A new mechanism to produce X-ray lines with unique morphology and spectrum

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24 May 2017

Why Photon Lines?

Dark Matter Indirect Detection

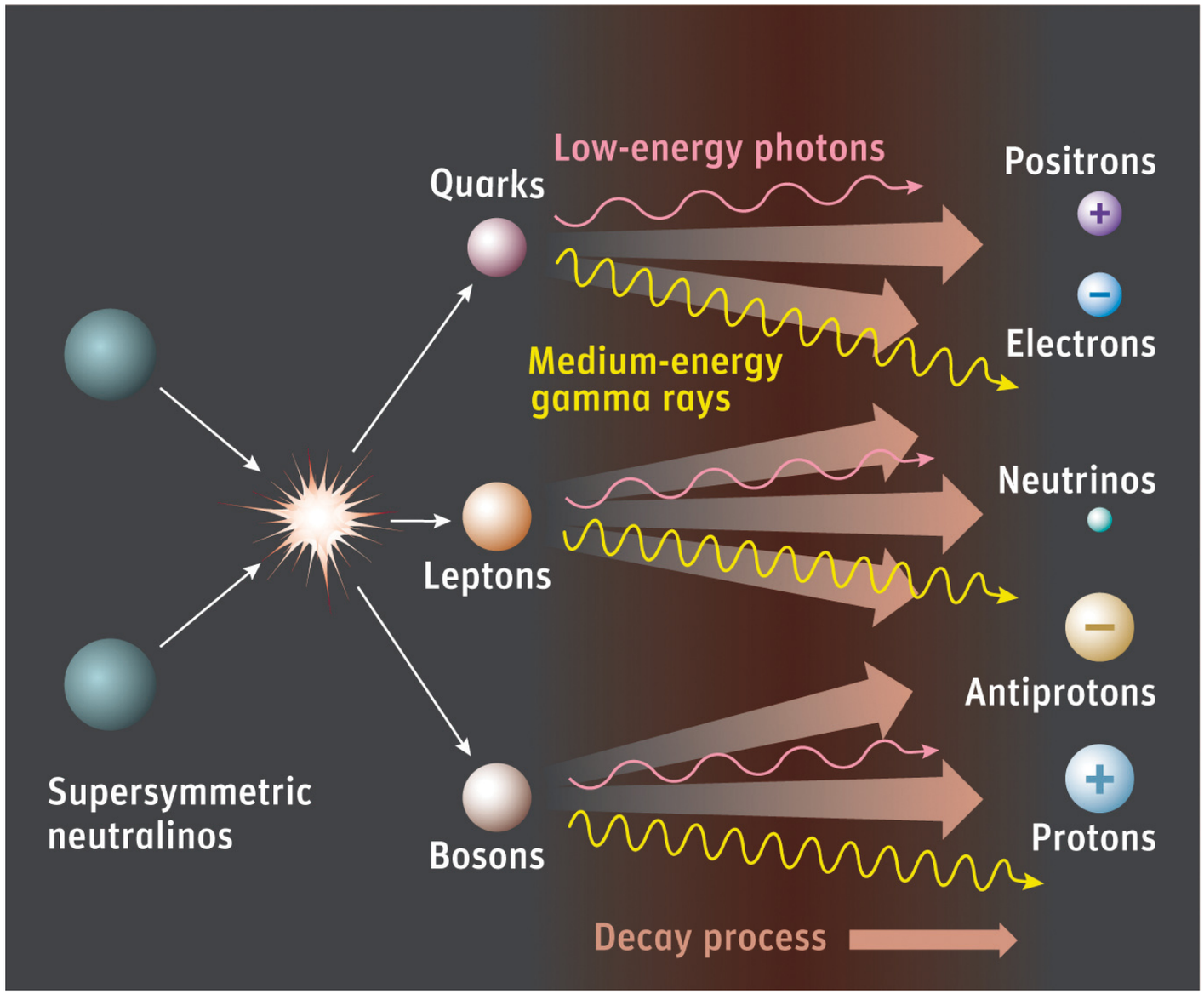

Image credit: http://2.bp.blogspot.com/_mazRoHLuLl0/S8vDDnfah1I/AAAAAAAAAaQ/1Cxtj7Zs6DA/s1600/188434main_DkMatter_lg.jpg

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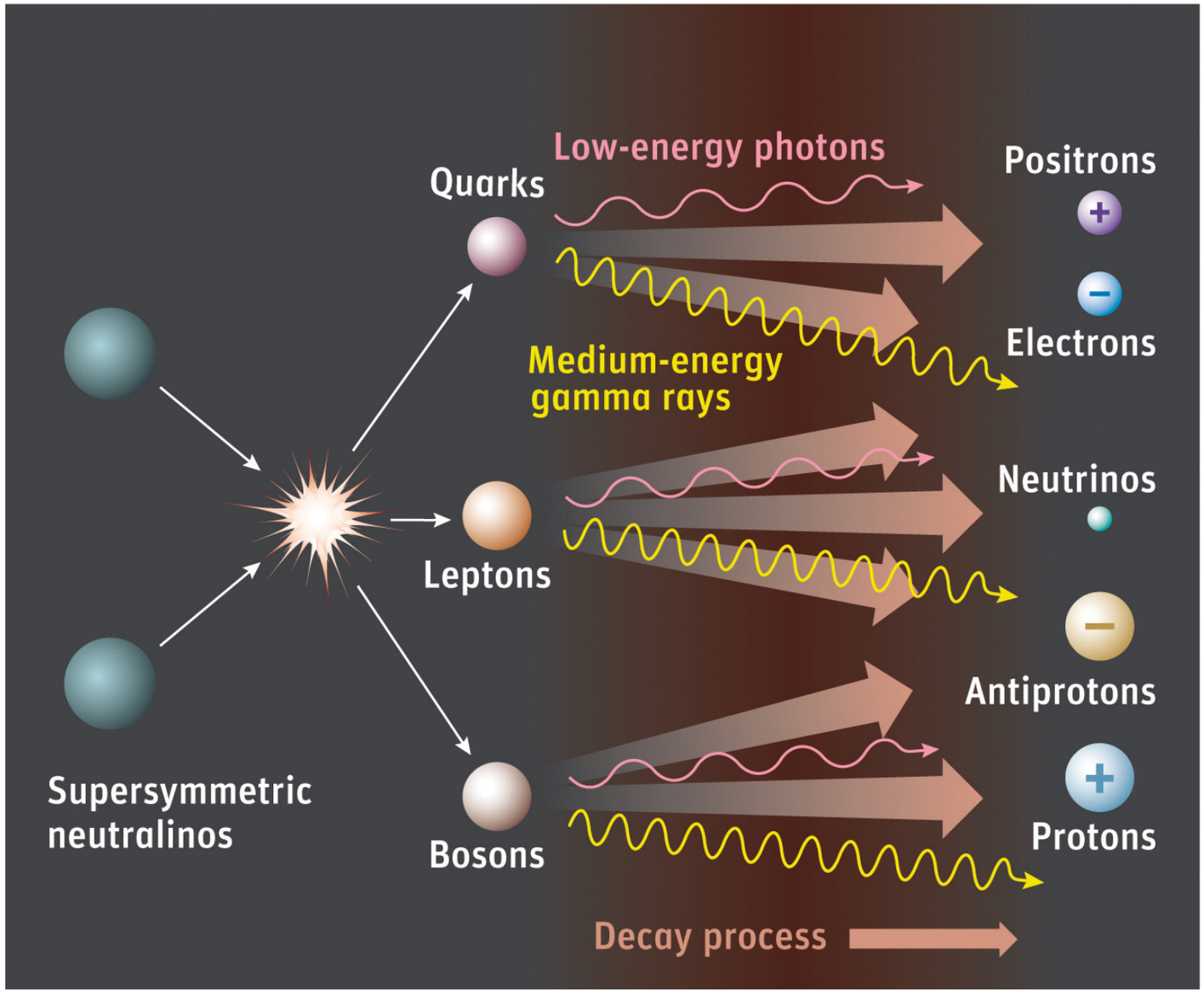

Photons

- Direction
- Energy

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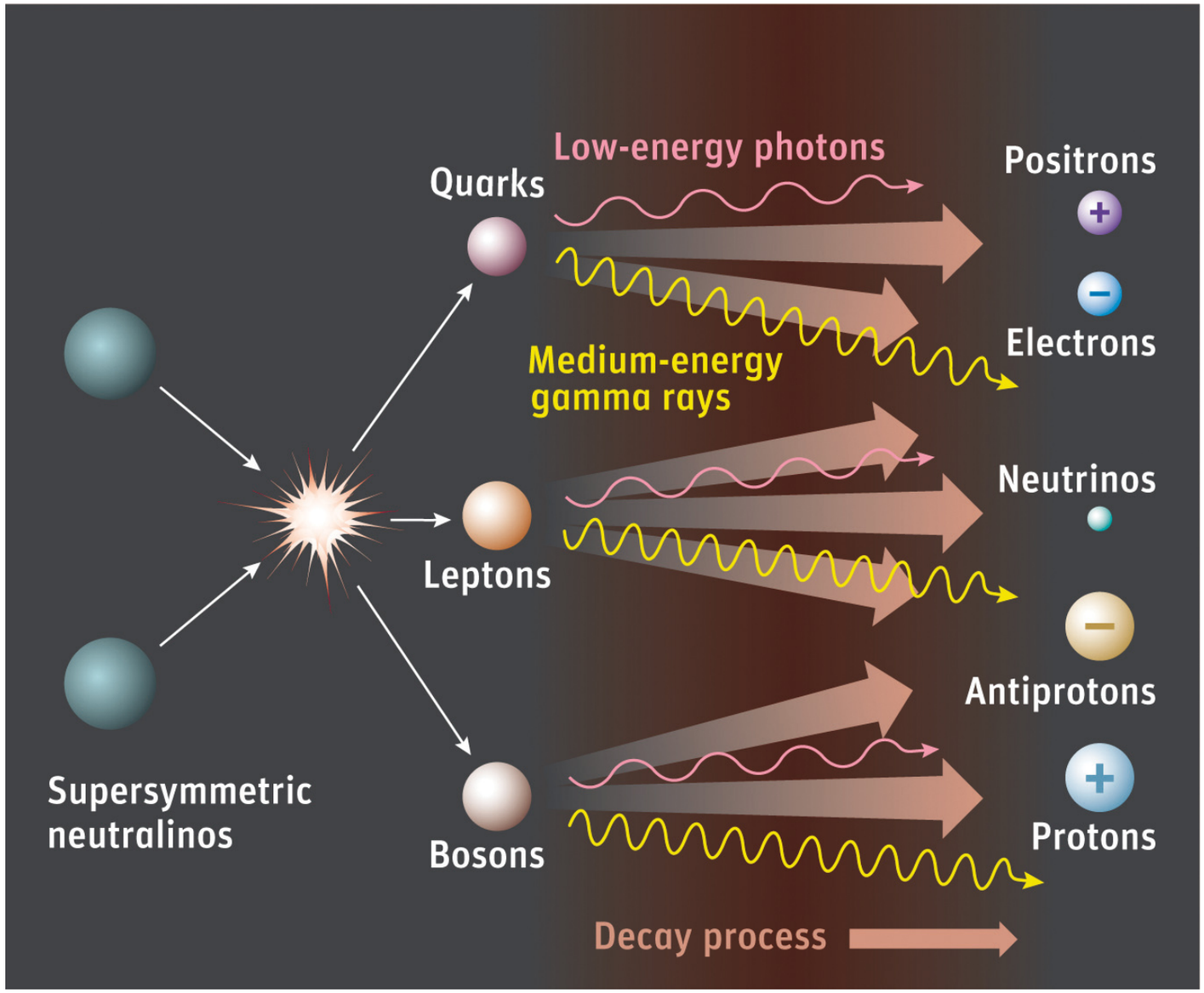

