Boosted Dark Photons

VARUN MATHUR

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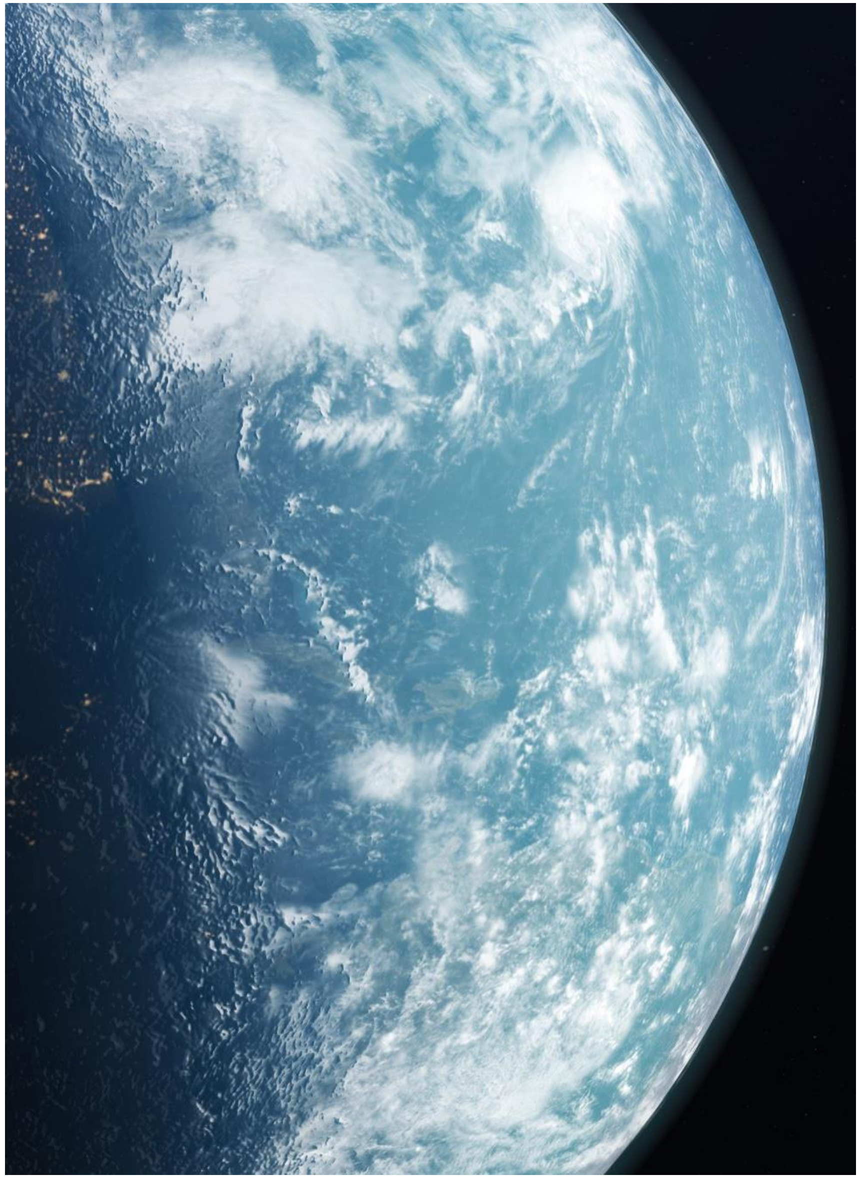
Outline

- Dark photons as boosted dark matter
    - Why Dark photons
    - Why boosted dark matter
    - How do we avoid constraints from self interacting dark matter?
    - How do we avoid constraints from dark matter milicharge?
    - Are plasma mass and in medium mass effects important?



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Dark Photons as Boosted Dark Matter

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Why Dark Photons

- The portals allow coupling of Standard Model(SM) to dark sector at a renormalizable level.
- As we move from the energy frontier to the intensity frontier, these low dimensional operators might pick up new physics that colliders missed[1]
- Kinetic mixing can yield either a dark photon mediator or dark matter being millicharged under field redefinitions
- If m is small compared to scales of interest (eg SM plasma mass), dark photons decouple from the SM

$$\mathcal{L} \supset -\frac{1}{4}\hat{F}^2 - \frac{1}{4}F'^2 - \frac{1}{2}\epsilon\hat{F}F' + \frac{1}{2}m^2A'^2 + gA'J_\chi + J_{\rm EM}\hat{A}$$

