SIGNATURE FROM PRIMORDIAL BLACK HOLE EVAPORATION

ROBERTA CALABRESE

Based on

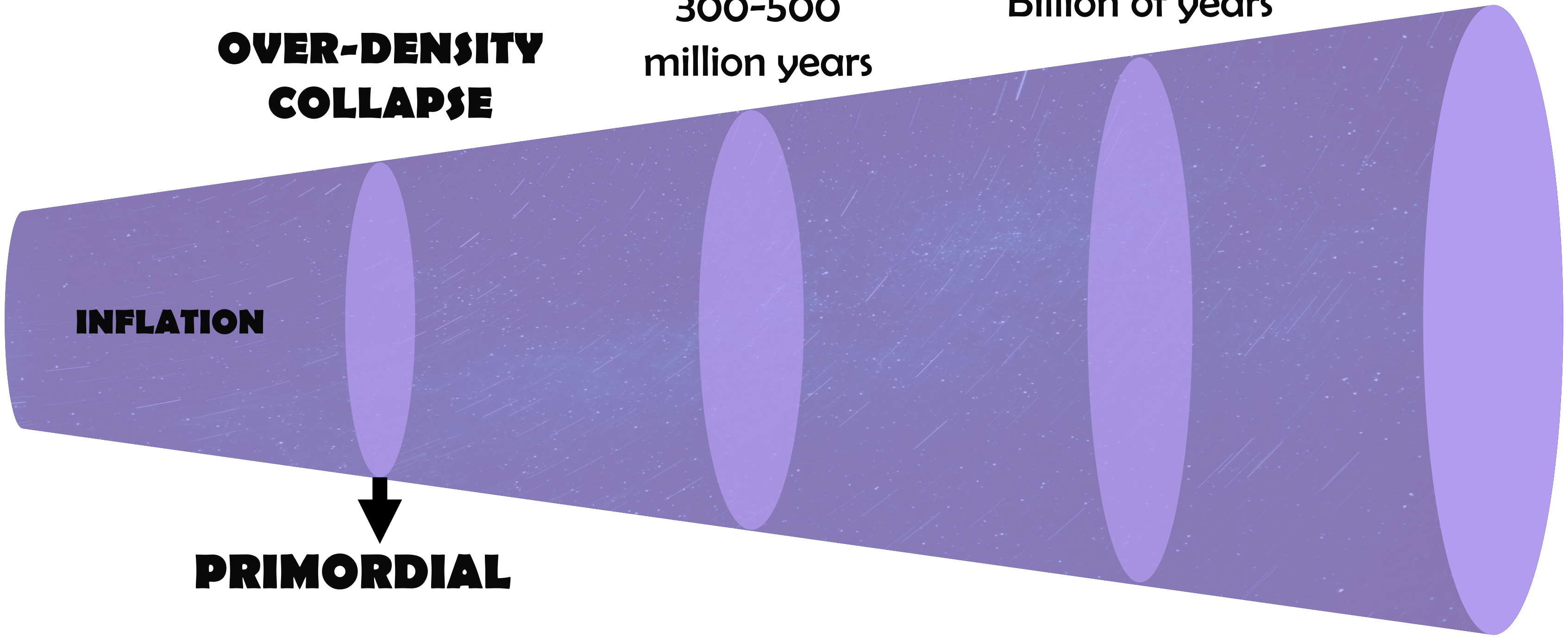
- PRD 105 (2022) 2, L021302
- PLB 829 (2022) 137050

