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Bi-Directional EPR Correlation in Cosmology and Planckeon Origin of Dark Energy

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I. Introduction

Since the advent of quantum mechanics in the mid-1920s there have benn continued interpretational controversies surrounding its counter-intuitive nature such as the wave-particle duality and the instantaneous collapse of the particle wave function at the detection point. But the paradox of nonlocal EPR[1] correlation between distant events without nonlocal interactions has been more problematic in recent times by Bell's experimental non locality test[2,3] proposed in 1964, though the paradox was first noticed by Schrödinger[4] and discussed in the dialogue between Einstein and Bohr[5] at 1935 Solvay Council. In emphasis of the signal transmission in EPR correlation Cavaicanti and Wiseman[6] asked: "What Bohr could have told Einstein at Solvay had he known about Bell experiments ?" In his recollection in 1990 Bell[7] wrote: "Suppose quantum mechanics were found to *resist* precise formulation. Suppose that when formulation beyond FAPP (For All Practical Purposes)[8] is attempted, we find an unmovable finger obstinately pointing outside the subject....to the Mind of the Observer..., or only Gravitation ?" We here show that the solution of quantum paradoxes can be found outside the EPR's reality criterion of local cauality[9] but within the framework of time-symmetric quantum electrodynamics for finite spacetme.[10] A cosmlogical implication of the bi-directional signal transmission P↔Q without common source S in the inflationary cosmology and a possible orgin of dark energy are also discussed.

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II. EPR Correlation in EPR Loophole

At the Solvay council EPR asked: "Are there spooky actions at a distance in quantum dmechanics ?" Recently, Yin et al.[11] led by Q. Zhang measured a superluminal speed of spooky acions between counter-propagating pair of photons emitted from an opticaly pumped atom in spin 0 state. During the measurement the locality and the freedom-of-choice loopholes of previous expriments were maximally closed by observing a 12-hour continuous violation of Bell's numerical expression (inequality) to EPR's reality criterion of local causality and separability of distant events. Let the spacetime positions of the photon source and the detection points be $S(x_S, t_S)$, $P(x_P, t_P)$ and $Q(x_Q, t_Q)$. Then the lower bound of the speed c_S of the spooky actions

$$c_S = |x_Q - x_P|/|t_Q - t_P| \qquad (1)$$

can be superluminal as $|t_Q - t_P| \to 0$. Here we can see a local and causal link P←S→Q ($t_S < t_P \approx t_Q$) and the nonlocal and a causal (spooky) link P→Q ($t_P < t_Q$). Let ε_P and ε_Q be the unit polarization vectors of photons measured at P and Q. The experiments verified the quantum expectations of the correlation function $C_{QM(}(\boldsymbol{\varepsilon}_P,\boldsymbol{\varepsilon}_Q) = \boldsymbol{\varepsilon}_P\boldsymbol{\varepsilon}_Q = \cos\theta$, where θ is the Hilbert space angle between $\boldsymbol{\varepsilon}_P$ and $\boldsymbol{\varepsilon}_Q$, and showed a clear rejection of classical theories obeying Bell's inequlities. The experiments also confirmed the insenstivty of C_{QM} to observer's delayed decision as to which direction to measure each photon's polarization at P and Q after the photon left the source at S—too late for a message to reach the opposite photon,[8] making the causal link P←S→Q improbable and the bi-directional link P↔S↔Q probable in the loophole of EPR's reality criterion of local causlity between P and Q,

