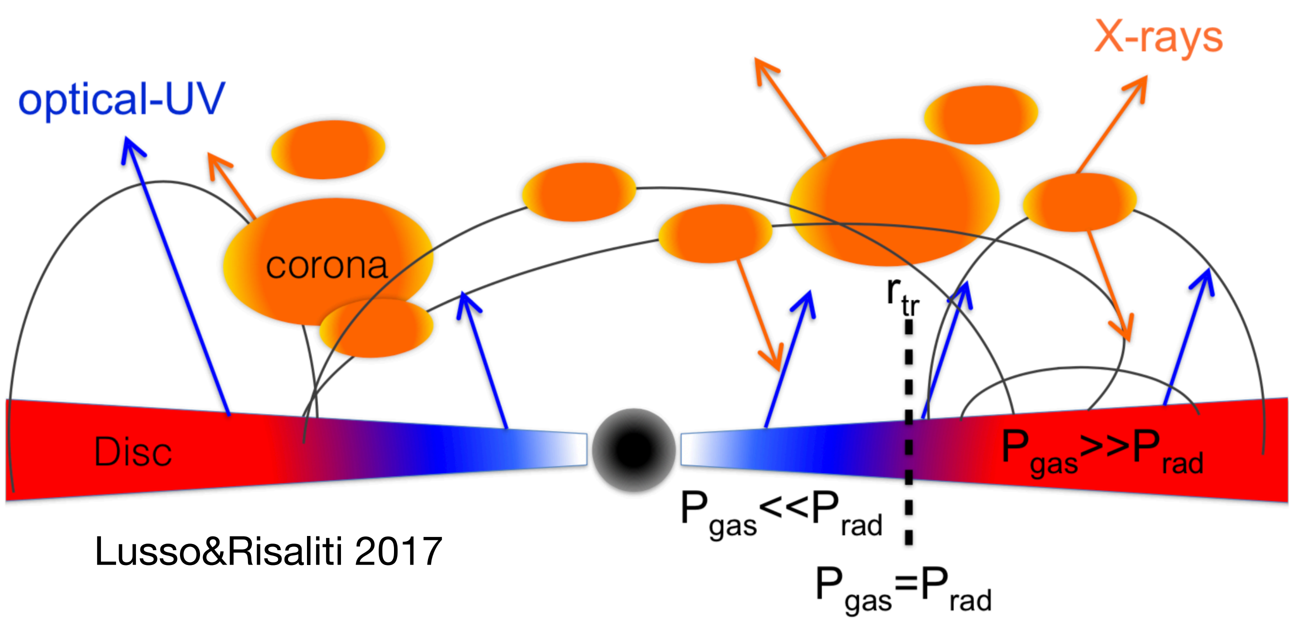
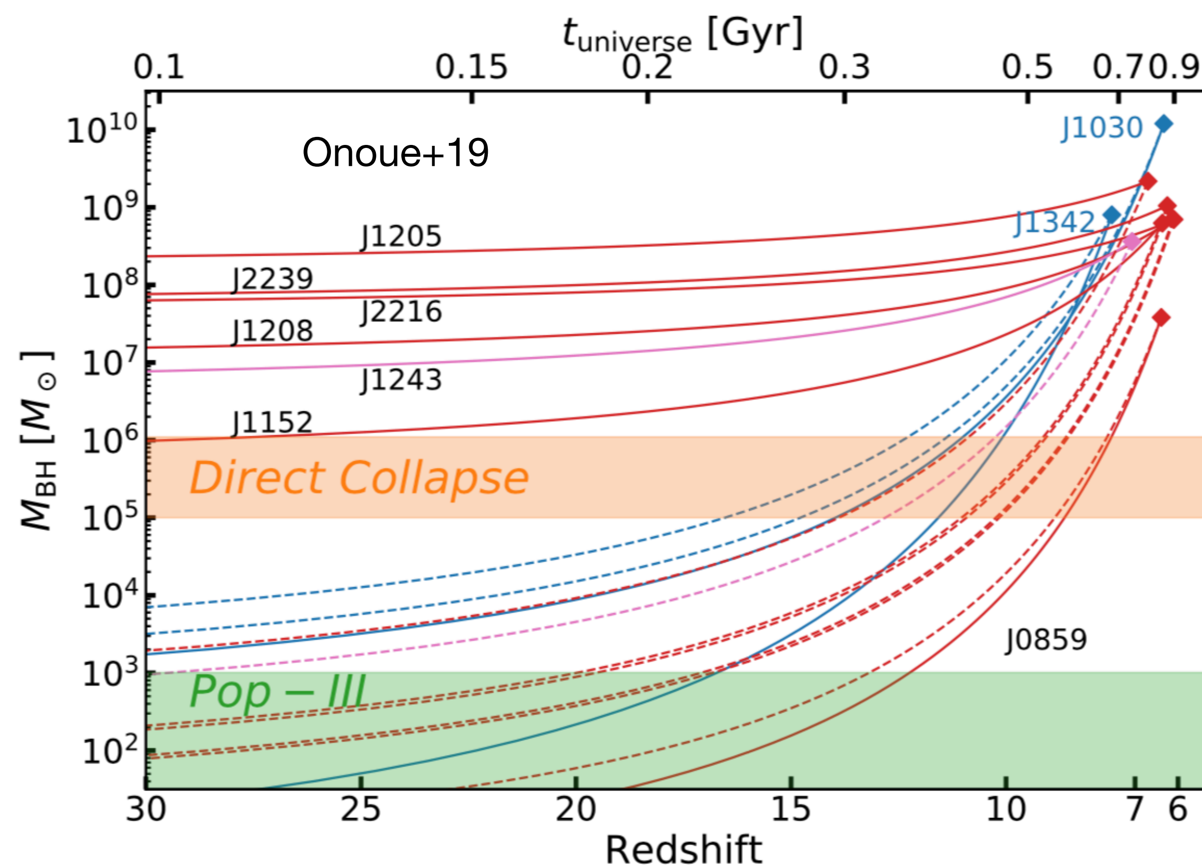
X-rays from QSOs in the first Gyr of the Universe

F. Vito
PUC (Chile) / CASSACA (China)

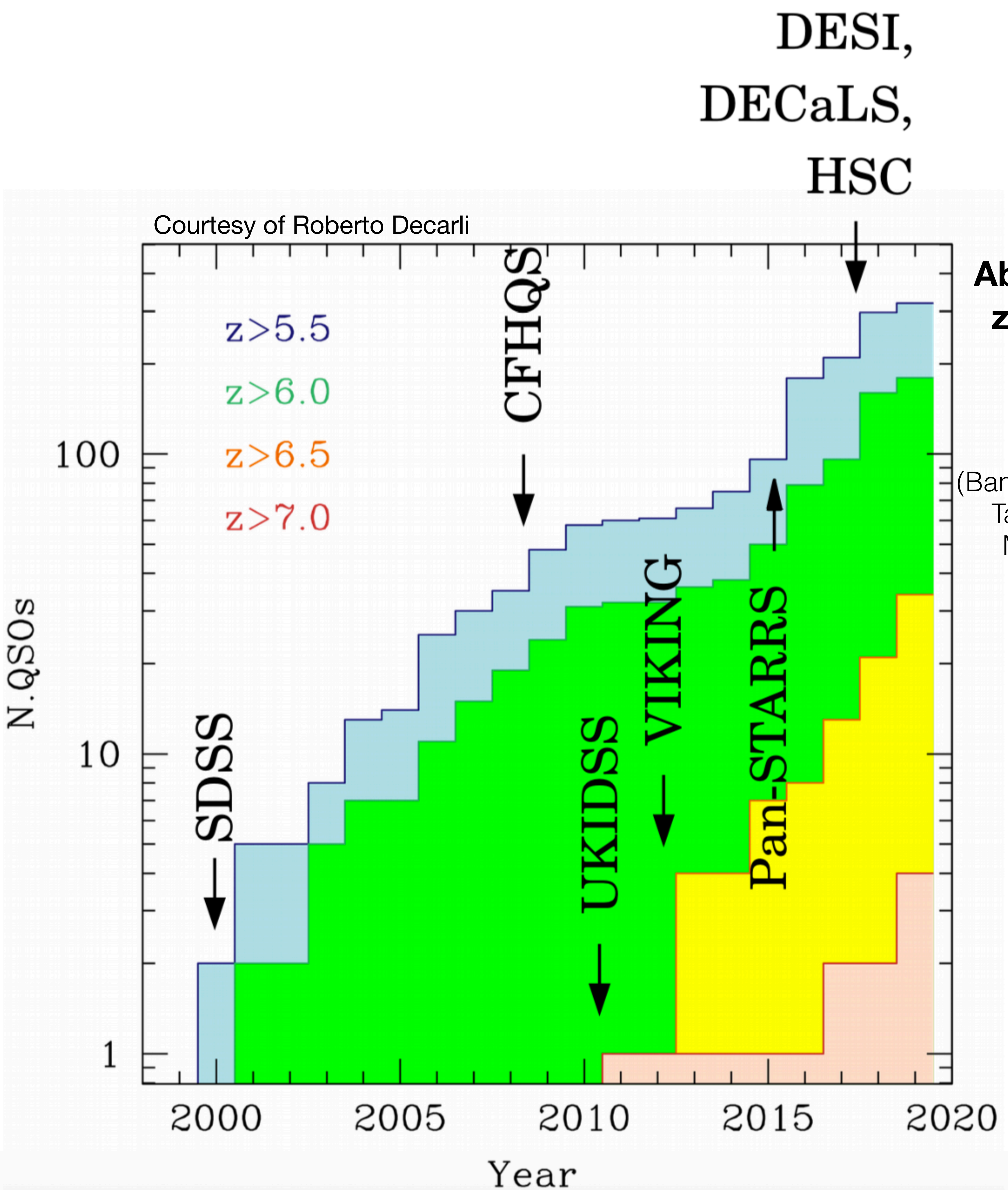
with W.N. Brandt, F.E. Bauer, F. Calura, R. Gilli, B. Luo, O. Shemmer, C. Vignali, G. Zamorani
M. Brusa, F. Civano, A. Comastri, R. Nanni, N. Cappelluti, M. Volonteri



Testing self-similarity of QSO accretion physics up to $z > 6$



Witnessing SMBH accretion as close as possible to the initial conditions of SMBH formation

