Finding Exotic Particles with Fireballs

Melissa Diamond
Queen's University
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Based on **2106.03879,** 2303.11395 and ongoing work with Damiano Fiorillo, Gustavo Marques Tavares, Irene Tambora, and Edoardo Vitagliano

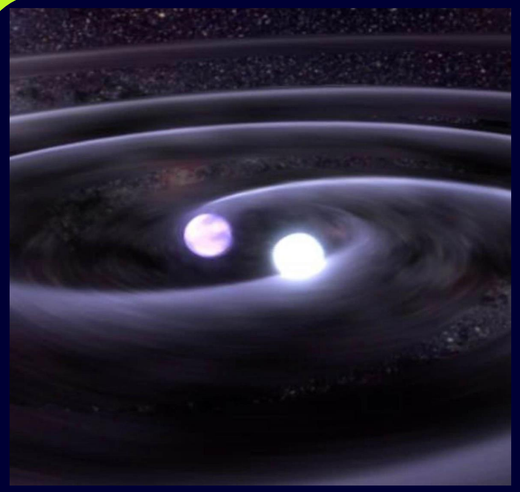
05.09.2023

Queen's University

Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

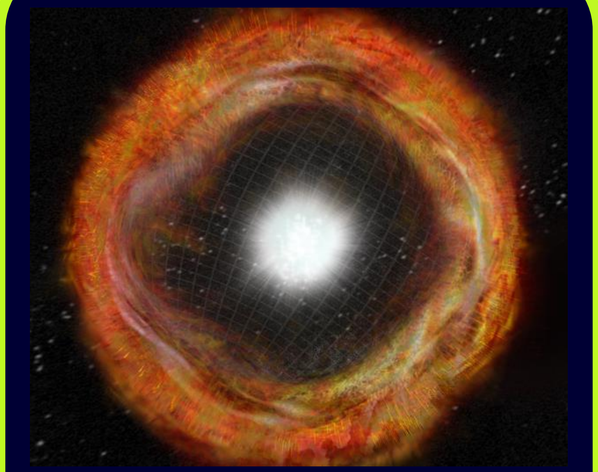
Hot Neutron Stars

A powerful tool for exploring dark matter and beyond the standard model (BSM) particles



Binary neutron star mergers

- $\rho \sim 10^{14}$ g/cm^3
- T> 30 MeV



Core Collapse Supernovas

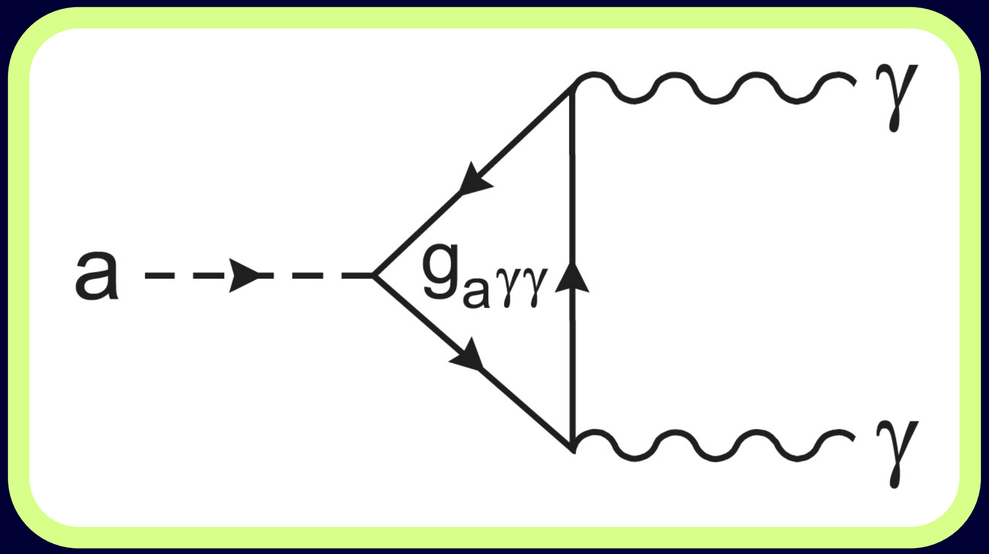
Can thermally produce particles with masses up to 100's of MeV, and couplings to the SM weaker than neutrinos

