Inflation and light Dark Matter constraints from the Swampland

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String Pheno Conference
University of Liverpool
July 7, 2022

Based on work to appear soon
with Miguel Montero and Julian Muñoz

Motivation

- The Swampland program uses string theory as a laboratory to check which EFTs can/cannot be embedded into a UV theory of quantum gravity

  $\implies$ Swampland conjectures

- But the more exciting thing is to use these statements to learn non-trivial things about the real world!

- In particular, there are few papers connecting Swampland to Dark Matter models or to matter fields during inflation

- We explore this question

Eg: [Shiu, Soler, Ye '13]
[Agrawal, Obied, Vafa '19]
[Montero, Vafa, Valenzuela '22]
[Anchordoqui, Antoniadis, Lust '22]
...

See also talks by Michele, Burt and Joe

Outline

- Swamplanding Review:
    - Weak Gravity Conjecture (WGC)
    - Festina Lente (FL)
- Applications:
    - Darkly/Milli- charged particles
    - Models with non-Abelian gauge fields
    - Inflation

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Weak Gravity Conjecture (WGC)

Statement:

In QG with $U(1)$ gauge fields, there exists a particle with charge-to-mass ratio bigger than or equal to that of a large extremal black hole. I.e. there exists a particle whose mass and charge satisfy:

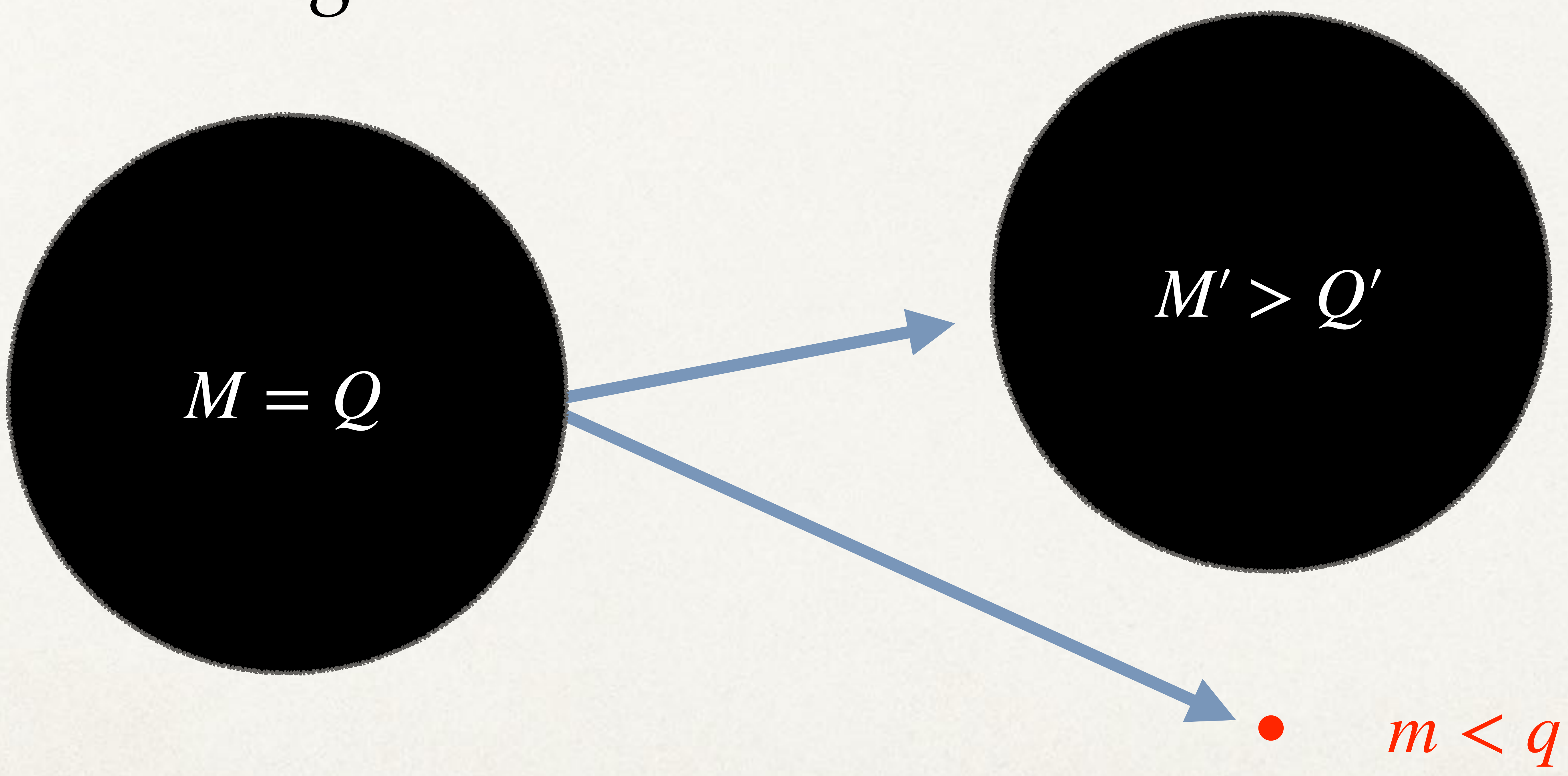
$$m \leq qgM_{\text{Pl}}$$

q is an 'elementary' quantized charge and g is the gauge coupling.

[Arkani-Hamed, Motl, Nicolis, Vafa '06]
Review: [Harlow, Heidenreich, Reece, Rudelius '22]
See also talk by Gary Shiu

Weak Gravity Conjecture (WGC)

