Association for Information and Image Management
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

September 16, 1992 LBL-32852

Space and Time from Quantum Mechanics *†

Geoffrey F. Chew

Theoretical Physics Group
Physics Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720

*Talk to the Center for Pure and Applied Mathematics, Faculty Club, Berkeley, September 10, 1992.

†This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

Classical mechanics historically preceded quantum mechanics and thus far has not been displaced from primary status; the path to construction of quantum theory has remained rooted in classical ideas about objective reality within space and time. Use of a less correct theory as underpinning for a more correct theory not only is unaesthetic but has spawned the perplexing and never-resolved puzzle of measurement. A growing number of physicist-philosophers torture themselves these days over "collapse" of the quantum-mechanical state vector when "measurement" is performed. Additionally, pointlike structure of the spacetime manifold underlying local classical fields has endowed quantum theory with mathematical dilemmas.

It has been proposed by Gell-Mann and Hartle that objectively-realistic ideas such as measurement may lack *a priori* status - - the predominantly-classical present universe having evolved as a "relic of the big bang". Other authors such as D. Finkelstein, Penrose, Wheeler and von Weizsäcker have suggested that spacetime itself need not be *a priori* but may stem from quantum mechanics. Haag has written recently that "spacetime without (quantum) events is probably a meaningless concept." Henry Stapp and I have for several years been exploring a simple quantum system devoid of classical underpinning, even spacetime, but admitting within the Hilbert space a special Lie-group-related category of vector known as "coherent state". As I shall emphasize later, groups unitarily representable in our Hilbert space include the Poincaré group, which relates to 3 + 1 spacetime. Coherent states generally are labeled by parameters associated with unitary group representations, and it has long been recognized that when such parameters become large a classical objective interpretation may result.* Stapp and I have been attempting to understand space and time via large coherent-state parameters. Six years ago I presented to this gathering a preliminary report on our enterprise; today I provide an update. Details may be found in a Lawrence Berkeley Laboratory preprint, LBL-32694.

Motivated by big-bang inflationary cosmology, we have found within our Hilbert space a "state vector of the universe" expressed through coherent states whose parameters grow sufficiently during "inflation" as to provide meaning

*Example: The coherent state $|\theta,\varphi\rangle_j \equiv e^{iJ_3\varphi}e^{iJ_1\theta}|j,j\rangle$ for $j >> 1$, represents a classical rotator of angular momentum j and direction θ,φ. Group is O(3), with generators $J_1 J_2, J_3$. For $j = 0$ there is no classical interpretation.

for "observable relativistic spacetime of particles" in coexistence with "absolute spacetime of events". The term "inflation" refers to a rapid increase in the scale of the universe immediately following big bang. The phenomenon known to physicists as "stationary phase" or "decoherence" yields in our model, as an outcome of an inflation that has made "horizon" much larger than quantum coherence length, approximate significance via particles and events for an objectively-observable universe. Particles and events are needed, in combination, to provide meaning for a spacetime that admits observation. Particles are born and die in events.

It is commonplace that parameter largeness can endow physical approximations with accuracy. Newtonian mechanics, even though inexact, exhibits enormous accuracy for many purposes because of largeness of the inverse Planck constant and of the velocity of light. Objective reality within 3+ 1 spacetime is an idea even more widely applicable than Newtonian mechanics and our model attributes its extraordinary accuracy to an extremely-large but hitherto inadequately-appreciated parameter. Roughly speaking, this parameter is the ratio by which scale increased between big bang and the threshold of the "particle era" - - when the universe began to be describable as built from separate particles. The precise model definition of our reality-building parameter, that we denote by the symbol α, involves a unitary Hilbert-space representation of the dilation group. Standard inflationary cosmology leads us to guess that $\alpha >> 10^{30}$. (Huge although finite.)

