Title: The problem of time meets the problem of constants: could Quantum Cosmology be happening now?

Speakers: Joao Magueijo

Series: Cosmology & Gravitation

Date: April 20, 2021 - 11:00 AM

URL: http://pirsa.org/21040022

Abstract: Abstract: TBD

The problem of time meets the problem of the constants

(Could Quantum Cosmology be happening "now"?)

João Magueijo

2021

Imperial College, London

The background to the problem of time:

(without dwelling too much on its philosophy…)

- Due to the Hamiltonian constraint, time (coordinate time) drops out of a potential Schrodinger equation.
- "Observables" cannot depend on time.
- The time reparameterization invariance of the theory leads to a prediction of no evolution in the actual world.
- Faced with this we may take two views.
  - The Platonic view: time is an illusion of this cave of sorrows we are unlucky to inhabit.

Maybe what we perceive as “time” and change is in the realm of shadows: we are watching a bad quality film. The “real” world has notime and no change!

Our senses cannot deceive us that much (even if they always do a little bit…)

- The Aristotelian stance.
  - Something is wrong with the theory

- No wonder Quantum Gravity is usually banished to the "Planck epoch", translatable as "the realms of bullshit".

We need a "time" to make contact with the real world!

- Obviously not the coordinate time (meaningless).
- A physical, "relational" time. The problem, then, is an embarrassment of riches: too many times.
- Is that OK?
- Here I will argue that it is not only OK, but it is a feature of the physical world, with different time zones in action and adjustment of clocks across them a fact of life.
- It is possible that phenomenology and testability arises from this feature of the world.

Let's combine this with the problem of the origin and value of the constants of Nature

Dirac and Manci on their honeymoon, Brighton, January 1937

The proposal in this talk:

- Time is the conjugate of the constants of Nature.
- Possibly the canonical conjugate classically.
- Certainly the quantum mechanical complementary.

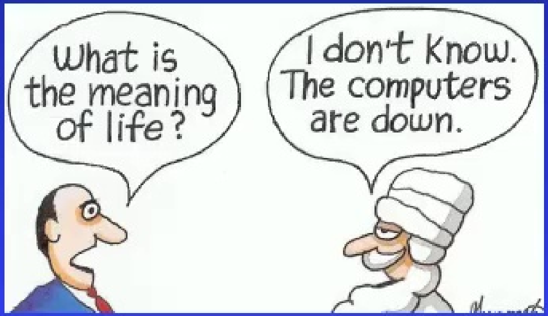
- Constants appear as constants of motion, implied by equations of motion.
- The fundamental constants will appear side by side with all the other constants of motion.

This is important for a much bigger question: the origin and stability of the laws of physics.

- Universe that makes its laws as it goes along (John Wheeler's "everything comes out of higgledy-piggledy").
- A self-taught Universe?

The Autodidactic Universe

Stephon Alexander[1,2], William J. Cunningham[3,4], Jaron Lanier[5], Lee Smolin[3], Stefan Stanojevic[5,6], Michael W. Toomey[1,5], and Dave Wecker[5]

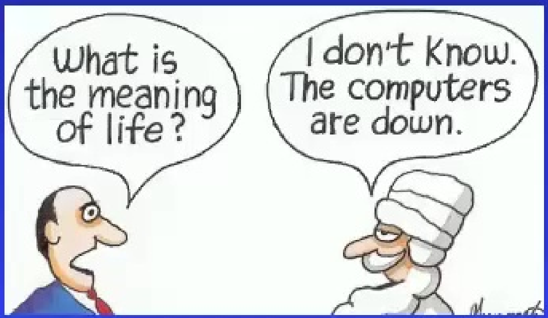


This is important for a much bigger question: the origin and stability of the laws of physics.

- Universe that makes its laws as it goes along (John Wheeler's "everything comes out of higgledy-piggledy").
- A self-taught Universe?

The Autodidactic Universe

Stephon Alexander[1,2], William J. Cunningham[3,4], Jaron Lanier[5], Lee Smolin[3], Stefan Stanojevic[5,6], Michael W. Toomey[1,5], and Dave Wecker[5]



- If we are going to entertain time-dependence in the laws of physics, we'd better know what physical time is in the first place.

Roadmap of the talk (expect many detours…)

- Background 1: Unimodular gravity revisited…
- Background 2: The rehabilitation of the Chern-Simons state.
- The basic proposal illustrated in minisuperspace.
- The semiclassical states and contact with the real world.
- Alternative states: is new phenomenology around the corner?

