Title: Structure formation beyond the standard paradigm

Date: Oct 27, 2004 12:55 PM

URL: http://pirsa.org/04100016

Abstract:

Remaining colloquia this term:

Nov

3 James Robert Brown "Thought Experiments"

10 Chatan Nayak "Topological Phases of correlated electrons (with a nod to quantum computing)"

Rachel Bean postponed

17 Robert Dijkgraaf (stringy)

24

Dec

1 Curt Callen (biology)

8 Mark Trodden (cosmology)

15

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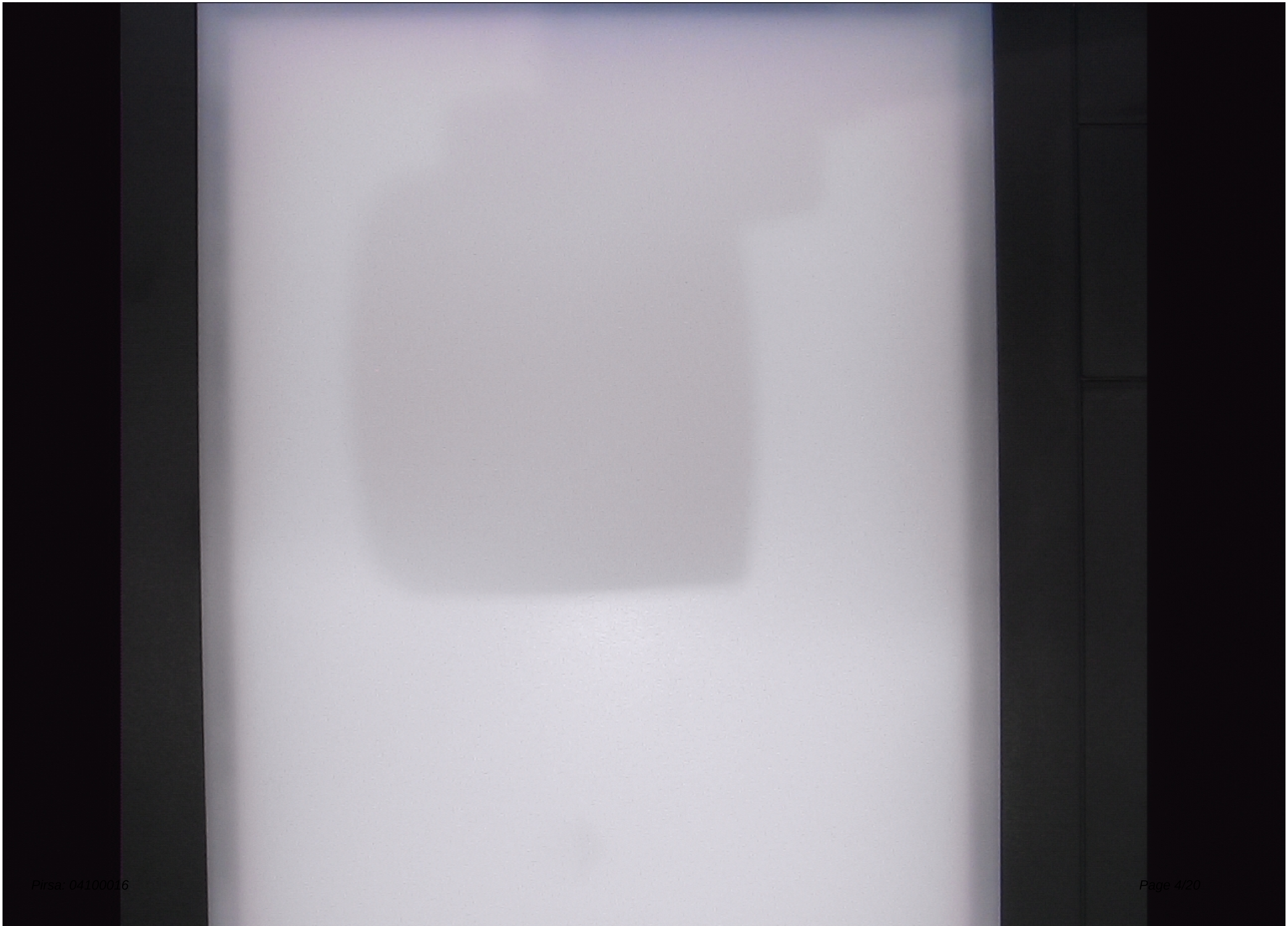
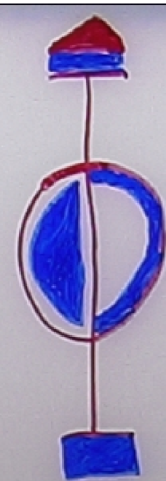
Speaker	Title	Date/Tin
Corinne Magnogue, Oregon State	tba	2004-12 11:00 AI
Liam McAllister	tba	2004-12 2:00 PM
Oleg Lunin, IAS	BPS Deformations of AdSp x Sq	2004-11 11:00 AI
Arthur Lue, University of Texas, San Antonio	Leakage into extra dimensions and cosmic acceleration	2004-11 2:00 PM
Frederik Denef, Rutgers	tba	2004-11 2:00 PM
Leonid Chekhov, Steklov Institute, Moscow	Quantum Teichmuller and Thurston theories	2004-11 2:00 PM
Nick Halmagyi, USC	tba	2004-11 11:00 AI
Larissa Lorenz, UW	Inflation with a UV cutoff	2004-11 12:30 PI
Anastasia Volovich, UCSB	Yang-Mills amplitudes from twistor string theory	2004-1C 11:00 AI
Gautam Mandal, Tata Institute, Mumbai	tba	2004-1C 2:00 PM
James Gray, Durham	tba	2004-1C 11:00 AI
Robert Spekkens, PI	Contextuality for preparations, transformations, and unsharp measurements	2004-1C 4:00 PM
Stefan Hofmann, Stockholm University	Structure formation beyond the standard paradigm	2004-1C 2:00 PM
Vladimir Miransky, UWO	Relativistic field theories in a magnetic background as noncommutative field theories	2004-1C 11:00 AI
Ivette Fuentes-Schuller, PI	Holonomic quantum computation in the presence of decoherence	2004-1C 4:00 PM





