A Particle Physicist's Perspective on EDGES

Sam McDermott

with Asher Berlin, Dan Hooper, & Gordan Krnjaic

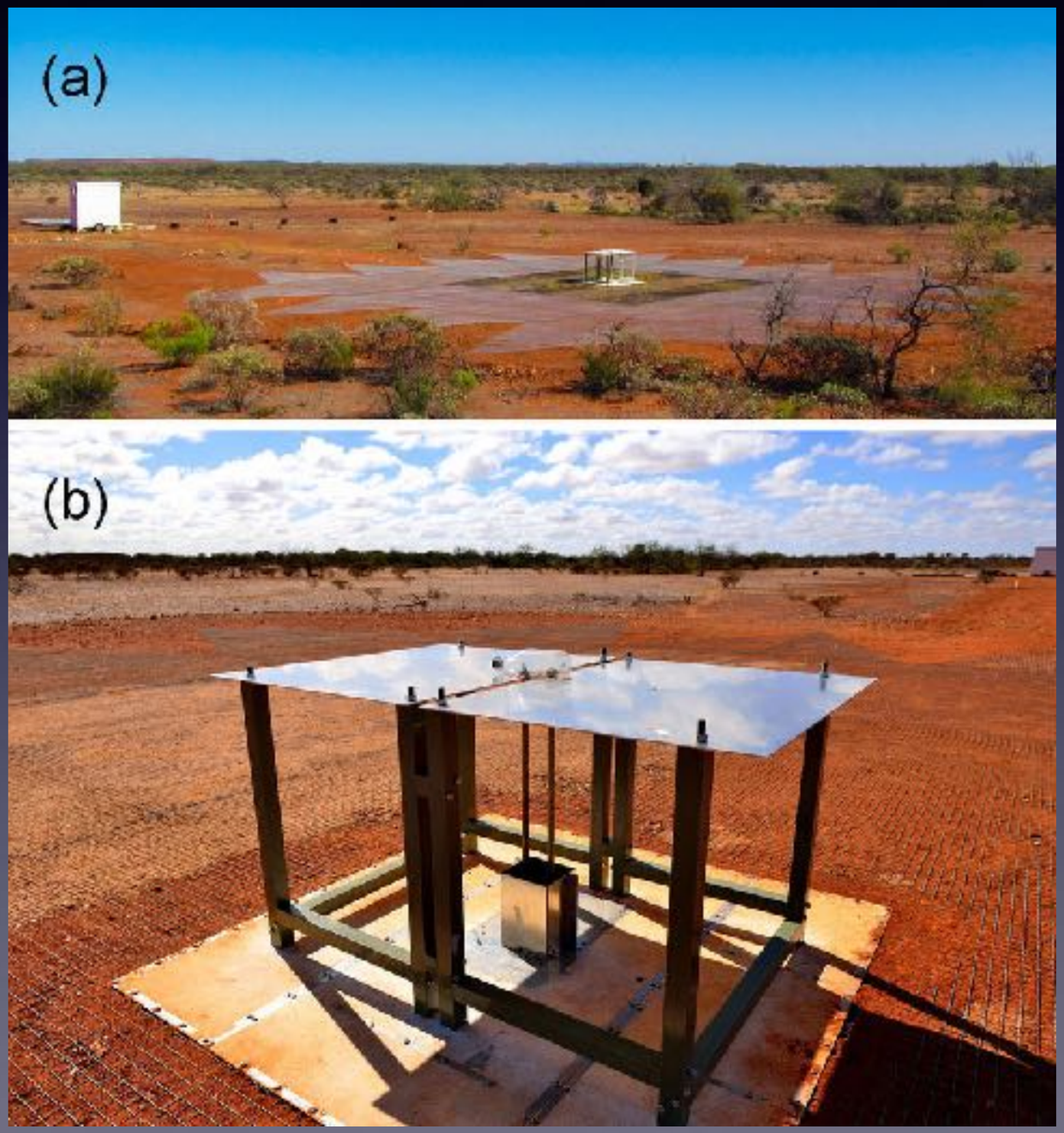
1803.02804, PRL

Fermilab

EDGES

Bowman et al, Nature 555 (2018)

Experiment to Detect the Global Epoch of reionization Signature



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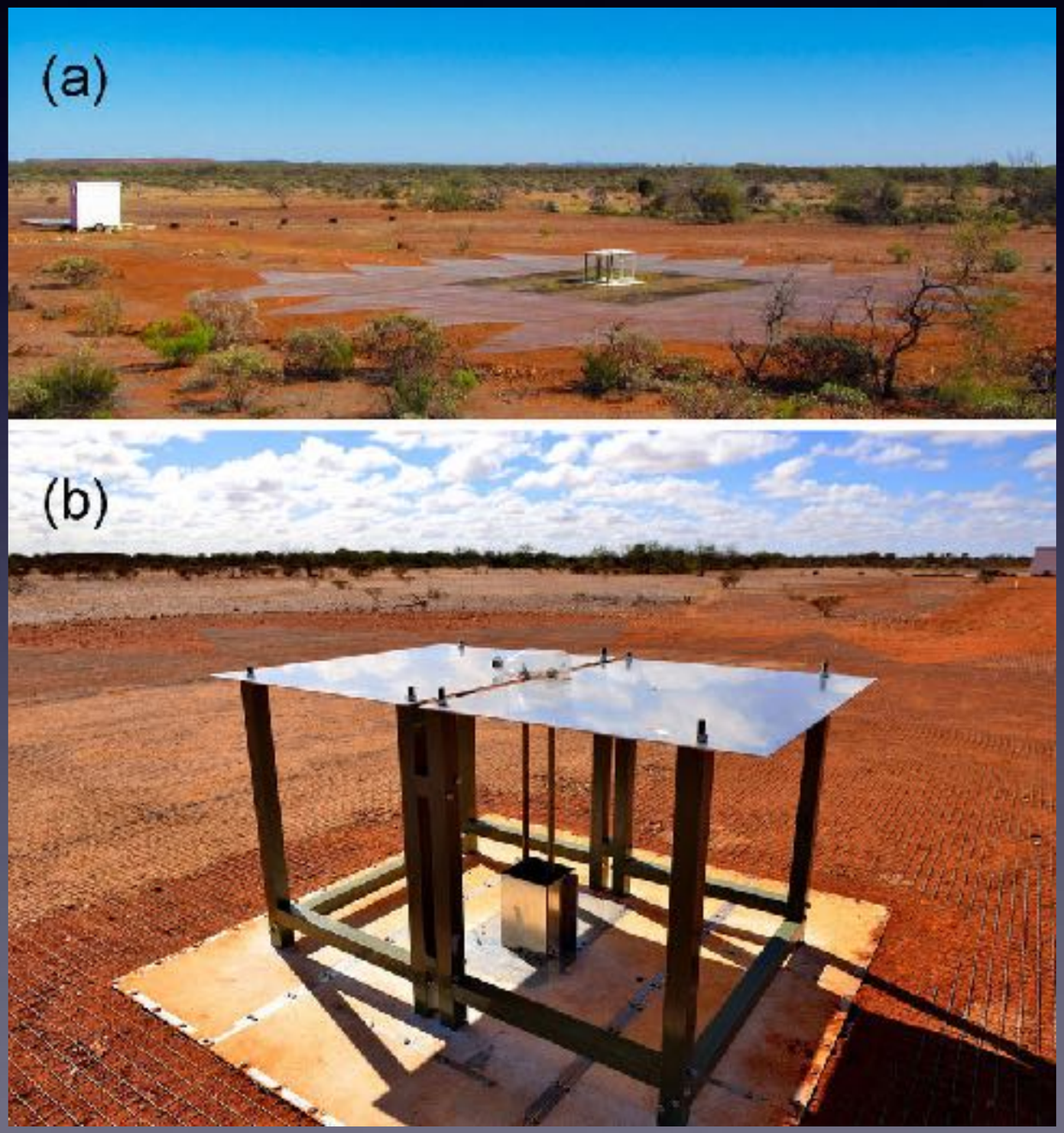
Detects the absorption strength of the spin flip transition of neutral H in the 1s state



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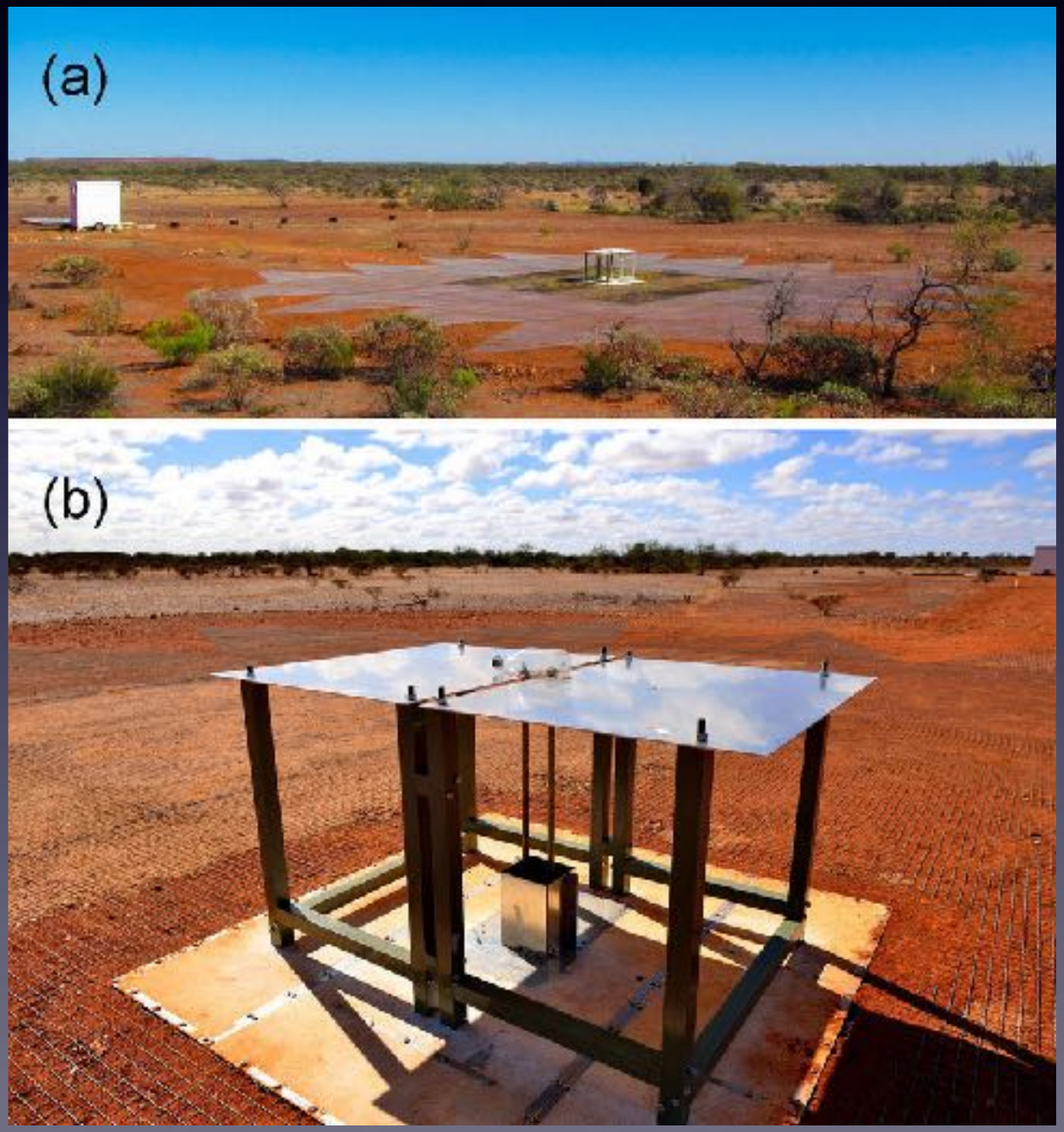
$T_{21} \sim (T_s - T_{CMB,0})/(1+z)$



EDGES

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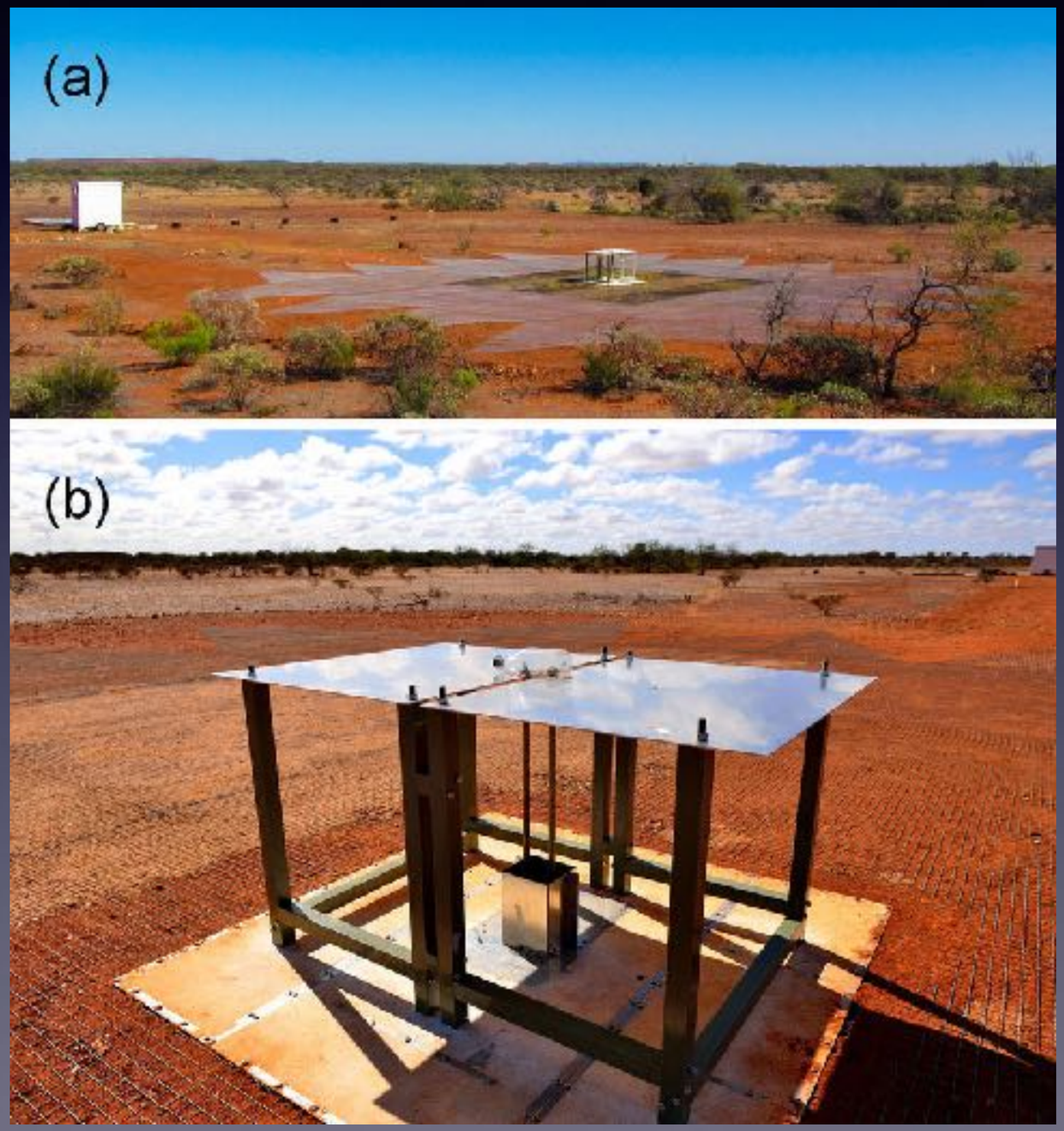
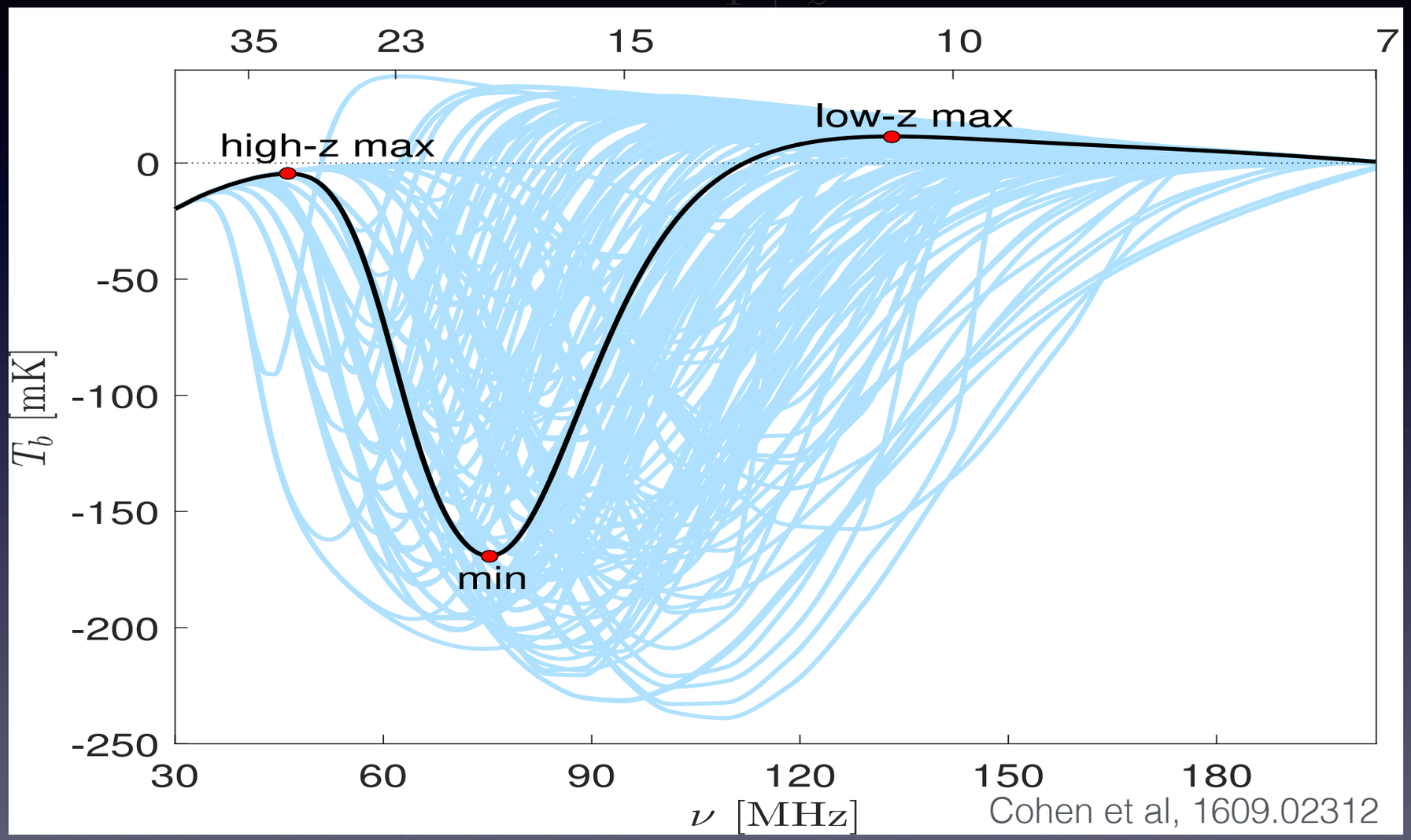
$T_{21} \sim (T_s - T_{CMB,0})/(1+z)$

$T_{21,SM} > -200$ mK

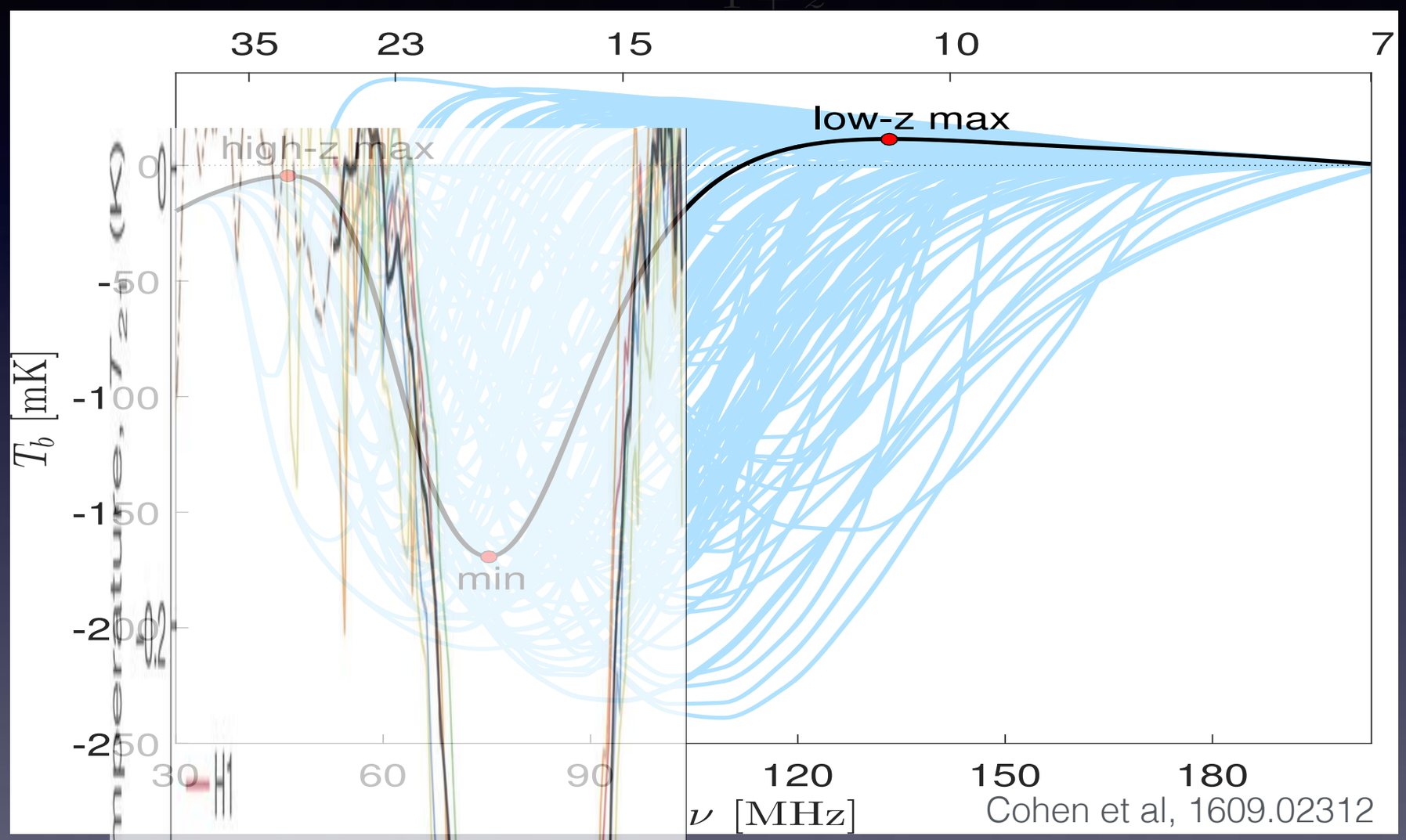


EDGES



Cohen et al, 1609.02312

EDGES



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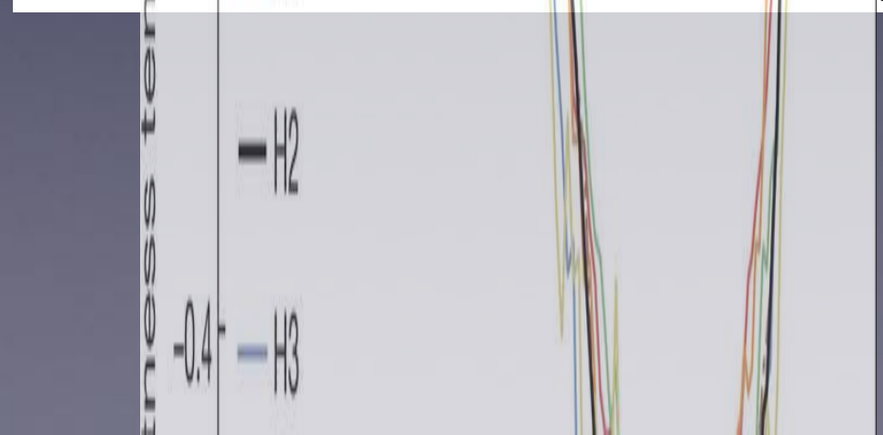

