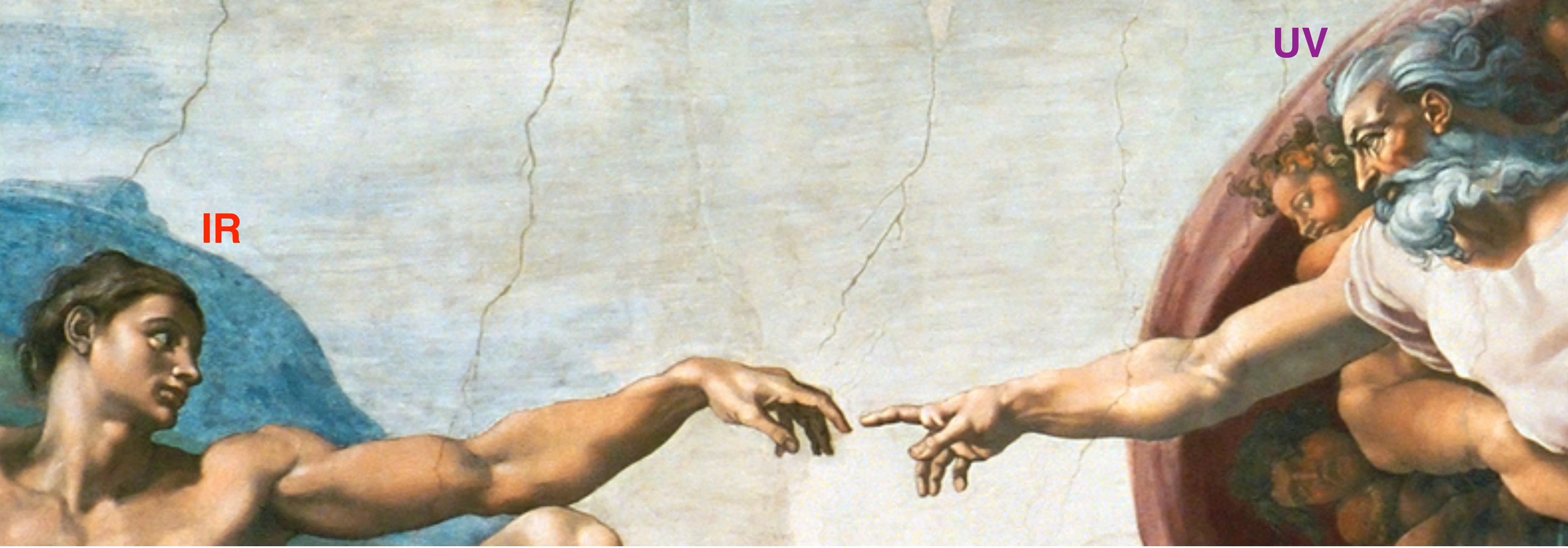
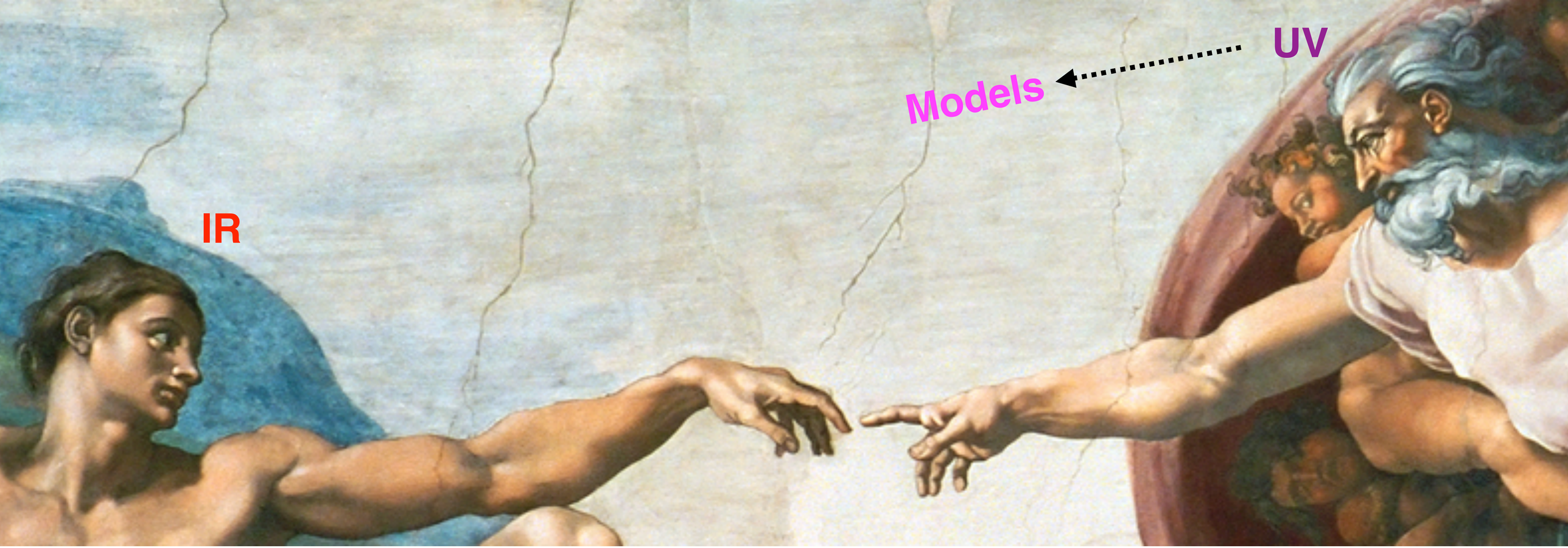


