THE FREQUENCY OF INTRINSIC X-RAY WEAKNESS AMONG BAL QUASARS

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Outline

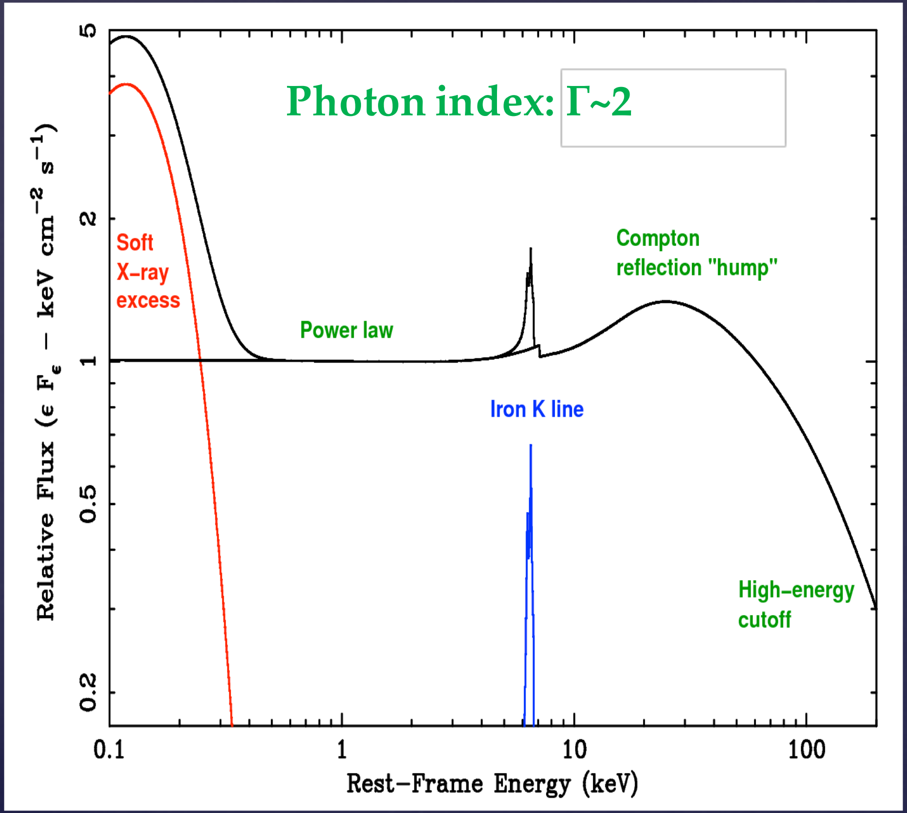
- Introduction to AGN X-rays
- Intrinsically X-ray Weak Broad Absorption Line Quasars
- Summary and Future Work

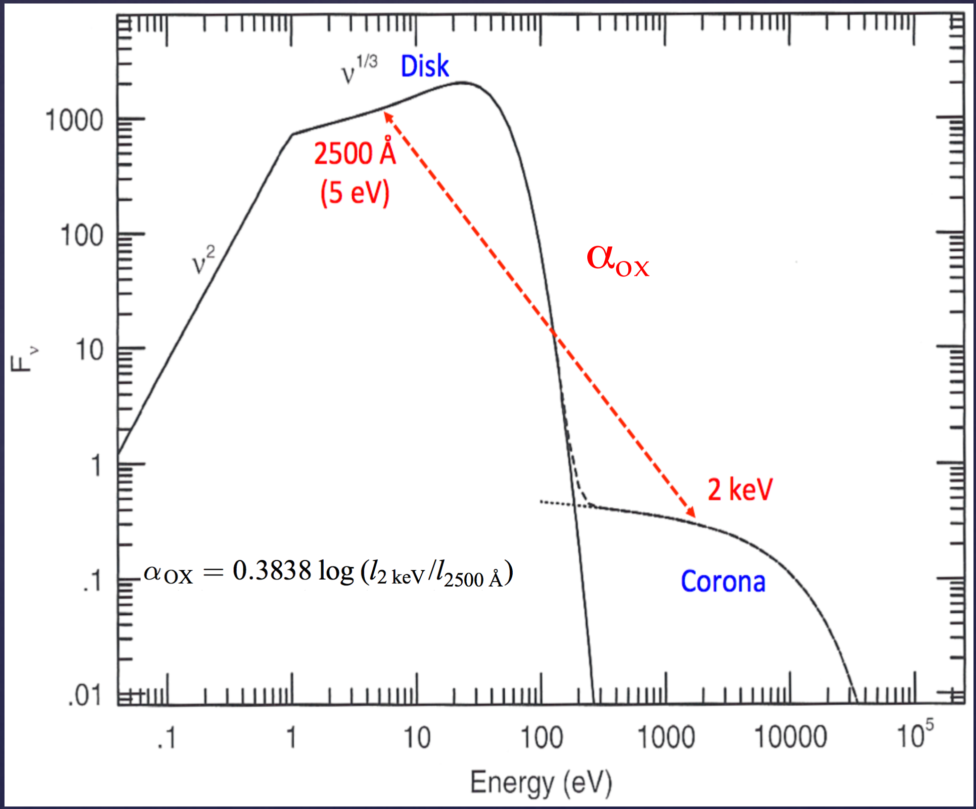
AGN X-rays

From immediate vicinity of black hole.

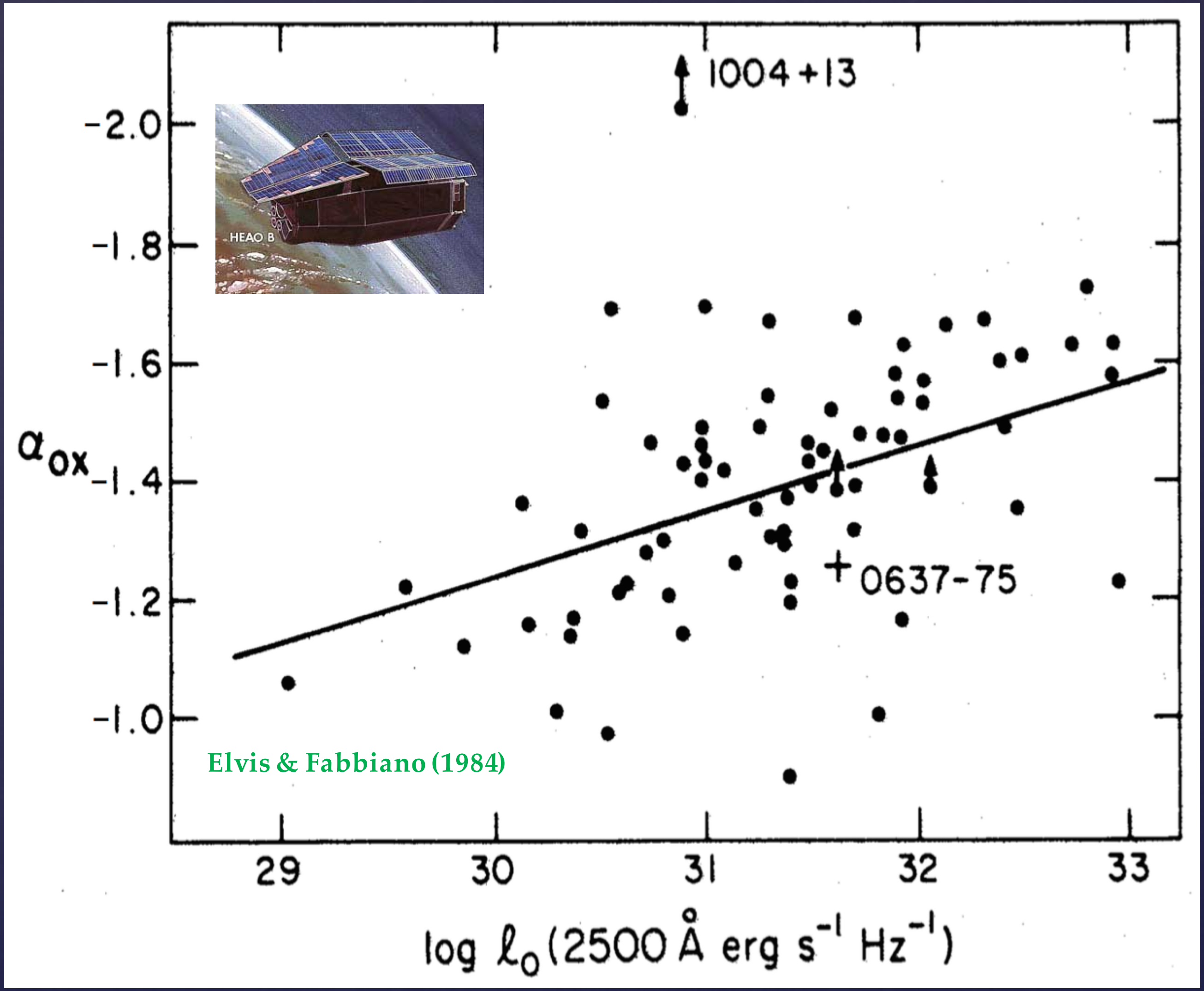
Accretion-disk corona is empirically *robust*, even if poorly understood.

