Abstract: There is a huge body of work in Loop Quantum Cosmology comprising of several thousand journal articles. I will provide an overview of conclusions, focusing on the difficult conceptual and mathematical issues that accompany the notion of a bounce and opening the way for phenomenological implications that will be discussed by Ivan Agullo.
Bounce in LQC & its implications
Bounce in LQC & Its Implications

Novel Physics: Quantum Riemannian Geometry
Bounce in LQC & Its Implications

Novel Physics: Quantum Riemannian Geometry, sharp results on upper bounds of observables.

WDW Theory $\Psi(a,\phi)$, WDW Eqn.: Quantum Hamiltonian Constraint: $\hat{C}^{\Psi} = 0$
192. **New Physics**: Quantum Riemannian Geometry, sharp results on upper bounds of observables.

WDW Theory \( \Psi(a, \phi) \), WDW eq. Quantum Hamiltonian Constraint: \( \hat{C} \Psi = 0 \).
Novo Physics: Quantum Riemannian Geometry; sharp results on upper bounds of observables.

WDW Theory $\psi(a, \phi)$, WDW $\psi^+$. Quantum Hamiltonian Constraint $\hat{C}_H \psi = 0$

Hilbert space $H_{\text{phys}}$ on $SO(3)$

$\psi(a, \phi) \in H_{\text{phys}}$ s.t. $\hat{C}_H$ is S-A-on it. $\psi_{\text{phys}} = \int d\lambda \, \tilde{\psi}_{\hat{C}_H} \psi_{\text{kin}}$
Nove Physics: Quantum Riemannian Geometry; sharp results on upper bounds of observables.

Wigner W(\alpha, \phi), WDW eq.: Quantum Hamiltonian Constraint \( \hat{C}_H \psi = 0 \)

Hilbert space of phys. \( \mathcal{H}_{\text{phys}} \)

\( \psi(\alpha, \phi) \in \mathcal{H}_{\text{phys}} \) s.t. \( \hat{C}_H \) is SA-on it.

\[ \psi_{\text{phys}} = \int dx \, e^{i\frac{\lambda}{\delta(C)} \hat{C}_H} \psi_{\text{kin}} \]
Novo Physics: Quantum Riemannian Geometry; sharp results on upper bounds of observables.

WDW Theory $\psi(r, \phi)$; WDW Eqn.: Quantum Hamiltonian Constraint: $T_{H}\psi = 0$

Hilbert space $H_{\text{phys}}$: solutions:

$\psi(r, \phi) \in H_{\text{phys}}$ s.t. $T_{H}$ is self-adjoint; $\psi_{\text{phys}} = \int d\lambda \frac{e^{i\lambda x}}{\delta(C)} \psi_{\text{kin}}$

$\psi(\lambda) = e^{i\lambda x}$ compact; $C = \frac{1}{2} = 0$. 

Pirsa: 17060095
New Physics: Quantum Riemannian Geometry; sharp results on upper bounds of observables.

WDW Theory $\psi(a,\phi)$, WDW equation: Quantum Hamiltonian Constraint $\hat{C}_H \psi = 0$.

Hilbert space $H_{\text{phys}}$ on $\mathcal{S}$.

$\psi(a,\phi) \in H_{\text{phys}}$ subject to $\hat{C}_H$ is $\mathcal{SA}$-on $\mathcal{H}$.

$\psi_{\text{phys}} = \int dx \psi(a,\phi) e^{i \chi} \exp \left( \frac{i}{\hbar} \delta C \right)\psi_{\text{kin}}$.
For physical observables:

WDW theory $\Psi(a, b)$, WDW $\Psi$: quantum Hamiltonian constraint $\hat{C}_H \Psi = 0$

Hilbert space $\mathcal{H}_{\text{phys}}$ on $\mathbb{C}$:

$\langle a | b \rangle = \delta_{ab}$

$\hat{\Psi} = \text{SA on } \mathbb{H}$

$\hat{\Psi} = \int \mathcal{D}E \mathcal{D} \Omega \exp \left( i \int \hat{E}_i \hat{C}_i \right) \langle \hat{\Psi} \rangle_{\hat{H}_\text{kin}}$

