A Bi-Directional Big Bang / Crunch Universe within a Two-State-Vector Quantum Mechanics?

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Abstract
A two boundary quantum mechanics incorporating a big bang / big crunch universe is carefully considered. After a short motivation of the concept we address the central question how a proposed a-causal quantum universe can be consistent with what is known about macroscopia and how it might find experimental support.

Keywords: Two state vector interpretation of quantum mechanics, resurrection of macroscopic causality, big bang / big crunch universe

In the literature searching for consistent interpretation of quantum mechanics the Einstein, Podolsky and Rosen „paradox“ [19] plays a dominant role. Many solutions were proposed. There are two main options. One can change or limit the ontology of wave functions (or fields) like it is done in the old Copenhagen interpretation (see p.e. [8, 9]) or one can admit retro-causation (see p.e. [5, 16, 33]).

In our view there is actually a more decisive „paradox“ of quantum statistical nature. We are at \( \tau_0 = 0 \). Consider two wavelets (or suitably regulated point fields) of identical particles created around the time \( \tau_1 < \tau_0 \) and \( \tau_2 < \tau_0 \) in areas within our backward light cone and annihilated around the times \( \tau_3 > \tau_0 \) and \( \tau_4 > \tau_0 \) in areas within our forward cone. Considering the essential part \( a(\tau_1) a(\tau_2) a^\dagger(\tau_3) a^\dagger(\tau_4) \) one obtains two contributions:

\[
[a(\tau_1) a^\dagger(\tau_3)] [a(\tau_2) a^\dagger(\tau_4)] \pm [a(\tau_1) a^\dagger(\tau_4)] [a(\tau_2) a^\dagger(\tau_3)]
\]

There are restriction on the functional behavior of each commutator but the effect considered is independent of the details of their behavior.

The probability of the creation and annihilation process depends on the square of the amplitude and the relative phase of both contributions enters. The point is now that this phase also depends on the Hamiltonian for \( \tau > \tau_0 \). If the Hamiltonian is manipulated by us at \( \tau_0 \) it those impacts the \( \tau < \tau_0 \) creation probability happening in our backward light cone. In our opinion the effect destroys the first option (which restricts retro causation just to wave functions not considered ontological) as here in principle observable probabilities are involved.
In previous papers we discussed less abstract implementations of this paradox. We carefully considered [12] the Humbury-Brown Twiss effect used in astronomy [13] and multi-particle physics [29, 27]. We also presented [13] a simple gedanken experiment with two radio antennae sitting in the focal points of a mirrored ellipsoid possibly emitting each a single photon at \( t = -\Delta T \) with an electronically chosen phase. The photons are then absorbed at \( t = +\Delta T \) at opposite sides. Everything is known and calculable. A dark spot on the surface put just before \( t = 0 \) allows for an extra counting interference contribution. If in a positive region it increases the emission probability at \( t = -\Delta T \) in a manifest retro causal way.

In our opinion there is no escape to avoid backward causation. However retro causation requires extremely rare conditions which can be ignored in macroscopic considerations.

Measurements inhabit the interface between quantum dynamics (quantum mechanics without jumps) and macroscopy. How does retro causation change the concept of measurements. A measurement is usually associated with a collapse removing the other components. Formally it is represented by a renormalized to-one-state projection operator. Retro causation allows the measurement to happen any time after the initial splitting. To postpone the collapse p.e. into an extended detector will not effect the Born rule for the initial splitting. The argument is not completely trivial as one initial option could asymmetrically lead to more candidate states to collapse to. It follows from unitarity of the evolutions of both components between the splitting and the measurement.

In the coherence concept [26] one considers an open system and assumes that the measurement occurs if a witness reaches for all practical purposes the „outside“ attributable to macroscopy. We here consider a closed universe with an initial and final state. Extending the basic idea of the coherence concept, the measurement with its collapse is taken to occur if a witness reaches the „external“ final state.

