Finding Exotic Particles with Fireballs
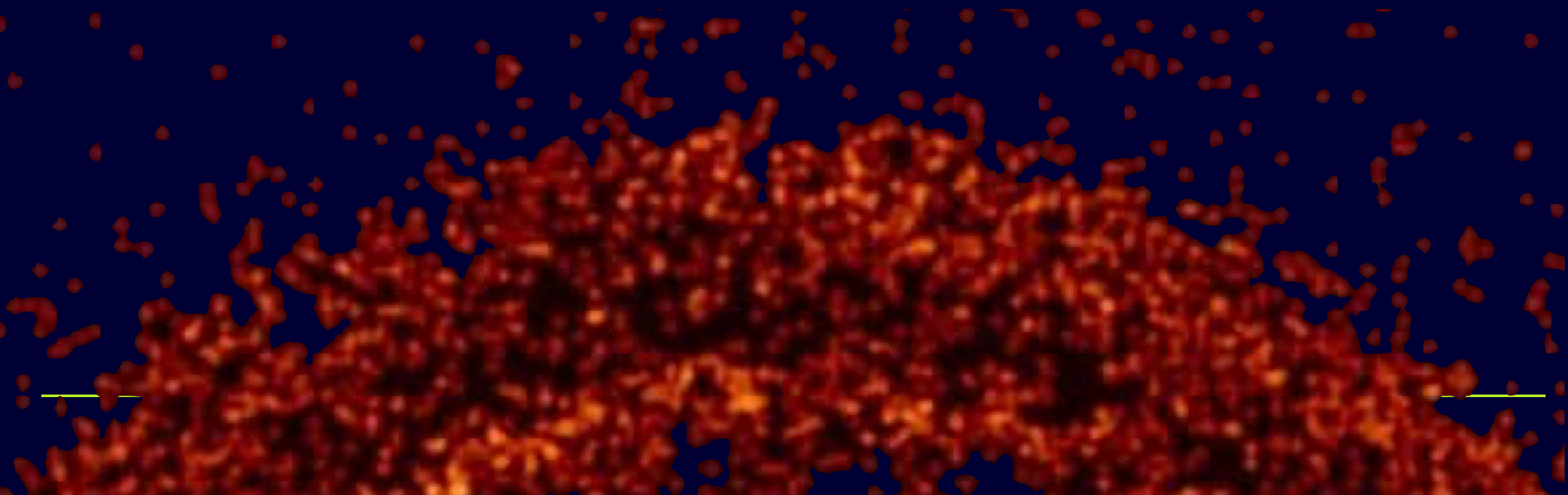
Melissa Diamond
Queen's University
UF The Early Universe: A Window to New Physics
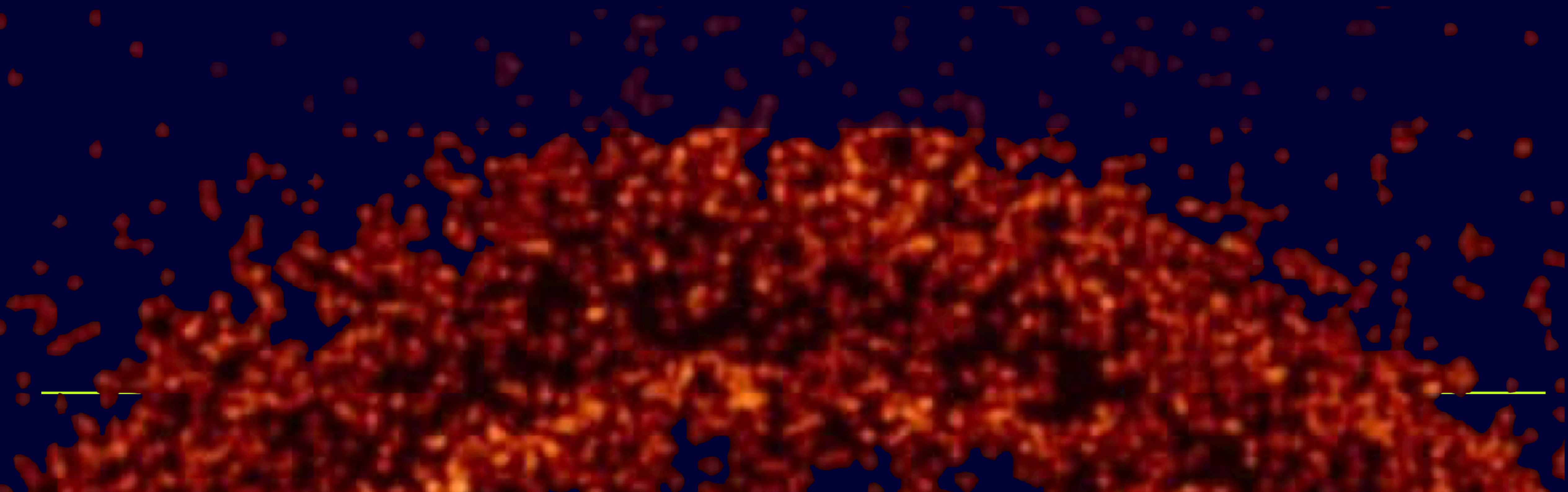
Based on **2106.03879 , 2303.11395, 2305.10327**
with Damiano Fiorillo, Gustavo Marques Tavares, Irene Tambora, and Edoardo Vitagliano

10.22.2023

Introduction

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Hot compact source produces BSM particles

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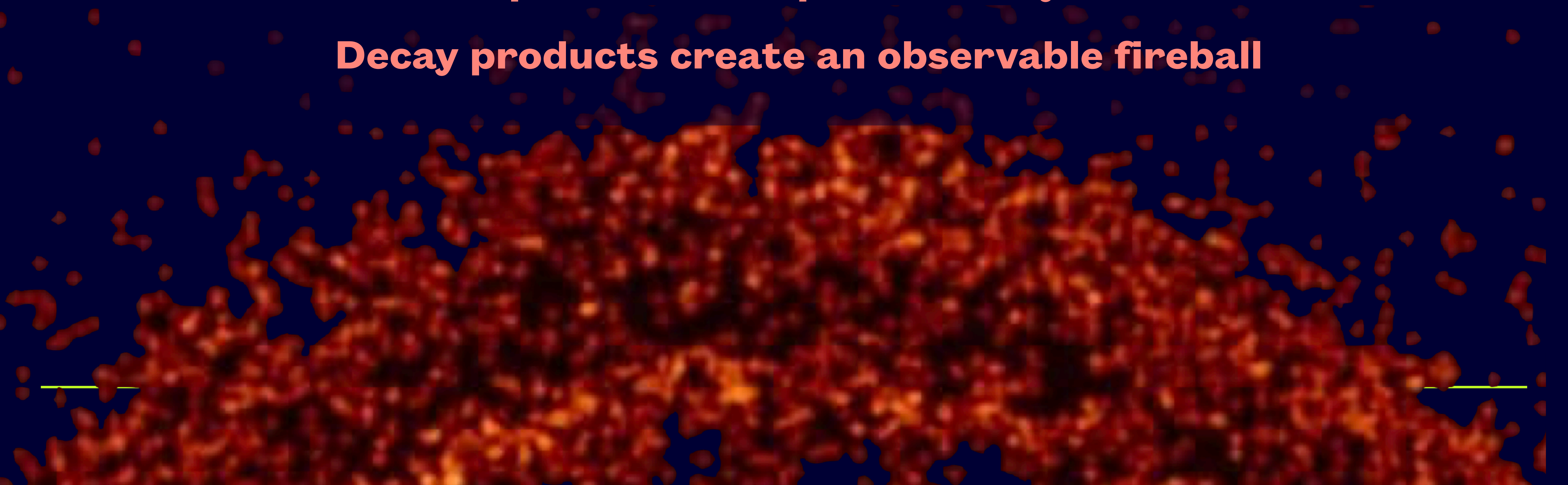BSM particles escape and decay to SM
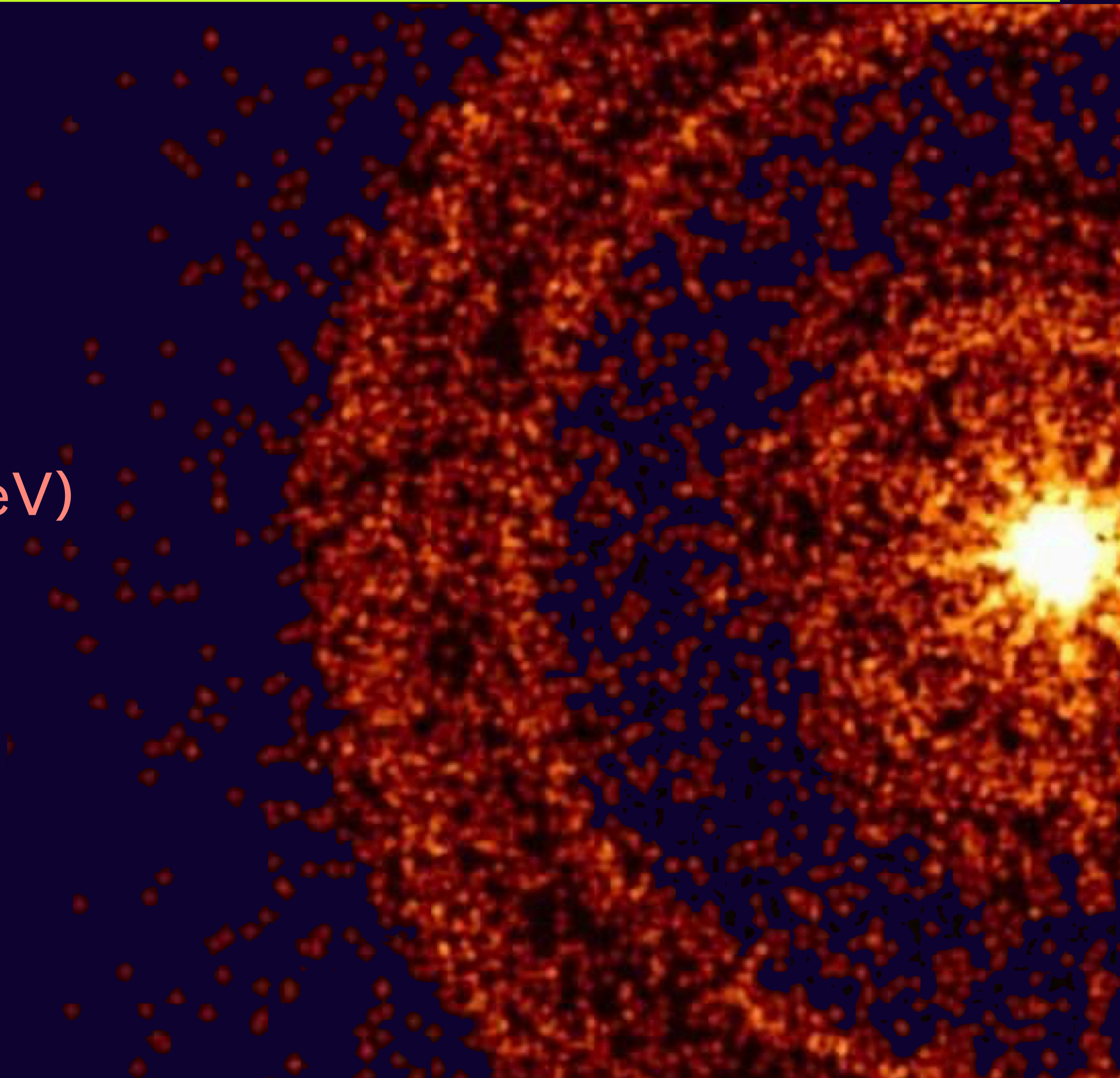
Introduction

Hot compact source produces BSM particles

BSM particles escape and decay to SM

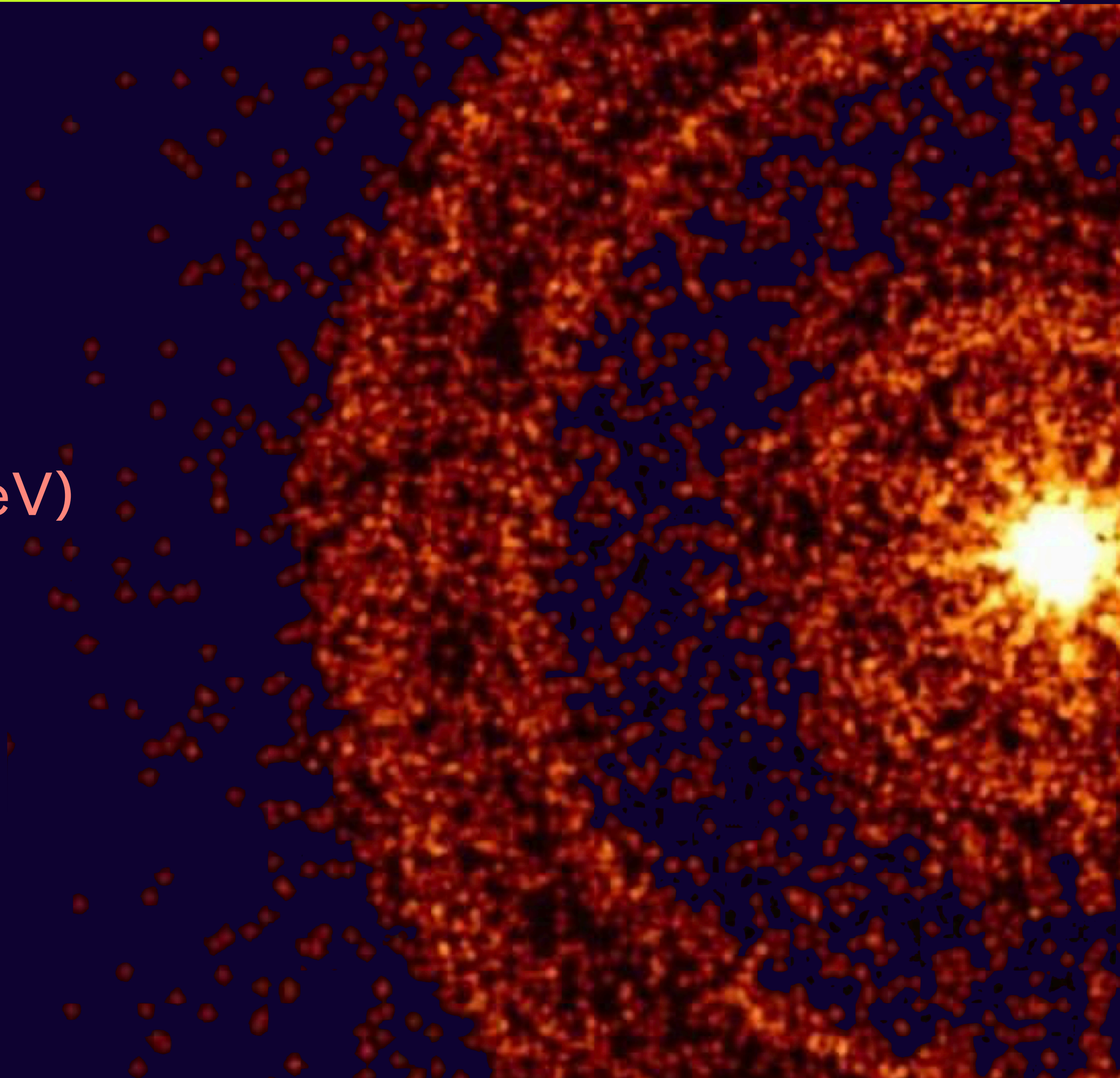Decay products create an observable fireball

Contents

- Compact Sources

- The BSM Models with m=(MeV-GeV)

- Making a fireball

- Revising existing constraints

- Adding new constraints

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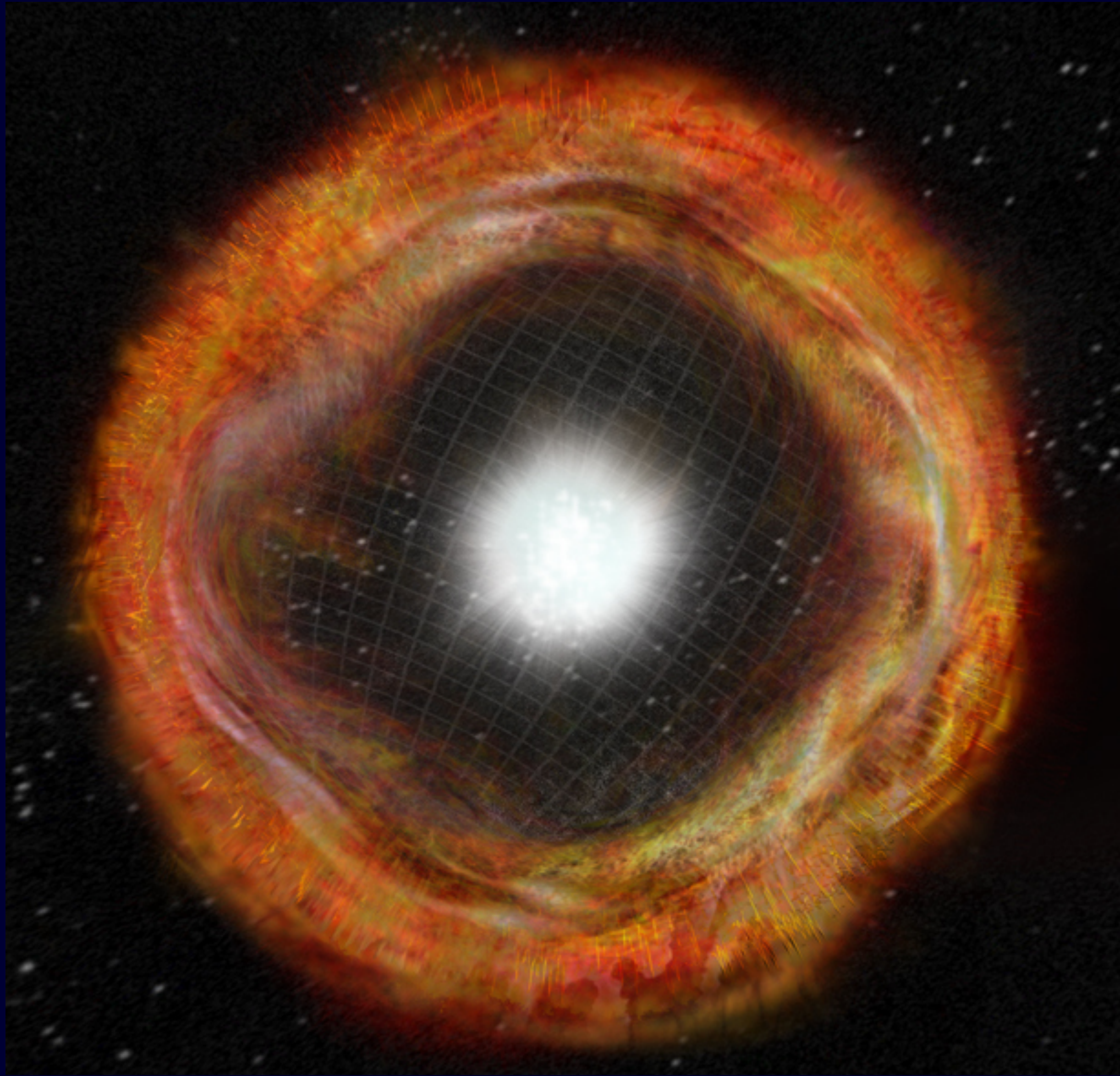
- Revising existing constraints

