

X-ray Winds In Nearby-to-distant Galaxies (X-WING) - I: Legacy Surveys of Galaxies with Warm Absorbers and Ultrafast Outflows in $z \sim 0-4$

Satoshi Yamada (RIKEN)

Collaborators :

Taiki, Kawamuro (RIKEN), Misaki Mizumoto (U. of Teacher Education Fukuoka), Hirofumi, Noda (Osaka U.), Claudio, Ricci (UDP), Shoji, Ogawa (ISAS/JAXA), Yoshihiro, Ueda (Kyoto U.), Teruaki, Enoto (Kyoto U.), Mitsuru, Kokubo (NAOJ), Takeo, Minezaki, Hiroaki, Sameshima, Takashi, Horiuchi, and Shoichiro, Mizukoshi (U. of Tokyo)

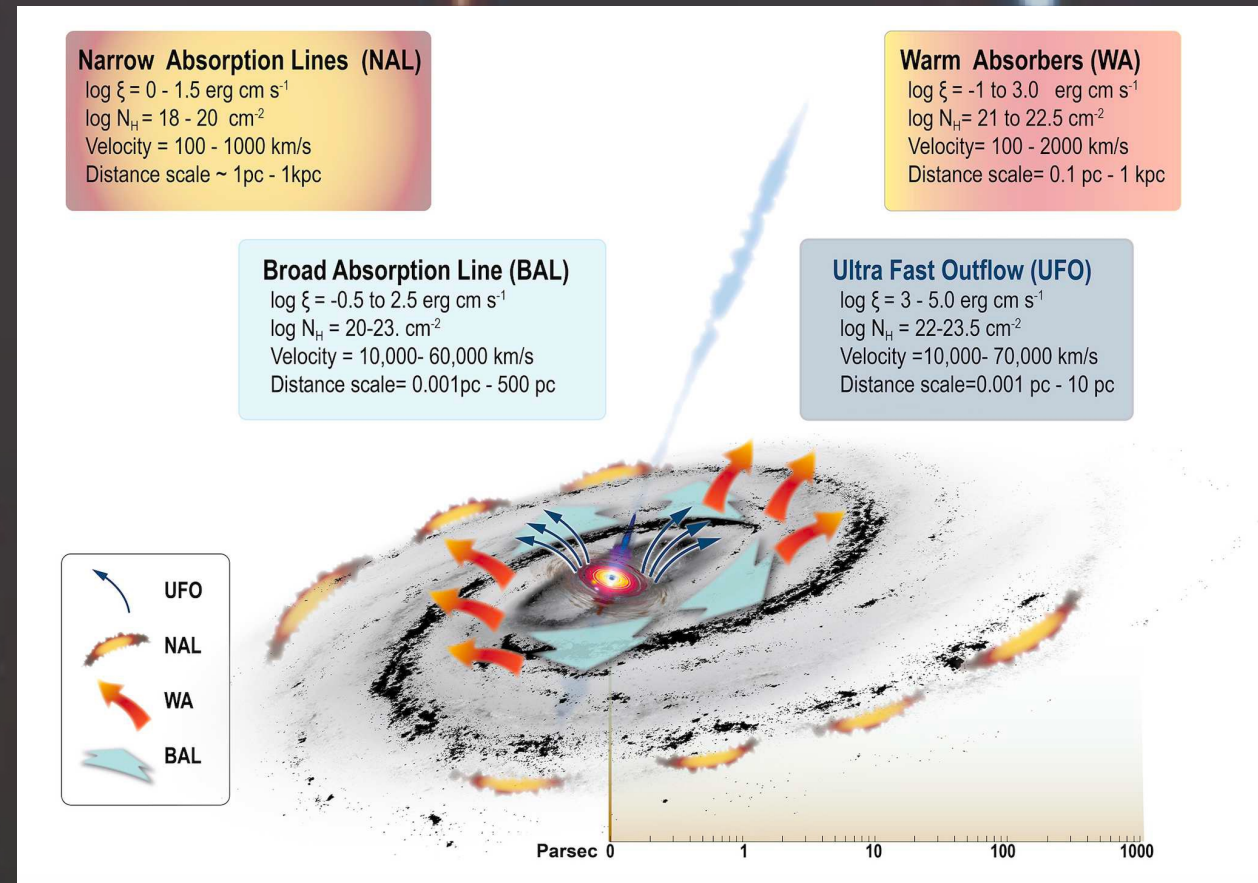
AGN Feedback

- Active Galactic Nuclei (AGNs) are an important population for understanding
 - Supermassive black hole (SMBH) growth
 - AGN feedback onto their host galaxies
- AGN feedback: a key role in explaining the strong connection between SMBHs and host galaxies (e.g. $M-\sigma$ relation)
- However, **the multi-scale structure of outflows** makes it difficult to unveil the feedback effect.



Multiphase Outflows

- The AGN outflows are composed of diverse components (e.g. Laha+21, Nature)
 - **X-ray**
 - **Ultrafast outflow (UFO; $v \sim 0.1-0.3c$)**
 - **Warm absorber (WA; $v \sim 100-2000$ km/s)**
 - UV: broad/narrow absorption line (BAL/NAL)
 - Optical: ionized/neutral outflow
 - IR: hot ionized/mol., dusty, cold mol.
 - Submm/radio: cold mol. (+ relativistic jet)
- What is its overall stratified structure?
(e.g., Velocities, locations, and outflow rates)



What is X-WING?

SH **You**

Hi, ChatGPT. What is X-WING?

What is X-WING?

SH

You

Hi, ChatGPT. What is X-WING?



ChatGPT

X-WING typically refers to a type of starfighter in the fictional Star Wars universe. The Incom T-65 X-wing starfighter is a versatile and iconic spacecraft used by the Rebel Alliance and later the New Republic in their fight against the Galactic Empire. X-WINGS are known for their agility, speed, and ability to engage both atmospheric and space combat.



What is X-WING?

- X-WING (= X-ray Winds in Nearby-to-distant Galaxies)
 - Database of multiphase outflows for AGNs with X-ray winds

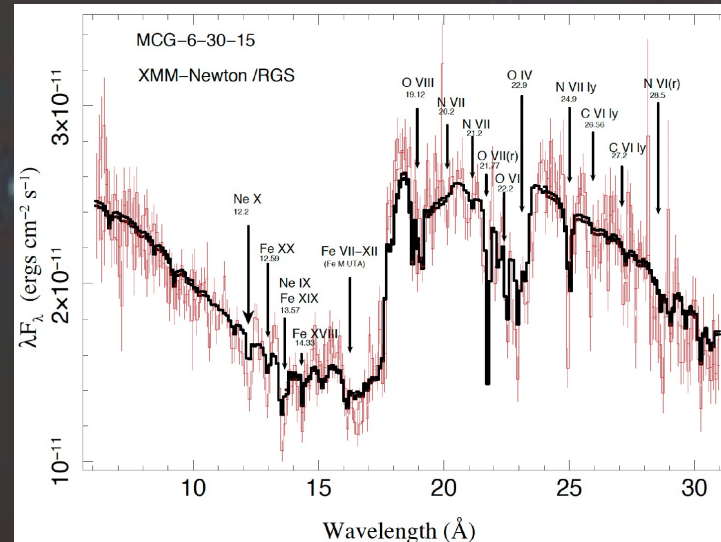


What is X-WING?