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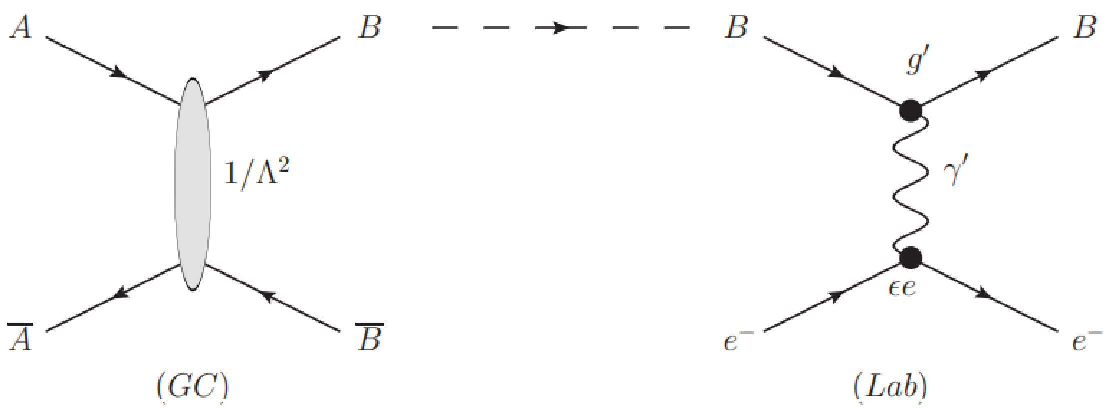
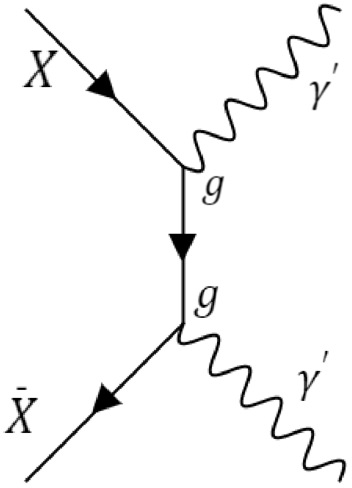
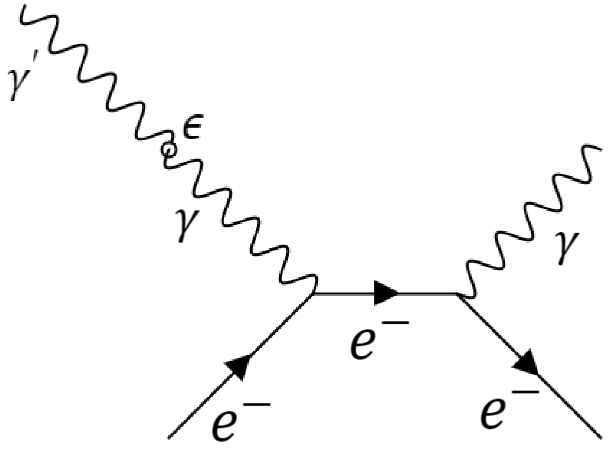
[1]B.Batell,M.PospelovandA.Ritz,"ExploringPortalstoaHiddenSectorThroughFixedTargets", Phys.Rev. D80(2009)095024[0906.5614].
[2]R. Lasenby, Journal of Cosmology and Astroparticle Physics 2020, 034 (2020)

Boosted Dark Matter

- While Dark Matter must be cold, a subcomponent could be boosted at late times.
- Agashe et al[1] suggest a simple two component DM where DM annihilates to another dark state in the galactic centre which is relativistic and can be detected at intensity experiments.
- Since then multiple scenarios for making boosted dark matter have been proposed for example Cosmic Ray upscattering
- We propose skipping dark B state altogether and considering dark photons as boosted dark matter.



