SIGNATURES FROM PRIMORDIAL BLACK HOLE EVAPORATION

ROBERTA CALABRESE

Based on:

- Phys.Lett.B 829 (2022) 137050
- Phys.Rev.D 105 (2022) 2, L021302
- Phys.Rev.D 105 (2022) 10, 103024

In collaboration with:

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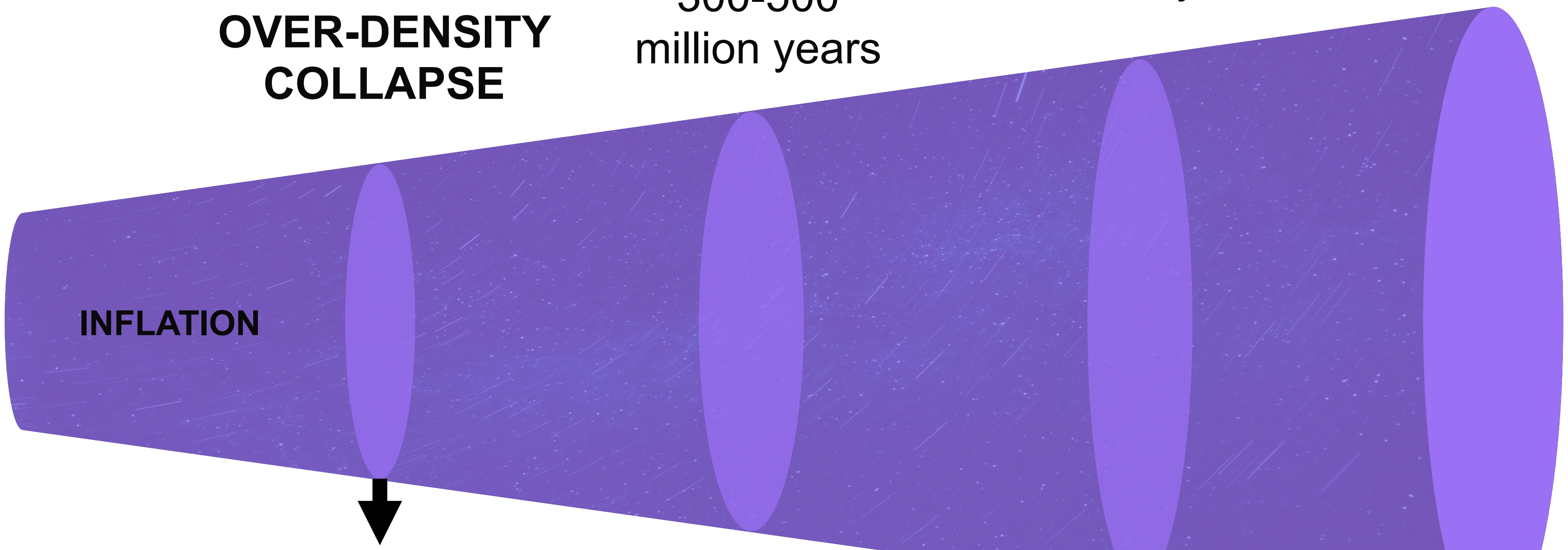
PRIMORDIAL BLACK HOLE

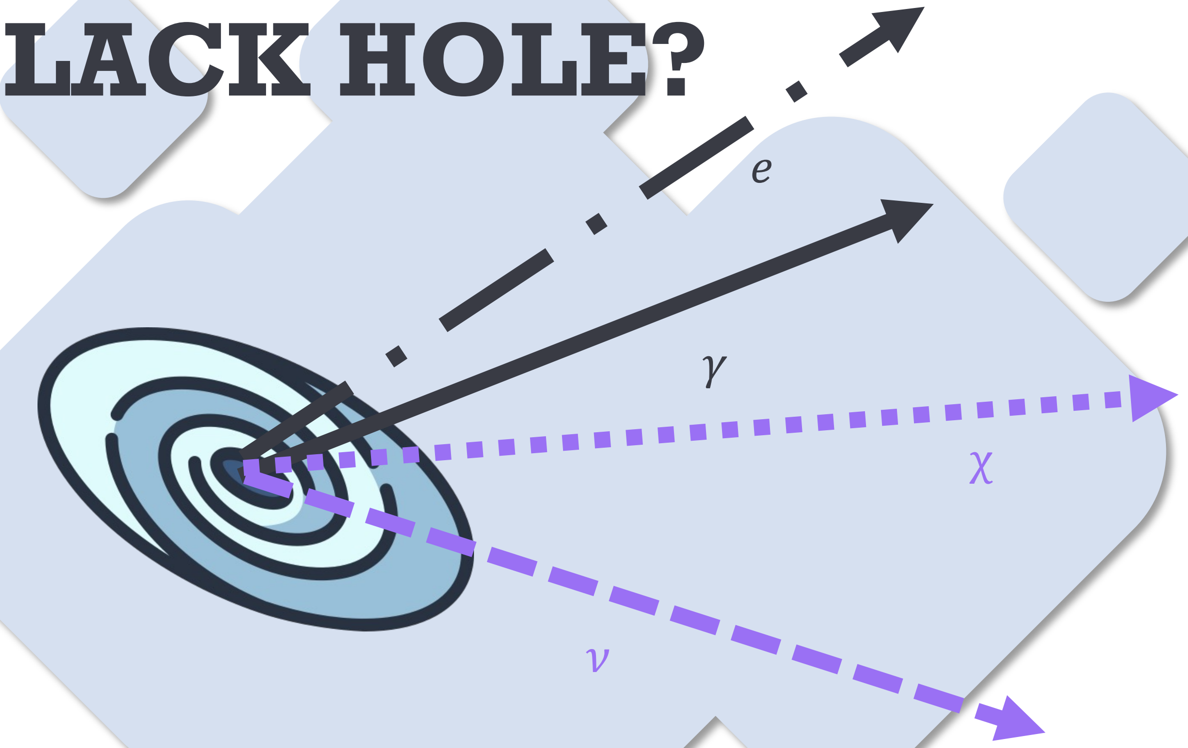


PRIMORDIAL BLACK HOLES

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

WHY PRIMORDIAL BLACK HOLE?