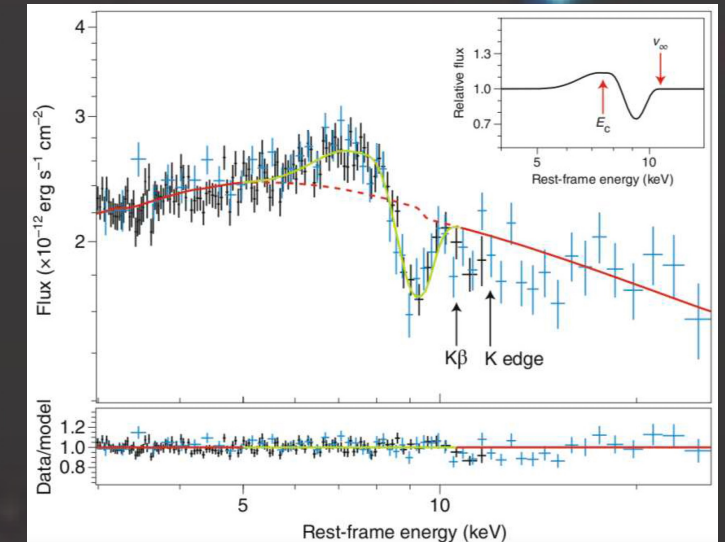
- X-WING (= X-ray Winds in Nearby-to-distant Galaxies)
 - Database of multiphase outflows for AGNs with X-ray winds
- X-ray Winds
 - Ultrafast outflows (UFOs): **the closest winds to the SMBH !!!**
 - highly ionized (\Rightarrow Fe XXV/XXVI)
 - High-speed winds ($\sim 0.1-0.3c$)
 - Warm absorbers (WAs)
 - lower ionized winds
 - Slower winds ($\sim 100-2000$ km/s)



WA (Laha+21)

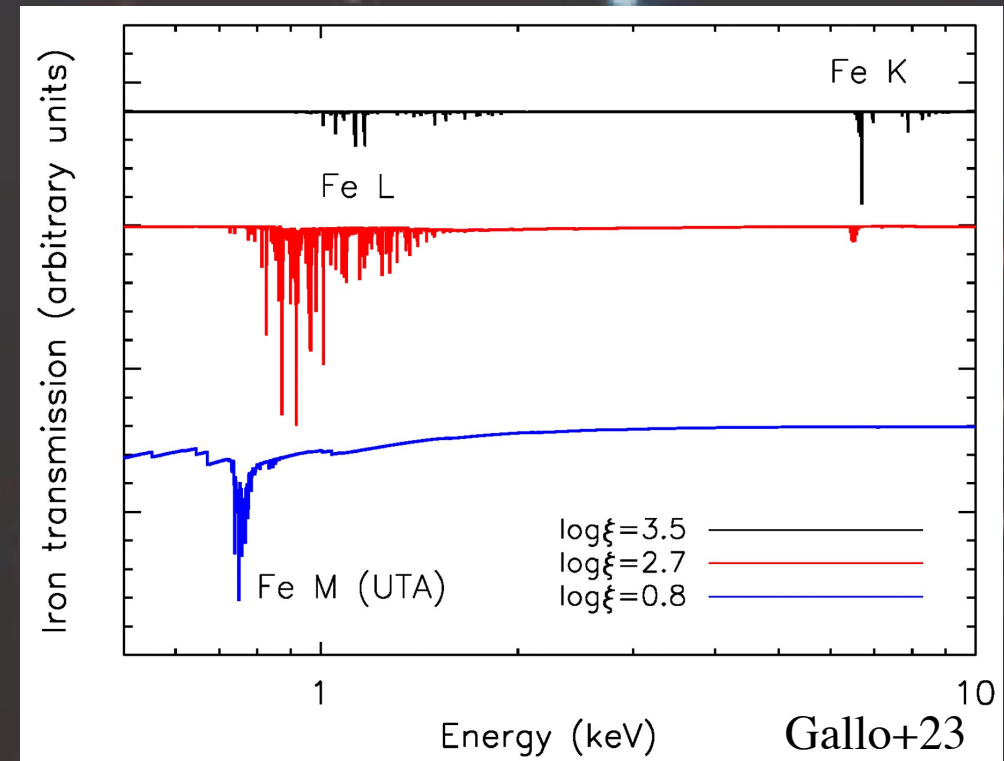
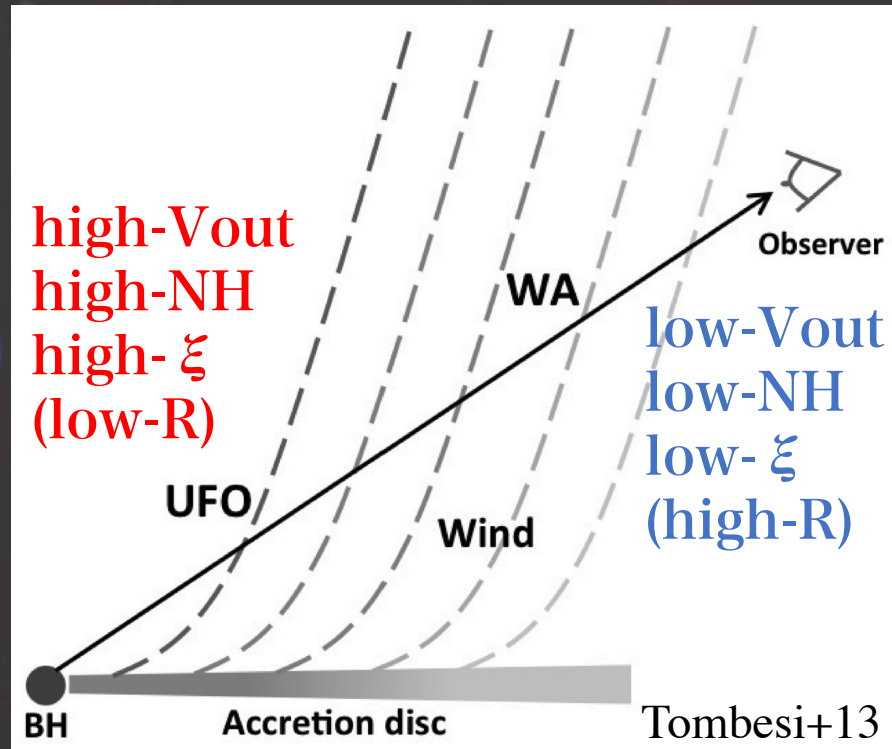


UFO (Nardini+15)



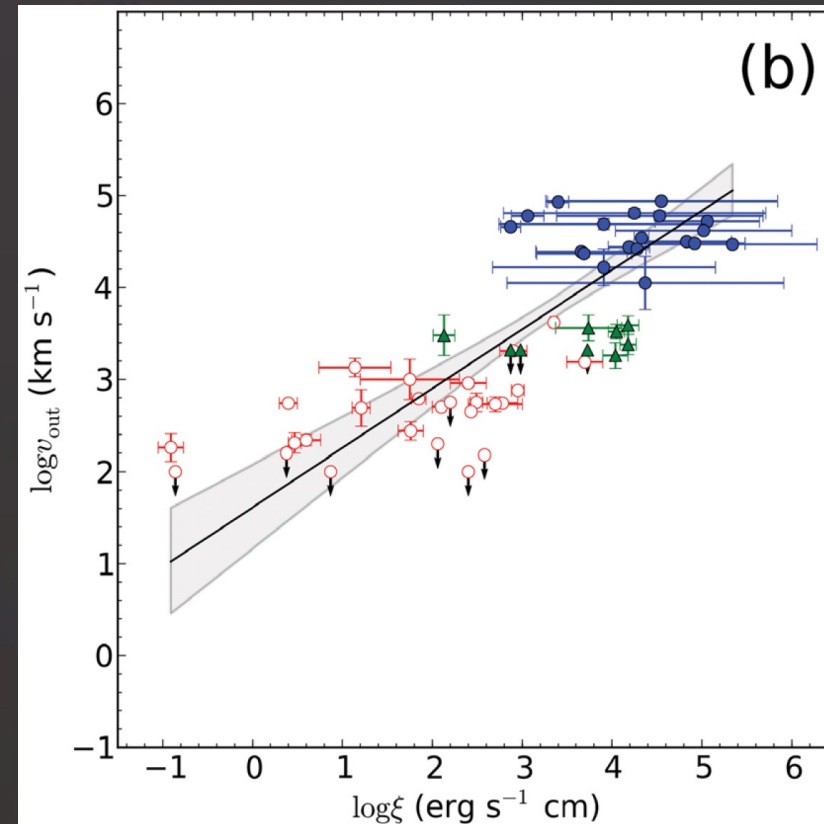
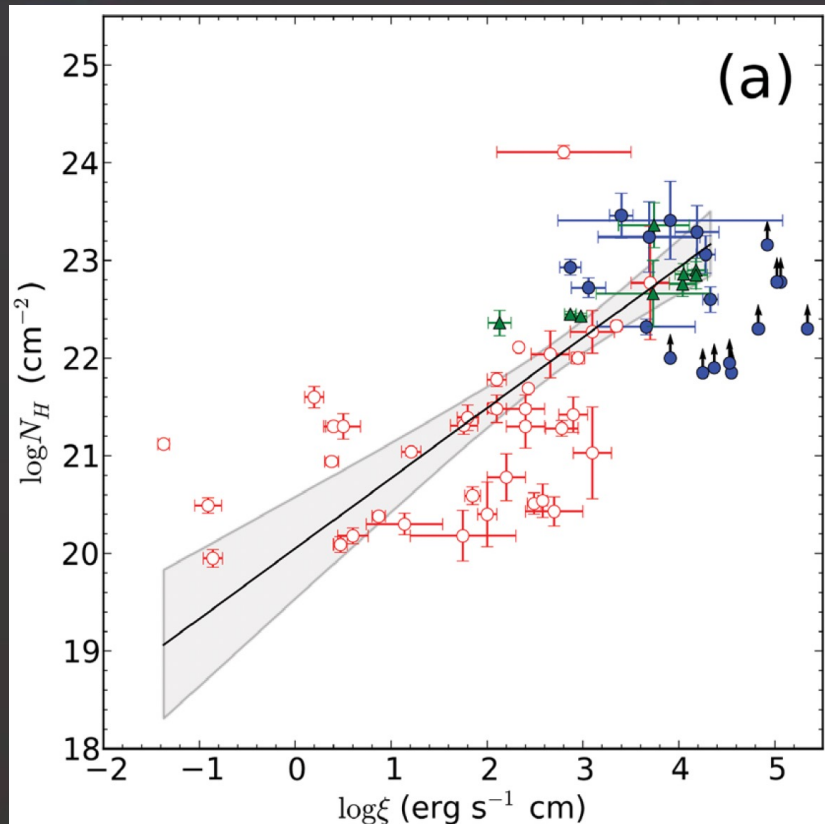
Basic Parameters of X-ray Winds

