Inflation Models: Solving problems of the BB

Primordial Universe 2022 Conference

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Introduction

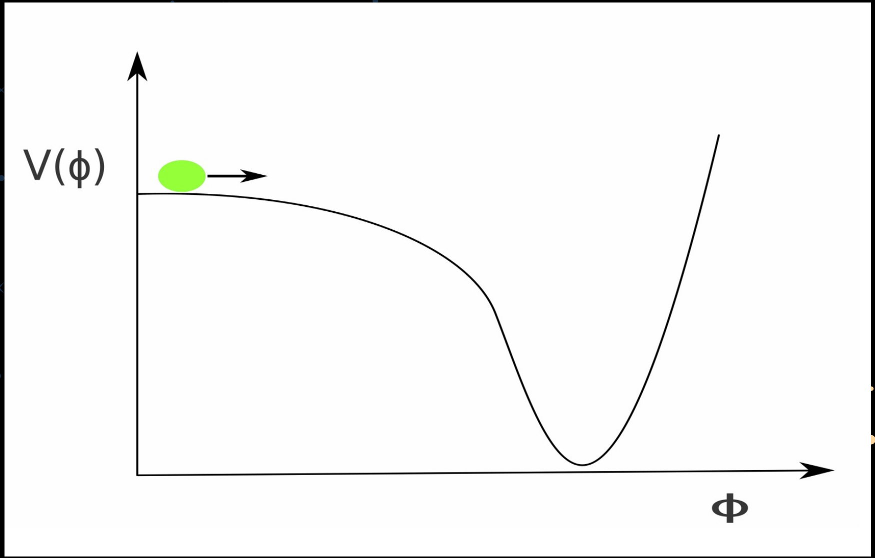
- This theory was motivated by **key problems** with the hot Big Bang theory
- Inflation describes a period time, immediately after the big bang, when the universe underwent an exponential expansion

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$\ddot{a} > 0 \Leftrightarrow \frac{d}{dt}\left(\frac{1}{aH}\right) < 0 \Leftrightarrow p < -\rho/3$$

Introduction

- Inflation can be modelled as the progression of a scalar field over a potential energy curve
- Slow-roll parameters define the conditions for inflation to exist and persist
- The number of e-folds (*N*) required to solve the problems of the BB theory is 50 ~ 70



Vázquez, J. A., Padilla, L. E., & Matos, T. (2018). Inflationary cosmology: from theory to observations. arXiv preprint arXiv:1810.09934.

Problems of the Big Bang model

01

The Flatness Problem

02

The Horizon Problem

03

The Exotic Relics Problem

04

The fluctuations Problem

The Flatness Problem

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} \qquad |\Omega - 1| = \frac{|k|}{a^2 H^2}$$

component	$\rho(a)$	**a(t)**	**H(t)**
radiation	$\propto a^{-4}$	$\propto t^{1/2}$	1/(2t)
matter	$\propto a^{-3}$	$\propto t^{2/3}$	2/(3t)
cosmological constant	$\propto a^{0}$	$\propto \exp\left\{\sqrt{\frac{\Lambda}{3}}t\right\}$	const

The Flatness Problem

$$\frac{|\Omega - 1|_{T=T_{Pl}}}{|\Omega - 1|_{T=T_0}} \approx \left(\frac{a_{Pl}^2}{a_0^2}\right) \approx \left(\frac{T_0^2}{T_{Pl}^2}\right) \approx \mathcal{O}(10^{-64})$$

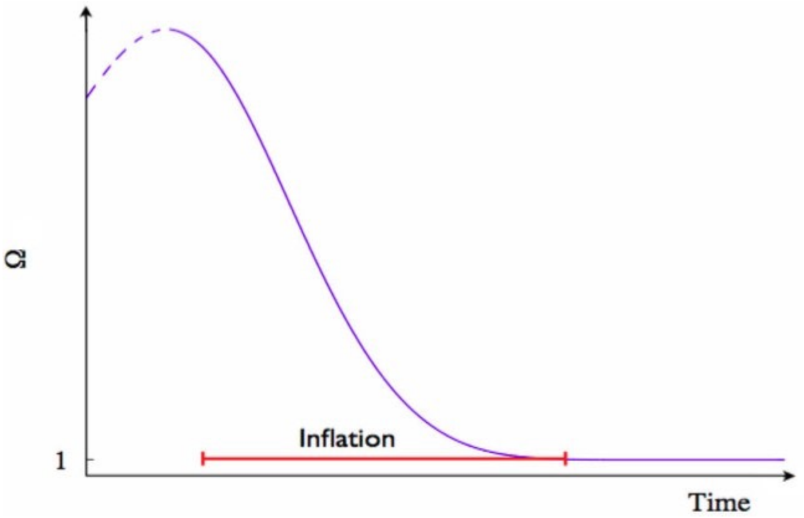
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2}$$

