Quantum nonlocality observable on a non-statistical level: idea, experimental evidence, fundamental consequences

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Today quantum nonlocality is discussed only in the context of EPR situation where we face a macroscopic system which is fundamentally indivisible insofar as it consists of entangled distant particles. But quantum formalism implies a one more type of indivisibility. It is the indivisibility of a quantum state *per se* regardless of its configuration in the real space. In this work, we propose an idea of how this type of indivisibility may also be relevant to macrocosm giving rise to an alternative type of quantum nonlocality which, in contrast to EPR nonlocality, is observable on a non-statistical level. It is light-induced electron transitions with *macroscopic* spatial discontinuity. We provide strong evidence for these transitions in a modification of low-temperature quantum Hall state of matter, which is characterized by a great number of *macroscopic* orbit-like quantum states. We thereby demonstrate a deeper-than-relativistic spatial dynamics requiring a deeper kinematics beyond the Minkowski model of spacetime. Such kinematics was proposed by Karl Popper as well as by John Bell through the idea of a deeper non-Lorentz-invariant spatial level identified as precisely the aether in the Lorentz-Poincare's version of relativity. We argue that this idea may be integrated into the Bohm-Hiley's model of undividable Universe which thus appears to be precisely the deeper-than-relativistic model relevant at any lengthscale. Ultimately, this approach opens the door to the solution of such fundamental problems as the problem of interpretation of quantum formalism as well as the problem of unification of quantum and relativity theories.

1. Introduction

At present, quantum nonlocality is a synonym of the Einstein-Podolsky-Rosen (EPR) nonlocality that occurs in a macroscopic quantum system which is fundamentally indivisible insofar as it consists of entangled distant particles [1]. This nonlocality is observable through statistical measurements based on the Bell theorem [2-7]. But precisely due to the statistical character of the observation, EPR nonlocality fundamentally cannot be used for a nonlocal signalling [8-9]. As a result, it leaves room for the Minkowski model of spacetime though, in view of so-called quantum dilemma (either nonlocality or realism), at the cost of sacrificing physical realism.

However, there is an interpretation of EPR nonlocality beyond quantum dilemma. It was proposed by Karl Popper as well as by John Bell who regarded EPR nonlocality as an argument to revive the Lorentz-Poincare's version of relativity even though "… *it would shock most of us who have grown up in the Einsteinian period to see that Einstein's beautiful interpretation of special relativity is mistaken* ..." [10] More specifically, they supposed that the so-called aether is actually a deeper non-Lorentz-invariant spatial level responsible for "… *a real causal sequence which is defined in the aether*..." [11] In fact, it is the idea of a deeper quantum kinematics beyond the Minkowski model of spacetime and ironically it is precisely the idea which would rehabilitate the Einstein's philosophical view of physics, according to which "… *without the belief that it is possible to grasp reality with our theoretical constructions, without the belief in the inner harmony of our world, there could be no science*..." [12].

Nevertheless, insofar as the Popper-Bell's idea disavows Einstein's relativity, it remains extremely unattractive for physical community at least in the absence of a stronger empiric argument. And, in this context, Bell intuitively guessed that EPR experiment is not the ultimate experiment that can be done to resolve the problems of quantum nonlocality and "... *it is very probable that the solution to our problems will come through the back door*..." [11] But even if one relies on Bell's intuition, what could be such a "back door" is still a puzzle.

On the other hand, even in times of Bell, there was a hope that an empirical solution to the problem of nonlocality may come from the low-temperature states of matter which demonstrate an essentially quantum behaviour on a macroscopic level. This hope was mainly provoked by the boom related to the discovery of superconductivity which thereby was in the focus of all discussions related to the problem. However, as it has soon been realized, this hope is ephemeral. As it was shown by Anthony Leggett, superconducting materials cannot tell us something new about quantum nonlocality insofar as they consist of indistinguishable particles obeying quantum statistics [13]. As a result, Bell himself had to admit that *"…One tends to say 'Oh, superconductivity shows macroscopic quantum mechanics', but not in the sense we are concern with in Einstein-Podolsky-Rosen correlations..."* [11].