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Astrophysical background

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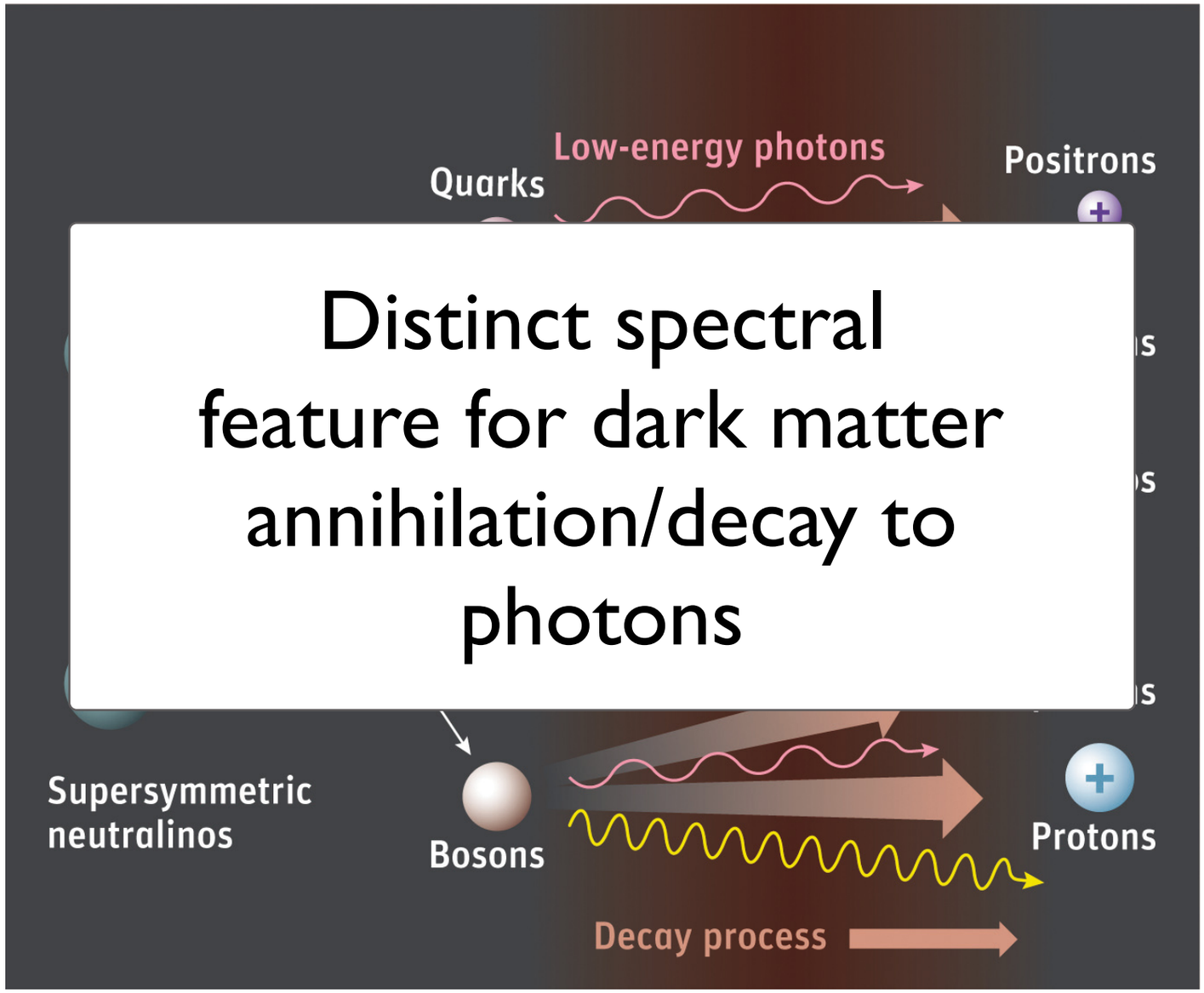

Distinct spectral feature for dark matter annihilation/decay to photons

Photons

- Direction
- Energy

Astrophysical background

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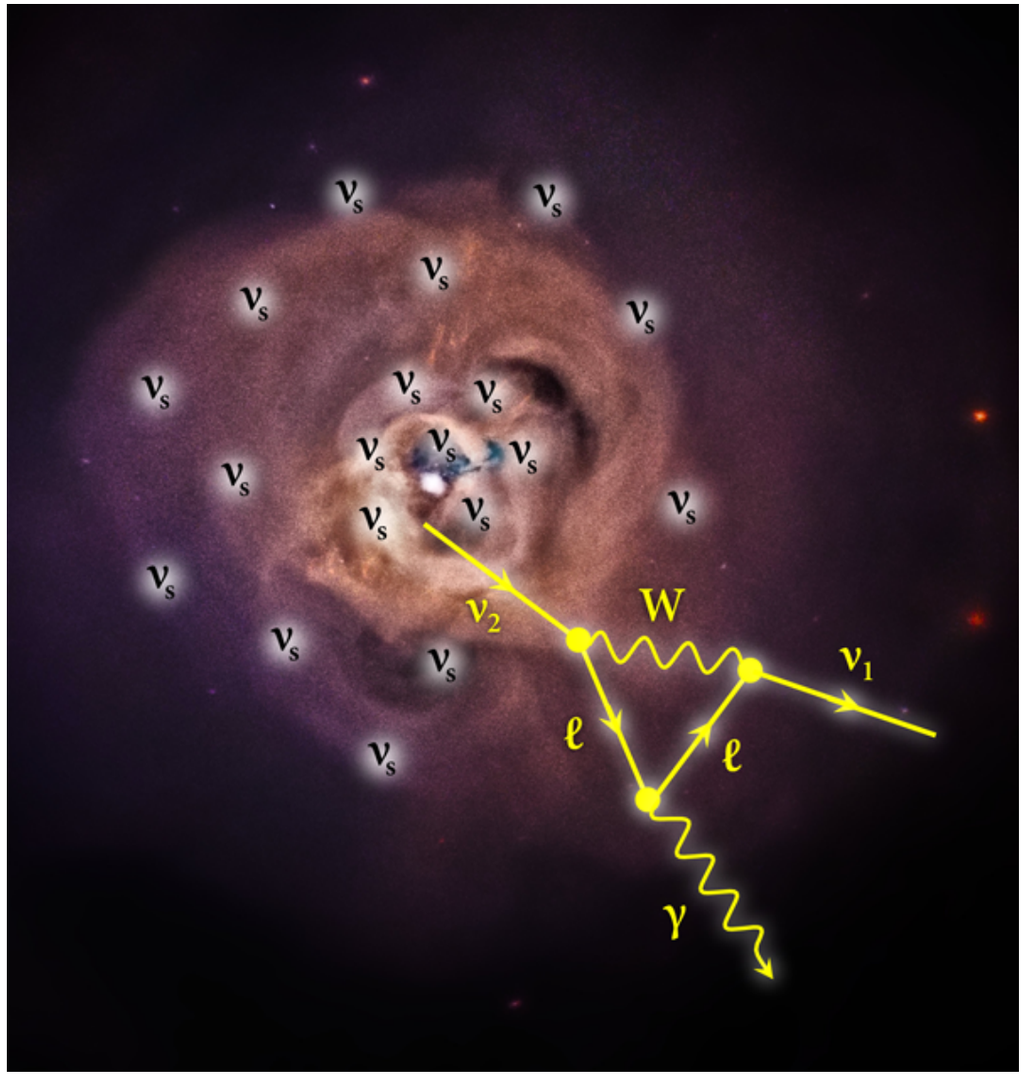
Why X-Rays?



