ASTRO-H Studies of Accretion Flow onto Supermassive Black Hole

2015 October 21
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AGN meeting @ Rikkyo Univ.
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I. Introduction
In black hole (BH) binaries, disk black body appears in X-ray band.

- Inner disk temp. with $M_{\text{BH}} \sim 10M_\odot$ is consistent with b.body temp. of $\sim 1$ keV.
- Broad-band continuum with high energy cutoff at several hundreds keV.
- Comptonization to disk b.body (Inhomogeneous corona, Maxima+08).
- With higher $\eta$, disk b.body becomes dominant, changing accretion state.

BHB spectra are explained with truncated disk and broad corona.

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1. Accretion Flow onto Black Hole

In black hole (BH) binaries, disk black body appears in X-ray band

- Inner disk temp. with $M_{BH} \sim 10M_\odot$ is consistent with b.body temp. of ~1 keV
- Broad-band continuum with high energy cutoff at several hundreds keV
  - Comptonization to disk b.body (Inhomogeneous corona, Maxima+08)
- With higher $\eta$, disk b.body becomes dominant, changing accretion state

BHB spectra are explained with truncated disk and broad corona
2. Assumed Accretion Flow onto Supermassive BH

Seyferts have $\eta \sim 0.001–1$, which is a range between L/H and H/S state in BHBs.

Tanaka+95: Relativistically Broadened Fe line $\Rightarrow$ Max BH spin in MCG-6-30-15

With various satellite broad-band spectra, the soft and hard X-ray excesses have been interpreted as relativistically-blurred reflection (RBR).

Red wing cannot be explained without central compact corona (e.g., Wilkins+15)

$\Rightarrow$ Compact corona with the inner disk radius of $R_{in} < 3 R_s$
3. Geometry Assumed in Optical AGN Studies

In optical variations, shorter wavelength precedes longer ones in many Sys (cf. Collier+99, Cackett+07, Mchardy+14)

The good correlations were found between optical and X-ray in several Sys

⇒ Optical variation is generated by X-ray illumination

☆ Disk is always assumed to have \( R_{in} \sim 3 \ R_s \) with compact X-ray region

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4. Positioning of Our Studies of SMBH Accretion

☆ The corona has been regarded compact, and the accretion disk has been assumed to have $R_{\text{in}} < 3 R_s$, regardless of $\eta$, in optical and X-ray studies.

☆ Accretion onto SMBH in Seyferts is assumed to be in the High/Soft state, and to have no state transition

→ However, no clear evidence...

☆ We need to determine geometry and state of accretion flow in Seyferts without model assumptions as possible.

→ X-ray and optical variabilities should be utilized

☆ In this study, we focus two Seyfert galaxies, NGC 3516 and NGC 3227, with $\eta < 0.01$, which corresponds to the Low/Hard state having truncated disk and broad corona in BHB.
II. Geometry and State of Accretion Flow in NGC 3516

→ With X-ray and Optical Correlation
5. Hints of Geometry: X-ray and Optical Correlation

To study accretion geometry, we performed X-ray–optical simultaneous monitoring for 1 year

- Target: low-\(\eta\) Seyfert NGC 3516
- X-ray obs: Suzaku 50 ks \(\times\) 7 with various intervals, days, weeks, months
- B band obs: Japanese 5 telescope Pirka, Kiso, MITSuME, Nayuta, Kanata

\(\Rightarrow\) Historically faint phase in X-ray and optical

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6. X-ray and Optical Correlation in NGC 3516

☆ Hard primary X-ray is well correlated with B band
☆ JAVELIN and CCF method reveal that X-ray preceded opt. by $\sim 1.7\pm0.7$ days
☆ Opt. flux increase calculated by B-band is explained by X-ray irradiation

$$F = \frac{3GM_{BH}M}{8\pi R^3} + \frac{(1 - A)L_X}{4\pi R_X^2 \cos \theta}$$

Standard disk term ↔ X-ray irr. term
7. Contradiction b/w Lag and $\eta$ in H/S state

☆ Results in our monitoring of NGC 3516

1. X-ray preceded B band $\rightarrow$ X-ray irradiation made optical variation
2. B band lag $\tau$ against X-ray is $\sim 1.7$ days $\rightarrow$ $\sim 400 \, R_S/c \, (M_{BH} \sim 2.5 \times 10^7 \, M_\odot)$
3. X-ray and optical are in very faint phase $\rightarrow$ $\eta = 5 \times 10^{-4} - 0.01$
4. B-band flux explained by X-ray irr. $\rightarrow$ Standard disk term can be 0

☆ $\tau$ inconsistent with $\eta$ (Actual $\tau$ larger than that expected from $\eta$ by $\sim 20$ times)

$\rightarrow$ High/Soft state (compact corona) is unsuited for NGC 3516 in the faint phase
8. Geometries of Corona and Disk

☆ Disk should be truncated to make $\tau \sim 1.7$ days and $\eta \sim 5 \times 10^{-4} - 0.01$ consistent

- Hot accretion flow in Low/Hard state
- X-ray bright point $\sim 1.7$ ld far from disk
- Optical flux is not by $\alpha$-viscosity but X-ray irr. (particularly N3516)

☆ In many Seyferts, optical lag $\tau$ is too large to explain their $\eta$ (e.g., Cackett+07)

- NGC 4051, 3C390.3 $\rightarrow \tau$ larger than that expected from $\eta$ by $\sim 2$ times
- Mrk 509, MCG+8-11-11 $\rightarrow \tau$ larger than that expected from $\eta$ by $\sim 3$ times
- NGC 5548 $\rightarrow \tau$ larger than that expected from $\eta$ by $\sim 5$ times

Seyferts generally have broad corona in the Low/Hard state!

