How dark matter, axion walls, and graviton production lead to observable Entropy generation in the Early Universe

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The D'Albembertain operation in an equation of motion for emergent scalar fields implying a Non-zero scalar field

$$\phi \xrightarrow[T \to 2.7^0\ Kelvin]{} \varepsilon^+ \approx 0^+$$

Penrose quintessence scalar field evolution

$$\ddot{\phi} - \nabla^2 \phi + \frac{\partial V}{\partial \phi} = 0$$

Friedman – Walker metric employed as well as as the following potential

$$V(\phi) \sim -\left[\frac{1}{2} \cdot \left(M(T) + \frac{\Re}{6}\right)\phi^2 + \frac{\tilde{a}}{4}\phi^4\right] \equiv$$

$$-\left[\frac{1}{2} \cdot \left(M(T) + \frac{\kappa}{6a^2(t)}\right)\phi^2 + \frac{\tilde{a}}{4}\phi^4\right]$$

T ~ high and next, T ~ Low :

$$\phi^2 = \frac{1}{\tilde{a}} \cdot \left\{ c_1^2 - \left[\alpha^2 + \frac{\kappa}{6a^2(t)} + \left(M(T) \approx \varepsilon^+ \right) \right] \right\}$$

$$\xrightarrow[M(T \sim high) \to 0]{} \phi^2 \neq 0$$

$$\phi^2 = \frac{1}{\tilde{a}} \cdot \left\{ c_1^2 - \left[\alpha^2 + \frac{\kappa}{6a^2(t)} + \left(M(T) \neq \varepsilon^+ \right) \right] \right\}$$

$$\xrightarrow[M(T \sim Low) \neq 0]{} \phi^2 \approx 0$$

Axion mass

$$m_a(T) \cong 0.1 \cdot m_a(T = 0) \cdot (\Lambda_{QCD} / T)^{3.7}$$

DeSitter space time geometry as given by Park (2003)

$$\Lambda_{4-\mathrm{dim}} \approx c_2 \cdot T^{\beta}$$ Leading to Barvinsky vs. Park

$$\Lambda_{4-\mathrm{dim}} \propto c_2 \cdot T \xrightarrow[graviton-production]{} 360 \cdot m_P^2 << c_2 \cdot \left[T \approx 10^{32} K \right]$$

Large scale values of the absolute magnitude of the cosmological vacuum energy are largely due to:

$$\rho_{VAC} \sim \frac{\Lambda_{observed}}{8\pi G} \sim \sqrt{\rho_{UV} \cdot \rho_{IR}}$$

$$\sim \sqrt{l_{Planck}^{-4} \cdot l_H^{-4}} \sim l_{Planck}^{-2} \cdot H_{observed}^{2}$$

$$H_{initial} \geq 10^{39} - 10^{43}$$

$$a(End - of - \inf)/a(Beginning - of - \inf) \equiv \exp(N)$$

If $\Lambda_{initial} \sim c_1 \cdot [T \sim 10^{32}\ Kelvin]$ then

$$\Lambda_{initial} \sim [10^{156}] \cdot 8\pi G \approx huge \quad number$$

$$dS^2 = -F(r) \cdot dt^2 + \frac{dr^2}{F(r)} + d\Omega^2$$

$$F(r) = 1 - \frac{2M}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3} \cdot r^2 \xrightarrow[T \to 10^{32}\ Kelvin \sim \infty]{} -\frac{\Lambda}{3} \cdot (r = l_P)^2$$

Λ has temperature dependence, then we get a Wheeler De Witt Equation solution with a pseudo time component put in, Crowell (2005)

$$\frac{\partial F}{\partial r} \sim -2 \cdot \frac{\Lambda}{3} \cdot \left(r \approx l_P\right) \equiv \eta\left(T\right) \cdot \left(r \approx l_P\right)$$

$$\Psi\left(T\right) \propto -A \cdot \left\{\eta^2 \cdot C_1\right\} + A \cdot \eta \cdot \omega^2 \cdot C_2$$

It so happens that here, C1 and C2 have pseudo cyclic and evolving time function behavior, and are part of the (pseudo) time dependent solutions to the (pseudo) time dependent Wheeler-De Witt equation, as written by Crowell (2005). The wave functional is similar to the WKB wave functionals and are an approximate solution.

