PRIMORDIAL BLACK HOLES AS DARK SECTOR FACTORIES

Based on arXiv:2212.11980, arXiv:2409.13811, and arXiv:2606.13788
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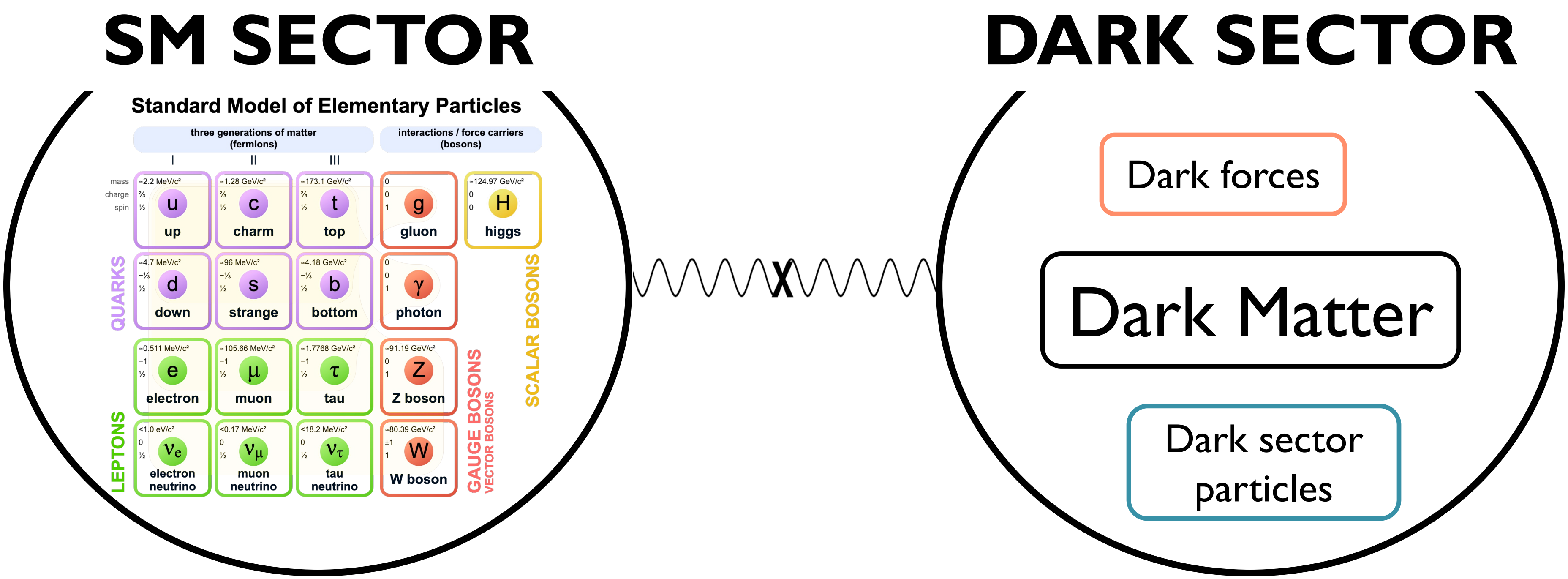
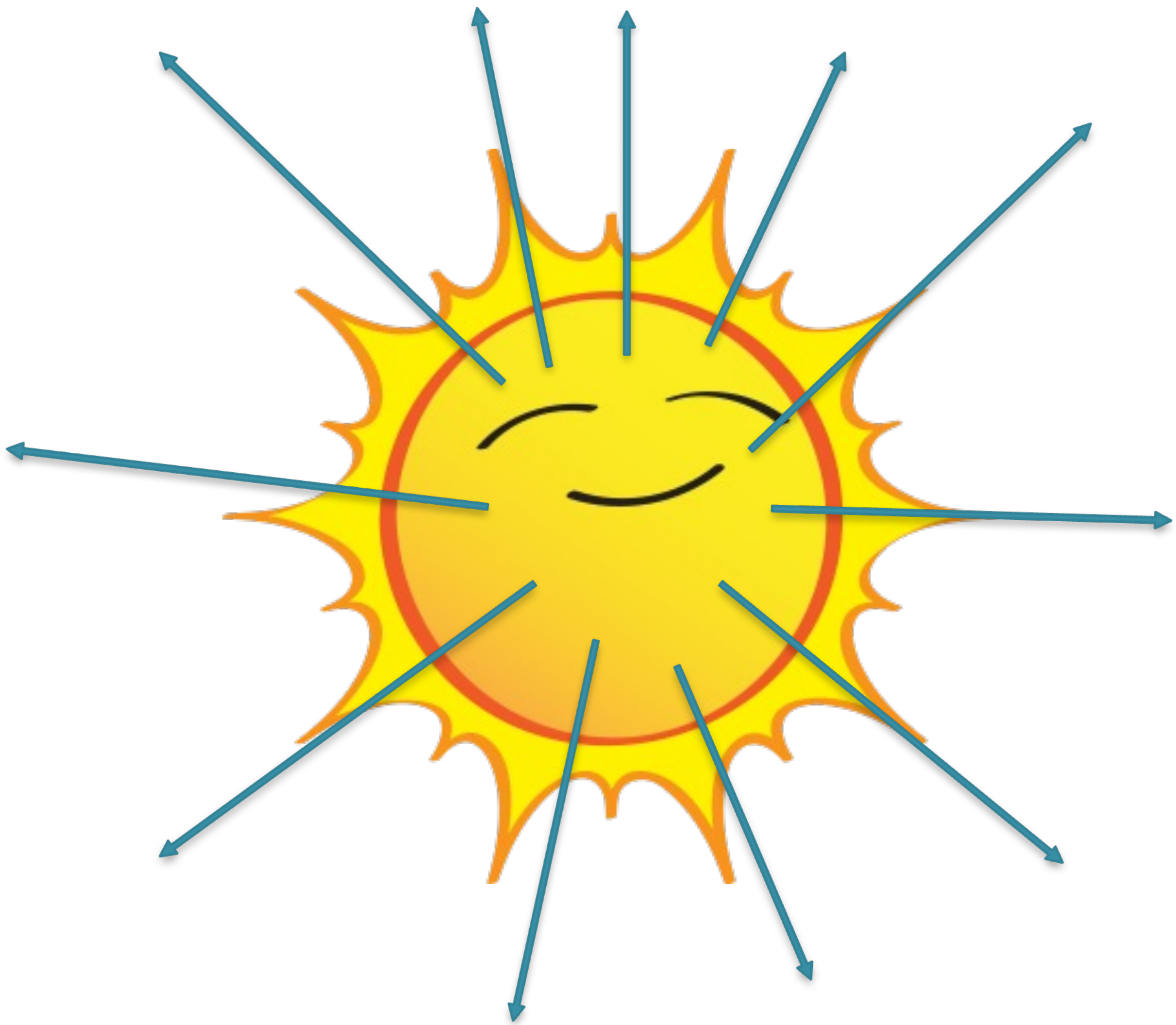
2026.08.21 FLASY 2026

ASTROPHYSICAL PROBES OF DARK SECTOR

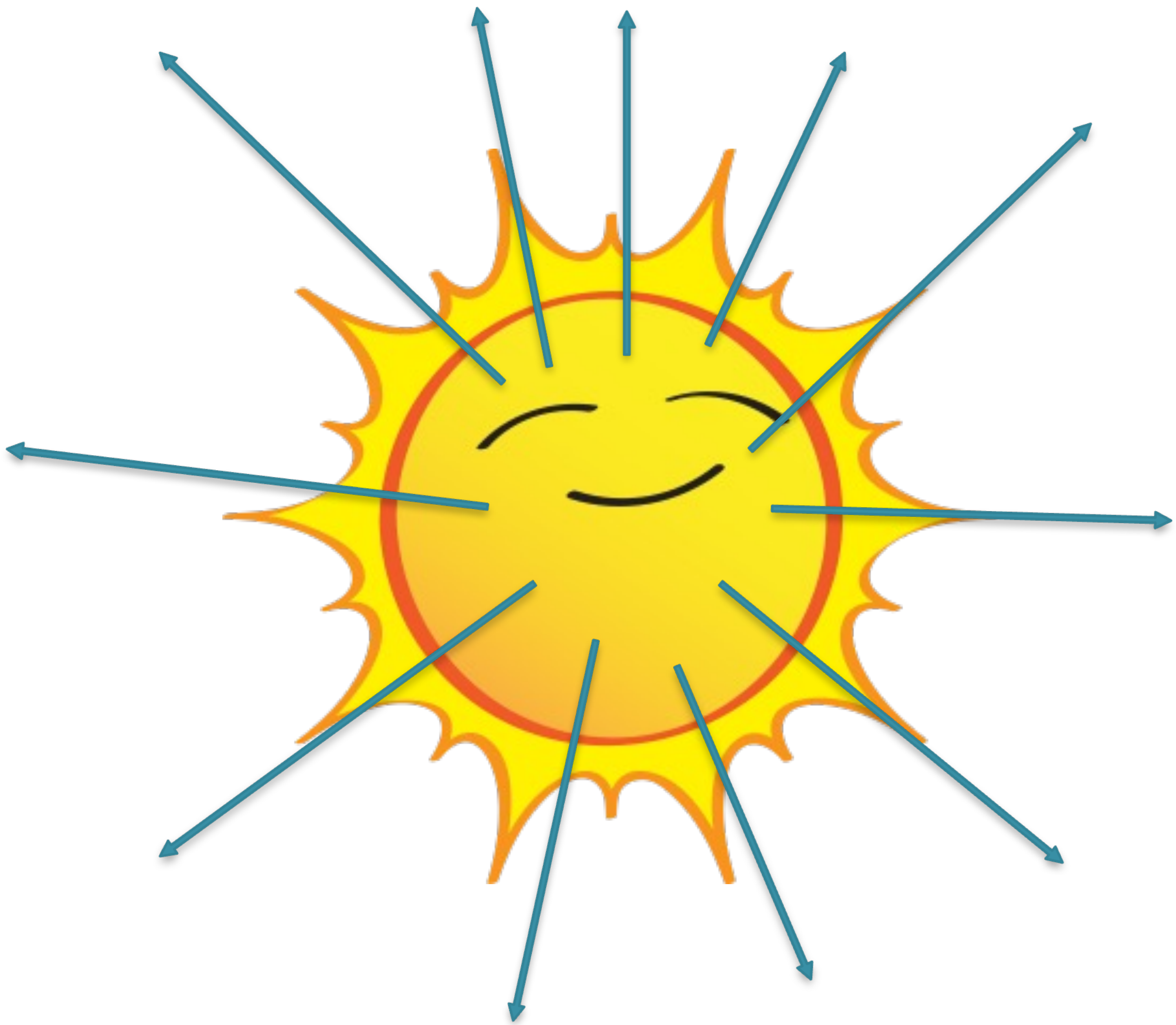
Dark Sectors



Particle Production from Stellar Objects



Evolution History of Stars



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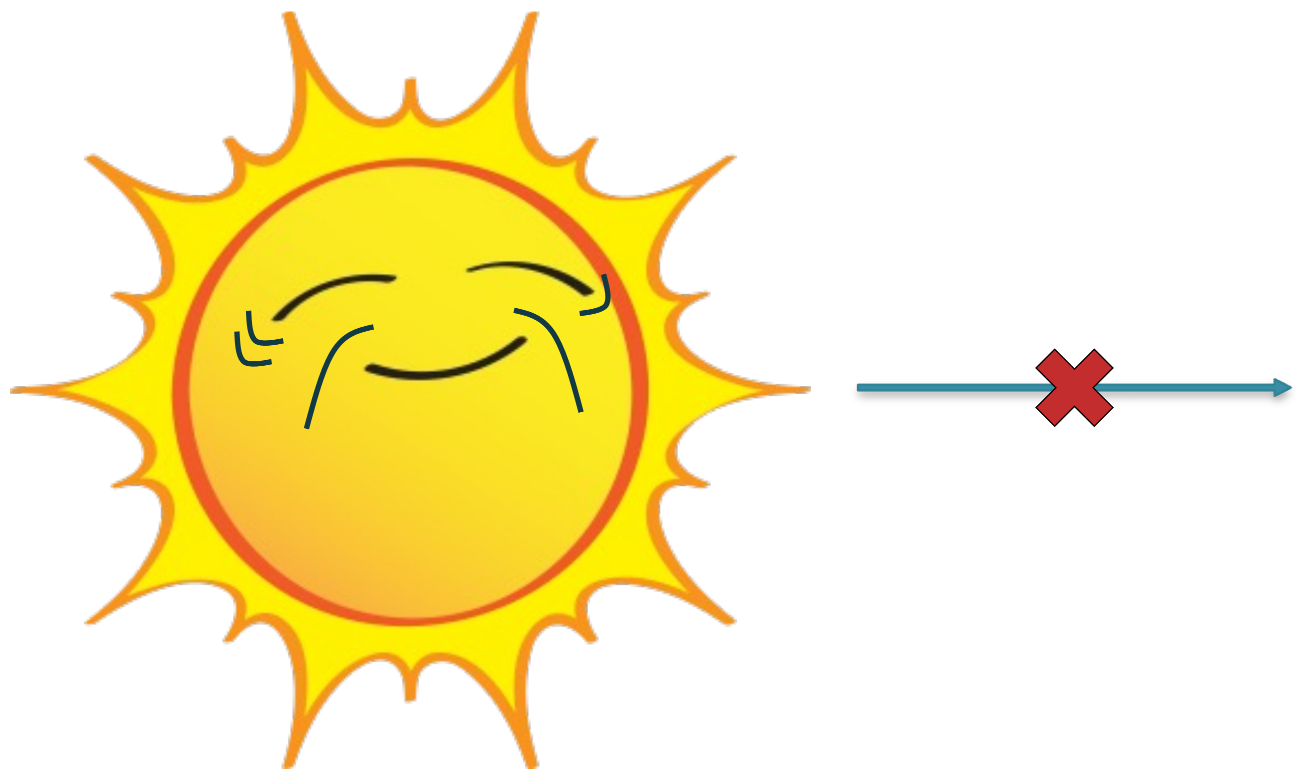
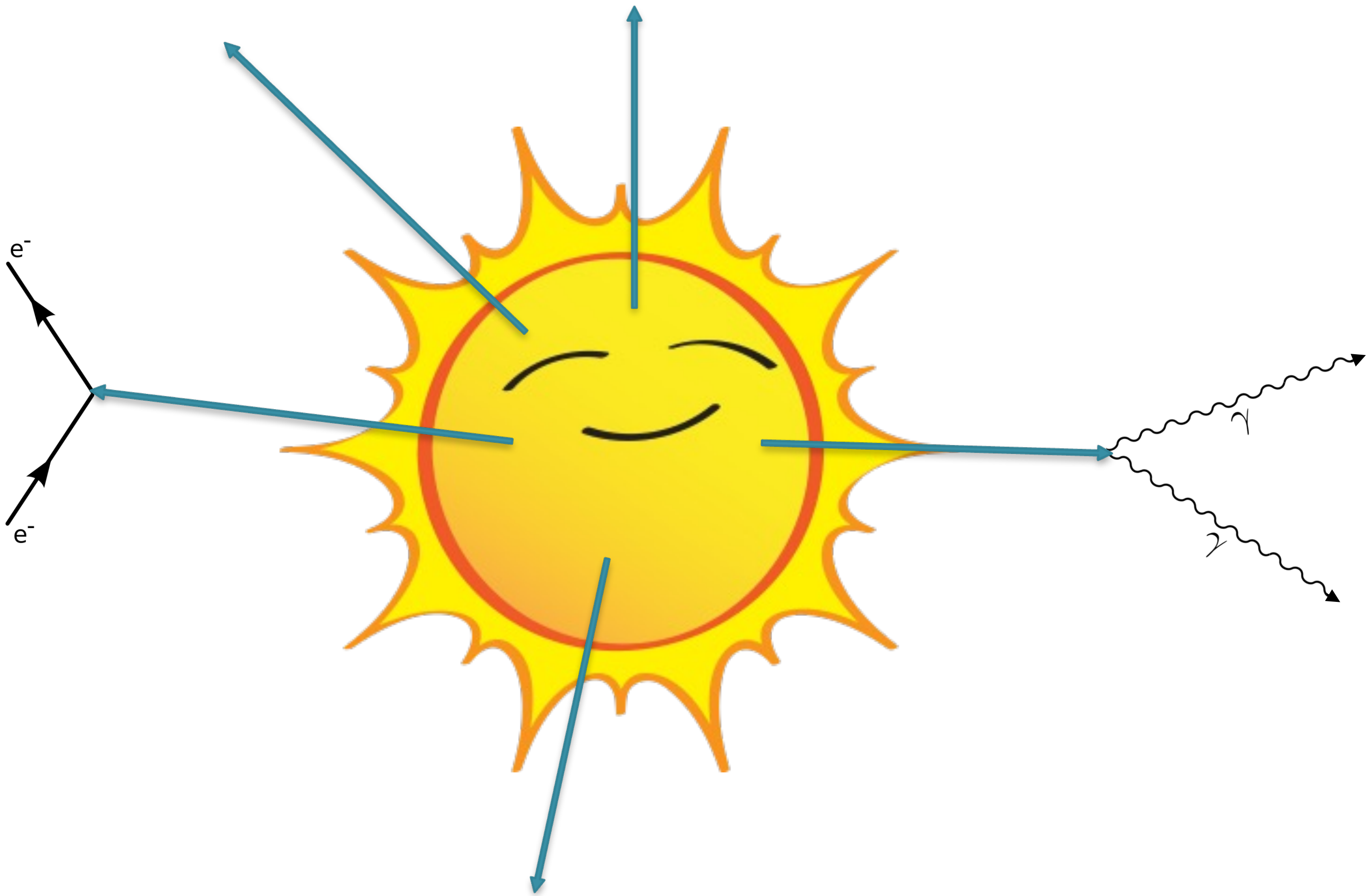
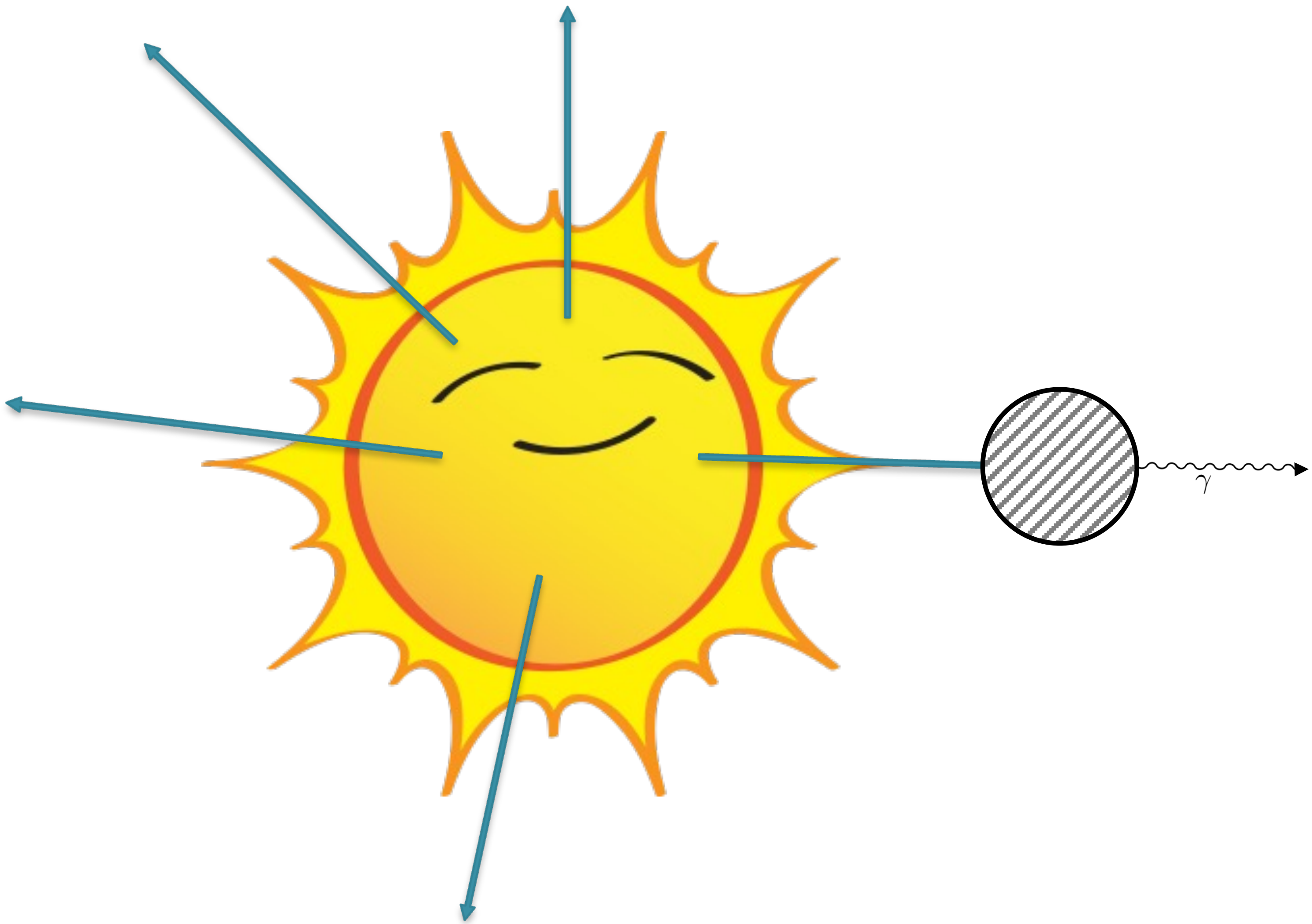


