Counting galaxies and inflationary fields with future redshift surveys

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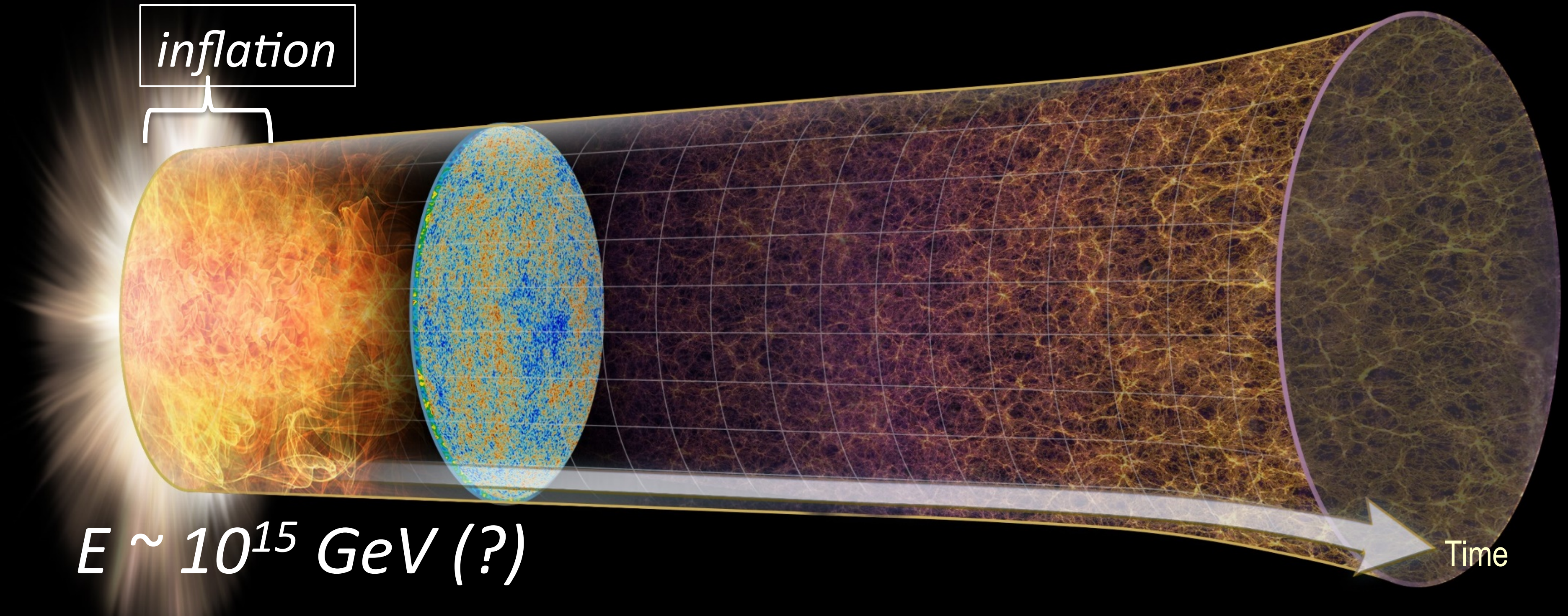
CosKASI, 대전, 4/21/2017

What is the physics behind inflation?

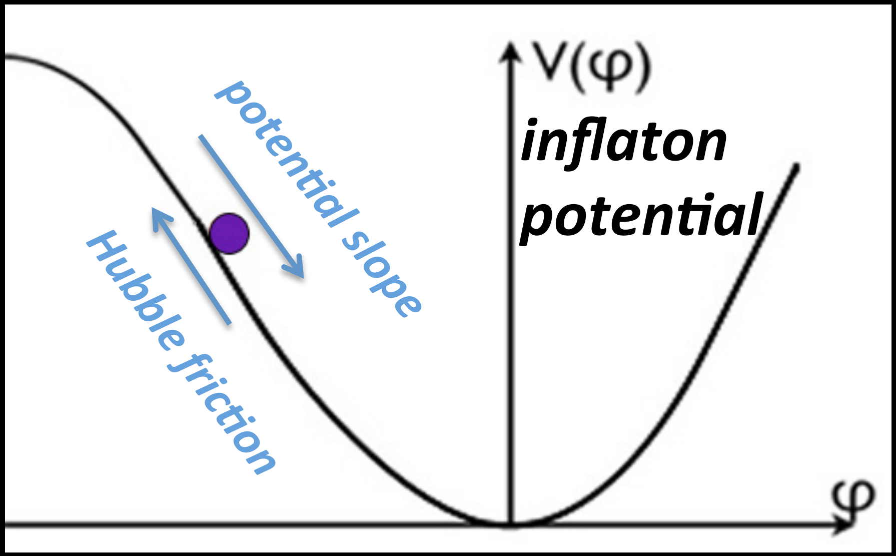
Motivation:

- *understand initial conditions of Universe*
- *probe particle physics beyond the standard model at extremely high energies*



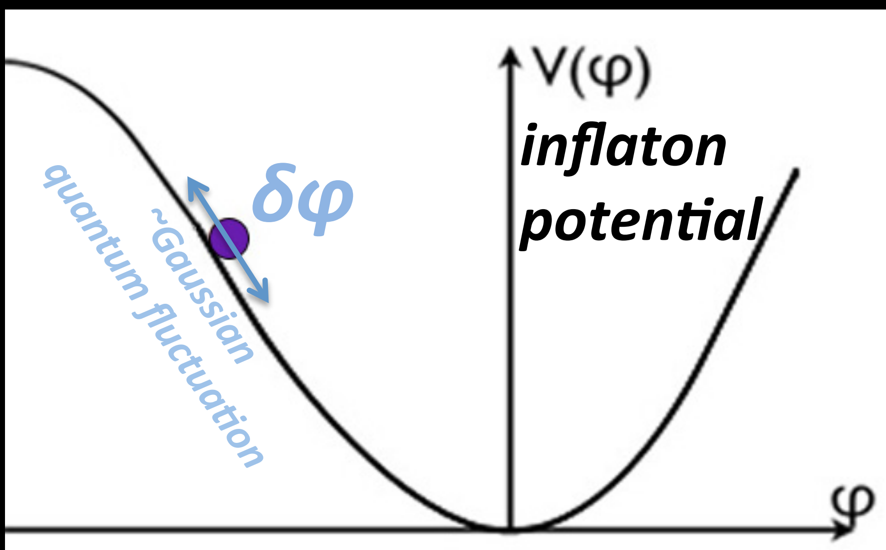
Single-field inflation

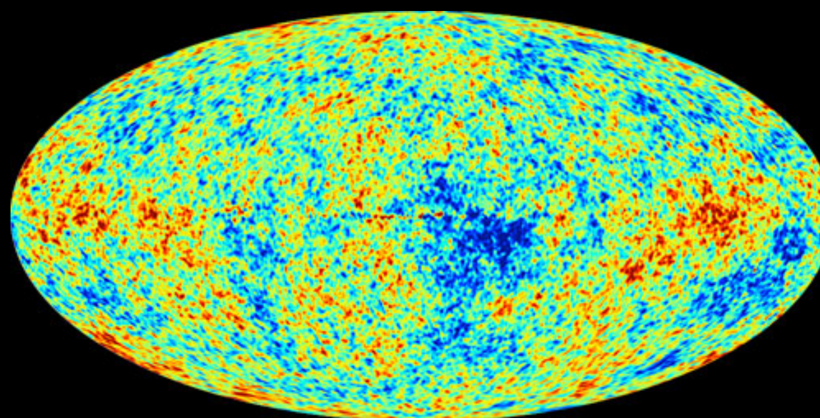
(1) *slow-roll inflation generates N ~ 60 e-folds of (quasi-)exponential expansion*

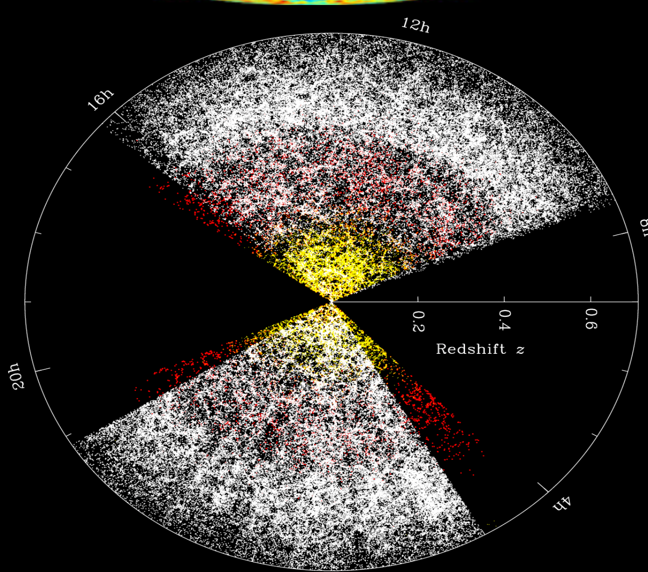


Single-field inflation

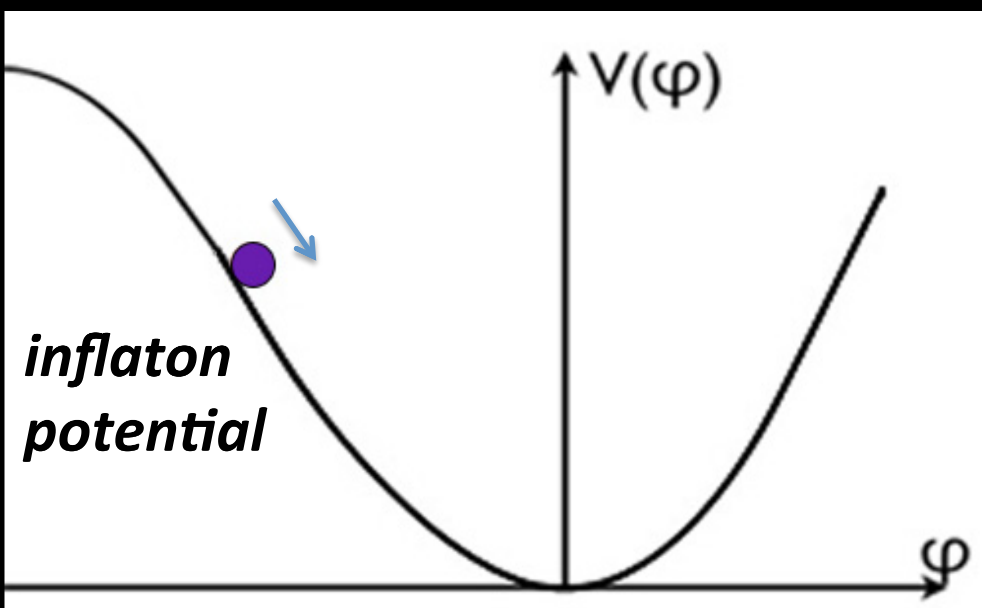
(2) *quantum fluctuations in inflaton seed large-scale structure of the Universe*



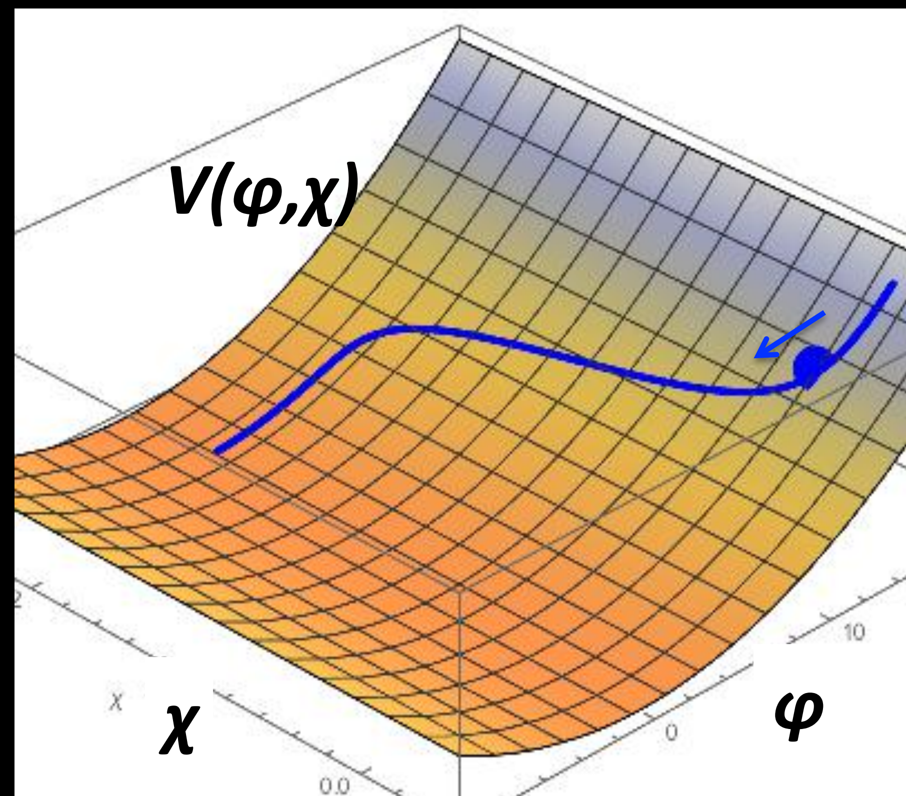




Was inflation driven by a single field or by multiple fields?



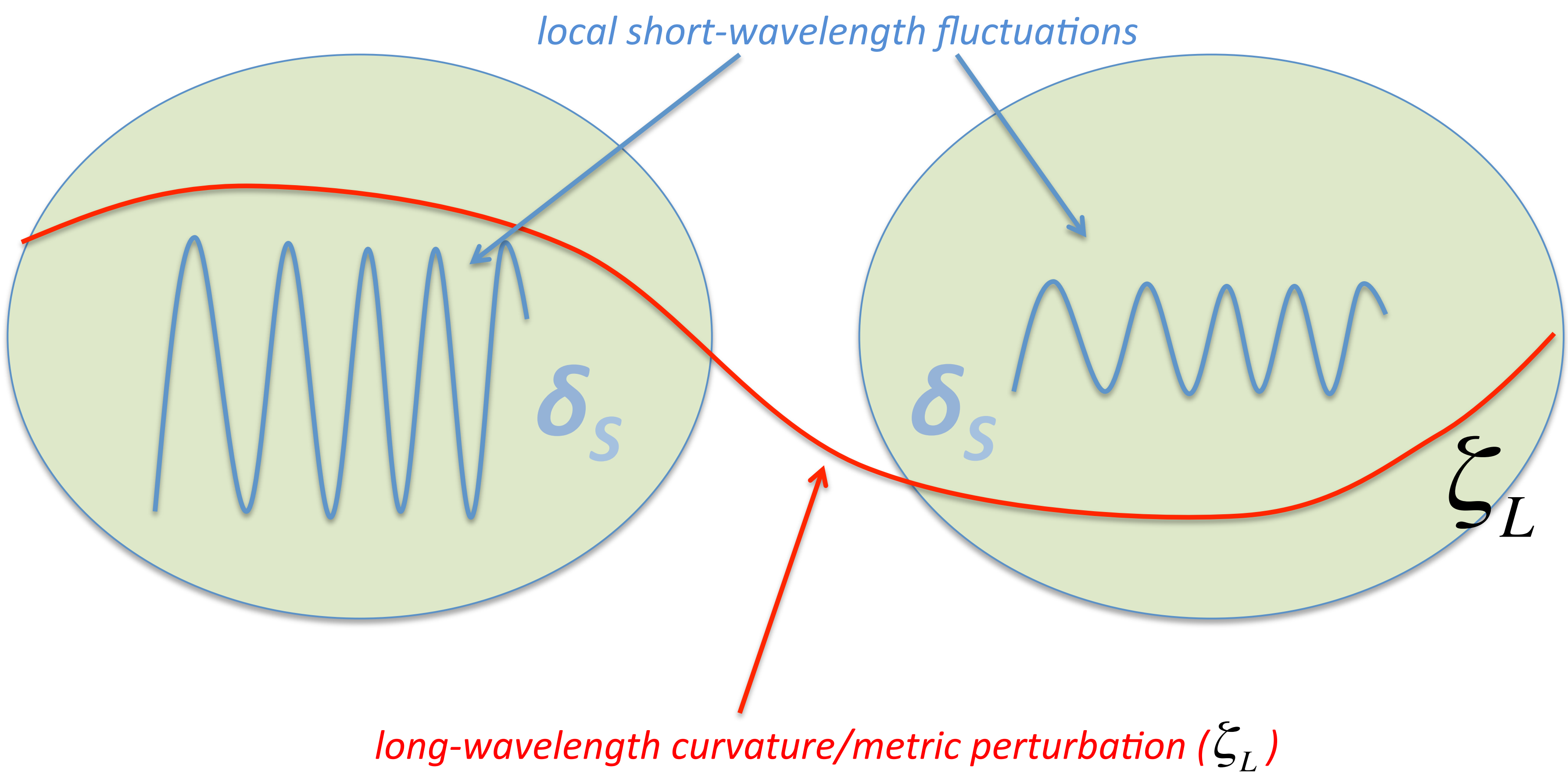
single-field inflation



multifield inflation

Local non-Gaussianity

modulation of small-scale perturbations by long mode, "mode coupling"



Connection to local ansatz

primordial (Bardeen) potential

Local ansatz: $\Phi(\vec{x}) = \phi(\vec{x}) + f_{NL}\left(\phi^2(\vec{x}) - \left\langle \phi^2(\vec{x}) \right\rangle\right)$

