SUPERGRAVITY MODELS OF INFLATION WITH NEW FAYET-ILIOPOULOS TERMS

BASED ON

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this is part of my continuing pursuit of physics using effective actions, a method that was introduced to me in 1986 by Costas in memorable all-night marathons at UCLA

- THE STANDARD GENERAL SUPERGRAVITY POTENTIAL
- NEW CONTRIBUTIONS TO THE POTENTIAL FROM NEW F-I TERMS
- ONE GOOD PROPERTY OF THESE NEW TERMS
- WHY DID IT TAKE ~40 YEARS TO DISCOVER THEM?
- THE ANSWER, AND THE BOUNDS IT IMPLIES
- A MODEL OF SUPERGRAVITY INFLATION WITH NEW F-I TERM:
- 1) LIFTING THE KKLT POTENTIAL
- 2) GRAVITY MEDIATION AND OBSERVABLE SECTOR MASSES

By 1982 the scalar potential of supergravity was written down in full generality (Cremmer et al)

$$V = e^G (G_A G^{A\bar{B}} G_{\bar{B}} - 3) + V_D$$

G=G(z,z*) is a function of the chiral multiplet scalars

When the kinetic term of the gauge fields is canonical, the D-term potential of the gauge group with coupling constant g is

$$V_D = \frac{1}{2} g^2 D_I D_I, \quad D_I = G_I k^I + G_{\bar{I}} k^{\bar{I}}$$

$$k^I = \text{Killing vector}$$

This formula also includes the standard supergravity Fayet-Iliopoulos term, which arises from gauging an R-symmetry

It was only in 2018 that new contributions to the scalar potential that arise from fully supersymmetric terms were discovered

New Fayet-Iliopoulos terms [Cribiori et al. (2017)] in the Kaehler invariant form found by Antoniadis et al. (2018)

$$\left[(S\bar{S}e^{-K/3})^{-3}\frac{W^2\bar{W}^2}{T(\bar{w}^2)\bar{T}(w^2)}V_D\right]_D$$

W is the field strength of the real multiplet V and

$$w^2 = \frac{W^2}{(S\bar{S}e^{-K/3})^2}, \quad T = \text{chiral projector}, \quad V_D = (D, ...)$$

The bosonic part of this mess reduces to just… D !

The real multiplet V gauges an ordinary U(1) symmetry under which the superpotential has weight 0.

Under an R-symmetry the superpotential has weight 3.

Constraints on the New F-I terms come from the multi-fermion terms

The new F-I terms appear in the bosonic Lagrangian density as

$$\frac{1}{2}D^2 - \Xi D + \sum_{n\geq 0, m\geq 0} D^{-n} M_{Pl}^{-m} O^{2n+m+4}$$

$$\Xi \sim M_{Pl}^2 \xi + \text{ smaller, scalar field dependent terms}$$

$$O^{2n+m+4} = \text{multi-fermion operator of dimension } 2n+m+4$$

the Planck mass power m is non-negative. m=0 is given by terms that exist also in the global supersymmetric limit

$$\Xi \int d^4\theta (D_\alpha W^\alpha + \bar{D}^{\dot{\alpha}} \bar{W}_{\dot{\alpha}}) \frac{W^2 \bar{W}^2}{D^2 W^2 \bar{D}^2 \bar{W}^2}$$

on shell:

$$D_{on-shell} \sim \Xi \sim M_{Pl}^2 \xi$$

when Ξ is sub-Planckian the smallest cutoff is for m=0

$$\Lambda^2 \lesssim D \equiv M_S^2$$

This coefficient determines the energy scale at which the supergravity effective theory breaks down.
To describe inflation it must be larger than the inflationary Hubble scale

$$H_I^2 \lesssim \Lambda^2 \lesssim D_{on-shell} \sim M_{Pl} H_I$$

so the supersymmetry breaking scale determined by the D-term cannot be arbitrarily small

$$M_S \gtrsim H_I$$

In the rest of this talk I will sketch a model of supersymmetric inflation employing the new F-I term, high-scale supersymmetry breaking, and gravity mediation.