Not not normalizable in $\mathbb{H}_{\text{kin}}$
WDW Theory \( \psi(a, \phi) \), WDW eqns:

Hilbert space \( \mathcal{H}_{\text{phys}} \) on \( \cos \) is SA on it:

\[
\phi(a, \phi) \equiv \text{finite state } \Rightarrow \mathcal{H} \text{ is } \text{SA on it}:
\]

\[
\psi_{\text{phys}} = \int \psi_{\text{kin}} e^{i/a} \, \delta(\phi)
\]

Not not normalizable in \( \mathcal{H}_{\text{kin}} \)

\( \text{Group averaging} \)
WDW Theory $\Psi(a, \phi)$, WDW $\psi_{\text{phys}}$. Quantum Hamiltonian Constraint: $\hat{C}_{\text{phys}} = 0$.

Hilbert Space $\mathcal{H}_{\text{phys}}$ is compact.

$\psi_{\text{phys}} = \int dx e^{i(x\hat{C}_{\text{phys}})} \psi_{\text{kin}}$

Not not normalizable in $\mathcal{H}_{\text{kin}}$.

$\mathcal{H} \subset \mathcal{H}_{\text{kin}} \subset \mathcal{D}^\infty$

$\langle \psi_{\text{phys}} | \psi_{\text{phys}} \rangle = \langle \psi_{\text{kin}} \|^2 \rangle$

Group averaging.
WDW Theory $\psi(a, \phi)$, WDW Eq.: Quantum Hamiltonian Constraint: $\dot{\psi} + \frac{i}{\hbar} \psi = 0$

Hilbert space $\mathcal{H}_{\text{phys}}$ on $\mathcal{S}$:

$\psi(a, \phi) \in \mathcal{H}_{\text{kin}}$ + $\mathcal{S}$ is SA on $\mathcal{S}$.

$U(a) = e^{ia^2}$ is compact, $\mathcal{S} = \{ a | a^2 = 0 \}$

"Group averaging":

$\langle \psi_1 \mid \psi_2 \rangle = \langle \psi_{\text{phys}} \mid \psi_{\text{phys}} \rangle$

$\mathcal{S} \subset \mathcal{H}_{\text{kin}} \subset \mathcal{H}$

Not not normalizable in $\mathcal{H}_{\text{kin}}$. 

Gelfand-Riesz H.S.
Novo Physics: Quantum Riemannian Geometry; sharp results on upper bounds of observables.

WDW Theory $\Psi(x, \phi)$; WDW Eqn.: Quantum Hamiltonian Constraint

Hilbert space $\mathcal{H}_{\text{phys}}$ on $SO(3)$:

$\Psi(x, \phi) \in \mathcal{H}_{\text{phys}}$, $\mathcal{H}_{\text{phys}}$ is $SA$-on $\mathcal{C}$

$\mathcal{C} = e^{iX^a \xi_a}$ compact, $\mathcal{C}^{-1} = i \mathcal{C} = 0$

"Group averaging" 

$\langle \Psi_{\text{phy}} \mid \Psi_{\text{phy}} \rangle = \langle \Psi_{\text{phys}} \mid \Psi_{\text{phys}} \rangle$

$\Phi \subset \mathcal{H}_{\text{kin}} \subset \overline{\Phi}$

Not normalizable in $\mathcal{H}_{\text{kin}}$
WDW Theory $\psi(a, \phi)$, WDW-Ehrl: Quantum Hamiltonian Constraint: $\hat{C}_H \psi = 0$

Hilbert space $\mathcal{H}_{\text{phys}}$ on solvts

$\psi(a, \phi) \in \mathcal{H}_{\text{kin}} \text{ st } \hat{C}_H \text{ is SA on it}$

$0 \psi = e^{-i\frac{\hat{H}}{\hbar}} \text{ compact; } \hat{C}_H = \frac{i}{\hbar} \nabla = 0$

Not not normalizable in $\mathcal{H}_{\text{kin}}$

Group averaging:

$\langle \psi_1 \mid \psi_2 \rangle = \langle \psi_{\text{phys}} \mid \psi_{\text{kin}} \rangle$

Self and Riesz HS.