Gaussian auxiliary field

Long-short split: $\Phi = (\phi_L + \phi_S) + f_{NL}(\phi_L + \phi_S)^2$

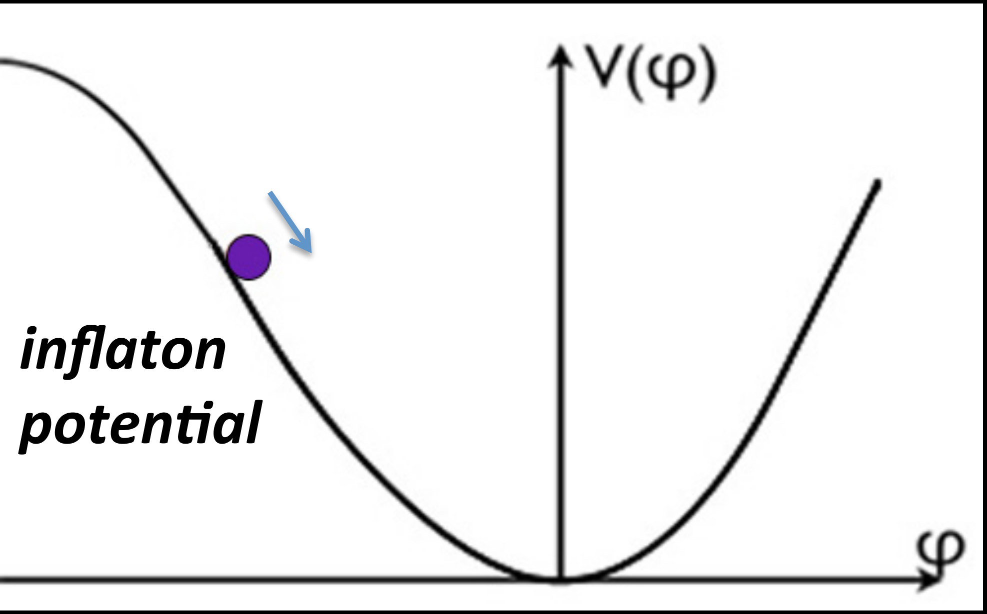
independent long and short components

Mode-coupling: $\Phi_S = \phi_S + \boxed{2 f_{NL} \phi_L \phi_S} + \ldots$

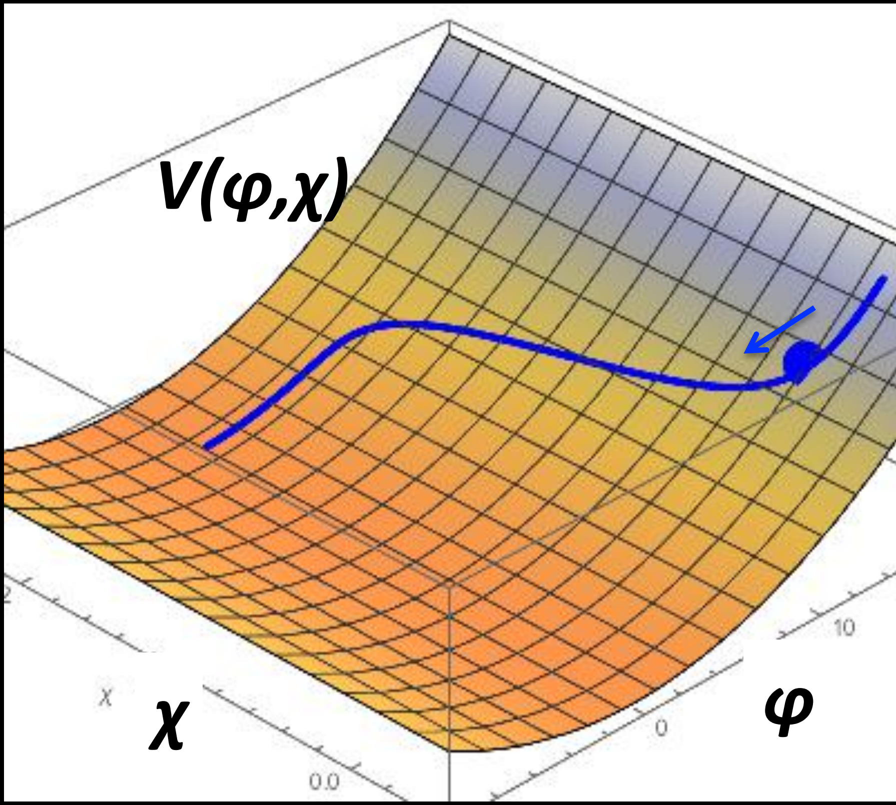
Local non-Gaussianity distinguishes between single- and multifield

$f_{NL} = 0$ (*)

f_{NL} non-zero

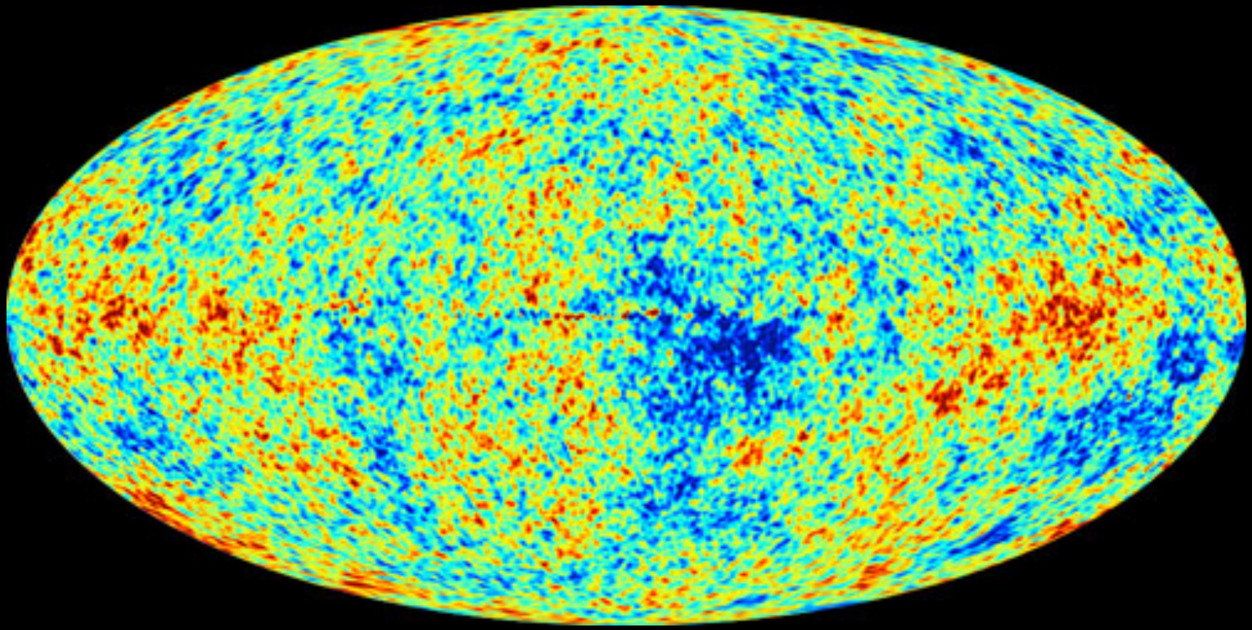


single-field inflation



multifield inflation

Current best constraints come from CMB bispectra

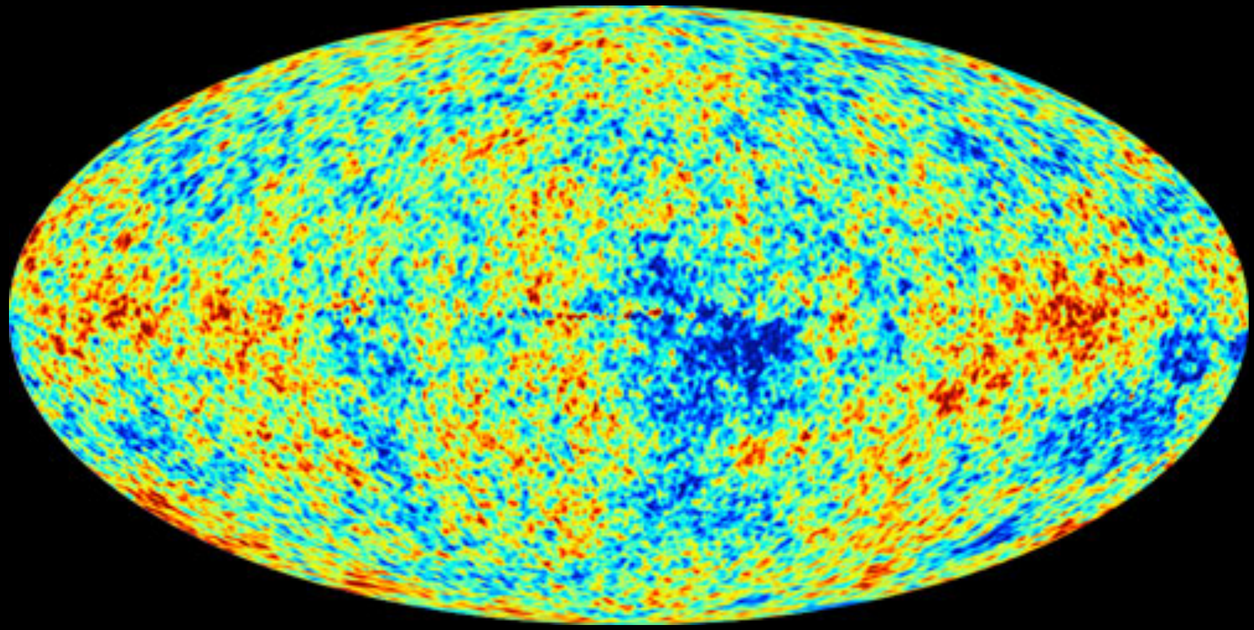


f_{NL} = 0.8 +/- 5.0 (68% CL)

Planck 2015, paper XVII

How much non-Gaussianity does multifield inflation predict?

de Putter, Gleyzes, Doré 2017



f_{NL} = 0.8 +/- 5.0 (68% CL)

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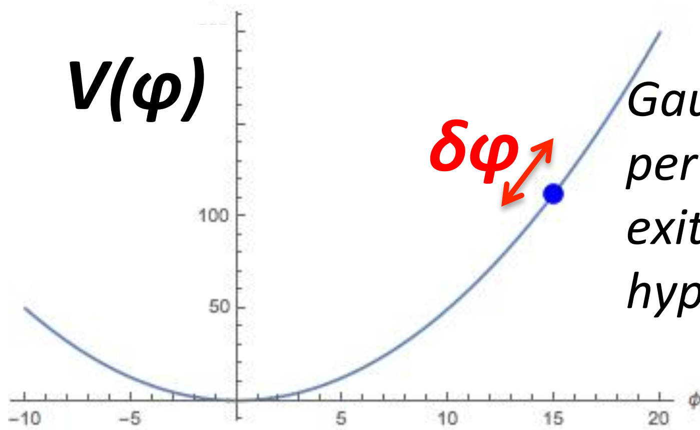
Separate-Universe description of primordial fluctuations

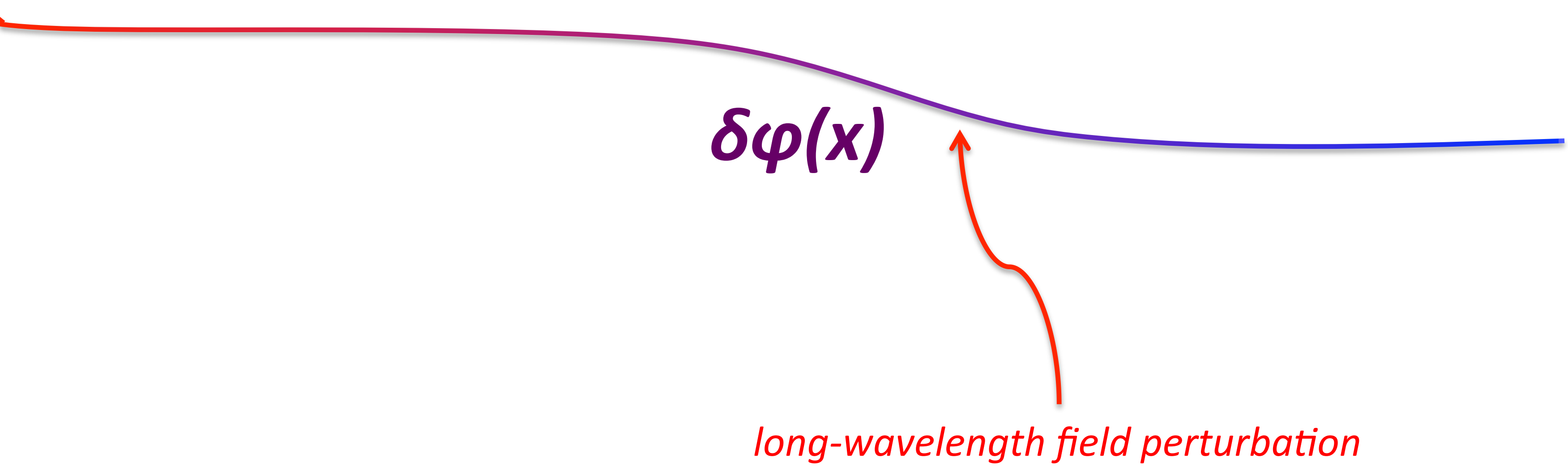
Starobinsky 1985, Sasaki & Stewart 1996,…



Gaussian field perturbations at horizon exit (spatially flat hypersurface/gauge)

Separate-Universe description of primordial fluctuations

Starobinsky 1985, Sasaki & Stewart 1996,…



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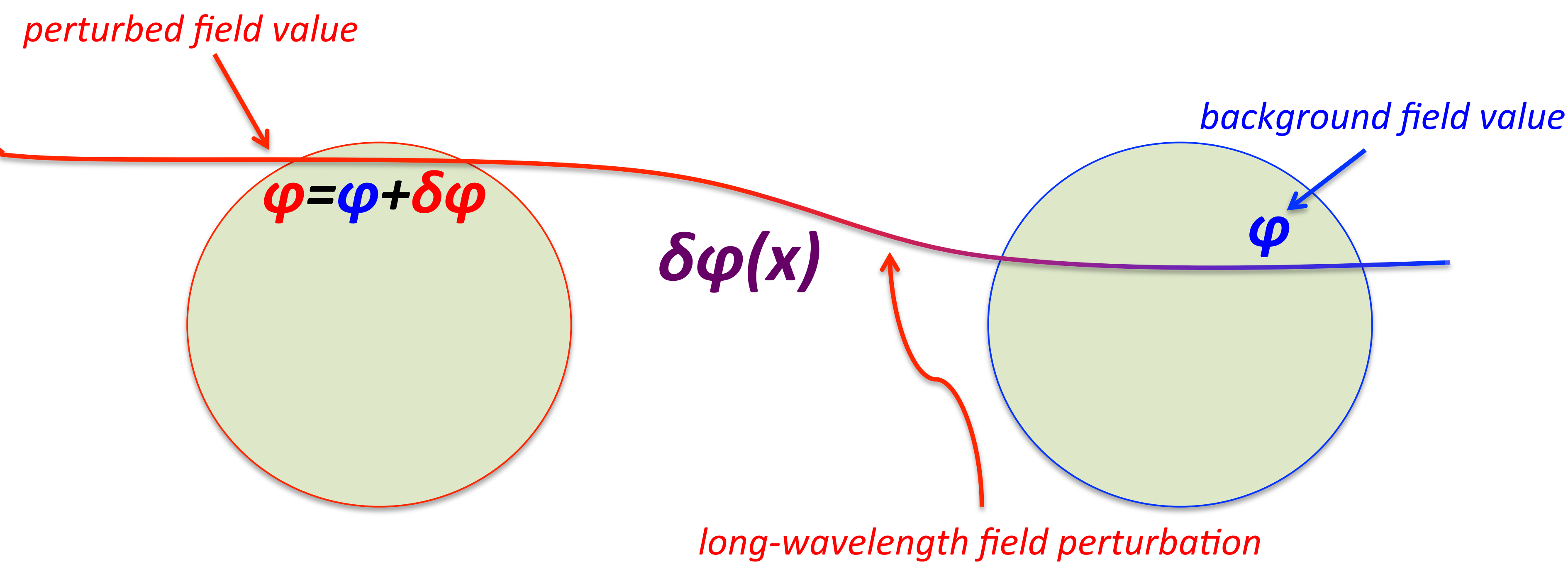

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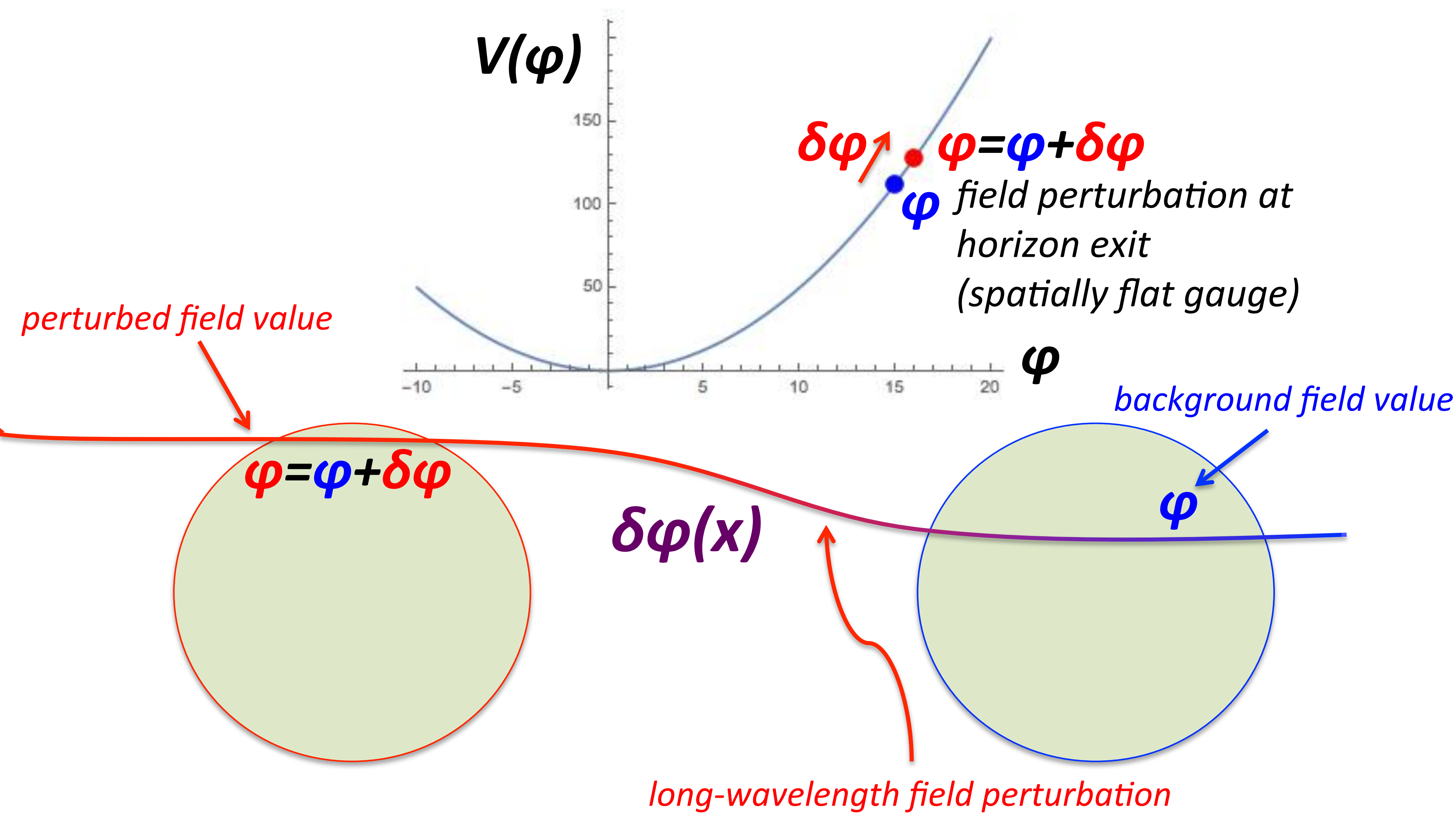

