The Sensitivity Floor for Primordial Black Holes Neutrino

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Outline

- Primordial black holes (PBHs)

1. PBHs as Dark Matter
2. Hawking Radiation
3. Constraints on PBHs by $\bar{\nu}_e$ Fluxes Upper limits
4. The Sensitivity Floor for Primordial Black Holes Neutrino

Evidence for Dark Matter

There is compelling astrophysical and cosmological evidence supporting the existence of dark matter (DM).

- Rotation Curve
- Cosmic Microwave Background
- Collisions of Galaxy Clusters
- Large Structure Formation

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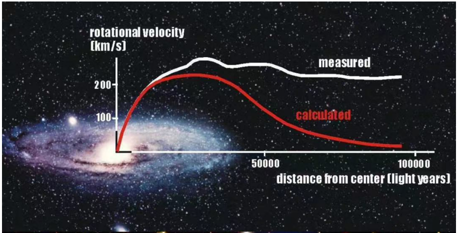
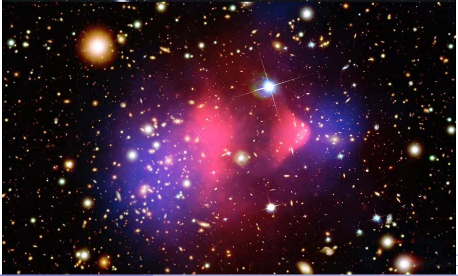




Experimental Motivation

Experimental Anomalies

- The discrepancies between observation and theoretical prediction could be the hint for new physics

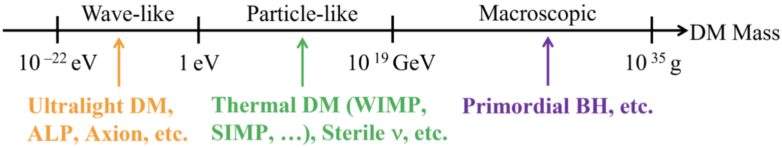
Null Observations

- Due to the increasing sensitivity, we can improve the measurement limits and exclude a significant region of the model parameter space

Theoretical Motivation

The SM cannot be the complete theory of the fundamental constituents of the universe.

- The SM does not contain gravity
- The neutrinos have mass
- The dark matter and dark energy
- Matter–antimatter asymmetry
- Strong CP problem



Primordial Black Hole Dark Matter

Dark matter is non-baryonic, stable, cold, and weakly interacting.

- PBHs form due to the gravitational collapse of overdensities
- Lifetime of PBHs can be longer than the age of the Universe
- PBHs can be non-relativistic
- PBHs are expected to only interact gravitationally

Primordial Black Hole Dark Matter

- PBHs could have formed with a broad range of masses in the early universe at different time after the big bang.

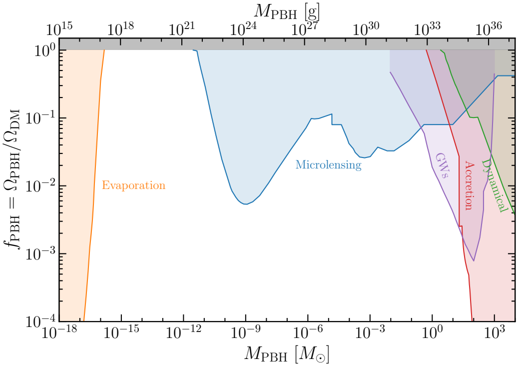
- The lifetime of a black hole is approximately given by,

$$t_{\textsf{evap}} = t_{\textsf{Universe}} \left(\frac{M_{\mathrm{PBH}}}{5 \times 10^{14} g} \right)^3 ,$$

  where M_{PBH} is the PBH initial mass, and $t_{\textsf{Universe}} \approx 13.8$ Gyr is the age of the Universe. We can infer that PBHs weighing less than $5 \times 10^{14}\,\mathrm{g}$ would have evaporated by now.

Primordial Black Hole Dark Matter

If the PBHs exist today, it would be a part of the DM, and we represent the PBHs abundance, a fraction of the DM denstity, as $f_{\rm PBH} \equiv \dfrac{\Omega_{\rm PBH}}{\Omega_{\rm DM}}$.



[https://github.com/bradkav/PBHbounds.]