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The Sources

Binary Neutron Star Mergers

- 10 km region with $\rho \sim 10^{14}$ g/cm^3

- T~ 30-80MeV

- Remnant survives 1 -1000 ms

- Debris contained within ~1000 km

Core Collapse Supernovas

- 10 km region with $\rho \sim 10^{14}$ g/cm^3

- T~ 30 MeV

- Hot emission for 1-10 s

- Debris spread over ~ 10^7 km

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BSM Models

Dark Photons

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

- Massive Vector

- Kinematically mixes with the photon

- Connects dark sector to standard model

- Can decay to $e^+ + e^-$

Dark Photons

Produced Through:
Nucleon-Nucleon Bremsstrahlung

$$n + p \rightarrow n + p + A$$
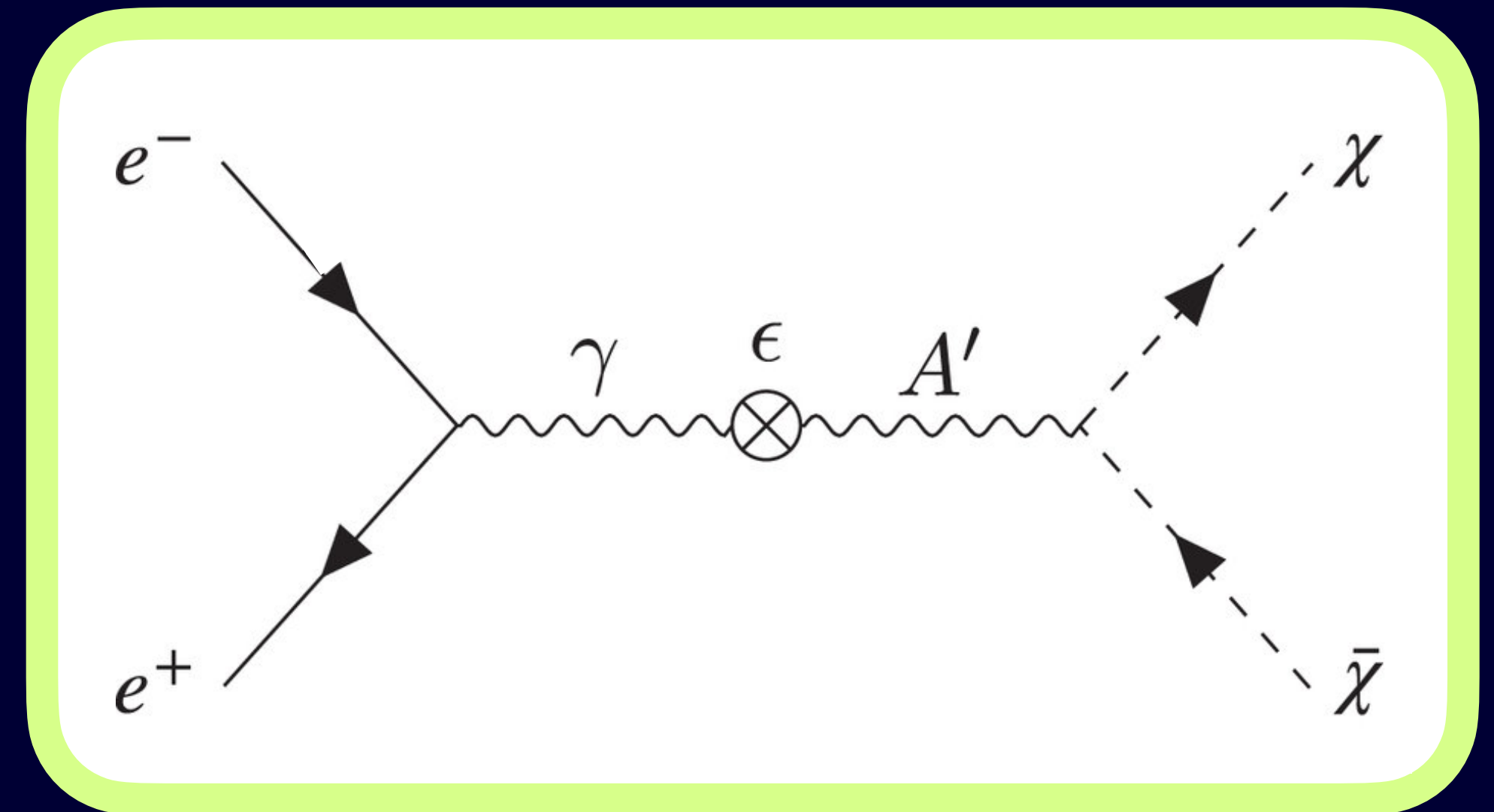
dN/dVdt $\propto \epsilon^2 n_p n_n$

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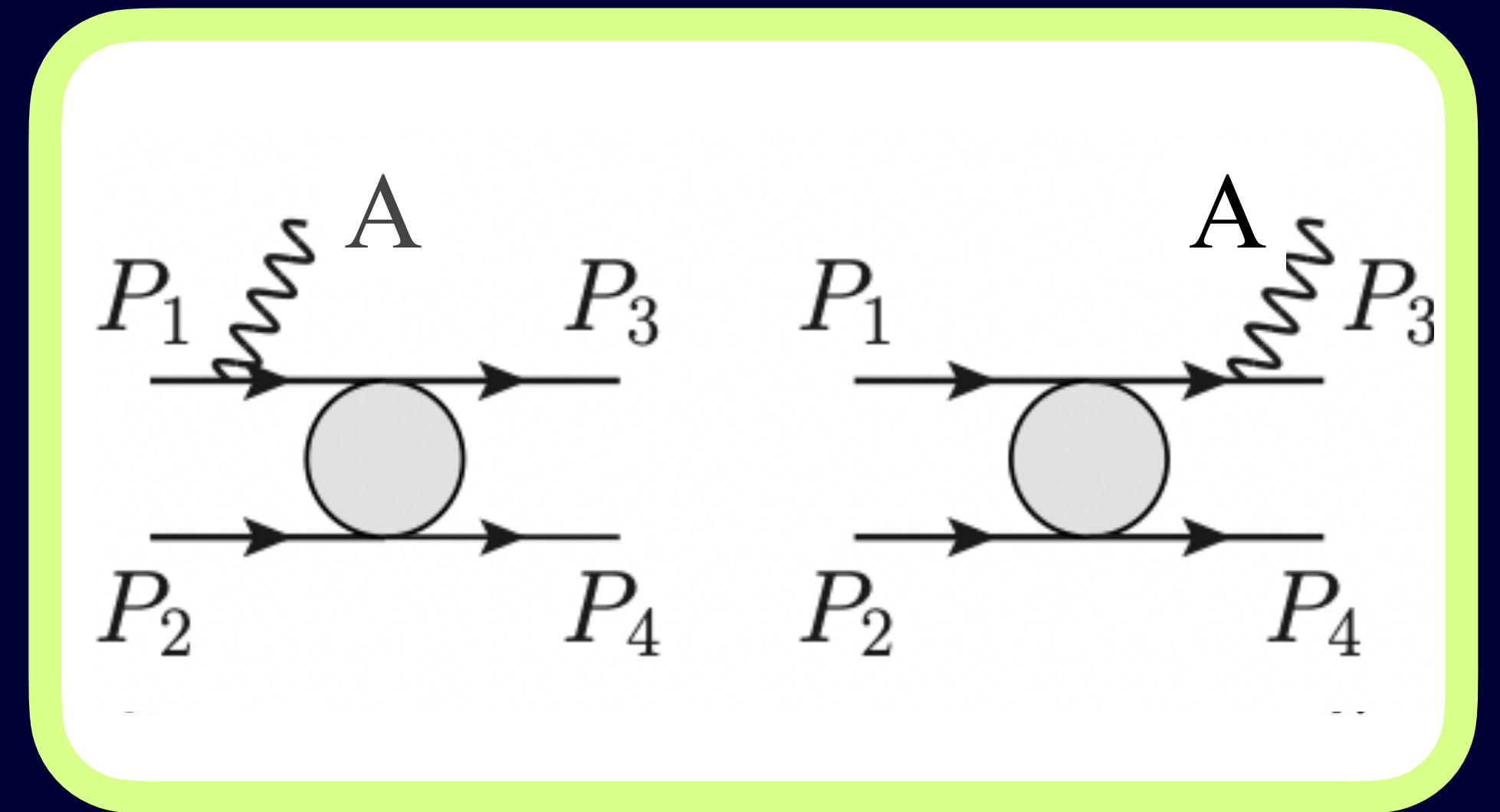
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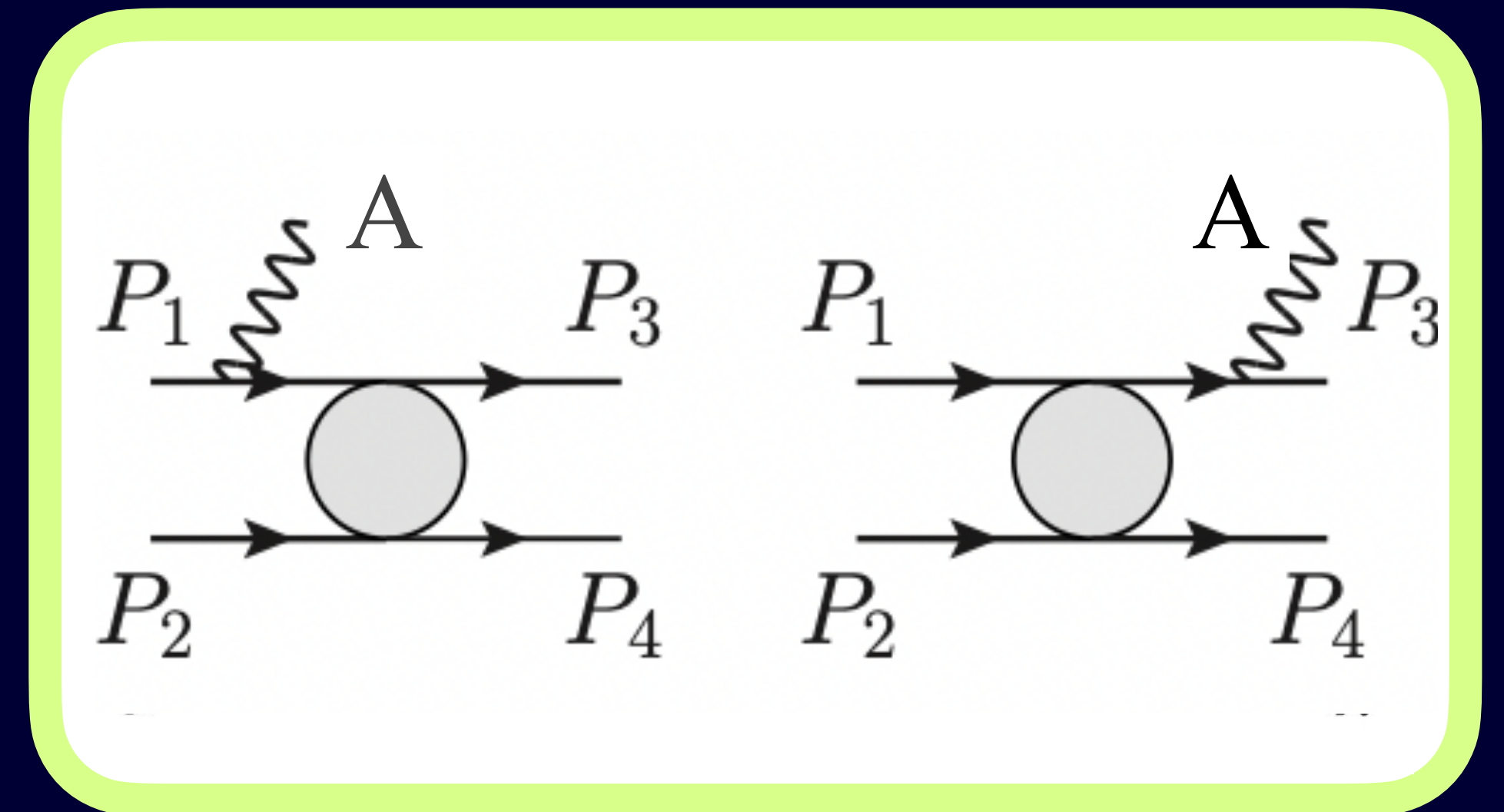
Axions

$$\mathcal{L} \supset -\frac{1}{4}FF' - \frac{1}{2}m_a^2 a^2 + G_{a\gamma\gamma}aE \cdot B$$

- Massive psuedo-scalar

- Couples to $E \cdot B$

- Can decay to two photons

Axions

Produced through:

1. Photon coalescence

$$\gamma + \gamma \rightarrow a$$
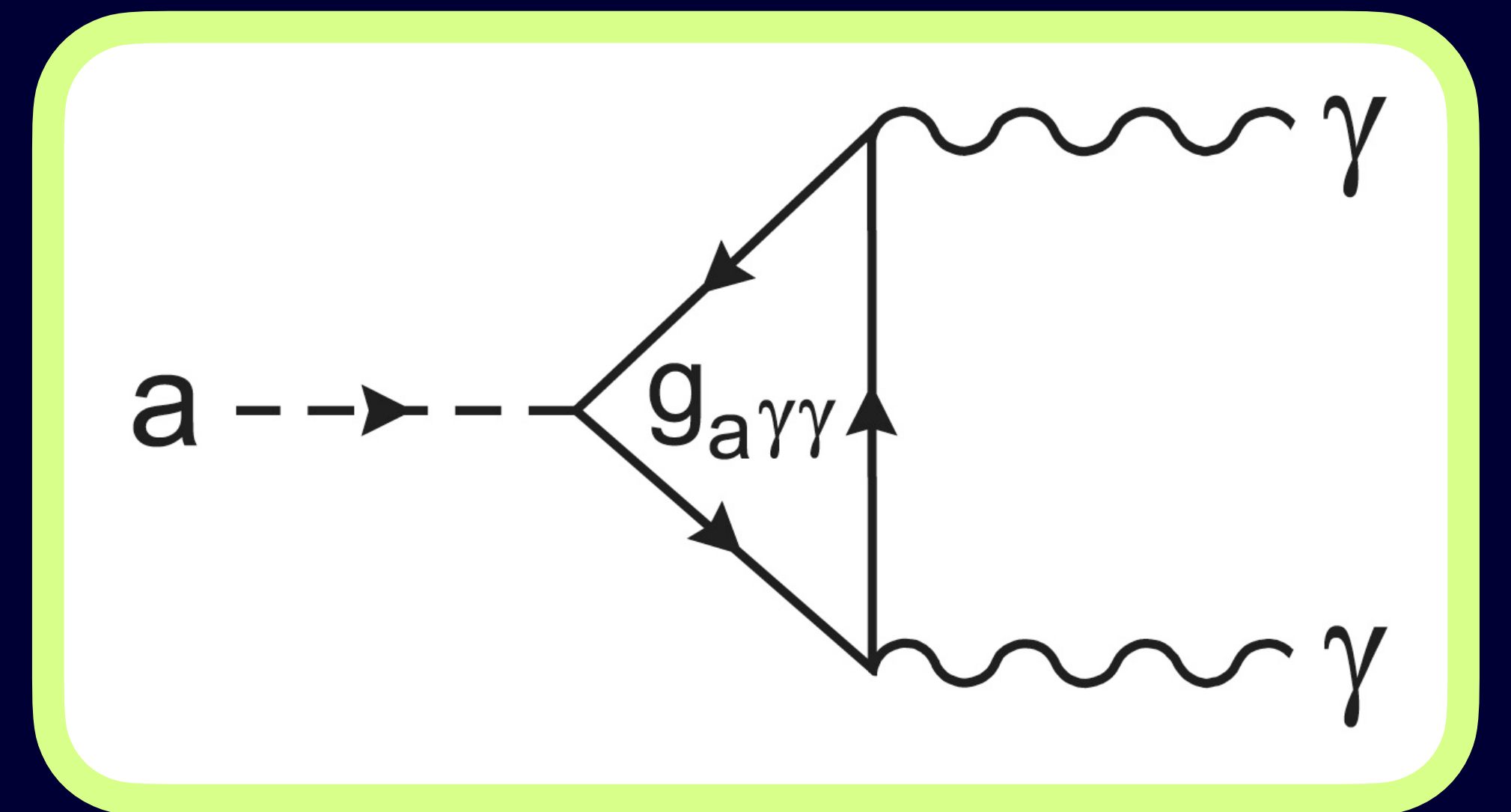
2. Primakoff Process

