The FL bound and its implications

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[Miguel Montero, Thomas Van Riet, GV ‘19] 1910.01648

[Miguel Montero, Thomas Van Riet, GV ‘20] 2001.11023

[Miguel Montero, Thomas Van Riet, GV, Cumrun Vafa ‘21] 2106.07650

DESY 22/09/2021 Bright ideas for a dark universe

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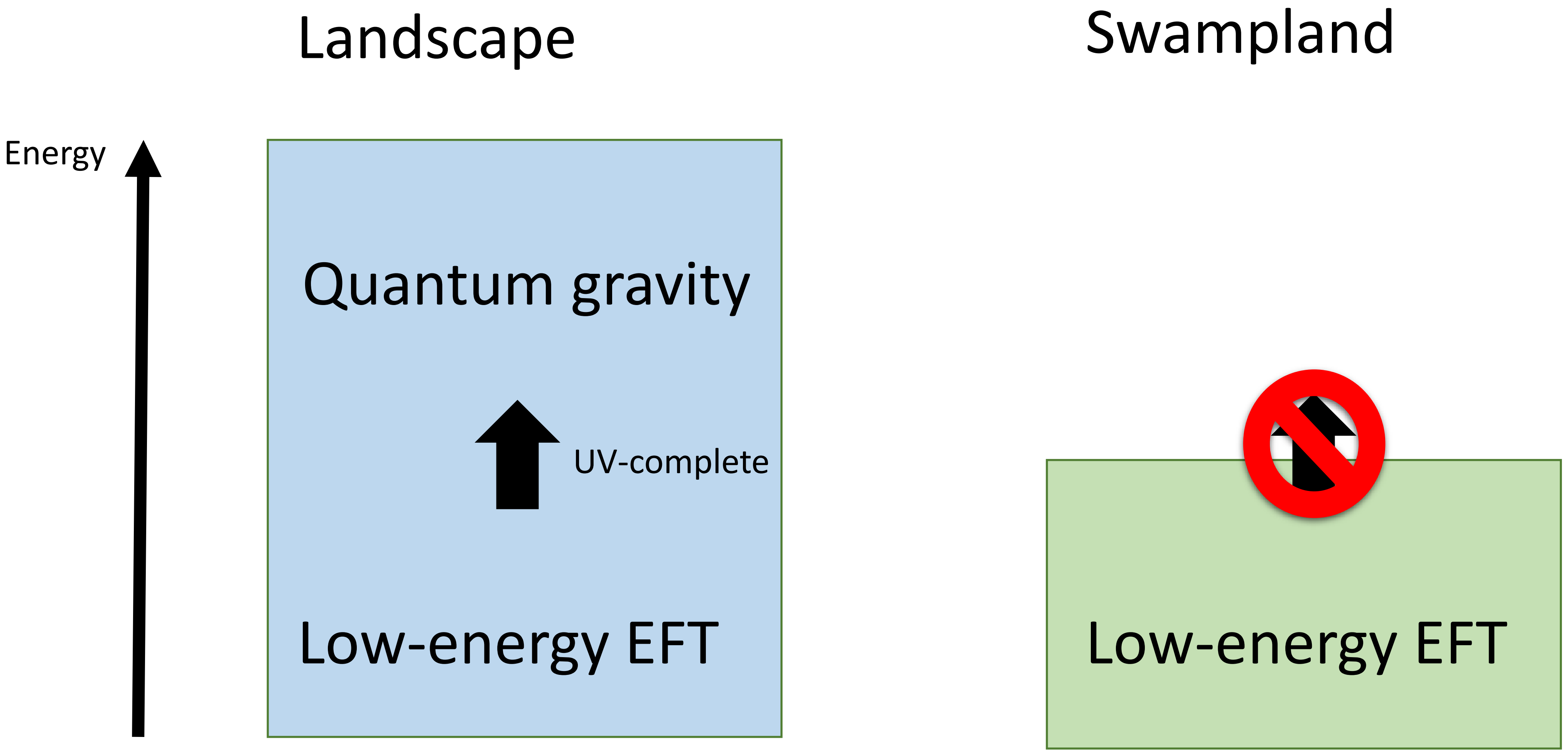
Motivation