Ingredients: hidden sector chiral multiplet T
observable sector chiral multiplets z

Superpotential:

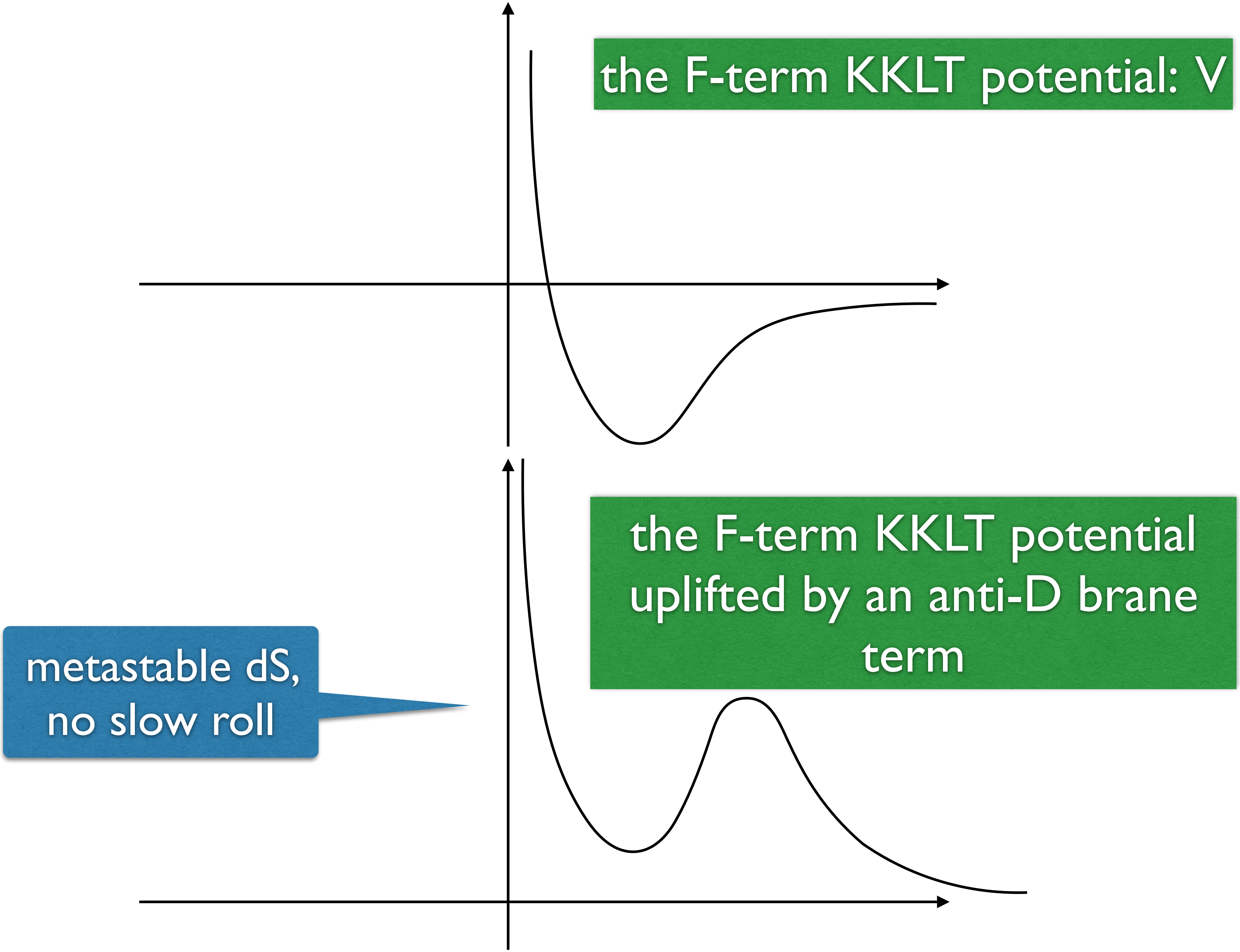