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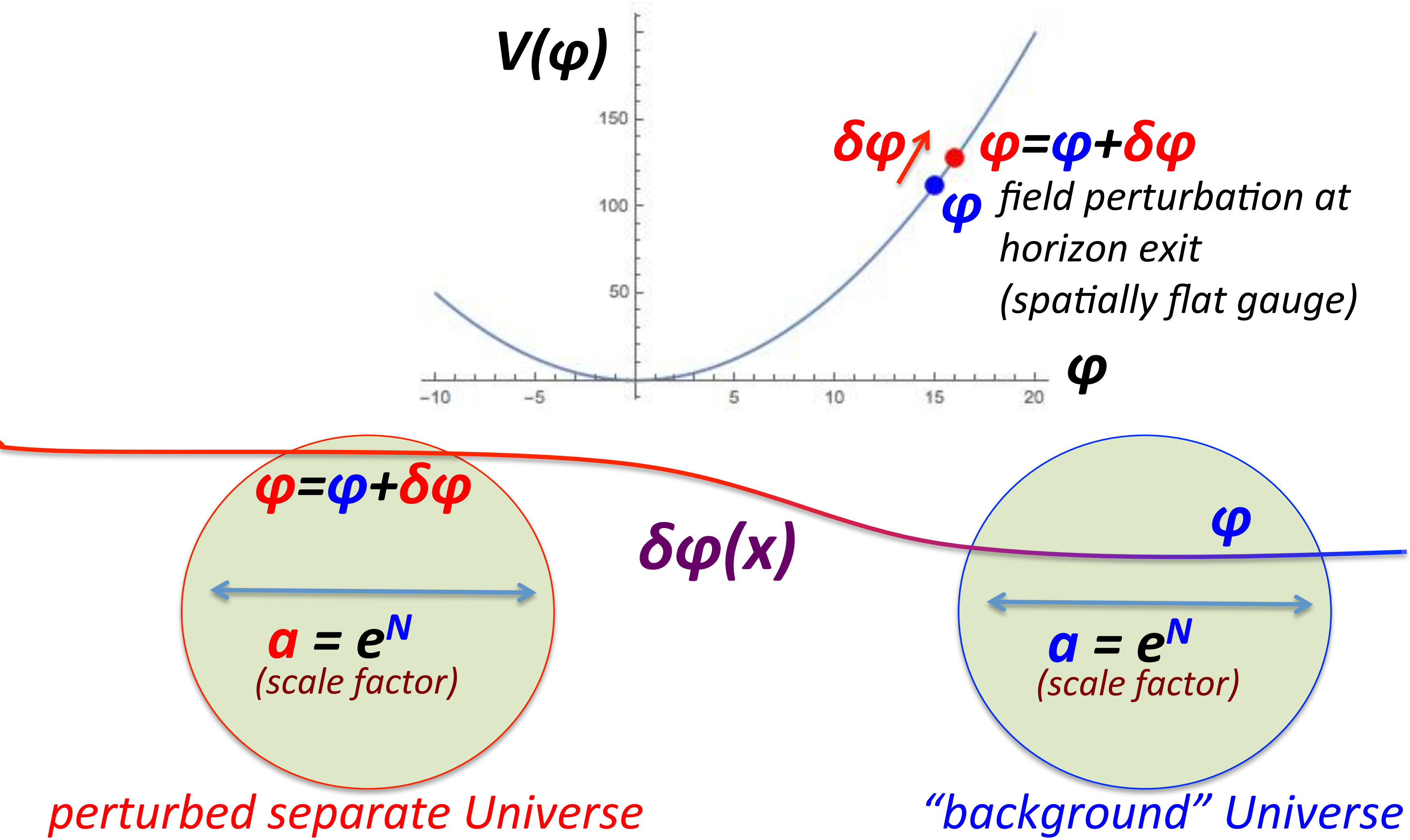

Separate-Universe description of primordial fluctuations

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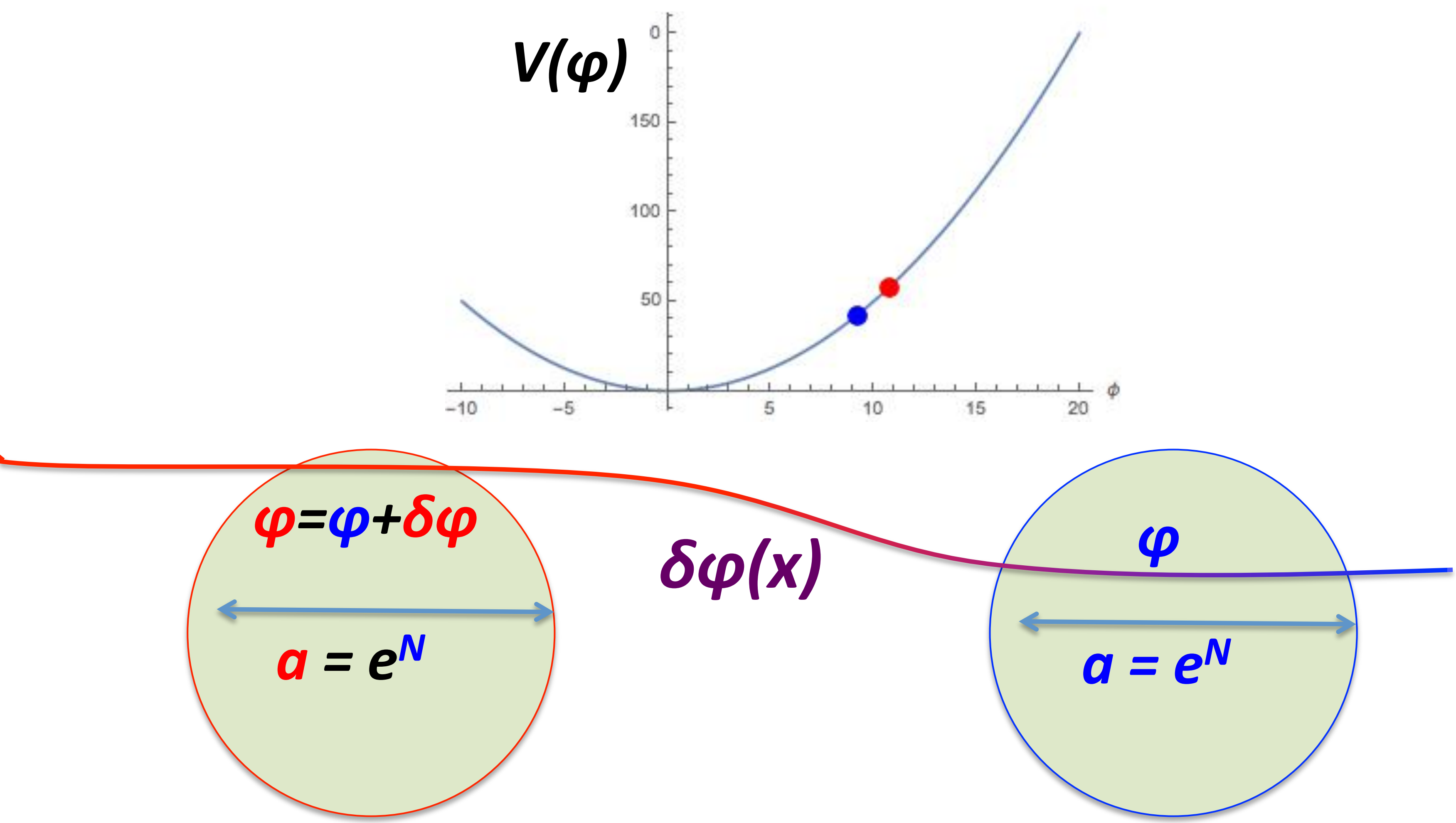

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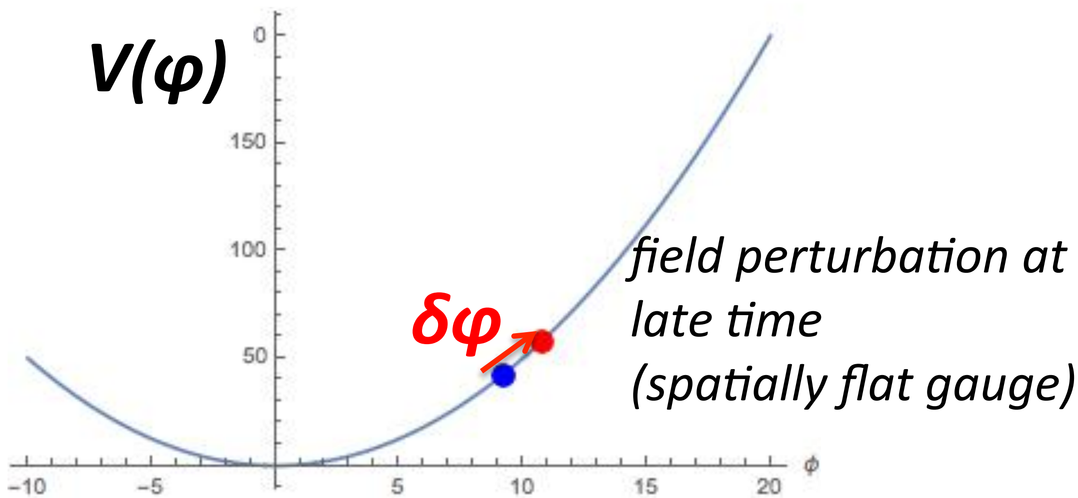
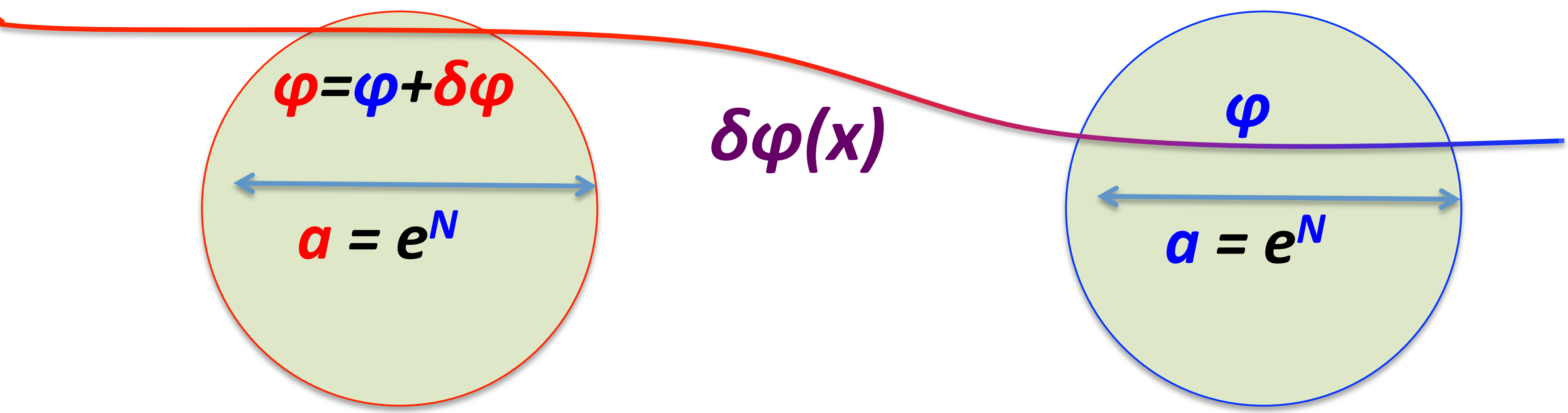
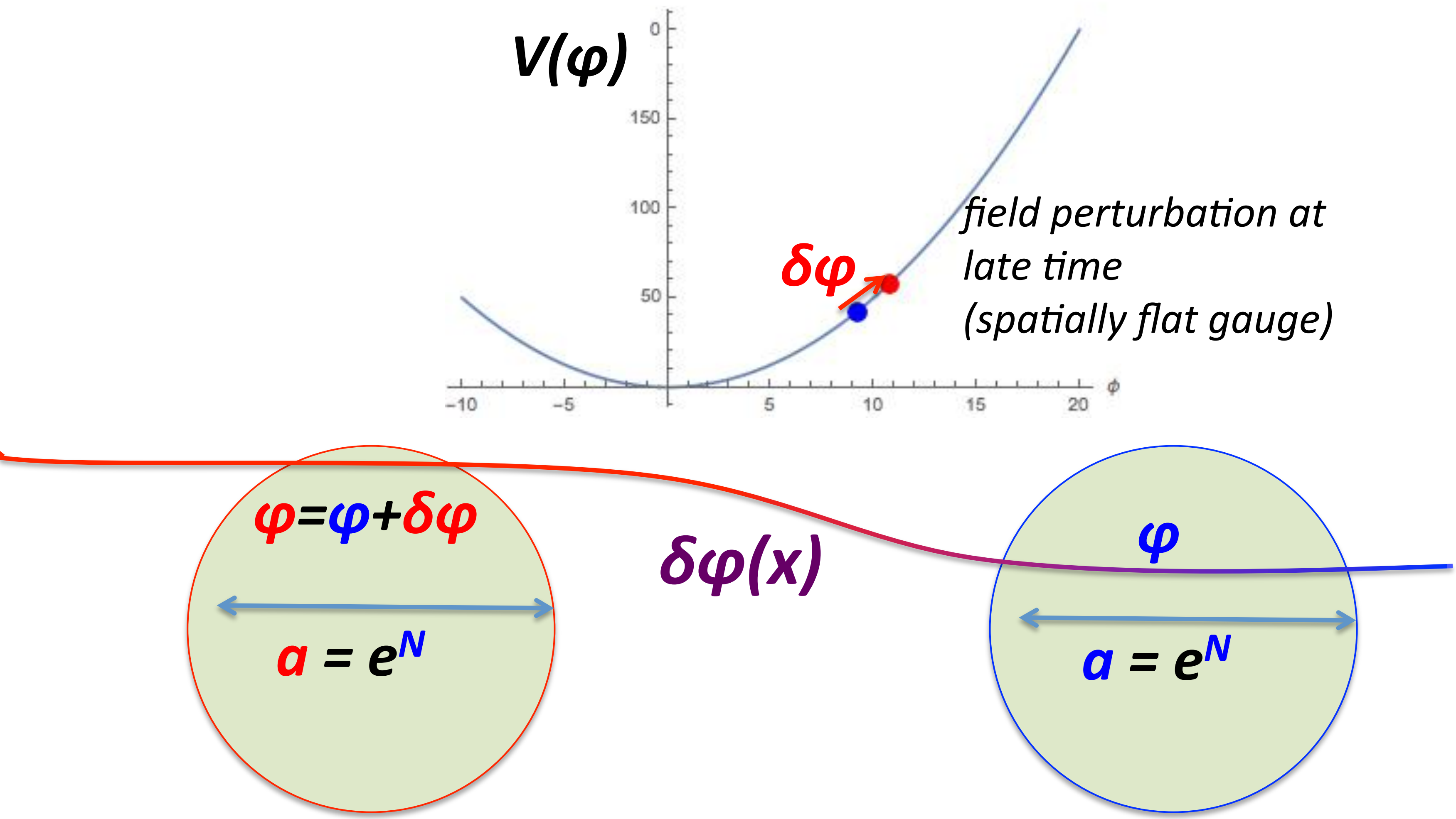




ζ is spatial curvature perturbation on constant energy density hypersurface



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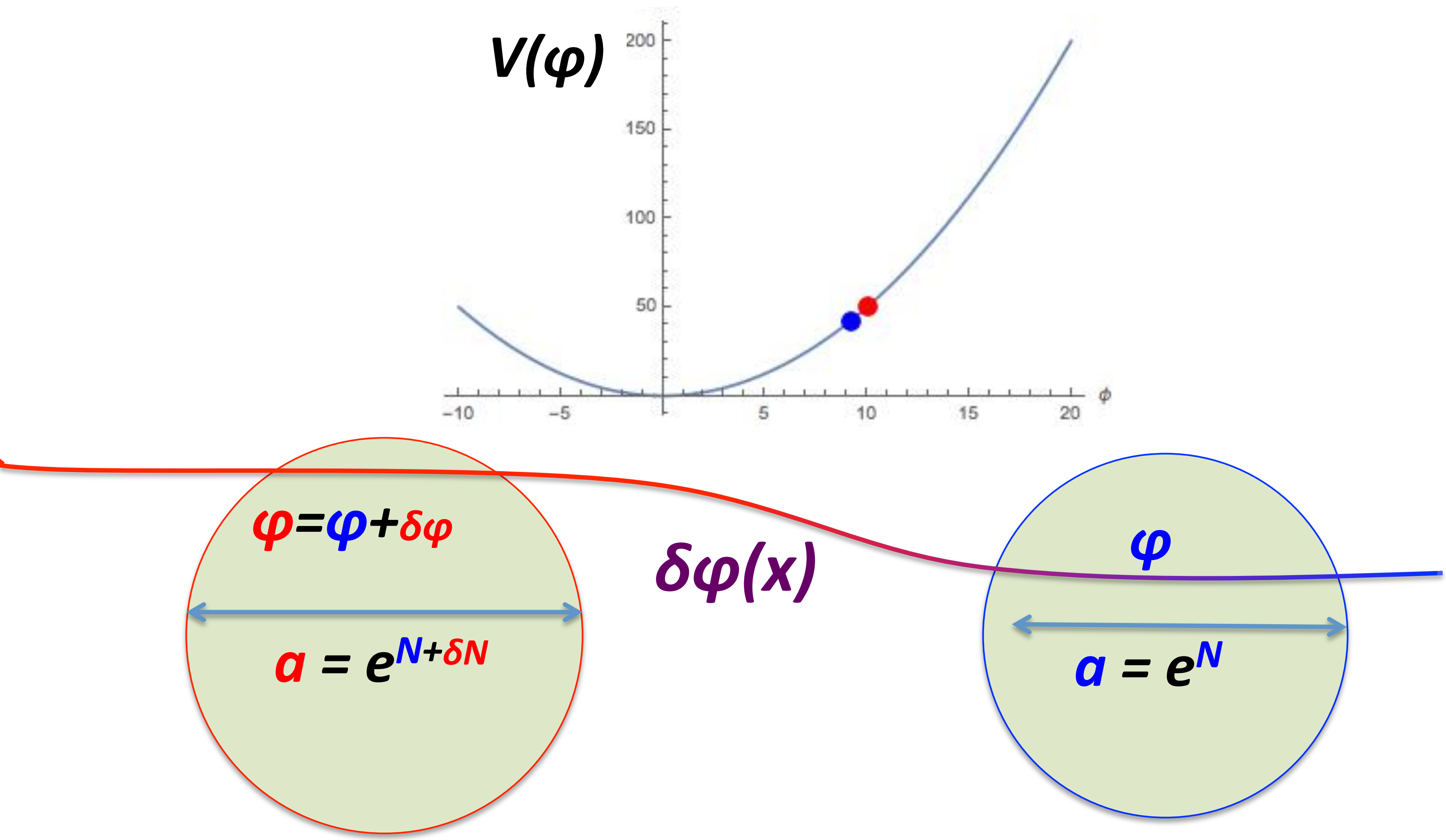