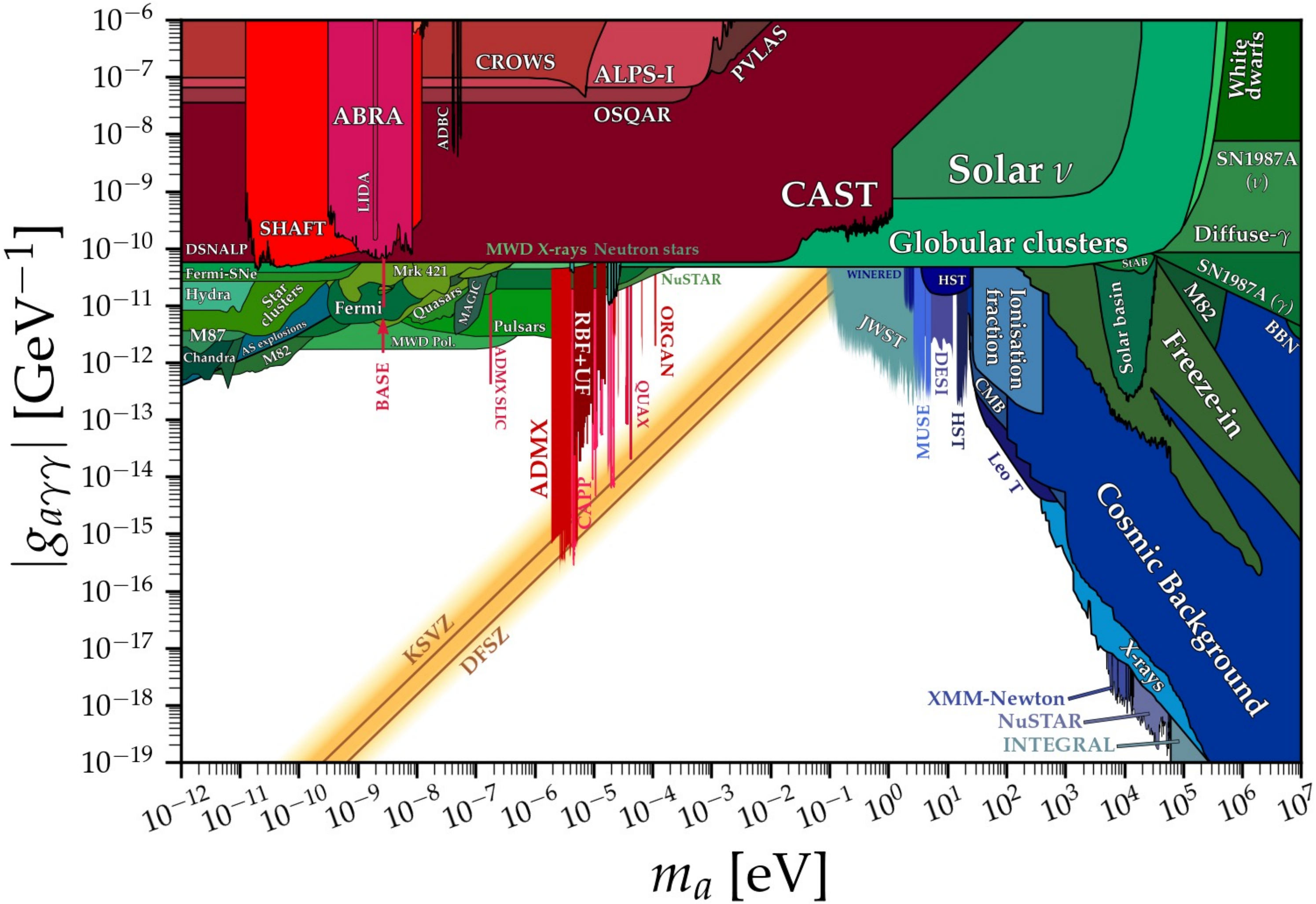
Decay to EM energy



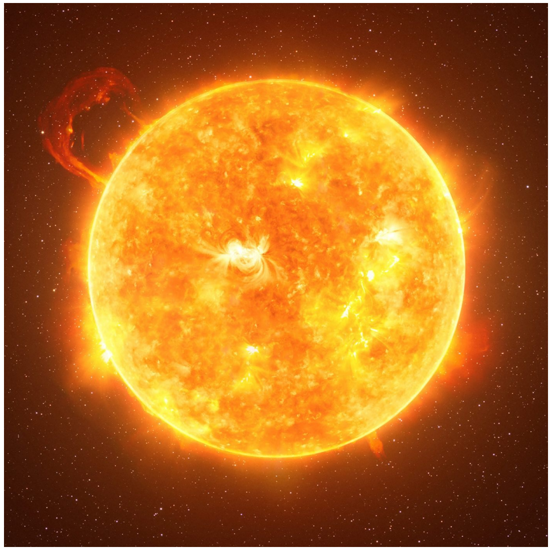
Conversion to EM energy



Axion Constraints



Astrophysical Sources



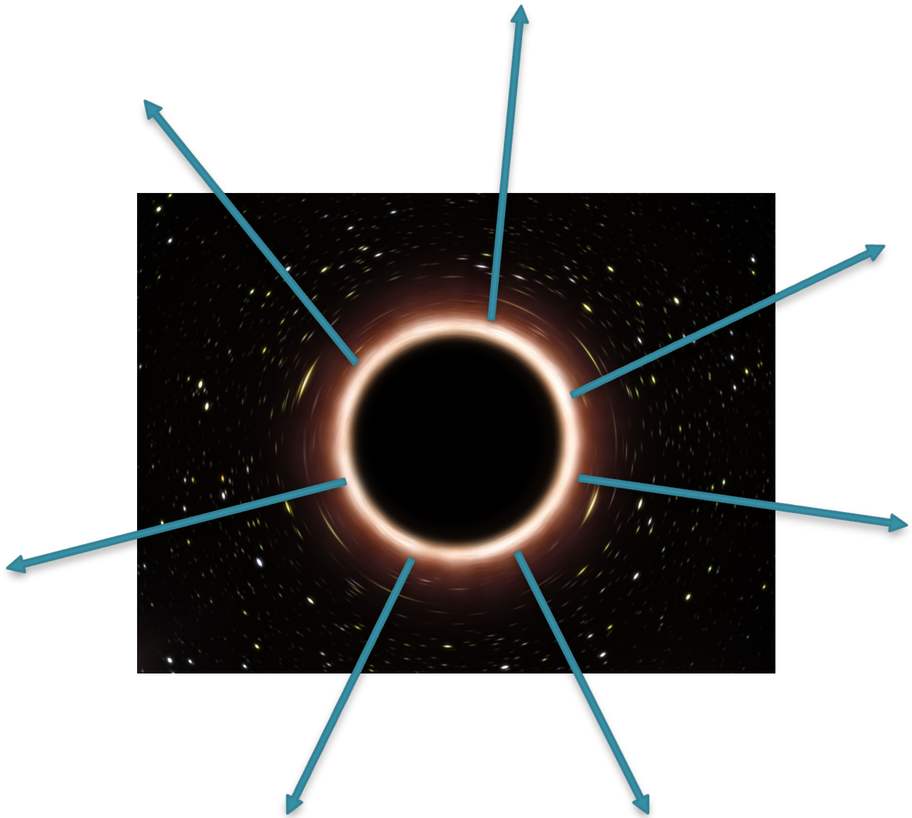
The Sun

Supernovae

White dwarfs

And many more…

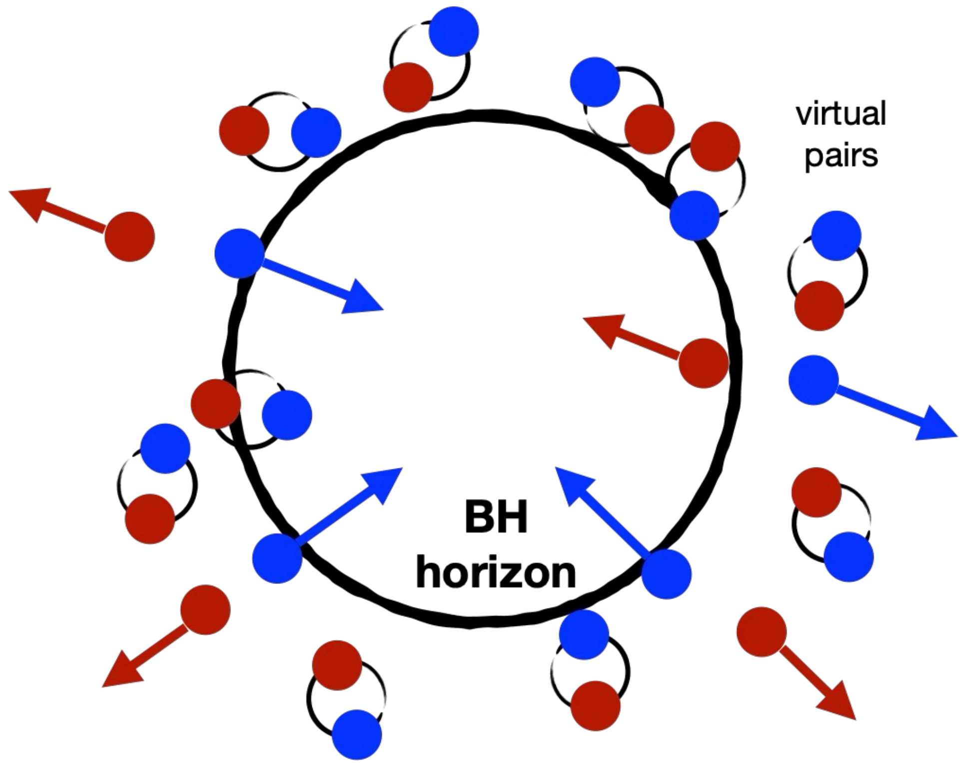
Another source: Black Holes



- Blackholes emit particles gravitationally via Hawking radiation
- We can use BHs as a new source for dark sector particles

HAWKING RADIATION

Hawking Radiation



- BHs emit thermal radiation due to quantum effects near the horizon

Hawking, 1974

Hawking Temperature

- Hawking radiation is a purely gravitational process
- Every particle can be emitted from BHs regardless of its interaction as long as $m \lesssim T_{\rm BH}$
- $T_{\rm BH} = \dfrac{1}{8\pi G M_{\rm BH}}$
- Intuition from the uncertainty principle:

$$\Delta x \sim r_s = 2GM \ \rightarrow \ T \sim \Delta p \sim \frac{1}{\Delta x} \sim \frac{1}{GM}$$

