Determining the spin of light primordial black holes with Hawking radiation

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Hawking evaporation

BHs emit particles with a quasi-blackbody spectrum [Hawking, 1974-75]

$$T_H = \frac{M_P^2}{4\pi M} \frac{\sqrt{1-\tilde{a}^2}}{1+\sqrt{1-\tilde{a}^2}} \simeq \left(\frac{10^{10}\ \mathrm{kg}}{M}\right)\ \mathrm{GeV} \qquad \tilde{a} = \frac{M_P^2}{M^2} J$$

Relevant for light primordial black holes formed in the early universe!

Standard lore: BHs lose spin faster than mass…

$$\Delta M \sim 5 T_H \qquad \Delta J \sim m \quad \Rightarrow \quad \Delta \tilde{a} \sim \frac{5}{4\pi}\tilde{a} - m < 0$$

…except for scalar emission! [Taylor, Chambers & Hiscock (1997)]

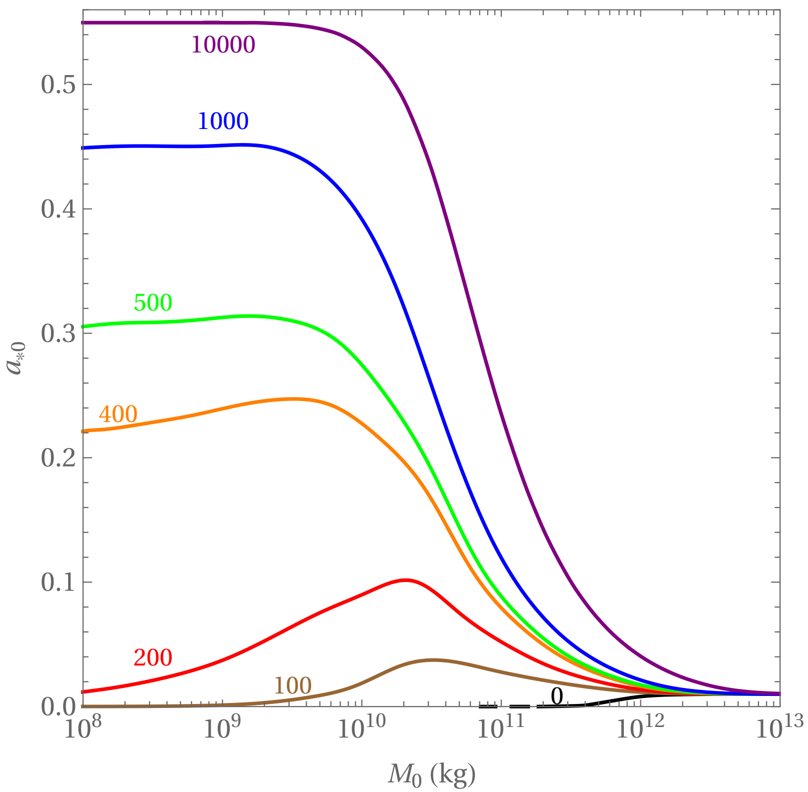
PBH evaporation in string axiverse scenario (>100 light axions)

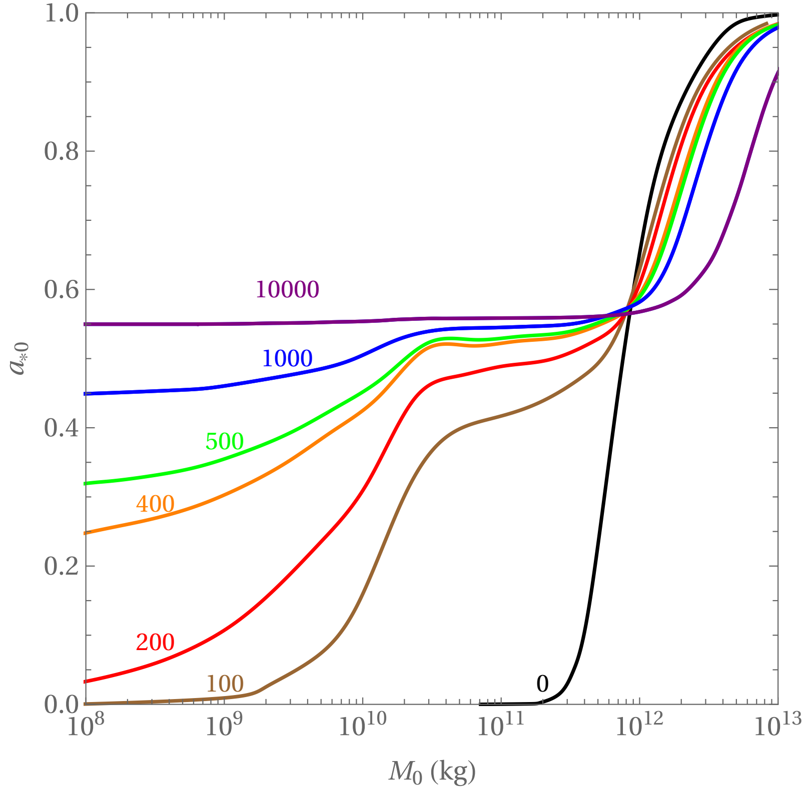
[Marco Calzà's talk 2021]

Hawking evaporation in the string axiverse

[Calzà, March-Russell & JGR, arXiv:2110.13602]

PBH evaporation with Standard Model + gravitons + N_a light axions





$$\tau_{BH} \sim 14 \left(\frac{M}{10^{12}\ \mathrm{kg}} \right)^3 \ \mathrm{Gyrs}$$

PBH superradiance: Filipe Serrano's & Ricardo Z. Ferreira's talks

How to measure PBHs mass and spin?

