High-energy Particle Emission and Cumulative Background from Low-Luminosity AGN

1) SSK, Murase, & Toma, 2015, ApJ, 806,159
2) Fujita, SSK, Murase 2015, PRD, 92, 023001

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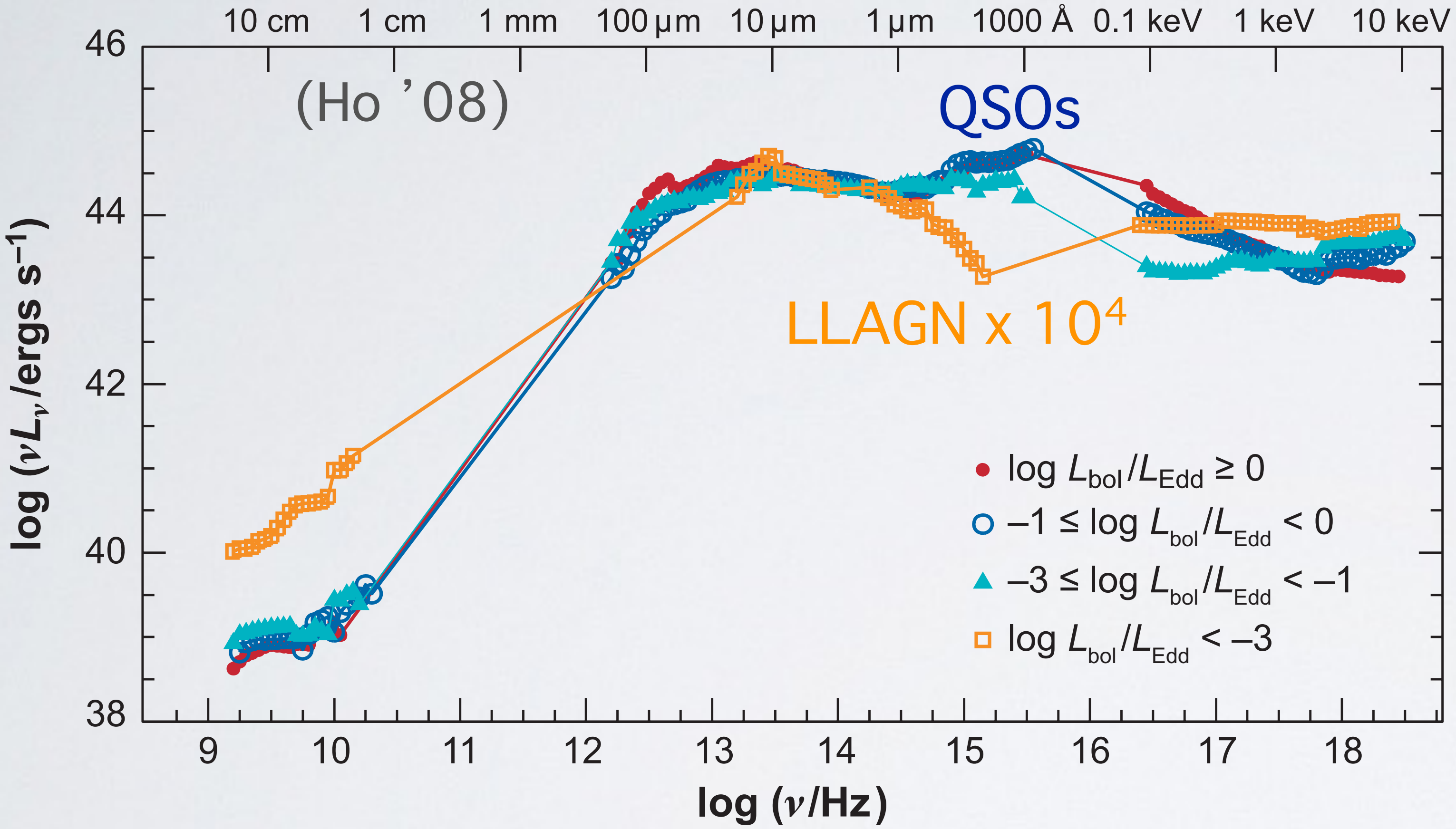
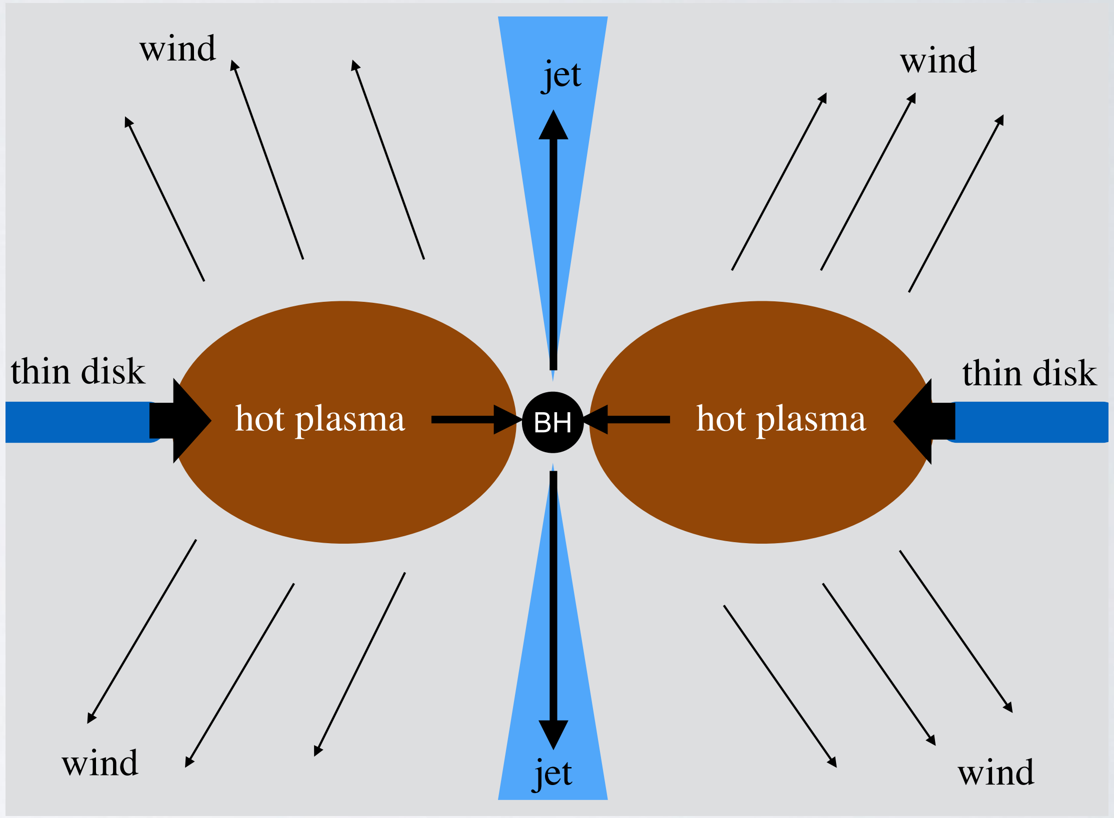
INTRODUCTION

Low-luminosity AGN (LLAGN)

Spectral Energy Distribution



Schematic picture



No Blue Bump → No Standard Disk

——>Radiation Inefficient Accretion Flow (RIAF)

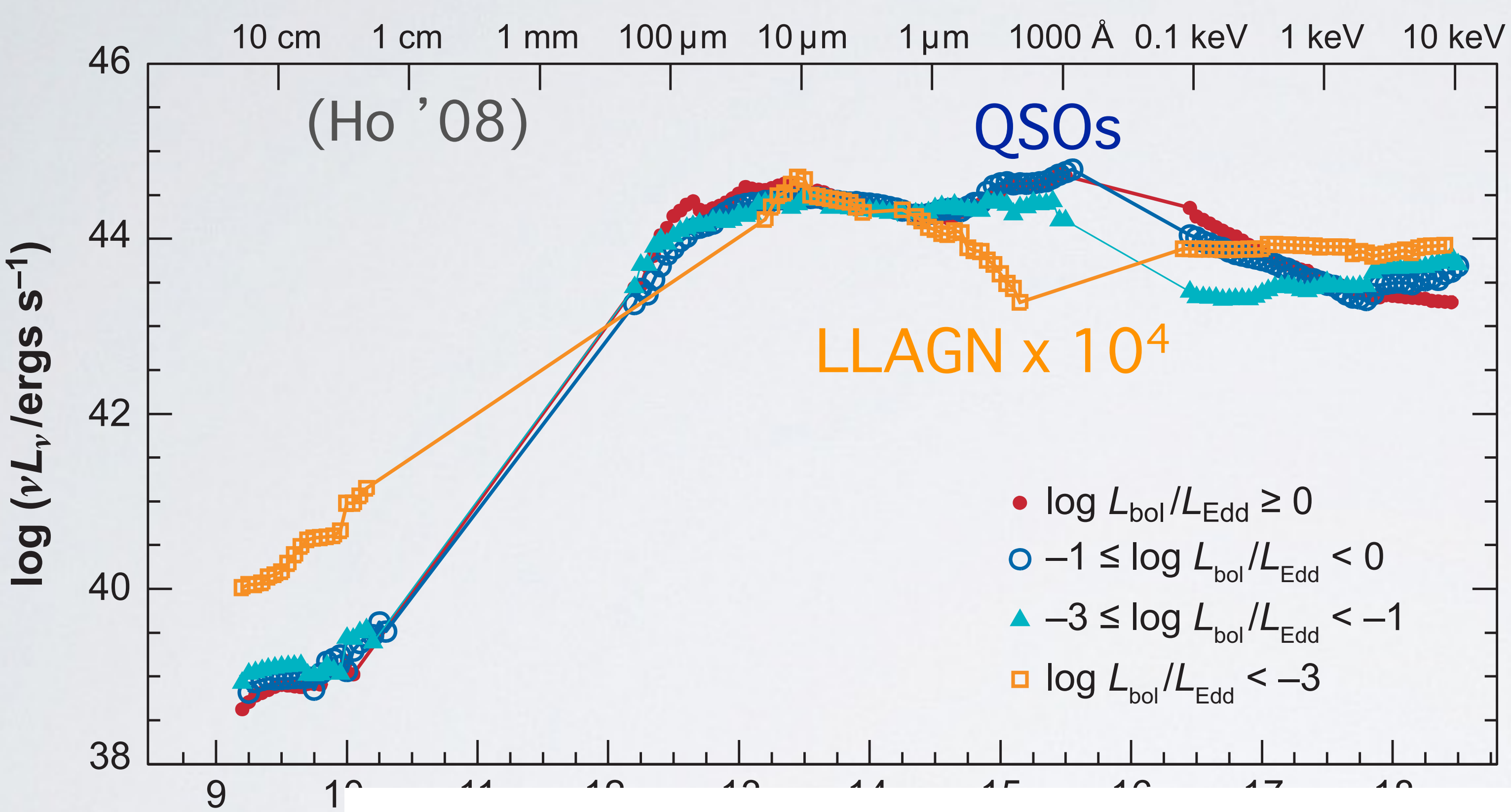
(Narayan &Yi 94, Yuan + 03,Abramowicz & Fragile 13, Yuan & Narayan 14)

Hot & Tenuous ——> Inefficient Coulomb Collision

(Mahadevan & Quataert 97)

Low-luminosity AGN (LLAGN)

Spectral Energy Distribution



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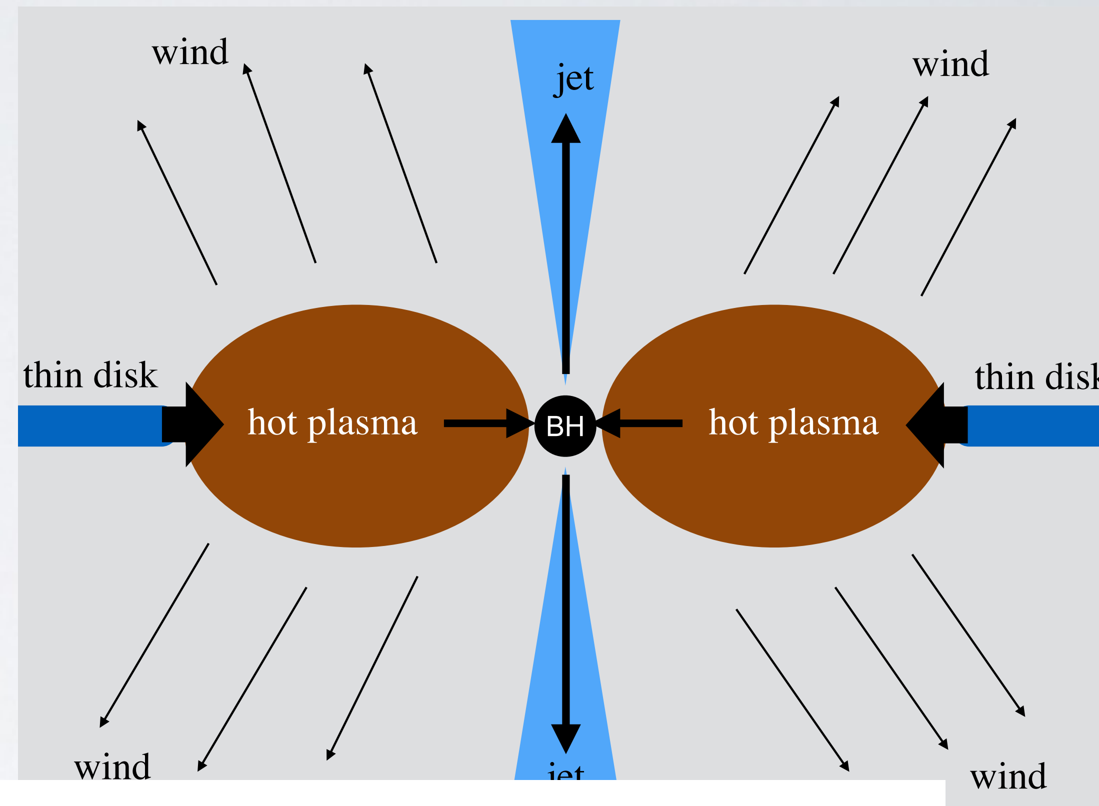