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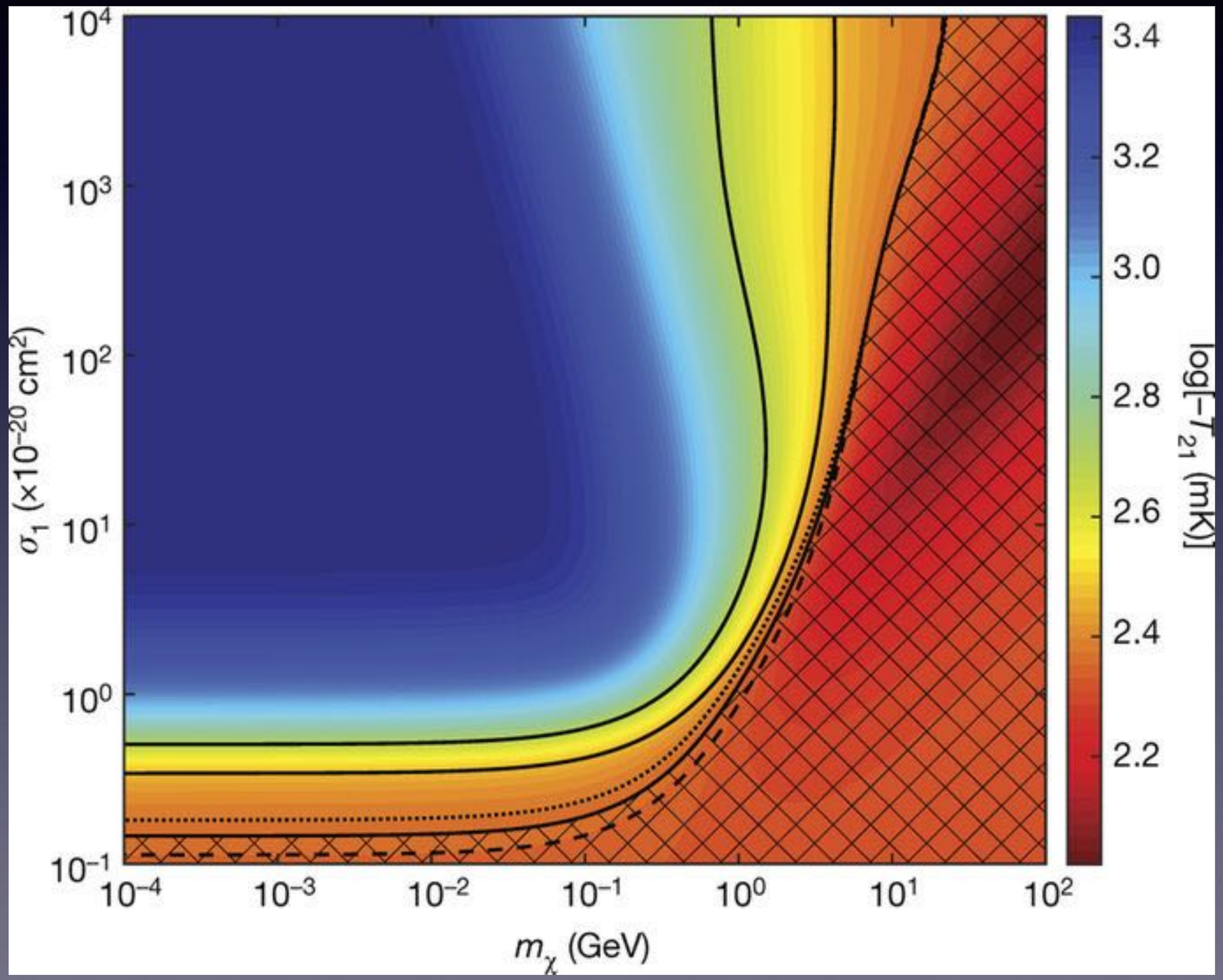
(Putative) EDGES Signal



Barkana
Nature 555
(2018)

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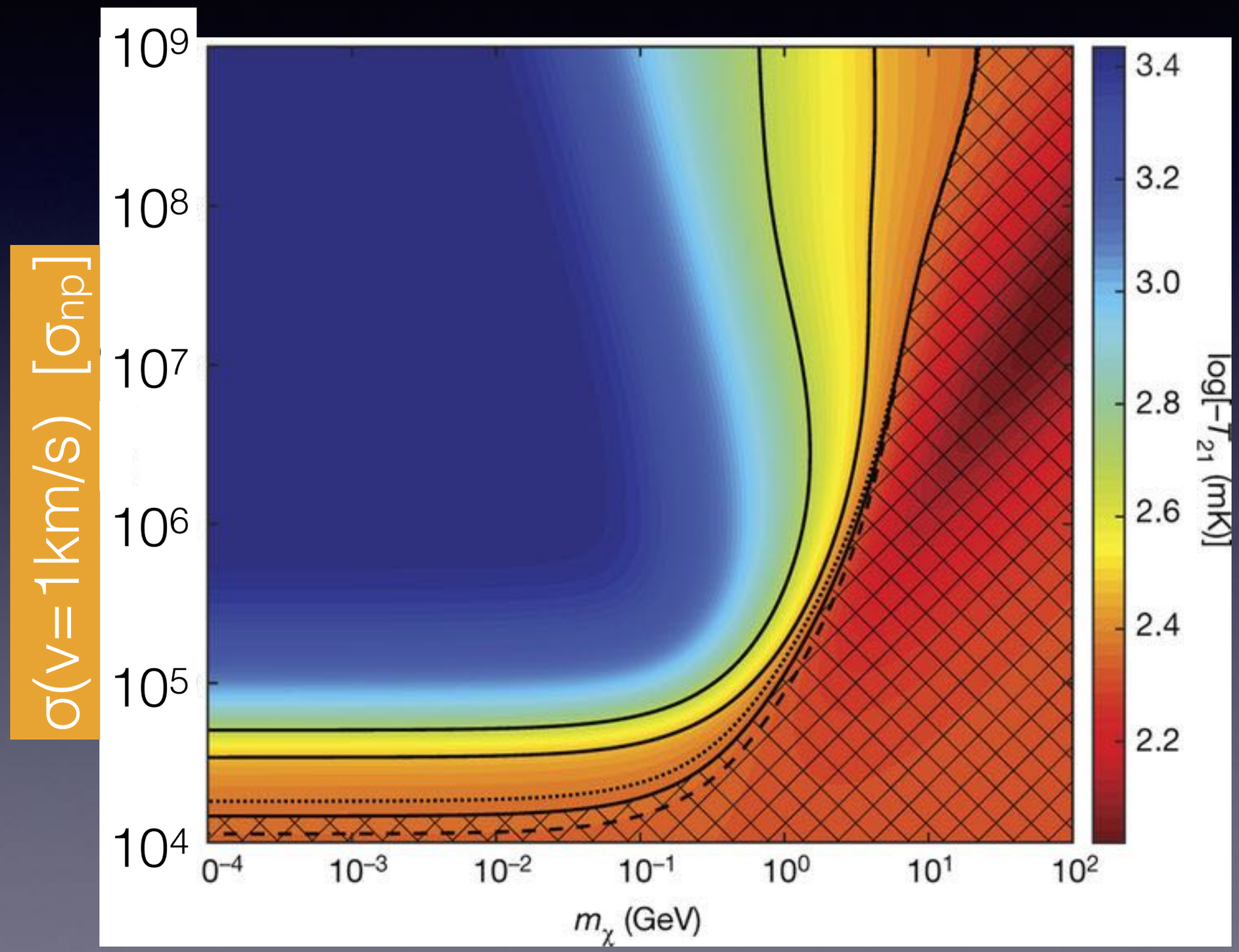

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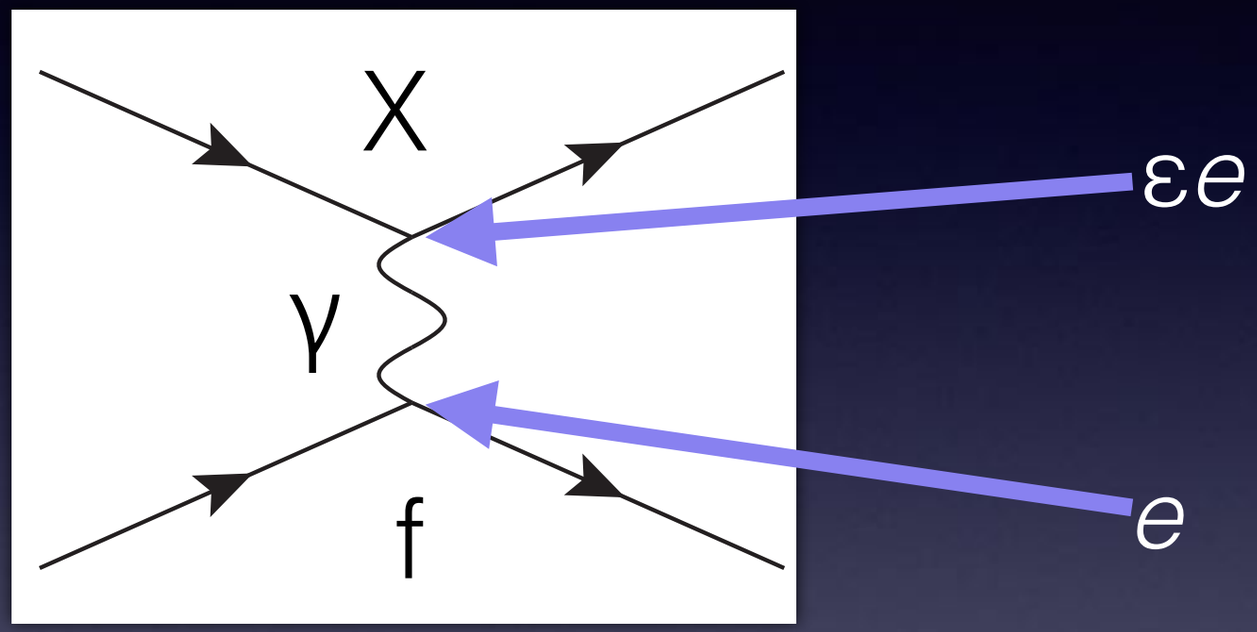
Nature 555
(2018)

Millicharge Scattering



$$\frac{d\sigma_{X\,f}}{d\Omega} = \frac{\alpha_{\rm EM}^2 \epsilon^2}{4\mu_{X\,f}^2 v_{\rm rel}^4 \sin^4(\frac{\theta}{2})} \rightarrow$$

$$\rightarrow \sigma_t \simeq \frac{2\pi\alpha_{\rm EM}^2 \epsilon^2}{\mu_{X\,f}^2 v_{\rm rel}^4} \left[60 + \ln\left(\frac{x_e \epsilon^2}{10^{-12}}\right)\right]$$

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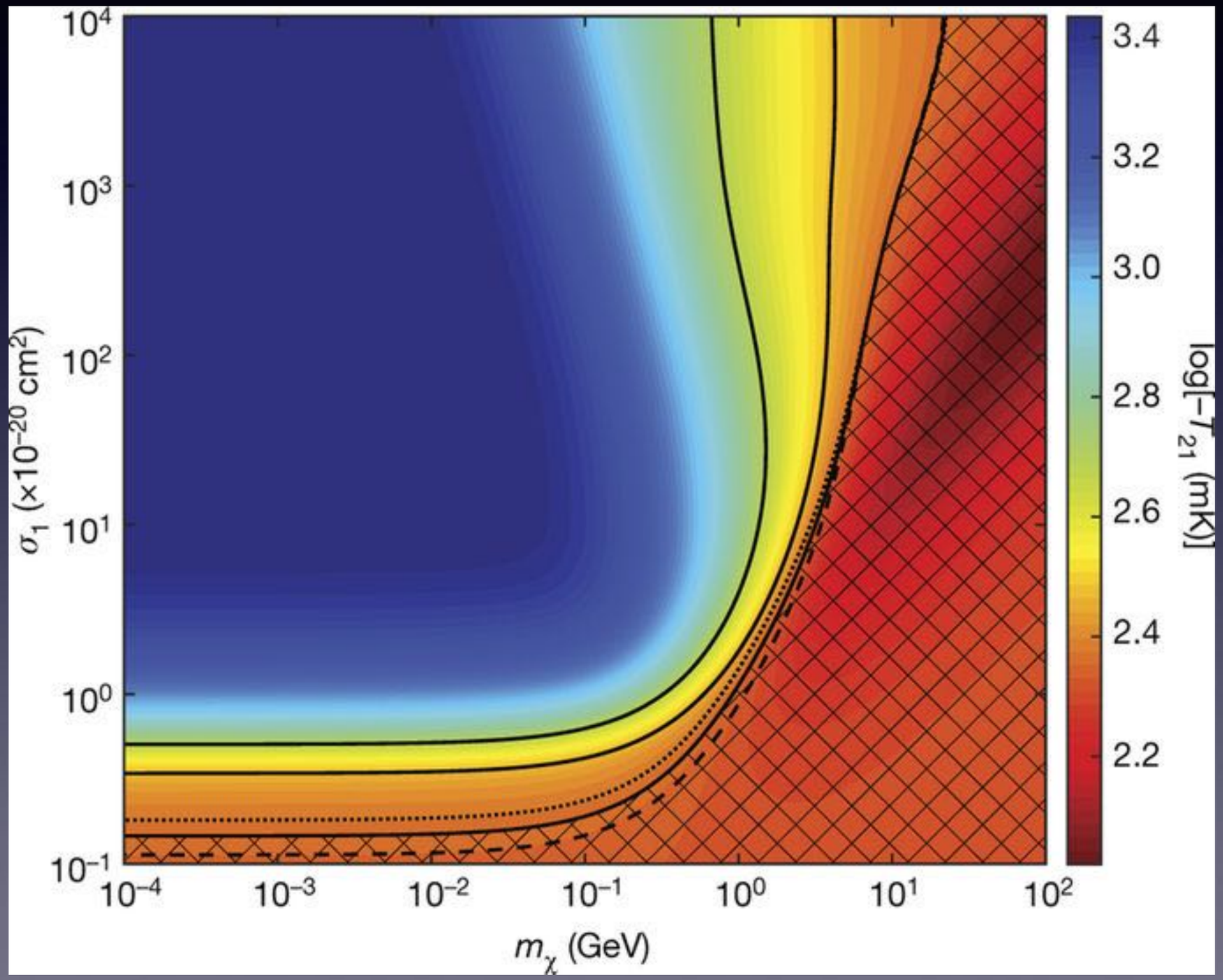

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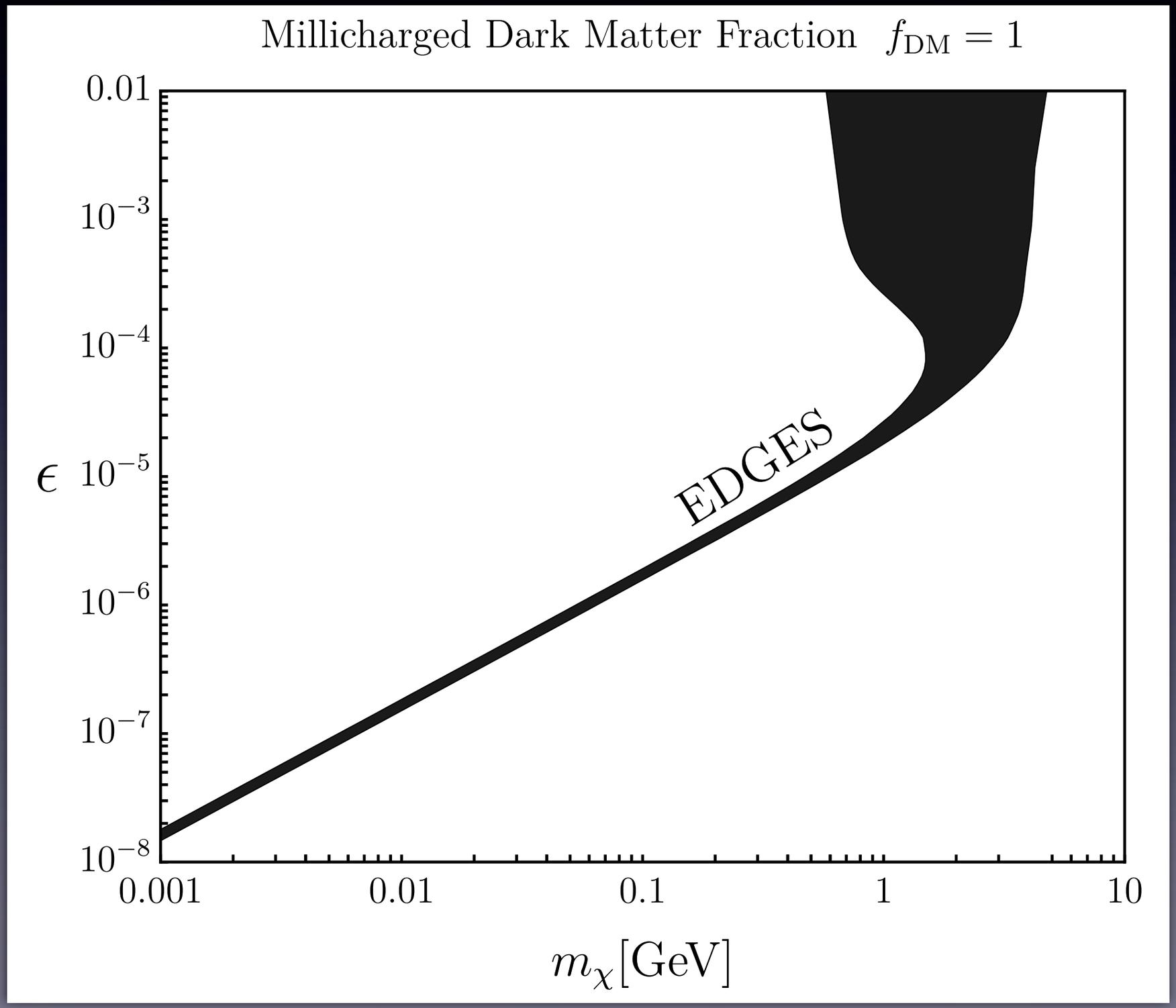

see also:
Muñoz & Loeb
1802.10094
(Nature 557)

Barkana et al.,
1803.03091

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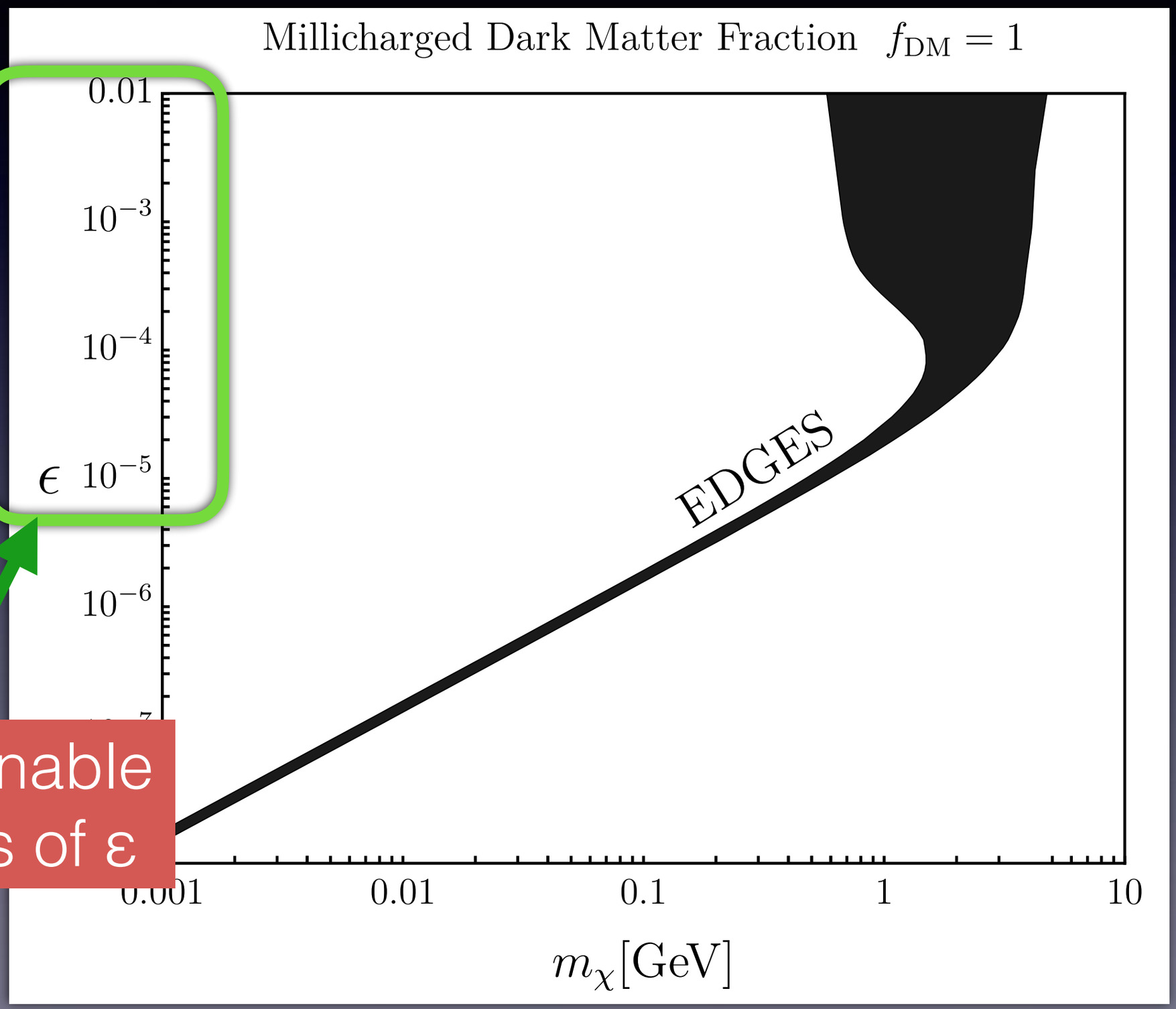

Reasonable values of ε

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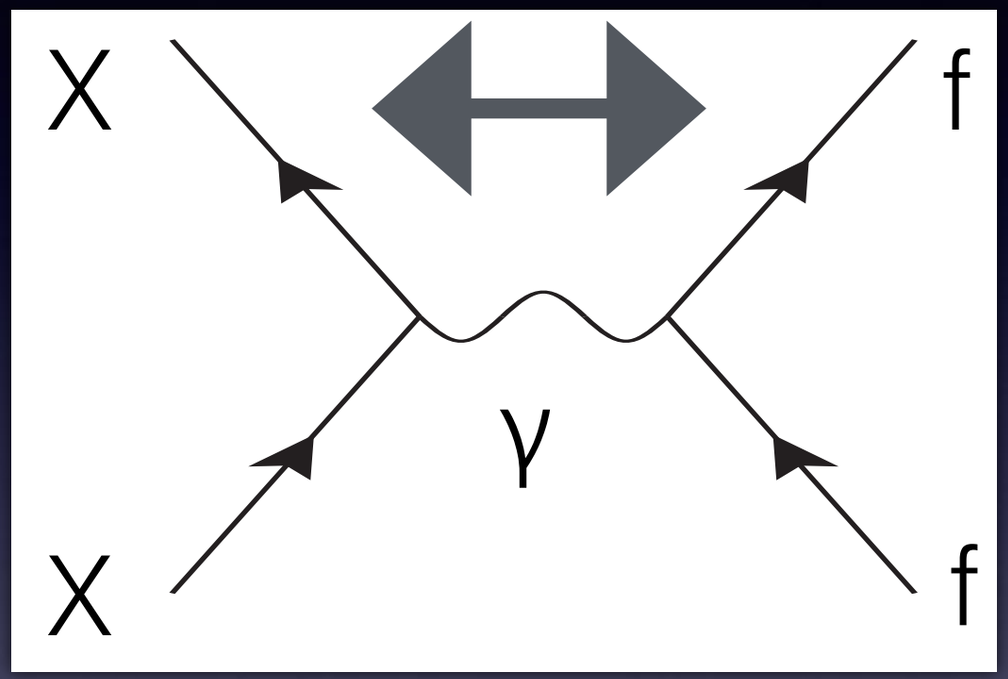
Outline

1. Astrophysical & Cosmological Implications
2. Future Directions

Early Univ. Production



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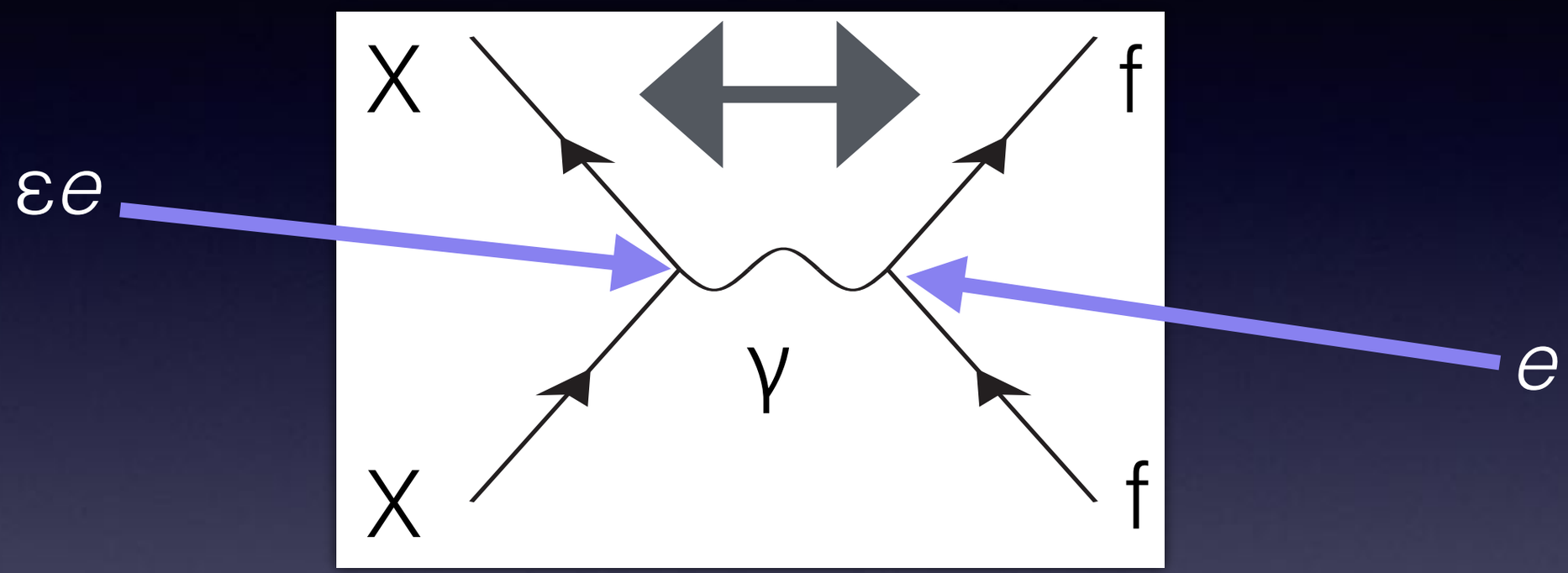

