CMB Features of Brane Inflation

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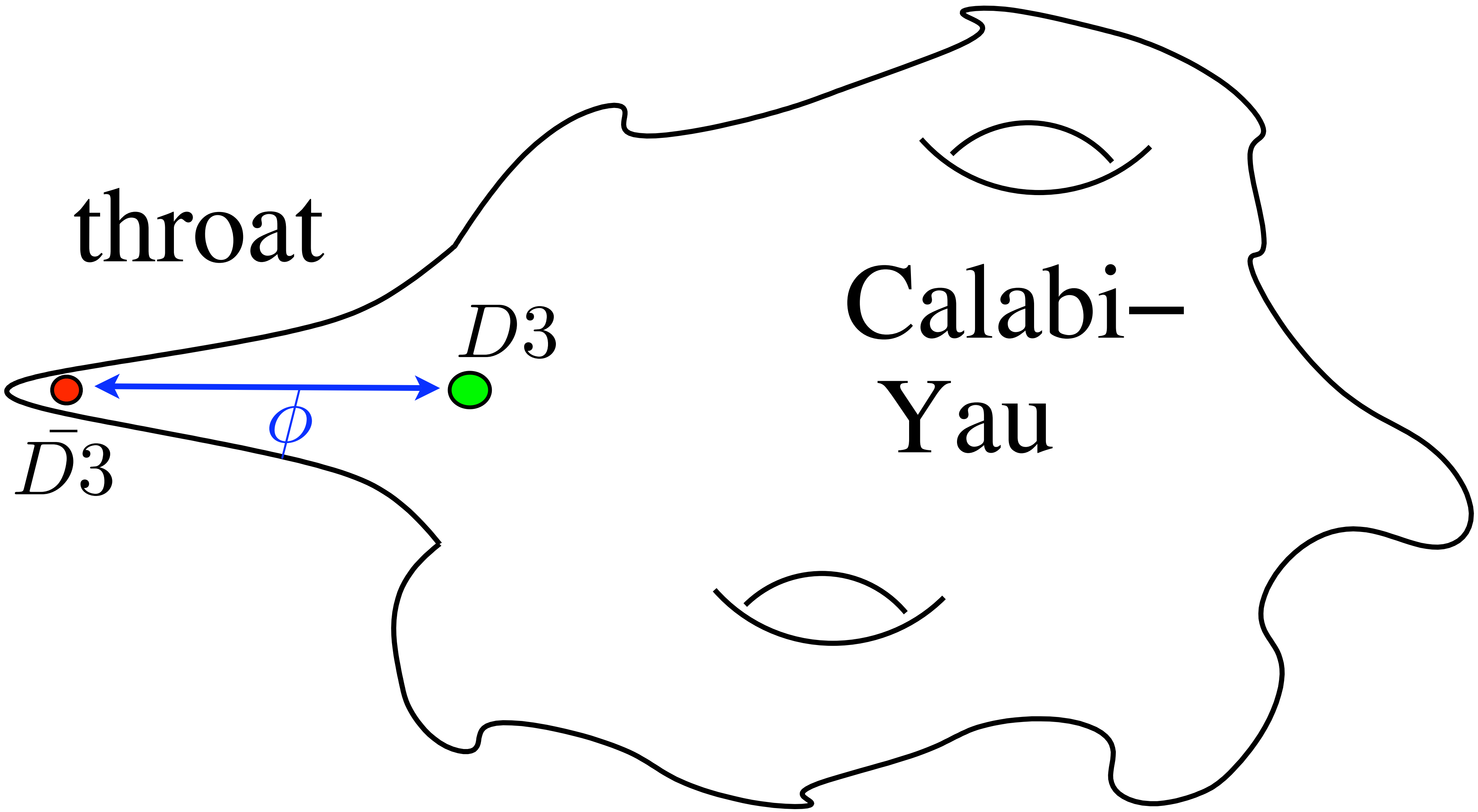
hep-th/0702107, arXiv:0710.1812, arXiv:0802.0491