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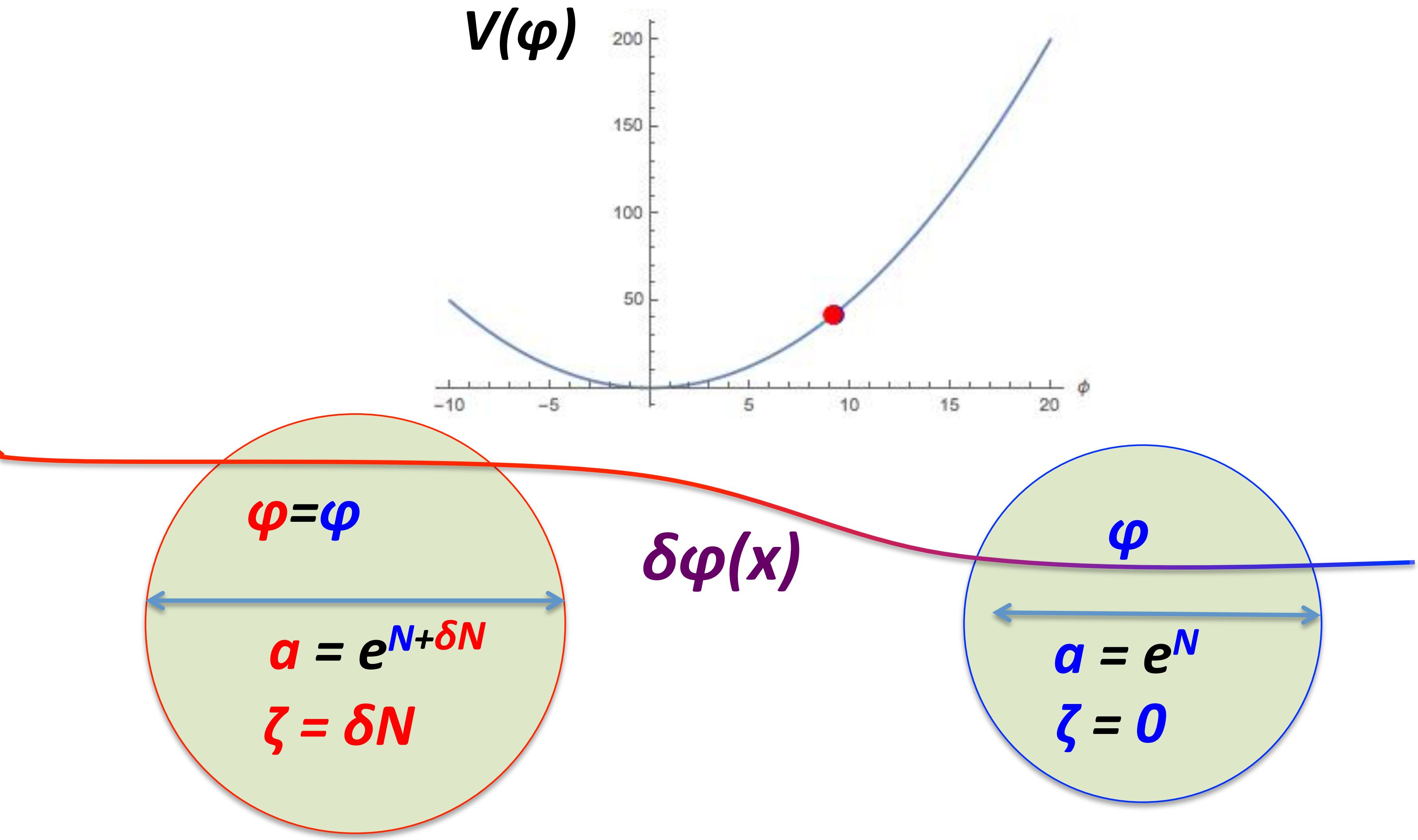
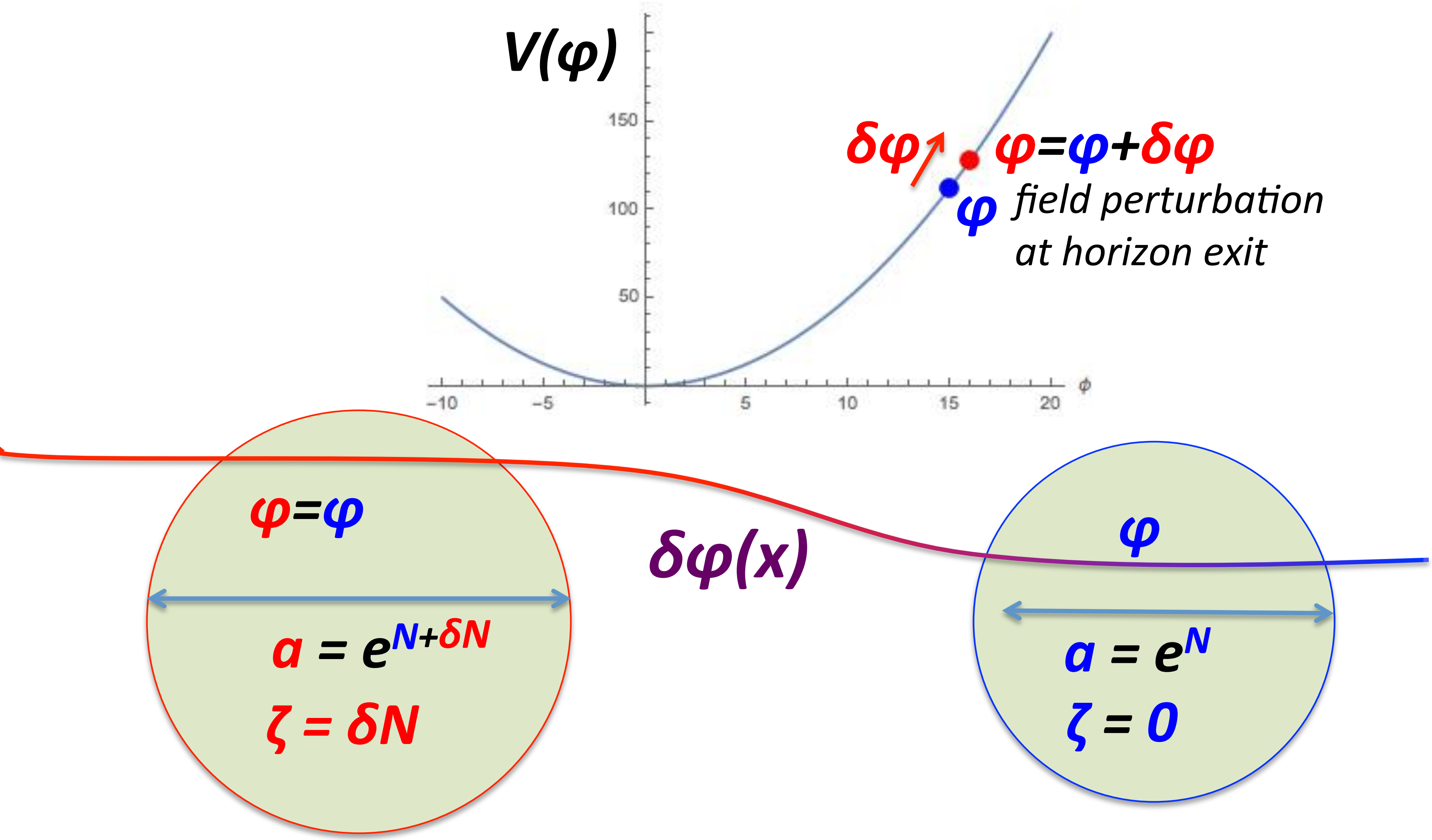
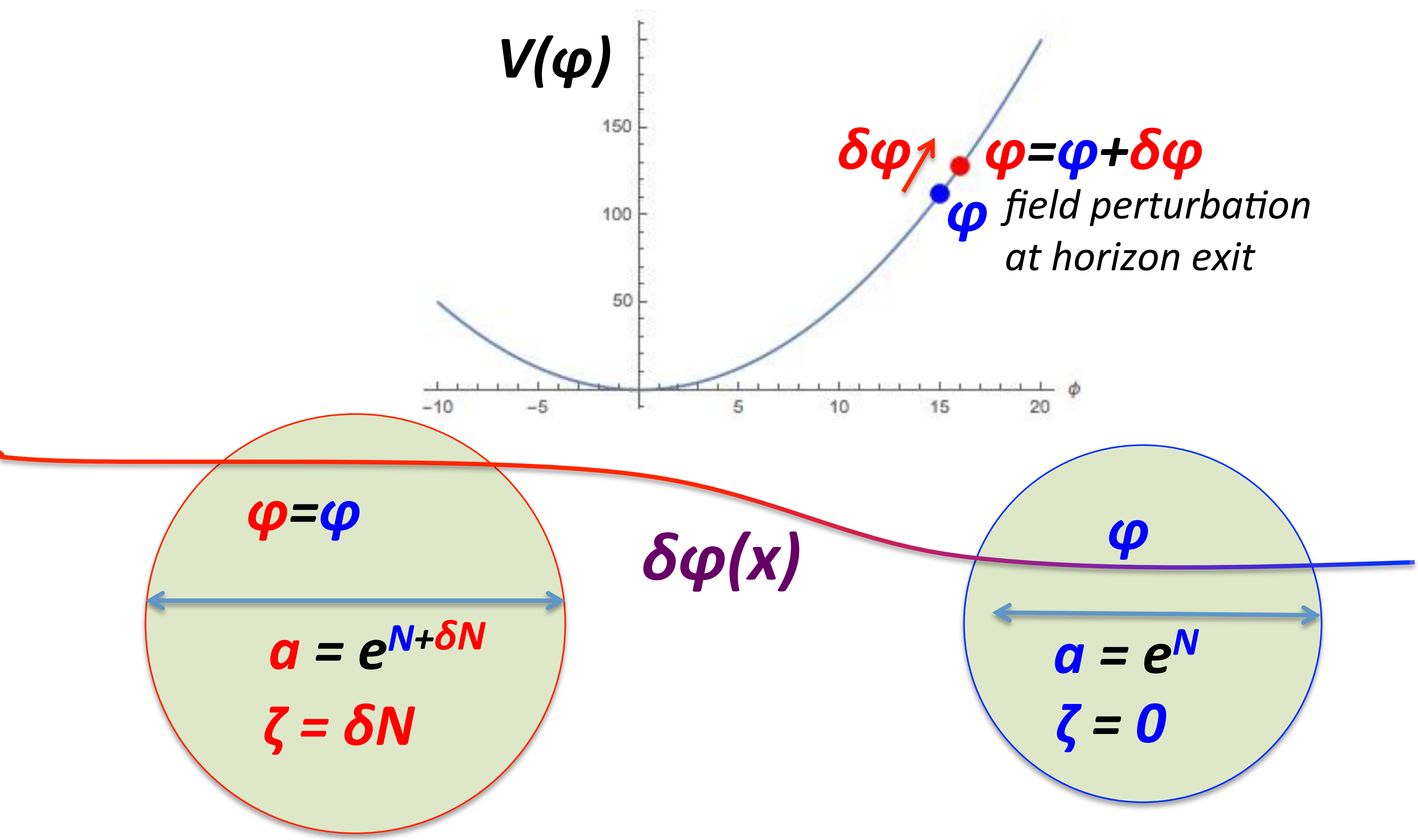


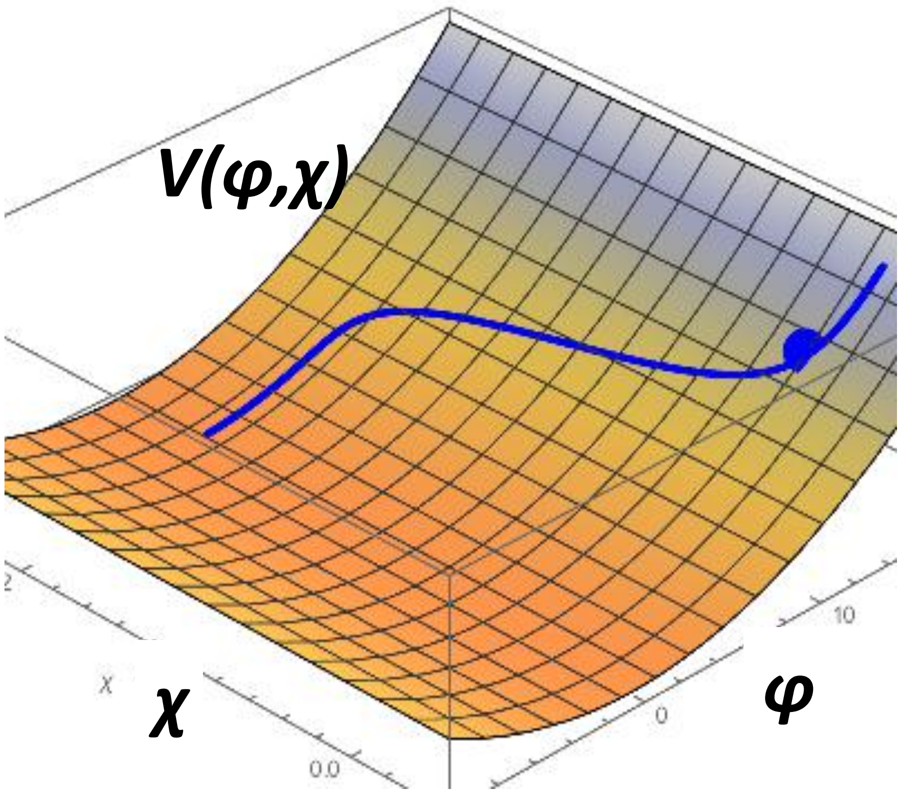
Curvature perturbation is difference in number of e-folds of expansion, $\zeta = \delta N$



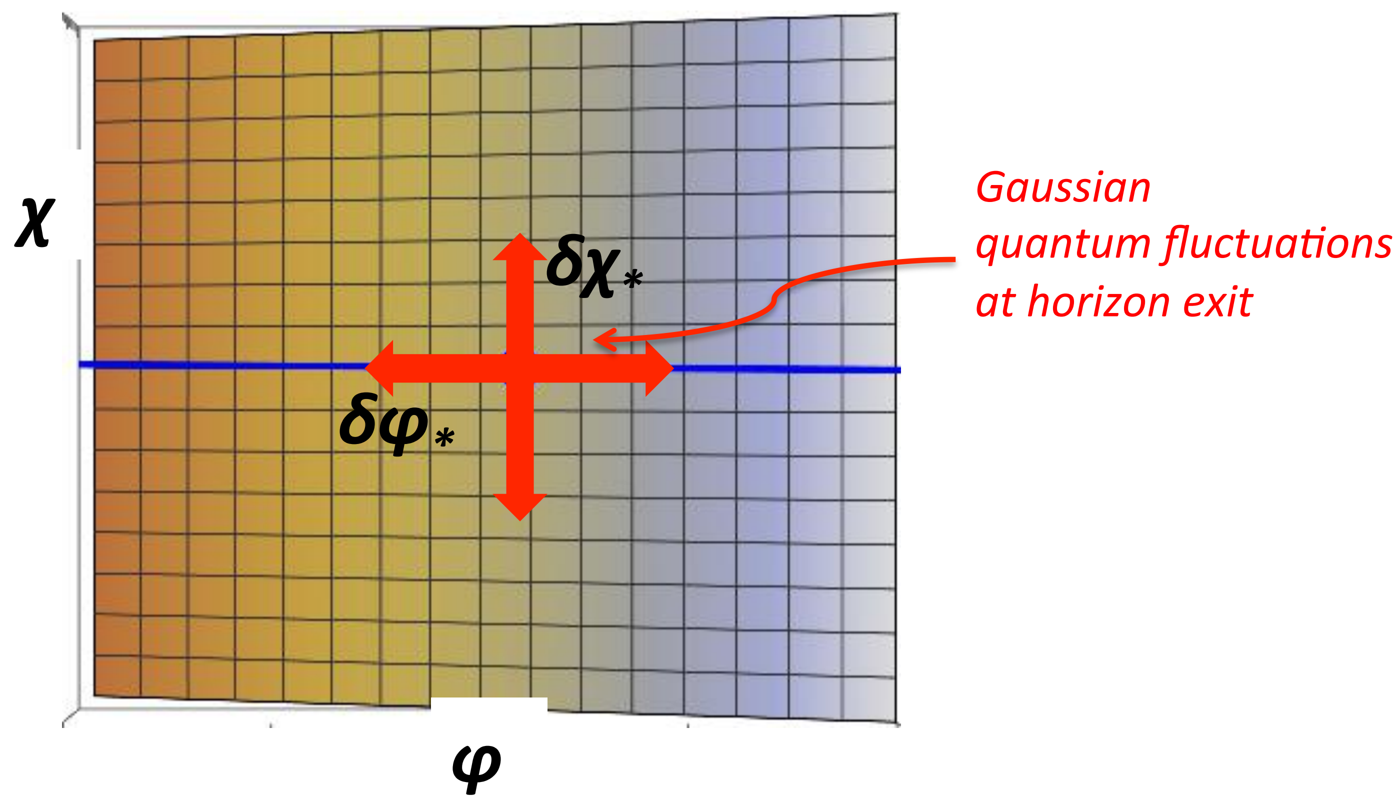
$\zeta = \delta N$ conserved because perturbations adiabatic (along background trajectory)



Non-Gaussianity in multifield Inflation



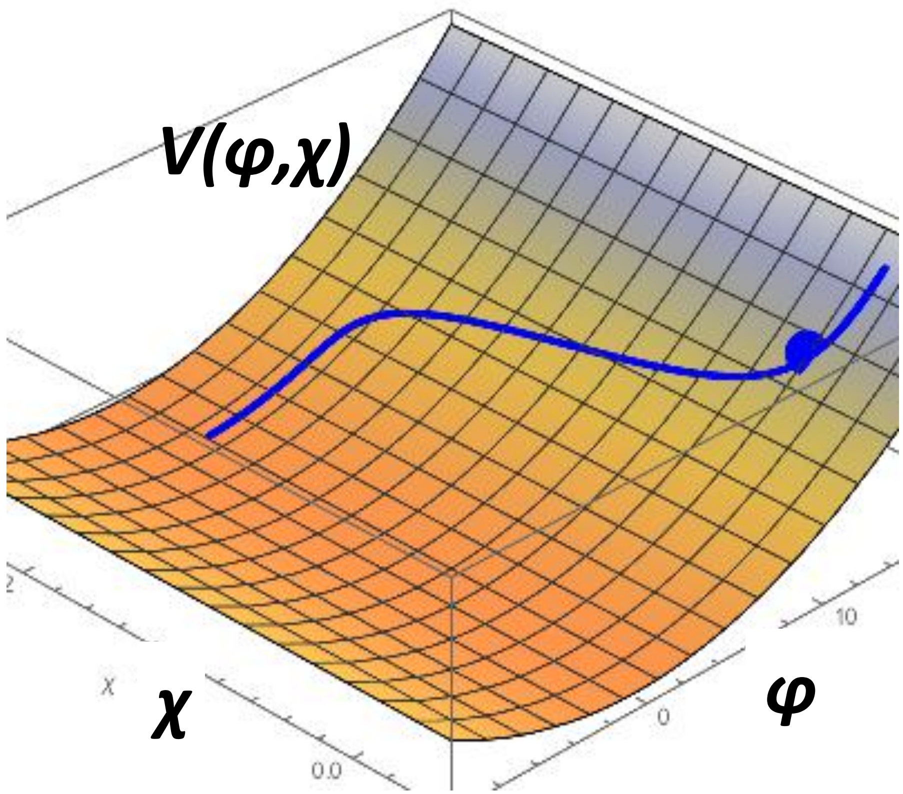
Multifield inflation includes (relevant) non-adiabatic perturbations



Spectator multifield models

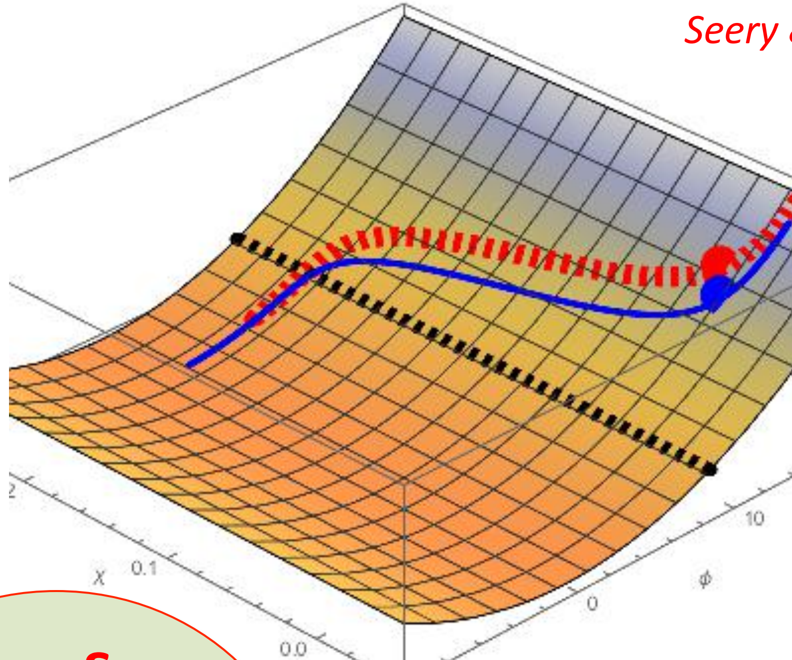
2-field Inflation with:

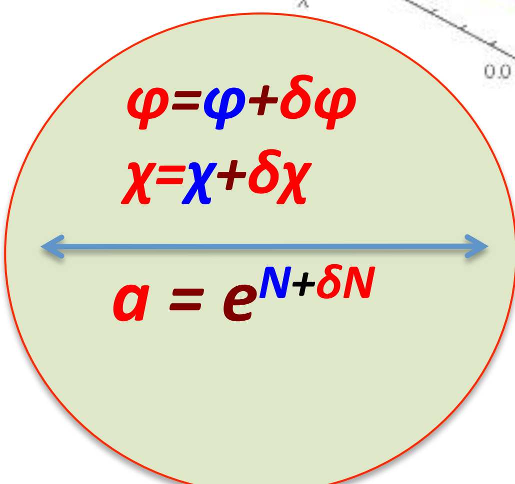
- **Sum-separable potential, $W(\varphi,\chi) = U(\varphi) + V(\chi)$**
- **Inflaton field φ, which drives Inflation**
- **“Spectator field” χ**



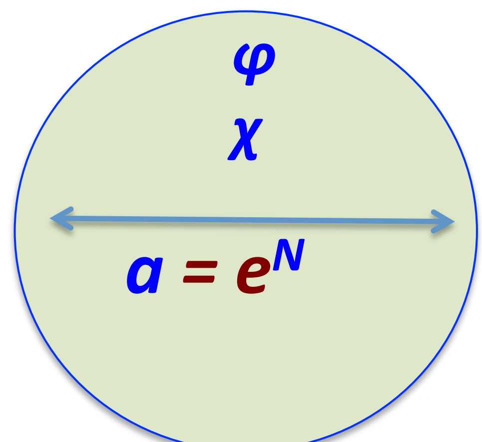
Generation of non-Gaussianity in separate-Universe formalism

Seery & Lidsey 2005, Vernizzi & Wands 2006





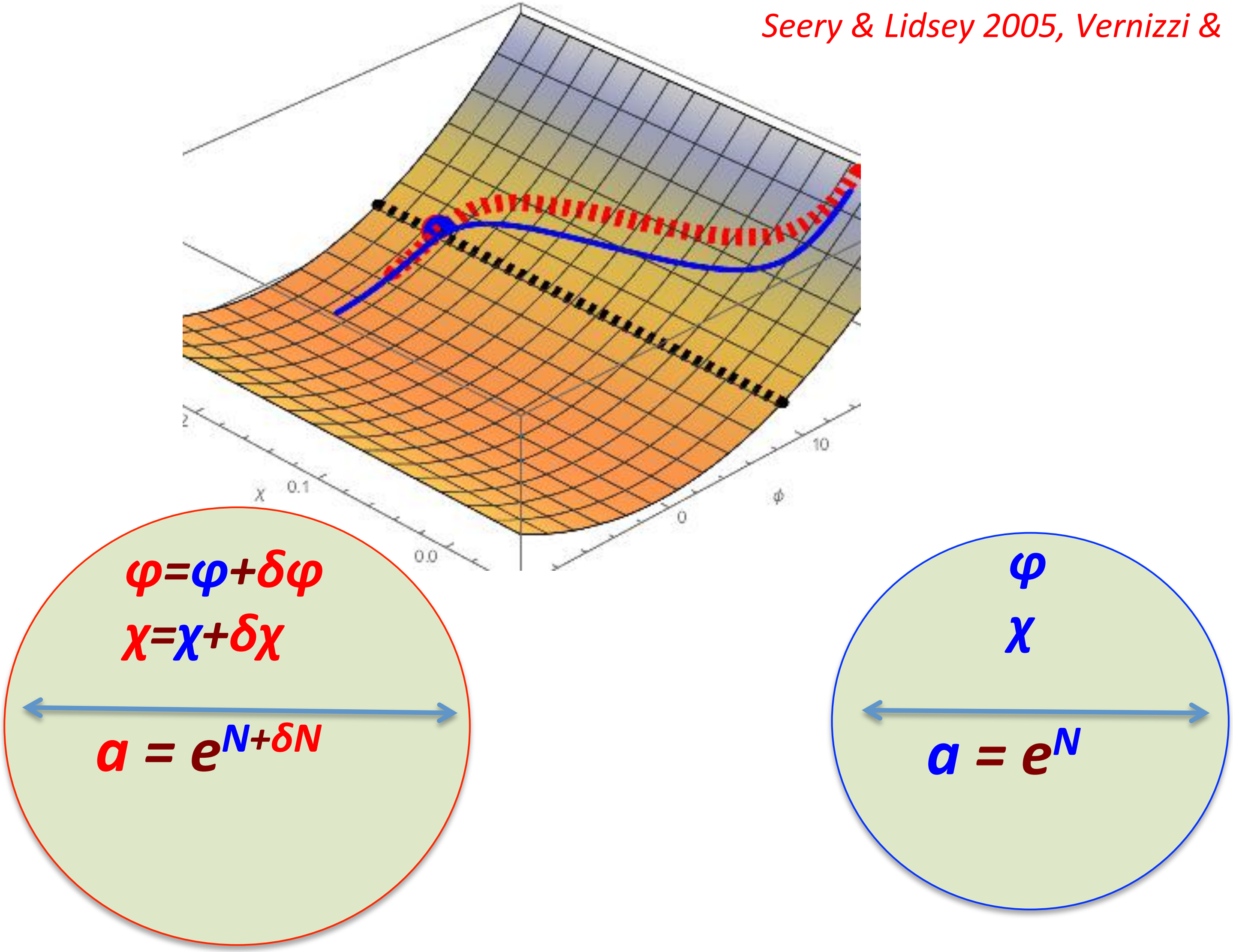
perturbed separate Universe



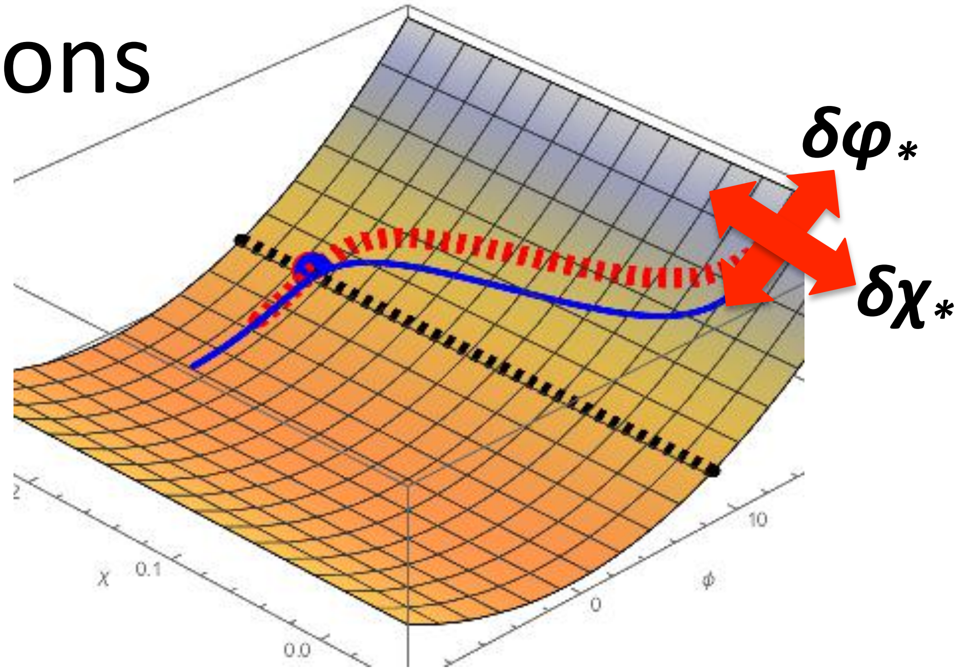
"background" Universe

Generation of non-Gaussianity in separate-Universe formalism

Seery & Lidsey 2005, Vernizzi & Wands 2006

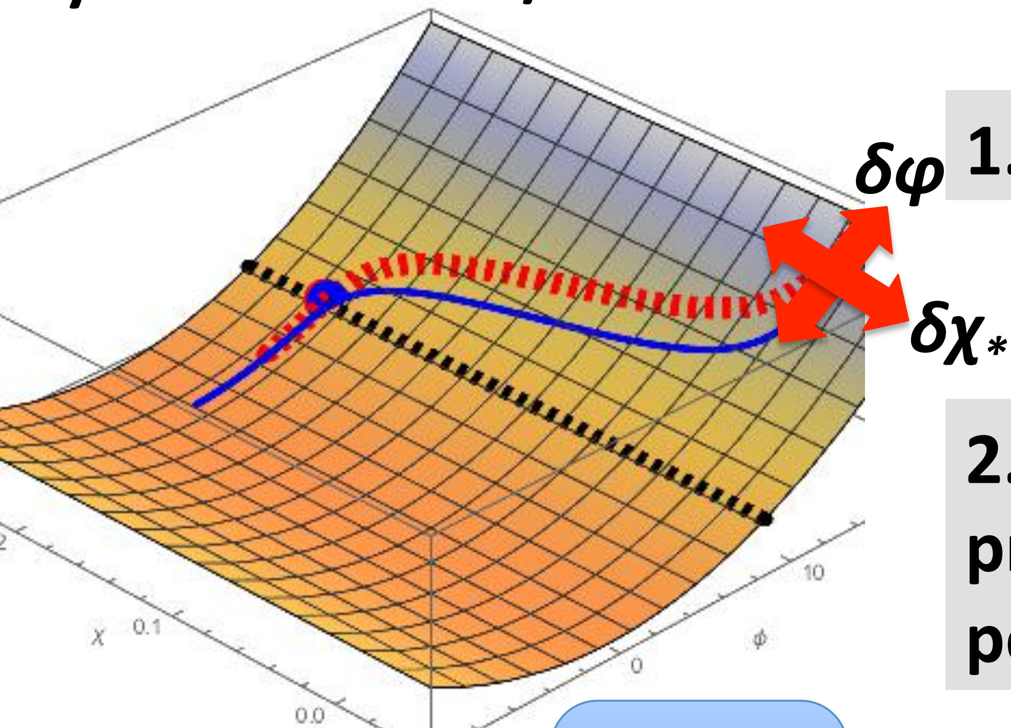


Primordial curvature perturbations depend on initial inflaton *and* spectator fluctuations



$$\zeta = \delta N = \frac{\partial N}{\partial \phi}\delta\phi_* + \frac{\partial N}{\partial \chi}\delta\chi_*$$

Inflaton domination: curvature ζ dominated by adiabatic/inflaton fluctuations



1. Inflaton φ "drives" Inflation

2. Inflaton φ generates primordial curvature perturbations

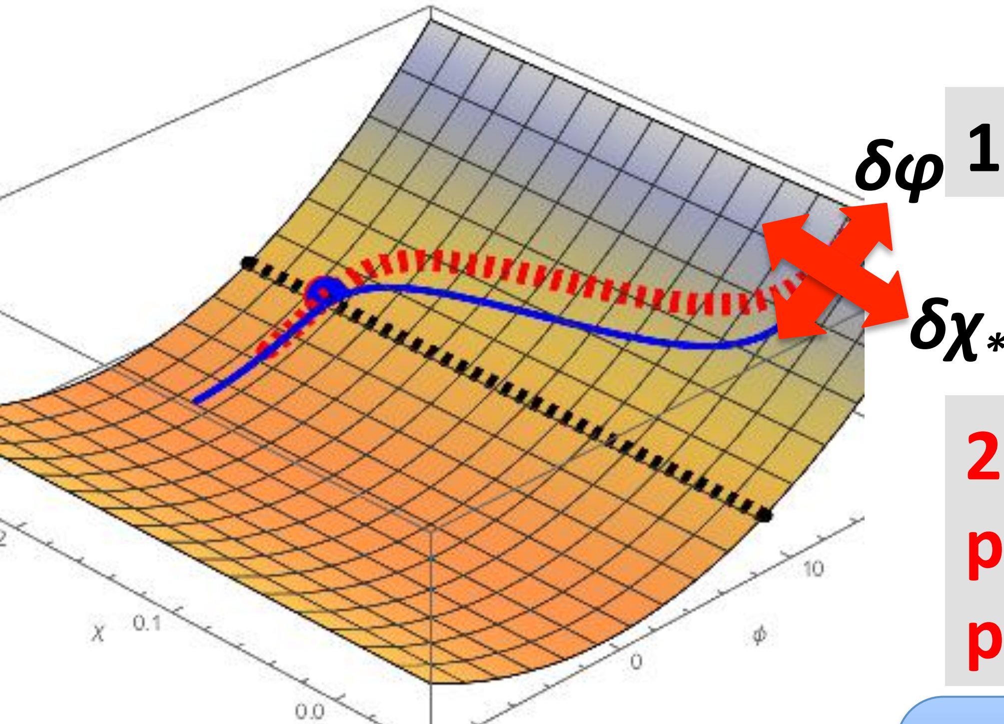
$$\zeta = \delta N = \boxed{\frac{\partial N}{\partial \phi}\delta\phi_*} + \frac{\partial N}{\partial \chi}\delta\chi_*$$

inflaton contribution

"single-field Inflation":

$$f_{NL} = 0$$

Spectator domination: ζ dominated by non-adiabatic/spectator fluctuations



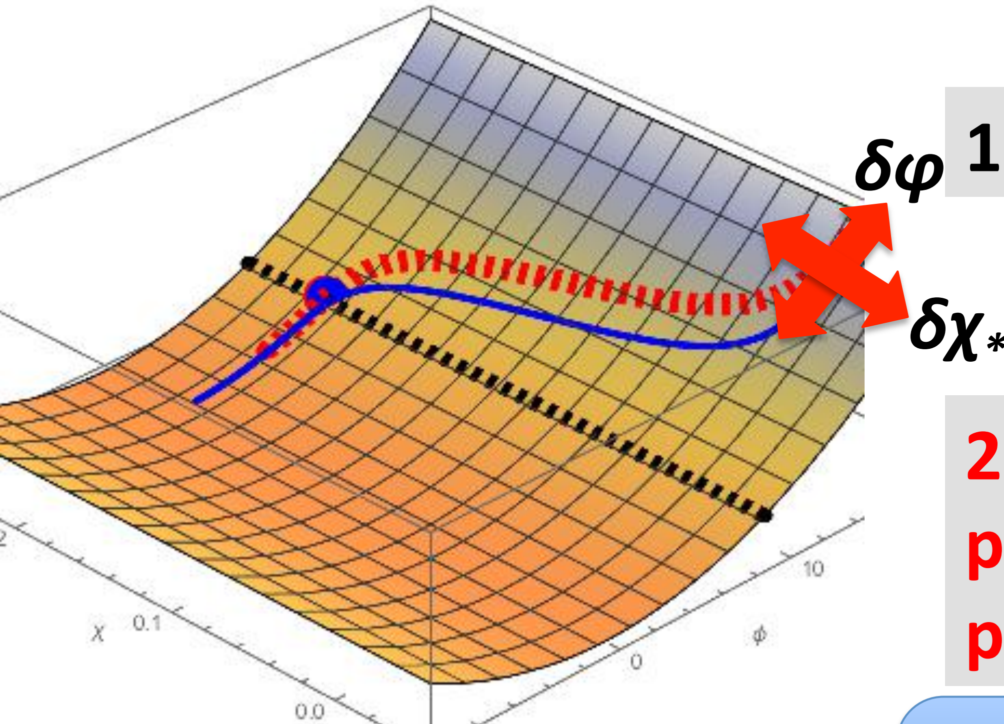
1. Inflaton φ "drives" Inflation

2. *Spectator χ* generates primordial curvature perturbations

$$\zeta = \delta N = \frac{\partial N}{\partial \phi}\delta\phi_* + \boxed{\frac{\partial N}{\partial \chi}\delta\chi_*}$$

spectator contribution

Spectator domination: non-linearity in conversion may generate non-Gaussianity



1. Inflaton φ "drives" Inflation

2. *Spectator χ* generates primordial curvature perturbations

$$\zeta = \delta N = \frac{\partial N}{\partial \phi}\delta\phi_* + \boxed{\frac{\partial N}{\partial \chi}\delta\chi_*} + \boxed{\frac{1}{2}\frac{\partial^2 N}{\partial \chi^2}\delta\chi_*^2}$$

spectator contribution ***non-Gaussianity***

cf. de Putter, Doré, Green & Meyers 2017

Questions

- *How generic are spectator-dominated models?*

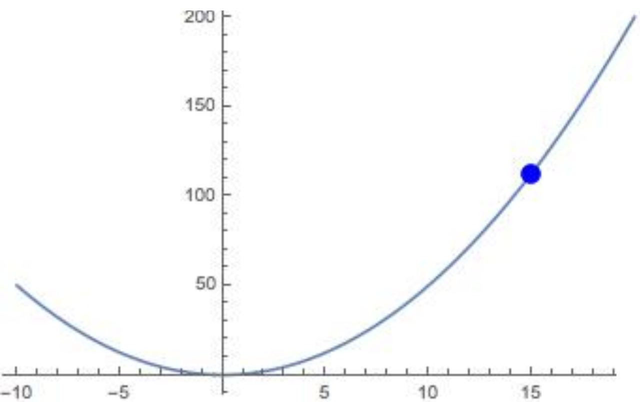
- *What are their observational predictions (f_{NL}, etc)?*

Spectator models: $W(\varphi,\chi) = U(\varphi) + V(\chi)$

The inflaton field φ:

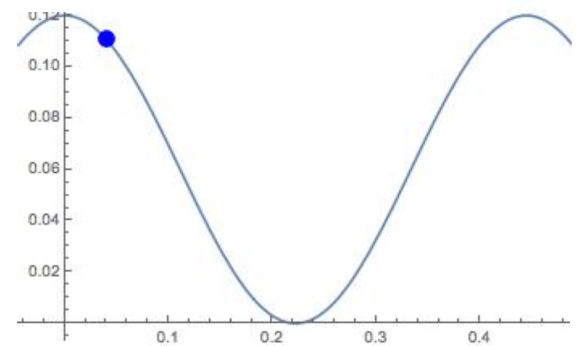
power law potential,

$U(\varphi) \sim \varphi^2$

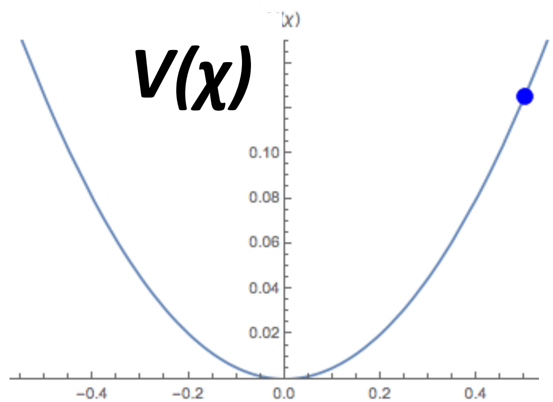


The spectator field χ:

A. Axion



B. Curvaton

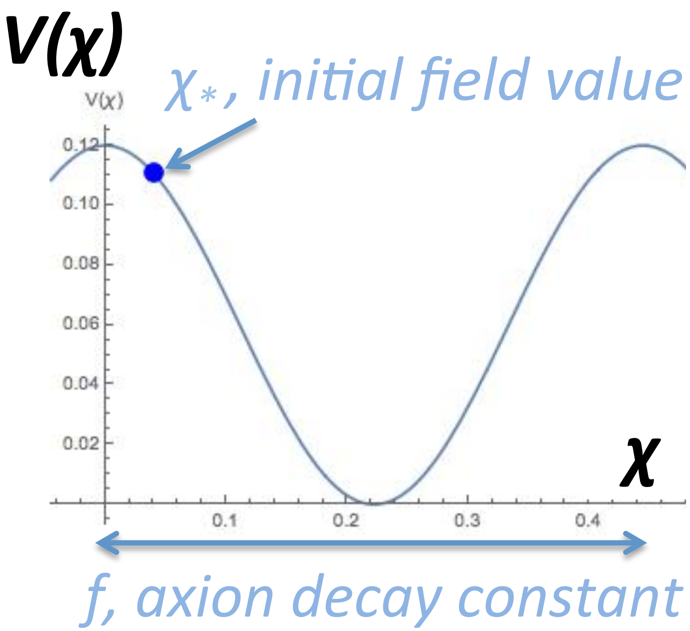


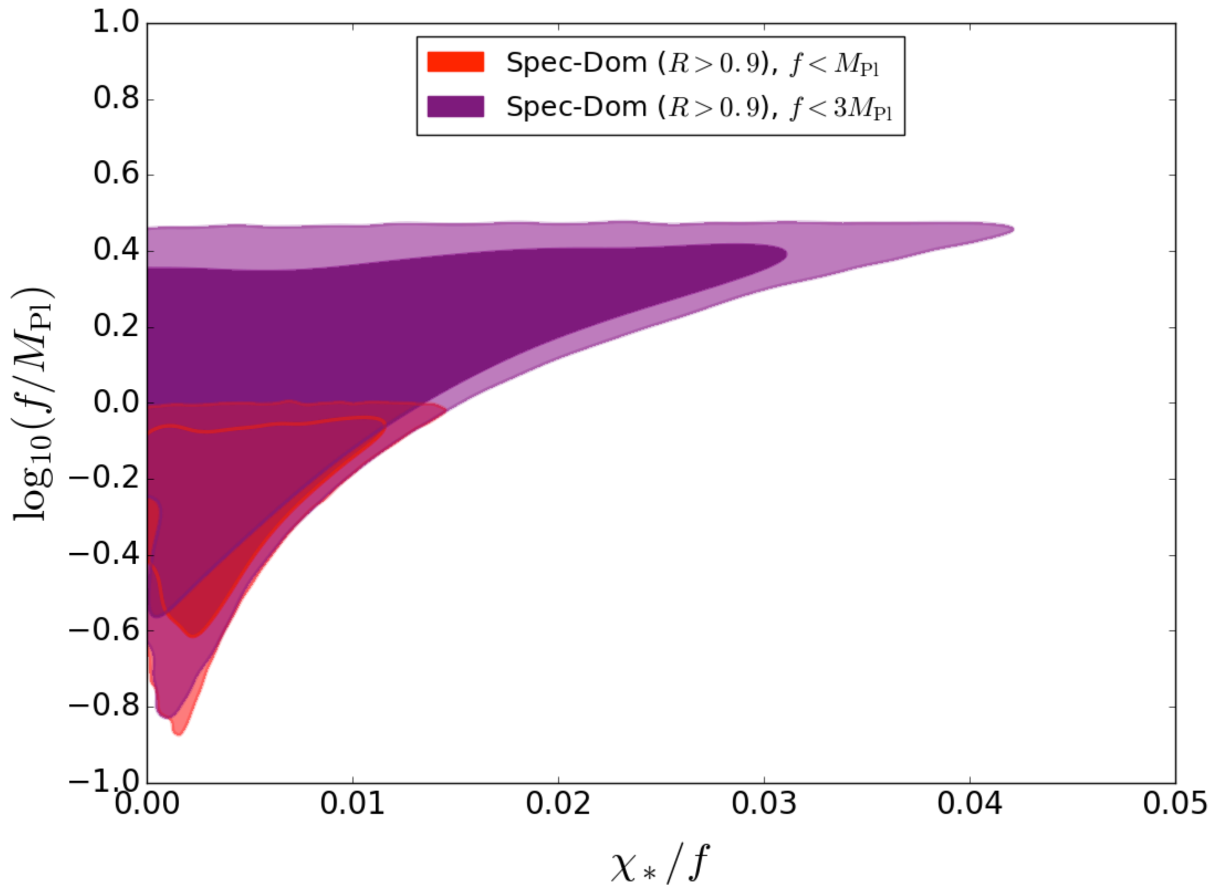
C. Modulated reheating

$$\Gamma_\phi = \Gamma_\phi(\chi)$$

The spectator-dominated regime requires fine-tuning

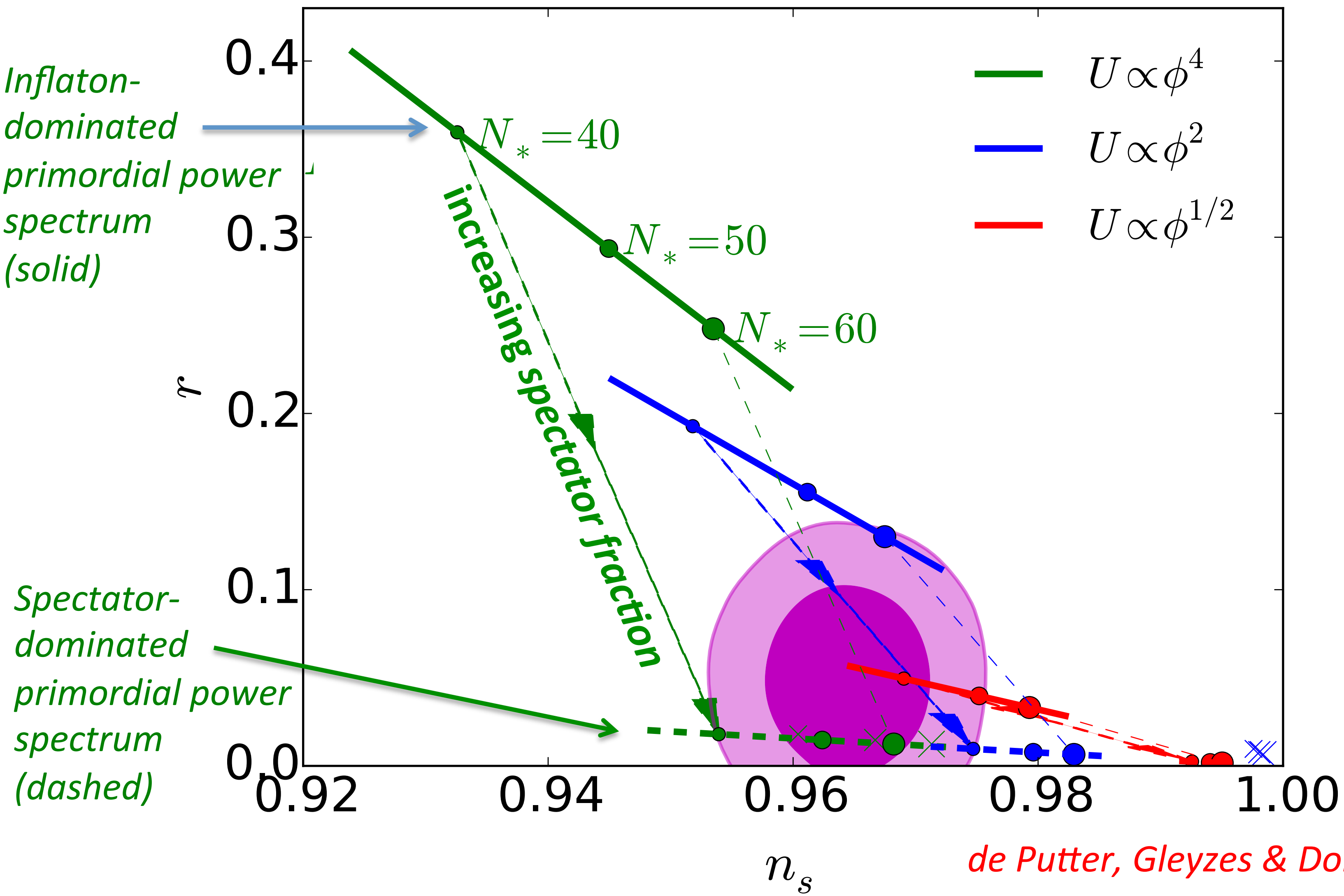
A. Axion model:





de Putter, Gleyzes & Doré 2017

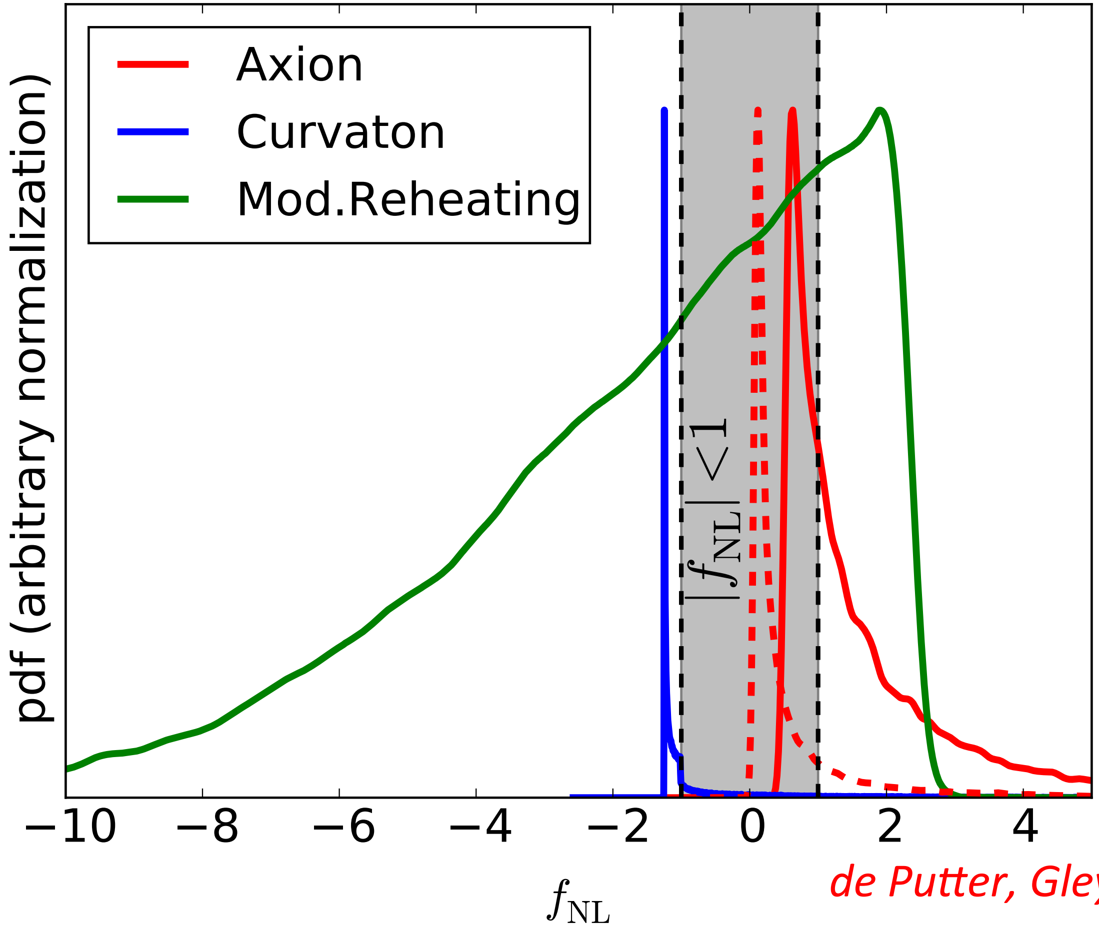
Spectator-dominated models predict **low** tensor-to-scalar ratio ***r***



de Putter, Gleyzes & Doré 2017

Spectator-dominated models predict f_{NL} of order 1

Results based on MCMC runs with current CMB temperature and polarization power spectra (Planck 2015)



de Putter, Gleyzes & Doré 2017

Summary so far

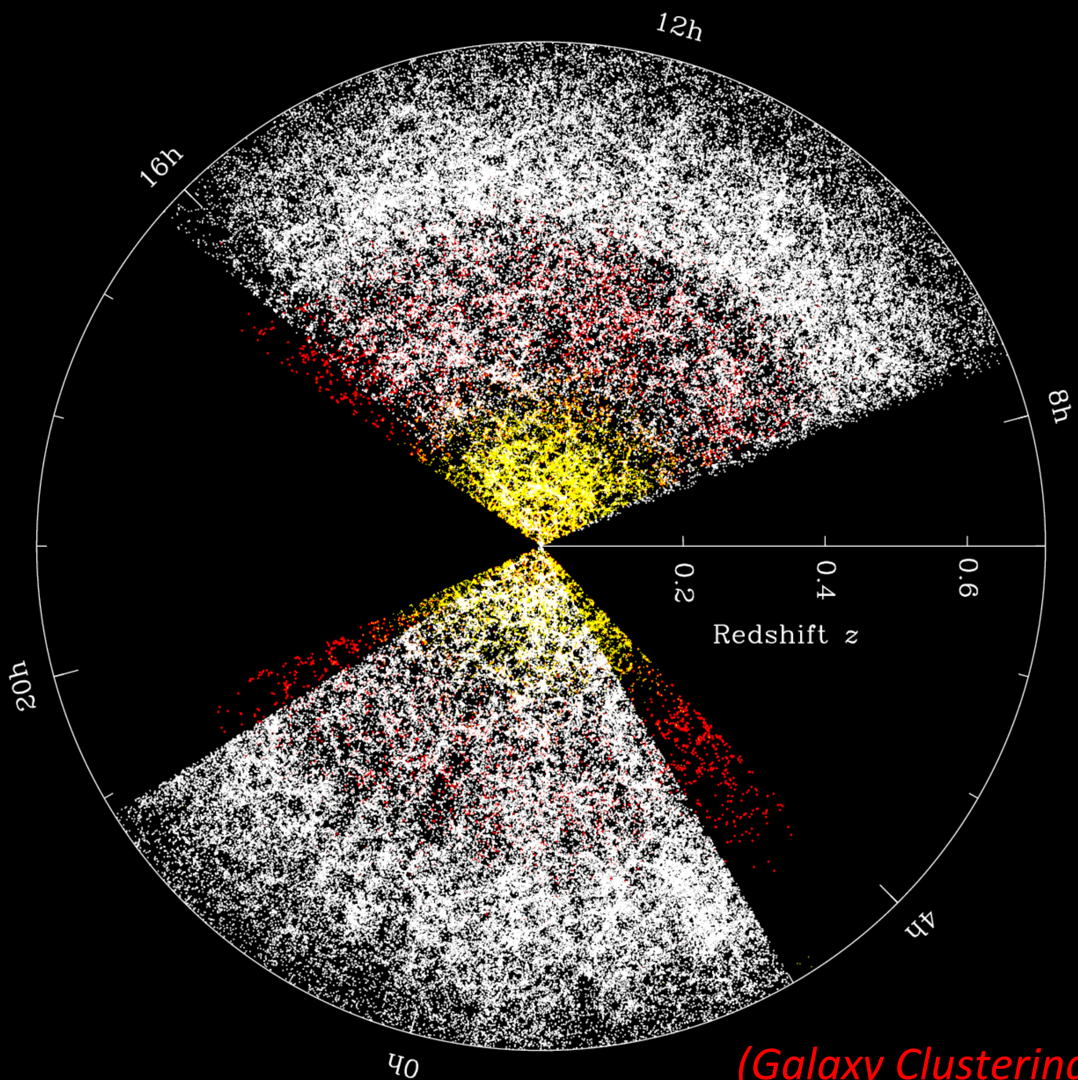
- In *spectator-dominated* models, the inflaton field drives inflation and a spectator field generates the primordial curvature fluctuations

- Spectator-dominated models appear fine-tuned in larger multifield parameter space

- Spectator-dominated models suppress tensor-to-scalar ratio, but typically lead to f_{NL} of order 1

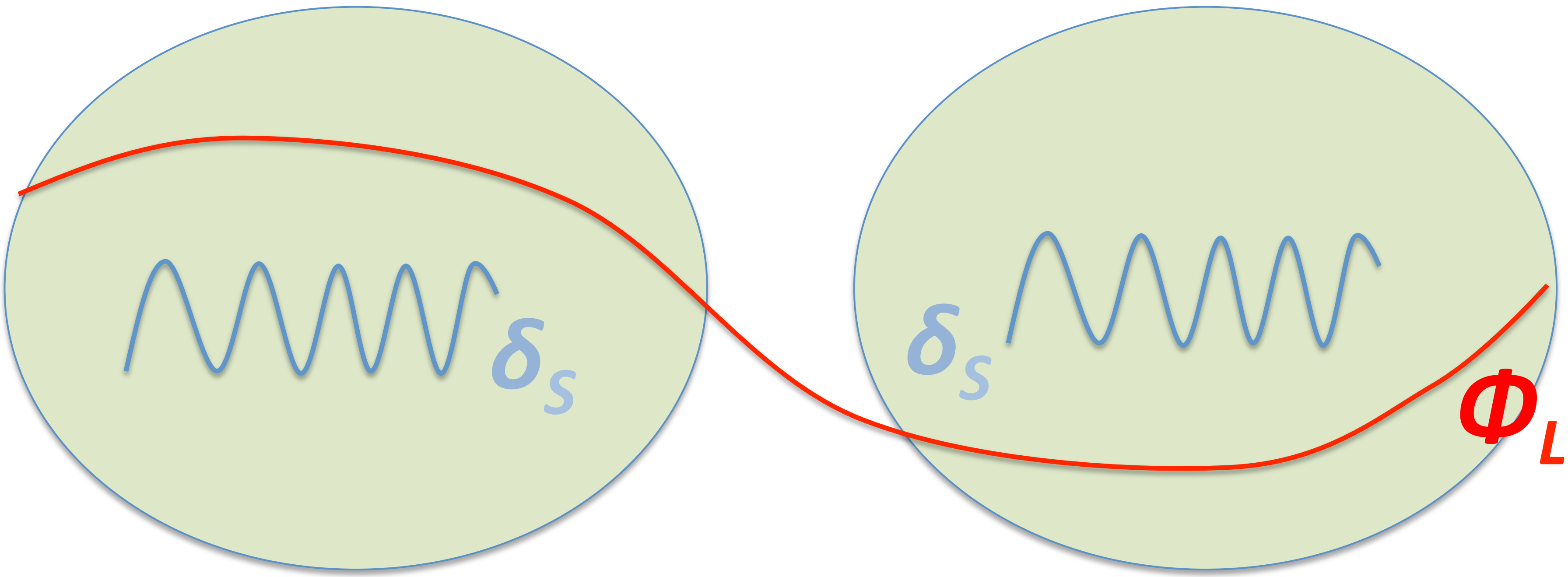
How to measure $\boldsymbol{\sigma(f_{NL}) \sim 1}$?

