Neutrino physics, dark matter & relic gravitational waves

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Non-zero scalar field

Leads to…

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

Penrose quintessence scalar field evolution assumes flat space time

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

T ~ high:

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

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

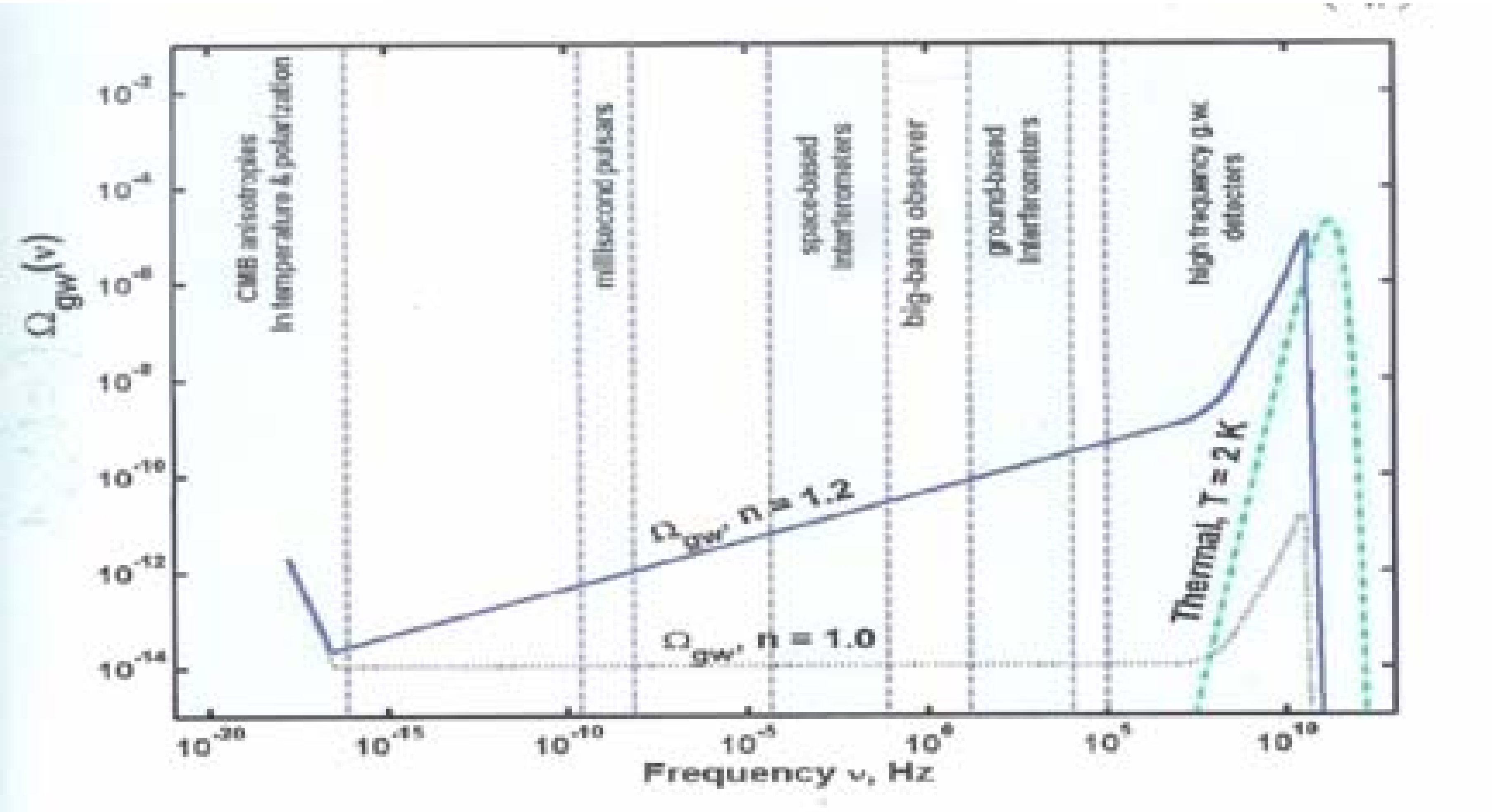
T ~ low:

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

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

Energy density of relic gravitational waves

$$\Omega_{gw}(\nu) = \frac{\pi^2}{3} h^2(\nu) \left(\frac{\nu}{\nu_H} \right)^2$$



