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Scan Quantum Mechanics: Quantum Inertia Stops Superposition

Beatriz Gato-Rivera [1,2]

[1] Instituto de Física Fundamental, IFF-CSIC Spanish National Research Council, Serrano 123, 28006 Madrid, Spain; bgator@iff.csic.es
[2] Nikhef Theory Group, Science Park 105, 1098 XG Amsterdam, The Netherlands

Abstract: Scan Quantum Mechanics (SQM) is a novel interpretation in which the superposition of states is only an approximate effective concept due to lack of time resolution. Quantum systems scan all possible states in the "apparent" superpositions and switch randomly and very rapidly among them. A crucial property that we postulate is quantum inertia I_q, that increases whenever a constituent is added, or the system is perturbed with all kinds of interactions. Once the quantum inertia reaches a critical value I_{cr} for an observable, the switching among its eigenvalues stops and the corresponding superposition comes to an end. Consequently, increasing the quantum inertia of a quantum system by increasing its mass, its temperature, or the strength of the electric, magnetic and gravitational fields in its environment, can lead to the end of the superpositions for all the observables, the quantum system transmuting into a classical one, as a result. This process could be reversible, however, by decreasing the size of the system, its temperature, etc. SQM also implies a radiation mechanism from astrophysical objects with very strong gravitational fields that could contribute to neutron star formation. Future experiments might determine the critical quantum inertia I_{cr} corresponding to different observables, which translates into critical masses, critical temperatures and critical electric, magnetic and gravitational fields.

Keywords: quantum superpositions; quantum measurement; quantum inertia; quantum-to-classical transition

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1. Introduction

> *<<If one wishes to provoke a group of normally phlegmatic physicists into a state of high animation—indeed, in some cases strong emotion—there are few tactics better guaranteed to succeed than to introduce into the conversation the topic of the foundations of quantum mechanics, and more specifically the quantum measurement problem.>>* Anthony J. Leggett in 'The Problems of Physics' [1]

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Since its formulation in the 1920s and 1930s, the foundations of quantum mechanics have provided an endless source of intense and passionate debate and inspiration. Far from obsolete, the different interpretations of quantum mechanics have become a most vivid and popular topic of scientific inquiry in the last four decades, because the conventional Copenhagen interpretation, widely accepted for practical purposes, leaves too many questions unanswered. Whereas the microscopic world is astonishingly strange, counter intuitive, and very probably non-deterministic by its own nature, the macroscopic world relies, to a great extent, on intuitive, deterministic laws. Measurements of the microscopic

entities by classical devices are supposed to produce the collapse of the corresponding wave function into one of its possible states, the likelihood of each being given by the square of the accompanying coefficient, as dictated by Born's rule. That is, from all possible states in the superposition only one is realized in the measurement process, whereas the others just evaporate, as if macroscopic classical devices had the magical power to collapse wave functions. Moreover, the dividing line between macroscopic classical and microscopic quantum objects is completely unknown, even though many experiments have been performed in the last years trying to approach this frontier. These and some other questions have given rise to a plethora of different interpretations and proposals regarding quantum mechanics over the years.

In this paper, which is a very extended version of the conference proceedings [2], based on earlier work [3], we present a novel interpretation of some aspects of quantum mechanics. Our proposal, *Scan Quantum Mechanics* (SQM), is not radically different from conventional quantum mechanics since we let the mathematical formalism unmodified, as an effective correct description of quantum systems. However, we put forward a mechanism underlying the superposition of quantum states, and a criterion for deciding the validity of the quantum description versus the classical description of physical systems. To be precise, we postulate a property of all systems, quantum and classical alike, *quantum inertia* I_q, in such a way that quantum behaviour only manifests itself for values of I_q below some critical ones I_{cr} (one critical value for each observable). As a result, quantum inertia with its critical values marks the dividing line between the quantum and the classical worlds.

In the light of this interpretation, the answers to several long-standing crucial questions and paradoxes are most intuitive. This applies especially to the questions related to the superposition of quantum states, the measurement problem, the elements of reality and the dividing line between quantum and classical behaviour, as we just mentioned. Other less intuitive but unavoidable features of SQM, like in conventional quantum mechanics, are the lack of well defined properties for quantum systems, randomness in the output of measurements and nonlocality, not only for quantum correlations but also for positions in space (i.e., quantum jumps instead of classical continuous trajectories).

Nevertheless, SQM can be tested with a number of laboratory experiments—we propose some of them—and by astrophysical observation, since it implies a new radiation mechanism from astrophysical objects immersed in very strong gravitational fields. This mechanism could contribute to neutron star formation and gives rise to non-thermal emission of X-ray synchrotron radiation.

In what follows, as the purpose of this presentation is to emphasize the physical concepts of SQM, we will consider only pure states keeping the mathematical formalism to a minimum. In Section 2, we will present the main features of our proposal and we will discuss their applications to shed some light on a number of mysterious and controversial aspects of conventional quantum mechanics. In Section 3, we consider SQM versus several other interpretations and proposals for quantum mechanics, comparing some of their differences and similarities. The most relevant past and present experiments in quantum mechanics are reviewed and reinterpreted in a more intuitive way in the light of SQM, as we will see in Section 4. We also propose some experiments in order to determine the critical values I_{cr} of the quantum inertia for some observables. These values are experimental input, not derivable by current theory, as is the case for the masses of elementary particles in the Standard Model of particle physics. Finally, the discussion in Section 5 is devoted to conclusions and final remarks.

2. Scan Quantum Mechanics

2.1. Basic Ideas

Scan Quantum Mechanics consists basically of an interpretation of the wave function in which the superposition of the available quantum states, at any instant, is only an effective approximate concept. The mathematical formalism is the same as in conventional quantum mechanics because there is no need to propose any modifications.

For simplicity, let us consider a quantum system with only one observable. To be precise, the system is in a normalized superposition $\psi = \sum_k c_k |a_k\rangle$ of orthonormal eigenvectors $|a_k\rangle$ of an hermitian operator A, with eigenvalues a_k, that represents the observable. Then, the measurement is supposed to collapse the initial state of the system, or wave function ψ, to a unique well defined state, say $|a_m\rangle$, with the value of the observable equal to a_m, the probability of encountering this value being given by the Born rule, i.e., $|c_m|^2$. In this setting, SQM differs from conventional quantum mechanics in essentially three postulates:

1. The quantum system scans all the available eigenstates described by the wave function ψ and switch among them randomly at very high speed. Consequently, due to lack of time resolution, the system appears to be in a superposition of the different eigenstates $|a_k\rangle$, with eigenvalues a_k, at any instant. In other words, the system can be regarded, effectively, as being in a superposition of states.

2. The relative time the quantum system spends in a particular state $|a_m\rangle$ coincides with the probability $|c_m|^2$ of finding that state during a measurement.