Non-thermal particles naturally exist inside RIAFs

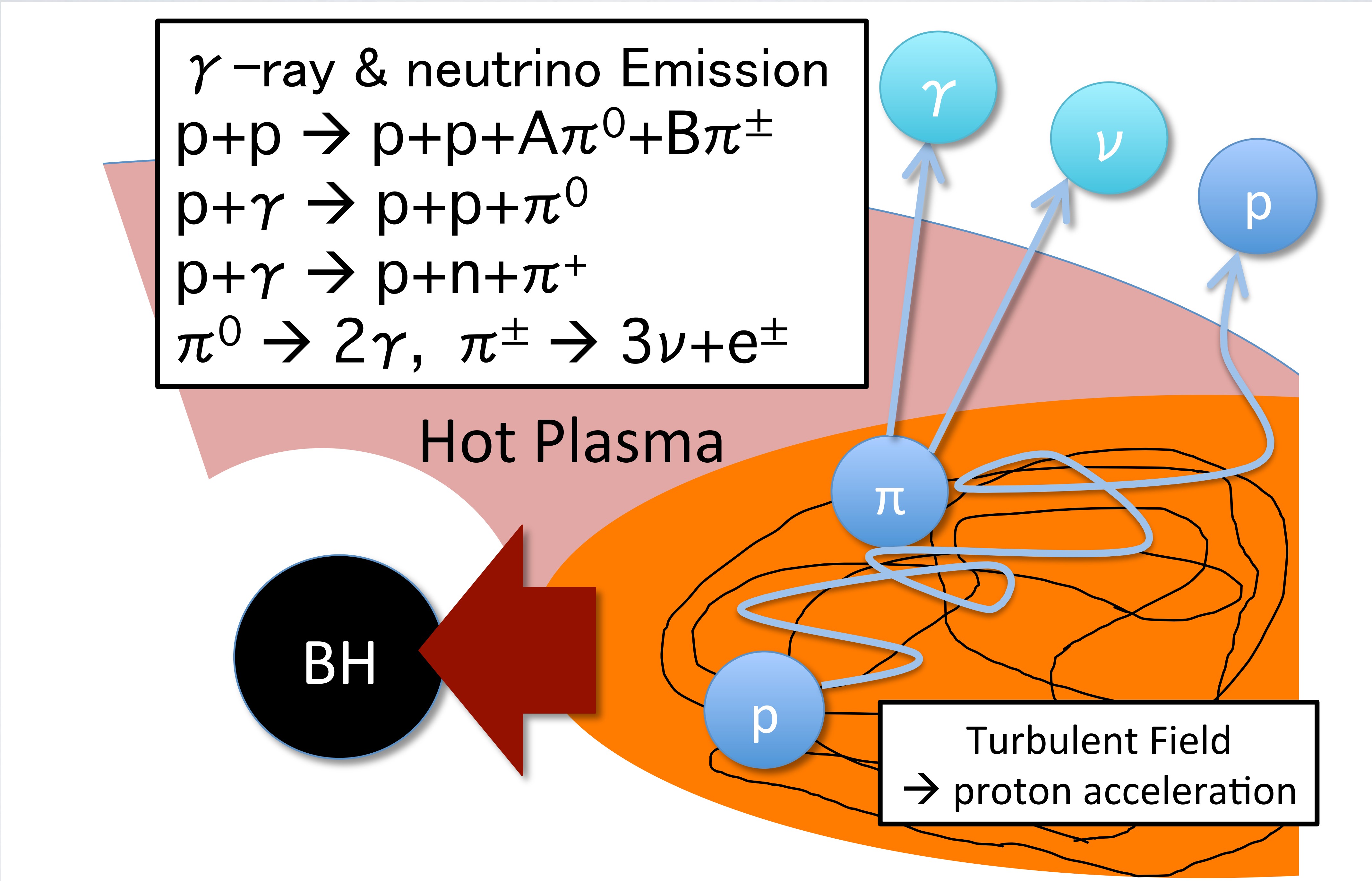
(Narayan &Yi 94, Yuan + 03, Yuan & Narayan 14)

Hot & Tenuous ——> Inefficient Coulomb Collision

(Mahadevan & Quataert 97)

Emission from Hot Accretion Flow

e.g.) Narayan & Yi 94; Narayan, Sadowski + 12



cf.) Begelman+90; Niedzwiecki+13

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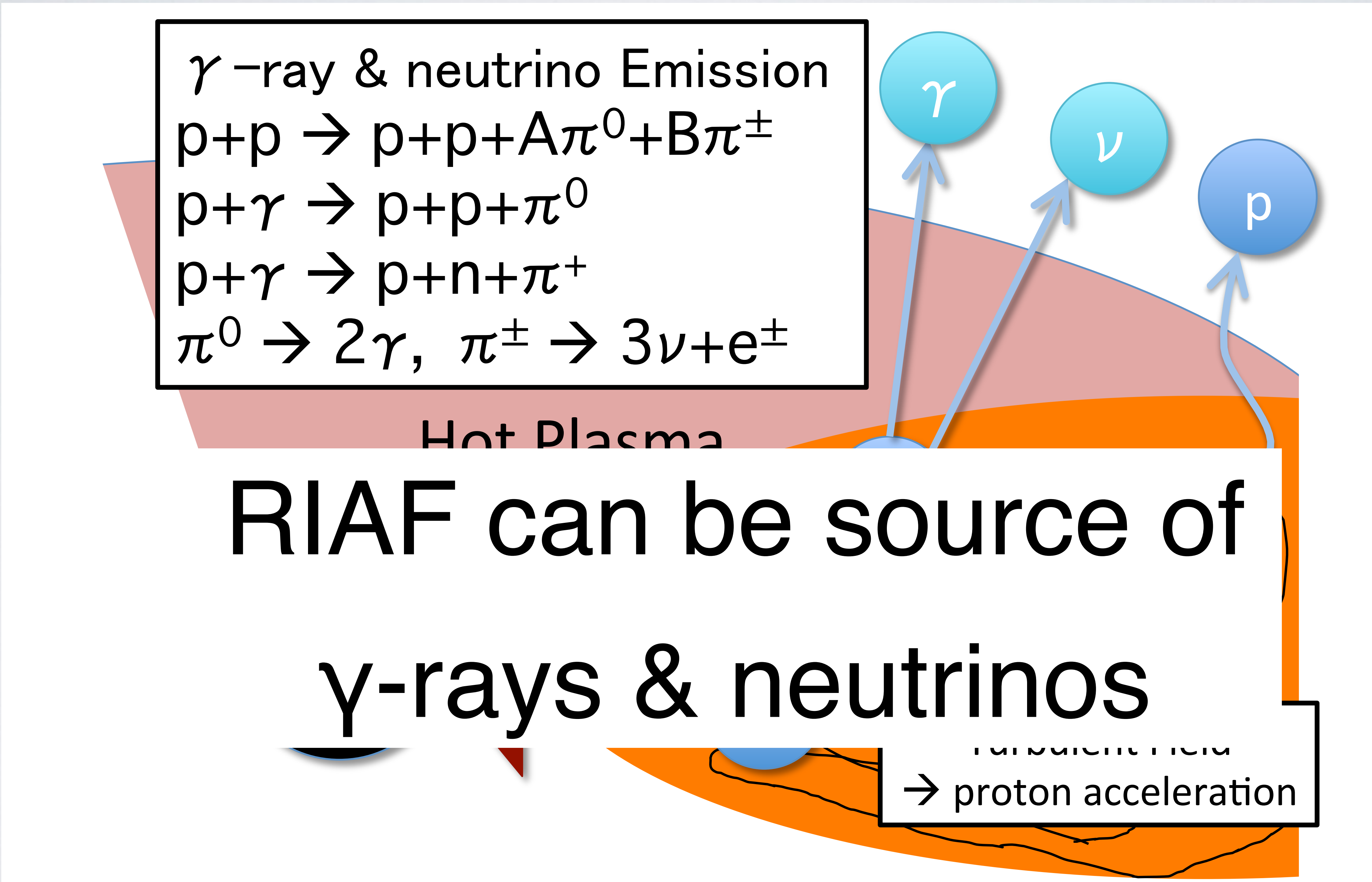


RIAF can be source of

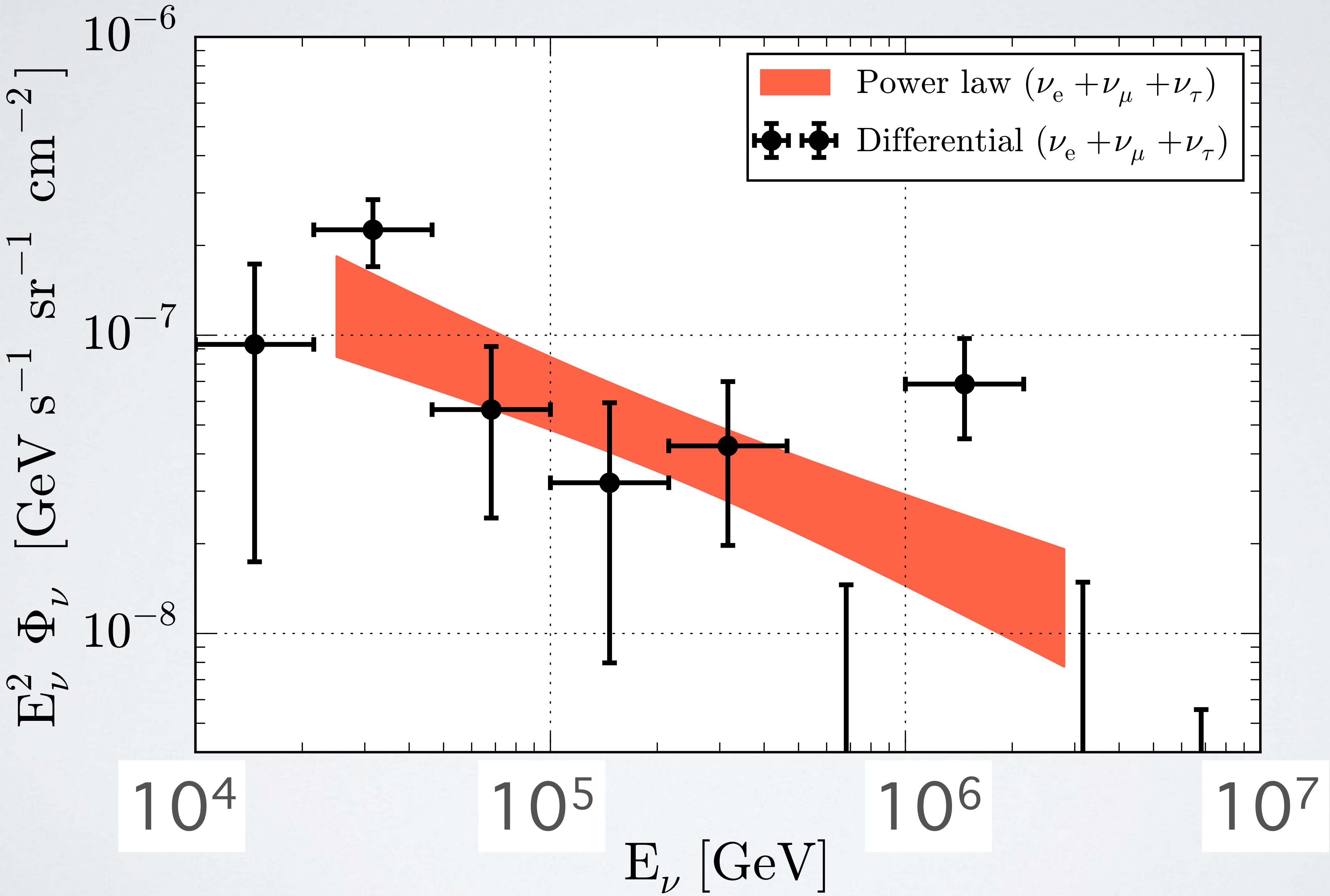
γ-rays & neutrinos

cf.) Begelman+90; Niedzwiecki+13

Observation of Astro-Neutrinos

Aartsen et al. '13,15

- IceCube detected the diffuse neutrinos



Observation of Astro-Neutrinos

. '13,15

• IceC

candidates

Starburst Galaxies (Tambbora+14; Senno+15;)

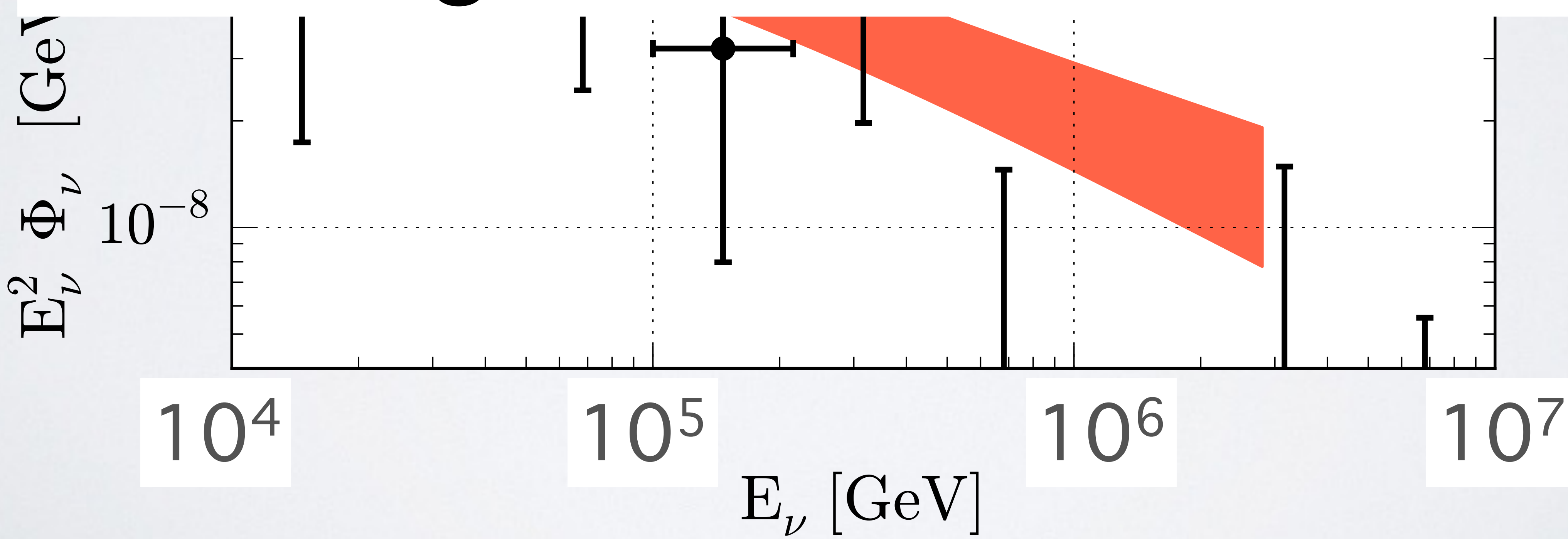
GRB, LLGRB (Murase&Ioka13; Bustamante+15; Kawanaka+15)

AGN jets (Dermer+14; Murase+14; Tavecchio+14;)

AGN cores (Stecker13;Kalashev+15;khiali+15)

Galactic (Ahlers&Murase14;Bai+14;Neronov&Semikoz15)

The origin is still under debated



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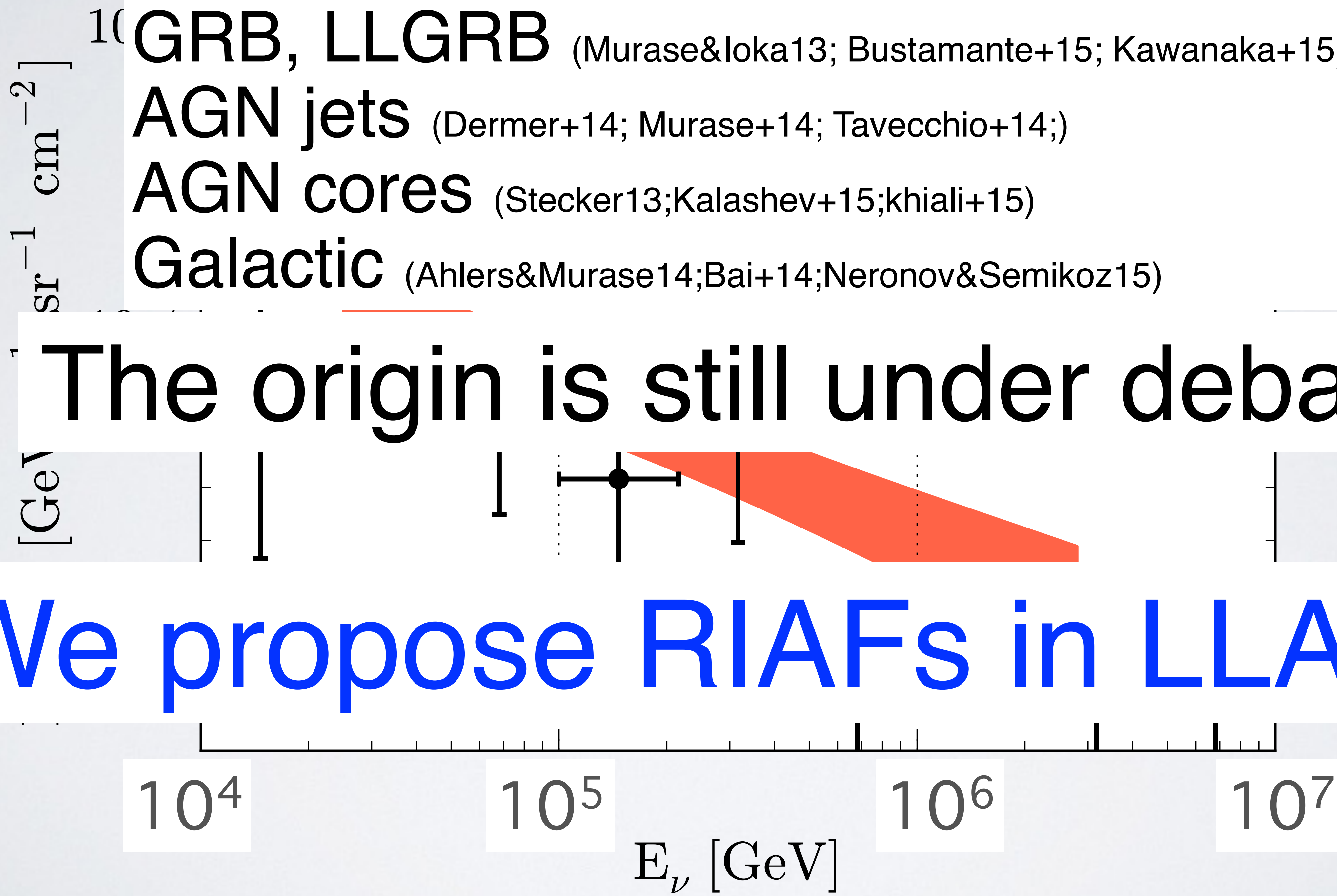
The origin is still under debated

We propose RIAFs in LLAGN



NEUTRINO EMISSION FROM LLAGNs

SSK, Murase, & Toma, 2015, ApJ, 806,159

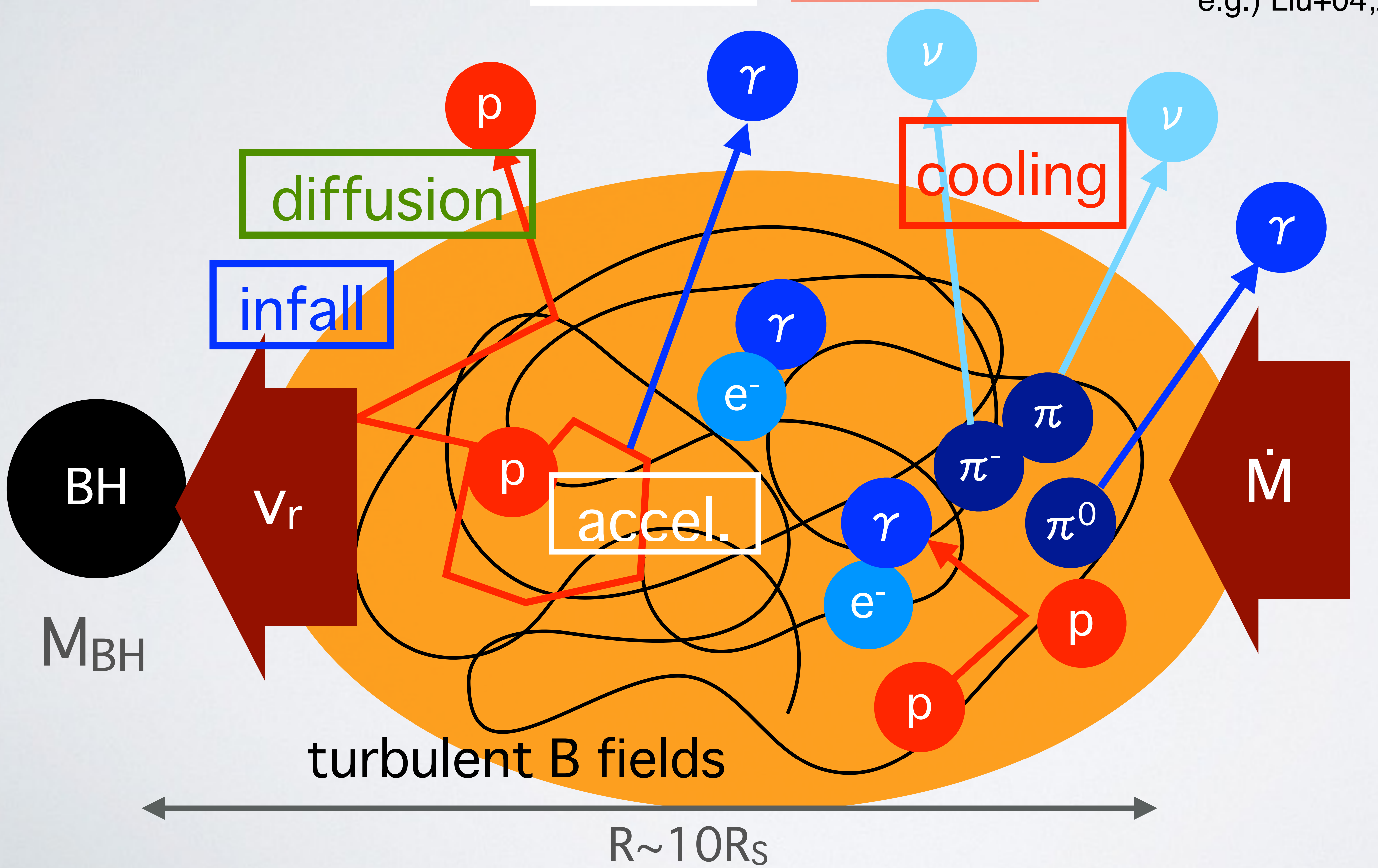
LLAGN Model

SSK, Murase, & Toma, 2015, ApJ, 806,159

- Stochastic Acceleration inside One-Zone RIAF

$$\frac{\partial}{\partial t}F(p) = \frac{1}{p^2}\frac{\partial}{\partial p}\left[p^2\left(D_p\frac{\partial}{\partial p}F(p) + \frac{p}{t_{\rm cool}}F(p)\right)\right] - F(p)\left(t_{\rm diff}^{-1} + t_{\rm fall}^{-1}\right) + \dot{F}_{\rm inj},$$

e.g.) Liu+04;Asano&Terasawa 09;



Typically
$R \sim 3\times10^{13}$ cm
$v_r \sim 7\times10^{8}$ cm/s
$n_p \sim 1\times10^{9}$ cm^{-3}
$B \sim 5\times10^{2}$ G

Target Photons of pγ

- Photon fields inside RIAF:

Synchrotron & SSC from thermal electrons

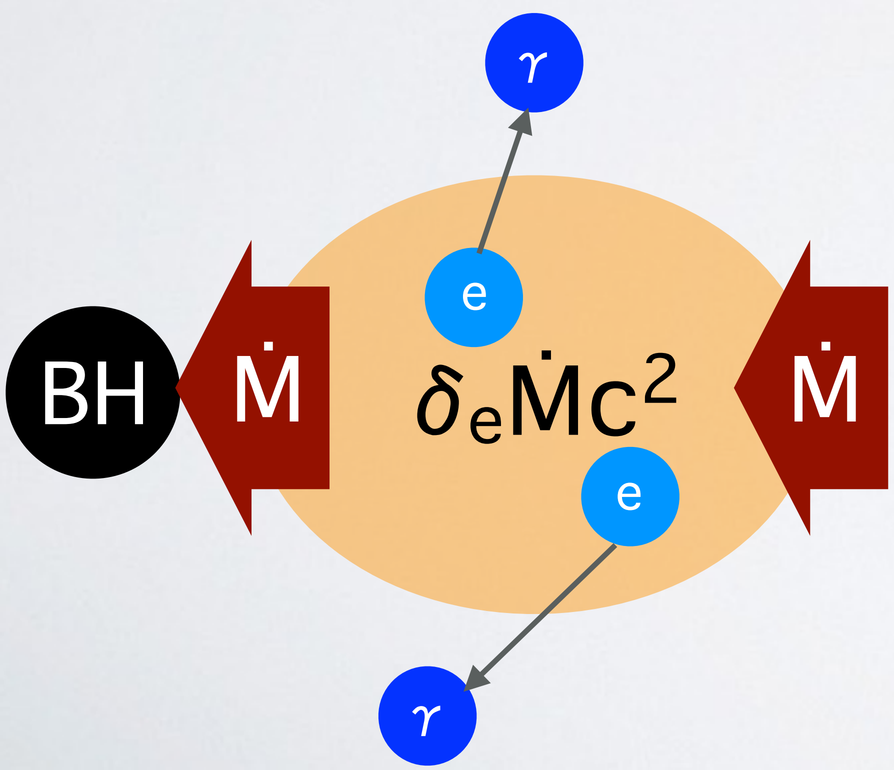
・Thermal balance

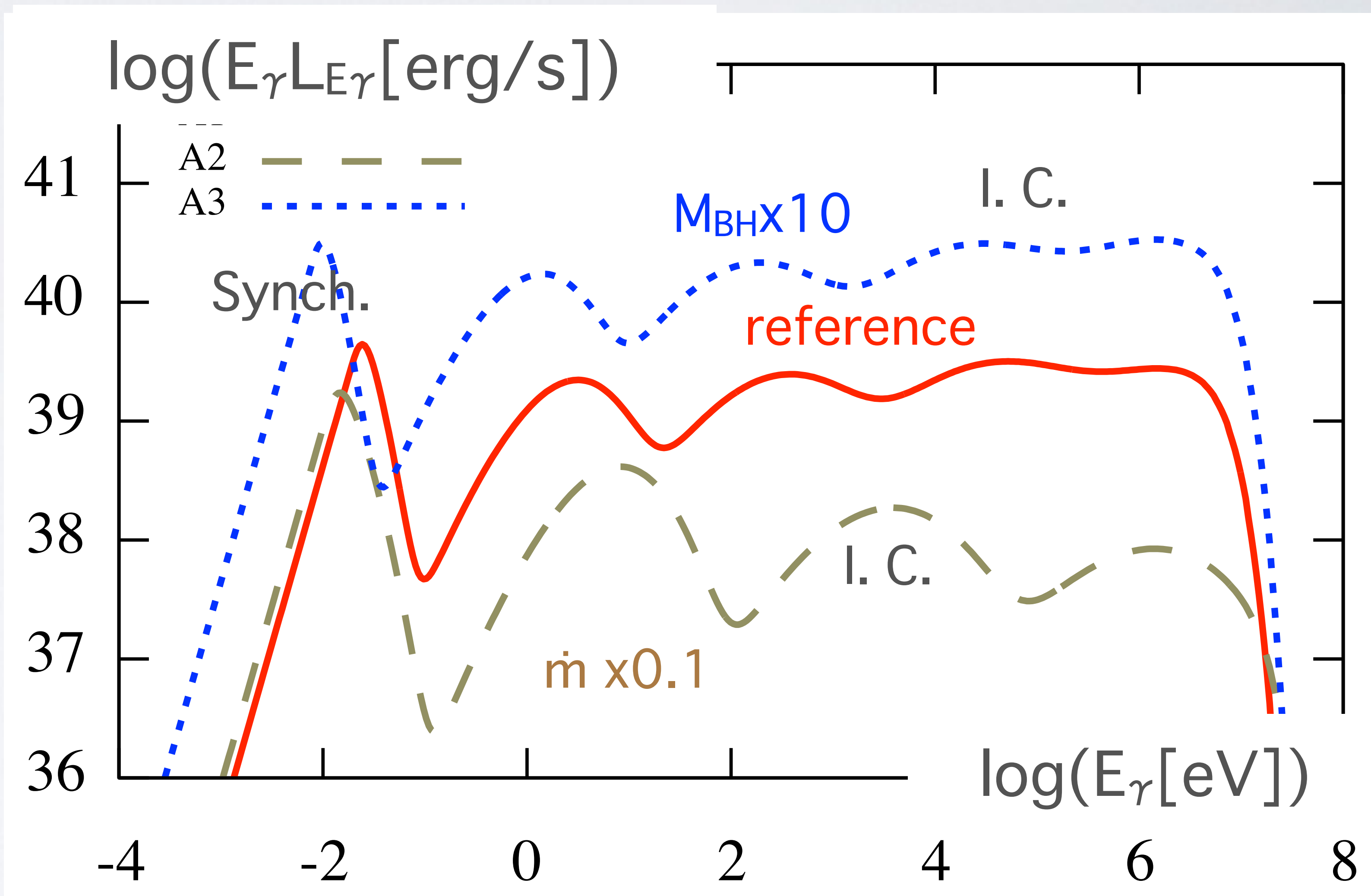
$\delta_e \dot{M} c^2 = L_{rad}(T_{rad})$

・Virialization

$kT_{e,vir} = GM_{BH} m_p/(9R)$

$T_e = \min(T_{rad}, T_{vir})$





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SSK, Murase, & Toma, 2015, ApJ, 806,159

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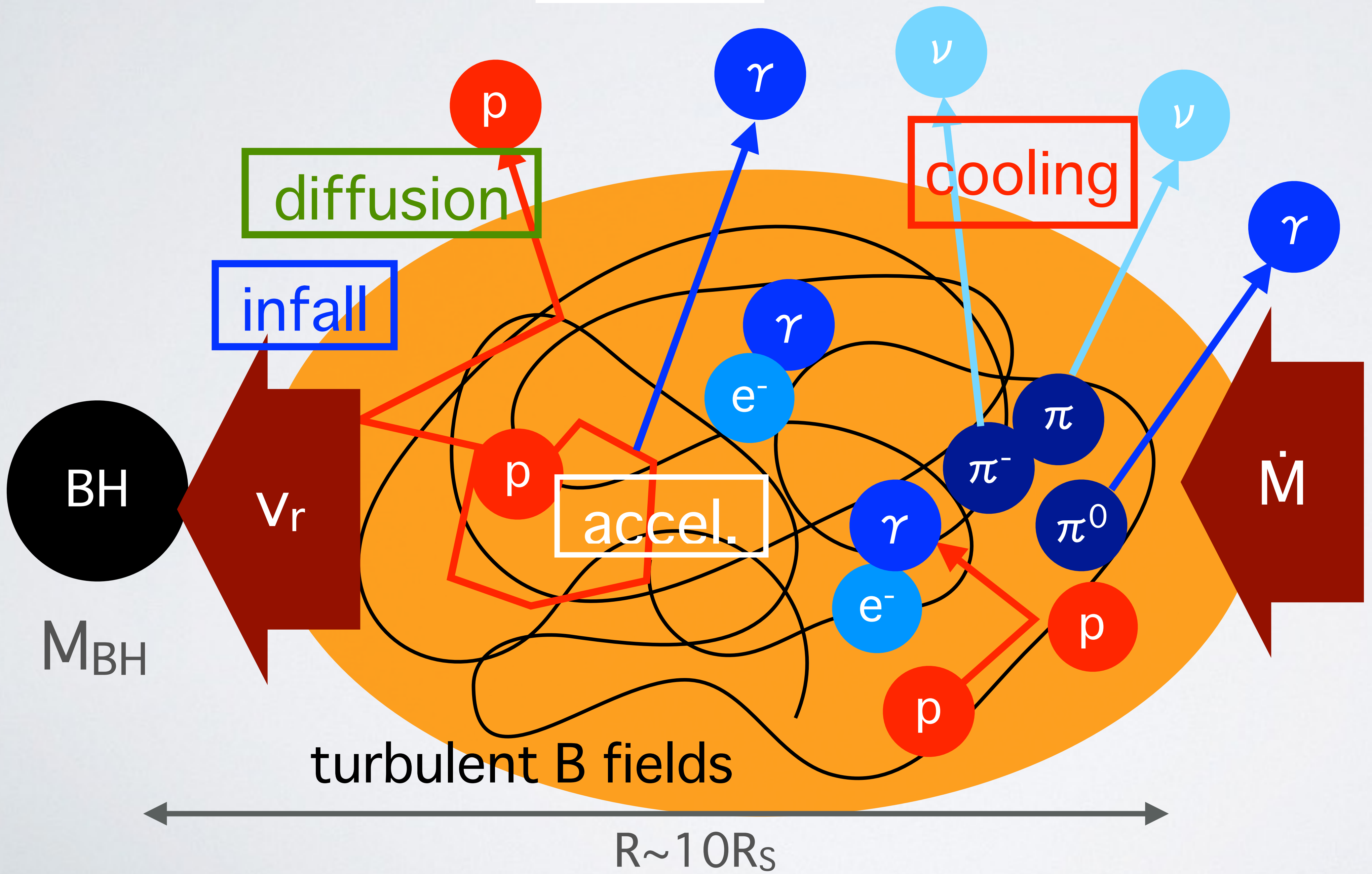

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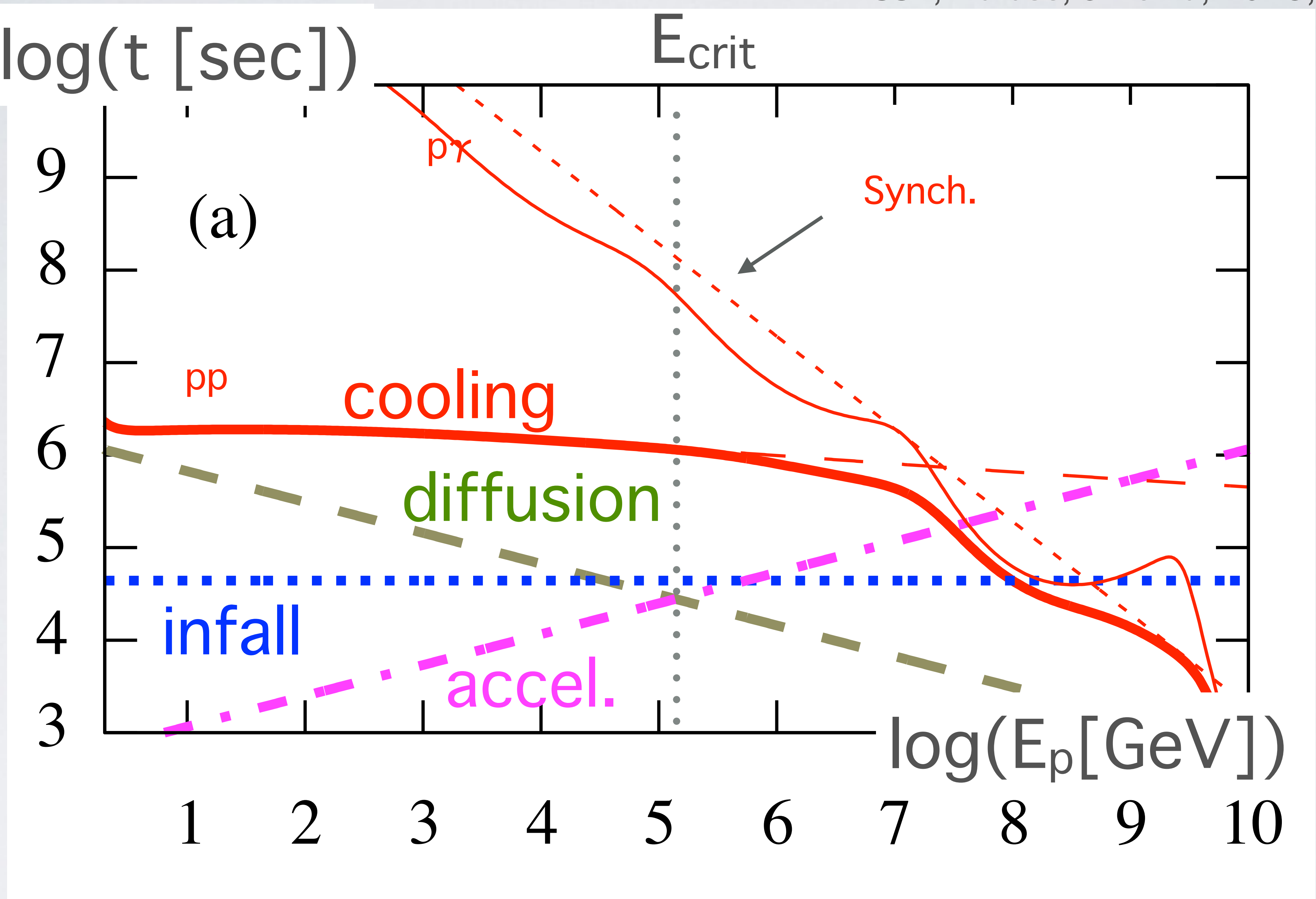
Comparison of Timescales

SSK, Murase, & Toma, 2015, ApJ, 806,159



- Maximum energy is limited by diffusion
- Efficiency of pion production $f_{\pi} < 0.1$

