Axions and Festina Lente

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COSMIC WISPers 1st general meeting

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[Montero, Van Riet, GV ’19], [Montero, Vafa,Van Riet, GV ’21], [Guidetti, Righi, GV, Westphal ‘22]

Outline

- What is Festina Lente [Montero, Van Riet, GV ’19], [Montero, Vafa,Van Riet, GV ’21]
- Axions and Festina Lente [Guidetti, Righi, GV, Westphal ‘22]
- Pheno implications

Swampland conjectures/bounds

Festina Lente is a swampland bound

Swampland bounds: constraints on low-energy EFT by demanding couple consistently to quantum gravity

Swampland constraints and black holes

Swampland bounds: constraints on low-energy EFT by demanding couple consistently to quantum gravity

Argued for both from string theory analysis and by demanding that Black holes “behave nicely”

In particular

-No Global Symmetries Conjecture

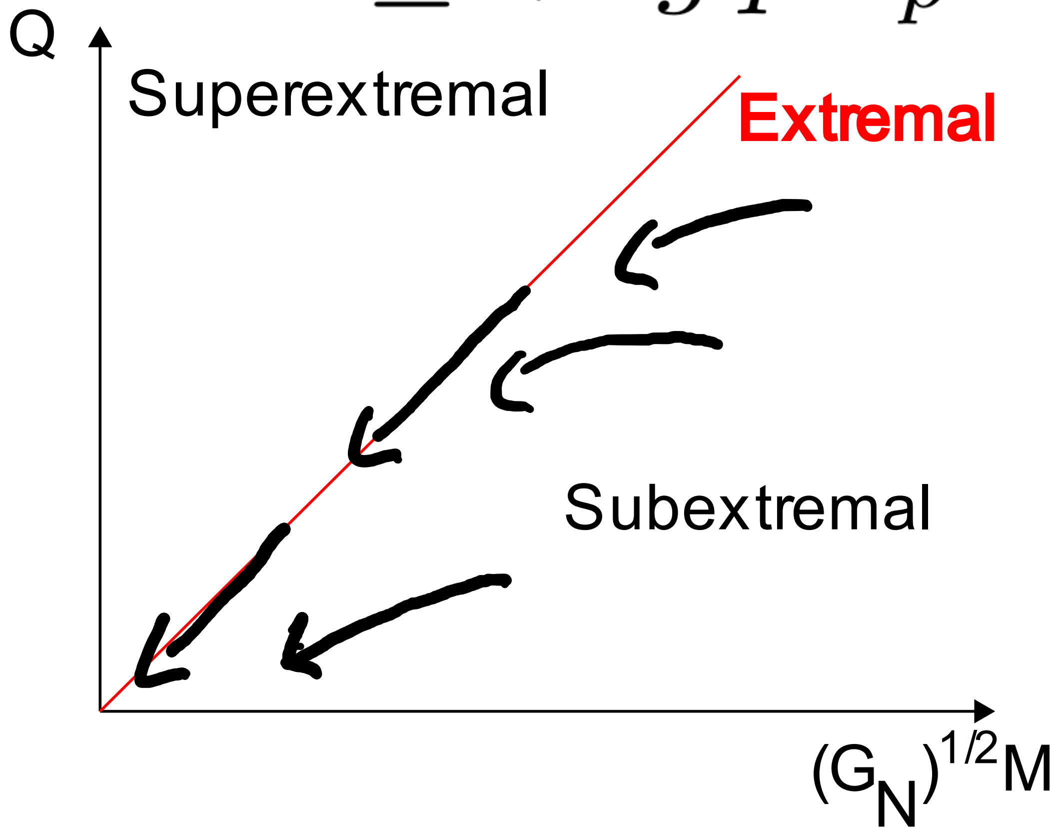
-Weak Gravity Conjecture

Follow from demanding that black holes in flat space evaporate back to empty space

Analogue in de Sitter space?

