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SPRING SCHOOL ON SUPERSTRING THEORY AND RELATED TOPICS

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Brane Inflation
PART 4

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Brane inflation

IV. More on the KKLMMT scenario :

Seiberg duality cascade
and its possible observational consequences

Henry Tye

with Girma Hailu
hep-th/0611353 (to be revised/expanded)

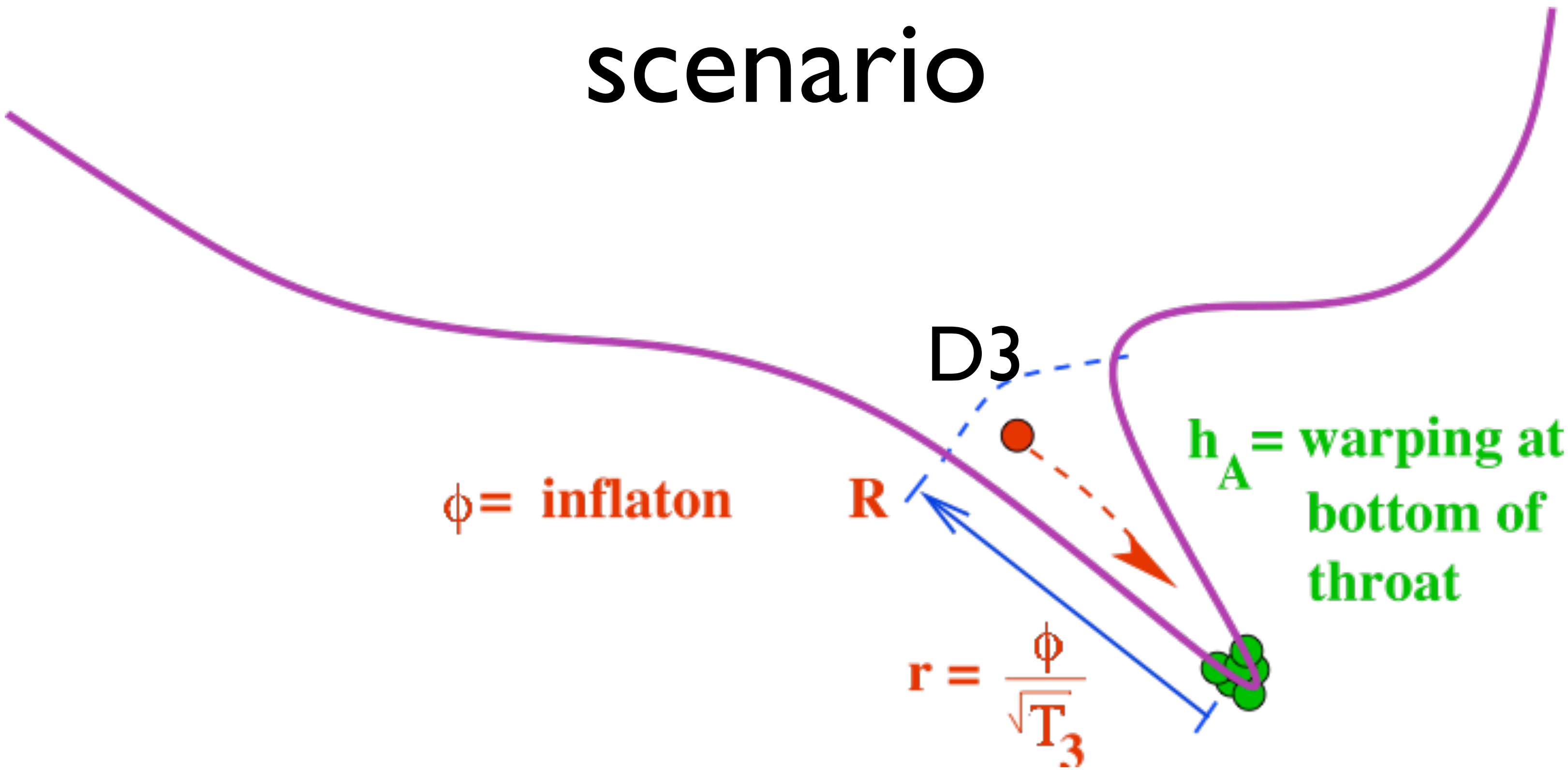
with X. Chen, G. Hailu, J. Xu, R. Bean
in progress

ICTP, Trieste 3/24/07

Recall

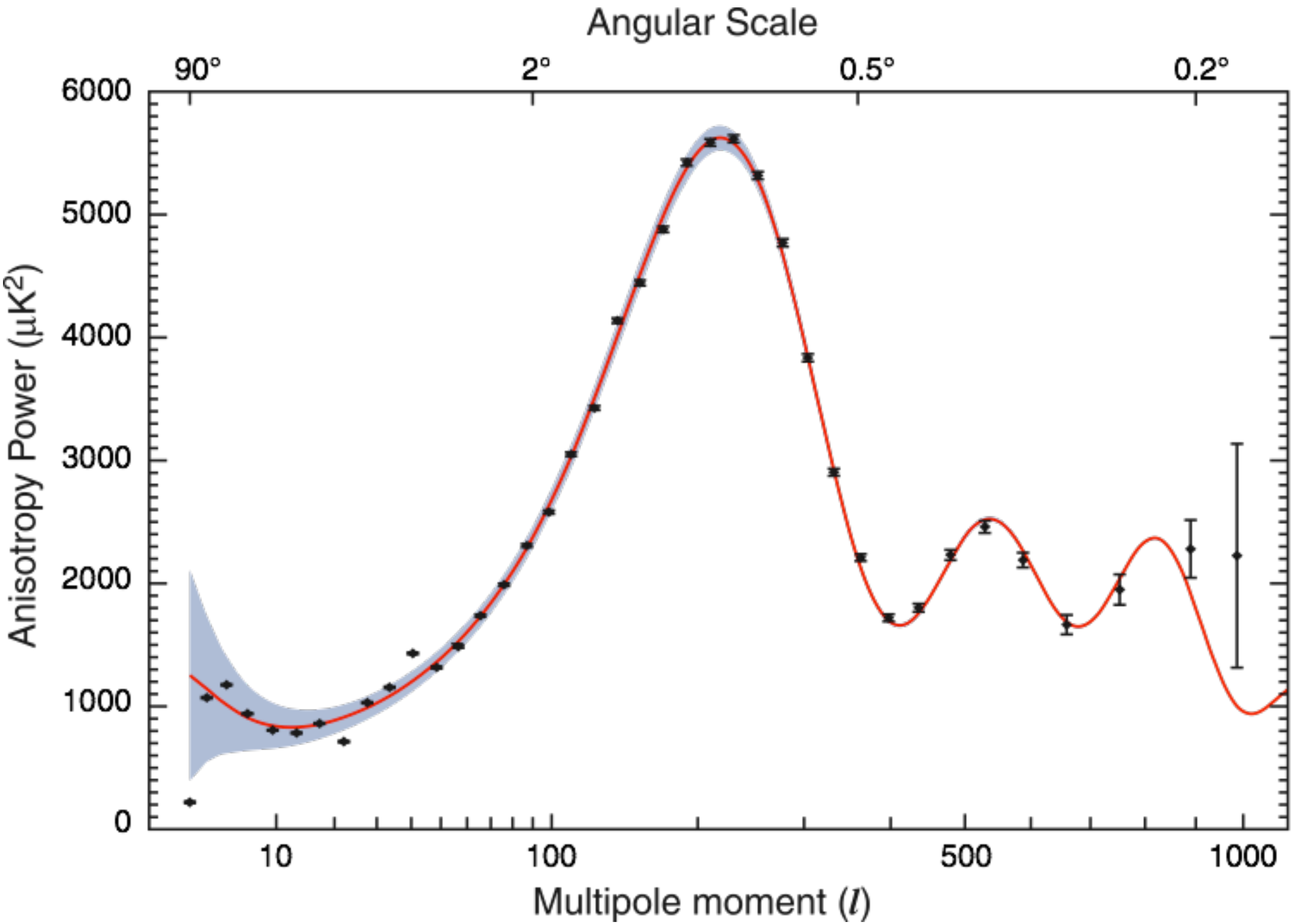
- We are looking for inflationary scenarios in string theory that fit existing data and predict new distinctive stringy features that may be tested in the near future.
- (1) Non-gaussianity due to DBI action, (2) large tensor mode in CMB that deviates from the slow-roll prediction and (3) cosmic strings.
- In comparison with WMAP and other data so far, the KKLMMT slow-roll scenario seems to work best.

