Could the neutrino emission of TXS 0506+056 come from the core of the active galactic nuclei?

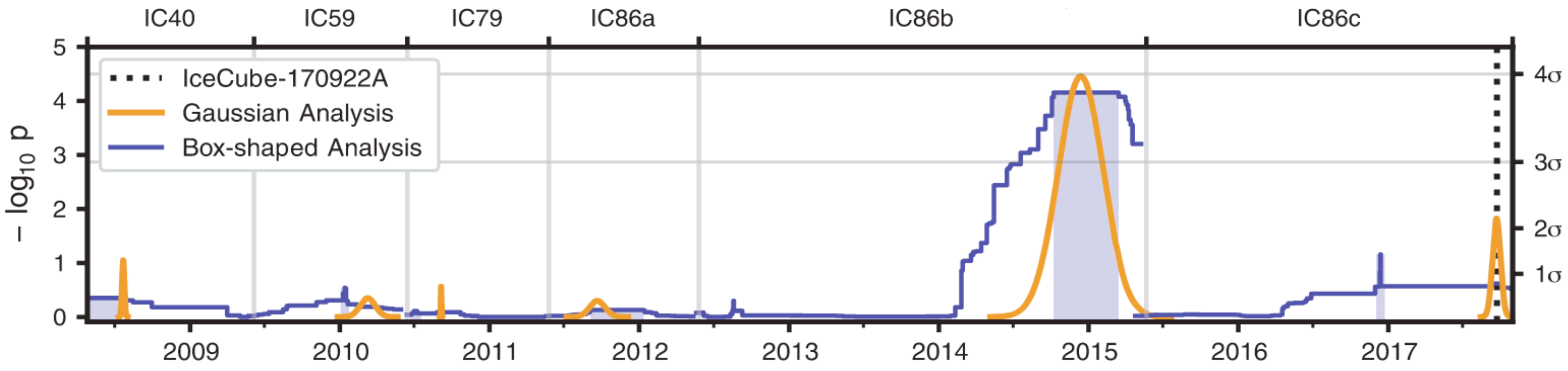
Speaker：Qi-Rui Yang （杨骐瑞）
Collaborators: Xiang-Yu Wang, Ruo-Yu Liu
Nanjing University

南京大學
NANJING UNIVERSITY

OUTLINES

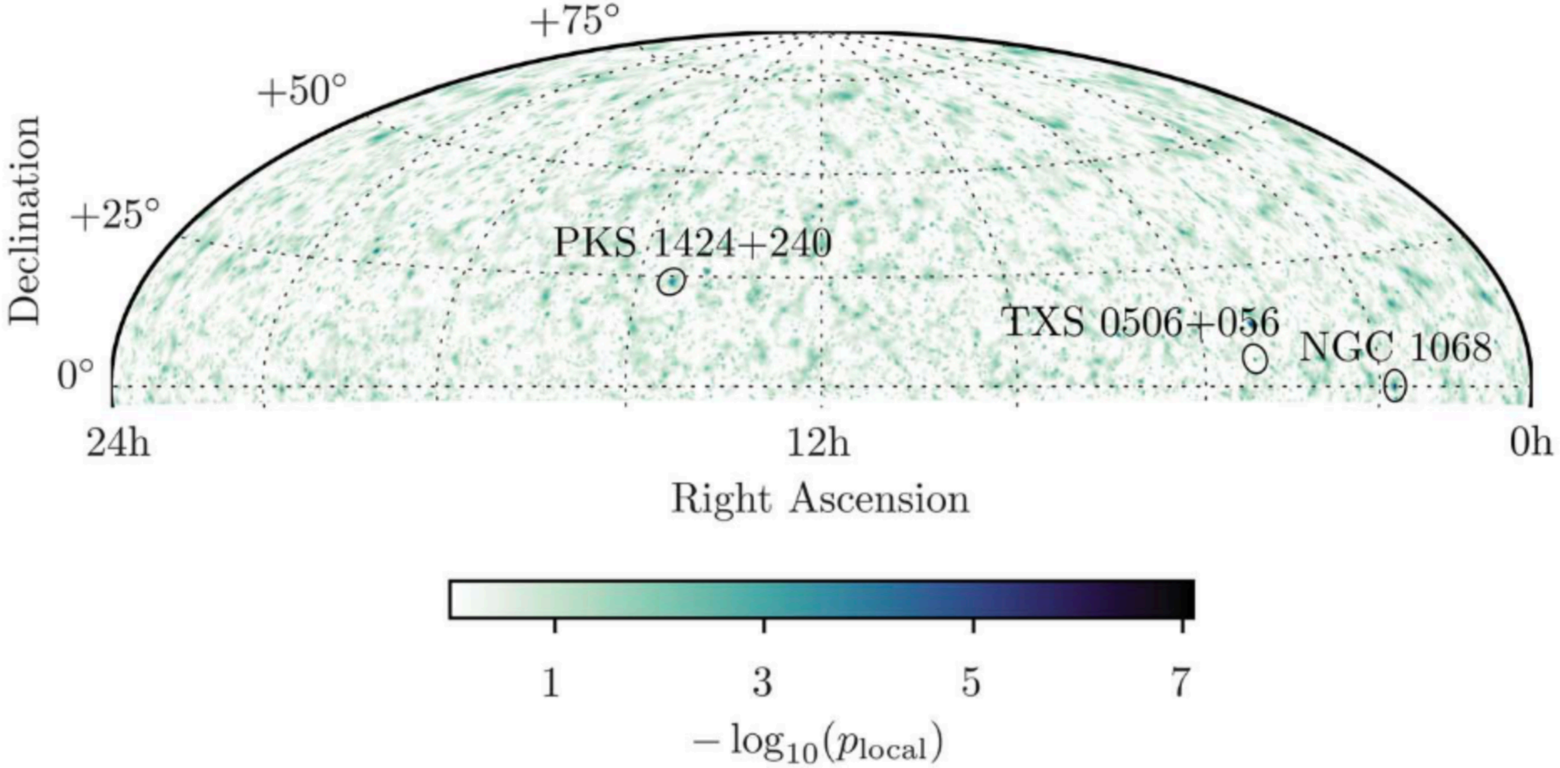
01 Introduction

- Blazar, z =0.3365± 0.0010
- A high-energy (290 TeV) muon neutrino event, IceCube170922A, was detected in both spatial and temporal coincidence with the γ-ray flare of the known blazar TXS 0506+056.
- 3.5σ excess of 13±5 high-energy neutrino events was discovered in the period between 2014 September and 2015 March, known as 2014-2015 neutrino flare.