Credit: Image: NASA/CXC/SAO/E.Bulbul et al., Overlay: APS/Alan Stonebraker

Sterile Neutrinos

- Produced through oscillations

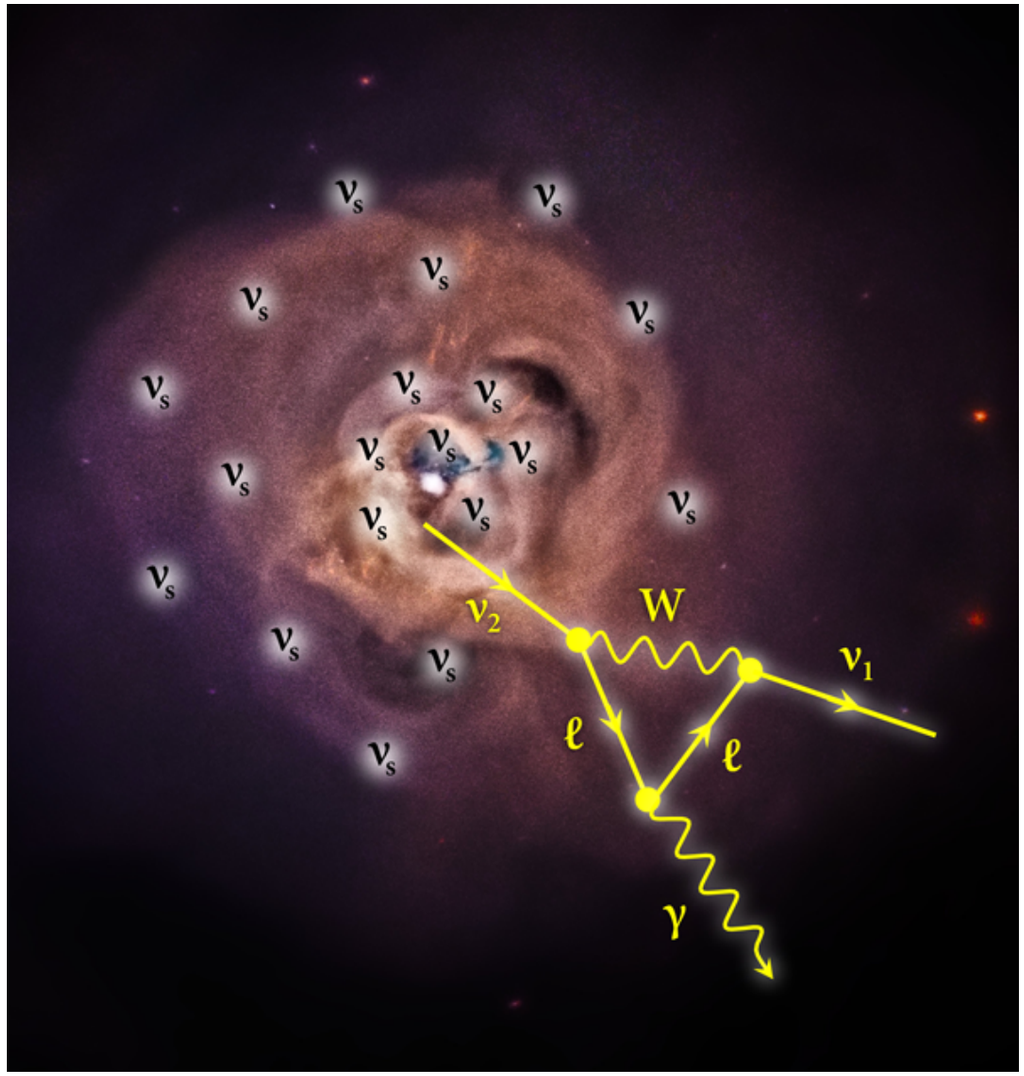
$$\Omega_{N_R} h^2 \simeq 0.1 \, \frac{\sin^2 2\theta}{10^{-8}} \left(\frac{m_{N_R}}{3\,\mathrm{keV}} \right)^{1.8}$$

Dodelson, Widrow, PRL72 (1994), (hep-ph/9303287)

- Production can be enhanced by lepton asymmetry

Shi, Fuller, PRL82 (1999), (astro-ph/9810076)

Why X-Rays?



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Sterile Neutrinos

- X-ray lines source

$$N_R \rightarrow \nu_L \gamma$$

$$E_\gamma \simeq m_{N_R}/2$$

$$\Gamma_{N_R \rightarrow \nu_L \gamma} \simeq \frac{1}{1.5 \times 10^{32}\,\mathrm{sec}} \frac{\sin^2 2\theta}{10^{-10}} \left(\frac{m_{N_R}}{\mathrm{keV}}\right)^5$$

Pal, Wolfenstein, PRD25 (1982)

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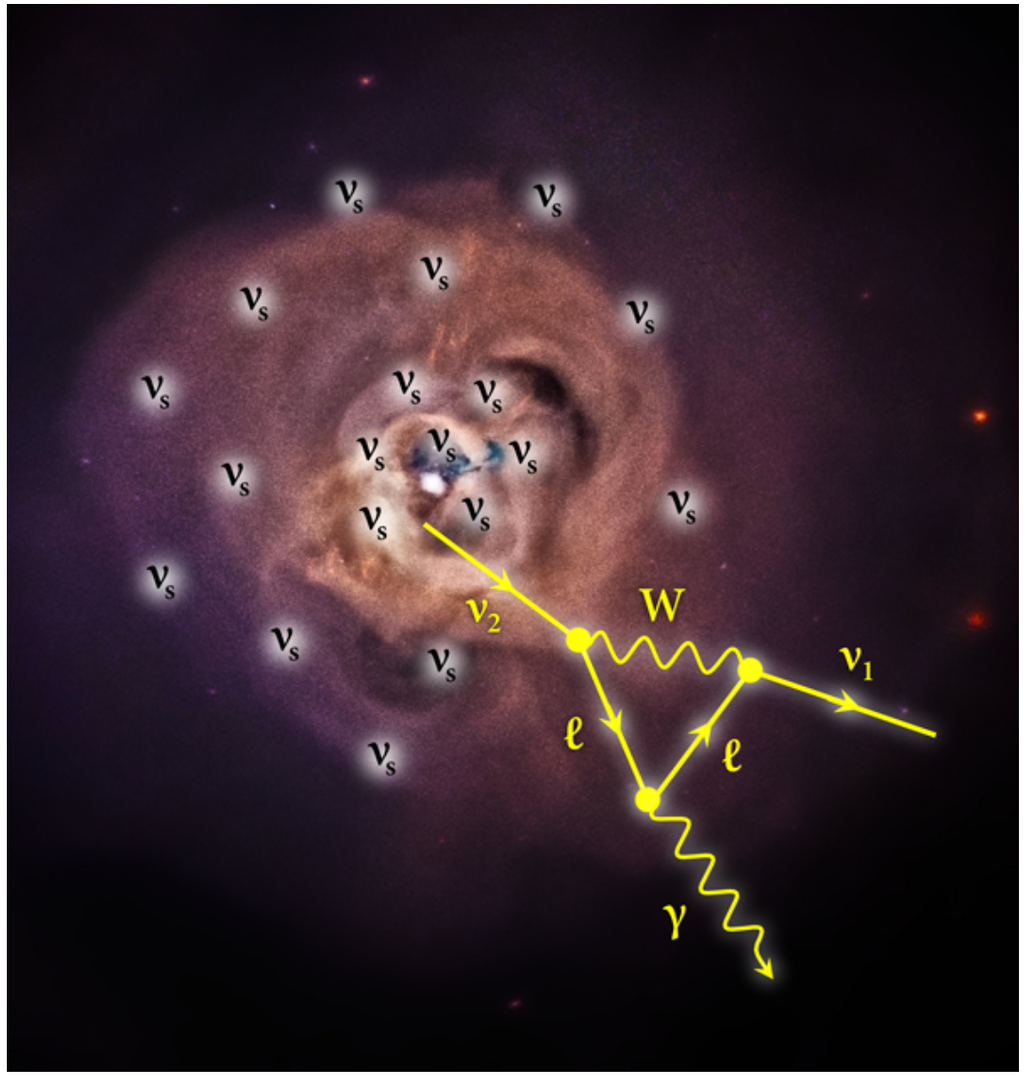

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Pal, Wolfenstein, PRD25 (1982)

Other DM candidates produce X-ray lines

In this talk I will introduce a new mechanism

FD, Hambleton, Profumo, Stefaniak, PRD93 (2016), (arXiv:1603.04859)

FD, Profumo, arXiv:170X.XXXXX

A Line at 3.5 keV

Discovered in 2014

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Stacked clusters and Perseus ✓

Bulbul et al., Astrophys.J.789 (2014), (arXiv:1402.2301)

Center of the Milky Way ✓

Jeltema and Profumo, MNRAS450 (2015), (arXix:1408.1699)

M31 (Andromeda) ?

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A sterile neutrino can account for the line!

$$N_R \rightarrow \nu_L \gamma$$

$$m_{N_R} \simeq 7\,\mathrm{keV}$$

$$\sin^2(2\theta) \simeq 7 \times 10^{-11}$$

Is it from Dark Matter?

X-ray lines expected from atomic transitions

$$E_B \simeq Z^2 \times 13.6\,\mathrm{eV}$$

Ions with Z~20:
lines around 3.5 keV

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K XVIII (Helium-like Potassium) has an excitation line at 3.5 keV!

$$K^* \rightarrow K\,\gamma$$

Brightness of the potassium line not known conclusively

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Are we observing dark matter or potassium?

Complementary Probes

Look for the line somewhere else

Morphology of the 3.5 keV photons

Complementary Probes

Look for the line somewhere else

No 3.5 keV line in dark matter dominated dwarf galaxies
and galaxies with low plasma temperature

Malyshev, Neronov, Eckert, PRD90 (2014), (arXiv:1408.3531)
Anderson, Churazov, Bregman, Mon.Not.Roy.Astron.Soc. 452 (2015), (arXiv:1408.4115)
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Photon morphology correlated with plasma

Carlson, Jeltema, Profumo, JCAP1502 (2015), (arXiv:1411.1758)

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Known dark matter interpretations (e.g. sterile neutrino) inconsistent with complementary observations!

Where are we in 2017?

