Observable Flashes from Dark Photons in Binary Neutron Star Mergers

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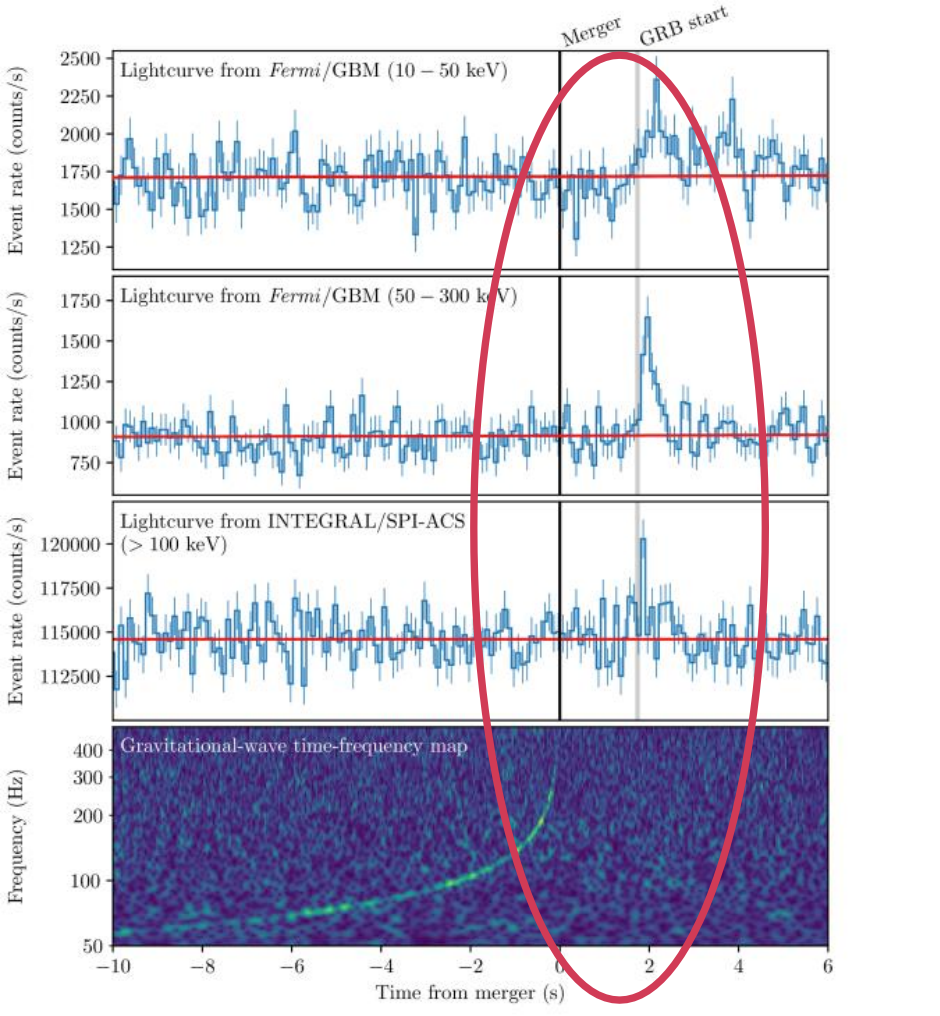
Ongoing work with Gustavo Marques Tavares

Multimessenger Astrophysics



SN1987a
Neutrinos + photons=
broad constraints on new physics

GW 170817
Gravitational waves + photons=
A new probe of extreme physics

How can we use Binary Neutron Star Mergers to probe new physics?

Binary Neutron Star Mergers
A Window into the Dark Sector

Neutron star merger produce MeV scale particles

Dark sector decay -> produce gamma ray signal

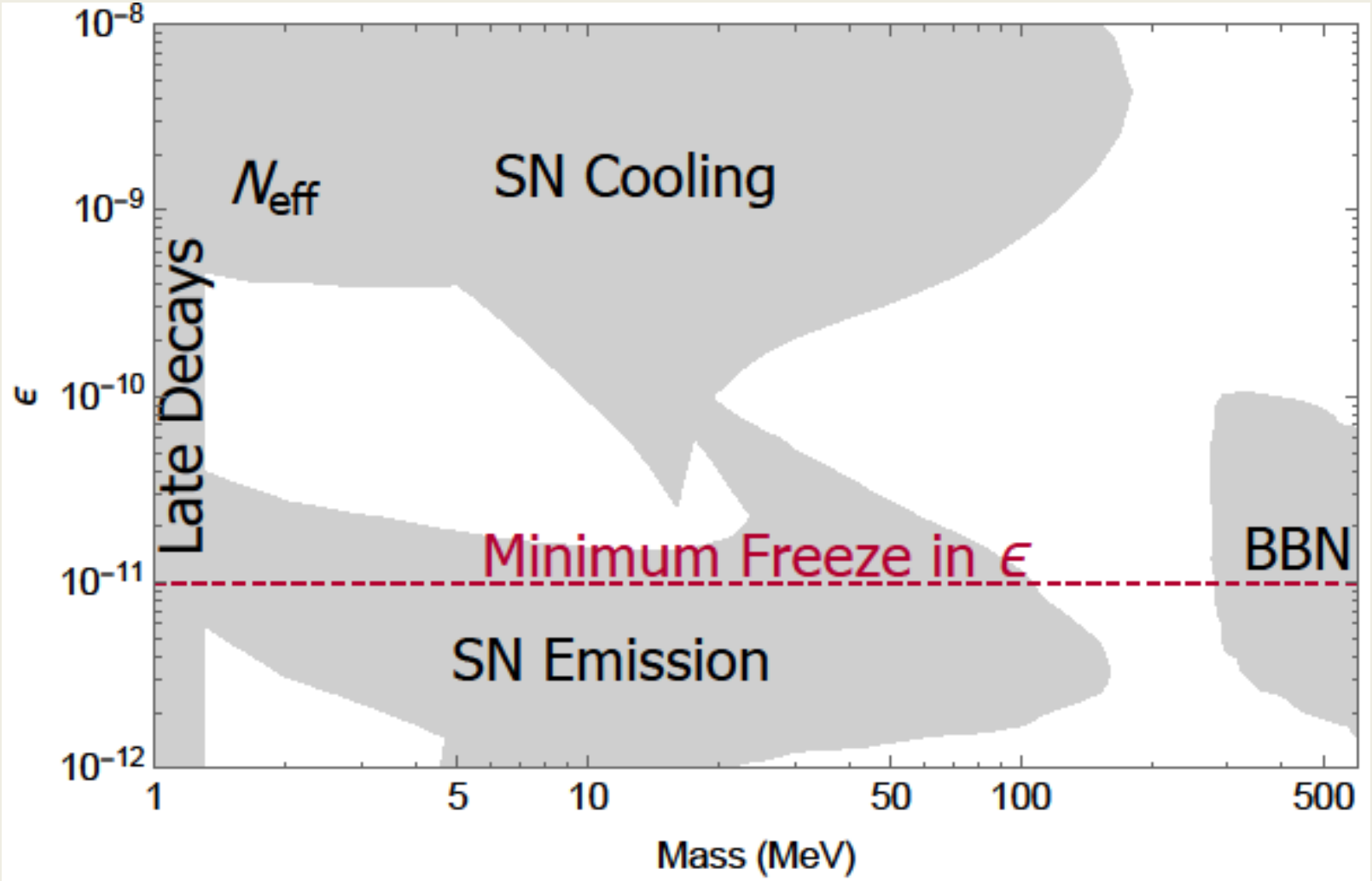
Detect unique dark sector signals using gravitational waves and photons together

