ICFP 2026
The International Conference on Fundadmental Physics from Quanta to Cosmos

Multi-Messenger probing of Memory Burdened Primordial Black Holes as Dark Matter



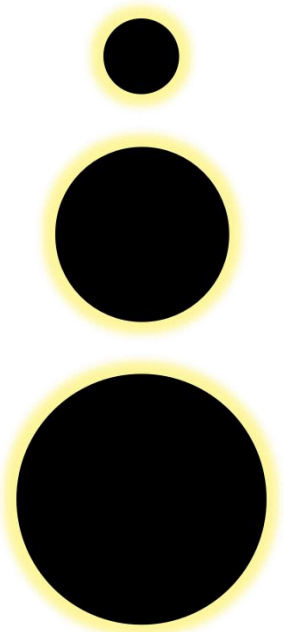
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Institute of Theoretical Physics, CAS

2026.10.24

based on
Gamma-ray: arXiv:2505.19857 (Phys.Lett.B 876 (2026) 140404)
Neutrino: arXiv:2606.16145
Antinuclei: in prepare...

Motivations of PBHs…

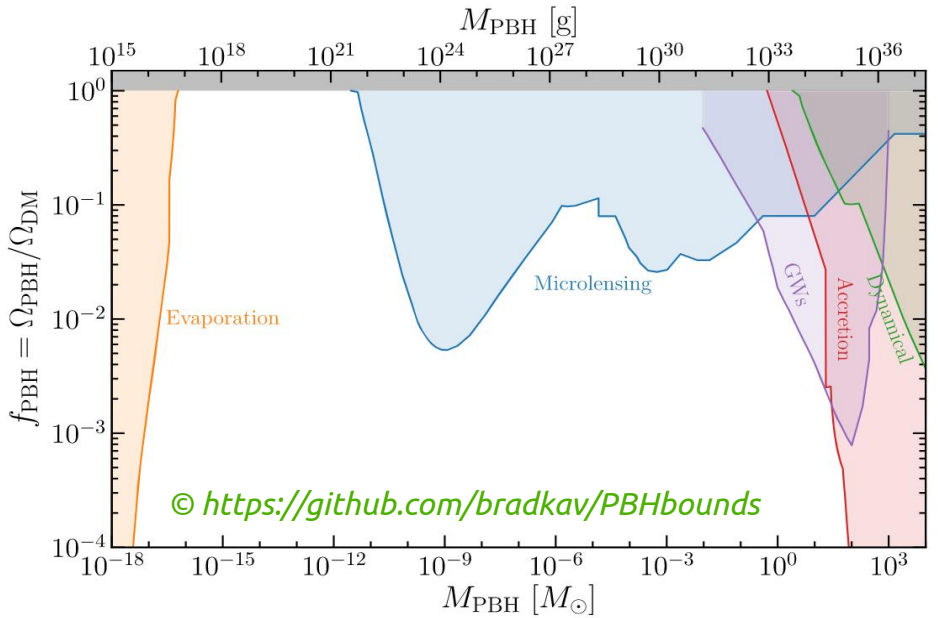
PBH



Planck mass M_P

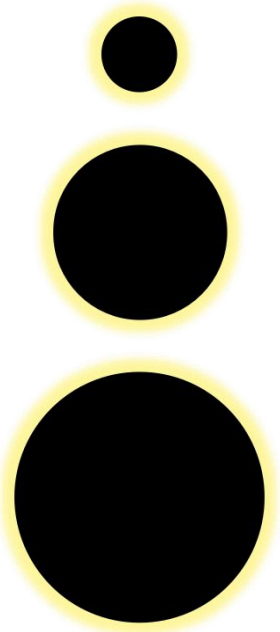
10^5 Solar mass

- Asteriod mass window
- Non-baryonic and still exist
- Non-relativistic and nearly collisionless
- No new physics required
- Not rival against particle DM



Motivations of MB PBHs...

PBH

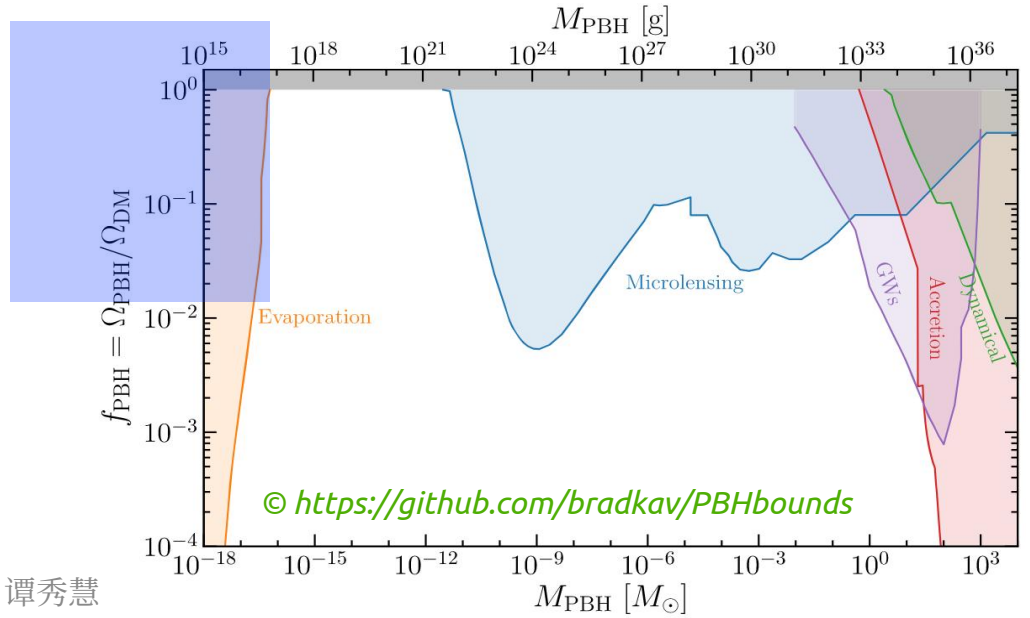


Planck mass M_P

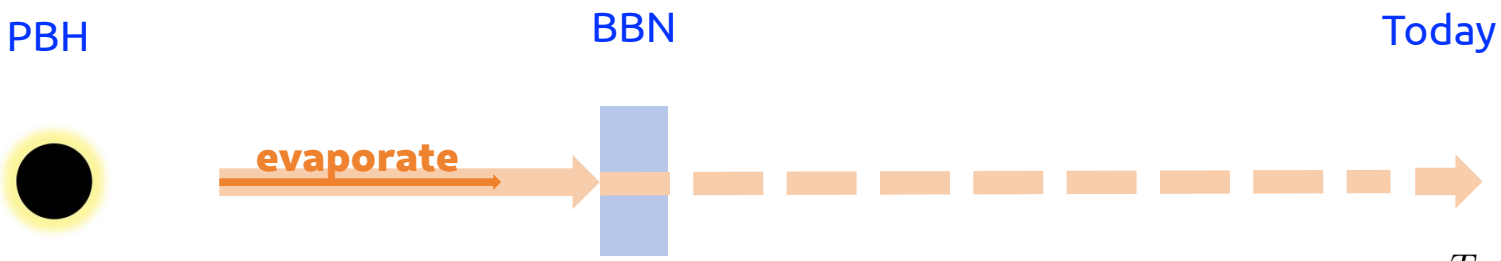
10^4-10^{14} g

10^5 Solar mass

- **New window below M<10^{15} g: Memory burden**
- No new physics required
- Not rival against particle DM
- Available signals to observe:
  - **electromagnetic signals**
  - **neutrinos**
  - **cosmic rays**
  - gravitational waves

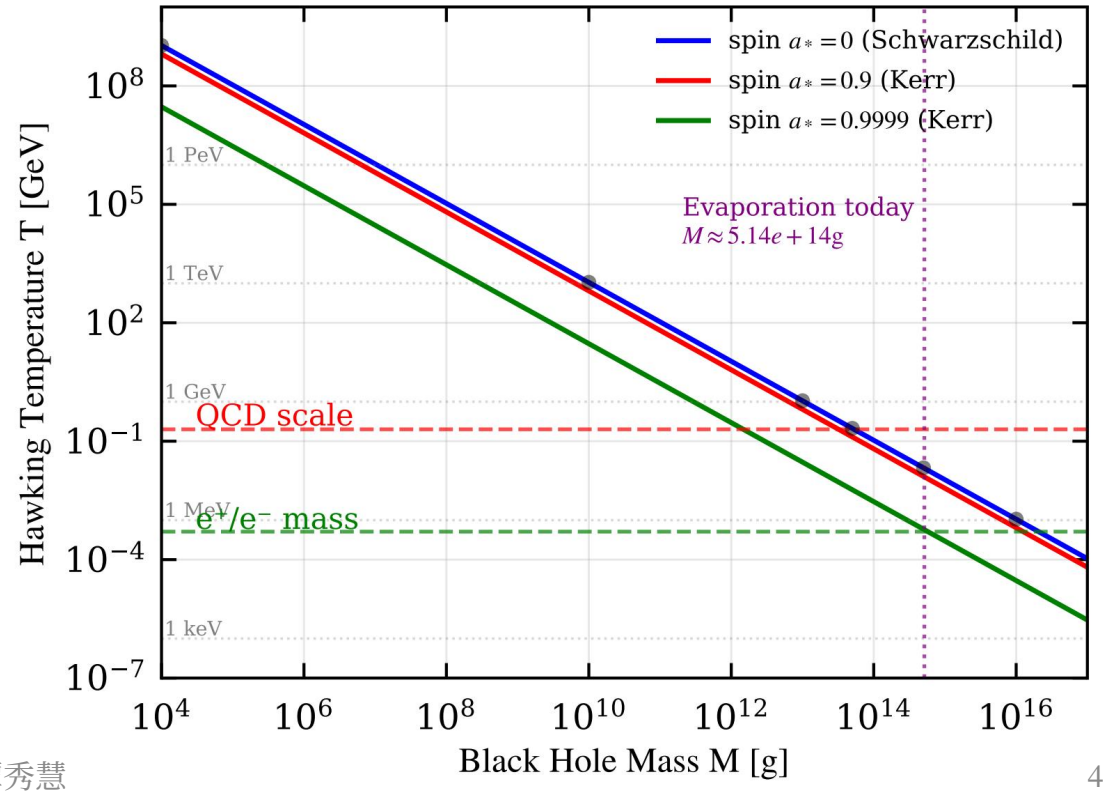


Memory burdend PBHs as dark matter



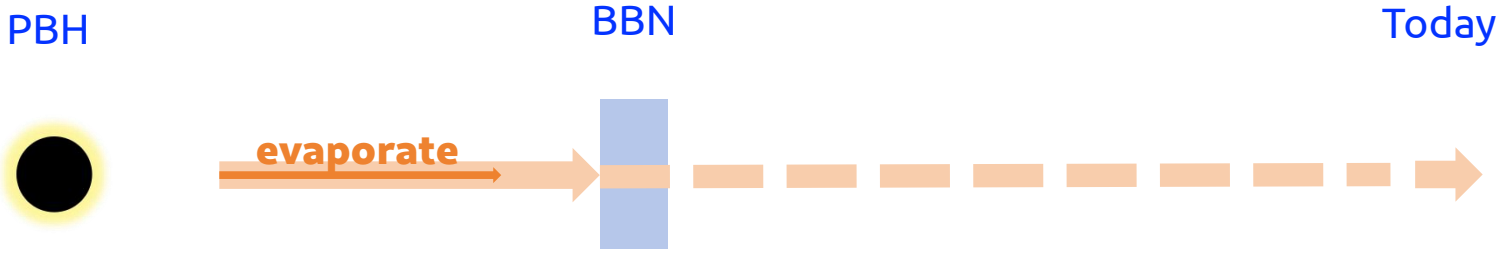
Semiclassical
Memory Burden

$$T_{\rm BH} = \frac{\hbar c^3}{8\pi k_{\rm B} G M_{\rm BH}} \simeq 10^9 \left(\frac{10^{14}\ {\rm g}}{M_{\rm BH}}\right)\ {\rm GeV}$$