Potassium origin of the observed
3.5 keV line very plausible

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The dust will settle soon

High resolution X-ray telescopes
(Hitomi follow-up > 2020,
Athena > 2020, Lynx > 2030)

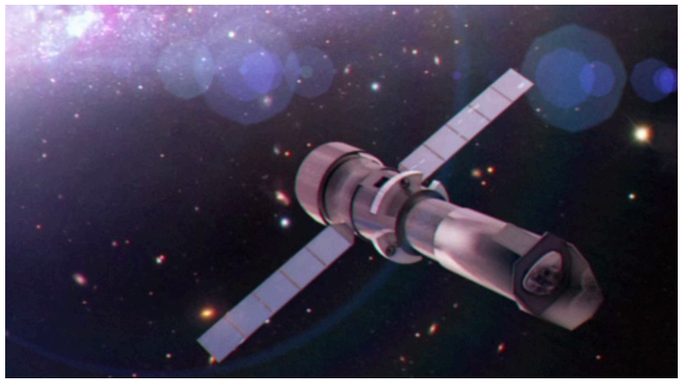

Image credit: http://www.the-athena-x-ray-observatory.eu

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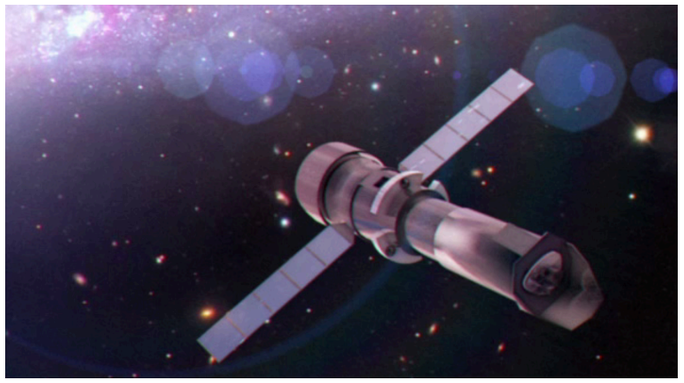

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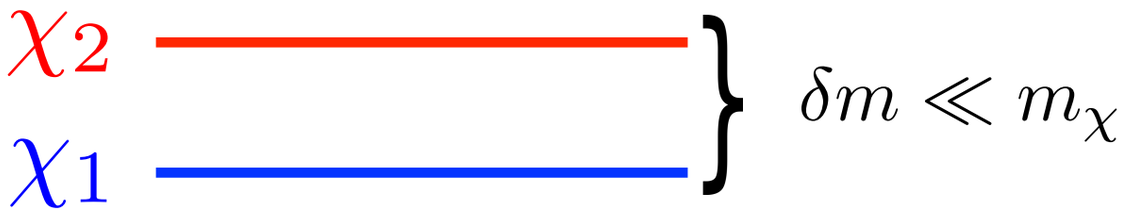
What if the line is dark matter?
We need to think creatively...

An “exciting” mechanism

(At least) two-state system with suppressed elastic scattering



$$\chi_1 f \rightarrow \chi_1 f$$

$$\chi_1 f \rightarrow \chi_2 f$$

FD, Profumo (in progress)

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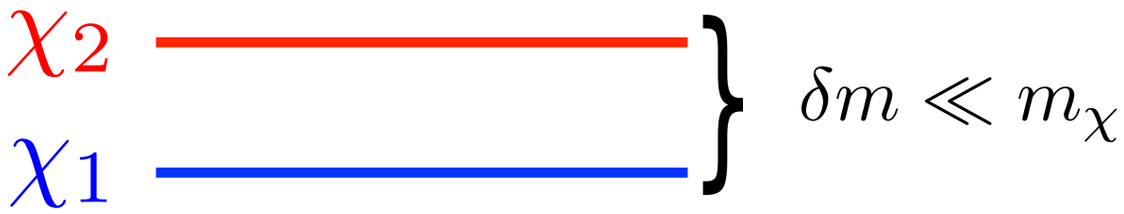
(At least) two-state system with suppressed elastic scattering



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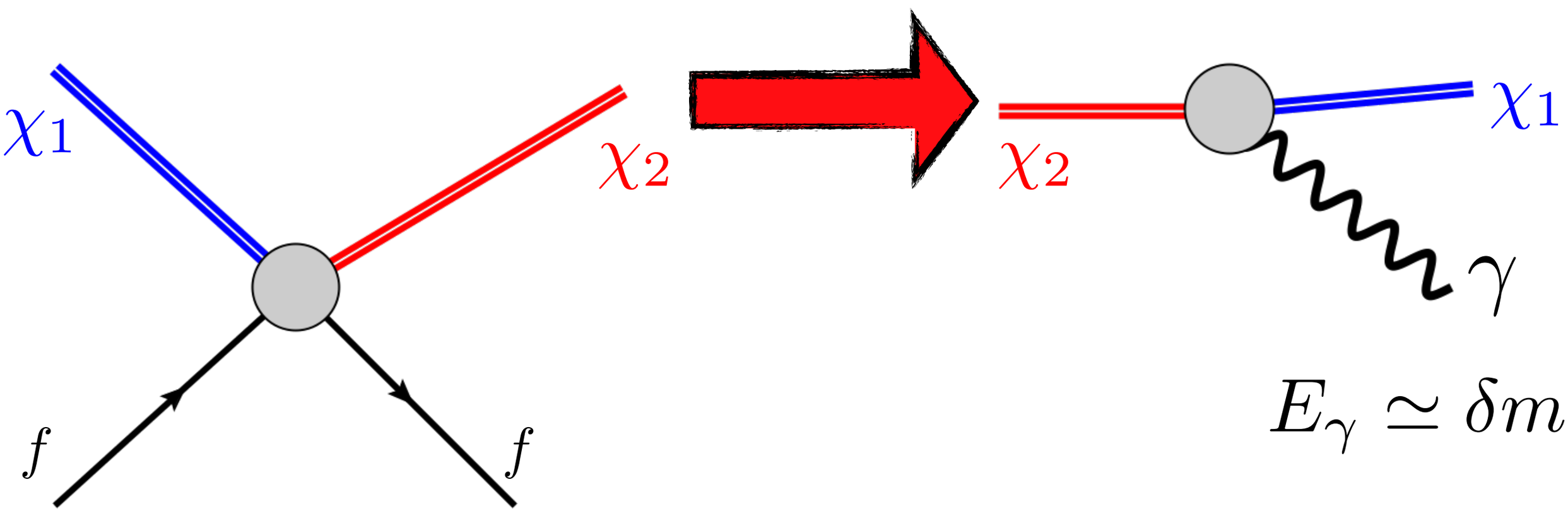
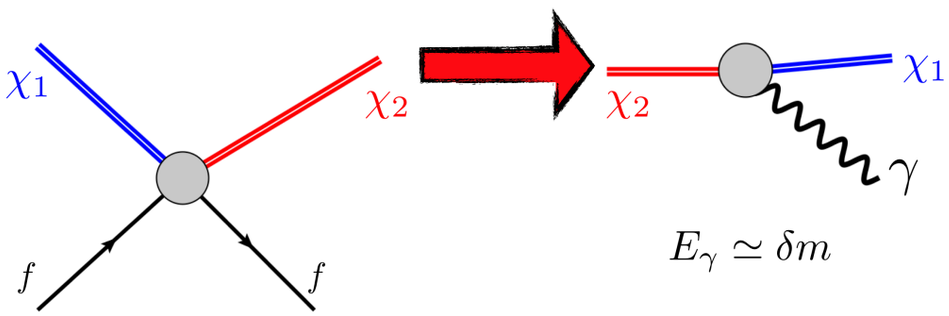


$$E_\gamma \simeq \delta m$$

FD, Profumo (in progress)

Features of the Line



Photon Flux

$$\frac{dN_\gamma}{dE_\gamma d\Omega} \propto \int_{l.o.s.} dl(\Omega)\, n_\chi\, n_f \times \langle \sigma v_{\rm rel} \rangle \times \mathcal{F}(E_\gamma)$$

FD, Profumo (in progress)

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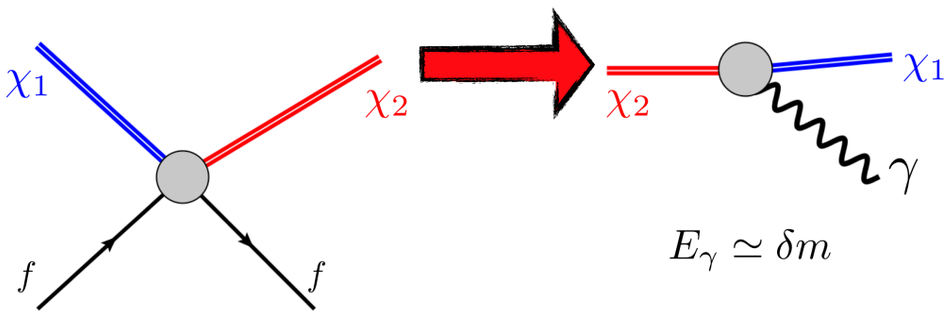