Recall the KKLMMT slow-roll scenario



Is there any distinctive stringy signature in this scenario ?

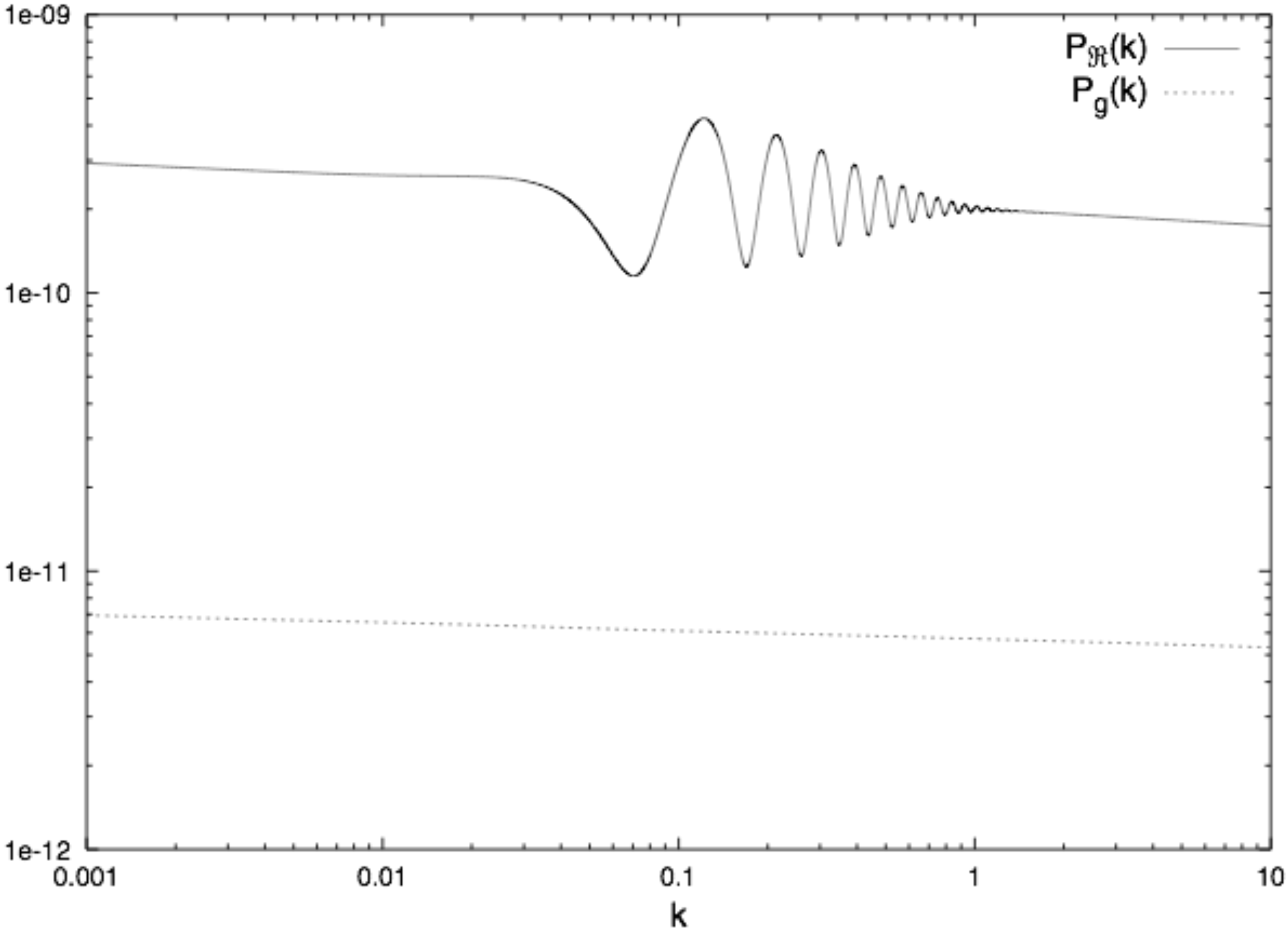
WMAP 2006



Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
Anisotropy Power (μK²)
10
100
500
1000
Multipole moment (l)

Inflaton going over a step

$$\frac{\delta\rho}{\rho} \sim \frac{H^2}{\dot{\phi}}$$



J. Adams, B. Cresswell, R. Easther, astro-ph/0102236

Step in chaotic inflation

$$V(\phi) = \frac{1}{2}m^2\phi^2\left(1 + c\tanh\left(\frac{\phi - b}{d}\right)\right)$$

$$\frac{\ddot{a}}{a} = H^2(1-\epsilon) \qquad \epsilon \sim 10^{-2} \qquad \epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2$$

$$\frac{c}{\epsilon} \simeq 1/5 \quad \Rightarrow \quad c = \frac{\delta V}{V} \sim 10^{-3}$$