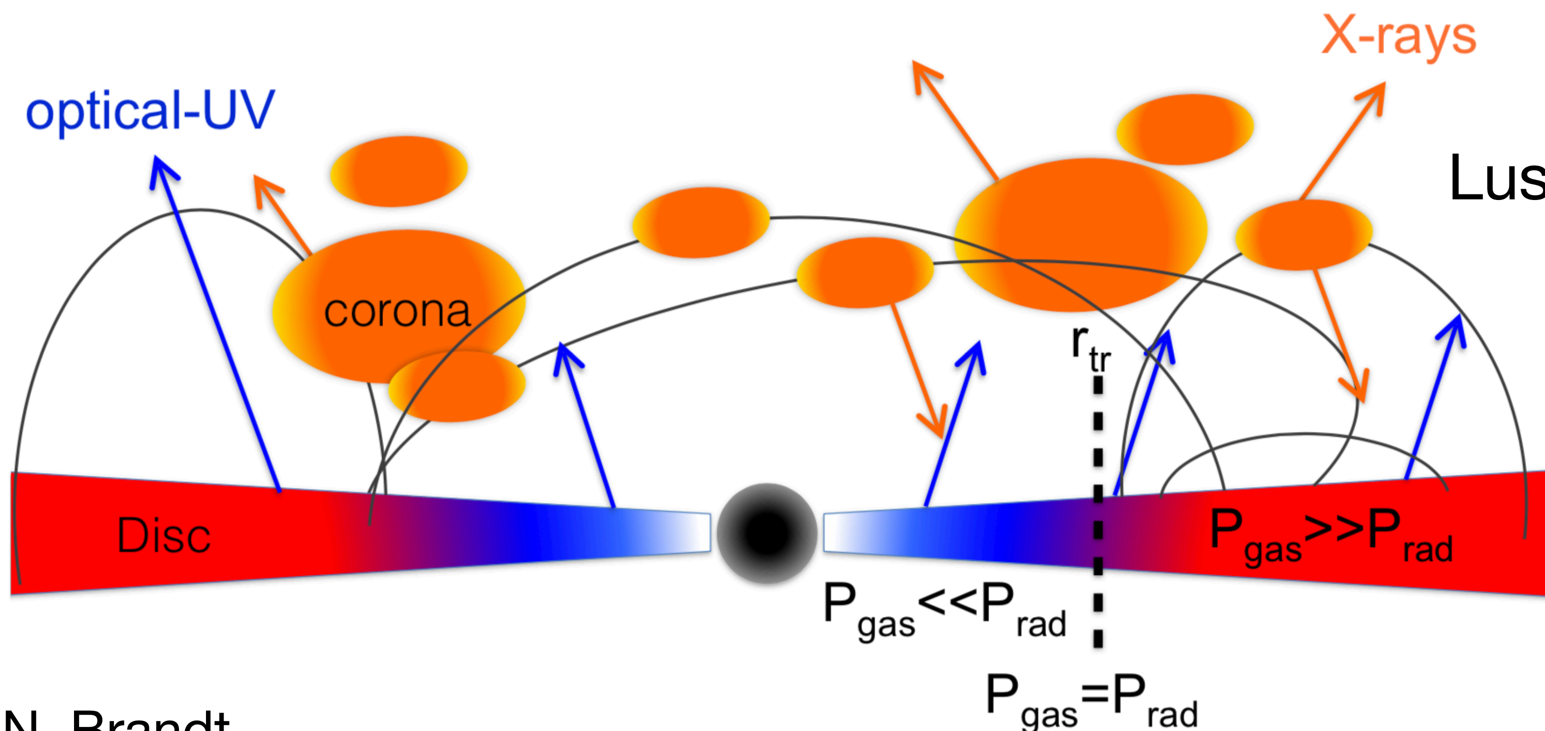


About 200 QSOs discovered so far at z>6 (i.e. <1 Gyr after the Big Bang), thanks to wide area (>1000 deg^2) optical/NIR surveys

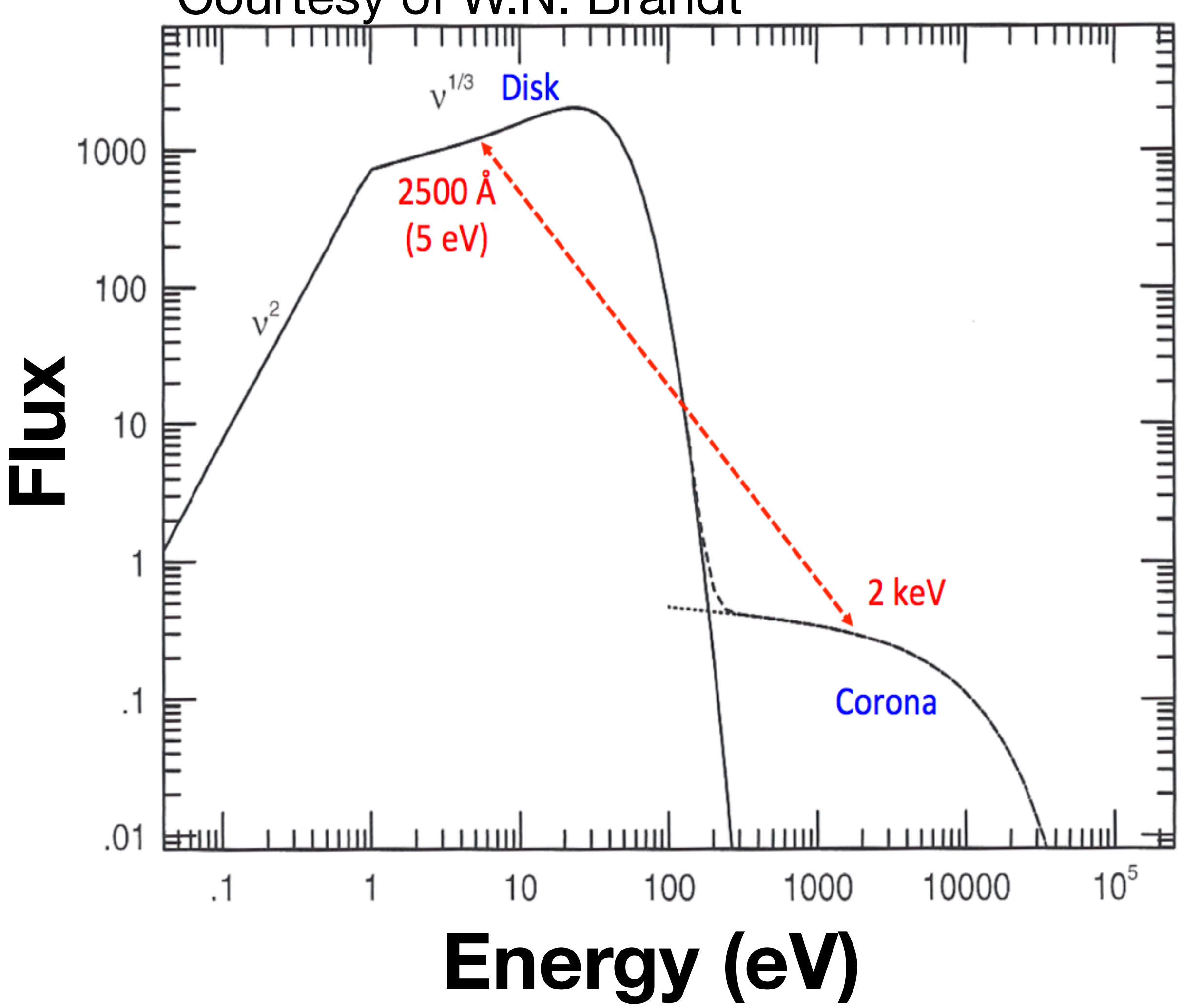
(Banados+16, +18, Mazzucchelli+17, Reed+17, +19, Tang+17, Wang+17, +18a, +18b, Chehade+18, Matsuoka+18a,+18b, +19, Yang+18, Fan+19, Pons+19)

(only ~15 z>6 QSOs with X-ray data, <8% of the known population)

Testing accretion mode (accretion disk + hot corona)

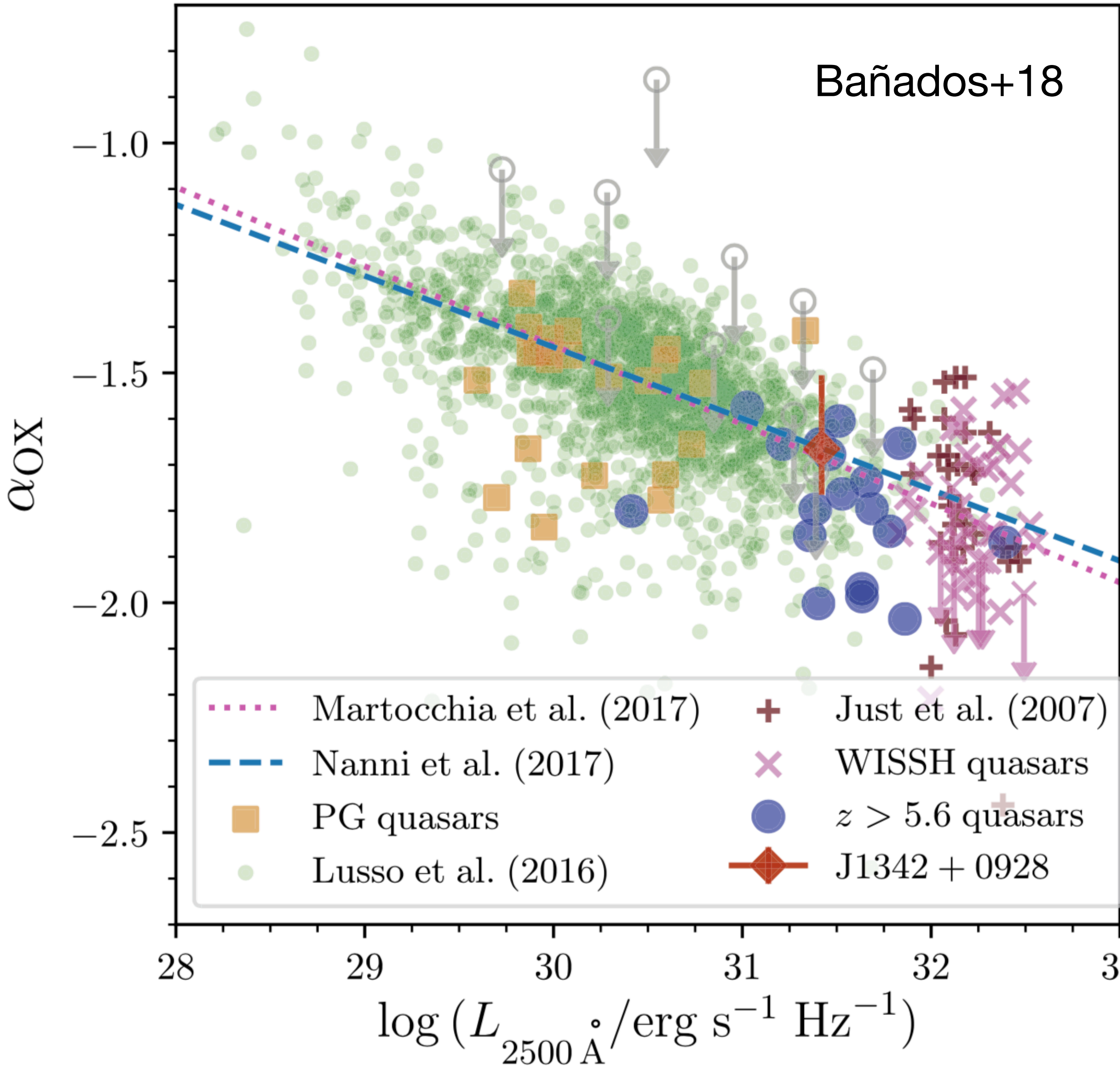


Courtesy of W.N. Brandt



$$\alpha_{ox} = 0.38 \times \log \frac{L_{2\,\mathrm{keV}}}{L_{2500\,\text{Å}}}$$

