EVAPORATING BLACK HOLES IN THE PRESENCE OF DARK SECTORS

Aidan Symons

With
Michael Baker and Andrea Thamm
at
The University of Massachusetts, Amherst

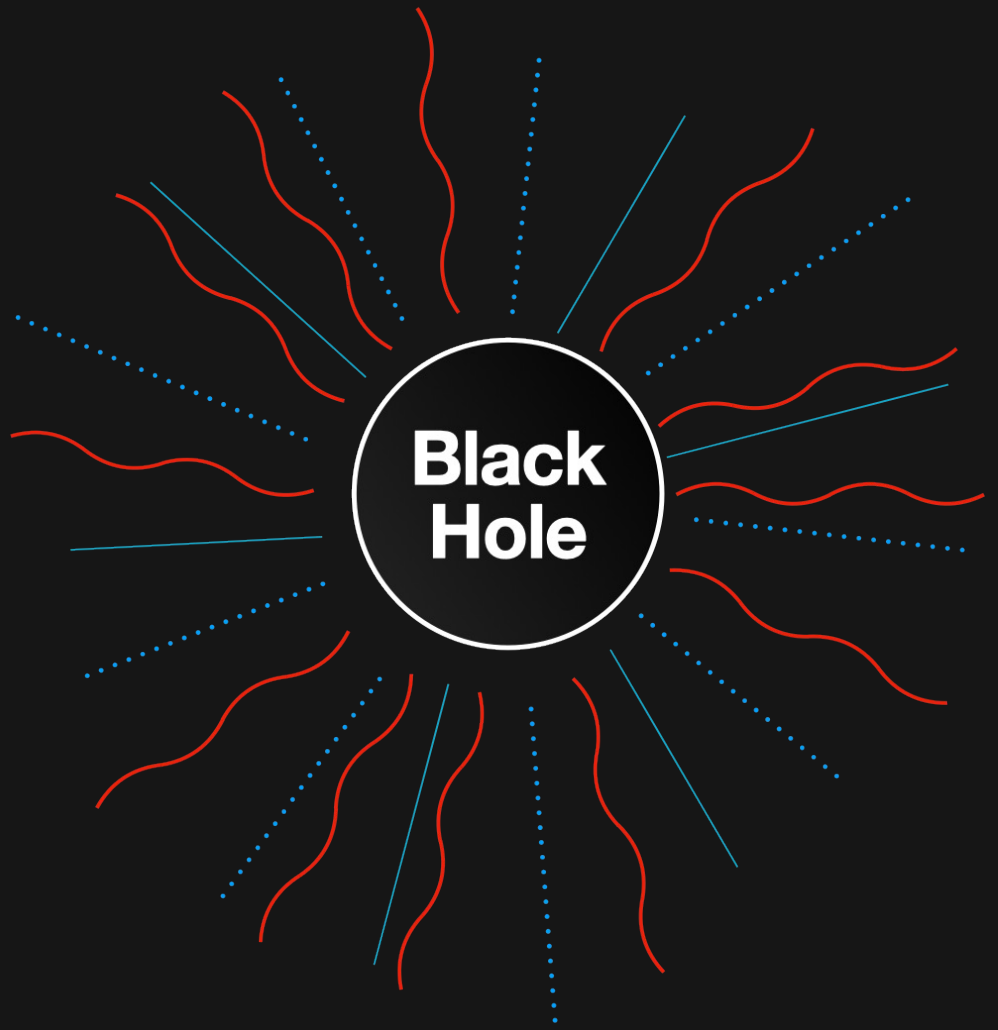
Talk Outline

Introduction

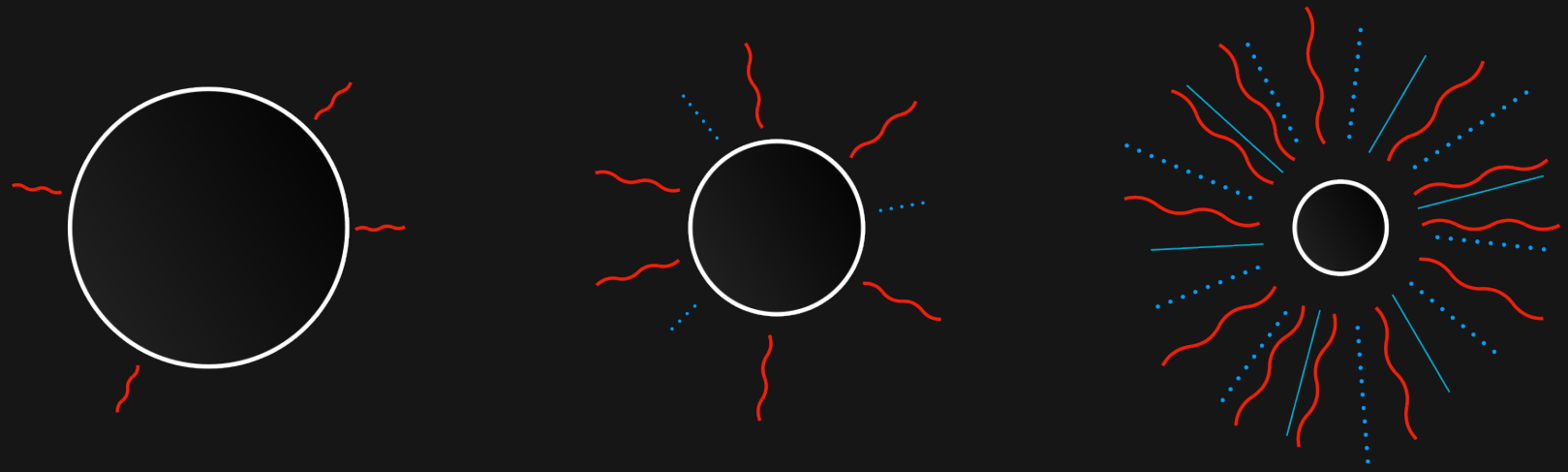
Hawking radiation

EBH observational characteristics

Introduction


Black
Hole

$$T_{BH} \propto \frac{1}{M_{BH}}$$



Time →

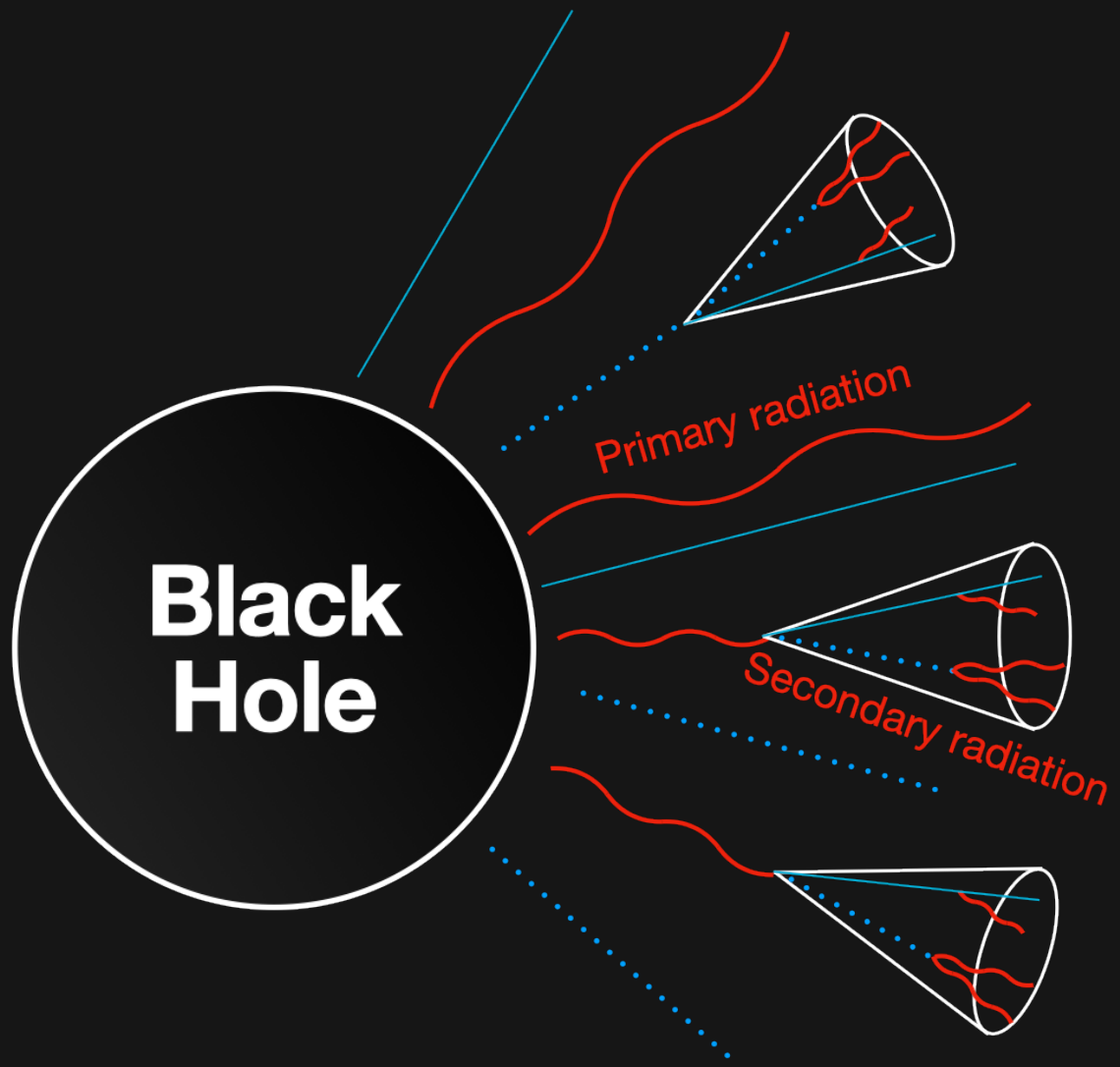
Hawking Radiation = Gravitational

Species i emitted if $T_{BH} \gtrsim m_i$

All fundamental particles eventually influence spectra

Hawking radiation

Hawking Radiation



Primary radiation

$$\frac{d^2N_{prim}}{dEdt} = \frac{1}{2\pi\hbar}\frac{\Gamma(E, M_{BH}, s)}{e^{E/kT} \pm 1} n_{dof}$$

Secondary radiation

$$\frac{d^2N_{sec}}{dEdt} = \sum_i \int_0^\infty dE' \, \frac{d^2N_i{}^{primary}}{dE'dt} \, \frac{dN_{i\to s}}{dE}$$

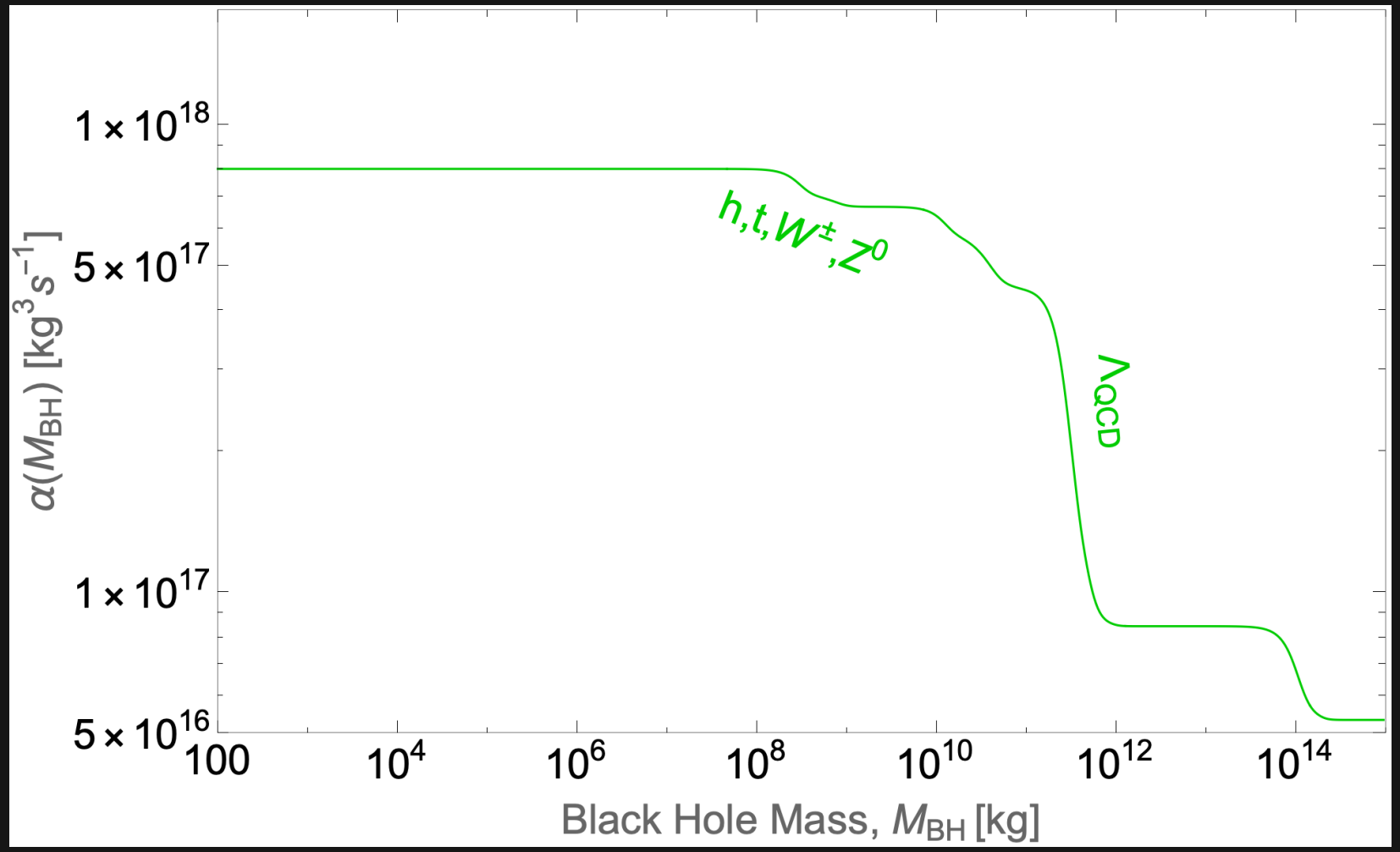
Hawking Radiation

$$\frac{dM_{BH}}{dt} = -\frac{\alpha(M_{BH})}{{M_{BH}}^2}$$

$$\alpha(M_{BH}) \propto \sum_i \int_0^\infty \frac{d^2 N_i^{primary}}{dEdt} EdE$$

