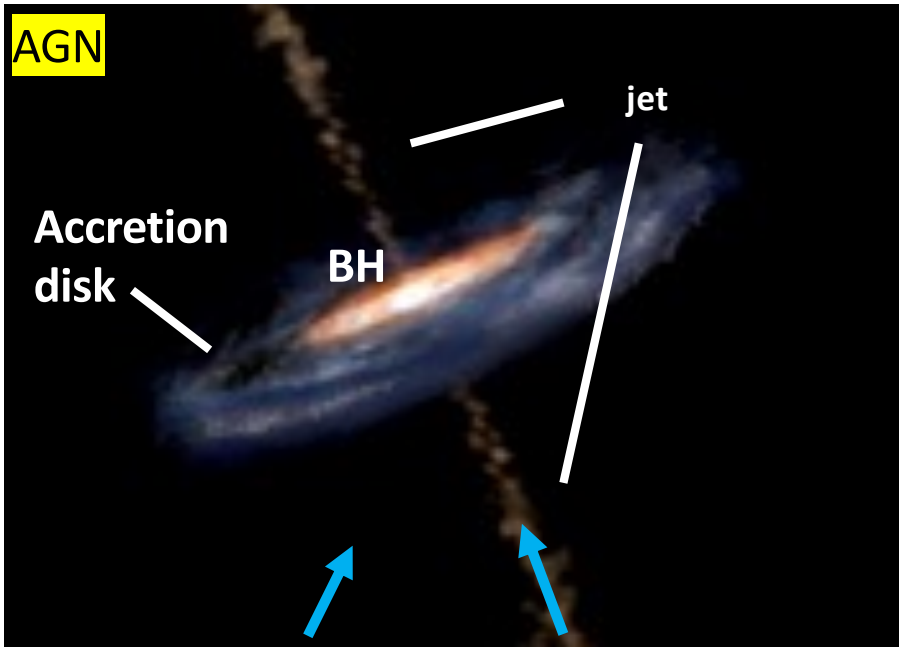
Systematic X-ray study of GeV Gamma-ray emitting radio galaxy

Hiroto Matake, Yasushi Fukazawa(Hiroshima University)

1. Radio Galaxy



8% of all Active galactic nuclei (AGN) emits strong radio emission.

- radio galaxy
- blazar

Radio galaxy(RG)
weaker beaming effect compared to blazar
→ jet core, accretion disk and the fainter part of jet radiation can be observed

Open problem of AGN
- how to emit jet from central engine
- how to accelerate jet

Key to solve these problem
- resolve the relation between jet and accretion disk emission

→RGs is important objects

1. Radio galaxy

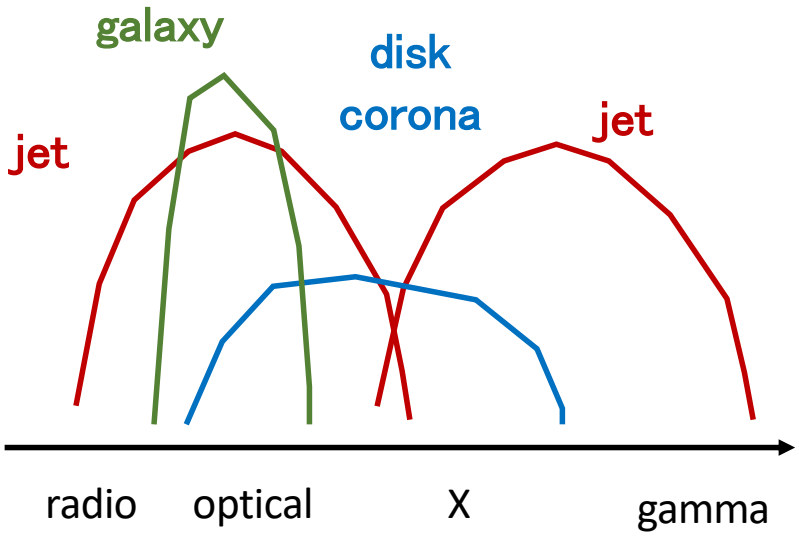
The relation between jet and accretion disk emission

・we can investigate when we decompose jet and accretion disk emission in SED. →constrain the parameters from SED

X-ray

both jet and disk/corona

→investigate the contribution from jet and accretion disk in the X-ray spectra.



We can compare the power between jet and accretion disk, and get information and infer the physical properties of jet.

2. Purpose of research

Purpose of research

Decompose X-ray emission components into jet and disk/corona for GeV gamma-ray radio galaxies

Sample

21 objects in 4FGL-DR2 catalog, including

61 radio galaxies and observed 4 times by Swift/XRT

previous : about 10 objects (There is 8 objects in Fukazawa et al. 2015.) → 21 objects

Statistical analysis

Data

gamma : flux, Photon Index(4FGL-DR2 catalog)

X : flux, Photon Index, Hardness ratio(data analysis by Swift/XRT)