Power spectrum

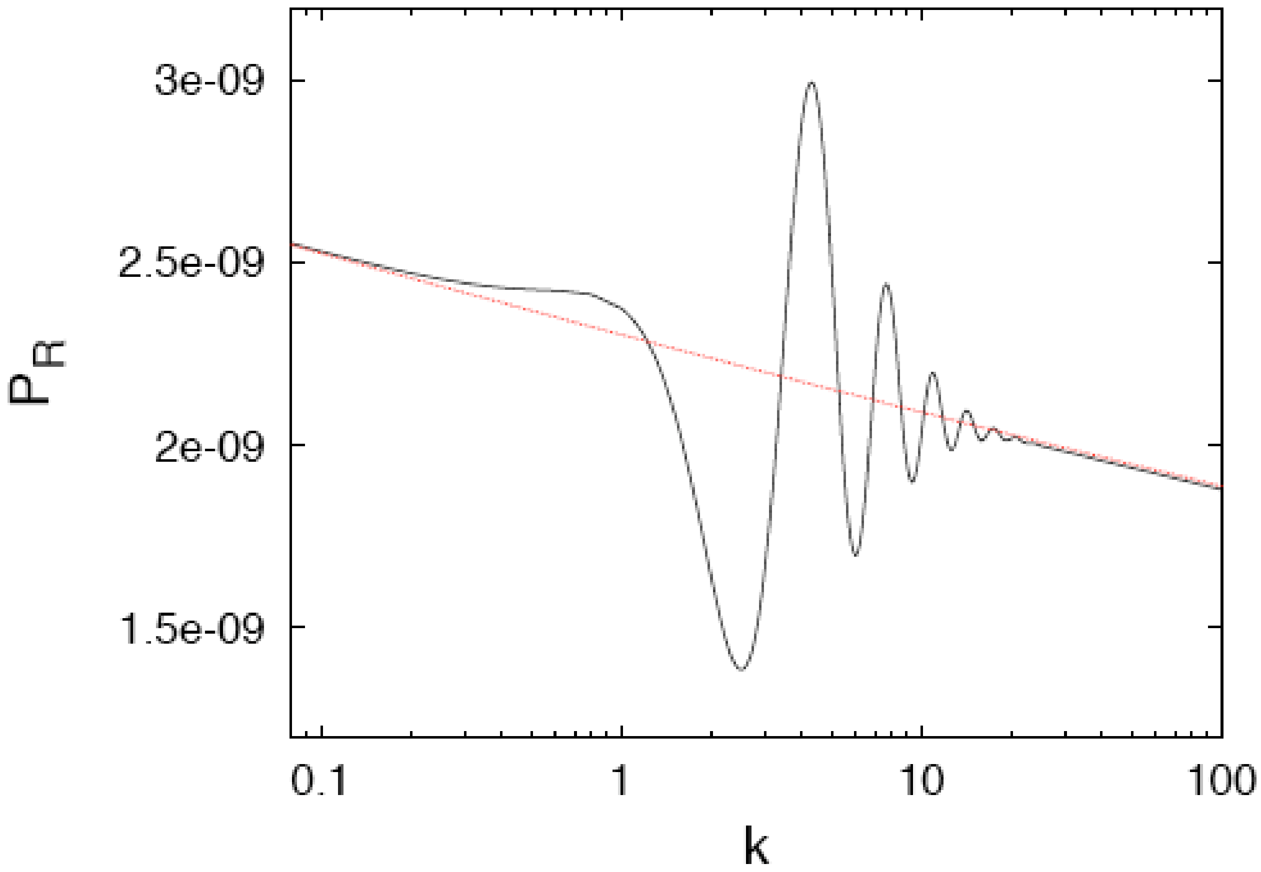


FIG. 3: Primordial power spectrum for a model with $m = 7.5 \times 10^{-6}$, $b = 14$, $c = 10^{-3}$ and $d = 2 \times 10^{-2}$ (solid black line) with wavenumber k given in units of $aH|_{\phi=b}$. The dotted red line depicts the spectrum of the same model with c set to zero.

Step fitting

$$\delta\chi^2 = 15$$

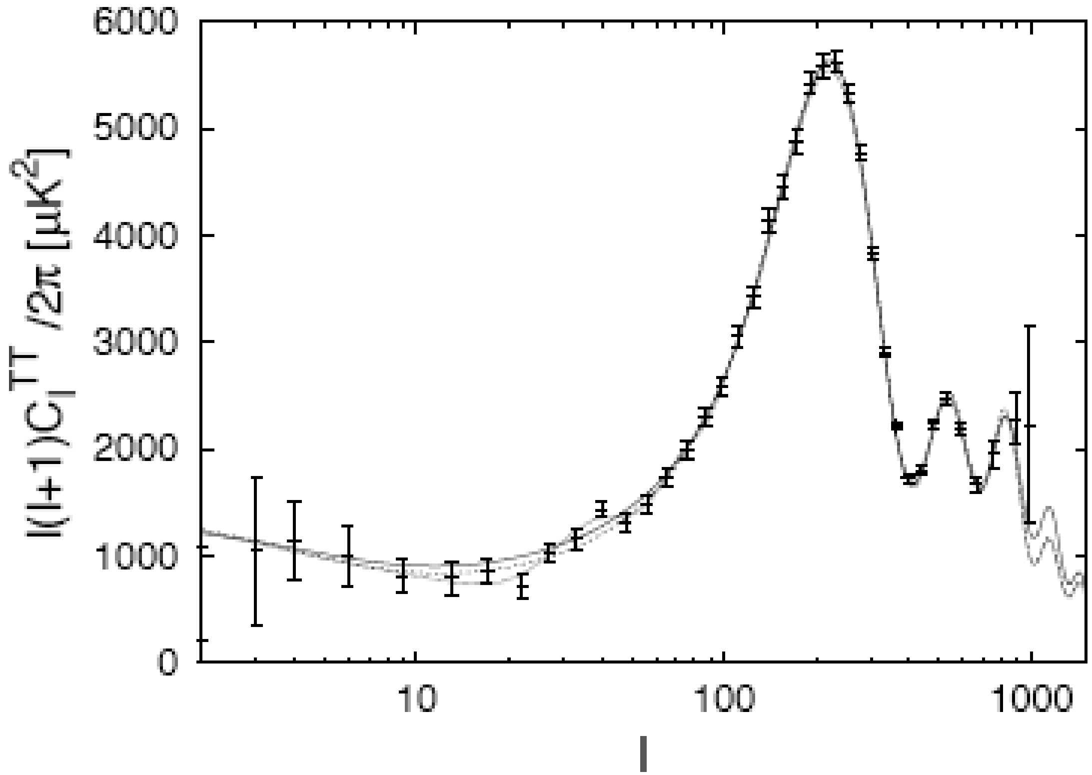


FIG. 3: This plot shows the temperature anisotropy angular power spectrum of the best fit step model (WMAP only, solid line) and, for reference, the best fit 6 parameter power law ΛCDM model (dashed line). The dotted line shows the effect of a feature near $b = 14.8$ for WMAP data only, i.e., the "local" best fit at the lower peak in Figure 2.