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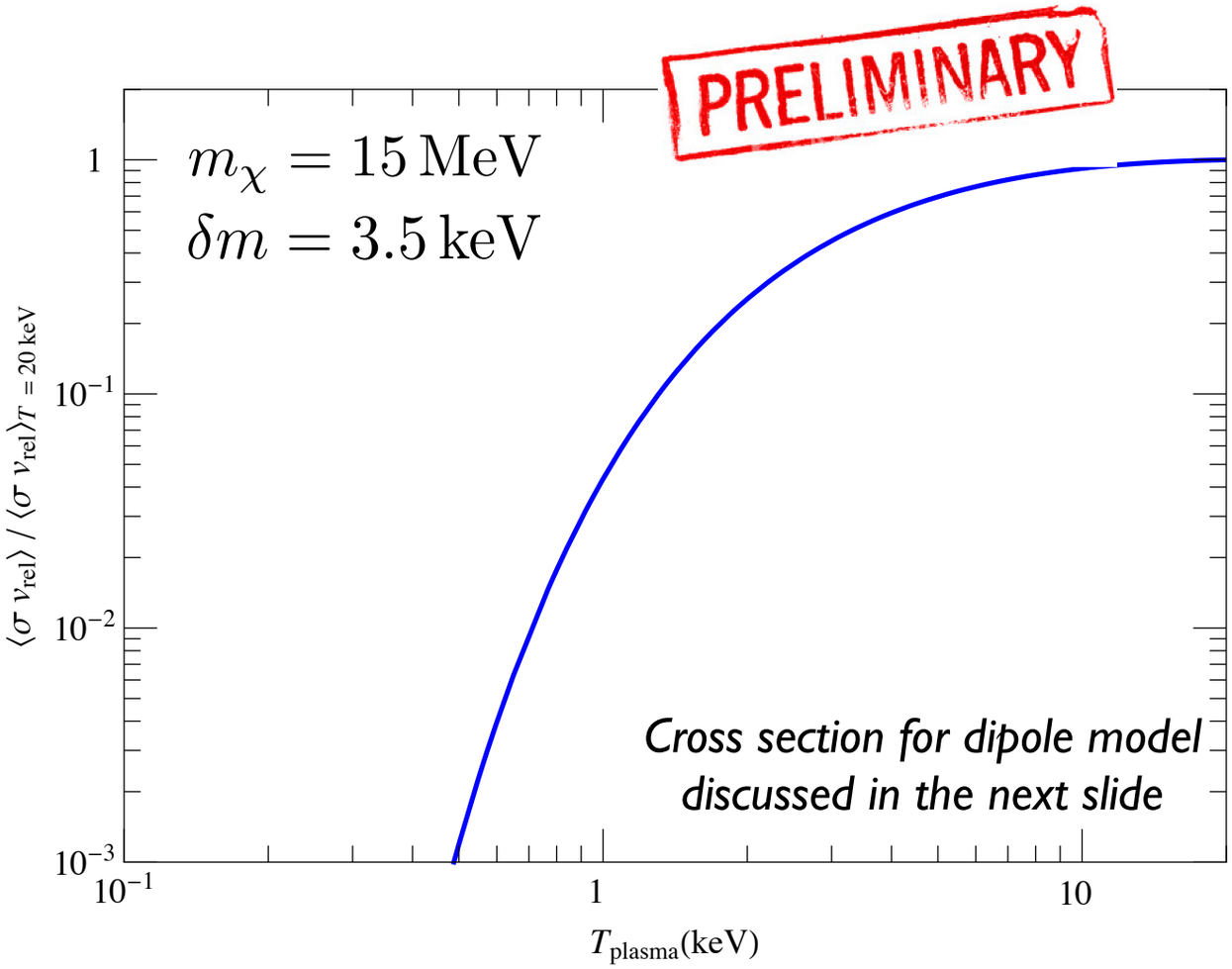
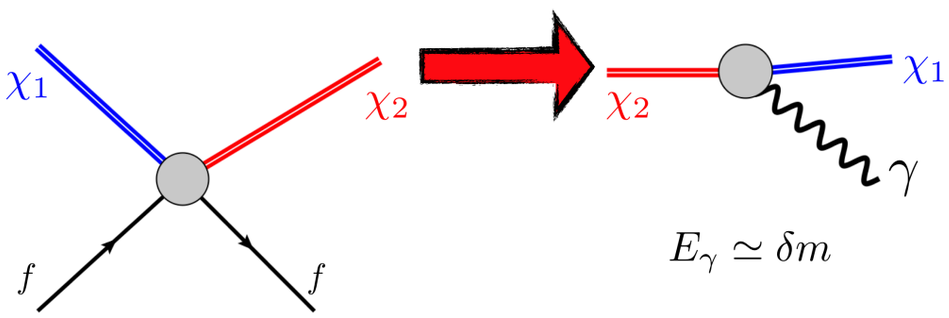


Lines only from
"hot regions"
(as for the 3.5 keV line)

FD, Profumo (in progress)

Features of the Line



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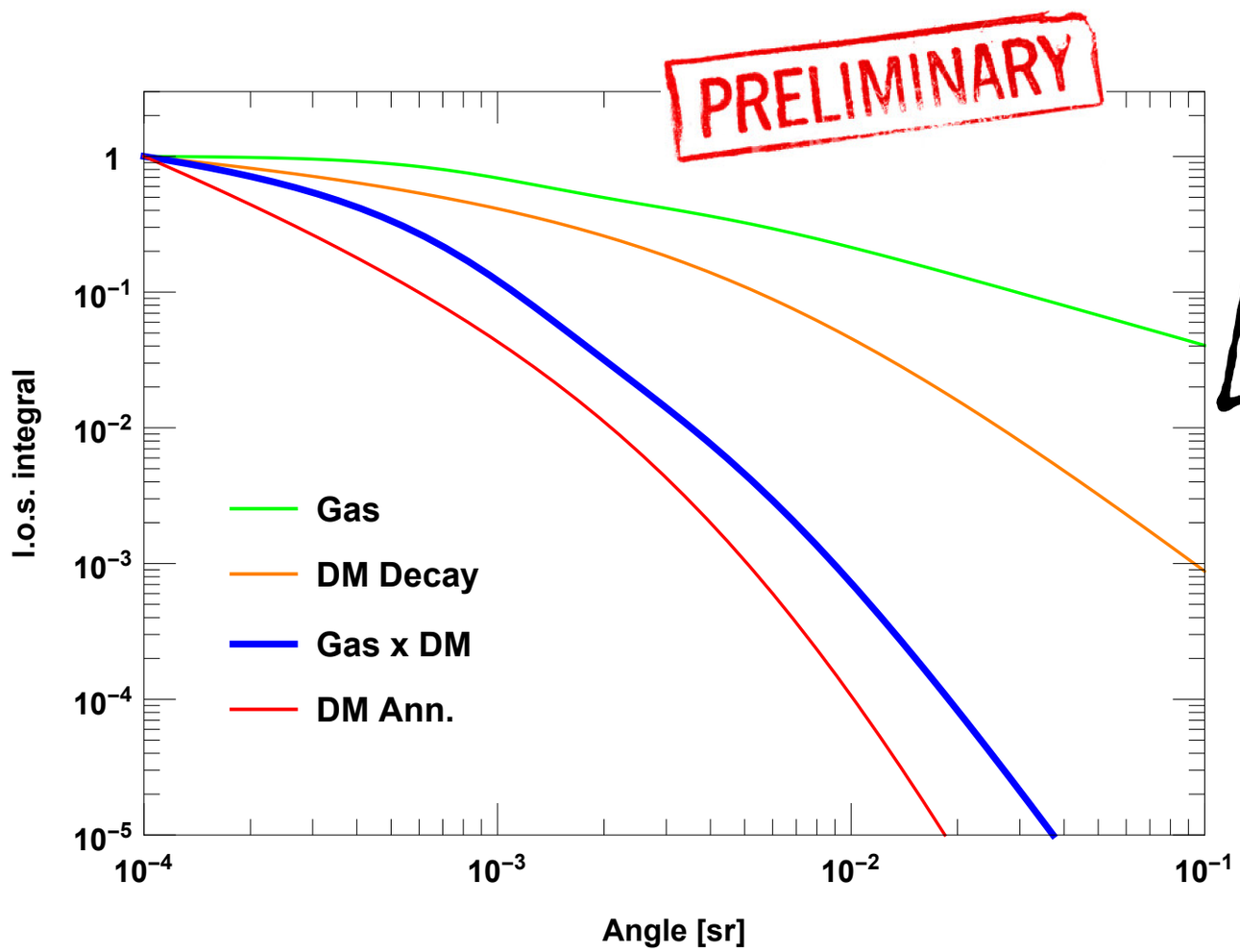
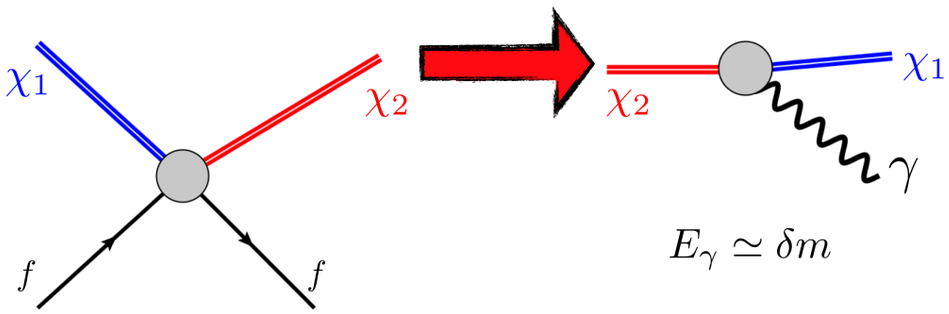


Morphology tracks the plasma distribution *(as for the 3.5 keV line)*

FD, Profumo (in progress)

Features of the Line



Photon Flux

$$\frac{dN_\gamma}{dE_\gamma d\Omega} \propto \int_{l.o.s.} dl(\Omega)\, n_\chi\, n_f \times \langle \sigma v_{\rm rel} \rangle \times \mathcal{F}(E_\gamma)$$

Doppler shift due to velocity dispersion

Peculiar shape of the line,
a testable third option for the 3.5 keV line

FD, Profumo (in progress)

A simple EFT

Field Content	Interactions
Two Weyl fermions, Standard Model singlets	Effective dimension 5 dipole operators

FD, Hambleton, Profumo, Stefaniak, PRD93 (2016), (arXiv:1603.04859)

A simple EFT

Field Content	Interactions
Two Weyl fermions, Standard Model singlets	Effective dimension 5 dipole operators

Mass Eigenstates

Small mass splitting is natural

Interaction is off-diagonal

$$\mathcal{L}_{\text{dipole}} = -\frac{i}{2\Lambda}\,\overline{\psi_2}\Sigma^{\mu\nu}\left(c_M + i c_E \gamma^5\right)\psi_1\, F_{\mu\nu}$$

FD, Hambleton, Profumo, Stefaniak, PRD93 (2016), (arXiv:1603.04859)

The 3.5 keV Line

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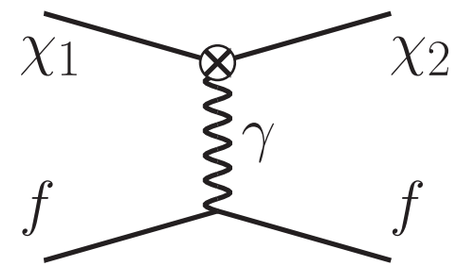

Can we account for the 3.5 keV line?

Yes!

