

---

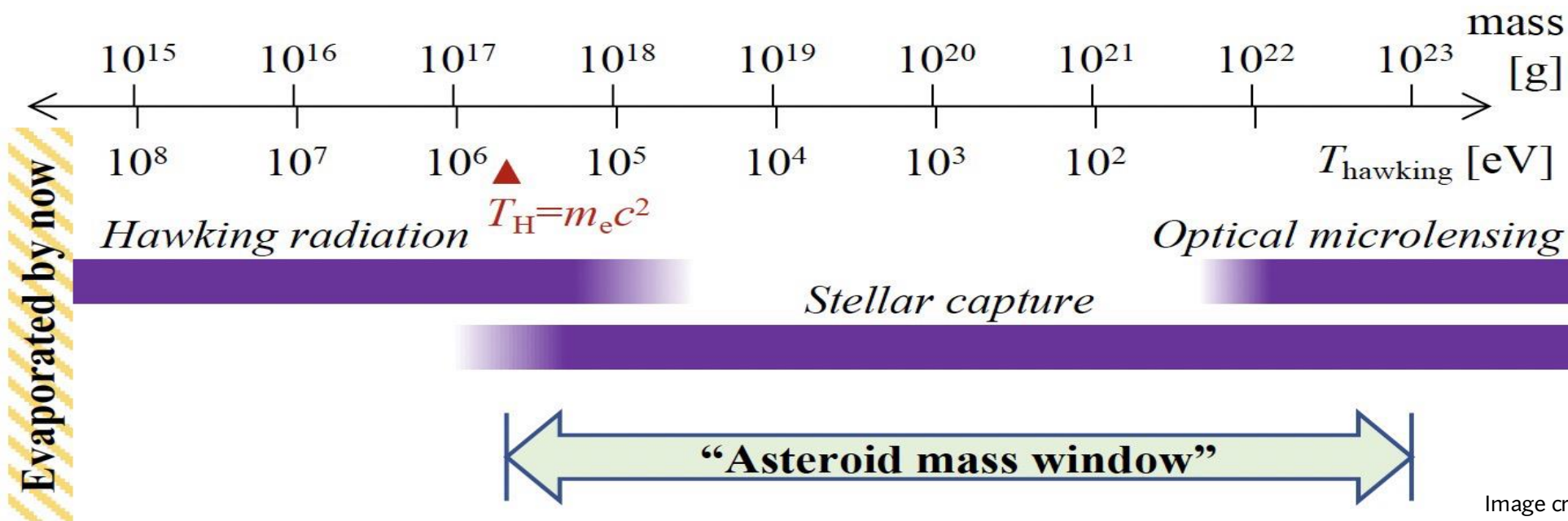
# Dissipative QED Corrections to the Hawking Electron Spectrum from Primordial Black Holes

By Bowen Chen (The Ohio State University)

Collaborators: Emily Koivu, Makana Silva, Gabriel Vasquez, Cara Nel, and Christopher Hirata

PHENO 2026 Symposium

May 12, 2026



- PBHs in the asteroid-mass window remain a viable dark-matter candidate  
Predicted by GR in the early Universe; “Cold and dark” ; Do not require BSM particles
- Hawking radiation constrains the low-mass side of the window  
Produce  $\gamma$ ,  $e^\pm$ , and  $\nu$ ; indirect-detection signals (gamma ray background & 511 keV line)
- The low-mass edge,  $T_H \sim m_e$ , the  $e^\pm$  channel becomes important

Precision PBH constraints require an accurate  $e^\pm$  spectrum!

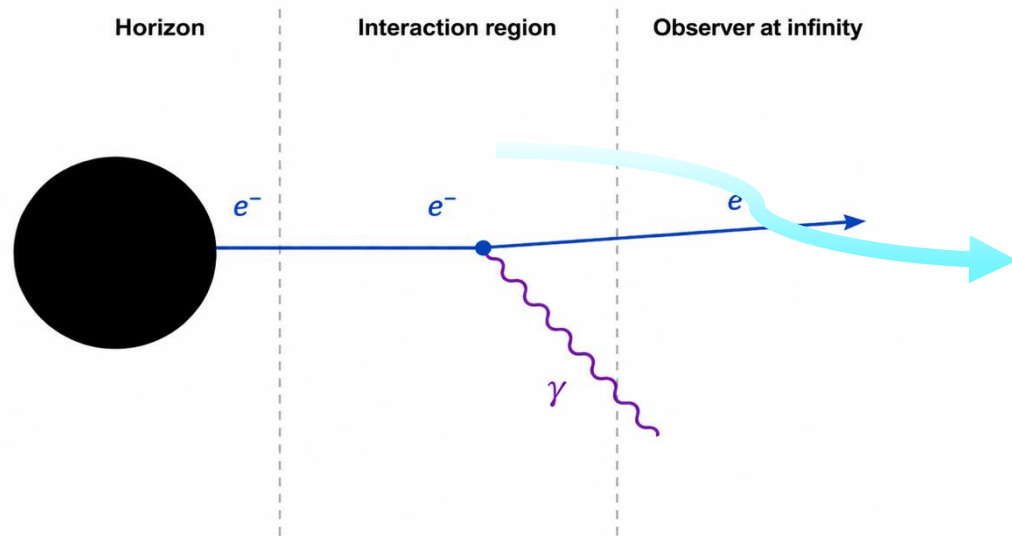
# What Spectrum Are we Correcting?