Discussion: “String Universality, Particle Physics, and Cosmology”

Strings 2021, São Paulo

Gary Shiu



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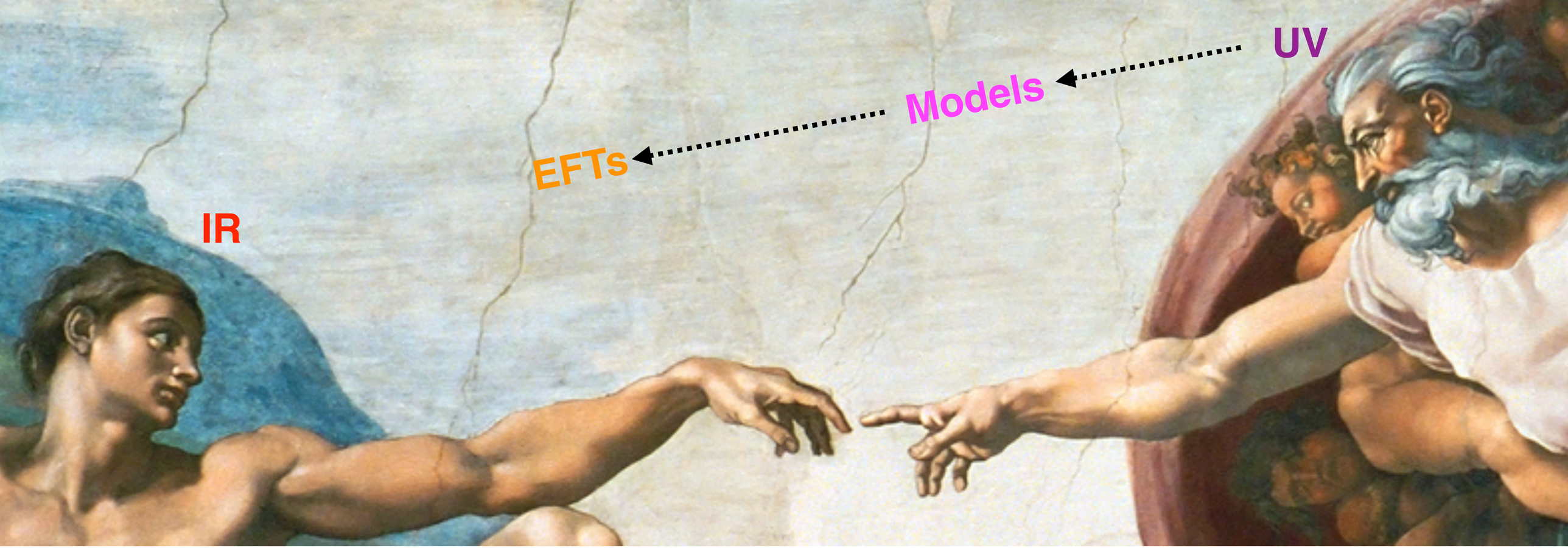

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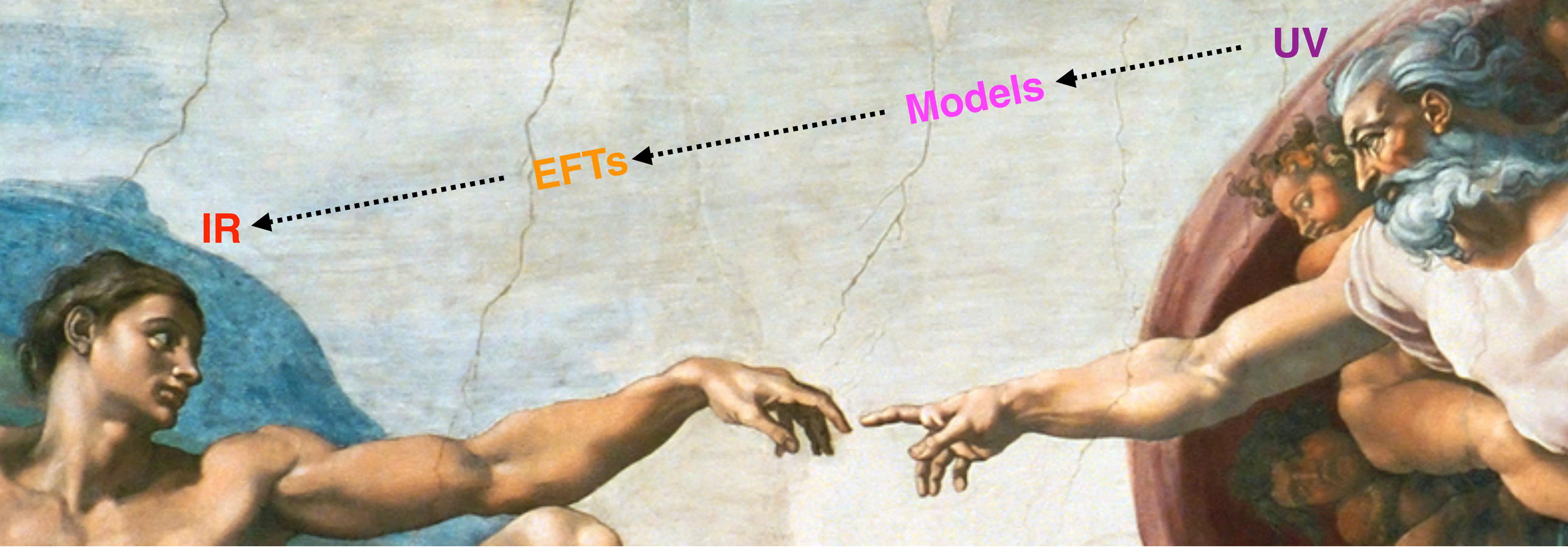