L. Covi, J. Hamann, A. Melchiorri, A. Slosar, L. Sorbera, astro-ph/0606452

Bringing back the dilaton in brane inflation

$$\phi = \sqrt{T_3} r$$

$$S_{D3} = \int d^4 x a^3(t) \left[T_3 h^4(\phi) \left(-e^{-\Phi} \sqrt{1 - \dot{\phi}^2 / h^4(\phi)} + 1 \right) - V_{D\bar{D}} \right]$$

$$\Rightarrow$$

$$S_{D3} \approx \int dx^4 a^3(t) \left[e^{-\Phi} \frac{\dot{\phi}^2}{2} - T_3 h^4(\phi)(e^{-\Phi} - 1) - V_{D\bar{D}} \right]$$

KS case $\rightarrow \Phi = 0$

A. Dymarsky, I. Klebanov, N. Seiberg, hep-th/0511254

The new term

$$V_{D3} = T_3 h^4(\phi)(e^{-\Phi(\phi)} - 1)$$

KS case $\quad \rightarrow \Phi = 0 \qquad\qquad V_{D3} = 0$

If the dilaton runs and the warp factor has steps, then the inflaton potential has steps.

Strategy

- argue that the anomalous mass dimension has a correction that depends on which step the RG flow is at
- this means that the coupling flows depend on which step the RG flow is at
- Using gauge/gravity duality, we see that the dilaton runs and it has a kink at the position where Seiberg duality transition takes place
- this leads to steps in the warp factor
- which then leads to steps in the inflaton potential

Gauge/gravity duality

$$SU(N+M)\times SU(N)$$

$$T_i = 8\pi^2/g_i^2$$

$$(\Box, \bar{\Box}) \qquad (\bar{\Box}, \Box)$$

$$W_{\rm tree} = w\Big((A_1B_1)(A_2B_2) - (A_1B_2)(A_2B_1)\Big)$$

$$\beta_1 = \mu\frac{dT_1(1)}{d\mu} = 3(N+M) - 2N(1-\gamma_1(1))$$

$$\beta_2 = \mu\frac{dT_2(1)}{d\mu} = 3N - 2(N+M)(1-\gamma_2(1))$$

$$\beta_\eta = \mu\frac{d\eta(1)}{d\mu} = 1 + 2\gamma_\eta(1)$$

$$M = 0 \rightarrow \gamma = -1/2$$

Klebanov-Witten model

The warped geometry

$$H(r) = h^{-4}(r)$$

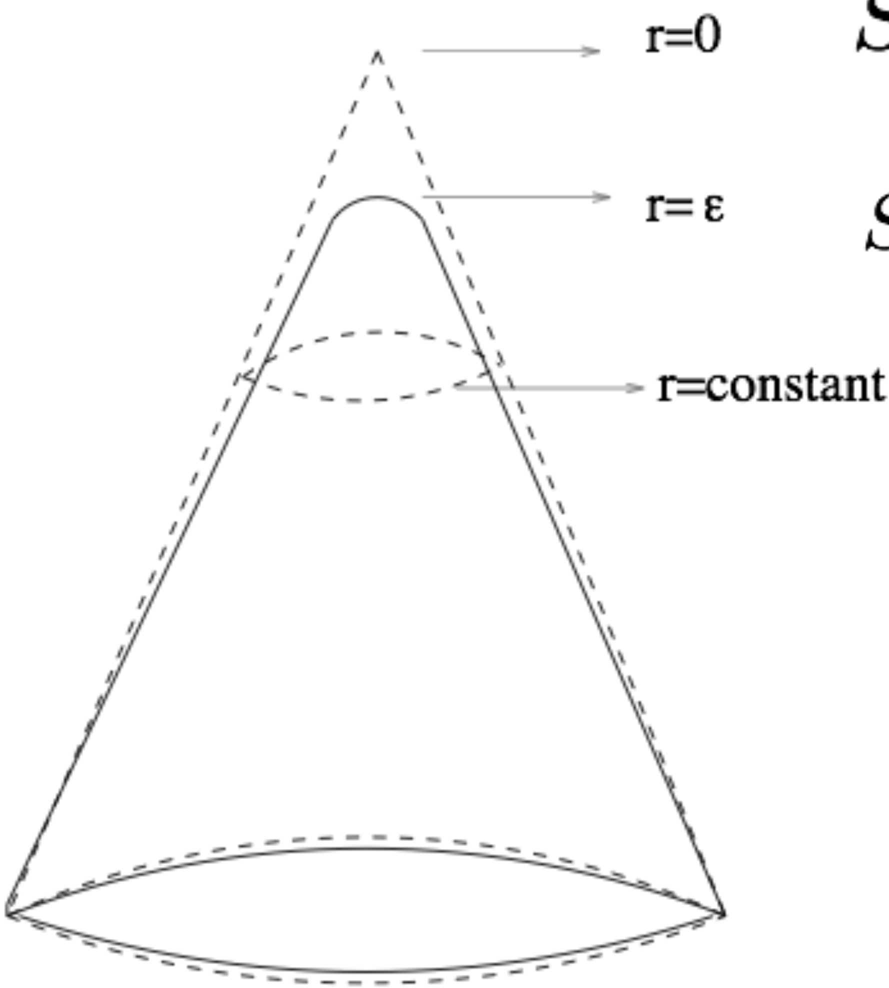
$$ds^2 = H^{-1/2}(r)(-dt^2 + a(t)^2 d\mathbf{x}^2) + H^{1/2}(r)(dr^2 + r^2 ds^2_{T^{1,1}})$$

$$M = 0 \to H(r) \simeq \frac{27\pi\alpha'^2 g_s N}{4r^4}$$

$$H(r) \simeq \frac{27\pi\alpha'^2}{4r^4}\left(g_s N + \frac{3}{2\pi}(g_s M)^2[\ln(r/r_0) + 1/4]\right)$$

$$N = KM \qquad r_l \sim r_0 \exp\left(-\frac{2l\pi}{3g_s M}\right)$$

Warped deformed conifold



$$SU(N) \times SU(N)$$

$$SU(N+M) \times SU(N)$$

$$S^3 \times S^2$$

$$T^{1,1} \sim \frac{SU(2) \times SU(2)}{U(1)}$$

Klebanov-Strassler throat

$$SU((K+1)M) \times SU(KM) \qquad r = r_0$$

$$\downarrow \qquad l = 1$$

$$SU((K-1)M) \times SU(KM) \qquad r = r_1$$

$$\downarrow \qquad l = 2$$

$$SU((K-1)M) \times SU((K-2)M) \qquad r = r_2$$

$$\downarrow \qquad \downarrow$$

....

