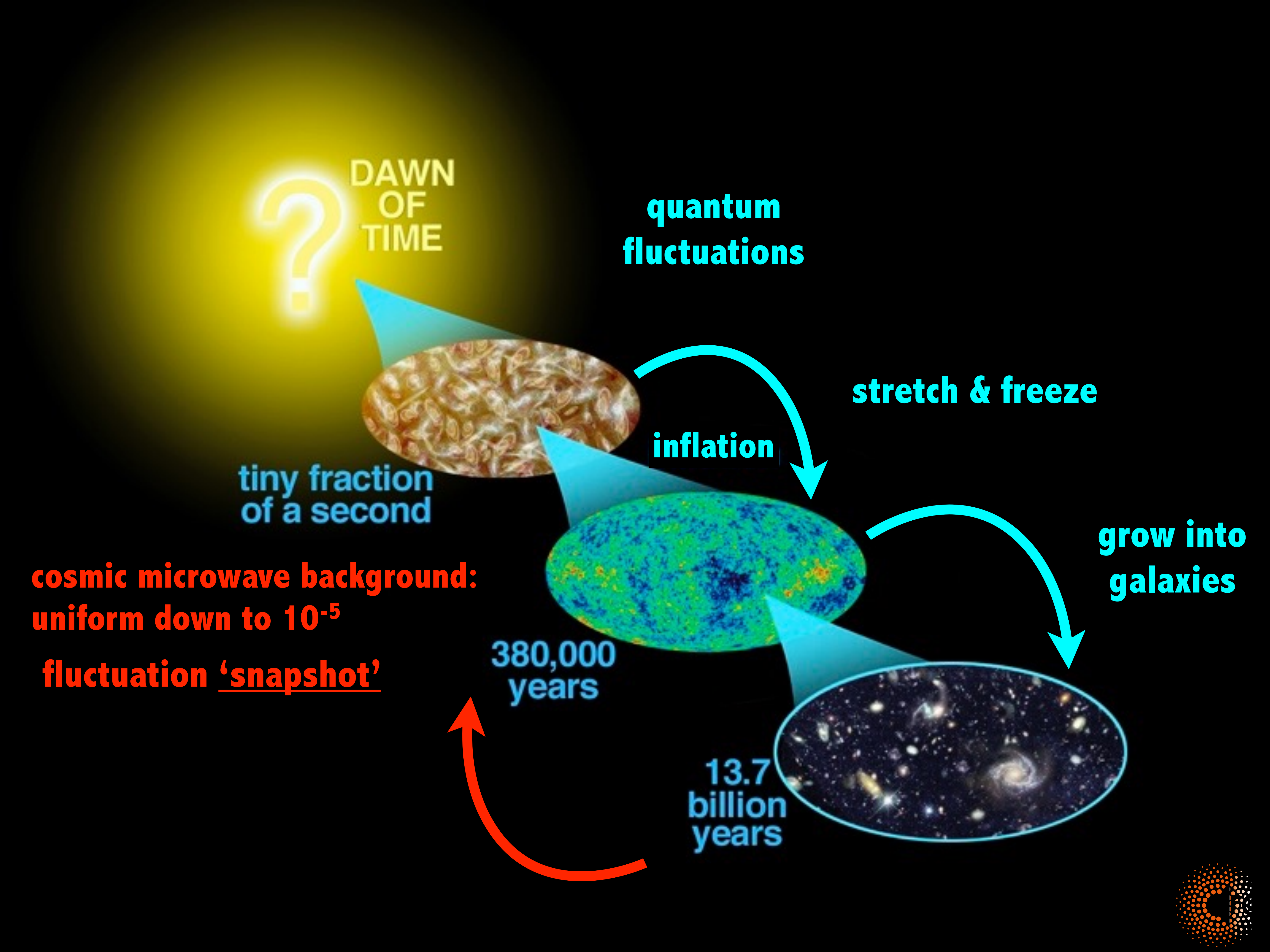
Back-reacted (rel)Axion Monodromy for Inflation & Relaxation in String Theory

with Hebecker, Rompineve [1512.03768]
with McAllister, Schwaller, Servant, Stout [1610.05320]

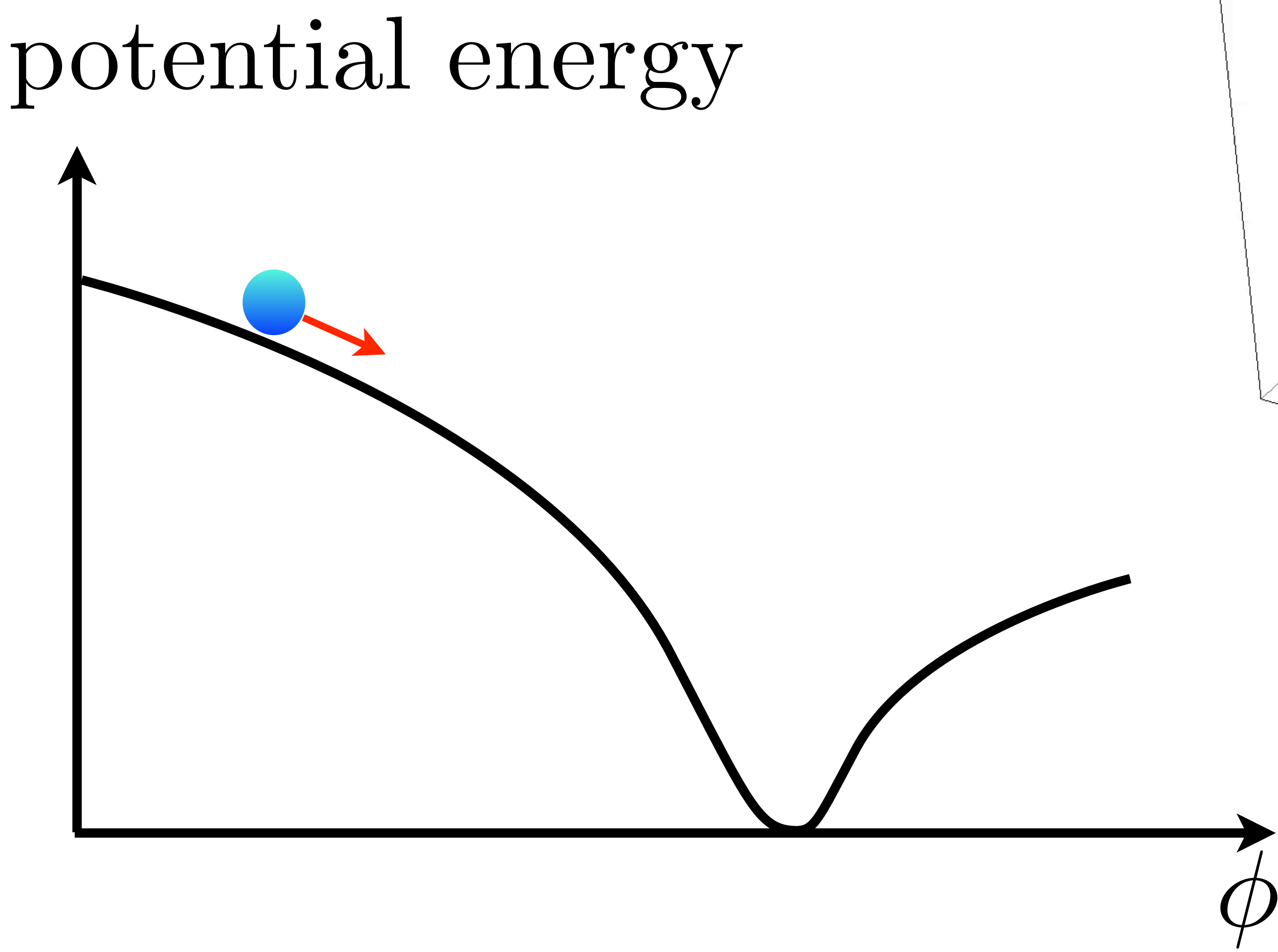
And work with: I. Ben-Dayan, W. Buchmüller, E. Dudas, K. Dutta, R. Flauger, R. Kallosh, A. Linde, J. Moritz, E. Pajer, F. Pedro, A. Retolaza, M. Rummel, F. Rühle, E. Silverstein, P. Vaudrevange, A. Uranga, C. Wieck, T. Wrase, G. Xu