Dark photons

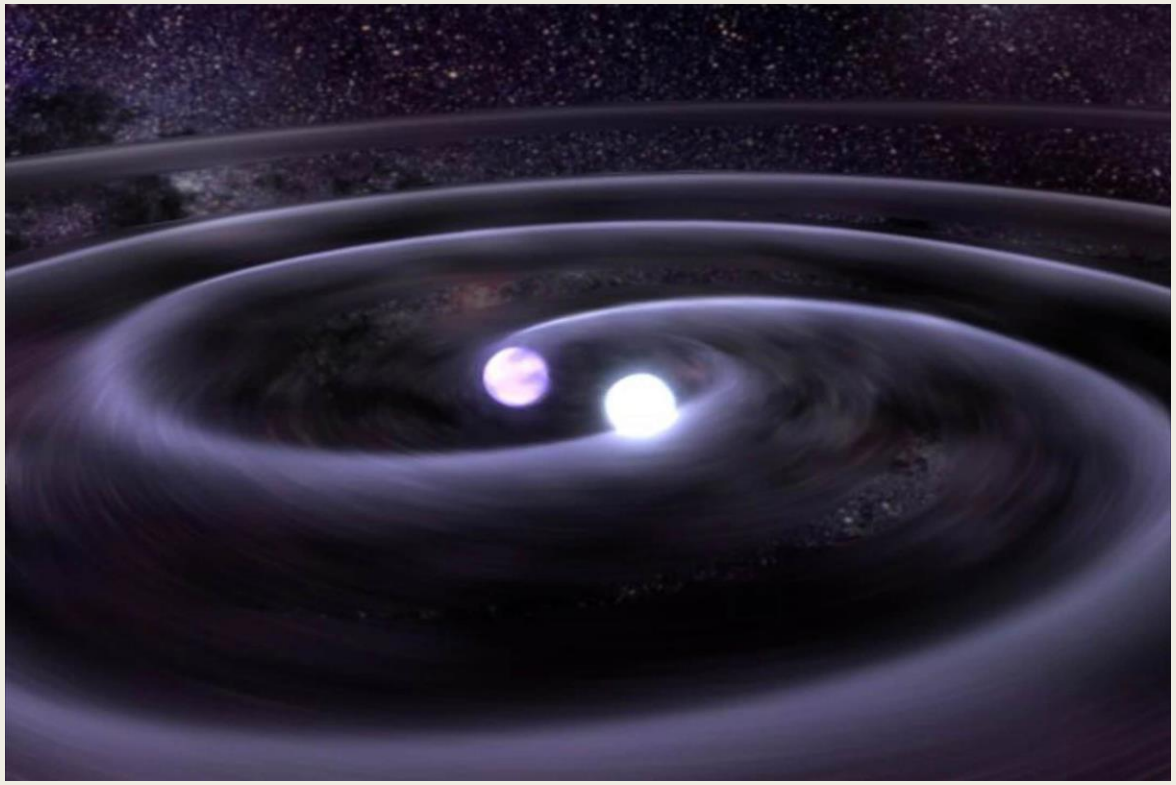
$$\mathcal{L} \supset -\frac{1}{4}F'^2 - \frac{\epsilon}{2}FF' + \frac{m'^2}{2}A'^2$$

- Massive Vector
- Kinematically mixes with the photon
- Connects dark sector to standard model

