Search for Dark Photon Trident via PBH Signatures

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Searching for Dark Photon Tridents Through Primordial Black Hole Signatures

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The detection of gamma-ray signals from primordial black holes (PBHs) could provide compelling evidence for their role as a dark matter candidate, particularly through the observation of their Hawking radiation. Future gamma-ray observatories, such as e-ASTROGAM, and the next-generation telescopes, are poised to explore this possibility by measuring both Standard Model (SM) and beyond-the-SM particle emissions. A particularly promising avenue involves production of dark photons by PBHs, which is a hypothetical particle that decays into photons. In this work, we investigat the trident decay of dark photons focusing on their primary emission from PBHs. We assume that the dark photons produced via Hawking radiation decay into photons well before reaching Earth, thereby enhancing the detectable gamma-ray flux. The energy spectrum of the photons decaying from the dark photons is distinct from that of direct Hawking-radiated photons due to higher degree of freedom, leading to observable modifications in the gamma-ray signal. Using the asteroid-mass PBHs as a case study, we demonstrate that future gamma-ray missions could detect dark-photon signatures and distinguish them from conventional Hawking radiation. This approach enables the exploration of previously inaccessible parameter spaces in dark photon mass $m_{A'}$ and their coupling to photons, offering a novel pathway to uncover the properties of dark sectors and the nature of PBHs.

Outline

- Introduction : PBH as DM, Hawking radiation, motivation..
- Dark photon theory & its trident decay
- Signatures from PBH :photon spectrum altered due to trident decay
- Numerical Analysis & Results

  - methodology, discovery & distinguishability limits
- Conclusion

I. Introduction

PBH as a Dark Matter Candidate

- Primordial black holes (PBHs) may account for some or all of dark matter due to their non-luminous nature and longevity.
- PBHs with masses larger than 10^{15} g can survive until today, contributing to CDM

- PBH Formation:

- Generated in the early Universe through collapsing over-dense regions under gravity.
- Key formation scenarios include inflationary perturbations, bubble collisions from first-order phase transitions, and cosmic string collapse.
- These mechanisms cover a broad range of mass scales, influencing which PBHs might survive until today, and hence, which ones could still be contributing to ρ_{DM}.

Hawking Radiation

- Once the PBH mass falls below around 10^{15}g, PBHs emit both SM and BSM particles significantly. (CMP43(1975),PRD15(1977))
- The emitted particle spectra depend only on $T_{\mathrm{H}} \sim \frac{1}{M_{\mathrm{PBH}}}$, the masses and spins of the particles, regardless of their interaction strengths.
- Therefore, in collider experiments, production of feebly interacting particles is highly suppressed, but PBHs don’t care about it.
- PBHs lighter than 10^{15} g are expected to have completely evaporated by now, unless new physics alters their lifetime. → standard picture of HR

Memory Burden Effect

- Considering the back-reaction of emission on the quantum states of BH may modify the standard picture of Hawking radiation → "memory burden effect"

(G. Dvali, 1810.02336, Dvali etal. RPD110(2024))

- This effect arises from the quantum information stored in BH, which acts to resist further evaporation.
- Once BH loses a significant fraction of its initial mass, the back-reaction becomes strong enough to suppress or slow down the evaporation process, thereby extending its lifetime.
- Due to the memory burden effect, even lighter PBH($<10^9$ g) could survive to this day.
- For such a lighter PBH the photon spectrum would be shifted to higher energies

Memory Burden Effect

- If MBE is considered, the evaporation process of a PBH can be divided in two phases: (i) semi-classical Hawking-like phase, during which the PBH evolves according to the standard picture. (ii) burdened phase, characterized by the stabilization of the PBH by memory burden.
- When the PBH enters its burdened phase, its emission rate becomes suppressed according to

$$\frac{\mathrm{d}M_{\mathrm{PBH}}^{\mathrm{mb}}}{\mathrm{d}t} = \frac{1}{S(M_{\mathrm{PBH}})^k}\frac{\mathrm{d}M_{\mathrm{PBH}}}{\mathrm{d}t} \quad \text{with} \quad k > 0\,.$$

$$S(M_{\mathrm{PBH}}) = 4\pi M_{\mathrm{PBH}}^2$$

$$\frac{\mathrm{d}M_{\mathrm{PBH}}}{\mathrm{d}t} \sim \frac{1}{G^2 M_{\mathrm{PBH}}^2}$$

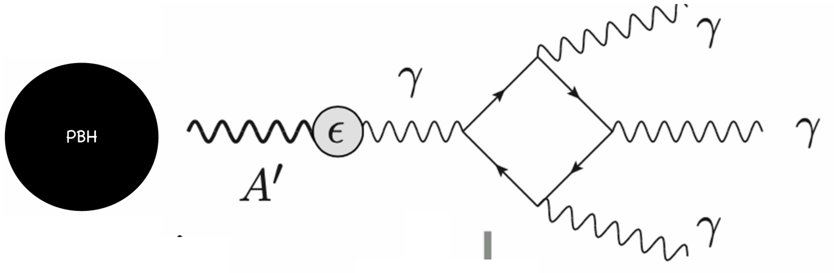
Motivation

- Rather than focusing solely on PBHs themselves, we extend our search to include BSM particles that may be emitted via Hawking radiation.
- This approach broadens our probe of new physics by leveraging the unique signatures associated with PBH evaporation.
- We aim to investigate the potential signature of dark photons emitted from PBHs which could provide a new window into both dark sector physics and the nature of BH evaporation.

II. Dark Photon & Its Trident Decay

Dark Photon and its Trident Decay

- Dark photon arises from a U(1) extension of the SM, and mixes with photon.
- If $m_{A'} < 2m_e$, the dominant decay mode is via loop-level trident mode A′ → 3γ.



Dark photon trident decay (2406.1944)

- Photon spectrum from this 3-body decay is distinct from that of 2-body decay
- This signal is likely inaccessible in colliders due to extremely low detectability arising from small kinetic mixing, loop suppression, and limited resolution.
- But, we may overcome these challenges by considering this decay via Hawking radiation from PBH.