Formally the postponed measurement point can be written (ignoring normalization) as a shift of the corresponding projection:

\[
< \text{initial} | U_1 \cdot \text{Projection} \cdot U_2 | = < \text{initial} | U_1 \cdot U_2 \cdot \text{Projection}' |
\]

Obviously this projections can then be included in the final state density matrix:

\[
\rho \propto \sum_i \text{Projection}_i' \cdot \rho_0 \cdot (\sum_i \text{Projection}_i')^\dagger
\]

As the number of decisions fixed by projection is huge \( \rho \) has to be very restrictive. It presumably suffices to consider a single fixed final state:

\[
\rho = |\text{final} > < \text{final}|
\]

and to do the same for the initial state density matrix. Both assumptions are not crucial.
The collapse of a measurement contain besides the projection operator a huge re-normalization factor

\[ \frac{1}{\langle \text{initial} | \text{Projection} | \text{initial} \rangle} \]

and for the wave function side of the universe a measurements means:

\[ \langle \text{initial} | U_1 \cdot \text{Projection} \cdot U_2 | \text{final} \rangle / \langle \text{initial} | U_1 \cdot U_2 | \text{final} \rangle . \]

It is the two boundary formalism developed by Aharonov and co-workers \[1, 4\] and others \[22, 25\].

It is actually quite close to a multiverse interpretation \[20, 34\]. In this interpretation „our“ universe is determined by a community of „our“ observers. Only branching is considered. At the end „our“ universe is one out of \(2^{\text{decisions}}\) others. The point is now that nothing changes for „our“ present situation if shortly before its end a projection operator is entered eliminating all other universes for the remaining time. However restricting the consideration to „our“ universe it can now be described in a two boundary way. If the projection operator factorizes it exactly corresponds to the two boundary state situation.

It is of course not certain that the final state is reached by a decisive witness. A trivial example is drawn in Fig. 1. A sideways polarized electron is initially split in a up and down component. If a sufficiently good vacuum (e.c.t.) avoids traces the shown arrangement destroys the up/down distinction. Such coexisting intermediate paths clearly exist in the quantum world. An obvious requirement is to eliminate them on a macroscopic level. We assume that the witnesses reaching the final state are structured sufficiently detailed to practically always satisfy this requirement.

Consider the Schrödinger cat. If the box containing the cat would really be perfectly insulated and kept for \(10^{10}\) years (or covering an entire closed grandpa-paradox temporal loop in the framework of general relativity) the coexistence of a live or dead cat (or grandpa) would be possible. In a finite size box all possible states will typically be reached eventually which effectively destroys traces in the final state and eliminates its power to prevent coexisting macroscopic states.

Even ignoring the time requirement the box will never be completely insulated and thermal (or lower energy) photons will witness the macroscopic situation. Such photons or their offspring will eventually make it to the thin sky and so eventually reach the the end of the expanding universe. In this way the sky plays a significant role. It replaces the conscious observer often discussed in
literature [37]. Of course the reflection-less dark sky of the expanding universe is also the cause of the thermodynamical time arrow [38].

The mechanism to fix the macroscopic situation is not simple. Tiny interactions with a strongly self interacting system might even enhance the stability of quantum states (discussed in [32] for biological systems). Intense self interactions within the surrounding system somehow limit the decisiveness of the eventual final state. It somehow resurrects the quantum Zenon stability. The effect [6] is usually eliminated as the required macroscopic outcome (like an emission of a photon in atomic physics [7]) leads to a tide correlation of the interaction times in the evolution of the amplitude and its conjugate eliminating one power in the dependence on the decreasing „measuring“ interval essential for the effect. For the evolution of the universe - at least after freeze out of a plasma state - we consider such effects statistically irrelevant.

In contrast to the quantum world macroscopic considerations should not allow for distinct coexisting pathways. A large number of effective measurements must reduce ambiguities to allow for one macroscopic description. In the two boundary description these measurements must stored in the boundary states. This means that the overlap

\[ \langle \text{initial} \mid \text{final} \rangle \sim 0.5^{\text{decisions}} \]

estimated in [26] must be tiny.

We are aware fixing the macroscopic situation is not an easy task for the dark sky and the huge number of needed decisions is a problematic point in this interpretation. A single cosmic ray particle entering the atmosphere sometimes produces thousands of particles all causing different new macroscopic situations which somehow have to be traced.