$$W(T, z^I) = W_0 + Ae^{-aT} + W(z^I)$$

hidden sector KKLT potential

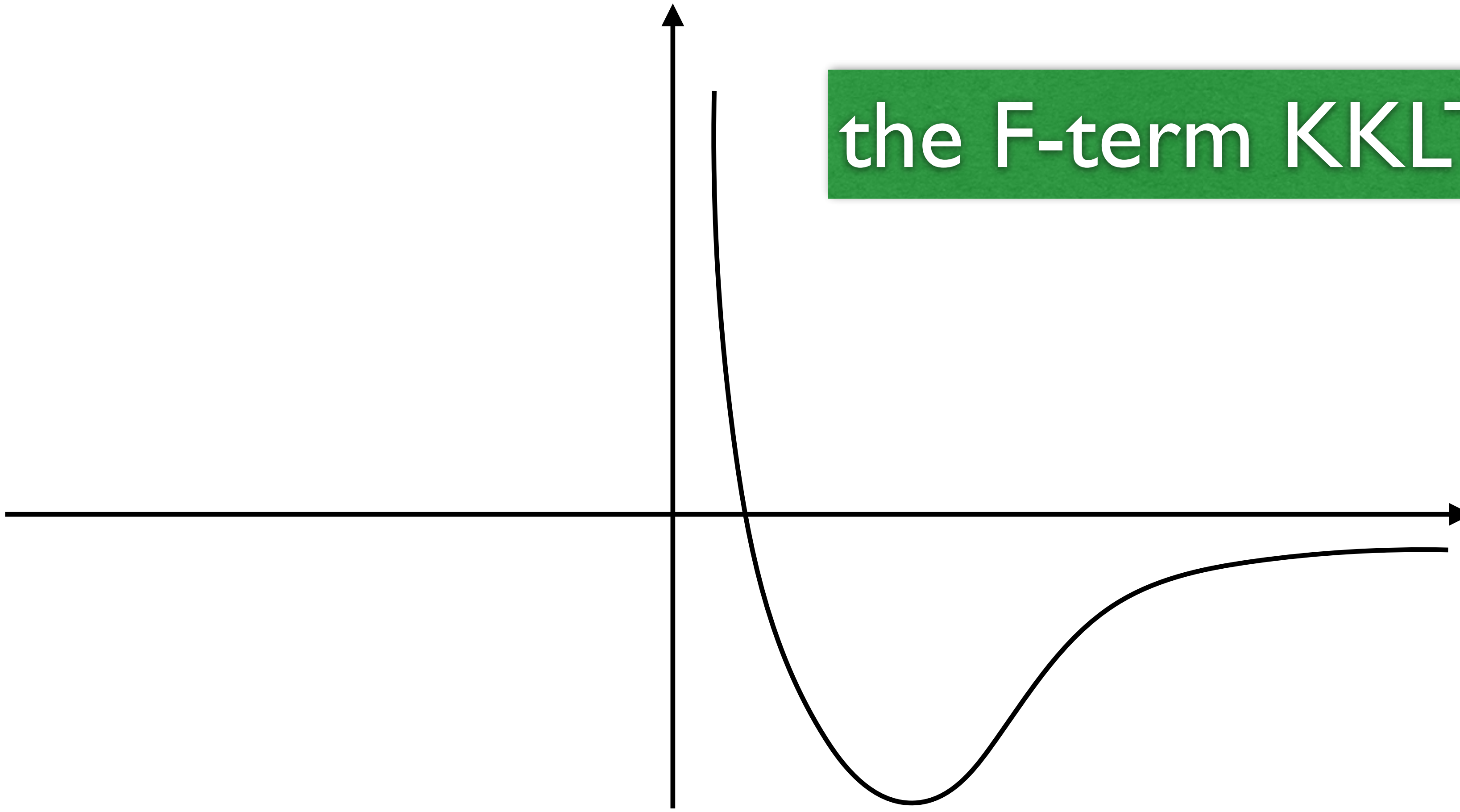
observable sector potential

Kaehler potential:

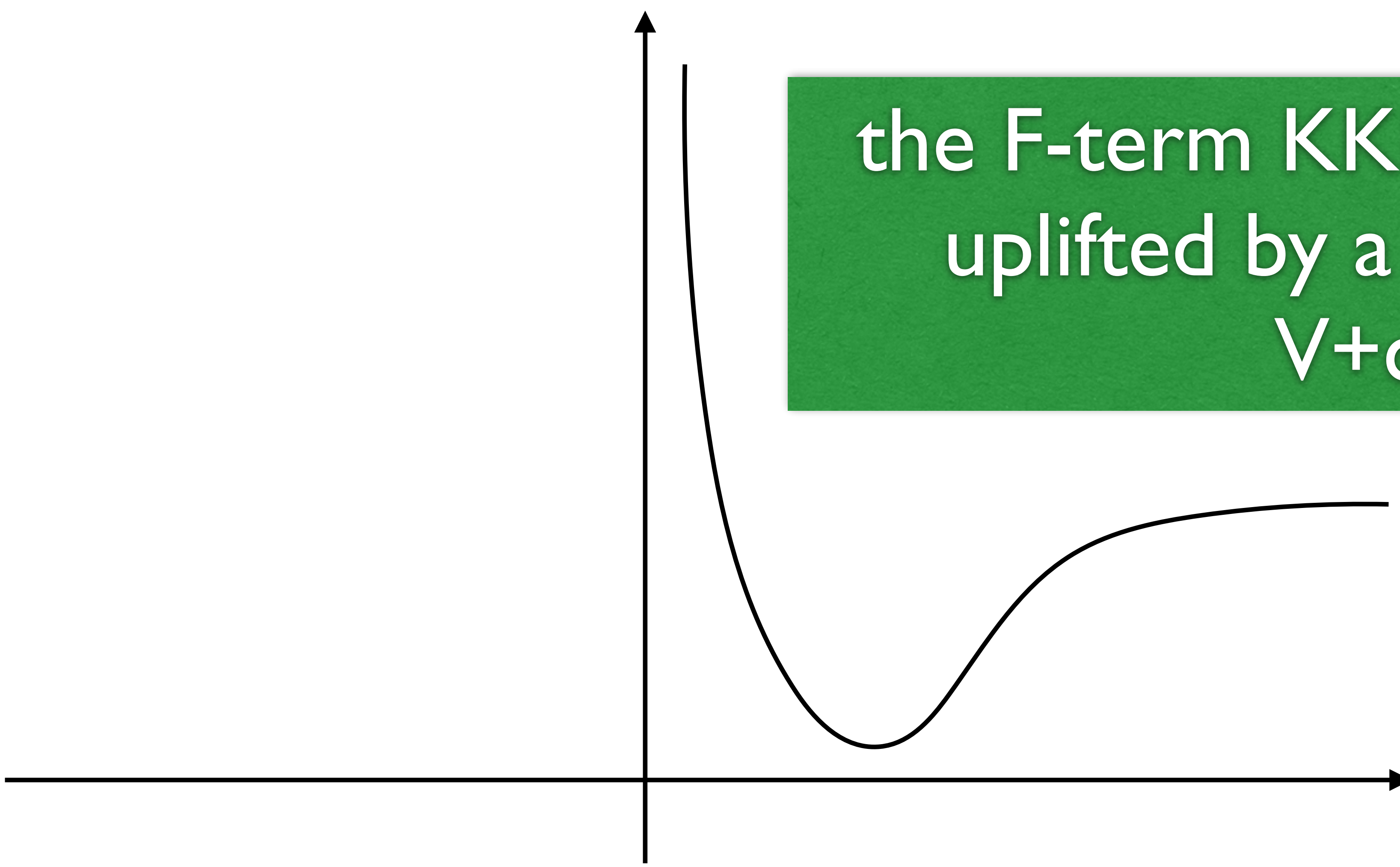
$$K = -3\log(T + \bar{T} - z^I \bar{z}^{\bar{I}}/3)$$