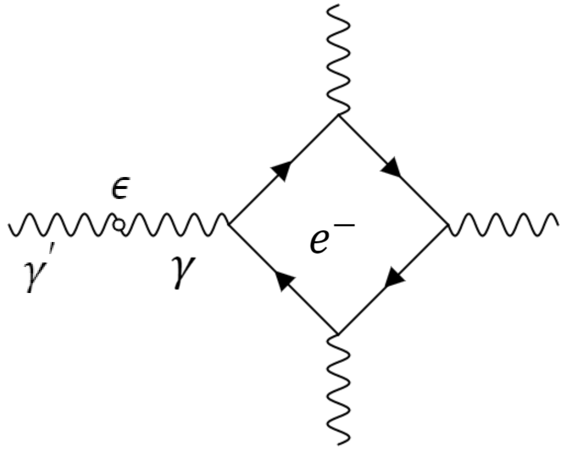


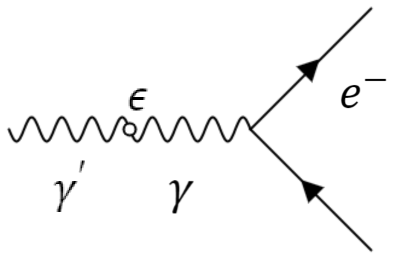


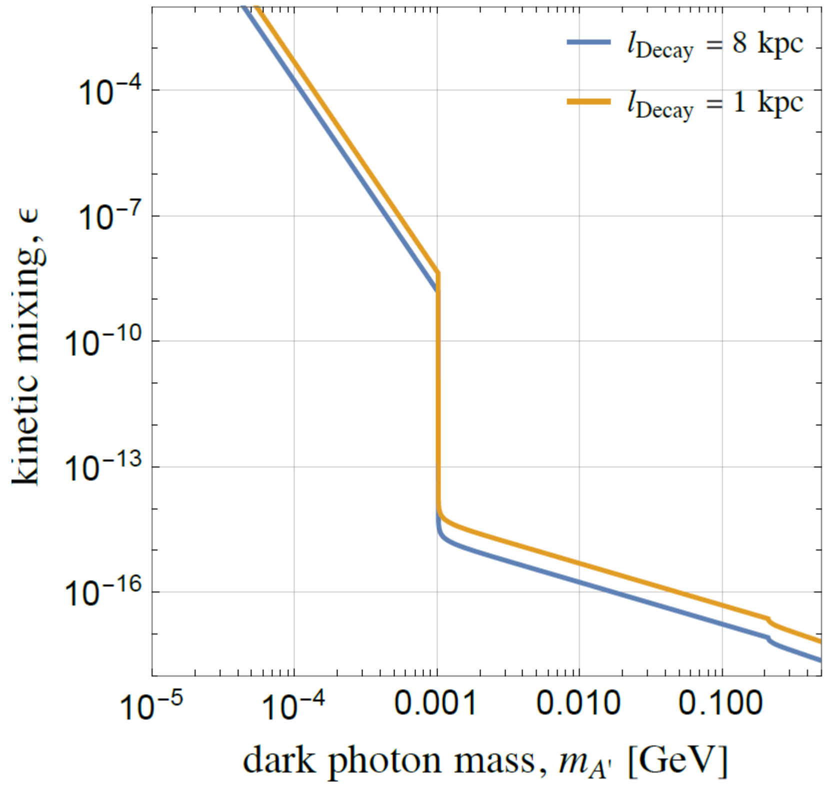
[1]K. Agashe, Y. Cui, L. Necib and J. Thaler, (In)direct Detection of Boosted Dark Matter, JCAP 1410 (2014) 062 [1405.7370].

Decay and attenuation

- Will Dark photon decay before it reaches us?
- Euler Heisenberg decay to three photons and electron positron decay once the mass becomes large enough
- We calculate the maximum kinetic mixing which allows dark photons to reach us
- As dark photons pass through various depths of the earth to reach our detectors, there is an upper bound that we can probe.

