Peculiar obstructions in string vacua and cosmology

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Based on:
- **arXiv:1812.11909 - PRD 100, 066009, 2019;**

See also:
- arXiv:1705.11071 - PRD 96, 083529, 2017;
- arXiv:1910.06233;

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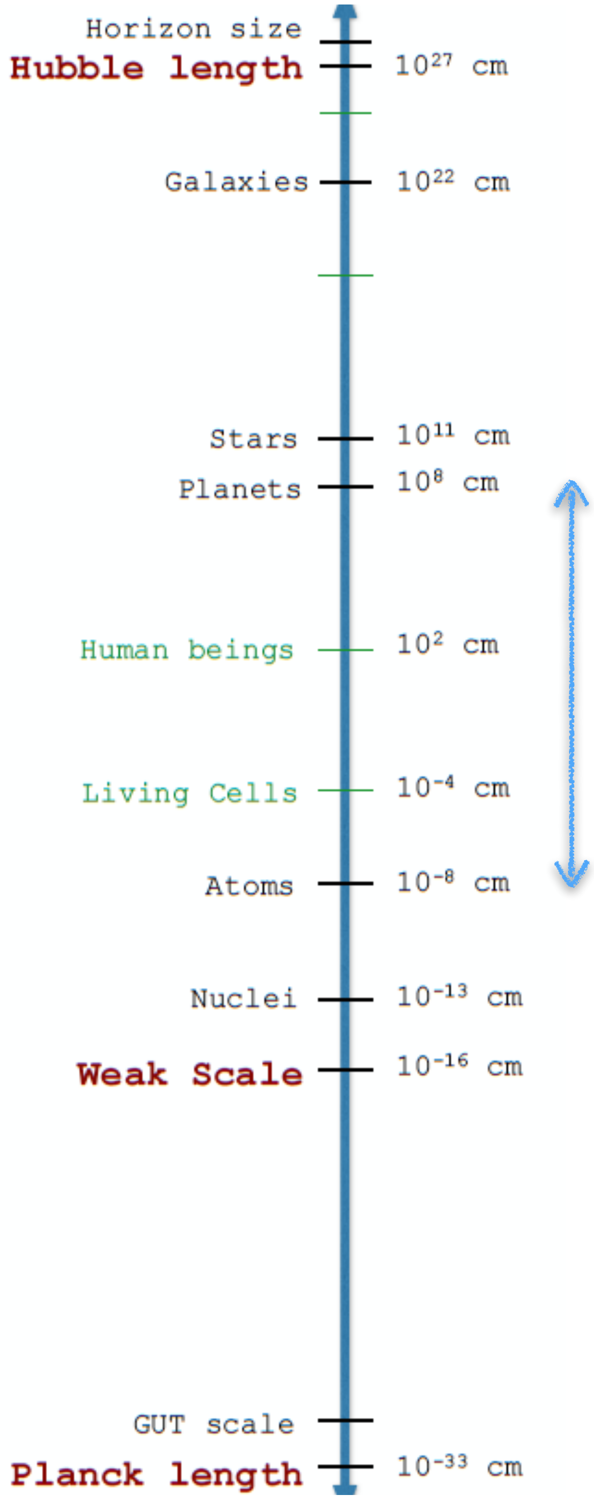
Introduction

Fundamental physics...

General relativity: spacetime

Quantum Field Theory: elementary particles

- The standard model of elementary particle physics (QFT),
- The standard model of cosmology (GR + QFT).



The Standard Model of particles

(1) Spacetime symmetry:

- ✦ Spacetime symmetry group is Poincare group,
- ✦ All fields irreducible representation of Lorentz group,
- ✦ Allow only spins 0, 1/2 and 1;

(2) Internal symmetry:

- ✦ SM is a gauge theory (local, continuous internal symmetries),
- ✦ Internal (gauge) symmetry group: $SU(3) \times SU(2) \times U(1)$
- ✦ Thus, spin 1 gauge fields in adjoint representation;

(3) Spinors:

- ✦ Left Handed Weyl fermions in three copies of the representation

$$(3, 2, +\frac{1}{6}) \oplus (\bar{3}, 1, -\frac{2}{3}) \oplus (\bar{3}, 1, +\frac{1}{3}) \oplus (1, 2, -\frac{1}{2}) \oplus (1, 1, +1)$$

(4) Scalar:

- ✦ A complex scalar in representation

$$(1, 2, -\frac{1}{2})$$

(5) Lagrangian:

- The most general, consistent with symmetries,
- Ensure that EW symmetry is spontaneously broken,
- Only one dimension-full parameter: weak scale.

The Standard Model of Cosmology

At early enough times (T ~ few MeV)

(1) Gravity: General Relativity
(2) To leading order: spacetime geometry is spatially flat FRW metric (space-like hypersurfaces: homogeneous, isotropic, spatially flat),
(3) Matter
  - Dark Matter: cold, collisionless,
  - cosmological constant (with a very tiny value: $\ell_{\rm Pl}^2 \Lambda \approx 3 \times 10^{-122}$),
  - SM particles: photons, neutrinos (and anti-neutrinos), electrons (and positrons), protons and neutrons
(4) Initially,
  - baryon to photon ratio is $\mathcal{O}(10^{-9})$
  - asymmetry in neutral leptons negligible
  - asymmetry in charged leptons s.t. the net electric charge is zero.
(5) At sub-leading order: scalar metric perturbations:
  - adiabatic,
  - Gaussian
  - nearly scale-invariant (tilted red)

New fundamental physics?

* Neutrino masses
* Baryon Asymmetry
* Dark Matter
* Dark Energy
* Inflation
* vacuum stability

* UV sensitivity (SM Higgs, Vacuum energy, inflation),
* strong CP problem,
* the flavour problem,
* precision electroweak constraints,
* Why this gauge group?
* Why 3 generations?
* Why 1+3 spacetime dimensions?
* Broadly: why the SM and cosmological parameters have the values they have?

* graviton-graviton scattering at Planck scale,
* Resolving the gravitational singularities,
* UV finiteness?
* Hints from BH physics? e.g. holography, information loss paradox, calculation of entropy of BHs from microphysics;
* Other lessons: given GR and QM, no operational way to measure length scales smaller than Planck length etc.

The “Standard Model” of Cosmology

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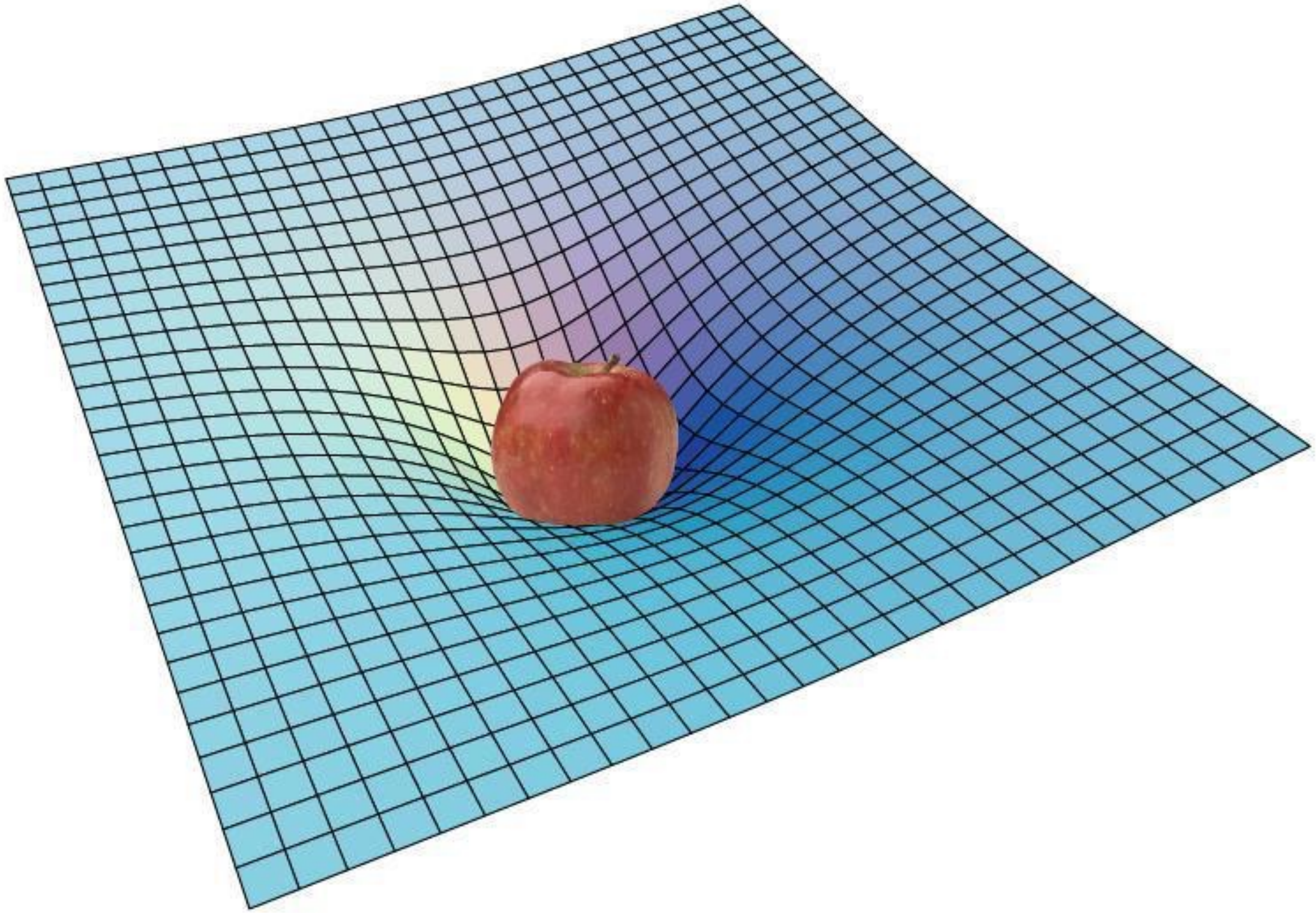
(5) At sub-leading order: scalar metric perturbations:

- **adiabatic,**
- **Gaussian**
- **nearly scale-invariant (tilted red)**

Why this geometry?