Annihilation: $\sigma v = \pi \alpha^2 \varepsilon^2 / m_X^2$

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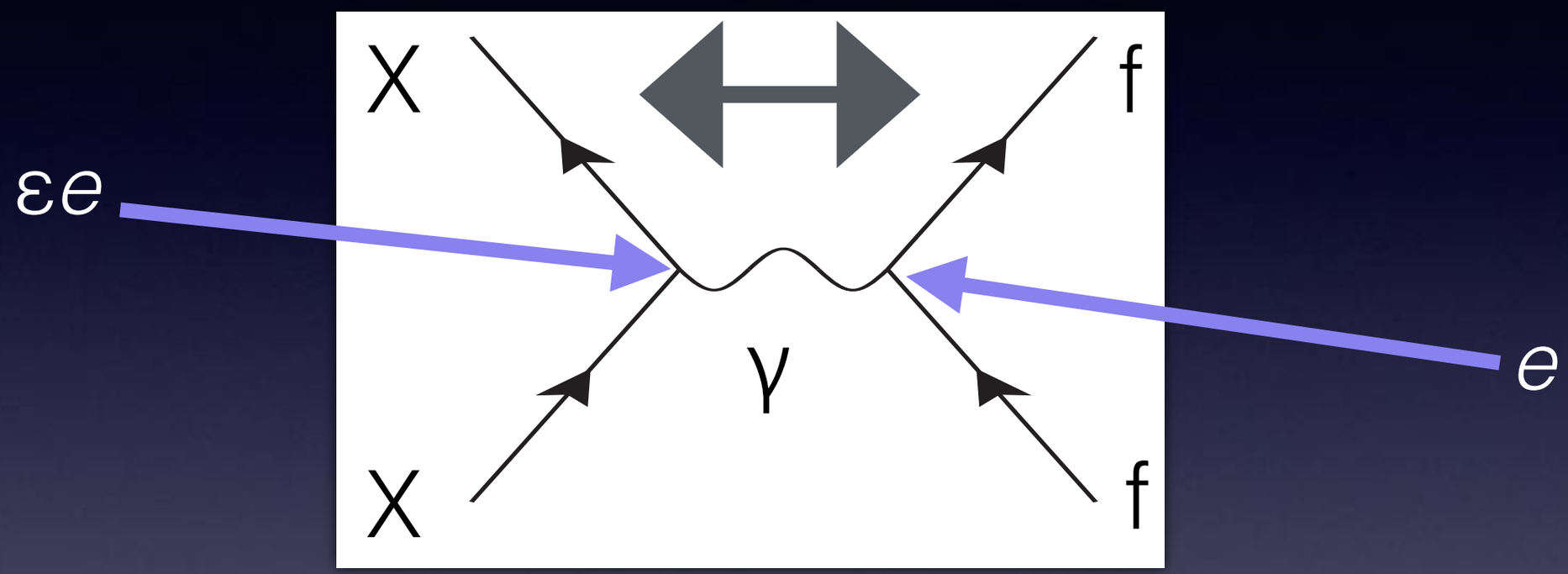

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Thermalized: $n_X \sigma v(T=m_X) \sim H(T=m_X) \Rightarrow \varepsilon > 10^{-7} (m_X/\mathrm{GeV})^{1/2}$

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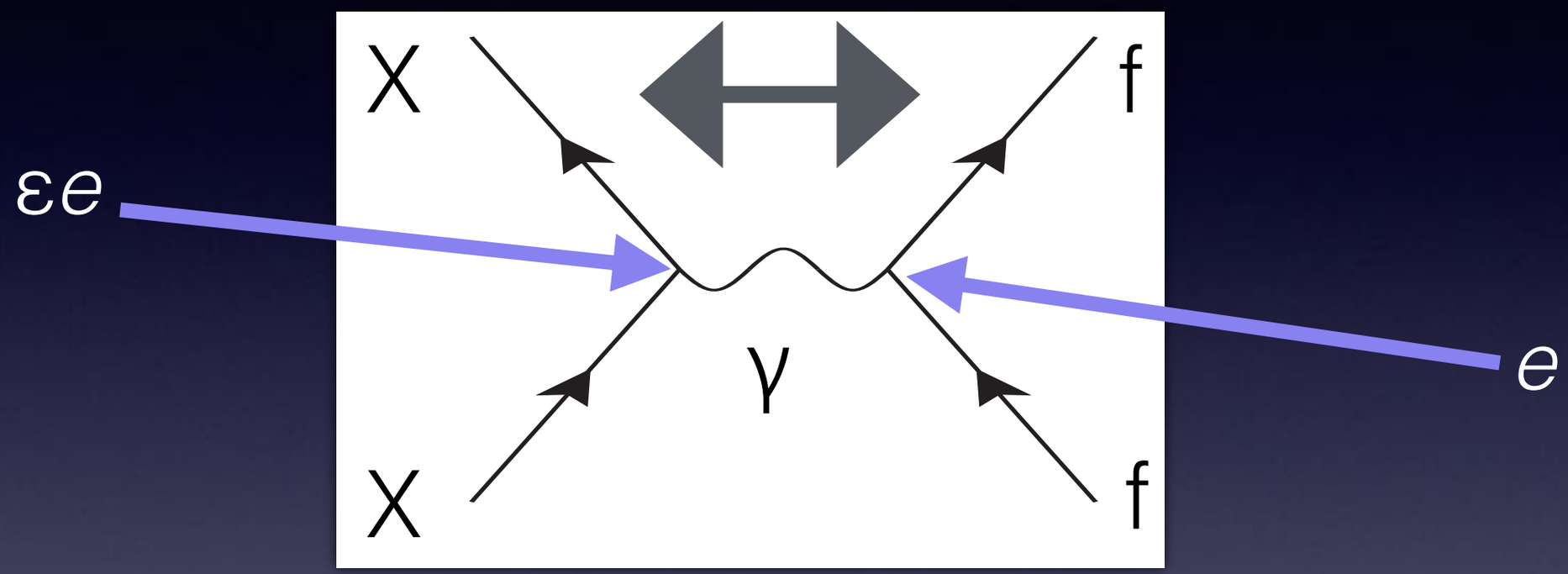

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Relic abundance: $\sigma v \approx \sigma v_{th} (\varepsilon/10^{-3})^2 / (m_X/\mathrm{GeV})^2$

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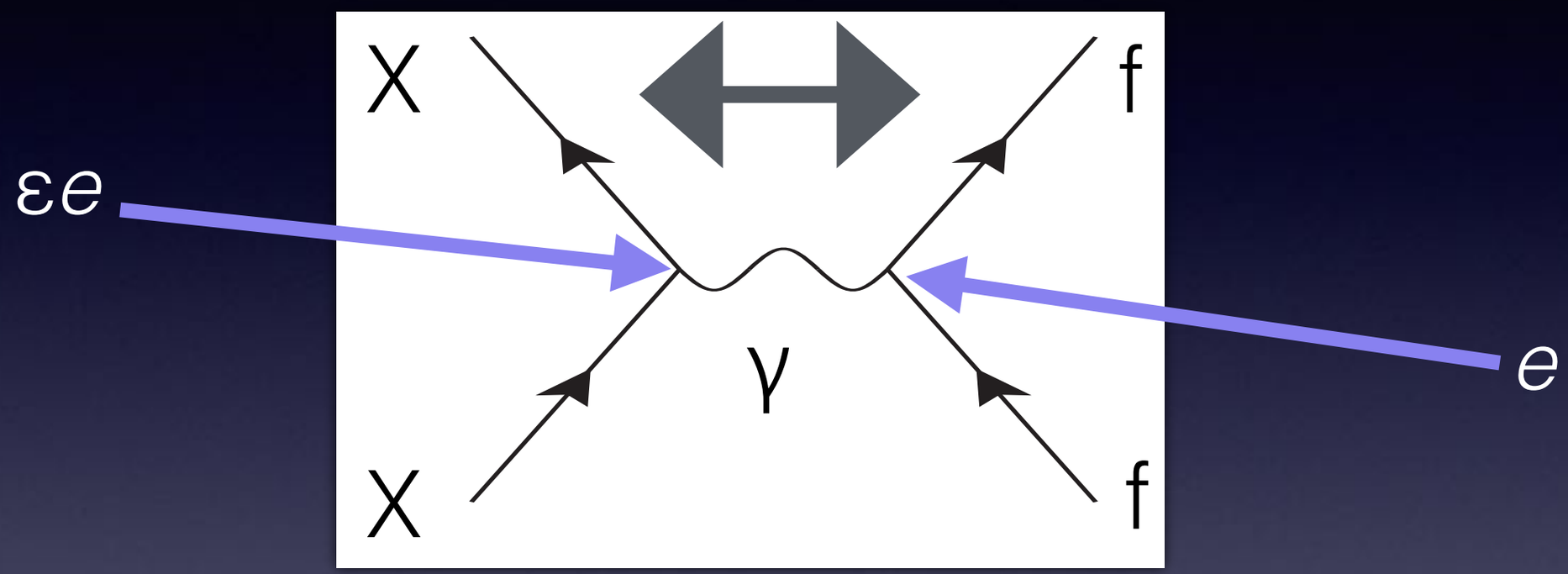

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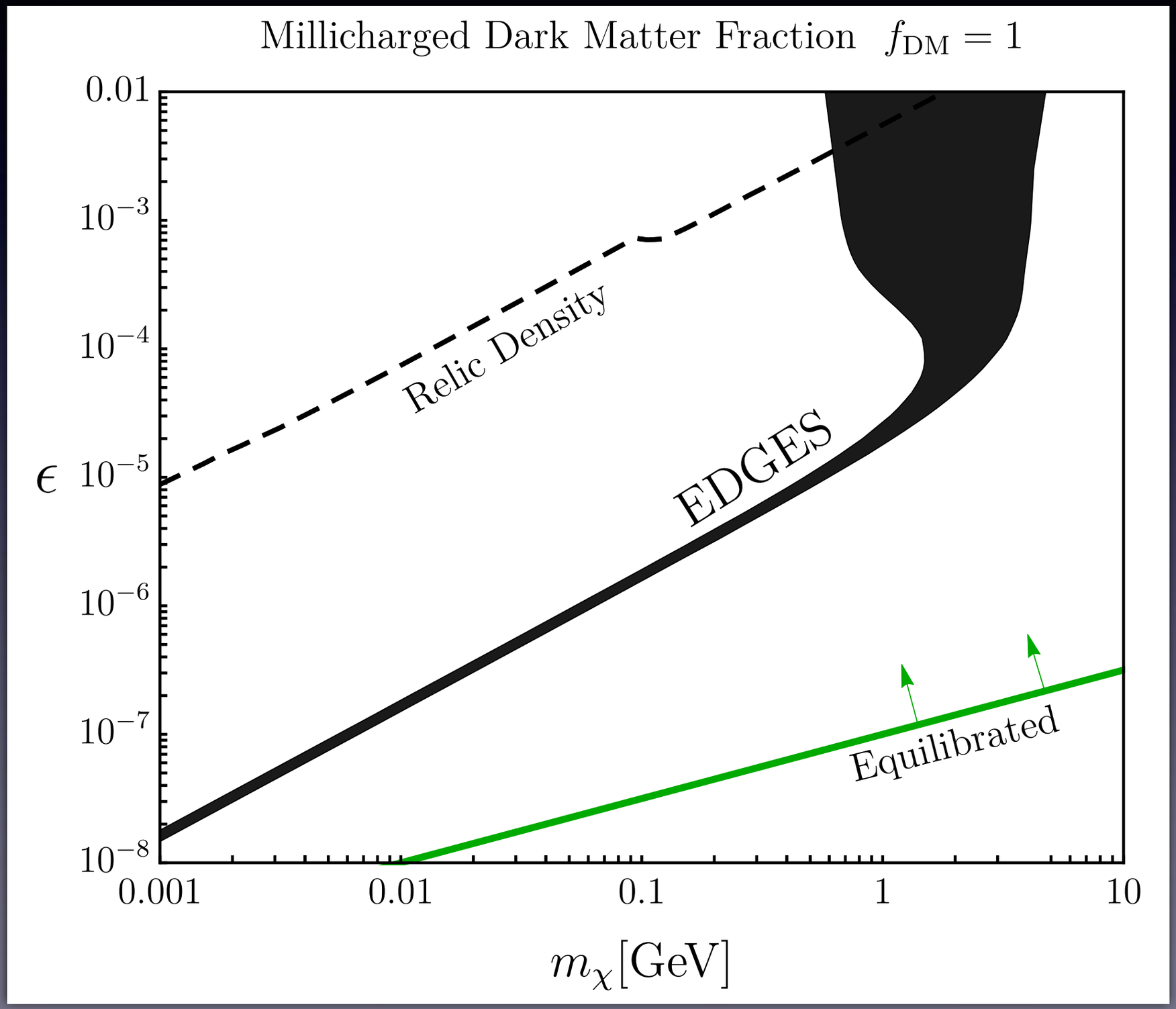
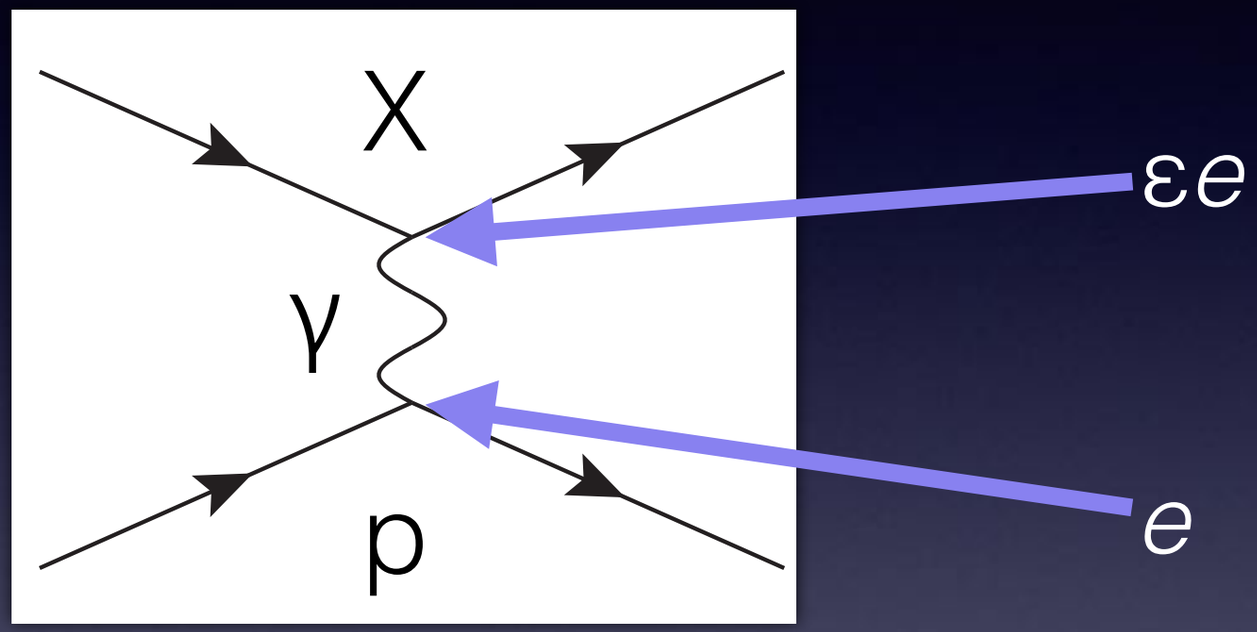
Relic abundance: $\Omega_{DM} h^2 \approx 0.1\ (m_X/\mathrm{GeV})^2 / (\varepsilon/10^{-3})^2$

Relic Density

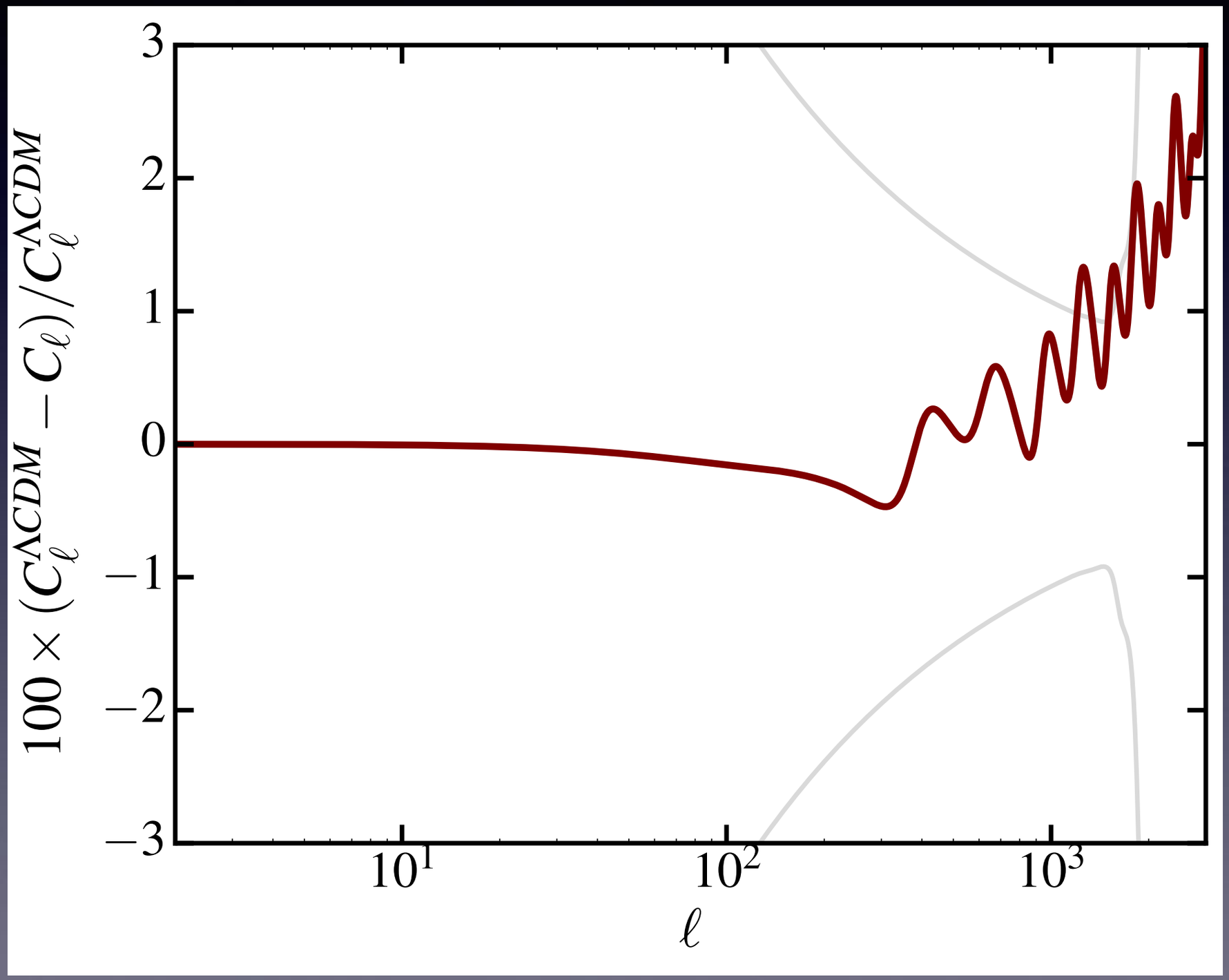


CMB



Baryons should not scatter efficiently with dark matter at the time of CMB: $\Gamma_{\chi p} < H_{rec}$

CMB



Gluscevic & Boddy, 1712.07133

CMB

Rate of change of baryon temperature:

Dubovsky et al., hep-ph/0311189
& 1310.2376
McDermott, Yu, & Zurek 1011.2907

$$\frac{\langle \frac{d}{dt}\delta T\rangle}{T} = \frac{4}{\sqrt{2\pi}}\frac{\rho_X \sigma_0 \mu_{Xp}^2}{3 m_X m_b v_{\rm rel}} \cdot \frac{1}{T}$$

$$\simeq \frac{4}{3\sqrt{2\pi}}\frac{\rho_X \sigma_0 \mu_{Xp}}{m_X + m_p}\left(\frac{\mu_{Xp}}{T^3}\right)^{1/2} \sim \frac{\epsilon^2}{(m_X + m_p)\sqrt{\mu_{Xp}}}$$

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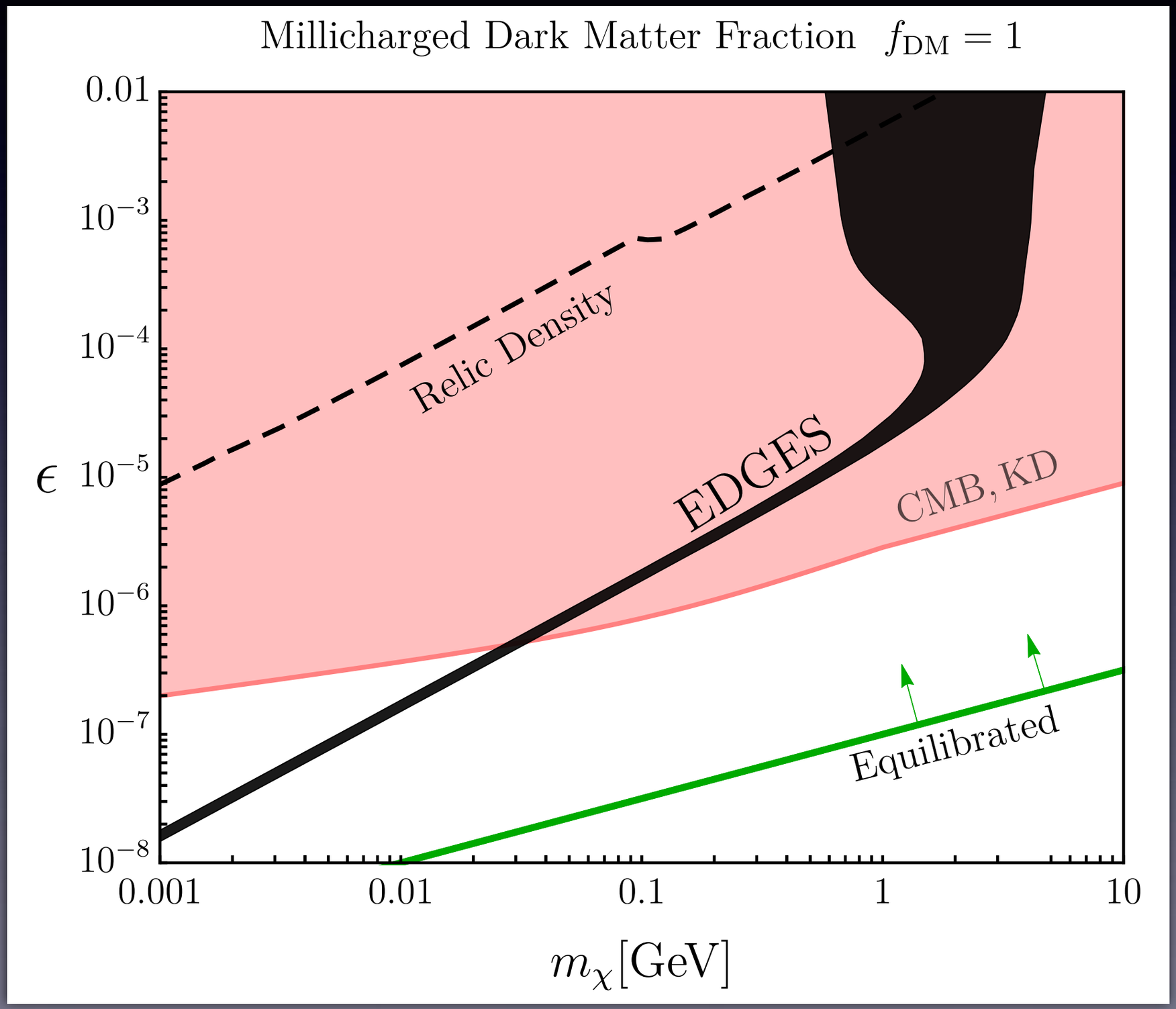
(warning — new work indicates this is too conservative)

Gluscevic & Boddy, 1712.07133
Boddy & Gluscevic, 1801.08609

Xu, Dvorkin, & Chael, 1802.06788
Slatyer & Wu, 1803.09734

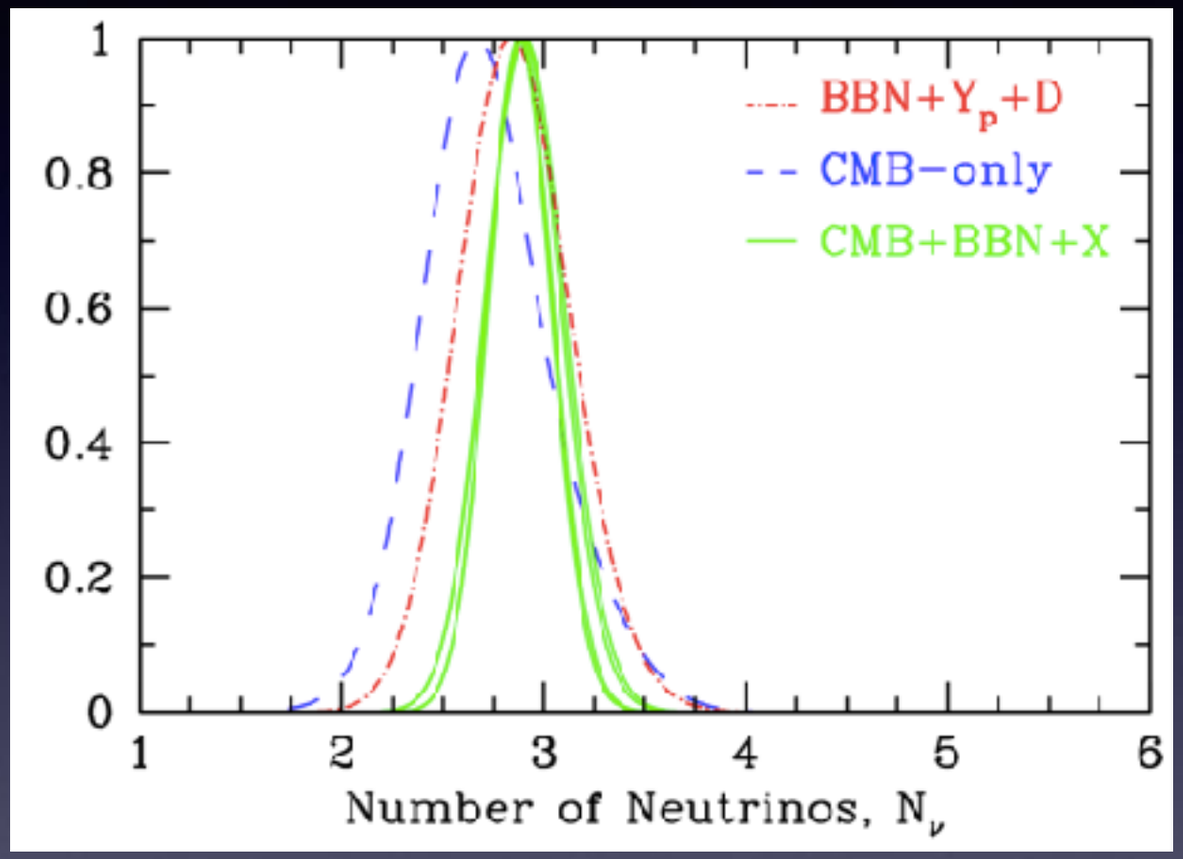
de Putter et al., 1805.11616
Gluscevic et al., to appear