However, although superconductivity is certainly the most famous macroscopic quantum effect, there is a lesser known effect of that kind, the discovery of which was awarded the Nobel Prize in 1985 [14]. It is the so-called integer quantum Hall (IQH) effect which manifests itself through a strict quantization of transverse conductivity of two-dimensional (2D) electron gas in a strong magnetic field. In this effect, the origin of macroscopic quantum behaviour is quite different from that in the case of superconductivity. Following the theory by Robert Laughlin and Bertrand Halperin, it is related to the quantum states which are strongly reminiscent of quasi-one-dimensional electron orbits those are always of the lengthscale of system itself [15-16]. But the crucial point is that being in these states the electrons are distinguishable insofar as they are spatially separated. As a result, their behaviour may be observable on the level of individual particles. Nevertheless, IQH system has never been regarded in the context of nonlocality. Perhaps it is due to the fact that the Laughlin-Halperin (LH) macroscopic orbits are essentially edging states so that their absolute number is always much less than the number of microscopic states in system interior [17]. As a result, they are hardly detectable through macroscopic measurements other than the magneto-transport ones so that even the name of the effect is directly associated with the measuring method.

In this work, however, we argue that the very fact of LH macroscopic orbits opens the door to a new type of quantum nonlocality which ultimately is a consequence of fundamental indivisibility of these orbits. It is light-induced electron transitions with macroscopic spatial discontinuity. To demonstrate these transitions experimentally, we realize a modification of IQH system with a number of LH-type macroscopic orbits that fill the entire system and hence are accessible in photo-voltaic measurements. Our experiments unambiguously show that such transitions do exist precisely in accordance with quantum principles. We thereby strongly support the Popper-Bell's idea of a deeper non-Lorentz-invariant spatial level and argue that this idea may be integrated into the Bohm-Hiley's model of undividable Universe which is thus precisely the deeper-than-relativistic model relevant at any lengthscale. Ultimately, this approach gives rise to a new look at such fundamental problems as the problem of interpretation of quantum formalism as well as the problem of unification of quantum and relativity theories.

2. The idea of a spatially-discontinuous electron dynamics

Basically, the fundamental indivisibility of a quantum state stems from the fact that quantum formalism addresses to a multi-dimensional Hilbert space rather than to the real space so that an indivisible point of the former may be relevant to a certain volume of the latter. In fact, it is precisely the indivisibility which compelled Bohr to introduce the concept of fundamental "non-existence" of electron in a quantum state without measurement though an explicit mysticism of this concept is still regarded as a problem (the so-called measurement problem). By default, today it is generally believed that, in contrast to EPR-type indivisibility, the indivisibility of individual quantum states has nothing to do with quantum nonlocality. But actually the very fact of LH macroscopic orbits puts this belief into question. And to clarify this idea, consider a *gedanken* experiment (Fig. 1).

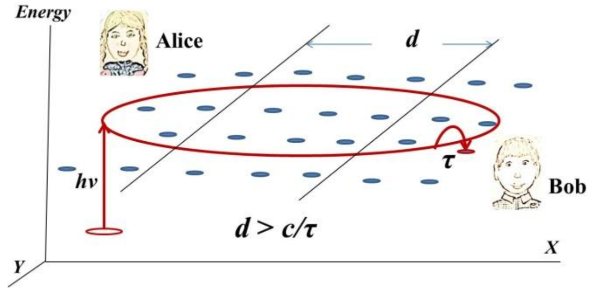

Figure 1. *Gedanken* experiment to illustrate a quantum nonlocality caused by the fundamental indivisibility of a macroscopic orbit-like quantum state

Suppose there is 2D electron system which has a quasi-one-dimensional macroscopic quantum orbit as well as a number of point-like charged scatterers distributed uniformly over the layer. Suppose these scatterers are responsible for the electron transition from orbit into a nearby vacant state during a characteristic time τ. Select two spatial domains (Alice's and Bob's) separated by the distance d so that each one covers, for example, one fourth of the orbit. Suppose Alice excites electron from a deep local level into the orbit by photon of a proper energy. As a result, owing to the scattering, the electron will be localized somewhere near the orbit during the time τ. But the crucial point is that this localization may occur in Bob's domain with exactly the same probability (one fourth) as in Alice's domain. In fact, it is a direct consequence of the indivisibility of the orbit. But this means that electron may overcome the Alice-to-Bob distance without having been in any spatial positions in-between. And if the orbit is as large as $d/\tau > c$ (c – the speed of light), then the *nominal* electron speed may be faster than light. Moreover, it is easy to see that the probability of such transition can easily be enhanced even up to unity, for instance, by shifting all scatterers to Bob's domain.

