Tachyon Mediated Non-Gaussianity.

Louis Leblond
Texas A&M

Cosmo 08
University of Wisconsin-Madison

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Bhaskar Dutta, Jason Kumar, L.L.
L.L. and Sarah Shandera

Non-Gaussianity in the CMB

- Gaussianity is a consequence of the slow-rolling conditions (from which the inflaton behaves like a free field).

- Detectable NG can be generated by going beyond the standard single field slow-roll approximation.

    - non-standard kinetic term (e.g. DBI)

Silverstein & Tong

    - Multi-fields (this talk, present a string theory motivated D-term inflation with NG from multi-fields)

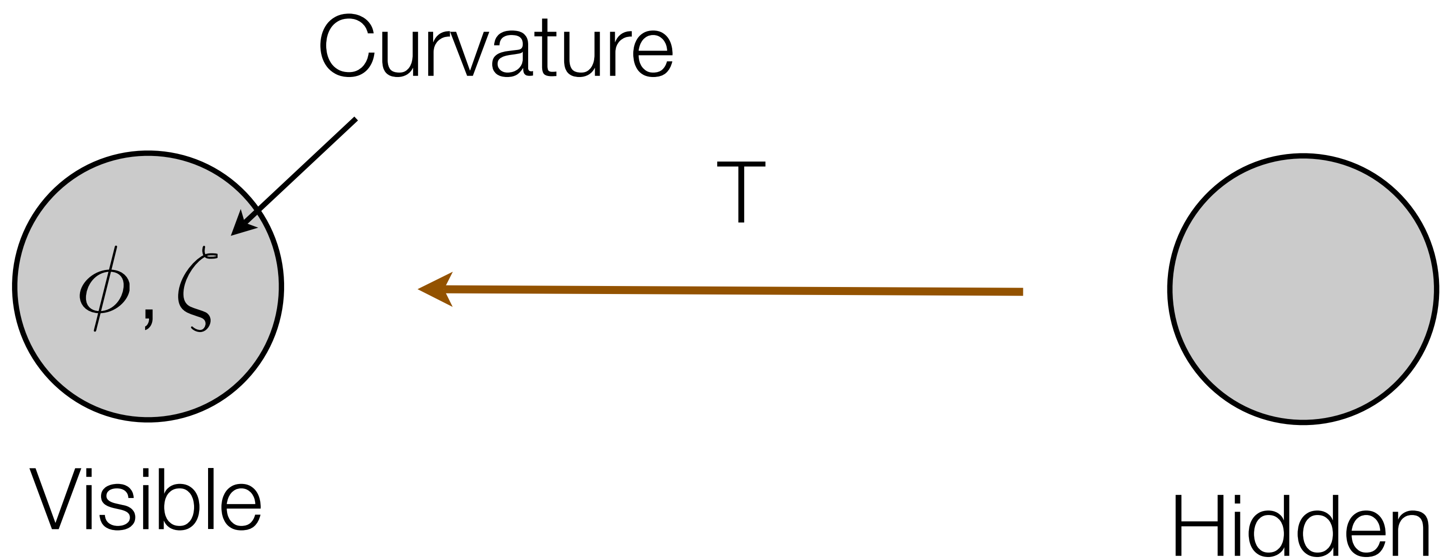
$$\zeta(\vec{x},t) = \zeta_{Gauss} + \frac{3}{5} f_{NL}(\zeta^2_{Gauss} - \zeta^2_{Gauss})$$