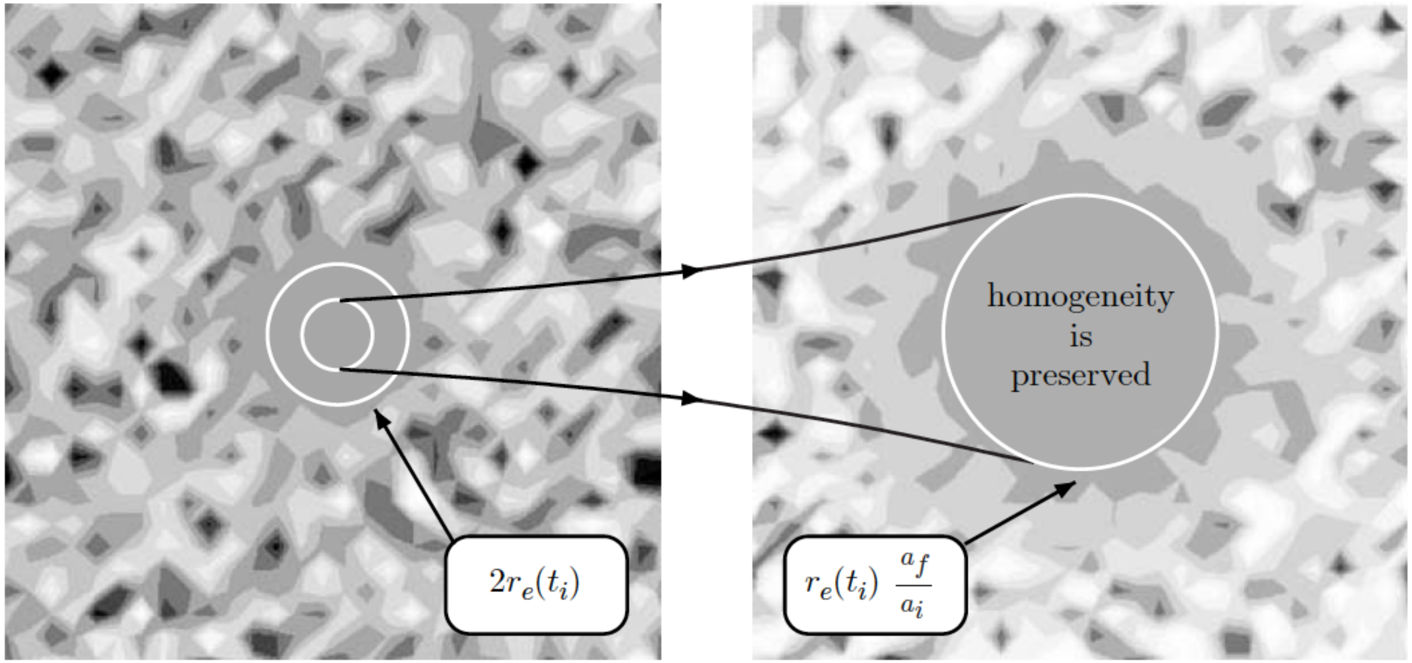
Why do we find ourselves in a spatially flat FRW (homogeneous and isotropic spacetime)?

From microphysics…

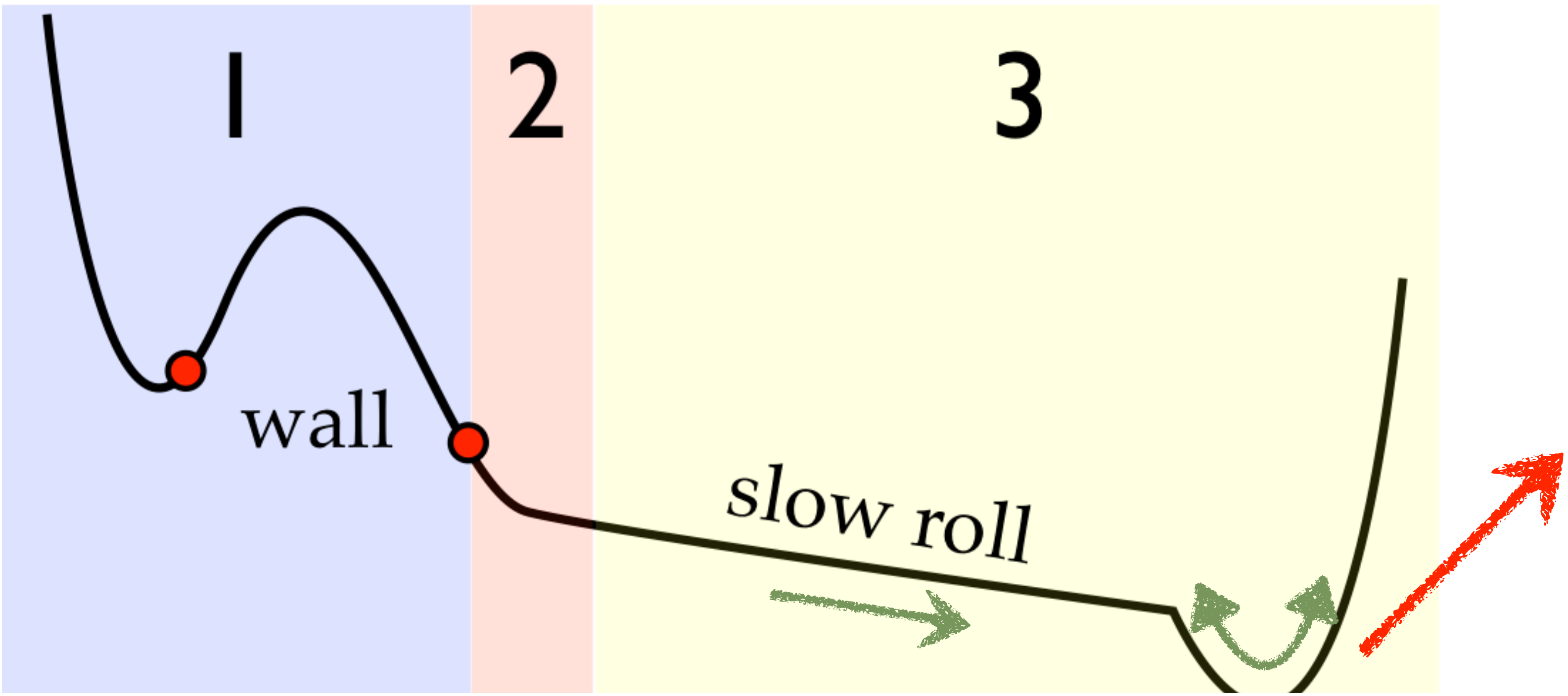
Every realistic microscopic theory is specified by…

- ⋆ Gauge group,
- ⋆ Representation of fermions,
- ⋆ Representation of scalars, and,
- ⋆ **the Scalar Potential**

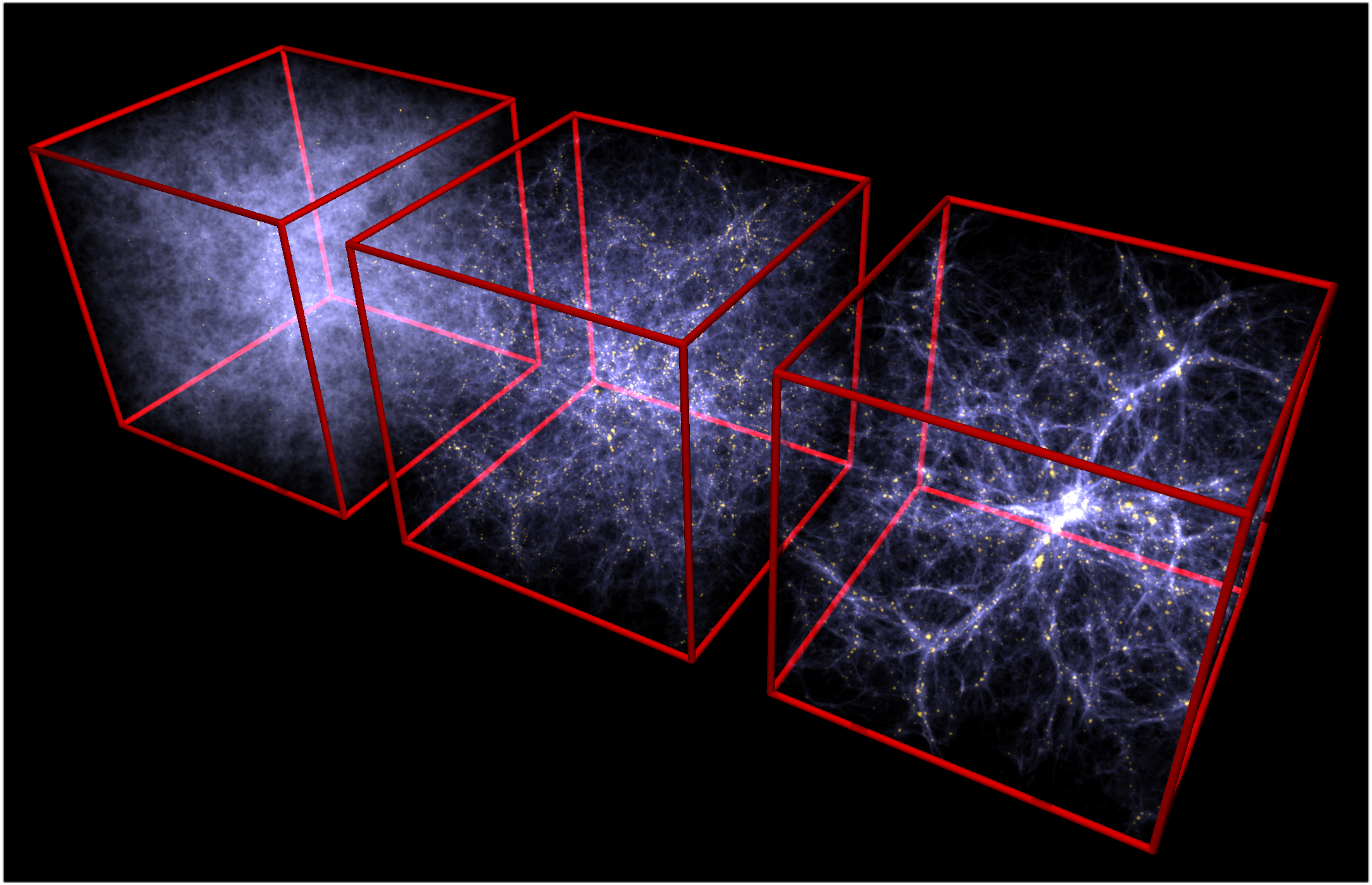
Cosmic inflation

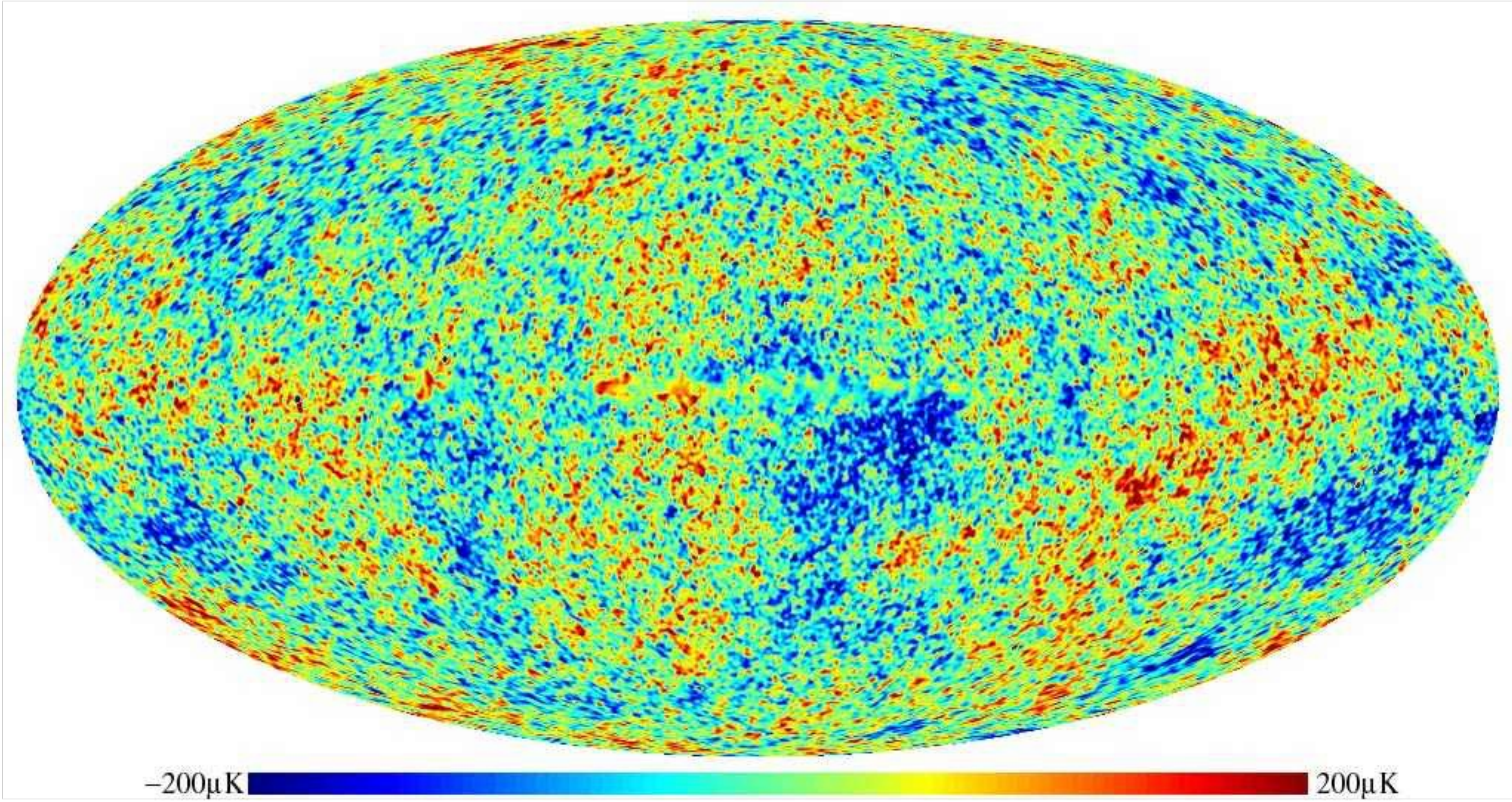


<u>Additionally:</u> why perturbations of the kind posited in SM!

