boolean logic.

How does the above described quantum concepts relate to time perception and to the idea of mind? An organism develops and ages both by genetic programming and by external influences. As discussed, the brain becomes moulded by personal experiences. Because of the continuous accumulation of information there is perception of a past to future time-arrow in the mental domain (**Primas, 2003**). On the other hand one does not “consult” more recent memories before reaching memories of a more distant past. Indeed, the major principle of memorizing is a-temporal association, not unlike searching information with a few key-words in a computer network. Hence our mind might “perceive” backward causation, i.e. the effect of expected situations on current activity. Classically, time perception might be divided into two apparently different aspects referring to an external process (e.g. clock) or to internal processes (experience, memories). **Primas (2003)** distinguishes tenseless (causal) and tensed time, respectively.

Memories do often not precisely refer to the original events, they become more and more vague, perhaps modified by overwriting and associated with apparently unrelated impressions or memories during aging. Memories are rather unstable and are often more than once recreated during life. Hence memory might be described or perceived by the external observer as well as by the introspective subject as stochastic and probabilities, rather than being stored and retrieved in temporal order. Regarding the two concepts of time as implied by a symmetry breaking of a timeless level of reality that is psycho-physiologically neutral, Primas conceives the tensed time of the mental domain as quantum-correlated with the parameter time of physics via “time-entanglement” (**Primas 2003; Atmanspacher, 2011**). Such a dual time concept may imply that the distinction between mental and material originates from the particular, above-mentioned modes of time, yet could be caused by the same psychophysically level.

This may also represent a parallel with conscious and unconscious brain function with collective components of a universal consciousness seen as remnants of lost holism at this level (**Atmanspacher, 2011; Zizzi, 2006**), interestingly places human consciousness in the perspective of a cosmic quantum computing universe in which among many possible universes finally a single one is selected from a superposed state of quantum registers by gravity-induced self-reduction. This is similar to the objective reduction put forward by **Penrose and Hameroff, 2011** and highlights the role of human observers in dictating future modes of computation, including both classical and quantum approaches and mathematical intuition. The latter aspect was worked out by Tegmark in an intriguing theory of everything: the Mathematical Universe (**Tegmark, 2008**).

Although the psycho-physiological time refers to an apparently time-neutral intra-subjective processes and memory, it does, however, not exclude the common temporal order of neural processes. According to the classical neurophysiology, nerves have an exclusive direction of

information distribution: from the dendrites via the soma along the axons and via the nerve endings neurotransmission to postsynaptic cells. In the central nervous systems many, if not all, long distance projecting neurons have accompanying neurons projecting in the opposite direction. Nevertheless, considering the time frames of neurons, there is definitively a direction of time that interferes with the idea of randomness and isoenergeticity. One solution could be that the mind or the mental processes are primarily confined to nervous structures without a clear cut temporal orientation, i.e. networks of local circuits of inter-neurons and glia of the cerebral cortex.

This section illustrates possible applications of QM theories on perceptual and psychological processing, i.e. potentially providing models for these processes. Of note, the psychological QM theories do not make assumptions or proposals on the very nature of “mind”. Considering Searle’s emergent materialistic idea that brain configurations exist that equate mental processes, we tentatively conclude that at least some brain processes behave quantum-like. For example, a superposition state, preceding behavior, appears to be concomitant with electrophysiological signals, in line with the philosophical QM analysis pictured by us above.

### ***5. QM approaches in neurobiology: the state of art***

Whereas the previous section considers quantum theories as a tool (or metaphor) to describe or understand mental and cognitive processing, this and the following section discusses the idea that the physical quantum concepts do physically apply to the mind: the mental domain is considered as an aspect of wave information. A special position takes the feature of *superposition*: quantum particles can be present in multiple spatial locations or states and be described by one or more pure state wave functions simultaneously of which a single state can finally be selected. **Penrose, (1989)** suggested that the underlying space /time geometry in fact bifurcates during the superposition process and wave collapse occurs in a non-computable manner. Because of the property of *quantum coherence*, individual wave/particle lose their separate identity and form a unity that can be described by a single wave function. These concepts are considered the “hard quantum theories”, as opposed to the “soft” or formal theories of the previous section. QM adherents refer often to Wolfgang Pauli (**Pauli, 1994**), the eminent quantum scientist who suggested that the mental and the material domain are governed by common ordering principles, and should be understood as “complementary aspects of the same reality” (see **Atmanspacher and Primas, 1977; Primas 2003**). The “hard” mental QM theories apply either to specific brain structures/molecules (this section) or to quantum fields and dimensions (section 6) or both.

**Vannini and Di Corpo (2008), Hu and Wu (2010), and Tarlaci (2010)** listed and attempted to categorize the various published quantum brain models, without a detailed treatment of the individual models. Vannini and Di Corpo distinguish models based on consciousness creating reality, models based on probability aspects of QM and models based on already established QM order principles. Hu and Wu differentiate in models based on QM elements of entanglement and coherence and models on the relation of QM with consciousness that can include materialistic modes (consciousness emerges from material brain), dualistic mind/matter models and panpsychistic modes. The first two papers emphasize the potential testability of the various models. More detailed reviews can be found in **Pereira (2003)** and **Tuszynsky and Woolf (2010)**, the latter as an introductory chapter of the instructive book: “Emerging Physics of Consciousness”, while an excellent and critical overview of the field is provided by **Atmanspacher (2011)**.

A number of, more or less specific, scientific journals are currently, or were, devoted to this subject: NeuroQuantology: Quantum Biosystems, Mind and Matter, and AntiMatters. An the important website is Quantum Mind see: <http://www.quantum-mind.co.uk/>. Stanford Encyclopedia of Philosophy (see quantum mechanics and quantum theory) *also* provides an excellent reference.

Additional publications on the topic can be found in: J Consciousness Exploration& Research, J New Dualism, Dualism Review, Journal of Cosmology, J Scientific Exploration, Biosystems, Journal of Consciousness Studies, Cognitive Neurodynamics, Science and Consciousness Review, Journal of Mathematical Psychology, Chaos, Solitons and Fractals, Open Systems and Information Dynamics, International Journal of Quantum Chemistry, The Noetic Journal, Neuroscience and Biobehavioral Reviews, Experimental Neurology, J. of Mind and Behavior Physics of Life Reviews, Syntropy Journal, Biological Cybernetics and Kybernetik.

Before we delve into the physical aspects of the quantum brain, a number of common misunderstandings on QM modeling should be dealt with:

- There is no *single* theory on quantum mechanical aspects of brain function. In fact a spectrum of more or less independent models have been proposed, that all have their intrinsic potential and problems (see **table 1**, for references see the above mentioned reviews and **Meijer, 2012**).
- In spite of the introduction, already in the first part of the 20<sup>th</sup> century and the spectacular successes of the theory ever since, some still see quantum physics as a sort of esoteric part of science. However it rather represents a revolutionary refinement of classical physics, for example taking into account that the theory was required in order to build an adequate atomic model and more recently to explain experimentally demonstrated teleportation of particles (see **Zeilinger, 2000**) as well as principles of downward causation (**Wheeler, 2002**) and time symmetry (see **Aharonov, 2010**). It is also the basis for laser, semi- and super- conductance, and microchip technology as well as MRI brain scanning (**Marcer and Schempp, 1997**). It should also be kept in mind that classical physics can be fully derived from quantum physics, not the other way around.
- Quantum physics is, by some rejected, since so many interpretations of the theory are at stake (Copenhagen, Many worlds, Implicate order, Interactional theory, Micro- macro- scale definition, Environmental de-coherence, Relational quantum mechanics etc.). Yet a number of common elements such as the true particle/wave aspect, instead of only a probability function, (**Pusey et al., 2012**), superposition, entanglement/non-locality and coherence/de-coherence phenomena are experimentally established and remain very usable in practice, although the related semantics should be carefully defined.
- It is often stated that quantum wave information coherence cannot be maintained long enough in the brain due to interaction with the macro-environment of the brain components. Yet, on this point major differences in decoherence-time calculations exist, as based on various models and their intrinsic assumptions (see **Hagan et al., 2002 and Tegmark, 2000, Lloyd, 2011**). A central point here is that sub-compartments could be present at the molecular or sub-molecular level, that by their special arrangements are quantum noise protected or coherence stabilized. Examples are internal parts of channel proteins (**Bernroider, 2004**), and stabilization by clustered (gel/sol) arrangements of cytoplasmic water clusters (see **Hameroff and Penrose, 1996, Penrose and Hameroff, 2011**). The latter authors proposed a hierarchic model encompassing nerve cell depolarization, gel/sol transitions of resulting in disconnection of microtubuli, shape/volume pulsation of dendrites including reorganization of synaptic contacts and finally sol/gel transition stabilizing a new state. Through coherence and macroscopic entanglement, life time of wave information can be much longer than in the classical phase, as a



consequence of coherence/decoherence dynamic equilibria, allowing nonlocal remote interaction in large numbers of entangled neurons. Such ge/sol oscillations could even be a primary to excitation/depolarization triggered by normal sensory stimuli and are supposed to interact with zero-point vacuum dipole vibrations (the bi-vacuum matrix model of **Kaivairanen, 2006**).

- It should be realized that decoherence, does not, per definition imply *destruction* of information since, firstly, it is not compatible with the quantum principles of non-cloning and non-deletion, secondly a cyclic process of decoherence and re-coherence processes cannot be excluded (see **Hartmann, et al 2006; Li and Paraoano (2009); Atmanspacher, 2011**) while thirdly, even if such decoherence does occur, it may result in mixture of possibilities that may be accommodated by the collection of perceivable worlds in the brain (**Stapp, 2012**). Decoherence may even be preferred above wave function collapse as a means of processing information (**Rosa and Faber, 2004**).
- It has been proposed by **Vattay and Kauffman, 2012**, that a decoherent state can be converted back to a coherent state by the input of adequate phase and amplitude information. The resulting coherent states can last long enough in warm biological systems in order to, for example, enable coherent search processes for antenna-mediated transport of photon energy in photosynthesis. The author postulates that similar “poised realm” or micro-domains, on the edge of chaos, could also be instrumental in the human brain as sites where a dynamic interplay of decoherence and re-coherence takes place (see also the model proposed in section 8).
- It is often assumed that QM is only valid for a description of nature on the micro-scale (elementary particles etc.). Yet convincing evidence was more recently presented that quantum physics can be applied to macromolecules (**Zeilinger, 2000**), and to the surprise of many, even can occur in warm and wet biological systems (photosynthesis: **Engel et al., 2010**) and brains of birds in relation to magnetic sensing and navigation (for references see **Arndt et al., 2009, Lloyd, 2011**). Lloyd concluded: *Quantum coherence plays a strong role in photosynthetic energy transport, and may also play a role in the avian compass and sense of smell. In retrospect, it should come as no surprise that quantum coherence enters into biology. Biological processes are based on chemistry, and chemistry is based on quantum mechanics. If an organism can attain an advantage in reproduction, however slight, by putting quantum coherence to use, then over time natural selection has a chance to engineer the necessary biochemical mechanisms to exploit that coherence. Different types of quantum processes that operate at the same time scale can interact strongly either to assist or to impede one another. In photosynthetic energy transfer, the convergence of quantum time scales gives rise to more efficient and robust transport. Evolved biological systems exhibit the quantum Goldilocks effect: natural selection pushes together time scales to allow quantum processes to help each other out.*
- A spectrum of atoms/molecules has been suggested to operate in a quantum manner: Ca<sup>2+</sup>- and K<sup>+</sup>- ions, H<sub>2</sub>O, enzymes, membrane receptor and channel proteins, membrane lipids, neurotransmitter molecules, in addition to macromolecular structures such as DNA/RNA, gap junctions, pre-synaptic vesicles, microtubules and micro-filaments (**Tuszinsky and Woolf, 2010**)
- Since our integral universe can be described by the current laws of QM and relativity, it does not seem warranted to place the human brain outside nature: some see even cosmic architecture mirrored in our complex brain (**Kak, 2009; Amoroso, 2003**)
- The discussion around higher brain functions is frequently obscured by modalities of promissory materialism: “at present we do not understand consciousness but within 20 years the problem will be resolved !” Not only is such an extrapolation scientifically unwarranted but certainly cannot be falsified. Even more damaging is the assumption that one will find the

solution by further using current technology, instead of postulating new (for example quantum) models and innovative experimental approaches.