- Zeroth-order Hawking radiation gives a free-field  $e^\pm$  spectrum set by thermal occupation  $\times$  angular momentum barrier transmission [Page 1977].

$$\frac{dN^{(0)}}{dh dt} = \sum_k \frac{2j+1}{2\pi} \frac{|T_{1/2,k,h}|^2}{e^{h/T_H} + 1}$$

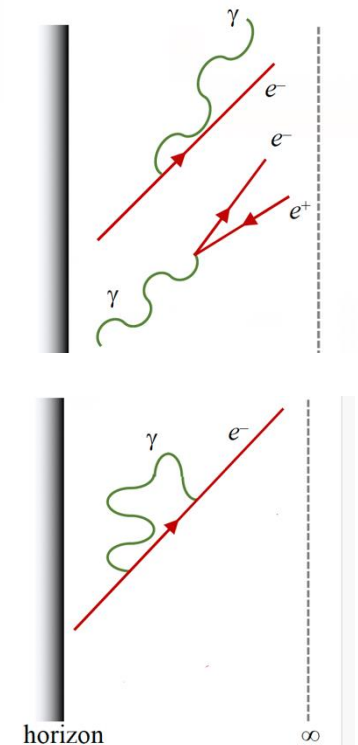
- Our goal: Turn on the interaction among particles and compute the  $O(\alpha)$  QED correction to the electron spectrum

$$\frac{dN_{e^\pm}^{(1)}}{dh dt} = \frac{dN_{e^\pm}^{(0)}}{dh dt} + \frac{dN_{e^\pm}^{(\alpha)}}{dh dt}$$



Dissipative interaction  
(directly change particle number) **What this work focuses on**

Exchange/conservative interaction (modify the propagation/transmission)



# From QED Interaction to Electron Spectrum

Observable: outgoing electron occupation

$$\frac{dN_{e^-}^{(1)}}{dh dt} = \frac{1}{2\pi} \sum_{km} \frac{d}{dt} \langle \hat{b}_{\text{out},k,m,h}^\dagger \hat{b}_{\text{out},k,m,h} \rangle$$

Dynamics: QED interaction Hamiltonian

$$\frac{d}{dt} \langle \hat{b}_{X,k,m,h}^\dagger \hat{b}_{X',k,m,h'} \rangle = -i \langle [\hat{b}_{X,k,m,h}^\dagger \hat{b}_{X',k,m,h'}, H] \rangle$$

$$H_{\text{int}} = e \int d^3x \sqrt{-g} \bar{\psi} \gamma^\mu A_\mu \psi$$

Schwarzschild-mode expansion [Silva et al. 2023]

$$H_{\text{int}} = e \sum_{\gamma, e, e'} \hat{a}_\gamma \left[ \underbrace{\hat{b}_e^\dagger \hat{d}_{e'}^\dagger}_{\text{pair creation}} I^{++} + \underbrace{\hat{d}_e \hat{b}_{e'}}_{\text{pair annihilation}} I^{--} + \underbrace{\hat{b}_e^\dagger \hat{b}_{e'}}_{\text{electron scattering}} I^{+-} + \underbrace{\hat{d}_e \hat{d}_{e'}^\dagger}_{\text{positron scattering}} I^{-+} \right] + \text{h.c.}$$

