Constraint on neutrinos from PBHs with the KamLAND upper limit data

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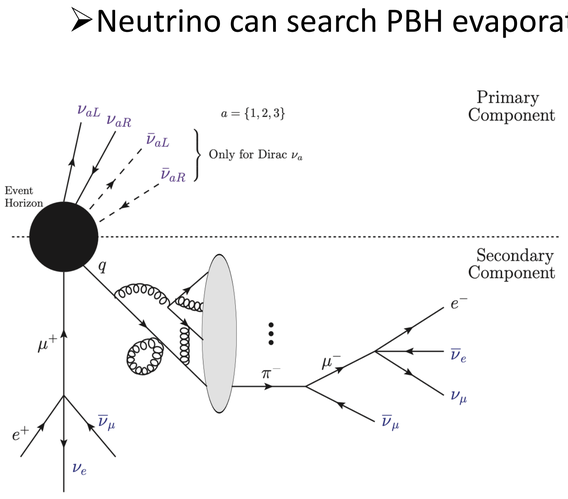
1.Primordial Black Holes (PBHs)

◆Primordial Black Holes (PBHs)

- PBHs were formed after inflation.
- PBHs are one of the candidates for Dark Matters (DMs).
- PBHs lose the energy as neutrinos emission by Hawking radiation [1].

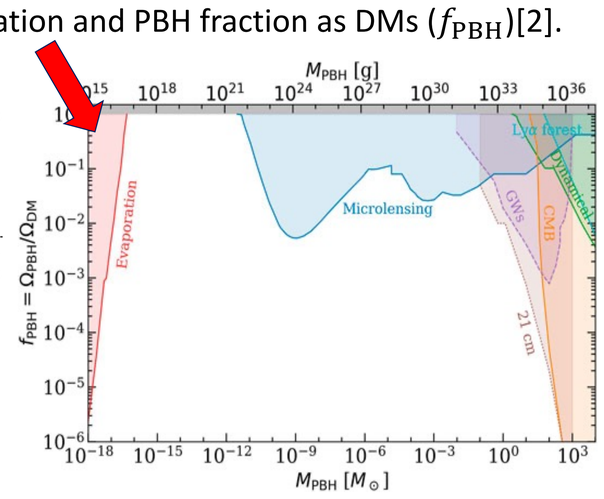
> Primary component : Direct emission as Hawking radiation
> +
> Secondary component : Decay of leptons and hadrons

- Neutrino can search PBH evaporation and PBH fraction as DMs (f_{PBH})[2].



Primary Component

Secondary Component



◆PBH Neutrino Flux

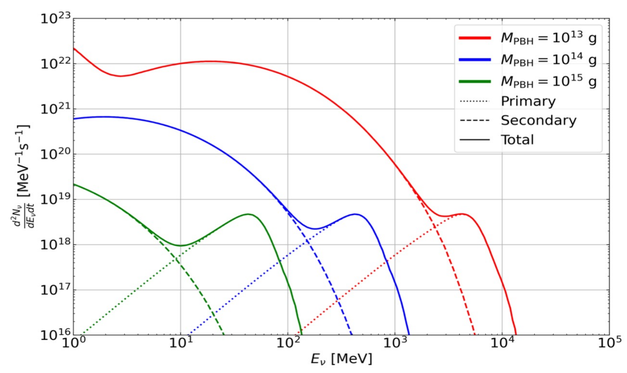
- The PBH neutrino emission rate is calculated for sum of *Primary* and *Secondary Component*[3].
- The PBH neutrino flux is calculated separately for *Extragalactic (EG)* and *Galactic (Gal)*.

$$\frac{dF_{EG}}{dE} = \frac{f_{\mathrm{PBH}}\rho_{\mathrm{DM}}}{M_{\mathrm{PBH}}} \int_{t_{min}}^{t_{max}} dt\,(1+z)\,\frac{d^2N}{dE'dt}\Big|_{E'=(1+z)E}$$

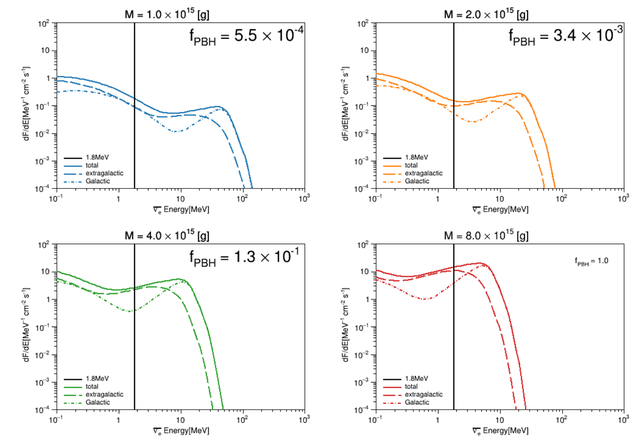
$$\frac{dF_{Gal}}{dE} = \frac{d^2N}{dEdt}\frac{f_{\mathrm{PBH}}}{M_{\mathrm{PBH}}} \int \frac{d\Omega}{4\pi} \int_0^{l_{max}} dl\;\rho_{NFW}[r(l,\phi)]$$