Sum over **all** particles, i

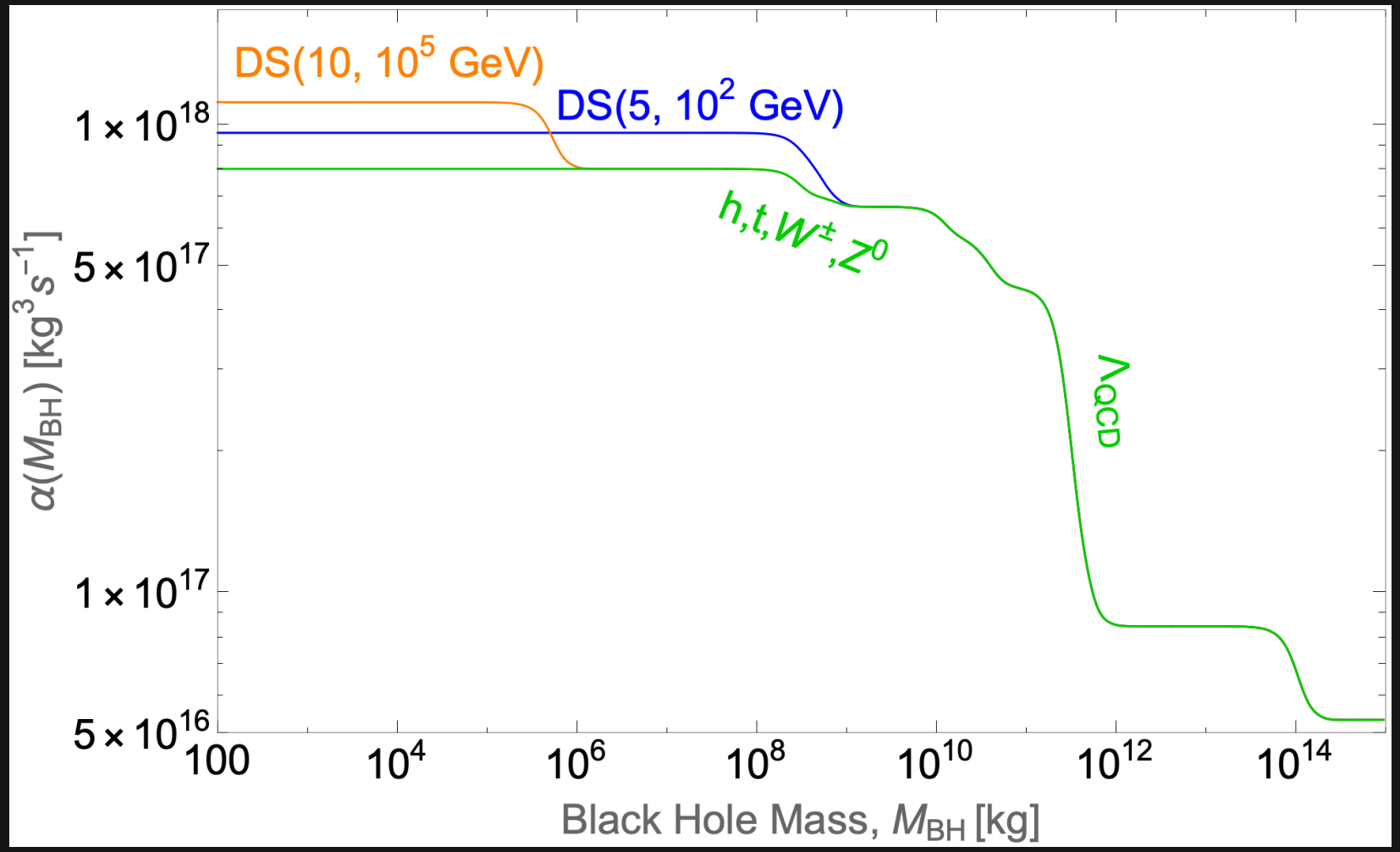
Hawking Radiation



$$\frac{dM_{BH}}{dt} = -\frac{\alpha(M_{BH})}{{M_{BH}}^2}$$

$$\alpha(M_{BH}) \propto \sum_i \int_0^\infty \frac{d^2N_i}{dEdt} EdE$$

Hawking Radiation



$$\frac{dM_{BH}}{dt} = -\frac{\alpha(M_{BH})}{{M_{BH}}^2}$$

$$\alpha(M_{BH}) \propto \sum_i \int_0^\infty \frac{d^2N_i}{dEdt} EdE$$

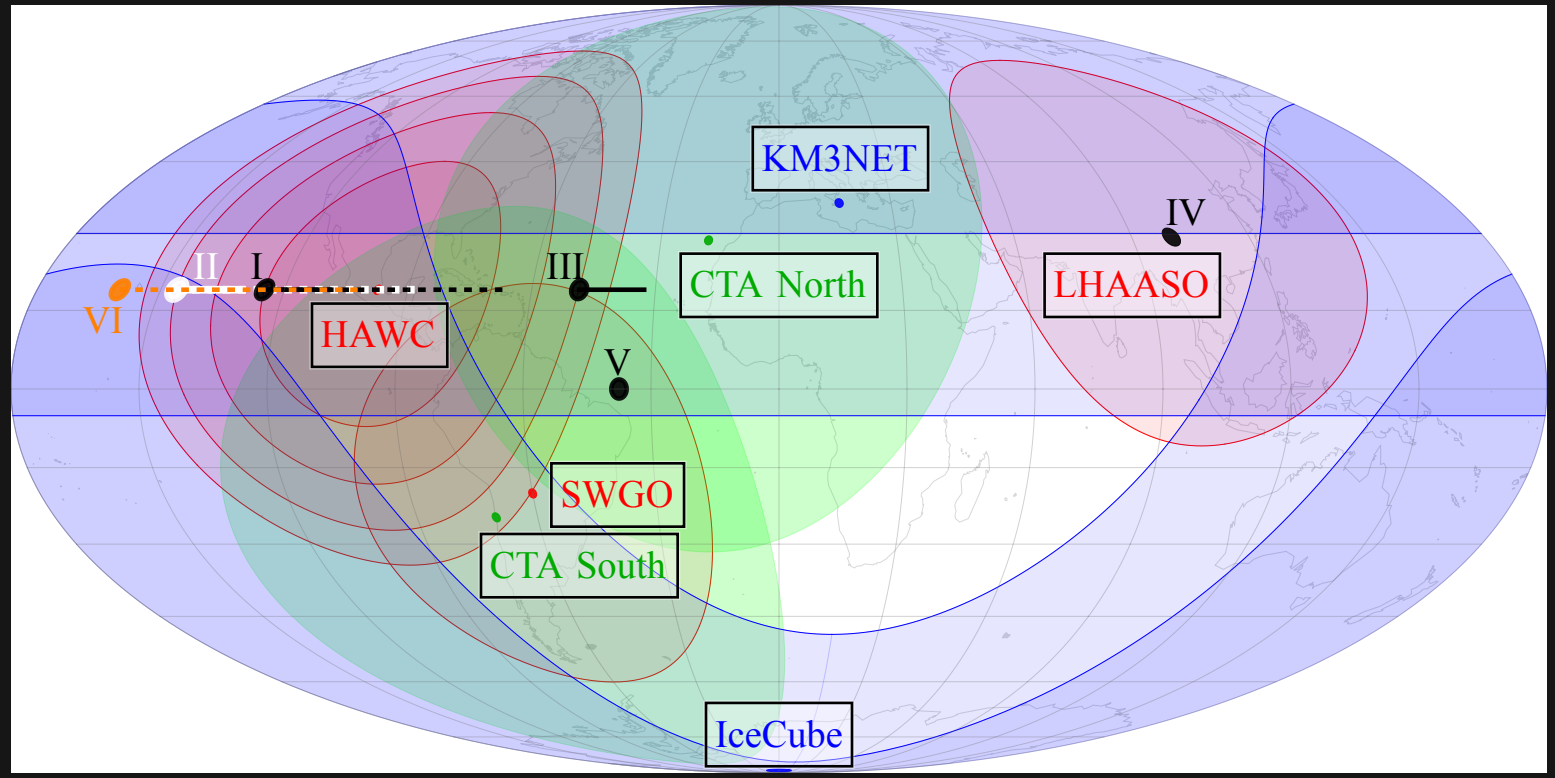
Observational characteristics

Compute time bins assuming SM and DS

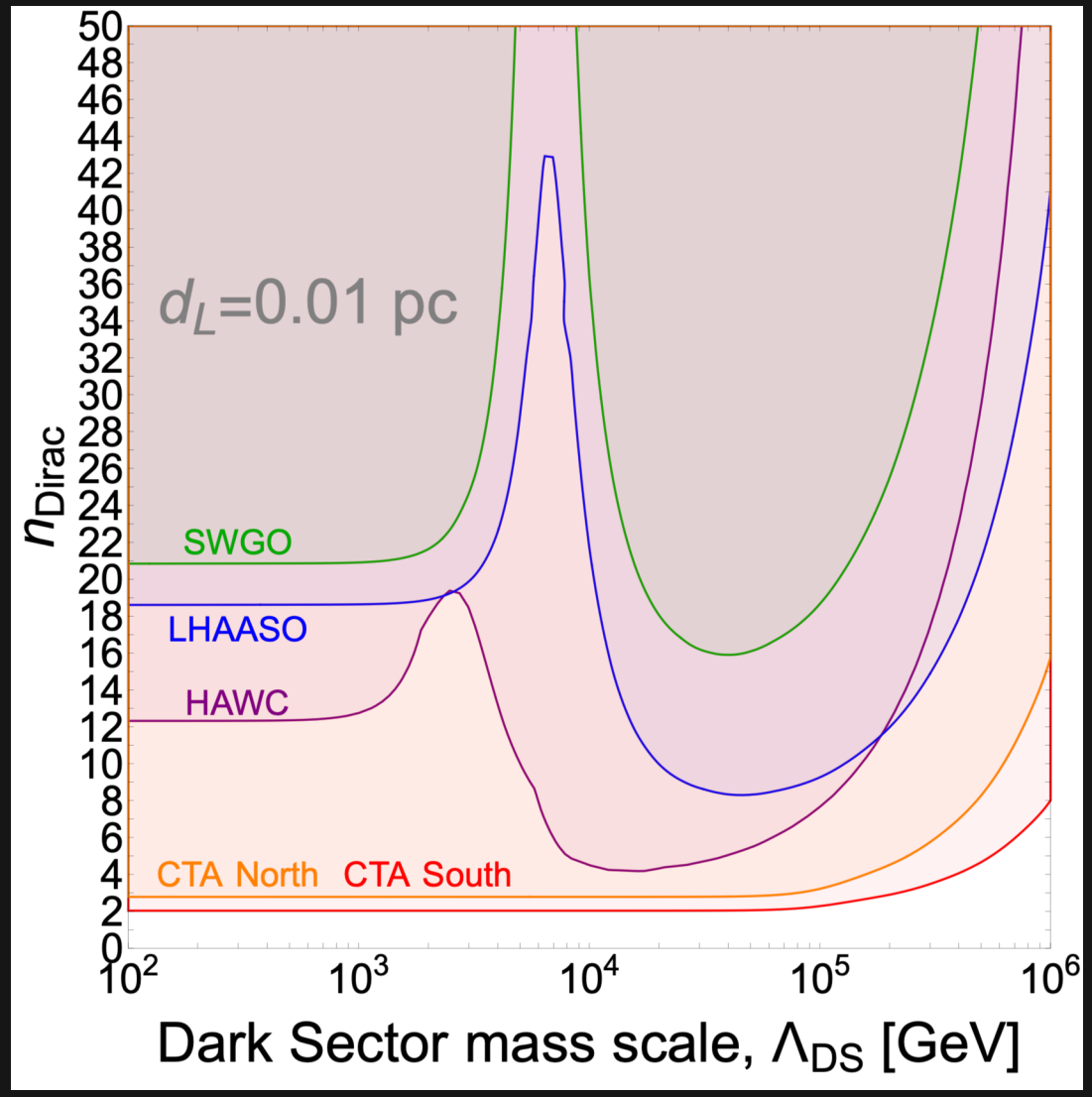
$$N = \frac{1}{4\pi d^2} \int dE\, A_{eff}(E) \int dt\, \frac{d^2 N_{total}}{dE dt}(M_{BH}(t), E)$$

Compare SM and DS predictions with a statistical test

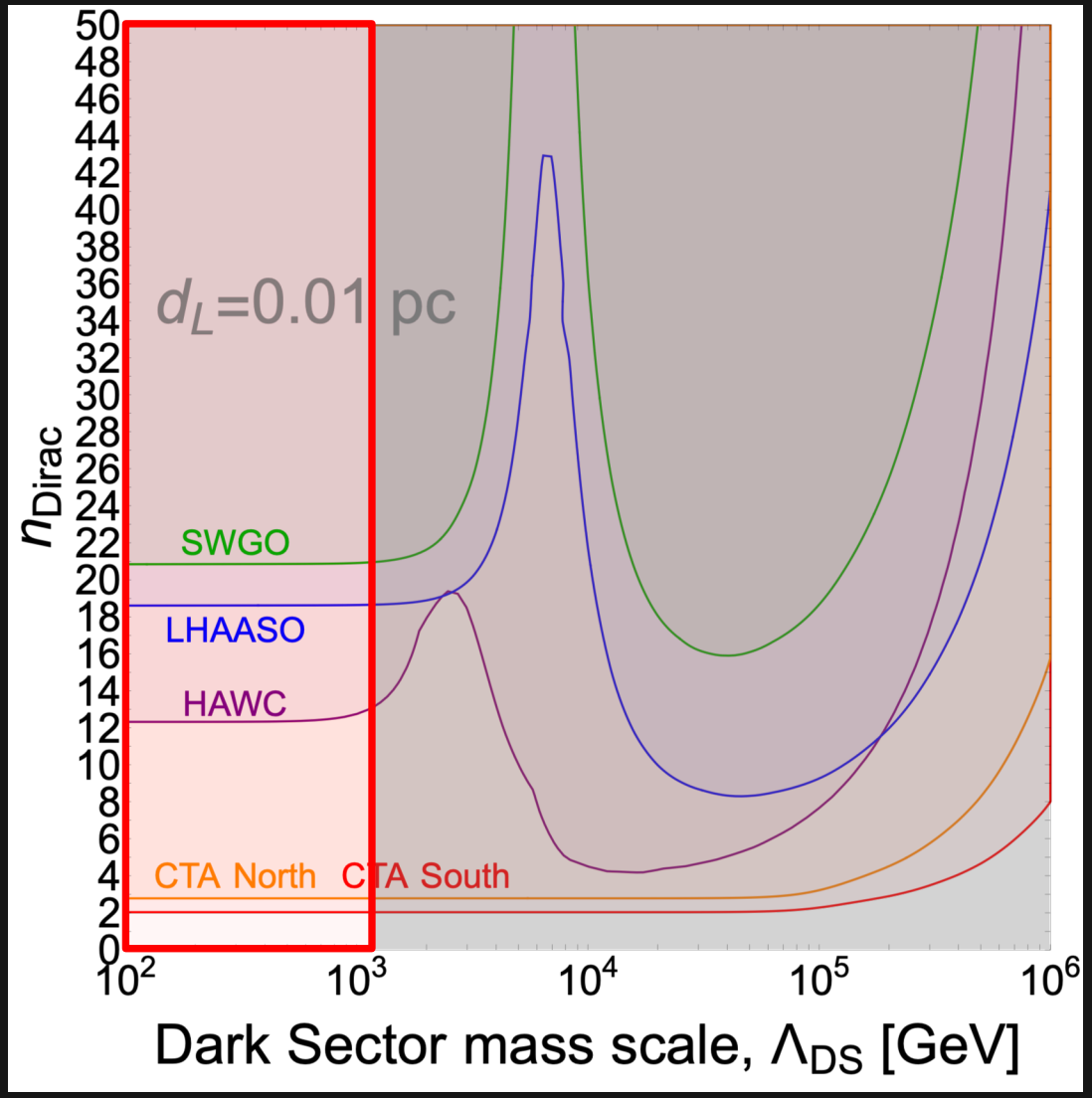
Observational characteristics



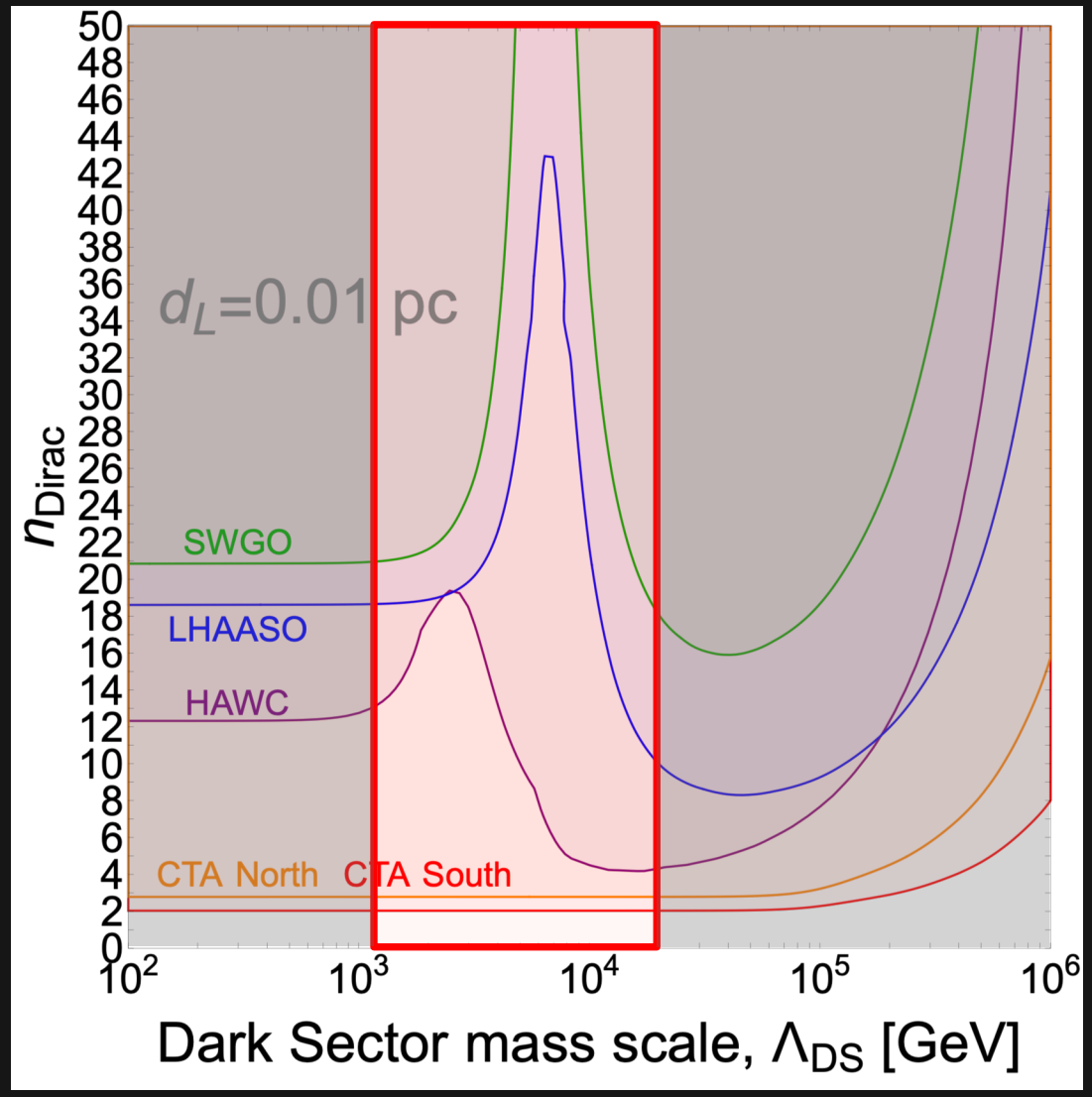
Observational characteristics



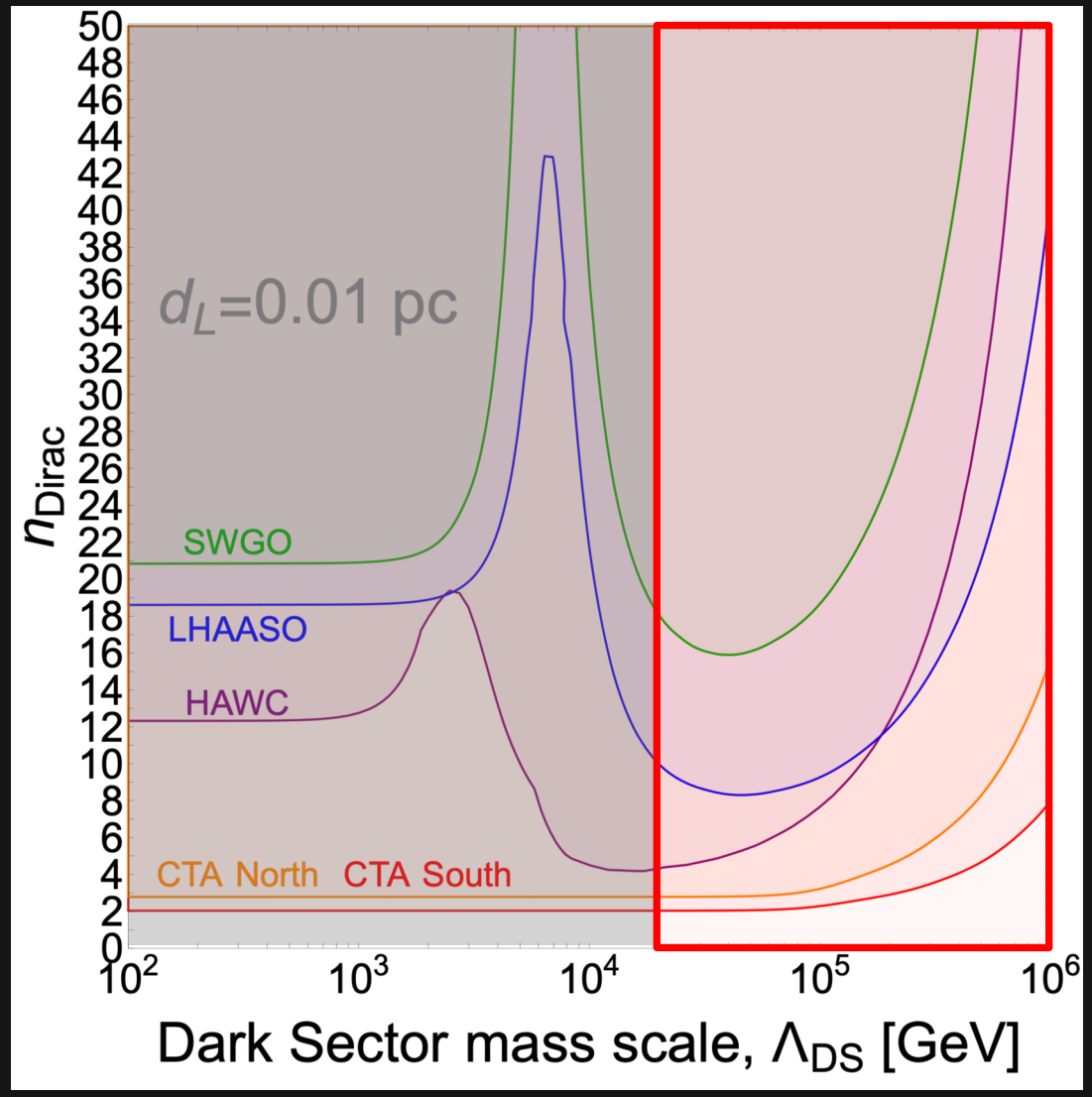
Observational characteristics



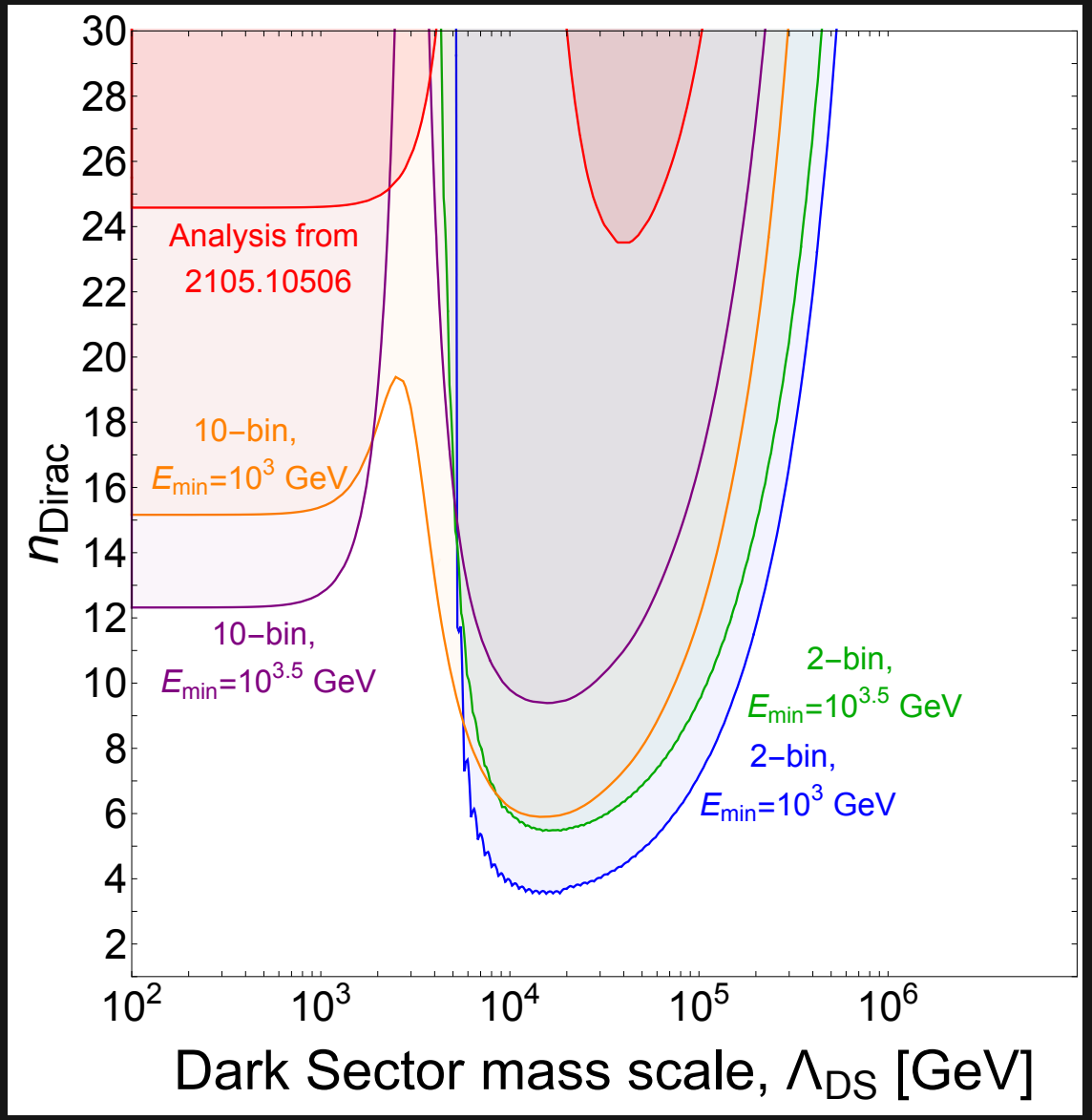
Observational characteristics



Observational characteristics



Observational characteristics



Summary

Dark sector influences Hawking radiation

Existing & upcoming experiments searching for EBHs could probe dark sectors

Potentially sensitive to $\mathcal{O}(10)$ Dirac fermions up to $\sim 10^6$ GeV

References

References

Black hole evaporation: S.Hawking Nature 248, 30–31 (1974)

Primary radiation: T.Ukwatta et al.1510.04372

Secondary radiation using HDMSpectra: Capanema et al. 2110.05637

BlackHawk v2.0: A.Arbey, J. Auffinger 2108.02737

HDMSpectra: C.Bauer et al. 2007.15001

This project extends the analysis of M.Baker, A.Thamm 2105.10506v3

As far as I know, the idea of using Hawking Rad. to probe BSM DoF was introduced in 1510.04372, considering a single 5 TeV squark.

Backup slides

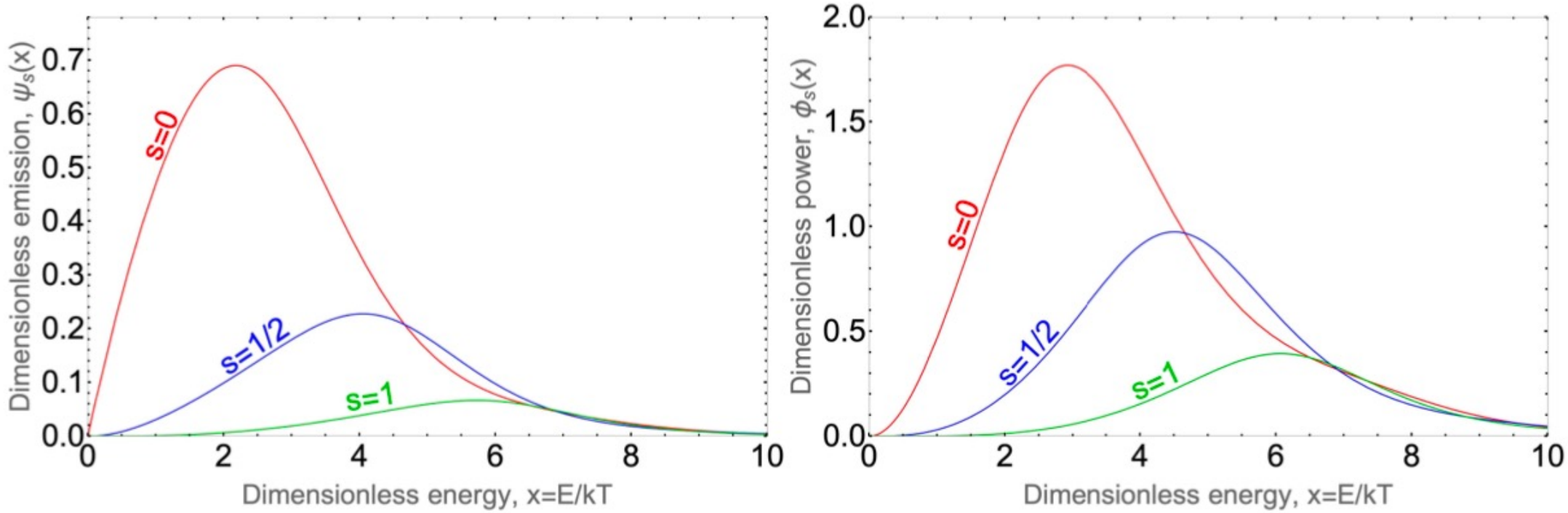


Figure 1.3: $\psi_s(x)$ and $\phi_s(x)$, the dimensionless particle and power emission rates per DoF, respectively.

Made using BlackHawk

Backup Slides

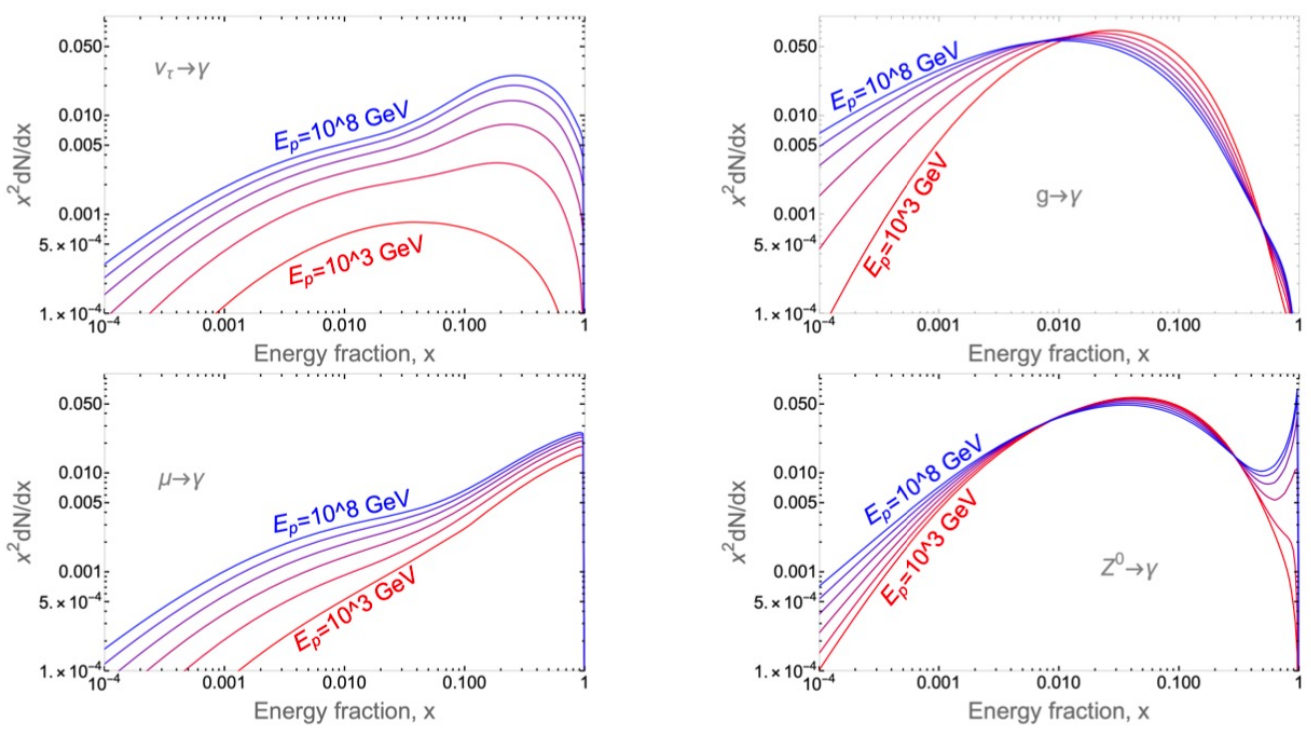


Figure 2.2: Examples of FFs for various primary species. The primary energies range from 10^3 to 10^8 GeV, red corresponding to lower E_p and blue to higher E_p. See Ref.[19] for more examples with different combinations of primary/secondary species. Note that the x values here refer to $\bar{x}$ defined in the main text.

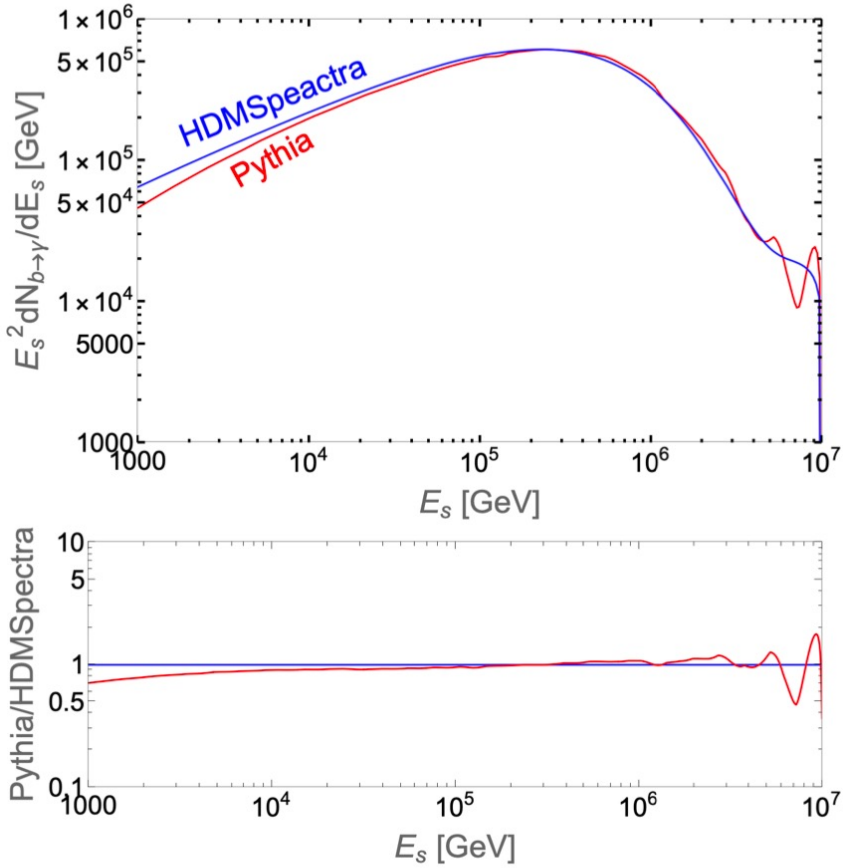


Figure 2.1: Comparison between fragmentation functions for $b \to \gamma$ produced via Pythia and HDMSpectra, where $E_p = 10^7$ GeV. The disagreement is almost always less than a factor of 2.

Made using HDMSpectra

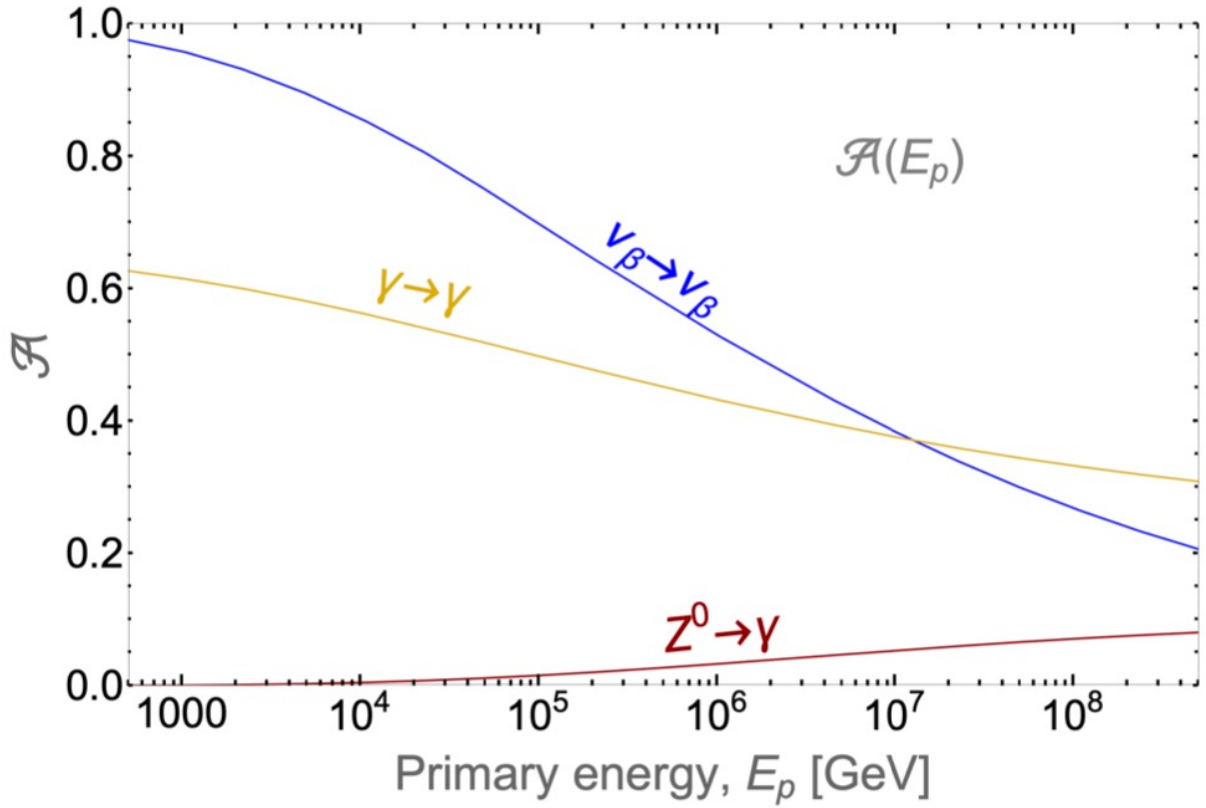


Figure 5.1: $\mathcal{A}^{i\to f}(E_p)$ functions for primary i contributing to the total spectra of f with $x = 1$. Due to the relation between Z^0 and γ as a result of electroweak symmetry breaking, the process $Z^0 \to \gamma$ with $x = 1$ at energies $E_p \gg \Lambda_{EW}$ must be accounted for.

Made using HDMSpectra

$$\frac{d^2N_\gamma^{\text{total}}}{dEdt} = \frac{d^2N_\gamma^{\text{sec}}}{dE_s dt} + \mathcal{A}^{\gamma\to\gamma}(E_p)\frac{d^2N_\gamma^{\text{pri}}}{dE_p dt} + \mathcal{A}^{Z^0\to\gamma}(E_p)\frac{d^2N_{Z^0}^{\text{pri}}}{dE_p dt},$$

$$\left.\frac{d^2N_{\nu_\beta}^{\text{total}}}{dEdt}\right|_{PBH} = \frac{d^2N_{\nu_\beta}^{\text{sec}}}{dE_s dt} + \mathcal{A}^{\nu_\beta\to\nu_\beta}(E_p)\frac{d^2N_{\nu_\beta}^{\text{pri}}}{dE_p dt},$$

$$\left.\frac{\mathrm{d}^2N_{\text{tot}}^{\nu_\alpha}}{\mathrm{d}t\mathrm{d}E}\right|_{\oplus} = \sum_{\beta=e}^{\tau}\sum_{i=1}^{3}|U_{\alpha i}|^2|U_{\beta i}|^2\left.\frac{\mathrm{d}^2N_{\text{tot}}^{\nu_\beta}}{\mathrm{d}t\mathrm{d}E}\right|_{\text{PBH}}$$

Explanation for these can be found in Capanema et al. 2110.05637

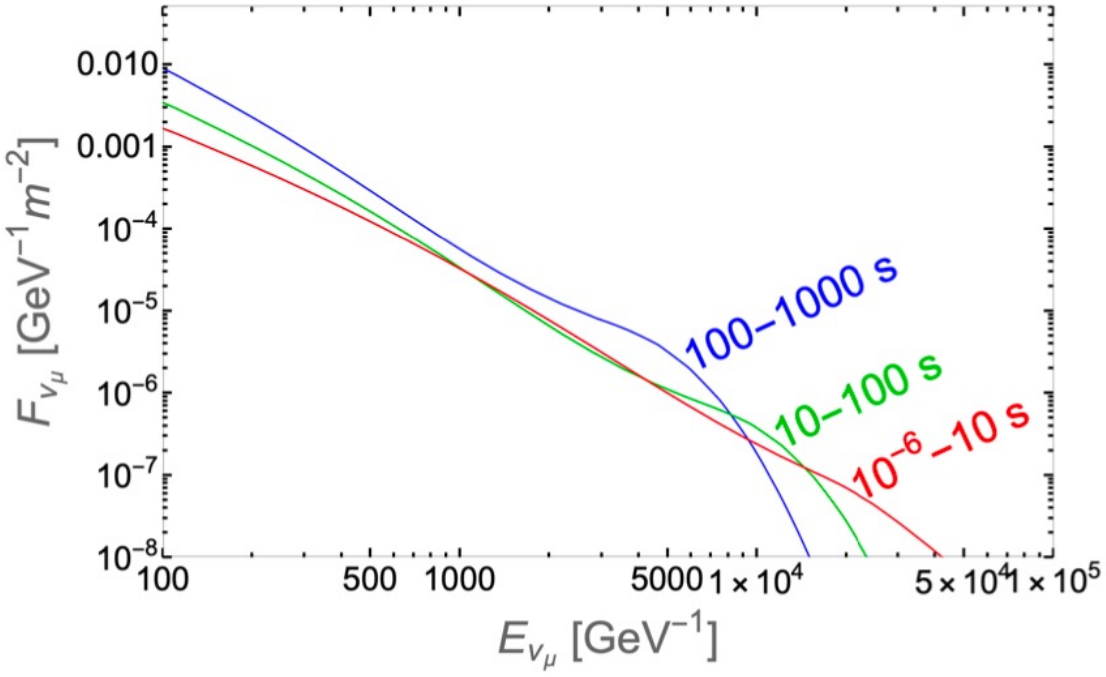
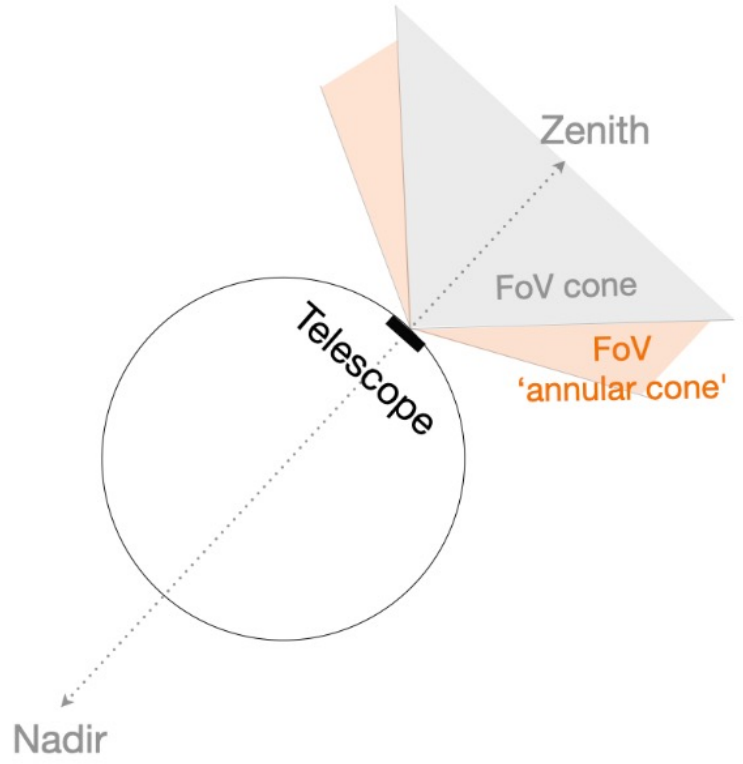
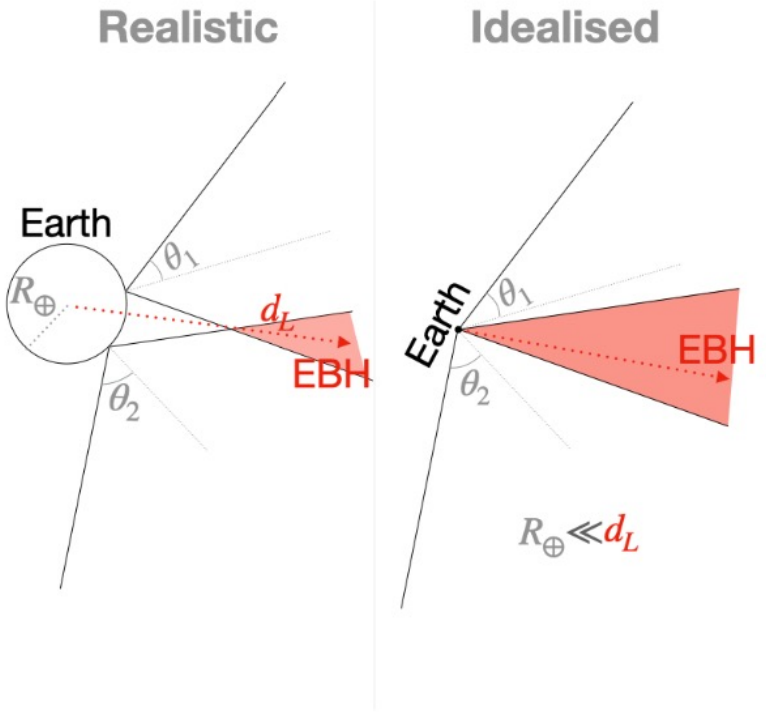


Figure 5.4: Fluences for ν_μ from an EBH 0.01 pc distant across the time intervals $100\ s \leq \tau \leq 1000\ s$ (in blue), $10\ s \leq \tau \leq 100\ s$ (in green), and $10^{-6}\ s \leq \tau \leq 10\ s$ (in red). We see that at lower energies the longer exposure time dominates over the greater emission rate at shorter times, but higher energies are only appreciably accessible at late times.

Backup Slides



(a) The FoV of an experiment can be modelled by partitioning the full FoV into cones and annular cones with different effective areas. The Zenith and Nadir points are points on the celestial sphere 'above' and 'below' the experiment.



(b) Approximation used for the geometry of the FoV overlaps. Assuming the distance to the point of nearest intersection between overlapping FoVs is on the order of $R_\oplus$, then the FoV cones are assumed to share an apex.

Figure 4.5: Approximate geometric configuration used for the FoV overlaps.