[Calzà, March-Russell & JGR, arXiv:2110.13602]

Determining present mass-spin distribution gives unique probe of total number of light scalars (< MeV). How to measure this?

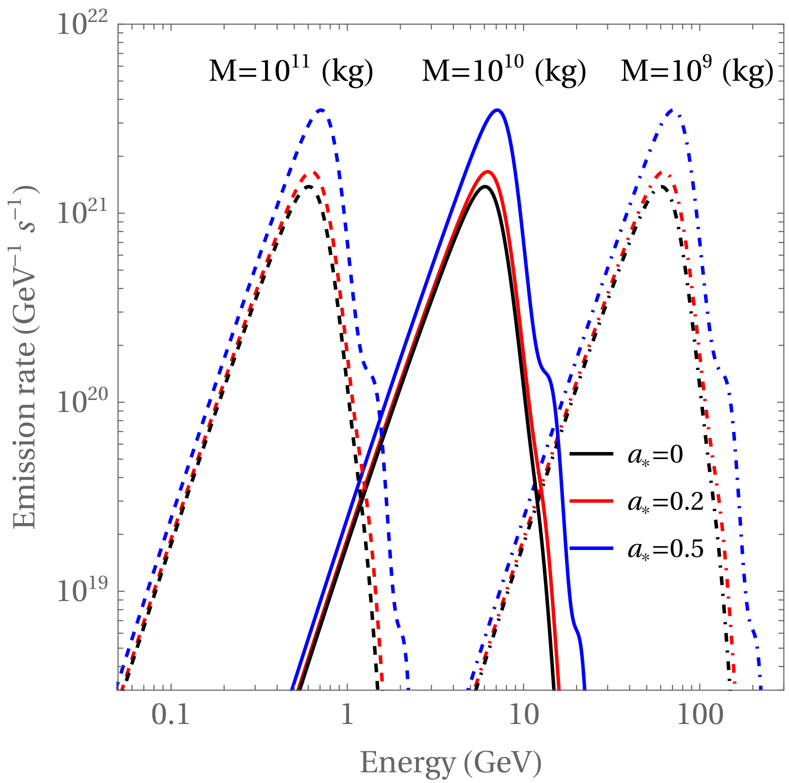
A: Hawking radiation (photons)

PBH spin enhances photon emission but need to know distance to PBH:

$$d_{PBH} \simeq 40\,\mathrm{AU}\ (M_0/10^{10}\mathrm{kg})^{1/3}(10^{-7}/f_0)^{1/3}$$

$$v_{PBH} \simeq 40 - 60\ \mathrm{AU/yr}$$

Could use parallax if PBH is near Earth but need to include secondary photons



Complete Hawking photon spectrum

Secondary photons: charged particles, decays, quark hadronization

$$\frac{d^2 N_{P,i}}{dtdE_i} = \frac{1}{2\pi} \sum_{l,m} \frac{\Gamma^a_{l,m}(\omega)}{e^{2\pi(\omega - m\Omega)/\kappa} \pm 1} ,$$

$$\frac{d^2 N_{S,\gamma}}{dtdE_\gamma} = \sum_i \int dE_i \frac{d^2 N_{P,i}}{dtdE_i} \frac{d^2 N_{\gamma,i}}{dE_\gamma}$$

For charged particles (electrons, muons, pions, etc):