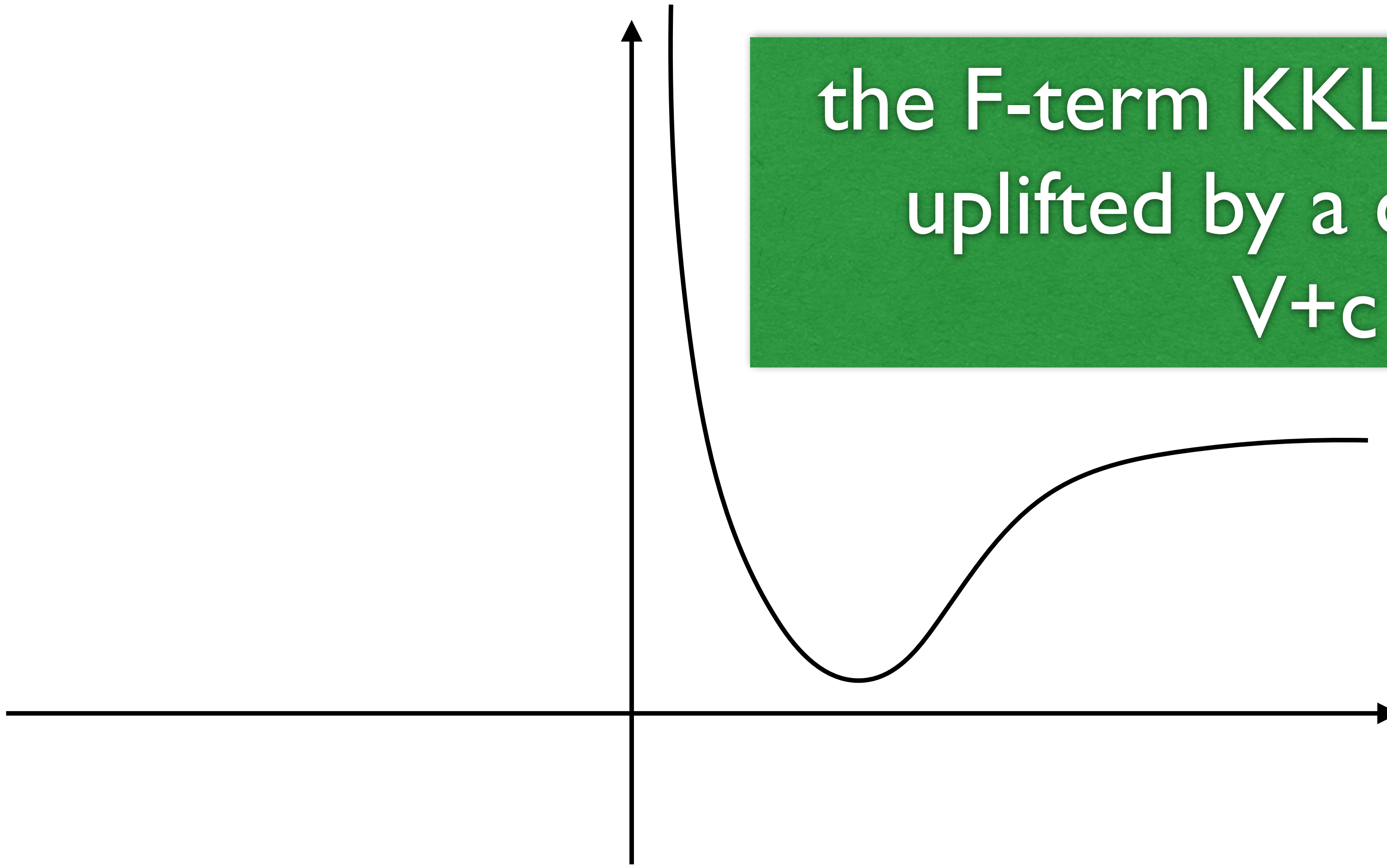

the F-term KKLT potential: V
the F-term KKLT potential uplifted by an anti-D brane term
metastable dS, no slow roll