Use hot neutron stars to look for BSM particles that escape the star, but decay to the SM before reaching Earth with masses between 1 MeV and 1 GeV

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 $E \cdot B$
- Thermally produced in NS
- Can decay to two photons before reaching earth
- $g_{a\gamma\gamma} \sim 10^{-9} - 10^{-10}$ GeV $^{-1}$



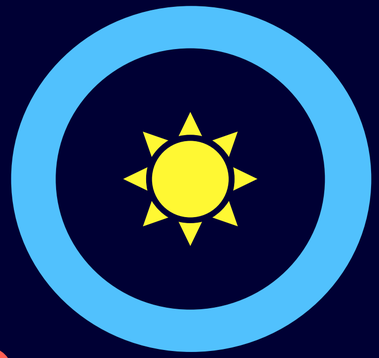
The Fireball

From source to signal

Exotic particles radiated by source

Decay to standard model

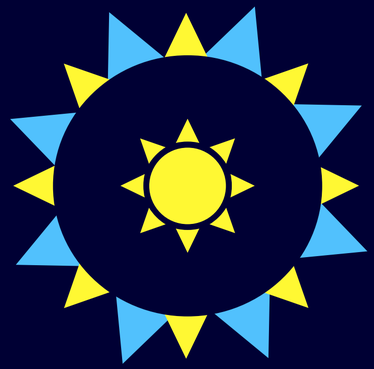
Expanding plasma shell

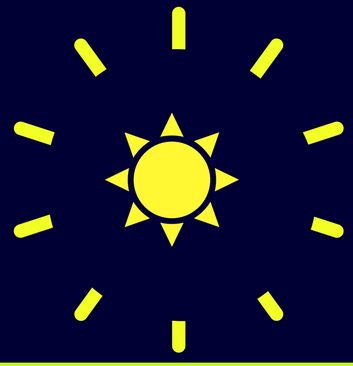


Pair production and scattering are fast

Pair production and scattering are slow

Reprocessed thermal Fireball



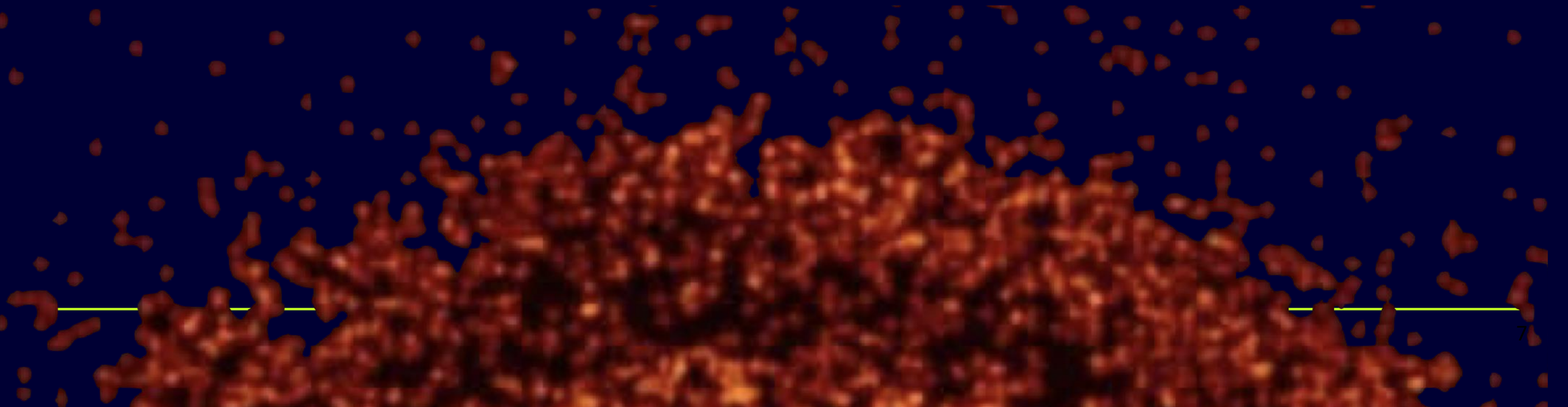


Decay products free stream. No fireball

The Fireball

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

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



The resulting signals

Fireball

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

Identified by:

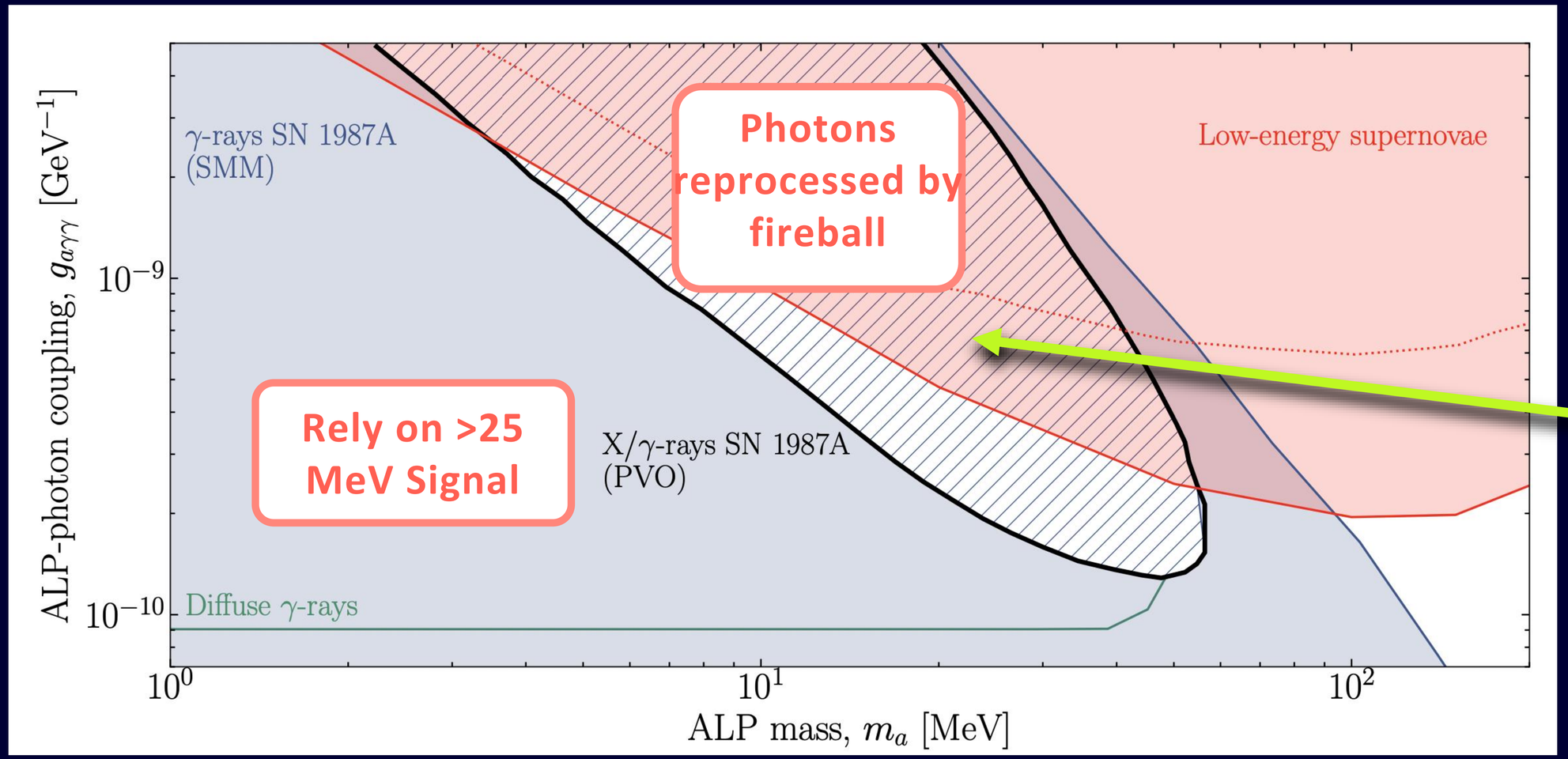
- total energy
- energy spectrum
- signal timing and duration
- isotropy

