# Inflation From Intersecting Branes

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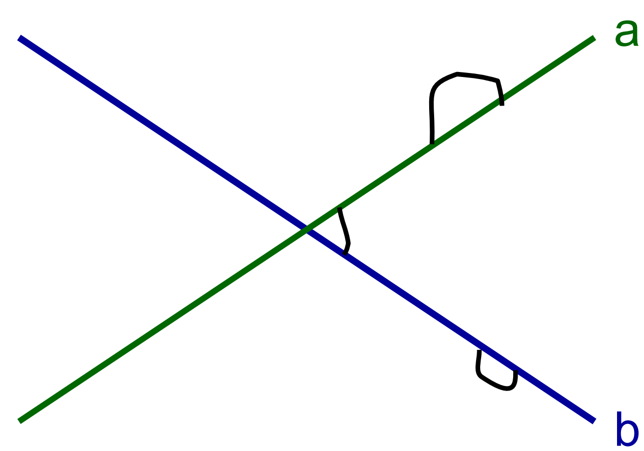
# String Inflation

- inflation the main theoretical paradigm for early cosmology
  - lots of experimental corroboration and future tests
  - consistent quantum gravity provides new constraints, ideas
- in string theory, two main ideas
  - inflaton is closed string modulus (size or shape of extra dimensions)
    - hard to arrange flat potential and stabilize compactification
  - brane position is inflaton
    - Liam McAllister discussed this
    - coupling to volume can generate $\eta$-problem
    - in specific models, may not enough room in throat to get enough e-folds → might be hard to get to work
- we look at a third idea in Intersecting Brane Models
  - inflaton is an open non-vectorlike string living at a topological intersection of branes
    - roughly, the "shape" of branes at intersection
    - D-term inflation
    - utilize extra gauge symmetry

# IBM setup

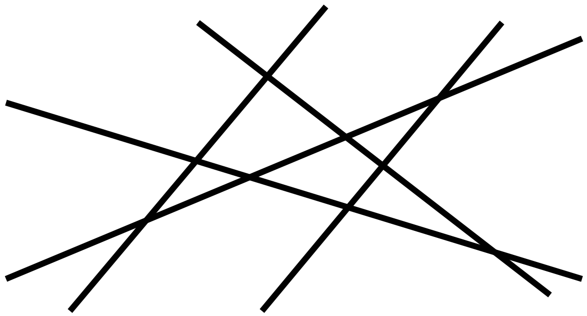
- compactify IIA(B) on orientifolded CY 3-fold
  - 10D → 4D, N=8 → N=1
- bgd. has space-filling charge → must cancel (Gauss' Law)
  - add D6-branes (generic)
- open strings give gauge theory, matter
  - visible, (pseudo-)hidden sector
- general features
  - extra gauge groups (many)
  - generic bifundamental matter

- $I_{ab}$ counts bifund. matter
  - generically nonzero, since 3-cycles intersect



# D-term inflation from open strings in IBM hidden sector

- with N brane stacks
  - N U(1)'s
  - O(N²) bifundamental scalars
  - many flat directions for $V_D$
- what we want
  - split off one of the N D-terms
    - $V_D = V_{inf} + V_{rest}$
  - go out on $V_{rest}$ flat direction
    - Yukawa couplings then lift waterfall directions
    - $V_{inf}$ inflates
  - Coleman-Weinberg pot.→ flat dir. rolls back until tachyon forms, ending inflation
  - additional $V_F$ terms suppressed by large gauge invariance in hidden sector



$$V_{\inf} \approx \frac{g^2}{2}\left(|\varphi_+|^2 - |\varphi_-|^2 - \xi\right)^2$$

$$W = \lambda S \varphi_+ \varphi_- \qquad V_F = \lambda^2 S^2 \varphi_+^2 + \ldots$$

$$V_{CW} = \frac{V_0 g^2}{8\pi^2} \log\left(\frac{\lambda^2 S^2}{\Lambda^2}\right)$$

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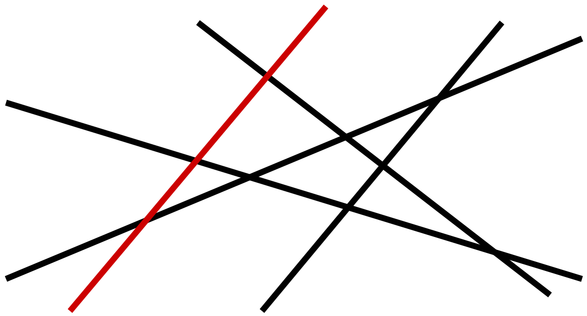