the F-term KKLT potential: V



the F-term KKLT potential uplifted by a constant: V+c



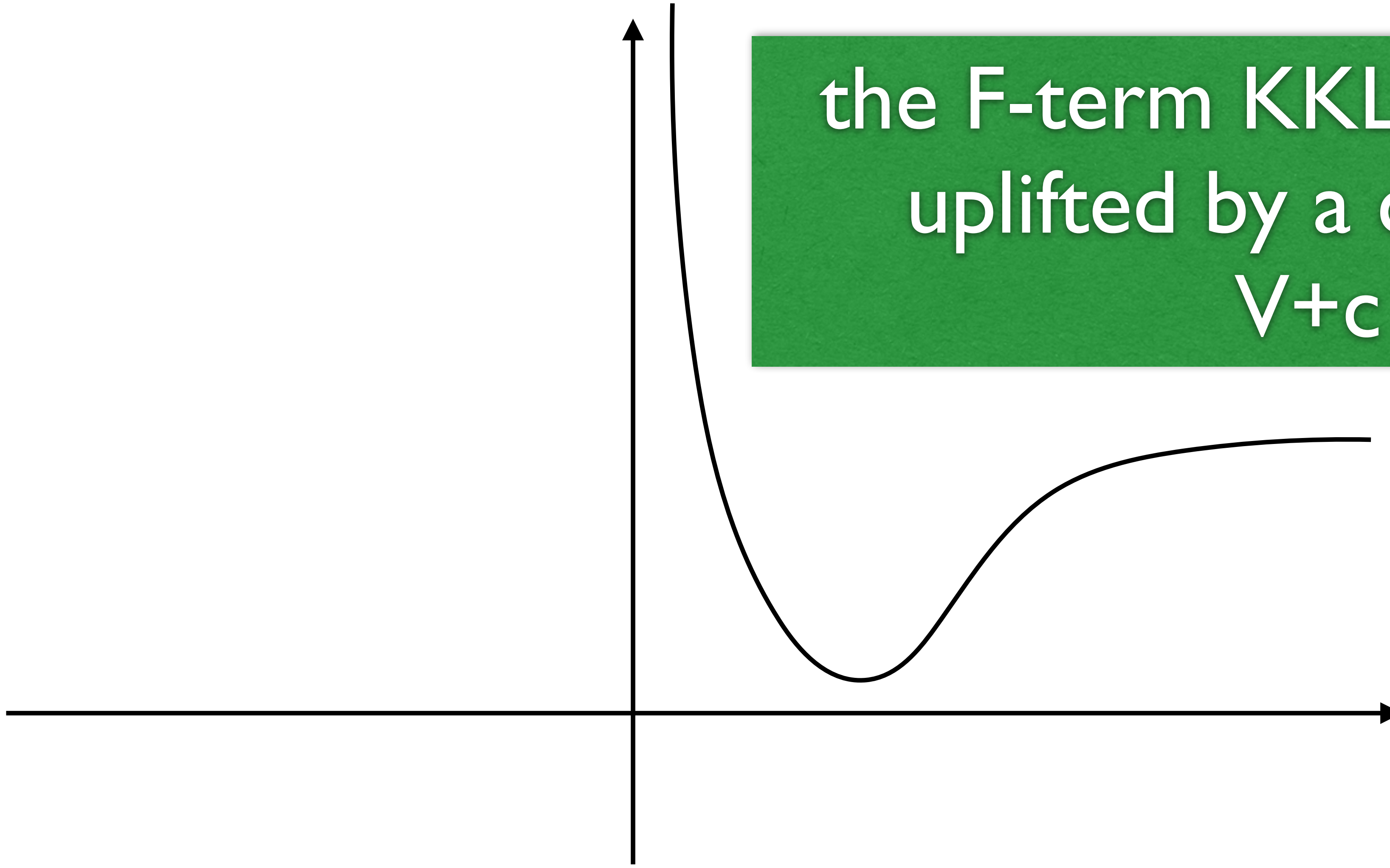


the F-term KKLT potential uplifted by a constant: V+c

Lift with standard supergravity F-I term?

Difficult to make KKLT superpotential invariant under R-symmetry, because its key properties follow precisely from it being non homogeneous under R-symmetry

New F-I term does not require R-symmetry. It is perfectly tailored to give the uplift



the F-term KKLT potential uplifted by a constant: V+c

Problem: D-term SUSY breaking, so the mass splitting in the observable sector is model-independent

Worse: scalars in the observable sector are tachyonic.

The cure to these problems is to make the new FI term field dependent, add relevant interactions in the superpotential of the observable sector that carry the SUSY breaking to the observable sector and introduce further terms that become singular when SUSY is unbroken

The problem

$$G \equiv K + \log|W|^2 = -3\log(T + \bar{T} - z^I \bar{z}^{\bar{I}}/3) - \log|W_0 + Ae^{-aT} + W(z)|^2$$

To begin with set W(z)=0

After inflation the T field settles to its minimum and the mass matrix of the scalars in the observable sector at z=0 is

$$M^2_{I\bar{J}} = -2e^G \delta_{I\bar{J}} \quad \text{(in units } M_{Pl} = 1)$$

The vacuum energy in the presence of the new F-I term is

$$V_{min} = -3e^G + \frac{1}{2}g^2\xi^2 \quad (M_{pl} = 1)$$