(Tananbaum+1979 and many others since)



$$\alpha_{ox} \propto -0.15 \times \log L_{2500\,Å}$$

(e.g., Steffen+06, Just+07, Lusso+10,+16, Nanni+17)

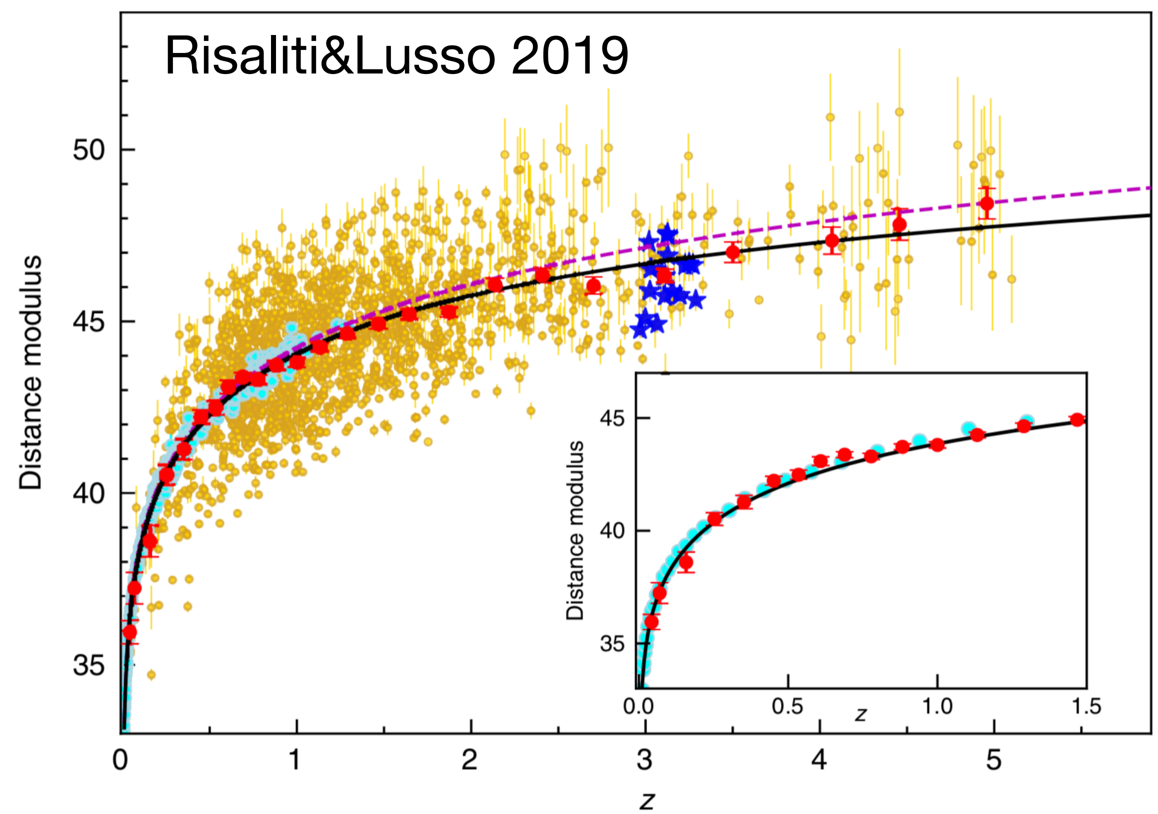
Hot corona contribution decreases at high luminosity

No (strong) evolution with redshift **(e.g. Lusso&Risaliti 2017)**

but poorly sampled at *z*>6!!

Possible implications for cosmology

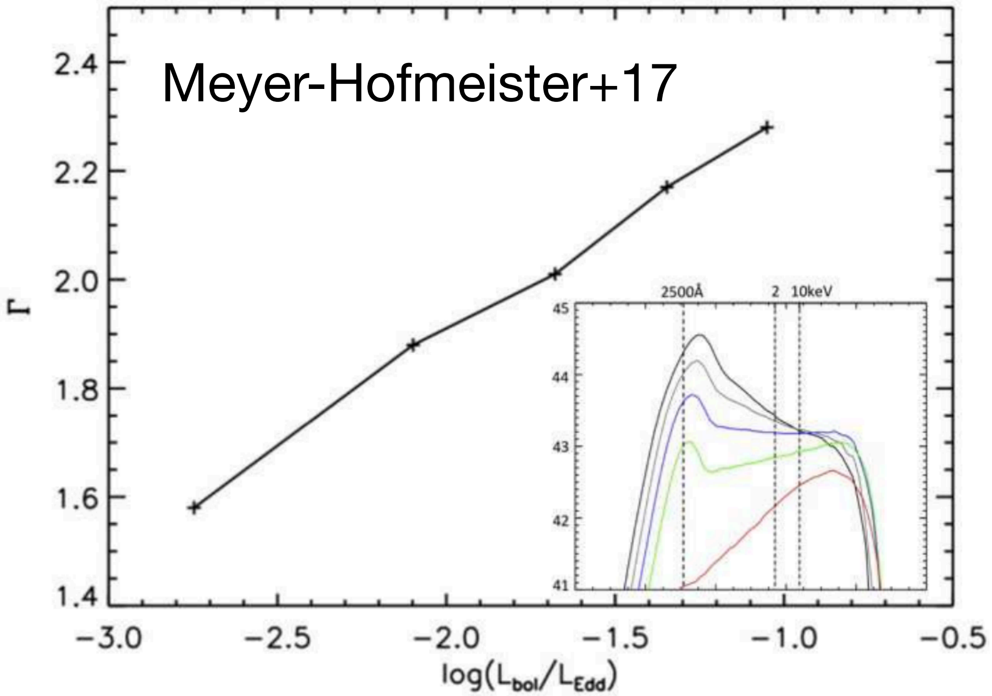
(Risaliti&Lusso 2018)

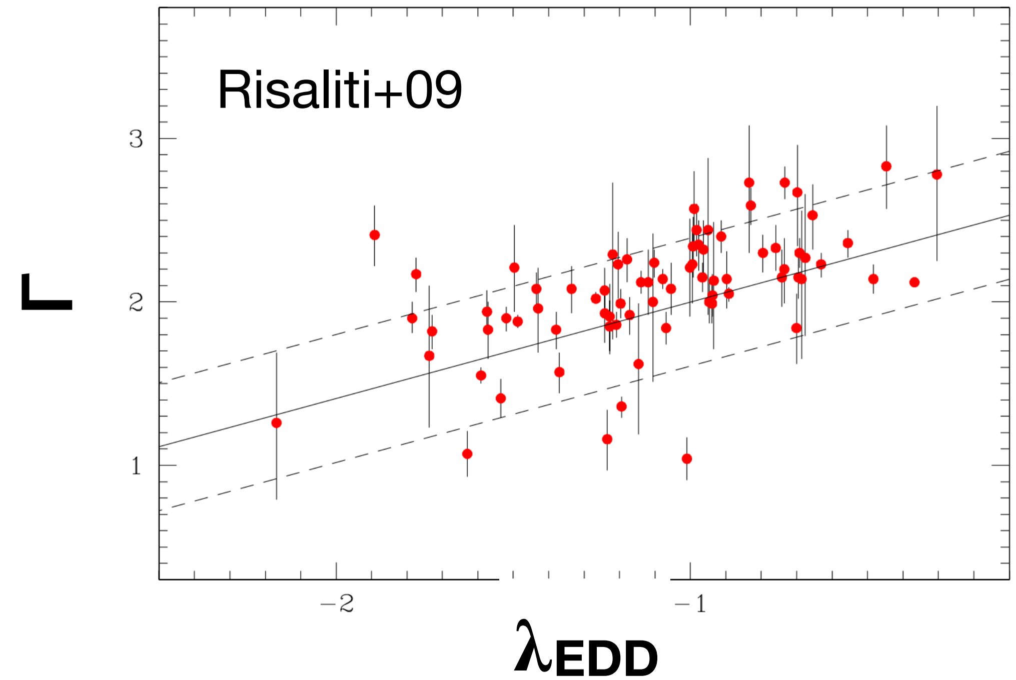


X-ray photon index (Γ) as a probe of accretion

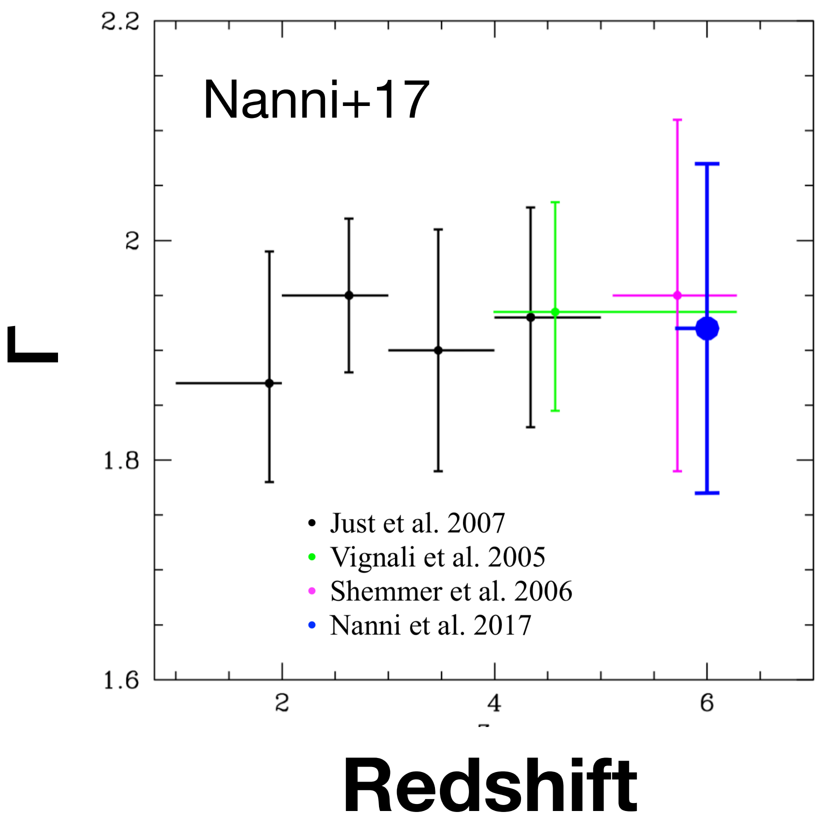
$N(E) \propto E^{-\Gamma}$

Γ includes information on the physical conditions (e.g. temperature) of the hot corona and its interplay with the accretion disk





e.g., Shemmer+08, Brightman+13, Fanali+13, but see also Trakhtenbrot+17



No (strong) evolution with redshift

but poorly sampled at *z*>6!!