AGN X-ray Spectral Components

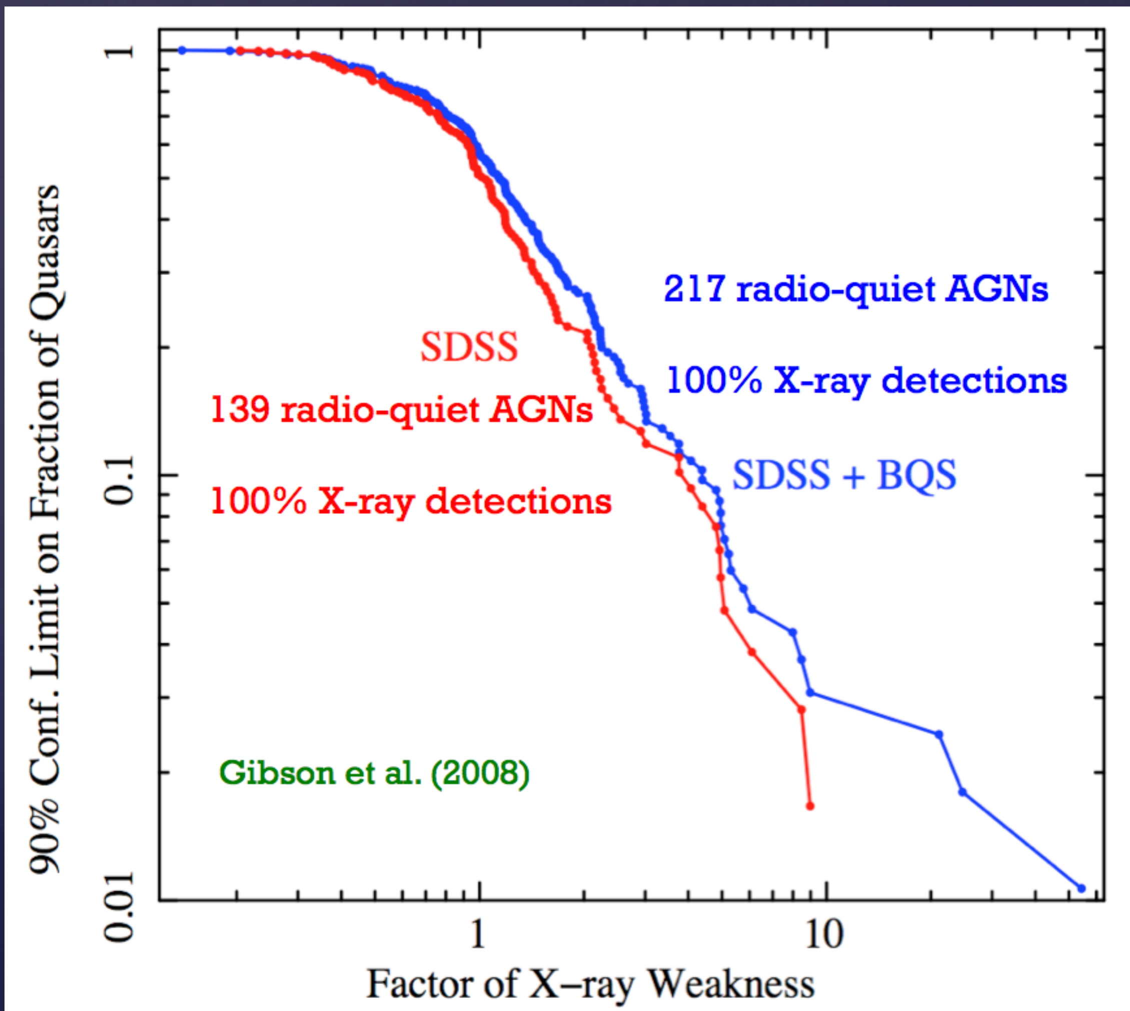




α_{ox} and X-ray Weak AGNs

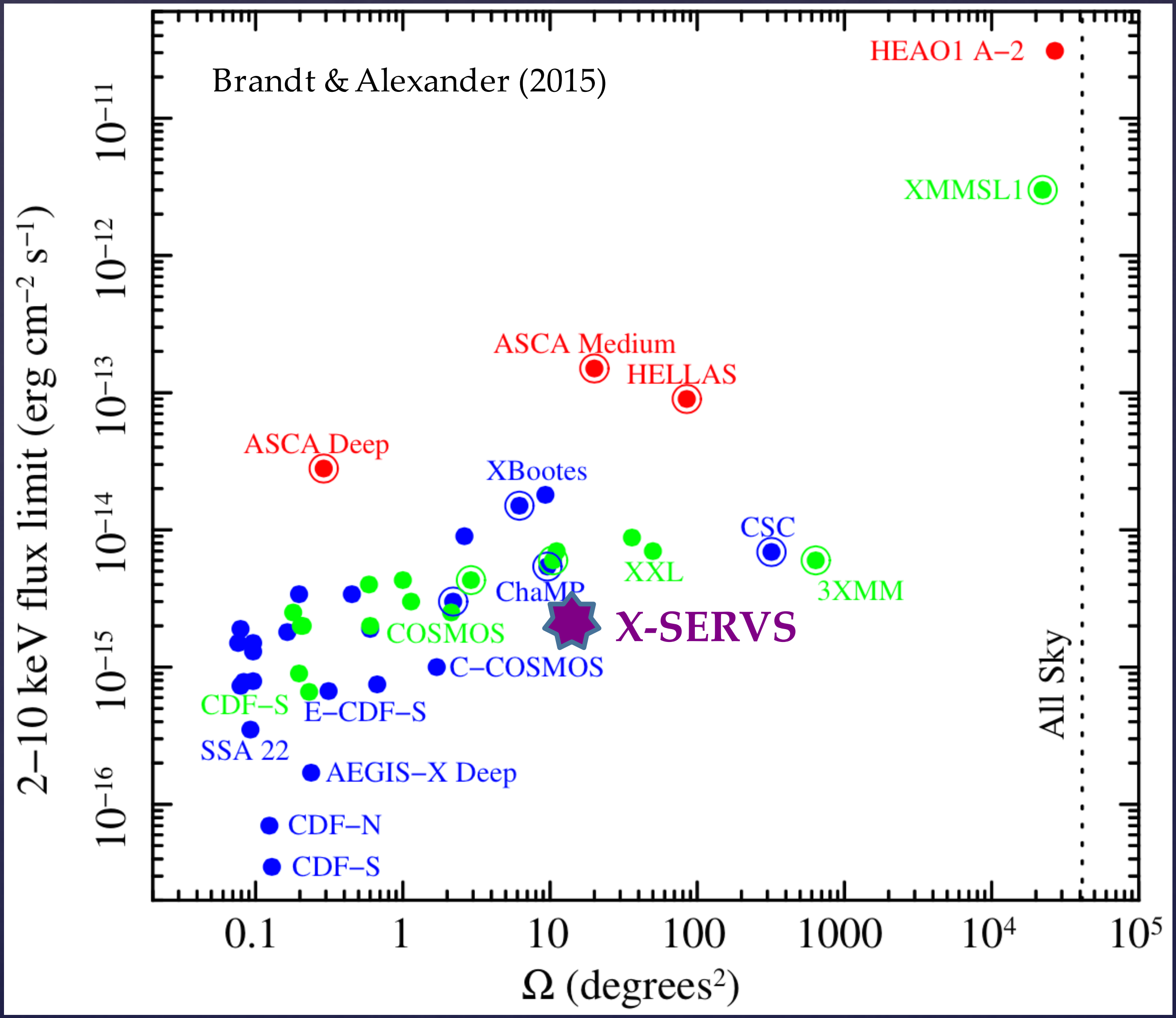


Robustness of Quasar X-ray Emission



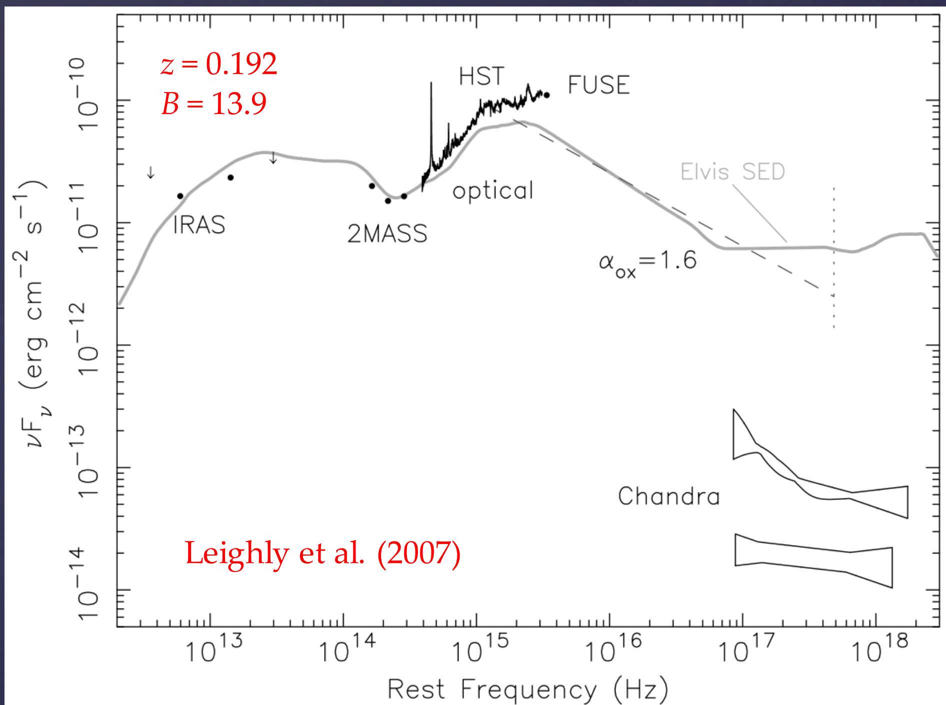
For type 1 quasars, which are optically selected luminous AGNs, significant X-ray emission appears universal (excluding broad absorption line quasars; see below).

Central to the X-ray Survey Industry

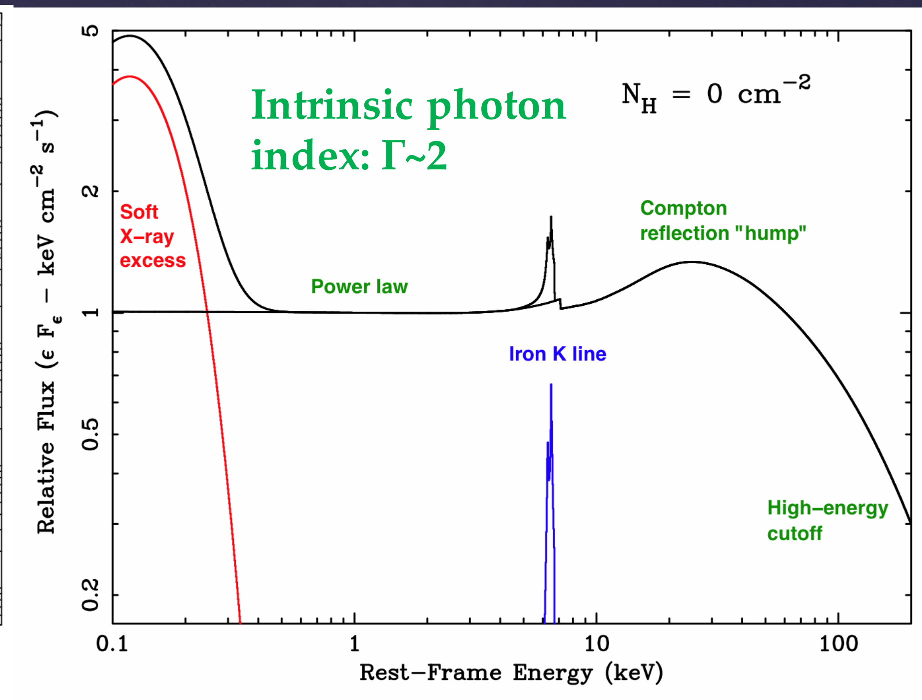


An X-ray Weak Outlier: PHL 1811

Broad-Band SED of PHL 1811



Outlier from Luminosity-α_{ox} Relation



Has an X-ray weak spectral energy distribution (SED).

No apparent X-ray absorption (soft spectral shape). No UV BALs or mini-BALs. X-ray variability.

