Focus week on string cosmology
October 7, 2010

Effects of Light Fields During Inflation

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based on:

TK & Shinji Mukohyama Phys.Rev.D 81, 103504 (2010)

Light Fields During Inflation

- Additional light fields often show up in microscopic descriptions of cosmic inflation, especially for large-field models.
- They may have negligible influences on the inflaton dynamics, but can still produce significant curvature perturbations during inflaton.
- We study under which conditions their effects become significant.
- Results are applied to monodromy-driven D-brane inflation models, where the wrapped brane's oscillation modes can become light.

Inflaton Lagrangian Corrected by Tiny Modulus Corrections

ϕ : inflaton

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2$$

$$-V(\phi)$$

Inflaton Lagrangian Corrected by Tiny Modulus Corrections

ϕ : inflaton $\qquad\qquad$ σ : modulus

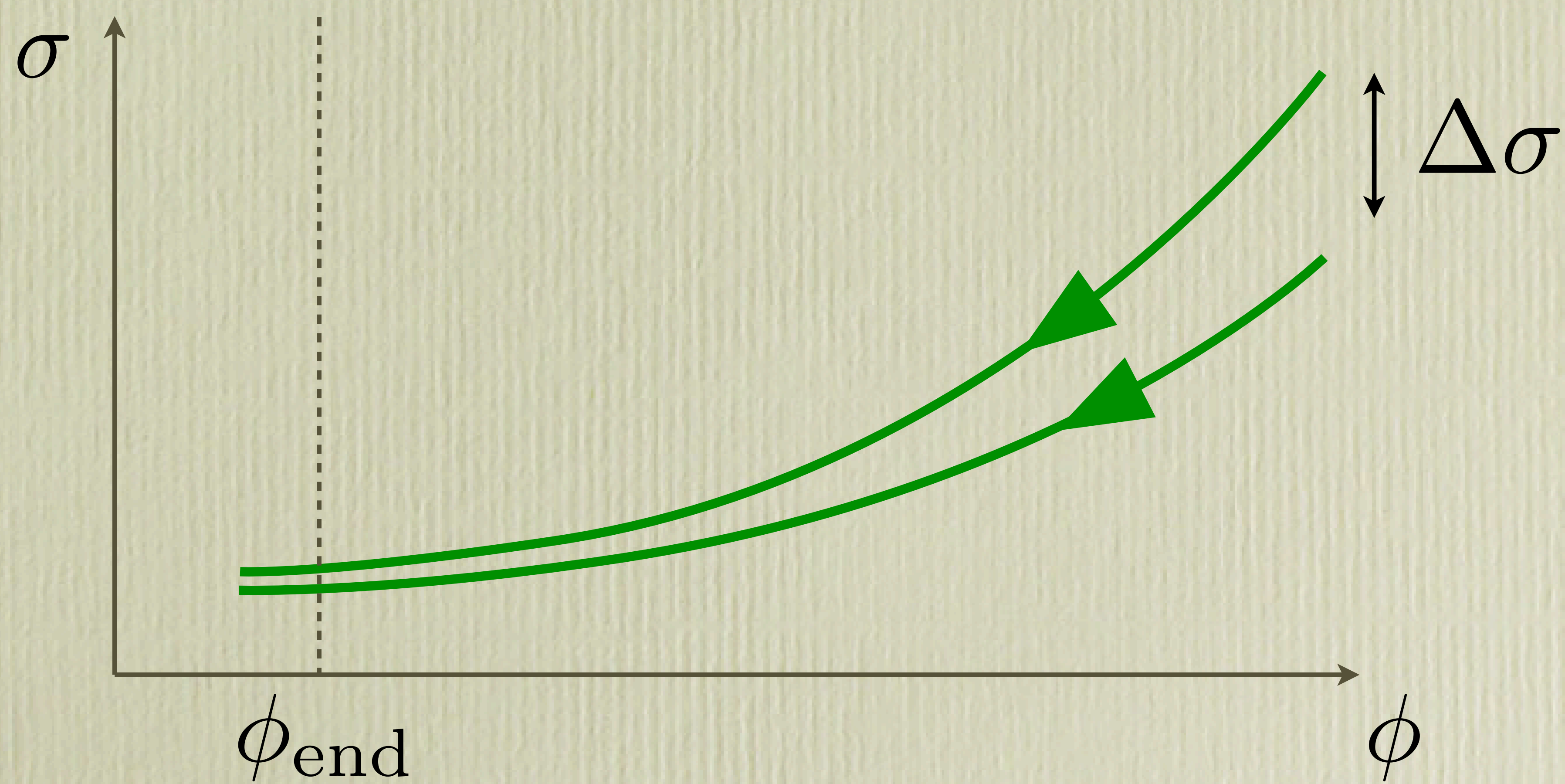
$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 \left(1 - f\frac{\sigma^2}{\mu^{2-m}\phi^m}\right) \quad -\frac{1}{2}(\partial\sigma)^2$$

$$-V(\phi) \left(1 + g\frac{\sigma^2}{\mu^{2-m}\phi^m}\right)$$

from e.g., nonminimal Kähler potentials,
fields nonminimally coupled to gravity,
monodromy-driven D-brane inflation models

Curvature Perturbations

$$\delta\mathcal{N} = \frac{\partial\mathcal{N}}{\partial\phi}\delta\phi + \frac{\partial\mathcal{N}}{\partial\sigma}\delta\sigma + \cdots$$