Discussion: “String Universality, Particle Physics, and Cosmology”

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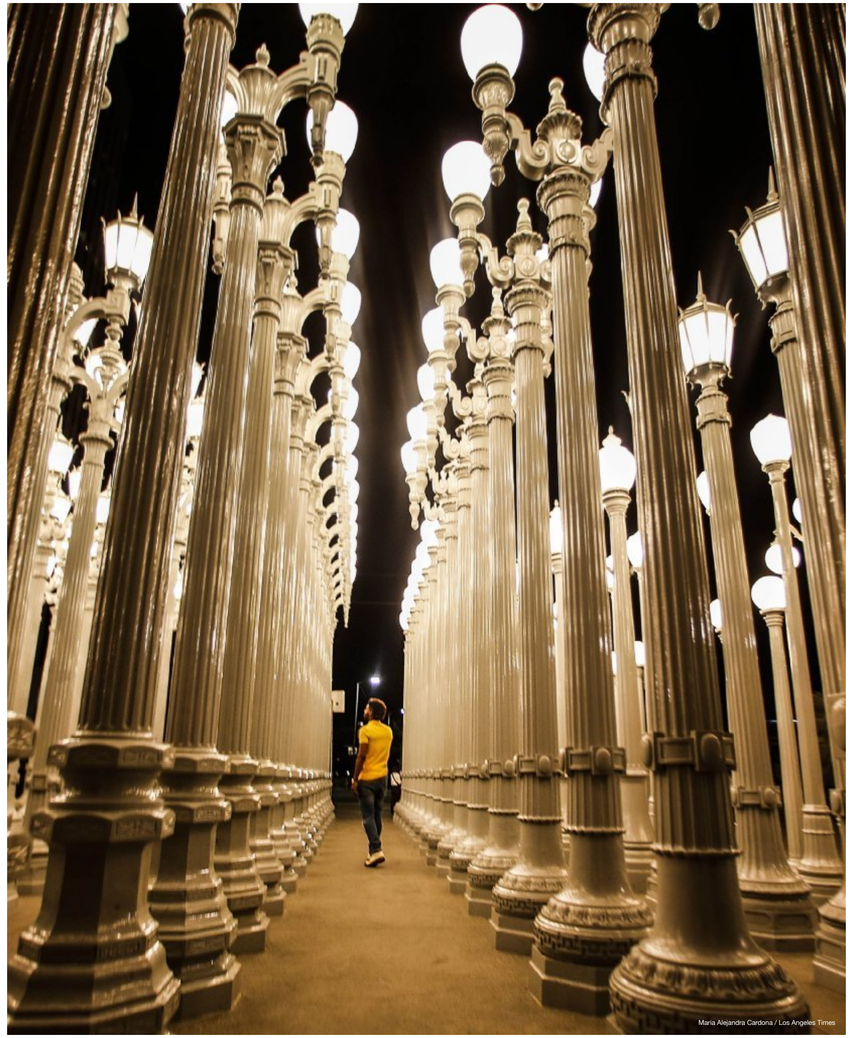
Some general lessons (observations)

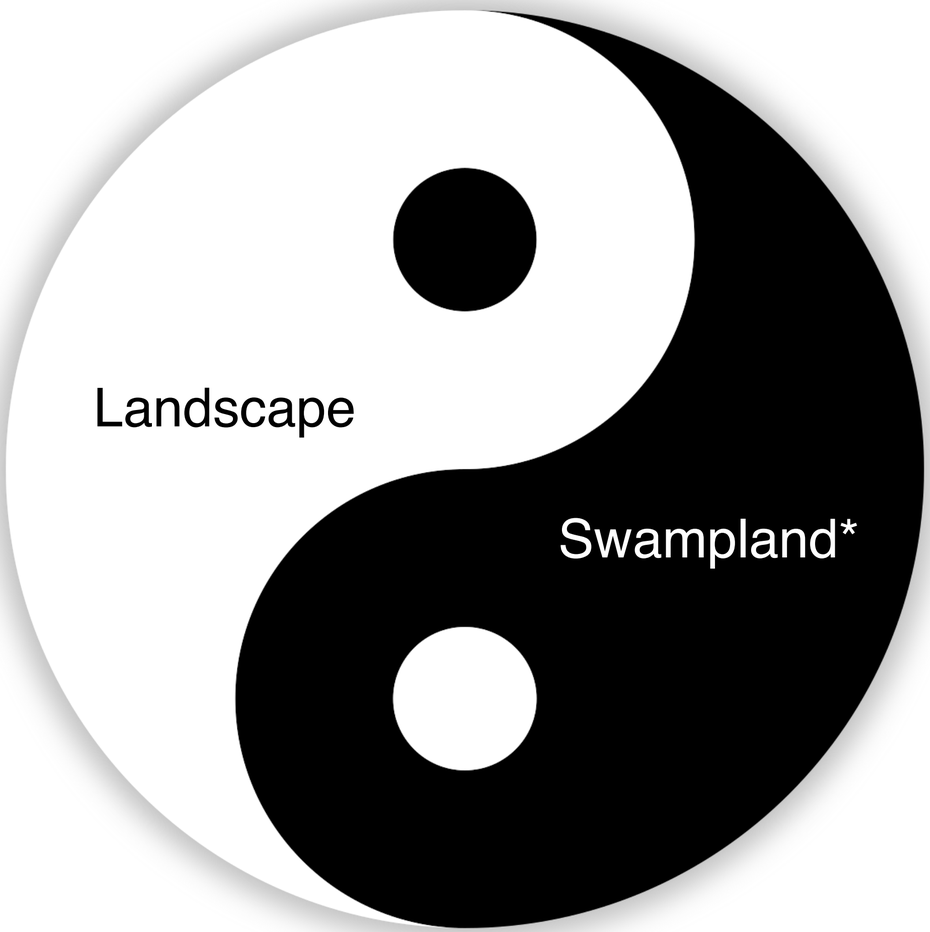
- No exact global symmetries
  - Worldsheet [Banks, Dixon, ’88]; Holography [Harlow, Ooguri, ‘18]
- Restricted gauge and matter content (rank of gauge groups, # and reps of matter, …)
  - See Cvetic’s discussion; Brane probes and anomaly inflow [Kim, GS, Vafa, ’19]; …
- Tree-level Regge boundedness: $\lim_{s\to\infty,\ t<0:\text{fixed}} |M(s,t)| \leq \mathcal{O}(s^2)$ [See Monday’s discussions]
  - Worldsheet amplitudes; Related to chaos bound [Maldacena, Shenker, Stanford,’15];[Chandorkar, Chowdhury, Kundu, Minwalla, ’21]; …
- Ubiquity of Moduli and Dualities
  - instantons, racetrack; with also fluxes, branes, O-planes, … [More in tomorrow’s discussion sessions]