3. The quantum switching among the available states depends on a crucial property shared by all physical systems, quantum inertia I_q, that increases whenever a constituent is added, or the system is perturbed with all kinds of interactions. If the value of I_q is below a critical one for the observable, $I_q < I_{cr}$, then the quantum switching is at work and the wave function ψ describes the system exactly as in conventional quantum mechanics. If, on the contrary, the value of I_q reaches or exceeds the critical one, $I_q \geq I_{cr}$, then the system is unable to switch among the different eigenvalues of the observable. As a consequence, the quantum switching freezes, the superposition of states disappears—leaving behind a classical system with a well defined value of the observable—and the system's wave function ψ stops providing the correct description of the system.

The generalization of postulates 1 and 2 for quantum systems with more than one observable is trivial. As regards postulate 3, its generalization is straightforward. Obviously, once the quantum inertia I_q reaches the critical values I_{cr}^A, I_{cr}^B, I_{cr}^C,...., for all the observables A, B, C,...., all quantum superpositions stop and the system becomes classical, with well defined values for the observables. The situation in between, when I_q has reached one or more of the critical values for the observables, but not all of them, leads to hybrid quantum/classical systems, like in the case of mesoscopic systems.

Observe that, as long as $I_q < I_{cr}$ for the quantum system, SQM is indistinguishable from conventional quantum mechanics for all practical purposes although, in principle, it provides a more accurate description at very small time scales for which we lack experimental resolution. Moreover, since the quantum systems are also evolving unitarily with time, as dictated by the Schrödinger equation, the role of time in SQM is twice as prominent as in conventional quantum mechanics.

For $I_q \geq I_{cr}$, however, the wave function ψ of the physical system rather than collapsing goes 'out of order', in the sense that it does not provide the correct description of the system once the switching among the quantum states has stopped. (Notice that in SQM a wave function represents only a mathematical description of a quantum system, without any physical existence or 'substance', in agreement with conventional quantum mechanics).

A different issue is whether the Schrödinger equation should be modified, by adding a non-linear term in the Hamiltonian, in order to account for the effect of the quantum inertia,

eventually leading to the end of the superposition of states. For us this is not at all obvious because our impression, as we will discuss later, is that there are two levels of physical reality: the quantum level and the spacetime level, the former being more fundamental than the latter. In our views, quantum inertia lies deep inside the quantum level—not showing up in the spacetime dynamics explicitly—and its major (or unique) role is to affect the ability of physical systems to switch among the available quantum states.

Another major premise of SQM is that the masses of the particles, the interactions among them, and many other perturbations and interactions coming from the environment (temperature, gravitational, electric and magnetic fields, collisions,...), all could contribute to the load of quantum inertia I_q of a physical system, apart from their contributions to the system's Hamiltonian, either to the kinetic or to the potential energy. Consequently, if due to these contributions I_q reaches or surpasses the critical value I_{cr} for an observable A, then the system stabilizes to only one state, say $|a_m\rangle$, with eigenvalue a_m that could be observed by the measuring devices of our classical world.

An important feature of the quantum switchings is their *reversibility*. That is, if the load of quantum inertia I_q of a quantum system is pushed up until or above the critical value I_{cr} but it can be decreased back below I_{cr}, by lowering the temperature, the intensity of electric, magnetic and gravitational fields, or by any other means, then as soon as $I_q < I_{cr}$ the quantum switchings will resume activity leading to the apparent superposition of states again, and the wave function ψ will come back to work giving a correct effective description of the system, as a result.

For the purpose of visualization, one could regard the quantum available states as located at degenerate minima of a potential, the quantum system oscillating very rapidly among these minima, like a special type of quantum tunneling. The load of quantum inertia I_q raises the barriers among the different states until the switching finally stops, when $I_q \geq I_{cr}$, and the system gets trapped in one of the minima as a consequence. The other way around, lowering the potential barriers below I_{cr}, by decreasing I_q, will immediately resume the frantic oscillations of the system among the minima of the potential.

In SQM, positions in space and momenta are treated as any other observable. To be precise, we propose that the systems will be switching among available positions in space, without passing through intermediate points, as long as $I_q < I_{cr}$, where I_{cr} is the critical quantum inertia that stops the quantum jumps. Therefore, as soon as $I_q \geq I_{cr}$, the systems will stop switching among positions and will follow classical continuous trajectories (momenta eigenstates) instead, like tiny bullets. Quantum jumps are therefore the rule in SQM, and the possibility that the quantum jumps become continuous classical trajectories, whenever $I_q \geq I_{cr}$, opens up a world of new effects that would have to be taken into account for the study of many physical phenomena.

We see that in SQM there are more elements of reality than in conventional quantum mechanics, where there are only 'potentialities of being'. Nevertheless, those elements of reality last only very short time, since the systems are switching continuously and randomly from one quantum state to another (and from a position in space to another). Moreover, quantum states only become well defined physical states after all the switchings have stopped and the systems have stabilized, becoming classical ones, as a result.

Due to its relationship with the quantum probabilities, the time spent by the systems in each available state must be quantized in terms of a time unit, that we call *quantum switching time* t_S. Now one may wonder whether the quantum switchings are really random or follow certain deterministic rules instead. For example, suppose that we have a quantum system in a superposition of three states $|a\rangle$, $|b\rangle$ and $|c\rangle$, such that the probabilities to find the corresponding values a, b and c by means of a measurement are $P(a) = 0.25$, $P(b) = 0.50$ and $P(c) = 0.25$. Does the quantum switching follow a specific pattern, quantified in terms

of the switching time t_S, like $(a, b, b, c, a, b, b, c, a, b, b, c, ...)$ or $(b, a, b, c, b, a, b, c, b, a, b, c....)$? If this were the case, then exact knowledge of the state of the system at a given time (if this could be possible!) plus exact knowledge of the switching pattern would provide exact knowledge of the resulting physical state that one could measure at any subsequent instant, even though the original quantum system lacks a well defined quantum state. However, there is no reason a priori for the quantum switching to follow a specific pattern because the only requirement is that the times spent in the different states must be proportional to their probabilities as given by the corresponding coefficients in $|\psi|^2$.

As a matter of fact, specific patterns for the quantum switchings would require the existence of hidden variables that SQM does not need and, in addition, would conflict with experimental results, namely with the violation of the Leggett inequalities [4] that discard many interpretations of quantum mechanics that make use of nonlocal hidden variables. We remind the reader that the experimental violation of the Bell inequalities [5] discards only the local hidden variable interpretations of quantum mechanics, i.e., it does not discard the nonlocal ones. Consequently, we conclude that the patterns followed by the quantum switchings must be random and therefore it is not possible to predict which will be the output—the physical state that we can observe—after the switchings stop.