....

$$\downarrow$$

$$SU(2M) \times SU(M)$$

Anomalous mass dimension

$$\beta_1 = \mu \frac{dT_1(1)}{d\mu} = 3(N+M) - 2N(1-\gamma_1(1)) \qquad \gamma_1(1) = -\frac{1}{2} - \frac{3}{2}\frac{M}{N}$$

$$\beta_2 = \mu \frac{dT_2(1)}{d\mu} = 3N - 2(N+M)(1-\gamma_2(1)) \qquad \gamma_2(1) = -\frac{1}{2} + \frac{3}{2}\frac{M}{N+M}$$

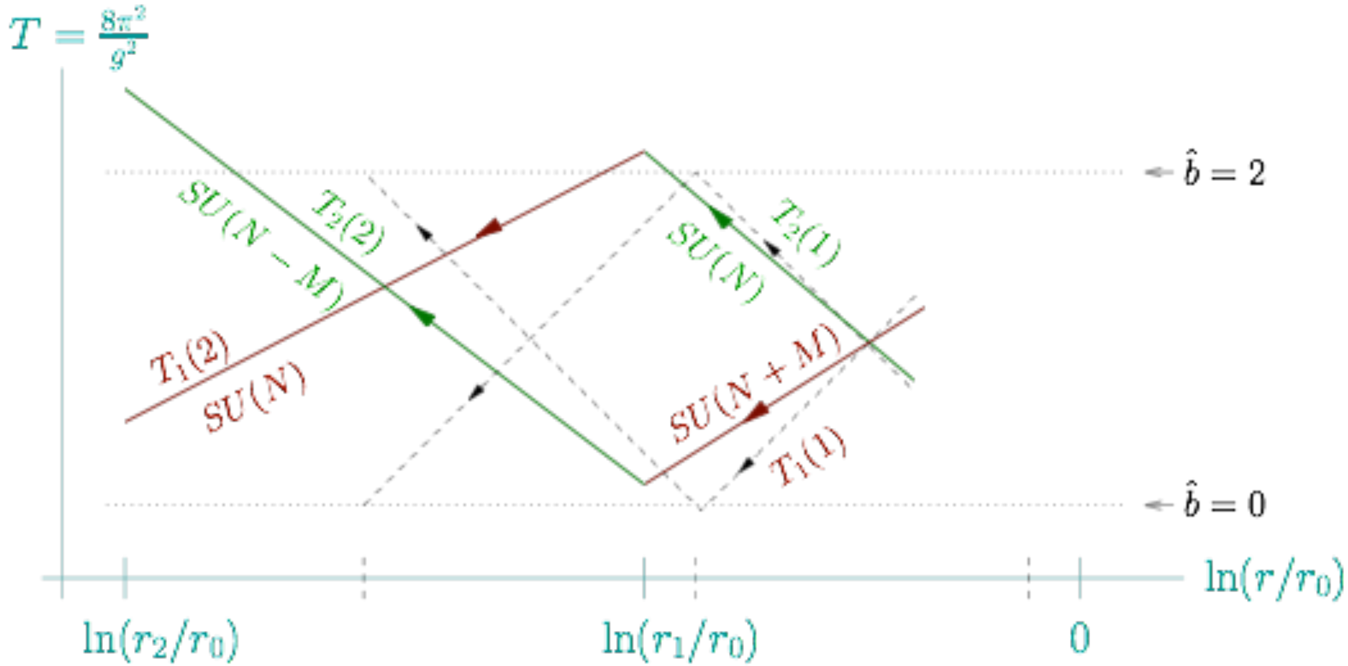
$$N = KM$$

$$\gamma(1) = -\frac{1}{2} - \frac{3}{4}\frac{M^2}{N(N+M)}$$

$$T_1 + T_2 = \frac{2\pi}{g_s e^{\Phi}} \qquad b_2 \equiv \frac{1}{2\pi^2\alpha'}\int_{S^2} B_2$$

$$T_1 - T_2 = \frac{2\pi}{g_s e^{\Phi}}(\hat{b} - 1) \qquad \hat{b} = b_2 \pmod 2$$

RG flow and Seiberg duality transition



SUGRA equations

$$d\star d\Phi = g_s^2 e^{2\Phi} F_1 \wedge \star F_1 - \frac{1}{2} e^{-\Phi} H_3 \wedge \star H_3 + \frac{1}{2} g_s^2 e^{\Phi} \tilde{F}_3 \wedge \star \tilde{F}_3,$$

$$d\star (e^{2\Phi} F_1) = -e^{\Phi} H_3 \wedge \star \tilde{F}_3,$$

$$d\star (e^{\Phi} \tilde{F}_3) = F_5 \wedge H_3,$$

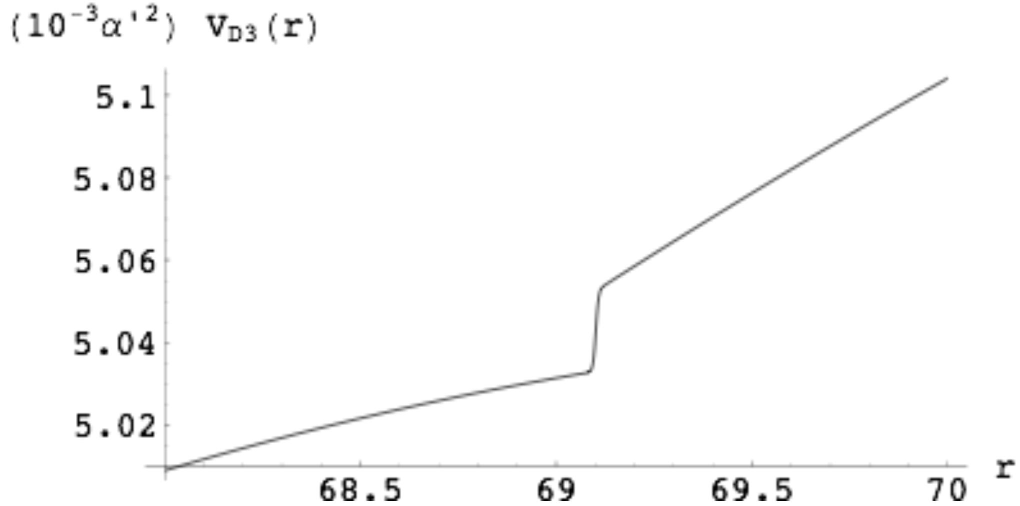
$$d\star (e^{-\Phi} H_3 - g_s^2 C_0 e^{\Phi} \tilde{F}_3) = -g_s^2 F_5 \wedge F_3.$$