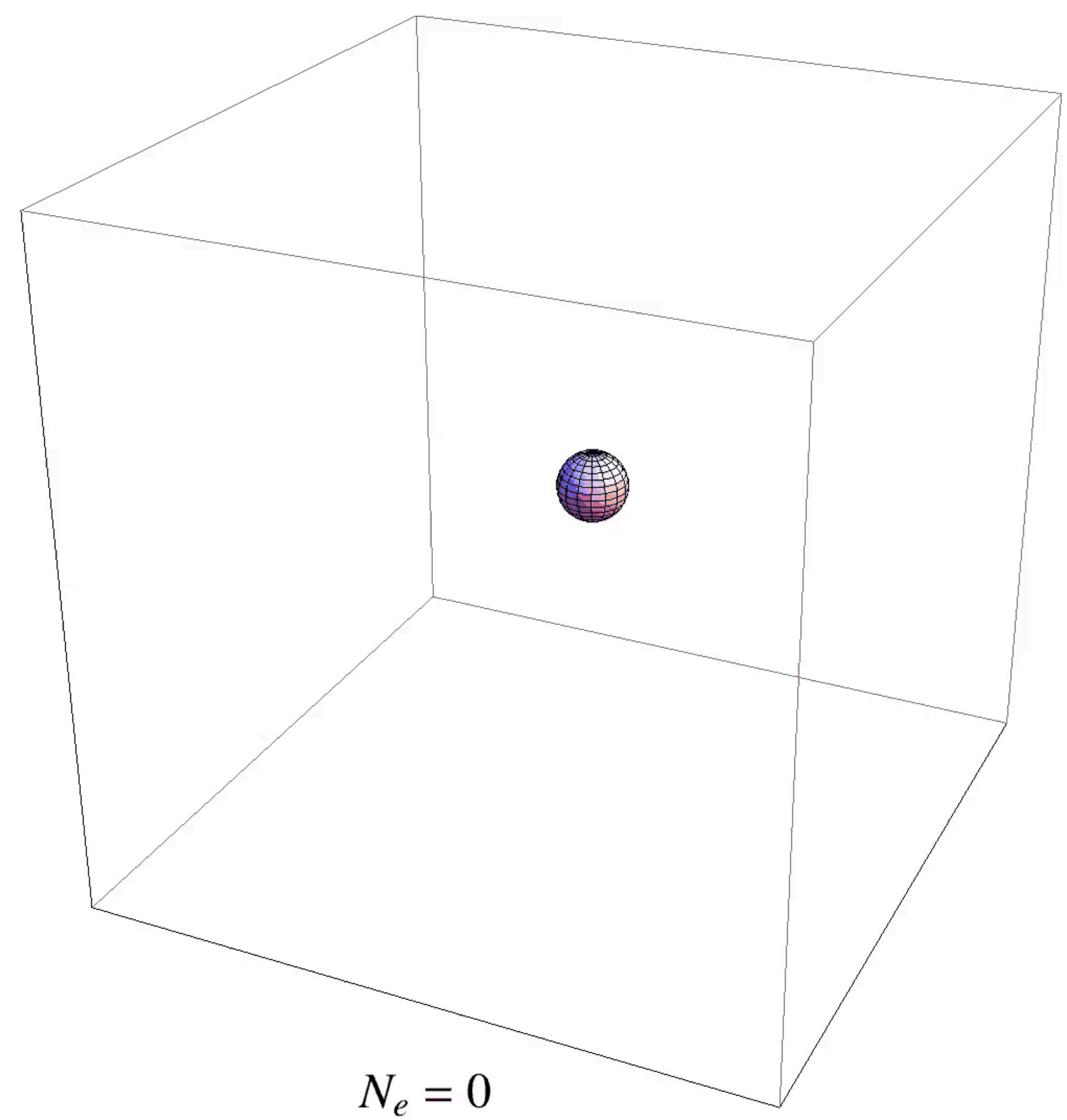
Alexander Westphal
(DESY)


DAWN OF TIME
quantum fluctuations
stretch & freeze
inflation
tiny fraction of a second
grow into galaxies
cosmic microwave background:
uniform down to 10^-5
fluctuation 'snapshot'
380,000 years
13.7 billion years

Inflation ...

(ideas by Guth, Linde & Steinhardt around 1980)