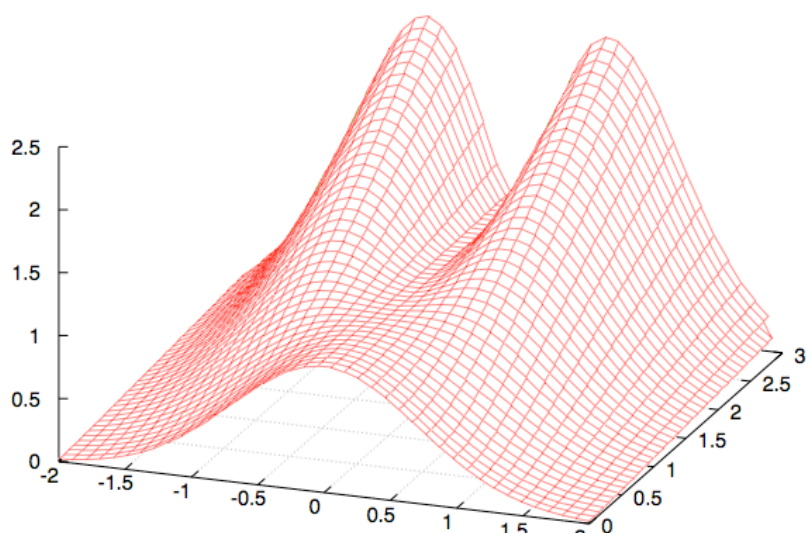
WMAP5

$$-9 < f_{NL} < 111$$

Tachyon Mediated Non-Gaussianity

- In Hybrid inflation





many string theory models are of this type

A Quick History

- In multi-fields inflation, curvature (ζ)is NOT constant after horizon exit and NG can be generated in its evolution.

Bernardeau & Uzan
Bernardeau, Kofman, Uzan

- In general, one needs to integrate these effects over the whole trajectory but in many systems, the effects can all be located at the end simplifying the analysis.

  - Curvaton: a new field starts dominating the energy density well after the end of inflation.

Linde & Mukhanov
Lyth & Wands
Moroi & Takahashi

  - Modulated Reheating: Reheating starts everywhere in sync, but the final temperature is modulated.

Dvali, Gruzinov & Zaldarriaga

  - Modulated End: The onset of reheating is modulated but then proceed everywhere the same.

Lyth
Alabidi & Lyth

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Basic Idea

- Couple Hybrid inflation (2 fields) to an extra field. (Here Tachyon = Waterfall field)

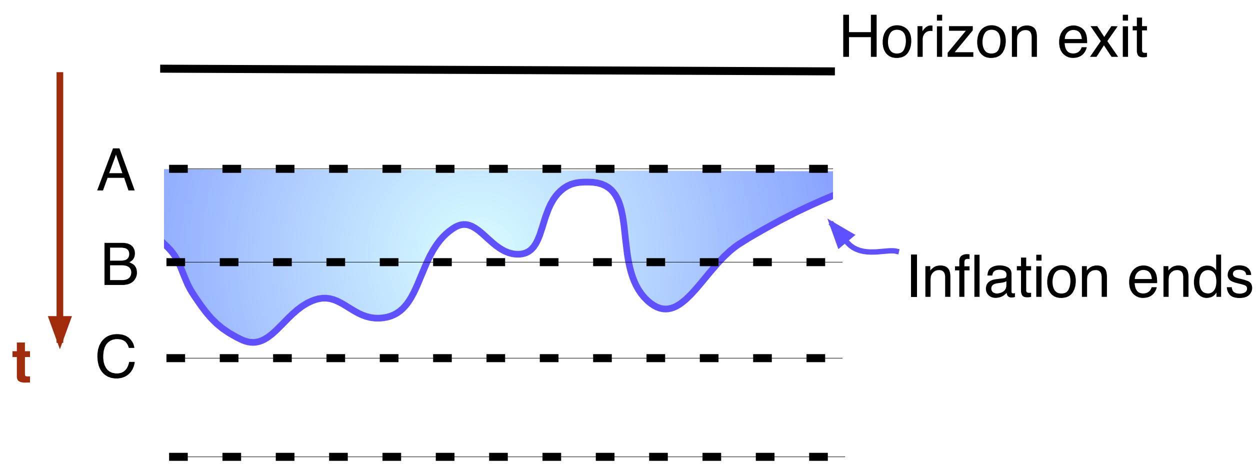
$$V = V_{\mathrm{inf}}(\phi) + V_{\mathrm{hid}}(\chi) + V_{\mathrm{mess}}(\phi, \chi, T)]$$

- There is no direct coupling between ϕ and χ. They couple only through the T which is very massive during inflation.

- Inflation ends at a critical value of the inflaton for which the mass of the tachyon is zero.