Vs

Free Streaming

Typical energies around
10s of MeV

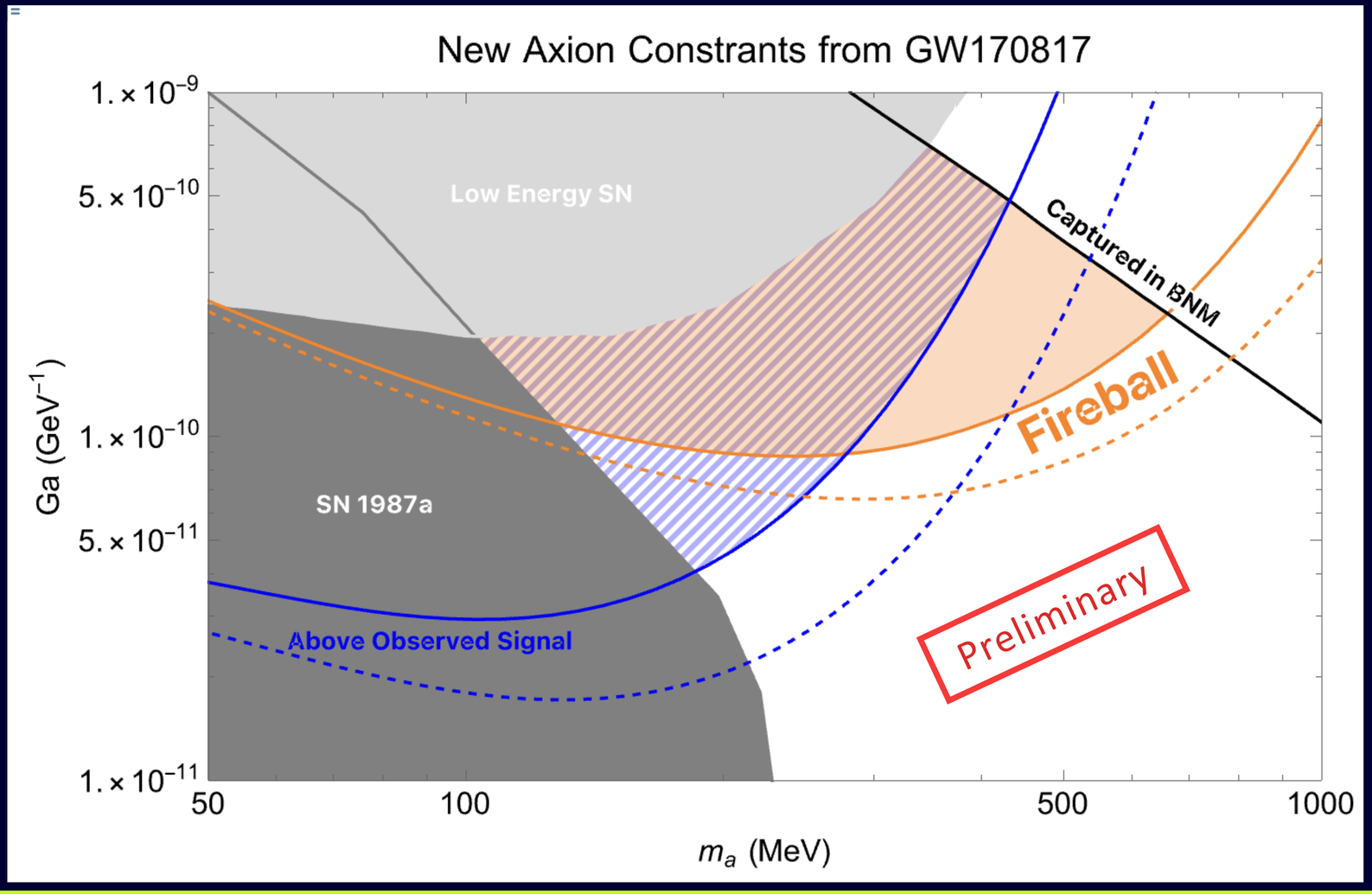
Updating Axion constraints



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

Arxiv 2303.11395

New Axion Constraints



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

Conclusions

- Hot neutron star transients are large sources of light BSM particles
- Axions from these can produce observable signals
- Final signal depends on whether fireball forms
- More observations and better modeling will allow us to explore new parameter space