- Hawking Radiation

  S. W. Hawking, CMP 87 (1983) 577

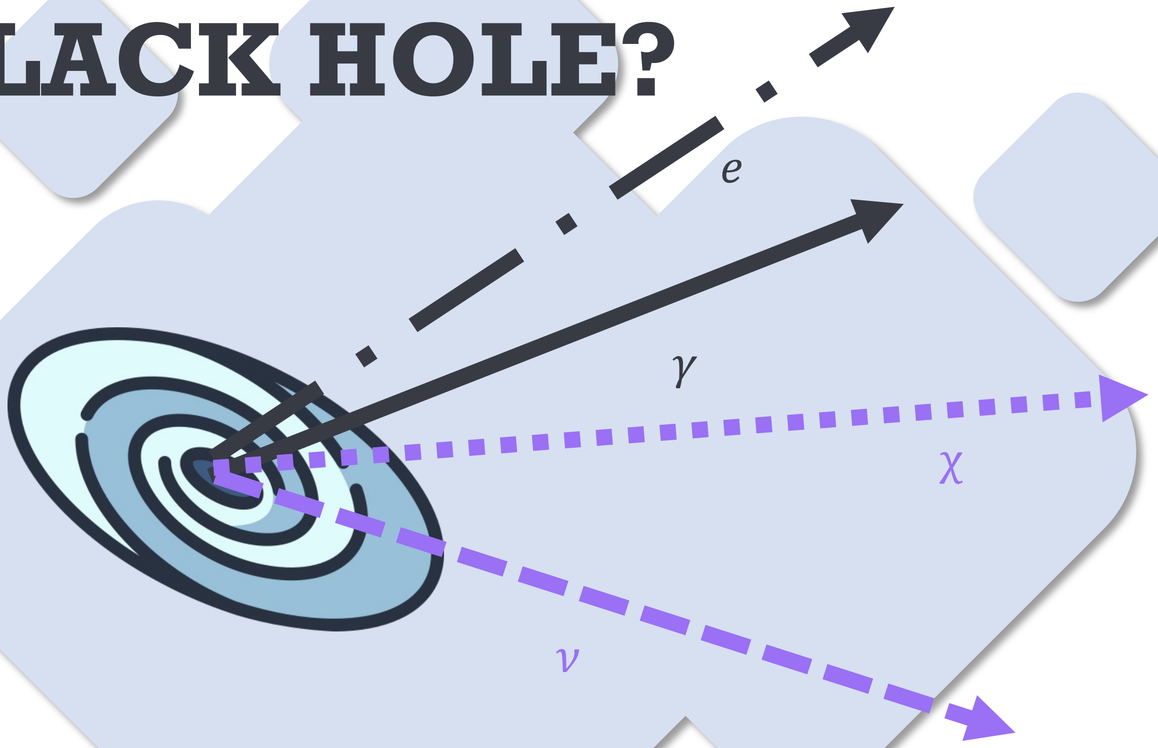
- Dark Matter
  - Primordial Black holes as dark matter candidates

    B. J. Carr and S. W. Hawking, Mon. Not. Roy. Astron. Soc. 168 (1974), B. J. Carr, Astrophys. J. 201 (1975)

  - Primordial Black Holes as Dark Matter source

    L. Morrison et al, JCAP 2019, I. Baldes et al, JCAP 2020, N. Bernal and O. Zapata, JCAP 2021

WHY PRIMORDIAL BLACK HOLE?



- Baryogenesis and Leptogenesis

  S. W. Hawking, Nature 1974; Y. B. Zeldovich, Pisma Zh. Eksp. Teor. Fiz. 1976

- Seeds for Supermassive Black Holes

  B. J. Carr and M. J. Rees, ”Mon. Not. Roy. Astron. Soc. 206 (Feb. 1984)

- Information on the early universe
- And for many other reasons!

MAIN IDEA

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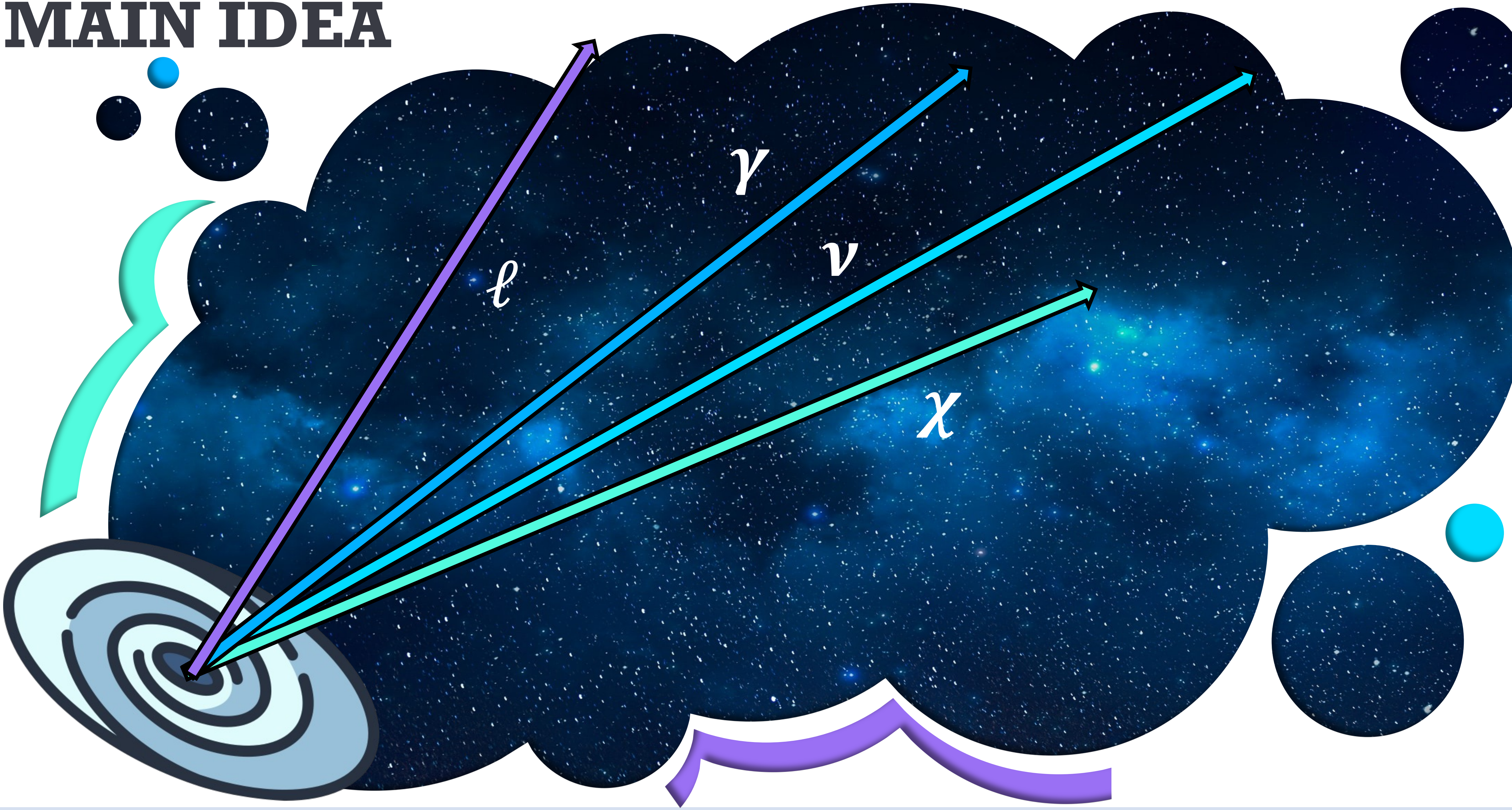

