ASTRO-H Studies of Accretion Flow onto Supermassive Black Hole

2015 October 21

The Institute of Physical and Chemical Research (RIKEN)

Nishina center

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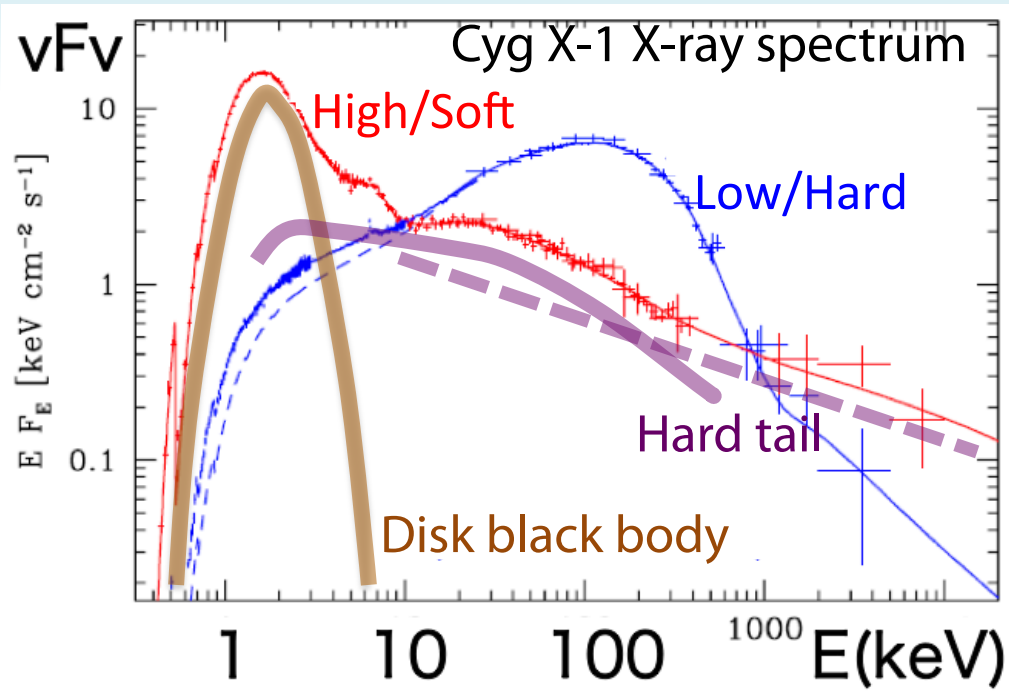
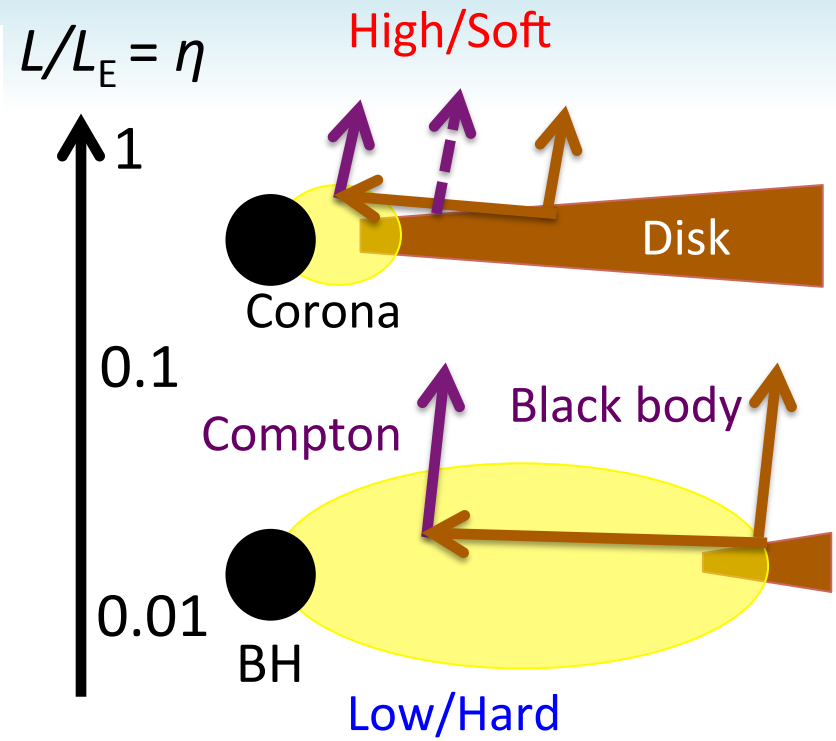
AGN meeting @ Rikkyo Univ.

1. Contents

I. Introduction

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 η , disk b.body becomes dominant, changing accretion state

BHB spectra are explained with truncated disk and broad corona

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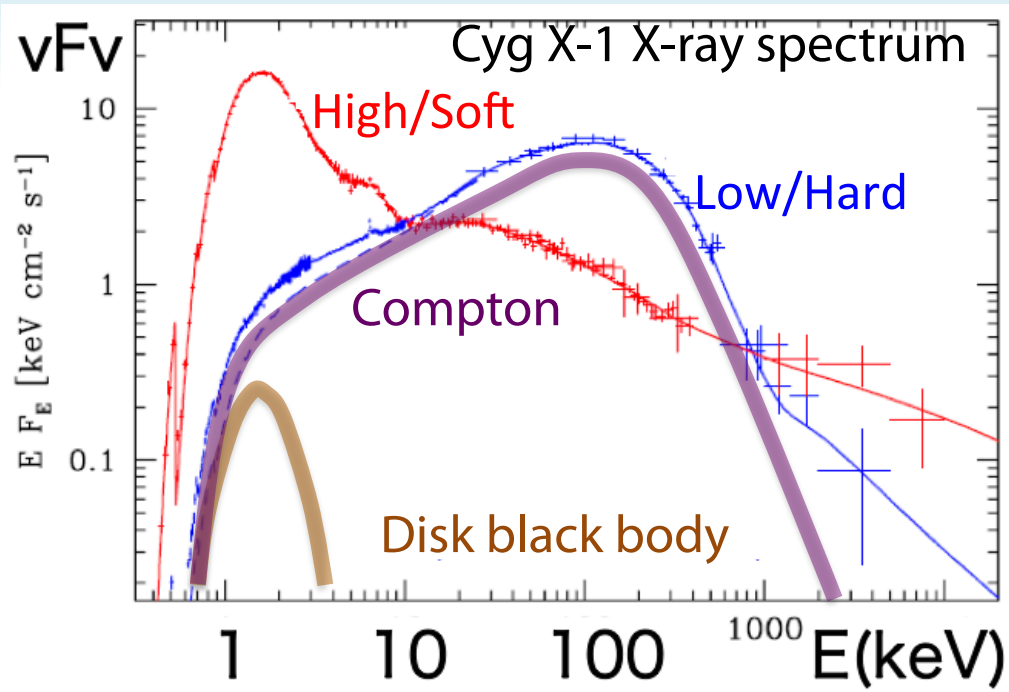