- Some QM models are based on the interaction of brain components with experimentally detected quantum fields (**Yasue and Jibu 1995, Vitiello, 1995, Pessa and Vitiello, 2003**). The central aspects of realistic quantum field theory hold that the essence of material reality is a set of fields. These fields obey the principles of special relatively and quantum theory and the intensity of a field at a point gives the probability for finding its associated quanta as the fundamental particles that are observed by experimentalists. These fields may holographically project into each other, implying interactions/interpenetrations of their associated quantum waves. Vitiello proposes a virtual shadow brain working in a time-reversed mode that stabilizes coherence and neural memory structures (see also section 5).
- It could be worthwhile to project neo-darwinism and its biological evolution theories against the canvas of potential QM mechanisms, in the sense that parallel quantum superpositions and backward causation mechanisms can provide explanations and/or alternatives for evolution jumps and so-called emergent phenomena (see **Davies, 2004; Murphy, 2011; Auletta et al., 2008 Davies and Gregersen, 2010; Ellis, 2005; Vattay et al 2012**). Recently, models were proposed for the transfer of information in biological evolution on the basis of quantum formalisms (**Bianconi and Rahmede, 2012, Djordjevic, 2012**).
- On the basis of QM concepts one should be prepared to envision uncommon and even utterly strange manifestations of quantum entanglement: certain transpersonal human experiences (**Kak, 2009; Radin and Nelson 2006; Di Biase, 2009 a, b, Jahn and Dunne, 2007**) should *not* be seen as potentially be *explained* by QM, but rather *required* (**Radin and Nelson, 2006**) by the concept that our world is part of a quantum universe (**Vedral, 2010; Lloyd, 2006; Barrow and Tipler, 1986**).

## 6. QM and higher brain functions

Here we explore the “hard” QM theories as possible theories bridging the classical neuronal and mental concepts. QM theories does indeed apply to the same brain physiological phenomena, but introduce also typical features such as particle/wave duality, entanglement and non-locality, as well as wave interference and superposition. In addition processes such as quantum coherence and resonance of wave interactions are at stake (see **Fig. 4**).

**Fig. 5** illustrates some of these “hard” quantum brain concepts. It is not our purpose to assess the various QM theories in detail, rather we intend to discuss some of their major implications regarding the concept of a “quantum brain”. The key position of proteins in the quantum-mediated initiation and execution of mental activities was already emphasized. Several QM theories are based on specific properties of proteins, as for instance micro-tubular proteins, (**Penrose, 1989; Hameroff, 2007**), proteins involved in facilitating synaptic transmission (e.g. **Beck and Eccles 1992; Beck 2001**), including Ca<sup>2+</sup> channels, see **Stapp, 2009**), as well as specific channel proteins, instrumental in the initiation and propagation of action potentials (K<sup>+</sup> channels, **Bernroider and Roy, 2004**, see **Fig. 5**).

QM theories also extends the mind to different spaces and time dimensions and some consider the individual mind (partly) as an expression of a universal mind through holonomic communication with quantum fields. In the latter approach, the human brain is conceived as an interfacing organ that not only produces mind and consciousness but also receives information necessary for full deployment of these mental phenomena (see next session). The central question here is whether

neuronal cells are the sole units for information processing in the brain rather than sub-cellular organelles or molecules (Schwarz et al., 2004).

<i>Author</i>	<i>Year</i>	<i>Author</i>	<i>Year</i>
Amaroso	2009	Lockwood	1989
Baaquie and Martine	2005	Marshall	1989
Beck and Eccles	2000	Mender	2007
Bernroider	2000	Penrose and Hameroff	2010
Bohm	1980	Pereira	2003
Bondi	1998	Pitkänen	1990
Culbertson	1963	Pribram	1971
Di Biase	2009	Romijn	2000
Flanagan	2003	Santinover	2002
Fröhlich	1968	Sarfatti	2011
Goswami	1993	Stapp	1993
Hari	2008	Talbot	1991
Herbert	1987	Umezawa and Ricciardi	1967
Hu and Wu	2005	Vannini and Di Corpo	2009
Järvilehto	2004	Vitiello	1995
Josephson	1991	Walker	1970
Kaivarainen	2006	Wolf	1995
King	1989	Yasue	1995

Table 1: Quantum Brain Models proposed from 1960 and further (see for references Meijer, 2012; Vannini and Di Corpo, 2008; Hu and Wu, 2010, and Tarlaci, 2010).

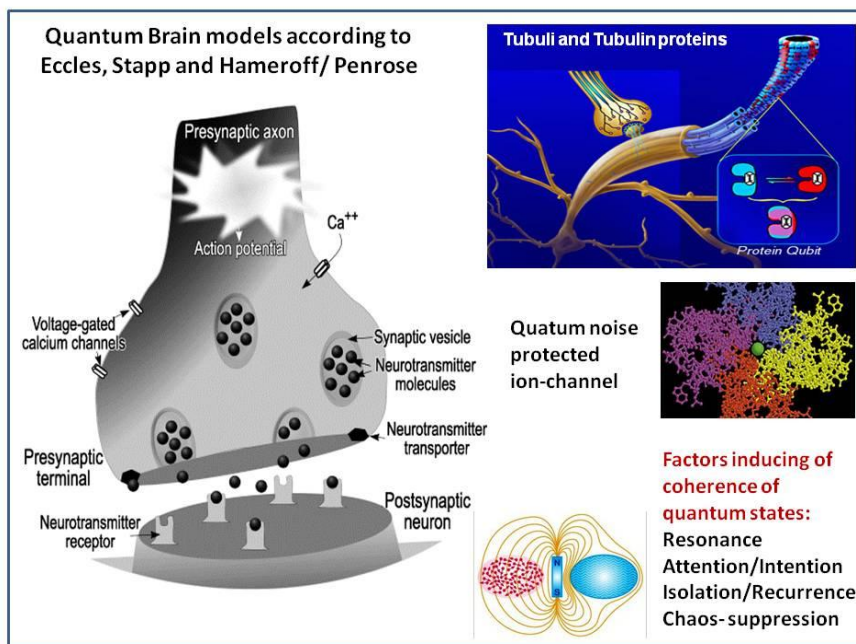


Fig 5. Some aspects of quantum brain models: Synaptic transmission by vesicular exocytosis of neurotransmitter molecules, Ca<sup>2+</sup>-influx via Ca<sup>2+</sup>-channel protein in the neuronal membrane facilitates fusion of synaptic vesicles in the presynaptic terminal. The fusion of sufficient vesicles leads to transmitter

*release and depolarization of the postsynaptic membrane, this fusion process bears a quantum probability character.*

As mentioned in section 5, a major debate about these theories concerns the possibility of coherent quantum states in the “warm” and wet internal milieu of the brain. (see e.g. **Atmanspacher, 2011**). The defenders of the quantum brain models have argued that *in vivo* molecular configurations exist that enable the modulation of quantum states through efficient protection and shielding of the wave interaction compartments in the cells (**Hagan et al., 2002**).

The particular local collapse of the wave function, in this manner, produces new information. As originally proposed by Eccles, this is realized by membrane protein induced fluxes of Ca<sup>2+</sup> or K<sup>+</sup> ions, that than increase the probability of fusion of neurotransmitter-filled vesicles in the synapses, leading to the firing of the particular neuron or even groups of neurons. The central hypothesis here is that synaptic transmission represents a typical (quantum) probability state in which the total number of vesicles available for exocytosis is critical for an all or none response of neuronal firing (**Beck and Eccles, 1992; Beck, 2001**). Coherent neuronal perturbations and especially their entangled state are supposed to provide non-local “binding” of sensory and cognitive brain centers, and may also enable perception of qualia and the unitary sense of “conscious self” (**Hameroff, 2007**). As the "mesoscopic" scale of brain activity where the "binding" process is expected to occur is in the vicinity of the quantum domain, the binding principle is likely to be a quantum non-local effect, probably the only known physical mechanism able of performing such a task. One possibility is the formation of a quantum photonic field (**Flanagan, 2006**); another possibility is the formation of coherent states on the level of trans-membrane ion fluxes such as that of Ca<sup>2+</sup> as suggested by **Pereira, 2003, 2007**, see section 8, **Fig. 8**).

**Hameroff and Penrose (2011)** argue against mechanisms of all or none- firing of axonal potentials as suggested by Beck and Eccles, since such binary states do not include non-linear and not computable characteristics of consciousness. They rather prefer the model of **Davies, 2010** (see the chapter in the book edited by **Tuszynski and Woolf, 2010**), proposing that consciousness is related to traveling waves in the brain as a uniting life principle on multiple scales. The latter is based on energy dissipation, enzyme catalysis, protein folding that maintains energy balance in an excitable system such as the brain, conditions that are also compatible with the present isoenergetic model. Non-linearity in brain processes is modeled using the well-known Schrödinger equation, adjusted with a non-linear term, as proposed earlier by Walker (see **Behera, 2010** in the same book), by which robustness of a classical approach is combined with the more flexible elements of quantum theory.

The originators of this hypothesis (**Penrose, 1989; Hameroff, 2007**) have discussed that microtubule, in principle, can maintain quantum states (i.e. superposition) lasting at least 10<sup>-6</sup> seconds, long enough to be instrumental in the transfer of quantum wave information. Such lasting quantum states are possible because of the shielding of hydrophobic pockets in the particular proteins, as well as the formation of coherent clusters of these molecules that thereby share a common quantum wave function (so called Bose-Einstein Condensates). There is indirect evidence that microtubules may be relevant for neurocognition: increased synthesis in relation to postnatal development with regard to synaptogenesis and visual learning and as counterpart aging deficits in memory as well as interactions with general anesthetics (**Penrose and Hameroff, 2011; Tuszynski and Woolf, 2010; Kalvairainen, 2005**). Yet such correlative studies should not only be further substantiated with experiments that show quantum states in isolated tubules, as reported by

(**Bandyopadhyay, 2011**), but rather and most importantly, directly demonstrate tubular involvement in higher brain functions in situ.

In conclusion: tubular and synaptic channel proteins exhibit conformational transitions within  $10^{-9}$  seconds that may last for  $10^{-6}$  seconds or even longer, (**Beck and Eccles 1992; Beck 2001; Bernroider and Roy, 2004, Kaivairainen, 2005**). These perturbations may last long enough to be finally detected as miniature neuronal potentials (**Hamill et al., 1981, Hagan et al., 2002**). The particular mechanisms also imply a manifestation of non-local quantum effects due to distant coherence, a phenomenon that was even recorded in laser stimulated neuronal cell cultures in which classical physical explanations were excluded (**Pizzi et al., 2004**).

The coherence of such quantum states among brain proteins has been suggested to lead to *material* changes in brain physiology through orchestrated collapse of quantum coherent clusters of tubulin proteins, triggered by quantum gravity expressed at the spin (Planck scale) level. On the basis of a recent theory on the nature of gravity (**Verlinde, 2011**), postulating that gravity is not a force but rather an entropic compensation for the movement of mass/information, the first author (DKFM) speculated that gravity may represent an reaction on the entropic displacement of information as it occurs in high density in the human brain (**Meijer, 2012**).

Anyhow, there should be a mechanism to integrate signal processing within a single neuron with other, even distant, neurons and consequently non-local effects due to quantum entanglement should play a role also in this case. These quantum processes may explain phenomena such as qualia, meaning, sensation of unity, intentionality as well as conflict solving, reliability in the sense of correspondence with the outer world and the sense of self. The latter is related to the feeling of causal power that could result from a quantum/classical interface in which classical synaptic processes create a quantum coherent state that enables quantum computation that exert a back-influence on the original synaptic process (**Pereira, 2003, 2007**). The existence of nonlocality in brain function, being a basic property of the universe strongly argues for an underlying deep reality out of space/time as originally proposed by **Bohm (1990)** in the form of an implicate order. Bohm claimed that these mechanisms also play a role in different forms of transpersonal and extrasensory perception by wave resonance with an universal quantum field (**Kak, 2009, Jahn and Dunne, 2007, Kafatos and Draganescu, 2000, Kafatos 2009**, see section 6).

The main issue of the present essay is that wave information provides a potential coupling to mental processes. For instance, wave information could be transmitted from and into the brain by wave resonance and may locally collapse to matter entities through conscious observation, including sufficient individual attention and intention (**Stapp, 2009**). **Stapp (2012)** argued recently that this does not represent an interference effect between superposed states, as assumed by **Hameroff and Penrose (1996)**, but that through environmental de-coherence, superpositions will be converted to multiple mixtures of information. Since our brain contains a large collection of perceivable worlds, it is able by supercausal free choice and subsequent common random choice to make a fit with one or more of the abovementioned mixed information modalities. The particular waves than spread out and rapid sequence repetitions (the so called Zeno effect) may sufficiently maintain coherence in parts of the brain. Of note, Stapp does not see free will as based on quantum probability aspects. He states: *“In the original Copenhagen formulation this extra process is initiated by what is called “A free choice on the part of the experimenter.” The phrase “free choice” emphasizes the fact that, while a definite particular choice is needed, this choice is not determined by any known law or rule: The purely physical aspects of the theory have, therefore a significant causal gap, which opens the door to a possible causal input from the mentally side of reality”*.

Quantum information may exert physical effects via a bottom-up flow of information starting at spin networks (**Penrose, 1989; Hu and Wu, 2010**), that can be passed on as wave forms of elementary particles/atoms, to be ultimately expressed at the level of neuronal molecules (see section 8). We consider the latter flow of information more feasible than being directly transferred through vibratory interference at the molecular level. According to this integral quantum model, perturbations at the various spatiotemporal domains allow both time- symmetric forward and backward causation and therefore top-down influence of quantum fields (see section 7).