Hugeness of the arbitrary parameter α (the only arbitrary parameter in our model) underpins accuracy for objective reality by promoting large values for coherent-state parameters. A huge value of α sustains our model while at the same time symptomizing model incompleteness; a better model would determine α.†

The Hilbert-space vectors that provide model contact with objective reality we call "event-particle coherent states". These are based on complex Heisenberg-Weyl and complex conformal groups. The particle concept represents stability. (An electron is an electron is an electron.) The event concept represents change

†The prime number $2^{127} - 1$, that has attracted attention from some combinatorially-oriented investigators, provides an example of what future development might call forth in an elucidation of α.

(death followed by birth, as when a neutron decays into a proton, electron and neutrino). Particles are born and die in quantum events. Finite duration of existence for a particle means Heisenberg uncertainty in mass and corresponding blurring of identity. Our model associates the conflicting notions of particle and event with canonically-conjugate non-commuting operators so that focus on one notion blurs the other. It is hugeness of the parameter α that allows these concepts to be simultaneously (approximately) viable in the present universe and thereby to render this universe objectively observable. Prior to inflation there were no particles, no observable spacetime, no objective reality.

Use here of the adverb "prior" reflects presence in our model of an *a priori* feature akin to but different from time. We describe evolution through a discrete sequence of "steps" labeled by an integer τ (Steps are not localized in either space or time.) Evolution is represented by a unitary transformation on our Hilbert space that connects our state vector at some value of τ to that at the preceding step:

$$|\tau\rangle = e^{-i\mathcal{H}} \, |\tau - 1\rangle.$$

The hermitian operator $\mathcal{H}$ we call the "evolution generator". (The state vector $|\tau\rangle$ describes the entire universe at τ.)

It has been possible to find an evolution generator such that, with huge α and τ greater than some finite value - - for convenience chosen as $\tau = 0$ - - evolution over an interval $\Delta\tau \sim \ln \alpha$ is approximately describable in terms of a single event localized in a noncompact 3 + 1 spacetime whose scale increases with increasing τ. Event time emerges at "big bang" as an approximate notion; later I give the precise relation between a fluctuating (post-big-bang) event time and the evolution-parameter τ. Essential to our model is an "arrow of evolution" boundary condition on the universal state vector $|\tau\rangle$ in the limit as $\tau \rightarrow -\infty$, corresponding to a universe that "was always expanding", even "before" big bang - - before spacetime-localized events became meaningful.

Our Hilbert space is a direct product of 16 simple Fock spaces. Fock-space basis vectors are labeled by positive integers, are connected by annihilation-creation operators and relate in natural fashion to graphs. All operators on the space are representable as functions of annihilation-creation operators. Each of our annihilation-creation operators is a 4 $\times$ 4 matrix, allowing topological connection with graphs embedded in oriented 2-dimensional surfaces; our attention was initially directed to this system by the dual topological models that led to string theory. Later Eyvind Wichmann made us appreciative of the algebraic connection between 4 × 4 matrices and complex conformal transformations in 3 + 1 spacetime. Ever since Wichmann's intervention, our emphasis has been on coherent states related to the complex conformal group. (My report 6 years ago was given before we appreciated the complex-conformal connection; at that time I described an approach based on graphs. Graphical-combinatoric analysis of the model has not been abandoned but placed on back burner.)

There is no *a priori* physical significance for the 16-valued label on our Fock space. Physics in our model attaches to large coherent-state parameters.

Our Fock space admits a unitary representation of GL(4,c), which with center removed is isomorphic to the 30-parameter complex conformal group. Group generators are represented by bilinears in annihilation-creation operators. Complex Poincaŕe transformations constitute a subgroup, as do complex dilations. The evolution generator is invariant under homogeneous complex conformal transformations - - i.e., complex "Lorentz transformations" and complex dilations - - but not under (inhomogeneous) "Poincaré displacements". Because we associate Poincaré-displacement generators with the sum of individual-particle energy-momenta, nonconstancy of these generators corresponds to interaction between <u>different</u> particles - - i.e., to particle <u>collisions</u>.

