The furthest Quasars in the X-rays

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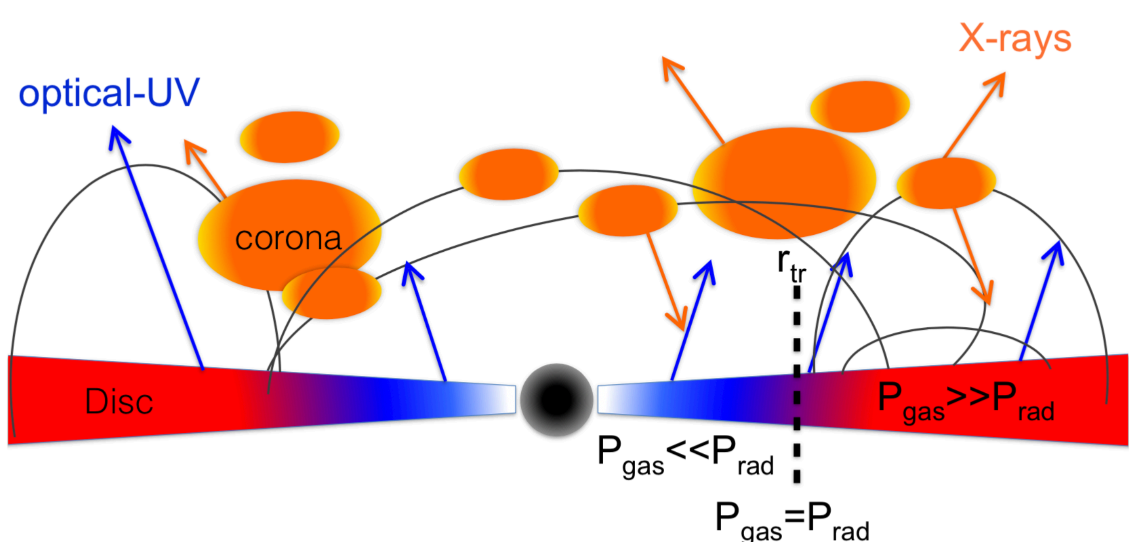
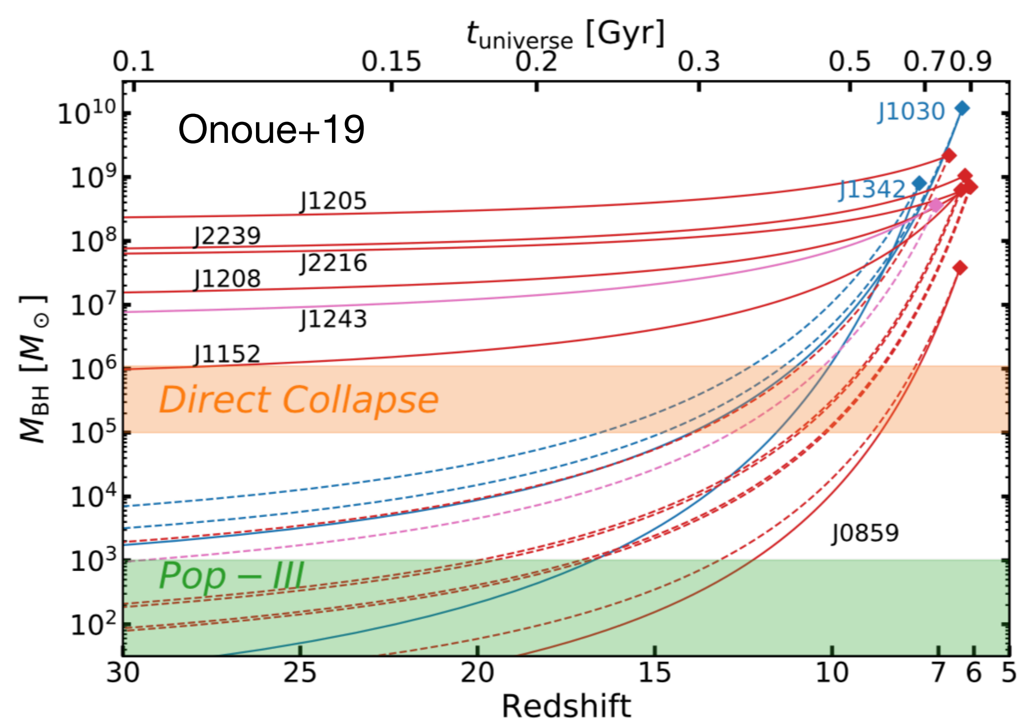
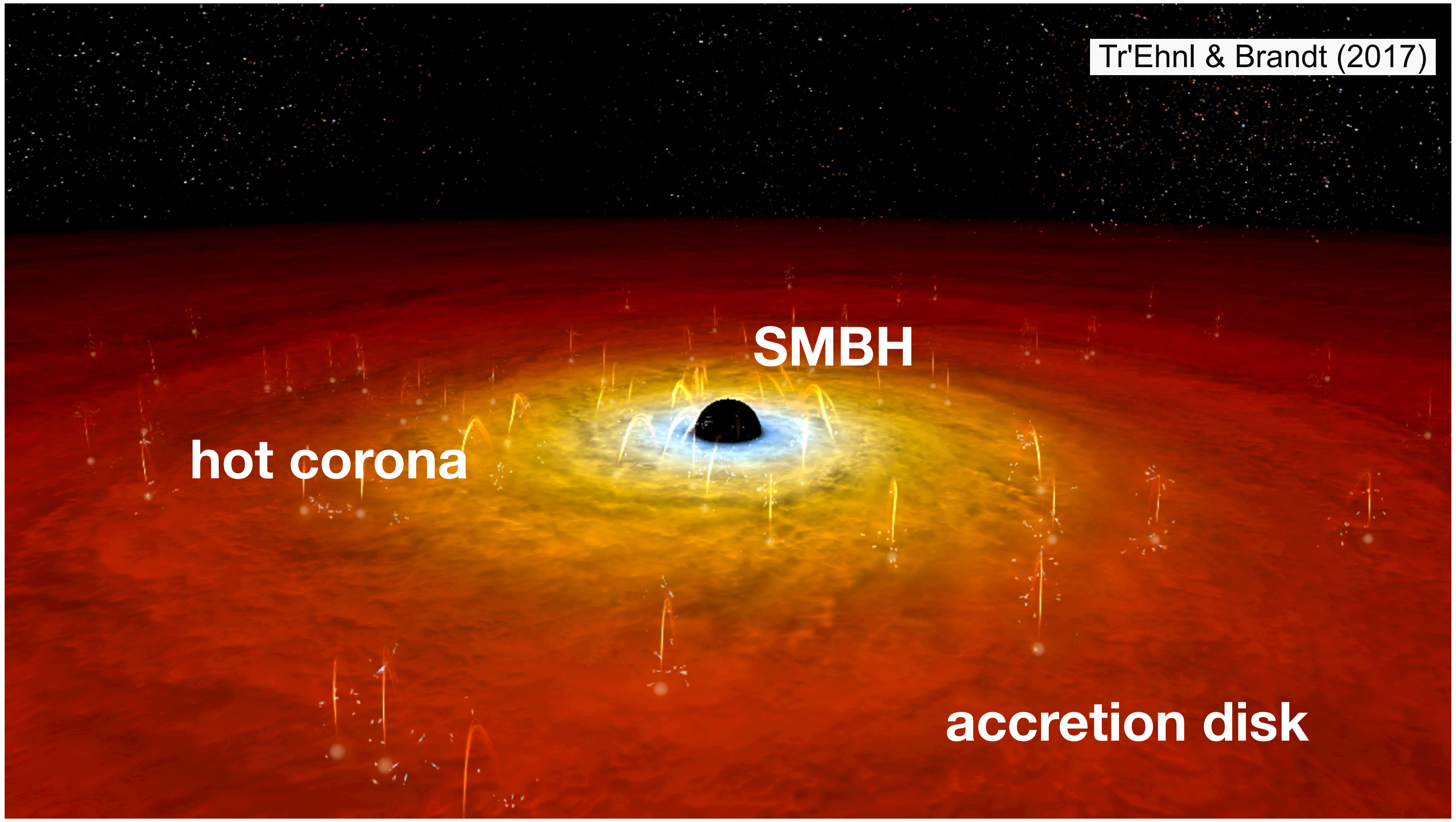
M. Brusa, F. Civano, A. Comastri, R. Nanni, N. Cappelluti, M. Volonteri, and others



