Little Red Dots as hidden neutrino sources

Riku Kuze(YITP)

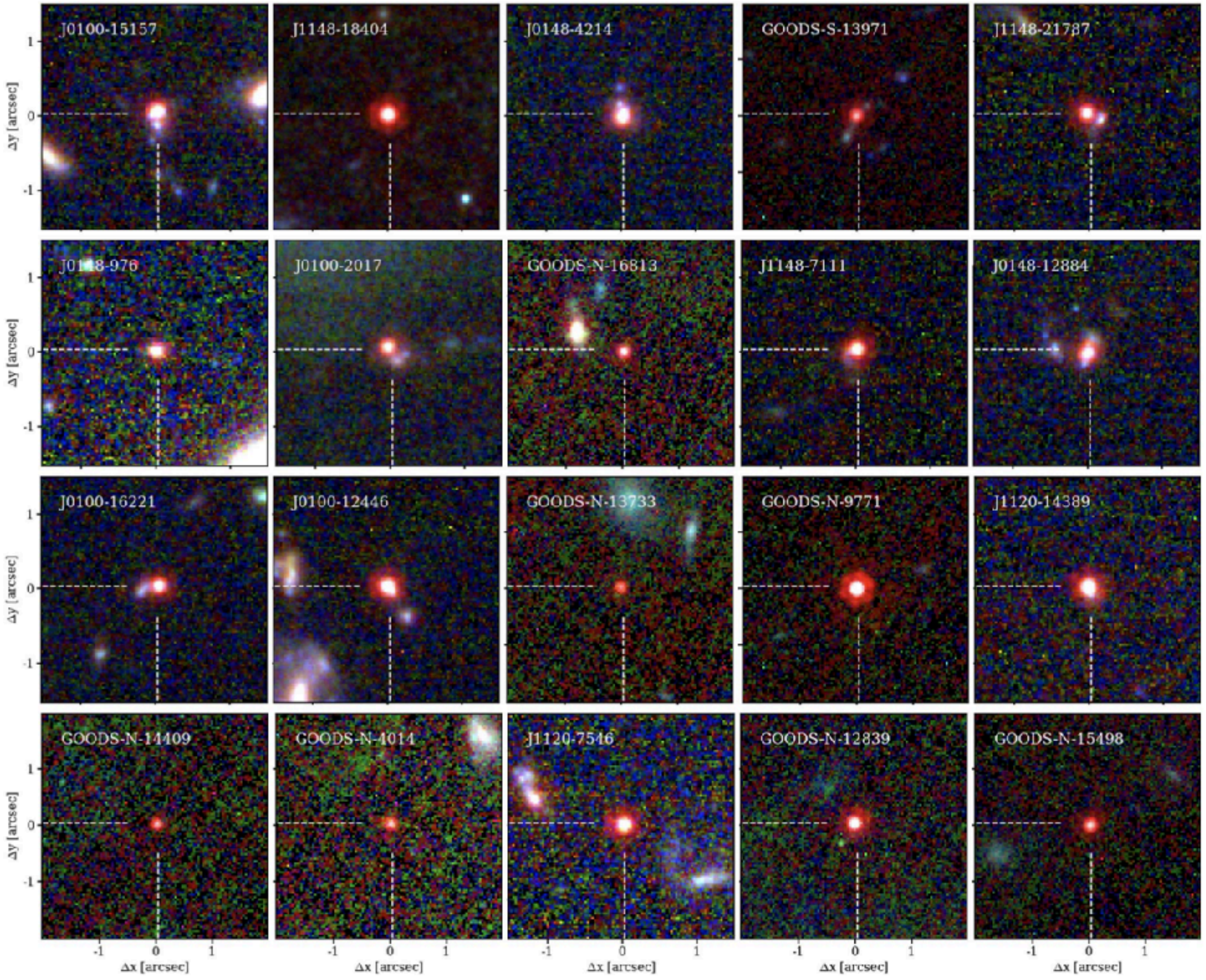
YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

Collaborators:
Kunihito Ioka(YITP), Kohta Murase(Penn State),
Shigeo S. Kimura(Tohoku), Kohei Inayoshi(Peking)

RK+2026 Phys. Rev. D 113, 083048

Little Red Dots(LRDs)

Matthee+2024



Discovered by JWST(2023)

Features of LRDs:

- Red and compact objects($R \lesssim 100$ pc)
- $z \gtrsim 4$, $\Phi(z\sim 4) \simeq 10^{-4.5}$ cMpc^{-3}

(e.g., High-z gal. $\Phi(z\sim 4) \simeq 10^{-2.5}$ cMpc^{-3})

- LRD candidates: a few $\times 10^2$
- Almost no detection in radio/X-ray
- Line width: $\sigma_v \simeq 1000$ km s^{-1} -> AGN like?

$L_{\rm Bol} \simeq 10^{44-46}$ erg s^{-1}-> $M_{\rm BH} \sim 10^7 M_\odot$?

$$L_{\rm Edd} \simeq 1.3\times 10^{38}\left(\frac{M_{\rm BH}}{M_\odot}\right)\ {\rm erg\ s^{-1}}$$

Little Red Dots(LRDs)

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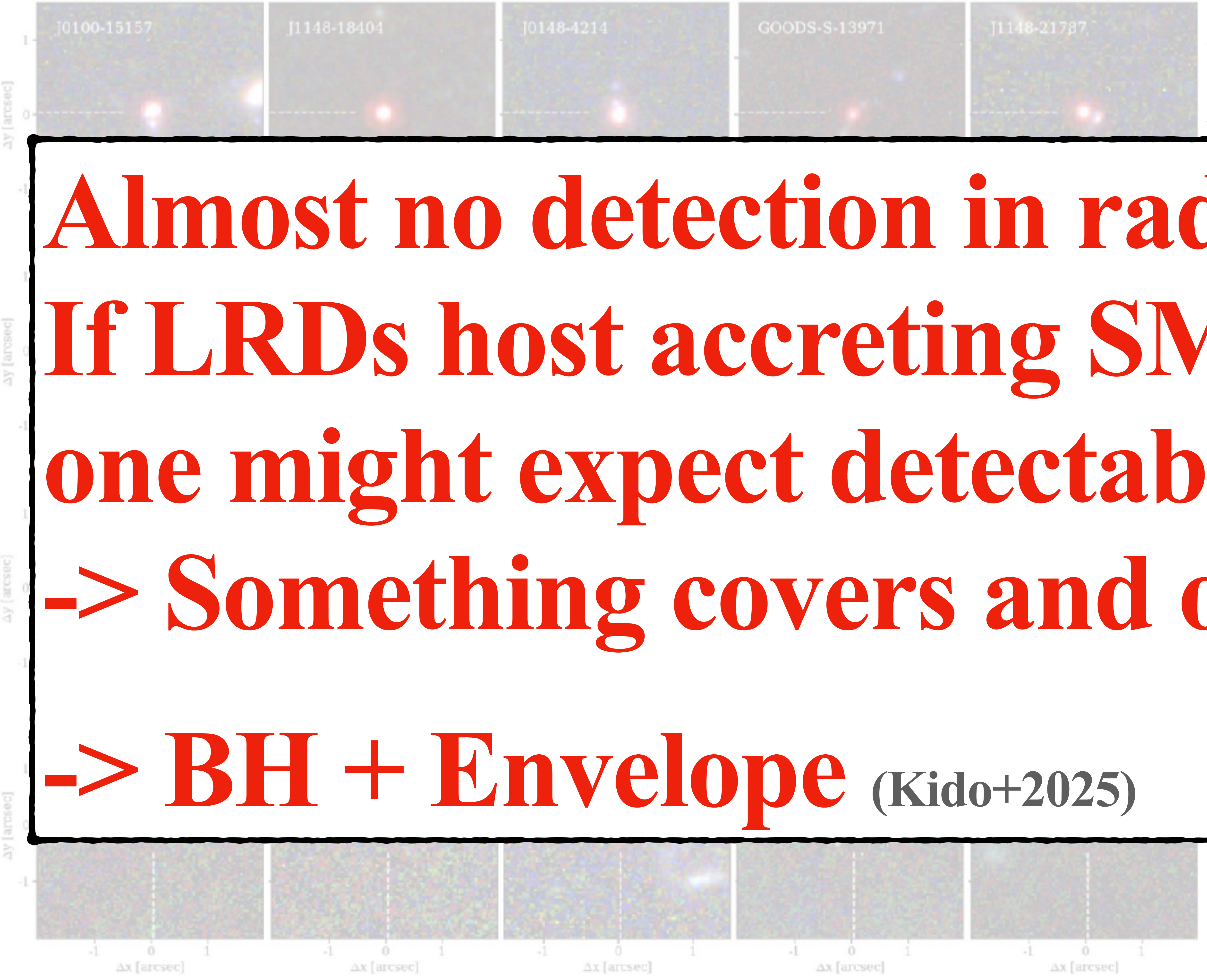


Discovered by JWST(2023)

Features of LRDs:

pc)

like?

Almost no detection in radio and X-ray bands.
If LRDs host accreting SMBHs,
one might expect detectable X-ray emission.
-> Something covers and obscures X-ray ?

-> BH + Envelope (Kido+2025)

$$L_{\rm Edd} \simeq 1.3 \times 10^{38} \left(\frac{M_{\rm BH}}{M_\odot} \right) \ {\rm erg\ s^{-1}}$$

BH + Envelope model

Little Red Dots: SMBHs embedded in dense envelopes

Kido et al. 2025

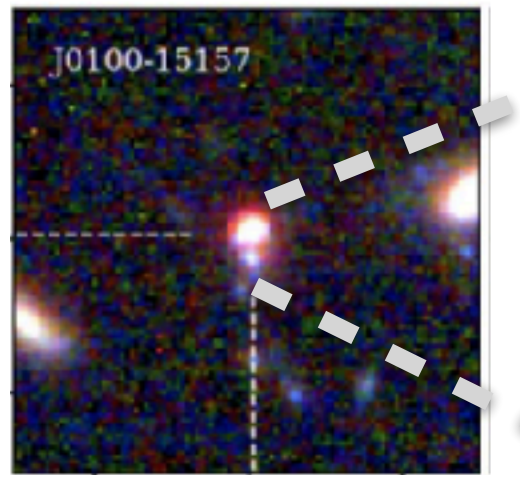
Assumption:

- Spherical mass accretion from ISM
- Hydrostatic

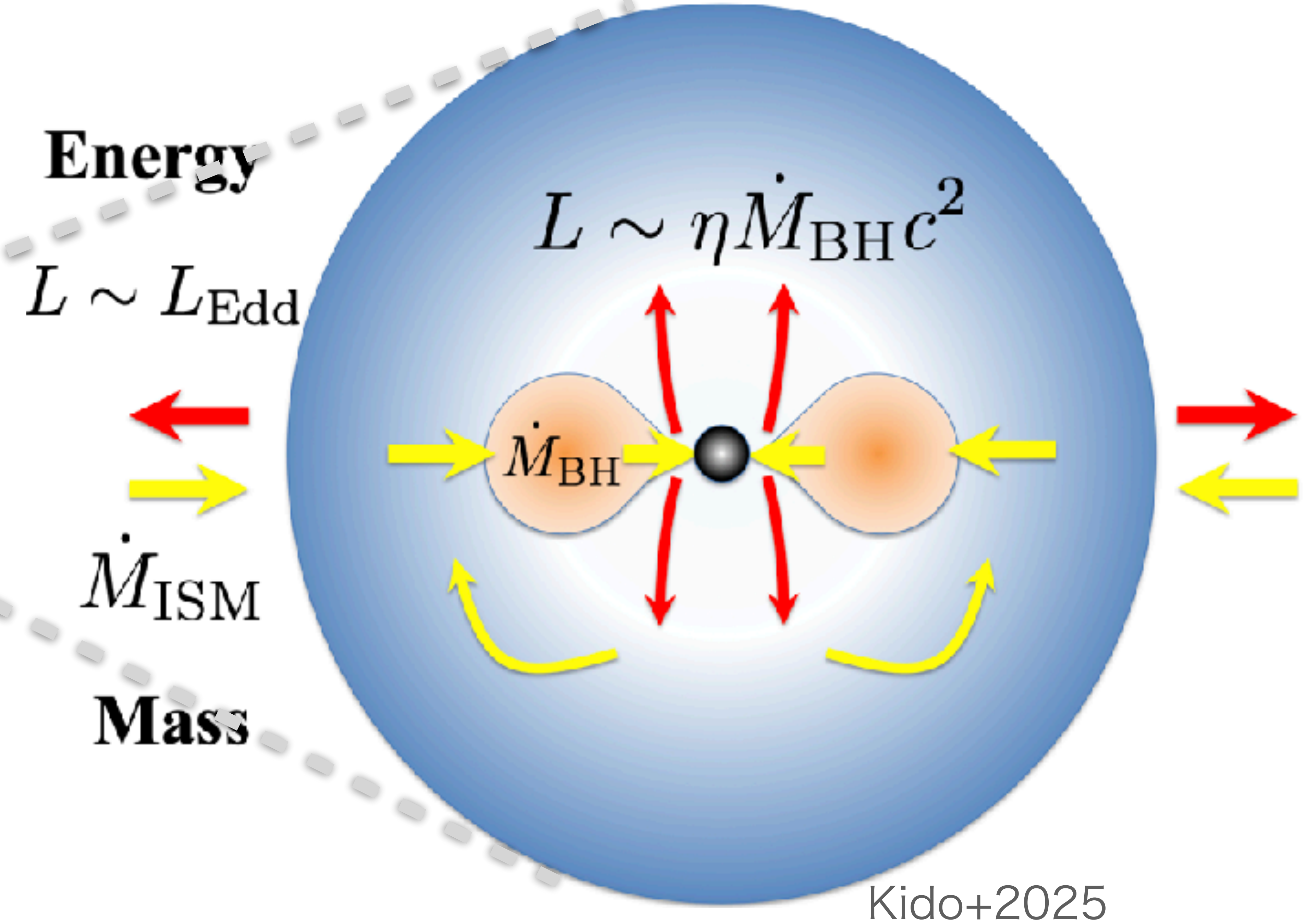
The envelope is supported by gas and radiation pressures.

Super-Eddington accretion + Free-fall

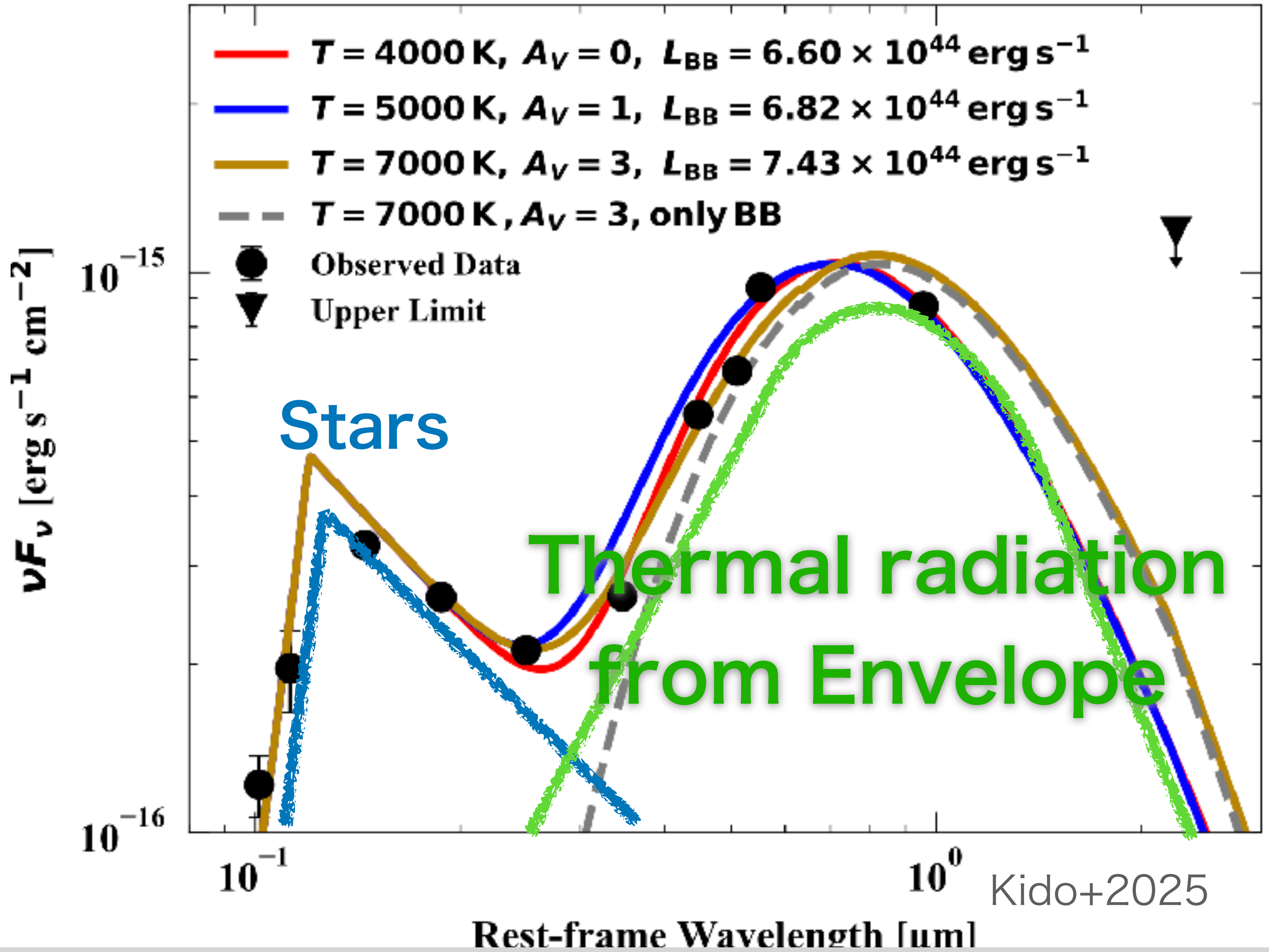
$$r_{\rm ph} \simeq 2\times10^{16}\ {\rm cm},\quad T_{\rm ph} = \left(\frac{L_{\rm Edd}}{4\pi\sigma_{\rm SB} r_{\rm ph}^2}\right)^{1/4} \simeq 7000\ {\rm K}$$



Matthee+2024



Kido+2025



Kido+2025

BH + Envelope model

Little Red Dots: SMBHs embedded in dense envelopes

Kido et al. 2025

Assumption:

Super-Eddington accretion + Free-fall

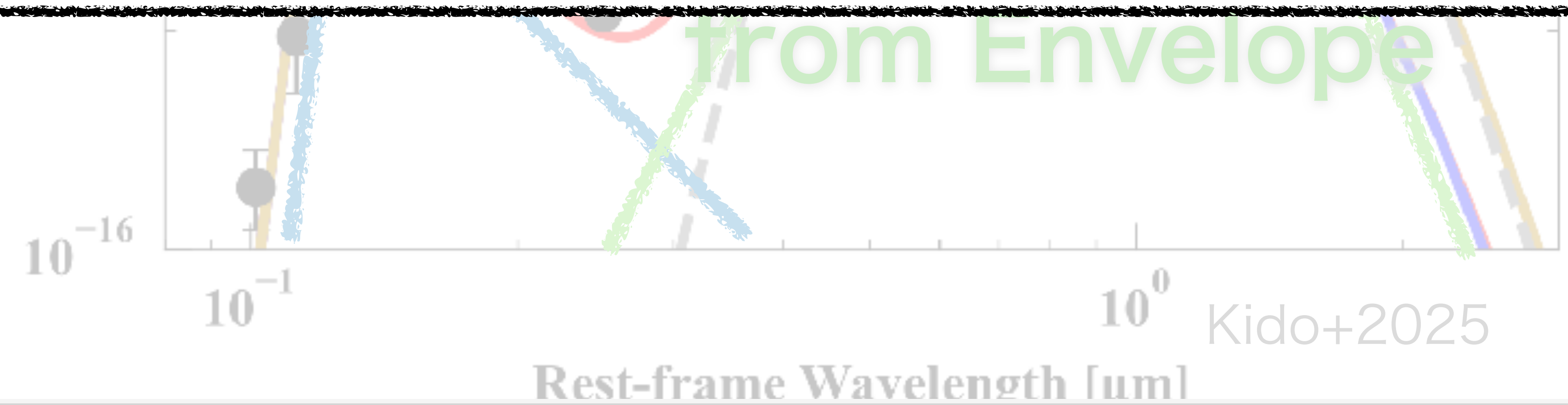
Copious photons & particles around BH…

If **non-thermal particles are generated** inside this envelope,

they will **interact with photons and particles** and **produce neutrinos.**

Matthee+

Kido+2025



Kido+2025

Why neutrinos from LRDs?