CMB Bound

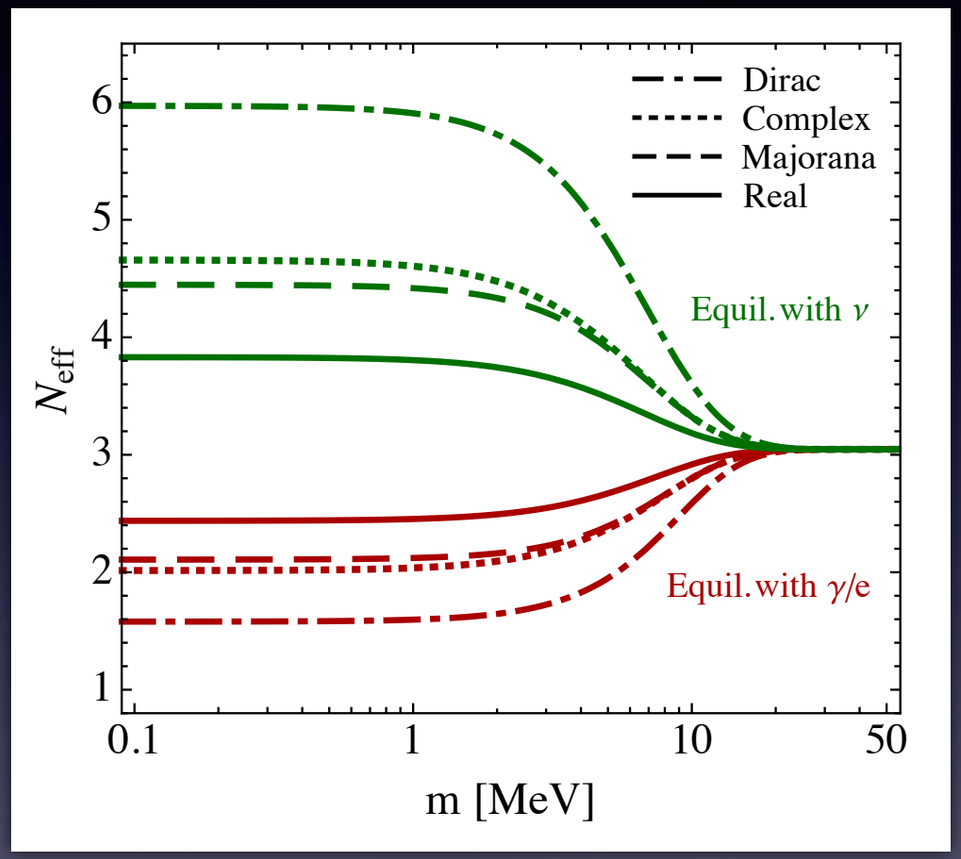

Millicharged Dark Matter Fraction $f_{\rm DM} = 1$
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
ϵ
Relic Density
EDGES
CMB, KD
Equilibrated
0.001
0.01
0.1
1
10
m_χ[GeV]

BBN

Cyburt et al, 1505.01076



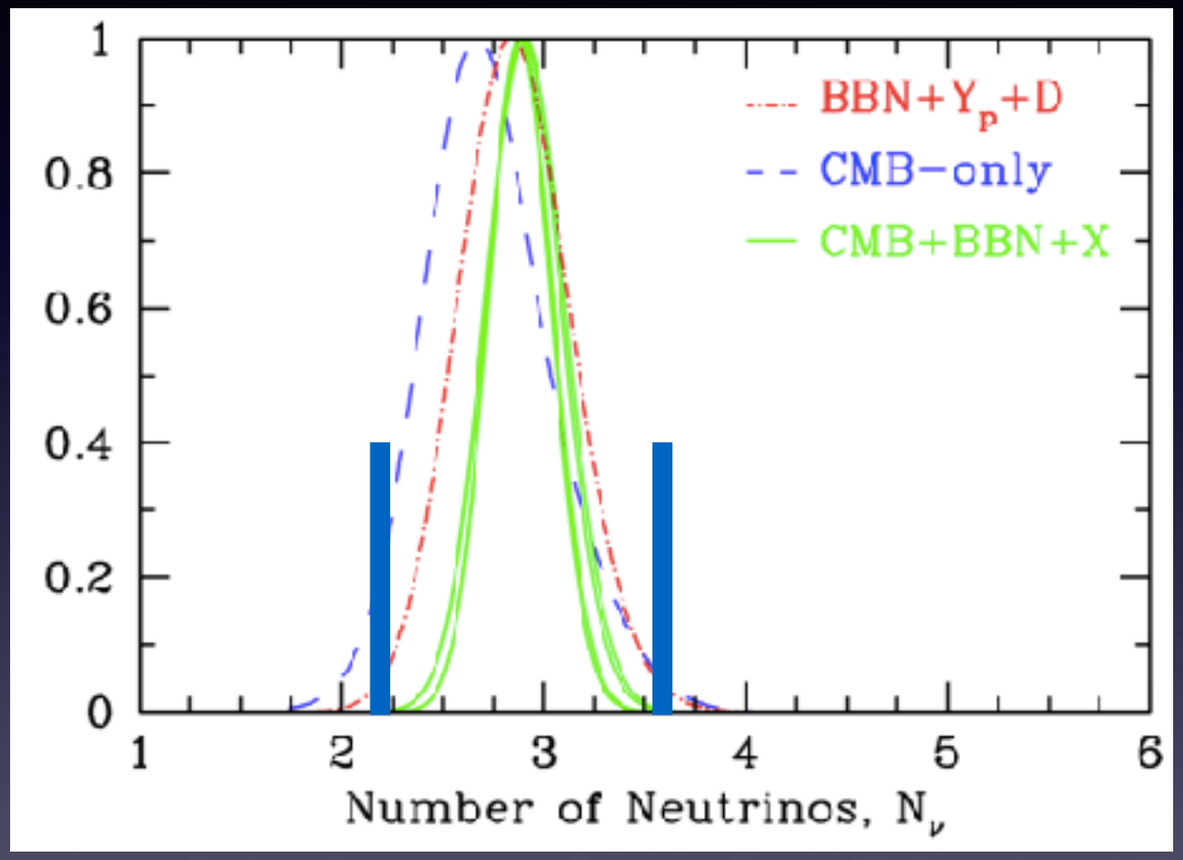
Boehm et al, 1303.6270



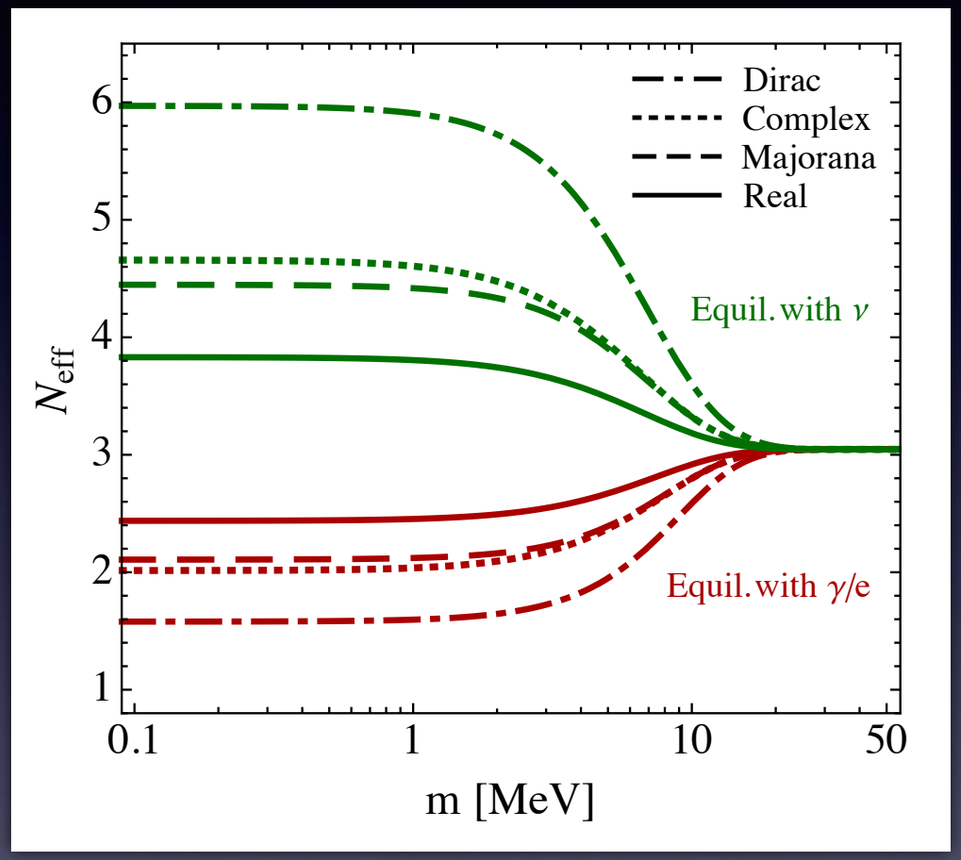
$N_\nu > N_{\nu,SM}$ at time of SM nucleosynthesis injects entropy, screws up agreement w/ observation

BBN

Cyburt et al, 1505.01076



Boehm et al, 1303.6270



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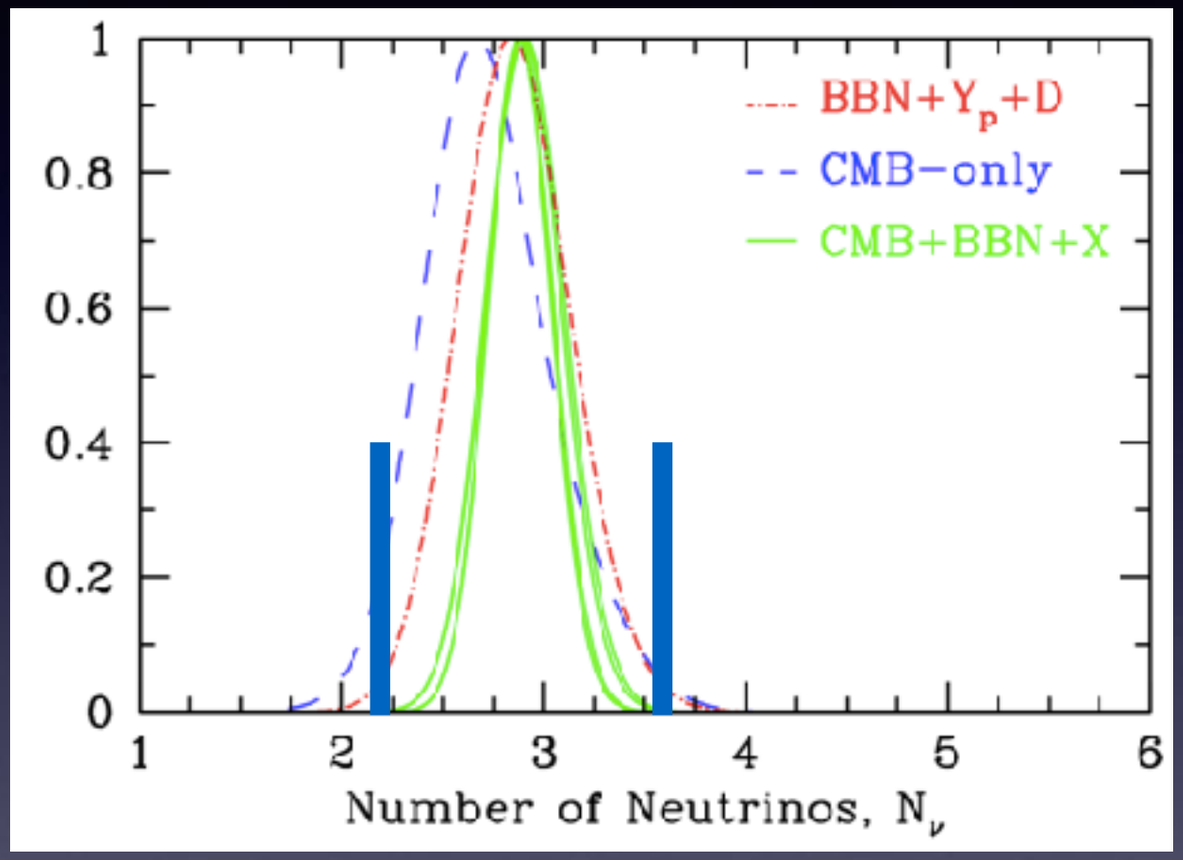

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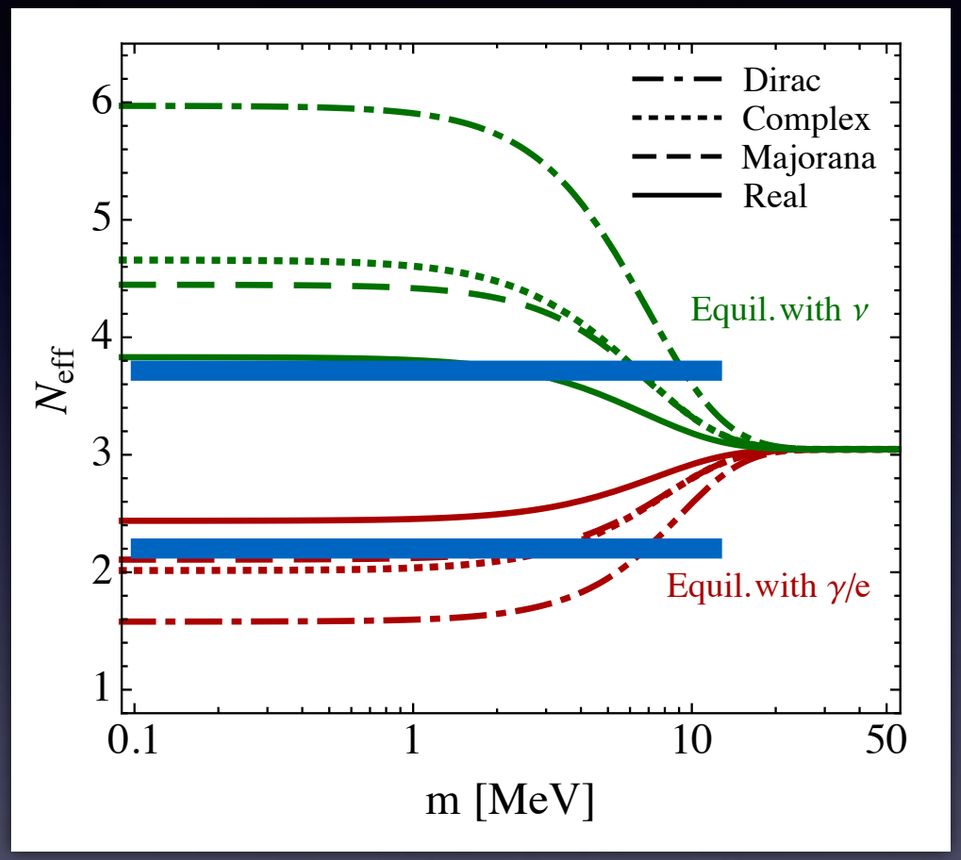

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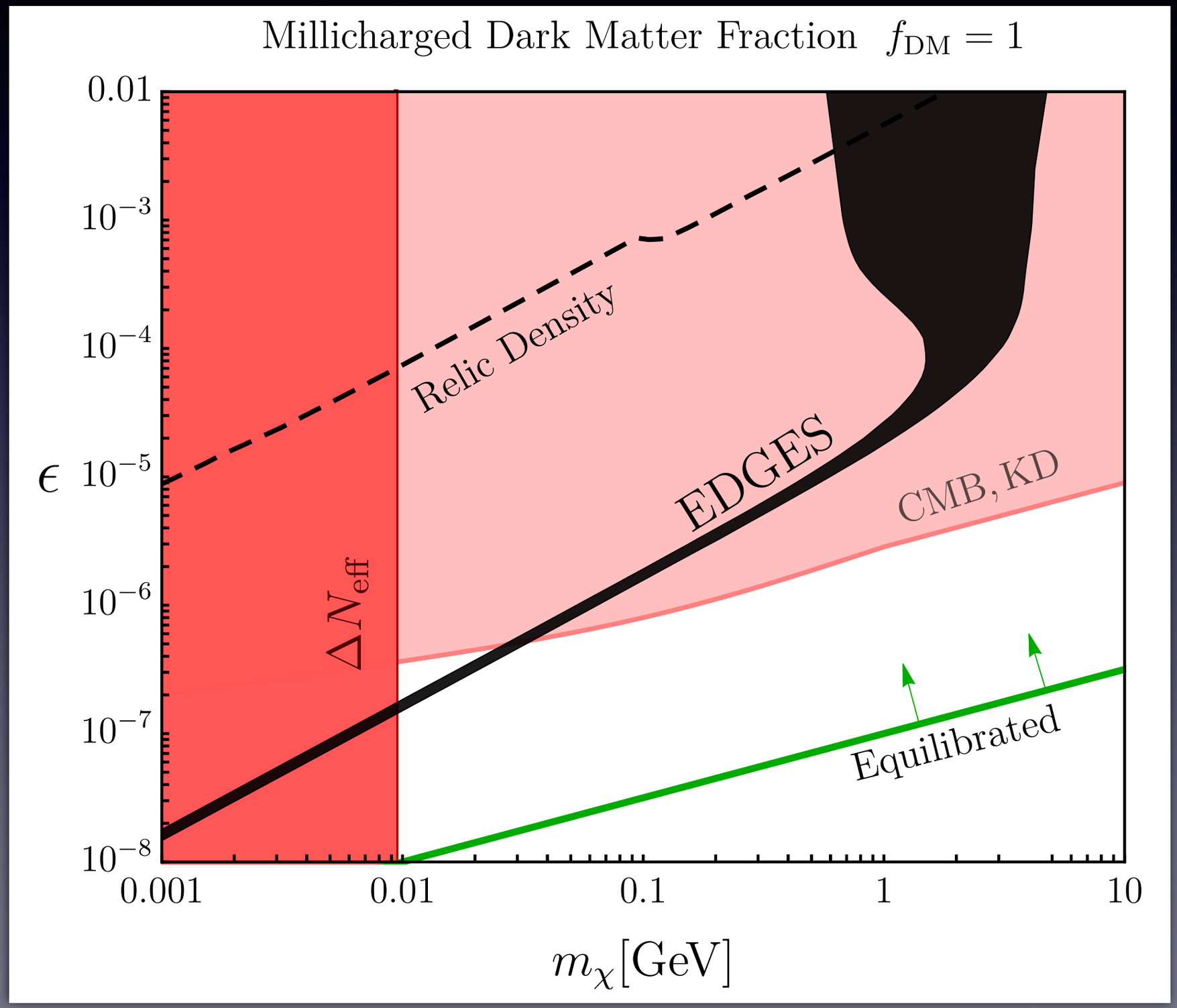
Generically rules out $m_X \lesssim 10$ MeV

BBN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10
m_χ[GeV]
Relic Density
EDGES
CMB, KD
$\Delta N_{\rm eff}$
Equilibrated

Crash Course: SN1987A

Credit: Colin Legg

Core collapse supernova in the LMC detected simultaneously in Jan 1987 with three instruments (Baksan, IMB, and Kamiokande II)

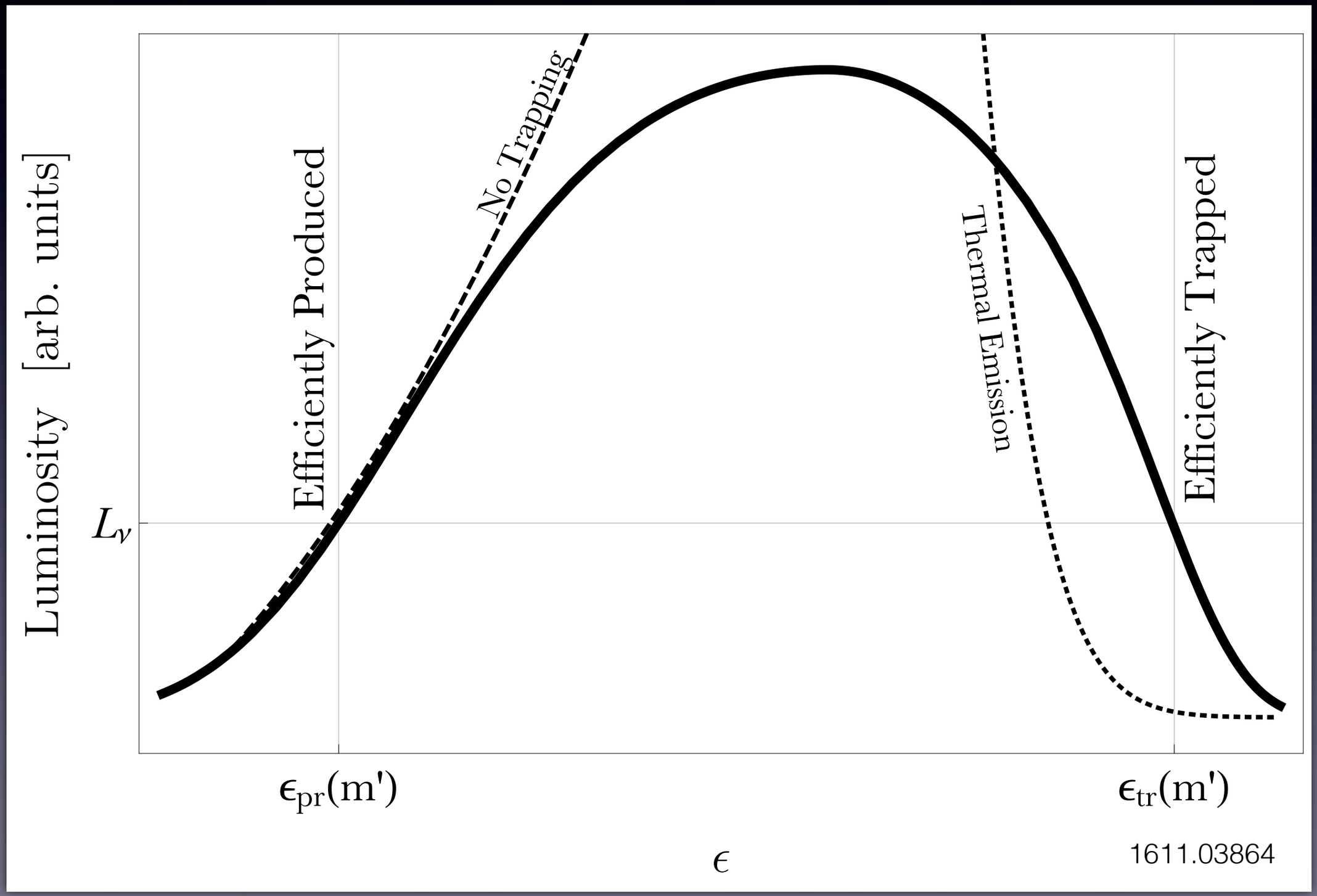
~ 99% of the difference in grav. binding energy radiated away in the form of neutrinos over ~ 10 seconds

Crash Course: SN1987A

Credit: Colin Legg

- Cooling phase is consistent with analytic expectation
- …but wouldn’t be if a new “energy sink” competed with Standard Model processes
- Limited amount of luminosity may be diverted to novel particles $\Longleftrightarrow$ bounds on new coupling with SM

Bounds (schematic)