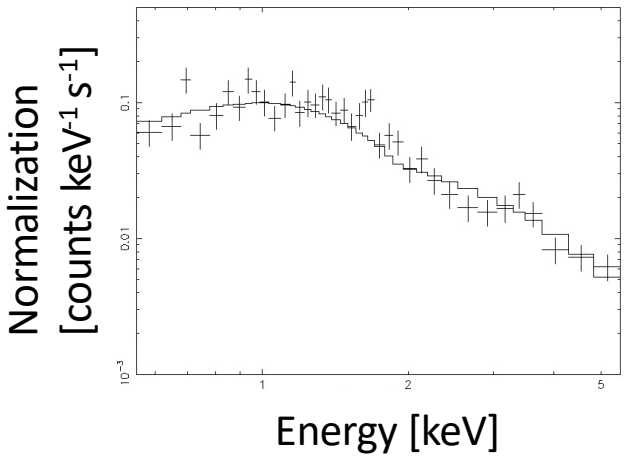
3. X-ray data analysis

①Spectral fitting with single power law model

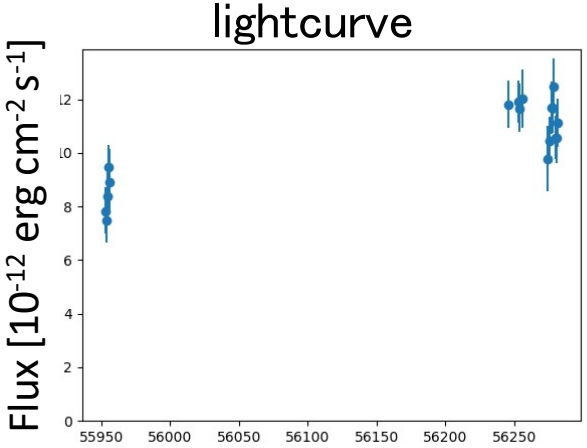
ex) IC 310

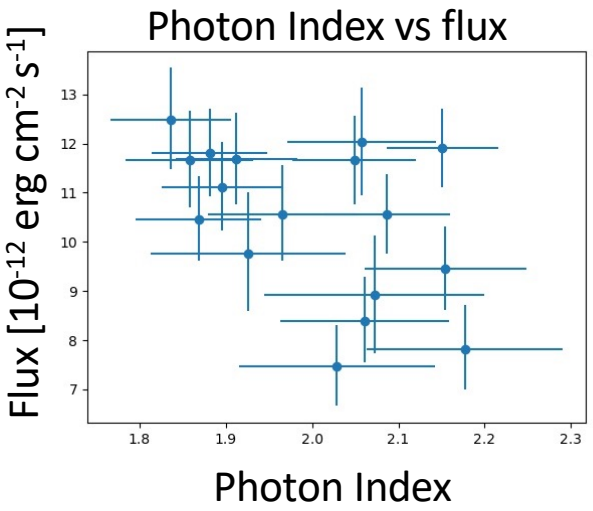
→ **Ave. flux**
Ave. photon index

1 obs data



All obs data





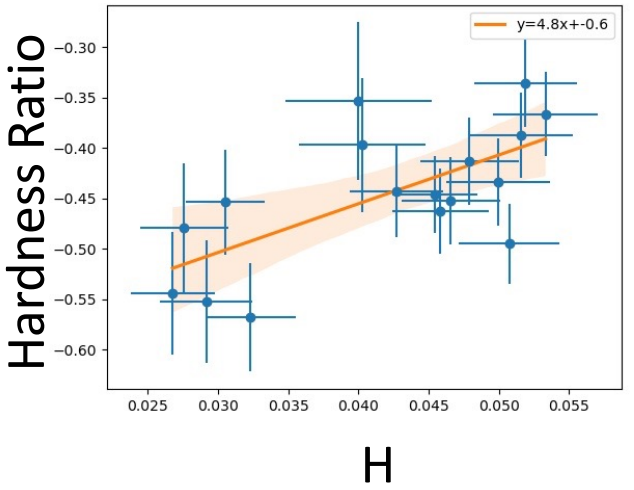
②Following in Connolly et al.2016, we introduce Hardness Ratio(HR)

S : photon counts in 0.5 – 2.0 keV

H : photon counts in 2.0 – 10.0 keV

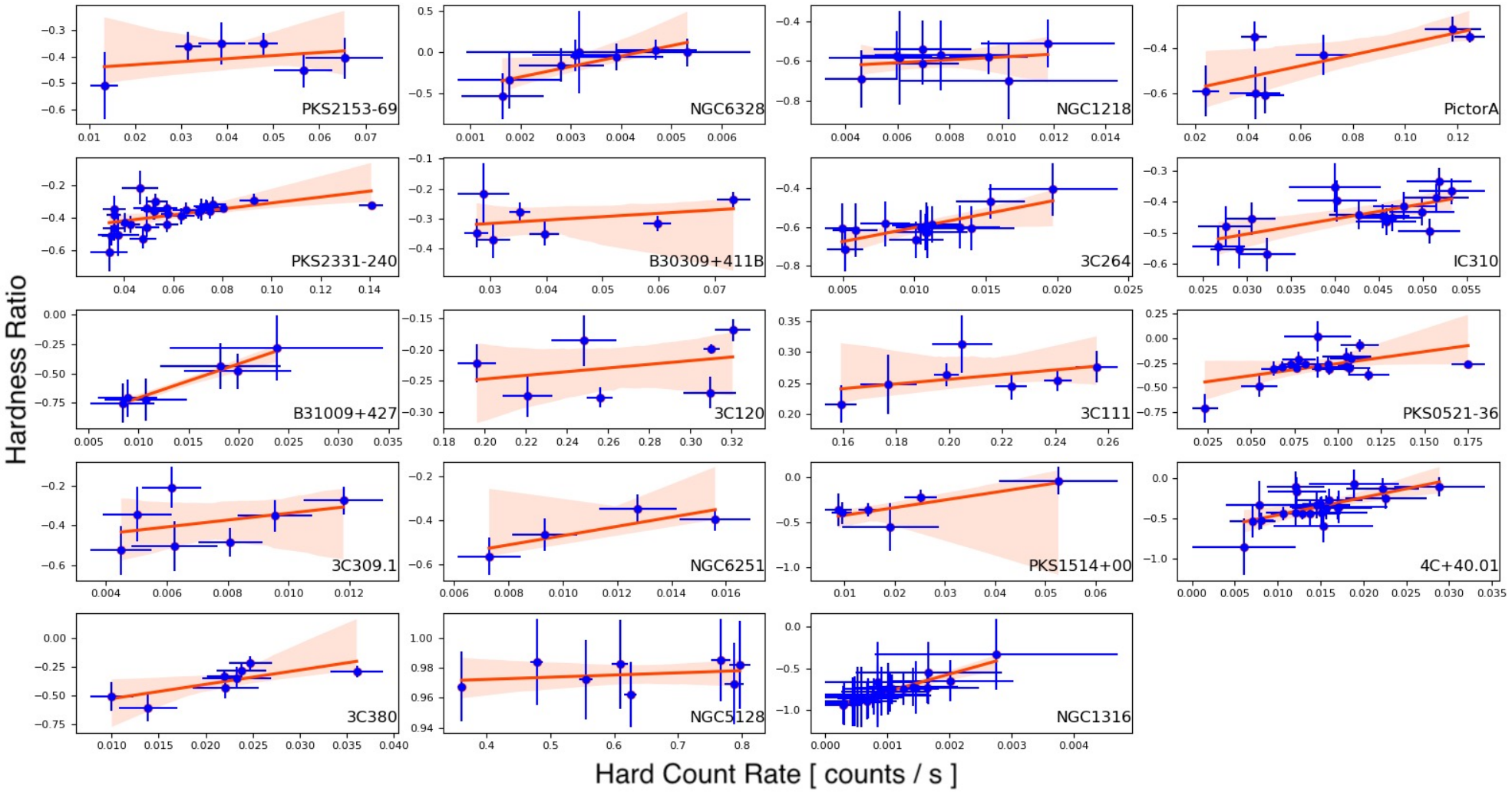
Hardness Ratio(HR):