$\Phi \subset \mathcal{H}_{\text{kin}} \subset \Phi$

NDE: Scalar field $\phi (m=0)$.
WDW Theory $\psi(a, \phi)$, WDW $\psi$:

Hilbert space $\mathcal{H}_{\text{phys}}$ on solutions:

$\psi(a, \phi) \in \mathcal{H}_{\text{kin}}$,

$\mathcal{H}_{\text{H}}$ is $SA$-on it:

$\psi_{\text{phys}} = \int dx_1 e^{i C_{\chi} \phi / \hbar} \psi_{\text{kin}}$

Not not normalize in $\mathcal{H}_{\text{kin}}$

$\Phi < \mathcal{H}_{\text{kin}} < \Phi$

"Group averaging""$

\langle \psi_{\text{kin}} | \psi_{\text{kin}} \rangle = \langle \psi_{\text{phys}} | \psi_{\text{phys}} \rangle$

Self-adjoint Riesz HS.

NDE: Scalar field $\phi (m=0)$.

$\psi_{\text{phys}}(a, \phi)$
WDW Theory $\psi(a,\phi)$, WDW eqn. Quantum Hamiltonian Constraint: $\hat{C}_H \psi = 0$

Hilbert Space $H_{\text{phys}}$ on states:

$\psi(a,\phi) \in H_{\text{kin}}$

$\text{tr} C$ is self-adjoint:

$\psi_{\text{phys}} = \int dx \, e^{i \hat{E}_H} \psi_{\text{kin}}$

Not normalizable in $H_{\text{kin}}$

Group averaging:

$\langle \psi_{\text{kin}} | \psi_{\text{kin}} \rangle = \langle \psi_{\text{phys}} | \psi_{\text{phys}} \rangle$

Self and Rissed HS:

NDE: Scalar field $\phi$ ($m=0$).

$\psi_{\text{phys}}(a,\phi)$.
WDW Theory $\Psi(a, \phi)$, WDW R\textsuperscript{H} Hilbert Space $H_{\text{phys}}$ on $SO(3)$:

$\Psi(a, \phi) \in H_{\text{kin}} \quad \text{such that} \quad \Phi^2 = \mathbb{I}$

$\psi(x) = e^{-i \phi \chi}$ compact, $\chi = \frac{1}{2} \Phi = 0$

Group averaging $\langle \psi(x) \mid \psi(x') \rangle = \langle \Psi_{\text{phys}} \mid \Psi_{\text{phys}} \rangle$

NDL: Scalar field $\phi$ (mass $\equiv 0$)

$\Phi_{\text{phys}}(a, \phi)$, $\Phi_{\text{kin}} \in \Phi$, Unbound
LGC:

1. New Kinematic Setup
2. New Dynamics
LQC:

1. New Kinematic Setup
2. New Dynamics

LQG:

(\text{Some} \ \text{math})

Spin connection
1. **New Kinematic Setup**
   
   $L_C := \left( \mathcal{O}_1, \mathcal{O}_2, \mathcal{O}_3 \right)$

   Spin connection $\mathcal{A}_a$

2. **New Dynamics**

   $E^a \sim \text{orthonormal track}$

   $a$
LQC:
1. New kinematic setup
   \( \mathcal{L}_0 \) - \( \mathcal{L}_1 \)

2. New Dynamics
   \( E^a \sim \text{on the normal track} \)
   \( \tilde{A}_a \text{ spin connection} \)
LGC:

1. New Kinematic Setup
2. 

LSEC: \[ ... \]

(E_i \sim \text{orthonormal Tad}(\cdot))

Backround 2nd Algebta: \( h_y, \frac{F}{S} \) fluxes

\[ \gamma \rightarrow \gamma = P \exp \gamma \delta \eta \]
LGC: New Kinematic Setup

Log: \( \phi_2, \phi_3, \phi_4 \)

\( (A_a)^{\text{Spin Connection}} \)

Background Ind Alsobo: \( \gamma, F \) Fluxes

Reps of this LAF, LOST Theorem, unique if you ask different
LQC:
LQG: \((3, \text{ spin connection})\)