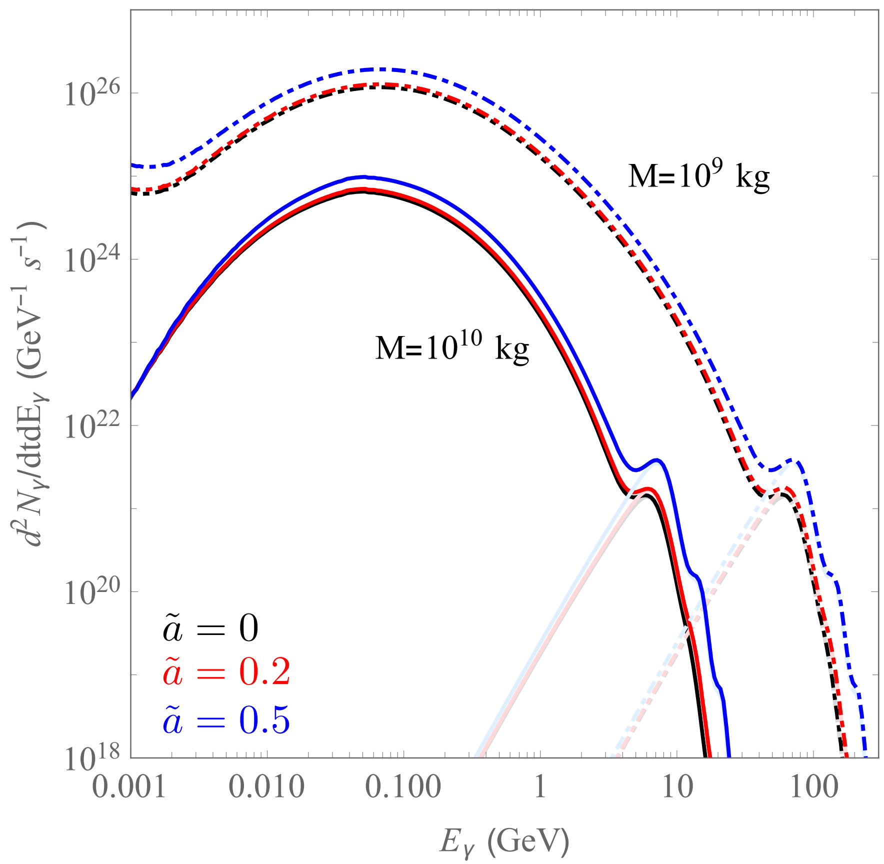
$$\frac{dN_i^{FSR}}{dE_\gamma} = \frac{\alpha}{\pi Q_i} P_{i\to i\gamma}(x) \log\left(\frac{1-x}{\mu_i^2} - 1\right) ,$$

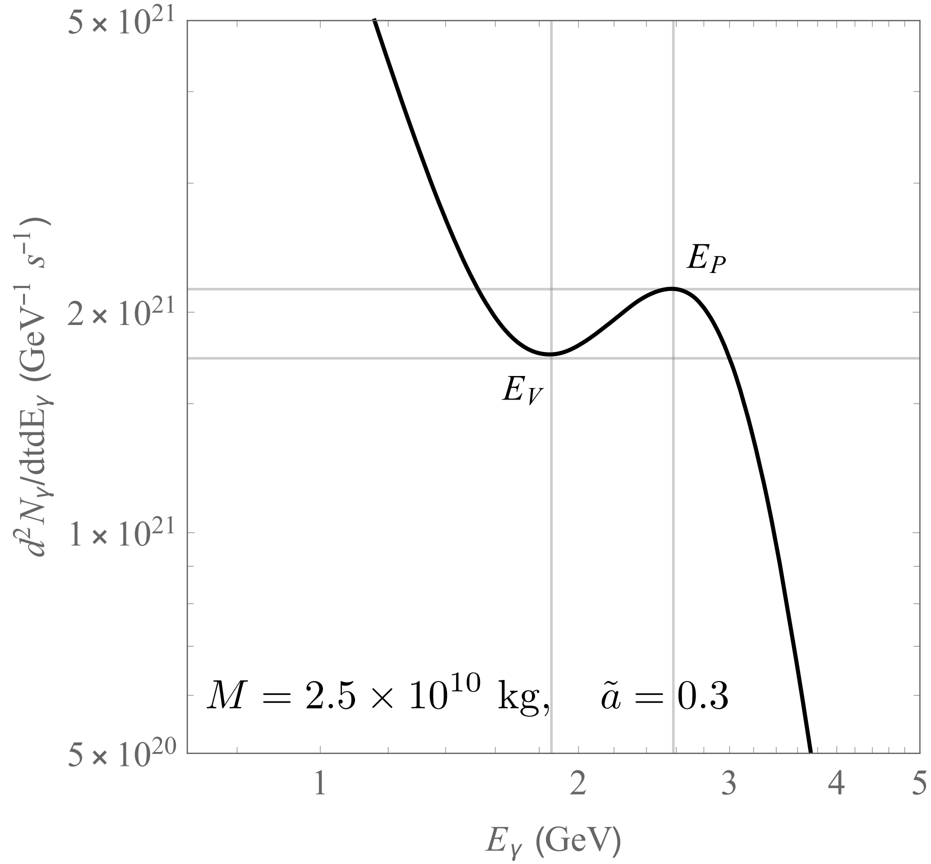
$$P_{i\to i\gamma}(x) = \begin{cases} \frac{1+(1-x)^2}{x} & \text{for } i = e^\pm,\ \mu^\pm \\ \frac{2(1-x)}{x} & \text{for } i = \pi^\pm \end{cases}$$

General: use BlackHawk code (+ PYTHIA & Hazma)

[Arbey & Auffinger (2019-)]