Primordial Black Holes

- We need a small BH mass for larger particle emission

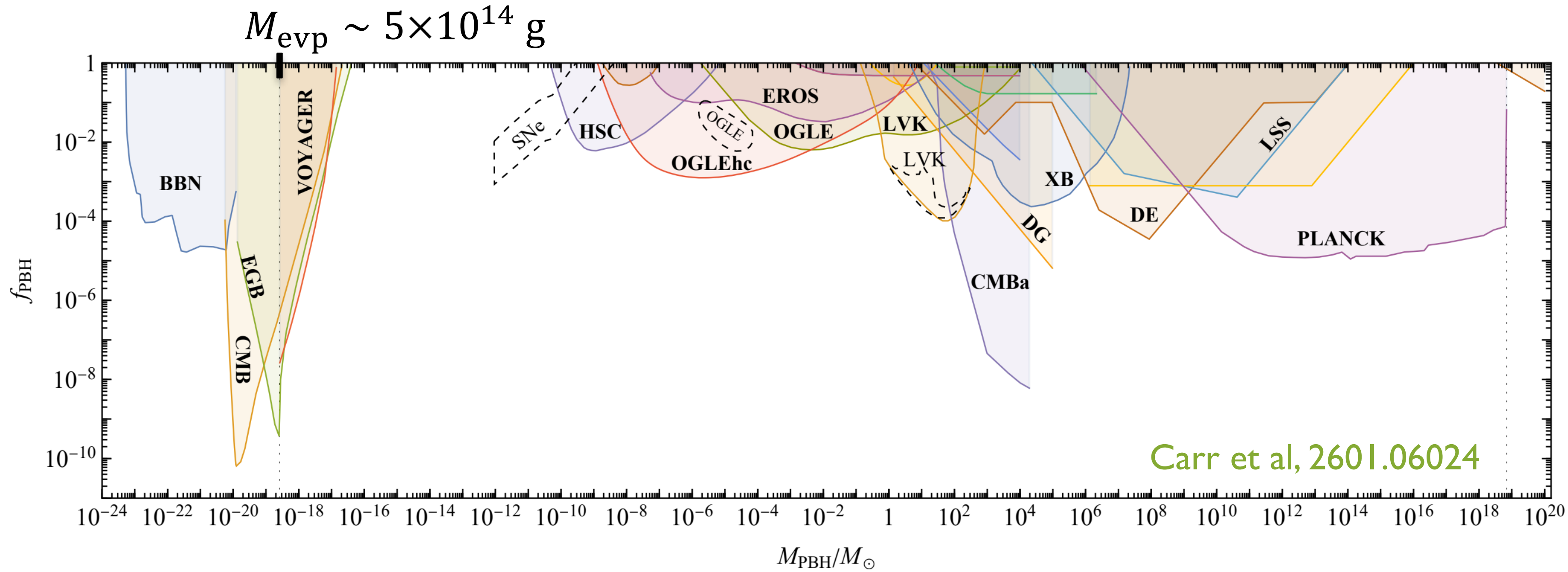
- Astrophysical BHs are heavier than the Chandrasekhar limit

$$T_{\mathrm{BH}} \sim 10^{-11}\,\mathrm{eV}\left(\frac{M_{\odot}}{M_{\mathrm{BH}}}\right)$$

- PBHs form in the early Universe by collapse of Hubble patches, so they can have any mass

$$T_{\mathrm{BH}} \sim 10\,\mathrm{MeV}\left(\frac{10^{15}\,\mathrm{g}}{M_{\mathrm{BH}}}\right)$$

Primordial Black Holes



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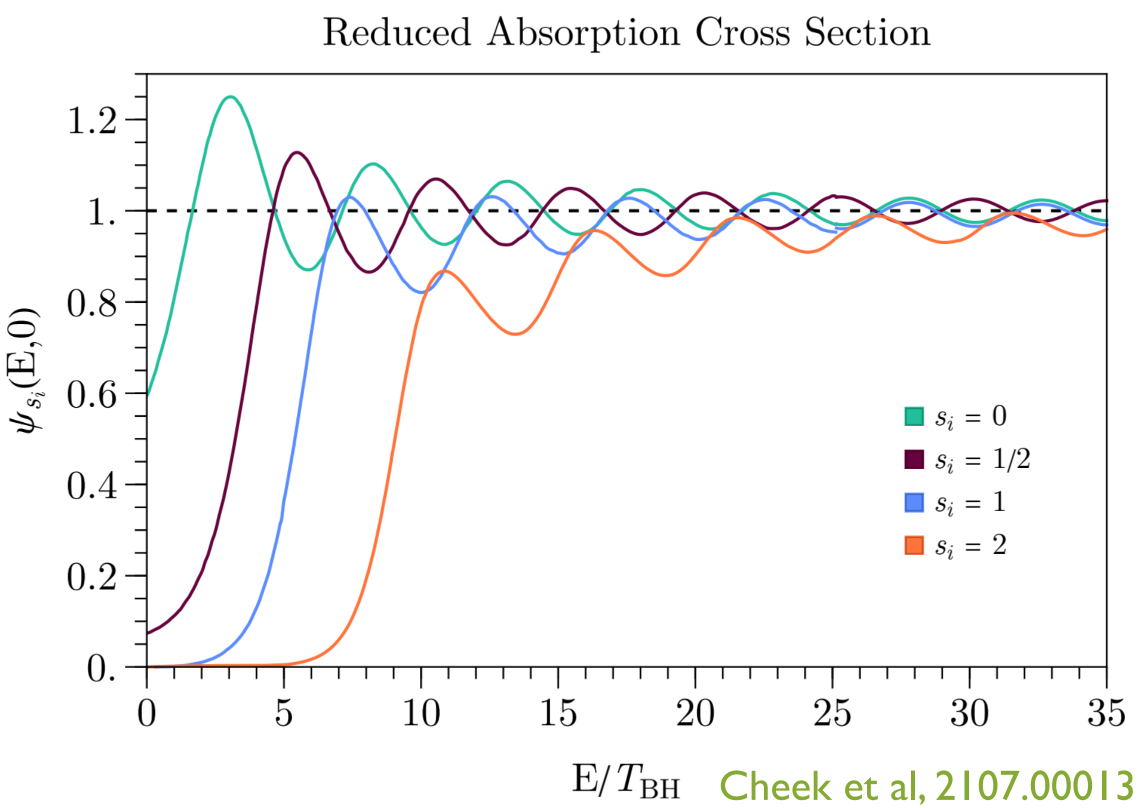
Particle Emission Rate

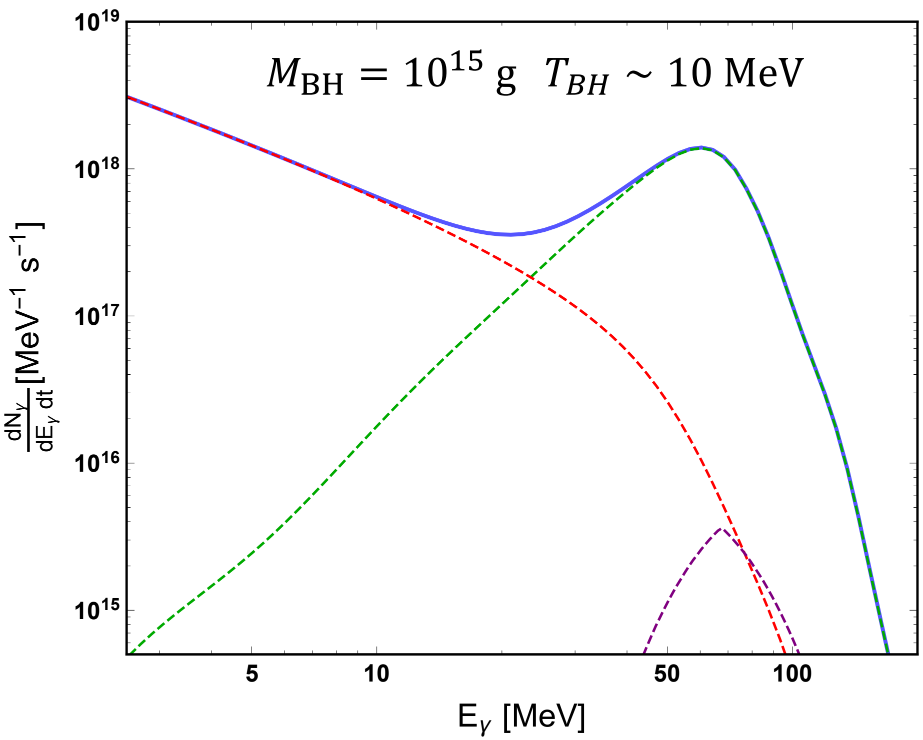
- $$\frac{\partial N_i}{\partial E_i \partial t} = \frac{g_i}{2\pi} \frac{\Gamma_i}{e^{E_i/T_{\mathrm{BH}}} \pm 1}$$
- $$\Gamma_i = \frac{\sigma_{s_i} p^2}{\pi}$$
  is the greybody factor
- $$\psi_{s_i} = \frac{\sigma_{s_i}}{\sigma_{GO}}$$
- $$\sigma_{GO} = 27\pi G^2 M_{BH}^2$$
- The greybody factor depends on particle spins

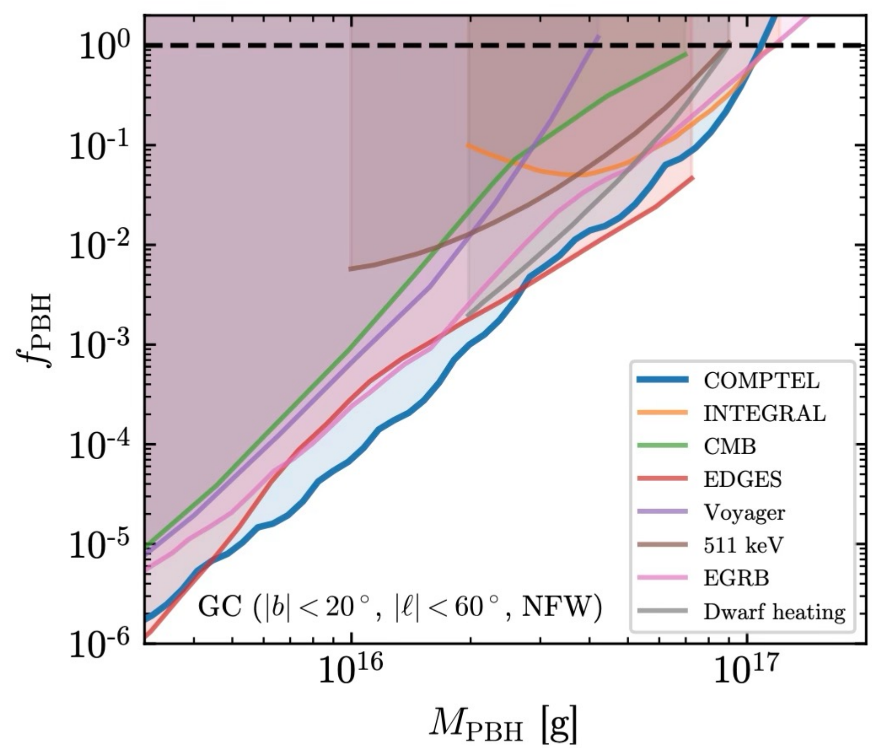


Cheek et al, 2107.00013

Photon spectrum of Hawking radiation

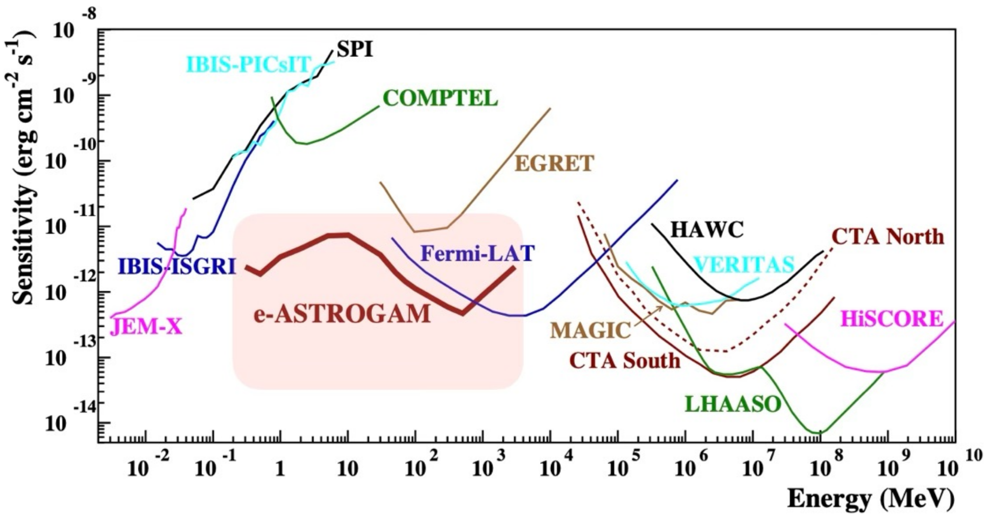
$$\frac{\partial N_{\gamma,\mathrm{tot}}}{\partial E_\gamma \partial t} = \underbrace{\frac{\partial N_{\gamma,\mathrm{primary}}}{\partial E_\gamma \partial t}}_{\text{primary photon}} + \underbrace{\sum_{i=e^\pm,\mu^\pm,\pi^\pm} \int dE_i \frac{\partial N_{i,\mathrm{primary}}}{\partial E_i \partial t} \frac{dN_{i,\mathrm{FSR}}}{dE_\gamma}}_{\text{final-state radiation}} + \underbrace{\sum_{i=\pi^0} \int dE_i 2 \frac{\partial N_{i,\mathrm{primary}}}{\partial E_i \partial t} \frac{dN_{i,\mathrm{decay}}}{dE_\gamma}}_{\text{pion decay}}$$



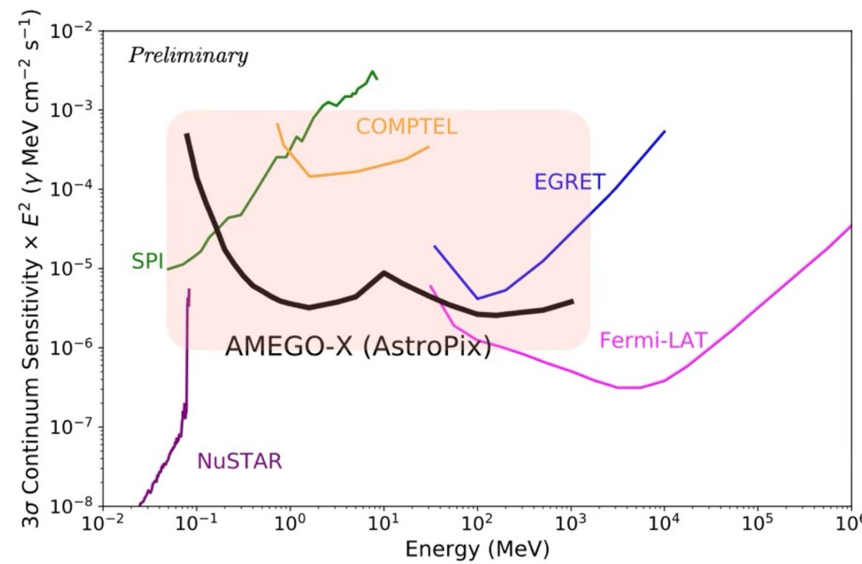


Coogan, Morrison, and Profumo, 2010.04797

Future gamma-ray telescopes



e-Astrogam, 1611.02232

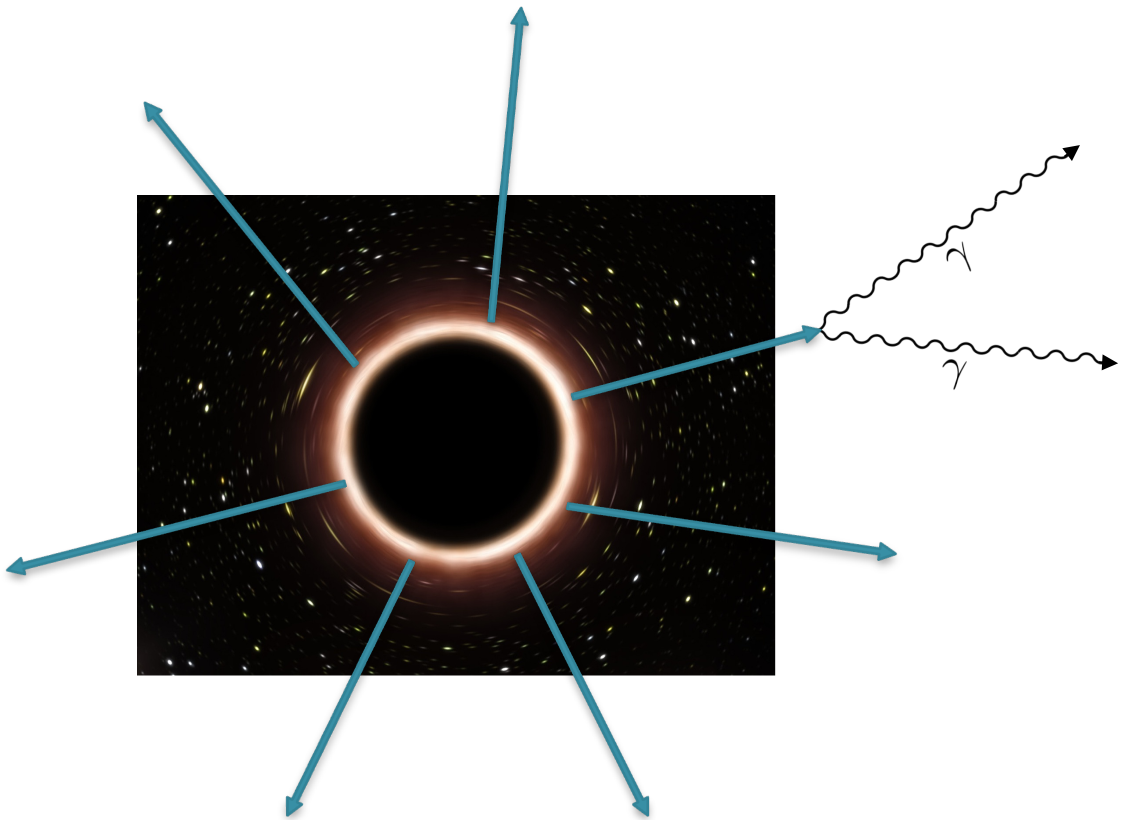


AMEGO-X 2108.02860

- Covers gamma-ray energy $0.1\ \mathrm{MeV} \lesssim E_\gamma \lesssim 100\ \mathrm{MeV}$
- Corresponds to $10^{14}\ \mathrm{g} \lesssim M_{\mathrm{BH}} \lesssim 10^{17}\mathrm{g}$