So, we see that the principle of indivisibility of a macroscopic orbit-like quantum state may lead to an inherently nonlocal effect. It is light-induced electron transition with macroscopic spatial discontinuity. But this effect is clearly incompatible with such a deep thing as the Minkowski model of spacetime. That is why, to be sure that it is not a "mind game", we strongly need to implement our *gedanken* experiment.

3. Modified IQH system as a material to test spatially-discontinuous dynamics

To find a material suitable for the implementation, we start with a brief description of what is known as the IQH system. As we already noted, the IQH system is actually a 2D electron gas in presence of strong quantizing magnetic field. In system interior, electrons are in microscopic states, the so-called cyclotron orbits, and their energy spectrum is a series of strongly-degenerated equidistant Landau levels (Fig. 2a). However, in the vicinity of system edges, the degeneracy may be lifted due to a combine effect of quantizing magnetic field and in-plane electric field which arises in a very narrow strip near system edges. The width of the strip is of the order of cyclotron radius and it is precisely the strip where the LH orbits emerge in which electrons behave as spontaneous currents flowing throughout the perimeter of the sample (see inset in Fig. 2a).

As we see, even the conventional IQH system may potentially be the desired material, especially because typically it has a great number of point-like charged scatterers with the scattering time of shorter than 10ps. Moreover, as the length of 2D structures may be of a few centimeters, it is easy to estimate that here there is a potentiality to reach the condition $d/\tau >> c$.

The only problem is that the LH orbits are essentially edging states and therefore they hardly can be detected in macroscopic measurements related to a photo-excitation of electrons.

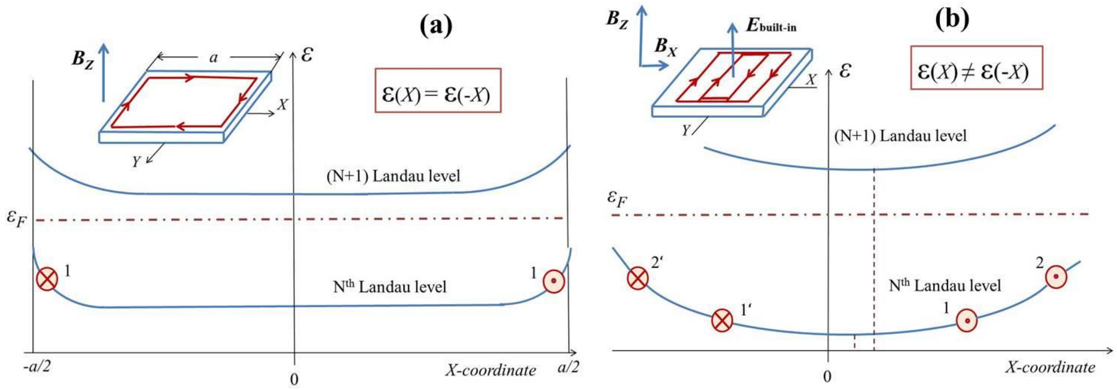

Figure 2. Macroscopic quantum orbits in IQH-type systems

(a) The energy spectrum of conventional IQH system. Landau level degeneracy is lifted near the edges (*a* – the sample length) where LH orbits emerge. One such orbit is shown in the figure. Dash-dot line is the Fermi energy. Inset shows schematically the configuration of LH orbits in the real space. **(b)** Calculated energy spectrum of an infinite 2D system with strongly asymmetric confining potential if magnetic field has both the quantizing and the in-plane components. Here Landau levels may transform into energy bands consisting of spatially-separated quantum states where electrons behave as spontaneous currents flowing in opposite directions along the *Y*-axis. Two pairs of identical counterflowing currents are shown in the figure. The bands are shifted from zero point depending on their Landau quantum number. Vertical dashed lines show bands' minima. Inset shows schematically the expected spatial configuration of LH-type orbits in a real finite system of that kind.