Backup Slides

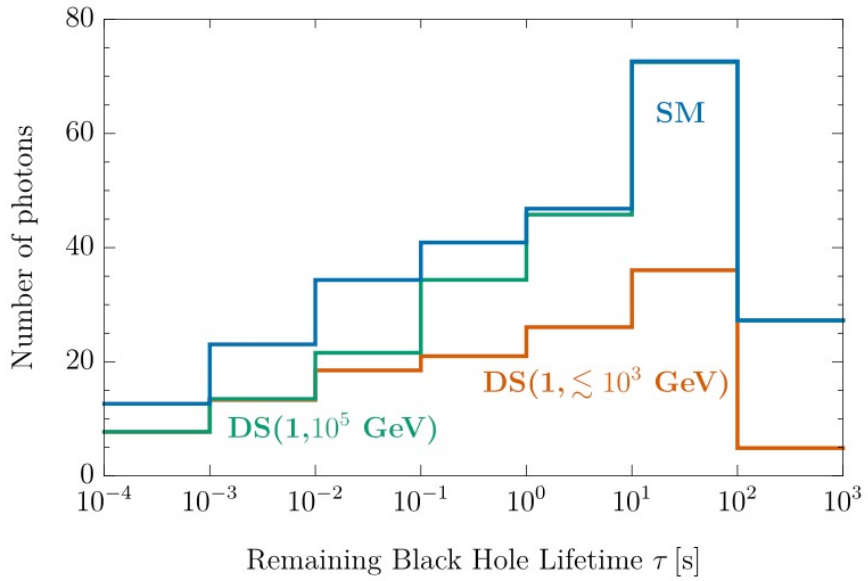


FIG. 3. The number of photons observed in each time window for an EBH observed at 0.01 pc for the SM and dark sector models at different mass scales.

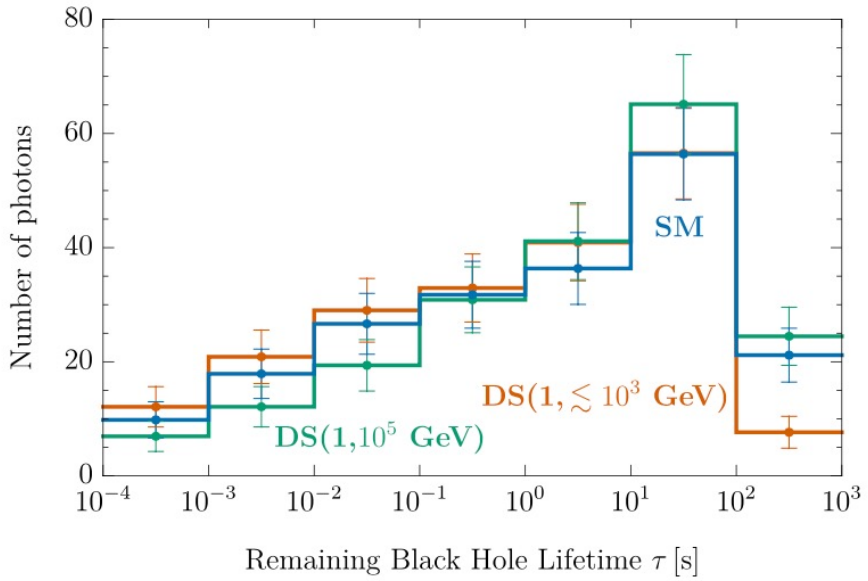


FIG. 4. The number of photons observed in each time window normalised to 200 total photons, for the SM and dark sector models at different mass scales. The error bars include statistical and 5% systematic errors.

Michael J. Baker and Andrea Thamm
2105.10506v3

Backup Slides

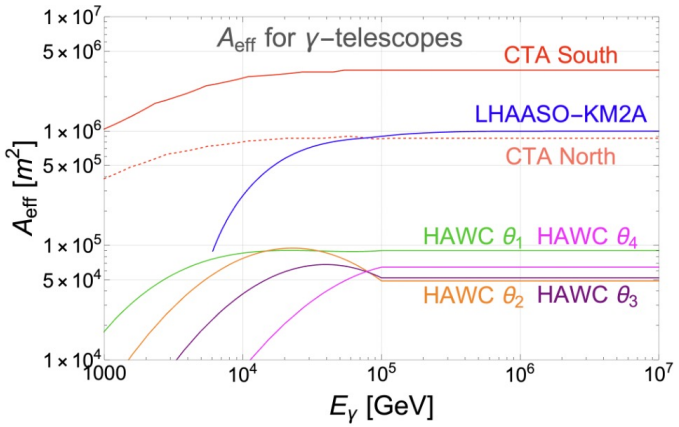
	HAWC	LHAASO	CTA South	CTA North	SWGO
Location [(°N,°E)]	(19.0, -97.3)	(29.4, 100.1)	(-24.6, -70.4)	(28.7, -17.9)	(-24.2 – -13.5, ∼-70)
Field of View [sr]	0.64 (θ_1 band), 2.5 for all θ bands	1.5–2	$0.019 - 0.069$	***	1.5–2†
Effective Area [m^2]	$\sim 8 \times 10^4$	1.0×10^6	3.4×10^6	8.5×10^5	$\sim 3.6 \times 10^5$
Energy Resolution	∼ 23%-40%	∼ 20%	∼ 5%	***	$\lesssim$ 30%
Time Resolution	$\mathcal{O}$(100 ps)	0.5 ns	***	***	***
Angular Resolution	0.228°	$0.25° - 0.33°$	$\lesssim 0.05°$	$\lesssim 0.05°$	∼ 0.15°
CR Rejection	2×10^{-3}	10^{-3}–10^{-5}	$< 10^{-2}$	$< 10^{-2}$	10^{-4}
Background spectrum rate at 20 TeV [Gev^{-1} s^{-1}]	2.8×10^{-6}	3.3×10^{-5}	1.8×10^{-3}	4.3×10^{-3}	
Up-time	∼ 100%	∼ 100%	***	***	∼ 100%†
Completion	2015	2021	2025	2025	R&D 2024
References					

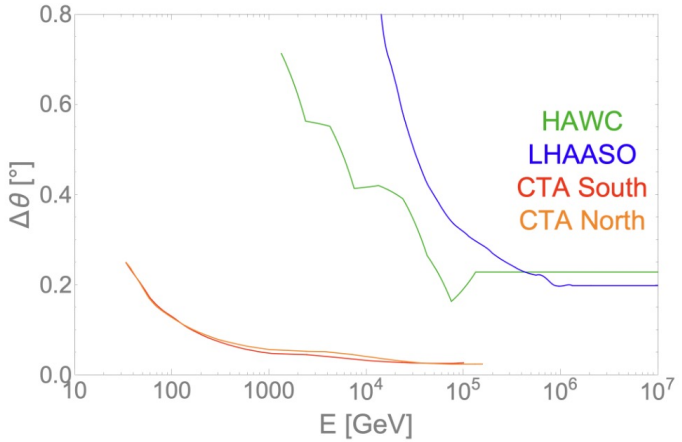
Table 1. † – our motivated assumption

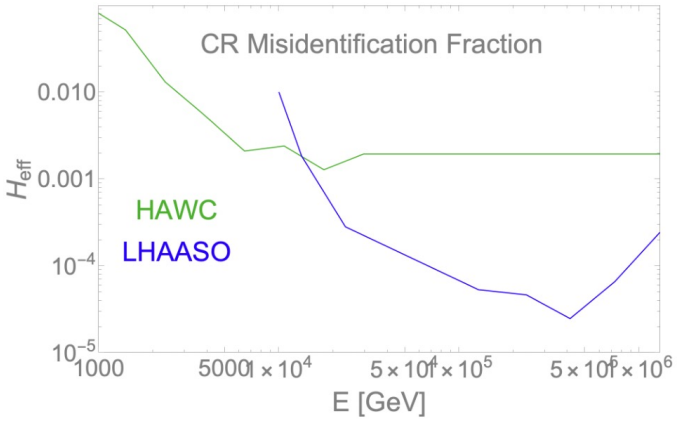
	IceCube Gen1	IceCube Gen2	KM3NET
Location [(°N,°E)]	(-90, 0)	(-90, 0)	(16, 36.3)
Effective Area [m^2]	89	700	130
Time Resolution	***	***	***
Angular Resolution	$\sim 0.5°$	***	0.1°
Up-time	$\sim 100\%$	$\sim 100\%$	$\sim 100\%$
Completion	Operating	2033	Under construction
References			

