Title: Quantum Gravity Talk

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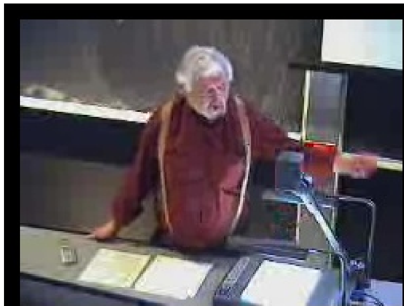
Abstract:

WHAT IS TIME?

- Newton: "Time is absolute" - ???
- Should he not have said:
  "Time is universal" ?
- Define time:
  The duration of a process is determined from the correlation of points on a standard trajectory (clock) and the configurations of matter in the evolution of a process
- Universality means:
  Agreement among observers as to the value of this duration for all clocks and all observers, given initial synchroniz



a frame moving with constant velocity
is rendered quantitative by:

1] The angular change of my watch needle

2] Counting rail ties crossed

— provided

1] synchronize initially: 0^{th} tie = 0 angle

2] Synchronize units $\Delta\theta/\omega = \Delta x/v$

3] System is isolated: $E = \text{constant}$

(Random cosmic rays causing random jiggles upsets the game)

Note: The above clocks are useful being inertial trajectories (the watch is a wrapped up inertial trajectory). In terms of such

Why and how universality? (Parentani) 4

- Hamilton – Jacobi theory

x_1^0 and x_1 are points on 1, with energy E_1

x_2^0 and x_2 are points on 2 with energy E_2

- $$t_{E_1}(x_1^0, x_1) = \frac{\partial S_1}{\partial E_1} = \frac{\partial}{\partial E_1}\int_{x_1^0}^{x_1} p_1\, dx_1$$

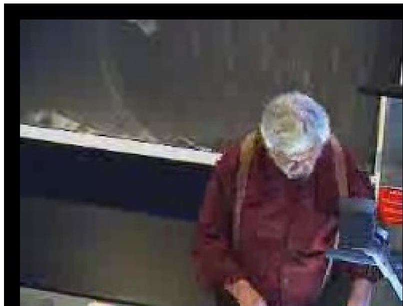
$$= \int_{x_1^0}^{x_1} \frac{m_1\, dx_1'}{\sqrt{2m_1(E-V(x_1))}}$$

$$\equiv \int_{x_1^0}^{x_1} \frac{dx_1'}{v(x_1')}$$

- $$t_{E_2}(x_2^0, x_2) = \frac{\partial S_2}{\partial E_2} = \int_{x_2^0}^{x_2} \frac{dx_2'}{v(x_2')}$$

Nature of correlation

We observe x_1^0, x_2^0 initially (synchronization, position of watch needle and initial rail tie)



- After the initial interaction the systems evolve independently. Nevertheless they are one dynamical system to which the principle of least action applies as a whole

- Question: Given this, when we observe x_1, x_2

  why is $t_{E_1}(x_1) = t_{E_2}(x_2)$?

  The whole is isolated: $E = E_1 + E_2 = \text{const}$

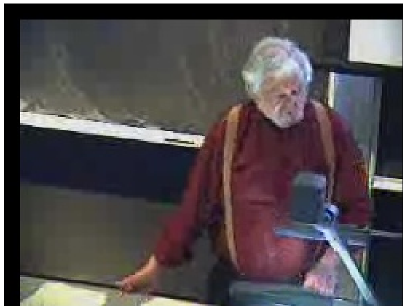
  $$E_1 = \epsilon; \quad E_2 = E - \epsilon$$

- For what values of the energy split does the system pass through x_1 and x_2 i.e. when 1 hits x_1 then 2 hits x_2?

- Answer $\quad \dfrac{\partial S}{\partial \epsilon} = 0$

$$\frac{\partial S_1}{\partial E_1} + \frac{\partial S_2}{\partial (E-E_1)} = 0$$

$$t_1(x_1) - t_2(x_2) = 0$$



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Some subjective remarks

1) We do injustice to our science when we couch the laws of physics ab initio in terms of time. Man invented time by correlating events in his life to celestial periodic systems (or the earth's rotation). We then abstract, solve Newton's equations in terms of time. e.g. to get a Keplerian orbit $r(t)$; $\phi(t)$. But more fundamental is $r(\phi)$; or observationally $r(\phi_1, \phi_2)$ where ϕ_2 is the angle on an earthbound clock so that $\phi_1 = \phi_1(\phi_2)$, $r = r(\phi_2)$ where ϕ_2 is ~~earthbound~~ earthly time. correlated to both r and ϕ_1