LRDs are high-z objects

-> Detecting neutrinos is difficult

$z = 5 \rightarrow D \simeq 50\ \mathrm{Gpc} = 1.5 \times 10^{29}\ \mathrm{cm},$

$L_\nu \simeq 0.01 L_{\mathrm{Edd}} \simeq 10^{43}\ \mathrm{erg\ s^{-1}}$

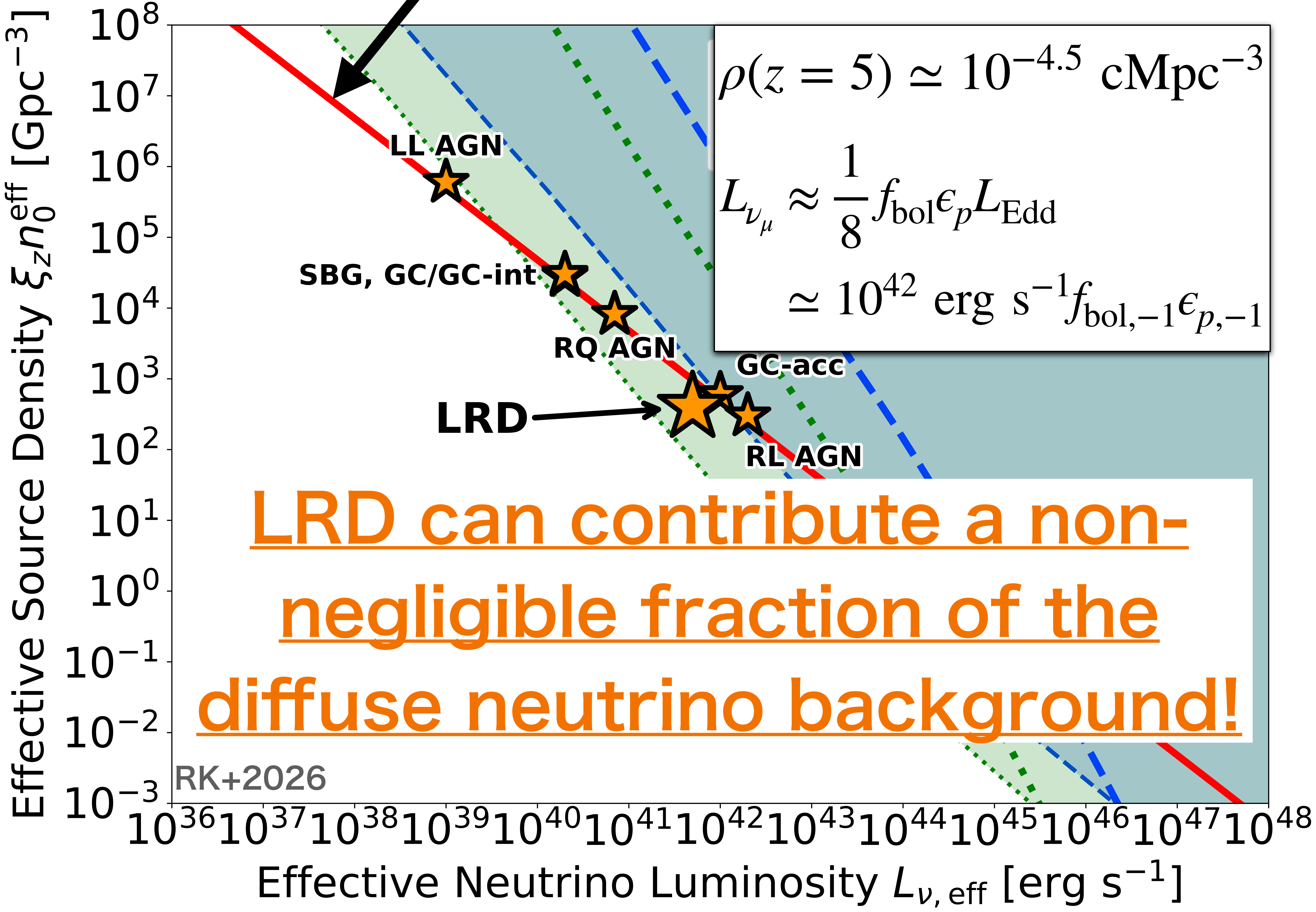
-> $F_\nu = \dfrac{L_\nu}{4\pi D^2} \simeq 3.5 \times 10^{-17}\ \mathrm{erg\ cm^{-2}\ s^{-1}}$

-> Detecting neutrinos with current neutrino detectors is very challenging.

・LRDs: **High luminosity** & **Large number density**

-> They may contribute to the diffuse neutrino background.

Red solid line: **Required number density** and **neutrino luminosity** to explain the diffuse neutrino background.



$\rho(z=5) \simeq 10^{-4.5}\ \mathrm{cMpc^{-3}}$

$L_{\nu_\mu} \approx \dfrac{1}{8} f_{\mathrm{bol}} \epsilon_p L_{\mathrm{Edd}}$

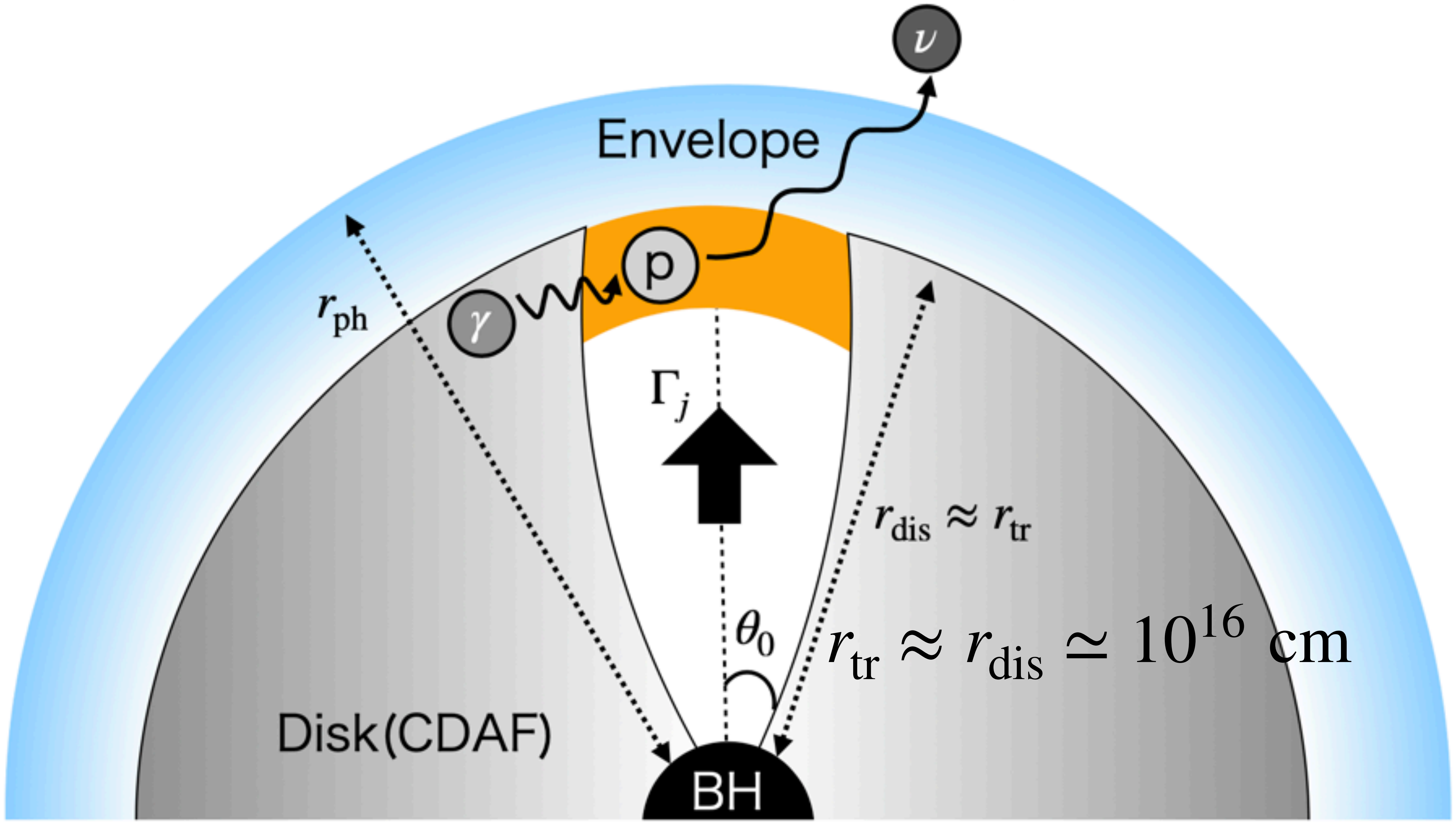
$\simeq 10^{42}\ \mathrm{erg\ s^{-1}} f_{\mathrm{bol},-1} \epsilon_{p,-1}$

LRD can contribute a non-negligible fraction of the diffuse neutrino background!

Neutrino emission environment

$M_{\rm BH} \approx M_{\rm env} \simeq 10^{6-6.5} M_\odot, \;\; L_j \approx L_{\rm Edd}, \; \Gamma_j \simeq 2.0, \;\; \theta_0 = 1.0$

$r_{\rm ph} \simeq 1.5 \times 10^{16} \; {\rm cm} \; L_{44.6}^{1/2} T_{\rm eff,5000}^{-2}$



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＊We consider a funnel as a particle acceleration site.

・Formation scenario

Accreting gases have **some angular momentum.**

-> **A funnel is formed due to the angular momentum barrier.**

• Neutrino emission process:

Funnel interior is dilute.

-> Photomeson production ($p + \gamma \rightarrow p + \pi$)

• What is the target photon field ?

Thermal radiation from the surrounding disks.

We need to estimate the temperature of the surrounding disks at the jet dissipation region.

Efficiency of $p\gamma$ interactions

$M_{BH} \approx M_{env} \simeq 10^{6-6.5} M_{\odot}, \;\; L_j \approx L_{Edd}, \; \Gamma_j \simeq 2.0, \;\; \theta_0 = 1.0$

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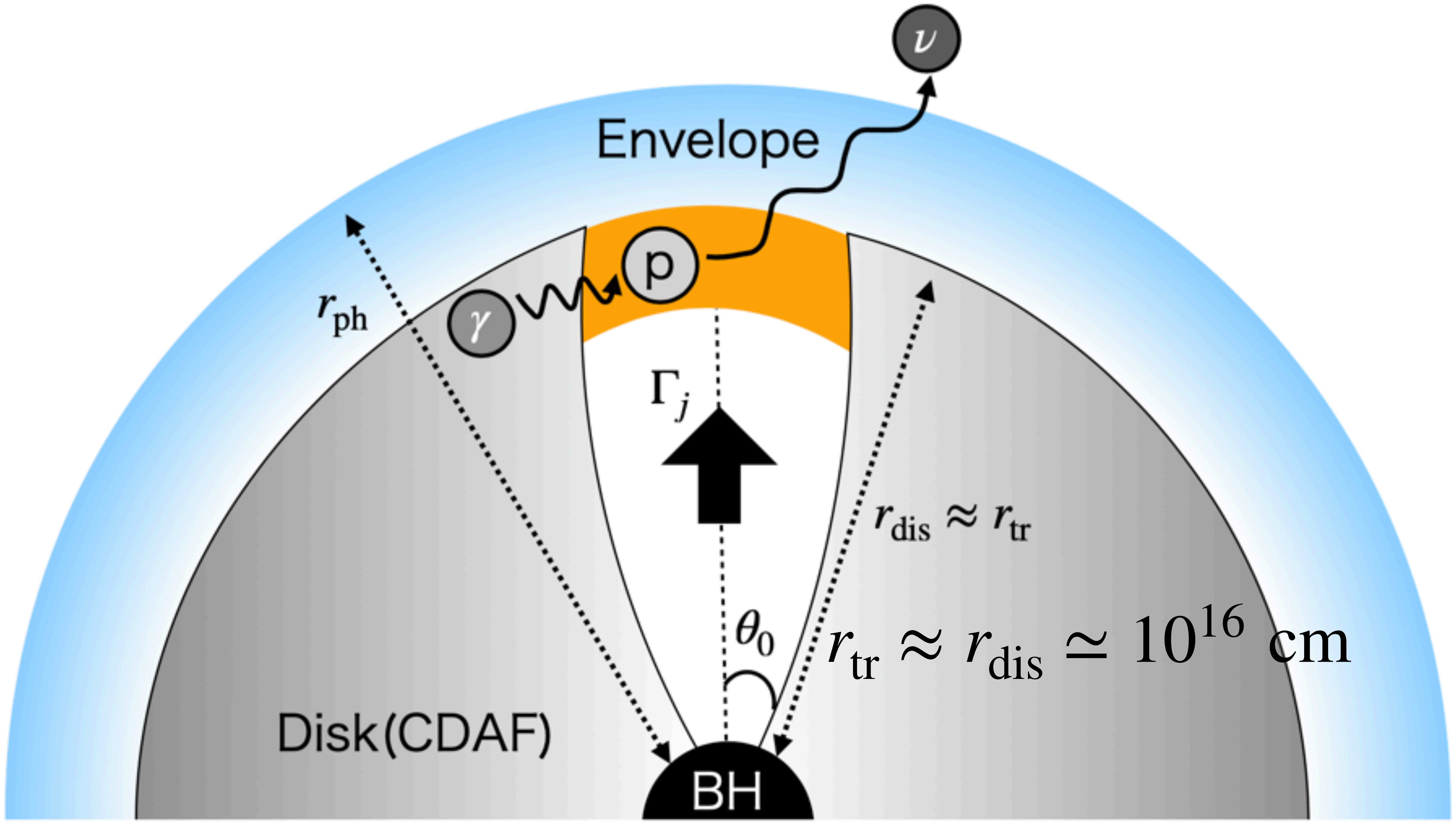