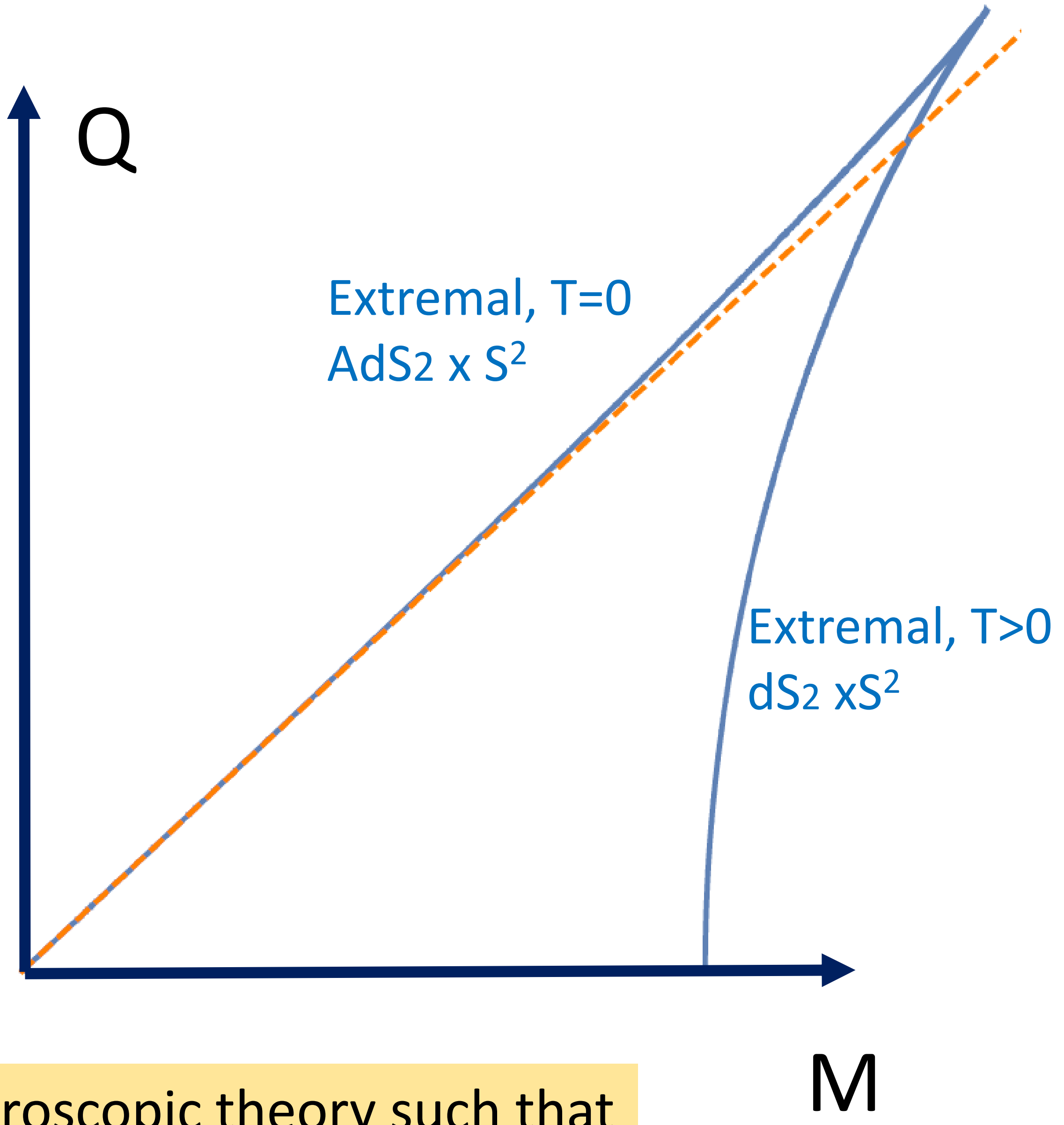
Weak Gravity Conjecture:

$$m \leq \sqrt{2} g q M_p$$



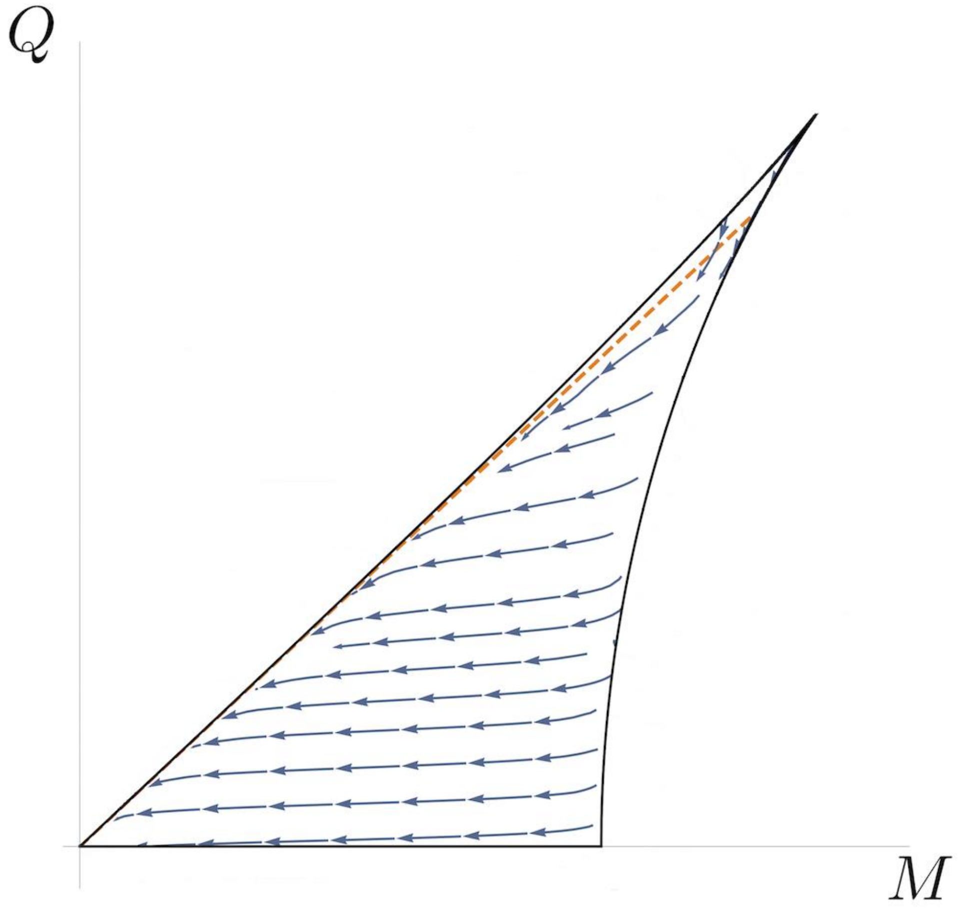
Weak gravity analogue in de sitter?

- **Left extremal branch**. Like in flat space. Extremal BHs with charge approximately equal to mass in Planck units
- **Right extremal branch. Charged Nariai.** Gigantic black holes probing cosmic horizon. Super-extremal if black hole horizon catches up with cosmic horizon. Should be forbidden = *Cosmic censorship*.



Guiding principle: constrain microscopic theory such that black holes *do not decay to the super-extremal side*.

