THE ROLE OF QUANTUM PHENOMENA IN OUR UNDERSTANDING OF THE UNIVERSE.

Jayant V. Narlikar
Tata Institute of Fundamental Research
Bombay 400005 - INDIA

Abstract. *This discussion concerns the intimate connection berween the quantum phenomena and the large scale structure of the universe. Examples are given to illustrate not only how quantum theory has advanced our perception of the universe but also that the interaction with the universe may be necessary to understand how a microscopic system operates under the laws of quantum mechanics.*

Introduction.

In the first half of my talk I will be faithful to the title and discuss how quantum physics provides important inputs to our understanding of the universe. In the second half I will turn the title around and discuss how a knowledge of the large scale structure of the universe my be needed to interpret some of the basic rules of quantum physics.

To begin with, note that the two important observations on which modern cosmology is based are possible only because the electromagnetic radiation obeys the laws of quantum theory. Take the first of the two results, the one obtained by Edwin Hubble[1] in 1929. It relates the shifts in the lines of spectra of far away galaxies to their distances from us. The crucial observation here is of discrete nature of radiation. The absorption lines in the spectra arise because of a quantum mechanical result. These lines stand out at a series of isolated wavelengths against the continuum radiation. Hence it is possible to measure their shift.

The second observation, first made by Arno Penzias and Robert Wilson[2] in 1965 and subsequently followed up by others, establishes the existence of a radiation background in the universe. This background has the spectrum of a black body a typical signature of quantum mechanics. In fact it was attempts to understand the phenomenon of black body radiation that led Max Planck to the quantum theory. And the fact that the spectrum of the observed radiation is very close to black body is taken as a proof that the radiation is a relic of an early hot era in the history of the universe, when matter and radiation existed in thermodynamic equilibrium.

---

1 Hubble E., (1929) Proc. Nat. Acad. Sci. (U.S.A.), **15**, 168.

2 Penzias A. and Wilson R.W., (1965) Ap. J., **142**, 419.

Having said this, however, I would like to pose a wider question. Is quantum physics relevant to the structure of the universe as a whole?

This question may be paraphrased thus: To what extent is quantum physics necessary to understand the global dynamics of the universe? Can we rely on Einstein's general relativity to tell us all relevant details of the structure of the universe in purely classical terms? Or do we need inputs from quantum theory?

Quantum Cosmology.

It is simpler to begin our search for the answer to this question by asking for a general criterion which tells us whether classical physics is sufficient to provide explanation of any given phenomenon, or whether one must have recourse to quantum theory. Does such a criterion exist?

Fortunately it does. It was formally stated by Dirac[3] and is as follows. Classical physics is described by laws obtained from the variation of the so-called action functional S:

$$\delta S = 0 \qquad (1)$$

The action can be defined fairly simply for any given system and its magnitude can be computed. The rule is that if:

$$\mid S \mid \gg \hbar \qquad (2)$$

then the stationarity principle of classical physics, as given by (1) holds. If, however:

$$\mid S \mid \leq \hbar \qquad (3)$$

then quantum physics takes over. New rules apply.

The costant $\hbar$ appearing in (3) is Planck's constant divided by 2π. Its magnitude therefore plays a crucial role in determining the classical/quantum behaviour of a physical system.

As an example, consider the hydrogen atom. Measurements tell us that its characteristic size is 10^{-8} cm. If we evaluate S for the electron–proton system that makes up the atom we find that $\mid S \mid \sim \hbar$. Hence we should study the system quantum mechanically rather than classically.

The same criterion applied to cosmology suggests (at first sight) that classical rather than quantum laws are relevant to the structure of the universe, taken as a

[3] Dirac P.A.M., (1935) **The Principles of Quantum Mechanics,** Oxford: The Clarendon Press.

whole. The characteristic size of the present universe is $\sim 10^{28}$ cm and the action S evaluated for it easily satisfies the inequality $|S| \gg \hbar$.

Does this mean that nothing is gained by bringing quantum physics to cosmology? Far from it! In fact, if we take the classical cosmology seriously it leads us to quantum cosmology. Consider the phenomenon of singularity of space–time. Popularly known as the big bang epoch, the singular event corresponds to the entire universe being compressed in a space of zero volume.