- Outflow velocity (V_{out}), hydrogen column density (NH), and ionized parameter (ξ)
 - $\xi = L_{ion}/nR^2$, where L_{ion} is ionized luminosity, n is density, and R is the distance.
 - **UFOs show high ξ (or small R)** => detected by Fe XXV/XXVI absorption lines.
 - **Warm absorbers show low ξ (or large R)** => detected in the soft X-ray band.



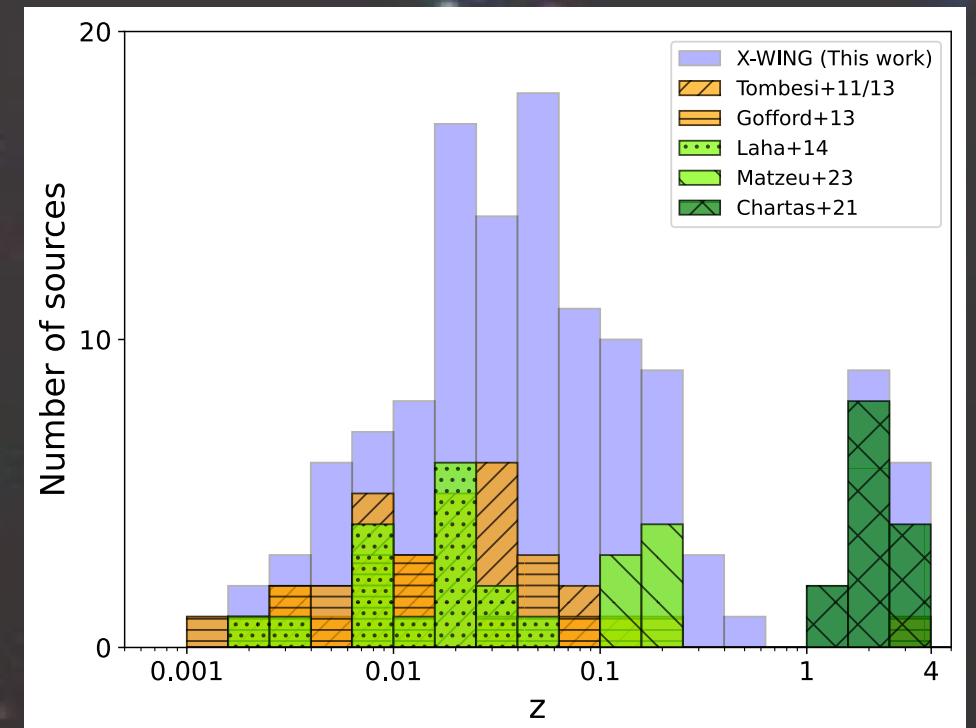
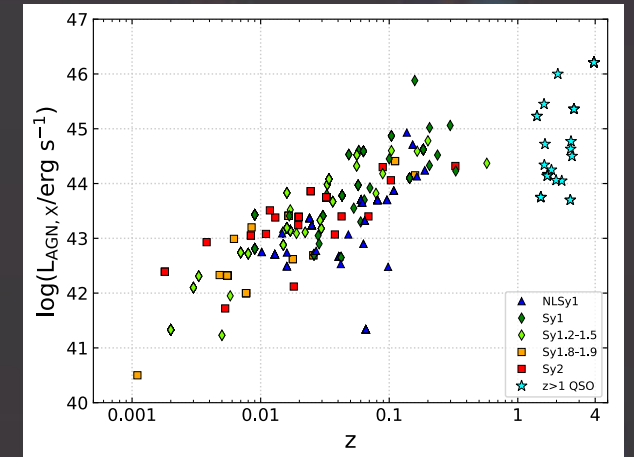
Surveys of X-ray Winds

- Tombesi+13: UFOs and warm absorbers
 - Positive correlations: e.g., $\log \xi - \log N_H$, $\log \xi - \log v_{\text{out}}$
 - However, sample/detection biases should be discussed. **=> Let's see the X-WING database!**