However, one would propose an idea of how to overcome this difficulty. The idea is based on the fact that 2D systems may have a strongly asymmetric confining potential or equivalently the so-called "built-in" electric field ($\boldsymbol{E}_{\text{built-in}}$). In this case, if magnetic field has not only quantizing component ($\boldsymbol{B}_Z$) but also an in-plane component ($\boldsymbol{B}_X$), then all electrons are in crossed electric and magnetic field. Calculations with simplified models allow one to assume that here Landau level degeneracy may truly be lifted throughout the whole system. As a result, Landau levels transform into something like energy bands shifted along the *X*-axis depending on their Landau quantum number [18-19]. These bands also consist of spatially-separated macroscopic quantum states in which electrons behave as quasi-one-dimensional spontaneous currents. But in infinite models, these currents are infinite insofar as they flow in strictly opposite directions along the *Y*-axis (Fig. 2b).

Surely, in a real finite system, such currents cannot exist. But one would assume (still speculatively) that each pair of identical counterflowing currents is actually a quantum orbit extended along the *Y*-axis and closed through the edges (see inset in Fig. 2b). In this case, we get a series of energy bands consisting of a number of Laughlin-Halperin-type (LH-type) orbits with a slightly different spatial distribution due to the difference in bands' shift. And if so, then, in presence of a dissipative scattering, light-induced vertical transitions between the bands may result in a detectable net current along the *Y*-axis. Phenomenologically, it is the so-called photo-voltaic effect [20-21]. Here it is caused by an inner asymmetry related to a nonzero vector product $\boldsymbol{E}_{\text{built-in}} \times \boldsymbol{B}_X$. But the crucial point is that if the effect is truly related to the LH-type orbits, then it should demonstrate an extraordinary behaviour: (1) light-induced current should *not* be suppressed by quantizing component of magnetic field ($\boldsymbol{B}_Z$) precisely because it is expected to be a sum of a number of spatially-separated one-dimensional elementary currents and (2) light-induced current should be a strong, non-periodic function of *X*-coordinate even if the external excitation is strictly uniform. The latter point reflects the fact that the emergence of LH-type orbits should be accompanied by their spontaneous self-ordering which breaks translational symmetry along the *X*-axis so that the system should behave as an indivisible whole.

4. Evidence for macroscopic quantum orbits filling up the modified IQH system

Method. To test our speculations experimentally, we use GaSb-InAs-GaSb single quantum well structures grown by the method of molecular beam epitaxy (MBE) where InAs conducting layer (15nm wide) is sandwiched between two thin AlSb barriers (3nm each) to avoid the so-called hybridization of electrons from different layers. The structures are spatially-uniform in the *XY*-plane and have a high electron density of about $2{\cdot}10^{12}cm^{-2}$. To provide an asymmetry of confining potential, surface-to-well distance is as short as about 20nm so that the so-called surface potential easily penetrates into the well giving rise to the "built-in" electric field of the order of 100kV/cm [22-23]. Also, the selected structures are characterized by a high density of point-like charged scatterers so that the electron momentum relaxation time is as short as about 3ps and the electron mean free path is as low as about 1μm.

Thus, the structures are such that they have no macroscopic parameters with the dimension of length to the exclusion of their own sizes in the *XY*-plane. These sizes are 20mm along the *X*-axis and 16mm the *Y*-axis (Fig. 3a). Each sample is supplied by four pairs of short ohmic contacts (2mm each) so that the contact-to-edge distance is not less than 1.5mm. The sample temperature is about 2K and it is much less than the typical energy of Landau quantization. External magnetic field is tilted from the normal by 15° in the *XZ*-plane.

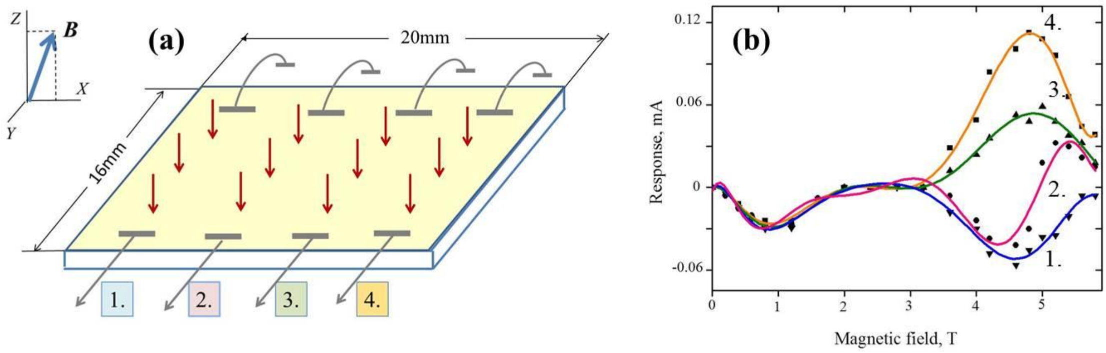

Figure 3. Evidence for a macroscopic quantum ordering in modified IQH system
(a) Sketch of the experiment. All sample area is covered by the laser beam. Light-induced responses are detected through four contact pairs shifted from each other along the *X*-axis **(b)** The outcome. Solid lines are a guide for the eyes. They are numbered in accordance with the numbering of contact pairs.