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<u>To estimate the temperature,</u>
<u>we assume the force balance.</u>

At the jet dissipation region, $F_{rad} \sim F_{grav}$

$$\frac{1}{3} a T^4 \approx \frac{G M_{BH} \rho}{r}$$

-> $T(r_{dis}) \simeq 1.7 \times 10^5 \text{ K } r_{dis,16}^{-1} M_{BH,6.5}^{1/4} M_{env,6.5}^{1/4}$

Then, the optical depth of the $p\gamma$ interactions is

$$\tau_{p\gamma} \approx n'_{\gamma} \sigma_{p\gamma} r_{dis} \theta_j(r_{dis})$$
$$\simeq 9.0 \times 10^3 r_{dis,16}^{-5/2} M_{BH,6.5}^{5/4} M_{env,6.5}^{3/4} (\Gamma_j/2)(\theta_0/1) \gg 1$$

Non-thermal particles within the funnel produce neutrinos through photomeson production ($p + \gamma \rightarrow p + \pi$) before escape!

Spectrum Calculation: Timescales

Code: **AMES**(**A**strophysical **M**ulti-messenger **E**mission **S**imulator)

B. T. Zhang&Murase 2023, Wei Yu-Jia+2025

Basic Equation: Kinetic Equation

$$\frac{\partial n_{E_p}}{\partial t} = \dot{n}_{E_{p,\mathrm{inj}}} - \frac{n_{E_p}}{t_{\mathrm{esc}}} + \frac{\partial}{\partial E_p}\left(\frac{E_p}{t_{p,\mathrm{cool}}} N_{E_p}\right) - \frac{n_{E_p}}{t_{p\gamma}} + \frac{\partial}{\partial t}\left(n_{E_p}^{\mathrm{p-gen}}\right)$$

Injection Escape Cooling Secondary Injection

$$\dot{n}_{E_{p,\mathrm{inj}}} \approx \dot{n}_0 E_p^{-2} \exp\left(-\frac{E_p}{E_{p,\mathrm{cut}}}\right)$$

$$\frac{L_p}{V} = \frac{\epsilon_p L_j}{V} = \int \dot{n}_{E_p,\mathrm{inj}} E_p dE_p, \quad \epsilon_p = 0.1$$

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One-zone & Steady-state approximations

The photon field is dense ($\tau_{p\gamma} \gg 1$).

-> **Cooling is dominant** rather than escape

Cooling processes:

Photomeson production: $p + \gamma \rightarrow p + \pi$

Bethe-Heitler process: $p + \gamma \rightarrow p + e^{+} + e^{-}$

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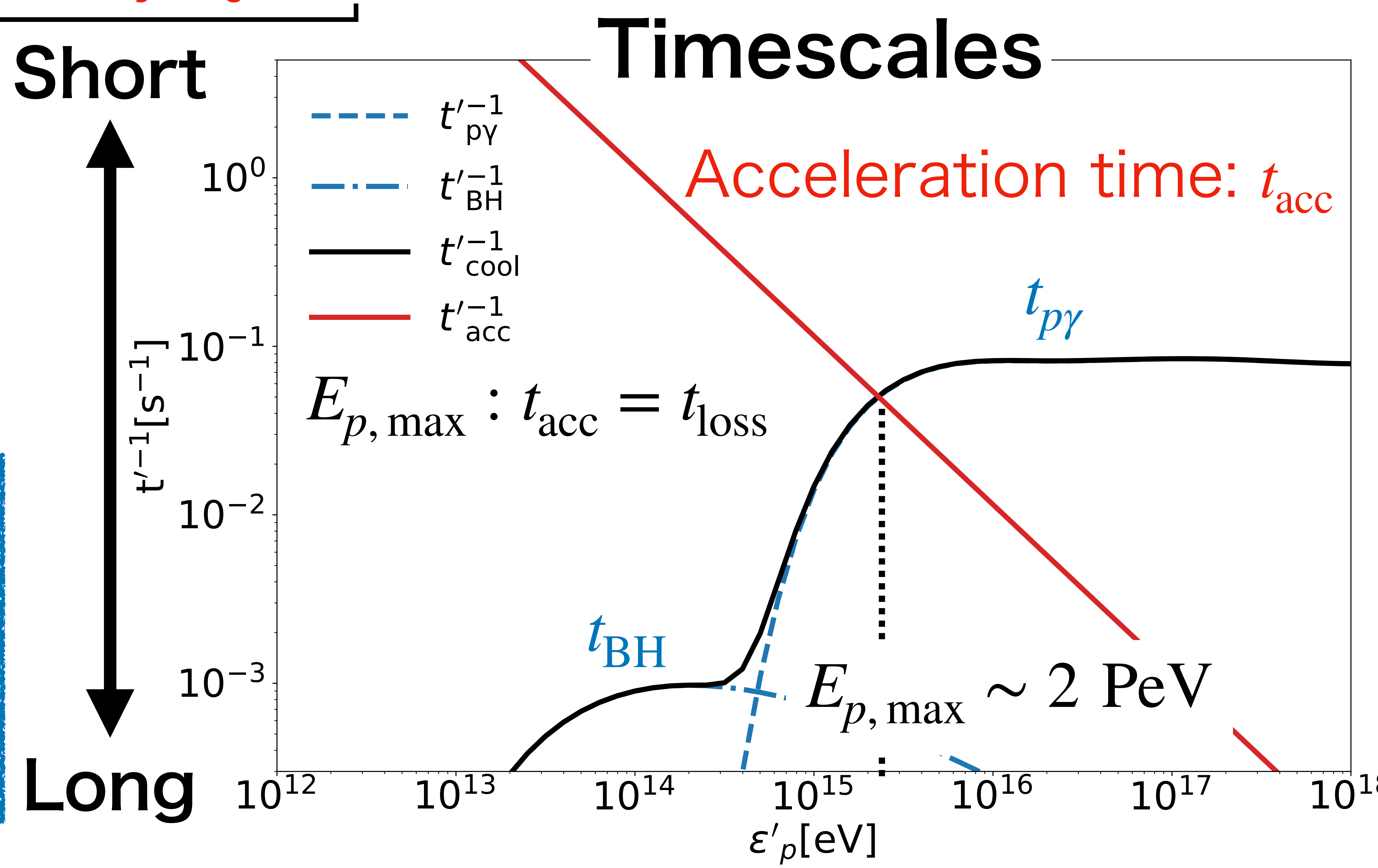

Spectrum Calculation: Spectra

Code: **AMES**(**A**strophysical **M**ulti-messenger **E**mission **S**imulator)

B. T. Zhang&Murase 2023, Wei Yu-Jia+2025

Basic Equation: Kinetic Equation

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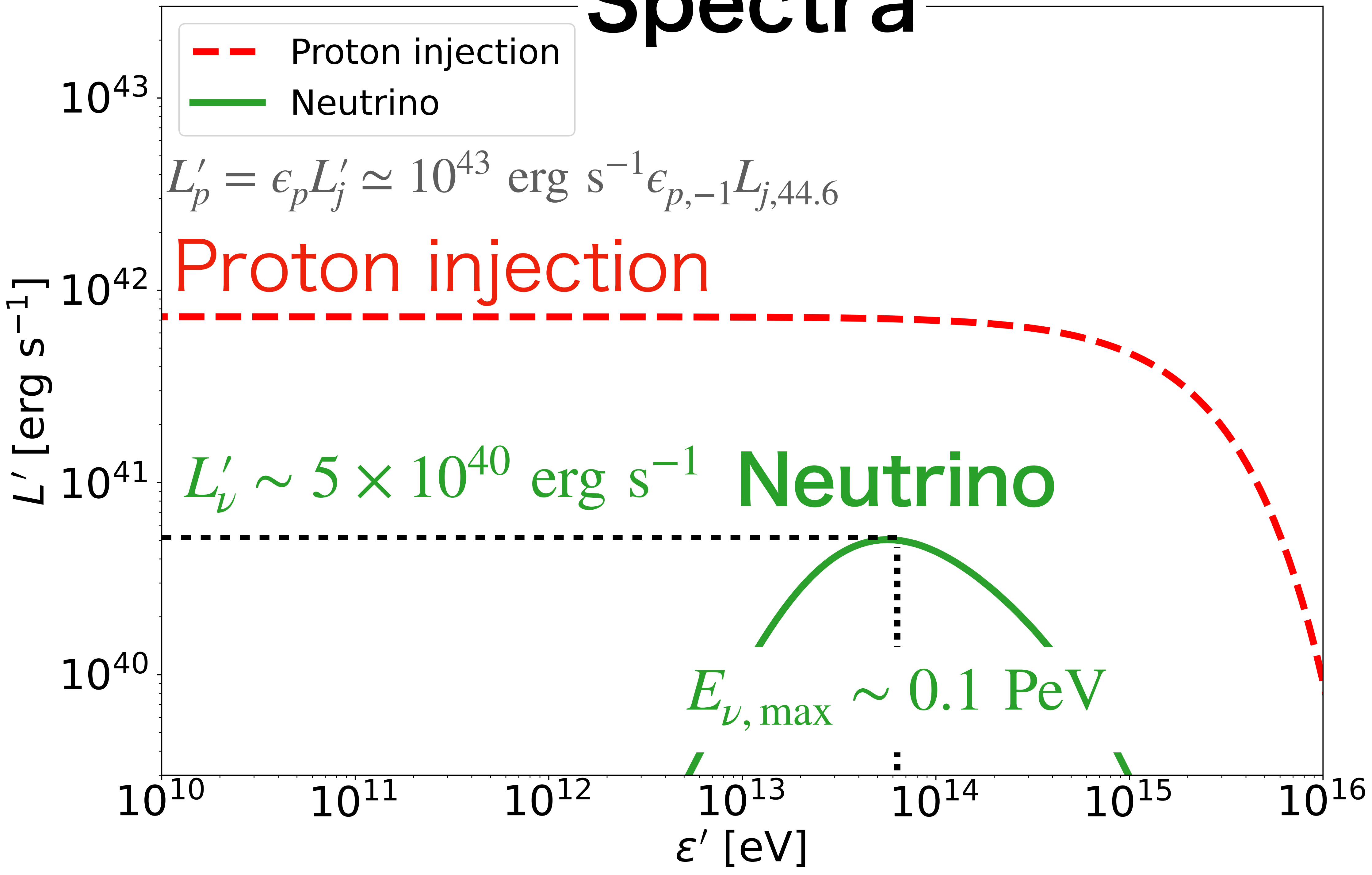
Spectra



