Collaps, Expansion, and Variable Speed of Light

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Abstract

This paper presents an information-theoretic view of how an observer within a quantum system will perceive his world. It is argued that because of the indistinguishability of quantum particles, a coherent state will appear to an observer within the system like a singularity. As superposition is lost, space appears to expand, although to the outsider it is merely the collapse of the wave function. Implications of these ideas to cosmology are considered. The superluminal expansion of space provides a basis to understand inflationary cosmologies. This expansion may be taken to be equivalent to a much faster speed of light during the inflationary period. These ideas can be tested by checking for ‘higher’ speed of light from photons emitted by decohering atoms.

Keywords: Inflationary universe, big bang, speed of light

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1 Introduction

The collapse or reduction of the wave function upon measurement is perhaps the most troubling aspect of quantum mechanics. This collapse is supposed to occur instantaneously. As David Bohm observed in his *Quantum Theory* long ago, “The exact region to which it collapses is not determined by the state of the wave function before collapse... This type of collapse of the wave function does not occur in any classical theory.” It is because of this that some researchers have proposed that quantum mechanics may not be a complete theory. If one insisted on using classical logic or reductionist arguments, this collapse leads to paradoxes such as those of the Schrödinger’s Cat or the Wigner’s Friend.

Here we reconsider the question of collapse from the point of view of the reference frame of an hypothetical observer within the quantum system. This may appear pointless until it is realized that the initial state of the universe is believed to have been a pure quantum state described by a gigantic wave function. Therefore, we already are observers within an evolving system. If this view is justified for the universe, it should be applicable to other quantum systems as well.

The postulated wave function of the universe at initial time has evolved through a process that has elements that go beyond the framework of quantum theory (since the Schrödinger equation only transforms a pure state into another), or interacted with a system outside the universe, into a system that has classical subsystems, like the one to which we and our measurement apparatus belongs. In cosmology, we extrapolate backwards in time to estimate the nature of time and space when the system was in a pure quantum state.

Quantum theory is a set of rules allowing the computation of probabilities for the outcomes of tests, that follow specified preparations. In the standard interpretation of quantum mechanics, the observation records the transition from potentiality to actuality, but the observational means must be described in terms of classical physics. The observation then is a record of the interaction between the quantum and the classical worlds.

Having argued that it is appropriate to consider the frame of reference of an observer within the quantum system, it is clear that at Planck time from the initial condition, the universe will be one of ceaseless creation and destruction. But at greater time scales, one would expect more structure and
this is what we would like to explore.

But an examination of such observations comes with its own problems. To record an observation, one needs a classical subsystem. In this preliminary study, we postulate an imaginary observer that is somehow able to make measurements without interacting with the system. We then consider the question of the problem of the collapse of the wave function. We argue that this collapse will appear as an expansion of the space to an observer inside the system.

We first look at quantum information from outside. Then the observation of a large system in a pure state from within is considered. This is followed by extrapolation of these ideas to the wave function of the universe. Lastly, we consider the question of speed of light appearing to have been different in the remote past.

2 Information in a Quantum System

Information, logarithmically proportional to the number of possibilities (patterns), provides a way to examine the nature of a quantum process. We also note that quantum theory itself has been viewed as a theory of obtaining information about nature [1]. In a recent study [2], I argued that information associated with the quantum system as it is observed from outside increases exponentially with the size of the measurement apparatus. Investigating the information provided about a specified distributed apparatus of \( n \) units in the measurement of a quantum state, it was shown that, in contrast to such measurement of a classical state, which is bounded by \( \log(n+1) \) bits, the information is bounded by \( 3.7 \times n^{7/2} \) bits. This means that the use of quantum apparatus offers an exponential gain over classical apparatus.

This unbounded information is a consequence of the superposition at the basis of the quantum state. It is because of this that after the spin of a particle has been measured to be in a particular direction, there is still a probability \( \cos^2 \theta / 2 \) of spin in a new direction at an angle of \( \theta \) from the previous one. One would expect that this property of unbounded information, for which there is no parallel in the classical world, will have an equally dramatic analog in observations from within the quantum system.

Now, let’s consider the question of information from within the quantum system. But when we count patterns, we cannot visualize them in classical
sense as spread over a certain physical space; we must speak of extension for a quantum object amongst its states.