IceCube Collaboration et al. 2018a

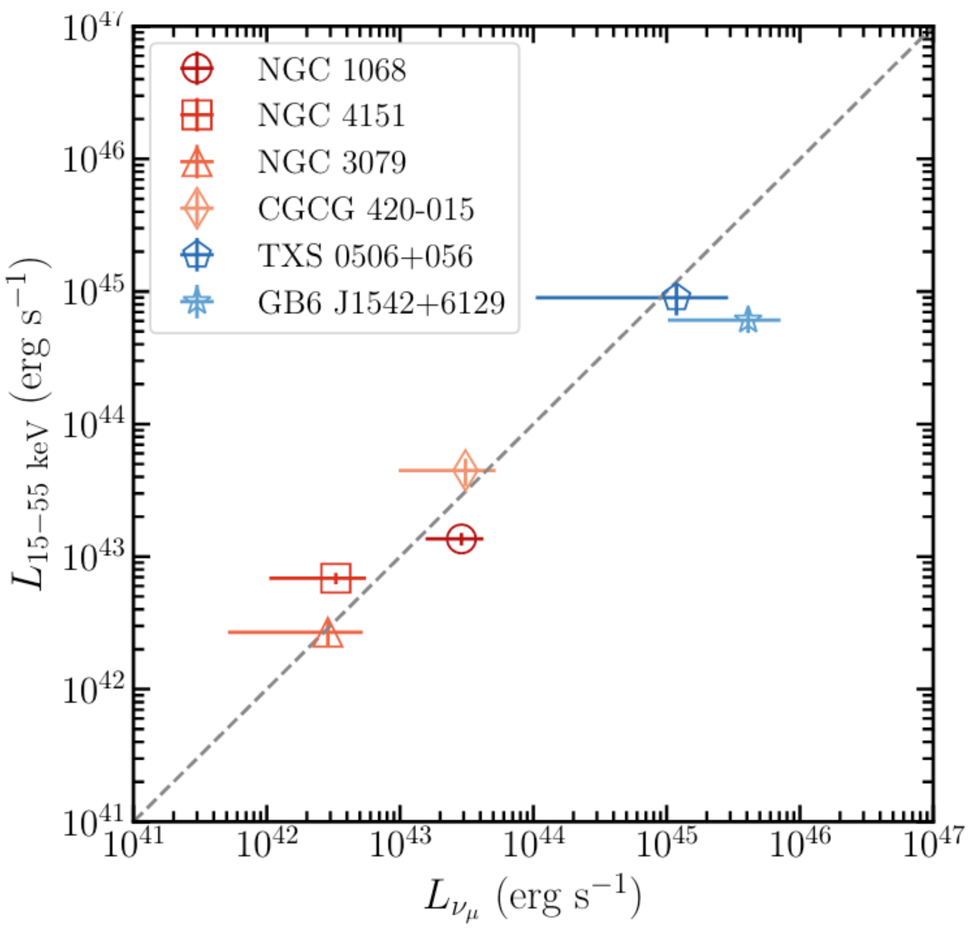
IceCube Collaboration. 2022



- Sky map of the scan for point sources in the Northern Hemisphere. TXS 0506+056 relates to a time-integrated signal over the duration of 9.5yr, whereas previous analyses have found evidence for transient emission
- Local significances of 3.5σ,

01

Introduction

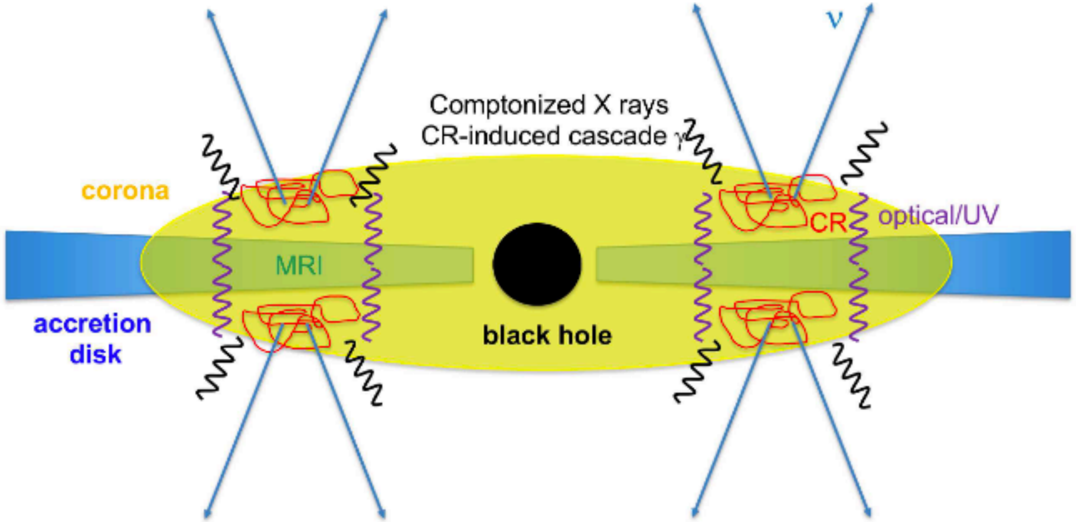


Kun et al. 2024

- Neutrino emission from radio-quiet Seyfert galaxies is unlikely to be related to their weak jets (NGC 1068)
- Neutrino flux is about 5 times higher than the average γ-ray flux for 14-15 flare
- A hint of gamma-absorption is also observed in the diffuse neutrino flux, pointing to the so-called "hidden" neutrino sources.
- **Core region can be a common origin**, implying non-jet origin