\([A_a, \text{ spin connection}] \sim \mathbf{E}_l\) through transformation

Background ind. Algeb.: \(h \gamma, \mathbf{F}_S\) fluxes

Reps of this AHF, LOST theorem: unique rep if you ask diff. inv. elementary excitations

\(\rightarrow\) Riem Geo observables: discrete eigenvalues
LQC: 1. New Kinematic setup

LQG: \((\mathcal{S}_{\hat{a}}, \mathcal{S}_{\hat{b}}, \mathcal{L}_{\hat{a}, \hat{b}})\),

\[A_{\hat{a}}\] spinconnection

Background 2nd Algebta: \(h_{\gamma} \rightarrow F_{\gamma}\) fluxes

Reps of this LHF, LOST theorem, unique rep if you ask different elementary excitations.

\[\sum_{\mu_{\nu}, \nu_{\mu}} E_{\mu_{\nu}} \sim \text{orthogonal trans.} \]

\(E_{\mu_{\nu}} \sim \text{orthogonal trans.}\)

LQC: \(A_{\hat{a}} \sim C_{\hat{a}}\)

with an eye to the full theory.
LQC:
1. New Kinematic Setup
2. New Dynamics

\( \mathcal{A}_a \) spin connection

\( E^a_i \sim \text{orthonormal frames} \)

\( \phi \) fluxes

\( \psi \) states

Rep of this \( \mathcal{A}^+ \mathcal{A} \)

LOST Theorem: unique rep if you ask different elementary excitations

\( \text{Riem Geo observables: discrete eigenvalues} \)

LQC:
\( \mathcal{A}_a \sim \mathcal{E}_a \)

with an eye to the full theory, observables: \( \phi_i, \psi_i \)

Fluxes \( \sim p \)
\[ \text{LG:} \quad (\phi \text{, } \rho) \text{,} \quad (A, \text{spin connection}) \]

Background 2nd Albert: \( h_x, F \) fluxes.

Rupps of this AHP, LOST theorem, unique \( \text{rep} \) if you ask different elements.

Riem Geo observables: discrete eigenvalues.

\[ \text{LG&G:} \quad A \sim C \text{,} \quad E \sim P \text{,} \quad \psi(x) \sim L^2(C^0) \]

Unique \( \text{rep} \): \( \psi(x) \) not \( L^2(C^0) \).
LQC:

\( A_\alpha \sim C \mathbb{E}_\alpha \), \( E^a_i \sim P^{o_0} \)

with an eye to the full theory, observables: \( h_\gamma \sim e^{i\mathcal{E}} \)

unique rep: \( \psi(C) \) not \( L^2(C^\mathbb{R}) \)

Inequivalent to stel Schrodinger rep.

\( E^a_i \sim \text{orthogonal trans.} \)

Background 2nd Algeb.: \( h_\gamma \), \( f_\delta \) fluxes.

Reps of this AHP: LOST Theorem, unique rep if you ask different elementary excitations.

\( LQC: \) spin connection.
Bounce in LGC & Its implications

192. New physics: Quantum Riemannian Geometry; sharp results on upper bounds of observables.

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Hilbert space $\mathcal{H}_{\text{phys}}$ on states:

$\Psi(\alpha, \phi) \in \mathcal{H}_{\text{phys}}$ if $\hat{C}_H$ is SA on it.

$\Psi_{\text{phys}} = \int dx_1 e^{i \phi x_1} \psi_{\text{kin}}$

Not not normalizable in $\mathcal{H}_{\text{kin}}$

$\Phi \in \mathcal{H}_{\text{kin}} \subset \Phi$

$\phi$

$\Psi_{\text{kin}}(\alpha, \phi)$, $\hat{P}$: Unbounded.

Gelfand, Riesz H.S.