Can we elevate these observations to some general principles?



- Are we sure these features are not consequences of us looking under the lampposts?
- If we can identify the general principles behind, these features are universal and have wider applicability than the limited (though large) number of string vacua that have been constructed.
- The goal of the Swampland program [See Valenzuela's review talk] is to identify these general principles, using knowledge of black hole physics, holography, various bootstrap approaches, scattering amplitudes, dualities, …
- Works on the Swampland suggest upgrades of these observations (Weak Gravity Conjecture, cobordism conjecture, various distance and dS conjectures, …).

More roads lead to Rome …

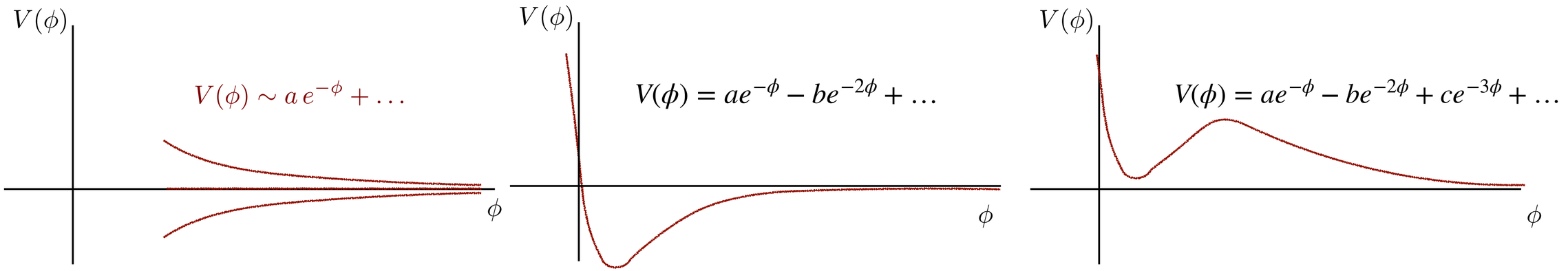


- The Swampland approach does not undermine the importance of constructing top-down models.
- One should not dismiss models based on proposed swampland criteria unless they are proven, but we should at least treat them as important warning signs.
- Lessons learned from the Swampland are potentially universal, not just features of specific models.
- Complementary approaches that teach us what is possible/impossible in string theory.

*SWAMP=Stop With Amateur Meaningless Phenomenology (h/t Nikolay Bobev)

Moduli Stabilization

- A prerequisite of string phenomenology (physical couplings, early and late cosmology).
- Dine-Seiberg problem: no free-parameter in string theory, couplings=moduli vevs, e.g. $g_s = e^{-\phi}$



- If terms of different orders compete to give a minimum, why are higher order terms unimportant?
- The abundance of flux compactifications allows one to find minima at weak coupling (e.g. by tuning fluxes) but if the number of flux vacua is finite (bounded by tadpole conditions), the stabilized coupling is not parametrically weak.
- The DeWolfe, Giryavets, Kachru, Taylor (DGKT) construction gives infinitely many flux vacua, but parametrically weak coupling, large volume dS vacua still not possible [Junghans];[Banlaki, Chowdhury, Roupec, Wrase].
- Exponential falloff is a universal behavior of V>0 potential in any direction at parametrically large distances in field space (and not just dilaton), which follows from the distance conjecture and entropy bound [Ooguri, Palti, GS, Vafa].

Controlled dS Constructions?