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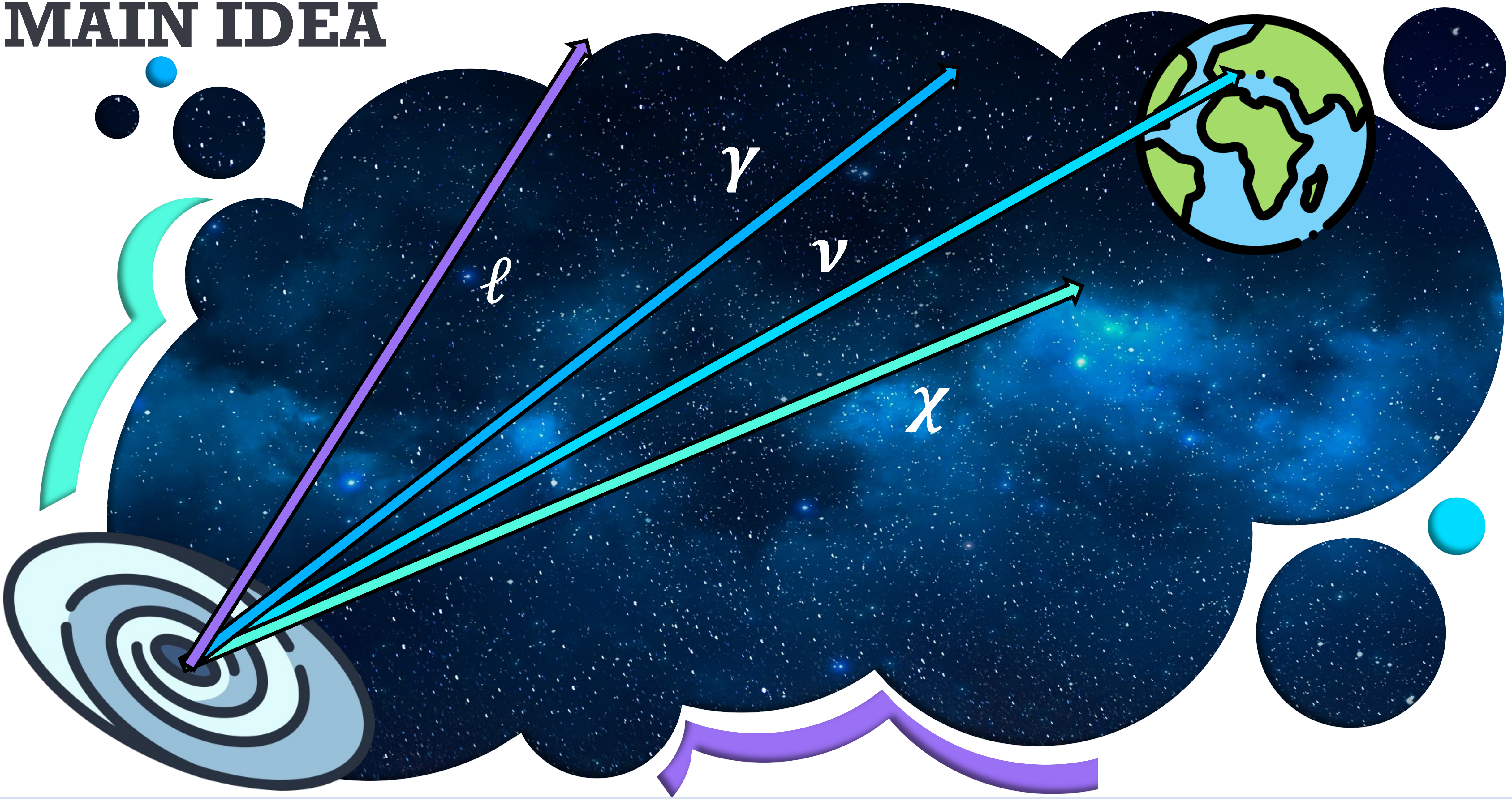
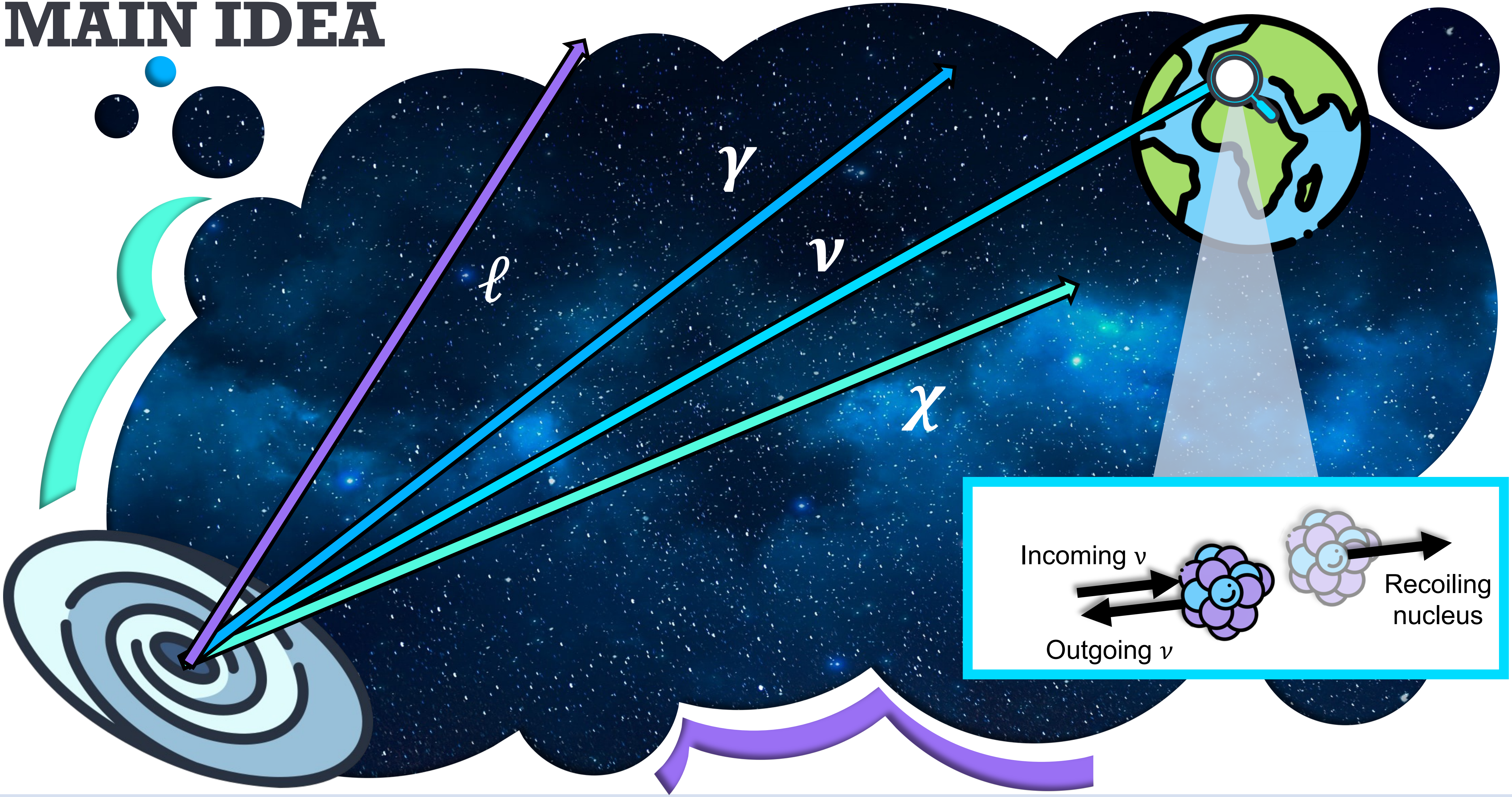
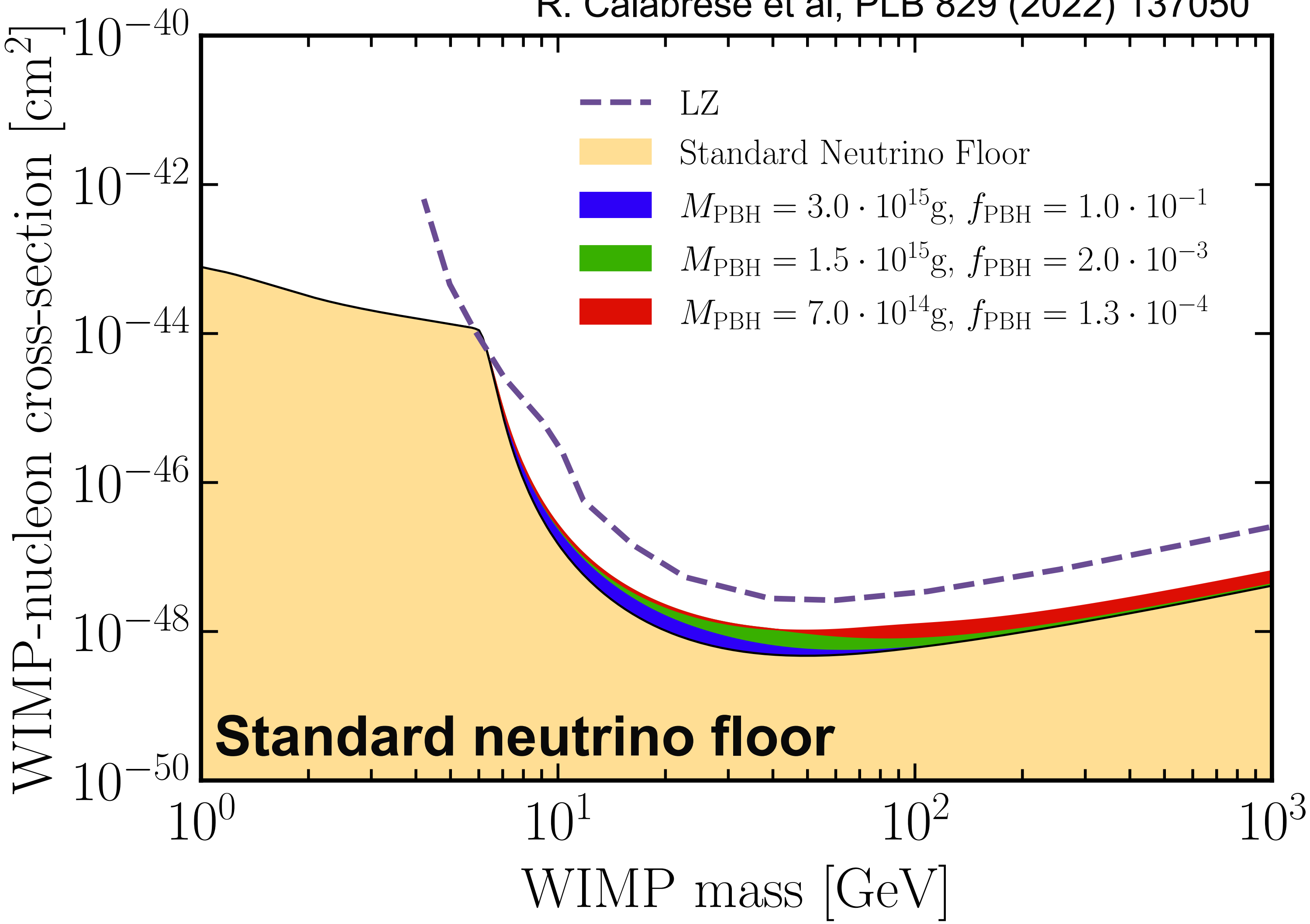