Quasistatic $m^2 \gg qE$

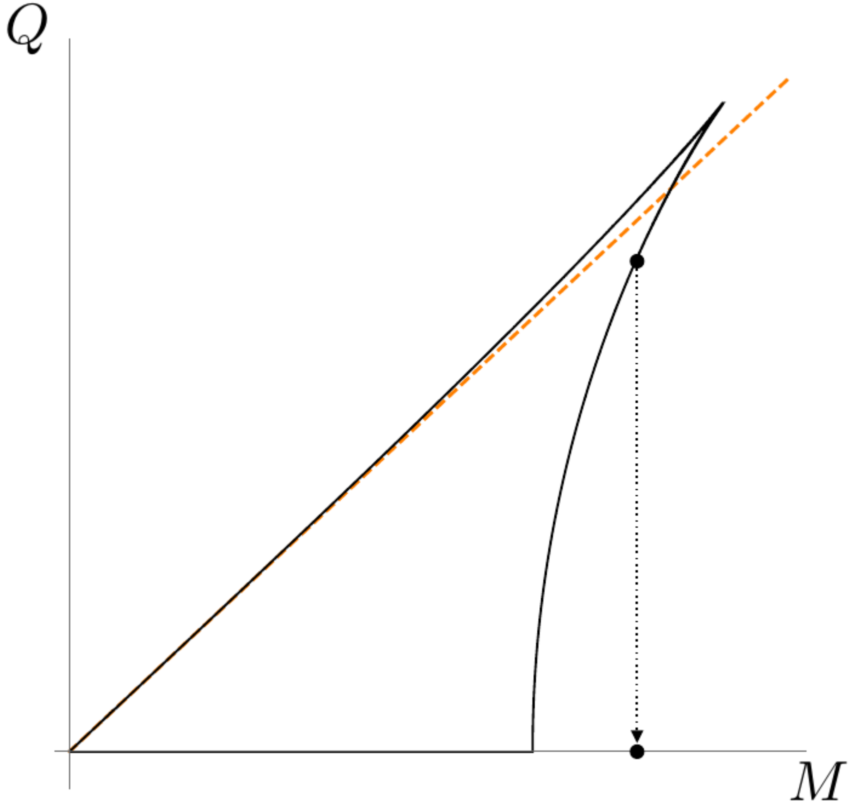


$$\frac{dM}{dQ} = \frac{\dot{M}}{\dot{Q}} = G\sqrt{U(r_g)}\,\frac{\mathscr{T}}{\mathscr{J}} + \frac{Q}{r_g}$$

$$\mathscr{T} = \frac{\sigma}{(4\pi)^3}\left[r_c^2 U'(r_c) - r_+^2 U'(r_+)\right]$$

$$\mathscr{J} = \sqrt{\frac{g^2 G}{4\pi\ell^2}}\,\frac{2}{\sqrt{U(r_g)}r^2}\,\frac{r_c^2\, r_+^2}{r_c^2 + r_+^2}\int_{r_+}^{r_c} dr'\,\Gamma(r')$$

Rapid regime $m^2 \ll qE$



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

All charged particles should obey

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

Festina Lente (FL) bound: [Montero, Van Riet, GV '19]

Black holes should decay, but not too quickly

(Also evidence for bound from string theory)

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

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

Electron m=0,5MeV so satisfies this bound

All particles must obey this bound.

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 long-range nonabelian gauge fields massless!

SU(N) gauge theories must always be either confined or Higgsed, with characteristic scale above Hubble scale

Applications of Festine Lente

So far have mainly compared FL with known physics. FL makes strong predictions which agree with the real world! Of course this is more postdiction

But any new physics must also obey this bound see e.g.

-Dark Sector constraints [Montero, Munoz, Obied ‘22]

-SUSY breaking: gravity mediation strongly preferred [Dalianis, Farakos, Kehagias ‘23]

-Inflation: early universe H larger [Montero, Van Riet, GV ’19]

-Axion constraints [Guidetti, Righi, GV, Westphal ‘22]

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Festina Lente for axions?

So far have discussed U(1) gauge theory and charged particles.

How to get analogous bound for axions and instantons?

String theory:

Consider charged particle to be D*p*-brane wrapping *p*-cycle, to translate Festina Lente into geometric statement

Now consider Euclidean D*(p-1)*-brane wrapping this cycle and translate the geometric statement into a statement about instantons and axions.

Axionic Festina Lente

S: instanton action
f: axion decay constant

$$\frac{M_P}{Sf} \lesssim \sqrt{\frac{M_P}{H}}$$

Axionic Festina Lente + Axion WGC

S: instanton action
f: axion decay constant

Left bound: Axion WGC
Right bound: Axionic Festina Lente

$$\frac{1}{\sqrt{2}} \leq \frac{M_P}{Sf} \lesssim \sqrt{\frac{M_P}{H}}$$

Kinetic mixing

$$\mathcal{L} \supset -\frac{1}{2g_{\rm v}^2} F' \wedge \star F' - \frac{1}{2g_{\rm h}^2} G' \wedge \star G' + \frac{\chi}{g_{\rm v} g_{\rm h}} F' \wedge \star G' - \frac{a'}{8\pi^2} G' \wedge G'$$

Diagonalize this action

$$\mathcal{L} \supset -\frac{1}{4}\left(1-\chi^2\right) F \wedge \star F - \frac{1}{4} \hat{G} \wedge \star \hat{G} - \frac{a}{NSf}\left(\hat{G} \wedge \hat{G} + \chi \hat{G} \wedge F + \chi F \wedge \hat{G} + \chi^2 F \wedge F\right)$$

Contains coupling between axion and visible photon $\mathcal{L} \supset -g\, a\, F \wedge F$

(g dimension of inverse mass, experiment g<$10^{-10} GeV^{-1}$ for photon)