IN THE SKY

S.H., Stockholm University

Oliver Winkler, & University of New Brunswick

PLAN

- Orthodox introduction of P_{Φ}
  the superstar in cosmology
- Planckian imprints in P_{Φ} so far
- A Quantum Cosmology set-up
- The Husain-Winkler model
- P_{Φ} in $\langle HW \rangle$
- Outlook

PLAN

- Orthodox introduction of $\mathcal{P}_{\Phi}$

  the superstar in cosmology

- Planckian imprints in $\mathcal{P}_{\Phi}$ so far

- A Quantum Cosmology set-up

- The Husain-Winkler model

- $\mathcal{P}_{\Phi}$ in $\langle HW \rangle$

- Outlook

$\mathcal{P}_\Phi$ OWER SPECTRUM

$\mathcal{C}$ FRW background:

$$ds^2 = dt^2 - a_{ce}^2(t)\, dx^2$$

cosmic time — classical scale-factor — comoving coordinates

Φ on $\mathcal{C}$ FRW background:

$$H_s[\Phi, \pi, a_{ce}] = \int vol\, \rho_s(\Phi, \pi, a_{ce})$$

energy density

Define vacuum at "initial time":

$$A(\Phi, \pi; k, t_i)\, |0, t_i\rangle = 0 \quad \forall k$$

Solution (Schrödinger picture in Φ-representation):

$$|\Psi[\Phi(k,t_i), t]|^2 \sim \exp\left[-\frac{(Lk)^3}{2\pi^2} \frac{|\Phi(k,t_i)|^2}{\mathcal{P}_\Phi(k,t)}\right]$$

minimal uncertainty wavefunction

CONNECTION TO QFT

Orthodox calculation of $\mathcal{P}_\phi$ from the model of inflation:

$$\Phi(k,t) = W(k,t)\,A(k,t_i) + W^*(k,t)\,A^\dagger(k,t_i)$$

annihilates vacuum state

But,

$$\Phi(k,t)\,|\Omega\rangle$$

which quantum state ?

Assume $|\Omega\rangle = |0\rangle$. Then,

$$\mathcal{P}_\Phi(k,t) = \frac{(Lk)^3}{2\pi^2}\langle 0|(\Phi^*\Phi)(k,t)|0\rangle$$

Orthodox result at horizon exit:

$$\mathcal{P}_\Phi(k,t_*) = \left(\frac{H}{2\pi}\right)^2\Big|_{k=aH}$$

RELEVANCE OF $\mathcal{P}_\Phi$

For a generic fluctuation $F(k,t)$ in the linea regime:

$$\mathcal{P}_F(k,t) = \mathcal{P}_\Phi(k,t_*)\, T_F(k,t)\, D_F^2(k)$$

$\mathcal{P}_\Phi(k,t_*)$	$T_F(k,t)$	$D_F^2(k)$
↑ initial spectrum	↑ gravitational evolution	↑ damping factor
↑ model of inflation	↑ cosmological perturbation theory	↑ nonequilibrium physics
↑ QFT of Φ	↑ General Relativity	↑ QFT of F