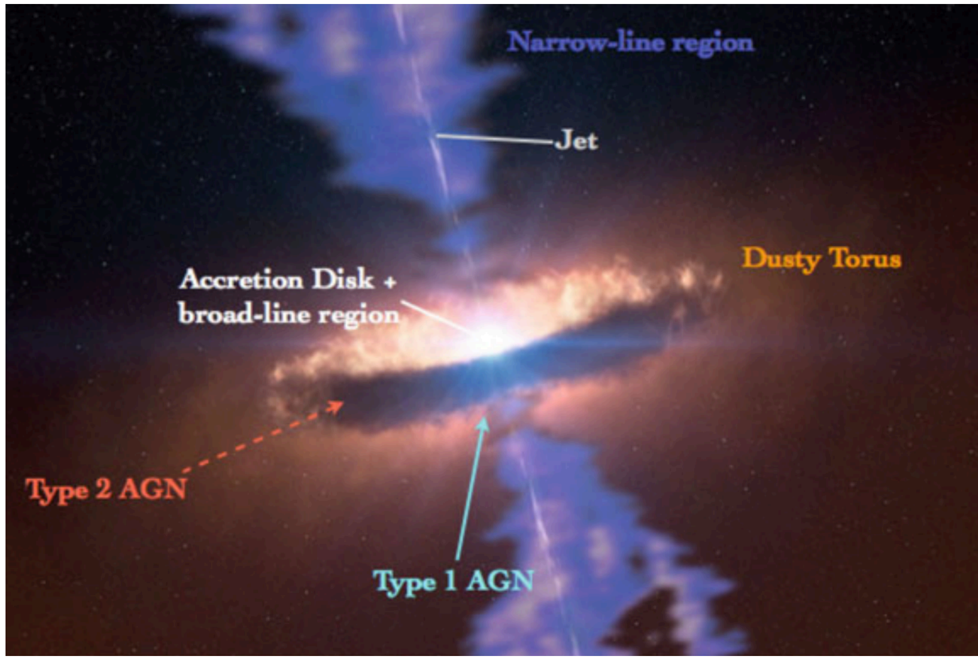
Lusso&Risaliti 2017

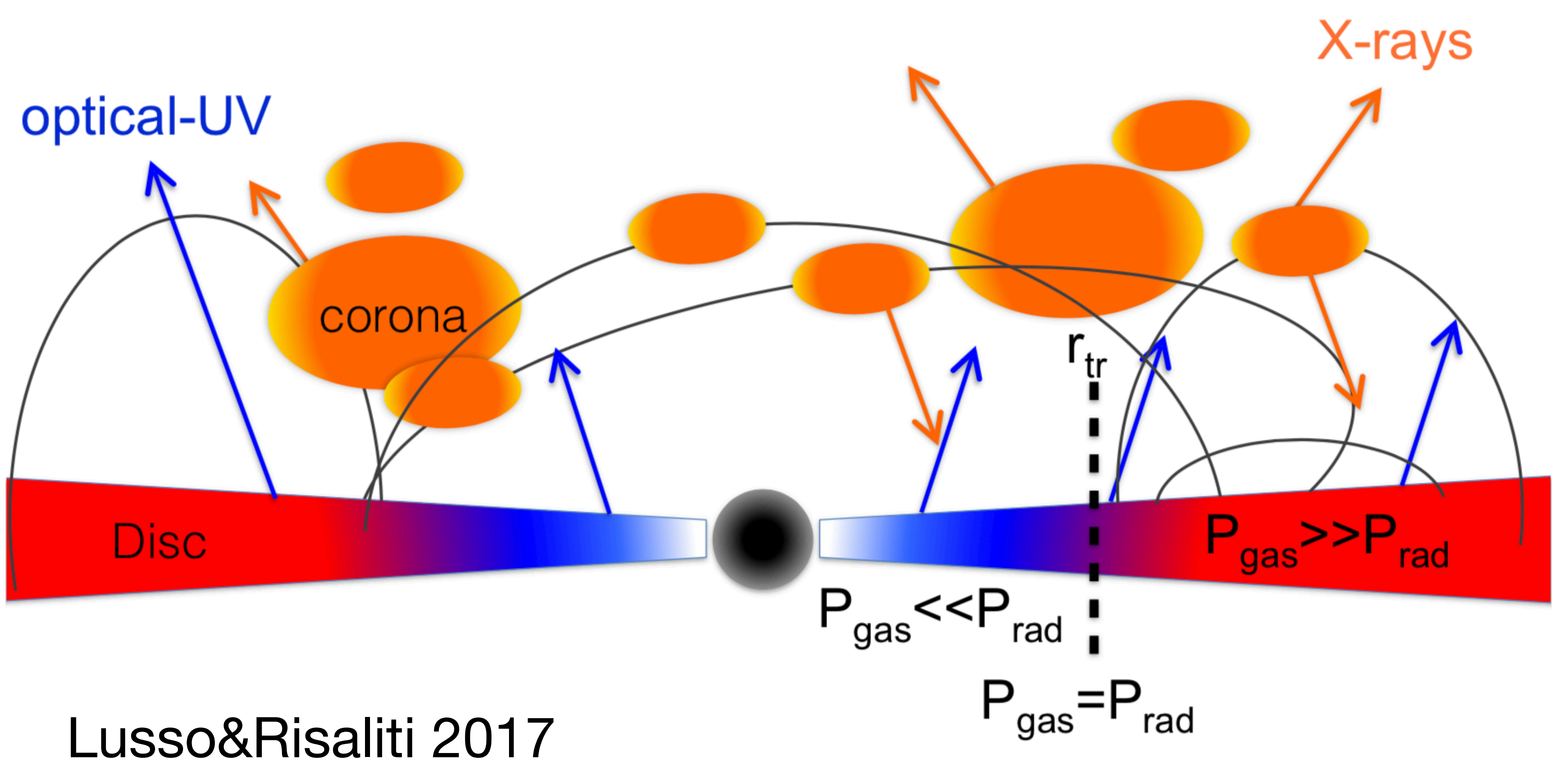


One slide recap: Active Galactic Nuclei



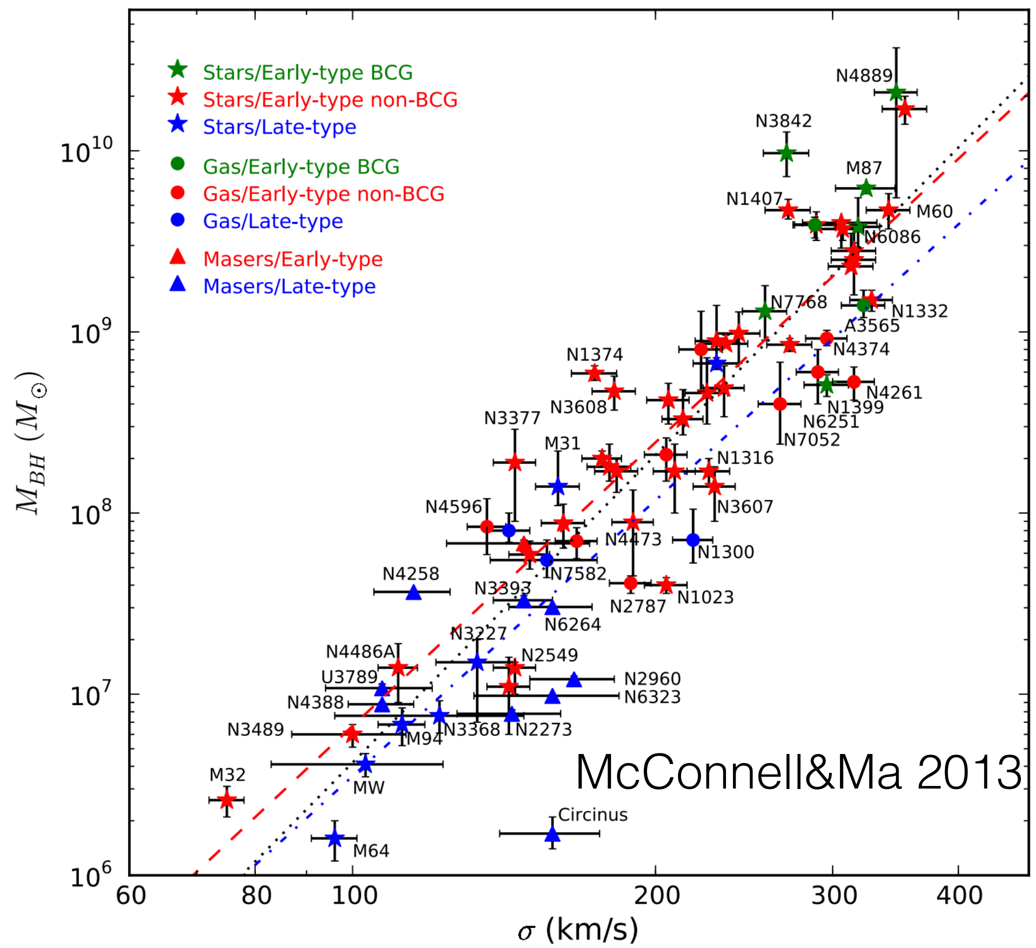
Honig 2016

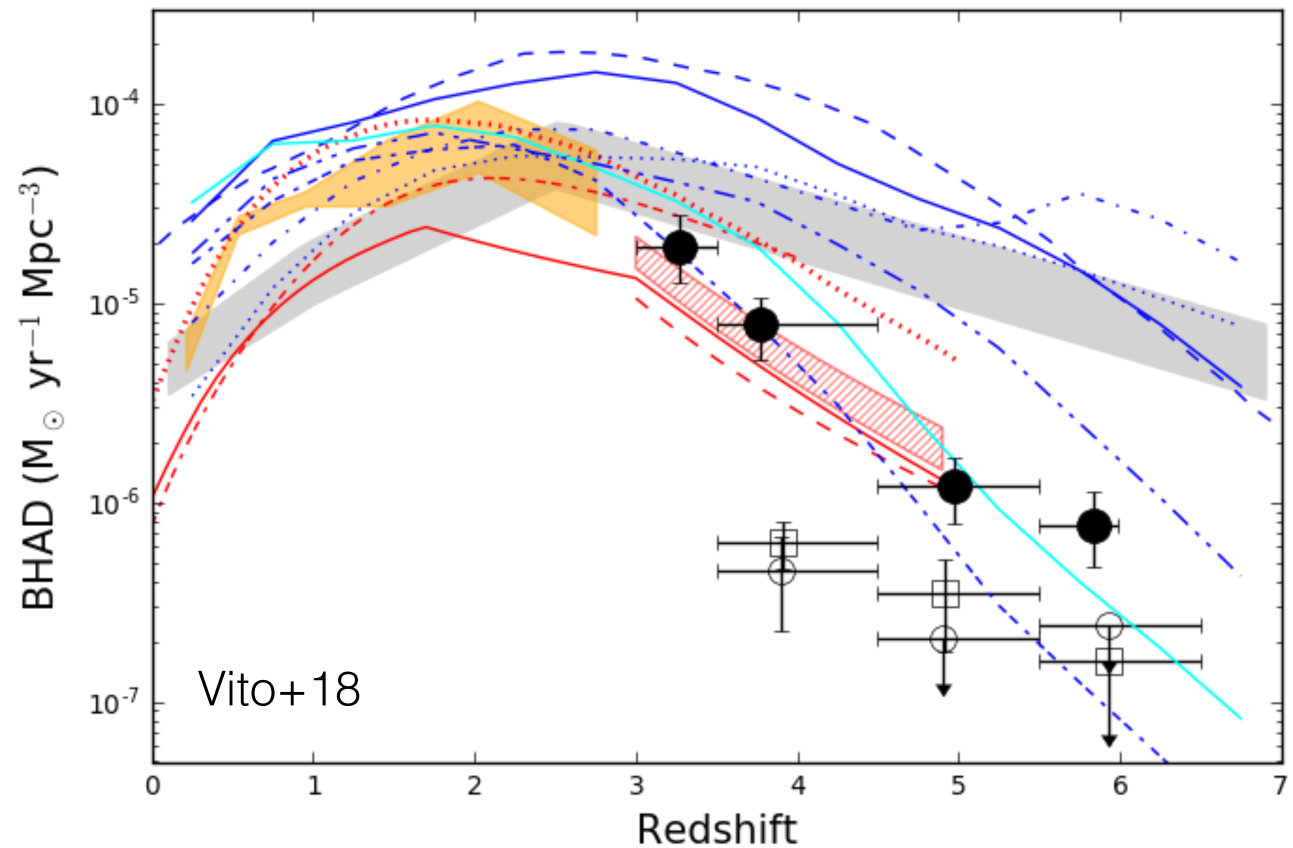




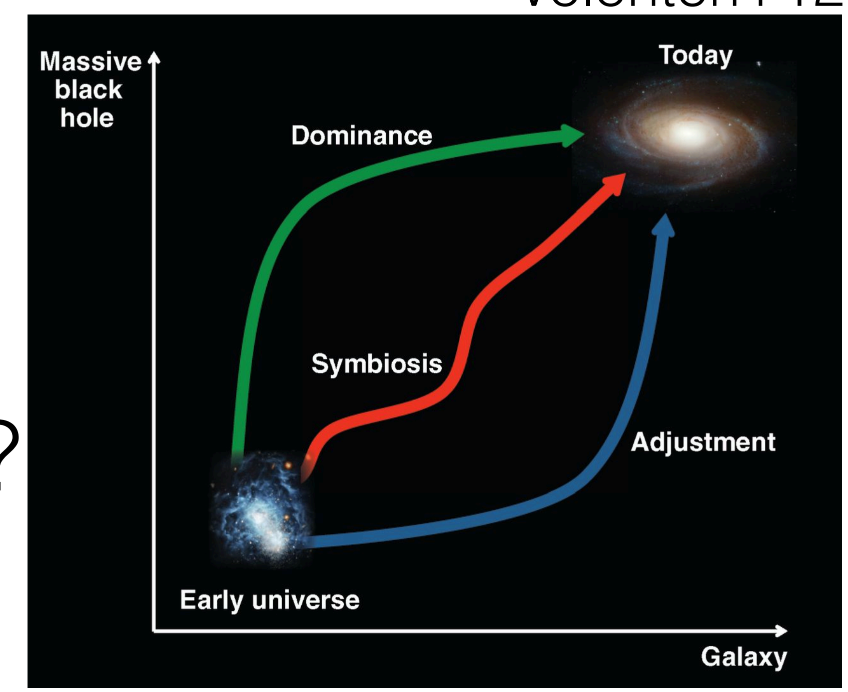
Lusso&Risaliti 2017

SMBH and galaxies co-evolve





Volonteri+12

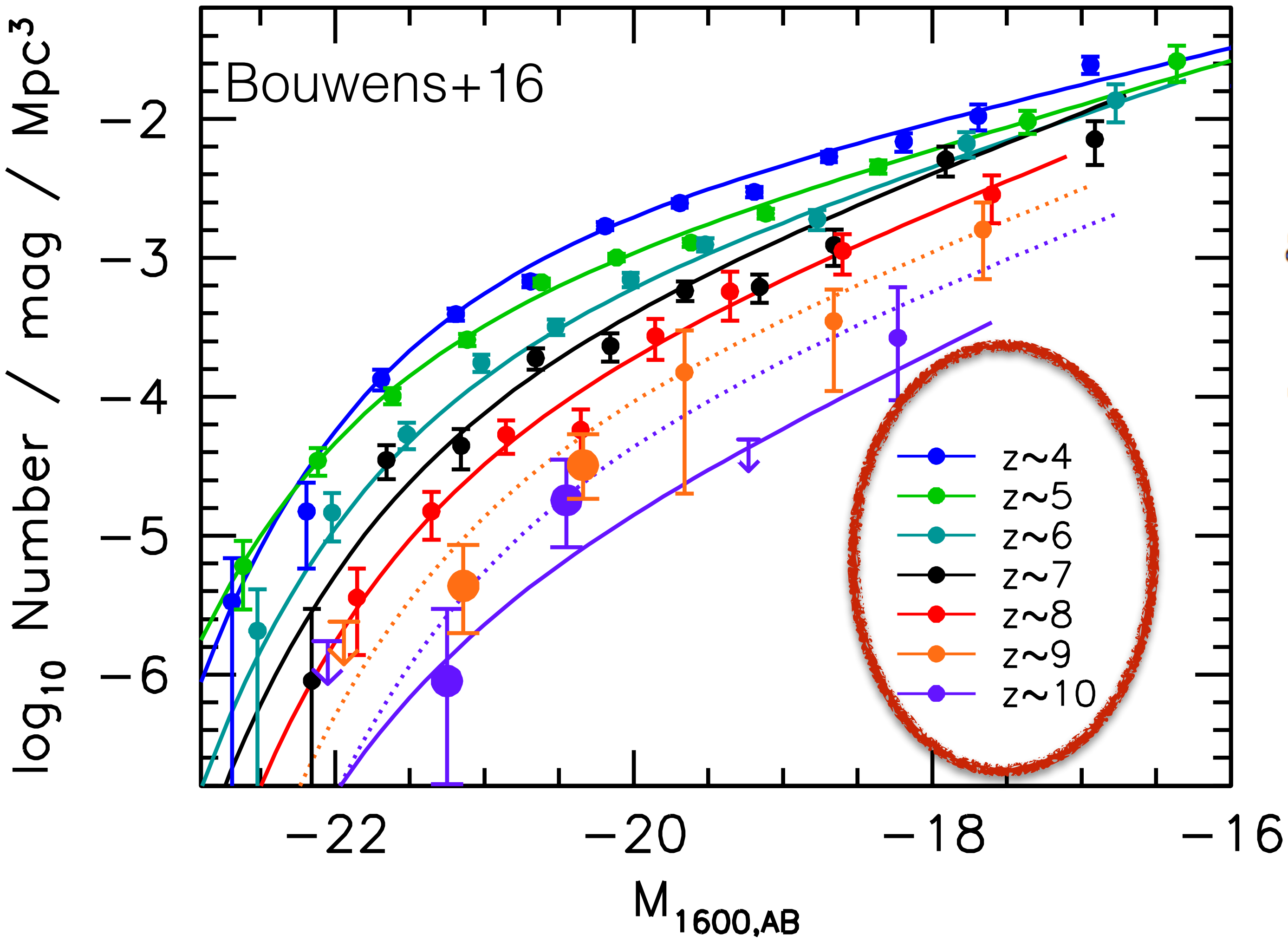


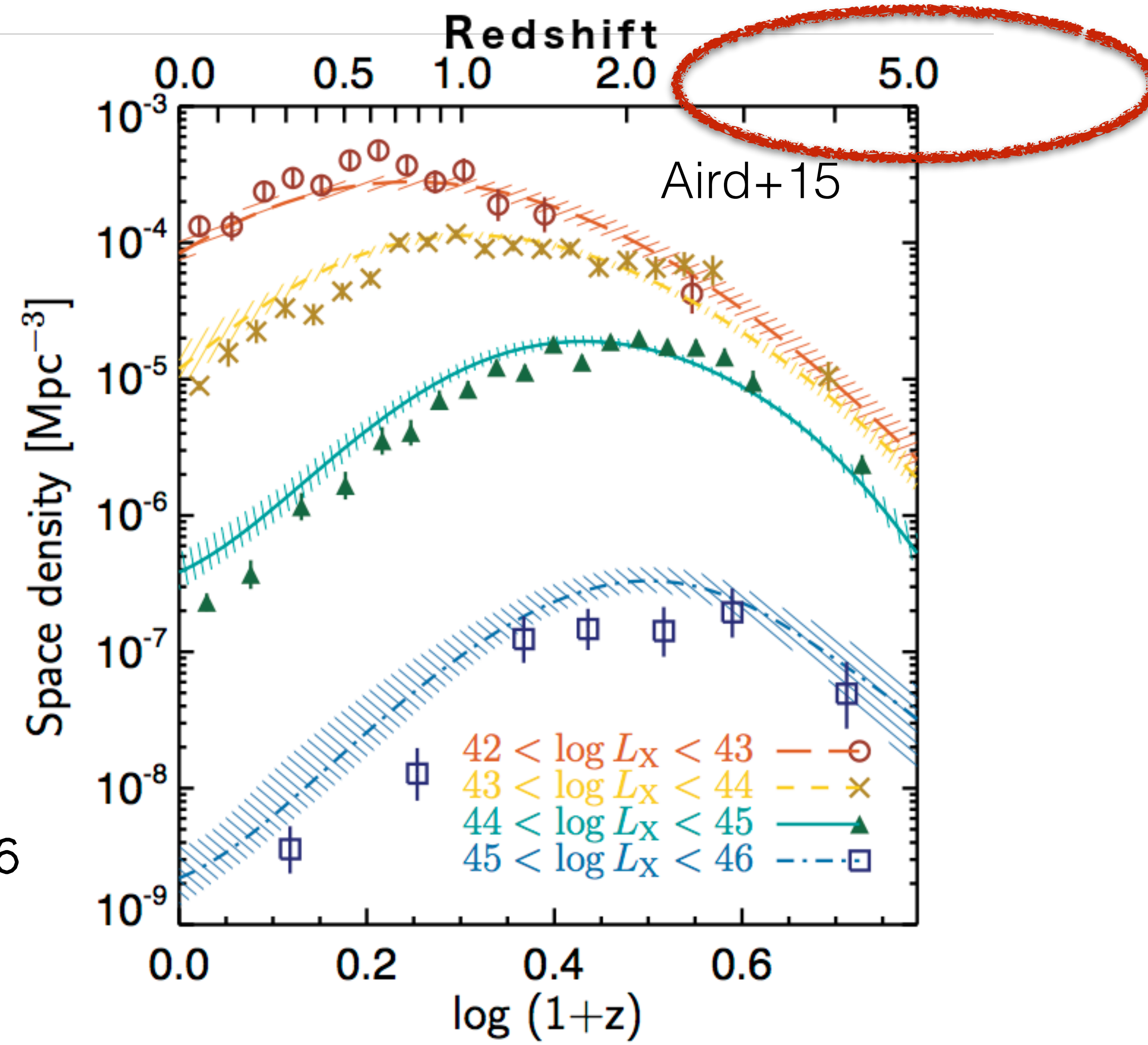
- SFRD and BHAD track each other
- M_{BH} vs M_{bulge} relation
- Downsizing

Do these relations hold at high redshift?
And how are they established?

