X-ray Studies of Supermassive Black Holes and Jetted AGNs with *XRISM*

2021 January 20

Osaka University, Japan

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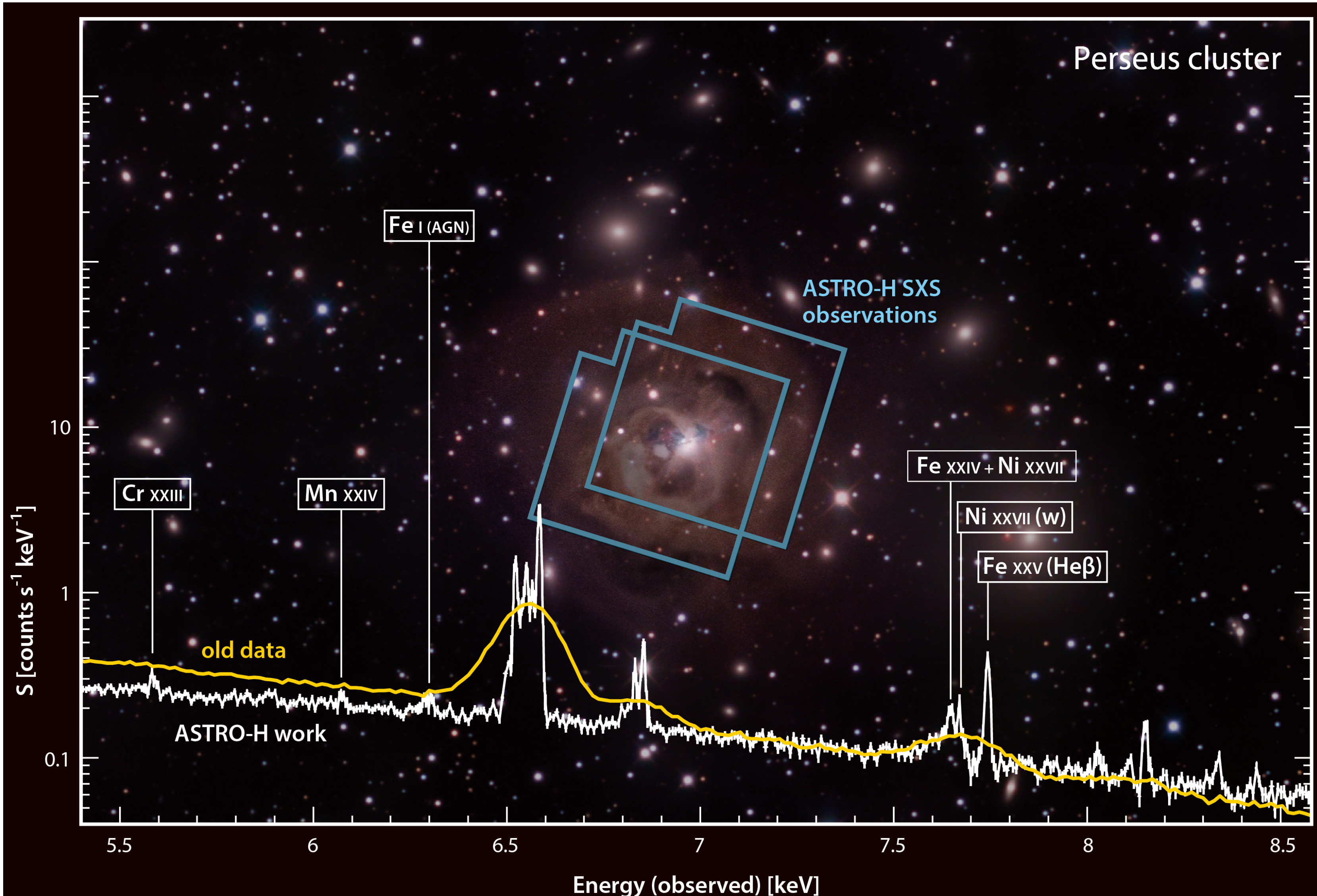
Outline of This Talk

1. X-ray Microcalorimeter onboard X-ray satellite
2. Studies of Differences b/w Radio-Loud and Radio-Quiet AGNs
    I. Nuclear Structures and Disk Winds (*Hitomi* results & *XRISM* prospects)
    II. X-ray Measurements of Supermassive Black Hole Spins (*XRISM* prospects)
3. Supermassive Black Hole Accretion State Transition

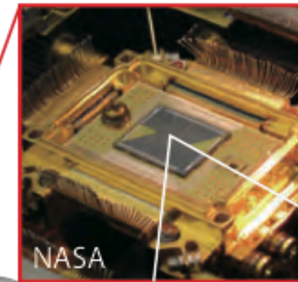
1. X-ray Microcalorimeter onboard X-ray Satellite

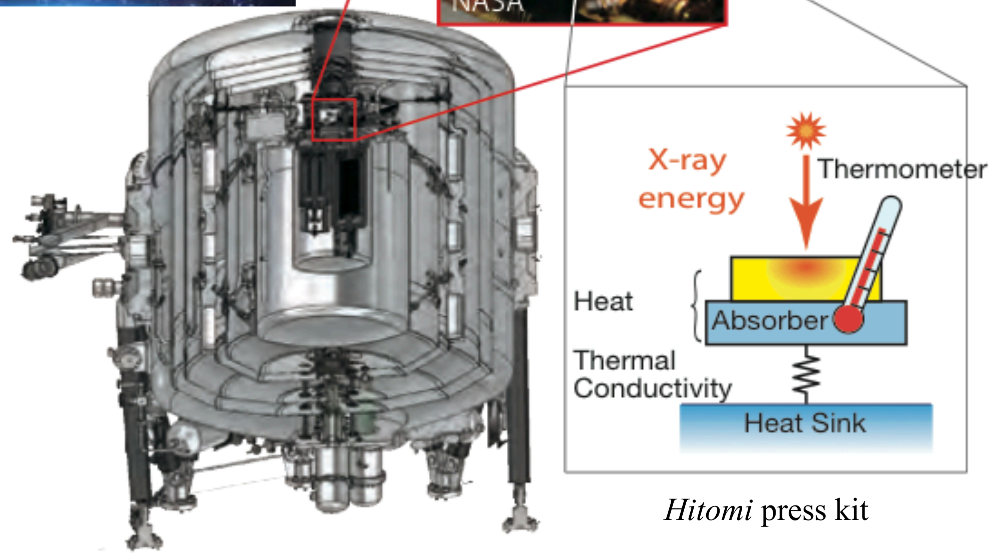
1. *Hitomi* X-ray Microcalorimeter Spectroscopy

Hitomi collaboration (2016, 2018), Credit: JAXA/Ken Crawford (Rancho Del Sol Observatory)



2. X-ray Microcarorimeter onboard *Hitomi*

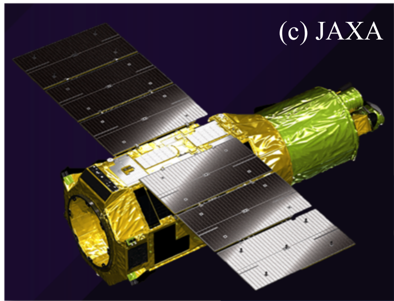




Hitomi press kit

☆ X-ray microcalorimeter on the 6th Japanese X-ray satellite ***Hitomi*** observed Perseus (*Hitomi* co. 16, 18).

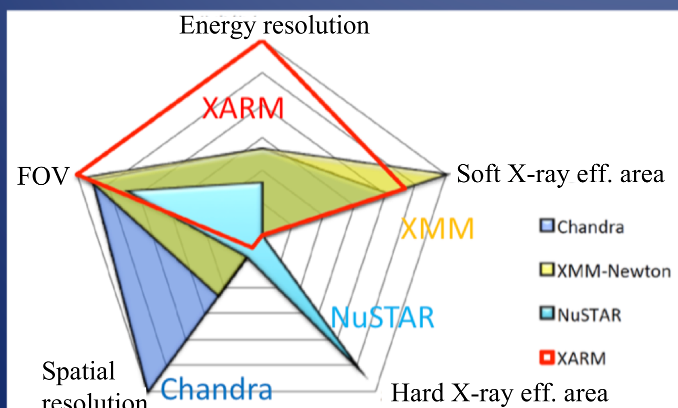
☆ However, *Hitomi* was lost ~1 month after the launch because of attitude control troubles.



3. *XRISM* (2022 JFY~)

The Science Council of Japan Master Plan symposium, Tashiro-san presentation

ment	FOV/pix	ΔE (FWHM @6 keV)	Energy band
Resolve (XMA + X-ray microcalorimeter)	2.9’ □ / 6 x 6 pix	7 eV (goal 5 eV)	0.3 – 12 keV
Xtend (XMA + X-ray CCD)	38’ □/ 1280 x 1280 pix	< 250 eV at EOL (< 200 eV at BOL)	0.4 – 13 keV



☆ Development of the recovery mission of *Hitomi* **“X-Ray Imaging and Spectroscopy Mission (*XRISM*)”** is ongoing.

☆ The launch is planned in 2022 JFY. We are now performing FM tests.

3. *XRISM* (2022 JFY~)

宇宙航空研究開発機構
米国航空宇宙局

欧州宇宙機関
首都大学東京
金沢大学
大阪大学
宮崎大学
埼玉大学

SRON(Neitherlands Institute for Space Research)
University of Geneva
Canadian Space Agency

Gravitation AstroParticle Physics Amsterdam
Canadian Light Source Inc.
University of Chicago
中央大学
University of Durham
愛媛大学

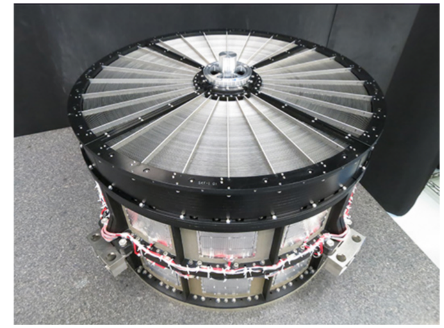
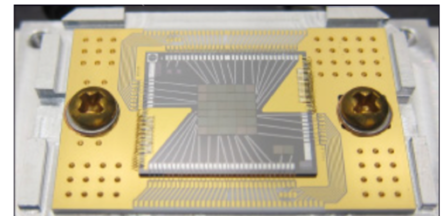
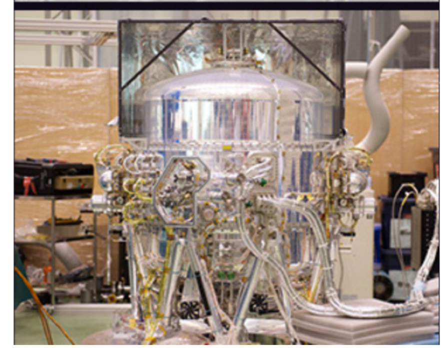
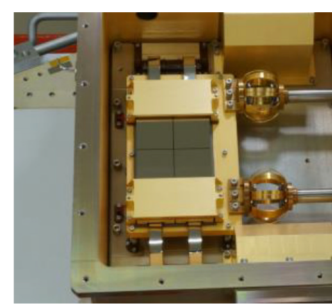
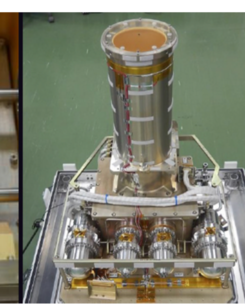
European Sauther Observatory
藤田医科大学
Harvard-Smithsonian Center for Astrophysics
広島大学
関東学院大学
近畿大学

関西学院大学
京都大学
Lawrence Livermore National Laboratory
Leiden University
University of Maryland
Massachusetts Institute of Technology