The basic question is: how are quantum waves or quantum fields finally perceived by the human brain and how they influence or even induce phenomena as (self)consciousness? Organisms do indeed visually perceive photons that exhibit wave/particle duality; humans even sense less than ten photons, whereas insects may even detect a single photon (**Baylor et al., 1979; Menini et al., 1995**). Sensitive detection is possible with dedicated cellular structures as for instance in the mammalian retina that amplify the energy of a single photon by a cascade of processes, based on changes of protein conformations and cellular potential energy, leading to the electrochemical stimulation of neurons projecting to the brain. Recently, photosensitive proteins have been coupled to ion-channel proteins with biotechnical techniques, so that the neural activity can be modified or inhibited *in vivo* by light introduced via optic microfibers (**Lima and Miesenböck, 2005; Boyden et al., 2005; Tsai et al., 2009**). These experimental approaches demonstrate that quantum effects may directly affect neural function, but it remains to be shown more definitely, that this also does occur directly inside the *human* brain as it was demonstrated in the brain of *birds* (see the discussion by **Arndt et al., 2009, Lloyd, 2011**).

Another issue is whether, more or less, random quantum events can be orchestrated in such way that the information becomes meaningful for the brain. Thus the major challenge is to *directly* demonstrate that proteins such as in microtubules, K<sup>+</sup>-channels or synaptic vesicles and associated proteins become informative to the organism. It has been put forward that a combination of quantum mechanisms and non-linear (chaos) theory have to be considered in the amplification of subtle external information necessary for immediate action (**King, 2003**). Future information (feeling of future events) may be realized by time-reversed sensing of such an event on the basis of an attractor state. According to the “supercausal” model of consciousness of Chris King, the constant interaction between information coming from the past and information coming from the future leads to that quantum entities that are always confronted with bifurcations between past and future causes. This involves fractal structures and chaotic dynamics that enable free choices to be performed. Consequently consciousness should be a property of all living structures in which each biological process is forced to choose between information coming from the past and information coming from the future (**King, 2003**). Such models (including that of **Vannini and Di Corpo, 2008**) attribute consciousness to principles of relativity, quantum physics, and fractal geometry and on the basis of established physical applications of these theory’s, would, in principle, allow experimental testing to falsify them. It is of interest that top-down recurrent connections in higher order in the associative cortex was shown to be indispensable conscious perception (**Boly et al., 2011**).

In more general terms: processing and amplification of quanta/wave information in the brain may underlie the presumed higher brain or mental functions. If one assumes that such detection mechanisms does indeed operate in the brain, than the next question is whether the information to be processed is *exclusively* associated with quantum waves or quantum states or, alternatively, with the specific proteins that carry them. This is more than a semantic question: it implies to us that a



theory stating that *all* information relevant for us, human beings, is carried by quanta or wave information, may ignore a realistically biological implementation. The authors prefer a functional combination on the basis of complementary classical and quantum mechanisms, that nature offers. Before further discussing the related ideas of possible forward- and backward- causation, superposition and entanglement in the mental space, we shortly treat the idea that that individual mind is, at least partly, an expression of universal consciousness as opposed to the concept the mind is merely an attribute of matter.

### **7. Space/time dimensions and universal consciousness**

In this section we consider QM options that assume some sort of multidimensionality. One line of thinking involves to the idea that there are more dimensions than the four classical space-time dimensions. The other assumes extra dimensions that enable a mental component of matter.

The central item here is that brain function may be altered by immersion in external quantum fields that penetrate our organism including the nervous tissue and thus personal world. In quantum field theory, the fabric of space is visualized as consisting of fields, with the field at every point in space and time being a quantum harmonic oscillator, interacting with neighboring oscillators. Further, and also critically importantly, the wave solutions are present in pairs. This means that whenever the phase arrangements of intersecting plane waves produce an electron, they will also necessarily produce the opposite-phase positron next to it (they will also have opposite spin states). This explains matter-antimatter pair production which is occurring everywhere in space all the time. Consequently, space vibrates in two distinct patterns (particles and quantum fields) which it is constantly switching between the two modalities, while matter and antimatter, in particle or wave form travel in opposite time directions (see **Vannini and Di Corpo, 2010**). For example, wave information from the so called “zero point energy field, ZPE” (**Rueda and Haisch, 2005**) may produce changes in the structuring of water molecule assemblies within neurons, a quantum phenomenon that is much less influenced by local decoherence, and can even be combined with the abovementioned role of tubular protein events (**Kaivairanen, 2005; Amoroso, 1999**)

On the basis of earlier work of Umezawa (**Ricciardi and Umezawa, 1967**) and Yasue and Jibu (**1995**), memory states were projected as parts of vacuum states of quantum fields, among others by Vitiello and coworkers (**Vitiello, 1995; Pessa and Vitiello, 2003**) in which the brain continuously interacts with its environment (called dissipation), causing a doubling of the collective brain modes in the environment (our double revealed!). According to this model, this yields the possibility of external memory storage without the internal need of memory overprinting. The dissipation process was supposed to generate the unidirectional time perception but implies entanglement with the coded vacuum states. In later interpretations aspects of chaos and quantum noise as well as more classical elements such as electric and magnetic fields were included in a search for a transitional and dynamic brain model housing both classic neurobiological and quantum/chaos aspects (**Freeman and Vitiello, 2006, 2008**).

A further refinement of mental dimensions are the various holographic (or holonomic) theories that have been proposed (**Pribram and Carlton, 1986; Pribram and Gill, 1969**). A hologram, in fact, is the condensation of a 3 dimensional image into a 2 dimensional frame: the original 3-dimensional image (object) can be reconstructed (or viewed) with appropriate source of light. A reconstruction is already possible with only a part of the translucent plate, since every part of the picture contains information of the whole. Yet, the smaller that part is, the less accurate the image becomes,

exhibiting a lower resolution. The brain or parts of the brain might then be understood as an interference hologram of incoming data and already existing data. If the particular information is properly exposed (“analyzed”), a rather complete information about the outer world is obtained: the brain might then be considered as an analytic device. Often it is stated that the brain is subject to chaotic processes, thought to be stochastic or unpredictable. This, however should be reinterpreted: chaotic in this case means that small perturbations in an otherwise deterministic (3- or 4-dimensional) universe might eventually lead to relatively large changes when sufficiently long time elapses, in other words *non-linearity* is at stake.

Another quantum-associated option is the concept of a multidimensional world, of which we normally perceive only three spatial and one temporal (from past to future) dimension. **Bohm and Hiley, 1987; Atmanspacher, 2011**) hypothesizes that additional dimensions are necessary to describe quantum processes and to avoid probabilistic theories. Bohm proposed that our apparently 3-dimensional spatial world has a two-arrow (bidirectional) time dimension. In this concept the stochastic (or double stochastic) character of quanta might be explained by deterministic processes, through steering of particles in our world by so called pilot waves originating from an underlying quantum field: *the implicate order*. According to Bohm, the individual mind or consciousness is an inherent property of all matter (and energy), and as such it is part of or rather an expression of this universal quantum field.

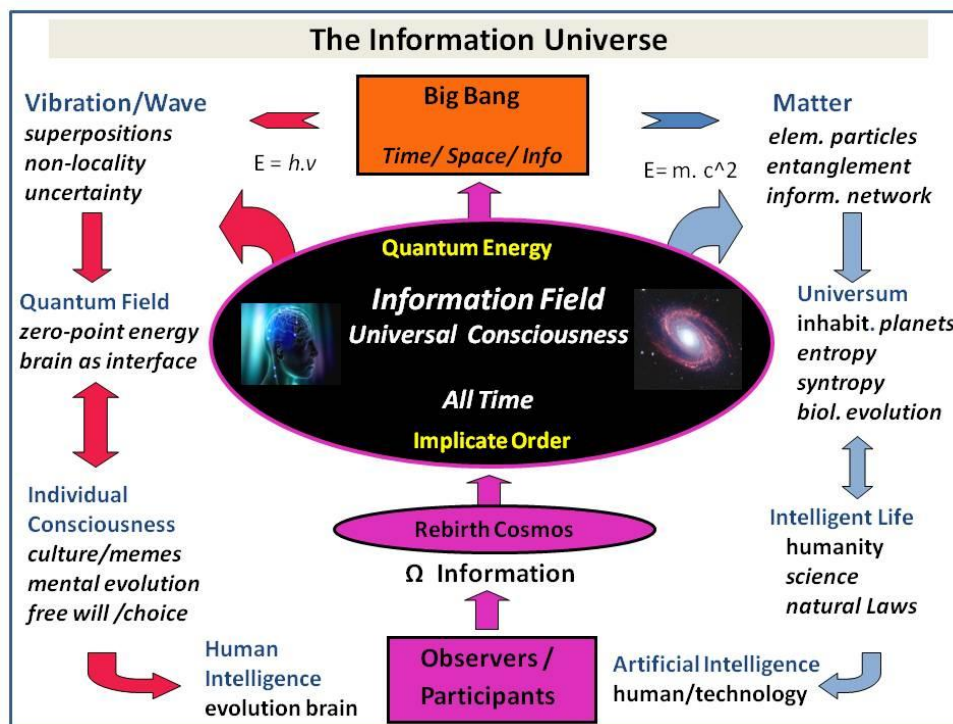
This concept of quantum field also explains the phenomenon of entanglement (non-locality), i.e. the possibility that localized particles of matter (and/or energy) might instantaneous interact (or better, are correlated) even at long distances. The universe is seen as a giant superposition of waves, representing an unbroken wholeness of which also the human brain is a part. In this framework mind and consciousness are superposed states and thoughts, intentions and acts of observation can lead to the local collapse of wave information (**Atmanspacher, 2011**). Recent experimental work on molecular teleportation (**Zeilinger, 2000**) and in line with MRI technology (**Marcer and Schempp, 1997**), is suggestive to envision that through entanglement of particles non-local quantum information can be recovered locally as useable information: information creates matter (or energy) and vice versa. A similar mechanism may play a role between resonant waves of the universal quantum field in interaction with a holographic extension of the brain.

According to this hypothesis, mental processing, including consciousness, information can be transferred from a quantum field domain of and, as a result, the individual mind is entangled with a universal mind (**Eyckman, 1998**). Bohm describes this as the unfolding of information from an implicate order into an explicate order: the world that we know. These ideas have been associated by several founding fathers of quantum physics with the Upanishads idea that the personal self-equals the omnipresent all-comprehending eternal self (**Schrödinger, 1986, Bohm, 1990, Pauli, 1994, Wigner, 1992**). In 1963, **Culbertson** already put forward the SRM (space-time reductive materialism) model and suggested that consciousness is an aspect of the causal networks of space/time and all subjective experiences occur in that domain, while individual memory may in fact be a sort of re-experiencing of space/time events. This is in line classical panpsychism in which all matter is to some extent conscious and also resembles idea’s on external memory by the abovementioned holographic and brain dissipative theories of Pribram and Vitiello.

The proposed quantum field that is non-local and super-mergent on the conventional physical space, is perceived as an infinitive number of universes in a row. The 4<sup>th</sup> dimension of this block universe (**Minkowsky, 1920**) contains all events from the past as well as the possible events from the future: there is no single arrow of time. The future does already exist, but it is a matter of time to reach that

“destination or location”. Time proceeds both forward (our conception of time) and backward (**Price, 1996**). We all stay in a small bell of consciousness, and experience time only in a limited, subjective way, that cannot be shared with others (**Hawking, 1988**).

The American physicist **John Archibald Wheeler (1990, 2002)** suspects that reality exists not because of physical particles, but rather because of the act of observing the universe. "Information may not be just what we *learn* about the world. It may be what *makes* the world." In other words: when humans ask questions about nature, there is an active transfer of information in the domain of quantum waves where, in principle, backward causation from the future is possible. The second arrow (from future to past) remains hidden (unnoticed) for us, because life is trapped in the momentum of time. Entanglement means that particles separated at any distance, under certain conditions, can have mutually determined properties (are correlated). In this block universe multiple path's or life lines are laid out of which the individual chooses a single one. Consequently this concept allows free choice and therefore is not deterministic. Such non-locality becomes manifest by observation (or collapse of the wave aspect), as has been shown by electron spin orientation or polarized light. This might also be viewed as backward causation.



**Fig. 6:** An integrated scheme depicting the Universe as a circular flow of information with its material (right part of the figure) and mental (left), aspects. The latter does not imply a dualistic approach, rather a complimentary and unitary matter/mind modality is assumed. This concept assumes a central quantum information field, that provides the very basis for creation of our universe and dynamically evolves further through cyclic feed-back processes from the present reality, in which natural (among others human) and artificial intelligence play crucial roles in observation and participation (see text for further explanation, see also **Meijer, 2012**).

According to **Wheeler's (1990)** and Feynman's electrodynamics, emitters coincide with retarded fields, which propagate into the future, while absorbers coincide with advanced fields, which propagate backward in time. This time-symmetric model leads to predictions identical with those of

conventional electrodynamics. For this reason it is impossible to distinguish between time symmetric results and conventional results.