Galaxy clustering can strongly improve primordial non-Gaussianity constraints



(Galaxy Clustering in BOSS)

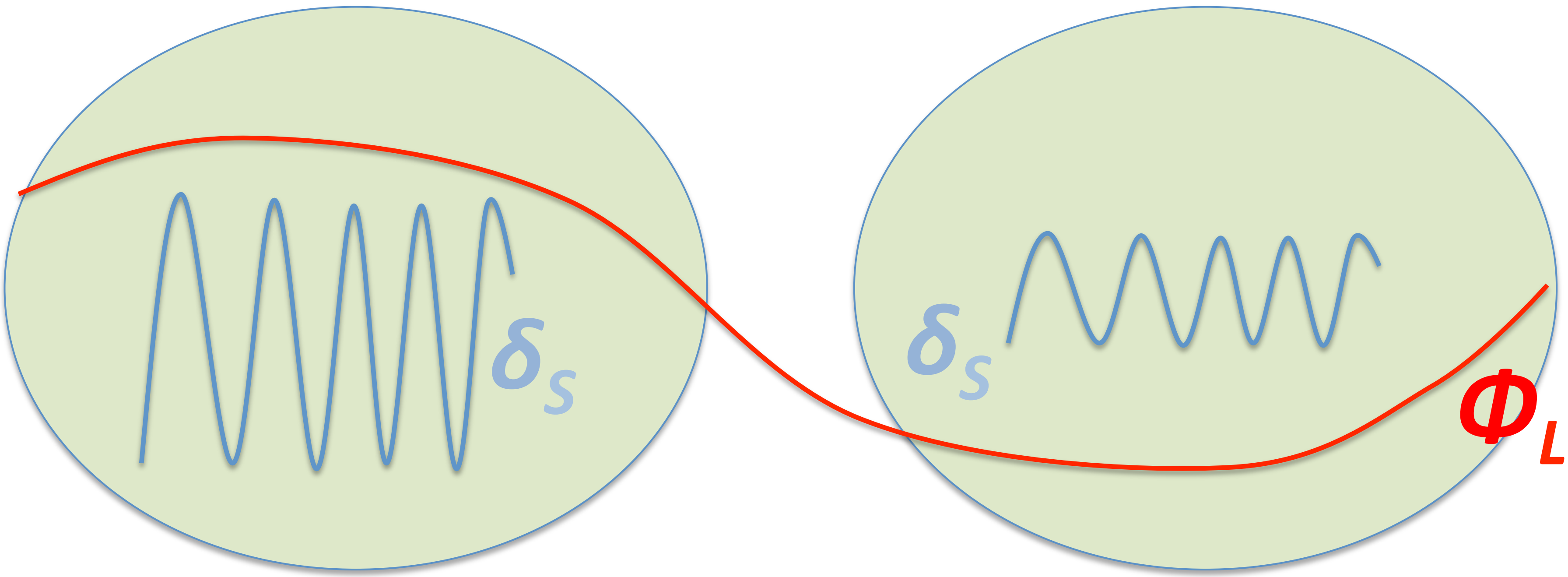
In absence of primordial non-Gaussianity, large-scale halo bias is scale-independent



$$\delta_h(\vec{k}) = b_1 \delta_m(\vec{k})$$

Primordial non-Gaussianity leads to scale-dependent halo bias

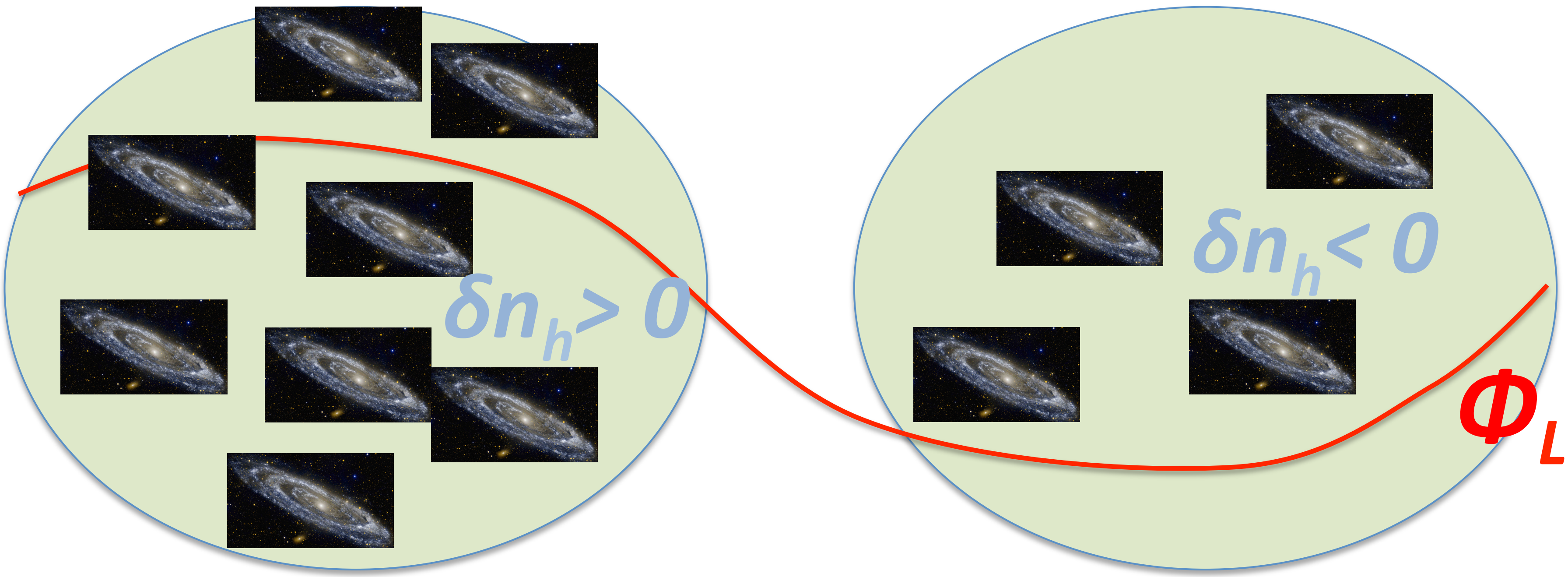
Dalal, Doré, Huterer & Shirokov 2008



$$\delta_h(\vec{k}) = b_1 \delta_m(\vec{k}) + \ldots$$

Primordial non-Gaussianity leads to scale-dependent halo bias

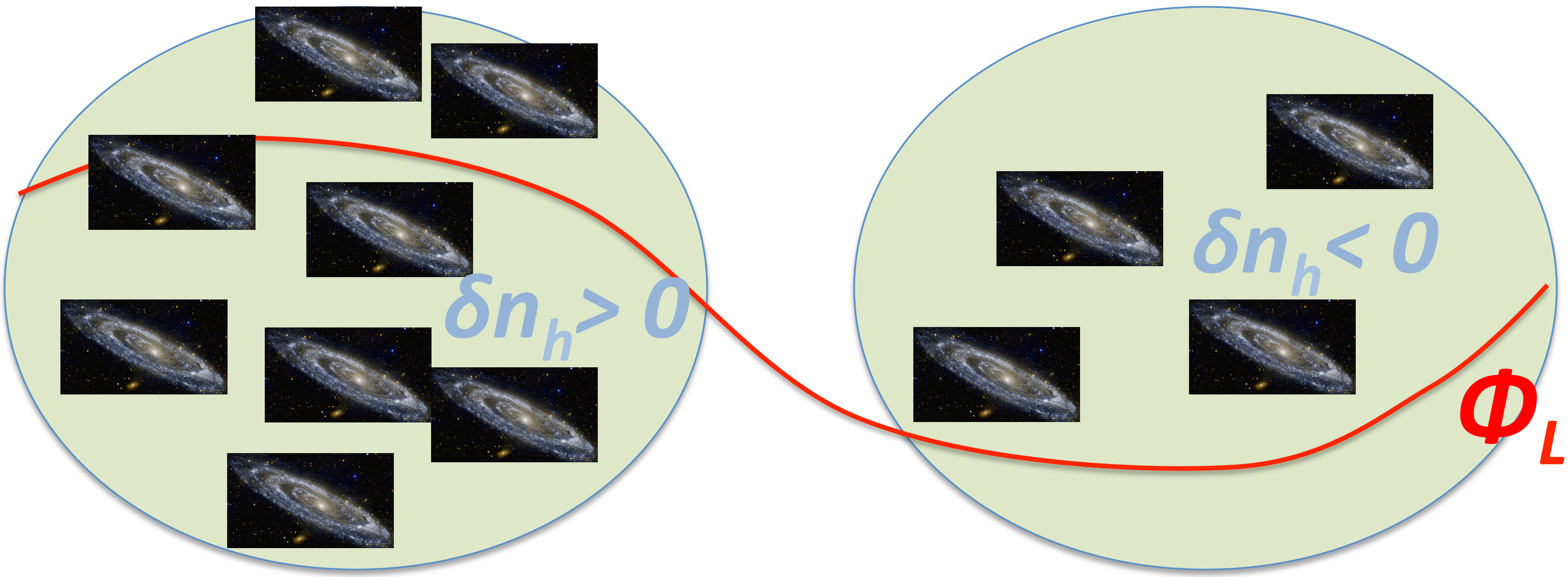
Dalal, Doré, Huterer & Shirokov 2008



$$\delta_h(\vec{k}) = b_1 \delta_m(\vec{k}) + c\, f_{NL} \Phi(\vec{k})$$

Primordial non-Gaussianity leads to scale-dependent halo bias

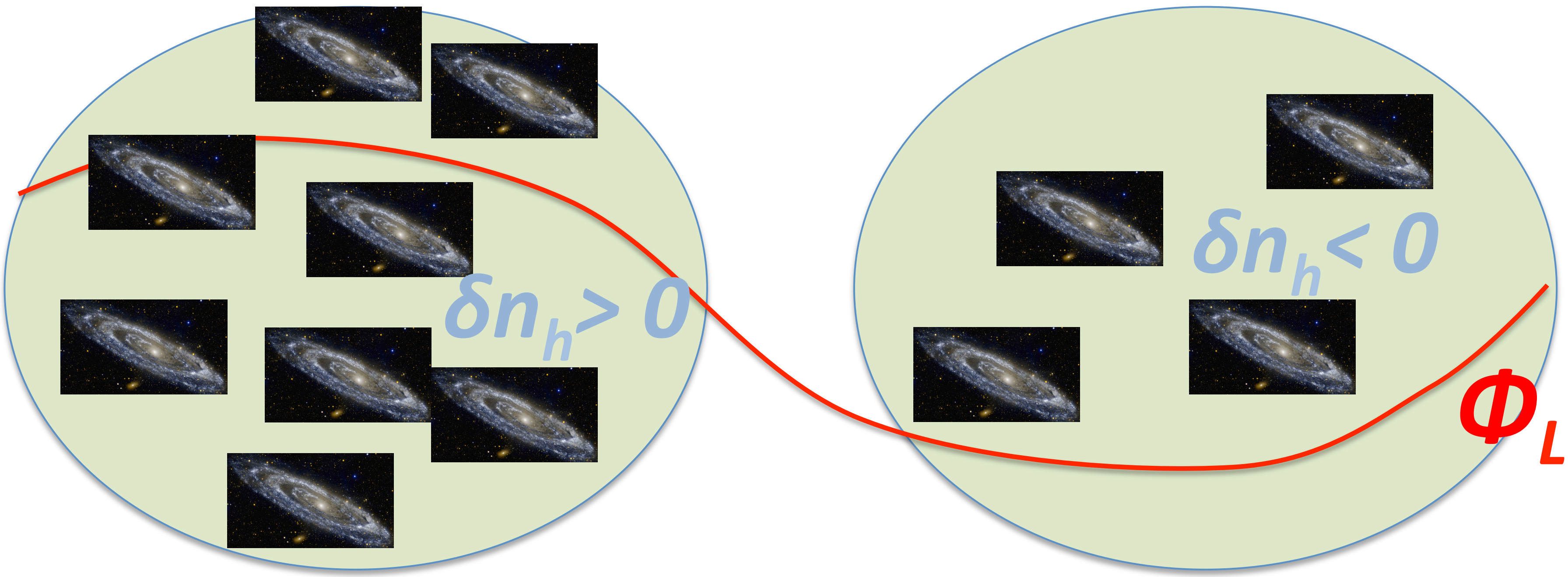
Dalal, Doré, Huterer & Shirokov 2008



$$\delta_h(\vec{k}) = b_1 \delta_m(\vec{k}) + c\, f_{NL} \Phi(\vec{k}) = (b_1 + \Delta b(k))\ \delta_m(\vec{k})$$

Primordial non-Gaussianity leads to scale-dependent halo bias

Dalal, Doré, Huterer & Shirokov 2008

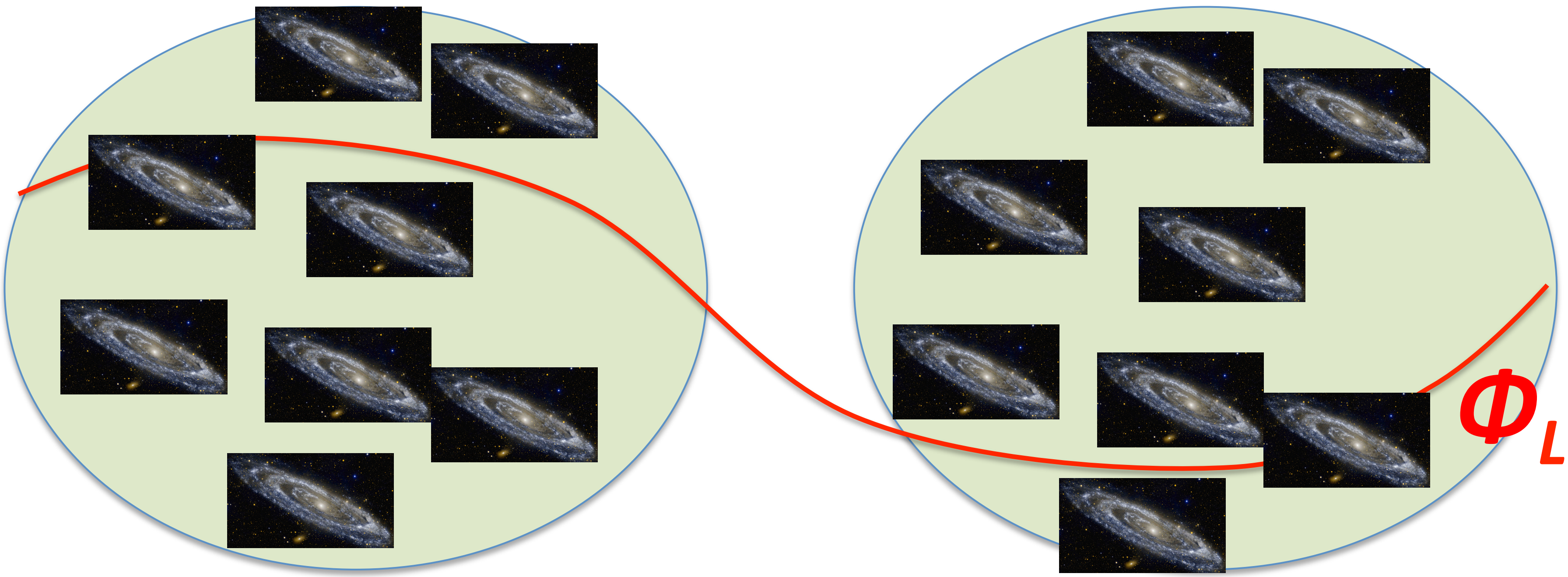


$$\Delta b(k) = 2 f_{NL} (b_1 - 1)\delta_c \frac{3\Omega_m H_0^2}{k^2 T(k) D(z)}$$

- unique signal: $\Delta b(k) \propto k^{-2}$
- requires ultra-large scales: $\Delta b(k \sim H_0) \sim f_{NL}$

Is there (any) scale-dependent bias in single-field Inflation?

de Putter, Doré & Green 2015
Dai, Pajer & Schmidt 2015



$\Delta b(k) = 0$ ***When properly treat GR "gauge effects", no physical scale-dependent bias remains***

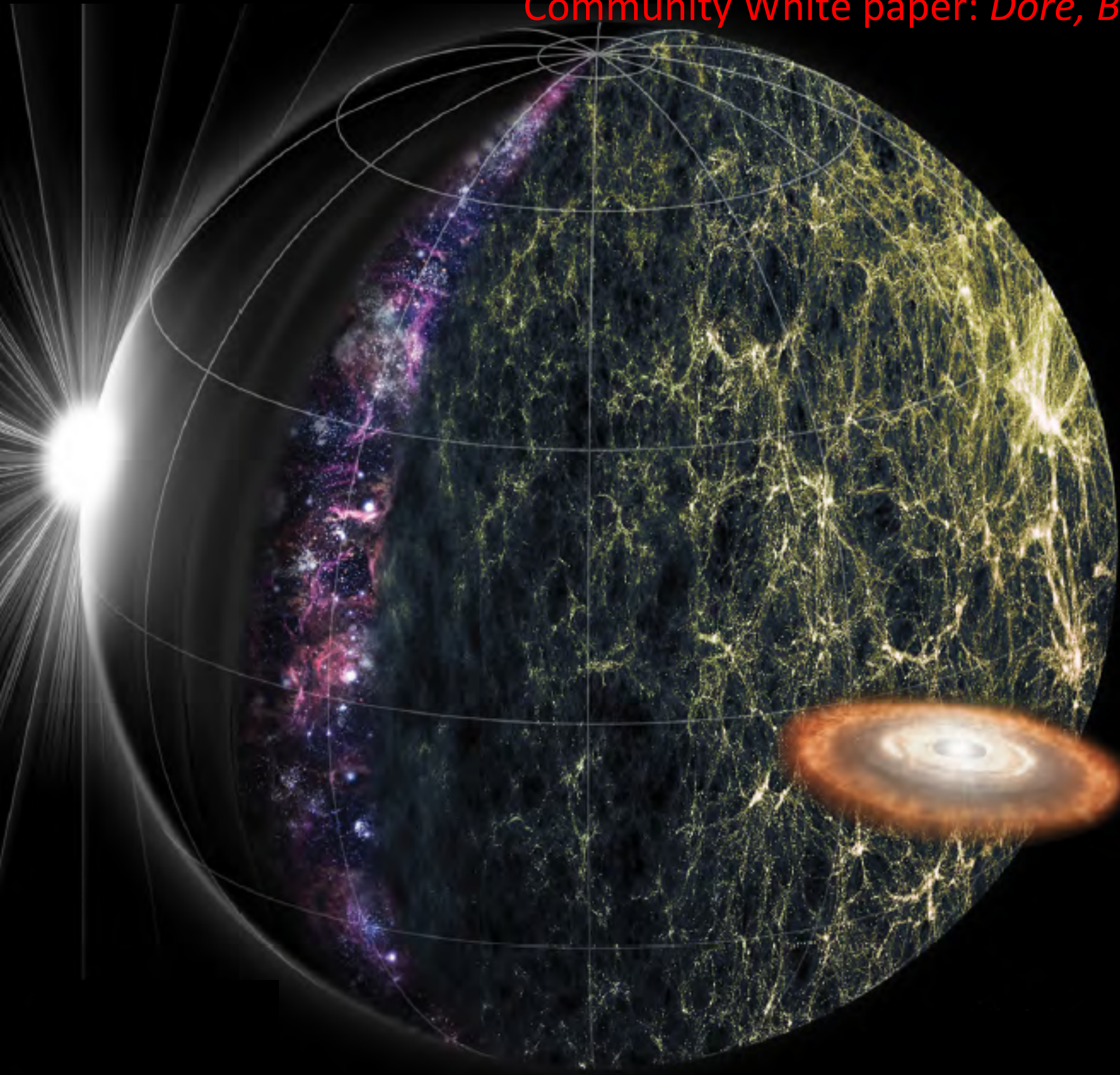
Galaxy clustering on ultra-large scales: what does it take to reach $\boldsymbol{\sigma(f_{NL}) \sim 1}$?

de Putter & Doré 2014

- Survey volume
  - *V = many 100's $(h^{-1}\ \mathrm{Gpc})^3$ for $\sigma(f_{NL}) \sim 1$*
- Redshift accuracy
  - *High redshift accuracy NOT needed*

SPHEREx: an All-Sky Spectral Survey

White Paper: *Doré, Bock,…, de Putter, et al (1412.4872)*
Community White paper: *Doré, Bock,…, de Putter, et al (1606.07039)*
Website: *spherex.caltech.edu*