$$HR = \frac{H - S}{H + S}$$



→ **Slope of Hardness Ratio**

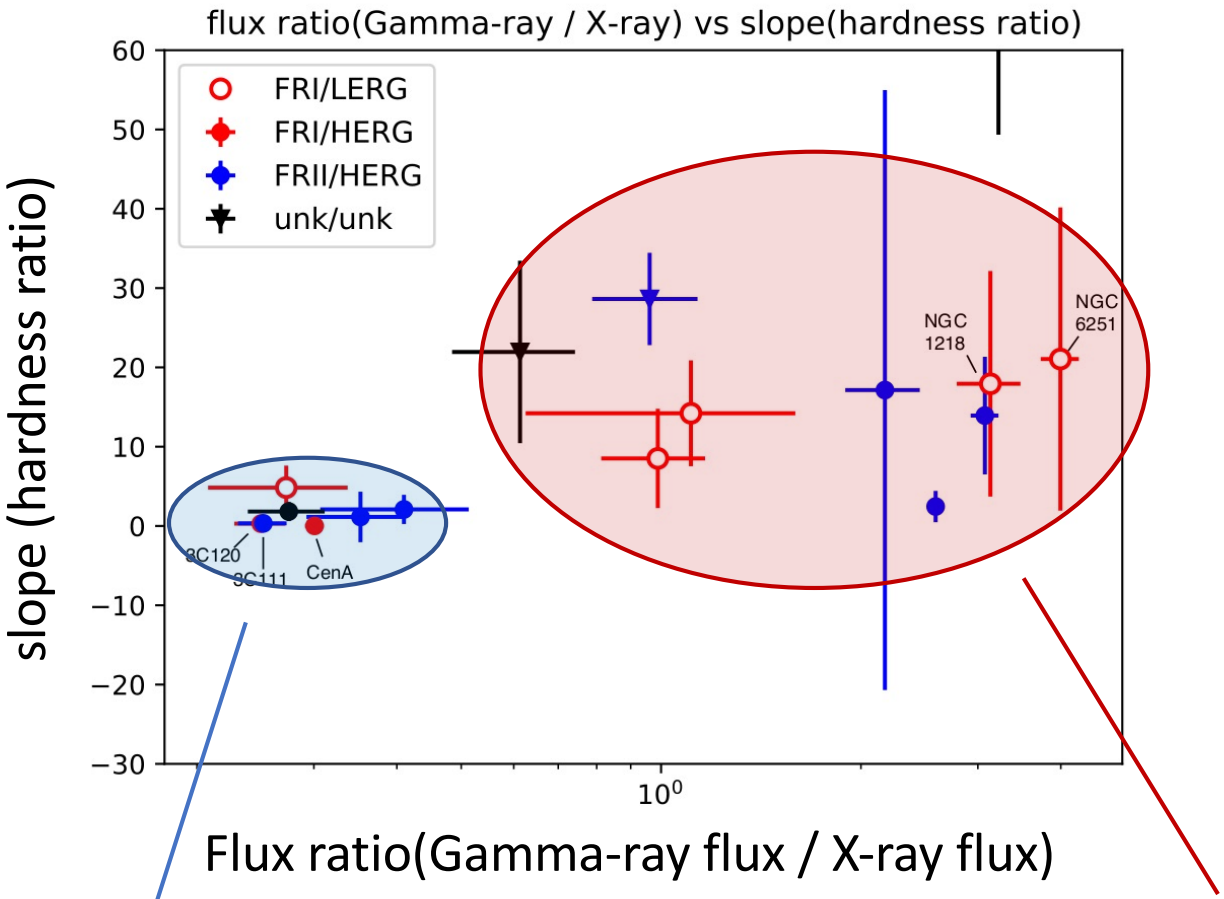
3. X-ray data analysis



All objects show positive slope.
We use slope value to treat quantitatively.

4-1. Result 1

①Time variation



- Gamma-ray flux is relatively low
- weak harder-when-brighter trend

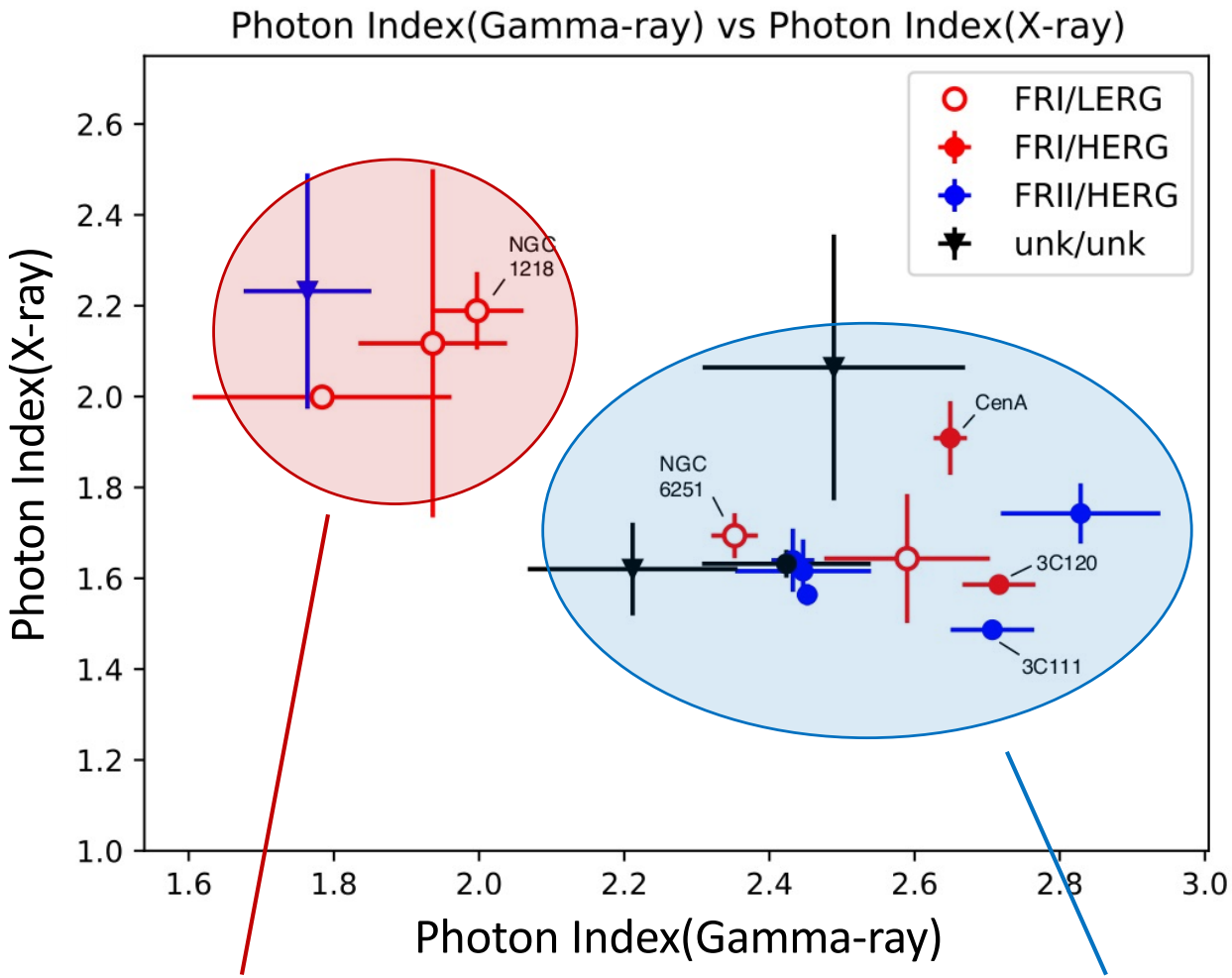
→ jet is weak in X-ray?

- Gamma-ray flux is relatively high
- strong harder-when-brighter trend

→ jet radiation in X-ray is inferred

4-2. Result 2

②Photon Index of X-ray and Gamma-ray

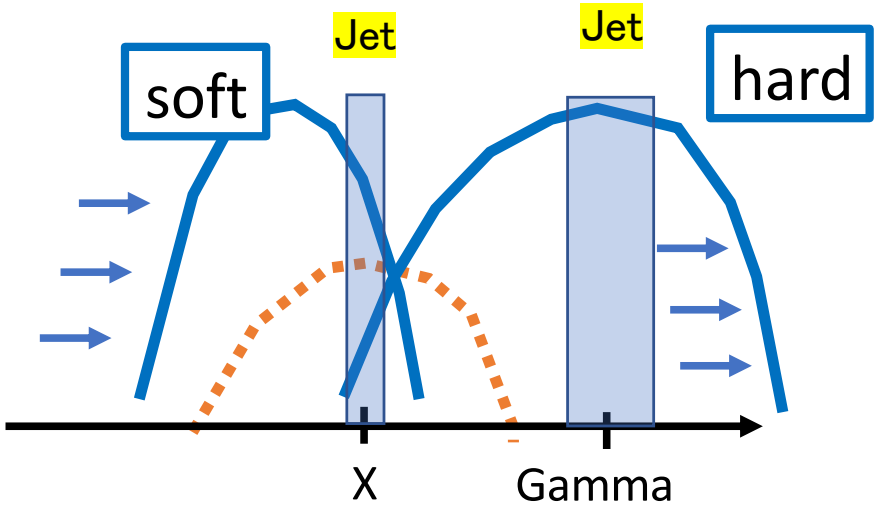


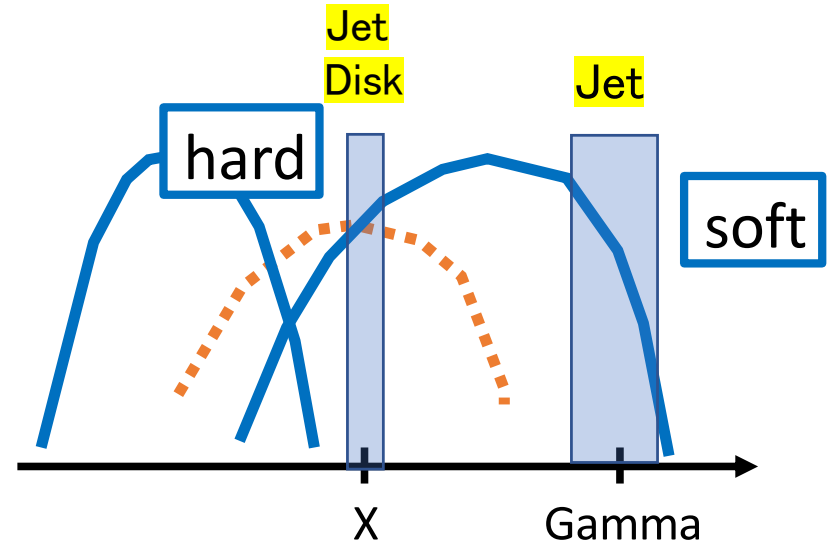
Gamma-ray: hard
X-ray: soft

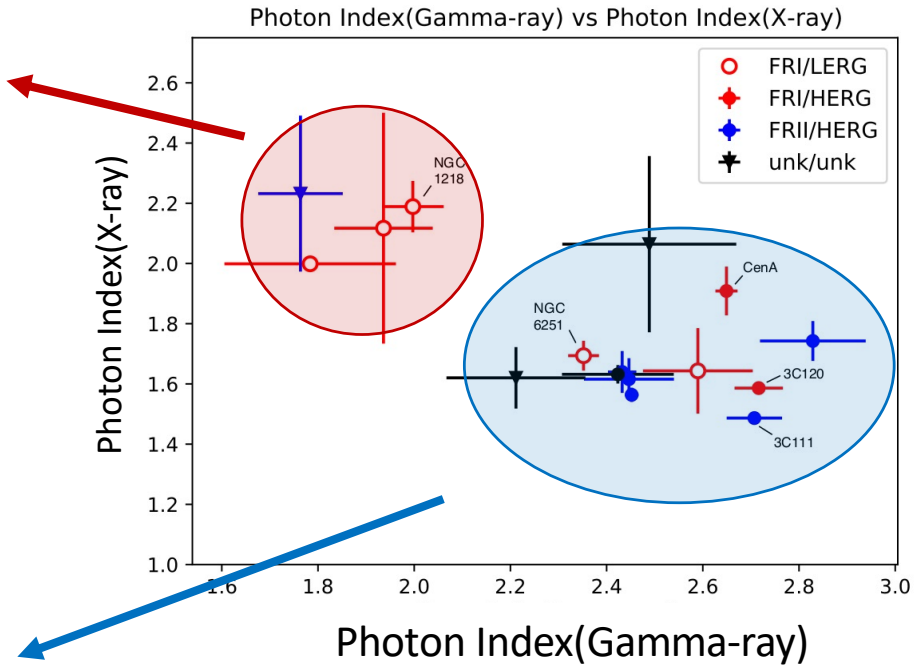
Gamma-ray: soft
X-ray: hard

4-2. Result 2

②Photon Index of X-ray and Gamma-ray

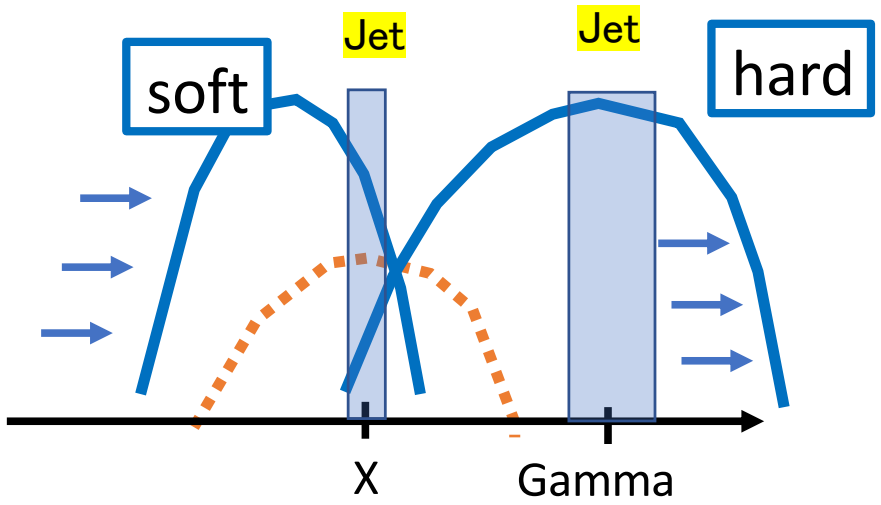


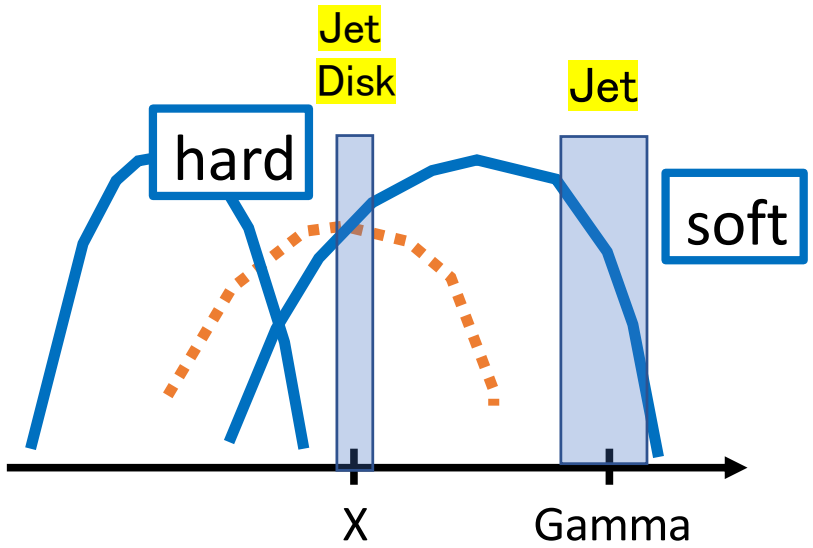




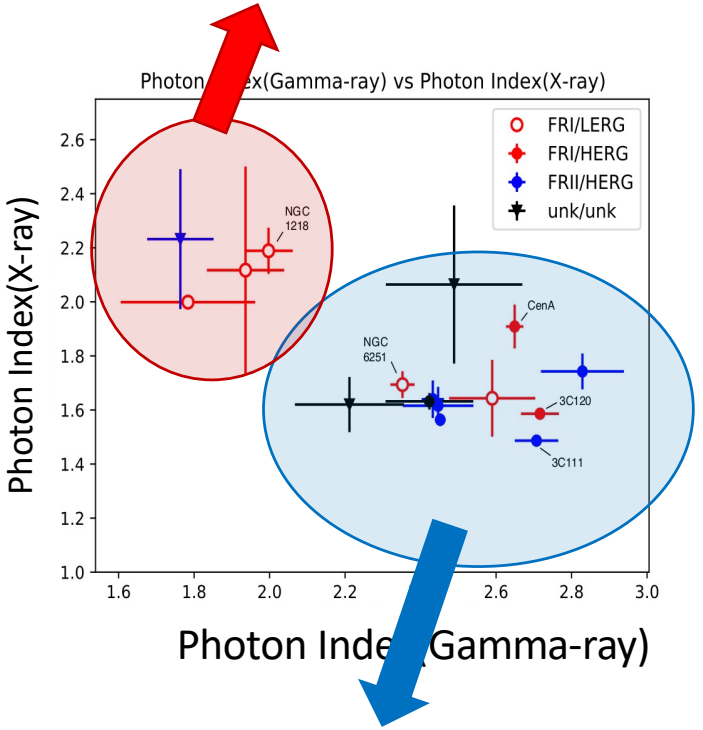
4-2. Result 2

②Photon Index of X-ray and Gamma-ray





Jet radiation in X-ray



Either accretion disk of jet,
Or both radiations

5. Conclusion Result

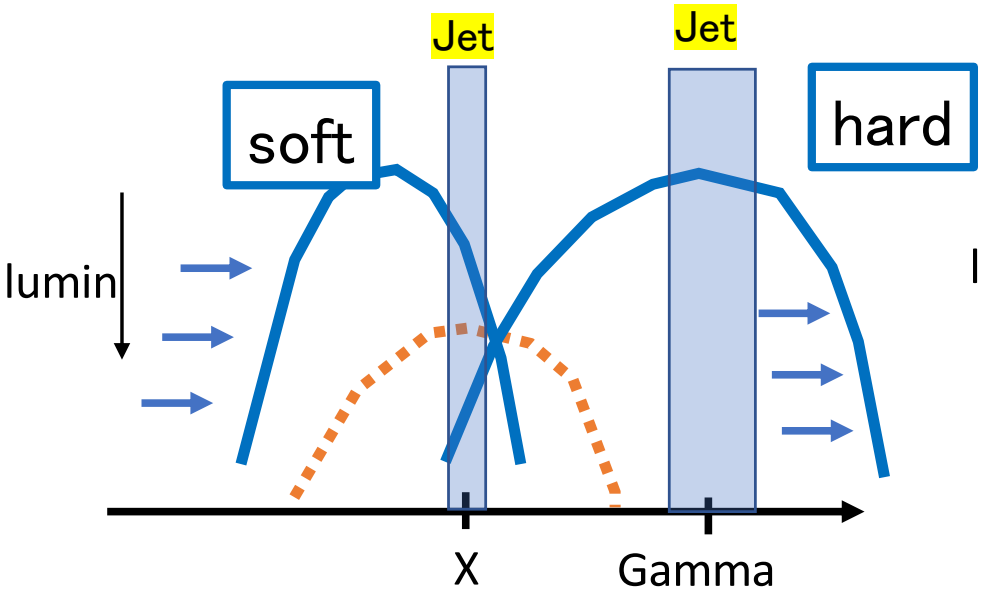
	Object	Result① Slope vs flux ratio	Result② P. I.	Accretion rate L_X/L_{Edd}	Radio and Optical Classification
Jet dominant	NGC 1218	jet	jet	< 0.01	FR-I / LERG
	3C 264	jet	jet	< 0.01	FR-I / LERG
	B3 1009+427	jet	jet	> 0.01	FR-II / unk
AD dominant	3C 111	disk	disk and/or jet	> 0.01	FR-II / HERG
	PKS 0518-45/Pictor A	disk	disk and/or jet	> 0.01	FR-II / HERG
	NGC 5128/Cen A	disk	disk and/or jet	> 0.01	FR-I / HERG
	3C 120	disk	disk and/or jet	> 0.01	FR-I / HERG
	B3 0309+411B	disk	disk and/or jet	> 0.01	FR-II / HERG
	PKS 2153-69	disk	disk and/or jet	< 0.01	FR-II / HERG
	PKS 2331-240	disk	disk and/or jet	> 0.01	unk / HERG
Jet and AD mixed	NGC 1316/Fornax A	jet	disk and/or jet	< 0.01	FR-I / LERG
	PKS 1514+00	jet	disk and/or jet	< 0.01	FR-I / LERG
	NGC 6251	jet	disk and/or jet	< 0.01	FR-I / LERG
	NGC 6328	jet	disk and/or jet	< 0.01	unk / unk
	3C 380	jet	disk and/or jet	> 0.01	FR-II / HERG
	3C 309.1	jet	disk and/or jet	> 0.01	FR-II / HERG
	PKS 0521-36	jet	disk and/or jet	> 0.01	FR-II / HERG
	4C +40.01	jet	disk and/or jet	> 0.01	unk / unk
	IC 310	disk	jet	< 0.01	FR-I / LERG

5. Conclusion

low accretion rate