Background 1: Unimodular gravity

- It is well known that Lambda may be demoted to an integration constant with the procedure.

$$S \to S + \frac{1}{16\pi G_0} \int d^4x \Lambda \partial_\mu T^\mu_\Lambda$$

- Then the constancy of Lambda becomes the result of an equation of motion:

$$\frac{\delta S}{\delta T^\mu_\Lambda} = \partial_\mu \Lambda = 0$$

- No longer are the constancy and value of Lambda set in stone…

Background 1: Unimodular gravity

- The zero component of T (which is the canonical conjugate of Lambda in the Hamiltonian formulation) provides a definition of time. The "time formula" is…

$$\frac{\delta S}{\delta \Lambda} = 0 \implies \partial_\mu T^\mu_\Lambda = 2\sqrt{-g}$$

(which turns out to be Misner volume time)

W. G. Unruh, Phys. Rev. **D40**, 1048 (1989).

M. Henneaux and C. Teitelboim, Physics Letters **B 222**, 195 (1989).

Why not do this with every other constant of Nature?

- We will be doing the same (illustrated in minisuperspace…):

$$S \to S + \frac{1}{16\pi G_0}\int d^4x \sum_i \alpha_i \partial_\mu T_i^\mu$$

$$\frac{\delta S}{\delta T_i^\mu} = \partial_\mu \alpha_i = 0$$

with any constant that's handy at a given time in the life of the Universe

- The "time formula"…

$$\frac{\delta S}{\delta \alpha_i} = 0 \implies \partial_\mu T_i^\mu + \frac{\delta S_0}{\delta \alpha_i} = 0$$

- The "times" are all equivalent classically (a lapse redefinition), but not so quantum mechanically.

Background 2: let's do things in connection space, instead of metric

- "Loop" Quantum Gravity before the loops.
- A Gauge theory based on SO(3,1)… (before complexification, too).
- Once one goes back to basics, the Chern-Simons state is not so bad…The rehabilitation of the CS/Kodama state:

$$\psi_K(A) = \mathcal{N} \exp\left(\frac{3}{l_P^2 \Lambda} Y_{CS}\right) \qquad Y_{CS} \to i\Im(Y_{CS})$$

- The usual pathologies disappear.

A. Randono, [arXiv:gr-qc/0504010 [gr-qc]].
A. Randono, [arXiv:gr-qc/0611073 [gr-qc]].
A. Randono, [arXiv:gr-qc/0611074 [gr-qc]].
W. Wieland, [arXiv:1105.2330 [gr-qc]]

- Contact is made with Chern-Simons time.

L. Smolin and C. Soo, Nucl. Phys. B **449**, 289-316 (1995)

If this may sound anachronic to the QG crowd, it sounds outlandish to cosmologists…

- For whatever reason we tend to think of the main cosmological variable as the expansion factor, a.
- I'm asking for a description in terms of b:

$$E^a_I = a^2 \delta^a_I$$

$$A^I_j = ib\delta^I_j$$

$$b \approx \dot{a}$$

- Come to think of it, it is not so outlandish: the comoving Hubble scale… responsible for the horizon problem.

If this may sound anachronic to the QG crowd, it sounds outlandish to cosmologists…

- For whatever reason we tend to think of the main cosmological variable as the expansion factor, a.
- I'm asking for a description in terms of b:

$$E^a_I = a^2 \delta^a_I$$

$$A^I_j = i b \delta^I_j$$

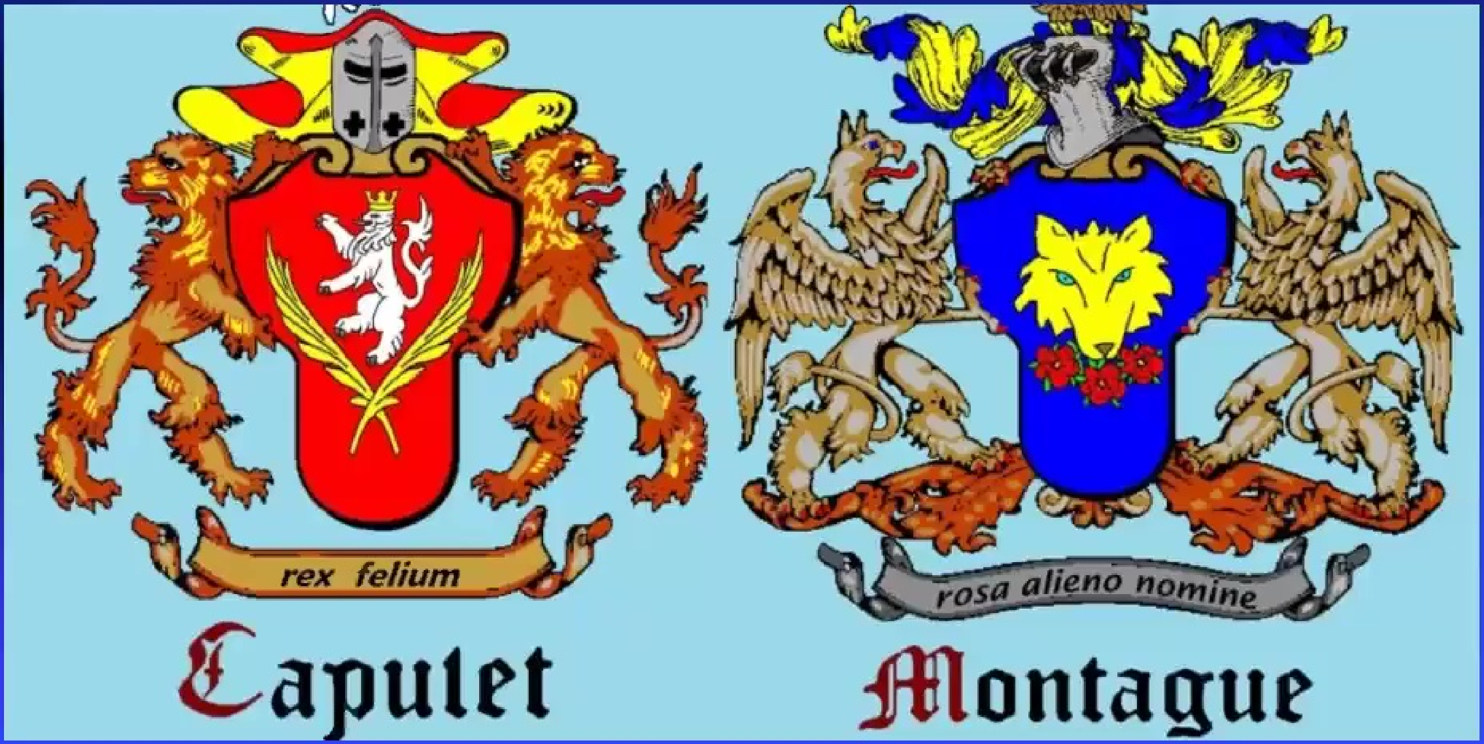
$$b \approx \dot{a}$$

- Come to think of it, it is not so outlandish: the comoving Hubble scale… responsible for the horizon problem.
- Or may be it is. Test case: are we experiencing a bounce? Do you find this surprising?

Also, watch out for what and who you are calling “anachronic”

- The two languages (metric and connection) are complementary representations of the same thing.
- The Fourier dual of the (REAL!!!) Chern-Simons (Kodama) state is…
  - The Hartle-Hawking wavefunction.
  - (The Vilenkin wavefunction).

TWO ENEMY FAMILIES



$$S = 3\kappa V_c \int dt \left(2a^2\dot{b} + 2Na\left(b^2 + k - \frac{\Lambda}{3}a^2 \right) \right)$$

$\kappa = 1/(16\pi G_N)$

V_c is the comoving volume

$$\{b, a^2\} = \frac{1}{6\kappa V_c}$$

$$\left[\hat{b}, \hat{a^2}\right] = \frac{il_P^2}{3V_c}$$

$$\hat{a}^2 = -\frac{il_P^2}{3V_c}\frac{d}{db}$$

$$\hat{\mathcal{H}}\psi = \left(\frac{i\Lambda l_P^2}{9V_c}\frac{d}{db} + k + b^2 \right)\psi = 0$$

$$\psi_{CS} = \mathcal{N}\exp\left[i\left(\frac{9V_c}{\Lambda l_P^2}\left(\frac{b^3}{3} + kb \right) + \phi_0 \right) \right]$$