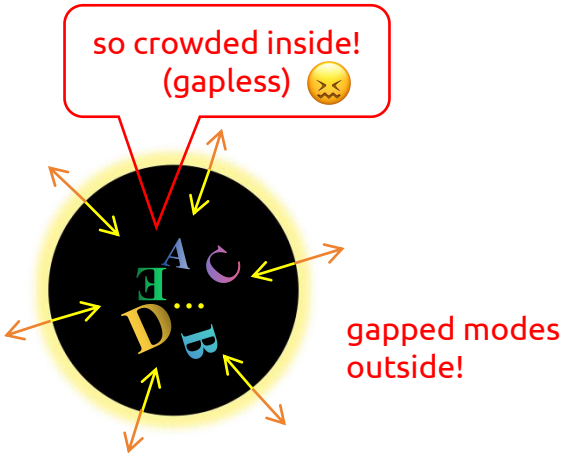


Memory burdend PBHs as dark matter

Memory burdend PBHs: *Information loaded in a system resists its decay.*



Semiclassical
Memory Burden

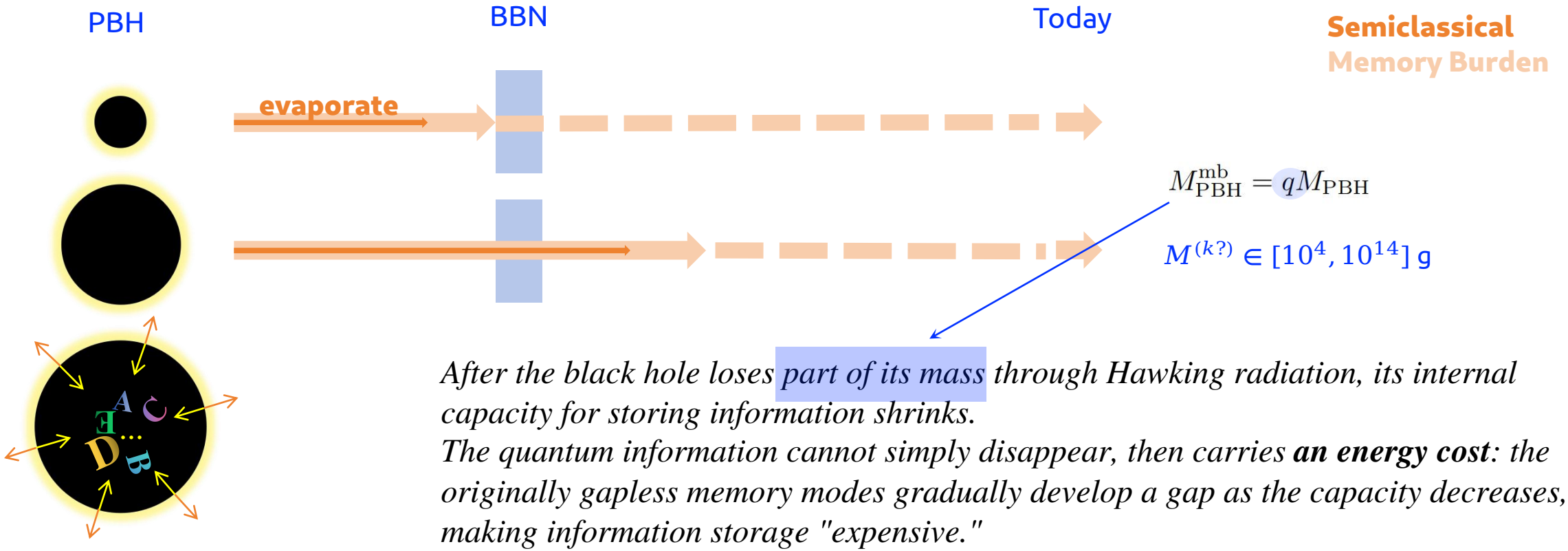


Inside the object, the information is stored in the excitations of ***gapless modes****.*
At the same time, the asymptotic modes at outside of the PBHs are highly gapped.
Information inside creates a back-reaction which resists against the decay of the object.

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Memory burdend PBHs as dark matter

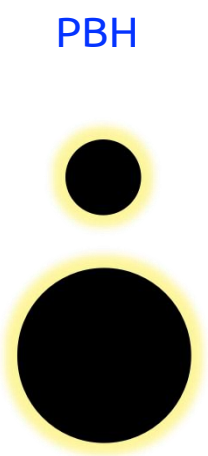
Memory burdend PBHs: *Information loaded in a system resists its decay.*



After the black hole loses part of its mass through Hawking radiation, its internal capacity for storing information shrinks.
The quantum information cannot simply disappear, then carries ***an energy cost****: the originally gapless memory modes gradually develop a gap as the capacity decreases, making information storage "expensive."*
This acts as a barrier that prevents them from continuing to radiate at its original rate.

Memory burdend PBHs as dark matter

Memory burdend PBHs: *Information loaded in a system resists its decay.*



PBH BBN Today

Semiclassical
Memory Burden

evaporate

$$T_{\rm BH} = \frac{\hbar c^3}{8\pi k_{\rm B} G M_{\rm BH}} \simeq 10^9 \left(\frac{10^{14}\ {\rm g}}{M_{\rm BH}}\right)\ {\rm GeV}$$

$$M_{\rm PBH}^{\rm mb} = qM_{\rm PBH}$$

$$\frac{{\rm d}M_{\rm BH}}{{\rm d}t} = -\frac{\mathcal{G}\pi g_{\star,H}}{480}\frac{M_P^4}{M_{\rm BH}^2}$$

graybody factor Planck mass

$$\frac{{\rm d}M_{\rm BH}}{{\rm d}t} = -\epsilon\kappa(t)\frac{M_P^4}{M_{\rm BH}^2}$$

$M^{(k?)} \in [10^4, 10^{14}]$ g

$$\Gamma_{\rm BH}^0 = \frac{3\epsilon M_P^4}{M_{\rm in}^3}$$

$$M_{\rm BH}(t) = M_{\rm in}\left[1 - \Gamma_{\rm BH}^0 (t - t_{\rm in})\right]^{1/3}$$

Semiclassical

$$\tau_{\rm SC} = t_{\rm ev}^0 - t_{\rm in} = \frac{1}{\Gamma_{\rm BH}^0} \simeq 2.4\times 10^{-28}\left(\frac{M_{\rm in}}{1\ {\rm g}}\right)^3\ {\rm s}$$

$$\kappa(t) = \begin{cases} S(M_{\rm BH})^{-k}, & \text{fast;} \\ \delta\dfrac{\tau_{\rm SC}}{2t}, & \text{slow;} \\ \dfrac{R_{\rm PBH}(f_{\rm PBH}, t) q \tau_{\rm SC}}{f_{\rm PBH}\rho_{\rm DM,0}} M_{\rm BH}, & \text{merger.} \end{cases}$$

Memory Burden

$$\Gamma_{\rm BH}^k = 2^k(3+2k)\epsilon M_P\left(\frac{M_P}{qM_{\rm in}}\right)^{3+2k}$$

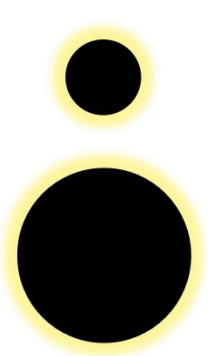
$$\tau_{\rm MB} = t_{\rm ev}^k - t_{\rm in} = \tau'_{\rm SC} + \frac{1}{\Gamma_{\rm BH}^k} \simeq (1-q^3)\frac{M_{\rm in}^3}{3\epsilon M_P^4} + \frac{1}{2^k(3+2k)\epsilon M_P}\left(\frac{qM_{\rm in}}{M_p}\right)^{3+2k}$$

Memory burdend PBHs as dark matter

Memory burdend PBHs: *Information loaded in a system resists its decay.*

PBH BBN Today

Semiclassical
Memory Burden



evaporate

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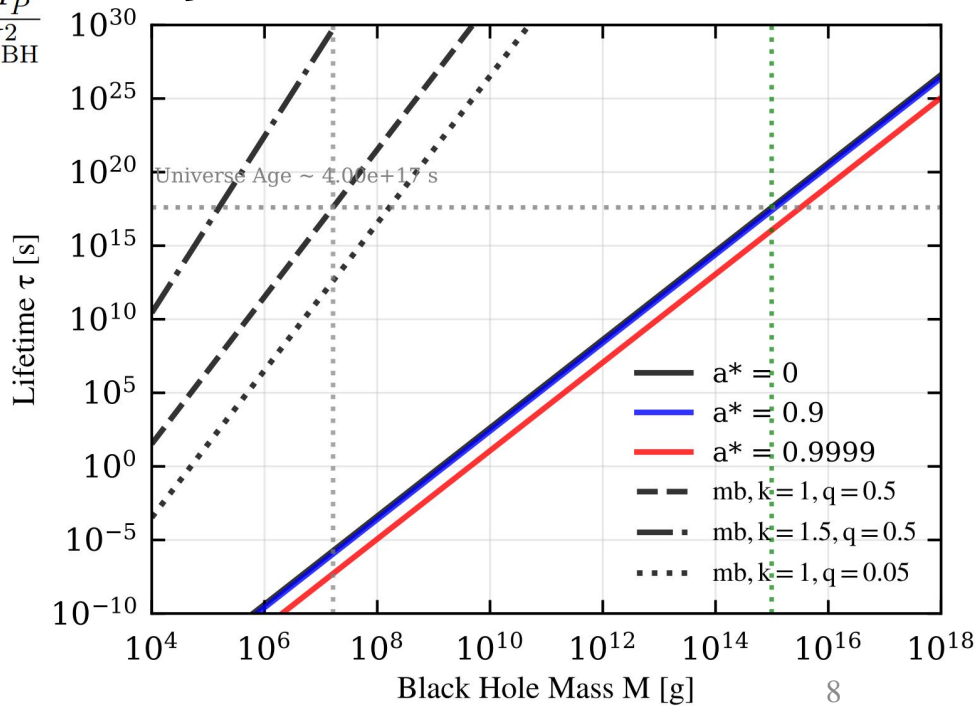
} $M^{(k?)} \in [10^4, 10^{14}]$ g