- This is also the kinematic condition that allows extremal black holes to decay while remaining subextremal:



[Arkani-Hamed, Motl, Nicolis, Vafa '06]
Review: [Harlow, Heidenreich, Reece, Rudelius '22]

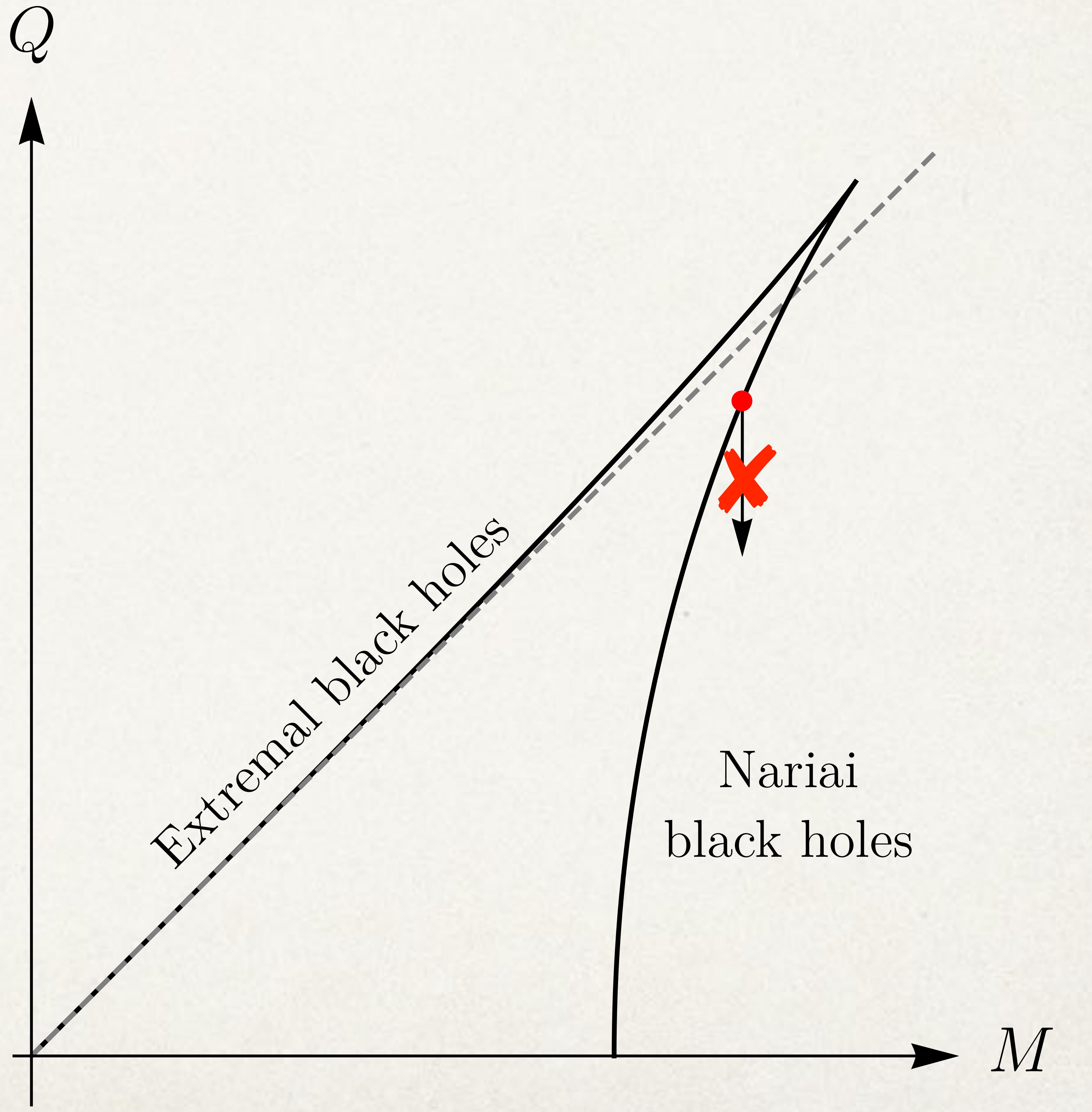
Festina Lente (FL)