FD, Hambleton, Profumo, Stefaniak, PRD93 (2016), (arXiv:1603.04859)

The 3.5 keV Line

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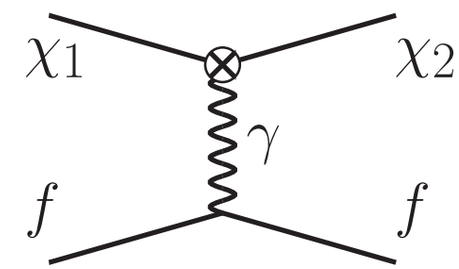

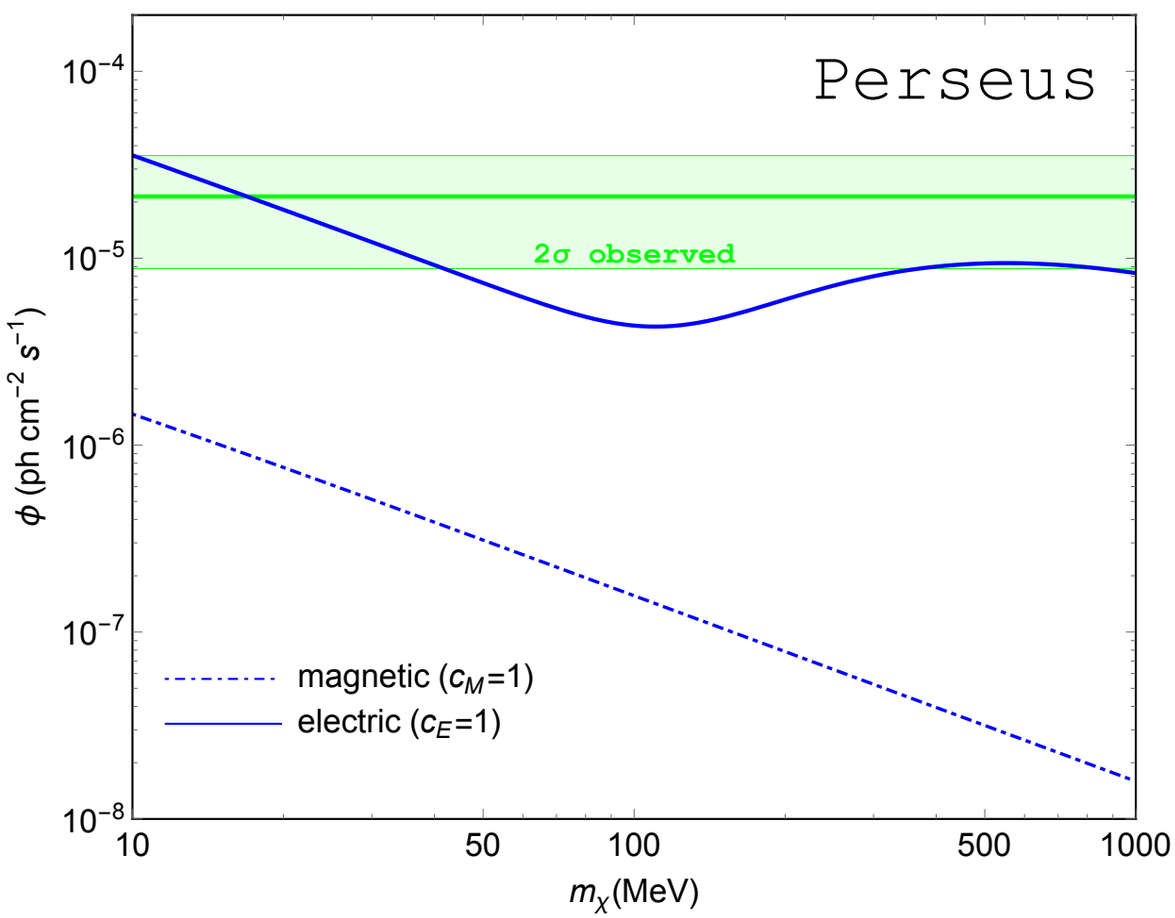

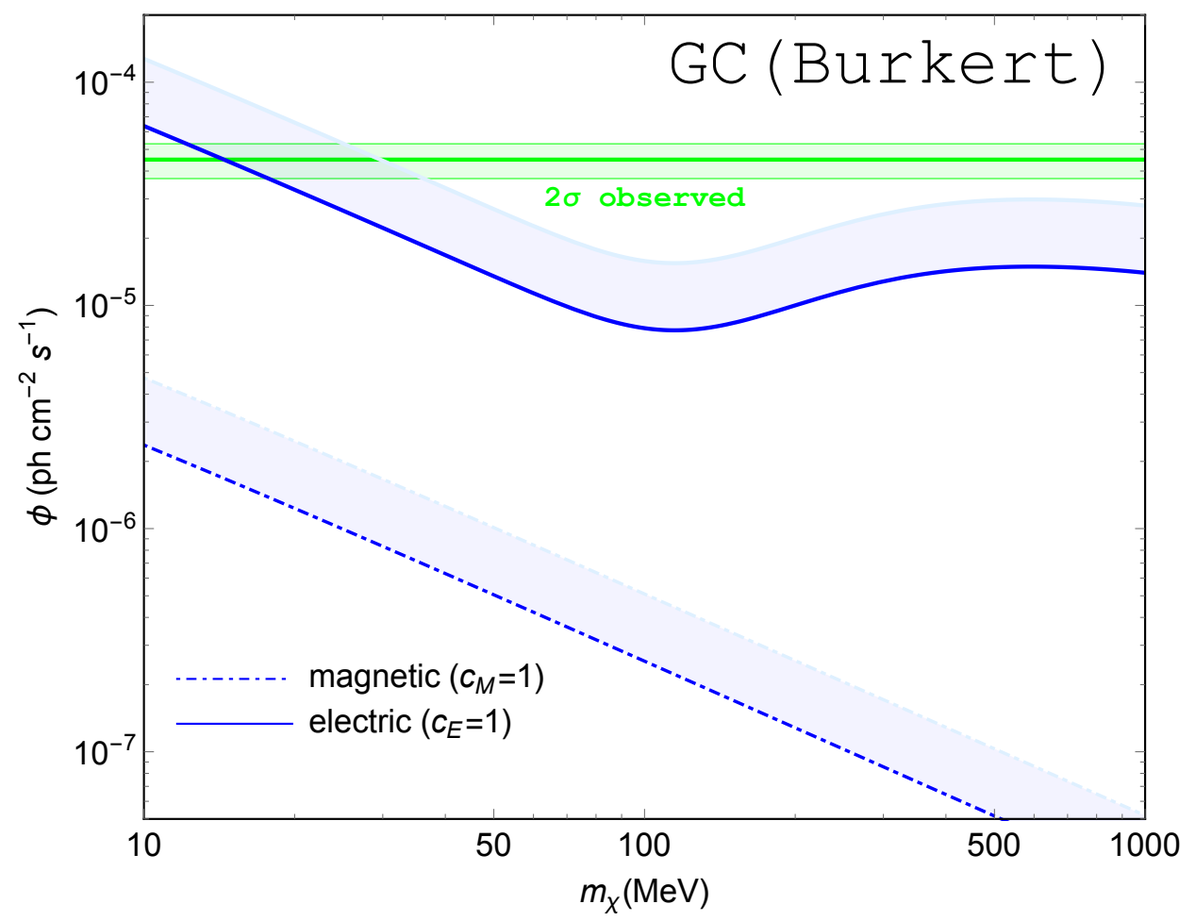

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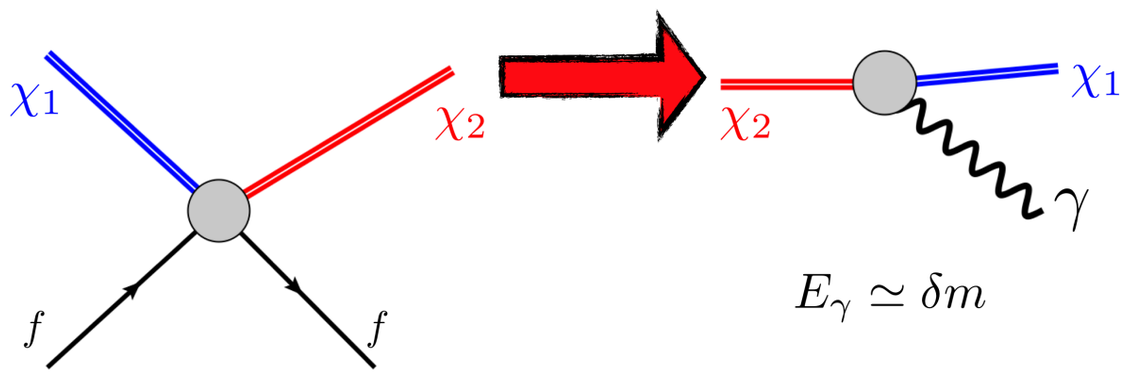
Outlook

New mechanism for X-ray lines



- Lines from "hot" regions
- Plasma morphology
- Peculiar spectral shape

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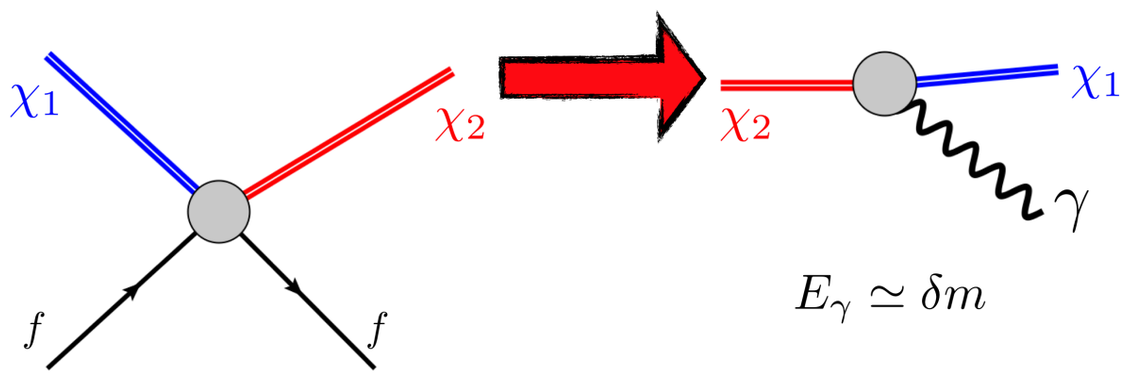

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Future work

Write down UV complete theories (dipole, dark photon…)

Investigate discovery reach for future telescopes, consistently with particle physics constraints

Impact for structure formation (delayed kinetic decoupling)

