Title: Selection of the Initial Conditions from the Landscape Multiverse

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Abstract: I will briefly review the predictions of the theory of the Selection of the Initial Conditions of the Universe from the Landscape Multiverse and focus on recent and upcoming evidence. In this theory, the wavefunction of the universe propagating on the landscape is localized via Anderson localization. Decoherence of the wavefunction is triggered by the backreaction of massive superhorizon fluctuations. Thus the selection of the initial conditions is determined by the quantum dynamics of gravitational (vacuum energy) vs. matter degrees of freedom. Dynamics selects only high energy universes as 'survivors' while low energy universe become 'terminal'.

I will describe how the nonlocal quantum entanglement associated with decoherence provides a second source of perturbations and gives rise to a series of derived predictions. Three of the signatures of the theory predicted in 2006 (the giant void; a suppressed \sigma_8; and, the dark flow) were tested soon afterwards. The fourth prediction will be tested by LHC in a year.

Selection of the Initial Conditions of the Universe from the Landscape Multiverse

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The Question:

- **Why Did Our Universe Start In Such An Incredibly Low Entropy Special State?**

- **Philosophy Advocated** (since 2004): **Need a Multiverse to Meaningfully Address This Question ! Shift the Paradigm Away From Symmetry Breaking.**

Discovery of the Landscape of String Theory is Good News: 'Lucky or 'Mad' – 2004 ?!

Proposal: "QM on Landscape"

1. Allow WaveFn. Of the Universe to Propagate on the Landscape, "WDW Eqn. ", [LMH, CQG22; LMH+AK EPJC49], *2004*

2. Include Decoherence. Triggered by Long λ Massive Fluctuations. Need Observer that 'Watch/Measure' the System, [LMH+RH, PRD74, etc.], *2005*

3. Derive Predictions to Test the Theory. Calculate Nonlocal Quantum Entanglement from Decoherence = Shift to WaveFn. Trajectory, [LMH+RH+TT, PRD 77 and PRD 77], *2005-2006*

Method :

1. Use the derived landscape distribution **V(ϕ)**, (Douglas and Denef, 2004).

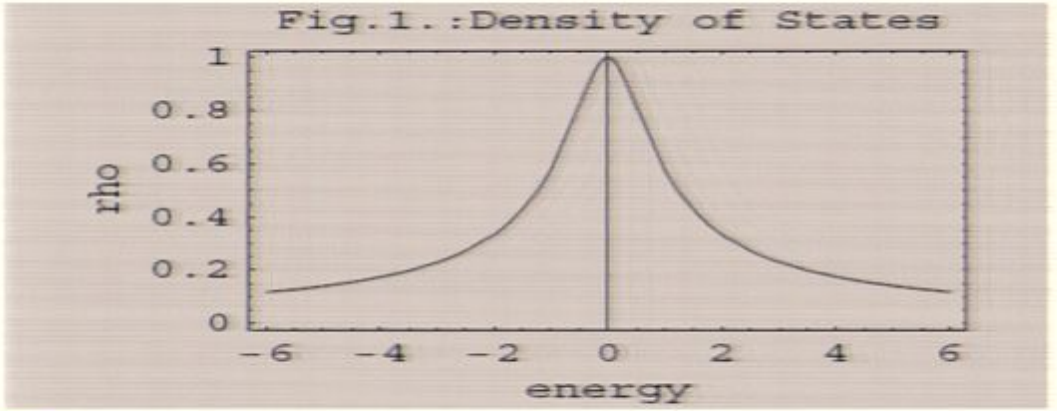
2. **WDW** Eqn. on Minisuperspace defined by **[a, ϕ].**

3. Include fluctuations '**fn**' of metric and moduli, (including internal structure of vacua peaked around the mean value). Minisuperspace: **[a , ϕ , fn]** becomes INFINITE –Dim.

WDW becomes Master Equation

CAUTION: * MUST SOLVE AS N-BODY PROBLEM *

WdW EQN:



$$\hat{\mathcal{H}}\Psi(a,\phi)=0$$

$$\mathcal{H}=\frac{1}{2e^{3\alpha}}\left[-p_\alpha^2+p_\phi^2+e^{6\alpha}V(\phi)\right]$$

- With

$$p_a=\frac{\partial L_g}{\partial \dot{a}}=-\frac{a\dot{a}}{N}. \qquad p_\phi=\frac{\partial L_\phi}{\partial \dot{\phi}}=-a^3\dot{\phi}.$$

where

$$L_g=\frac{1}{2}N\left[-\frac{a\dot{a}^2}{N^2}-a^3\Lambda\right] \; ; \quad L_\phi=\frac{a^3N}{2}\left(-\frac{\dot{\phi}^2}{N}-V(\phi)\right)$$