In his “Transactional Interpretations of Quantum Mechanics, **John Cramer (1988)** stated that *“Nature, in a very subtle way, may be engaging in backwards-in-time handshaking: The transaction between retarded waves, coming from the past, and advanced waves, coming from the future, gives birth to a quantum entity with dual properties of the wave/particle. Thus the wave property is a consequence of the interference between retarded and advanced waves, and the particle property is a consequence of the point in space where the transaction takes place”*. The transactional interpretation requires that waves can really travel backwards in time. This assertion seems counterintuitive, as we are accustomed to the fact that causes precede effects. It is important to underline, however, that, unlike other interpretations of QM, the transactional interpretation takes into account special relativity theory which describes time as a dimension of space, as mentioned earlier. Of note, the completed transaction erases all advanced effects, so that no direct advanced wave signaling is possible: “The future can affect the past only very indirectly, by offering possibilities for transactions” (**Cramer, 1988**).

**King, 2003** stated: *“the hand-shaking space-time relation implied by the transactional interpretation makes it possible that the apparent randomness of quantum events masks a vast interconnectivity at the sub-quantum level, reflecting Bohm’s implicate order, although in a different manner from Bohm’s pilot wave theory. Because transactions connect past and future in a time-symmetric way, they cannot be reduced to predictive determinism, because the initial conditions are insufficient to describe the transaction, which also includes quantum boundary conditions coming from the future absorbers. However this future is also unformed in real terms at the early point in time emission takes place”*.

The principle of backward causation has been experimentally demonstrated recently. Aharonov’s team and various collaborating groups (see **Aharonov, 2010**), studied whether the future may influence the past by sophisticated quantum physics technology. Aharonov concluded that a particle’s past does not contain enough information to fully predict its fate, but he wondered, if the information is not in its past, where could it be? Clearly, something else must also regulate the particle’s behavior. Aharonov and coworkers proposed a new framework called *time-symmetric quantum mechanics*. Recent series of quantum experiments in about 15 different laboratories around the world seem to actually confirm the notion that the future can influence results that happened before those measurements were even made.

Generally the protocol included three steps: a “pre-selection” measurement carried out on a group of particles; an intermediate measurement; and a final, “post-selection” step in which researchers picked out a subset of those particles on which to perform a third, related measurement. To find evidence of backward causality, meaning information flowing from the future to the past, the effects of, so called, weak measurements were studied. Weak measurements involve the same equipment and techniques as traditional ones but do not disturb the quantum properties in play. Usual (strong) measurements would immediately collapse the wave functions in superposition to a definite state. The results in the various groups were amazing: repeated post-selection measurement of the weak type changed the pre-selection state, revealing an aspect of non-locality. Thus it appears that the universe might have a destiny that reaches back and “collaborates” with the past to bring the present into view. On a cosmic scale, this idea could also help explain how life arose in the universe against tremendous odds and confirms the idea that knowledge was inherited from a common information pool (**Meijer 2012, Kak, 2009, Jahn and Dunne, 2007**).

It has been estimated that the brain's basic range of activities is driven by between 100.000 and 1 billion different chemical reactions every *minute*. The average human brain contains a minimum of 20 billion individual neurons or nerve cells and each neuron can interact with 1000 to 10.000 other neurons. In fact some  $10^{12}$  to  $10^{13}$  interconnections come into play in this regard. The aforementioned estimate of possible interactions in the human brain is likely an underestimate, since it solely refers to the neuronal cells and not to the other cell types in the brain that outnumber neurons at least 10 times.

All of this represents a workspace with a “horizontal type” of cellular organization, but there is also an underlying deep structure of hierarchically-nested microstructures of cellular organelles, cytoplasm, molecules, their constituting atoms, elementary particles, string modalities of the latter (as yet hypothetical), as well as spin networks at the Planck scale. This constitutes an immense multi-layered “vertical”, emergent-organization that, at the various levels, may become interconnected, among others due to electrochemical forces and quantum entanglement (see section 8, **Fig. 7 and 8**). These connections are far from being well ordered since in fact, chaos is very central in brain's processes. This chaos, which comprises a real turmoil of diffuse stimuli-processing activities, is the precursor of a coherent equilibrium at higher levels. Brain researchers have observed a similar phenomenon in which the creative mind initially processes totally chaotic and even contradictory concepts, that ultimately translate into the initiation of order and stability in the later stages of the creative process (**Vitiello and Freeman, 2006; King, 2003**).

Hence, contrary to the law of entropy, biological evolution as expressed in brain function, is moving towards a state of neg-entropy or syntropy (**Schrödinger, 1986, Vannini and Di Corpo, 2008**). In this process useful information is collected that enables evolution to unfold in an "open system" so as to allow the brain to absorb new information and adapt it in an extremely rapid manner and in highly complex ways. **Ilya Prigogine (1997)** proposed that each organized system dynamically shifts between a state of entropy and neg-entropy, i.e. between chaos and order. Moreover the greater the system's potential instability, the more readily it adapts and will anticipate future events. As mentioned earlier, the latter may be related to backward causation in quantum coherent parts of the brain.

Several authors have indicated that in brain function local (*internal*) electromagnetic fields play a crucial role in the coordination of the various parts of the brain (**Mc Fadden, 2007**). The latter author developed the conscious electromagnetic (CEMI) field theory, postulating that consciousness is a product of an electromagnetic field of the brain that is clearly demonstrated by EEG signals and could explain binding of various brain activities and provide the wave-mechanical drive of free will. It is postulated that digital information within neurons is pooled and integrated in the form of such a field, and that this electromagnetic information field feeds back to influence neuronal firing and is downloaded to motor neurons in order to communicate its state to the outer world. The model thereby introduces a sort of dualism rooted in a physical, instead of a metaphysical framework.

This theory, as well as the well-known geomagnetic influence on internal clock function, may indicate that our brain acts as an open system that can receive electromagnetic and, very likely, also quantum signals, the latter originating from universal quantum fields. A supposed example of the latter, is the earlier mentioned zero-point energy (ZPE) field, that may function as a general information storing quantum domain, that penetrates the entire universe including life organisms (**Rueda and Haisch et al., 2005, Lazslo, 2007**). It is supposed to be a-temporal, containing all time and all possible paths for human history and individual life and in this sense can be regarded as a

many-world domain (see also **Kamenshchik and Teryaev, 2013**), bridging the quantum physics interpretation of Everett and Bohm. It has been recently proposed that Casimir phenomena of the ZPE field, that can transform virtual particles in particles with mass, dimensionally could operate in the neural synaptic space at the level of the cerebral manifold, being instrumental in the creation of cosmological consciousness (**Burke and Persinger, 2013**). The influence of the latter field on the brain can also be top-down (**Kaivairainen, 2005**), due to entanglement with this universal knowledge field, in which the human brain may function as an interfacing unit for bidirectional exchange of quantum information, thereby enabling super-intuition and post-selection of final states, including backward causality in biological evolution (**Meijer, 2012**). In conclusion: concepts that take into account aspects of a universal consciousness or a quantum knowledge field can entirely be based on established physical theory.

## ***8. An attempt to integrate the two supercausal brain models***

### ***The two models in a complimentary mode***

So far we have described and analyzed the two kinds of mind theories independently, one with a predominantly quantum physical and others with a neurobiological signature. We have advanced the idea of brain isoenergicity and high potential energy as general principles of both “normal” or classical brain physiology. A major weakness of the of emergent materialistic concept underlying the isoenergicity and potential energy model as well as various alternative QM models, is that the actual physical configuration of the mental state remains to be defined. The principles of isoenergicity, however, does not exclude a role of amplification of QM processes via various types of brain constituents at the micro- and macro- levels. It is, in our opinion, beyond any question that QM is relevant to understand cerebral molecular and sub-molecular processes. Moreover QM-theories appear useful to model the time structure of brain information processing. The QM theories can be divided into two lines of ideas: either the brain is considered as part of a universal quantum field or that, at least some, brain molecules enable and support the mental state. A central issue of the current QM-theories is whether and how random quantum events are orchestrated in such way that they become meaningful information for the organism. The various molecules assumed to be directly involved such as tubulins, plasma water and ion-channels are unspecific in terms of biological functioning: i.e. they are involved in a multitude of neuronal functions; for instance a wide variety of neurons and other cells such components. Yet, specific quantum wave information may be accommodated in the brain by holographic wave resonance with either of these cellular elements even at the most basic micro-levels.

Therefore we provide a framework for bridging the two seemingly unrelated approaches. We came to the conclusion that both approaches are not mutually exclusive and may well operate in concert, yielding the concept of a bi-cyclic mind (interacting bottom up and top-down information flows) that collectively act as a *cyclic operating mental workspace* (see **Fig. 7**). Complementarity is considered as a useful concept for consciousness studies, as pointed out by **Pauli, (1994)** and more recently by **Walach and Römer (2000)**. The combined mechanisms, in our view, are housed in a number of nested, spatio-temporal, domains that allow the bidirectional flow of information, while within the various domains direct communication is supposed between the particular isoenergetic and quantum modalities, for example through wave /particle transitions and/or coherence/decoherence cycles (**Fig. 7**). Within this dynamic context, the causal (our normal) time perception and tensed time perception, although separate phenomena, may still become correlated.



### *A potential cosmic character of mind*

Some QM mind theories assume that personal consciousness is part of some kind of a cosmic or universal consciousness. In section 6, we referred to a recent theory on the nature of gravity (**Verlinde, 2011**) proposing that information (in terms of entropy, i.e. energy and time) is a fundamental principle of both QM and Newtonian physical laws (**Meijer, 2012**). Whether or not a physical configuration contains useful information intrinsically depends on the interpretation by an observer, i.e. the human mind (as, for instance, proposed in the Copenhagen interpretation of QM). If so, than local gravity as induced by entropic displacement of matter and information is also created by the universal mind in interaction with the human mind. This suggestion implies that mental states may not exclusively been associated with “hard” QM theories, but to even more general entropic principles.

In the authors view, consciousness is more than reflexive cognition or a causally closed physical/physiological phenomenon. Hence, we consider, on the basis of physical mechanisms, additional aspects such as emergent information processing as well as time reversed and field mediated transfer of information. Both of the presented models collectively contain one or more of the following ingredients: 1<sup>st</sup> they avoid classical causation, raising the possibility that mental states are not governed by presumably deterministic neural processes; 2<sup>nd</sup> they imply some form of universal consciousness with which the individual mind and consciousness interact; 3<sup>rd</sup> they assume that human consciousness can exert causal power in the physical world; 4<sup>th</sup> they may explain transitions of mental modalities from sub- or unconscious thoughts and processes to consciousness and *vice versa*; 5<sup>th</sup> they make a distinction between time perception and common physical (external) time; 6<sup>th</sup> they allow non-temporality of the past, present and future, i.e. allowing backward causation.

### *Multidimensional and time aspects*

In this respect we emphasize the attractiveness of a multidimensional space-time universe and related field theories explaining non-local information processing. We also assigned the possibility of time-symmetry and consequential backward causation being founded in advanced physical concepts, in multidimensional mathematical theories and in the QM concepts. Taking into account these aspects, the question arises how the brain is positioned in this holonomic system and acts as a quantum sensing agent. Of note, in some of the mentioned QM brain theories, dualism of mind and matter is tacitly assumed, but not preferred by the present authors, since they presume a physical basis for both classically defined brain function and quantum field mediated information flow.

We have speculated on the creation of a “personal universe” (as related to the “universe of consciousness” of **Edelman and Tononi, 2000** during life and the possibility of a bidirectional time domain in which the bifurcation of past and future events produce the present (see the supercausal model of **King, 2003**). That future events may influence the past, was originally suggested by **Cramer, 1988** and experimentally researched by the earlier mentioned **Aharonov, 2010** and various associated groups. Interestingly, so-called two time physics was also proposed by **Bars et al., 2007**, claiming that proper modeling of nature requires at least two time dimensions. This information takes the form of hidden symmetries, dualities and other non-trivial structures, which are hard to notice by the 1T physicist. For systems that are already understood, 2T-physics tells us that the description of dynamics via the usual 1T-formalism should be interpreted as emergent dynamics that holographically represents an image of a deeper, higher dimensional, structure in one extra space and one extra time. Recently, a field theoretic description of 2T-physics has been

established. Amazingly, the best understood fundamental theory in physics, the Standard Model of Particles and Forces (SM) in 3+1 dimensions, is reproduced as one of the “shadows” of a parent field theory in 4+2 dimensions.

Clearly, any organism (and also the brain) is an open system, implying a continuous interaction with the environment. QM theories of the brain/mind assume that, apart from sensory information, wave information is continuously imported in the brain and concomitantly exported. Moreover, a viable open system maintains a maximal potential energy and isoenergeticity for expressing a maximum alternative brain states by sequential as well as parallel transitions. Hence, not only a personal universe can be build up and maintained in individual life, but according to QM concepts, a concomitant personal state is produced within a universal knowledge domain, that is a dynamic field accumulating new data and personal experiences during life (see **Fig. 6**). These field properties may obey other laws (or descriptions) than the laws that are instrumental in the description of the world from which they originate. Universal consciousness, originally pictured by David Bohm as an implicate order, exhibits a physical nature that allows bidirectional interactions with human consciousness and mind (**Grandpierre, 1997**).