Another interesting question, especially relevant when there are many possible states, is whether a given quantum system would actually switch among all possible states or only among a subset of them. In our opinion, to switch randomly among only a subset of all the available states is a perfectly consistent possibility taking into account that wave functions only make complete sense, experimentally, when applied to large ensembles of identical quantum systems. For example, let us consider the position of a particle at a time t, described by the wave function $\psi(x, t)$ that evolves unitarily according to the Schrödinger equation. According to SQM, the particle switches positions extremely fast among a large number of them—respecting the probabilities given by $|\psi(x, t)|^2$—but not necessarily among all the infinite number of positions. The particle, however, does not move back and forth like in a brownian motion following classical trajectories, but appears and disappears here and there randomly, without crossing intermediate positions, as we mentioned before.

The foregoing discussion is most helpful in order to understand what is going on when the position of a particle is given by a superposition of two trajectories, like in interferometry experiments, either by means of a double slit or a beam splitter. The particle then has 50% probability to follow one route or the other.

In conventional quantum mechanics, due to the particle-wave duality the particle follows both routes, showing its wave-like nature, until it is detected. Then magically the wave-like nature transmutes into a particle-like nature because the detectors do not register a wave but just the impact of a particle. In contrast, in SQM the particle is a wave-like corpuscle—meaning that it is equipped with some wave-like behaviour—which bears little resemblance with classical corpuscles and even less with classical waves, and follows the two routes jumping very fast between them, without passing through intermediate positions.

In the case that there is a double-slit setting, the particle actually passes through the two slits unless the thickness of the double-slit screen is extremely thin, because the particle will be able to switch many times trajectories while crossing through the slits. If one or two detectors are placed just behind the two slits in order to determine which slit the particle came across, then obviously the particle will impact on only one of the detectors since it will stop switching trajectories (and often even existing) afterwards.

We see therefore that SQM offers a very intuitive explanation to the fact that in interferometry experiments the particle follows the two trajectories whereas it can be detected in only one. We will come back to interferometry experiments in Section 4.

To finish the basic ideas underlying SQM, we will now consider the nature of the wave functions. Are they existing physical entities (as proposed by de Broglie, Schrödinger and Bohm) or only mathematical descriptions of the systems at hand? Although SQM is somehow compatible with both views, our personal preference, as said before, is that ψ is only a mathematical description of a quantum system. For this reason, we find the expression 'collapse of the wave function' unfortunate because nothing is collapsing. Rather, the mathematical description of the system, given by ψ, simply does not work because the system's quantum inertia has reached or exceeded the critical value: $I_q \geq I_{cr}$.

In our opinion, the wave-like behaviour of quantum systems is very probably a direct consequence of the fact that elementary particles are excitations of quantum fields, and therefore bear the imprint of a wave-like perturbation in their very nature. This must be the reason why in 'one by one' interferometry experiments the quantum systems interfere with themselves (as there are not other systems available to interfere with), even though the interference patterns become apparent only for statistical ensembles. As a matter of fact, for pedagogical reasons it would be most convenient if quantum systems such as particles, atoms and small molecules were not regarded as corpuscles neither as waves but something in between, simply as entities that are somehow 'programmed' to behave like waves but look more like corpuscles when they are detected.

2.2. Quantum Switching Time

As was argued before, the time that quantum systems spend in each available state must be quantized in terms of a time unit: the quantum switching time t_S. To be consistent, t_S must depend on the quantum inertia I_q. The simplest guess is:

$$t_S = C \ \frac{h}{I_{cr} - I_q} \ , \quad I_q < I_{cr} \ , \tag{1}$$

where h is the Planck constant and C is just a dimensionless constant. Observe that this expression only holds for the quantum world, where $I_q < I_{cr}$. The classical world, on the other hand, corresponds to $I_q \geq I_{cr}$, where $t_S \to \infty$. The quantum inertia has dimensions of energy or mass, as we set the speed of light $c = 1$. Observe that the minimum value of t_S, given by $t_{Smin} = C\, h/I_{cr}$, is obtained when the quantum inertia vanishes, unless it can reach negative values, $I_q < 0$, a possibility that we do not consider. Let us remark that a true superposition at any instant would correspond to $t_S = 0$, since then the system would be in all available states simultaneously, but this can only occur in the case $I_{cr} \to \infty$.

In the spirit of conventional quantum mechanics, it is tempting to propose a lower bound relating the indeterminacy on the quantum inertia ΔI_q with the indeterminacy on the switching time Δt_S, such that:

$$\Delta I_q \, \Delta t_S \geq h/4\pi. \tag{2}$$

We assume that different observables have different values of the critical quantum inertia I_{cr} and different values of the quantum switching time t_S, as a result. This we find most natural since, for example, switching among positions in space is a very different process than switching among spin states, or photon polarizations. If this is the case, quantum and classical behaviour can co-exist in quantum systems and these do not transmute completely into classical systems until all the observables have given rise to well defined classical properties. Mesoscopic systems are known precisely for displaying mixed quantum/classical effects, and this is explained in SQM as produced by the fact that different observables have different values of I_{cr}.

In principle, the values of the critical quantum inertia I_{cr} for the observables of the system must be obtained, or at least estimated, by experiment. This is similar to the case of the masses of the elementary particles: they are experimental input and so far no theory or model has been able to predict them. Nevertheless, the relation $I_{cr} = C\, h/t_{Smin}$ already provides interesting insight into the values of I_{cr} as function of the minimum switching time t_{Smin}. For example, if we set $C = 1$, for t_{Smin} equal to the Planck time: $t_{Pl} = 5.39 \times 10^{-44}$ s, one gets for the critical quantum inertia $I_{cr} = 7.67 \times 10^{19}$ GeV $= 1.367 \times 10^{-7}$ kg. This value is far too large for a critical mass M_{cr} in order to mark the dividing line between the quantum and classical worlds, and therefore should be discarded.

In Table 1 some other values of I_{cr} are given as function of t_{Smin}, setting $C = 1$. We can compare these values with the masses of molecules currently used in interferometry experiments aiming to find the classical versus quantum dividing line regarding mass and size [6]. For this it is useful to remember that the mass of a nucleon (proton or neutron) is slightly below 1 GeV and slightly bigger than an atomic mass unit (amu), used in atomic and molecular physics. The proton mass is $m_p = 0.938272$ GeV while 1 amu $= 0.931494$ GeV. At present, the largest molecules for which quantum mechanical behaviour has been confirmed in interferometry experiments are in the mass range of 10^6 amu, whereas the smallest objects known to behave according to classical mechanics in those settings have a mass of order 10^{-9} kg (or 10^{18} amu). As a result, there are 12 orders of magnitude to search for a critical mass M_{cr} in interferometry experiments, the corresponding values of t_{Smin} ranging from 10^{-41} to 10^{-30} s, as follows from $t_{Smin} = h/I_{cr}$. This means 12 orders of magnitude to find the dividing line where the center of mass motion of an object obeys quantum mechanics, or classical mechanics, in interferomery experiments. However, the situation may be radiacally different for other kinds of experiments and superpositions. For example, Bild et al. have recently found superpositions of two opposite-phase oscillations in a 16-microgram mechanical oscillator, what amounts to 10^{17} constituent atoms [7].