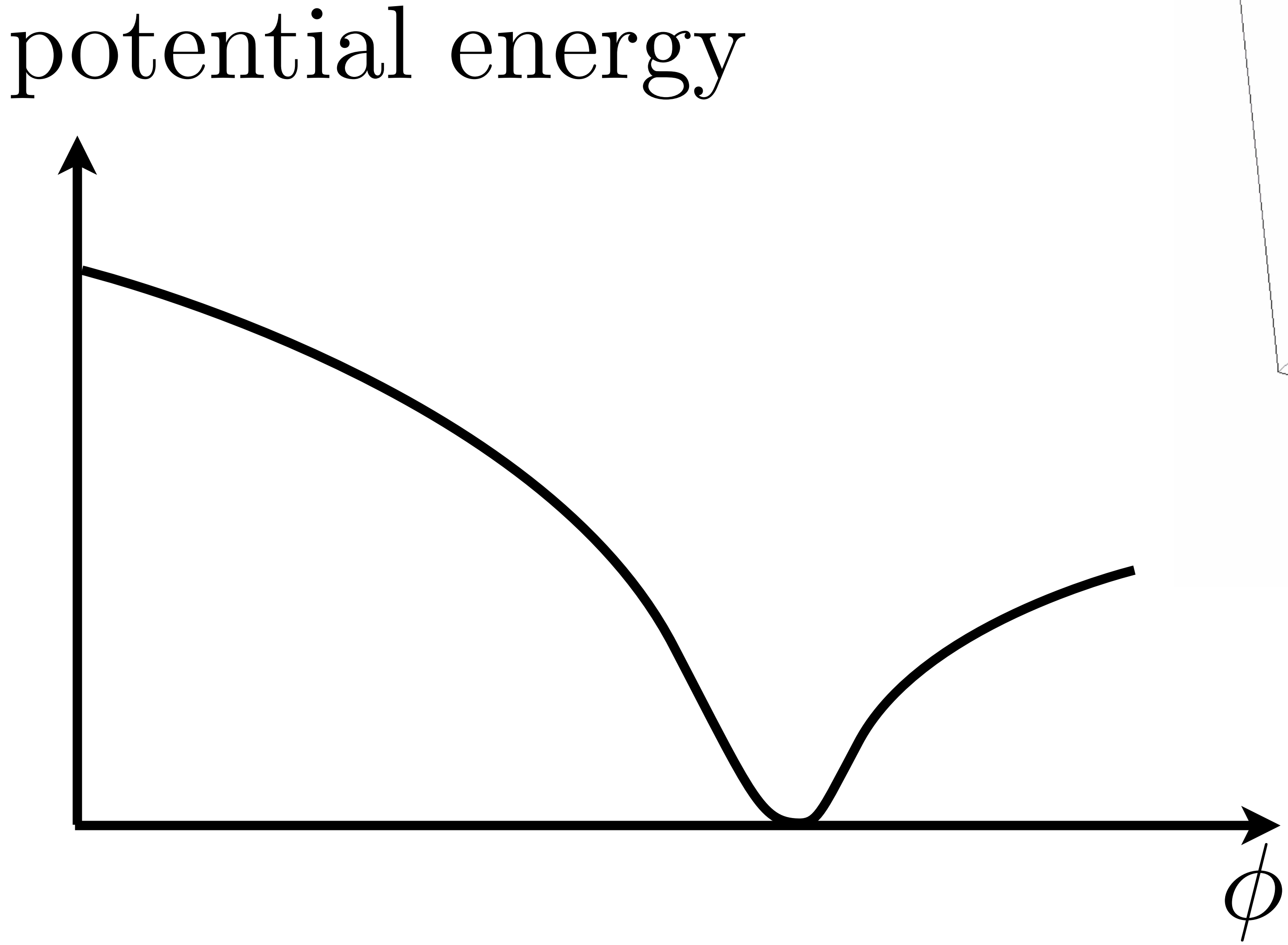


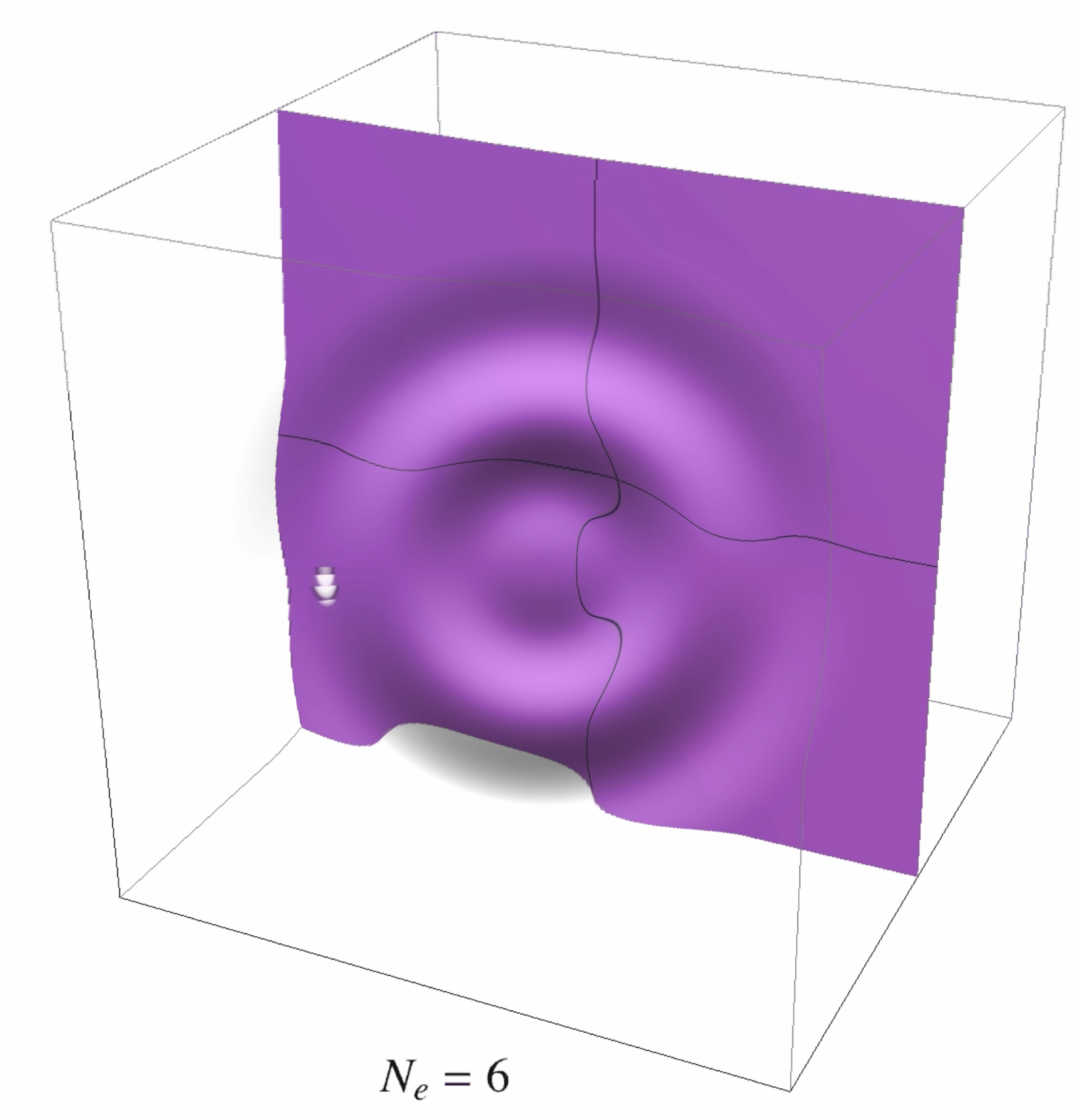


Universe Size: e^{N_e}

Inflation ...

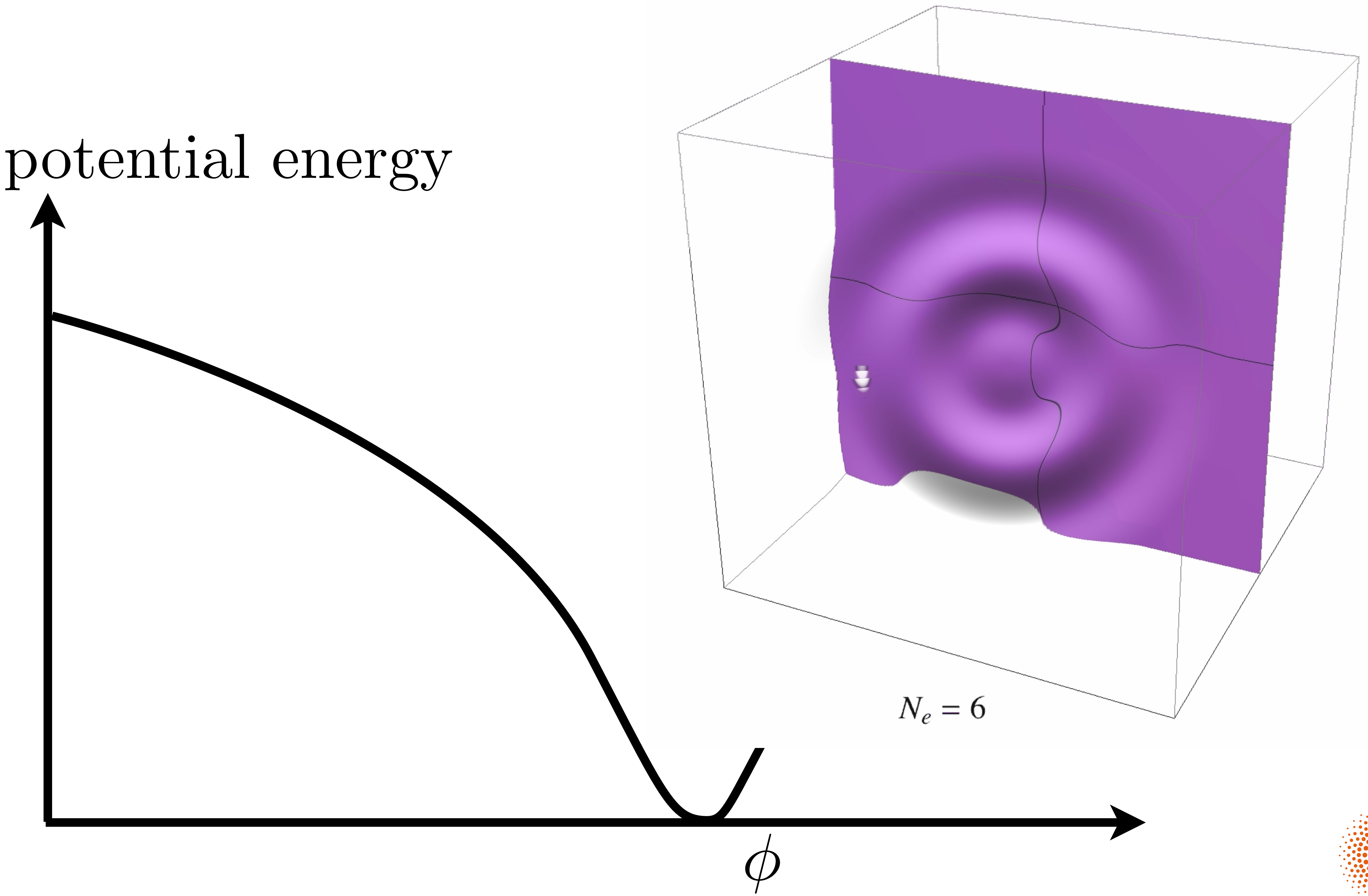
(ideas by Guth, Linde & Steinhardt around 1980)





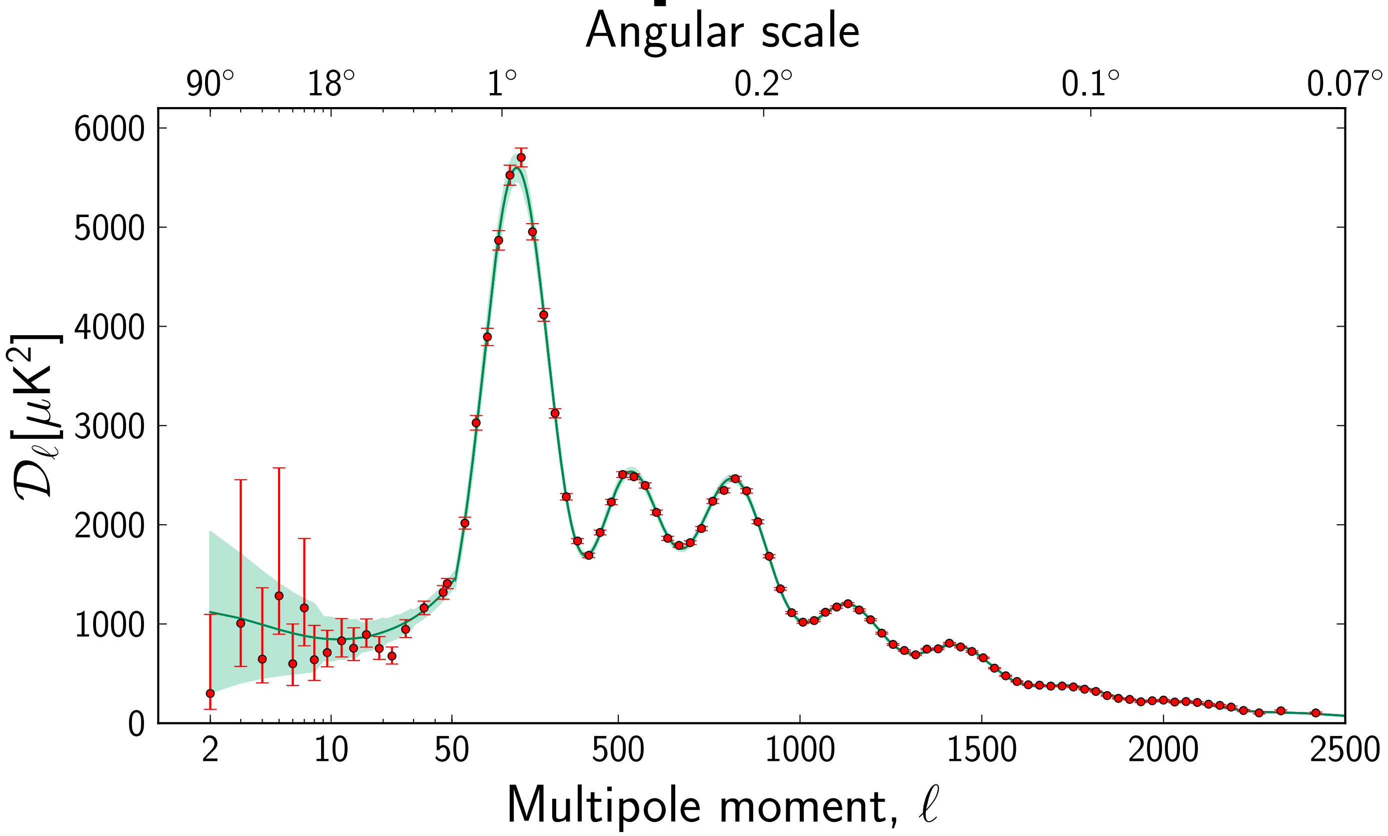
Inflation ...