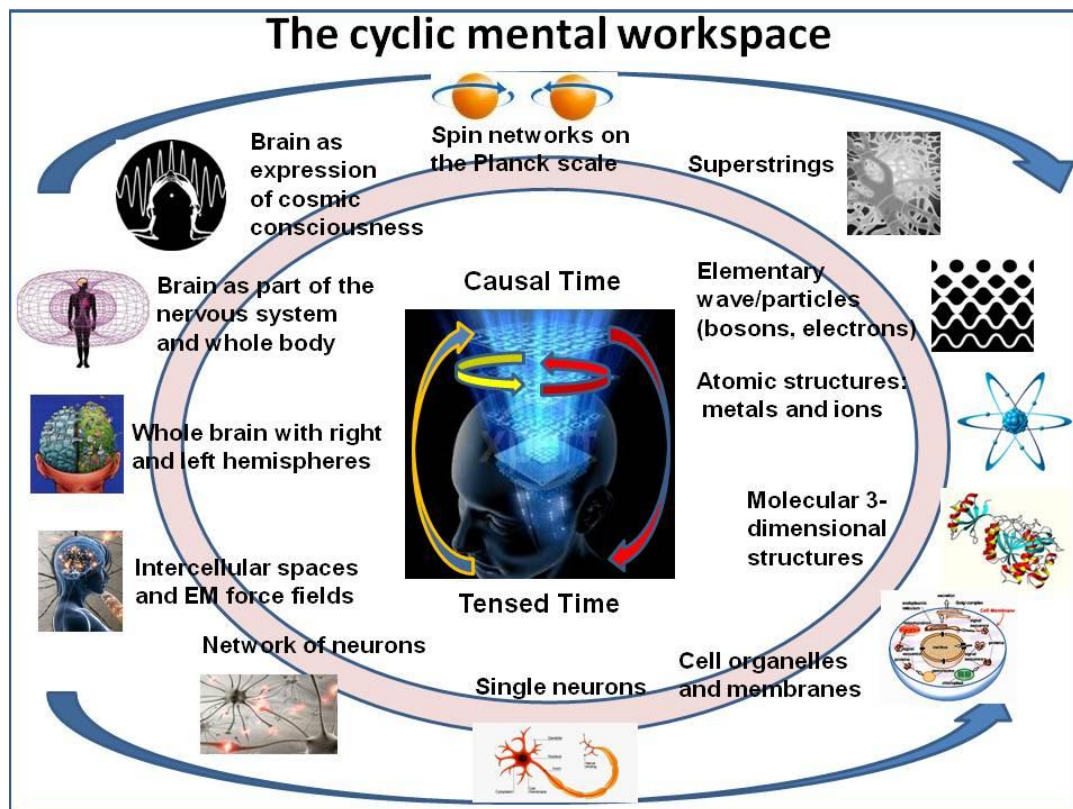
### ***Bi-cyclic operating workspace: top-down and bottom up flow of information***

The quantum field theories display both bottom up and top-down aspects, and this is also true for the various isoenergetic (emergent) processes, yet the latter may predominantly operate in a spatio-temporal bottom up direction (**Korf, 2010, 2013**). The latter would start at the Planck scale and gradually become expressed at higher molecular and cellular levels. Interestingly, such a combined vertical counter-flux of information (see **Fig. 7**) would provide an integrated cybernetic control system that may enable highly efficient and rapid perturbations in brain function, with some delay also being expressed at the “horizontal” neuronal network level. Such a versatile operating system may also allow neural signal amplification as well as forward and backward causation, the latter through holographic interference (**Pribram, 1986, Mitchell and Staretz, 2011**) of past (memory) and future informational aspects.

This physically based brain structure may be instrumental in a *complementary* mode of recurrent type of information processing that may be crucial for integral mental perception and causation and can also accommodate symmetric time concepts (for the latter see: **Atmanspacher 2011; Primas 2009; Aharonov et al. 2010**). We propose that such a specialized “multi-layered” physical brain compartment, may represent a workspace in which the two bridging and super-causal isoenergetic and quantum processes, act in concert in a complementary manner. We envision this operating system being organized as a number of nested, spatio-temporal, domains that allow the bidirectional flow of information (bottom up and top-down, large arrows in the center block of **Fig. 7**).

Within the various domains, an optimal communication might occur between the isoenergetic and quantum-based information flows, through wave/particle transitions as well as coherence/decoherence cycles (horizontal arrows in **Fig. 7**). Within this dynamic context, the causal (our normal) time perception and tensed time perception are separated but can be in correlated states. The supposed interacting cycles of both the isoenergetic and quantum mediated streams of information may exhibit nonlinear features, enabling the amplification of minimal information signals for the realization of rapid action of the organism in relation to interpreting the environment. In a sense this micro-model shows similarities with the sequence- seeking and counter stream macro-model for information processing in the cortex (**Ullman, 1991**).

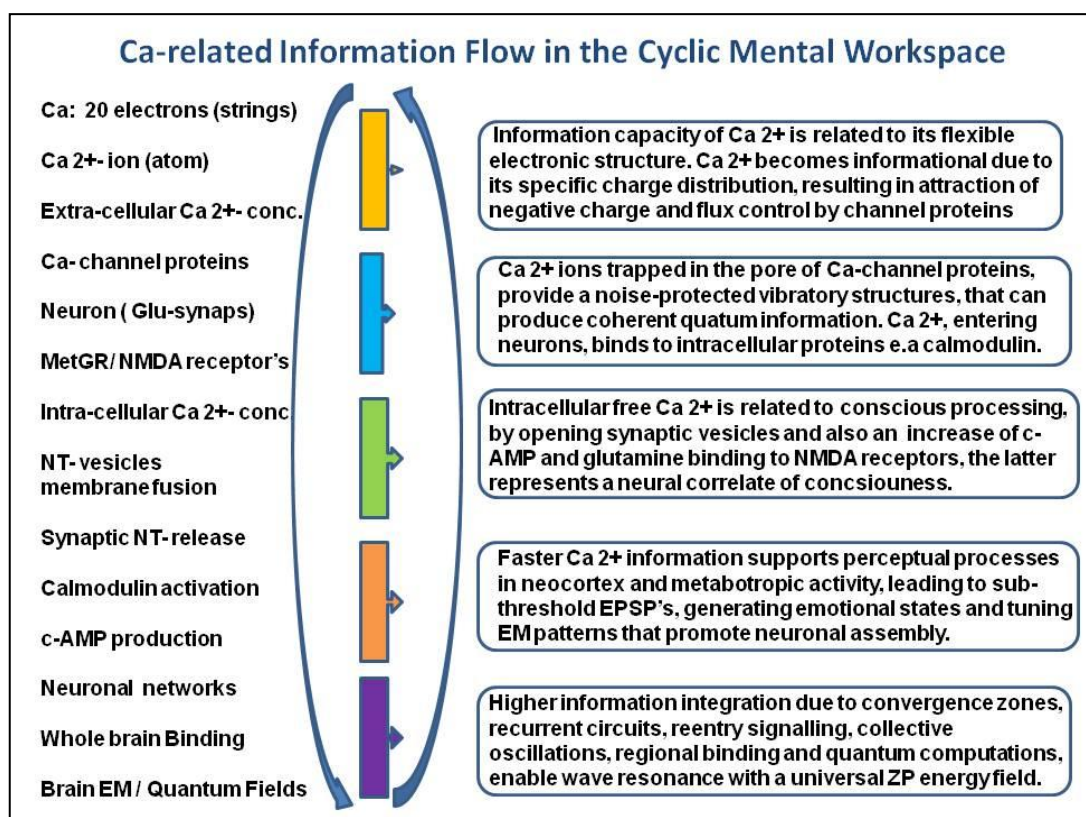
In order to show how such a cyclic mental workspace could operate at the atomic/molecular and field levels, we present one example of a potential bidirectional information flow, that is based on the central role of  $\text{Ca}^{2+}$  ions under the control of various neuronal proteins. In this concept  $\text{Ca}^{2+}$  is viewed upon as an informational vehicle influencing the activity state of the neuron, (**Fig. 8**, based on the data of **Pereira and Furlan, 2007**). Similar schemes could be imagined for other molecular mechanisms, mediating the tuning of cellular activity into large scale patterns, in the context of the creation of higher mental functions. As potential candidates, the hydrogen atom in relation to  $\text{H}_2\text{O}$  and unpaired electron spins as present in DNA, other metal ions, as well as present in  $\text{O}_2$  and  $\text{NO}$  molecules (if associated with membrane proteins), have been proposed (**Hu and Wu, 2004**).



**Fig. 7:** Potential cybernetic effects on various levels of brain organization: Starting in the upper middle part and following a sequence to the right the following elements are pictured: spin networks on the Planck scale, superstring modalities of elementary particles, elementary wave/particles (bosons, electrons), atomic structures such as metals and ions, molecular 3-dimensional structures, cell organelles and membranes, single neurons, networks of neurons, intercellular spaces and electromagnetic force fields, whole brain with right and left hemispheres, brain as part of the nervous system and whole body, and finally brain as holographic expression of cosmic consciousness. A hypothesized mental workspace is depicted in the center with bidirectional (circular) of quantum and isoenergetic information flows. The two domains may be quantum correlated.

We emphasize that the sequential steps (on the right in **Fig. 7**) may both contain quantum-based and classical neurological mechanisms, except the spin- and/or string-mediated initiation events that should be merely seen as quantum processes. At the bottom micro-level, such an information flow may be initiated on the level of string mediated collapse of wave function (**Mavromatos and Nanopoulos, 1995**) and/or may operate through spin-dependent transformation of classical and quantum mechanical information, that may also be the basis for the so-called quantum potential or pilot waves of the implicate order proposed by **David Bohm, 1987**). The corresponding 4-

dimensional space-time domain also introduces aspects of two-times physics, tensed and causal time. **Penrose, 1989**, proposed that spin networks could be fundamental in the description of space-time in a background lacking manner (see for the latter also **Rovelli, 1996 and Smolin, 2004**). In the brain, spin-networks were pictured as electron-unpaired electron spins that represent pixels, collectively forming a “mind screen” that is known to be highly sensitive to fluctuating internal magnetic fields and action potentials. Such perturbations were considered to modulate neural dynamics but also could enhance synchronization and stochastic resonance as have been noticed in brain (**Hu and Wu, 2004**). The particular spin chemistry bridges classical neural activity, serving as input via the magnetic influences on biochemical processing. Spin network dynamics may enable a quantum decoherence-resistant entangled modality of wave collapse since, through tunneling, they are rather insulated from the environment in decoherence-free subspaces, while repeated attention/intention (Zeno effect) may help in promoting coherent quantum states (**Hu and Wu, 2004**).



**Fig. 8:** The role of Ca<sup>2+</sup> ions in the bottom-up and top-down information flow from the micro- to macro-level in the neuronal organization of the brain, as related to higher cognitive functions and consciousness.

The informational aspect of Ca<sup>2+</sup> is encoded in positive and negative charges within micro-sites on the surface of a spectrum of flexible macromolecules that allow binary choices at various spatio-temporal levels. The latter may also depend on ultra-rapid conformational changes in proteins in pico-seconds, as influenced by locally induced electromagnetic fields, that thereby obtain a probabilistic electro-magnetic vibratory character, an aspect that could also play a role in the present isoenergetic brain model. In turn, local magnetic fields can influence neural firing patterns and induce regional convergent zones of brain activity that are produced through sub-threshold EPSP 's and inhibitory inter-neuronal synaptic activity, being amplified by reentry and recurrent circuitry (**Pereira and Furlan, 2007**). Total brain activity is determined by genetic and epigenetic

information, neuro-plasticity, as well as functional cycles of efferent and afferent signals (internal copies and external mirror information), that reflect the interaction with the whole body and its environment and dynamically produce our inner worldview, earlier referred to by us as “personal universe”.

It should be mentioned here that much of the sequential steps depicted in **Fig. 8** are situated in *single neurons*. Yet, our model, in the higher-order levels, requires an integrating modality in which the firing patterns of millions of neuronal networks are translated in an meaningful overall brain response. Sensory processing involves the formation of wave packets affecting large populations of neurons, instrumental in the reciprocal *broadcasting* of excitatory patterns located at several brain regions (**Freeman and Vitiello, 2006**), and inducing neuronal assembly.