Does there exist a five-dimensional version of an instanton in the worm hole transition regime ? We will then look at Reissner-Nordstrom metric embedded in five dimensional space- time

$$M_g(r) = \int \left[T_0^{\,0} - (T_1^{\,2} + 2 \cdot T_2^{\,2}) \right] \cdot \sqrt{-g_4}\, dV_3$$

$$\approx \pi \cdot c_1^2 \cdot \left[\frac{r^3}{3} - 2M \cdot \frac{r^2}{2} + Q \cdot r - \frac{\Lambda}{15} \cdot r^5 \right] +$$

$$4\pi \cdot c_1 \cdot \left[r^2 - 8 \cdot M \cdot r - \frac{\Lambda}{3} \cdot r^4 \right] \xrightarrow[r \to \delta]{} \varepsilon^+ \approx 0$$

Space time line metric in five dimensions , Wesson, modified :

$$dS_{5-\dim} = \left[\exp(i\pi/2) \right] \cdot \left\{ \begin{array}{l} e^{2\Phi(r)} dt^2 \\ + e^{2\tilde{\Lambda}(r)} dr^2 + R^2 d\Omega^2 \end{array} \right\}$$

$$+ (-1) \cdot e^{\mu} dl^2$$

$\{\ \}$ **is Reissner-Nordstrom line metric in four dimensional space**

$$e^{2\Phi(r)} = \left(1 - \frac{2M}{r} + \frac{Q^2}{r^2}\right) \qquad e^{2\tilde{\Lambda}(r)} = \left(1 - \frac{2M}{r} + \frac{Q^2}{r^2}\right)^{-1}$$

$$\mu_{Maximum} \approx c_1 \cdot r_{Maximum} \sim l_P \equiv 10^{-35}\,cm$$

$$T_0^0 = \left(\frac{-1}{8\pi}\right) \cdot \left(1 - \frac{2M}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3} r^2\right) \cdot \left(\frac{c_1^2}{4} + \frac{c_1}{r} + \frac{c_1}{4} \cdot \left[\frac{\frac{2M}{r^2} - \frac{2Q}{r^3} - \frac{2\Lambda r^2}{3}}{1 - \frac{2M}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3} r^2}\right]\right)$$

Determinant:

$$\sqrt{-g_4} = \left(1 - \frac{2M}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3} r^2\right)$$

Conclusion, CLAIM

1st we have a causal discontinuity at the onset of space time

Start with the Friedmann eqn.

This assumes a value we say holds even through early times to the present.

$$(\dot{a}/a)^2 = \frac{8\pi G}{3} \cdot [\rho_{rel} + \rho_{matter}] + \frac{\Lambda}{3}$$

We make the following definitions

$$\rho_{rel} \equiv \left(\frac{a_{present-era}}{a(t)} \right)^4 \cdot (\rho_{rel})_{present-era}$$

$$\rho_m \equiv \left(\frac{a_{present-era}}{a(t)} \right)^3 \cdot (\rho_m)_{present-era}$$

Friedmann equation for the evolution of a scale factor $a(t)$

$$\left[\frac{a(t^* + \delta t)}{a(t^*)}\right] - 1 <$$

$$\frac{\left(\delta t \cdot l_P\right)}{\left(\sqrt{3/8\pi\Lambda}\right)} \cdot \left[\frac{1}{24\pi \cdot a^2(t^*)} + \frac{1}{\Lambda} \cdot \left[(\rho_{rel})_0 \cdot \frac{a_0^4}{a^6(t^*)} + (\rho_m)_0 \cdot \frac{a_0^3}{a^5(t^*)}\right]\right]^{1/2}$$

$$\xrightarrow[\delta t \to \varepsilon^+, \Lambda \neq \infty, a \neq 0]{} \left(\frac{\delta t \cdot \left[l_P / a(t^*)\right]}{\sqrt{3/8\pi}}\right) \cdot \sqrt{\frac{(\rho_{rel})_0 a_0^4}{a^4(t^*)} + \frac{(\rho_m)_0 a_0^3}{a^3(t^*)}} \approx \varepsilon^+ << 1$$

,

We get a violation of Dowker partial ordering if we have

$$\left[\frac{a(t^* + \delta t)}{a(t^*)}\right] < 1 \quad .$$

<u>HOW</u> does this lead to entropy production ?