Naively, quantum gravity hard to test/observe directly at low energy, only expect quantum gravity effects to become important at M_p : (



Swampland program: conjecture and argue for web of consistency conditions

Electric weak gravity conjecture

[Arkani-Hamed, Motl, Nicolis, Vafa '07]

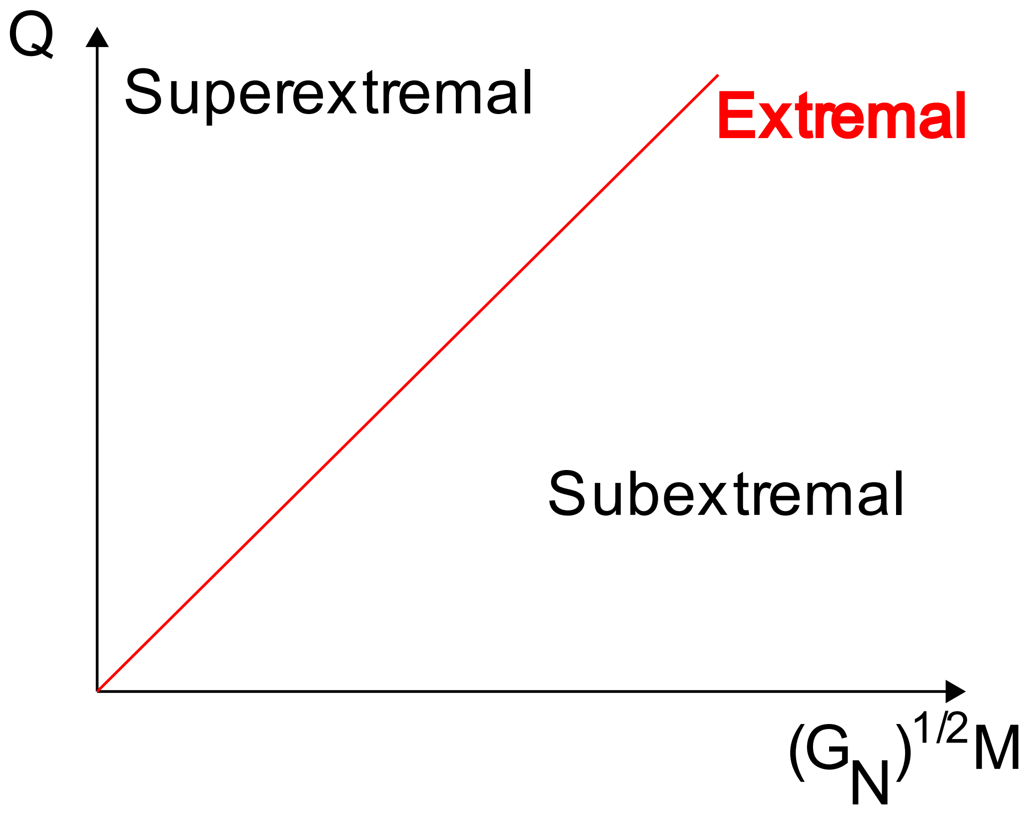
There must be a state with

$$m < \sqrt{2}\, g\, q\, M_p$$

In any gravity theory with a U(1) gauge field

Black hole gave original argument for this

Charged black holes in flat space



Electric weak gravity conjecture:
All U(1) charged black holes must be able to decay
-> must have states with

$$m < \sqrt{2}\, g\, q\, M_p$$

Electric weak gravity conjecture

There must be a state with

$$m < \sqrt{2}\, g\, q\, M_p$$

In any gravity theory with a U(1)

Black hole gave original argument for this, by now evidence from many other directions

Different swampland conjectures tend to form a web that reinforce each other

This talk

Apply this Swampland philosophy to de Sitter space (and more!)

de Sitter describes our current cosmic expansions and inflation, so should hopefully get interesting constraints

