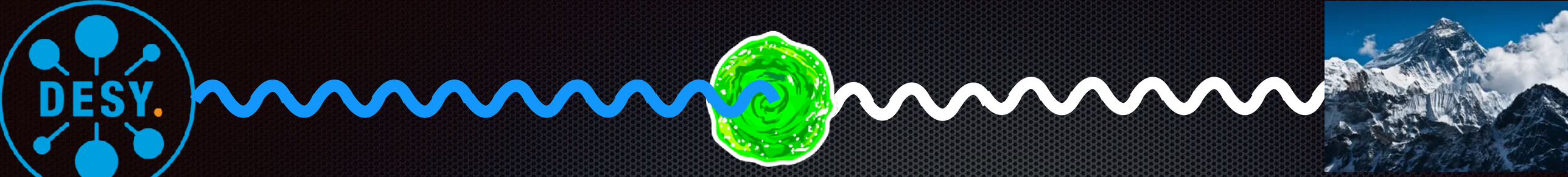


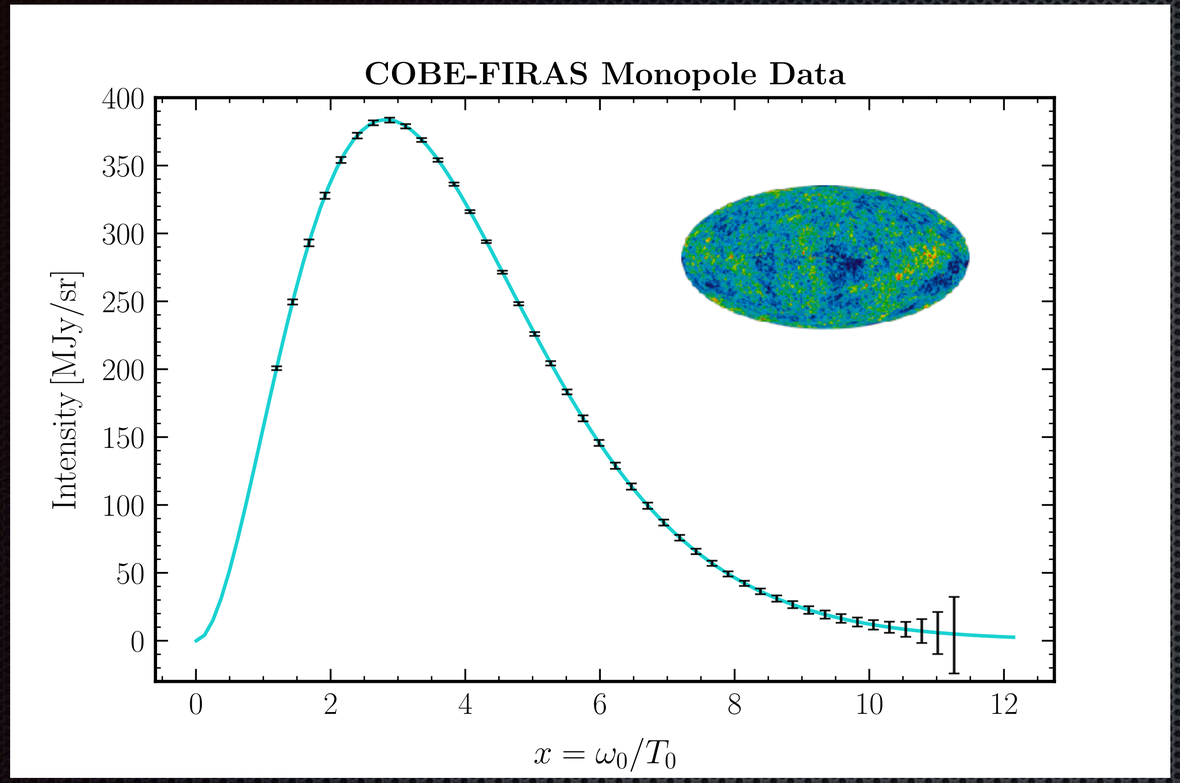
Shaping Dark Photon Spectral Distortions

Speaker: **Xucheng Gan (DESY)**

2409.12940

Collaborators:
Giorgi Arsenadze, Andrea Caputo, Hongwan Liu, Joshua Ruderman

CMB Spectrum



Error bars are multiplied by 100

CMB is blackbody

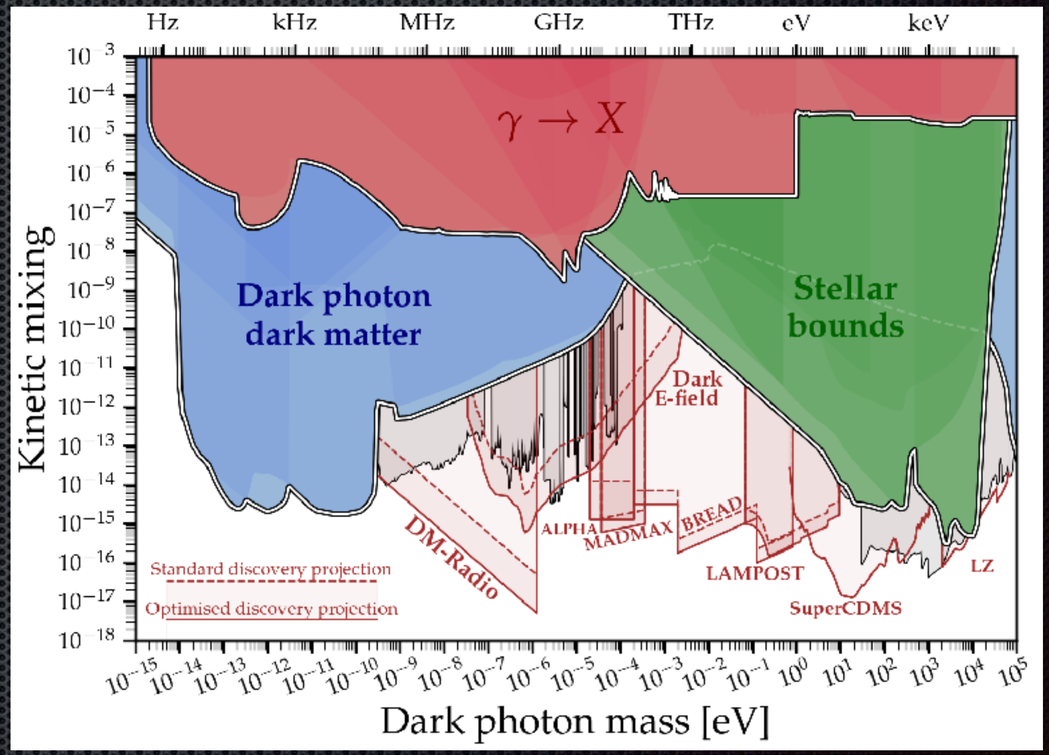
Any process remove or inject photons

$$\chi + \chi \to \mathrm{SM} + \mathrm{SM}$$

$$\gamma \to A'$$

Why the Dark Photon ?