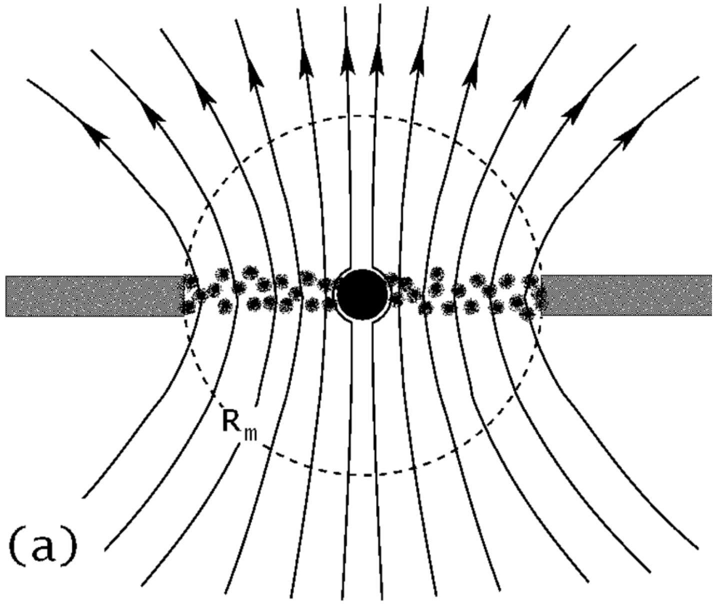
“Core Region” Disk+Corona

Murase et al. 2020



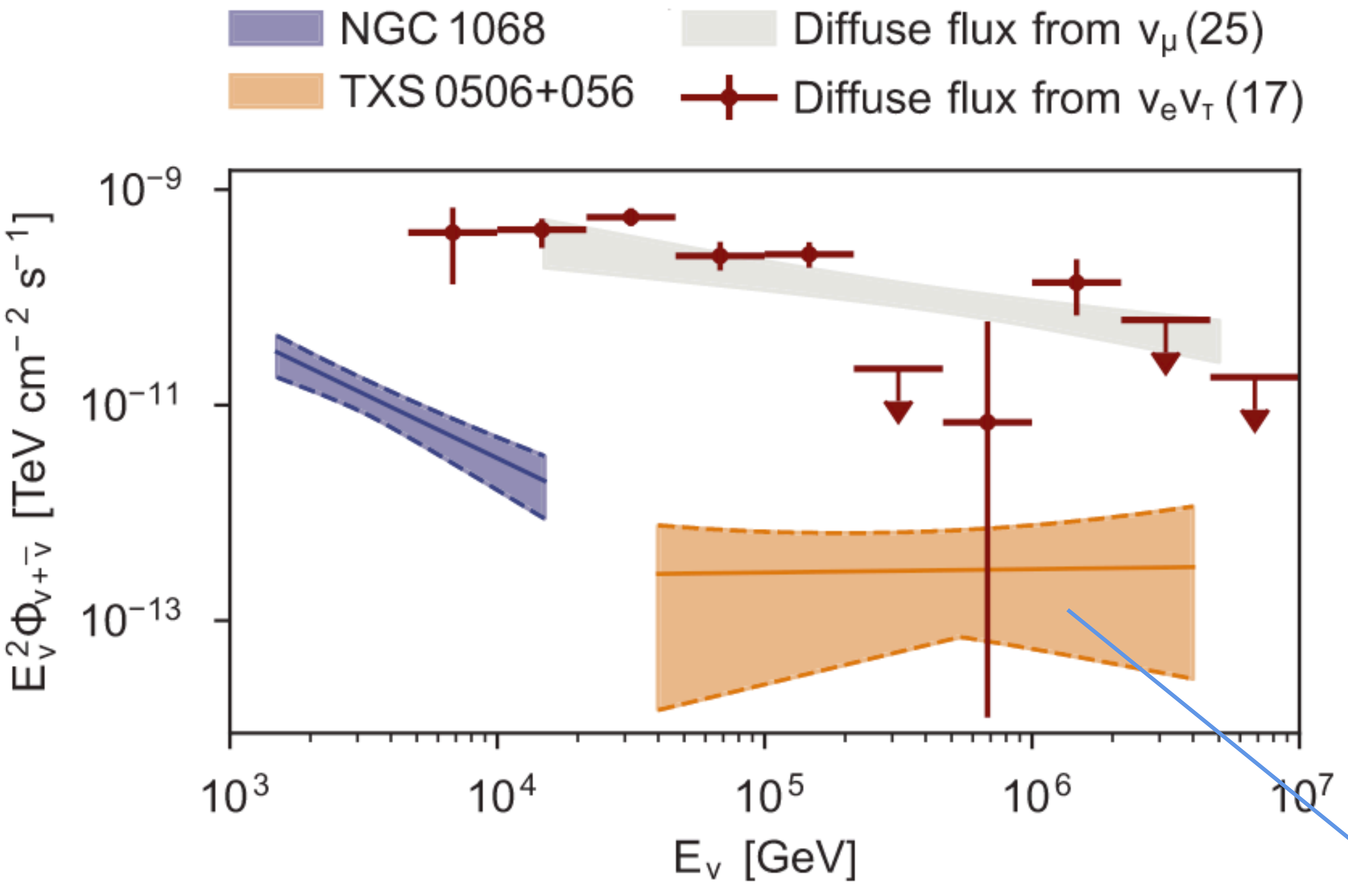
MAD (Magnetically arrested disk)

Narayan et al. 2003



- Photon Field: “Big Blue Bump”+ power-law X-ray component
- CR can be accelerated in the MAD (Magnetically Arrested Disk, $\beta \sim 1$)
- Emission region set within 10 R_g

02 Steady-state neutrino emission



IceCube Collaboration. 2022

Energy Range: 40 TeV - 4 PeV

Luminosity upper limit : $1.3 \times 10^{45}\ erg\ s^{-1}$
Luminosity lower limit: $7 \times 10^{43}\ \mathrm{erg\ s^{-1}}$
Central Value: $5.6 \times 10^{44}\ \mathrm{erg\ s^{-1}}$

Index: $\Gamma \approx 2.04$

Steady-state Emission

Steady-state neutrino emission

- For high-energy protons accelerated within MAD, we can estimated the CR luminosity from Eddington luminosity.

$$L_{CR} = \epsilon_{CR}\dot{m}L_{\rm 0506,\ Edd} = 6\times10^{45}{\rm erg\ s^{-1}}\left(\frac{\epsilon_{\rm CR}}{0.3}\right)\left(\frac{\dot{m}}{0.5}\right)\left(\frac{M_{BH}}{3\times10^{8}M_{\odot}}\right)$$