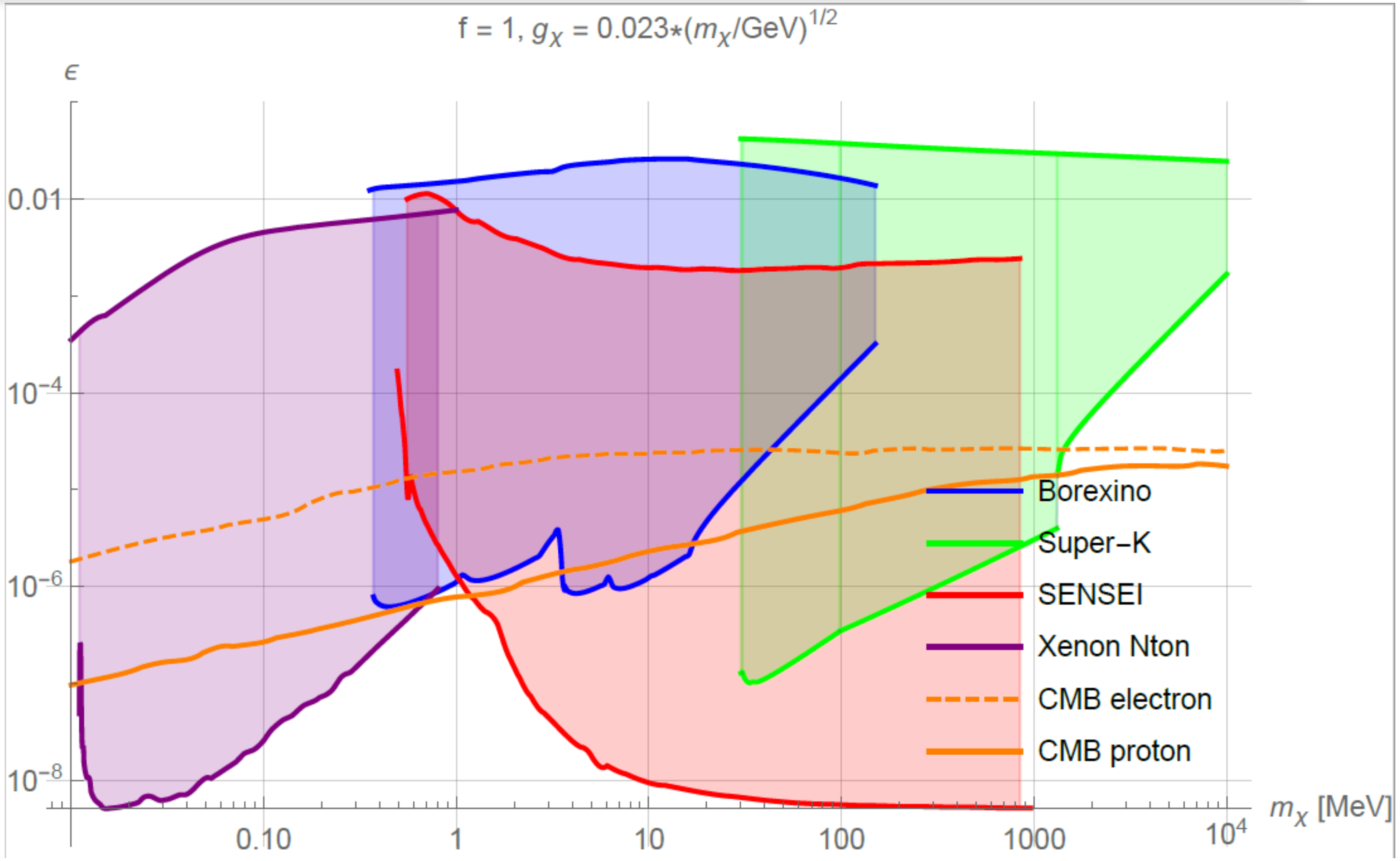






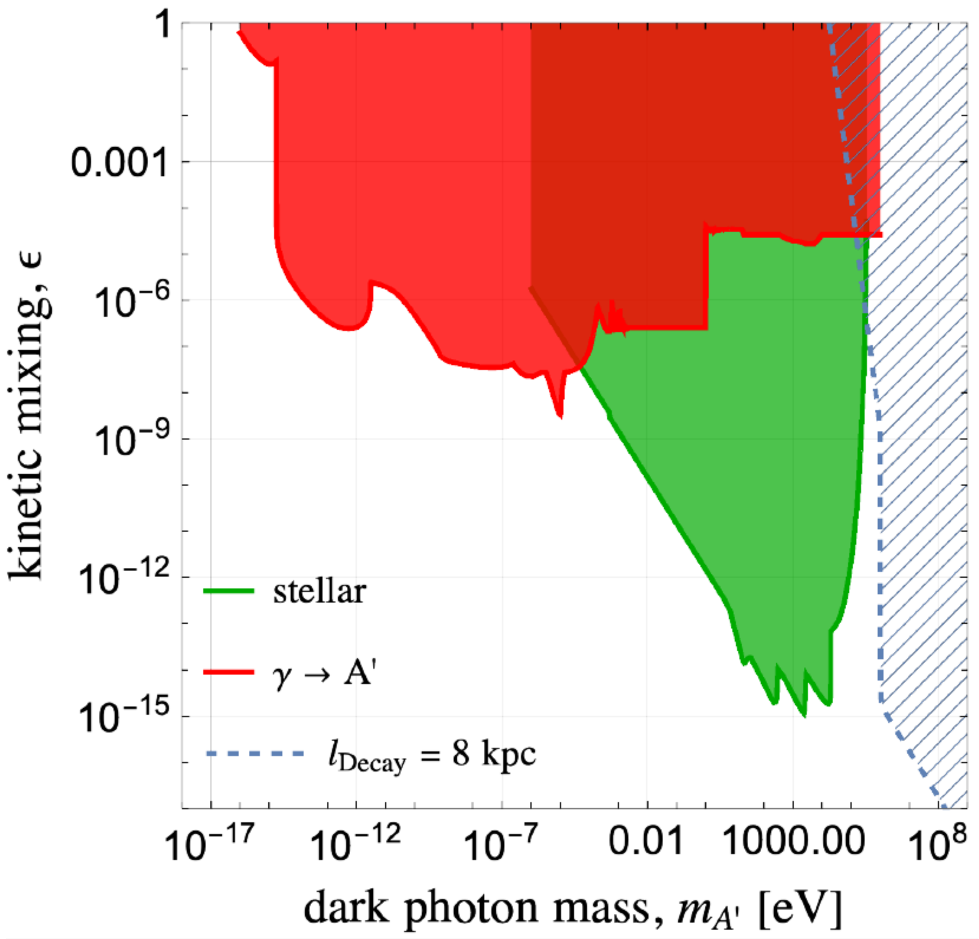
First pass at bounds

Assuming:
- Thermal relic g
- Only Compton like scattering in the detectors
- Mass of the dark photon is small enough that it is highly boosted



Other bounds

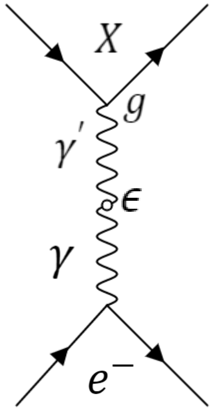
- Dark photons are a very popular BSM candidate and there are a variety of existing constraints on kinetic mixing without assuming dark photons are dark matter:
- Photon dark photon conversion bounds from different sources including Neff
- Stellar cooling bounds- could depend on the mass generation mechanism



Andrea Caputo, Alexander J. Millar, Ciaran A. J. O'Hare, and Edoardo Vitagliano. Dark photon limits: A handbook. Phys. Rev. D, 104(9):095029, 2021