when this term is >0 the scalars are tachyons.
When it vanishes they saturate the Breitenlohner-Freedman bound

Solution: introduce a field dependence on the FI term

$$\Xi = \xi + c_{I\bar{J}} z_I \bar{z}_{\bar{J}}$$

the mass matrix of the scalars in the observable sector at z=0 now can be large and positive

$$M^2_{I\bar{J}} = -2e^G \delta_{I\bar{J}} + \xi c_{I\bar{J}}$$

the fermions in chiral multiplets receive masses from relevant terms in the observable-sector superpotential

$$W(z) = m_{IJ} z^I z^J + O(z^3)$$

to give mass to the gauginos we introduce another term that becomes singular when SUSY is unbroken

$$\left[W_\alpha(U)W^\alpha(U)W_\beta(V)W^\beta(V)S_0^{-3}W(T,z^I)^{-1}\right]_F$$

It does not generate a new UV cutoff because W is never zero, but it does generate a mass term for SM fermions:

$$L_{gaugino\ mass} \sim H_I \bar{\lambda}\lambda$$

SUMMARY+CONCLUSIONS+OPEN QUESTIONS

- THE NEW FI TERMS INTRODUCE GREAT FREEDOM IN THE CONSTRUCTION OF SUPERGRAVITY LAGRANGIANS
- THEY HAVE A CUTOFF THAT CANNOT BE PARAMETRICALLY LARGER THAN THE SUPERSYMMETRY BREAKING SCALE, SIMILARLY TO NON-LINEAR REALIZATIONS OF SUPERSYMMETRY
- Q: DO THE NEW F-I TERMS ARISE FROM OLD F-I TERMS THROUGH DECOUPLING/SINGULAR LIMITS?
- Q: DO THEY COME FROM STRING THEORY? DO THEY BELONG TO THE LANDSCAPE OR THE SWAMPLAND?
- Q: COSMOLOGY AND NATURALNESS WITH KKLT + NEW FI