$\mathcal{P}_\Phi$ is universal

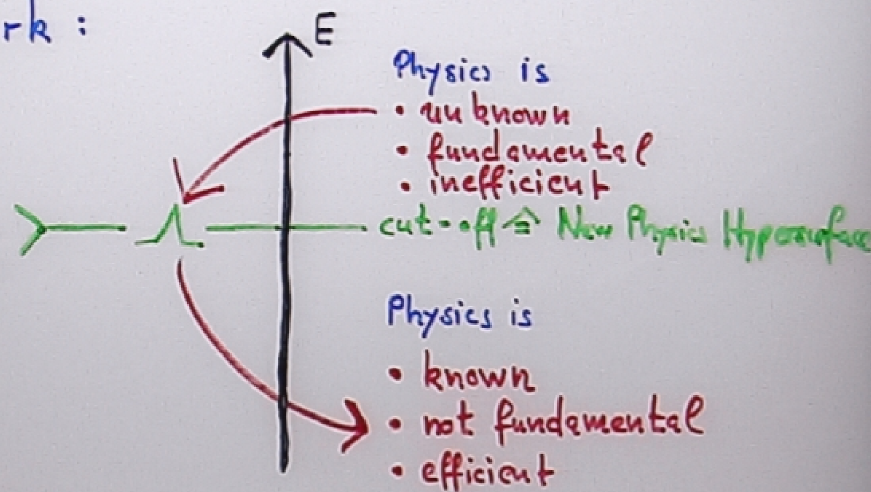
T_F is fixed by the cosmological model

D_F: depends strongly on F

PLANCKIAN IMPRINTS (I)

Framework:

$$\eta_0(k) = -\frac{\Lambda}{Hk}$$



- Impose initial conditions not at "$-\infty$"
- Initial time is k-dependent due to Λ
- Vacuum for each mode at different times

Result:

$$\mathcal{P}_\phi(k, t_*) = \left(\frac{H}{2\pi}\right)^2 \left(1 + \mathcal{O}\left[(H/\Lambda)^n\right]\right)$$

Question: $n = ?$

Answer: $n = 1, 2, \dots$

PLANCKIAN IMPRINTS

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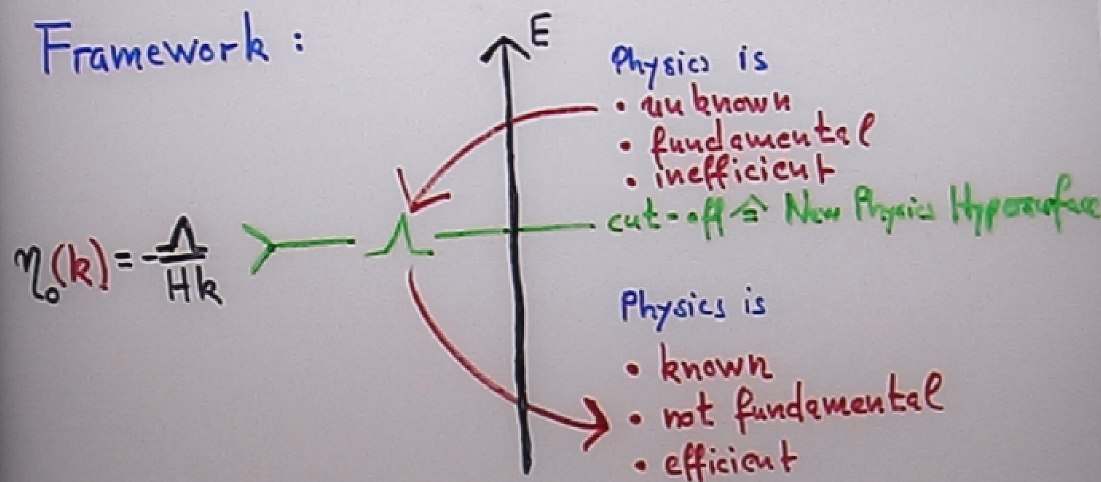

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PLANCKIAN IMPRINTS (II)

Framework: String Theory effectively modifies

$$\Delta x \cdot \Delta p \geqq \frac{1}{2}\left[1 + (\ell_s \Delta p)^2 + \dots\right]$$

$$\rightarrow \quad \Delta x^{min} \sim \ell_s \neq 0$$

minimal length scale

Incorporate ℓ_s in an effective low energy field theory by modifying $[x, p]$ in accordance with $\exists \ell_s$.