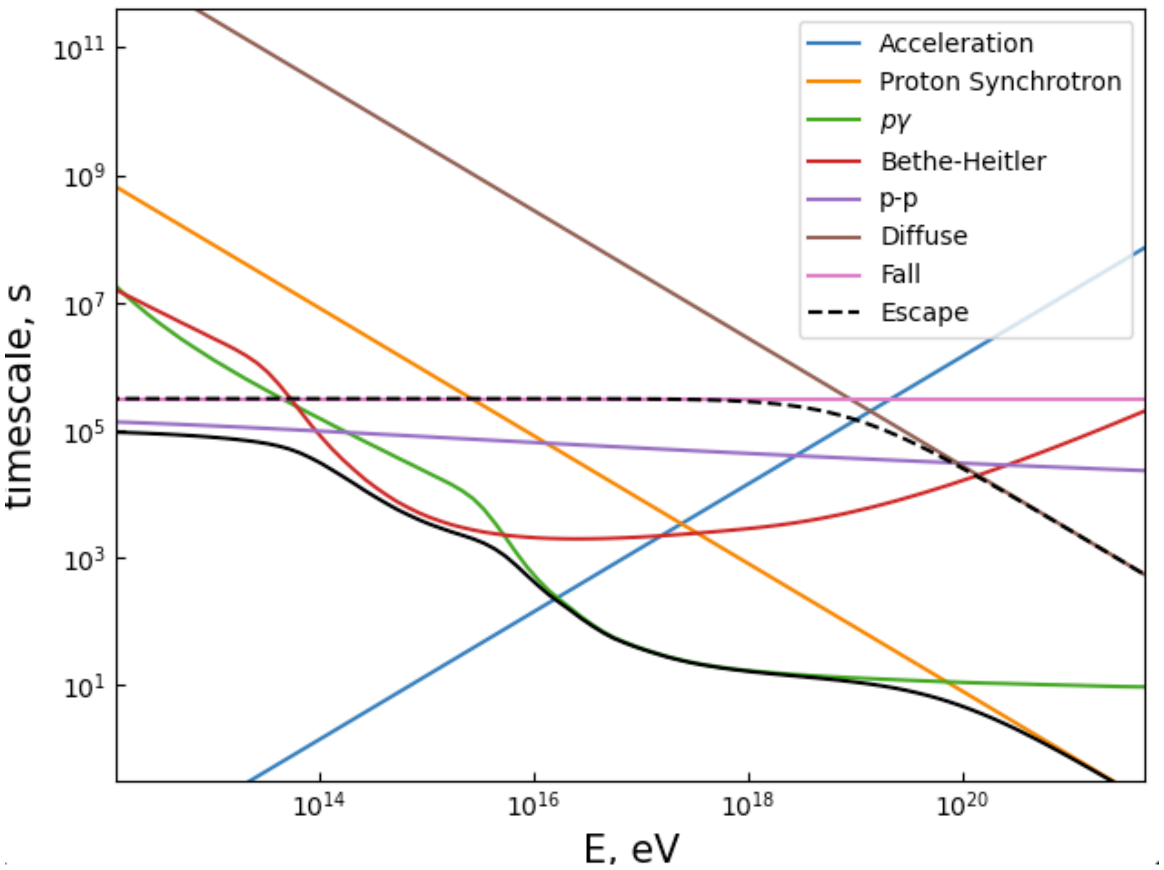
$$L_{\rm 0506,\ Edd} \approx 4\times10^{46}{\rm erg\ s^{-1}}\left(\frac{M_{BH}}{3\times10^{8}M_{\odot}}\right)$$

- High-energy neutrinos are produced via pp and $p\gamma$ process. The estimated neutrino luminosity is illustrated as

$$L_{\nu} = \frac{1}{8}f_{pp,p\gamma}\epsilon\dot{m}L_{0506,Edd}$$

02

Timescale from the core region of TXS 0506+056



- We do not focus on specific acceleration mechanisms; instead, different acceleration channels are represented by the acceleration factor η

$$t_{acc} \approx \eta r_L / c \quad \eta \sim 300$$

- The maximum energy of accelerated protons is given by

$$E_{p,\max} \approx 10 \text{ PeV} \left(\frac{\dot{\mathrm{m}}}{0.5}\right)^{1/2} \left(\frac{\mathrm{R}}{10\mathrm{R_g}}\right)^{-5/4} \left(\frac{\mathrm{M_{BH}}}{3\times 10^8 \mathrm{M_\odot}}\right)^{5/4} \left(\frac{\beta}{1}\right)^{-1/2} \left(\frac{\eta}{300}\right)^{-1} \left(\frac{\mathrm{n_\gamma}}{4\times 10^{15}\ \mathrm{cm^{-3}}}\right)^{-1}.$$

02 pp and $p\gamma$ efficiency

- For the neutrino energy range that we are interested (40 TeV - 4 PeV) , the interaction efficiencies are numerically obtained by $f_{p\gamma} \sim 0.2$ $f_{pp} \sim 0.07$

- Neutrino luminosity via $p\gamma$

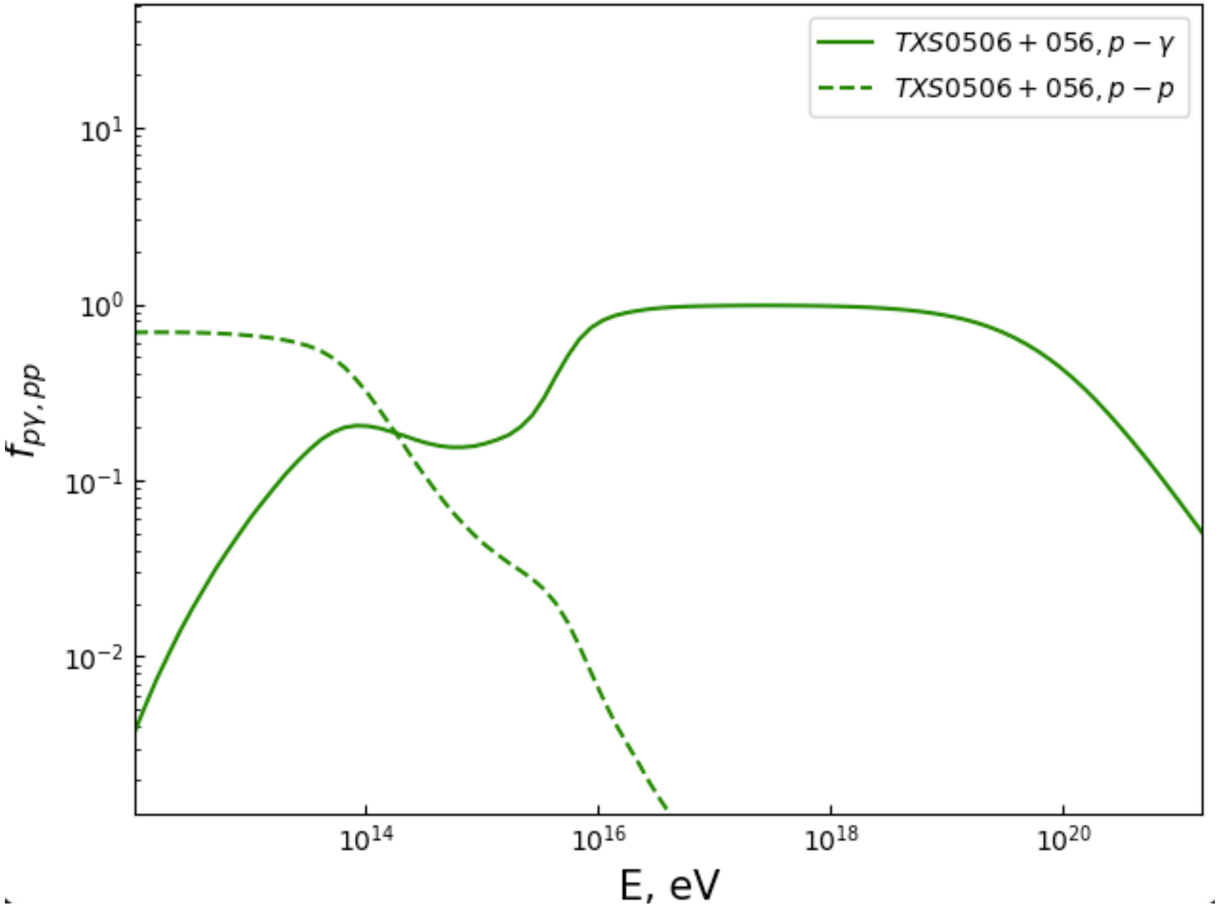
$$L_{\nu_\mu,p\gamma} = \frac{1}{8}\epsilon_{\rm CR} f_{p\gamma} \dot{m} L_{\rm Edd}$$