New *Chandra* observations of 10 *z*>6 QSOs

Chandra Cycle 19 Large Program (~430 ks)

Vito+ in prep.

New observations

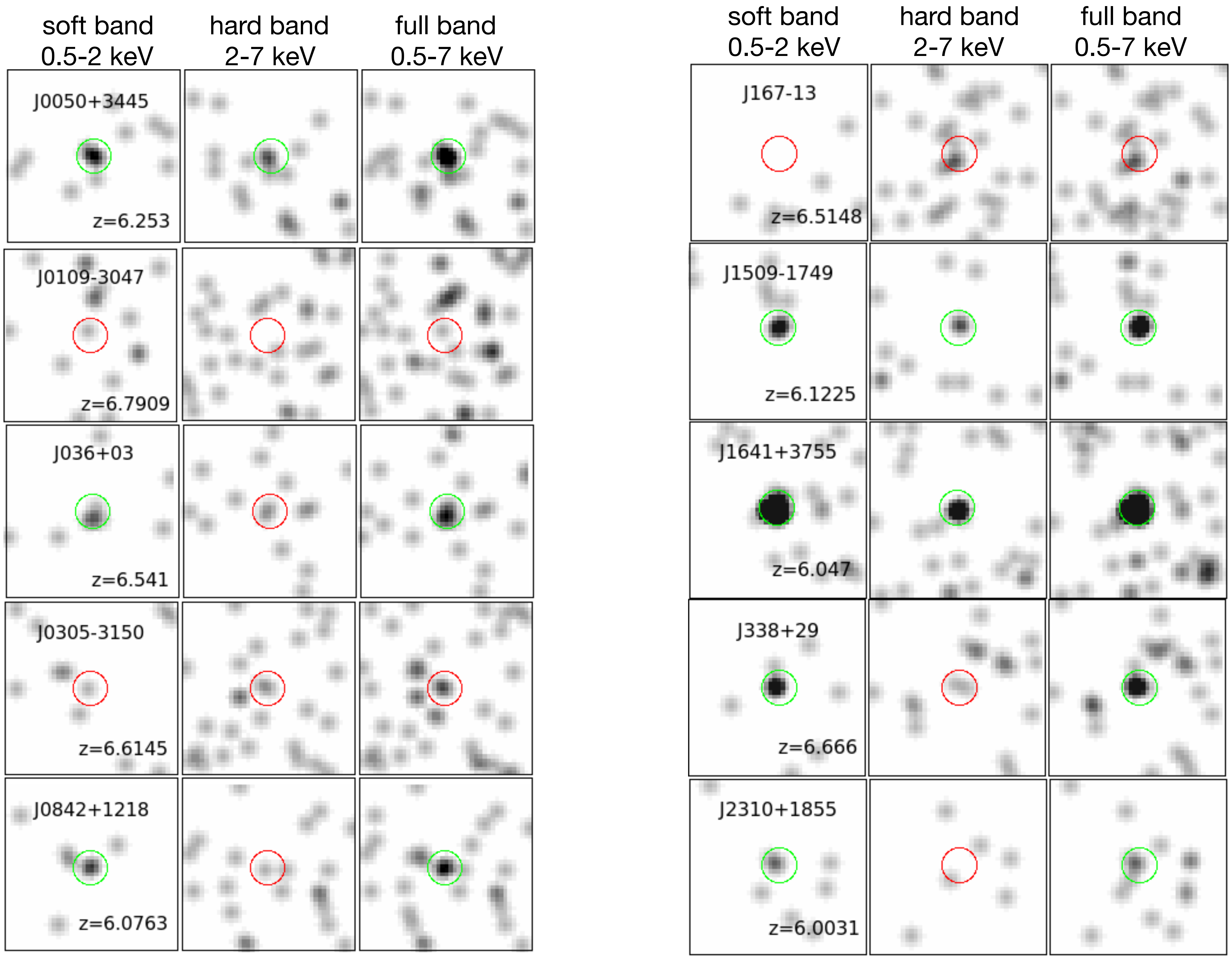
Archival data

Table 1. Physical properties of the $z > 6$ QSOs with new or archival X-ray observations.

ID (1)	RA (2)	DEC (3)	z (4)	$M_{1450\text{Å}}$ ($m_{1450\text{Å}}$) (5)	$\log(\frac{L_{bol}}{L_\odot})$ (6)	$\log(\frac{M_{BH}}{M_\odot})$ (7)	λ_{Edd} (8)	Ref. (disc./z/M_{BH}) (9)	R (10)
New targets									
CFHQSJ0050+3445	00:50:06.67	+34:45:21.65	6.253 (Mg II)	−26.70 (20.11)	13.45	9.41	0.34	W10/W10/W10	< 11.4
VIKJ0109−3047	01:09:53.13	−30:47:26.31	6.7909 ([C II])	−25.64 (21.30)	13.06	9.12	0.27	V13/V16/M17	< 34.1
PSOJ036+03	02:26:01.87	+03:02:59.42	6.541 ([C II])	−27.33 (19.55)	13.67	9.48	0.48	V15/B15/M17	< 2.1
VIKJ0305−3150	03:05:16.92	−31:50:55.9	6.6145 ([C II])	−26.18 (20.72)	13.26	8.95	0.63	V13/V16/M17	< 20.0
SDSSJ0842+1218	08:42:29.43	+12:18:50.58	6.0763 ([C II])[a]	−26.91 (19.86)[a]	13.52	9.29	0.53	dR11/D18/dR11*[a]	< 1.3
PSOJ167−13	11:10:33.98	−13:29:45.60	6.5148 ([C II])[b]	−25.57 (21.25)	13.03	8.48	1.11	V15/M17/M17	< 34.3
CFHQSJ1509−1749	15:09:41.78	−17:49:26.80	6.1225 ([C II])[a]	−27.14 (19.64)[a]	13.61	9.47	0.42	W07/D18/W10[a]	< 1.2
CFHQSJ1641+3755	16:41:21.73	+37:55:20.15	6.047 (Mg II)	−25.67 (21.09)	13.07	8.38	1.51	W07/W10/W10	< 10.5
PSOJ338+29	22:32:55.14	+29:30:32.31	6.666 ([C II])	−26.14 (20.78)	13.24	9.43	0.20	V15/M17/M17	< 21.0
SDSSJ2310+1855	23:10:38.89	+18:55:19.93	6.0031 ([C II])	−27.80 (18.95)	13.85	9.62	0.52	Wa13/Wa13/J16	< 3.9
QSOs with previous X-ray data									
SDSSJ0100+2802	01:00:13.02	+28:02:25.92	6.3258 ([C II])	−29.14 (17.69)	14.33	10.03	0.62	Wu15/Wa16/Wu15*	< 1.2
ATLASJ0142−3327	01:42:43.73	−33:27:45.47	6.379 ([C II])[a]	−27.82 (19.02)[a]	13.85	—	—	C15/D18/—	< 4.2
CFHQSJ0210−0456	02:10:13.19	−04:56:20.90	6.4323 ([C II])	−24.53 (22.33)	12.65	7.90	1.76	W10/W13/W10	< 28.1
CFHQSJ0216−0455	02:16:27.81	−04:55:34.10	6.01 (Ly α)	−22.49 (24.27)	11.91	—	—	W09/W09/—	< 23.1
SDSSJ0303−0019	03:03:31.40	−00:19:12.90	6.078 (Mg II)	−25.56 (21.21)	13.03	8.61	0.81	J08/K09/dR11*	< 11.4
SDSSJ1030+0524	10:30:27.11	+05:24:55.06	6.308 (Mg II)	−26.99 (19.84)	13.55	9.21	0.68	F01/K07/dR11*	< 1.5
SDSSJ1048+4637[c]	10:48:45.07	+46:37:18.55	6.2284 (CO 6-5)	−27.24 (19.57)	13.64	9.55	0.38	F03/Wa10/dR11*	< 0.5
ULASJ1120+0641	11:20:01.48	+06:41:24.30	7.0842 ([C II])	−26.63 (20.38)	13.42	9.39	0.33	M11/V12/M17	< 0.7
SDSSJ1148+5251	11:48:16.65	52:51:50.39	6.4189 (CO 6-5)	−27.62 (19.24)	13.78	9.71	0.36	F03/Wa11/dR11*	$0.7^{+0.2}_{-0.2}$
SDSSJ1306+0356	13:06:08.27	+03:56:26.36	6.0337 ([C II])[a]	−26.82 (19.94)[a]	13.49	9.30	0.48	F01/D18/dR11*[a]	< 1.5
ULASJ1342+0928	13:42:08.27	+09:28:38.61	7.5413 ([C II])	−26.76 (20.34)	13.47	8.89	1.14	B18a/V17/B18a	< 4.7
SDSSJ1602+4228	16:02:53.98	+42:28:24.94	6.09 (Ly α)	−26.94 (19.83)	13.53	—	—	F04/F04/—	$0.8^{+0.2}_{-0.2}$
SDSSJ1623+3112	16:23:31.81	+31:12:00.53	6.26 ([C II])	−26.55 (20.27)	13.39	9.15	0.54	F04/Wa11/dR11*	< 2.3
SDSSJ1630+4012	16:30:33.90	+40:12:09.69	6.065 (Mg II)	−26.19 (20.58)	13.26	8.96	0.62	F03/I04/dR11*	< 2.2
HSCJ2216−0016[c]	22:16:44.47	−00:16:50.10	6.10 (Ly α)	−23.62 (23.16)	12.32	—	—	M16/M16/—	< 40.9

