Exploding Primordial Black Holes

(Based on 2503.10755)

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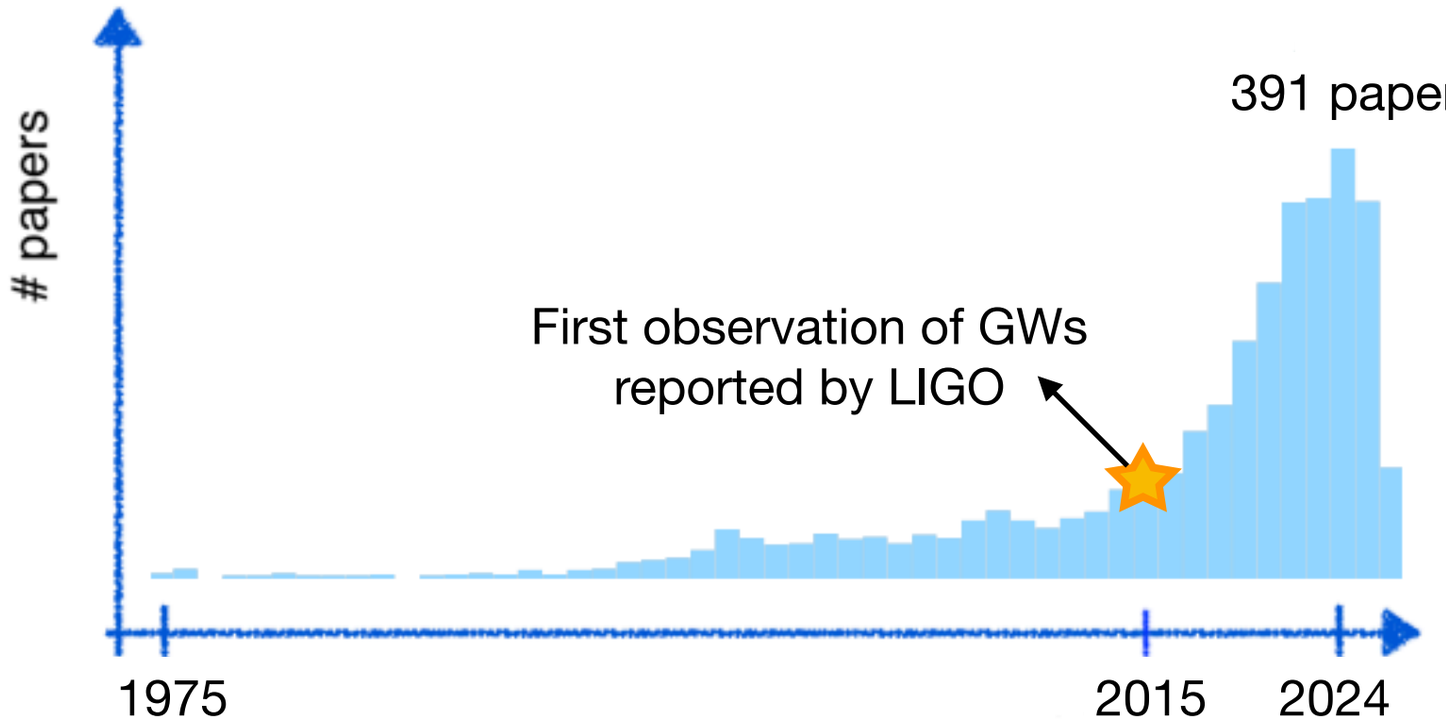
Primordial Black Holes

Firstly discussed in the 60s and 70s by Zeldovich & Novikov and Carr & Hawking.



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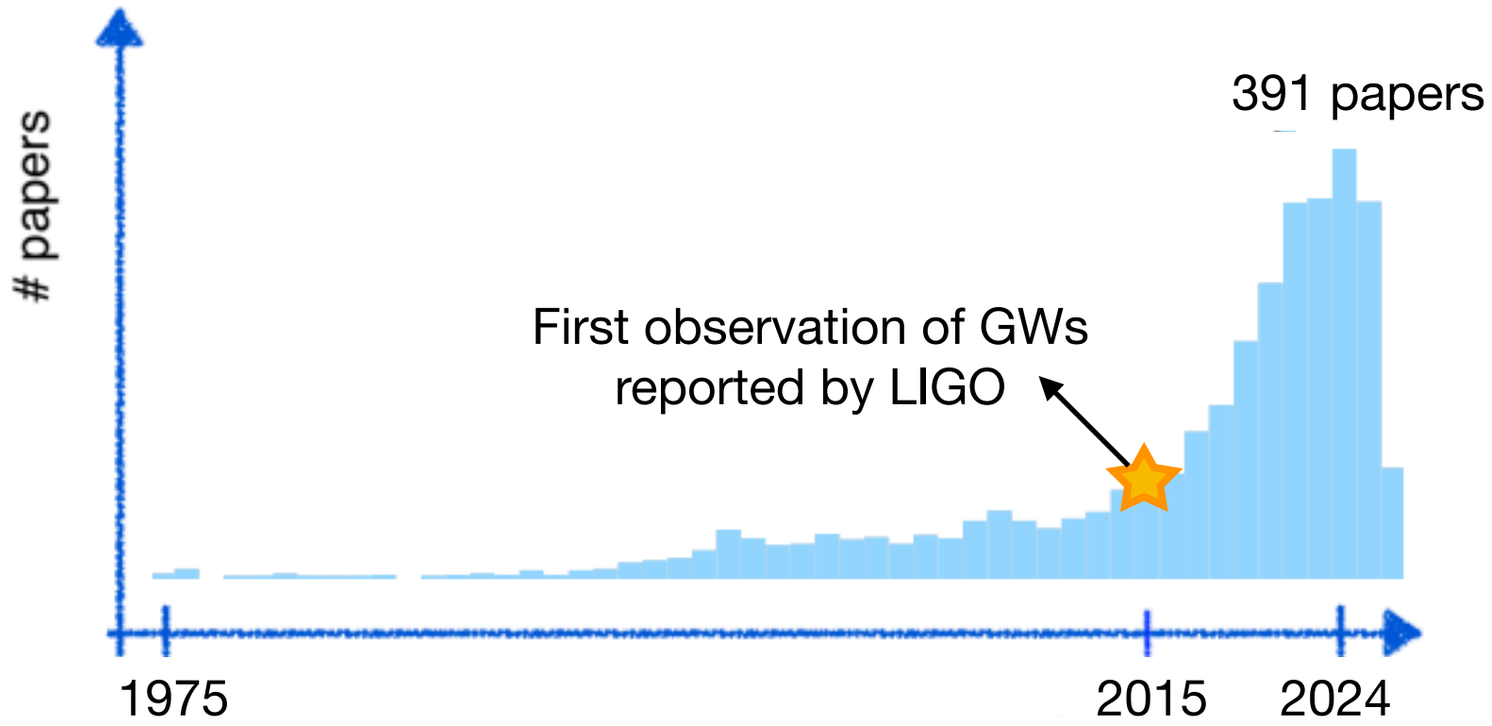


Observational evidence?	BHs in pair instability gap detected by LIGO SMBHs detected at very high redshift NANOGrav detection of stochastic GW background

