Possible Evidence of Superstring Excitations from CMB Power Spectrum

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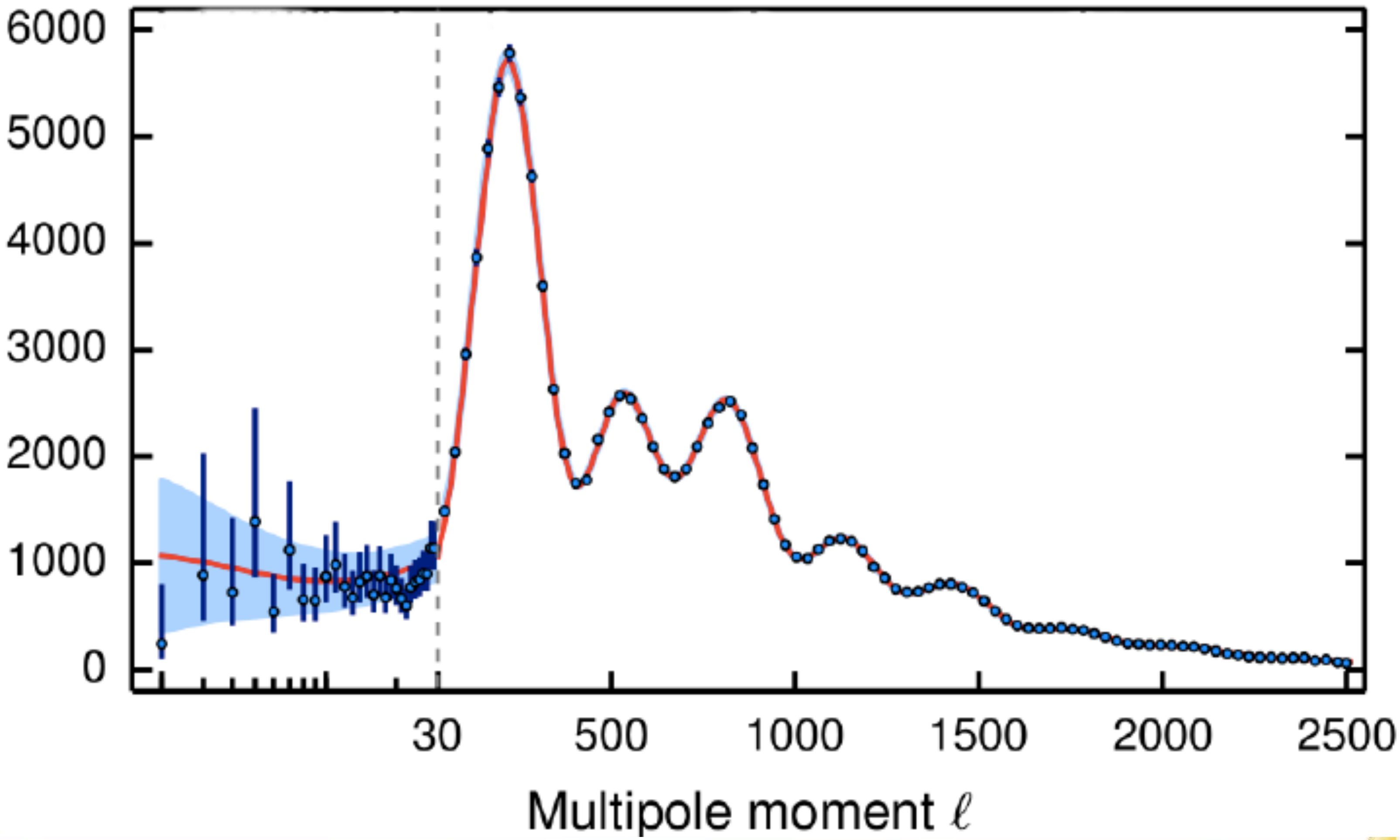
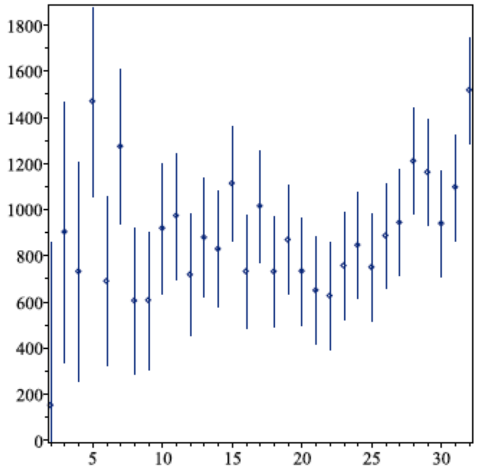
The Usual One !!!