Now close enough to the big bang epoch the universe would have been considerably smaller than what it is now. if we evaluate $|S|$ for such a universe we find that $|S| \leq \hbar$ provided the size of the universe L satisfies the condition:

$$L \leq L_P = \sqrt{\frac{G\hbar}{c^3}} \simeq 1.6 \times 10^{-33} cm \tag{4}$$

Known as the *Planck length*, L_P depends on three fundamental constants, $\hbar$, G (the constant of gravitation) and c (the speed of light). The big bang universe satisfied this inequality prior to the *Planck epoch:*

$$t_P = \sqrt{\frac{G\hbar}{c^5}} \sim 5.4 \times 10^{-44} sec. \tag{5}$$

In other words, quantum cosmology becomes a relevant subject when studying the early epochs $t \leq t_P$. However, this conclusion raises further questions.

What important inputs can quantum cosmology provide if its operation was confined to such very early epochs? Is it not just an abstract exercise in the study of quantum gravity?

Some recent studies[4] show that contrary to the above doubts quantum cosmology does provide possible solutions to some outstanding cosmological problems. Let me outline these problems and then indicate how they might be solved by quantum considerations.

1) The most fundamental problem is the one mentioned earlier, that of the initial singularity. Classical relativity tells us that the singular epoch is inevitable, even in the more general physically relevant solutions of Einstein's equations[5]. At this epoch the mathematical and physical description of the universe breaks down. For want of anything better, this epoch is identified with the *beginning* of the universe. Strictly speaking, however, this conclusion is not indicative of a profound deduction from the classical theory; rather it springs from its weakness in allowing

[4] Narlikar J.V. and Padmanabhan T., (1986) **Gravity, Gauge Theories and Quantum Cosmology,** Dordrecht: Reidel.

[5] Hawking S.W. and Ellis G.F.R., (1973) **The Large Scale Structure of Space–Time,** Cambridge: Cambridge University Press.

its equations to *go singular.* The appearance of infinities is an indication of the incompleteness of the theory. A more complete framework ought to do away with this defect altogether.

2) A consequence of the singular origin of the universe is the appearance of the so called *particle horizons.* To understand this effect imagine the clock to start from the singular epoch. At any time $t>0$, a typical observer O is surrounded by a sphere of radius $R=ct$ with this property: no observer outside the sphere can causally influence O. This simple result is based on the fiat that all interactions of physical significance travel at most with the speed of light. This spherical barrier around each observer is known as the particle horizon.

Particle horizons are thus inhibitors of propagation of information. In particular, in the early universe, two observers beyond one another's particle horizons would not *know* about the respective existence of each other. Thus unless the universe started out as a highly homogeneous system, there is no way for it to have achieved homogeneity in subsequent times. The particle horizons inhibit mixing of matter over large scales, making it impossible to make conditions operating in causally separated regions uniform. It becomes difficult therefore to understand the relatively high degree of large scale homogeneity in which we find the universe today. In particular, if the microwave background is a relic of the past, why is it so homogeneous?

3) The third problem, known as the *flatness* problem refers to the three types of homogeneous and isotropic solutions of classical cosmology, first obtained by Friedman. In Type I solution the space is *flat,* i.e., it has the geometry of Euclid. In Type II solution the space has negative curvature. However, it continues to expand for ever, although at faster rate compared to Type I model. In Type III solution the space has positive curvature and it expands more and more slowly than Type I model so much so that after a while expansion ceases altogether and gives way to contraction back to singularity.

Now in both Type II and III models there is a characteristic time associated with expansion. Let us denote it by T. In a Type II model, for t$\geq$T, the universe has expanded so much that all galaxies find themselves more or lesss isolated. (In the present state of the universe we do see lot of other galaxies; so this has not yet happened). In Type III case we may associate T with the entire duration of the expansion phase.

What is T? If the big bang theory is correct, T must be associated with the physics of the starting conditions. The only time scale we have so far come across is the Planck time $\sim 10^{-43}$ s. It could be raised somewhat to $\sim 10^{-37}$ s if we choose to associate it with the characteristic times of grand unified theories. But either way, T is far too short to be realistic! In other words the question one must answer is, how has the universe managed to survive for so long ($\sim 10^{10}$ billion years $\sim 3\times10^{17}$ seconds) if T was so small?

The only way out is to have recourse to the Type I model, and to argue that the universe is spatially flat. For, this model has the expansion factor:

$$S \propto t^{2/3} \tag{6}$$

with no characteristic time scale involved. So one is forced to justify why the universe is spatially flat, either exactly or very nearly so.