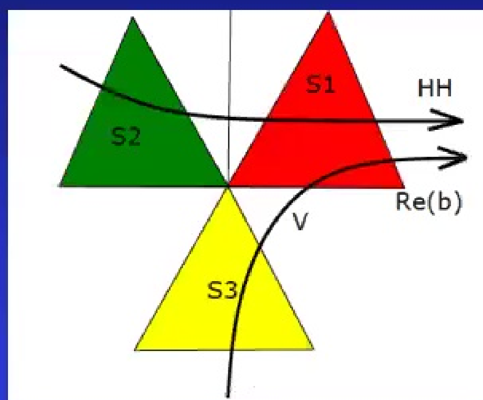
$E_I^a = a^2\delta_I^a$

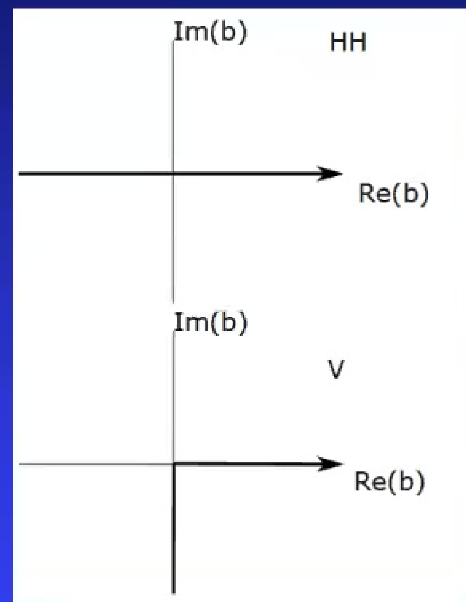
$$\psi_{a^2}(a^2) = \frac{3V_c}{l_P^2}\int \frac{db}{\sqrt{2\pi}} e^{-i\frac{3V_c}{l_P^2}a^2 b}\psi_b(b)$$

$$\psi_V \propto \mathrm{Ai}(-z) + i\mathrm{Bi}(-z)$$

$$z = -\left(\frac{9V_c}{\Lambda l_P^2}\right)^{2/3}\left(k - \frac{\Lambda a^2}{3}\right)$$

$$\psi_H \propto \mathrm{Ai}(-z)$$





Obviously, peace comes with a price…

Obviously, peace comes with a price…

- Indeed even just "talking" between the two factions comes with assumptions…
- These assumptions are not dirt swept under the carpet: they are important clues.

$$E^a_I = a^2\delta^a_I \qquad \psi_{a^2}(a^2) = \frac{3V_c}{l_P^2}\int \frac{db}{\sqrt{2\pi}}\, e^{-i\frac{3V_c}{l_P^2}a^2 b}\,\psi_b(b)$$

- The square of a is the natural variable (in Bianchi, etc, there are equivalent ones). The natural variable should cover the whole real line: this implies Euclidean regions.

The simple idea:

- Seek constants such that in some regions of phase space the following equivalence holds true *approximately*:

$$H = 0 \qquad \mathcal{H} = H_0 - \alpha = 0$$

(so, we are happy about this procedure being non-"fundamental", leading to "effective" or "emergent" times).

- We will target different constants in different regions.
- We possibly will even have a choice of different constants in each region.

The basic illustrative model:

- Einstein-Cartan gravity (but it could be anything else)
- Minisuperspace (but covariant local versions generalizations can be built).

$$S = \frac{3V_c}{8\pi G_0}\int dt\left(a^2\dot{b} - Na\left[-(b^2+k) + \sum_i \frac{m_i}{a^{1+3w_i}}\right]\right)$$

- Notational explanation:

The basic illustrative model:

- Einstein-Cartan gravity (but it could be anything else)
- Minisuperspace (but covariant local versions generalizations can be built).

$$S = \frac{3V_c}{8\pi G_0}\int dt\left(a^2\dot{b} - Na\left[-(b^2+k) + \sum_i \frac{m_i}{a^{1+3w_i}}\right]\right)$$

- Notational explanation: $b = \dot{a}/N$ on-shell $k = 0, \pm 1$

Λ $m_i = \Lambda/3$ $w_i = -1$

dust and radiation $m_i = C_i 8\pi G_0/3$ $w_i = 0, 1/3$

$m_i = C_i 8\pi G_N/3$

$m_i = -kc^2$ and $w_i = -1/3$

massless scalar field $m_i \propto \Pi_\phi/G_N$ and $w_i = 1$

$m_i = \Lambda_0 c^2/3$ and $w_i = -1$

Then, we can do the following manipulations for each ingredient i:

- Seek specifically the approximate format for H const.

$$H = 0 \qquad \mathcal{H} = H_0 - \alpha = 0 \qquad \mathcal{H} = h_i(b)a^2 - \alpha_i = 0$$

- When one i dominates:

$$h_i(b) = (b^2 + k)^{\frac{2}{1+3w_i}}$$
$$\alpha_i = m_i^{\frac{2}{1+3w_i}},$$

with $w_i = -1/3$ to be treated separately

(Aside, maybe better skipped here…Don't need to do this, but it is equivalent to a canonical transformation recasting a non-quadratic dispersive relation into "linearizing variables", cf. DSR)

Our proposal is therefore to mimic unimodular gravity as follows:

- Consider a theory which extends the standard one via:

$$S \to S + \frac{3V_c}{8\pi G_0} \int dt \dot{\alpha}_i p_i$$

and let us explore: $T_i \equiv p_i$

- The constancy of the "constants" becomes circumstantial, the result of the equations of motion, in MSS:

$$\{\alpha_i, p_i\} = \frac{8\pi G_0}{3V_c} \qquad \dot{\alpha}_i = \{\alpha_i, H\} = 0$$

(itself an expression of the time-independence of the Hamiltonian with respect to the much more physical time

…and we become the proud owners of a time and a Schrodinger equation:

$$\left[H_0(b) - i\frac{l_P^2}{3V_c}\frac{\partial}{\partial T_i}\right]\psi(b, T_i) = 0$$

(with fixed $l_P = \sqrt{8\pi G_0 \hbar}$ should G be the target, for simplicity).