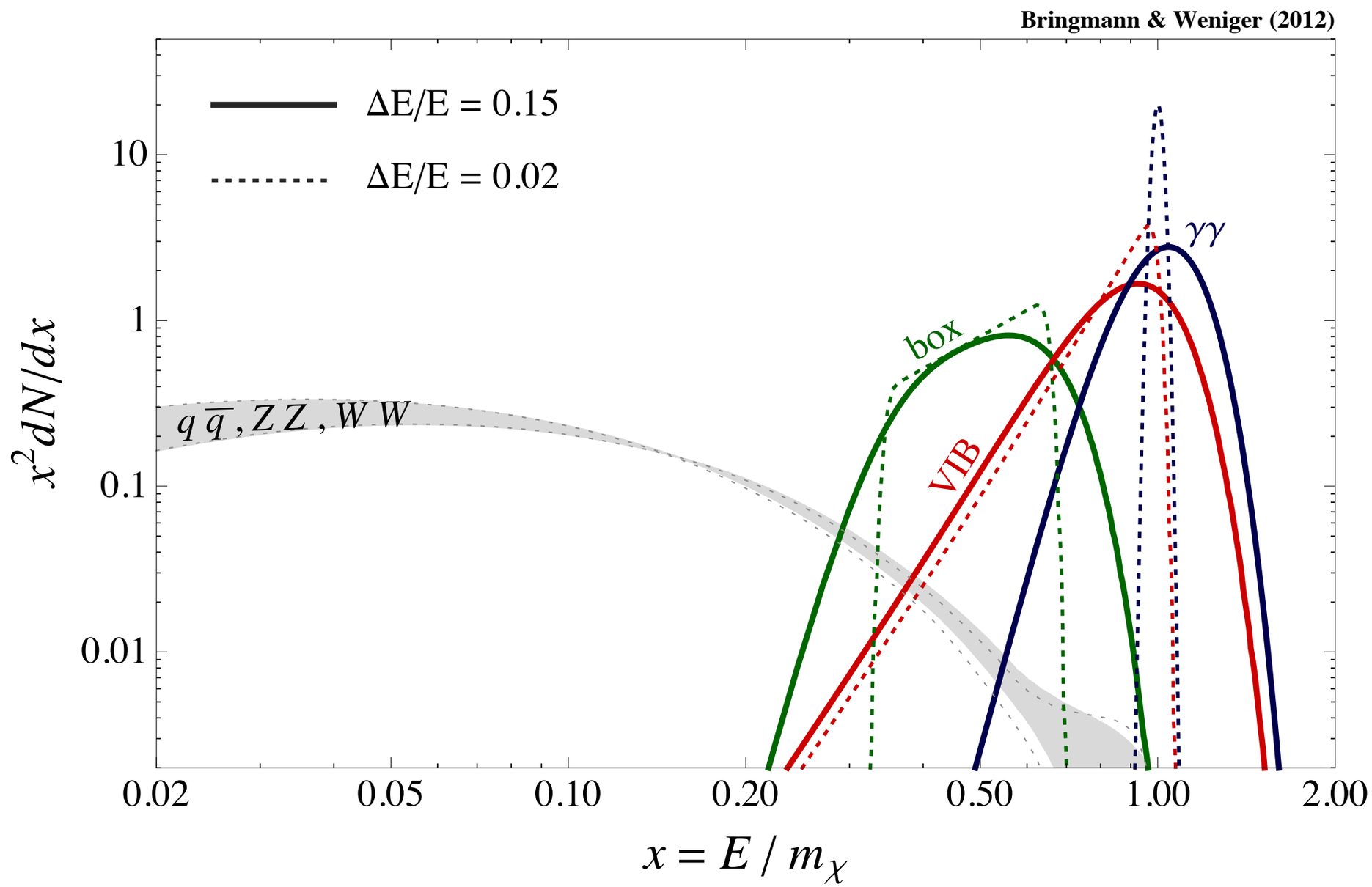
Lines in other regions (e.g. GeV)

FD, Profumo (in progress)

BACKUP

Why Lines?

$$\chi\,\chi \;\rightarrow\; \phi_{\rm SM}\,\phi_{\rm SM}$$



Bringmann, Weniger, Phys.Dark Univ. 1 (2012), (arXiv:1208.5481)

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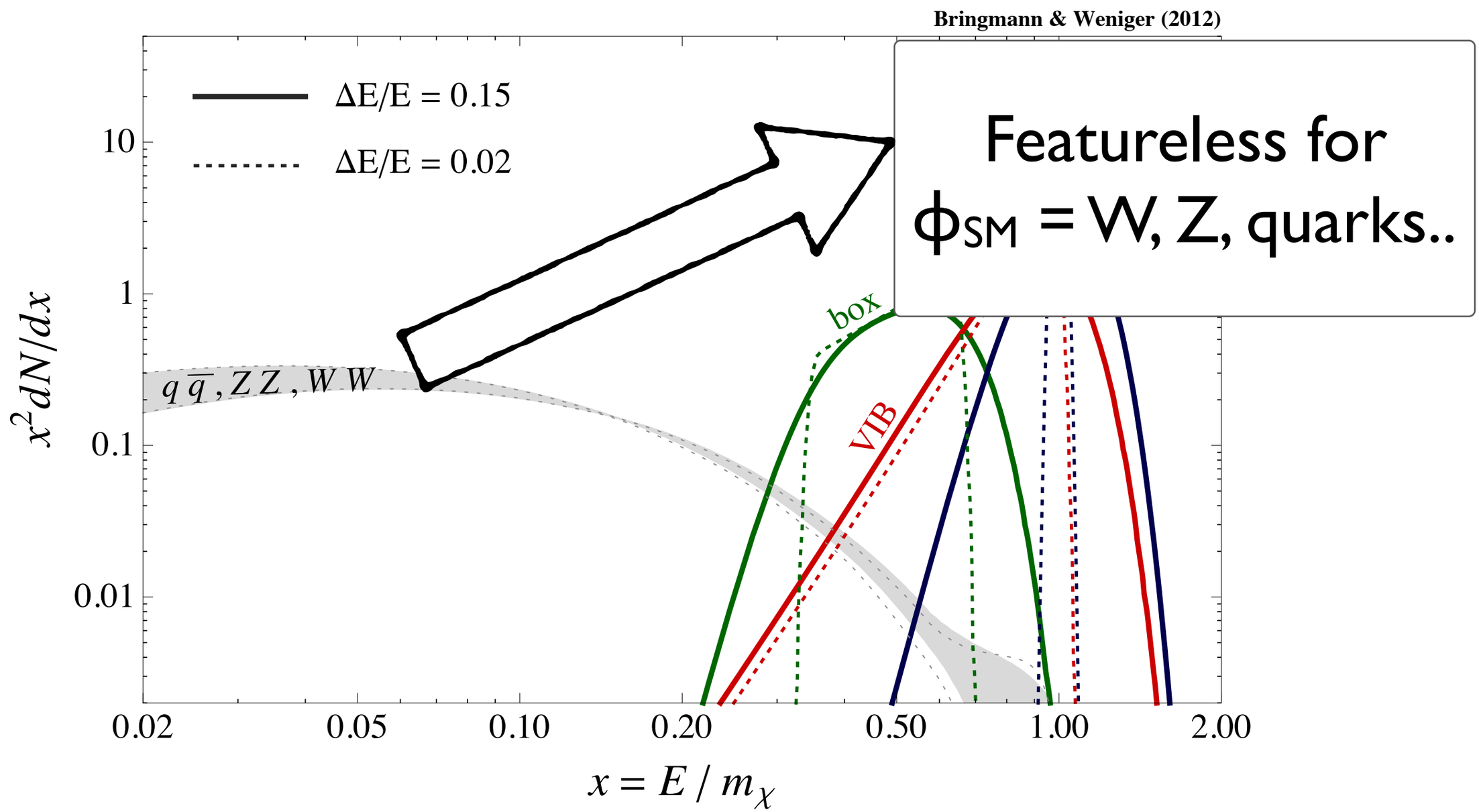

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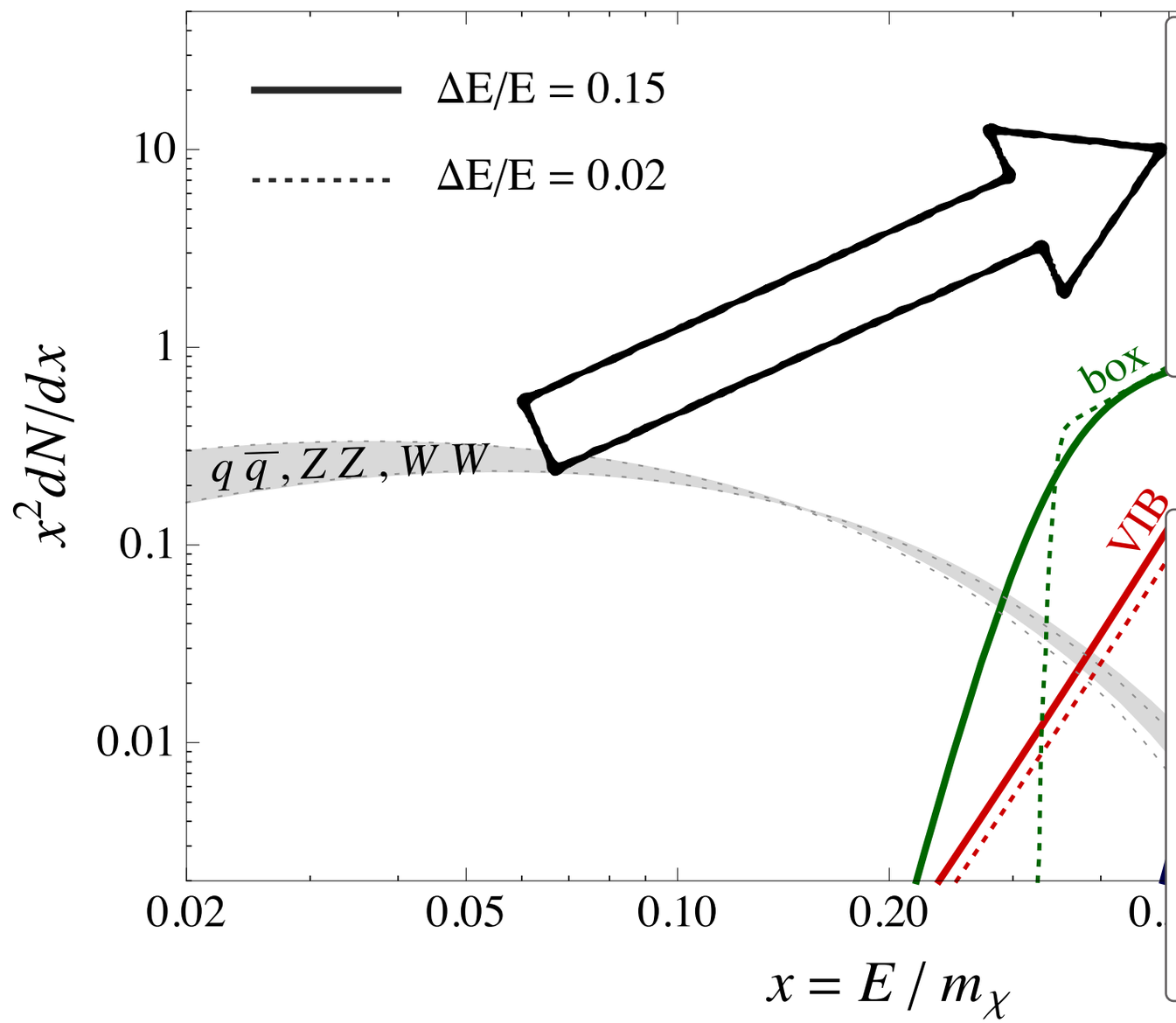
Bringmann & Weniger (2012)