University of Michigan
名古屋大学
奈良教育大学
奈良女子大学
日本福祉大学
理化学研究所

立教大学
Saint Mary's University
芝浦工業大学
静岡大学
東北学院大学
東京大学

東京理科大学
早稲田大学
University of Waterloo
University of Wisconsin
Yale University

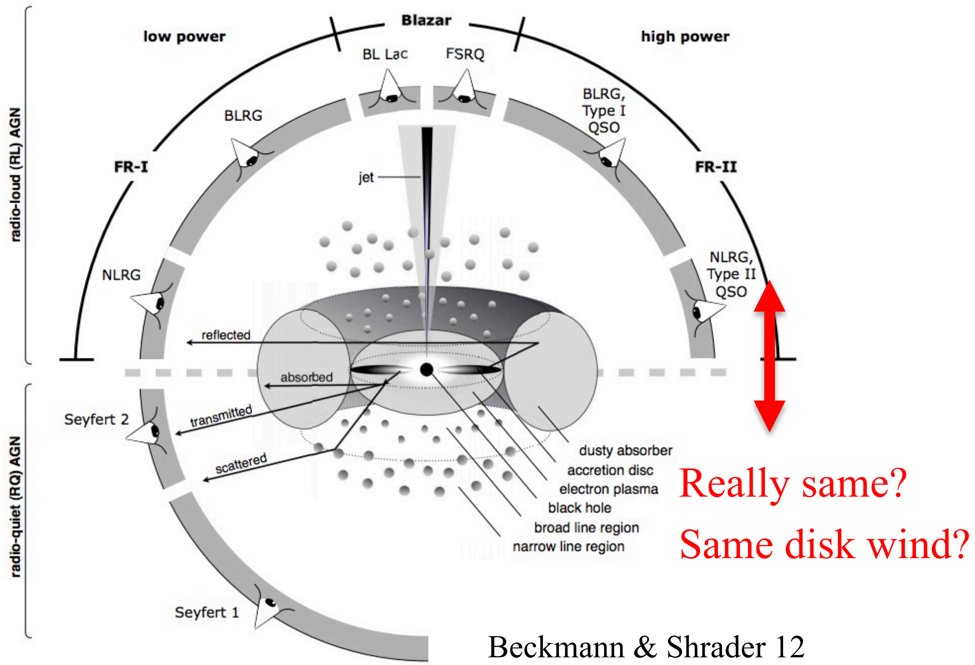






https://xrism.isas.jaxa.jp

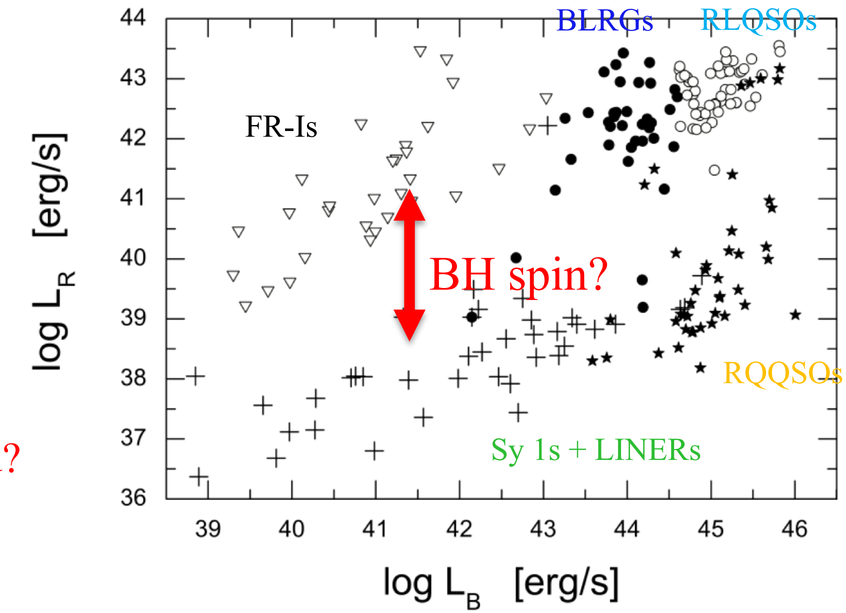
2. Studies of Differences between Radio-Loud and Radio-Quiet AGNs

(*Hitomi* results & *XRISM* prospects)

4. Picked-up Topics with X-ray Precise Spectroscopy



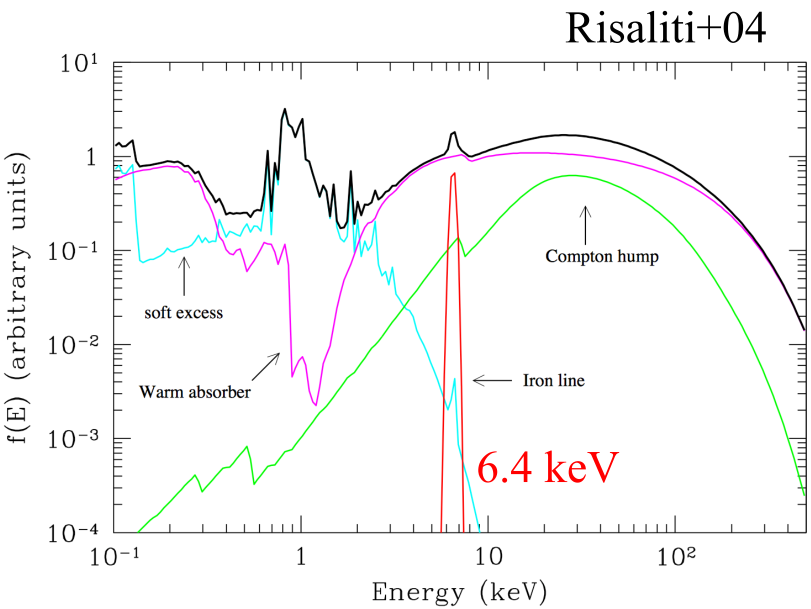
Beckmann & Shrader 12

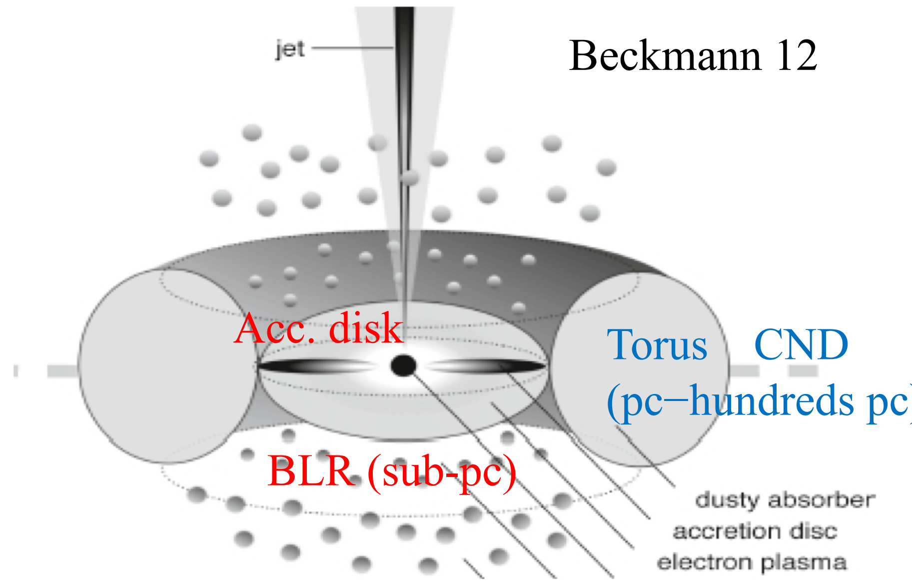


☆ In the AGN unified model, radio-loud and radio-quiet AGNs are believed to have an identical AGN structure. However, not conclusive yet.

☆ AGN radio-loudness (the bimodality of the optical−radio plane) is suggested to reflect BH spins. However, it has been difficult to constrain BH spins.

5. Probe to Study Nuclear Structure: Fe-Kα Line





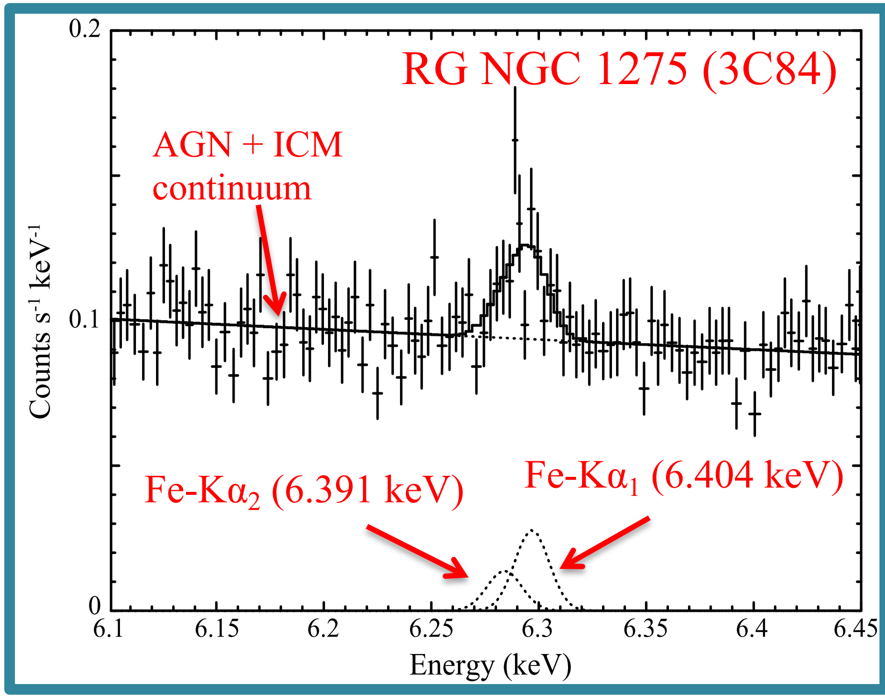
☆ Profile of narrow & neutral Fe-Kα line

- Accretion disk? Broad-line region (BLR)? ➔ *V* width > 2000 km/s (FWHM)
- Torus? Circumnuclear disk (CND)? Outer? ➔ *V* width < 100s km/s (FWHM)

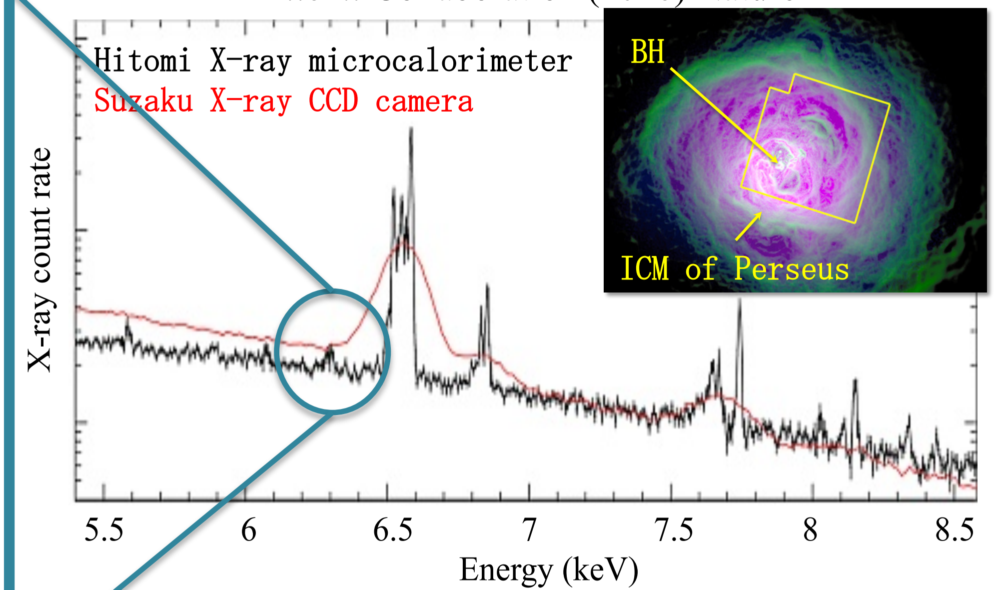
☆ The *E* res. of X-ray CCDs cannot distinguish the difference. X-ray calorimeter can!

☆ **The origin (line profile) of Fe-Kα reflects nuclear structures**

6. *Hitomi* Detection of Fe-Kα from NGC 1275



Hitomi Collaboration (2016) Nature



Hitomi co. (2018) PASJ, 70, 13 (corr. HN)

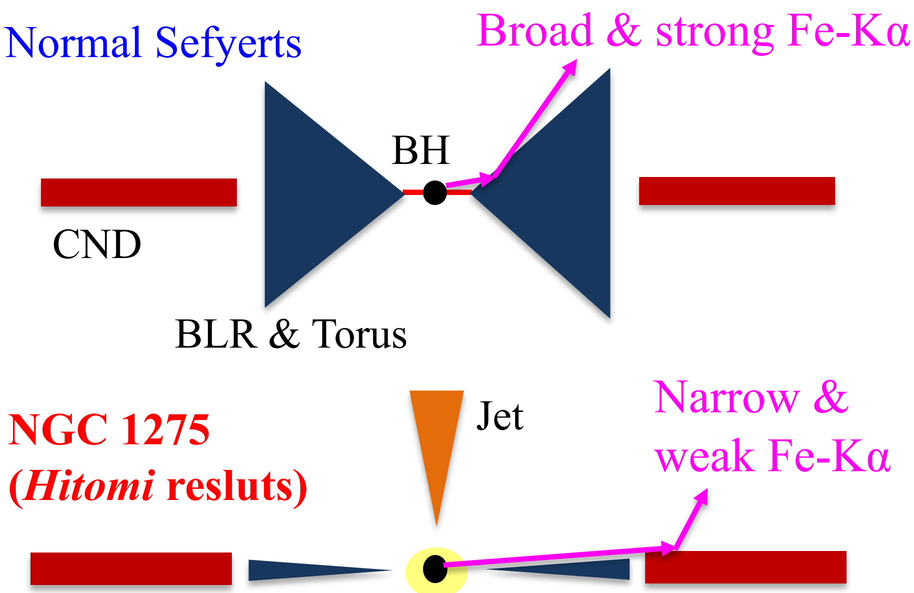
☆ NGC 1275 is the first AGN, observed with X-ray Calorimeter $\Delta E/E$ = 5 eV/6 keV