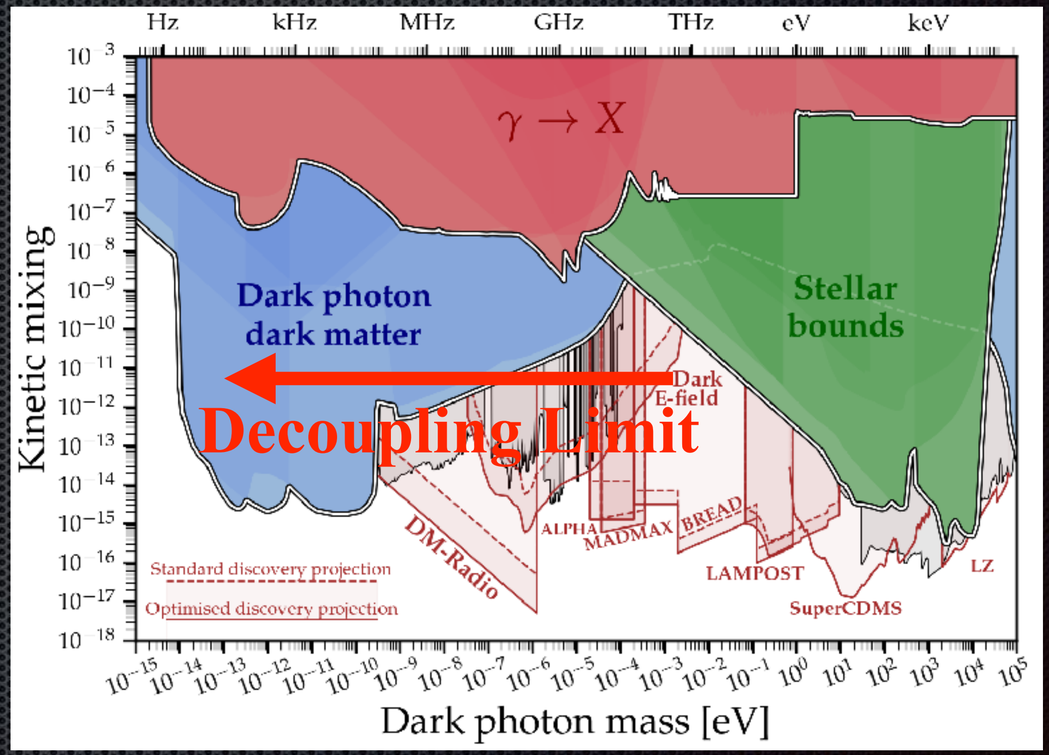
Bob Holdom 1985



Dark Photon Limits Website

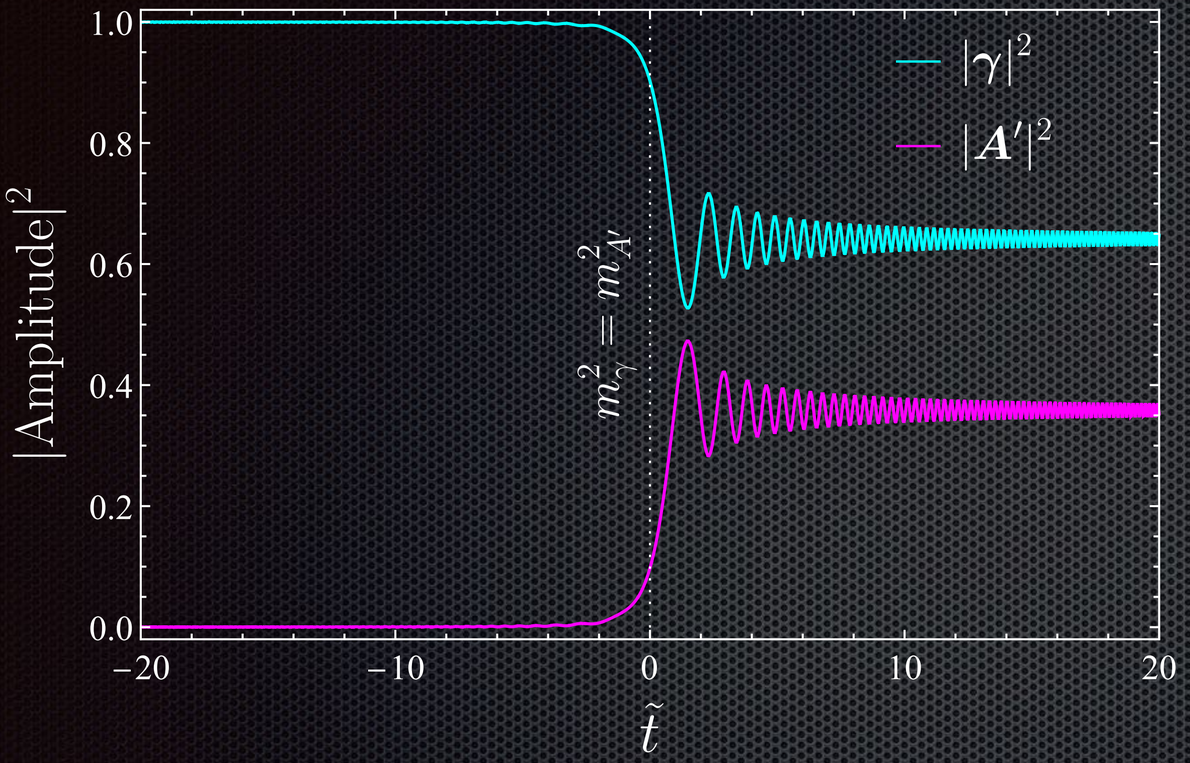
Why CMB Spectral Distortion ?

Bob Holdom 1985

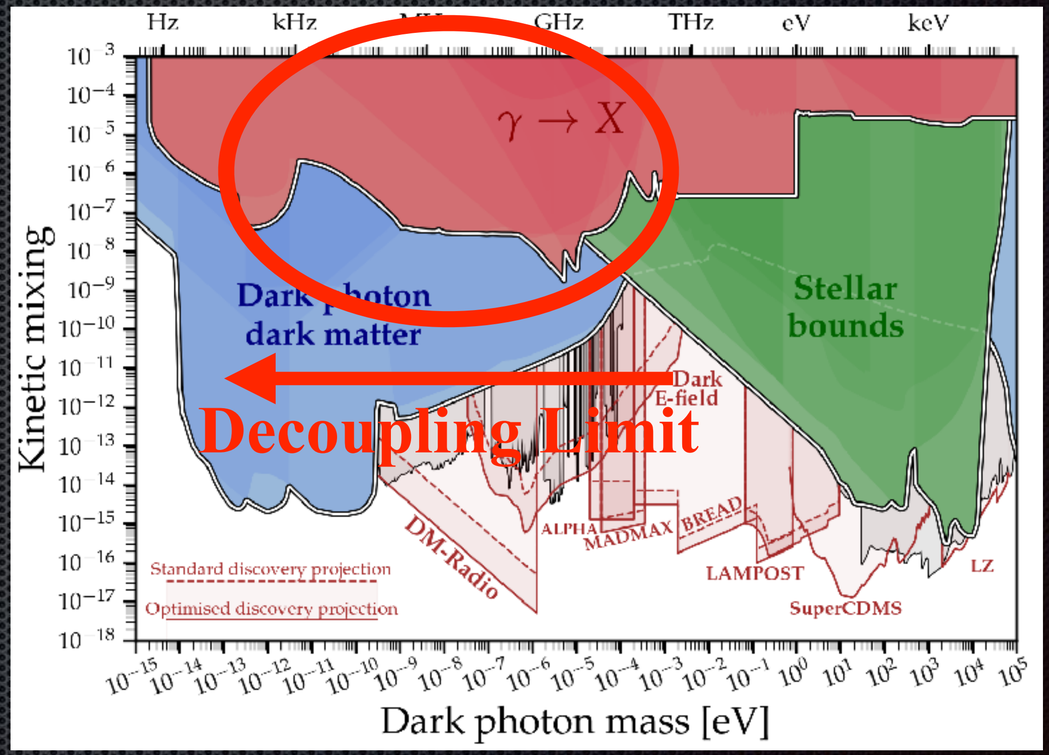


Dark Photon Limits Website

Why CMB Spectral Distortion ?



