Time Correlation between X-rays and Neutrinos from Seyfert Galaxies

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Seyfert Galaxies as Neutrino Sources

NGC 1068

- identified as a possible neutrino source by IceCube (wih 5σ)
- Seyfert Galaxy (**doesn't have strong jet**)

→ Seyferts are now getting attentions as the neutrino sources.

Other Seyfert galaxies

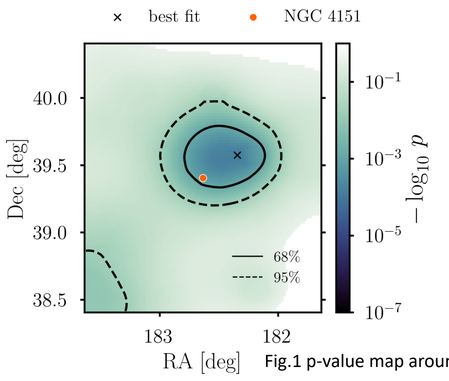
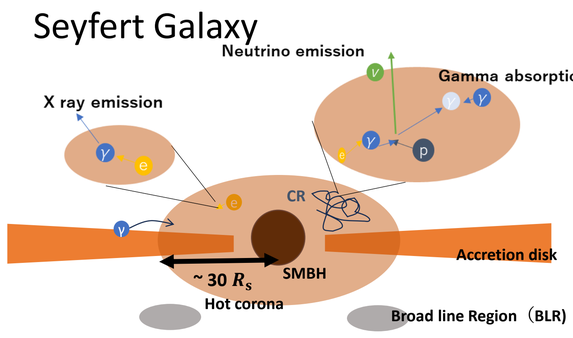


Fig.1 p-value map around NGC 4151 [1]

Table1. type of Seyfert galaxies and p-value as a neutrino source [1]

	type	p_{local}
NGC 1068	Sey2	5.0 σ
NGC 4151	Sey1	3.2 σ
CGCG 420-015	Sey2	3.5 σ

Possible Mechanism -Disk Corona Model-



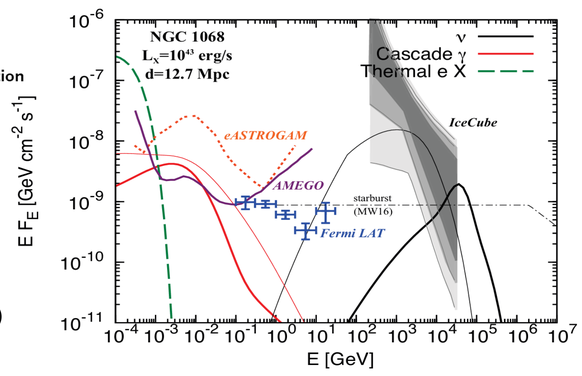


Fig.2 Flux by observations and disk corona model [2]

- Plasma turbulences accelerate CRs
- Can explain neutrino and gamma-ray emissions from Seyferts
- Neutrino emissions are proportional to X-ray

$$E_\nu^2 \Phi_\nu \propto \left(\frac{15 f_{\mathrm{meson}}}{1+f_{\mathrm{BH}}+f_{\mathrm{meson}}}\right)\xi_{\mathrm{CR}} L_X \qquad f\text{: optical depth} \qquad \xi_{\mathrm{CR}} = \frac{L_{\mathrm{CR}}}{L_X} \quad [2]$$

Problem
Low significance due to fewer ν detections

Approach with multi messenger analysis X-ray and neutrinos!!

Research Goals

- Develop a new method to determine the significance of AGNs
- Constrain ξ_{CR} of the disk corona model

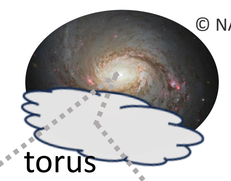
by observing the time correlation between X-ray & neutrinos flux

→ Seyfert 2 is unfavorable for X-ray analysis because of torus
We can't see the corona directly in X-ray

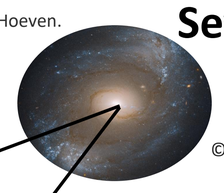
→Focus Seyfert 1, NGC 4151

- Brightest Seyfert 1 for MAXI
- Continuous observation by MAXI for 15 years

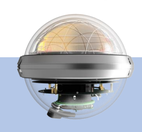
Seyfert 2 (NGC 1068, CGCG420-015)



Seyfert 1 (NGC 4151)



ν



IceCube

- Taking data since 2011

X

MAXI

- Japanese all sky monitor in X-ray

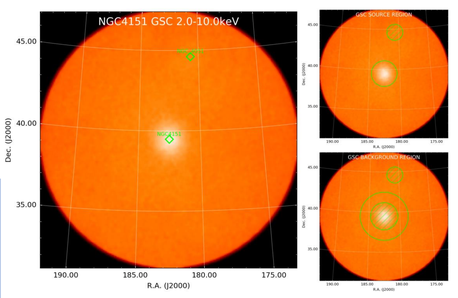


Fig.3 Image of NGC 4151 by MAXI [3]

Methods

Toy simulation before using IceCube data

X-ray luminosity variation of NGC4151 by MAXI (70days bin)