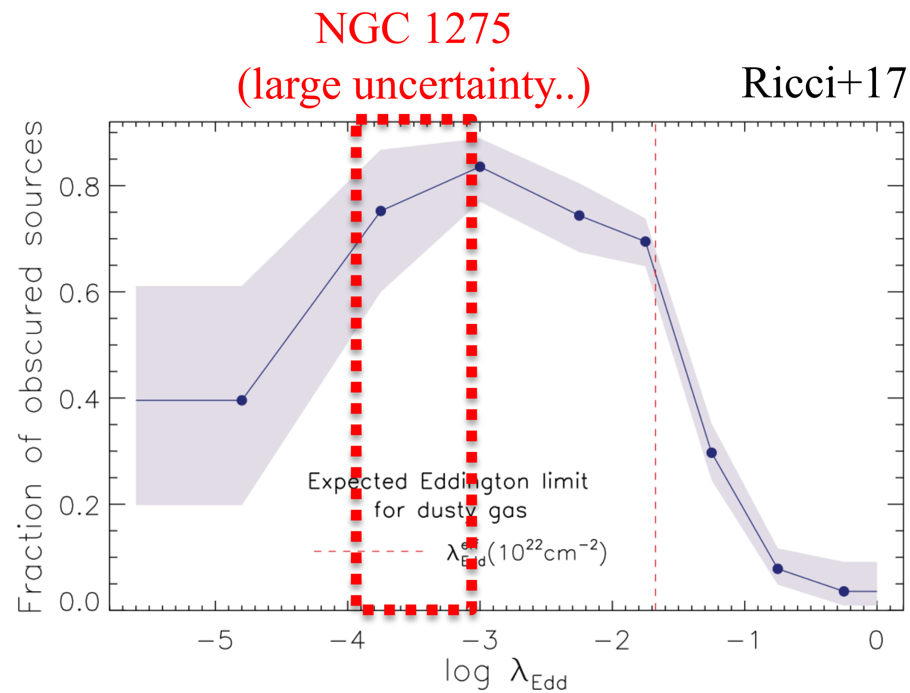
	L/L_{Edd}	*V* width (km/s)	EW (eV)
NGC 1275	**~ $10^{-3\text{-}4}$**	**500–1600** (< 2750 BLR)	**~20**
Seyferts	~ $10^{-1\text{-}2}$	> 2500 (~*V* of BLR)	~150

→Fe-Kα from BLR

☆ The Fe-Kα line presumably comes from CND in NGC 1275. A BLR is absent, a torus has low covering fraction (otherwise, Fe-Kα must be broad and strong).

7. Is the Strange Torus Structure Related to Jet Activity?





☆ NGC 1275 has $L/L_{\mathrm{Edd}} \sim 10^{-3\text{-}4}$ and strong jet activity. Its L/L_{Edd} may correspond to normal covering fraction of torus (Ricci+17).

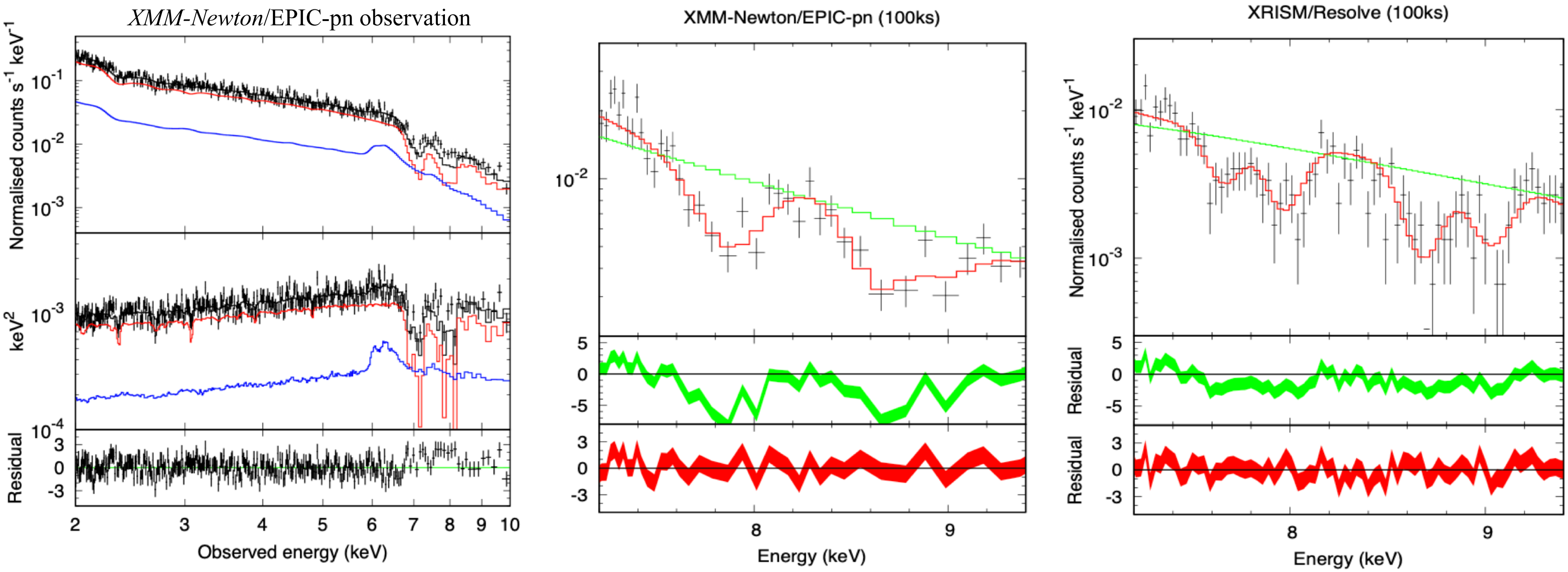
☆ Is the strange BLR & torus structure in NGC 1275 (*Hitomi* co. 18) related to the jet activity, low L/L_{Edd}, or both?

☆ Systematic study of narrow Fe-Kα lines from RGs & LLAGNs with *XRISM* + ALMA imaging of cold matter accretion within tens pc (Nagai-san's talk!)

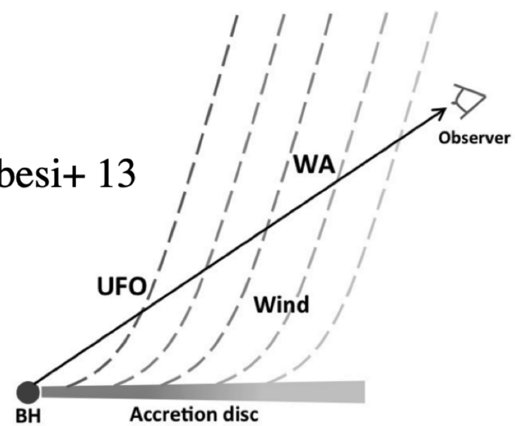
Disk Winds (*XRISM* prospects)

8. Disk Wind Detected with *XRISM*

PG1211+143 *XMM* observation and *XRISM* Simulation (Mizumoto+20)



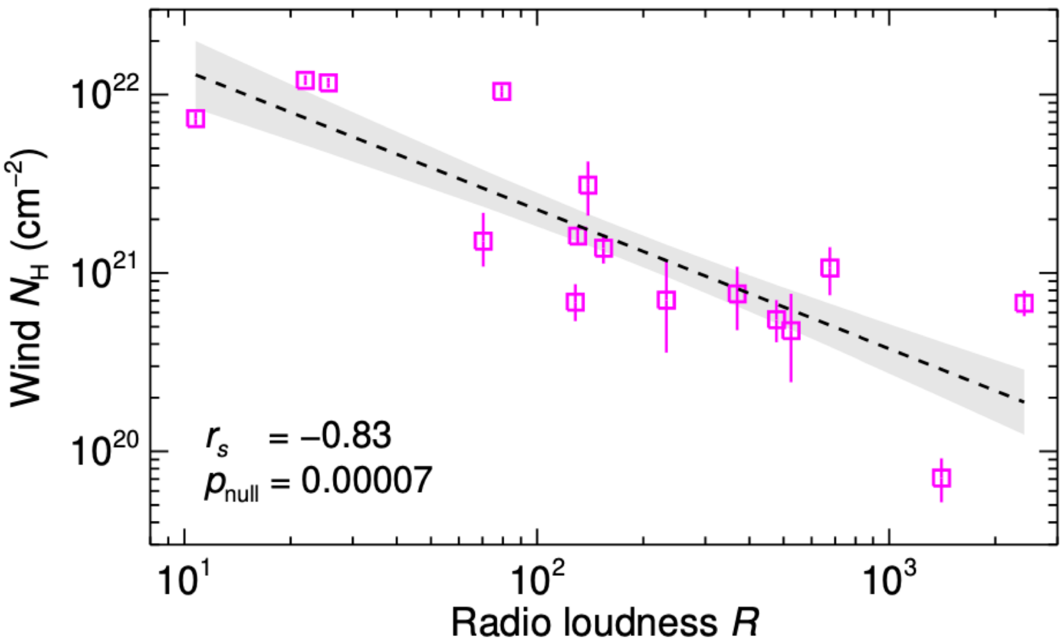
Tombesi+ 13



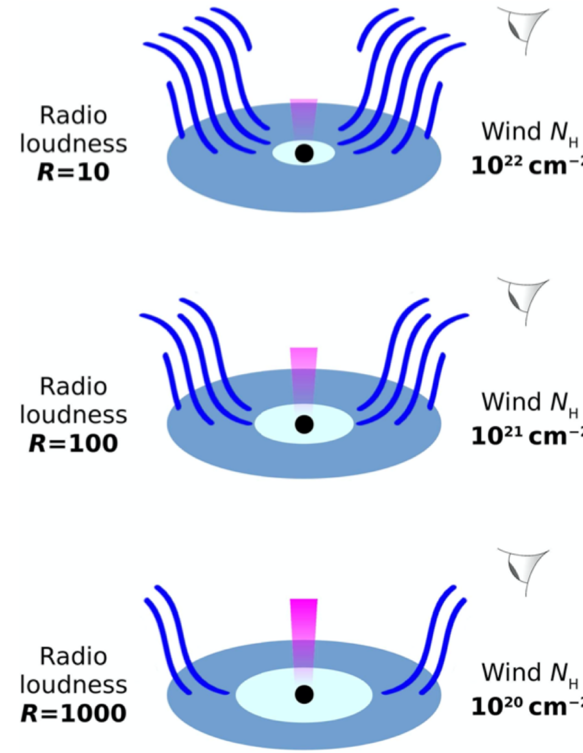
☆ Ab. features by warm absorbers, disk wind and ultrafast outflow (UFO; Nomura-san's talk!) can be significantly detected.

☆ Absorption lines with different ionization degree and velocities can be identified. N_{H}, ξ, and v/c of winds can be constrained.

9. Relation between Jet and Disk Wind



Mehdipour & Costantini 19



☆ Mehdipour & Costantini 19 reported an inverse correlation b/w radio-loudness and N_H of disk wind in X-ray bright RGs.

➔ Is a disk wind driven magnetically? So, does a disk wind declines when a jet gets stronger?

☆ Systematic study of disk wind abs. lines in RGs with *XRISM* is necessary to verify the wind-jet bimodality.