Hawking Radiation

- The curvature of spacetime near the event horizon of a black hole causes the vacuum state of the quantum fields to become excited, leading to the emission of particles.

$$\left.\frac{d^2 N_i(E,t)}{dtdE}\right|_{\text{primary}} = \frac{g_i}{2\pi} \frac{\Gamma_i\left(E, M_{\text{PBH}}\right)}{e^{E/T_{\text{BH}}} \pm 1},$$

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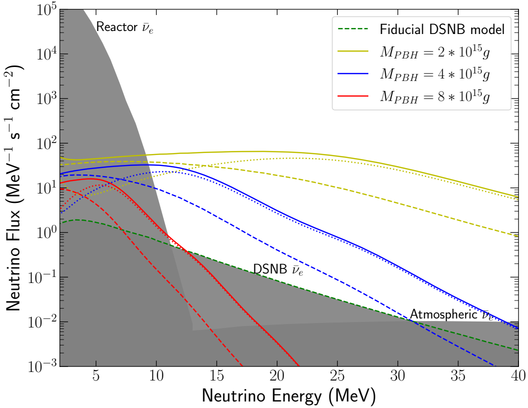
- The differential neutrino flux can be separated into the galactic and extragalactic contribution

$$\frac{d\Phi_{\text{MW}}}{dE_\nu} = \frac{d^2N_\nu}{dE_\nu dt}\frac{f_{\text{PBH}}}{M_{\text{PBH}}}\int\frac{d\Omega}{4\pi}\int_0^{\ell_{\max}} d\ell\rho_{\text{NFW}}(r(\ell,\phi)),$$

$$\frac{d\Phi_{\text{EG}}\left(E_o\right)}{dE_o} = \frac{cf_{\text{PBH}}\rho_{\text{DM}}}{M_{\text{PBH}}}\int_{z_{\min}}^{z_{\max}}\frac{dz}{H}\frac{d^2N_\nu((1+z)E_o,t)}{dE_\nu dt}.$$

Hawking Radiation



Atmospheric $\bar{\nu}_e$ [K. et al.2018]
DSNB $\bar{\nu}_e$ [Moller2018]
Reactor $\bar{\nu}_e$ [Battistoni2005]

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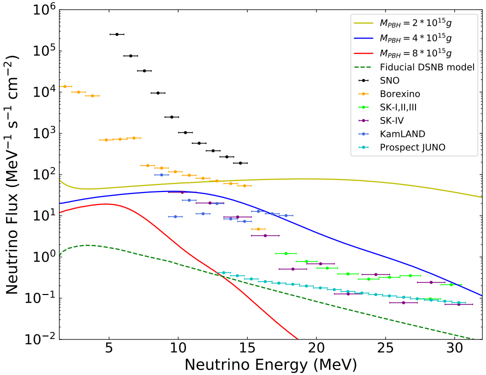
Figure: Three dominant antineutrino backgrounds, and galactic (dotted), extragalactic (dashed) and total (solid) $\bar{\nu}_e$ fluxes from PBHs evaporation as a function of energy with $f_{\mathrm{PBH}} = 1$, assuming a monochromatic mass distribution.

$\bar{\nu}_e$ Fluxes Upper Limits

The primary electron antineutrino detection channel in most experiments is inverse-beta decay, $\bar{\nu}_e + p \to n + e^+$.



SNO[Aharmim et al.2004]
Borexino [M. et al.2021]
SK-I,II,III[K. et al.2012]
SK-IV[K. et al.2021]
KamLAND[Abe et al.2022]
JUNO[Abusleme et al.2022]
DSNB[Moller2018]

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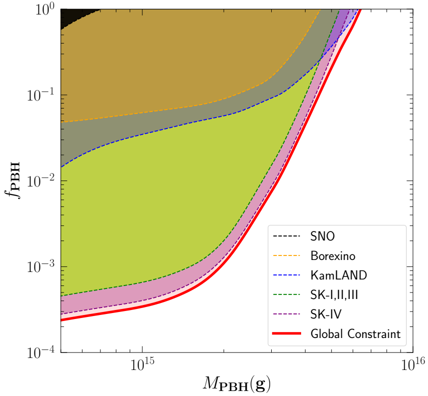
Upper Limit on Dark Matter Fraction of PBHs f_{PBH}



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Since these various experiments are independent, all the $\bar{\nu}_e$ fluxes upper limits can be taken into account to obtain a global constraint.