NDE: Scalar field $\phi$ ($m=0$).
Dynamics: 

\[ \dot{C}_H \text{ on skin (or almost periodic \( f \))} \]

Need new tools: 

\[ F_{ab} \stackrel{!}{=} \lim_{A \to 0} \frac{\text{hP}}{\text{area}} \]
Dynamics: Ĉ on /kin (of almost periodic fn)

Need new tools: \[ F_{ab} = \lim_{A \to \Delta} \frac{h_{AB}}{\text{area}} \]

\[ \Delta \] min non zero area envalo
Dynamics: \( \hat{C}_\text{H} \) on \( \mathbb{R}^\infty \) (of almost periodic \( f_a \))

Need new tools: \( \hat{F}_{ab} = \lim_{\Delta \to 0} \frac{h^2}{\text{area}} \)

\( \hat{p} \): eigenvalues: Have an upper bound on \( \hat{\mathcal{H}}_\text{phys} \)

\( \Delta p_{\text{max}} = \frac{18\pi}{\Delta k} \)
Dynamics: C^4 or Klein (of almost periodic f) 

Need new tools: \[ F_{ab} = \lim_{\Delta \to 0} \frac{\Delta_{\text{area}}}{\Delta} \]

\( \hat{P} \): eigenvalues: have an upper bound on \( H_{\text{phys}} \)

\( \Delta^2_{\text{min}} \): \( \text{non-zero} \) \( \text{area eigenvalue} \)

3. Quantum physics essential. BUT for states that are sharply peaked @ late times.
Dynamics: $E_1$ on $H_{kin}$ (of almost periodic $\psi$) 

Need new tools: $F_{ab} = \lim_{A \to A^+}$ 

$\hat{P}$: eigenvalues. Have an upper bound on $H_{phys}$ 

$P_{eff} = \frac{18 \pi}{\Delta^2} P_0$ 

Quantum Physics essential. BUT for states that are slowly peaked @ late times. Effective eqs: 

$\left( \frac{\Delta}{\alpha} \right)^2 = \frac{h^2}{\frac{81 \pi}{3}} \left( 1 - \frac{r}{r_{surf}} \right)$. Reichardt also modifies.
Need new tools: \[ F_{ab} = \lim_{A \to \Delta} \text{Area} \]

Eigenvalues: have an upper bound on \( \mathcal{H} \) for states that are sharply peaked at late times.

Quantum physics essential: BUT, effective eqns.

\[
\left( \frac{\alpha}{a} \right)^2 H^2 = \frac{819}{3} \left( 1 - \frac{\rho}{\rho_{\text{crit}}} \right),
\]

Paichadhu also modified same continuity Eqb.
4. Examples:
Potential Tension bet. UV & IR & Extrem Care
Examples:
- Potential Term
- Entropy bounds
- UV/IR
- Bousso part

Extreme Case
4. Examples

- Potential Tension bet
- Entropy bounds

\[ \text{UV a IR} \quad \& \quad \text{Extreme Case} \]

\[ \text{Bosso Paradigm} \quad S_B = S_{dA} \cdot S^a \]

\[ S_B \leq \frac{A_B}{4 \ell^2} \]

\[ L_B \]
4. Examples:
- Potential Tension bet
- Entropy bounds
  1) Entropy current
  2) QG
  3) sharp geometry

\[ S_B = S_{\text{Bousso polymorphism}} = S_{\text{th}} S^2 \]

\[ S_B \leq \frac{A_B}{4 l_p^2} \]

\[ \text{Extremal case} \]
Quantum Physics essential. BUT: for states that are sharply peaked @ late times, effective eqns:

\[ \left( \frac{a_i}{a} \right)^2 = H^2 - \frac{g}{8} \left( \rho - \rho_{\text{crit}} \right) \]

Raichadhuri also modified, same continuity Eq.
Potential Tension bet. UV a IR. & Extrem. Gen

Entropy bounds. Boussos paradigm. \( S_B = S_B \cdot S^a \)

1) Entropy current
2) QG
3) Sharp Geometries
Potential Tension bet. UV & IR

- Entropy bounds
  1) Entropy current
  2) Q.G.
  3) Sharp Geometry

\[ \text{Boussos paradox}\, \quad S_B = S_{\text{da}} \cdot S^a \]

Same continuity, Eq. \( y \)

\[ S_B \leq \frac{A_B}{4 \, L^2} \]
Potential Tension bet. UV a IR

Entropy bounds

1) Entropy current
2) Q G
3) sharp Geometry

Same continuity Eq.