Observe also in Table 1 that the values of t_{Smin} in unambiguous quantum territory, like 10^{-27} s, corresponding to 4407 protons (4439 amu), are orders of magnitude smaller than the smallest lifetime of particle decay, (10^{-25} s corresponding to the W and Z bosons of the weak interactions). This provides a consistency check for our proposal since values of t_{Smin} larger than the lifetime of particles could lead to conflict.

Table 1. Some values of the critical quantum inertia I_{cr}, expressed in GeV and kg, as function of the minimum switching time t_{Smin} in seconds, using the relation $I_{cr} = h/t_{Smin}$.

t_{Smin} (s)	I_{cr} (GeV)	I_{cr} (kg)
10^{-42}	4.135×10^{18}	7.37×10^{-9}
10^{-40}	4.135×10^{16}	7.37×10^{-11}
10^{-38}	4.135×10^{14}	7.37×10^{-13}
10^{-36}	4.135×10^{12}	7.37×10^{-15}
10^{-34}	4.135×10^{10}	7.37×10^{-17}
10^{-32}	4.135×10^{8}	7.37×10^{-19}
10^{-31}	4.135×10^{7}	7.37×10^{-20}
10^{-29}	4.135×10^{5}	7.37×10^{-22}
10^{-27}	4.135×10^{3}	7.37×10^{-24}

2.3. Sources of Quantum Inertia

Now let us discuss in some detail the possible contributions to the quantum inertia I_q of the physical systems coming from different sources. In this respect, the major assumption of SQM is that anything that has an effect on the Hamiltonian must also have an effect on the quantum inertia I_q, whose domain of applicability and influence lies deep inside the 'quantum realm', and has little or nothing to do with the classical spacetime 'at the surface'.

We have already discussed the contribution to the quantum inertia from the masses of the constituents of the physical systems. This contribution is very intuitive and could be the major reason behind the dividing line between quantum and classical systems, since carefully increasing the number of constituents of a quantum system will eventually lead to its transmutation into a classical one when reaching a critical mass M_{cr}. The explanation given by SQM to this puzzling behaviour is amazingly simple because it reduces to the statement that the load of the system's quantum inertia I_q has reached or exceeded the critical value I_{cr} associated with the critical mass M_{cr}. As a consequence, it should be possible to experimentally determine the I_{cr} associated with M_{cr}, simply by performing interferometry experiments using quantum systems with many atoms, like large molecules or tiny crystals, that allow the experimenters to add more and more atoms gradually, one by one if possible. In this regard, it should be noted the excellent review [6] of nanoparticle interferometry with complex organic molecules and inorganic clusters.

The many perturbations and interactions coming from the environment must also contribute to the load of quantum inertia. Here we have temperature, gravitational, electric and magnetic fields, and collisions with all kinds of matter and radiation. One has to take into account that these perturbations affect different observables in different ways and also that different observables have, in principle, different values for the critical inertia I_{cr}.

As regards temperature, it is well known for decades that in some simple macroscopic systems it is possible to induce superpositions of states by lowering the temperature until a few degrees above the absolute zero; for example, superpositions of magnetic flux with opposite directions. More recently the contrary effect has also been shown; for example, observations of quantum decoherence of fullerens heated at 3000 K in a Talbot-Lau interferometer [8]. Depending on the interpretation of quantum mechanics, these results are attributed to the decrease or increase of thermal noise—allowing the more subtle quantum effects to manifest or to completely dilute—or they are explained using environmental decoherence or spontaneous collapse of the wave function.

Although thermal noise is ubiquitous, and some decoherence mechanisms might be at work too, SQM offers a complementary explanation that might allow us understand what is really going on. Namely, apart from the thermal noise, above certain critical temperature T_{cr} the quantum inertia of the system I_q surpasses the critical value I_{cr} associated with T_{cr} and, as a result, the system becomes purely classical (with no tunneling possible, for example). Below the critical temperature, $T < T_{cr}$, however, the system recovers its quantum behaviour, such as the tunneling capability.

In the case of borderline systems, like large molecules and tiny crystals, one would expect to be able to observe this mechanism, and also in some special macroscopic systems. For this reason, we think that all known experimental effects and phenomena that make use of very low temperatures must be reanalyzed taking into account the possibility of a critical temperature T_{cr} corresponding to a critical quantum inertia I_{cr}. This includes Bose-Einstein condensates and phenomena such as superfluidity and superconductivity, which at present are not completely well understood. We will come back to this issue in Section 4.

Gravitational fields have been considered already for a long time as a possible cause for the collapse of the wave functions or for decoherence. In Section 3 we will say a few words about these proposals that were put forward to solve the measurement problem. According to SQM, gravity must affect the behaviour of quantum systems in two different ways, apart from the corresponding contribution to the potential energy in the Hamiltonian. On one hand, increasing the strength of the gravitational fields must increase the load of quantum inertia I_q of the systems immersed in them, with the corresponding increase in the switching time t_S, like any other interactions will do. Therefore, It should be possible that the quantum switchings of a system stop altogether under a strong enough gravitational

field, a possibility with very interesting implications for astrophysical objects with very strong gravitational fields, as we will see.

On the other hand, as explained by General Relativity, very strong gravitational fields may slow down dramatically the evolution of all physical systems with time, as perceived by external observers. But, of course, this must include the quantum switchings as well! As a result, it could be possible, at least in principle, to observe from a distance the quantum switching among different states provided the dilation of t_S were important enough.

As to the implications for astrophysical objects with very strong gravitational fields, the disappearance of the quantum jumps would provide an additional mechanism for neutron star formation complementing the known ones. Namely, the atoms or molecules immersed in such strong gravitational fields could become sort of 'classical' in the sense that their electrons could stop switching among the positions in the electronic cloud, following classical continuous trajectories instead. This would lead to the collapse of atoms and molecules due to the emission of X-ray synchrotron radiation and provides an efficient mechanism for the capture of electrons by the protons inside the nuclei, turning the atoms and molecules into neutrons as a result.

Collisions with matter and radiation could also stop the switchings of the quantum systems and even destroy them altogether. This happens with particle detectors and most devices that measure quantum systems—generically called observers. Collisional decoherence has been studied quantitatively using a Talbot-Lau interferometer [9] by gradual admision of different gases into a vacuum chamber and it was found that at room temperature a single scattering event per molecule of fullerens suffices to fully destroy the interference. As said before, we think that these experiments must be reanalyzed taking into account the possibility of a critical quantum inertia I_{cr}.

Some interpretations of quantum mechanics in the past gave a crucial role to conscious observers, in order to 'collapse' the wave functions (see more details in next section). According to SQM, the interaction of a quantum system with an observer (with or without consciousness) is only a particular type of interaction that should increase the system's load of I_q above the critical value. If this is not the case, and under the action of the observer the quantum inertia still stays below the critical value, $I_q < I_{cr}$, then the observer has failed to turn the superposition of states into a single well defined state; in other words, the observer has failed to 'collapse' the wave function.