Appears intrinsically X-ray weak!

Extreme Objects Are Interesting and Probably Valuable

Let’s find more of these …

- To constrain their frequency
- To probe their nature

Identifying Intrinsically X-ray Weak AGNs

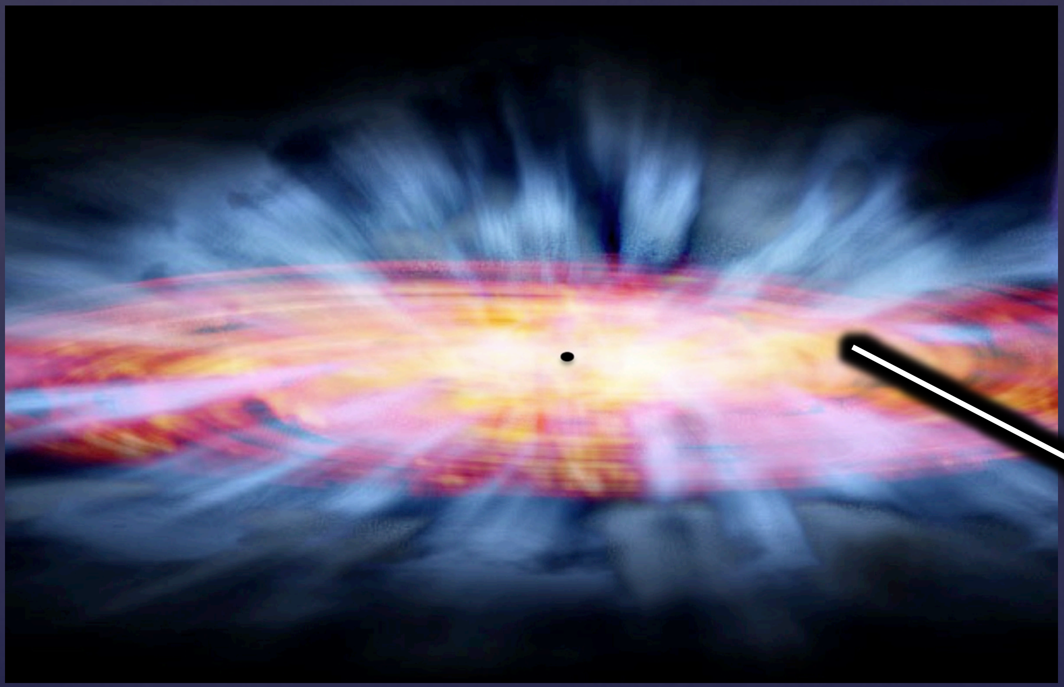
- X-ray weak (relative to the α_{ox}–L relation)
- X-ray weakness not entirely accounted for by absorption

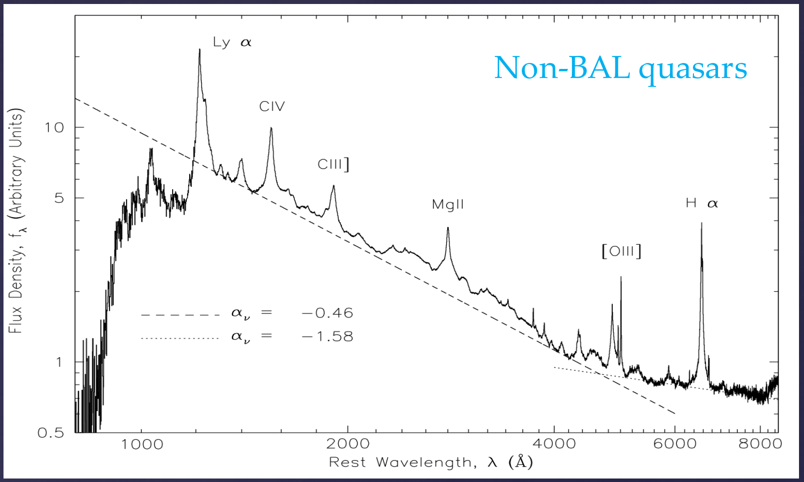
Absorption vs. Intrinsic X-ray Weakness

- Spectral fitting of <8 keV X-rays not sufficient to recover the intrinsic X-ray absorption, e.g., Compton-thick + reflection could produce a soft spectrum.
- Must use hard X-rays: soft spectrum rules out Compton-thick absorption.
- *NuSTAR* observations or go to high-z.