(ideas by Guth, Linde & Steinhardt around 1980)



Data !

PLANCK 2015 - **most precise CMB data**

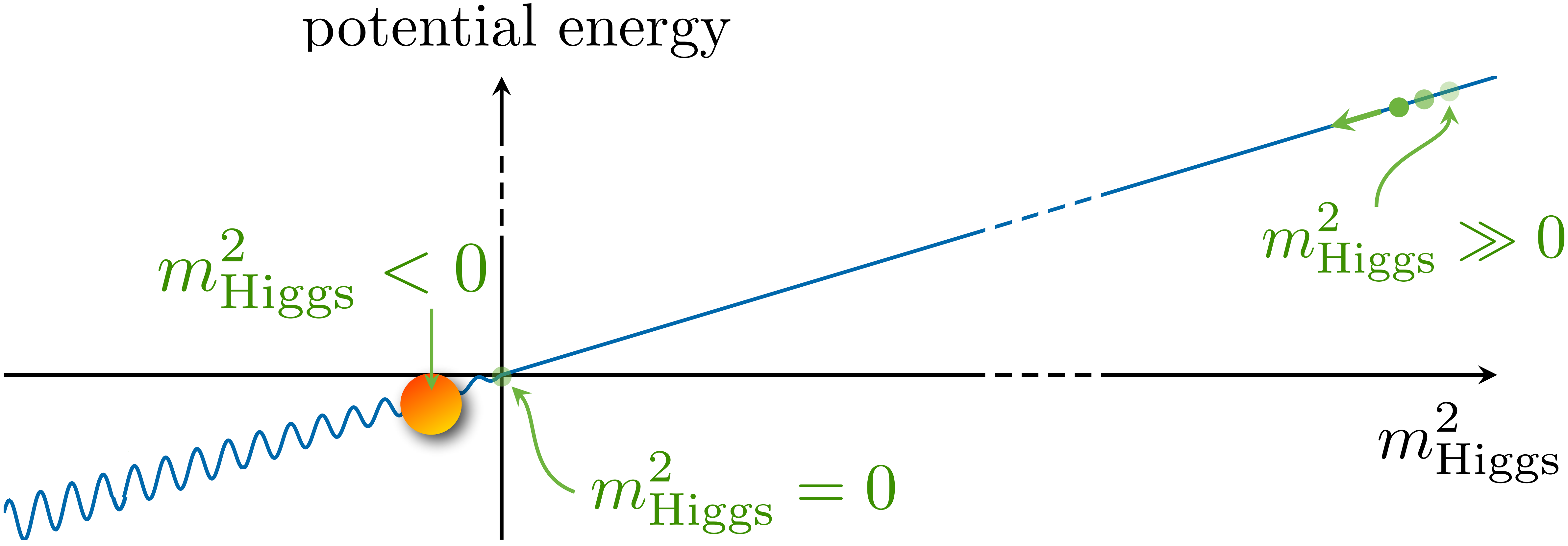


BICEP2, Keck Array, BICEP3,, Spider … since 2014:
search for gravitational waves from inflation

LHC @ 8 TeV: **Evidence for Scalars!**
Higgs Discovery 2012 !

Light Higgs from Relaxation

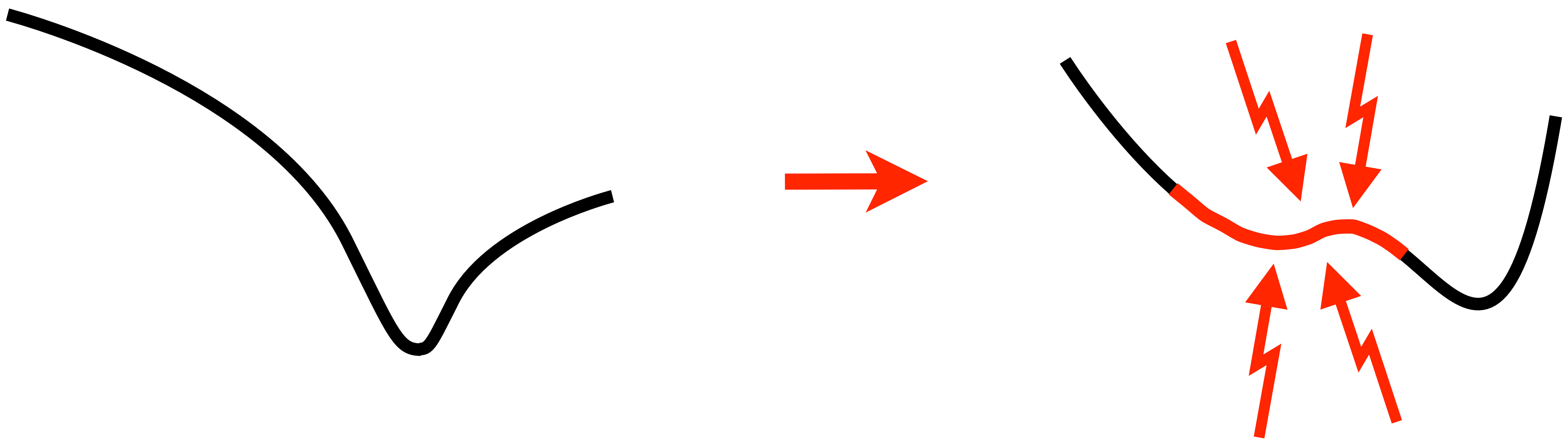
$$m^2_{\text{Higgs}} = M^2 - gM\left(\phi_{\text{init}} - \phi\right)$$



Graham, Kaplan & Rajendran '15

Quantum Theory ... Blessing & Bane

• quantum theory can kill inflation / relaxation — *quantum corrections* !



• need **quantum gravity** for **control** !

• use **string theory** to build **inflation** ...

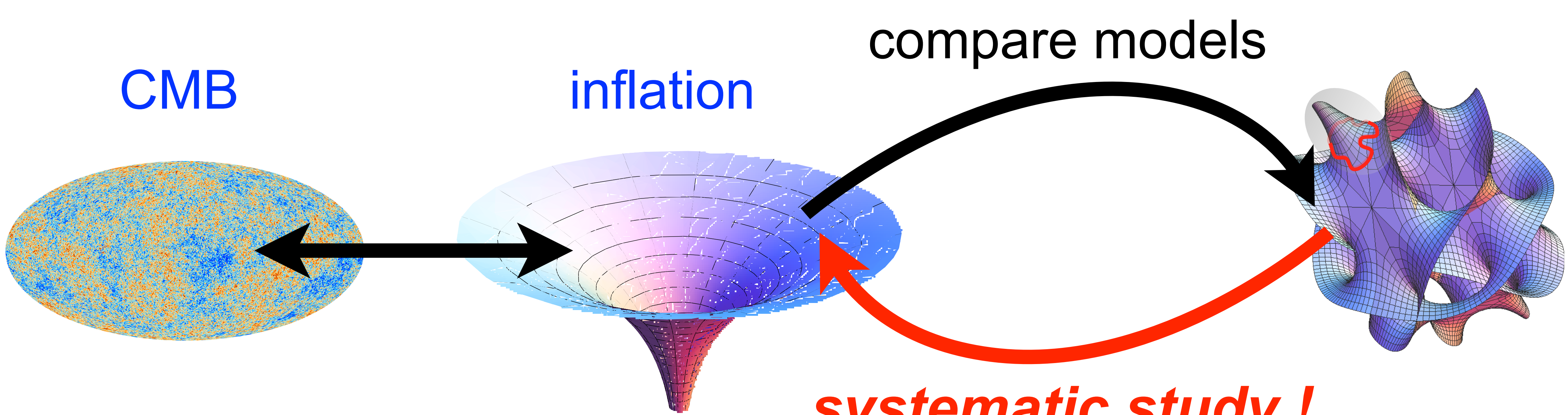
The Goal

- energy scale of inflation – 10^{13} x LHC – close to **Planck Scale** !