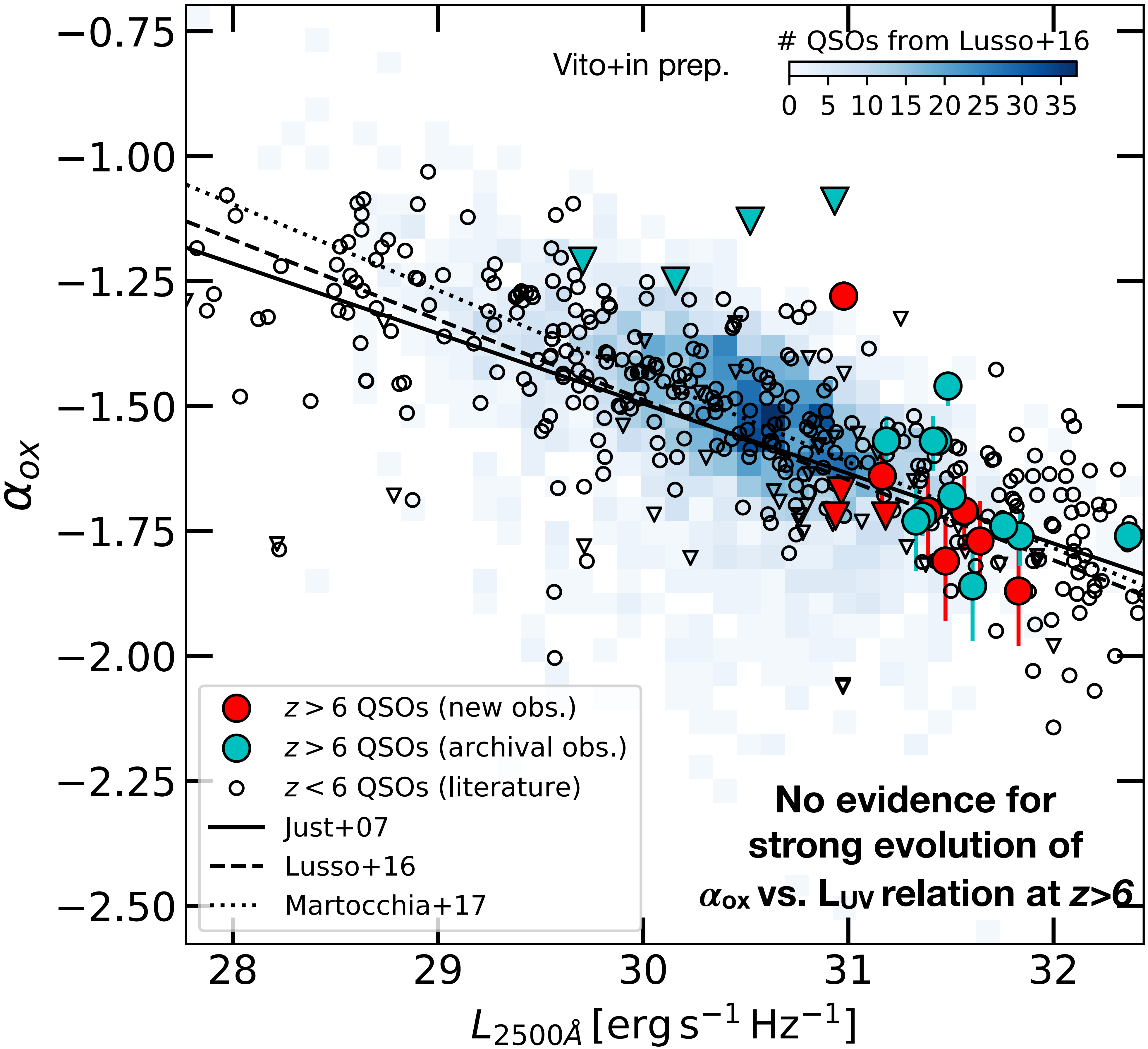
Now we have 25 *z*>6 QSOs with sensitive X-ray data and can start doing robust statistical analysis

New *Chandra* observations of 10 $z>6$ QSOs

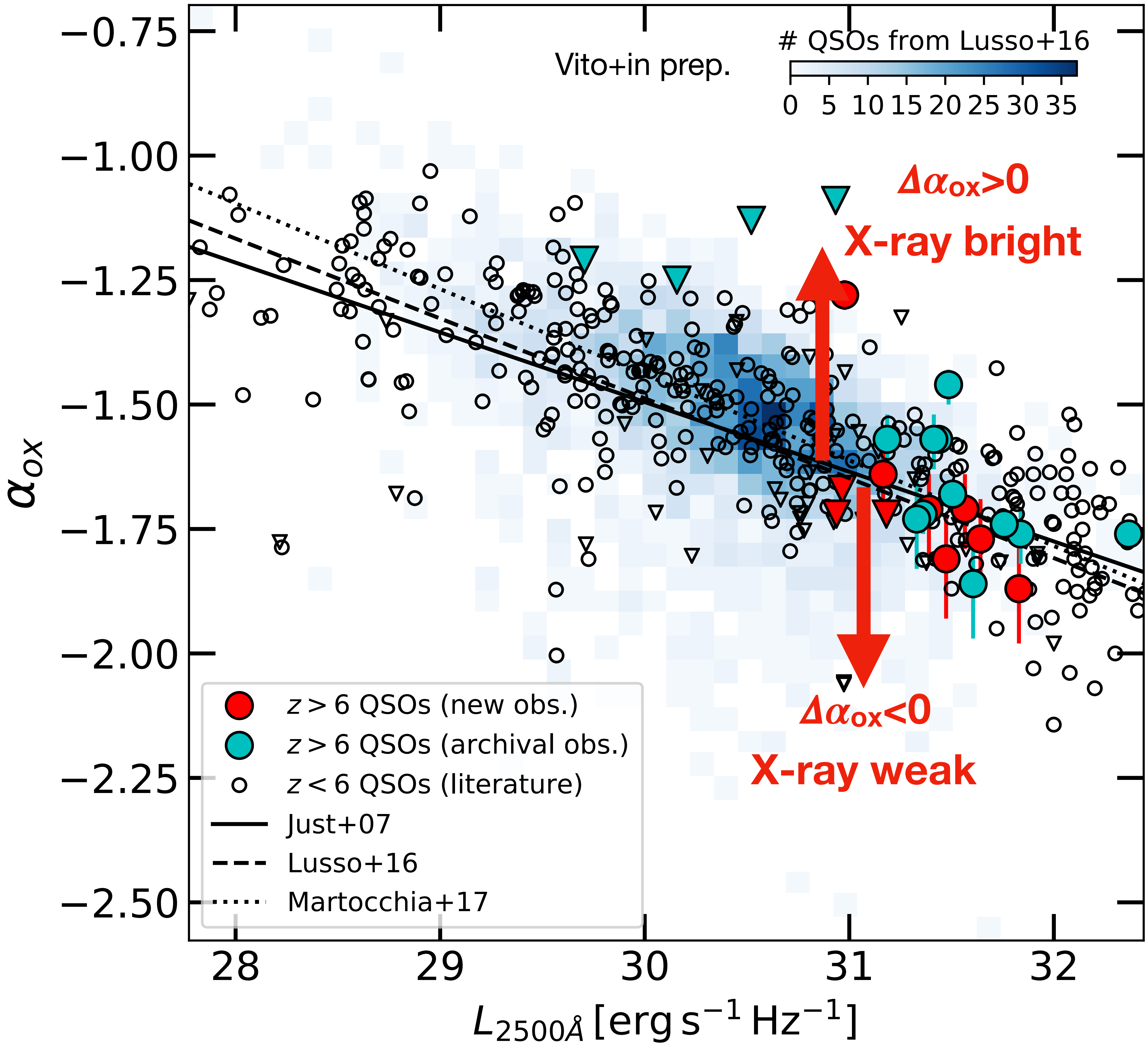


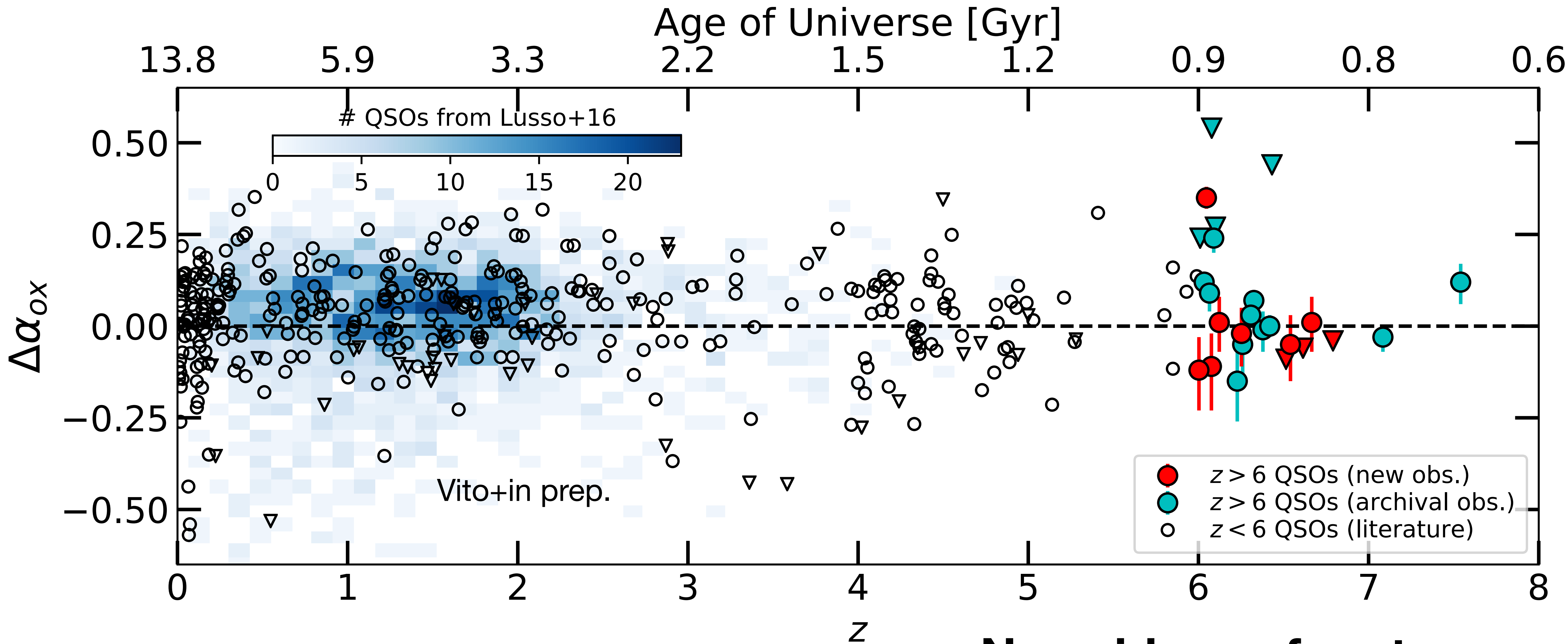
Detected (P>0.99) Vito+in prep. Undetected