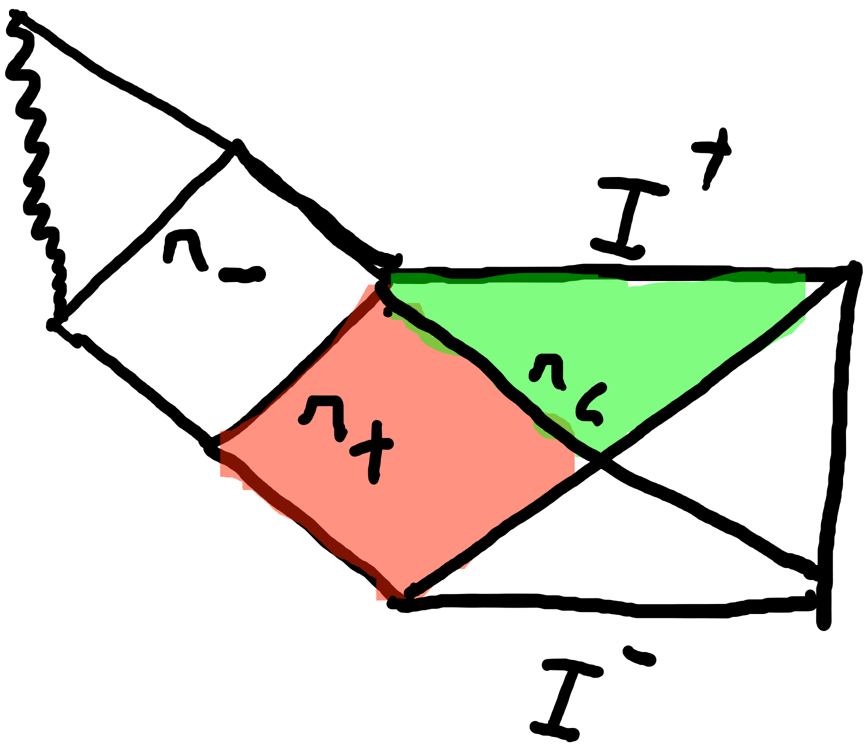
Outline

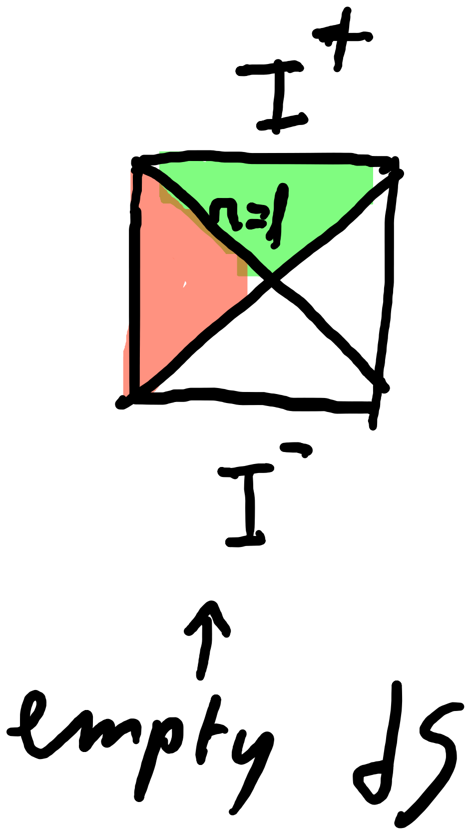
Part I: Explain FL bound and motivation for it

Part II: Implications of the FL bound

Part I:
The FL bound..