Optically-pumped terahertz ammonia laser is used as a source of radiation which is incident normally to the sample surface and covered the whole sample area. The energy of light quanta (13.7meV) is close to the gap between Landau levels when $\boldsymbol{B_Z}$ is about 4.6T. Under these conditions, the electron lifetime at a higher Landau level is expected to be about 30ps [24]. To avoid heating, the laser operates in a single-pulse regime with the pulse duration of about 100ns and with the intensity of the order of $200W/cm^2$. Light-induced responses are detected from each contact pair in a short-circuit regime with the time resolution of about 20ns. *No* external electric bias is applied to avoid any field-induced transport of electrons.

Results. Fig. 3b shows the magnetic field dependence of light-induced responses. It is clearly seen that there are two branches where responses are nonzero. In the low-field branch (about 0.8T), responses are almost identical and they quickly disappear with increasing of $\boldsymbol{B_Z}$. In fact, it is precisely the behaviour of a system of free (indistinguishable) electrons. However, there is also a high-field branch where responses occur despite of a strong Landau quantization. Roughly, they reach their maximum under the so-called cyclotron resonance (CR) conditions when the energy of light quanta is close to the gap between Landau levels (about 5T). But the crucial point is that here each response clearly has “its own face” which differs drastically from any other one. It is precisely what should be in a system of spatially-separated (distinguishable) electrons those are ordered along the *X*-axis without any periodicity. Thus, the above experimental scheme gives us a unique opportunity to compare *in situ* the responses of indistinguishable electrons with that of distinguishable electrons and hereafter we will take this opportunity to elucidate the role of this factor.

However, to be sure that the difference between the responses is truly related to a macroscopic ordering but not to an uncontrollable inhomogeneity, we continue our measurements but now in reverse magnetic field. Fig. 4a shows the responses of indistinguishable electrons while Fig. 4b shows that of distinguishable electrons before reversal and, to compare, Figs. 4c and 4d (respectively) show the outcome of the same measurements after the reversal. It is seen that the responses of indistinguishable electrons behaves quite trivially: each one merely changes its sign. On the contrary, in the system of distinguishable electrons, we see a rotation of the whole picture by 180° about *Z*-axis. This means that macroscopic ordering does exist so that the reversal of magnetic field results in a system re-ordering in such a way that fundamental symmetry relations hold only on the level of system as a whole but may not hold on a lower level.