Consequences:

1) $\int d^3p/\hbar^3 \longrightarrow \int d^3p \, J(p)/\hbar^3$

$J(p) \searrow$ for $p \nearrow$

$\Rightarrow$ # d.o.f. decreases at high energies

"trans-Planckian damping"

2) $\omega_{phys} \leqq \ell_s^{-1}$

"modified dispersion relation"

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SETUP FOR QFRW-COSMOLOGY

CFRW-Cosmology

$$H(a,p) = -\frac{3}{8}\frac{p^2}{a} \quad , \quad \{a,p\} = 8\pi G_N$$

QFRW-Cosmology Ingredients:

(I) Hilbert space $\mathcal{H}_{QFRW}$

(II) Choices : a, "p" $\vee$ "a", p

(III) Quality management :

a^{-1} well-defined

Example :

$$\hat{a}|a\rangle = a|a\rangle \quad , \quad |a\rangle \in \mathcal{H}_{QFRW} \quad , \quad a \in \mathbb{R}$$

$$\text{"}\hat{p}\text{"}|a\rangle = \oint_{\tilde{a}} c(\tilde{a})\,|\tilde{a}\rangle$$

$$\langle 0|\widehat{a^{-1}}|0\rangle = \text{finite}$$

$$\leadsto \widehat{a^{-1}} \circ \hat{a} \neq \text{id}$$

Φ IN $\langle$QFRW$\rangle$ - COSMOLOGY

Hilbertspace: $H_{QFRW} \otimes H_{\Phi}$

Idea: Background Field Method

$$H_s[\Phi, \pi; a, a^{-1}, p] \longrightarrow H_s[\Phi, \pi; \langle a\rangle, \langle a^{-1}\rangle, \langle p\rangle]$$

$$H_s = \int \langle vol\, \rho_s \rangle$$

$$\langle \rho_s \rangle = \frac{1}{2}\left(\langle a^{-3}\rangle \pi\right)^2 + \frac{1}{2}\left(\langle a^{-1}\rangle \nabla\Phi\right)^2 + V(\Phi)$$

Equation of motion for Φ:

$$\ddot{\Phi} - \left[3\frac{\langle \dot{a}\rangle}{\langle a\rangle} + 2\frac{\langle \dot{a}^{-3}\rangle}{\langle a^{-3}\rangle}\right]\dot{\Phi}$$

$$-\left(\langle a^3\rangle\langle a^{-3}\rangle\right)^2\left[\left(\langle a^{-1}\rangle\nabla\right)^2\Phi - \frac{dV}{d\Phi}\right]$$

$$= 0$$

closed

Equation of motion for $\langle a\rangle$:

$$\frac{\langle \dot{a}\rangle}{\langle a\rangle} = \frac{8\pi}{3} G_N \langle \rho_s\rangle$$

THE HUSAIN-WINKLER MODEL

Goal: Singularity resolution in QFRW-Cosmology

Idea: Hilbertspace $L^2(\mathbb{R}_{Bohr})$

allows for normalisation of plane waves

Price: $\nexists\, p$

Cooking recipe:

$$a\,|\mu\rangle = \sqrt{8\pi}\, L_p\, \mu\, |\mu\rangle$$

$$a^{-1}|\mu\rangle = \frac{1}{\sqrt{8\pi}}\,\frac{1}{L_p}\, d^2(\mu)\,|\mu\rangle$$

Achievements:

(I) $\langle\mu|\nu\rangle = \delta_{\mu\nu}$

(II) a and a^{-1} are multiplication operator on $\{|\mu\rangle\}$

(III) $a|0\rangle = 0 \;\wedge\; a^{-1}|0\rangle = \frac{1}{\sqrt{8\pi}}\frac{1}{L_p}|0\rangle$ finite

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$\mathcal{P}_\Phi$ IN <HW>-COSMOLOGY

$$\mathcal{P}_\Phi(k,\mu)\Big|_{z=1} =$$

$$\left(\frac{H}{2\pi}\right)^2\Big|_{z=1}\left[1+\left(\frac{3}{2}\right)^2(1-\gamma_E)^2\,(\sqrt{8\pi}\,L_p)^2\left(\frac{H}{k}\right)^2+\cdots\right]\Big|_{z=1}$$

$\uparrow$ $\mathcal{P}_\phi$ in CFRW

$\uparrow$ $\mathcal{O}(L_p^2)$ correction from QFRW

Danielsson vacua :

$$\mathcal{P}_\Phi = \left(\frac{H}{2\pi}\right)^2\Big|_{z=1}\left[1+\left(\frac{3}{2}\right)^2(1-\gamma_E)^2\,(\gamma 3)^2\left(\frac{k}{k_*}\right)^{-2(1+\epsilon)}+\cdots\right]$$

$$\frac{\Delta\mathcal{P}_\phi}{\mathcal{P}_\phi^{CFRW}} \equiv \frac{\mathcal{P}_\phi}{\mathcal{P}_\phi^{CFRW}} - 1 \approx 10^{-9}\left(\frac{k}{k_*}\right)^{-2}$$

OUTLOOK

- Ambiguities
- Comparison to Bojowald
- P_Φ for $a \sim L_P$
- ⋮

Quantum Cosmology

⋮

?

- P_Φ in Loop Quantum Gravity