Thank You

M.DIAMOND@QUEENSU.CA

Axions

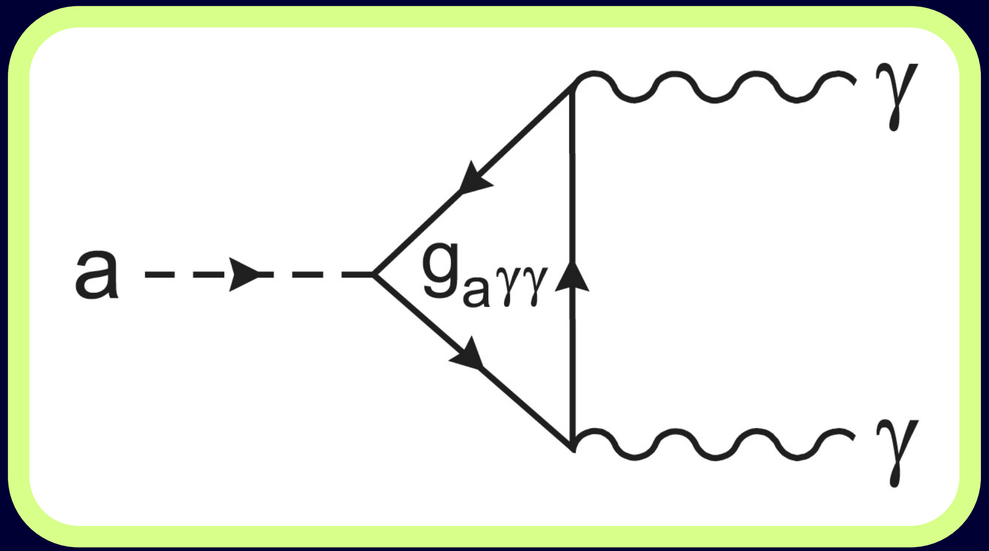
Produced through:

1.Photon coalescence

$\gamma + \gamma \rightarrow a$

2.Primakoff Process

$\gamma + Ze \rightarrow Ze + a$



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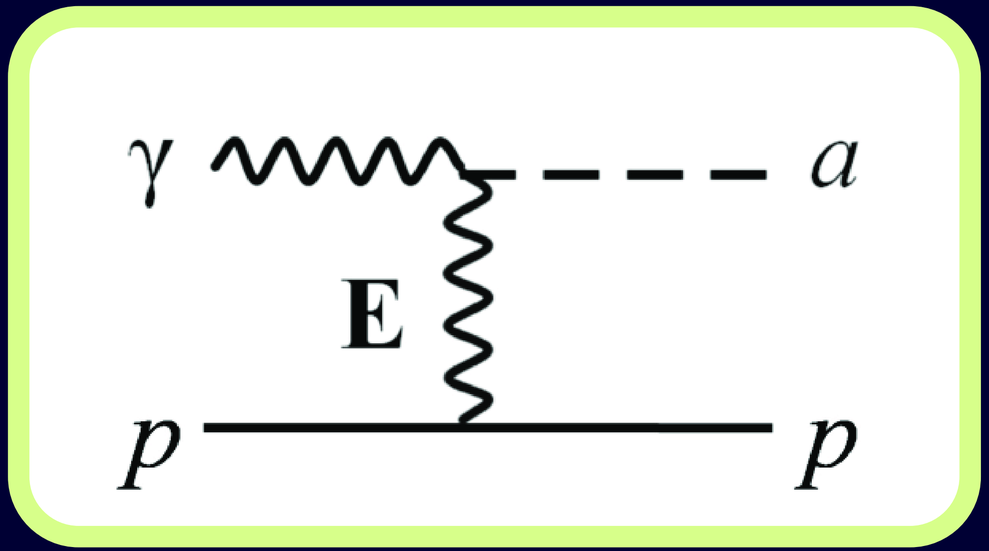


The resulting signals

Fireball

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

Identified by:

- total energy
- energy spectrum
- signal timing and duration
- isotropy

Vs

Gamma Ray Burst

- Typical energies around 100s of keV
- Beamed
- Non-thermal and thermal components