Cosmo 08

Brane Inflation (Dvali & Tye, KKLMMT, DBI)



Brane Inflation in Warped Throat

Consider D3 Branes moving in the $AdS_5 \times X_5$ background

$$ds^2 = h^2(r)(-dt^2 + a(t)^2 d\mathbf{x}^2) + h^{-2}(r)(dr^2 + r^2 ds^2_{X_5}),$$

in the UV region, $ds^2_{X5} = ds^2_{T^{1,1}}$

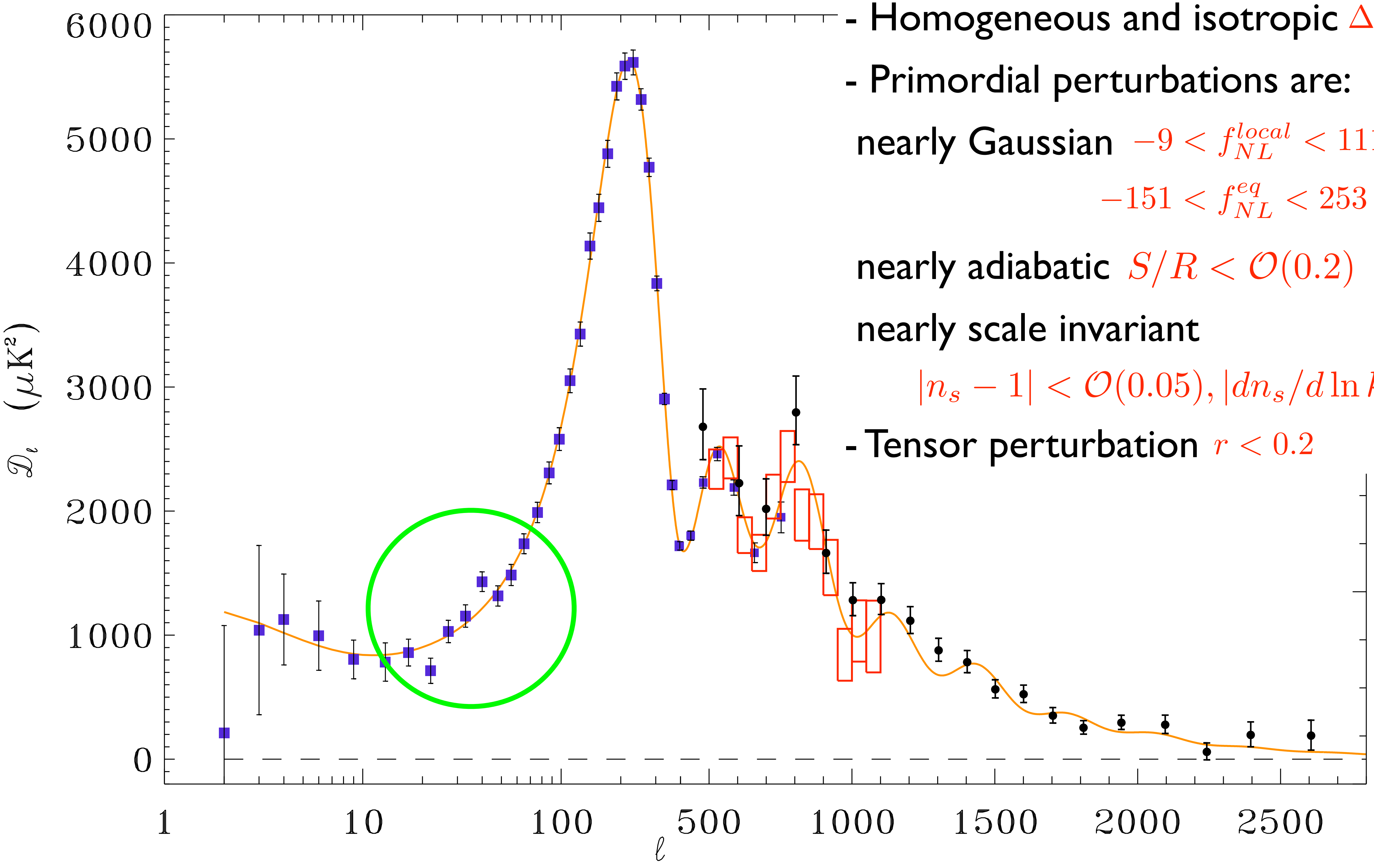
$$S = \int d^4x\sqrt{-g}\left[-e^{-\Phi}T(\phi)\sqrt{1-\frac{\dot{\phi}^2}{T(\phi)}} + T(\phi) - V(\phi)\right]$$