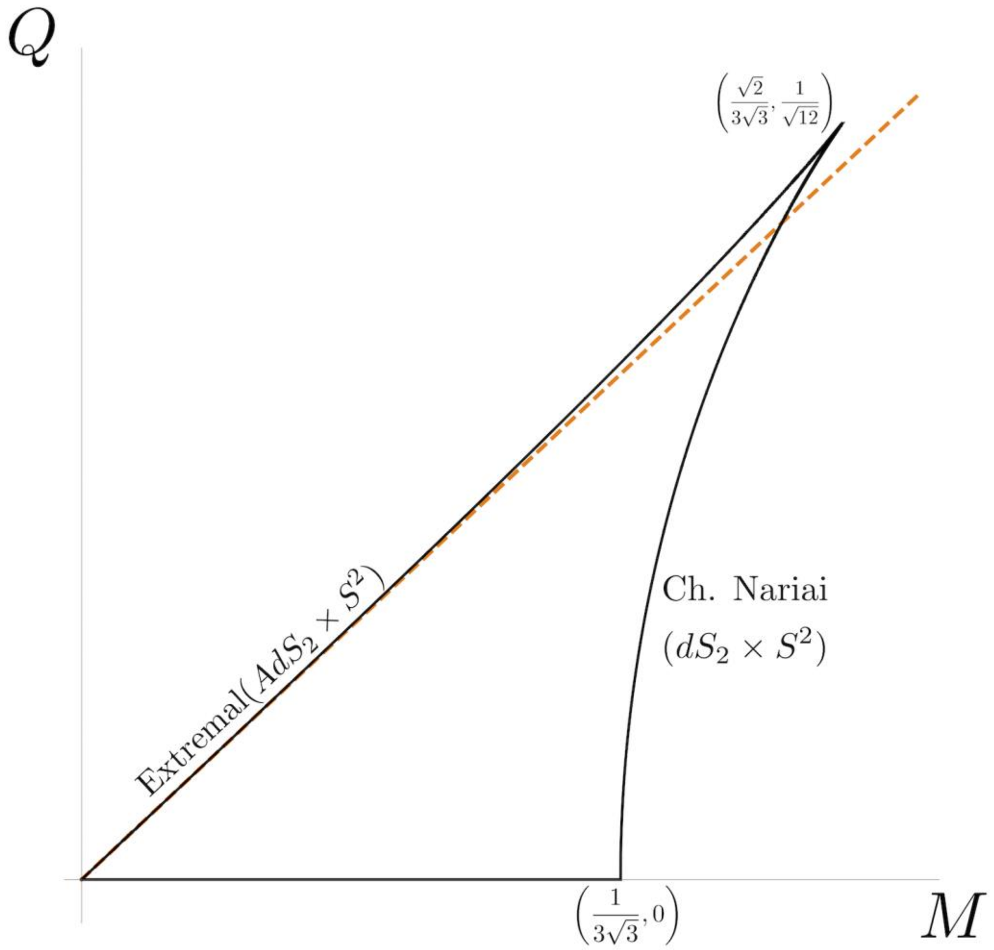
Black holes in de Sitter space





There are now three horizons. Size cosmic horizon backreacts, shrinks, due to presence black hole $r_c \leq l$

Black holes in de Sitter space



Total entropy given by

$$S = \frac{\pi}{4G_N}\left(r_+^2 + r_c^2\right)$$

But empty de Sitter space has highest entropy due to backreaction cosmic horizon.

We will demand all charged black holes evaporate back to empty de Sitter, seems like the sensible behaviour

