Inflation, B-mode targets and fundamental physics

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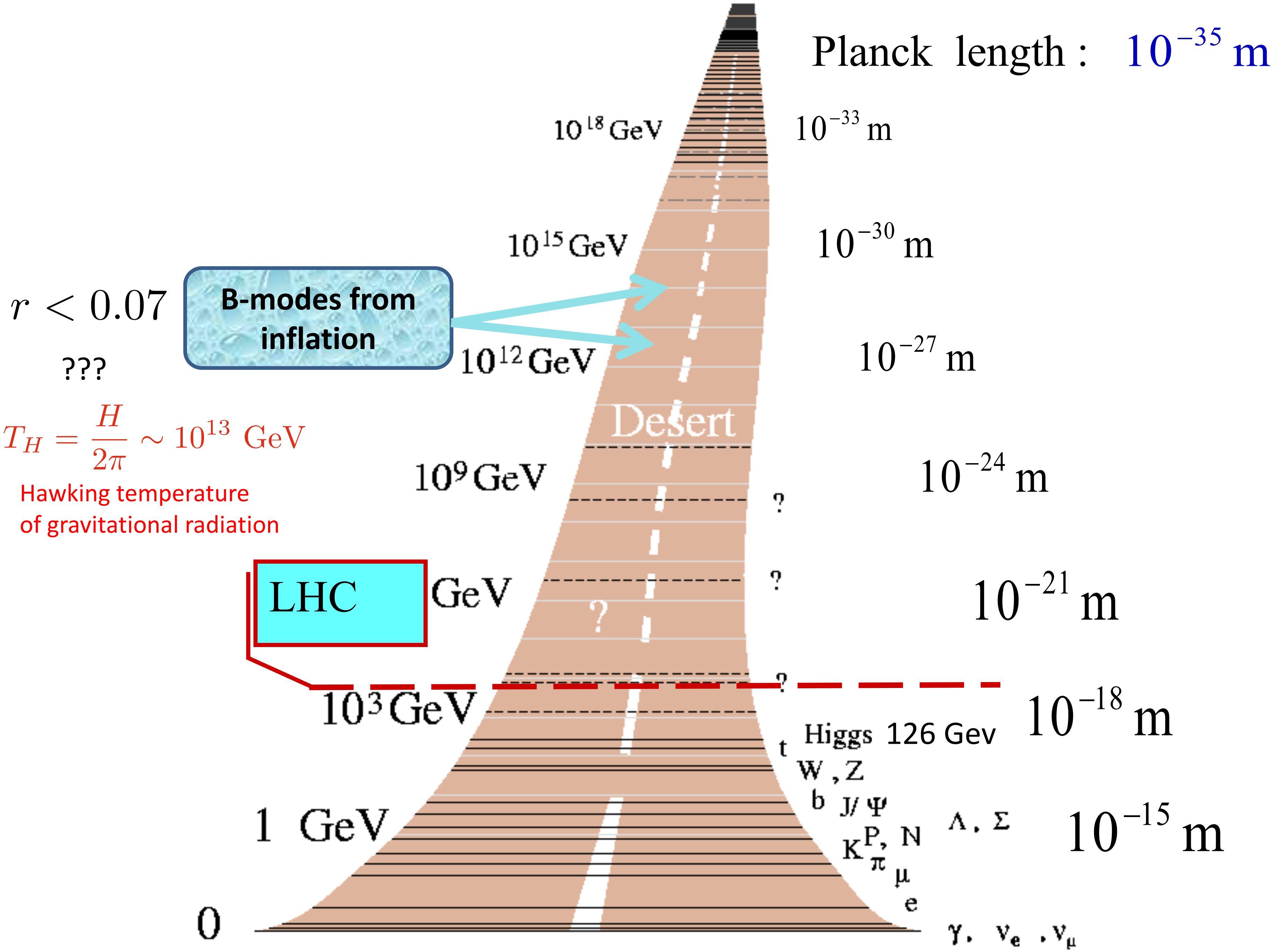
B-mode from space workshop

Berkeley, December 4, 2017

Based on work with **A. Linde and S. Ferrara, D. Roest, T. Wrase, Y. Yamada**



Planck length : 10^{-35} m
10^{18} GeV
10^{-33} m
10^{15} GeV
10^{-30} m
$r < 0.07$
B-modes from inflation
???
10^{12} GeV
10^{-27} m
$T_H = \frac{H}{2\pi} \sim 10^{13}$ GeV
Hawking temperature
of gravitational radiation
Desert
10^9 GeV
10^{-24} m
?
LHC
GeV
?
10^{-21} m
?
10^3 GeV
10^{-18} m
Higgs 126 Gev
t
W , Z
b J/ Ψ
1 GeV
Λ , Σ
K P, N
π
μ
e
10^{-15} m
0
γ , ν_e , ν_μ

The energy scale of inflation

$$V^{1/4} \sim 1.04 \times 10^{16} \text{ GeV} \left(\frac{r}{0.01}\right)^{1/4}$$

GUT

The energy of inflationary perturbations

$$H = \frac{1}{M_{Pl}}\sqrt{V/3} \sim 2.6 \times 10^{13}\text{GeV}\left(\frac{r}{0.01}\right)^{\frac{1}{2}}$$