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Memory Burden

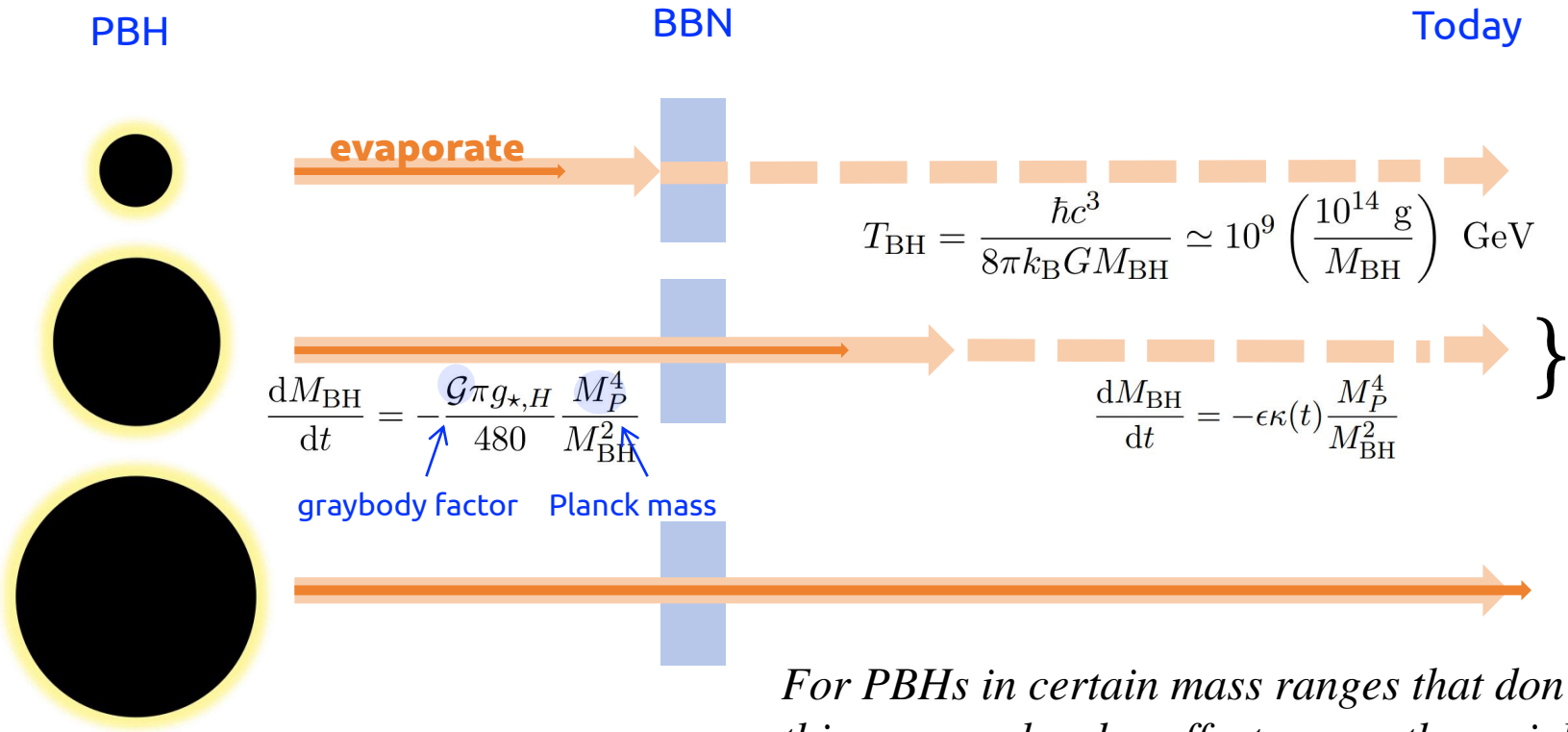
$$\tau_{\rm SC} = t_{\rm ev}^0 - t_{\rm in} = \frac{1}{\Gamma_{\rm BH}^0} \simeq 2.4\times 10^{-28}\left(\frac{M_{\rm in}}{1\ {\rm g}}\right)^3\ {\rm s}$$

Semiclassical



Memory burdend PBHs as dark matter

Memory burdend PBHs: *Information loaded in a system resists its decay.*



For PBHs in certain mass ranges that don't mess with big bang nucleosynthesis, this memory burden effect means they might not fully evaporate.

Heavier PBHs keep on evaporating.

Gamma rays from MB PBHs @galactic sources

Memory burdend PBHs:

$$S(M_{\rm PBH}) = \frac{4\pi M_{\rm PBH}^2 G k_B}{\hbar c} \approx 2.6\times 10^{10} k_B \left(\frac{M_{\rm PBH}}{1\ {\rm g}}\right)^2$$

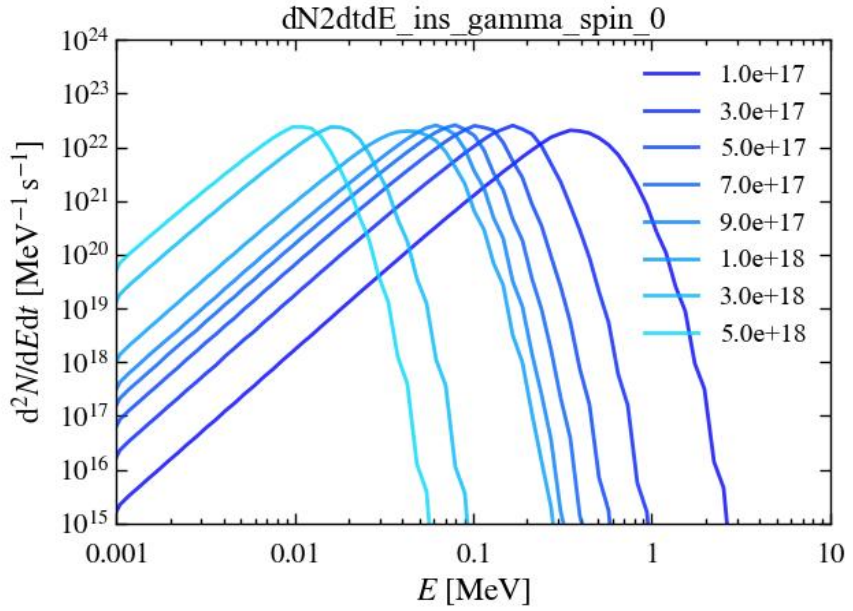
$$M_{\rm PBH}^{\rm mb} = q M_{\rm PBH}$$

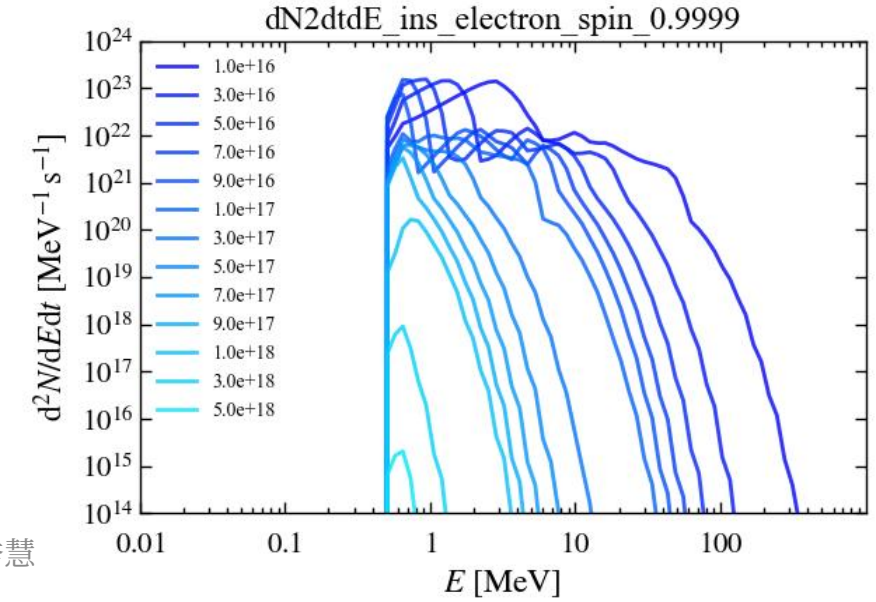
$$\frac{{\rm d}M_{\rm PBH}^{\rm mb}}{{\rm d}t} = \frac{1}{S(M_{\rm PBH})^k}\frac{{\rm d}M_{\rm PBH}}{{\rm d}t}, k>0$$

$$\frac{{\rm d}^2 N_\gamma^{\rm mb}}{{\rm d}E{\rm d}t} = S(M_{\rm PBH})^{-k}\frac{{\rm d}^2 N_\gamma}{{\rm d}E{\rm d}t}$$

The memory burden suppresses particle production by a factor of S^{-k}, where S is the entropy.

This actually helps us detect high-energy photons from even very light PBHs! 😏



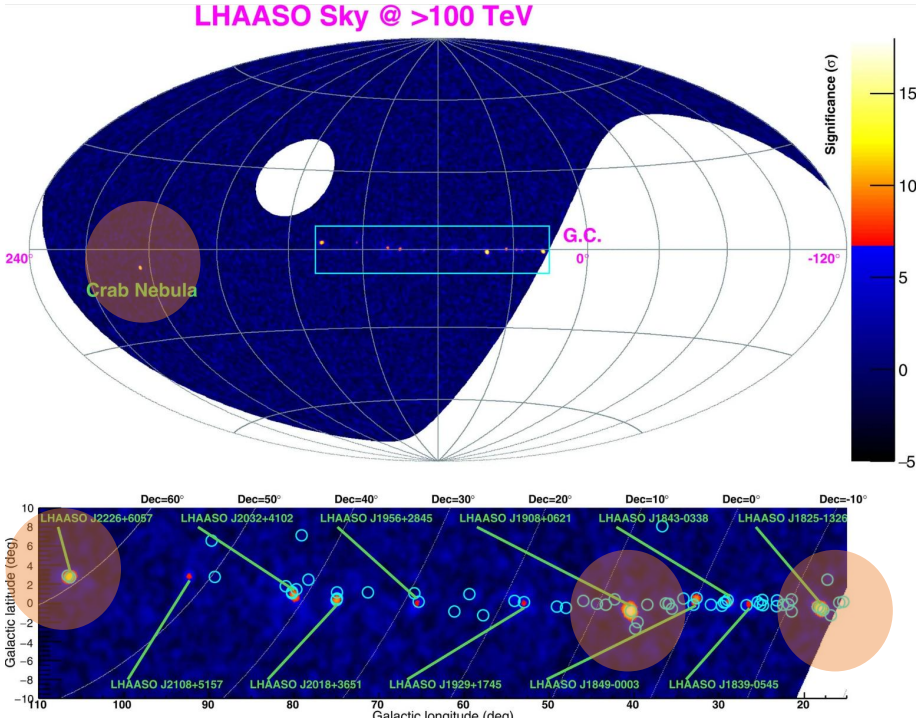


Gamma rays from MB PBHs @galactic sources

The Gamma rays from memory burdend PBHs for GS:

$$\frac{\mathrm{d}^2\phi_\gamma^{\mathrm{GS}}}{\mathrm{d}E_\gamma \mathrm{d}t} = \frac{f_{\mathrm{PBH}}}{4\pi M_{\mathrm{PBH}}^{\mathrm{mb}}} \frac{\mathrm{d}^2 N_\gamma^{\mathrm{mb}}}{\mathrm{d}E\mathrm{d}t} \mathcal{D}(E_\gamma, \Delta\Omega)$$

$$\mathcal{D}(E_\gamma, \Delta\Omega) = \frac{1}{\Delta\Omega} \int_{\mathrm{ROI}} \mathrm{d}\Omega \int_{\mathrm{l.o.s}} \mathrm{d}s \rho_{\mathrm{DM}}(r) e^{-\tau_{\gamma\gamma}(E_\gamma, s, b, \ell)}$$



4 GS (Galactic Sources):
Crab Nebula
LHAASO J226+6057
LHAASO J1908+0621
LHAASO J1825-1326

Galactic Center where DM is concentrated. If PBHs are the DM, lots of small PBHs would be along our line of sight.

PBH contributes when integrate along this direction.