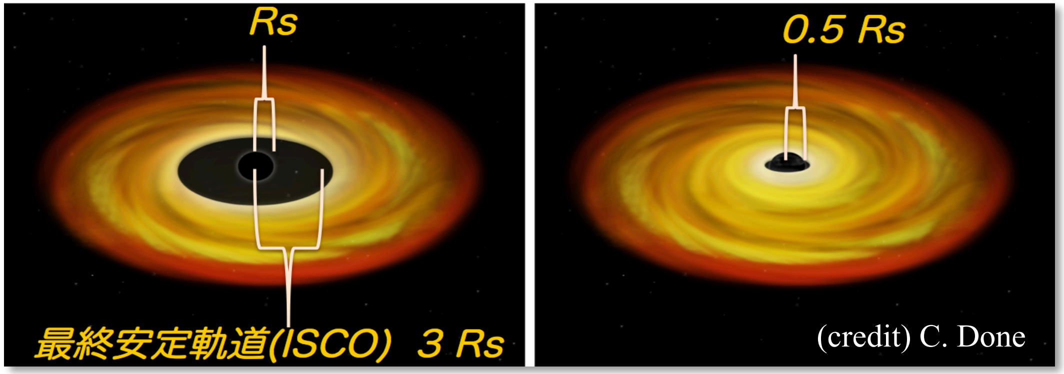
SMBH Spin Measurement

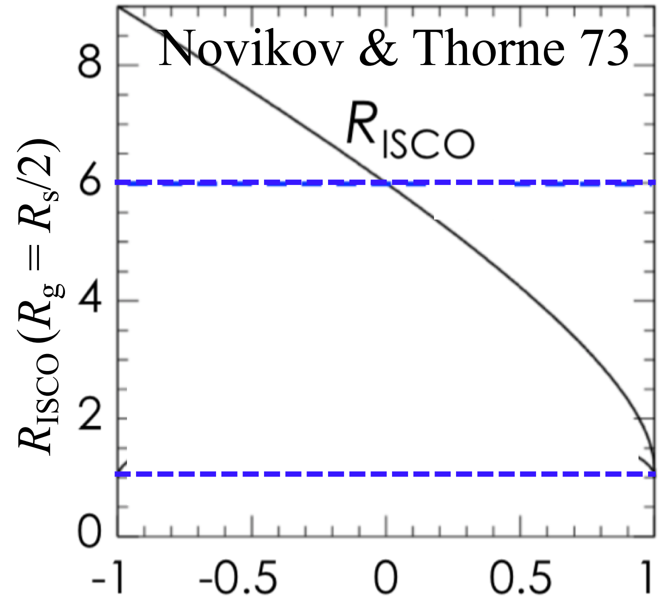
(*XRISM* prospects)

10. Relativistically-Blurred Fe-Kα Line in X-ray

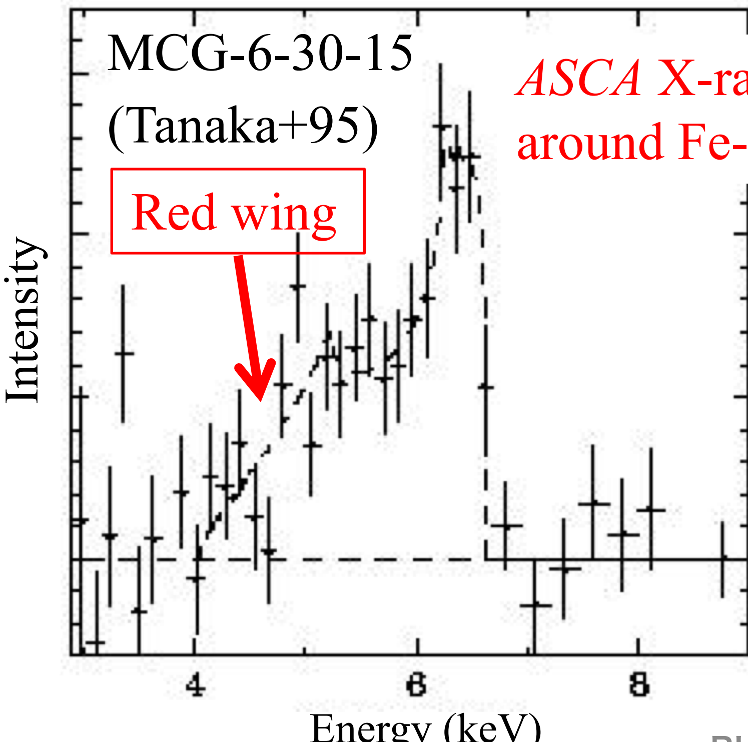
Schwarzschild BH

$a^* \sim 1$ Kerr BH





Spin parameter $a^* = 2J/(M_{BH}R_sc)$



ASCA X-ray spectrum around Fe-Kα

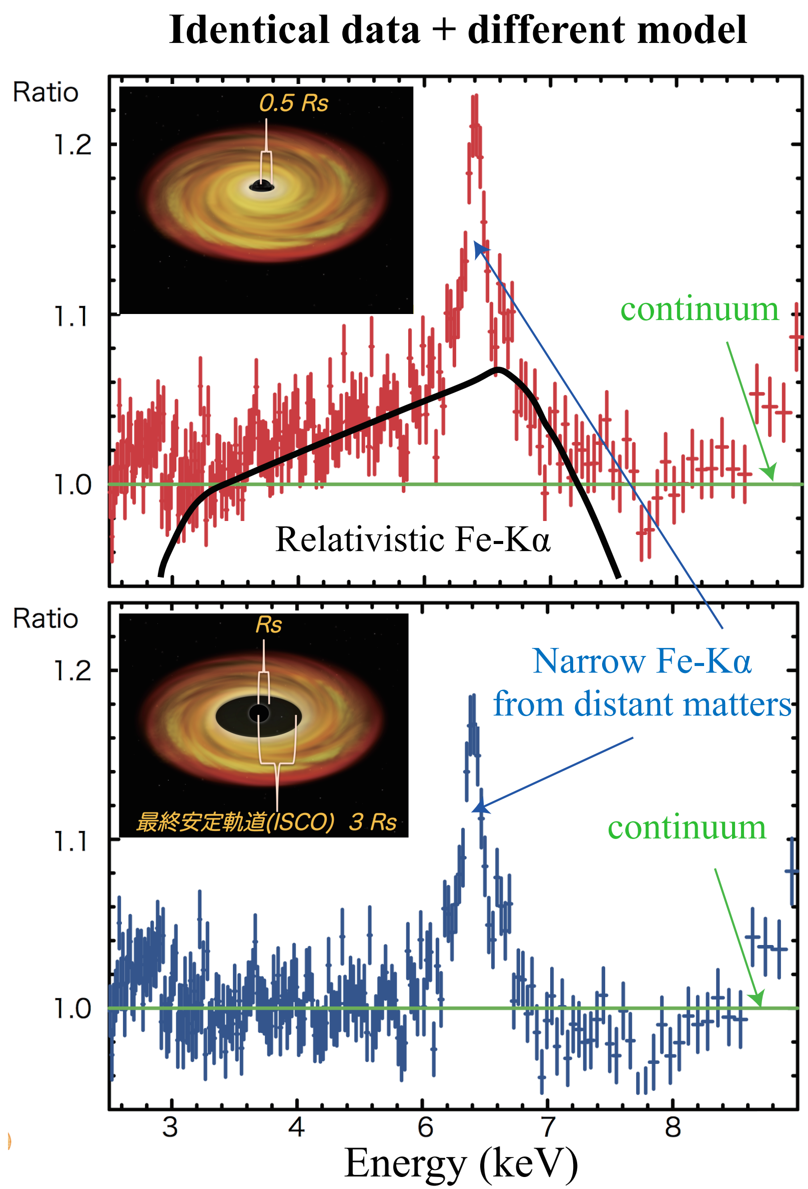
☆ Fe-Kα broadened by Doppler + Grav. redshift
Line width → Inner radius R_{in} → R_{ISCO} → a^*

☆ The relativistically-broadened Fe-Kα was reported by *ASCA* for the first time, and $a^* \sim 1$ (Tanaka+95)

$a^* = 0$: Red wing range up to ~5 keV

$a^* \sim 1$: Reach to ~3−4 keV ← Tanaka+95

11. Problems of the Previous X-ray Spin Measurements



☆ In a few tens AGNs, BH spins were measured. Many have $a^* \sim 1$ (e.g., Reynolds19)

☆ Also reproduced by models with $a^* = 0$, mainly because of the following two.

① Depends on continuum assumption (Red wing is ~5% of continuum)

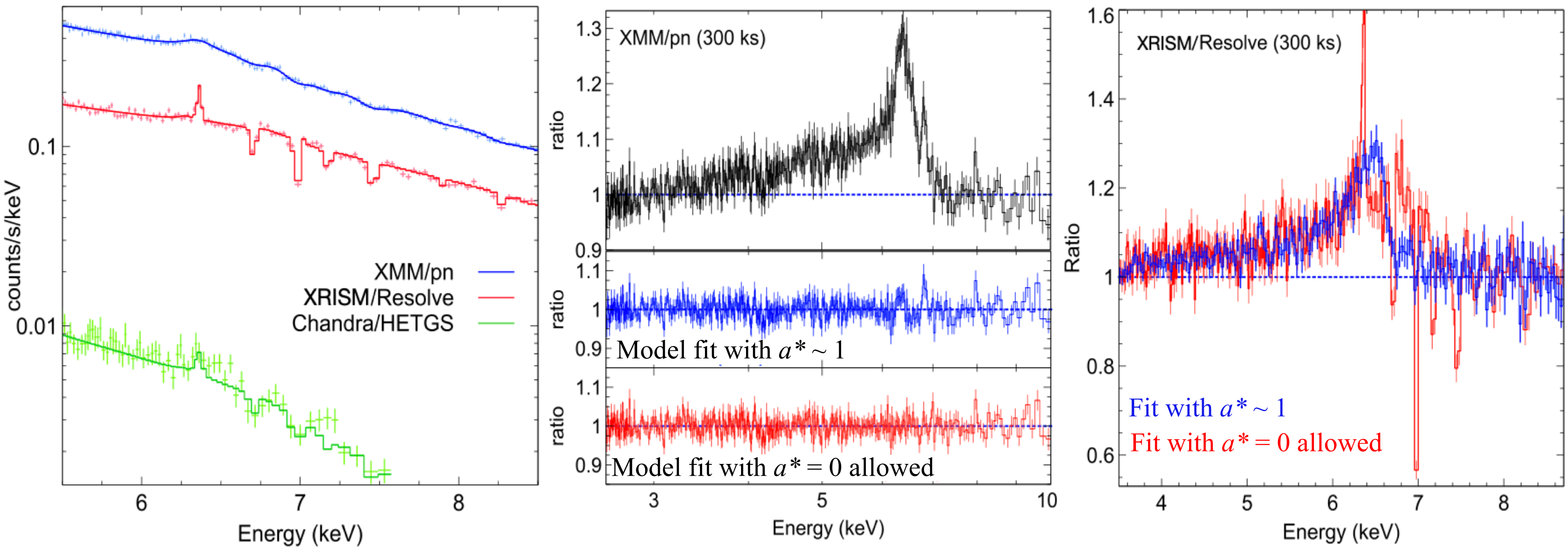
➔ Broad band coverage (and variability) by *XRISM* + other X-ray satellites

② Affected by fine spectral structures such as neutral and ionized Fe lines

➔ High energy resolution (~30 times higher than previous detectors) of *XRISM*

12. MCG-6-30-15 BH Spin Measurement with *XRISM*

XRISM white paper



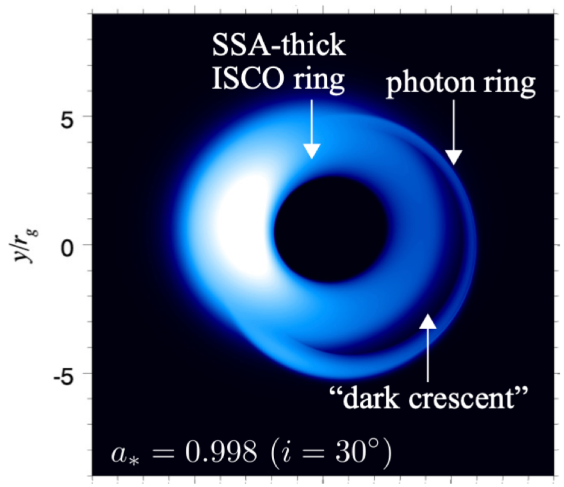
☆ Ionized abs. lines can be quantified with *XRISM*. Continuum can be determined.

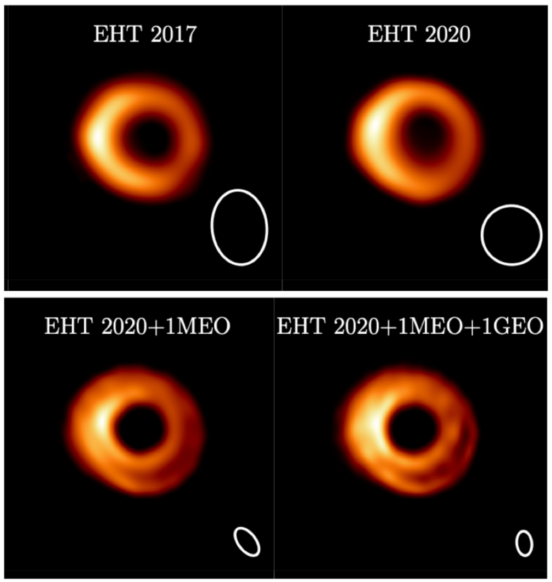
☆ From the Fe-Kα profile after subtraction of the continuum and fine spectral features, we can constrain $a*$ if Fe-Kα is really broad.

☆ Even opposite models with $a* = 0$ and ~1 cannot be distinguished by previous X-ray spectra. *XRISM* will make progress in understandings of BH spin ($a*$)!