Dark photon parameter space



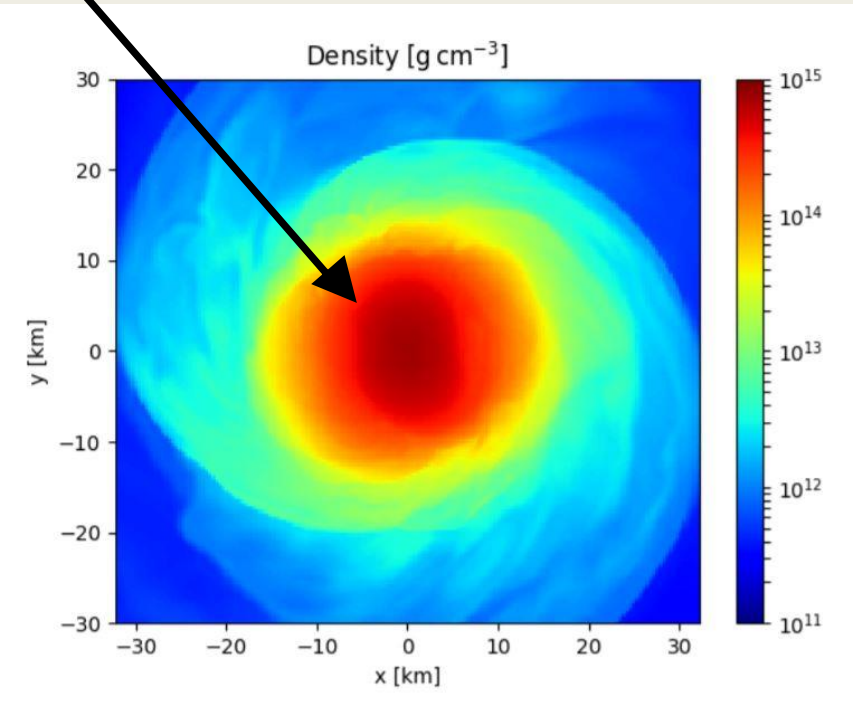
Why Binary Neutron Star Mergers?



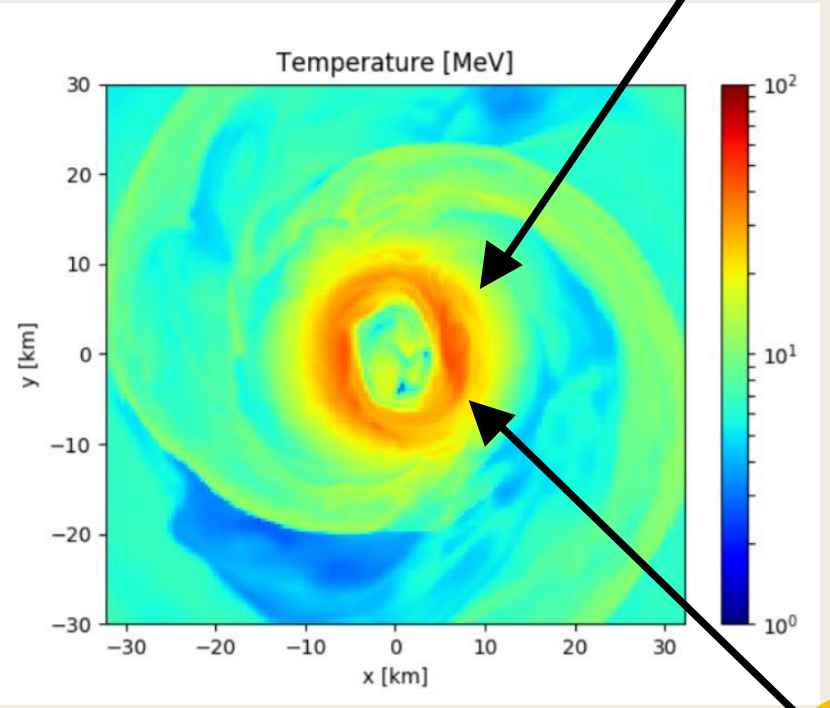
- Solar mass in a 10 km region $\rho \sim (100\ \text{MeV})^4$
- Friction and tidal heating heat the remnant to **T~ 30 MeV**
- Merger remnant long lived, remaining hot for **1 -1000 ms**
- Debris contained within **~1000 km**