2) Have we come closer to an epistemological appreciation of time? I think not. All of this requires motion i.e. visits on a

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1) We do injustice to our science when we couch the laws of physics ab initio in terms of time. Man invented time by correlating events in his life to celestial periodic systems (or the earth's rotation). We then abstract, solve Newton's equations in terms of time. e.g. to get a Keplerian orbit $r(t)$; $\phi(t)$. But more fundamental is $r(\phi)$; or alternatively $r(\phi_1, \phi_2)$ where ϕ_2 is the angle on an earthbound clock so that $\phi_1 = \phi_1(\phi_2)$, $r = r(\phi_2)$ where ϕ_2 is ~~earthbound~~ earthly time correlated to both r and ϕ_1

2) Have we come closer to an epistemological appreciation of time? I think not. All of this requires motion i.e. visits on a ~~[illegible]~~ sequence of points are required. But motion is inevitable → COSMOLOGY

Cosmological Time

Time present and time past
Are both perhaps present in time future
And time future contained in time past
If all time is eternally present
All time is unredeemable

T S Eliot, Burnt Norton

Cosmological Time

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- We shall work in large scale cosmology; gravity has 1 degree of freedom, scale factor
- Dynamics is governed by the Wheeler-DeWitt constraint

$$H_{Tot}\,\Psi_{Tot}(a,\phi)=0 \qquad 1)$$

ϕ = all degrees of freedom of matter

1) follows ~~of~~ from invariance under temporal reparametrization

- Suppose $H_{Tot}\tilde{\Psi} = \frac{\hbar}{i}\frac{\partial}{\partial t}\tilde{\Psi}$

then $\quad \Psi = \int dt\,\tilde{\Psi}$; all time is eternally present

Born Oppenheimer idea (Brout, Venturi 1989)

built on Banks (1985)

$$\Psi(a,\phi) = \psi(a)\,\chi(a,\phi) \qquad 1)$$

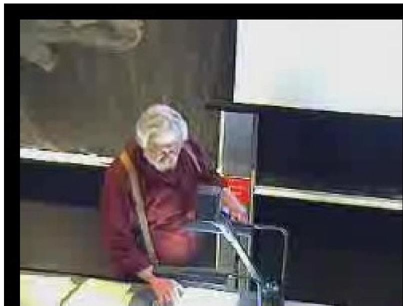
$$[H_g(a) + H_M(a,\phi)]\,\chi\psi = 0 \qquad 2)$$

(For simplicity take χ normalizable – applicable to a closed universe – not necessary but makes for easier conversation)

Contracting 2) with $\langle\chi$ gives

$$[H_g(a) + \langle\chi|H_M|\chi\rangle]\,\psi(a) = 0 \qquad 3)$$

(Born Oppenheimer nuclei are subject to an effective (adiabatically) potential determined by the electronic wave function. Similarly $\psi(a)$ encodes the expansion occasioned by the mean matter energy)



... WKB for $\psi(a)$. Then the action in $\psi(a)$

is the classical action determined by the solution

$$-H^2 + \frac{K}{a^2} + \frac{8\pi}{3}\rho = 0 \qquad 4)$$

$$H = \dot{a}/a \quad (\text{expressed as momentum})$$

$$m_{P\ell} = 1$$

Equation for χ in Born Oppenheimer

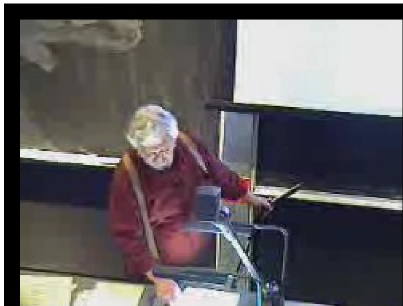
Put ψ back in to give

$$[H_M - \langle H_M \rangle]\chi + i\,\frac{\partial S_{eff}}{\partial a}\,\frac{\partial \chi}{\partial a} =$$

$$= 0 + \text{corrections}$$

Relative Corrections are $O\left(\frac{(H_M - \langle H_M \rangle)^2}{\langle H_M \rangle^2}\right)$

$$= O\left(\frac{1}{N}\right)$$



If $O(1/N)$ is negligible

$$\frac{\partial S}{\partial a}\frac{\partial \chi}{\partial a} = \pi(a)\frac{\partial \chi}{\partial a} = \dot{a}\frac{\partial \chi}{\partial a}$$