[Montero, Van Riet, Venken ’19]

Same principle as WGC but applied to charged black holes in dS space.

- If charged particles are too light, there’s a decay channel that allows charged Nariai black holes to leave the extremality region.
- To forbid this decay channel, we need to ensure that **every particle in dS** must have:

$$m^2 \geq qgM_{\text{Pl}}H$$



De Sitter space

Quick Recap

Weak Gravity Conjecture:

There exists a particle with $qg \geq m/M_{\mathrm{Pl}}$.

Festina Lente bound:

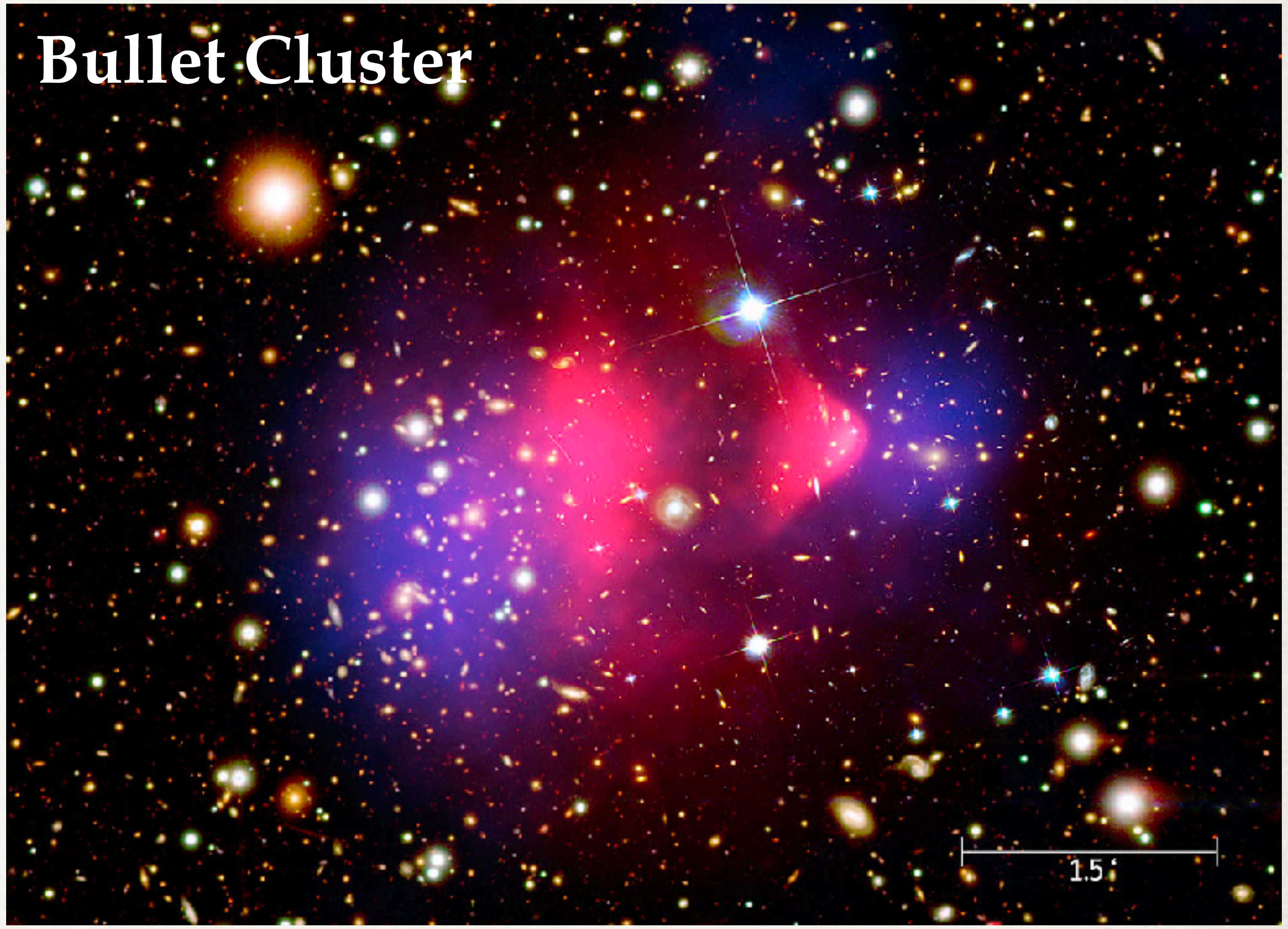
All particles in dS have $m^2 \geq qgM_{\mathrm{Pl}}H$