$$|\Omega - 1| = \frac{|k|}{a^2 H^2}$$

Solving The Flatness Problem

$$\ddot{a} > 0 \Leftrightarrow \frac{d}{dt}\left(\frac{1}{aH}\right) < 0 \Leftrightarrow p < -\rho/3$$

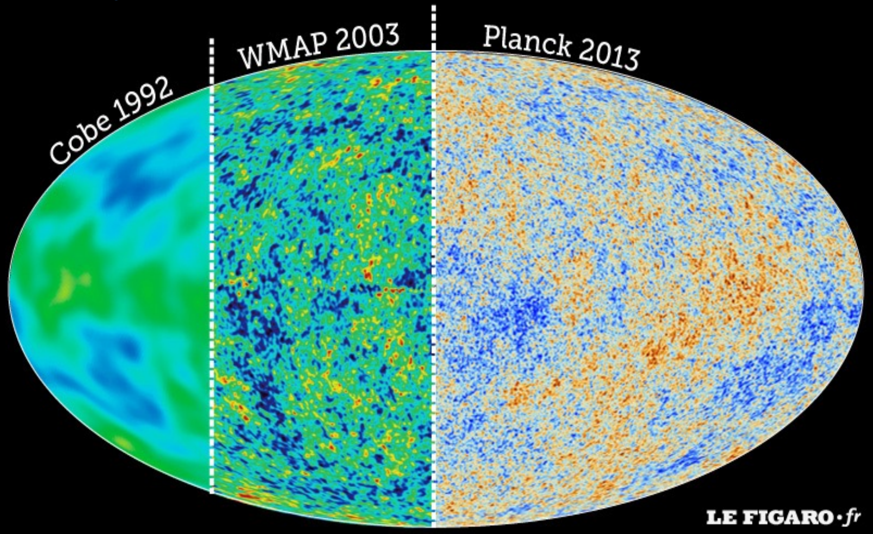
$$|\Omega - 1| = \frac{|k|}{a^2 H^2}$$



Liddle, A. R. (1998). An introduction to cosmological inflation. High energy physics and cosmology, 260.

The Horizon Problem

- The CMB radiation is uniform in all directions
- After ~ 10^5 years, the Universe cooled sufficiently to allow photons to decouple from matter
- The observable Universe is ~ 10^{10} years