Backreaction-Master Equation

Backreaction of Long Wavelength Perturbations Decoheres our Universe from other patches on Phase Space.

$$h_{ij} = a^2(\Omega_{ij} + \epsilon_{ij}), \quad \phi = \phi_0 + \Sigma_n f(a)_n Q^n.$$

WDW becomes Master Equation

$$\left[\hat{H}_0 + \Sigma_n H_n\right] \Psi(a, \phi, f_n) = 0.$$

$$\hat{H}_0 \Psi(a, \phi, f_n) = < -\Sigma_n \frac{\partial^2}{\partial f_n^2} + e^{6\alpha} U(a, \phi,) f_n^2 > \Psi.$$

y=

SOLUTIONS :

(ANDERSON LOCALIZATION)

Solutions Exist Only in a Band of High Energy Initial Conditions , (Up to String M, then Poincare Rec.).

$\Psi \sim \mathrm{Exp}[-(S_0 + S_f)]$, Solutions only for :

$S \sim S_\Lambda - S_f > 0$ "Condition for Survival"

Only Those Can Overcome the Backreaction of Fluctuations and Produce a 'Survivor' Universe. Low Energy I.C. are 'Terminal'.

REMARKS:

- High Energy Inflation Not a Special State. The most probable when gravity is switched on. (Gravity is a 'negative heaat capacity system')
- Selection of the Low Entropy Initial State, determined by Out-of-Eqlb. quantum dynamics of grav. +matter D.o.F's.
- Universe can not be born from a high entropy state, thus Arrow of Time locally.
- Classicality Not Assumed, (decoherence).
- Many Worlds embedded in the Landscape. But No Splitting once Universe(s) Decohere.

Deriving Predictions:

- Trace forward the shift in wavefn.path, from quantum entanglement with all else, from decoherence time.

- It produces (superhorizon) Nonlocal modification of Friedman Eqn.

Astrophysical Tests:

Entanglement Imprints on Friedman Equation

$$H^2 = \frac{1}{3M_{\rm P}^2}\left[V(\phi) + \frac{1}{2}\left(\frac{V(\phi)}{3M_{\rm P}^2}\right)^2 F(b,V)\right] \equiv \frac{V_{\rm eff}}{3M_{\rm P}^2} \qquad (4.2)$$

where

$$F(b,V) = \frac{3}{2}\left(2+\frac{m^2M_{\rm P}^2}{V}\right)\log\left(\frac{b^2M_{\rm P}^2}{V}\right) - \frac{1}{2}\left(1+\frac{m^2}{b^2}\right)\exp\left(-3\frac{b^2M_{\rm P}^2}{V}\right). \qquad (4.3)$$

Constrain SUSY Scale from Flatness and CMB Conditions

$$(\nabla T/T)_{\rm quad} \approx r_H^2\nabla^2\delta\phi = (ck_1/H_0)^2\delta\phi \approx 0.5(r_H/L_1)^2(\delta\rho/\rho)_1.$$

$$\Delta V/(\Delta\phi)^4 \leq O(10^{-7})$$

$$10^{-10}M_P < b < 10^{-8}M_P$$

Modified Newtonian Potential.

Void Predicted at z<1 with size ~200Mpc Observed

$$\Phi = \Phi^0 + \delta\Phi \simeq \Phi^0 \left[1 + \frac{f(b,V)}{\rho} \left(\frac{r}{L_1(k,b)} \right)^2 \right].$$

CMB: Running n_s. Suppressed sigma_8.

LSS: Power Enhanced at Cluster Scales.