Parameter doubling associated with complex extensions of Poincaré and dilation groups leads us to coherent states that represent <u>pairs</u> of coexisting 3 + 1 spacetimes. A noncompact spacetime of <u>events</u>, with big bang located at the origin, is complemented by a compact relativistic <u>particle</u> spacetime attached to <u>each</u> event. A complexified Heisenberg-Weyl group is involved. It is necessary to pay simultaneous attention to Heisenberg-Weyl and to conformal; Poincaré displacement generators are shared between the two groups.

Due to shortness of time available, I must now confine myself to no more than a few further model highlights:

A) The evolution generator is a symmetric bilinear in inhomogeneous complex-conformal generators that are themselves bilinear in annihilation-creation operators (i.e., $\mathcal{H}$ is quartic).

B) All symmetry generators except that for real dilation are assigned zero expectation value. The parameter α is defined to be the expectation of the dilation generator. Nonzero α provides the "arrow of evolution".

C) During the interval $0 < \tau \lesssim \ln \alpha$, evolution may approximately be represented by a single event ("big bang") at $\tau = 0$, located at the origin of a noncompact event 3-space, followed by exponential expansion of spacetime scale, $R_\tau \propto e^\tau$, through a factor of order α. The single localized (big-bang) event is unaccompanied by particles.

D) For $\tau \gtrsim \ln \alpha$ this single-parameter approximation, based on the complex Poincaré-displacement group, breaks down. An extension - - a multiparameter representation based on localized events plus particles- - has been developed, invoking the complex Heisenberg-Weyl group. Each localized event, belonging to some value of the evolution parameter τ, carries its own compact 3 + 1 relativistic spacetime of radius (or "horizon") R_τ in which particles locate relative to the event and to each other.

E) Stationary phase (decoherence) leads to "straightline" (relativistic) particle trajectories in compact spacetime that originate and terminate in localized events.

F) The (noncompact) time of an event relates by the formula

$$t_e = \mathcal{R}_\tau \cosh \beta_e.$$

to a Lorentz-group parameter $\vec{\beta}_e$ that gives event spatial location according to

$$\vec{r}_e = R_\tau \frac{\vec{\beta}_e}{\beta_e} \sinh \beta_e.$$

Thus event time at fixed $\vec{\beta}_e$ increases with τ so long as R_τ increases with τ. (In a special Lorentz frame that might be called the "event frame", $\vec{\beta}_e' = 0$ and $t_e' = R_\tau$.)

Standard cosmology leads us to a conjecture, now under investigation, that once a large number of particles has developed (following the inflation interval), most τ dependence of the universal state vector associates with creation-annihilation of particles and relatively little with scale expansion. Scale is expected to continue expanding but at a rate much slower than exponential.

Our coherent states fail to provide, in straightforward fashion, particle trajectories in noncompact event spacetime - - which I call "absolute spacetime". A particle "moves" through a succession of shortlived compact relativistic spacetimes each tied to creation in some event of other particles. The interval of evolution occupied by each such spacetime, which generally houses a large set of particles, is short because unitarity rapidly damps out the associated amplitude. The life span of an individual particle is far longer than that of large sets in which this particle appears. Using events as interspace linkage, we are seeking a piecewise mapping of particle-trajectory segments from the succession of relativistic (compact) particle spacetimes onto absolute (noncompact) spacetime. Because such an "absolute" particle trajectory depends on energy and location of other particles, we hope to find a curved path consistent with gravitation.

One test of our model will be its capacity to describe gravity. Another will be verification that events occur at intersection of particle trajectories. Such tests promise to require mathematical techniques different from those so far invoked.

Ignored so far in model analysis have been zero-mass particles. Our Hilbert space admits zero-mass-particle coherent states but qualitatively-new effects are well known to arise for so-called "soft photons"- - of energy below the energy fluctuations of massive particles. Soft photons and "gentle events" are responsible for classical electromagnetism. A third major model test is correspondingly posed.

Detailed properties of massive particles eventually may be addressed, but priority will be given to the foregoing 3 challenges: gravity, locality of particle interaction and electromagnetism.

DATE FILMED

8 / 19 / 93

END