Dark Photon and its Trident Decay

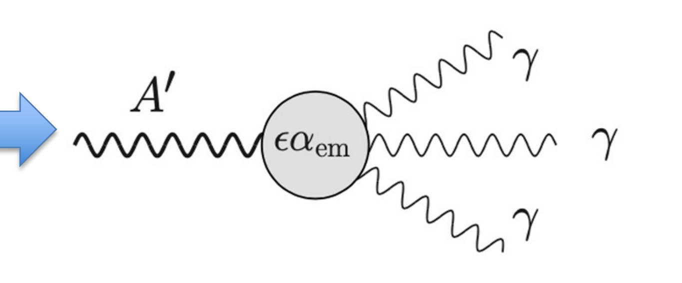
- The Lagrangian for the dark photon is given by

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{2}m^2_{A'}A'_\mu A'^\mu - \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}, \qquad F'_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu,$$

- The mass term for the dark photon can arise from a dark Higgs mechanism (Mondino et al PRD103(2021)) or the Stueckelberg model (Kingmna et al, JHEP03(2007))

- By integrating out fermions at one-loop, the resulting effective Lagrangian follows the Euler-Heisenberg form:

$$\mathcal{L}^{\mathrm{EH}}_{A'} = \frac{\epsilon\alpha_{\mathrm{em}}}{45m_e^4}\left(14F'_{\mu\nu}F^{\nu\lambda}F_{\lambda\rho}F^{\rho\mu} - 5F'_{\mu\nu}F^{\mu\nu}F_{\alpha\beta}F^{\alpha\beta}\right),$$



Dark Photon and its Trident Decay

- The decay width in the Euler-Heisenberg limit

$$\Gamma_{\rm EH} = \frac{17\epsilon^2\alpha_{\rm em}^4}{11664000\pi^3} \times \frac{m_{A'}^9}{m_e^8} \simeq 1{\rm s}^{-1} \times \left(\frac{\epsilon}{0.003}\right)^2 \times \left(\frac{m_{A'}}{m_e}\right)^9$$

- To account for corrections beyond the Euler-Heisenberg limit, the full decay width can be expressed as

$$\Gamma_{A'\to 3\gamma} = \Gamma_{\rm EH} \times f_{\rm loop}(m_{A'}) = \Gamma_{\rm EH}\left[1 + \sum_{n=1}^{\infty} c_k \left(\frac{m_{A'}^2}{m_e^2}\right)^n\right],$$

(T. Tait et al: 2406.1944)

- Coefficients in the expansion of the decay width for a dark photon mass below twice the electron mass up to the sixth order
- The series is expected to converge

	c_k	$c_k \times 4^k$
c_1	335 / 714	1.88
c_2	128,941 / 839,664	2.46
c_3	44,787 / 1,026,256	2.79
c_4	1,249,649,333 / 108,064,756,800	5.92
c_5	36,494,147 / 12,382,420,050	3.02
c_6	867,635,449 / 1,614,300,688,000	2.20

III. Signature from PBH

Photon Spectrum from Trident Decay

- The energy spectrum of photons produced in dark-photon trident decay :

$$\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma} = \frac{2x^3}{17m_{A'}}(1715 - 3105x + \frac{2919}{2}x^2),$$

(T. Tait et al: 2402.01839)

$x = 2E_\gamma/m_{A'}$ varies between 0 and 1.

- Energy spectrum from the dark photon trident decay in the laboratory(lab) frame can obtained using the following formula :

$$\frac{dN'_\gamma}{dE'_\gamma} = \frac{1}{2}\int dE_\gamma \, d\cos\theta \, \frac{dN_\gamma}{dE_\gamma}\delta\left(E'_\gamma - \gamma(E_\gamma + \beta p\cos\theta)\right)$$

$$= \frac{1}{2}\int_{E'_1}^{E'_2} dE_\gamma \frac{dN_\gamma}{dE_\gamma}\frac{1}{p\beta\gamma},$$

$$E'_2 = \gamma(E'_\gamma + p'\beta)$$

$$E'_1 = \gamma(E'_\gamma - p'\beta)$$

Photon Spectrum from Trident Decay

- The total photon spectrum is computed by integrating contributions from all relevant decay and radiation channels.

$$\frac{\partial N_{\gamma,\mathrm{tot}}}{\partial E_\gamma \partial t} = \frac{\partial N_{\gamma,\mathrm{primary}}}{\partial E_\gamma \partial t} + \int dE_{A'} \frac{\partial N_{A',\mathrm{primary}}}{\partial E_{A'} \partial t} \frac{dN_{A',\mathrm{decay}}}{dE_\gamma} + \int dE_{\pi^0}\, 2\frac{\partial N_{\pi^0,\mathrm{primary}}}{\partial E_{\pi^0} \partial t} \frac{dN_{\pi^0,\mathrm{decay}}}{dE_\gamma} + \sum_{i=e^\pm,\mu^\pm,\pi^\pm} \int dE_i \frac{\partial N_{i,\mathrm{primary}}}{\partial E_i \partial t} \frac{dN_{i,\mathrm{FSR}}}{dE_\gamma}.$$

$$\frac{\partial N_{i,\mathrm{primary}}}{\partial E_i \partial t} = \frac{g_i}{2\pi} \frac{\Gamma_i(E_i, M, m_i)}{e^{E_i/T_H} \pm 1},$$

Γ_i : greybody factor

T_H : Hawking temperature ($1/8\pi GM$)

$$\frac{dN_{i,\mathrm{FSR}}}{dE_\gamma} = \frac{\alpha}{\pi Q_i} P_{i\to i\gamma}(x) \left[\log\left(\frac{1-x}{\mu_i^2}\right) - 1\right],$$

$$\frac{dN_{\pi^0,\mathrm{decay}}}{dE_\gamma} = \frac{\Theta(E_\gamma - E_{\pi^0}^-)\Theta(E_{\pi^0}^+ - E_\gamma)}{E_{\pi^0}^+ - E_{\pi^0}^-},$$

$$E_{\pi^0}^\pm = \frac{1}{2}\left(E_{\pi^0} \pm \sqrt{E_{\pi^0}^2 - m_{\pi^0}^2}\right),$$

$$P_{i\to i\gamma}(x) = \begin{cases} \frac{2(1-x)}{x}, & i = \pi^\pm \\ \frac{1+(1-x)^2}{x}, & i = \mu^\pm, e^\pm \end{cases}$$

$$x = \frac{2E_\gamma}{Q_i},\ \mu_i = \frac{m_i}{Q_i},\ \text{and } Q_i = 2E_i.$$