$$T_3 \sim \frac{m_s^4}{g_s} = \frac{m_s^4}{\langle g_s \rangle}e^{-\Phi(r)}$$

$$T(\phi) = T_3 h^4(\phi)$$

$$\begin{aligned} V(\phi) &= V_{D\bar{D}}(\phi) + \text{corrections} \\ V_{D\bar{D}}(\phi) &= V_0\left(1 - \frac{V_0}{4\pi^2 v}\frac{1}{\phi^4}\right) \\ V_0 &= 2T_3 h_A^4 \end{aligned}$$

Our Current Understanding of the Early Universe



- Homogeneous and isotropic $\Delta^2_{\mathcal{R}} = 2.4 \times 10^{-9}$
- Primordial perturbations are:

nearly Gaussian $-9 < f_{NL}^{local} < 111$

$-151 < f_{NL}^{eq} < 253$

nearly adiabatic $S/R < \mathcal{O}(0.2)$

nearly scale invariant

$|n_s - 1| < \mathcal{O}(0.05), |dn_s/d\ln k| < \mathcal{O}(0.05)$

- Tensor perturbation $r < 0.2$

Three Scenarios

- non-relativistic slow roll **(KKLMMT)**

$$-e^{-\Phi}T(\phi)\sqrt{1-\frac{\dot{\phi}^2}{T(\phi)}}+T(\phi)-V(\phi)$$

If $e^{-\Phi}\neq 1$, geometric features in warp factor shows up in power spectrum and non-gaussianity.

$$= \frac{1}{2}e^{-\Phi}\dot{\phi}^2-\left[T(\phi)(e^{-\Phi}-1)+V(\phi)\right]$$

(Bean, Chen, Hailu, Tye, JX, arXiv:0802.0491)

- DBI (UV) : steep potential attracting the brane to the bottom. **(Silverstein & Tong)** $V(\phi)=m^2\phi^2$

$$f_{NL}^{eq}\sim-\frac{M_{pl}^4}{\phi^4} \qquad \frac{\phi}{M_{pl}}\lesssim\frac{1}{\sqrt{KM}}$$

(Baumann & McAllister, hep-th/0610285)
(Bean, Shandera, Tye, JX, hep-th/0702107)

- DBI (IR) : steep potential driving the brane out of the throat. **(Chen)** $V(\phi)=-m^2\phi^2$