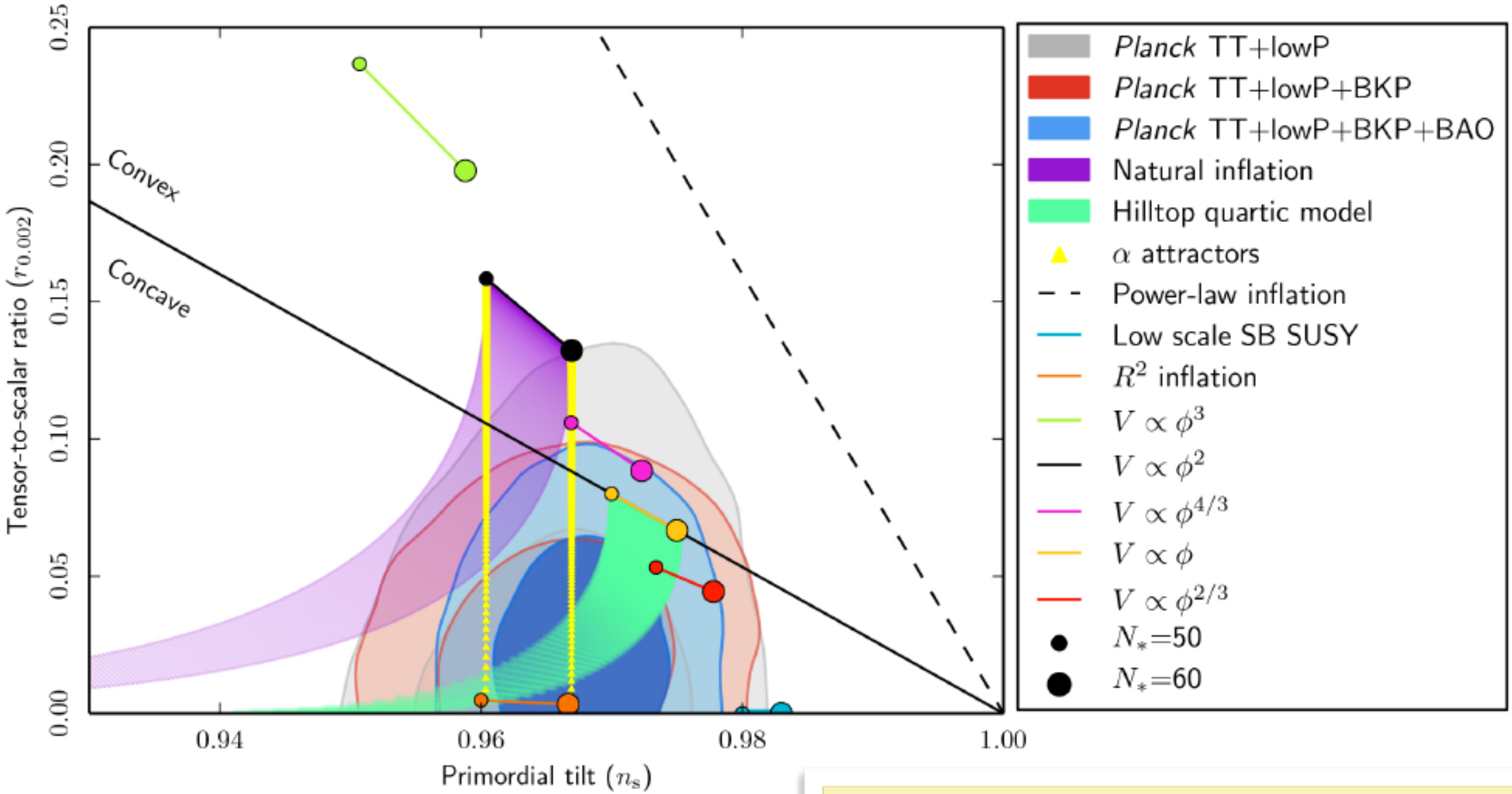


Hot
Big Bang!




−200μK
200μK

Large field inflation



$$\Delta_\zeta^2(k) = A_s \left(\frac{k}{k_p}\right)^{n_s - 1}$$

$$r = \frac{A_t}{A_s}$$

Negligible:

- **running,**
- **non-Gaussianity,**
- **non-adiabatic perturbations etc.**

Too many models?

Some conceptual issues

UV sensitivity of inflaton potential

$$\varepsilon = \frac{M_{\rm pl}^2}{2}\left(\frac{V'}{V}\right)^2 \ll 1$$

$$\eta = M_{\rm pl}^2 \frac{V''}{V} \ll 1$$

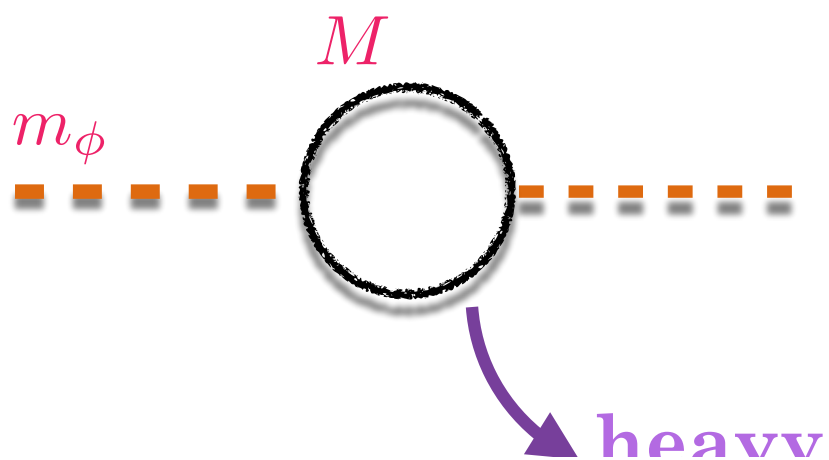
$$H^2 \approx \frac{V(\phi)}{3M_{\rm Pl}^2}$$

Why is the inflaton so light ?

$$\eta \approx \frac{m_\phi^2}{H^2} \ll 1$$

The eta problem

$$m_\phi^2(\mu = M) \approx m^2(\mu = M) + \frac{\# g^2}{16\pi^2} M^2$$



$$\delta m_\phi^2 \sim g^2 M^2$$

Why is the inflaton potential so flat?

UV sensitivity

(+4290)

\+ (-46732189437128946372819789 23)

\+ (+47583920542)

\+ (+74583921578290132781905478 25)

\+ (-321)

+(UNKNOWN, BUT LARGE CONTRIBUTIONS)

= ORDER (1) NUMBER E.G. 3

Possible but extremely peculiar!

UV sensitivity is ubiquitous...

Higgs mass

$$\delta m_H^2 \sim \alpha_{\rm GUT} M_{\rm GUT}^2$$

Vacuum energy

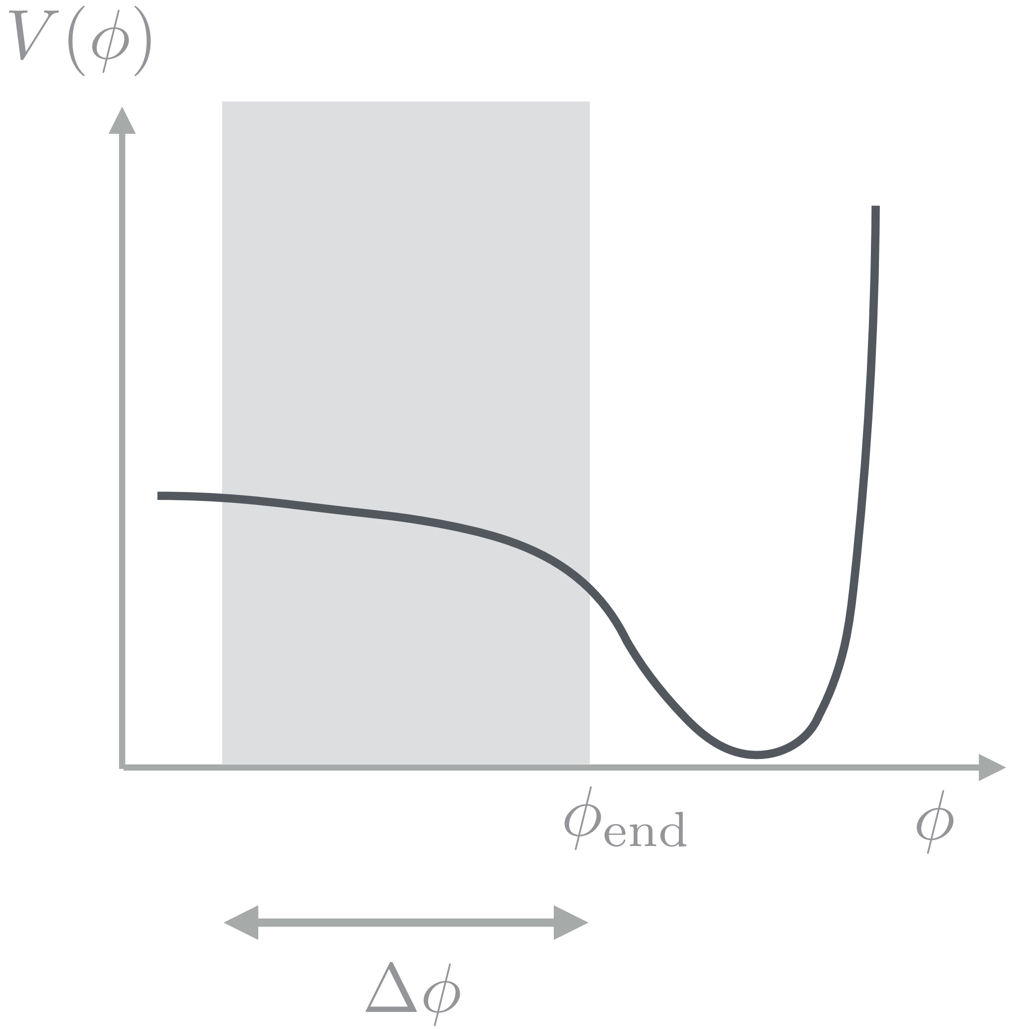
boson

$$\langle \rho \rangle_{\rm vac} = \pm\ s\ \frac{m^4}{16\pi^2} \ln\left(\frac{m^2}{\mu^2}\right)$$

fermion

helicity

Lyth bound and future CMB observations...



$$\frac{\Delta\phi}{M_{\rm Pl}} \approx \left(\frac{r}{0.01}\right)^{1/2}$$

Current observational bound:

$r < 0.064$

In future, the bounds will get tighter.