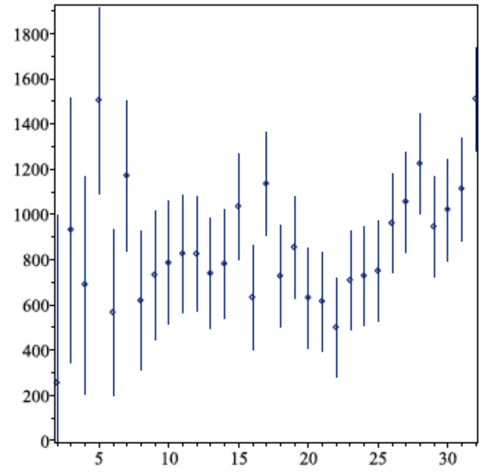
Planck Collaboration. [Astron. & Astrophys. 594 (2015) A20 (2016)]

Low l (l ≤ 32) Anomaly

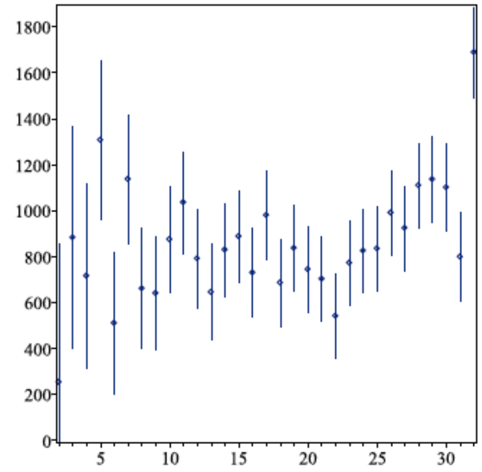
WMAP 9



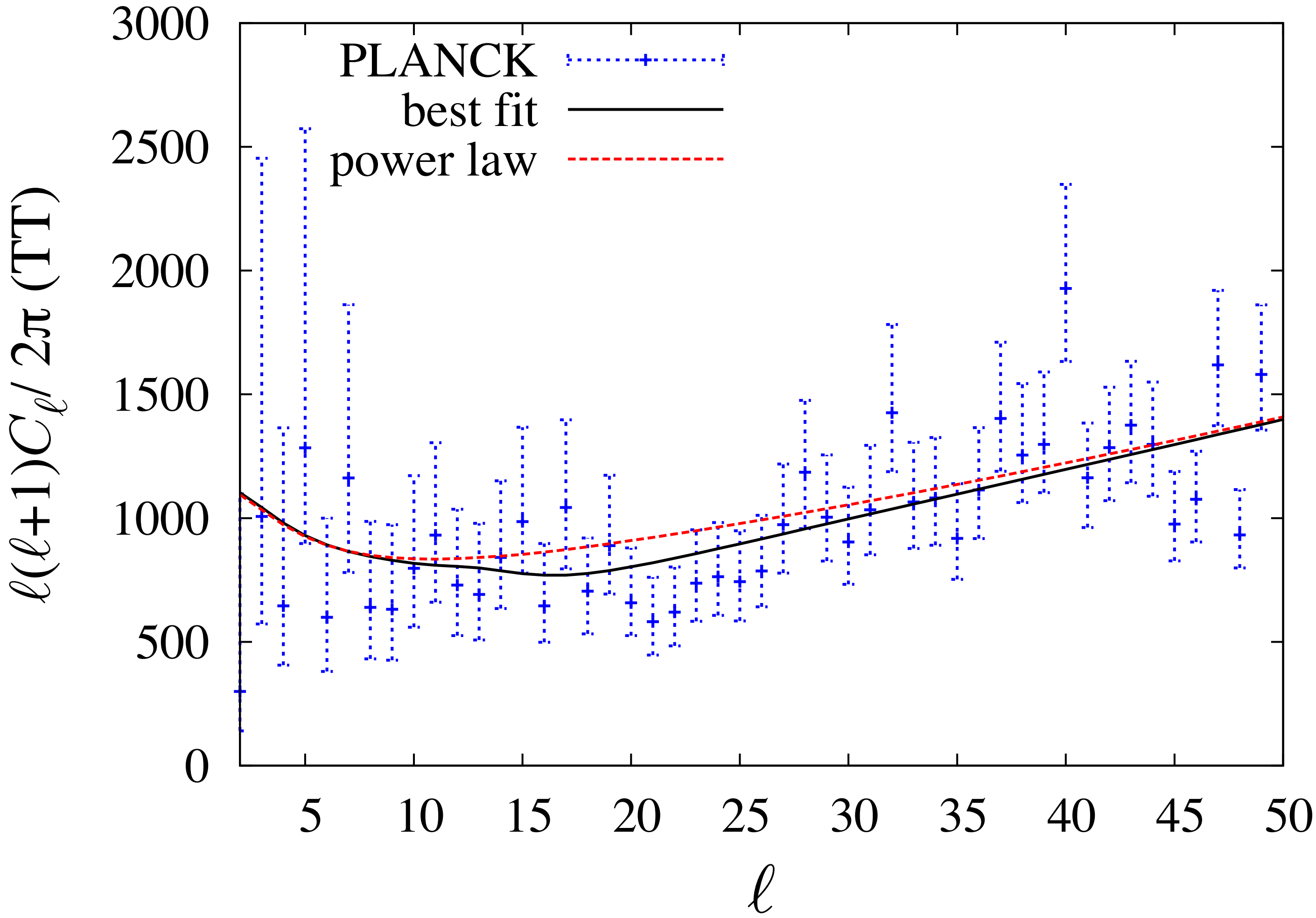
Planck 13



Planck 15



Best Fit Model



Resonant Particle Production

- Early rapid expansion of the universe is achieved through the vacuum energy of the inflaton field
- Inflaton is coupled to the massive particles (mass $\sim$ inflaton field value)[Chung et al. arXiv hep-ph/9910437, Mathews et al. arXiv astro-ph/0406046]
- The total Lagrangian density is given as :

$$
\begin{aligned}
\mathcal{L}_{\text{tot}} &= \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) \\
&+ i\bar{\psi}\gamma^\mu\psi - m\bar{\psi}\psi + N\lambda\phi\bar{\psi}\psi
\end{aligned}
$$

- the fermion has the effective mass :

$$M(\phi) = m - N\lambda\phi$$

- This vanishes for a critical value of the inflaton field, $\phi_* = m/N\lambda$

- The fermion vacuum expectation value is :

$$\langle\bar{\psi}\psi\rangle = n_*\Theta(t - t_*)\exp\left[-3H_*(t - t_*)\right]$$

  where Θ is a step function.

- The modified E.O.M. for the scalar field is:

$$\ddot{\phi} + 3H\dot{\phi} = -V'(\phi) + N\lambda\langle\bar{\psi}\psi\rangle$$

- The density fluctuation when it crosses the Hubble radius in case of simplest slow roll approximation is:

$$\delta_H(k) \approx \frac{H^2}{5\pi\dot{\phi}}$$

- In this case using the above equation for the fluctuation as it exists the horizon the perturbation in the primordial power spectrum is :

$$\delta_H = \frac{[\delta_H(a)]_{N\lambda=0}}{1+\Theta(a-a_*)(N\lambda n_*/|\dot{\phi}_*|H_*)(a_*/a)^3 \ln(a/a_*)}$$

