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Research Article

Non-linear Dynamics and Chaotic Trajectories in Brain-Mind Visual Experiences during Dreams, Meditation, and Non-Ordinary Brain Activity States

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Abstract

The present report discusses brain visual experiences in conditions of low degree of openness of the brain toward the environment, for example, while dreaming, during meditation, or in non-ordinary brain activity states such as under the effects of psychoactive substances, in the state of coma, or in other states of reduced sensory perception, among others. In the present report, for brevity, such states are referred to as brain-mind visual experiences, implying that such a visual activity is not one connected to the actual vision as in the state of wakefulness. In the dissipative many-body model, the criticality of the dynamics is enhanced in low openness brain states and is at the origin of movie-like sequences of images in visual experiences. These sequences and the abrupt shifts from one image pattern to another are depicted by chaotic trajectories through the memory space. Truthfulness and realism felt in the visual experiences are discussed in terms of the algebra of the doubling of the degrees of freedom in the dissipative model. In the present discussion,

a few aspects of the visual experiences of a subject during an Amazonian Ayahuasca ceremony are considered.

Keywords
Brain-mind visual experiences; dissipative quantum model of brain; memory states; chaotic trajectories; quantum field theory; models of cortical dynamics in perception; cognitive behavior

1. Introduction

The research on the dynamical laws underlying the rich phenomenology of biology has strengthened the interplay between physics and biology during the fifties and sixties of the past century. The research work conducted by Ilya Prigogine [1], and Herbert Fröhlich [2] pioneered the study of the role of dissipative systems and coherent boson condensation in biological systems through the use of the formalism of statistical mechanics, non-linear dynamical systems, and quantum field theory (QFT).

It was in this context that Ricciardi and Umezawa [3] proposed to study the neuronal dynamics within the mathematical frame of many-body physics. Early research works reported by Karl Lashley [4] and the subsequent ones by Karl Pribram [5] and Walter Freeman [6] were indeed indicating the necessity to supplement the studies focused on the properties of the single neuron and glia cell with the dynamical concepts of fields and many-body collective modes. In this context, the model developed by Ricciardi and Umezawa was extended by one of the authors (GV) to include the dissipative character of the functional activity of the brain [7].

Within the frame of the dissipative model, the aim of the present report is to account for the experiences of movie-like sequences of images in the functional activity of the brain, for examples in dreams or dream-like and sleeping states [8], during meditation, under non-ordinary states induced by psychoactive molecules (for example, DMT, i.e., Dimethyltryptamine, or N,N-DMT [9-11] which is closely related to serotonin, the neurotransmitter affected by a wide variety of psychedelics), perhaps under anesthesia, in certain coma states, etc. It is noteworthy, however, that the analysis presented in the present report is focused on the dynamical features that are common to the brain states during the above-stated conditions (dreams, meditation, anesthesia, etc.), and does not focus particularly on, for instance, dream activity, meditative activity, etc., nor is it focused on brain pharmacology. The interest is rather in the general dynamical mechanisms allowing these brain activities, i.e., the dynamical core shared by all these brain activities, despite their differences.

The present work demonstrates that the enhancement of the criticality of the dynamics in the low openness states of the brain is responsible for the movie-like sequences of images, scenarios, and events. Such experiences are globally referred to as brain-mind visual experiences for brevity. The locution ‘brain-mind’ is used to recall that the visual activity being referred to is not the one connected to the actual vision as in the state of wakefulness.

The dissipative model offers the unique possibility of working in the space of memory states and considering the trajectories in such a space depicting the movie-like sequences of the images

in the visual experiences. The model is able to account for laboratories observations, such as the formation of extended assemblies of neurons in the synchronous amplitude-modulated and phase-modulated oscillations, their irreversible sequences, duration, and size, the fractal self-similarity of the brain background activity, the power-law distribution of power spectral densities, etc. [6, 7, 12-15].

The present report is organized in the following manner. The dynamical approach to brain-mind visual experiences is presented in Sections II and III, wherein criticality, openness, and deterministic chaos in the complex brain activity are also discussed. Section IV discusses intentionality and the formation of meanings within the action-perception cycle, along with the truthfulness and realism aspects felt during the brain-mind visual experiences. Section V presents conclusive remarks. The main aspects of the dissipative model are summarized in Appendix A. The present discussion also refers to a few aspects of narration by a subject who participated in an Ayahuasca ceremony in the Amazon forest. This narration is presented in Appendix B.

2. Criticality and Openness of Brain Dynamics

It might be useful, to begin with a few essential features of the dissipative quantum model of the brain. Further details are provided in Appendix A.