We take into account the MB effect in the analysis

Photon Spectrum from Trident Decay

- The photon flux observed near Earth:

$$\frac{d\Phi_\gamma}{dE_\gamma} = \bar{J}_D \frac{\Delta\Omega}{4\pi} \int dM \frac{f_{\rm PBH}(M)}{M} \frac{\partial N_{\gamma,tot}}{\partial E_\gamma \partial t},$$

$$\bar{J}_D = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{\rm LOS} dl \, \rho_{\rm DM}.$$

$f_{\rm PBH}$: fraction of DM composed of PBH

- Using a Navarro–Frenk White(NFW) profile

$$\rho_{\rm DM}(r) = \frac{\rho_s}{\frac{r}{r_s}\left(1+\frac{r}{r_s}\right)^2} \Theta(r_{200} - r),$$

$$r_s = 11 \text{ kpc}, \ \rho_s = 0.838 \text{ GeV/cm}^3, \ r_{200} = 193 \text{ kpc}$$

- For a region of interest within $|R| < 5^\circ$ of Galactic Center

$$\bar{J}_D = 1.597 \times 10^{26} \text{ MeV cm}^{-2}\text{sr}^{-1}, \qquad \Delta\Omega = 2.39 \times 10^{-2} \text{sr}.$$

Photon Spectrum from Trident Decay

- We take into account the average probability of dark photon decaying during its propagation from the GC to Earth

$$\langle P_{A',\text{decay}} \rangle \equiv \frac{\Phi_{A',\text{dec}}}{\Phi_{A',\text{tot}}},$$

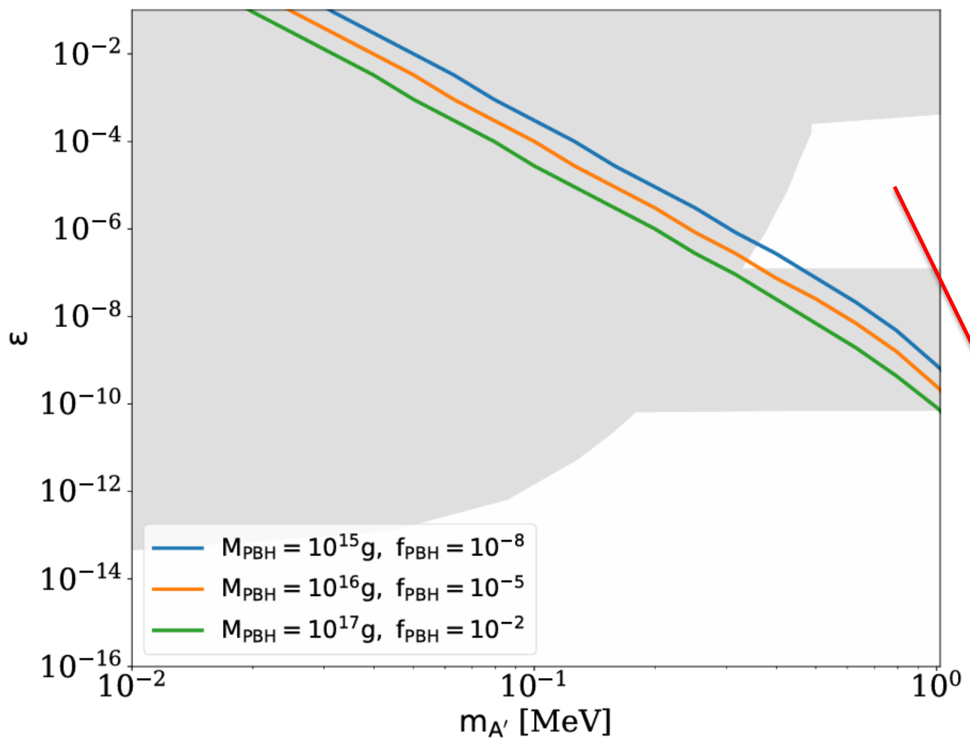
$$\Phi_{A',\text{tot}} = \int_{\Delta\Omega} \frac{d\Omega}{4\pi} \int_{\text{LOS}} d\ell \int dE_{A'} \frac{f_{\text{PBH}}\rho_{\text{DM}}}{M_{\text{PBH}}} \frac{\partial N_{A',\text{primary}}}{\partial E_{A'} \partial t} = \bar{J}_D \frac{\Delta\Omega}{4\pi} \frac{f_{\text{PBH}}}{M_{\text{PBH}}} \int dE_{A'} \frac{\partial N_{A',\text{primary}}}{\partial E_{A'} \partial t}$$

$$\Phi_{A',\text{dec}} = \int_{\Delta\Omega} \frac{d\Omega}{4\pi} \int_{\text{LOS}} d\ell \int dE_{A'} \frac{f_{\text{PBH}}\rho_{\text{DM}}}{M_{\text{PBH}}} \frac{\partial N_{A',\text{primary}}}{\partial E_{A'} \partial t} P_{A',\text{decay}}(E_{A'}, \ell).$$

- The decay probability :

$$P_{A',\text{decay}}(E_{A'}, D) = 1 - \exp\left(-D\, \Gamma_{A' \to 3\gamma} \frac{m_{A'}}{\sqrt{E_{A'}^2 - m_{A'}^2}} \right),$$

- Since $\Gamma_{A' \to 3\gamma} \propto \epsilon^2$, we can determine the value of ϵ, for a given $m_{A'}$ and $\langle P \rangle$