Applications

Darkly charged particles

- Suppose there's a dark photon A', with gauge coupling g'
- By the WGC, there must exist a 'dark electron' χ with mass m_χ
- We can apply FL to this dark sector and get the bound

$$g' \leq \frac{m_\chi^2}{M_{\text{Pl}} H}$$



X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.

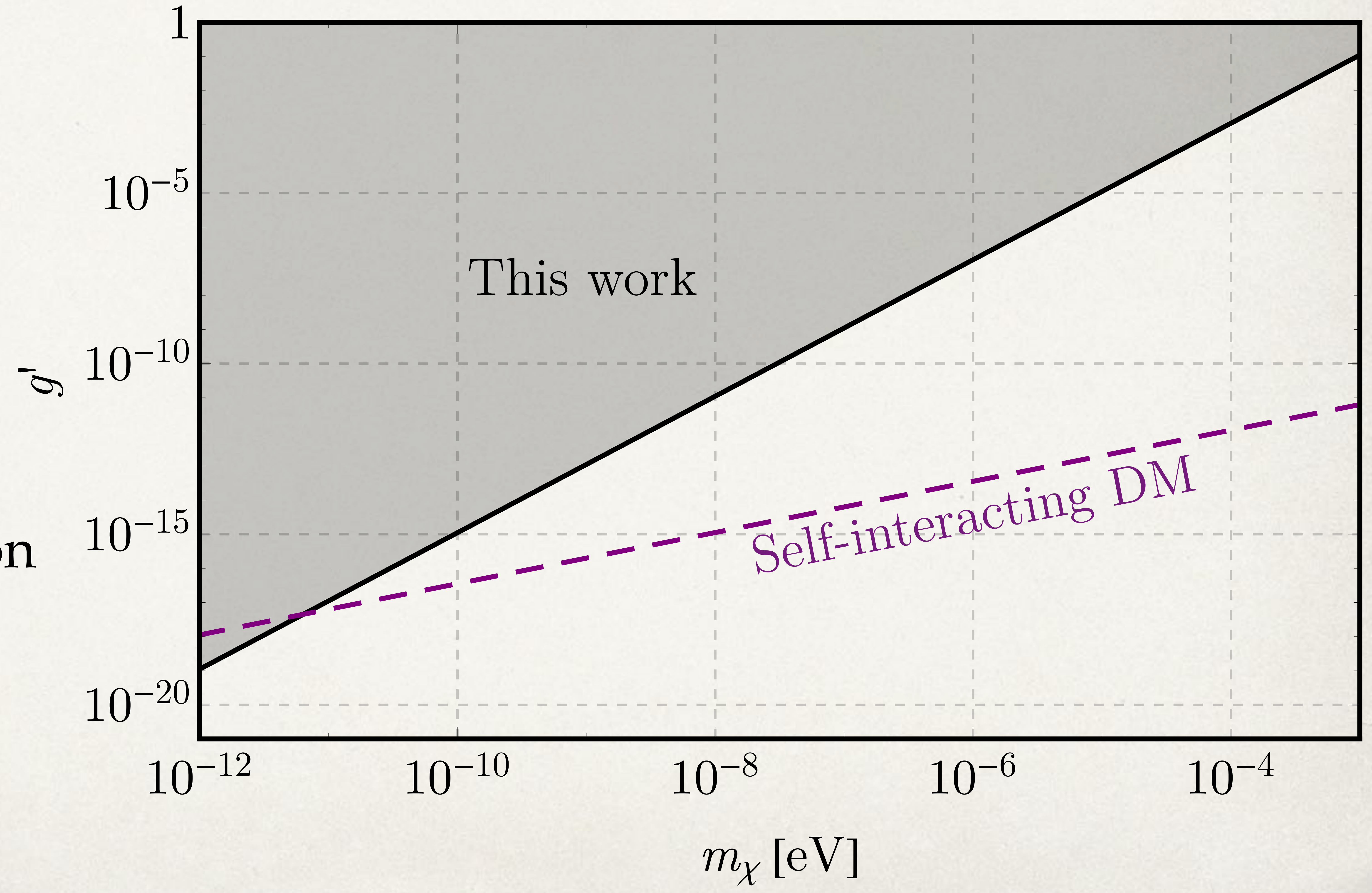
Darkly charged particles

$$\mathscr{L} \supset -\frac{1}{4}F^2 - \frac{1}{4}F'^2$$

- FL applied to the dark photon gives:

$$g' \leq \frac{m_\chi^2}{M_{\rm Pl} H}$$

- No assumption on the interaction with our sector
- No assumption on the DM abundance



Millicharged Particles (I)

- Suppose the dark photon kinetically mixes with our photon:

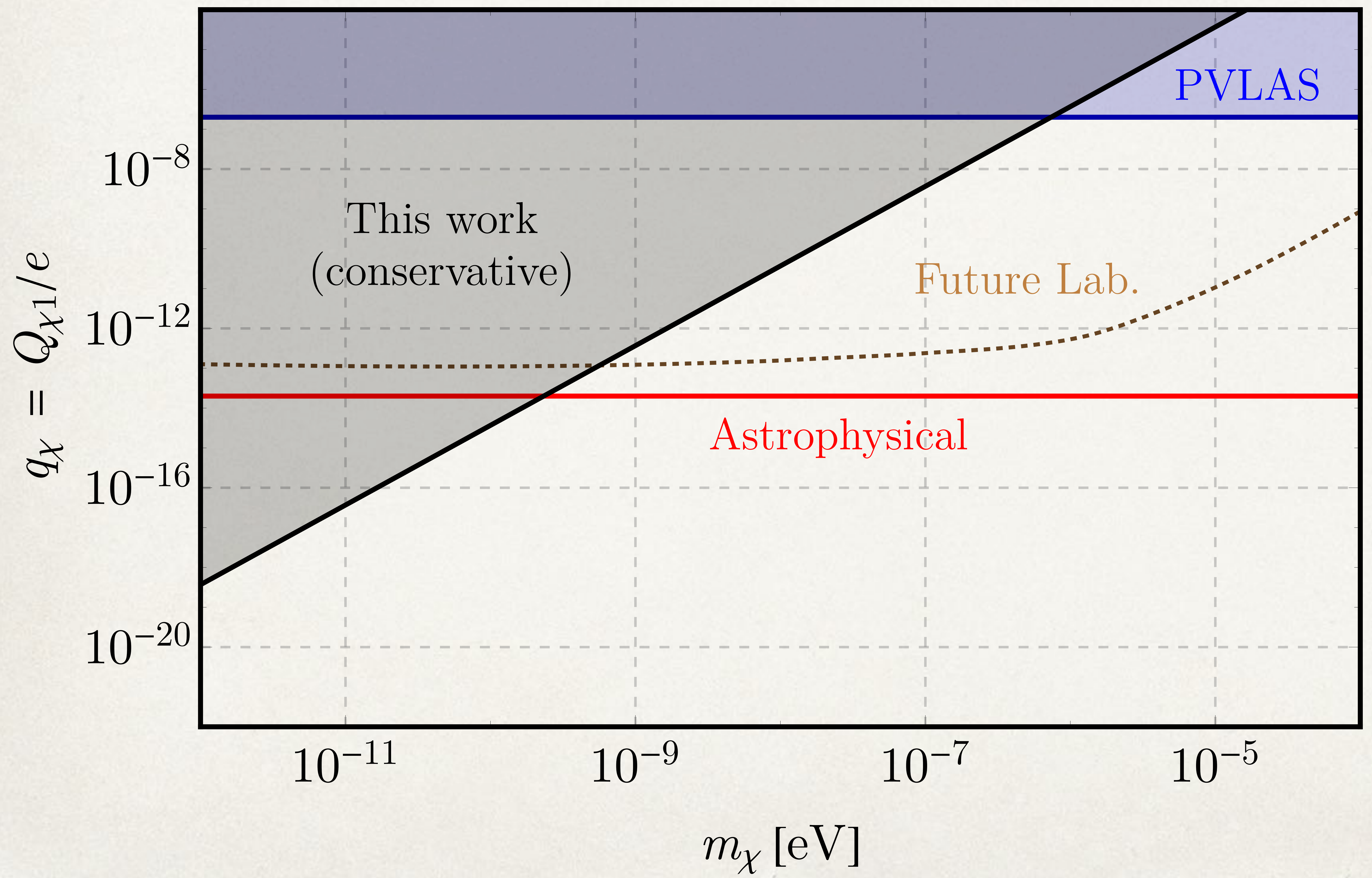
$$\mathscr{L} \supset -\frac{1}{4}F^2 - \frac{1}{4}F'^2 + \frac{\epsilon}{2}FF'$$