The brain is permanently open to its environment, exchanging energy and information with it through the perceptive channels. Inputs reaching the brain produce, through the action-perception cycle [13, 16], responses that are aimed at the best being-in-the-world of the subject, i.e. to reach the equilibrium through the balancing of the fluxes of energy, information, etc. The brain identifies in the environment, the sources, and the sinks for its energy requirements and waste, respectively. The environment, therefore, appears to be its complement in the in/out (time) mirroring of fluxes, its *Double*. The description of the system and its environment as a closed whole implies doubling of the degrees of freedom of the system, i.e., $A_{\mathbf{k}}$: $A_{\mathbf{k}} \rightarrow A_{\mathbf{k}} \times \tilde{A}_{\mathbf{k}}$, where $\tilde{A}_{\mathbf{k}}$ denotes the degrees of freedom of the environment and $\mathbf{k}$ denotes the momentum ($A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ actually describe the dipole correlation modes and their time-reversed copies, respectively; cf. Appendix A).

A distinctive feature of QFT, and consequently of the dissipative model, is the existence of an infinite number of state spaces for the system, each one being physically distinct from [and inequivalent to] the others. It is possible to record memory in the minimum energy state (the vacuum or ground state) of each of these state spaces. Memory recording is achieved through a process of condensation of the quanta $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ in the vacuum, which appears to be a coherent state with a definite fractal dimension [17]. Since $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ describe the dipole correlation modes, the memories are described as correlation patterns (ordered patterns). The collection N of the numbers $N_{A_{\mathbf{k}}}$ and $N_{\tilde{A}_{\mathbf{k}}}$, [for any $\mathbf{k}$, $N = \{N_{A_{\mathbf{k}}}, N_{\tilde{A}_{\mathbf{k}}}, \text{with } N_{A_{\mathbf{k}}} = N_{\tilde{A}_{\mathbf{k}}}, \forall \mathbf{k}\}$], is the specific code of each memory (N is referred to as the memory order parameter). Memory "recalling" is achieved through the excitation of these quanta from the vacuum.

The use of EEG, ECoG, fNMR, and other techniques in neuroscience has revealed the formation of assemblies of myriads of neurons undergoing synchronous amplitude-modulated (AM) and phase-modulated (PM) oscillations. These AM and PM oscillation patterns are described in the model as coherent condensation patterns of neuronal long-range correlations in the brain ground

state. Cortical activity is observed to go through these "multiple spatial patterns in sequences during each perceptual action that resemble cinematographic frames on multiple screens" [18-20].

Establishing links with the environment transforms into a *dialogue* between the self and the Double in a dialectical process of *identification* vs. *distinction*. It has been proposed that the act of consciousness resides in such a dialogue with the Double [7, 21].

It has been shown [22] that, as the number n of the links increases (or decreases), the allowed size for the correlation domains increases (or decreases). This is consistent with the observations demonstrating that the more the brain associates with its environment, the more are the neuronal connections formed [23].

The physical inequivalence (orthogonality) among the memory states ensures that the corresponding [different] memories do not interfere with each other, and any "confusion" among these memories cannot arise. One may demonstrate that orthogonality is strict when the number of links n is maximum. Then, a phenomena such as "fixation" or "being trapped" in a certain specific memory state (in one attractor in the attractor landscape; cf. Appendix A) may occur. However, in practice, it is quite difficult to reach the maximum number of links with the environment. A higher or lower degree of openness may be reached according to several factors, occasional (such as sleeping, drug consumption, meditation, etc.) or the ones due to the age (such as during the childhood or the older ages).

On the contrary, for reduced openness, the model predicts smaller memory domains and a 'smoothing' of the physical inequivalence among the memory states along with an enhanced possibility of *phase transitions* (*criticality*). Then, the "paths" or trajectories through the memories may occur, producing "association" of the memories, or in certain cases "confusion" of memories. Although, in a dynamical regime of *criticality*, minimization of free energy at each time *t* is continuously pursued [7].

In a 'normal' state of openness, the possibility of memory flows is allowed only up to a certain degree. This is the state of "attention", of being *open* to what is occurring around us, the awareness of the *Now* (the warning inside the Metro reads: "please pay attention, *mind the gap!*").

Therefore, it is concluded in the present report that, when the number of links becomes minute such that the system almost fails to connect with the environment and is almost closed on to itself, an interrupted "flow" of memories may occur, and it becomes possible to "travel" through the memory states; the dynamics is almost completely dominated by criticality and movie-like sequences or abrupt shifting of images may be experienced.

3. Deterministic Chaos in the Complex Brain Activity

In the cases of extremely reduced openness considered earlier, the association or confusion of memories might lead to deformation or corruption of the memory code components $N_{A_{\mathbf{k}}}(and\ N_{\tilde{A}_{\mathbf{k}}})$, for few or several $\mathbf{k}$s, resulting in "pieces", "bits", or "debris" of memories [7, 21], which might be recalled in movie-like sequences, outside of their original recording context and assembled in certain emerging/new contexts.

Flows of images associated to such memory debris are observed to occur in dreams [7, 21, 22, 24-27], in certain altered states of the brain dynamical regime such as under the effect of anesthesia [28], and in certain stages of deep meditation [29, 30]; this may also occur in association with slow breathing techniques [31] or whenever the openness is indeed reduced such

as in response to psychoactive substances (see the narration reported in Appendix B). Such visual experiences may also occur under the influence of external rhythmically modulated stimuli, in space (visual rhythms) or in time (musical rhythms). The repetitive persistence of these stimuli may become dominant to the point of excluding any other different input, thereby reducing the openness (similar to what happens during hypnosis).