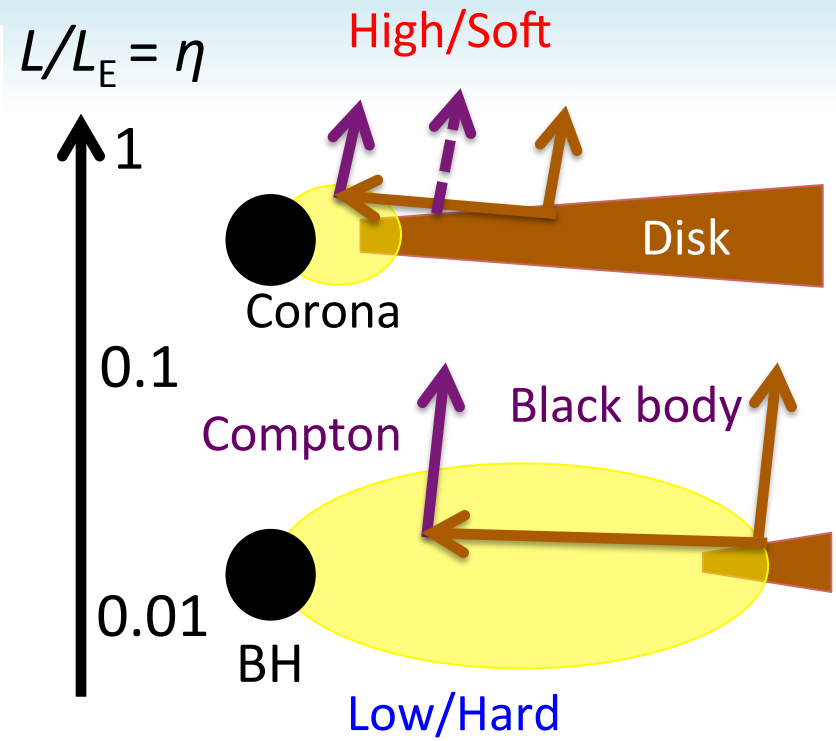

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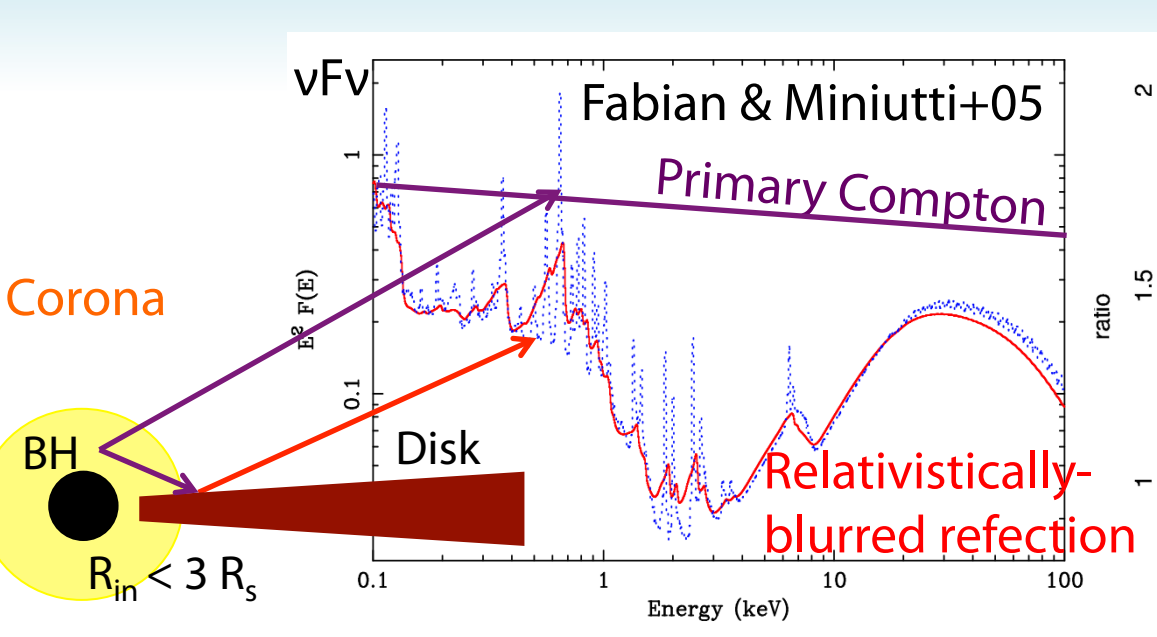
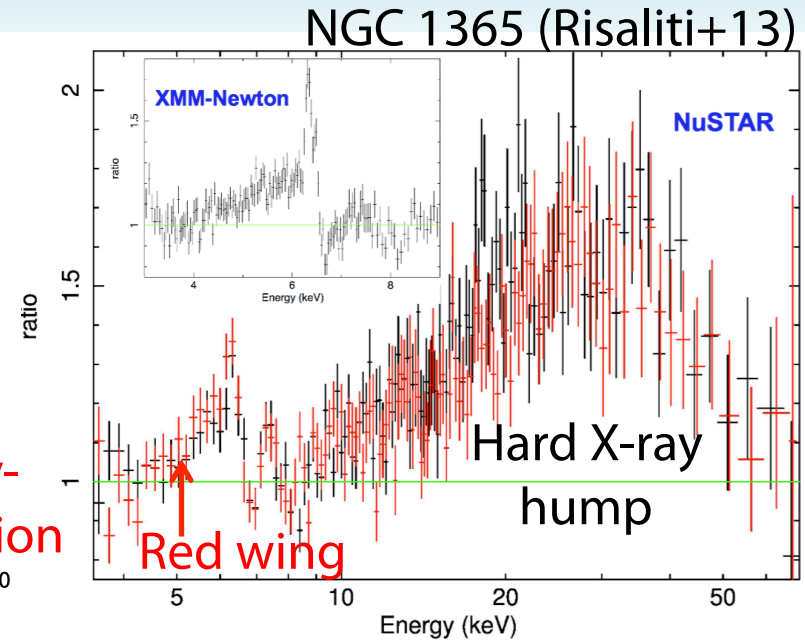
2. Assumed Accretion Flow onto Supermassive BH





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

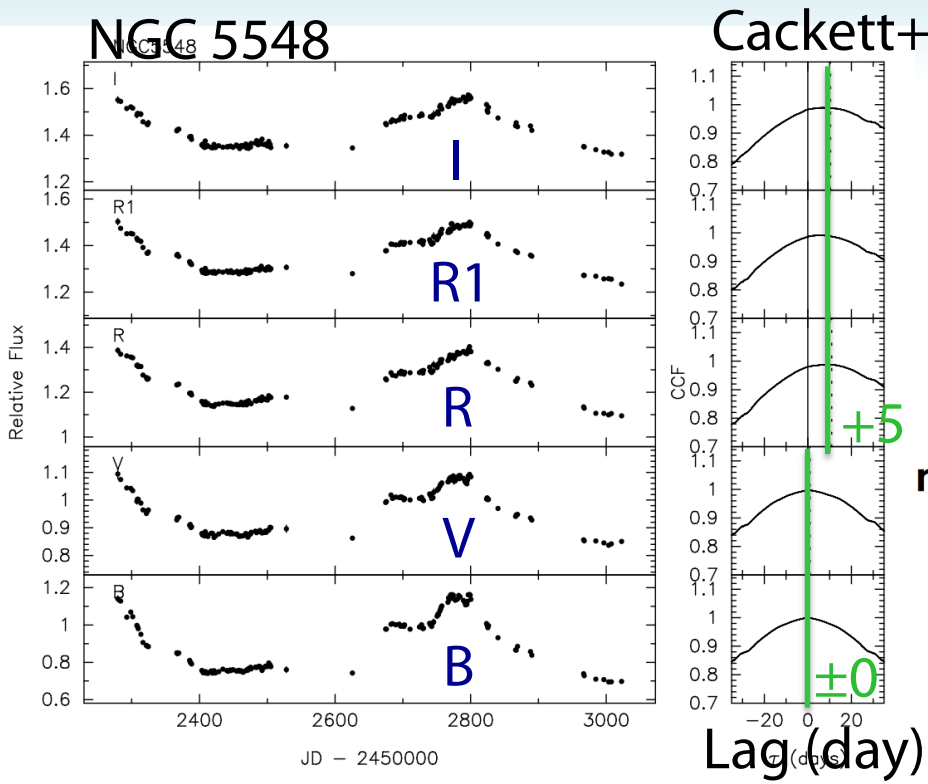
☆ Tanaka+95 : Relativistically Broadened Fe line ➔ Max BH spin in MCG-6-30-15