- It's only when we insist on monochromatic solutions:

$$\psi(b, T_i; \alpha_i) = \psi_s(b; \alpha_i)\exp\left[-i\frac{3V_c}{l_P^2}\alpha_i T_i\right]$$

that we find the timeless WdW equation we started from:

$$\mathcal{H} = H_0 - \alpha = 0$$

Not surprising: fix the complementary of time (the "constant") and time becomes totally undefined.

Thinking in terms of the connection instead of the metric is good for you

- Let's backtrack to the first term in the action:

$$S = \frac{3V_c}{8\pi G_0} \int dt \left(a^2 \dot{b} \right.$$

$$\{b, a^2\} = \frac{8\pi G_0}{3V_c} \implies \hat{a}^2 = -i \frac{l_P^2}{3V_c} \frac{\partial}{\partial b}$$

- Hence the monochromatic solutions are plane waves in a special space. Recall we sought: $\mathcal{H} = h_i(b) a^2 - \alpha_i = 0$. Then:

$$\left(-i \frac{l_P^2}{3V_c} \frac{\partial}{\partial X_i} - \alpha_i \right) \psi_s = 0$$

$$X_i(b) = \int \frac{db}{h_i(b)}$$

$$\psi_s(b; \alpha_i) = \mathcal{A}(\alpha_i) \exp \left[i \frac{3V_c}{l_P^2} \alpha_i X_i(b) \right]$$

For Lambda, this is nothing but the (real) Chern-Simons state:

- Can go through the procedure with w = -1, to find:

$$H = 6\kappa V_c N a \left(-(b^2+k) + \frac{\Lambda}{3} a^2 \right)$$

$$\mathcal{H} = \frac{1}{b^2+k} a^2 - \frac{3}{\Lambda} = 0$$

$$\mathcal{H} = h(b) a^2 - \alpha = 0$$

$$h(b) = \frac{1}{b^2+k}$$
$$\alpha = \phi = \frac{3}{\Lambda}$$

$$X_\phi(b) = \int \frac{db}{h(b)} = \frac{b^3}{3} + kb$$

$$\psi_s(b;\alpha_i) = \mathcal{A}(\alpha_i) \exp\left[i \frac{3V_c}{l_P^2} \alpha_i X_i(b) \right]$$

$$\psi_{CS} = \mathcal{N} \exp\left[i \frac{9V_c}{\Lambda l_P^2} \left(\frac{b^3}{3} + bk \right) \right]$$

We have, therefore, found generalizations of the CS functional for other forms of matter.

- For example for a radiation dominated Universe the Chern-Simons functional would become:

$$
\begin{aligned}
X_r(b) = \int \frac{db}{b^2+k} &= \quad \frac{1}{\sqrt{k}}\arctan[\tfrac{b}{\sqrt{k}}] && \text{if } k>0 \\
&= \quad -\frac{1}{b} && \text{if } k=0 \\
&= -\frac{1}{\sqrt{|k|}}\mathrm{argtanh}[\tfrac{b}{\sqrt{|k|}}] && \text{if } k<0
\end{aligned}
$$

- The Fourier duals in the metric representation are actually the recently found: S. Gielen and L. Menéndez-Pidal, Class. Quant. Grav. **37**, no.20, 205018 (2020).
- Likewise for dust, a massless scalar field, etc.

More importantly, to these "spatial" wave functions we must add the unitary time evolution factor:

- The full solution is:

$$\psi(b, T_i; \alpha_i) = \psi_s(b; \alpha_i) \exp\left[-i\frac{3V_c}{l_P^2}\alpha_i T_i\right]$$

$$\psi(b, T_i; \alpha_i) = \mathcal{A}(\alpha_i) \exp\left[i\frac{3V_c}{l_P^2}\alpha_i (X_i(b) - T_i)\right]$$

- By choosing the coordinates we did (X instead of b and alpha instead of m) we have planes waves with trivial dispersion in MSS.
- In terms of b and the original constants there is dispersion.
- The X and alpha are like linearizing variables in DSR

By demoting constants from "set in stone" to circumstantial constant

- We gained a time variable
- We expanded the space of solutions.

$$\psi(b, T_i) = \int d\alpha_i \mathcal{A}(\alpha_i) \exp\left[i \frac{3V_c}{l_P^2} \alpha_i (X_i(b) - T_i)\right]$$

- No need to invoke hypothetical non-trivial inner products to get normalizable solutions.