$$\sim 1.7 \times 10^{44}\ {\rm erg\ s^{-1}} \left(\frac{\epsilon_{\rm CR}}{0.33}\right)\left(\frac{\rm f_{p\gamma}}{0.2}\right)\left(\frac{\rm \dot{m}}{0.5}\right)$$

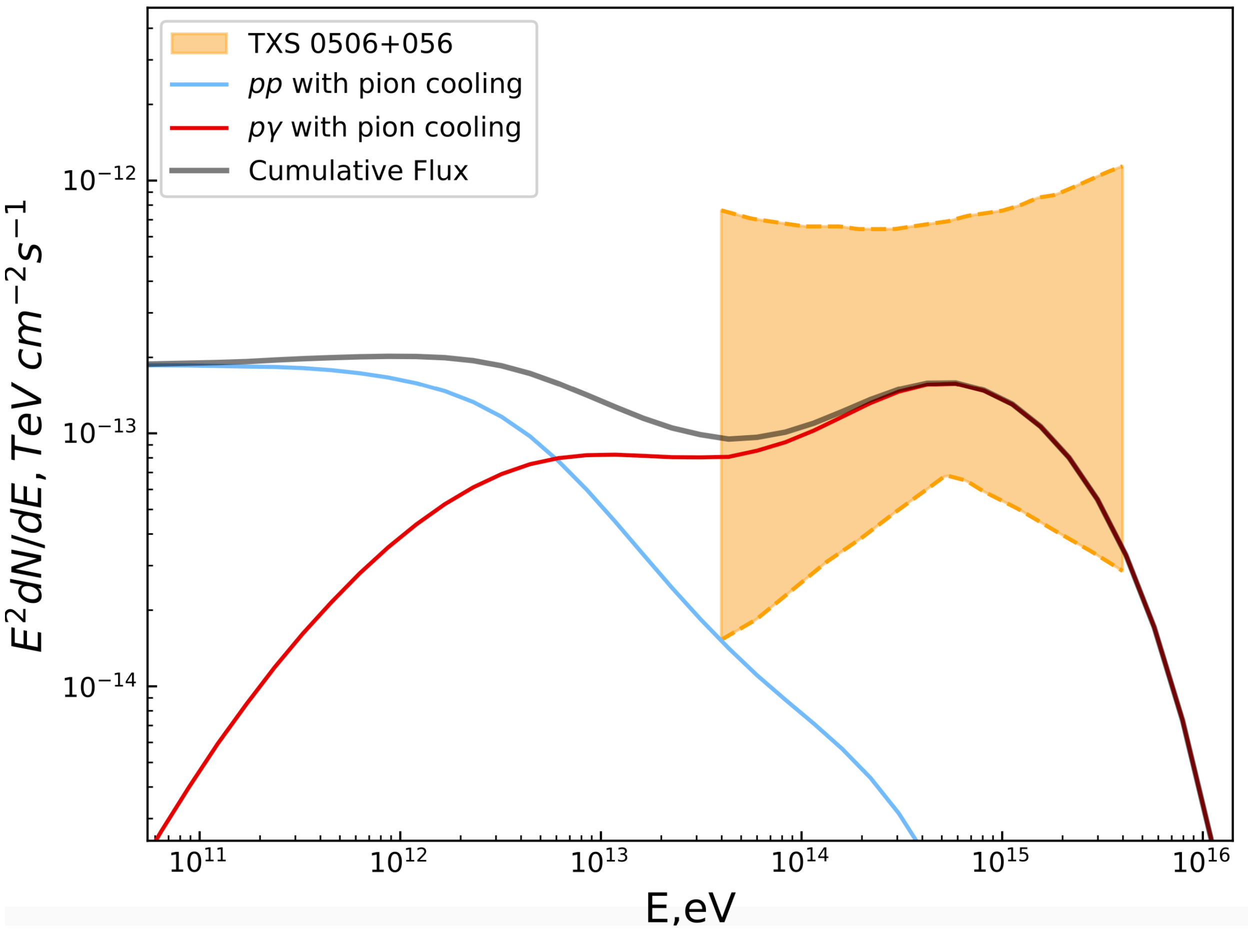
- Neutrino luminosity via pp

$$L_{\nu_\mu,pp} = \frac{1}{8}\epsilon_{\rm CR} f_{pp} \dot{m} L_{\rm Edd}$$

$$\sim 5 \times 10^{43}\ {\rm erg\ s^{-1}} \left(\frac{\epsilon_{\rm CR}}{0.33}\right)\left(\frac{\rm f_{pp}}{0.07}\right)\left(\frac{\rm \dot{m}}{0.5}\right)$$