S. Bird et al. **Did LIGO detect dark matter?** *PRL* 116 (2016) 20, 201301

B. Carr et al. **Observational evidence for PBHs: A Positivist Perspective.** *Phys.Rept.* 1054 (2024) 1-68

V. De Luca al. **NANOGrav data hints at PBHs as DM.** *PRL* 126 (2021), 041303

PBH Direct Observation

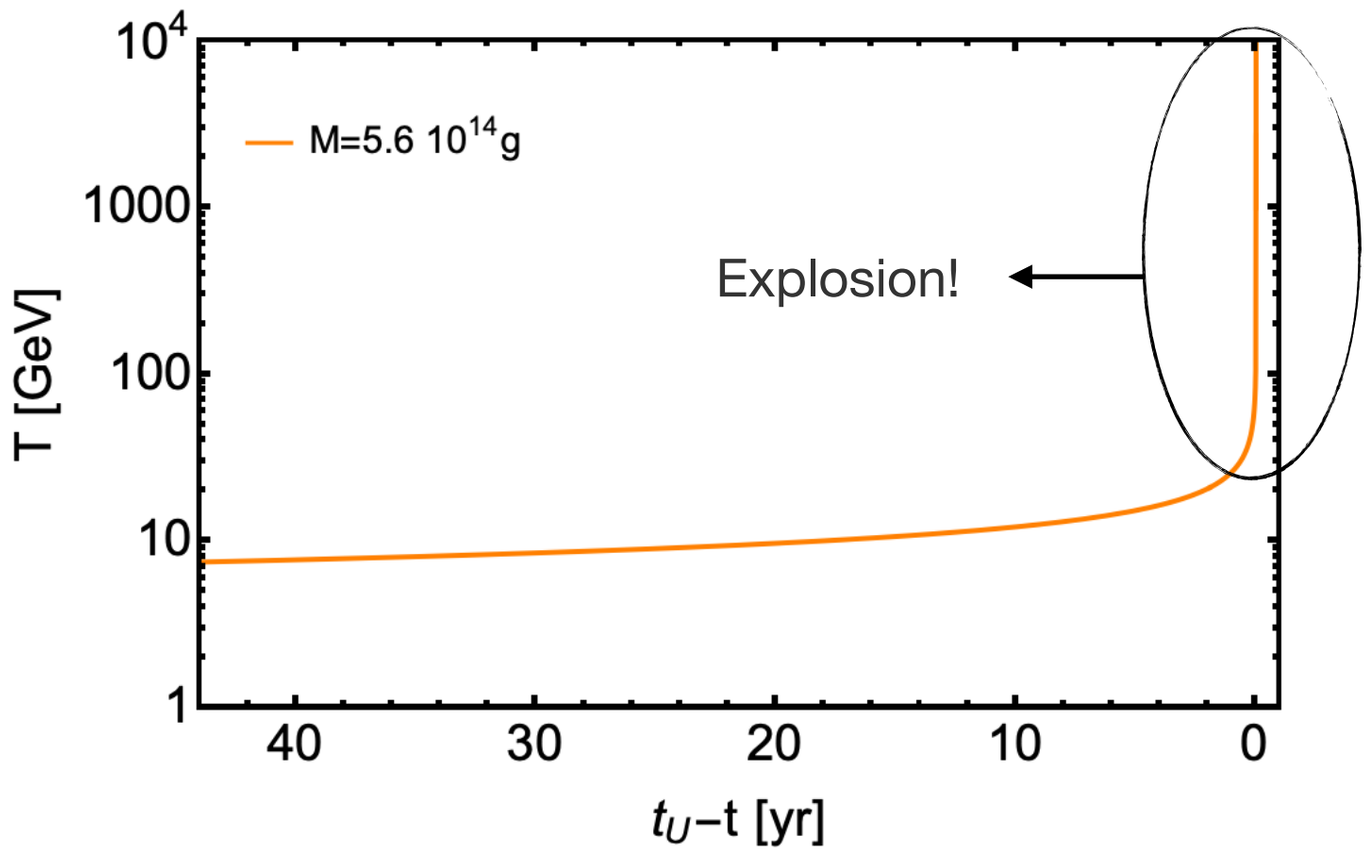
Hawking radiation

$$T^{S}_{\mathrm{PBH}} = \frac{M^2_{\mathrm{Pl}}}{8\pi M_{\mathrm{PBH}}} \approx 1.05\mathrm{MeV} \times \left(\frac{10^{16}\mathrm{g}}{M_{\mathrm{PBH}}}\right)$$

Runaway process!

Black hole explosions?

S.W. Hawking. *Nature* 248, 30-31 (1974)



PBH Direct Observation

Hawking radiation

$$T^{S}_{\rm PBH} = \frac{M^2_{\rm Pl}}{8\pi M_{\rm PBH}} \approx 1.05{\rm MeV} \times \left(\frac{10^{16}{\rm g}}{M_{\rm PBH}}\right)$$

$$Q^*_D = Q_D M_{\rm Pl}/M_{\rm PBH}$$

$$T^{RN}_{\rm PBH} = \frac{M^2_{\rm Pl}}{2\pi M_{\rm PBH}} \frac{\sqrt{1-(Q^*_D)^2}}{(1+\sqrt{1-(Q^*_D)^2})^2}$$

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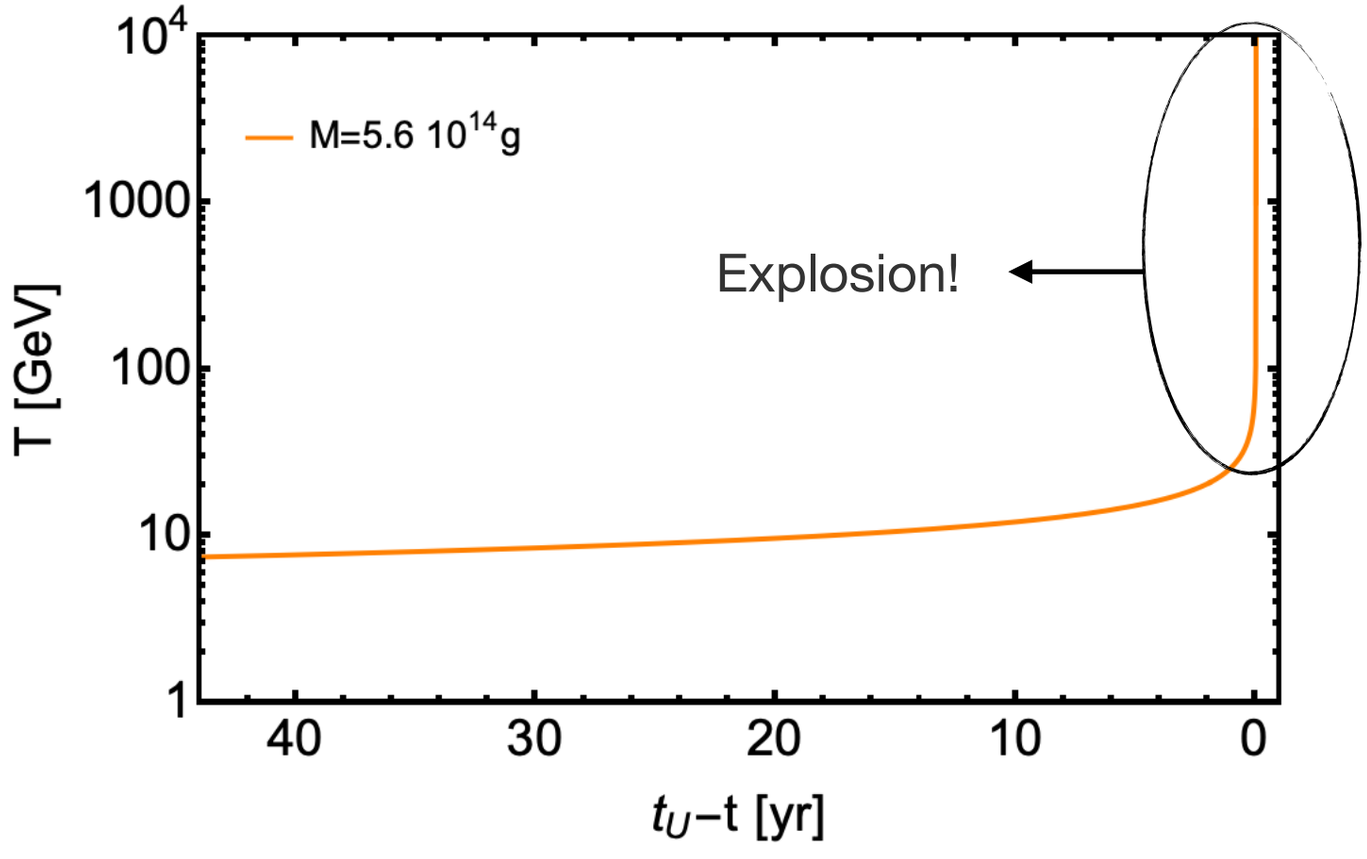


Exploding PBHs

Unprecedented observation!