If primordial gravitational wave will be detected

$$r \approx 10^{-2} \qquad H \approx 2.6 \times 10^{13}\text{GeV}$$

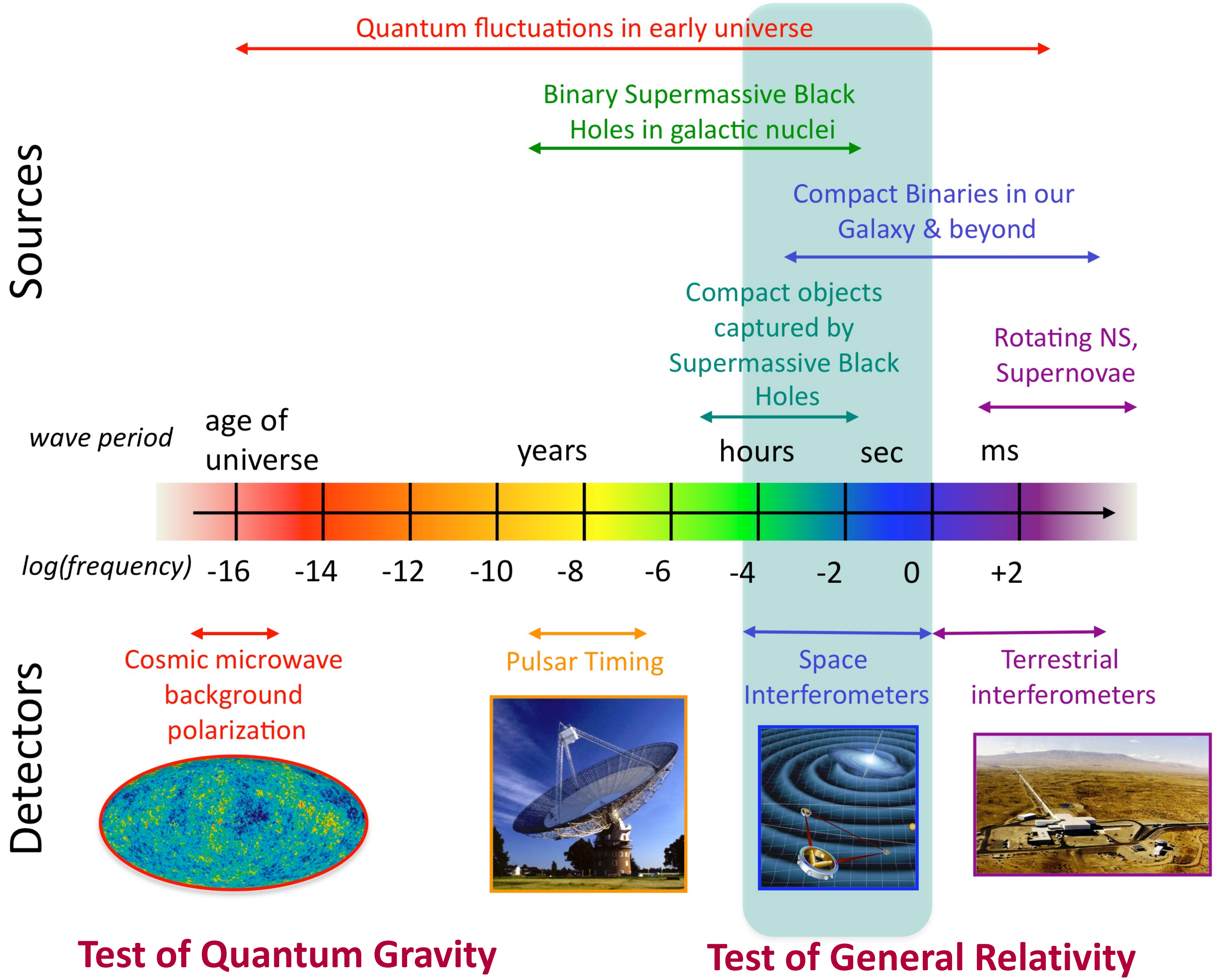
$$r \approx 10^{-3} \qquad H \approx 0.8 \times 10^{13}\text{GeV}$$