Energy fluctuations due to the wormhole and their link to entropy generation

1. Start with a semiclassical:

$$\frac{\partial^2 \delta\,\rho(x)}{\partial t^2} - c_s^2 \Delta \cdot \delta\rho(x) - 4\pi \cdot G\rho_0 \cdot \delta\rho(x) = \sigma \cdot \Delta\delta\, S(x)$$

2. Fourier-transform to (assuming almost constant values of k and x)

$$\delta\rho(x) \cong -\frac{8\sigma}{c_s^2}\delta\, S(x)$$

3. Due to increasing temperature:

$$\delta\rho(x) \propto \Lambda_{initial} \rightarrow \Lambda_{\max}$$

A direct linkage between energy density fluctuations and entropy

<u>In early universe conditions</u> we make the following identification

ρ_2 is energy density dimensions (Lloyd)

$$\left|\delta\rho(x)\right| \cong 8\sigma \cdot \delta S(x) \quad \left[\# operations\right]_2 \approx \rho_2 \cdot \left(c \equiv 1\right)^5 \cdot t_P^4 \leq 10^{120}$$

Observable bits of information in our (prior) universe (Smoot)	10^{180}
Holographic principle-allowed states in universe evolution/development	10^{120}
Initially available states at onset of inflationary era (thermal flux)	10^{10}
Observable bits due to quantum/ statistical fluctuation	10^{8}

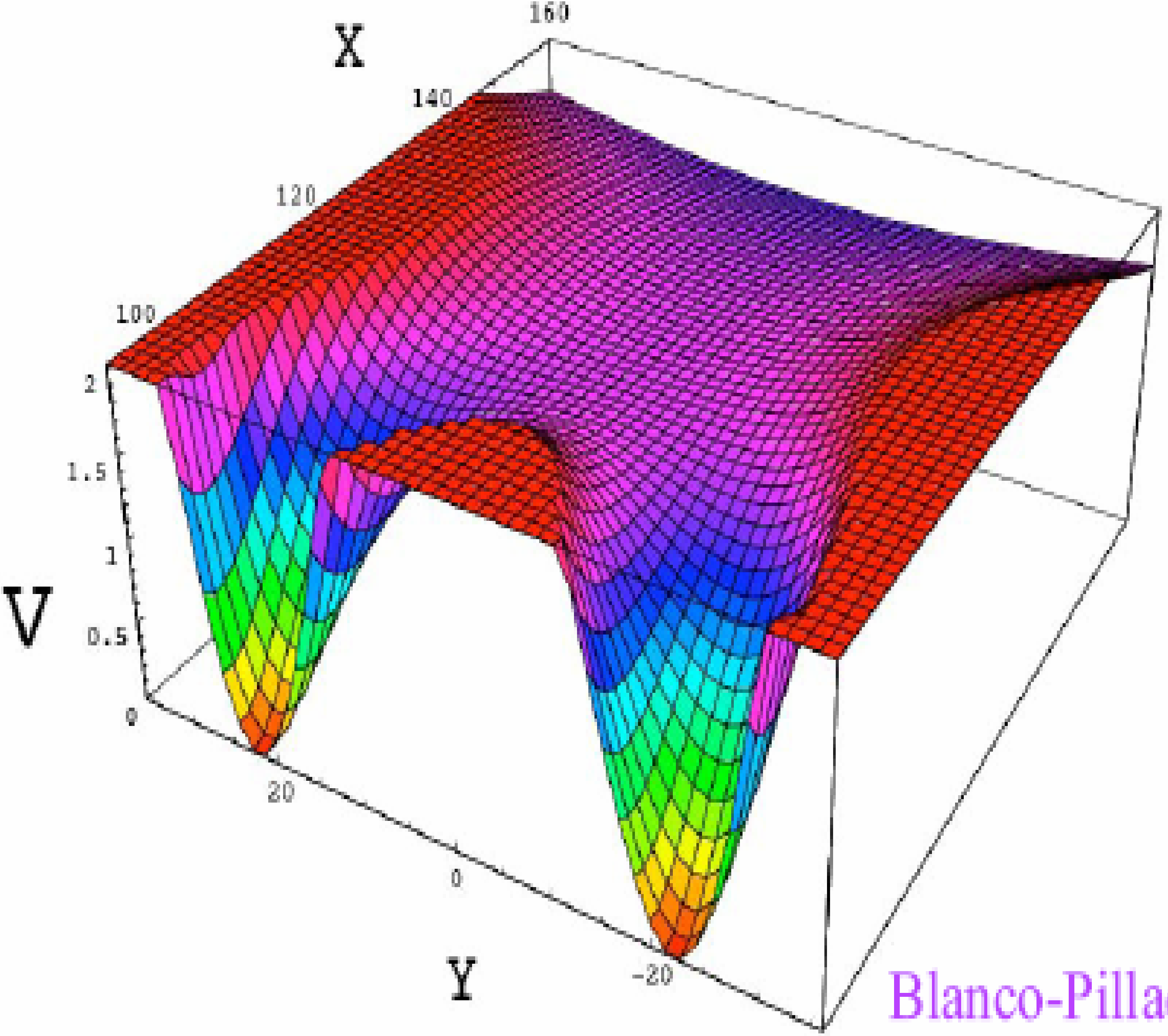
Growth of early structure that may arise