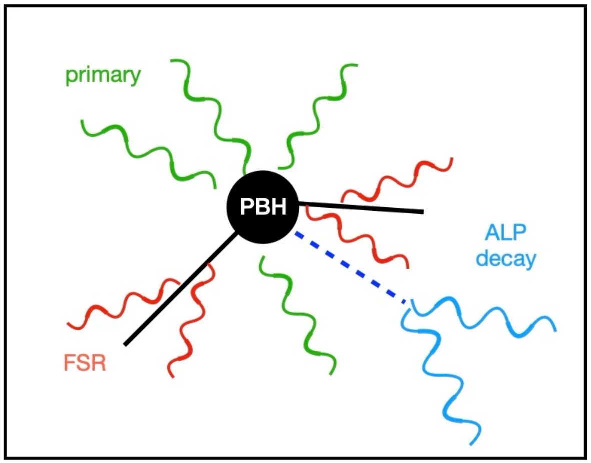
AXION SEARCHES

Axions from PBH

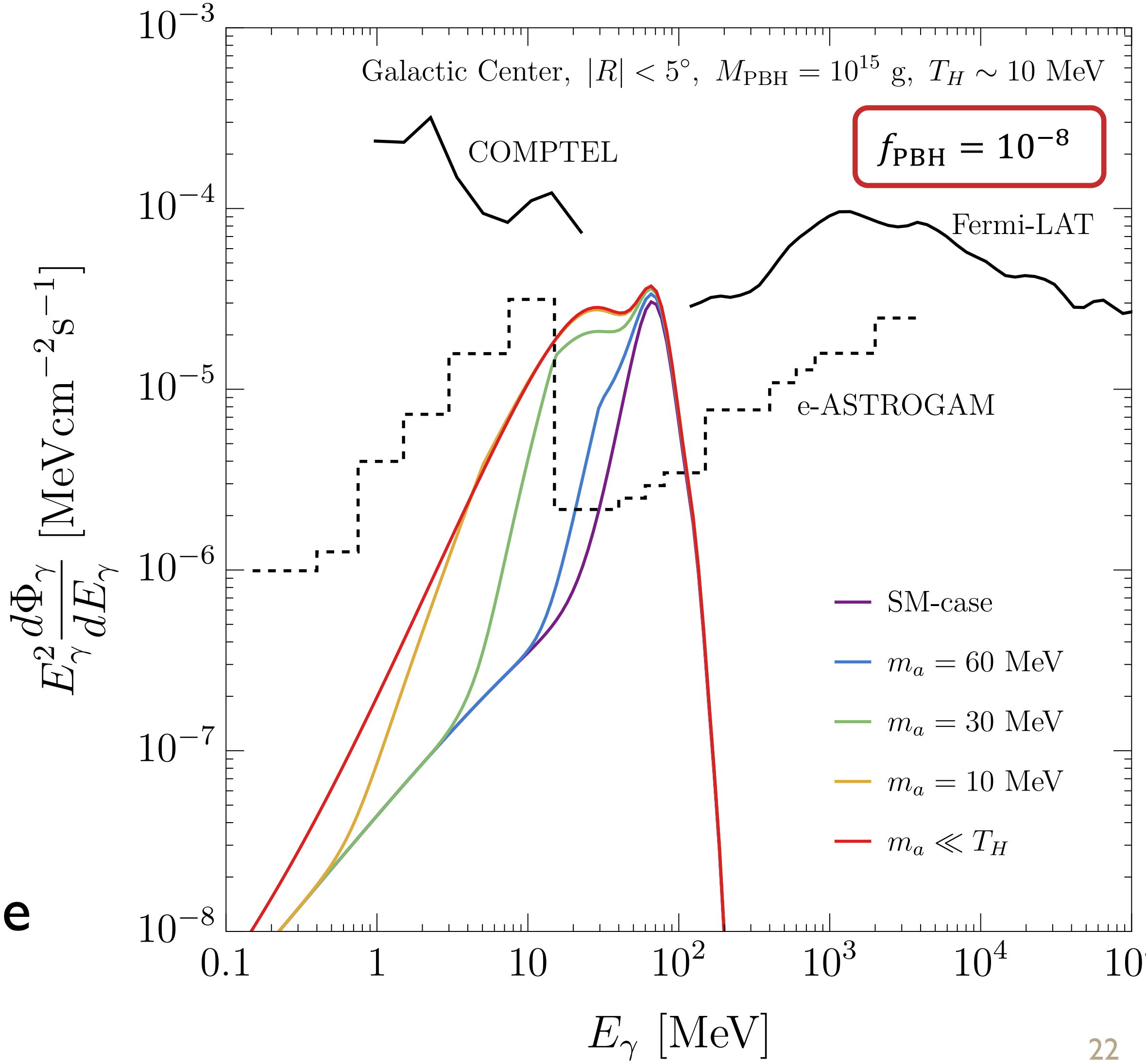


- How to see the dark sector particles from PBHs?
- It's possible if the particle decays into photons
- An obvious example is the axion

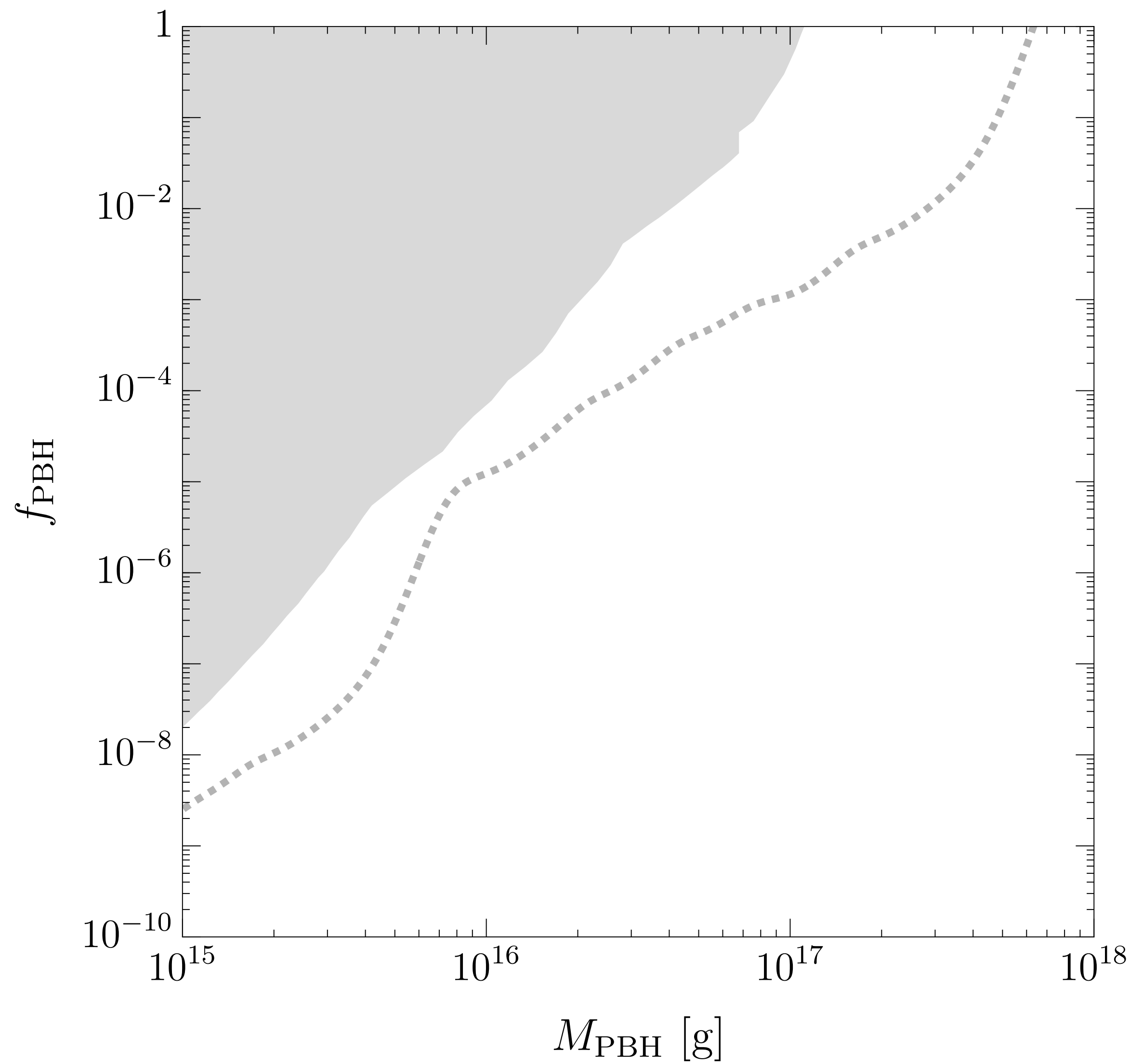
PBH photon spectrum with axions



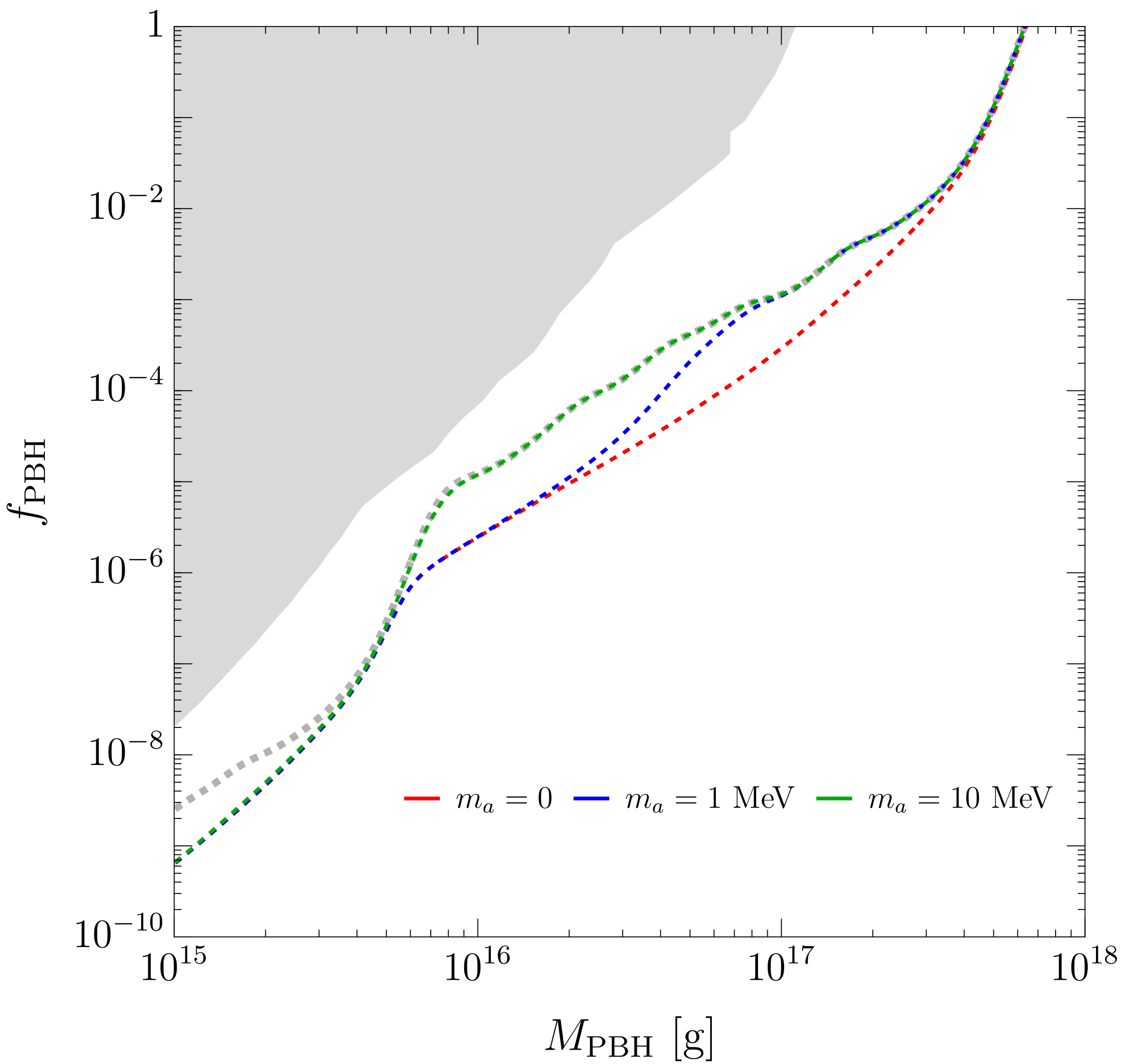
- Axion decay gives a double-peak feature
- Once the PBH photon spectrum is discovered, we can tell the existence of the axion