This motivates some authors to add a kind of dynamical jump process to the theory. We consider it unsatisfactory as it seems at hoc [23] or if gravitation is used [31, 21] effectively so.

Our final state has not to store the complete macroscopic situation but just nail it down in the subspace of possibilities. With a given macroscopic scales the number of situations in a closed universe is not formally infinite. Also there are efficient witnesses which are „cheap“ and macroscopically unnoticeable. A single 30 cm radio wave photon possibly emitted from a circuit board or the brain of Wigner’s conscious observer carries away an undetectable energy of \(10^{-25}\) J. In the region of atmospheric transparency a radio frequency \(\gamma\) can easily escape to the dark sky.

We stress that we do not investigate a new theory which replaces the old one in a tricky way. The formalism just uses and extends the well established quantum dynamics. Quantum dynamics allows to calculate amplitudes between an initial and final state with convincing precision not available in any macroscopic field of physics. It is taken as the underlying theory. No arbitrary scale limiting its validity [23] is introduced. That such a two vector state concept can be considered a self consistent, time symmetric interpretation of quantum theory was also claimed by Aharonov and Cohen [3] and others [30].

The central difficulty in this interpretation is to understand how the causal classical physics can arise in the symmetric two boundary theory. To proceed
we introduced two transition rules which prohibit manifest macroscopic backward causation. They essentially state that there can be no post selection and that the a-causality discussed above can usually be ignored as it requires phase correlations in macroscopically distant sources and unusual not phase averaging observations.

In macroscopic physics there is a causal decision tree. At each branching a decision how the future evolves is made. The critical point is to understand the option „not chosen“. In macroscopia quantum phases (and some minute changes) are averaged out. With such incomplete macroscopic knowledge on both boundaries separate, „chosen“ or „not chosen“ macroscopic paths can appear if the distant between the boundaries is sufficiently huge.

The apparent time direction of the decision tree originates in our relative proximity to the initial time and our huge distance to the final one.

Even with the limited macroscopic knowledge about the present situation a lot is known about the past (Knowledge about fundamental processes like the formation of stars is powerful.). Our assumption is that given the full initial and present state in all macroscopically reachable details there is only one macroscopic evolution path reaching us.

It is not easy for macroscopically different states to evolve to the same macroscopic state. Of course there can be strange attractors following and hiding earlier expansion periods which could allow for ambiguous macroscopic evolutions. The assumption is that such exceptions do not play any significant role in our mostly rather empty universe.

The situation is different with the really distant final state. Here a complete knowledge of the macroscopic boundaries still allows for multiple coexisting paths. Our postulate is now that if the exact quantum boundary conditions with all their given phases e.c.t. are implemented these ambiguities vanish and the actually taken macroscopic path is determined. In a classical consideration this selection is mistaken to happen at the instance of the branching and it appears that such decisions affects the choice of the future path.

This picture of the universe is perfectly consistent but there is one annoying point. Self organization with an intrinsic time arrow seems to play a central role also in the evolution of the universe. This time arrow is not available in the final state. The concept is that it suffices if these decisions encoded in the final state are effectively random just like the decisions in the usual theory with jumps. But still, to have the final state as a somehow external entity which at least in principle decides everything touches basic scientific principles.

A reasonable scenario of the universe contains a big bang (at \( t = 0 \)), a state of maximum extend (at \( t = \frac{1}{2}T_{\text{crunch}} \)), and a big crunch (at \( t = T_{\text{crunch}} \)). As there is no intrinsic time arrow the „forward moving“ world is formally symmetric to the „backward moving“ one. Can the two state picture work in such a universe ?

As above all macroscopic decision have to be encountered by a corresponding loss and again an extreme miss match

\[
\langle \text{bang}|\text{crunch} \rangle = 10^{-\text{huge}}
\]
is needed. It does not mean fine tuning as there is a rich structure which naturally rarely fits. It just requires that in the huge state of maximum extent the probability of matching entanglements vanishes. Essentially only one matching „border“ state should remain and the \( \langle \text{bang} | \text{one effective final state} \rangle \) picture should be resurrected.