Gamma rays from MB PBHs @galactic sources

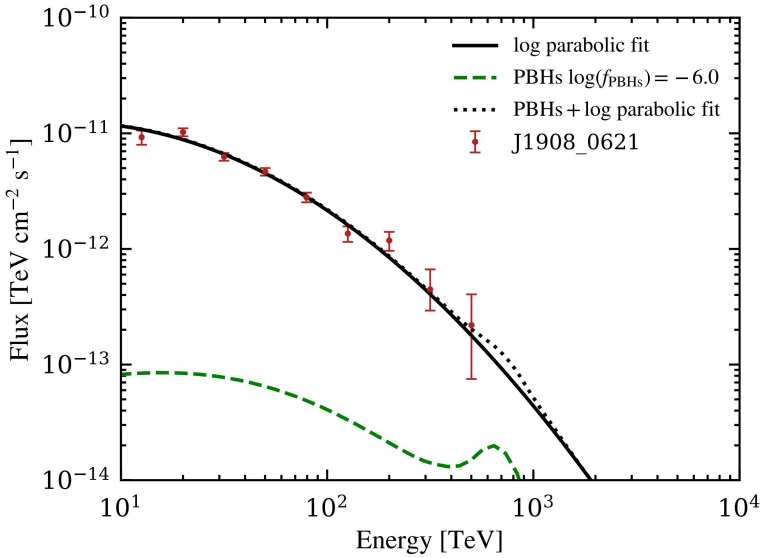
With IC spectrum:

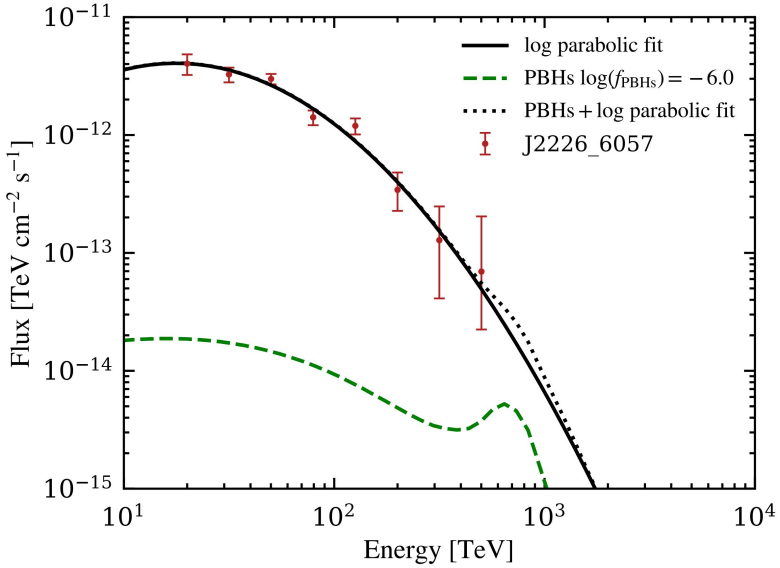
Expected Inverse-Compton (IC) emission spectrum from accelerated electrons within a magnetized nebula.

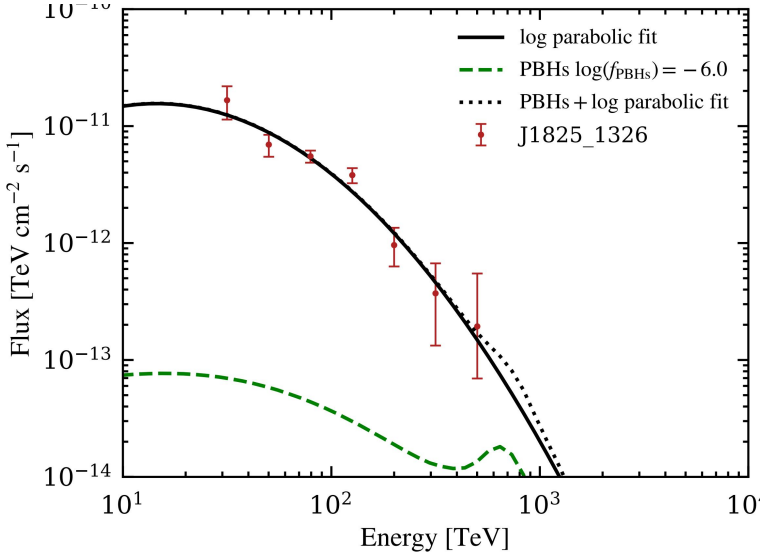
This spectrum is described by a log-parabolic function.

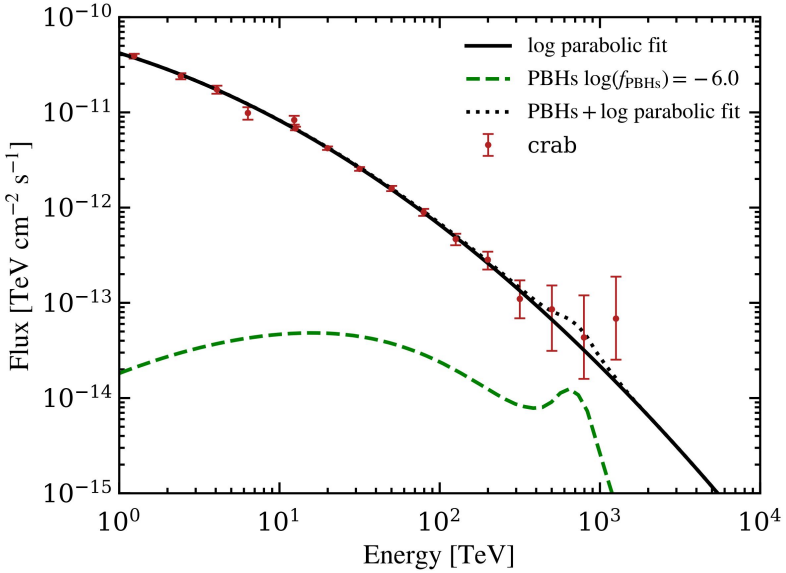
$$\frac{\mathrm{d}\phi_\gamma^{\mathrm{IC}}}{\mathrm{d}E_\gamma} = F_0 \left(\frac{E}{E_0}\right)^{-a-b\log(E/E_0)}$$

$$\chi^2 = \sum_{i,j} \left[\frac{\phi_{i,j}^{\mathrm{predict}}(\theta) - \phi_{i,j}^{\mathrm{data}}}{\sigma_{i,j}^{\mathrm{data}}}\right]^2$$







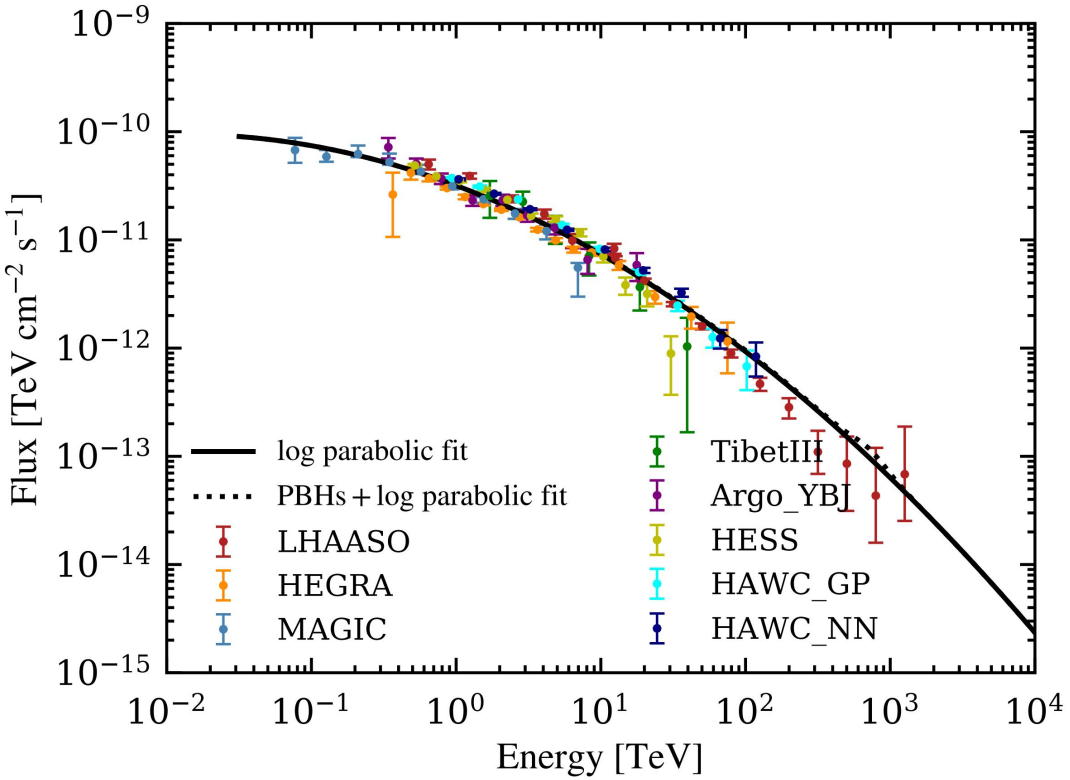


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Gamma rays from MB PBHs @galactic sources

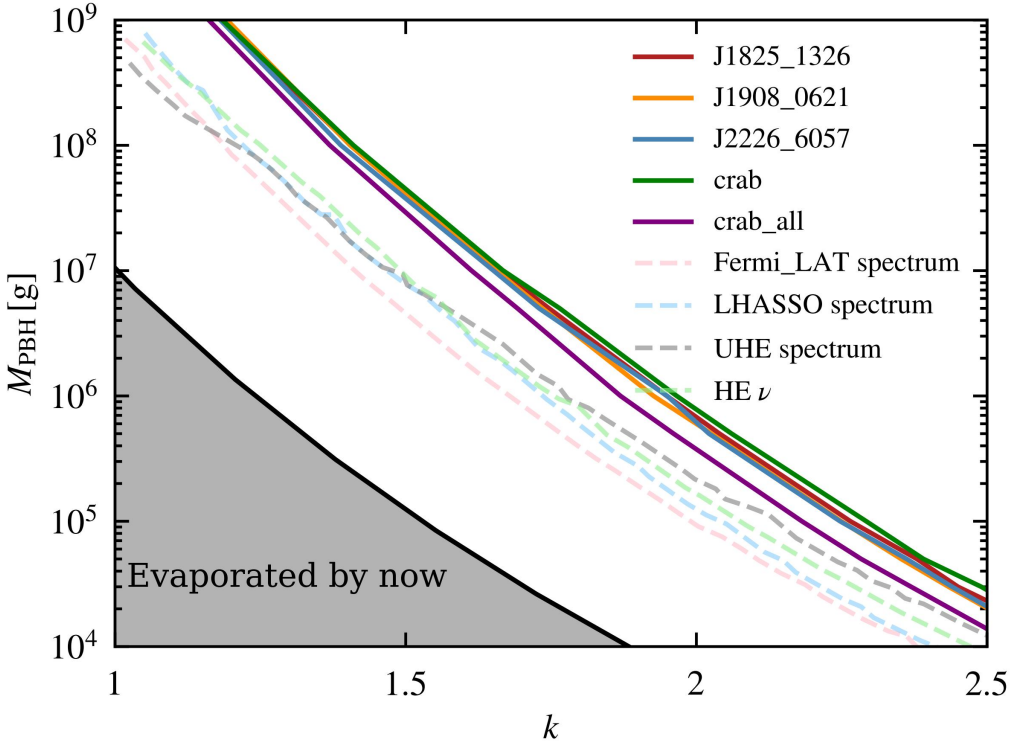
With more crab data:

$$\chi^2 = \sum_{i,j}\left[\frac{\phi_{i,j}^{\rm predict}(\theta) - f_j^{n-1}\phi_{i,j}^{\rm data}}{f_j^{n-1}\sigma_{i,j}^{\rm data}}\right]^2 + \sum_j\left[\frac{(f_j-1)}{\delta f_j}\right]^2$$



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When fix fraction 1 for the entropy index k, implying that the region above the lines corresponds to PBHs that can fully constitute the DM component of the Universe and have not yet evaporated.