Broad Absorption Lines (BALs)

Radiatively Driven Accretion-Disk Wind with Wind Velocities of ~ 1000-30000 km s^{-1}





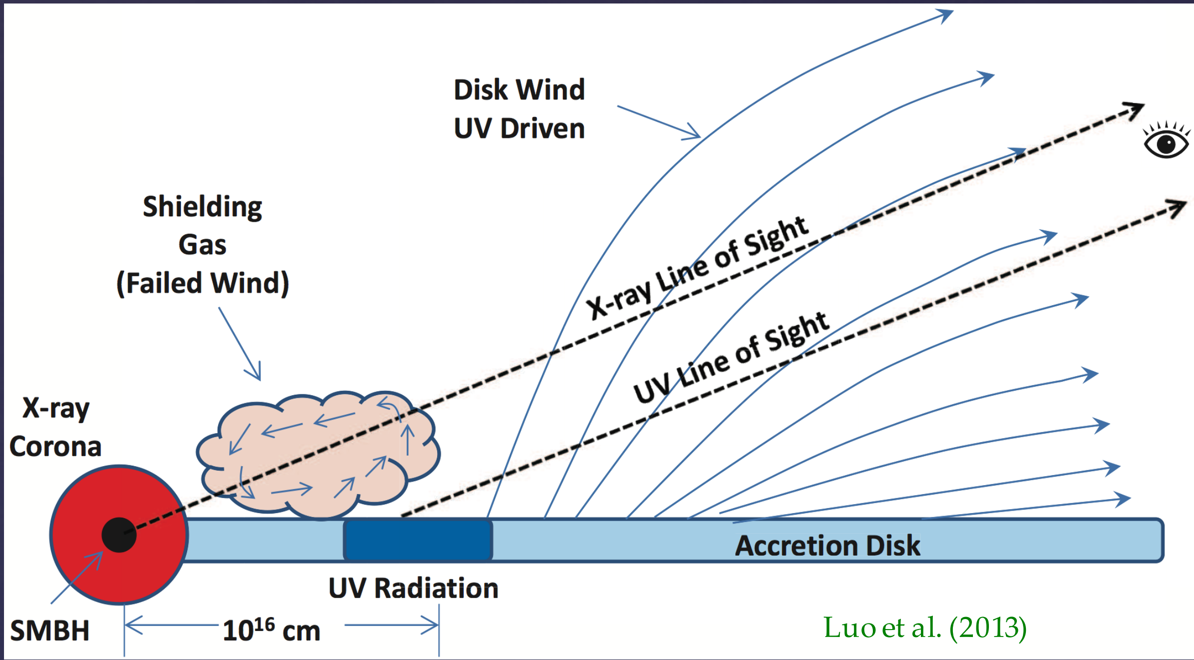
1500 A

Commonly see blueshifted transitions of, e.g., C IV, Si IV, Mg II, Al III.

Role of X-ray Shielding

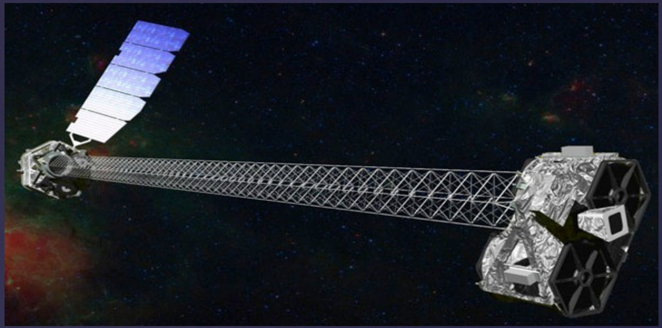
Schematic Model of Equatorial BAL Outflow

e.g., Murray et al. (1995); Proga et al. (2000)

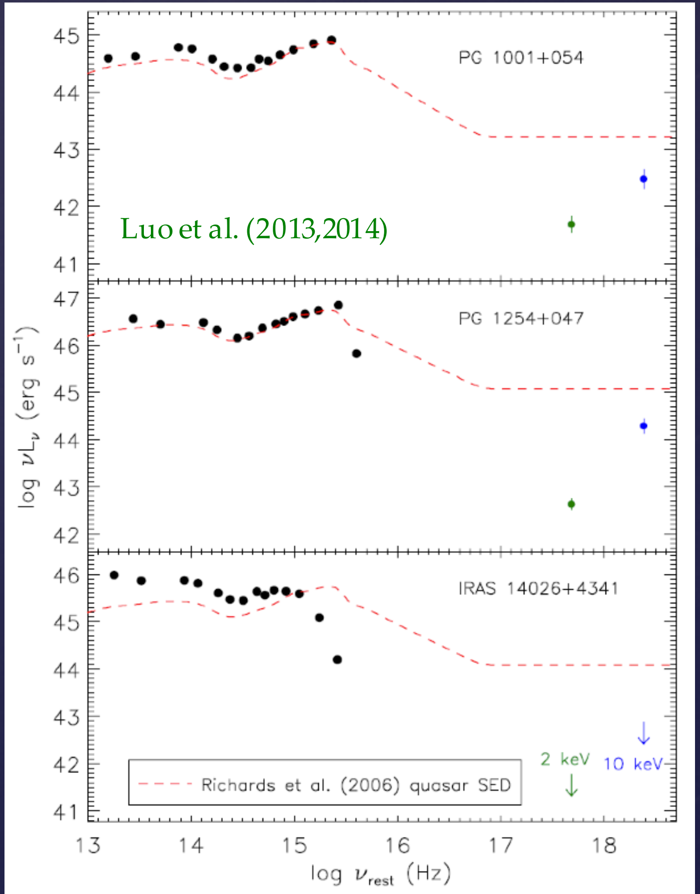


- Quasar X-ray emission can be problematic for launching winds.
- Proposed "shielding gas" is central to BAL wind driving - prevents wind over-ionization.
- Such shielding gas is commonly observed in X-ray absorption with $N_H \sim 10^{21}$-10^{23} cm^{-2}.
- Usually excluded from the search for intrinsically X-ray weak AGNs.