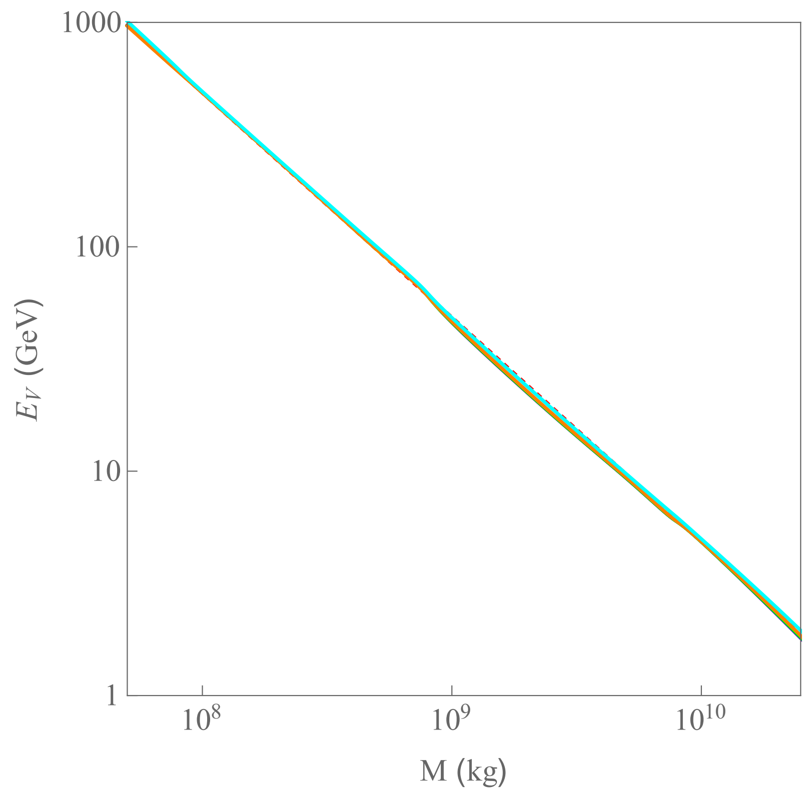
Low mass PBHs (5×10^{7} – 2.5×10^{10} kg)

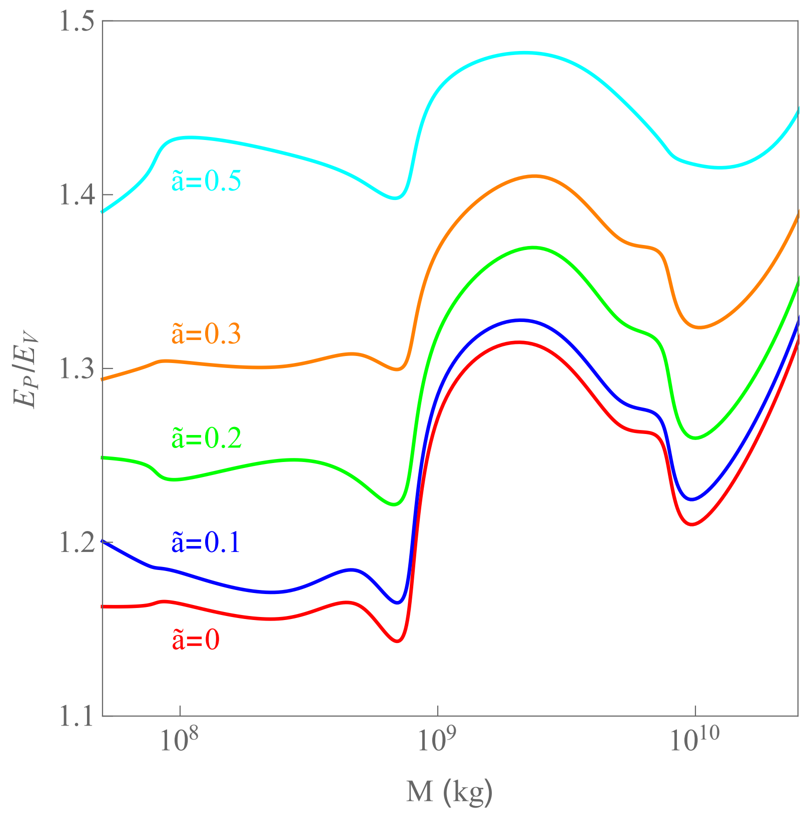




Clear "valley-peak" structure

Low mass PBHs (5×10^7 – 2.5×10^{10} kg)

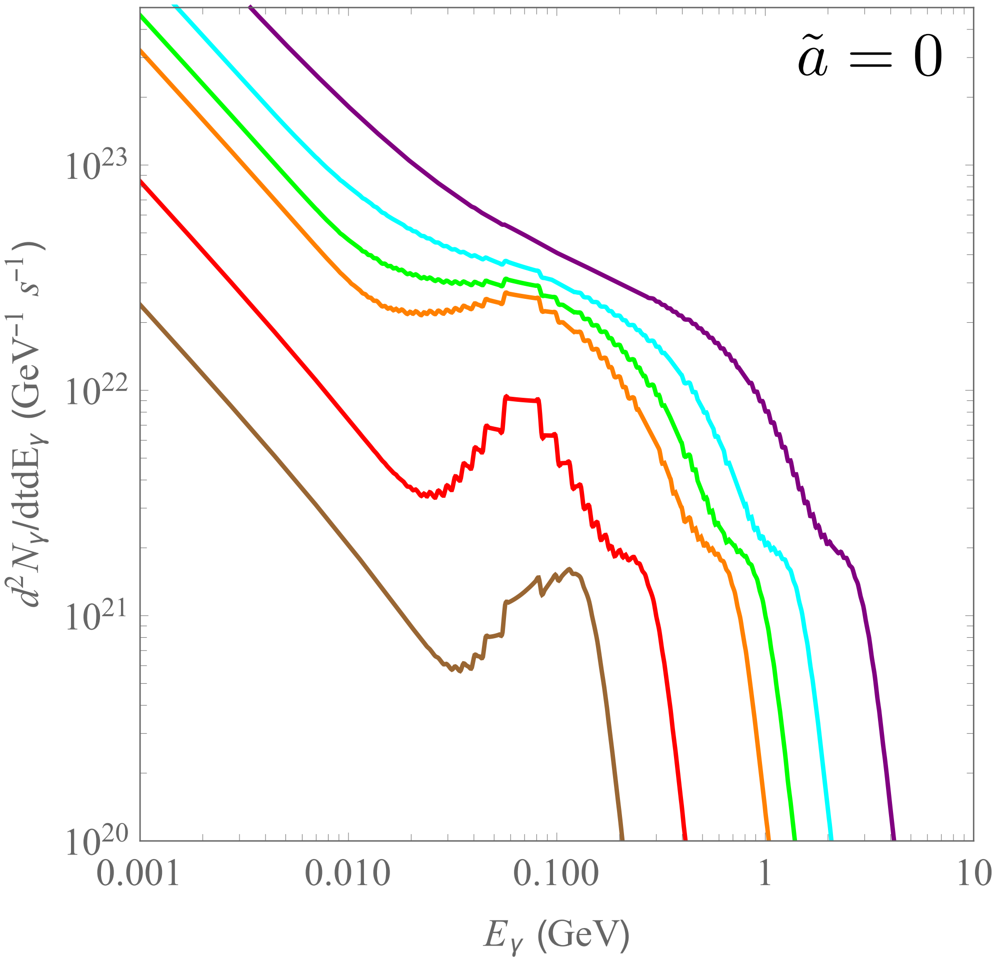


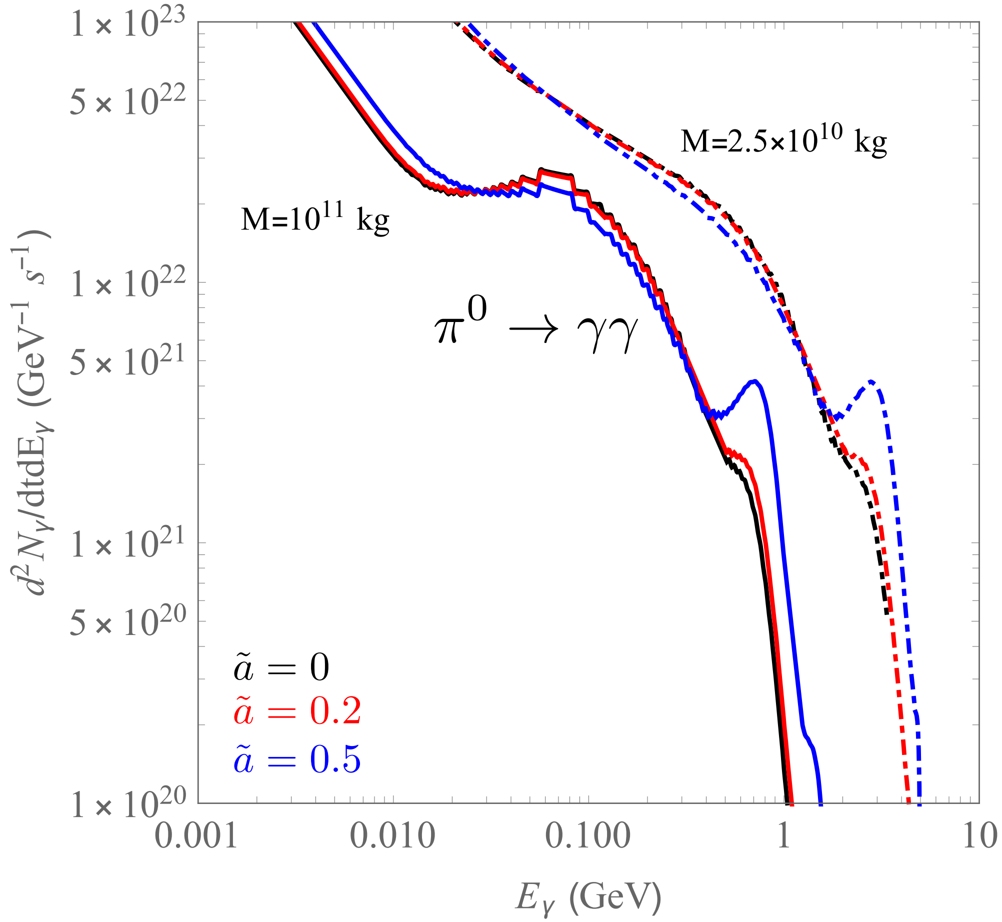


Can determine mass & spin independently of distance!