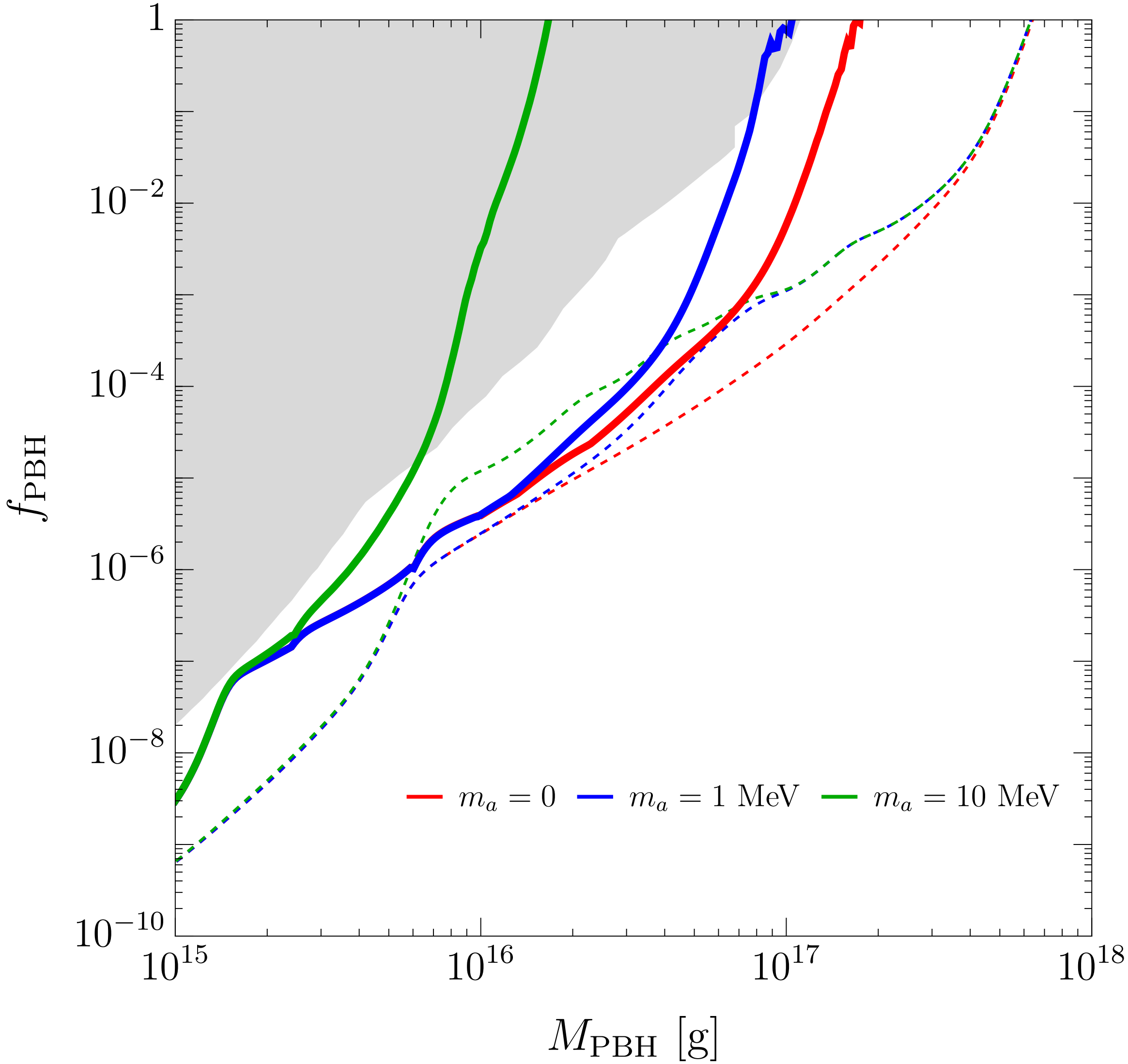
Future PBH sensitivity for SM



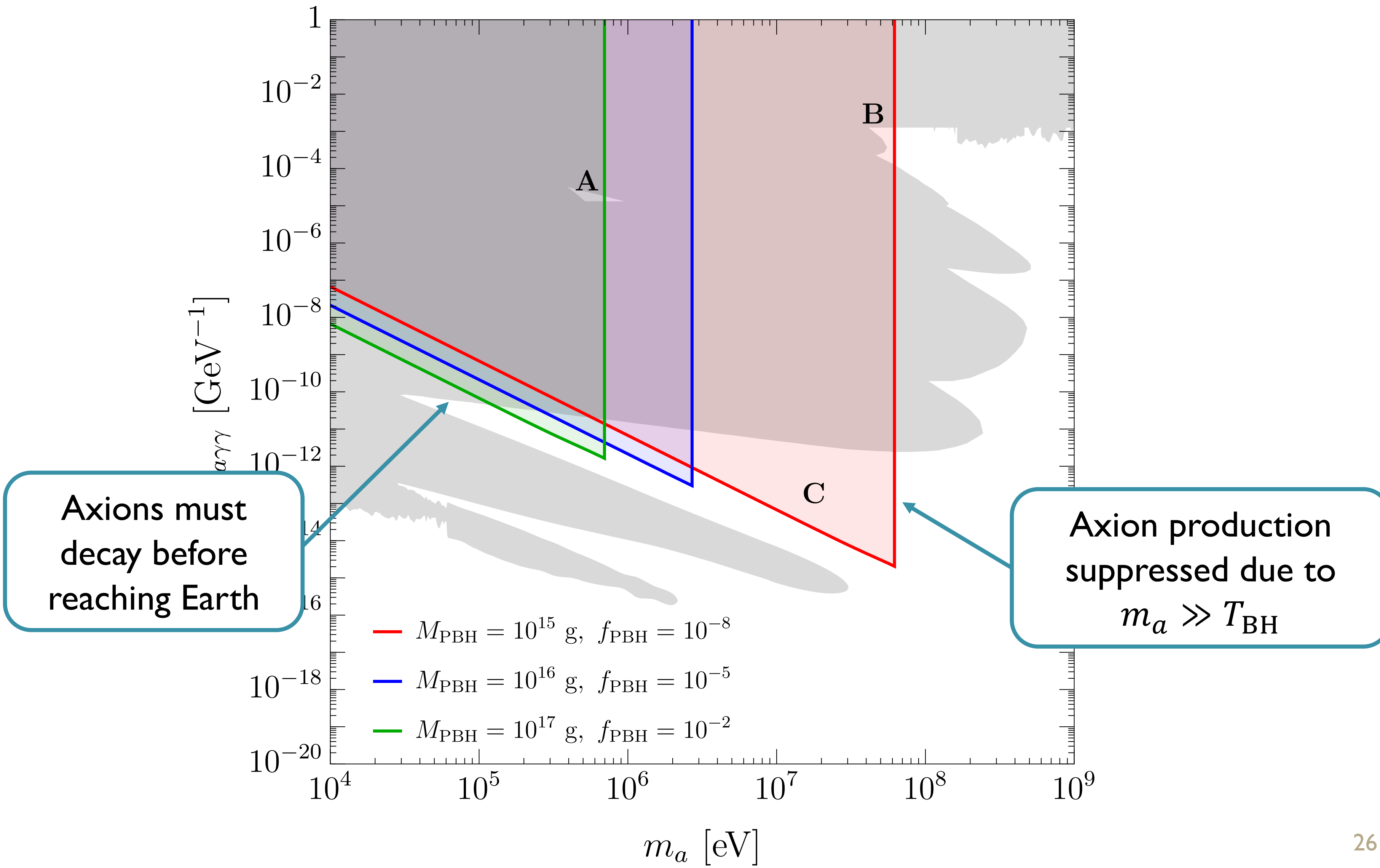
Future PBH sensitivity for SM+axion



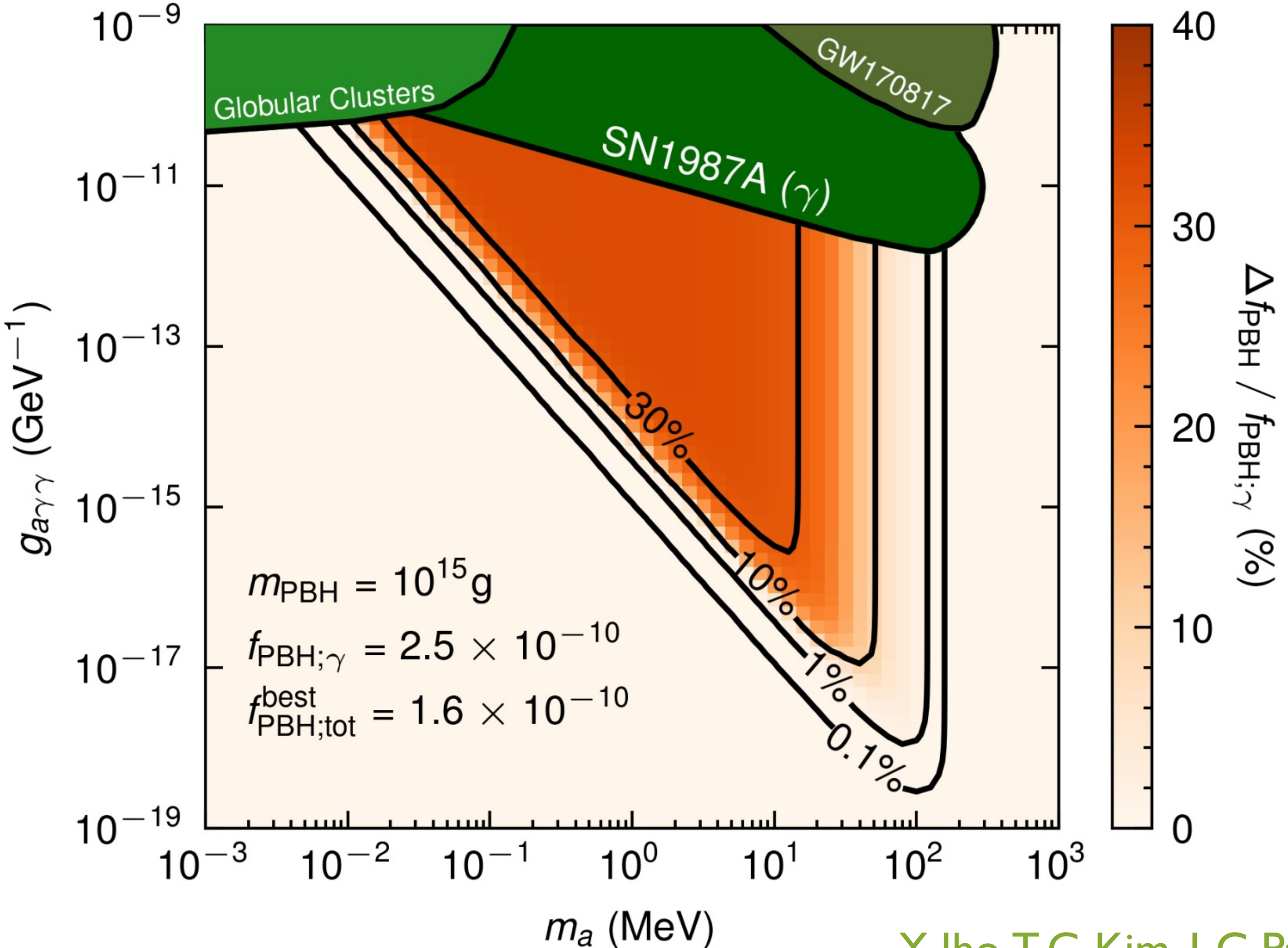
Axion discovery sensitivity



Axion that can be probed with PBH



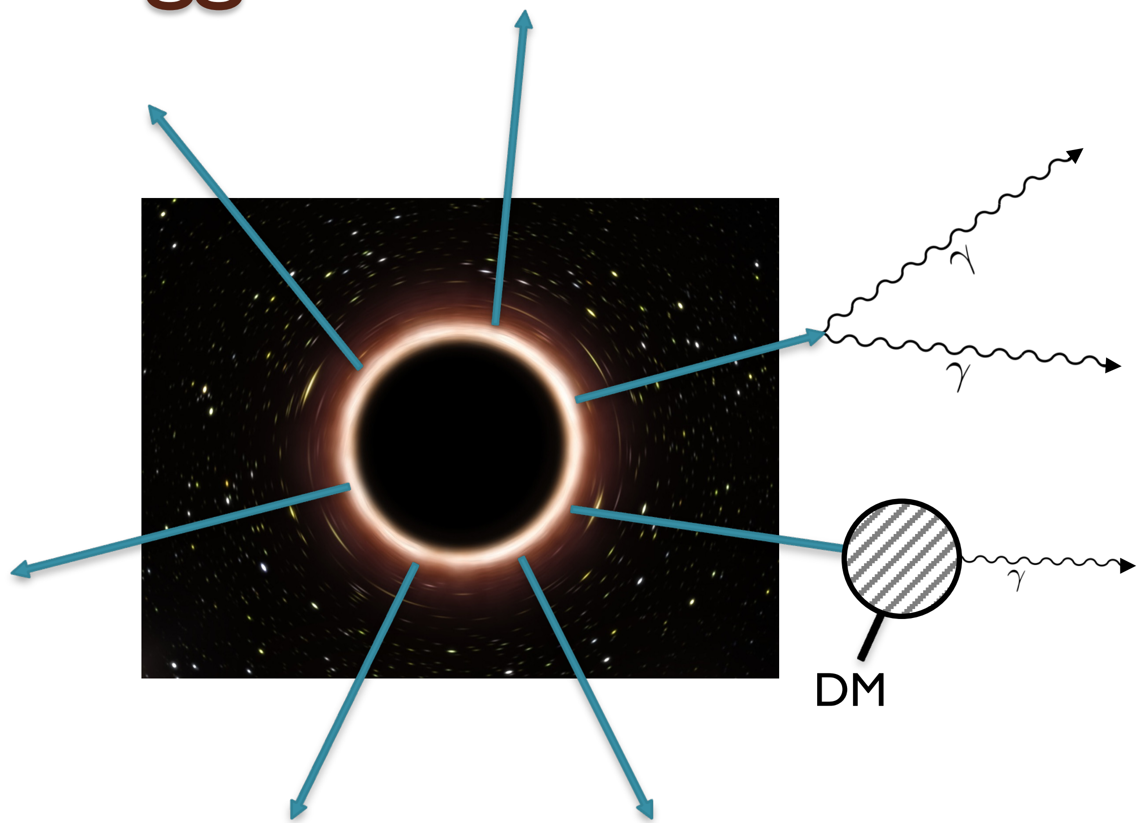
Extragalactic Search



Y Jho, T-G Kim, J-C Park, SC Park, and Y Park, 2212.11977

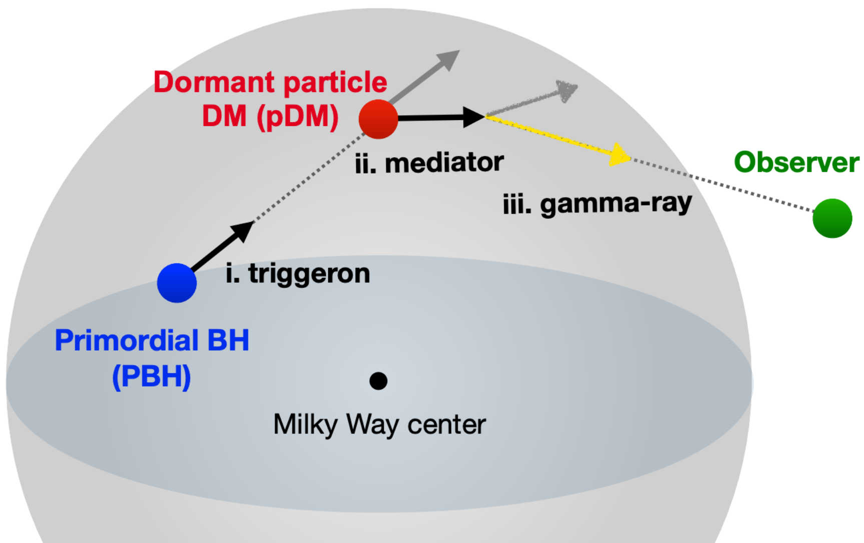
PBH-INDUCED DARK MATTER SIGNALS

Triggeron from PBH



- Dark matter may give visible signals after interacting with a dark sector particle from PBHs

Triggeron Mechanism

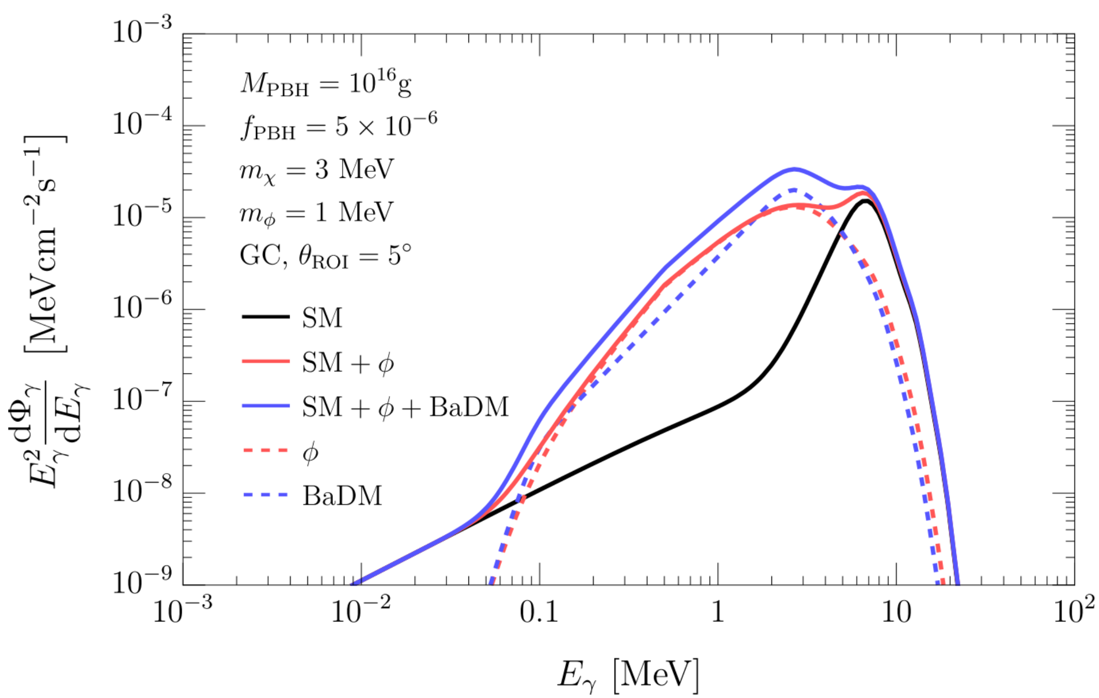


$$\begin{aligned}
\text{(i) emission:} &\quad \text{PBH} \;\rightarrow\; \text{triggeron} \;\; \text{(via Hawking radiation)};\\
\text{(ii) annihilations:} &\quad \text{triggeron} \;+\; \text{pDM} \;\rightarrow\; \text{mediator} \;+ \text{other} \;;\\
\text{(iii) decays:} &\quad \text{mediator} \;\rightarrow\; \text{SM} \;+ \ldots \;.
\end{aligned}$$

Boosted anti-DM (BaDM) model

$$\text{BaDM model:} \quad \begin{cases} \text{emission:} & \text{PBH} \to \bar{\chi} \\ \text{annihilations:} & \bar{\chi}\chi \to \phi\phi \\ \text{decays:} & \phi \to \gamma\gamma \end{cases}$$