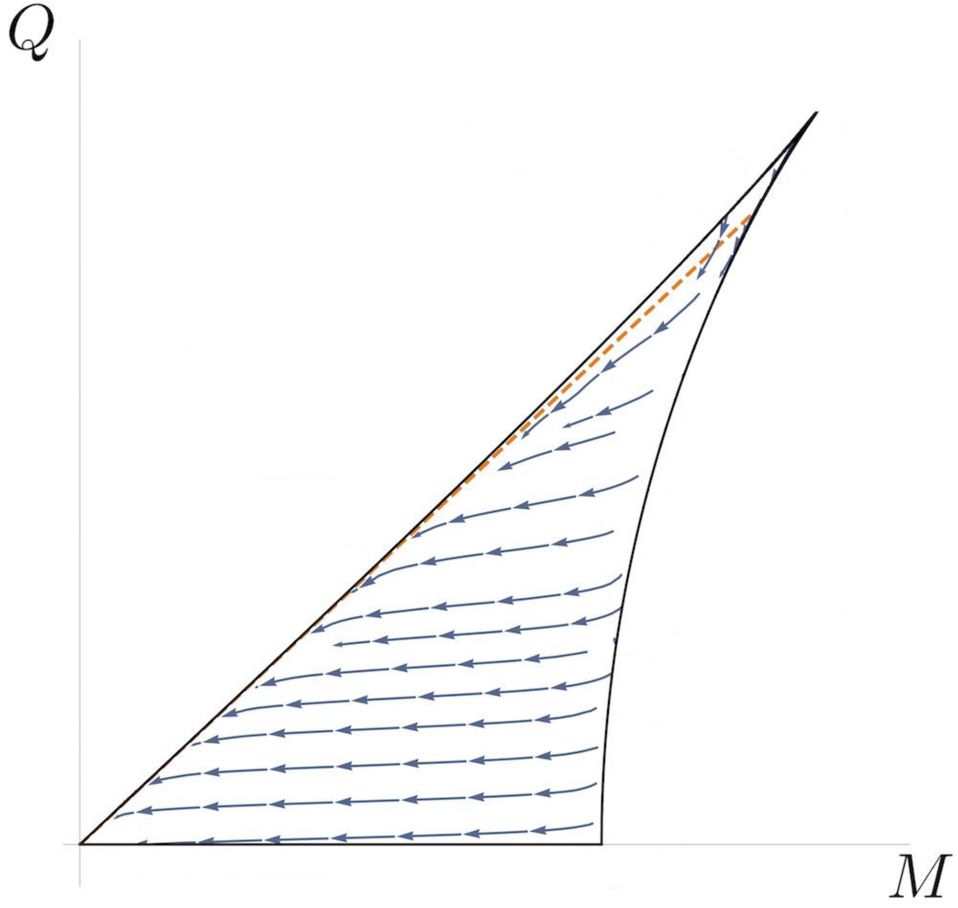
How BHs evaporate will depend on mass m and charge q of particles/states in theory.

Total entropy given by

$$S = \frac{\pi}{4G_N}\left(r_+^2 + r_c^2\right)$$

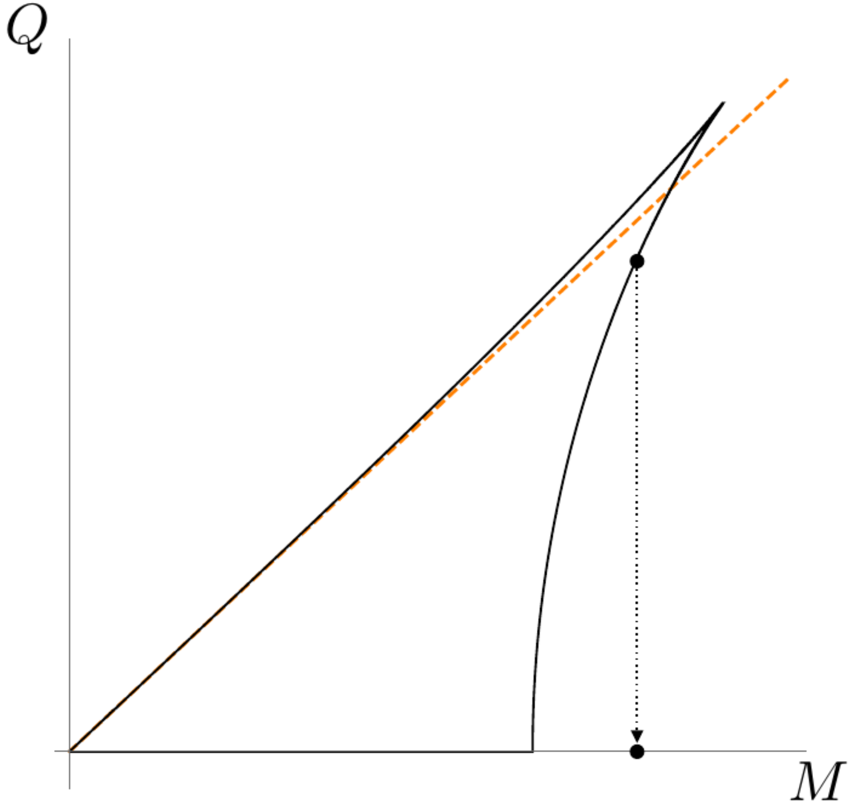
But empty de Sitter space has highest entropy due to backreaction cosmic horizon.

