THEORY OF THE ORIGINS OF THE UNIVERSE :

Selection of the Initial Conditions from the Landscape Multiverse

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The Question:

- WHY DID OUR UNIVERSE START IN SUCH AN INCREDIBLY LOW ENTROPY SPECIAL STATE?
- <u>PHILOSOPHY ADVOCATED</u> (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 Potential, "WDW Eqn. ", [LMH, CQG22; LMH+AK EPJC49], 2004-2005
- 2. Include Decoherence. Triggered by Long λ Massive Fluctuations. Need Observer that 'Watch/Measure' the System, [LMH+RH, PRD74, etc.], <u>2005</u>
- 3. Derive Predictions to Test the Theory. Calculate Nonlocal Quantum Entanglement from Decoherence = Shift to WaveFn. Trajectory, [LMH+RH+TT, 'Avatars of the Landscape I' PRD 77 and 'Avatars of the Landscape II' PRD 77], 2005-2006

<u>Method</u> :

- Use the derived landscape distribution V(φ), (Douglas and Denef, 2004). (The Landscape Potential has the Structure of White Noise).
- WDW Eqn. on Minisuperspace defined by geometry and moduli,
 [a, φ]. This give the wrong and trivial answer!
- Decoherence: Must 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 Equation:



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

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

With :

$$p_{a} = \frac{\partial L_{g}}{\partial \dot{a}} = -\frac{a\dot{a}}{N}, \quad p_{\phi} = \frac{\partial L_{\phi}}{\partial \dot{\phi}} = -a^{3}\dot{\phi}.$$
 Where :
$$L_{g} = \frac{1}{2}N\left[-\frac{a\dot{a}^{2}}{N^{2}} - a^{3}\Lambda\right], \quad L_{\phi} = \frac{a^{3}\mathcal{N}}{2}\left(-\frac{\dot{\phi}^{2}}{\mathcal{N}} - V(\phi)\right)$$

Backreaction-Master Equation

Backreaction of Long Wavelength Perturbations Decoheres our Universe from other patches on Phase Space. They are the Environment.

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

WDW becomes Master Equation

$$\begin{bmatrix} \hat{H}_0 + \Sigma_n H_n \end{bmatrix} \Psi(\alpha, \phi, f_n) = 0. \qquad \hat{H}_0 \Psi(\alpha, \phi, f_{\mathfrak{P}}) = \langle -\Sigma_n \frac{\partial^2}{\partial f_n^2} + e^{6\alpha} U(\alpha, \phi,)f_n^2 \rangle \Psi.$$



ANDERSON LOCALIZATION)

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

 $\Psi^{\sim} \operatorname{Exp}[-(S_0 + S_f)], \text{ Solutions only for }:$ $S^{\sim} S_{\Lambda} - S_f > 0 \qquad \underline{\text{`Condition for Survival''}}$

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

REMARKS:

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

Deriving Predictions:

- Calculate and trace forward the shift in wavefunction path induce by quantum entanglement with all else, from decoherence time.
- The Entaglement Effect contributes a (superhorizon) Nonlocal modification term in the Friedman Equation. This term is derived, there is no room for guessing or tweaking.

Astrophysical Tests:

Entanglement Imprints on Friedman Equation

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

where

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

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

12/2/201

Predictions from Modified Newtonian Potential (2005-2006)

Void Predicted at z<1 with size ~200Mpc. Observed in 2006-2012+, (Rudnick et al, WMAP), Waiting for Planck ?

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

CMB: Running n_s. Suppressed sigma_8. Observed WMAP/SDSS 2008 +

LSS: Power Enhanced at Cluster Scales. Planck 2012-2013 ?



FIG. 1: CMB 11 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 ACDM case (solid-line) and the data from WMAP3 are also plotted.

FIG. 2: Matter power spectra for the same values of b as Fig.1,

Signatures Planck Can Also Check to Uniquely Discriminate this Theory:

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 Λ CDM (solid-line) is also plotted.

PREDICTIONS ('05-'06)

- 1. Giant Void
- 2. Sigmas = 0.8
- 3. Bulk Flow of Structure, 'Dark Flow'.
- 4. SUSY Breaking Scale Much Higher, (<u>Higgs Not</u> <u>Fundamental</u>)
- CMB Fine Scale at High I's : Cross Correlations

TESTS ('06-'12)

- WMAP, Rudnick et al. (8 months later), now Planck
- WMAP and SDSS '07
- NASA, (Kashlinsky et al., Watson et al.,) '08-'12
- LHC....'12 +1/espilon
- Planck '12

Significance of the Theory :

- Explains the Origins of the Universe: Why Did the Universe Start in Such an 'Incredibly Special State'
- Theory is Generic: Any Initial Conditions Phase Space/Landscape Structure that Contains Any Amount of Disorder in Distribution of Energies will Generically Localize Wavefunctions, a.k.a Produce Family of Universes Born at High Energies and Decohered !
- Theory Provides a Formalism on How to Calculate in Any Phase Space of Initial Conditions. No Phenomenology, No Anthropics, and No Guessing Needed. All Information Can Be Obtained By solving Physics Equations. Only Assumption: Quantum Mechanics is Valid.
- Any Initial Conditions Phase Space that is Perfectly Ordered (e.g. SUSY sector), Does Not Localize Wavefunctions = It Can Not Produce Universes!
- A Series of Predictions. *No Postdictions*. Highly Constrained in 'tweaking' parameters 'to fit' tests. Thus Observations Can Directly Rule Out or Confirm the Theory.
- Lessons Learned: Two Ingredients in Any Theory of the Origins of the Universe are CRUCIAL: i) Decoherence Must Be Included; ii) Phase Space Multiverse Must be Solved for as an N-Body Problem in Order to Capture All Relevant Physics.
- Price= Extend Physics to Multiverse Framework | But Observational Tests Provide Strong Evidence Already for the Rich Structure Beyond our Universe and for the Multiverse!

In a Nutshell:



