# Black Hole Explosions Beyond the Standard Model

Michael J. Baker

New Horizons in Primordial Black Hole Physics
(NEHOP)
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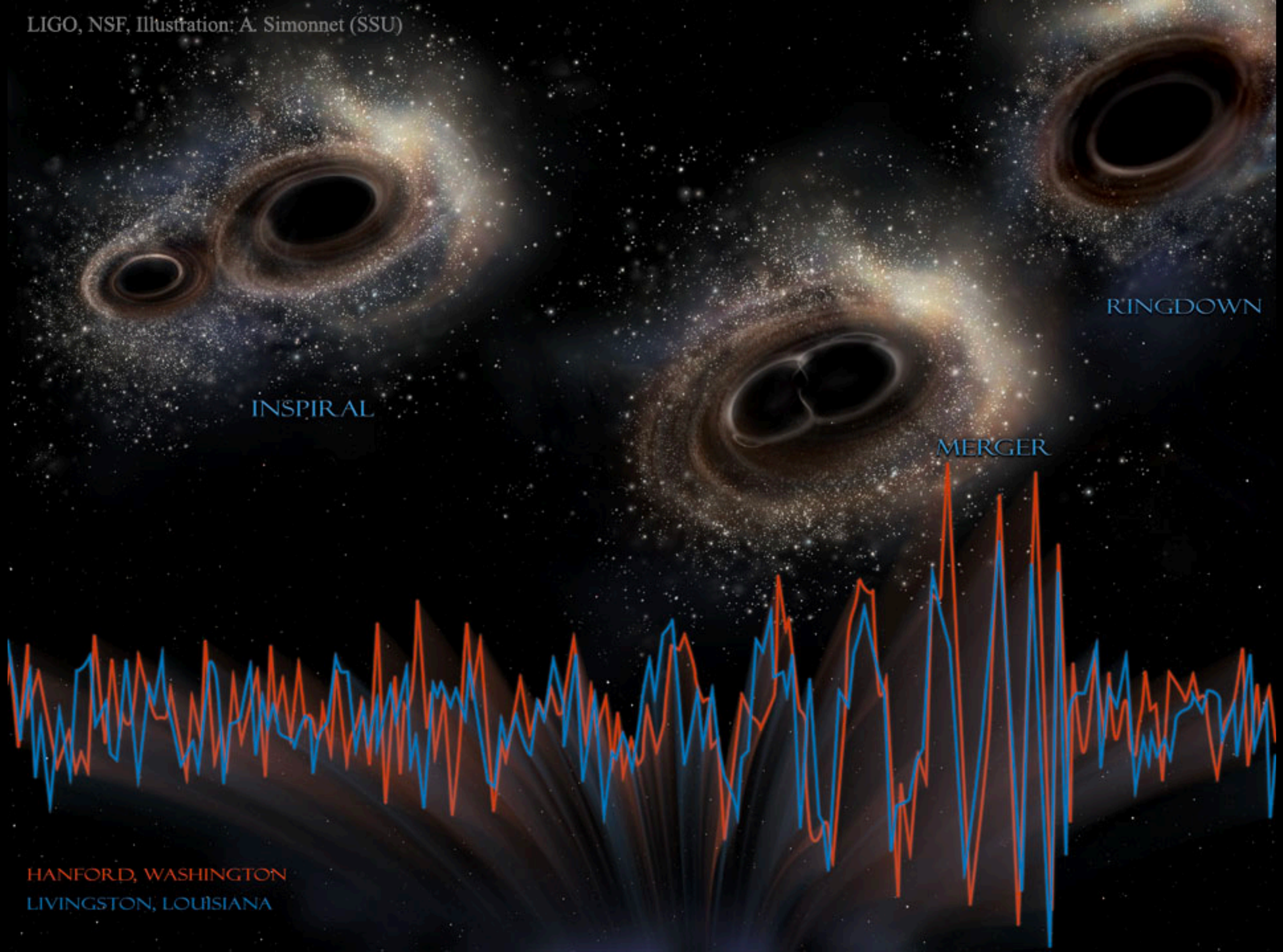
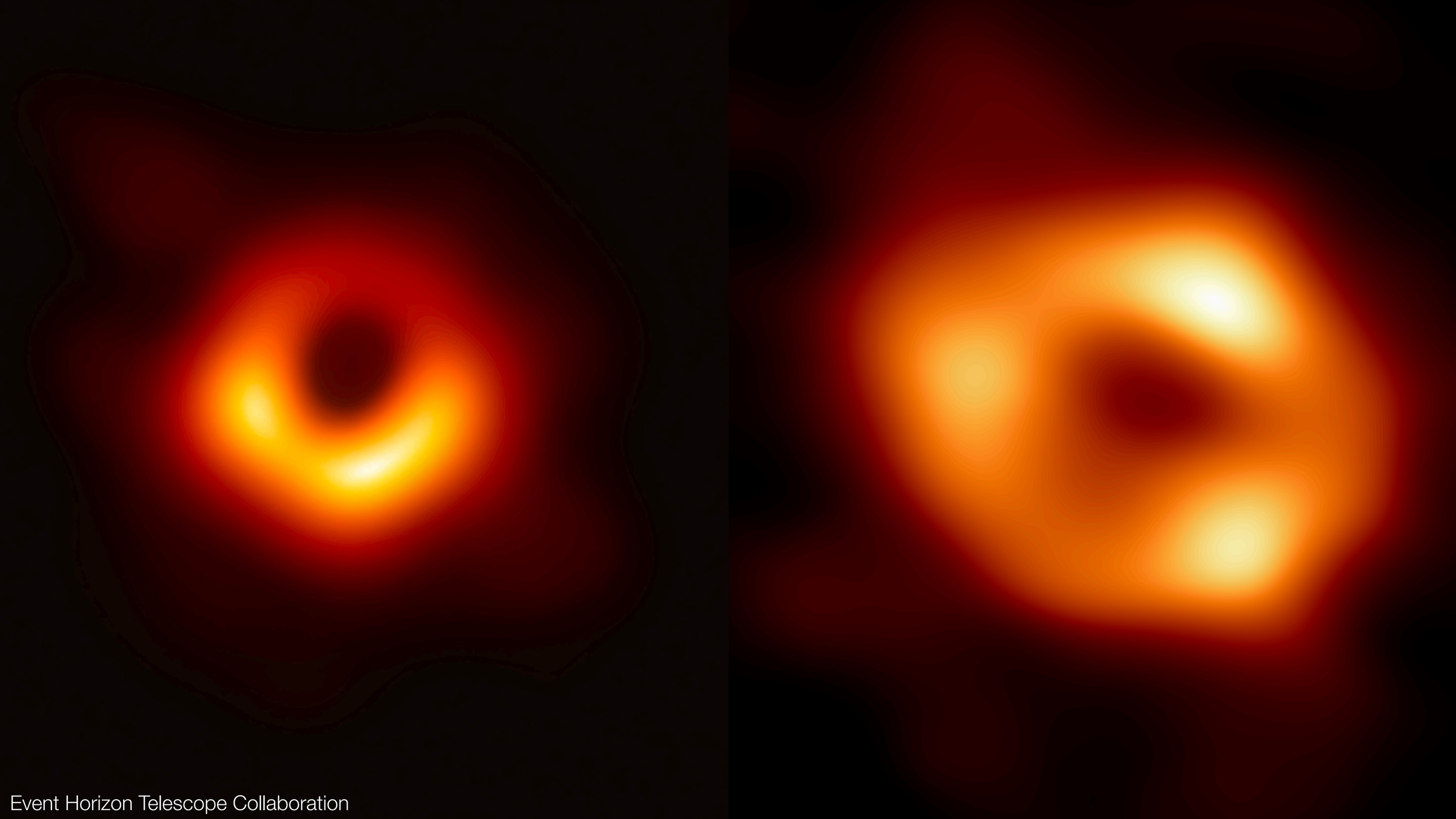
2105.10506, 2210.02805 - MJB, A. Thamm


# Outline

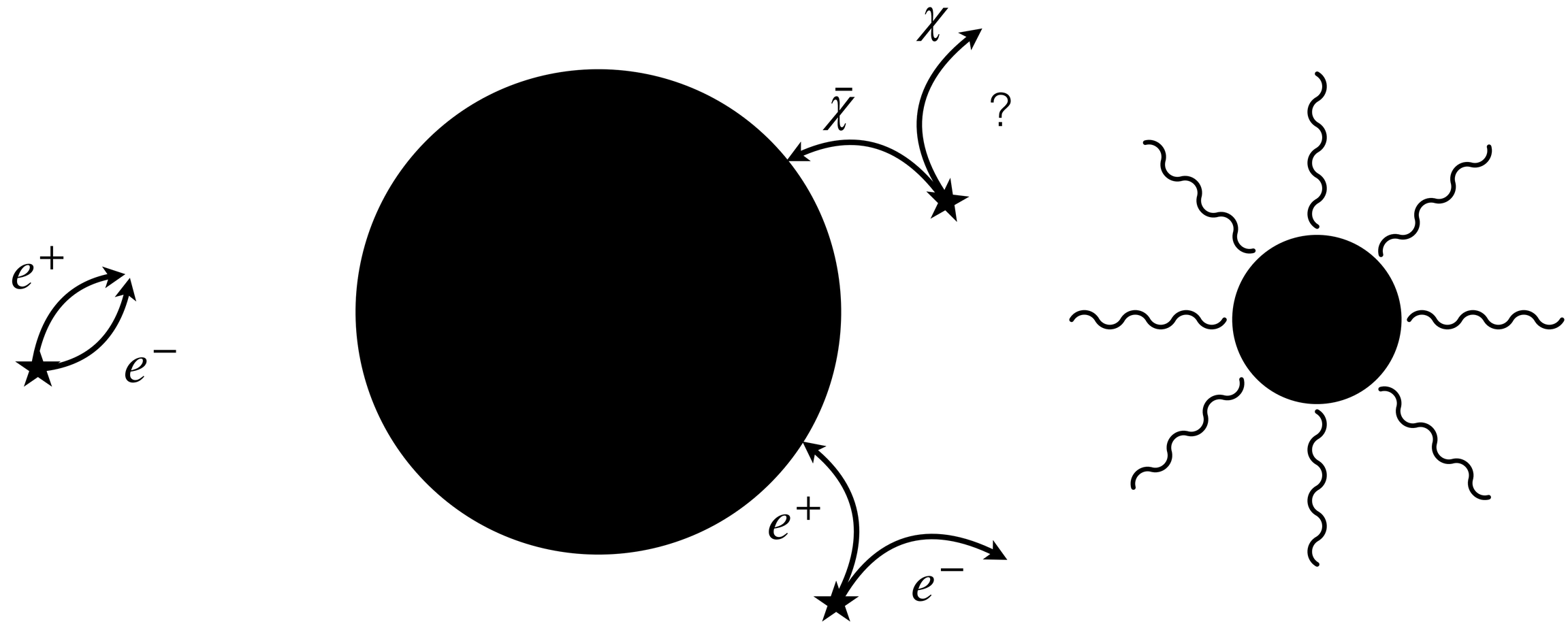
- Introduction
- Black Hole Explosions
  - Standard Model
  - Beyond the Standard Model
- Conclusions


LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA



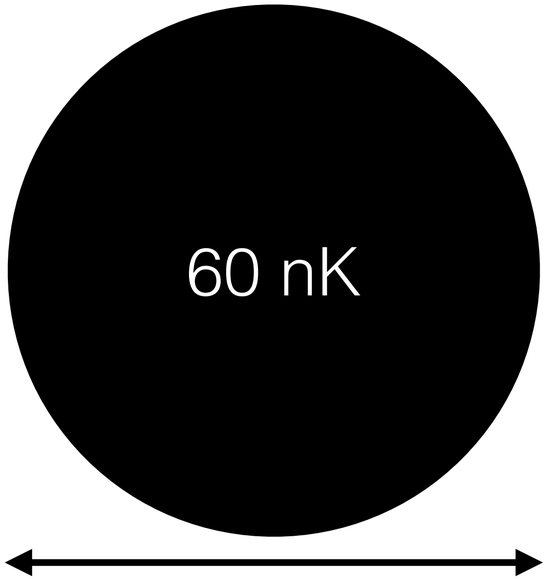
Event Horizon Telescope Collaboration

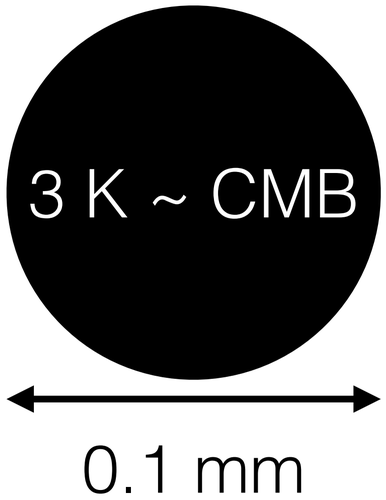
# Hawking Radiation

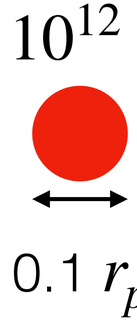


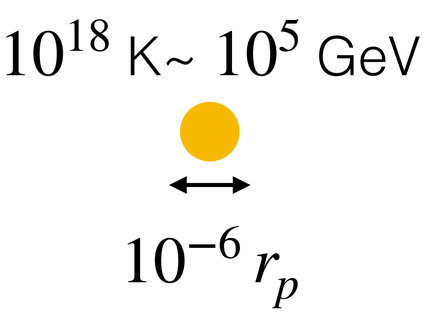
# Hawking Radiation

Mass: Sun Moon 10 x  



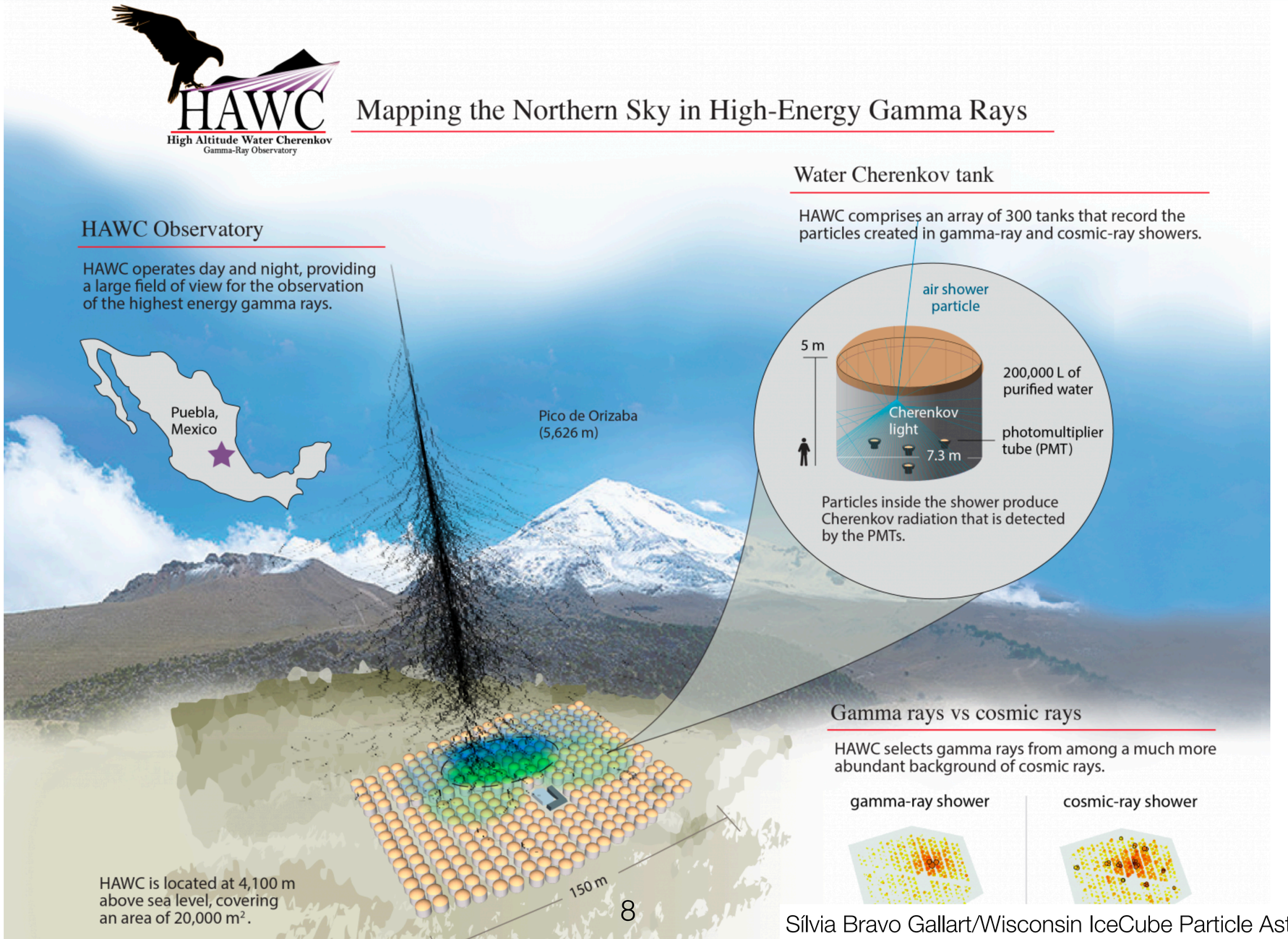




Lifetime: $10^{67}$ years $10^{44}$ years 13.8 Gyr 1 s

# Primordial Black Holes

- Motivations
  - Remove unwanted monopoles or domain walls
  - Seeds for SMBHs or LSS
  - Dark matter?
- Production mechanisms
  - Density perturbations generated during inflation
  - Topological defects
  - Scalar condensates
  - First order cosmological phase transition

# HAWC Observatory






Sílvia Bravo Gallart/Wisconsin IceCube Particle Astrophysics Center (WIPAC)

# Overview

- So,
  - There could be black holes which are exploding today
  - As the black hole shrinks, it heats up (finally reaching $T \sim M_{\mathrm{Pl}}$)
  - The black hole radiates all fundamental d.o.f. (SM and BSM) lighter than $T$
  - Experiments are currently looking for their final explosion

- We ask the question:
  - What could we learn about BSM physics if an exploding black hole were observed today?

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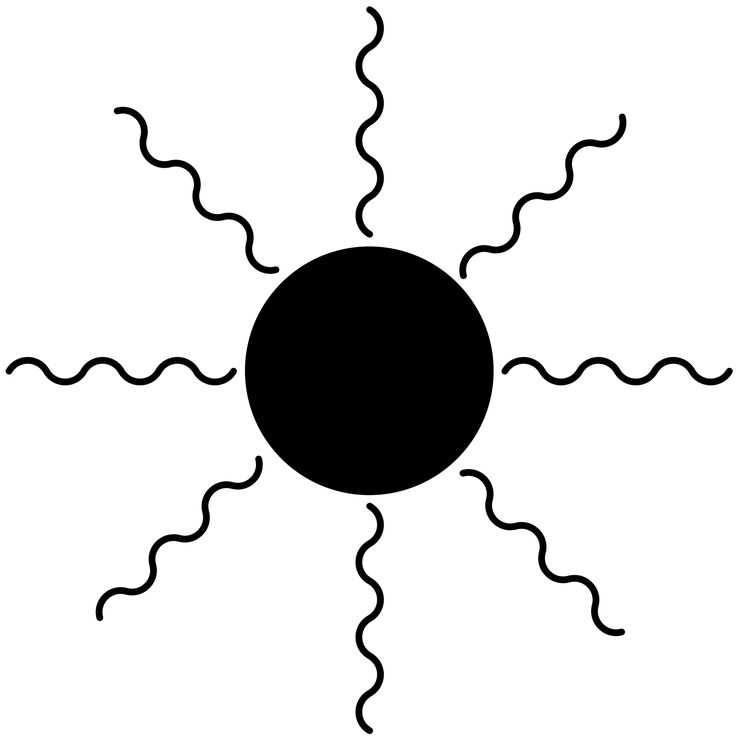
# Primary Particles and Mass Evolution



$$\frac{d^2 N^i_{\rm p}}{dtdE} = \frac{n^i_{\rm dof}\Gamma^i(M,E)}{2\pi(e^{E/T}\pm 1)}$$

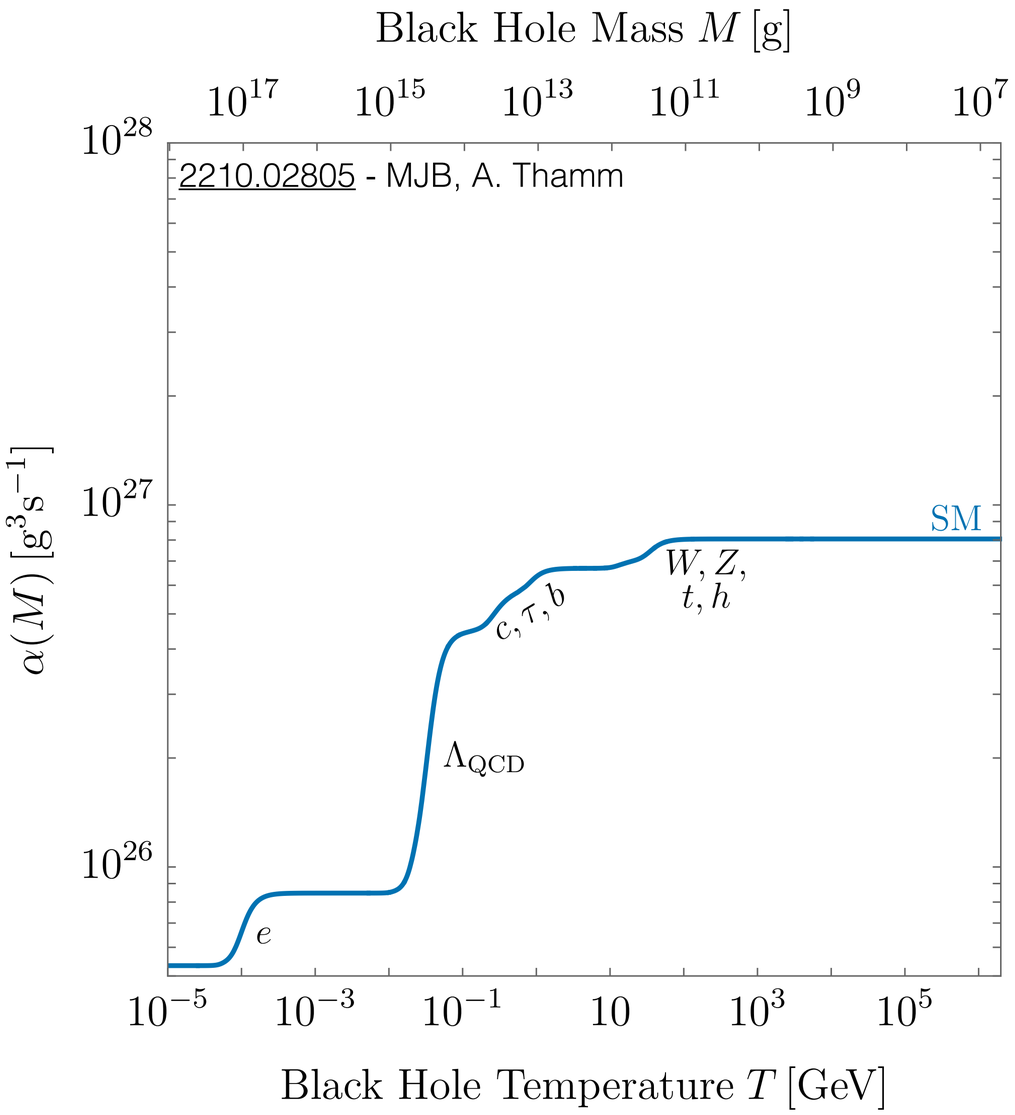
$$T = \frac{1}{8\pi GM}$$

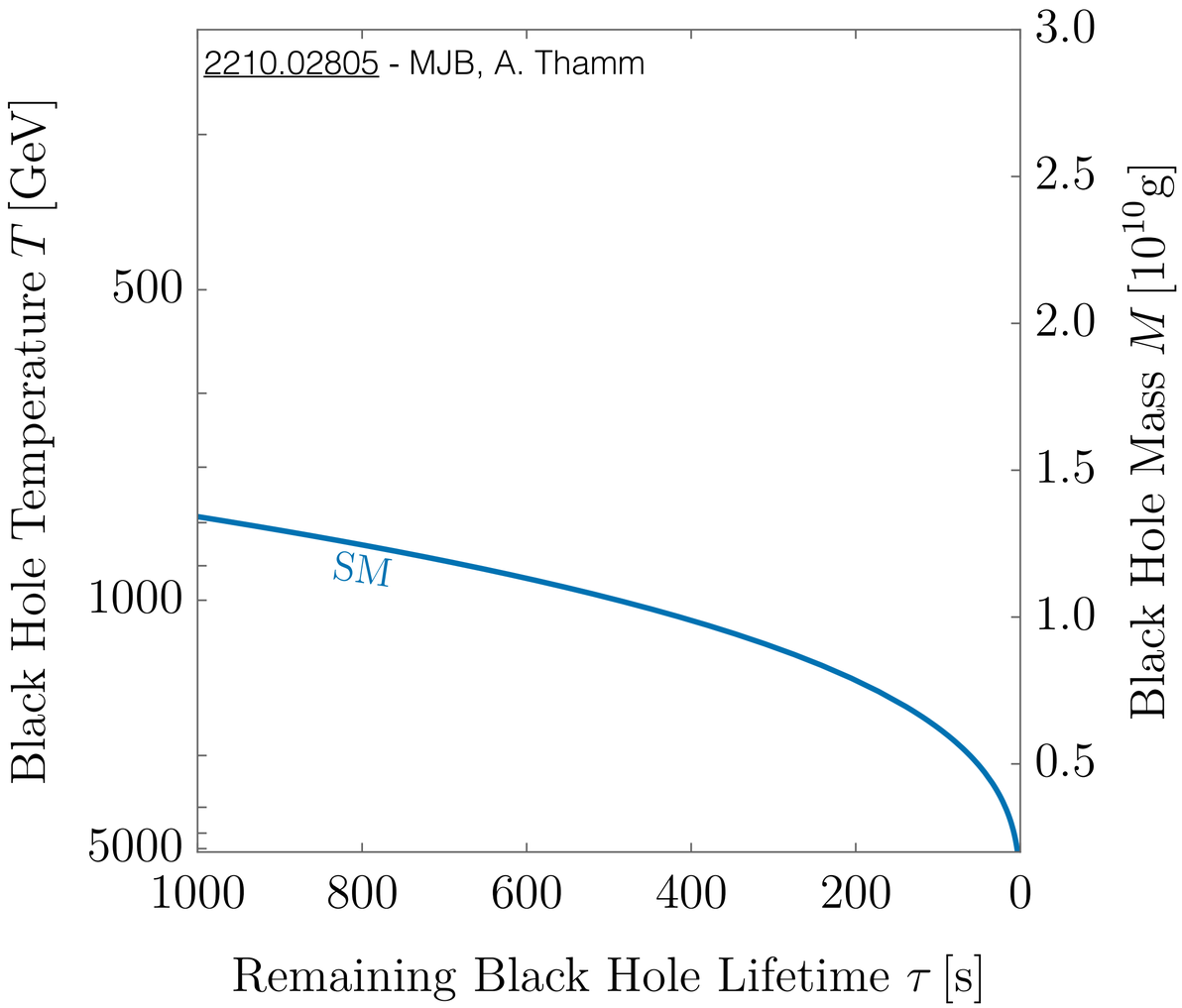
$$\frac{dM}{dt} = -\frac{\alpha(M)}{M^2}$$

$$\alpha(M) = M^2 \sum_i \int_0^\infty \frac{d^2 N_{\rm p}}{dtdE}(M,E) E dE$$

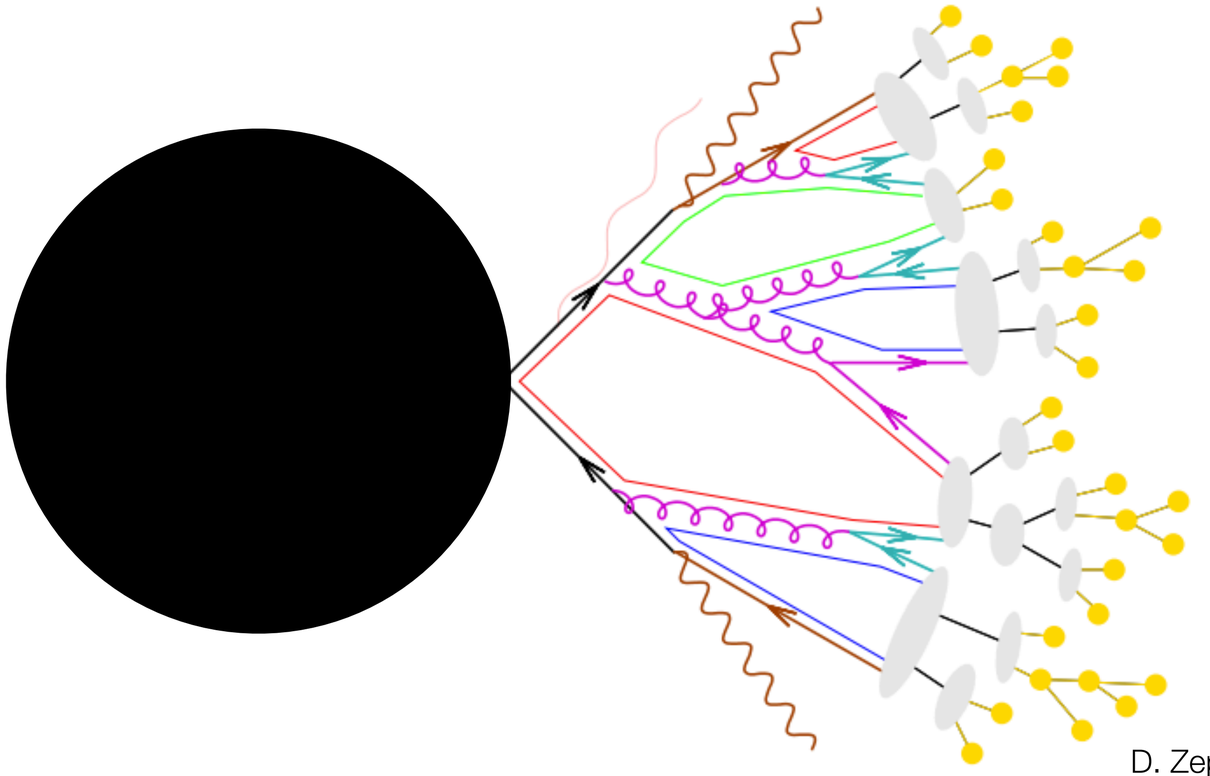
# Primary Particles and Mass Evolution

$$\frac{dM}{dt} = -\frac{\alpha(M)}{M^2} \qquad \alpha(M) = M^2 \sum_i \int_0^\infty \frac{d^2 N_{\rm p}}{dt dE}(M, E) E dE$$

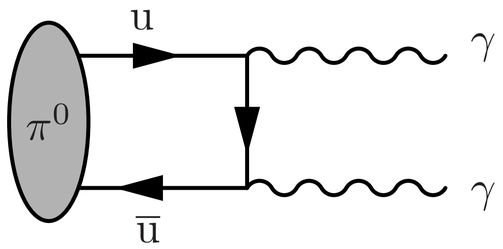


# Secondary Photons

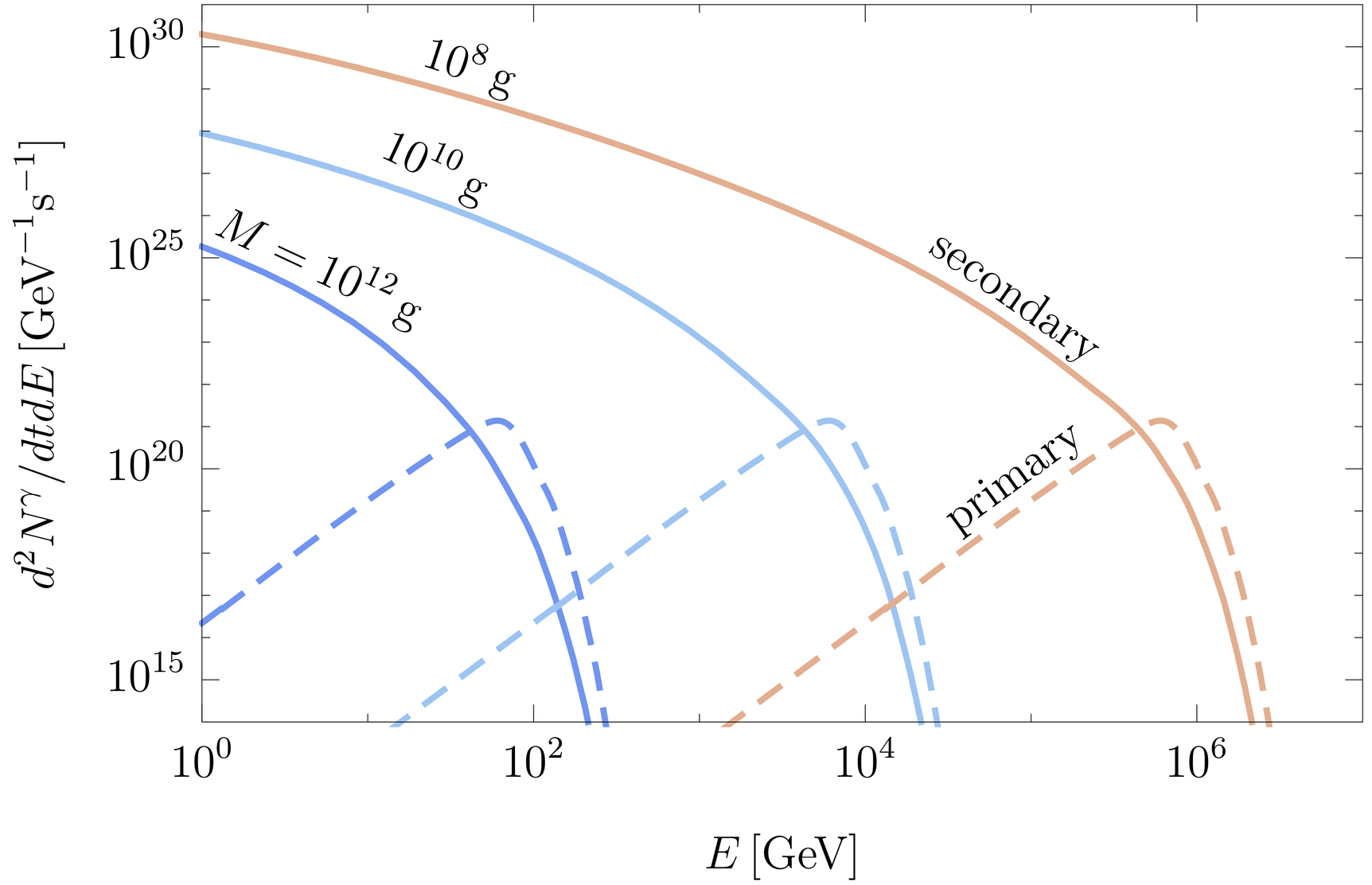


D. Zeppenfeld

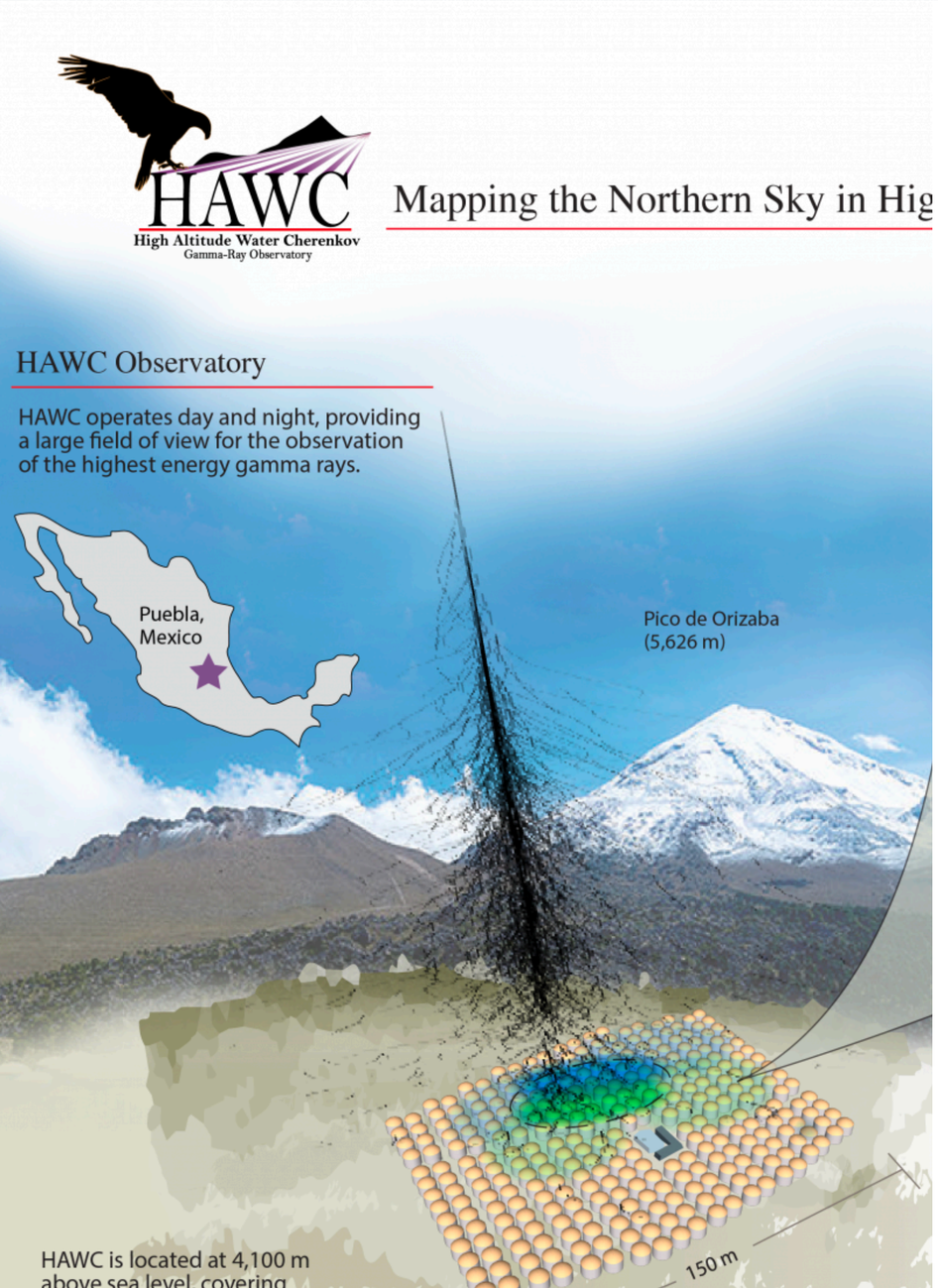


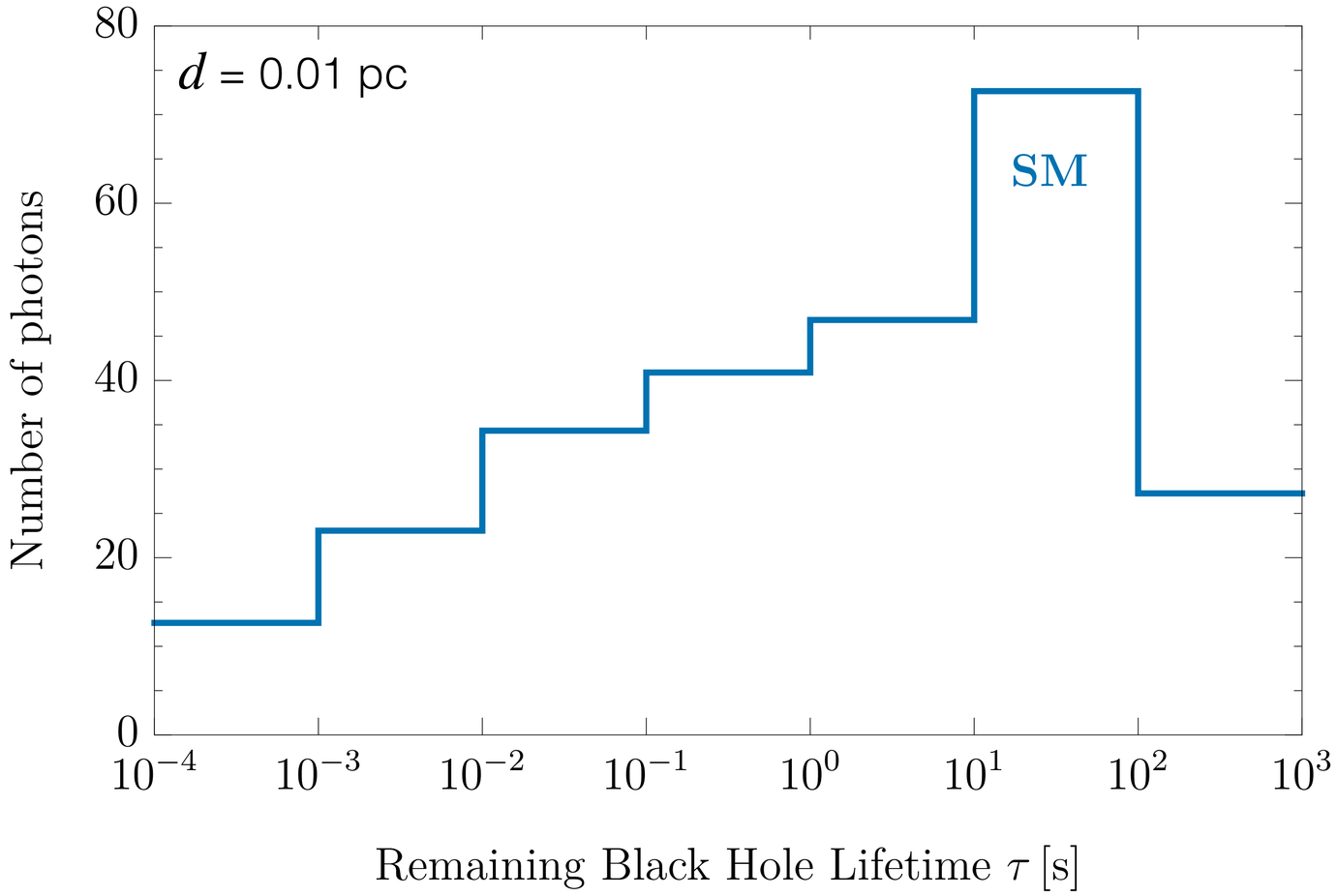

$$\frac{d^2 N_{\mathrm{s}}^{\gamma}}{dt dE} = \sum_i \int_0^{\infty} \frac{d^2 N_{\mathrm{p}}^{i}}{dt dE_{\mathrm{p}}}(M, E_{\mathrm{p}}) \frac{dN^{i\to\gamma}}{dE}(E_{\mathrm{p}}, E) dE_{\mathrm{p}}$$

# Primary and Secondary Photon Spectra



# Photon Spectra at HAWC



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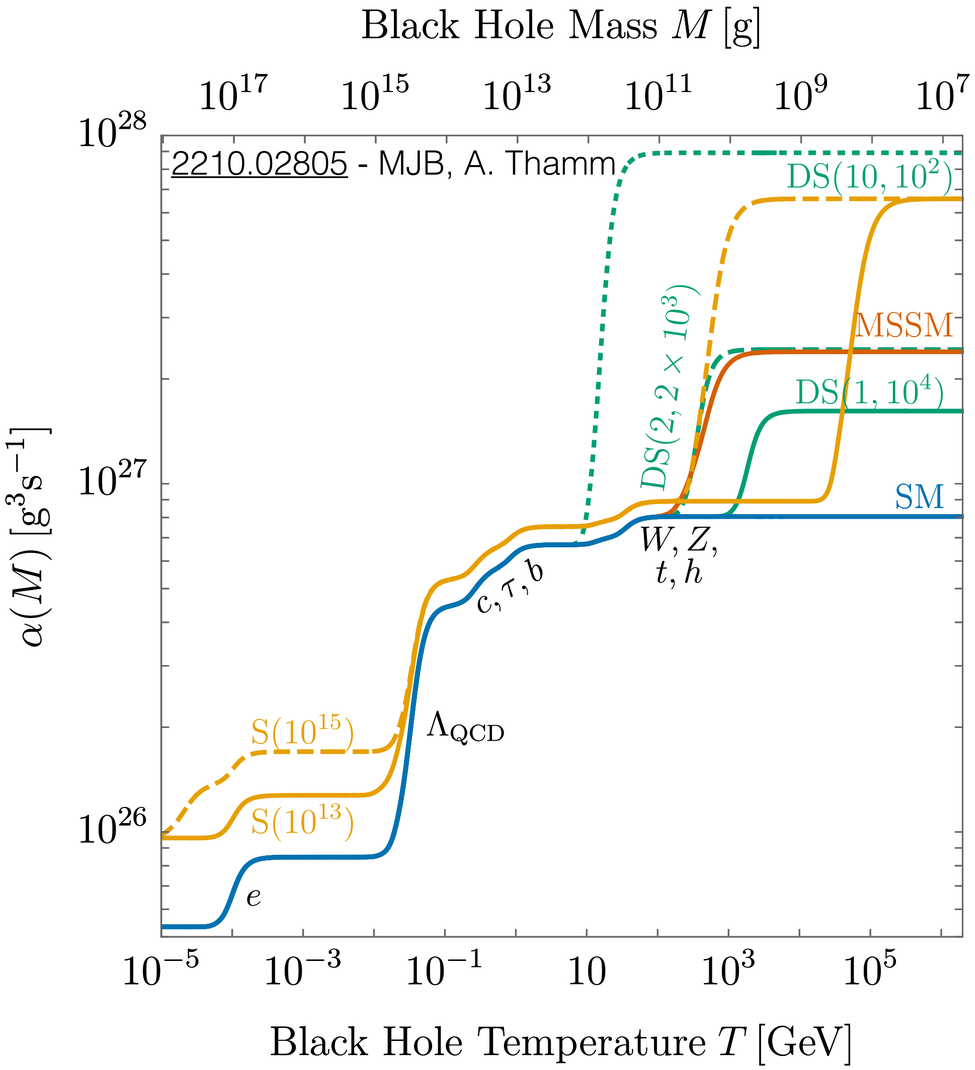
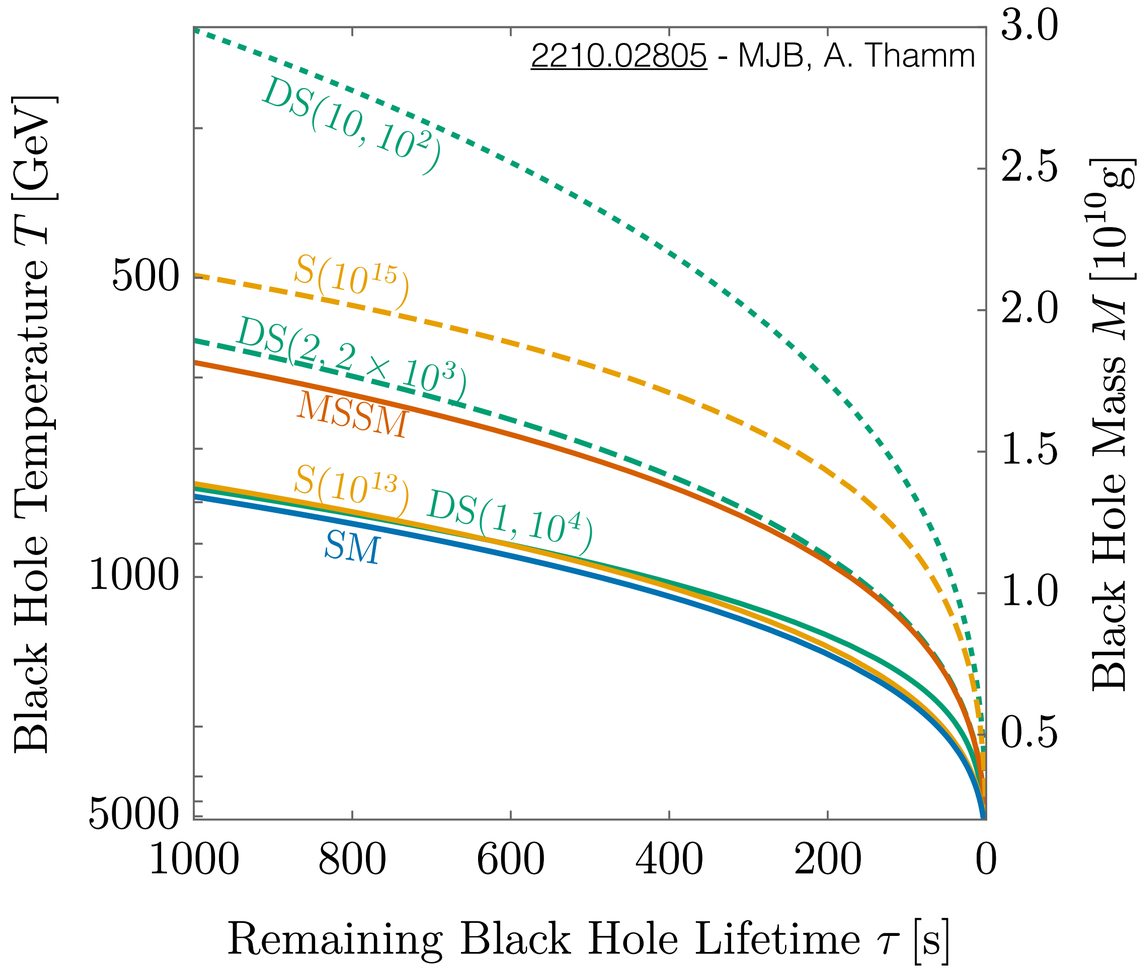
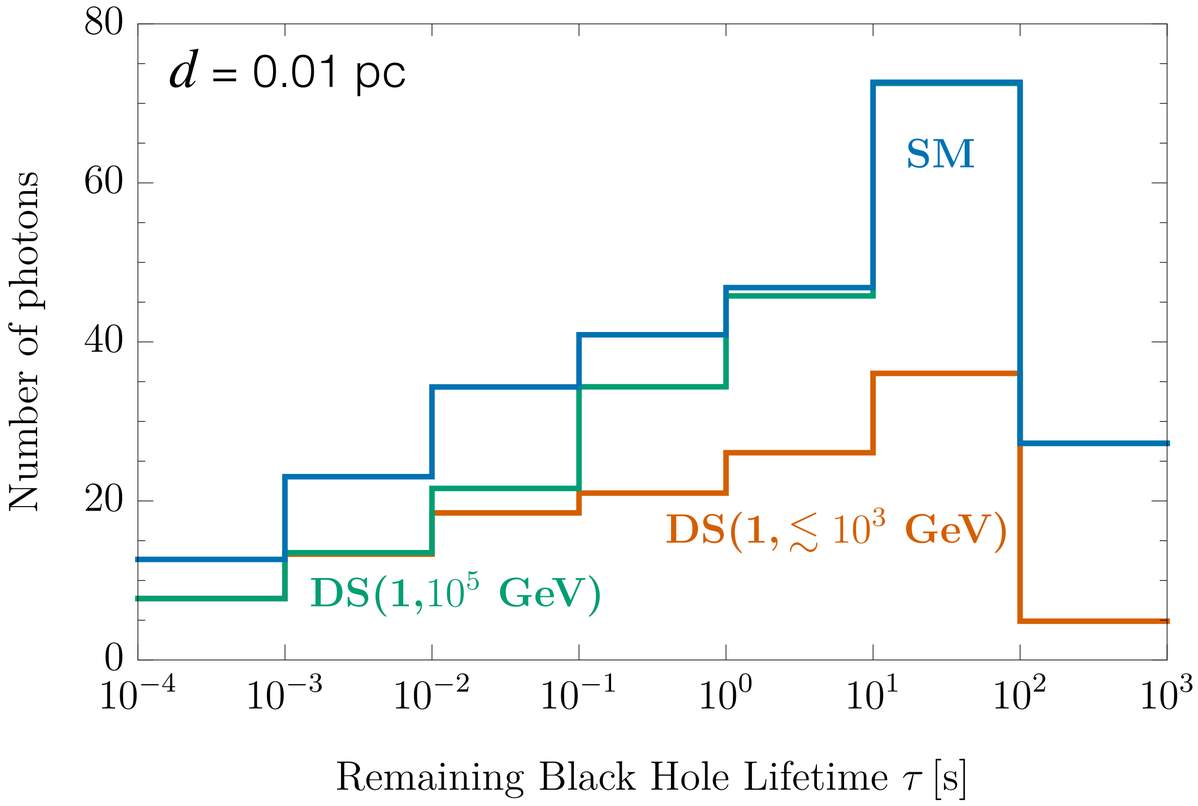
# Primary Particles and Mass Evolution Beyond the Standard Model