Interestingly, in the present work we find that there exist common dynamical features underlying the different conditions in which the brain-mind visual experiences occur. Although these conditions refer to distinctly different phenomena and behaviors (ranging from dreaming to meditation, anesthesia, psychoactive substances, among others), all of these conditions are characterized by a low level of openness of the brain toward its environment, which in turn implies the criticality of the dynamics, as discussed in the previous section. The additional result that is derived from the model is that the weak inputs or noisy perturbations drive the system through the memory states and, therefore, play an important role in the complex brain activity, in general as well as particularly in the brain-mind visual experiences.

In this context, it is being remarked that deterministic chaos is a crucial feature of neuronal dynamics [12, 14, 32-36]. As stressed by Freeman, "The chaos is evident in the tendency of vast collections of neurons to shift abruptly and simultaneously from one complex activity pattern to another in response to the smallest of inputs. This changeability is a prime characteristic of many chaotic systems. In fact, we propose it is the very property that makes perception possible. We also speculate that chaos underlies the ability of the brain to respond flexibly to the outside world and to generate novel activity patterns, including those that are experienced as fresh ideas" [32].

Consistent with these remarks by Freeman, it has been demonstrated that trajectories through coherent states are indeed classical chaotic trajectories [17, 37]. Therefore, even slight changes in the initial conditions may lead to diverging trajectories. For instance, in dreams or dream-like and sleeping states, where inputs are not so strong [8, 27, 38-43], the result is the occurrence of sudden shifts from one memory to another due to the chaoticity of the dynamics favored by its enhanced criticality. As a consequence, one may experience abruptly changing scenarios and feel overwhelmed by a series of emotions. These "debris" of memories might even be felt by the dreamer with the flavor of new, never-lived situations, as not belonging to his past, in that intricate blend or mix, presenting sometimes an obscure core, as the center of a vortex, which Freud has called [44] the "dream navel" [21].

It is also interesting that the common experience is that pain is absent in dreams, where the model predicts small correlated domains. On the other hand, it is known that the pain threshold may change under the effects of certain specific drugs, such as morphine, which may indeed be reducing the extent of neuronal connections.

In the case of anesthesia, after the patient resumes to the waking state, a sense of surprise that a period of time has passed since the effects of anesthesia commenced is frequently reported. This is clearly due to the patient's detachment from the environment during the period under anesthesia. Anesthesiology studies appear to suggest that in the anesthetic recovery stages, certain dreaming or dream-like activity occurs [28, 45].

It is interesting to ask whether the brain-mind visual experiences occur in certain comatose states as well, the mechanisms of which are not yet completely understood. Excluding the cases of extreme damage to the brain, closure to the external world leads to the conjecture that the brain-mind visual experiences may also occur in certain comatose states as well as in vegetative states,

which are mediated by decreased coordinated activity among the small, short-lived, and unstable neuronal assemblies [46].

It should be noted, for the sake of completeness, that the formation of extended correlation domains may also be inhibited by a rapid succession of strong perceptual inputs which might dominate the emotional state of the subject; the subject's arousal may reach extremely high levels, preventing him/her from focusing attention on any of the inputs. This may also occur when neuronal recruitment is enhanced by certain chemicals. Several competitive domains are formed in short time intervals, and their inflation would correspond to lack of information "in the average". As a consequence, the subject is unable to respond to these inputs coherently, which translates to a deficiency in his/her functional relational activity [21].

In summary, in the afore-stated non-ordinary states, in the condition of quasi-closure, the subject's response to the external noisy inputs is reduced considerably, and his/her level of awareness of the environmental changes is quite low or even absent in certain scenarios. Nevertheless, in such a state, the smallest of perturbations that are not filtered out may induce chaoticity in brain behavior. In the absence of reactive feedback, the subject becomes a "spectator of himself", in a process of identification with his Double no longer distinguishable from himself, which occurs in the open, normal state of awareness.

4. Intentionality and Meanings, Truthfulness and Realism in Brain-Mind Visual Experiences

In the brain's functional activity, one crucial element to be considered is the intentionality, which enters as a characteristic ingredient in action-perception cycle.

Pribram [5, 47] stressed that there always exists a content of "attention" in perception and of "intention" in action. There is an active perception in one's relation with the world, guided by one's changeable volition and intention in pursuing one's best to-be-in-the-world. Freeman remarked that neuronal activity serves "as a unified whole in shaping each intentional action at each moment" [48]. The brain constructs *meanings* out of perceptual experiences. Meanings arise from the dynamic correlations in the landscape of the attractors constructed out of the brain's perceptual history [13, 49-52], and are the basic substance of the subject's identity, manifesting themselves in the "intended actions" following the "active perception."