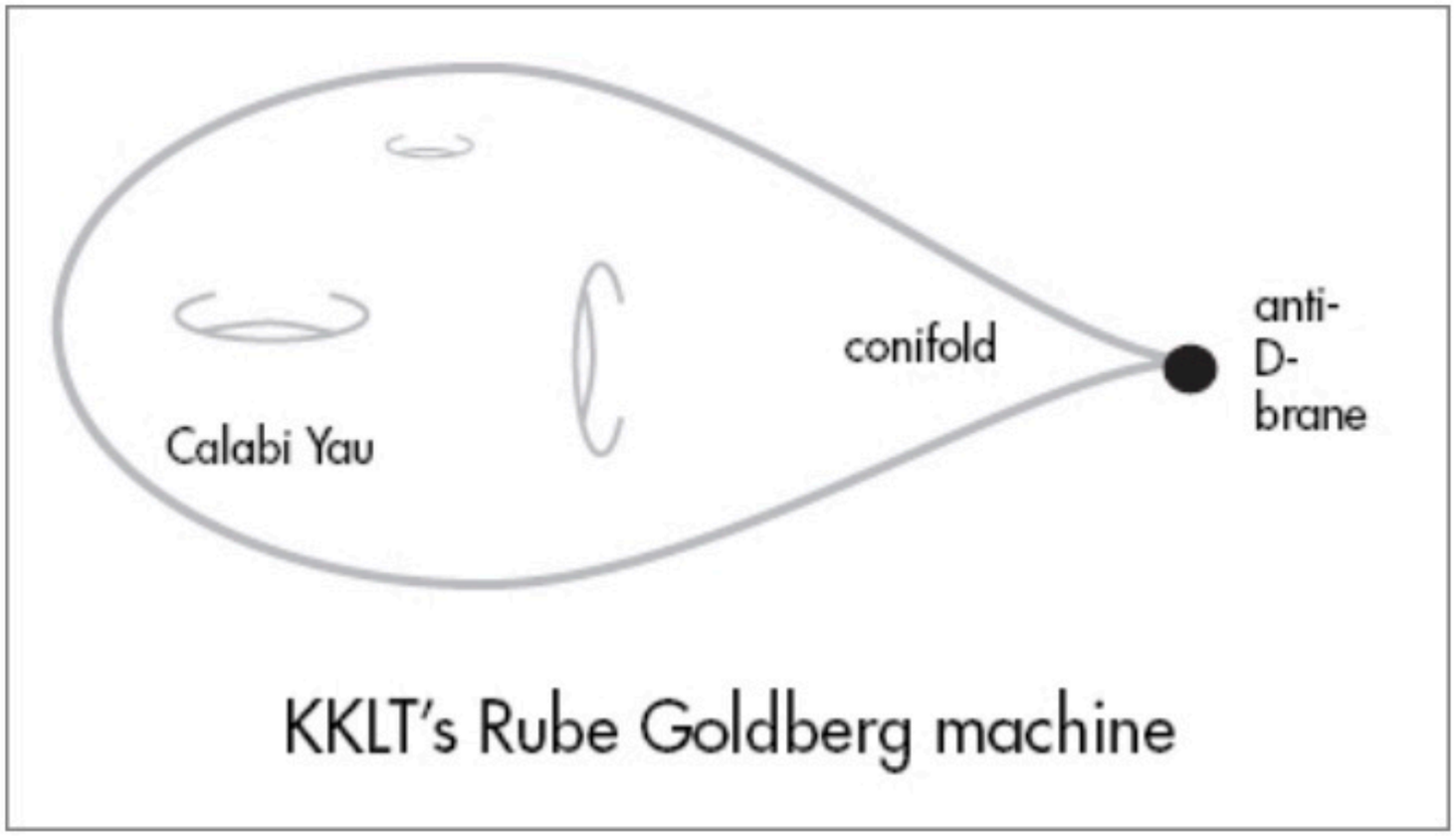


Figure taken from "The cosmic landscape' by Leonard Susskind

- No parametric control does not mean no control.
- Motivate careful studies of dS vacua and quantifying corrections.
- Existing dS constructions often involve a balance of classical, perturbative and non-perturbative contributions; making estimation of error challenging.
- Progress in understanding these constructions as well as controlled issues will be discussed by Soler [More in tomorrow's discussions].

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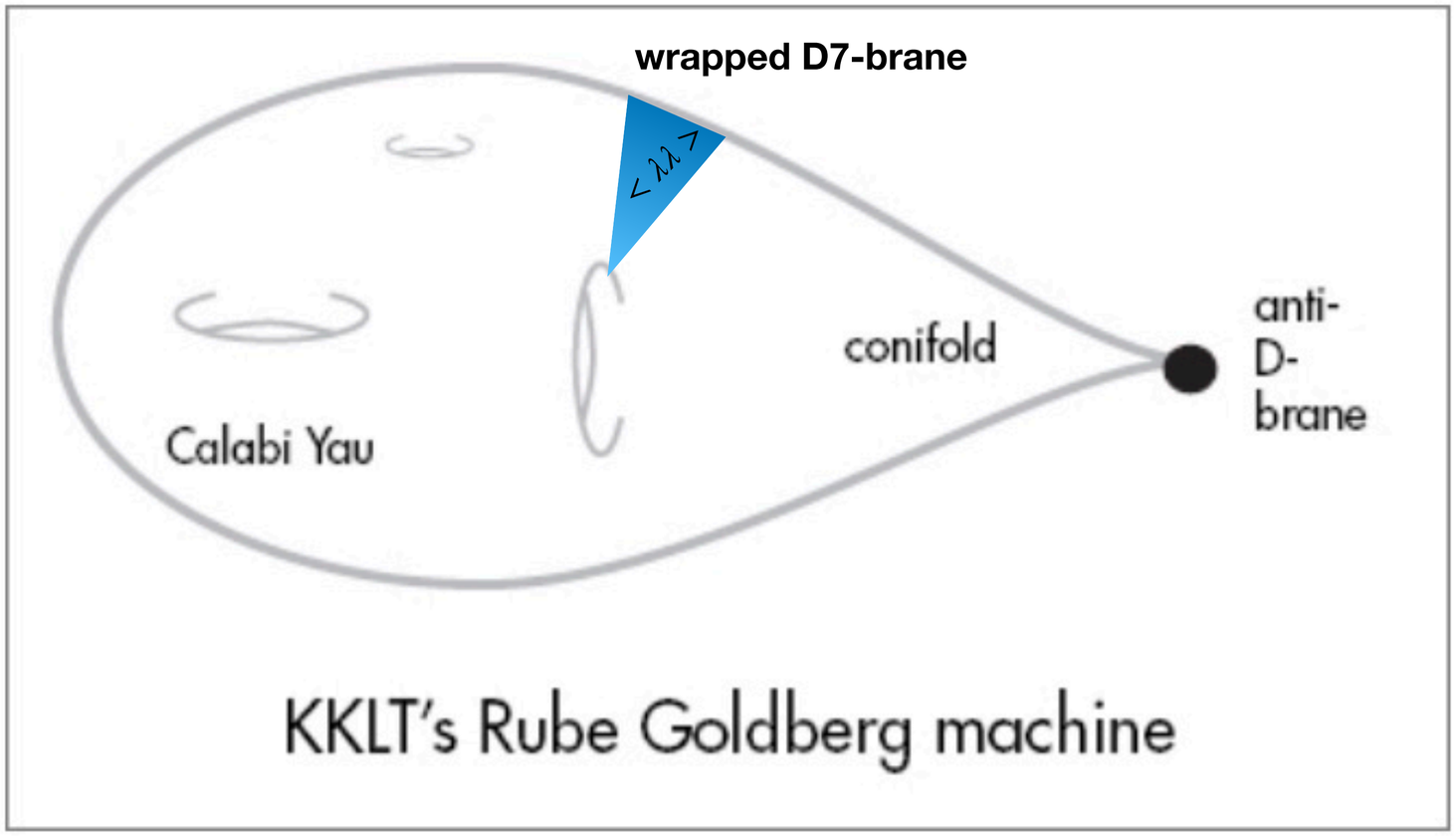