Interestingly, in this process calcium waves along the astroglial syncytium may play a role, contributing to collective oscillations and synchrony and thereby to efficient binding of distributed neuronal activity. Yet, proper information integration, transmission and exchange with outer information domains requires a guided interactive quantum process, in which the classical separation of sender and receiver is overcome through an act of measurement and proper resonance with the information source. This implicitly should be based on the phenomenon of entanglement and consequently on unitary and conscious field properties of the neural and exo-systems (**McFadden, 2007, John, 2001, Bohm, 1987**). This allows the continuous exchange of meaningful information with global magnetic fields as proposed by **Mc Fadden, 2007 and Burke and Persinger, 2013** and/or a universal quantum knowledge field as earlier proposed by **Bohm and Hiley, 1987** (see also **Fig. 6**). The latter concept was suggested to also contain personal information (our mental double in the universal consciousness domain, **Vitiello, 1995**, see section 7). Of note, the bottom-up and top-down vertical neural pathways depicted in **Fig. 7**, likely form a fine-tuned organization of neurological/ biochemical signature, functionally connected with quantum-based information processing. This requires that each sequential step should provide an output of the type that can be used in either of the two supposed systems: quantum wave information should be collapsed or decohered to material signals (for instance during synaptic vesicle release or through the earlier mentioned Casimir effects in the synaptic cleft) and material/physical information should be translated to a wave form. Both of these processes could be situated in micro-sites that house coherence/decoherence conversion capability as recently suggested by **Kauffman, 2012** (see section 5). Alternatively, rather separately organized neurological and quantum pathways could “horizontally” communicate by correlated time domains or be helped by local resonant or entanglement properties (see **Fig. 7**). In this respect, a number of potential intra-neuronal and inter-neuronal connective mechanisms should be taken into account. Solitons, described as dissipative waves or tunneling bio-photons, have been proposed as intracellular local effectors by **Georgiev and Glazebrook (2006)**. Interestingly, even a process of photon quantum teleportation (**Salari et al., 2011**) have been suggested for long distance signaling in the brain, a process that both employs classical and quantum elements. **Ehresmann et al., 2011**, stresses the dynamic character of a multi-scale flexible brain structure, varying over time and with a hierarchy of complexification levels, in which higher cognitive and mental processes can develop. This occurs within a 4-dimensional global landscape with retrospective and prospective elements that, among others, result in changes in the synchronization of neuronal assemblies as well as dynamic adaption of neuronal contacts. Such a multidimensional space/time brain structure, being open to external electromagnetic and quantum fields, could also provide an interpretation framework for understanding of the, until now, non-comprehensible time delays in subconscious and conscious perception, the inner knowing of qualia as well as the subjective experience of transpersonal and extra-sensory events such as intuition, serendipity, clairvoyance and telepathy.

*In summary: we postulate a double “countercurrent” operating workspace (see Fig. 7 and 8), representing a complementary mode of isoenergetic and quantum information processing. This workspace houses cycling (vertically and horizontally interacting) information flows that may be instrumental in highly rapid mental perception and causation and can accommodate time symmetry as well as nonlinear elements. The vertically directed cycle of flow includes interaction with electromagnetic and quantum fields that enable vice versa exchange of information with a universal knowledge field.*

## **9. Final considerations and discussion**

The present overview highlights the dilemma’s arising in understanding the time trajectories following internal and external stimuli of the brain. They are not fully comprehensible in terms of classical neurobiology of neuronal communication. In other words: current knowledge of the brain is insufficient to explain higher mental processes such as qualia and consciousness. Our core argument is that the basic constituting elements of the brain, including neurons, neuronal aggregates, molecules and metabolism become only crucial for higher brain functions when considered in the context of a combination of emerging and quantum properties. Hence we propose two super-causal modalities to explain such fast brain processes through super-positional quantum wave transfer and/or immediate protein perturbations, enabling reaction times below the millisecond range.

In this framework, we considered two non-classical models that may be operative in these phenomena: the isoenergetic model proposed earlier (**Korf 2010, Fig. 2**) and a variety of quantum models that also have been dealt with in an earlier report on the “information universe” (**Meijer 2012, and Fig. 6**). We consider isoenergeticity as an emerging property, implying that brain states might change with minimal energy via, for instance, random transitions of molecular configuration. Yet, only when operating in concert, quantum transitions provide useful additional information of the outer world or out of internal biological processes. The model is based on the assumption that there are minimal inter-neuronal energy barriers and that brain metabolism is primarily aimed to guarantee isoenergeticity and high potential energy. Such a brain conformation is considered as optimal to translate minor perturbations, including elementary quanta into physiological activity and originates in evolution (see for a more detailed analysis, **Korf and Meijer, 2013**).

The quantum models are based on the idea that mental states emerge from elementary quantum transitions and quantum fields. QM theories introduce such counterintuitive phenomena as backward causation and feeling the future, in addition to non-linear information processing. Alternatively, the QM theory of mental processes may be conceived as a metaphor, as an epistemic theory, rather than as an ontological concept (see section 5). In the previous section we concluded that the isoenergetic approach and the quantum mechanical concepts are not mutually exclusive and may in fact exhibit some degree of mutual dependence.

Our key notes are: 1) there exist configurations or states of the brain that may be directly associated with mental processes that have a physical and/or wave informational aspect; 2) the two mind theories describing the presumed emergent or backward causative brain configurations, remain to be further developed and/or refined (see supplement); 3) The latter is also related to subjective (intrapersonal and potential transpersonal) experiences and perception of qualia; 4) quantum concepts and models, useful to understand mental processing, apply to the presumed physical



complexities of the brain as well as a universal knowledge domain that is 4-dimensional with bidirectional time; 5) substance or multi-aspect *dualism*, is rejected by us in favor of *complementarity* of brain processes; 6) the creative power of biological evolution (the tendency to develop life by embodiment of useful information), can be attributed both to elementary physical phenomena such as self-aggregation into emergent higher complexity and to quantum field mediated backward causation through selection of parallel superpositions; 7) it is unlikely that either of these processes alone constitutes the life-conferring properties of nature including the proper functioning of the human brain.

The two theories, discussed in this paper, collectively contain one or more of the following ingredients: 1<sup>st</sup> they avoid classical causation and embrace uncertainty, raising the possibility that mental phenomena cannot be governed by presumably deterministic nervous processes (and thus leave room for intuition and free will); 2<sup>nd</sup> they stress the role of some form of universal consciousness with which the individual mind and consciousness interact; 3<sup>rd</sup> they assume that human consciousness can exert causal power in the physical world; 4<sup>th</sup> they may explain transitions of mental modalities from sub- or unconscious thoughts and processes to consciousness and *vice versa*; 5<sup>th</sup> they make a distinction between time perception and common physical (external) time; 6<sup>th</sup> they include the possible non-temporality of past, present and future, i.e. allowing backward causation.

Such quantum mind/brain mechanisms can be fully described in physical and biological terms, as related to various levels of organization from the micro- to macro scales (see section 5 and 6). In some of these QM brain theories dualism of mind and matter is tacitly assumed, but such a concept is not preferred by the present authors. Any organism (and the brain) is considered as an open system, meaning a continuous interaction with the environment. Hence, apart from sensory information, wave information or quanta are continuously imported, while at the same time wave information is exported. An open system is necessary to achieve and maintain a maximal capacity for expressing as many alternative brain states, neural configurations, behavior etc. as possible. As a general principle, sequential as well as parallel transitions of multiple states can be realized, that is when the energy barriers between these brain states are low or more generally defined, occur at a higher potential energy. Hence, not only a personal brain is build up and maintained in individual life, but at the same time a concomitant personal state is produced within a universal consciousness domain, that is a dynamic knowledge field accumulating new data and personal experiences during life. These new properties within this field, obey other laws (or descriptions) than the laws that are instrumental in the description of the world from which they originate.

Localization of the accumulating transitions is not only the basis of experience and behavior, but also of consciousness. Only by a localization in the space-time universe of the brain we become aware of otherwise unconscious processes or thoughts, not because we directly observe these thoughts (as is in the perspective of a homunculus), but because their localization is the result of unconscious (cognition and emotion) and also conscious activity (i.e attention and intention). In practice it takes some time before unconscious events become conscious: most neurophysiological experiments indicate that about 350 msec are required for a human to become conscious of or making a decision for action on the basis of sub-consciously provided information. Interestingly, such rather long delays are also in line with the idea that consciousness and mind are immanent properties of collective quantum states, that intrinsically bear information of past and future aspects. In other words: the particular sub-conscious information represents data derived from future states 350-500 msec preceding the time that the particular information reaches the conscious domain (see the original paper of **Libet, 2006**). Evidence was developed to demonstrate that this phenomenon



depends on an antedating of the delayed experience. There is a subjective referral backward in time to coincide with the time of the primary cortical response to the earliest arriving sensory signal. The subjective referral in time is analogous to the well-known subjective referral in space.

We propose the brain as an organ with a high and potential energy to be maintained as constant as possible. This is achieved by energy metabolism, providing fast recovery from decreased potential energy as the result of neural activity. Thus far we have stressed the idea that the brain is an organ with hitherto unrecognized properties that might be directly related to mental activity. This idea has been extended by Hasson and coworkers by proposing the possibility of brain-to-brain coupling. This is achieved, among others, by mimicking and empathy as a central feature for creating and sharing a social, cultural, world (**Hasson et al., 2012**).

Crucial additional aspects of such emergent information processing, as well as intuitive, time reversed, exploration and/or potential field- mediated transitions of information are assumed in our paper. Such aspects can be understood in terms of a non-reductionist conception of the relation between the lived and the living, between conscious experience and biological processes since state factors can be interpreted as bearers of future information. **Beauregard and O'leary (2007)** stated: *"More than a century ago, William James proposed that the brain may serve as a permissive / transmissive / expressive function rather than a productive one, in terms of the mental events and experiences it allows"*

James, Bergson and Huxley, and more recently, **Jahn and Dunne (2004)** speculated that the brain acts as a filter or reducing valve by blocking out much of, and allowing registration and expression of only a narrow band of, perceivable reality. They state that in the course of evolution, the brain has been trained to eliminate most of those perceptions that do not directly aid our everyday survival. A hypothesis of the development of the brain in two opposite directions (improvement of technical and logical abilities, yet loss of contemplative/spiritual potential) represents a challenging one from all kinds of perspectives (see **Bitbol and Luisi, 2011**).

Some QM theories are solely based on bottom-up information flow processes from the micro-level. However, assuming that brains are immersed in and directly influenced by quantum fields, a top-down modality should be integrated. The latter mechanism may be particularly relevant for the cerebral cortex: many QM-brain theories focus on mental i.e. top-down processes, implying a prominent role of the cerebral cortex as the primary source of quantum interaction. In summary: the bottom-up processes are crucial to inform the organism and its brain about the outer world, whereas the top-down mechanism is instrumental in realizing the integral non-conscious and conscious behavior.

Some have argued that the brain might act as a quantum computer, but this possibility seems highly unlikely if not impossible, because the brain temporal-spatial structure is too diverse while computer-like processes can only be achieved in an environment non-compatible with life. Moreover it may be a fundamental feature of brain processes that they are not calculable (**Penrose, 1989**). If, according to **Hameroff and Penrose, 2004**, noise protected brain structures facilitate the transfer of quantum information into and from the brain, then an important issue is how the organism does react to that kind of information. This is also relevant in the context of the biological evolution, i.e. relevant information helps the organism, or the species, to survive and adapt to environmental challenges. It stands to reason that in these interactions nature will use all useful information available, including quantum wave resonance that, in contrast to collapsed modalities such as matter, contains information on past and future states.

In the present essay we consider the possibility that the brain and its mental aspects are somehow coupled to the universe, i.e. that apart from neurobiological QM processes, cosmological QM processes affect brain transitions. A unified theory of mind and matter have been postulated earlier on the basis of *information*, viewed upon as the most fundamental element for the description of the fabric of reality (Meijer, 2012, Samal, 2001). On the basis of such an informational interaction, some aspects of cosmic physics, as for instance the second law of thermodynamics (the entropy law), might apply directly to the brain. In other words: life, with its potential energy and isoenergeticity as well as the ability to screen and collect useful information, does in a way counteract the destructive tendency of increased entropy and at the same time may employ entropic gravity mechanisms to materialize essential knowledge. Perhaps this bimodal modality has been foreseen by Erwin Schrödinger as the potential contribution of quantum processes in creating mental dimensions.

### ***Acknowledgements***

The support of the following colleagues is highly appreciated: Jan Engberts, Ab Gramsbergen, Han Wassenaar, Jan Minderhoud, Rob Haaxsma as well as Fokko Bosker, Bernard Doornbos, Hans Mooij and Drozdostoy Stoyanov.

### ***References***

- Aharonov Y, Popescu S, Tollaksen J (2010). A time-symmetric formulation of quantum mechanics, *Physics Today*, November, 27-32.
- Allefeld C, Atmansacher H, Wackerkanm J (2009). Mental states as macro-states emerging from brain electrical dynamics. *Chaos*; 19 (1) 1-32.
- Amoroso RL (1999). An Introduction to Noetic Field Theory: The Quantization of Mind. *Noetic Journal* Vol.2 No.1, 28-39
- Arndt, M., T. Juffmann, and V. Vedral, (2009). Quantum physics meets biology, *HFSP Journal*, 3(6): 386–400. doi: [10.2976/1.3244985](https://doi.org/10.2976/1.3244985)
- Atmanspacher H, Rotter S (2008). Interpreting neurodynamics: concepts and facts. *Cogn. Neurodyn.*; 2: 297-318.
- Atmanspacher H (2007) Contextual emergence from physics to cognitive neuroscience. *Journal of Consciousness Studies*; 14 (1/2):18-36.
- Atmanspacher H (2011). Quantum approaches to consciousness *Stanford Encyclopedia of Philosophy*. 1-33. (Internet).
- Atmanspacher H, Primas H (1977). The Hidden Side of Wolfgang Pauli: An eminent physicist's extraordinary encounter with depth~psychology. *Journal of Scientific Exploration*; 11 (3): 369-386.
- Atmanspacher, H, Filk T, Römer H (2004). Quantum Zeno features of bi-stable perception. *Biol. Cybern.* 90: 33-40.
- Attwell D, Iadecola C (2002). The neural basis of functional brain imaging signals. *Trends Neurosci*; 25: 621–5.