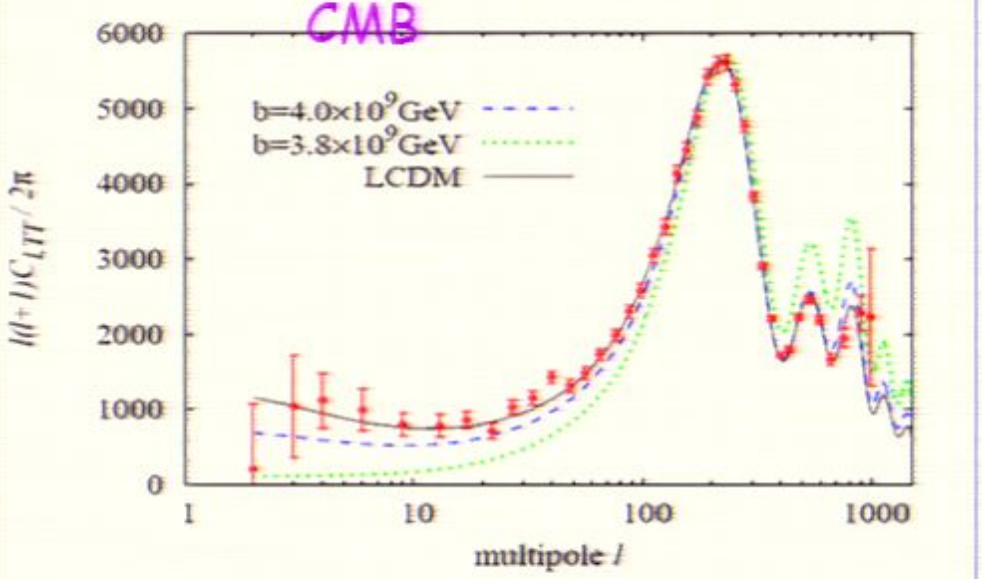
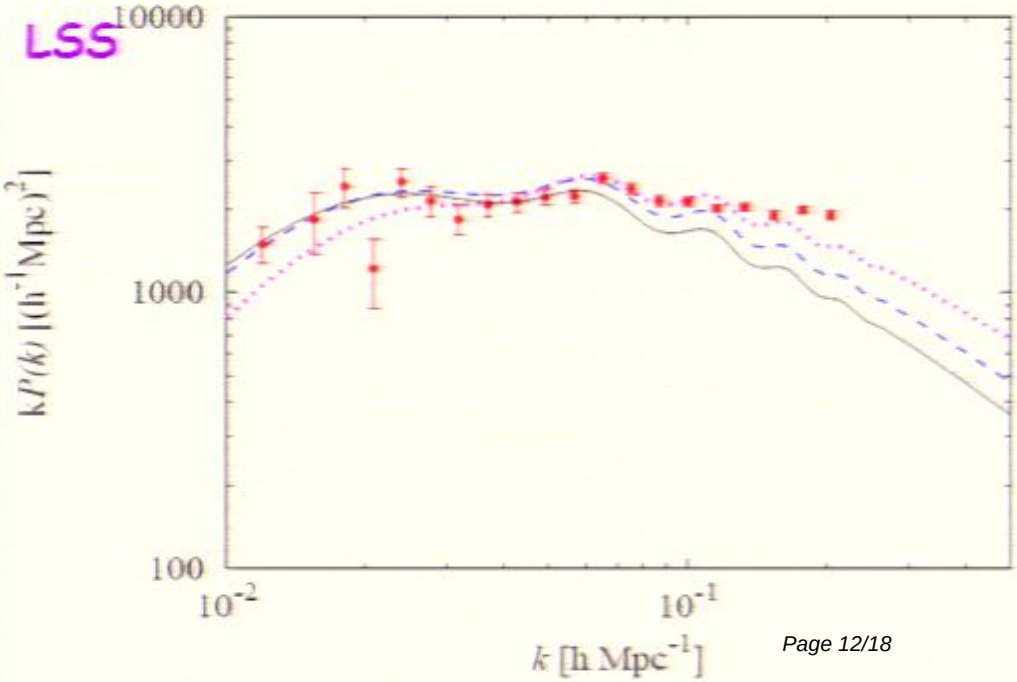


FIG. 2: TT power spectra for the cases with $b = 4.0 \times 10^9$ GeV (dash-line) and 3.8×10^9 GeV (dot-line). For reference, the spectrum for the ΛCDM case (solid-line) and the data from WMAP3 are also



Signatures Planck May Check:

Cross-Correlating Cosmic Shear with CMB

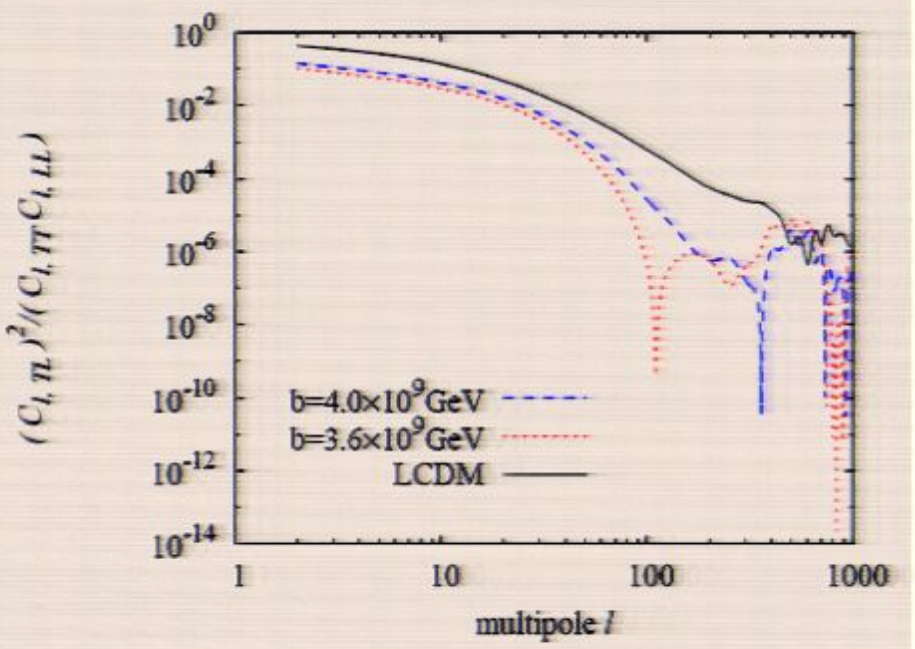


FIG. 4: The same as Fig.3 except we plotted the larger range of multipoles here.

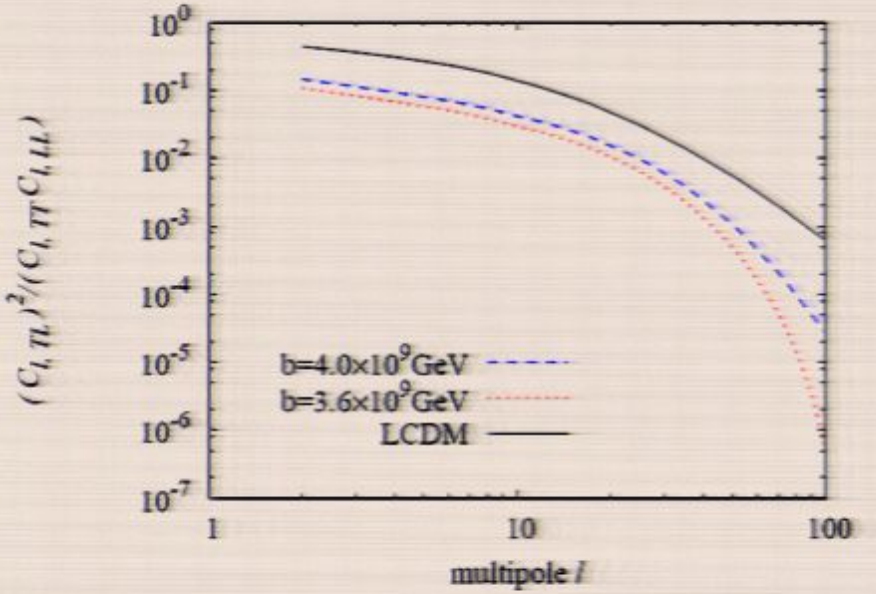


FIG. 3: Cross correlation between lensing and temperature are plotted. We assumed $b = 4.0 \times 10^9$ (dash-line) GeV and 3.6×10^9 GeV (dot-line) in this figure. For comparison, the case with ΛCDM (solid-line) is also plotted.

PREDICTIONS ('05-'06)	TESTS
• 1. Giant Void	• WMAP, Rudnick et al. (8 months later), now Planck
• 2. $\text{Sigma}_8 = 0.8$	• WMAP and SDSS '07
• 3. Bulk Flow of Structure, 'Dark Flow'.	• NASA, (Kashlinsky et al., Watson et al.,) '08-'11
• 4. SUSY Breaking Scale, <u>Higgs Not Fundamental</u>	• LHC….'12 +1/espilon
• CMB Fine Scale at High l's	• Planck '12

I Think Scepticism is Useful,

(especially when it proves me right..-;)

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by Zeeya Merali From the October 2009 issue; published online November 4, 2009 .....

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But only a year later, 2010, the story changed as we heard on Tuesday: arXiv:1012.3667 Peiris et al.

THE VOID IS THERE!!! AND STILL AT THE SCALE AND DISTANCE WE PREDICTED IN 2006.

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Significance:

- Explains: Why Did the Universe Start in Such an 'Incredibly Special State' ?
- A Series of Predictions. *No Postdictions*. Highly Constrained in 'tweaking' parameters 'to fit' tests.
- **Tests provide strong evidence for the rich structure beyond our universe and for the Landscape!**