Of particular relevance:

- Coherent/squeezed states:

$$\mathcal{A}(\alpha_i) = \sqrt{\mathbf{N}(\alpha_{i0}, \sigma_i)}$$

$$\psi(b, T_i) = \mathcal{N}\psi(b, T_i; \alpha_{i0}) \exp\left[-\frac{\sigma_i^2 (X_i - T_i)^2}{(l_P^2/3V_c)^2}\right]$$

- They saturate the inevitable Heisenberg relation arising in any construction of this sort:

$$\sigma_T \sigma_\alpha \geq \frac{l_P^2}{6V_c}$$

- For a coherent state the uncertainties are equally spread:

$$\sigma_i^2 = \frac{l_P^2}{6V_c}$$

In fact we don't even need to resort to plane-wave superpositions:

- The Hamiltonian constraint can be simply written as:

$$\left(\frac{\partial}{\partial X_i} - \frac{\partial}{\partial T_i}\right)\psi = 0$$

- Implying solutions: $\psi(b) = F(T_i - X_i)$

(e.g. solitons in X).

- Suggesting the conserved current: $j^0 = j^1 = |\psi|^2$

Other interesting states exist:

- In the quasi-topological theories:

S. Alexander, M. Cortês, A. R. Liddle, J. Magueijo, R. Sims and L. Smolin, Phys. Rev. D **100**, no.8, 083506 (2019); Phys. Rev. D **100**, no.8, 083507 (2019).
J. Magueijo and T. Złośnik, Phys. Rev. D **100**, no.8, 084036 (2019).

$$\mathcal{A} \propto \mathrm{const}$$

- Implying the light ray:

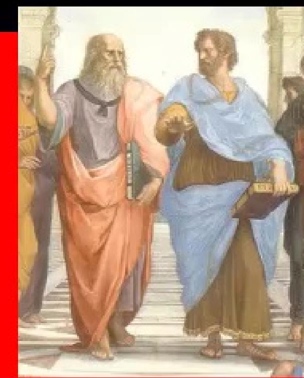
$$\psi \propto \delta(T_i - X_i)$$

- This is actually the conformal constraint found in that theory.

Roadmap of the talk (expect many detours…)

- Background 1: Unimodular gravity revisited…
- Background 2: The rehabilitation of the Chern-Simons state.
- The basic proposal illustrated in minisuperspace.
- The semiclassical states and contact with the real world.
- Alternative states: is new phenomenology around the corner?

Something resembling the “real” world therefore emerges.



- Note the Hamilton’s second equation (in addition to $\dot{\alpha}_i = \{\alpha_i, H\} = 0$) is an expression of the “time formula”:

$$\dot{T}_i = \{T_i, H\} = -\frac{1+3w_i}{2} N a^{-3w_i} \alpha^{\frac{3w_i - 1}{2}}$$

- In fact the classical trajectory is given by: $\dot{T}_i = \dot{X}_i$
- So any peaked wave function sees its peak follow the classical trajectory.
- Obviously only coherent states have the right T function. (Ehrenfest theorem might not be enough to hide quantum fluctuations in T)

Other interesting states exist:

- In the quasi-topological theories:

S. Alexander, M. Cortês, A. R. Liddle, J. Magueijo, R. Sims and L. Smolin, Phys. Rev. D **100**, no.8, 083506 (2019); Phys. Rev. D **100**, no.8, 083507 (2019).
J. Magueijo and T. Złośnik, Phys. Rev. D **100**, no.8, 084036 (2019).

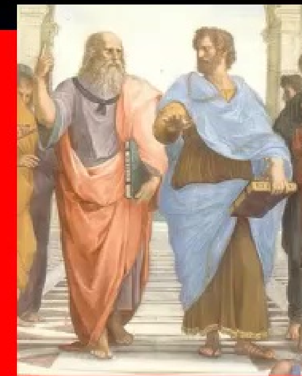
$$\mathcal{A} \propto \text{const}$$

- Implying the light ray:

$$\psi \propto \delta(T_i - X_i)$$

- This is actually the conformal constraint found in that theory.

Something resembling the "real" world therefore emerges.