New research opportunities

- Direct inferences about the early universe Hubble parameter and scale factor
- Energy density requires GW frequency $\sim 10^{10}$ Hz (10 GHz)
- Sensitivity required for that frequency: $\sim 10^{-30}$ $\delta m/m$
- The Li-Baker Chinese HFGW Detector expected to be sensitive to such relic HFGWs

DeSitter space-time geometry

$$\Lambda_{4-\mathrm{dim}} \approx c_2 \cdot T^{\beta}$$

Park (2003)

Barvinsky vs. Park

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

$$\frac{\Lambda_{4-\mathrm{dim}}}{\left|\Lambda_{5-\mathrm{dim}}\right|} - 1 \approx \frac{1}{n}$$

Now for some neutrino physics and speculations on Dark Matter candidates

Abandoned DM candidates

1. **MACHOS**

2. **Standard neutrino candidate**

   (problem: the MASS of the neutrinos)

3. **Champs and Simps**

   (Reference: physics beyond the Standard Model and Dark matter – H. Muramaya, Session LXXXVI of Les Houches, 2006)

Present candidates for DM?

(aside from SUSY or WIMPS)

Mass problem with Neutrinos as DM candidate

- **M~300 GeV**

  Thermal relic value (from experiment) requires at least this mass of a candidate DM particle (H. Murayama)

- **Well above traditional Neutrino masses**

- **M value ties in with electroweak symmetry breaking**

Tremaine-Gunn argument

“For Neutrinos to dominate the halo of dwarf galaxies, one would need to pack them so much that the Pauli Exclusion principle would be violated.”

S. Tremaine and J. E. Gunn , PRL 42, 407 (1979)

Traditional neutrino masses → WDM

- Moving at c during structure formation
- Would interfere with structure formation, often erase at small scales
- Ultra-fast-moving neutrinos are WDM candidate (ruled out)

Φ

Meissner & Nicolai: extend standard model

With classically conformal Langrangian, with the usual Higgs doublet and one extra weak scalar field:

$$\tilde{\phi}(x) = \varphi(x) \cdot \exp\left[\frac{ia(x)}{\sqrt{2}\mu}\right]$$

K.A. Meissner and H. Nicolai, “ Neutrinos, Axions, and Conformal Symmetry”, arXiv: 0803.2814v2, 2 April 2008

Majoran as axion candidate

(without SUSY)

- a(x) yields pseudo-Goldstone particle associated with “spontaneous breaking of a new global (modified Lepton number) symmetry”
- Shares properties with axion
- Conformal symmetry eliminates conformal Lagrangian contributions
- Masses for particles like neutrinos -- heavier than the SUSY neutrino candidate, but same “branching ratio” (a(x) is massless)

Classically conformal Lagrangian

$$\varsigma_{\text{int}} = stuff - \frac{\lambda_1}{4} \cdot \left(\Phi^+ \Phi\right)^2 - \frac{\lambda_2}{2} \left(\Phi^+ \Phi\right)\left(\phi^+ \phi\right) + \frac{\lambda_3}{4} \left(\phi^+ \phi\right)^2$$

Role of conformal symmetry

- Power zero to power 2 terms do not arise
  (normally expected in this Lagrangian)
- Higgs not needed

  (would break conformal symmetry of the Lagrangian)

Parameter space treatment

$$\lambda_1 = 3.77, \lambda_2 = 3.72, \lambda_3 = 3.73$$

$$\langle H \rangle = \left\langle \sqrt{\Phi^+ \Phi} \right\rangle = 174 GeV, \langle \varphi \rangle = 958 GeV$$

$$H' = H \cos\beta + \varphi \cdot \sin\beta$$

$$\varphi' = -H \cdot \sin\beta + \varphi \cos\beta$$

$$m_{H'} = 207 GeV, m_{\varphi'} = 477 GeV, \sin\beta = 0.179$$

Bottom line

$$m_{\varphi'} > \vartheta(order)400 \quad GeV$$

Derived "axion" is coupled to photons via an energy scale of

$$f_a = \vartheta(10^{15}\,GeV)$$

How does this lead to entropy production and what are observational consequences?