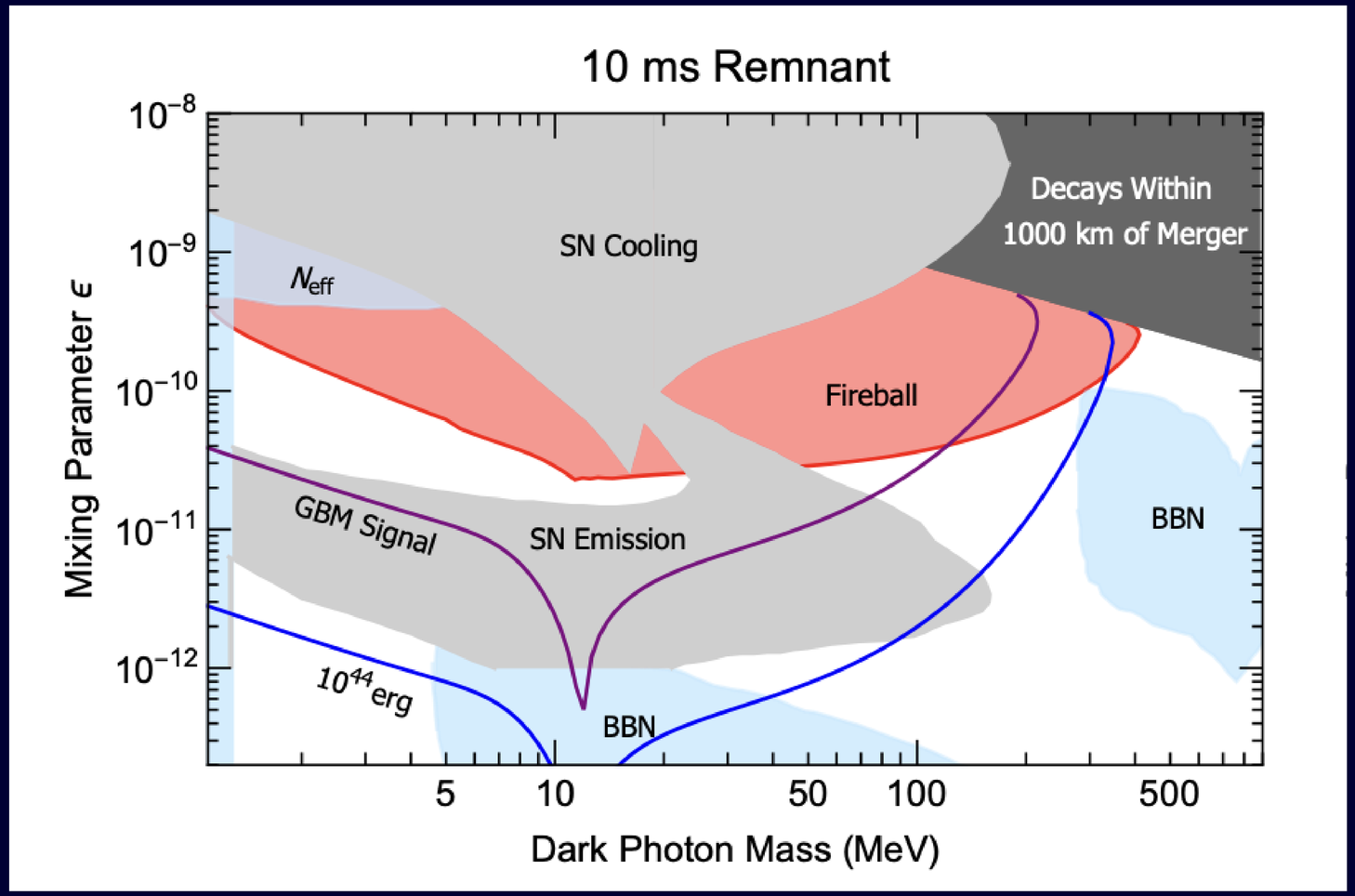
Binary Neutron Star Mergers

- 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

New Dark Photon Constraints??



Estimates using a simplified model of GW170817.