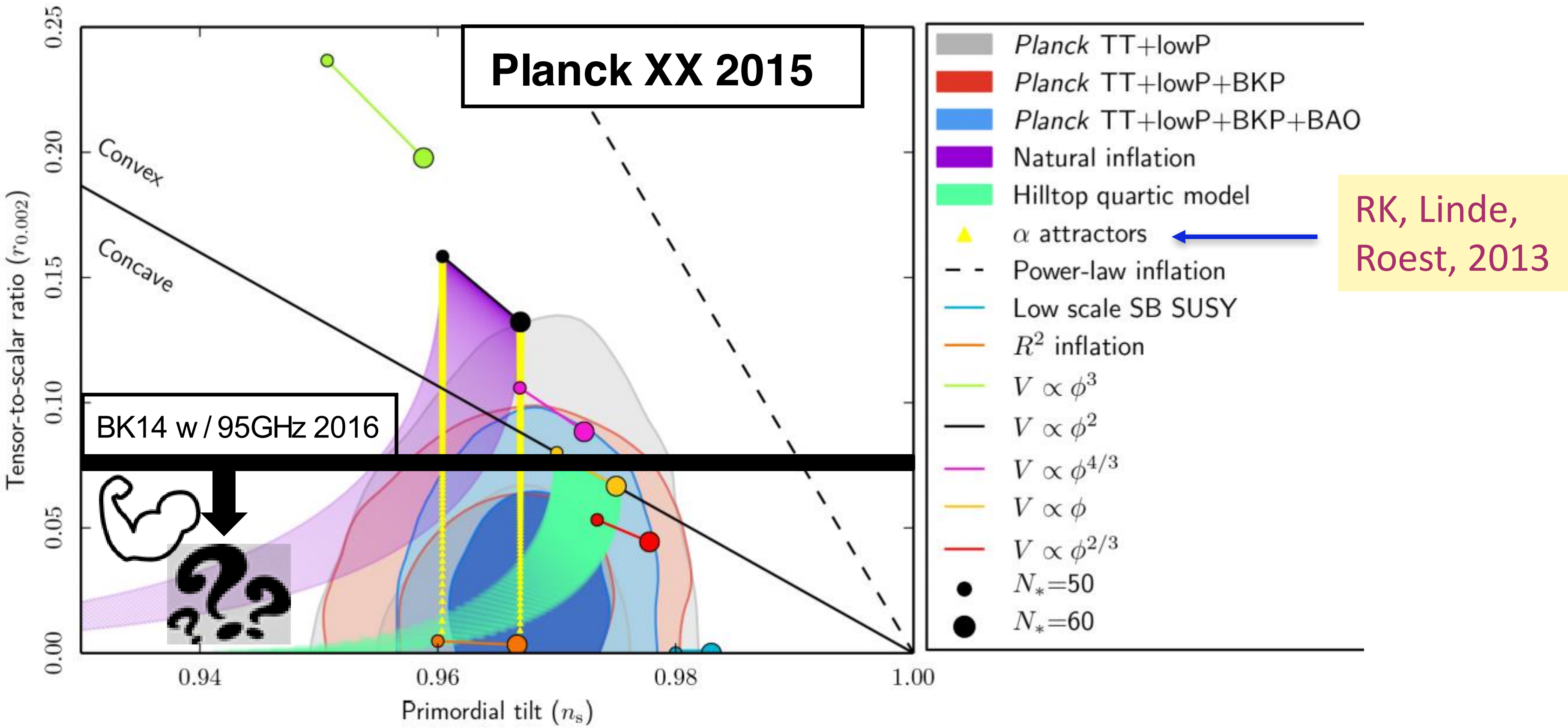
we will probe energies billion times higher than the energies probed at LHC

LIGO detected GW from binary black holes and neutron stars, with the wavelength of thousands of kilometers

But, the primordial GW affecting the CMB have a wavelength of billions of light-years!!!

The Gravitational Wave Spectrum





If B-modes will be discovered soon, $r > 10^{-2}$ natural inflation models, axion monodromy models, α-attractor models,…, will be validated