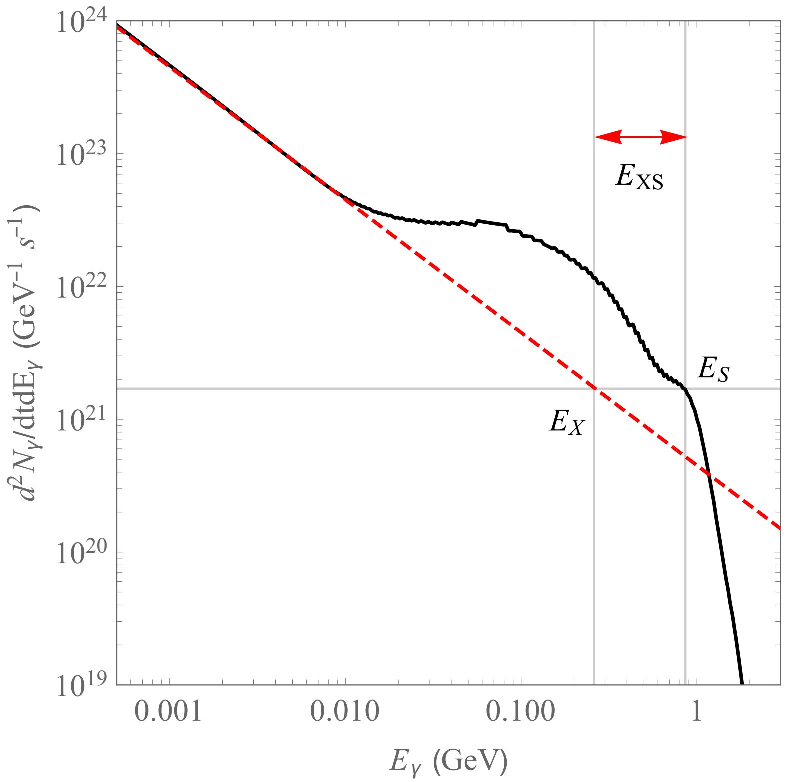
(<10% energy resolution)

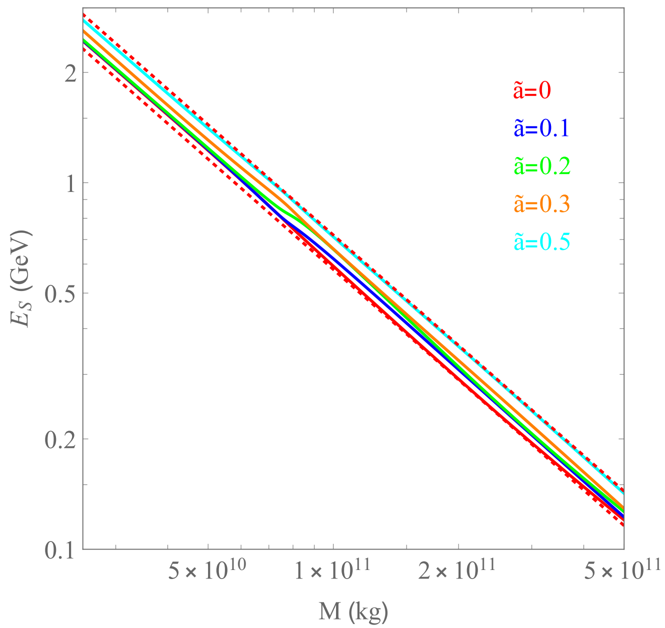
Intermediate mass PBHs (2.5x10^{10} – 5x10^{11} kg)