Such a profound intentional component emerges as "meaningfulness" in the brain-mind visual experiences as well. It might "guide" the chaotic trajectories leading to the "rearrangement" of memory traces into fresh scenarios and events which may even appear completely disjointed from the waking experience. Such traces are, however, related to the waking experience through the deep red thread of intentionality and meaningfulness, univocally associated to the subject's identity, to the "affectivity [which] is the primordial form of subjectivity" [53]. This profound intentional component may represent the 'unconscious wish', postulated by Freud, in dreams [44], and has been recognized by Globus in the lucid dreaming phenomenon [54, 55], where the dreamer has a certain form of control over the dream scenarios. This is why the brain-mind visual experiences carry relatively hidden, veiled meanings. According to the arguments presented in the previous section, visual scenarios are fed with "pieces" or "debris" of the previously recorded memories. Certain feelings or context settings might be anticipated in the brain-mind visual experiences on the basis of a persisting intentional component, and may then (re-)appear in the future perceptual experiences (cf. the narration in Appendix B). This is not to talk of any

precognition capability or of violation of causation. It is merely to state that the correlations in the attractor landscape originating from the brain-mind visual experiences may, at certain times, find occasional resemblance to the correlations originating from the active perceptual experiences in a future waking state.

Therefore, in the movie-like flow of images in non-ordinary states, dreams, and other brain-mind visual experiences, the recollection of the existing correlations in the attractor landscape may indicate unforeseen contexts, giving rise to the problem of “truthfulness" or “realism" of such contexts and of their meanings as felt by the subject within the boundaries of his/her beliefs, knowledge, and emotional states.

In order to consider this point, it is observed that the algebra of the doubling of the degrees of freedom implies that $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ are entangled modes [37, 56]. As a consequence, any ‘observation’ of the $A_{\mathbf{k}}$ modes is, in fact, dependent on the $\tilde{A}_{\mathbf{k}}$ modes, which thus constitute the “address" for the $A_{\mathbf{k}}$ modes, and vice-versa. The conclusion is that the brain modes and the mental (Double) modes cannot be separated, i.e., there exists no separation between mental activity and brain activity. This implies that a sort of “truth-evaluation-function" is implicit in the dissipative model formalism [7, 57-59]. In other words, in the dialogue with one’s Double, the subject finds the possibility of confirming or rejecting the truthfulness of one’s working hypotheses. One’s “confidence" in one’s perceptual experiences is based on the process of feedback-adjustment-feedback, in the continuous matching with the Double. Intentional actions are planned in accordance with the hypotheses provided by the Double through the reconstruction of past perceptual experiences. The experience of changes in perception following repeated trials in the action creates the perception of time and causation [59, 60].

It is stressed that each step of brain activity characterized by criticality is formally expressed by the free energy minimization condition. Recording a memory is the consequence of a process of breakdown of symmetry induced by the perceptive stimulus (cf. Appendix A). In one’s “active” selection among the perceptual inputs, one focuses “only on those inputs that one judges worthwhile to expend one’s energy for, the ones to which a “value” is attributed, those which involve one’s emotions [21], one’s affectivity” [53]. Using these selected inputs, one’s memory (non-oblivion) is constructed, which depicts one’s identity and one’s “truth”. Non-oblivion and truth coincide in the ancient Greek $\alpha\lambda\eta\theta\epsilon\iota\alpha$ [21]. The landscape of the attractors constructed in the previous experiences is reshaped in this manner with any fresh input, and meanings are constructed. Memory is the memory of meanings [56, 61].

All these features are present in the movie-like sequences in non-ordinary states, dreams, or dream-like states.

In brain-mind visual states, the perception of time is conditioned by the (quasi-)closure of the subject’s state. The lack of synchronization to a reference clock manifests in the loss of time-ordering of the events as recorded originally in the waking perceptual state. Mixing of memory traces with the emergence of fresh scenarios occurs then. The feelings of truthfulness and realism of these fresh scenarios derive from the fact that the traces of memories are actually traces of meanings, interwoven together by the red thread of intentionality stated earlier; they carry the seal of the subject’s identity.

Truthfulness and realism are further strengthened by the previously-stated matching, almost identification, of the self with its Double in the low level of openness. The (quasi-)closure of the

subject and his/her emotional state are interrupted by the "waking-up" experience, thereby restoring the openness of the system and the awareness of the distinction between the self and the Double (*It was only a dream!*).

In the experience presented in Appendix B, the subject reported the "appearance of a gray painting, similar to the screen of an old black-and-white TV when the signal was lost; when that strange TV in the middle of the Amazon could "retune", a new scene appeared". Interestingly, this kind of "blacking-out of the signal" might find correspondence with the phenomenon of "null spike" (cf. Appendix A), which is observed to separate two behavioral frames in the brain activity [16]. Null spikes represent singularities appearing in the transitions between different dynamical regimes (*phase transitions*) corresponding to different configurations of correlations in the attractor landscape. The null spike behaves as a caesura, similar to the shutter diaphragm of old fashioned cameras. In the transition, the coherence of the condensate vanishes (null spike), and soon after, another coherent condensate initiates [62]. The phenomenon may be observed through an EEG in normal brain activity [18, 63]. In brain-mind visual experiences, null spike corresponds to the closing of a movie-like flow, clearing the field, and opening of another movie-like flow.