$$\gamma + Ze \rightarrow Ze + a$$

dN/dVdt $\propto G_{a\gamma\gamma}^2$

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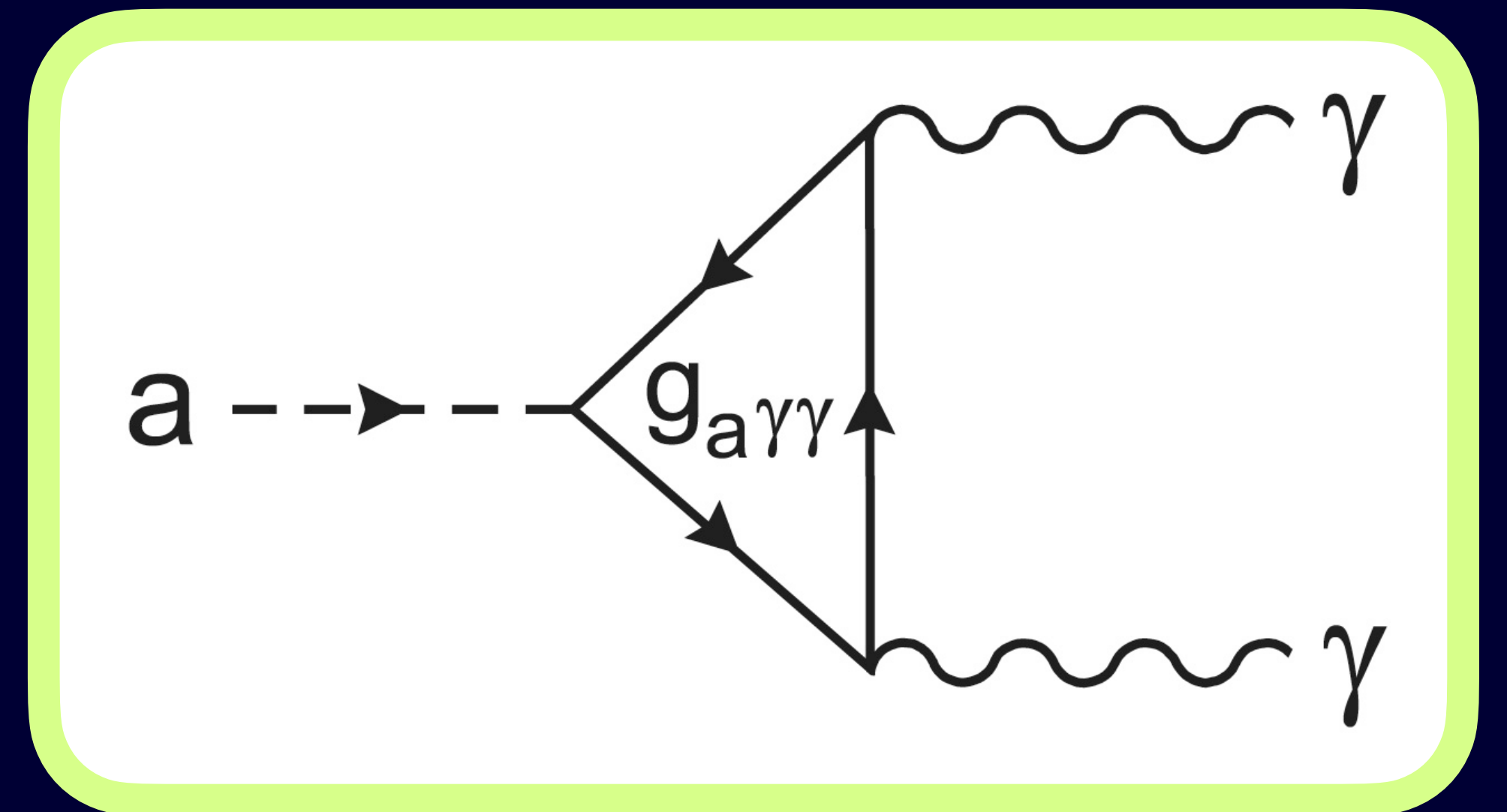
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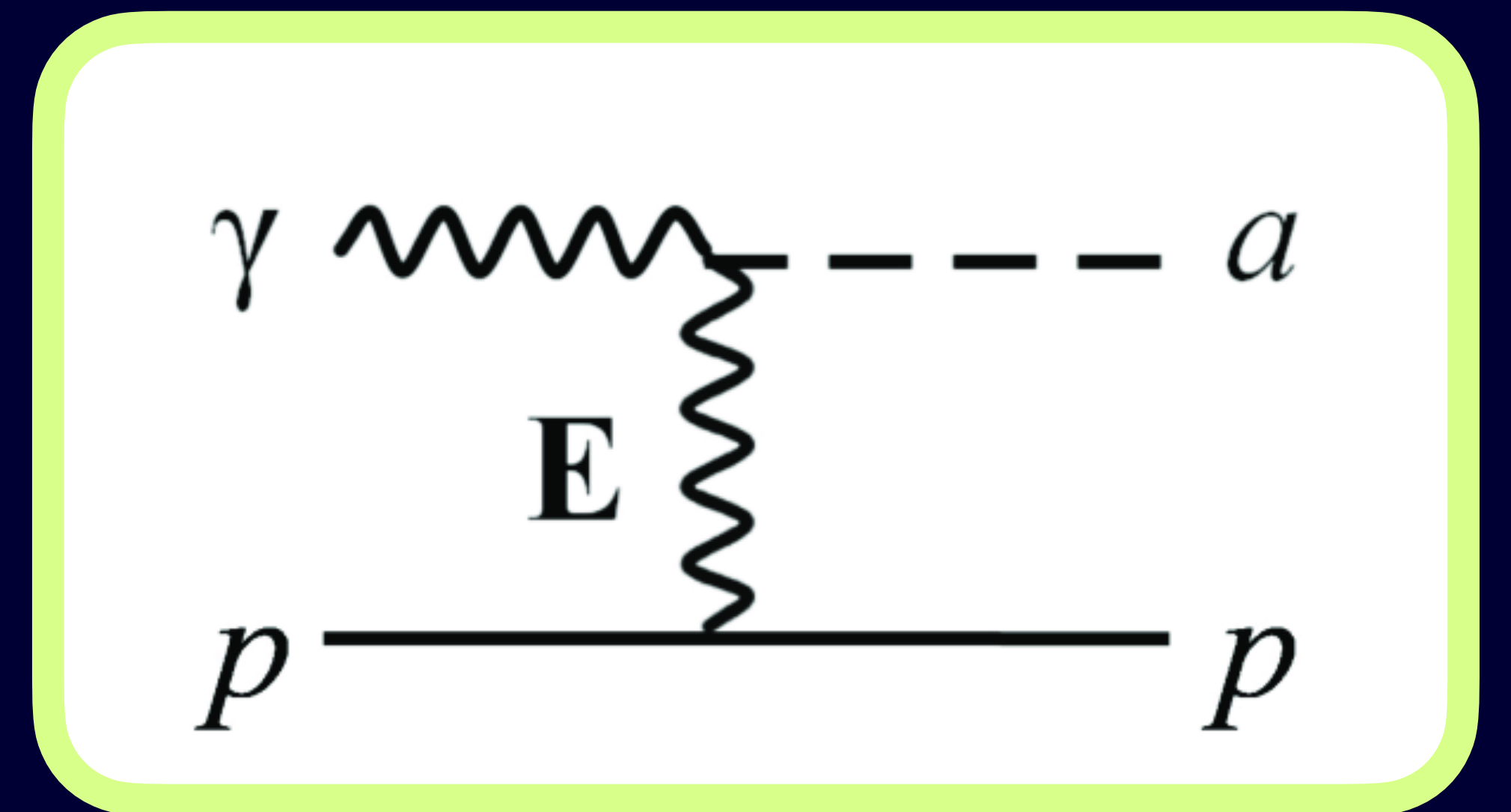
The Fireball

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Exotic particles radiated by source

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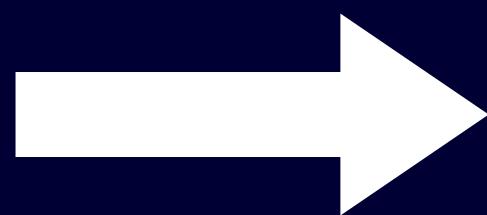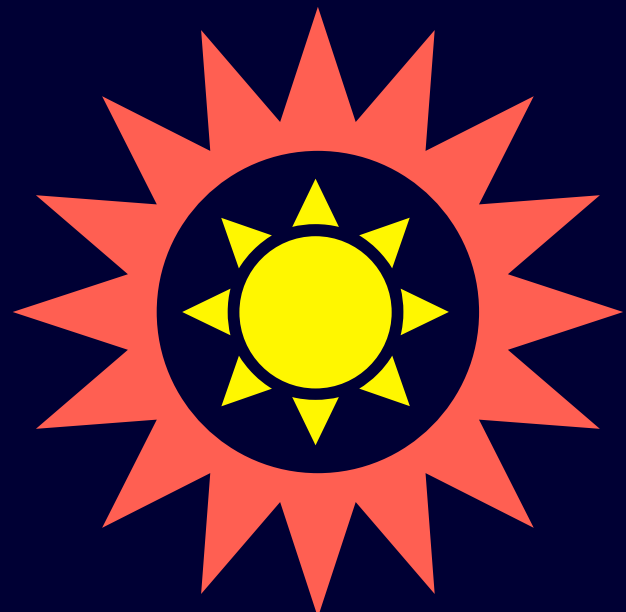
Decay to standard model

The Fireball

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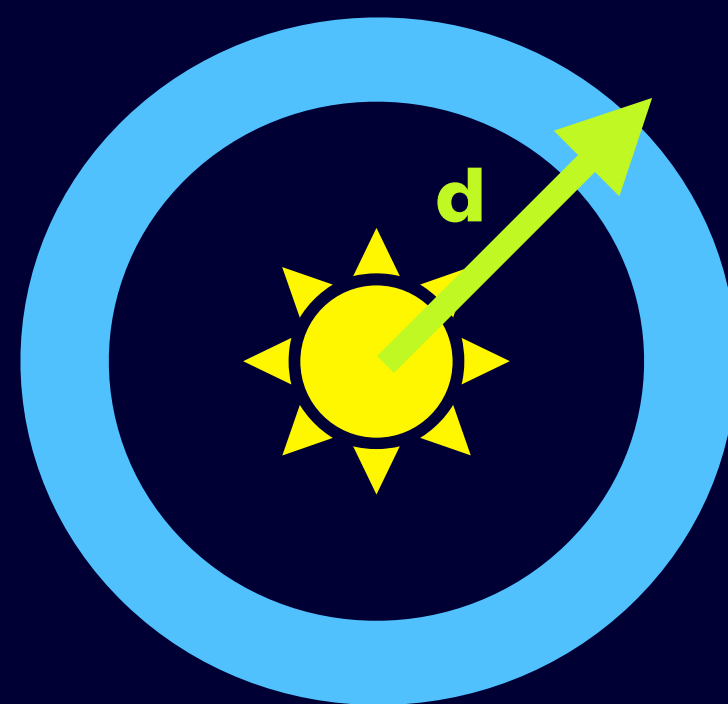
Expanding plasma shell

d
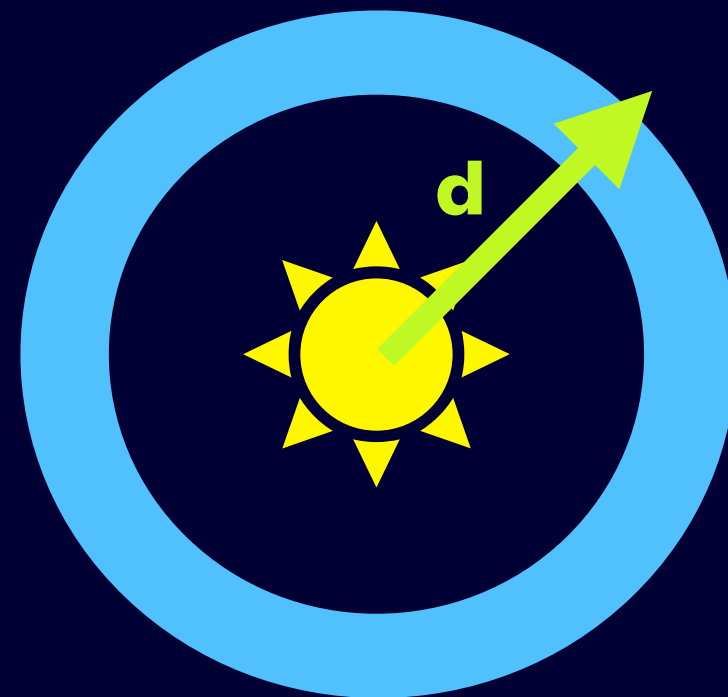
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Dark Photons

$$d \propto \epsilon^{-2} m^{-1}$$

Axions
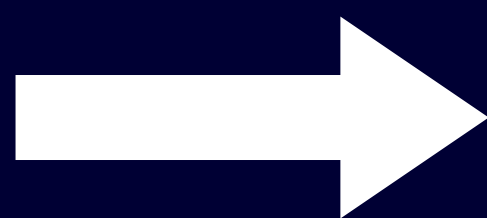
$$d \propto G_{a\gamma\gamma}^{-2} m^{-4}$$

The Fireball

Exotic particles radiated by source
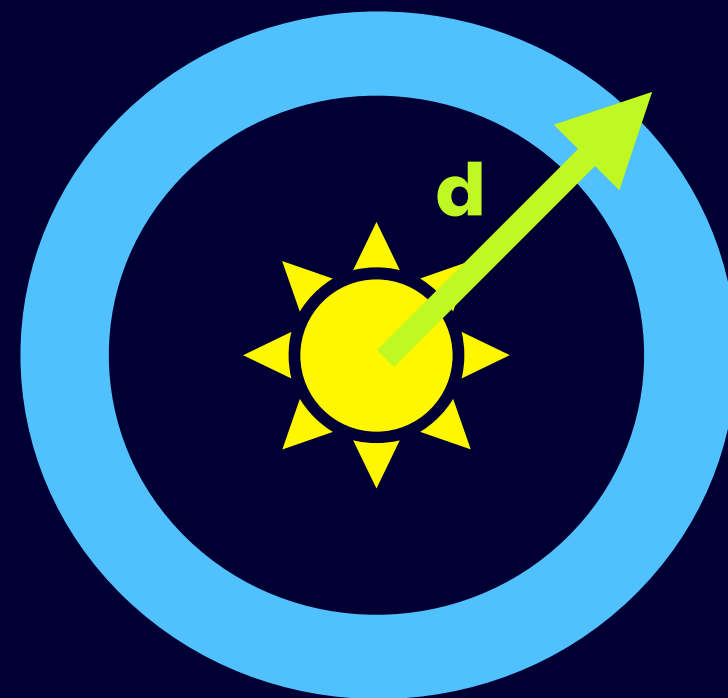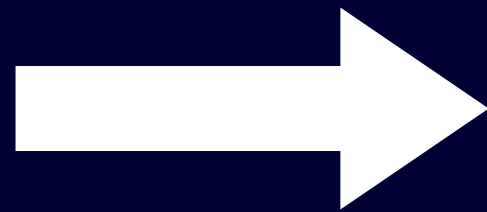
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Pair production and scattering are slow

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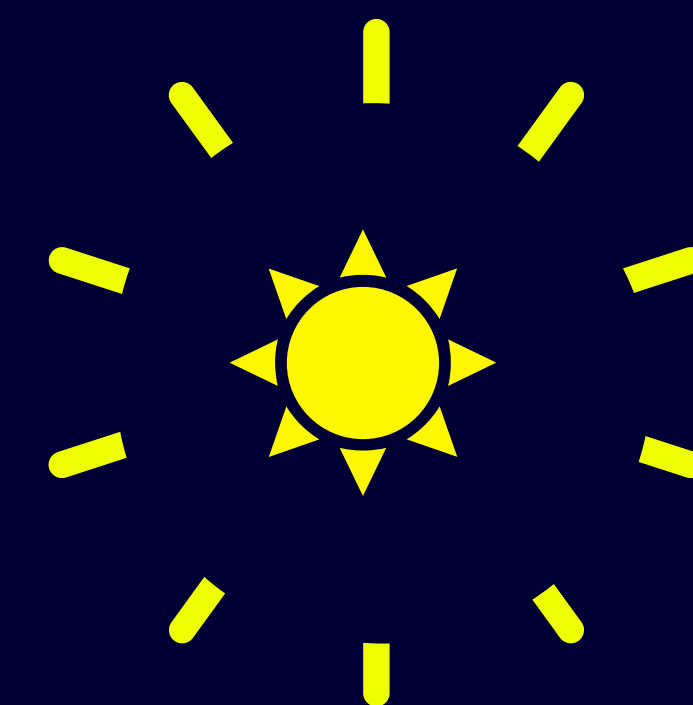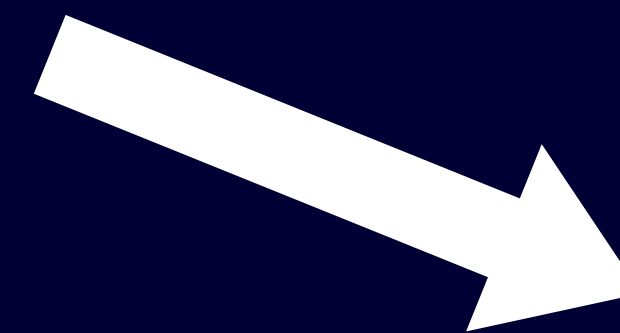
Decay products free stream.
No fireball

The Fireball

Exotic particles radiated by source

Expanding plasma shell

Pair production and scattering are fast
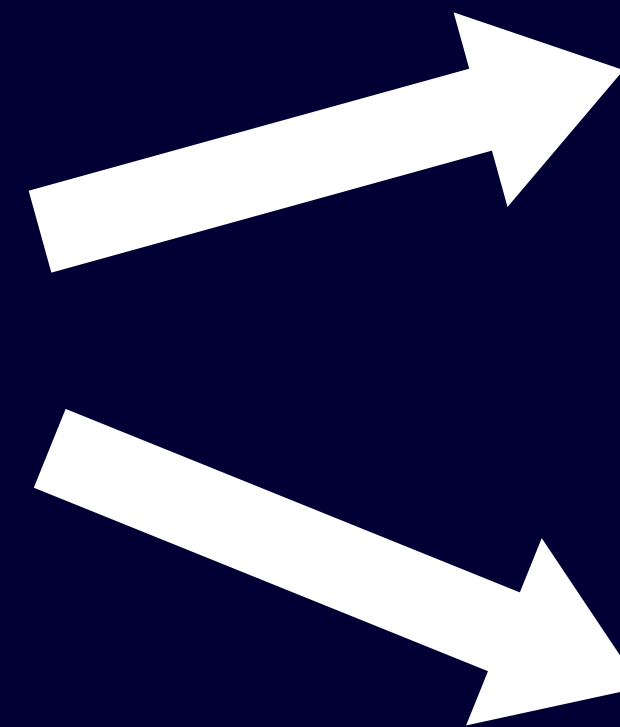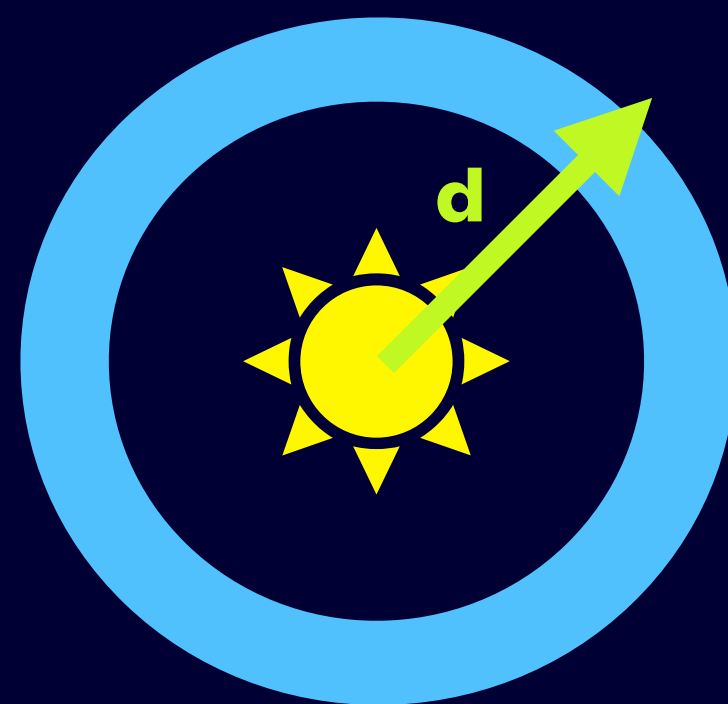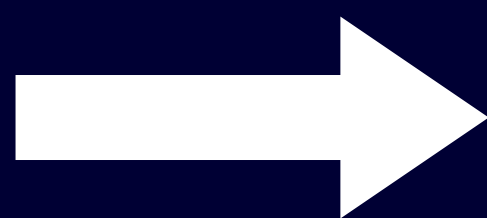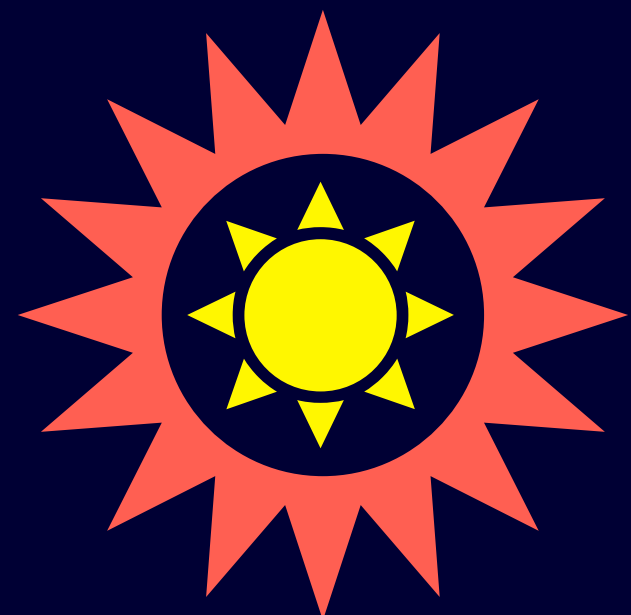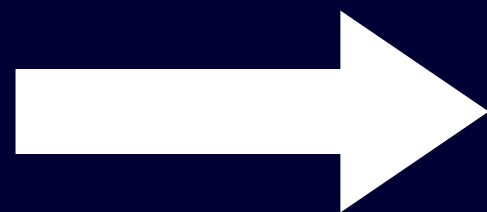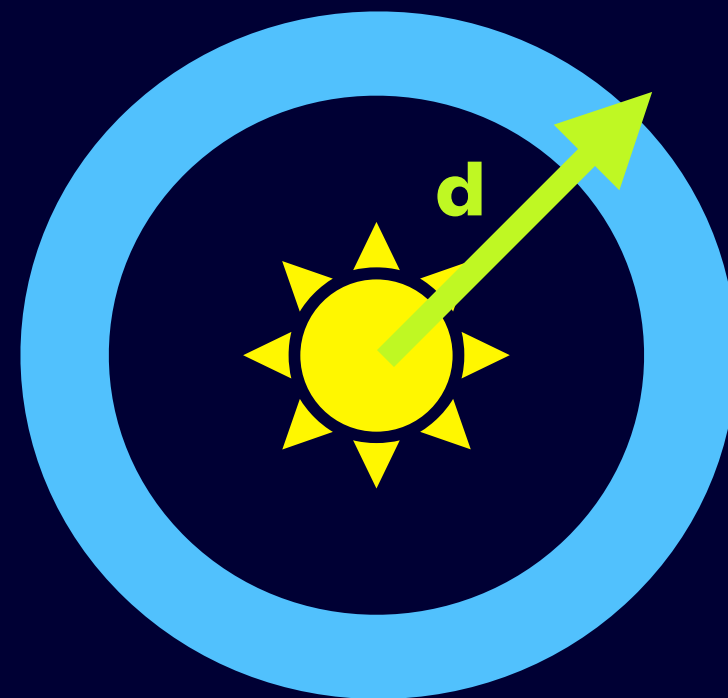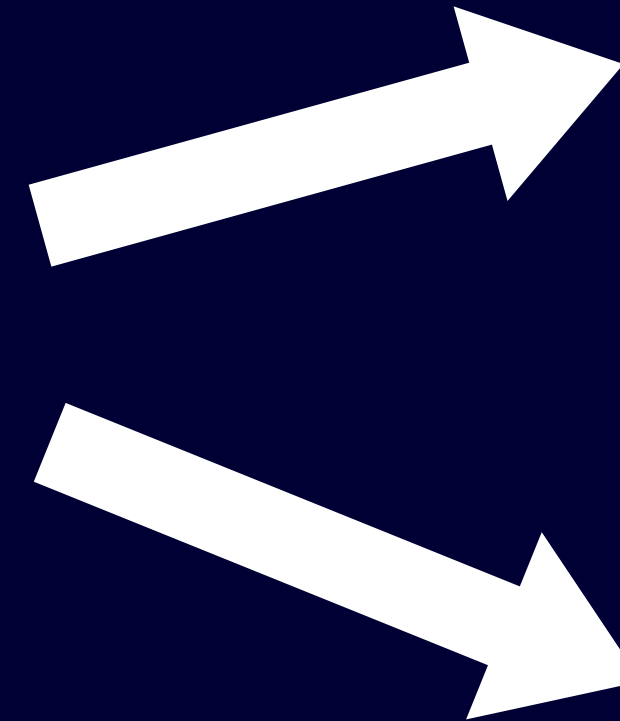