5-10km shell

T=30MeV

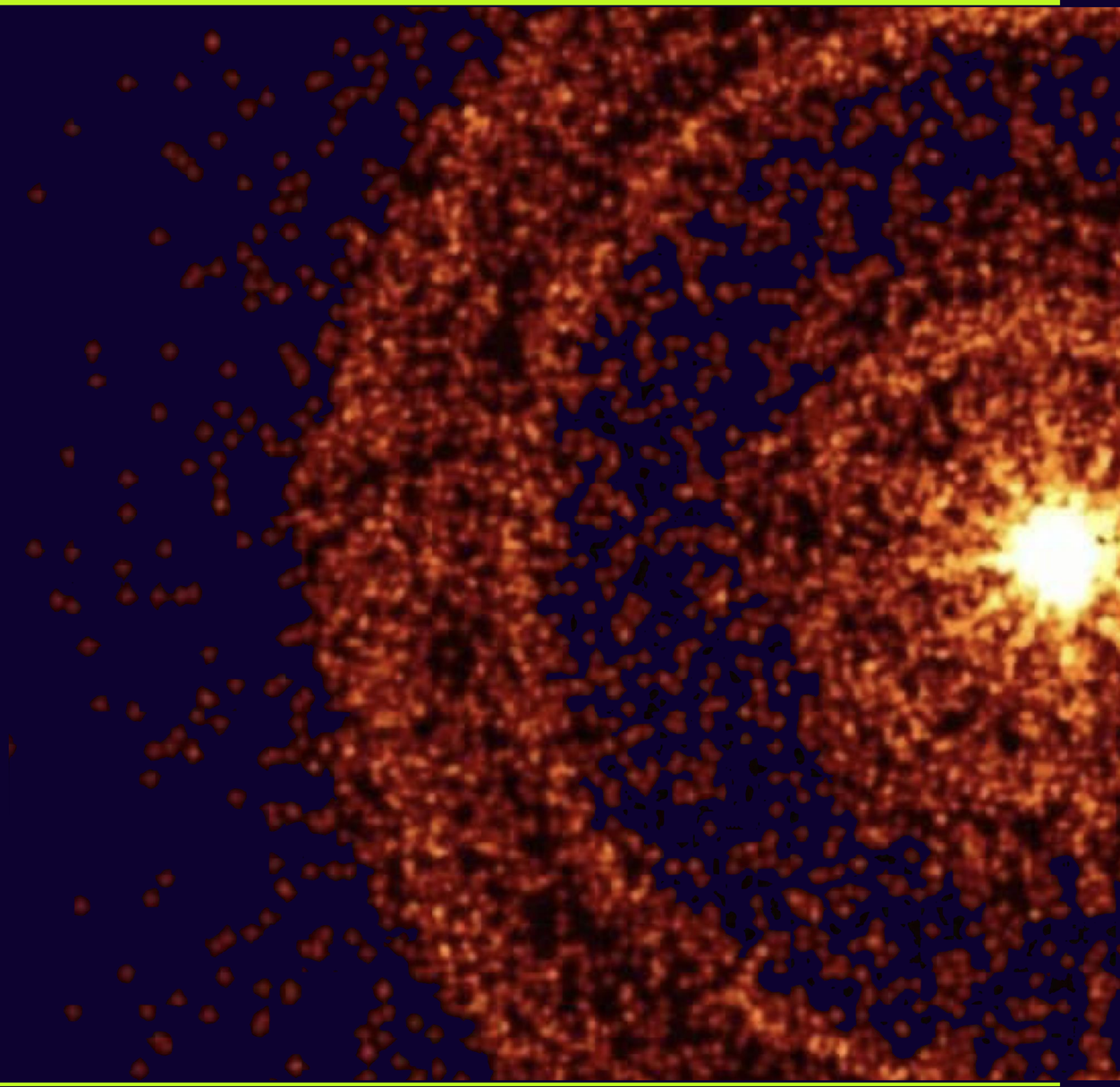
$\rho = 4 \times 10^{14}$

Duration= 10ms

https://arxiv.org/abs/2106.03879

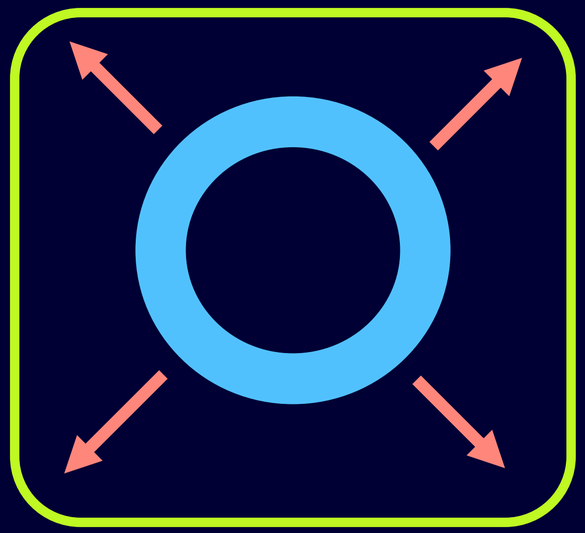
Contents

- Compact Sources
- Axions with m=(MeV-GeV)
- Making a fireball
- Revising existing constraints
- Adding new constraints