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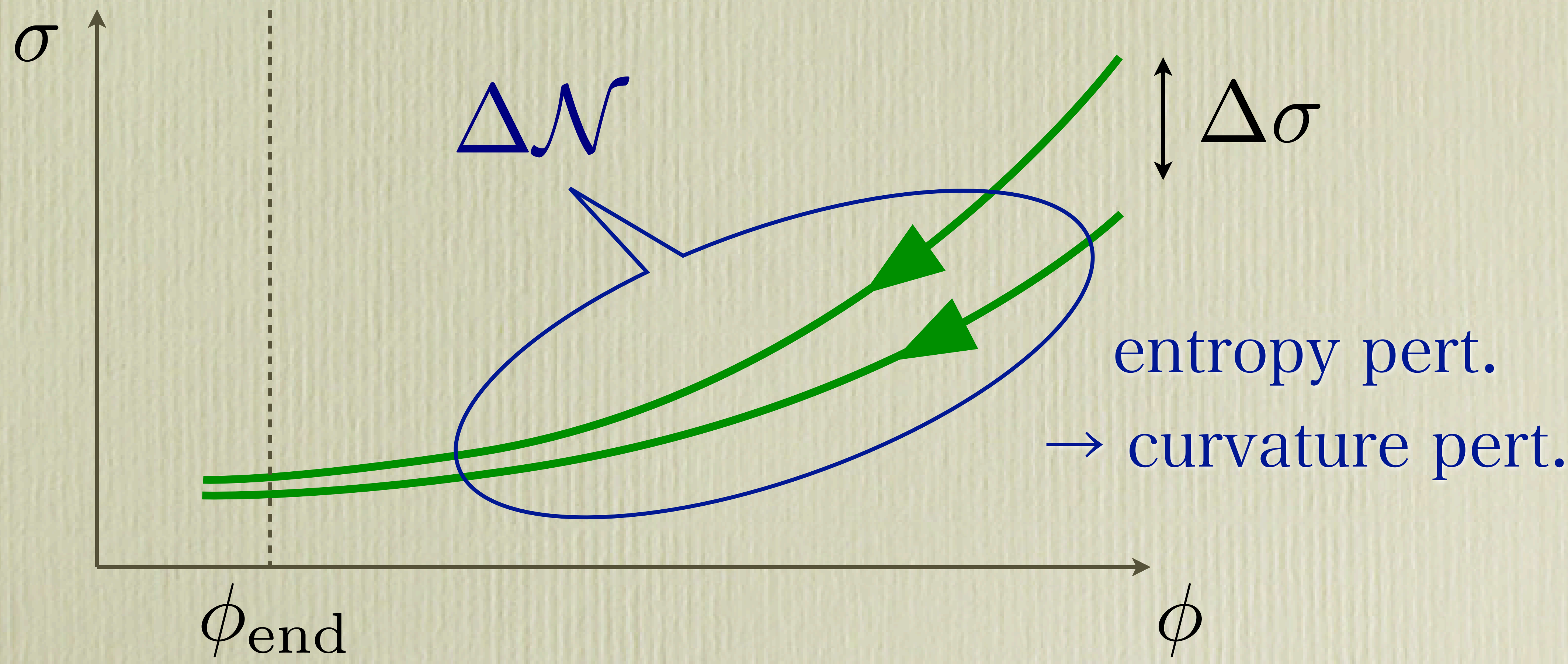

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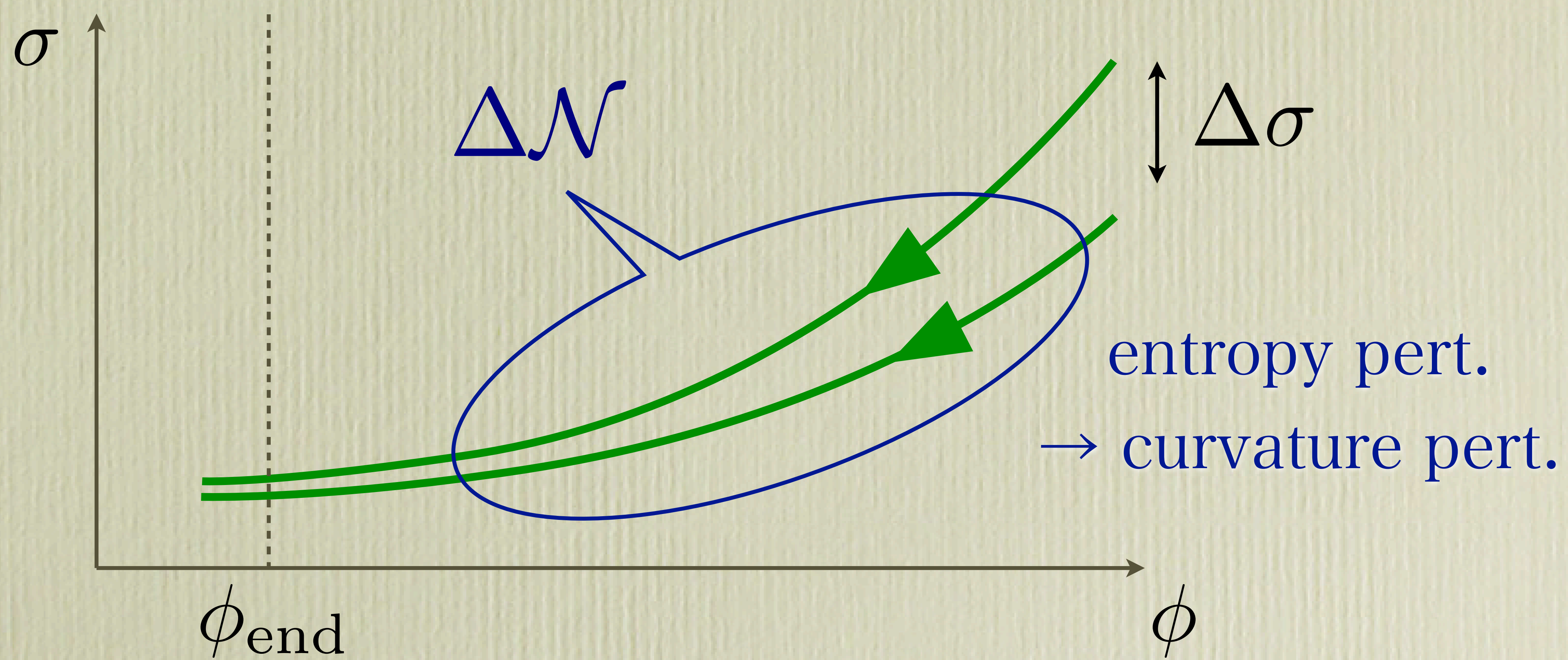

$\frac{\delta\mathcal{N}}{\delta\sigma}$ becomes dominant over $\frac{\delta\mathcal{N}}{\delta\phi}$ when conversion is sufficient

When is σ effective?

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2\left(1 - f\frac{\sigma^2}{\mu^{2-m}\phi^m}\right) - \frac{1}{2}(\partial\sigma)^2 - V(\phi)\left(1 + g\frac{\sigma^2}{\mu^{2-m}\phi^m}\right)$$