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

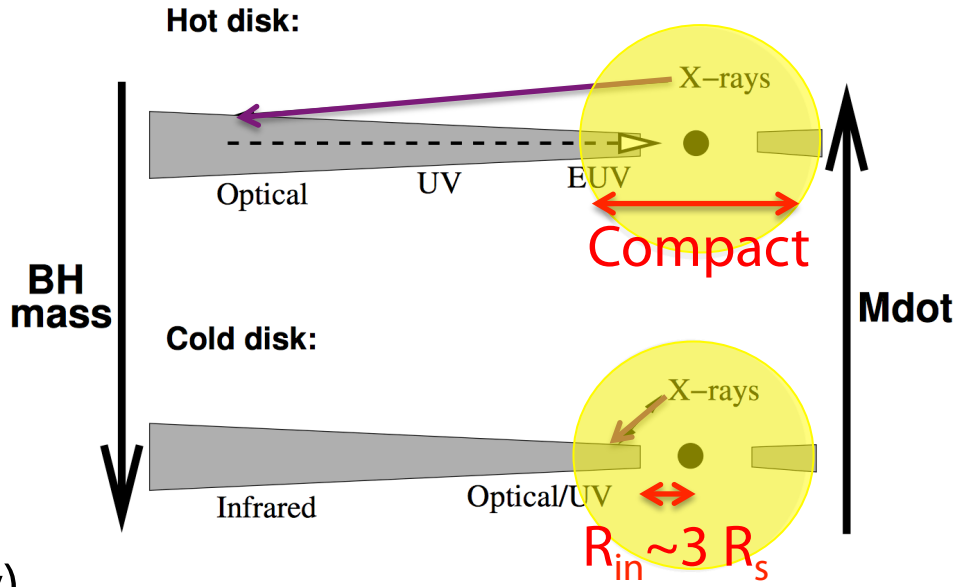
☆Red wing cannot be explained without central compact corona (e.g., Wilkins+15)

➔ **Compact corona with the inner disk radius of $R_{in} < 3\ R_s$**

3. Geometry Assumed in Optical AGN Studies



Geometry assumed in optical studies (Uttley+06)



☆ 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} ~ 3 R_s with compact X-ray region**

4. Positioning of Our Studies of SMBH Accretion

☆ The corona has been regarded compact, and the accretion disk has been assumed to have $R_{in} < 3\ R_s$, regardless of η, 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.

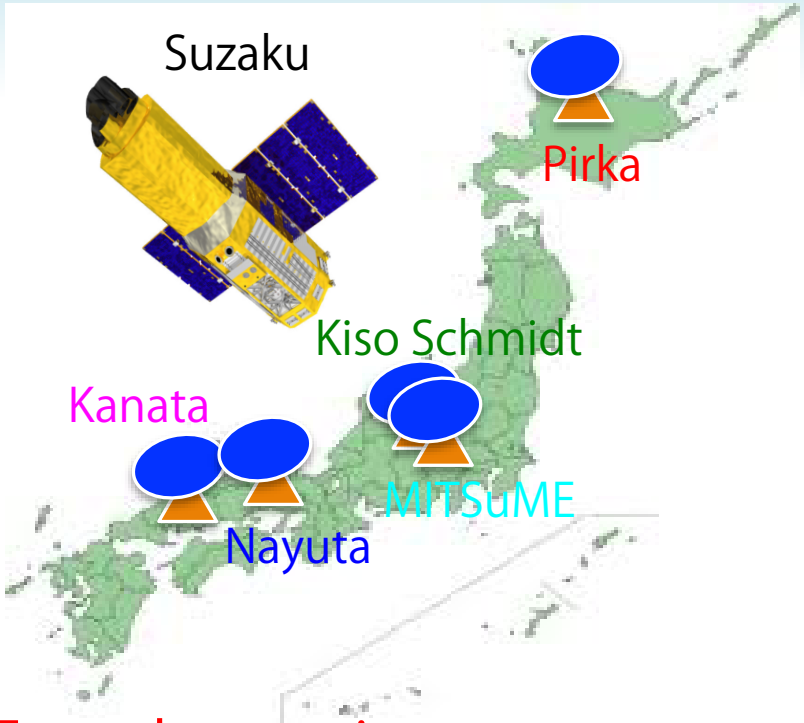
➔ X-ray and optical variabilities should be utilized

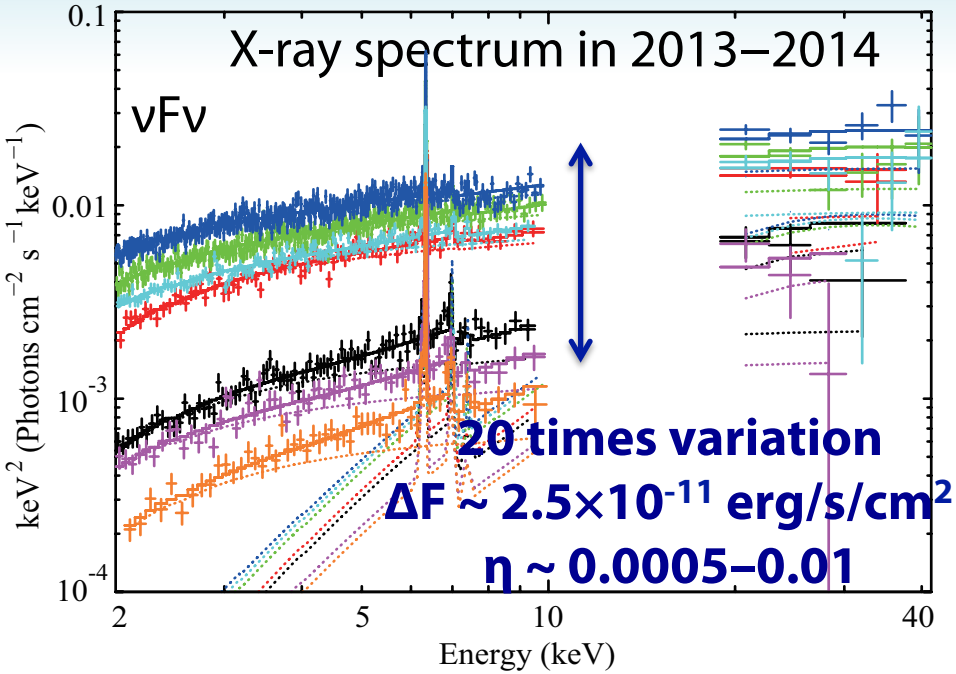
☆ In this study, we focus two Seyfert galaxies, NGC 3516 and NGC 3227, with $\eta < 0.01$, which corresponds to the Low/Hard state having truncated disk and broad corona in BHB.