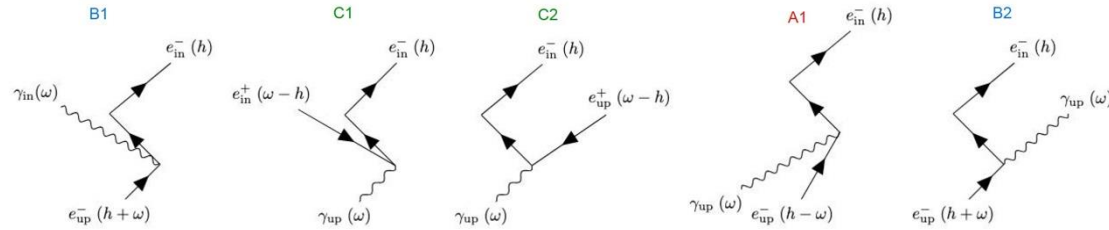
$I^{\pm\pm}$ : overlap of two fermion modes and one photon mode

Schematic structure:

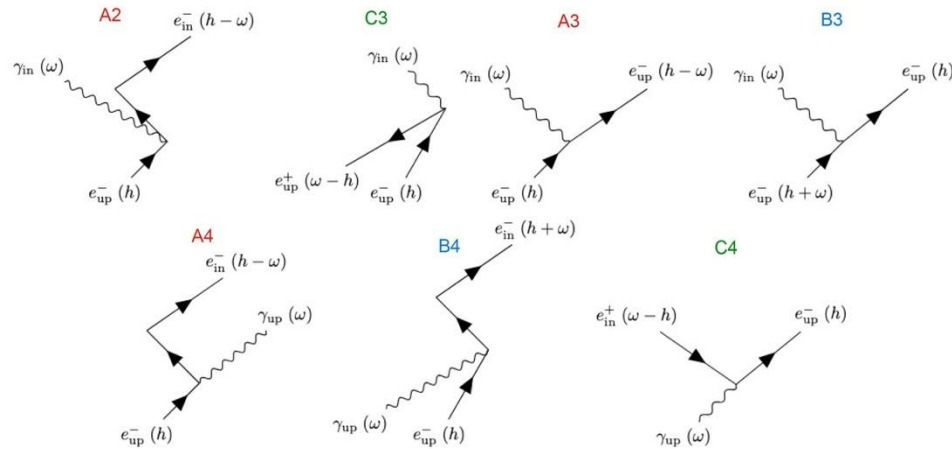
$$\frac{dN_{e^-}^{(1)}}{dh dt} \sim \sum_{\text{channels}} \int d\omega \underbrace{\text{selection rule}}_{j, p \dots} \underbrace{[\text{reflection/transmission coefficients}]}_{|R|^2, |T|^2, \text{Re}(T^* R)} \underbrace{[\text{thermal factors}]}_{\text{Bose/Fermi}} \underbrace{[I_\alpha^* I_\beta]}_{I \text{ overlap}}$$

**This expansion gives 22 allowed dissipative channels.**

5 reflected electron contribution terms with common factor  $|R_{1/2,k,h}|^2$



7 transmitted electron contribution terms with common factor  $|T_{1/2,k,h}|^2$



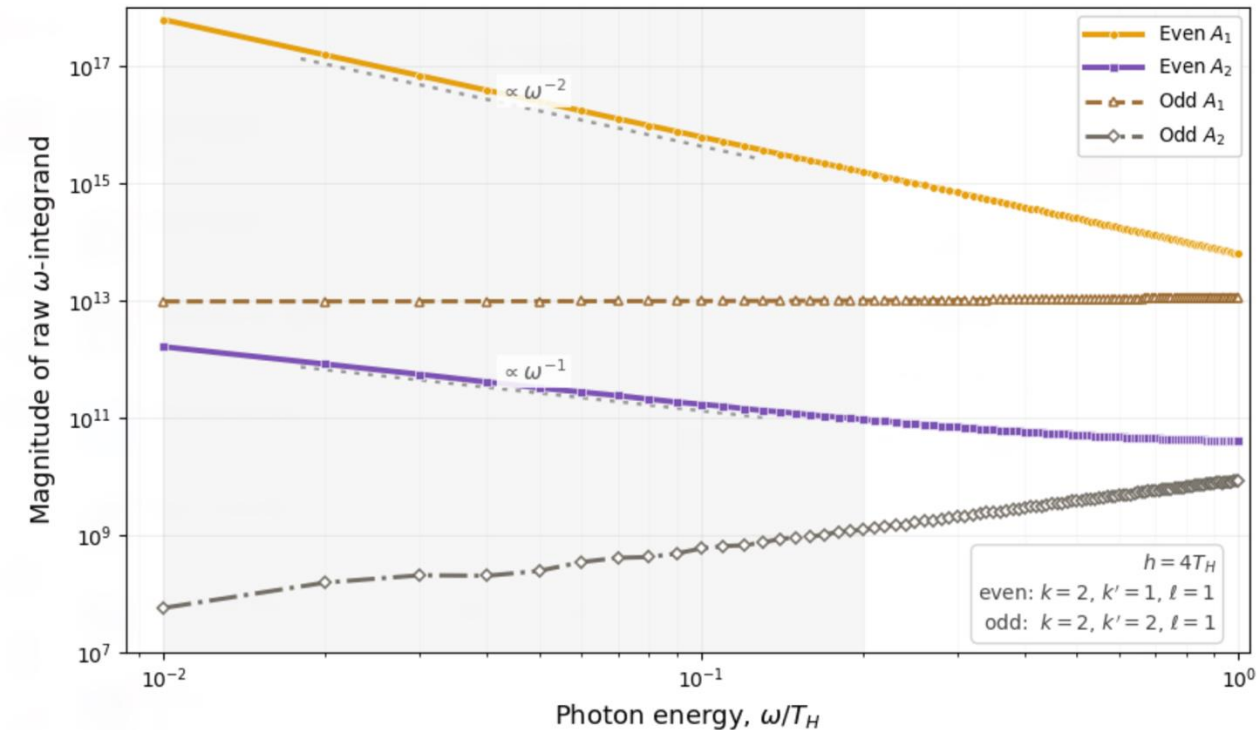
10 terms arise from interference effects between two different vertices with common part  $\text{Re}(T_{1/2,k,h}^* R_{1/2,k,h})$