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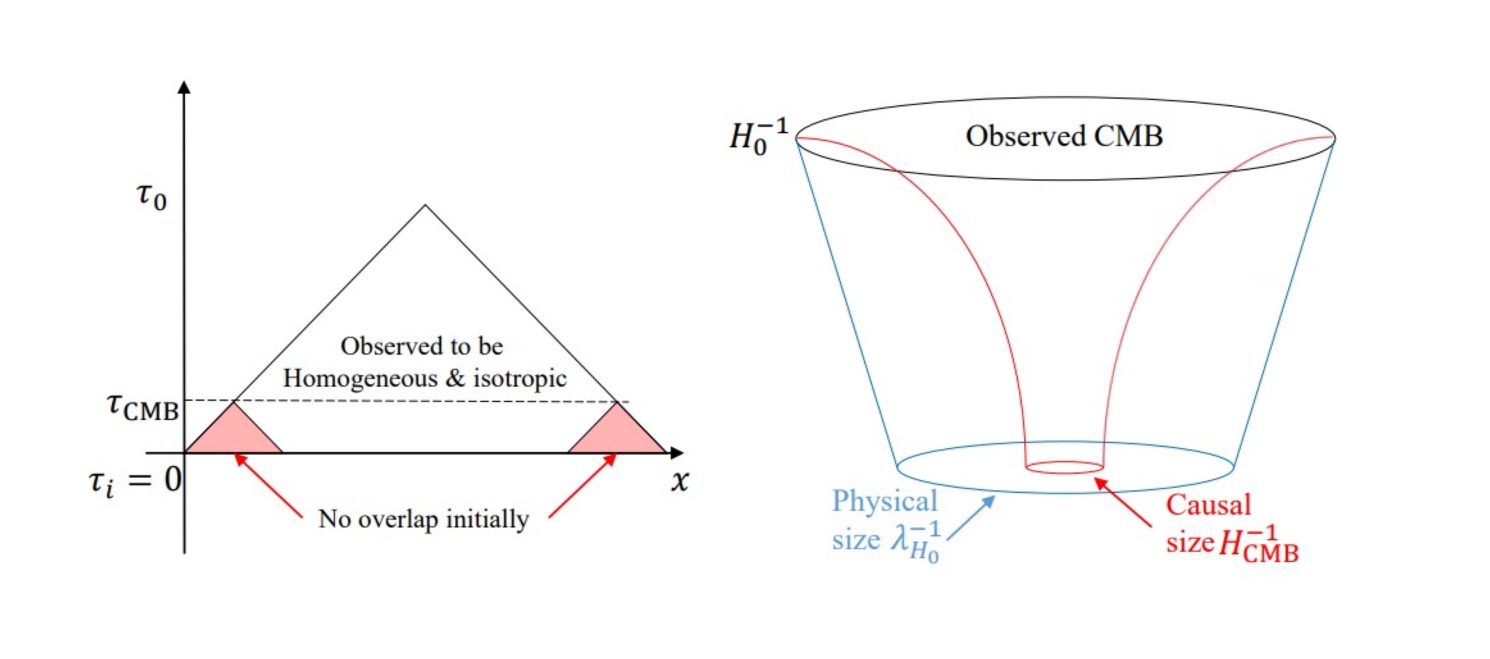
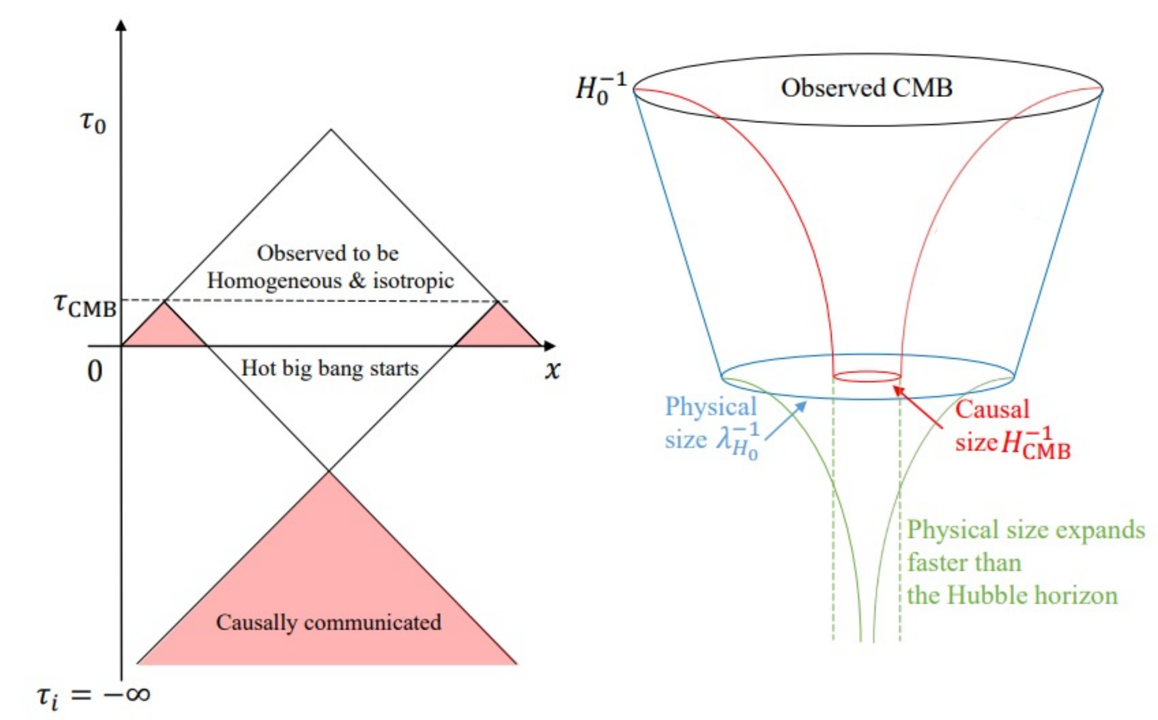
The Horizon Problem



Gong, J. O. (2017). Multi-field inflation and cosmological perturbations. International Journal of Modern Physics D, 26(01), 1740003.