III. EPR Correlation on Double-Light Cone

Dirac[12] defined the two-point corrlation function or propagator $\Delta(x,t)$ between S(0,0) and P(x,t), and visualized the signal transmission S↔P on the light cone with the origin S as vertex:

$$(\partial^2/c^2\partial^2 t^2 - \partial^2/^2\partial^2 x^2)\Delta(x,t) = 0, \qquad (2)$$

$$\Delta(x,t) = \alpha(t)\delta(c^2t^2 - x^2)$$

$$= [\delta(ct - x) - \delta(ct - x)]$$

$$= \Delta_{future} - \Delta_{past} = \Delta_{ret} - \Delta_{advt} , \quad (3)$$

where $\alpha(t) = t/|t| = 1$ $(t > 0)$; $= -1$ $(t < 0)$. There an electron at S(0, 0) moves under the retarded (causal) action Δ_{ret} of a charged partcle at P on the past light cone $\delta(ct + x)$ of S as well as the advanced (retrocausal) action Δ_{adv} of a charged particle at Q on the future light cone $\delta(ct - x)$ of S, giving a divergence-free radiation damping of the electron at S. The bi-directional EPR link, $P(x_P, t_P) \leftrightarrow S(x_S, t_S) \leftrightarrow Q(x_Q, t_Q)$, can be visualized on the future light cone of the optically pumped metastable atom at S(0, 0) by replacing the step function $\alpha(t)$ by the square (step-up and down) function $\beta(t) = 0$ $(t < t_S)$; $= 1$ $(t_S < t < t_{P/Q})$; $= 1$ $(t > t_{P/Q})$

$$\Delta(|x_{P/Q} - x_S|, |t_{P/Q} - t_S|)$$
$$= [\delta(c|t_{P/Q} - t_S| - |x_{P/Q} - x_S|)$$
$$-\delta[(c|t_{P/Q} - t_S| - |x_{P/Q} - x_S|]/|x_{P/Q} - x_S| . \quad (4)$$

The double-light cone[13] $[\delta_{ret} - \delta_{adv}]$ in Eq.(5) tells that the detection point P/Q on the left/right arms of the future light cone of S is reached by retarded wave $\exp i(\omega t - kt)$ from S while advanced wave $\exp i(\omega t + kx)$ from P/Q reaches S on the right/left arms of the past light cone of P/Q, forming a bi-directional sinusoidal wave, $\exp i\omega t \sin kx$, standing in phase between S and P/Q with nodes fixed in space at $x = n\pi/k$ (n = integer).

IV. Bi-Directional Microscope

"Is the star (moon) there when nobody looks" asked Tetrode (Mermin).[14] At the 1947 Solvay Council Heisenberg proposed a thought experiment measuring the electron position on microscope's object plane. There the photon wave collapsing at S in the retinaof the oberver entails the retrocollapse (appearance) of an elecon at P scattering the photon to be observed at S. That is, the electron is not at P when nobody looks. at S. This point was emphasized by Weizäcker[15] in his delayed-choice thought experiment measuring the transverse photon momentum on the focal plane of Heisenberg's microscope. If the microscope is very long, the observer at S can make choice as to which property of the electron, position or momentum, to measure after the scattering process has taken place at P. To see the bi-directional signal transmission S↔P in microscope we write Eq.(4) in momentum space[14]

$$\Delta_{\omega,k}(|x_P - x_S|, |t_P - t_S|)$$
$$= [\exp ikc|t_P - t_S| \; |\sin k|x_P - x_S||]/|k|, \quad (5)$$

getting an uncertainty relation between photon momentum $p = \hbar k$ and the microscope length

$$p|x_P - x_S| = nh/2, \quad (6)$$

where n is the number of nodes of the sinusoidal wave standing between S and P.

V. Cosmological EPR Correlation

In an attempt to resolve EPR problem Dirac[17,18] revived early ideas of aether transmitting light signal between distant points separated by spacelike distance, but was rejected by Einstein as it could not be fitted in his 4-dimensional formulation of relativity. Dirac[18] further poposed a bi-directional EPR connection between points P and Q located on the 4-dimensional hyperboloid $(ct)^2 - r^2 = l_{pl}^2$ crossing the light cone at $ct = l_{pl}$ at $r = 0$ with spacelike velocity:

$$dr/dt = ct/r = c(1 + l_{pl}^2/r^2)^{1/2}, \quad (7)$$

defining 3-dimensional Lorenz sphere $r^2 = l_{pl}^2$. We can likewise embed the Lorenz sphere into the radial line element ds of de Sitter universe in Reissner-Nordstroem form:[20]