Steady-state neutrino emission spectrum



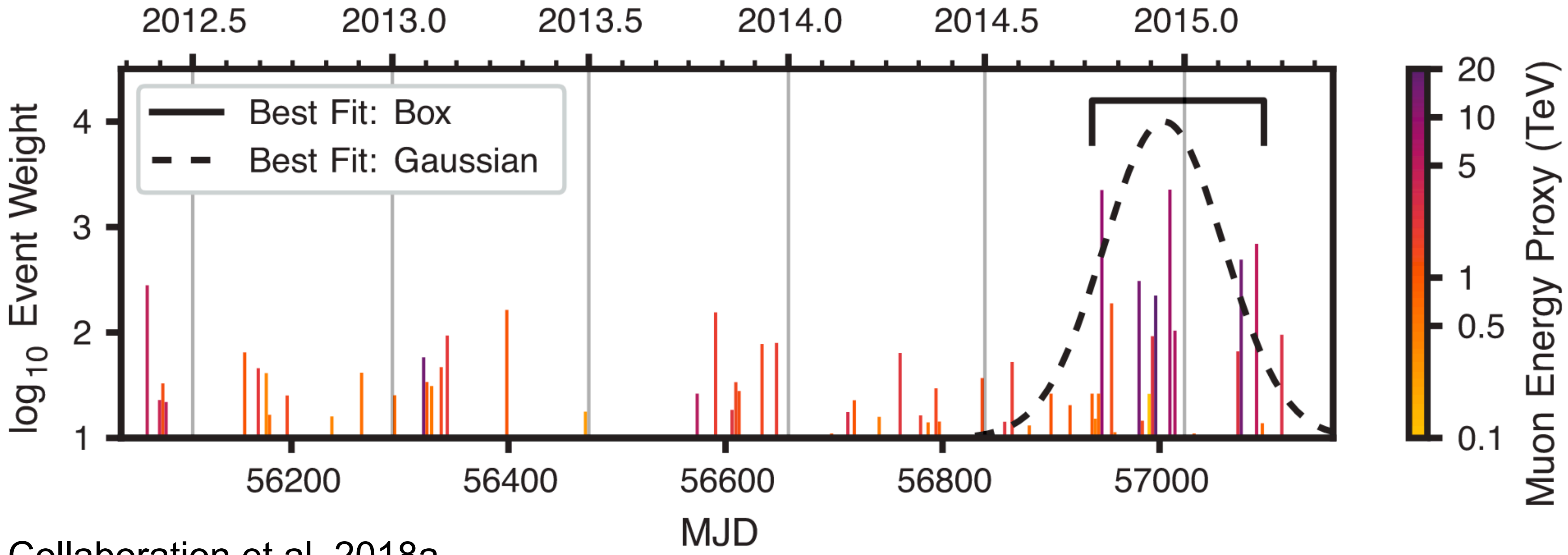
- With pion's cooling considered, the neutrinos' energy spectrum forms a natural cutoff
- $p\gamma$ dominates the steady-state neutrino emission.

$$\xi_\pi = Min\{t_{\pi,loss}/\tau_\pi, 1\}$$

$$\sim 0.6 \left(\frac{E_\pi}{10\ \mathrm{PeV}}\right)^{-2/3} \left(\frac{\beta}{1}\right)^{1/3}$$

2014-2015 flare neutrino emission

- The neutrino flare between 2014-2015 last 158 days
- Best-fitting spectral index $\Gamma = 2.1$
- Energy range: 32 TeV and 3.6 PeV.
- Isotropic neutrino luminosity $1.2^{+0.6}_{-0.4} \times 10^{47}$ erg s^{-1}
- 13 ± 5 muon-neutrino events that are present in addition to the expected background.