LRD number densities

To evaluate the contribution to the diffuse neutrino background, we need to consider the **LRD populations at each redshift.**

3 models

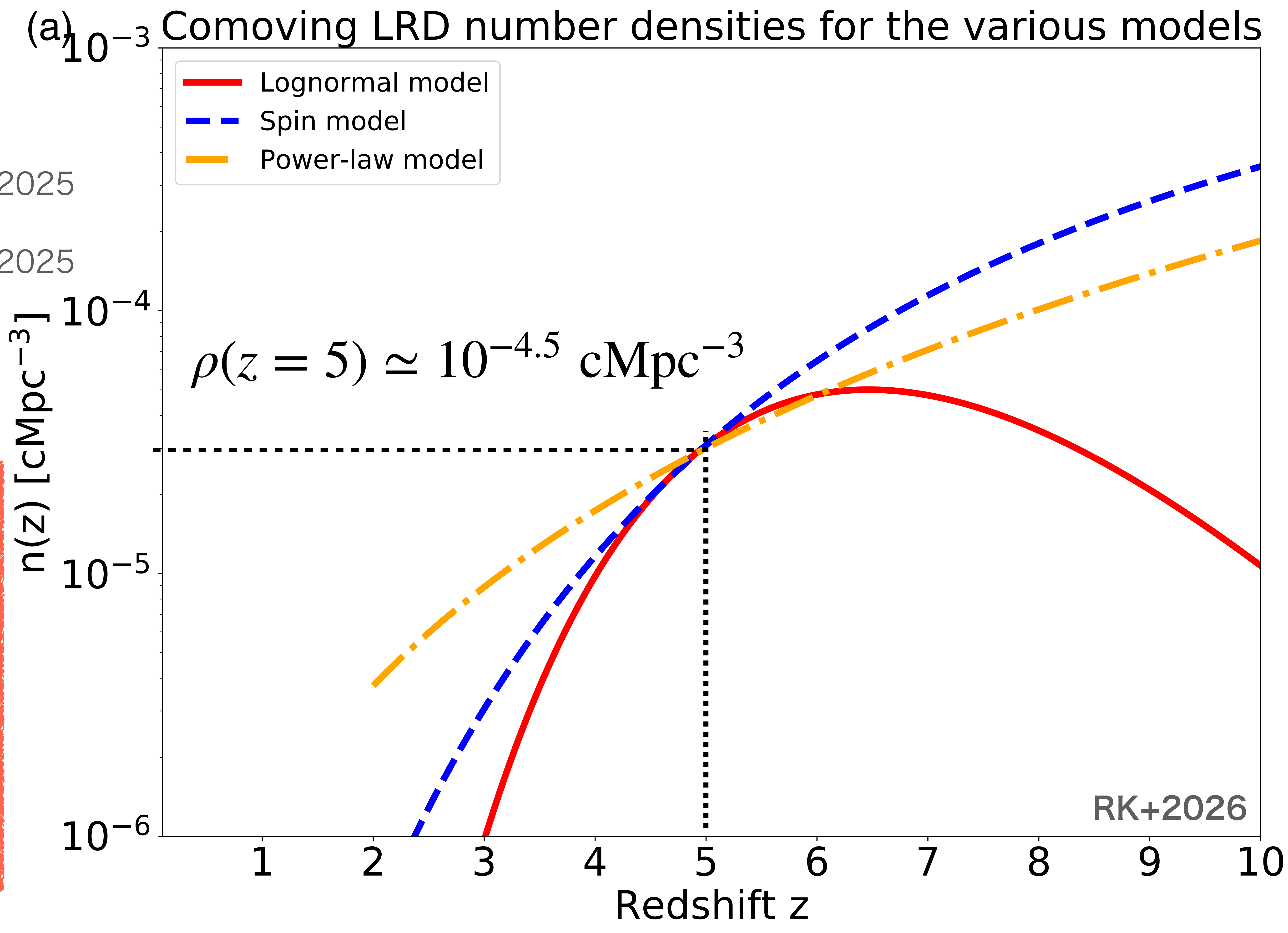
Observation (i) Lognormal model Inayoshi 2025

Theory (ii) Spin model Pacucci&Loeb 2025

Comparison (iii) Power-law model

- **Neutrino luminosity**
- **LRD population**

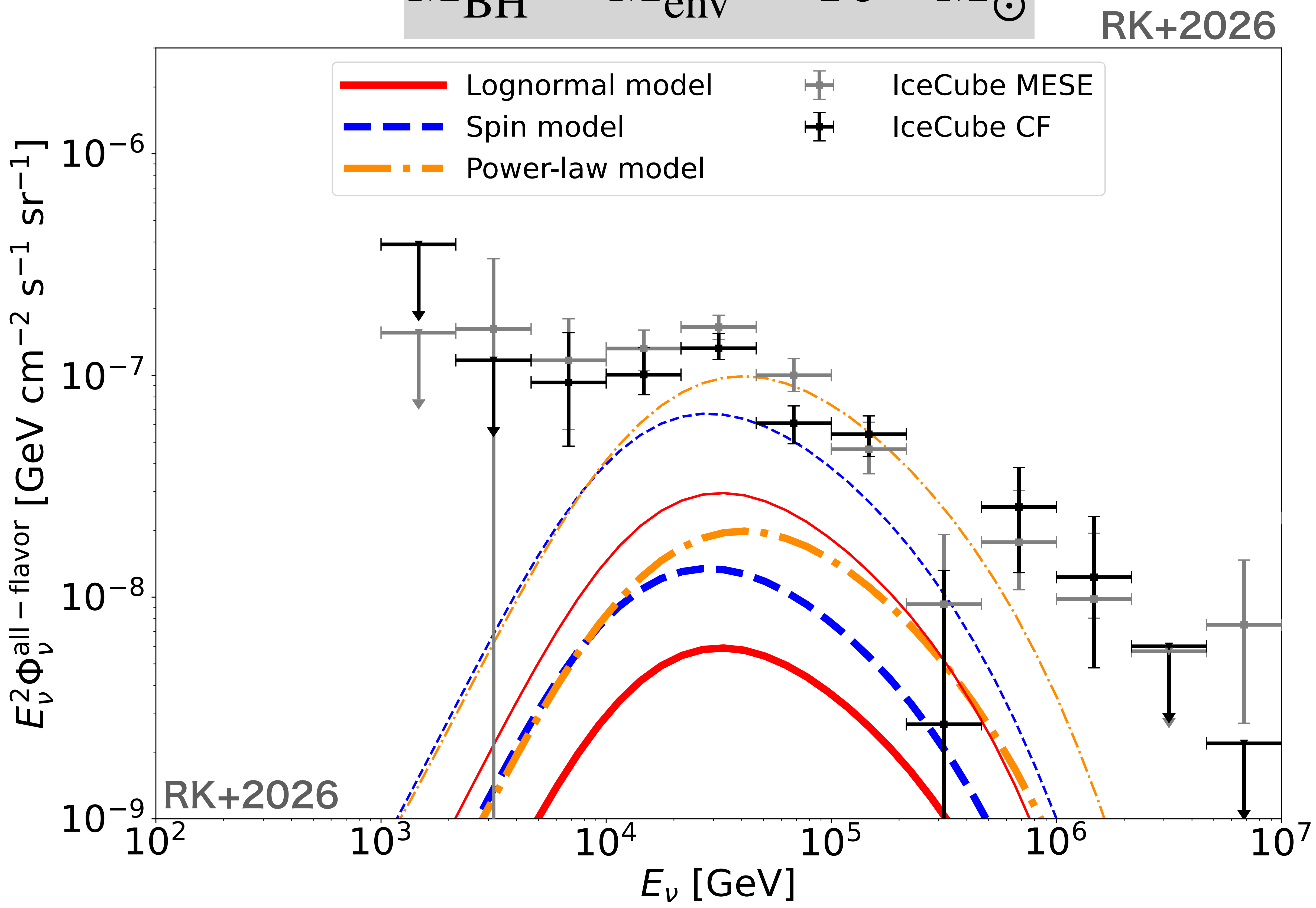
-> **We can evaluate the contribution to the diffuse neutrino background.**



Contribution to the diffuse neutrinos (1)