Boussos paradigm \( S_B = S_{\text{dA}} \cdot S^a \)

\[ S_B \leq \frac{A_B}{4 \ell_p^2} \]

\[ S_{\text{LC}} \leq 0.97 \frac{A_B}{\ell_p^2} \]

\[ S_{GR} \]

Bound violated completely in the Planck regime.
Potential Tension bet. UV a IR
Entropy bounds
Entropy current
SG
(a) Sharp geometry
Result emerges just in the effective description automatically

Same continuity Eqn.

\[ S_B = Sda \cdot S^a \]
\[ S_B \leq \frac{A_B}{4 \pi^2} \]
\[ S_{LB} \leq 0.97 \frac{A_B}{4 \pi^2} \]

Bound violated completely in the Planck regime
- Potential Tension bet. UV and IR and Extremal Case
- Entropy bounds
  1) Entropy current
  2) QG
  3) Sharp Geometry

Bousso Paradigm: \( S_B = S_{DA} \cdot S_a \)

\[ S_B \leq \frac{A_B}{4 \ell^2} \]

\[ S_{GC} \leq \frac{A_B}{4 \ell^2} \]

\[ S_{GR} \leq \frac{A_B}{4 \ell^2} \]

\[ S_{SB} \leq \frac{A_B}{4 \ell^2} \]

Result emerges just in the effective description as the Planck rescaling is completed completely in the Planck regime.
Observation:
1. QFT on FLPN → QFT on FLRW geometries.

1. What is the new physics responsible for the bounce?
2. Might this new physics resolve the singularity for the perturbations as well as the background?
3. Does this new physics have any observational signature?
4. What general principles underlie the theory beyond wanting to resolve the singularity?
5. Does a consistent picture for cosmology require that both the background and the perturbations are quantized?
6. Does the bounce or pre-bounce phase help in setting initial conditions?
Observations:

1. QFT on FLRW -> QFT on G_FLRW geometries
2. Key factor: $\Lambda$ physics compared to curvature

1. What is the new physics responsible for the bounce?
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Observations:

1. QFT on FLPN $\rightarrow$ QFT on G FLPW geometries.

2. Key factor: $\chi_{\text{phys}}$ compared to curvature $\chi_{\text{phys}}$.

If $\chi_{\text{phys}} < R_{\text{crit}}$.

1. What is the new physics responsible for the bounce?

2. Might this new physics resolve the singularity for the particles as well as the background?

3. Does this new physics have any observational signature?

4. What general principles underlie the theory beyond wanting to resolve the singularity?

5. Does a consistent picture for cosmology require that both the background and the perturbations are required?

6. Does the bounce or pre-bounce phase help in setting initial conditions?
Observations:

1. QFT on FLPN → QFT on G FLPN geometries.
2. Key factor: $\Phi_{\text{phys}}$ compared to curvature $\kappa_{\text{phys}}$.

If $\Phi_{\text{phys}} < \Phi_{\text{universe}} = \Phi_{\text{init}}$ in $\mathbb{E}$.

1. What is the new physics responsible for the bounce?
2. Might this new physics resolve the singularity for the perturbations as well as the background?
3. Does this new physics have any observational signatures?
4. What general principles underlie the theory beyond wanting to resolve the singularity?
5. Does a consistent picture for cosmology require that both the background and the perturbations are quantized?
6. Does the bounce or pre-bounce phase help in setting initial conditions?
Observation:

1. QFT on FLPN $\rightarrow$ QFT on G FLPN geometries.

2. Key factor $\lambda_{\text{phys}}$ compared to curve radius $\kappa_{\text{phys}}$.

If $\lambda_{\text{phys}} < \text{Radius} = \text{Radius in FLPN}$

$$\sum_{y} x_{y} + \alpha^{2}(n) \left( \frac{\kappa_{\text{phys}}^{2}}{\kappa_{\text{phys}}} \right) x_{k} = 0$$

1. What is the new physics responsible for the bounce?

2. Might this new physics resolve the singularity for the perturb as well as the background?

3. Does this new physics have any observational signature?

4. What general principles underlie the theory, beyond wanting to resolve the singularity?

5. Does a consistent picture for cosmology require that both the background and the perturbations are equal?

6. Does the bounce or pre-bounce phase help in setting initial conditions?
1. QFT on FLRW $\rightarrow$ QFT on $Q\text{-FLRW}$ geometries.