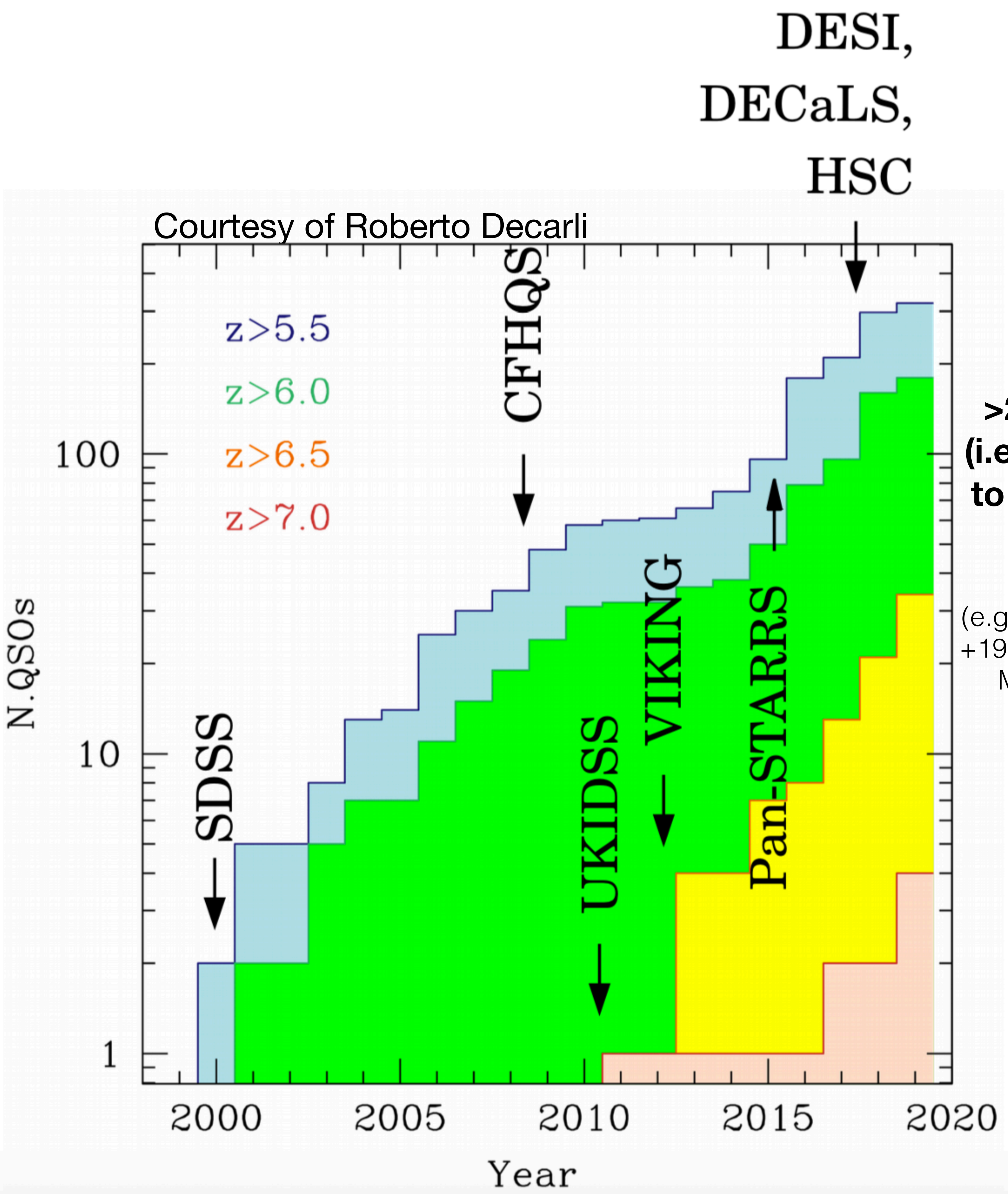
e.g. “overmassive” high-M BH (e.g. Walter+04, Wang+13, Barnett+15), “undermassive” low-M BH (from simulations, e.g. Habouzit+16)?

Galaxy vs. AGN luminosity functions





<u>Need to improve our knowledge of AGN at high-z!</u>



>200 QSOs discovered so far at z>6 (i.e. <1 Gyr after the Big Bang), thanks to wide area (>1000 deg²) optical/NIR surveys

(e.g. Banados+16, +18, Mazzucchelli+17, Reed+17, +19, Tang+17, Wang+17, +18a, +18b, Chehade+18, Matsuoka+18a,+18b, +19, +19, Yang+18,+20, Fan+19, Pons+19, Belladitta+20)