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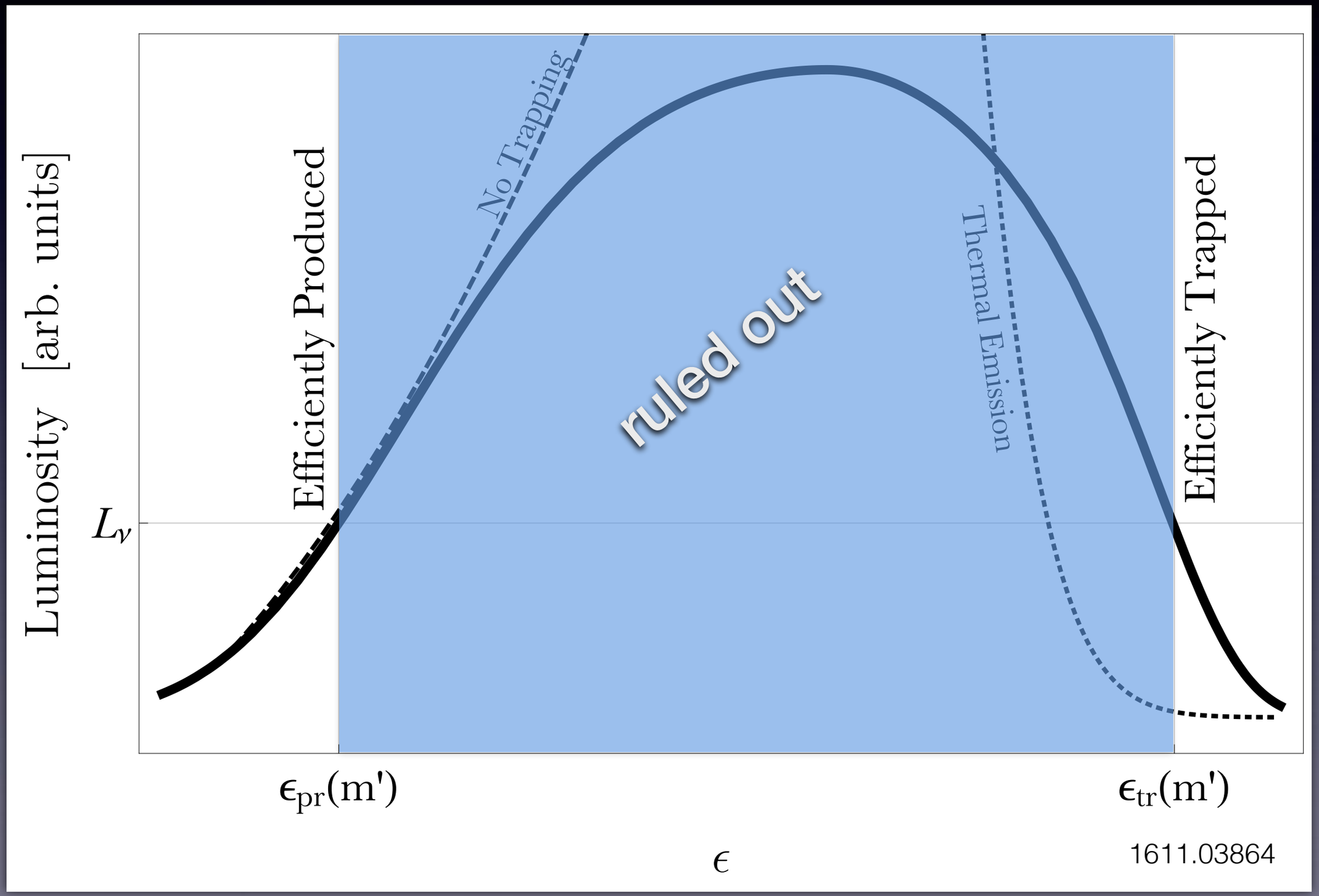
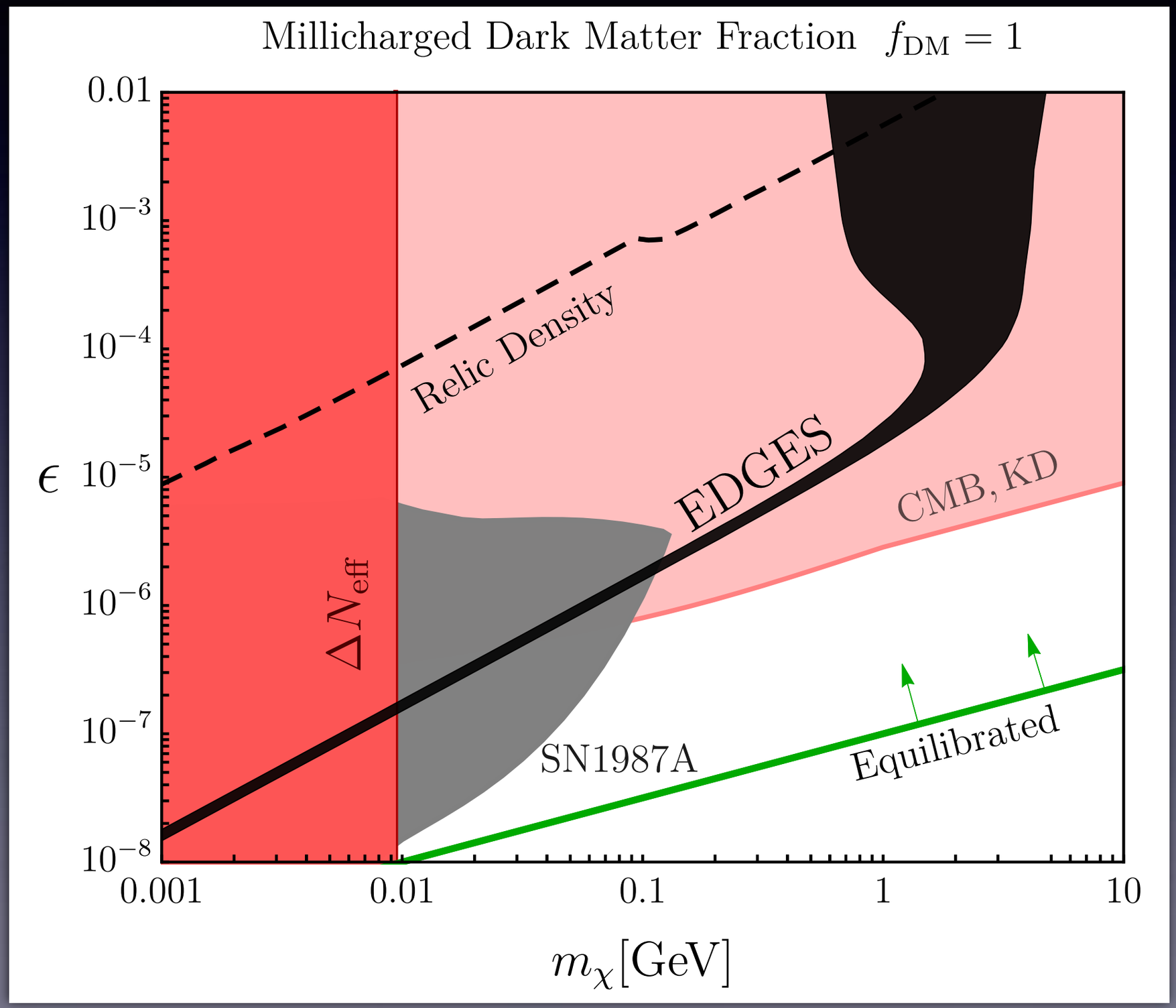


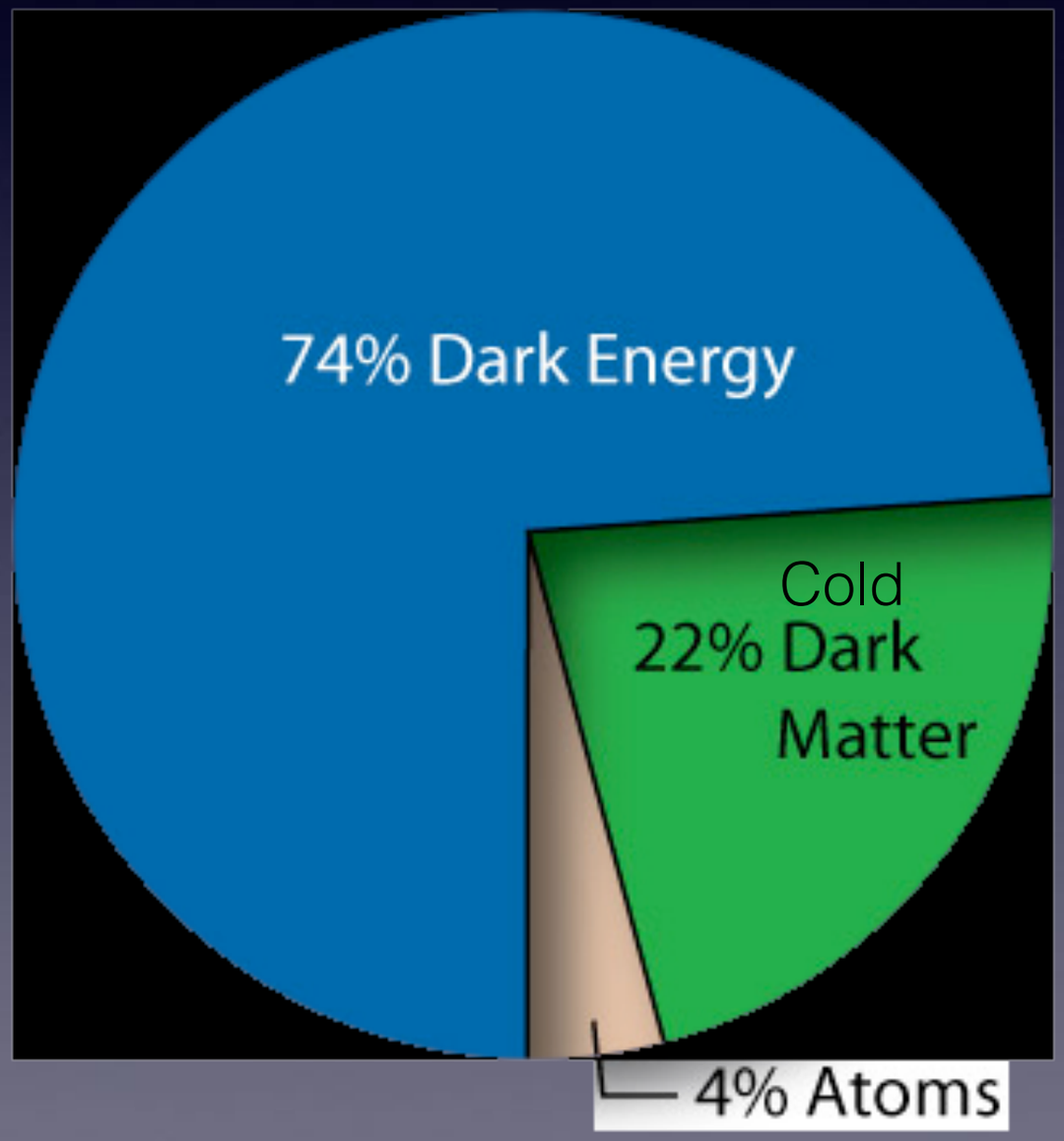
EDGES Constraints



Caveats?

Perhaps only a subdominant component of dark matter has a millicharge (the rest is cold, collisionless, etc)

http://www.solstation.com/x-objects/darkhalo.htm



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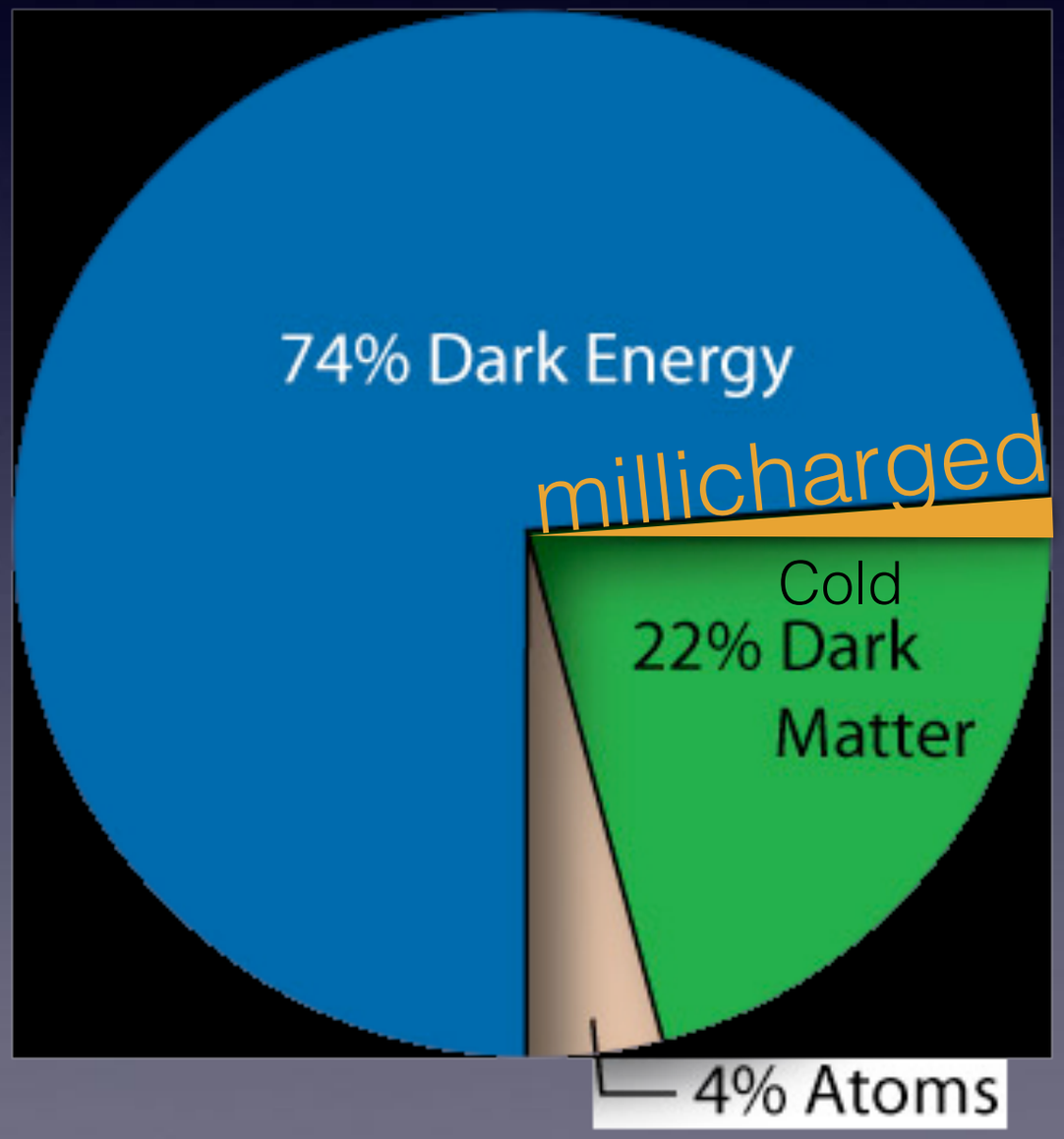

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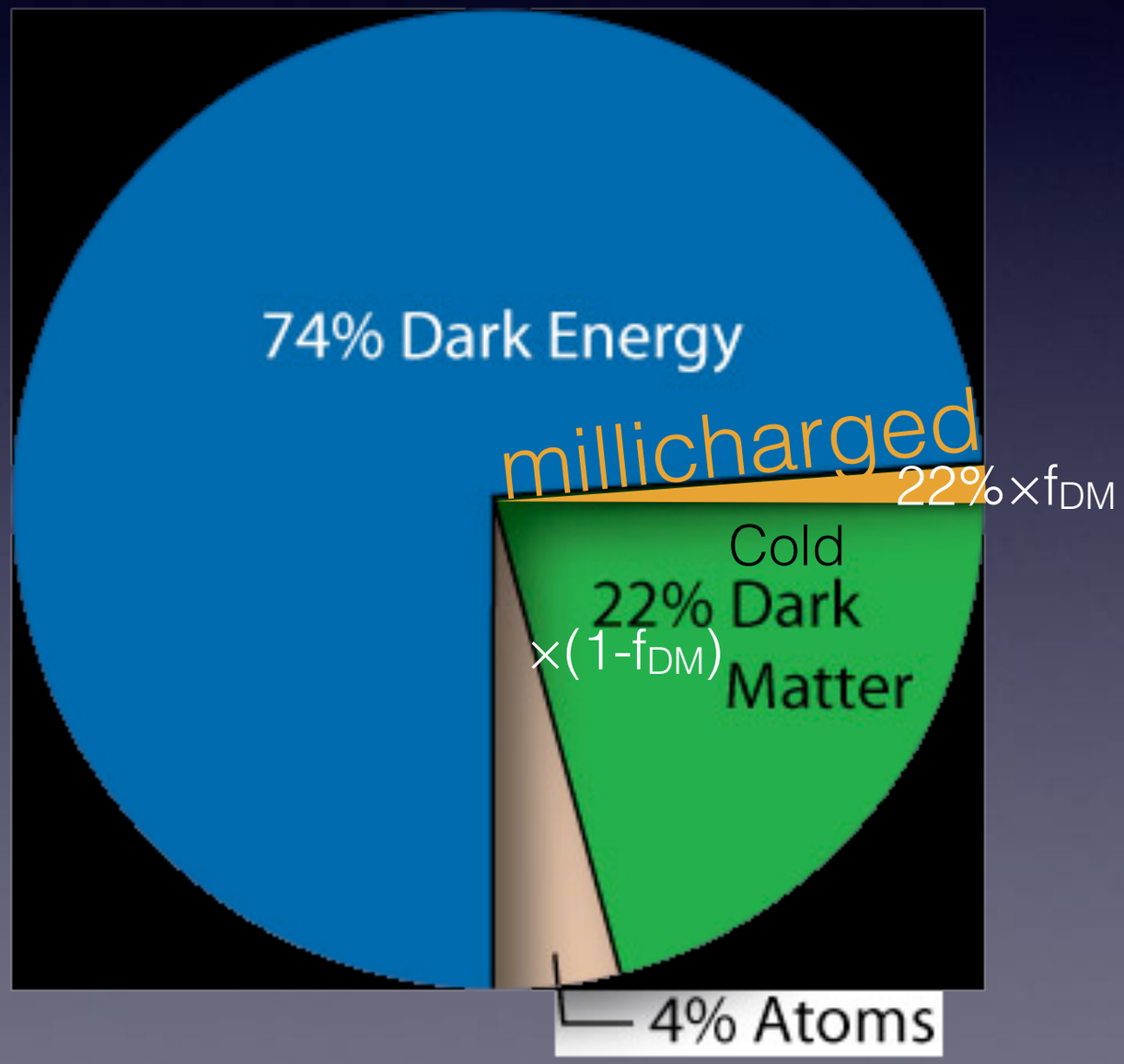

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- Preferred region, relic density curve, CMB bounds change
- BBN and SN don't

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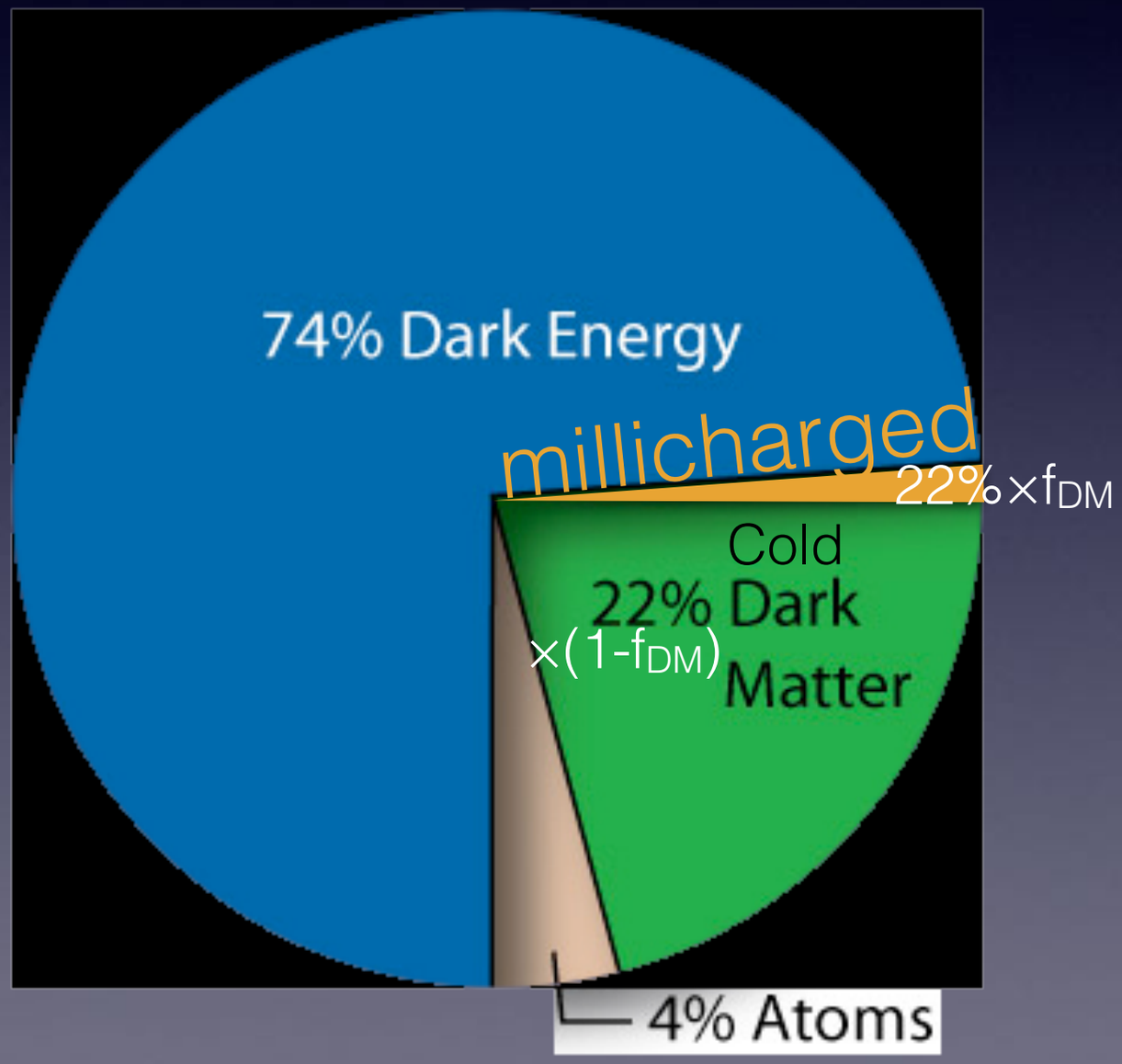

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$\sim f^{3/4}$ (Munoz and Loeb, 1802.10094)

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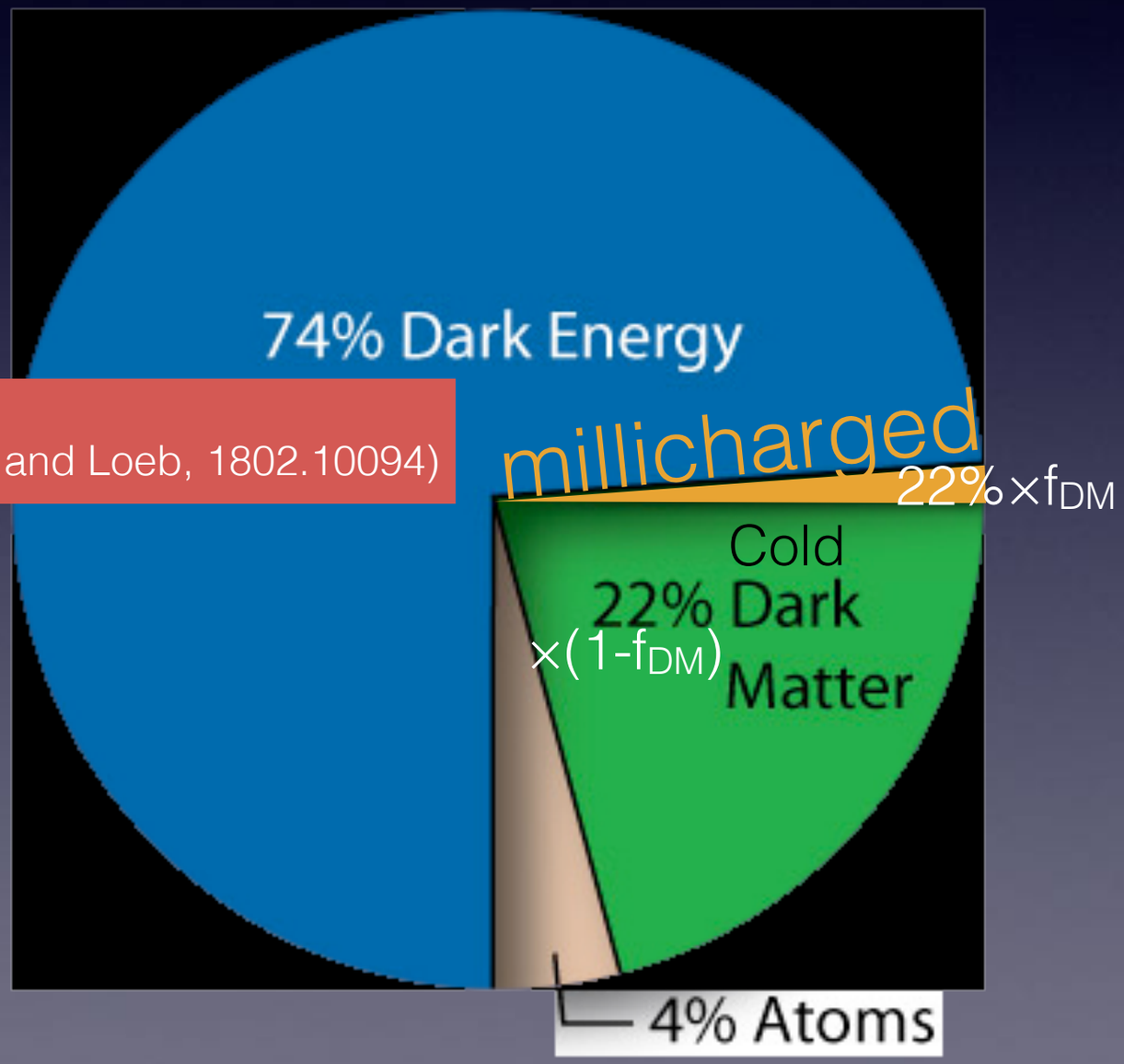