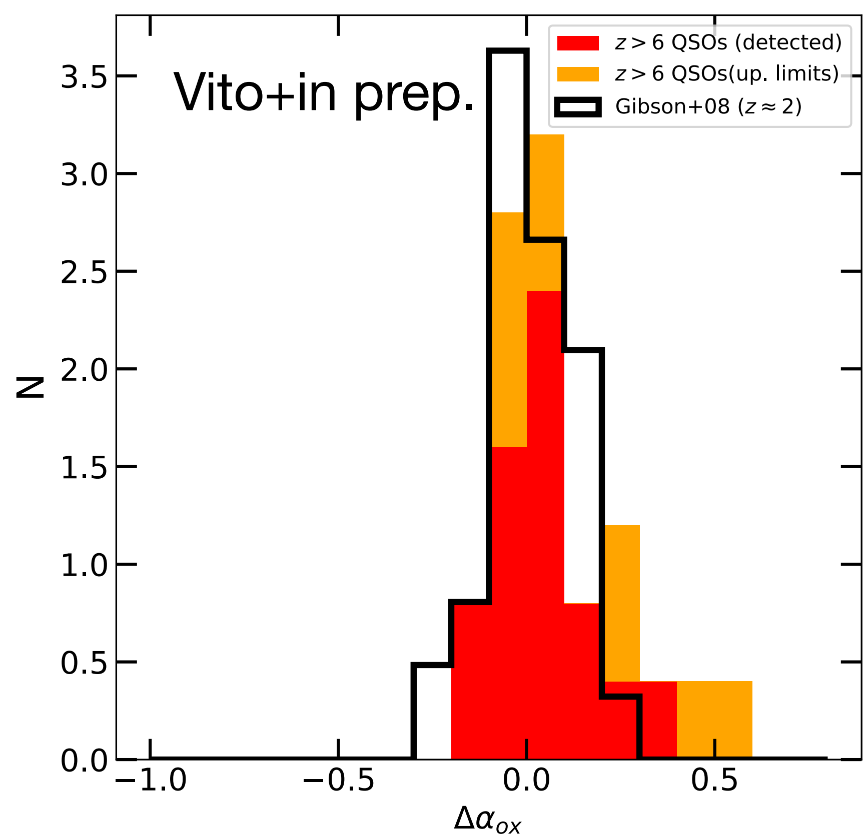
α_{ox} vs. L_{UV} relation extended at $z>6$



$\Delta\alpha_{ox}=\alpha_{ox}(obs)-\alpha_{ox}(expect.)$





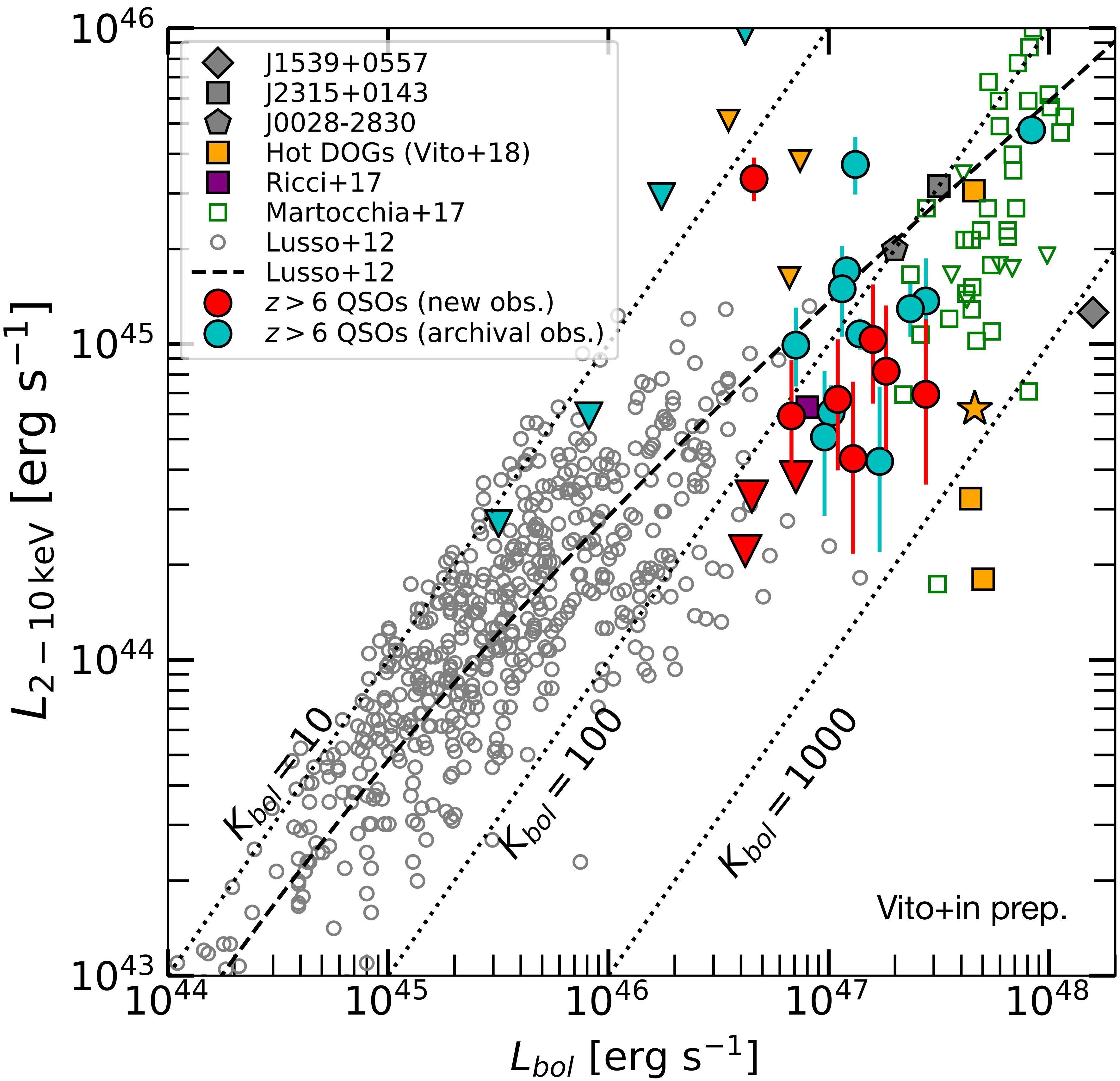


Compared also with "ultra-clean" z=2 QSO sample by Gibson+08

No evidence for strong evolution of α_{ox} vs. L_{UV} relation at z>6

No apparent relation b/w α_{ox} and M_{BH} or λ_{EDD}, but small sample size and large uncertainties

Bolometric correction: L_{bol} / L_X



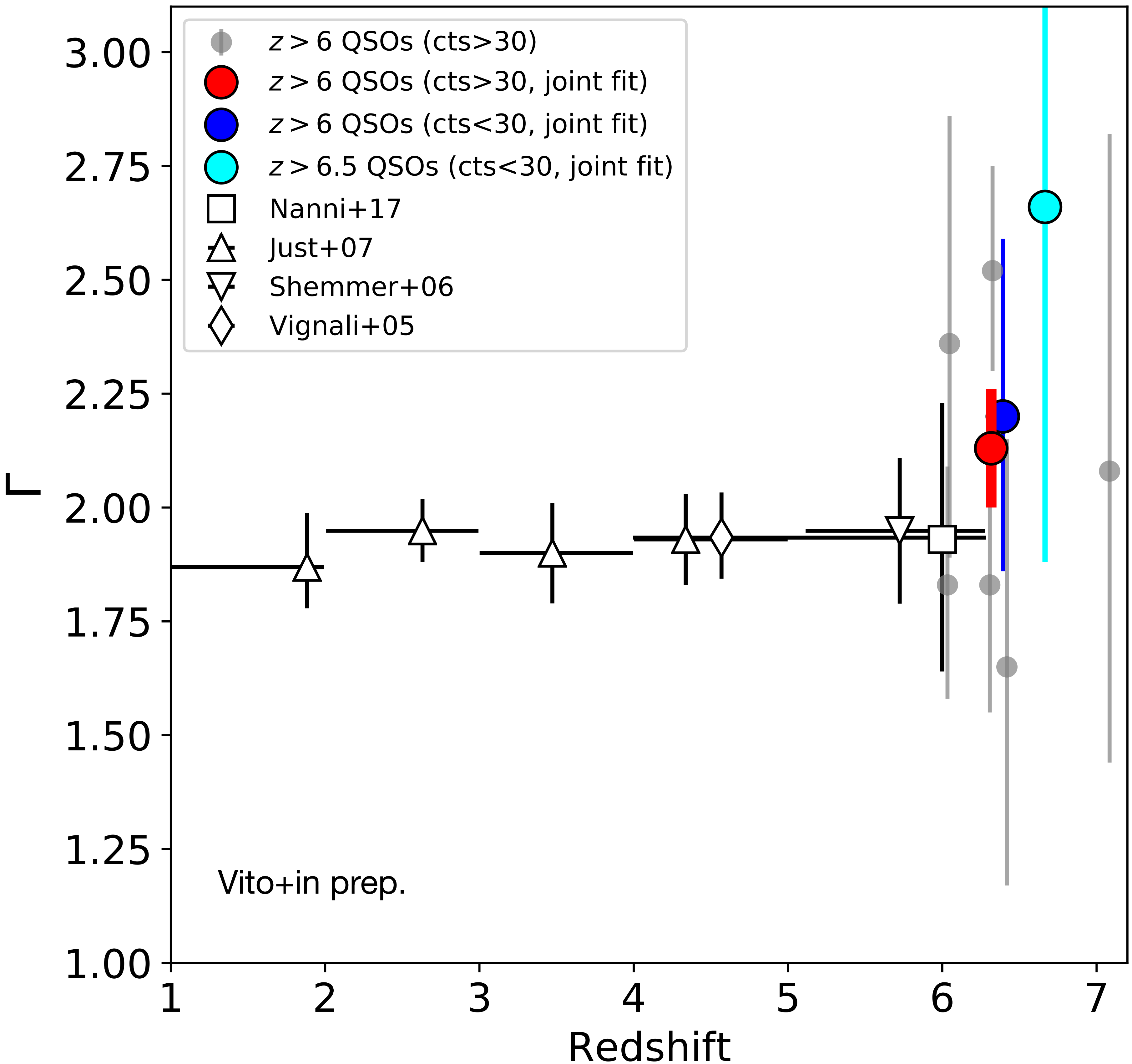
Populate the luminosity regime b/w “normal” AGN and hyper-luminous QSOs, and extend at z>6

Larger $K_{\rm bol}$ at higher luminosities, in agreement with steeper $\alpha_{\rm ox}$ at higher luminosities

Change of the accretion-disk/hot-corona physics/geometry at high luminosities/$\lambda_{\rm EDD}$

but same change at all redshifts

Average QSO photon index as a function of z



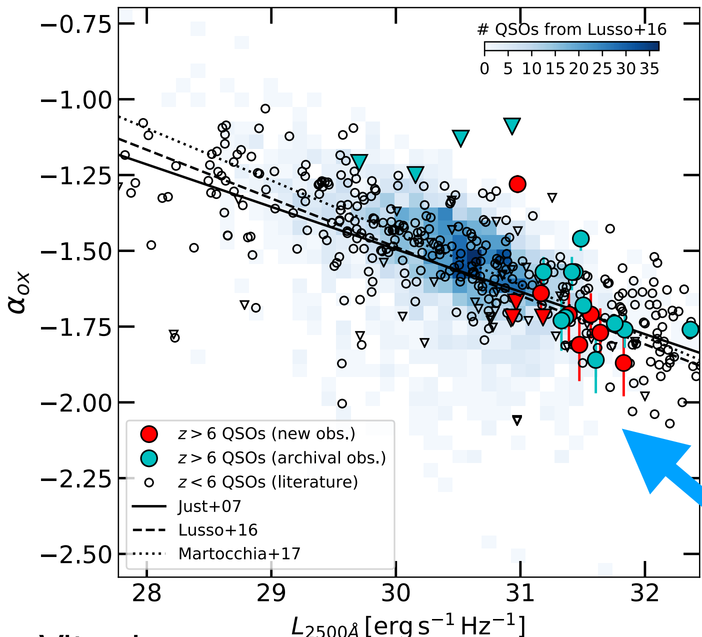
$\langle\Gamma\rangle \approx 2.1\text{-}2.2$ for $z>6$ QSOs