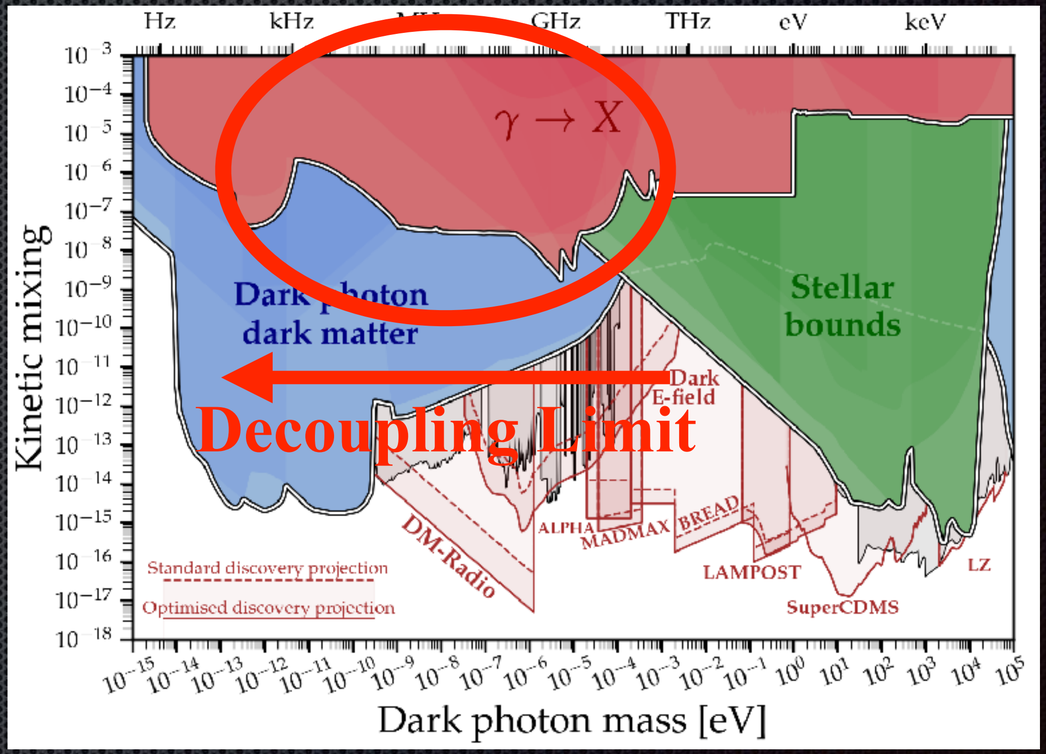
Berlin, Dror, **Xucheng Gan**, Ruderman 2022



Dark Photon Limits Website

Why CMB Spectral Distortion ?

CMB spectral distortion is currently the most sensitive test for the dark photon with $10^{-15}\text{eV} < m_{A'} < 10^{-3}\text{eV}$.



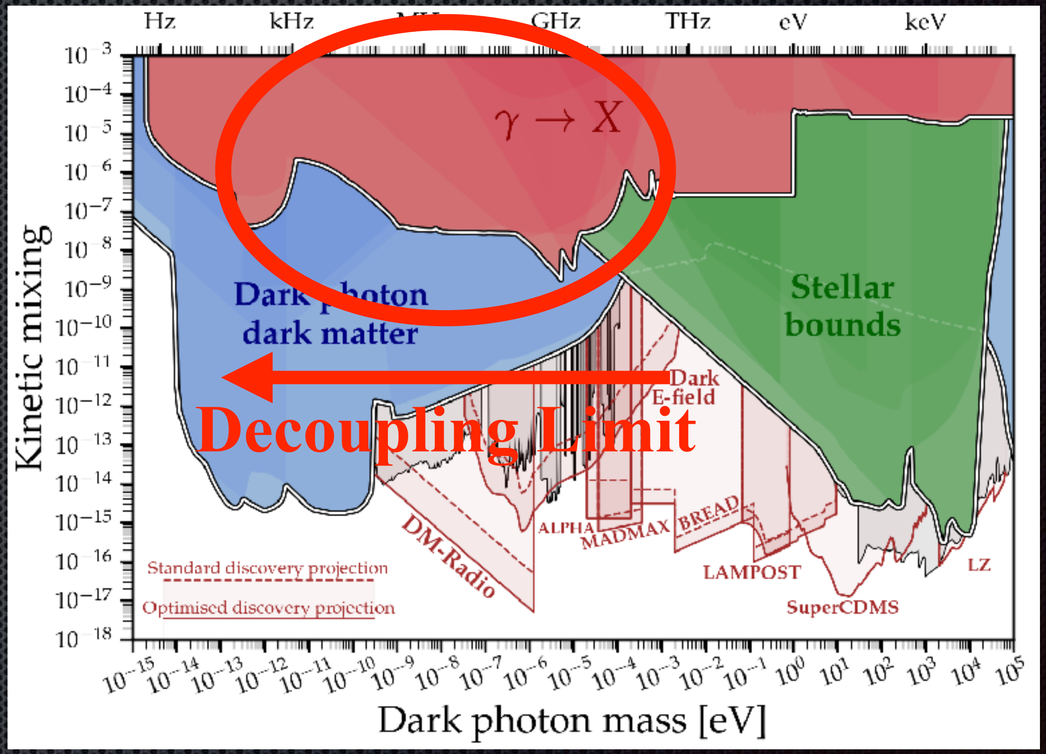
Dark Photon Limits Website

Why CMB Spectral Distortion ?

RAD : $P_{\gamma \to A'} \sim \frac{\epsilon^2}{x} \times 10^{11}$

COBE – FIRAS : $P_{\gamma \to A'} \sim 10^{-4}$

COBE – FIRAS : $\epsilon_{\rm est} \sim 3 \times 10^{8}$



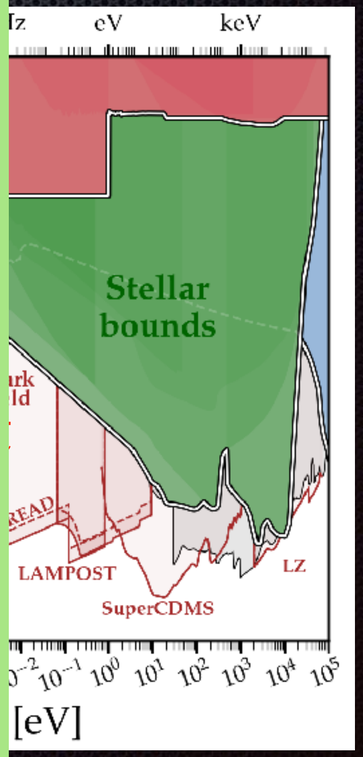
Dark Photon Limits Website

Why CMB Spectral Distortion ?

CMB sp
currentl
test for t
with 10⁻

Questions:

1. Correct formalism?
2. Correct constraint?
3. Correct smoking gun?



Dark Photon Limits Website

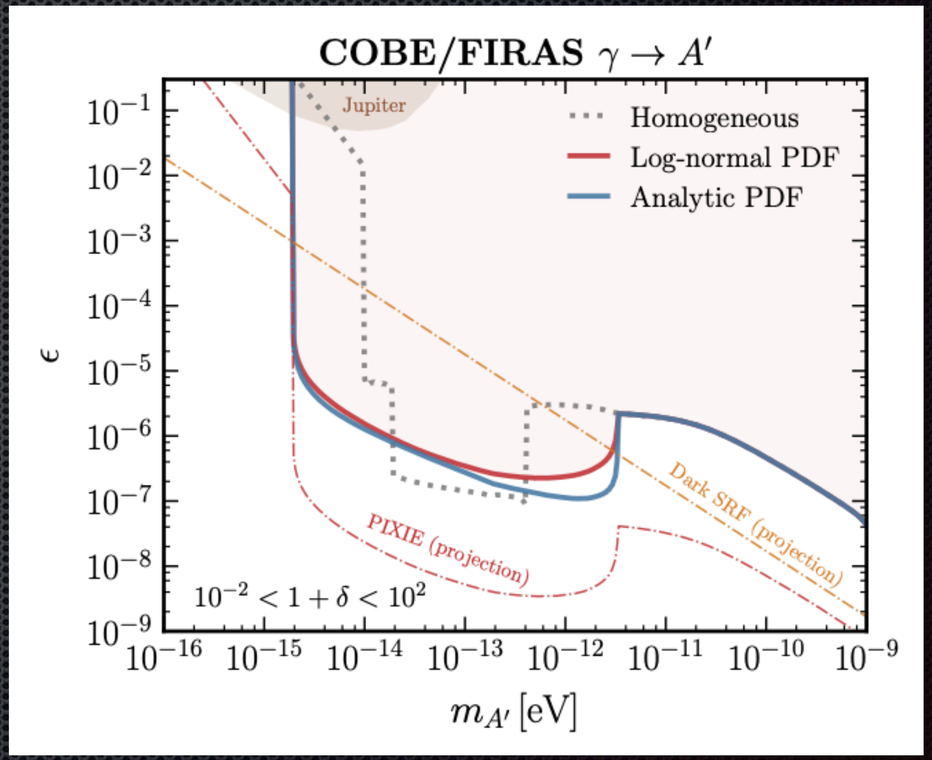
Previous Treatments

$$I(\nu) = \bar{I}_0(\nu) \cdot (1 - P_{\gamma \to A'})$$

Mirrizi, Redondo, Sigl 2008

Caputo, Liu, Mishra-Sharma, Ruderman 2020

Works perfectly in low redshift



Caputo, Liu, Mishra-Sharma, Ruderman 2020

Previous Treatments

$$I(\nu) = \bar{I}_0(\nu) \cdot (1 - P_{\gamma \to A'})$$

Mirrizi, Redondo, Sigl 2008

Caputo, Liu, Mishra-Sharma, Ruderman 2020

High redshift

Compton Scattering

$$e^- + \gamma \leftrightarrow e^- + \gamma$$

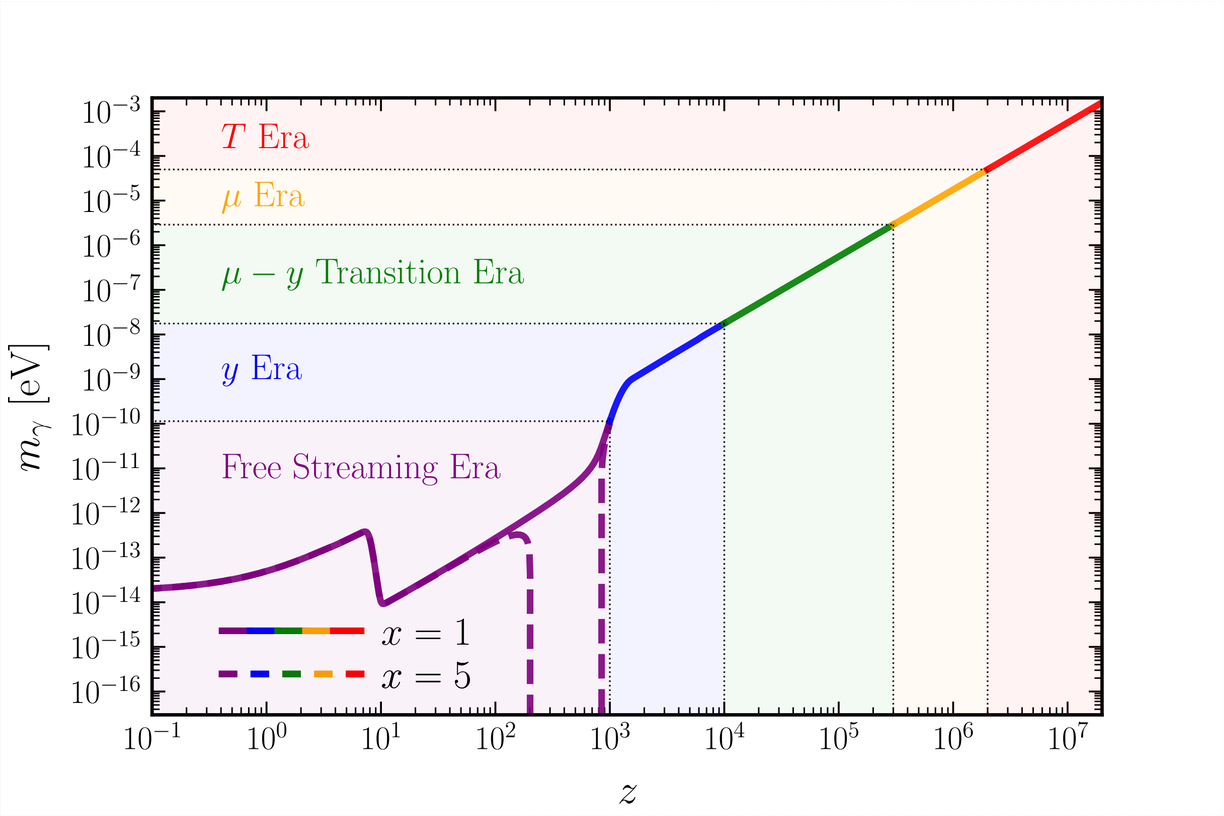
Double Compton Scattering

$$e^- + \gamma \leftrightarrow e^- + \gamma + \gamma$$

Bremsstrahlung

$$e^- + X \leftrightarrow e^- + X + \gamma$$

Previous Treatments



$$\frac{\Delta f_\gamma}{\bar{f}_\gamma} = -P_{\gamma \to A'}$$

$$e + \gamma \to e + \gamma$$

$$\frac{\Delta f_\gamma}{\bar{f}_\gamma} = \mu M(x) + y Y(x) + t T(x) + \delta_{\text{free}}$$

Arsenadze, Caputo, Xucheng Gan, Liu, Ruderman, 2409.12940

Previous Treatments

Recast $|\mu|$ and $|y|$ with

$$\Delta I_\gamma(x; T_0) = \int dz'\, G^{th}(x', z'; T_0) \frac{d(Q/\overline{\rho}_\gamma)}{dz'}$$

McDermott, Witte 2019

Dark Photon Limit Website

$\gamma \to A'$ is **NOT** thermalized energy injection ($P_s \to 0$)

We need self-consistent treatment of $\mu - y$ Transition Era

Our Treatments

Thermalized Energy Removal

$P_s = 0$

$$\Delta I_\gamma(x; T_0) = \int dz'\, G^{th}(x', z'; T_0) \frac{d(Q/\bar{\rho}_\gamma)}{dz'}$$

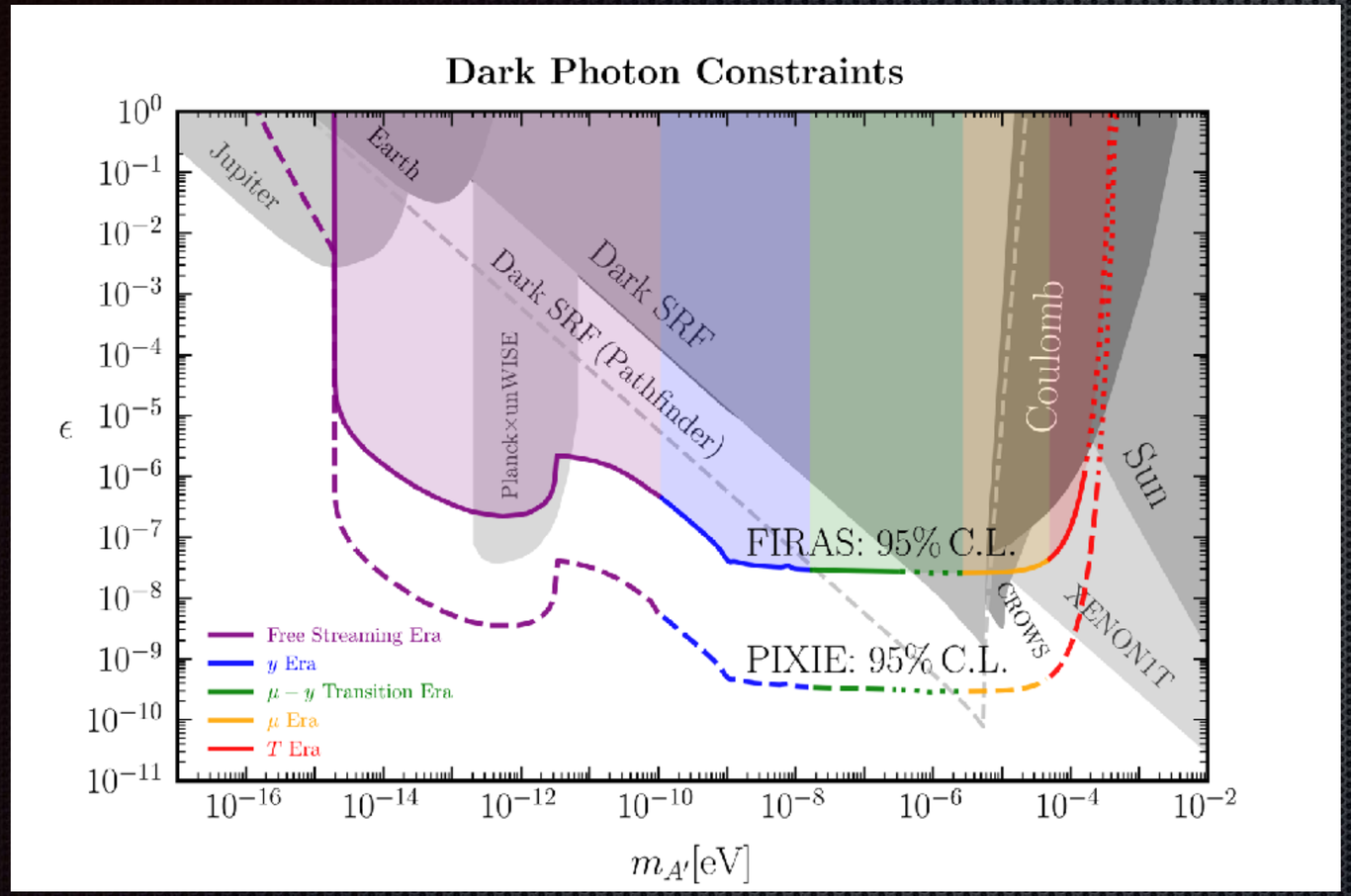
Photon Removal

$P_s = 1$

$$\Delta I_\gamma(x; T_0) = \int dx' \int dz'\, G(x; x', z'; T_0)\, \mathcal{S}(x', z')$$