- Note the Hamilton's second equation (in addition to $\dot{\alpha}_i = \{\alpha_i, H\} = 0$) is an expression of the "time formula":

$$\dot{T}_i = \{T_i, H\} = -\frac{1+3w_i}{2} N a^{-3w_i} \alpha^{\frac{3w_i-1}{2}}$$

- In fact the classical trajectory is given by: $\dot{T}_i = \dot{X}_i$
- So any peaked wave function sees its peak follow the classical trajectory.
- Obviously only coherent states have the right T function. (Ehrenfest theorem might not be enough to hide quantum fluctuations in T)

Comment on Chern-Simons time and on unimodular gravity:

- Note that we have lots of points of contact with

  L. Smolin and C. Soo, Nucl. Phys. B **449**, 289-316 (1995)

  M. Henneaux and C. Teitelboim, Physics Letters **B 222**, 195 (1989).

but with a significant difference of interpretation.

- $X_i = \Im(Y_{CS})$ is not a time variable, but a spatial variable.
- Time, instead, is the conjugate of Lambda, as in unimodular gravity, or rather, to simplify the dispersion relations, the conjugate of $\alpha = 3/\Lambda$
- The two can be confused because the peak of the wave function follows the outgoing light ray: $T_i = X_i$

Something resembling the "real" world therefore emerges.

- Note the Hamilton's second equation (in addition to $\dot{\alpha}_i = \{\alpha_i, H\} = 0$) is an expression of the "time formula":

$$\dot{T}_i = \{T_i, H\} = -\frac{1+3w_i}{2} N a^{-3w_i} \alpha^{\frac{3w_i-1}{2}}$$

- In fact the classical trajectory is given by: $\dot{T}_i = \dot{X}_i$
- So any peaked wave function sees its peak follow the classical trajectory.
- Obviously only coherent states have the right T function. (Ehrenfest theorem might not be enough to hide quantum fluctuations in T)

Roadmap of the talk (expect many detours…)

- Background 1: Unimodular gravity revisited…
- Background 2: The rehabilitation of the Chern-Simons state.
- The basic proposal illustrated in minisuperspace.
- The semiclassical states and contact with the real world.
- Alternative states: is new phenomenology around the corner?

We live in the land of plenty… of times. Is this a problem? Part I: not necessarily

- The basic implication is that at a fundamental level we have not one Schrodinger equation, but a PDE in multiple concurrent times:

$$H\left[b, a^2; \boldsymbol{\alpha} \rightarrow i\frac{l_P^2}{3V_c}\frac{\partial}{\partial \boldsymbol{T}}\right]\psi = 0$$

- True that the general solution can be very complex:

$$\psi(b) = \int d\boldsymbol{\alpha}\mathcal{A}(\boldsymbol{\alpha})\exp\left[-i\frac{3V_c}{l_P^2}\boldsymbol{\alpha}\boldsymbol{T}\right]\psi_s(b;\boldsymbol{\alpha})$$

(multi-time is all the same classically, but not quantum mechanically).

- But we also have well-behaved semi-classical multi-time states:

$$\psi(b) = \int d\alpha \mathcal{A}(\alpha) \exp\left[-i\frac{3V_c}{l_P^2}\alpha T\right]\psi_s(b;\alpha)$$

$$\mathcal{A}(\alpha) = \prod_i \sqrt{\mathbf{N}(\alpha_{0i}, l_P^2/6V_c)}$$

- Then, $\psi_s(b;\alpha)$ is a piecewise plane wave in the $X_{\alpha_i}(b)$
- Region by region one time comes to reign, leaving the others behind.
- Except that… this does not need to be the case.

- But we also have well-behaved semi-classical multi-time states:

$$\psi(b) = \int d\alpha \mathcal{A}(\alpha) \exp\left[-i\frac{3V_c}{l_P^2}\alpha T\right]\psi_s(b;\alpha) \qquad \mathcal{A}(\alpha) = \prod_i \sqrt{\mathbf{N}(\alpha_{0i}, l_P^2/6V_c)}$$

- Then, $\psi_s(b;\alpha)$ is a piecewise plane wave in the $X_{\alpha_i}(b)$

- Region by region one time comes to reign, leaving the others behind.
- Except that… this does not need to be the case.

Roadmap of the talk (expect many detours…)

- Background 1: Unimodular gravity revisited…
- Background 2: The rehabilitation of the Chern-Simons state.
- The basic proposal illustrated in minisuperspace.
- The semiclassical states and contact with the real world.
- Alternative states: is new phenomenology around the corner?

We live in the land of plenty… of times. Is this a problem? Part II: Possibly… or maybe not

- Of course there are also alternative states to these.
  - Non-factorizable states: entangled constants.
    For such states we feel a hangover of the previous phase in the new one.
  - States which Coherent state in some constants but not others.
    What if Lambda is not a coherent state (and everything else is)? Could quantum cosmology be around the corner?