$$-0.046\leq\frac{dn_s}{d\ln k}\leq-0.01$$

Due to a stringy suppression of power spectrum on large scales

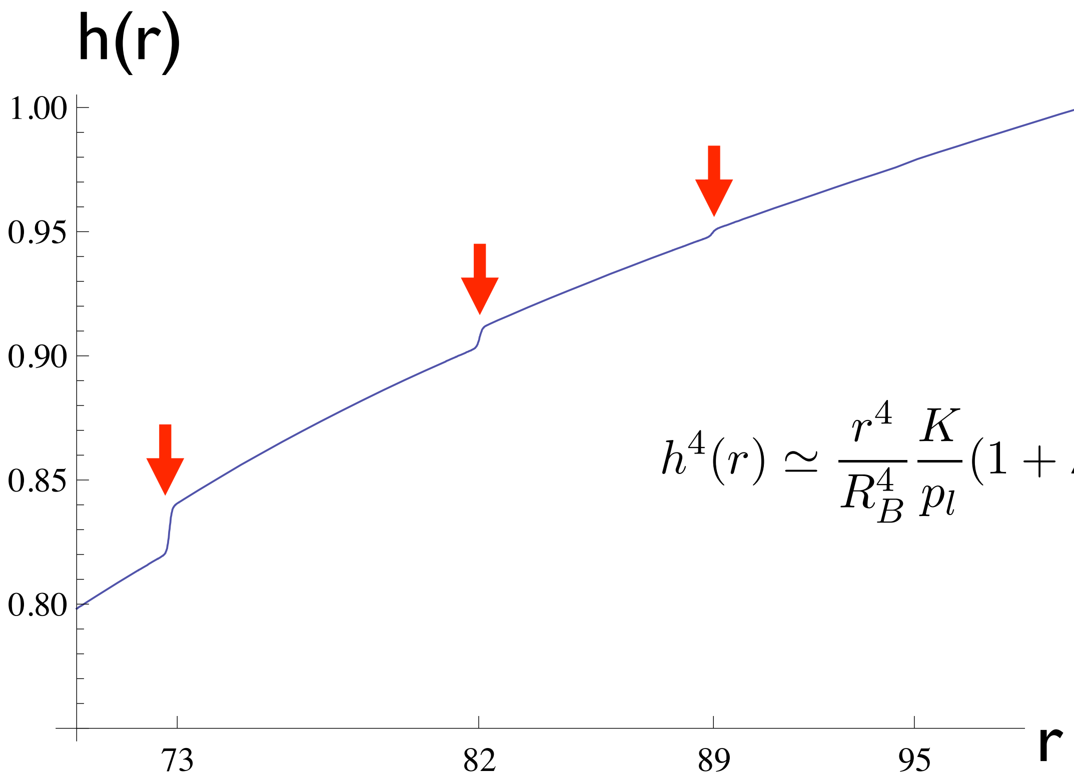
$$-270\leq f_{NL}^{eq}\leq-70$$

(Bean, Chen, Peries, JX, arXiv:0710.1812)

Sharp features in Brane Inflation

- Background geometry is not smooth and dilaton runs.

(Hailu & Tye)



$$\ln(r_{p+1}) - \ln(r_p) \simeq \frac{2\pi}{3g_s M}$$

$$h^4(r) \simeq \frac{r^4}{R_B^4}\frac{K}{p_l}(1+\Delta)\ , \quad \Delta = \sum_{p_i}^{K} \frac{3g_s M}{16\pi}\frac{1}{p^3}\left[1+\tanh\left(\frac{r-r_p}{d_p}\right)\right]$$

- For slow roll, steps in the potential

$$V_{eff}(\phi) = T(\phi)(e^{-\Phi}-1) + V(\phi) \qquad \frac{\Delta V}{V} \equiv c$$

- For DBI, steps in the speed limit $T(\phi)$ $\quad \frac{\Delta T}{T} \equiv b$