The parameter space for dark photons that can be explored using PBHs

- The curves correspond to $\langle P \rangle$=99%
- In the numerical analysis, we require $\langle P \rangle \geq$ 99%
- The gray region is disallowed by experimental constraints (JCAP07 (2012) 026)
- So, this PBH dark-photon scenario can probe the unexplored parameter space

$$10^{-7} \leq \epsilon \leq 10^{-3} \text{ and } m_{A'} \geq 0.5 \text{ MeV}$$

IV. Numerical Analysis

Methodology

- For numerical results, we perform the likelihood analysis by assuming a reference model that generates an observable gamma-ray signal (PRD105,123009, PRD108, 023014), which, in our case, corresponds to the astrophysical background given by exps.
- Two test models for PBH are (i) the SM scenario, (ii) the dark photon scenario
- The probability that the Test model reproduces the gamma-ray signal predicted by the reference model follows the Poisson statistics represented as

$$\mathcal{L} = \exp\left(\sum_i n_i \ln \sigma_i - \sigma_i - \ln n_i!\right)$$

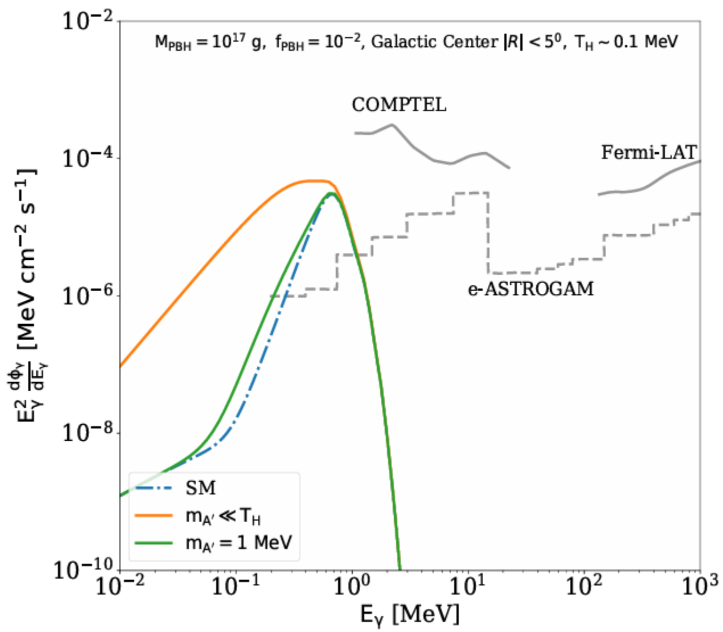
n_i: observed photon counts from reference
σ_i : expected photon counts from test model

- To assess how distinguishable the test model is from reference, the test statistic (TS) is introduced

$$\mathrm{TS} = -2\ln\left(\frac{\mathcal{L}}{\mathcal{L}_{\mathrm{Ref}}}\right) = \Sigma^2,$$

→ A significance threshold of $\Sigma = 3$ is adopted

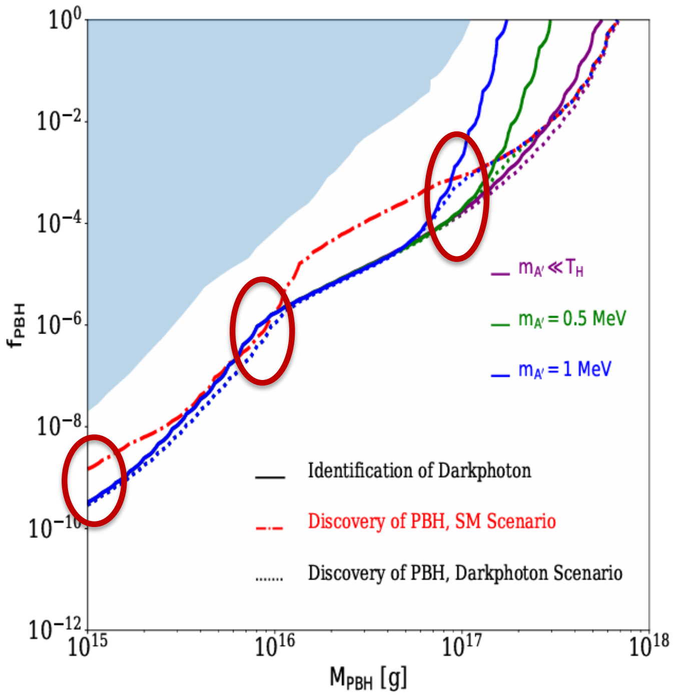
Photon spectrum from PBH: SM vs Dark Photon



- Production of dark photon is suppressed after the primary photon peak.
- E_γ is typically lower than the initial $E_{A'}$

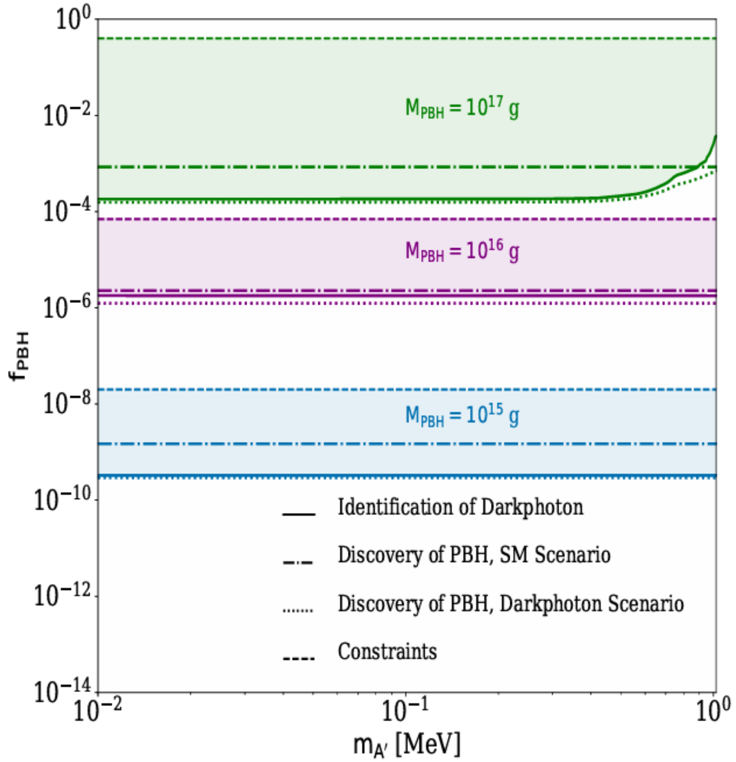
Distinguishability Limits

- To identify discovery regions, we scan the parameter space of each test model and select the points where $\Sigma > 3$.
- The resulting curves represent the discovery (lower) limits for each case