Applying aFL provides lower bound on kinetic mixing

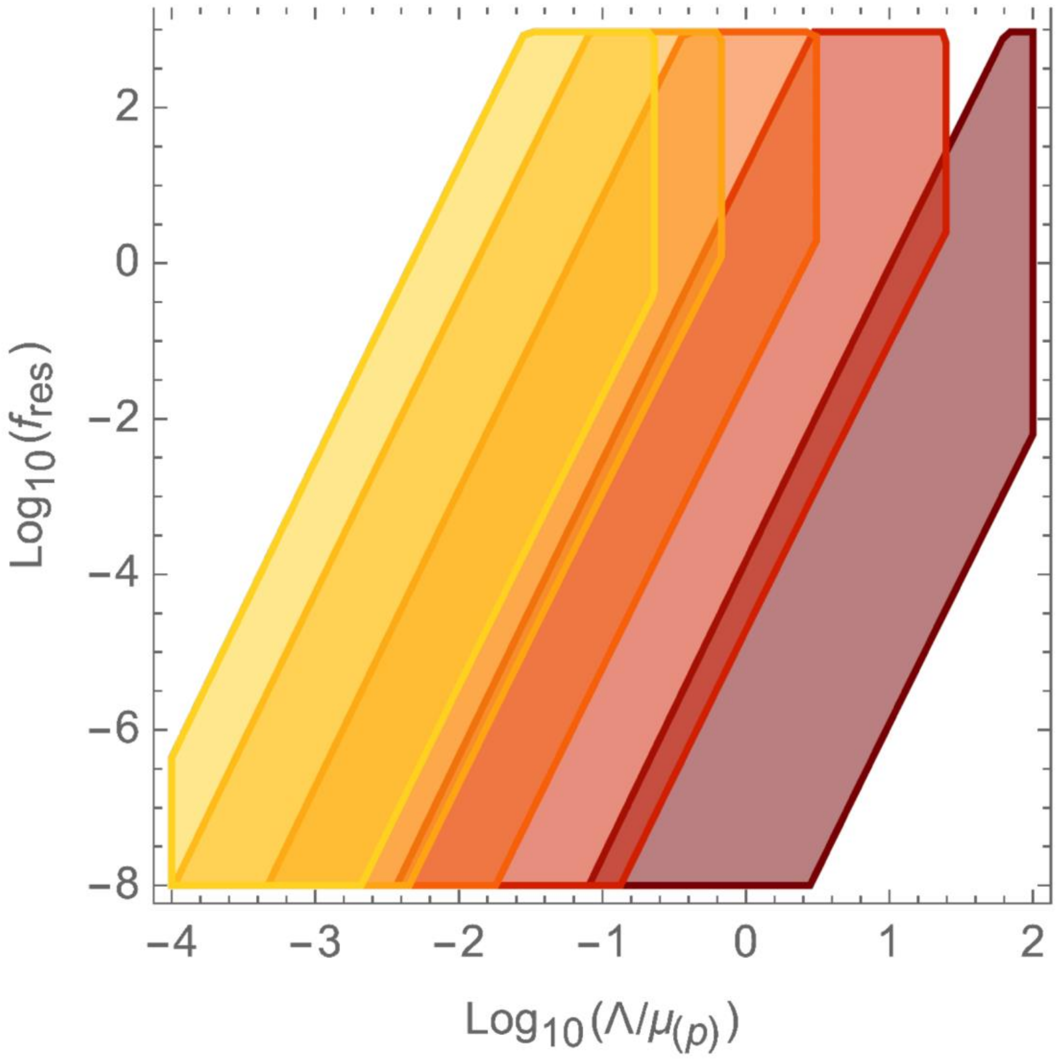
$$\chi^2 > \mathcal{O}(1) g \sqrt{H M_P} \sim g V^{1/4}$$

Axion monomedry inflation Non-gaussianity

$$V(\phi) = \mu^{4-p}\phi^p + \Lambda^4 \cos\left(\frac{\phi}{f}\right)$$

Axion FL + WGC bound observables to an interval, e.g. resonant non-Gaussianities

p=2
p=1.5
p=1
p=0.5
p=0.1



String compactifications

Geometrically WGC+aFL bound the size of cycles in Einstein frame as

$$\frac{1}{2} \leq \frac{2V_X|q^{\Sigma^p}|^2}{V_{\Sigma_p}^2} \lesssim \frac{M_P}{H}$$