Jet $\propto \dot{m}$

Disk/corona $\propto \dot{m}^2$ for low $\dot{m}$

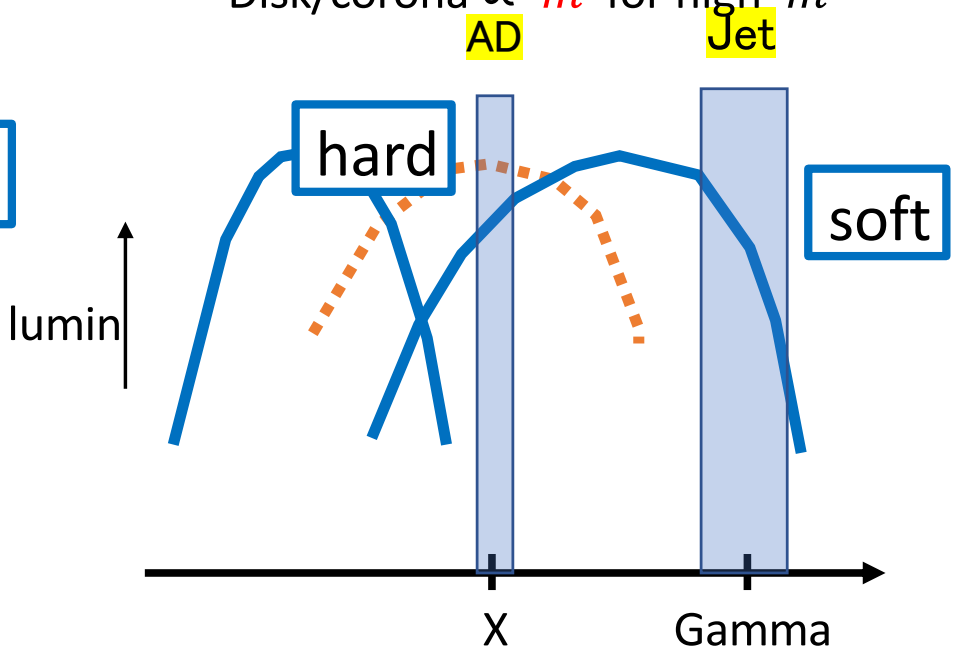


Jet dominant in X-ray

high accretion rate

Jet $\propto \dot{m}$

Disk/corona $\propto \dot{m}$ for high $\dot{m}$



AD dominant in X-ray

middle accretion rate

Both jet and AD radiation mixed in X-ray

7. Conclusion

Purpose of research

We divide the radiation character either jet or disk in X-ray.

→X-ray spectra of radio galaxy

→Fermi observation in gamma-ray

We can divide 3 radiation type in X-ray,

1. **Strong** harder-when-brighter, and **hard** spectra in Gamma-ray and **soft** spectra in X-ray and **low** accretion rate.

   → jet dominant type
2. **Weak** harder-when-brighter, and **soft** spectra in Gamma-ray and **hard** spectra in X-ray and **high** accretion rate.

   →AD dominant type
3. **Strong** harder-when-brighter, and **soft** spectra in Gamma-ray and **hard** spectra in X-ray.

