Instituto de Física Teórica presents:

Back to the Swamp

Madrid, 26-28 September 2022

Cosmo & Swamp

Gary Shiu

(Discussion with Fernando Quevedo)

“Swamp Stirrers”

craiyon

AI model drawing images from any prompt!

How to stir cosmo & swamp

Pendulum Swung too Far?

Are there 10^{500} de Sitter vacua?
or none?

Inflation in string theory?

Detectable level of gravitational waves generated by inflation?

de Sitter on trial?

Are we too harsh on de Sitter?

- **A commonly voiced opinion:** “There isn’t a fully moduli stabilized (MS)SM constructed from string theory, why are we so critical about de Sitter vacua in string theory?”

- Need to establish a fair baseline for comparison.

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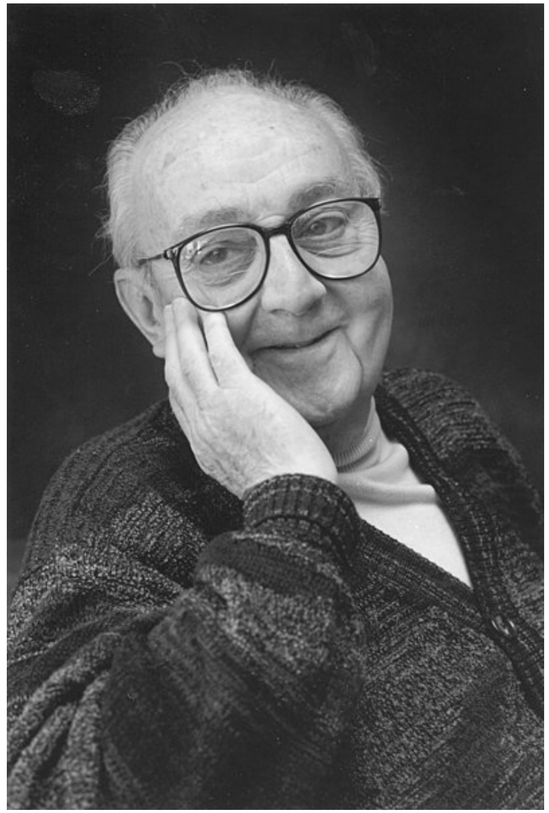

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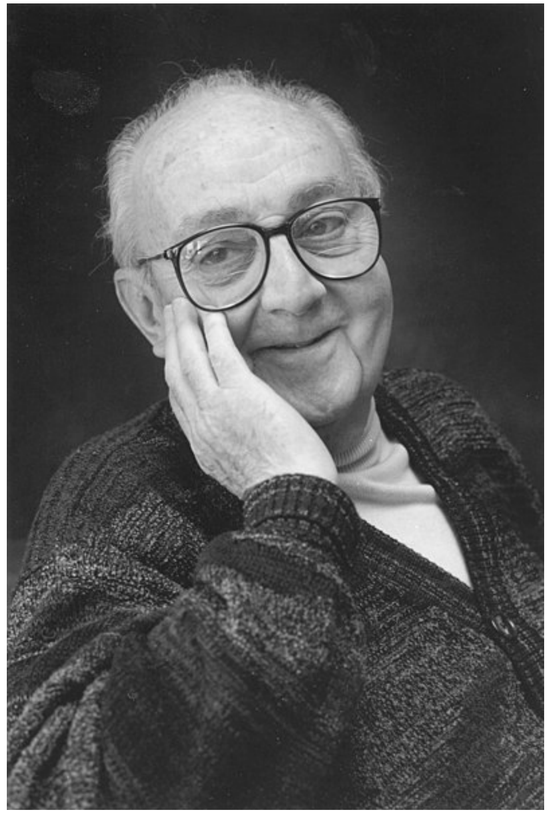