- Auletta G, Ellis G.F.R, and Jaeger L (2008). Top-down causation by information control: from a philosophical problem to a scientific research programme. *J. R. Soc. Interface* vol. 5, no. 27, 1159-1172.
- Bandyopadhyay A (2011). Direct experimental evidence for quantum states in microtubules and topological invariance. Abstracts: Toward a Science of Consciousness 2011, Stockholm, Sweden,  
<http://www.quantumbionet.org/admin/files/Massimo%20Pregmolato%20-%20Rita%20Pizzi%202011.pdf>
- Barrow JD and Tipler FJ (1986). *The Anthropic Cosmological Principle*. Oxford University Press.
- Bars I, Chen SH and Qu'elin G (2007). Dual Field Theories In  $(d - 1) + 1$  Emergent Spacetimes From A Unifying Field Theory In  $d + 2$  Spacetime1, arXiv:0705.2834 [hep-th].
- Baylor DA, Lamb TD, Yau KW (1979). Responses of retinal rods to single photons. *J Physiol. Mar*; 288:613-34.
- Beauregard and O'leary (2007). *The Spiritual Brain: A Neuroscientist's Case for the Existence of the Soul*. Harper Collins.
- Beck F (2001). Quantum brain dynamics and consciousness. In: *The physical nature of consciousness*. Ed. Ph. van Loocke, Amsterdam Benjamins: 83-116.
- Beck F and Eccles J (1992) Quantum aspects of brain activity and the role of consciousness. *Proceedings of the National Academy of Sciences USA*; 89:11357-11361.
- Beck, F and Eccles J (2003). *Quantum Processes in the Brain: A scientific basis of consciousness*. In N. Osaka (Ed.), *Neural Basis of Consciousness*. Amsterdam, Philadelphia: John Benjamins.
- Bernroider G and Roy S (2004). Quantum-Classical Correspondence in the Brain: Scaling, Action Distances and Predictability behind Neural Signals *Forma*, 19: 55–68.
- Bianconi G Rahmede C (2012). Quantum mechanical formalism for biological evolution. <http://arxiv.org/abs/1011.1523>.
- Bitbol M and Luisi PL (2011). Science and the Self-Referentiality of Consciousness. *Journal of Cosmology*, 14: 1-18.
- Bode S, He AH, Soon CS, Trampel R, Turner R, et al. (2011). Tracking the Unconscious Generation of Free Decisions Using Ultra-High Field fMRI. *PLoS ONE* 6(6): e21612. doi:10.1371/journal.pone.0021612
- Bohm D (1990). A new theory of the relationship of mind and matter. *Philosophical Psychology*.: 3: 271-286.
- Bohm, D and Hiley, BJ (1987). An ontological basis for the quantum theory, *Physics Reports*, 144: 323-348.
- Boly M, et al (2011). Preserved feedforward but impaired top-down processes in the vegetative state. *Science* 13 May 332 (6031): 858-862, DOI: 10.1126/science.1202043
- Borsboom D, Cramer AGJ., Schmittmann VVD et al. (2011). The small world of psychopathology. *PLoS ONE* 6; e277407
- Boyden, E. S, Zhang F, Bamberg E, Nagel G, Deisseroth K (2005). "Millisecond-timescale, genetically targeted optical control of neural activity". *Nat. Neurosci* 8 (9): 1263–8. doi:10.1038/nn1525. PMID 16116447.
- Burns J (2010). What does the mind do that the brain does not ? In: R.L. Amoroso (Ed.), *The Complementarity of Mind and Body: Fulfilling the Dream of Descartes, Einstein and Eccles* (117-134). Hauppauge, NY: Nova Science.
- Busemeyer J R and Bruza P D (2012). *Quantum models of cognition and decision*. Cambridge University Press, Cambridge: 1- 403.

- Burke RC and Persinger M A (2013). Convergent quantitative solutions indicating the human hippocampus as a singularity and access to cosmological consciousness. *NeuroQuantology*. 11: 1-7.
- Carhart-Harris RL and Friston KJ (2010). The default-mode, ego-functions and free-energy: a neurobiological account of Freudian ideas. *Brain*. 133 (4):1265-1283. Epub 2010 Feb 28.
- Churchland PM (1988). *Matter and consciousness: a contemporary introduction to the philosophy of mind*. revised edition. Cambridge Massachusetts: MIT Press.
- Collini E, Wong CY, Krystyna E, Curmi P M G, Brumer P, Scholes G D (2010). Coherently wired light-harvesting in photosynthetic marine algae at ambient temperature. *Nature* 463: 644-647.
- Conrad, M (1994) Amplification of superpositional effects through electronic-conformational interactions. *Chaos, Solitons and Fractals*, 4: 423- 438.
- Cramer J (1988). An Overview of the Transactional Interpretation. *International Journal of Theoretical Physics*, 27: 227.
- Culbertson J (1976). *Sensations Memories and the Flow of Time*, Cromwell Press.
- Davies PCW and Gregersen N H (2010). *Information and the Nature of Reality: From Physics to Metaphysics*. Cambridge: Cambridge University Press.
- Davies PCW (2004). *Quantum Fluctuation of Life*. <http://arxiv.org/ftp/quant-ph/papers/0403/0403017.pdf>
- De Zwart JA, van Gelderen P, Jansma JM, Fukunaga M, Bianciardi M, Duyn JH, (2009). Hemodynamic nonlinearities affect BOLD fMRI response timing and amplitude. *Neuroimage*; 47:1649-58.
- Den Boer JA (2003). *Neurofilosofie: hersenen, bewustzijn, vrije wil (Neurophilosophy: brain, consciousness, free will)*. Amsterdam Boom Publ.: 19-302.
- Di Biase F (2009a). A Holoinformational Model of Consciousness. *Quantum Biosystems*, 3: 207-220.
- Di Biase F (2009b). Quantum-holographic informational consciousness. *NeuroQuantology*, 7: 657-664.
- Djordjevic B (2012). Quantum biological channel modeling and capacity calculation. *Life*, 2: 377-391, doi:10.3390/life2040377.
- Edelman GM, Tononi G (2000). *The universe of consciousness. How matter becomes imagination*. Basic Books New York.
- Eijkman E (1998). *Universal Consciousness*. <http://web.inter.nl.net/hcc/E.Eijkman/Conscious.html>
- Ellis G F R (2005). *Physics and the real world*. <http://www.mth.uct.ac.za/~ellis/realworld.pdf>
- Engel GS, Calhoun TR, Read EL, Ahn TK, Mancal T, Cheng YC, Blankenship RE, Fleming GR (2007). Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems. *Nature*, 446: 782-786.
- Ehresmann A C (2011). *A Multi-scale Dynamical Model for Neuro-Bio Systems. Application to Neural Processing and to Aging*. <http://ehres.pagesperso-orange.fr/Neuro-bio.pdf>
- Flanagan BJ (2007). On the unification of Mind and Matter. *NeuroQuantology*, 5 (4): 331-345.
- Freud S. (1930). *Das Unbehagen in der Kultur*. Wien, Internationaler Psychoanalytischer Verlag: 1-136. *Civilization and its Discontents*. London Hogarth Press & Institute of Psychoanalysis. New York, Cape and Smith: 1-144.

- Freeman, W.J., and Vitiello G (2006). "Nonlinear brain dynamics as macroscopic manifestation of underlying many-body field dynamics". *Physics of Life Reviews* 3(2): 93–118.
- Freeman, W.J., and Vitiello (2008). "Dissipation and spontaneous symmetry breaking in brain dynamics". *Journal of Physics A* 41, 304042.
- Grandpierre A (1997). *The Physics of Collective Consciousness*. *World Futures. J Gen Evolution* 48(1-4): 23-56.
- Georgiev D D (2006). Dissipation waves for information transfer in neurobiology- Some implications. *Informatica*, 30: 221-232.
- Hagan, S. Hameroff, SR, Tuszynski, JA (2002). Quantum computation in brain microtubules: Decoherence and biological feasibility. *Phys. Rev. E*. 65, 061901.
- Haggard P (2005). Conscious intention and motor cognition. *Trends Cogn Sci* 9: 290–295.
- Haggard P, Eimer M (1999). On the relation between brain potentials and the awareness of voluntary movements. *Exp Brain Res* 126: 128–33.
- Hameroff SR, (2007). The brain is both a neurocomputer and quantum computer. *Cognitive Science*; 31: 1035-1045.
- Hameroff, SR, and Penrose, R (1996). "Conscious Events as Orchestrated Spacetime Selections", *Journal of Consciousness Studies*, 3(1): 36-53.
- Hamill OP, Marty A, Neher E, Sakmann B., Sigworth FJ (1981). Improved patch-clamp techniques for high resolution current recording from cells and cell-free membrane patches. *Pflugers Arch*, 391: 85-100
- Hartmann L, Düer W and Briegel, HJ (2006). "Steady state entanglement in open and noisy quantum systems at high temperature". *Physical Review A* 74, 052304.
- Hasson U, Ghazanfar AA, Galantucci B, Garrod S, Keysers C (2012). Brain-to-brain coupling: a mechanism for creating and sharing a social world. *Trends in Cognitive Sciences*, 16 (2): 114-121.
- Hawking S (1988). *A Brief History of Time*. Bantam Dell Publishing Group.
- Hu, H and M. Wu (2010). Current landscape and future direction of theoretical and experimental quantum brain/ mind/ consciousness research, *J. Consciousn. Exploration& Research* 1: 888-897.
- Hu H and Wu M (2004). Possible roles of neural electron spin networks in memory and consciousness. *Cogprints ID 3544*, see also *NeuroQuantology*, 2006: 5-16.
- Jahn RG and Dunne BJ (2004). *Sensors, Filters, and the Source of Reality*. *Journal of Scientific Exploration*, 18(4): 547–570.
- Jahn RG and Dunne BJ, (2007). A modular model of mind/matter manifestations. *Explore*, 3:311-24, reprinted from *J. Scientific. Exploration*, 2001.
- Jensen CS, Rasmussen HB, Misonou H. (2011). Neuronal trafficking of voltage-gated potassium channels. *Mol Cell Neurosci*; 48: 288-297.
- John ER (2001). A field theory of consciousness. *Consciousness and Cognition*, 10: 184-213.
- Kak S (2009). *The Universe, Quantum Physics and Consciousness*. *J.Cosmol.* 3: 500-510.
- Kamenshchik A and Teryaev OV (2013). Many-Worlds Interpretation of Quantum Theory, Mesoscopic Anthropic Principle and Biological Evolution. *NeuroQuantology*, 11, suppl. 1: 129-148
- Kaivarainen A. (2005). Hierarchic model of consciousness. *NeuroQuantology*, 3: 180-219.

- Kafagos M and Draganescu M (2000). Towards an integrative science.  
[http://www.racai.ro/~dragam/TOWARD\\_1.HTM](http://www.racai.ro/~dragam/TOWARD_1.HTM)
- Kafatos M (2009). Cosmos and Quantum: Frontiers from the Future. *J. Cosmol.* 3: 511- 528.
- Kauffman S (2012). Is there a "poised realm between quantum and classical worlds?"  
[http://stuartkauffman.com/index\\_25\\_1612352741.pdf](http://stuartkauffman.com/index_25_1612352741.pdf)
- Kelso JAS (1995). *Dynamic patterns: The self-organization of brain and behavior.* Cambridge MA:MIT Press.
- Kiebel SJ, Dauizeau J, Friston KJ (2008). A hierarchy of time-scales and the brain. *PLoS Computational Biology*, 4 (11) e1000209.
- Kim J (2005). *Physicalism, or something near enough.* Princeton University Press. Princeton and Oxford: 1-174.
- King CC (2003). Chaos, Quantum-transactions and Consciousness, *NeuroQuantology*, 1(1): 129-162.
- Korf J and Gramsbergen JB. (2007).Timing of potential and metabolic brain energy. *J Neurochem.* 103(5):1697-1708.
- Korf J (2010). The isoenergetic brain: the idea and some implications. *Neuroscientist* 16 (2): 118-24.
- Korf J (2012). The Mind as an Emerging Configuration of the Personal Brain. *Dial Phil Ment Neuro Sci*; 5(1): 21-24.
- Korf J and Meijer D K F (2013). Complementary concepts on quantum information flow and isoenergeticity of the brain. Submitted for publication.
- Kühlbrandt W (2004). Biology, structure and mechanism of P-type ATPases. *Nature Reviews Mol Cell Biol*; 3: 282-295.
- László, E (2007).*The Akashic Field.* New York: Dutton.
- LeDoux J (2003). *Synaptic Self How Our Brains Became Who We Are.* Paperback Penguin Books: 1-250.
- Libet B (2006). Reflections on the interaction of the mind and brain. *Prog Neurobiol.* 78(3-5): 322-326.
- Li, J and Paraoanu, GS (2009). "Generation and propagation of entanglement in driven coupled-qubit systems". *New Journal of Physics* 11, 113020.
- Lima, S Q and Miesenböck G (2005). "Remote control of behavior through genetically targeted photostimulation of neurons". *Cell* 121 (1): 141–52. doi:10.1016/j.cell.2005.02.004. PMID 15820685.
- Lloyd S (2006). *Programming the Universe: A Quantum Computer Scientist Takes On the Cosmos,* Knopf Doubleday Publishing Group (Random House).
- Lloyd S (2011). Quantum coherence in biological systems. *J. Phys.: Conf. Ser.* 302, 012037 *Journal of Physics: Conference Series* 302 (2011) 012037 doi:10.1088/1742-6596/302/1/012037
- Mangia S, Giove F, Tkáč I, Logothetis NK, Henry PG, Olman CA, Maraviglia B, Di Salle F, Uğurbil K. (2009). Metabolic and hemodynamic events after changes in neuronal activity: current hypotheses, theoretical predictions and in vivo NMR experimental findings. *J Cereb Blood Flow Metab.*; 29: 441-463
- Marcer, P J and Schempp W (1997). *Model of the Neuron Working by Quantum Holography* Informatica 21: 51 McFadden J (2001). *Quantum Biology.* Norton, New York 9-534
- Mavromatos NE, Nanopoulos (1995) Non-critical string theory formulation of microtubule dynamics and quantum aspects of brain function.  
<http://cds.cern.ch/record/282463/files/9505401.pdf>
- McFadden J (2007). Conscious Electromagnetic Field Theory. *NeuroQuantology*, 5: 262-270