ex.) $V(\phi) \propto \phi^n$

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positive mass^2

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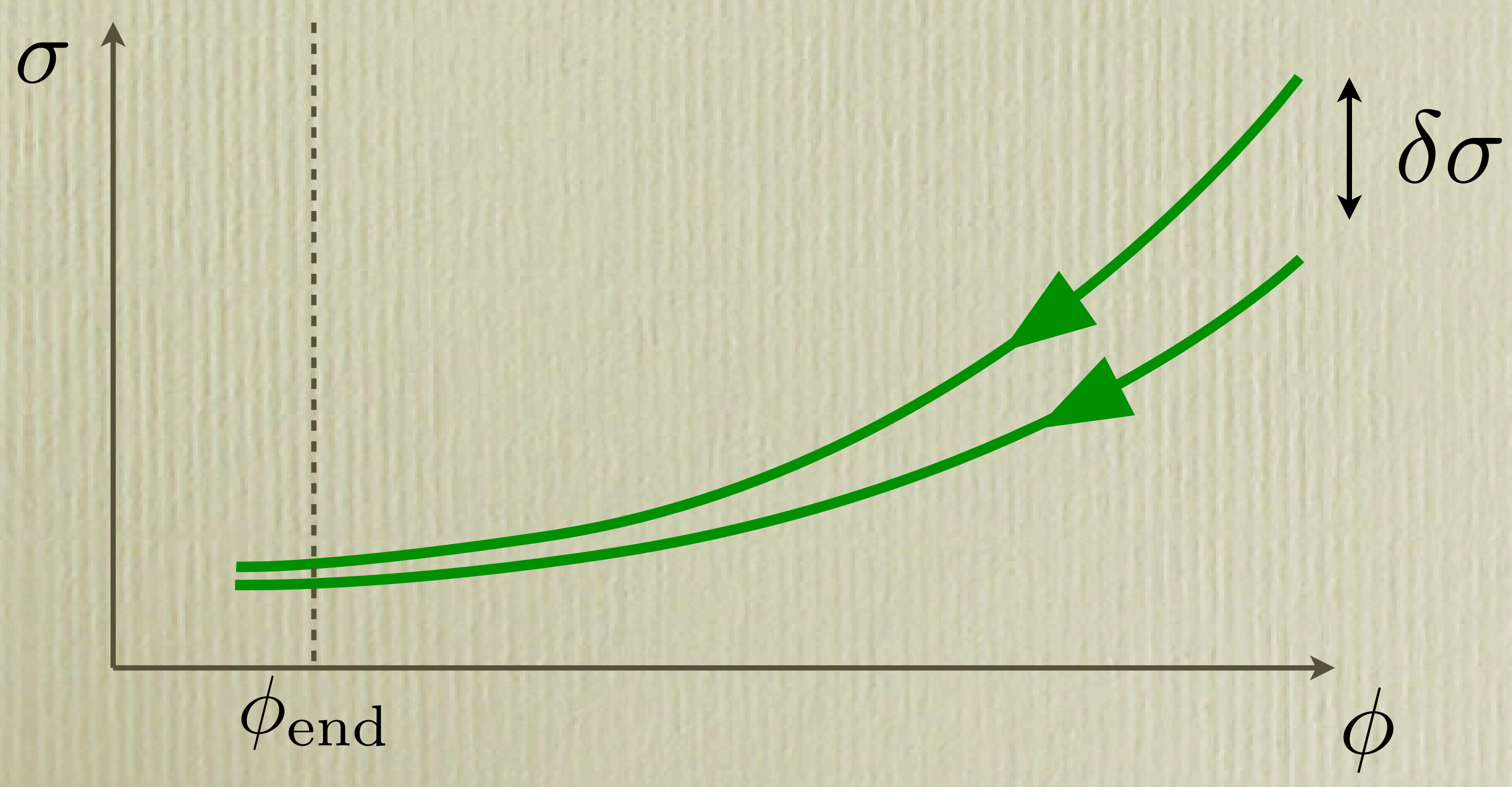

$$\frac{\partial\mathcal{N}/\partial\sigma}{\partial\mathcal{N}/\partial\phi} \sim \frac{\sigma}{\phi}$$

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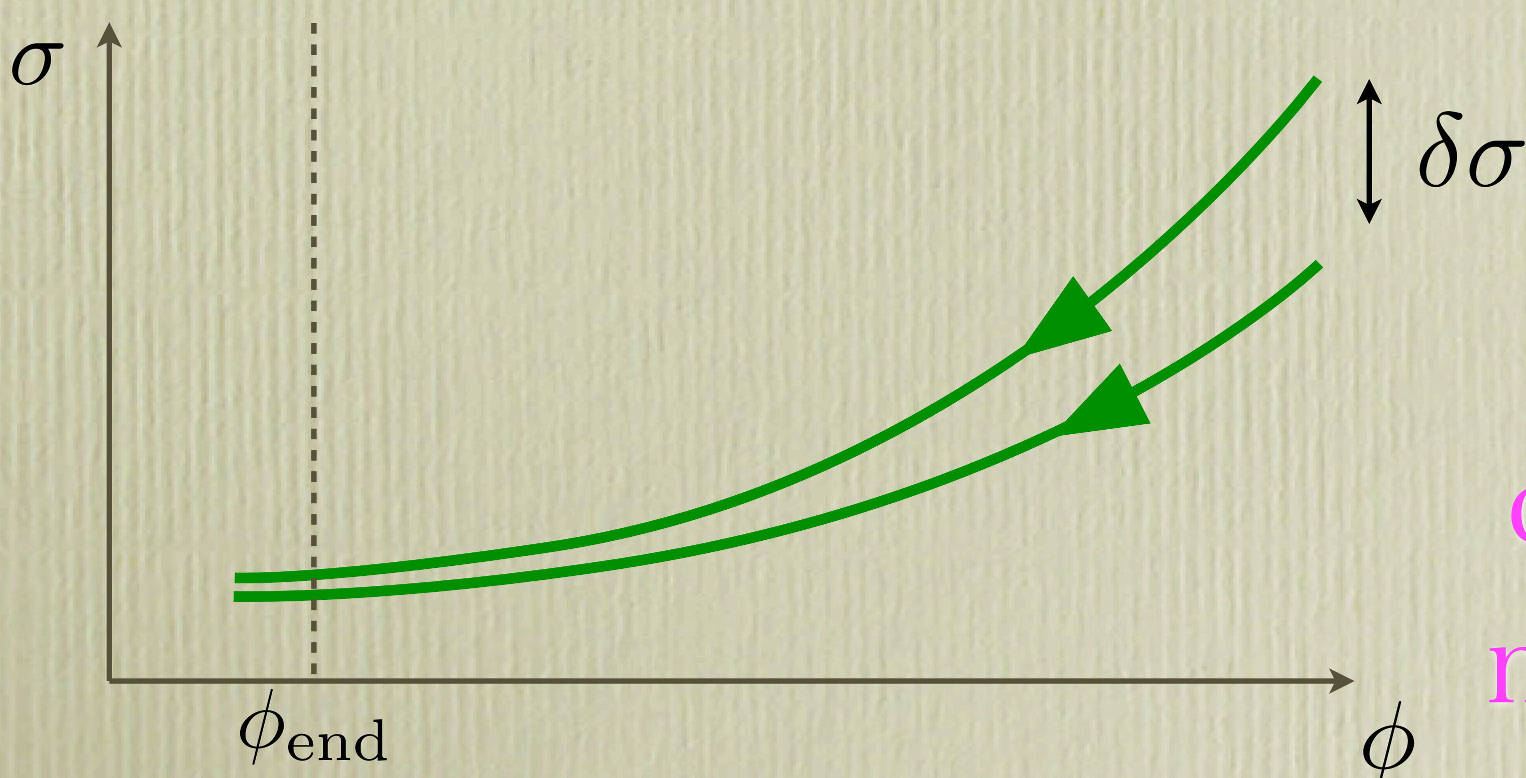

$$\frac{\partial\mathcal{N}/\partial\sigma}{\partial\mathcal{N}/\partial\phi} \sim \frac{\sigma}{\phi}$$

curvature pert. from σ

negligible unless $\sigma \gtrsim \phi$

When is σ effective?