   → jet and AD mixed type

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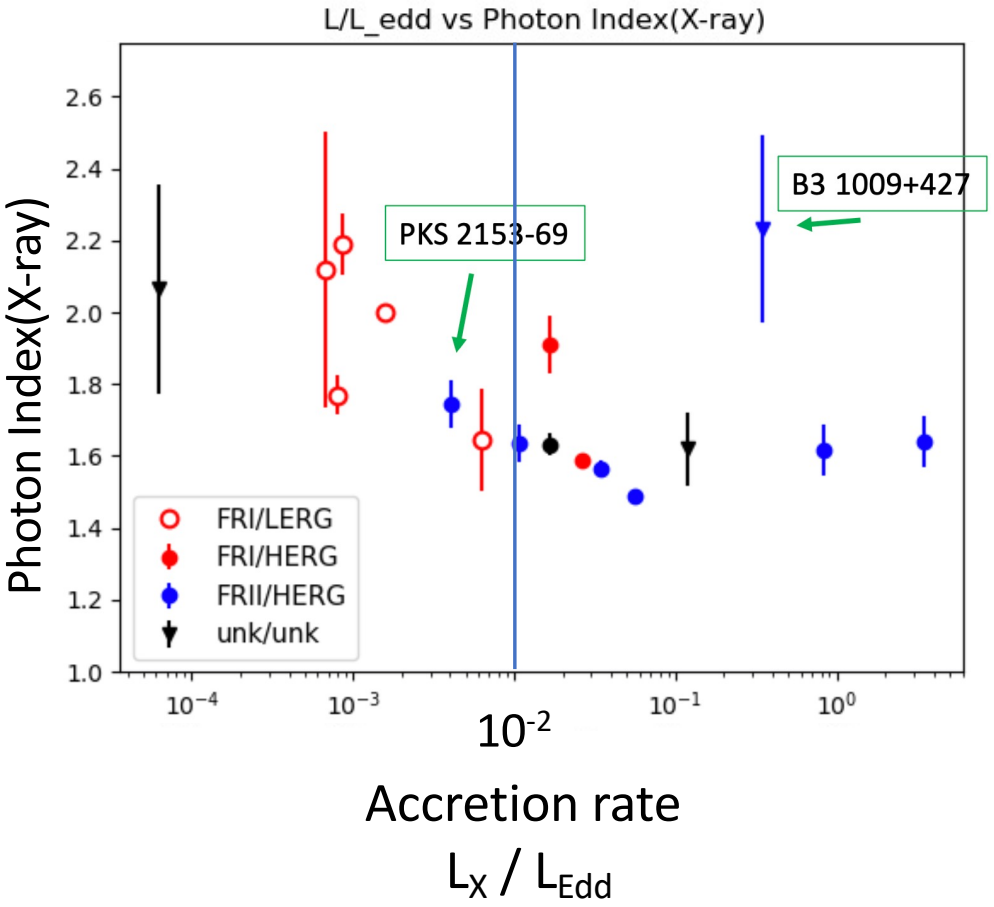
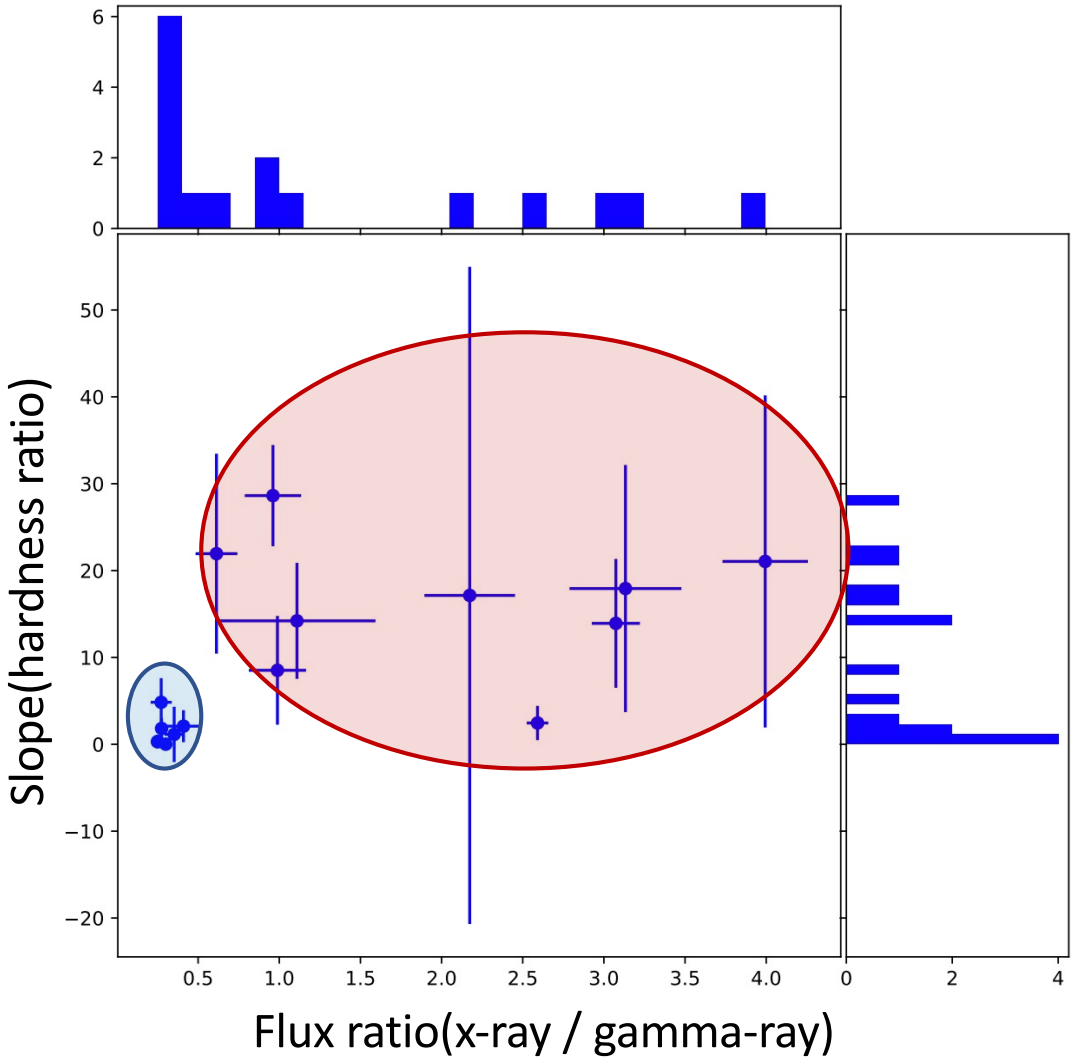
Accretion rate