In collaboration with

M. Chianese, D.F.G. Fiorillo, G. Miele, S. Morisi, A. Palazzo, N. Saviano.

INFN
Istituto Nazionale di Fisica Nucleare
NAP THEORY

PRIMORDIAL BLACK HOLE



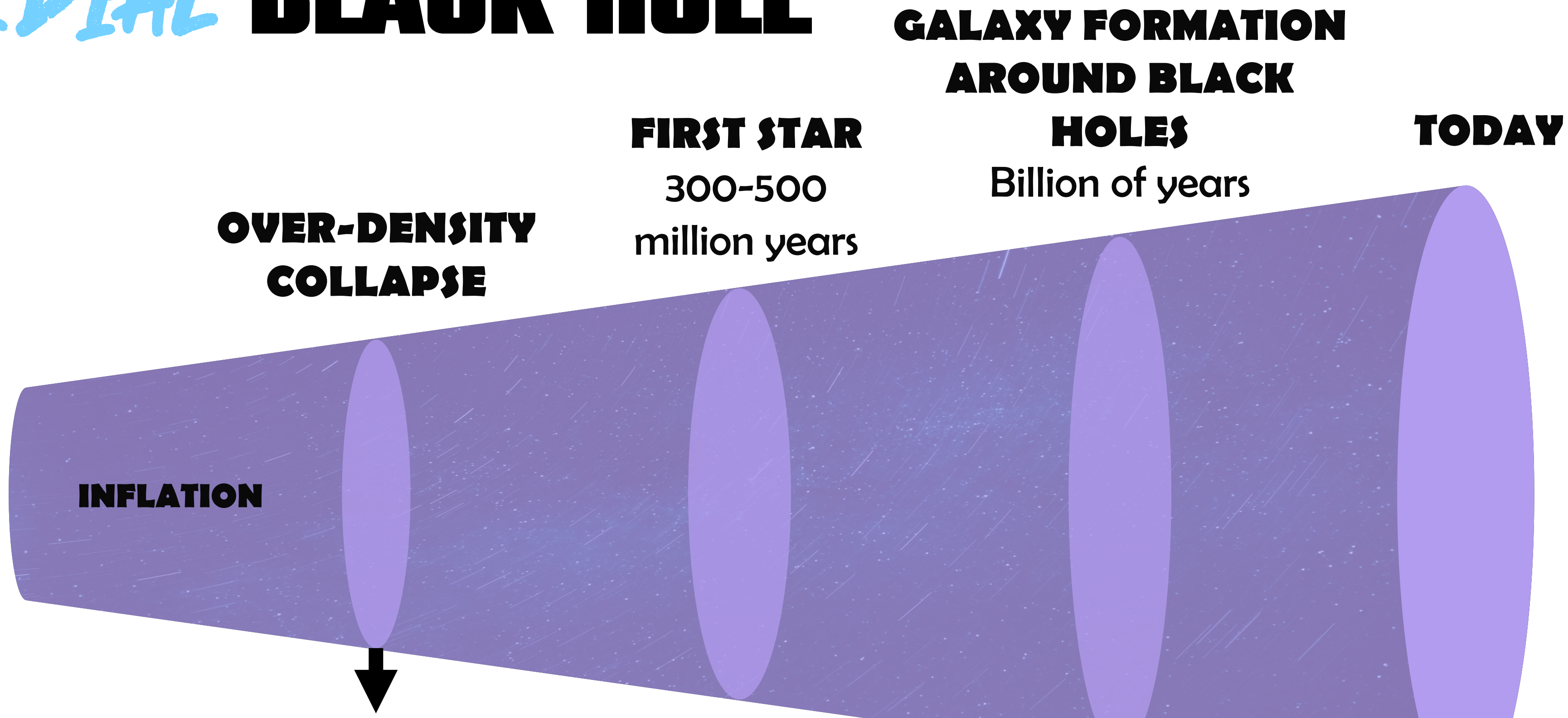
MASS $[0.1 - 10^{50}]\mathrm{g}$

CHARGE

SPIN

S. W. Hawking, *Commun.Math.Phys.* 1975
B. J. Carr, *Astrophys.J.* 1975
J. Auffinger, arXiv: 2206.02672

PRIMORDIAL BLACK HOLE



PRIMORDIAL BLACK HOLES

MASS $[0.1 - 10^{50}]\text{g}$

CHARGE

SPIN

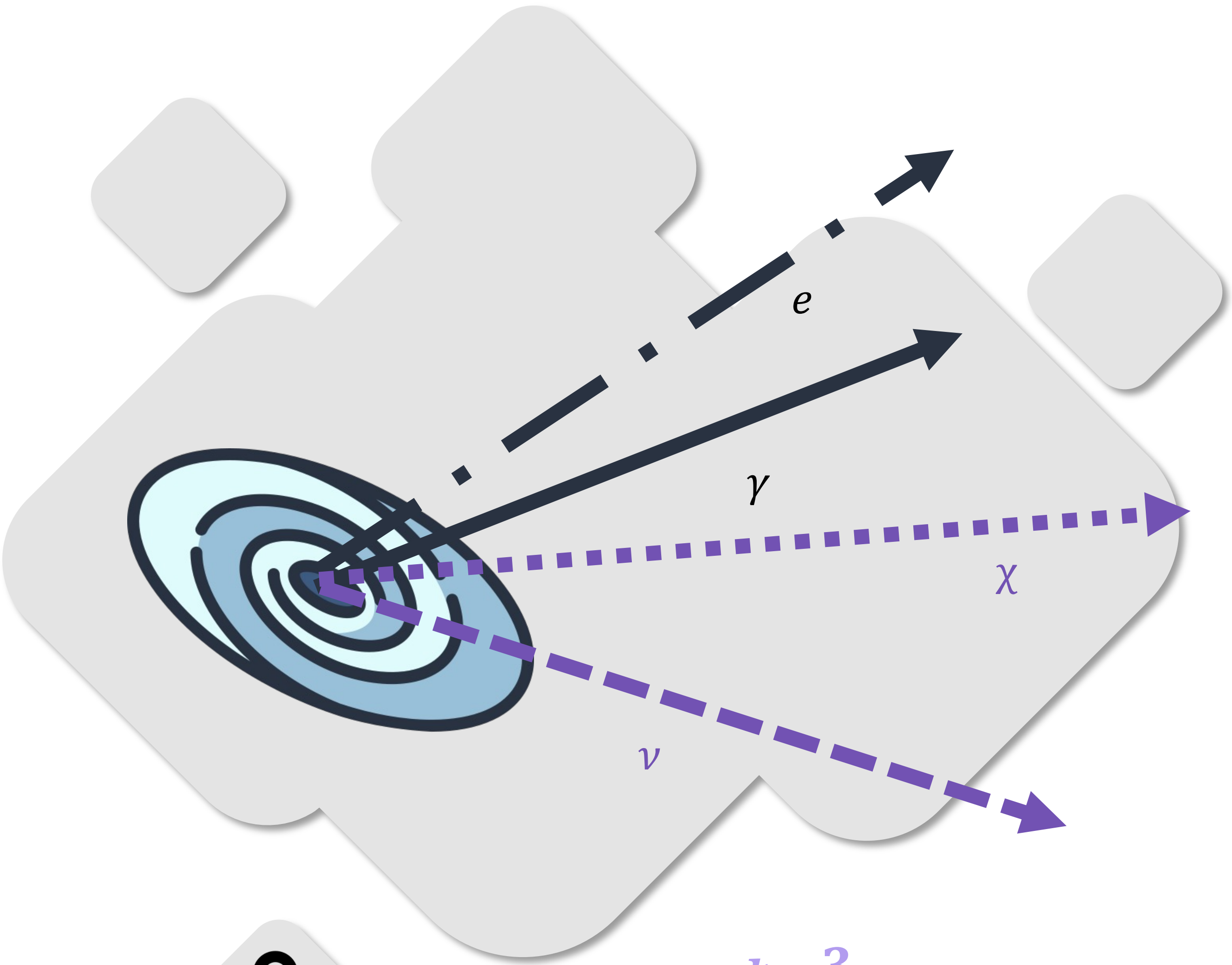
We focus on

MASS $[5 \cdot 10^{14} - 10^{16}]\text{g}$

NEUTRAL

NON-ROTATING

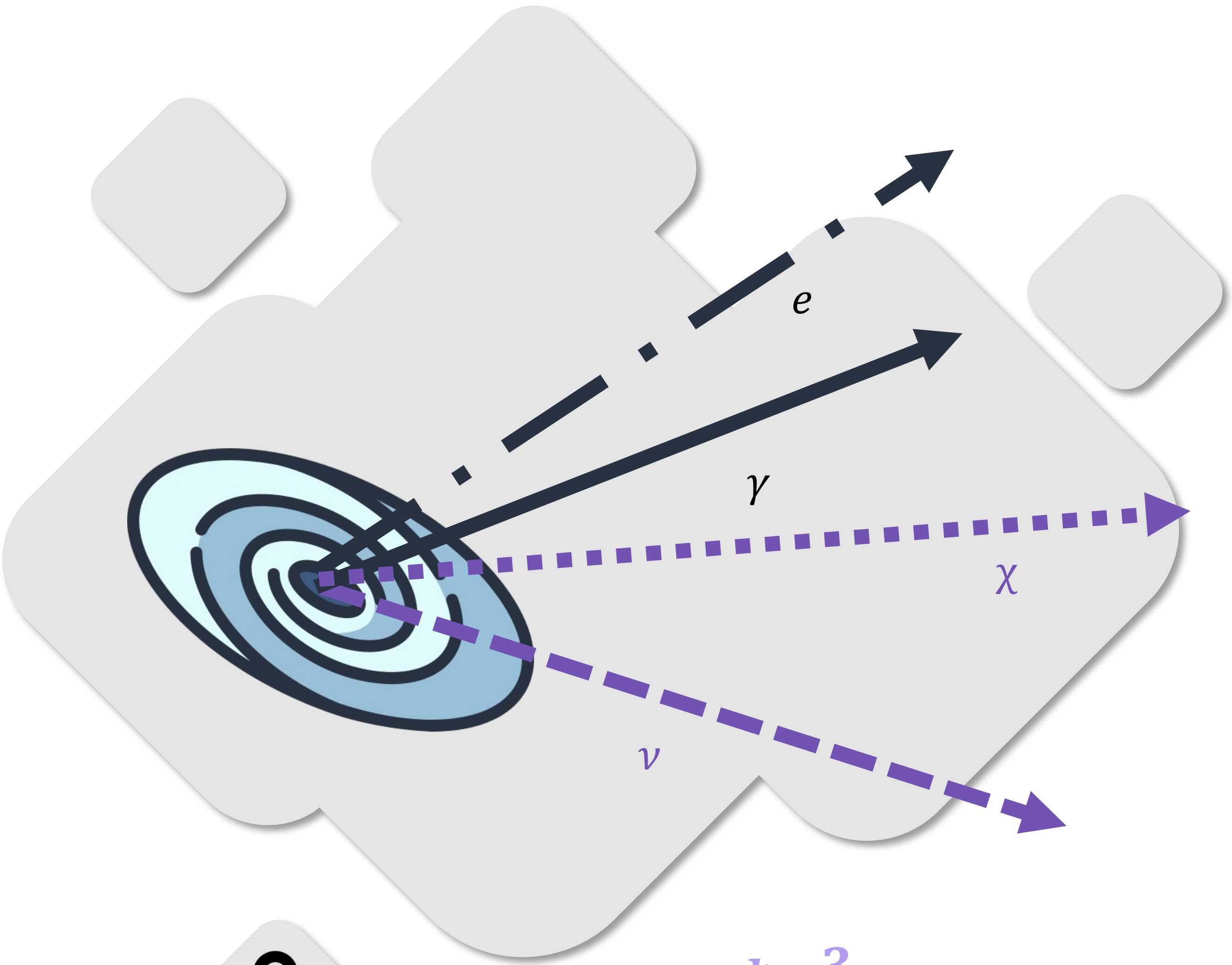
S. W. Hawking, *Commun.Math.Phys.* 1975
B. J. Carr, *Astrophys.J.* 1975
J. Auffinger, arXiv: 2206.02672