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~ $f^{1/2}$

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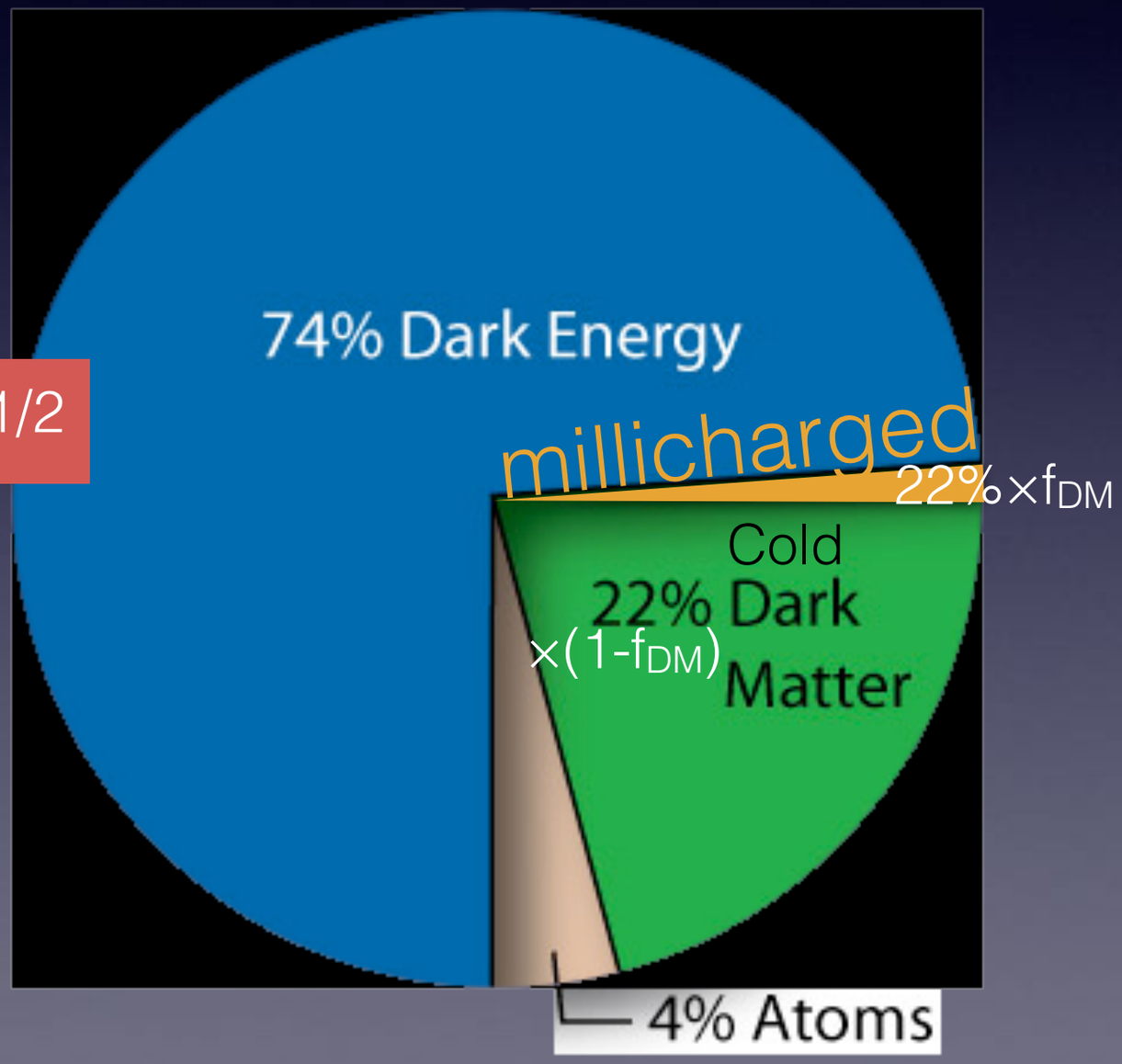

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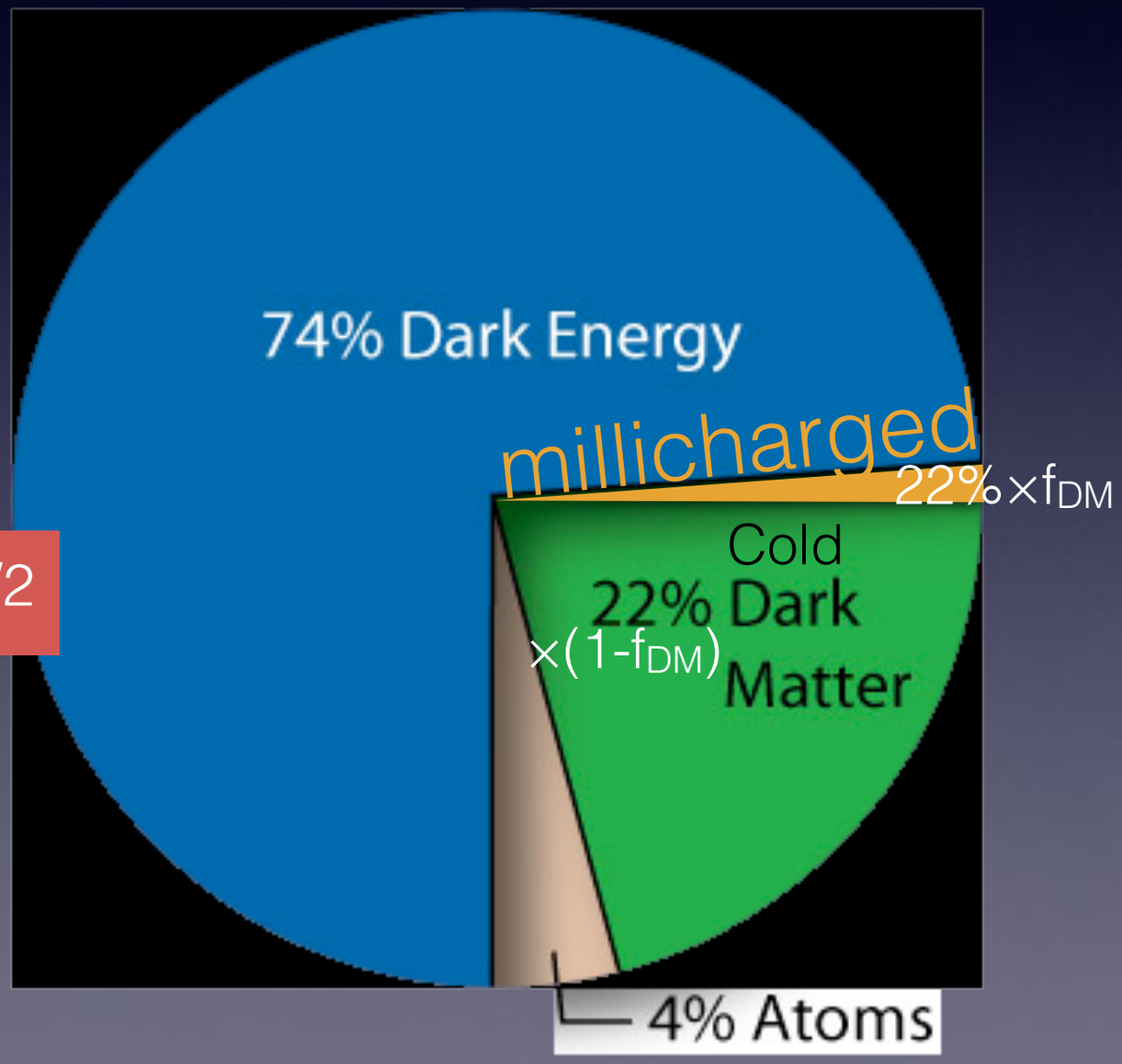

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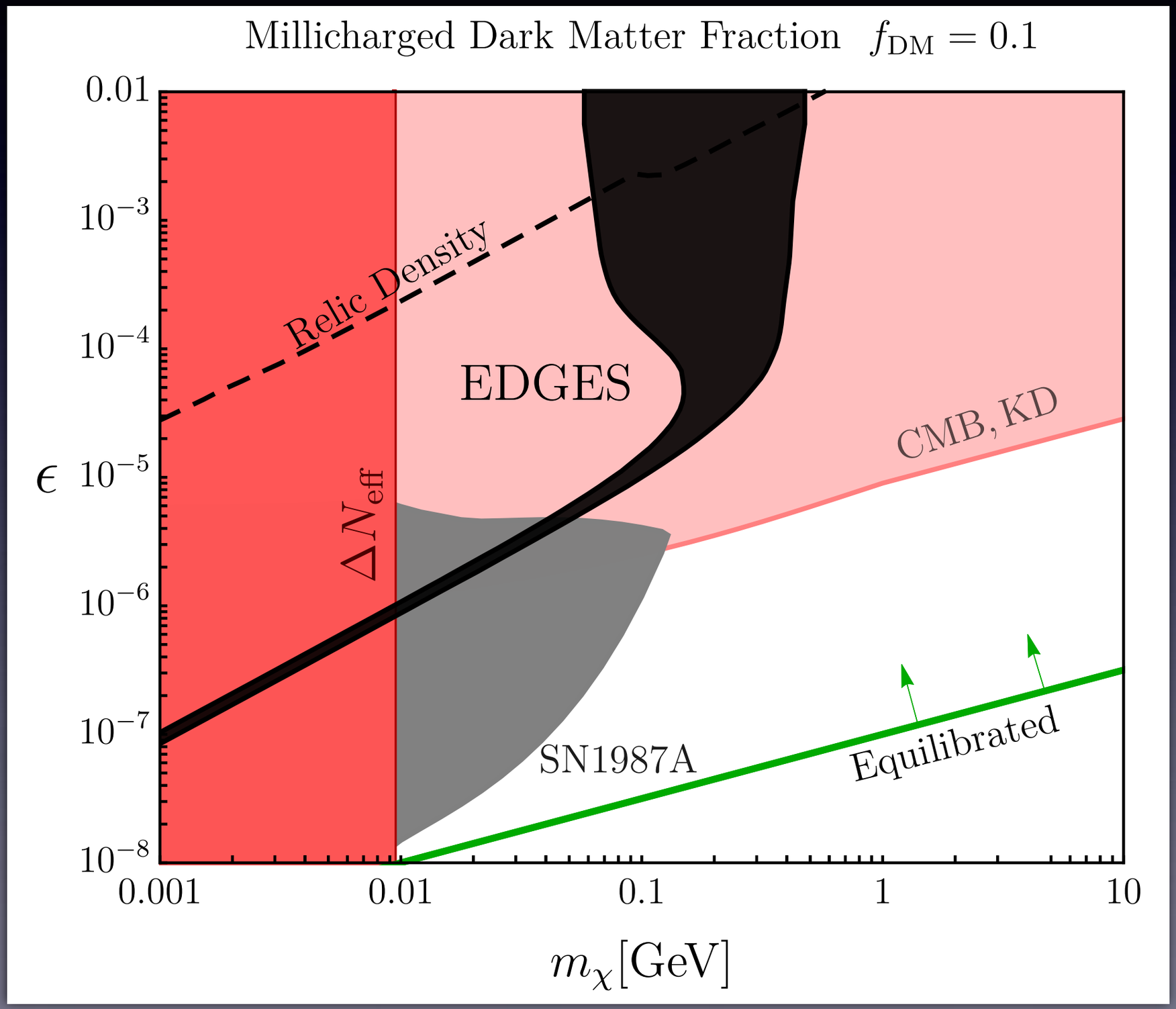

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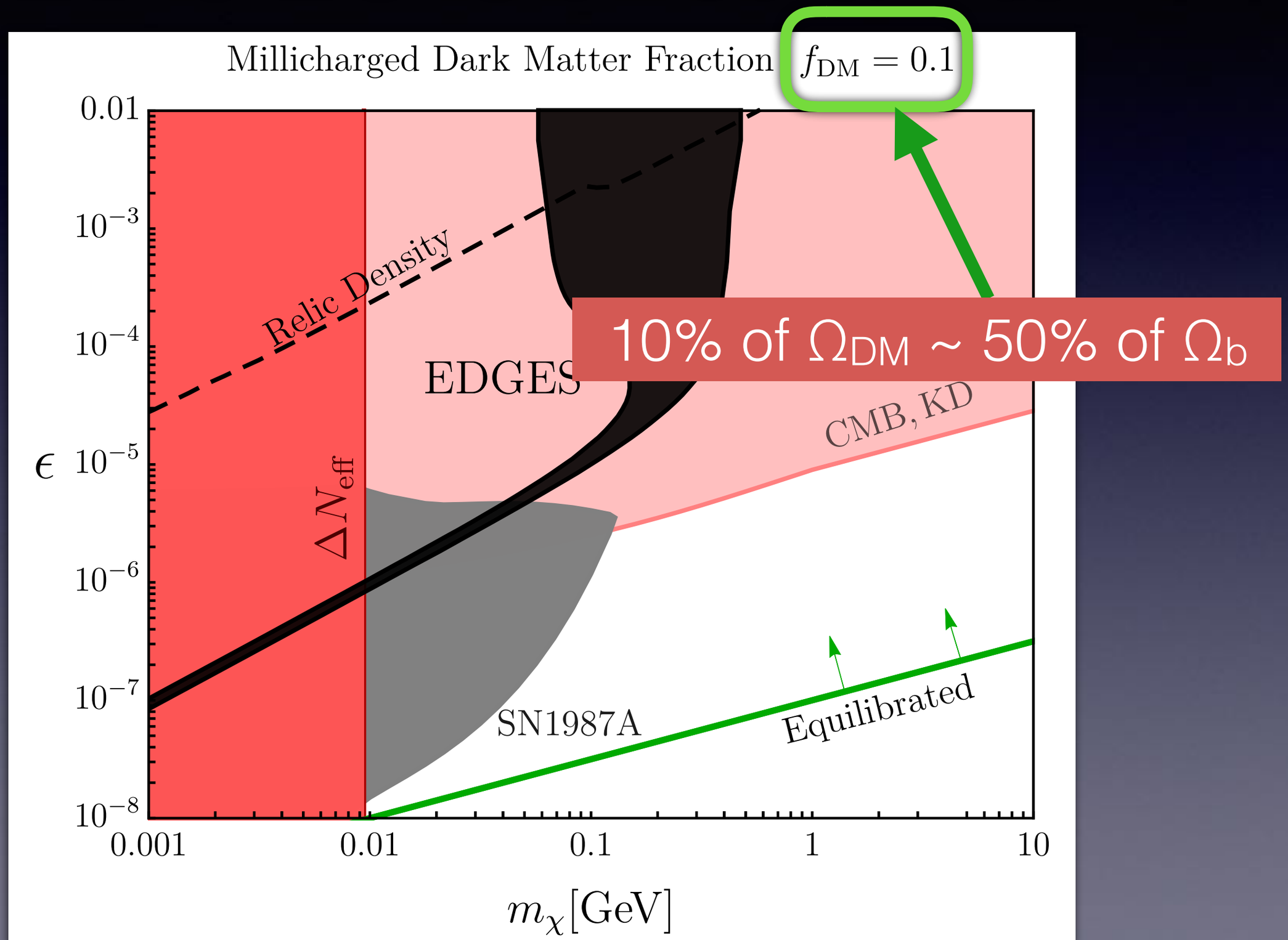
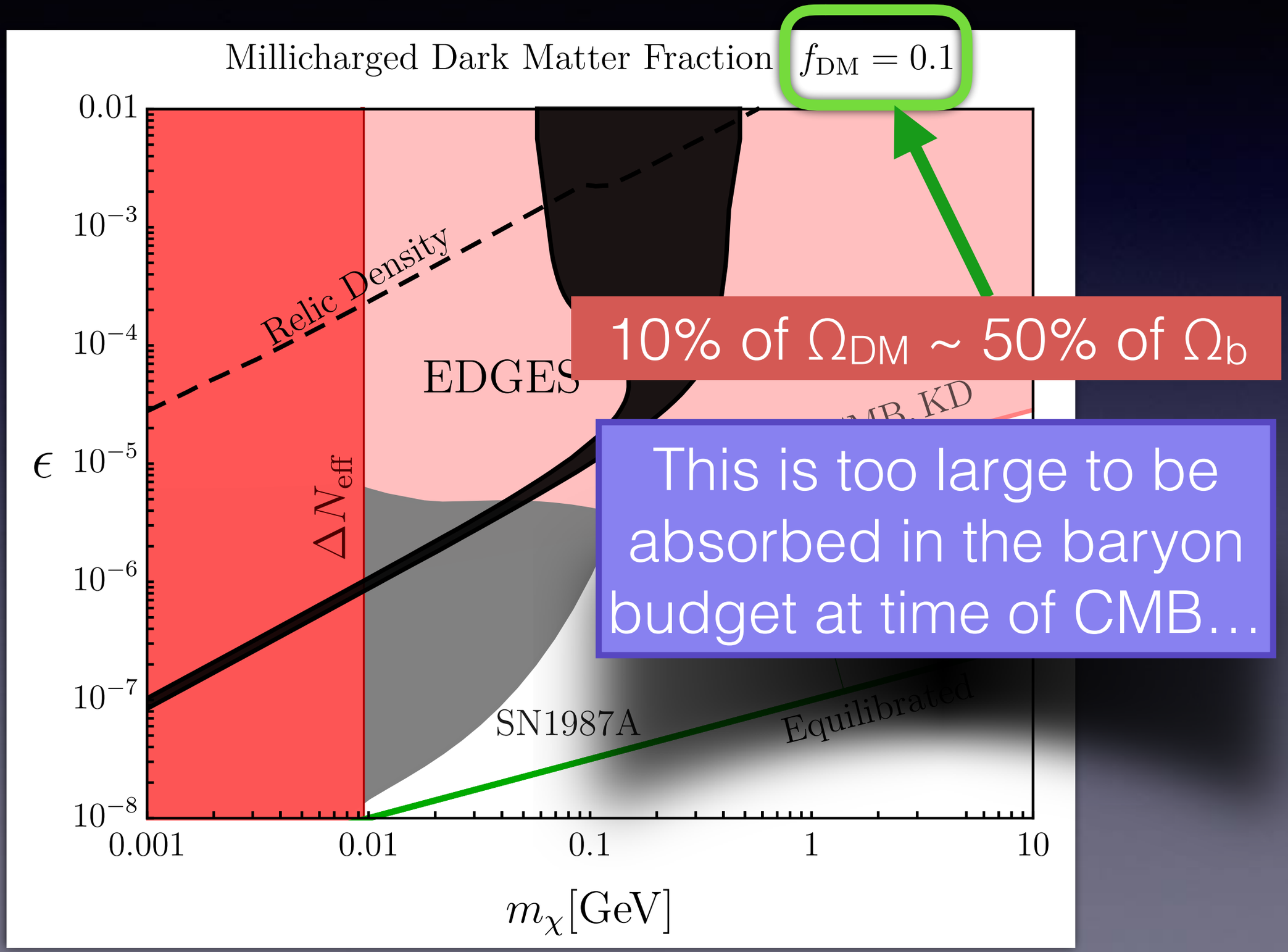
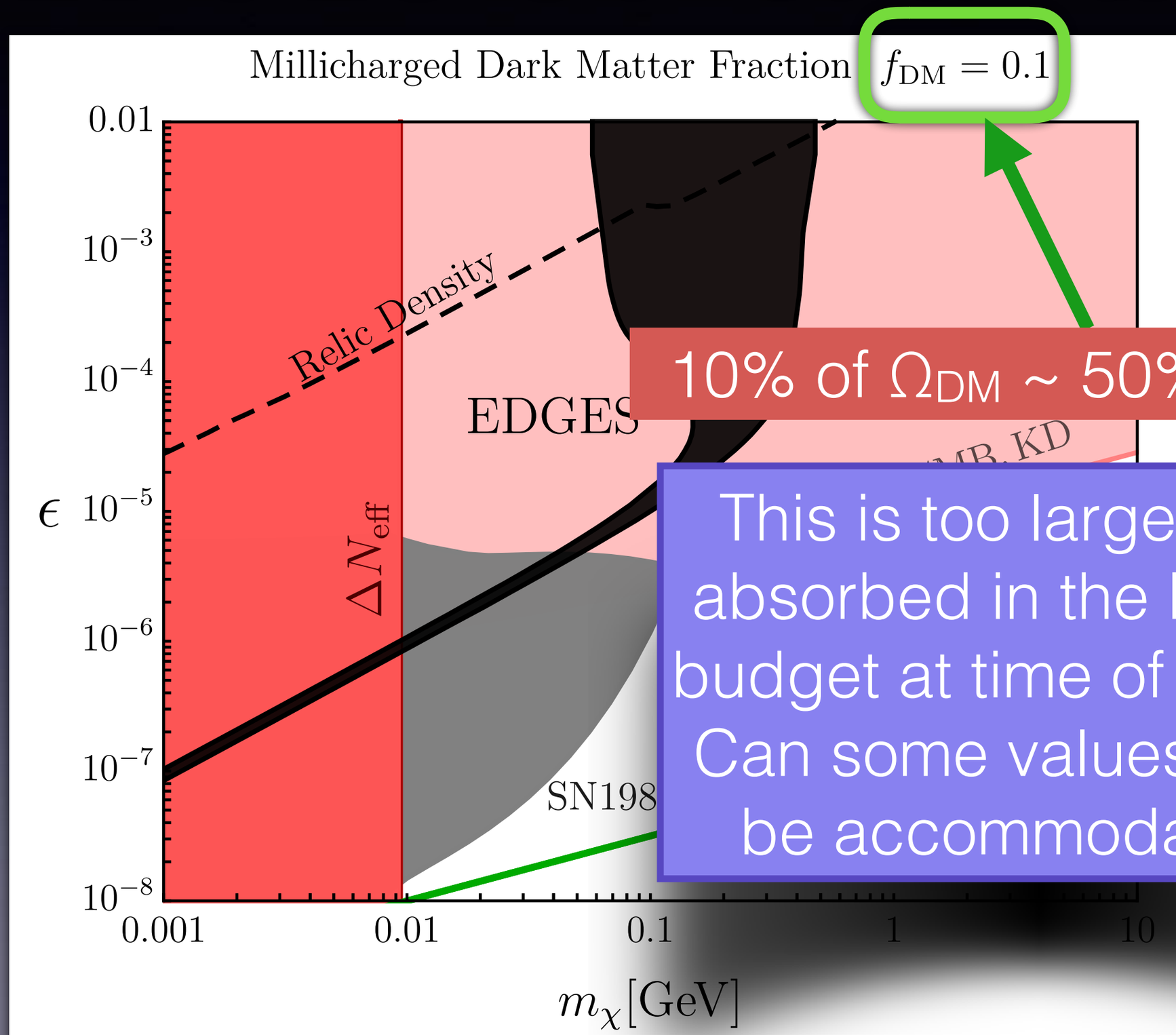


EDGES Constraints



EDGES Constraints

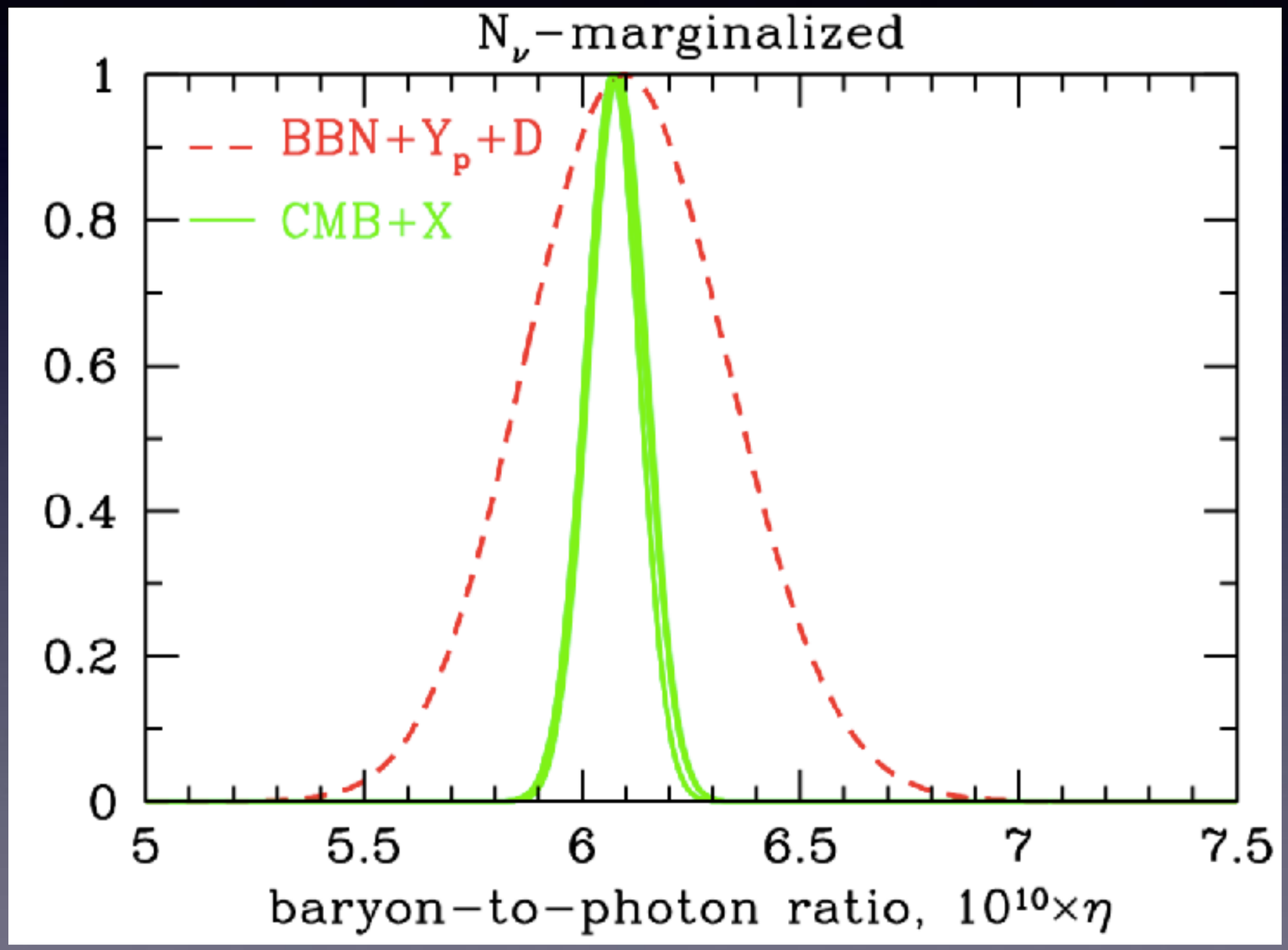


10% of Ω_{DM} ~ 50% of Ω_b

This is too large to be absorbed in the baryon budget at time of CMB… Can some values of f_{DM} be accommodated?