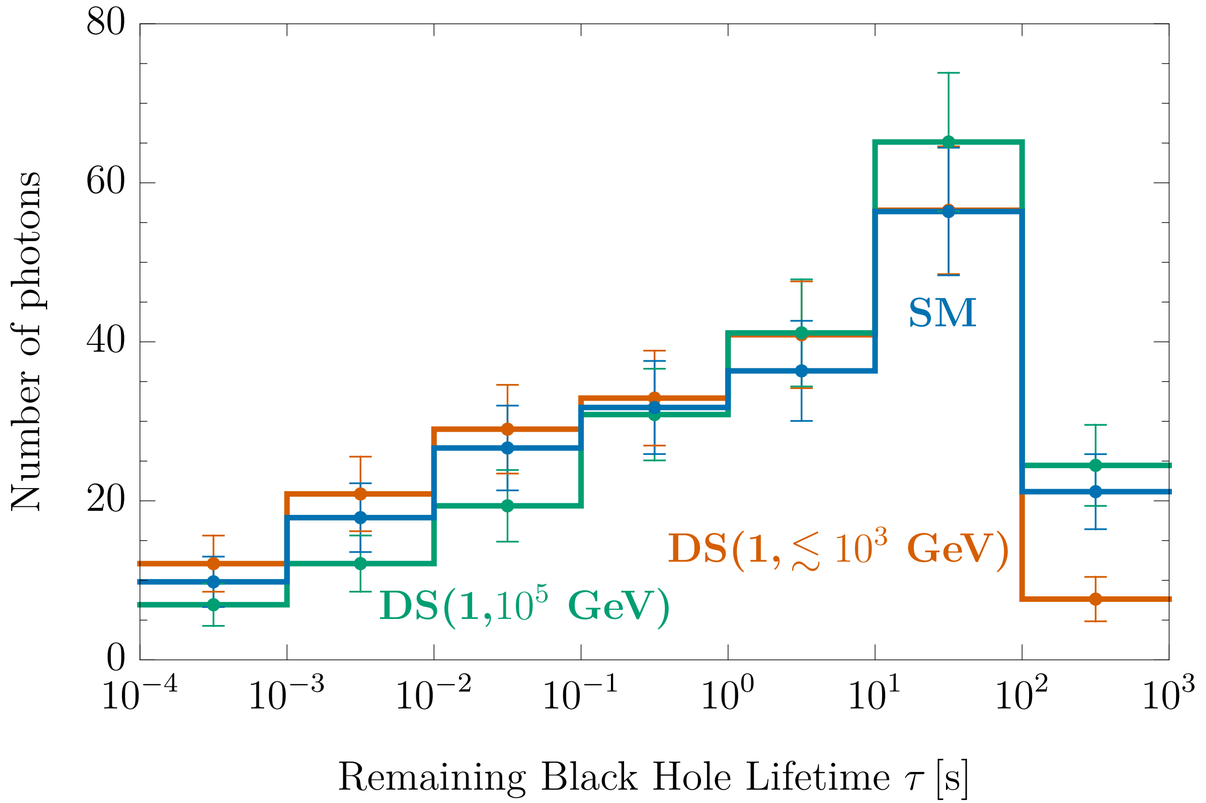


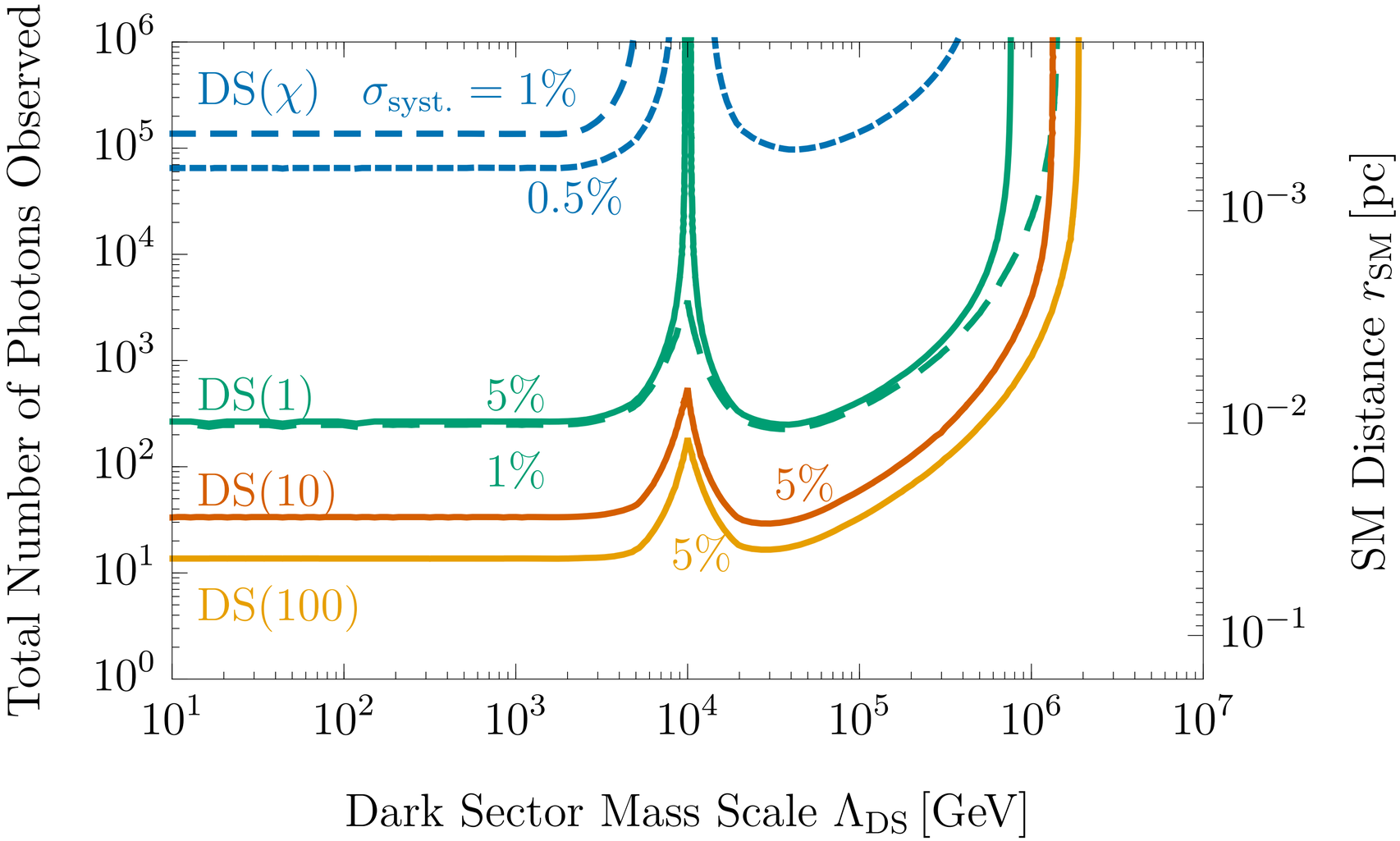
# Photon Spectra at HAWC




Normalised



# Dark Sector Exclusion Plot



# What is the probability of observation?

If there are $\sim 3000$ EBHs $\mathrm{pc}^{-3}\,\mathrm{yr}^{-1}$, then 83% (1.4%) chance of at least one event closer than 0.05 (0.01) pc giving $\gtrsim$10 (200) photons at HAWC in next 5 years

| Distance Scale | Limit | Method | Caveats |
|---|---|---|---|
| Cosmological Scale | $< 10^{-6}\,\mathrm{pc}^{-3}\mathrm{yr}^{-1}$ | (1) | Clustering (e.g., by 7 orders of mag.) |
| Galactic Scale | $< 0.42\,\mathrm{pc}^{-3}\mathrm{yr}^{-1}$ | (2) | |
| Kiloparsec Scale | $< 0.0012\,\mathrm{pc}^{-3}\mathrm{yr}^{-1}$ | (3) | Production and propagation of antiprotons |
| Parsec Scale | $< 4.6 \times 10^{5}\,\mathrm{pc}^{-3}\mathrm{yr}^{-1}$ | (4) | |
| | | | Mass Distribution, QCD, BSM |

**Table 1**: PBH Limits vary with distance scales: (1) from 100 MeV extragalactic $\gamma$-ray background assuming no clustering [1,6], (2) from 100 MeV anisotropy measurement [7], (3) from antiproton flux [8] and (4) from Very High Energy (VHE) searches [9].

[1310.0073]

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# Conclusions

- Exploding Black Holes could potentially be observed in the near future
- They would give us unprecedented information on BSM physics, and give definitive information on the particle spectrum of nature
- More work to be done to see if it's reasonable to hope for an observation

Thank you!