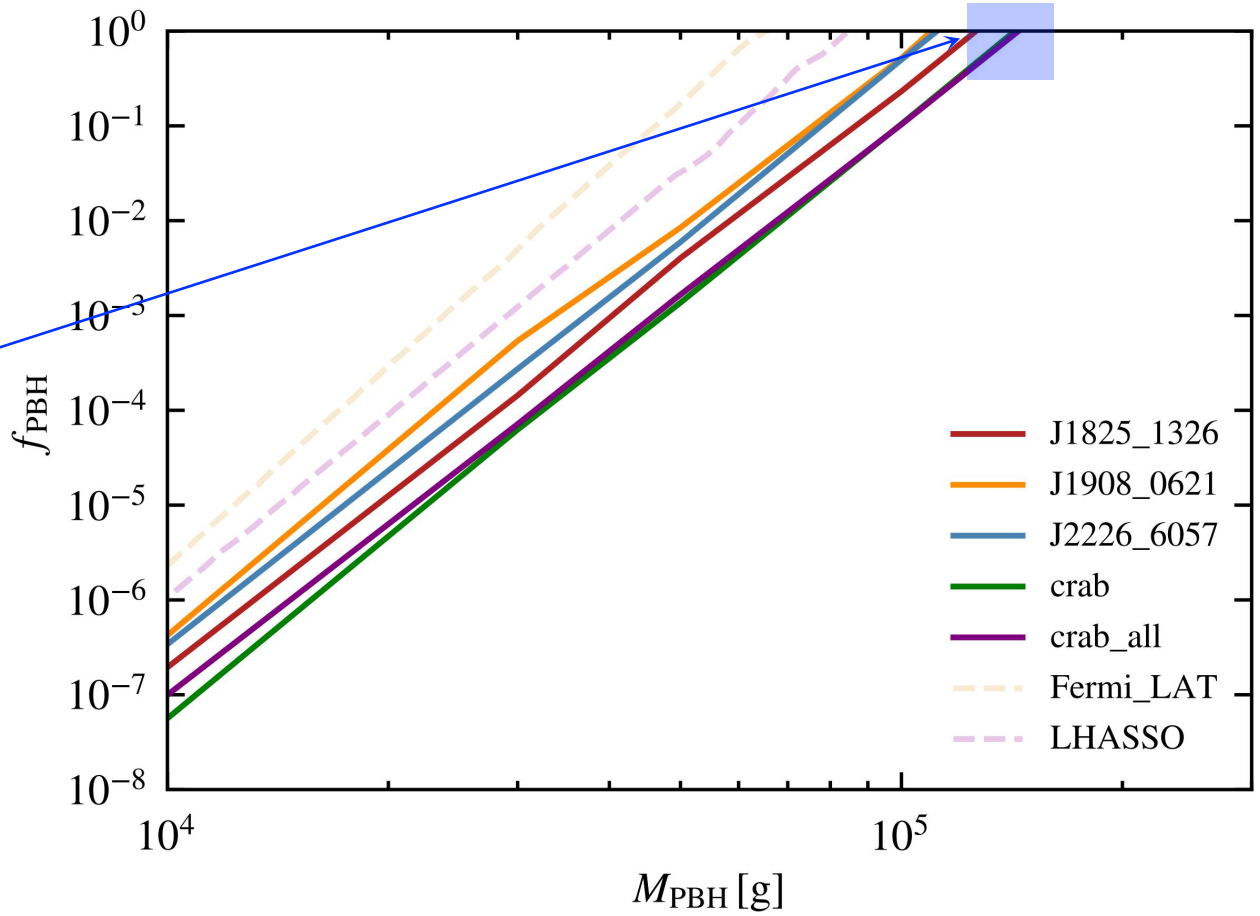


Gamma rays from MB PBHs @galactic sources

The bounds at the 95% C.L at **k=2:**

In the farcion and mass of PBHs plane of light PBHs resulting from the LHAASO observations of 4 GS.

Crab gives the strongest results, ruling out PBHs with $\leq 1.4 \times 10^5$ *g as full DM abundence.*



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Neutrinos from MB PBHs @DSphs

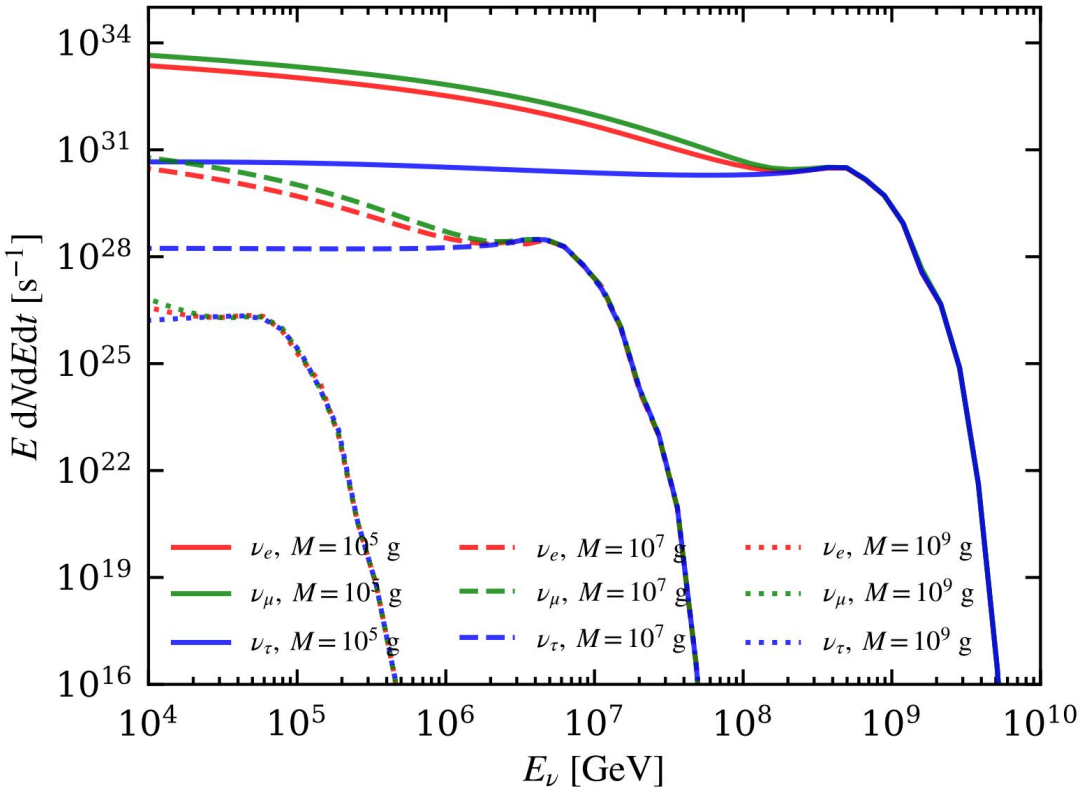
Memory burdend PBHs:

$$\frac{\mathrm{d}^2 N_\nu^{\mathrm{MB}}}{\mathrm{d}E_\nu \mathrm{d}t} = S(M_{\mathrm{PBH}})^{-k} \frac{g_\nu}{2\pi} \frac{\Gamma_{s_\nu}(x)}{e^x + 1}$$

$$\left.\frac{\mathrm{d}^2 N_{\nu_\alpha}^{\mathrm{MB}}}{\mathrm{d}E_\nu \mathrm{d}t}\right|_{\oplus} = \sum_{\beta=e}^{\tau} P_{\alpha,\beta} \left.\frac{\mathrm{d}^2 N_{\nu_\beta}^{\mathrm{MB}}}{\mathrm{d}E_\nu \mathrm{d}t}\right|_{\mathrm{PBH}}$$

$$P_{\alpha\beta} = \sum_{i=1}^{3} |U_{\alpha i}|^2 |U_{\beta i}|^2$$

Pontecorvo-Maki-Nakagawa-Sakata (PMNS) mixing matrix U



The production ratio at the source is 1 : 1 : 1. Consequently, the total flux remains equally partitioned among the three flavors after propagation over astronomical distances.

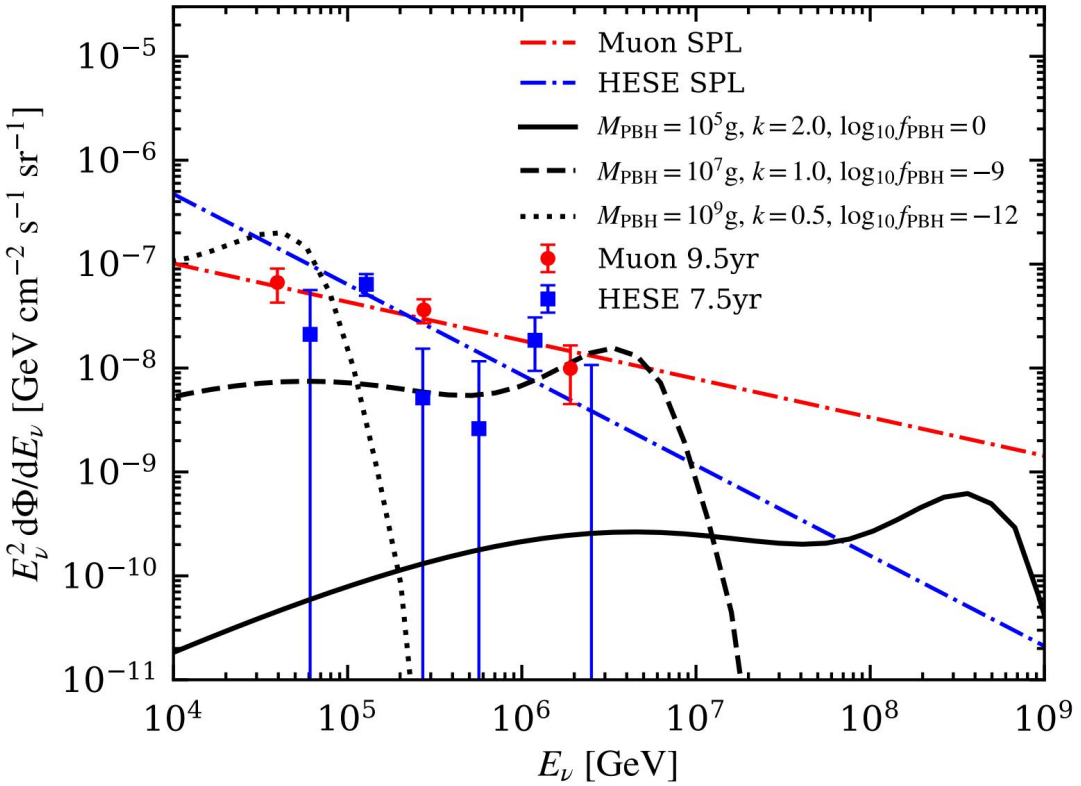
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Neutrinos from MB PBHs @DSphs

The neutrinos from memory burdend PBHs for DSphs:

$$\frac{\mathrm{d}\phi_{\nu_\alpha}^{\mathrm{dSph}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{f_{\mathrm{PBH}}}{4\pi M_{\mathrm{PBH}}} \frac{\mathrm{d}^2 N_{\nu_\alpha}^{\mathrm{MB}}}{\mathrm{d}E_\nu \mathrm{d}t} \mathcal{D}(\Omega) \qquad \frac{\mathrm{d}\phi_{\nu_\alpha}^{\mathrm{ext}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{c}{4\pi} n_{\mathrm{PBH},0} \int_0^{z_{\max}} \frac{\mathrm{d}z}{H(z)} \left. \frac{\mathrm{d}^2 N_{\nu_\alpha}^{\mathrm{MB}}}{\mathrm{d}E_\nu \mathrm{d}t} \right|_{\oplus} [E_\nu(1+z)]$$