Effect on CMB Power Spectrum

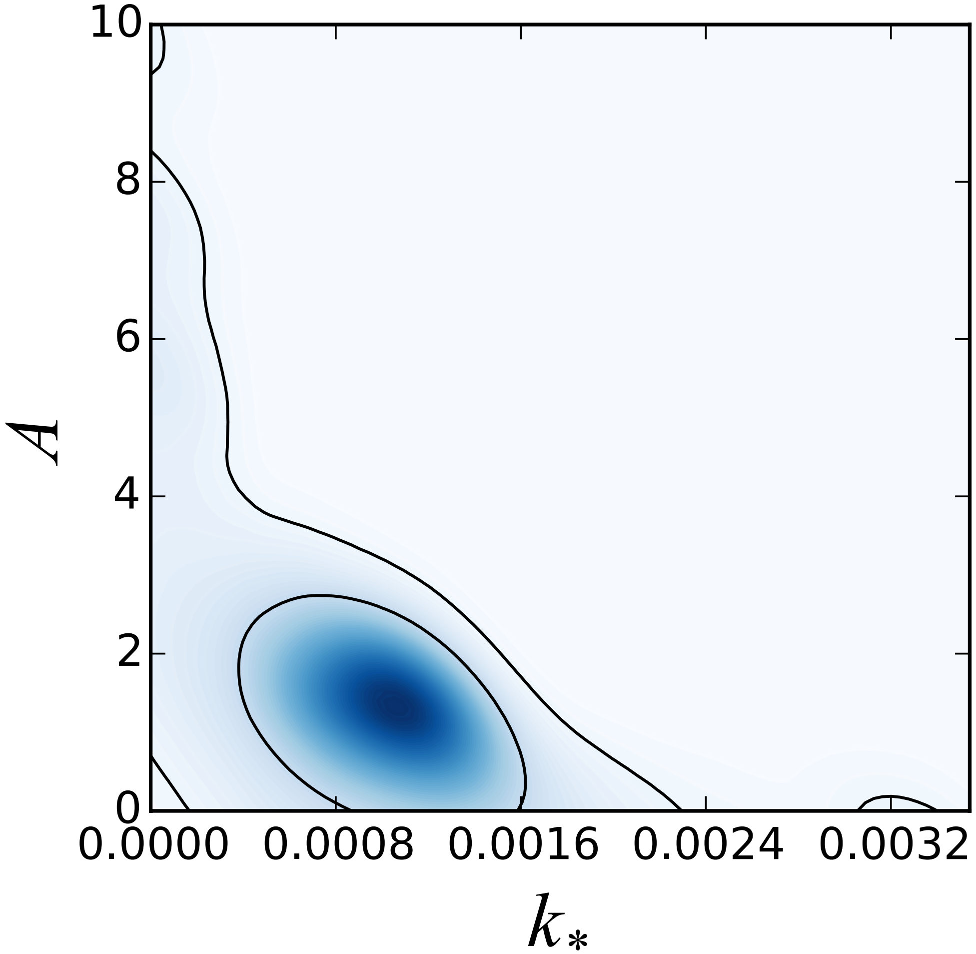
- $k_*/k = a_*/a$
- $\delta_H(k) = \dfrac{[\delta_H(a)]_{N\lambda=0}}{1+\Theta(k-k_*)A(k_*/k)^3\ln(k/k_*)}$
- $k_* \approx \dfrac{\ell_*}{r_{lss}}$
- $A = |\dot{\phi}_*|^{-1} N\lambda n_* H_*^{-1}$
- $\Delta T/T = \sum_l \sum_m a_{lm} Y_{lm}(\theta,\phi)$ $(2 \leq l < \infty$ and $-l \leq m \leq l)$

Analysis

- Multi-dimensional Markov Chain Monte-Carlo analysis is performed using Planck Data and the CosmoMC code
- We have marginalized over five parameters which do not alter the matter or CMB transfer function
- The standard parameters which are varied are: A and k_*, along with the six parameters, $\Omega_b h^2, \Omega_c h^2, \theta, \tau, n_s, A_s$
- n_s and A_s are normalized at $k = 0.05 Mpc^{-1}$

Mathews,Gangopadhyay,Ichiki, Kajino [Phys. Rev. D 92, 123519 (2015)]

Constraints on A and k_*



Mathews, Gangopadhyay, Ichiki, Kajino [Phys. Rev. D 92, 123519 (2015)]

Open RNS Mass Spectrum

- $M = \sqrt{(n/\alpha')}$
- n is the integer eigenvalue of the number operator counting the contribution of the fermionic oscillators .
- The presence of a single open string with a mass $M = \sqrt{(n_0/\alpha')}$ should be accompanied by $n_{-1} = n_0 - 1$…. and $n_{+1} = n_0 + 1$……modes.
- Quadruple Suppression is due to a state with M_{+1}.
- There should be a state with $M_{-1} = \sqrt{[(n_0 - 1)/\alpha']}$.

Number of Oscillations on The String

- $m = N\lambda\phi_*$
- $V(\phi) = \Lambda_\phi m_{pl}^4 \left(\frac{\phi}{m_{pl}}\right)^\alpha$
- $\phi_* = \sqrt{2\alpha\mathcal{N}_*} m_{pl}$
- $\mathcal{N}_* = \frac{1}{m_{\rm pl}^2}\int_{\phi_{end}}^{\phi_*} \frac{V(\phi)}{V'(\phi)} d\phi \; = \mathcal{N} - \ln(k_*/k_H)$
- $M = \sqrt{(n/\alpha')} = N\lambda\phi_* = N\lambda\sqrt{2\alpha}\sqrt{\mathcal{N} - \ln(k_*/k_H)}$
- $M(\ell_*)^2 \propto (\mathcal{N} - \ln(k_*/k_H))$

Mathews,Gangopadhyay,Ichiki, Kajino arXiv:1701.00577 [astro-ph.CO]

Prediction of The Next State

- $$\ln(k_*/k_H) = \mathcal{N} - \left(\frac{n-1}{n}\right)[\mathcal{N} - \ln(k_*(20)/k_H)]$$