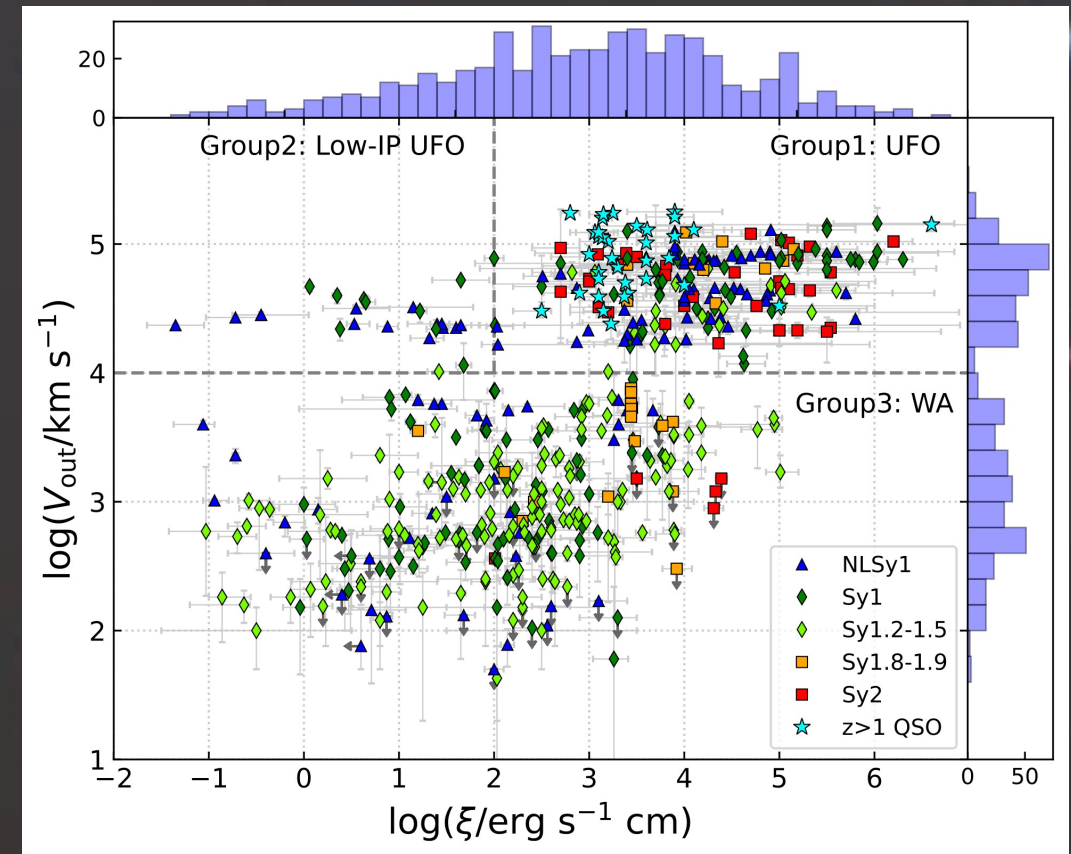
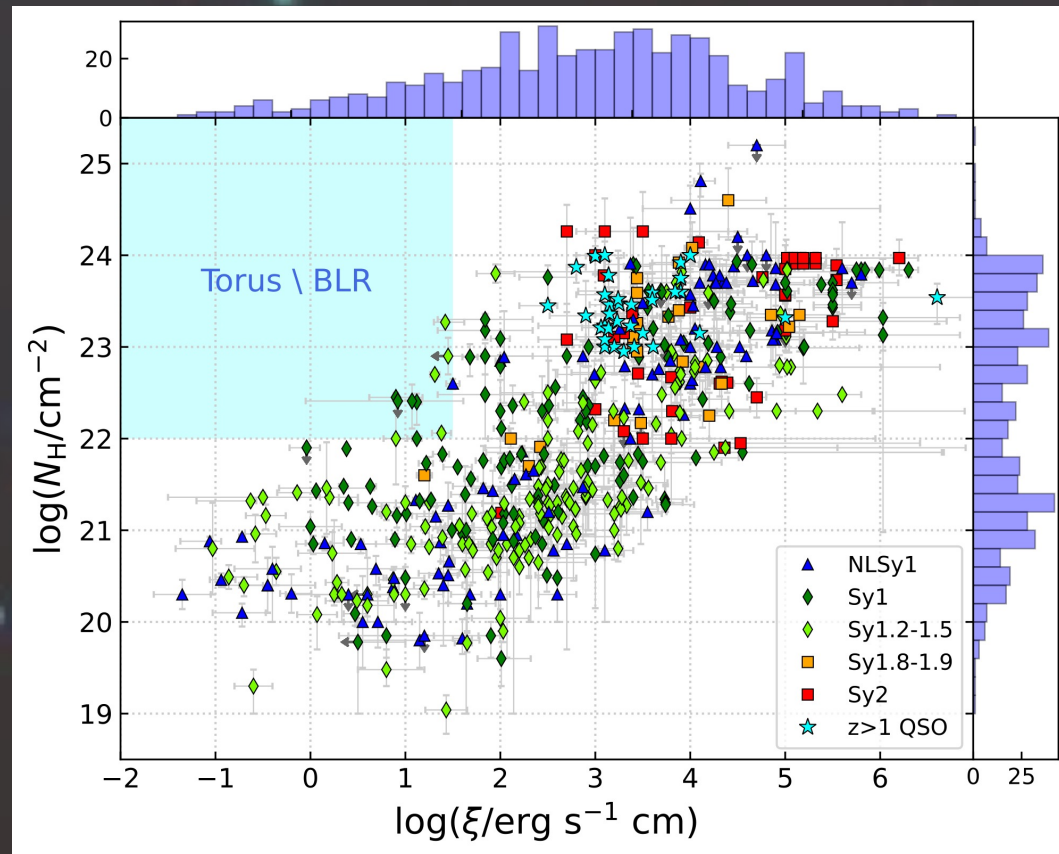
X-WING Database (Yamada+, in prep.)

- The database of the X-ray wind activities measured in previous studies.
- Utilized instruments
 - WA: Chandra/HETGs, LETGs, XMM/RGS
 - UFO: Chandra/ACIS, XMM/pn, MOS, NuSTAR, Swift/XRT, Suzaku/XIS
- **Sample: ~130 AGNs** with UFOs and/or warm absorbers
 - **reported from ~1999 to 2023 (~240 papers)!!**
 - Tombesi+11,12,13, Gofford+13,15, Laha+14,16, etc.
- >300 OBSIDs, ~540 X-ray outflows (UFO+WA)
 - Duplicated reports are merged.
 - All errors and upper limits: 90% confidence level



X-WING: Distributions of V_{out} , N_{H} , and ξ

- V_{out} , N_{H} , and ξ distributions are classified by optical types (\sim inclination?).
 - We reduce the sample biases as much as possible.
 - Not just linear relations (with large dispersion) \Rightarrow **Verification of the detection biases**

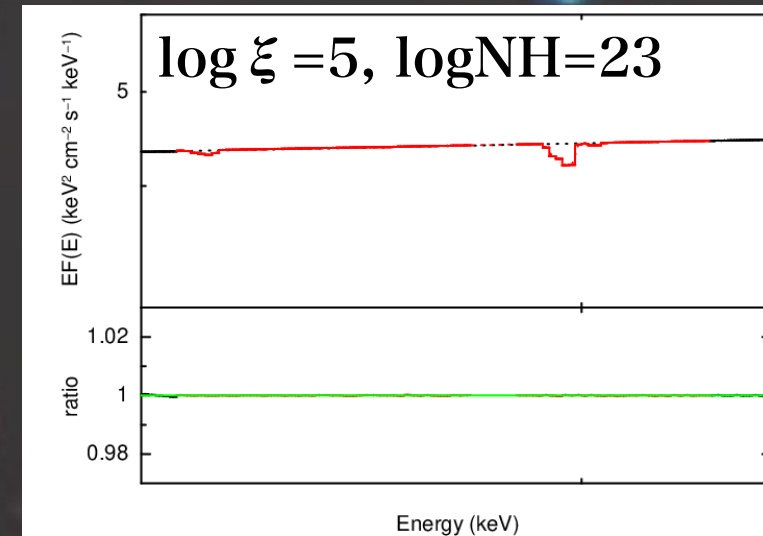
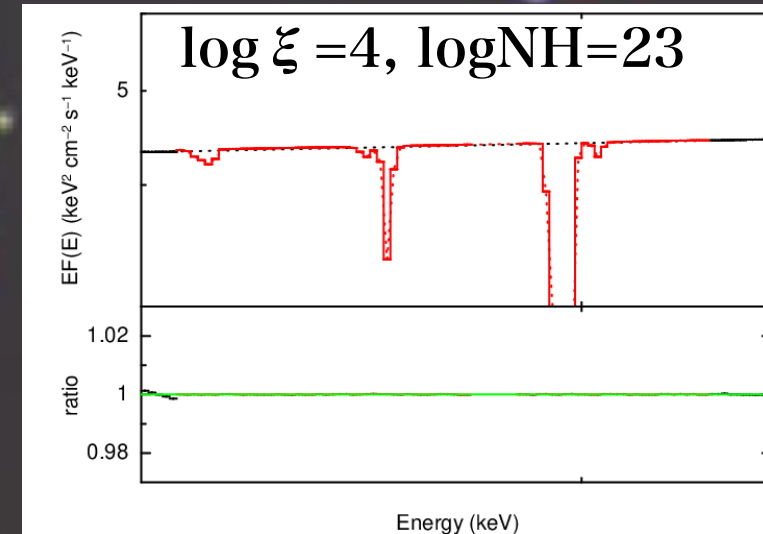


Detection Limits of UFOs

- Signal-to-noise (S/N) ratio of the line detection:

$$S/N = \sqrt{A(E) t F(E)} \frac{W}{\sqrt{\max(\Delta E, W)}}$$

- $A(E)$ is effective area, t is exposure time, and $F(E)$ is photon flux.
- **W is the equivalent width (EW)**, while ΔE is the energy resolution.
(see ASTRO-H white paper, Kaastra+14)
- We simulate the EWs of individual Fe XXV/XXVI lines with XSTAR.
 - $\log \xi = 3-5$ and $\log \text{NH} = 20-24$
=> The detection limits of UFOs.

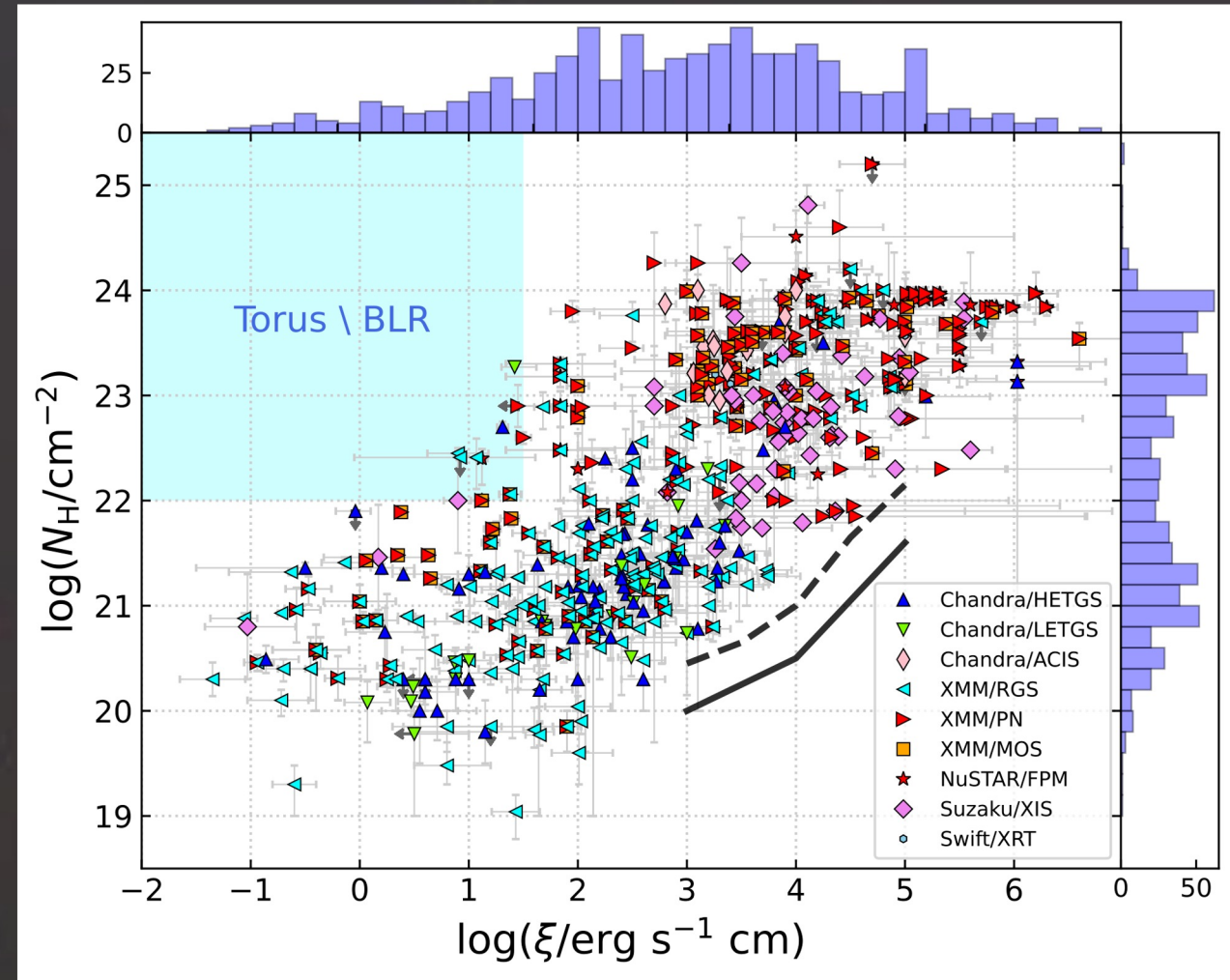


$\log \xi$ vs. $\log N_H$: Linear Relation or Detection Bias?

- $\log \xi$ vs. $\log N_H$ classified by utilized instruments.
- The case of NGC 4151 (an early release target)
 - Flux(2-10 keV) = $5e-11$ erg/s/cm², $t = 180$ ks
 - XMM/pn (dashed) and XRISM (GVO; solid)
- High- ξ & Low- N_H (bottom-right side):
 - The XMM limit is consistent with the data!!

\Rightarrow Detection bias is strongly affected!!

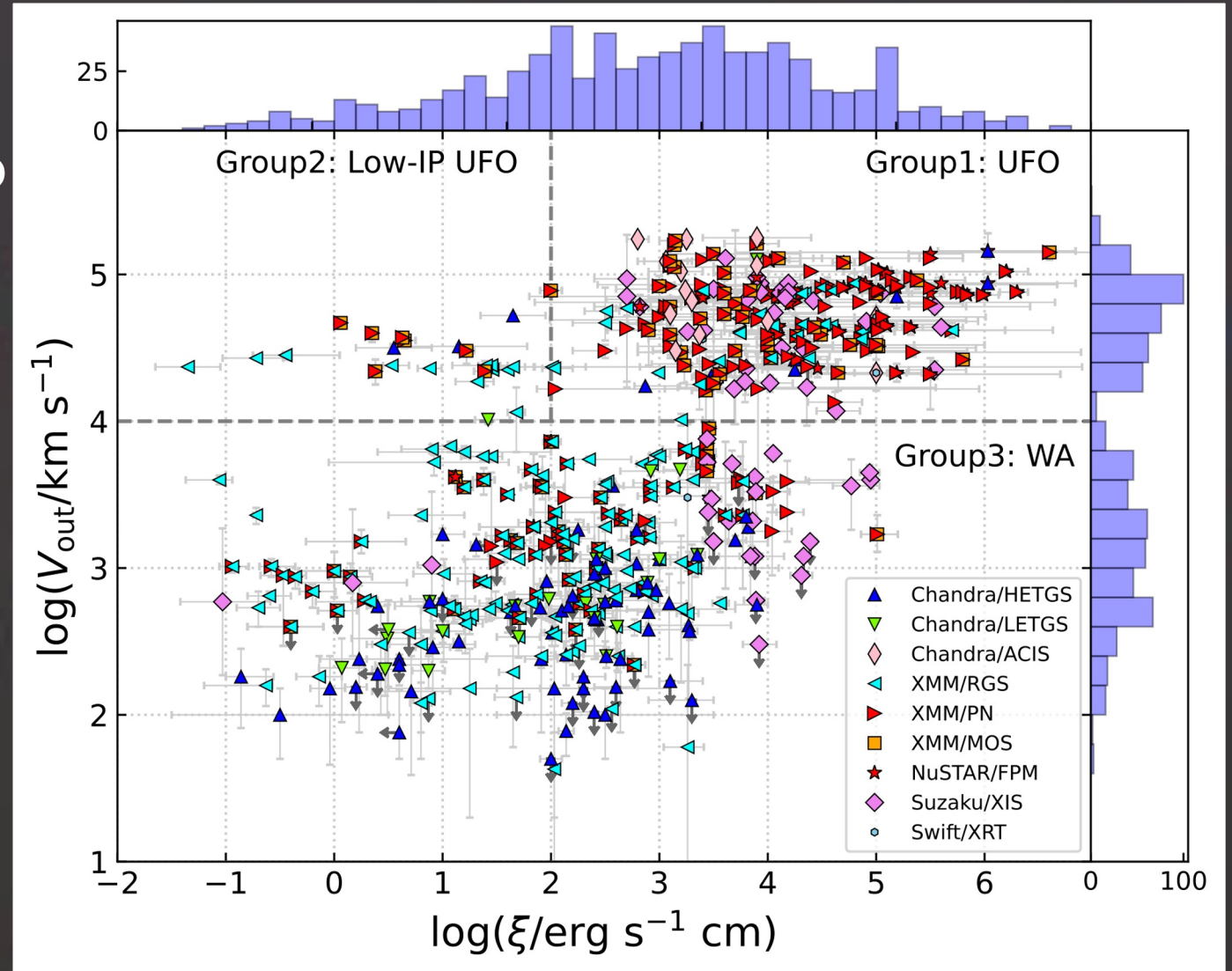
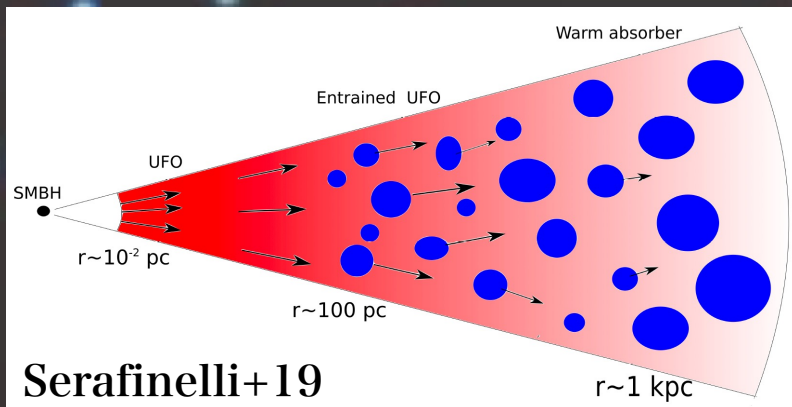
(not a physical ξ - N_H correlation)
- XRISM will lower the detection limit!!
 $\Rightarrow \Delta \log \xi \sim 1$ or $\Delta \log N_H \sim 0.5$ dex.