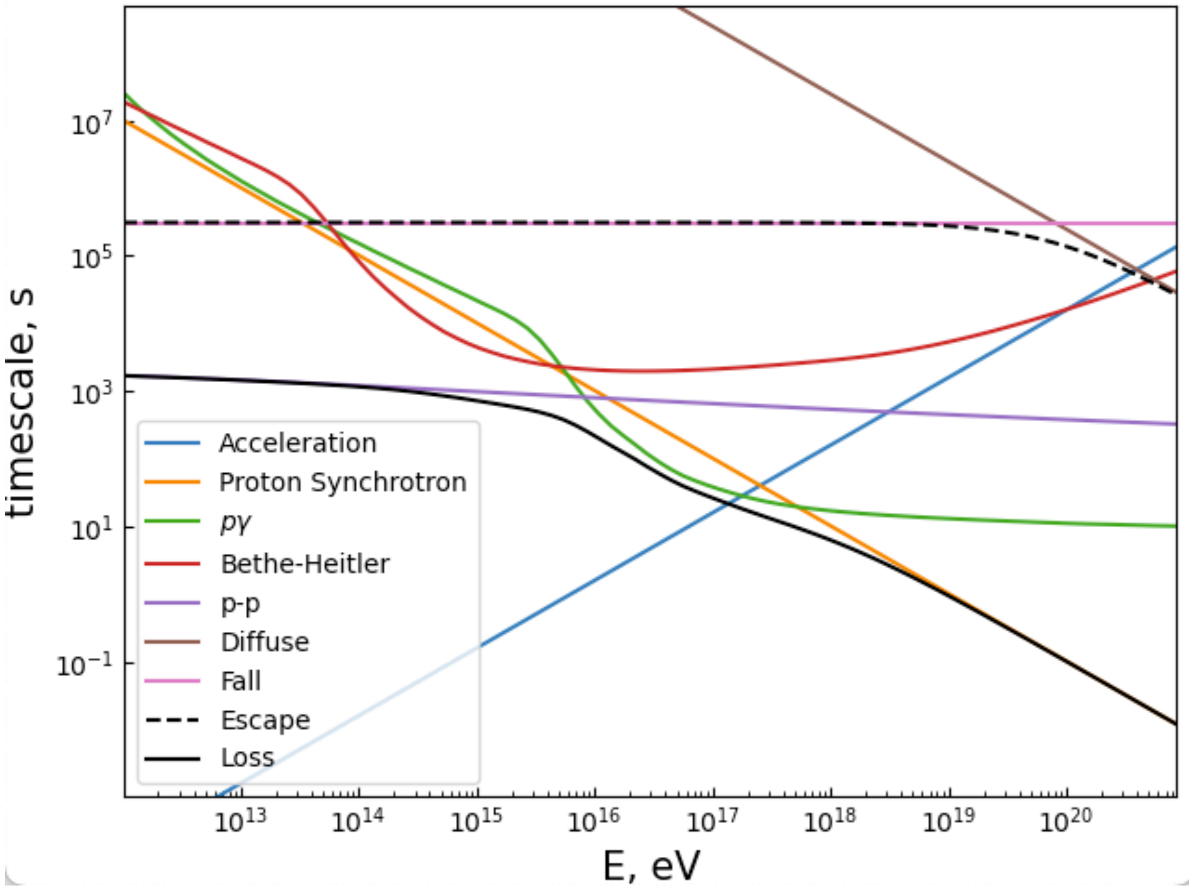


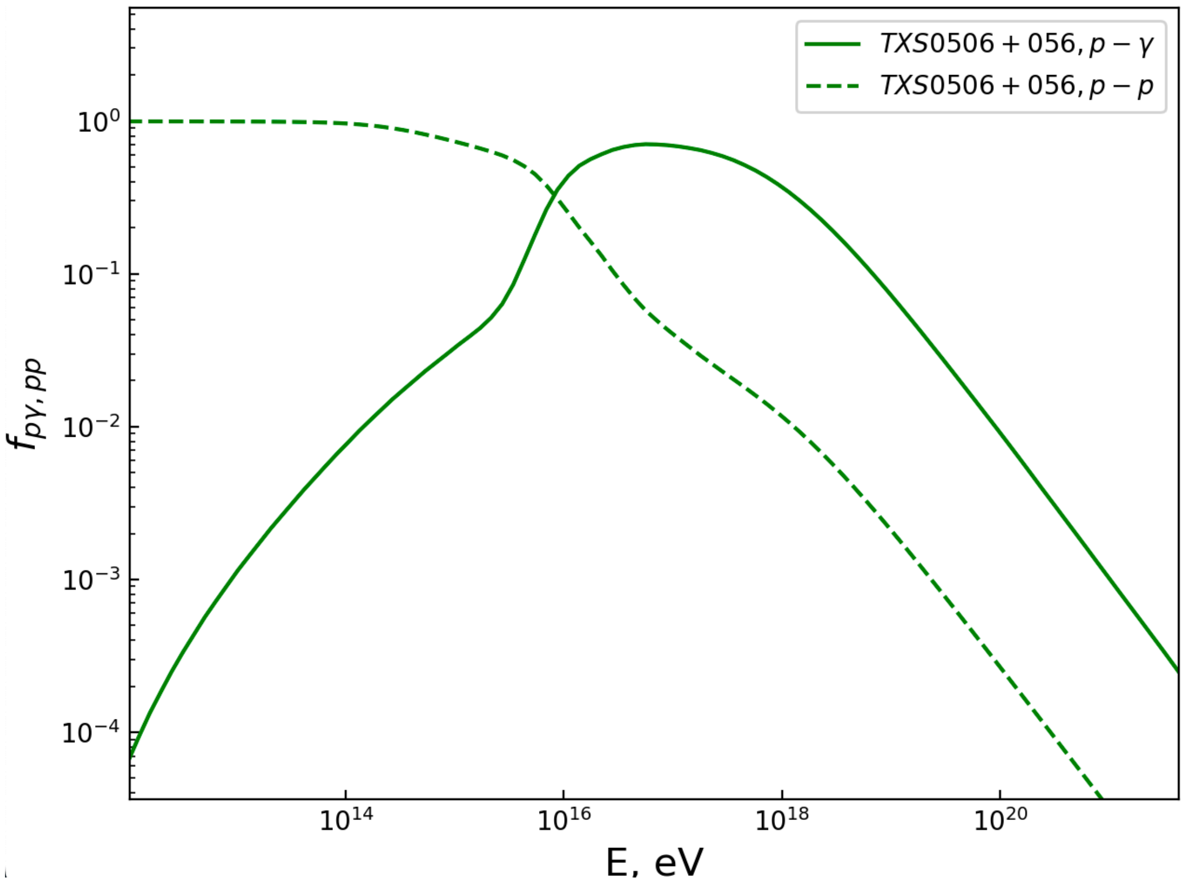
IceCube Collaboration et al. 2018a

Timescale and efficiency in flare scenario

- We consider a Super-Eddington accretion with $\dot{m} \sim 40$ to explain the flare emission