5. Conclusion

Using the dissipative quantum model of the brain, the brain-mind visual experiences occurring during non-ordinary states, dreaming activity, meditation, and other low openness functional activities of the brain were discussed.

The low degree of openness of the brain in the afore-stated states induces enhancement of the criticality of the dynamics, which leads to enhancement in the possibility of "traveling" within the memory space through chaotic trajectories. Movie-like sequences of images and abrupt changes in the relatively familiar scenarios are generated consequently in the form of brain-mind visual experiences.

The feeling of truthfulness and realism associated with these visual experiences is derived from the quasi-identification of the self with the Double, a trace of the continual matching in the feedback-adjustment-feedback process occurring within the intentional context of the state of wakefulness.

It was conjectured that a similar description might also be applied to cases under anesthesia and certain pathological cases, such as certain states of coma and conditions where the openness of the brain toward the environment is reduced.

The existence of an infinite number of unitarily inequivalent representations of the canonical commutation relations in QFT, on which the space of the memory states is constructed, has been crucial to the analysis conducted in the present work.

According to the findings of the present work, a relatively severe closure of the brain to the world may produce a dramatic lack of "meaningfulness" within the subject's action-perception cycle. Such conditions of closure occurring for certain reasons in the subjects during their wakefulness state might be the actual reason underlying the subject's deficit in social communication and interaction, with the exhibition of restricted, repetitive patterns of behavior, interests, or activities. It would be interesting to ask the question whether brain-mind visual

experiences occur in such cases as well. The investigation of this query should be considered for future research, with the inclusion of autism spectrum disorder, if possible.

The present research work is dedicated to the memory of Karen Sharon and Eliano Pessa. Karen, during her association with the research work of Karl Pribram and Walter Freeman, contributed to the cultural atmosphere and dense activity at the foundation of modern neuroscience. Eliano, with his deep insights and expertise in neural networks and non-linear dynamical systems, provided important contributions to the formulation of the dissipative model.

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Additional Materials

Appendix A. The Dissipative Quantum Model of the Brain-a Summary.

This section provides, for the sake of completeness, a summary of the dissipative model. Refer to [7, 13, 64] for the mathematical formalism and additional details regarding the model.

The brain exchanges energy and information with the environment to which it is open. The water molecules of the bath in which the cells and all the cellular structures are immersed are characterized by their electric dipoles. The dynamical symmetry of a system comprising randomly oriented dipoles is the spherical continuous $SU(2)$ symmetry (three-dimensional rotation symmetry). The dissipative quantum model of the brain considers neurons, glial cells, and the other biological units to be classical objects. In this regard, the dissipative model is substantially different from the other quantum models of the brain.

In the dissipative model of the brain, the perceptual inputs received by the brain induce the breakdown of the $SU(2)$ symmetry. According to general theorems of QFT [65-68], spontaneous breakdown of symmetry (SBS) induces the formation of long-range correlations among the system components, and the formation of these correlation waves is ruled by the inner dynamics of the system (which is why the symmetry breakdown is regarded as spontaneous). The quanta associated with these correlation waves are the Nambu-Goldstone (NG) quanta. In the case considered here, the electrical dipoles of the water molecules enter in a coherent oscillation regime [7, 69], and the NG quanta $A_{\mathbf{k}}$ are referred to as the dipole wave quanta (dwq).

The system's ground state or vacuum (the minimum energy state) is characterized by the *coherent* condensation of these dwq in domains, the size of which is controlled by the degree of openness of the brain to the environment. The coherent condensation of dwq promotes and facilitates the formation of the observed AM and PM assemblies of myriads of neurons oscillating coherently. The $A_{\mathbf{k}}$ modes are referred to as the system's degrees of freedom.

The dwq condensation produced in response to a given input serves as a code N for the input information and represents the recording of its memory in the ground state of the brain (the "memory state"). Memory "recalling" is then achieved through the excitation of the dwq condensed in the vacuum, in response to input similar to the one that caused their condensation in the first place [3].

A crucial point is that an infinite number of physically (unitarily) non-equivalent state spaces or representations of the canonical commutation relations exist in QFT, each one with its own vacuum state, such that in each one of these, it is possible to record different information with code N.

A huge (infinite, in principle) memory capacity is, therefore, possible [7]. The manifold of the representations forms the landscape of the attractors (the vacuum states).

In each representation, the conditions for free energy minimization are satisfied. Transitions through these representations are induced through variations in the entropy operator. When the coherence weakens, "the wave packet terminates with a null spike, clearing the field and opening the way for the next wave packet" [62].

The openness of the brain toward its environment is described through the introduction of the doubling of the system's degrees of freedom, $A_{\mathbf{k}} \to A_{\mathbf{k}} \times \tilde{A}_{\mathbf{k}}$, where $\tilde{A}_{\mathbf{k}}$ denotes the environment's degrees of freedom. In the 'closed' system $\{A_{\mathbf{k}}, \tilde{A}_{\mathbf{k}}\}$, the fluxes of energy, information, etc. are balanced, and the free energy is minimized at the equilibrium.