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Gravitational Positivity Bounds

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

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

- To an effective field theorist, $c_{1,2,3}$ are arbitrary numbers. However, a negative c_i —no matter how small — violates unitarity and causality (superluminal propagation)

- Gravity introduces subtleties — 1) superluminality is ambiguous (due to field redefinition involving the metric); 2) tree-level graviton exchange dominates the t-channel amplitude violating the Froissart bound.

- In string theory, this UV behavior is tamed by a tower of higher spin (Regge) states:

$$M(s,t) \sim -\frac{1}{M_P^2}\frac{s^2}{t} \quad \to \quad M(s,t) \sim -\frac{1}{M_P^2}\frac{s^{2+\gamma t+\mathcal{O}(t^2)}}{t} \quad \text{as } s \to \infty \ (t < 0 : \text{fixed})$$

- This (strict) Regge boundedness is assumed in the S-matrix bootstrap approach to derive quantitative bounds on the higher derivative couplings in gravitational theories [See Rastelli's talk and references therein for recent developments, and Carot-Huot's talk for the AdS case].

- These gravitational positivity bounds were used to derive the mild form WGC [Hamada, Noumi, GS, '18]; [Bellazzini, Lewandowski, Serra, '19]; …

UV Sensitivity of Inflation

- Given the UV sensitivity of inflation, it is worthwhile to uncover possible consistency conditions on the irrelevant operators (at least up to dim 6 Planck suppressed operators).
- ∃ models where infinitely many irrelevant operators are important, e.g., DBI inflation [Silverstein, Tong];[Alishahiha, Silverstein, Tong]:

$$\mathscr{L} = \frac{1}{f(\phi)}\sqrt{1 + f(\phi) g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi} - \frac{1}{f(\phi)} + V(\phi)$$

- Models of this type have sizable non-Gaussianity with distinctive "shape"; [Chen, Huang, Kachru, GS] computed & classified such non-Gaussianity for a general class of theories:

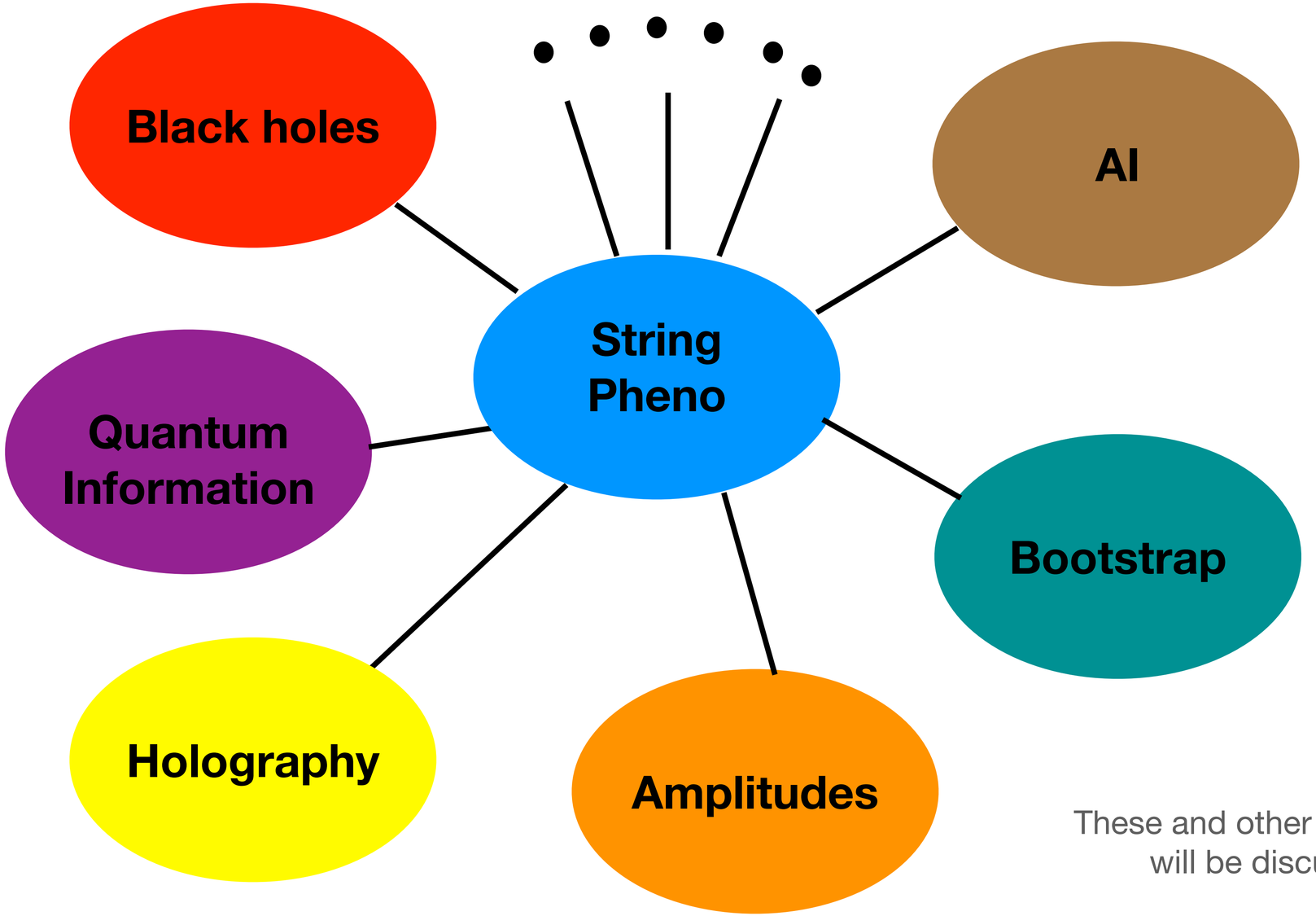
$$\mathscr{L} = P(X,\phi) \quad \text{where} \quad X = -\frac{1}{2} g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$$

- Within this class, DBI inflation stands out as a well-motivated model as we can trace its possible UV origin, but ∃ other models e.g., k-inflation [Arrmendariz-Picon, Damour, Mukhanov]:

$$P(X,\phi) = \frac{4}{9}\frac{(4-3\gamma)}{\gamma^2}\frac{1}{\phi^2}(-X + X^2)$$

- For some field values and choice of model parameter, the dominant energy condition is not satisfied and one finds superluminal propagation. Many such models are likely in the Swampland.

Looking Forward



These and other interesting connections will be discussed by Montero.