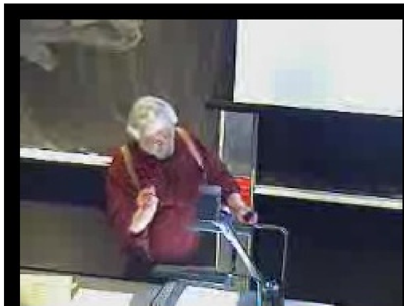
$$= \frac{\partial \chi}{\partial t}$$

$$\therefore [H_M - \langle H_M \rangle]\chi = i\frac{\partial \chi}{\partial t}$$

Lesson:

The WKB phase of the gravitational wave function driven by the mean energy of matter encodes time

<u>Note</u>:
Time is a concept of non-stationari
If χ is an energy eigenfunction, the is no time. "Stationary" is well cho



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Time is a measure of interference among the different energy components of Ψ, each of which bears its WKB phase.

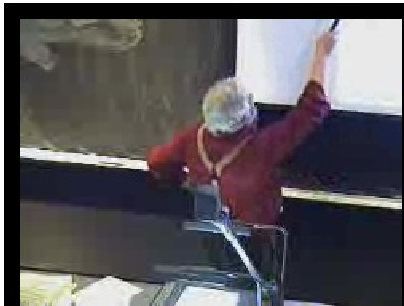
An explicit calculation of the physical effects of time is:

Parentani's derivation of the golden rule

Model: 2 level atom interacting with radiation field

At $a = a_0$, atom is excited

~~At~~ $a = \alpha$, what is the amplitude for de-excitation $+ \gamma$



Wheeler De Witt Equation

$$[H_0 + H_{int} + H_g]\,\Psi(a,\phi) = 0$$

With $H_{int} = 0$

$$\Psi(a) = \sum_n c_n \psi_n^{(0)}(a)$$

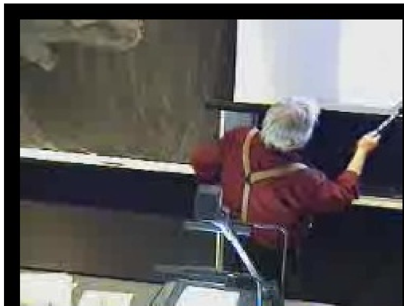
$\psi_n^{0}(a)$ = basis functions (eigenfunctions of $H_0 + H_g$)

$$= e^{iS_g(a,n)}\, \chi_n \Big/ \sqrt{2\Pi(a,n)}$$

S_g = action of gravity driven by E_n
(owing to the constraint)

χ_n specific occupation numbers of radiation and state of an atom

Consider the WKB: $\exp iS_g(a,n)/\sqrt{2\Pi}$ to carry the gravitational recoil occasioned by the energy of matter



$$S_q = \int^a \Pi(a'; \epsilon(\{n\}))\, da'$$

L12

Set this into the WD equation to $O(\frac{1}{N})$ to find

$$i\partial_a C_{\{n\}} = 2a \sum \langle n'| H_{int} |n\rangle \times \frac{\times\, e^{i\int^a [\Pi(a';n') - \Pi(a';n)]\, da'}}{\Pi(a,n)} \times C_{n'}$$

$$\Pi(a) = [2a\, \epsilon_{\{n\}}]^{1/2} = O(\sqrt{N})$$

$$\Delta\Pi = O(1)/\Pi(a)$$

But $\frac{\partial \Pi}{\partial E}\, da = dt = O(1)$ by our watch

$$i\partial_t C_n = \sum_{n'} C_{n'} \langle n'|H_{int}|n\rangle\, e^{i\int^t \Delta E\, dt'}$$

$$\Delta E = E_{n_2+1} + E_{\gamma} - E_{n_2} - E_{\gamma}$$

Lesson

- The WD constraint defines the a dependent phase in the energy component defined through the gravitational action
- Using H-J, the phase difference among these components is $\Delta E t$
- Time is a "maquillage" which encodes how gravity follows transitions in matter, owing to the energy constraint

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$$S_q = \int \Pi(a'; \epsilon(\{x\})]\, da'$$

Set this into the W-D equation to $O(\frac{1}{N})$ to find

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