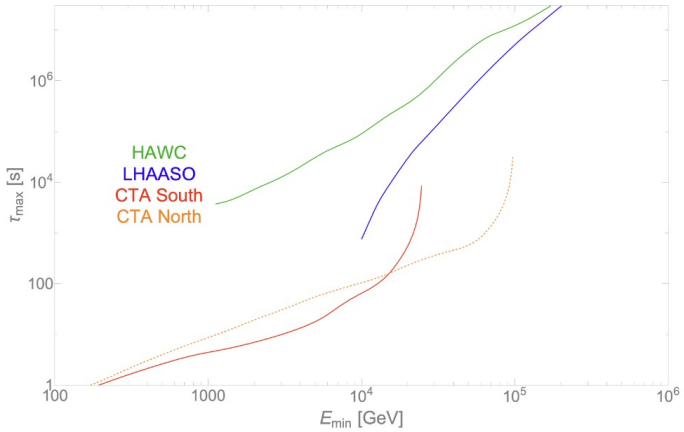
Table 2. NEUTRINOS

Backup Slides

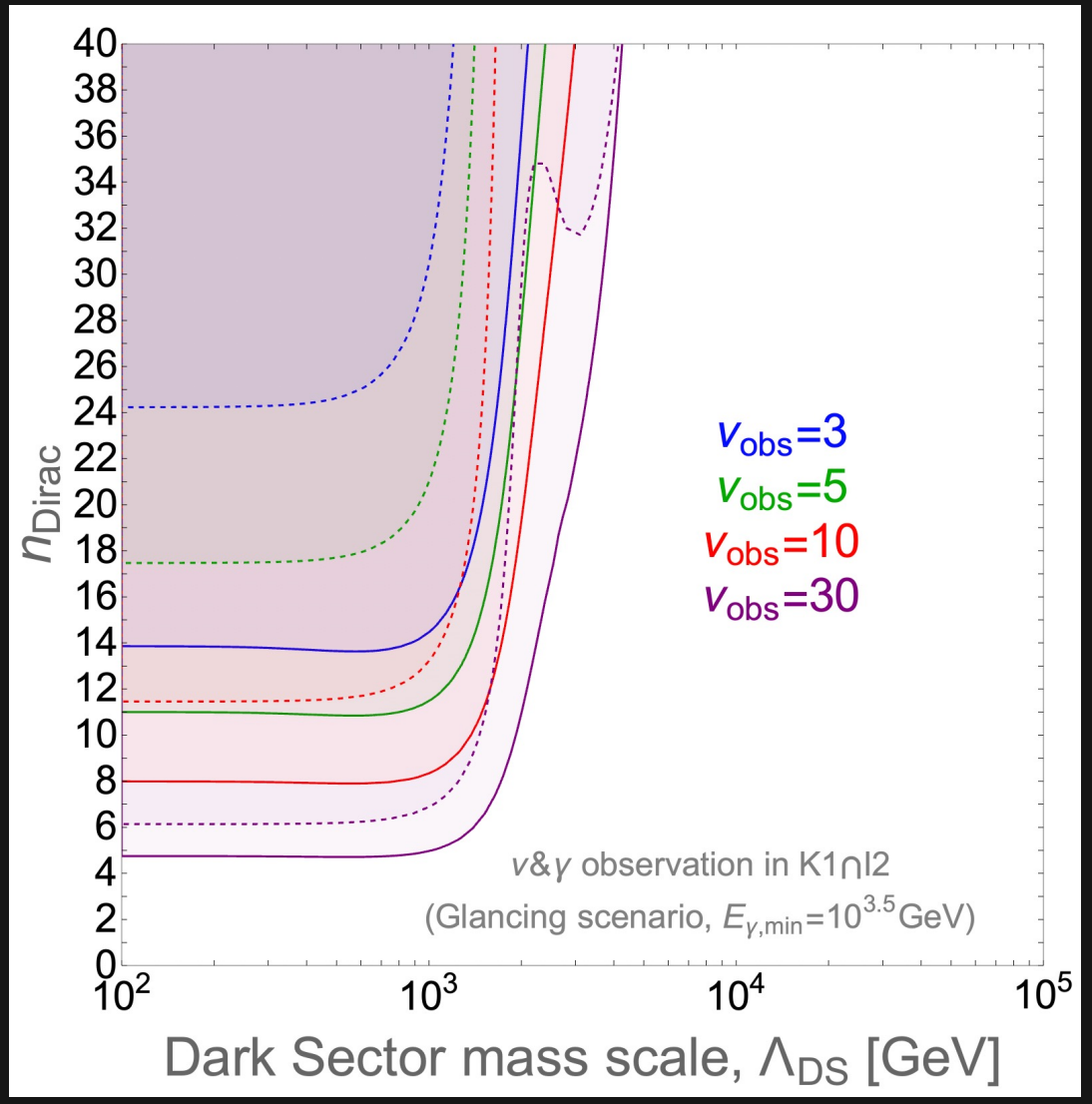


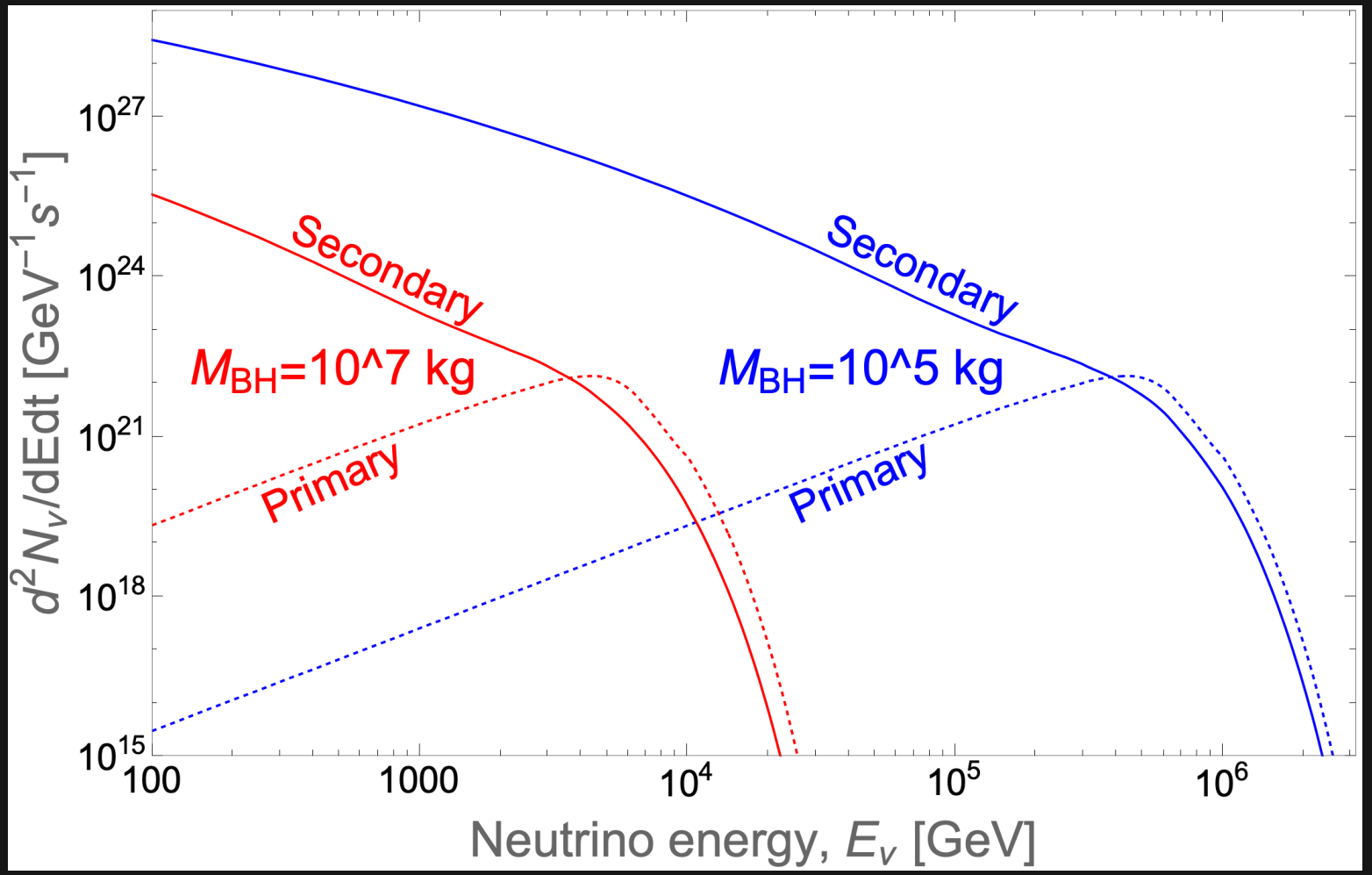


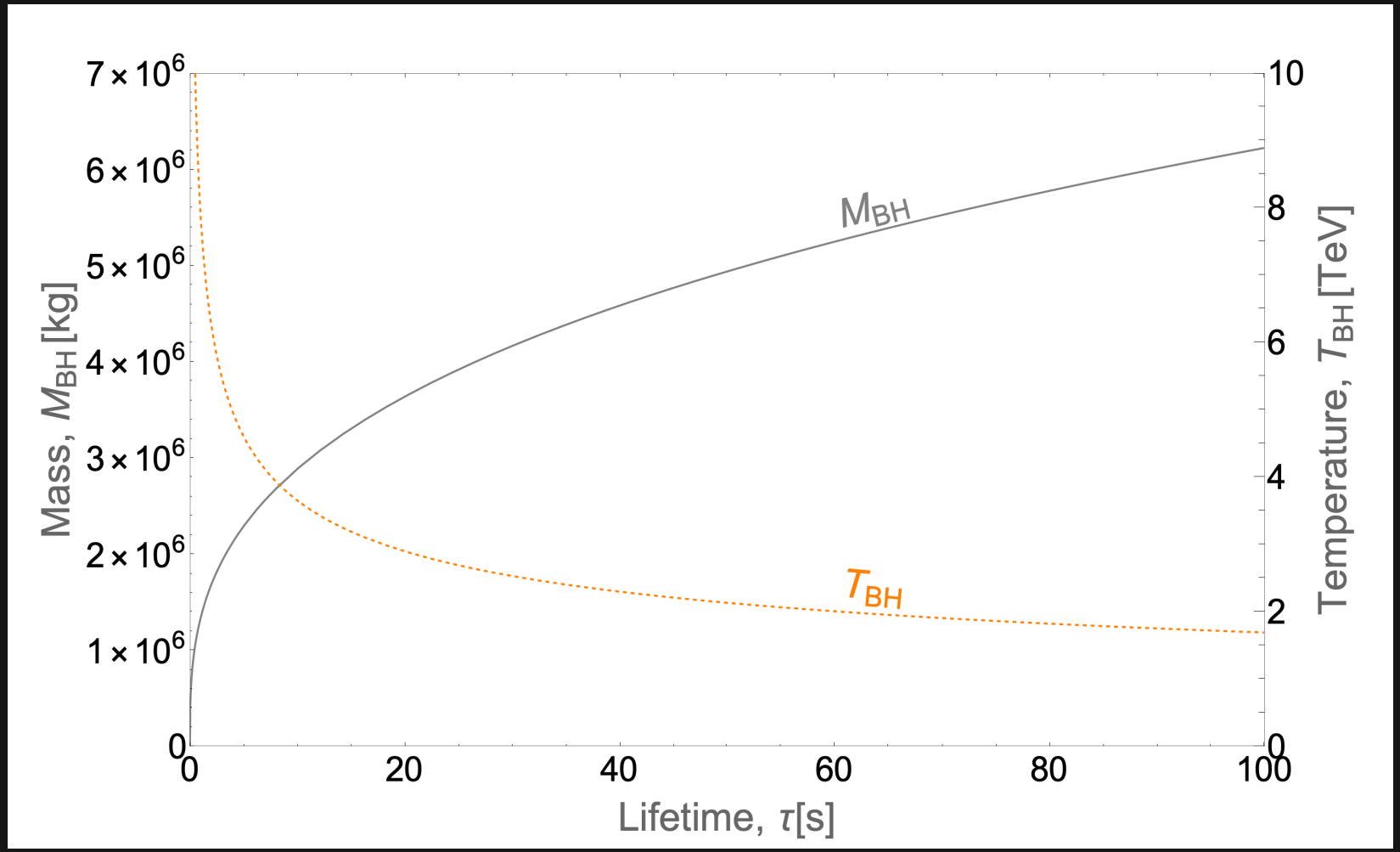




$$\tau_{\max}^{-1} \simeq \int_{E_{\min}}^{E_{\max}} dE \, \frac{\mathrm{d}\Phi}{\mathrm{d}E}(E) \, A_{eff}^{(\mathrm{H+He})}(E) \, 2\pi \big(1 - \cos\left(\Delta\theta(E)\right)\big) \, \eta(E).$$


n_{Dirac}
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10^2
10^3
10^4
10^5
Dark Sector mass scale, Λ_{DS} [GeV]
v_{obs}=3
v_{obs}=5
v_{obs}=10
v_{obs}=30
ν&γ observation in K1∩I2
(Glancing scenario, $E_{\gamma,min}=10^{3.5}$GeV)


Secondary
Secondary
M_{BH}=10^7 kg
M_{BH}=10^5 kg
Primary
Primary
$d^2N_v/dEdt$ [GeV^{-1}s^{-1}]
10^{27}
10^{24}
10^{21}
10^{18}
10^{15}
100
1000
10^4
10^5
10^6
Neutrino energy, E_v [GeV]


7×10^6
6×10^6
5×10^6
4×10^6
3×10^6
2×10^6
1×10^6
0
Mass, M_{BH} [kg]
10
8
6
4
2
0
Temperature, T_{BH} [TeV]
M_{BH}
T_{BH}
0
20
40
60
80
100
Lifetime, τ[s]