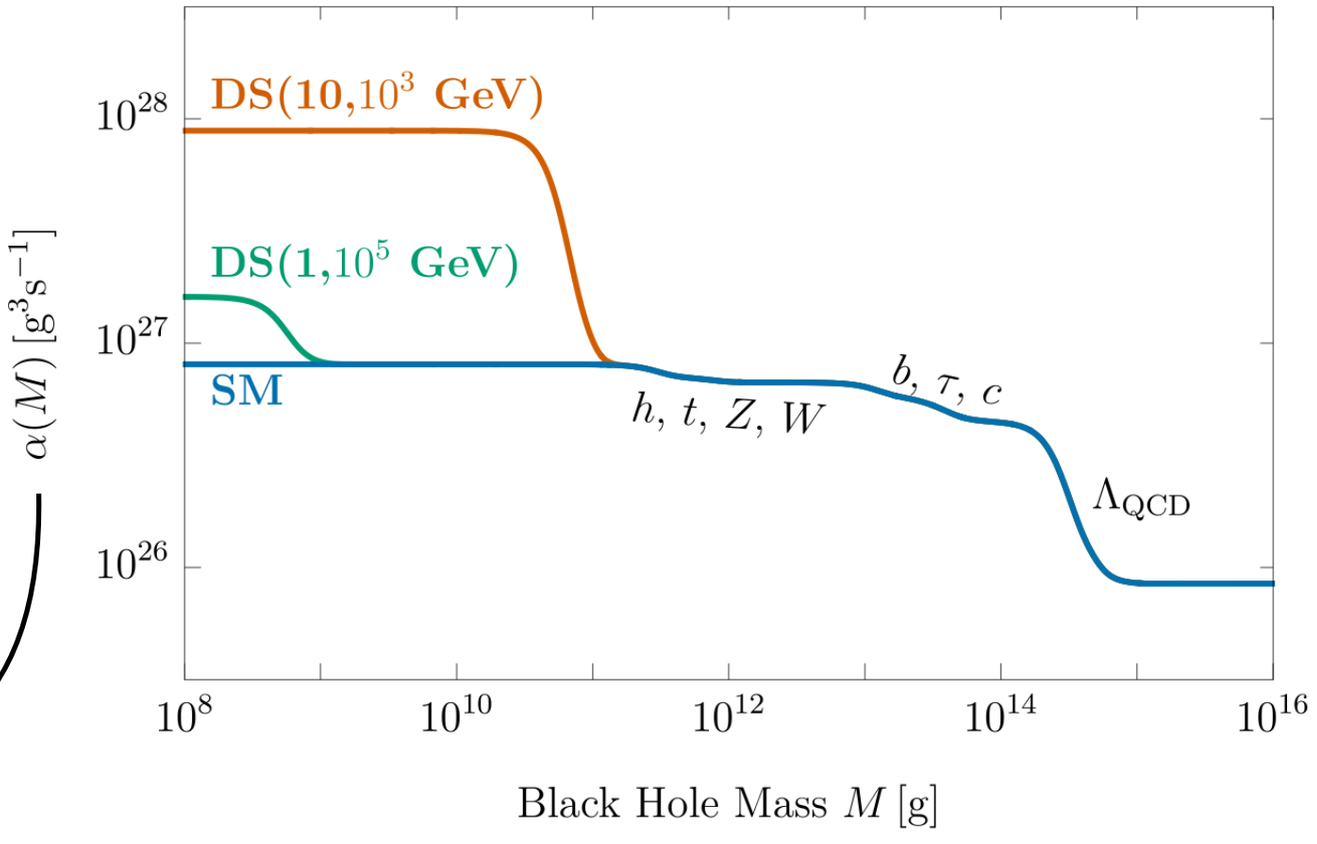
Experimental evidence for **Hawking radiation**

Experimental evidence for **PBH**

BSM physics
(dark sector secluded from visible sector?)

T.N Ukwatta et al. *Astropart.Phys.* 80 (2016) 90-114
M.J. Baker et al. *SciPost Phys.* 12 (2022) 150
M.J. Baker et al. *JHEP* 01 (2023) 063

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



Exploding PBHs

We **can** observe an exploding PBH!

Current HAWC limit is $\dot{n} < 3400\mathrm{pc}^{-3}\mathrm{yr}^{-1}$

HAWC Collaboration. *JCAP* 04 (2020) 026

Prospective LHAASO limit is $\dot{n} \lesssim 1000\mathrm{pc}^{-3}\mathrm{yr}^{-1}$