The currently fashionable inflationary scenarios seek to eliminate the horizon and flatness problems while the singularity problem is ignored. In spite of several years of research by a large number of excellent brains in the field, an acceptable inflationary model is yet to emerge. Let us see how quantum inputs resolve these problems.

Conformal Quantization.

To study the quantum effects of gravity, one needs to quantize Einstein's general relativity. This is sooner said than done! There are several conceptual and technical difficulties that render the job impossible at present. Impossible, if one insists on a *perfect* and *rigorous* theory of quantum gravity.

A somewhat less ambitious project does succeed, however, in giving us glimpses of what quantum inputs can do for cosmology. Described in detail in note 4 the basic ideas are outlined below.

Let us once again consider the electron–proton system that makes the hydrogen atom. in classical electrodynamics, an electron going round the proton radiates energy and so it steadily approaches and ultimately falls into the proton. The characteristic timescale for this to happen is $e^2/mc^3 \sim 10^{-23}$ second, where e and m are the charge and mass of the electron. Thus, in the classical framework, the hydrogen atom has a very transient existence.

To look at the quantum analogue of the problem one quantizes the motion of the electron, leading to the Schrödinger equation. The various states of the electron are described in terms of radial and angular quantum numbers. The important conclusion is that stationary solutions of the Schrödinger equation exist, describing a hydrogen atom that has lasting existence.

This important conclusion can be captured by a simplified approach wherein only the radial distance between the electron and proton is quantized. Thus we are asking the question: *Does the radial distance shrink to zero as in the classical case, or do stationary states exist when the weve-function depends on radial separation only?* The answer is *yes* to the second alternative.

Likewise we can limit our discussion of quantum gravity to scale changes only. The three questions of singularity, horizon and flatness turn out to depend on how the scale factor of the universe behaves with time. The framework for describing scale changes is provided by conformal transformations.

In a conformal transformation we introduce an arbitrary positive function of spacetime Ω that changes length scales from one point to another. At the same point however, length ratios in different directions do not change (hence the adjective *conformal).* Thus Ω serves the purpose of stretching or compressing the spacetime, not necessarily by the same ratio at all points. By varying Ω we can go over a wide variety of spacetime geometries (but of course, not all geometries).

Restricting discussion to conformally related geometries has a conceptual advantage. The causality structure is preserved as we go from one geometry to another. The light cones do not change. Thus, in a quantum transition from one spacetime geometry to another the casual connections so basic to physics are preserved.

Where does quantization of Ω lead to us? We can define a wavefunctional of Ω that in a sense is the wavefunctional of the universe. Changes in Ω tell us how quantum mechanically the universe should behave. Propagators for Ω can be constructed which link the wavefunctionals between two spacelike hypersufaces.

The important aspects of this work may be summarised as follows:

1) Since we are interested more in the past history of the universe, we use the propagators *backwards* in time. That is, we are interested in knowing what the wavefunctional of the universe was like in the past, given what it is like at present. note that this mode of enquiry is the reverse of the usual quantum mechanical question about how a quantum state would evolve to the future. We discover, not surprisingly, that the quantum uncertainty about Ω grows as we probe closer to the $t=0$ epoch.

2) In any given class of conformally related geometries, there is one which satisfies Einstein's equations and therefore has singularity at $t=0$. But what about others? It can be shown that given the present state of the universe, it is **most unlikely** to have come from a geometry with a singularity. Singular geometries have a zero measure in the probability space. In other words, the classical *big bang* is more the exception than the rule.

3) Having deduced that the universe most likely **did not** have a singular origin, it is then possible to extend the spacetime further back in the past. In the extended spacetime there are no particle horizons. Thus the horizon problem is solved.

4) If we argue that the entire universe evolved as a conformal fluctuation of the empty flat (Minkowski) spacetime, then it is possible to show that most likely it would go into the Type I, flat Friedman model. This resolves the flatness problem.

Thus quantum cosmology can in principle lead to conclusions that are not only significantly different from classical cosmology but also have bearing on the present state of the universe.

As mentioned above, nonconformal changes of geometry are not covered by these ideas and some new techniques are needed to explore these.

Quantized Redshifts?

In the last few years evidence has been steadily accumulating on there being a discrete structure in the distribution of redshifts of a number of extragalactic objects (for a review see[6,7]). In the classical Friedman models redshifts arise from the expansion of the universe. Thus, if the scale factor of the universe was S when light left a remote object and it arrives at the observer now when the scale factor is S_0, the object will appear to the observer to have a redshift:

$$1 + z = \frac{S_0}{S} \tag{7}$$

To obtain discrete redshifts therefore we need a theory that quantizes S.