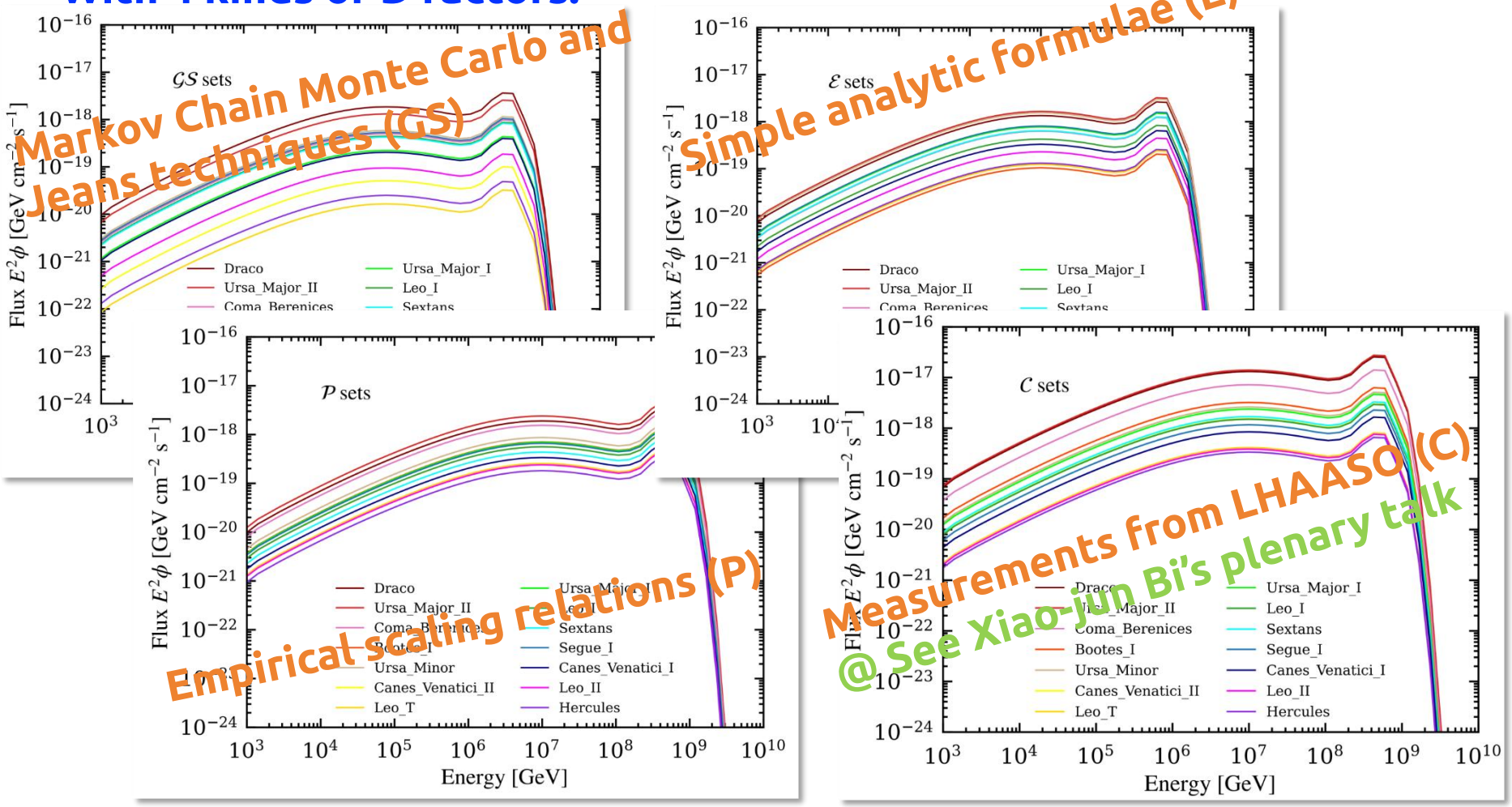
DSphs (name)	RA (deg)	DEC (deg)	d (kpc)	$r_{1/2}$ (pc)	$\log_{10}\mathcal{D}$ (GeV cm^{-2}) ($\mathcal{C}$ set)	($\mathcal{GS}$ set)	($\mathcal{E}$ set)	($\mathcal{P}$ set)
Draco	260.05	57.92	82	182	$19.38^{+0.24}_{-0.32}$	$18.53^{+0.10}_{-0.12}$	$18.39^{+0.25}_{-0.25}$	$18.54^{+0.11}_{-0.14}$
Leo I	152.12	12.30	250	292	$18.44^{+0.33}_{-0.42}$	$17.91^{+0.15}_{-0.20}$	$17.89^{+0.28}_{-0.28}$	$18.01^{+0.20}_{-0.28}$
Leo II	168.37	22.15	205	158	$17.85^{+0.62}_{-0.40}$	$17.24^{+0.35}_{-0.48}$	$17.62^{+0.25}_{-0.25}$	$17.64^{+0.50}_{-0.33}$
Sextans	153.26	-1.61	86	523	$18.49^{+0.28}_{-0.21}$	$17.89^{+0.13}_{-0.23}$	$18.07^{+0.29}_{-0.29}$	$17.90^{+0.11}_{-0.09}$
Ursa Minor	227.28	67.23	66	269	$18.68^{+0.33}_{-0.15}$	$18.03^{+0.16}_{-0.13}$	$18.45^{+0.24}_{-0.24}$	$18.20^{+0.14}_{-0.08}$
Boötes I	210.02	14.50	66	187	$18.77^{+0.40}_{-0.54}$	$17.90^{+0.23}_{-0.26}$	$17.28^{+0.64}_{-0.38}$	$18.11^{+0.25}_{-0.30}$
Canes Venatici I	202.02	33.56	218	423	$18.19^{+0.40}_{-0.39}$	$17.57^{+0.36}_{-0.72}$	$17.78^{+0.11}_{-0.11}$	$17.79^{+0.26}_{-0.27}$
Canes Venatici II	194.29	34.32	160	68	$18.45^{+0.50}_{-0.74}$	$16.97^{+0.24}_{-0.23}$	$17.37^{+0.40}_{-0.40}$	$18.01^{+0.36}_{-0.51}$
Coma Berenices	186.74	23.90	44	57	$19.12^{+0.46}_{-0.73}$	$17.96^{+0.20}_{-0.25}$	$18.06^{+0.32}_{-0.32}$	$18.45^{+0.29}_{-0.44}$
Hercules	247.76	12.79	132	98	$17.79^{+0.62}_{-0.61}$	$16.66^{+0.42}_{-0.40}$	$17.38^{+0.45}_{-0.45}$	$17.52^{+0.50}_{-0.51}$
Leo T	143.72	17.05	407	142	$17.88^{+0.65}_{-0.69}$	$16.48^{+0.22}_{-0.25}$	$17.35^{+0.37}_{-0.37}$	$17.67^{+0.53}_{-0.60}$
Segue I	151.77	16.08	23	21	$18.33^{+0.69}_{-0.63}$	$17.99^{+0.20}_{-0.31}$	$18.17^{+0.39}_{-0.39}$	$18.08^{+0.53}_{-0.49}$
Ursa Major I	158.71	51.92	97	199	$18.64^{+0.50}_{-0.48}$	$17.61^{+0.20}_{-0.38}$	$18.15^{+0.25}_{-0.25}$	$18.10^{+0.28}_{-0.29}$
Ursa Major II	132.87	63.13	30	99	$19.41^{+0.43}_{-0.57}$	$18.38^{+0.25}_{-0.27}$	$18.48^{+0.39}_{-0.39}$	$18.64^{+0.28}_{-0.31}$



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Neutrinos from MB PBHs @DSphs

With 4 kinds of D factors:



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Generally, the D-factor values determine the strength of the constraints, larger D-factor values correspond to higher dark matter densities, produce stronger neutrino fluxes and consequently more detectable events.

Neutrinos from MB PBHs @DSphs

14 denoting the total number of dSphs

nuisance parameter

$$\mathrm{TS} = -2\ln\left(\frac{\mathcal{L}(\hat{\mu},\hat{\boldsymbol{\xi}})}{\mathcal{L}(\mu_0,\hat{\boldsymbol{\xi}})}\right)$$

$$\mathcal{L}(\hat{\mu},\hat{\boldsymbol{\xi}}) = \max_{\mathcal{D}} \prod_{l=1}^{N_l} \prod_{j} \prod_{i=1}^{N_j} \left[\mathcal{L}_i^j(\hat{\mu}^j, \hat{\boldsymbol{\xi}}_i^j | \mathcal{D}_l) \times \mathcal{L}_{\mathcal{D}}(\mathcal{D}_l | \mathcal{D}_{0,l}, \sigma_{\mathcal{D}_l})\right]$$

each i-th muon-track event in the j-th data sample

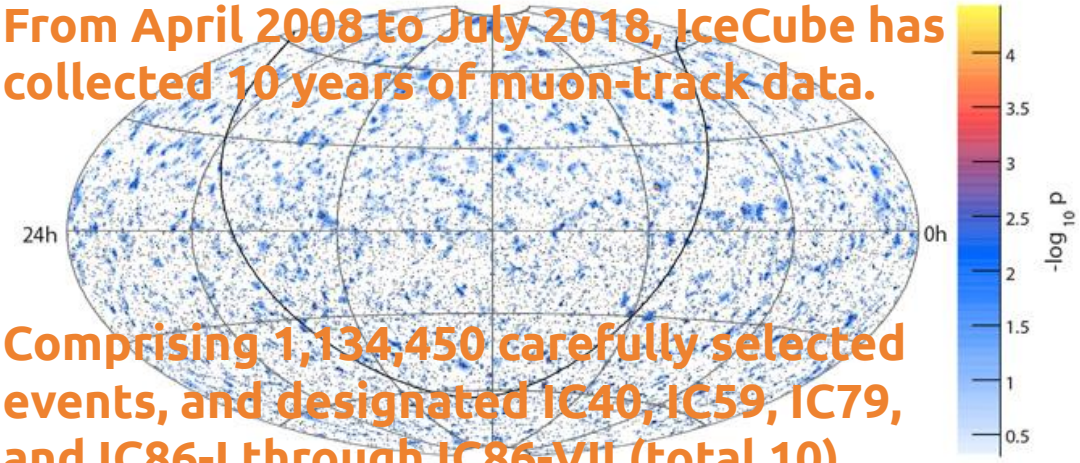
$$= \max_{\mathcal{D}} \prod_{l=1}^{N_l} \prod_{j} \prod_{i=1}^{N_j} \left[\left(\frac{\hat{\mu}^j \mathcal{D}_l}{N_j} S_i^j + \left(1 - \frac{\hat{\mu}^j \mathcal{D}_l}{N_j}\right) B_i^j\right) \times \mathcal{L}(\mathcal{D}_l | \mathcal{D}_{0,l}, \sigma_{\mathcal{D}_l})\right]$$

$$\mathcal{L}_{\mathcal{D}}(\mathcal{D}_l | \mathcal{D}_{0,l}, \sigma_{\mathcal{D}_l}) = \frac{1}{\ln(10)\mathcal{D}_{0,l}\sqrt{2\pi}\sigma_{\mathcal{D}_l}} \exp\left[-\frac{(\mathcal{D}_l - \mathcal{D}_{0,l})^2}{2\sigma_{\mathcal{D}_l}^2}\right]$$

$$\hat{\mu}^j = \kappa 4\pi T_{\mathrm{obs}}^j \int_{E_{\mathrm{min}}}^{E_{\mathrm{max}}} \mathrm{d}E_\nu A_{\mathrm{eff}}^j(E_\nu, \delta_s) \left.\frac{\mathrm{d}^2 N_{\nu_\alpha}^{\mathrm{MB}}}{\mathrm{d}E_\nu \mathrm{d}t}\right|_{\oplus}$$

$$\kappa = f_{\mathrm{PBH}}/(4\pi M_{\mathrm{PBH}})$$

From April 2008 to July 2018, IceCube has collected 10 years of muon-track data.



Comprising 1,134,450 carefully selected events, and designated IC40, IC59, IC79, and IC86-I through IC86-VII (total 10).