MAIN IDEA



MODIFICATION OF NEUTRINO FLOOR FROM PRIMORDIAL BLACK HOLE EVAPORATION

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

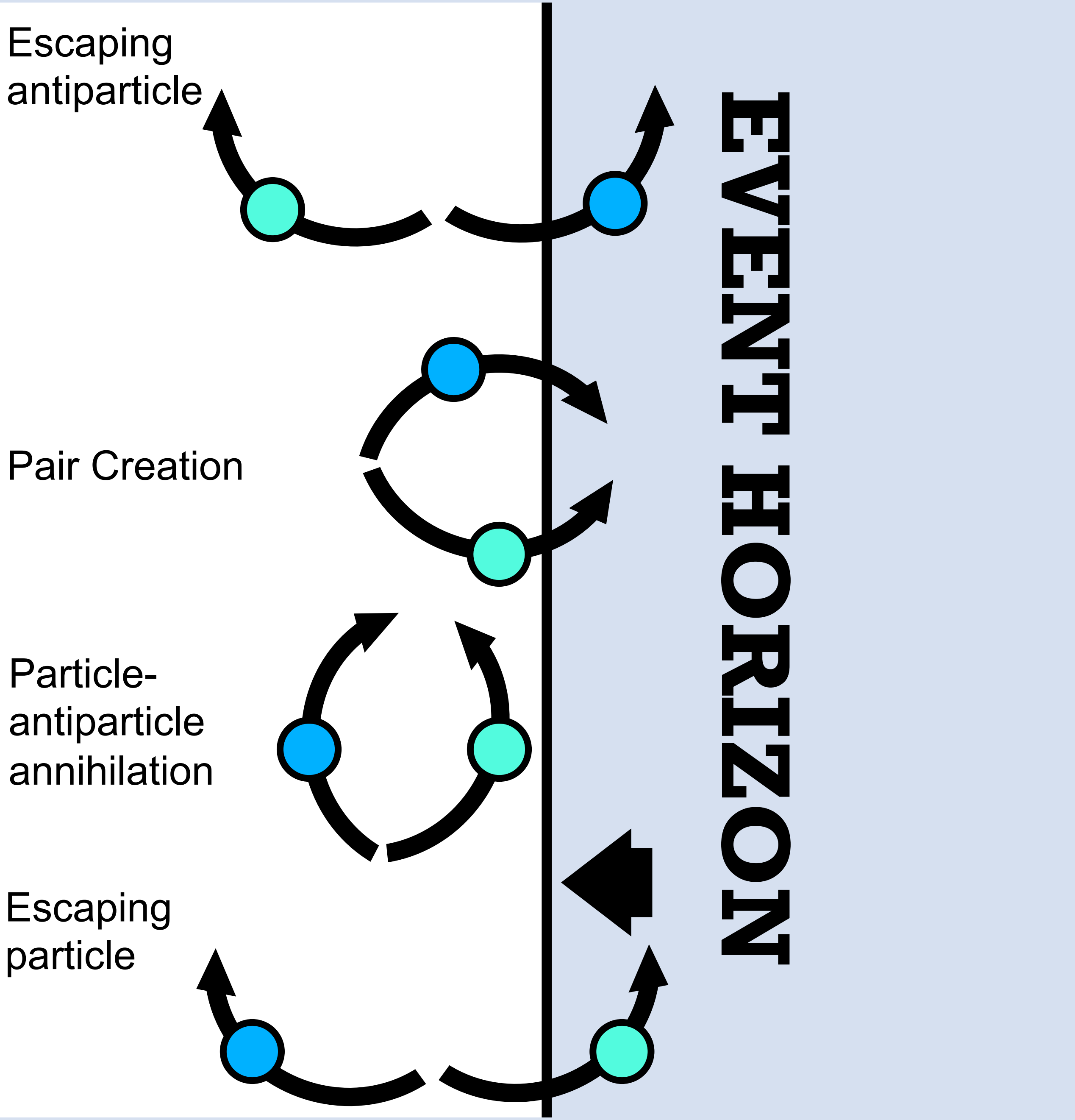


HAWKING RADIATION

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?