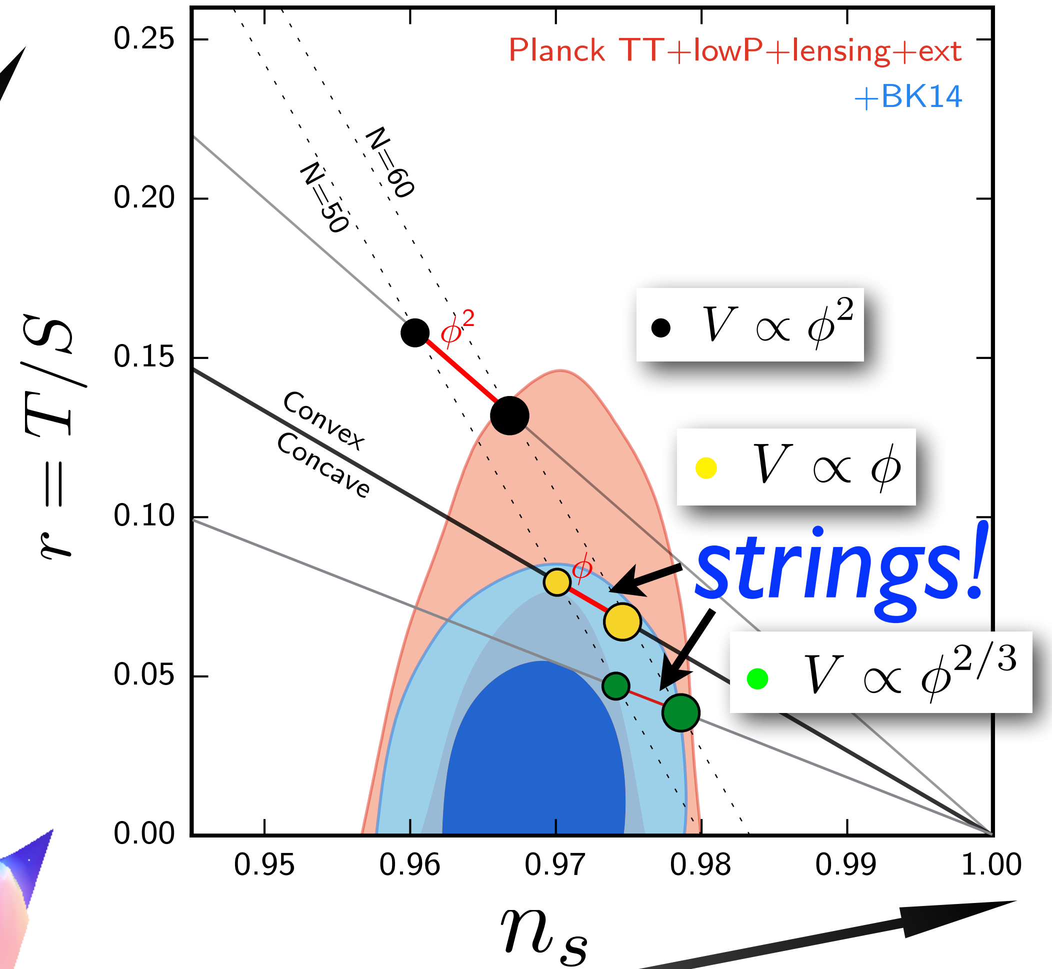
  ➜ unique window to **quantum gravity** !

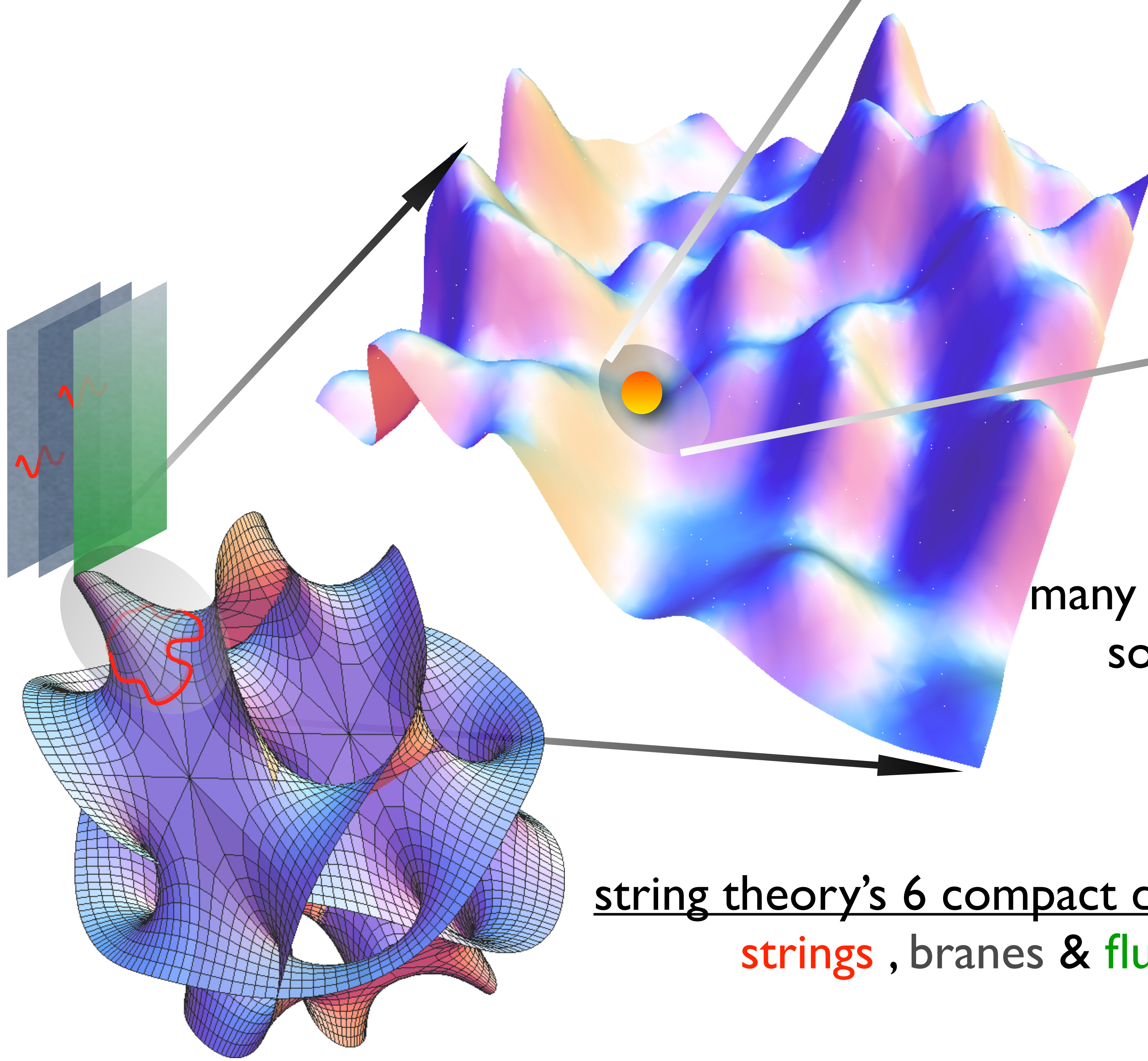
- **proposal:**

  test string theory with inflation & CMB, or relaxation!