Selection of high-*z* QSO candidates

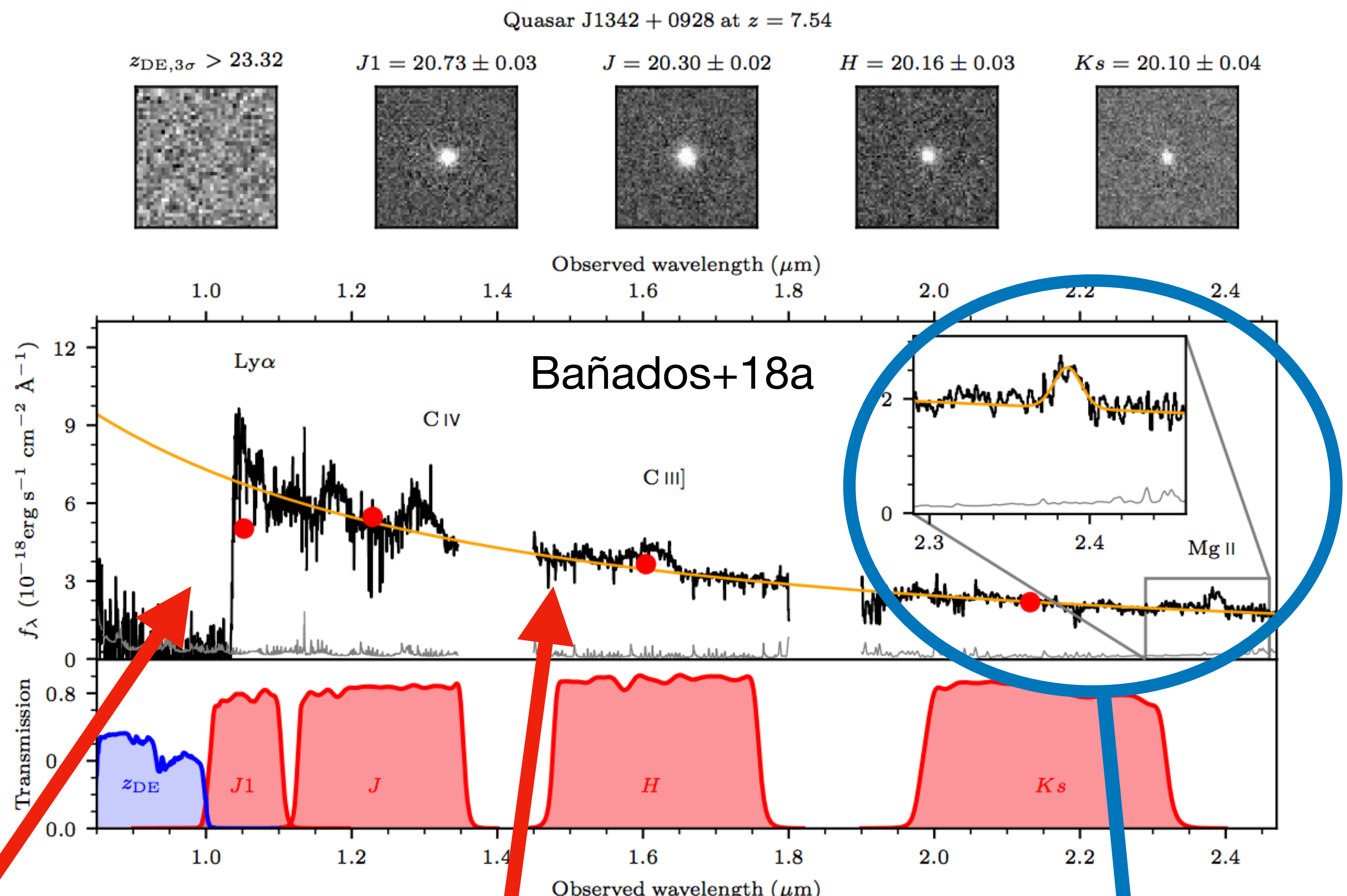


Figure 1. Photometry and combined Magellan/FIRE and Gemini/GNIRS near-infrared spectrum of the quasar J1342+0928 at $z = 7.54$. The FIRE data were taken on 11–12 March 2017 for a total integration time of 3.5

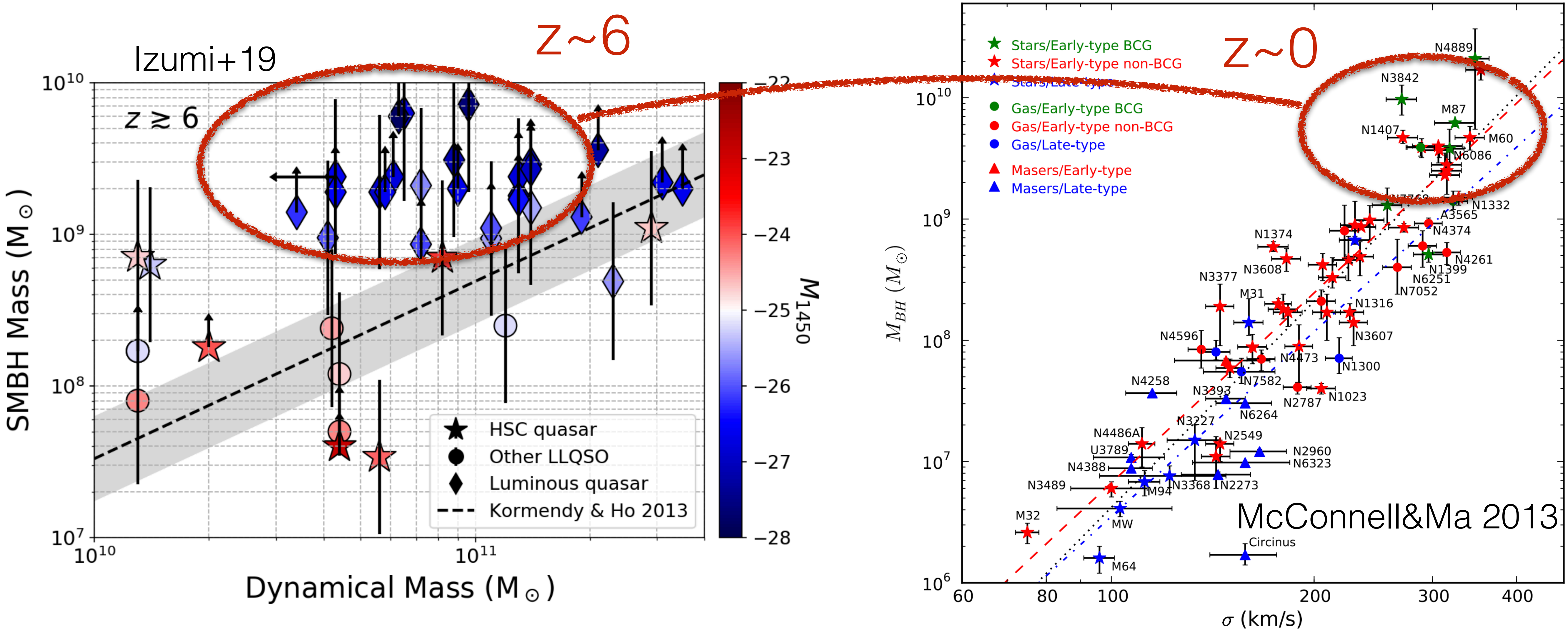
Lyα forest (λ<1216 Å)
+
Lyman break (λ<912 Å)

Blue continuum emission
(by selection only Type I QSOs!)
(but see Matsuoka+16,17,18,19)

Virial BH mass estimate

Optically selected z≳6 QSOs are extremely massive!

log(M_BH/Msun)~9-10 (with large uncertainties, e.g., Wu+15, Banados+18)



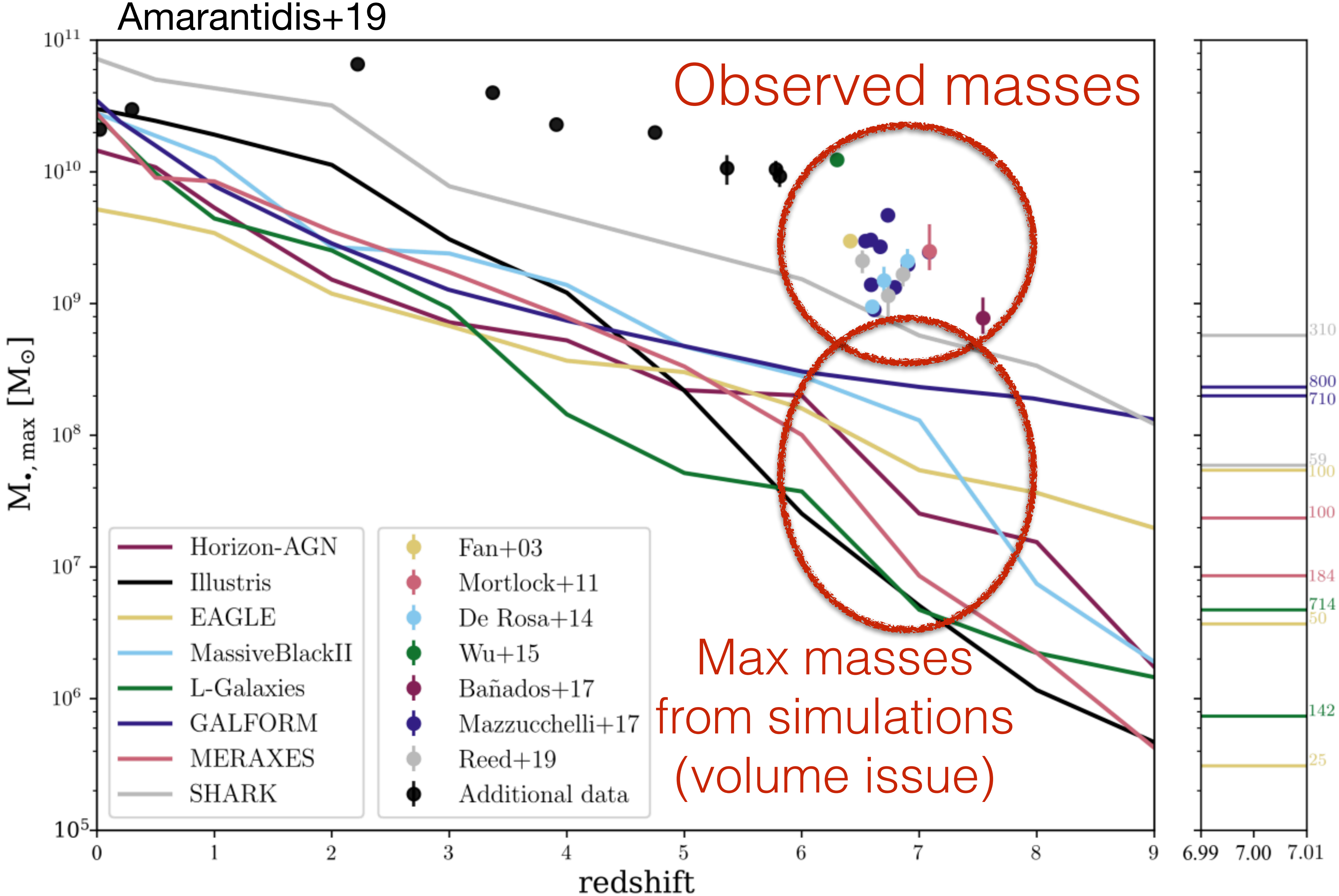
How can you form such massive BH in <1Gyr??

Optically selected z≳6 QSOs are extremely massive!

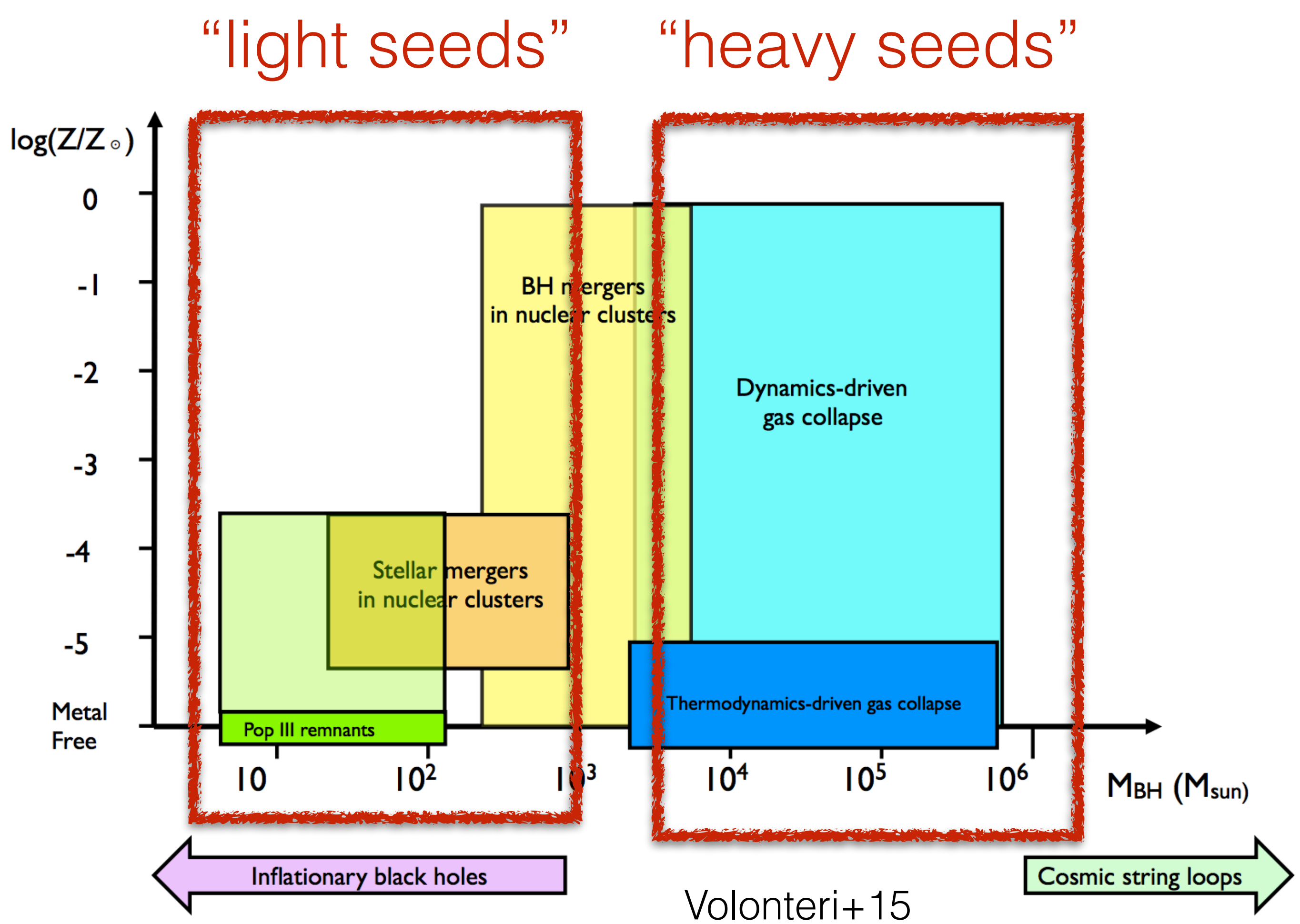
log(M_BH/Msun)~9-10 (with large uncertainties)