Featureless for ϕ_{SM} = W, Z, quarks..

Photons

Astrophysical background ☹

Bringmann, Weniger, Phys.Dark Univ. 1 (2012), (arXiv:1208.5481)

Why Lines?

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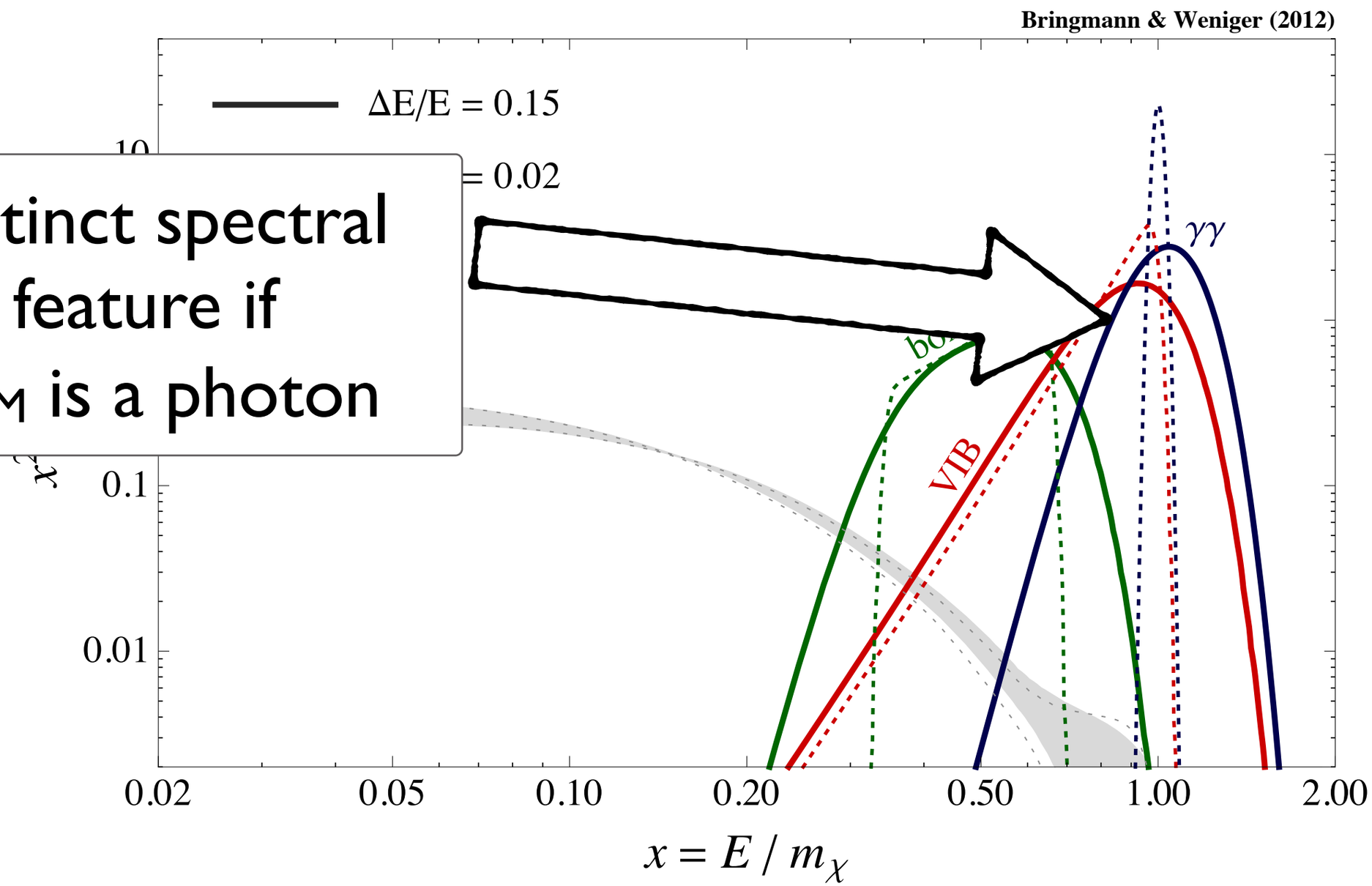

Distinct spectral feature if ϕ_{SM} is a photon

Bringmann, Weniger, Phys.Dark Univ. 1 (2012), (arXiv:1208.5481)

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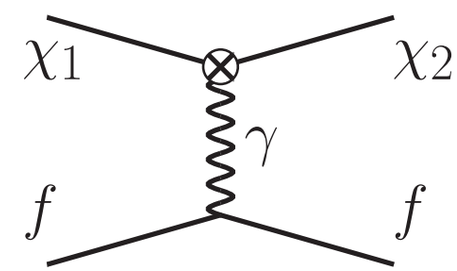
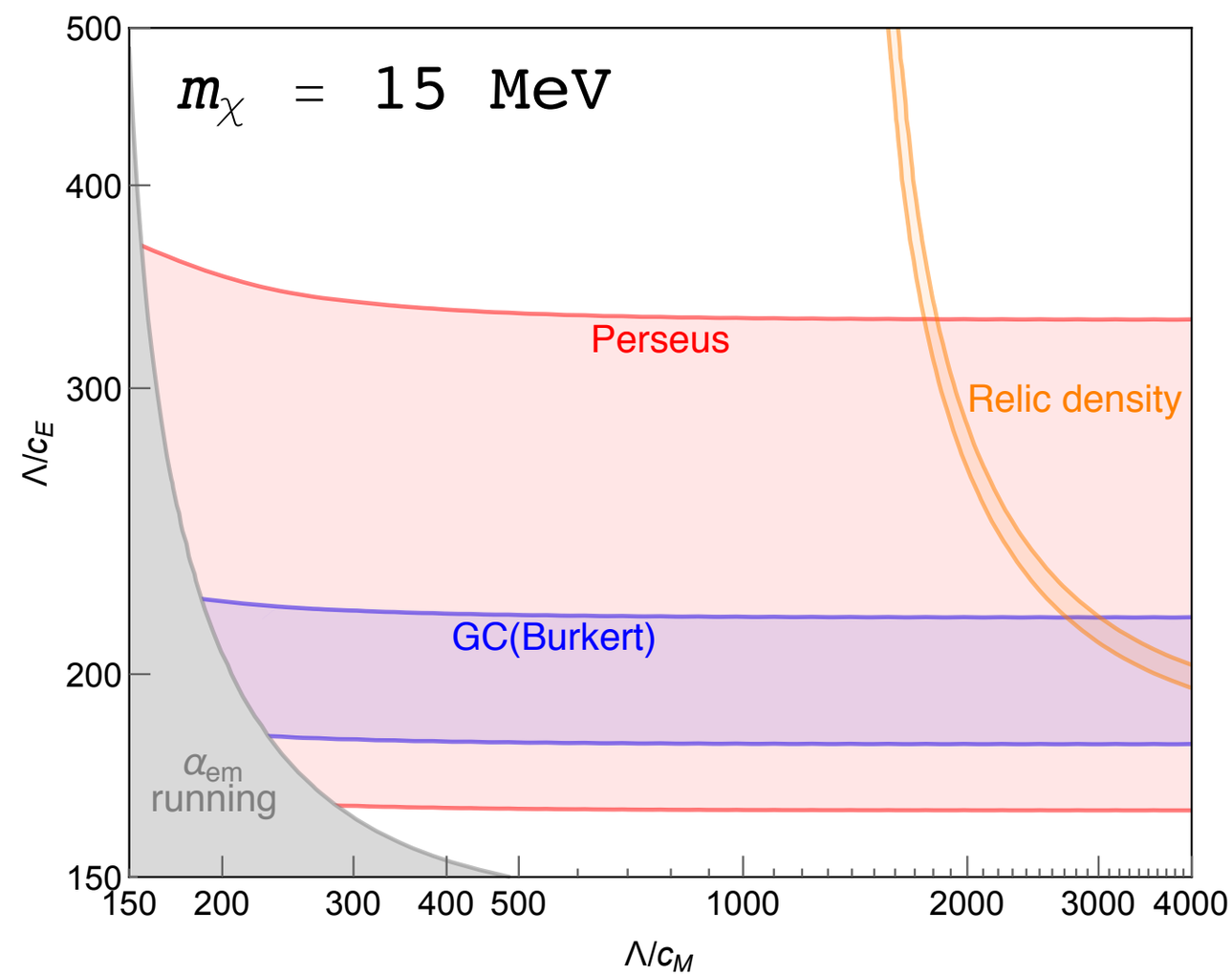


Interpretation consistent with a *thermal relic* and *particle physics constraints*



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