Ω_b: BBN vs. CMB

Cyburt et al, 1505.01076



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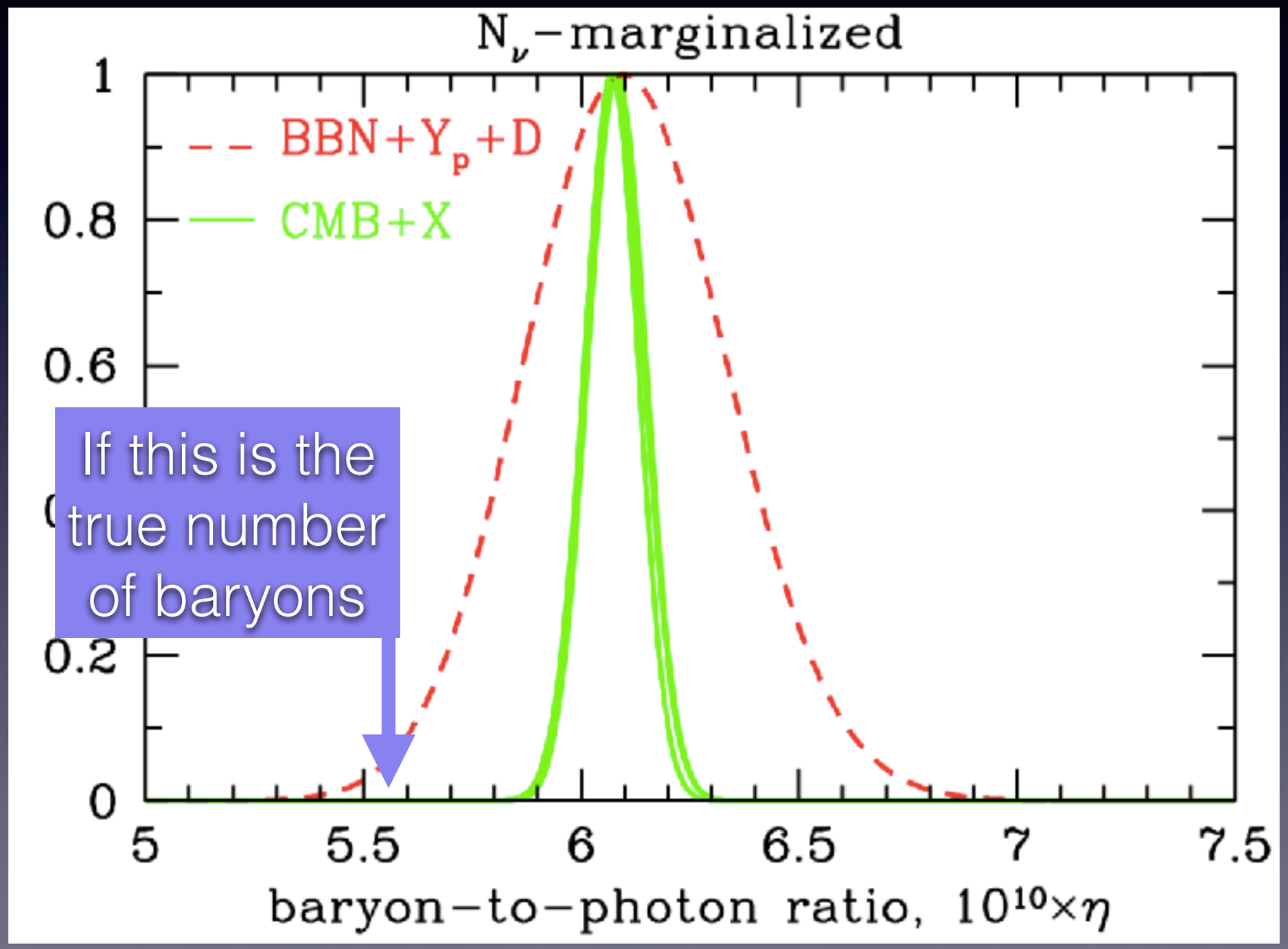

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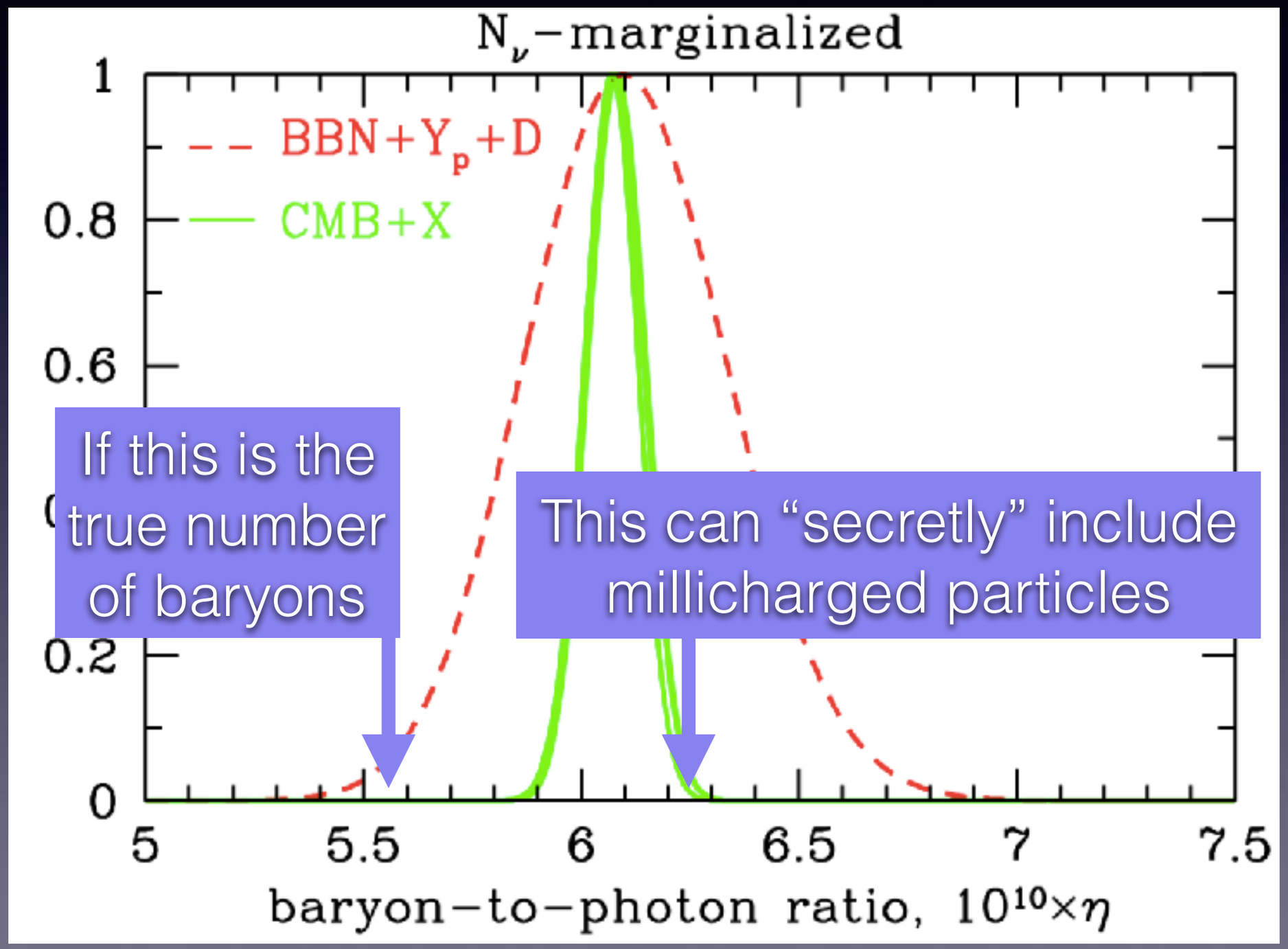

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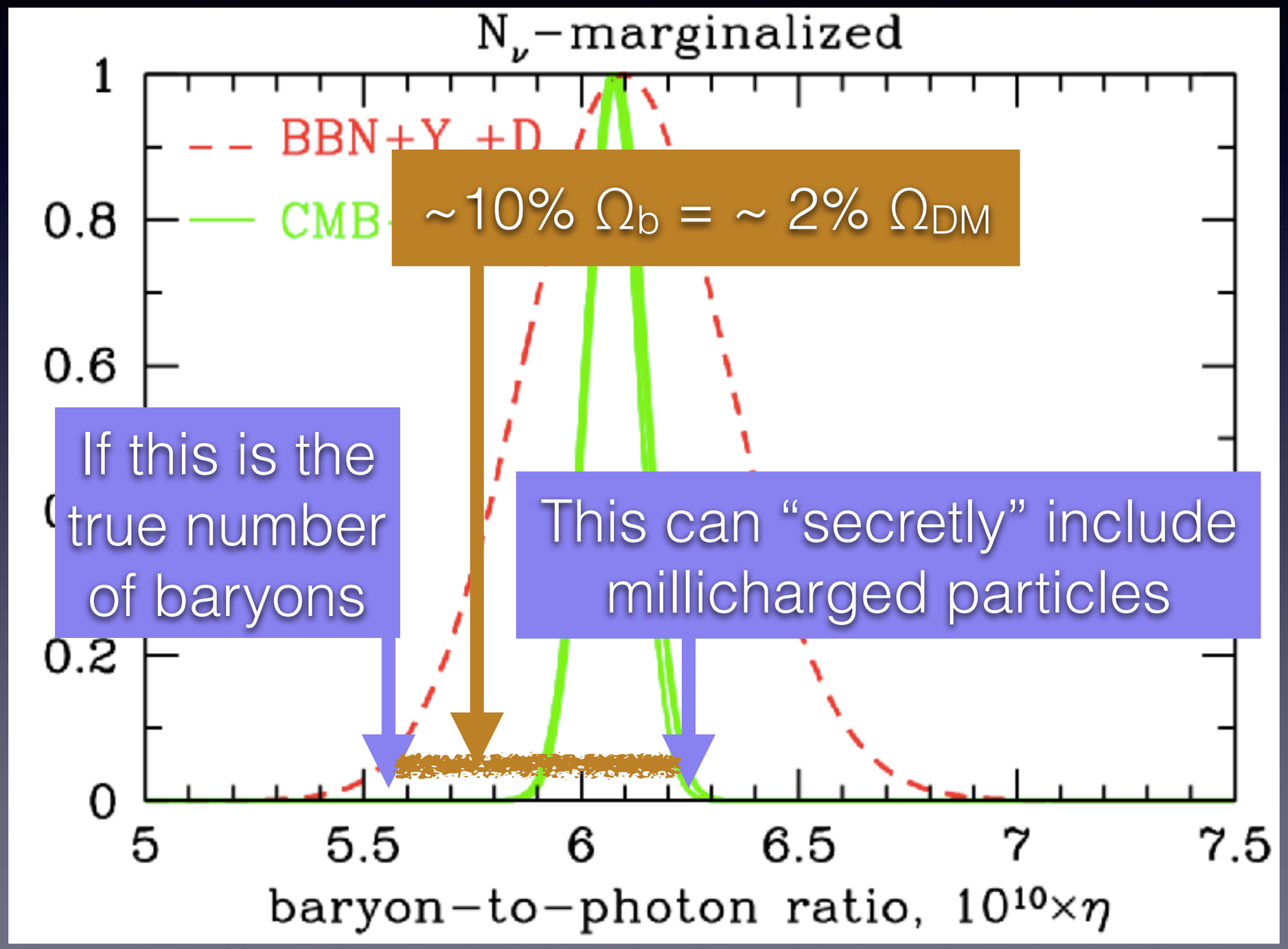

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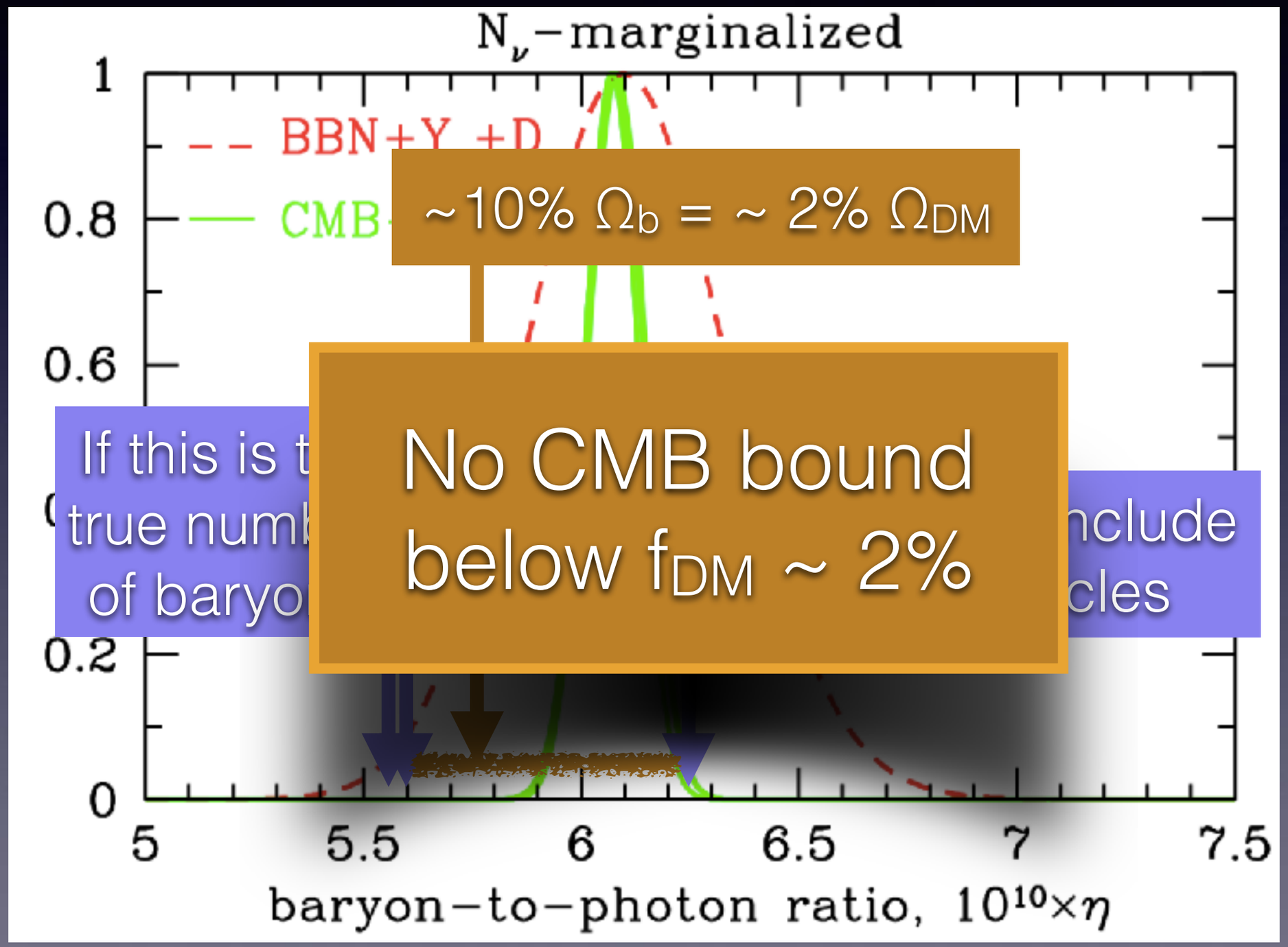

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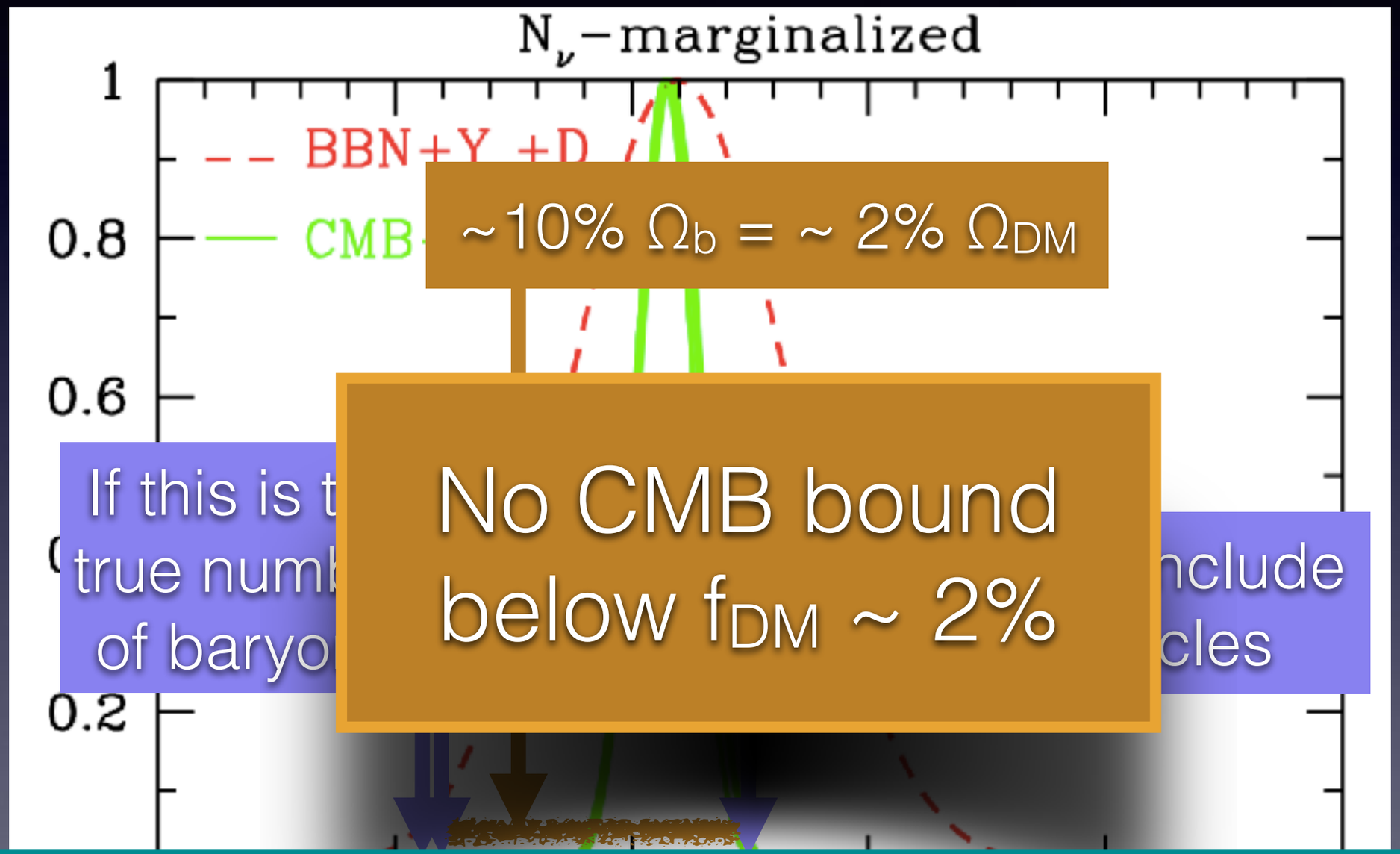
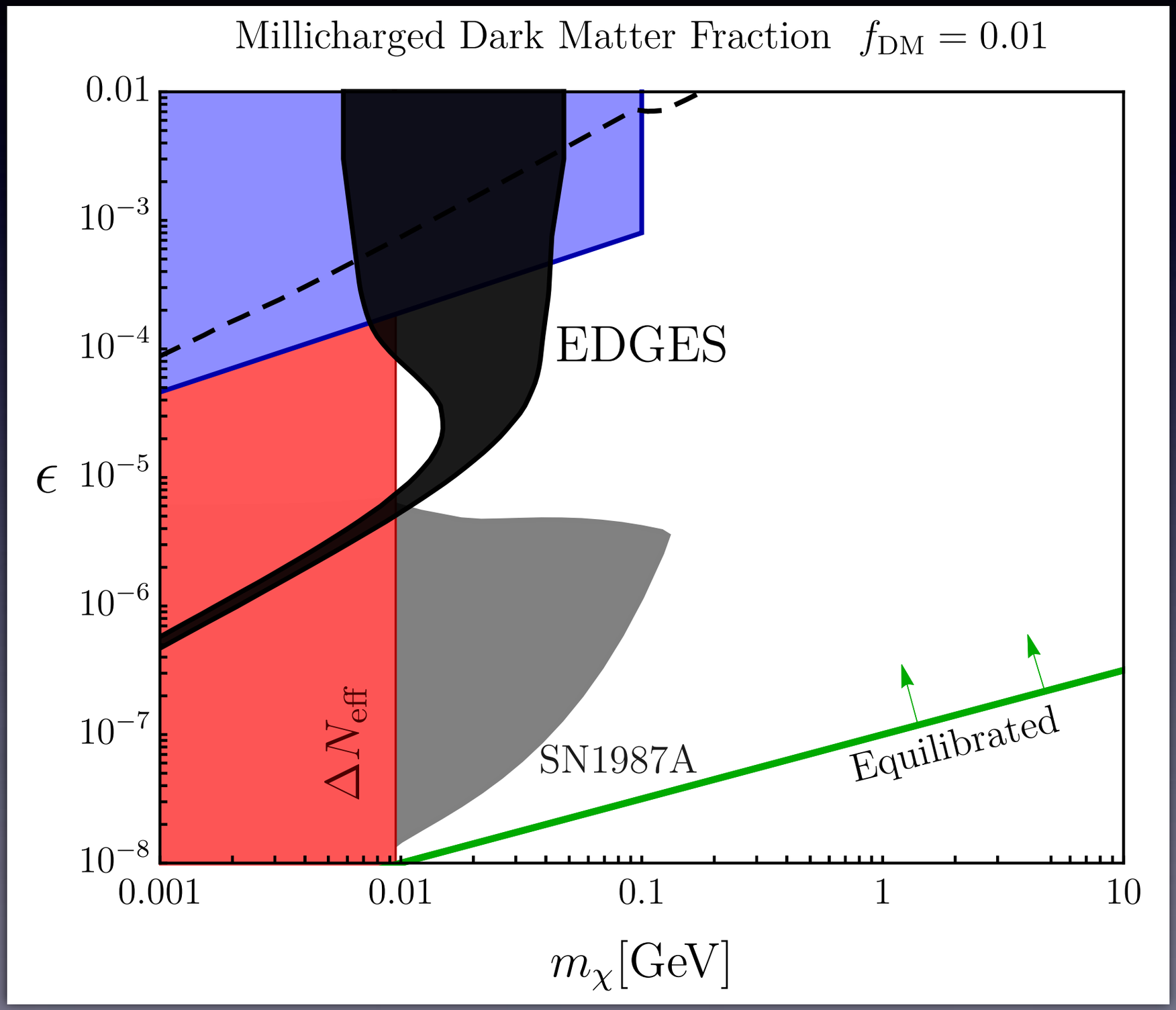
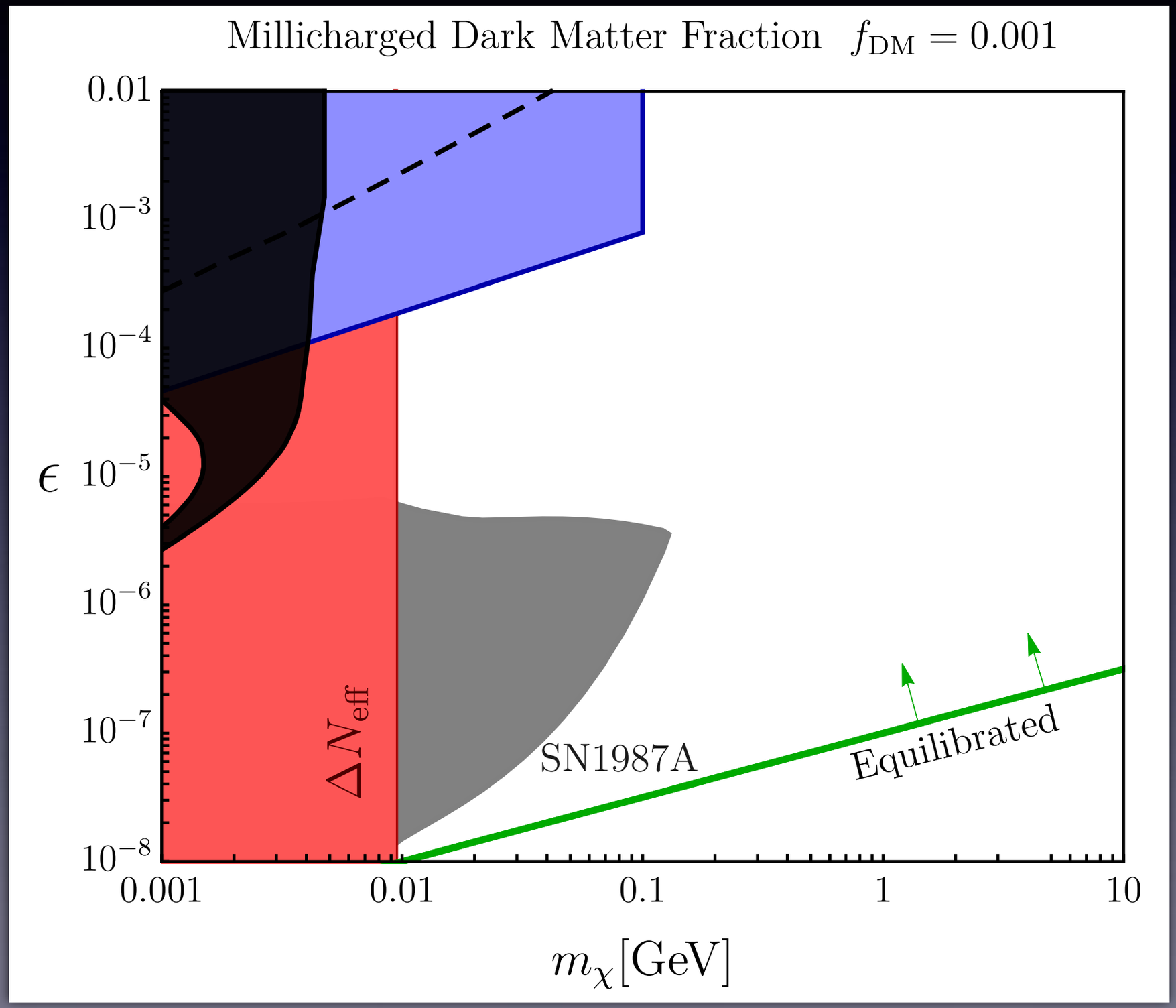


1805.11616, de Putter et al.: “we derive a new upper limit on the fraction of tightly coupled dark matter…<0.6% ”