First, consider:

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

For energy density, and entropy

- **Start with a semiclassical…**

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

- **In early universe conditions…**

$$\left|\delta\rho(x)\right| \cong 8\sigma \cdot \delta S(x)$$

Bits transferred via wormhole to baby universe

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}

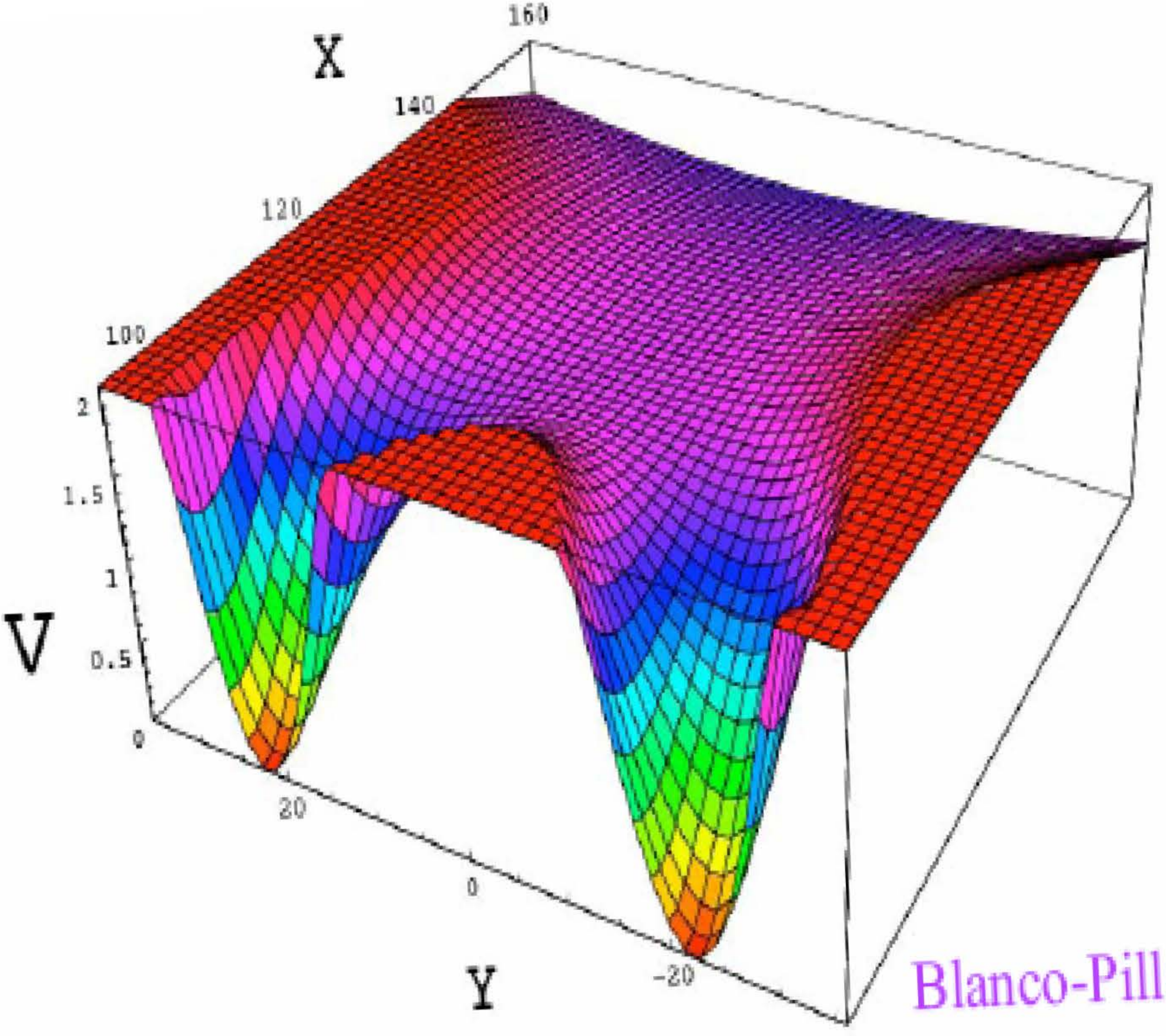
Growth of early structure that may arise