Other bounds

- Direct detection only needs one factor of g- SENSEI
- Galactic disk spin down places extremely strong constraints on the milicharge $g\epsilon$.[1]
- Milicharge is also strongly constrained by CMB experiments[2]
- Self interacting dark matter is also well constrained by the bullet cluster due to either individual 2-2 scattering or due to collective plasma instability effects.[3]
- The plasma instability and ISM spin down are too strong, to avoid them we need the mass of dark photon greater than the standard model plasma mass $10^{-15} - 10^{-12} eV$.



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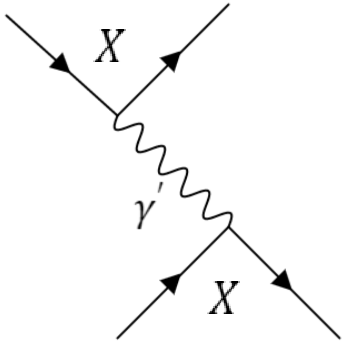
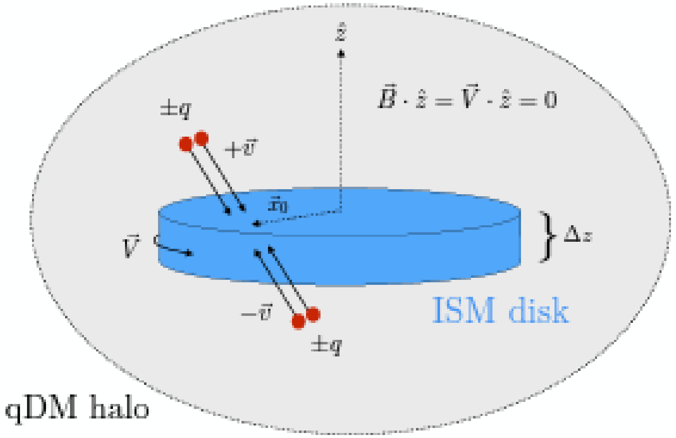
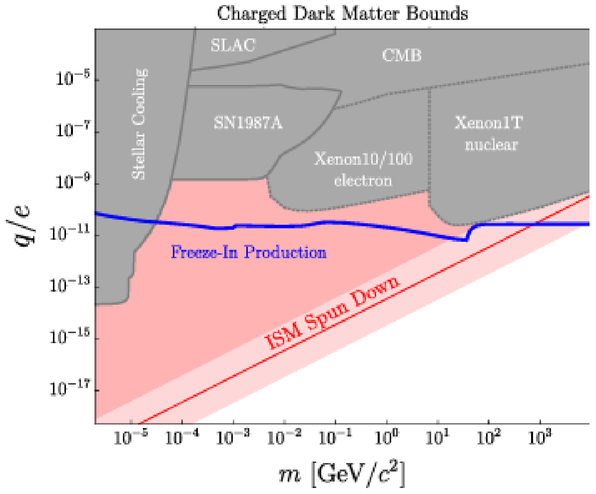