The Power Spectrum

- The power spectrum

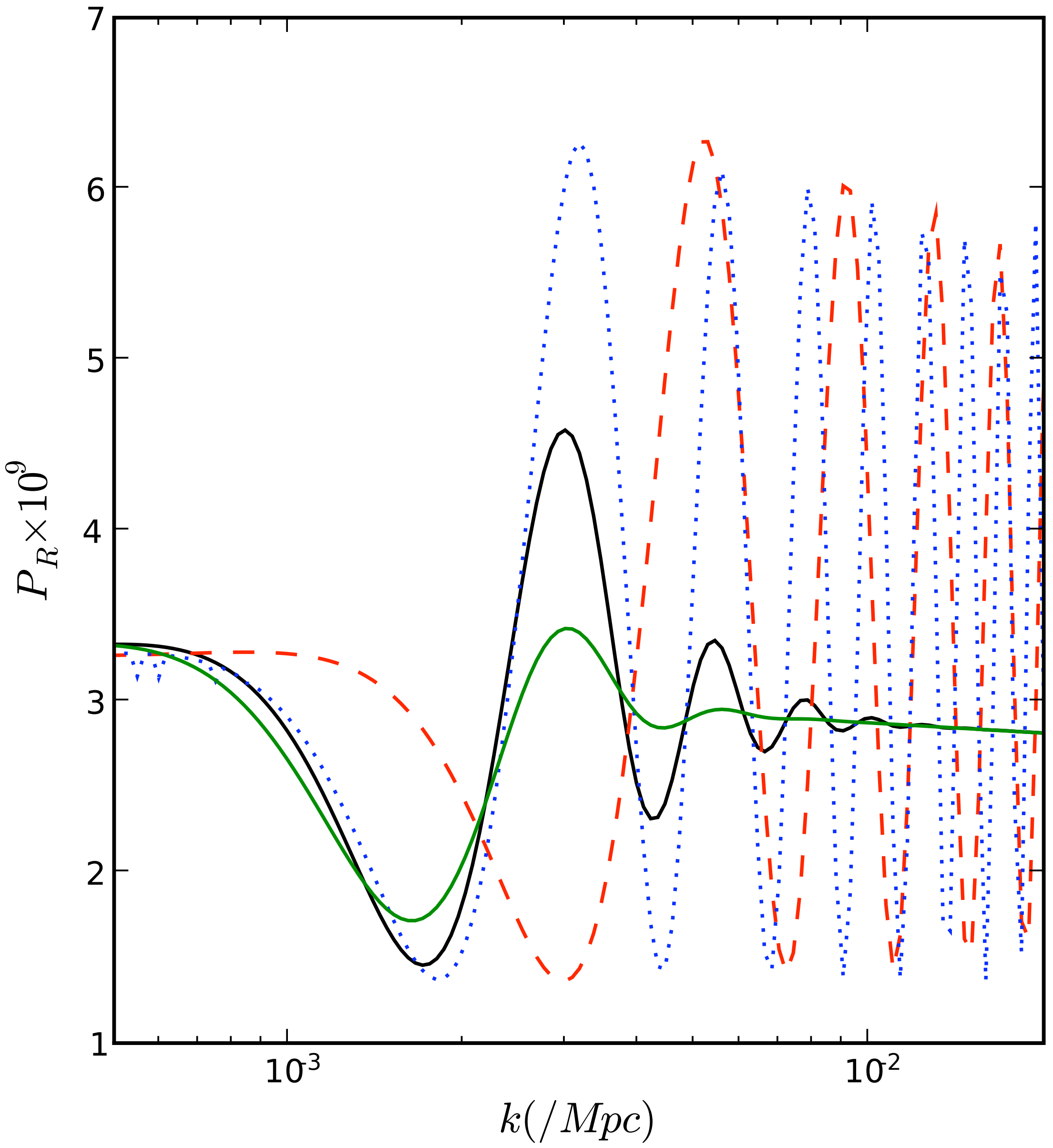
$$v_k'' + \left(k^2 c_s^2 - \frac{z''}{z}\right) v_k = 0 \qquad v_k \equiv z u_k \ , \quad z \equiv a\sqrt{2\epsilon}/c_s$$

$$P_{\mathcal{R}} \equiv \frac{k^3}{2\pi^2}|u_{\mathbf{k}}|^2 \sim \left(\frac{H^2}{2\pi\dot{\phi}}\right)^2$$