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

BLACK HOLE TEMPERATURE

The emission is Black Body like

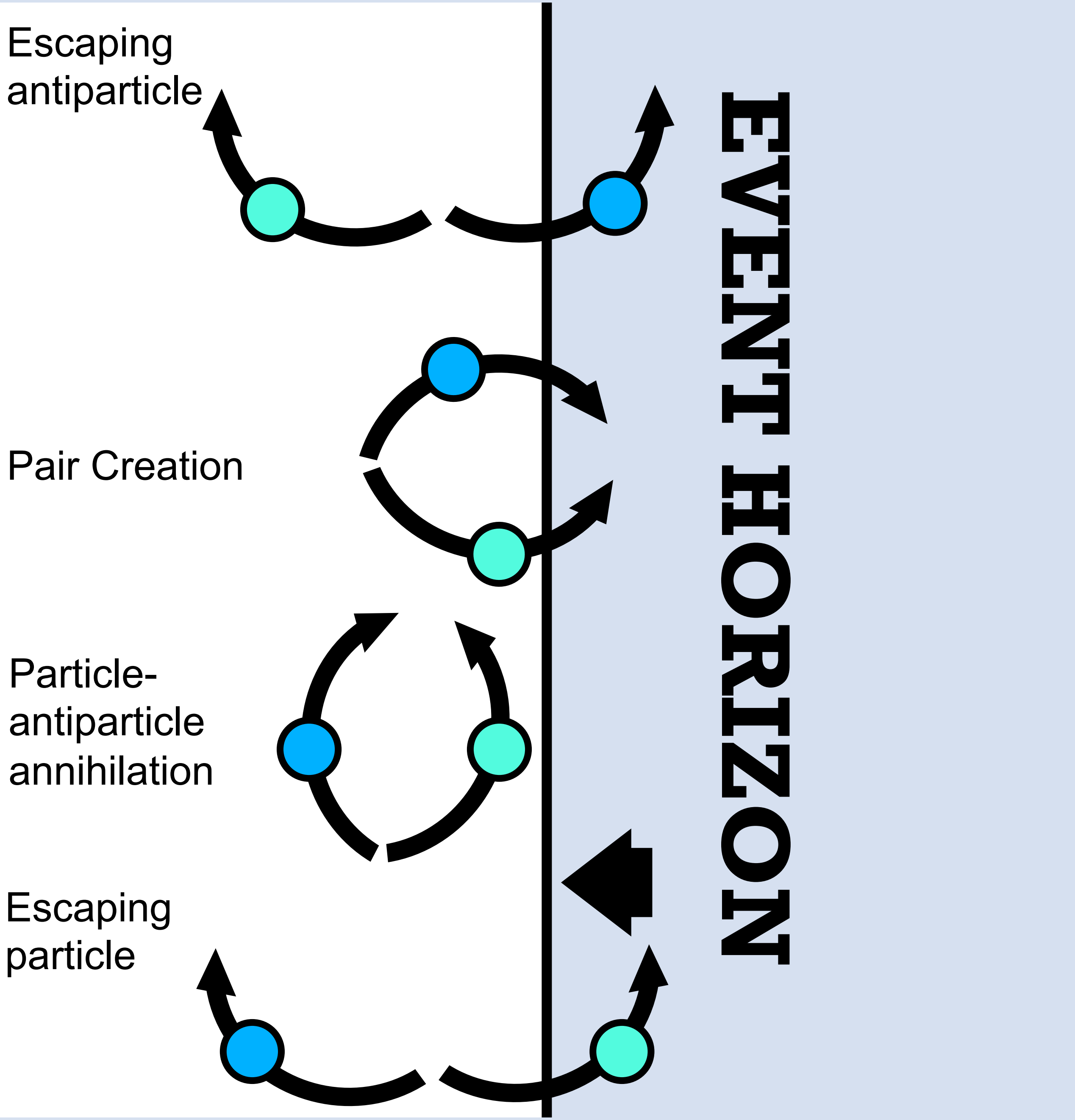
$$T_{BH} = \frac{\kappa}{2\pi}$$

Surface gravity

Let's consider a Neutral and Spinless Black Hole.

The temperature is

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



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

PARTICLE EMISSION

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

Primary emission

Particles emitted directly by Hawking radiation

χ Degrees of freedom

Grey body factor

$$\frac{dN}{dt\,dE_\chi} = \frac{g_\chi}{2\pi}\,\frac{\Gamma^\chi(E_\chi, T_{PBH})}{\exp(E_\chi/T_{PBH}) - (-1)^{2s_\chi}}$$

χ spin

χ Energy

Computed using **BLACKHAWK** (A. Arbey and J. Auffinger, Eur.Phys.J.C 79 (2019); A. Arbey and J. Auffinger, Eur.Phys.J.C 81 (2021); J. Auffinger, Eur.Phys.J.C 82 (2022))