log ξ vs. log V_{out} : Three Groups of Outflows

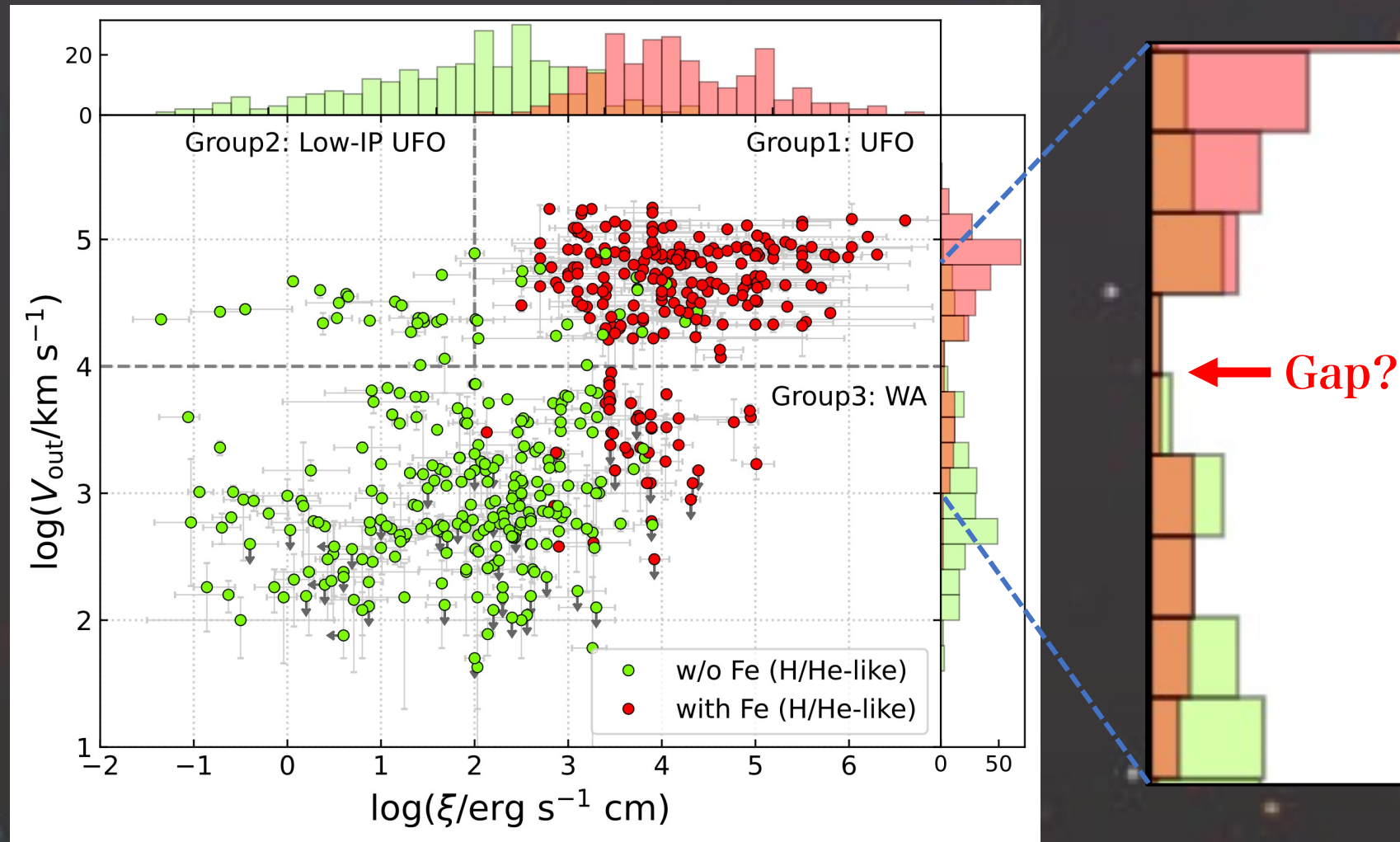
- We classified the X-ray winds:
 - UFO ($V > 10,000 \text{ km/s}$, $\log \xi > 2$)
 - low-ionized-parameter (low-IP) UFO (same V , but $\log \xi < 2$)
 - WA ($V < 10,000 \text{ km/s}$)

=> entrained UFO at $r \sim 100 \text{ pc}$?
- We find a gap at $V \sim 10,000 \text{ km/s}$??



Detection with Fe XXV/XXVI or Other Lines

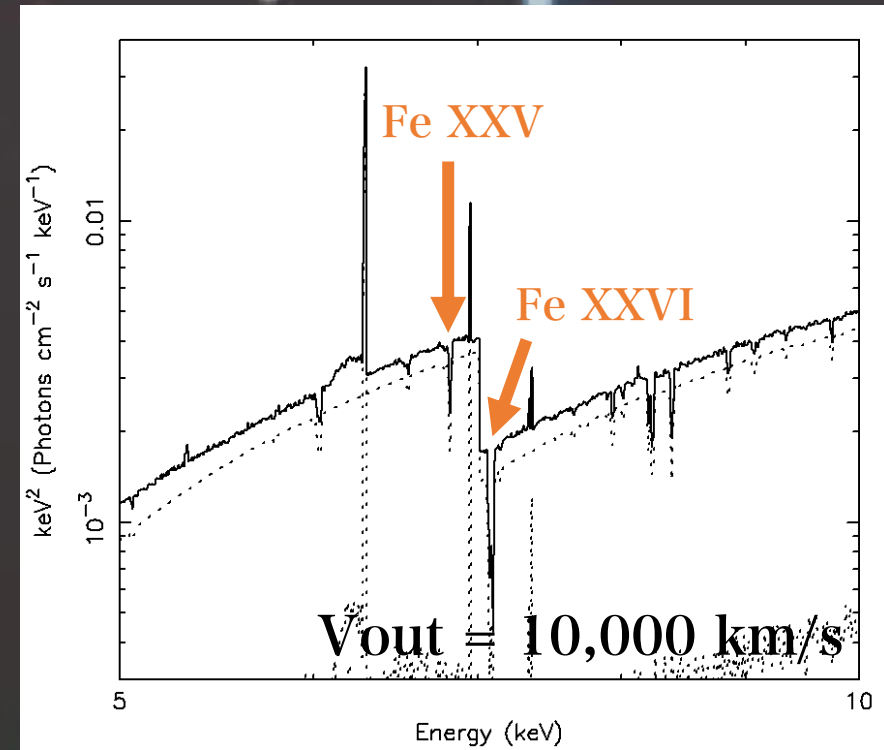
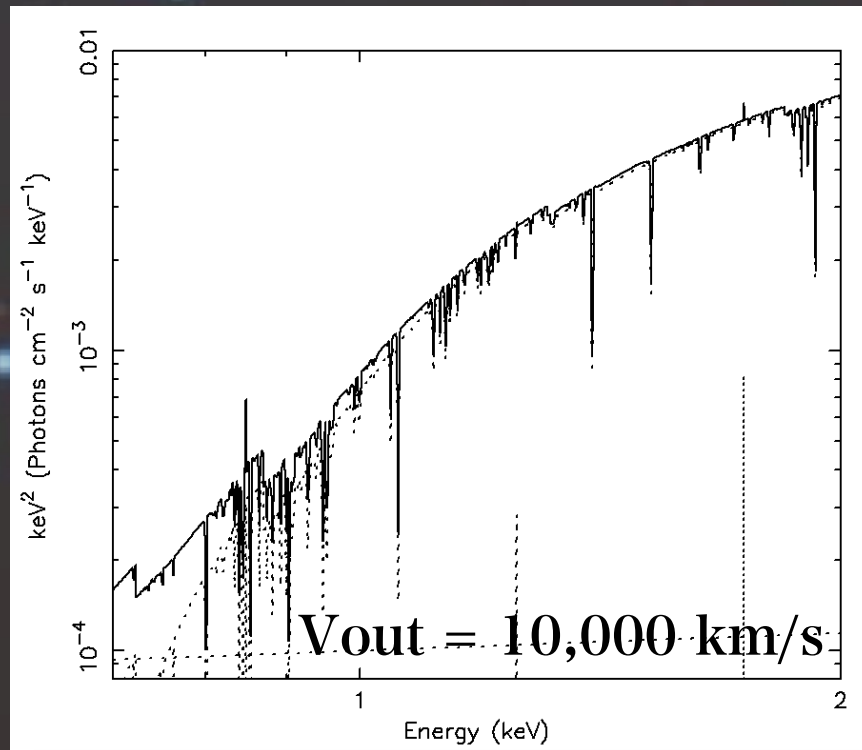
- The Vout gap is suggested with both the Fe XXV/XXVI line (>6keV; red) and other lines (<6 keV; green).