A Couple Candidates Suggested By *NuSTAR*

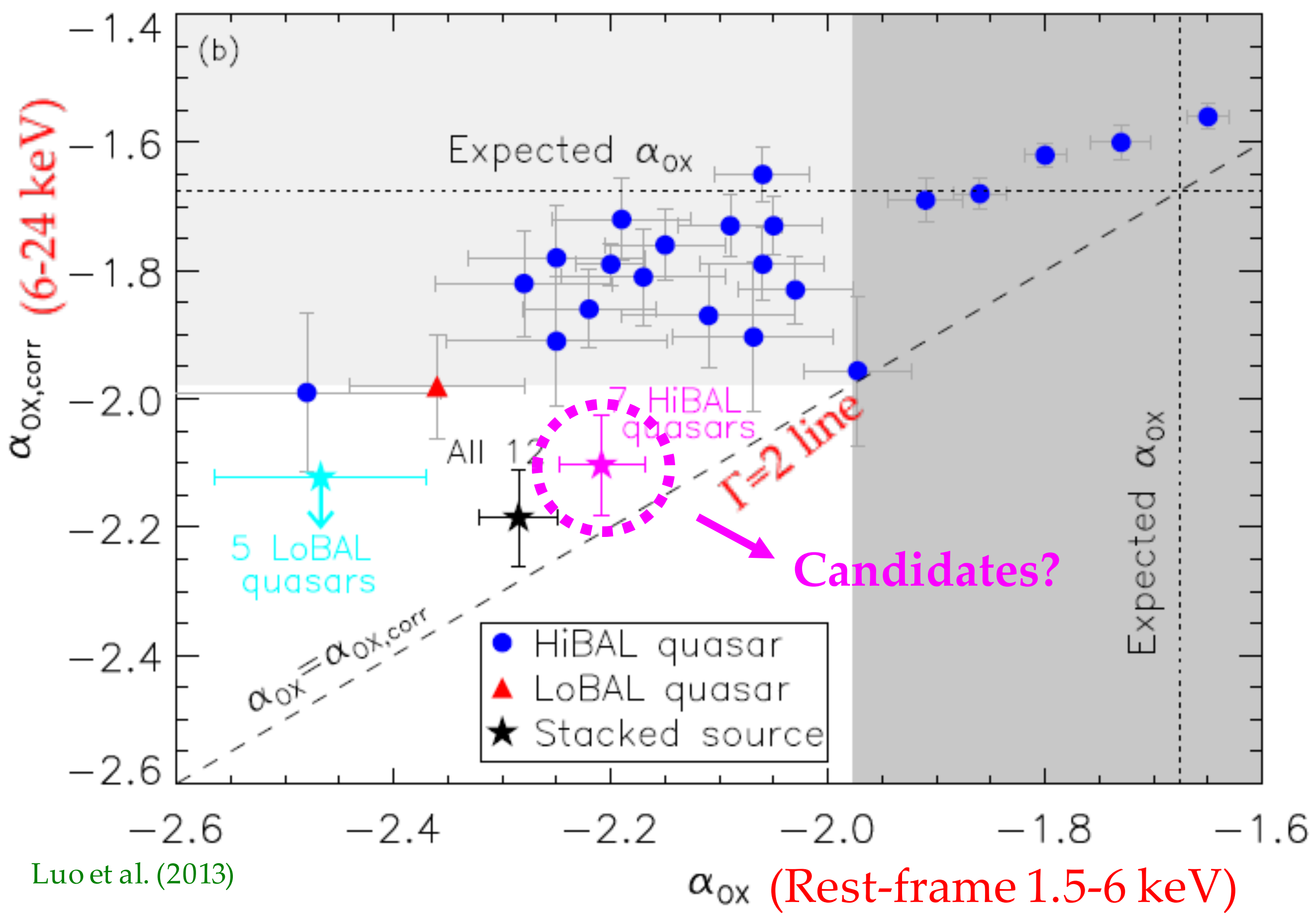


- 3-24 keV hard X-rays
- X-ray weak by factors of ~10
- Soft photon index Γ~1.8 indicated via *stacking analysis*
- No individual candidates



Intrinsically X-ray Weak BAL Quasar Population Constrained by *Chandra*

Chandra Stacking Results for $z \sim 1.5$-3 LBQS BAL Quasars from the Gallagher et al. (2006) Sample



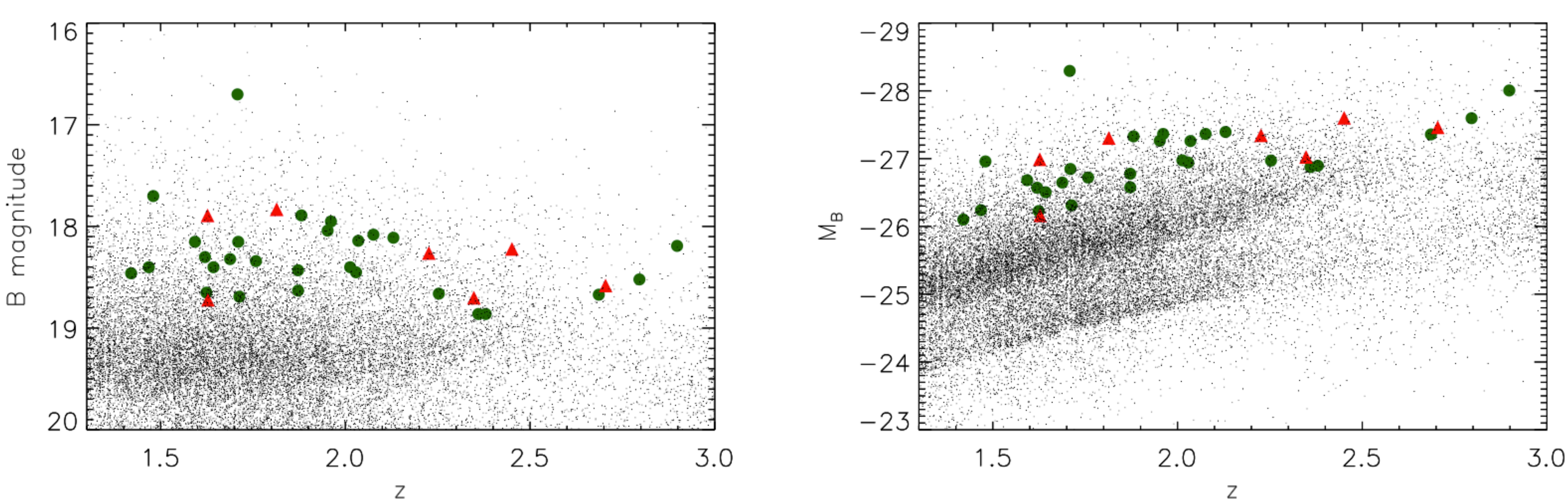
Luo et al. (2013)

- At high redshifts, *Chandra* nearly samples the *NuSTAR* band.
- Outside the shaded regions: X-ray weak.
- Close to the slanted line: soft spectral shape.
- Candidates suggested via stacking analysis.

New Chandra Observations

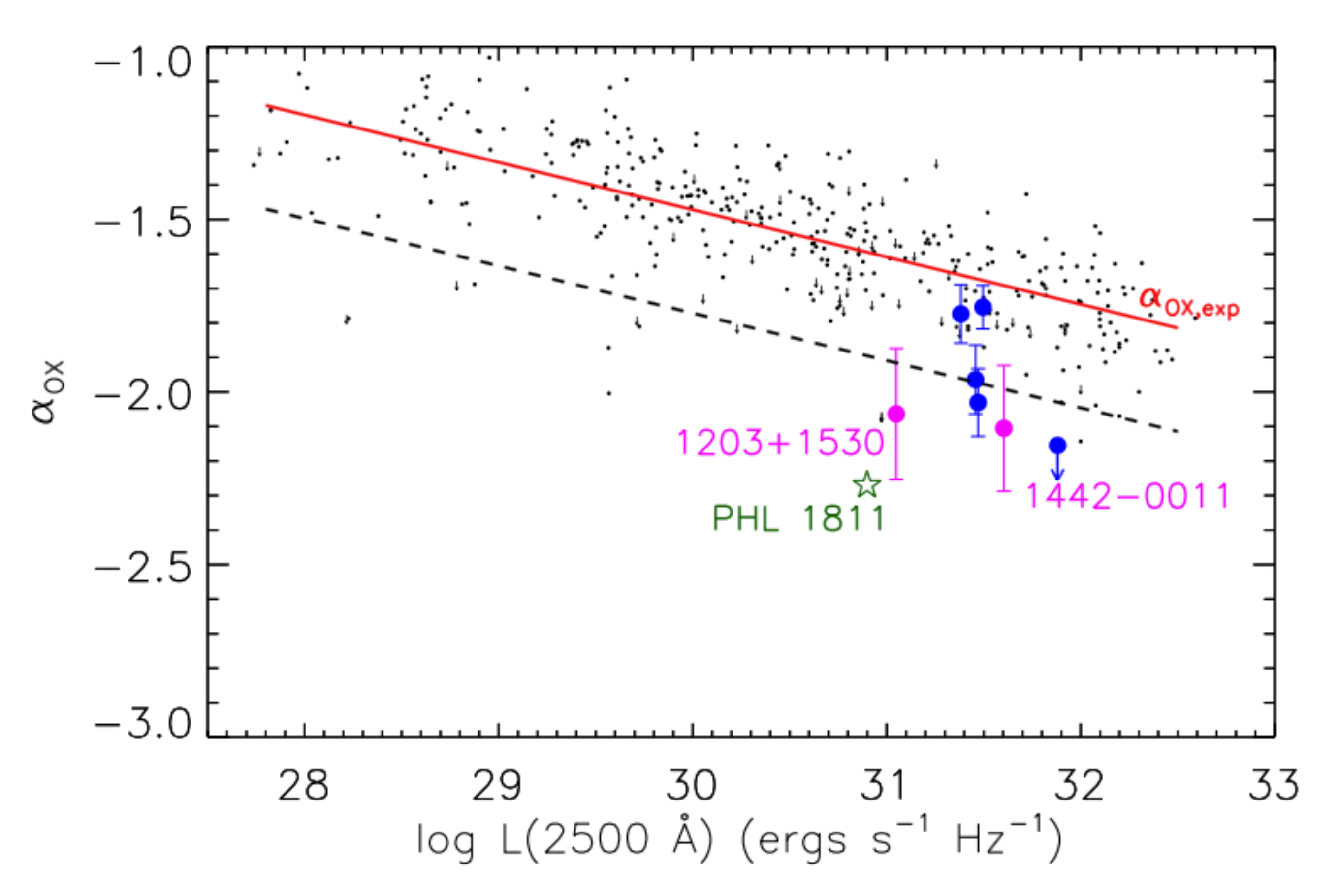
Object Name (LBQS B) (1)	Redshift (2)	B_J (3)	Observation Star Date (4)	Observation ID (5)	New Obs. Exposure (ks) (6)	Combined Exposure (ks) (7)
0021−0213	2.35	18.68	2009 Oct 30	8918	29.80	36.55
1203+1530	1.63	18.70	2016 Apr 22	17465	11.95	19.02
1212+1445	1.63	17.87	2016 Apr 13	17466	11.17	15.67
1235+1453	2.70	18.56	2016 May 2	17467	11.27	17.91
1442−0011	2.23	18.24	2016 May 18	17468	10.67	14.95
1443+0141	2.45	18.20	2016 May 12	17469	10.08	16.02
2201−1834	1.81	17.81	2015 May 23	17470	8.60	13.69

- Targeting the 7 hard-band undetected HiBAL quasars.