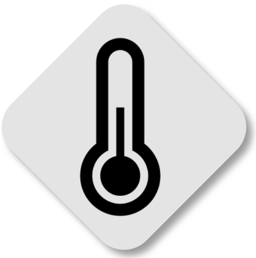


PRIMORDIAL BLACK HOLE
EVAPORATION

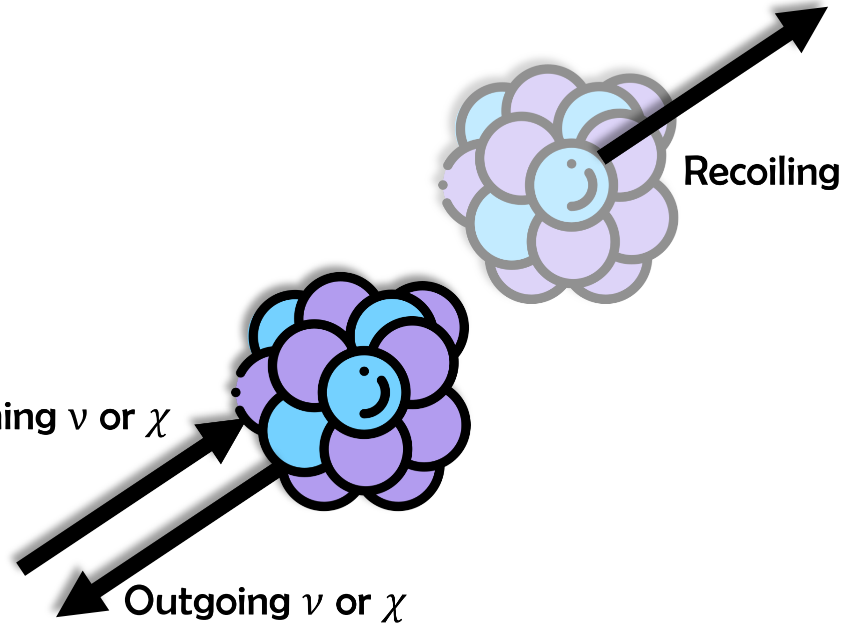
$$T = \frac{\hbar c^3}{8\pi G k_B M_{PBH}}$$ ← **HAWKING TEMPERATURE**

S. W. Hawking, CMP 87 (1983) 577
G.W. Gibbons and S. W. Hawking, PRD 15 (1977)
H. J. Trashen, arXiv gr-qc/0010055





$$T = \frac{\hbar c^3}{8\pi G k_B M_{PBH}}$$

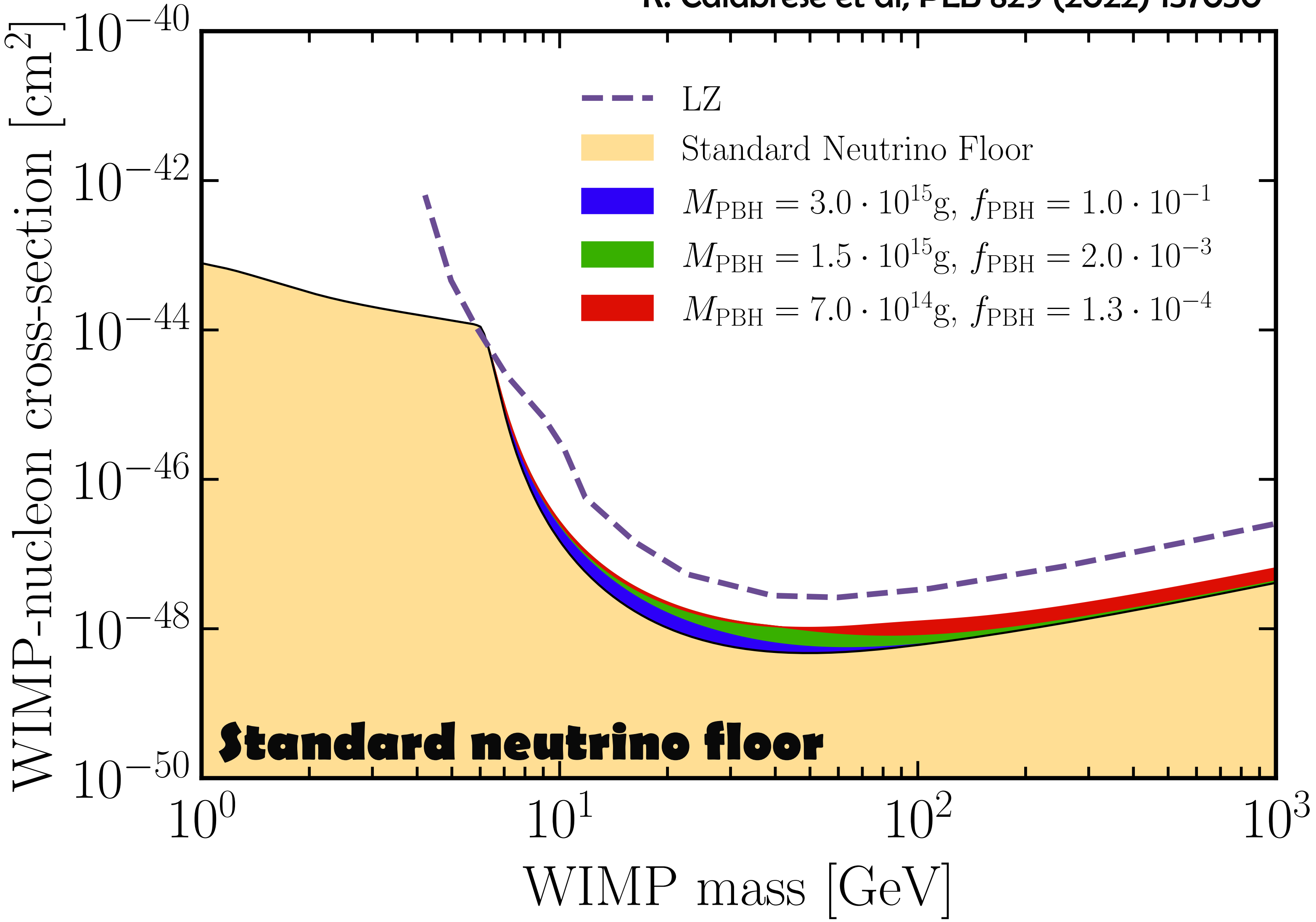


Direct Detection experiments

(e.g., ArDM, DARKSIDE, DARWIN, DEAP, LUX, LZ, PANDAX, XENON)