Consistent with z=1-6 results

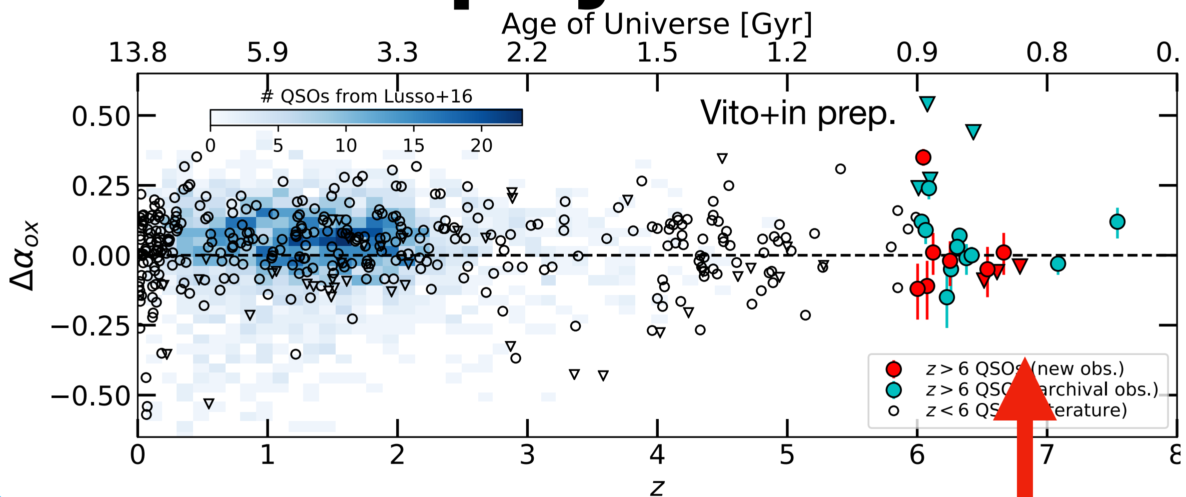
"Universal" accretion mode (λ_{EDD} dependent, redshift independent)

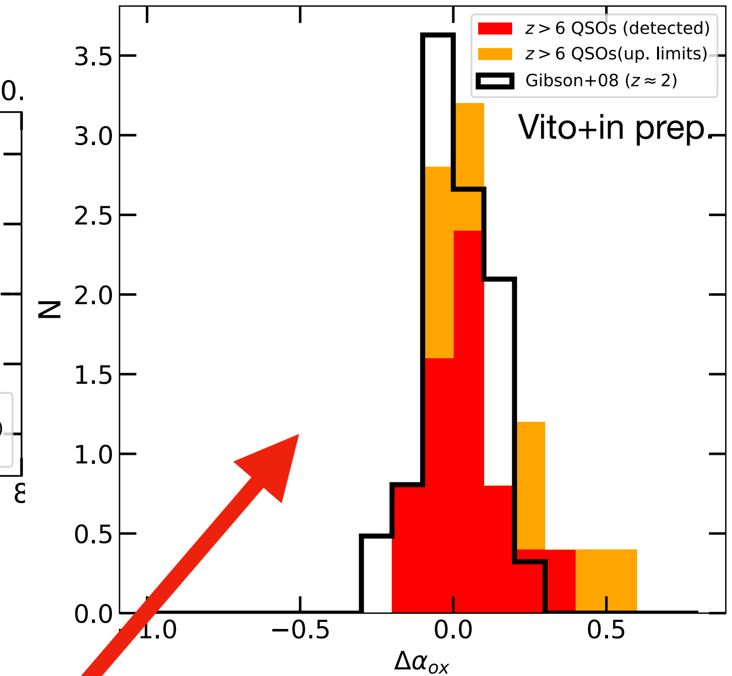
(but hint of a steepening?)

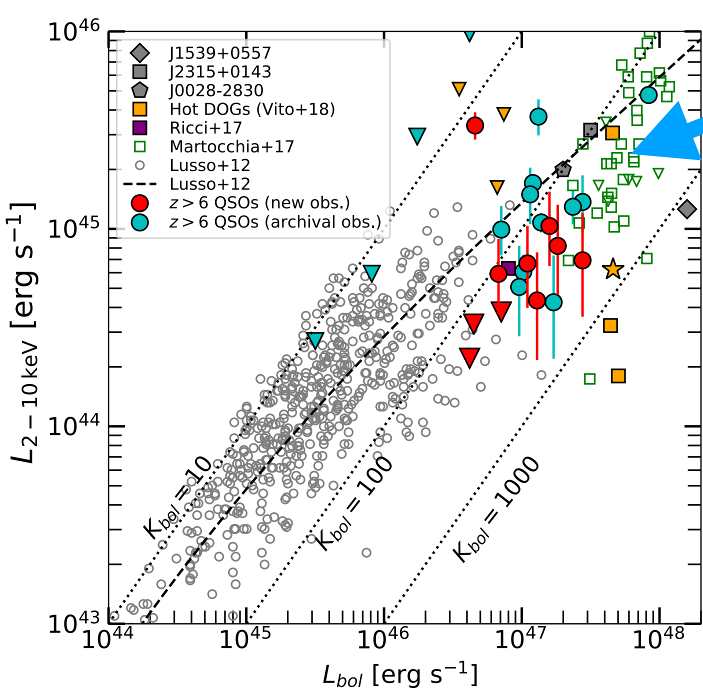
Conclusion: No significant change of the QSO accretion physics at *z*>6



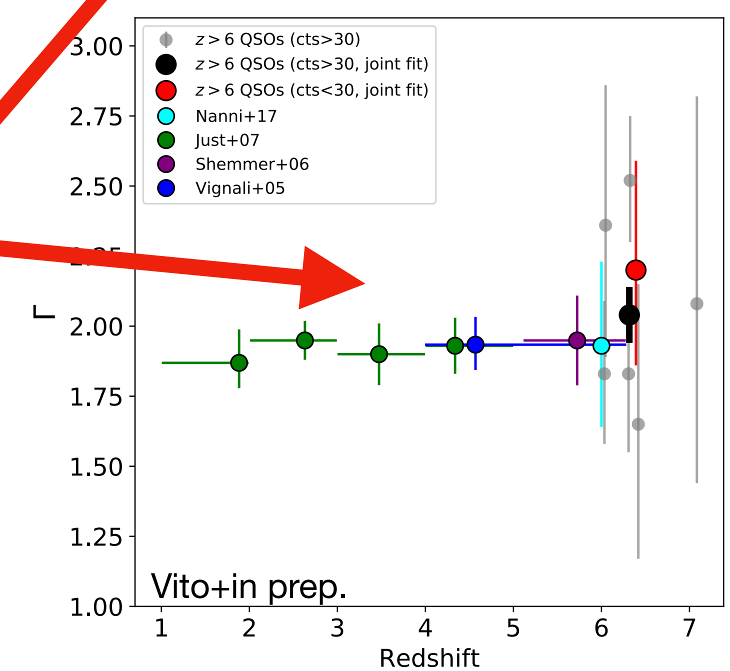
Vito+in prep.