test string theory with inflation & CMB



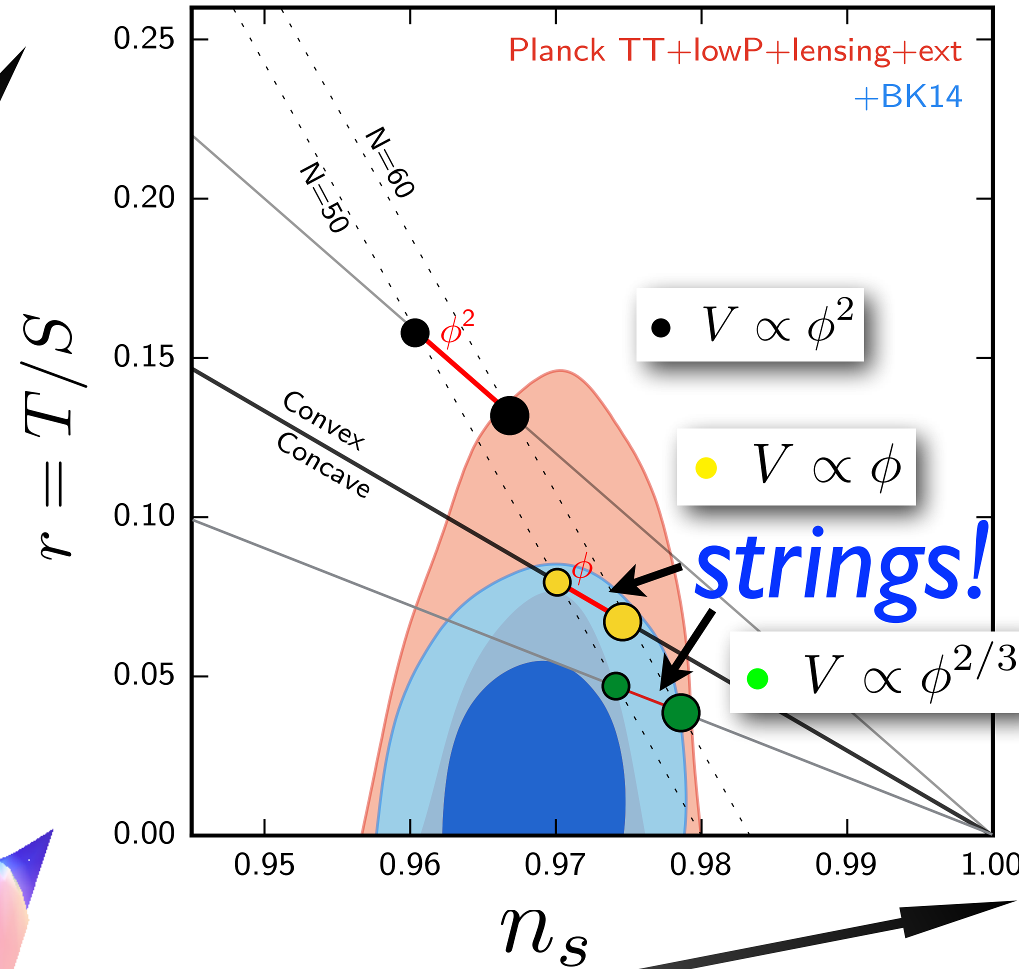


cosmological CMB data

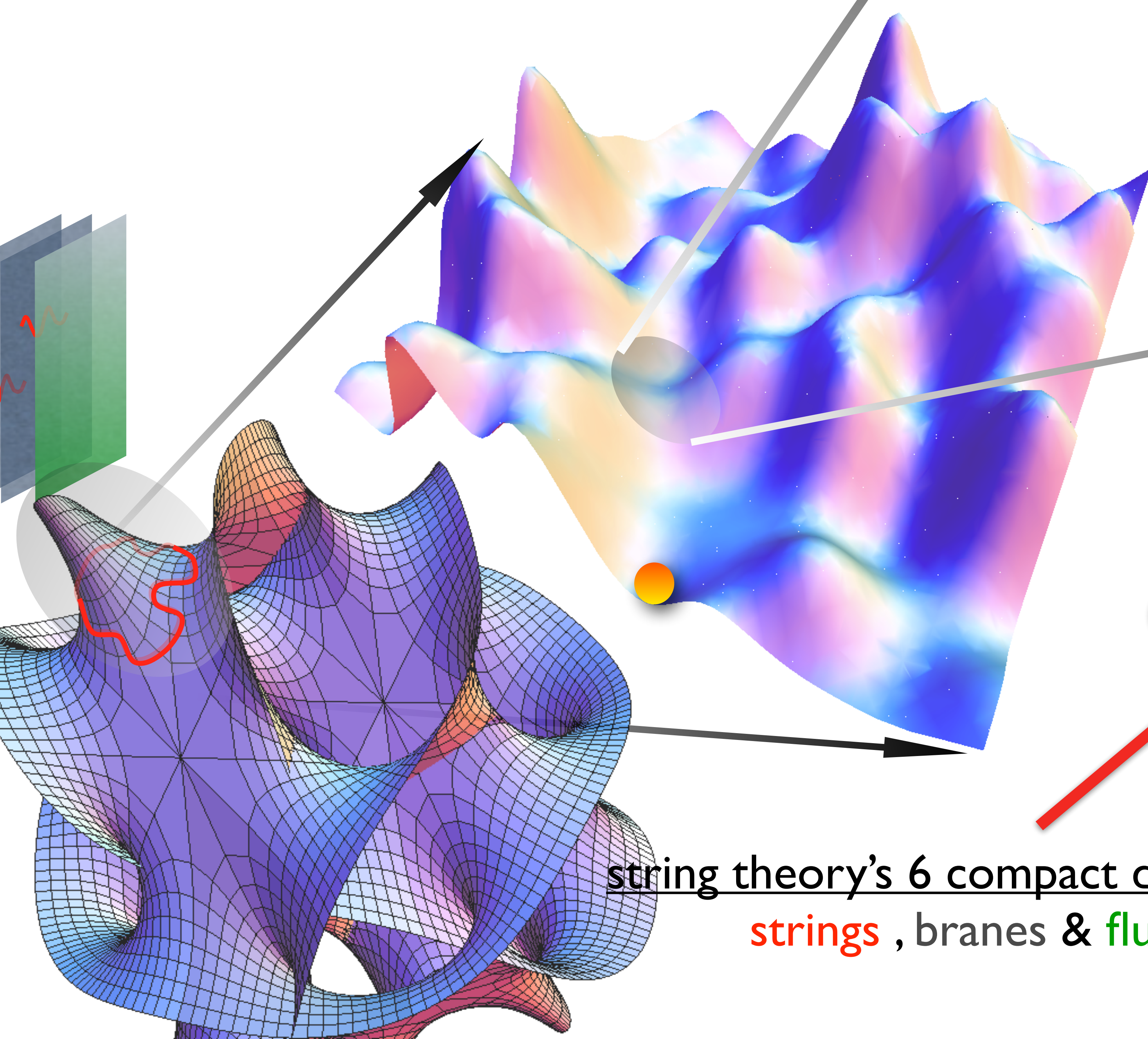
the string theory *landscape*:
many isolated *vacua*, connected by tunneling
some mountain slopes drive *inflation*

string theory's 6 compact dimensions:
strings , branes & fluxes

test string theory with inflation & CMB



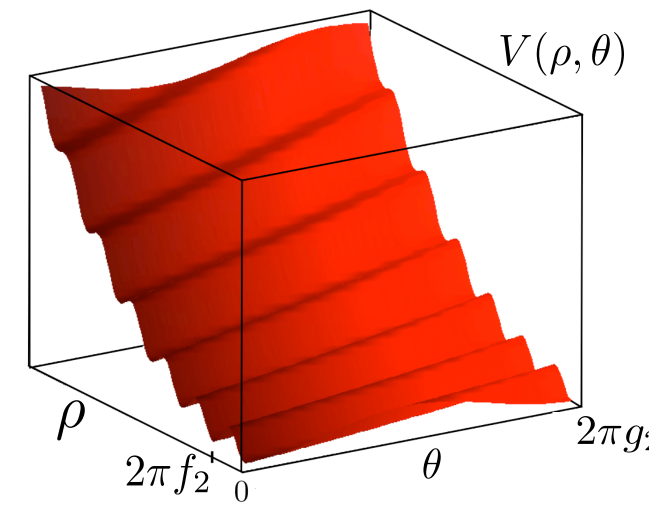
cosmological CMB data



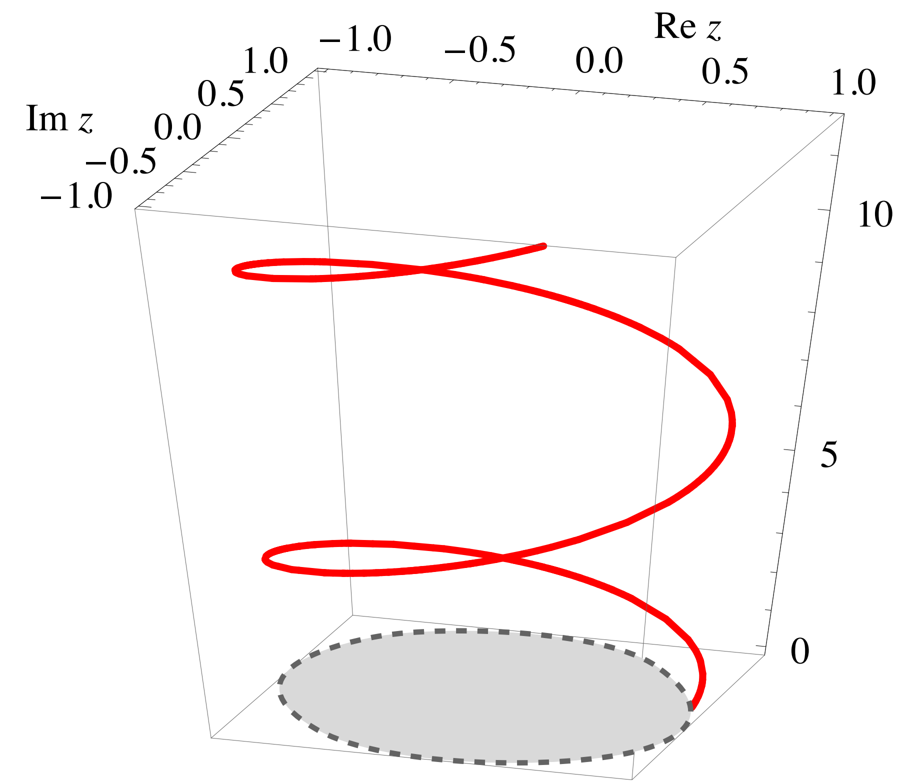
moduli & axions:
light scalars …

string theory's 6 compact dimensions:
strings , branes & fluxes

- string theory — use axions …



crucial scale: f — not M_P !



backreaction at ϕ >> f !