Planckian field excursion!

Wilsonian effective theory

Specify:

- Symmetries and field content,
- UV cut-off and Wilson coefficients.

$$\mathcal{L}_{\text{eff}}[\phi] = \mathcal{L}_{\ell}[\phi] + \sum_{i=1}^{\infty} c_i \frac{\phi^{4+2i}}{\Lambda_0^{2i}} + d_i \frac{(\partial\phi)^2 \phi^{2i}}{\Lambda_0^{2i}} + e_i \frac{(\partial\phi)^{2(i+1)}}{\Lambda_0^{4i}} + \cdots \,,$$

- Low energy experiments, irrelevant operators,
- Relevant operators sensitive,
- Inflaton rolls beyond the cut-off!
- How come the later terms not important?
- Symmetries of UV theory could be helpful.

Why large field inflation?

- Simple potentials,
- No tuning of initial field value and time derivative,
- Testable (in near future).

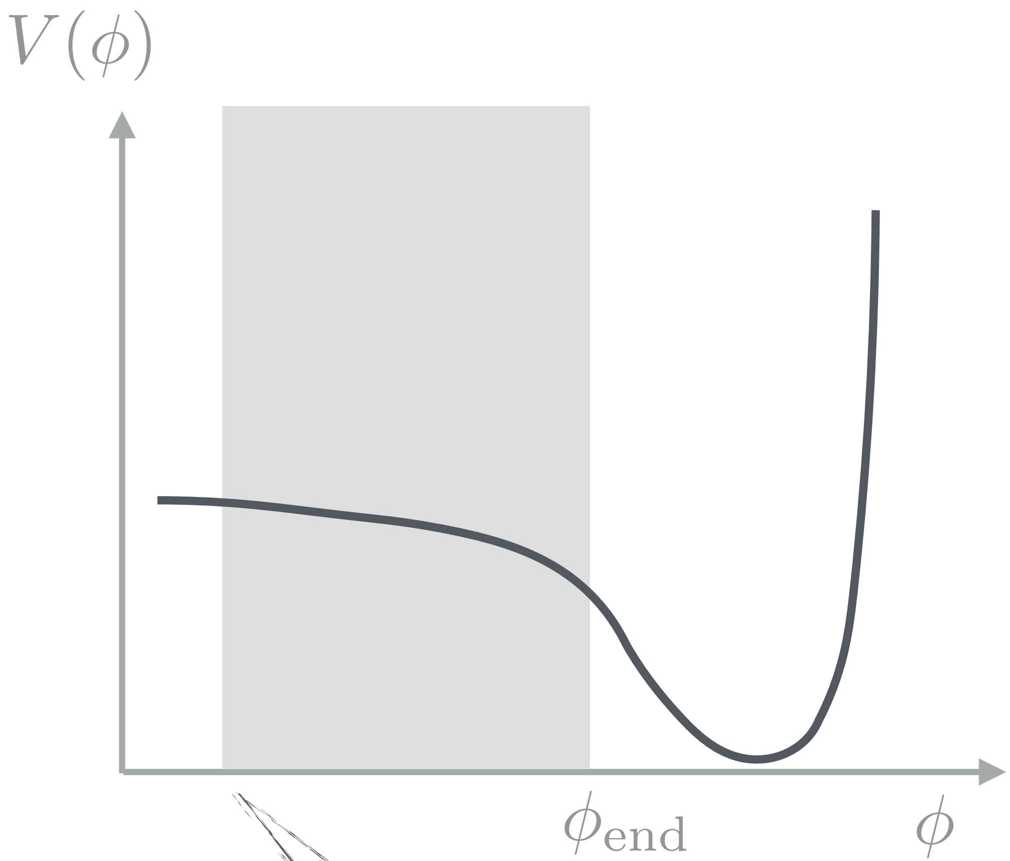
$$\frac{V^{1/4}}{M_{\rm Pl}} \approx 10^{-2} \left(\frac{r}{0.1}\right)^{1/4}$$

For inflaton charged under a gauge symmetry...

- field value and potential gauge dependent: how trustworthy is Wilsonian argument?
- Vacuum energy is gauge independent

What could possibly go wrong?

New particles below the cut-off!



The effective theory contains only inflaton and gravity

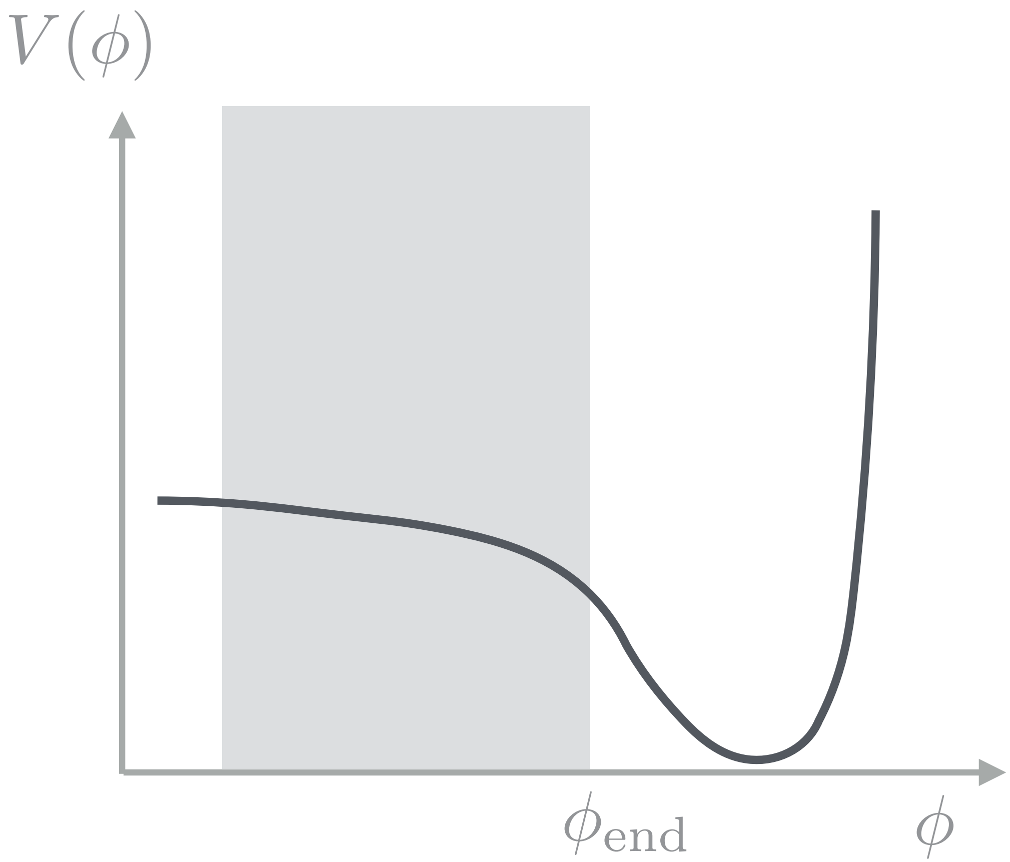
$$\mathcal{L} \supset y\bar{\psi}\psi\phi$$

$$M_n^2 = M^2 + \frac{n^2}{R^2}$$

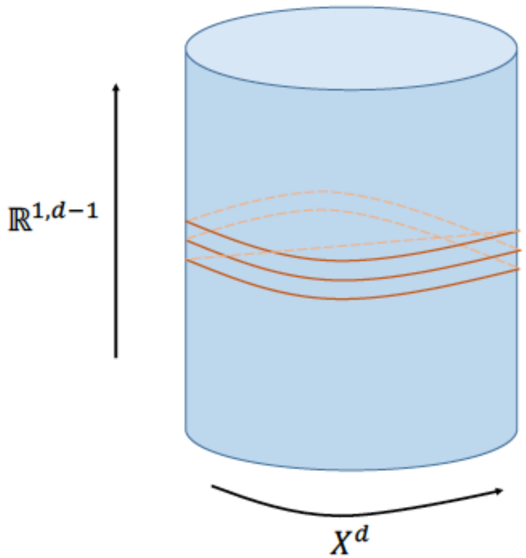
$$2\pi R = \int_0^1 \sqrt{g_{55}}\, dx^5$$

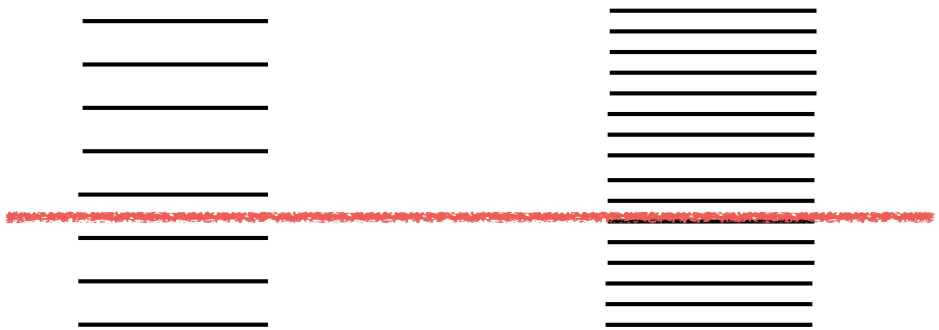
scalar under 4D transformations

Quantum Gravity issues?

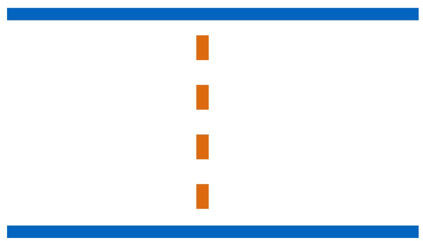


$$M^2_{n,w} = \left(\frac{n}{R}\right)^2 + \left(\frac{wR}{\alpha'}\right)^2$$





Inflaton could mediate a force weaker than gravity!



$$M_\psi \sim y\phi$$

$$F_s \sim g^2$$

$$F_g \sim \frac{(g\phi)^2}{M^2}$$

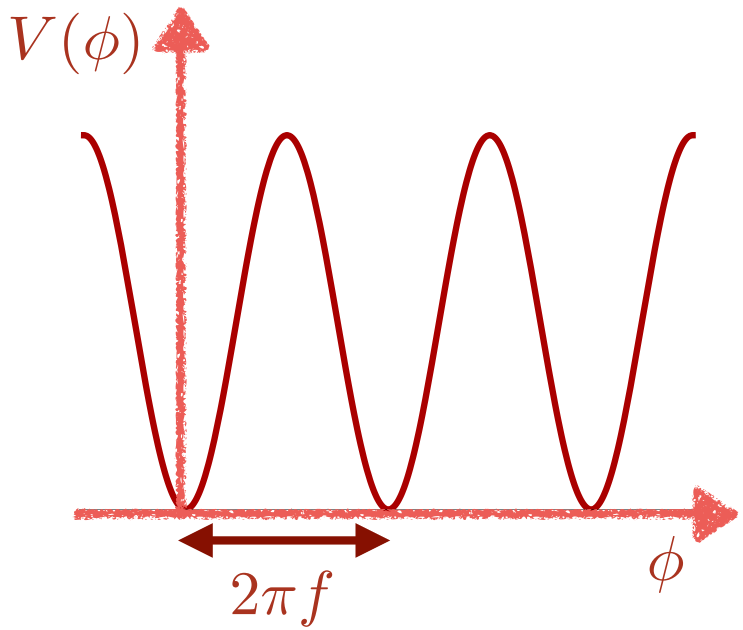
Punchline...