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



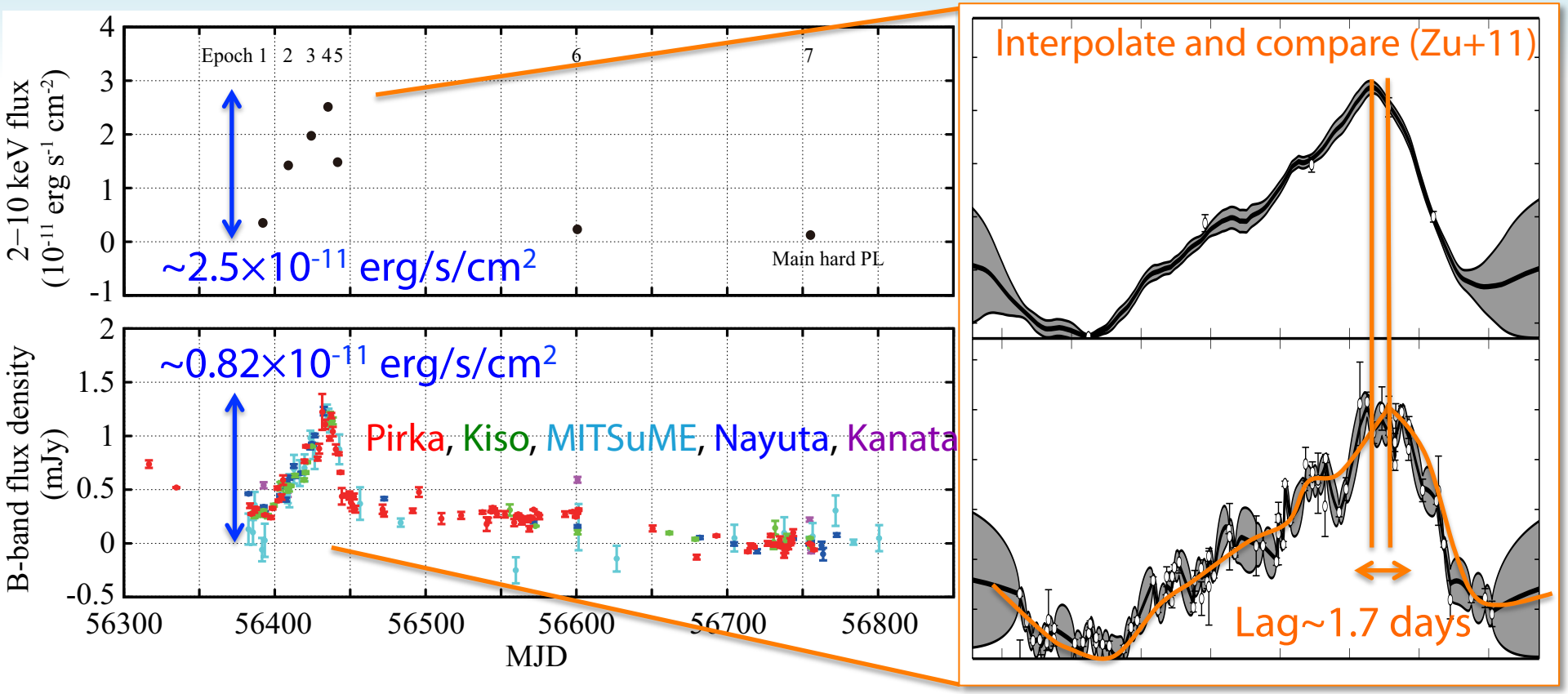


☆ To study accretion geometry, we performed X-ray–optical simultaneous monitoring for 1 year

- Target: **low–*η* Seyfert NGC 3516**
- X-ray obs: Suzaku 50 ks × 7 with various intervals, days, weeks, months
- B band obs : Japanese 5 telescope Pirka, Kiso, MITSuME, Nayuta, Kanata

➔ **Historically faint phase in X-ray and optical**

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 ~1.7±0.7 days

☆ Opt. flux increase calculated by B-band is explained by X-ray irradiation

Standard disk term → $$F = \frac{3GM_{\rm BH}\dot{M}}{8\pi R^3} + \frac{(1-A)L_{\rm X}}{4\pi R_{\rm X}^2}\cos\theta$$ ← X-ray irr. term

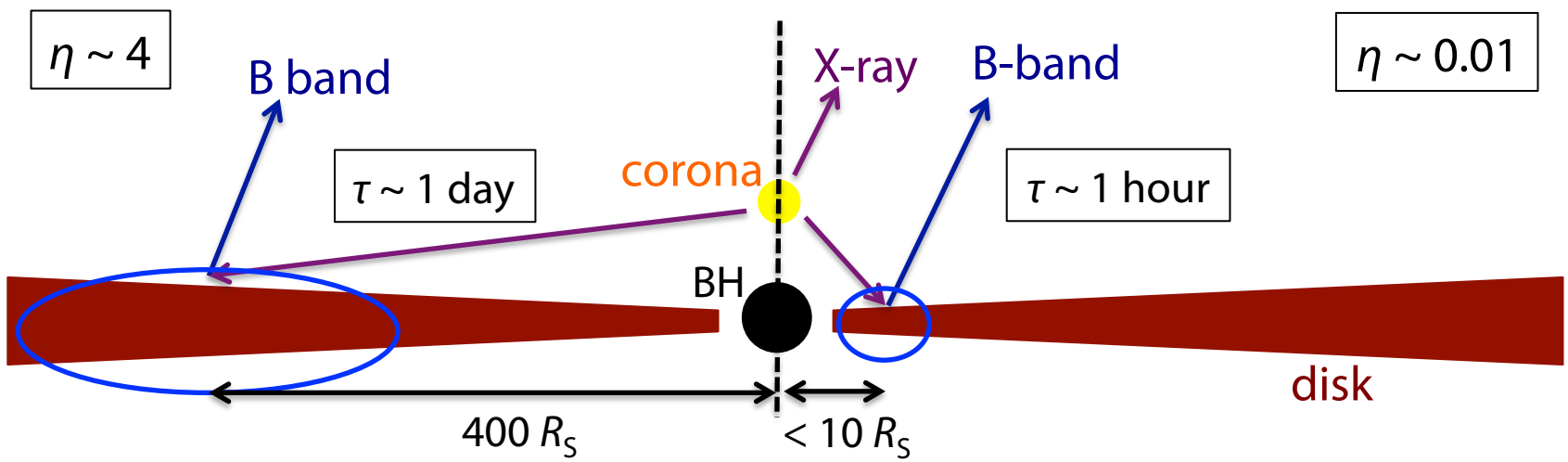
7. Contradiction b/w Lag and η in H/S state

☆ Results in our monitoring of NGC 3516

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

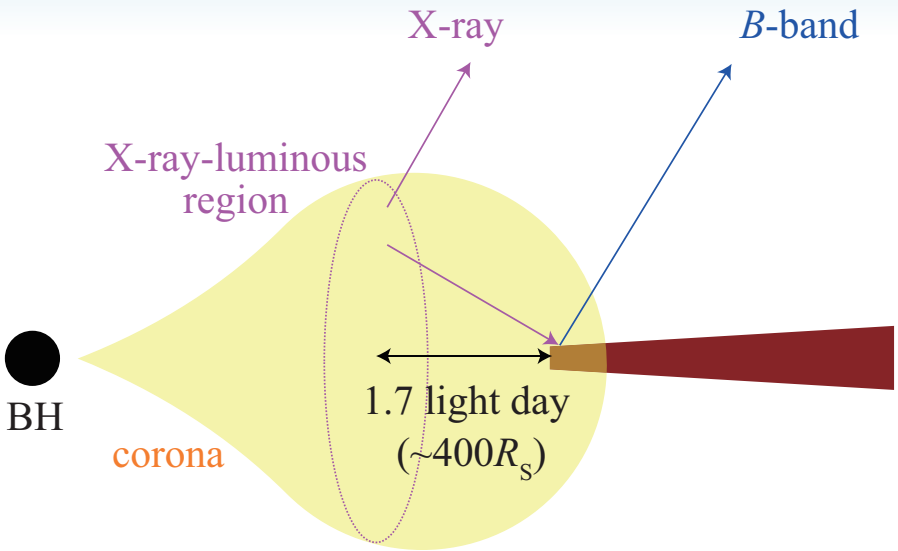
☆ τ inconsistent with η (Actual τ larger than that expected from η by ~20 times)

→ High/Soft state (compact corona) is unsuited for NGC 3516 in the faint phase



8. Geometries of Corona and Disk

Noda et al. (2015) in prep



☆ Disk should be truncated to make τ ~1.7 days and η ~ 5×10^{-4}–0.01 consistent

- **Hot accretion flow in Low/Hard state**
- X-ray bright point ~1.7 ld far from disk
- Optical flux is not by α-viscosity but X-ray irr. (※ particularly N3516)

☆ In many Seyferts, optical lag τ is too large to explain their η (e.g., Cackett+07)

- NGC 4051、3C390.3 …→ τ larger than that expected from η by ~2 times
- Mrk 509、MCG+8-11-11→ τ larger than that expected from η by ~3 times
- NGC 5548 → τ larger than that expected from η by ~5 times