With V_X the CY volume and V_{Σ_p} the volume of cycle Σ_p. q defined from Kahler metric:

$$|q^{\Sigma}|^2 = K^{ij} q_i^{\Sigma} q_j^{\Sigma}$$

$$q_i^{\Sigma^p} = \int_{\Sigma^p} \omega_i$$

$$\int_X \omega_i \wedge \star\omega_j = K_{ij}$$

String Inflation

Consider blow-up inflation driven by small cycle τ_{inf}. Size bounded

$$\frac{H}{M_P} \lesssim \frac{\tau_{\rm inf}^{3/2}}{V_X} \lesssim 4$$

Preference for low-scale inflation. Slowroll at horizon exit: $\epsilon^* < \dfrac{3 \cdot 10^6}{V_X^2}$

Typical volume $V_X \sim 10^6$

Gives tensor-to scalar ratio $r < 5 \cdot 10^{-5}$

Multifield

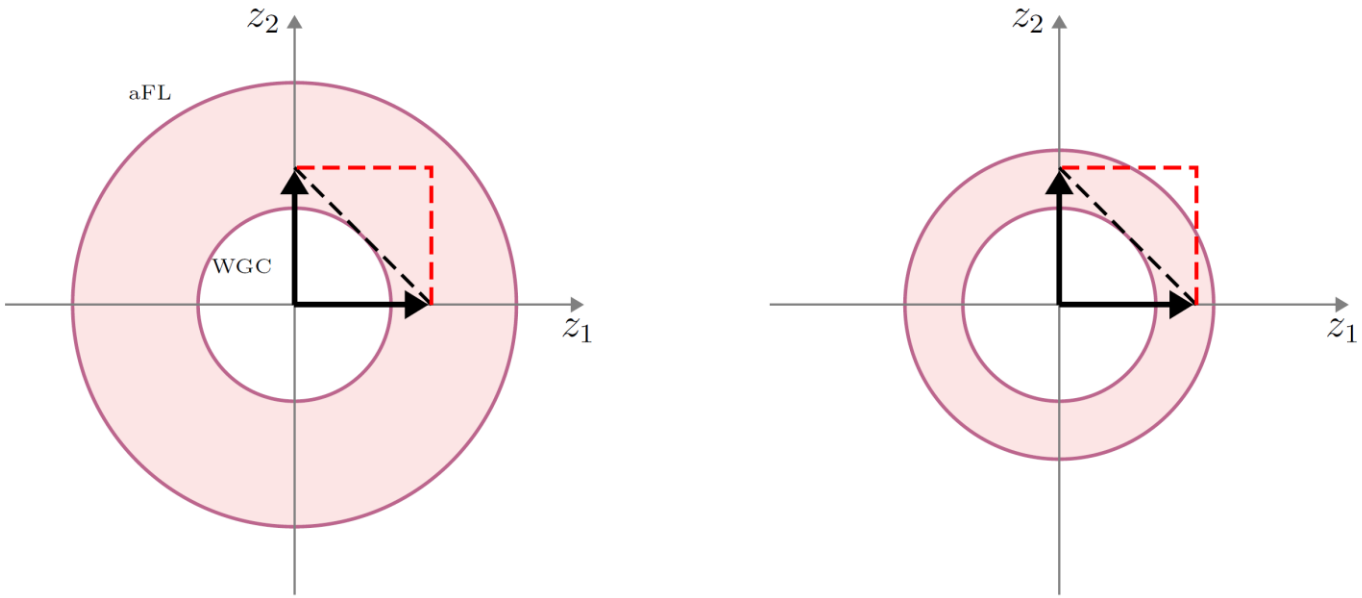
Multiple axions

$$\phi_i, \; i = 1, \ldots, N$$

$$V \sim \sum_a A_a e^{-S_a} \cos\left(\sum_i \frac{\phi_i}{f_{ai}}\right)$$

$$\mathbf{z}_a = (\mathbf{z}_a)_i \, \mathbf{u}^i = \frac{M_P}{f_{ai} S_a} \mathbf{u}^i$$

$$1 < ||\mathbf{z}_a|| < \sqrt{\frac{M_P}{H}}$$



In order to generically remain inside shell bound

$$N < \frac{M_P}{H}$$

Summary

$$\frac{M_P}{Sf} \lesssim \sqrt{\frac{M_P}{H}} \qquad m^2 \gtrsim q\, g M_P H$$

(Axionic) Festina Lente provides phenomenologically interesting constraints

Stronger during inflation

Direct conceptual argument for gauge theory FL, would be nice to have direct argument for aFL, so far none. Same issue with WGC