Decay to standard model

d

Dark Photons

$$d \propto \epsilon^{-2} m^{-1}$$

Axions

$$d \propto G_{a\gamma\gamma}^{-2} m^{-4}$$

Pair production and scattering are slow

Decay products free stream.
No fireball

The Fireball

Exotic particles radiated by source

Decay to standard model

Expanding plasma shell

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Dark Photons
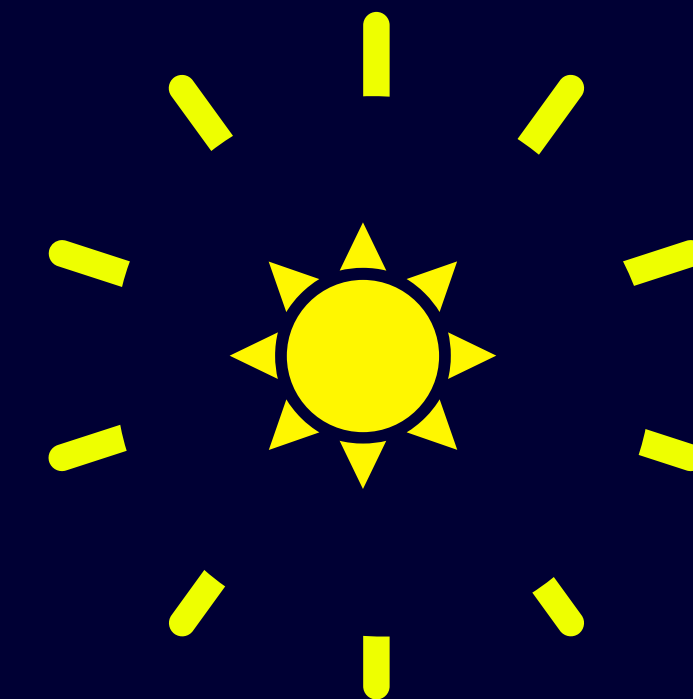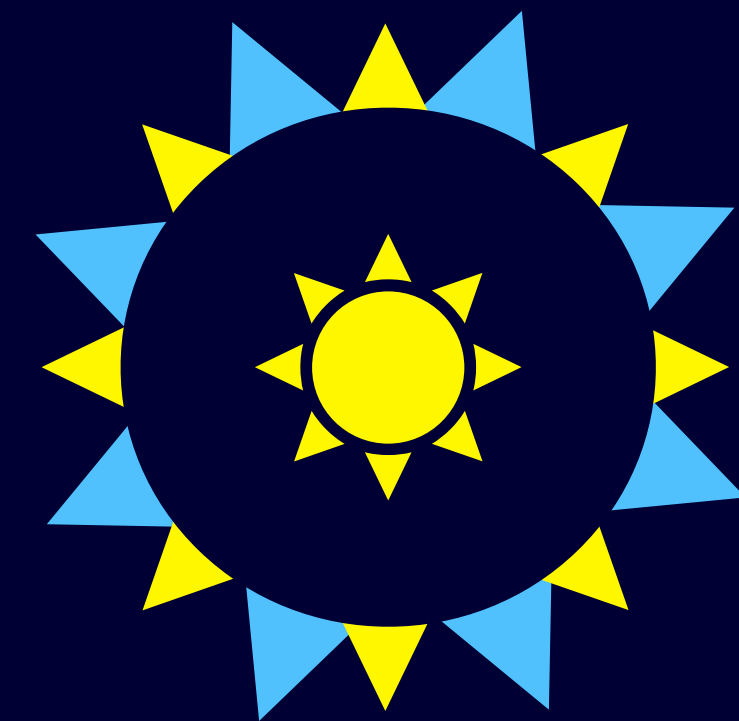
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Pair production and scattering are fast

Pair production and scattering are slow

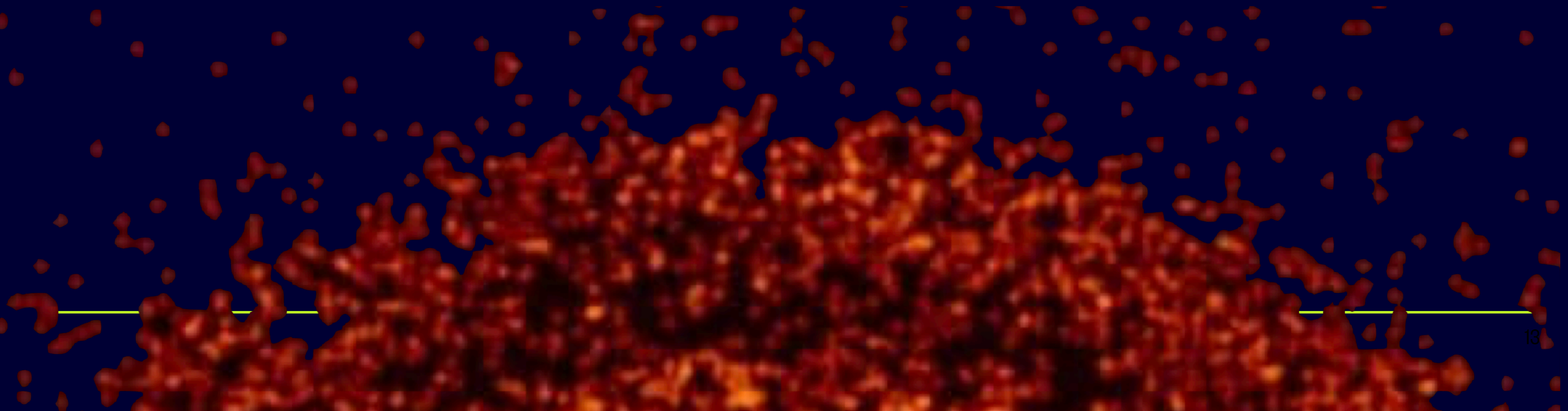**Reprocessed thermal Fireball**

**Decay products free stream.
No fireball**

The Fireball

An opaque thermalized expanding shell of photons and e^+ and e^-

Thermal energy drives accelerated relativistic expansion until the shell becomes cool enough to be transparent

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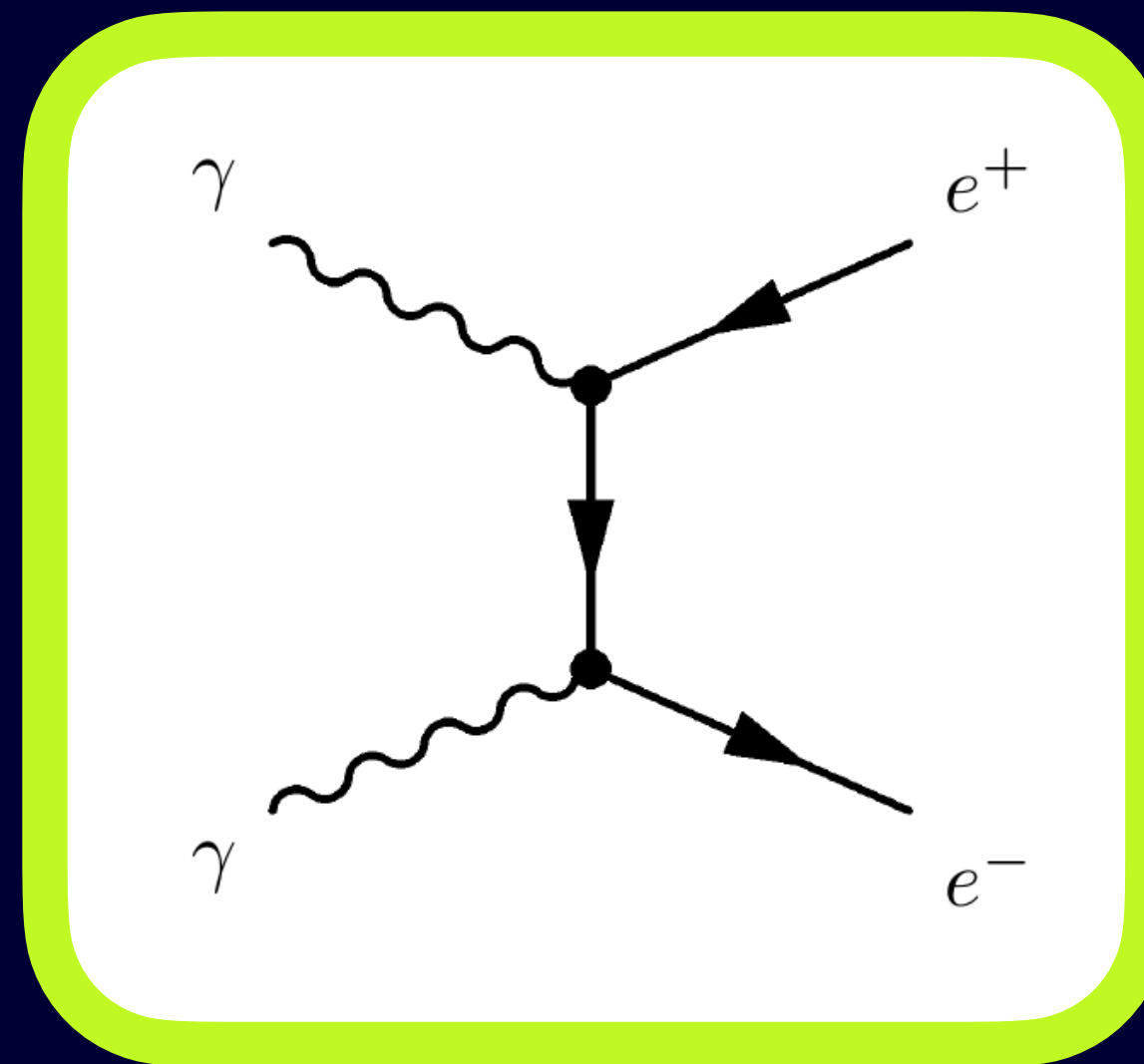
"Fast Scattering"

Expansion
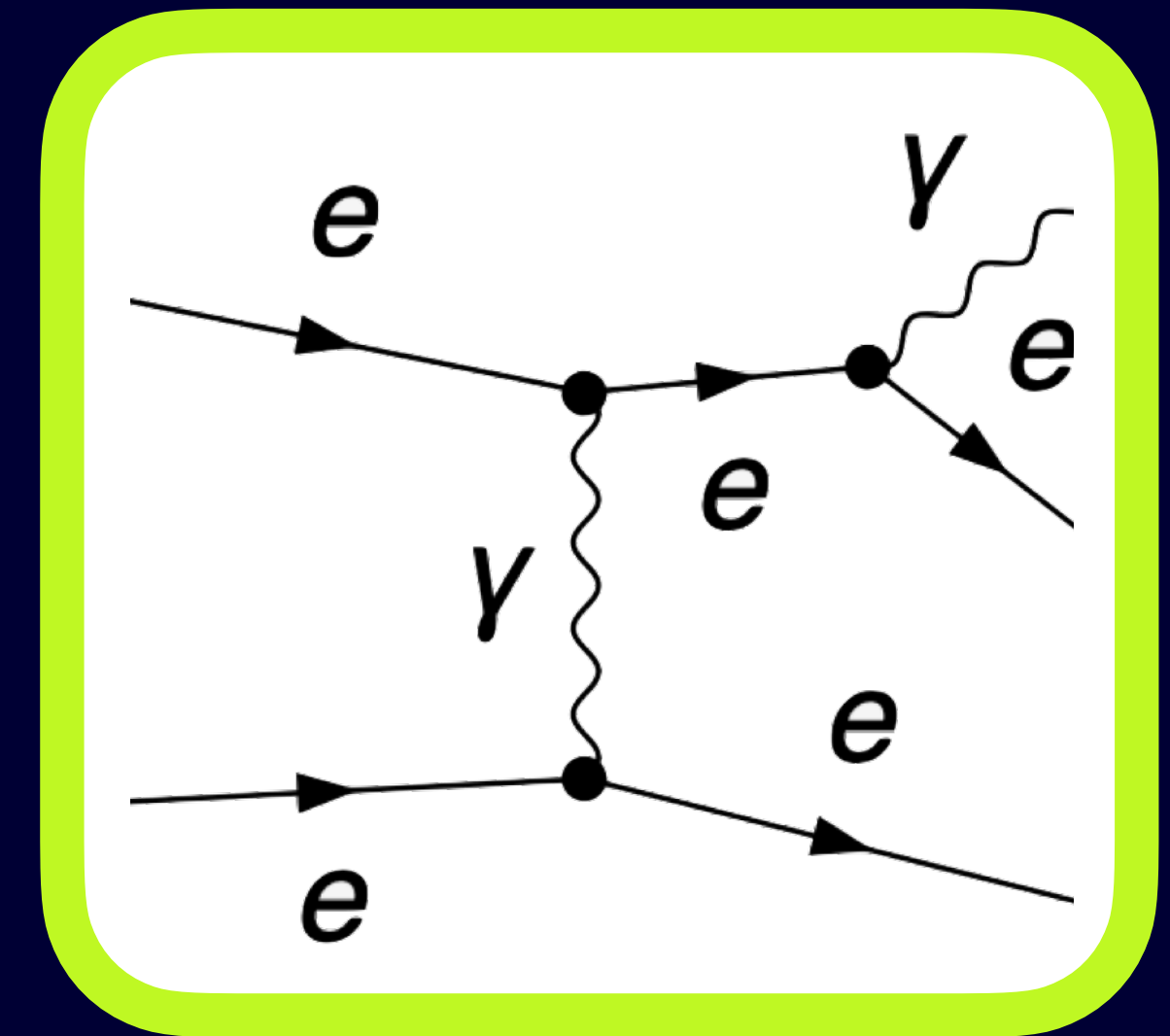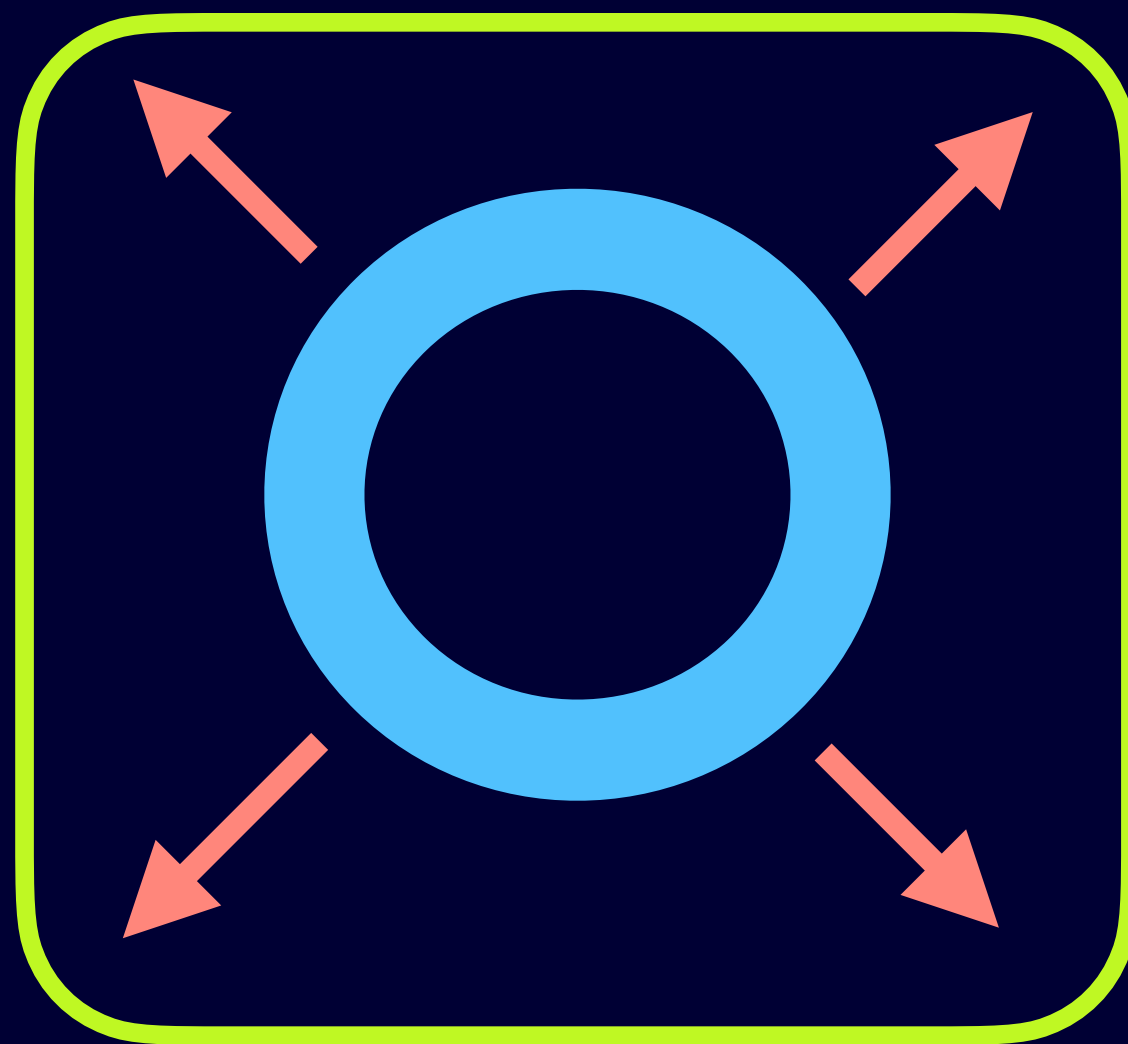
vs