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

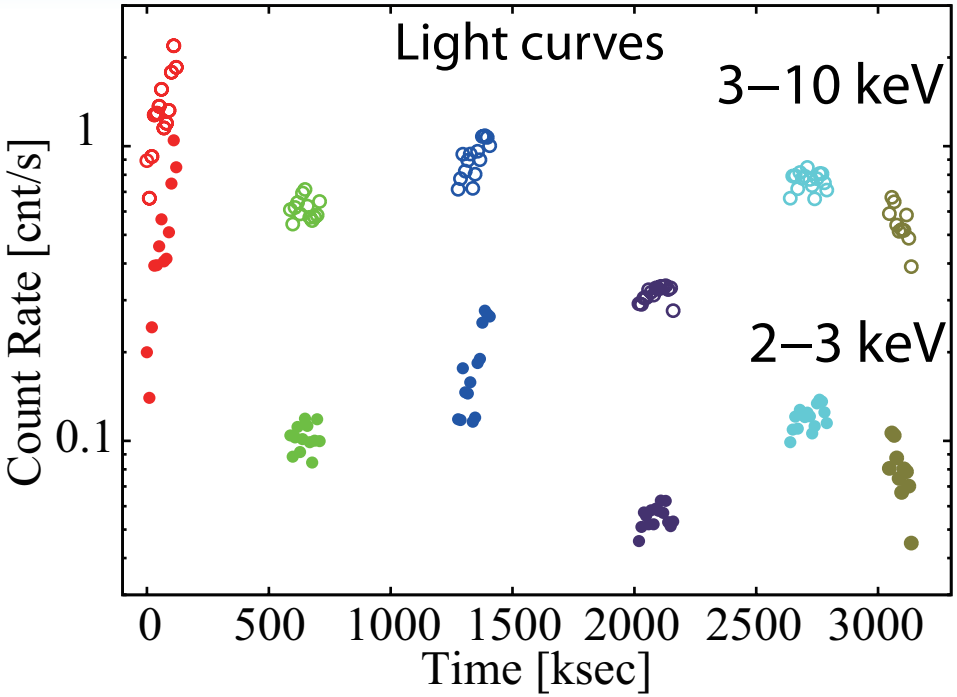
III. Phase Change of Accretion Flow in NGC 3227

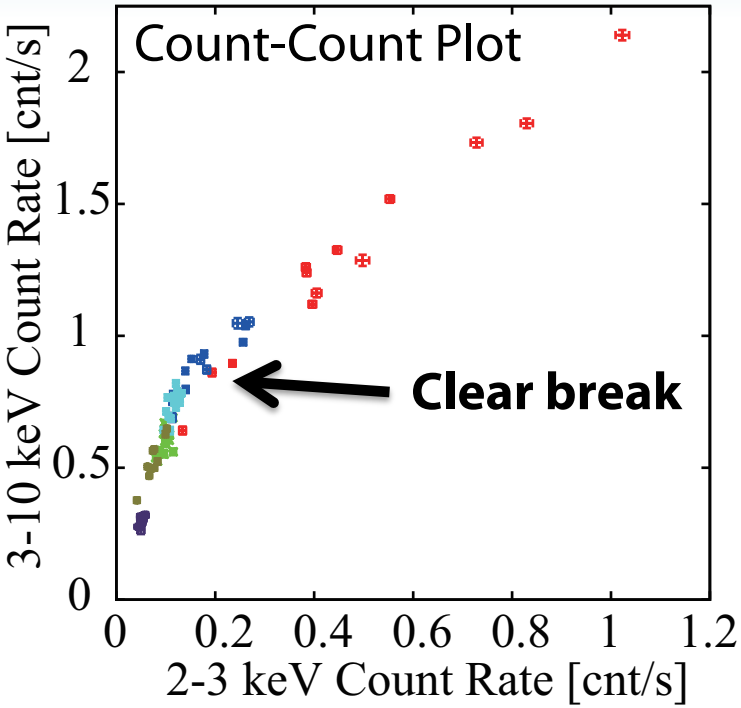
➔ With Drastic Change of X-ray Variability

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

Noda et al. 2014, ApJ, 794, 2

Suzaku 6 observation (each exp. ~50 ksec)





☆ 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

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

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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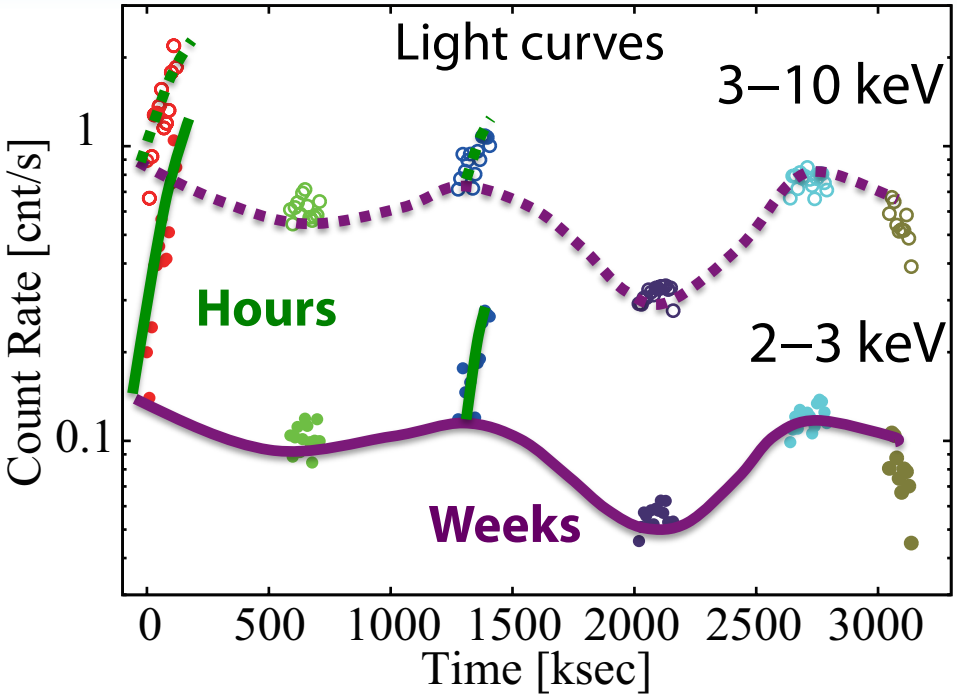