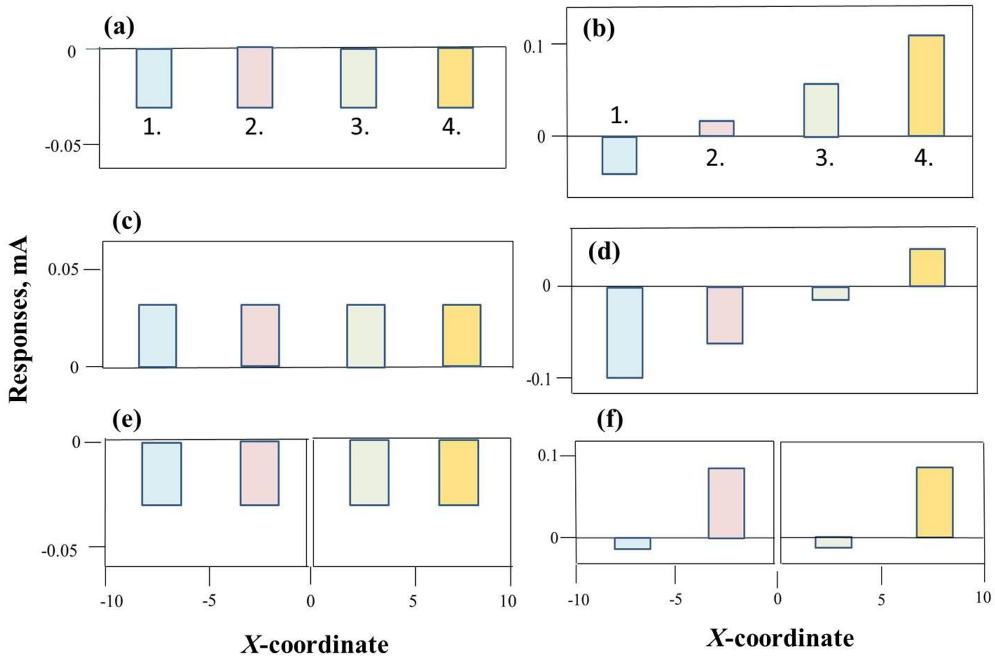

Figure 4. Evidence for an indivisible behaviour of modified IQH system

(a) Responses of the system of indistinguishable electrons (***B*** = 0.8T); **(b)** Responses of the system of distinguishable electrons (***B*** = 5T); **(c)** Responses of indistinguishable electrons in reverse magnetic field; **(d)** Responses of distinguishable electrons in reverse magnetic field **(e)** Responses of indistinguishable electrons after splitting the sample; **(f)** Responses of distinguishable electrons after splitting the sample.

Finally, to complete our preliminary experiments, we split the sample along the *Y*-axis into two identical fragments and then repeat our measurements. As we see, the responses of indistinguishable electrons are almost insensitive to the splitting (Fig. 4e). On the contrary, the responses of distinguishable electrons change drastically in such a way that they become identical in both fragments (Fig. 4f). And this is despite the fact that there are no “classical” ways “to let them now” about the splitting as the long-range Coulomb interaction should be screened within a microscopic distance.

Thus, our preliminary experiments show unambiguously that modified IQH system does have a number of LH-type macroscopic orbits which fill the entire system and are responsible for light-induced electric responses under strong Landau quantization. Moreover, in a broader sense, the modified IQH system may be interpreted in terms of a peculiar quantum phase that emerges from conventional IQH system through a continuous quantum phase transition induced by the vector product $\boldsymbol{E}_{\textbf{built-in}} \times \boldsymbol{B}_X$ and accompanied by the breaking of translational symmetry. As a result, we get a phase which actually is an antipode of the superconducting quantum phase in the sense that it is characterized by the lowest degree of collectivization of electrons whose wavefunctions are of the lengthscale of system itself. The point is that here the electrons are not only in different quantum states (like free electrons) but also are spatially-separated. On the contrary, in a superconducting phase, electrons not only have the same spatial characteristics but also are in the same quantum state due to the Cooper pairing. In fact, the new phase is reminiscent of a gigantic *single* atom but, in contrast to the true atom, it has a gigantic number of spatially-separated orbitals of a *controllable* lengthscale which potentially may be arbitrary large. And such a single-atom-like quantum phase is precisely what we need to test the existence of spatially-discontinuous dynamics.

5. Evidence for spatially-discontinuous dynamics

Method. In many respects, our main test is similar to the preliminary experiment in Fig. 3a. But now the sample is covered by a non-transparent metallic plate with four rectangular windows, each of which is 3mm along the *X*-axis and 12mm along the *Y*-axis (Fig. 5a). In this case, if only the window No.1 is open, then, in terms of our *gedanken* experiment, the domain No.1 is the Alice's domain while the domain No.4 is the Bob's domain. The only difference is that now we use a great number of photons capable of providing electron transitions to a higher Landau where there are a great number of vacant macroscopic orbits.

The idea of the test is as follows. If spatially-discontinuous dynamics is a fiction, then the illumination of only Alice's domain should result *only* in a response from this domain. No responses should occur from Bob's domain because it is almost impossible for excited electrons to overcome continuously the Alice-to-Bob distance which is *four orders* longer than their mean free path, especially if one takes into account that, to complete such a "journey", they have only 30ps as it is precisely their lifetime.