Slow evaporation $m^2 \gg qE$



$$\frac{dM}{dQ} = \frac{\dot{M}}{\dot{Q}} = G\sqrt{U(r_g)}\frac{\mathcal{T}}{\mathcal{J}} + \frac{Q}{r_g}$$

Rapid regime $\quad m^2 \ll qE$

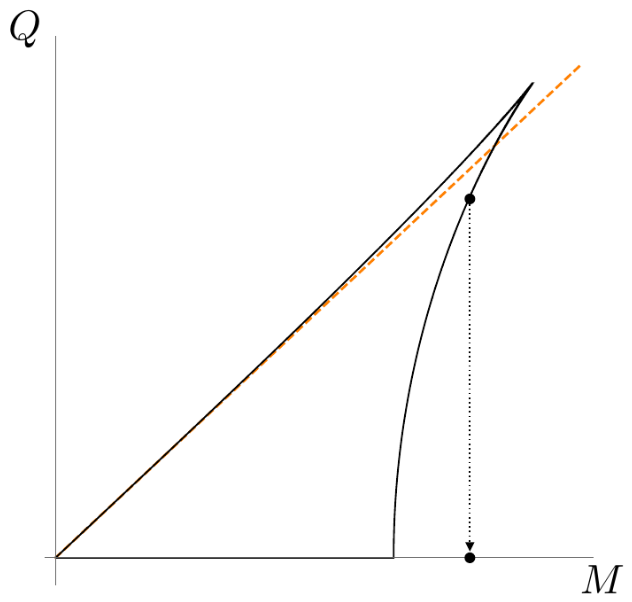


Demand black holes evaporate back to empty de Sitter space = avoid rapid regime

$$m^2 \gtrsim q\, g M_P H$$

Festina Lente (hurry slowly) bound:
Black holes should decay, but not too quickly

$$m^2 \gtrsim q\, g M_P H$$



Black hole argument based on our intuition of sensible BH behaviour, but do not have proof BHs must behave this way (Worked for WGC)

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Since then have expanded in various ways

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Extensions

The Festina Lente (FL) bound: If the signs of V' and f' are the same, and the inequalities

$$\frac{V'}{V} \leq (d-3)\frac{f'}{f} \quad \text{and} \quad V'' \geq \frac{V'}{f'}\left(f'' - 2\frac{f'^2}{f}\right) \tag{2.16}$$

are satisfied, there exist classically stable electric Nariai solutions to which we can apply the bound that **every** particle of charge q and mass m must satisfy the inequality