- Future observations would put tight constraints on large field inflation,
- Inflation appears to be a sensible mechanism,
  - But harder to come up with concrete models,
- Large field inflation is
  - trivial if one does it carelessly,
  - almost impossible if one does it carefully.

Kim-Nilles-Peloso (KNP) Mechanism in QFT

Axion potential

$$\langle\theta'|H|\theta\rangle = 4\pi\delta(\theta-\theta')\left[\sum_{n=1}^{\infty} e^{-nS_1}\cos n\theta\right] + \text{const} \qquad \theta \to \frac{\phi}{f}+\pi$$



$$V(\phi) = \Lambda_1^4 \sum_{n=1}^{\infty} e^{-nS_1}\left[1-\cos\left(\frac{n\phi}{f}\right)\right]$$

$$S_1 \gg 1 \qquad V(\phi) = \Lambda^4\left[1-\cos\left(\frac{\phi}{f}\right)\right]$$

- Compact field space,
- Natural inflation: axion is the inflaton,
- For large f, large field inflation, typically, f is Planckian

Global symmetries

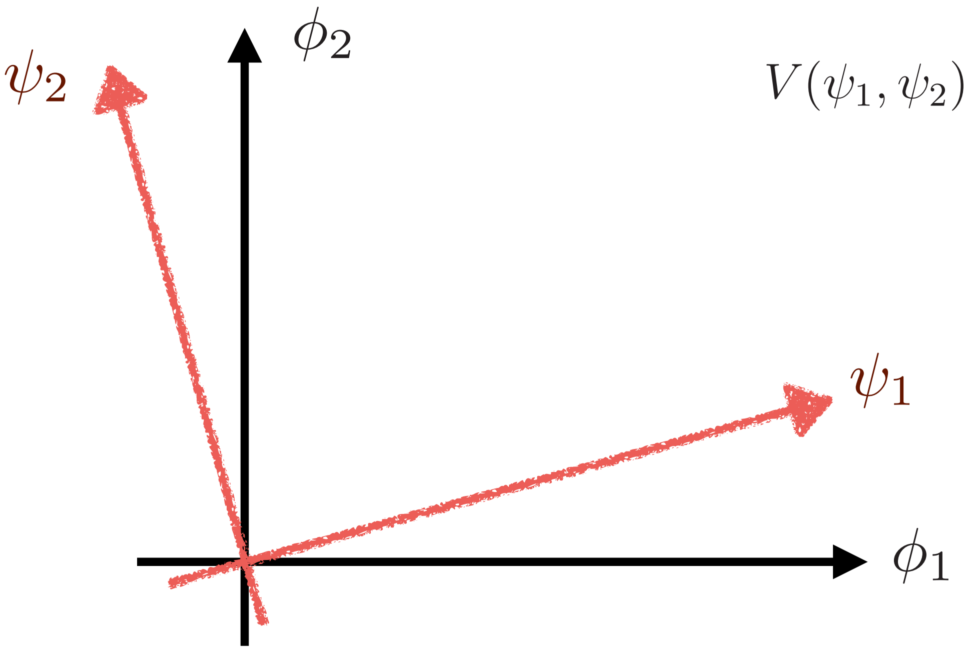
- Natural inflation: axion is a PNGB of a spontaneously broken (and anomalous) global U(1) symmetry,
- Super-Planckian f could be untrustworthy,
  - No continuous global symmetries in QG,
  - Gravitational instantons?
  - When f can be deduced from QG, it is sub-Planckian.

$$S_{\rm gravity} = \frac{nM_p}{f} \implies \delta V \sim e^{-S_{\rm gravity}}$$

KNP mechanism

$$V(\phi_1,\phi_2) = \sum_{i=1}^{2} \Lambda_i \left(1 - \cos\left[\frac{\phi_1}{f_i} + \frac{\phi_2}{g_i}\right]\right),$$

$$\psi_1 = \frac{g_1\,\phi_1 + f_1\,\phi_2}{\sqrt{f_1^2 + g_1^2}}\,, \quad \psi_2 = \frac{f_1\,\phi_1 - g_1\,\phi_2}{\sqrt{f_1^2 + g_1^2}}\,,$$



$$V(\psi_1,\psi_2) = \Lambda_1 \left(1 - \cos\left[\frac{\psi_1}{f_1'}\right]\right) + \Lambda_2 \left(1 - \cos\left[\frac{\psi_1}{f_2'} + \frac{\psi_2}{f_{\rm eff}}\right]\right)$$

$$f_{\rm eff} = \frac{f_2\,g_2\,\sqrt{f_1^2 + g_1^2}}{|f_1\,g_2 - g_1\,f_2|}\,.$$

$$f_1' = \frac{f_1 g_1}{\sqrt{f_1^2 + g_1^2}}, \qquad f_2' = \frac{f_2 g_2 \sqrt{f_1^2 + g_1^2}}{f_1 f_2 + g_1 g_2},$$

$$m_{\psi_1}^2 \simeq \Lambda_1 \left(\frac{1}{f_1^2} + \frac{1}{g_1^2}\right), \quad m_{\psi_2}^2 \simeq \frac{\Lambda_2\,(f_2\,g_1 - f_1\,g_2)^2}{g_2^2\,f_2^2\,(f_1^2 + g_1^2)}$$

$$\overline{\psi}_1 = 0$$

Kim-Nilles-Peloso (KNP) Mechanism in string theory

Four dimensional vacua

- Just like GR: no prior geometry (different solutions have different geometry),
- String propagation on a slightly curved background:
  - Einstein equations + small corrections,
- Product manifold:
  - E.g. Cylinder, torus etc;
- Vacuum solution of ten dimensional equations: “maximally symmetric spacetime times a six dimensional compact manifold”

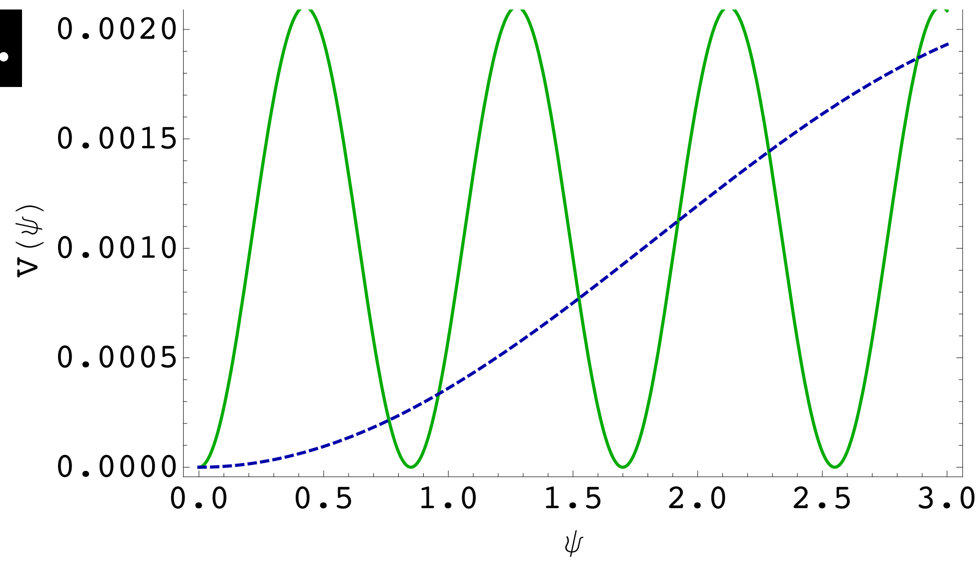
Scalar fields

- **Geometric moduli:**
  - Kahler moduli: size of extra dimensions
  - Complex structure moduli: shape of the extra dimensions,
- How many?
    - topology of the manifold (Hodge numbers),
- **Axions:**
  - scalars from zero modes of higher form potentials turned on in extra dimensions,
  - no energy cost
- No potential (to begin with),
- The values of these fields need to be fixed: potential;

Fluxes

- Turn on field strength of higher form potentials in extra dimensions,
  - some energy cost,
- Generates a potential for some scalar fields,
- fluxes are quantized,
- Topology determines how many different kinds of fluxes possible.

Well controlled constructions...



$$V(\phi) = A\left[1 - \cos\left(\frac{\phi}{f}\right)\right]$$

- Quantity f to be deduced (e.g. axion decay constant, vacuum energy etc);
- A typical calculation: $f = f_0 + f_1 + f_2 + \cdots\ ,$
- Successive terms: smaller (additional factors of small quantities);
  - both perturbative and non-perturbative contributions,
- all terms till f_i are known, the subsequent ones are unknown, are they small?
- Necessary condition: $g_s \ll 1 \qquad \alpha'^3/\mathcal{V}_6 \ll 1$
- Is it sufficient?

Beyond trustworthy regimes?

Natural inflation???

- Whenever we can deduce f, making it Planckian also takes us out of the trustworthy regime e.g. small volumes etc.

Extra natural inflation???

$$R g_{4D} M_p \ll 1 \qquad M_p^2 \sim g_s^{-2} M_s^8 V_6 \qquad S_{\rm gauge} = \frac{1}{\alpha'^3} \int d^{10}x \sqrt{-G} e^{-\phi} |F_2|^2$$

$$g_{4D}^2 \sim \frac{g_s}{V_6 M_s^6} \qquad g_s^{-1/2} M_s R \ll 1 \qquad g_s^{-1/2} \gg 1 \qquad R \ll \ell_s$$

Supergravity

- 10 D supergravity to 4 D supergravity,
- Kahler potential, super potential and scalar potential

$$\mathcal{L} = K^{i\bar{j}} \partial_\mu \phi_i \partial^\mu \phi^\dagger{}_{\bar{j}} - V_F$$

$$K_{i\bar{j}} = \frac{\partial^2 K}{\partial \phi_i \partial \bar{\phi}_{\bar{j}}}$$

$$V_F = e^{\frac{K}{M_p^2}} \left[K^{i\bar{j}} D_i W D_{\bar{j}} \bar{W} - \frac{3|W|^2}{M_p^2} \right] ,$$

$$D_i W = \partial_i W + \frac{W \partial_i K}{M_p^2}$$

$$U_\lambda = u_\lambda + i\nu_\lambda$$

$$S = s + i\sigma$$

Type IIA flux vacua

- Type IIA string theory, type IIA supergravity,
  - Massive type IIA supergravity,
- Just using the ingredients mentioned, all geometric moduli get fixed,
- A linear combination of RR axions get fixed,
- Additional ingredient: Euclidean D2 brane instanton (next slide):
  - all moduli can be fixed,
- Supersymmetric AdS vacua easy to find,
- dS vacua much harder (don't exist?),
- Study large field excursion in this toy set up;