Vout Gap at $\sim 10,000$ km/s: Is It Real?

- Abs lines detected in the < 2 keV band:
 - Most studies identified the set of blueshifted lines. \Rightarrow Maybe the gap is real.
 - n.b. they are low-IP UFOs, not UFOs.
- Fe XXV/XXVI line (> 6 keV):
 - Fe XXVI line \sim Fe-K edge (due to neutral matter)
 - Fe XXV/XXIV abs lines are mixed with Fe emi.

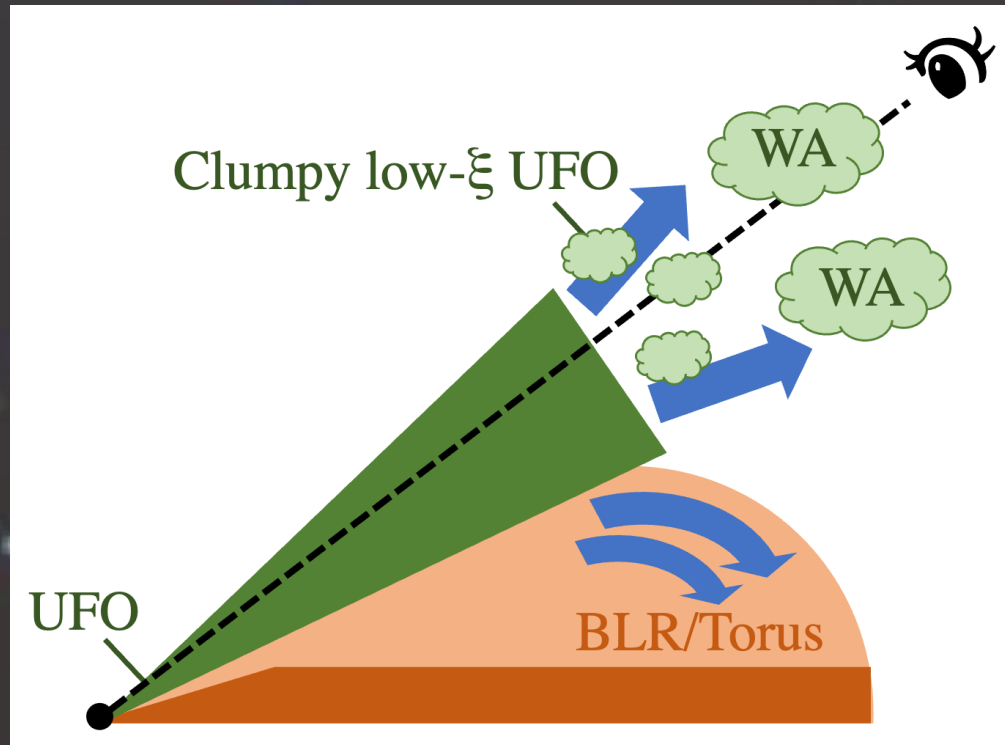
\Rightarrow XRISM must be needed to reduce the artifacts.



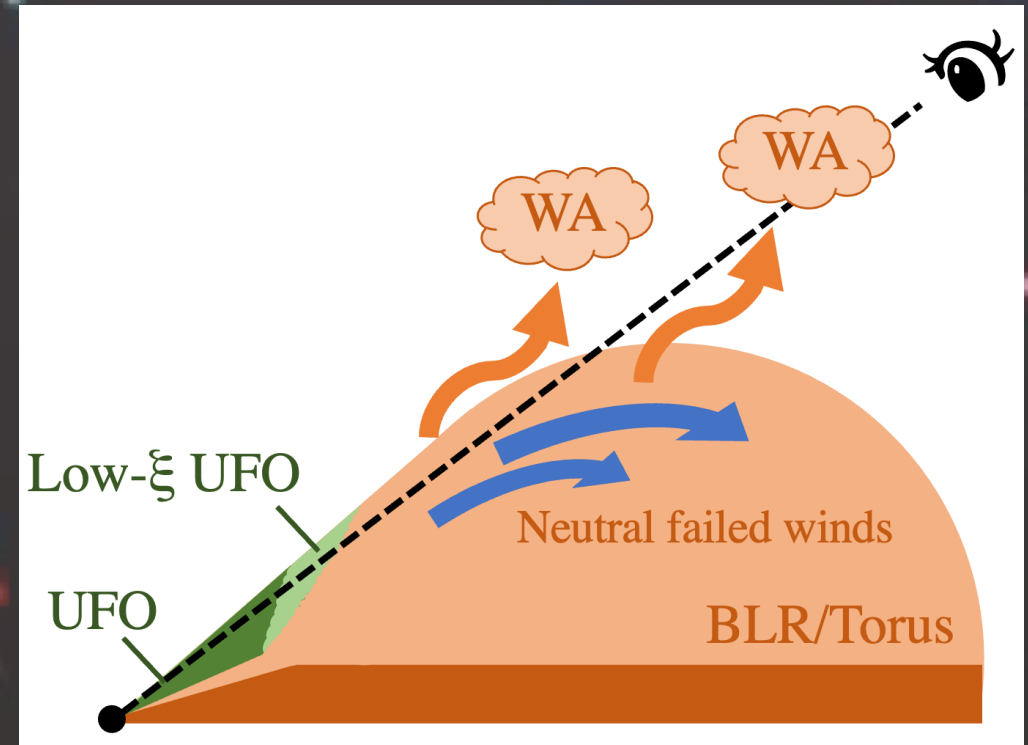
Continuous or Discontinuous?

- If the gap at $V_{out} \sim 10,000$ km/s is real, **the origin of UFOs and WA might be quite different?**
 - X-ray wind surveys with XRISM will answer whether the V_{out} gap is real or not!!

Continuous (w/o V_{out} gap)



Discontinuous (with V_{out} gap)



Database will be available publicly (in Feb-Mar)