4-1. Result 1

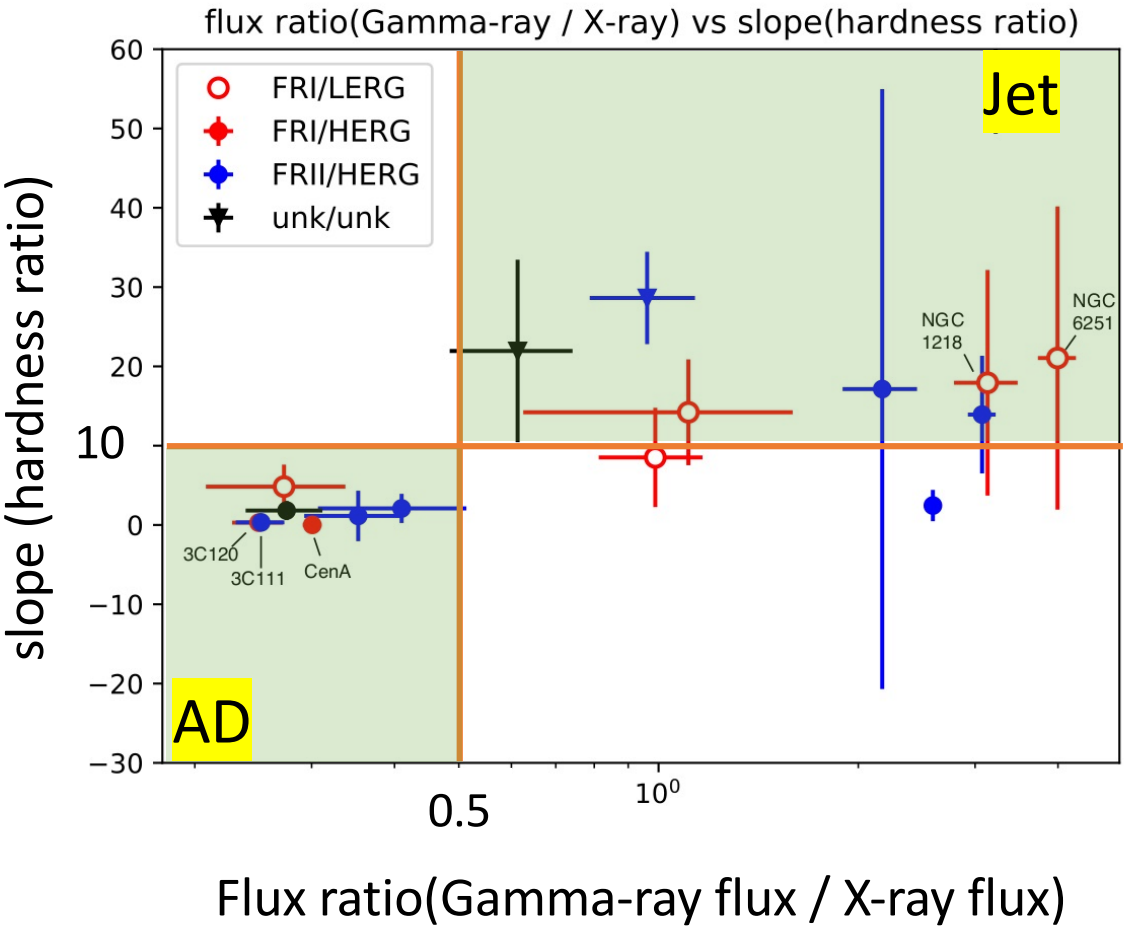
①time variation



Clearly, there is a group where both slope and flux ratio show low value.

4-1. 研究結果　その1

①time variation



Jet and AD mixed type objects is in jet group.

→ jet trend appear strongly in this figure.

4-1. 研究結果　その1

①time variation

Seyfert galaxy shows AD spectra in X-ray

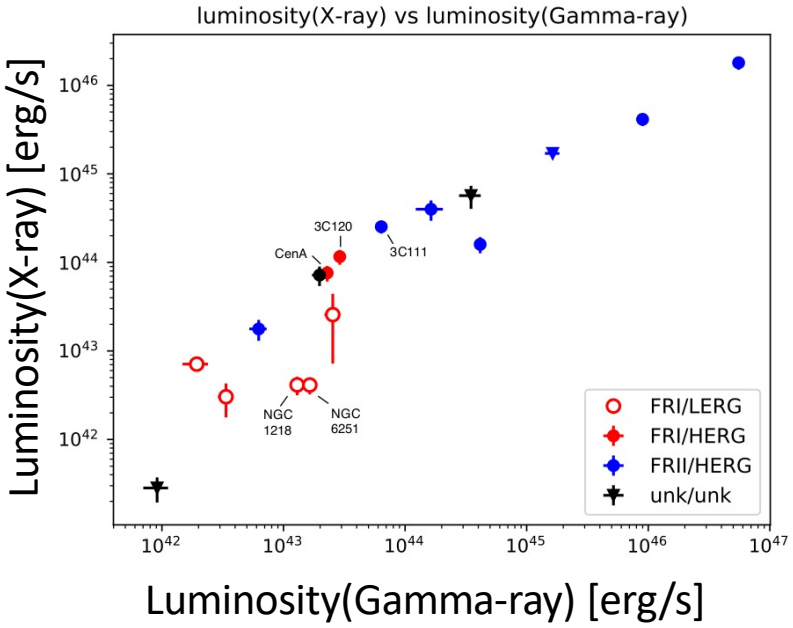
- Standard AD → softer-when-brighter trend

Radio galaxy shows jet and AD radiation in X-ray

- Jet dominant → strong harder-when-brighter trend
- AD diominant → harder-when-brighter trend + softer-when-brighter trend → weak harder-when-brighter trend

Thus, this is not clearly divided jet and AD trend, and jet trend is strongly appeared.

他の検出器での解析



The combination of FR classification and HERG/ LERG classification is well divided using luminosity.

- $10^{44} < L_X, L_G$ → FR-II/HERG
- $10^{43} < L_X, L_G < 10^{44}$ → FR-I/HERG
- other $L_X < 10^{43}$ → FR-I/LERG