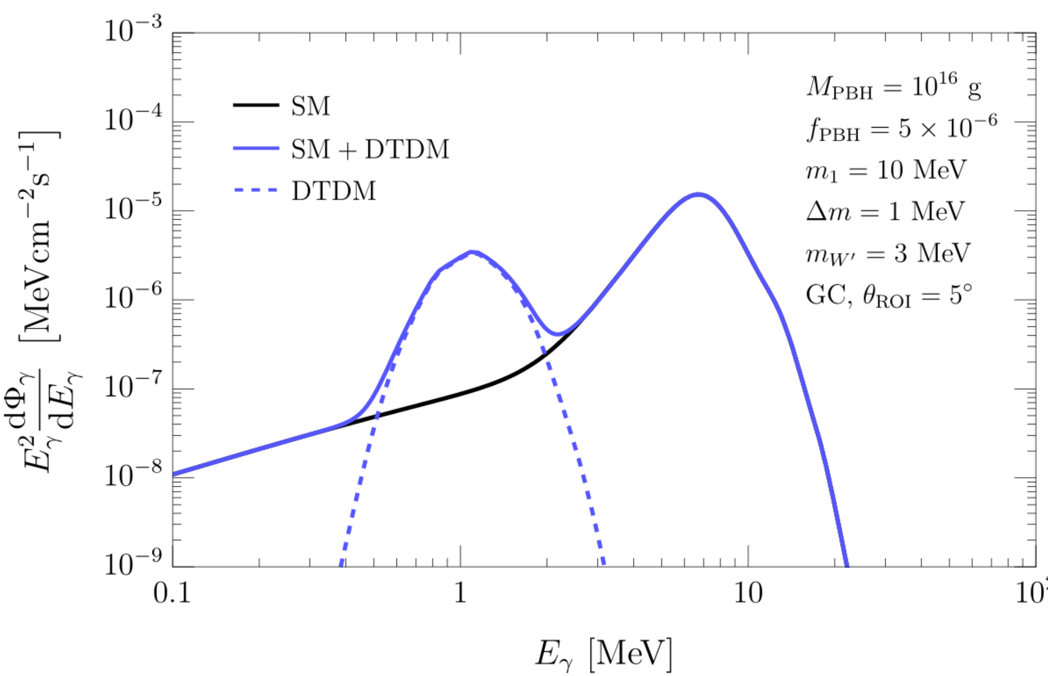
$$\text{Kinematics:} \quad m_\phi < m_\chi \lesssim \mathcal{O}(\text{few}) \times T_{\text{PBH}}$$



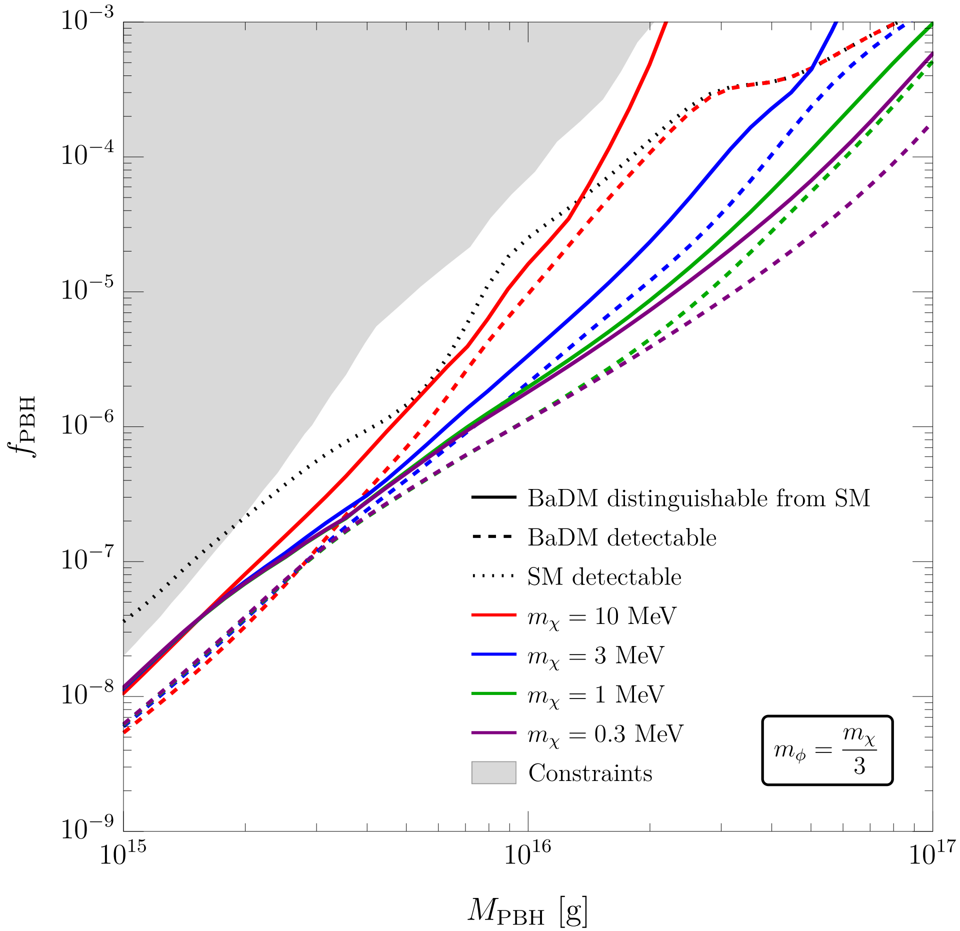
Dipole Transition DM (DTDM) model

$$\text{DTDM model:} \quad \begin{cases} \text{emission:} & \text{PBH} \to W^{a\prime} \\ \text{annihilations:} & W^{a\prime}\chi_1 \to W^{b\prime}\chi_2 \\ \text{decays:} & \chi_2 \to \chi_1\gamma \\ \text{(but not:} & \chi_2 \not\to \chi_1 W') \end{cases}$$

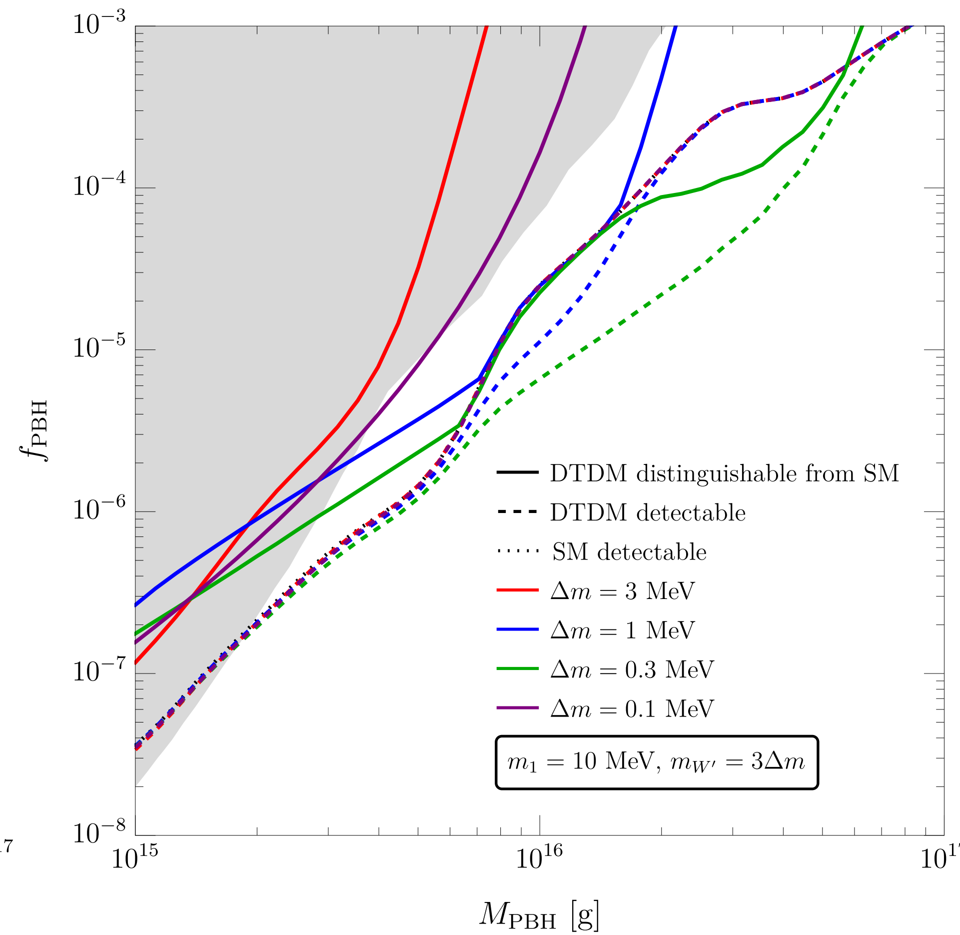
$$\text{Kinematics:} \quad \Delta m < m_{W'} \lesssim \mathcal{O}(\text{few}) \times T_{\rm PBH} \ll m$$



Model discovery sensitivities



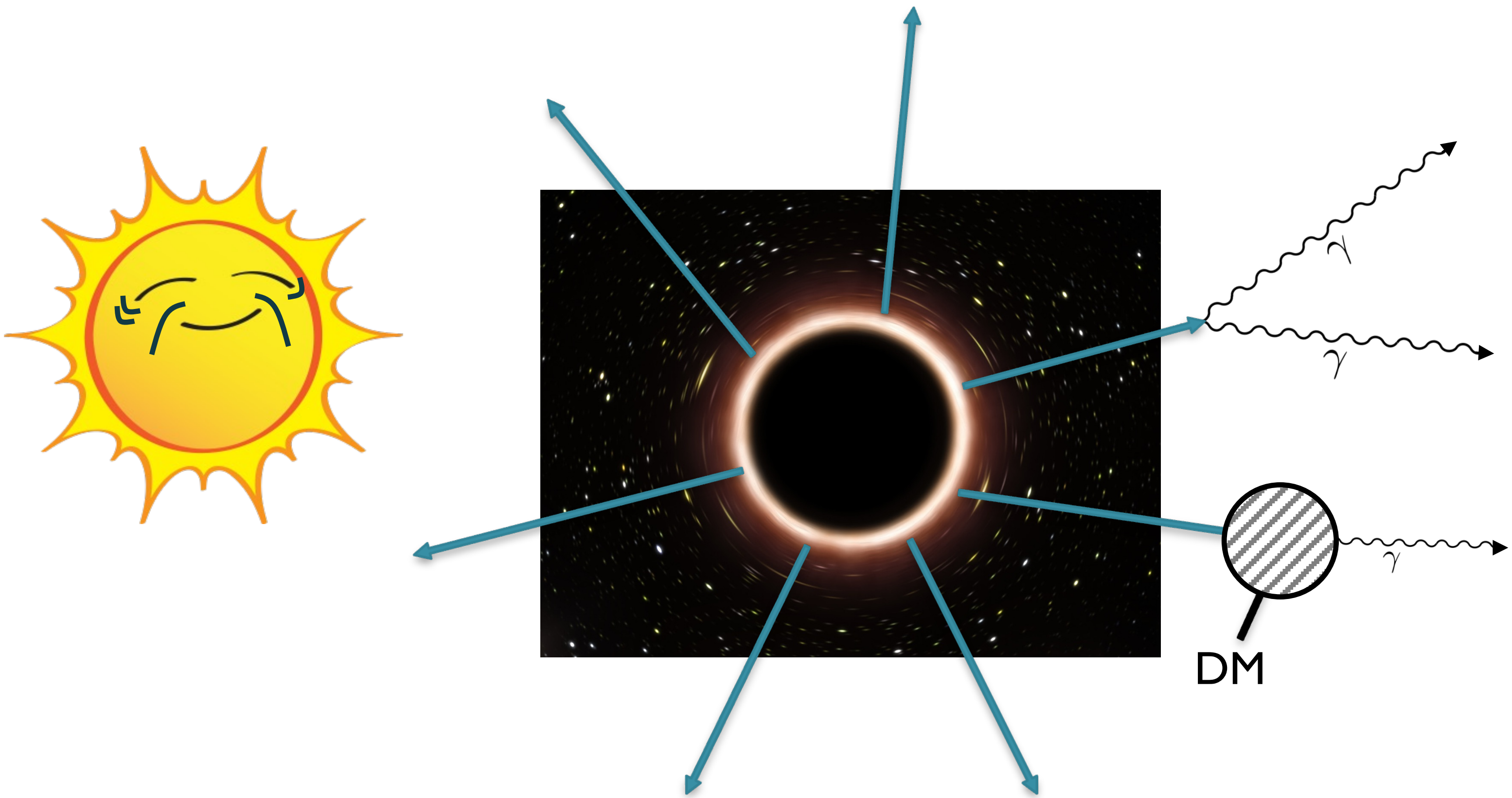
BaDM Model



DTDM Model

THE TAIL OF
THE PBH MASS FUNCTION

Black hole mass evolution

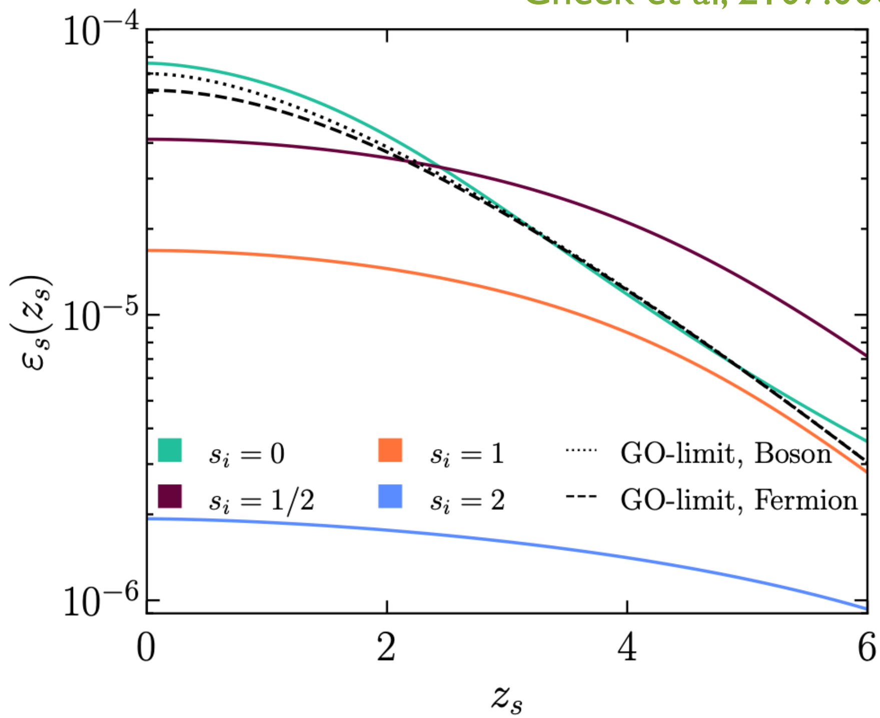


- Black holes lose their mass faster if more d.o.f exist
- The evolution of the PBH mass spectrum can tell the existence of light d.o.f regardless of their interactions with the SM

