Weak Gravity, Super-Planckian Fields and the Swampland Conjecture

[DK, Eran Palti, arXiv:1610.00010]

Daniel Klaewer

Max-Planck-Institute for Physics, Munich

String Phenomenology 2017, Virginia Tech

$\Delta p \cdot \Delta q \geq \frac{1}{2} \hbar$

Max-Planck-Institut für Physik

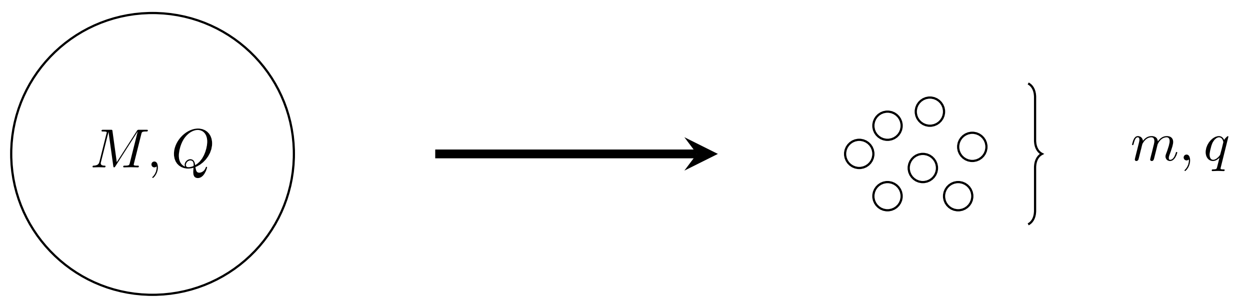
Outline

- Weak Gravity Conjecture (WGC) is motivated from semi-classical reasoning (spectrum of stable states, black hole decay)
- Swampland Conjecture (SC) is motivated from string theory
- Evidence for connection between the two, not relying on string theory
- We analyse super-Planckian spatial displacements of moduli
- Local versions of Weak Gravity Conjecture + bound on $\Delta\Phi$ result in Swampland Conjecture behavior

Introduction - The WGC

[Arkani-Hamed, Motl, Nicolis, Vafa ‘06]

- WGC: charged BHs should decay

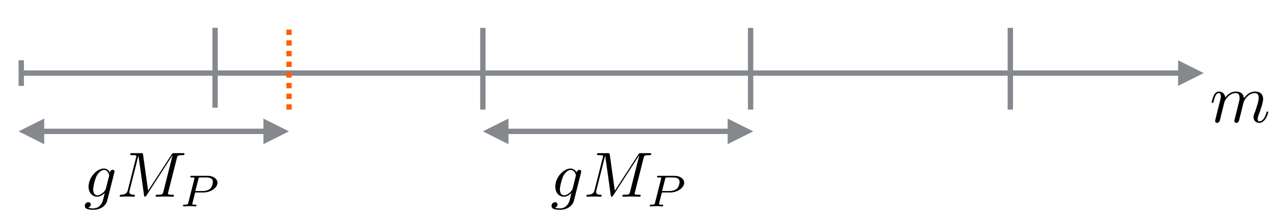


- This requires existence of particle with $m \lesssim gM_P$ (electric WGC) and cutoff to EFT $\Lambda \lesssim gM_P$ (magnetic WGC)

- Consistency with dimensional reduction requires lattice WGC

> There should exist a sub-lattice of the charge lattice consisting of super-extremal particle states
> [Heidenreich, Reece, Rudelius ‘16]

- Single $U(1)$:



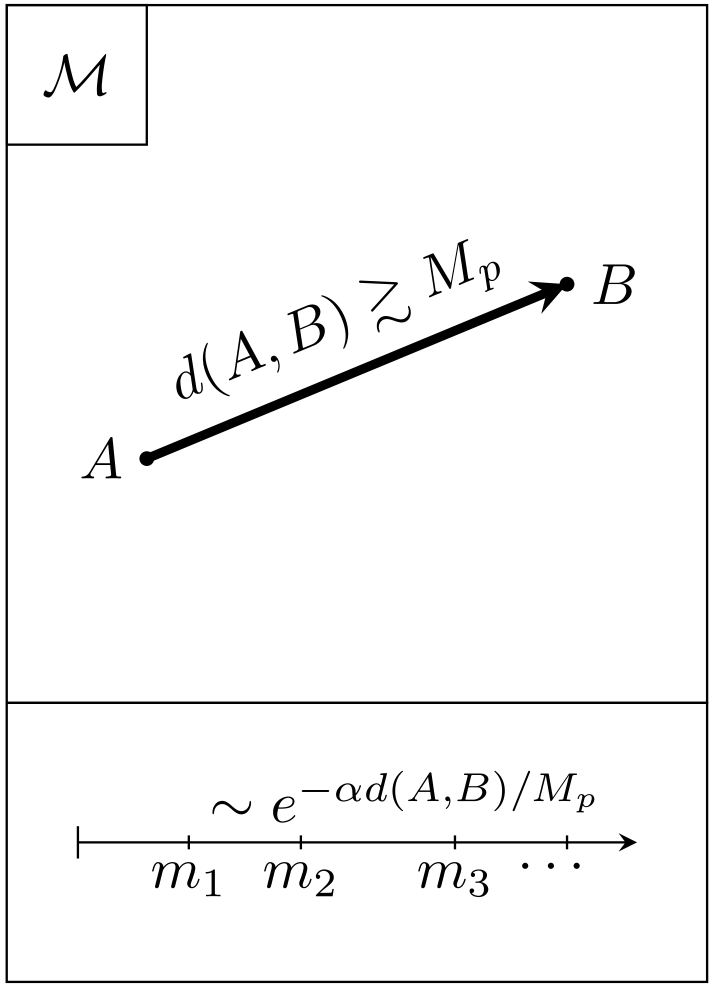
Introduction - The SC

[Ooguri, Vafa '06]

- Displacements in continuous moduli space of quantum gravity
- Asymptotic displacements ($d \to \infty$):

Compared to A, the theory at B has an infinite tower of light particles with mass scale decreasing exponentially in the distance

$$m_B \sim m_A e^{-\alpha d(A,B)/M_P}$$



- E.g. in ST: 1) IIB dilaton (F/D oscillators)

  2) IIA dilaton (F osc./M KK modes)

  3) ST on torus (KK/winding modes)

- However: no semi-classical basis for this so far!

A Refinement of the SC

- Obvious ways to "violate" the SC: 1) Shift symmetric axions

  2) Monodromous axions (subtle)

- Amount of violation is finite and can be quantified

- Moduli space has sub-Planckian diameter in axionic directions [Banks, Dine, Fox, Gorbatov '03], [Brown, Cottrell, Shiu, Soler '15], [Montero, Uranga, Valenzuela '15]

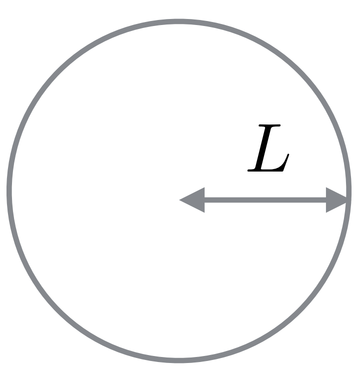
- Monodromous axions: potential leads to backreaction on saxions, SC behaviour seems to appear at $\Delta\phi = \mathcal{O}(1) M_P$ [Baume, Palti '16] [Blumenhagen, Valenzuela, Wolf '17]

- This motivates the refined SC:

$$m_{\mathrm{SC}}(\phi_0 + \Delta\phi) \leq m_{\mathrm{SC}}(\phi_0) e^{-\alpha \Delta\phi / M_P} \quad \text{for} \quad \Delta\Phi > \mathcal{O}(1) M_P$$

WGC → SC?

- Two unrelated infinite towers of states? Inefficiency of QG?
- In highly supersymmetric settings often $g \sim e^{-\alpha\phi}$
- e.g. toroidal KK reduction



$$S \supset \int \frac{dL \wedge \star dL}{L^2} \qquad \phi \sim \ln L$$

$$g \sim \frac{1}{L} \qquad m_{\rm KK} \sim \frac{1}{L} \sim e^{-\alpha\phi}$$

→ Lattice Weak Gravity Conjecture implies Swampland Conjecture

Our Setup

- WGC setup of $U(1)$ and gravity but the gauge coupling is a modulus

$$S = \frac{1}{2}\int \left[\star R - 2d\phi \wedge \star d\phi - \frac{1}{g(\phi)^2} F \wedge \star F\right]$$

- Natural question: Lattice WGC tower = SC tower?

$$g(\phi_0 + \Delta\phi) \leq g(\phi_0) e^{-\alpha \Delta\phi / M_P} \quad \text{for} \quad \Delta\phi > \mathcal{O}(1) M_P$$

- Study spherically symmetric solutions with gauge field background

→ induces running of $\phi(r)$

- Ingredients: 1) Local electric WGC gives relation to SC

  2) Local magnetic WGC constrains running of $g(\phi(r))$

  3) Gravitational bound on growth of $\phi(r)$ (avoid collapse)