$\phi_c(\chi)$

modulated by quantum fluctuation of the hidden field



From field perturbations to curvature.

delta N formalism $\zeta = \delta N$

Sasaki & Stewart

$$N = \int_{\phi_*}^{\phi_c(\chi)} \frac{H}{\dot{\phi}} d\phi$$

The new field only change the end of inflation

* = horizon exit

$$\delta N = -\frac{H}{\dot{\phi}}\delta\phi\Big|_* + \frac{H}{\dot{\phi}}\frac{\partial \phi_c}{\partial \chi}\delta\chi\Big|_{\phi_c} + \frac{1}{2}\frac{H}{\dot{\phi}}\frac{\partial^2 \phi_c}{\partial \chi^2}\left(\delta\chi^2 - < \delta\chi^2 >\right)\Big|_{\phi_c} + \cdots$$

Usual contribution

Note sign difference

"transfer function" $\gamma \equiv \frac{\partial \phi_c}{\partial \chi}\Big|_{\phi_c}$

The 2-pt function

$$\mathcal{P}_2^{\zeta} = \frac{H_*^2}{8\pi^2 M_{pl}^2}\left(\frac{1}{\epsilon_*} + \frac{\gamma^2\kappa^2}{\epsilon_f}\right)$$

$\eta_\chi \sim 0.01$

$N_e \sim 55$

$\kappa \sim 0.6$

include a "damping" $\kappa \sim e^{-\eta_\chi N_e}$

most models must have $\gamma < 1$

- In most models, the potential is steeper at the end than at horizon exit (could argue it is unnatural to have it the other way around)

In brane inflation, inflation ends with a tachyon. Coulombic potential is too steep while the DBI regime does better. Most recent analysis found no effects.

Lyth & Riotto
L.L. & Shandera
Chen, Gong, Shiu

counter example: hilltop potential which flattens out at the end

Alabidi and Lyth

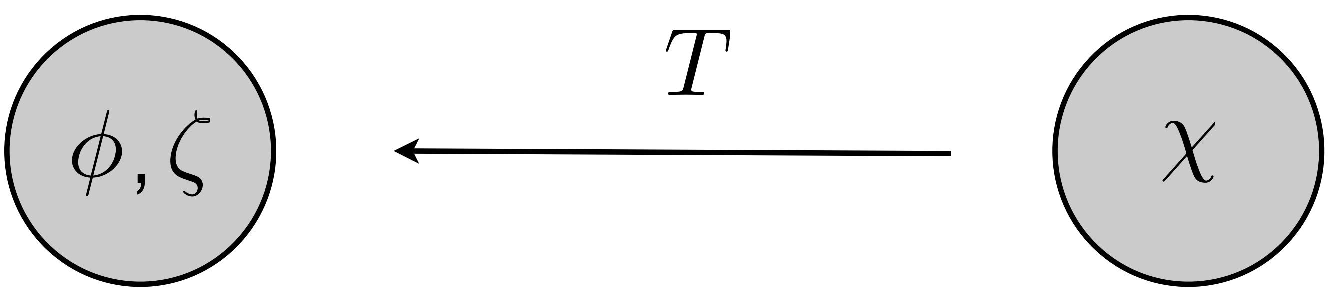
The intrinsic contribution to f_{NL}

In most model the contribution to the 2-pt will be negligible but the 3-pt function can be significant.
Because, the hidden field is NOT the inflaton, its potential can be steeper and it can be strongly interacting.

$$< \delta\zeta^3 > \longleftarrow < \delta\chi^3 >$$

$$f_{NL}^{\rm int} \sim \frac{N_e M_p \gamma^3 \kappa^6}{H^2} \frac{\epsilon_*^2}{\epsilon_f^{3/2}} V_{,\chi\chi\chi} \longleftarrow F(\vec{k}_1, \vec{k}_2, \vec{k}_3) \sim -N_e H^2 V_{,\chi\chi\chi} \kappa^6 \frac{\sum k_i^3}{\prod k_i^3}$$

Falk, Rangarajan, Srednicki, '93
Zaldarriaga
Lyth, Malik Seery
Bernardeau, Brunier
Barnaby, Cline



