A natural framework for chaotic inflation

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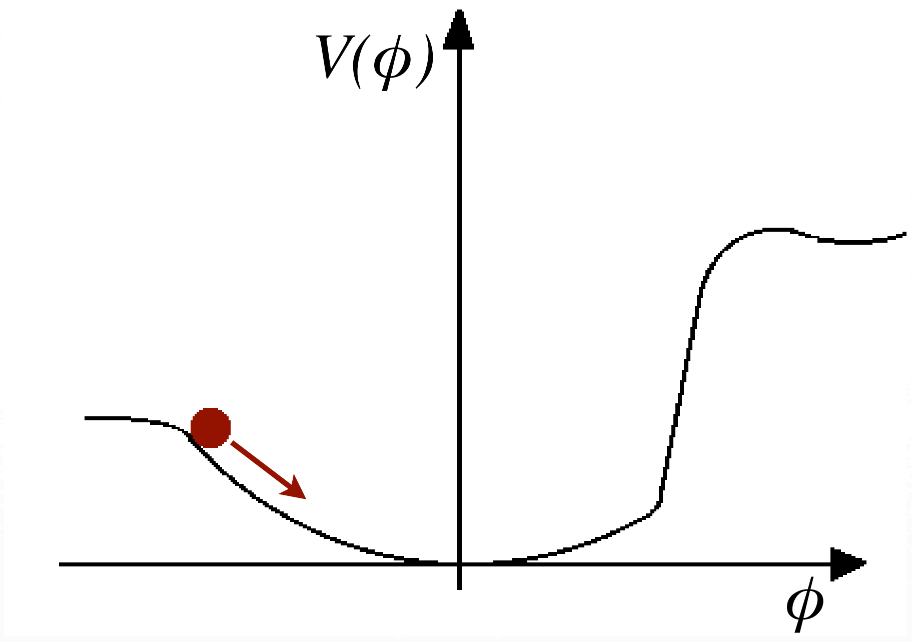
with A. Lawrence and N. Kaloper, in preparation
see also Kaloper and LS 2008

The standard picture for inflation



✓ very early Universe filled by scalar field ϕ, potential $V(\phi)>0$

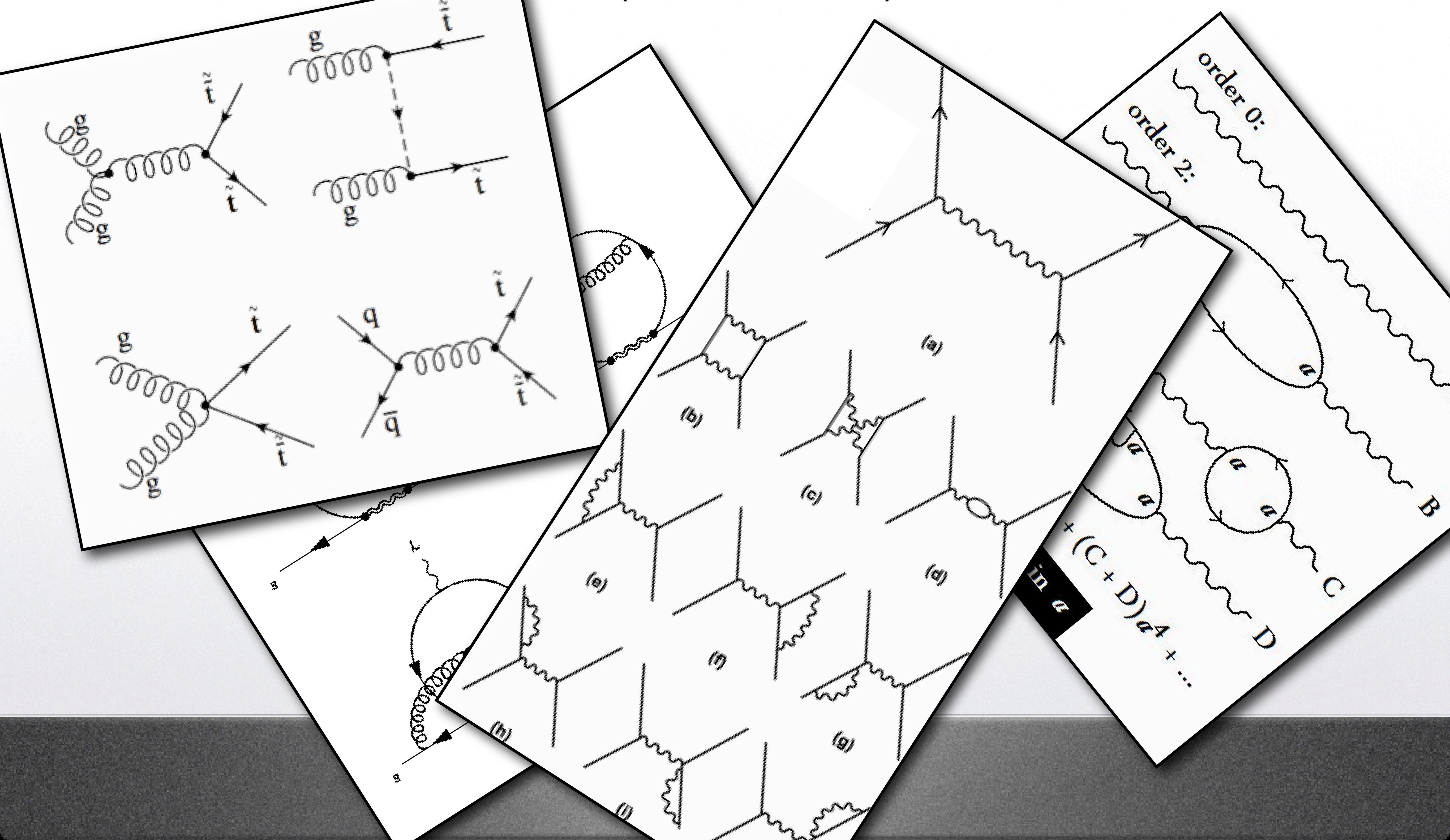
✓ to induce acceleration, $V(\phi)$ must be *flat*