MODIFICATION OF NEUTRINO FLOOR FROM PRIMORDIAL BLACK HOLE EVAPORATION

R. Calabrese et al, PLB 829 (2022) 137050



TOTAL NEUTRINO FLUX FROM PRIMORDIAL BLACK HOLES

R. Calabrese et al, PLB 829 (2022) 137050

BLACKHAWK (*Eur. Phys. J.C* 81 (2021)) $\rightarrow \frac{dN}{dtdE_\nu}$

Neutrino flux from Primordial Black Hole

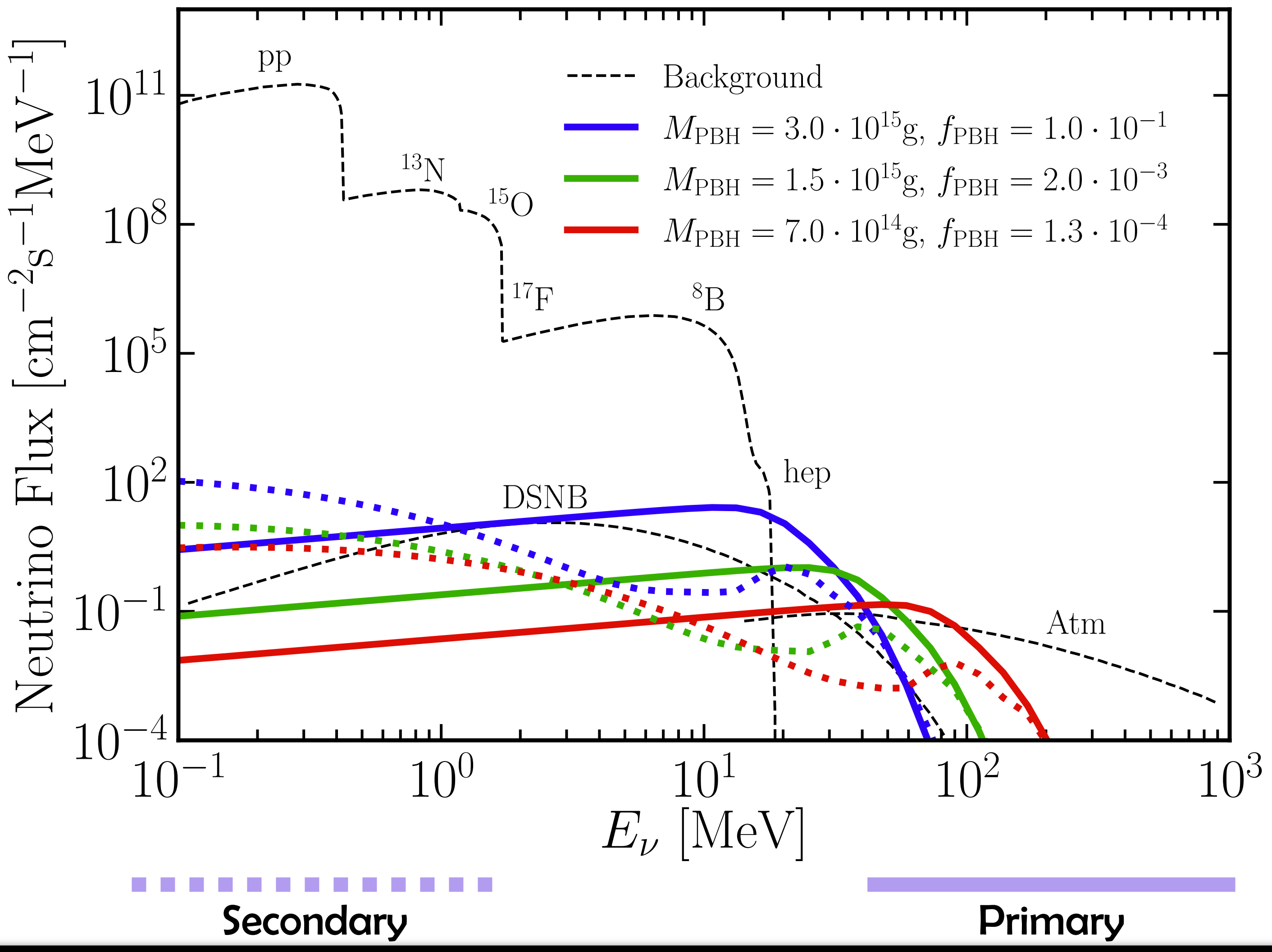
1. $\frac{d\phi_\nu^{EG}}{dE_\nu} = \int dt[1+z(t)] \frac{f_{PBH}\rho_{DM}}{M_{PBH}} \frac{dN}{dt\, d\widetilde{E_\nu}}\Big|_{\widetilde{E_\nu}=E[1+z(t)]}$

2. $\frac{d\phi^{MW}}{dE_\nu} = \int \frac{d\Omega}{4\pi} \frac{dN}{dtdE_\nu} \int dl\, \frac{f_{PBH}\rho_{NFW}[r(l,\psi)]}{M_{PBH}}$

$$\frac{d\phi}{dE_\nu} \propto f_{PBH} = \frac{\Omega_{PBH}}{\Omega_{DM}}$$

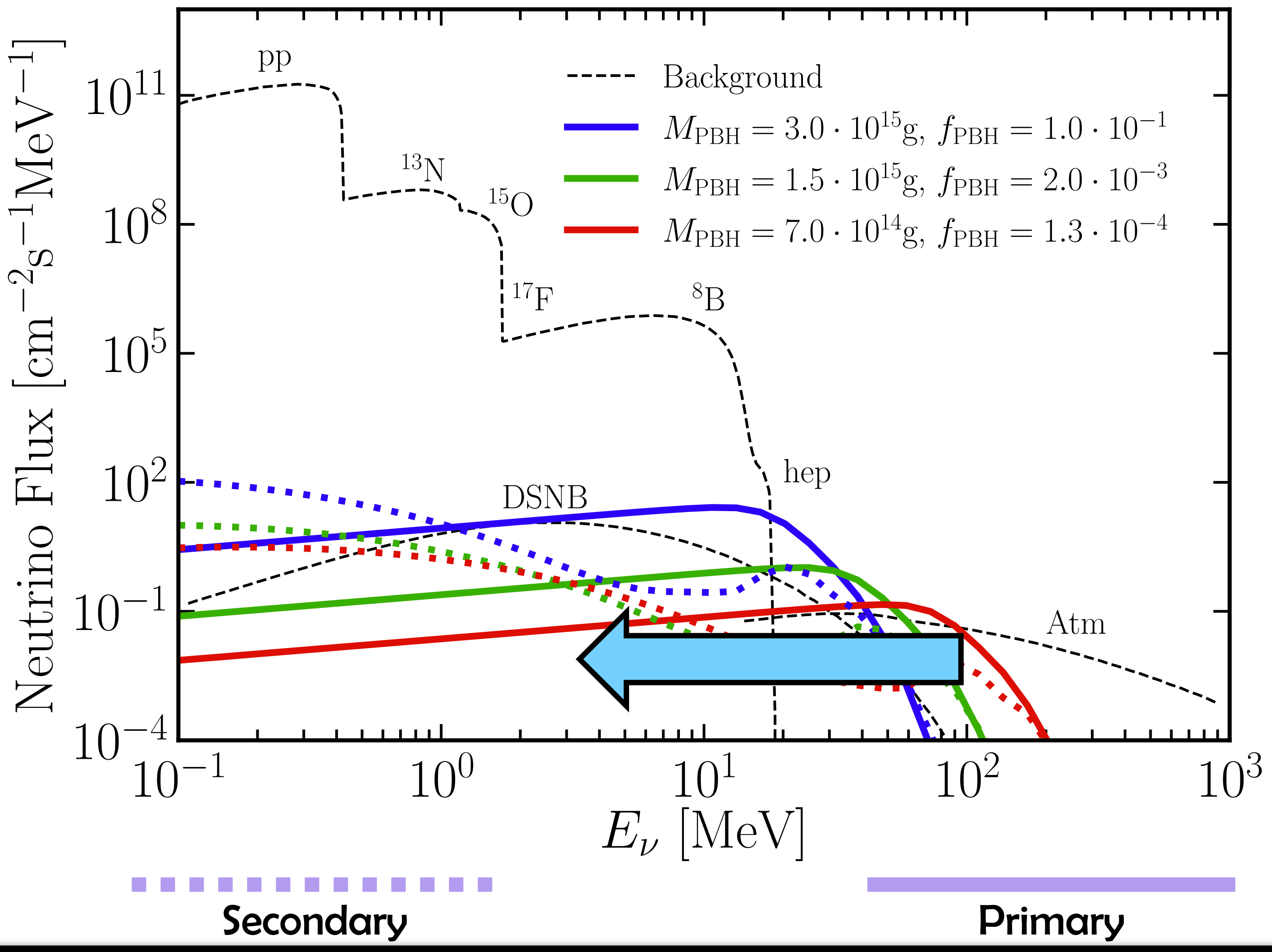
TOTAL NEUTRINO FLUX FROM PRIMORDIAL BLACK HOLES

R. Calabrese et al, PLB 829 (2022) 137050



TOTAL NEUTRINO FLUX FROM PRIMORDIAL BLACK HOLES

R. Calabrese et al, PLB 829 (2022) 137050



CEνNS EVENT RATE IN DARWIN

The event rate from Coherent Neutrino-Nucleus Scattering

$$\frac{dR_{\nu N}}{dE_r dt} = n_T \epsilon(E_r) \int dE_\nu \frac{d\sigma}{dE_r} \frac{d\phi}{dE_\nu} \Theta\left(\frac{2E_\nu^2}{m_T + 2E_\nu} - E_r\right)$$

Maximum recoil energy

Recoil energy: kinetic energy of the scattered atom

CEνNS EVENT RATE IN *DARWIN*

The event rate from Coherent Neutrino-Nucleus Scattering

$$\frac{dR_{\nu \mathrm{N}}}{dE_r dt} = n_T \epsilon(E_r) \int dE_\nu \frac{d\sigma}{dE_r} \frac{d\phi}{dE_\nu} \Theta\left(\frac{2E_\nu^2}{m_T + 2E_\nu} - E_r\right)$$