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2\left(1 - f\frac{\sigma^2}{\mu^{2-m}\phi^m}\right) - \frac{1}{2}(\partial\sigma)^2 - V(\phi)\left(1 + \boxed{g\frac{\sigma^2}{\mu^{2-m}\phi^m}}\right)$$

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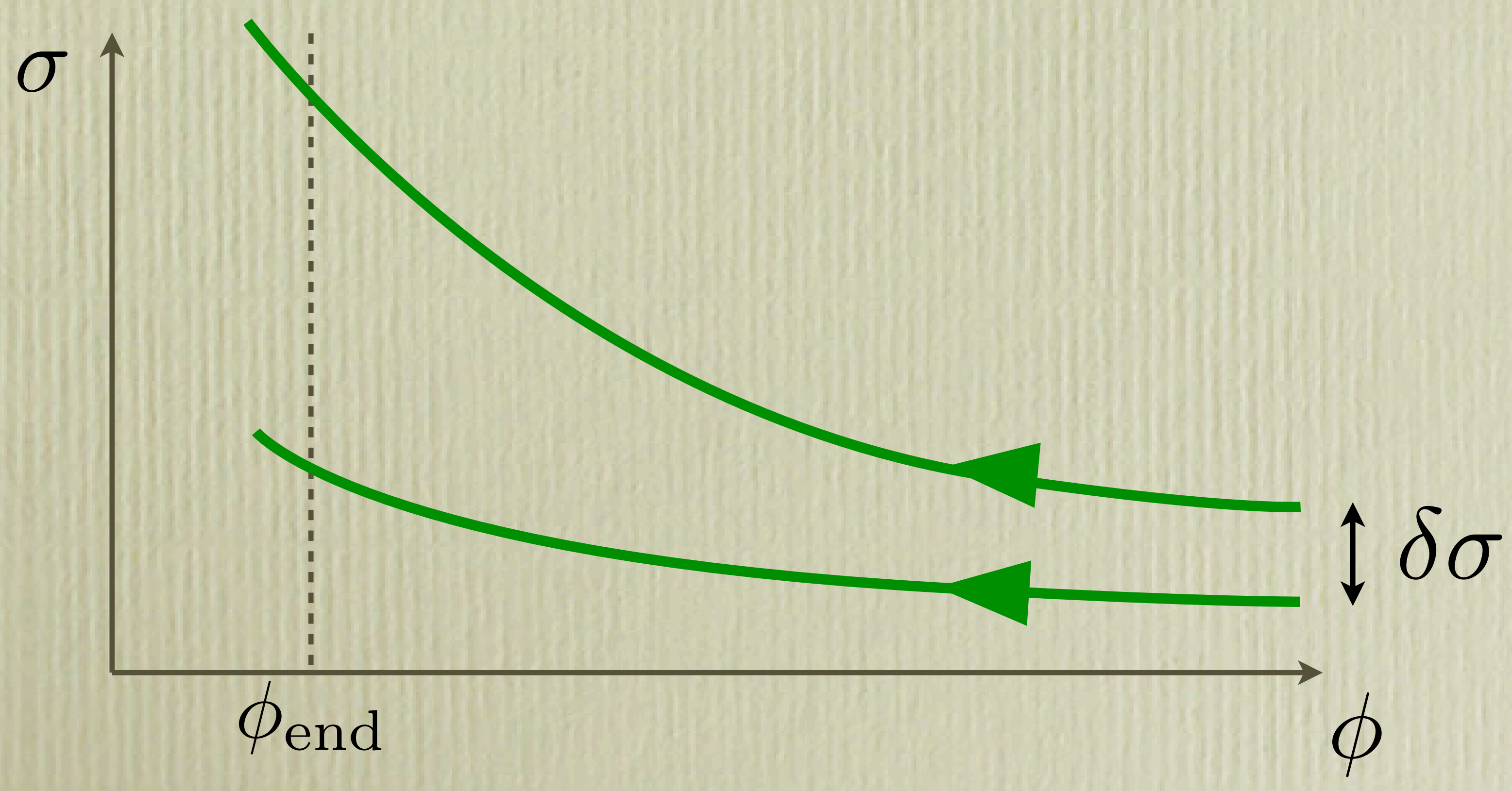