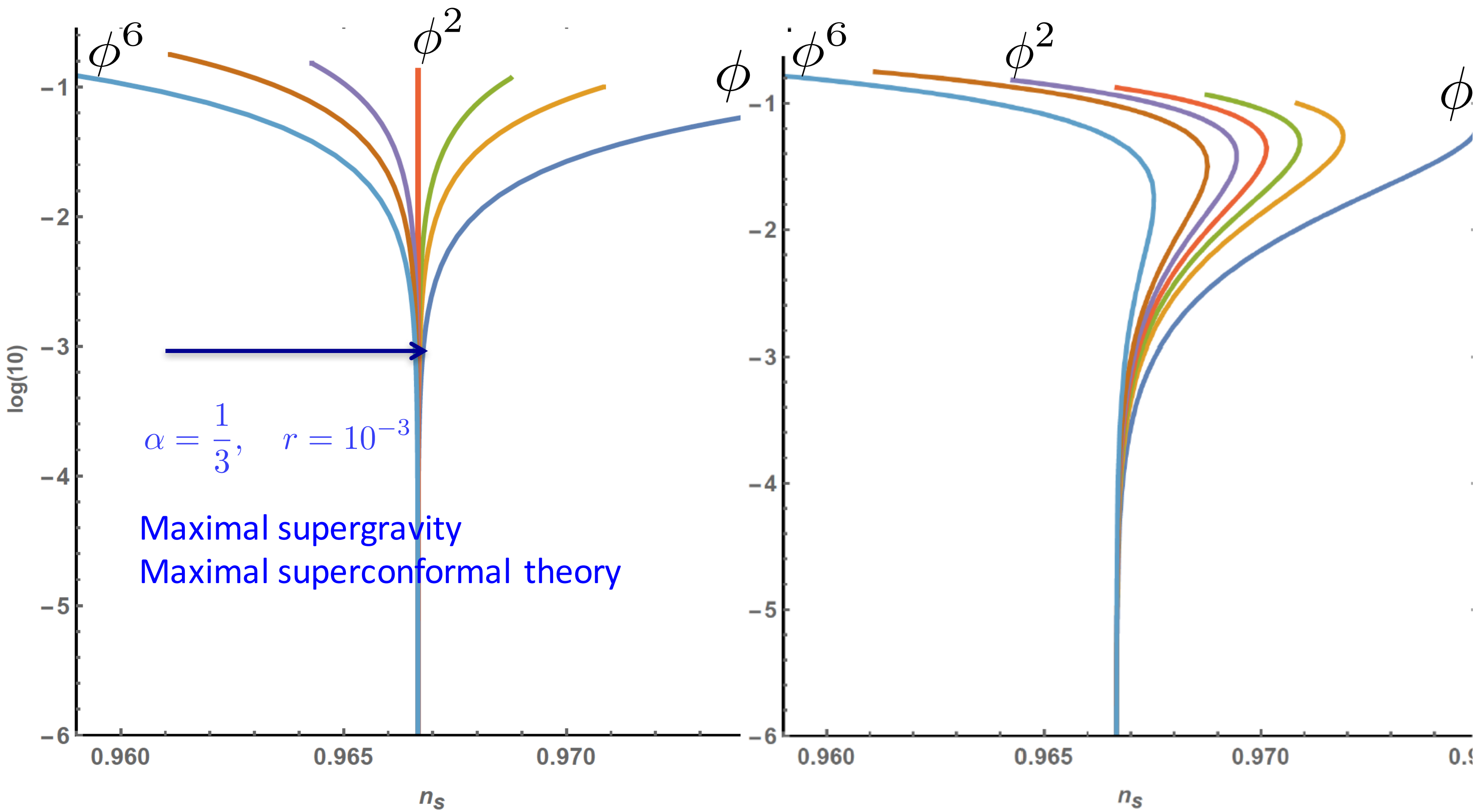
No need to worry about log scale r

Otherwise, we switch to log r to see $10^{-3} < r < 10^{-2}$

α-attractors

Simple Fanned T-models

Simple Fanned E-models

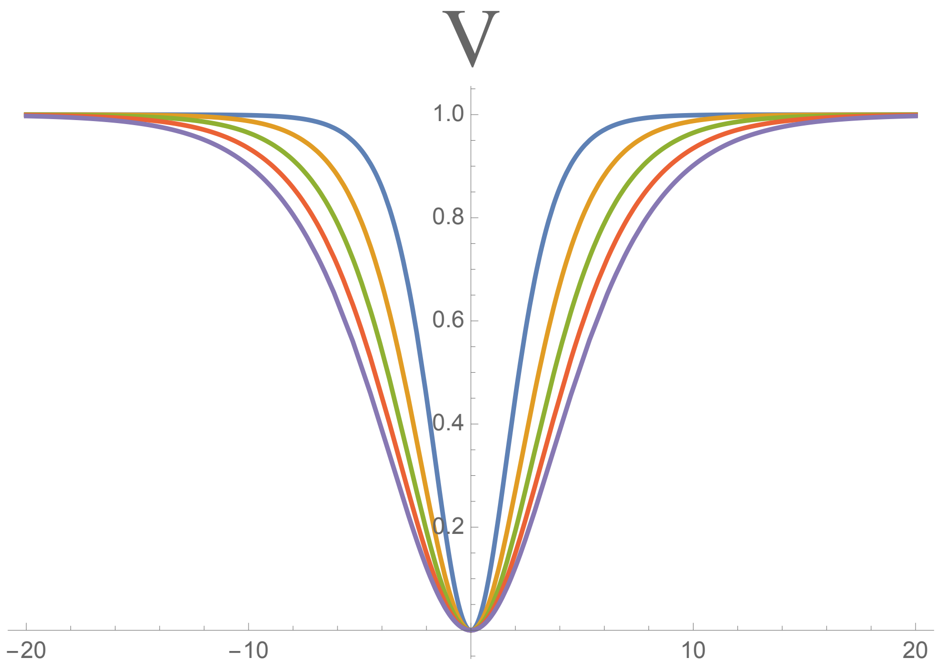


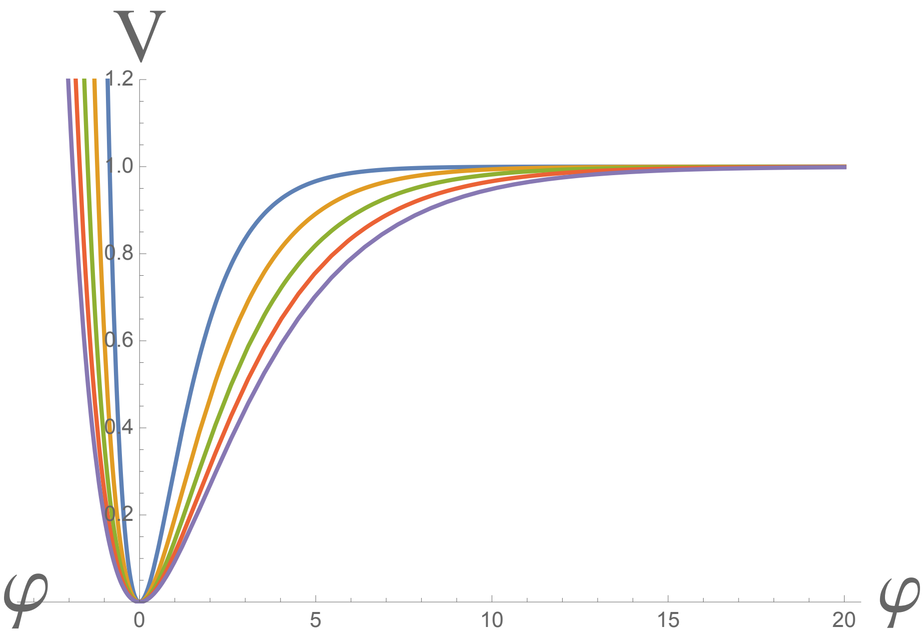
$$\left(\tanh\frac{\varphi}{\sqrt{6\alpha}}\right)^{2n}$$