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Neutrinos from MB PBHs @DSphs

14 denoting the total number of dSphs

$$\mathrm{TS} = -2\ln\left(\frac{\mathcal{L}(\hat{\mu},\hat{\boldsymbol{\xi}})}{\mathcal{L}(\mu_0,\hat{\boldsymbol{\xi}})}\right)$$

$$\mathcal{L}(\hat{\mu},\hat{\boldsymbol{\xi}}) = \max_{\mathcal{D}} \prod_{l=1}^{N_l} \prod_{j} \prod_{i=1}^{N_j} \left[\mathcal{L}_i^j(\hat{\mu}^j,\hat{\boldsymbol{\xi}}_i^j|\mathcal{D}_l) \times \mathcal{L}_{\mathcal{D}}(\mathcal{D}_l|\mathcal{D}_{0,l},\sigma_{\mathcal{D}_l})\right]$$

each i-th muon-track event in the j-th data sample

$$= \max_{\mathcal{D}} \prod_{l=1}^{N_l} \prod_{j} \prod_{i=1}^{N_j} \left[\left(\frac{\hat{\mu}^j\mathcal{D}_l}{N_j}S_i^j + \left(1-\frac{\hat{\mu}^j\mathcal{D}_l}{N_j}\right)B_i^j\right) \times \mathcal{L}(\mathcal{D}_l|\mathcal{D}_{0,l},\sigma_{\mathcal{D}_l})\right]$$

$$\mathcal{L}_{\mathcal{D}}(\mathcal{D}_l|\mathcal{D}_{0,l},\sigma_{\mathcal{D}_l}) = \frac{1}{\ln(10)\mathcal{D}_{0,l}\sqrt{2\pi}\sigma_{\mathcal{D}_l}} \exp\left[-\frac{(\mathcal{D}_l-\mathcal{D}_{0,l})^2}{2\sigma_{\mathcal{D}_l}^2}\right]$$

The spatial probability distribution functions between dSph locations and IceCube neutrino events must be carefully considered, ***as sources positioned far from most detected events inevitably yield weaker connection.***

$$S_i^j = S_{\mathrm{spat}}^j(\vec{x}_i|\sigma_i,\vec{x}_s,\sigma_s)S_{\mathrm{ener}}^j(E_i|\vec{x}_i,\gamma),$$

$$B_i^j = B_{\mathrm{spat}}^j(\delta_i)B_{\mathrm{ener}}^j(E_i|\delta_i).$$

$$S_{\mathrm{spat}}^j(\vec{x}_i|\sigma_i,\vec{x}_s,\sigma_s) = \frac{1}{2\pi(\sigma_s^2+\sigma_i^2)}\exp\left[-\frac{D(\vec{x}_i,\vec{x}_s)^2}{2(\sigma_s^2+\sigma_i^2)}\right]\frac{D(\vec{x}_i,\vec{x}_s)}{\sin D(\vec{x}_i,\vec{x}_s)}$$

$$S_{\mathrm{ener}}^j(E_i|\vec{x}_i,\gamma) = \frac{\int \Phi_\nu(E_\nu)A_{\mathrm{eff}}^j(E_\nu,\delta_s)\mathcal{M}_j(E_i|E_\nu,\delta_s)\mathrm{d}E_\nu}{\int \Phi_\nu(E_\nu)A_{\mathrm{eff}}^j(E_\nu,\delta_s)\mathrm{d}E_\nu}$$

$$B_{\mathrm{spat}}^j(\delta_i) = \frac{N_{\delta_i\pm3}^j}{N_j\times\Delta\Omega}$$

$$B_{\mathrm{ener}}^j(E_{\mathrm{rec}}|\delta_i) = \frac{N_{i'j}^j}{N_{\delta_i\pm3}^j\Delta E_{i'}}$$

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Neutrinos from MB PBHs @DSphs

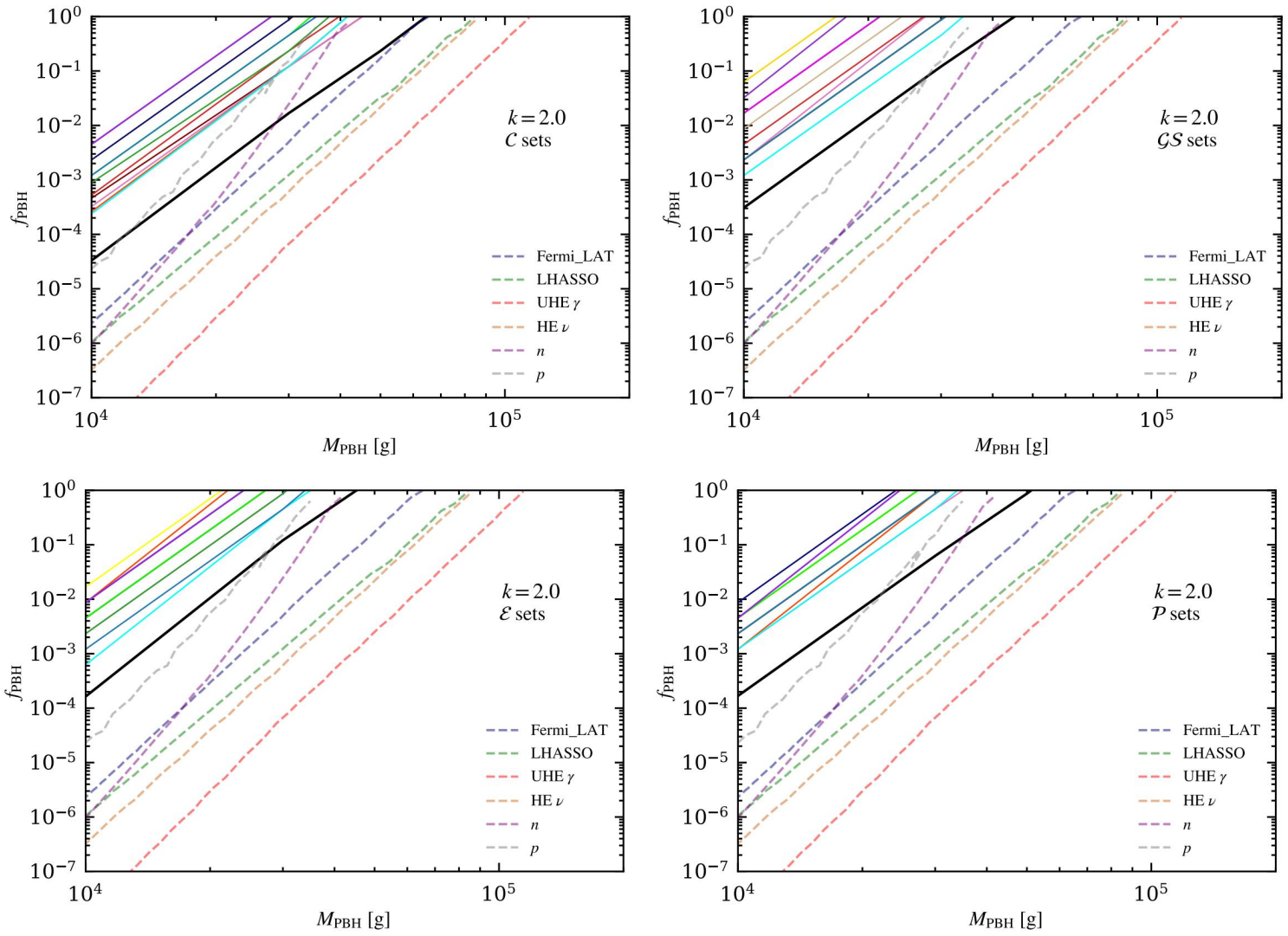
With k=2:

The strong suppression due to entropy effects significantly limits detectable events.

$$\frac{\mathrm{d}^2 N_\nu^{\mathrm{MB}}}{\mathrm{d}E_\nu \mathrm{d}t} = S(M_{\mathrm{PBH}})^{-k} \frac{g_\nu}{2\pi} \frac{\Gamma_{s_\nu}(x)}{e^x + 1}$$

The energy spectrum peak corresponding mass range is larger than IceCube range.

like 10^5 g PBH peasks at 100 PeV, out of Icecube range TeV to PeV.



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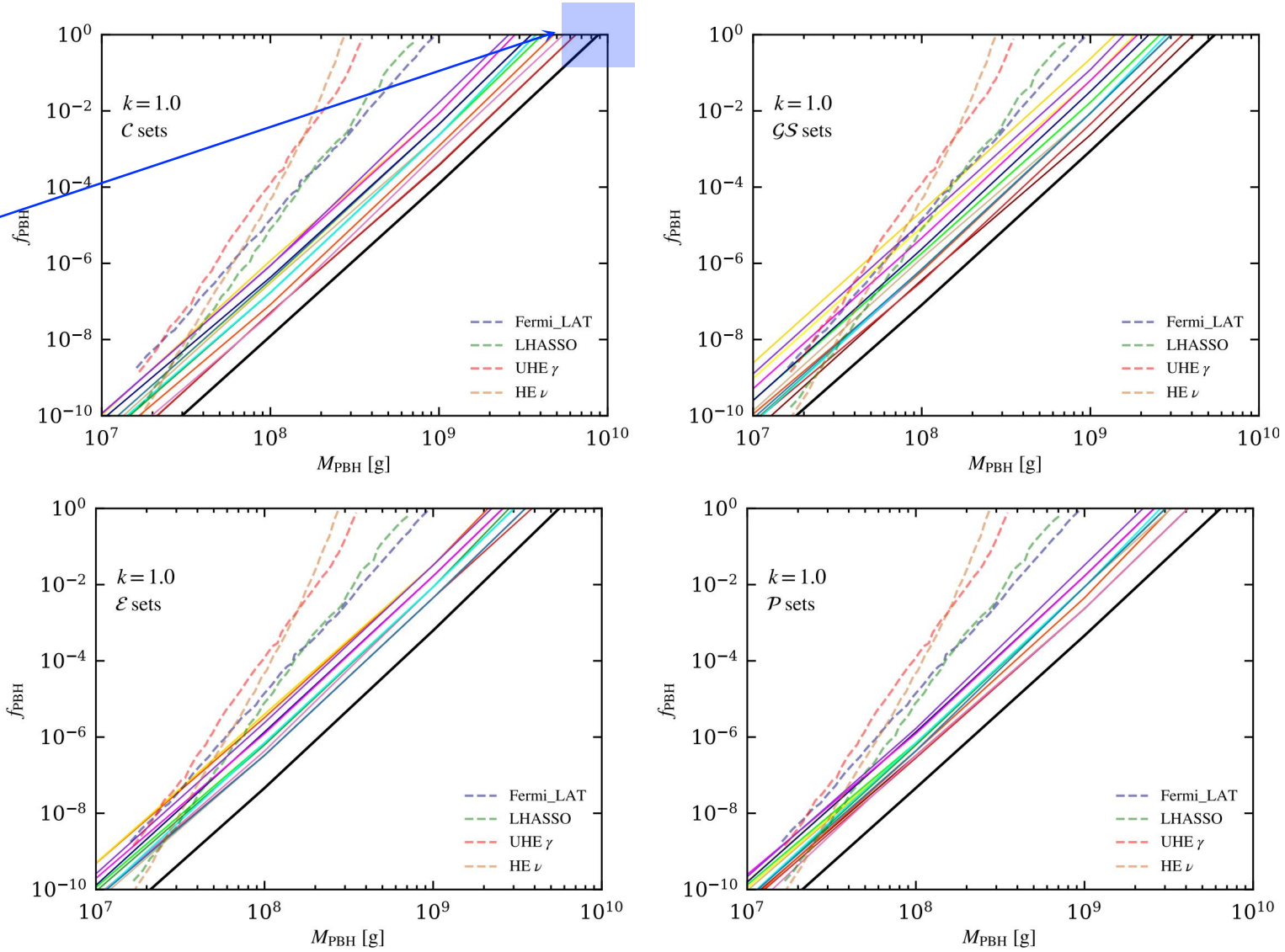
Neutrinos from MB PBHs @DSphs

With k=1:

The spectrum is harder and matches IceCube's energy range.