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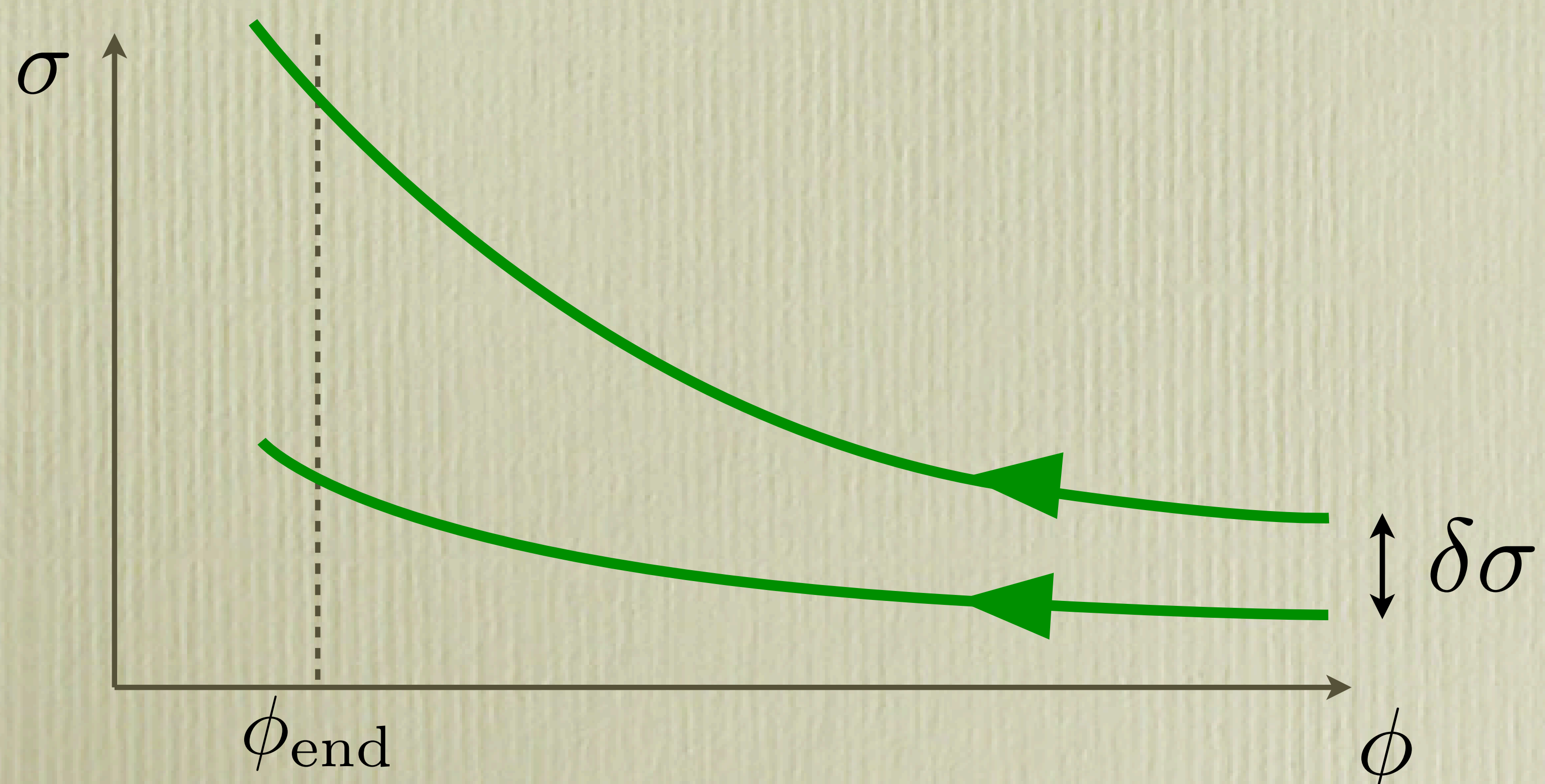
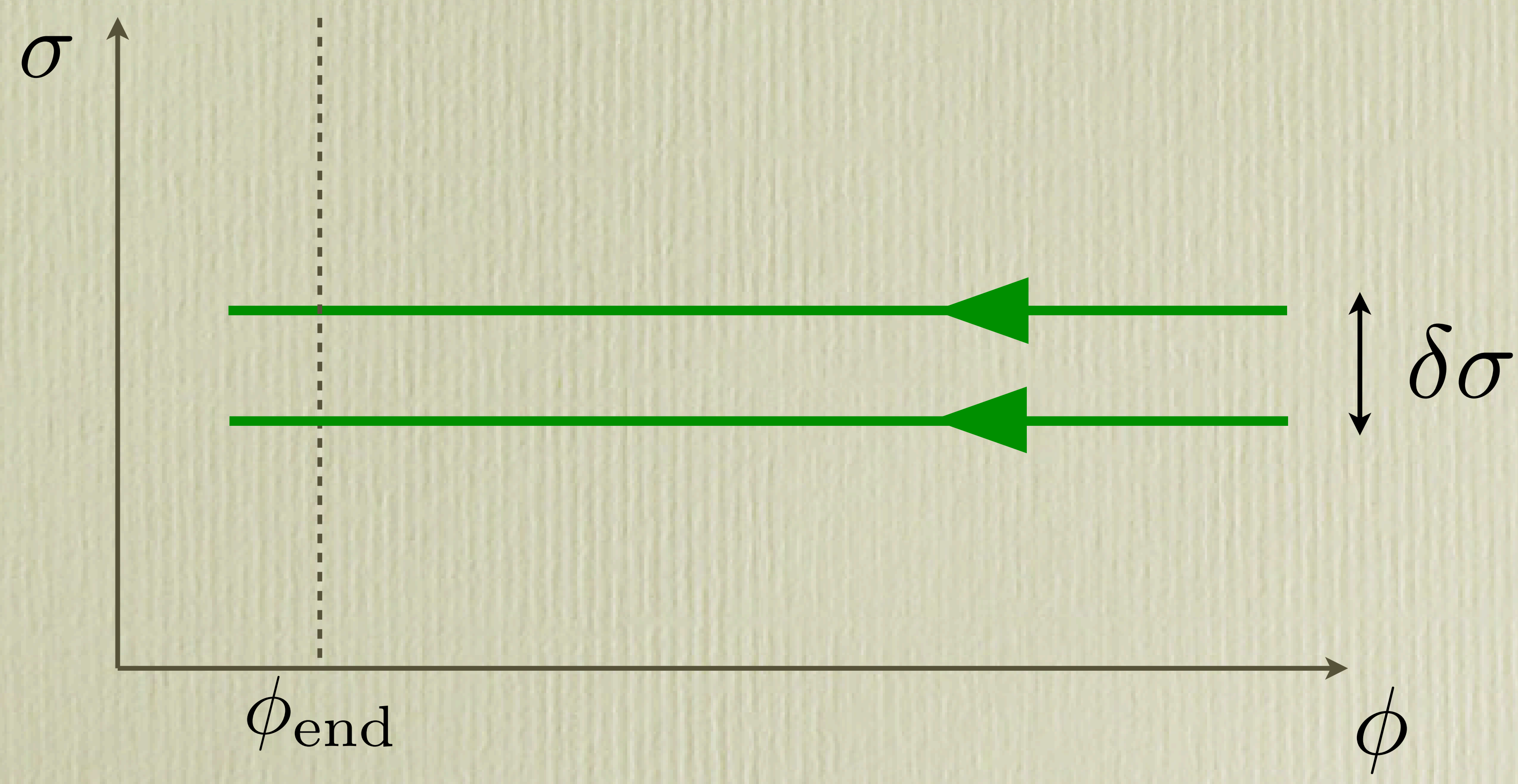


$$\frac{\partial\mathcal{N}/\partial\sigma}{\partial\mathcal{N}/\partial\phi} \sim \frac{\sigma}{\phi}\left(\frac{\sigma_{\rm end}}{\sigma}\right)^2$$

$\delta\mathcal{N}$ from $\delta\sigma$ can become dominant!

Modulating the Kinetic Term

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2\left(1 - \boxed{f\,\frac{\sigma^2}{\mu^{2-m}\phi^m}}\right) - \frac{1}{2}(\partial\sigma)^2 - V(\phi)$$



$\delta\mathcal{N}$ from $\delta\sigma$ can become dominant!