$$\left(1 - e^{\sqrt{\frac{2}{3\alpha}}\varphi}\right)^{2n}$$

Starobinsky and Higgs, α=1, n=1

Plateau potentials α-attractors





$$\frac{1}{2}R - \frac{1}{2}\partial\varphi^2 \;\; - \alpha\mu^2\Big(\tanh\frac{\varphi}{\sqrt{6\alpha}}\Big)^2$$

$$\frac{1}{2}R - \frac{1}{2}\partial\varphi^2 \;\; - \alpha\mu^2\Big(1 - e^{-\sqrt{\frac{2}{3\alpha}}\varphi}\Big)^2$$

Simplest T-model in canonical variables Simplest E-model

$$\frac{1}{2}R - 3\alpha\frac{\partial Z\partial\bar{Z}}{(1-Z\bar{Z})^2} - V_0 Z\bar{Z}$$

$$\frac{1}{2}R - 3\alpha\frac{\partial T\partial\bar{T}}{(T+\bar{T})^2} - V_0(T-1)^2$$

In geometric variables

Meaning of the measurement of the curvature of the 3d space

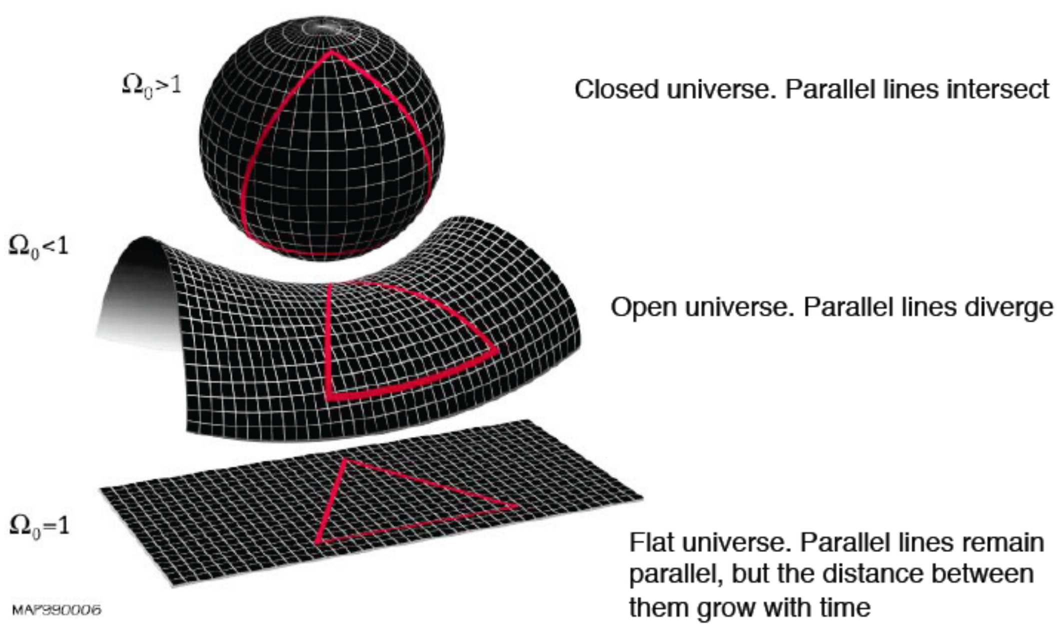
k=+1, k=-1, k=0

Spatial curvature parameter

$$ds^2 = -dt^2 + a(t)^2 \gamma_{ij} dx^i dx^j$$

$$\Omega_K = -0.0004 \pm 0.00036$$

Closed, open or flat universe



In the context of new supergravity cosmological models, measuring r means measuring the curvature of the hyperbolic geometry of the moduli space

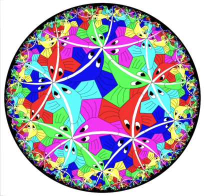
$$n_s = 1 - \frac{2}{N}\,, \qquad r = \alpha \frac{12}{N^2}$$