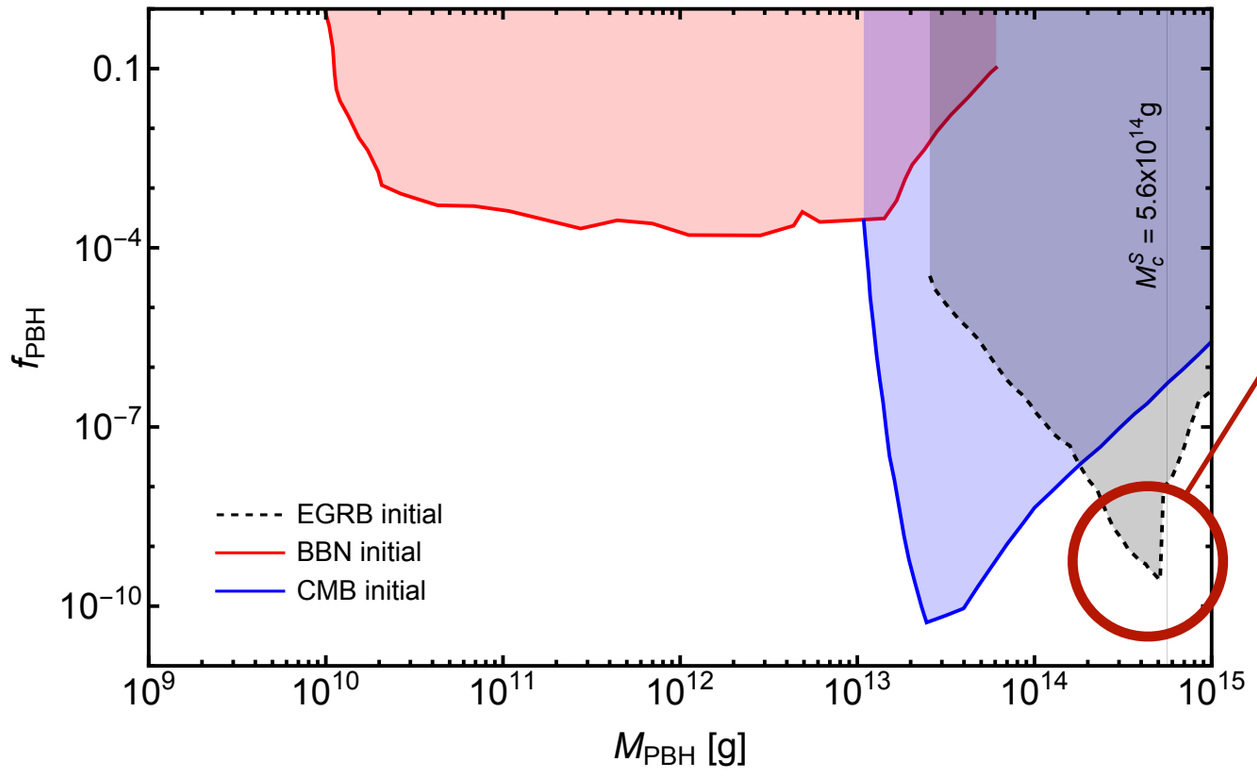
LHAASO Collaboration. 2408.10897

Prospective CTA limit is $\dot{n} \lesssim 36\mathrm{pc}^{-3}\mathrm{yr}^{-1}$

CTA Collaboration. 2504.17478

BUT…

Exploding PBHs



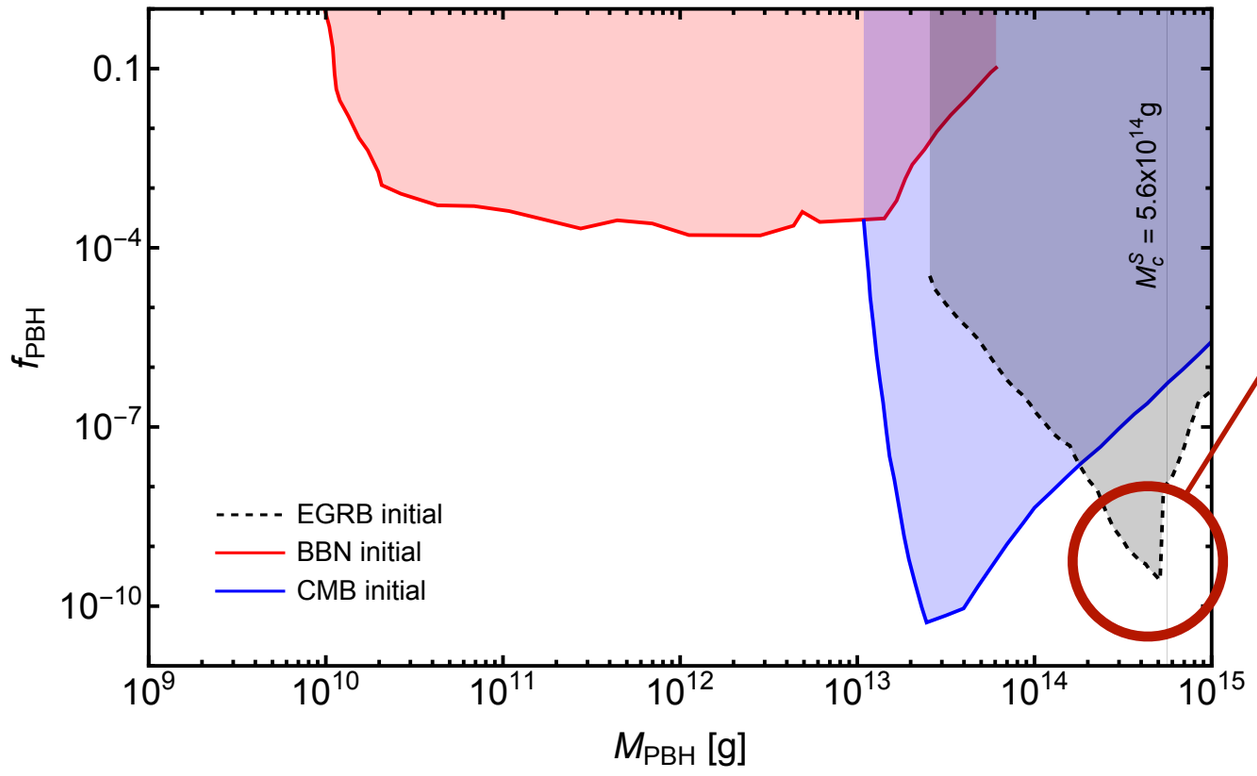
Exploding Schwarzschild PBHs are very massive and constrained!

Low number density

$$N_{\rm PBH} = f_{\rm PBH}\frac{\rho_{\rm DM}}{M_{\rm PBH}}$$

Low burst rate…

Exploding PBHs



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$$N_{\rm PBH} = f_{\rm PBH}\frac{\rho_{\rm DM}}{M_{\rm PBH}}$$

Low burst rate…

Telescopes are capable of searching for a PBH burst within a distance of ~$\mathcal{O}(0.1)$pc

Reasonably motivated burst rates are around $\dot{n} \lesssim 0.1\mathrm{pc}^{-3}\mathrm{yr}^{-1}$ X. Boluna et al. *JCAP* 04 (2024) 024

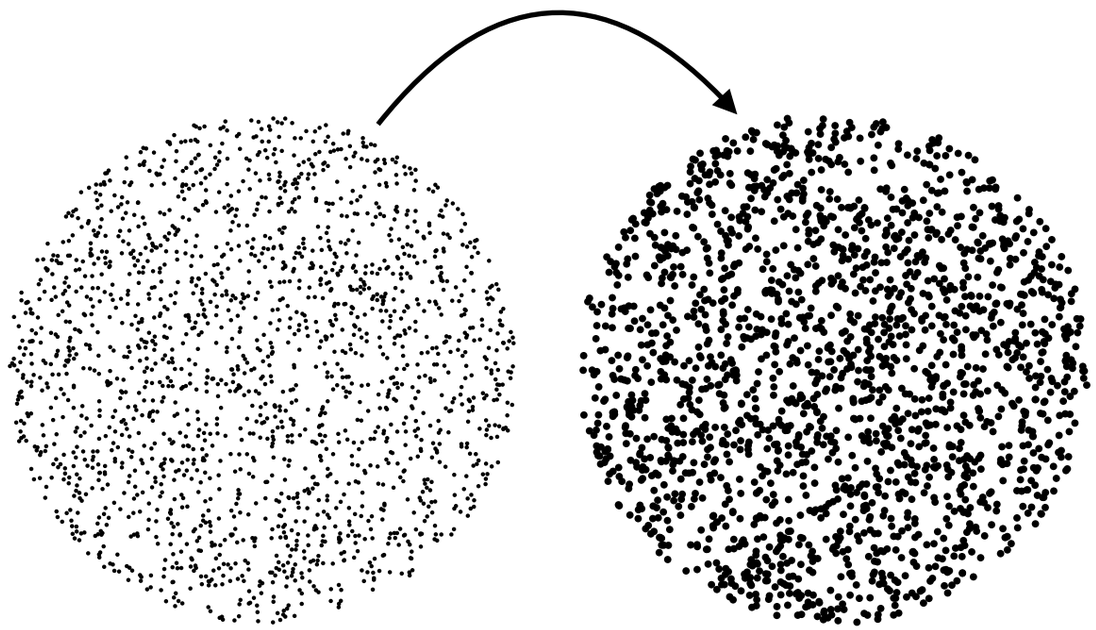
One event in $\mathcal{O}(10^4)$yr….

How to enhance the (local) burst rate?