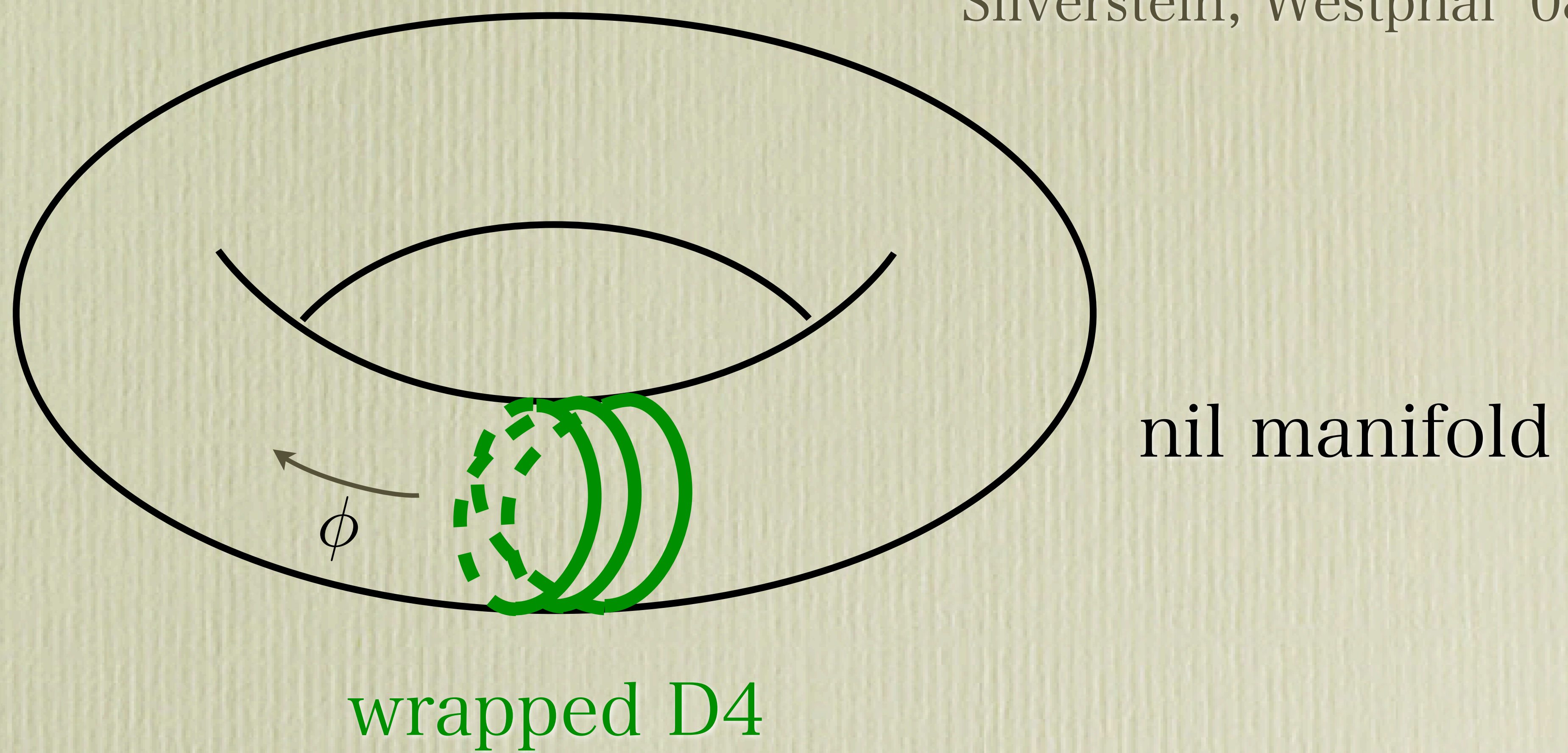
Results So Far

Curvature perturbations from modulus corrections become significant when:

- its effective mass becomes tachyonic
- mainly modulating the inflaton kinetic term

ex.) large-field inflation from monodromy in wrapped D-branes

Silverstein, Westphal '08



monodromy elongates wrapped cycle and yields large-field inf.

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 \; -\mu^{10/3}\phi^{2/3}$$

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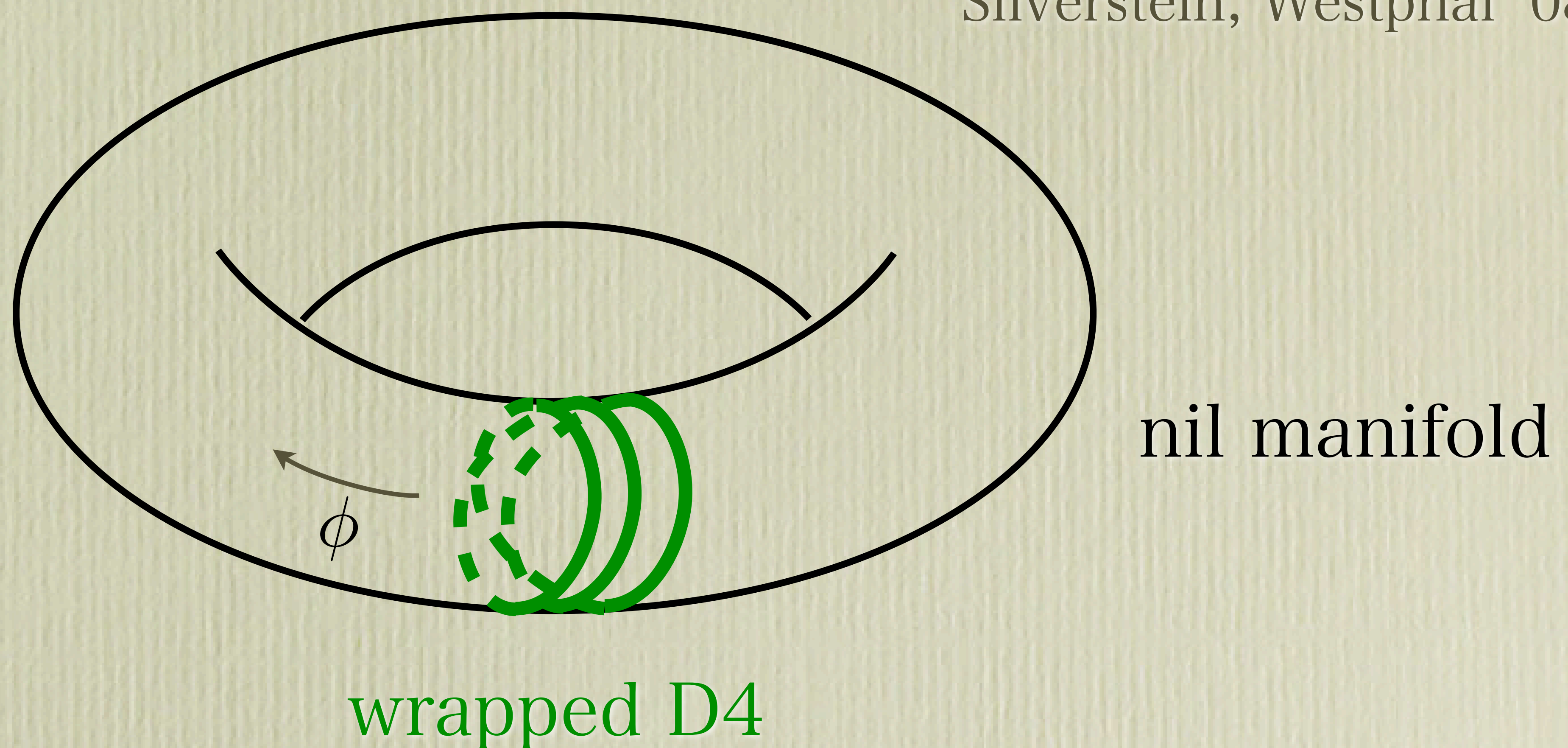
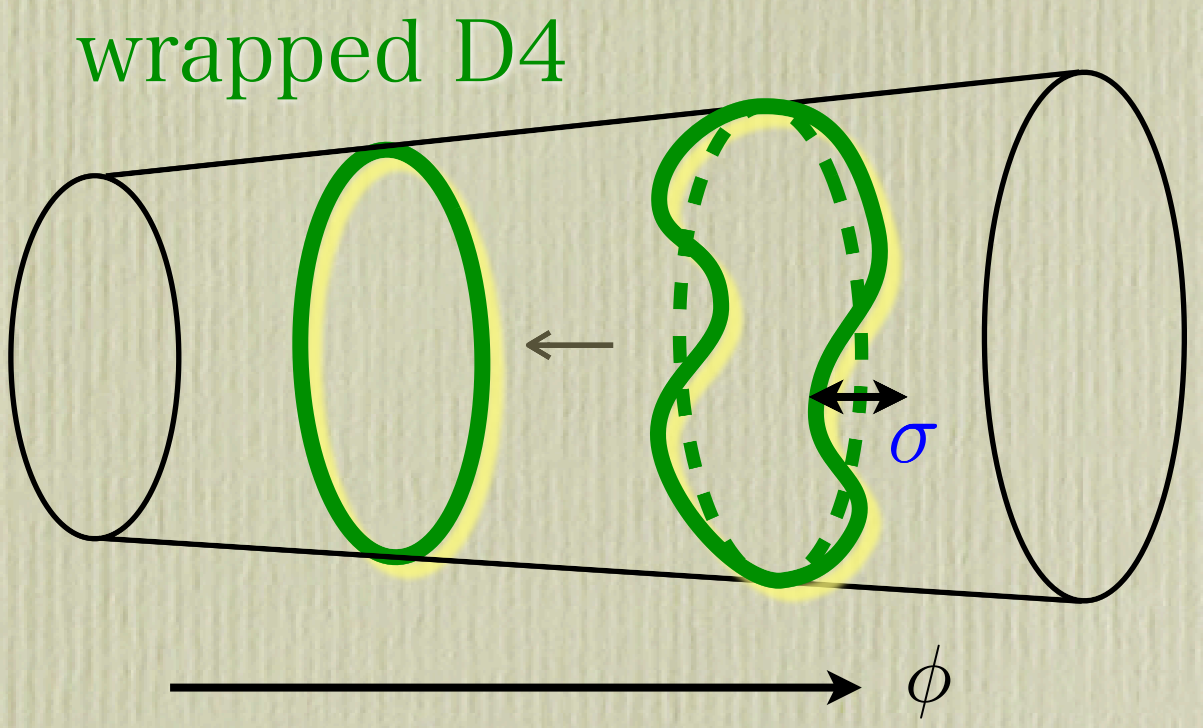