PBH evaporation

Cheek et al, 2107.00013

- $\dot{M}_{\rm BH} = -\varepsilon(M_{\rm BH})\frac{M_P^4}{M_{\rm BH}^2}$

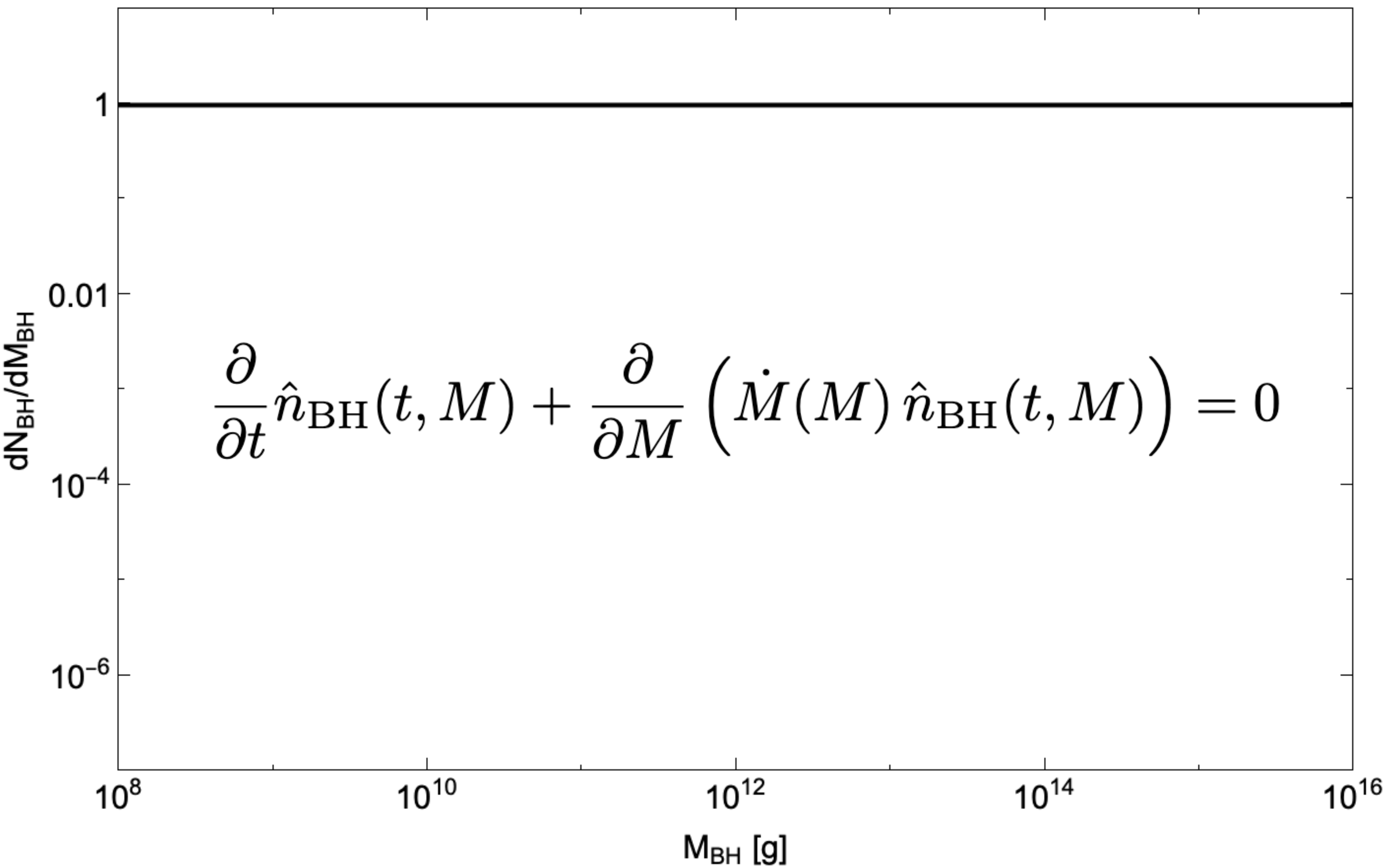


- $\varepsilon(M_{BH}) = \sum_i g_i \varepsilon_i(z_i)$

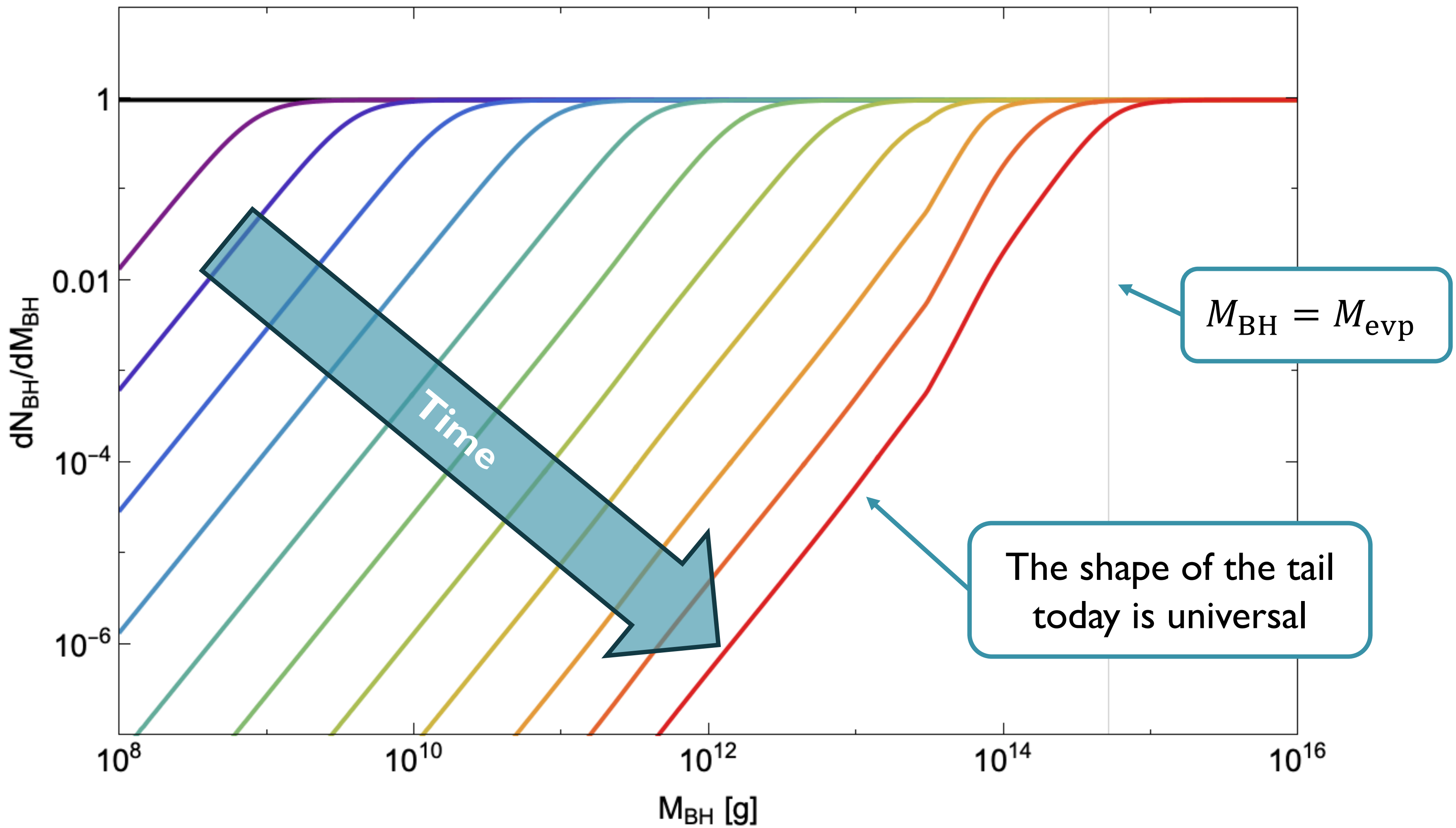
- $z_i = m_i / T_{\rm BH}$

- If there are more d.o.f,
  $\dot{M}_{\rm BH}$ is larger and the PBH evaporates faster