A total of $n$ indistinguishable particles in $N$ states will be associated with $\binom{N+n-1}{n}$ distinct patterns if they are bosons, and with $\binom{N}{n}$ distinct patterns if they are fermions. On the other hand, for distinguishable (classical) objects the number of patterns is $N^n$.

Considering the number of patterns, we get most for bosons and the least for fermions, with classical particles somewhere in between. For example, if $N = n = 4$, the number of patterns for fermions is 1, for classical objects is about 10, and for bosons is 210. This explains why bosons are very efficient in the transmission of information. And it is the working of the Exclusion principle, at the basis of the behavior of fermions, that explains the stability of matter.

The information capacity of a system of mass $m$ has been estimated variously using dimensional arguments or considering the energy expended to store or erase a bit of information [3, 4] in the presence of the background cosmic radiation of $2.7^\circ$ K. Since one bit of information requires $kT \ln 2$, where $k$ is the Boltzmann constant, one can, by using the mass-energy of the universe, compute its total information processing capacity per unit time.

The information capacity of an electron is about $3 \times 10^9$ bits per second, while the total information capacity of the universe is about $10^{98}$, or say about $10^{100}$, bits per second. These capacity numbers represent the upper bound on information that can be associated with any quantum wave function description of the electron or the universe.

But this information arises only upon interaction with observers, prior to which interaction it remains latent. Because of the unitary nature of the transformations in a quantum system, information will manifest itself only to an observer who reduces the wave function. This means that we must, to remain consistent, postulate a reduction affected by the environment outside of the universe.

### 3 Collapse of Wave Function Reconsidered

Let us consider a quantum system consisting of a large number of particles. To the observer outside the system, the particles, being indistinguishable, are
simultaneously present at all the locations. Or we can represent the particles as a wave which cannot be localized.

Let us now shift the frame of reference to the quantum system. Within it, particles do not have a point of reference. Since each particle is equivalent to any other, each particle may be supposed to be located at the same point. This may sound strange but it is no more so than particles flying backward in time or universe splitting into many copies of itself. It means that with respect to an observer on a particle, space has collapsed so that the locations of particles inferred by an observer outside actually belong to the same position. In other words, the particle space will appear very different from classical space to an observer within.

Now let us imagine that this quantum system interacts with an observer outside of the system. This will cause the wave function of the system to collapse into one of the component states. The particles, which were simultaneously present all over the space (with respect to the outside observer), now find themselves in definite locations. From the point of an observer within the system, the particles which were earlier co-located now fly off extremely rapidly to acquire definite locations. Or the single wave now spawns many particles.

This process is akin to a sudden expansion of the space, as the objects occupy definite possibilities in the classical space of the observer. In this view, ordinary space arises after the quantum system has decohered. Subsequent to this collapse, one is justified in the use of classical notions of space.

When this system has interacted with an outside one the system decoheres. Each particle sees its neighbor travel away to a distance that, on average, corresponds the dimensions of the decohered system. In other words, the observer within perceives the system to expand very quickly.

This expansion may be seen to be in two phases: the initial phase of rapid expansion, representing the inflationary phase; a slower later phase, arising out of the slowed later decoherence.

If photons are transmitted by particles that are undergoing decoherence, it will appear to an observer outside of the system that they were traveling at speeds much faster than the speed of light. This increase in the apparent speed could, in principle, be measured. This expansion may be seen as a mutually repulsive force amongst the particles.

If the system is large, then one must also consider the scenario of the observer system interacting with it in a graduated manner. This case will be
4 Expansion of Space in Cosmology

We assume that the ideas applicable to individual quantum systems are also applicable to the universe. Corresponding to the instantaneous reduction of the wave function for individual quantum systems is the inflation of the universe.

Let’s consider that at the initial condition the universe consisted of \( n \) particles in the same state. Consider, further, that Big Bang is a result of the interaction of the universe \( U \) with the observer \( M \), causing the state to decohere. The \( n \) particles would then get distributed over the \( N \) states.

It is realistic to assume that the interaction of \( U \) and \( M \) occurs somewhat gradually. We assume that \( M \) is sufficiently inhomogeneous so that we can look at its interaction with \( U \) as a sequence of interactions mediated through the subsystems \( M_i \). This does two things: i) it makes the overall evolution of \( U + M \) nonlinear, ii) it causes an immediate reduction of parts of the wave function of \( U \), followed by further continuing reduction in a recursive manner.