- (red) dot-dashed line : discovery limit of $f_{\rm PBH}$ for differentiating PBH with SM from bg.
- dotted lines : discovery limit of $f_{\rm PBH}$ for differentiating PBH with dark-photon from bg.
- Above each solid curve, the dark-photon induced signal is more readily distinguishable from bg. than that of the SM scenario

Distinguishability Limits



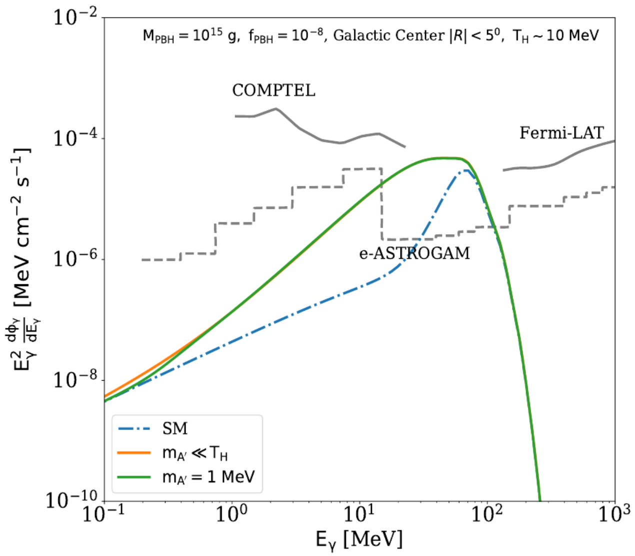
- dot-dashed line : discovery limit of f_{PBH} for differentiating PBH with SM from bg.
- dotted lines : discovery limit of f_{PBH} for differentiating PBH with dark-photon from bg.
- the solid curves : distinguishability limits between the dark-photon and SM scenarios

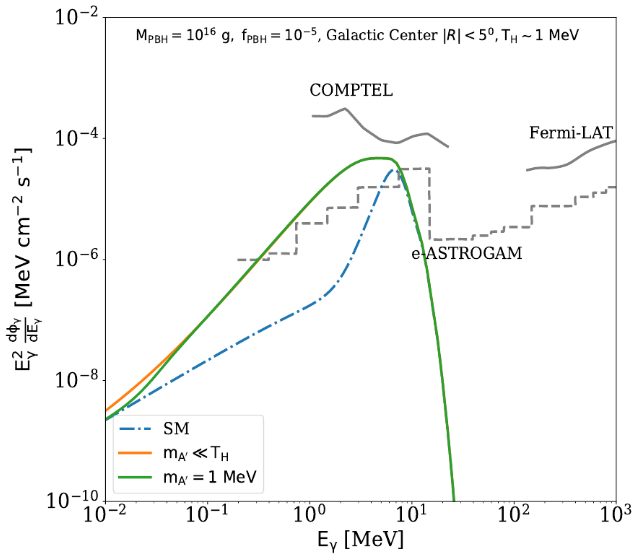
- For small $m_{A'}$, these curves remain relatively flat, as A' behaves effectively as relativisitc particle due to their high energies.
- For large $m_{A'}$, it becomes non-relativistic and its production is exponentially suppressed once $T_H < m_{A'}$

Conclusion

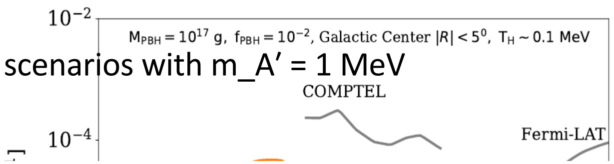
- We studied gamma-ray signals from PBHs, focusing on dark photon emission via Hawking radiation.
- The trident decay of dark photons produces distinct gamma-ray spectrum, helping to distinguish this scenario from the standard one.
- We showed that future detectors like *e-ASTROGAM* could explore new regions of dark photon parameter space, especially for asteroid-mass PBHs.
- These results suggest PBH evaporation could serve as a promising window into BSM.

15. Simulated Spectra (MPBH = 10^{15}g)





Comparison between SM and dark-photon scenarios with m_A’ = 1 MeV



16. Simulated Spectra (MPBH = 10^{16}g)

radiation (FSR) of primary particles. The total photon spectrum is expressed as:

$$\begin{aligned}
\frac{\partial N_{\gamma,\mathrm{tot}}}{\partial E_\gamma \partial t} &= \frac{\partial N_{\gamma,\mathrm{primary}}}{\partial E_\gamma \partial t} + \int dE_{A'}\, \frac{\partial N_{A',\mathrm{primary}}}{\partial E_{A'} \partial t} \frac{dN_{A',\mathrm{decay}}}{dE_\gamma} \\
&+ \int dE_{\pi^0}\; 2 \frac{\partial N_{\pi^0,\mathrm{primary}}}{\partial E_{\pi^0} \partial t} \frac{dN_{\pi^0,\mathrm{decay}}}{dE_\gamma} \\
&+ \sum_{i=e^\pm,\mu^\pm,\pi^\pm} \int dE_i \frac{\partial N_{i,\mathrm{primary}}}{\partial E_i \partial t} \frac{dN_{i,\mathrm{FSR}}}{dE_\gamma}. \qquad (9)
\end{aligned}$$

where:

$$\begin{aligned}
\frac{dN_{\pi^0,\mathrm{decay}}}{dE_\gamma} &= \frac{\Theta(E_\gamma - E^-_{\pi^0})\Theta(E^+_{\pi^0} - E_\gamma)}{E^+_{\pi^0} - E^-_{\pi^0}}, \qquad (10) \\
E^\pm_{\pi^0} &= \frac{1}{2}\left(E_{\pi^0} \pm \sqrt{E^2_{\pi^0} - m^2_{\pi^0}}\right), \qquad (11)
\end{aligned}$$