$$R_K = -\frac{2}{3\alpha}$$

scalar fields are coordinates of the Kahler geometry

Decreasing r, decreasing α, increasing curvature R_K

$$3\alpha = R^2_{\rm Escher} \approx 10^3 r$$



Hyperbolic geometry of a Poincaré disk

http://mathworld.wolfram.com/PoincareHyperbolicDisk.html

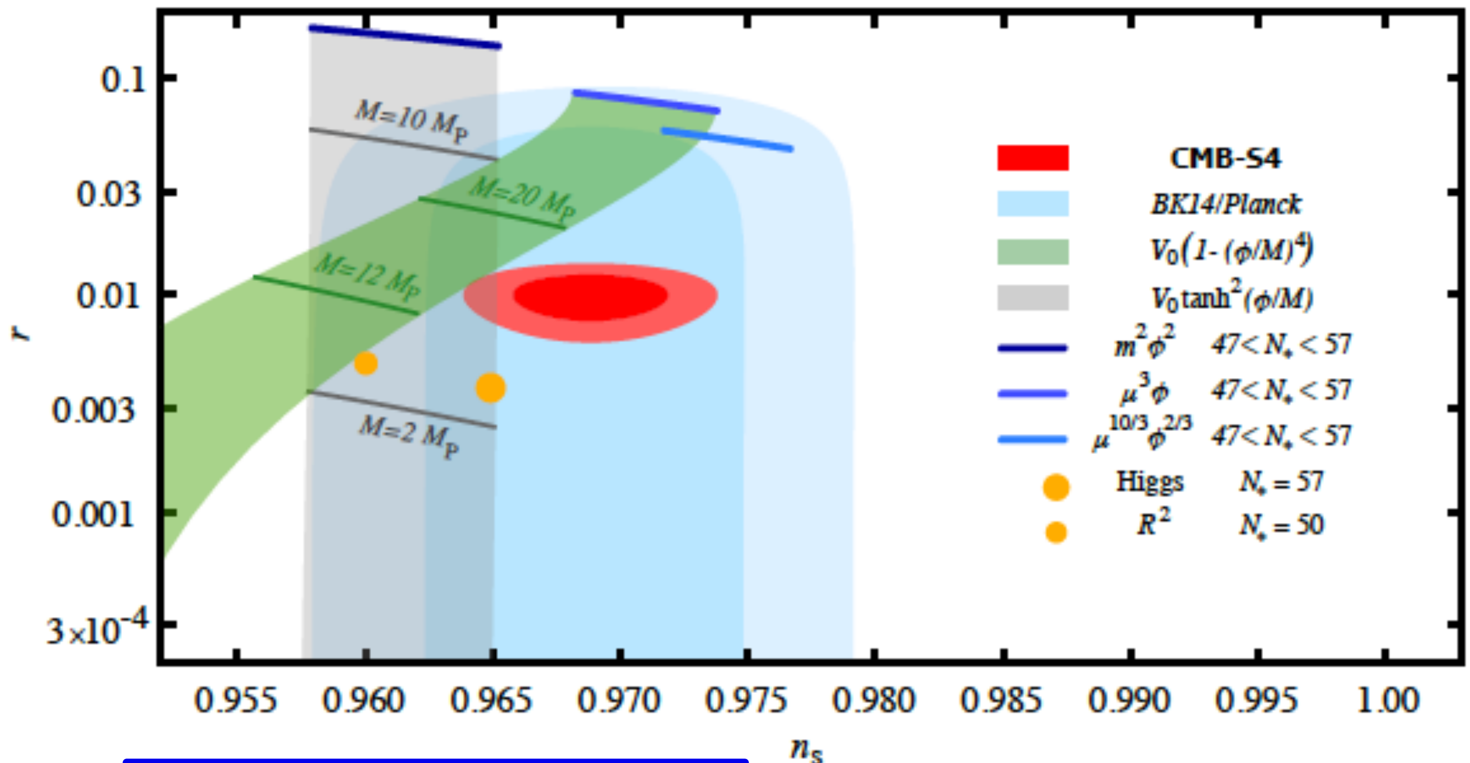
For a unit size Poincare disk:

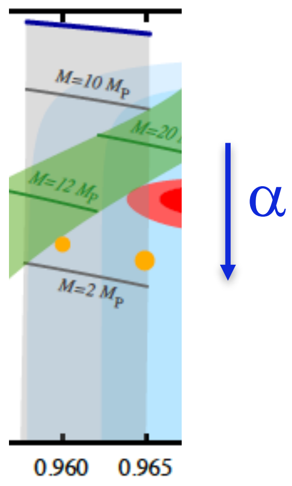
$$r \sim 10^{-3} \qquad \alpha = \frac{1}{3}$$

Next CMB satellite mission target

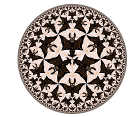
Alpha-Attractors and B-mode Targets

CMB-S4



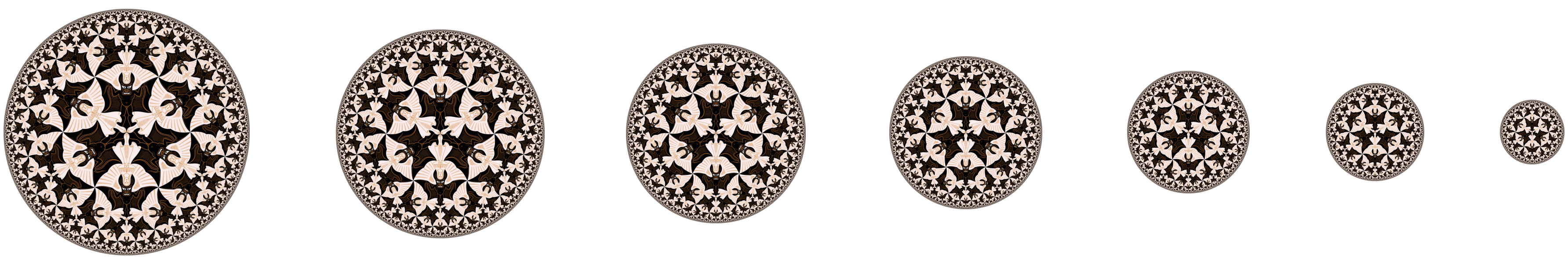


$$n_s = 1 - \frac{2}{N}\,, \qquad r = \alpha\,\frac{12}{N^2}$$

Based on CMB data on the value of the tilt of the spectrum n_s as a function of N we have deduced that hyperbolic geometry of a Poincaré disk  suggests a way to explain the experimental formula