[Holdom '86]

- Then the dark electron χ will be millicharged:

$$Q_{\chi 1} = \epsilon g' < g' \leq \frac{m_\chi^2}{M_{\rm Pl}H} \quad \Longrightarrow \quad q_\chi = \frac{Q_{\chi 1}}{e} \leq \left(\frac{m_\chi}{1.6\ \mathrm{meV}}\right)^2$$

Millicharged Particles (conservative bound)



Electric charge of the dark electron:

$$q_\chi = \frac{Q_{\chi 1}}{e} \leq \left(\frac{m_\chi}{1.6 \text{ meV}} \right)^2$$

- No assumption on abundance of the dark electron

Millicharged Particles (aggressive bound)

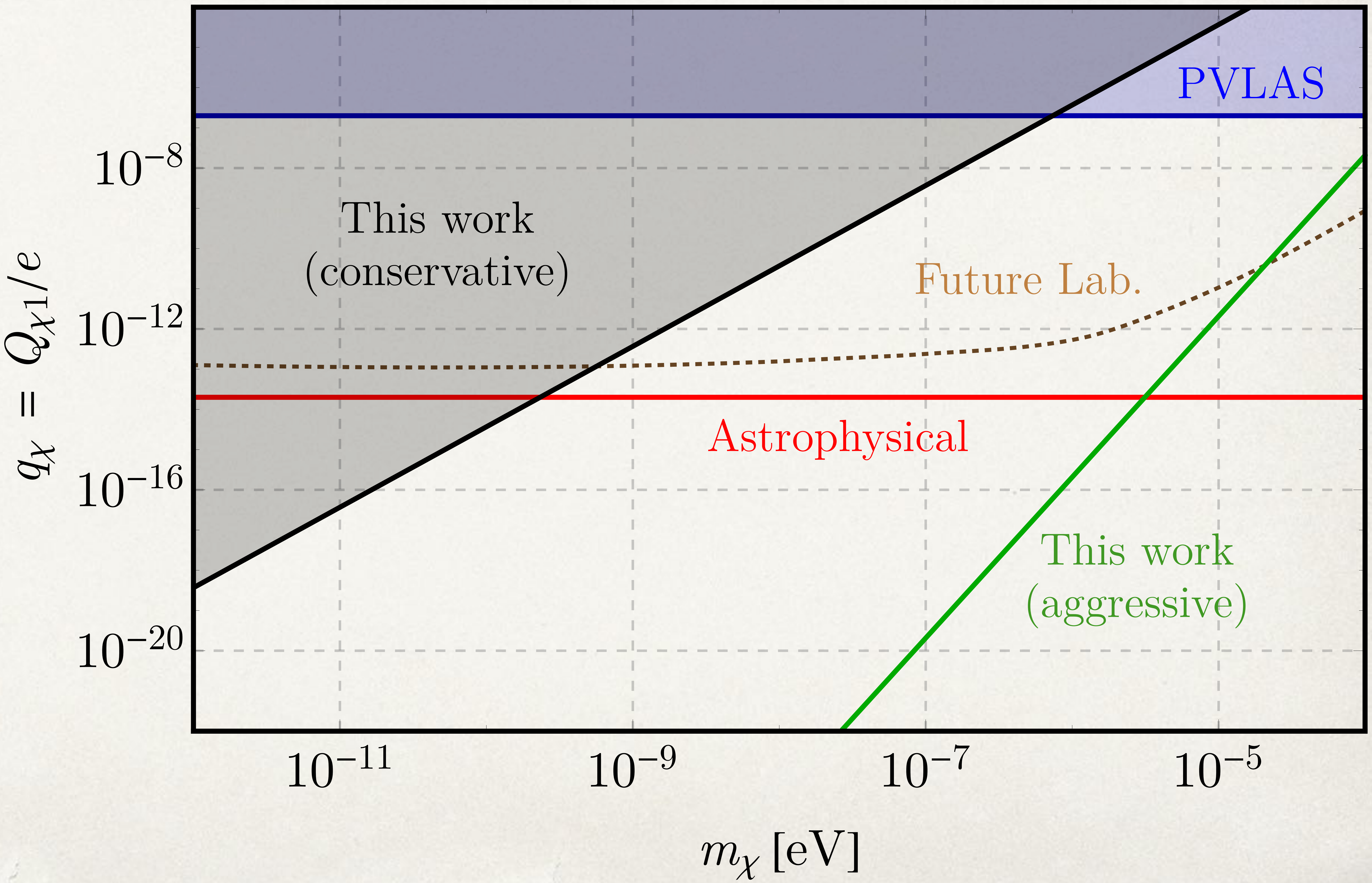
Assuming a one-loop kinetic mixing $\epsilon \approx \dfrac{eg'}{16\pi^2}$,

we can get a more aggressive bound:

$$q_\chi \lesssim \left(\frac{m_\chi}{10\ \text{meV}}\right)^4$$

Eg: [Dienes, Kolda, March-Russell '96]
[Goodsell, Ramos-Sanchez, Ringwald '11]
[Benakli, Branchina, Lafforgue-Marmet]
[Obied, Parikh '21]+…

See also talk by Arthur Hebecker



Models with non-Abelian gauge fields

- In dS, weakly coupled non-Abelian gauge fields are inconsistent with FL

  $\Longrightarrow$ all non-Abelian gauge fields must either be confined or Higgsed.

- E.g. (our universe):
  - QCD confines at $\Lambda_{QCD} \sim 100$ MeV well before accelerated expansion sets in.
  - $SU(2)$ is Higgsed at the even higher electroweak scale ~ 100 GeV
- This rules out many phenomenologically interesting models

Models with non-Abelian gauge fields

- We will consider three examples with non-Abelian fields in relation to Festina Lente:
  - Dark Matter
  - Dark Energy
  - Inflation

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Non-Abelian Dark Matter

[Buen-Abad, Marques-Tavares, Schmaltz '15]

- Weakly coupled dark $SU(N)$ with matter in the fundamental
- Incompatible with FL

Models with non-Abelian gauge fields

- We will consider three examples with non-Abelian fields in relation to Festina Lente:
  - Dark Matter
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CC Relaxation

[Ji, Kaplan, Rajendran, Tanin '21]