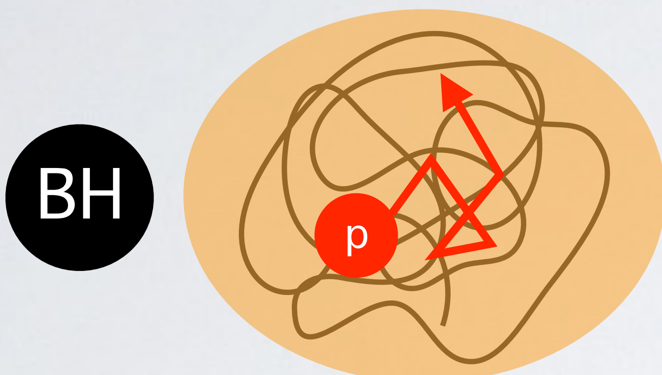
Neutrino Spectrum from a LLAGN

SSK, Murase, & Toma, 2015, ApJ, 806,159

- Turbulent strength ζ

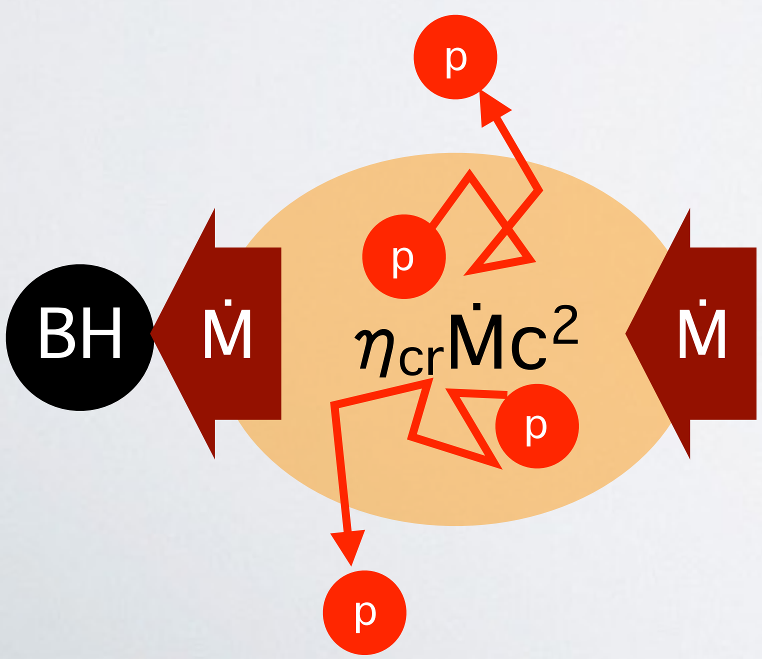
Kolmogorov: $P(k) \propto k^{-5/3}$

$$\zeta = 8\pi \int P(k)dk/B_0^2$$

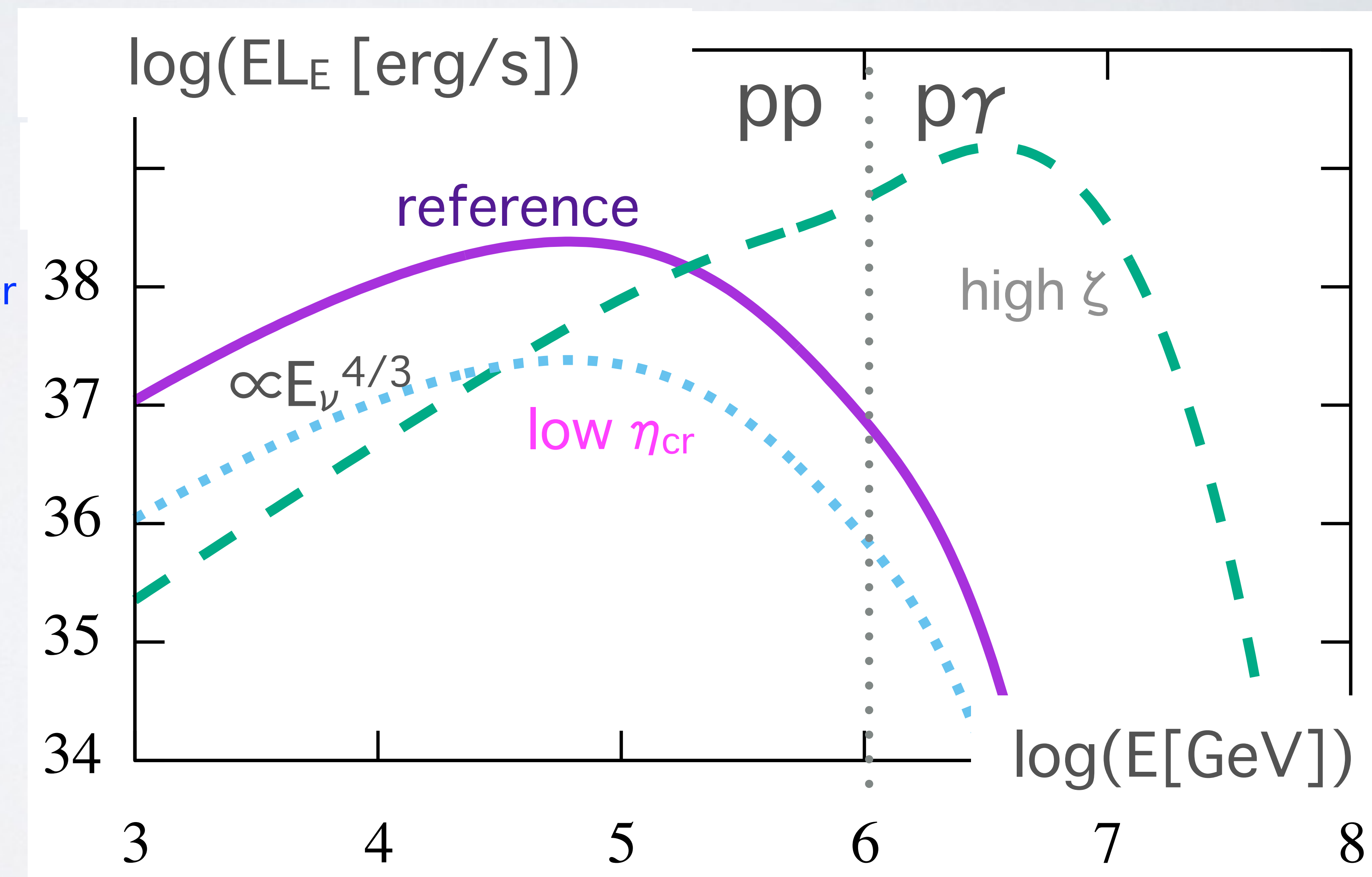


- Injection efficiency η_{cr}

$L_{p,tot} \sim \eta_{cr} \dot{M} c^2$

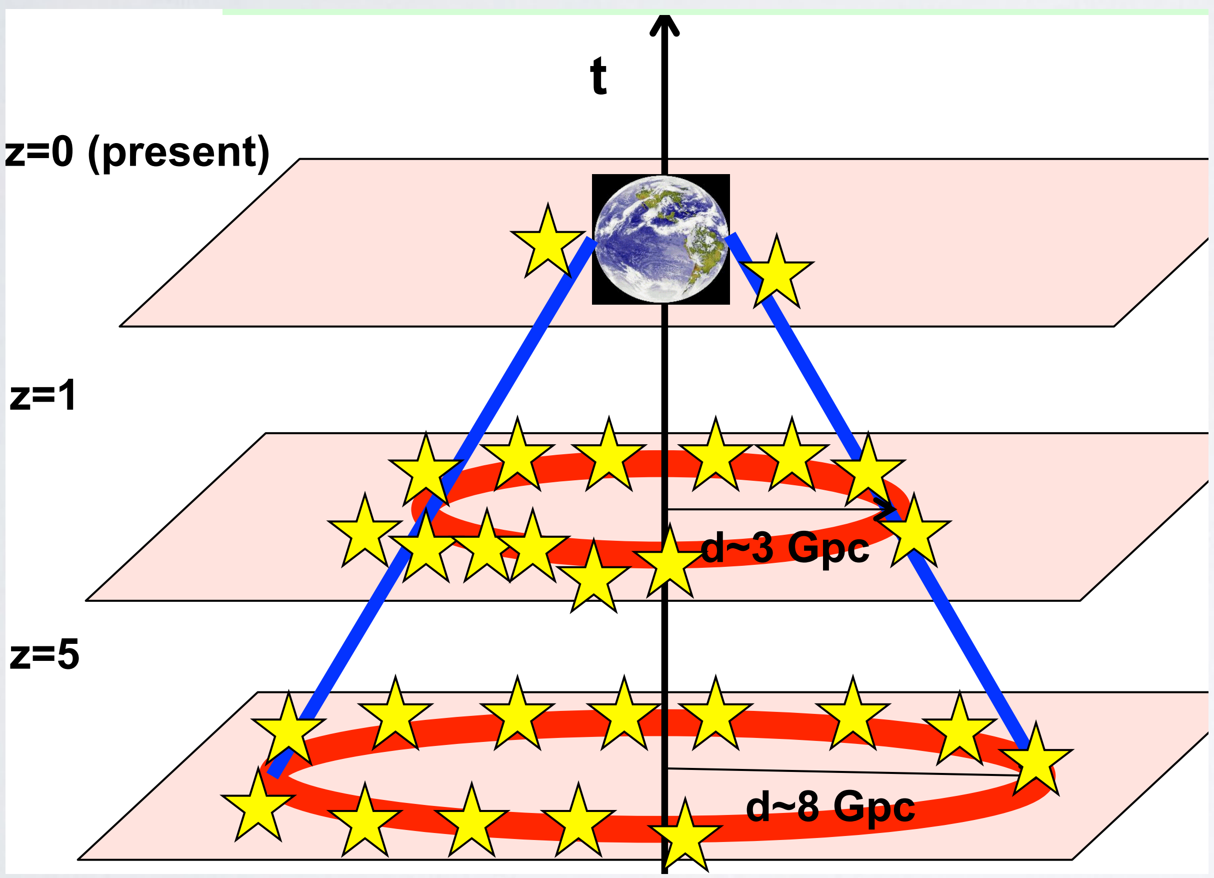


- high ζ → high E_{peak}
- low η_{cr} → low L_E
- $E\nu > 10^6$ eV → pγ dominant

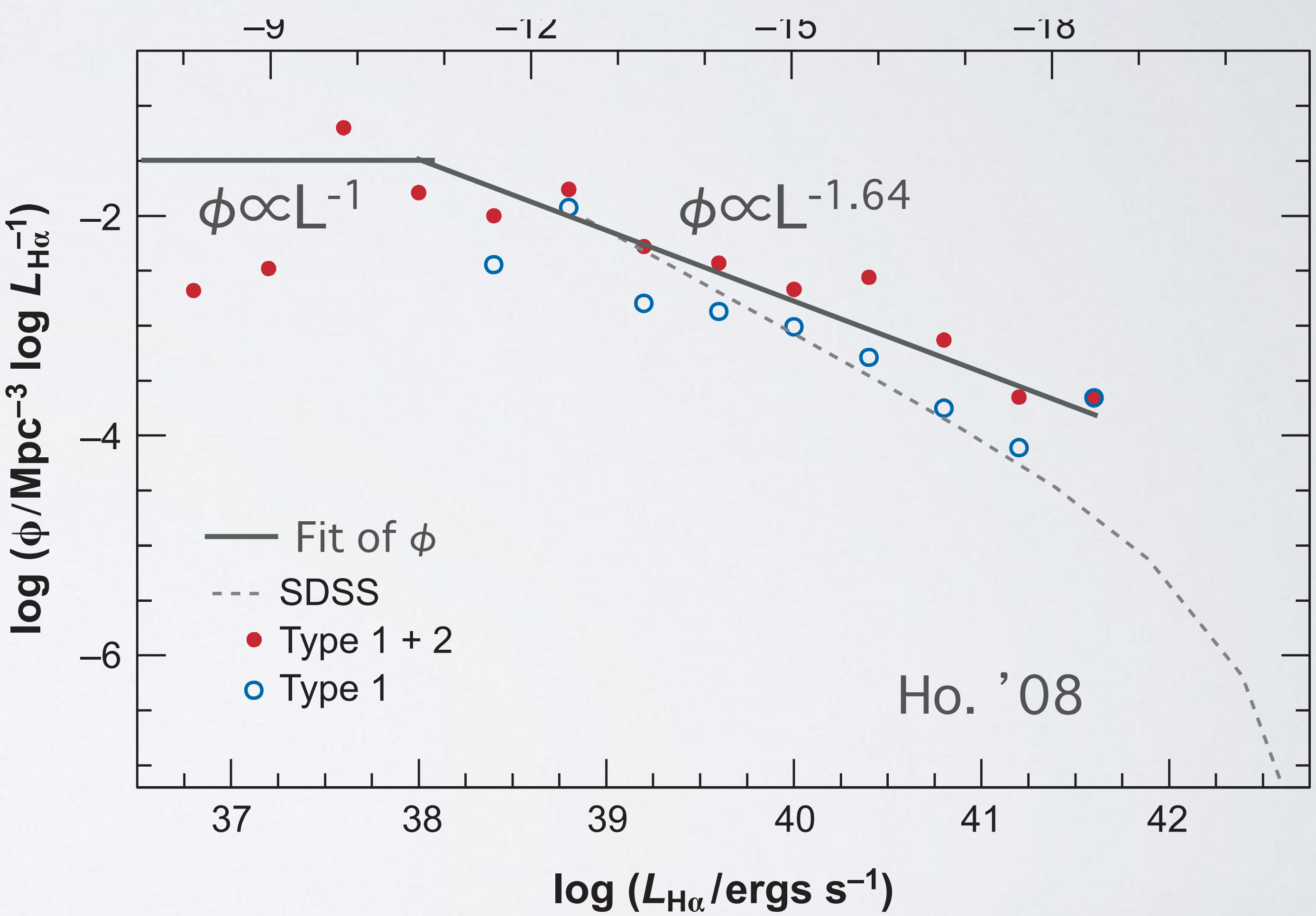


Cumulative Background

ν flux from all the sources



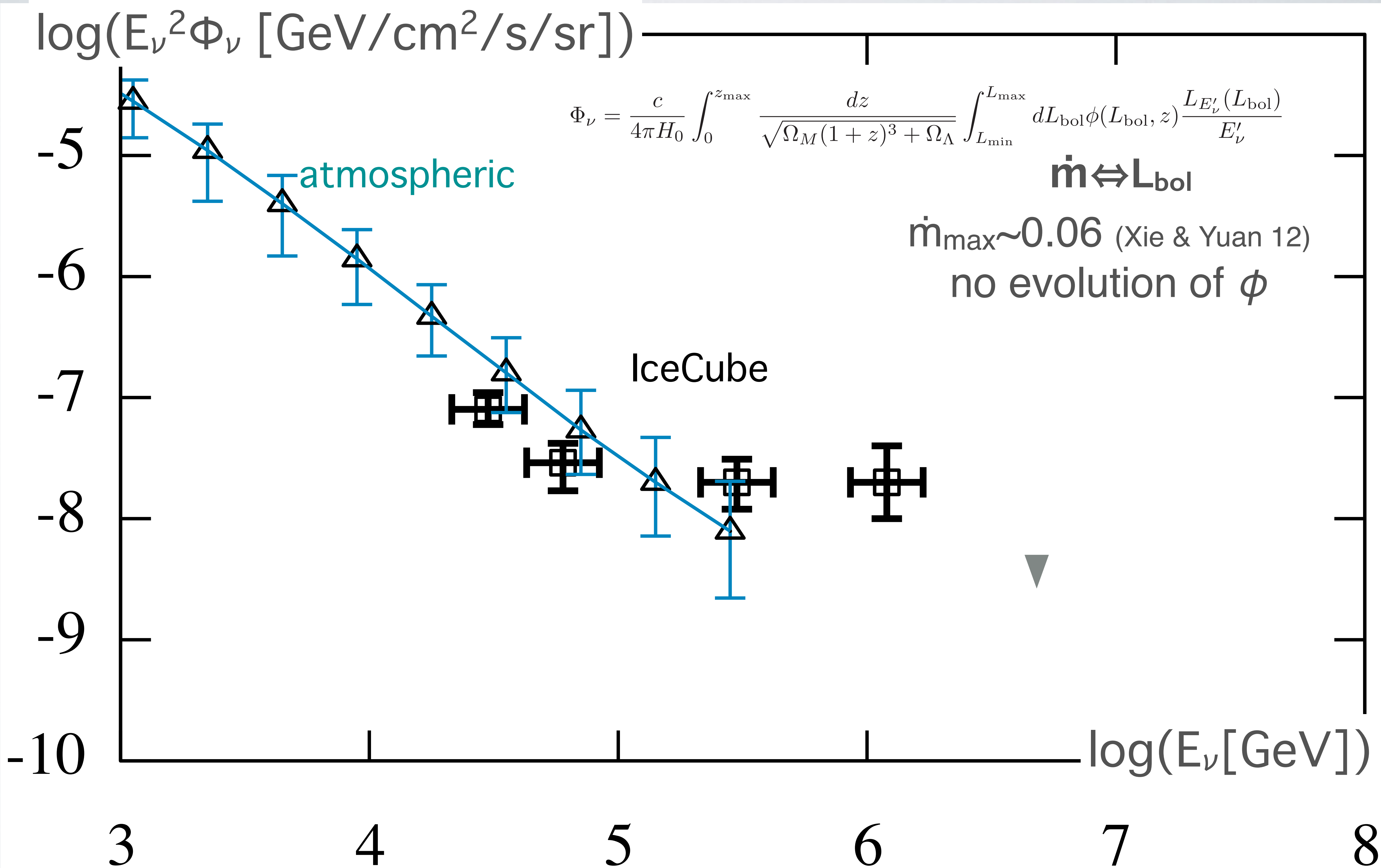
$$\Phi_\nu = \frac{c}{4\pi H_0}\int_0^{z_{\max}} \frac{dz}{\sqrt{\Omega_M(1+z)^3+\Omega_\Lambda}} \int_{L_{\min}}^{L_{\max}} dL_{\rm bol}\phi(L_{\rm bol},z)\frac{L_{E'_\nu}(L_{\rm bol})}{E'_\nu}$$



$$\phi(L_{H_\alpha}) = \frac{n_*/L_*}{(L_{H_\alpha}/L_*)^{s_1}+(L_{H_\alpha}/L_*)^{s_2}}$$