An analogue to race track inflation by string theorists, allowing for the following identification:

$$\left|\frac{\Delta E}{l_P^3}\right| \sim \left|\frac{\Delta P \in 150\pi^2}{l_P^3}\right| \approx |\Delta S|$$

Can also have inflation without branes

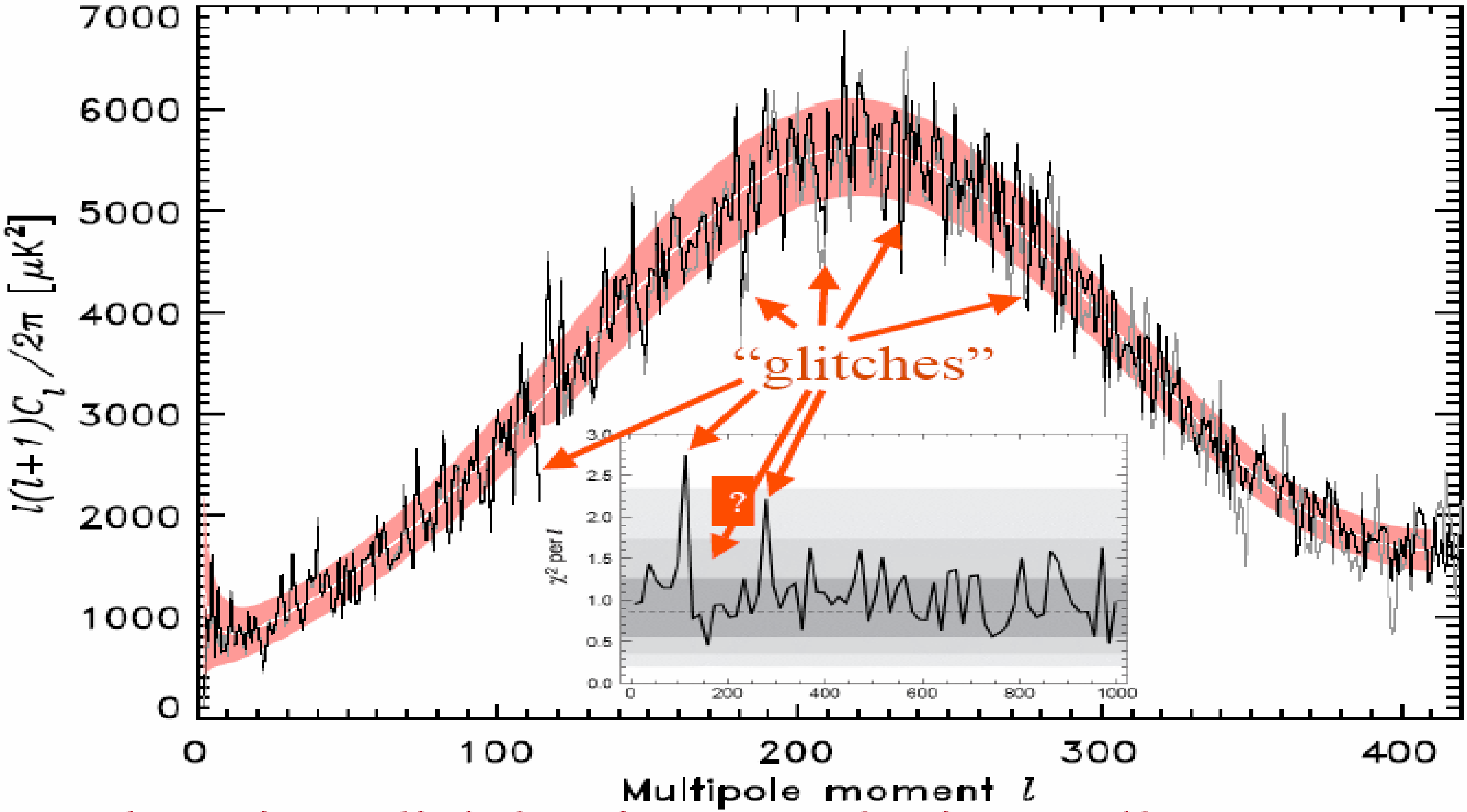
E.g.,achieve eternal topological inflation (with a similar *quadratic* potential) in "racetrack" model with two gaugino condensates