An important remark here is that in some experimental settings the researchers involved do not plan to destroy the system, usually a particle, in the measurement process, but only to get some information about it, like the trace it leaves in a bubble chamber, for example. Some of these procedures are called *weak measurements* and the experiments usually involve one of these weak measurements for the momentum of the particle followed by a normal (*strong*) measurement for its position, consisting in crashing the particle against a screen or a detector. In our opinion, the weak measurements could disrupt quantum systems much more than the experimenters are aware of, for example stopping the quantum jumps among the available positions, so that the system continues its way as a tiny bullet, following a continuous classical trajectory (that can be confused with a bohmian trajectory, which is also a continuous classical trajectory). We will say a few more words about these experiments in Section 4.

3. Scan Quantum Mechanics vs. Other Interpretations and Proposals

In the next paragraphs we will say a few words about the similarities, differences and possible compatibilities of SQM with some other interpretations and proposals regarding non-relativistic quantum mechanics. We will only focus on their basic assumptions since a more detailed discussion of their features is beyond the scope of this section. And we

will leave out of the discussion several interpretations and proposals that have essentially nothing in common with SQM, like the Bohm's Pilot-Wave Interpretation [10], the Relational Quantum Mechanics [11], the Everett's Relative State Interpretation [12], the Cellular Automaton Interpretation [13], the Quantum Histories approach [14] and the Transactional Interpretation [15]. The last one, however, postulates a quantum level of reality different from the spacetime level, reminiscent of our proposal of a deeper quantum level subject to the action of the quantum inertia; in other words, a quantum realm where quantum inertia not only exist, but also reigns. But this is all the resemblance, as the Transactional Interpretation has many sharp differences with SQM.

The interested readers can find useful the short panoramic views on quantum mechanics interpretations given in refs. [16,17], the latter about models of wave function collapse (for a humoristic overview see also [18]). In any case, SQM is the only interpretation of quantum mechanics where the concept of quantum inertia underlying the quantum-classical transition has been introduced, also the only one in which the quantum systems are switching rapidly among the available states, leading to an apparent superposition due to lack of time resolution, and the only that predicts a mechanism for neutron star formation with the release of X-ray synchrotron radiation.

Environmental decoherence, due to entanglement overdose, is only partially compatible with SQM because it assumes that macroscopic classical systems behave quantum-mechanically, i.e., they are described by wave functions, and their interactions with the environment make practically impossible to identify interference phenomena [19,20] (see also [6]). Gravitation was also proposed to solve the measurement problem through decoherence due to time dilation [21], but this proposal received much criticism [22,23]. Recently, however, Danielson, Satishchandran and Wald have shown that for a massive or charged body in a spatial superposition, a black hole can decohere the superposition by capturing the radiation of gravitons or soft photons, respectively [24]. Although in SQM macroscopic classical systems do not behave quantum-mechanically, the mechanism underlying environmental decoherence is compatible with SQM when applied to truly quantum systems, i.e., with their quantum inertia load below the critical value: $I_q < I_{cr}$. In this case, both effects—the increase of I_q due to the interactions with the environment and the decoherence mechanism—will contribute to the final loss of coherence. These two effects combined could well be behind the phenomenon of entanglement sudden death [25].

The collapse of the wave function due to consciousness, or mental abilities, a proposal that was very popular many decades ago, especially due to E. Wigner, could only be compatible with SQM if they would be capable of increasing the quantum inertia of the systems until or above the critical value I_{cr}, like any other interaction. Since the current understanding of consciousness—the awareness of one's own existence—and mental abilities is rather scarce, we cannot discuss this issue any further. Nevertheless, let us remind that although many aspects of the mind can be built in computers and other artificial intelligence machines, the emergence of consciousness just from complex matter and interactions is very amazing. This has lead some scientists to conjecture that consciousness could be an elementary property of matter, just like mass or electric charge, and has lead some others to propose that consciousness could be non-physical at all [26–29].

Collapse Models [17]. Now let us consider the proposal to replace the Schrödinger equation with a nonlinear version of it, which gives rise to several models, known generically as collapse models. As was explained in Section 2, SQM does not need to invoke a nonlinear Schrödinger's equation, but this does not mean that the nonlinear versions of the Schrödinger equation are incompatible with it. As we said, one may wonder whether the effect of quantum inertia I_q should show up manifestly in spacetime, giving rise to a

nonlinear Schrödinger's equation; but our impression is that quantum inertia only affects the quantum switching among the states in the Hilbert space, its action being confined there, not interfering with the dynamics in spacetime. We must point out, however, that some proposals for quantum mechanics making use of nonlinear Schrödinger's equations are truly incompatible with the essence of SQM. For example, the proposals that incorporate spontaneous sudden collapse of the wave function ψ in this manner [17,30]. In SQM the quantum-to-classical transition is far from spontaneous and due solely to the system's quantum inertia exceeding the critical value for each observable: $I_q \geq I_{cr}$. Moreover, in the event that an amount of I_q is released afterwards, pushing I_q down below the critical value, $I_q \leq I_{cr}$, then ψ is expected to describe the system again as soon as the quantum switchings among the states resume activity. This reversibility is an essential property of SQM, unless the system is destroyed by the perturbations or in the measurement process, obviously, and is not shared by the collapse models.

Gravitation. Another class of proposals that make use of nonlinear versions of the Schrödinger equation are those that signalize gravitation as the major (or only) cause for the collapse of the wave function ψ [31–33] (see ref. [34] for a brief survey). For example, in Penrose's proposal, the collapse of ψ is always a gravitational phenomenon. These interpretations take into account the system's own gravitational field in the Hamiltonian, resulting in the nonlinear Schrödinger–Newton equation [35], where the gravitational self-interaction term depends on $|\psi|^2$ and leads to the collapse of ψ. In SQM gravitation is like any other interaction, whether it is produced by external sources or is the system's own interaction. Therefore, if the action of a gravitational field does not increase the load of quantum inertia I_q of a quantum system above the critical value I_{cr}, then the corresponding gravitational strength fails to stop the superposition of states, i.e., to 'collapse' (to disable rather) the system's wave function ψ. In our opinion, only very strong gravitational fields, like those produced by neutron stars and black holes, would be able to accomplish this task, although less strong ones together with some other interactions (thermal bath, etc.) could also produce the same effect.

4. Past, Present and Future Experiments

Now we will discuss in the light of SQM some important experiments that have been made over the years in order to test conventional quantum mechanics.

4.1. Interferometry Experiments

Let us start with interferometry experiments. The double-slit experiment has been running for more than two centuries by now. Designed in 1801 by T. Young in order to investigate the wave-like nature of light, for a very long time the experiment and its variations made use of photons exclusively. In 1961, for the first time electrons were used instead, followed some years later by neutrons, then by atoms, and finally by molecules. The tendency to apply the experiment to bigger, 'more macroscopic' quantum systems has continued until the present, with the use of increasing larger molecules involving thousand of atoms.