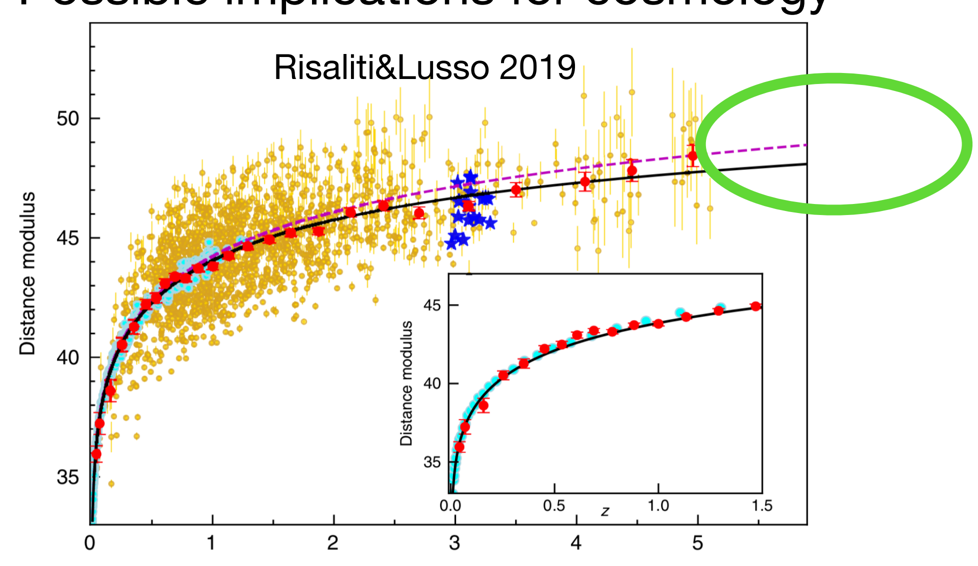




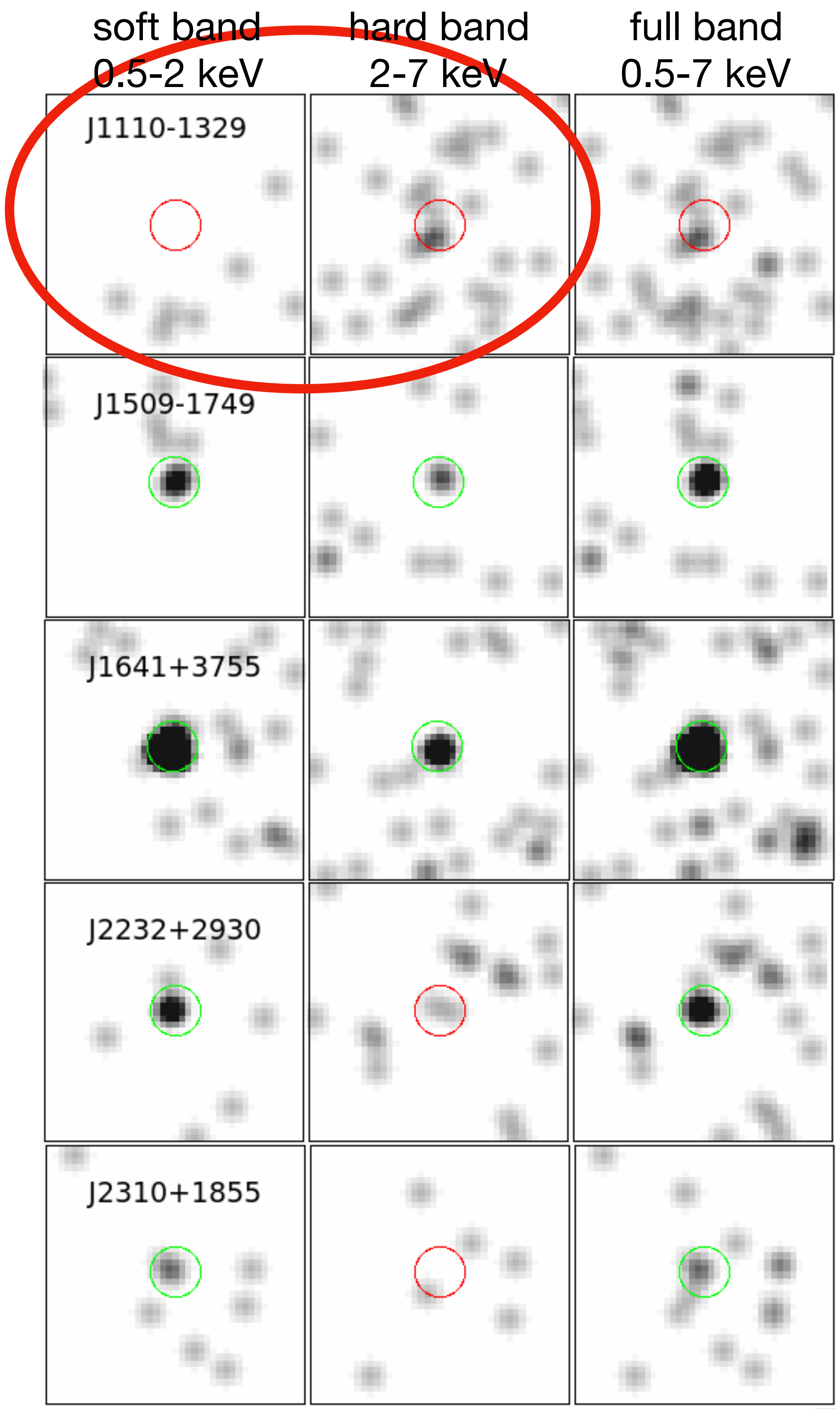
Same dependence on luminosity (i.e., λ_{EDD}?) at all redshifts



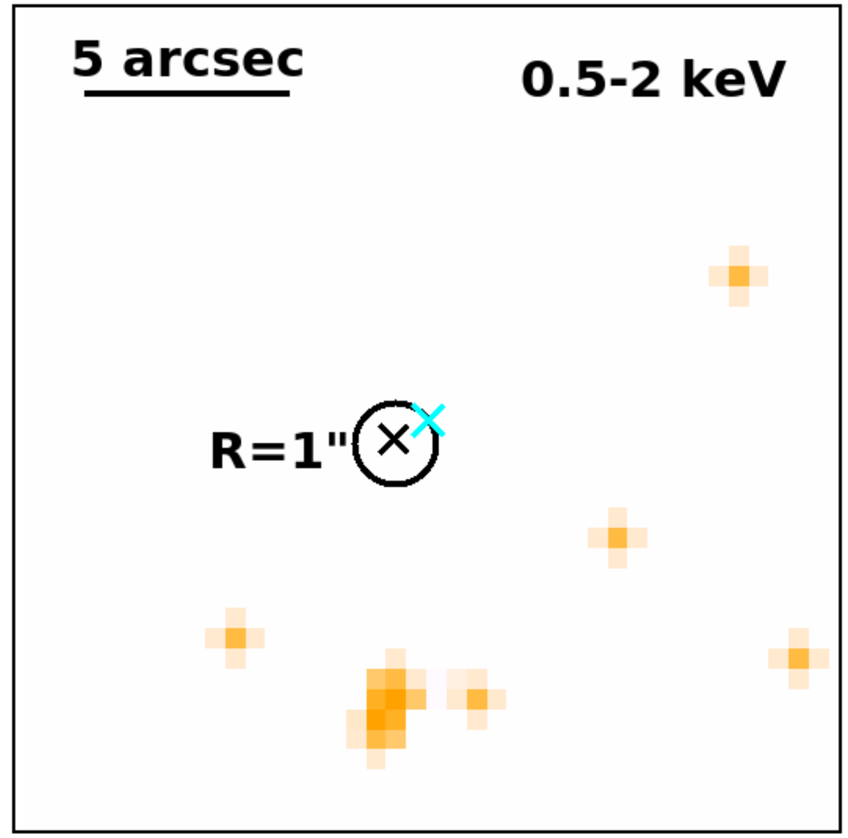
Possible implications for cosmology

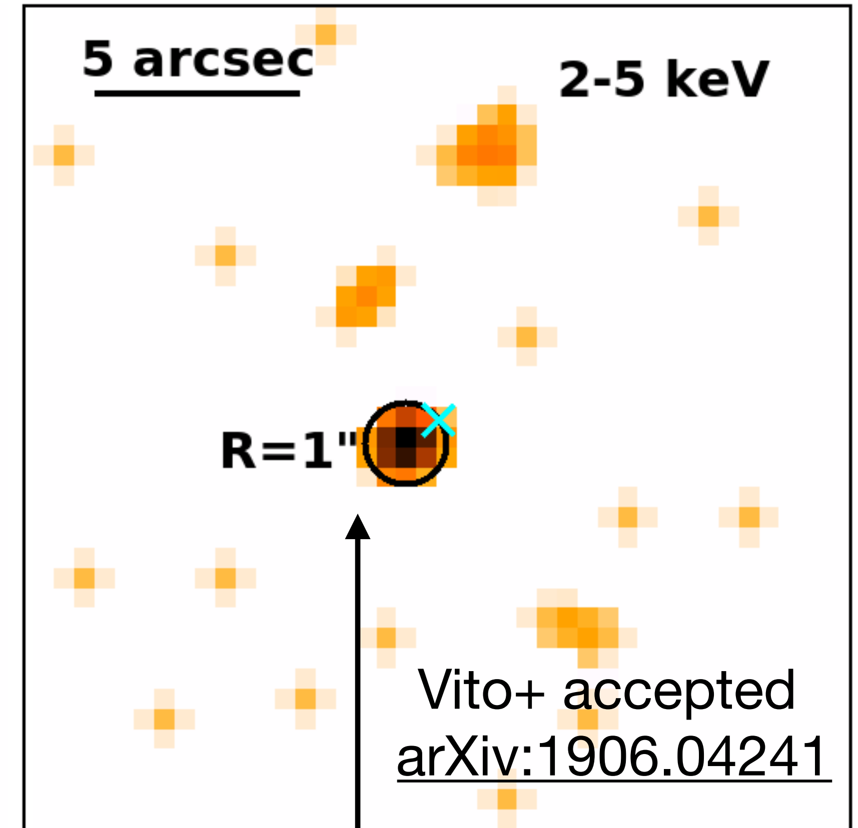


PSO167-13 (*z*=6.515): first heavily obscured QSO candidate at *z*>6!

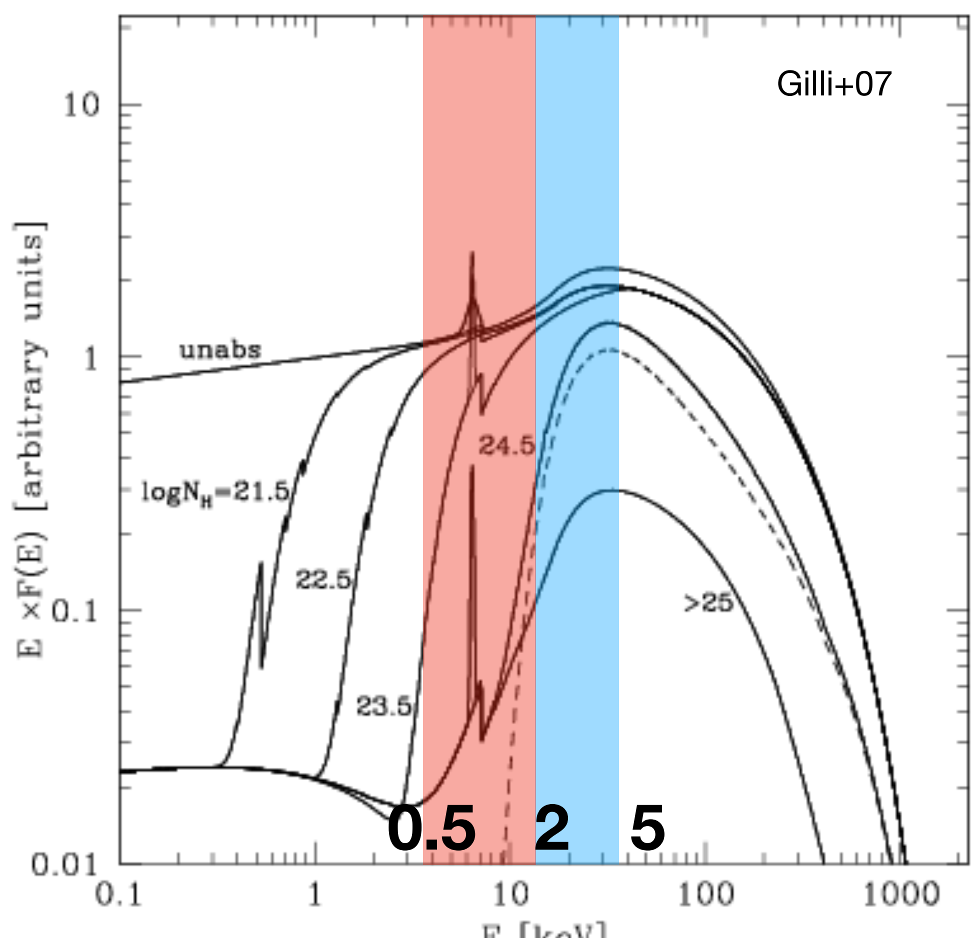


Vito+in prep.





3 photons
(P=0.9996,
Weisskopf+07)



$N_H > 2 \times 10^{24}$ cm^{-2}

at 68% confidence level

$N_H > 6 \times 10^{23}$ cm^{-2}

at 90% confidence level

First heavily obscured QSO candidate at *z*>6!

PSO167-13 (*z*=6.515): first heavily obscured QSO candidate at *z*>6!

X-ray to optical/sub-mm offset of ~1 arcsec, but significant positional uncertainty.

Why an optically type I QSO is heavily obscured in X-rays?

- **WLQ?**
- **BALQSO?**
- **Changing look QSO?**