Secondary emission

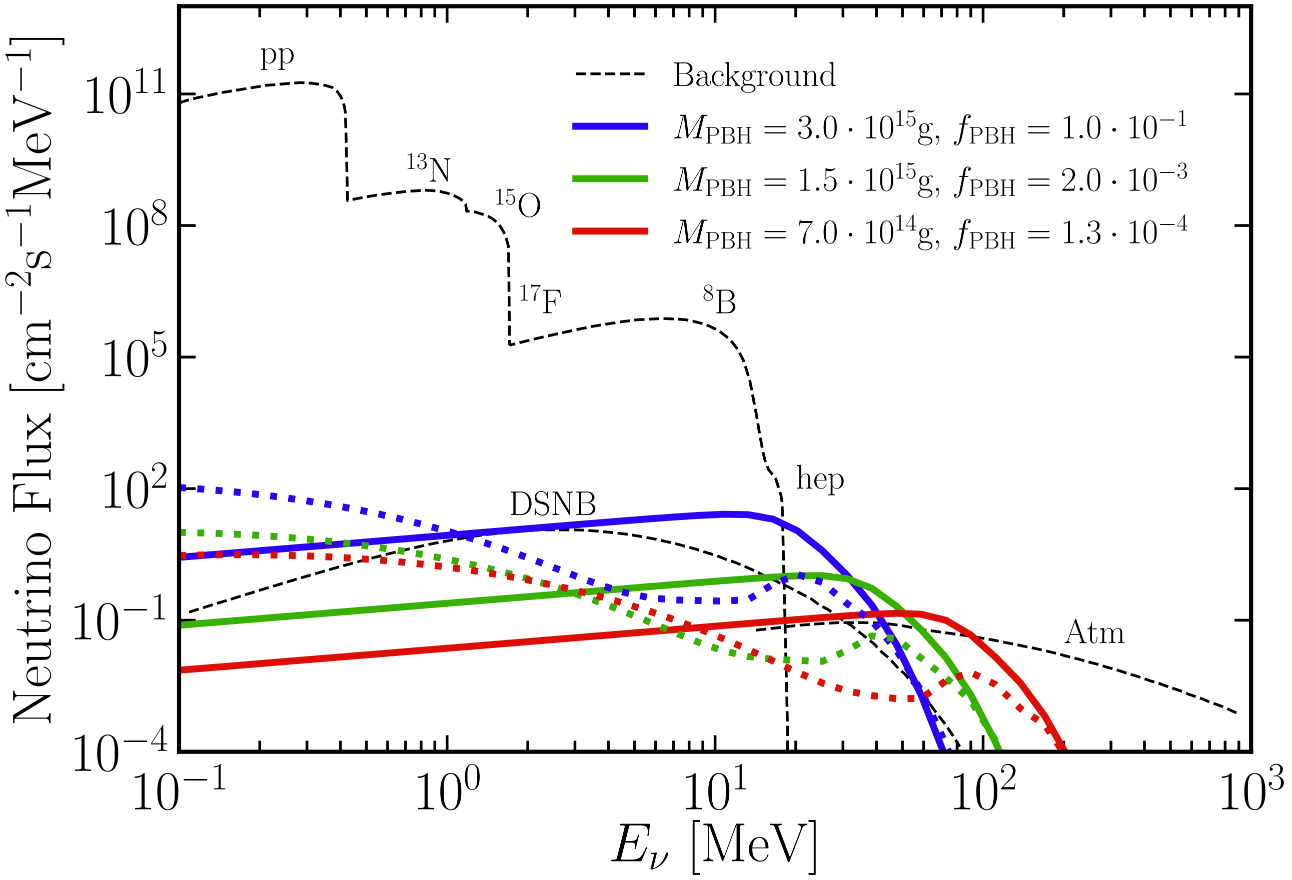
Particles produced by the decays or interaction of primary particles