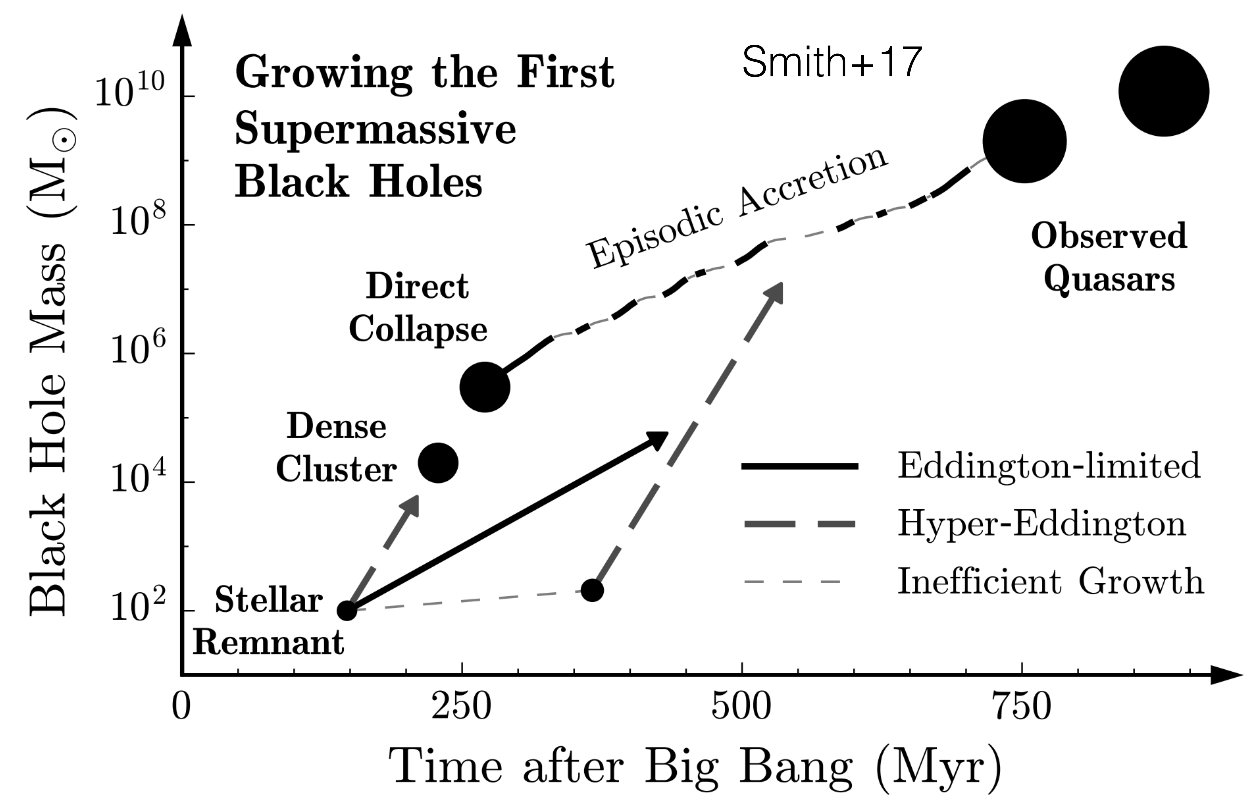
(e.g., Mortlock+11, Wu+15, Banados+18, Yang+20)

Amarantidis+19



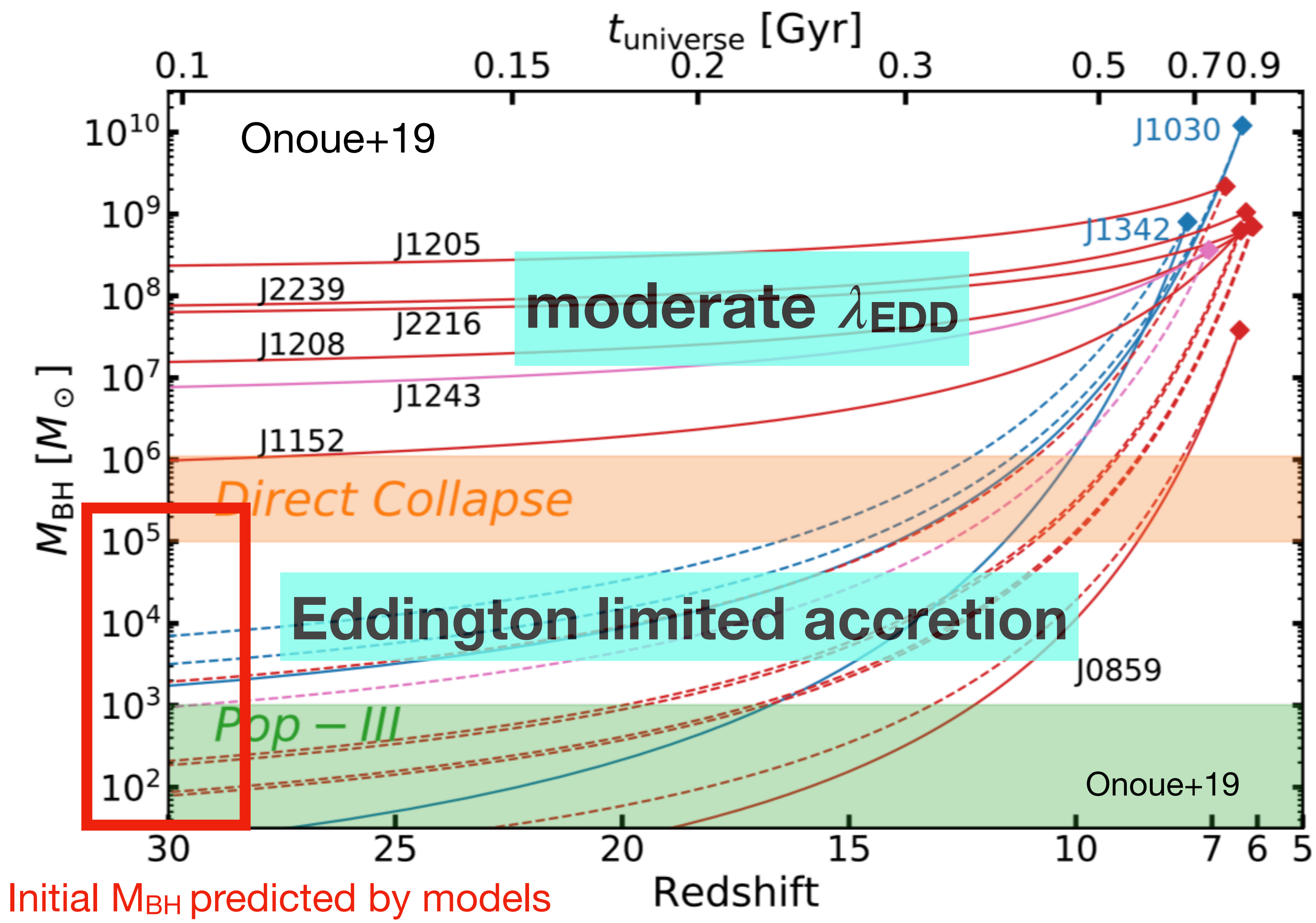
SMBH formation

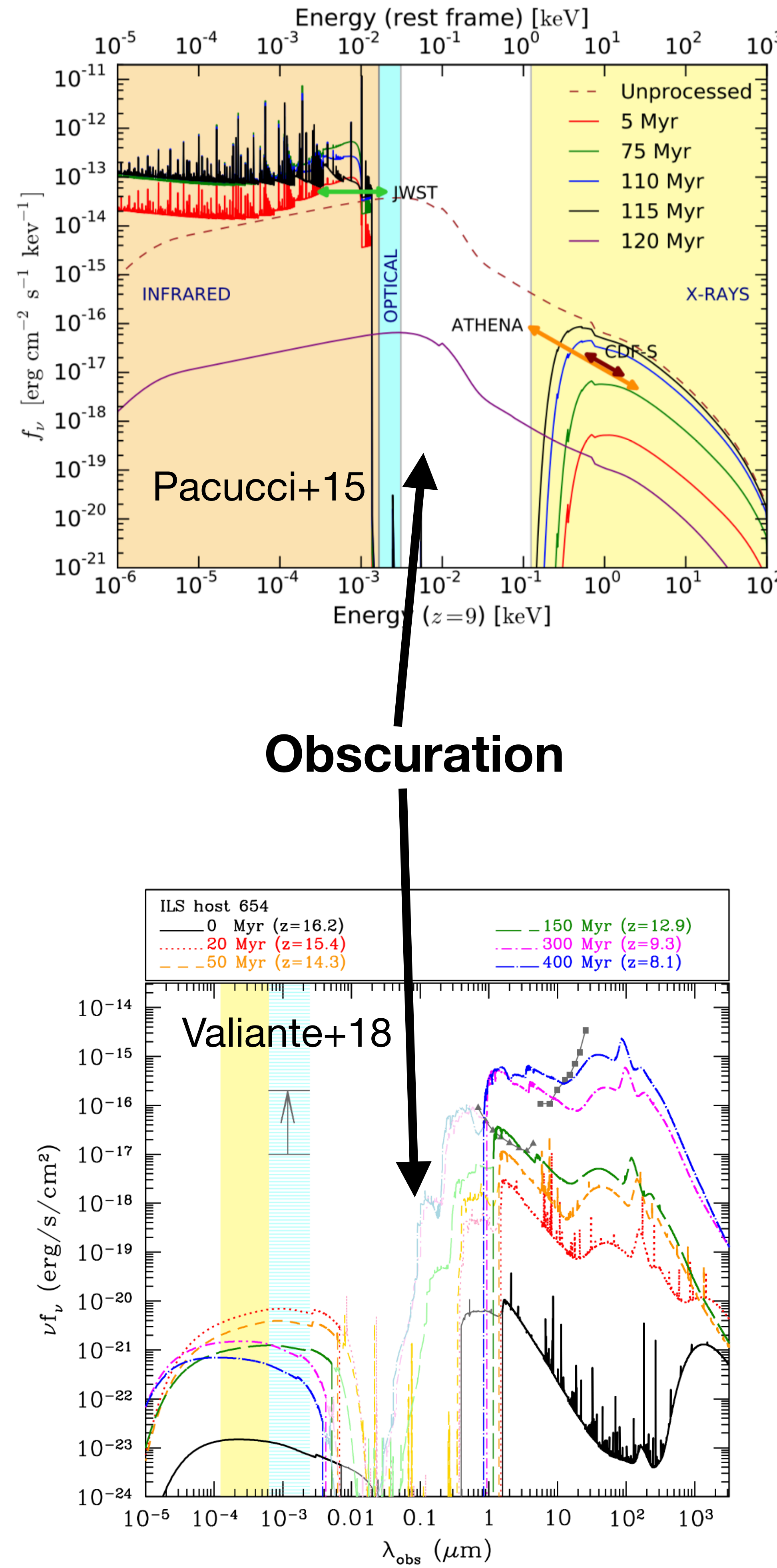




Seed mass distribution, Eddington ratio distribution, occupation fraction, radiation efficiency, feedback, etc….

$$M_{SMBH}(t) = M_{seed}(t_{form})\, e^{[(1-\varepsilon)/\varepsilon]\Delta t/t_{Edd}} \qquad \varepsilon = 0.1 \quad t_{Edd} = 0.45\ \mathrm{Gyr}$$