BNM Characteristics

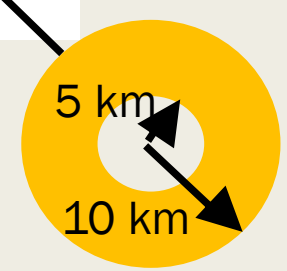
$\rho \sim 4 * 10^{14}\ g\ cm^3$



T~ 30 MeV



Perego, A., Bernuzzi, S., Radicce, D., Eur. Phys. J. A 55, 124



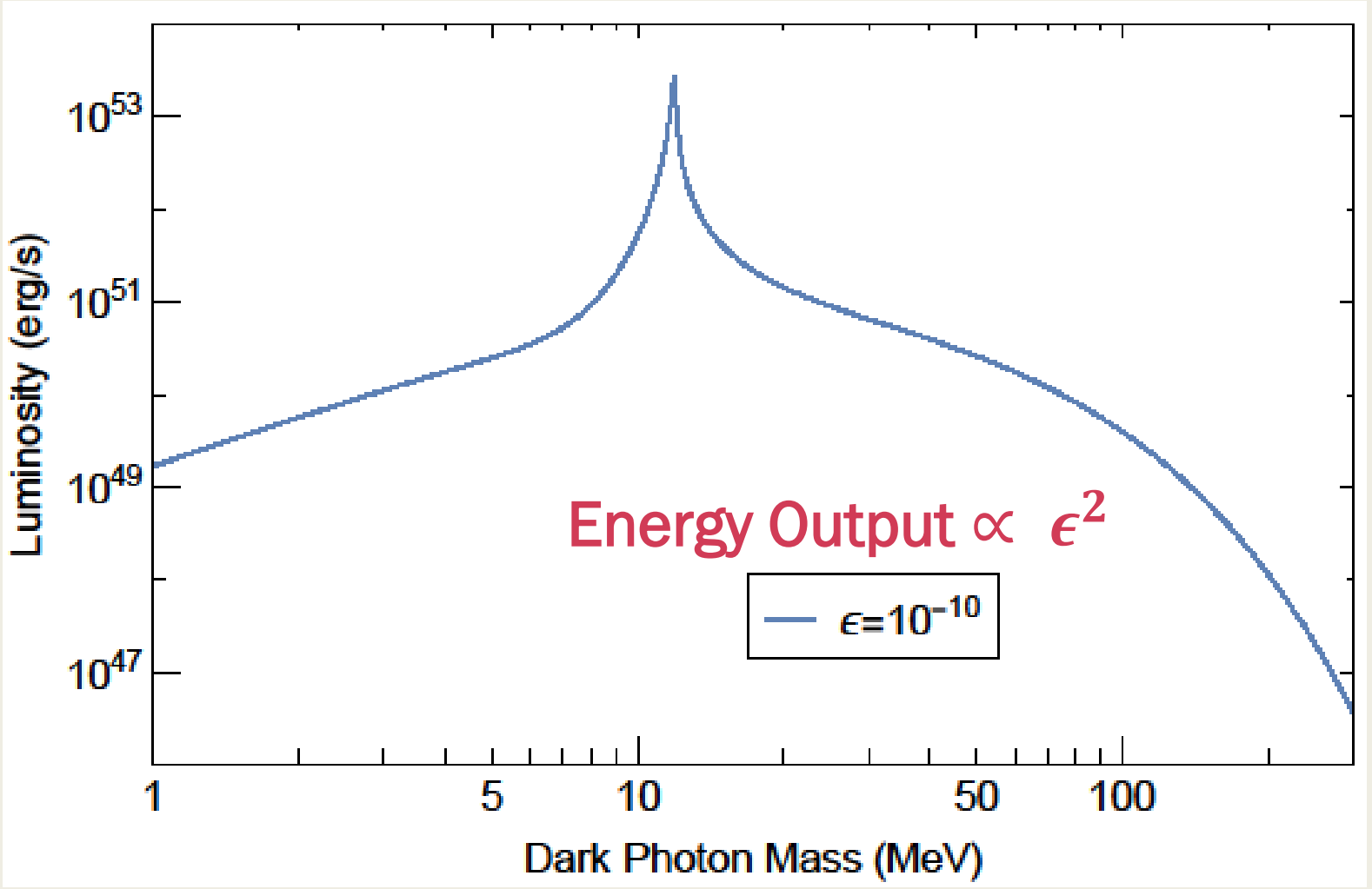
$Y_p \sim 0.1$

Emission Times: 10ms, 1s

Dark Photon Emission—Proof of Concept

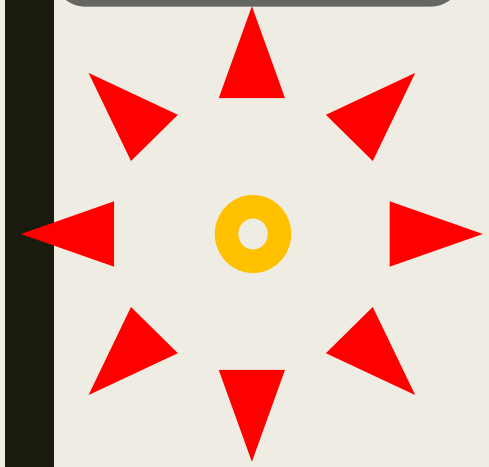
For comparison:

GRB 170817A
$E_{Tot} \sim 10^{45}$erg



From Merger to Observable signal

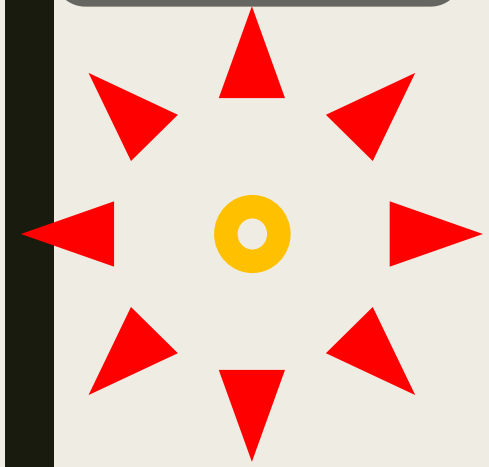
Merger Remnant Radiates Dark Photons



Energy Output $\propto \epsilon^2$

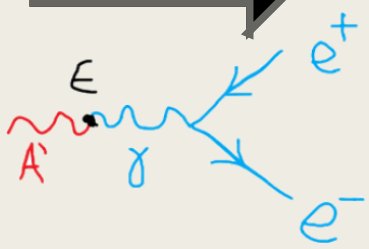
From Merger to Observable signal

Merger Remnant Radiates Dark Photons

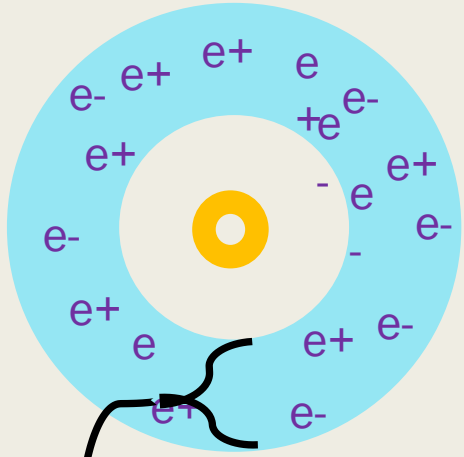


Energy Output $\propto \epsilon^2$

Dark Photons Decay



Expanding plasma shell formed

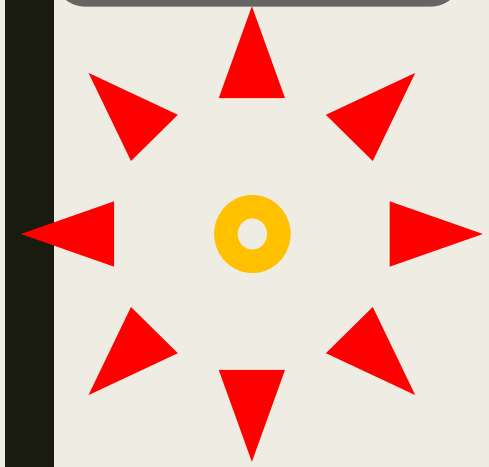


$$d \sim \left(\frac{10^{-9}}{\epsilon}\right)^2 \left(\frac{10\ \text{MeV}}{m'}\right) 10^4\ \text{km}$$