Solving The Horizon Problem

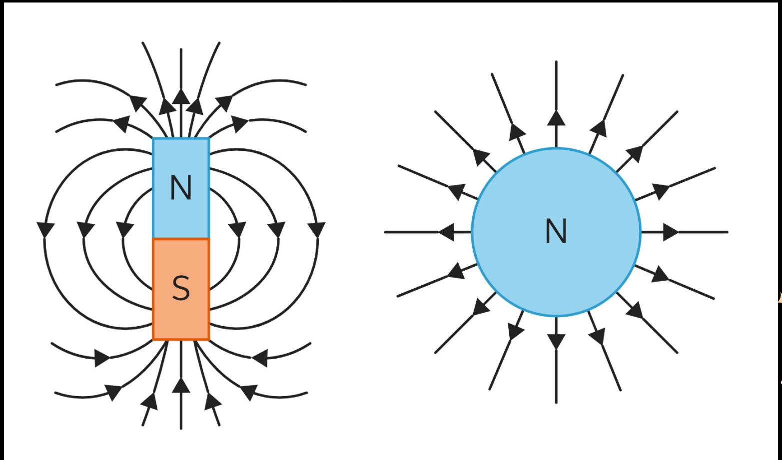


$$\frac{d}{dt}\left(\frac{1}{aH}\right) < 0$$

Gong, J. O. (2017). Multi-field inflation and cosmological perturbations. International Journal of Modern Physics D, 26(01), 1740003.

The Exotic Relics Problem

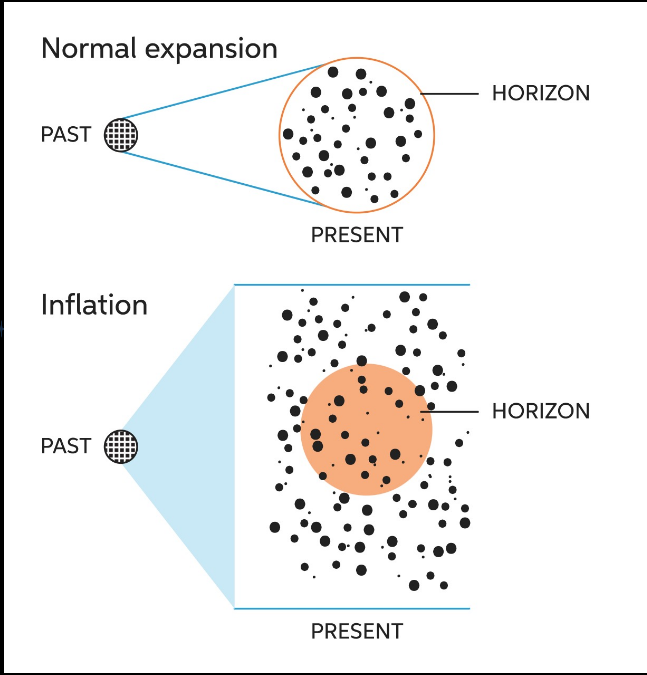
- Modern particle physics theories predict a number of “undesirable relics” (e.g. Magnetic monopoles, Domain Walls, Supersymmetric particles)
- These particles have yet to be observed
- Either do not exist or they do exist but they are hard to detect



https://www.chegg.com/learn/physics/introduction-to-physics/monopole-problem

Solving The Exotic Relics Problem

- The rapid inflation of space causes the density of primordial monopoles and other relics to drop exponentially
- As a result, these particles would be dispersed throughout the Universe