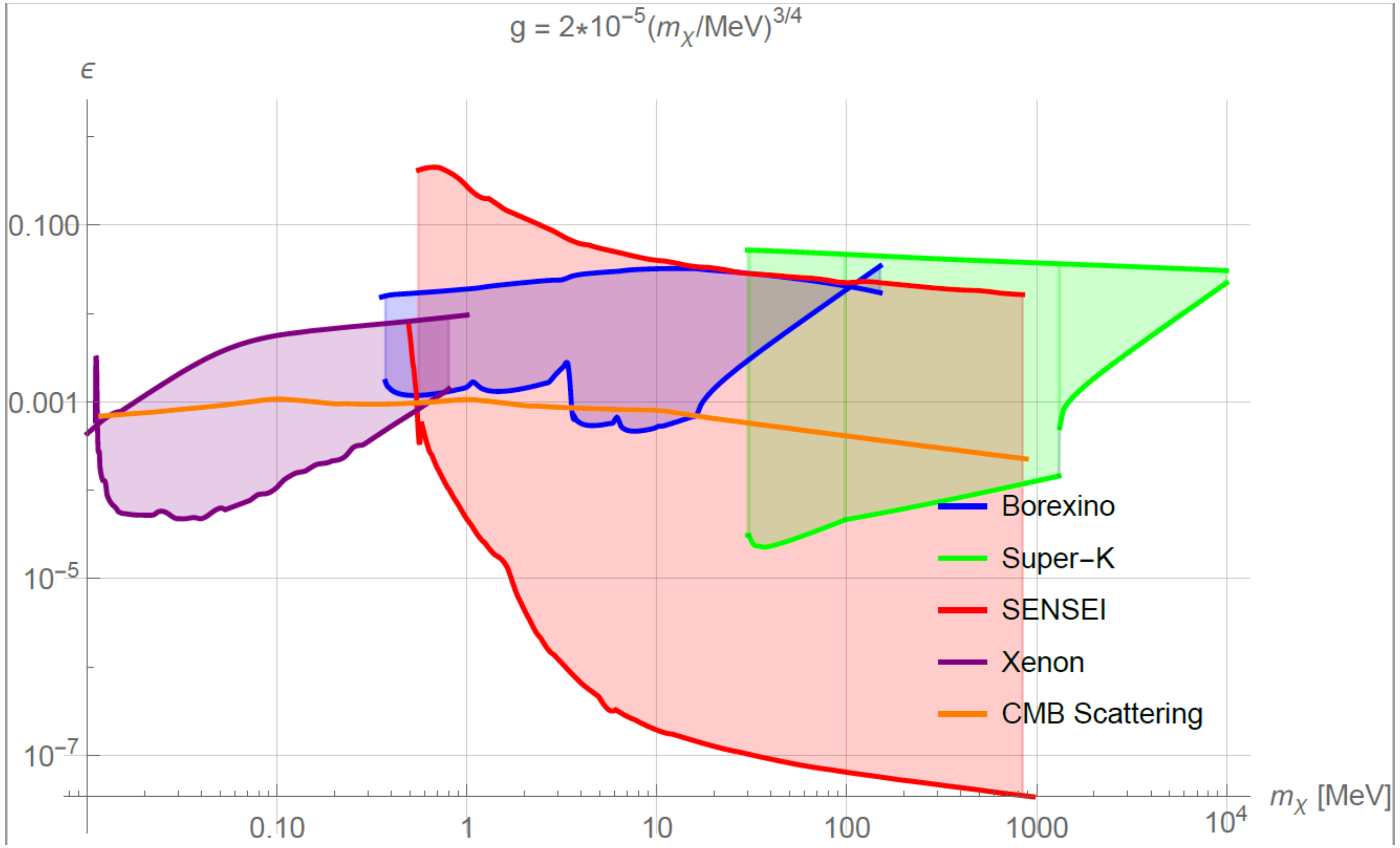
Constraint on q=$g\ \epsilon$ from Stebbins[1]

[1]A.StebbinsandG.Krnjaic,“NewLimitsonChargedDarkMatterfromLarge-ScaleCoherentMagnetic Fields,”JCAP12(2019)003,arXiv:1908.05275[astro-ph.CO].
[2] M. A. Buen-Abad, R. Essig, D. McKeen, and Y.-M. Zhong, Physics Reports 961, 1 (2022)
[3]] R. Lasenby, Journal of Cosmology and Astroparticle Physics 2020, 034 (2020)

Second pass at bounds

Assuming:

- 2-2 scattering bound on g
- Only Compton like scattering in the detectors
- Mass of dark photon such that in medium effects can be ignored.
- One possible way is to compare with $m_\gamma = E_\gamma\sqrt{1-1/n^2} = 0.56\mathrm{E}_\gamma$ for Xenon.