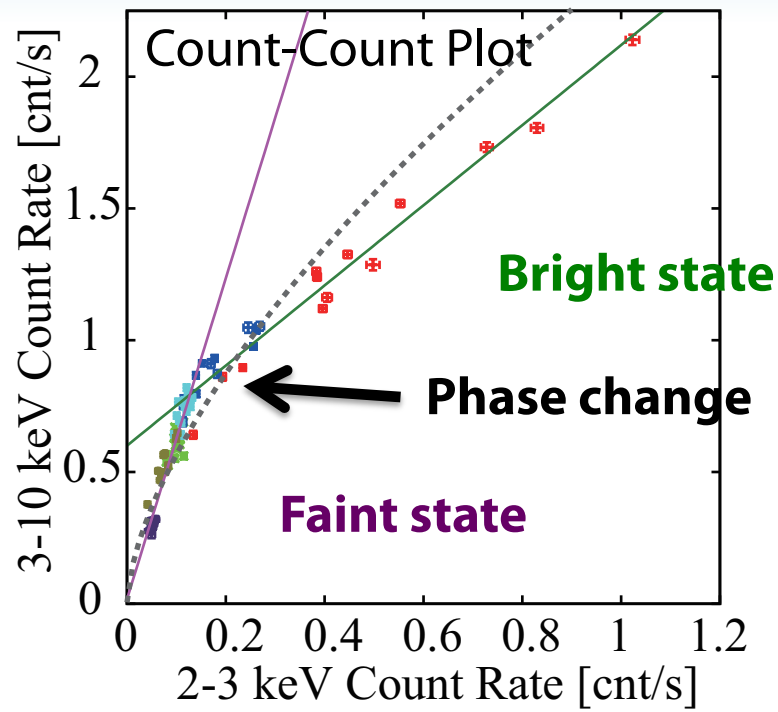

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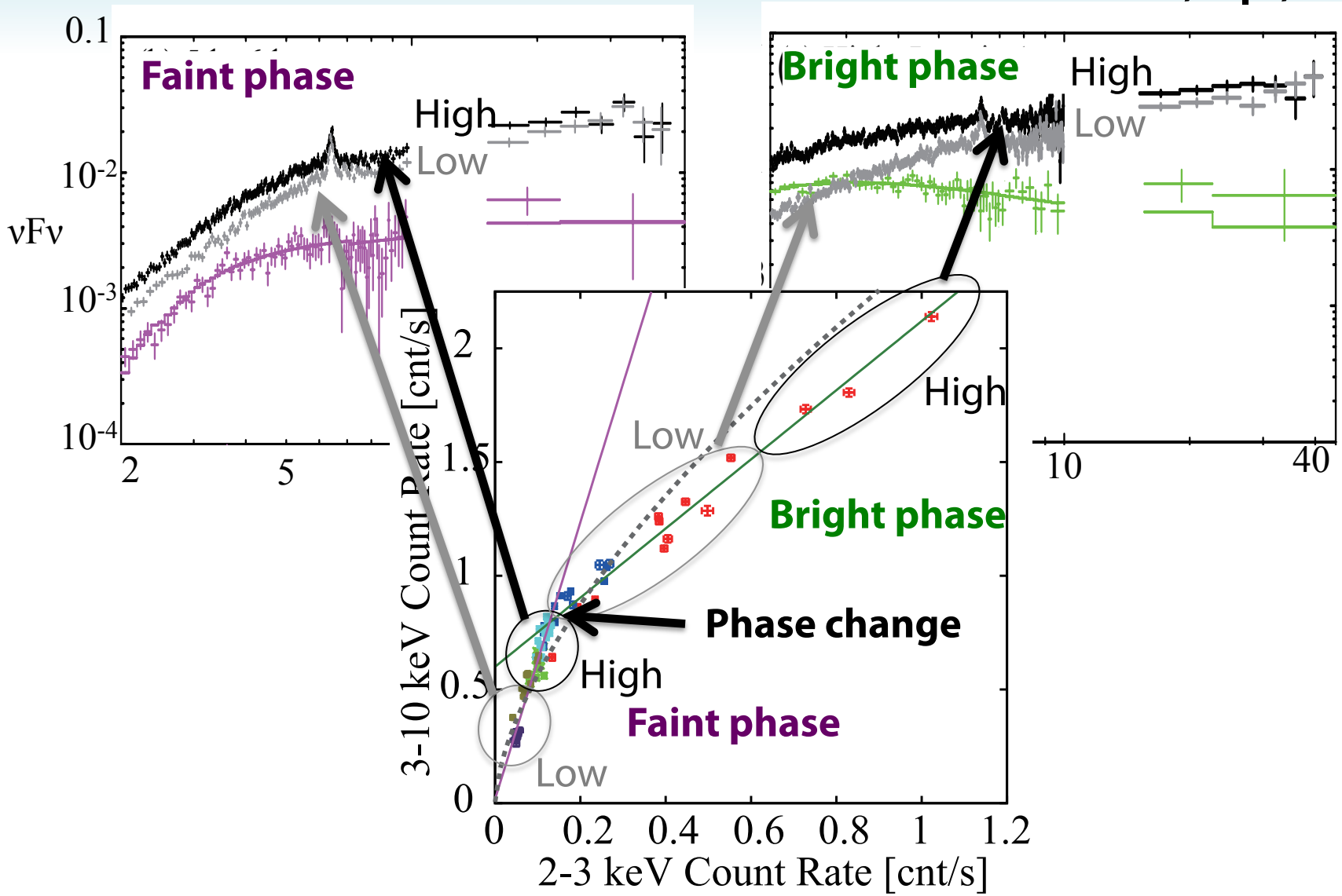

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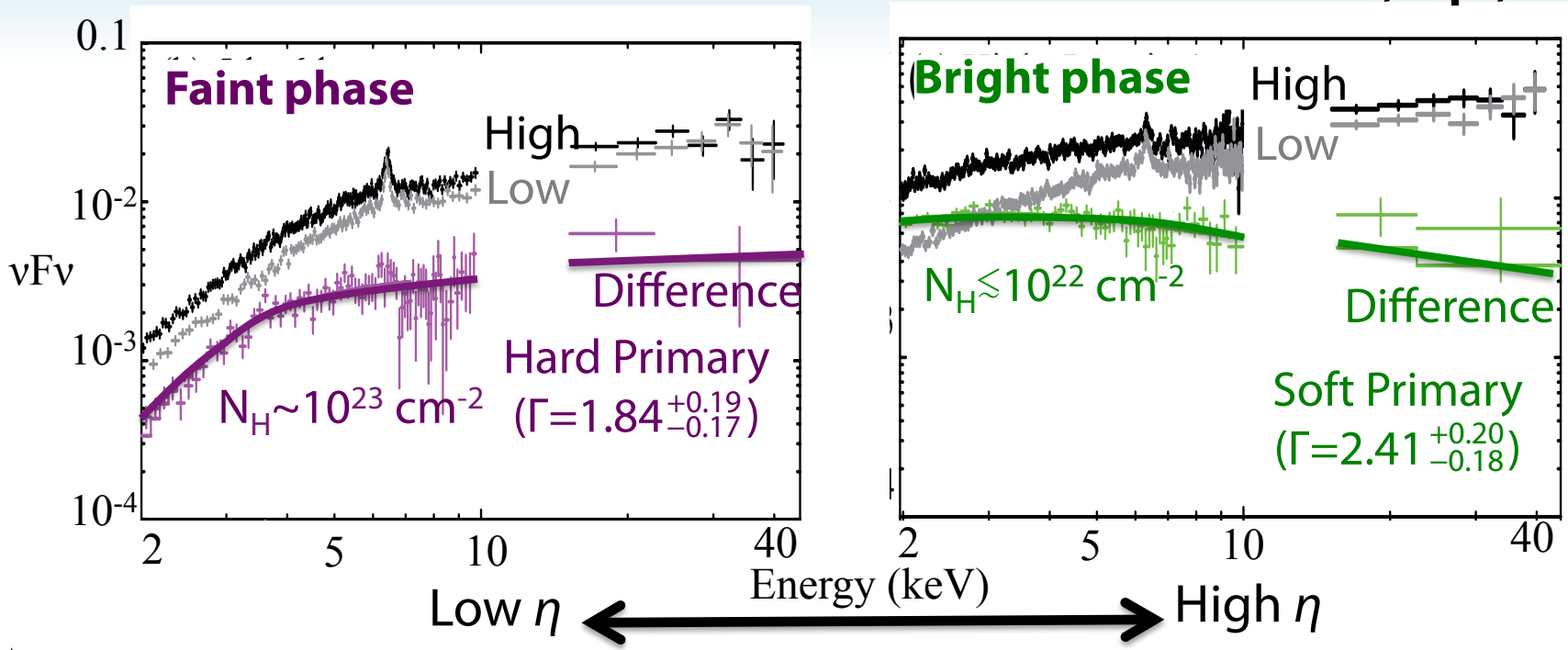

☆ Accretion onto SMBH causes two distinct primary X-ray (often simultaneously)