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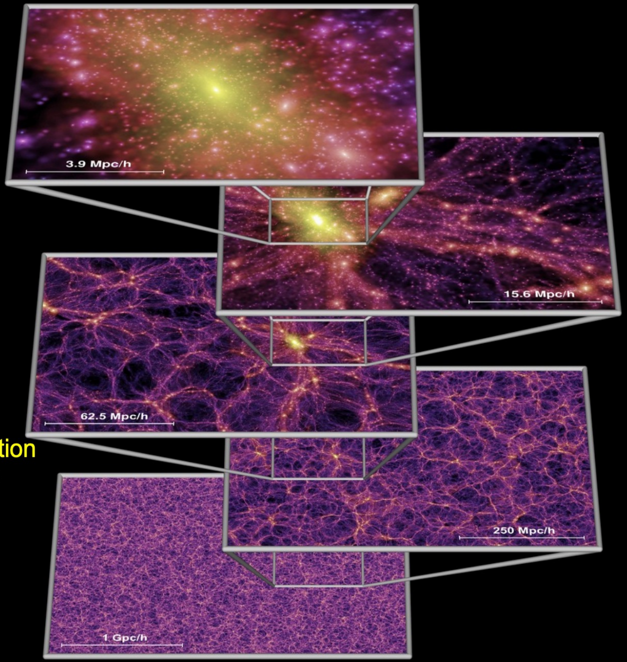
The Fluctuations Problem

- The Universe is homogeneous at large scales, but not at smaller scales
- The hot Big Bang model does not provide a mechanism that explains this observed structure



'Millennium' simulation
Springel et al. (2005)

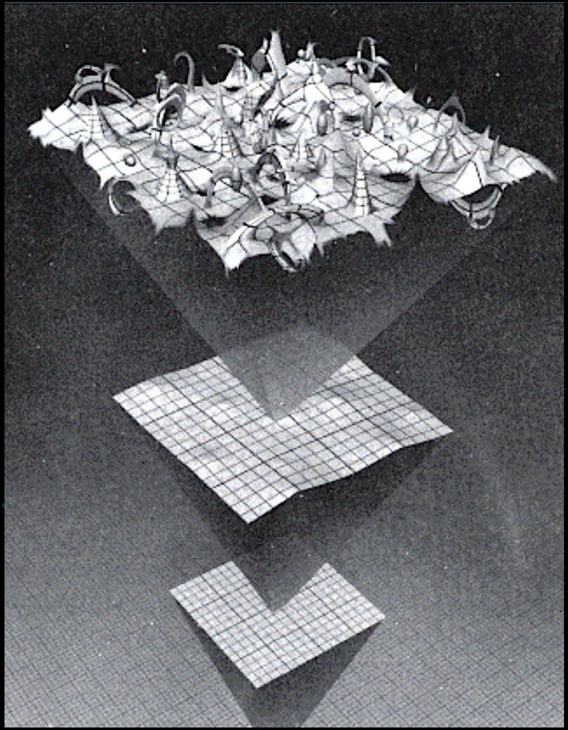
ΛCDM

https://www.astro.umd.edu/~richard/ASTRO620/Springel-1_2.pdf

Solving The Fluctuations Problem

$$\phi(\mathbf{x}, t) = \phi_0(t) + \delta\phi(\mathbf{x}, t)$$

- The origin of these perturbations is due to **random quantum fluctuations** of the inflaton
- Fluctuations are expanded into much larger scales