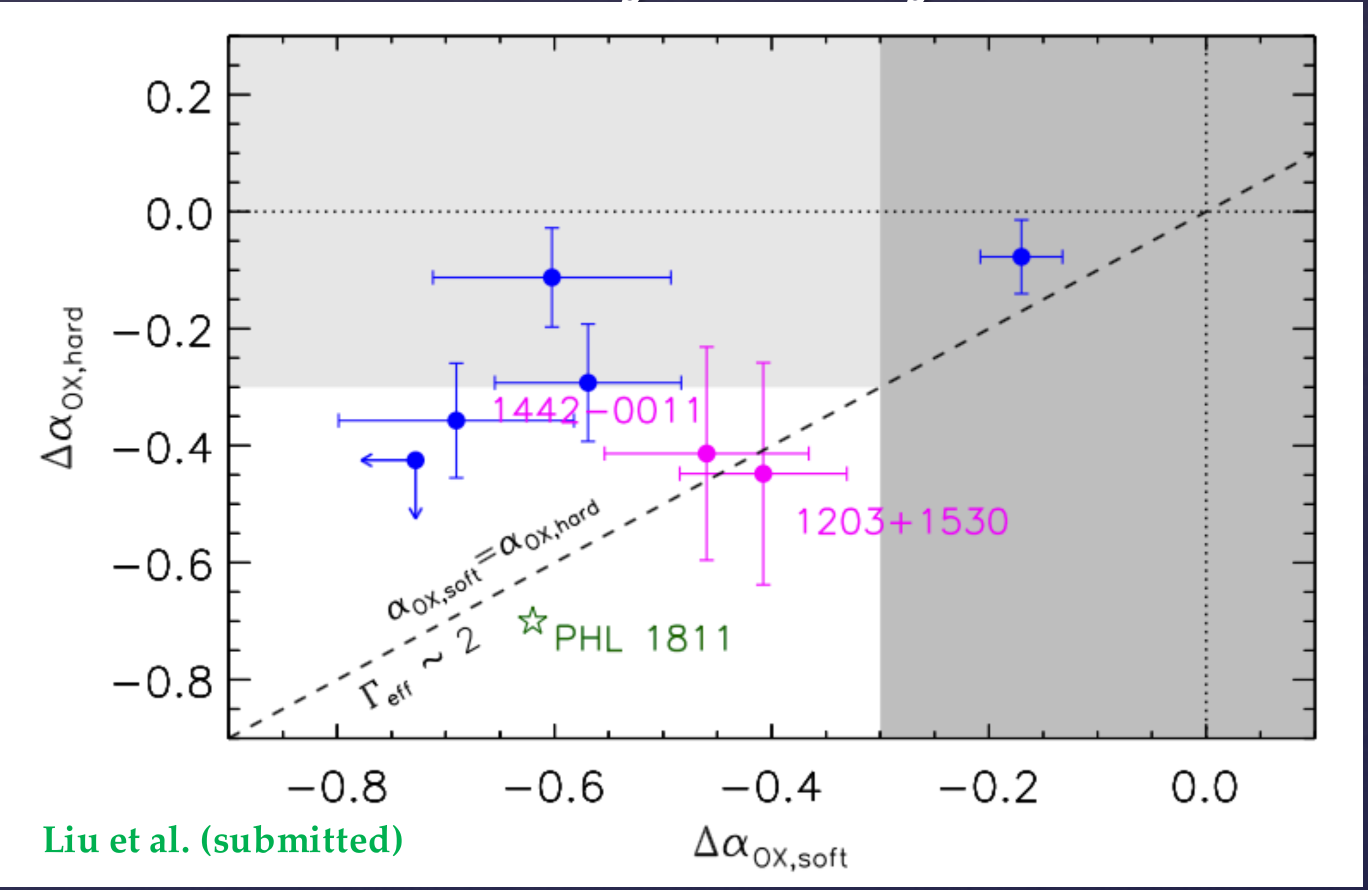
- Among the most luminous quasars in the optical/UV.
- More representative of the typically studied BAL quasar population than those low-luminosity and low-redshift objects amenable to observations with *NuSTAR*.
- A well-defined BAL quasar sample with systematic X-ray investigations.

Six Are Now Hard-Band Detected



- Four are hard X-ray weak ($\Delta\alpha_{ox}$ >-0.3)

Two Candidates For Being Intrinsically X-ray Weak

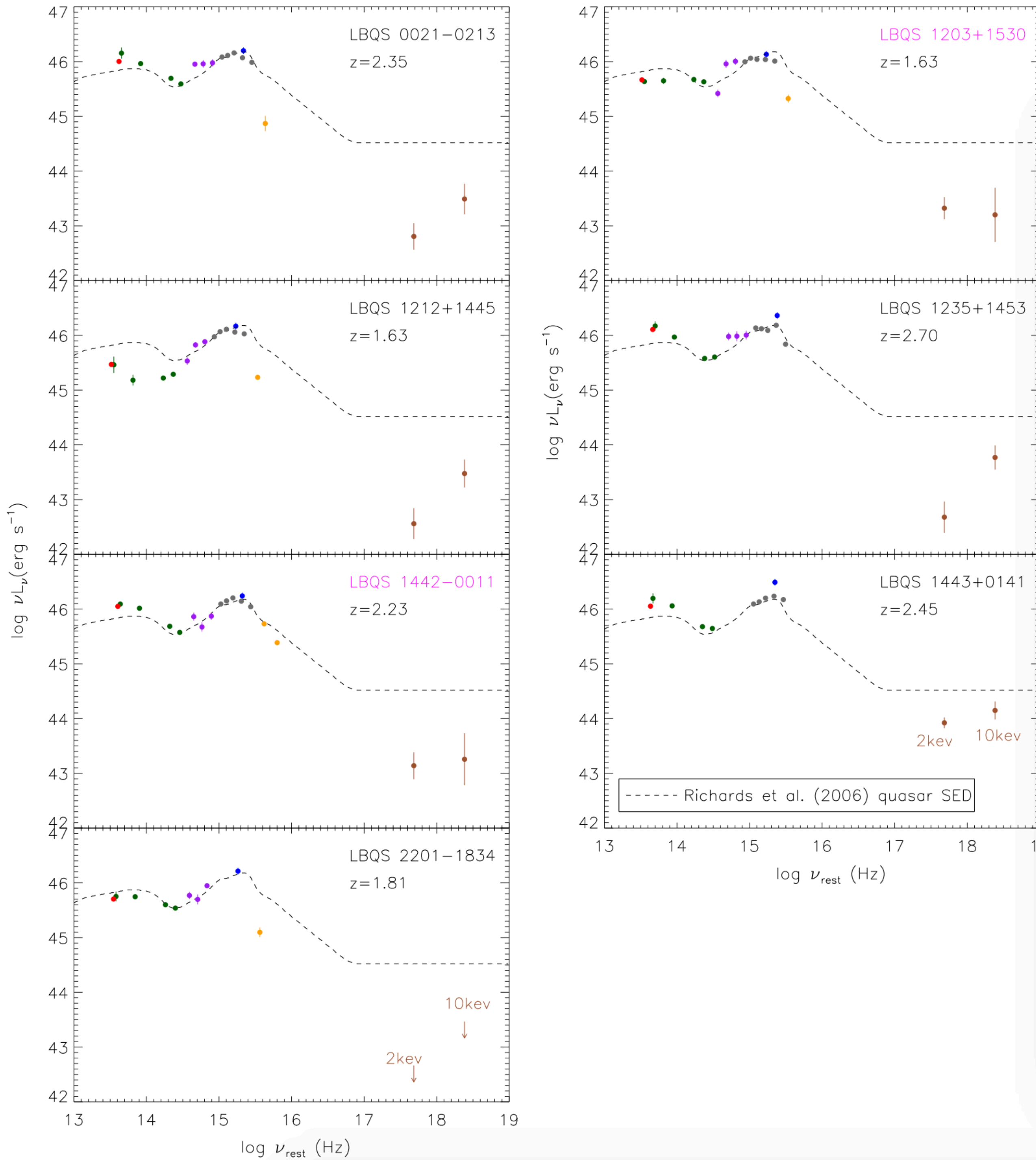


- LBQS 1203+1530 and LBQS 1442-0011.
- Best candidates besides PHL 1811.