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III. Phase Change of Accretion Flow in NGC 3227

⇒ With Drastic Change of X-ray Variability
10. Hints of Accretion State: X-ray Variability Change

*Suzaku* 6 observation (each exp. ~50 ksec)

**Light curves**

- 3–10 keV
- 2–3 keV

**Count-Count Plot**

- Clear break

☆ Spectral hardness drastically changes at the count rate of ~0.16 cnt/s in 2–3 keV
Not due to absorption variation ➔ Dominant primary X-ray changes

☆ Two types of primary X-ray are present, differently from the popular assumption

Difference spectrum (High–Low spectrum) analyses for individual branches give us spectral shapes of the primary X-ray (Noda+13; 14)

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10. Hints of Accretion State: X-ray Variability Change

Suzaku 6 observation (each exp. ~50 ksec)

- Light curves
- 3–10 keV
- 2–3 keV

Time [ksec]

Count Rate [cnt/s]

0 500 1000 1500 2000 2500 3000

Hours

 Weeks

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☆ Two types of primary X-ray are present, differently from the popular assumption
Difference spectrum (High–Low spectrum) analyses for individual branches
give us spectral shapes of the primary X-ray (Noda+13; 14)

Count-Count Plot

Bright state

Faint state

Phase change


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11. Discovery of Two Different Primary X-ray Phases


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Accretion onto SMBH causes two distinct primary X-ray (often simultaneously)

**Hard Primary**: Flat spectrum ($\Gamma \sim 1.8$); strong neutral absorption ($N_H \sim 10^{23} \text{ cm}^{-2}$); t.scale is $\sim$ weeks; dominates with low $\eta$

⇒ Compton in the Low/Hard state

**Soft Primary**: Steep spectrum ($\Gamma \sim 2.4$); weak neutral absorption ($N_H \lesssim 10^{22} \text{ cm}^{-2}$); t.scale is $\sim$hours; appears with high $\eta$, together with Hard Pri.

⇒ Hard tail in the High/Soft state
Accretion onto SMBH causes two distinct primary X-ray (often simultaneously)

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**Soft Primary**: Steep spectrum ($\Gamma \sim 2.4$); weak neutral absorption ($N_H \lesssim 10^{22}$ cm$^{-2}$); t.scale is $\sim$hours; appears with high $\eta$, together with Hard Pri.

- Hard tail in the High/Soft state
NGC 3227 shows phase change from Faint to Mixture phase

Faint phase → **Hard Primary** (Low/Hard)

Mixture phase → **Hard Primary** + **Soft Primary** (Low/Hard + High/Soft)

☆ Many Seyferts like MCG-6-30-15, IC4329A, NGC 4051, … are in the Mixture state (→ Maxima-sensei’s talk at this afternoon)
IV. ASTRO-H Studies of Accretion in Seyferts
13. Our Studies of Accretion onto SMBH with ASTRO-H

☆ Hard and Soft primary X-ray both can illuminate disk, increasing optical

- Correlation between Soft pri. and opt. is good as well as Hard Primary?
- How large amount of energy is given to disk by X-ray irradiation?
13. Our Studies of Accretion onto SMBH with ASTRO-H

Can wind contribute the state transition from High/Soft to Low/Hard?

☆ Hard and Soft primary X-ray both can illuminate disk, increasing optical
  • Correlation between Soft pri. and opt. is good as well as Hard Primary?
  • How large amount of energy is given to disk by X-ray irradiation?

☆ In an accretion flow, two different states with different accretion rate
  (Low/Hard and High/Soft states) are present at the same time
    • At boundary between the two regions, wind can take away accreting
      mass, changing state in a flow?
14. ASTRO-H Observations of Seyferts

☆ Perform sim. observations of ASTRO-H and ground telescopes on Sy having multiple primary X-ray like MCG-6-30-15, NGC 4051, NGC 3227

1. Broad spec. with HXI/SGD ➞ Precise luminosity of Soft and Hard pri.
2. Fe-K abs. features with SXS ➞ Wind strength
3. Optical variations ➞ Variation of disk luminosity

State transition in an accretion flow

X–opt. correlation and energy deposit to disk by X-ray illumination

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15. Summary

- With the simultaneous monitor of X-ray and optical, NGC 3516 was found in the Low/Hard state, with the disk truncated at \( \sim 400 \text{ Rs} \) and a hot accretion flow formed at inner region.

- By analyzing the drastic change of X-ray variability, NGC 3227 was found to show the phase change from the Faint (Low/Hard) to Mixture (Low/Hard + High/Soft) phase.

- By observing Seyferts with ASTRO-H and ground-based telescopes, we can establish the geometries and states of accretion flows onto supermassive black holes.