As pointed out in Section 2, SQM can help us visualize the behaviour of a particle moving in superpositions of two trajectories, either by means of a double-slit setting or a beam splitter. First of all, remember that the propagation of the particles along each trajectory has wave-like properties, although this becomes only evident if large numbers of particles are involved. In other words, single particles do not create interference patterns, neither diffraction nor other wave-like patterns, but just single marks at their arrival at the corresponding screens or detectors. Nevertheless, these marks seem to have some 'knowledge' about the underlying wave-like nature of the particles, in the sense that each

particle somehow 'interferes' with itself, since it cannot interfer with any other subsequent particle in order to create the observed interference patterns made by many collective impacts. As noted in Section 2, that knowledge could well be a direct consequence of the fact that elementary particles are excitations of quantum fields.

SQM states that the particle switches very fast between the two wave-like trajectories, without passing by intermediate positions. Therefore, if there is a double-slit screen, the particle actually passes through the two slits, unless the thickness of the screen is extremely small, because the particle will be able to switch many times trajectories while crossing through the slits. If two detectors are placed behind the two slits, the particle will crash on only one of them, obviously, whereas if only one detector is placed behind one of the slits the particle may or may not crash against it. If the particle manages to avoid the detector that blocks one of the trajectories, then it will finally crash against the second screen coming from the other trajectory. Finally, if there are no detectors in between the double-slit screen and the second screen, then the particle will impact on the latter leaving an impact behind, the accumulation of many such impacts producing an interference pattern.

As a general rule, in interferometry experiments the superpositions can also involve some other properties of the particles besides their trajectories. For example, in the case of neutrons, interferences are observed in perfect agreement with conventional quantum mechanics when the superpositions are made between different spin orientations too, and even between different gravitational pulls if there is a gravitational gradient between the two trajectories, as was already observed in 1975 [36]. SQM tells us in these cases that the neutrons are switching between the two trajectories, on the one hand, and between the two spin orientations or the two gravitational pulls, on the other.

It is also worth mentioning that, in 2011, using weak measurements [37] on the momenta of the particles, followed by normal, strong measurements of the positions of the particles, the Toronto group of Steinberg claimed to have reproduced the average trajectories of single photons in a double-slit interferometer. For this experiment [38] they used about 30,000 single photons impacting on a screen placed gradually farther and farther behind the two-slit screen. The trajectories obtained seemed to coincide with the continuous classical trajectories of the Bohm's approach to quantum mechanics [39] and they apparently answered the question from which slit the photon passed through. However, the usefulness and reliability of weak measurements are subject of much controversy. Unlike the results of strong measurements, weak values are not constrained to lie within the eigenvalue spectrum of the observable being measured. In addition, weak-value probabilities can take negative values and measured weak values may be anomalously large, like 100 for the spin of an electron and about 100 for the effective photon number in one arm of the interferometer even if the entire interferometer contains only one photon. And the authors themselves gave a warning: 'For the experimentally reconstructed trajectories for our double slit, it is worth stressing that photons are not constrained to follow these precise trajectories; the exact trajectory of an individual quantum particle is not a well-defined concept'. SQM can also shed some light on the fact that the trajectories found in that experiment seem to coincide with classical continuous trajectories. Namely, the weak measurements of the particles, supposedly to produce only slight modifications on the momenta, might not be so weak after all and could, perhaps, halt the switching of the particles between the two trajectories due to the increase of their quantum inertia above the critical value, forcing the particles to follow classical continuous trajectories instead.

Interferometry experiments using beam splitters are in many cases equivalent to the ones using two-slit screens. One only needs a beam splitter, two mirrors—in order to make the split trajectories to converge again—and appropriate detectors. Eventually, other devices are placed intercepting the trajectories, depending on the experiments at hand. For

example, a weak measurement can be accomplished with a thin piece of birefringent calcite that changes the polarization of the photons passing through. As before, the increase of quantum inertia of the particles due to these weak measurements could eventually halt their switching between the two routes. Then the particles would continue following a continuous classical trajectory until they could release the excess of quantum inertia—resuming the switching between the two trajectories—or until they impact against the detector.

4.2. The Tourmaline Crystal

The behaviour of polarized light passing through a tourmaline crystal provides another beautiful example where SQM improves our intuition and understanding about what is actually happening inside the crystal. Tourmaline crystals have the property of letting through only plane-polarized light perpendicular to its optic axis. As a result, if the incident light is polarized perpendicular to the optic axis, it will all go through; if parallel to the axis, none of it will go through; while if polarized at an angle α with respect to the axis, a fraction $sin^2\alpha$ will go through.

Dirac discusses this behaviour of the light passing through tourmaline crystals in his book 'The Principles of Quantum Mechanics' [40] and wonders how one can understand these results in terms of polarized photons: 'This picture leads to no difficulty in the cases when our incident beam is polarized perpendicular or parallel to the optic axis. We merely have to suppose that each photon polarized perpendicular to the axis passes unhindered and unchanged through the crystal, while each photon polarized parallel to the axis is stopped and absorbed. A difficulty arises, however, in the case of the obliquely polarized incident beam. Each of the incident photons is then obliquely polarized and it is not clear what will happen to such a photon when it reaches the tourmaline'. Then Dirac explains that the obvious experiment is to use single photons and to observe what appears on the back side of the crystal: 'According to quantum mechanics the result of this experiment will be that sometimes one will find a whole photon—of energy equal to the energy of the incident photon—on the back side and other times one will find nothing. When one finds a whole photon, it will be polarized perpendicular to the optic axis. One will never find only a part of a photon on the back side. If one repeats the experiment a large number of times, one will find the photon on the back side in a fraction $sin^2\alpha$ of the total number of times. Thus we may say that the photon has a probability $sin^2\alpha$ of passing through the tourmaline and appearing on the back side polarized perpendicular to the axis and a probability $cos^2\alpha$ of being absorbed'.

The description offered by SQM to the passing of light through a tourmaline crystal differs substantially from the picture held by conventional quantum mechanics, given by Dirac. First of all, when a photon passes through a crystal its quantum inertia will necessarily increase (unless the crystal has a very low temperature), and the exact increment could depend on a number of factors such as the crystal structure or pattern, chemical composition, temperature, incident angle of the photon and its polarization. Thus, according to SQM, the picture that the photons polarized perpendicular to the optic axis pass unhindered and unchanged through the tourmaline crystal is not exactly correct, even though these photons are recovered out of the crystal as if nothing had happened to them. Second, if the crystal is birefringent, like tourmaline or calcite, the polarization of the incident photon may split into a superposition of two perpendicular polarization states with different probabilities. SQM then states that the photon will switch very fast and randomly between the two polarization states, staying longer in the state with larger probability, and increasing its quantum inertia I_q in the process, until it eventually reaches a critical value I_{cr} associated to the switching between polarization states. If this value is reached and exceeded inside the crystal, then the switching stops and the photon continues

its way in a well defined polarization state. In the case of the tourmaline crystals, if the switching stops when the photon is polarized parallel to the optic axis, then the material absorbs the photon and nothing is observed on the back side of the crystal, whereas if the switching stops when the photon is polarized perpendicular to the optic axis, then the photon reaches the back side of the crystal.

