Extragalactic Evidence for Quantum Causality

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In the conflict between Albert Einstein and Niels Bohr over the fundamental nature of reality, quantum mechanics was the experimental data being interpreted. The Copenhagen school maintained, crudely speaking, that reality at the microscopic level was to some extent subjective and acausal. Einstein, on the other hand, believed that no event was without cause and proposed the famous Einstein-Podolsky-Rosen paradox attacking the conclusions of quantum mechanics as being self-contradictory. The paradox, of course, was that quantum mechanics was observed to be experimentally true.

The EPR proposal for an operational definition of reality was eminently sensible: If an event could be predicted with certainty it was real. The difficulty was that EPR did not discuss the aspect of locality. I would suggest extending their definition to read: To the extent that an event can be predicted it is locally causal; to the extent that an observed event is unpredictable it is real but only causal on a non-local scale.

Of course, if we consider non-locality we are dealing with cosmology, the nature of the universe as a whole. But what do we know about cosmology that directly bears on quantum mechanics? Most astronomers would vehemently respond, Nothing. But in fact I believe evidence has been growing over the past two decades that the most fundamental property observable in galaxies and quasars, the redshift, is quantized. Starting in 1972, observations (Tifft 1972, 1976,1980) revealed galaxies were quantized in steps of cz=72 kms^{-1}. Every test of accurate data since then has strengthened this conclusion (Arp, in press). Starting in 1971 it was discovered that quasar redshifts tended to be quantized according to the formula $\Delta\log(1 + z) = 0.089$ (Karlsson 1977). (That is in redshifts z = .06, .30, .60, .96, 1.41, 1.96, 2.64, 3.47.) Subsequent tests have increasingly established the general validity of this formula (Arp *et al.* 1988).

But notice that these extragalactic redshifts are not only discretized, they are periodic. They are not random.

In the conventional Big Bang model, the observations would require quasars to exist in concentric shells at preferred expansion velocities and that our own galaxy be situated at the center of these concentric shells. But if any feature exists on a scale large compared to the universe, then a position can be marked with respect to it. This would contradict the requirement of the cosmological principle that expansion must take place around every point in space in such a way that no point in space is distinguishable from any other. Therefore, either we must give up the cosmological principle as a description of the physics of the universe or move the quasars in, much closer than their redshift-inferred distances.

Some astronomers concluded decades ago that direct observational evidence requires quasars to be very nearby and from time to time be born within or near active galaxy nuclei (Arp 1987). New material is ejected from older galaxies in the form of compact, high redshift quasars, which evolve with decaying intrinsic redshift into new galaxies in a cascading process of galaxy formation within a possibly endlessly cyclical universe. If this, or some model like it is true, then what could the observed periodicity of redshifts be telling us about the universe?

The conclusion that new galaxies are being created in the universe reminds us that in recent years physicists have described the possible emergence of new matter via fluctuations of the "material vacuum" (Guth 1981). (That is appearance of matter in a volume in which none was previously detected.) Now an operational definition of the universe must be: Everything that can be detected now or in the future. Therefore, we would have to consider "creation" of new matter as a transformation, with time, of some previously existing potential. The most general transformation possible would be from a property which pervaded a large volume of space to a property which was localized. If galaxies are being formed of new matter this is a link between local physics and non-local cosmology.

But quantum mechanics, it seems to me, deals with precisely this process. When small enough particles are considered, they are observed to exist both as waves and particles (the so called wave-particle duality explored by Louis deBroglie among others). The wave packet of a particle is never completely bounded. It extends with some non-vanishing amplitude to indefinitely large distances. So quantum mechanics deals with the transition from the extended to the local—from the universe to the elementary particles. To take another example, the Heisenberg uncertainty principle requires that the position and momentum of a particle cannot be simultaneously determined with an accuracy better than a small number called Planck's constant ($\Delta x \Delta p > h/2\mathbf{p}$). This means that at any precise point in space the motion of the particle is completely indeterminate. The particle exists only in the sense that it is part of the entire field we call the universe. Or if we specify a particle with an exact momentum it can be anywhere in space. Again we have quantum mechanics describing the connection between local and non-local properties.