- Meijer DKF (2012). The Information Universe. On the missing link in concepts on the architecture of reality. *Syntropy Journal*, 1: 1- 64.
- Meijer DKF (1989). Transport in the Hepatobiliary System. *Handbook of Physiology. Am. Phys. Soc.*, 3:717-758.
- Meijer DKF, Jansen PLM, Groothuis GMM (1999). Hepatobiliary disposition and targeting of Drugs and Genes. *Oxford Textbook of of Clinical Hepatology*, sect 1-13. vol. 1, Oxford University Press, 87-144.
- Menini A, Picco C, Firestain S (1995). Quantal-like current fluctuations induced by odorants in olfactory receptor cells. *Nature* 373, 435 - 437 (02 February); doi:10.1038/373435a0
- Minkowski H (1952). In: Lorentz HA, Einstein A, Minkowski H and Weyl H, (1952). *The Principle of Relativity: A Collection of Original Memoirs on the Special and General theory of Relativity*. New York: Dover.
- Mitchell ED and Staretz R (2011). The quantum hologram and the nature of consciousness. *Journal of Cosmology* 14:1-35.
- Murphy, N (2011). Avoiding Neurobiological Reductionism: the role of downward causation in complex systems. In: This chapter will appear in *Moral Behavior and Free Will*. <http://www2.lse.ac.uk/CPNSS/projects/orderProject/documents/Publications/MurphyHolyCross.pdf>
- Pauli W, (1994). *Writings on Physics and Philosophy*, ed. by C.P. Enz and K. von Meyenn. Springer, Berlin.
- Penrose R, (1989). *The Emperor 's New Mind*. Oxford University Press: 1-275.
- Penrose R and Hameroff S (2011). Consciousness in the Universe: Neuroscience, Quantum Space-time Geometry and Orch OR theory. In: *Cosmology of Consciousness. Quantum physics and the Neuroscience of Mind*: 51- 94 (selected from *J. Cosmology* vol. 3, 13 and 14.
- Pereira A (2003): The quantum mind/classical problem. *NeuroQuantology*, 1: 94- 118.
- Pereira A, Furlan FA (2007). Biomolecular Information, Brain Activity And Cognitive Function. In: *ARBS Annual Rev Of Biomdical Sciences*, 9: 12-29.
- Pessa E and Vitiello G (2003). "Quantum noise, entanglement and chaos in the quantum field theory of mind/brain states". *Mind and Matter* 1: 59–79.
- Pezzulo G, Barsalou LW, Cangelosi A, Fischer MH, McRae K, Spivey MJ. (2011). The mechanics of embodiment: a dialog on embodiment and computational modeling. *Front Psychol.* 2011;. *Philosophical Approach* (eds Juan José Sanguinetti, Ariberto Acerbi, José Angel Lombo)
- Pizzi, R, Fantasia A, Gelain F, Rosetti D, Vescovi A (2004). In: *Quantum Information and Computation II. Proceedings of SPIE 5436*, (ed.) Donkor, E.
- Plessner H (1928). *Die Stufen des Organischen und der Mensch. Einleitung in die philosophische Anthropologie*, Walter de Gruyter. Berlin Berlin / Leipzig 1928. (ed.1975)
- Popper KR and Eccles J C. (1977). *The self and its brain*. Springer International. Berlin, Heidelberg, London, New York.: 3-566.
- Potos EM Busemayer JR (2011). Formalizing heuristics in decision-making: a quantum probability perspective. *Front Psychology*; 2: 289. doi: 10.3389/fpsyg.2011.1100289
- Pribram K H and Carlton EH (1986). Holonomic brain theory in imaging and object perception. *Acta Psychologica*: 63: 175-180.
- Pribram KH and Gill MM (1969). Freud's "project" re-assessed. Preface to contemporary cognitive theory and neuropsychology. Basic books Inc., Publishers new York: 12-169.



- Price H (1995). *Time's arrow & Archimedes point*. Oxford University Press New York, Oxford: 3-260.
- Prigogine I (1997). *The end of certainty: time, chaos, and the new laws of nature*. The Free Press New York.
- Primas H (2009). Complementarity of mind and matter. in: *Recasting Reality*, Berlin. Springer: 171-209.
- Primas H (2003). Time-entanglement between mind and matter. *Mind & Matter*; 1: 81-119.
- Pusey MF, Barret J and Rudolph T (2012). On the reality of the quantum state. *Nature Physics*, 8: 475-478 <http://lanl.arxiv.org/abs/1111.3328>.
- Radin DI and Nelson R (2006). *Entangled Minds. Extrasensory experiences in the quantum reality*. New York: Simon & Schuster.
- Ricciardi, LM and Umezawa H (1967). "Brain and physics of many-body problems". *Kybernetik* 4: 44-48.
- Rosa LP, Faber J (2004) Quantum models of the mind: are they compatible with environmental decoherence? *Physical Reviews*, 70, 031902
- Rovelli C (1996). Relational Quantum Mechanics. *Int. J. of Theor. Phys.* 35: 16-37 [arXiv:quant-ph/9609002](http://arxiv.org/abs/quant-ph/9609002)
- Rueda A, Haisch B, (2005) Gravity and the quantum vacuum inertia hypothesis. *Ann. Phys. (Leipzig)* 14, 8: 479 – 498 / DOI 10.1002/andp.200510147
- Salari V, Rahnama M and Tuszynski J A (2010). On the Theoretical Possibility of Quantum Visual Information Transfer to the Human Brain. <http://arxiv.org/ftp/arxiv/papers/0809/0809.0008.pdf>
- Samal M K (2001). Speculations on a Unified Theory of Matter and Mind. [arXiv:physics/0111035](http://arxiv.org/abs/physics/0111035) [physics.gen-ph]
- Schrödinger E, (1986). *What is Life?* 1944. Eds: Pribram and Carlton
- Schwartz JM, Stapp HP, Beauregard M (2004). Quantum physics in neuroscience and psychology: a neurophysical model of mind-brain interaction. *Philosophical Transactions R Soc B*; 1598: 1-19.
- Searle J R (1992). *The rediscovery of mind*. MIT Press Cambridge, Mass 0-262-19321-3, 978-0-262-69154-3270
- Searle JR (2007). Dualism Revisited. *J Physiology (Paris)* 101: 168-178
- Searle JR (2000). Consciousness. *Ann Rev Neurosci* 23: 557-578.
- Smolin, L (2004) *Atoms of Space and Time*. *Sci. Am.* Febr.: 43-52
- Soon CS, Brass M, Heinze HJ, Haynes JD (2008). Unconscious determinants of free decisions in the human brain. *Nat Neurosci* 11: 543-545.
- Spivey MJ (2007). *The continuity of mind*. New York Oxford University Press.
- Spivey MJ (2012). The spatial intersection of minds. *Cogn Process.* Aug;13 Suppl 1:S343-6. doi: 10.1007/s10339-012-0520-6. PMID: 22843090
- Stapp HP (2009). *Mind, Matter and Quantum Mechanics*, Berlin-Heidelberg: Springer-Verlag.
- Stapp, HP (2012). Reply to a critic: Mind efforts, quantum zeno effect and environmental decoherence. *NeuroQuantology*,10: 601-605

- Stoyanov DS, Machamer PK and Schaffner KF (2012). Rendering clinical psychology an evidence-based scientific discipline: a case study. *Journal of Evaluation in Clinical Practice* 18: 149–154.
- Stoyanov DS (2010). The endophenotype project and the validation theory: integration of neurobiology and psychiatry. *Folia Med (Plovdiv)*. 52(1), 18-25.
- Tarlaci S (2010). A Historical View of the Relation between Quantum Mechanics and the Brain. *NeuroQuantology*, 8: 120-136
- Tegmark M (2000). The Importance of Quantum Decoherence in Brain Processes *Phys.Rev.E*61:4194-4206
- Tegmark M (2008). The Mathematical Universe. *Found Physics*, 38: 101-150
- Trueblood JS, Busemeyer JR (2012). A quantum probability model of causal reasoning. *Front. Psychology* 3: 138. doi: 10.3389/fpsyg.2012.00138.
- Tsai, H.C.; Zhang, F.; Adamantidis, A.; Stuber, G. D. et al. (2009). "Phasic firing in dopaminergic neurons is sufficient for behavioral conditioning". *Science* 324 (5930): 1080–4. Bibcode 2009Sci...324.1080T. doi:10.1126/science.1168878. PMID 19389999.
- Turenout M, Hagoort P, Brown CM (1998). Brain activity during speaking: from syntax to phonology in 40 milliseconds. *Science*.; 280: 572-574.
- Tuszynski JA. and Woolf N (2010). The Path Ahead. Introductory chapter in: *The Emerging Physics of Consciousness*. Springer verlag  
[http://www.newdualism.org/books/Tuszynski/Tuszynski-EPC-1\\_2006.pdf](http://www.newdualism.org/books/Tuszynski/Tuszynski-EPC-1_2006.pdf)
- Tuszynski JA and Woolf N (2010). *The Emerging Physics of Consciousness*. Springer verlag  
<http://doc.isiri.org.ir/documents/10129/21397/the+emerging+physics+of+consciousness.pdf.pdf>
- Ullman S (1991). Sequence seeking and counter streams: A model for information processing in the cortex. MIT artificial intelligence laboratory.  
<http://dspace.mit.edu/bitstream/handle/1721.1/6574/AIM-1311.pdf?sequence=2>
- Vannini A, Di Corpo U (2008) Quantum Models of Consciousness. *Quantum Biosystems*; 1(2): 165-184.
- Vattay G, Kauffman S, Niiranen S (2012). Quantum biology on the edge of quantum chaos. arXiv:1202.6433 (or arXiv:1202.6433v1)
- Vedral V, (2010). *Decoding Reality*, University Oxford Press, Oxford, U.K.
- Verlinde EP (2011). On the Origin of Gravity and the Laws of Newton. *JHEP* 04, 29.
- Vicari G (2009). Beyond Conceptual Dualism: Ontology of consciousness, mental causation, and holism in John R Searle's Philosophy of mind. *Value Inquiry Book Series* Amsterdam, New York NY Rudolphi, 196: 1- 192. ISBN 978-90-420-2466-3.
- Vitiello G (1995). "Dissipation and memory capacity in the quantum brain model". *International Journal of Modern Physics B*, 9: 973–989.
- Von Bertalanffy L (1950). An Outline of General System Theory, *British Journal for the Philosophy of Science*, 1: 139-164.
- Walach H, Römer H (2000). Complementarity is a useful concept for consciousness studies. A reminder. *Neuroendocrinology Letters*, 21: 221- 232.
- Walker EH (2000). *The Physics of Consciousness: The Quantum Mind and the Meaning of Life*. Perseus Press: Boston, MA.
- Wen W, He Y and Sachdev P (2011). Structural brain networks and neuropsychiatric disorders *Curr Opin Psychiatry* 24: 219-225.

- Wheeler JA (2002). Quotation from: Does the Universe Exist if We're Not Looking? Discover Magazine. Physics & Math / Cosmology June.
- Wheeler JA (1990). Information, physics, quantum: the search for links. Complexity, Entropy and the Physics of Information. Zurek, W H, Ed.; Addison-Wesley, Redwood City: 3–28.
- Wigner, E P (1992). As told to Szanton, Andrew The Recollections of Eugene P. Wigner. Plenum. ISBN 0-306-44326-0.
- Yasue K and Jibu M (1995). Quantum brain dynamics and consciousness, John Benjamins.
- Yu F H, Catterall WA (2003). Overview of the voltage-gated sodium channel family. Genome Biol 4: article 207.
- Zeilinger, A (2000). Quantum Teleportation. Sci. Amer. Febr.: 8-16
- Zizzi P (2006). Consciousness and Logic in a Quantum-Computing Universe. In: The Emerging Physics of Consciousness. The Frontiers Collection: 457-481, chapter 14, DOI: 10.1007/3-540-36723-3\_14, Springer, Berlin.