Cumulative Background

SSK, Murase, & Toma, 2015, ApJ, 806,159



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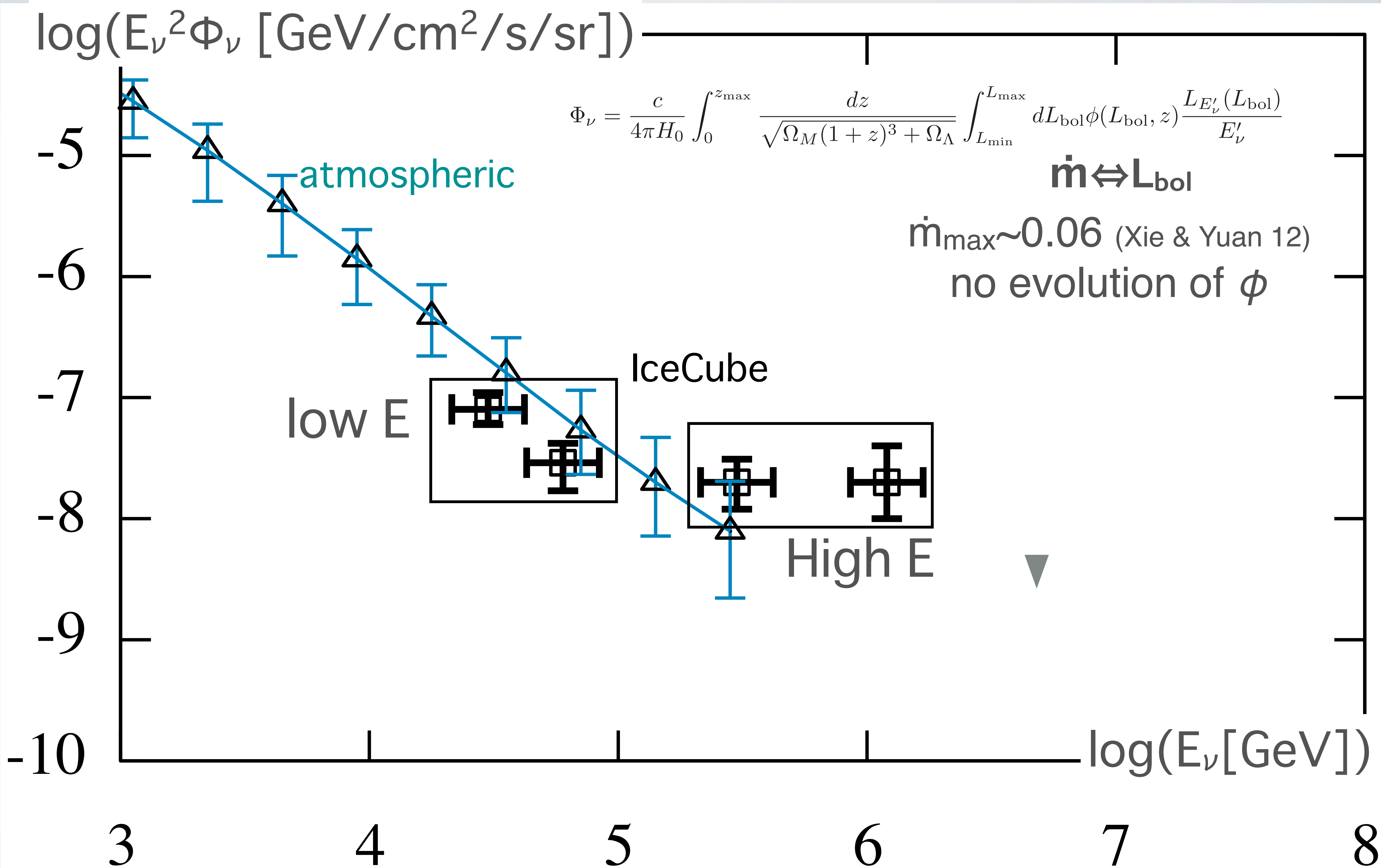

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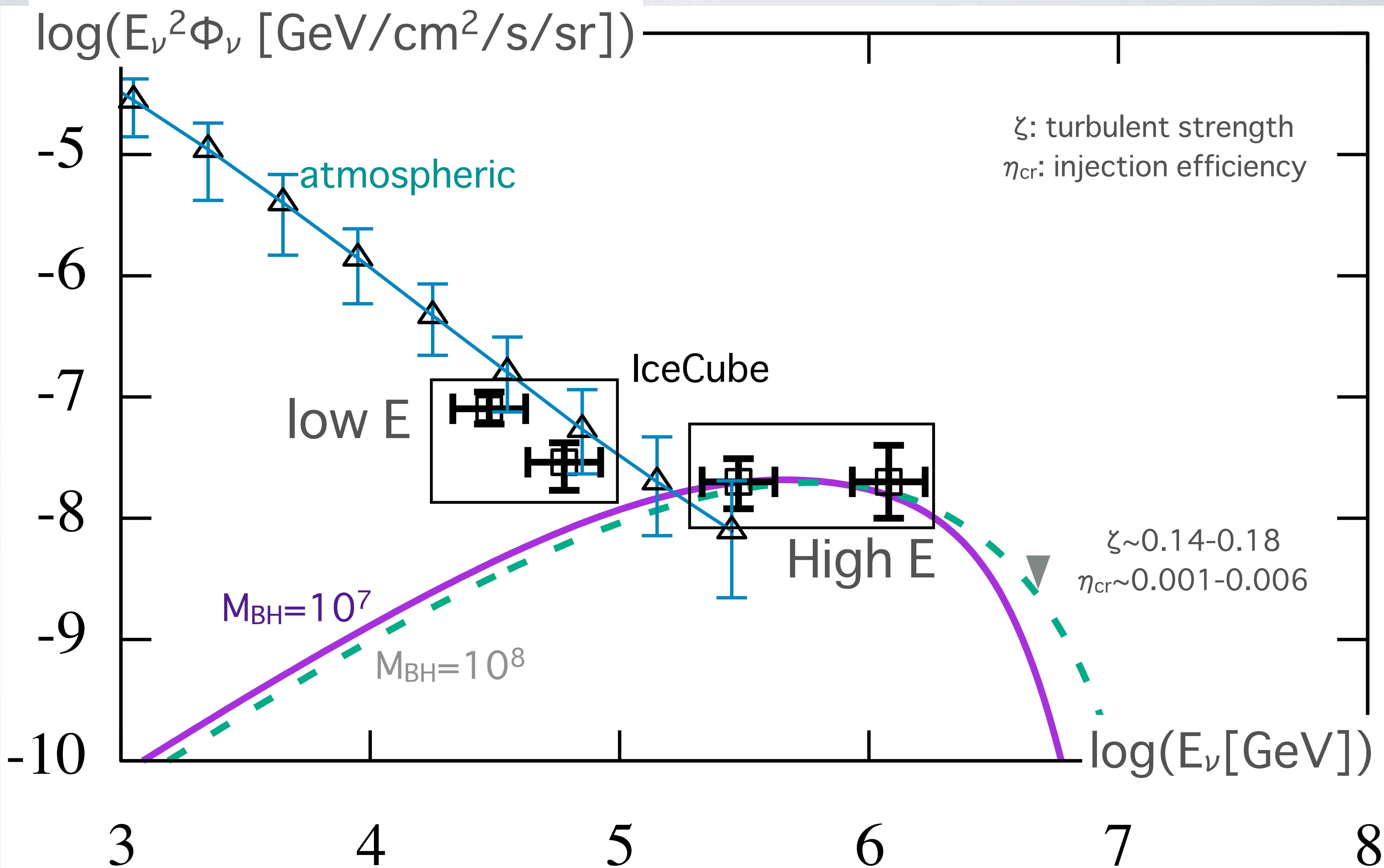

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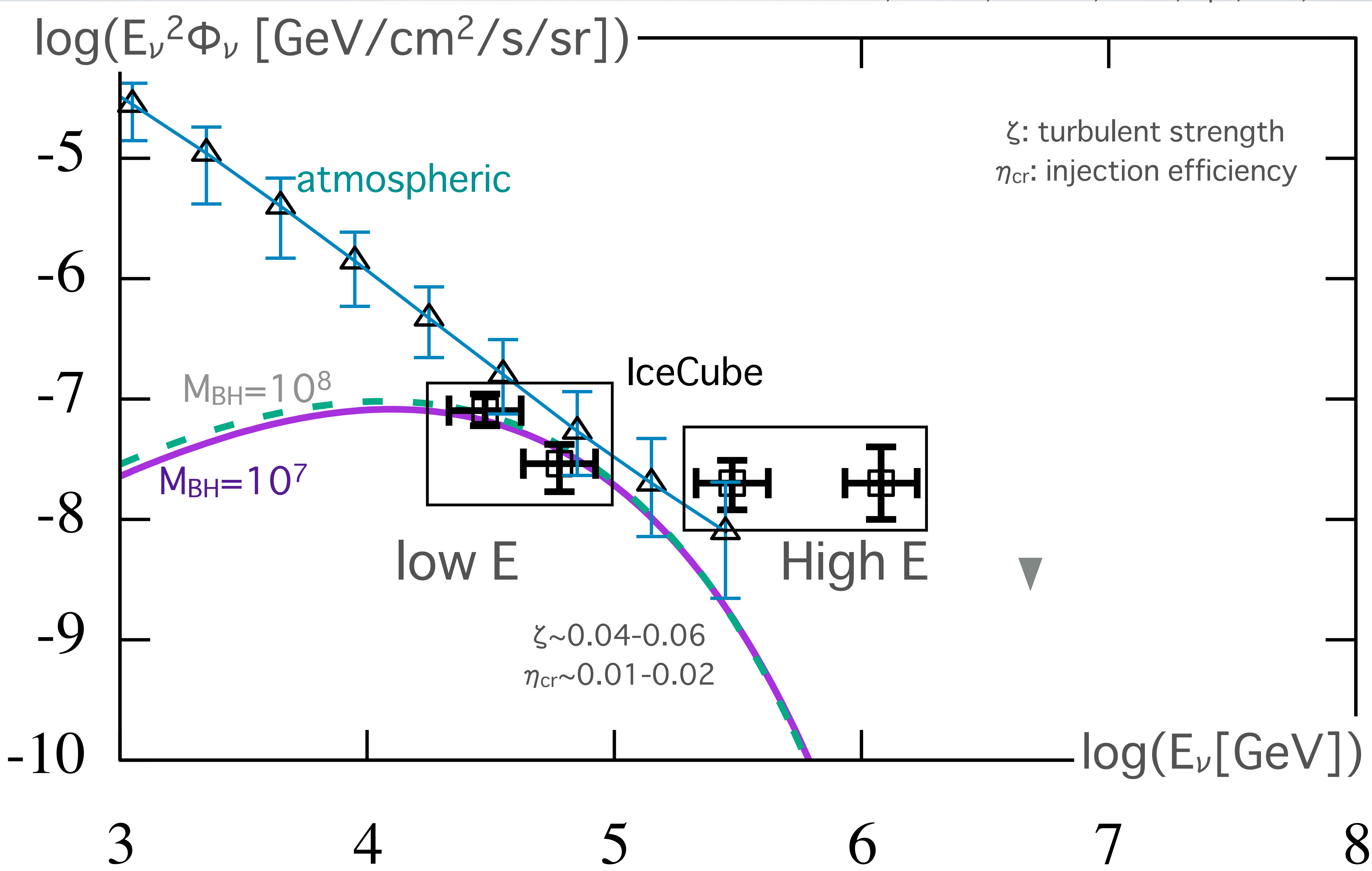

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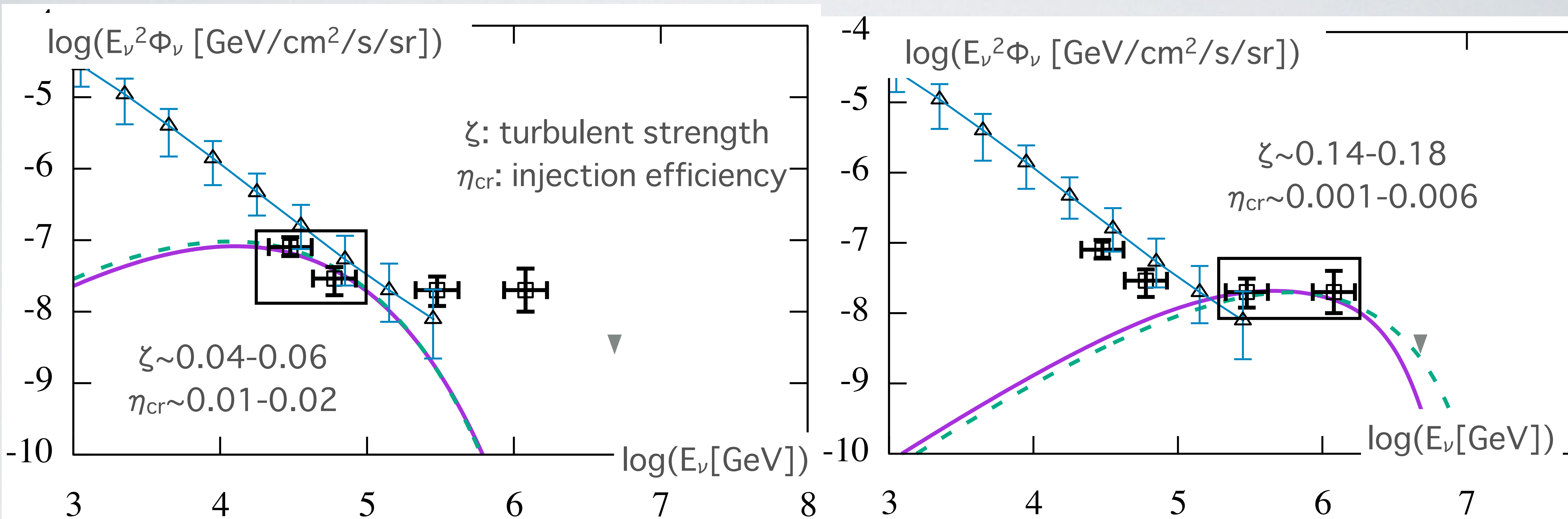
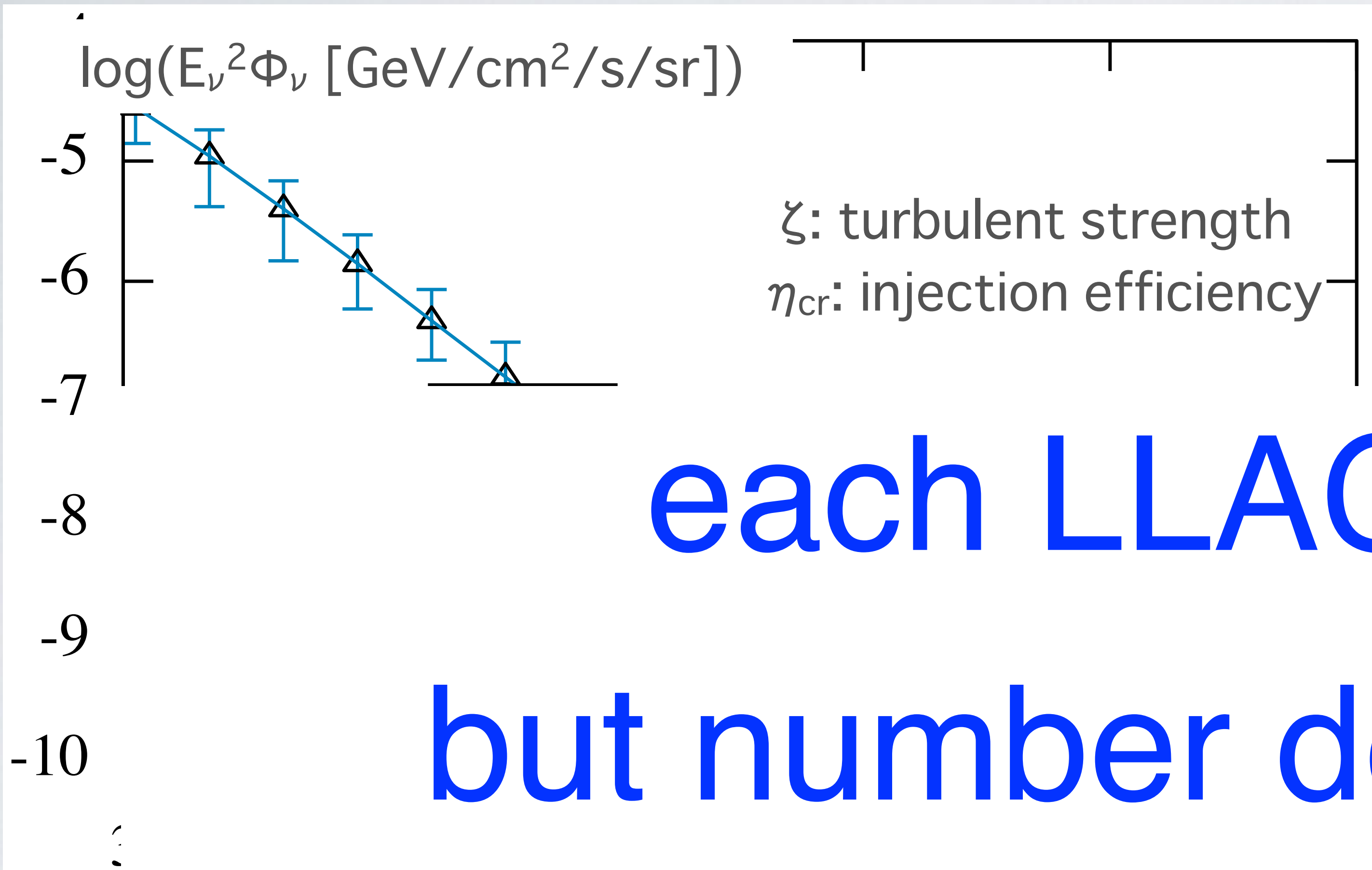