As we have just seen the conformal quantization theory gives just the right framework for this. Can we obtain discrete sets of S in this way? Technically we can. For, in the framework described there are stationary states of the universe with different constant average $< S >$, values (see note 4 for such models). It is, however, premature to assert that these states would account for the actual observations. More detailed theoretical work is needed to settle the issue, and investigations are in progress. Meanwhile it is worth pointing out another variation on this theme which may perhaps turn out to be more versatile.

In the conference preceeding this one, I had discussed the possibility of explaining anomalous redshifts of quasars, galaxies etc.[8] by using the variable mass hypothesis (VMH) of Hoyle–Narlikar theory of gravity[9]. In its simplest form the HN theory supplies an alternative view-point to relativity. For example, the relativistic cosmology explains redshifts as due to the expansion of the universe as indicated in formula (7). In the HN cosmology the spacetime is flat, Minkowskian, (i.e., the universe is static) but particle masses increase with time. Thus (7) is replaced by:

$$1 + z = \frac{m_0}{m} \tag{8}$$

where m=*mass* of a typical particle in the source while m_0=*mass* of the same particle at the observer.

To obtain quantized redshifts therefore one needs to quantize masses in the HN cosmology. The reason why this framework is more versatile is that it allows local inhomogeneities in the mass function so that newly created matter

[6] Burbidge G.R., (1981) Ann. N. Y. Acad. Sci., **375**, 123.

[7] Narlikar J.V., (1986) in **Quasars** eds. G. Swarup and V.K. Kapahi, Dordrecht: Reidel, p. 463.

[8] Narlikar J.V., (1987) in **New Ideas in Astronomy,** eds. F. Bertola, J. Sulentic and B. Madore, Cambridge: Cambridge University Press.

[9] Hoyle F. and Narlikar J.V., (1964) Proc. Roy. Soc., **A. 282,** 191 and (1966) Proc. Roy. Soc., **A. 294,** 138.

will have smaller mass than existing ambient matter in the same location and at the same epoch. Thus if a quasar is fired out of the galaxy in an explosive creation relatively recently, it will show a significantly higher redshift than the parent galaxy. Hence periodicities in $ln(1+z)$ observed by Depaquit et al.[10] may come out of quantization of mass of such recently created matter.

Note that periodicity in $ln(1+z)$ means periodicity in $ln(m)$, i.e., quantized masses should occur in geometric series. Also, for small z, $(z<<1)$ the periodicity should show up in z itself. Tifft's observations[11] are of this latter kind.

I now move on the second aspect of my talk.

Action at a Distance.

The Hoyle–Narlikar theory of gravity is an example of an action–at–a–distance theory. It starts from the basic assumption underlying Mach's principle[12] that inertia of matter is due to the background provided by the universe. Physicists have interpreted Mach's ideas (not explicitly quantified by him) in terms of many different theories. In the HN–theory the idea is expressed by a *propagator* that conveys inertia across space and time. The mass (inertial mass) of a typical particle can then be described as the sum of inertial contributions from all other particles in the universe.

This concept of direct interaction between particles dates back to Newton and Coulomb, in the areas of gravitation and electromagnetism. Both the Newton's and Coulomb's laws were expressed as action–at–a–distance laws. However, subsequent development of the electromagnetic theory revealed the inadequacy of the concept. In particular, experiments dealing with interactions between rapidly moving charges could not be explained by Coulomb's laws.

Gauss had correctly diagnosed the reason for failure: it lay in the concept of instantaneous action at a distance. In a letter dated March 19, 1845 to Weber, Gauss wrote:

I would doubtless have published my researches long since were it not that at the time I gave them up I had failed to find what I regarded as the keystone, **Nil actum reputans si quid superesset agendum,** *namely the derivation of additional forces – to be added to the interaction of electrical charges at rest, when they are both in motion – from an action which is propagated not instantaneously but in time as is the case with light.*

Unfortunately for the progress of the subject Gauss did not bring his brilliance to bear upon the problem. In two decades, Maxwell solved it by an entirely different method – by introducing the concept of the electromagnetic field as a dynamical entity interacting with particles. The success of Maxwell's approach

---

[10] Depaquit S., Pecker J.C. and Vigier J.P., (1985) Astr. Nach., **306**, I, 7.