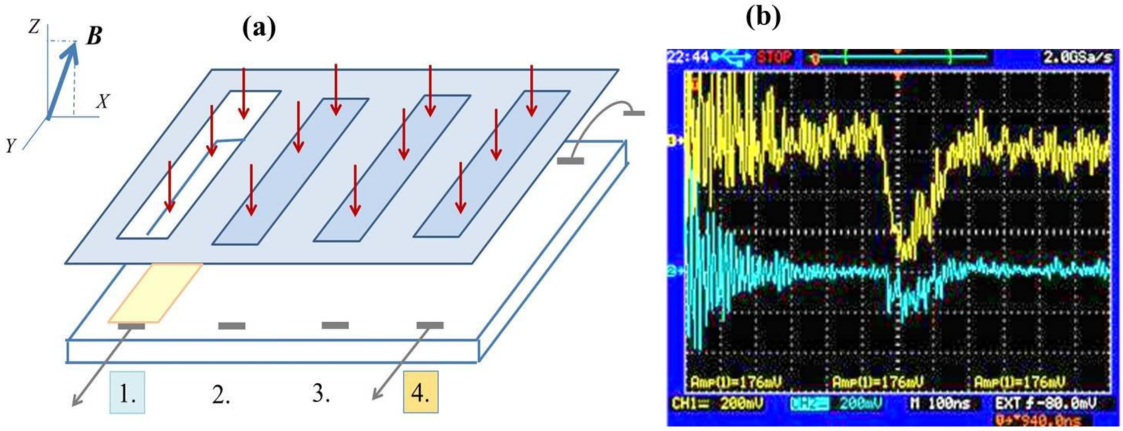

Figure 5. Evidence for spatially-discontinuous dynamics through macroscopic quantum orbits
(**a**) Sketch of the experiment. It is reminiscent of the experiment in Fig. 3a but now the sample is covered by a non-transparent plate with four rectangular windows. Responses are measured in the domain No. 1 as well as in the domain No. 4. **(b)** Typical tracks when *only* the window No. 1 is open ($\boldsymbol{B}$ = 5T): lower track is the response from *lightened* domain (No. 1); upper track is the inverted response from domain *in the dark* (No. 4). Both responses are equally pre-amplified. Timescale is 100ns/div.

On the other hand, if spatially-discontinuous dynamics nevertheless exists, then the illumination of only Alice's domain should result in a really amazing effect at least in terms of everyday (or "macroscopic") intuition: responses should occur in *both* domains and moreover the ratio between them should roughly be such as if these domains are *equally illuminated*. In other words, even if we illuminate only Alice's domain, the number of excited electrons should roughly be the *same* in both domains. Moreover, the electrons should emerge *almost simultaneously* in both domains no matter how large the Alice-to-Bob distance and no matter how large the concentration of scatterers between these domains. Actually, these expectations are based on the guess that most long-range LH-type orbits belong to these domains to the same extent and none of these domains has a visible advantage in the process of electron localization.

As we see, the above scenarios are so different that our test is rather qualitative than quantitative. Moreover, as such, the latter scenario is so astonishing that, if implemented, it *de facto* leaves no room for any alternative interpretations.

Results. As usual, we start with the system of indistinguishable electrons (***B*** = 0.8T) and, as usual here responses behave quite trivially. If both the window No. 1 and the window No. 4 are open, then we observe the same responses from both domains precisely like in Fig. 4a. Then, if we close the window No. 4, the response from this domain disappears while the other one remains and vice versa, if we close the window No. 1, then the response from this domain disappears while the other one remains.

However, what we observe in the system of distinguishable electrons (***B*** = 5T) leaves no room for any ambiguity indeed. If we open both the window No. 1 and the window No. 4, then there are responses from both domains and the ratio between them is similar to that in Fig. 4b. However, when we close the window No. 4, the response from this domain does *not* disappear. Instead, *both* responses are reduced *equally* (in a factor of two) so that the ration between them remains. As a result, the response from Bob's domain (in the dark!) is three times *higher* than the response from Alice's domain and moreover there is no a delay between them at least within the accuracy of our experiment (Fig. 5b). However, if we reverse magnetic field, then the ratio reverses as well like in the case of the full illumination (see Figs. 4b and 4d).

Thus, our test clearly shows that spatially-discontinuous dynamics does exist. But to demonstrate more directly a macroscopic spatial discontinuity of electron dynamics, we perform an additional experiment. We close the window No. 1 but open both the window No. 2 and the window No. 3. *No* responses are observed in this case. This means that there is a macroscopic "dead zone", the illumination of which does not result in detectable responses. But if we open the window No. 4, then both responses arise once again with roughly the same ratio. In other words, now Bob comes into contact with Alice through the same communication channel provided by the LH-type macroscopic orbits.