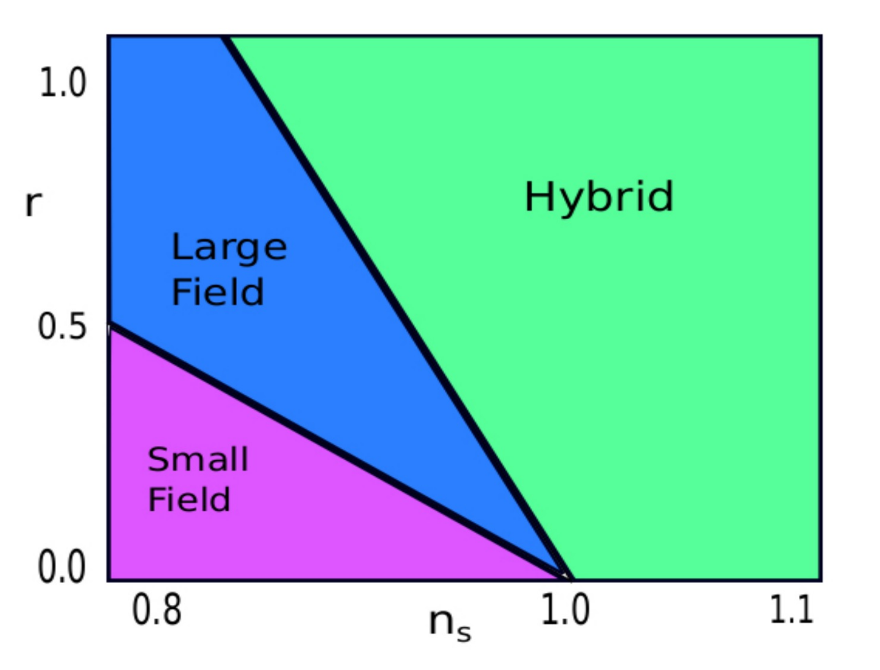
http://abyss.uoregon.edu/~js/ast123/lectures/lec17.html

Inflationary models

There are numerous inflations models in literature which can be **broadly categorized** as follows:

- Large Scalar Field Models
- Small Scalar Field Models
- Hybrid Models

$$V(\phi) = \Lambda^4 f(\phi/\mu)$$



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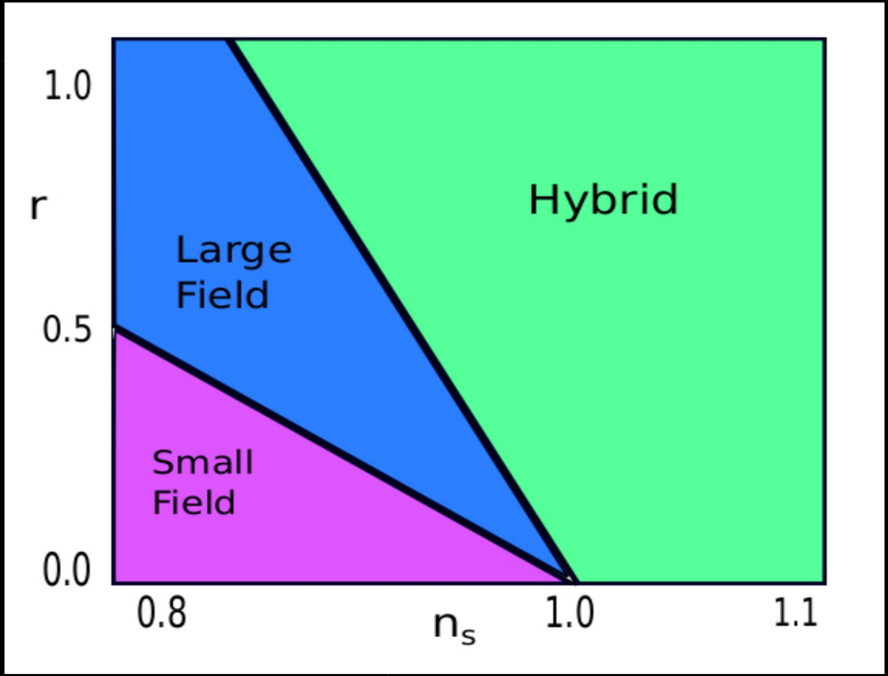
Inflationary models

The **steps** for comparison of model predictions to CMB observations:

- Compute slow roll parameters from a potential
- Find out the final scalar field value
- Compute the field for ~ 60 N
- Compute n_s and r to test against CMB data



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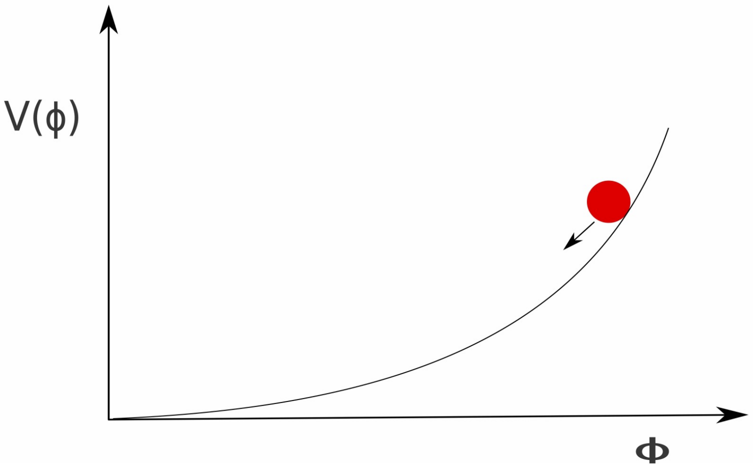
Large Field Models