T~m'

From Merger to Observable signal

Merger Remnant Radiates Dark Photons



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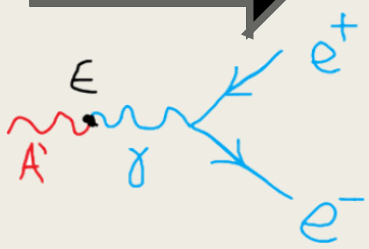
Dark Photons Decay



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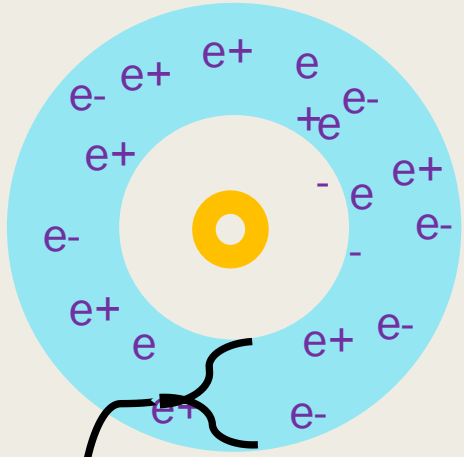
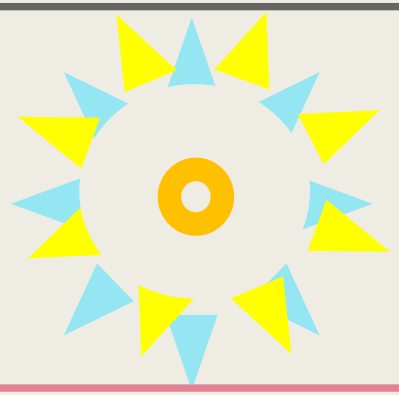


$d \sim \left(\frac{10^{-9}}{\epsilon}\right)^2 \left(\frac{10\ \text{MeV}}{m'}\right) 10^4\ \text{km}$

T~m'

e+e- scattering slow

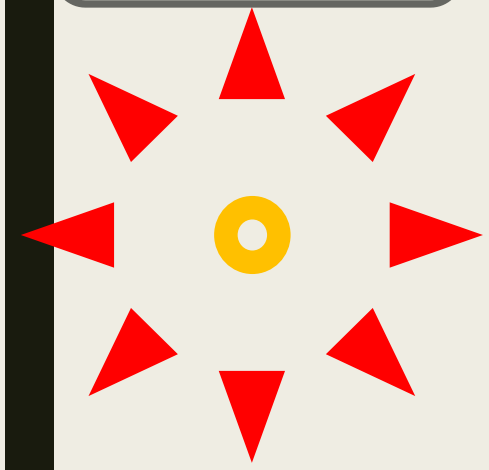
Non thermal signal



some γ formed
many e+ e- escape

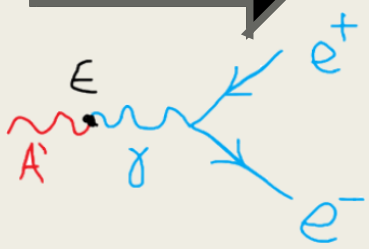
From Merger to Observable signal

Merger Remnant Radiates Dark Photons



Energy Output $\propto \epsilon^2$

Dark Photons Decay



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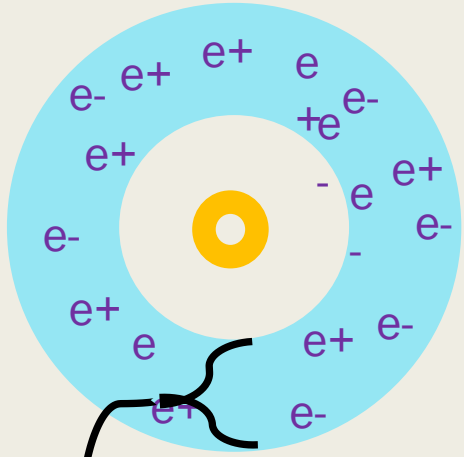
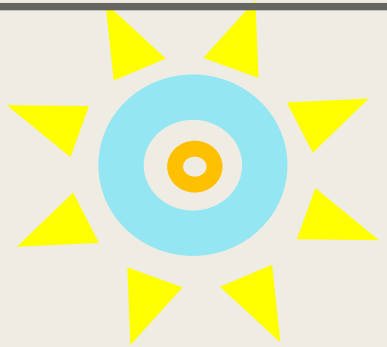


$$d \sim \left(\frac{10^{-9}}{\epsilon}\right)^2 \left(\frac{10\ \text{MeV}}{m'}\right) 10^4\ \text{km}$$

T~m'