- z''/z encodes all the information from the inflationary background
- Define three parameters $\epsilon \equiv -\frac{\dot{H}}{H^2} \ , \quad \tilde{\eta} \equiv \frac{\dot{\epsilon}}{H\epsilon} \ , \quad s \equiv \frac{\dot{c}_s}{H c_s} \ .$

$$\frac{z''}{z} = 2a^2H^2\left(1 - \frac{\epsilon}{2} - \underset{\substack{\Downarrow \\ \text{dominant in slow-roll}}}{\bigcirc\!\!\!\!\!\!\!\frac{3\tilde{\eta}}{4}} - \frac{3s}{2} - \frac{\epsilon\tilde{\eta}}{4} + \frac{\epsilon s}{2} + \frac{\tilde{\eta}^2}{8} - \frac{\tilde{\eta}s}{2} + \frac{s^2}{2} + \frac{\dot{\tilde{\eta}}}{4H} - \underset{\substack{\Downarrow \\ \text{dominant in} \\ \text{DBI inflation}}}{\bigcirc\!\!\!\!\!\!\!\frac{\dot{s}}{2H}}\right)$$

The Slow-Roll Power Spectrum



$$\frac{z''}{z} \sim 2a^2H^2\left(1 - \frac{c}{\epsilon}\frac{1}{\Delta N_e^2}\right) \qquad \frac{\Delta V}{V} \equiv c$$

$$\boxed{\frac{c}{\epsilon} \sim 1, \; \Delta N_e \ll 1}$$

⬍

observable

In KKLMMT, $\epsilon \sim 10^{-11}$ → $c \sim 10^{-11}$ **observable !!**

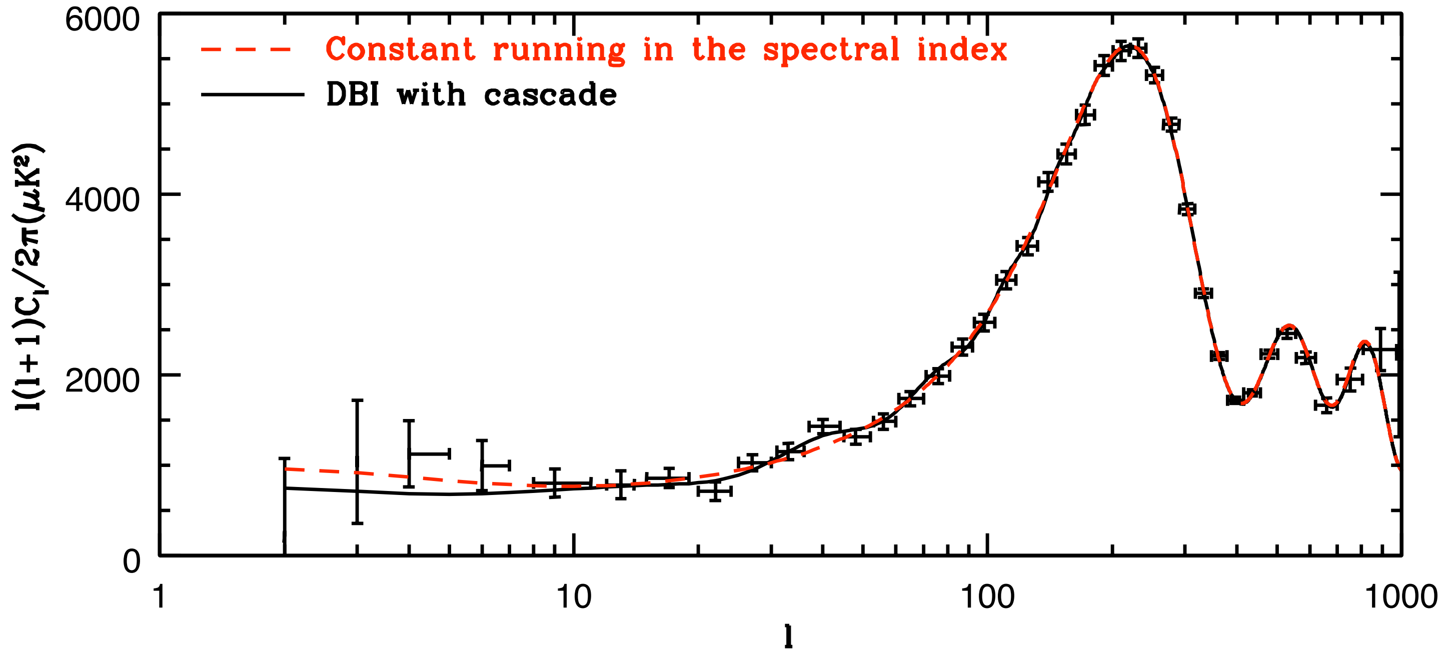
Best Fit:

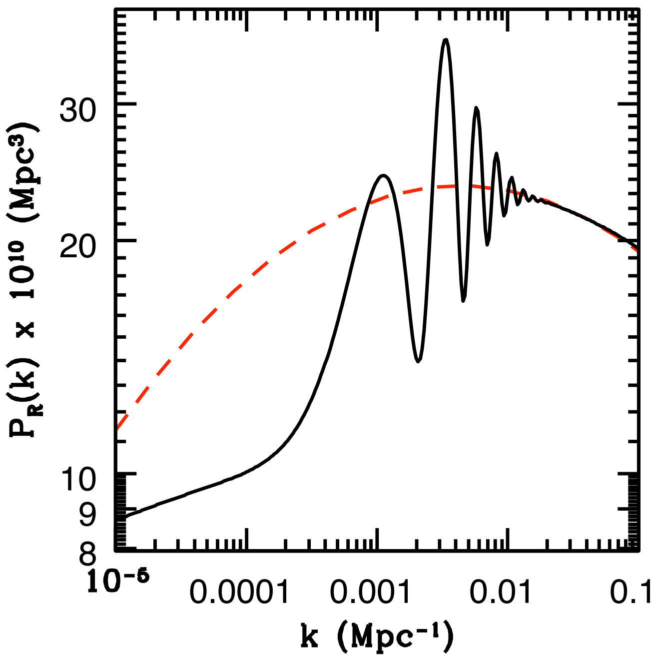
$$c/\epsilon = 0.2$$

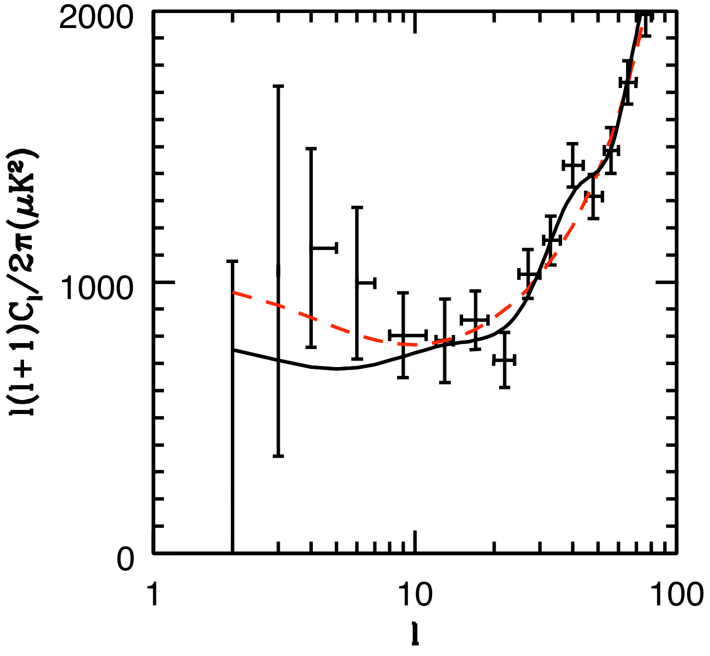
$$\sqrt{c}/d = \mathcal{O}(1)$$

(Adams, Ross, Sarkar 1997,
Leach, Liddle, 2001
Hunt, Sakar, 2004, 2007
Adams, Creswell, Easther, 2001
Peiris et al, 2003
Covi et al, 2006, 2007)