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

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

Can also have inflation without branes

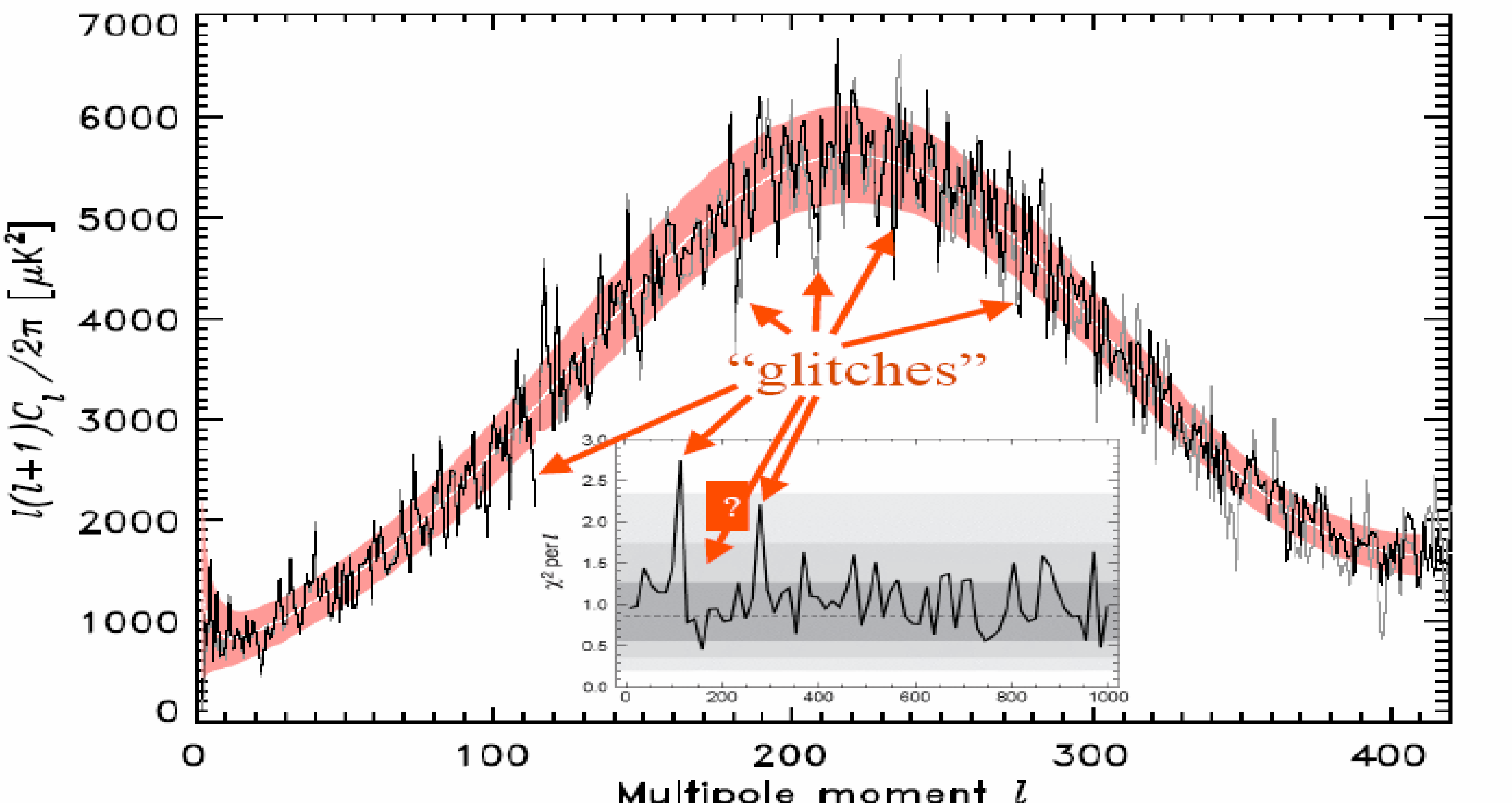
E.g., achieve eternal topological inflation (with a similar *quadratic* potential) in a “racetrack” model with two gaugino condensates



Blanco-Pillado *et al* (2004)