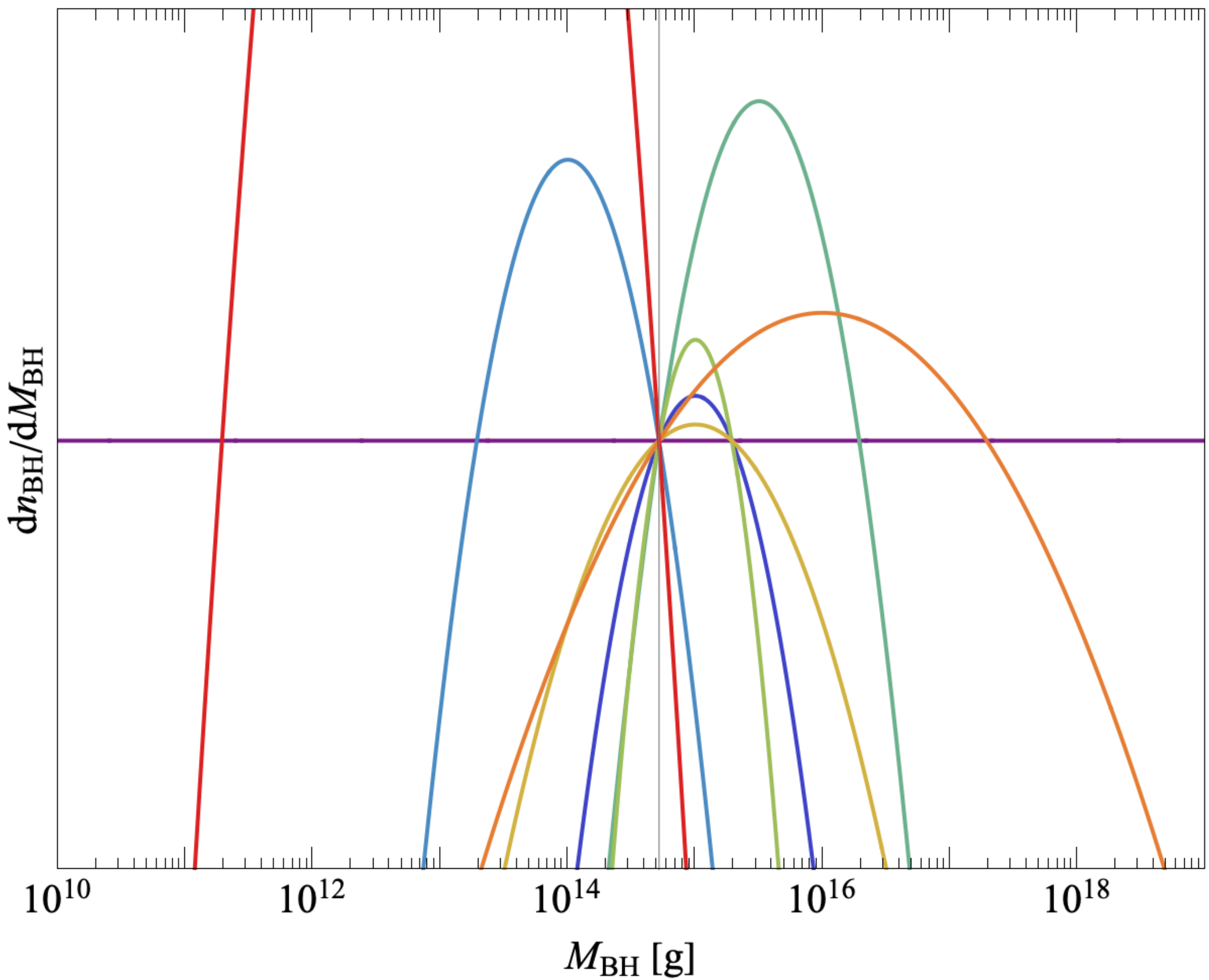
BH mass function evolution



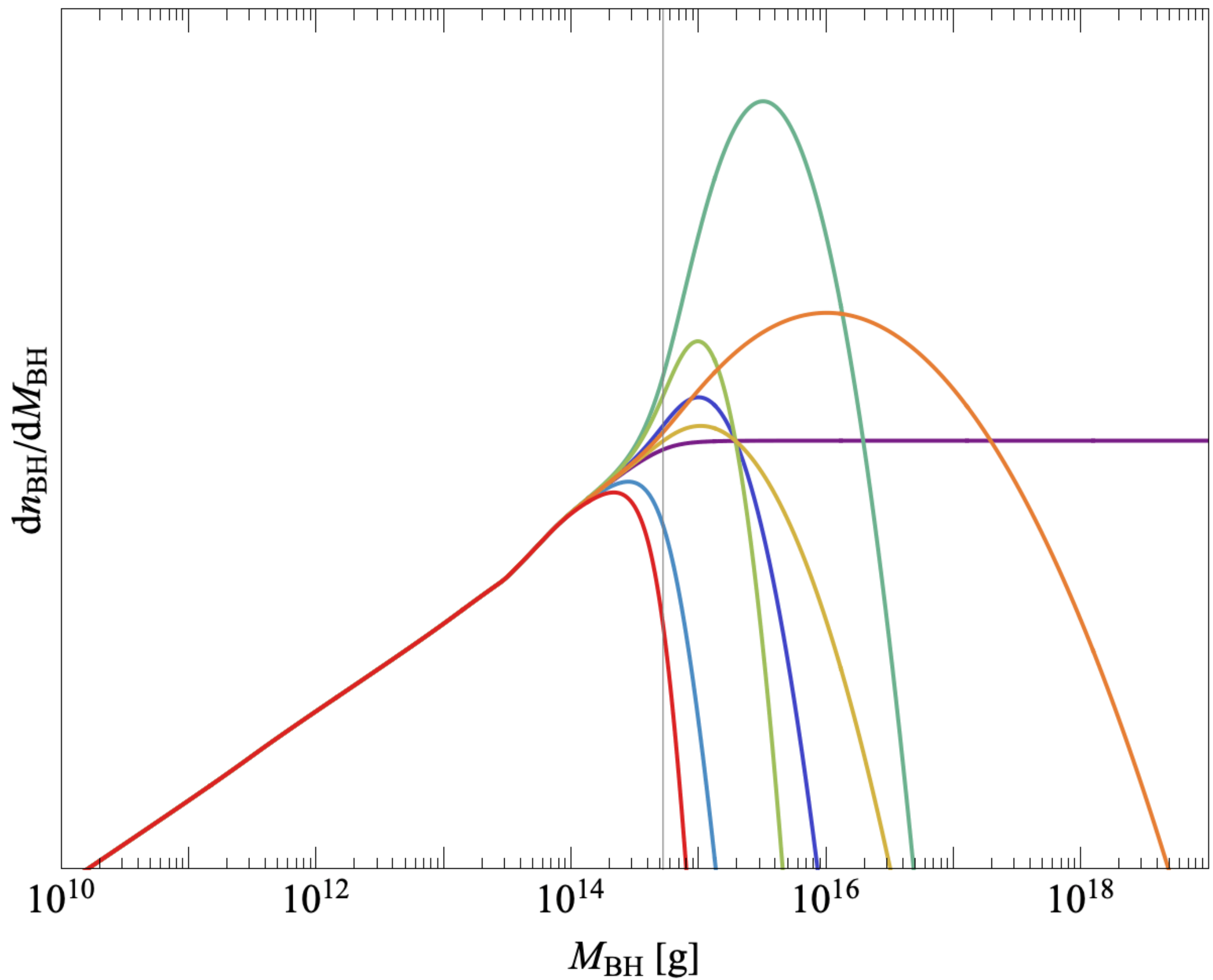
BH mass function evolution



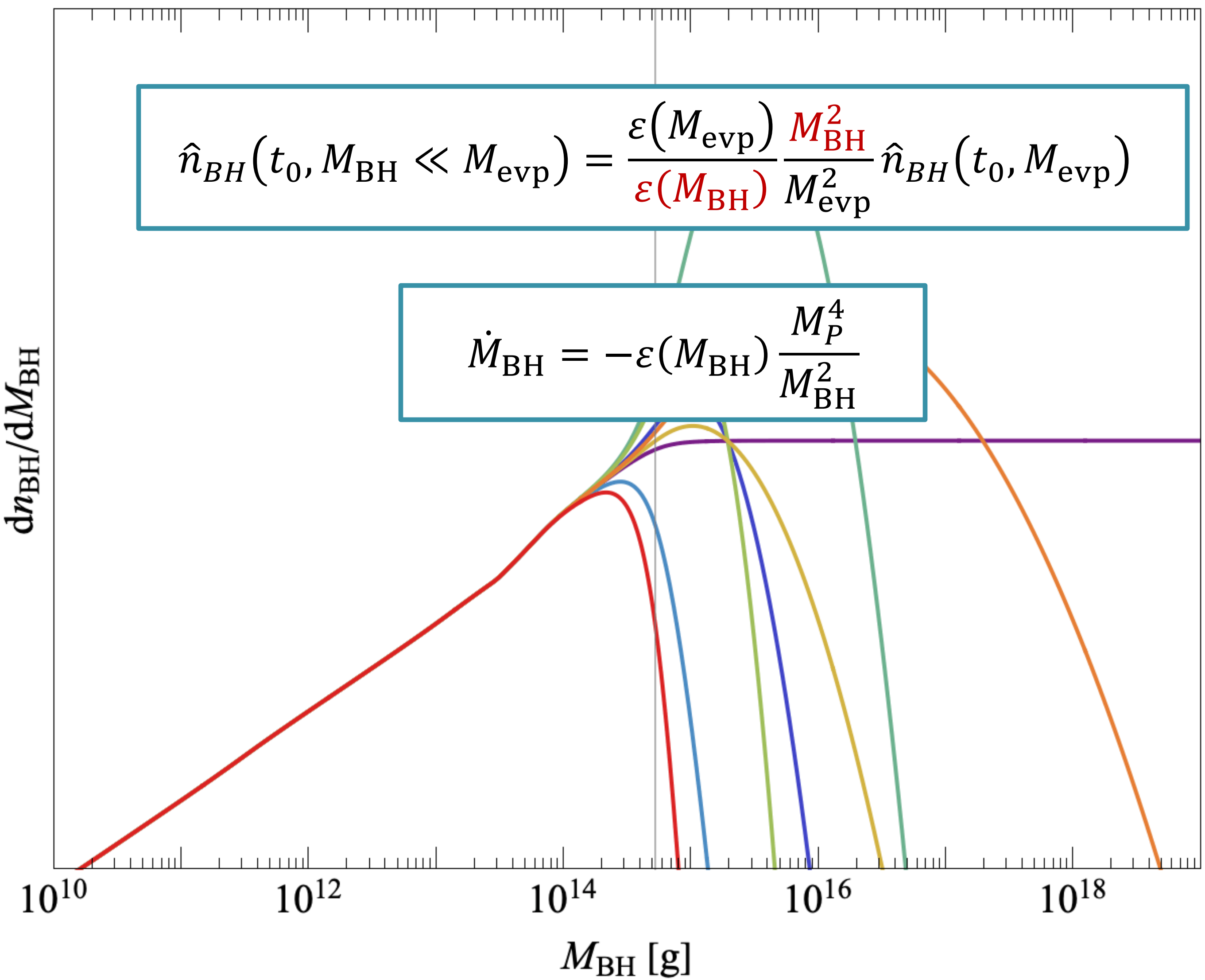
Different BH mass functions



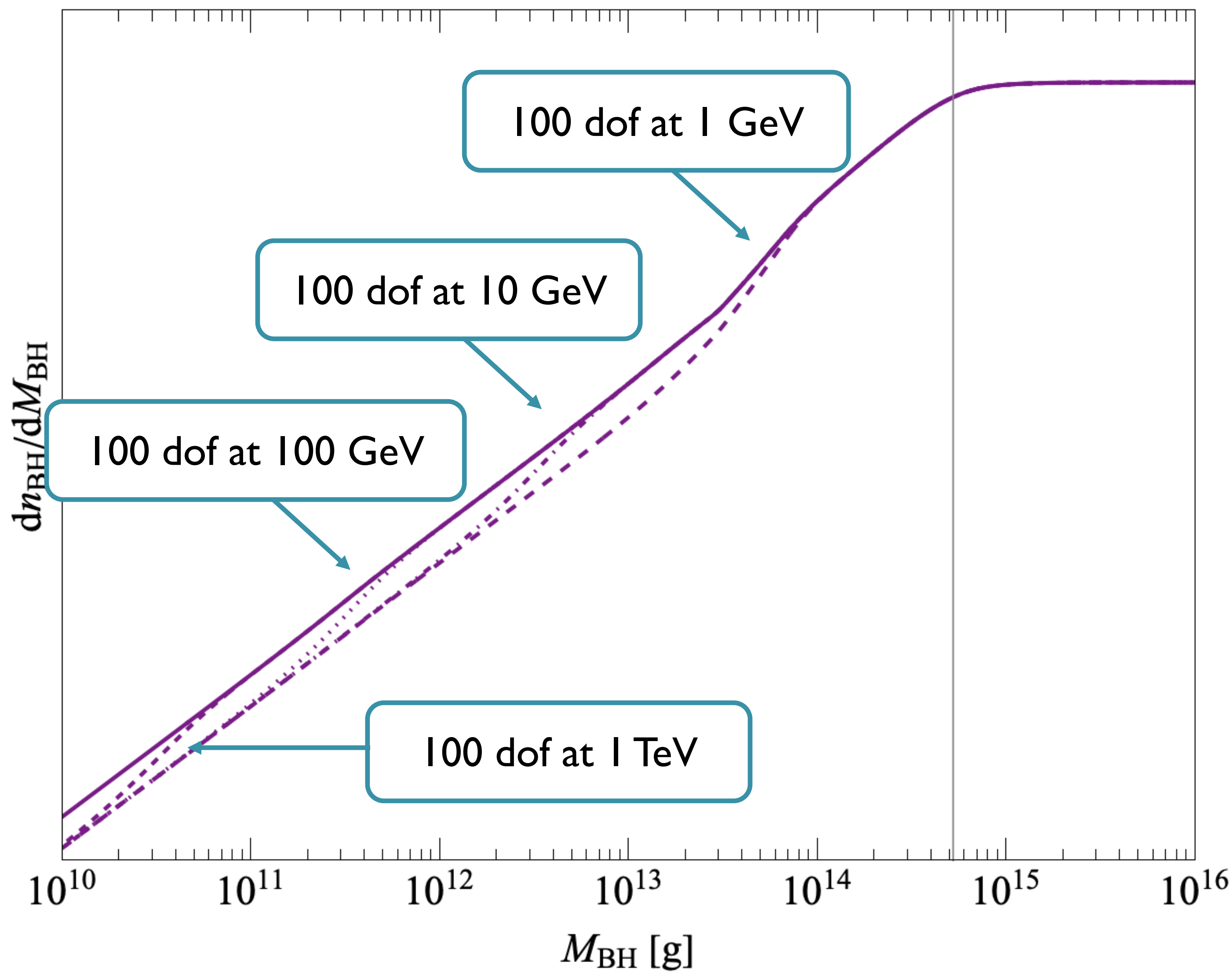
Different BH mass functions today



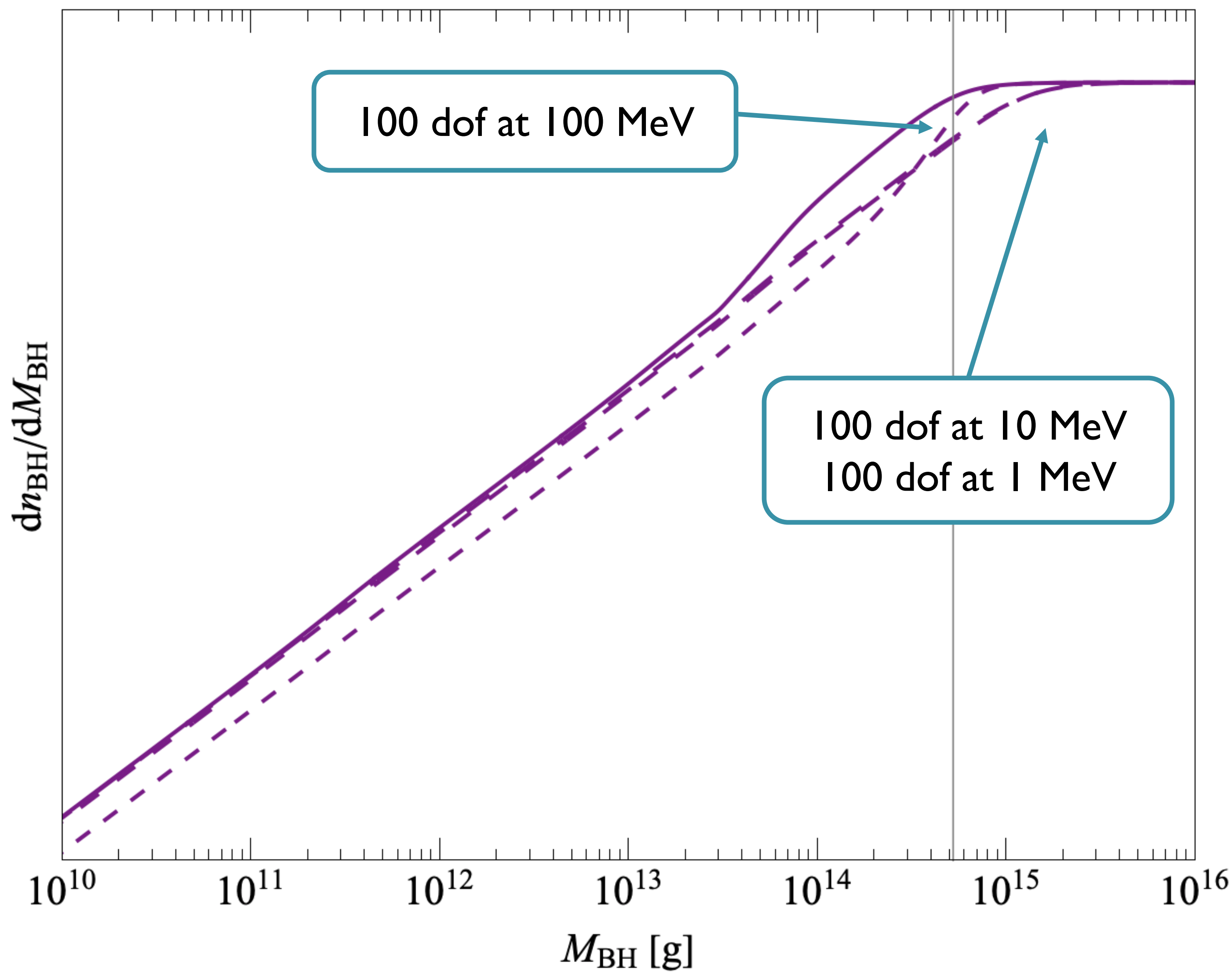
Different BH mass functions today



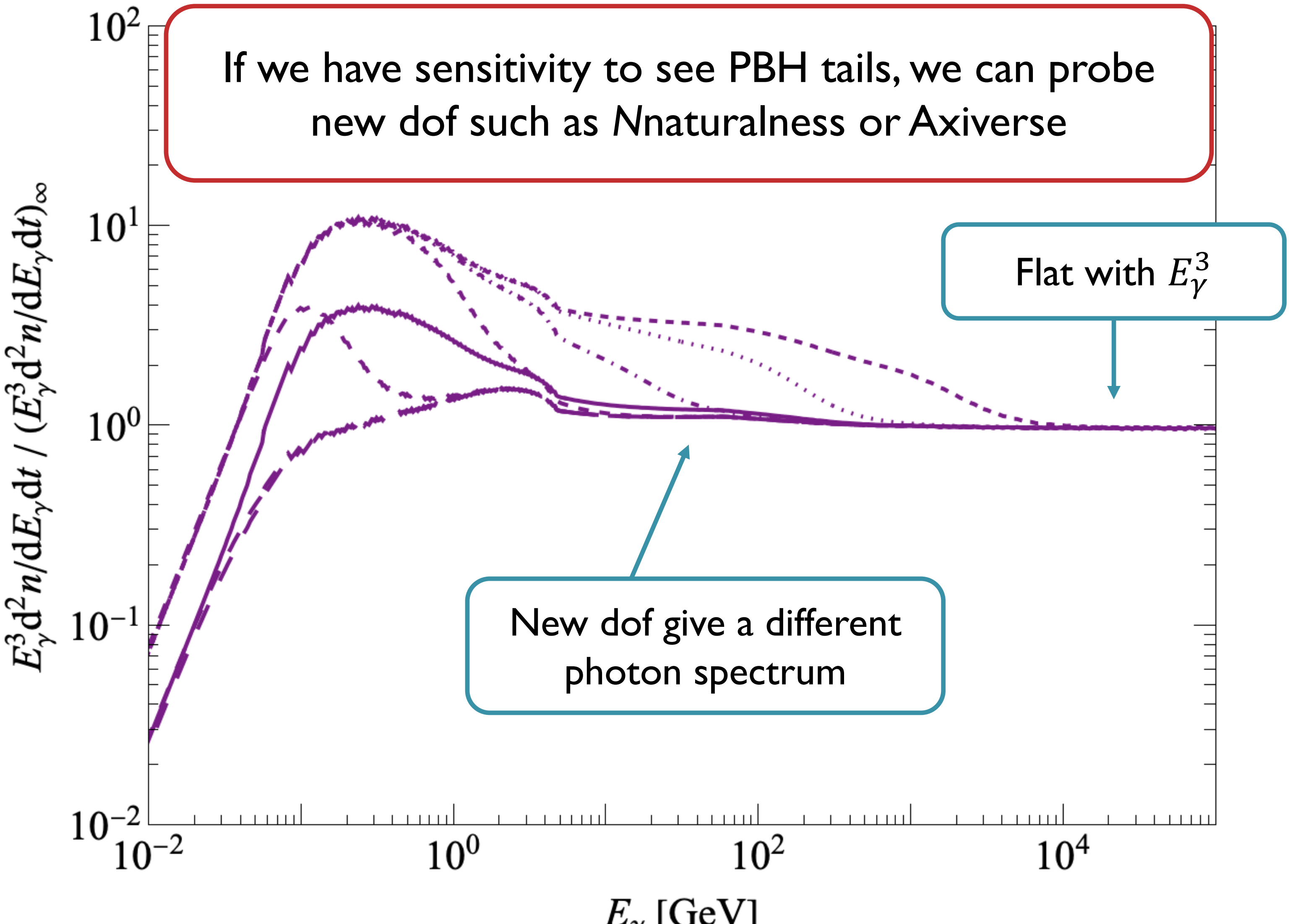
The tail changes if we have new physics



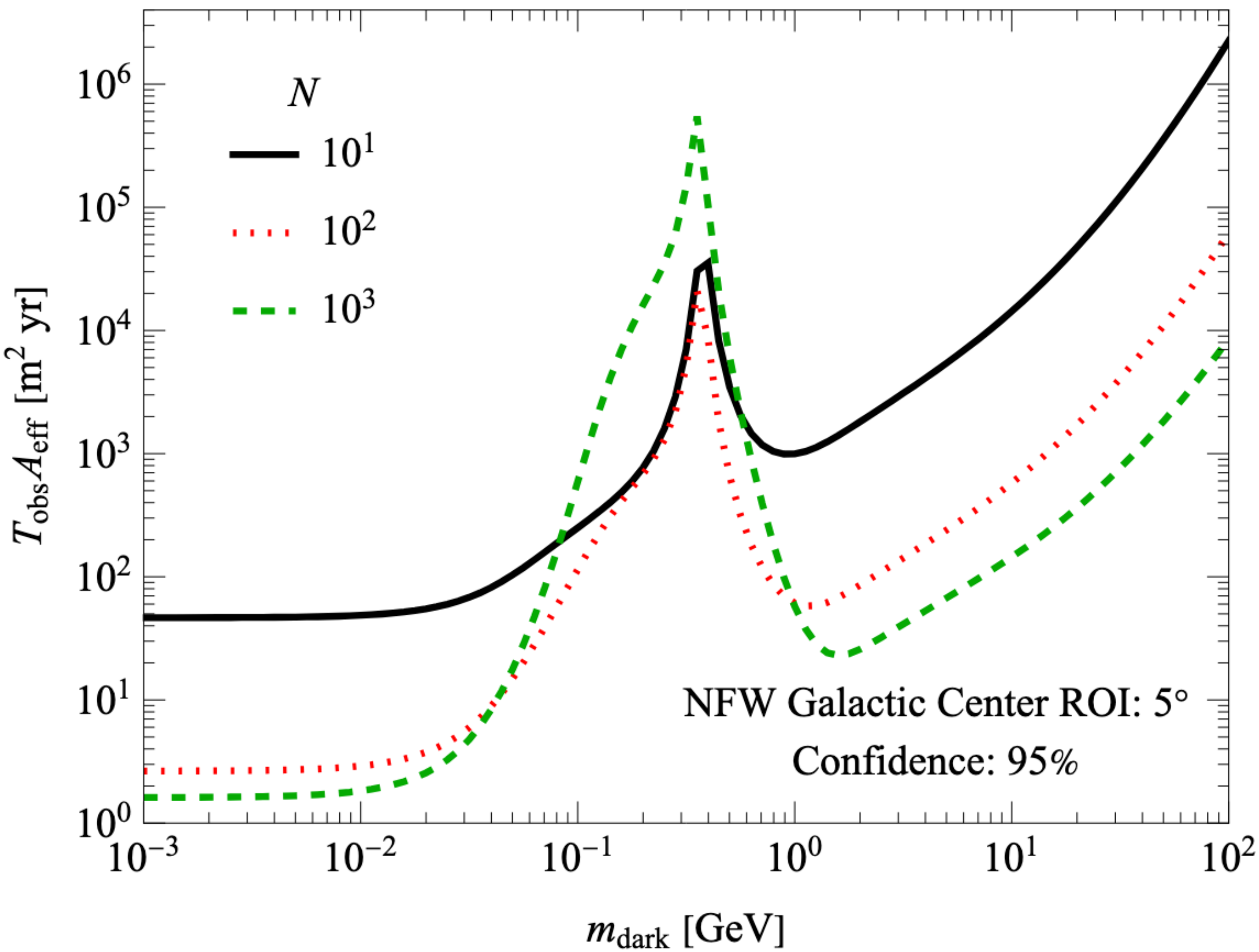
Even $M_{\rm evp}$ is affected



Photon Spectra



Future Sensitivity



SUMMARY

Summary

- PBHs can be good sources for dark sector particles

- Once the PBH spectrum is discovered, we can tell the existence of dark sector particles that
  - decay into photons
  - excite dark matter

- If we can see the tail of the PBH mass spectrum, we can tell the existence of additional dof regardless of their interactions with the SM

THANK YOU