Object Name	Net Counts		Band	Γ_{eff}	Flux (10^{-14} erg cm^{-2} s^{-1})		$\log L_X$ (erg s^{-1})
(LBQS B)	0.5-2 keV	2-8 keV	Ratio		0.5-2 keV	2-8 keV	2-10 keV
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0021 − 0213	$6.0^{+3.7}_{-2.5}$	$5.1^{+3.7}_{-2.4}$	$0.85^{+1.57}_{-0.44}$	$1.1^{+0.6}_{-0.6}$	0.20	0.79	44.2
1203 + 1530	$7.2^{+3.9}_{-2.7}$	$1.9^{+2.9}_{-1.4}$	$0.26^{+0.68}_{-0.11}$	$2.2^{+0.9}_{-0.9}$	0.40	0.34	43.9
1212 + 1445	$4.1^{+3.3}_{-2.0}$	$5.2^{+3.7}_{-2.4}$	$1.28^{+2.36}_{-0.58}$	$0.7^{+0.6}_{-0.8}$	0.23	1.60	44.0
1235 + 1453	$4.0^{+3.3}_{-2.0}$	$6.6^{+4.0}_{-2.7}$	$1.63^{+2.73}_{-0.71}$	$0.4^{+0.5}_{-0.8}$	0.20	1.90	44.3
1442 − 0011	$5.1^{+3.5}_{-2.2}$	$2.0^{+2.9}_{-1.4}$	$0.39^{+1.00}_{-0.16}$	$1.9^{+0.9}_{-0.8}$	0.33	0.47	44.2
1443 + 0141	$24.9^{+6.2}_{-5.1}$	$10.7^{+4.7}_{-3.4}$	$0.43^{+0.65}_{-0.30}$	$1.7^{+0.4}_{-0.3}$	1.47	2.50	45.0
2201 − 1834	< 4.0	< 4.1	...	1.0	< 0.25	< 1.38	< 44.1

Object Name (LBQS B)	Count Rate (0.5–2 keV)	$f_{2\ keV,soft}$	$f_{2\ keV,hard}$	$f_{2500\ Å}$	$\log L_{2500\ Å}$	$\alpha_{OX,soft}$	$\alpha_{OX,hard}$	$\Delta\alpha_{OX,soft}(\sigma)$	$\Delta\alpha_{OX,hard}(\sigma)$	f_{weak}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
0021 − 0213	$0.16^{+0.10}_{-0.07}$	0.34	1.78	2.34	31.46	$-2.24^{+0.10}_{-0.07}$	$-1.96^{+0.12}_{-0.08}$	−0.57(3.90)	−0.29(2.00)	5.78
1203 + 1530	$0.38^{+0.21}_{-0.14}$	0.90	0.71	1.68	31.05	$-2.02^{+0.09}_{-0.06}$	$-2.06^{+0.25}_{-0.12}$	−0.41(2.79)	−0.45(3.07)	14.68
1212 + 1445	$0.26^{+0.21}_{-0.13}$	0.31	2.28	4.46	31.47	$-2.36^{+0.13}_{-0.08}$	$-2.03^{+0.12}_{-0.08}$	−0.69(4.73)	−0.36(2.44)	8.51
1235 + 1453	$0.22^{+0.18}_{-0.11}$	0.19	3.54	1.48	31.38	$-2.26^{+0.14}_{-0.08}$	$-1.77^{+0.10}_{-0.07}$	−0.60(4.13)	−0.11(0.77)	1.96
1442 − 0011	$0.34^{+0.24}_{-0.15}$	0.86	1.13	3.45	31.60	$-2.15^{+0.11}_{-0.07}$	$-2.11^{+0.24}_{-0.12}$	−0.46(3.15)	−0.41(2.83)	11.94
1443 + 0141	$1.55^{+0.39}_{-0.32}$	3.50	6.12	2.28	31.50	$-1.85^{+0.04}_{-0.03}$	$-1.75^{+0.07}_{-0.05}$	−0.17(1.16)	−0.08(0.53)	1.59
2201 − 1834	< 0.29	< 0.37	< 2.29	9.40	31.88	< −2.46	< −2.15	< −0.73(4.99)	< −0.42(2.91)	> 12.78

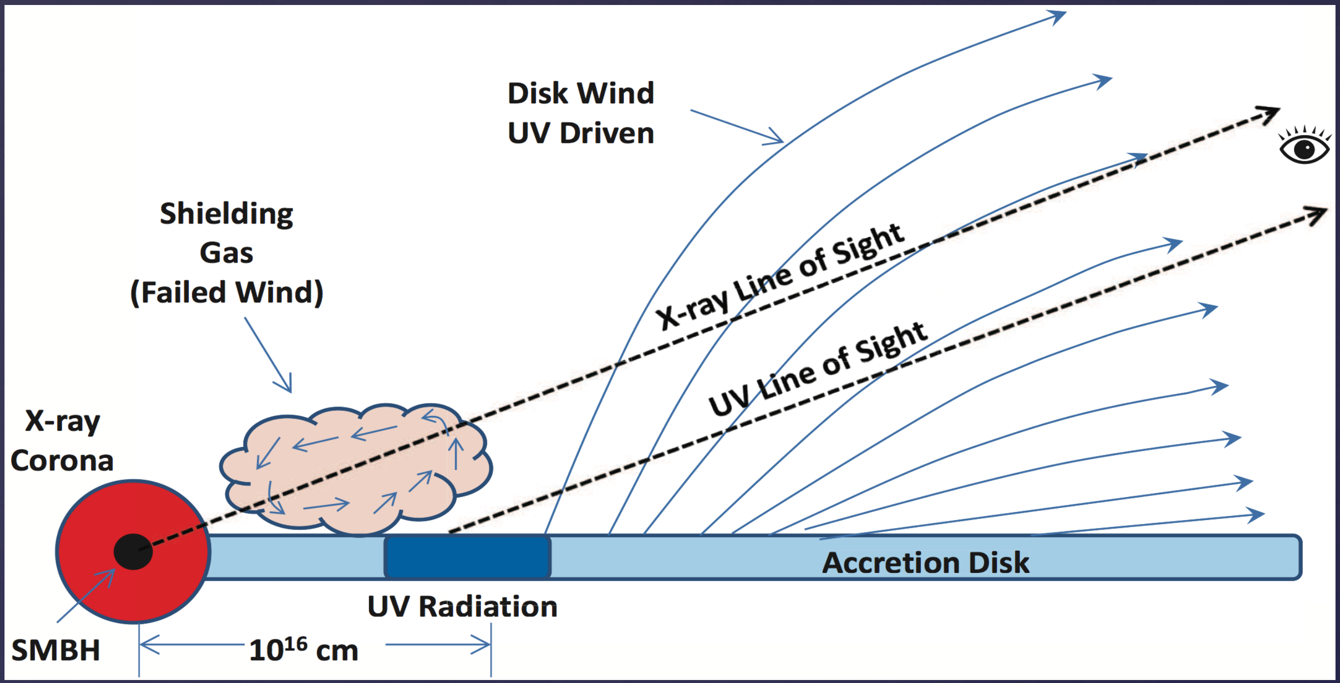
Typical SEDs



Frequency Constraints

- 7-10% among HiBAL quasars.
- LoBAL quasars are X-ray weaker in the hard band. Probably a higher fraction among these. Up to ~23% among BAL quasar.
- Fraction of intrinsically X-ray weak objects among BAL quasars is considerably larger than the <2% fraction among non-BAL quasars.