$\epsilon(E_r)$: Efficency

n_T: Number of target per tonne

$$\frac{d < \sigma v_\chi >}{dE_r}$$

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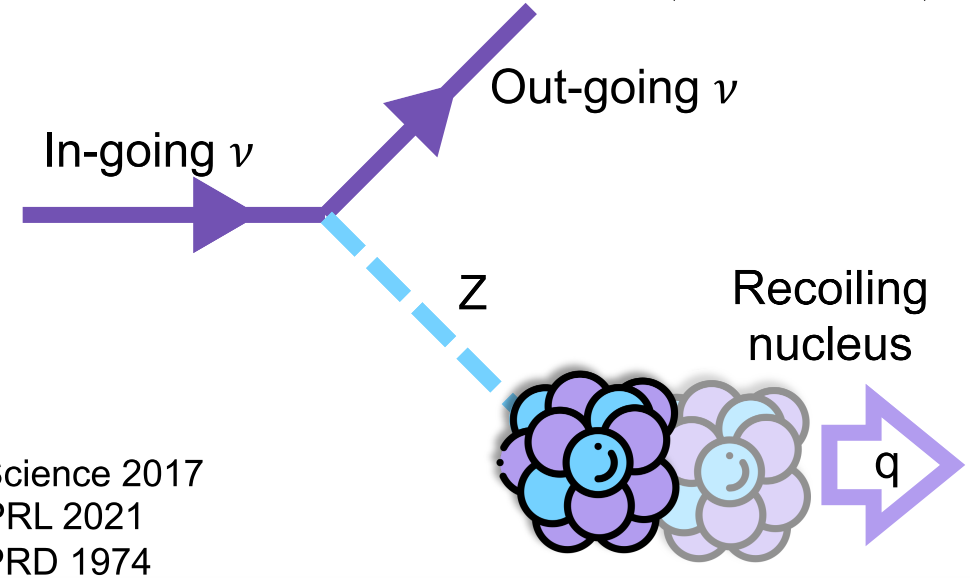
CEνNS EVENT RATE IN DARWIN

COHERENT NEUTRINO-NUCLEUS SCATTERING occurs between an active neutrino flavor and a nucleus

$$\frac{d\sigma}{dE_r} = \frac{G_F^2 m_T}{4\pi}\left[N - Z(1 - 4\sin^2\theta_w)\right]^2 \left(1 - \frac{m_T E_r}{2E_\nu^2}\right) F^2\left(\sqrt{2 m_T E_r}\right)$$



D. Akimov et al, Science 2017
D. Akimov et Al, PRL 2021
D.Z. Freedman, PRD 1974

CEνNS EVENT RATE IN *DARWIN*

COHERENT NEUTRINO-NUCLEUS SCATTERING occurs between an active neutrino flavor and a nucleus

Target mass

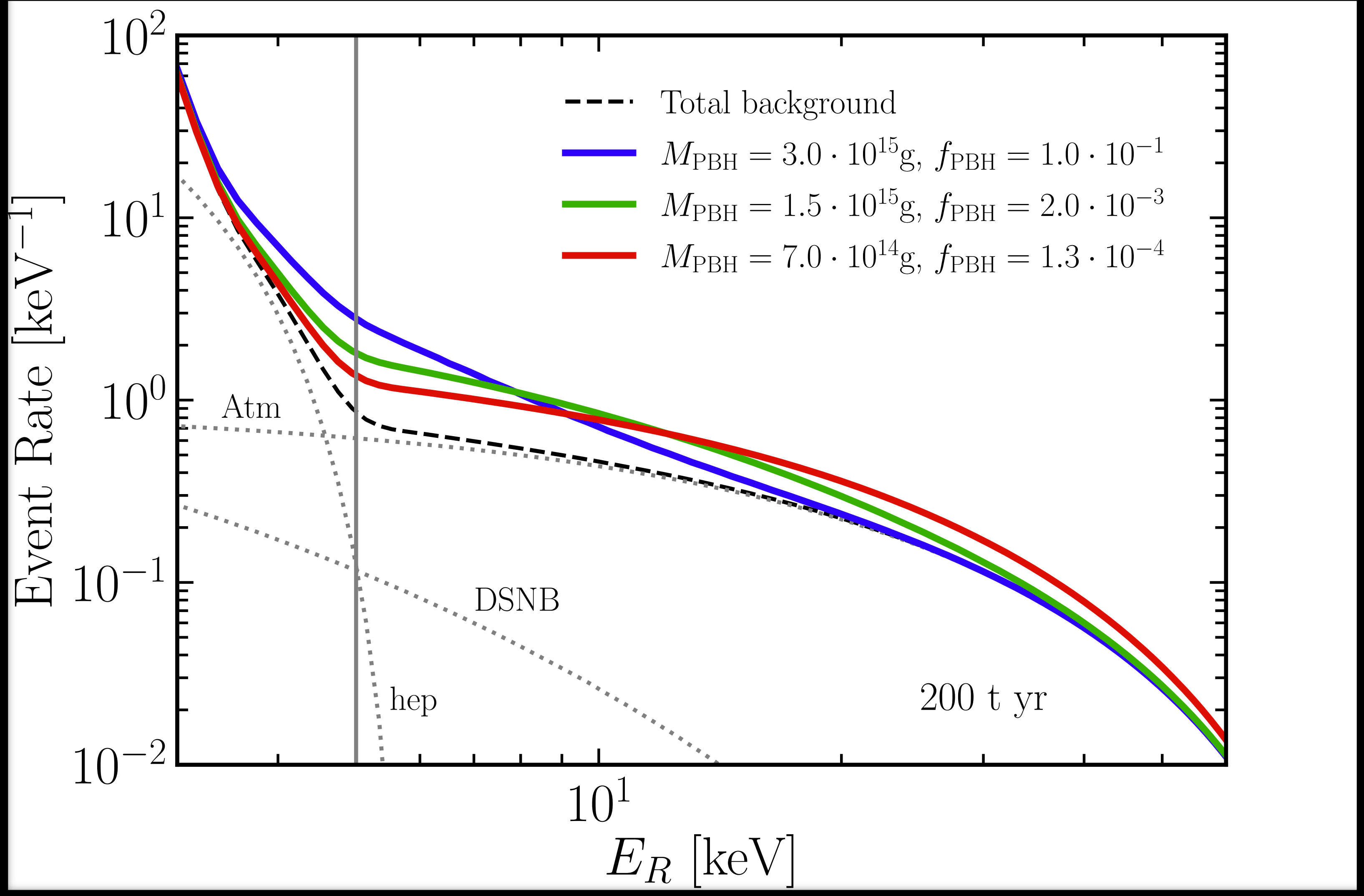
$$\frac{d\sigma}{dE_r} = \frac{G_F^2 m_T}{4\pi}[N - Z(1 - 4\sin^2\theta_w)]^2\left(1 - \frac{m_T E_r}{2E_\nu^2}\right)F^2\left(\sqrt{2m_T E_r}\right)$$