Non-perturbative ingredient

- instanton-like contribution to the path integral,
- semiclassical approximation: action of an "Euclidean Dp-brane"
- branes: soliton-like objects in string theory,
- Dp-branes charged under certain (p+1)-form fields

$$\mathcal{A} \sim e^{-S_E}$$

$$\mathcal{A} \sim e^{\left[-\left(\frac{\mu_2}{g_s}\int_{\Sigma_3} d^3x\sqrt{\det(G)}+i\mu_2\int_{\Sigma_3} C_3\right)\right]}$$

$$\mathcal{A} \sim e^{-T_p \mathrm{Vol}(\Sigma_3)+i\mu_2\int_{\Sigma_3} C_3}$$

$$V(\phi) \sim e^{-S_1}\cos(a)$$

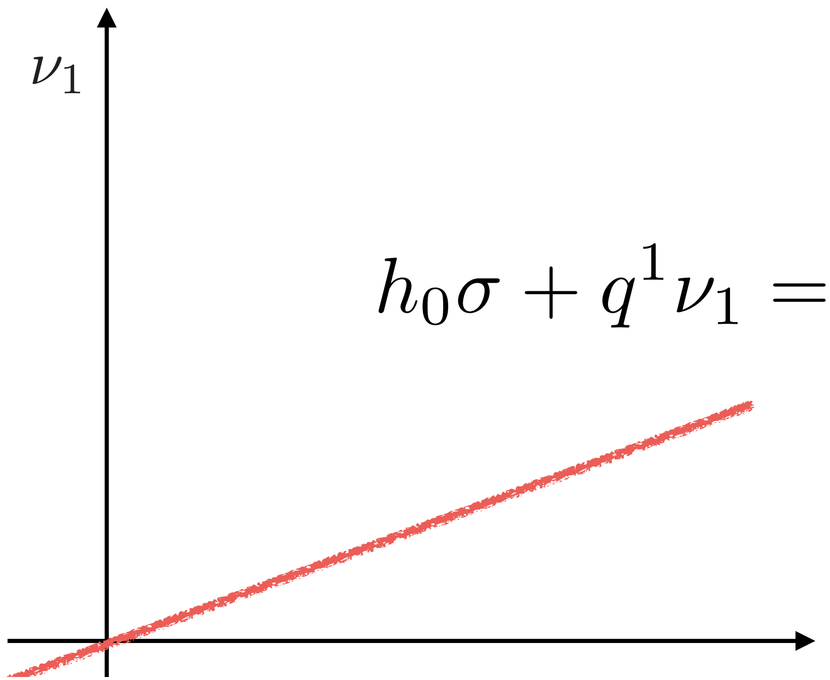
Low energy theory of axions and instantons

- Choose appropriate instanton,

$$\mathcal{L} = -\ f_\sigma^2(\partial\sigma)^2 - f_{\nu_1}^2(\partial\nu_1)^2 - \Big[V_0 + A' e^{-s}(1-\cos\sigma) + B' e^{-u_1}(1-\cos\nu_1)\Big],$$

$$f_\sigma = \frac{1}{2s}\ ,\ f_{\nu_1} = \frac{\sqrt{3}}{2u_1}\ .$$

$$V(\phi) \sim e^{-S_1}\cos(a)$$



$$h_0\sigma + q^1\nu_1 = 0$$

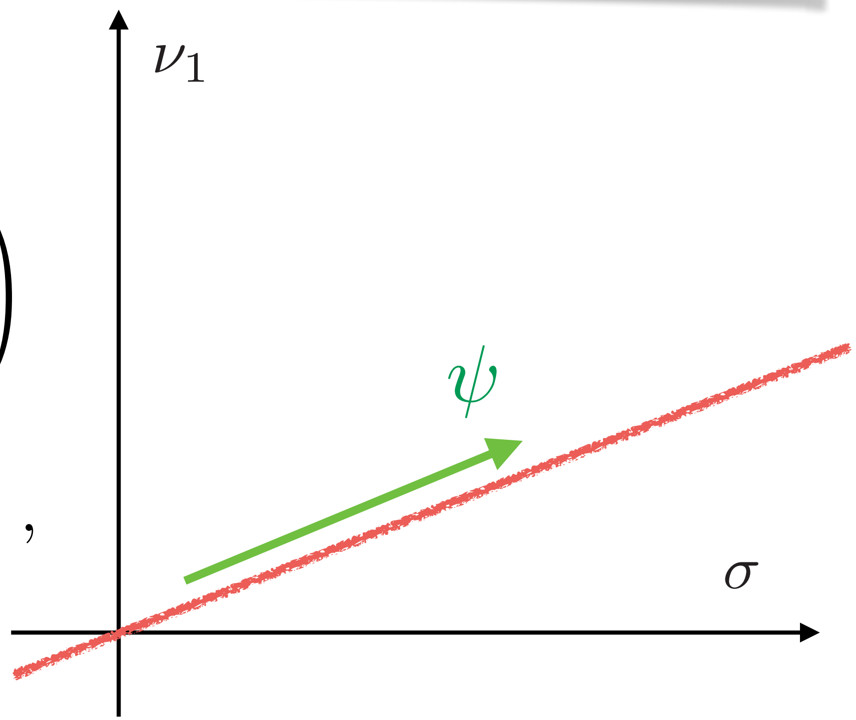
A simple realisation of KNP mechanism

- a two- dimensional axion field space,
- there is one heavy direction,
- in the direction orthogonal to it, which is flat at the perturbative level, the potential is generated by non-perturbative effects (and hence, is a cosine),
- CAUTION: is field space still compact?

Fluxes as free parameters

- Single axion and two instantons

$$\mathcal{L} = -\frac{1}{2}(\partial\psi)^2 - \left[V_0' + A'e^{-s}\left(1 - \cos\frac{\psi}{f_\psi^s}\right)\right.$$
$$\left. + B'e^{-u_1}\left(1 - \cos\frac{\psi}{f_\psi^{u_1}}\right)\right],$$



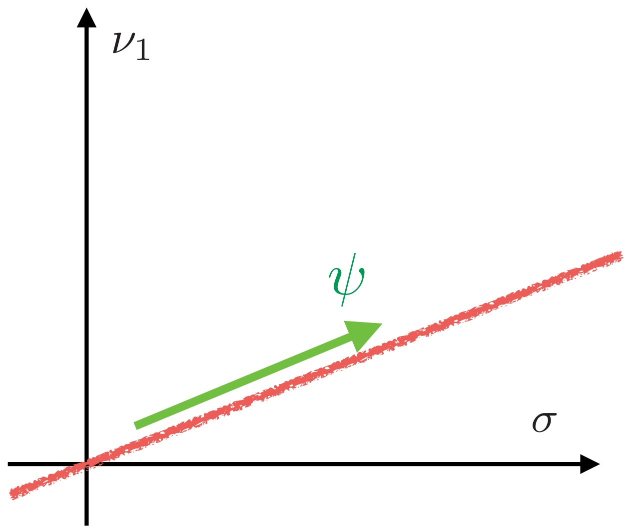
- Increase amplitude and period for only one cosine?

$$f_\psi^s = \frac{N}{q^1} = \frac{\sqrt{f_\sigma^2(q^1)^2 + f_{\nu_1}^2(h_0)^2}}{q^1}, \quad s = \frac{2f_0\mathcal{V}}{5h_0},$$
$$f_\psi^{u_1} = \frac{N}{h_0} = \frac{\sqrt{f_\sigma^2(q^1)^2 + f_{\nu_1}^2(h_0)^2}}{h_0}, \quad u_1 = \frac{3h_0 s}{q^1}.$$

Can we do it?

- Single axion and two instantons

$$\mathcal{L} = -\frac{1}{2}(\partial\psi)^2 - \left[V_0' + A' e^{-s}\left(1 - \cos\frac{\psi}{f_\psi^s}\right) + B' e^{-u_1}\left(1 - \cos\frac{\psi}{f_\psi^{u_1}}\right)\right] ,$$



- Can we do it?

$$f_\psi^s = \frac{N}{q^1} = \frac{\sqrt{f_\sigma^2 (q^1)^2 + f_{\nu_1}^2 (h_0)^2}}{q^1} , \quad s = \frac{2 f_0 \mathcal{V}}{5 h_0} ,$$

$$f_\psi^{u_1} = \frac{N}{h_0} = \frac{\sqrt{f_\sigma^2 (q^1)^2 + f_{\nu_1}^2 (h_0)^2}}{h_0} , \quad u_1 = \frac{3 h_0 s}{q^1} .$$

$$f_\sigma = \frac{1}{2s} , \quad f_{\nu_1} = \frac{\sqrt{3}}{2u_1} .$$

$$f_\psi^s = \frac{1}{\sqrt{3}s} = \frac{2 f_\sigma}{\sqrt{3}} ,$$

$$f_\psi^{u_1} = \frac{\sqrt{3}}{u_1} = 2 f_{\nu_1} .$$

E. Palti "*On Natural Inflation and Moduli Stabilisation in String Theory*," JHEP **1510**, 188 (2015) [arXiv:1508.00009 [hep-th]].

Weak Gravity Conjecture for axions

- Weak Gravity Conjecture for axions…
- An axion with decay constant f must couple to instantons with action S, such that

$$fS \leq M_p$$

$$\mathcal{L}(a) \supset -f^2(\partial a)^2 - \Lambda^4 \sum_{n=1}^{\infty} e^{-nS} \left(1 - \cos(na)\right)$$

  - If f is large, S must be small, so, higher order instanton corrections can’t be ignored,
  - this limits the “flat” or monotonic regions in potential,
  - Obviously deep implications for inflation!

Strong form of axionic WGC

- for any axion
  - there must always be an instanton where the axion appears with a decay constant that is sub-Planckian,
  - what is the action of this instanton? the action can be very large
    - this effect becomes an insignificant modification of the low-energy potential.
- The strong form of the WGC:
  - this sub-Planckian instanton must have an action less than that of the super-Planckian instanton responsible for the inflaton potential, and so it forms the dominant contribution to the potential.

$$V(\phi) \sim e^{-S_1} \cos\left(\frac{\phi}{f_1}\right) + e^{-S_2} \cos\left(\frac{\phi}{f_2}\right)$$

E. Palti "*On Natural Inflation and Moduli Stabilisation in String Theory*," JHEP **1510**, 188 (2015) [arXiv:1508.00009 [hep-th]].

Is it really true?