Up to approximately 10^{10} g, which significantly improves upon previous results.

Among the 14 dSphs, Ursa Major II provides the strongest, owing to its high D-factor value.



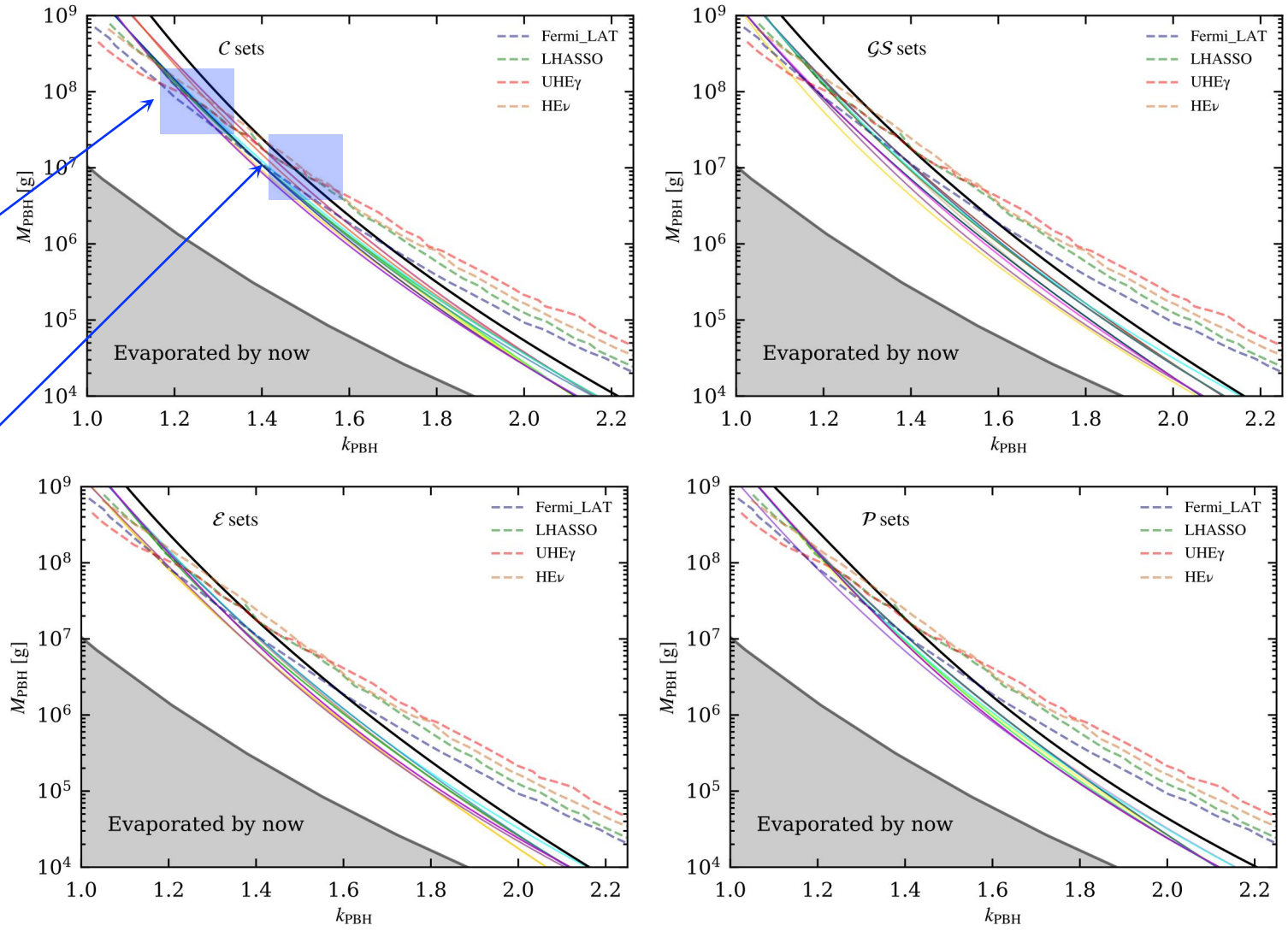
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Neutrinos from MB PBHs @DSphs

With k-M relation:

A clear trend with a different slope compared to previous studies, this reflects the growing sensitivity of the IceCube detector to harder neutrino spectra characteristic of more massive PBHs under the MB framework.

Stronger constraints than previous studies for k<1.3, and even for k<1.5 when all dSphs are combined.



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Anti-nuclei from MB PBHs @...

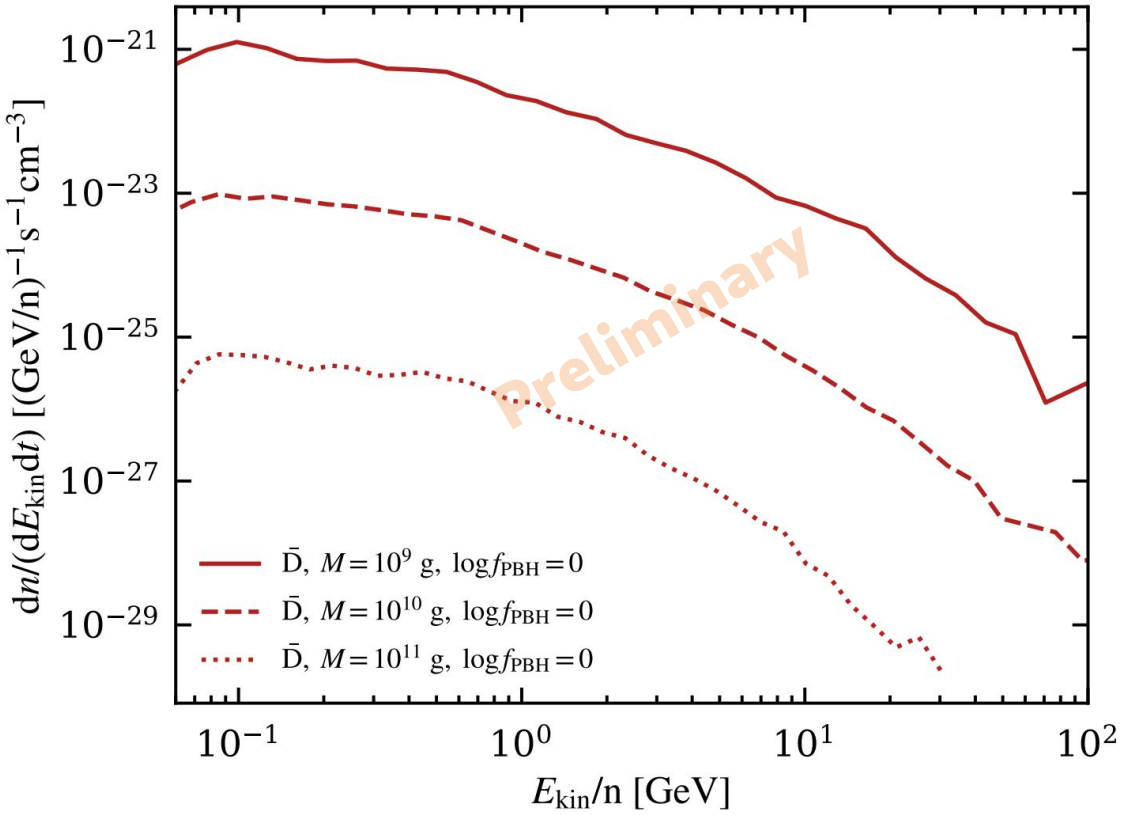
The anti-nuclei from memory burdend PBHs:

$$\frac{\mathrm{d}N^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{in}})}{\mathrm{d}E_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}\mathrm{d}t} = \sum_{i=g,q,W,Z,h} \int_{m_i}^{\infty} \mathrm{d}E_i \frac{\mathrm{d}N^{\mathrm{MB}}_i(E_i, M_{\mathrm{in}})}{\mathrm{d}E_i \mathrm{d}t} \times \frac{\mathrm{d}N^{\mathrm{MB}}_{i\to\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, E_i)}{\mathrm{d}E}$$

$$\frac{\mathrm{d}n^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{BH}})}{\mathrm{d}E\mathrm{d}t} = \int_{M_{\mathrm{min}}}^{M_{\mathrm{max}}} \mathrm{d}M \frac{\mathrm{d}N^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{in}})}{\mathrm{d}E_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}\mathrm{d}t} \frac{\mathrm{d}n}{\mathrm{d}M}$$

inject sources:

$$\mathcal{Q}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(r, z, E) = \frac{\rho_{\mathrm{PBH}}(r, z)}{\rho_{\odot}} \frac{\mathrm{d}n^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{BH}})}{\mathrm{d}E\mathrm{d}t}$$



© Xiu-hui Tan

Anti-nuclei from MB PBHs @...

The anti-nuclei from memory burdend PBHs:

$$\frac{\mathrm{d}N^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{in}})}{\mathrm{d}E_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}\mathrm{d}t} = \sum_{i=g,q,W,Z,h} \int_{m_i}^{\infty} \mathrm{d}E_i \frac{\mathrm{d}N^{\mathrm{MB}}_i(E_i, M_{\mathrm{in}})}{\mathrm{d}E_i \mathrm{d}t} \times \frac{\mathrm{d}N^{\mathrm{MB}}_{i\to\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, E_i)}{\mathrm{d}E}$$

$$\frac{\mathrm{d}n^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{BH}})}{\mathrm{d}E\mathrm{d}t} = \int_{M_{\mathrm{min}}}^{M_{\mathrm{max}}} \mathrm{d}M \frac{\mathrm{d}N^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{in}})}{\mathrm{d}E_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}\mathrm{d}t} \frac{\mathrm{d}n}{\mathrm{d}M}$$

inject sources:

$$\mathcal{Q}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(r, z, E) = \frac{\rho_{\mathrm{PBH}}(r, z)}{\rho_{\odot}} \frac{\mathrm{d}n^{\mathrm{MB}}_{\bar{p}(\bar{\mathrm{D}},{}^3\bar{\mathrm{He}})}(E, M_{\mathrm{BH}})}{\mathrm{d}E\mathrm{d}t}$$

When do sensitivity prediction, lighter constraints than previous, but still waiting for real data.

No astrophysical background as this signal.
A clean smoking-gun channel! 😀



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Very precise anti-positron data
No confirmed anti-deuterium detections



© Aramaki et al. 2015 AP74(2016)6

Design to detect sub-GeV anti-deuterium
Data are going to be released...

Take-home message

MB PBHs → Information resists decay → half mass, S^{-k} →

Gamma ray (4 GS, 1.4×10^{5} g) & **Neutrino** (14 dSphs, k=1 > k=2, 10^{10} g) & **Antinuclei**

the strongest single-band limits & **higher-sensitivity window** & **clean low-background channel**

- ○Memory burdened effect are particularly important for lighter PBHs.
- ○Tighter constraints derived in these two works.
- ○Right sources selection might help constraint PBHs.
- ○Mass function model, astrophycial processes, DM profiles, etc, need to be comfirmed.
- ○Looking forwaed to Multi-messenger analysis (including GWs together!) in the future.

Take-home message

MB PBHs → Information resists decay → half mass, S^{-k} →

Gamma ray (4 GS, 1.4×10^{5} g) & **Neutrino** (14 dSphs, k=1 > k=2, 10^{10} g) & **Antinuclei**

the strongest single-band limits & higher-sensitivity window & clean low-background channel

Thank you!