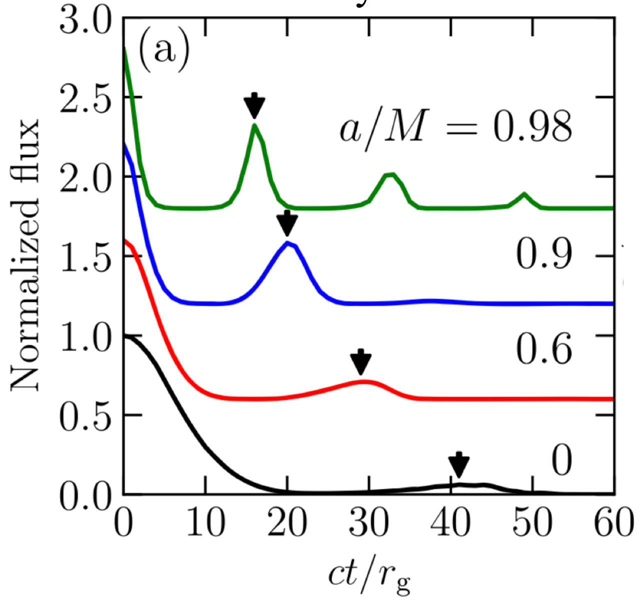
13. Synergy with the EHT

Kawashima+19





Moriyama+19



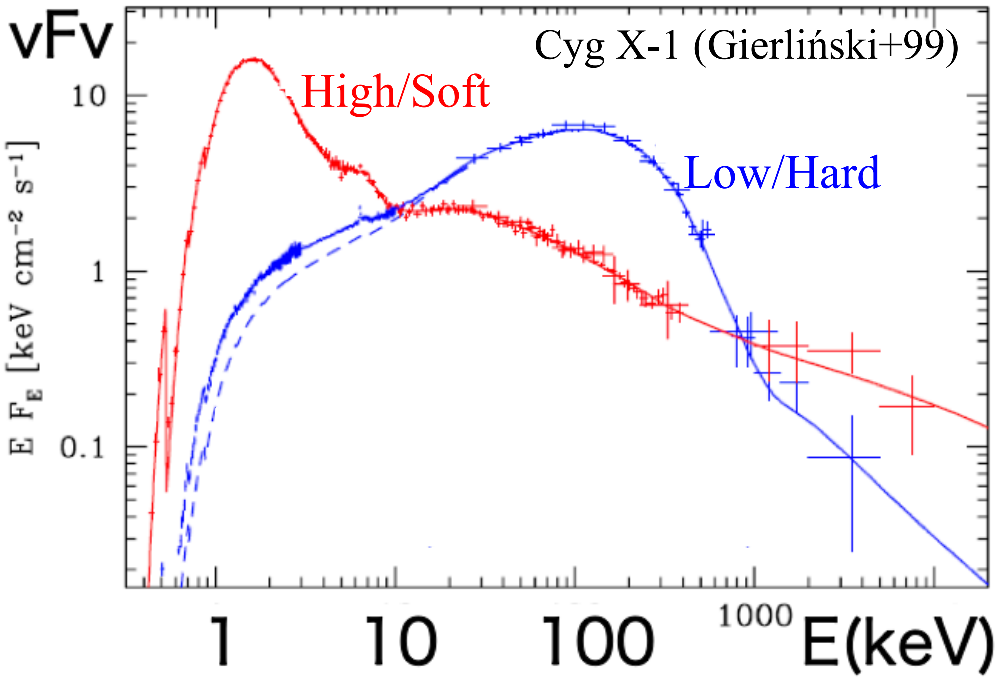
☆ With the EHT, BH spins of M87 (and RLAGNs) can be constrained via images and time variability of vicinity to BHs (Kawashima-san's talk!).

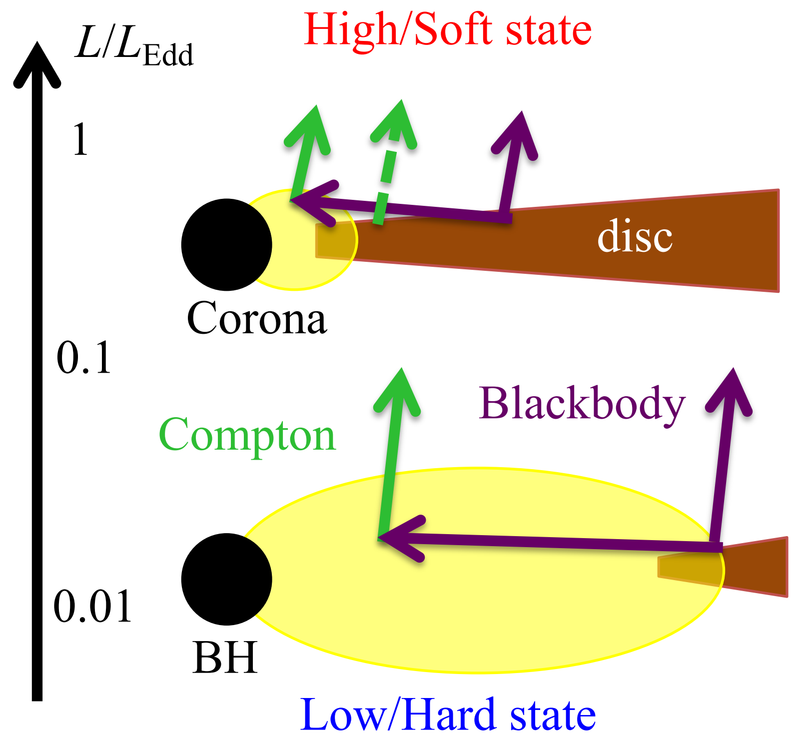
☆ X-ray measurements require highly accreting sources, so X-ray targets should be complementary to EHT targets.

☆ Some radio galaxies and radio-loud NLSy1s can be common targets of the EHT and *XRISM*, e.g., 3C120, 3C111, 1H0323-232, NGC 1275

4. SMBH Accretion State Transition

14. X-ray Spectrum and State Transition of BH Binary

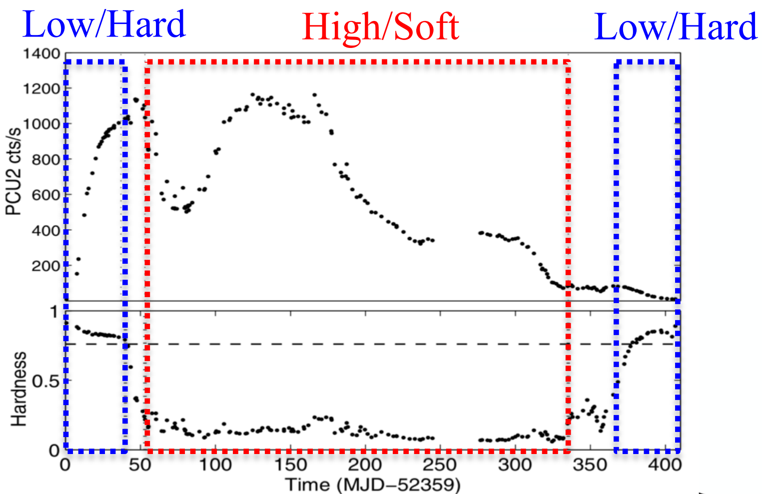




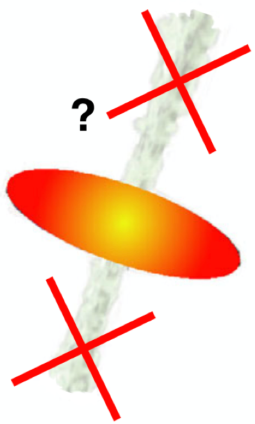
☆ Include disc black body and inverse Compton with high E cutoff at several hundreds keV (e.g., Yamada, HN+13)

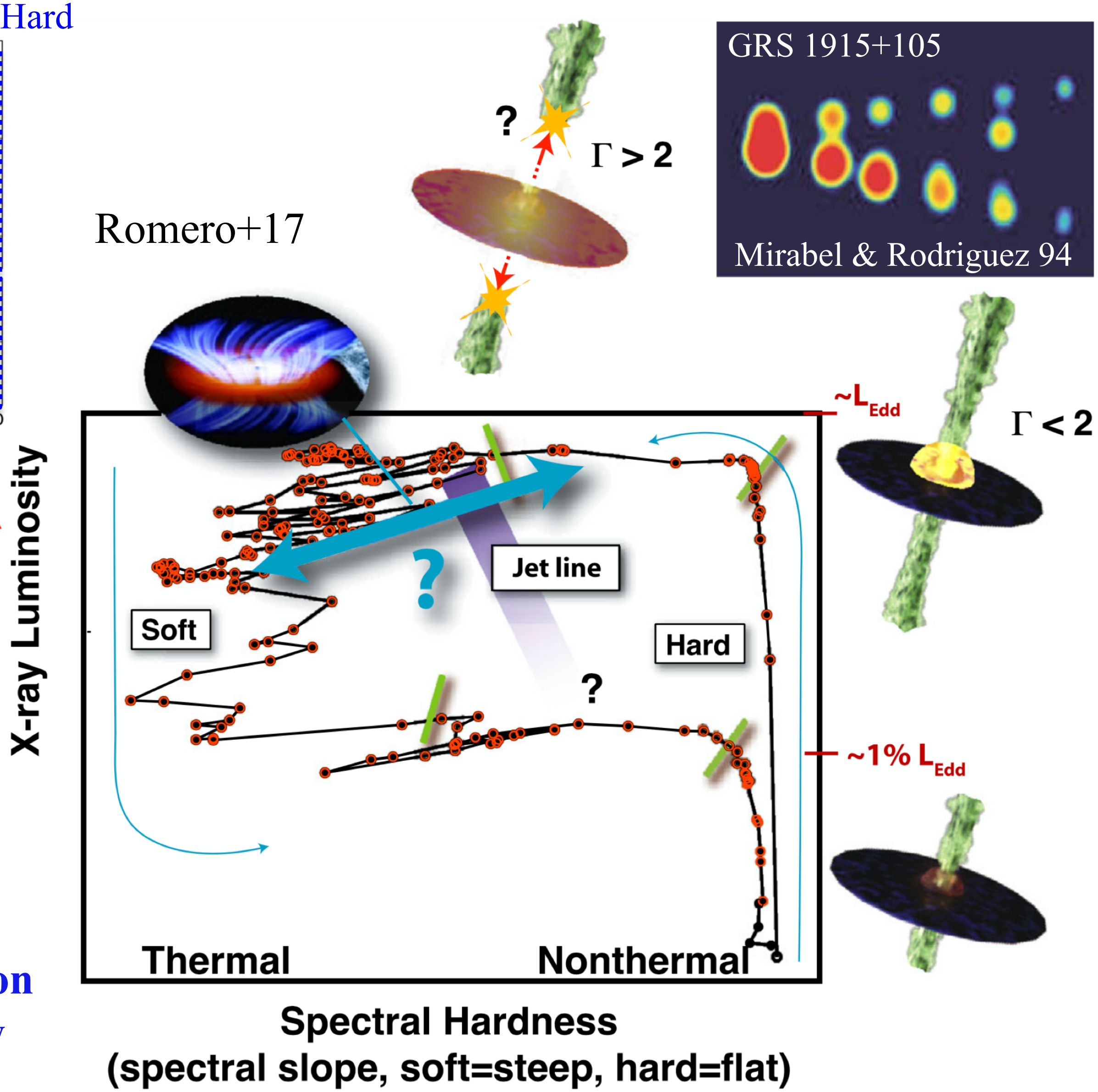
☆ With mass accretion rate, spectral state changes. Disc evaporates into corona, or corona condenses to disc, changing inner radius (e.g., Done+07)

15. Accretion State Transition and Jet Activity



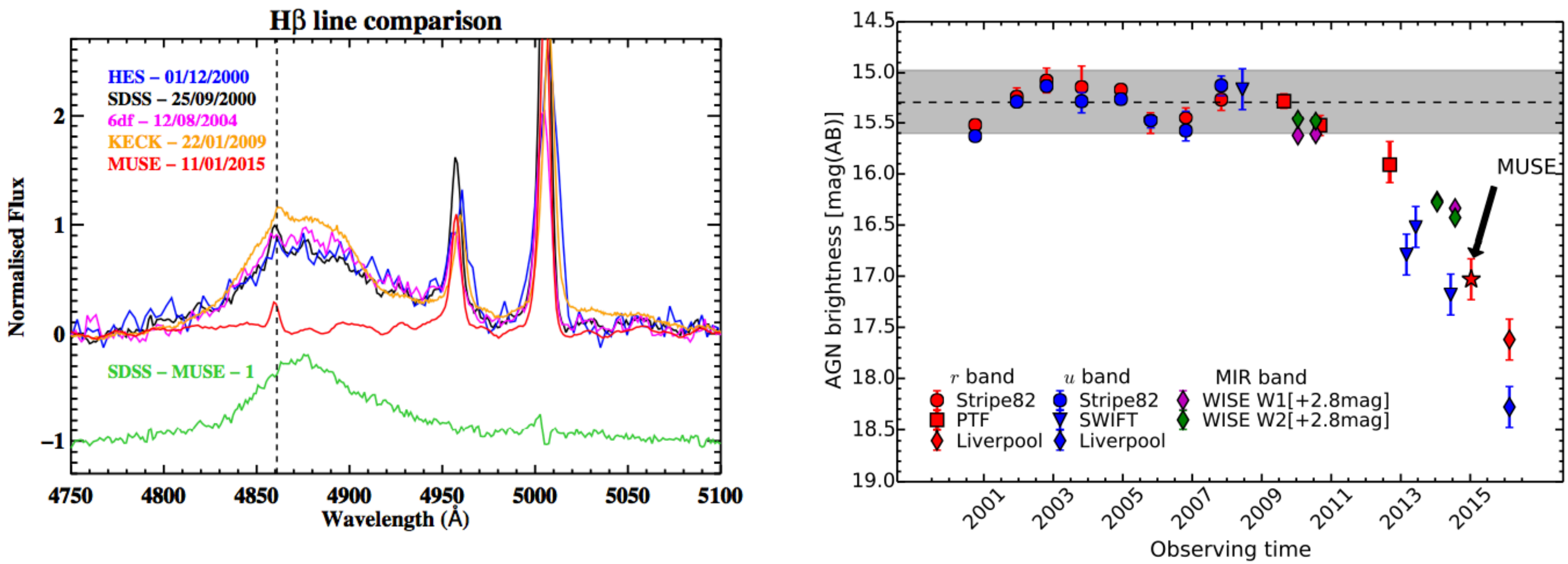
GX 339-4 (Belloni+05)





No clear results of state transition in AGNs (Believed to NOT show because of too long timescale).

