Title: About Semi-Classical Quantum Gravity

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Abstract:

Some Issues in

Semiclassical LQG

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October, 2004

Work by many + collaboration with:
A. Ashtekar, B. Bolen, L. Bombelli, O. Winkler.

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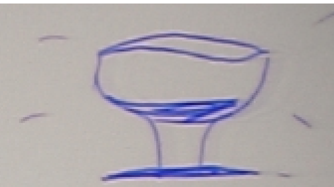
What is the Holy Grail?



Semiclassical LQG

- Solutions to constraints that for physical observables behave classical.
- Recover spacetime notion g_{ab} and with it
  - notion of time
  - causality
- Make QFT on a Quantum Geometry finite
- Give us enlingthment about
  - non-renormalizability of gravity
  - non-trivial fixed point
  - ⋮
- Your own favorite goal

The Landscape

Enough
Solutions

Kinematical
vs.
Dynamical

$g^{o}_{ab} \longrightarrow \Psi_{g^o}(A)$

$\mathcal{H}_{kin}$ vs $(Cyl)^*$

Vaccum
(+ linearizations)

The Landscape

Enough
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Kinematical
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$g^0_{ab} \longrightarrow \Psi_{g^0}(A)$

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Vacuum
(+ linearizations)

Kinematical vs. Dynamical ([illegible], Bombelli, [illegible])

Basic Question:

Can we avoid the hassle of actually solving constraints?

can we define kinematical semi-classical states that do the job?

Since we can not answer in a definite form unless we solve constraints ....

- go to models and try to build an intuition.
- Keep fingers crossed ...

(Bolen, Bombelli, &c)

Bianchi models

$$q_{ij} = e^{2\beta^0} \operatorname{diag}\left(e^{2(\beta^+ + \sqrt{3}\beta^-)},\ e^{2(\beta^+ - \sqrt{3}\beta^-)},\ e^{-4\beta^+}\right)$$

$$H(\beta_i, p_i) = \frac{1}{2}\left(-p_0^2 + p_+^2 + p_-^2\right)$$

$$|\langle \hat{O}_\alpha \rangle_\psi - O_\alpha(\bar{q}, \bar{p})| < \epsilon_\alpha \qquad (\Delta \hat{O}_\alpha)_\psi < \delta_\alpha$$

$$|\langle \hat{H} \rangle_\psi| < \epsilon \qquad (\Delta \hat{H}_I)_\psi < \delta_I$$

$\hat{P}_I$
$\hat{v}_I$

ϵ_p δ_p

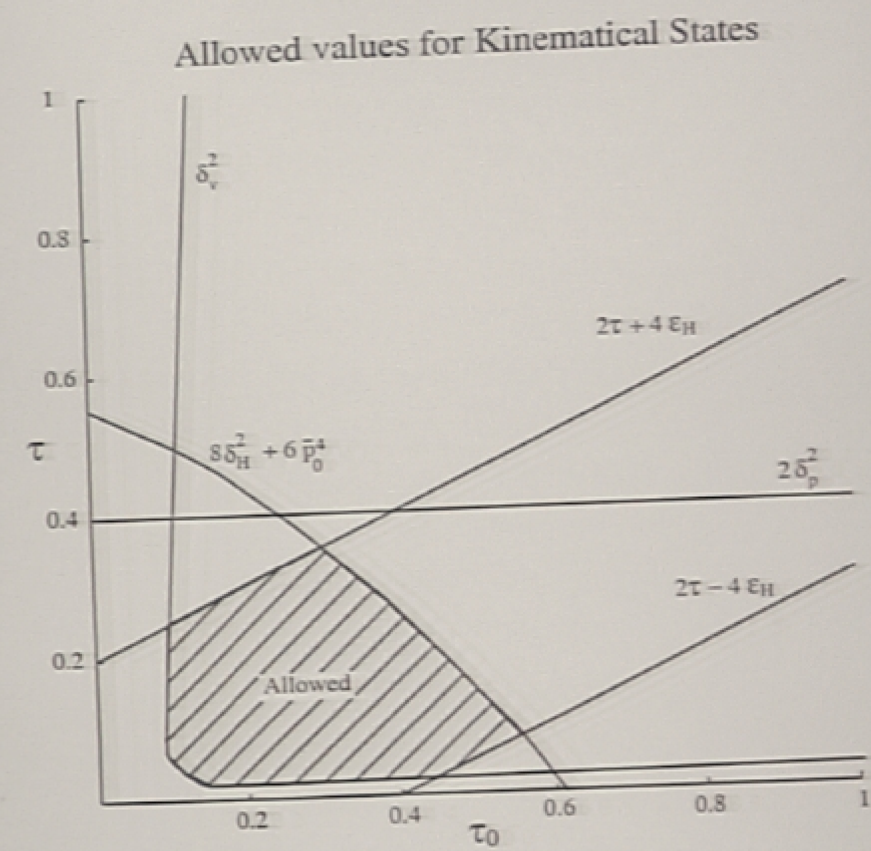
ϵ_v δ_v

Dirac observables

Kinematical $\quad \Psi_{kin} = \Pi N_i \exp\left[-\frac{(p_i - \bar{p}_i)^2}{2\sigma_i} - i(p_i - \bar{p}_i)\bar{\beta}_i\right]$