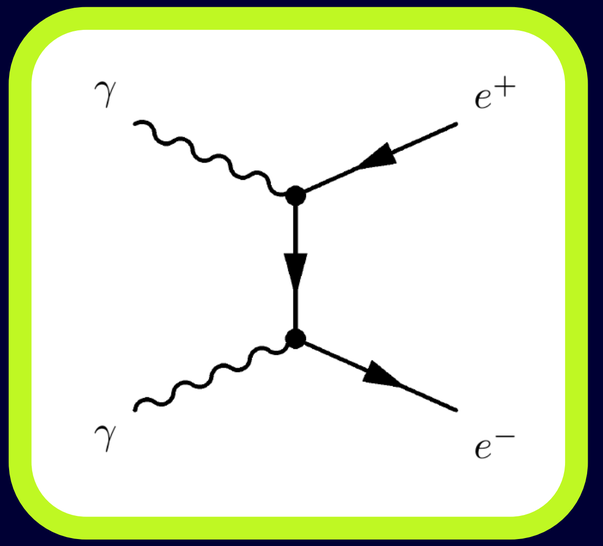
“Fast Scattering”

Expansion

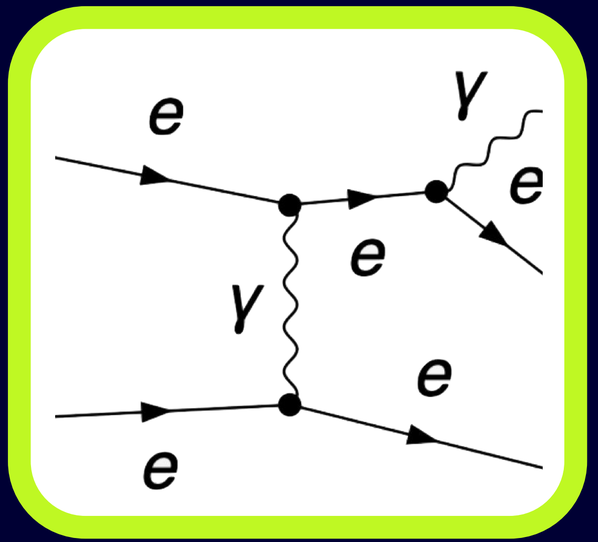


VS

Pair Production



Bremsstrahlung



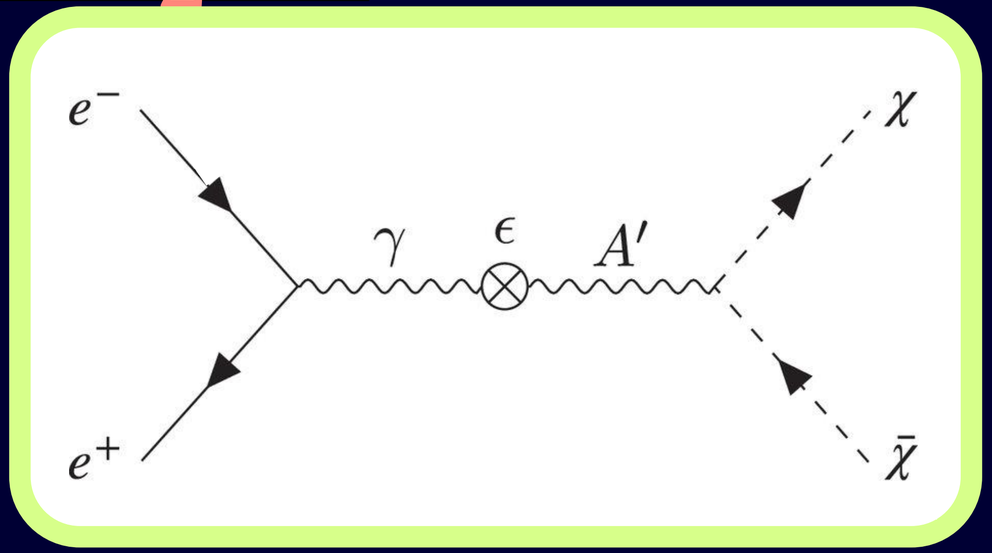
Dark photons $\rightarrow e^+ + e^-$

Axions $\rightarrow \gamma + \gamma$

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

$n + p \rightarrow n + p + A$