monodromy elongates wrapped cycle and yields large-field inf.

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 \;-\mu^{10/3}\phi^{2/3}$$

$\rightarrow$ oscillation modes can become light in the large-field limit

ex.) large-field inflation from monodromy in wrapped D-branes



ϕ : position of D4

σ_n : oscillation modes

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2$$

$$-\mu^{10/3}\phi^{2/3}$$

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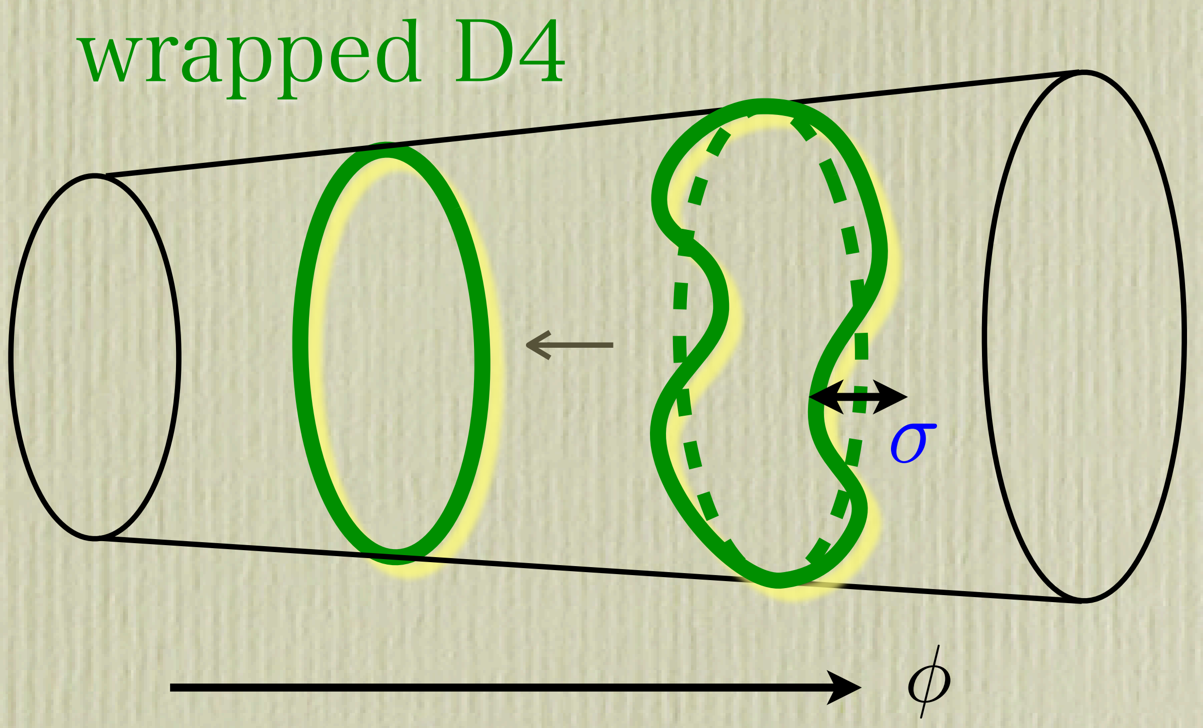

ϕ : position of D4

σ_n : oscillation modes

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2\left(1-\lambda^2\sum_{n\neq 0} n^2\frac{|\sigma_n|^2}{\phi^2}\right) - \frac{1}{2}\sum_{n\neq 0}(\partial\sigma_n)(\partial\overline{\sigma}_n)$$

$$-\mu^{10/3}\phi^{2/3}\left(1+\lambda^2\sum_{n\neq 0} n^2\frac{|\sigma_n|^2}{\phi^2} - \frac{1}{9}\sum_{n\neq 0}\frac{|\sigma_n|^2}{\phi^2}\right)$$

ex.) large-field inflation from monodromy in wrapped D-branes

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2 \left(1 - \lambda^2 \sum_{n\neq 0} n^2 \frac{|\sigma_n|^2}{\phi^2}\right) - \frac{1}{2}\sum_{n\neq 0}(\partial\sigma_n)(\partial\overline{\sigma}_n)$$