$$F(Q) = \frac{3j_1(QR_0)}{QR_0}\exp\left(-\frac{1}{2}s^2Q^2\right)$$

D. Akimov et al, Science 2017
D. Akimov et Al, PRL 2021
D.Z. Freedman, PRD 1974

CEνNS EVENT RATE IN DARWIN

R. Calabrese et al, PLB 829 (2022) 137050



CONSTRAINTS ON
PRIMORDIAL BLACK HOLE ABUNDANCE
FORM COHERENT NEUTRINO NUCLEUS ELASTIC SCATTERING

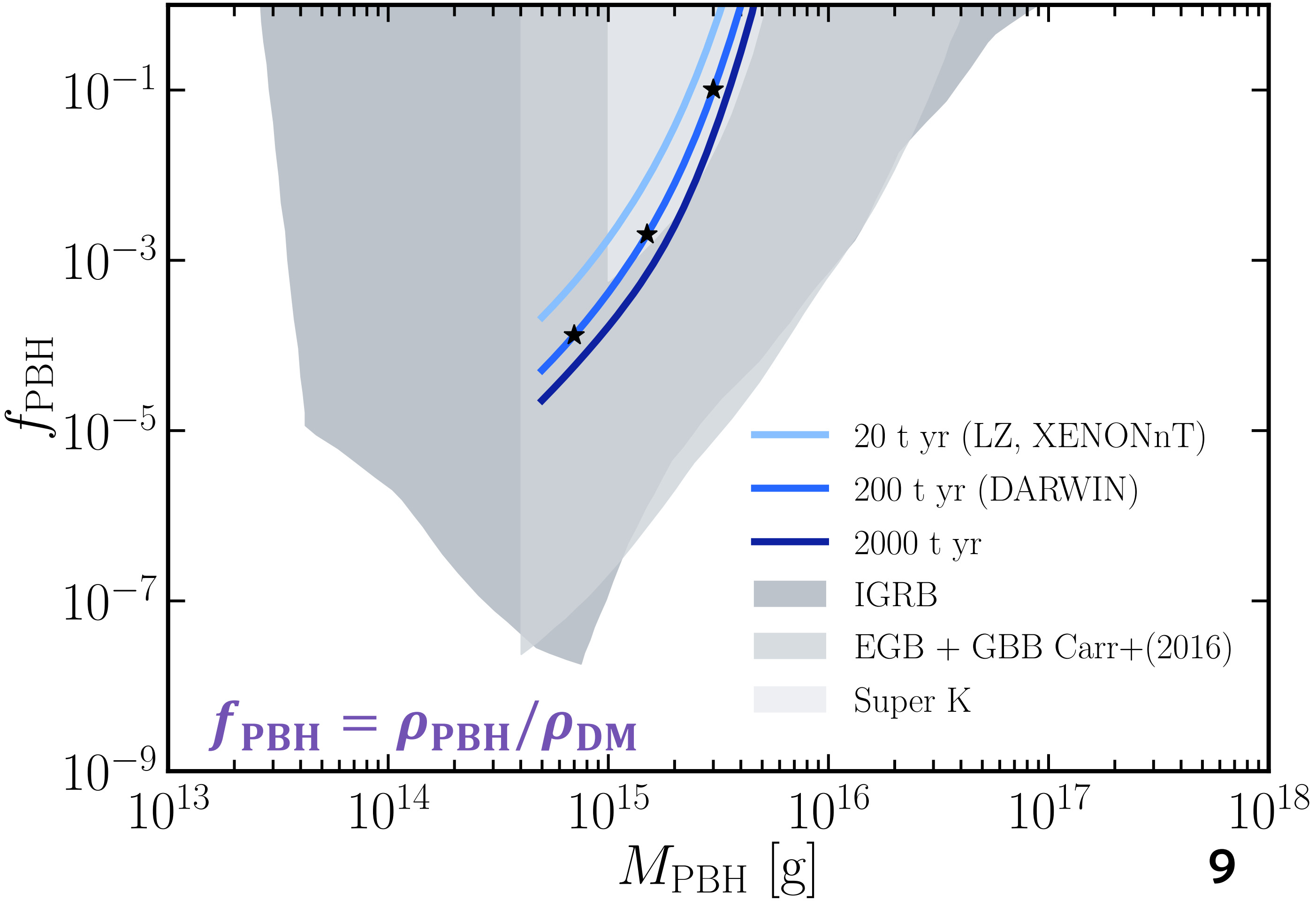
R. Calabrese et al, PLB 829 (2022) 137050

$$\chi^2 = \min_{\boldsymbol{\alpha}}[\chi^2(\boldsymbol{\theta},\boldsymbol{\alpha}) + (1-\boldsymbol{\alpha})^T \Sigma_{\alpha}^{-1}(1-\boldsymbol{\alpha})]$$

$$\chi^2(\boldsymbol{\theta},\boldsymbol{\alpha}) = -2\ln \frac{\prod P\left(\overline{N}^i_{bck},\ \ N^i_{PBH}(\theta) + N^i_{bck}(\alpha)\right)}{\prod P\left(\overline{N}^i_{bck}, \overline{N}^i_{bck}\right)}$$

α = Nuisance parameters

Σ_α= Covariance matrix (encodes the uncertainties on the Background)



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CONCLUSIONS

- Constraints on Primordial Black Holes abundance from Coherent Neutrino-Nucleus Elastic Scattering
- Dark Matter Direct Detection experiments used as Dark Matter Indirect Detection observatories

CONCLUSIONS

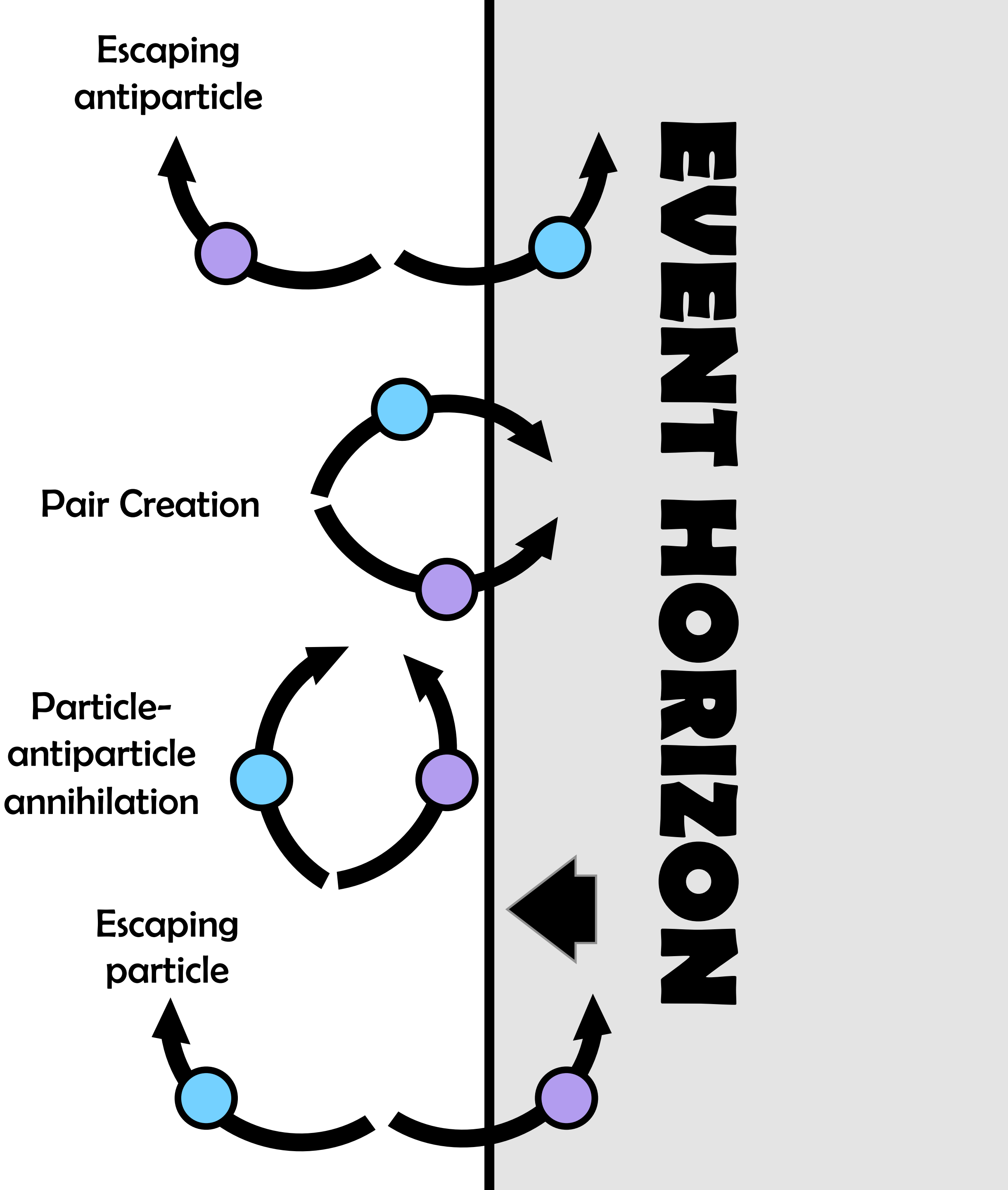
- ★ Constraints on Primordial Black Holes abundance from Coherent Neutrino-Nucleus Elastic Scattering
- ★ Dark Matter Direct Detection experiments used as Dark Matter Indirect Detection observatories

HAWKING RADIATION

Vacuum fluctuation: empty space is a medium in which particle and antiparticle pairs appear and disappear

$$E_p + E_{\overline{p}} = 0$$

What happens if such fluctuations are near the event horizon?



LIGHT DARK MATTER

EMISSION

Assuming the existence of a light dark matter candidate, χ.

Propagation effect have been taken into account: the energy loss was obtained in the **BALLISTIC-TRAJECTORY APPROXIMATION**.