$$ds^2 = c^2 g_{tt} dt^2 - g_{rr} dr^{22},$$
$$g_{tt} = g_{rr}^{-1} = (1 - \Lambda c^2/r^2 + l_{pl}^2/r^2)^{1/2}, \quad (8)$$

where Λ is the cosmological constant. Putting $ds^2 = 0$, we get light velocity:

$$dr/dt = cg_{tt}/g_{rr} = c(1 - \Lambda r^2/c^2 + l_{pl}^2/r^2). \quad (9)$$

We find that dr/dt is space like at $r \sim l_{pl}$ but decreases towards $dr/dt = c$ at $r = (cl_{pl})^{1/2}\Lambda^{1/4} \sim 10^{-12}\Lambda^{1/4}$ cm. From there dr/dt continues to decrease towards dr/dt = c, but rises again to space like velocity at the comological horizon $r = c\Lambda^{1/2}$ after a brief interlude of subluminal period.

Hawking[19] proposed a cyclic Lorenz-de Sitter model where an expanding and contracting universe starts and ends on the 4-dimensional Lorenz sphere $\tau^2 + r^2 = l_{pl}^2$ with imaginary time $\tau = it$. There the Hubble expansion $\sim \exp Ht$ is replaced by a cosmological wave function of radius $\sim \exp iH\tau \sim \exp i\Lambda\tau$, determining the temperature $T \sim H$, entropy $S \sim \Lambda^{-2}$ and the energy of radiation $E \sim \hbar c/R$ created by the de Sitter black hole capturing negative energy components of Zittering electrons[20] at temerture T.

In high dimensional string theory,[21] the parallel orbifold branes collide periodically in cycle, expanding and contracting with dark energy Λ.

VI. Mass Defect of Semiclosed Friedman Universe

The idea of semicosed Friedman universe was proposed by Zel'dovich and others[21] in 1970s as a possible model of quasistellar radio sources evolving from and joined-on to preexisting asymptotically flat space. The expansion history of the semicosed universe is dictated by the Hubble constant $H = 8\pi G/\rho_\Lambda$ and the dimensionless density parameter $\Omega_\Lambda = \rho_\Lambda/\rho_{c\Lambda}$ where ρ_Λ is the energy density and $\rho_{c\Lambda}$ the critical density.

For $0 < \Omega_\Lambda < 0.5$ the expanding univese in lower hemisphere is joined onto asymptotically flat outer space through Schwarzschild throat; for $0.5 < \Omega_\Lambda < 1$ the contracting upper hemisphere is joined onto outer space through double-valued Schwarzschild bottleneck; for $\Omega_\Lambda \sim 1$ the almost closed universe is joined onto asymptotically flat space extending to infinity through Planck scale throat. For an observer comoving with cosmological expansion and contraction history of semicosed Friedman universe can be described by the radial line element ds of the universe in Reissner-Nordstroem form:

$$ds^2 = c^2 g_{tt} dt^2 - g_{rr} dr^2,$$

$$g_{tt} = g_{rr}^{-1} = (1 - r^2/r_g^2 + l_{pl}^2/r^2)^{1/2}, \qquad (10)$$

where $r_g = 3c^2/8\pi G\rho_\Lambda$. The light velocity $dr/dt = c(1 - \Lambda r^2/c^2 + l_{pl}^2/r^2)$ is space like at $r \sim l_{pl}$. As r increases from $r = l_{pl}$, dr/dt decreases towads c at $r = (r_g l_{pl})^{1/2} \sim 10^2$cm for $r_g \sim 10^{28}$cm, to be compared with the radius of causally related small region ~ 10cm in inflationary model. With further increase of r towards horizon $r = r_g$, dr/dt reaches spacelike velocity $r = r_g$ after a long interlude of subluminal period: $l_{pl} << r << r_g$. In this period a detailed description of the semiclosed Friedman universe can be given by using the integral $\int dx\,(1 - r^2/r_g^2)^{1/2} = \sin^{-1}x$ to calculate the proper mass M_p and volume V_p of the universe:

$$M_p = \rho_\Lambda V_p = 2\pi\rho_\Lambda \int^R r^2 g_{rr} dr = (3/2)(R/r_g)^3[\sin^{-1}(R/r_g)$$

$$- (R/r_g)(1 - (R^2/r_g^2)^{1/2})]M, \qquad (11)$$

where $M = (4\pi R^3/3)\rho_\Lambda = \rho_\Lambda V$ is the Newtonian mass and volume V. Eq.(11) tells that the proper radius $R_p = \int^R g_{rr} r dr$ and volume $V_p = (4\pi R_p^3/3)$ increases with the increase of the world radius from $r \sim 0$, where $\sin_p^{-1}(R/r_g) \sim 0$, until V_p fills the half of the closed universe (lower hemisphere) of the closed Friedman universe, where $\sin^{-1}(l_{pl}/r_g) = \pi/2$. With further increase of r, R_p decreases towards $R_p \sim l_{pl}$, where $\sin^{-1}(l_{pl}/r_g) \sim \pi$, forming a gravitational semiclosure with $V_p \sim M_p \sim 0$ (with upper hemisphere) having Planck surface l_{pl}^2 and mass m_{pl}, creating Planck scale black holes liberating dark energy $E \sim \hbar c/l_{pl}$ or recreating a black Lorenz sphere outside the gravitational radius $R = r_g$, liberating dark energy $E \sim \hbar c/R$ with information content $(R/l_{pl})^2$ in asymptoticlly flat outer space.[22]

VII. Source of Dark Energy

We note that the negative equation of state $\rho_\Lambda + p_\Lambda c^2 < 0$ required by the dark energy is satisfied in the upper hemisphere of the semiclosed Friedman universe. There the density of gravitationally bound pairs of quantized metric fluctuations, or graviational Bohr atoms, dominate by creating negative attractive potential $Gm_{pl}^2/l_{pl} = \hbar c/l_{pl} = m_{pl}c^2$ capturing positive rest mass energy $m_{pl}c^p$ of single metric fluctuation, or Planckeons. In the lower hemisphere, where the positive equation of state $\rho_\Lambda + p\,c^2 > 0$ is satisfied, the free Planckeons prevails. The evolutionarily earlier upper hemishere is chracterized by the density parameter $0.5 < \Omega_\Lambda = (R/r_g)^2 = 1$ and the less earlier lower hemisphere by $0 < \Omega_m < 0.5$. The recently updated density parameters[23] fall into these ranges: $\Omega_\Lambda \sim 0.685$ and$\Omega_m \sim 0.266$. Adding the evolutionarily recent atomicmatter $\Omega_{atom} \sim 0.049$, we have$\Omega_{tot} = \Omega_\Lambda + \Omega_m + \Omega_{atom} = 0.965 \sim 1$ indicating the asymptotic flatness of the extragalactic space required for the asymptotic solutions of Einstein equations to be found useful.

VIII. Conclusion

We have shown that the quantum paradox of EPR correlation between distant points P and Q sharing a comon source S arises outside EPR's reality criterion of local causality, and can be solved within the framework of time-symmetric and relativistic quantum electrodynamics for finite spacetime[10] with singular boundary conditions allowing the bi-directional signal transmission P↔S↔Q on the double-light cone where the future and the past cones share a common light path connecting S and P/Q. A cosmlogical implication of the bi-directional and superluminal signal transmission P↔Q without a common source S in explaining the observed homogeneity of the universe and the possible Planckeon orgin of dark energy in the upper hemisphere of the semiclosed Friedman uiverse, joined onto an asymptotically flat space, are also discussed to explain the asymptotic flatness of the extragalactic space. In conclusion Planckeon origin of dark energħ in the upper hemisphere of the semiclosed Friedman universe is proposed.

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