Possible Evidence for Planck-Scale Resonant Particle Production during Inflation from the CMB Power Spectrum

Mayukh Raj Gangopadhyay
University of Notre Dame du Lac

Phenomenology 2015 Symposium
University of Pittsburgh
Pittsburgh, May 4 , 2015

Work done with Dr. G. J. Mathews, Dr. K. Ichiki, Dr. T. Kajino, arXiv: 1504.06913

Presentation Outline

Motivations

Motivations

- Power spectrum of fluctuations in the CMB provides strong constraints on the Physics of the early universe

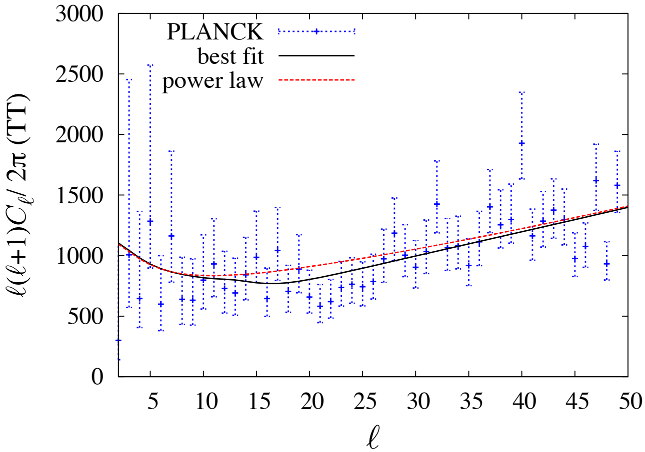
Motivations

- Power spectrum of fluctuations in the CMB provides strong constraints on the Physics of the early universe
- Origin of the primordial power spectrum is based upon quantum fluctuations generated during the inflationary epoch

Motivations

- Power spectrum of fluctuations in the CMB provides strong constraints on the Physics of the early universe
- Origin of the primordial power spectrum is based upon quantum fluctuations generated during the inflationary epoch
- A peculiar feature is observed in the power spectrum near multipole $\ell = 10 - 30$ region by both Planck and WMAP

CMB power spectrum in the range of $\ell = 0 - 50$ points



Inflation Resonant particle Production

Inflation Resonant particle Production

- Early rapid expansion of the universe is achieved through the vacuum energy of the inflaton field

Inflation 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]

Inflation 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 :

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

- Then the fermion has the effective mass :

$$M(\phi) = m - N\lambda\phi \tag{2}$$

- Then the fermion has the effective mass :

$$M(\phi) = m - N\lambda\phi \qquad (2)$$

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

- The fermion vacuum expectation value is :

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

where Θ is a step function.

- The fermion vacuum expectation value is :

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

where Θ is a step function.

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

$$\ddot{\phi} + 3H\dot{\phi} = -V'(\phi) + N\lambda\langle\bar{\psi}\psi\rangle \quad (4)$$

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

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

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

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

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

$$\delta_H = \frac{[\delta_H(a)]_{N\lambda=0}}{1 + \Theta(a - a_*)(N\lambda n_*/|\dot{\phi}_*|H_*)(a_*/a)^3 \ln(a/a_*)} \tag{6}$$

Presentation Outline

Results

Results

- Multi-dimensional Markov Chain Monte-Carlo analysis is performed using Planck Data and the CosmoMC code

Results

- 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

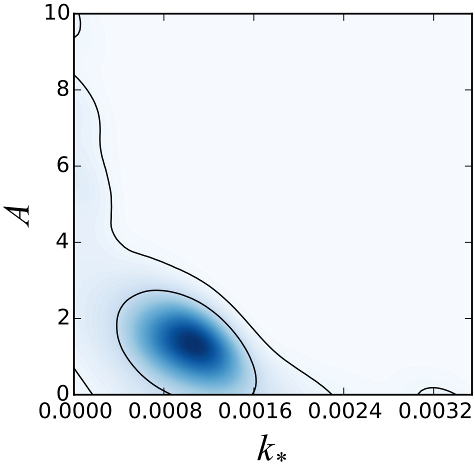
Results

- 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, $\Omega_b h^2, \Omega_c h^2, \theta, \tau, n_s, A_s$

Results

- 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 $k = 0.05 Mpc^{-1}$

Constrains on parameters A and k_*



- From the likelihood contours the mean value of $A = 1.7 \pm 1.5$ with maximum likelihood value of $A = 1.5$ and the mean value of $k_* = 0.0011 \pm 0.0004 hMpc^{-1}$

- From the likelihood contours the mean value of $A = 1.7 \pm 1.5$ with maximum likelihood value of $A = 1.5$ and the mean value of $k_* = 0.0011 \pm 0.0004 hMpc^{-1}$

- The values of A and k_* relate to inflaton coupling λ and fermion mass m for a given inflation model:

$$A = |\dot{\phi}_*|^{-1} N \lambda n_* H_*^{-1} \tag{7}$$

- From the likelihood contours the mean value of $A = 1.7 \pm 1.5$ with maximum likelihood value of $A = 1.5$ and the mean value of $k_* = 0.0011 \pm 0.0004 hMpc^{-1}$