Pair Production

Bremsstrahlung

Dark photons $\rightarrow e^+ + e^-$
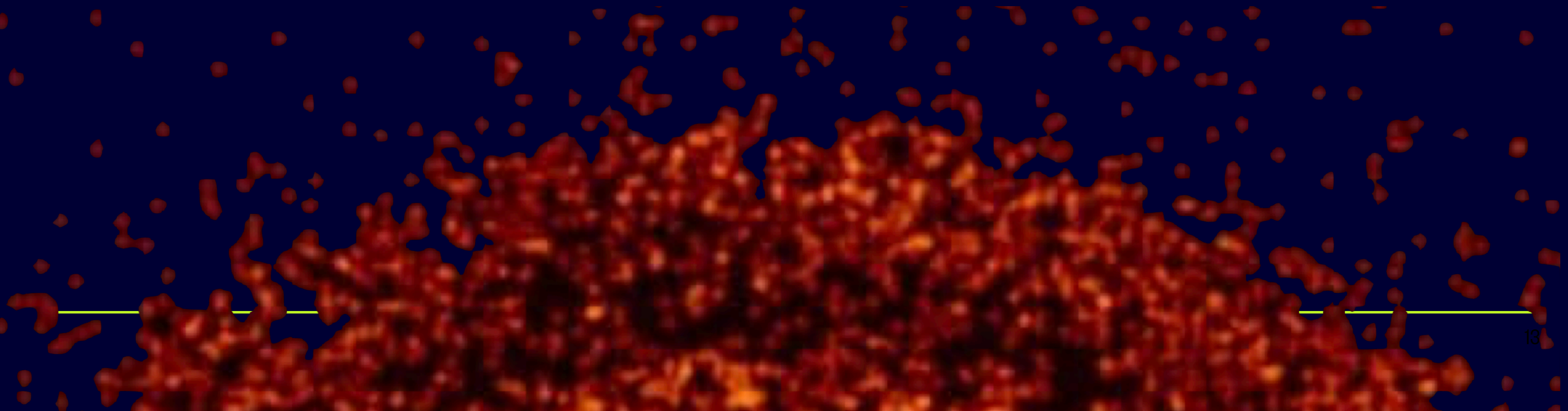
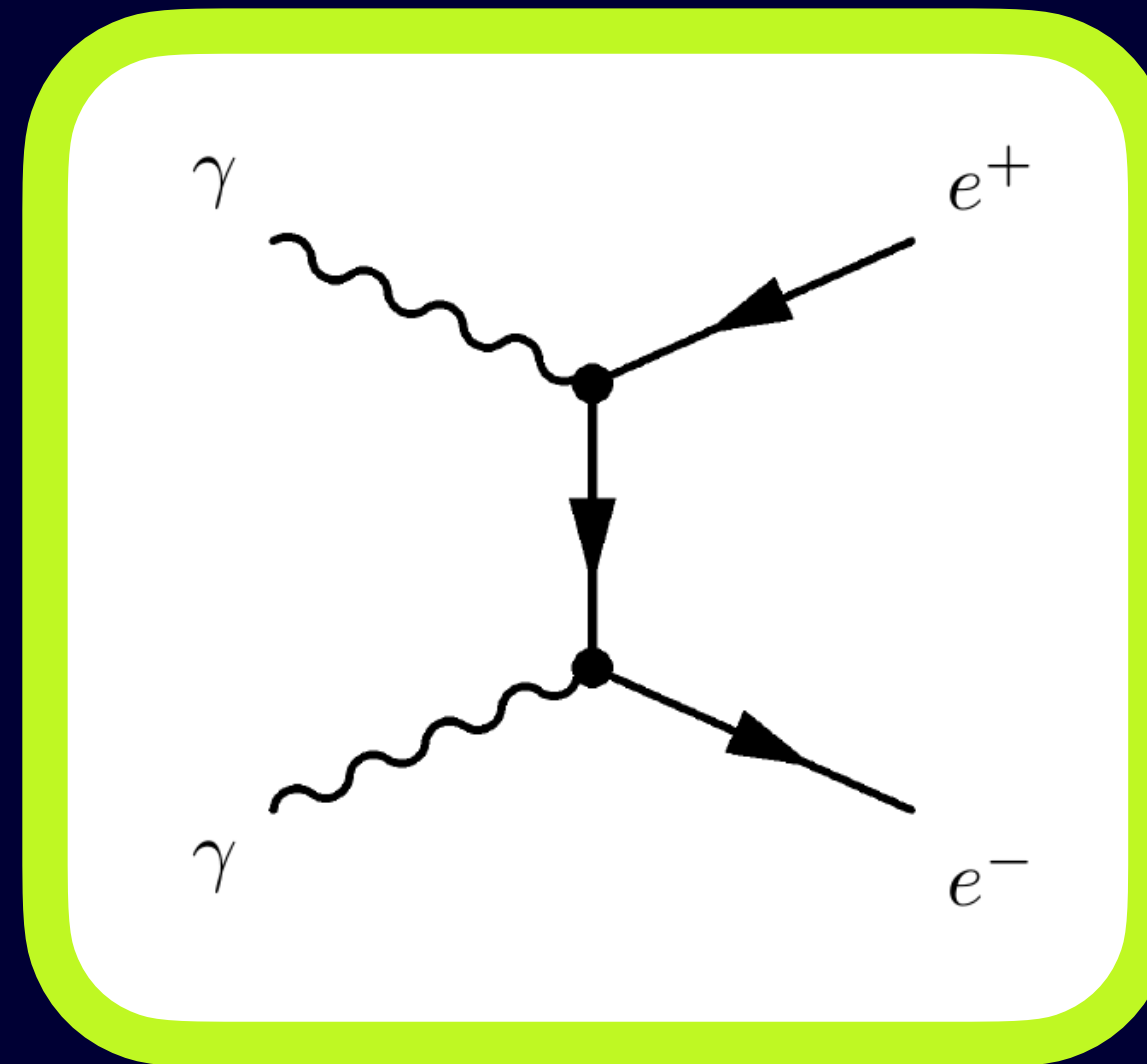Axions $\rightarrow \gamma + \gamma$
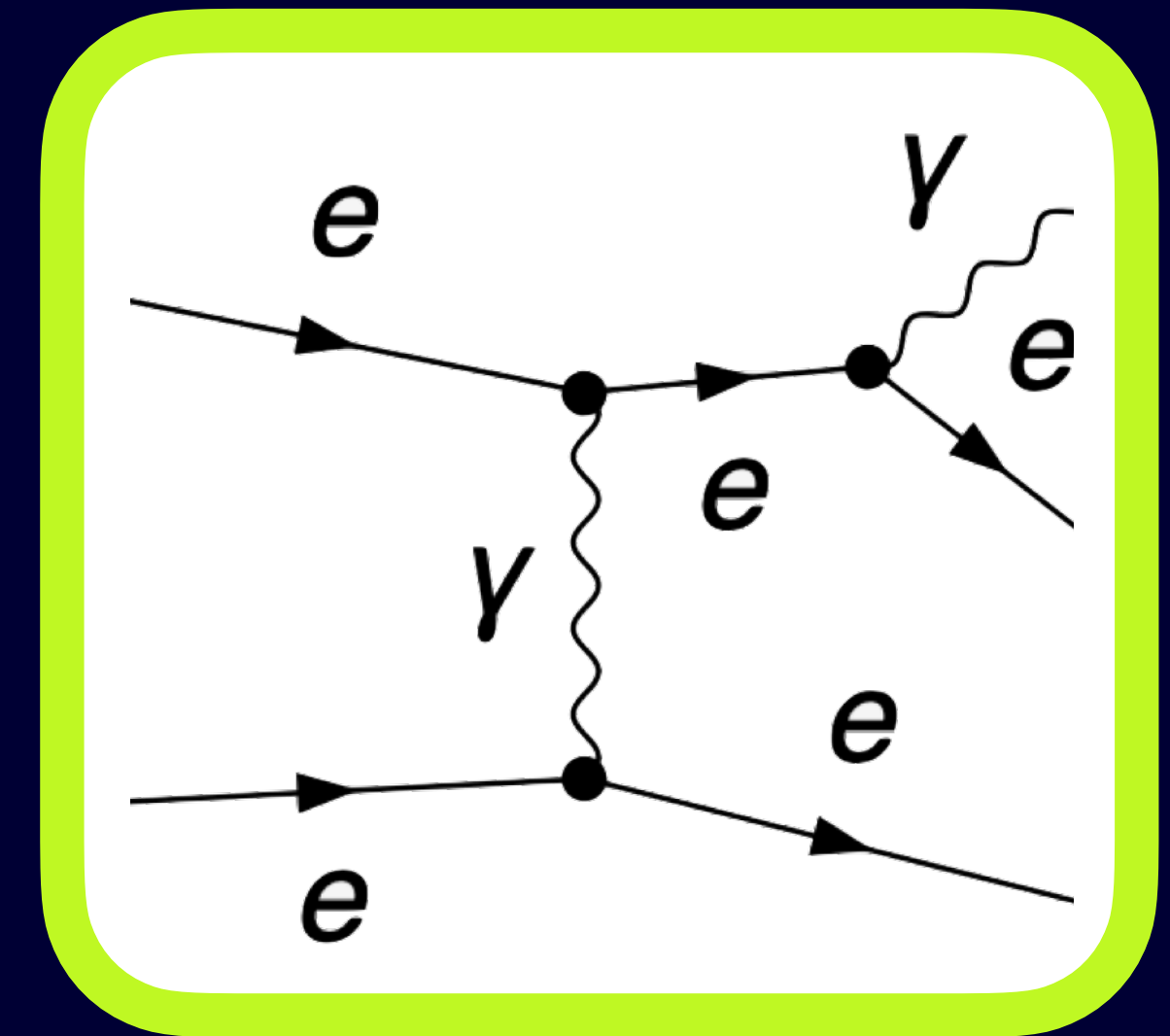
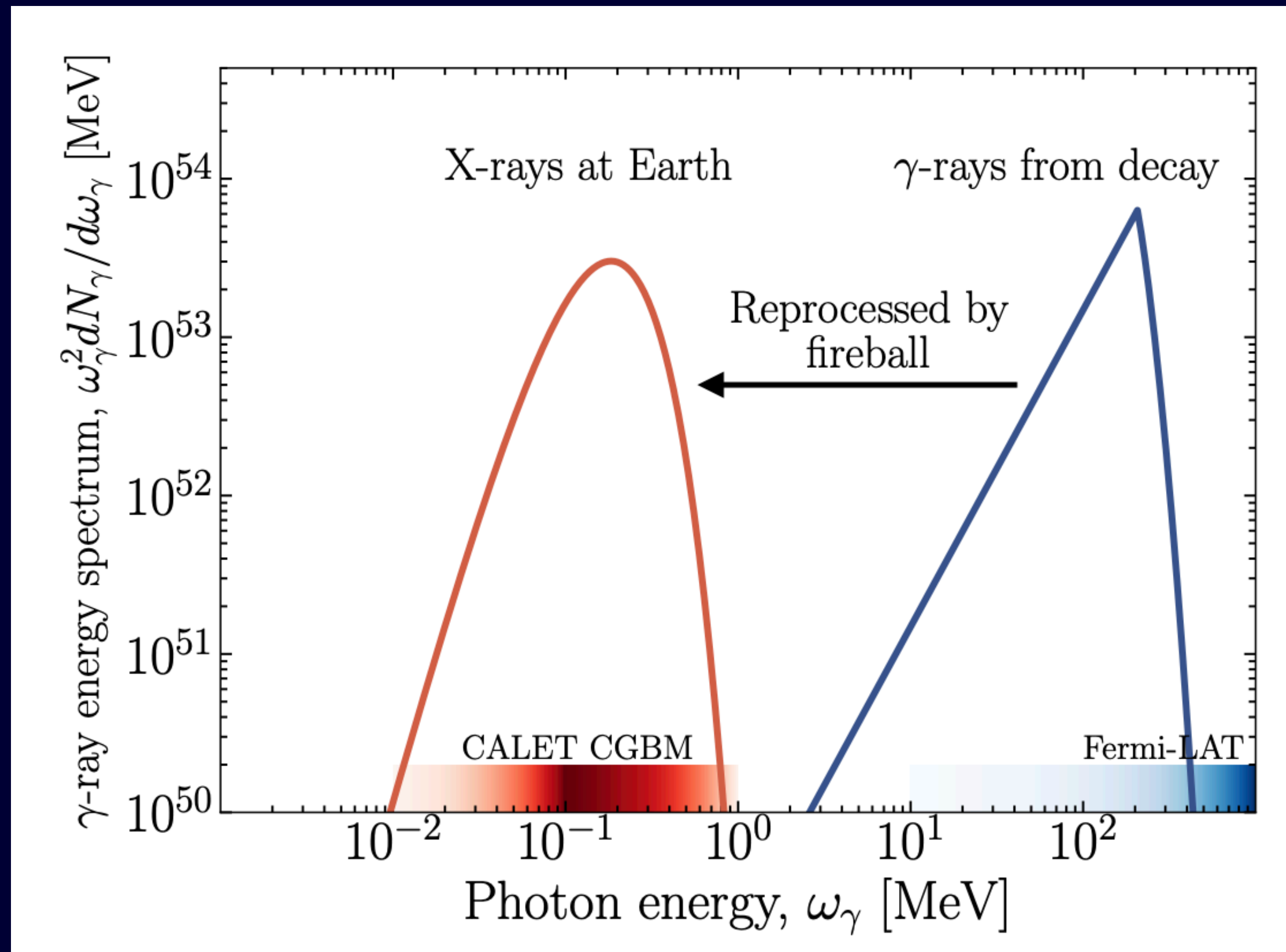# "Fast Scattering"
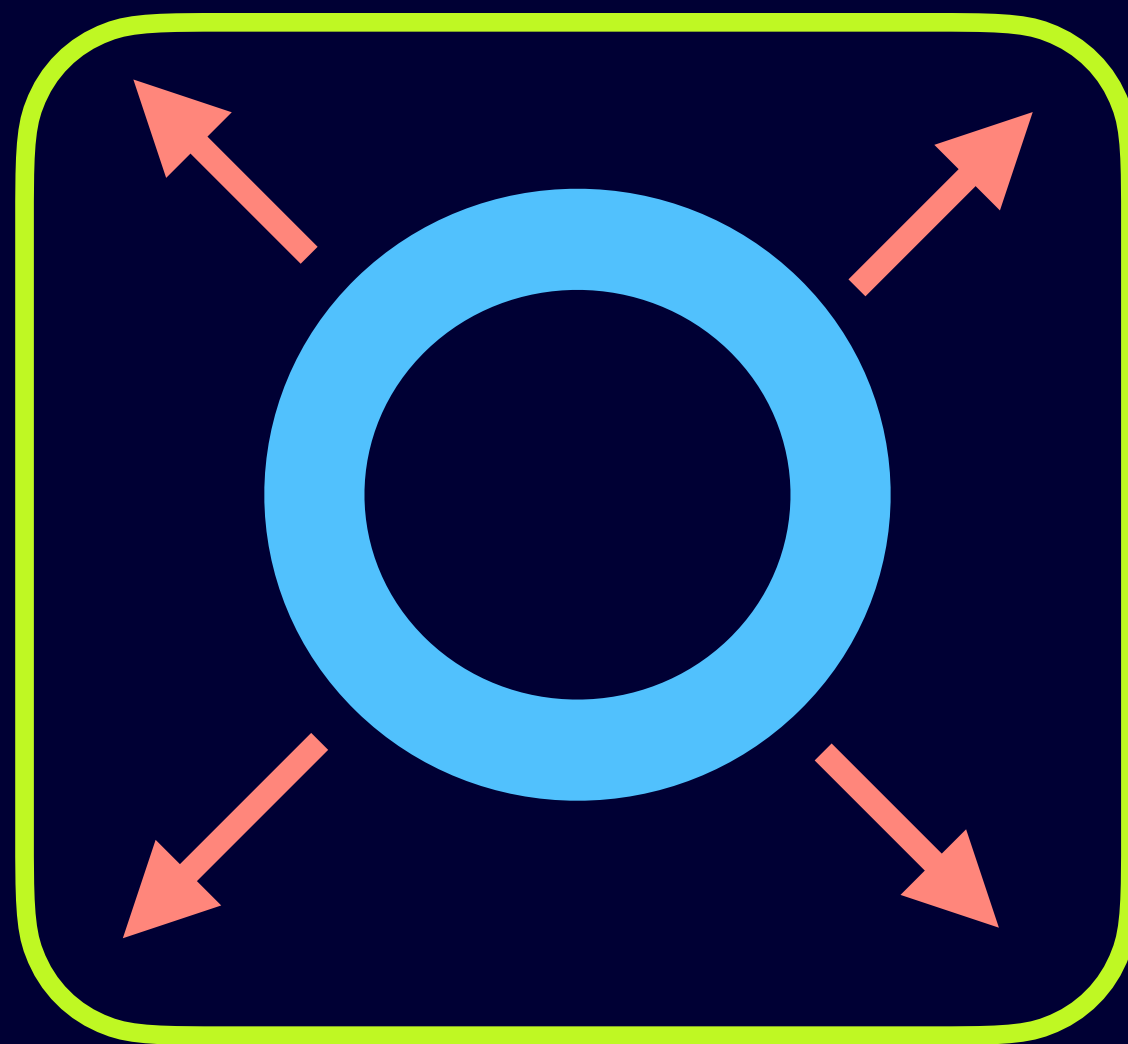
Expansion

VS

Pair Production

Dark photons $\rightarrow e^+ + e^-$

Axions $\rightarrow \gamma + \gamma$

Bremsstrahlung

The resulting signal

- **Resulting signal** should be roughly **thermal, boosted** and **isotropic** with energies around **100 keV**