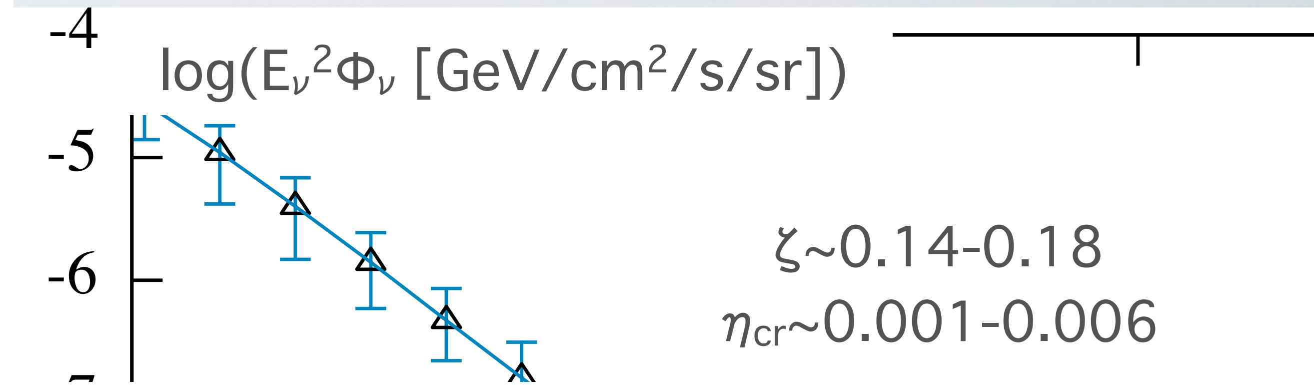
- LLAGN model can explain half part of IceCube events
- Injection efficiency: $\eta_{cr} \sim 10^{-3}$ - 10^{-2}
- Other sources may explain the other part.

(e.g., Starburst Galaxies, Low Luminosity GRBs)

Cumulative Background

SSK, Murase, & Toma, 2015, ApJ, 806,159





each LLAGN is faint

but number density is high

LLAGNs can emit enough neutrino

(e.g., Starburst Galaxies, Low Luminosity GRBs)

GAMMA RAYS FROM LLAGN

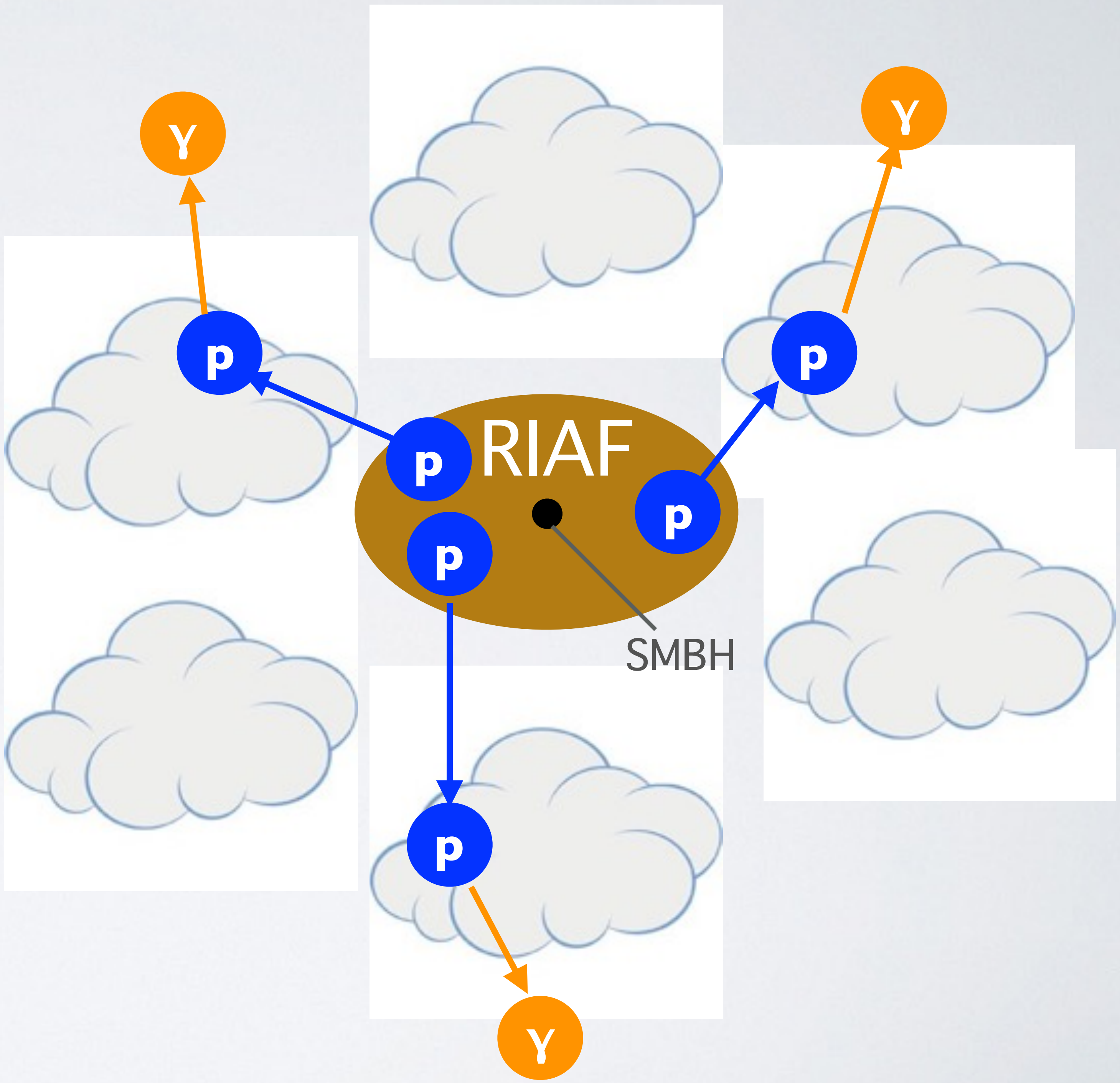
Fujita, SSK, Murase 15, PRD, 92, 023001

γ-rays by Escaping Protons

Fujita, SSK, Murase 15, PRD, 92, 023001

- Some LLAGNs are surrounded by the Giant Molecular Clouds (GMC)

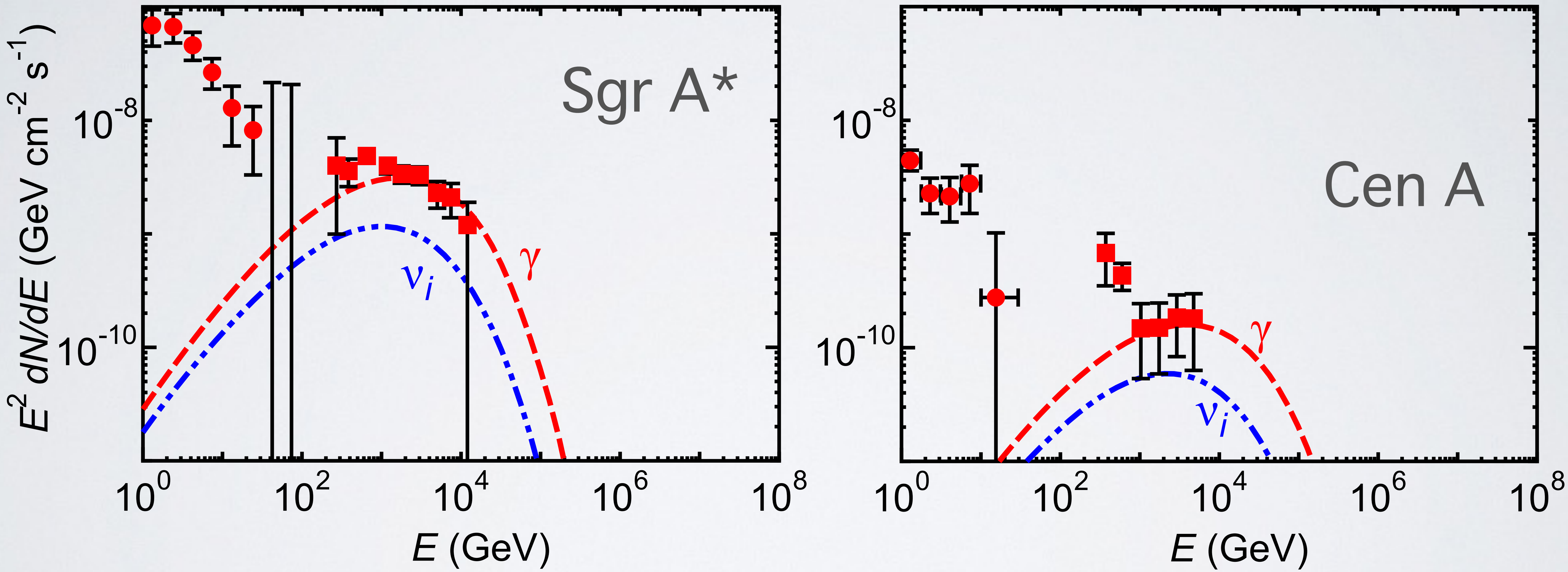
- Escaping protons emit gamma-rays through interaction with GMC



γ-rays by Escaping Protons

Fujita, SSK, Murase 15, PRD, 92, 023001

$$\frac{\partial f}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\kappa\frac{\partial f}{\partial r}\right) + Q$$