$$\mathcal{S}(x', z') = \frac{1}{\bar{n}_\gamma} \frac{d\bar{n}_\gamma}{dx'} \frac{\Gamma_{\gamma \to A'}(z')}{(1 + z')H(z')}$$

COBE-FIRAS Constraint Revisit



Arsenadze, Caputo, Xucheng Gan, Liu, Ruderman, 2409.12940

$z < 10^3$ Free Streaming Era

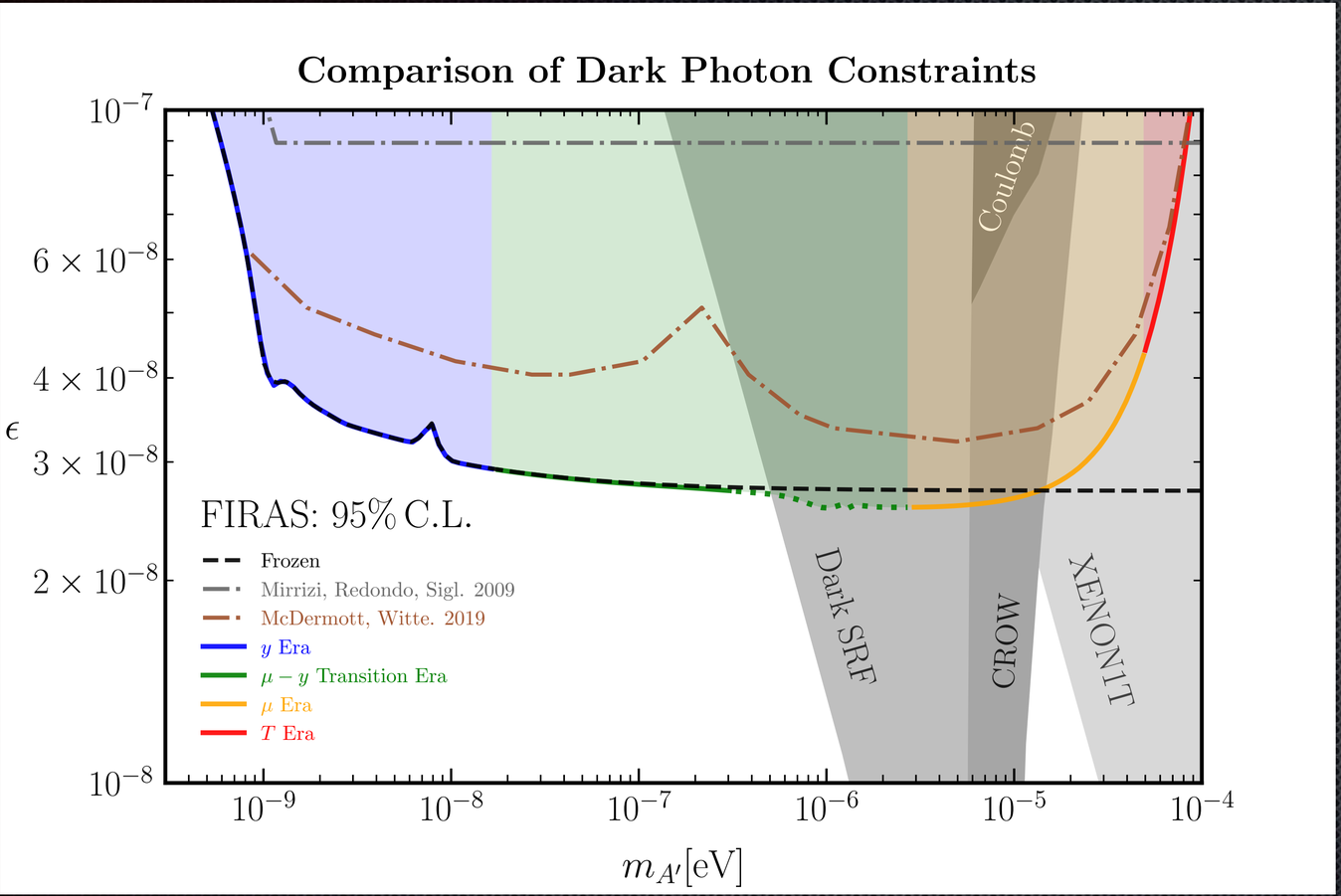
$10^3 < z < 10^4$ y Era

$10^4 < z < 3 \times 10^5$ $\mu - y$ Era

$3 \times 10^5 < z < 2 \times 10^6$ μ Era

$z > 2 \times 10^6$ T Era

Comparing with Previous Works

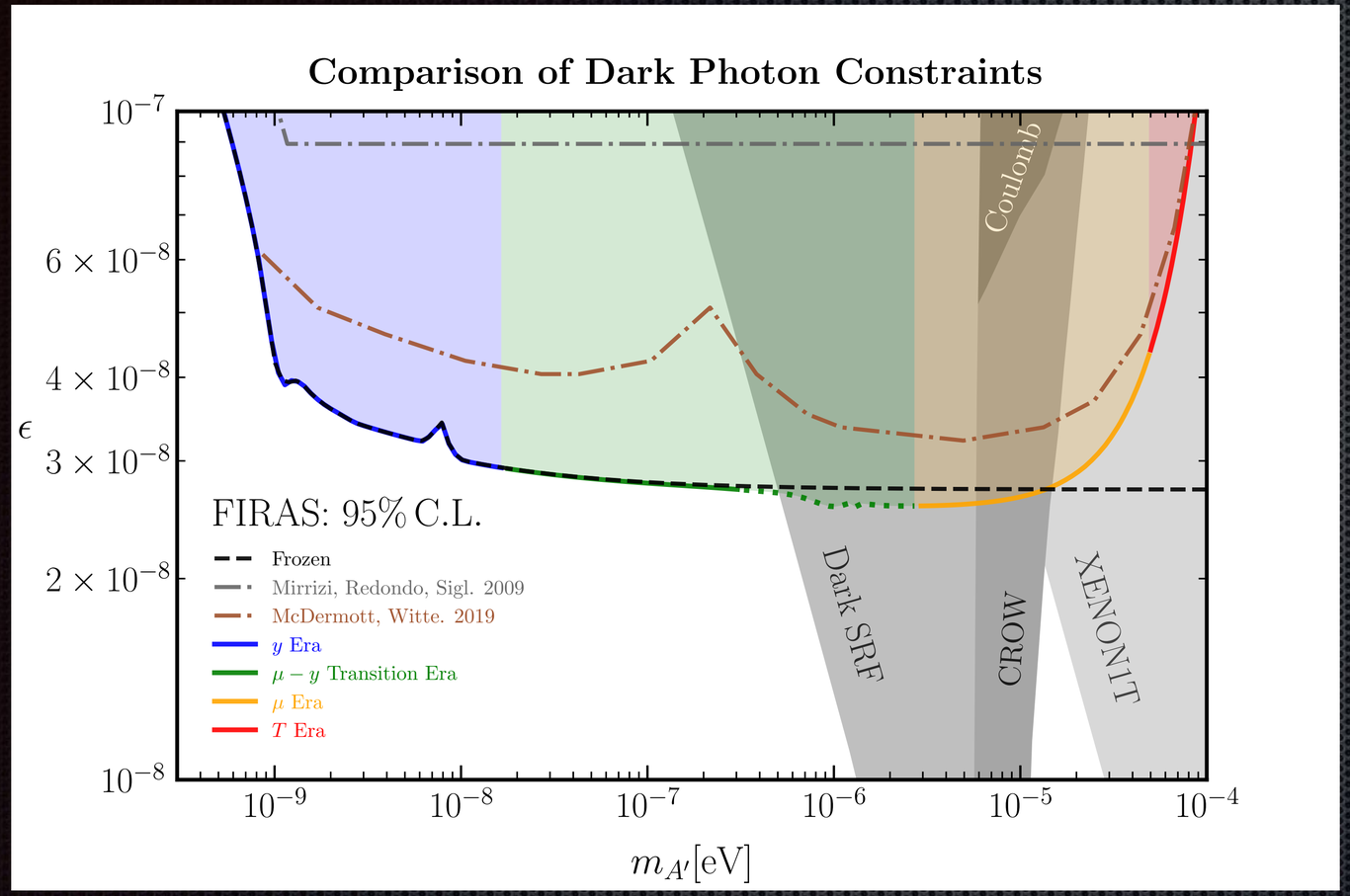


Arsenadze, Caputo, Xucheng Gan,
Liu, Ruderman, 2409.12940

Comments on Redondo et al. 09

1. Does not consider photon redistribution