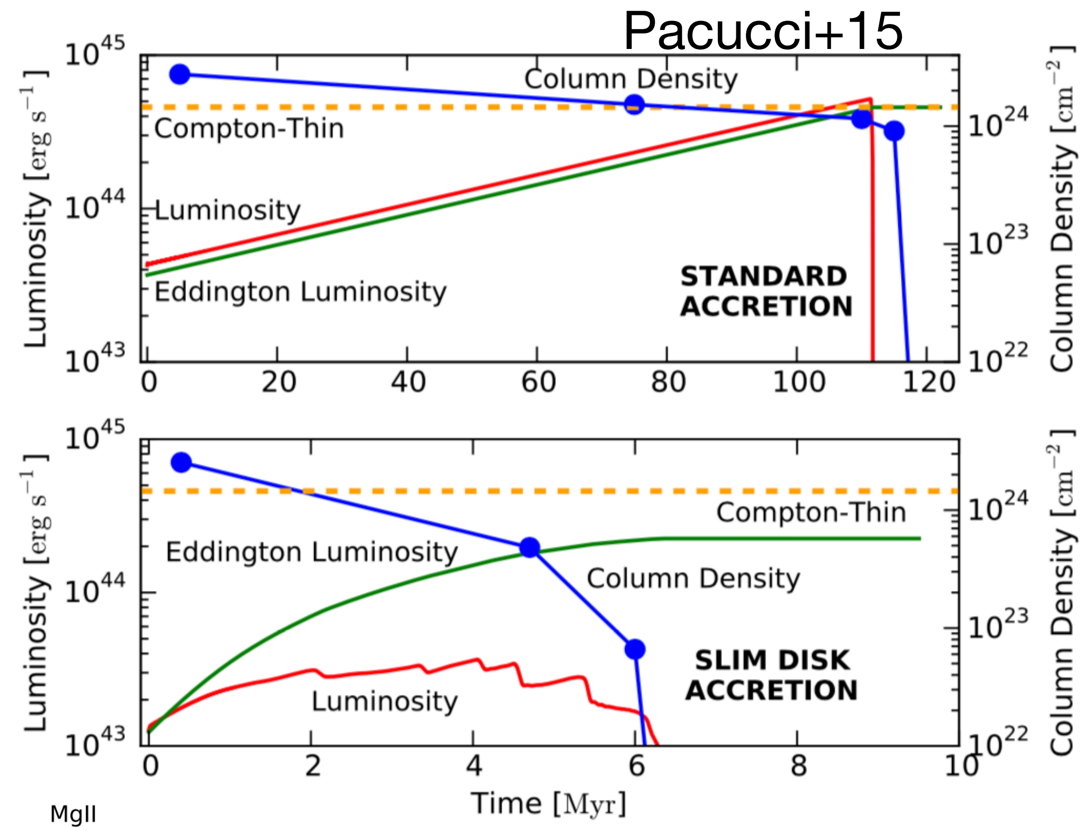
Models require fast accretion (i.e., high Eddington ratio λ_{EDD}), possibly in heavily obscured conditions, to match the observed M_{BH} at z=6-7.5

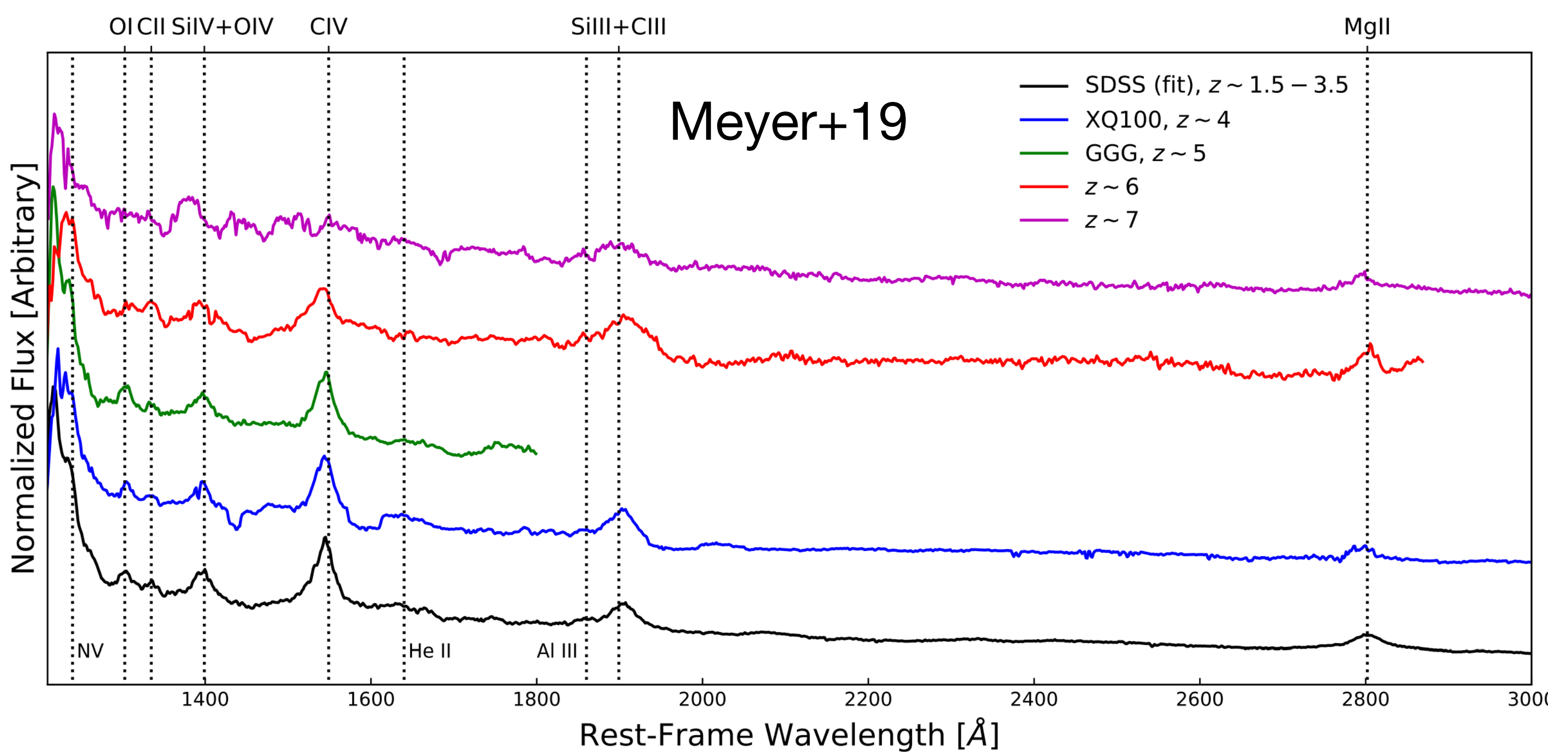
Approaching the Eddington limit, the Shakura-Sunyaev disk model approximation breaks down

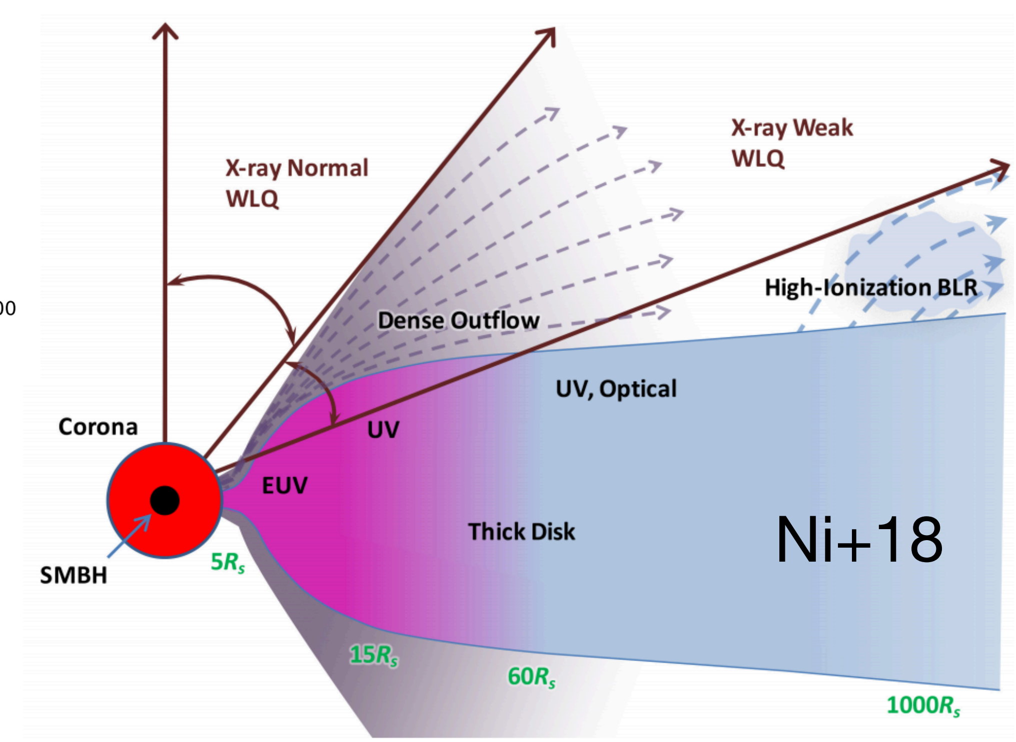
↓

Different accretion modes

(e.g. Jiang+17, Mayer+18, and reference therein)