PBH neutrino flux depends on f_{PBH} .

$$\frac{dF}{dE} = \frac{dF_{EG}}{dE} + \frac{dF_{Gal}}{dE} \propto f_{\mathrm{PBH}}$$



- In this study, we calculated the PBH fraction as DMs and we will show this result.

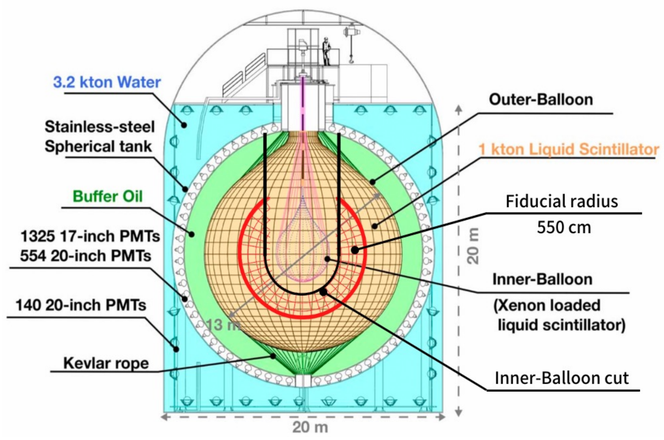


2.KamLAND Detector and $\bar{\nu}_e$ Selection[4]

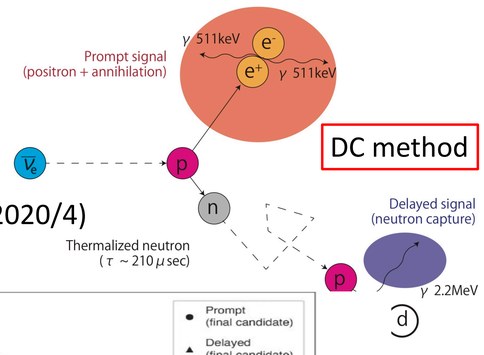
◆KamLAND Detector

- KamLAND uses an 1kton ultra-pure liquid scintillator (LS).
- KamLAND detects $\bar{\nu}_e$ via the inverse beta decay (IBD) using delayed coincidence (DC) method.

IBD reaction : $\bar{\nu}_e + p \rightarrow n + e^+$

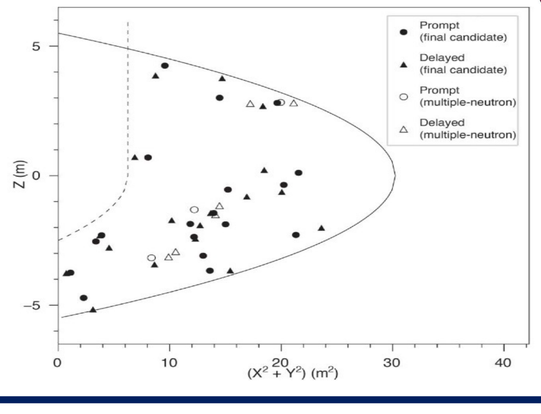


- KamLAND has many advantages.
  - Low energy threshold : $\mathrm{E}_\nu \geq 1.8$ MeV
  - High energy resolution : 6.4% / $\sqrt{E(\mathrm{MeV})}$
  - Long data taking period : 4528.5 days (2002/3 ~ 2020/4)
  - Low backgrounds : DC method



◆$\bar{\nu}_e$ selection

- Energy range : 7.5 – 30 M
- The fiducial radius : 550
- The inner-balloon cut
- 21DC pairs



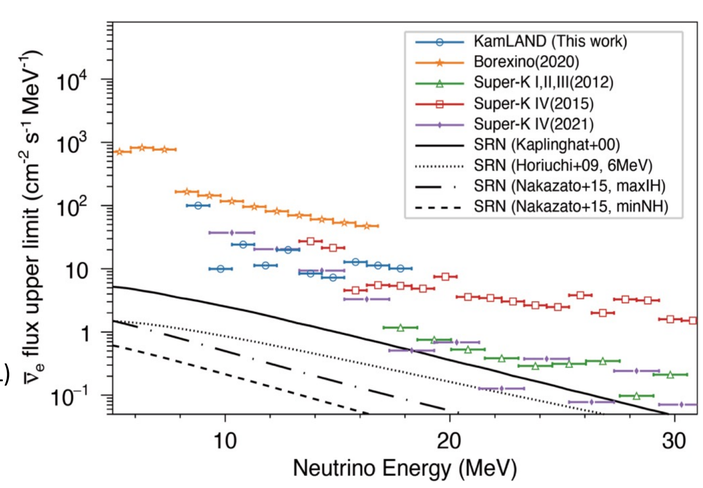
3.Analysis and Result

◆Analysis

- We calculate the χ^2[3] with the published KamLAND data[4].