They can also be grouped by overlap-integral type and energy assignment:

- A1 – A8:  $[[I^{+-}(h, h - \omega, \omega)]]$
- B1 – B7:  $[[I^{+-}(h + \omega, h, \omega)]]$
- C1 – C7:  $[[I^{++}(h, \omega - h, \omega)]]$

# IR Divergence Issue in the Raw Spectrum

IR divergence in individual dissipative channels



- Individual even-mode dissipative terms are IR-sensitive

$$1/\omega^2 : A_1 A_4 A_5 B_2 B_4 B_6 B_7$$

$$1/\omega : A_2 A_3 A_6 A_7 B_1 B_3 B_5$$

- All odd-parity channels remain finite
- All **C terms** remain finite

The raw dissipative spectrum cannot be interpreted term by term.

# IR Divergence Cancellation

The soft dissipative contribution must be combined with divergent part of the transmission-coefficient (conservative/exchange) correction to be physical:

$$\left(\frac{dN_\alpha}{dh dt}\right)_{\text{soft,diss}} + \sum_k \frac{2j+1}{2\pi} f_e(h) \delta |T_{\frac{1}{2},k,h}^+|^2 = \text{finite}$$

$$T_{\frac{1}{2},k,h}^+ \equiv \langle e_{\text{out},k,h,m} | e_{\text{up},k,h,m} \rangle$$

This piece comes from the principal-value part of the second-order effective Hamiltonian:

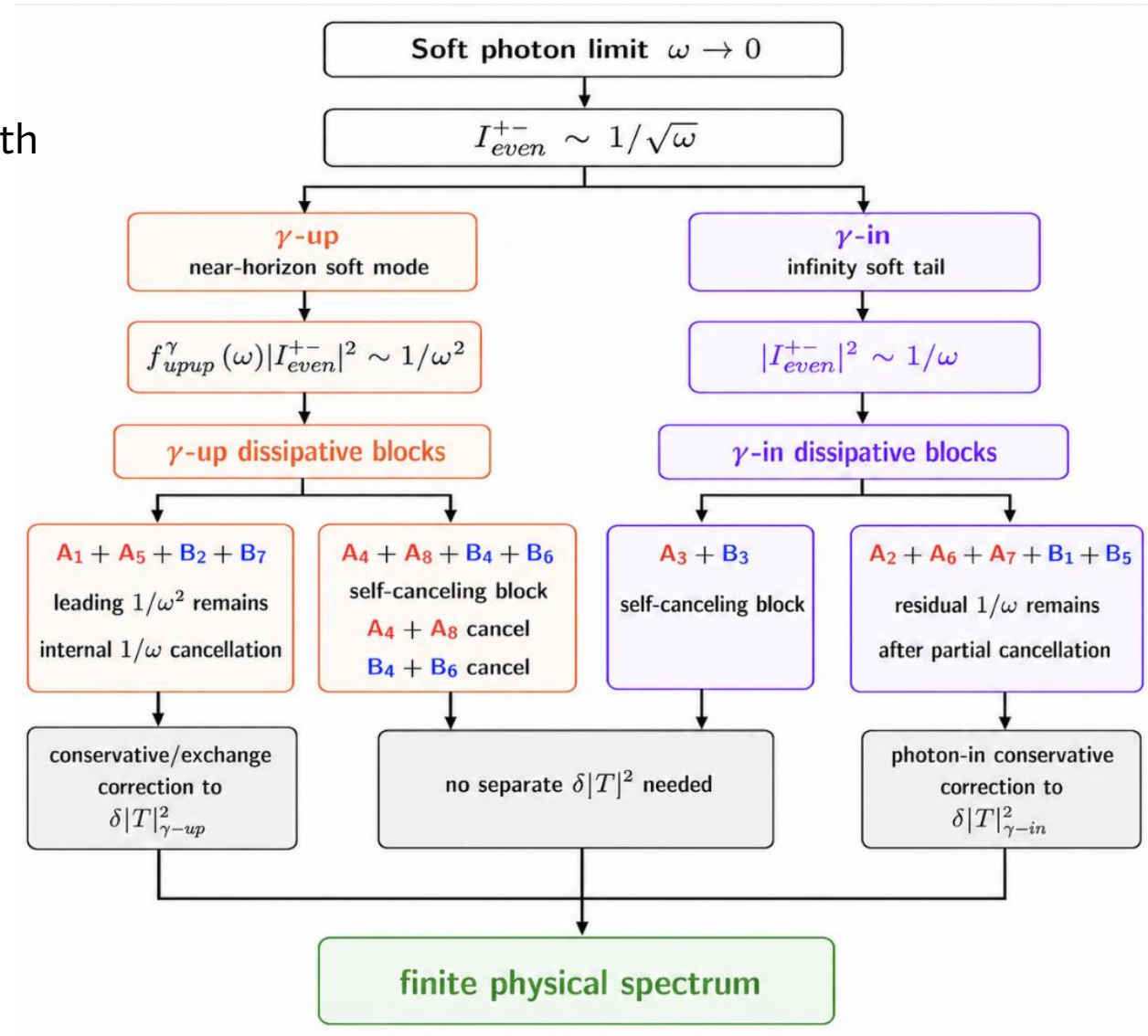
$$\Delta H_{\text{eff,cons}}^{(2)}(h) = \sum_{n \in \Omega} H_{\text{int}} |n\rangle \mathcal{P}\left(\frac{1}{h-h_n}\right) \langle n | H_{\text{int}}$$

$$Q = \{ \text{all intermediate electron/photon states} \}$$