$$m^4 \gtrsim 6(gqM_P H)^2 = 2(gq)^2 V. \tag{2.17}$$

$$f = \frac{1}{g^2}$$

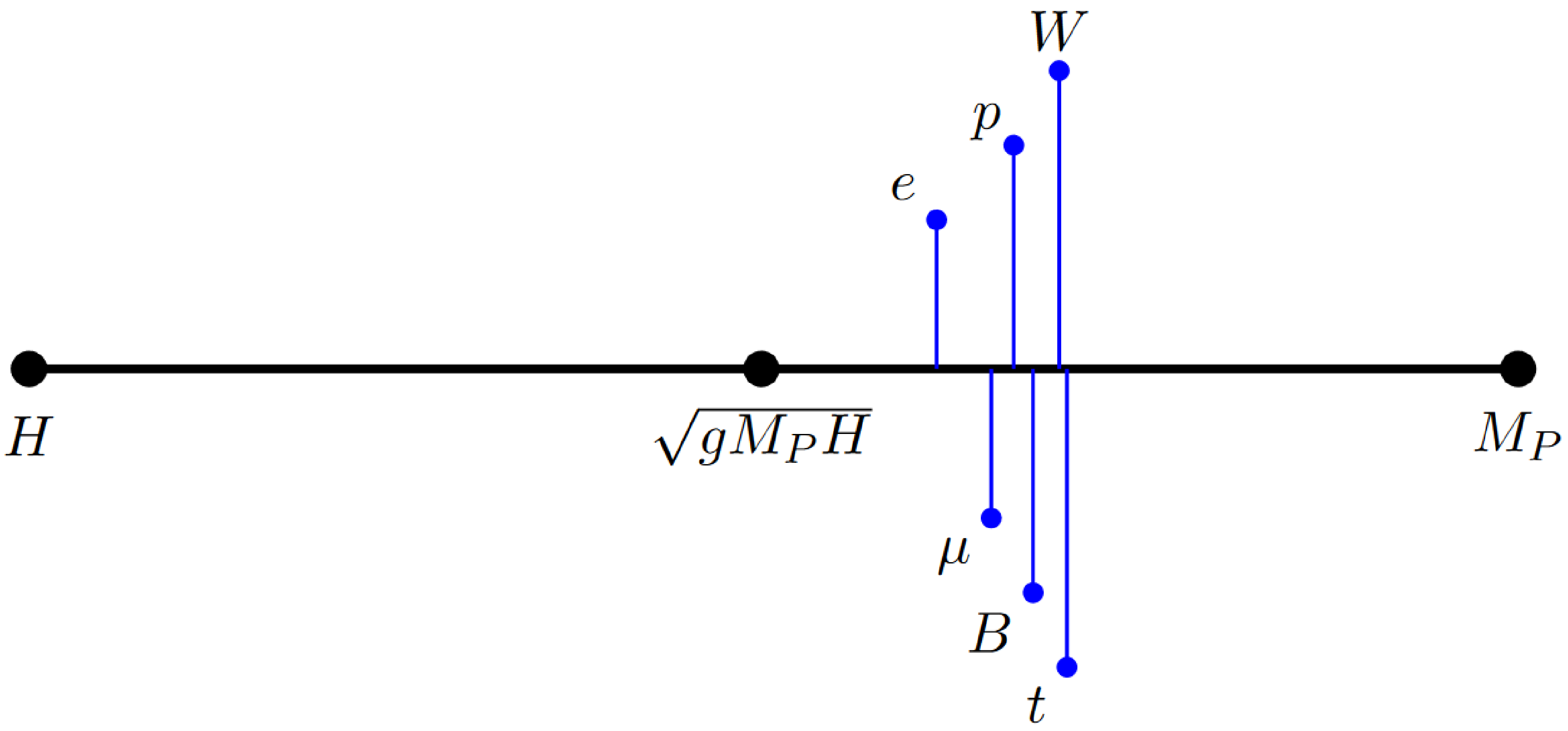
Part II:
..and its implications

$$m^2 \geq \sqrt{6} g q M_p H$$

Real world $\sqrt{g M_P H} \sim 10^{-3}\, eV$

Electron m=0,5MeV so satisfies this bound

Hierarchy



Non-Abelian gauge fields

SU(N) gauge theory:

Non-Abelian vector fields themselves charged under U(1) subgroup SU(N)

$$m^2 \gtrsim q\, g M_P H$$

Would violate our bound if massless

$$m_{\text{Gauge field}} \gtrsim H, \quad \text{or} \quad \Lambda_{\text{Confinement}} \gtrsim H$$

True in the real world!

Extra dimensions

When doing Kaluza-Klein reduction, have KK-photon

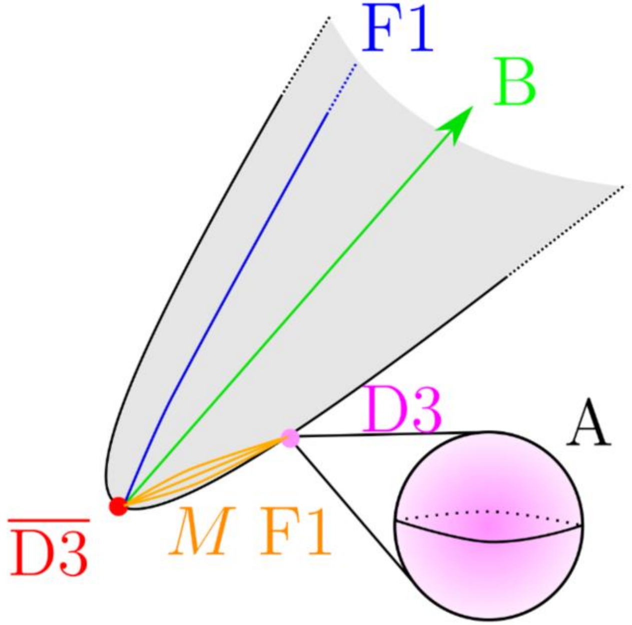
Fields charged under this, imposing FL bound with charged radion field