$$\chi^2 = \sum \frac{v_i^2}{\left(u_i/\sqrt{2.71}\right)^2} \qquad [5]$$

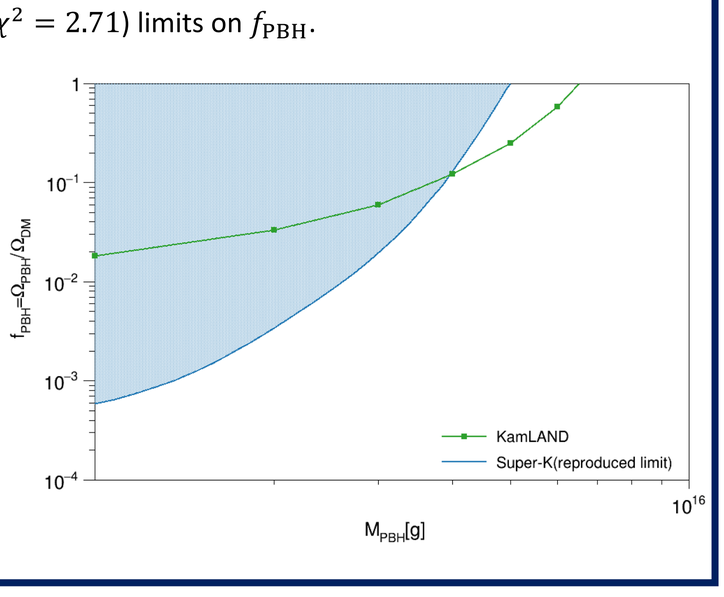
- v_i : PBH neutrino flux
- u_i : KamLAND upper limit data (90% CL)



- χ^2 depends on PBH fraction.
  ← PBH neutrino flux depends on PBH fraction.
  - ✓We compute the 90% CL ($\chi^2 = 2.71$) limits on f_{PBH}.

◆Result

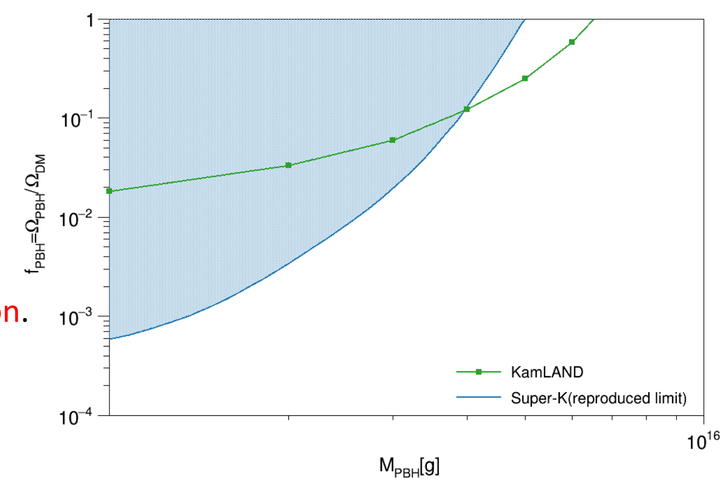
- We found the improvement of PBH limits for $M_{\mathrm{PBH}} = (4-7)\times10^{15}$ g.
- This result shows that PBHs are not DM for $M_{\mathrm{PBH}} = (5-7)\times10^{15}$g.



4.Summary and Prospect

◆Summary

- PBHs were formed after inflation and PBH mass (M_{PBH}) depends on collapse time.
- PBHs may play a role as one of the DMs.
- PBHs lose the energy by Hawking radiation.
- We prove that PBHs are not DM for $M_{\mathrm{PBH}} = (5-7)\times10^{15}$g.



◆Prospect

- We are calculating the restrictions on PBH fraction with shape and rate analysis of the KamLAND data.

  → We cannot show the result …

- We will consider evaporated PBHs ($M_{\mathrm{PBH}} < 8\times10^{14}$ g).

Reference [1]JCAP08(2020)014 [2] Front. Astron. Space Sci., 28 May 2021 [3]arXiv:2203.14979 [4] ApJ 925 14 2022 [5] ApJ 745 193 2012