$$n_s \approx 1 - \frac{2}{N}$$

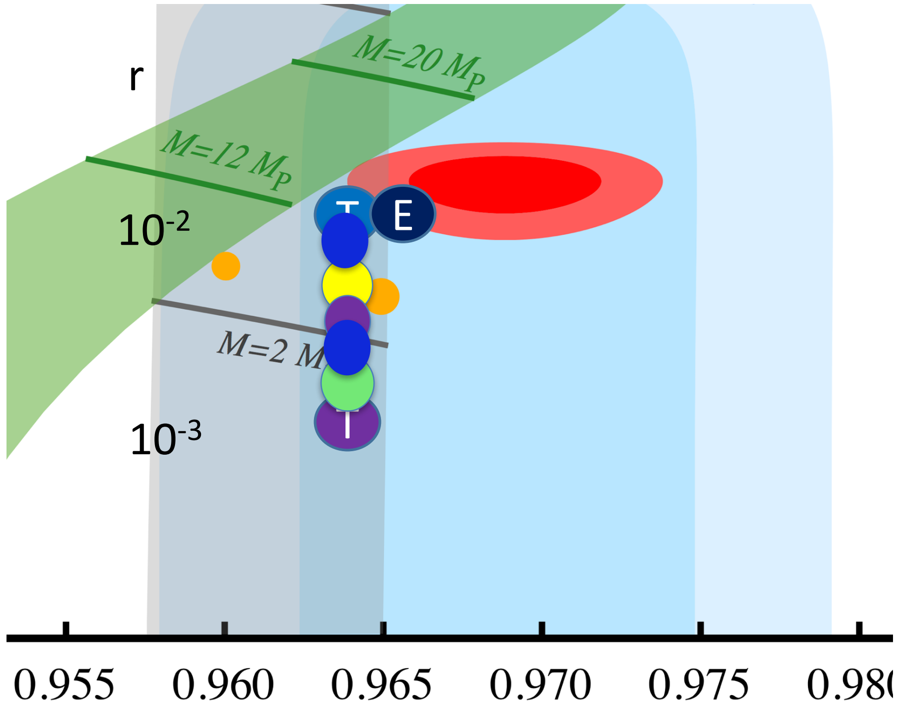
Using a consistent reduction from maximal $\mathcal{N}$=8 supersymmetry theories: M-theory in d=11, String theory in d=10, maximal supergravity in d=4, to the minimal $\mathcal{N}$=1 supersymmetry we have deduced the favorite models with hyperbolic geometry with $R^2_{Escher} = 3\alpha =$ 7,6,5,4,3,2,1



$r \approx 0.9 \times 10^{-2}$ $r \approx 1.3 \times 10^{-3}$

B-mode targets from disks merger

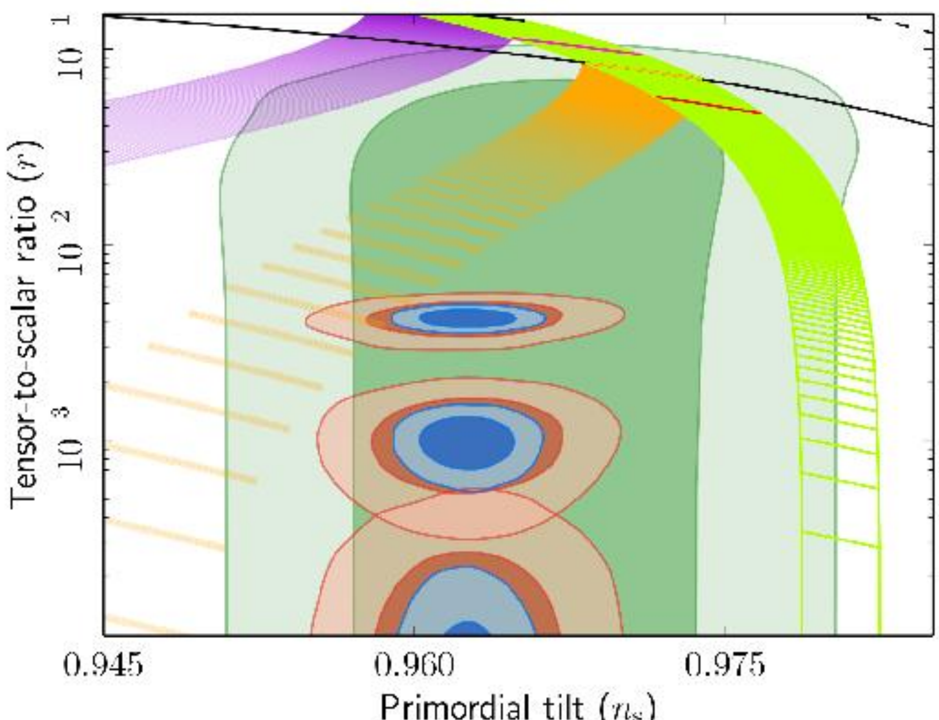
In contrast with $\mathcal{N}$=1 supersymmetry models where 3α is arbitrary