[11] Tifft W.J., (1987) in **New Ideas in Astronomy,** eds. F. Bertola, J. Sulentic and B. Madore, Cambridge: Cambridge University Press.

[12] Mach E., (1983) **Science of Mechanics,** London: Watts & Co.

made field theory respectable, at the cost of action at a distance.

Action–at–a–distance along Gauss's lines was revived, however, by a series of workers[13,14,15,16,17]. First, to introduce action propagating at finite speed c, one has to cope with the so called causality problem. This problem is easy to describe.

Imagine two charged particles A,B separated by a distance of one light–hour. When charge A is moved, say at 4 p.m., its action propagates to B and causes it to move at 5 p.m.. However, B's reaction to this must, by Newton's third law of motion, be equal and opposite. So it will start from B at 5 p.m. and reach A at 4 p.m.. In other words, a retarded action invokes advanced reaction.

In fact if we insist on time symmetry of physical laws, we must allow advanced interactions on equal footing with retarded ones. In the work of Schwarzschild, Tetrode and Fokker *(op. cit.)* the inevitable conclusion was that the basic action of each charge was totally symmetric between advanced and retarded components, being:

$$F_S = \frac{1}{2}(Advanced + Retarded) \tag{9}$$

instead of the observed:

$$F_0 = (Retarded) \tag{10}$$

In Maxwell's field theory also advanced and retarded solutions exist. However, there is no compelling reason to choose F_S. Rather, to be consistant with causality the choice is made in favour of F_0. In other words, Maxwell's theory does not explain why causality should operate in nature; it merely conforms with it.

For action at a distance, however F_S is a must. And so the discrepancy between (9) and (10) is significant. Largely because of this difficulty action–at–a–distance again remained in the background.

In 1945, exactly a hundred years after Gauss's conjecture, the difficulty was resolved in an ingenious fashion by Wheeler and Feynman (note 16). The clue to their solution is contained in the example of the charged pair (A,B) just described.

Recall that when A moved at 4 p.m., it got reaction from B instantaneously – at 4 p.m.. Although, for the sake of argument we assumed B to be 1 light–

---

[13] Schwarzschild K., (1903) Gottinger Nachrichten, **128**, 132.

[14] Tetrode H., (1922) Zeits f. Physik, **10**, 317.

[15] Fokker A.D., (1929) Zeits f. Physik, **58**, 386, (1929) Physica, **9**, 33 and (1932) Physica, **12**, 145.

[16] Wheeler J.A. and Feynman R.P., (1945) Rev. Mod. Phys., **17**, 157.

[17] Wheeler J.A. and Feynman R.P., (1949) Rev. Mod. Phys., **21**, 425.

hour away, the above conclusion is independent of B's distance from A. In other words, A's initial movement at 4 p.m. invokes instantaneous response from all other charged particles in the universe!

This deduction has profound implications. the movement of A is not isolated; it invokes a response from the whole universe. what is the response? Wheeler and Feynman performed a detailed calculation and found the response to have a very simple and elegant form:

$$F_R = \frac{1}{2}(Retarded - Advanced) \tag{11}$$

This is the force that acts on charge A as it begins to move. It can be easily identified as the radiation reaction.

In Maxwell's field theory it can be shown that an accelerated charge radiates energy. The loss of energy can be seen as related to a damping force on the charge. Dirac[18] had given an ad–hoc prescription for computing this force. His prescription was precisely that given by (11) above. It was ad–hoc because it had no field theoretic rationale behind it. Its sole merit was that it worked.

The Wheeler–Feynman revival of action–at–a–distance provided the rationale. The force arose as the inevitable response of the universe. Moreover, in the neighbourhood of the source charge the total effect is now given by adding F_R to F_S:

$$F_R + F_S = (retarded) = F_0 \tag{12}$$

Thus, with the response of the universe taken into account the discrepancy between theory and observation disappears.

Elegant though this solution was, it left two important issues hanging. First, Wheeler and Feynman had discussed their theory in a static universe which is globally time symmetric. so by a time–reversal of their argument it was possible to generate a fully advanced solution also, side by side with (12). To arrive uniquely at the retarded solution it was necessary to consider an expanding universe.

This was done by Hogarth[19] and By hoyle and Narlikar[20]. They showed that in an expanding universe the response cannot be time–symmetric. The nature of the response depends naturally on the composition and dynamics of the universe. Here some very interesting conclusions emerge.