It shifts the elastic transmission amplitude:

$$\delta T_{\frac{1}{2},k}(h) = \langle f | (-i) \Delta H_{\text{eff,cons}}^{(2)}(h) | i \rangle.$$

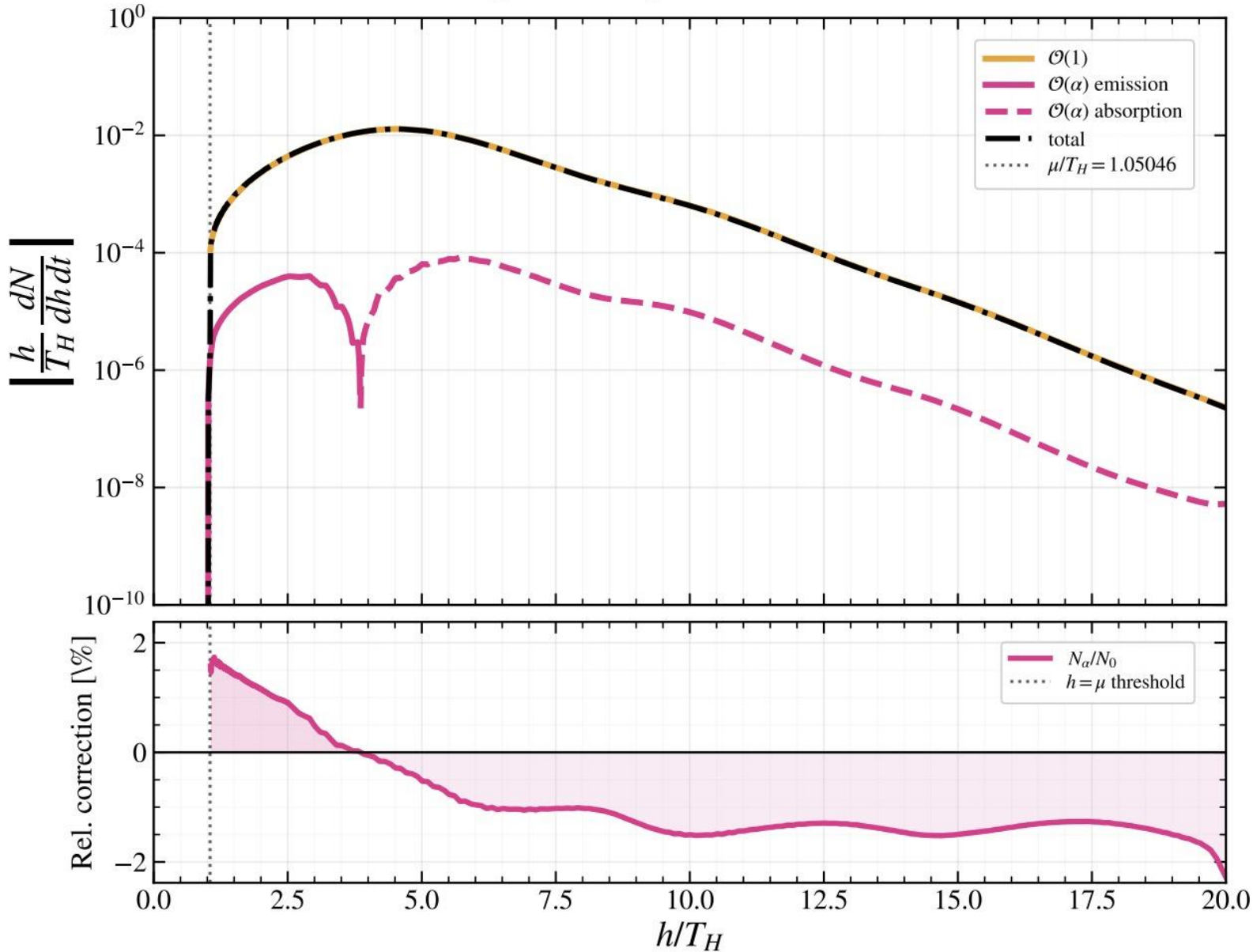
All IR divergences cancel exactly - no more, no less.