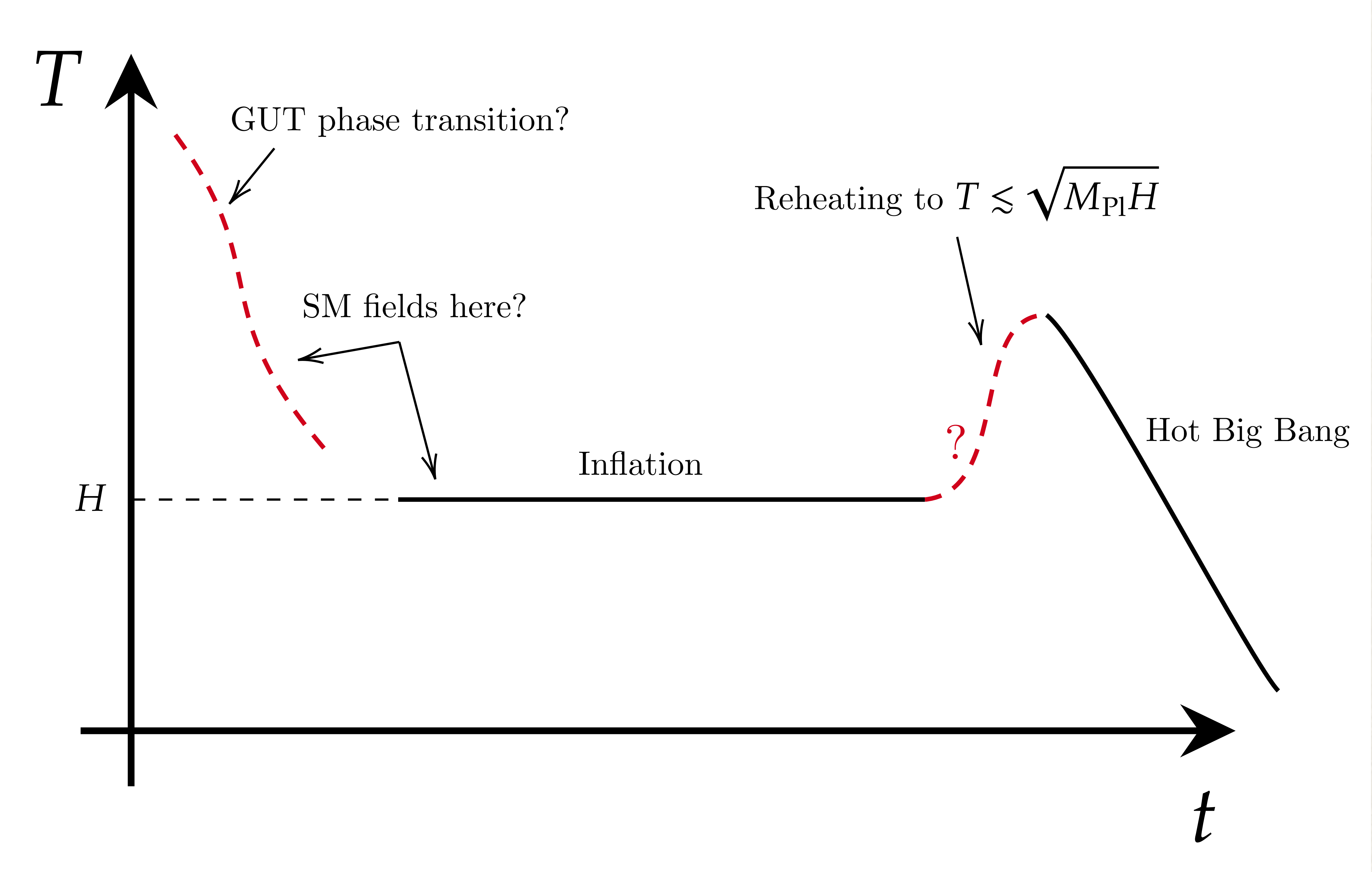
- Attempt to solve the cosmological constant problem using a dynamical mechanism
- Non-Abelian gauge fields used to generate primordial perturbations
- Incompatible with FL

Models with non-Abelian gauge fields

- We will consider three examples with non-Abelian fields in relation to Festina Lente:
  - Dark Matter
  - Dark Energy
  - Inflation?

General comments on inflation

- In fact, a more general question is: what happens to the SM during inflation?
- E.g.: Higgs inflation
- We need to ensure there are no massless weakly-coupled SM gauge bosons.
- Presents an opportunity for model building!



Conclusion

- I have presented some new implications for:
  - Darkly and milli- charged particles
  - Dark Energy models (e.g. CC relaxion)
  - Inflation
- Theoretical efforts are highly-complementary to experiments in constraining models relevant for astroparticle physics.

Thank you!