The Local Weak Gravity Conjecture

- Assume that the WGC holds locally on consistent solutions:

$$m(r) \lesssim g(r) M_P$$

- Also local version of the magnetic WGC: local length scales should be above WGC cutoff

$$\frac{1}{L(r)} \lesssim g(r) M_P$$

- Hubble scale ($H M_P \simeq \rho^{1/2}$) should be below WGC cutoff

$$\rho(r)^{1/2} \lesssim g(r) M_P^2$$

- Strong gravitational fields: curvature scale below WGC cutoff

$$\sqrt{R(r)} \lesssim g(r) M_P$$

Weak Curvature - Log Behavior

(see also [Nicolis '08])

- First work in Newtonian description (valid as long as $|\Phi| < 1$)

$$ds^2 = -\left[1 + 2\Phi(r)\right] dt^2 + \left[1 - 2\Phi(r)\right]\left(dr^2 + r^2 d\Omega^2\right)$$

- Consider power law profile

$$\phi(r) = \frac{\beta}{\alpha}\left(\frac{r}{r_F}\right)^{1/\beta}$$

$$\Delta\phi = \frac{\beta}{\alpha}\left(1 - \left(\frac{r_*}{r_F}\right)^{1/\beta}\right) \qquad \Delta\Phi = \frac{\Delta\phi}{\alpha}\left(1 + \left(\frac{r_*}{r_F}\right)^{1/\beta}\right) \geq \frac{\Delta\phi^2}{\beta}$$

- Consequently in the Newtonian regime $\beta > \Delta\phi^2$
- Since $\beta\left(1 - x^{1/\beta}\right) = -\ln(x) + \mathcal{O}(1/\beta)$ it follows that for $\Delta\phi > 1$ we quickly have

$$\Delta\phi \to \frac{1}{\alpha}\log\left(\frac{r_F}{r_*}\right)$$

Weak Curvature - Gauge Coupling

- For the log running of $\phi(r)$ have exponential running of $\rho(\phi)$

$$\frac{\rho(\phi(r_F))^{1/2}}{\rho(\phi(r_*))^{1/2}} = \frac{r_*}{r_F} \leq e^{-\alpha\Delta\phi}$$

- Introducing $\gamma = g/\rho^{1/2}$ we can write

$$\frac{g(\phi+\Delta\phi)}{g(\phi)} \leq \frac{\gamma(r_F)}{\gamma(r_*)} e^{-\alpha\Delta\phi}$$

- Magnetic local WGC: $\gamma > 1$

- From evaluating the equations of motion we estimate

$$\gamma(r_F) < -\alpha\partial_\phi(\ln g)|_{\phi(r_F)} \lesssim \alpha^2$$

→ SC behavior for $\Delta\phi > 1$

The Strongly Curved Case

- Relax the Newtonian assumption, general spherically symmetric solution

$$ds^2 = -e^{2U(r)}dt^2 + e^{-2U(r)}(dr^2 + f(r)r^2 d\Omega^2)$$

- Trace of EE is independent of $g(\phi)$
- We re-parametrize

$$U = -\frac{\alpha}{1+\alpha^2}\ln\left(H_1^{\alpha}H_2^{1/\alpha}\right) + \frac{1}{2}\ln f \qquad \phi = \frac{\alpha}{1+\alpha^2}\ln\left(\frac{H_1}{H_2}\right)$$

and find

$$2\alpha\frac{\nabla^2 H_1}{H_1} + \frac{2}{\alpha}\frac{\nabla^2 H_2}{H_2} + \frac{1+\alpha^2}{\alpha}\frac{\nabla^2(rf) - \frac{2}{r}}{rf} = 0$$

- Has simple solutions for H_i harmonic, for $\Delta\phi \gtrsim 1$ find $\phi \simeq \frac{\alpha}{1+\alpha^2}\ln r$
- We then find $\sqrt{R} \sim r^{-\frac{\alpha^2}{1+\alpha^2}}$, which together with $\sqrt{R} < g(r)M_P$

→ leads again to SC behavior!

Testing the SC in String Theory

- Several recent advances in testing the SC in string theory

  1) Proof of the SC in Calabi-Yau compactifications [Palti '17]

  2) Indications of SC as aspect of WGC different from those presented in this talk [Palti '17]

  3) Non-trivial tests of M_P as critical distance with non-geometric fluxes inducing axion monodromy, also including open string moduli [Blumenhagen, Valenzuela, Wolf '17]

- Axion monodromy inflation: need to evade the SC

  1) Delay SC behavior beyond M_P

  2) Complicated trajectories in field space

Conclusion

Summary

- First bottom-up evidence for the SC through the WGC
- Studied spatial displacements of gauge couplings
- The SC tower is identified with the lattice WGC tower

Open Questions

- Can the SC behavior be delayed beyond M_P after all?
- Can complicated potentials evade the SC?
- What are the constraints on α?

Thank You