Soft-Photon IR Cancellation Structure

$\mathcal{O}(\alpha)$  Dissipative QED Correction  
to the Hawking Electron Spectrum,  $M = 10^{21} m_{\text{Pl}}$

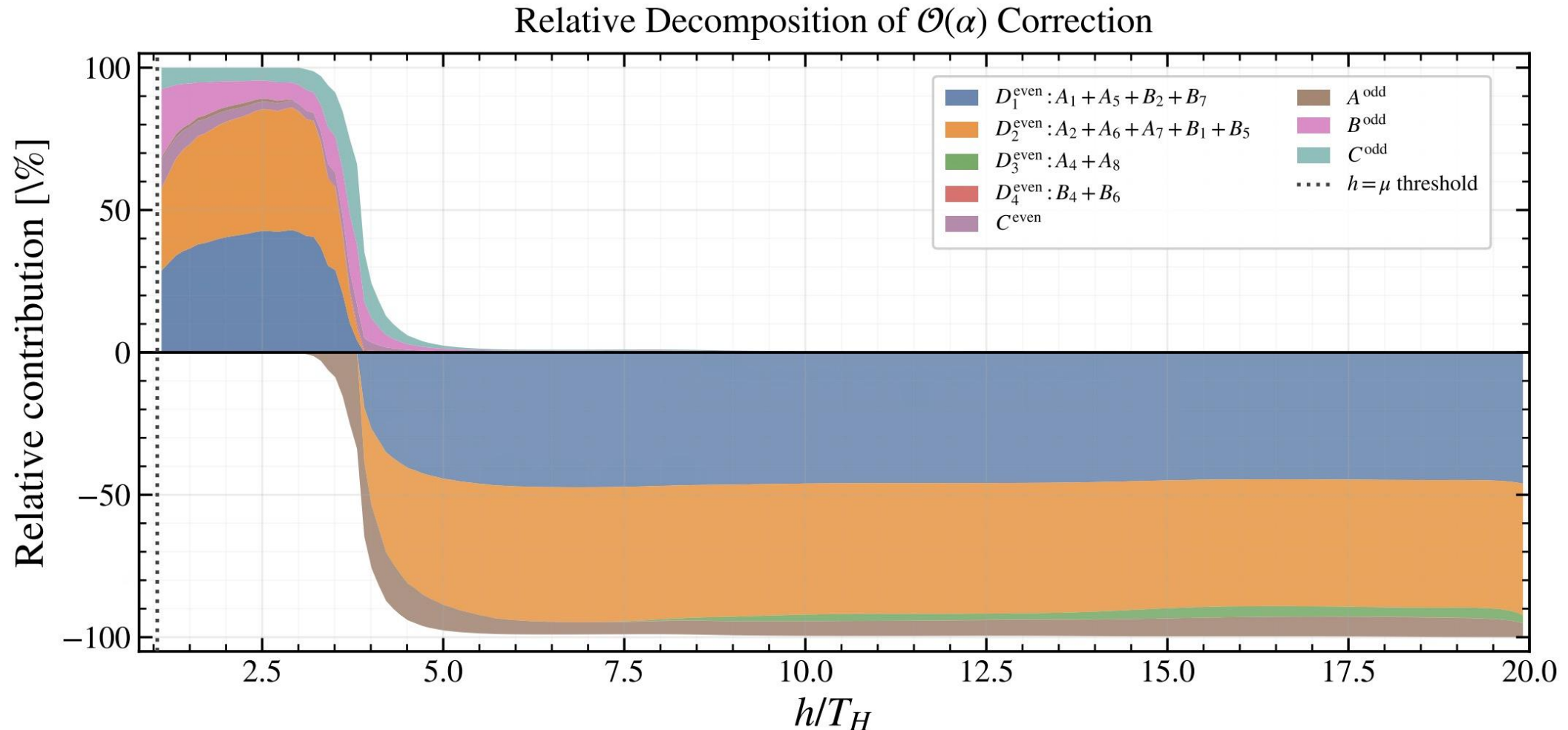
# Preliminary Numerical Results



$$M = 10^{21} m_{\text{Pl}} \sim 2 \times 10^{16} \text{ g}$$

- The  $\mathcal{O}(\alpha)$  correction is small compared with the free spectrum, overall less than 2%.
- The correction enhances the spectrum near threshold, but suppresses it over most of the high-energy tail.

# Channel Decomposition of the $O(\alpha)$ Correction



- The correction is mainly controlled by electron-scattering type dissipative blocks with in/up photon modes.
- Odd-parity contributions and  $C$  terms are subdominant over most of the spectrum.