- Worth understanding better!
- Choose CY s.t. one more axion present,
- Diagonalise Kahler metric, low energy theory

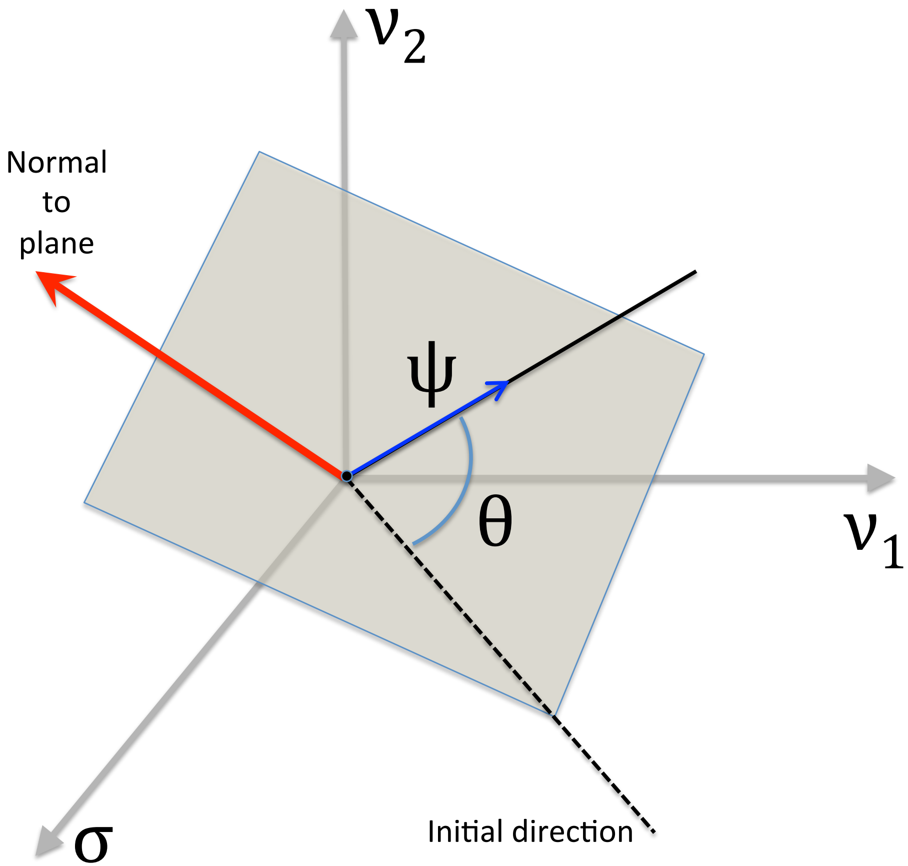
$$\mathcal{L} = \quad - \quad \frac{1}{2} f_{\sigma}^{2} (\partial\sigma)^2 - \frac{1}{2} f_{\tilde{\nu}_1}^{2} (\partial\tilde{\nu}_1)^2 - \frac{1}{2} f_{\tilde{\nu}_1}^{2} (\partial\tilde{\nu}_1)^2$$
$$- \quad \left[V_0 + A' e^{-s} (1 - \cos\sigma) + B' e^{-u_1} (1 - \cos\tilde{\nu}_1) + C' e^{-u_2} (1 - \cos\tilde{\nu}_2) \right]$$

- Explore various directions in field space (the spirit of KNP!),
- In terms of the displacement field...

$$\mathcal{L} = -\frac{1}{2}(\partial\psi)^2 - \left[V_0' + A' e^{-s} \left(1 - \cos\frac{\psi}{f_\psi^s}\right) + B' e^{-u_1} \left(1 - \cos\frac{\psi}{f_\psi^{u_1}}\right) + C' e^{-u_2} \left(1 - \cos\frac{\psi}{f_\psi^{u_2}}\right) \right]$$

G. Goswami "*Enhancement of axion decay constants in type IIA theory*," arXiv:1812.11909 [hep-th].

Is it really true?



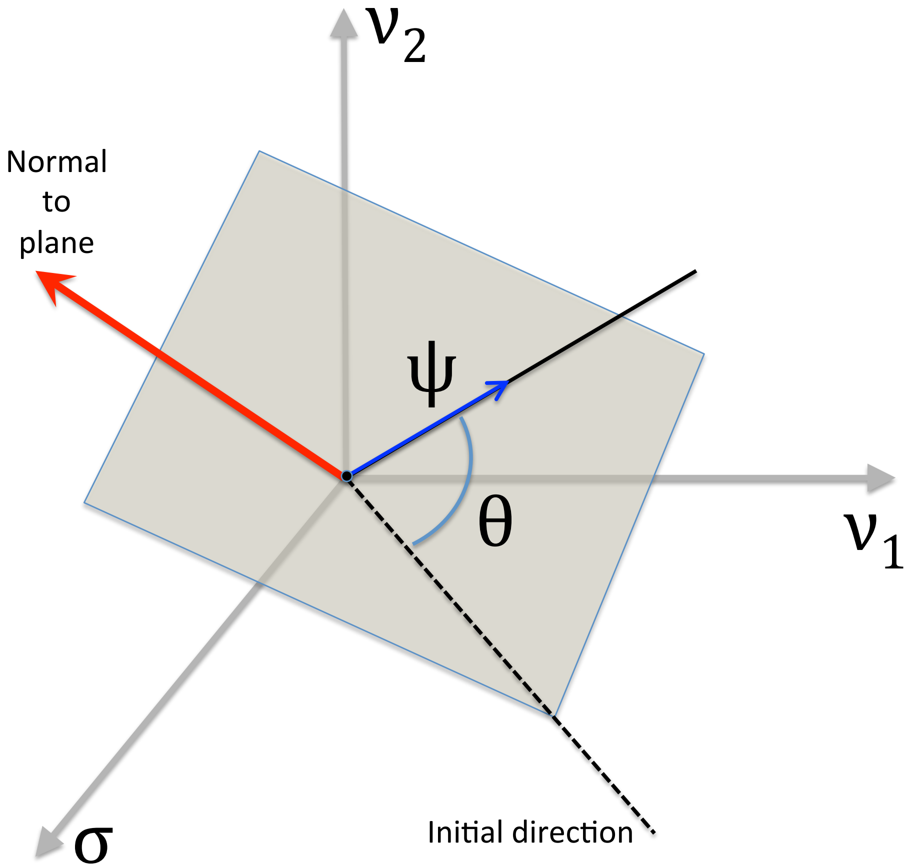
$$h_0\sigma + q^1\nu_1 + q^2\nu_2 = 0\ ,$$

$$\begin{aligned} f^s_\psi &= \left(\frac{f_\sigma}{\ell_\sigma}\right)\ , \\ f^{u_1}_\psi &= \left[\frac{\det P\ f_{\tilde\nu_1} f_{\tilde\nu_2}}{P_{22}\ell_{\tilde\nu_1} f_{\tilde\nu_2} - P_{21}\ell_{\tilde\nu_2} f_{\tilde\nu_1}}\right]\ , \\ f^{u_2}_\psi &= \left[\frac{\det P\ f_{\tilde\nu_1} f_{\tilde\nu_2}}{P_{11}\ell_{\tilde\nu_2} f_{\tilde\nu_1} - P_{12}\ell_{\tilde\nu_1} f_{\tilde\nu_2}}\right]\ . \end{aligned}$$

- Perturbatively flat plane,
- Initial direction, rotation, explore all directions in the plane,
- One more “parameter”: the angle of rotation.

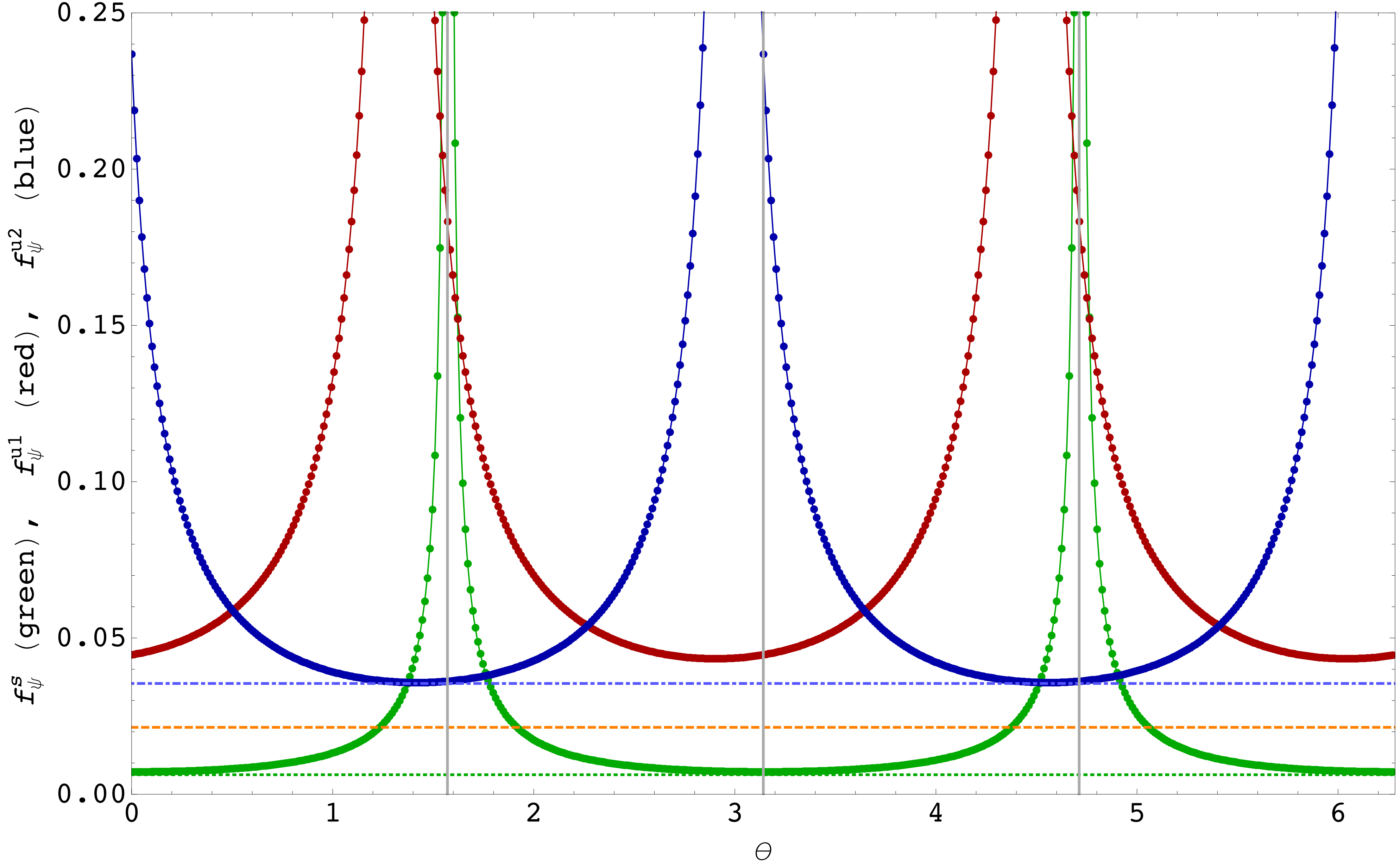
G. Goswami “*Enhancement of axion decay constants in type IIA theory*,” arXiv:1812.11909 [hep-th]

Is it really true?



- There exist search directions which are flat directions,
- Fluxes don't have to be adjusted, search direction to be chosen,
- When there are more axions, there are many more parameters available to specify a direction

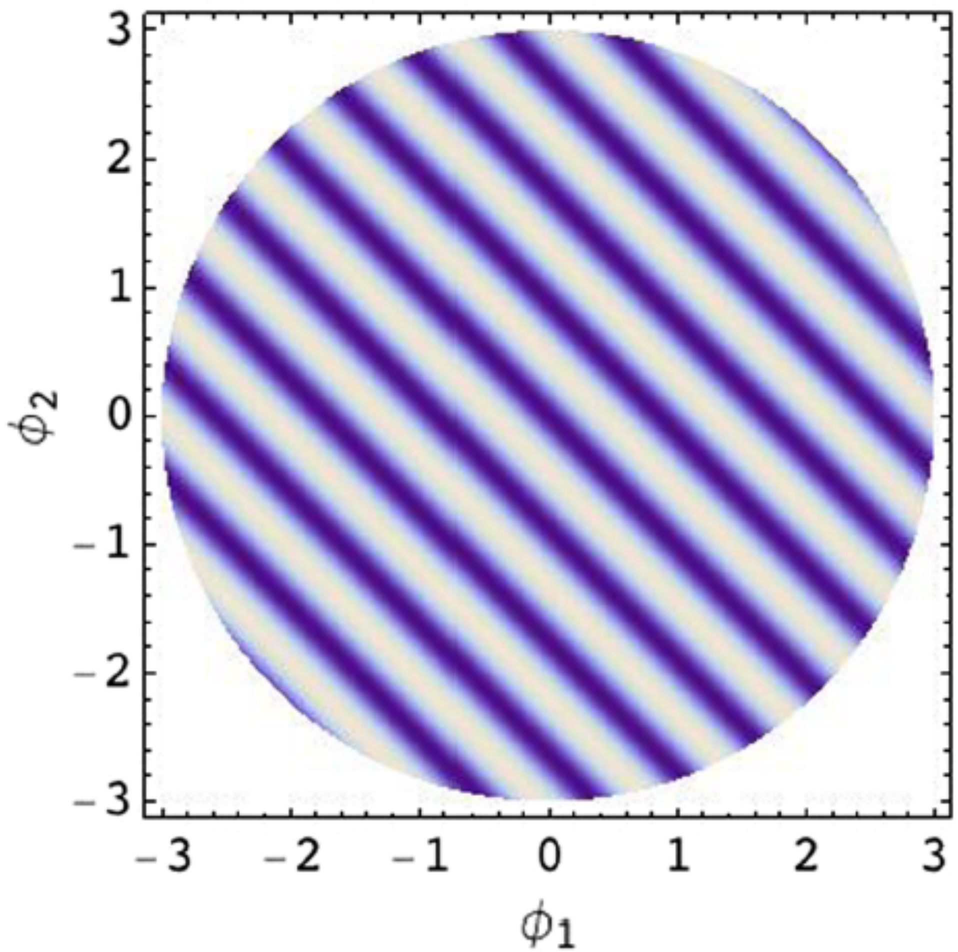
G. Goswami "*Enhancement of axion decay constants in type IIA theory*," arXiv:1812.11909 [hep-th]



G. Goswami "*Enhancement of axion decay constants in type IIA theory*," arXiv:1812.11909 [hep-th]

Enhancement...