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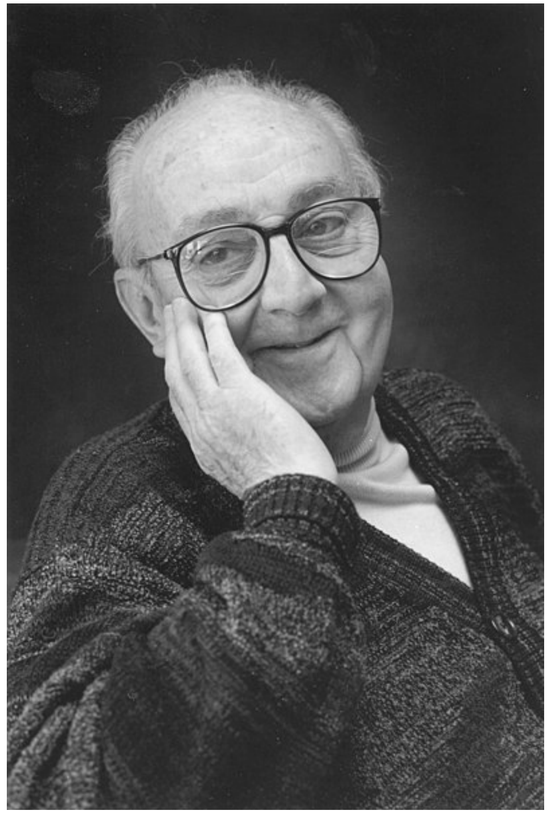

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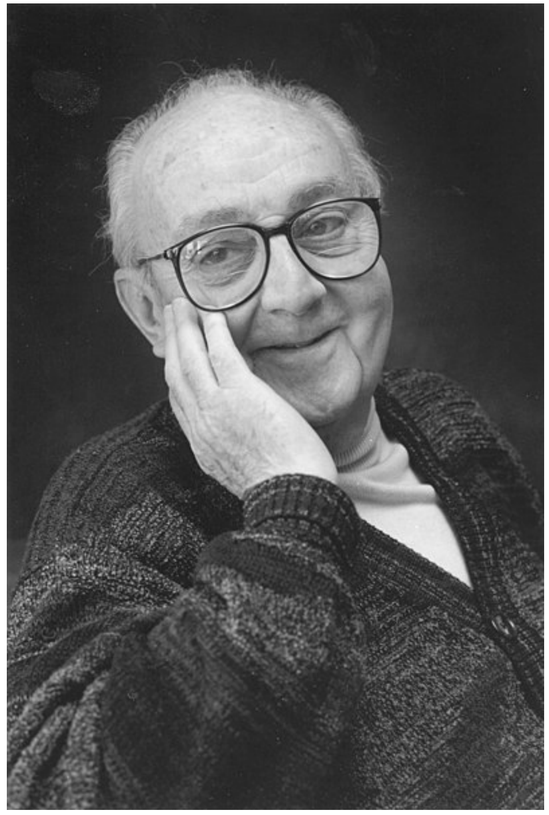

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Microstate counting of black hole entropy was done for 5d SUSY BPS black holes [Strominger, Vafa, ’96], not black holes in our world. Yet most would agree that it passes the *“we have it”* threshold.

Wishlist*

Particle Physics	Cosmology

* If we keep going, the two lists would eventually converge since particle physics and cosmology are inseparable in a string vacuum. Think of this as a priority list.

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Masses and couplings (and phases)	$\Lambda \sim 10^{-120} > 0$

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Moduli Stabilized MSSM-like vacua?

hep-th/0408059

MSSM vacua from Flux Compactifications

Fernando Marchesano and Gary Shiu
Department of Physics, 1150 University Avenue, University of Wisconsin, Madison, WI 53706

Building MSSM Flux Vacua hep-th/0409132

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hep-th/0506066

Fluxes, moduli fixing and MSSM-like vacua in a simple IIA orientifold

P.G. Cámara, A. Font[1] and L.E. Ibáñez

Departamento de Física Teórica C-XI and Instituto de Física Teórica C-XVI,
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Excerpt from the abstract:

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hep-th/0711.2512

Inflationary Constraints on Type IIA String Theory

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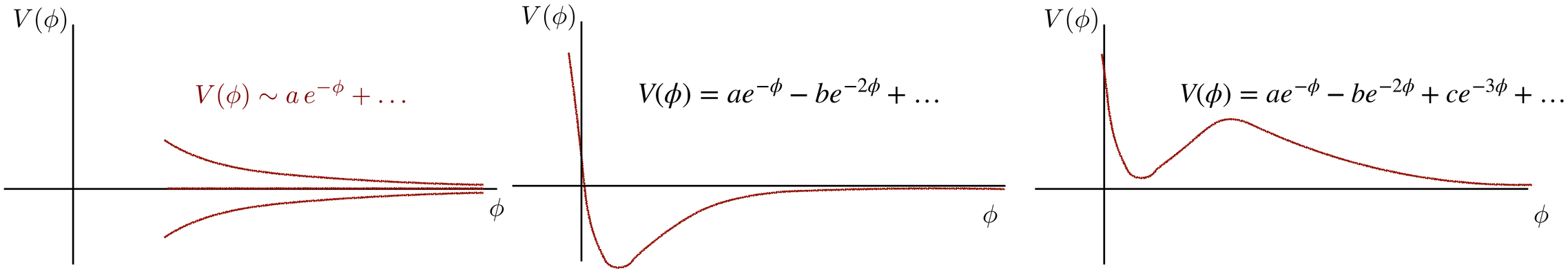
This is also the setup (DGKT) which gives infinitely many AdS vacua [DeWolfe, Giryavets, Kachru, Taylor]