TOTAL ν FLUX

Primary

Secondary

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



We are assuming

1) Majorana neutrinos

2) Primordial Black Holes with

Monochromatic mass distribution

$M_{PBH} \in [5 \cdot 10^{14} - 10^{16}]g$

No spin

No charge

TOTAL ν FLUX

Primary

Secondary

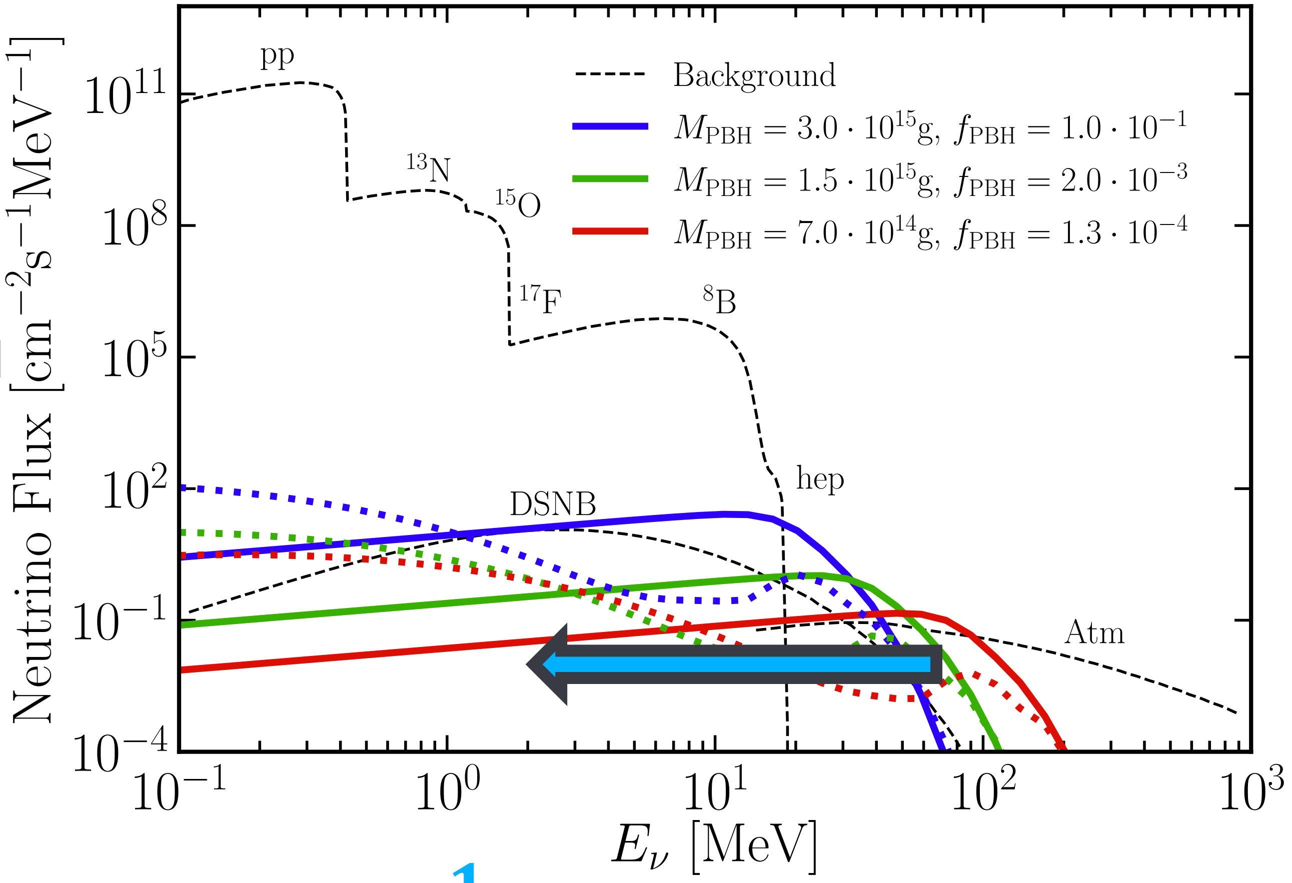
R.C. et al, PLB 829 (2022) 137050

Neutrino flux from Primordial Black Hole

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

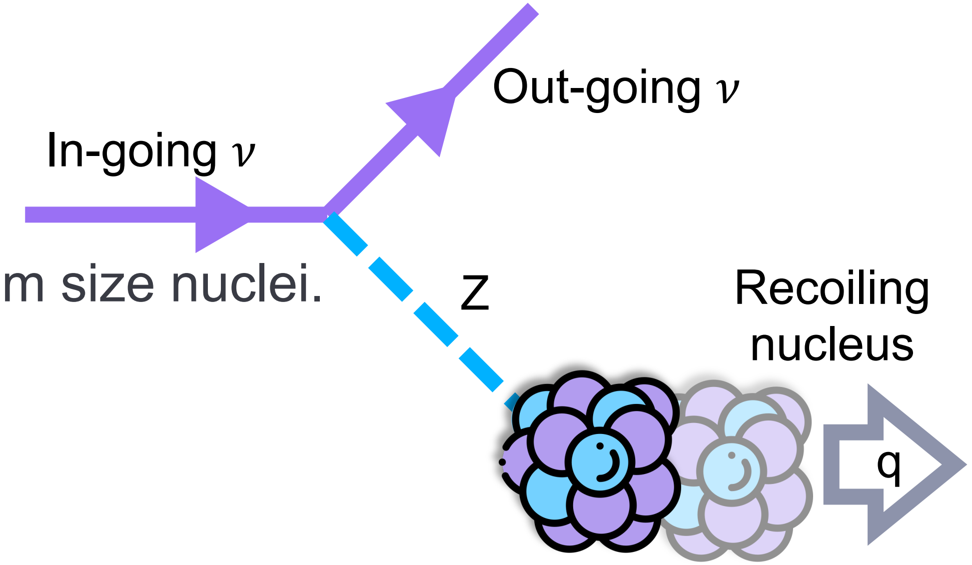
2. $$\frac{d\phi^{MW}}{dE_\nu} = \int \frac{d\Omega}{4\pi} \frac{\boldsymbol{dN}}{\boldsymbol{dtdE_\nu}} \int dl \frac{f_{PBH}\rho_{NFW}[r(l,\psi)]}{M_{PBH}}$$

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



$$\mathbf{T_{PBH}} \propto \frac{\mathbf{1}}{\mathbf{M_{PBH}}}$$

COHERENT ELASTIC ν NUCLEUS SCATTERING



The neutrino interact with a nucleus via exchange of a Z-boson.

It is a **coherent process** for energies below 50 MeV and medium size nuclei.

The cross-section is

Target mass

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

Recoil energy

Form Factor

The detection of such process is tricky because $E_r \approx keV$.