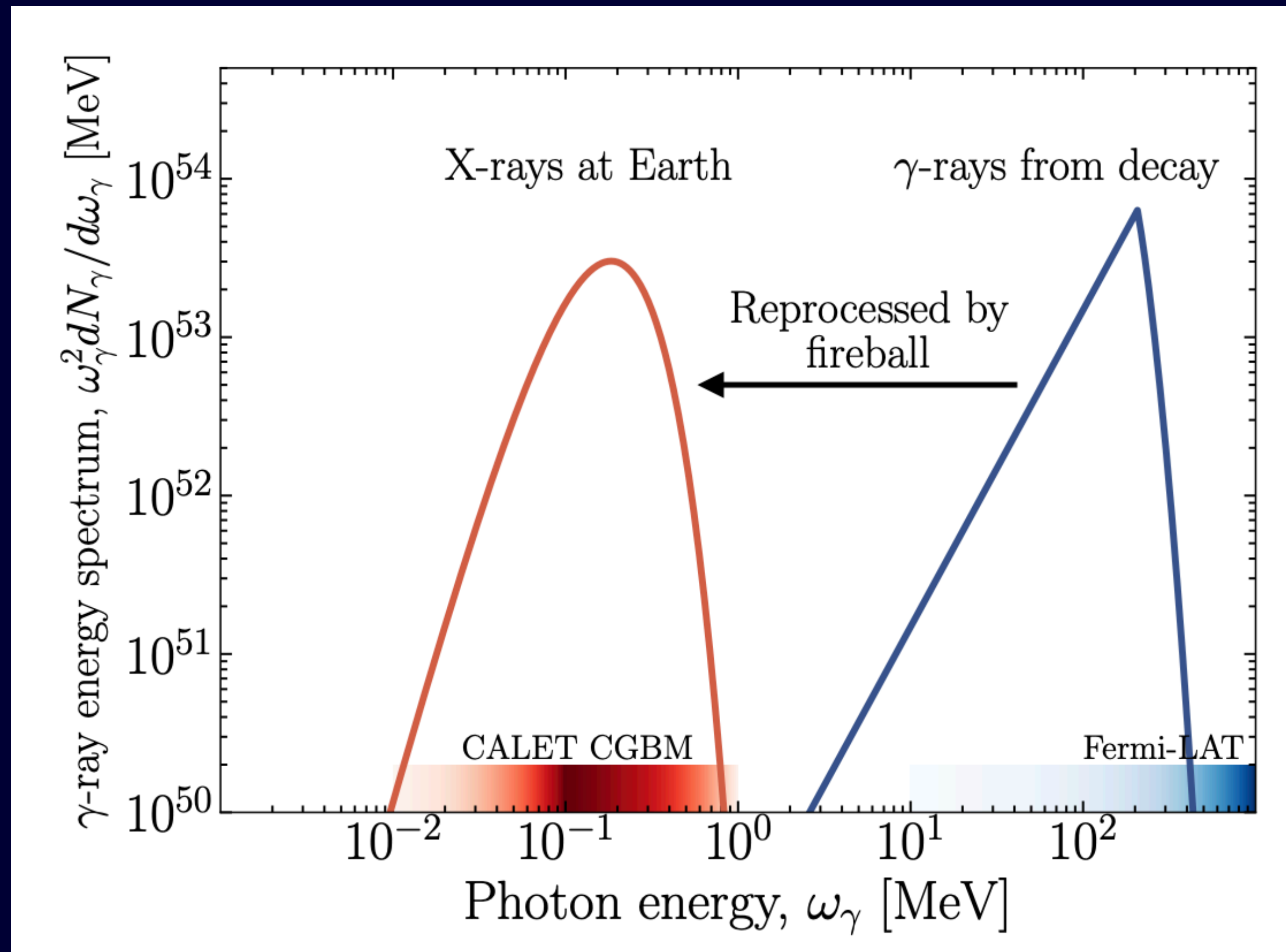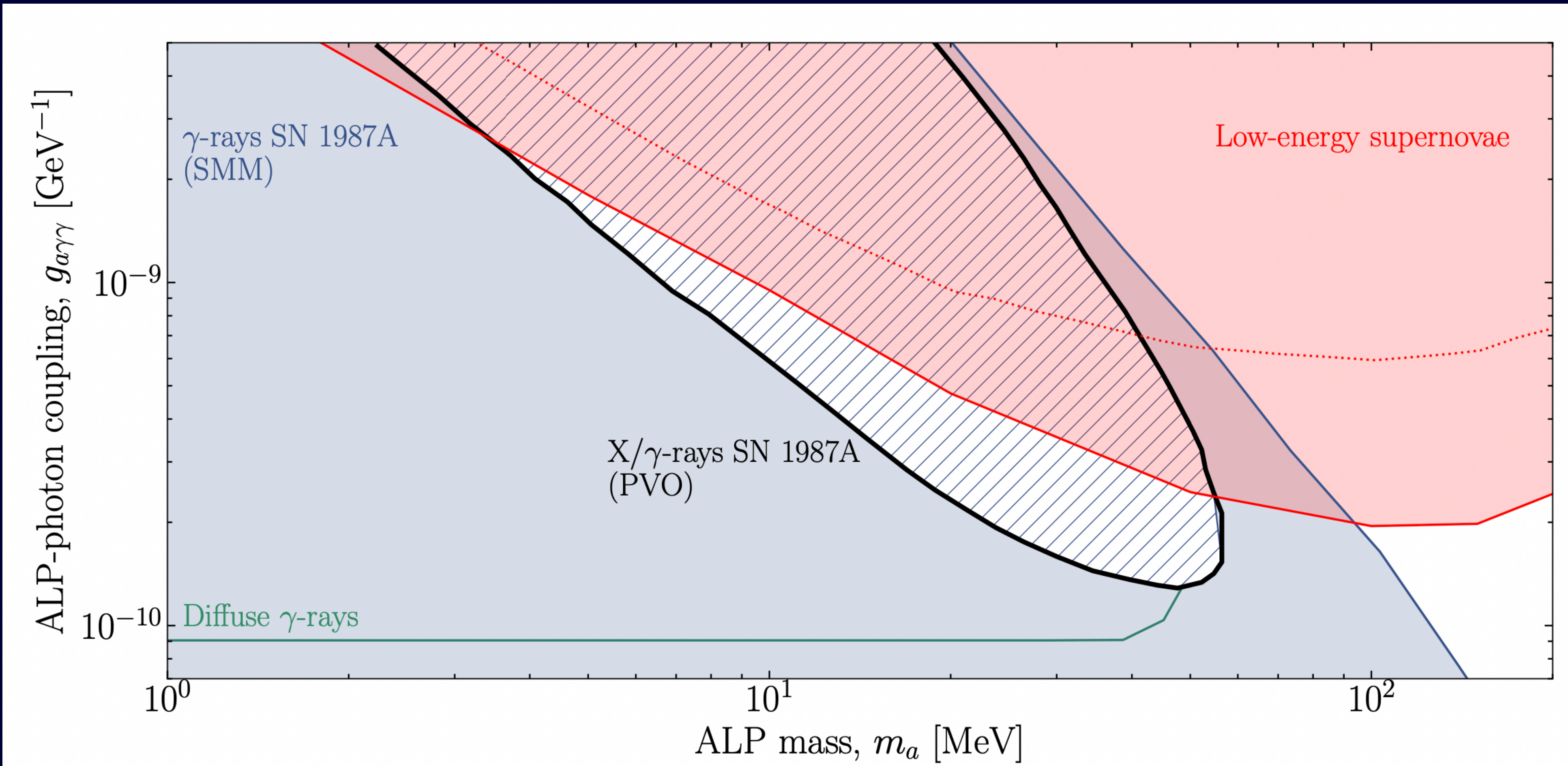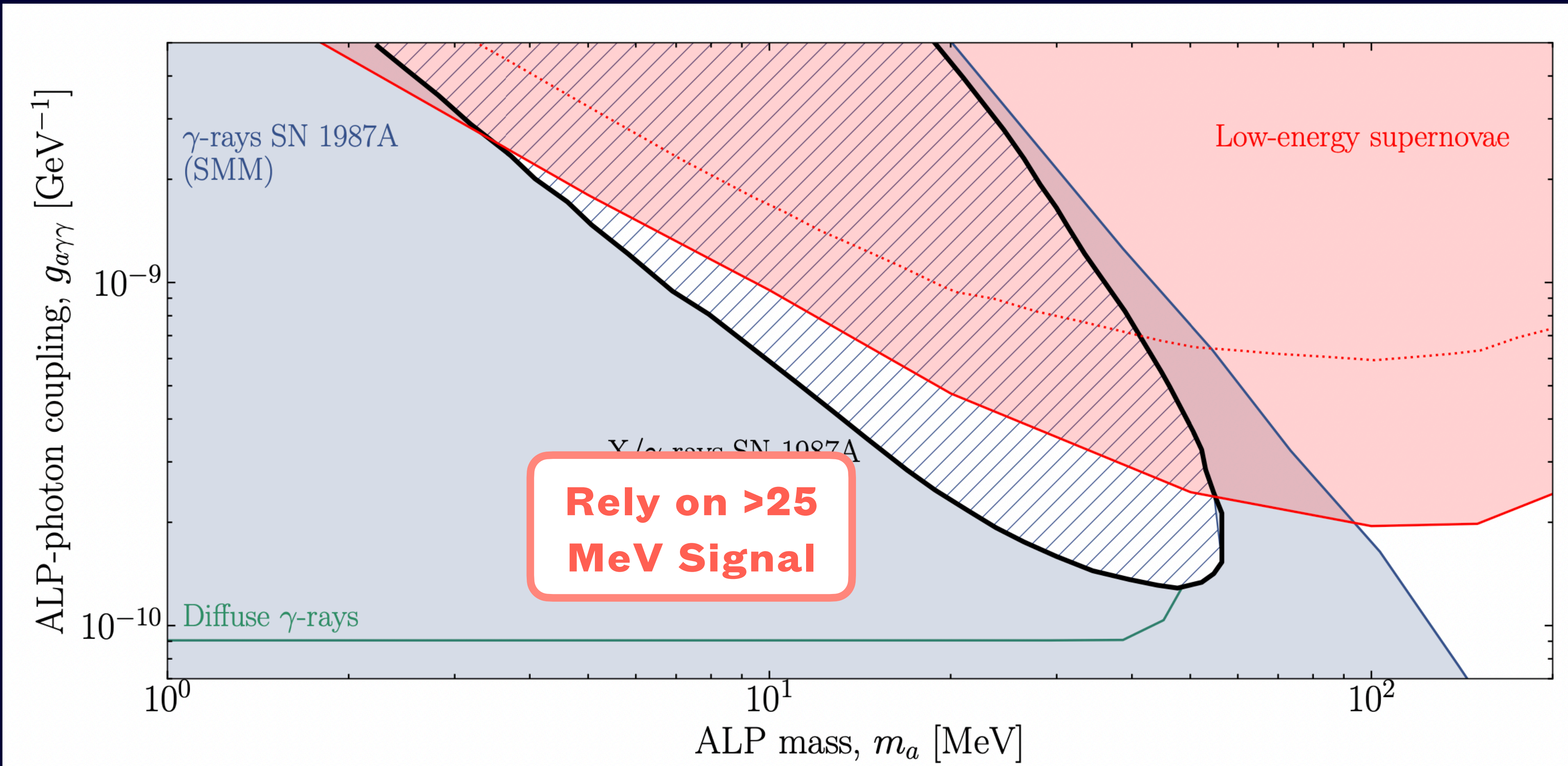# The resulting signal

2303.11395

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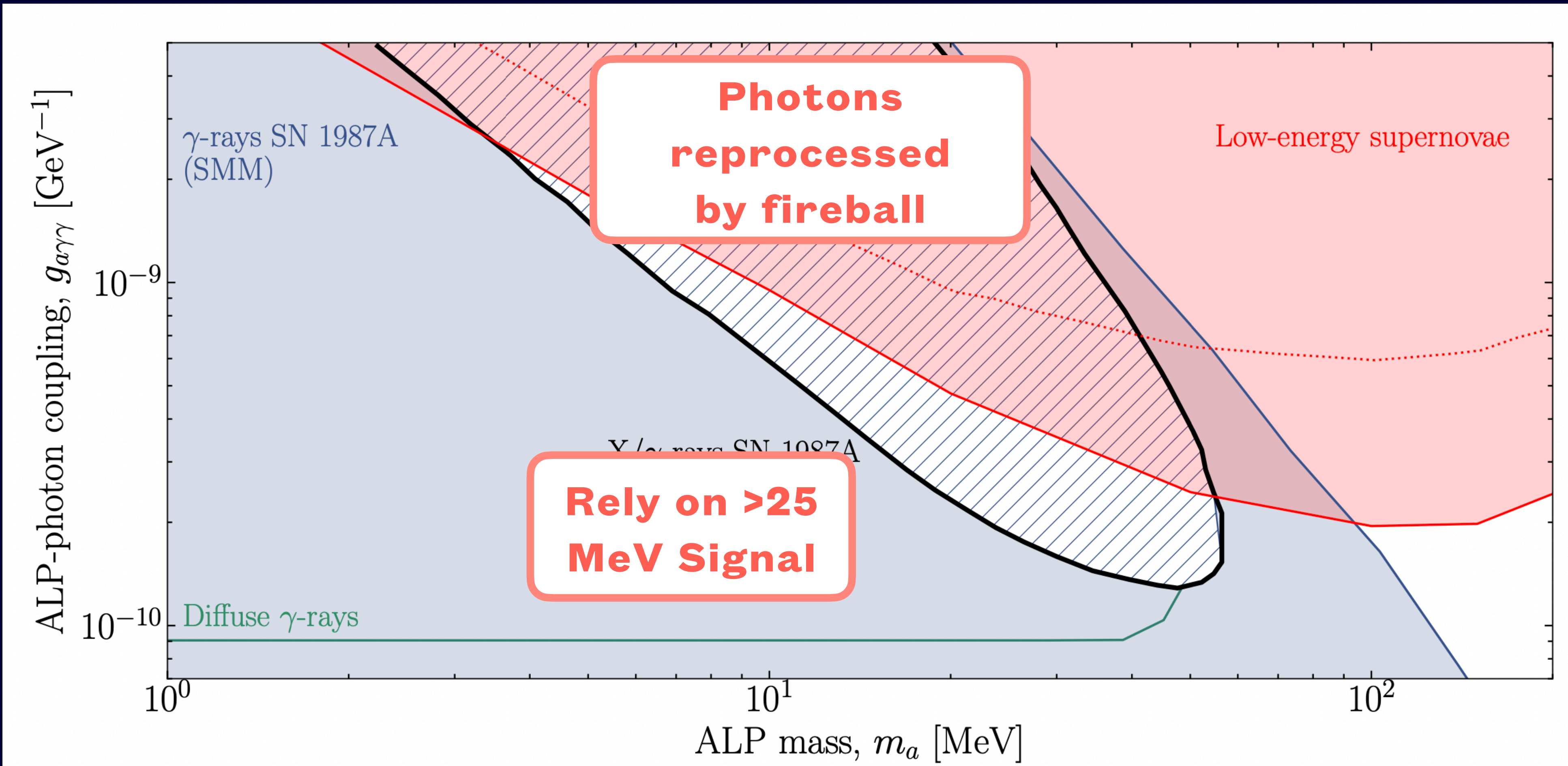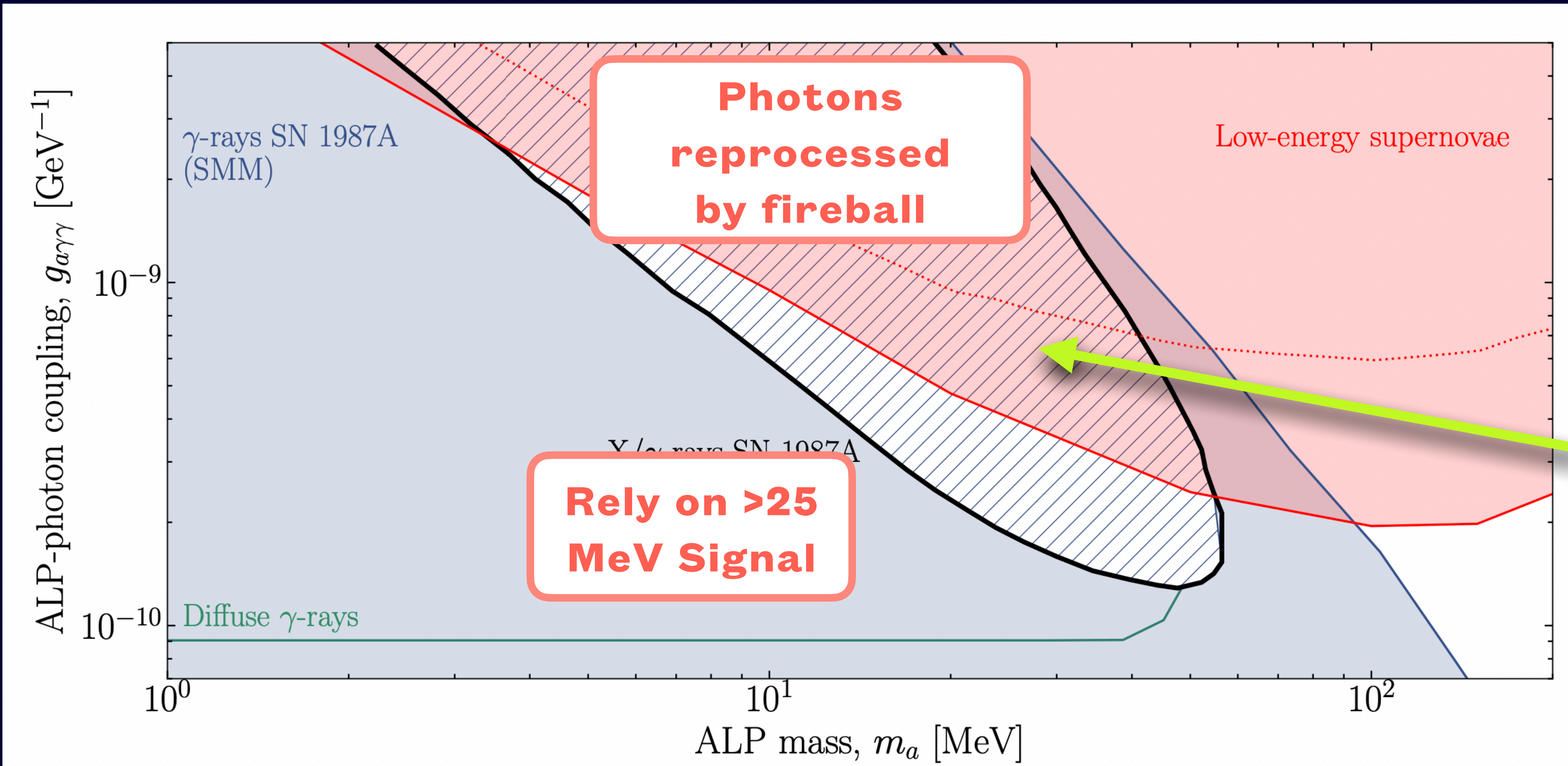
Updating Axion constraints