- found directions in axion field space such that the scalar potential along the direction is sufficiently flat
    - making sure that the effective decay constant due to one of the axions is large,
    - the vev of the saxion corresponding to the rest of axions are so large that their contribution to the scalar potential is negligible.
- this can always be done for any fixed choice of fluxes,
- Strong form of axionic WGC violated?
- will the field actually go along such a straight line trajectory (though its dynamics is determined by, among other things, its potential)?



3
2
1
0
−1
−2
−3
ϕ_2
−3 −2 −1 0 1 2 3
ϕ_1

Retry?

- Flat directions: higher order corrections need to be taken into account, so avoid,
    - work with the appropriate solution,
- Consider directions in which the field actually rolls:
    - direction of eigenvector of Hessian with smaller eigenvalue,
- Work with "Cartesian coordinates" in field space.
- Closer in spirit to original KNP mechanism.

KNP realised

$$(\sigma, \nu_1, \nu_2) \longrightarrow (\chi_1, \chi_2, \chi_3) \longrightarrow \chi_i = P_{il}\xi_l,$$

$$\downarrow$$

$$\psi_i = d_i \xi_i \qquad \text{(no sum over } i\text{)},$$

$$\longleftarrow$$

$$\psi_1 = \phi_1 V_1 + \phi_2 W_1,$$

$$\psi_2 = \phi_1 V_2 + \phi_2 W_2,$$

$$\psi_3 = \phi_2 W_3.$$

$$V(\phi_1, \phi_2) \quad = \quad \left[V_0 + A' e^{-s}\left(1 - \cos\left[\frac{\phi_1}{f_1} + \frac{\phi_2}{g_1}\right]\right) + B' e^{-u_1}\left(1 - \cos\left[\frac{\phi_1}{f_2} + \frac{\phi_2}{g_2}\right]\right) + C' e^{-u_2}\left(1 - \cos\left[\frac{\phi_1}{f_3} + \frac{\phi_2}{g_3}\right]\right)\right],$$

$$s \gg u_1 > u_2$$

Large f ?

- A very explicit realisation of the alignment mechanism,
- Still freedom left to adjust fluxes,
- The “decay constants” are completely known in terms of fluxes;
- Look for a combination of fluxes which gives a large effective decay constant;
- Tried 20,100 combinations of fluxes (in the regime of validity of calculations),
- The maximum value found is 0.66,
- I.e.
  - freedom to adjust fluxes to change the values of the individual decay constants,
  - cannot make effective decay constant super-Planckian.

broader issues:

Restrictions and obstructions

- Finding similar restrictions/obstructions is routine,
- Many kinds of restrictions known,
- Focus on those about scalar potentials: important for cosmology!

E.g.

arXiv.org > hep-th > arXiv:0711.2512

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High Energy Physics – Theory

Inflationary Constraints on Type IIA String Theory

Mark P. Hertzberg (MIT), Shamit Kachru (Stanford), Washington Taylor (MIT), Max Tegmark (MIT)

(Submitted on 16 Nov 2007 (v1), last revised 18 Jul 2008 (this version, v3))

We prove that inflation is forbidden in the most well understood class of semi-realistic type IIA string compactifications: Calabi-Yau compactifications with only standard NS-NS 3-form flux, R-R fluxes, D6-branes and O6-planes at large volume and small string coupling. With these ingredients, the first slow-roll parameter satisfies epsilon >= 27/13 whenever V > 0, ruling out both inflation (including brane/anti-brane inflation) and de Sitter vacua in this limit. Our proof is based on the dependence of the 4-dimensional potential on the volume and dilaton moduli in the presence of fluxes and branes. We also describe broader classes of IIA models which may include cosmologies with inflation and/or de Sitter vacua. The inclusion of extra ingredients, such as NS 5-branes and geometric or non-geometric NS-NS fluxes, evades the assumptions used in deriving the no-go theorem. We focus on NS 5-branes and outline how such ingredients may prove fruitful for cosmology, but we do not provide an explicit model. We contrast the results of our IIA analysis with the rather different situation in IIB.

String vacua are dirty!

- We do not know full string theory!
- Trustworthy regimes:
  - large volume, small string length,
  - small string coupling (but too small not useful),
  - Hierarchy of scales:
  - $M_{pl} > M_s > M_{KK} > M_{\rm mod} > H_{\rm inf} > M_{\rm inf}$
- Make many assumptions/approximations,
  - probe brane approximation,
  - large charge approximation,
  - Mode truncation,
- Every term in 4D effective action needs to be understood in terms of its stringy origin,

Obstructions

- Restrict to solutions which are "trustworthy",
- Result:
  - No dS local minima,
  - one of the two potential slow roll parameters large,
  - Even in AdS vacua,
    - no super-Planckian decay constants for axions,
    - 4D description valid? separation of scales,
  - distance conjecture,
  - restrictions on large field inflation?
- Caveat: leading order,
- But there are more general reasons for the validity
  - Weak Gravity Conjecture etc;
- Trans-Planckian censorship conjecture,

Cosmological consequences...

arXiv.org > astro-ph > arXiv:1910.06233

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Astrophysics > Cosmology and Nongalactic Astrophysics

Trans-Planckian Censorship Conjecture and Non-thermal post-inflationary history

Mansi Dhuria, Gaurav Goswami

(Submitted on 14 Oct 2019)

The recently proposed Trans-Planckian Censorship Conjecture (TCC) can be used to constrain the energy scale of inflation. The conclusions however depend on the assumptions about post-inflationary history of the Universe. E.g. in the standard case of a thermal post-inflationary history in which the Universe stays radiation dominated at all times from the end of inflation to the epoch of radiation matter equality, TCC has been used to argue that the Hubble parameter during inflation, $H_{\rm inf}$, is below $\mathcal{O}(0.1)$ GeV. Cosmological scenarios with a non-thermal post-inflationary history are well-motivated alternatives to the standard picture and it is interesting to find out the possible constraints which TCC imposes on such scenarios. In this work, we find out the amount of enhancement of the TCC compatible bound on $H_{\rm inf}$ if post-inflationary history before nucleosynthesis was non-thermal. We then argue that if TCC is correct, for a large class of scenarios, it is not possible for the Universe to have undergone a phase of moduli domination.

Comments: 9 pages, 3 figures, 2 tables
Subjects: **Cosmology and Nongalactic Astrophysics (astro-ph.CO)**; High Energy Physics - Phenomenology (hep-ph); High Energy Physics - Theory (hep-th)
Cite as: arXiv:1910.06233 [astro-ph.CO]
(or arXiv:1910.06233v1 [astro-ph.CO] for this version)

Bibliographic data

Cosmological consequences...

Swampland, Axions and Minimal Warm Inflation

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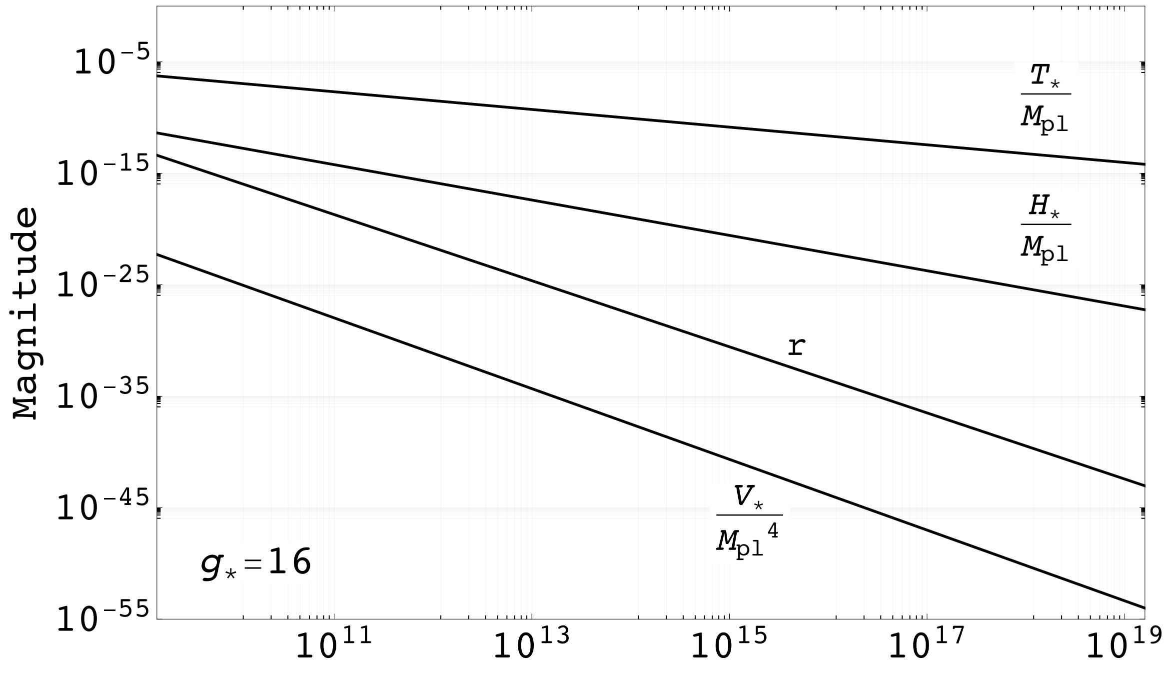
Warm inflation has been noted previously as a possible way to implement inflationary models compatible with the dS swampland bounds. But often in these discussions the heat bath dynamics is kept largely unspecified. We point out that the recently introduced Minimal Warm Inflation of arXiv:1910.07525, where an axionic coupling of the inflaton leads to an explicit model for the thermal bath, yields models of inflation that can easily fit cosmological observations while satisfying dS swampland bounds, as well as swampland distance bound and trans-Planckian censorship.



... in preparation...

Broader summary…

- Future observations would put tight constraints on large field inflation,
- Large field inflation model building is trivial if one is careless and cavalier but hopelessly difficult if one is careful,
- Even one toy model of large field inflation without any uncertainties is hard!
- Large axion decay constant may be forbidden,
- Restrictions on scalar potential from UV completion?
- Cosmological consequences.

Thank You