There is a class of universes to which the steady state universe of Bondi, Gold and Hoyle belongs, wherein the response is as given by (11) and we arrive

---

[18] Dirac P.A.M., (1938) Proc. Roy. Soc., **A 167**, 148.

[19] Hogarth J.E., (1962) Proc. Roy. Soc., **A 267**, 365.

[20] Hoyle F. and Narlikar J.V., (1963) Proc. Roy. Soc., **A 277**, 1.

at the observationally correct solution (12). There is another class of universes which generate the opposite response and lead to the observationally inconsistent advanced solutions. The standard big bang models belong to this class.

In this way, provided we live in the right type of universe we can understand many things which eluded field theory: **1)** Why a time–symmetric physical theory produces retarded solutions; **2)** Why the radiation reaction is given by (11); **3)** Why there is a connection between time asymmetries in electrodynamics and cosmology. Besides, the action at a distance theory works with fewer dynamical degrees of freedom than the field theory and is thus more economical.

The second incomplete aspect leads us back to quantum theory.

The Quantum Response of the Universe.

The work so far described concerns classical electrodynamics. To what extent can these ideas be extended to quantum electrodynamics? The answer provided by Hoyle and Narlikar[21,22] is *all the way.* I will not go into details of the work but highlight that aspect which concerns the present discussion.

Imagine an atomic transition in the laboratory wherein an electron jumps from one state to another. The process of change of state entails acceleration and hence an outgoing action. This action invokes response of the universe. Just as the source motion, being quantum mechanical is not deterministic, so is the response of the universe. However, in a self consistent calculation the response added to any locally perturbing agency will determine the actual transition. Thus there is a cause and effect loop which can be determined by the criterian of self consistency alone:

$$ExternalAgency \longrightarrow Transition \Longleftrightarrow Response$$

If no external agency is present we are dealing with spontaneous transition. It is interesting to find that the correct probability for spontaneous transition results from such a calculation, without recourse to field structure or second quantization.

Results like Lamb Shift, anomalous magnetic moment of the electron et. which are believed to arise from field–vacuum interactions can be explained by using the quantum response of the universe. Instead of having to invent a vacuum with non–trivial properties this theory relies on the back reaction from the universe. Recently Padmanabhan[23] has shown how the technique of conformal quantization described earlier eliminates the infinities of quantum electrodynamics in this framework.

The way the response of the universe enters a calculation helps clear up one

---

21 Hoyle F. and Narlikar J.V., (1969) Ann. Phys., **54**, 207.

22 Hoyle F. and Narlikar J.V., (1971) Ann. Phys., **62**, 44.

23 Padmanabhan T., (1985) Ann. Phys., **165**, 38.

of the conceptual difficulties of quantum mechanics, associated usually with the notion of the *collapse of the wavefunction.*

In the standard interpretation of such phenomena, a microscopic system is described by a wavefunction obtained as a sum of several eigenstates. The process of observation by an outside observer *collapses* the wavefunction onto one eigenstate that is observed. This process of collapse is somewhat mysterious and has not yet been properly interpreted.

In the Wheeler–Feynman type of framework it is found that the process of observation involves the response of the universe completing a selfconsistent loop. The result of the calculation is not an amplitude (which is a complex number) but a probability (which is real and positive) that corresponds to a definite eigenstate. The process appears mysterious in the conventional interpretation because the role of the universe is not taken into account.

I will not discuss this concept in further detail but draw attention to it as an important component of our perception of the quantum world. Those who are interested in following the idea further may find the article[24] by Fred hoyle thought–provoking. More recently John Cramer[25] has discussed somewhat similar concepts in a different manner, in his transactional interpretation of quantum mechanics.

Concluding Remarks.

To sum up, quantum theory and cosmology are two disciplines that are intimately connected. It is wrong to comportmentalize them as one dealing with microscopic system in our local laboratory and the other dealing with the large scale structure of the universe at far–away distances. Proper understanding of one cannot be obtained without the other.

---

[24] Hoyle F., (1982) Ann. Rew. Astr. Astrophys., **20**, 1.

[25] Cramer J.G., (1986) Rev. Mod. phys., **58**, 647.

Venice Conference on Cosmology and Philosophy

ORIGIN AND EVOLUTION OF THE UNIVERSE

A Hubble Centenary Conference

December 15–16, 1989

Venice, Italy