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

➔ **Compton in the Low/Hard state**

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

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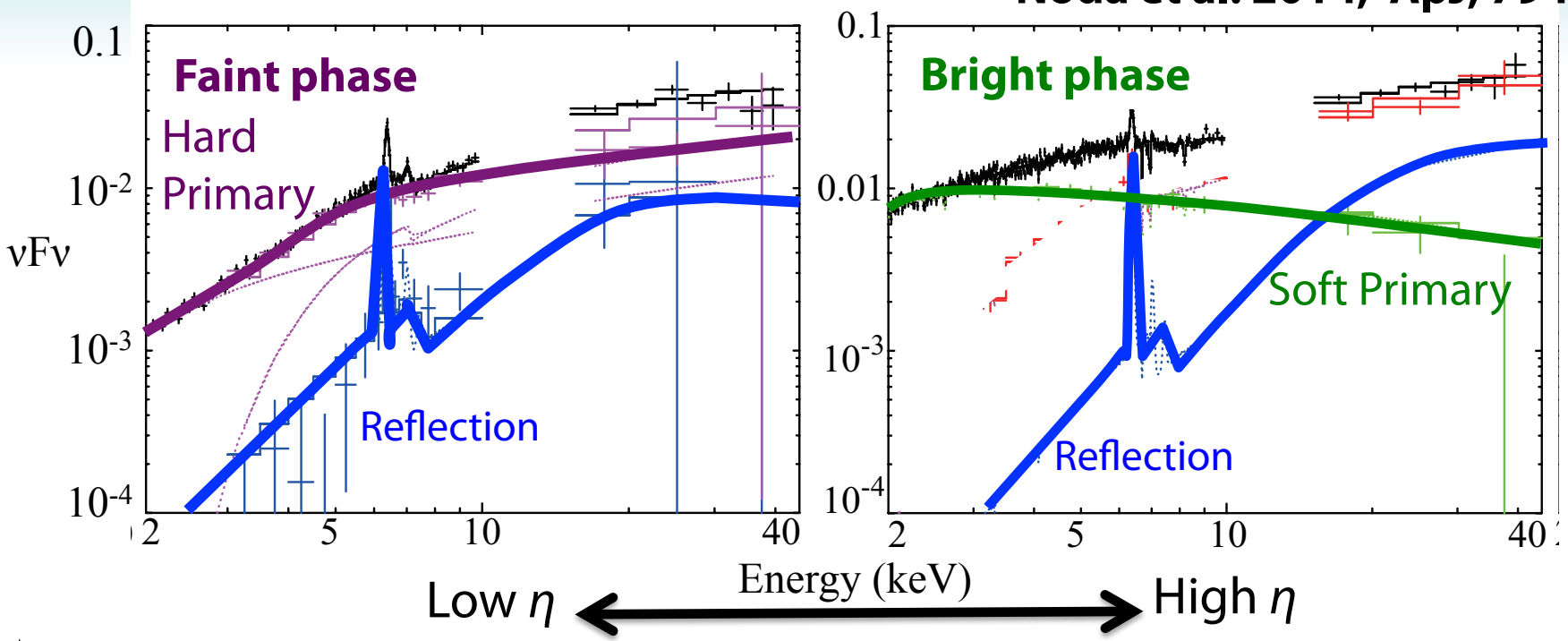

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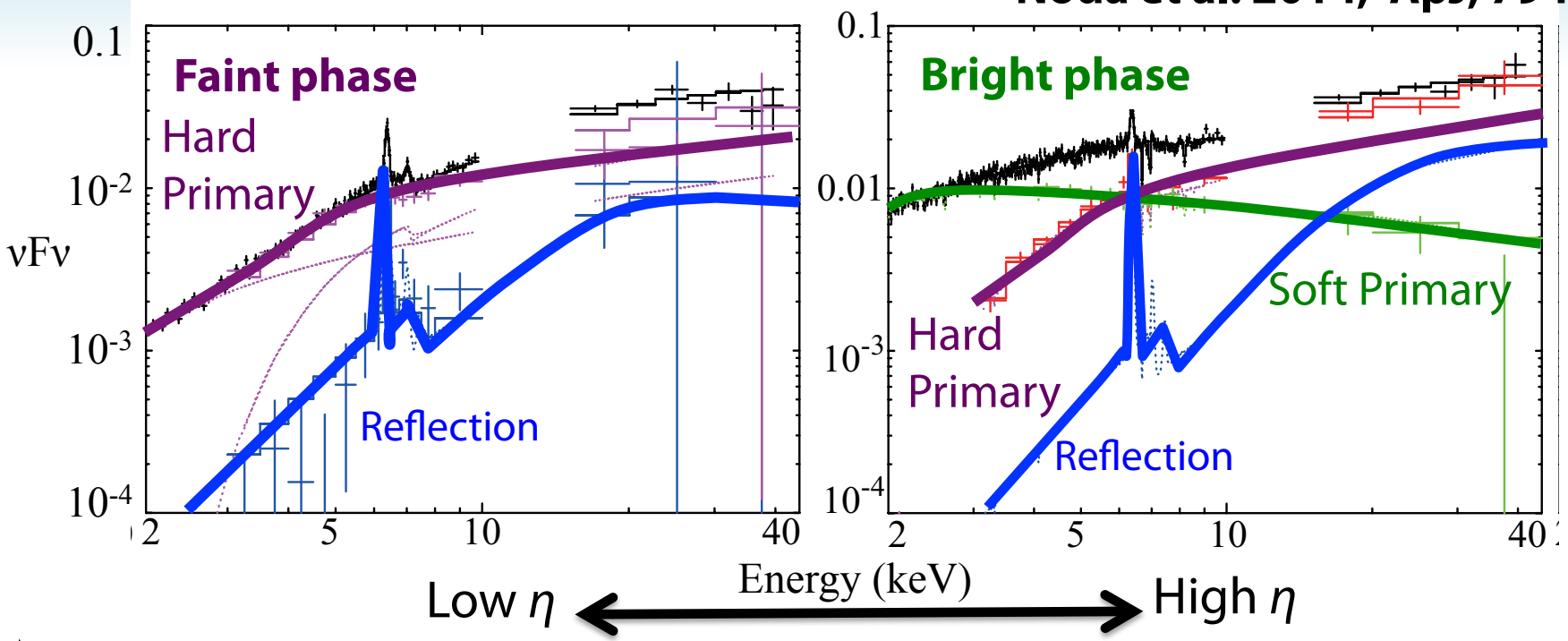

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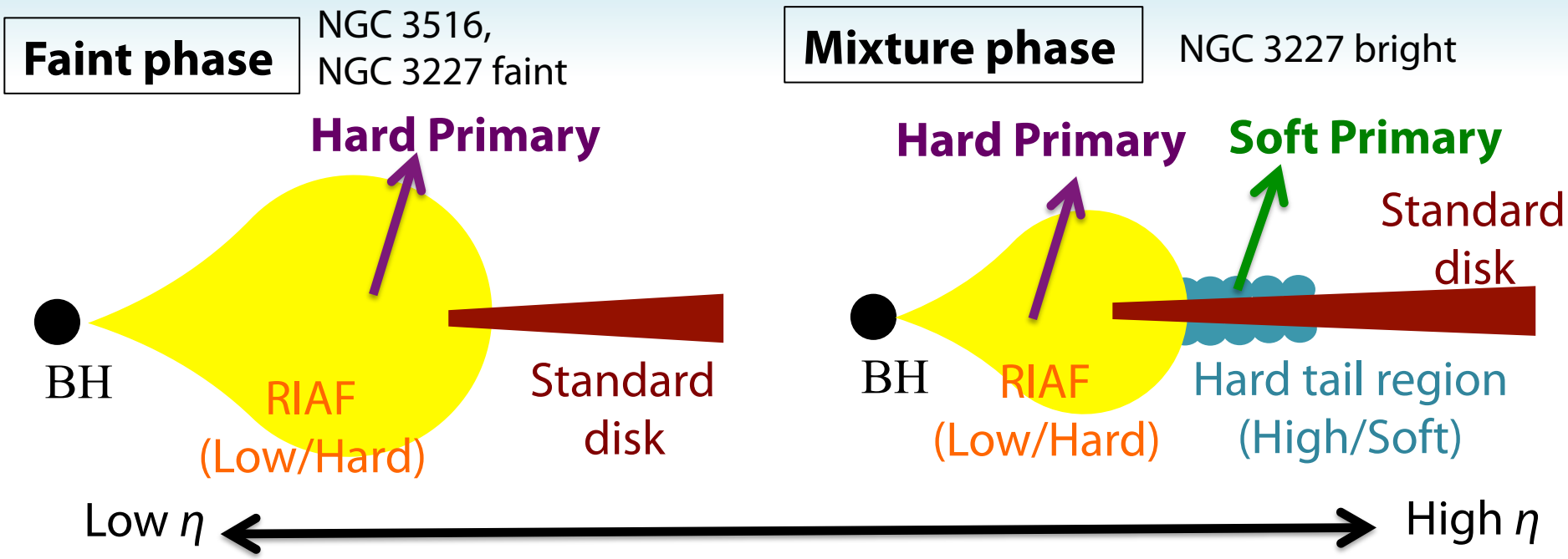
12. Interpretation of Phase Change of NGC 3227