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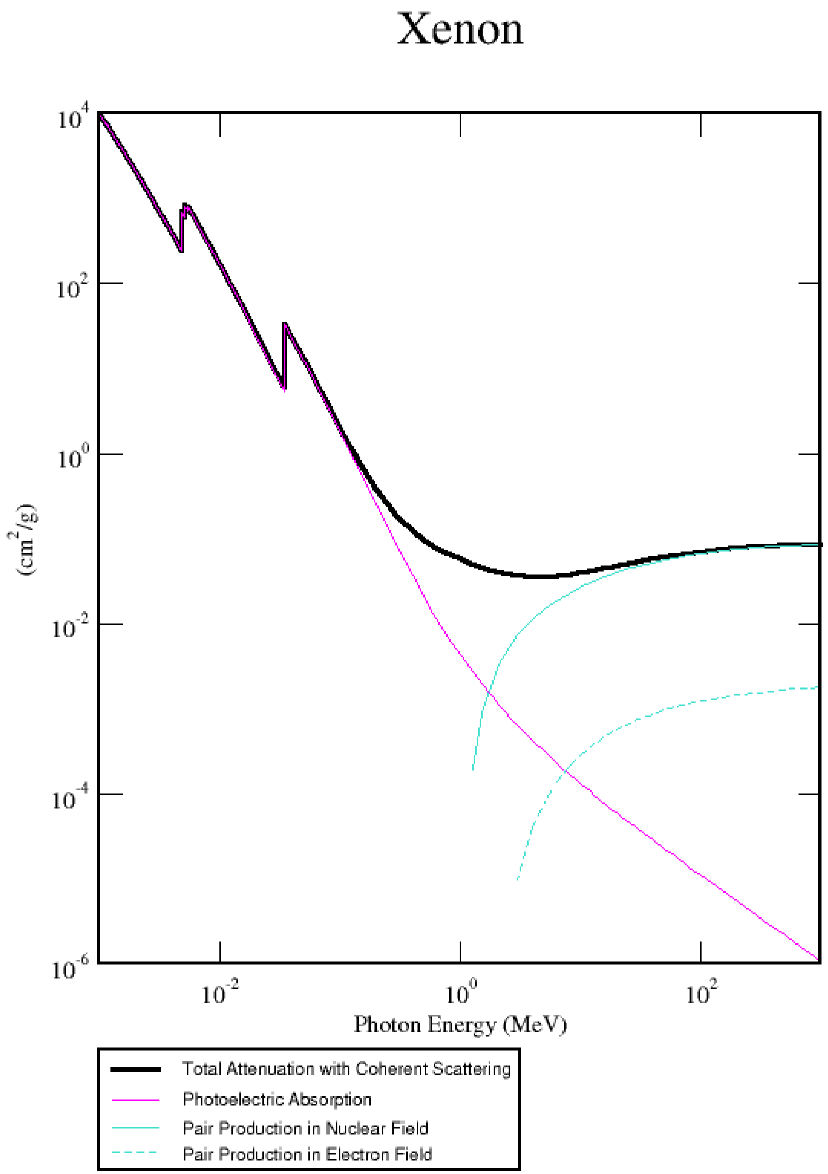
Gamma Ray absorbtion cross section