4.3. Entanglement Experiments

Now let us say a few words about some experiments performed in order to probe quantum entanglement, as described by conventional quantum mechanics. The search for correlations between entangled particles started in the 1970's by several groups [41]. Typically, the particles involved were photon pairs that had been emitted in electronic transitions from atoms of calcium or mercury and travelled in opposite directions with entangled polarizations. Each photon impacted on a polarization analyzer and the investigators could verify in this way that the correlations predicted by the quantum entanglement were confirmed massively, violating the Bell's inequalities in some settings [5]. However, some investigators were not completely satisfied because the orientations of the two analyzers were fixed before the photons were emitted, and they were afraid that somehow relevant information could be exchanged between them.

Finally, in 1981 the French group of Aspect and collaborators succeeded in switching the analyzers orientations faster than any light signal could be interchanged between them [42,43]. The results were the same as with the less sophisticated equipments but this time most researchers felt comfortable and the violation of the Bell's inequalities was finally established. As a consequence, all realistic local hidden variable interpretations of quantum mechanics were ruled out forever. Not everybody was satisfied, however, as there were complaints because the switchings of the analyzers orientations were periodic rather than random. Finally, in 2015 the Dutch-Spanish group of Hensen and collaborators succeded in obtaining a so-called loophole-free violation of a Bell inequality using entangled electron spins [44].

In 2003 Leggett [4] proposed an inequality for testing a class of realistic interpretations of quantum mechanics involving nonlocal hidden variables; that is, maintaining well defined individual properties of the particles. Experimental violations of the Leggett inequality were found in 2007 [45,46] using polarization states of photons, thereby discarding this class of realistic interpretations. Moreover, in 2010 the Leggett inequality was violated again, using the orbital angular momentum states of photons [47].

SQM predicts, in agreement with conventional quantum mechanics, that the exact values of the polarizations of the entangled particles are random but strictly correlated with each other, no matter the distance that separates the two particles. However, in our proposal each photon switches very rapidly and randomly among the available polarization states, the switchings of the two photons being exactly synchronized with each other. In the experiments described above, both switchings would stop instantly once the polarization of one of the photons were measured; in which case, the other photon would instantly acquire the correlated polarization.

4.4. Possible Experiments to Probe Scan Quantum Mechanics

In SQM, finding the dividing line between quantum and classical behaviour of a physical system amounts to finding the values of the critical quantum inertia I_{cr} associated to all the observables of that system, including its mass. Adding constituents to a system is perhaps the most effective way to increase its quantum inertia I_q, via the masses and interactions of the new constituents. But, as was explained in Section 2, all the interactions coming from the environment must also contribute to the quantum inertia of a physical

system. That is, temperature, gravitational, electric and magnetic fields and collisions with all kinds of matter and radiation. In addition, different interactions affect the observables in different ways and different observables are expected to have different values for the critical inertia I_{cr}.

For fixed environmental conditions, adding constituents to a quantum system until I_q reaches or exceedes the corresponding critical value, $I_q \geq I_{cr}$, results in the cessation of the system's quantum jumps between the two (or more) trajectories in interferometry experiments; in other words, the system has become classical and follows a well defined trajectory. As a consequence, no interference pattern can be created by repeating the experiment with a large number of identical systems, unless one or more of the external conditions change producing a decrease in I_q; for example, a drop in temperature. We conclude, therefore, that it should be technically possible to determine (or estimate, at least), for given external conditions, the critical quantum inertia I_{cr} associated to the mass of physical systems in general. In other words, it should be possible to find a *critical mass* M_{cr}, that depends on the environmental conditions, by performing interferometry experiments probing large molecules, in the lines reported in ref. [6], or nanocrystals to which the experimentalists could add or subtract atoms one by one.

Once the dividing line had been found between quantum and classical behaviour, regarding the mass of physical systems for fixed environmental conditions, the next interferometry experiments must be performed using borderline systems near the critical mass M_{cr}, varying slightly one of those conditions. For example, the temperature can be increased and decreased, both, in order to determine its effect on the quantum inertia I_q (as well as testing the reversibility of the process), with the possibility of finding a *critical temperature* T_{cr}. A technical difficulty will always appear, as was pointed out in Section 2. Namely, the difficulty to distinguish between the influence of temperature on the quantum inertia and the thermal fluctuations, which also spoil quantum coherence. In this respect, it is already known [8] that at 1500 K the fullerens still behave as quantum waves while they are indistinguishable from classical particles when they are close to 3000 K. It is also known that the critical temperature for effective quantum-to-classical transition decreases with increasing size [19,48], and it is conjectured that thermal decoherence should be avoidable for particles with masses up to 10^9 amu by cooling them to their vibrational ground state, below 77 K (see [6] and references therein).

Unfortunately, one cannot do similar tests increasing and decreasing the strength of gravitational fields substantially. Nevertheless, one can easily deduce that astrophysical bodies with gravitational fields weaker than those of neutron stars, for example white dwarfs, are uncapable to stop the switching of the electrons among positions in the atomic shells, since otherwise these objects would turn very quickly into neutron stars, emitting enormous amounts of X-ray synchrotron radiation in the process.

The effects of magnetic and electric fields on I_q could also be investigated in interferometry experiments using borderline systems. In addition, one could consider other tests, for example, the Stern-Gerlach experiment (1922) in which silver atoms passing through non-uniform magnetic fields split in two trajectories independently of the orientation of the magnetic field. This type of experiments should be repeated, lowering as much as possible the strength of the magnetic fields, in order to search for any thresholds pointing towards the existence of a critical I_{cr}.

Finally, let us notice that in refs. [6,17,49] a number of experimental settings and proposals were described in order to probe the quantum-to-clasical transition. Although these experiments were designed to test decoherence theory or collapse models, they can be applied to test SQM as well. That is, to test the existence of quantum inertia with critical values I_{cr}, giving rise to critical masses M_{cr}, as well as critical temperatures T_{cr} and other

critical parameters. For example, as mentioned in Section 2, collisional decoherence has been studied quantitatively using a Talbot-Lau interferometer [9] by gradual admision of different gases into a vacuum chamber and it was found that at room temperature a single scattering event per molecule of fullerens suffices to fully destroy the interference.

5. Discussion

In this paper we have presented the essential features of Scan Quantum Mechanics, a novel interpretation regarding the meaning of the superposition of states. Furthermore, we postulate a crucial property of all physical systems (quantum as well as classical) called quantum inertia I_q, that increases whenever a constituent is added to the system. I_q can also increase, or decrease, when the system is perturbed with all kinds of interactions: increasing or decreasing the temperature, increasing or decreasing the strength of electric, magnetic and gravitational fields in its environment, etc.