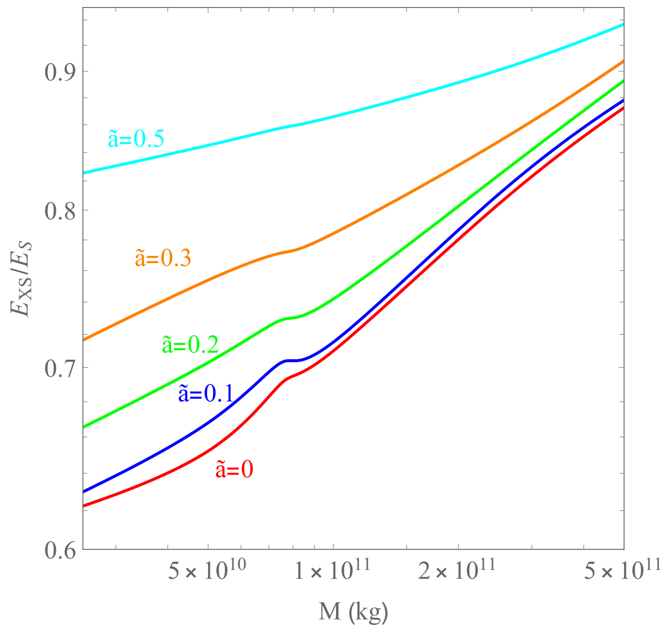




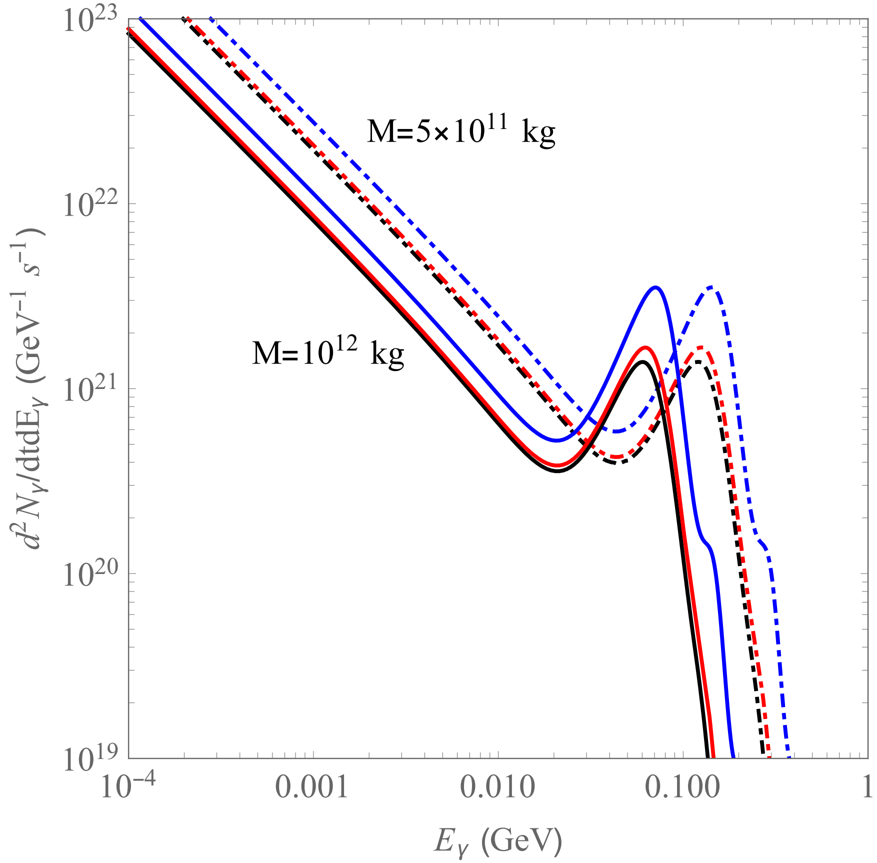
Intermediate mass PBHs ($2.5x10^{10}$ – $5x10^{11}$ kg)