Thick: $\epsilon_p = 0.1$, Thin: $\epsilon_p = 0.5$

$M_{\rm BH} = M_{\rm env} = 10^{6.5} M_\odot$



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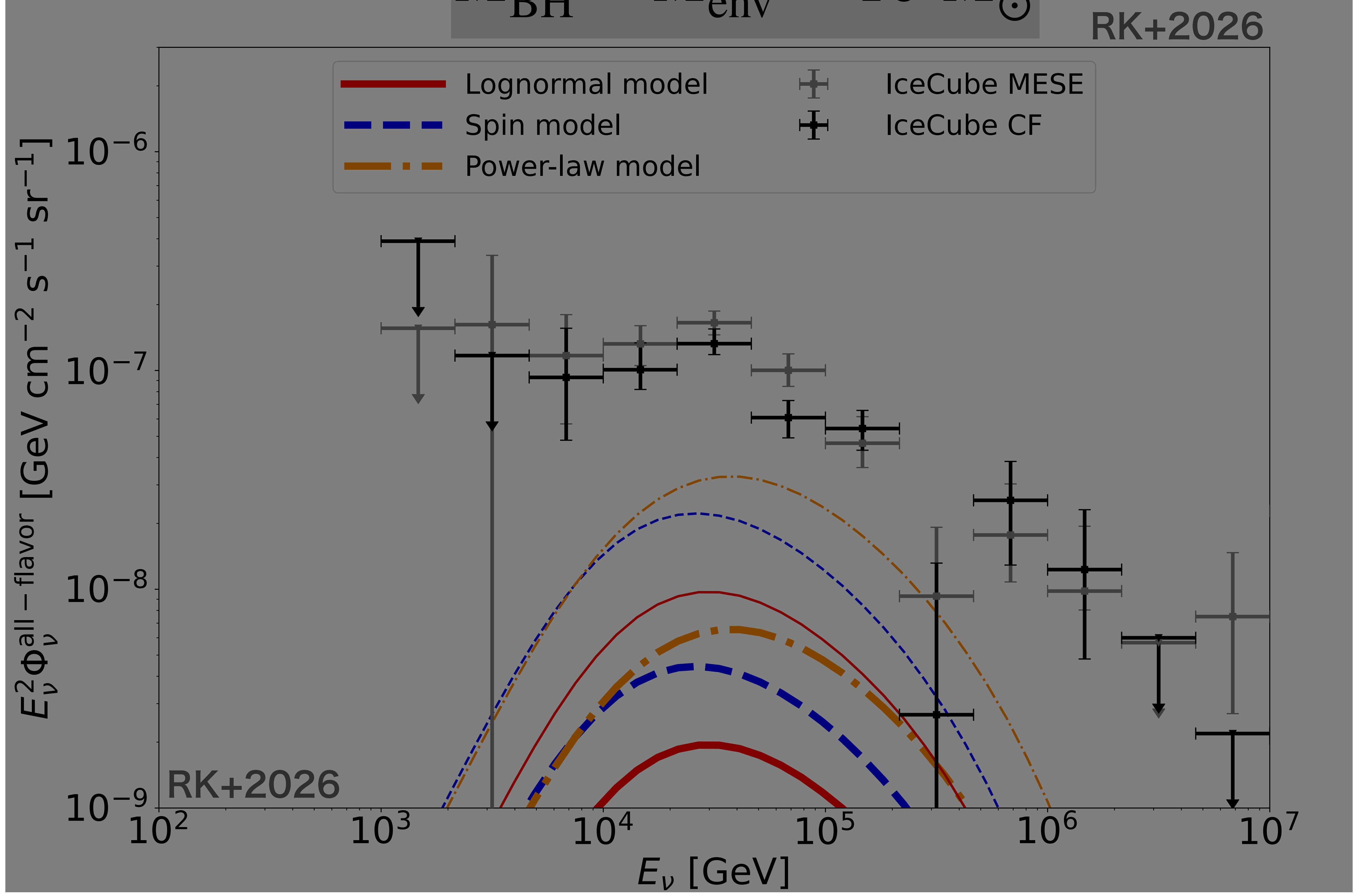
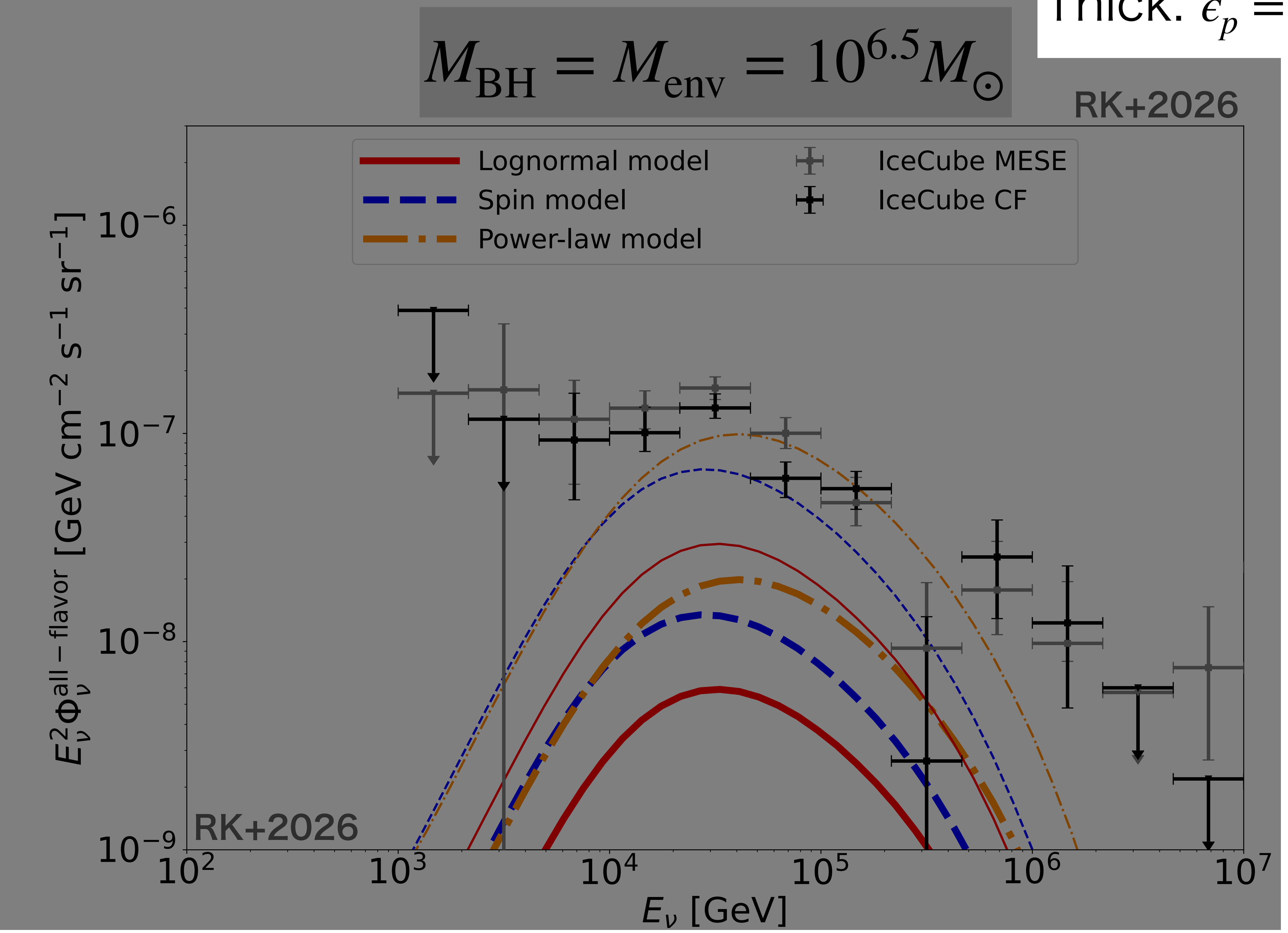


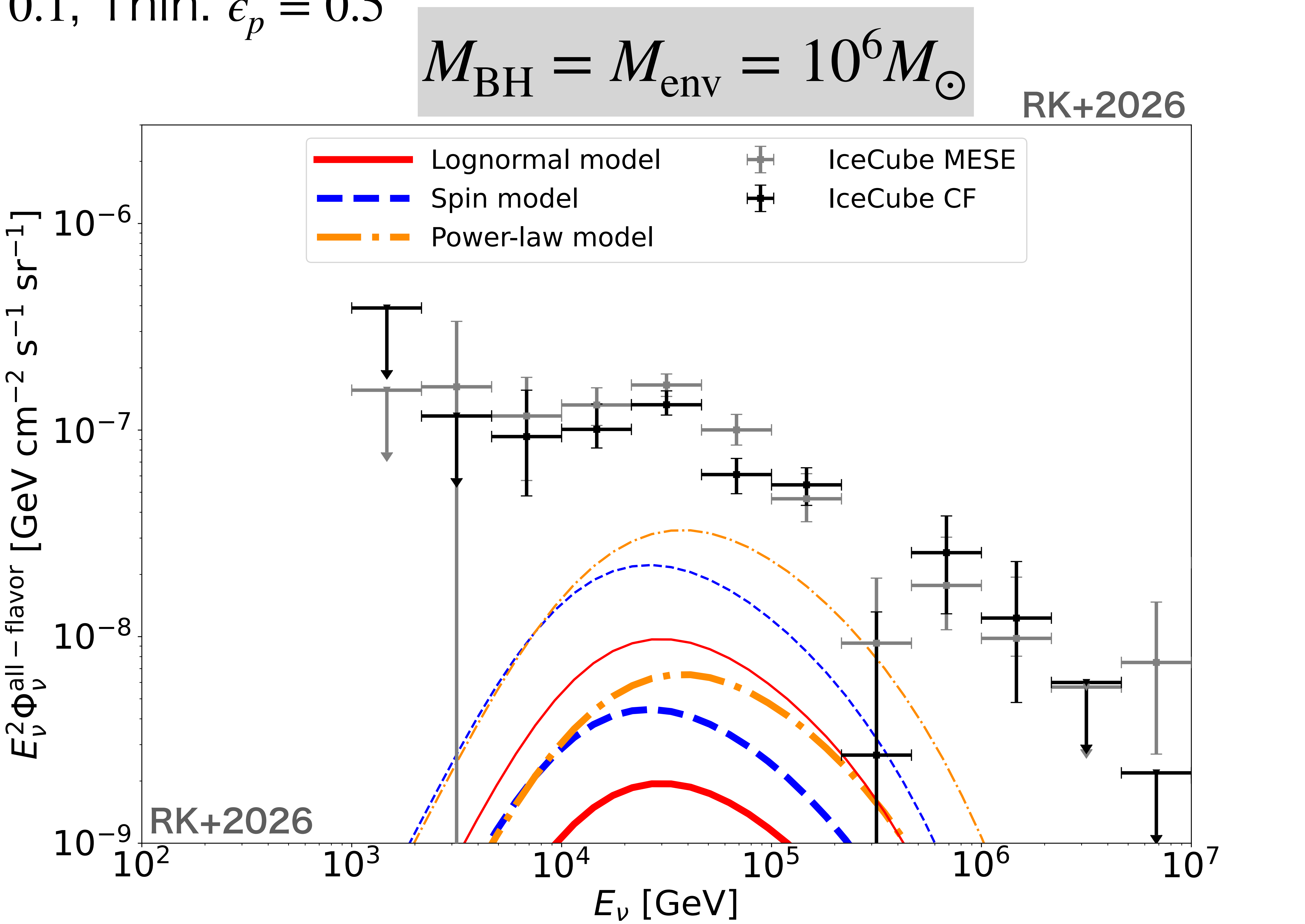
LRD populations: **Spin** or **PL** => **Contribute 20~30%** of diffuse neutrinos.

LRD populations: **Lognormal** => **Contribute 10%.**

Contribution to the diffuse neutrinos (2)

Thick: $\epsilon_p = 0.1$, Thin: $\epsilon_p = 0.5$





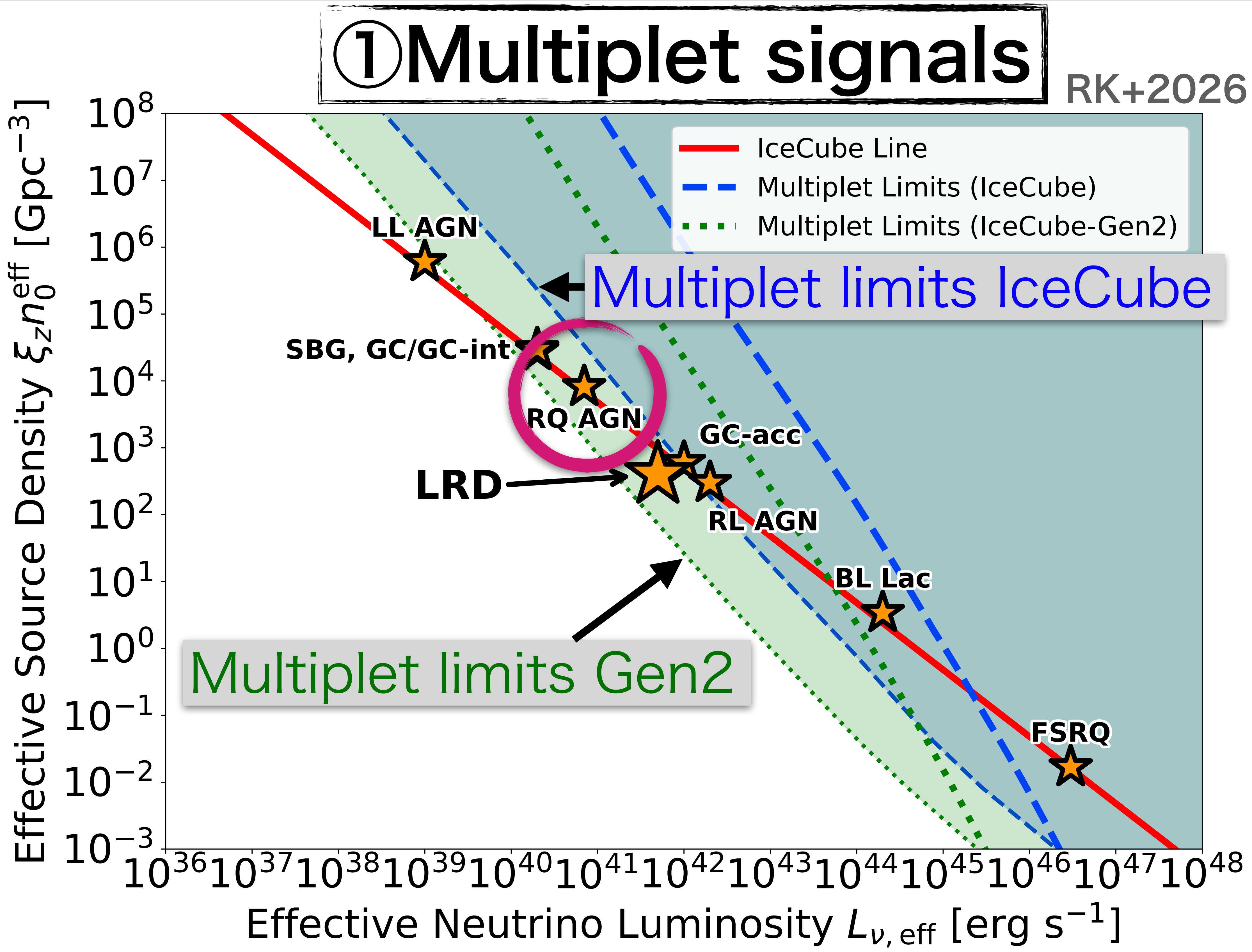
No dust -> Mass estimate changes.