A novel property is that the border state is now the result of evolutions. It makes self organizing periods natural.

What could be the relation between the forward and backward moving part of the universe? As the border state is identical there have to be some similarities.

Both the boundary big bang and the boundary big crunch states could be identical on a macroscopic level and the needed huge miss match could just be due to details of their microscopic or quantum dynamical part. There are lots of phases available.

Consider in such a scenario for the moment the border state only macroscopically. Even with the macroscopically equal bang/crunch state many macroscopic histories would contribute in both parts.

The extremely extended border state is actually identical on a quantum level for both sides. A somewhat daring assumption is now the this fact could suffice to require equal macroscopic histories. This opens an amusing option in which our macroscoping actually involves both quantum epochs.

Let us consider this option in more detail. Consider the situation with an electron wave with spin in the rightward direction the time \( t \) in the „forward moving“ world and an identical one at \( T_{\text{crunch}} - t \) in the „opposite moving“ world. A component \( \propto \langle \text{rightward} | \text{upward} \rangle \) represents an upward intermediate state at \( t + \epsilon \). We assume this state to be uniquely traced in witnesses reaching the effective final \( T - \epsilon \) state. The component which reaches the same intermediate state in the backward moving world at \( T - t - \epsilon \) has an identical size \( \propto \langle \text{rightward} | \text{upward} \rangle \)^\( \text{CPT} \). Averaging out unknown evolutions the probability of an upward spin is therefore

\[
P(\text{sideward} \rightarrow \text{upward}) = | \langle \text{sideward} | \text{upward} \rangle |^2.
\]

The seemingly statistical choice is no longer stored in a know-all-final state but in an intrinsically matching state. The contribution to the upward measurement is then:

\[
\langle \text{bang} | U(T, t) \cdot P_{\text{up}} \cdot U(t, T_{\text{match}}) \cdot P_{\text{match}} \cdot U(T_{\text{match}}, T_{\text{crunch}} - t) \cdot P_{\text{up}} \cdot U(T_{\text{crunch}} - t, T_{\text{crunch}}) | \text{crunch} \rangle
\]

(with \( P_{\text{match}} = 1 \) by continuity) and corresponding one for the downward spin.

We consider now for both cases the central second line. As argued the matching contributions are in both cases tiny say \( 10^{-\text{huge}} \) resp. \( 10^{-\text{huge}'} \). Given the extreme value of the exponents their natural statistical variations (\( \propto \sqrt{\text{huge}} \)) are
large. If $\text{huge} < \text{huge}'$ it therefore means $\text{huge} \ll \text{huge}'$ yielding a practically exclusive dominance of its contribution. This „random“ decision is no longer „würfelt“ (Einstein’s term for dice) but it is consequence of unknown „future“ evolutions.

The abolishment of the conventional time structure allows a curious scenario in which we live with our wave function in the forward moving world and with our conjugate function „eons apart“ in the tidily correlated opposite moving one.

A tiny violation of CPT symmetry [35] could be a signal for such a situation. Usually symmetry violations reflect properties of the Lagrangians or, if preferred, simply of an asymmetric vacuum (Parity violation needs a real grand unified theory like SO(10) broken down suitably by the vacuum. For a natural vacuum mechanism for CP violation we refer to [10, 11]).

Such mechanism do not apply to CPT violation. CPT is a basic feature of quantum dynamics or local field theories. Born’s definition:

$$\text{Probability} = \text{Amplitude}^{\text{CPT}} \cdot \text{Amplitude}$$

is manifestly invariant.

In the bi-directional universe the big bang and big crunch state are distinct on a quantum level and even their equality on a macroscopic level might just hold in good approximation. Slightly different amplitudes would then lead to a tiny CPT violation:

$$\text{Amplitude}^{\text{CPT}} \cdot \text{Amplitude}' \neq \text{Amplitude} \cdot \text{Amplitude}'^{\text{CPT}}.$$

Such a violation is a natural consequence of such asymmetric theories. As a CPT asymmetry can also arise p.e. in elaborate non local field theories [24] it would strongly support but not prove the bi-directional universe.

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