We get CMBR glitches

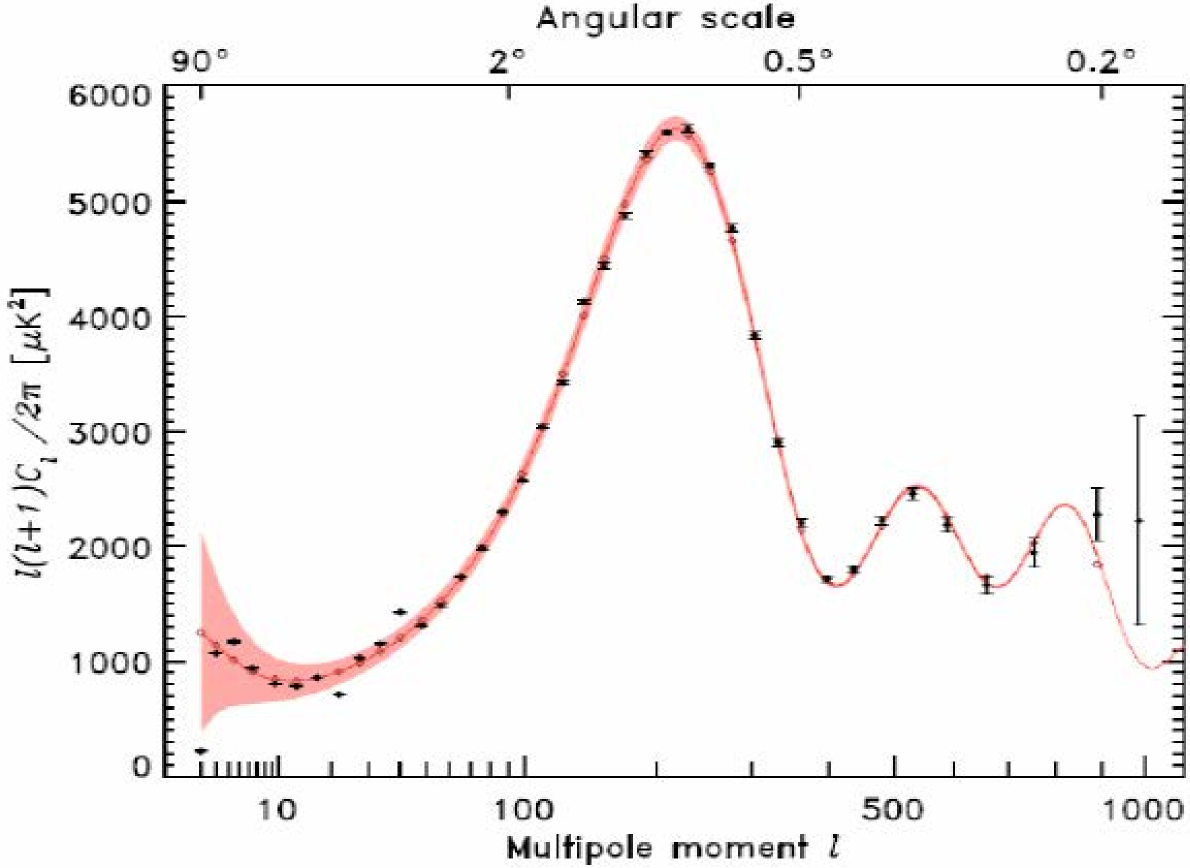
The excess χ^2 comes mostly from the *outliers* in the TT spectrum



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 =>

probability of only ~7% that this model is correct!