2. Key factor: $\Lambda_{\text{phys}}$ compared to $\Lambda_{\text{phys}}$ curvature.

If $\Lambda_{\text{phys}} \ll \Lambda_{\text{curvature}}$, then $\Lambda_{\text{phys}} \approx 0$.

$\frac{\partial^2 \rho}{\partial \ln a^2} + \frac{\Lambda_{\text{phys}}}{\kappa_{\text{phys}}} \rho = 0$.

3. Might this new physics resolve the singularity for the perturbations as well as the background?

4. Does this new physics have any observational signature?

5. What general principles underlie the theory beyond wanting to resolve the singularity?

6. Does a consistent picture for cosmology require that both the background and the perturbations are required?

7. Does the bounce or pre-bounce phase help in setting initial conditions?
1. QFT on FLRW → QFT on Q-FLRW geometries.
2. Key factor: $\Lambda_{\text{phys}}$ compared to curvatures.

If $\Lambda_{\text{phys}} < \Lambda_{\text{plan}t}$ in $\mathbb{R}^n$,

$$\frac{2}{3} x_t + a^2(n) \left( \frac{t^2}{a_{\text{phys}}^2} \right) \frac{\dot{a}(n)}{a(n)} = 0$$

3. Might this new physics resolve the singularity for the perturbations as well as the background?
4. Does this new physics have any observational signature?

5. What general principles underlie the theory, beyond wanting to resolve the singularity?
6. Does a consistent picture for cosmology require that both the background and the perturbations are correct?
7. Does the bounce or pre-bounce phase help in setting initial conditions?
1. QFT on FR BN $\rightarrow$ QFT on QFT on FL BN geometry.

2. Key factor: Physics compared to curvature.
   \[ k_{\text{phys}} \] compared to \( k_{\text{phys}} \) curvature.

If \( k_{\text{phys}} \ll R_{\text{curv}} \), then \( R_{\text{curv}} \) large.

3. Might this new physics play a role in resolving the singularity for the perturbations as well as the background?

4. Does this new physics have any observational signature?

5. What are the general principles underlying the theory, beyond wanting to resolve the singularity?

6. Does a consistent picture for cosmology require that both the background and the perturbations are consistent?

7. Does the bounce or pre-bounce phase help in setting initial conditions?
If $\lambda_{\text{phys}} << R_{\text{grav}} = \text{finite in } L^2$,

$$\sum_{k} x_k + z^2 \sum_{i} \left( \frac{k^2}{a^2} - \frac{\overline{z}^2}{\lambda_{\text{phys}}} \right) x_k = 0$$

Time $T$

Bounce Value

Lengths
Dynamics: Einstein on Klein (of almost periodic) \[ \frac{\hbar}{\text{area}} \]

Need new tools: \[ F_{ab}^i = \lim_{A \to \Delta} \]

\( \hat{p} \): eigenvalues; have an upper bound on \( H \) physics

P: matrix of eigenvalues of Hamiltonian, \( P_{ab} = \frac{18\pi}{\Delta^2} p_b \), \( \Delta \approx 1 \)

Quantum Physics essential, BUT for states that are sharply peaked @ late times, effective eqns:

\[ \left( \frac{a}{\Delta} \right)^2 H = \frac{8\pi G}{3} \left( \frac{\sigma_{\text{cut}}}{\Delta} \right) \]

Raichaduni also modifies, same continuity Eq.

[Note: The text on the blackboard is partially obscured or unclear in some parts.]
4. Examples:

- Potential Tension bet
- Entropy bounds

1) Entropy current
2) G.G.
3) Sharp geometry

Result emerges just in the effective description automatically.

\[ S_B \leq \frac{A R}{\alpha_p^2} \]

Bousso parandism \( S_B = S_{DA} S^2 \)

\[ S_{BC} \leq 0.97 \frac{A R}{\alpha_p^2} \]

\[ S_{CR} S_B \]

\[ \Delta \text{ fixed by BH entropy formula} \]