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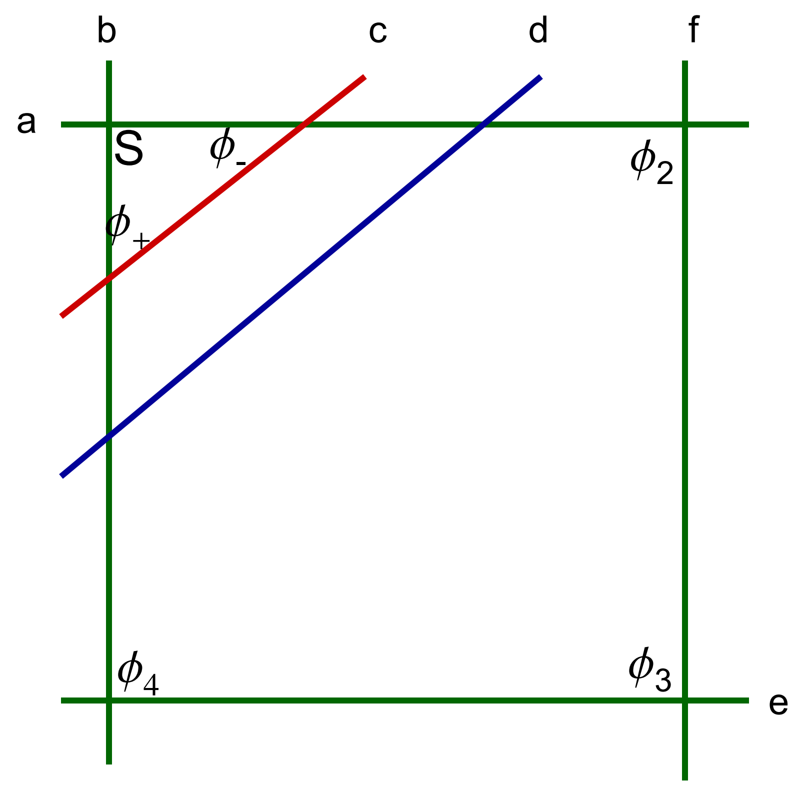
$$V_{inf} = V_c = g^2(|\phi_+|^2 - |\phi_-|^2 - \xi)^2$$

- flat direction → fields at corners of "square"
  - gauge inv. → turning fields in "polygons" can leave $V_{rest}$ invariant
  - for square, only non-vanishing Yukawa coupling is suppressed

$$W = \frac{\lambda'}{M_{pl}} S\varphi_2\varphi_3\varphi_4$$

- if $V_F \ll V_D$ → $\eta$ problem suppressed as in standard D-term inflation



# Need to match cosmology data

- constraints
  - roughly 60 efolds
  - $P_R \sim 10^{-9}$
  - $n_s \sim 1$
  - low cosmic string tension

- take $\xi \sim 10^{-5} M_{pl}^2$
- U(2), $I_{ac} > 1 \rightarrow$ cosmic string unstable (no $\Pi_1$)
- get $n_s \approx 0.98$ ( $< 2\sigma$ away from WMAP5 )
- for "square" $g^2\lambda'^2 < 10^{-13}$
  - $\lambda'$ exponentially suppressed (instanton effect)
  - less tuning for bigger polygon (more powers of $g^2$)
  - fine-tuning is only sign of intersection # , not coupling

# Non-gaussianity

- non-gaussianity of density perturbations
  - key current/upcoming cosmological observation
- difficult to arrange in single field models of inflation
- hard to arrange in known string models
  - though DBI-inflation can arrange it, has other difficulties
- but recent WMAP analyses suggest that non-gaussianity is an experimental possibility (Yadav,Wandelt ; WMAP 5-yr.)
  - $f_{NL} \sim 100$
  - Planck upcoming
- interested in string models which can accommodate this non-gaussianity

# Basic idea

- want NG perturbations in curvature spectrum
  - if non-linearity in a scalar field, then we want to communicate it to curvature
- natural thought→ use inflaton
  - problem→ to get NG pert., need higher order self-coupling
  - large enough self-coupling to generate NG would likely also ruin slow-roll
  - exceptions… like DBI
- so would like a multi-field model
  - string models naturally fit well