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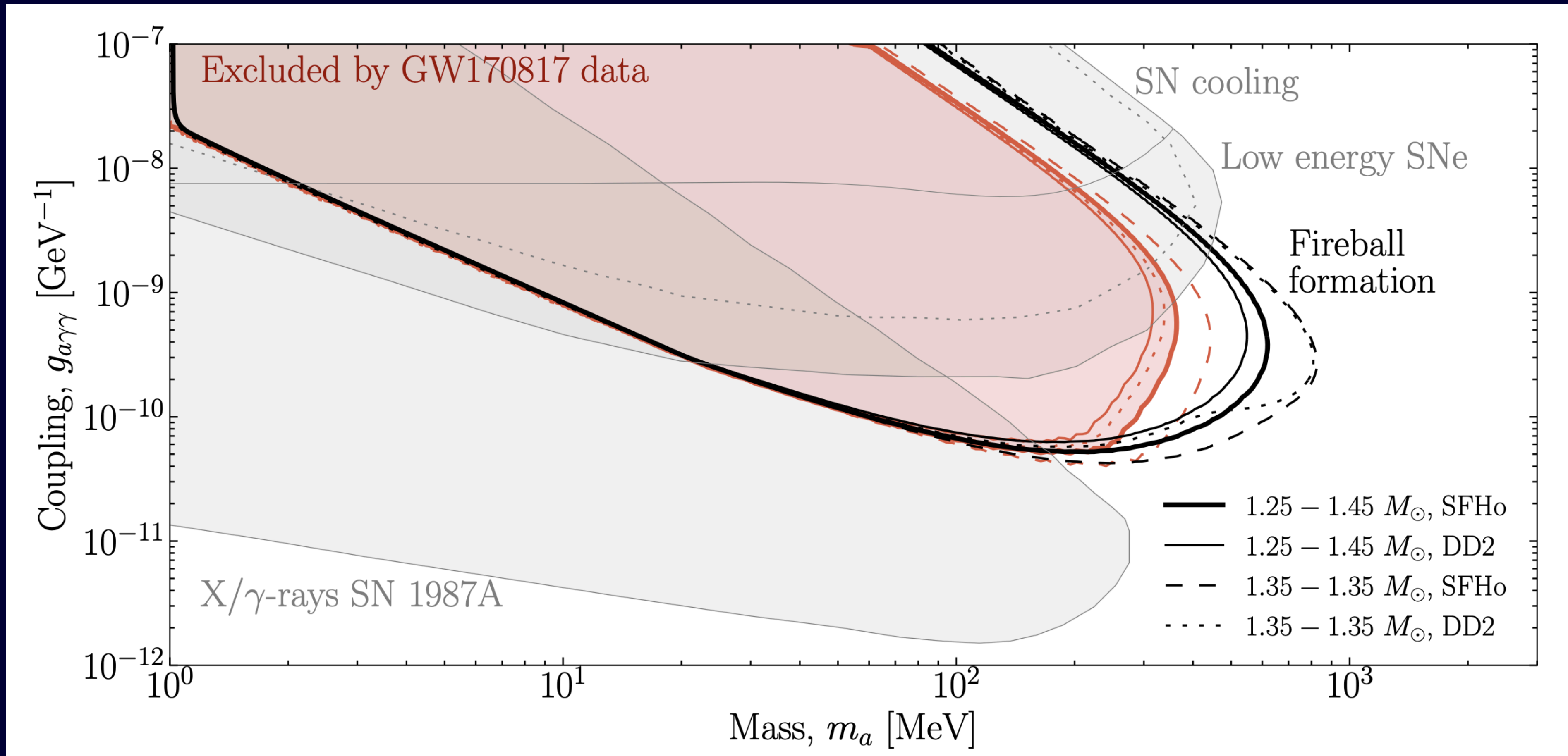
Updating Axion constraints

Updating Axion constraints

Photons reprocessed by fireball

γ-rays SN 1987A (SMM)

Low-energy supernovae

X/α-rays SN 1987A

Rely on >25 MeV Signal

Diffuse γ-rays

ALP-photon coupling, $g_{a\gamma\gamma}$ [GeV^{-1}]
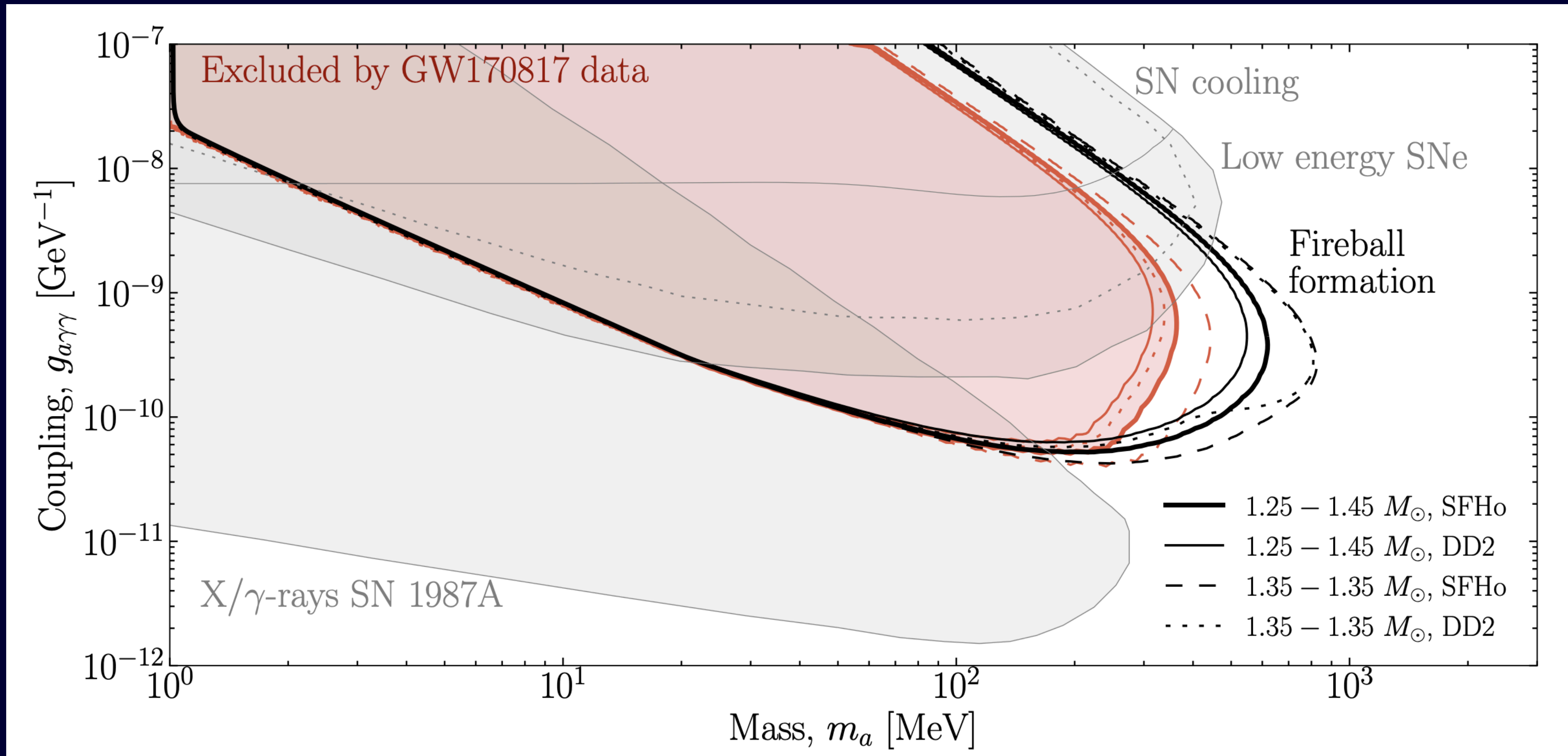
ALP mass, m_a [MeV]

Fireball reprocessing pushes signal into x-ray energies inaccessible to SMM but observable to Pioneer Venus Orbiter (PVO)
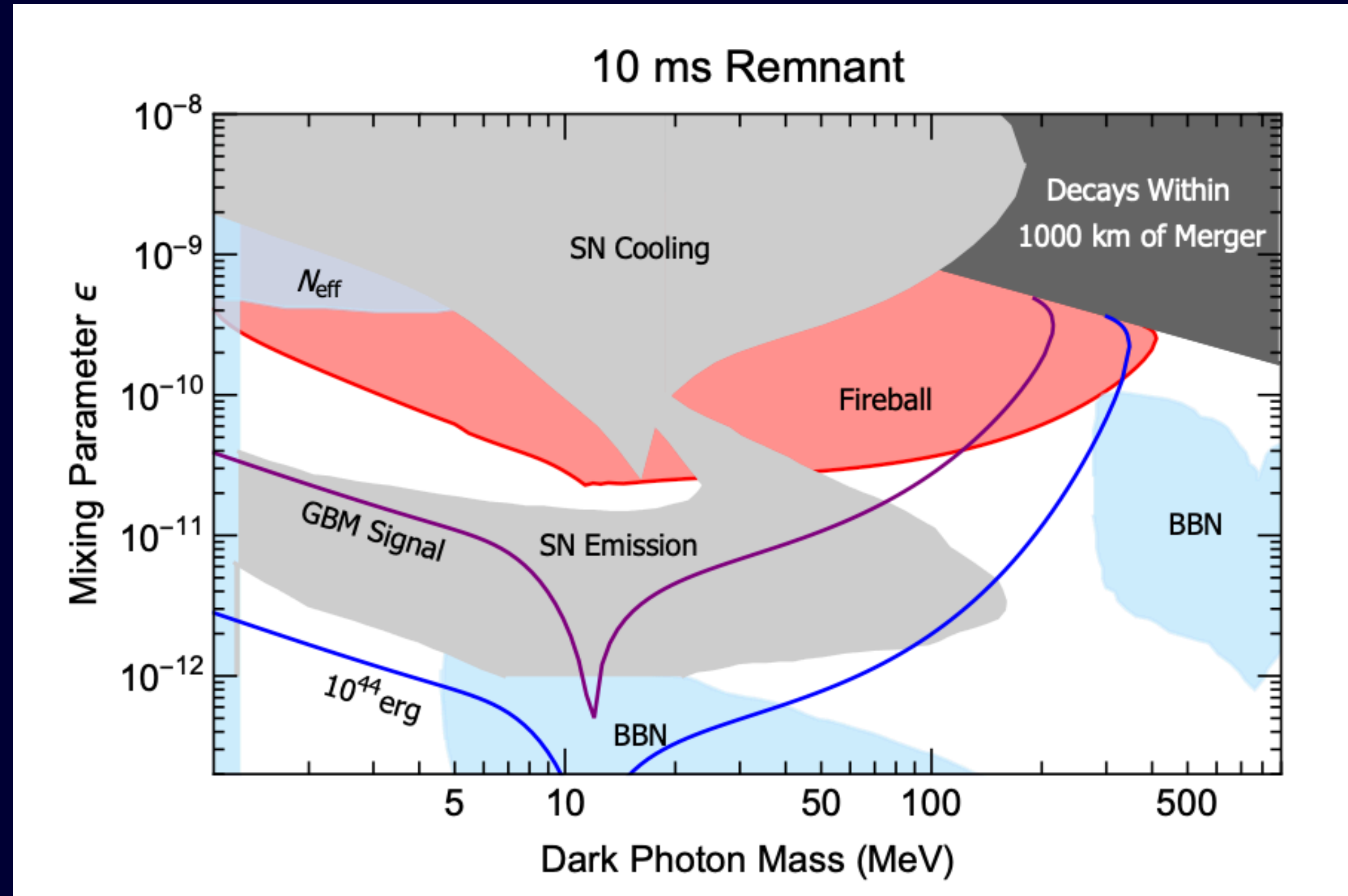
2303.11395

New Axion Constraints

Compare observed gamma ray burst signal from GW170817 to one predicted to result from axion fireball

2305.10327

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Compare observed gamma ray burst signal from GW170817 to one predicted to result from axion fireball

New Dark Photon Constraints??
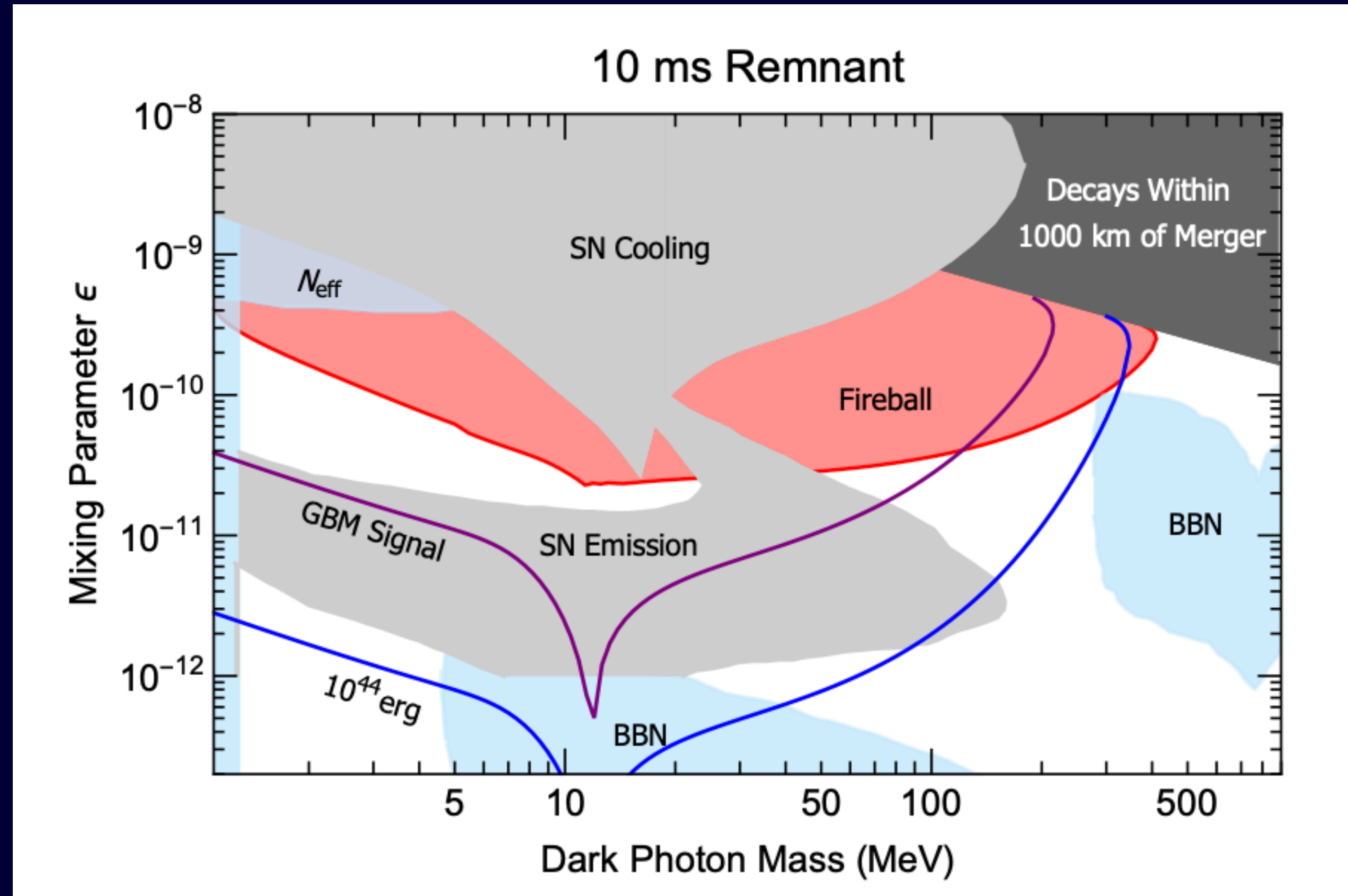

Estimates using a simplified model of GW170817.