The Non-linear Contribution

- From the non-linear piece in the delta N, we will get a non-zero 3-pt curvature even for gaussian χ

$$\delta N = -\frac{H}{\dot\phi}\delta\phi\Big|_* + \frac{H}{\dot\phi}\frac{\partial\phi_c}{\partial\chi}\delta\chi\Big|_{\phi_c} + \frac{1}{2}\frac{H}{\dot\phi}\frac{\partial^2\phi_c}{\partial\chi^2}\left(\delta\chi^2 - <\delta\chi^2>\right)\Big|_{\phi_c} + \cdots$$

The ratio of these two contributions

$$\beta \equiv \left|\frac{f_{NL}^{\rm int}}{f_{NL}^{\rm loc}}\right| = \frac{1}{3}\frac{\gamma}{\gamma_{,\chi}}\frac{V_{,\chi\chi\chi}}{H^2}N_e\kappa \xrightarrow{\gamma\sim\chi} \beta \sim \eta_\chi N_e \kappa^2$$

This is always smaller than 1 but one can still have a significant fraction of NG in intrinsic

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$$f_{NL}^{\rm loc} \sim -\frac{\partial\gamma}{\partial\chi}\gamma^2\kappa^4 M_p \frac{\epsilon_*^2}{\epsilon_f^{3/2}}$$

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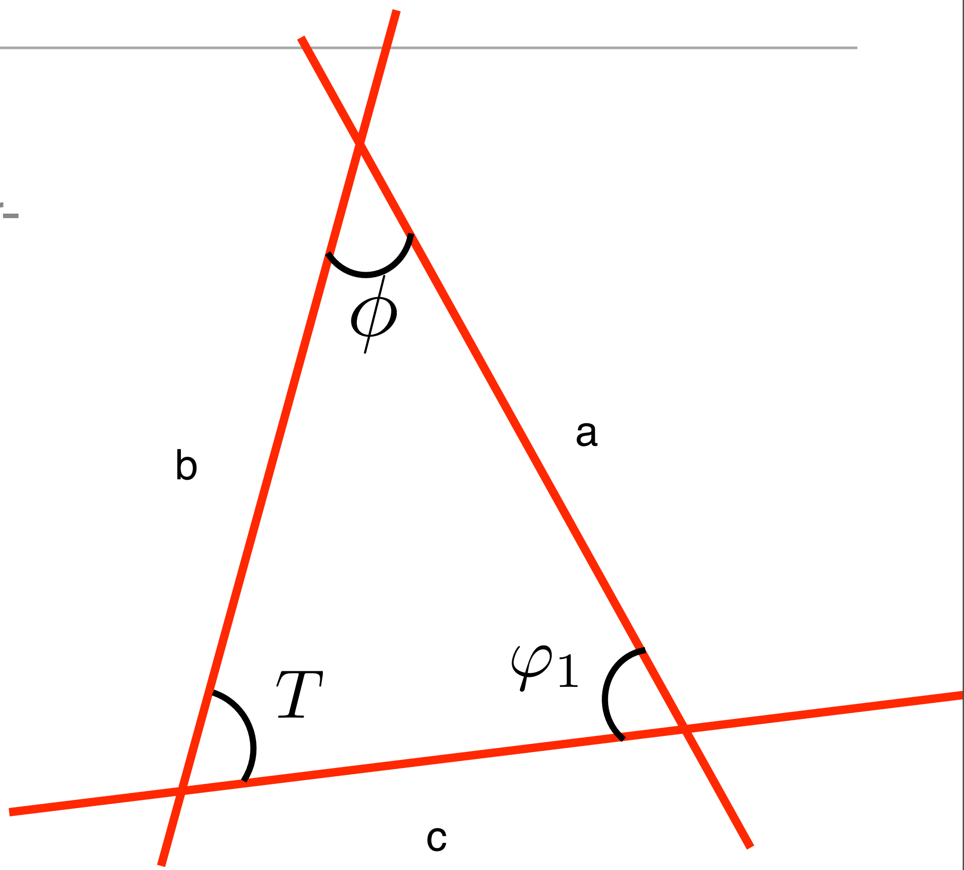
IBM-flation