The key object is the number density $N_{\rm PBH} = f_{\rm PBH} \dfrac{\rho_{\rm DM}}{M_{\rm PBH}}$

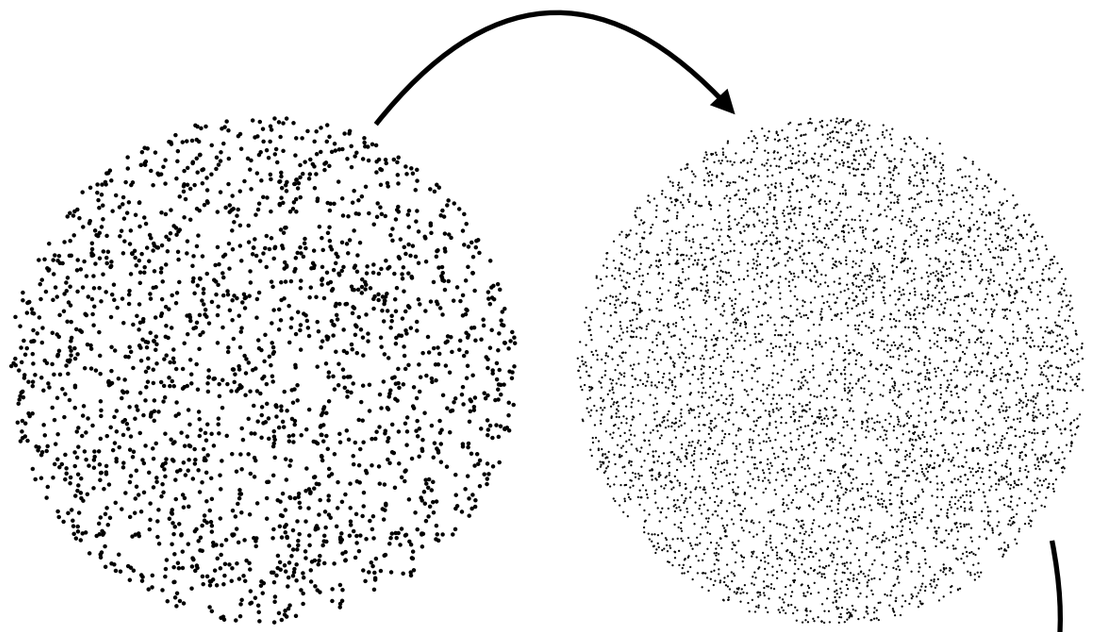
Same number density

Larger DM fraction



Larger number density

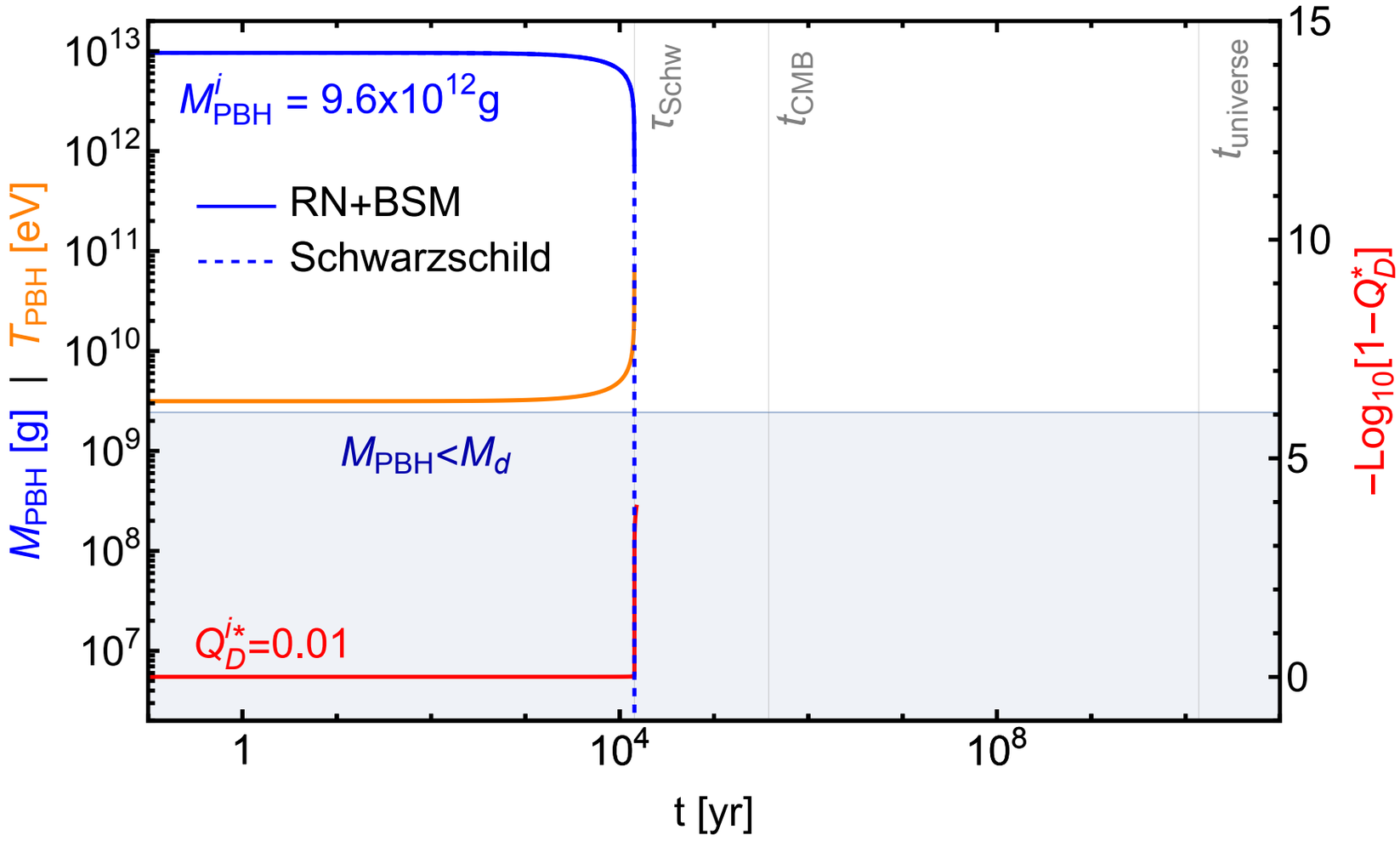
Same DM fraction



More PBHs → more bursts!

How to enhance the burst rate? (or how to produce lighter BHs with τ~t_U?)

The standard scenario (Schwarzschild + SM) leads to low burst rates.



How to enhance the burst rate?
(or how to produce lighter BHs with τ~t_U?)

The standard scenario (Schwarzschild + SM) leads to low burst rates.

We want to stop the evaporation process to extend the PBH lifetime.

Quasi-extremality

$$Q^* = \frac{Q}{M_{PBH}} M_P \to 1 \implies T^{RN} \to 0$$

Heavy charge carrier: $m \gg M_P^2/M_{PBH}$

Low accretion rate.

Y. Bai et al. PRD 101 (2020) 5, 055006
E. Alonso et al. PRD 108 (2023) 12, 125010
E. Alonso et al. PRL 132 (2024) 23, 231402

$$a^* = \frac{J}{M_{PBH}^2} M_P^2 \to 1 \implies T^K \to 0$$

It becomes Schwarzschild in a short period of time via emission of non-zero spin particles!