Dine-Seiberg Problem

- No free-parameter in string theory, couplings = moduli vevs, e.g. $g_s = e^{-\phi}$



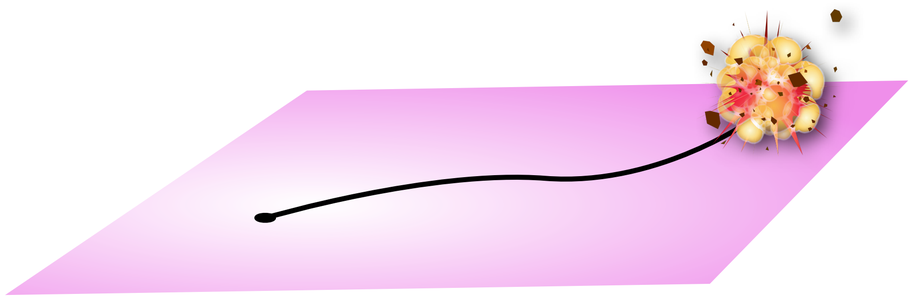
- If different order terms compete to give a minimum, why aren't higher order terms important?

- If # of vacua is finite (e.g. fluxes bounded by tadpoles), coupling is not parametrically weak. This applies to KKLT and LVS.

- DGKT [DeWolfe, Giryavets, Kachru, Taylor] gives infinitely many flux vacua, but parametrically weak coupling, large volume dS vacua still not possible [Junghans];[Banlaki, Chowdhury, Roupec, Wrase].

Entropy Bound

- Exponential falloff was argued to be a universal behavior of $V > 0$ potential in any direction at parametrically large distances in field space (not just the dilaton) [Ooguri, Palti, GS, Vafa].



Distance conjecture [Ooguri, Vafa]

$$m_{\text{tower}} \sim e^{-a\phi} \quad \text{for} \quad \phi \to \infty$$

- In spacetime with $V > 0$, there is a horizon and an entropy bound [Bousso].

$$S \leq R^2 = \frac{1}{V}$$

- At large field distances, tower of states dominate the entropy $\Rightarrow V(\phi) \sim e^{-c\phi}$

- Refined de Sitter conjecture: $|\nabla V| \geq \frac{c}{M_p} \cdot V$, or $\min\left(\nabla_i \nabla_j V\right) \leq -\frac{c'}{M_p^2} \cdot V$

Lifetime of de Sitter

- Whether the conjecture has any teeth observationally depends on the values of "order 1" constants c, c' ***and*** whether we are in the asymptotic regime.

- Trans-Planckian Censorship Conjecture (TCC) [Bedroya, Vafa, '19] posits that sub-Planckian fluctuations remain quantum. If true, this puts a bound on the lifetime of de Sitter:

$$t_{dS} \leq \frac{1}{H} \log \frac{M_p}{H}$$

- Computed OTOC in de Sitter space & established that de Sitter space is a fast scrambler [Aalsma, GS, '20]; the shortest time for a static observer to decode info from the horizon is:

$$t_{\text{scrambling}} \sim \frac{1}{H} \log S \sim \frac{2}{H} \log \frac{M_p}{H}$$

Further discussions in [Aalsma, Cole, Morvan, van der Schaar, GS, '21]

- Does not show breakdown at $t_{\text{scrambling}}$. Formation of a singularity is unavoidable for a static observer (for JT gravity in dS): $t_{\text{scrambling}} \ll t \ll t_{\text{trap}} \ll t_{\text{Page}} \equiv S_{dS}/H$ [Aalsma, Sybesma, '21].

“If it doesn't fit, you must acquit.” *

* Note that acquittal ≠ approval.