- Can realize D-term inflation, using open string between branes (strings are in vector-like rep)
- Using gauge invariance one can "brane engineered" flat direction by forbidding dimension 6 operators for example.
- and large NG mediated by the tachyon
- can get a regime with $n_s \sim 1$
- cosmic strings



$$W = \lambda \phi T \varphi_1 + \lambda_{NG} \chi T \varphi_2$$

Dutta, Kumar, L.L

Battye, Garbrecht, Moss
Bevis, Hindmarsh, Kunz, Urestilla

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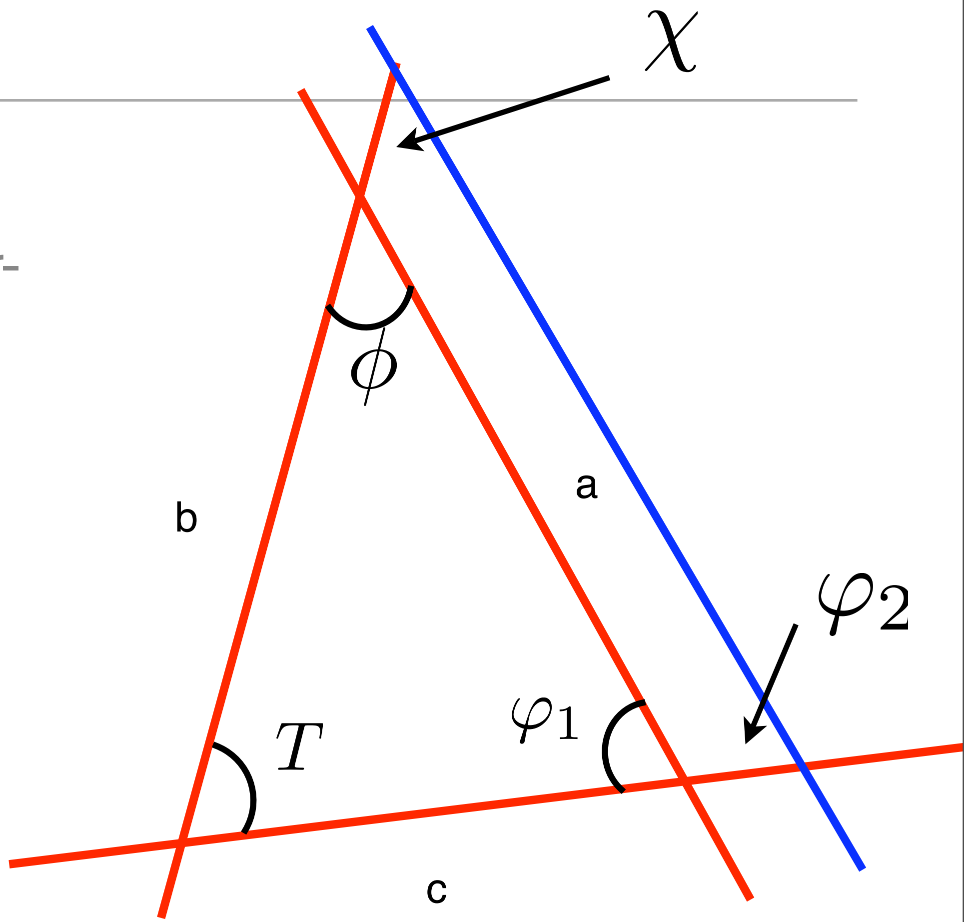

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Detailed example

- The tachyon mass depends on both ϕ and χ

$$m_T^2 = -g^2\xi + \lambda^2\phi^2 + (\lambda_{NG}^2 - qg_2^2)\chi^2$$

$\gamma \approx \chi$ so the non-linear contribution dominate

a point in parameter space

$$f_{NL}^{\text{int}} \sim -8\,, \quad n_s \sim 1.002\,,$$
$$f_{NL}^{\text{loc}} \sim 45\,, \quad G\mu \sim 7 \times 10^{-7}\,.$$

Conclusion

- One can generate observable NG at the end of hybrid inflation with a rich structure.
- Many models fails because the potential is too steep at the end. D-term inflation in the regime of flat spectrum can lead to observable NG.
- The NG has the local shape and both sign can be obtained.
- One can write a string theory motivated model with such features. Another, more detailed but similar models will be presented here. Haack, Kallosh, Krause, Linde, Lust, Zagermann
- A new look into multi-field DBI?

L.L. & Shandera
Huang, Shiu & Underwood
Langlois, Renaux-Patel, Steer, Tanaka