Weak Gravity Conjecture from Unitarity and Causality

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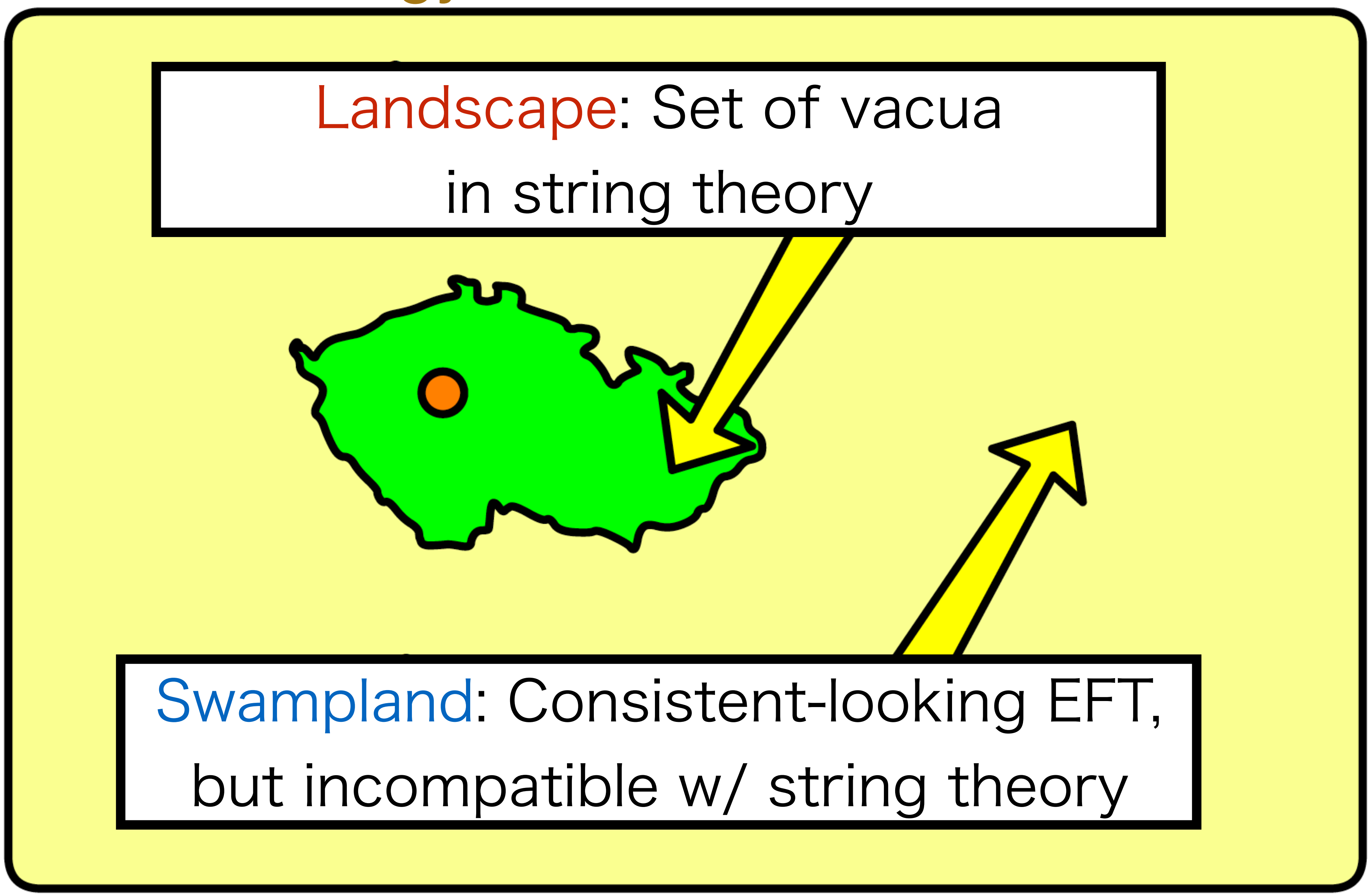
[Vafa ’05, Ooguri-Vafa ’06]

Landscape vs Swampland

Space of low energy EFT



[ArkaniHamed-Motl-Nicolis-Vafa ‘06]

Weak Gravity Conjecture(WGC)

- Statement:

  For U(1) gauge group, there exists at least one charged state which satisfies

$$|Q| \geq M$$

$2M_P^2=1$ unit

M: mass of the state,
Q: charge of the state

No counter-example in string theory.
However, this is still conjecture.

Message

- WGC follows from basic principles of QFT, unitarity & causality, for following two classes of theories.

[YH-Noumi-Shiu ’18]

- UV completion is weakly coupled and either

  (a) Theories w/ light (compared to string scale M_{st}) neutral boson (e.g. dilaton, moduli),

  (b) U(1) gauge boson from open string.

Black Hole as WGC state

- We focus on the possibility that Black hole(BH) is the state satisfying the WGC.

- If higher derivative corrections make extremal BH satisfy $|Q|>M$, then WGC is satisfied by extremal BH.

[Kats-Motl-Padi '06]

Effective action

- EFT of photon and graviton up to 4 derivative term.

$$S = \int d^4x\sqrt{-g}\Big[\frac{1}{4}R - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \alpha_1(F_{\mu\nu}F^{\mu\nu})^2 + \alpha_2(F_{\mu\nu}\widetilde{F}^{\mu\nu})^2 + \alpha_3 F_{\mu\nu}F_{\rho\sigma}W^{\mu\nu\rho\sigma} + \cdots\Big]$$

$W^{\mu\nu\rho\sigma}$: Weyl tensor

- Mass-charge ratio of extremal BH [Kats-Motl-Padi '06]

$$\frac{|Q|}{M} = 1 + \frac{2}{5}\frac{(4\pi)^2}{Q^2}(2\alpha_1 - \alpha_3) + \mathcal{O}(Q^{-4})$$

Higher derivative correction

- $2\alpha_1 - \alpha_3 \geq 0$ WGC.

[YH-Noumi-Shiu '18]

Strategy

- We show

F^4 term — F^2W term — Causality — Unitarity

$$\alpha_1 - 2\alpha_3 \simeq \alpha_1 > 0$$

if UV completion is (a) or (b):

(a) Theories w/ light neutral boson (e.g. dilaton, moduli)

(b) U(1) from open string

[YH-Noumi-Shiu '18]

Causality

- We show

F4 term   F2W term   Causality ↓

$$\alpha_1 - 2\alpha_3 \simeq \alpha_1$$

$$\alpha_3 \leq \mathcal{O}\left(\frac{1}{M_{st}^2}\right)$$

From causality argument, upper bound on α_3 is mass of closed string higher spin states.

[Camanho-Edelstein-Maldacena-Zhiboedov '14]

On the other hand, α_1 is much bigger in

(a) Theories w/ light neutral boson (e.g. dilaton, moduli).

(b) U(1) from open string.

[YH-Noumi-Shiu '18]

Unitarity

- We show

F^4 term F^2W term   Unitarity

$$\alpha_1 - 2\alpha_3 \simeq \alpha_1 > 0$$

We consider $\gamma\gamma$ scattering in forward limit.

The positivity of α_1 follows from

- Factorization of amplitude,
- Positive Residue (unitarity),
- Healthy behavior in UV (Froissart bound).

Spinning polynomial basis [Arkani Hamed-Huang-Huang '17] is used.

Summary

- WGC follows from unitary and causality if UV completion is weakly coupled and either

(a) Theories w/ light neutral boson (e.g. dilaton, moduli),

(b) U(1) gauge boson from open string.