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Distance and de Sitter conjectures on the Swampland

Hirosi Ooguri [a,b], Eran Palti [c,*], Gary Shiu [d], Cumrun Vafa [e]

Conclusions except below:

we would also like to emphasize that not having parametrically good control over couplings does not mean that no control is possible. Rather, we view our results as showing that establishing the validity or violation of the de Sitter conjecture will require careful studies of string theory vacua, quantifying corrections and sharpening estimate of errors in our existing techniques and developing more powerful tools. Given the importance of the dark energy problem, effort into this direction is well justified.

Small ≠ Harmless

- **Another commonly voiced opinion:**

> "If a construction is a small perturbation from one which is trustable (e.g. small uplift), why should there be any problem?"

- First consider QFTs without gravity, e.g.,

$$\mathscr{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{c_1}{\Lambda^4}(F_{\mu\nu}F^{\mu\nu})^4 + \frac{c_2}{\Lambda^4}(F_{\mu\nu}\tilde{F}^{\mu\nu})^2 + \dots \quad \text{or} \quad \mathscr{L} = \frac{1}{2}\partial^\mu\phi\partial_\mu\phi + \frac{c_3}{\Lambda^4}(\partial\phi)^4 + \dots$$

- A negative c_i —**no matter how small** — violates unitarity and causality.
- **Gravity introduces subtleties** (e.g. t-channel graviton exchange) [See Parra-Martínez's talk]
- The gravitational positivity bounds may be **only approximately positive** [Hamada, Noumi, GS, '18]; [Alberte, de Rham, Jaity, Tolley, '20]; [Tokuda, Aoki, Hirano, '20];[Caron-Huot, Mazac, Rastelli, Simmons-Duffin, '21].
- Does not undermine the point that small ≠ harmless.

String Corrections

- Assuming small parameters mean control, we should make sure that all couplings are small and volumes (in both string and Einstein frames) are large.

- In attempted controlled constructions, one encountered order 1 string frame volumes [Denef, Douglas, Florea, Grassi, Kachru, '05]; [Demirtas, Kim, McAllister, Moritz, Rios-Tascon, '21].

- **Exact results are rare:** exact in g_s and perturbatively exact in α' Kahler potential for the vector multiplet in a specific $N = 2$ compactification [Garcia-Etxebarria, Hayashi, Savelli, GS '12].

- Continuous efforts in computing perturbative α' corrections to the Kahler potential for $N = 1$ compactifications [Grimm, Savelli, Weissenbacher, '13]; [Grimm, Keitel, Savelli, Weissenbacher, '13]; [Junghans, GS, '14]; [Berg, Haack, Kang, Sjors, '14];[Minasian, Pugh, Savelli, '15]; [Ciupke, Louis, Westphal, '15]; [Grimm, Mayer, Weissenbacher, '17]; [Antoniadis, Chen, Leontaris, '18]' [Cicoli, Quevedo, Savelli, Schachner, Valandro, '21]; [Klaewer, Lee, Weigand, Wiesner, '21], …

- Need to sum over **genuine** $N = 1$ corrections to all orders (perturbative and non-perturbative) in α' , not just those inherent from $N = 2$.

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- In attempted controlled constructions, one encountered order 1 string frame volumes [Denef, Douglas, Florea, Grassi, Kachru, '05]; [Demirtas, Kim, McAllister, Moritz, Rios-Tascon, '21].

- **Exact results are rare:** exact in g_s and perturbatively exact in α' Kahler potential for the vector multiplet in a specific $N = 2$ compactification [Garcia-Etxebarria, Hayashi, Savelli, GS '12].

- Continuous efforts in computing perturbative α' corrections to the Kahler potential for $N = 1$ compactifications [Grimm, Savelli, Weissenbacher, '13]; [Grimm, Keitel, Savelli, Weissenbacher, '13]; [Junghans, GS, '14]; [Berg, Haack, Kang, Sjors, '14];[Minasian, Pugh, Savelli, '15]; [Ciupke, Louis, Westphal, '15]; [Grimm, Mayer, Weissenbacher, '17]; [Antoniadis, Chen, Leontaris, '18]' [Cicoli, Quevedo, Savelli, Schachner, Valandro, '21]; [Klaewer, Lee, Weigand, Wiesner, '21], …

- Need to sum over **genuine** $N = 1$ corrections to all orders (perturbative and non-perturbative) in α' , not just those inherent from $N = 2$.

You be the Judge!