☆ NGC 3227 shows phase change from Faint to Mixture phase

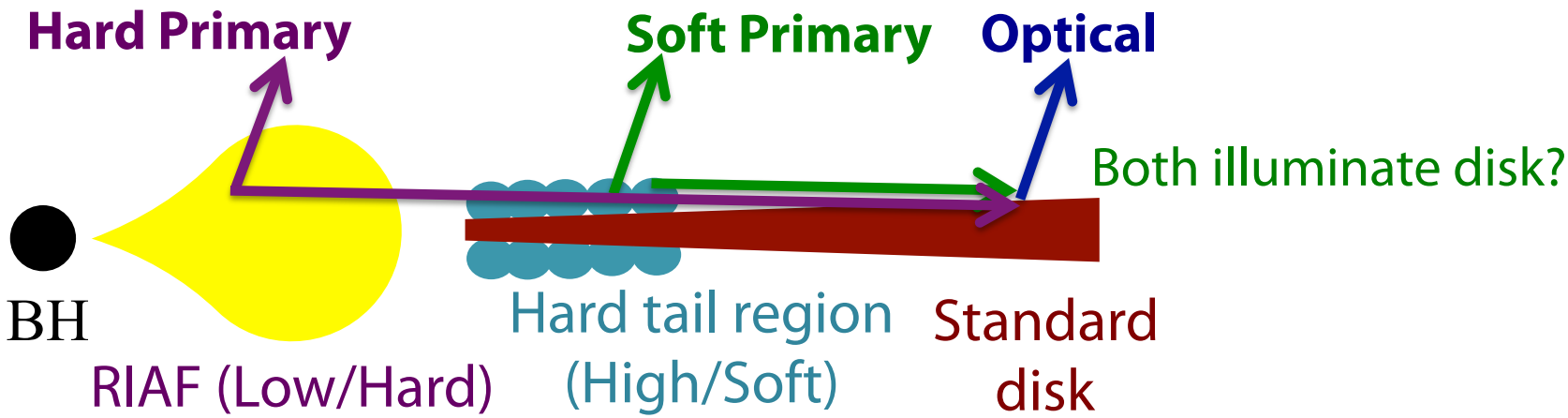
Faint phase → **Hard Primary** (**Low/Hard**)

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

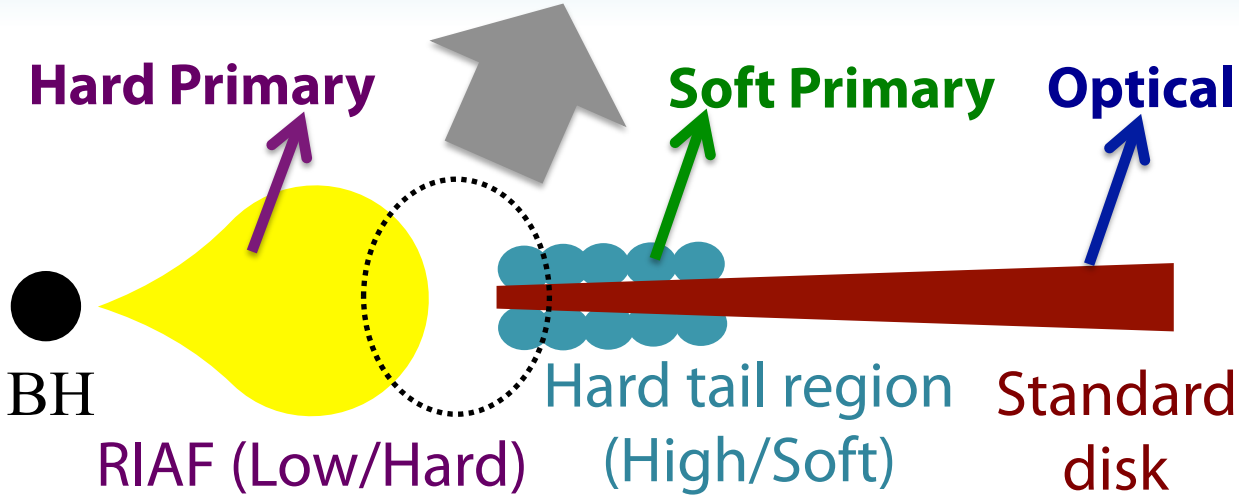


☆ Hard and Soft primary X-ray both can illuminate disk, increasing optical

- 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 ?



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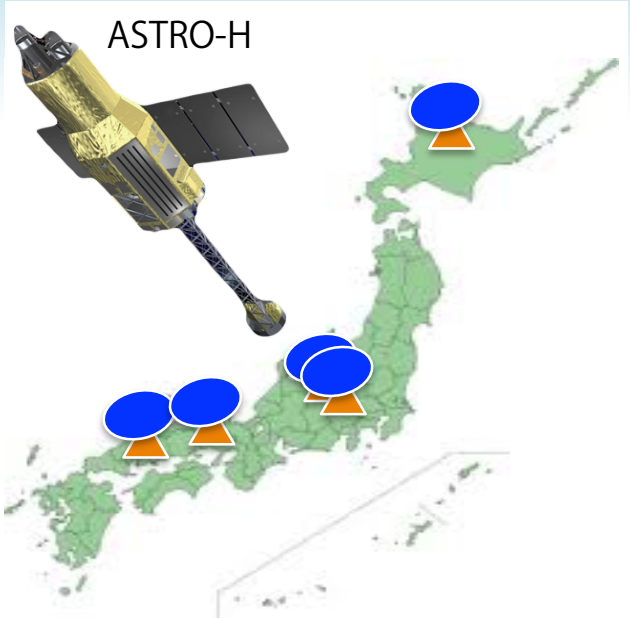
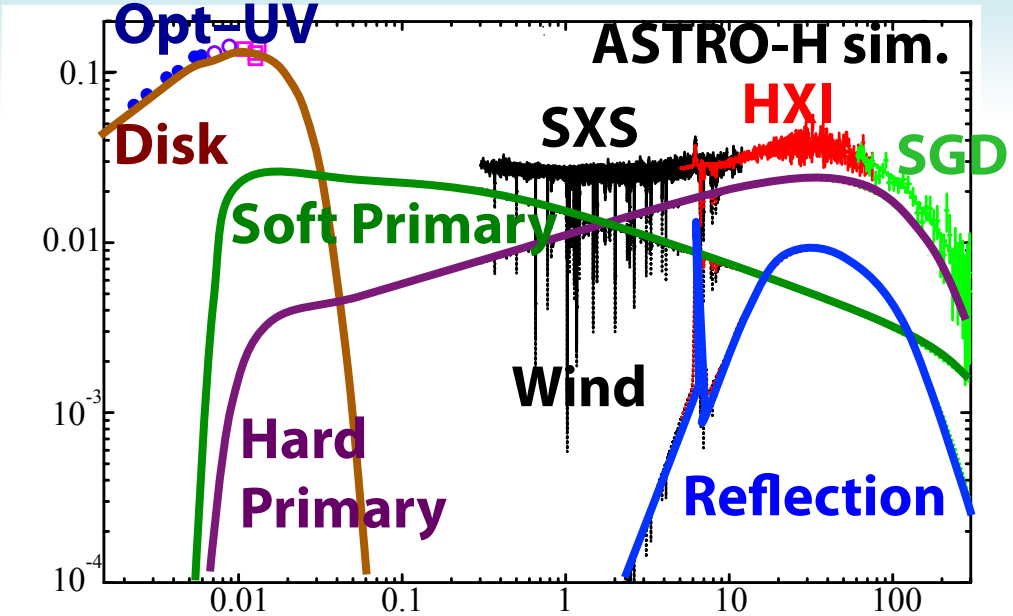
- How large amount of energy is given to disk by X-ray irradiation?

☆ 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

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 ~400 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.