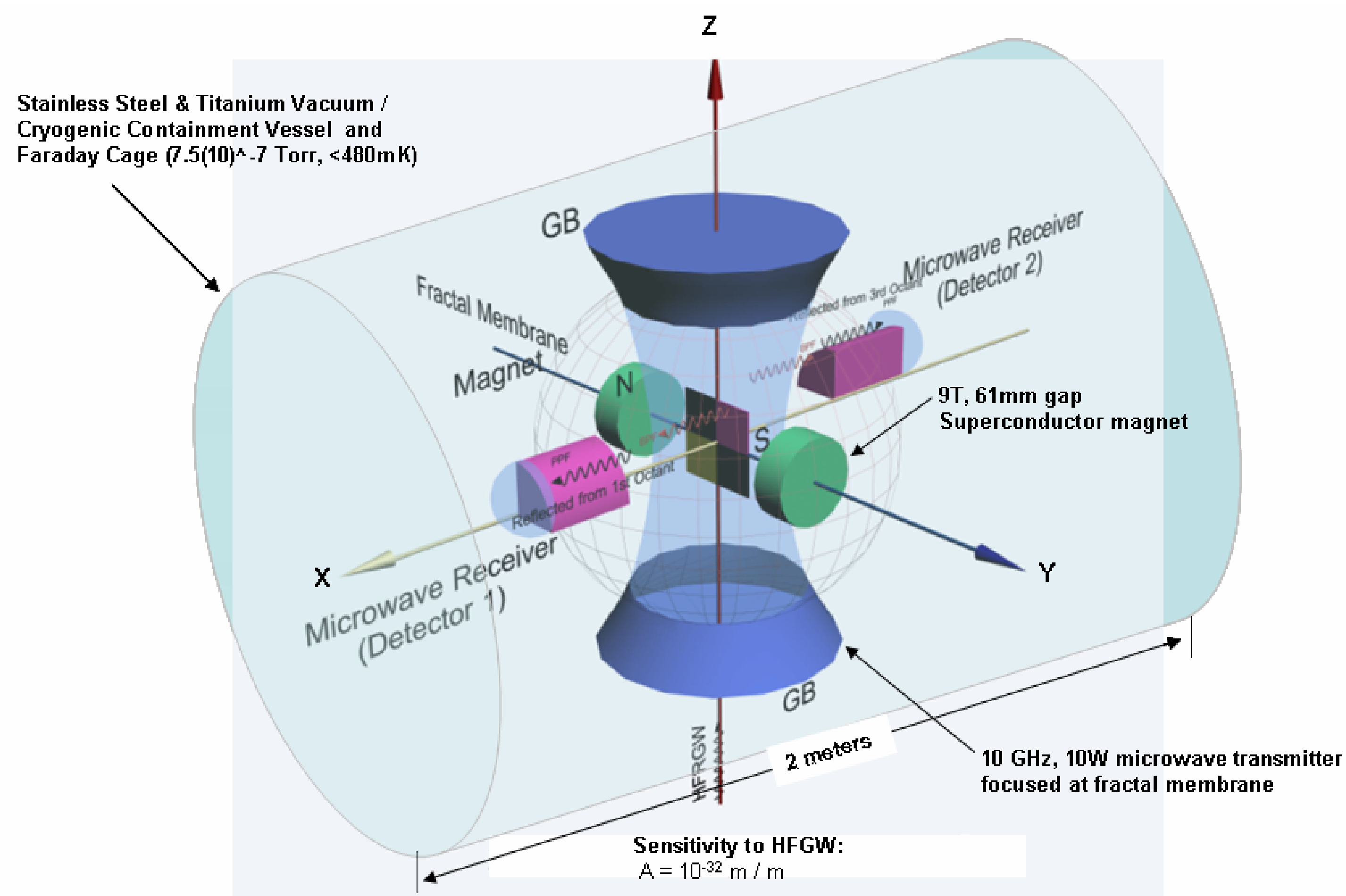
We have a LOT of work ahead of us -- especially if Sarkar's is correct

"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 inflation couples through gravity undergo symmetry breaking phase transitions as the universe cools during inflation."

Congruent with condensed matter analogy, which we claim is linkable to HFGWs and relic neutrino production

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)

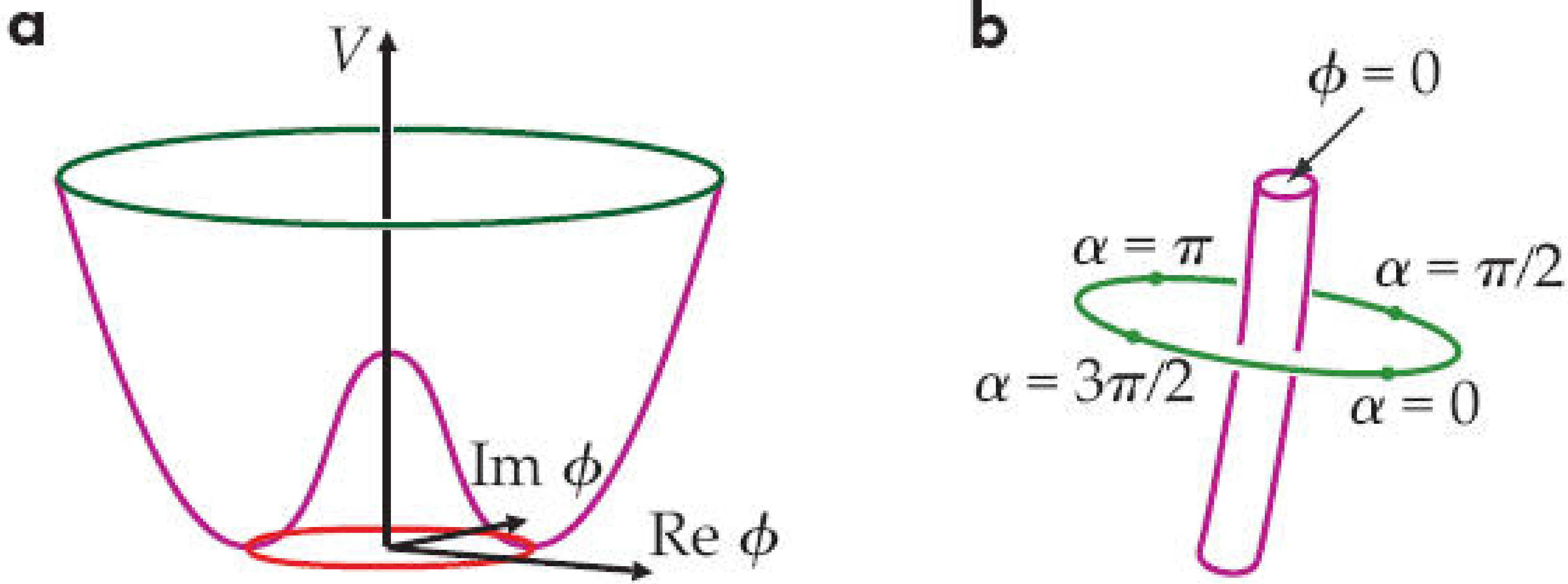
A practical HFGW detector as presented / designed by Dr. Li Fangyu, and Dr. Baker