2. Need hard cutoff at T-era
3. Out-of-date $X_e(z)$
4. Incorrect smoking gun

COBE-FIRAS Constraint Revisit



Arsenadze, Caputo, Xucheng Gan, Liu, Ruderman, 2409.12940

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Comments on McDermott et al. 19

1. Inconsistent treatment of $\mu - y$ era
2. Cannot smoothly transit to the free streaming era
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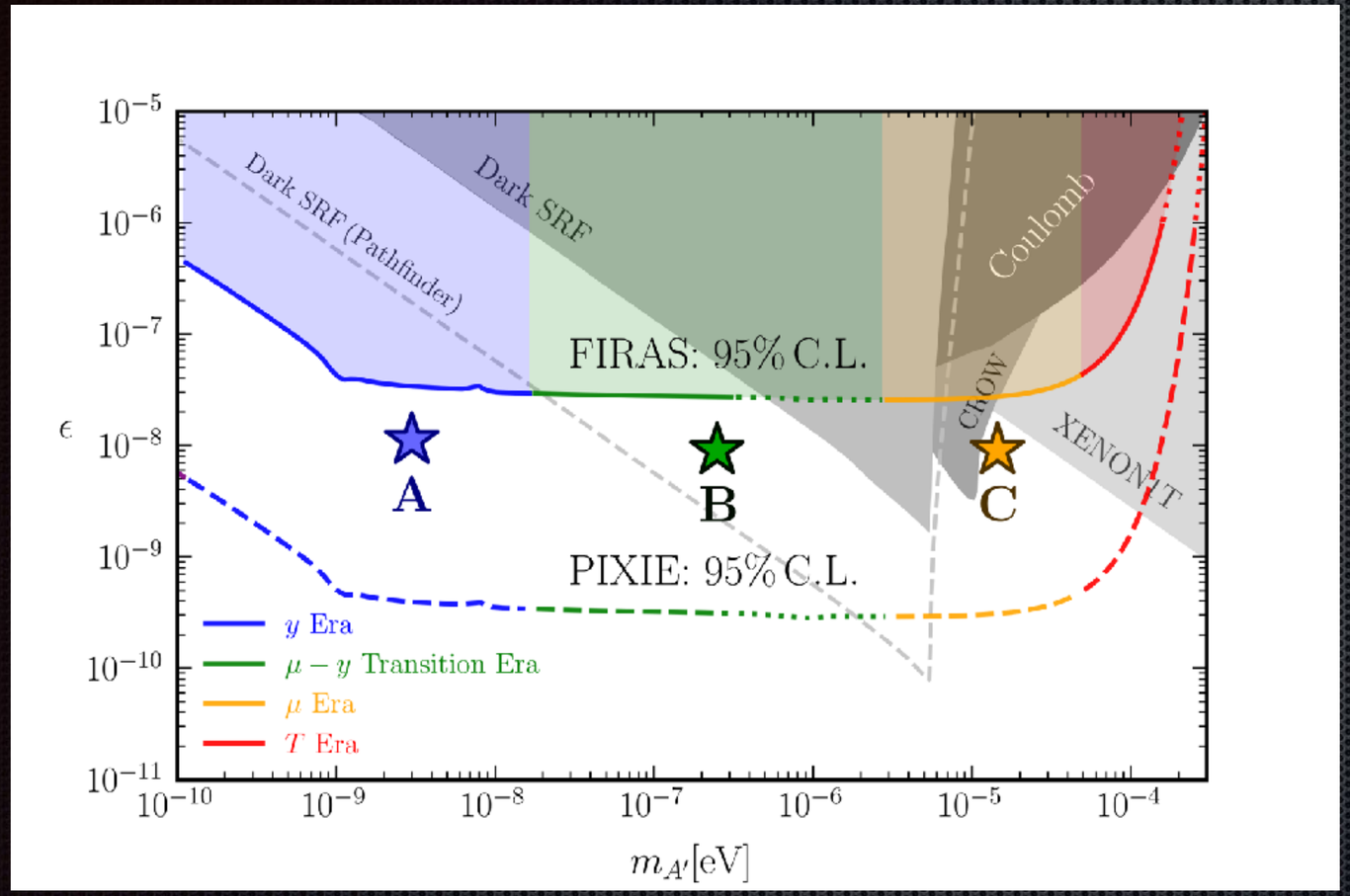
COBE-FIRAS Constraint Revisit



Arsenadze, Caputo, Xucheng Gan, Liu, Ruderman, 2409.12940

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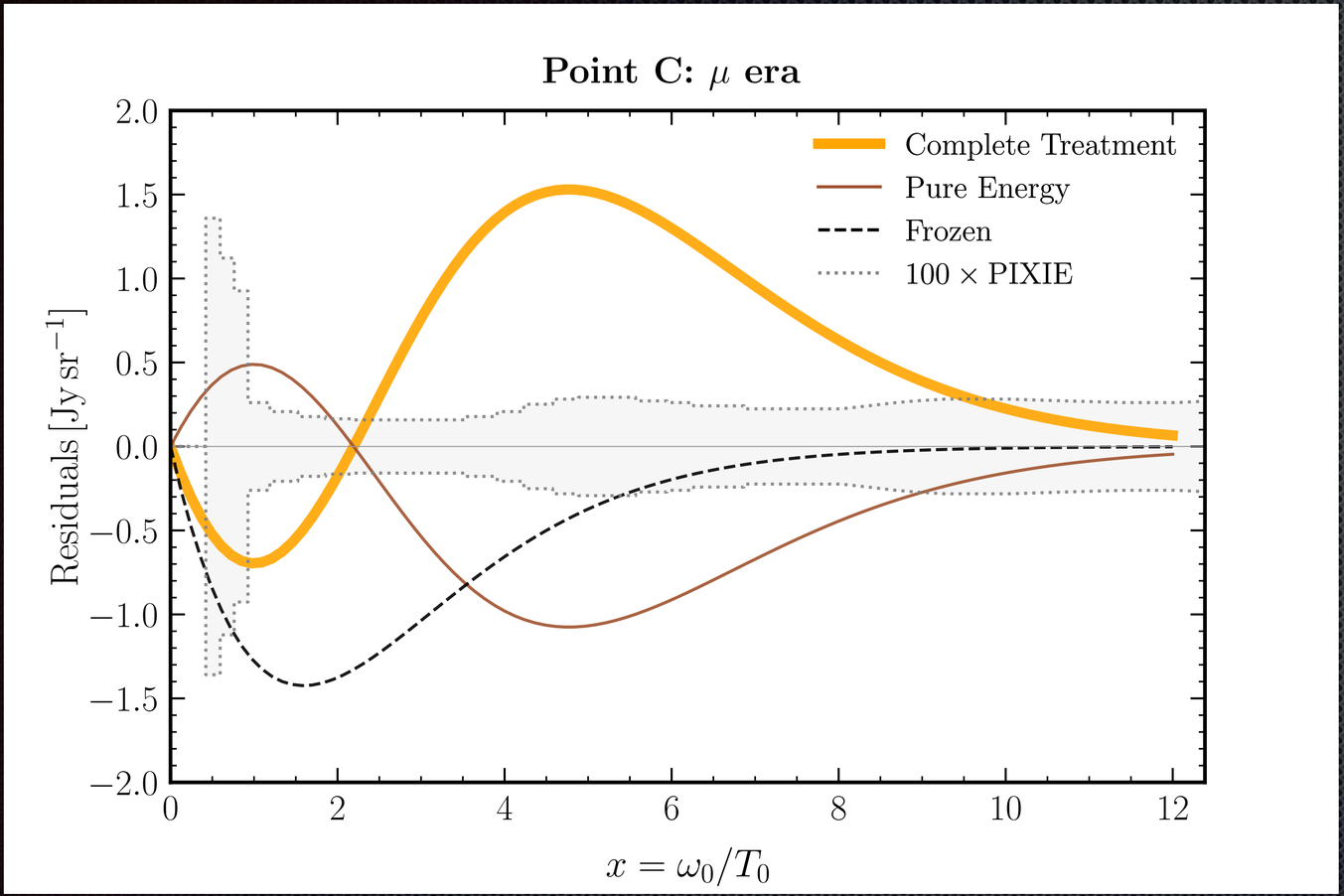