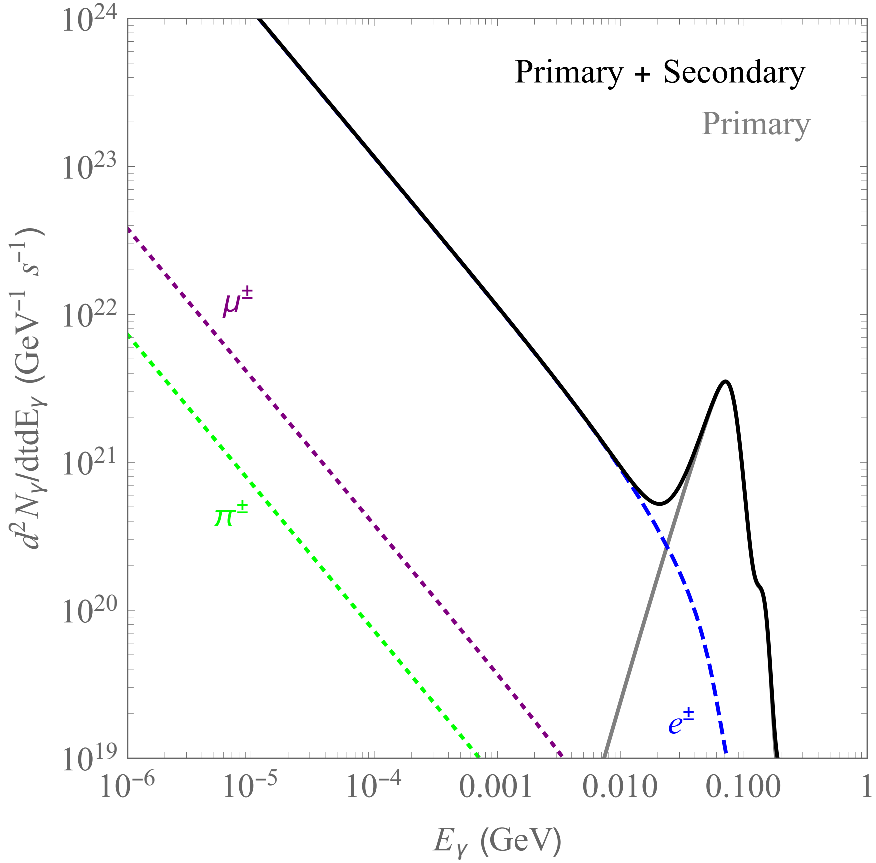




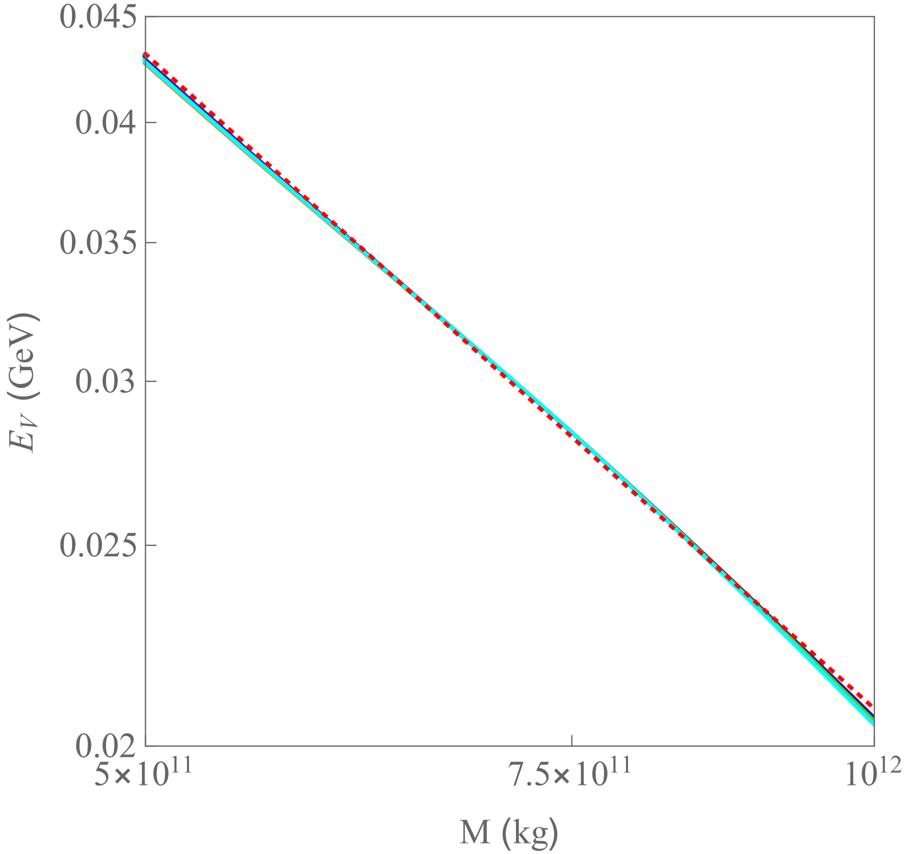


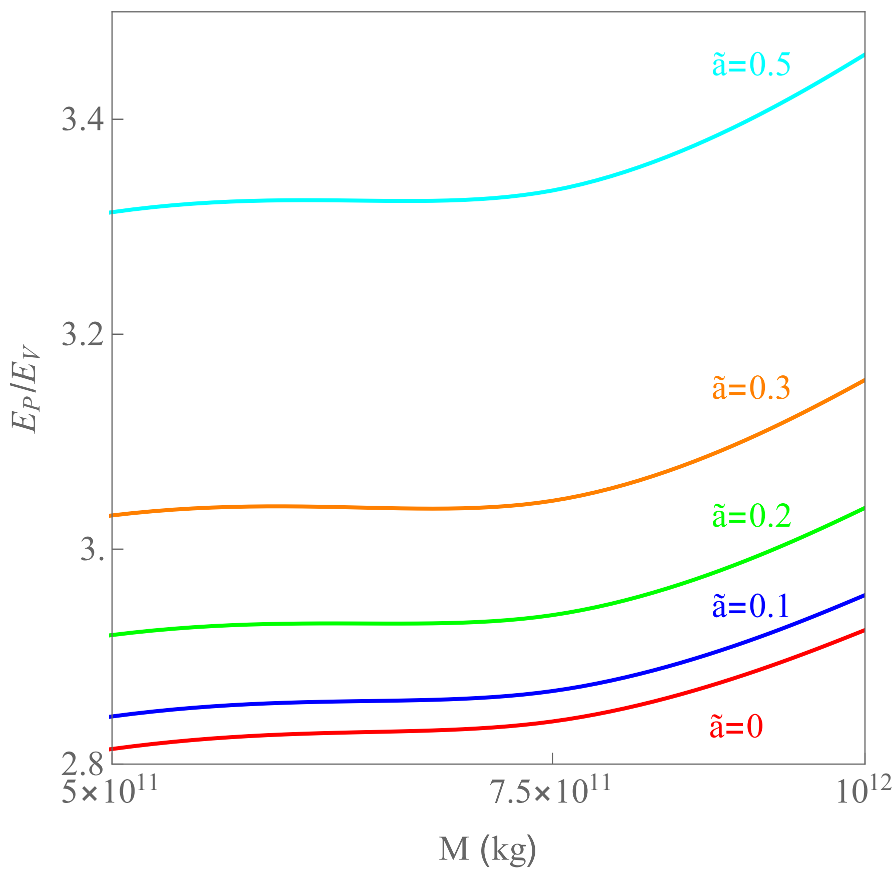
High mass PBHs (5x10^{11} – 10^{12} kg)





High mass PBHs ($5x10^{11}$ - 10^{12} kg)





Summary

- Mass & spin distribution of light PBHs may give us a unique probe of fundamental physics

- Can measure mass and spin from Hawking photons

- Method is independent of distance to PBH

- Need better gamma-ray telescopes (so far no PBHs ☹…)

$$\frac{d^2 N_\gamma}{dt dE_\gamma} \gtrsim 10^{24} \left(\frac{0.1\ \mathrm{GeV}}{E_\gamma}\right)^2 \left(\frac{d}{100\ \mathrm{AU}}\right)^2 \mathrm{GeV}^{-1}\mathrm{s}^{-1}$$ [AMEGO-X, ASTROGAM]

Could detect primary photons with MAST (<10% resolution, >10 GeV)!