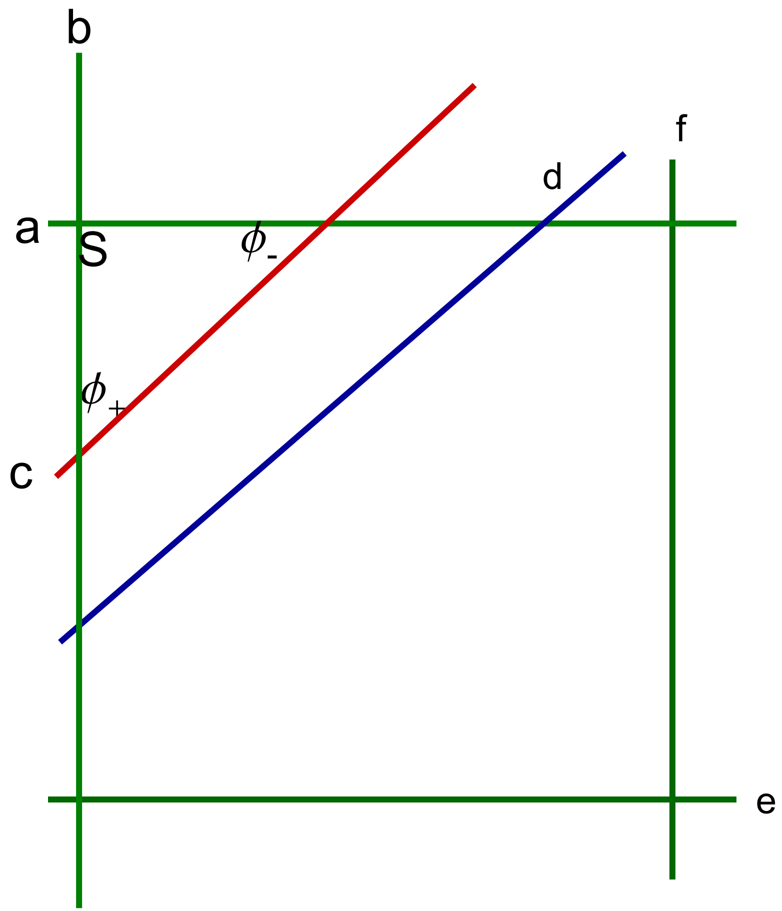
- we use this type of idea (Bernardeau,Brunier)
  - D-term inflation as normal
  - extra scalar $S_{NG}$ (not inflaton) with quartic self-coupling
  - Yukawa $\lambda S_{NG}\phi_{+}\phi_{NG-}$ couples new scalar to waterfall
    - $S_{NG}$ fluctuation contributes to waterfall mass
- upshot
  - $S_{NG}$ coupled to $\delta$N
  - $\delta$N essentially gives metric fluctuation $\zeta$
  - non-linearities transferred to curvature and give non-Gaussianity

# Accommodate in IBM

- important new field
  - $S_{NG}$ generates non-gaussian pert. from quartic coupling in D-term
- assume $\xi_g = 0$
  - $W_{NG} = \lambda_{NG} S_{NG} \phi_+ \phi_{NG-}$
  - Yuk./D-term pin $\langle S_{NG} \rangle = \langle \phi_{NG-} \rangle = 0$

$$m_{\phi_+}^2 = -g_c^2 \xi_c + \lambda^2 S^2 + \lambda_{NG}^2 \left\langle S_{NG}^2 \right\rangle - g_b^2 \left\langle S_{NG}^2 \right\rangle$$

- $g_g$ need not be very small
  - no need for flatness
  - significant non-gaussianity
- fluct. in $S_{NG}$ feed into end of inflation
  - perturbs number of efolds, time when reheating starts
  - feeds into curv. pert. spectrum