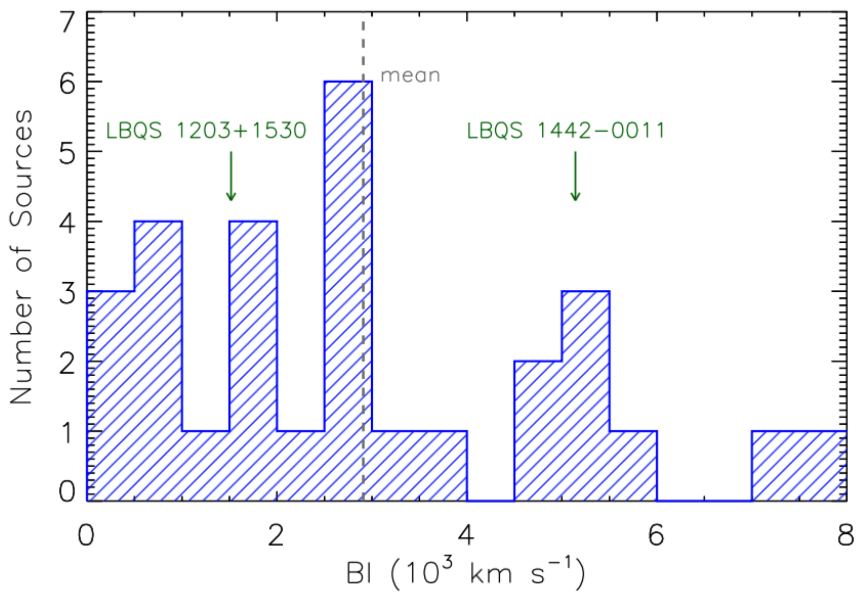
Relevance to Wind Launching



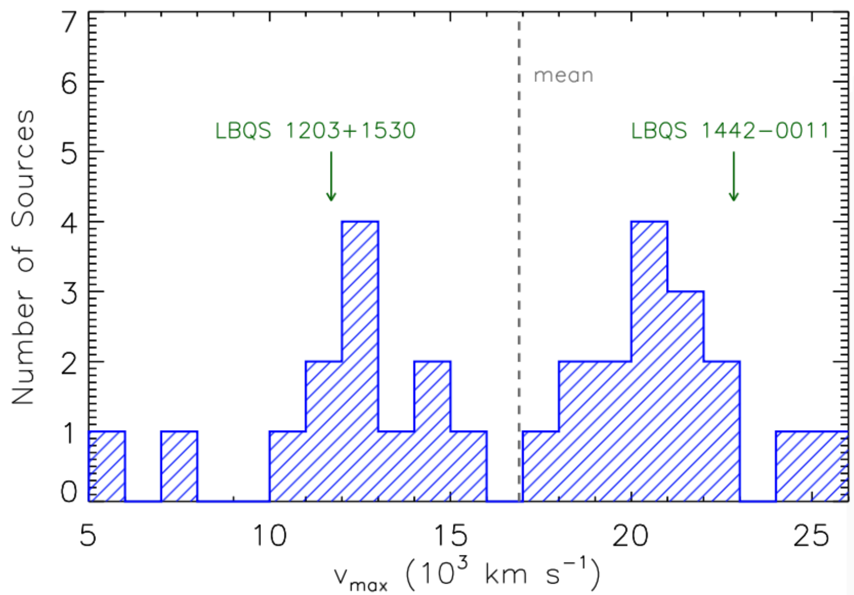
No luminous X-rays - no shielding gas required!

Perhaps intrinsically X-ray weak quasars preferentially launch strong winds with large covering factors, thereby preferentially appearing with BALs.

Wind Properties



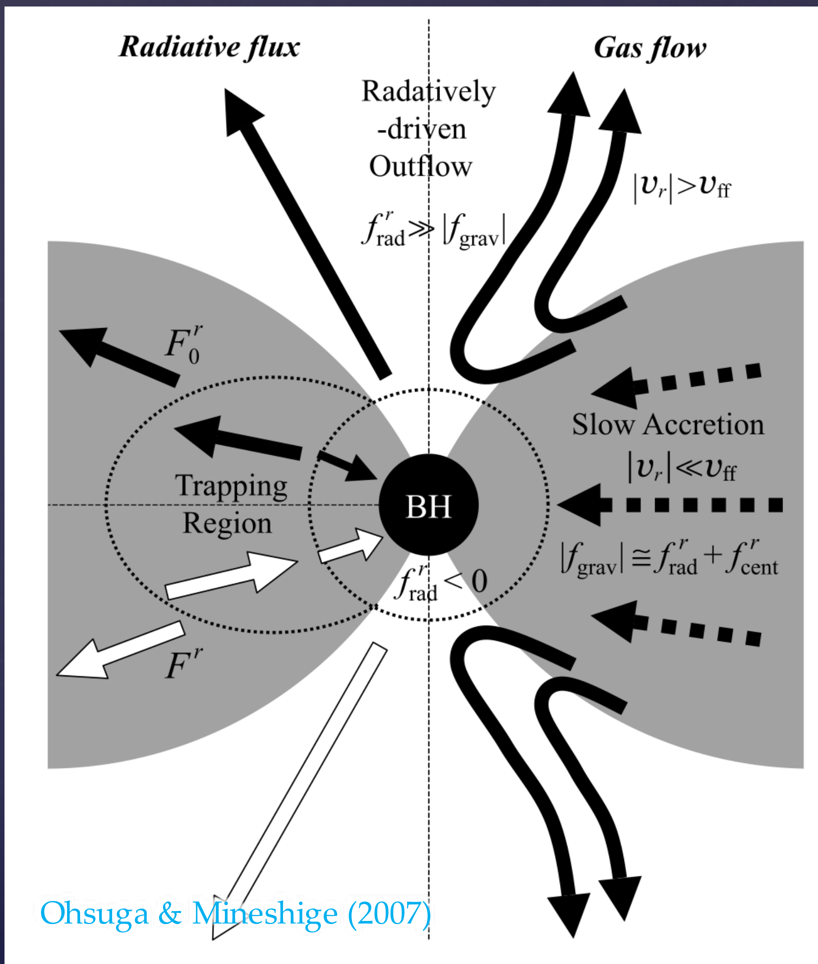
BALnicity Index



Maximum velocity

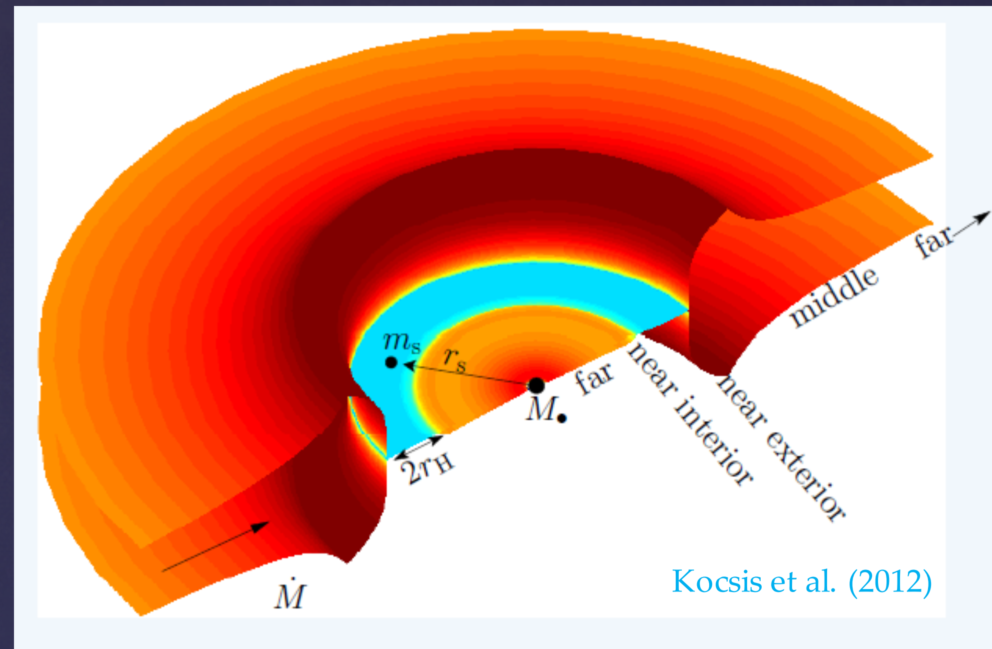
Physics Not Clear for *Intrinsic* X-ray Weakness

Supercritical Accretion?



Trapping of the radiation from the innermost parts of disk/corona

SMBH Binaries?



- Tidal torques from the binary open a gap in the circumbinary gas.
- Miss the inner, highest temperature disk region that produces the X-rays (e.g., Milosavljevic & Phinney 2005; Takamitsu & Kristen 2010).

Coronal Quenching? (e.g., see discussion in Leighly et al. 2007)

An Alternative Scenario

- A very compact Compton-thick absorber along the line of sight.
- No transmitted component (N_H>1E25).
- No Compton scattering (Compton hump) due to the compactness.
- Spectrum dominated by a scattered component from a large-scale highly ionized reflector. A couple percent of the intrinsic one.
- Unlikely.

Affecting X-ray Surveys?

- <23% among BAL quasars.
- <2% among non-BAL quasars.
- Thus <5% among the luminous type 1 AGN population.
- No significant effect on X-ray surveys for the census of these AGNs.

Summary

- Two candidates for intrinsically X-ray weak BAL quasars discovered (LBQS 1203+1530 and LBQS 1442-0011. Best ones besides PHL 1811.

- A 7-10% fraction among HiBAL quasars.

Future Work

- The two objects are only weakly detected in the hard band (~2.3 σ detections), with substantial uncertainties on Γ and X-ray weakness. Deeper Chandra or XMM-Newton observations required.
- Deeper observations on the LoBAL quasars to find more such extreme quasars.