16. Changing-Look AGN



Changing-Look AGN Mrk 1018 (McElroy+16)

☆ Some AGNs change their types defined by broad emission lines in ~10 years (type 1 → 1.9 or 1.9 → 1) ➔ "Changing-Look AGNs (CLAGNs)"

☆ Optical surveys discovered hundreds CLAGNs (Macleod+16, 19, Yang+18)

➔ **What happens in accretion flow?**

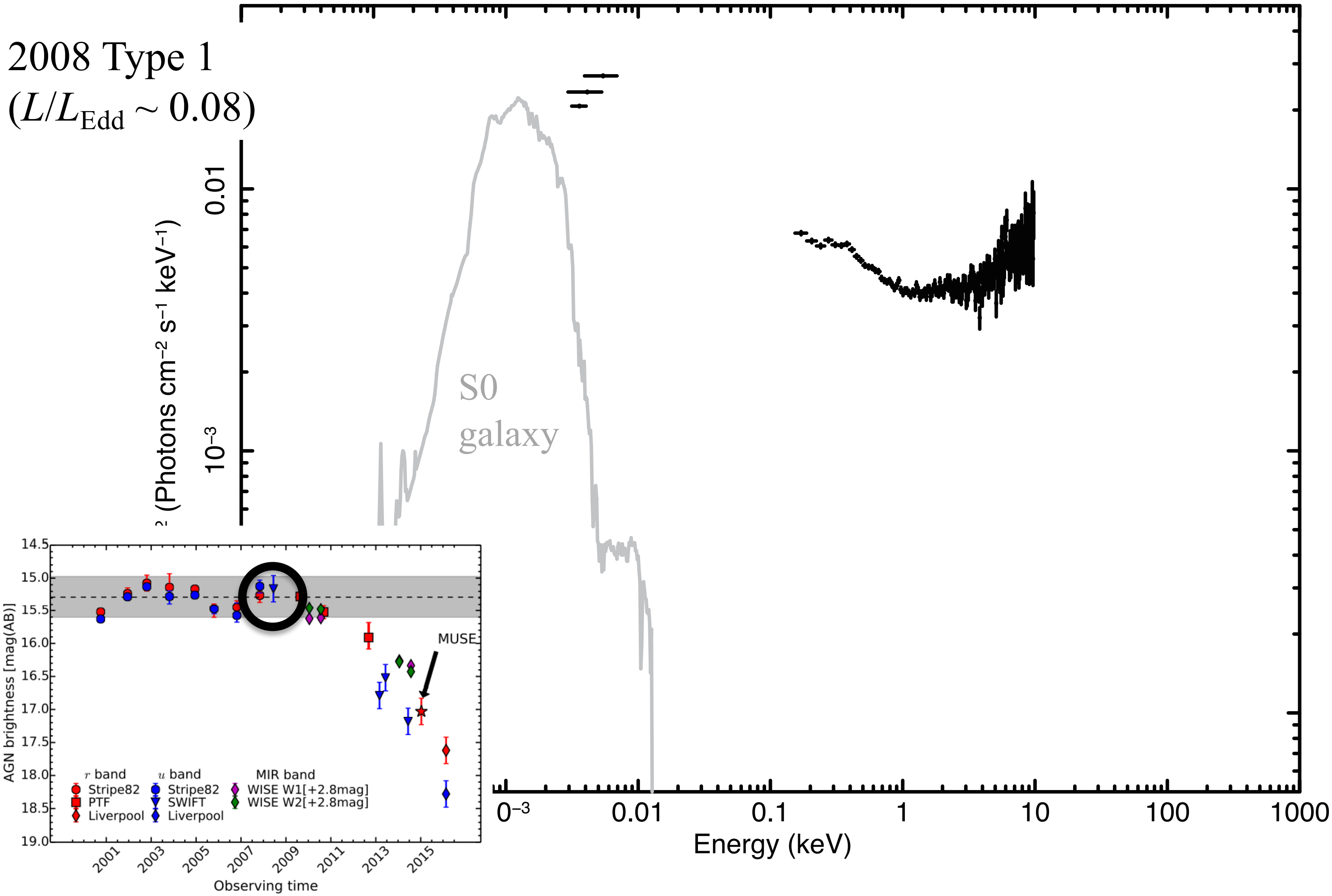
☆ In this study, we focused on CLAGN spectral change in optical, UV, and X-ray

17. Optical/UV/X-ray Spectral Change

(HN & Done 18)

XMM-Newton/OM & EPIC-PN de-absorbed spectra

2008 Type 1
($L/L_{\rm Edd} \sim 0.08$)

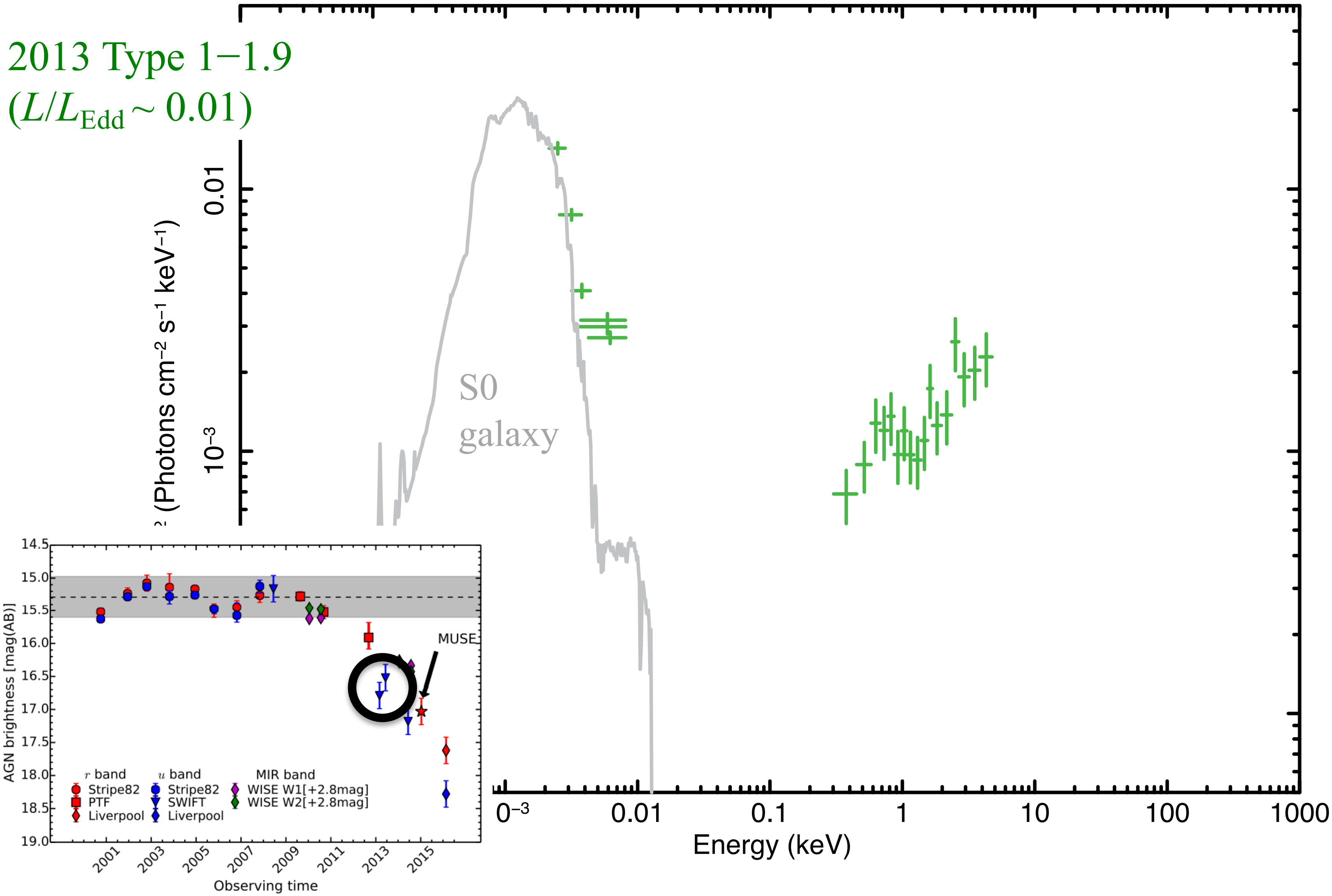


17. Optical/UV/X-ray Spectral Change

(HN & Done 18)

Swift/UVOT & XRT de-absorbed spectra

2013 Type 1−1.9
($L/L_{\rm Edd} \sim 0.01$)

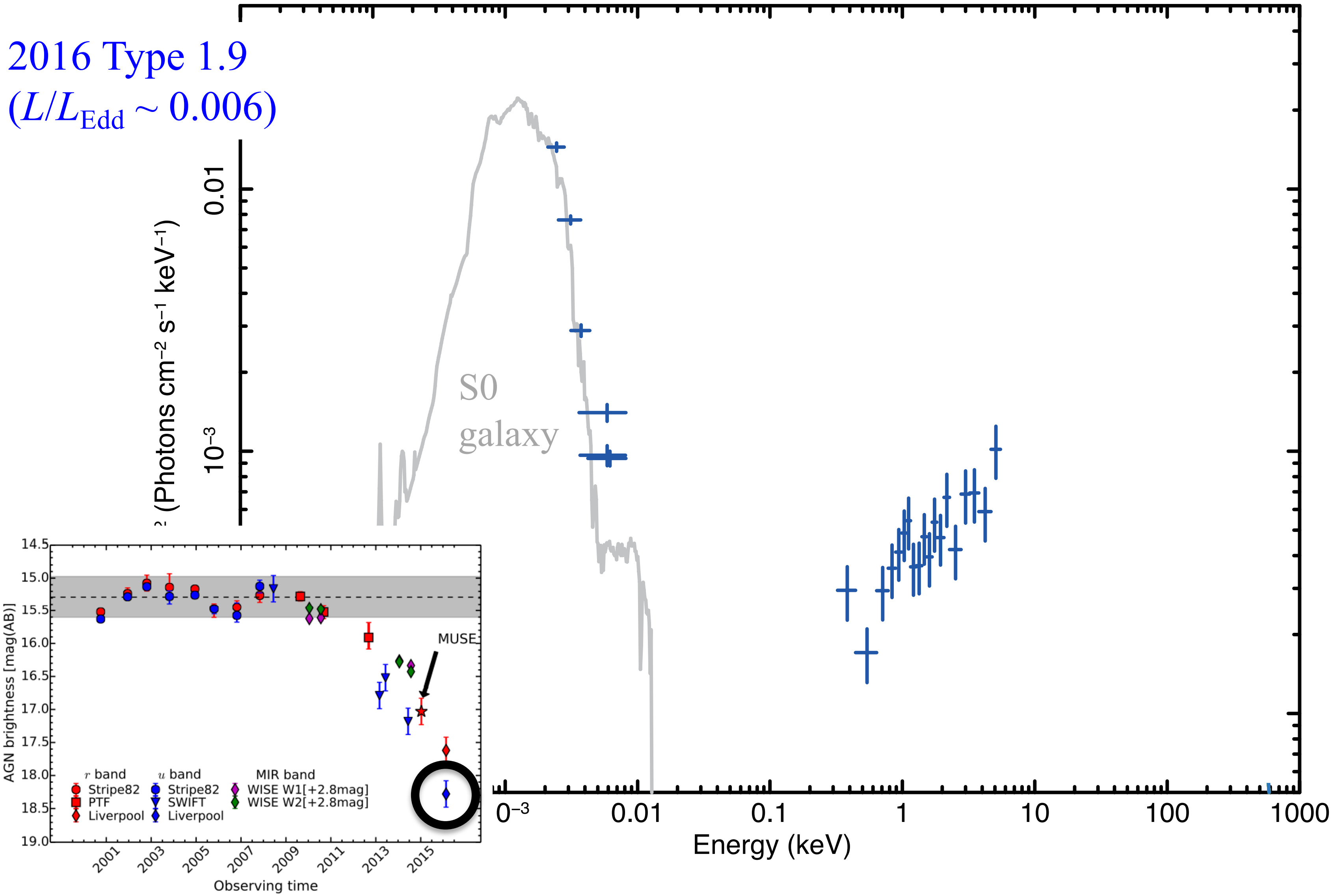


17. Optical/UV/X-ray Spectral Change

(HN & Done 18)