Arsenadze, Caputo, Xucheng Gan,
Liu, Ruderman, 2409.12940

μ Era Distortion

$$\mu_{inj} = \alpha_\rho x_{inj} \frac{3}{\kappa_c} \left[1 - P_s \frac{x_0}{x_{inj}} \right] \frac{\Delta n_{\gamma,inj}}{n_\gamma}$$

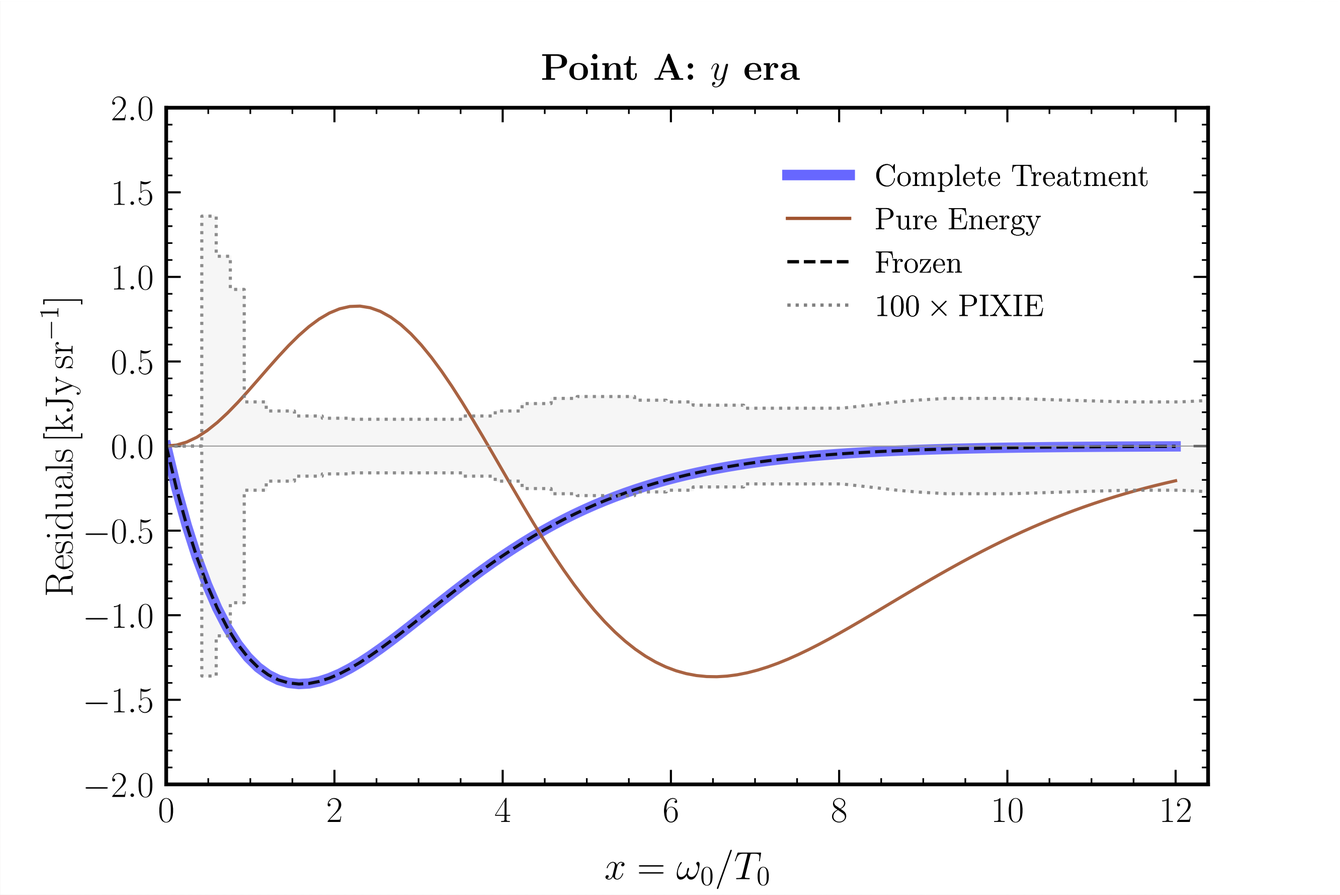
McDermott et al.: $P_s = 0$

Real Case: $P_s = 1$

$$\frac{\mu_{inj}|_{P_s=1}}{\mu_{inj}|_{P_s=0}} = 1 - \frac{x_0}{x_{inj}}$$

$x_{inj} < x_0$: μ flips the sign!

COBE-FIRAS Constraint Revisit



Arsenadze, Caputo, Xucheng Gan,
Liu, Ruderman, 2409.12940

y Era Distortion

$$G_y(x,x',z') = \alpha_\rho x' \cdot \big(1 - P_s(x',z')\big)\,\frac{Y(x)}{4}$$

$$+\alpha_\rho x' \cdot P_s(x',z') \cdot \frac{\bar{\rho}_\gamma(T_0)}{2T_0} \cdot \delta(x-x')$$