e+e- scattering **fast**

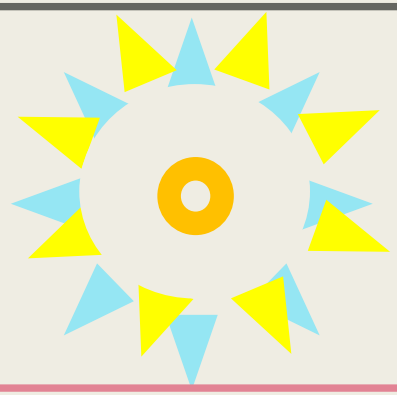
Thermal Fireball



Bright γ signal

e+e- scattering **slow**

Non thermal signal



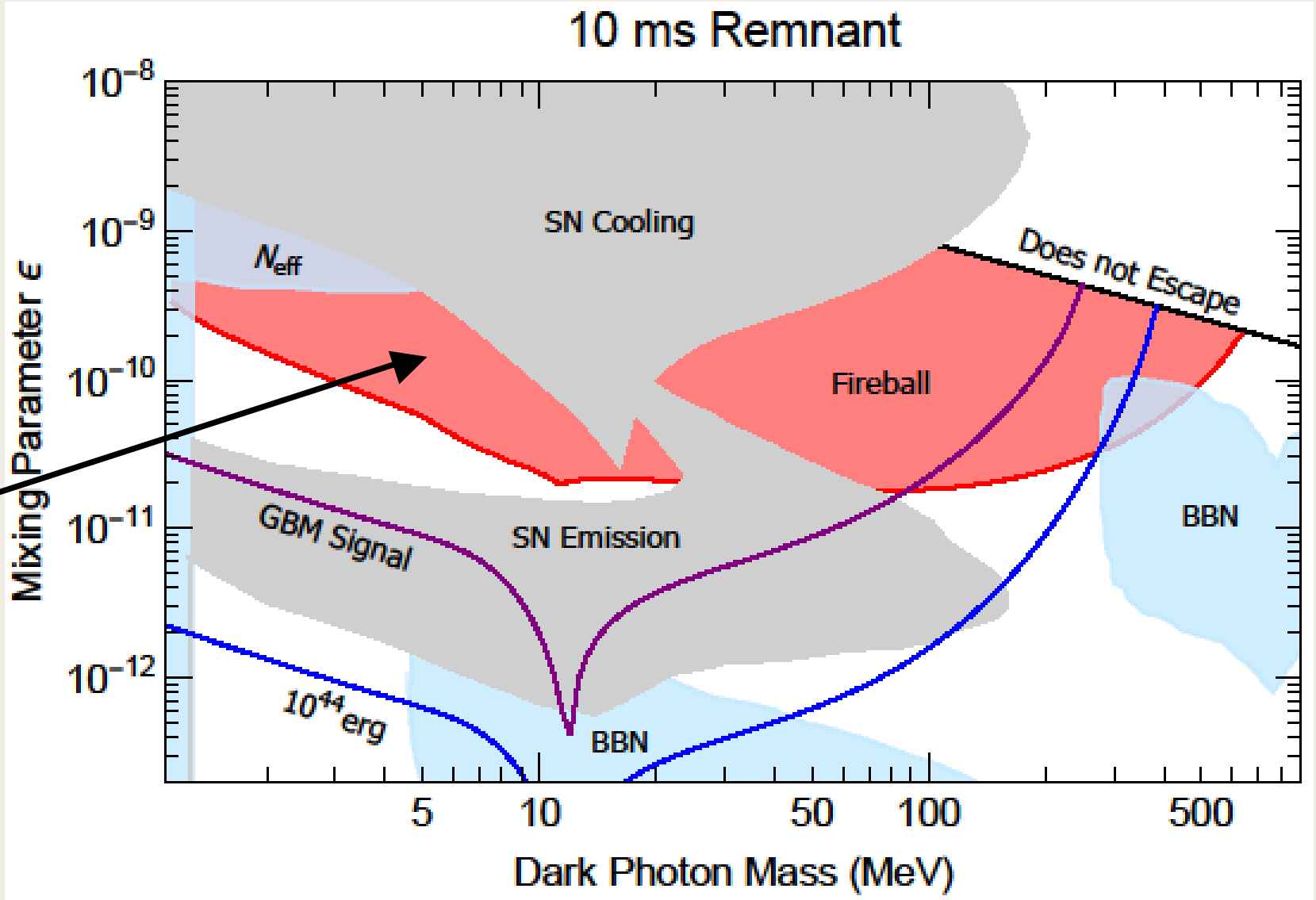
some γ formed
many e+ e- escape

The Thermal Fireball Case

- Plasma shell is initially opaque to photons and cooling by expansion
- Plasma thermalizes if pair annihilation and bremsstrahlung happen quickly compared to the expansion rate
- Bremsstrahlung drives the plasma temperature below m_e, number of electrons in plasma drops, and photons are free to escape
- **Resulting signal** should be roughly **thermal** and **isotropic**

$$\langle E_\gamma \rangle \sim 100 \text{ KeV}$$

Results



Observable signal

Conclusion and Outlook

- Binary neutron star mergers provide a new way to investigate the dark sector
- Future merger events should give information about the viable freeze in parameter space for dark photons with masses between 1-100 MeV
- Detection prospects will improve as midband gravitational wave detectors and new MeV telescopes come online

Thank you!