EDGES Constraints



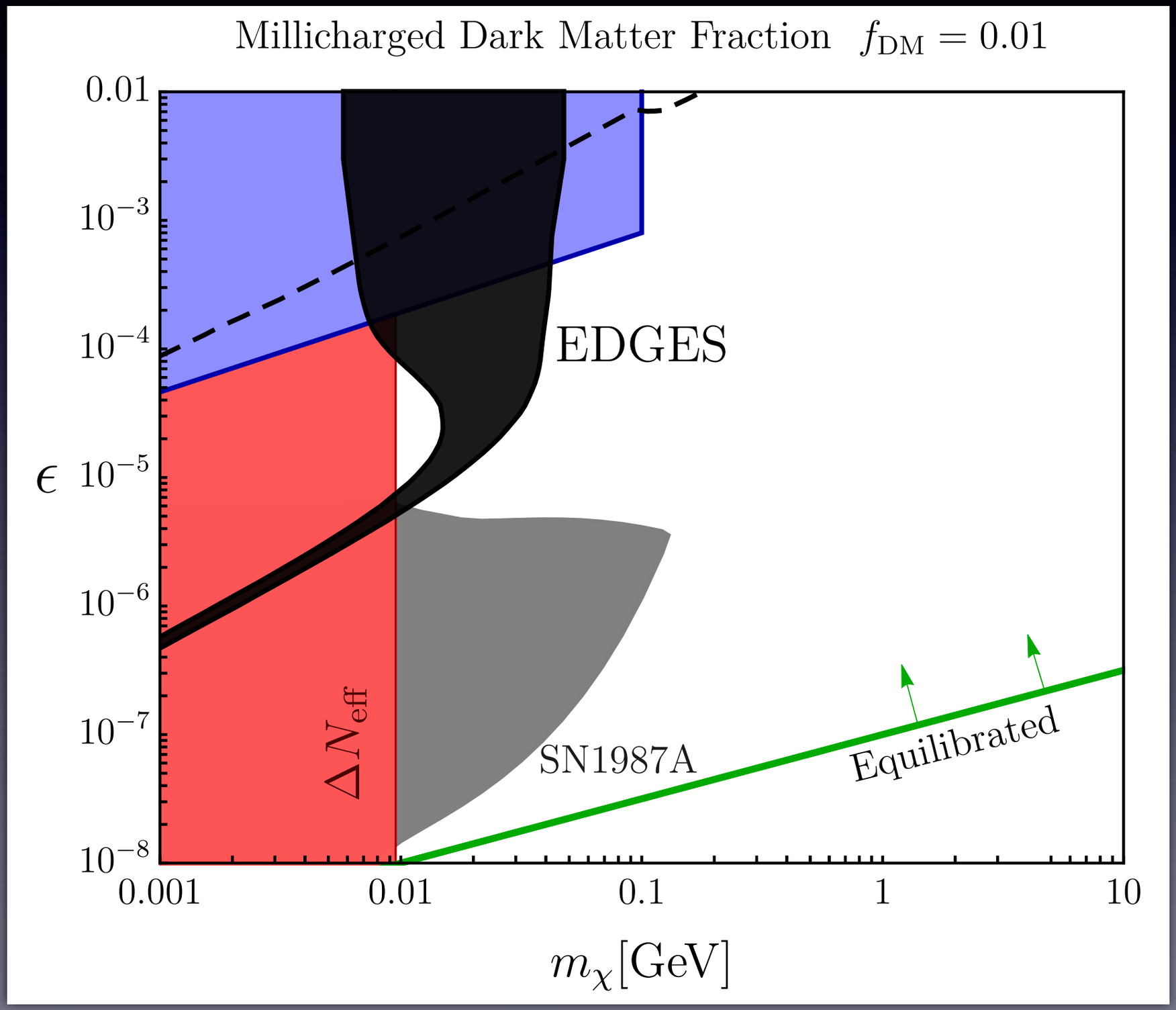
EDGES Constraints



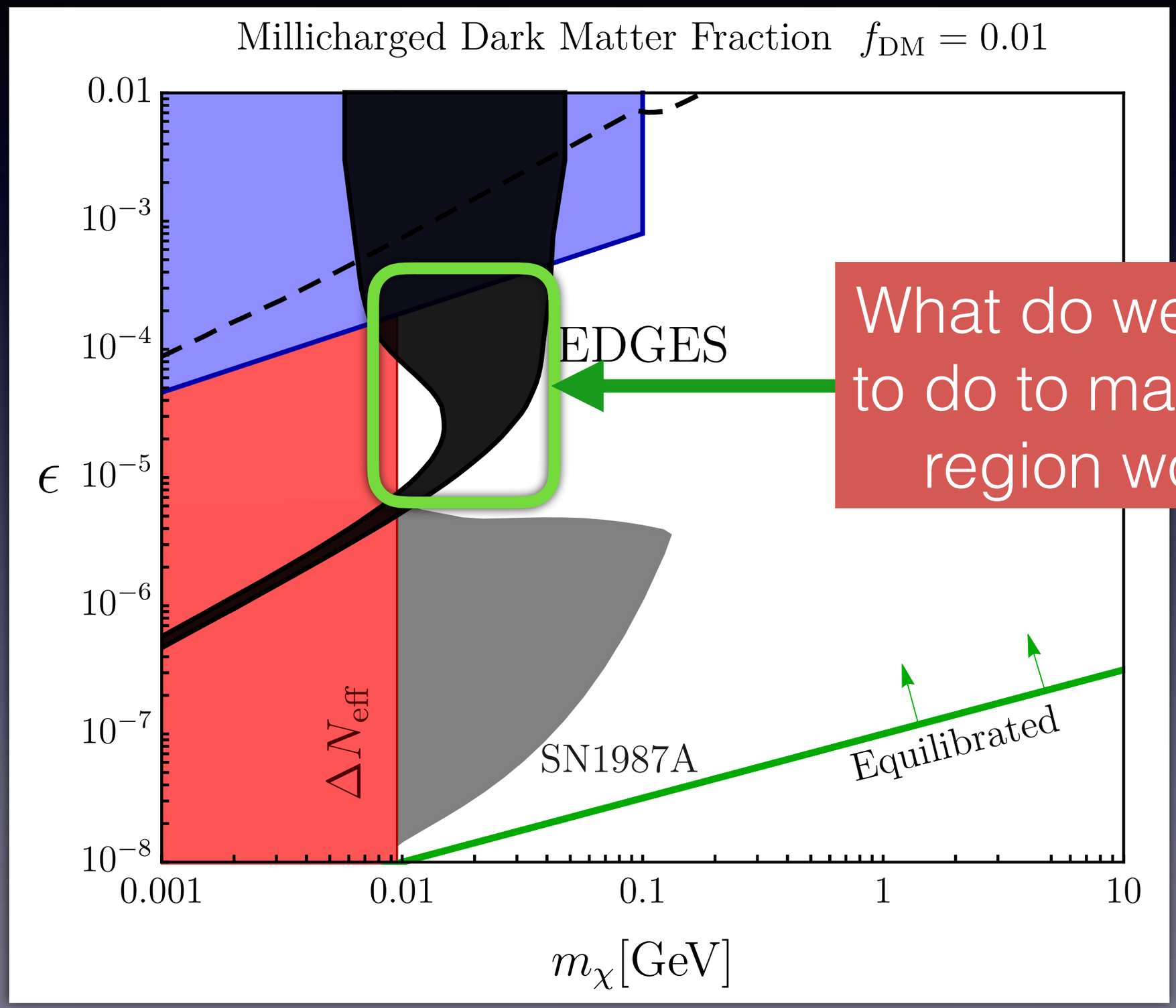
Outline

1. Astrophysical & Cosmological Signatures
2. Future Directions

EDGES, f_{DM}=1%


Millicharged Dark Matter Fraction $f_{\rm DM} = 0.01$
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
ϵ
EDGES
$\Delta N_{\rm eff}$
SN1987A
Equilibrated
0.001
0.01
0.1
1
10
m_χ[GeV]

EDGES, f_{DM}=1%



What do we need to do to make this region work?

Implications of f_{DM}=1%

1. Relic density via QED alone is problematic — how else to deplete thermal abundance?

Couple to New Force

Many possibilities, but some guidelines:

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- Shouldn’t couple to electrons

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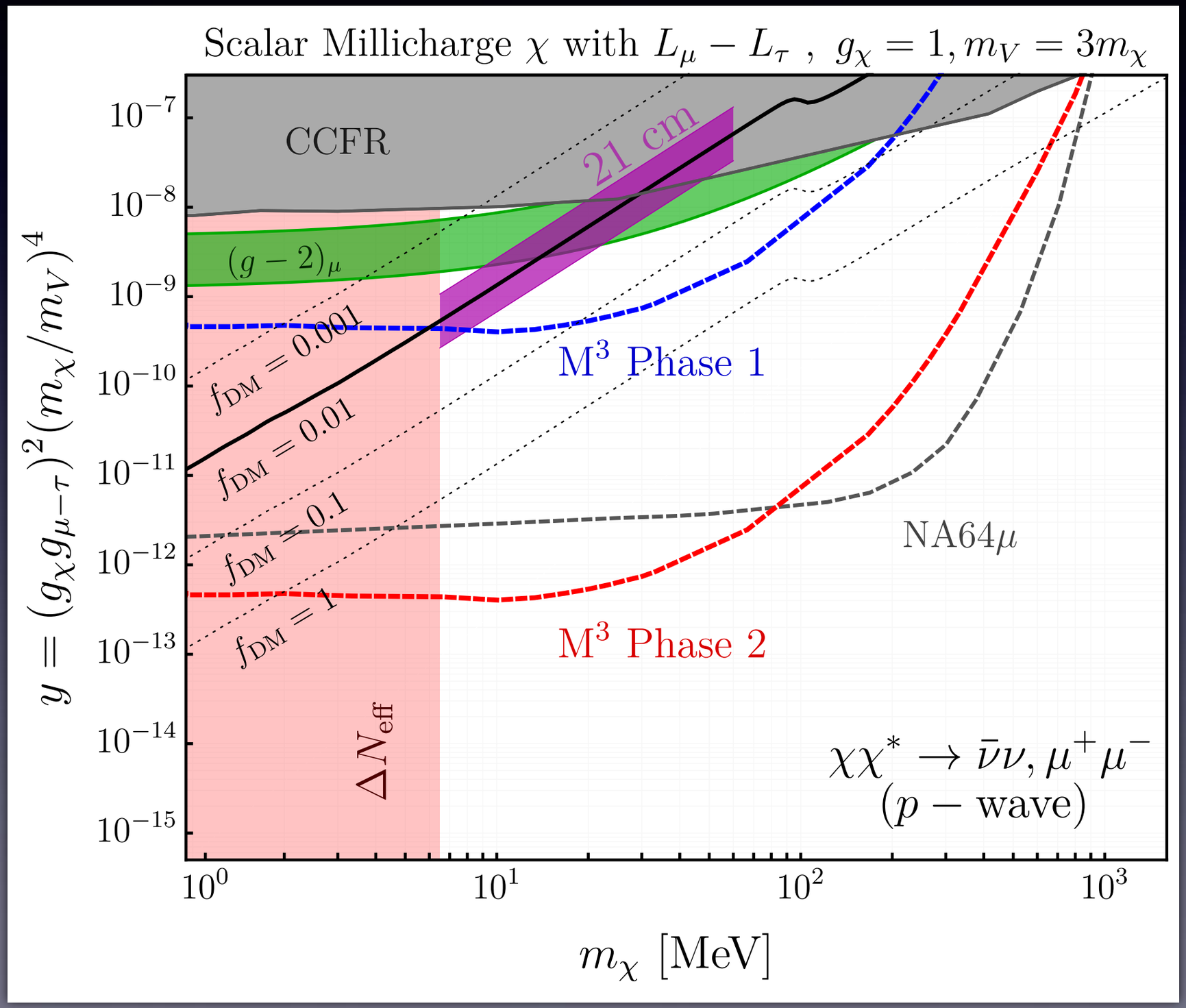
- Shouldn’t inject too much energy during cosmic dark ages

Couple to New Force

Many possibilities, but some guidelines:

- Shouldn’t couple to electrons
- Shouldn’t inject too much energy during cosmic dark ages
    - neutrinos
    - *p*-wave suppression

Couple to L_μ-L_τ



Implications of f_{DM}=1%

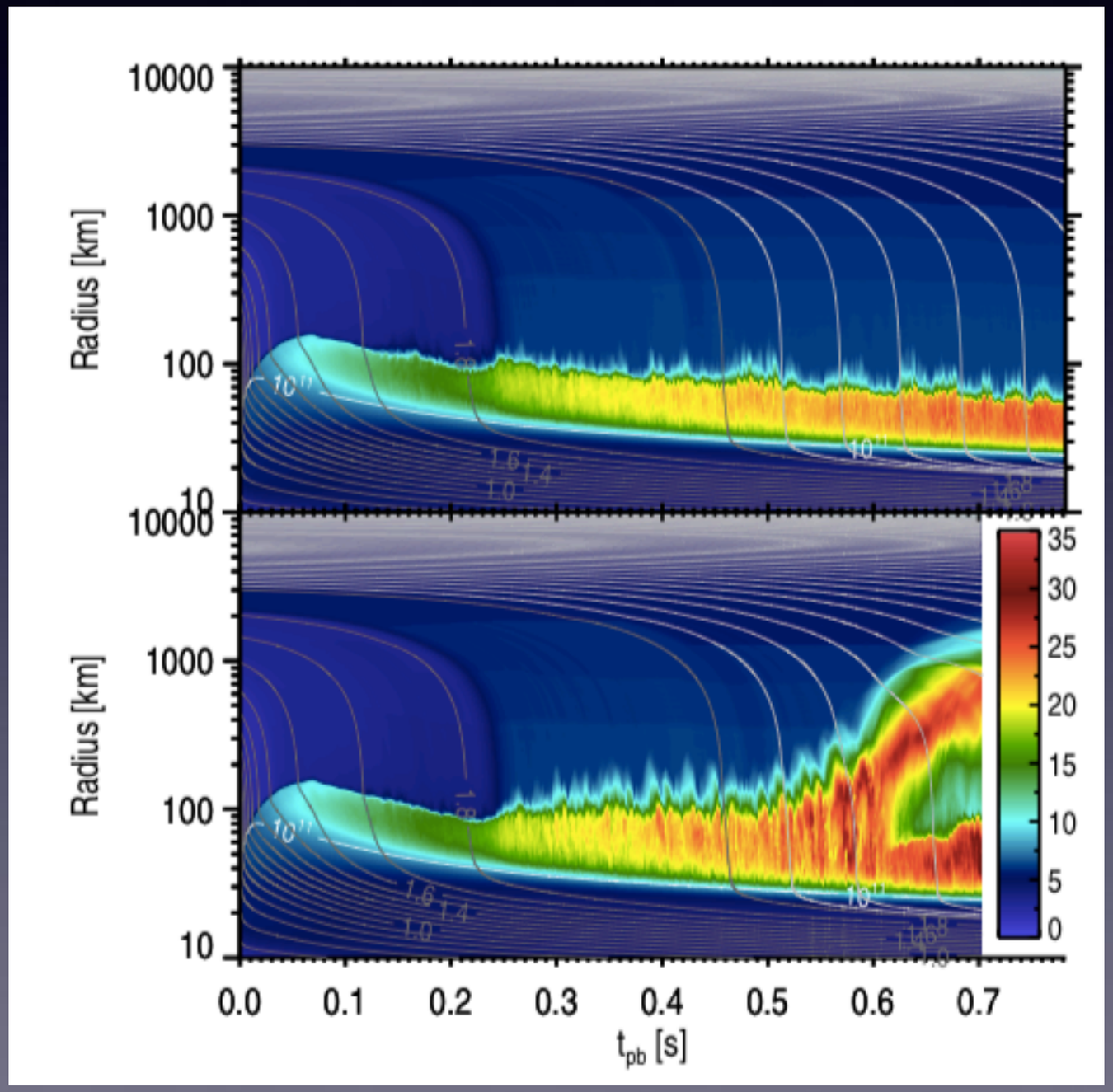
1. Relic density via QED alone is problematic — how else to deplete thermal abundance?

2. Thermal population introduced to SN1987A — how does this affect the eqn of state?

Muon creation in supernova matter facilitates neutrino-driven explosions

R. Bollig,[1,2] H.-T. Janka,[1] A. Lohs,[3] G. Martínez-Pinedo,[3,4] C.J. Horowitz,[5] and T. Melson[1]

Bollig et al 1706.04630



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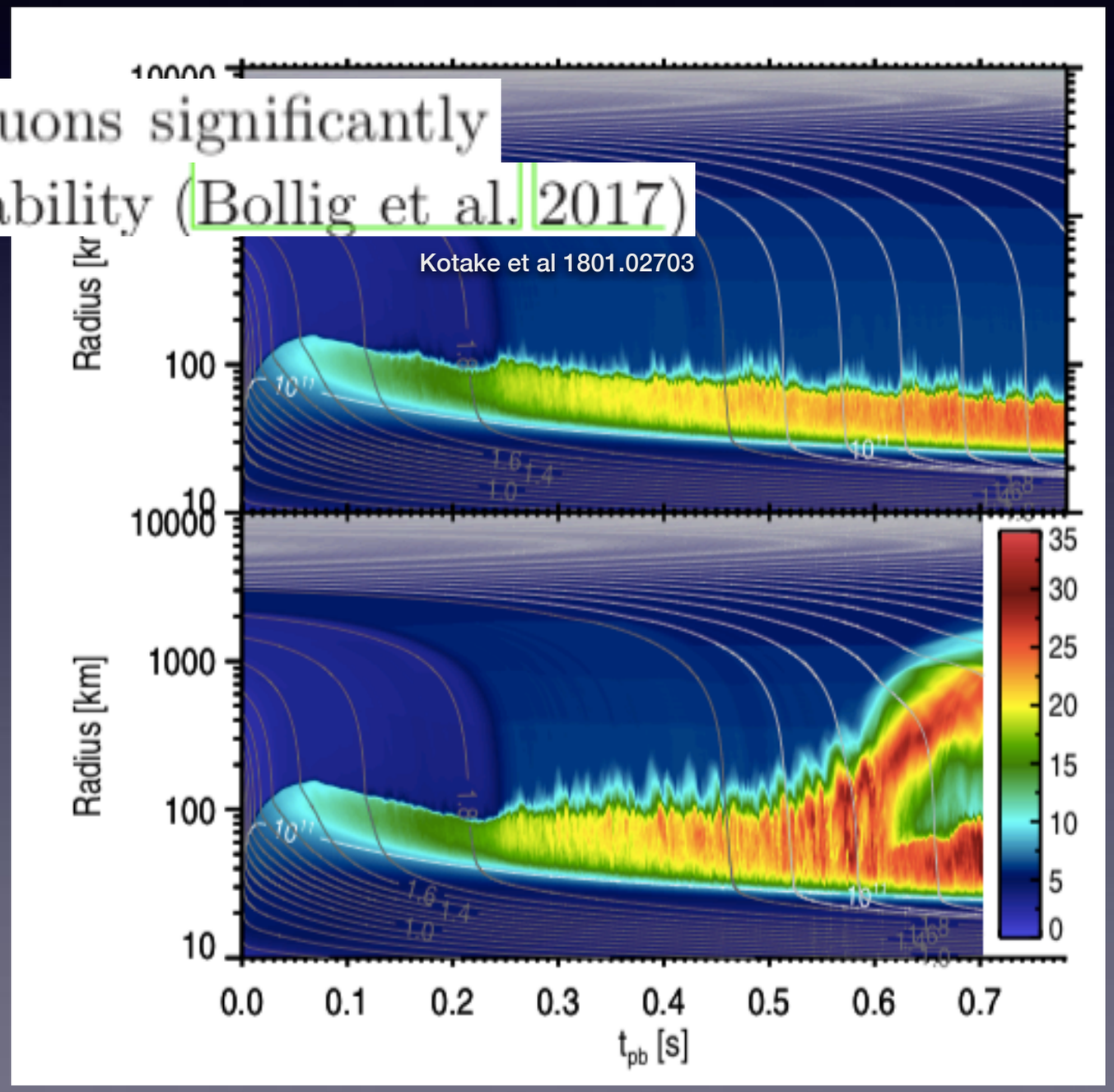
Bollig et al 1706.04630

Inclusion of muons significantly effects explodability (Bollig et al. 2017)



Kotake et al 1801.02703

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3. Primordial millicharged particles are evacuated from the disk — is any DD possible?

Direct Detection

Reopening the window on charged dark matter

0809.0436

Leonid Chuzhoy

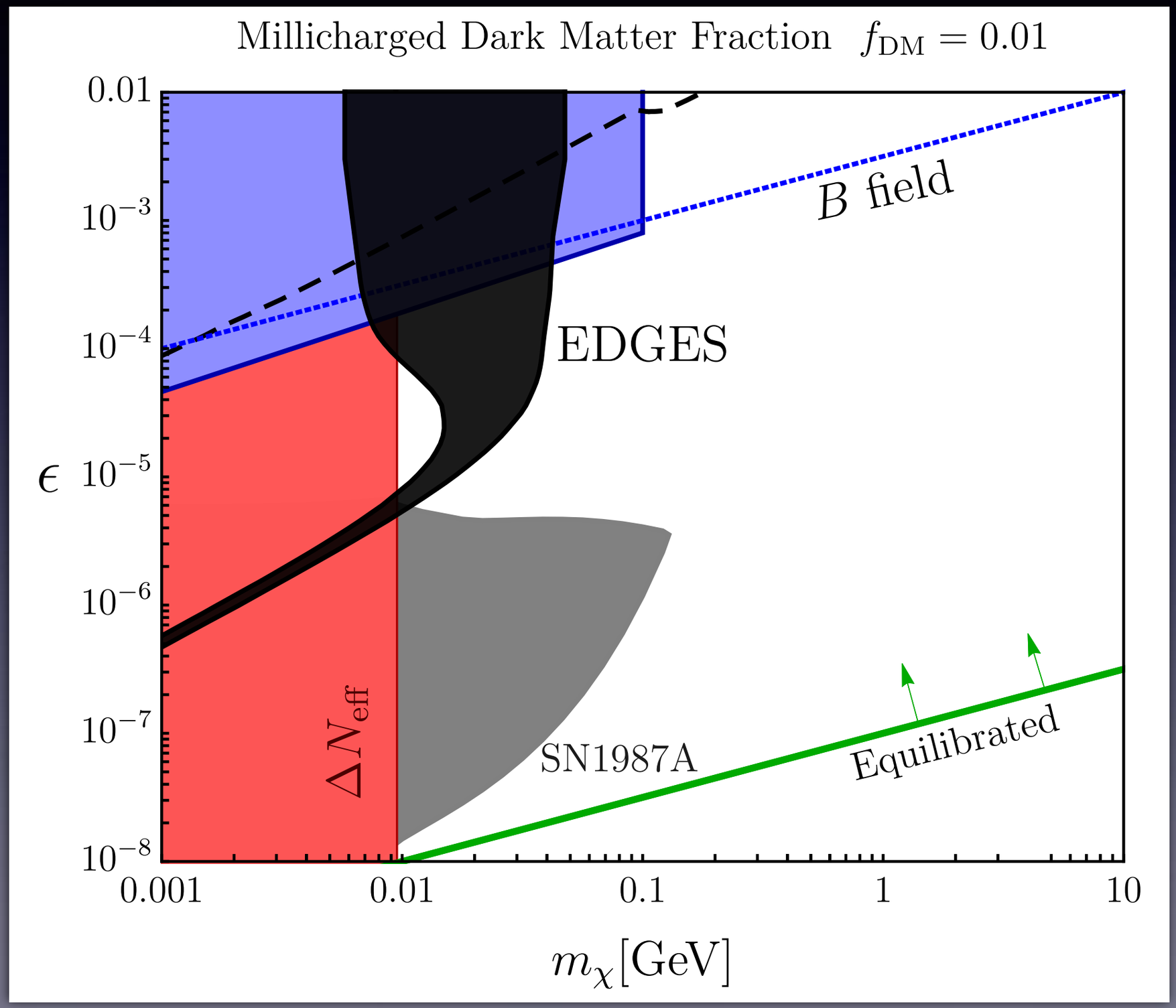
Department of Astronomy and Astrophysics, The University of Chicago, 5640 S. Ellis, Chicago, IL 60637, USA; chuzhoy@oddjob.uchicago.edu

Edward W. Kolb

Department of Astronomy and Astrophysics, Enrico Fermi Institute, and Kavli Institute for Cosmological Physics, The University of Chicago, 5640 S. Ellis, Chicago, IL 60637, USA

ABSTRACT: We reexamine the limits on charged dark matter particles. We show that if their mass and charge fall in the range $100(q_X/e)^2 \lesssim m_X \lesssim 10^8(q_X/e)$ TeV, then magnetic fields prevent particles in the halo from entering the galactic disk, while those initially trapped inside are accelerated through the Fermi mechanism and ejected within about $0.1 - 1$ Gyrs. Consequently, previous constraints on charged dark matter based on terrestrial non-observation are invalid within that range. ...

EDGES Constraints



DD for 1% of Ω_{DM}

- Such particles are evacuated from the disk…

DD for 1% of Ω_{DM}

- Such particles are evacuated from the disk…
- …but supernovae are hot!

DD for 1% of Ω_{DM}

- Such particles are evacuated from the disk…
- …but supernovae are hot!
- Do more appear? What is their phase space? What do they look like at DD experiments?
    - Boosted DM (Agashe et al., 1405.7370)
    - Marques-Tavares et al., in prep

Implications of f_{DM}=1%

1. Relic density via QED alone is problematic — how else to deplete thermal abundance?

2. Thermal population introduced to SN1987A — how does this affect the eqn of state?

3. Primordial millicharged particles are evacuated from the disk — is any DD possible?

4. We've "already seen" DM in the CMB power spectrum — CMB S4 or BBN improvement?

Conclusions

- EDGES has possibly detected evidence of dark matter scattering off baryons during the epoch of structure formation
- If it did, it's not "minimal" — a rich structure of auxiliary interactions and signals awaits
- We'll learn (a lot) more (fairly) soon

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What we find could surprise us!

Conclusions

Further 21cm-related talks at IDM

Monday:
Creque-Sarbinowski, Ridgway, Liu

Thursday:
Burns, Rogers, Fialkov, Ewall-Wice, Wu

Friday:
Muñoz

- EDGES has possibly detected evidence of dark matter scattering off baryons during the epoch of structure formation
- If it did, it's not "minimal" — a rich structure of auxiliary interactions and signals awaits
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