Different PBH mass changes photon spectrum and detection sensitivity

and

17. Simulated Spectra (MPBH = 10^{17}g)

with parameters $r_s = 11$ kpc, $\rho_s = 0.838$ GeV/cm^3, $r_{200} = 193$ kpc, and $r_\odot = 8.122$ kpc[69]. For a region of interest (ROI) within $|R| < 5°$ of the Galactic Center, the J-factor is $\bar{J}_D = 1.597 \times 10^{26}$ MeVcm^{-2}sr^{-1}, and the angular size is $\Delta\Omega = 2.39 \times 10^{-2}$sr.

In this study, we consider a monochromatic PBH mass distribution, which can arise, for instance, from the collapse of Q-balls [70] or a first-order phase transition [71]. Assuming $f_{\mathrm{PBH}}(M) = f_{\mathrm{PBH}}\delta(M - M_{\mathrm{PBH}})$ Eq. (14) simplifies to

$$\frac{d\Phi_\gamma}{dE_\gamma} = \bar{J}_D \frac{\Delta\Omega}{4\pi} \frac{f_{\mathrm{PBH}}}{M_{\mathrm{PBH}}} \frac{\partial N_{\gamma,\mathrm{tot}}}{\partial E_\gamma \partial t}. \tag{17}$$

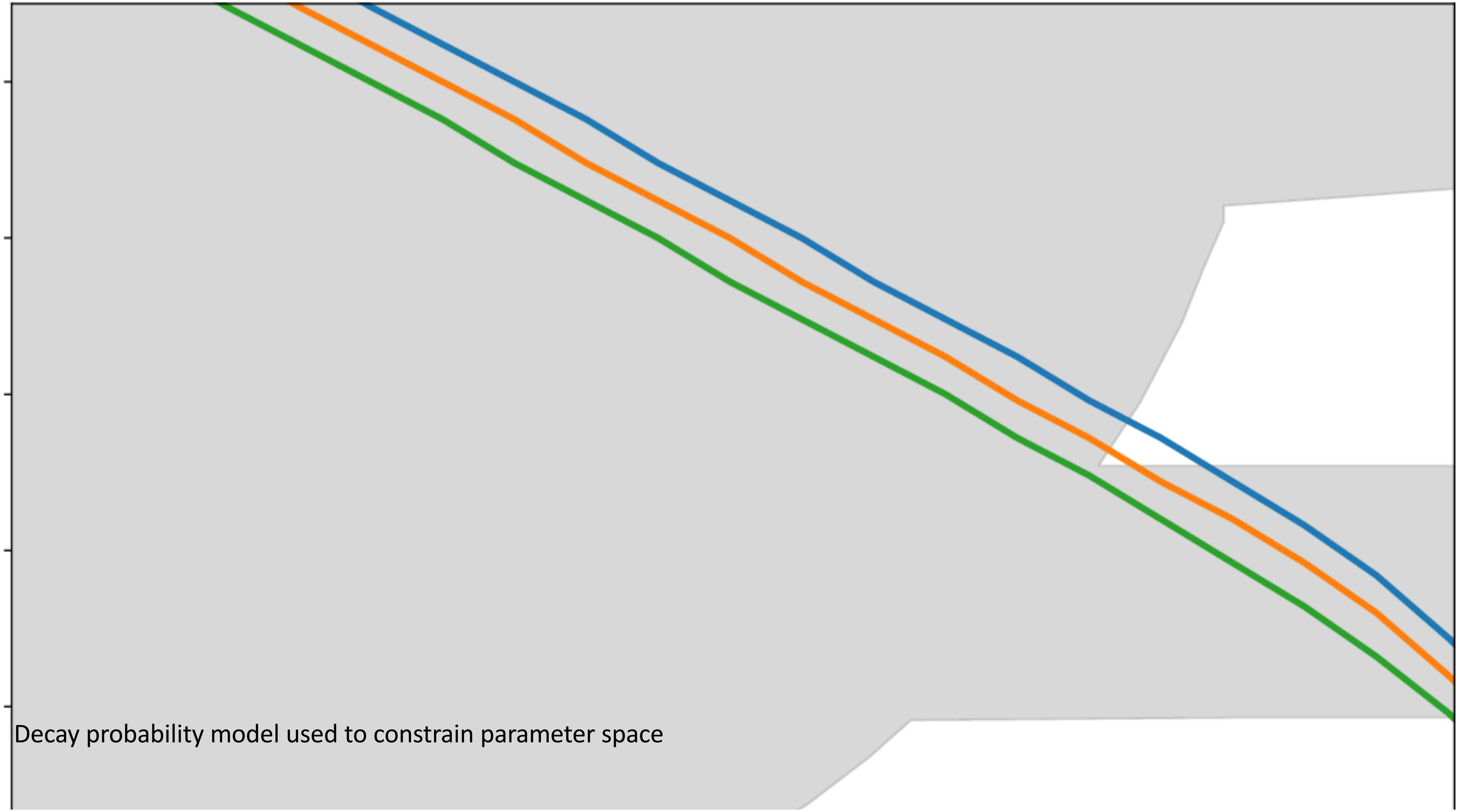
In the dark-photon-scenario, the gamma-ray spectrum arises from two contributions: (i) direct photon emission from PBHs and (ii) secondary emission resulting from dark-photon decays. Figure 1 illustrates the photon spectrum for this scenario, considering PBH masses of $M_{\mathrm{PBH}} = 10^{15}, 10^{16}$, and 10^{17} g, PBH abundance fractions of $f_{\mathrm{PBH}} = 10^{-8}$, 10^{-5}, and 10^{-2}, and a range of dark-photon masses.