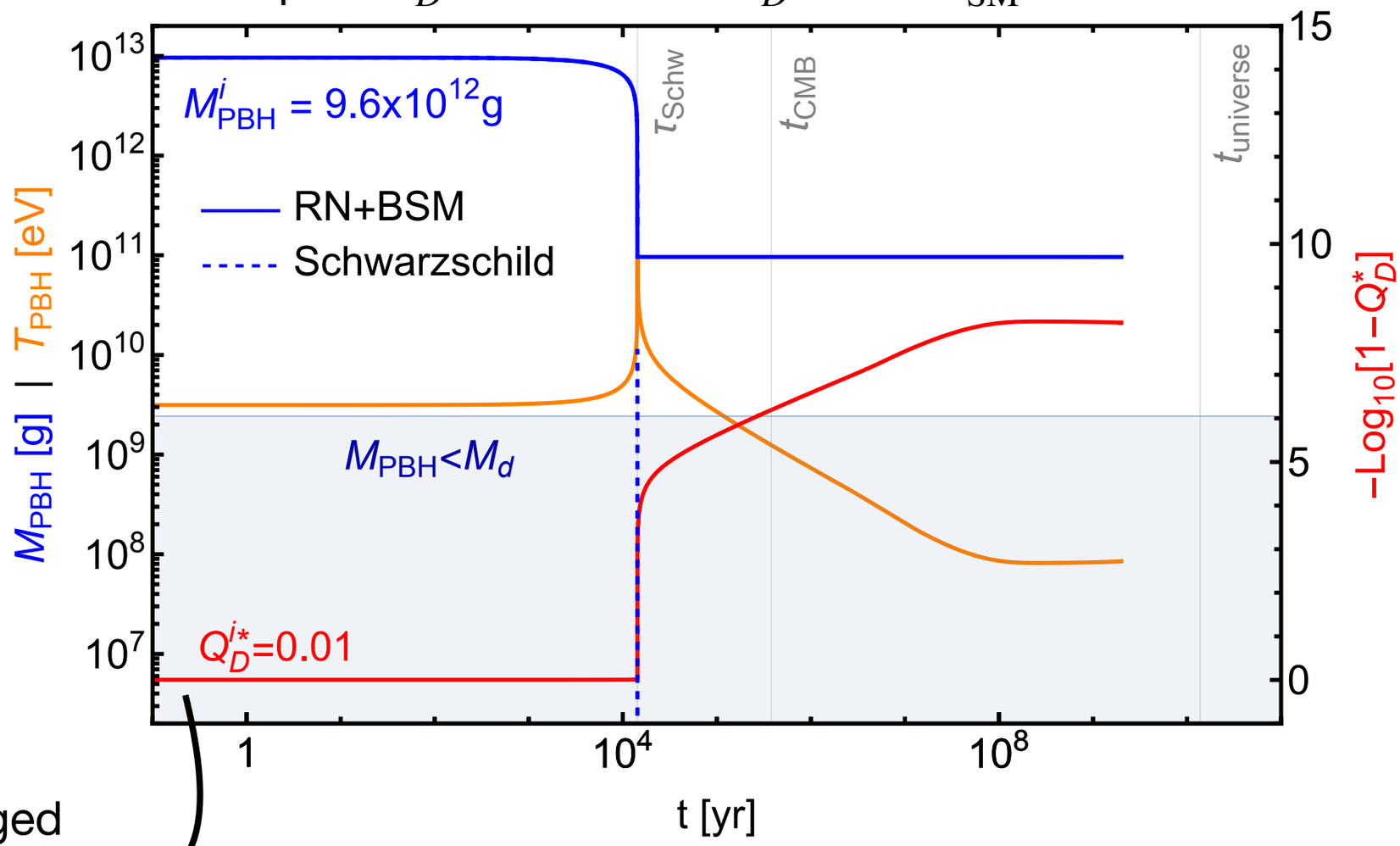
D. Page. PRD **14**, 3260

How to enhance the burst rate? (or how to produce lighter BHs with τ~t$_U$?)

We want to stop the evaporation process to extend the PBH lifetime.

Toy model: $\mathcal{L} \supset -\frac{1}{16\pi} F'^{\mu\nu} F'_{\mu\nu} + \overline{\ell_D}(i\not{D} - m_D)\ell_D$

Example: $m_D = 10^{10}\text{GeV} \quad e_D = 10^{-3} e_{\text{SM}}$



PBHs are initially charged

How to enhance the burst rate? (or how to produce lighter BHs with τ~t$_U$?)

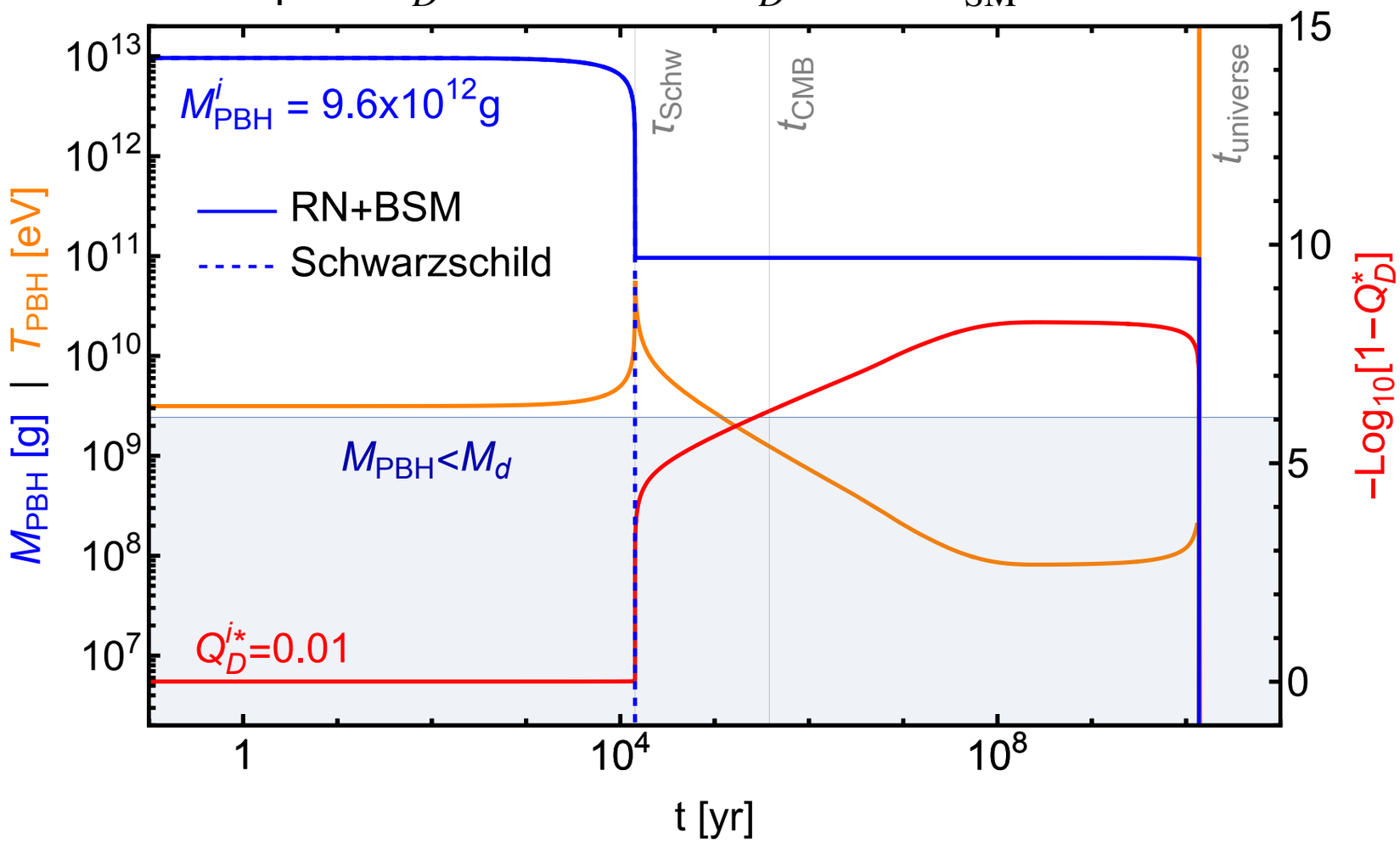
Explosion? $\Longrightarrow$

Schwinger effect!

$$\Gamma = \frac{(qE)^2}{4\pi^3}\exp\left(-\frac{\pi m^2}{qE}\right)$$

The intense PBH electric field leads to pair production and quickly discharges the black hole.