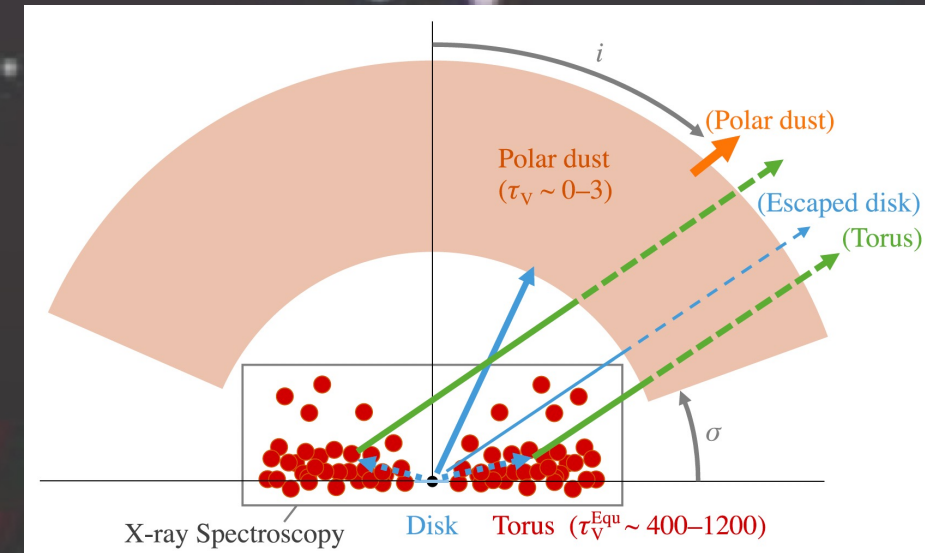
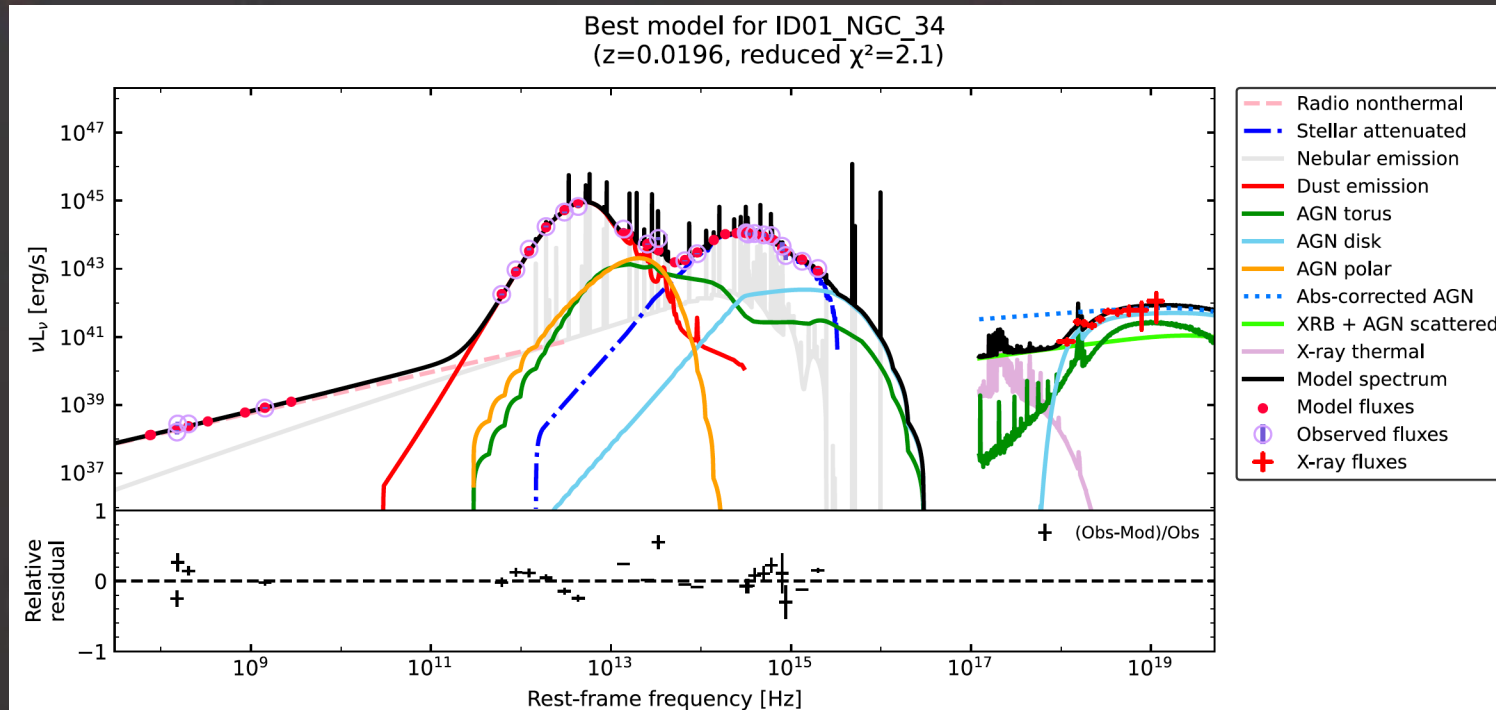
ID	Object	R.A.	Decl.	z	D_L	Class	$\log M_{BH}$	$\log L_{AGN,X}$	References (5,7,8,9)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1E 0754.6+3928	119.500218	+39.341388	0.0960	440.7	NLS1	8.00	43.70	(Md20;Md20;Md20;Md20)
2	1H 0323+342	51.171505	+34.179405	0.0630	282.7	NLS1	6.76	42.90	(Me19;Pl14;K22A;Ri17)
3	1H 0419-577	66.502995	-57.200492	0.1040	480.0	1.5	8.34	44.60	(To10;VC10;K22A;Ri17)

ID	Object	Start date	Inst.	Fe-K	$\log N_H^{(ion)}$	$\log V_{out}$	$\log \xi$	$\log L_{ion}$	Type
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nearby ($z < 1$) Galaxies									
1a	1E 0754.6+3928	2006-04-18	P	Y	$23.11^{+0.25}_{-0.41}$	$4.84^{+0.04}_{-0.04}$	$3.40^{+0.30}_{-0.30}$	44.15	UFO
1b	1E 0754.6+3928	2006-04-18	P	Y	$23.41^{+0.27}_{-0.51}$	$3.71^{+0.09}_{-0.12}$	$3.40^{+0.10}_{-0.10}$	44.15	WA
1c	1E 0754.6+3928	2006-04-18	P	n	$22.85^{+0.06}_{-0.07}$	<3.18	$2.00^{+0.05}_{-0.05}$	44.15	WA
1d	1E 0754.6+3928	2006-10-22	P	n	$22.60^{+0.05}_{-0.06}$	<3.04	$1.50^{+0.07}_{-0.07}$	44.15	WA
2a	1H 0323+342	2015-08-23	RPM	n	$20.86^{+0.07}_{-0.08}$	$2.94^{+0.09}_{-0.11}$	$0.15^{+0.20}_{-0.20}$	(non)	WA
2b	1H 0323+342	2015-08-23	RPM	n	$20.95^{+0.14}_{-0.20}$	$2.92^{+0.13}_{-0.18}$	$2.17^{+0.03}_{-0.03}$	(non)	WA
3a	1H 0419-577	2002-09-25	P	Y	<23.61	$4.37^{+0.06}_{-0.07}$	$3.69^{+0.87}_{-0.87}$	44.60	UFO

ID	Object	OBSID	References	Related References
(1)	(2)	(3)	(4)	(5)
Nearby ($z < 1$) Galaxies				
1a	1E 0754.6+3928	305990101	Middei et al. (2020)	
1b	1E 0754.6+3928	305990101	Middei et al. (2020)	
1c	1E 0754.6+3928	305990101	Middei et al. (2020)	
1d	1E 0754.6+3928	406740101	Middei et al. (2020)	
2a	1H 0323+342	764670101	Mehdipour & Costantini (2019)	
2b	1H 0323+342	764670101	Mehdipour & Costantini (2019)	
3a	1H 0419-577	148000201	Tombesi et al. (2012a)	Tombesi et al. (2011a)

X-WING Paper I-III (Yamada+, in prep.)

- Paper I: X-ray winds, L_x , SMBH masses, OBSID, observation time (variability), etc.
- Paper II (UV-to-radio SED fit): host galaxy, AGN activities (e.g. λ_{Edd}), and outflow rates of X-ray winds.
- Paper III (Multiphase outflow): UV/optical/IR/submm/radio outflows



Hard X-ray to radio SED model
(see Yamada+23, ApJS, 265, 37)

Summary

- X-WING (= X-ray Winds in Nearby-to-distant Galaxies)
 - Database of ~ 130 AGNs and >500 Winds (from >300 OBSID, ~ 240 papers)
- The distribution of ξ and NH covers the range of detection limit
 \Rightarrow XRISM will expand the parameter spaces and reduce the bias.
- We find a gap around $V_{out} \sim 10,000$ km/s.
 - Blueshifted Fe XXV/XXVI lines may be missed due to Kedge or the emission lines, but XRISM will solve whether the gap is real or not.
- X-WING database will be available publicly from ArXiv **in February or March for XRISM proposers!**
 \Rightarrow **If you're interested in our database of X-ray winds, please contact us (satoshi.yamada@riken.jp)!!**