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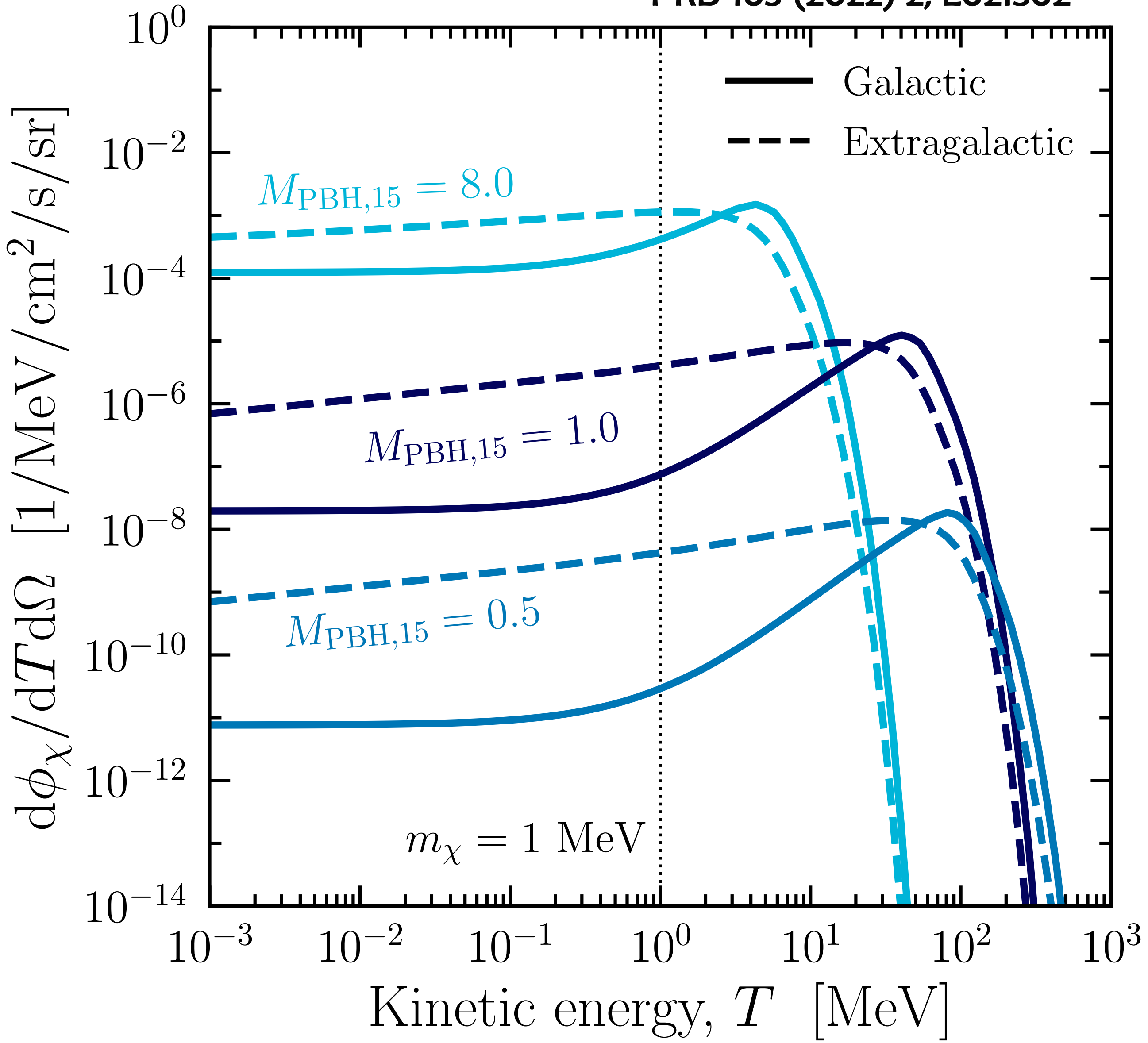
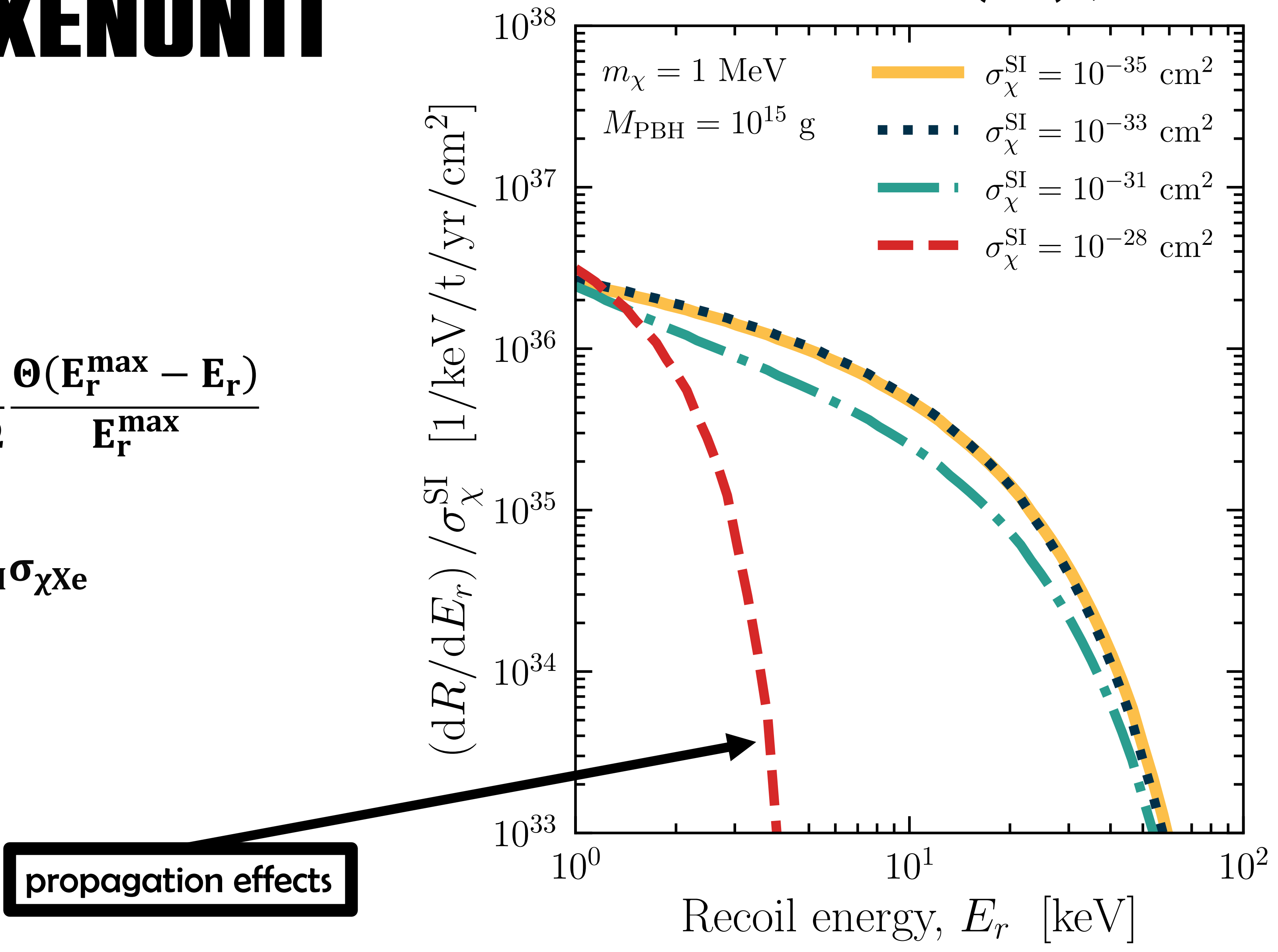


EVENT RATE IN XENON1T

$$\frac{dR}{dE_r} = \sigma_{\chi Xe} N_{Xe} \int dT_d \, d\Omega \frac{d\phi_\chi^d}{dT_d d\Omega} \frac{\Theta(E_r^{max} - E_r)}{E_r^{max}}$$

$$lim_{\sigma_{\chi Xe} \to 0} \frac{dR}{dE_r} \propto f_{PBH} \sigma_{\chi Xe}$$