Dynamical

$$\Psi_{Dyn} = N^{-1} \int d\lambda\, e^{-i\lambda \hat{H}}\, \Psi_{kin}.$$



Allowed values for Kinematical States
1
0.8
0.6
0.4
0.2
τ
δ_v^2
$2\tau + 4\,\varepsilon_H$
$8\delta_H^2 + 6\,\bar{p}_0^4$
$2\delta_p^2$
$2\tau - 4\,\varepsilon_H$
Allowed
0.2
0.4
0.6
0.8
1
τ_0

Other models

- Linear Constraints ✓
- Quadratic Constraints

$$H_1 = p_1^2 + q_1^2 + p_2^2 + q_2^2 = cte \qquad so(3)$$

$$H_2 = p_1^2 + q_1^2 - p_2^2 + q_2^2 = cte. \qquad so(2,1)$$

Kinematical coherent states do approximate physical ones in certain regime.

- Maxwell and 2+1 Gravity

We need to explore these examples and more to gain intuition.

The Landscape

Enough Solutions

Kinematical vs. Dynamical

$g^0_{ab} \longrightarrow \Psi_{g^0}(A)$

$\mathcal{H}_{kin}$ vs $(Cyl)^*$

Vacuum (+ linearizations)

- $\mathcal{H}_{kin}$ vs. $(Cyl)^*$

what is the proper home for semiclassical states?

$\mathcal{H}_{kin}$: T.O.H.-herent states
- (A_0, P_0) phase space point
- Γ graph (+ surfaces)

$(Cyl)^*$: Fock states → Coherent states
- Heat Kernels
- Fock motivated
- ?

$(Cyl)^* \ni \Psi_a \xrightarrow{\ \Gamma\ }$ Its shadow on Γ

$\Psi_\Gamma(A) \in \mathcal{H}_{kin}$

For both, how do we choose the graph?

Use statistical geometry!

- $\mathcal{H}_{kin}$ vs. $(Cyl)^*$

what is the proper home for semiclassical states?

$\mathcal{H}_{kin}$: T.O.H.-herent states $\begin{cases} (A_0, E_0) & \text{phase space point} \\ \Gamma & \text{graph (+ surfaces)} \end{cases}$

$(Cyl)^*$: Fock states $\rightarrow$ Coherent states $\begin{cases} \text{Heat Kernels} \\ \text{Fock motivated} \\ ? \end{cases}$

$(Cyl)^* \ni \Psi_o \xrightarrow{\Gamma}$ Its shadow on Γ

$\Psi_\Gamma(A) \in \mathcal{H}_{kin}$

For both, how do we choose the graph?

Use statistical geometry!

Trad[illegible] Viewpoint

Give $g^{\circ}_{ab} \longleftrightarrow (A^{\circ}, E^{\circ})$ classical spacetime

Find a state $\Psi_g(A_a)$ that approximates g°_{ab}

How? Use observables O and impose conditions on $\langle \Delta \hat{O} \rangle_{\Psi}$

Complementary Viewpoint

Imagine that the "true" nature at Planck scale is discrete. No space-time notion. Assume that a quantum state Ψ_Γ describes this geometry at Γ graph/complex.

How do we recover a space-time notion at large scales?

How do we estimate uncertainties in reconstruction?

Use statistical geometry ideas! (Bombelli)

Traditional Viewpoint

Give $g^{\circ}_{ab} \longleftrightarrow (A^{\circ}, E^{\circ})$ classical spacetime

Find a state $\Psi_g(A_a)$ that approximates g°_{ab}

How? Use observables $\mathcal{O}$ and impose conditions on $\langle \mathcal{O} \rangle_{\Psi}$

Complementary Viewpoint

Imagine that the "true" nature at Planck scale is discrete. No space-time notion. Assume that a quantum state Ψ_Γ describes this geometry at Γ graph/complex.

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The Vacuum

A lot of work has been devoted to the issue of finding the right vacuum state.

- **Fock motivated vaccum.**
  - take U(1) and translate the ordinary vacuum state $|0\rangle$ to the polymer description. It does not fit in $\mathcal{H}_K$ (Cyl*).
  - Use Heat-Kernel techniques (generalized by Thiemann) and build it
  - Hope that it also works in gravity
  - what "Laplacian" should we use?

- **Other techniques in $\mathcal{H}_K$** (Conrady)

- **De-Sitter and the Kodama State**

  The Kodama state "solves" the constraints for a cosmological constant Λ.

  It approximates de-Sitter space.

Outlook

- what are semi-classical states?
- How much can we say without dynamics?
- How do we in practice find them and compute?
- How far are we from true phenomenology?
- Who is going to come with the bright idea we need?

⋮

Thanks!