Blanco-Pillado *et al* (2004)

We get CMBR glitches

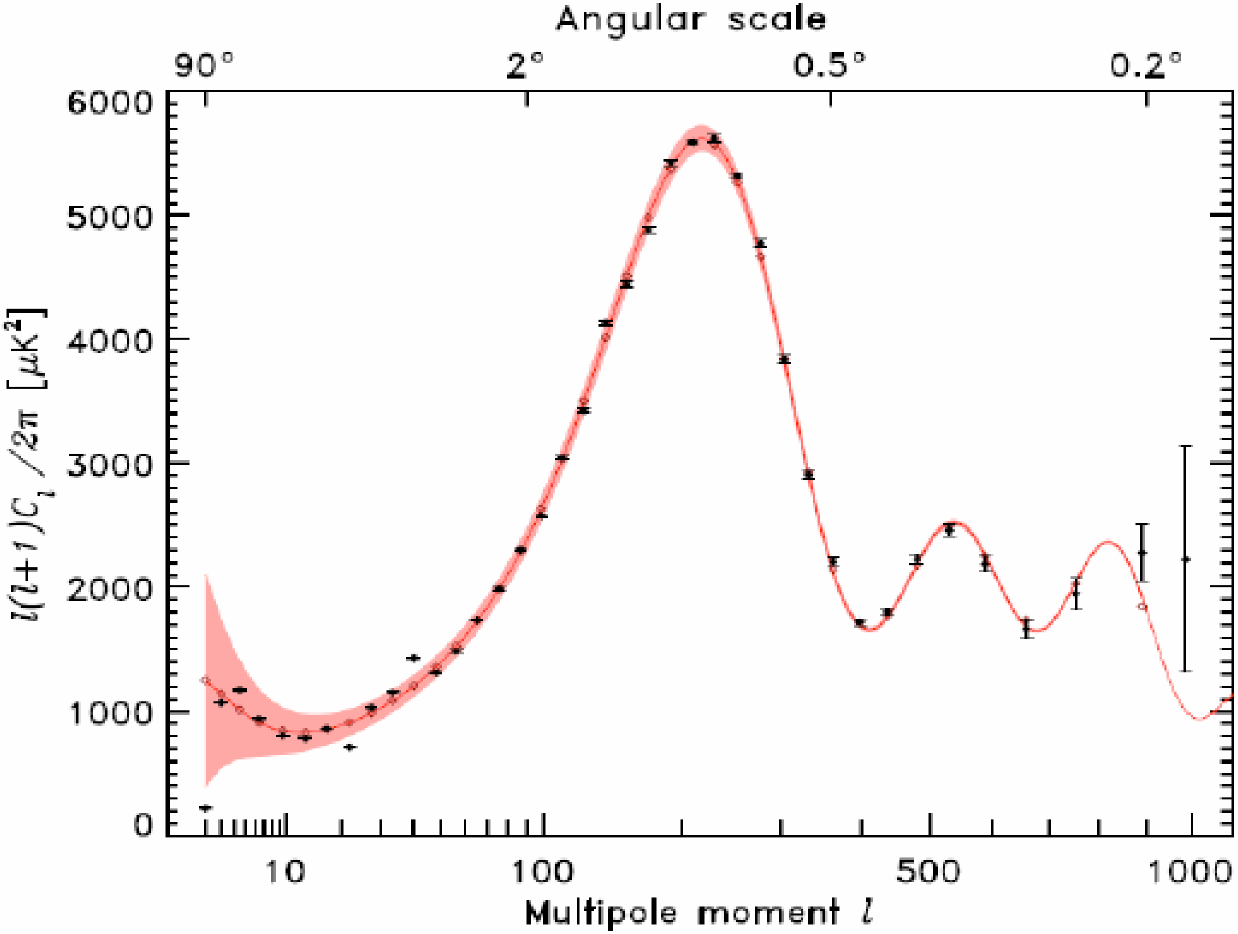
The excess χ^2 comes mostly from the *outliers* in the TT spectrum