Example: $m_D = 10^{10}\mathrm{GeV} \quad e_D = 10^{-3}e_{\mathrm{SM}}$



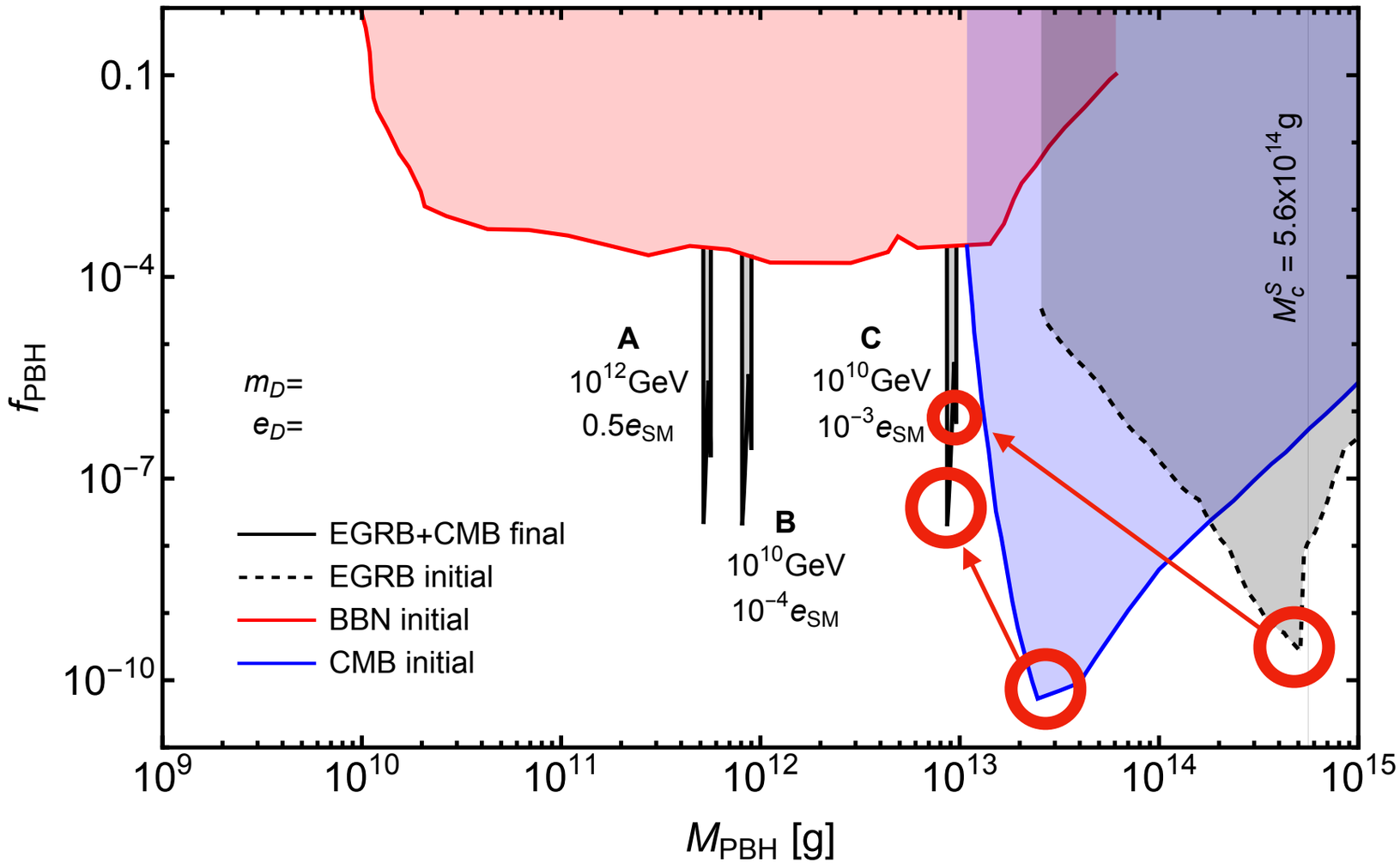
Indirect bounds on f_{PBH}

Toy Model:

$$\mathcal{L} \supset -\frac{1}{16\pi} F'^{\mu\nu} F'_{\mu\nu} + \overline{\ell_D}(i\not{D} - m_D)\ell_D$$

$$\frac{dM_{\rm PBH}}{dt} = -\frac{\alpha(M_{\rm PBH}, Q_D)}{M_{\rm PBH}^2} + \frac{Q_D}{r_+}\frac{dQ_D}{dt}\,,$$

$$\frac{dQ_D}{dt} \simeq -\frac{e_D^4}{2\pi^3 m_D^2}\frac{Q_D^3}{r_+^3}\exp\left(\frac{-\pi r_+^2 m_D^2}{Q_D\, e_D}\right)$$



$$N_{\rm PBH} = f_{\rm PBH}\frac{\rho_{\rm DM}}{M_{\rm PBH}}$$

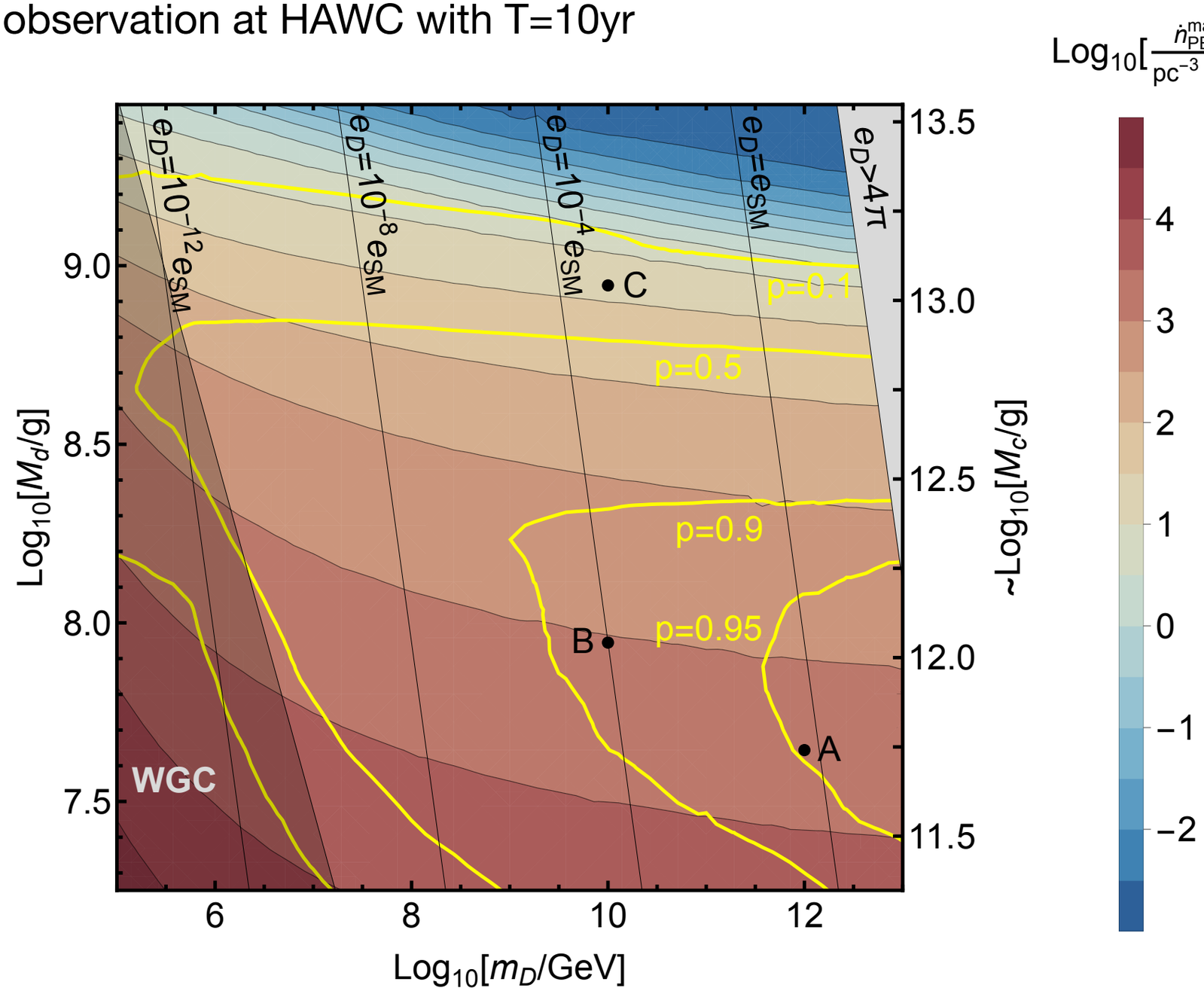
Number density and hence burst rate enhanced!!