---

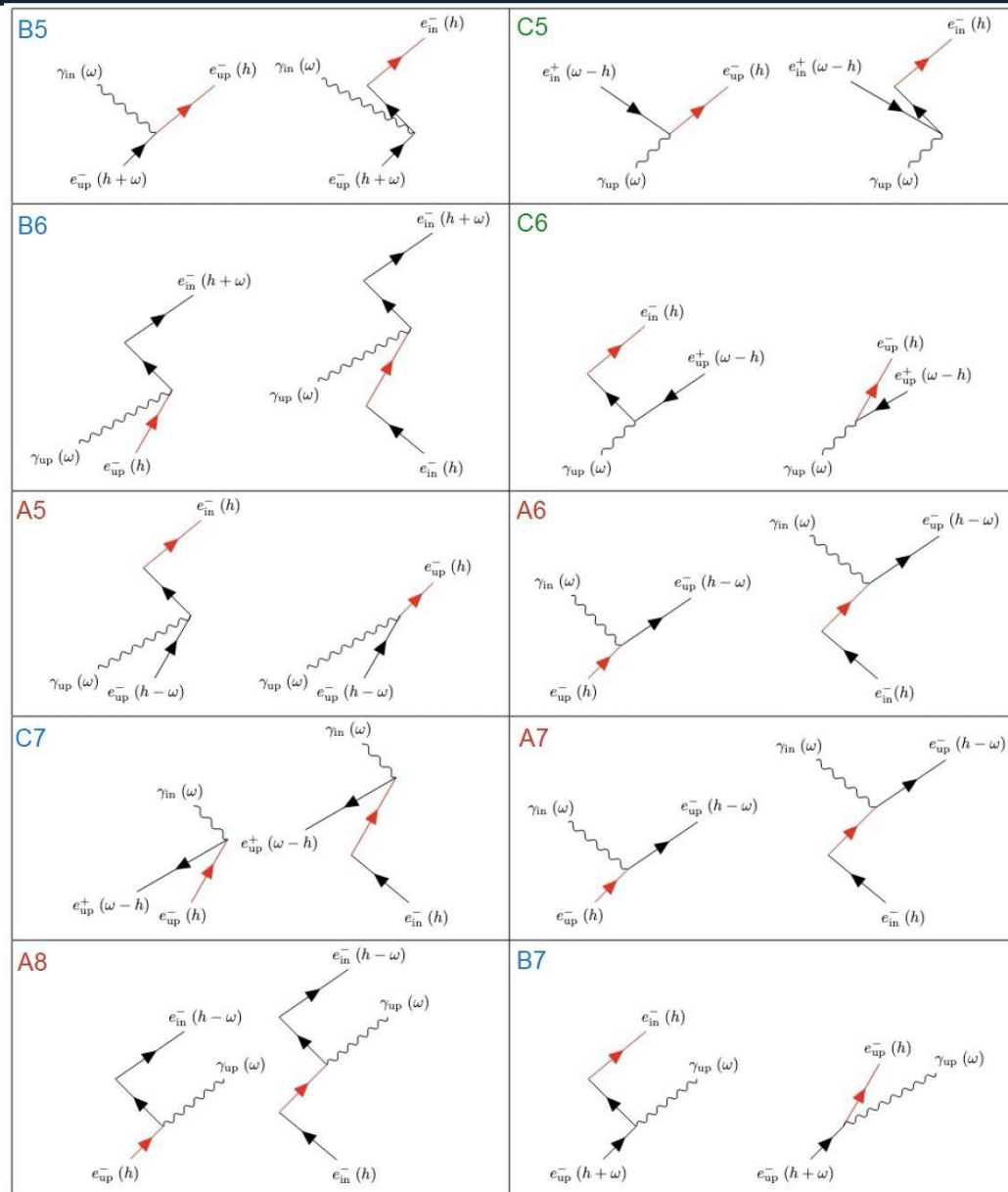
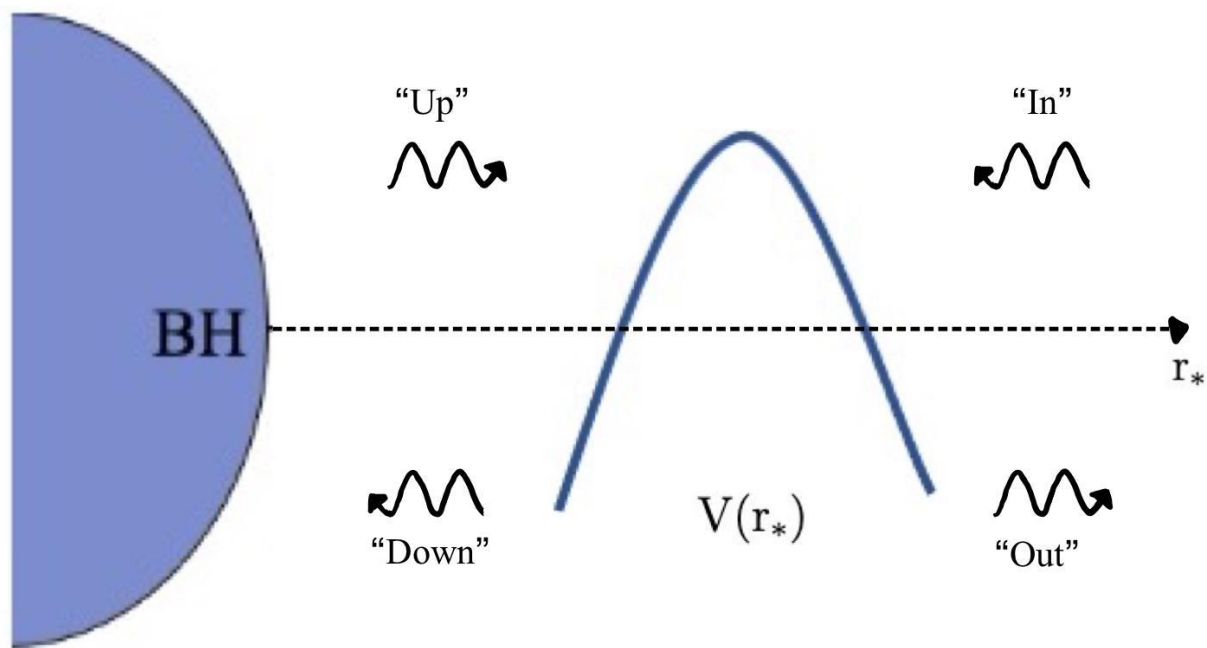
# Takeaways & Next Steps

- Built a systematic QED formalism for the Hawking electron spectrum.
- Identified the soft-photon IR structure and the required cancellation pattern.
- Obtained a preliminary corrected dissipative electron spectrum. Dominant processes are identified.

Next:

- More PBH masses for numerical computation
- For the full  $O(\alpha)$  electron spectrum correction, only dissipative part is calculated in this work. Contribution from exchange effect (Nel et al. in prep) and conservative part are left to be finished

**More Questions? Find me later or  
email at  
[chen.12686@osu.edu](mailto:chen.12686@osu.edu)**



# Convergence in $\ell$