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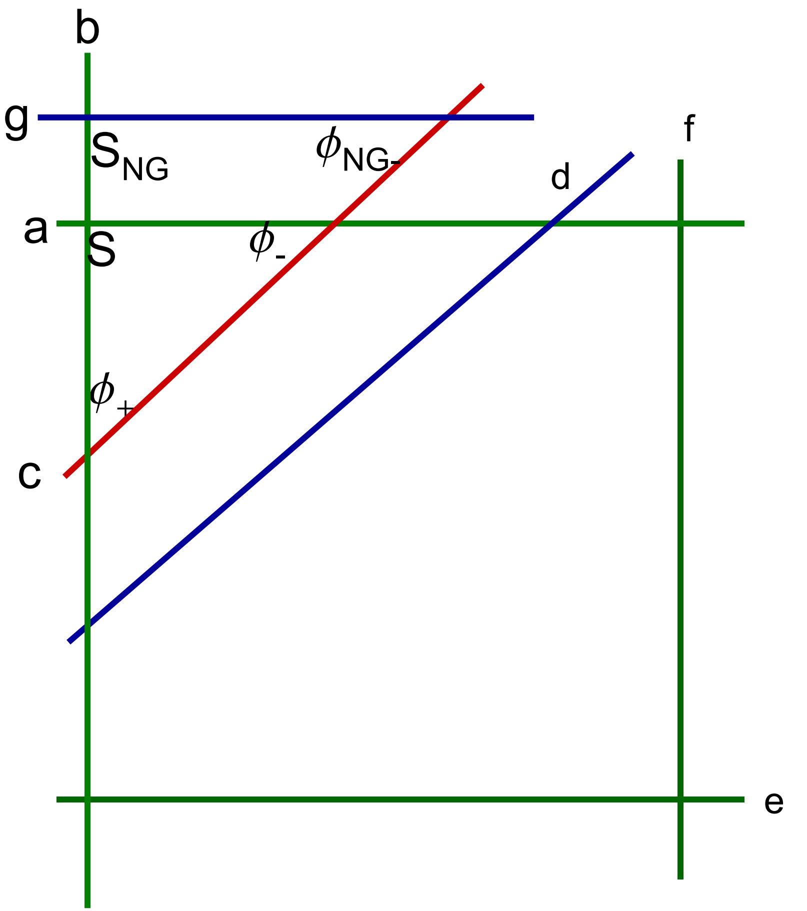

# Details on $f_{NL}$

- expand curvature perturbation in terms of gaussian perturbation

$$\delta N = \frac{\partial N}{\partial \phi}\delta\phi + \frac{\partial N}{\partial \chi}\delta\chi + \ldots$$

- $\nu$ = $S_{NG}$ quartic coupling
- $\gamma$ = "mixing" between $S_{NG}$ and S contributions to the mass of $\phi_+$

$$\langle \zeta(k_1)\ldots\zeta(k_n)\rangle_c = \delta(k_1+\ldots+k_n)P_n^{\zeta}(k_1\ldots k_n)$$

- $\chi^2 = \langle S_{NG}^2 \rangle$
- $\chi$ is distributed stochastically

$$f_{NL}^{\text{int}} = \frac{5N_e}{72\pi^2}\frac{\nu^2\bar{\chi}^4}{H^4}\frac{\left(g_b^2-\lambda_{NG}^2\right)^3}{\lambda^2}\left(1+3\frac{H^2}{\bar{\chi}^2}+6N_e\nu^2\right)$$

- sign of $f_{NL}$ depends on relative magnitudes of coupling

$$f_{NL}^{loc} = \frac{5}{72\pi^2}\frac{\bar{\chi}^2}{H^2}\frac{\left(g_b^2-\lambda_{NG}^2\right)^3}{\lambda^2}\left(1+\frac{1}{3}\frac{H^2}{\bar{\chi}^2}\right)$$

# Matching non-gaussianity results

- non-gaussianity sources
  - local from non-linear transfer from $\chi$ to $\delta$N
  - intrinsic from non-gaussian interactions and linear transfer to $\delta$N
  - shape (momentum dependence of 3-pt. function) different
- to get a feel for this model, we pick a point in parameter space
- get $n_s \sim 1$
  - consistent with cosmic string contributions (Battye, Garbrecht, Moss; Bevis, Hindmarsh, Kunz, Urestilla; Haack, Kallosh, Krause, Linde, Lust, Zagermann)

$$\xi \sim 2.98 \times 10^{-6} M_{pl}^2$$

$$\lambda \sim 2 \times 10^{-4}$$

$$g_b^2 - \lambda_{NG}^2 \sim 0.088$$

$$\nu \sim 0.65$$

$$g^2 \sim 10^{-3}$$

$$\bar{\chi} \sim 0.11 \frac{H}{\sqrt{\nu}}$$

$$n_s \sim 1.001$$

$$f_{NL}^{\mathrm{int}} \sim 22$$

$$f_{NL}^{loc} \sim 28$$

$$G\mu \sim 7.4 \times 10^{-7}$$

# Conclusion

- new model of inflation from intersecting brane models
  - extra gauge symmetry reduces fine-tuning
  - naturally multi-field
    - can induce non-gaussianity (local shape as well as intrinsic)

- both shapes could be observable at Planck
  - intrinsic shape similar to equilateral

- cosmology is a good arena for string theory
  - the tight constraints of consistent quantum gravity can illustrate new scenarios and features which otherwise would be less noticed

- connect new theory results with new observations

- much more to learn ….