- large fields need functional control

$$\mathcal{L} = (\partial\phi)^2 - V_0(\phi) - \sum_i g^{e_i} \left(\frac{\phi}{M}\right)^{d_i} \quad , \quad d_i > 0 \ , \quad e_i \geq 0$$

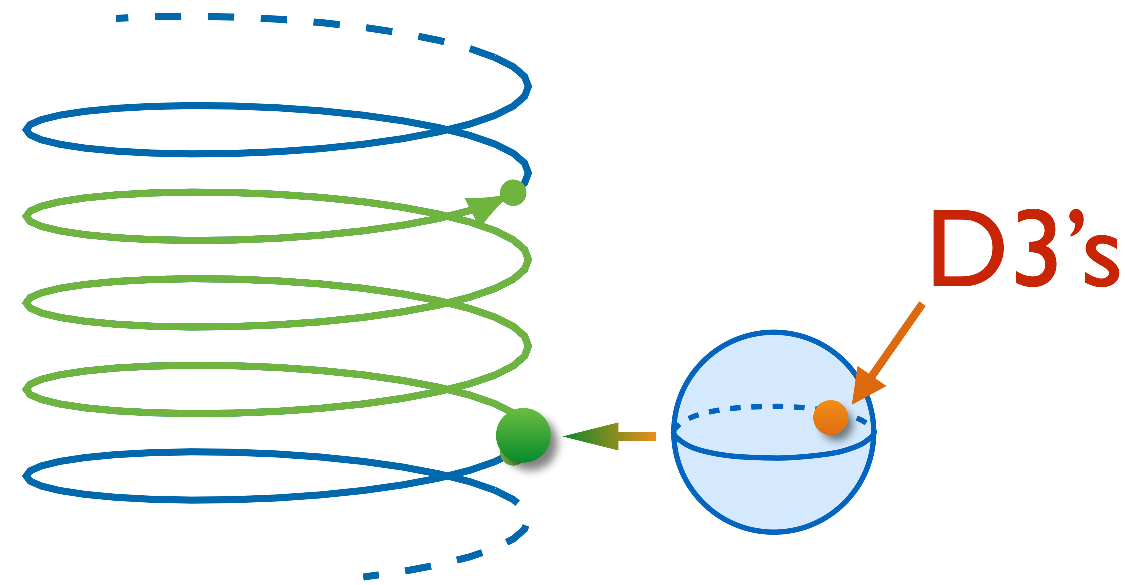
➥ $g \to 0$ limit: know your sequence $\{d_i, e_i\}$!

$e_i = 0$ spells disaster at $\phi >> M$ …

inflation: $$\frac{\phi}{f} = \mathcal{O}(100)$$

relaxions: $$\frac{\phi}{f} \gg 10^6 \qquad \ldots \qquad ??$$

$$\mathcal{L}_Q \sim q \int A_1$$

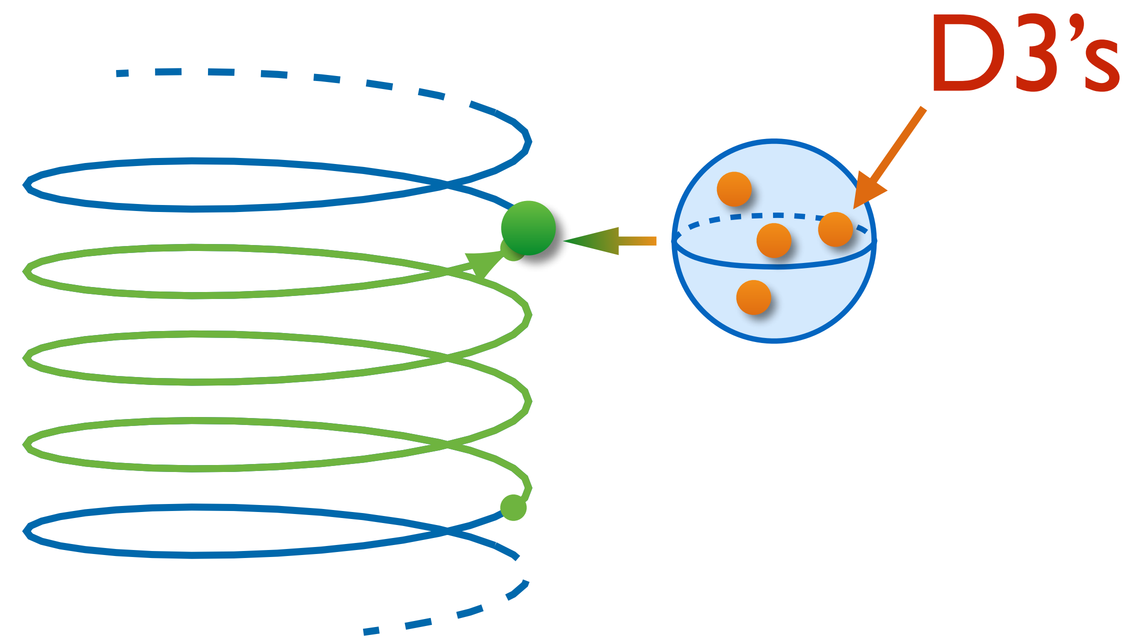


$$\mathcal{L}_Q^{NS5} \sim \int C_2 \wedge C_4 \sim \underbrace{\int_{S^2} C_2}_{q=N_w} \times \int_{\mathcal{M}_4} C_4 \sim N_w \underbrace{\int_{\mathcal{M}_4} C_4}_{\mathcal{L}_Q^{D3}}$$

charge *backreacts* on geometry

— charged vs neutral BH !

$$\mathcal{L}_Q \sim q \int A_1$$



$$\mathcal{L}_Q^{NS5} \sim \int C_2 \wedge C_4 \sim \underbrace{\int_{S^2} C_2}_{q=N_w} \times \int_{\mathcal{M}_4} C_4 \sim N_w \underbrace{\int_{\mathcal{M}_4} C_4}_{\mathcal{L}_Q^{D3}}$$

charge *backreacts* on geometry

— charged vs neutral BH !

- ‘gravity should be weak’

$$\frac{q}{m} > 1$$

[Arkani-Hamed et al. ’06]

since 2014: many follow-ups applying this to large-field axion inflation …

- magnetic WGC

dual coupling: $$\tilde{e} = 1/e$$

monopoles:

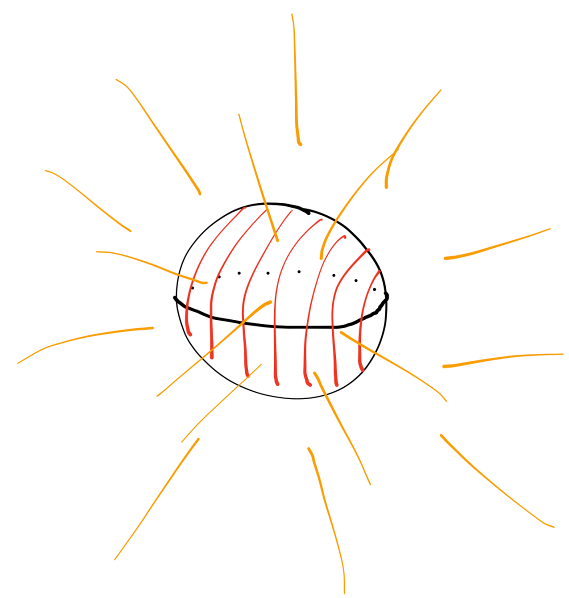
$$m_{mon} \sim \tilde{e}^2 \int_{r_{min}} |F_2|^2 \sim \frac{M}{e^2} \quad , \quad M \sim \frac{1}{r_{min}}$$

- no BH !

$$r_{min} \sim \frac{1}{M} > R_{BH} \sim m_{mon} \sim \frac{M}{e^2}$$

implies EFT cutoff: $M < e$

- string theory:



  - magn. D-brane
  - ! no BH ⟶ EFT cutoff:

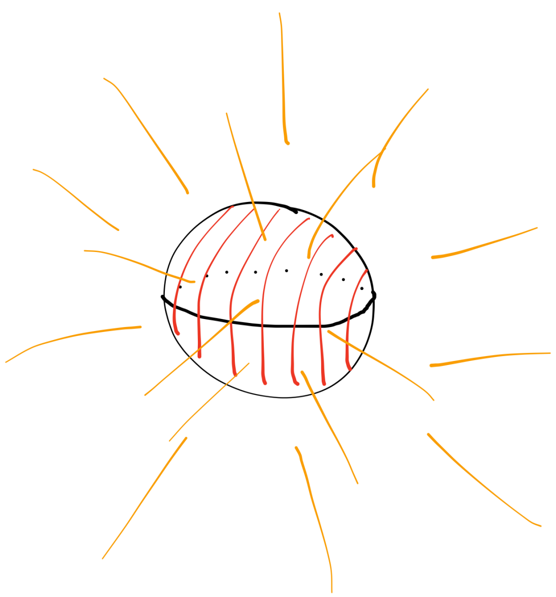
$$\boxed{M < e^{1/(p+1)}}$$

Hebecker, Rompineve & AW '15/'16

- no BH !

$$r_{min} \sim \frac{1}{M} > R_{BH} \sim m_{mon} \sim \frac{M}{e^2}$$

implies EFT cutoff: $M < e$



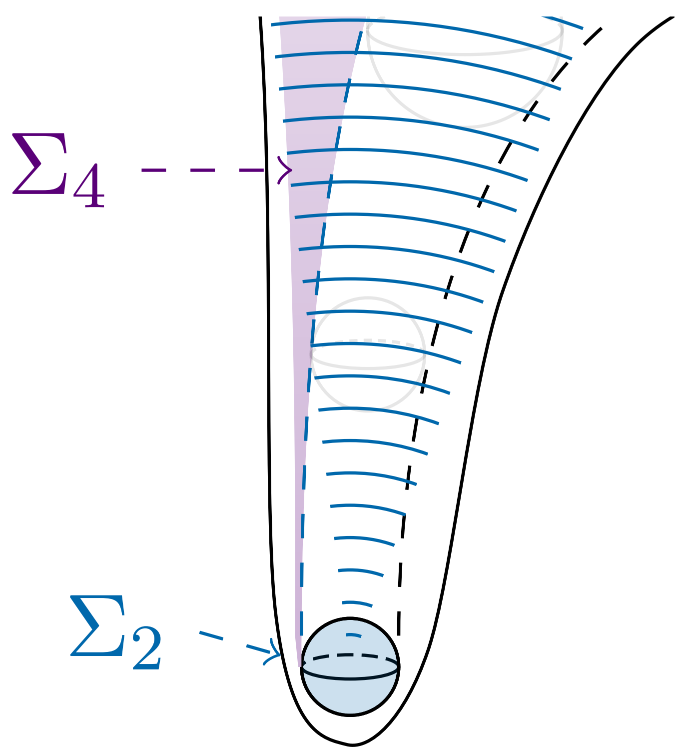
$$\boxed{M < e^{1/(p+1)}}$$

$$\boxed{H \sim m\phi < M < e^{1//3} \sim (mf)^{1/3}}$$

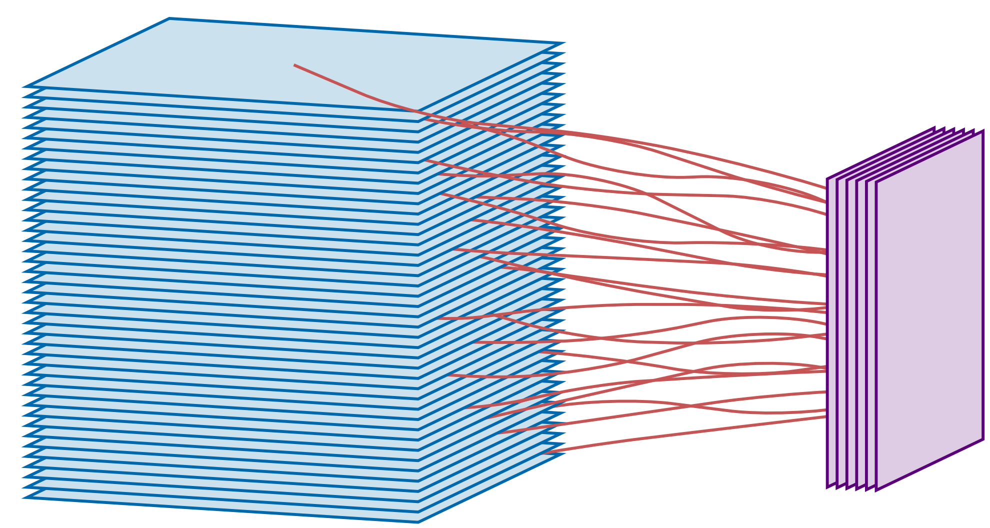
Hebecker, Rompineve & AW '15/'16

monodromy charge N_w is *physical* — backreacts

closed string picture:



open string picture:

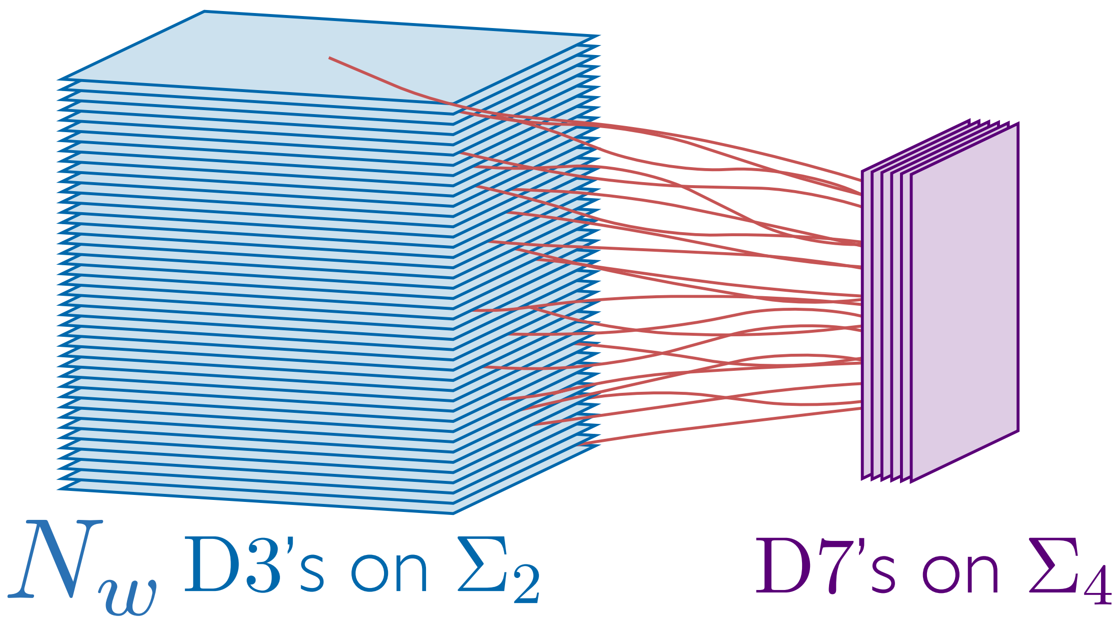


N_w D3's on Σ_2 D7's on Σ_4

$$\delta e^{-4A} \sim N_w \quad \longleftrightarrow \quad \delta g_{\rm YM}^{-2} \sim N_w$$

McAllister, Schwaller, Servant, Stout & AW '16

light & *charged* 3-7 string for every unit of N_w !



$$\delta\left(\frac{1}{g_{\rm YM}^2}\right)_{1-loop} \sim N_{3-7} = N_w$$

McAllister, Schwaller, Servant, Stout & AW '16

So ...

$$N_w \gtrsim 10^6 \quad , \quad c \sim 1/(2\pi)$$

$$\Lambda_c^3 \langle h \rangle \cos(\phi/f) \quad : \quad \Lambda_c^3 \sim e^{-\frac{1}{g_{YM}^2}} \to e^{-\frac{1}{g_{YM}^2} - cN_w} \to 0$$

Relaxions Run Away !

McAllister, Schwaller, Servant, Stout & AW '16

So ...

$$N_w \lesssim 100 \quad , \quad c \lesssim 1/(2\pi)$$

$$\Lambda_c^3 \cos(\phi/f) \quad : \quad \Lambda_c^3 \sim e^{-\frac{1}{g_{YM}^2}} \to e^{-\frac{1}{g_{YM}^2} - cN_w} \to finite!$$

Inflations proceeds - sometimes ...

McAllister, Schwaller, Servant, Stout & AW '16