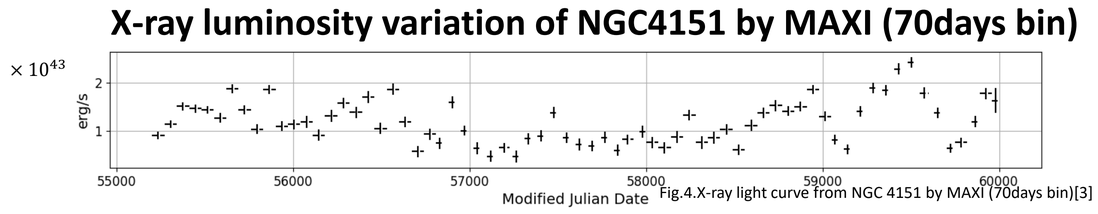


Fig.4.X-ray light curve from NGC 4151 by MAXI (70days bin)[3]

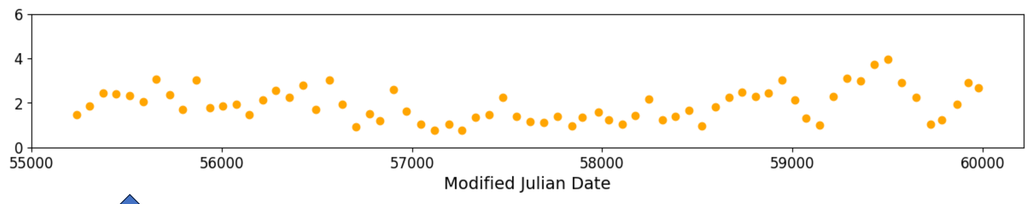
1

- **Transfer function** $f(t-t', C, \Delta T) = \dfrac{C}{\sqrt{2\pi}\Delta T} e^{-\left(\frac{t-t'}{2\Delta T}\right)^2}$

parameters C: ν ratio to X (corresponds to ξ_{CR})
ΔT: correlation time width (fixed as 10 days)

- **Neutrino BG** $\overline{P_\nu^{\mathrm{BG}}}$
- **Spectrum assumption**
- **The Effective area of IceCube**

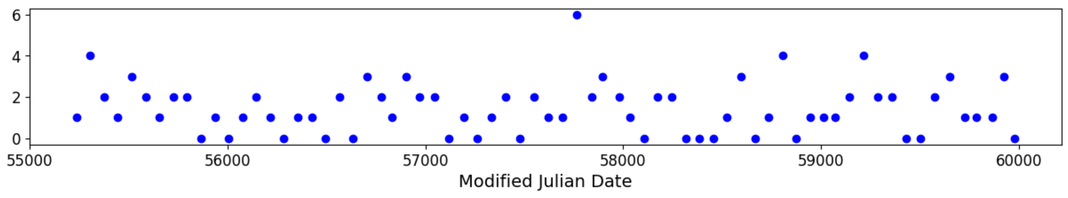
Number of ν detection expected from X-ray (exp)



2

maximize $\mathrm{TS} = \sum_{\text{data points}} \dfrac{\log \mathrm{P}(\mathrm{obs}|\mathrm{exp}+\overline{P_\nu^{\mathrm{BG}}})}{\log \mathrm{P}(\mathrm{obs}|\overline{P_\nu^{\mathrm{BG}}})}$ over C (& ΔT)

Pseudo data of the number of detections (obs)



3 Repeat and fit C (ΔT) for both BG and signal assumption

Sensitivity

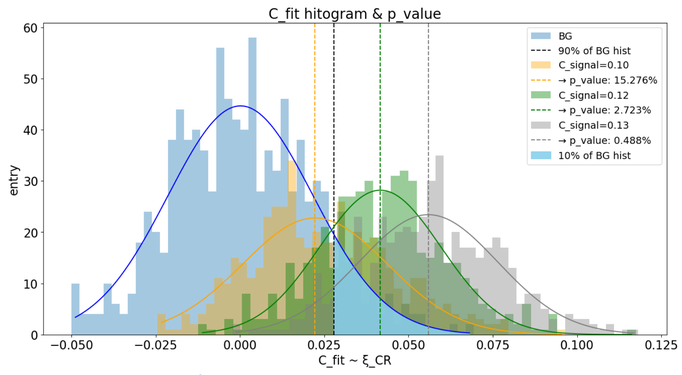


Fig.5 histograms of C_{fit} for BG and some C_{signal}

- Define p_{value} for each correlation assumption by calculating the level of separation of the C_{fit} hist from BG

A_{eff} of IceCube ν flux assumption

C_{signal} gives the number of expected ν

Fig.6 p_{value} for the number of expected ν detection

- Evaluate p_{value} for the number of expected ν detections in 10 yrs
- 10% p_{value} is given by 11.83 ν / 3804 days (smaller than the previous!!)

Conclusion & Future works

Multi messenger time correlation analysis can

- give a better sensitivity for Seyfert neutrino search
- constrain ξ_{CR} by observations

Next approach will be

- Using 90minutes bin X-ray data to consider time width

References

[1] IceCube collaboration (2024) https://arxiv.org/abs/2406.07601
[2] Murase et.al. (2020) Phys. Rev. Lett. 125, 011101
[3] MAXI on-demand process