6. Fundamental consequences

At first sight, our observations are a triumph of the Bohr's concept of fundamental "non-existence" of electron without measurement. But actually it is a Pyrrhic victory. The point is that the observation of a deeper-than-relativistic dynamics strongly requires a deeper-than-relativistic kinematics beyond the Minkowski model of spacetime. In a sense, the situation is reminiscent of that happened at the beginning of the last centenary. We mean the observation of a deeper-than-classical dynamics, which results in the recognition of a deeper-than-classical kinematics, that is, the Minkowski model of spacetime. But the distinct feature of the current situation is that, in contrast to relativity, Bohr's theory fundamentally cannot provide its own kinematics as it implies that "…*There is no quantum world. There is only an abstract quantum physical description…*" For the same reason, it cannot be the deepest physical theory even though it is the only theory which accounts for the dynamics we observe.

But one of the breakthroughs of our observations is that they open the door to an alternative interpretation of quantum formalism, which, in contrast to Bohr's theory, is capable of providing a quantum kinematics beyond relativity. It is the ontological (or causal) interpretation known also as de Broglie-Bohm pilot-wave theory [25-30]. The point is that today the basic argument against this theory is precisely the incompatibility of a realistic view of quantum nonlocality with Einstein's relativity which *de facto* implies an exhaustive character of relativistic kinematics. This argument is a stumbling-stone even for the ardent supporters of pilot-wave theory [31]. But now the very fact of spatially-discontinuous dynamics makes us free from having to squeeze quantum theory into the Procrustean bed of Lorentz invariance. As a result, the above argument merely disappears so that now we can see a deeper quantum kinematics which actually *is* in the pilot-wave theory though in a slightly veiled form.

Ultimately, this kinematics is based on the Bohm's concept of a quantum pre-space which is inherently non-Lorentz-invariant insofar as it obeys the so-called implicate order. Originally, this concept was assumed to be relevant only at the Planck scale as here the very notion of Lorentz invariance is meaningless. But insofar as we lower the status of Lorentz invariance from fundamental symmetry to an emergent phenomenon, one can identify Bohm's pre-space as precisely the Popper-Bell's non-Lorentz-invariant spatial level or precisely the aether in the Lorentz-Poincare's relativity. And now everything falls into place. We immediately obtain a deeper-than-relativistic model of Universe, which is relevant at any lengthscale. It is precisely the Bohm-Hiley's model of undivided Universe, which ultimately encourages us to a deeper, non-mechanistic view of physical world where "… *each element that we can abstract in thought shows basic properties … that depend on its overall environment, in a way that is much more reminiscent of how the organs constituting living beings are related, than it is of how parts of a machine interact…*" [27] And being free from any restrictions related to lengthscale, this model is really a "quantum revolution" in our ideas about the surrounding world.

In fact, we thus come to a strict hierarchy of fundamental physical theories as a solution to the problem of how to merge them into a coherent whole. In this hierarchy, quantum theory has the status of the deepest theory, which seems to be well-deserved for the most successful theory in the history of science. Accordingly, relativity (as well as classical physics) is only a limiting case which is relevant only to the systems of essentially-autonomous objects. Thus, following this hierarchy, the mission of quantum theory is not to sacrifice realism. Rather, it is a further development of realistic physics beyond relativity to account for the phenomenon of fundamental indivisibility, which may be relevant at any lengthscale. And it is just as relativity is a further development of realistic physics beyond classical mechanics to account for the phenomenon of fundamental inaccessibility of a faster-than-light continuous dynamics.

Finally, it is easy to see that the above hierarchy is precisely in the vein of Einstein's realistic insight into physics, which is still regarded as his deep misconception [32]. Moreover, in a sense, Einstein foresaw that sooner or later physics will go beyond his theory. In this context, Popper, for example, noted that "… *although Einstein defended his theory ferociously he had no illusions as to its status as the ultimate truth*" [33]. To be fair, there was only one thing which he cannot accept in quantum theory. It is the Bohr's refusal to regard physics as an attempt "*to grasp reality with our theoretical constructions*". Actually, it is precisely the core of Bohr-Einstein epistemological debates which definitely should not be viewed as an Einstein's attack on quantum theory. And now it seems the time to revise our view of Einstein's philosophical arguments and to recognize after all the ultimate success of his philosophical approach to quantum theory.

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