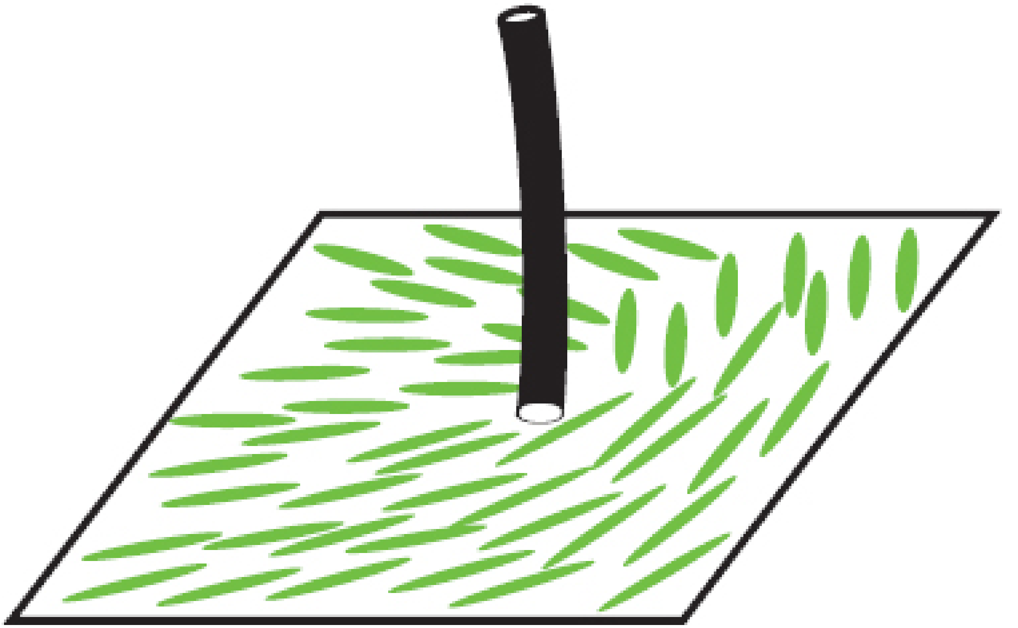
Birmingham (Polarization) HFGW Detector

Differential Polarization Angle of 10^{-40} Radians may Cause Measurable Femtosecond Time Difference

From the *Physics Today* article written by T. Kibble of Oxford, September 2007, starting at page 47



Symmetry breaking (a)
Vortex filament forms (b)



Tangle of defects about a vortex filament formed

Conclusion

1. Meisner and Nicolai go a long way to solving the 300 GeV problem as masses for a DM candidate

2. HFGWs are an integral part of relic DM production processes and accessing DM formation inevitably ties in with processes that permit relic GW generation

3. Solving the DM problem will go a long way toward helping address irregularities in the CMBR spectra (cited by Subir Sarkar at IUCAA December 2007 meeting in Pune, India)