$M_{\mathrm{KK}} \gtrsim V^{1/2}$ in Planck units

String compactifications with positive vacuum energy must be (weakly) scale separated

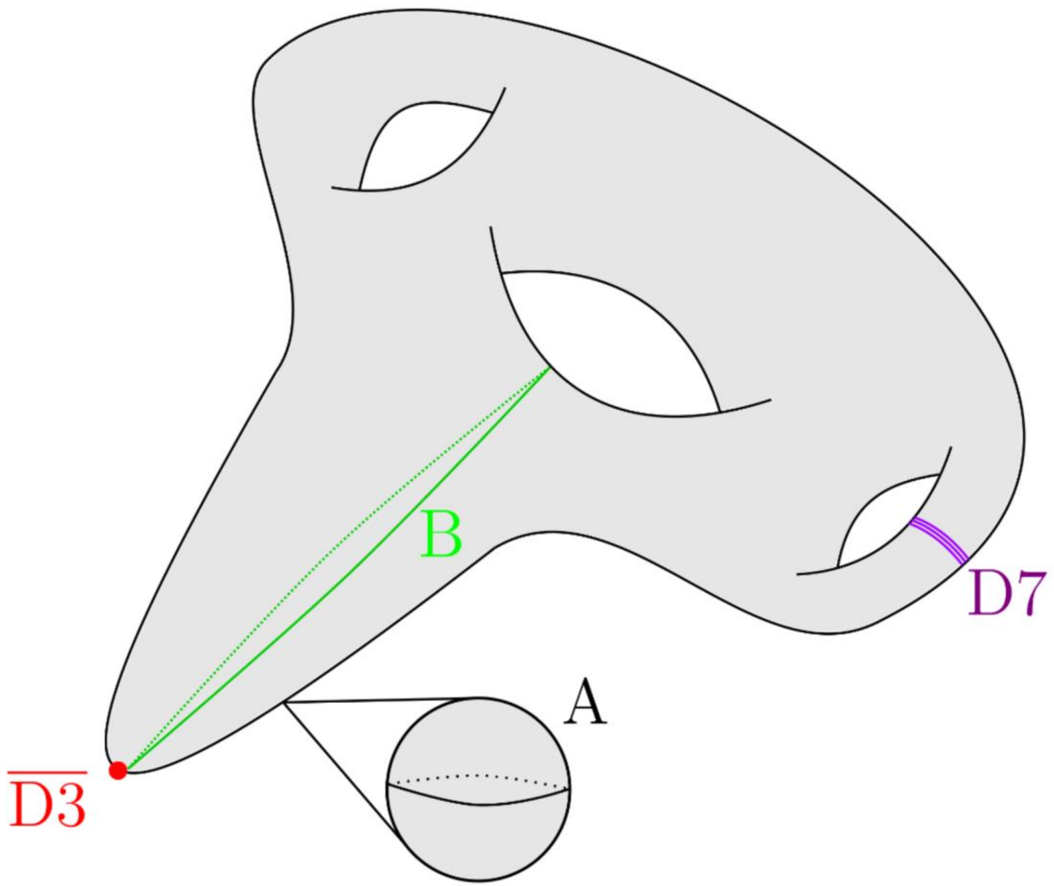
String compactifications

dS model building proposals such as KKLT or LVS rely on warped throats in the internal dimensions to uplift to de sitter



Their charged states obey FL bound in regime where throat is expected to be stable

All elements internal geometry must talk to each other when uplifting to de Sitter



Lack of decoupling -> hard to construct controlled de Sitter vacua in string theory

Conclusions

The Festina Lente (FL) bound: If the signs of V' and f' are the same, and the inequalities

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Have discussed some implications today

Many others: FL bound from charged domain walls, extension magnetic WGC in de Sitter space, nontrivial flat space field theory limit FL bound, constraints on SuGra models with charged gravitini, inflation constraints,..