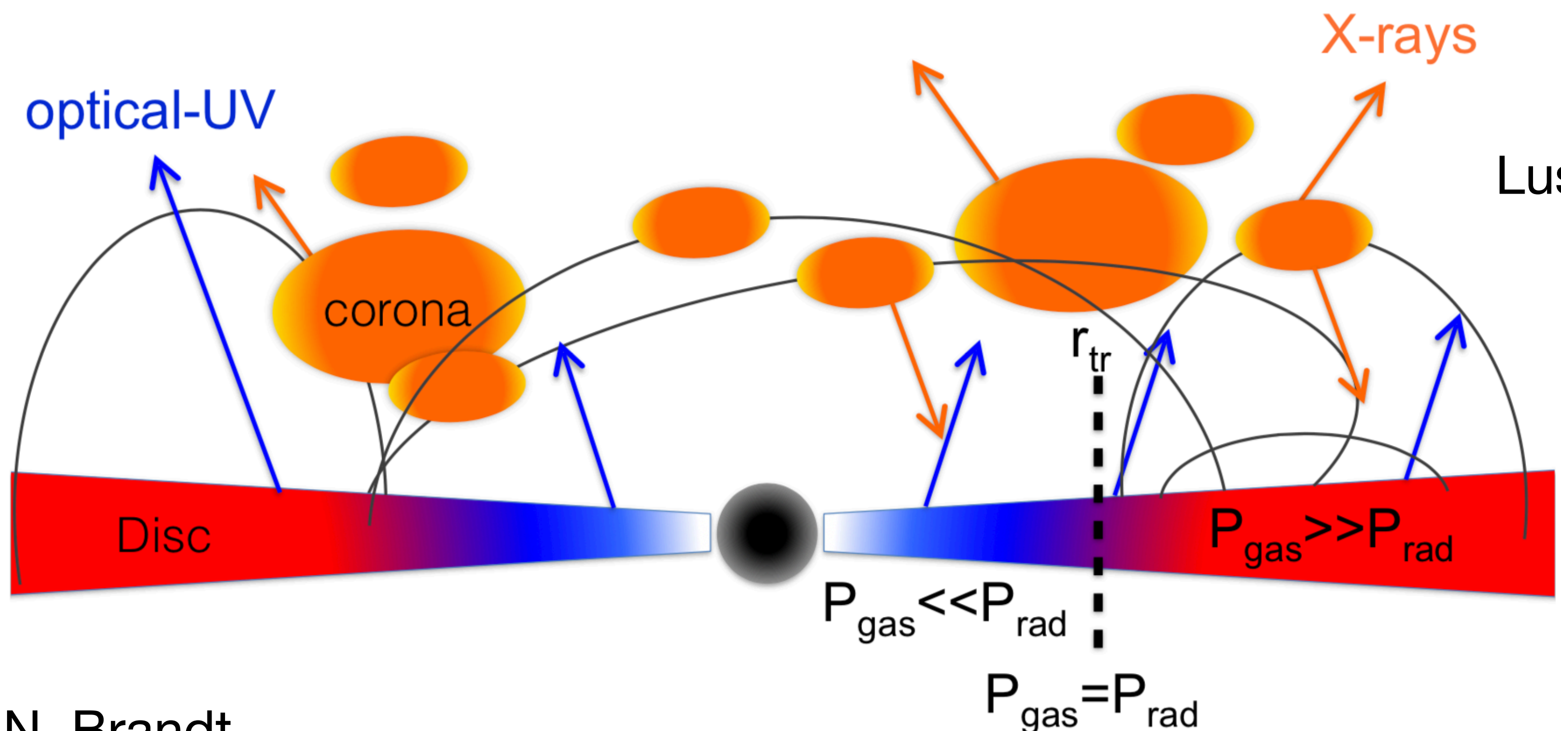


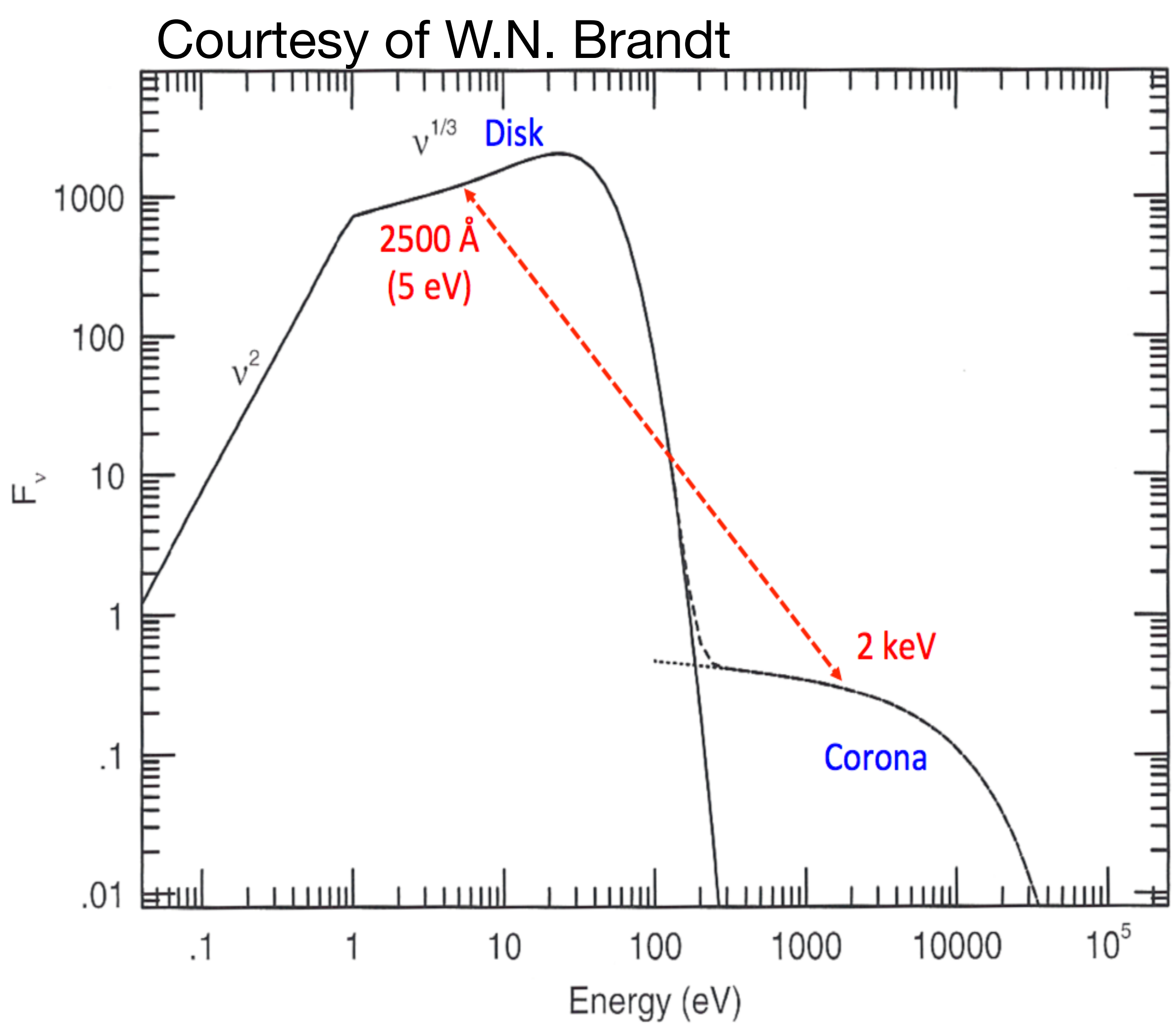


Higher fraction of WLQs at z>6 suggesting a change in the accretion mode?

(see also Shen+19, Bañados+16)

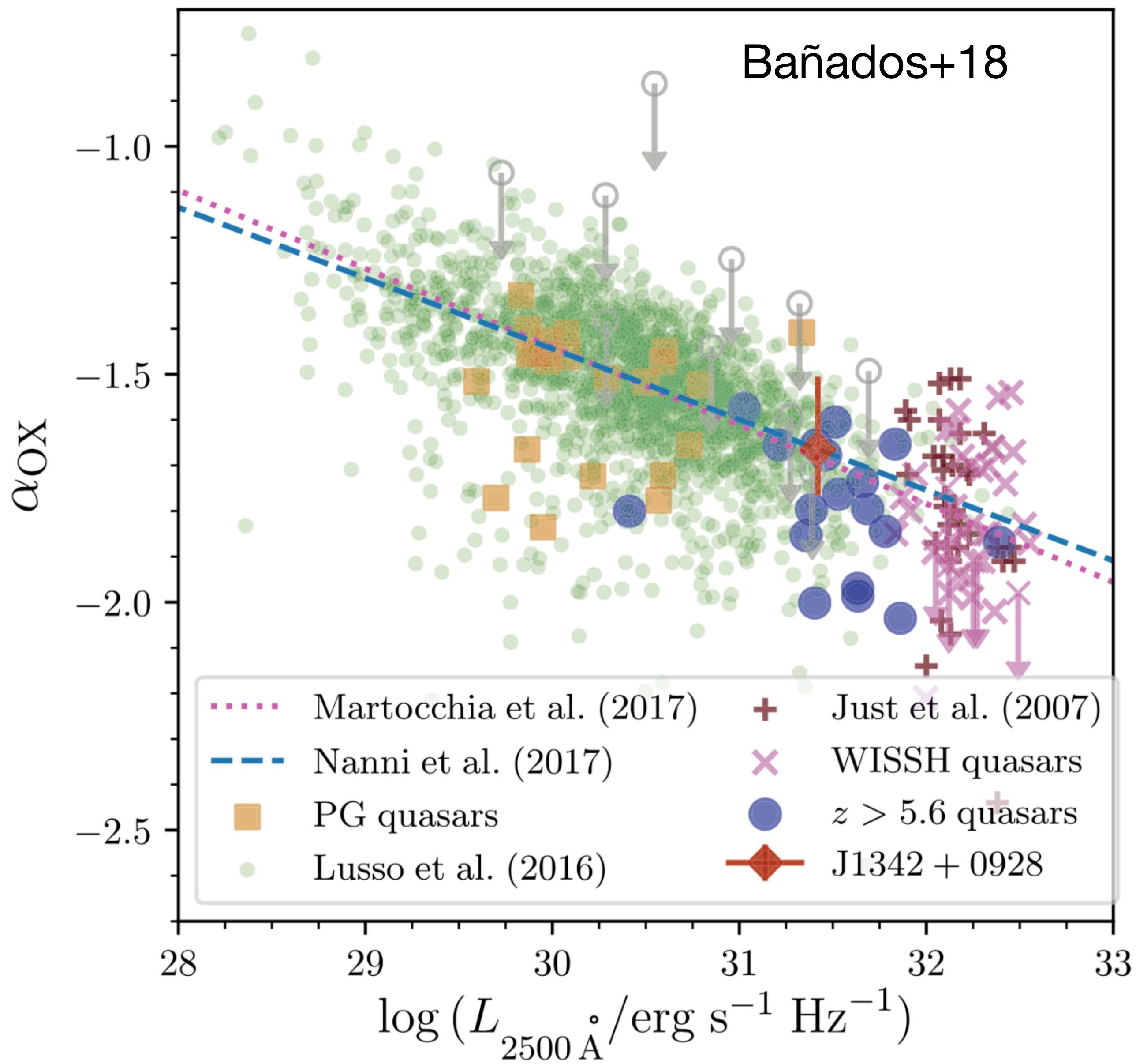
Testing accretion mode (accretion disk + hot corona)





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

(Tananbaum+1979 and many others since)



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

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

Hot corona contribution decreases at high luminosity

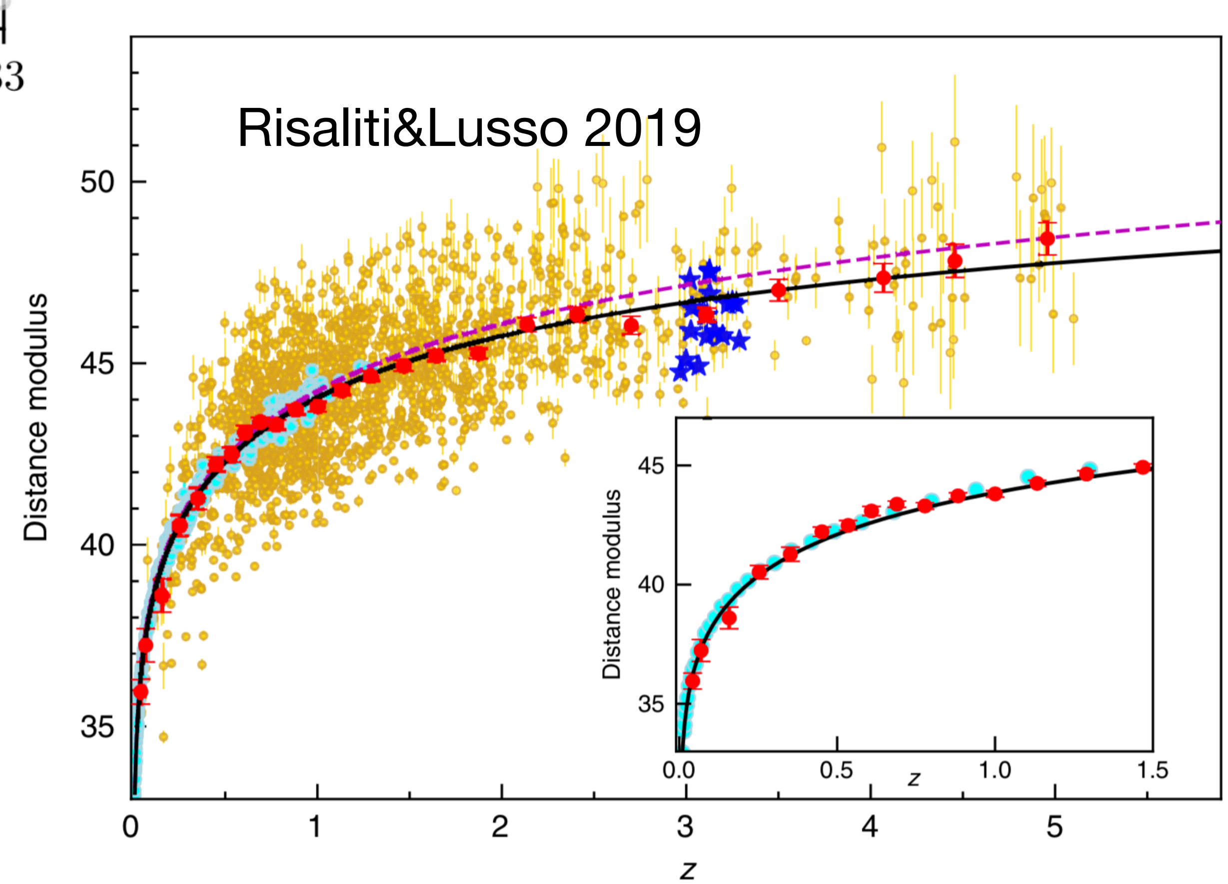
No (strong) evolution with redshift

(e.g. Lusso&Risaliti 2017)

but poorly sampled at *z*>6!!