$M_{\rm BH} = M_{\rm env} = 10^6 M_\odot$ **-> Low luminosities**

➡

If LRD populations are **Spin** or **PL** models, LRD can contribute around **10%** of the diffuse neutrinos.

Observational Test



・Radio-quiet AGN -> Same energy range as LRDs
e.g., Murase+2020
・IceCube-Gen2 can detect multiplet signals for RQAGN, but not for LRDs!

=> Multiplet detection may distinguish the contribution to the diffuse neutrinos.

Observational Test

①Multiplet signals

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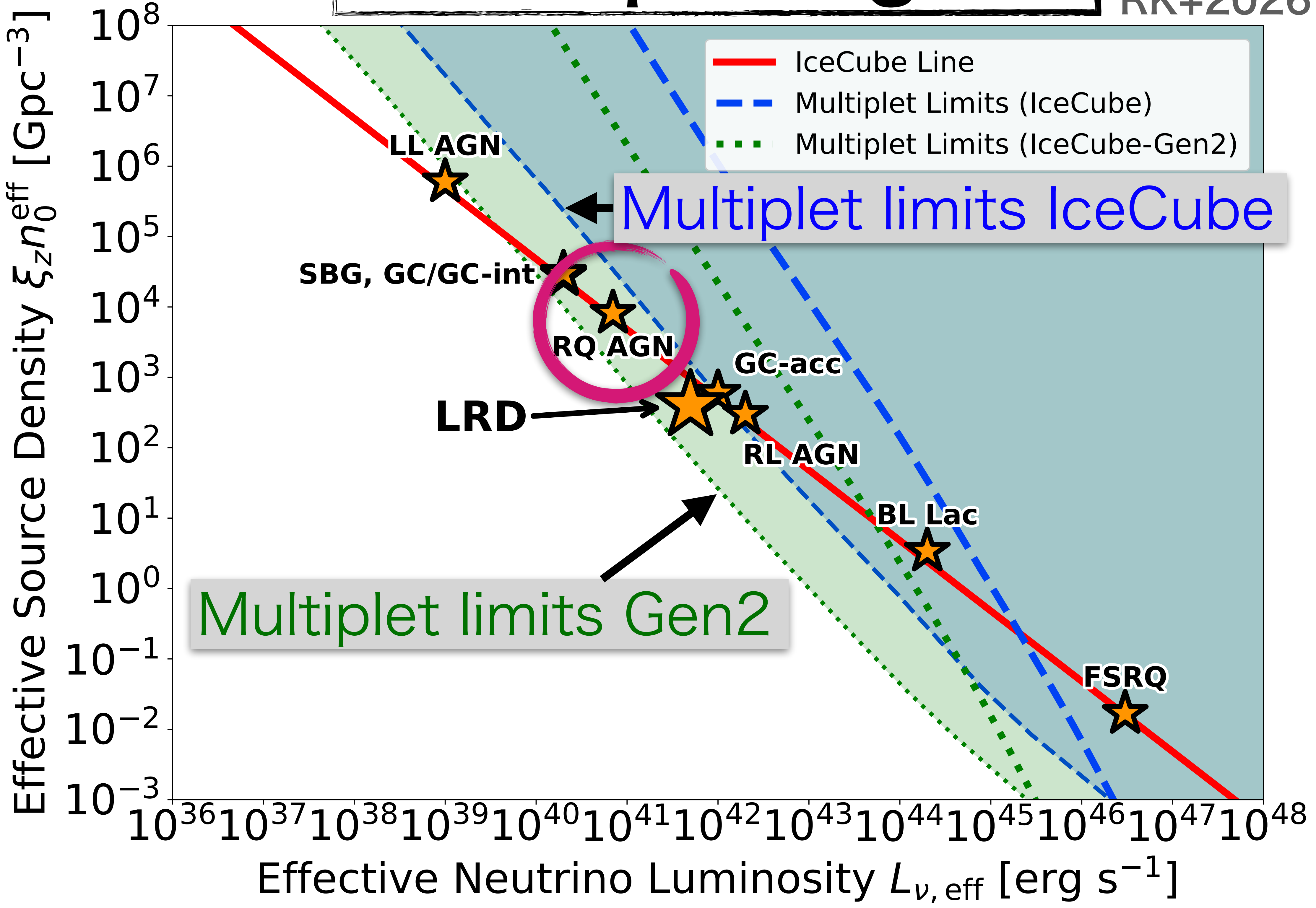

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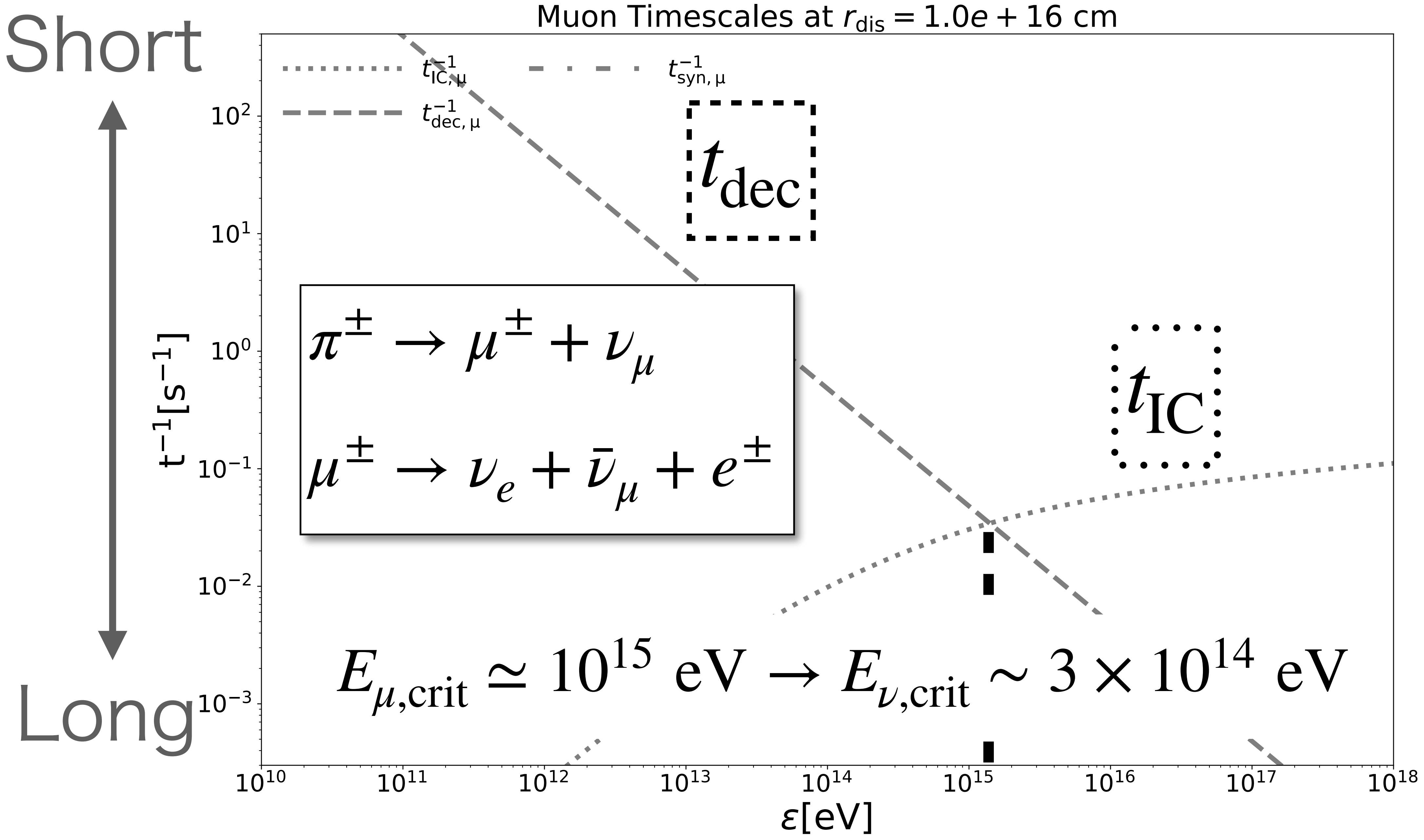
②Neutrino flavor composition



Dense photon field -> Efficient IC cooling

$$E_\nu \lesssim E_{\nu,\rm crit}:\ (\nu_e:\nu_\mu:\nu_\tau)_\oplus = (1:1:1)$$
$$E_\nu \gtrsim E_{\nu,\rm crit}:\ (\nu_e:\nu_\mu:\nu_\tau)_\oplus = (1:1.8:1.8)$$

Neutrino flavor composition will change depending on energy.
=> Implying LRD contributions!