Is the primordial density perturbation really **scale-free?**

In fact the 'power-law ΛCDM model' does not fit *WMAP* data very well

Best-fit: $\Omega_m h^2 = 0.13 \pm 0.01$, $\Omega_b h^2 = 0.022 \pm 0.001$, $h = 0.73 \pm 0.05$, $n = 0.95 \pm 0.02$



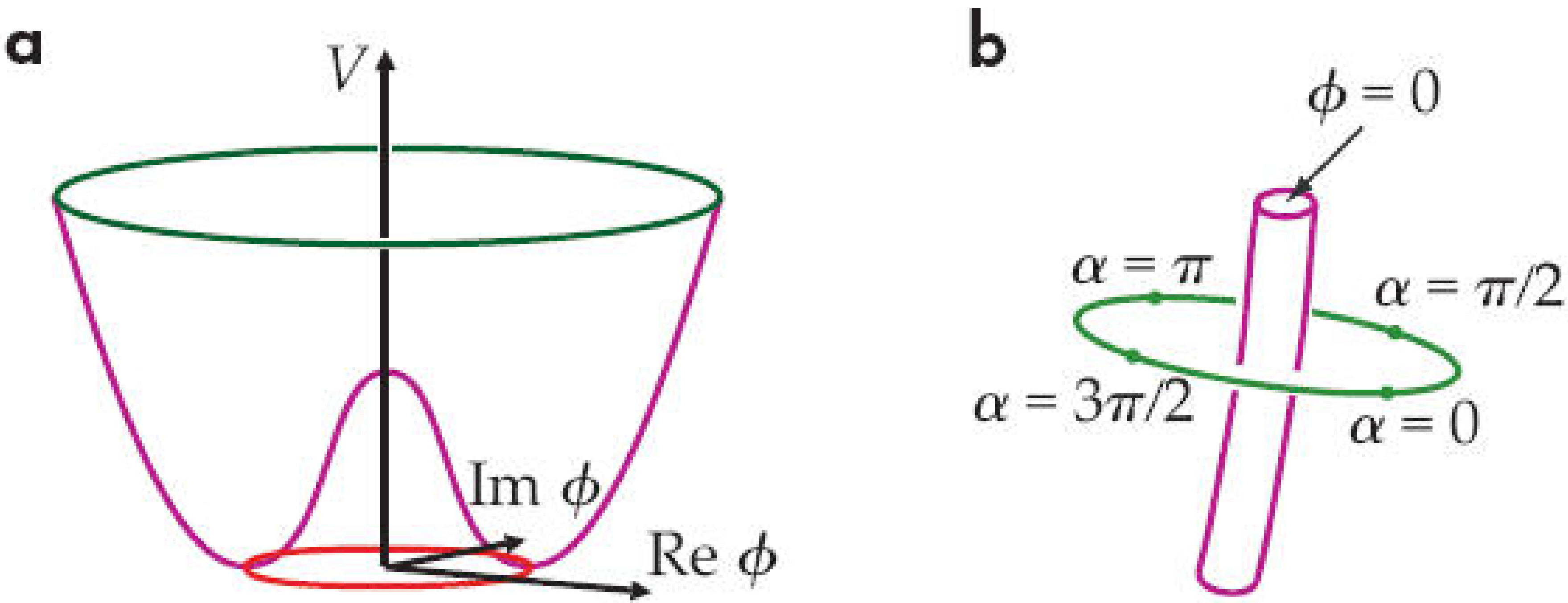
But the χ^2/dof = 1049/982 =>
problem of only ~ 7% that this model is correct

We have a LOT of work ahead of us, especially if Sarkar's is correct:

"Quasi-DeSitter spacetime during inflation has no "lumpiness" – it is necessarily very smooth. Nevertheless one can generate structure in the spectrum of quantum fluctuations originating from inflation by disturbing the slow-roll of the inflaton - in our model this happens because other fields to which the inflaton couples through gravity undergo symmetry breaking phase transitions as the universe cools during inflation."

Congruent with condensed matter analogy

- Ruutu, V. , Eltsov, V, Gill, A., Kibble, T., Krusius, M., Makhlin, Y.G., Placais, B., Volvik, G, and Wen, Z., “Vortex Formation in neutron – irradiated 3He as an analog of cosmological defect formation,” *Nature* 382, 334-336 (25 July 1996) This has been further rationalized via a recent *Physics Today* article written by T. Kibble of Oxford, September 2007, pp 47 - ..



Symmetry breaking (a) , and Vortex filament forms (b)

See arxiv.org/abs/0712.0029 for references to this slide show