Lower Hawking temperature suppresses heavy A' contributions

18. A′ Decay Probability

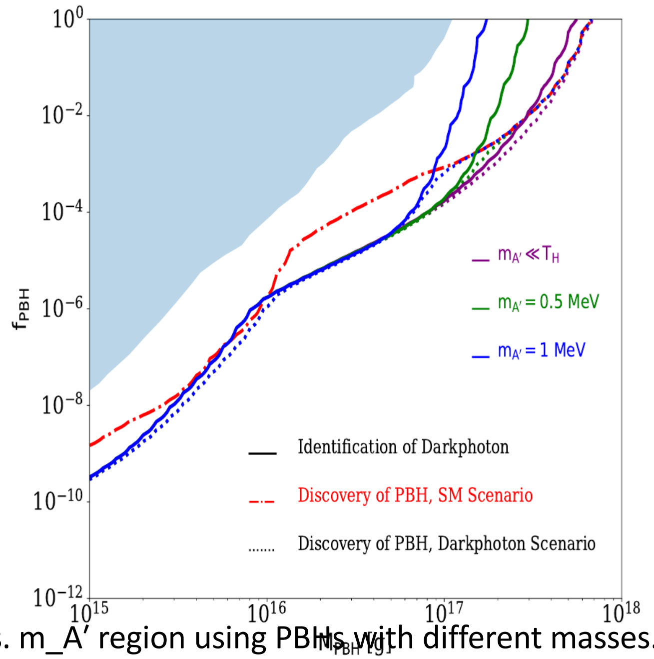
- For gamma-ray detection, A′ must decay before reaching Earth. Probability depends on distance, decay width, and energy.