The DBI Power Spectrum







$$\frac{z''}{z} \sim 2a^2H^2\left(1 - \frac{b}{\Delta N_e^2}\right)$$

$$\frac{\Delta T}{T} \equiv b$$

$$\frac{b}{\Delta N_e} \lesssim \frac{1}{c_s^3}$$

need b=-0.3, too large for steps due to duality cascade

Estimations of Non-Gaussianity

- Slow-roll: $\prod u_i \int a^2 \epsilon \tilde{\eta}' u_1 u_2 u_3' \Rightarrow \text{non\_G} \sim \mathcal{O}(\Delta\tilde{\eta})$

$$\Delta\epsilon \approx \Delta V/H^2 \approx 5c$$

$$\Delta t_{accel} \approx \Delta\phi/\dot{\phi} \approx d/\sqrt{cV} \ ,$$

$$\Delta\tilde{\eta} \approx \tilde{\eta} = \frac{\dot{\epsilon}}{H\epsilon} \approx \frac{7c^{3/2}}{d\epsilon} \ ,$$

$$c/\epsilon = 0.2 \quad \sqrt{c}/d = \mathcal{O}(1) \Rightarrow \text{non\_G} \sim \mathcal{O}(1)$$

- DBI: $(a^3\epsilon/c_s^4)\zeta\dot{\zeta}^2 \Rightarrow \text{non\_G} \sim \mathcal{O}(c_s^{-2})$

$$\frac{a^3\epsilon}{2c_s^2}\frac{d}{dt}\left(\frac{\tilde{\eta}}{c_s^2}\right)\zeta^2\dot{\zeta} \Rightarrow \text{non\_G} \sim \Delta\frac{\tilde{\eta}}{c_s^2} \sim \frac{\Delta s}{c_s} \sim \frac{1}{c_s}\frac{b}{\Delta N_e}$$

$$\frac{a\epsilon}{c_s^2}s\zeta(\partial\zeta)^2 \Rightarrow \text{non\_G} \sim \frac{s}{c_s^2}H\Delta t \sim \frac{\Delta c_s}{c_s^3} \sim \frac{b}{c_s^2}$$

$$\frac{b}{\Delta N_e} \lesssim \frac{1}{c_s^3}$$

Given $b = 0.01, \Delta N_e = 0.001, c_s = 0.1,$

$$\frac{1}{c_s}\frac{b}{\Delta N_e} \sim 100, \quad \frac{b}{c_s^2} \sim 1$$

Multiple Steps

- Duality cascade gives a series of steps,

$$\ln(r_{p+1}) - \ln(r_p) \simeq \frac{2\pi}{3g_sM}$$

- Feature on scale k in the power spectrum shows up on angular scale] on CMB

$$\frac{\pi}{l} \approx \frac{k^{-1}}{H_0^{-1}}$$

$$-\,dN_e \simeq d\ln k \simeq d\ln l \simeq H dt \simeq \frac{H}{\dot{\phi}}d\phi \qquad d\ln l \propto d\phi$$

- Take l=2, l=20 as two steps for example,

$$\ln(2) - \ln(20) = \ln(20) - \ln(l_3) \Rightarrow \ l_3 = 200,\ l_4 = 2000$$

Summary

- Brane inflation with D3 branes in KS throat is very rich in CMB phenomenology. (f_{NL}, $dn_s/d\ln k$, local features)
- Generically the dilaton runs, and features in the warp geometry translate into features in the slow-roll potential. The sensitivity to the steps is controlled by c/ϵ . Brane inflation is highly sensitive to small features in the inflaton potential because its small field nature.
- DBI scenario: sharp features in warp factor gives features in non-guassianity on top of the smooth $f_{NL} \sim -c_s^{-2}$.
- Sharp features if shows up in CMB power spectrum, they appears on several correlated scales, and accompanied by non-G. If no signal in CMB power spectrum, non-G has a better chance to see it.