- The values of A and k_* relate to inflaton coupling λ and fermion mass m for a given inflation model:

$$A = |\dot{\phi}_*|^{-1} N \lambda n_* H_*^{-1} \tag{7}$$

- Considering CMB normalization requirement and using Bogoliubov coefficient and SRA, we finally get :

$$A \sim 1.3 N \lambda^{5/2} \tag{8}$$

- We took a general monomial potential:

$$V(\phi) = \Lambda_\phi m_{pl}^4 \left(\frac{\phi}{m_{pl}}\right)^\alpha \tag{9}$$

- We took a general monomial potential:

$$V(\phi) = \Lambda_\phi m_{pl}^4 \left(\frac{\phi}{m_{pl}} \right)^\alpha \tag{9}$$

- The value of ϕ_* is given as:

$$\phi_* = \sqrt{2\alpha N(k_*)} m_{pl} \tag{10}$$

- For $k_* = 0.0011 \pm 0.0004\ h\ \mathrm{Mpc}^{-1}$, and $k_H = a_0 H_0 = (h/3000)$ $\mathrm{Mpc}^{-1} \sim 0.0002$, we have $N - N_* = ln(k_H/k_*) < 1$

- For $k_* = 0.0011 \pm 0.0004\ h\ \mathrm{Mpc}^{-1}$, and $k_H = a_0 H_0 = (h/3000)$ $\mathrm{Mpc}^{-1} \sim 0.0002$, we have $N - N_* = ln(k_H/k_*) < 1$

- $N(k_*) \sim N \sim 50$

- For $k_* = 0.0011 \pm 0.0004\ h\ \mathrm{Mpc}^{-1}$, and $k_H = a_0 H_0 = (h/3000)$ $\mathrm{Mpc}^{-1} \sim 0.0002$, we have $N - N_* = ln(k_H/k_*) < 1$
- $N(k_*) \sim N \sim 50$
- $\alpha = 2$ we have $\phi_* = 14\ m_{pl}$

- For $k_* = 0.0011 \pm 0.0004\ h\ \mathrm{Mpc}^{-1}$, and $k_H = a_0 H_0 = (h/3000)$ $\mathrm{Mpc}^{-1} \sim 0.0002$, we have $N - N_* = ln(k_H/k_*) < 1$

- $N(k_*) \sim N \sim 50$

- $\alpha = 2$ we have $\phi_* = 14\ m_{pl}$

- $\alpha = 4$ we have $\phi_* = 20\ m_{pl}$.

- For $k_* = 0.0011 \pm 0.0004\ h\ \mathrm{Mpc}^{-1}$, and $k_H = a_0 H_0 = (h/3000)$ $\mathrm{Mpc}^{-1} \sim 0.0002$, we have $N - N_* = ln(k_H/k_*) < 1$
- $N(k_*) \sim N \sim 50$
- $\alpha = 2$ we have $\phi_* = 14\ m_{pl}$
- $\alpha = 4$ we have $\phi_* = 20\ m_{pl}$.
- $N\lambda \approx 1$, we obtain $m \sim 10\ m_{pl}$

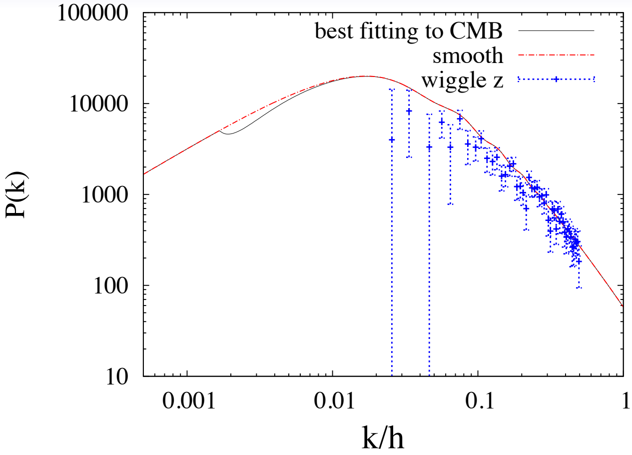


Figure: Comparison of the observed galaxy cluster function with the spectrum implied from the fits to the matter power spectrum with (solid line) and without (dashed line) resonant particle creation during inflation

Presentation Outline

Conclusions

Conclusions

- We have analyzed the CMB power spectrum in the context of a model for creation of N nearly degenerate Planckian-mass fermions during inflation

Conclusions

- We have analyzed the CMB power spectrum in the context of a model for creation of N nearly degenerate Planckian-mass fermions during inflation
- Marginal evidence for excess power in the Planck CMB power spectrum consistent with the hypothesis

Conclusions

- We have analyzed the CMB power spectrum in the context of a model for creation of N nearly degenerate Planckian-mass fermions during inflation
- Marginal evidence for excess power in the Planck CMB power spectrum consistent with the hypothesis
- Optimum feature at $k_* = 0.0011 \pm 0.0004\ h\ \mathrm{Mpc}^{-1}$ and $A \approx 1.7 \pm 1.5$

- Resonant creation of nearly degenerate particles with $m \sim 15 M_{Pl}$

- Resonant creation of nearly degenerate particles with $m \sim 15 M_{Pl}$
- This can ultimately be limited by the cosmic variance

- Resonant creation of nearly degenerate particles with $m \sim 15 M_{Pl}$
- This can ultimately be limited by the 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

Thank You