Higgs $N_* = 57$

R^2 $N_* = 50$

Seven new targets



$\sigma(n_s)$ = 0.0014

Improvement factor CORE to Planck 2015
3.4

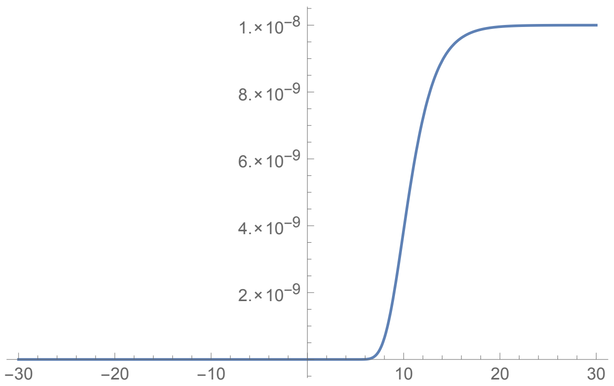
COrE : Cosmic Origin Explorer

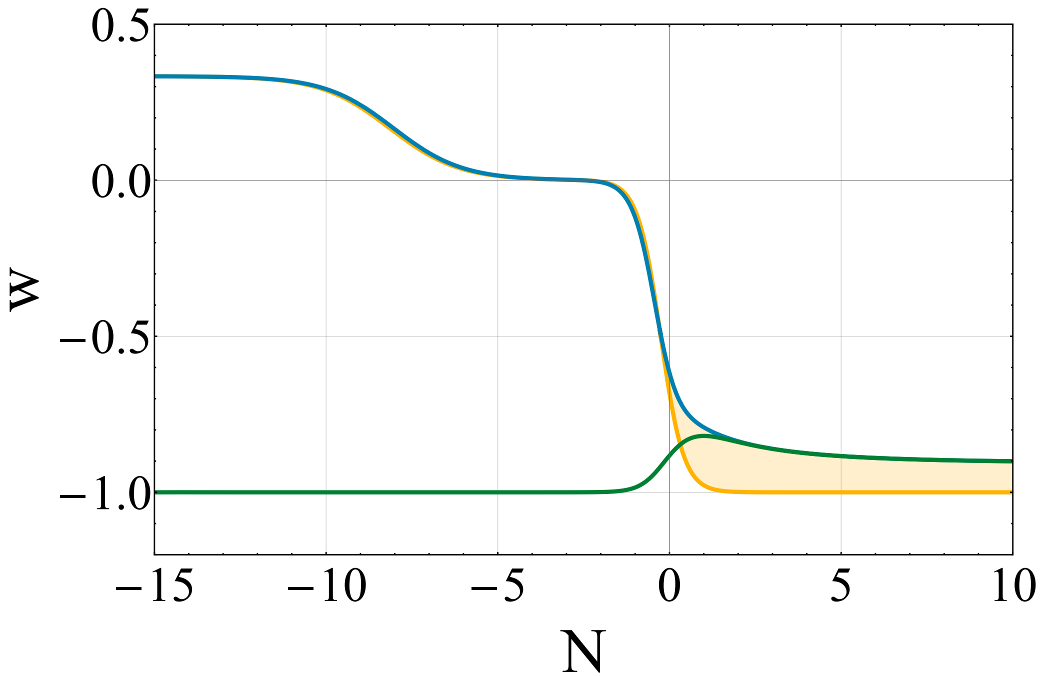
forecast regions for (n_s, r) for CORE (blue) and LiteBIRD (red)

Dark Energy with α-attractors : w=-1, in most cases

Work in progress: Y. Arkami et al

A simple quintessential inflation 2-shoulder α-attractor model





$$r = 4\,\frac{3\alpha}{N^2}$$

$$w_\infty = -1 + \frac{2}{3}\,\frac{1}{3\alpha}$$

$$3\alpha = 7 \qquad r \approx 10^{-2} \qquad w_\infty \approx -0.9$$

LiteBird? Euclid?

Short Summary of the talk

- B-mode detection, if it will take place, will probe energies at about 10^{13} GeV, billion times higher than the energies probed at LHC

- Whereas LIGO discovery of gravitational waves confirms General Relativity, a discovery of primordial gravitational waves will confirm our understanding of Quantum Gravity, up to energies of inflation, since we describe inflationary perturbations using both General Relativity and Quantum field Theory

- The range of B-mode space detectors $10^{-3} < r < 10^{-2}$ is particularly interesting since it has targets from the fundamental physics: string theory, M-theory, maximal supergravity

Seven values scanning the range between 10^{-3} and 10^{-2}

$$r \approx 3\alpha \frac{4}{N^2} \qquad n_s \approx 1 - \frac{2}{N}$$

α-attractor models

$3\alpha = 7,6,5,4,3,2,1$

Example
$n_s \approx 0.963$
N=55 e-foldings

Starobinsky and Higgs, $\alpha=1$