We would therefore expect that the creation of matter in space—in the sense of transformation from extended to local—would be a quantum-mechanical process. The elementary particles of matter would have, at least initially, the quantum characteristics of exhibiting only discrete values. For example, one property that should be quantized is the rate at which clocks run in this matter. This is because atoms in matter are like small clocks with their rates dependent on the mass of the electrons in their atomic orbits. The rates at which clocks run in any particular assemblage of matter (relative to our clocks) depends on the (relative to us) mass of the elementary particles which constitute its atoms. If we were to imagine the creation of new particles which form electrons and protons in some region of space, we would expect them to materialize with mass increasing from zero with time. We can attempt to justify particle origination starting from mass zero in a later remark, but here it is perhaps suggestive to note that the scale of the particle can only be defined with respect to the scale of the space with which it can communicate. The foregoing reasoning would lead us to expect the atomic clocks found in new matter to initially run slow (be intrinsically redshifted) and only at discrete (quantized) rates.

A more specific model to explain why such behavior would occur would be to say that the mass of a newly created particle depends on the gravitons it can exchange with its surroundings. Immediately after it has localized as a particle it can exchange gravitons at the speed of light with only a relatively small volume of the universe. As time goes on it exchanges gravitons with a larger volume of the universe, the mass of its electrons and other particles increase and its clocks speed up. (This would predict that if we could see younger and younger agglomerates of matter their intrinsic redshifts would be higher and higher.) Of course, this model of how a particle knows what its mass should be may not be correct. There may ultimately be a more satisfactory description than gravitons. But it would seem a logical requirement for the mass of a particle to depend on the proportion of the universe with which it can communicate at the light signal speed. I note that this does not violate the general relativistic requirement that gravitational forces are communicated instantaneously but that changes of gravitational forces are communicated with only the speed of light.

If we were to accept the arguments that galaxies and quasars are continuously created in the universe and that simple physical reasoning requires them to have intrinsic redshifts which are also quantized, we would, however, still not have accounted for periodicity, the regularity observed in the quantized redshifts. In the terms we have been discussing, this must be telling us something about order in the universe at large distances. Starting with periodicity in the highest redshift, we should be probing conditions in the recent universe, nearby. Then, as we go to periodicity in lower-redshift quasars we should be sampling conditions in the earlier and earlier universe, until finally, in the small, 72 kms^{-1} periodicity in galaxy redshifts, we are seeing so much of the total universe, back to such early times, that the quantum changes in particle mass from galaxy to galaxy are a very small percentage of the total mass. The periodicity exhibited by quasar redshifts, however, is unlikely to reflect mass shells centered on our own region of space. That was the incompatibility we mentioned earlier with the conventional Big Bang interpretation of extragalactic redshifts. It is possible, however, that multiple small bangs spaced throughout time could build into the universe a structure which was shell-like in time. In fact, if the multiple small bangs originate in matter creation episodes, by the previous discussion we would expect them to be quantized.

Now, it is interesting to note that since the introduction of inflationary theory a few years ago we have been led inexorably to the probability of emergence of new matter in the universe. First Allan Guth described the possibility of white holes growing into new universes (Guth 1981). Then Andre Linde discussed other mini-universes appearing within our inflationary universe (Linde 1987). Gunzig, Géhéneau and Prirogine (1987) assured us that matter creation terms were permissible in the geometry-energy tensor of general relativity—all discoveries which Fred Hoyle (1980) had anticipated with the discussion of his "C" (for creation field) in the 1948 Steady State theory. Experience has led some physicists to joke: "In physics if something is not specifically forbidden, it is mandatory."

But one of the architects of inflationary theory, D.V. Nanopolous, has now suggested that inflationary processes should show quantization (Nanopolous 1988). Is this not what the periodicity in extragalactic redshifts seems to be telling us? We might propose a model in which discrete inflationary universes expanded outward with some velocity like a Hubble constant and were contacted as a function of time by material from other epochs at their mass-inducing, light-signal speed. If the inflationary process or creation process were periodic then we might explain the ubiquitous periodicity we observe in the redshift. Of course, such speculations and generalizations do not tell us physically why or how the periodicity is being imprinted. I personally believe that to the person who explains quantitatively what the periodicity in redshifts means for the non-local laws of the universe will go credit for the deepest cosmological understanding yet obtained.

In closing, I cannot refrain from commenting on what strikes me as a great irony, perhaps typical of the science of the future. Einstein followed the conviction for most of his career that Ernst Mach was correct that the universe at great distances affected the behavior of local events. At the end, however, Einstein's formulation of physics was completely local, and he sadly abandoned Mach's principle. But in Einstein's battle with the Copenhagen school, and his insistence that "God doesn't play dice with the universe," I think it may turn out that he was right—but only because Mach's principle does operate and parts of local reality are only predictable by a very sophisticated knowledge of non-local causality.

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