D. Akimov et al, Science 357 (2017) 6356
D. Akimov et Al, PRL 126 (2021) 1, 012002
D.Z. Freedman, PRD 9 (1974) 1389

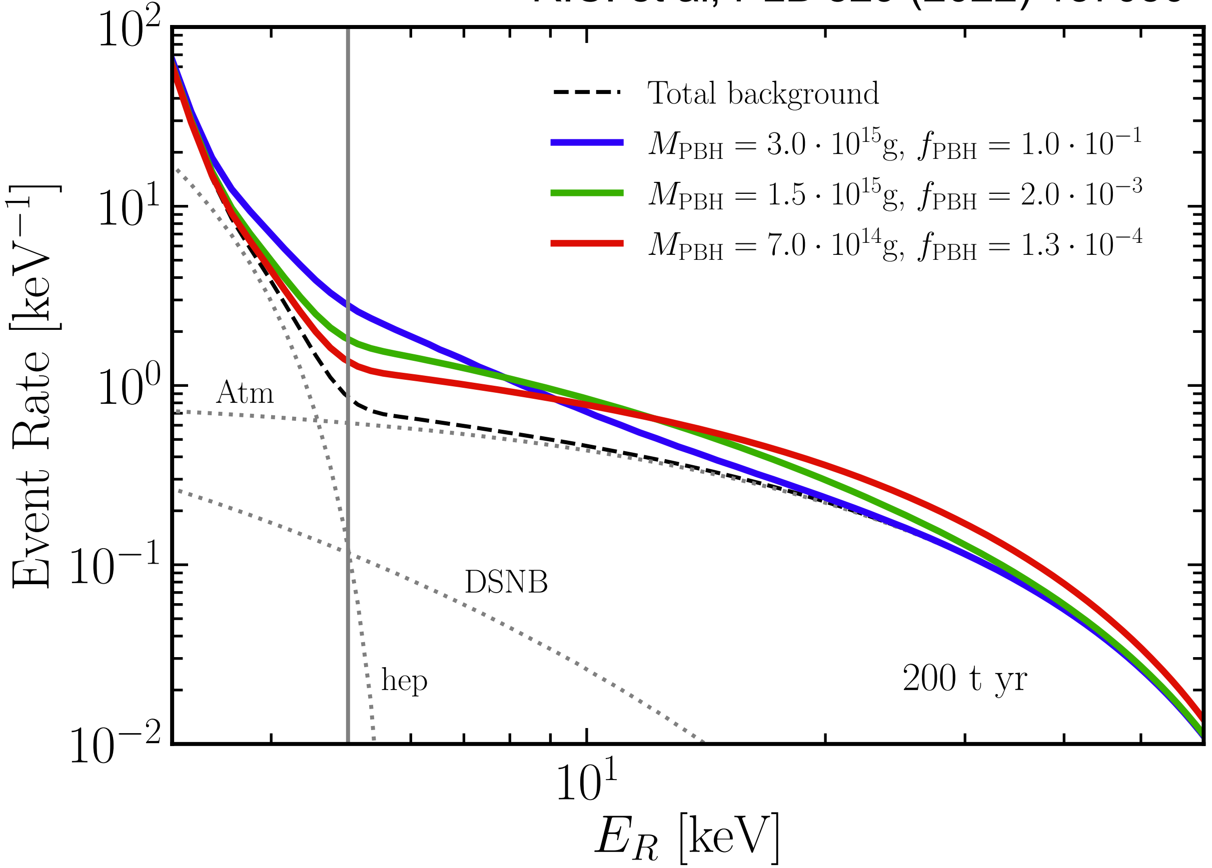
EVENT RATE IN DARWIN

Event rate from Coherent Neutrino-Nucleus Scattering

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

Event rate shape for lower masses ≈ background

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



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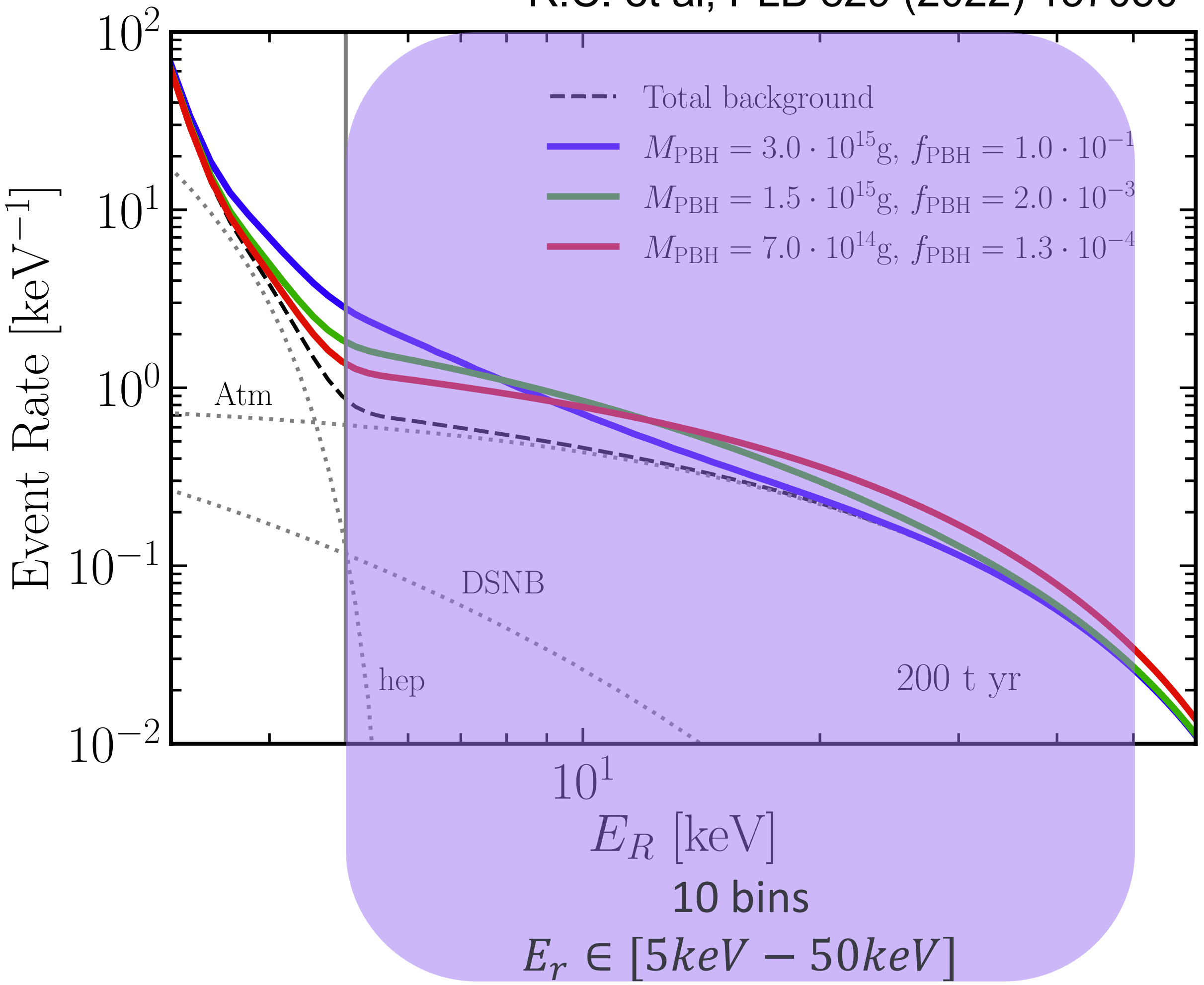


FORECAST CONSTRAINTS

We performed a binned analysis to fully exploit the spectral information

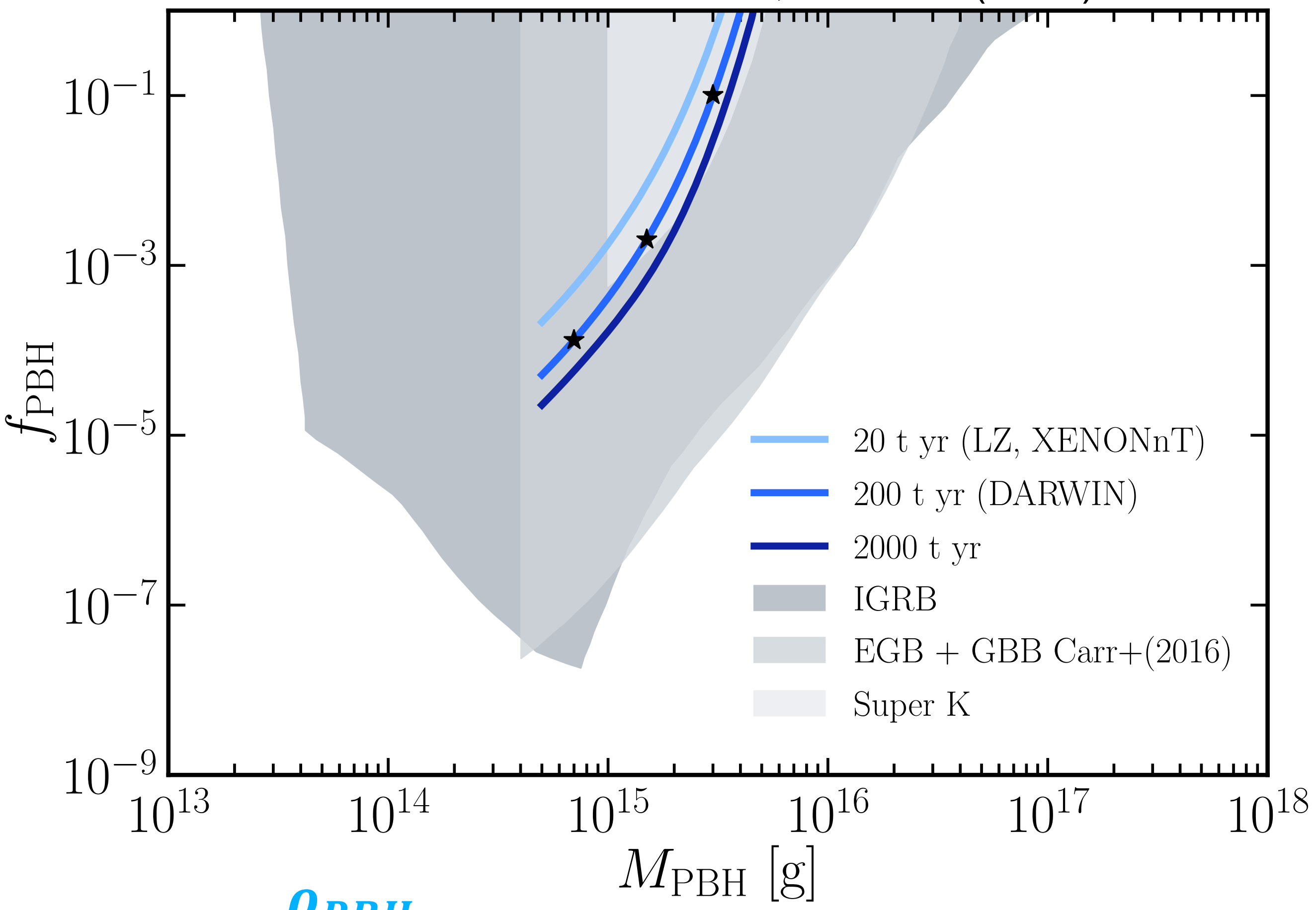
$$\chi^2 = \min_{\boldsymbol{\alpha}}[\chi^2(\boldsymbol{\theta},\boldsymbol{\alpha}) + (1-\boldsymbol{\alpha})^T \Sigma_{\boldsymbol{\alpha}}^{-1}(1-\boldsymbol{\alpha})]$$

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

$\boldsymbol{\alpha}$ = Nuisance parameters

$\boldsymbol{\Sigma_{\alpha}}$= Covariance matrix (encodes the uncertainties on the Background)

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



$$f_{PBH} = \frac{\rho_{PBH}}{\rho_{DM}}$$

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