e.g., Kashti&Waxman 2005, Kawanaka&Ioka 2015

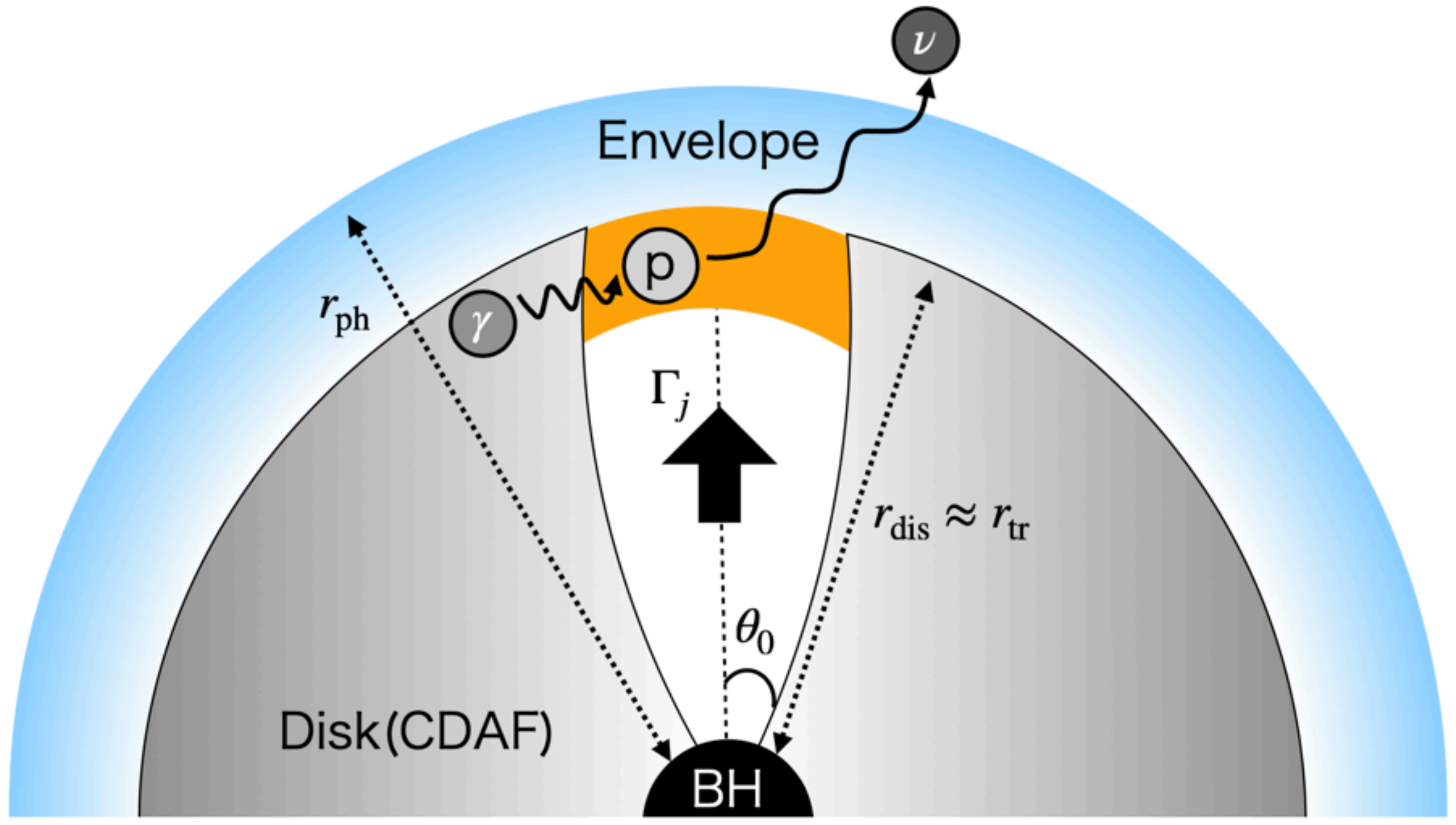
Conclusions

- Little red dots, compact and red galaxies at high-z, are reported by JWST.
  -> **SMBH embedded by the envelope** was proposed as the origin of LRDs.

Based on the BH+Envelope model, we discussed the neutrinos from LRDs.

- We consider the funnel as a particle-acceleration and dissipation site.
  -> Non-thermal particles interact with the **photons provided by the surrounding disks and produce high-energy neutrinos!**

- **Contribution to the diffuse neutrinos**:
  If LRD populations are Spin or Power-Law model, they can contribute ~20-30% of the diffuse neutrinos RK+2026, Phys. Rev. D 113, 083048



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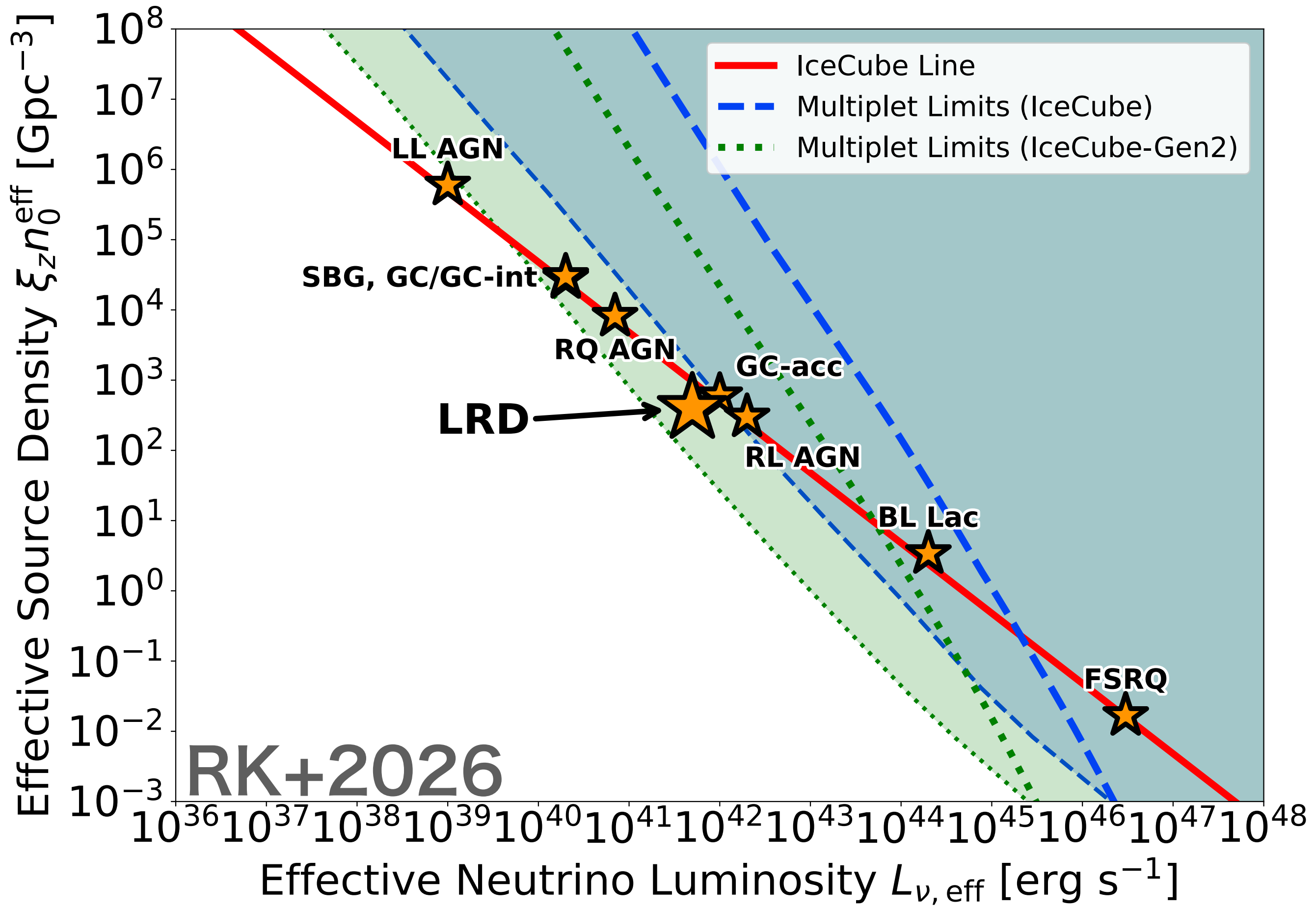

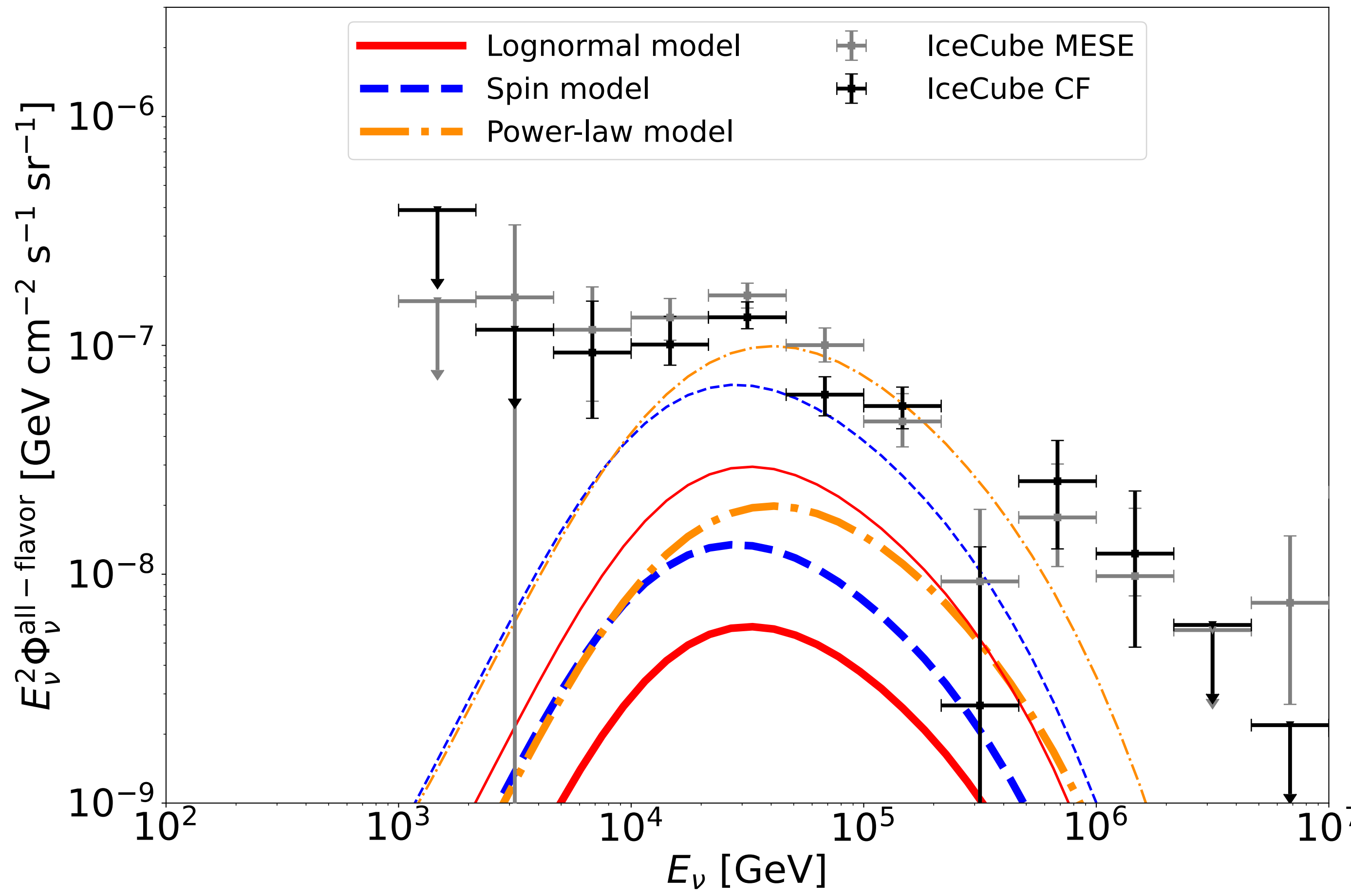

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Thank you for listening!!