Can we observe an exploding PBH in the near future?

Maximum burst rates consistent with indirect bounds for a log-normal mass function.

Probability of an observation at HAWC with T=10yr

$$M_d \equiv \frac{e_D M_{Pl}^3}{\pi m_D^2}$$



Neutrinos at KM3Net and IceCube?

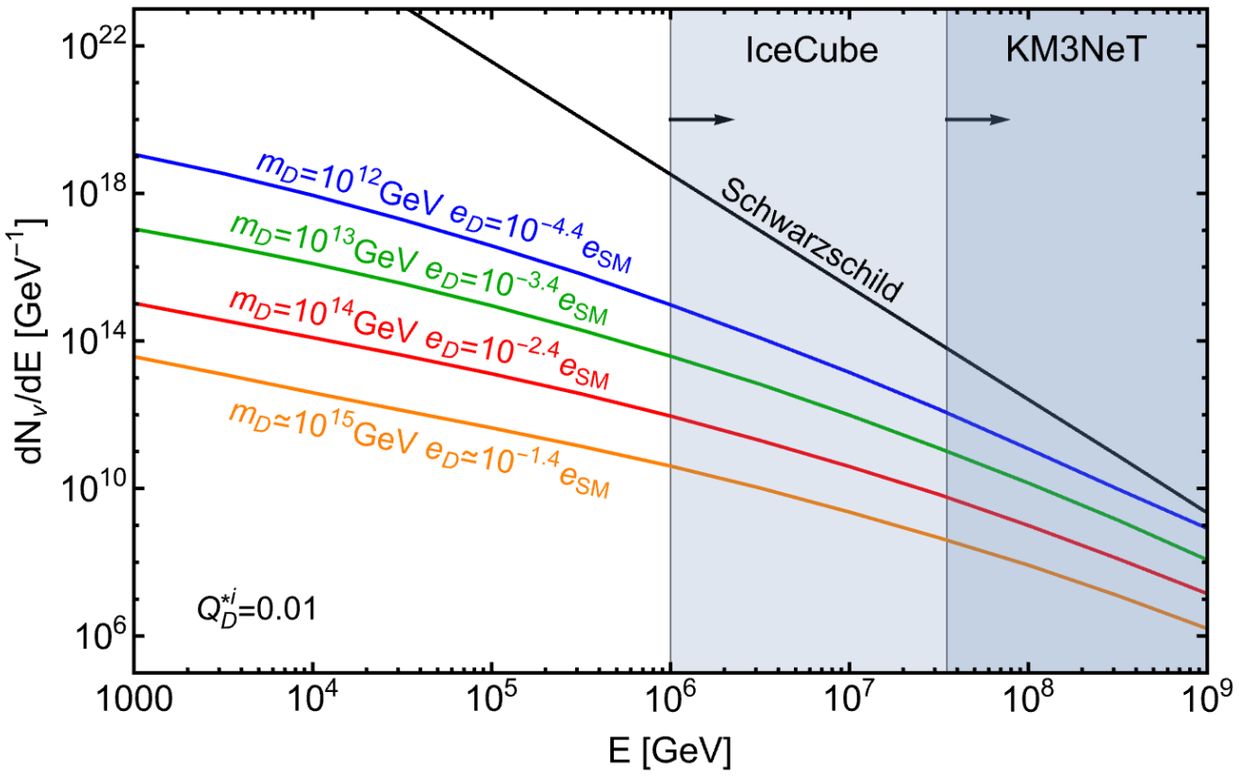
S. W. Li et al., (2025), arXiv:2502.04508 [astro-ph.HE]

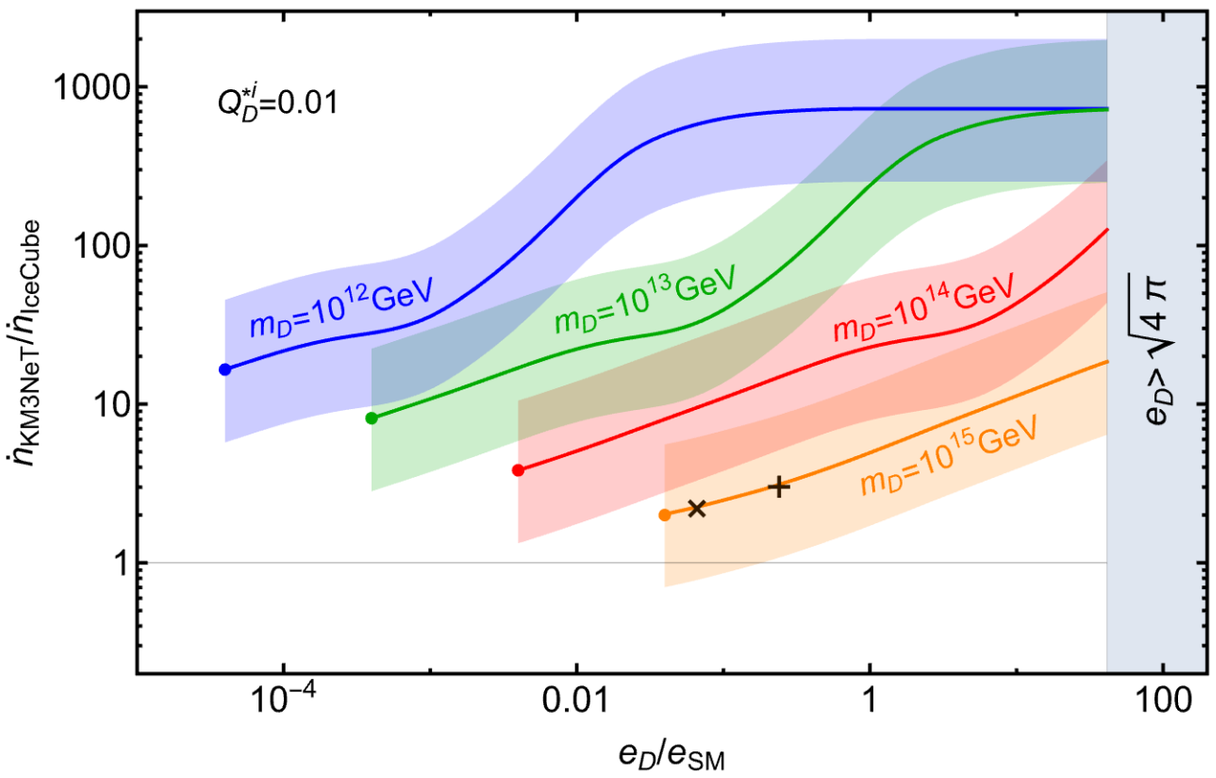
The KM3NeT Collaboration recently reported the detection of an extremely high-energy neutrino at E~220PeV, significantly above IceCube neutrinos at E~1PeV.
The most favored scenario is a transient point source. S. Aiello et al. (KM3NeT), Nature 638, 376 (2025)

PBHs at the origin of neutrino events?

A. P. Klipfel et al., (2025), arXiv:2503.19227 [hep-ph]
A. Boccia et al., (2025), arXiv:2502.19245 [astro-ph.HE]

PRELIMINARY RESULTS:





Conclusions

The observation of an exploding black hole would be an unprecedented event and would offer insights on fundamental physics topics.

We have the technological capacity (HAWC, LHAASO, CTA) to observe such event.

We provided the first explicit scenario that yields enhanced burst rates (by more than 4 orders of magnitude!) and good chances of seeing an exploding BH at HAWC.

Alternative models (extra dimensions, magnetic monopoles etc.) could also lead to interesting scenarios, further analysis is required.

Exploding PBHs might provide an explanation to recent observations of high-energy neutrinos!