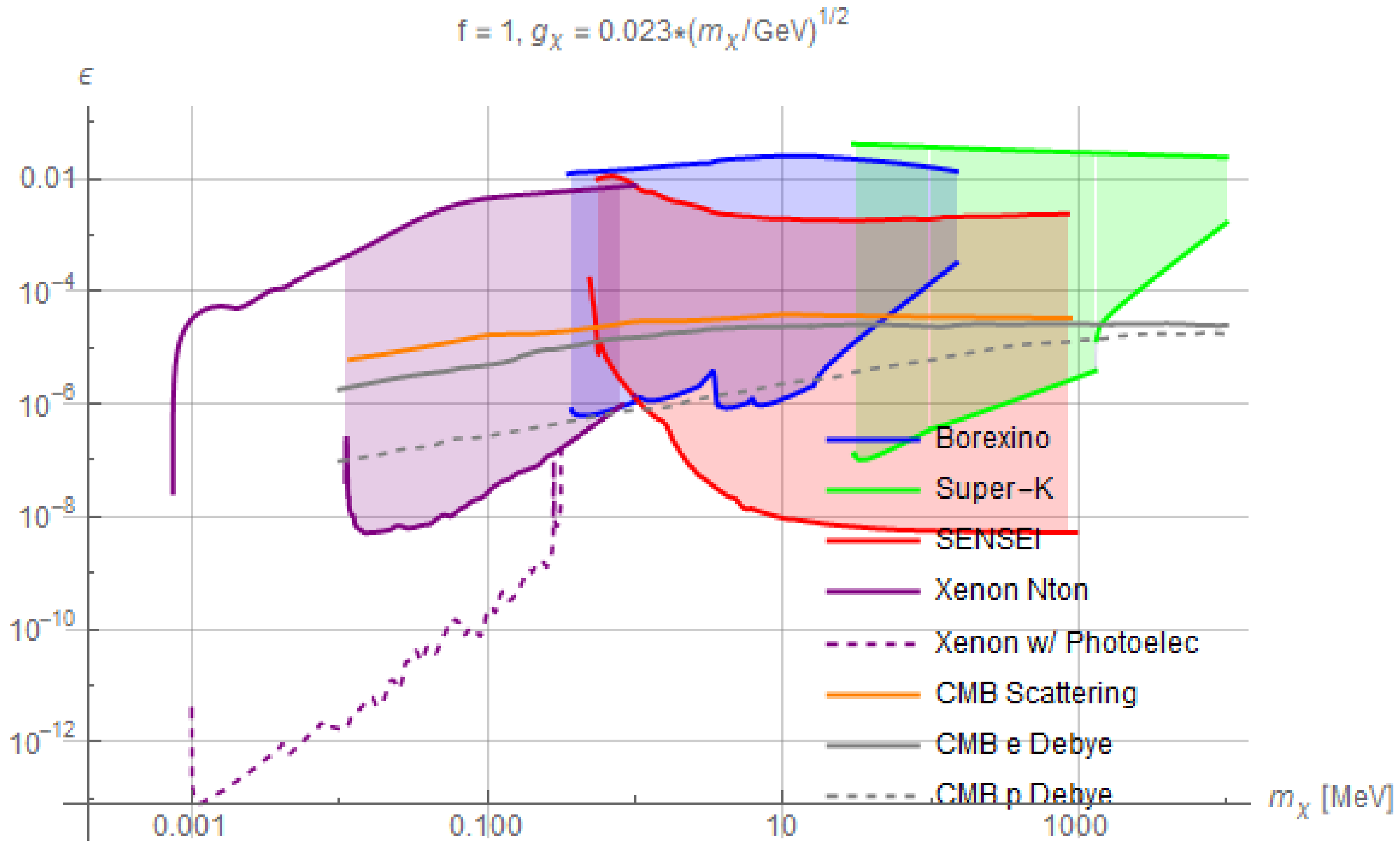


Cite: Publicly available NIST data https://physics.nist.gov/PhysRefData/Xcom/Text/ref.html

Third pass at bounds

Assuming:

- Thermal Relic g
- With photoelectric cross section
- No medium effects



Conclusion and Future Prospects

- Darkly charged dark matter yields interesting phenomenology of boosted dark photons
- While this model is highly constrained, there are interesting regions of parameter space that could be explored by large intensity frontier experiments.
- We will also place a model independent bound for dark photons without anything to do with dark matter that XENON, BOREXINO and Super-K can probe.
- We are considering in medium effects for the detectors, these may be important for both detection and attenuation, any ideas welcome.

In medium effects

$$\mathcal{L}_{\rm int} = -\frac{\kappa}{2} F_{\mu\nu} V^{\mu\nu} + e J^\mu_{\rm em} A_\mu \xrightarrow{\text{on-shell V}} \mathcal{L}_{\rm int} = -\kappa m_V^2 A_\mu V^\mu + e J^\mu_{\rm em} A_\mu .$$

- When the dark photon is on shell, we have $\partial_\mu V^\mu = 0$ and $\partial_\mu V^{\mu\nu} = -m_V^2 V^\nu$
- Thus there is a mass squared suppression of the detection prospects of a dark photon.
- This depends on the relative permittivity of the material
- The question is whether we can circumvent this effect by choosing dark photons above a certain mass