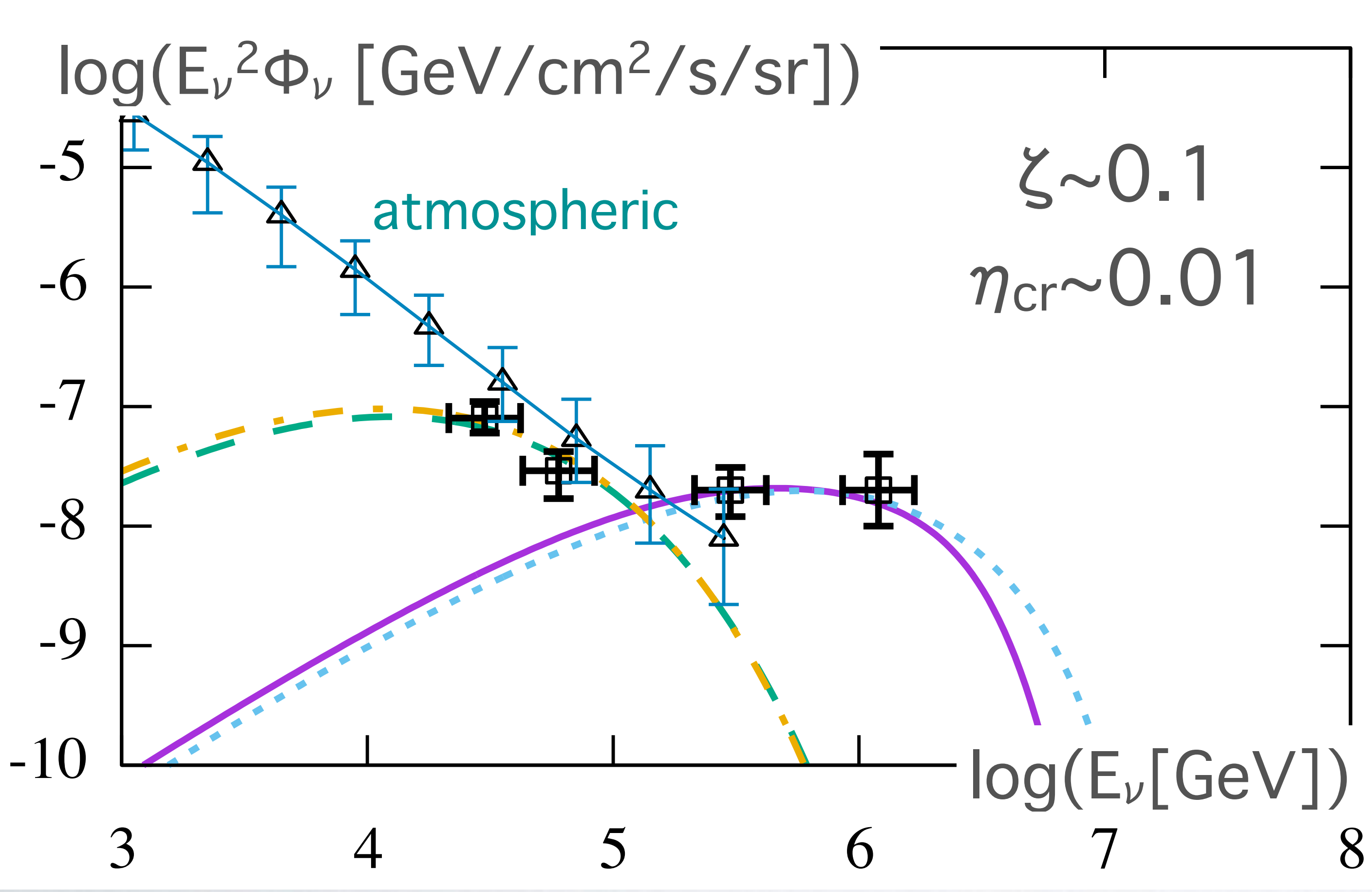
- This model is consistent with observed TeV flux from the Galactic Center & Centaurus A

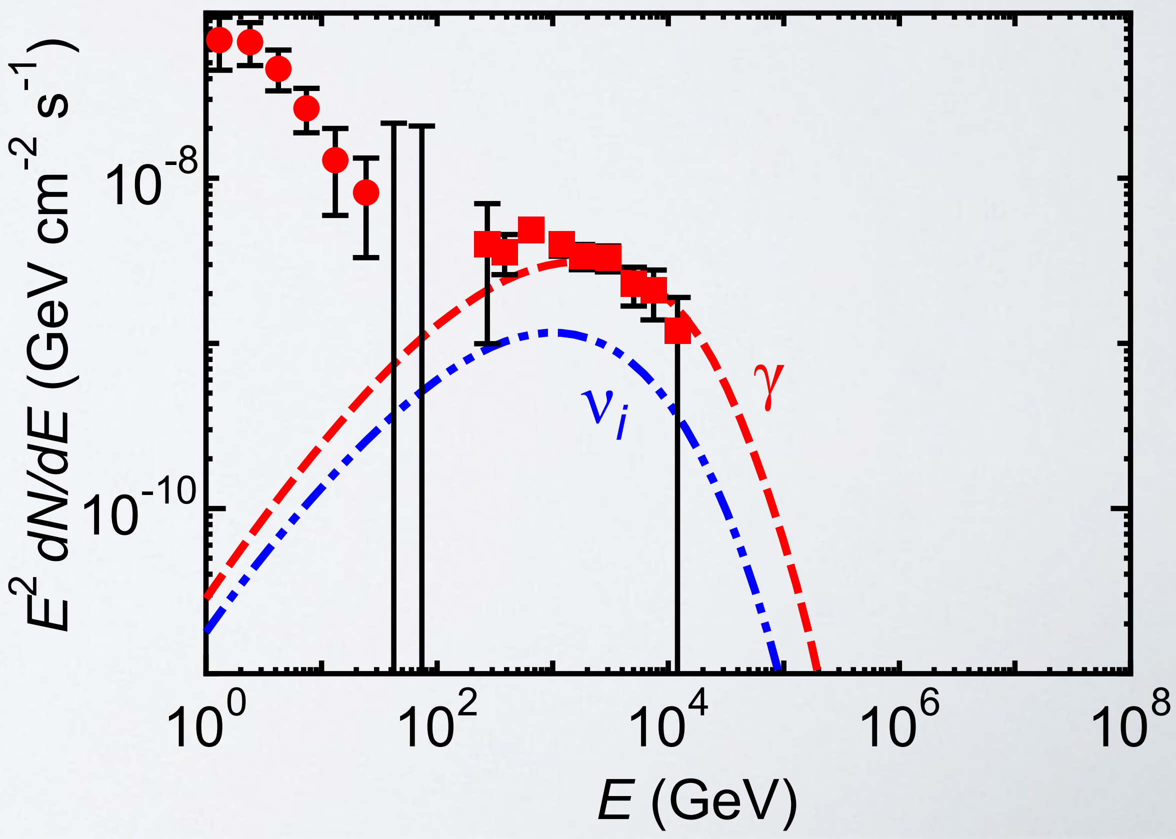
SUMMARY

SUMMARY

SSK, Murase, & Toma '15

- We propose LLAGN model as a source of IceCube events
- Calculating the proton spectra inside RIAFs, we find that
  1. Acceleration is limited by escape rather than cooling
  2. LLAGN can explain the IceCube neutrinos for either low energy or high energy data with reasonable parameter sets
  3. The escape p can emit γ by interaction with circum-nuclear matter





THANK YOU FOR YOUR ATTENTION

Gamma-rays from LLAGNs

SSK, Murase, & Toma, 2015, ApJ, 806,159

- pp & p$\gamma \rightarrow \pi^{\pm} + \pi^{0} \rightarrow \nu + \gamma$

Gamma-rays are inevitably generated with neutrinos

ExtraGalactic Background (EGB) constrains some models

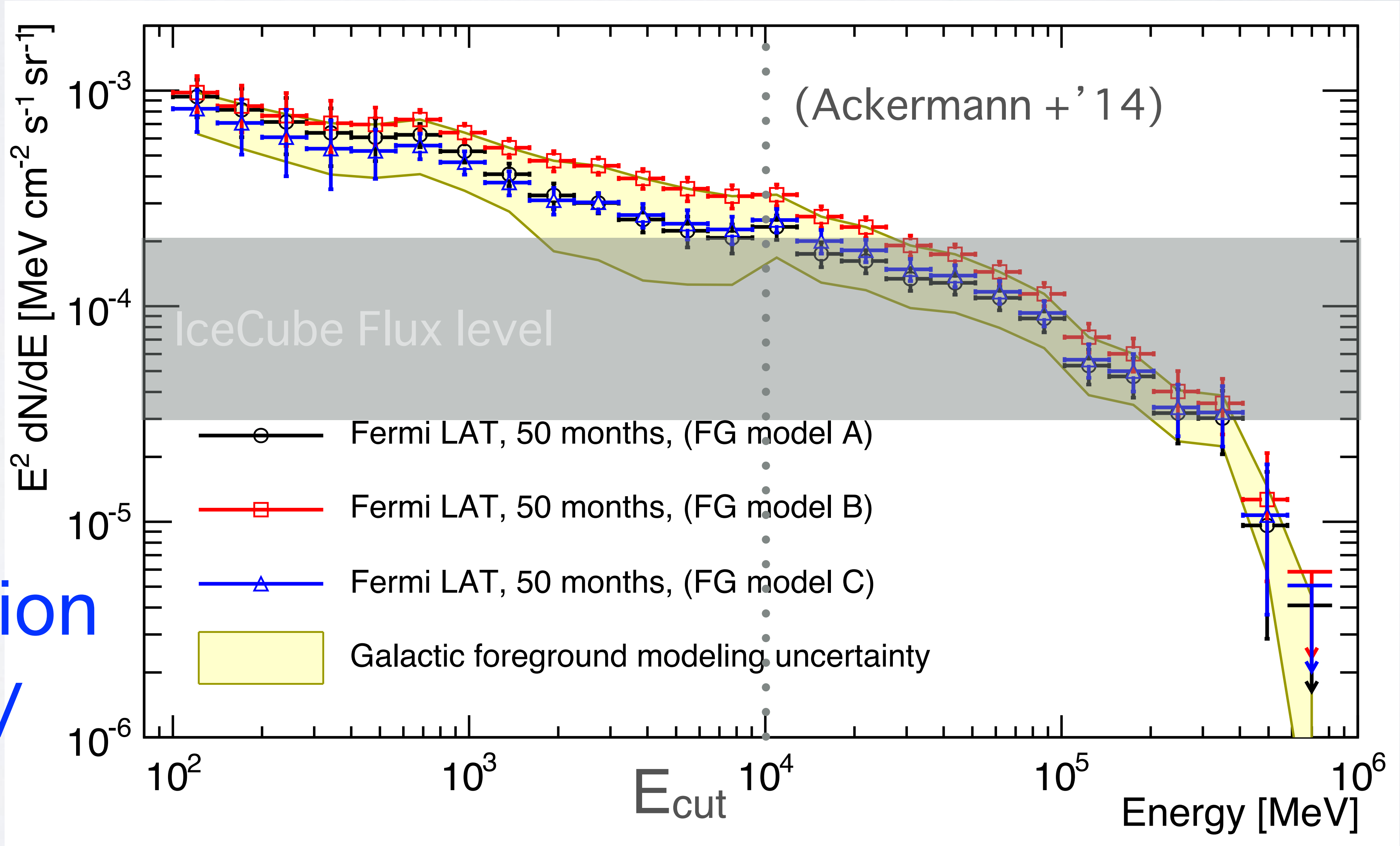
Murase+13; Murase+15

- Absorption:

$\gamma+\gamma\rightarrow e^{+}+e^{-}$

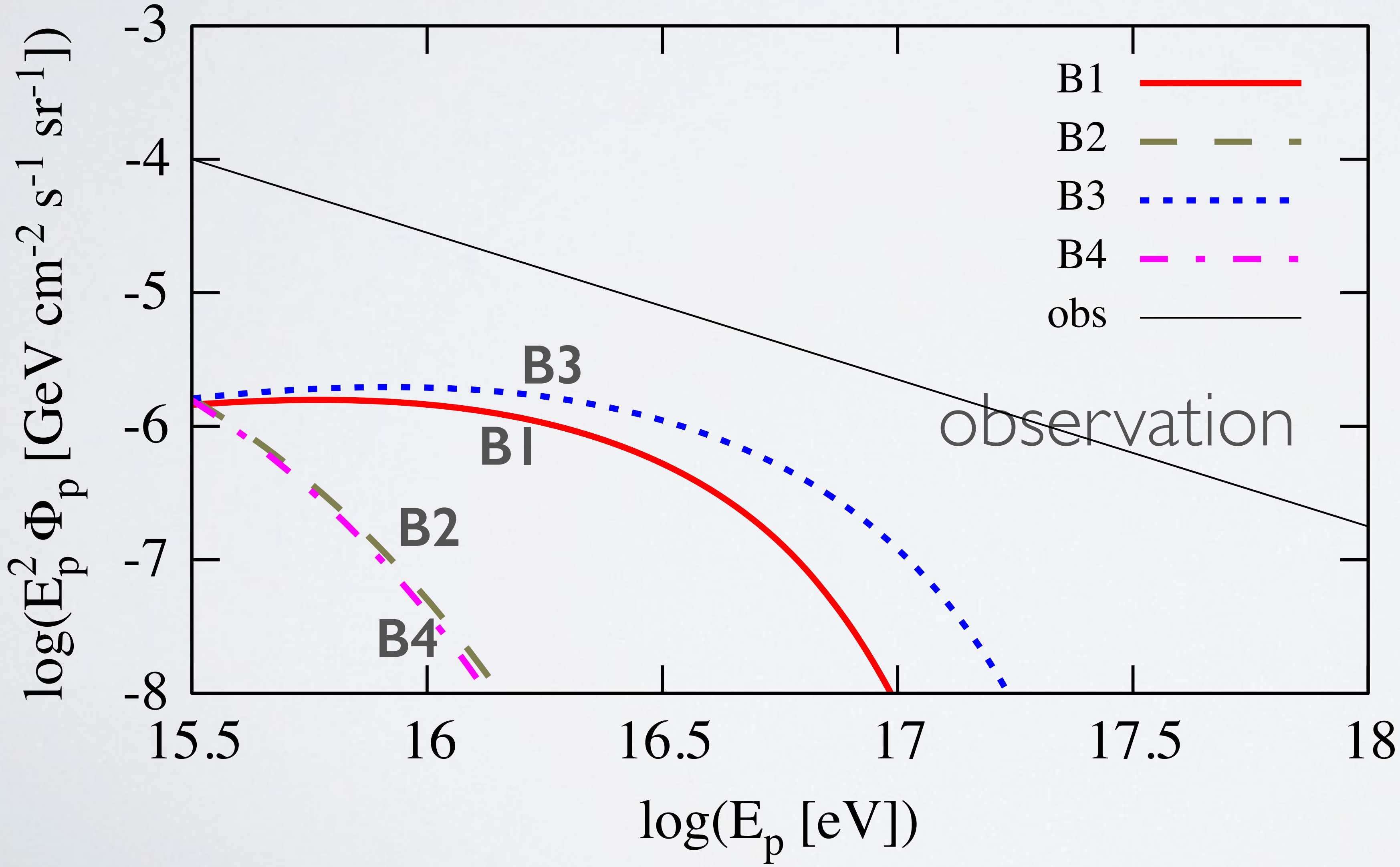
$E_{\gamma,cut} \lesssim 10$ GeV

→ No contradiction with EGB > 10GeV



Cosmic-ray Flux from LLAGNs

Suppose CRs travel IGM straightly with speed of light, which gives Maximum CR flux from LLAGN.
This Maximum CR flux is lower than observation



No evolution
$\phi(L_{bol})$ =const for z

fixed M_{BH}
$\dot{\mathbf{m}} \Leftrightarrow \mathbf{L_{bol}}$
α=0.1,
β=3,
r=10
q=5/3
z_{max}=7