The algebraic structure belongs to the q-deformed Hopf algebra. Changes in the deformation parameter $q_{\mathbf{k}}$, which governs the coherent condensation density, its fractal dimension, and the system entropy, correspond to the critical phenomenon of transitions from one representation to another, from "memory to memory" (*criticality*).

The memory code or the "order parameter" N is given by the collection of the numbers $N_{A_{\mathbf{k}}}$ and $N_{\tilde{A}_{\mathbf{k}}}$ of the $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ modes, respectively, which are condensed in the memory state; for each $\mathbf{k}$, $N_{A_{\mathbf{k}}} = N_{\tilde{A}_{\mathbf{k}}}$. It is because of coherence that N behaves as a classical field, a field independent of quantum fluctuations, even though it is of quantum origin. Coherence ensures the possibility of "change of scale", from micro- to macro-scale, from quantum to classical.

The states of the system $\{A_{\mathbf{k}}, \tilde{A}_{\mathbf{k}}\}$ are entangled (squeezed) coherent $SU(1,1)$ states, which are also finite temperature states. The entanglement is due to a phase-mediated long-range correlation between the $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ modes [37, 56].

The brain finds in its environment, the sources and the sinks for the exchanged energy, information, etc., i.e., what is 'going out' of the system is 'going in' to the environment and vice-versa. The opposite sign of the time variable describes the "in ↔ out" exchange for the two (the brain and the environment). Therefore, the mode $\tilde{A}_{\mathbf{k}}$ is the "time-reversed" copy of $A_{\mathbf{k}}$. The environment is then depicted as the "time-reversed image" of the system (or vice-versa). It is denoted as the *Double* of the system [7, 13, 21]. Time emerges as observable in the process of time mirroring with the Double.

In conclusion, the "collection of memory states" constitutes a manifold of coherent states (a landscape of attractors). Paths through these memory states may occur as time evolves, and different scenarios may be created in accordance with the different degrees of openness of the brain. These paths are demonstrated to be classical chaotic trajectories [17, 37].

The brain submits the object of its perceptual experience to a process of generalization (elimination of details unnecessary to that perceptual context) and abstraction (association to a category). In mathematical terms, this implies that the experience is situated in a specific attractor within the attractor landscape. In case of the absence of an attractor where a particular experience could be situated conveniently, the brain creates a new attractor. No perceptual

experience is ever added to the landscape as a new item is added to a list of items. On the contrary, the whole attractor landscape is reshaped by the new experience, generating meanings represented by the correlations among the recorded perceptual experiences. Memory is not the memory of information, rather the memory of meanings. The inputs received through the perception channels induce, as a response, the subject's intentional action on the environment, aimed to achieve his best to-be-in-the-world. Consequently, novel perceptual experiences arise, again leading to new intentional actions, and the cycle repeats. The intentionality of the action is founded on the hypotheses that the brain is capable of formulating. The action also has the value of a test of these hypotheses. It may, therefore, create confidence in the acquired knowledge (truthfulness), which leads to the addition of significance to the action, meaningfulness to the relation with the Double, and feelings of realism of emotional and perceptual states [52, 59].

Driven by dissipation, "brains generalize to other brains like themselves and then to animals and objects" [60] entering into those "affective states, that not only influence our behavior in a flexible way, but alter our conscious field, giving rise to specific feelings or moods, which constitute the first form of self-orientation in the world" [53]. Shared with the other systems in nature, the basic coherent character of the dissipative dynamics of the brain acquires the flavor of an [Jungian] archetype, shaping the affective relations with the Double. Consciousness, therefore, emerges as a "manifestation of the dissipative quantum dynamics of the brain" [7, 21].

Appendix B. The Narration of a Case of Brain-mind Visual Experiences Induced by Psychoactive substances.

This Appendix presents the narration of the experiences of a subject (a European adult woman, who is a researcher in the field of psychology), who traveled through the Amazon forest four years ago in order to spend some time at the Mayantuyacu center. At the center, she met Maestro Juan Flores and participated in a ceremony involving Ayahuasca, a brew regarded to have the capability of inducing brain-mind visual experiences.

Prior to commencing the narration, it is important to recall that the vegetal substances containing DMT, such as *Psychotria viridis* that grows in the Amazon forest, are among the main ingredients of Ayahuasca. DMT is present in a number of different natural sources, a few of which are of animal origin, such as in the Sonoran desert toad (as 5-methoxy-N,N-dimethyltryptamine or 5-MeO-DMT) [70-72]. Isolation of DMT from the human blood and urine has also been reported previously [73]. Julius Axelrod (Nobel Prize winner for Medicine in 1970) reported the presence of DMT in the human brain tissue [74]. Among the endogenous neurotransmitters and neuro-hormones [75-77], DMT is unique as it is a molecule sufficiently small to pass through the blood-brain barrier. The altered states of consciousness induced in response to this drug have been compared to highly mystical experiences [78].