5-10km shell

T=30MeV

$\rho = 4 \times 10^{14}$

Duration= 10ms

2106.03879

New Dark Photon Constraints??
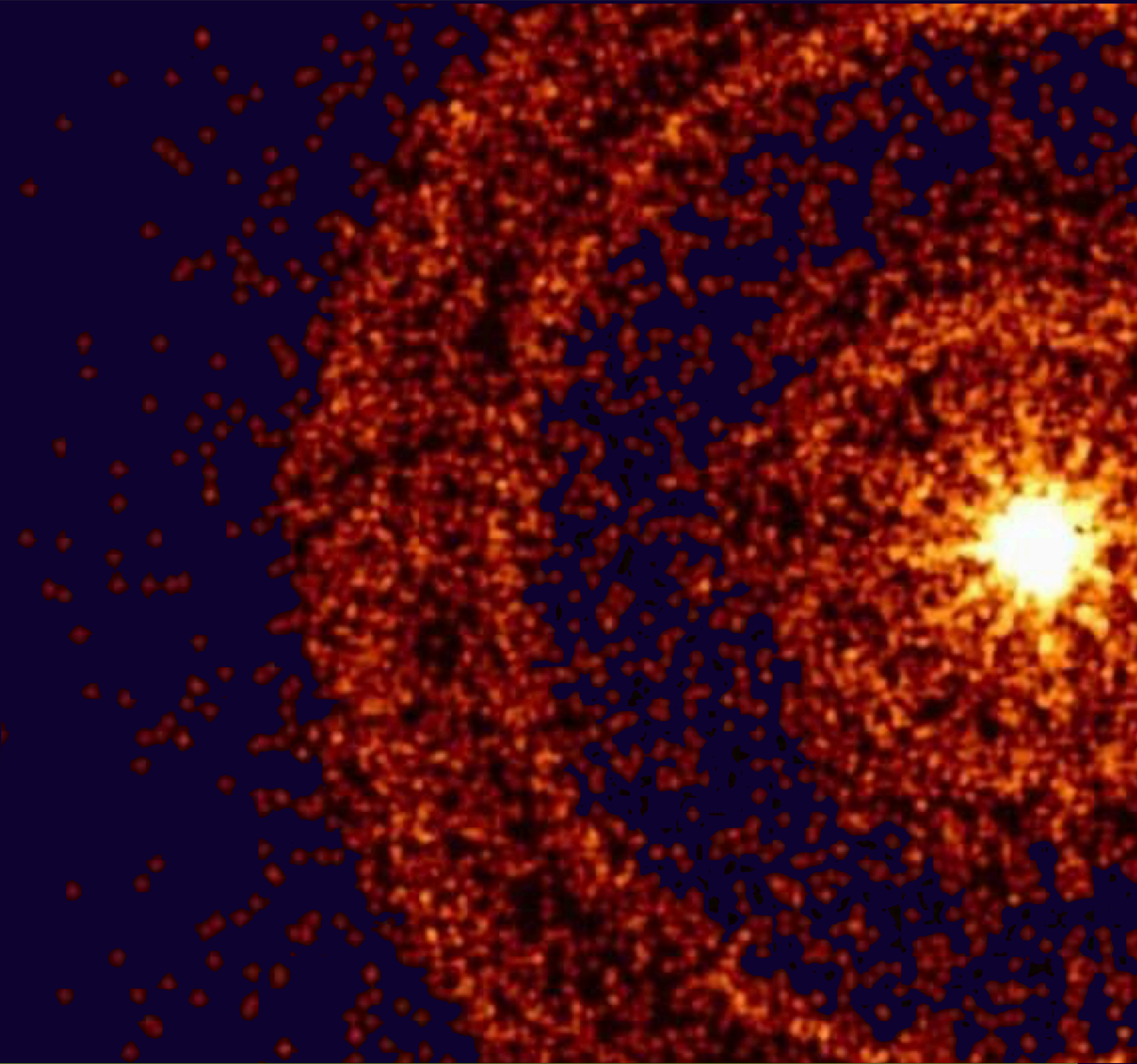

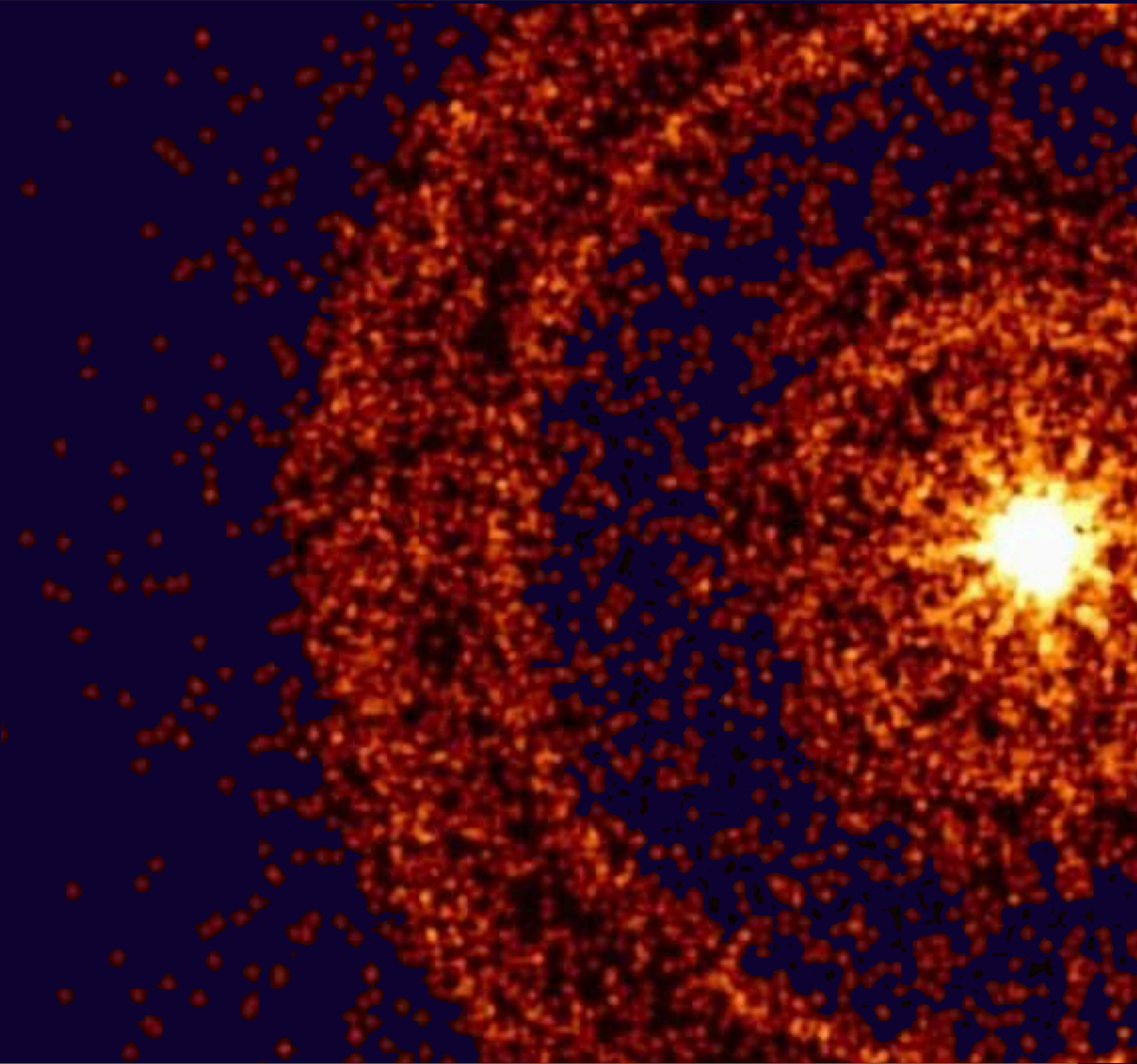Estimates using a simplified model of GW170817.

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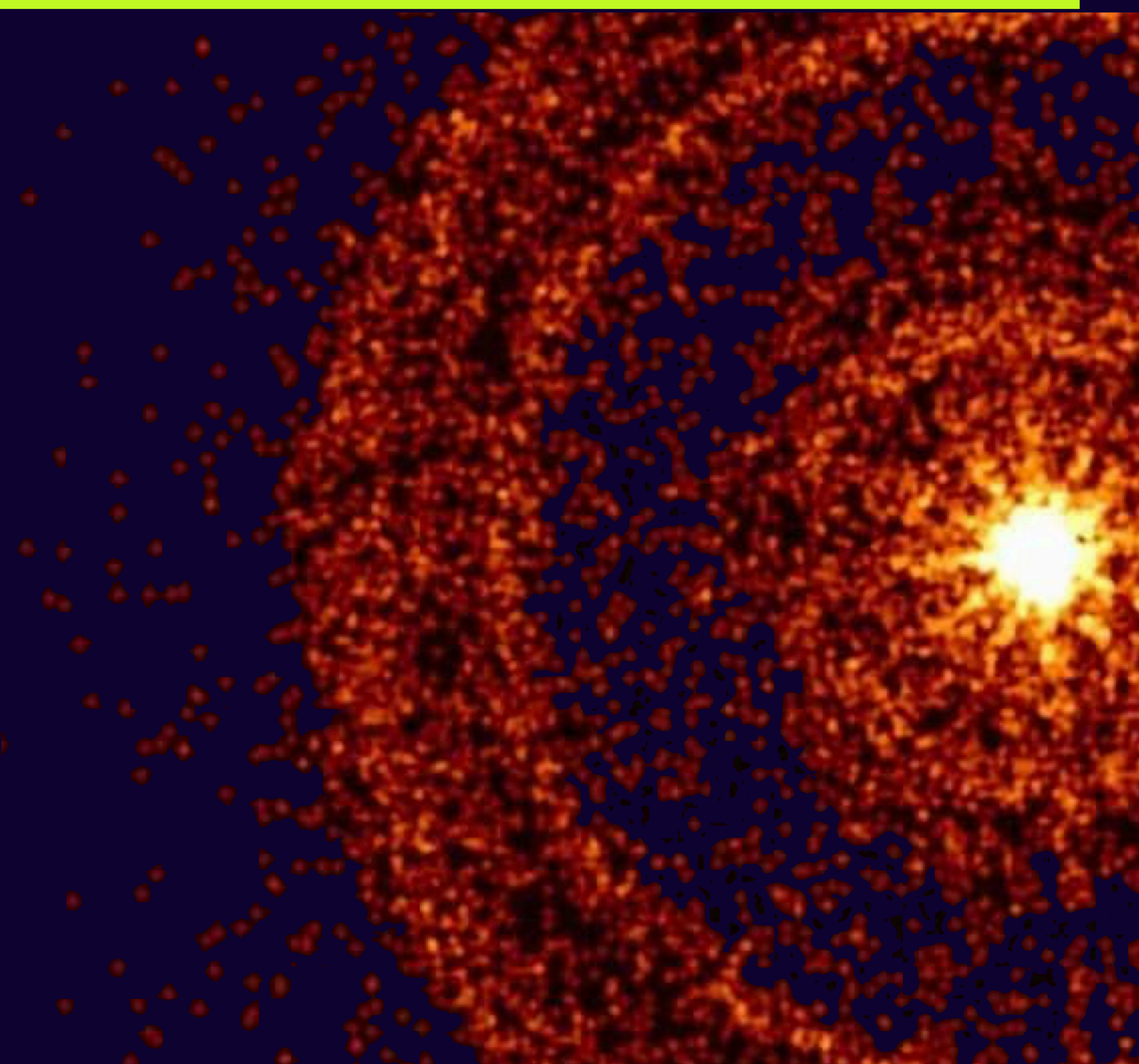
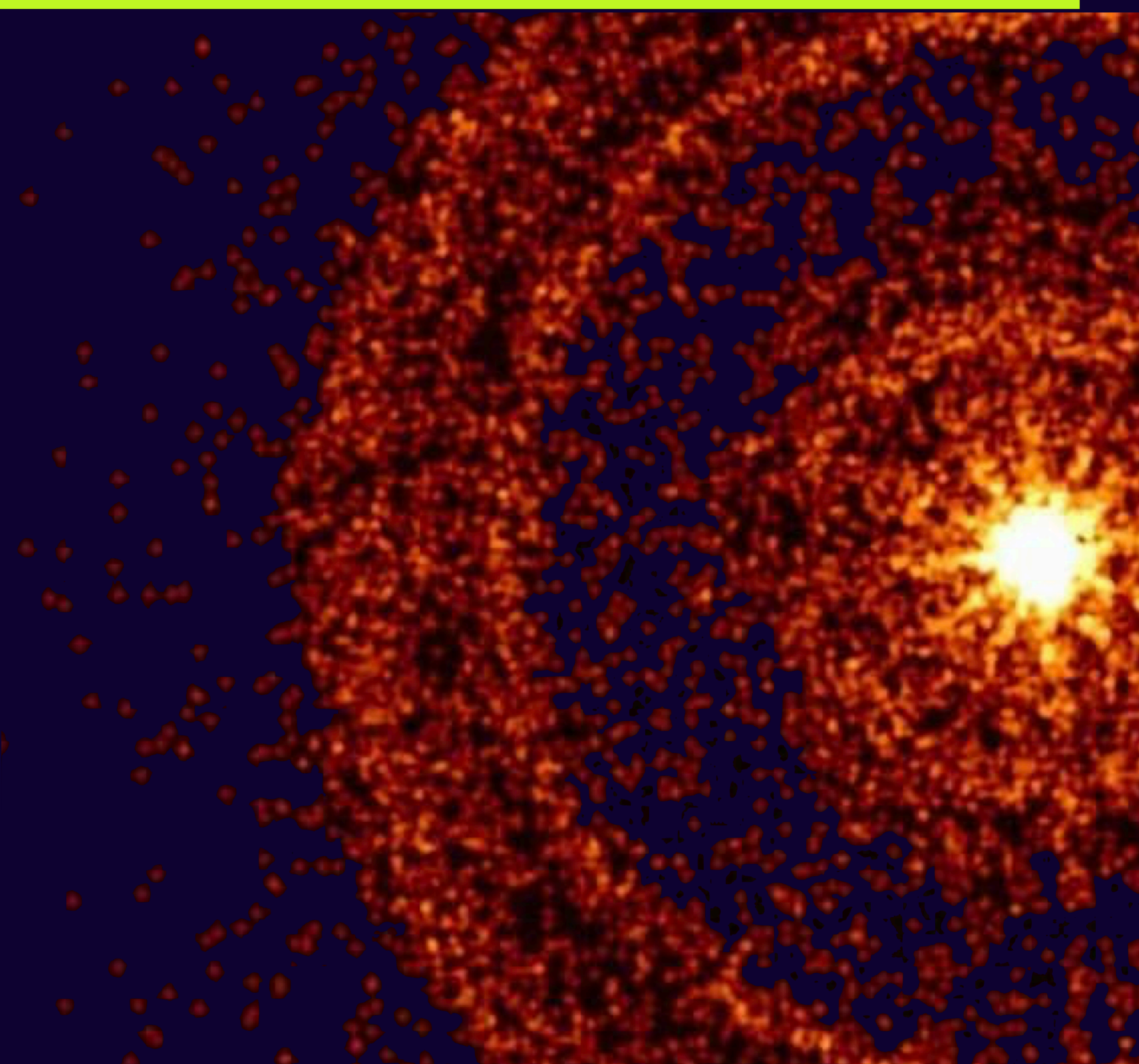Duration= 10ms

2106.03879

Conclusions

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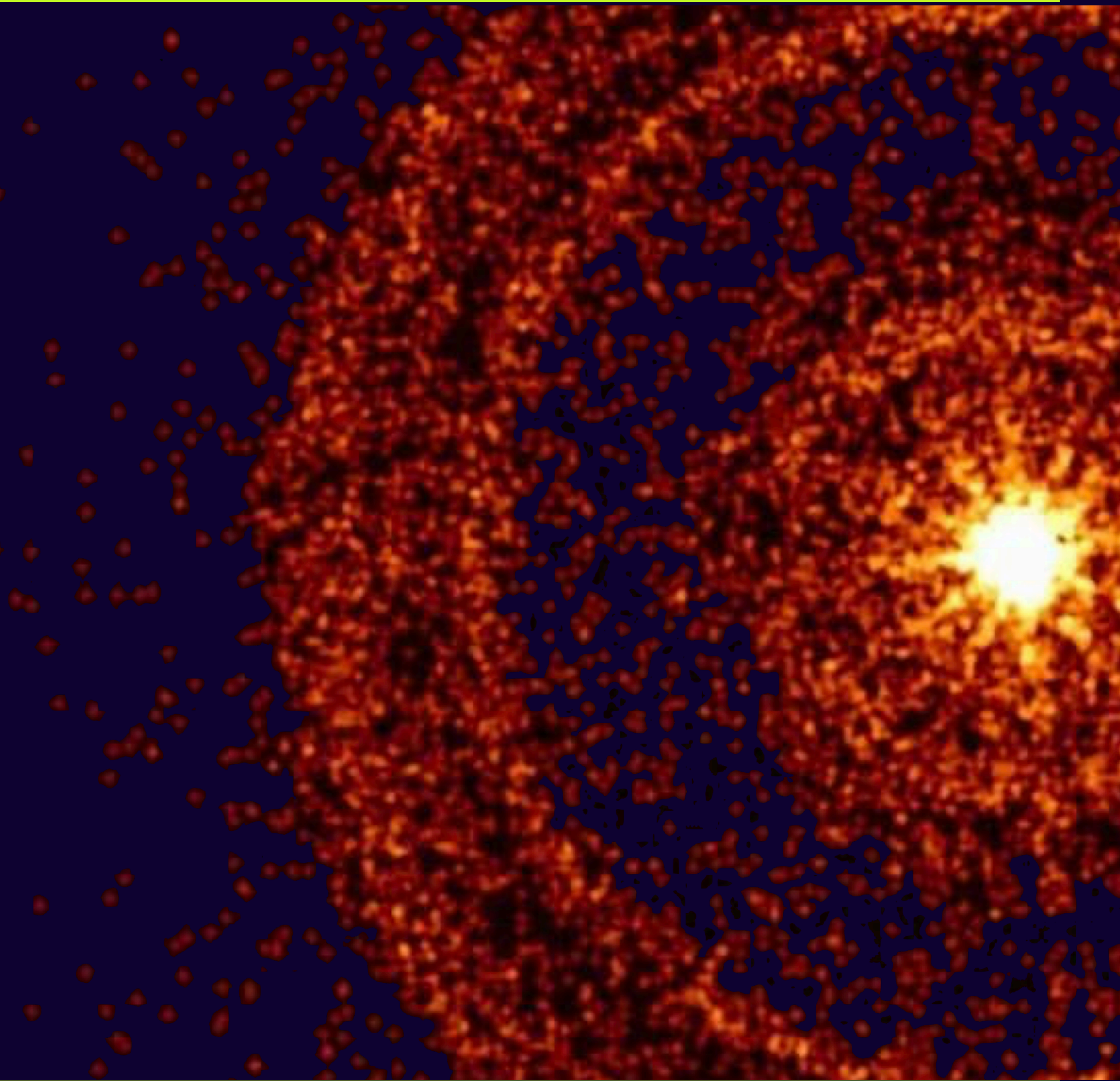- Compact transients are large sources of light BSM particles

Conclusions

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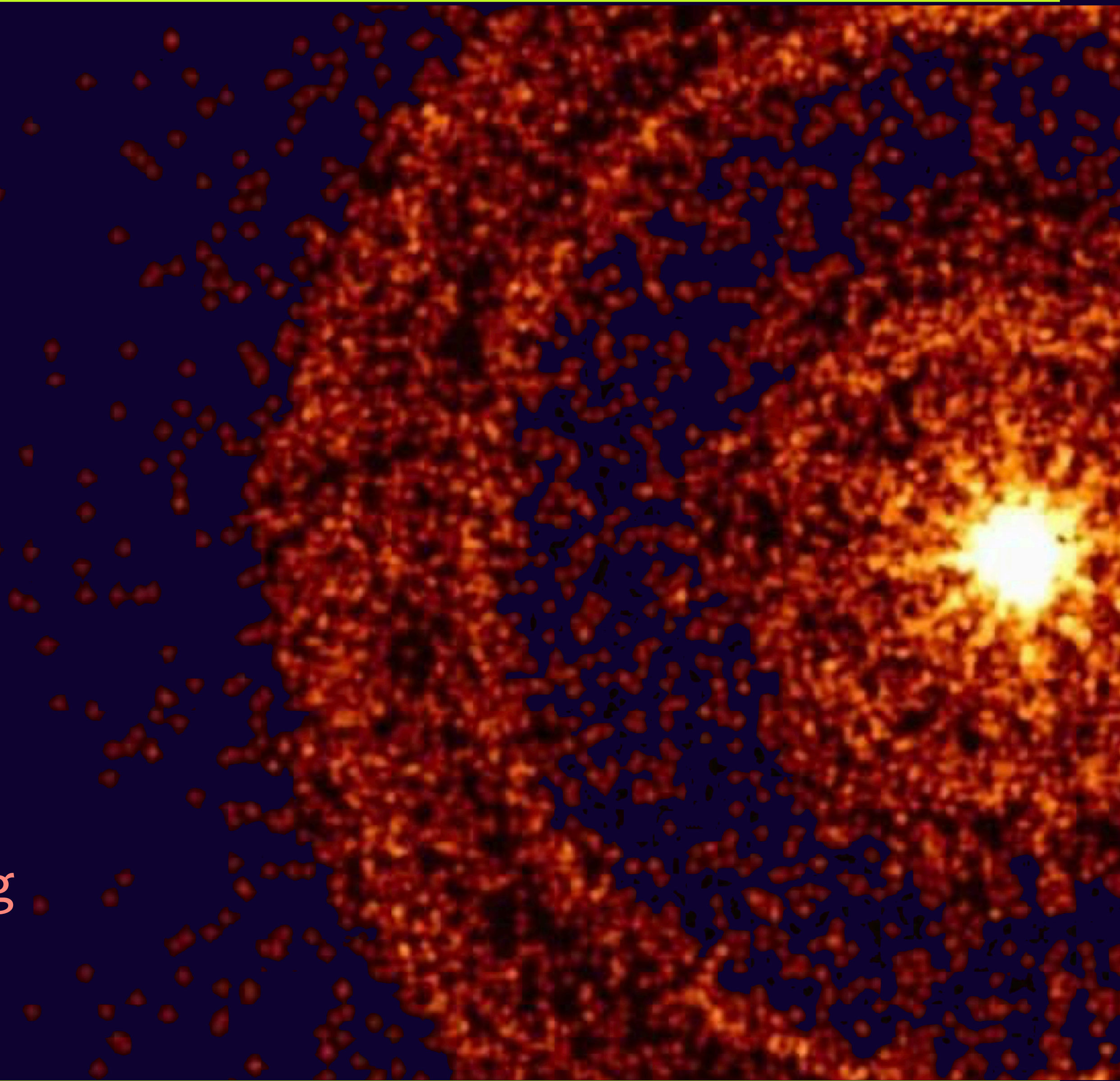
Conclusions

- Compact transients are large sources of light BSM particles

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- Final signal depends on whether fireball forms

- More observations and better modeling will allow us to explore new parameter space

Thank You