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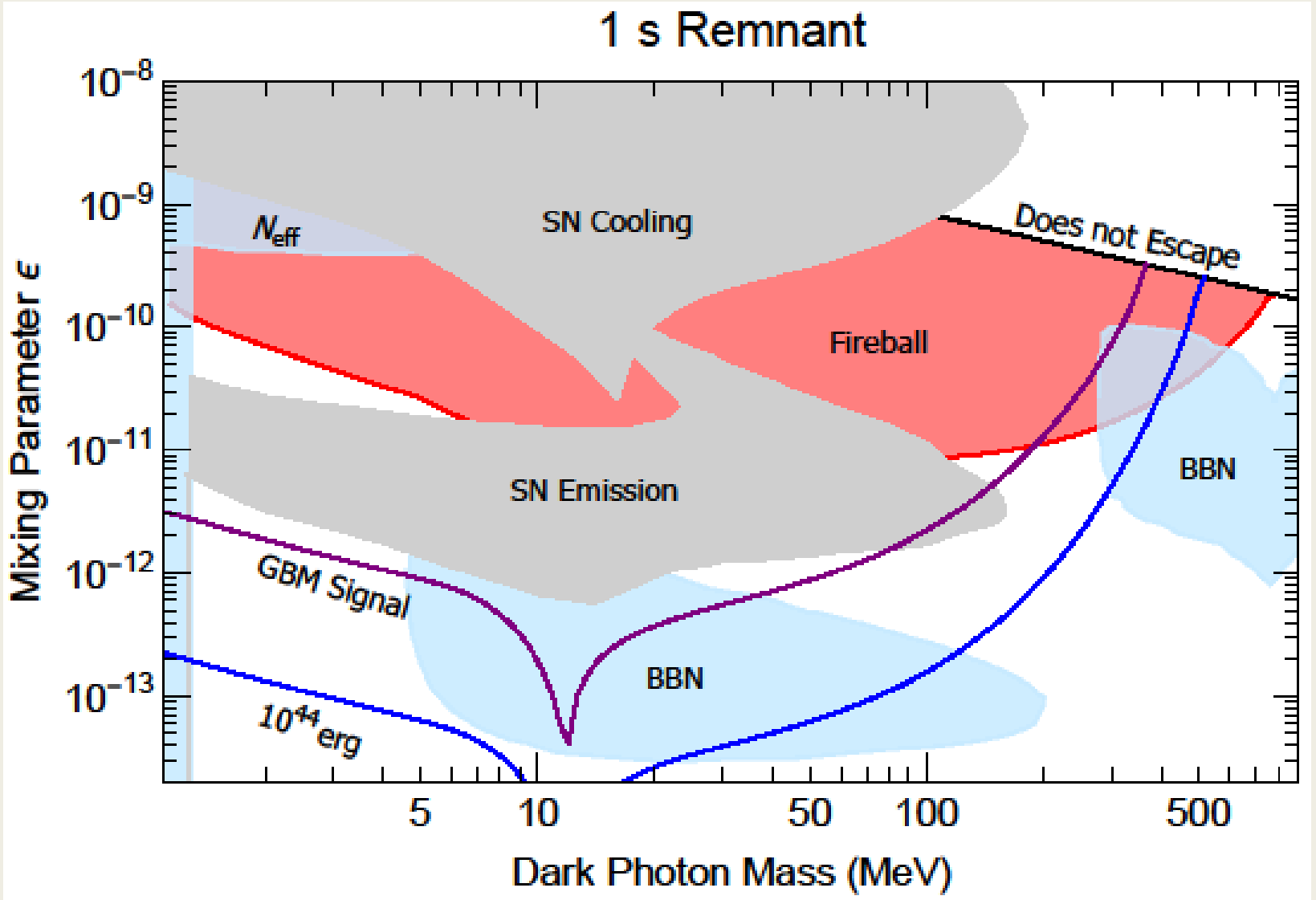
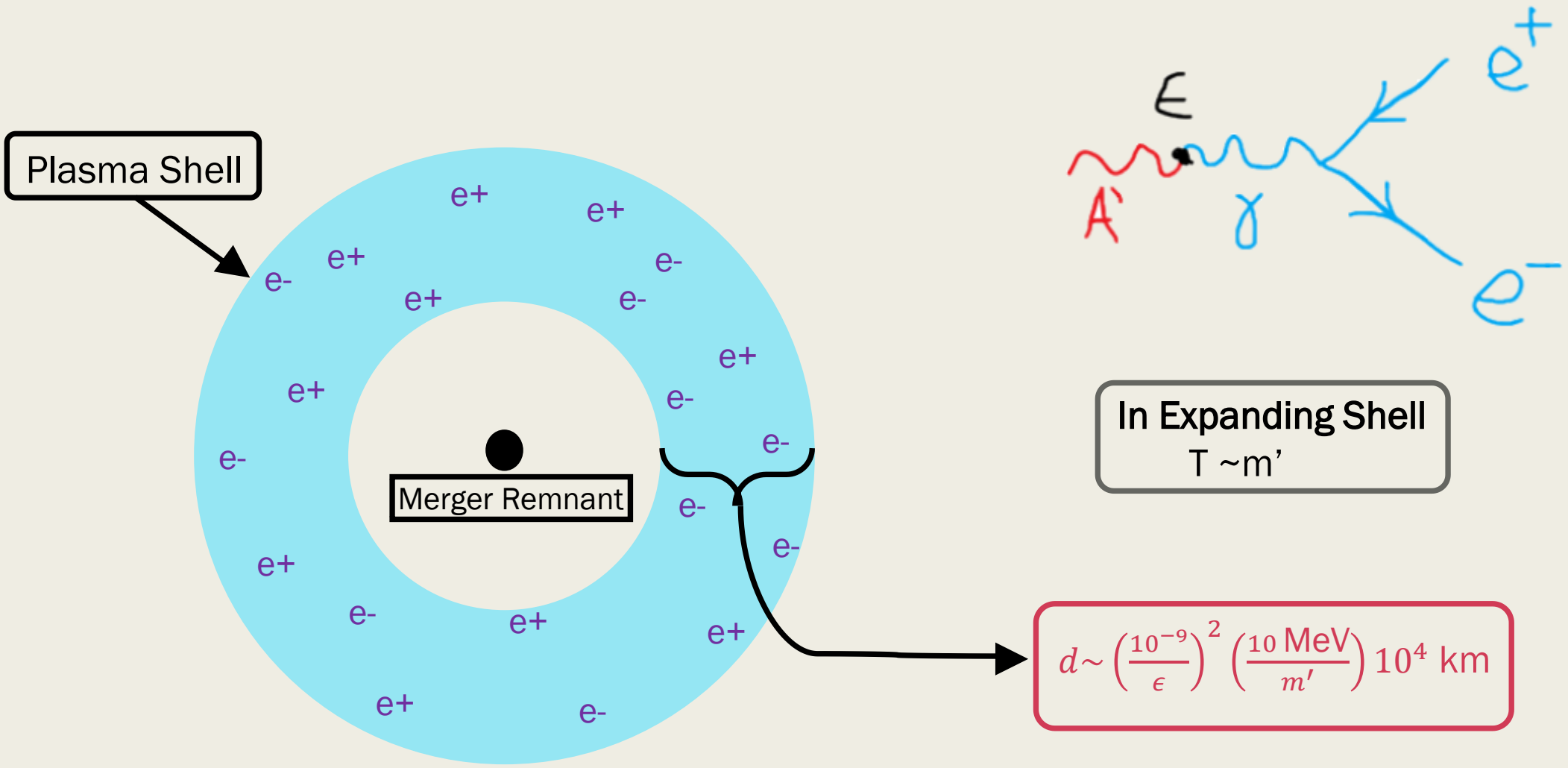
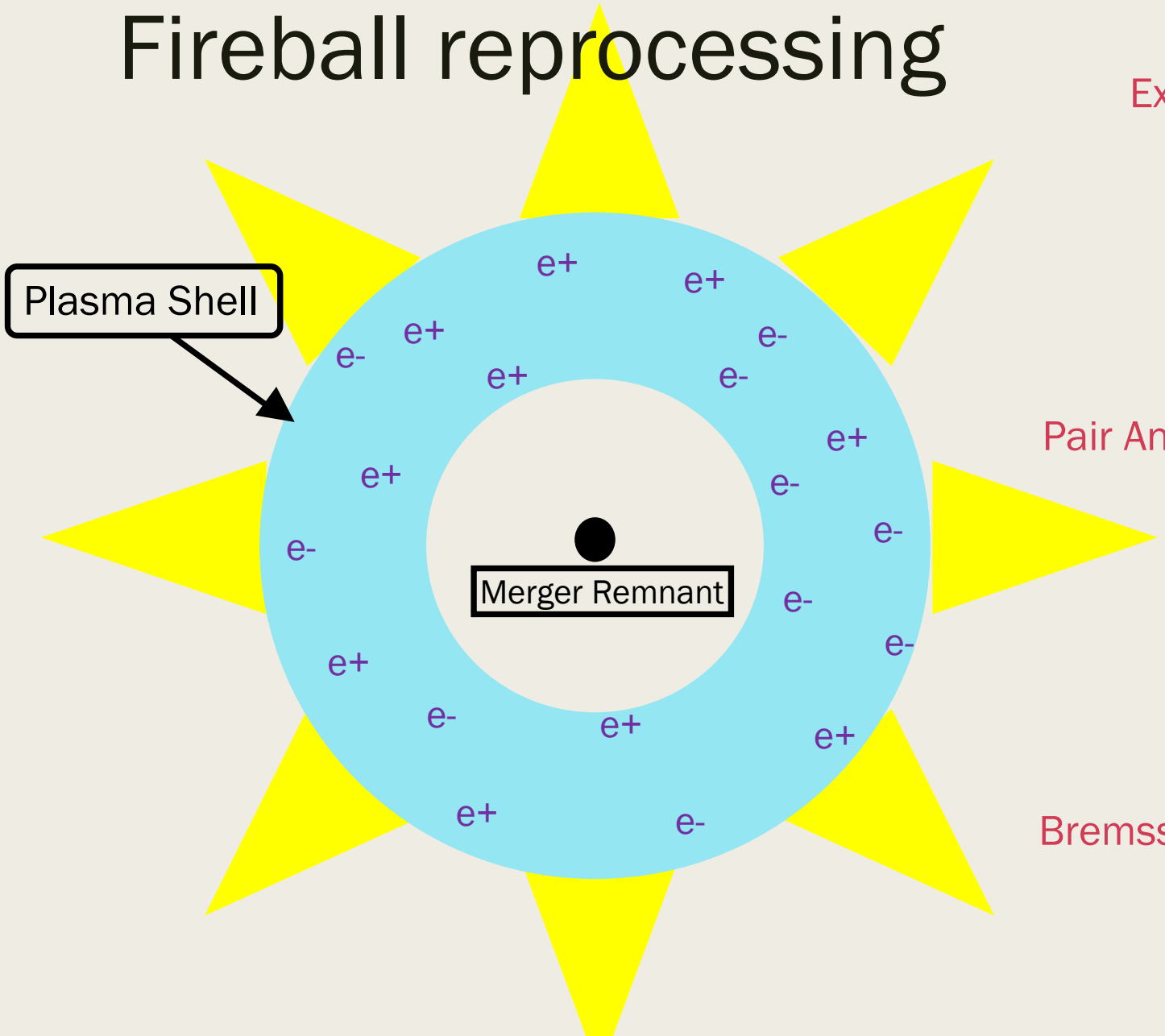
Results