Swift/UVOT & XRT de-absorbed spectra

2016 Type 1.9
($L/L_{\rm Edd}$ ~ 0.006)

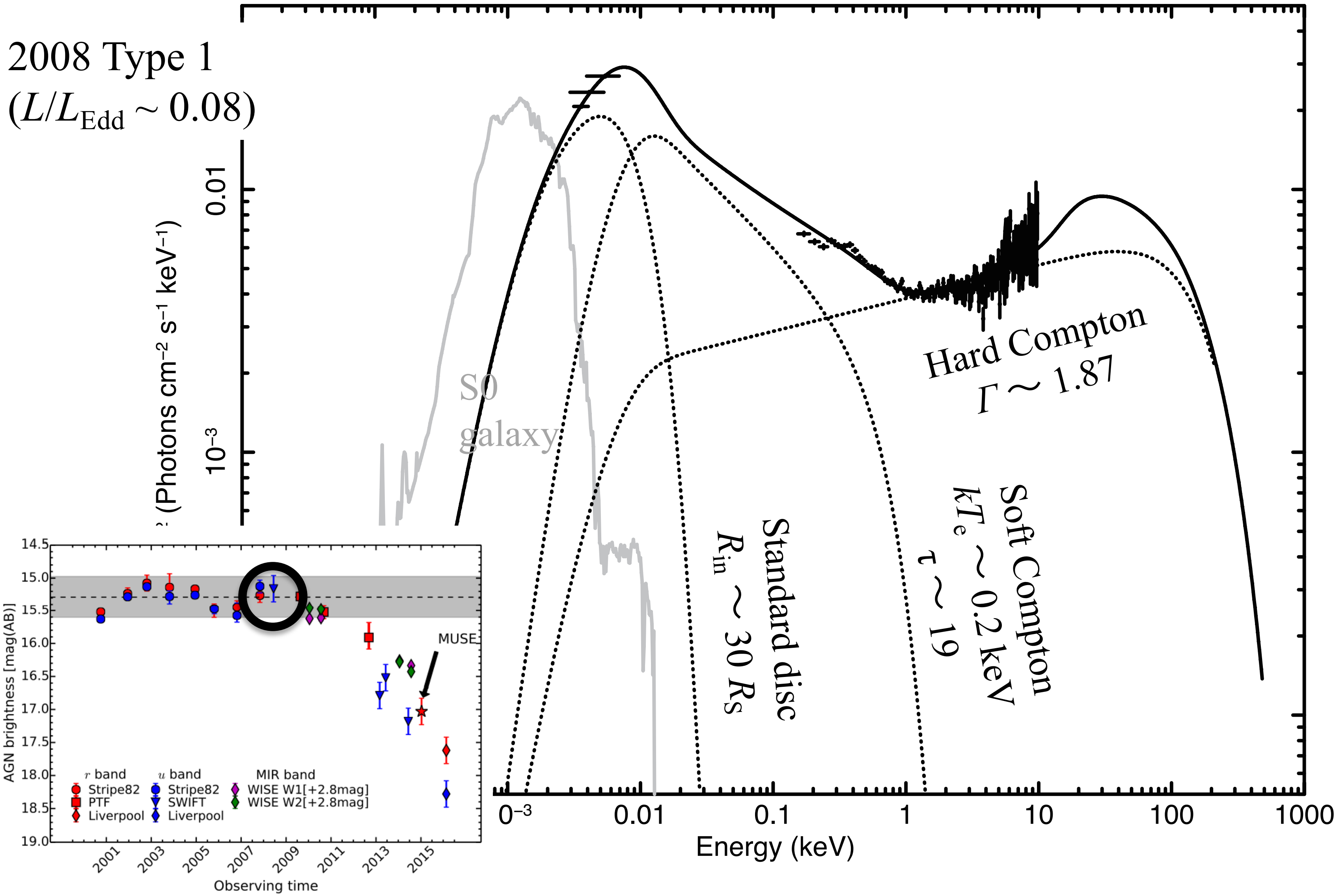


18. DiscBB + Soft excess + Hard Compton Model

(HN & Done 18)

XMM-Newton/OM & EPIC-PN de-absorbed spectra

2008 Type 1
($L/L_{\rm Edd} \sim 0.08$)

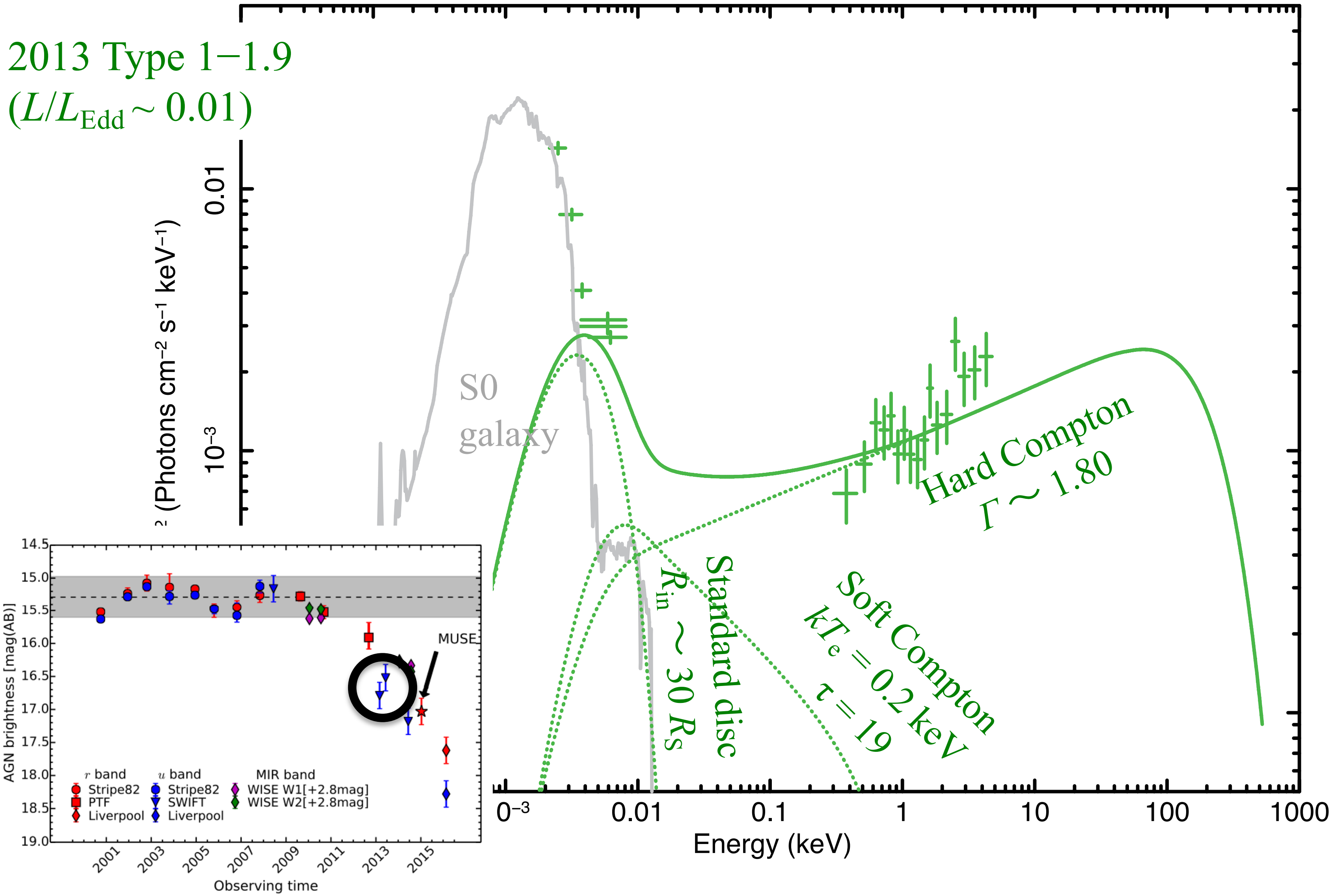


18. DiscBB + Soft excess + Hard Compton Model

(HN & Done 18)

Swift/UVOT & XRT de-absorbed spectra

2013 Type 1−1.9
($L/L_{\rm Edd} \sim 0.01$)

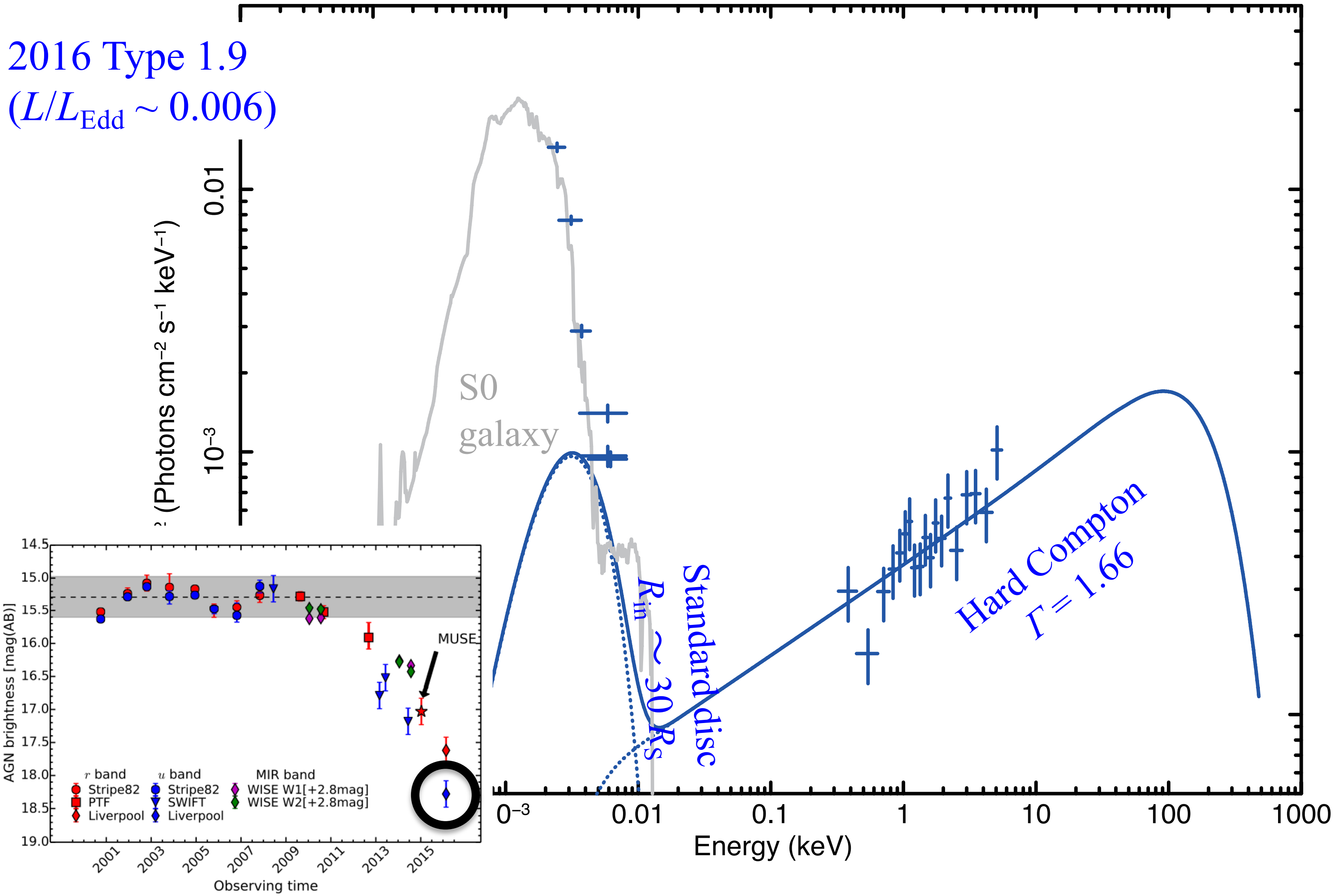


18. DiscBB + Soft excess + Hard Compton Model

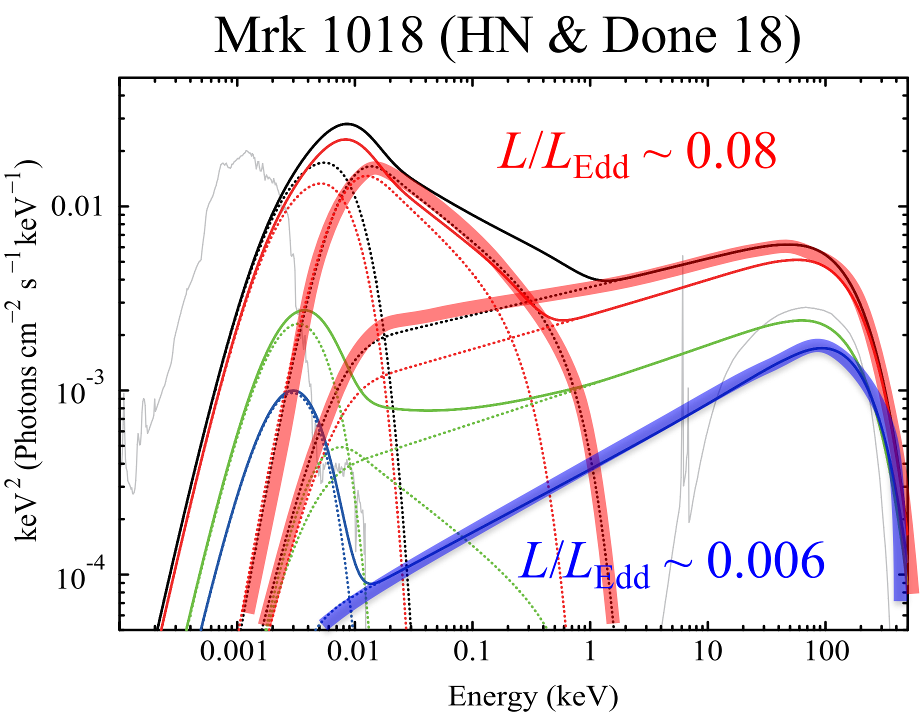
(HN & Done 18)