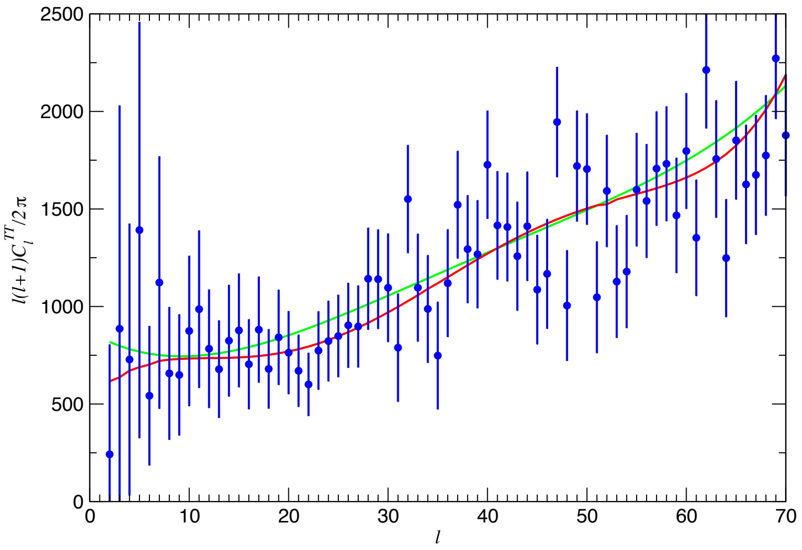
- $$\ell \approx 2,\ A = 1.7 \pm 1.5,\ k_*(2) = 0.00048 \pm 0.00025\ h\ \mathrm{Mpc}^{-1}$$

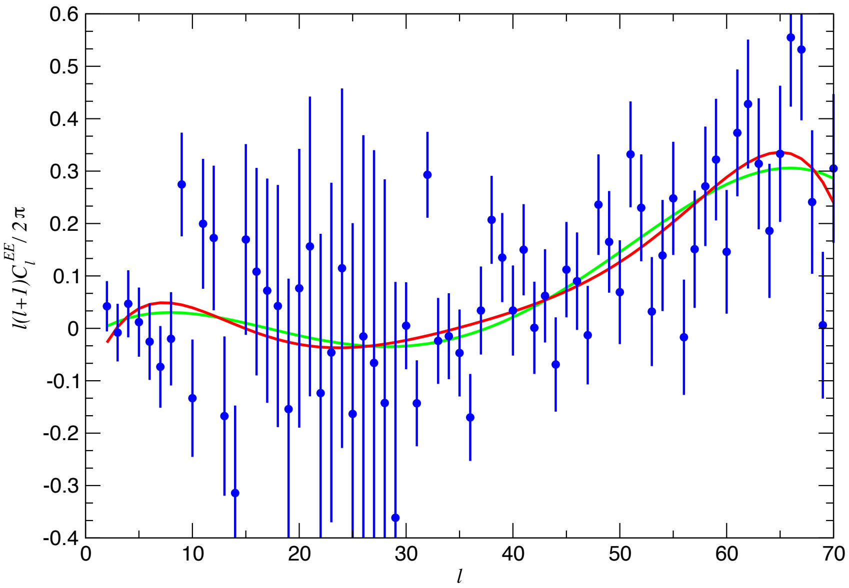
$$\ell \approx 20,\ A = 1.7 \pm 1.5,\ k_*(20) = 0.00149 \pm 0.00045\ h\ \mathrm{Mpc}^{-1}$$

$$\ell \approx 60,\ A = 1.7 \pm 1.5,\ k_* = 0.00462 \pm 0.00035\ h\ \mathrm{Mpc}^{-1}$$

Best Fit Model

- For TT CMB Power Spectrum $\Delta\chi^2$ = - 9
- For EE CMB Power Spectrum $\Delta\chi^2$ = - 5





- $\Delta\mathrm{BIC} \approx \Delta\chi^2 + (p \cdot \ln n)$
- $\Delta\mathrm{BIC} = +0.8$

Conclusions

- We have analyzed the possible dips at $l \approx 2$, 20 and 60 in the Planck CMB power spectrum in the context of a model for the resonant creation of oscillations on a massive strings.
- This can ultimately be limited by cosmic variance.
- But if our analysis is correct, this may be one of the first hints at observational evidence of new particle physics at the Planck scale.
- Precise determination of the CMB power spectrum for multipoles, particularly in the range of $\ell = 2\text{-}\ 100$ will reveal more mysteries (hopefully) in future.