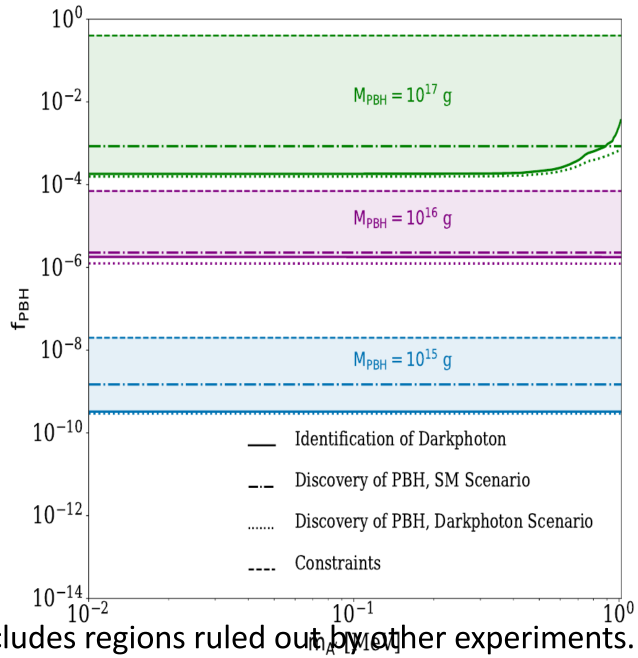
19. A′ Decay Probability Equation



Decay probability model used to constrain parameter space

20. Viable Dark Photon Parameter Space



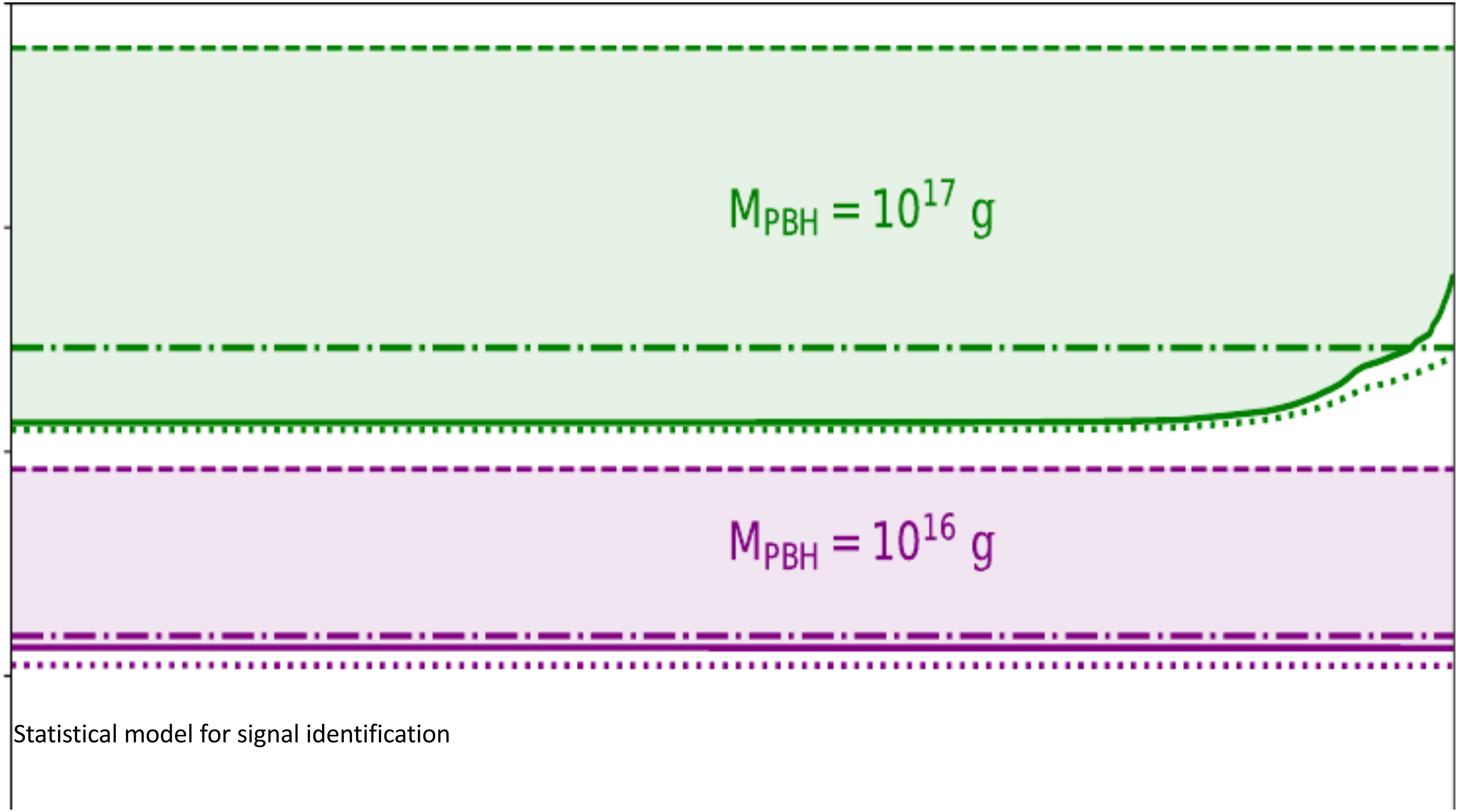


Explorable ϵ vs. m_A’ region using PBHs with different masses. Excludes regions ruled out by other experiments.

21. Likelihood Methodology

- Poisson-based likelihood used to compare SM and dark photon scenarios with astrophysical background as reference.

22. Poisson Likelihood Formula



Statistical model for signal identification

23. Discovery Reach: fPBH vs. MPBH

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25. Conclusion

- Dark photons from PBHs present a novel gamma-ray signature.
- Future missions (e-ASTROGAM) could uncover unexplored dark sectors.
- Study expands viable detection range for low-mass, weakly-coupled dark photons.

2. PBH Formation Scenarios

- (i) Collapse of overdense regions developed from primordial density fluctuations after inflation.
- (ii) First-order phase transitions

During transitions (e.g., QCD or electroweak), bubble collisions and shocks can concentrate energy density, triggering localized gravitational collapse.

- (iii) Collapse of exotic states like fermi-balls:
  - Objects like cosmic strings, domain walls, or fermion balls (stable configurations of fermions) may gravitationally collapse into PBHs under certain conditions.
- These mechanisms span a broad range of mass scales, influencing which PBHs might survive until today.

4. Motivation

- Instead of just looking for PBHs themselves, we're now opening up the search to the BSM particles emitted from PBHs.
- It’s a way of expanding our reach into BSM physics by following the unique signals that PBHs can give off.
- Future gamma-ray missions could detect PBHs and differentiate dark photon signatures from standard model emissions.
- Dark photon trident decays ($A' \to 3\gamma$) are the focus.
- Importance of $A' \to 3\gamma$ in Probing PBHs :

1) PBHs emit particles via Hawking radiation, including dark photons if they exist.

2) $A' \to 3\gamma$ is a rare loop-induced decay mode, leading to a unique gamma-ray signature.

3) The three-photon decay produces a photon spectrum distinct from standard Hawking emission or $A' \to \gamma\gamma$.

4) Detection of this signature could confirm both PBH existence and new physics beyond the Standard Model.

5) Future gamma-ray observatories can differentiate these signals using precise spectral analysis.

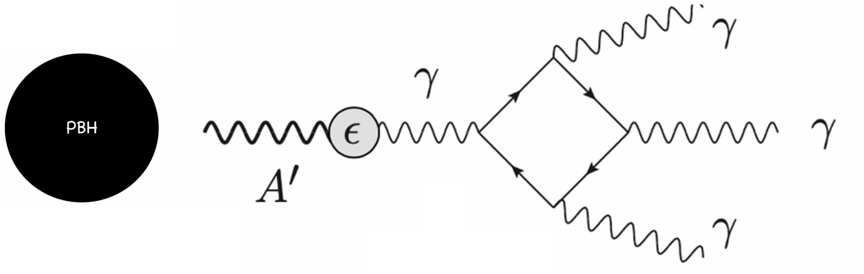
6) This process provides a novel probe of dark sectors and early-universe conditions.

- When the dark-photon mass exceeds 3 twice the electron mass, A′ decays into a pair of e+e−.
- If the mass is below the e+e− threshold, the dark photon decays into 3 photons. This occurs because the tree-level di photon decay channel is forbidden by the Landau-Yang theorem [45], and so the loop-level photon trident channel A′ → 3γ becomes the dominant one [46].

In this study, we expand the scope of gamma-ray searches for BSM physics, shifting the focus from PBHs alone to including new particles generated by PBHs, with the dark photon serving as a specific example. Specifically, we investigate the signal in the dark-photon scenario, where dark photons are emitted from PBHs via Hawking radiation, followed by their decays into 3 photons. This process is added to the direct photon emission from PBHs, resulting in a modification of the total spectrum. We then contrast this signal with the SM-scenario in which PBHs produce only SM particles. Since observations of galactic gamma-ray signals impose stricter constraints on PBH abundance compared to studies of dwarf spheroidal galaxies [50], we concentrate on the Milky Way's gamma-ray signal for the dark-photon-scenario.

5. Dark Photon and its Trident Decay

- Dark photon arises from a U(1) extension of the SM, and kinetically mixes with photon.
- If $m_{A'} < 2m_e$, the dominant decay mode is via loop-level trident mode A′ → 3γ.



Dark photon trident (2406.1944)

- The Lagrangian for the dark photon is given by

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{1}{2}m_{A'}^2 A'_\mu A'^\mu - \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu},$$

$$F'_{\mu\nu} = \partial_\mu A'_\nu - \partial_\nu A'_\mu,$$

4. Motivation

- Rather than focusing solely on PBHs themselves, we extend our search to include BSM particles that may be emitted via Hawking radiation.
- This approach broadens our probe of new physics by leveraging the unique signatures associated with PBH evaporation.
- In this study, we specifically investigate the production of dark photons from PBHs.
- When $m_{A'} > 2m_e$, , dark photons predominantly decay into a pair of e^+e^-, but for $m_{A'} < 2m_e$, they decay into three photons.
- The photon spectrum from this 3-body decay is distinct from that of 2-body decay
- In contrast, this photon-trident signal might not be accessible in collider exps. Due to too small kinetic mixing, loop suppression and low resolution.
- But, we may overcome these challenges by considering this decay via Hawking radiation from PBH.