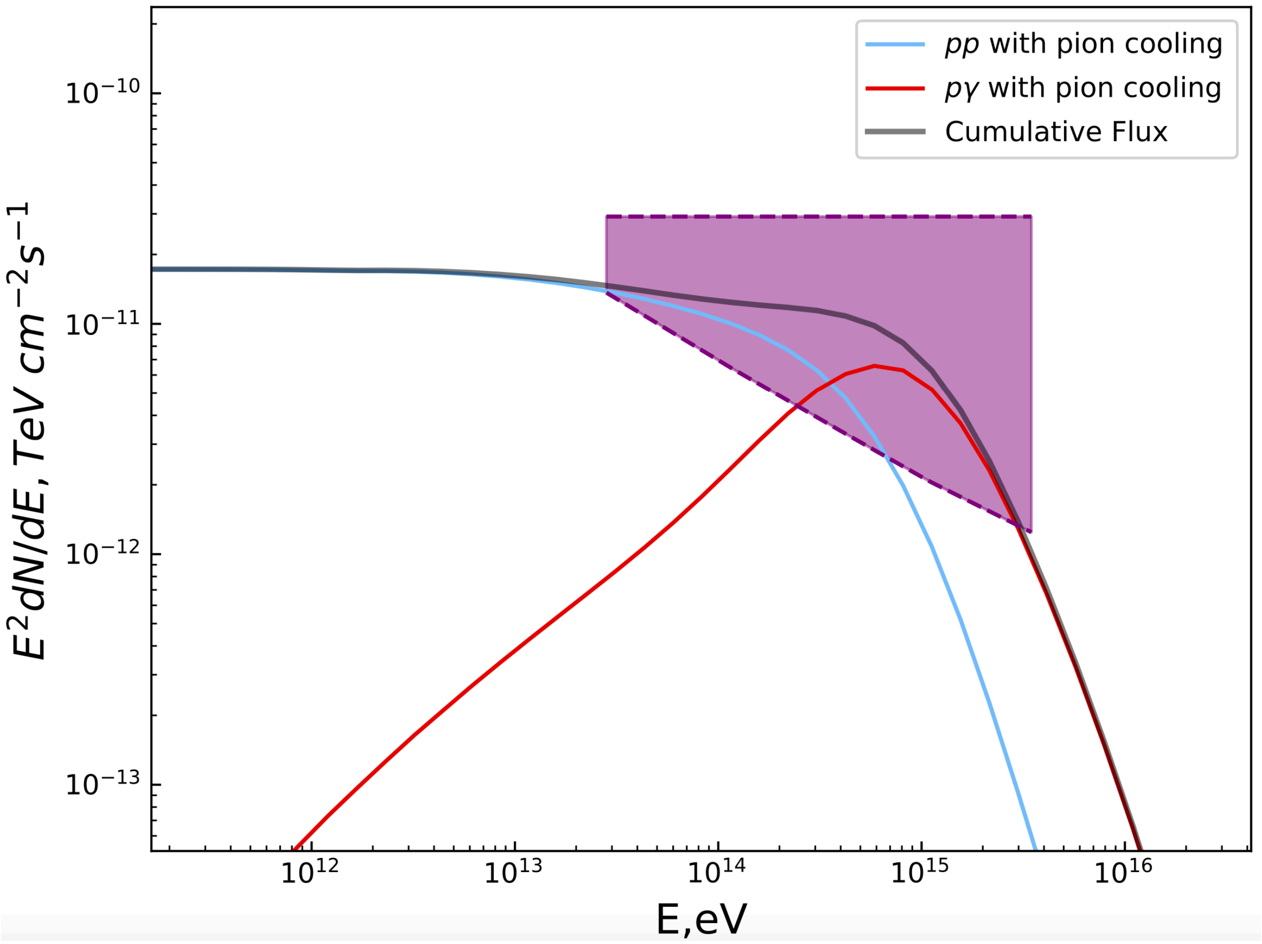
$$L_\nu = \frac{1}{8} f_{pp,p\gamma} \epsilon \dot{m} L_{0506,Edd} \sim 6 \times 10^{46}\ \mathrm{erg\ s^{-1}} \left(\frac{\epsilon_{\rm CR}}{0.33}\right)\left(\frac{\rm f}{1}\right)\left(\frac{\dot{\rm m}}{40}\right)$$





03

2014-2015 flare neutrino spectrum



- We consider a supper-Eddington accretion $\dot{m} \sim 40$ to explain the 14-15 neutrino flare emission
- pp and $p\gamma$ both contribute the 2014-2015 flare neutrino emission.

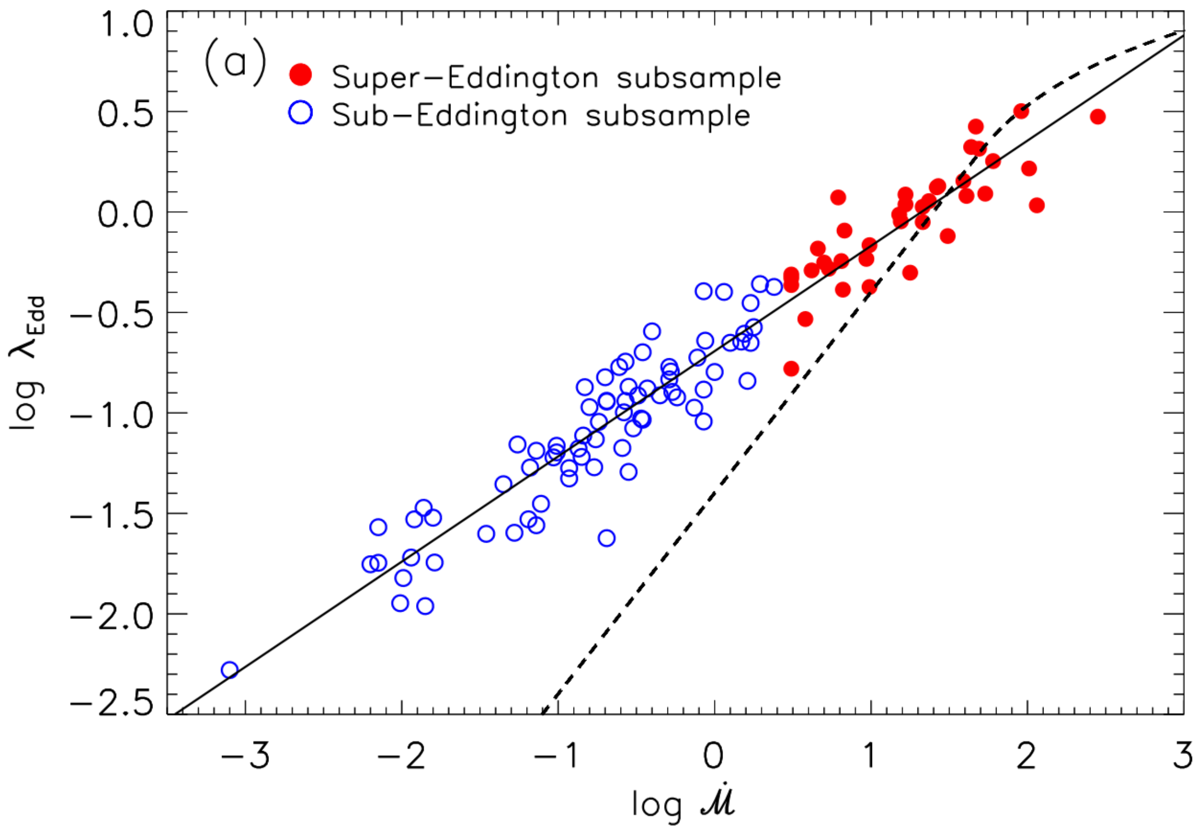
04

Summary

- In the case of Sub-Eddington accretion $(\dot{m} \sim 0.5)$ and MAD $(\beta \sim 1)$, the steady-state neutrinos of TXS0506 may come from its core region.

- The flare neutrino emission in the period of 2014-2015 can explained by the core region emission with the Supper-Eddington accretion $(\dot{m} \sim 40)$,

Supplementary material



Huang et al. 2020

- 14-15 flare X-ray upper limit at 10 keV: 10^{-11} erg cm^{-2} s^{-1}
- The Bolometric luminosity The evolution of X-ray and accretion rates is not linear with a power-law slope of 0.52
- The accretion rate increased by a factor of 80 from steady state to flare state; however, the X-ray luminosity likely rose by only a factor of 6-7, which would remain within the SWIFT upper limit of 2014-2015.