The wave function \( |Cosmos\rangle \) of the universe could then be written as:

\[
|Cosmos\rangle = \sum_i a_i |U_i\rangle |M_{1i}\rangle
\]

when the first subsystem \( M_1 \) has interacted with \( U \). This is followed by interactions of the interpenetrating \( U + M_i \) with other parts of \( M_i \).

The interaction with \( M_1 \) will lead to a rapid expansion. As other \( M_i \)'s interact, we will witness expansion in smaller clusters. This process will act in a recursive fashion so that the regions initially separated in large clumps will be reduced in the next step, and so on.

The reduction by this mechanism ensures that the universe will have homogeneity because \( U \) is initially in a superposition of all states.

Decoherence times

Joos and Zeh [5] have calculated the effect of decoherence from an external environment. The speed of decoherence depends on the number of particles
of the observer \( M \) interacting with the system. The decoherence factor \( g(t) \) is calculated to be

\[
|g(t)| \approx e^{-qt}
\]

where \( q \) is the total number of particles interacting with the system during the time \( t \). Since this exponent is a large quantity, the decoherence will take place extremely rapidly.

Consider the estimates of Joos and Zeh as a guide, where objects (ranging from dust to big molecule) under various conditions, from vacuum on earth in full light of the sun to laboratory vacuum, take from \( 10^{-13} \) to \( 10^{-36} \) seconds to decohere. (These conditions, rather than that of intergalactic vacuum, which is a consequence of the reduction, appear reasonable from the point of view of a comparison.) In a more direct interaction of \( U \) and \( M \), the decoherence times would be much smaller. The details of the interaction between \( U \) and \( M \) will determine the actual values of the decoherence. But one would expect that as the two systems begin their interpenetration, the expansion accelerates to a peak and then becomes progressively smaller in magnitude. This is clear by considering the two extreme cases: i) before the interaction begins, there is no expansion; ii) once the interaction is complete, the expansion stops.

It is interesting that the inflationary phase of the universe is estimated to have lasted from \( 10^{-35} \) to \( 10^{-24} \) seconds, an interval which sits around the values obtained for conditions on earth.

In practical terms, to an observer situated within, it would appear that the system expanded almost instantaneously. If it is assumed that the parts of the system kept in touch by means of photons, then it would be necessary to postulate that the speed of light in this phase was much greater than what it is now.

5 Variable Speed of Light

It has been suggested that accepting that the speed of light \( c \) in the early universe varied and it was much higher provides resolution to the horizon and flatness problems of cosmology [6]. In the standard Big Bang model, the homogeneity, isotropy, and flatness of the universe are features that are a result of the beginning as initial conditions. On the other hand, variable
speed of light makes it possible for the photons to have had the time to smooth out the temperature and density irregularities in the parts which have never interacted with each other. But this proposal and its variants require acceptance of time change of other fundamental constants. Ideas related to the time change of electric charge, $\hbar$ and the gravitational constant have been variously examined [7]. Therefore, this idea, although helpful in some sense, raises other difficulties.

In our view of expansion of space as a consequence of the collapse of the wave function of the universe, there is no need to consider these further time-varying constants of nature. The variation in the speed of light is just a projection of the collapse of the universe’s wave function to the reference frame of an observer within the system.

The observations from within the system that show the particles flying off instantaneously can be seen within the framework of a superluminal expansion or, if one wished to preserve the speed of light as the ultimate limit, by postulating that the speed of light was much greater at epochs close to Big Bang and thereafter it became smaller. But this variable speed of light is only an artifact of the model of explanation.

The characteristics of the early universe could be used to infer properties of $M$ and the nature of interaction of $U$ and $M$.

6 Discussion

The collapse scenarios sketched here are admittedly rather vague; they are intended just as an outline of a new way of looking at a quantum system from within. But these ideas have testable implications. One would expect to see higher speed of light for photons originating from atoms in a quantum system that is undergoing decoherence. But this higher speed of light would merely be an artifact related to the observer on the atom.

Our ideas exhibit scale invariance and this permits some testing of cosmological models in the laboratory without the need for any new physics. This is in contrast to recent theories where exotic forms of matter and forces have been postulated to account for anomalous observations at the cosmic level.

The view of expansion of space as a result of the collapse of the wave function of the universe provides us with the possibilities of new experiments
to check these ideas.

The idea of observation of the wave function of the universe raises many questions. How did the interaction between the universe $U$ and the environment $M$ take place? How did the giant wave function of $U$ get formed at the initial condition? Is there an infinity of universes that lie beyond ours?

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