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reduces σ's effects

amplifies σ's effects, though only slightly

ex.) large-field inflation from monodromy in wrapped D-branes

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2\left(1 - \lambda^2\sum_{n\neq 0} n^2 \frac{|\sigma_n|^2}{\phi^2}\right) - \frac{1}{2}\sum_{n\neq 0}(\partial\sigma_n)(\partial\overline{\sigma}_n)$$

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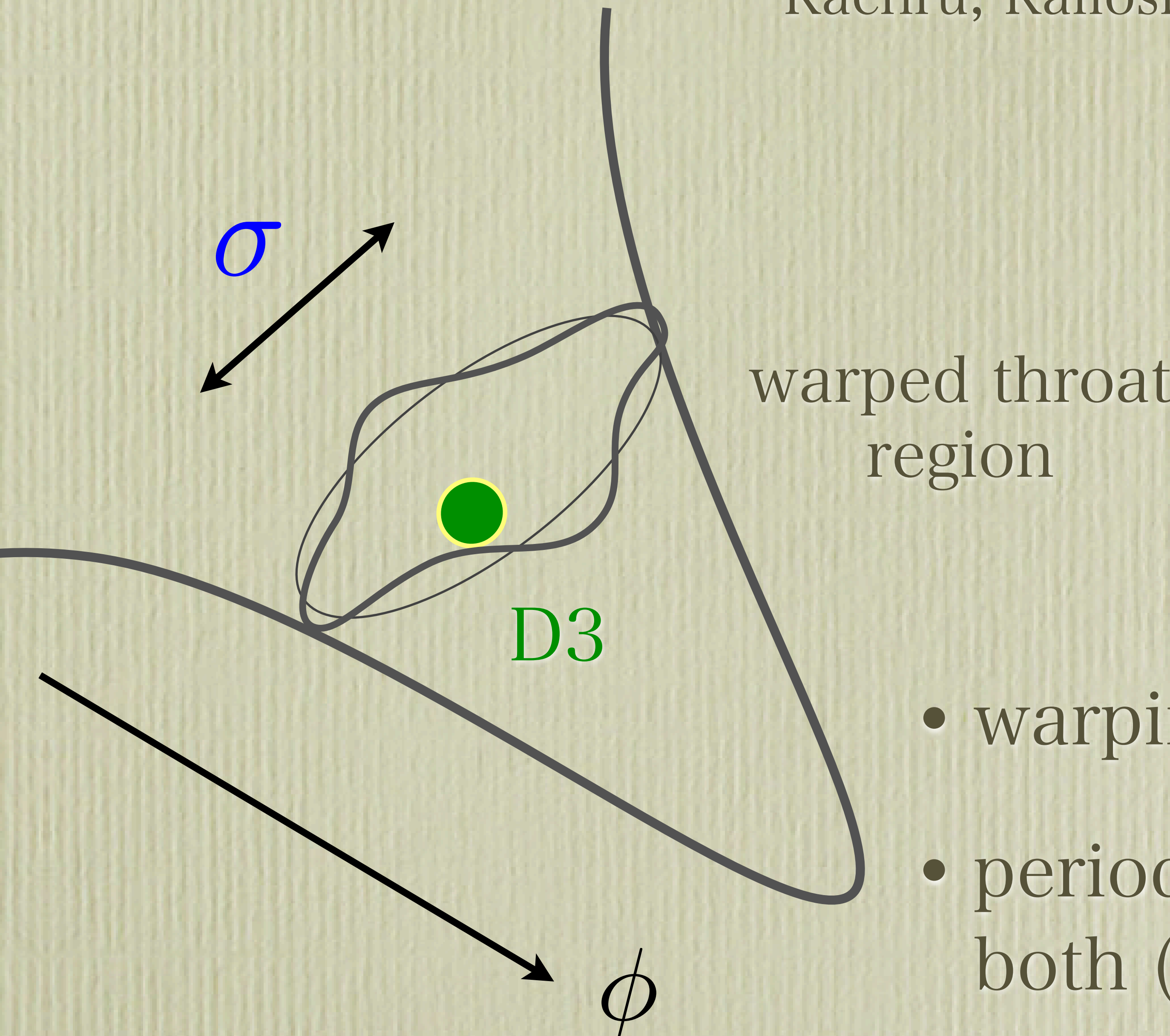
reduces σ's effects

amplifies σ's effects, though only slightly

→ oscillation modes can safely be ignored

ex.) warped D-brane inflation

Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi '03



ϕ : radial position of D3

σ : angular directions

- warping suppresses angular potentials
- periodic angular potentials contain both (local) minima and maxima
  $\rightarrow$ σ can become important
- full analysis with dynamical angular directions may be necessary

Summary

- Light fields can dominantly source curvature perturbations, while minimally affecting the inflaton dynamics.

- We studied under which conditions the light fields' effects become significant/negligible.

- Conversion of entropy to curvature perturbations can become significant when their effective masses are tachyonic, or when they mainly modulate the inflaton kinetic term.

- Can also work for beyond-slow-roll models, e.g. rapid-roll, DBI inflation.

Curvature Perturbations from σ

$$\frac{\mathcal{L}}{\sqrt{-g}} = -\frac{1}{2}(\partial\phi)^2\left(1 - f\frac{\sigma^2}{\mu^{2-m}\phi^m}\right) - \frac{1}{2}(\partial\sigma)^2 - V(\phi)\left(1 + g\frac{\sigma^2}{\mu^{2-m}\phi^m}\right)$$

$$V(\phi) \propto \phi^n$$

$$\frac{\delta\mathcal{N}}{\delta\phi} \simeq \frac{\phi}{nM_p^2} \qquad \frac{\delta\mathcal{N}}{\delta\sigma} \simeq \frac{1}{2}\left(\frac{m}{n} - \frac{f}{g}\right)\frac{\sigma}{M_p^2}\left\{1 - \left(\frac{\sigma_f}{\sigma}\right)^2\right\}$$

$$\frac{\partial\mathcal{N}/\partial\sigma}{\partial\mathcal{N}/\partial\phi} \sim \frac{\sigma}{\phi}\left\{1 - \left(\frac{\sigma_f}{\sigma}\right)^2\right\}$$

$$\mathcal{P}_{\zeta_\sigma} = \left(\frac{\partial\mathcal{N}}{\partial\sigma}\right)^2\left(\frac{H}{2\pi}\right)^2 \qquad n_s - 1 = \frac{\sigma_f^2 + \sigma^2}{\sigma_f^2 - \sigma^2}\,4g\frac{M_p^2}{\mu^{2-m}\phi^m} - n^2\frac{M_p^2}{\phi^2}$$

$$f_{\rm NL} = \left(\frac{m}{n} - \frac{f}{g}\right)^{-1}\frac{M_p^2}{\sigma^2 - \sigma_f^2}$$