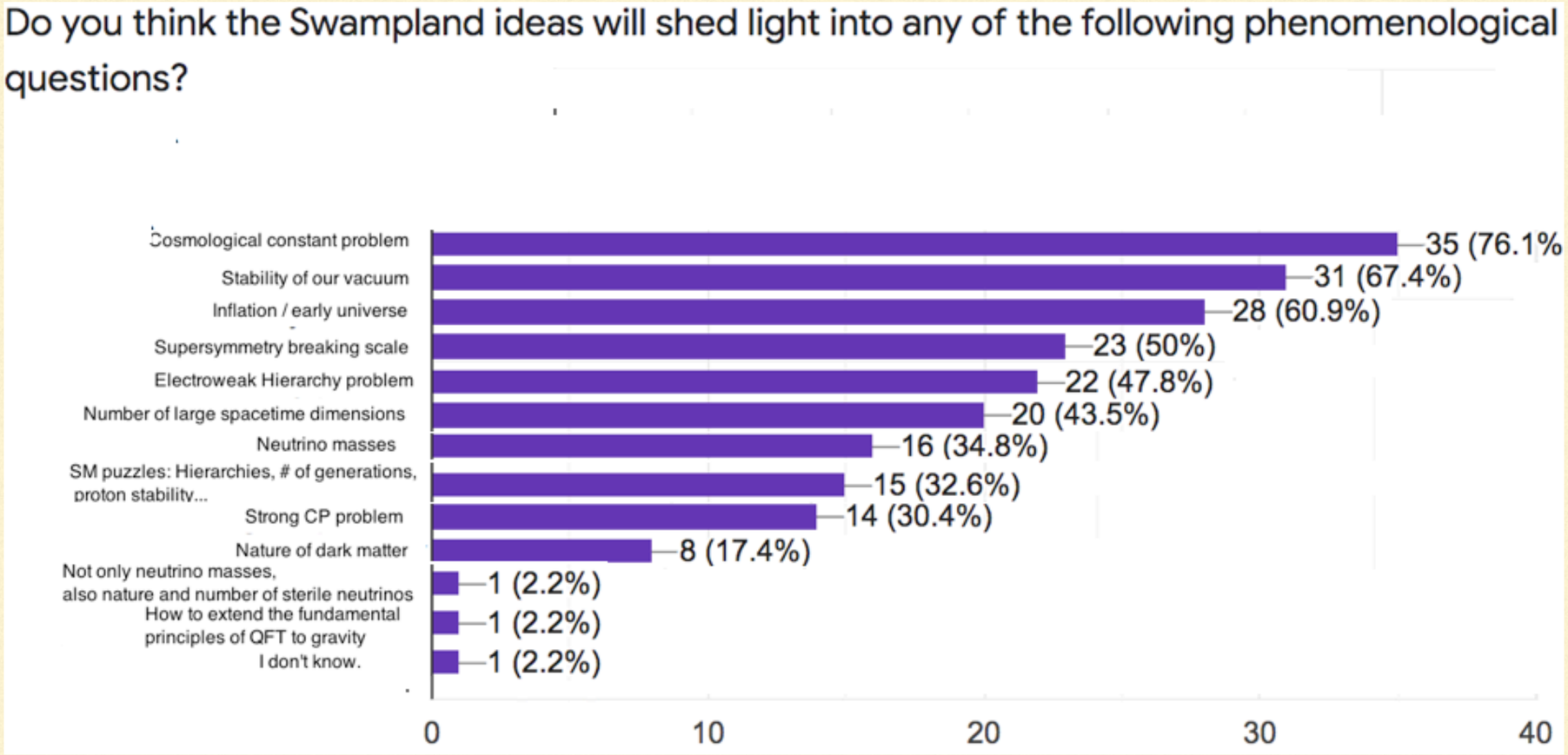
Open Questions

Contributions from Miguel Montero, Pablo Soler, and Ling Lin

A poll we carried out at the

Swampland Seminars & Open Mic Events

https://web.lists.fas.harvard.edu/mailman/lists/hetg-swampland.lists.fas.harvard.edu/



- Can we explain

$$m_\nu^4 \sim \rho_{\rm vacuum} = M_P^2 H^2$$

? Are light fermions **required** by quantum gravity?

[Ooguri-Vafa '16/Hamada-Shiu/Ibañez-Gonzalo-Valenzuela-(Martin-Lozano)-Herraez '17-'21/ Lust-Palti '19/ Rudelius '21/ MM-Van Riet-Vafa-Venken '19,'21]

[See Gonzalo's gong show talk]

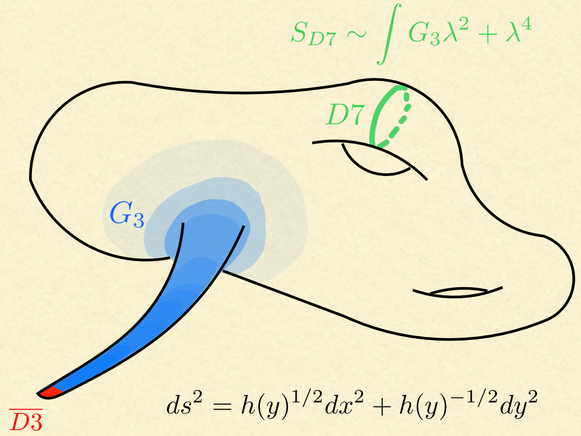
- Role of discrete parameters/symmetries in Swampland constraints?

$$m \leq \sqrt{2}\, g\, q\, M_P \quad \text{and} \quad q \leq N$$

$\mathbb{Z}_N$ How big can N be?

Relation to scale-separated vacua [Buratti-Calderon-Minino-Uranga '20]

- New insights & challenges in dS proposals (KKLT, LVS,…):



An apparent puzzle between 4d & 10d descriptions has been resolved by constructing **D7 action up to λ⁴**

[(Carta)-Moritz-(Retolaza)-Westphal '17,'18,'19/Gautason-Van Hemelryck-Van Riet-(Venken) '18,'19/Hamada-Hebecker-PS-Shiu '18, 19', 21'/Kallosh '19/ Bena, Graña, Kovensky, Retolaza '19/Kachru, Kim, McAllister, Zimet '19]

It has been argued that **generically** in KKLT, large parts of the bulk geometry become **singular**/stringy.

$$h(y) < 0 \text{ ???}$$

[Carta-Moritz-(Westphal) '19, '21 Gao-Hebecker-Junghans '20]

Other recent insights: small W_0, tadpole constraints, other constructions…

- Challenges are: mild issues / generic but avoidable / very serious ?

Similar questions about scale-separated AdS

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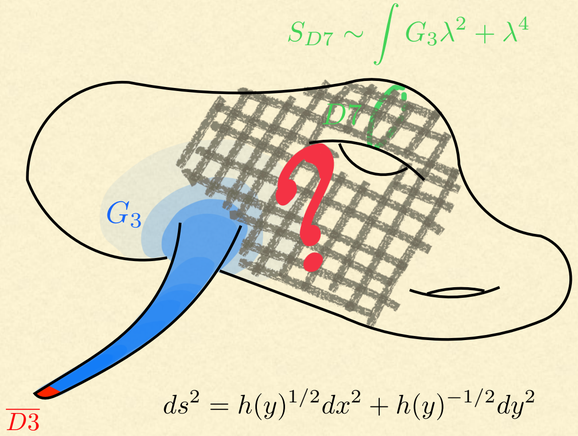

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Similar questions about scale-separated AdS

String Universality

- What can geometry teach us?

  - "Limitations" in model building can help quantify consistency conditions.
  - "Universal" string features may be an interplay of different physical aspects.

- What about non-gravitational theories?

  - "CFT distance conjecture" [Baume/Calderón-Infante '20, Perlmutter/Rastelli/Vafa/Valenzuela '20]
  - Classification of 6d SCFTs via F-theory [Heckman/Morrison/Rudelius/Vafa '15]

- Is there deeper unifying structure underlying different conjectures?

  - No-Global-Symmetries, Black Hole arguments, (String) Dualities, …
  - Synergies with S-matrix bootstrap / Positivity (cf. Monday's session) and holography

Particle physics

Neutrino-CC coincidence

Discrete syms/integer parameters in Swampland

Cosmology

dS & scale separated AdS:

Difficult but OK / strongly constrained / impossible

Singular bulk of KKLT?

String universality

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Richer structure in QFTs/CFTs

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Unifying principle(s)?

… but think **outside the box**(es)!