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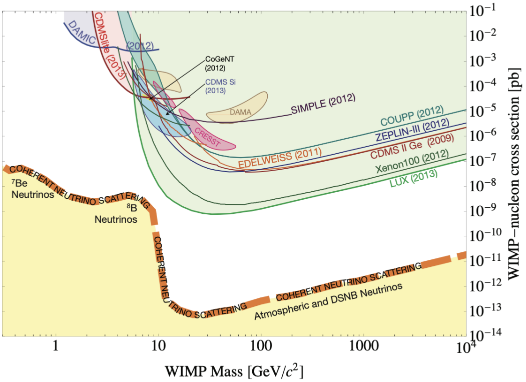

arXiv:1307.5458

- In the DM direct detection experiment, the recoil signal would be limited by coherent elastic neutrino-nucleus scattering

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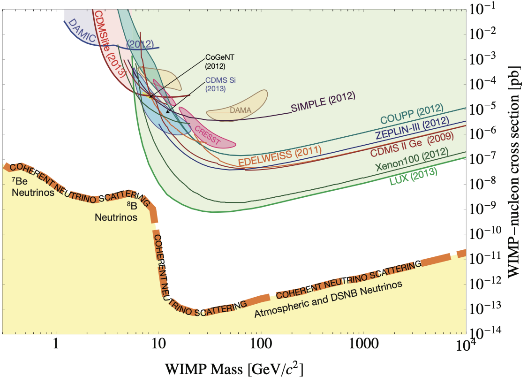

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- In the DM direct detection experiment, the recoil signal would be limited by coherent elastic neutrino-nucleus scattering
- The DSNB serves as an irreducible background that forms a sensitivity floor in PBHs parameter space

The Sensitivity Floor for Primordial Black Holes Neutrino

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- The DSNB has a different angular distribution from the signal produced by PBHs but the detector cannot distinguish between them.
- Additionally, their energy distributions are different, but the flux of DSNB is uncertain.
- Both of reactor neutrinos and atmospheric neutrinos can be measured accurately, so we do not take them into account by assuming they can be eliminated by other methods.

The Sensitivity Floor for Primordial Black Holes Neutrino

- To obtain the sensitivity floor, we estimate the number of expected events for PBHs and DSNB in the Hyper-Kamiokande,

$$N_i^{\mathrm{PBH(DSNB)}} = \varepsilon N_t t \int F_i^{\mathrm{PBH(DSNB)}} \sigma_i(E) dE,$$

where $\varepsilon = 67\%$ is the detector efficiency, $N_t = 2.5 \times 10^{34}$ is the number of targets, $\sigma_i(E)$ is the inverse beta decay cross-section.

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- We use the log-likelihood ratio,

$$\chi^2 = -2 \ln \frac{L\left(f_{\mathrm{PBH}}\right)}{L\left(f_{\mathrm{PBH}} = 0\right)},$$

where L are given by Poisson likelihood.

The Sensitivity Floor for Primordial Black Holes Neutrino

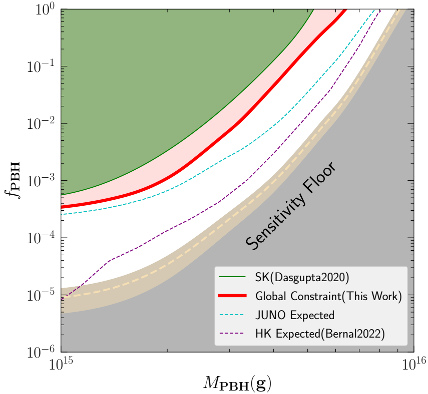

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Figure: Current and prospective upper bounds on PBHs, and the sensitivity floor for PBHs neutrino.

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- The current data excludes PBHs as the sole component of dark matter up to masses of $6.4 \times 10^{15}\,\mathrm{g}$. This represents a significant improvement of approximately 20% in comparison to the previous upper limits obtained from SK's data, which was around $5.2 \times 10^{15}\,\mathrm{g}$.

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- We consider the null observations of antineutrino flux from several neutrino detectors and set new constraints on the PBHs as a DM candidate.
- The current data excludes PBHs as the sole component of dark matter up to masses of $6.4 \times 10^{15}\,\mathrm{g}$. This represents a significant improvement of approximately 20% in comparison to the previous upper limits obtained from SK's data, which was around $5.2 \times 10^{15}\,\mathrm{g}$.
- In addition, since the DSNB is an unavoidable isotropic background, we thus estimate the sensitivity floor and show that it is difficult for neutrino detectors to detect the PBH DM above $9 \times 10^{15}\,\mathrm{g}$.

Thank you for your attention!