The narration: "My journey to the Amazon forest was a long trip. When looked at from above, the Amazonian rivers resemble large snakes, are brown and sinuous, move slowly, and are populated by animals and mangroves along the banks. In order to reach the Ashanika center named Mayantuyacu, one has to walk for a few hours across the jungle, encountering millennial trees, butterflies of a never-seen-before blue color which are referred to as "morpho" and which love to hide from and chase each other similar to little spirits. The temperature in the forest exceeds 30 ℃, and the humidity is quite high. The top of the hill allows a view of the center of

Mayantuyacu, which stands out against the horizon, surrounded by a cloud of steam produced by a small stream that flows next to it, with temperatures that oscillate between 27 ℃ and 94 ℃ (Note by the authors: [79–81]).

The days at the center pass slowly. All the people in Mayantuyacu sleep inside small structures placed around the maloca, a helical space dedicated to rituals and therapeutic activities. Juan Flores teaches with plants that have been used for thousands of years in the Ashanika tradition, the ethnic group to which he belongs. Flores is a master, as was his father, and knowledge, as in traditional indigenous medicines, is transmitted orally.

Trampling a square meter of land implies simultaneously crushing a hundred different plant species that could be selected and prepared in the Mayantuyacu "laboratory"; certain plants are used for headaches, while others are used to heal wounds.

The Amazon is the largest open-air pharmacy available to mankind, and its heritage is being increasingly put at risk by the global developments. The lungs of the Earth are at the risk of extinction because of the greed of the world from where I come; despite this, its custodians, including Flores, share with us, their millennial knowledge. Indeed, the decision of the necessity of this sharing was undertaken by plants themselves, says Flores. I, however, wonder how this inter-species communication is possible? Juan just smiles when someone asks these questions.

It is said that there are plants that are master plants capable of exhibiting the properties and characteristics of all the other plants.

I decided to participate in the ceremony with the Ayahuasca, a "master plant of visions". This plant is also used in the initiation rites of adolescents, as it allows them to gain the knowledge that could be useful in the present and future life.

The ceremony begins with a purification ritual; there is a plant with fragrant wood, the smoke of which is spread inside the maloca; all the participants are sitting in a circle in silence.

In the dark, the voice of Flores, who sings a song titled "icaro", or the vibration of each plant, rises. The master plant of visions is actually a liquid with the taste of licorice, which he hands to each participant in a small cup.

When Juan sings the song, something special happens to me; from the darkness of the maloca, a toroidal shape emerges in front of me, almost inviting me to cross it. I close my eyes. I approach it, remaining seated, and my body perceives a feeling of suction for a few moments. It feels as if my body's cells were squeezed into a narrow space. On the other side of the funnel, I open my eyes and there is another vision: it is daytime and nature appears different, as if suddenly animated, vivid. I remain aware of who I am and where I am, although, in front of me, the frames of a film begin to flow increasingly: an Amerindian dressed in white shows me the west coast of the United States, and there is music playing, different from the one I was hearing before, may be it's the sound of his flute, I'm not sure. Another space, another time.

Suddenly, in front of me, certain images begin to take form, as if I am in a journey back in time. I see a table where Jung and Einstein are sitting. The two are quietly discussing physics and synchronicity, and Einstein tells Jung that time does not exist.

Years later, emerging unharmed from a car accident in the United States, I bought a book with a captivating title, *Sinchronicity*, to keep me company and to overcome the shock of the accident. In the first few pages of this book I read, with a shiver down my spine, the report between Jung and Einstein, discovering that the encounter which was revealed to me by the Ayahuasca, in which Jung had discussed with Einstein time and synchronicity, had indeed historically happened, as it

was written in that book [*Synchronicity: An Acausal Connecting Principle* {Collected Works of C. G. Jung, vol.8, Paperback, 2010, C. G. Jung (Author), R. F.C. Hull (Translator), Sonu Shamdasani (Foreword)}]: ≪ Later in his life, Jung traced his idea of synchronicity to the influence of Albert Einstein, who held a professorship in Zurich in 1909–1910 and again in 1912–1913. Jung wrote: "Professor Einstein was my guest on several occasions at dinner. These were very early days when Einstein was developing his first theory of relativity, [and] it was he who had first started me off thinking about a possible relativity of time as well as space, and their psychic conditionality. Over thirty years later, this stimulus led to my relation with the physicist Professor W. Pauli and my thesis on psychic synchronicity".≫.

Today, it would not be wrong if I say that the images of that vision have profoundly influenced my subsequent research activity. The accident I just referred to occurred during a trip to California, which was directed by that first scene I had witnessed. I was going to San Francisco to meet the researchers who were, and still are, working on the theme of consciousness and its states, including the non-ordinary ones.

The most amazing thing for me was that during that first trip overseas, I came across the evidence that the images of the Amazonian vision were not just a fruit of my imagination, and rather corresponded to historical reality. If so, then that substance with a bitter taste similar to licorice had allowed me to take a journey back in time. Indeed, in the indigenous context, Ayahuasca is an "initiatory plant" administered to young people in a complex ritual system, enabling them to take a "journey" not just in their past, rather in the future as well, which allows them, in the moments of crisis, to see which is the right path.