PRD 105 (2022) 2, L021302



CONSTRAINTS ON LIGHT DARK MATTER

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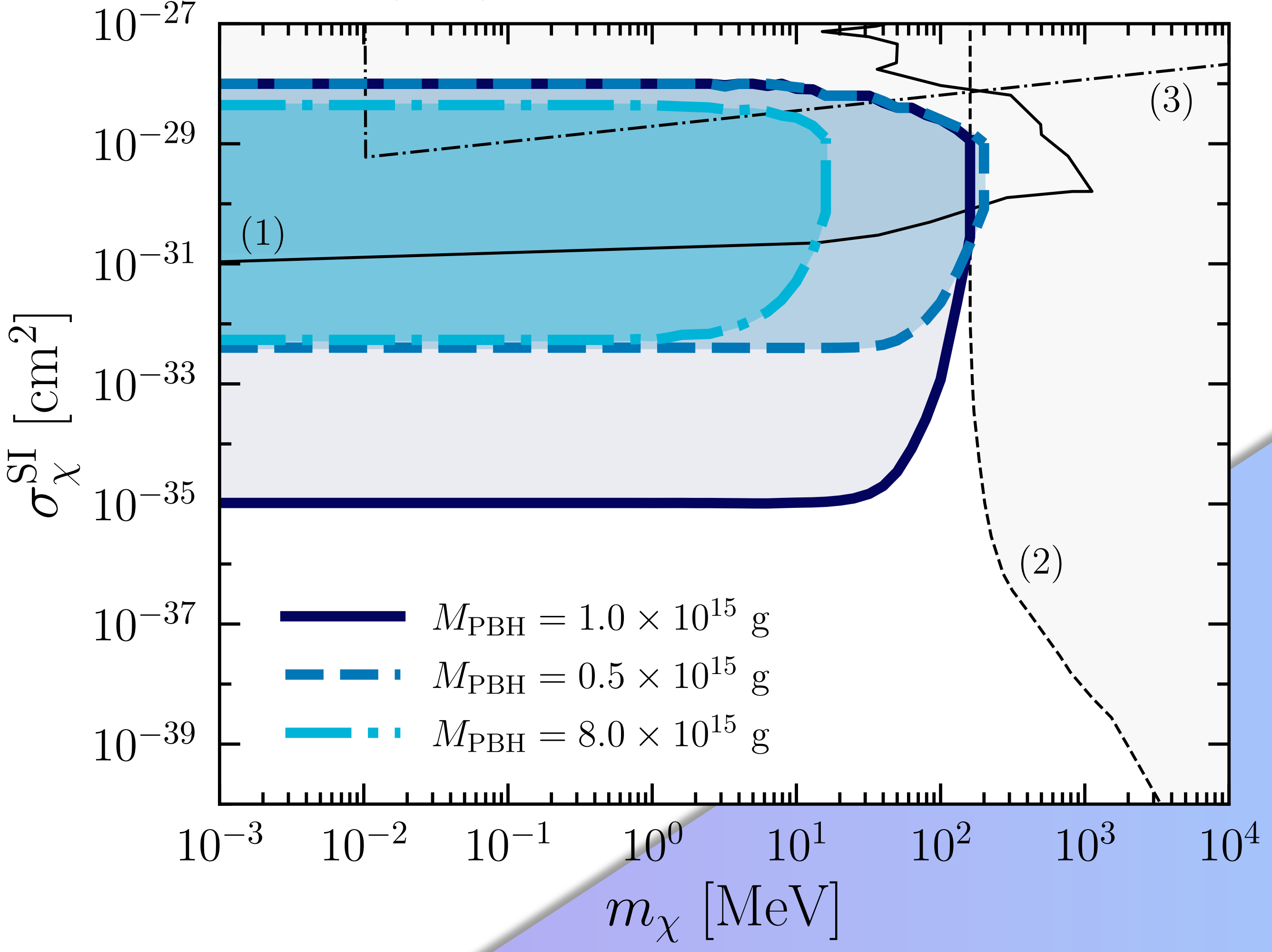

We obtained constraints on the σ_χ^{SI} from the non observation of excess in XENON1T for $E_r \in [4.9 - 40.9]$keV

(1) CRs up-scatterings

(2) CRESST experiment

(3) Cosmology

CONSTRAINTS ON PRIMORDIAL BLACK HOLES

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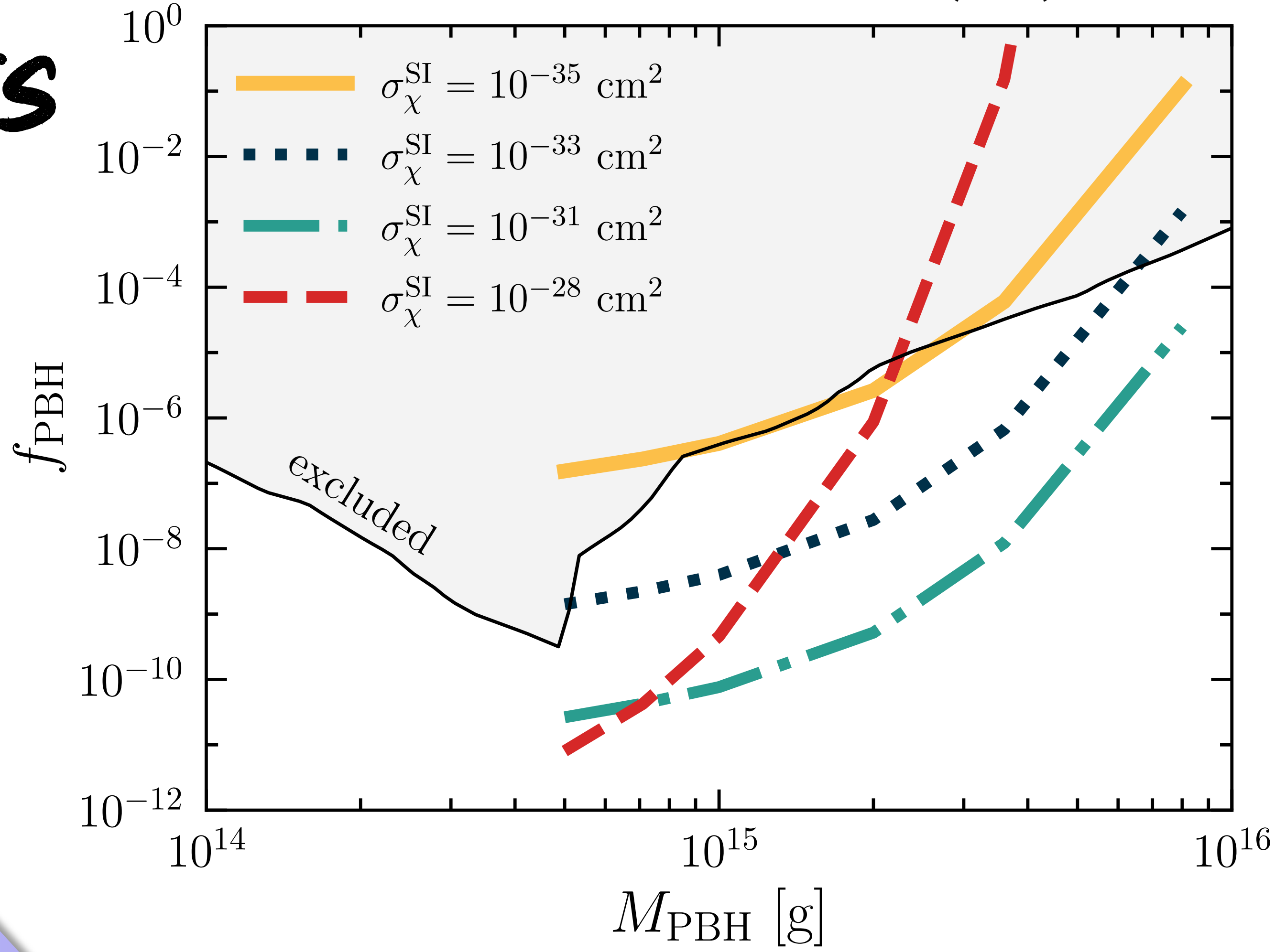

Assuming the existence of χ, it is possible to constraint the PBH abundance.

1. Valid for any light fermionic DM
2. Almost independent of m_χ
3. Propagation relevant for $\sigma_\chi^{SI} \gtrsim 10^{-31} cm^2$