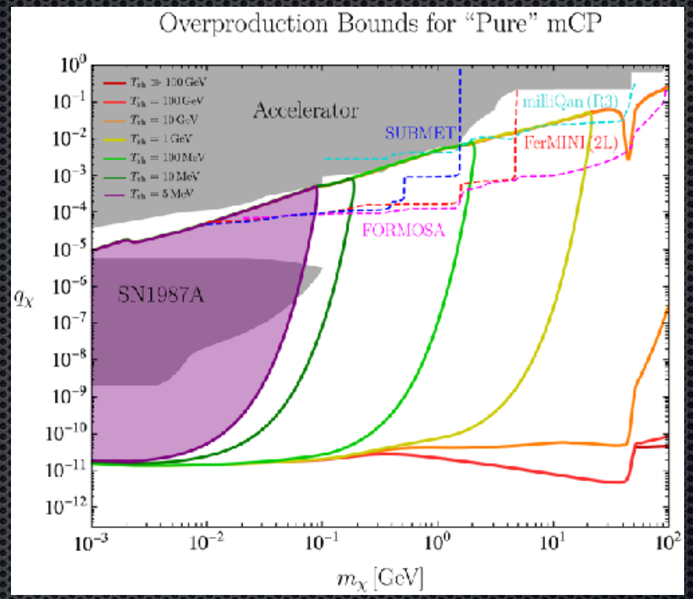
McDermott et al.: $P_s = 0$

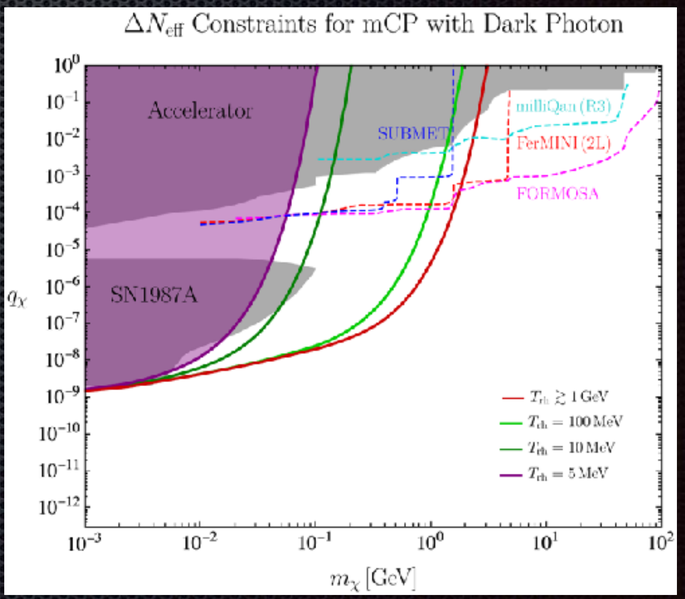
$$\Delta I(x) \propto Y(x)$$

Real Case: $P_s = 1$

$$\Delta I(x) \simeq -P_{\gamma\to A'}(x) \cdot I_0(x)$$

Irreducible Cosmic Millicharge Background





Xucheng Gan, Tsai, 2308.07951

1. propose the idea of "cosmic millicharge background"
2. detection of different reheating scenarios

Iles, Heeba, Schutz, 2407.21096

direct detection of "cosmic millicharge background" assuming $T_{rh} \gg m_\chi$

Summary

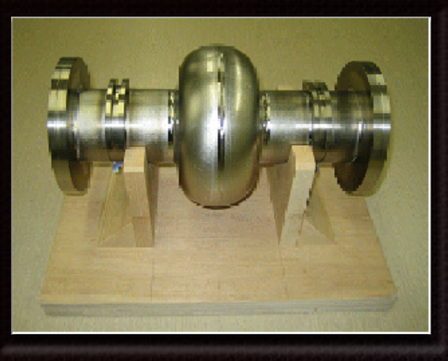
1. CMB spectral distortion is an extraordinary tool to test the photon injection/removal from BSM.

2. CMB spectral distortion is currently the best way to detect the ultralight dark photon in the mass range $10^{-10}\,\mathrm{eV} < m_{A'} < 10^{-3}\,\mathrm{eV}$.

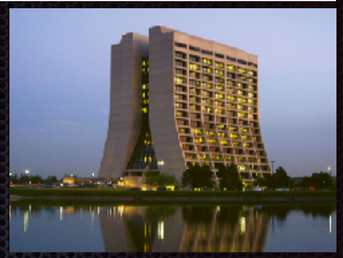
3. Previous treatments either neglected the photon redistribution from the Compton Scattering or used incomplete formalism considering the thermalized energy injection.

4. We revisit the dark photon and do it with complete formalism. We not only fix the dark photon COBE-FIRAS bound in the high redshift region but also predict the smoking guns for future PIXIE-like experiments.

Appendix



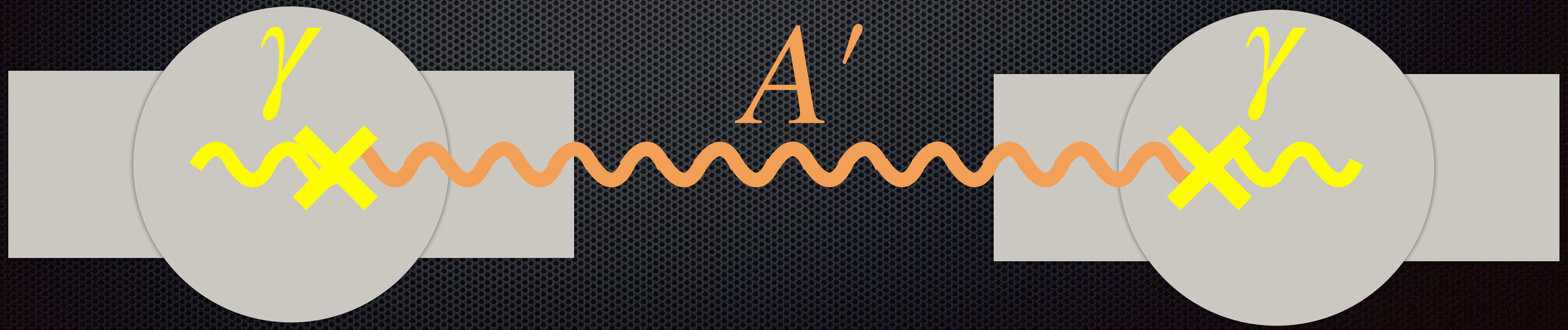
Dark SRF Experiment



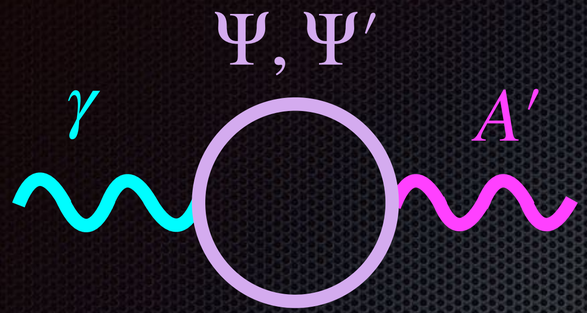
Light Shinning Through The Wall

Emitter Cavity
($\gtrsim 10^{25}$ Photons)

Receiver Cavity
(Empty)

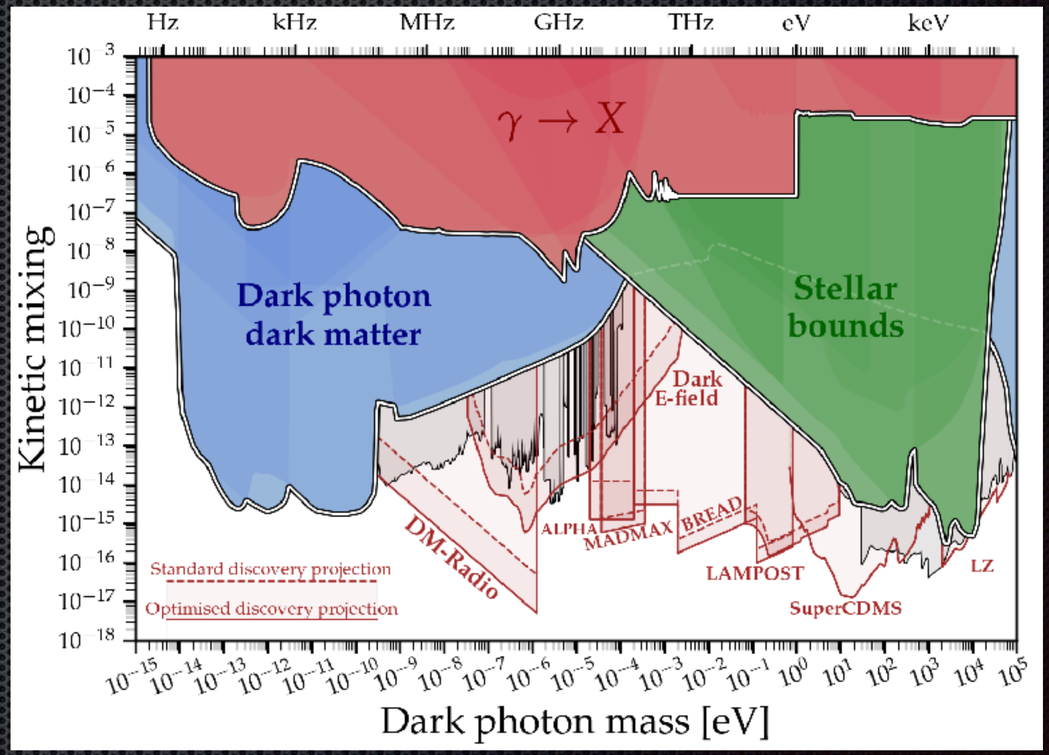


Why the Dark Photon ?



Atomic clock,
EP test,…

$$\mathscr{L} \supset \frac{1}{2}\frac{\phi}{\Lambda} FF'$$



Xucheng Gan, Di Liu 2023
arXiv.2302.03056

Dark Photon Limits Website

μ-y Transition Era