These considerations, however, I could make only later on. My vision was not limited to the scene of Jung and Einstein. The frames followed one another similar to a slow-motion movie, and the scenes were interspersed with the appearance of a gray painting, similar to the screen of an old black-and-white TV when the signal was lost; some of you might remember the knurling and the underlying buzz that remained until the connection was resumed. When that strange TV in the middle of the Amazon could "retune", a new scene appeared, coming from who knows where.

After Jung and Einstein, it was the turn of a nautilus (a spiral-shaped shell), with the word "mira la forma" next to it, which means "observe the shape" in Spanish.

What shape should I observe? All of a sudden, I heard a noise of machinery. I was always aware of being where I was, and I could not understand its origin. Was all this a figment of my imagination? Was it just a hallucination? Was I really watching a movie that someone had concocted for me? There was no time to find an answer to these questions. The movie is three-dimensional, and now I see things "from above". Below me, a new scene emerges: an enormous horizontal device, of which we could also see the interior, with a hexagonal shape. Several people are busy around it, while I do not understand what they are doing.

Years later, I had the opportunity to visit the C.E.R.N. of Geneva, where the subatomic particles and the famous Higgs boson are studied. There, I realized that what I had seen from above, during that vision, was just a particle accelerator, of which at that time, I did not know the slightest thing about.

The scenes of the vision had all been interesting, the most interesting things I had ever seen so far. At one point, still within the vision, the scene had moved to a mountainous environment; the images had defined themselves further to allow me to recognize the profile of the sacred mountain, the Machu Picchu, which I had already had the opportunity to visit years before.

However, the vision depicted it to me in the past. A small indigenous woman dressed in white, quite young, little older than a child, walked on the edge of a sort of crater, waiting to be sacrificed to some god.

After staying in Mayantuyacu, when I took a stop in Lima on my way back to Italy, I was invited to dinner hosted by a lady, through a common friend. When the woman presented herself at the door of the house to welcome me, I was not able to believe my eyes! It was the same woman from the vision, with a few more years added to her age. Amazing! Really incredible!

This was the first time I found myself encountering something that nothing in my studies had prepared me for. The images of the vision took shape in my daily life, in reality, which was something incredible for me, while it was something very natural within the culture that had produced it.

Let us return to the vision. After the Machu Picchu scene, other people had appeared who, just as me, were in the Maloca in that splendid Amazonian starry night.

Watching "the movie" of those in that circle with me had been even more surprising, as it implied that it was possible to somehow tune in to their "channel", to their visions!

It was similar to being inside an hourglass through which the sand appeared to flow gradually, with the impression, perhaps for the dark, perhaps for that strange drink, perhaps for suggestion, but no, it was not really a suggestion, that what I was watching was more real than the reality I was commonly used to.

At a certain point, my movie begins to turn toward a conclusion. The images fade, although the nature around me remains as "animated", with bright colors despite the darkness, as if it had a life that is usually not perceptible to our senses. The trees have almost human features, each one of them with its own particular character. I see a large brown tree, which uses a stick to strike a vigorous blow to the ground, almost to greet me. The darkness closes on the experience, similar to a curtain.

In the darkness of the night, there remain the sounds of the nature that continues its incessant works – the flowing water, the first songs of the birds that announce the day everything around me is alive, although it appears grainy compared to the perception I had of it during the vision as if it had lost that filigree life, a perspective that had been completely unknown to me until then. I doze off.

When I wake up the next morning, I would ask myself if all that I saw was "only" a dream. It vaguely recalls as a dream, actually, although it is not. I would be perfectly aware of having lived that waking experience.

Shakespeare said that we are made of the same substance that dreams are made of. Had he experienced something similar in the English woods? Who knows!

With that experience, I realized that it is necessary to create a bridge between that ancient reality and the modern western laboratories which conduct research on the psychoactive substances that are capable of activating and modifying the psychic state, which are referred to by the indigenous people as "teachers" or plants "Of knowledge".

Author Contributions

All authors have contributed equally to the work reported.

Competing Interests

The authors declare that no competing interests exist.

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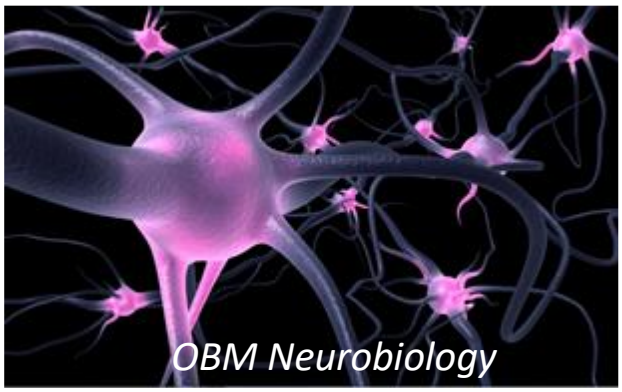

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