arXiv : 1105. 2398

Fine Feature in the Primordial Power Spectrum

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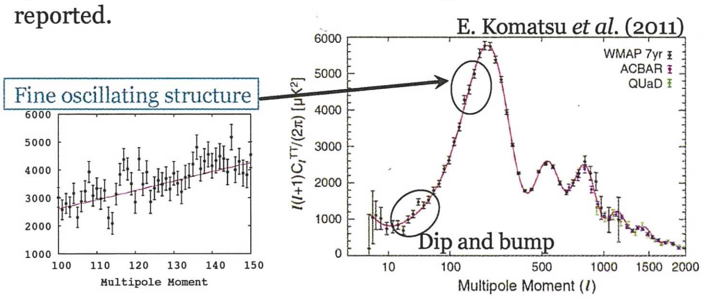
Introduction

The small characteristic features in the temperature power spectrum of the Cosmic Microwave Background have been reported.

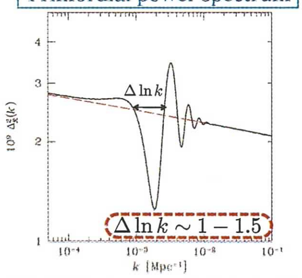


There are many attempts to explain such features about $\ell = 20 \sim 40$. For example, it can be explained due to the temporarily breaking off from the slow-roll dynamics of the inflaton field.

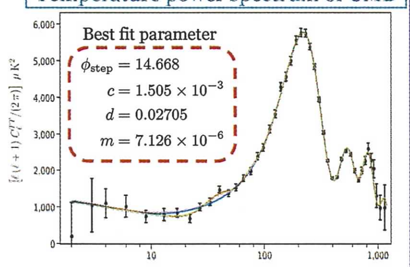
$$V(\phi) = \frac{1}{2} m_{\rm eff}^2(\phi)\,\phi^2, \qquad \text{J. Adams et al. (2001)}$$

$$m_{\rm eff}^2(\phi) = m^2 \left[1 + A \tanh\left(\frac{\phi - \phi_{\rm step}}{d}\right)\right].$$

Using this potential, the fine oscillation is generated on the primordial power spectrum. This oscillation gives the fine feature on the temperature spectrum at $\ell = 20 \sim 40$.



M. J. Mortonson et al. (2009)



D. K. Hazra et al. (2010)

It should be noted that the width of an oscillation in the primordial power spectrum is approximately $\Delta \ln k \sim 1 - 1.5$ in order to match the structure around $\ell = 20 \sim 40$. While, in order to match the structure around $\ell = 100 \sim 150$, the width is about $\Delta \ln k \sim 0.04$, which is much finer. K. Ichiki et al. (2010)

We investigate other possibilities of generating the fine feature of the primordial power spectrum by modifying the inflaton potential. We expect that the shorter the time scale of mass transition is, the finer the structure becomes.

Our claim

It turns out that it is hardly possible to recover the observed fine structure at $\ell = 100 \sim 150$ with simultaneously satisfying the width and the amplitude.

Formulae

E. D. Stewart (2001)

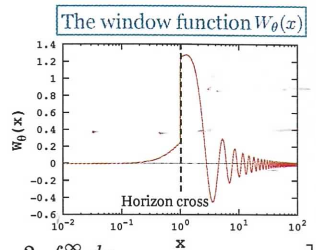
The time evolution of the curvature perturbation $\mathcal{R}_c$.

$$\frac{d^2 v_k}{d\tau^2} + \left(k^2 - \frac{1}{z}\frac{d^2 z}{d\tau^2}\right) v_k = 0 \qquad v_k \equiv z\mathcal{R}_c(k) \qquad z \equiv \frac{a\dot\phi}{H}$$

We introduce new variables,

$$y = \sqrt{2k}\,v_k \qquad x = -k\tau$$

$$f \equiv zx$$



Using this variables, the power spectrum of the comoving curvature perturbation is given by

$$\mathcal{P}_{\mathcal{R}}(k) = \left(\frac{k}{2\pi}\right)^2 \frac{1}{f_\star^2}\left[1 + \frac{2}{3}\left(\frac{f'}{f}\right)_\star + \frac{2}{3}\int_0^\infty \frac{du}{u} W_\theta(u) g(u) + \mathcal{O}(g^2)\right]$$

$$W_\theta(x) \equiv W(x) - \theta(x_\star - x) \qquad \theta(x) = \begin{cases} 1 & (0 < x) \\ 0 & (0 > x). \end{cases}$$

$$W(x) \equiv \frac{3\sin(2x)}{2x^3} - \frac{3\cos(2x)}{x^2} - \frac{3\sin(2x)}{2x}$$

Most dominant term

$$g(x) = \frac{f'' - 3f'}{f} = aH\tau\left[\frac{3}{2}\frac{\dot\phi^2}{H^2} + \frac{\dot\phi^4}{2H^4} + \frac{V_{\phi\phi}}{H^2} + \frac{\dot\phi V_\phi}{2H^3}\right] \qquad ' = \frac{d}{d\ln x}$$

We focus on the relation between the fine structure of the primordial power spectrum and the form of the source function $g(x)$.

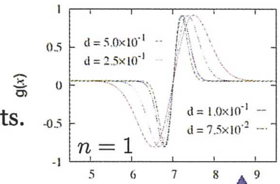
Result & Conclusion

We separate $g(x)$ into two components.

$$g(x) = g_{\rm GSR}(x) + g_{\rm gap}(x)$$

This term produces a power law component in the primordial power spectrum.

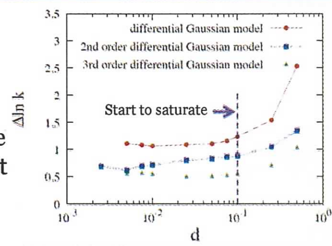
This term produces a fine structure in the primordial power spectrum.

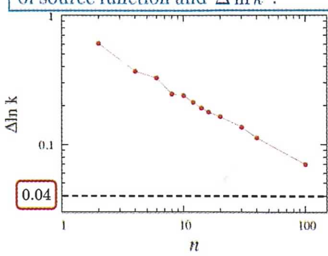


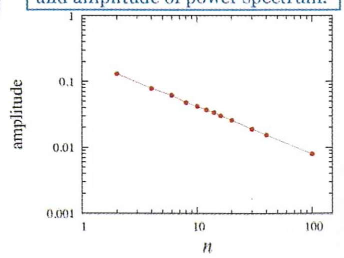
Model : nth order differential Gaussian

$$g_{\rm gap}(x) = A \exp\left[-\frac{(x-b)^2}{d}\right] \sum_{i=0}^{[n/2]} \frac{n!(-d)^{i-n}}{i!(n-2i)!}\{2(x-b)\}^{n-2i} \quad \text{for } n = 1, 2, \cdots$$

We show the dependence of the $\Delta \ln k$ on the parameter d. In fact, $\Delta \ln k$ decreases as d decreases for $d \gtrsim 1.0 \times 10^{-1}$. However, $\Delta \ln k$ starts to saturate for $d \lesssim 1.0 \times 10^{-1}$. It turns out that it is very difficult to realize the observed width in this case.







Next, we investigate higher order differential Gaussian models with $n \geq 2$. We find that the width of the structure becomes finer for higher order models. And we push the number of differentiation n much further up to 100. We can almost reach the observed value $\Delta \ln k = 0.04$. However, there is a caveat. If we take n to be a large number, the amplitude of the primordial power spectrum becomes smaller. It is too small to explain the observed structure.