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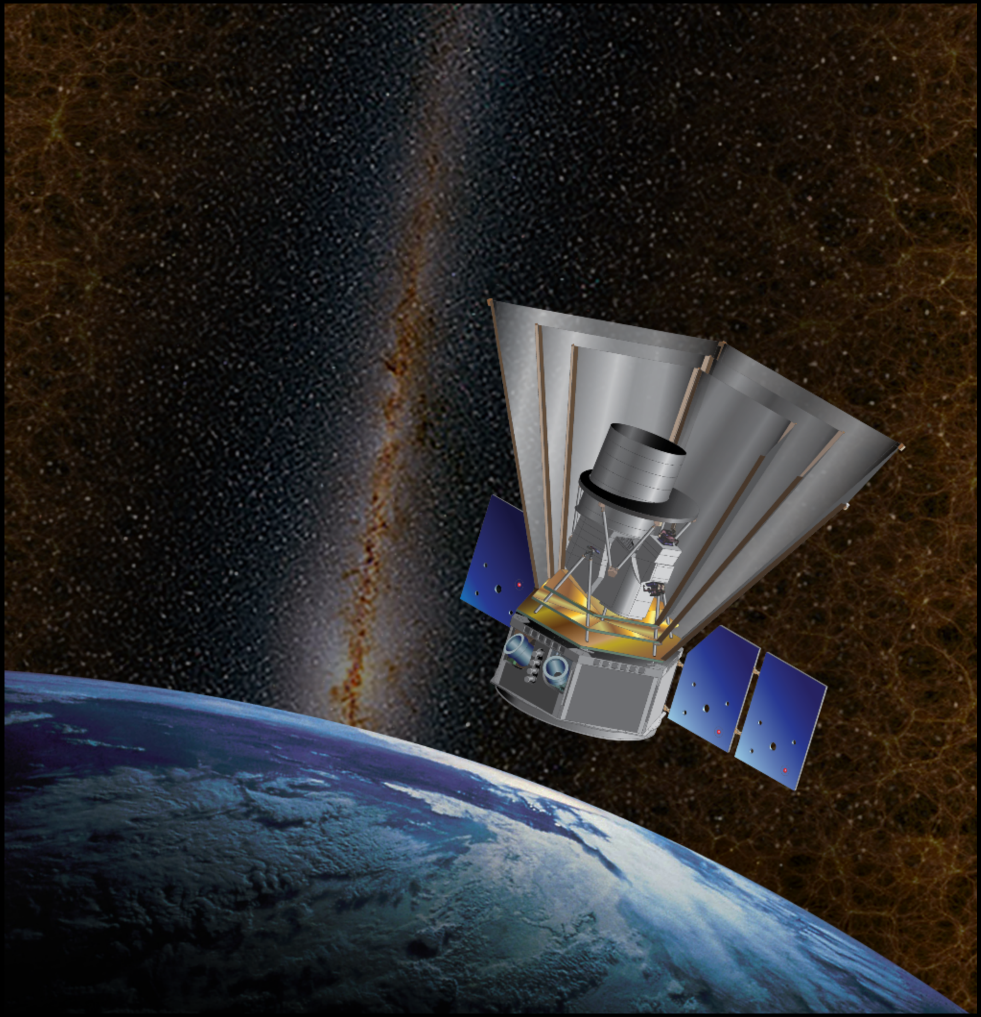
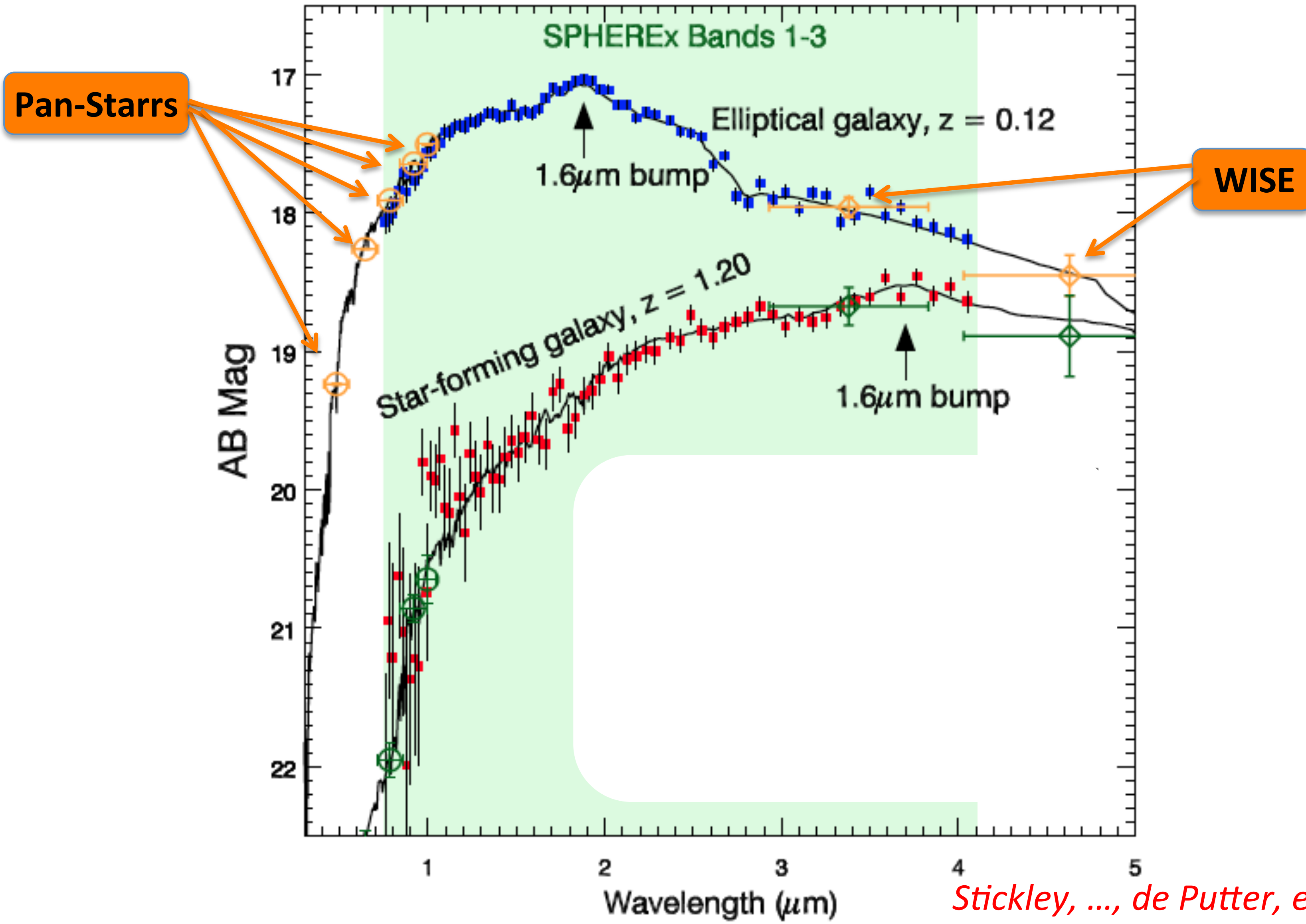


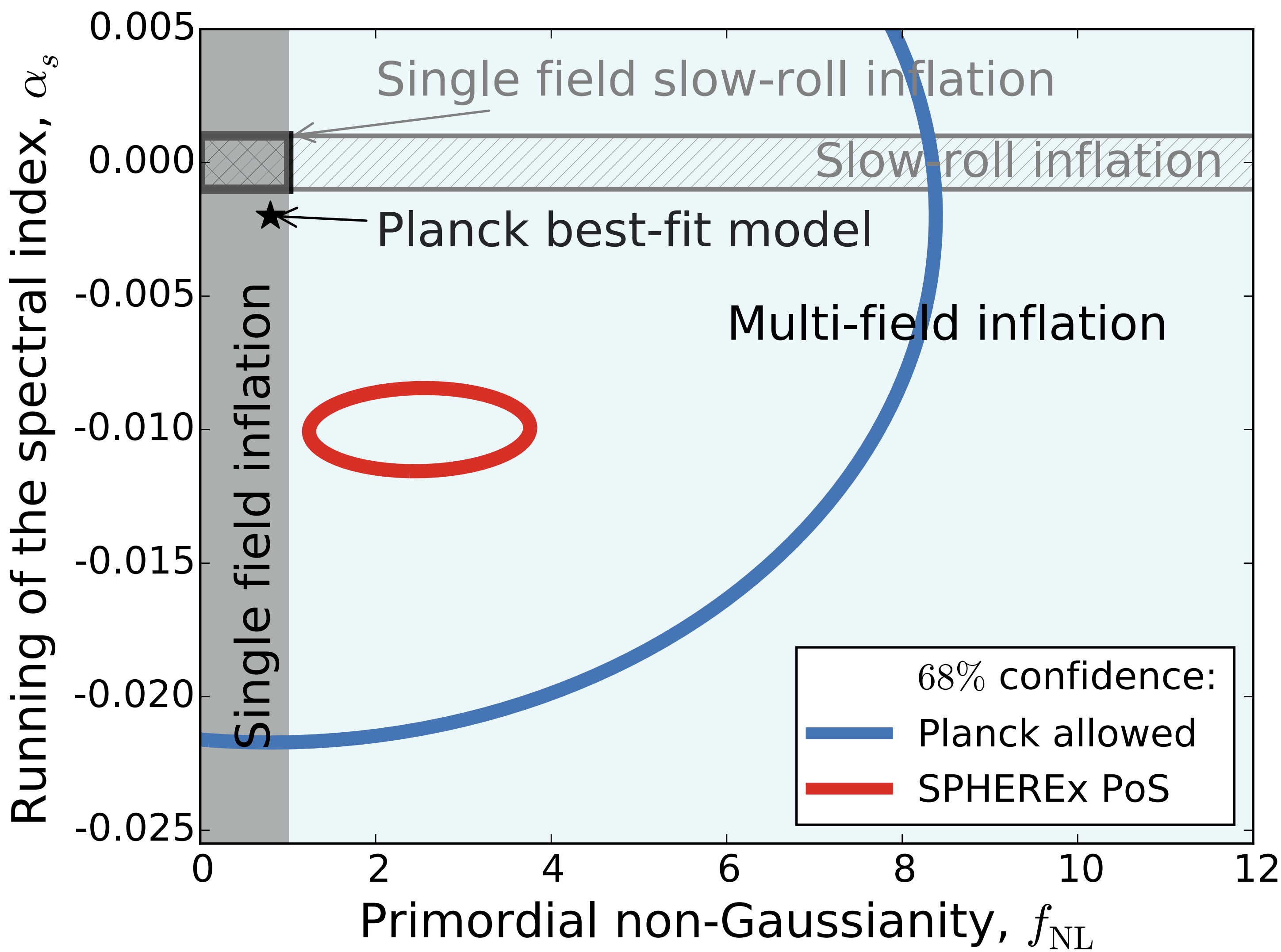
- ***λ = 0.75 – 5 μm***
- ***Resolution R = 41.5***
- ***Full-Sky***
- ***Pixel Size 6.2’’***
- ***Aperture 20cm***
- ***FoV 3.5° x 7°***

SPHEREx enables low-res spectroscopic redshifts for > 300M galaxies

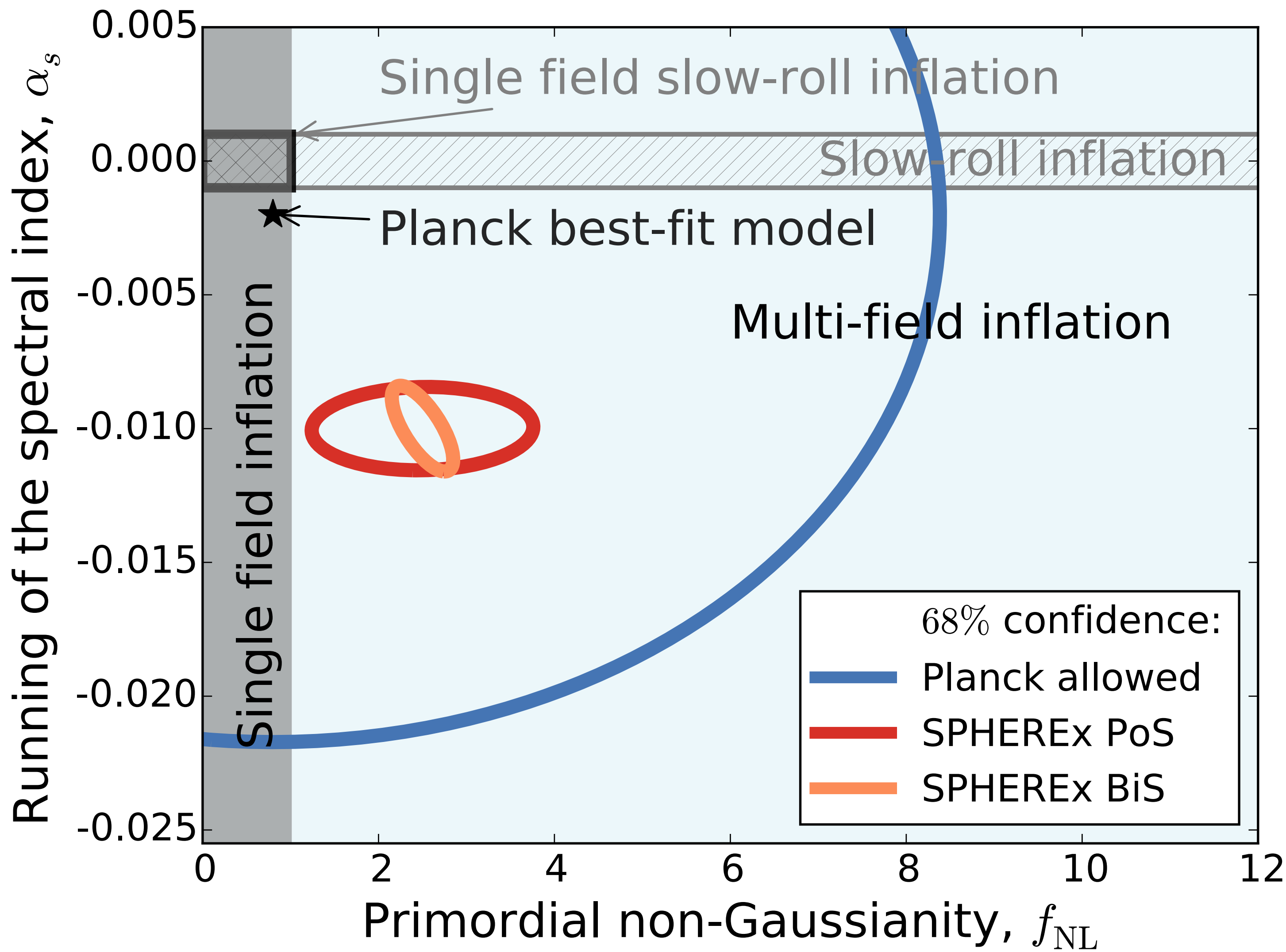


Stickley, ..., de Putter, et al 2016

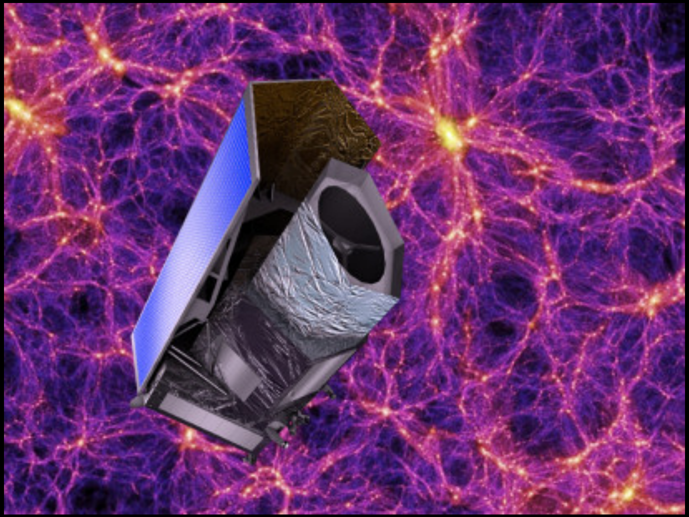
SPHEREx galaxy clustering can reach $\sigma(f_{NL}) < 1$



SPHEREx galaxy clustering can reach $\sigma(f_{NL}) < 1$

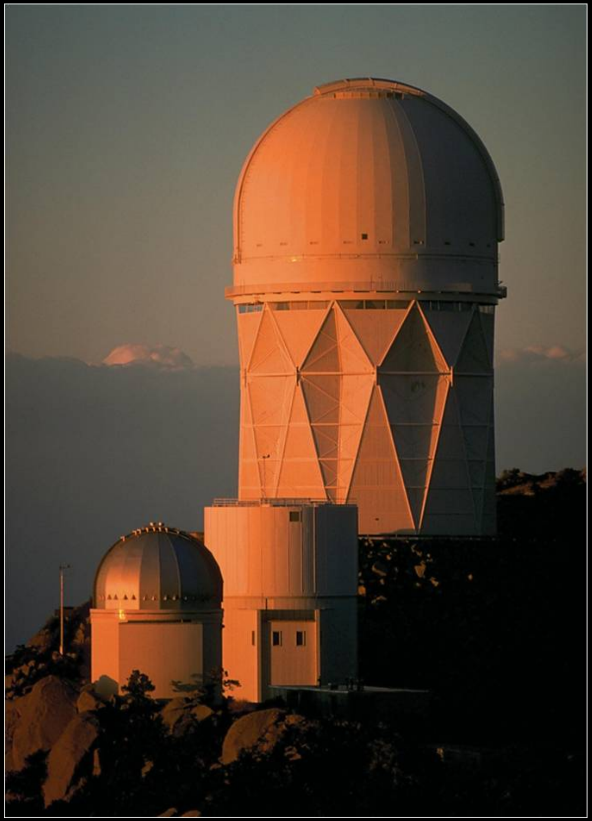


Exciting times ahead!



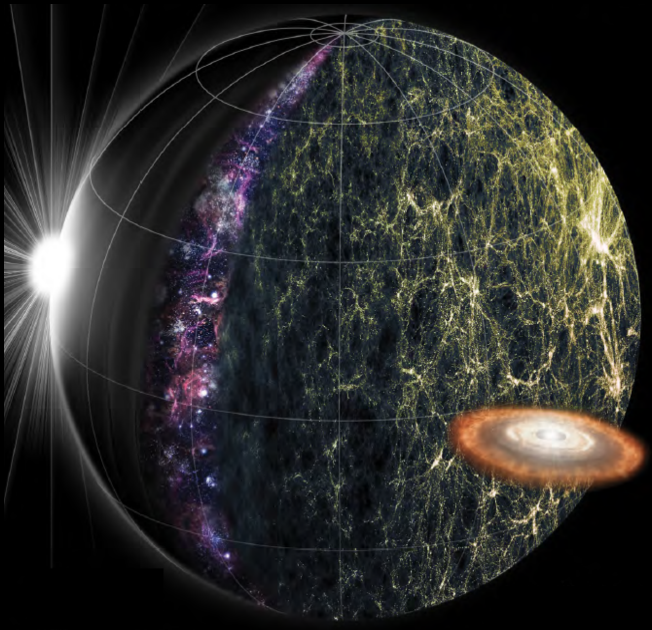
EUCLID

www.euclid-ec.org



DESI

Levi et al, 2013 (1308.0847)



SPHEREx *(proposal)*

spherex.caltech.edu (1412.4872)

Summary

- We performed MCMC sampling of parameter space of spectator multifield models using current CMB data
- In *spectator-dominated* models, the inflaton field drives inflation and a spectator field generates the primordial curvature fluctuations
- Spectator-dominated models appear fine-tuned in larger multifield parameter space
- Spectator-dominated models suppress tensor-to-scalar ratio, but typically lead to f_{NL} of order 1
- Future redshift surveys, such as SPHEREx, may reach $\sigma(f_{NL}) \sim 1$ sensitivity using scale-dependent bias