In SQM, quantum systems are in well defined states at each instant, but switching randomly and very fast among the available states described by the wave function, producing an effective apparent superposition of states due to lack of time resolution. We quantify the time spent in each state in terms of a unit called switching time t_S, which must depend on the system's quantum inertia I_q. We have proposed a relation between t_S and I_q in the expression given by Equation (1), and we have also proposed a lower bound relating the indeterminacy on the quantum inertia ΔI_q with the indeterminacy on the switching time Δt_S.

The switching among the available states is viewed as a natural fact of the quantum world, without the need of any specific cause, and only stops when the quantum inertia I_q reaches or exceedes a critical value I_{cr}, that may be different for each observable. Consequently, by reaching the critical value I_{cr} for a given observable, the corresponding switching time becomes infinite, $t_S \to \infty$, signalizing the end of the superposition, and the system stabilizes in one specific state with a well defined eigenvalue of that observable. Therefore, in SQM the origin of classicality, the dividing line between quantum and classical behaviour, is simply described by the relation $I_q \geq I_{cr}$. As a result, decreasing the load of quantum inertia of a system below I_{cr} for a given observable (whenever this is possible) should revert the process. This reversibility does not imply time reversal symmetry, however, as the switchings of the systems among the available states are random. If there is more than one value of I_{cr}, corresponding to different observables, then quantum and classical behaviour should co-exist when $I_q \geq I_{cr}$ for some observables but not for all. These hybrid systems should exist, especially at very low temperatures and weak gravitational fields, as it actually happens in mesoscopic systems.

Positions in space and momenta are treated in a similar way: the systems switch among the available positions, although not necessarily all of them, but a large subset at least. As a result, for quantum systems continuous classical trajectories do not exist, but quantum jumps are the rule. A very interesting case would be, precisely, a quantum system that reaches the critical inertia I_{cr} that stops quantum jumps, with the consequence that the system would have to move like a classical object. If this happens to electrons in atoms due to the action of very strong gravitational fields, then those atoms will look like tiny planetary systems, with the electrons emitting X-ray synchrotron radiation while falling into the nuclei. This possible non-thermal emission from astrophysical objects with strong gravitational fields, like neutron stars or black holes, proposed by SQM, should also be taken into account as an efficient mechanism for the conversion of atoms into neutrons in neutron stars and in accretion discs of some black holes, producing sudden explosions of X-rays in all directions (less intense, of course, than gamma-ray bursts). Obviously, the strength of the gravitational fields of white dwarfs is not enough to produce this mechanism,

as these stars would turn into neutron stars very quickly otherwise. Therefore, the strength of the gravitational fields of white dwarfs provides a lower bound for the *critical gravitational strength* G_{cr} necessary to ignite this mechanism. In other words, $G_{cr} > G_{wd}$, where *wd* stands for white dwarfs.

We have discussed SQM versus several other interpretations and proposals concerning quantum mechanics. Most of them treat classical macroscopic objects as quantum objects, with the corresponding wave functions that describe their behaviour, in sharp contrast with SQM. Also most of them use non-linear versions of the Schrödinger equation, a feature that SQM does not need. In our opinion, all these proposals lack a clear mechanism that allows to draw the dividing line between the two kinds of objects, i.e., between the quantum and the classical worlds.

One may wonder what causes the quantum switchings, in the first place. As we said, we think that these are facts of the quantum world and nothing special causes them, not a quantum potential or any forces, but these features are simply a primary, basic behaviour of the quantum systems, like randomness. More meaningful, perhaps, is turning the question upside down: What causes the classical systems not to switch between different states, i.e., not to have superpositions, and present well defined properties as a result? The answer given by SQM is quantum inertia I_q reaching or exceeding a critical value I_{cr}.

We assume that wave functions evolve unitarily with the Schrödinger equation, like in conventional quantum mechanics. But SQM is more asymmetric with respect to the roles played by space and time since we postulate that quantum systems are switching among states as time passes by. The role of time is therefore more relevant in SQM than in conventional quantum mechanics.

In our views, there are two levels of physical reality: the more fundamental, deep quantum level, with time but no space, and the spacetime level at the surface, the former imposing its rules on the latter, producing nonlocal effects such as quantum jumps and entanglement. For this reason, we think that the effect of the quantum inertia I_q in the physical systems remains deep at the quantum level, not showing up necessarily in the spacetime dynamics in the form of a non-linear term in the Hamiltonian of the Schrödinger equation or in any other way. In connection with this, the question arises as to whether quantum inertia would exert any action on the quantum vacuum; for example, showing some imprint on the Casimir effect. In our opinion, if I_q is an elementary property of the physical systems that does not 'surface' in the spacetime dynamics, then it cannot have any effect on the vacuum. However, it could also happen that I_q could be described rather as a quantum field of some sort (not necessarily scalar). In that case, it would have an impact on the vacuum, and in particular on the Casimir effect.

We have reviewed the most relevant past and present experiments in quantum mechanics, in the light of the more intuitive description offered by SQM. Moreover, we have also proposed some experiments to be performed in order to determine the critical values of I_{cr} for some observables, which would translate into critical masses M_{cr}, critical temperatures T_{cr}, critical gravitational, electric and magnetic fields, etc. In SQM all these critical values and quantities should be found, in principle, via experimentation because quantum inertia is a very basic, fundamental property that, very likely, cannot be expressed as function of any other physical properties. This may seem to be an unsatisfactory feature of SQM, but the same happens with the masses and couplings constants of all the elementary particles in the 50 years old Standard Model of particle physics, despite its many successes.

Some of these experiments could also investigate the possible reversibility between quantum and classical behaviour for some physical systems: adding or substracting constituents to the systems, increasing or decreasing the temperature, increasing or decreasing the strength of electric and magnetic fields in the environment, etc. As a matter of fact,

many experiments that have been performed, or proposed, in the last years by a number of groups in order to test the quantum-to-classical transition [6,9,17,49], apply similarly to determine (or estimate) the values of the critical quantum inertia I_{cr}, via critical masess M_{cr} for fixed environmental conditions, or via critical temperatures T_{cr}, or critical values of the other physical parameters.

We also think that mesoscopic systems, in general, as well as physical phenomena at very low temperatures, such as superconductivity, superfluidity and Bose-Einstein condensates, must be reanalyzed in the light of SQM, i.e., taking into account the possibility of existence of quantum inertia with critical values I_{cr} for the observables, giving rise to critical values of the masses, temperatures, electric and magnetic fields, etc.

Finally, let us emphasize that SQM is the only interpretation of quantum mechanics where the concept of quantum inertia underlying the quantum-classical transition has been introduced, also the only one in which the quantum systems are switching rapidly among the available states, leading to an apparent superposition due to lack of time resolution, and the only that predicts a mechanism for neutron star formation with the release of X-ray synchrotron radiation that could be detected by space-based telescopes, like the Chandra X-ray Observatory.

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