$$V(\phi) = \Lambda^4 \left(\frac{\phi}{\mu}\right)^p$$

$$n - 1 = -\frac{2+p}{2N}$$

$$r = \frac{4p}{N}$$



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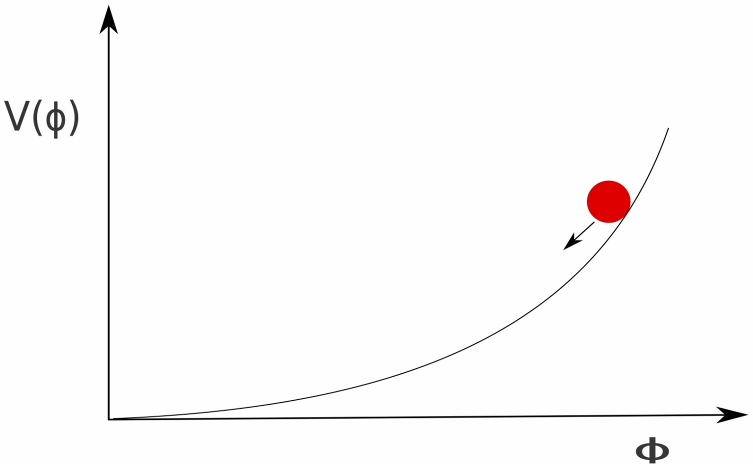
Large Field Models

$$V(\phi) = \Lambda^4 \exp(\phi/\mu)$$

$$n - 1 = -\frac{m_{\rm Pl}^2}{8\pi\mu^2}$$

$$r = 8(1 - n)$$



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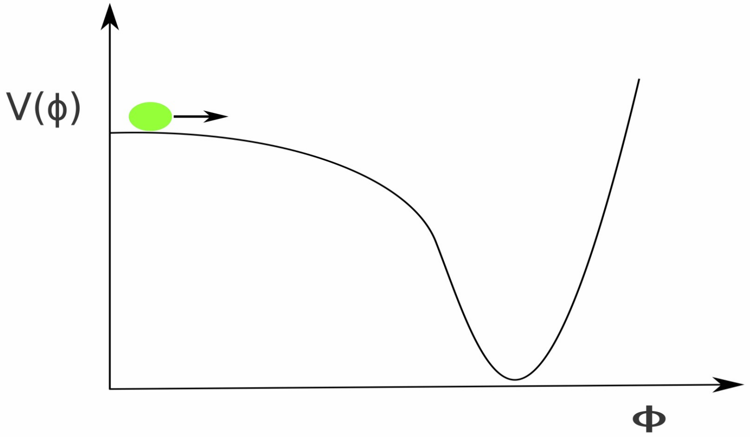
Small Field Models

$$V(\phi) = \Lambda^4 \left[1 - (\phi/\mu)^p\right]$$

$$n_s - 1 \simeq -\left(\frac{m_{\rm Pl}}{\mu}\right)^2$$

$$r = 8(1-n_s)\exp\left[-1 - N(1-n_s)\right]$$



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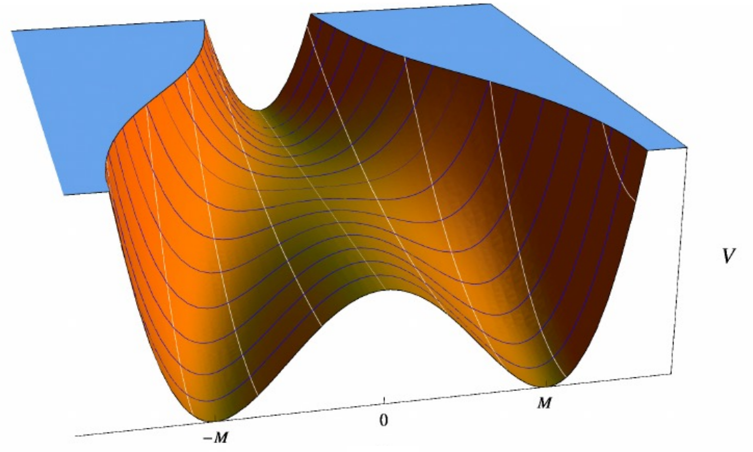
Hybrid Models