$$|V'(\phi)| << V(\phi)/M_P$$

✓ to have long enough inflation, $V(\phi)$ must *stay* flat for long enough

$$|V''(\phi)| << V(\phi)/M_P^2$$

...but, in general, quantum loops will contribute to V' and V''
(and V''' etc...)



Things can be not so bad...

If the system is invariant under $\phi \rightarrow \phi + c$ (**shift symmetry**)

then $V(\phi)=constant$

and perturbative effects do not spoil the flatness of $V(\phi)$

However, $V(\phi)=constant$ is an overkill

(inflation never ends!)

⇩

Assumption that shift symmetry

is broken in the action

Of course this does not mean that there is no problem...

E.g., couplings to matter (needed to reheat) or nonperturbative effects can break the (global) shift symmetry too much

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In this talk:

Can we generate a mass for the inflaton without breaking a shift symmetry of the action?

Our approach: use 4-forms

$$S_{4\ \mathrm{form}} = -\frac{1}{48}\int F^{\mu\nu\rho\lambda}\, F_{\mu\nu\rho\lambda}$$

$$F_{\mu\nu\varrho\lambda} = \partial_{[\mu} A_{\nu\varrho\lambda]}$$

tensor structure in 4d $\Rightarrow F_{\mu\nu\varrho\lambda} = q(x^\alpha)\, \varepsilon_{\mu\nu\varrho\lambda}$

equations of motion $D^\mu F_{\mu\nu\varrho\lambda} = 0 \Rightarrow q(x^\alpha)$ = constant

Sources for the 4-form: membranes

$$\mathcal{S}_{brane} \ni \frac{e}{6}\int d^3\xi \sqrt{\gamma} e^{abc}\partial_a x^\mu \partial_b x^\nu \partial_c x^\lambda A_{\mu\nu\lambda}$$

[$x^\alpha(\xi^a)$=membrane worldvolume]

$[e]$=mass^2

$q(x^\alpha)$ jumps by e across a membrane

$F_{\mu\nu\varrho\lambda}(x^\alpha)$ is locally constant

and

jumps in units of e

Let us couple the 4-form to a pseudoscalar

$$S = \int d^4x \left[-\frac{1}{2} (\nabla\phi)^2 - \frac{1}{48} F^2_{\mu\nu\rho\lambda} + \frac{\mu}{24} \phi \, \epsilon_{\mu\nu\rho\lambda} F^{\mu\nu\rho\lambda} \right]$$

Di Vecchia and Veneziano 1980
Quevedo and Trugenberger 1996
Dvali and Vilenkin 2001
Kaloper and LS 2008

Action invariant under shift symmetry:

under $\phi \to \phi + c$, $\mathcal{L} \to \mathcal{L} + c\,\mu\,\varepsilon^{\mu\nu\varrho\lambda} F_{\mu\nu\varrho\lambda}/24$

Let us couple the 4-form to a pseudoscalar

$$S = \int d^4x \left[-\frac{1}{2}(\nabla\phi)^2 - \frac{1}{48} F^2_{\mu\nu\rho\lambda} + \frac{\mu}{24}\phi\, \epsilon_{\mu\nu\rho\lambda} F^{\mu\nu\rho\lambda} \right]$$