$$d\tilde{F}_5 = H_3 \wedge F_3.$$

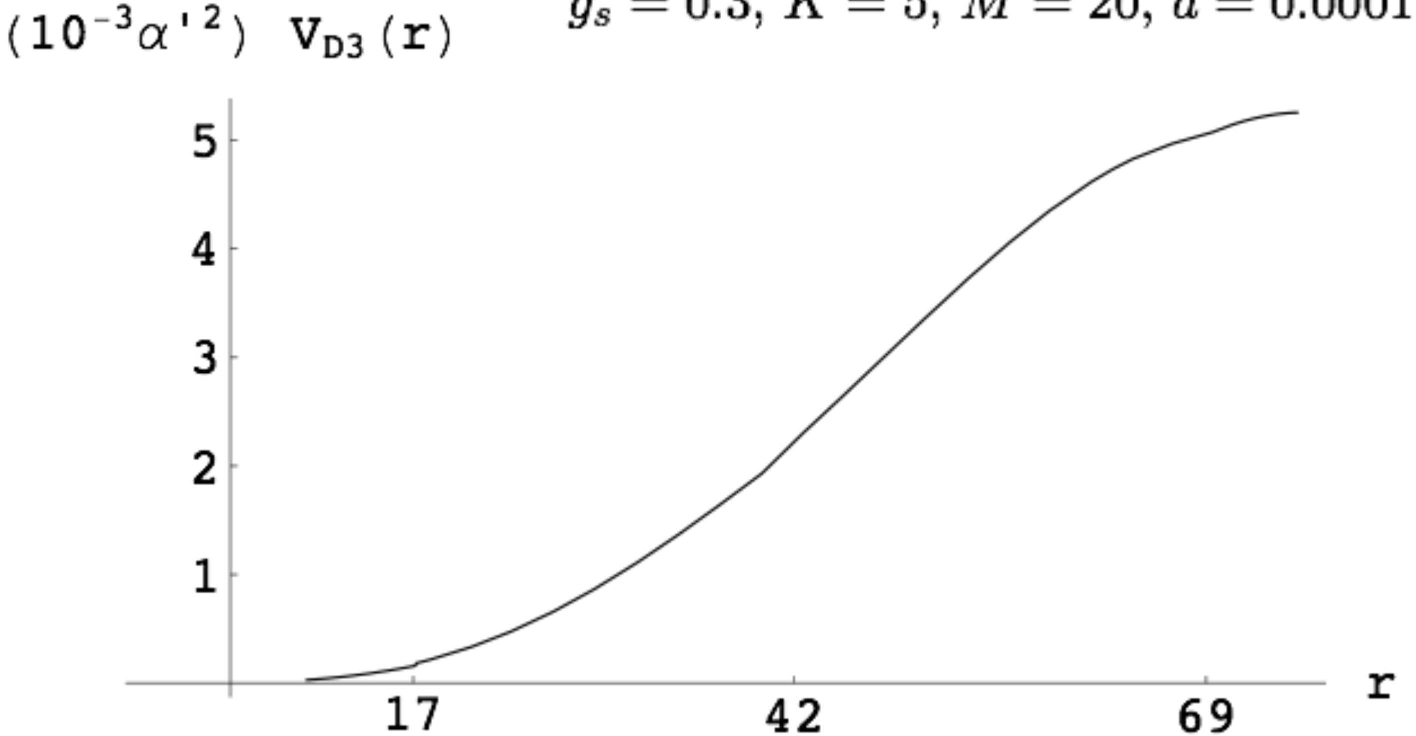
$$R = \frac{1}{2}(\partial\Phi)^2 + \frac{1}{2} g_s^2 e^{2\Phi} (\partial C_0)^2 + \frac{1}{24} e^{-\Phi} H_3^2 + \frac{1}{24} g_s^2 e^{\Phi} \tilde{F}_3^2.$$