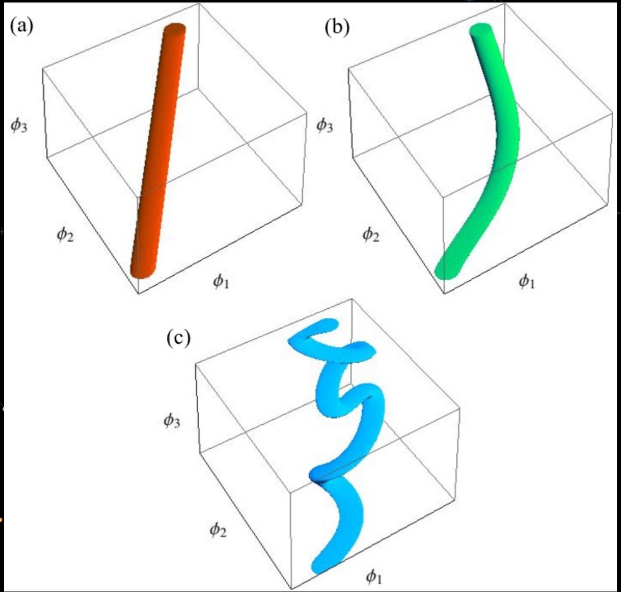
$$V(\phi) = \Lambda^4 \left[1 + (\phi/\mu)^p\right]$$

$$N(\phi) \simeq \left(\frac{p+1}{p+2}\right)\left[\frac{1}{\eta(\phi_c)} - \frac{1}{\eta(\phi)}\right]$$

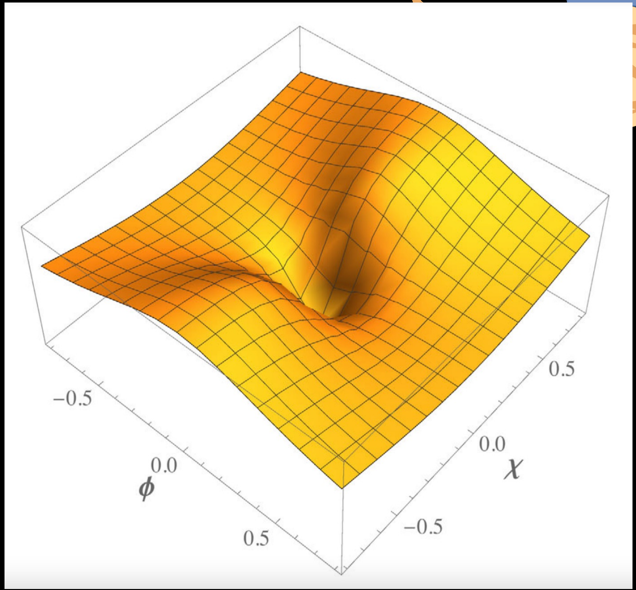
$$n_s - 1 \simeq 2\left(\frac{p+1}{p+2}\right)\frac{1}{N_{max} - N}.$$

Civiletti, M., Rehman, M. U., Sabo, E., Shafi, Q., & Wickman, J. (2013). R-symmetry breaking in supersymmetric hybrid inflation. Physical Review D, 88(10), 103514.

Multi-Field Inflation



Peterson, C. M., & Tegmark, M. (2013). Testing multifield inflation: A geometric approach. Physical Review D, 87(10), 103507.



DeCross, M. P., et al. (2018). Preheating after multifield inflation with nonminimal couplings. I. Covariant formalism and attractor behavior. Physical Review D, 97(2), 023526.

Conclusion

1. Inflation circumvents the problems of the hot Big Bang theory, but **it's not meant to replace it**.

2. There are several types of inflationary models which aim to **provide predictions** of the CMB

3. Inflation is frequently criticized for having **conceptual flaws**

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Thanks

Questions?

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