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Action invariant under shift symmetry:

under $\phi \rightarrow \phi + c$, $\mathcal{L} \rightarrow \mathcal{L} + c\, \mu\, \varepsilon^{\mu\nu\varrho\lambda} F_{\mu\nu\varrho\lambda}/24$

total derivative! $(F = dA)$

Equations of motion (away from branes)

Variation of the action

$$\begin{cases} \nabla^\mu (F_{\mu\nu\varrho\lambda} - \mu\, \varepsilon_{\mu\nu\varrho\lambda}\, \phi) = 0 \\ \nabla^2\phi + \mu\, \varepsilon^{\mu\nu\varrho\lambda} F_{\mu\nu\varrho\lambda}/24 = 0 \end{cases}$$

After simple manipulations

$$\begin{cases} F_{\mu\nu\varrho\lambda} = \varepsilon_{\mu\nu\varrho\lambda} (q + \mu\, \phi) \\ \nabla^2\phi - \mu^2 (\phi + q/\mu) = 0 \end{cases}$$

q = integration constant

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- The theory describes a massive pseudoscalar while retaining the shift symmetry!
- The symmetry is *broken spontaneously* when a solution is picked
- q changes by e across branes $\Rightarrow$ q is quantized

Embedding in stringy lagrangian

To fix ideas, let us focus on *11d SUGRA*, that contains a 4-form $F = dA$

$$S_{11D\ forms} = M_{11}^9 \int *F \wedge F + M_{11}^9 \int A \wedge F \wedge F$$

and consider a simple compactification on $M_4 \times T^3 \times T^4$

truncating as $A_{\mu\nu\varrho}(x^\alpha) \sim A_{\mu\nu\varrho}(x^\alpha)$, $\phi \sim A_{456}(x^\mu)$, $A_{789}(y^i)$

effective 4d action ⇒ $$S_{4D} = \int \left(-\frac{1}{48} F^2_{\mu\nu\rho\lambda} - \frac{1}{2} (\nabla\phi)^2 + \frac{\mu}{24} \phi\, \epsilon_{\mu\nu\rho\lambda} F^{\mu\nu\rho\lambda} \right)$$

$\mu \sim F_{78910}$ ⇒ The mass is quantized!

ϕ *as an angle*

Effective potential $V(\phi) \sim (q+\mu\phi)^2$

with q, μ quantized: discrete invariance

$$q \rightarrow q+n\, e, \;\; \phi \rightarrow \phi - n\, e/\mu = \phi - n\, f$$

Beasley and Witten 2002

at the level of action ϕ is still an angle!

Once a vev for q is chosen, the angle unwraps:

MONODROMY

Silverstein and Westphal 2008

Corrections to our lagrangian

- If we limit ourselves to $F_{\alpha\beta\gamma\delta}$ and ϕ, first correction that respects shift symmetry and gauge invariance is F^3/M^2 for some cutoff scale M ☆ Since $F \sim \mu\, \phi \sim \sqrt{\varrho}$, the expansion parameter is actually (energy/cutoff) ✓
- Other moduli ψ coupled to F via terms such as $f(\psi/M_P)\, F^2$ in the lagrangian ★ Depends on specific string compactification
- Instanton corrections generate terms $\sim \Lambda \cos(\phi/f)$, ok for small Λ (see later) ✓

Signatures

In the basic version, predictions identical to chaotic inflation (including gravitational waves!)

Potential CMB exotics from phase transitions during inflation:

Emission of branes can change q (and give a kick to ϕ) or μ during inflation

in progress

Bumps induced by instantons can give small corrections to $V(\phi)$

$$V(\phi) = \frac{\mu^2}{2} (\phi + q/\mu)^2 + \Lambda^4 \cos(\phi/f)$$

can generate observable nongaussianities in CMB

Chen et al, 2008

Signatures

Coupling $(\phi / f)\, \varepsilon^{\alpha\beta\mu\nu} F_{\alpha\beta} F_{\mu\nu}$ consistent with shift symmetry
(and needed to reheat)

Rolling ϕ amplifies vacuum fluctuations of $F_{\mu\nu}$,
producing *helical* E&M fields

Anber, LS, 2006

Lower bound on f
from requirement
that $F_{\mu\nu}$ stays small

Parity violating
fluctuations ⇒ CMB?

Conclusions

- Naturalness of inflaton potentials is a nontrivial issue - but it is NOT impossible!
- Shift symmetries play a central role in the construction of models of inflation
- String theory contains many 4-forms fields
- We can use 4-forms to obtain radiatively stable, massive pseudoscalars with a discretuum of masses and vevs
- Potential peculiar signatures
- Full stringy construction?