D3-potential

$$V_{D3}(r) = T_3 h^4(r)\left(e^{-\Phi} - 1\right)$$



$g_s = 0.3$, $K = 5$, $M = 20$, $d = 0.0001$ and $r_0 = 100$



Estimate

$$N = KM$$

$$\Delta V \simeq \frac{4T_3 r_1^4}{81\pi\alpha'^2 g_s N}\frac{1}{K^4}$$

$$\frac{\Delta V}{V} \simeq \frac{1}{3K^3}$$

$$\to \frac{1}{3(K-1)^3} \to \frac{1}{3(K-2)^3}$$

Large vs small inflaton field

Chaotic inflation :
large field

$$\frac{\phi}{M_{Pl}} \gg 1$$

$$\eta \sim \epsilon$$

$$\phi \sim 15 \qquad \epsilon \sim 10^{-2}$$

Brane inflation :
small field

$$\frac{\phi}{M_{Pl}} \ll 1$$

$$\eta \gg \epsilon$$

$$\epsilon = \frac{1}{2}(\frac{V'}{V})^2$$

In modified KKLMMT inflation

$$\epsilon \sim 10^{-3} \to 10^{-11}$$

$$\frac{c}{\epsilon} \simeq 1/5$$

$$c \sim 10^{-4} \to 10^{-12}$$

$$c \sim \frac{1}{3K^3}$$

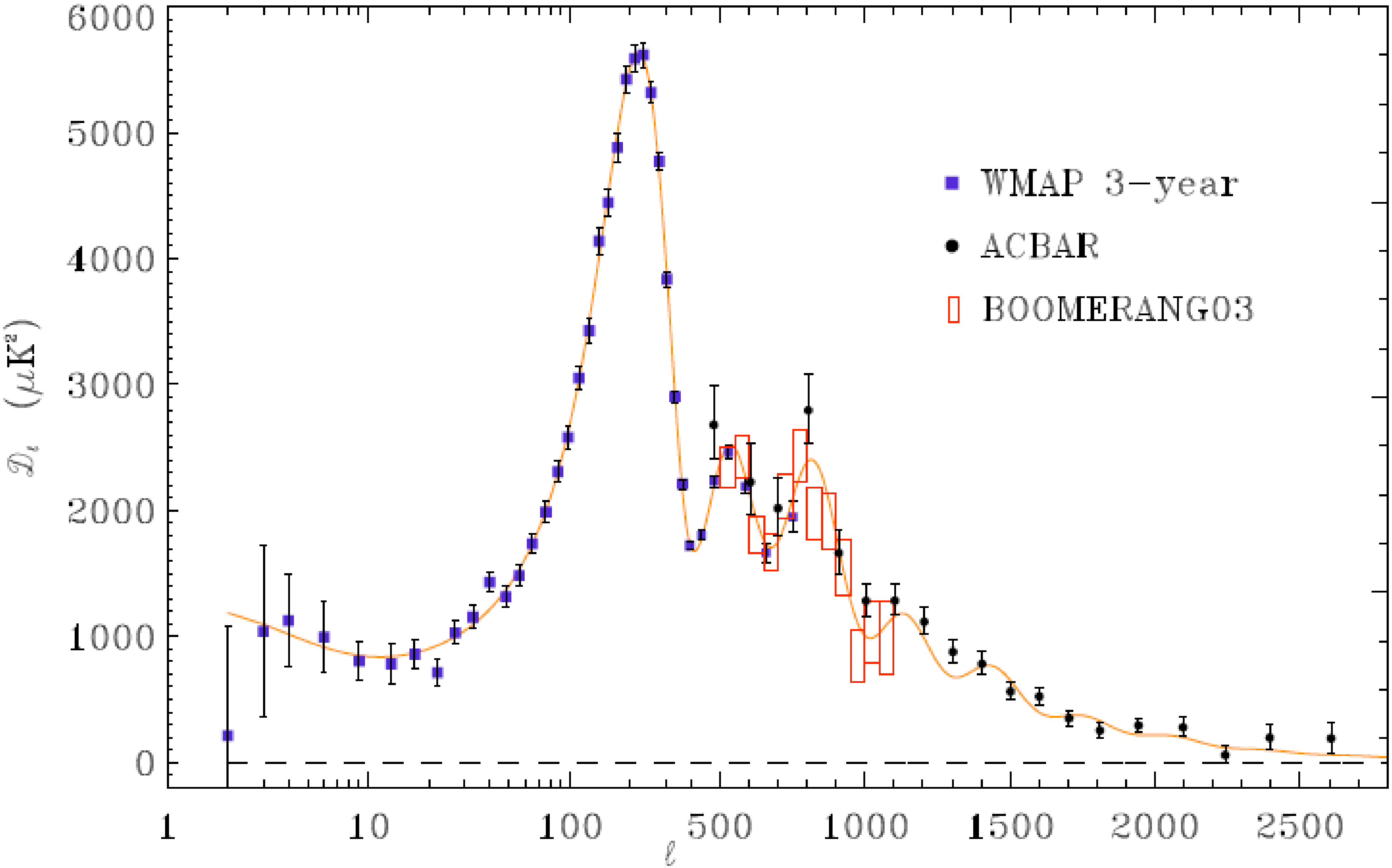
$$K \sim 15 \to 10^4$$

Predictions

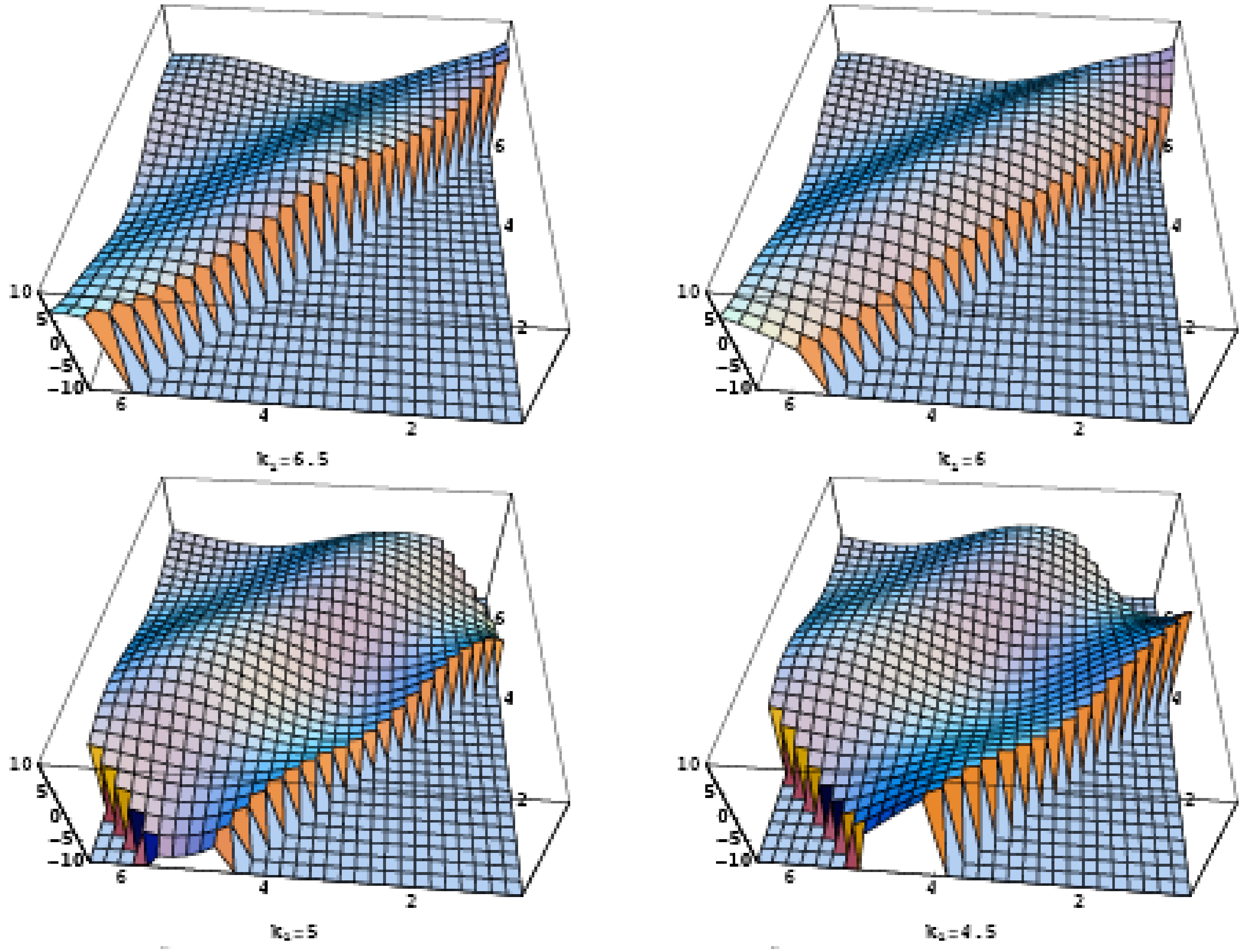
- After fitting the feature at l ~ 30 in WMAP data,