1 s Remnant
Mixing Parameter ϵ
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
N_{eff}
SN Cooling
Does not Escape
Fireball
SN Emission
BBN
GBM Signal
BBN
10^{44} erg
5
10
50
100
500
Dark Photon Mass (MeV)

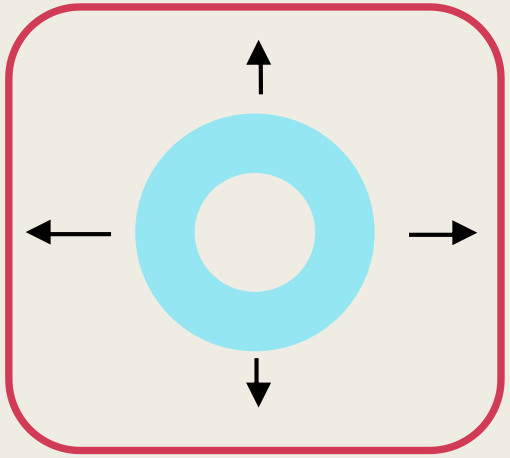
Dark photon decay



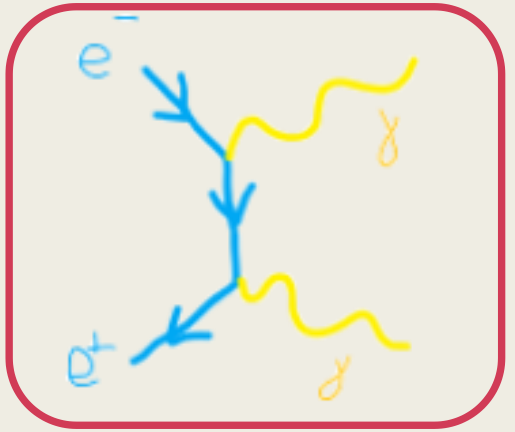
Fireball reprocessing



Expansion



Pair Annihilation



Bremsstrahlung