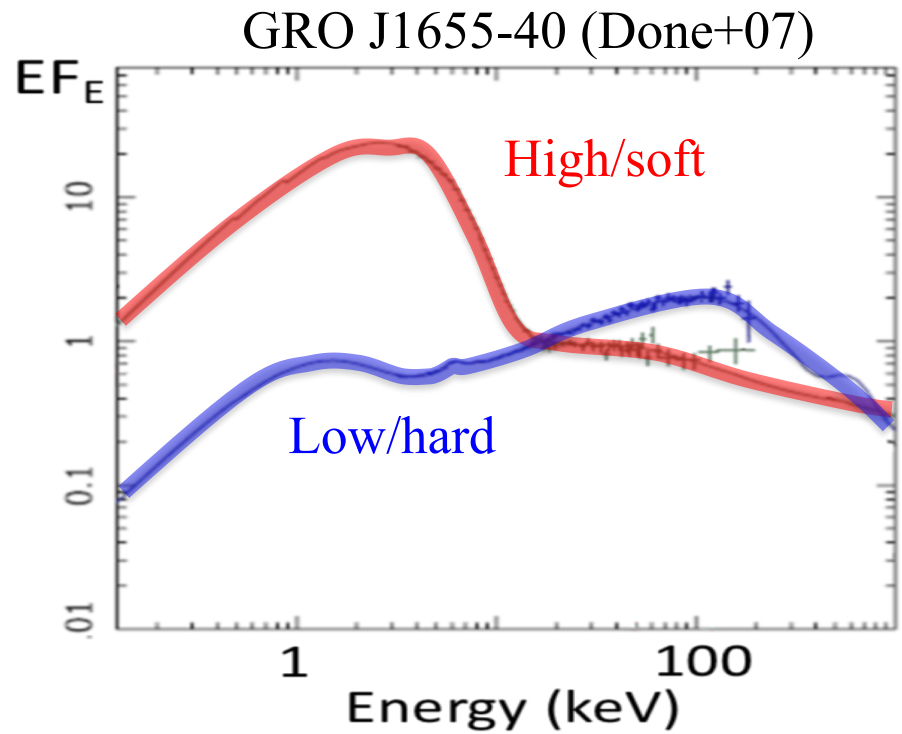
Swift/UVOT & XRT de-absorbed spectra

2016 Type 1.9
($L/L_{\mathrm{Edd}} \sim 0.006$)



19. State Transition in AGN





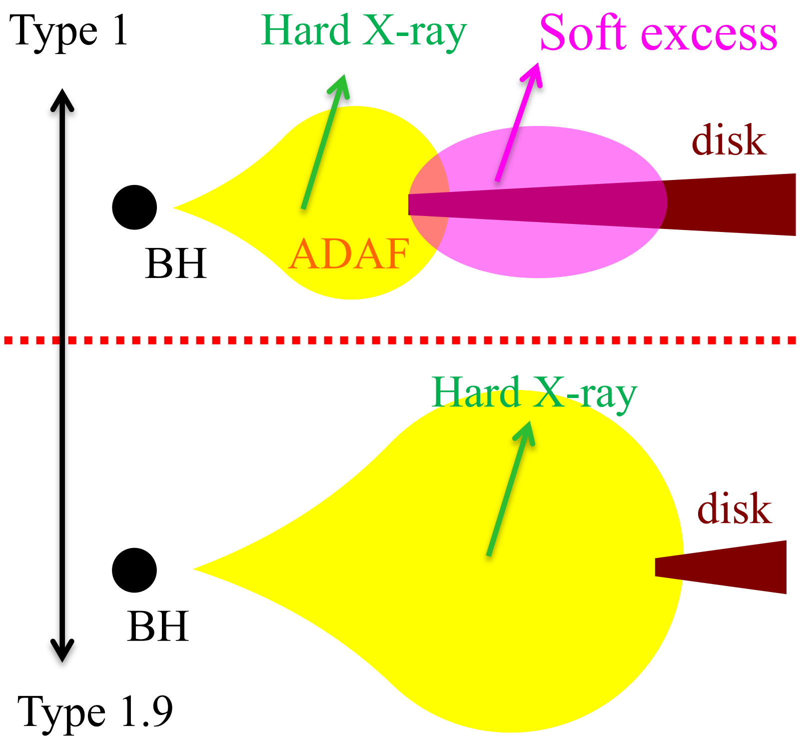
☆ SED change of CLAGN closely resembles that of BHB state transition

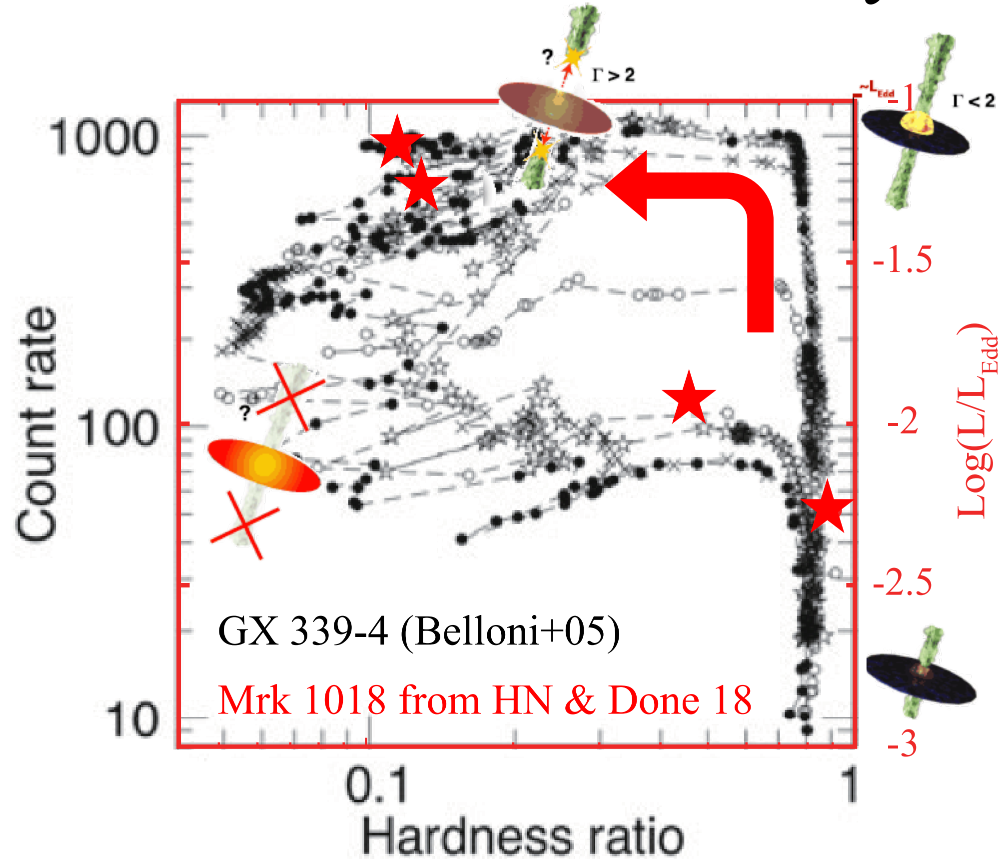
➔ State transition in SMBH accretion! (also see Igarashi-san's talk)

☆ Soft excess emission which contains most of UV photons powering BLR drastically changes its flux in the state transition

➔ The state transition causes changing-look phenomenon

20. AGN State Transition & Predicted Jet Activity





☆ State Transition from type 1.9 to 1 corresponds to that from the low/hard to high/soft state in BHBs in which the $\Gamma > 2$ jet ejections are observed!

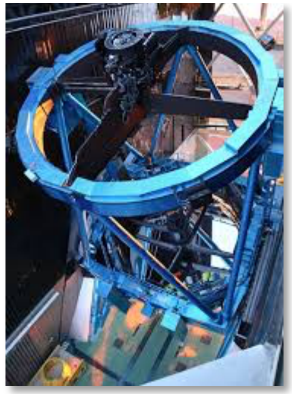
☆ The BLR and torus geometry can vary, changing the narrow Fe-Kα profile!

☆ **Why don't we propose and trigger ToO obs. of such turn-on (type 1.9 to 1) CLAGNs by VLBIs and *XRISM*?** (Mrk 590, NGC 3516, NGC 4151, …)

21. CLAGNs in Time-Domain MWL Astronomy Era

Optical and X-ray All-sky survey of CLAGNs

Subaru/HSC



LSST

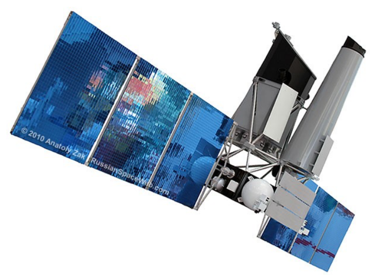
Tomo-e Gozen

ZTF

MAXI

ASSA-SN

eROSITA



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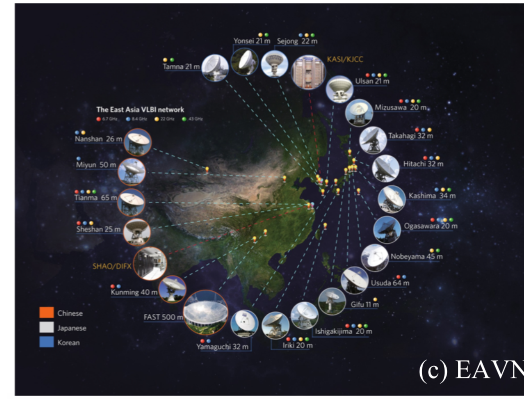

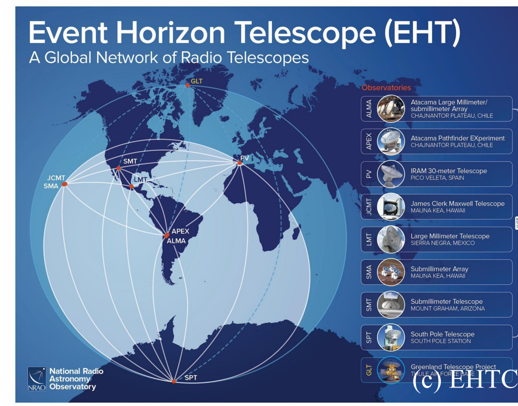

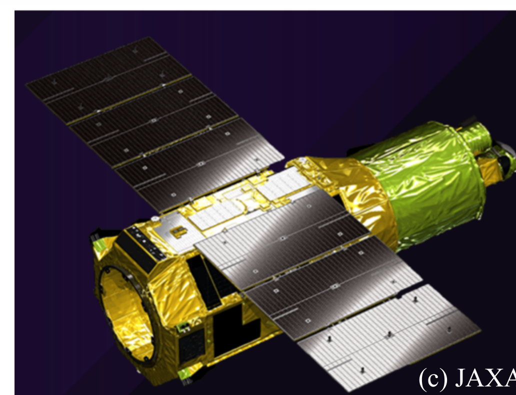

22. Summary

☆ The next X-ray satellite *XRISM* will be launched in 2022 JFY. The X-ray microcalorimeter achieves the high E resolution of $\Delta E/E$ = 5 eV/6 keV.

☆ With the precise X-ray spectroscopy by *XRISM*, we can constrain e.g., AGN structures, UFO features, and SMBH spins in radio-loud sources, and compare them with radio-quiet sources.

☆ CLAGNs, which change their AGN types in months−years, are probably caused by state transitions of SMBH accretion flows like the high/soft−low/hard transition in Galactic BHBs.

☆ CLAGNs are key to understand the jet activity change following mass accretion state change, and ToO observations of CLAGNs with VLBIs and *XRISM* may provide their evidences.

Thank you very much for your attentions!