  - it predicts additional steps : their positions, their heights and their widths
  - it predicts non-Gaussianity features due to the steps

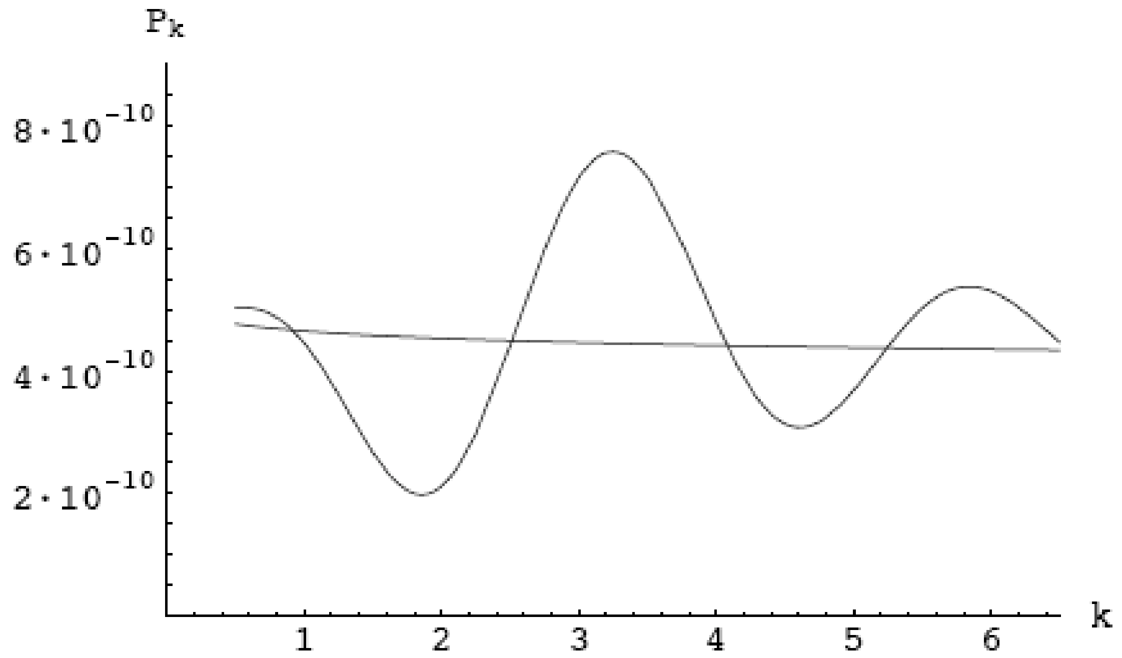
Data at high k (l) will improve



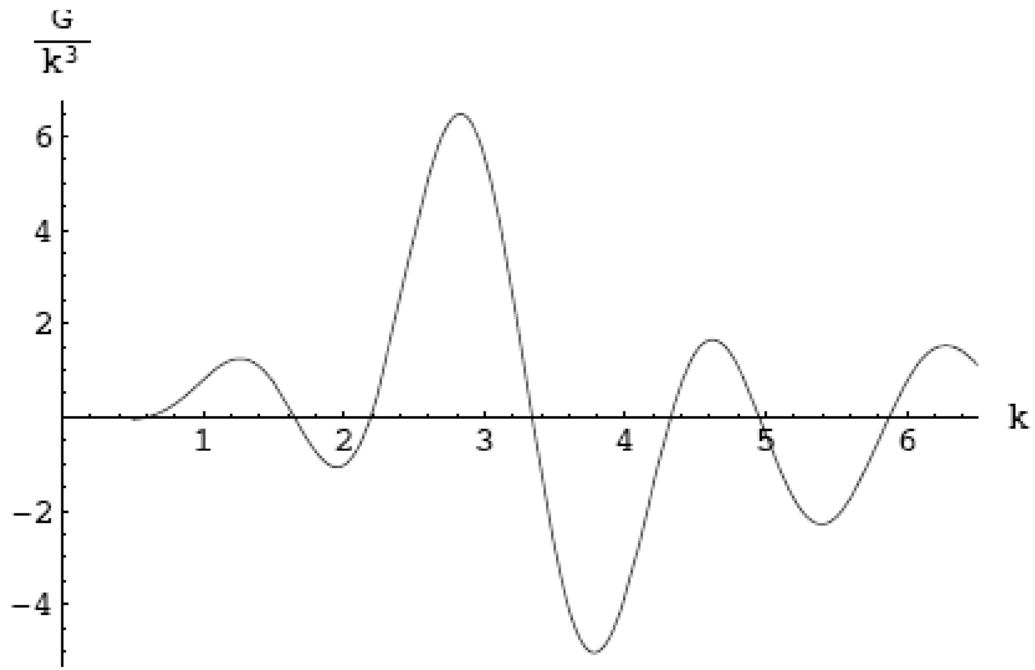
ACBAR Kuo etc., astro-ph/0611198



X. Chen, R. Easther, E. Lim, astro-ph/0611645



$$G(k,k,k)/k^3$$



X. Chen, R. Easther, E. Lim, astro-ph/0611645

$$f_{NL} \sim \frac{7c^{3/2}}{d\epsilon}$$

In chaotic inflation : too small to be seen in WMAP, but may be observable in PLANCK

In brane inflation, to be found out.

It is possible that this effect is present in existing WMAP data already.

Parameters and data points

The simplest KKLMMT model has 4 parameters :

$$\alpha', g_s, K, M$$

and 2 data points to fit : $\dfrac{\delta\rho}{\rho}, n_s$

Now with one more parameter for the width : λ

$\alpha', g_s, K, M, \lambda$

each feature has at least 3 more data points :
position, height and width, maybe even non-Gaussianity

The width of the l th step as $d = \lambda\Lambda_l = \lambda\sqrt{T_3}r_l$

Remarks

- A new plausible stringy signature in the KKLMMT-like scenario.
- It is still slow-roll, but the inflaton potential has tiny steps.
- It tested the brane world scenario in string theory, KKLMMT-like scenario, warped geometry, Seiberg duality and gauge/gravity duality.
- In contrast to non-Gaussianity in DBI, cosmic strings etc, this effect might have been observed already.
- A better understanding of Seiberg duality and gauge/gravity duality is crucial.