Even with factorizable coherent states there might be problems:

- Even with coherent states…
  - If you solve the horizon problem you pass the same b twice (e.g. with inflation in the past). The coherent packets from different times/epochs cross at the same point in b space. Do they interfere? Is there cross talk between different times?
  - Suppose there are two dominating constants in the same region of phase space. Then, the situation depends on the dynamics (e.g. a scalar field and G: how the two momenta interact).

We live in the land of plenty… of times. Is this a problem? Part II: Possibly… or maybe not

- Of course there are also alternative states to these.
  - Non-factorizable states: entangled constants.
    For such states we feel a hangover of the previous phase in the new one.
  - States which Coherent state in some constants but not others.
    What if Lambda is not a coherent state (and everything else is)? Could quantum cosmology be around the corner?

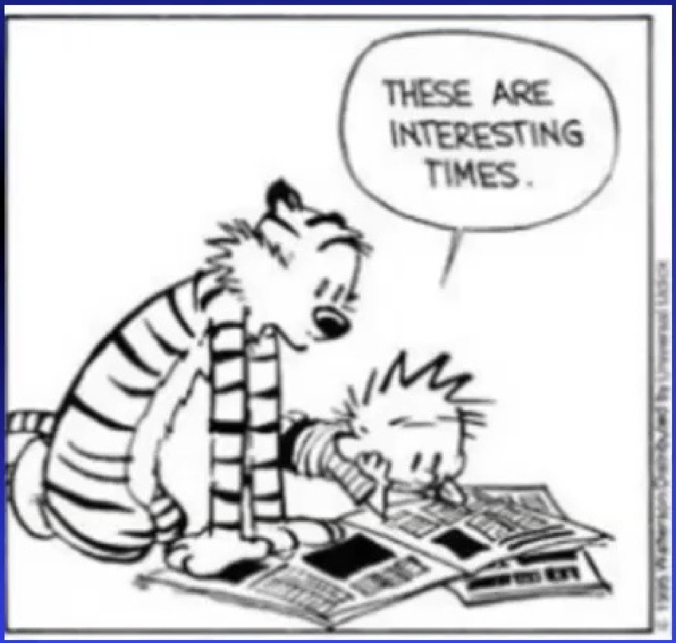
Even with factorizable coherent states there might be problems:

- Even with coherent states…
  - If you solve the horizon problem you pass the same b twice (e.g. with inflation in the past). The coherent packets from different times/epochs cross at the same point in b space. Do they interfere? Is there cross talk between different times?
  - Suppose there are two dominating constants in the same region of phase space. Then, the situation depends on the dynamics (e.g. a scalar field and G: how the two momenta interact).

- But so what? In a way the novelty of this proposal is not so much that we recover the semiclassical limit, but that we may depart from it.

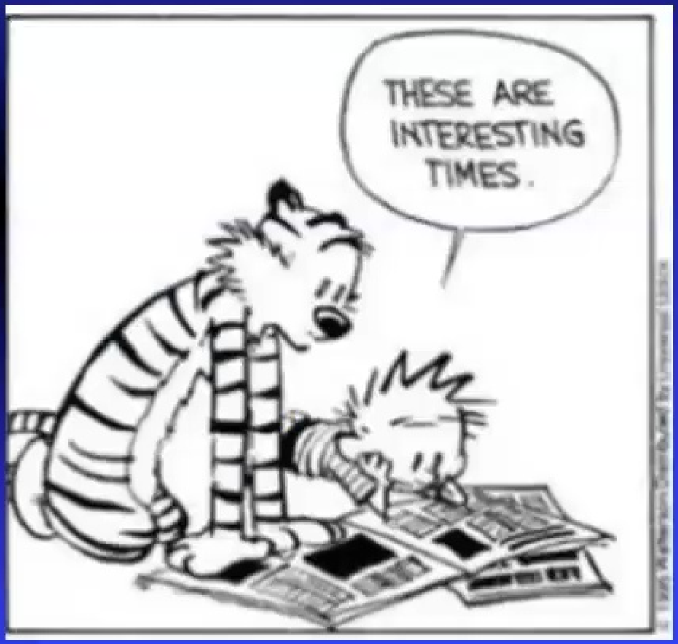
May we live in interesting times

("Better to be a dog in times of tranquility than a human in times of chaos."



May we live in interesting times

("Better to be a dog in times of tranquility than a human in times of chaos.")



The current phase of the Universe is special (w.r.t. the views in this talk) in two ways:

- The Universe is currently filled with ingredients with different equations of state but comparable densities:
  - we are in the process of handing over from one type of clock (and G or dust clock) to another (a Lambda clock).
- We moved from the $w>-1/3$ regime to $w<-1/3$.
  - We have just come out of a bounce in connection space! (Not metric space.)

THE END