Possible implications for cosmology

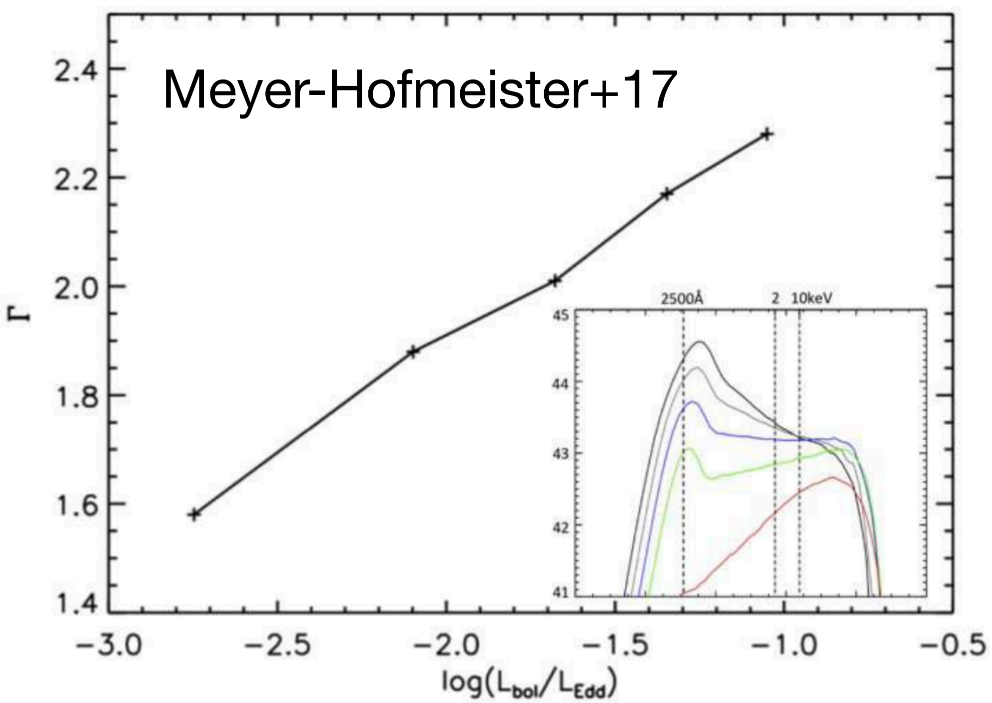
(Risaliti&Lusso 2018)

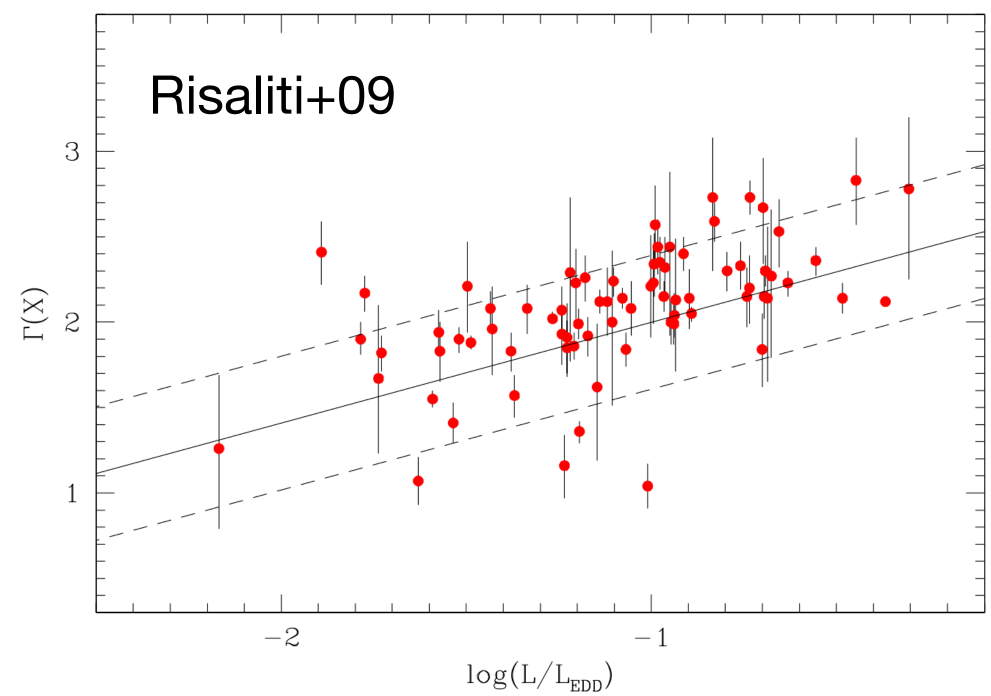


X-ray photon index (Γ) as a probe of accretion

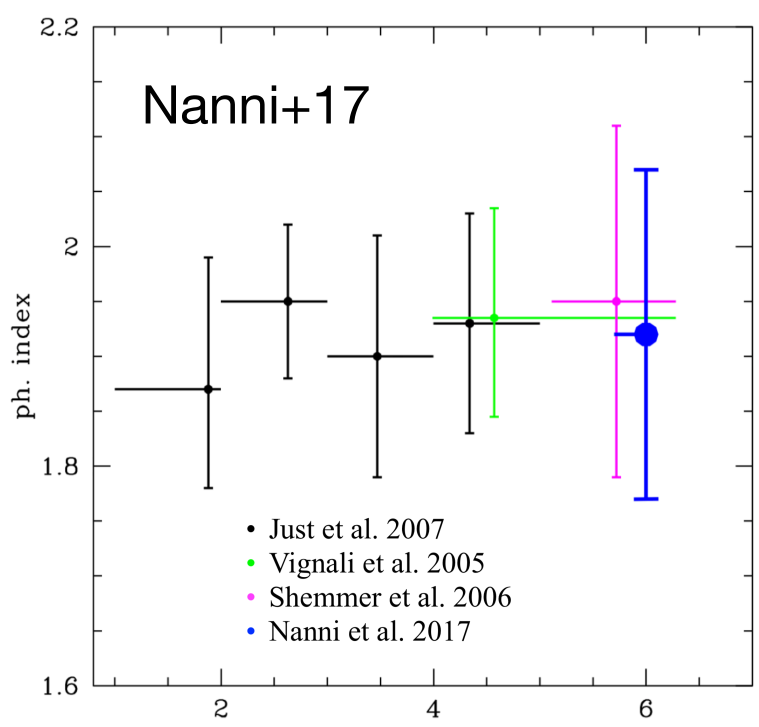
$$N(E) \propto E^{-\Gamma}$$

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

(e.g. Lusso&Risaliti 2017)

but poorly sampled at *z*>6!!

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

Chandra Cycle 19 Large Program (~430 ks, PI: Brandt)

New observations

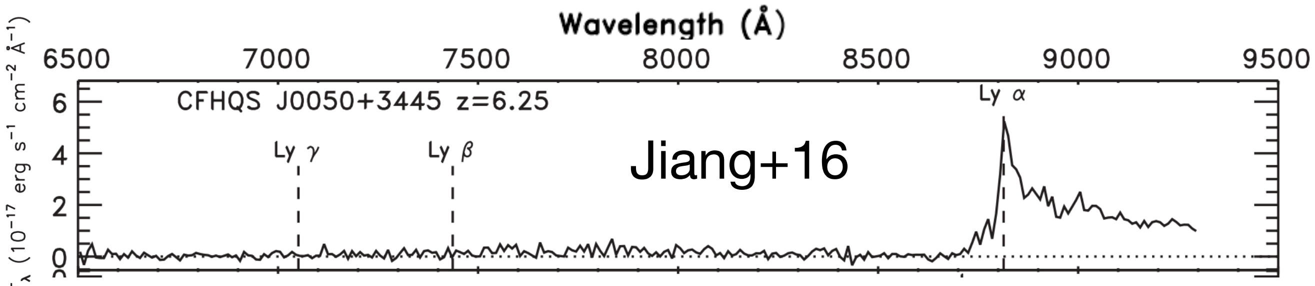
Archival data

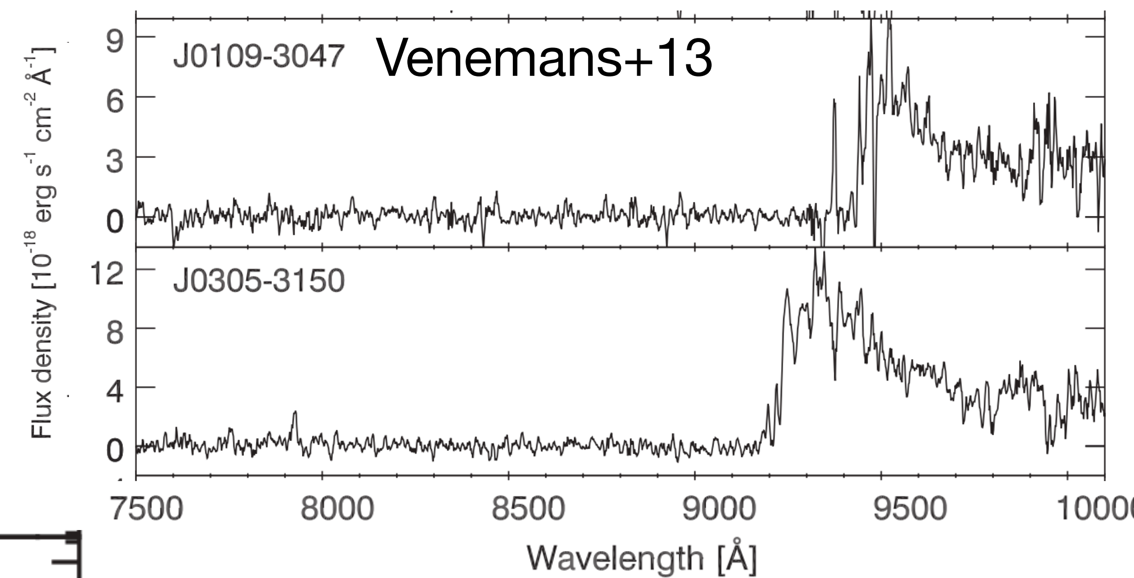
Vito+19b

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

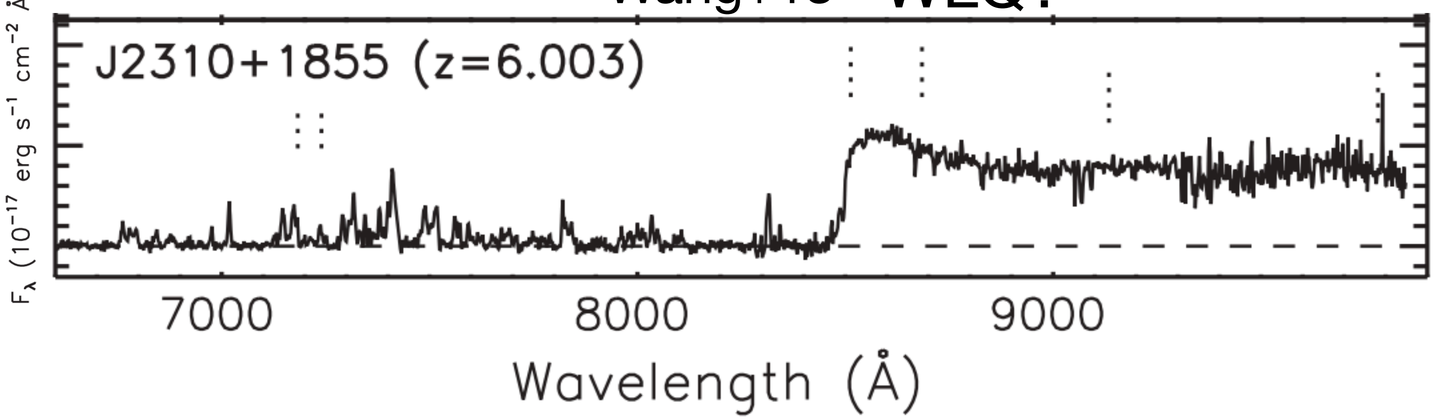
ID	RA	DEC	z	$M_{1450Å}$ ($m_{1450Å}$)	$\log(\frac{L_{bol}}{L_\odot})$	$\log(\frac{M_{BH}}{M_\odot})$	λ_{Edd}	Ref. (disc./z/M_{BH})	R
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				New targets					
CFHQSJ0050+3445	00:50:06.67	+34:45:21.65	6.253 (Mg II)	−26.70 (20.11)	13.45	9.41	0.34	W10/W10/W10	< 11.4
VIKJ0109−3047	01:09:53.13	−30:47:26.3	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	+03:02:59.4	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	+12:18:50.5	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

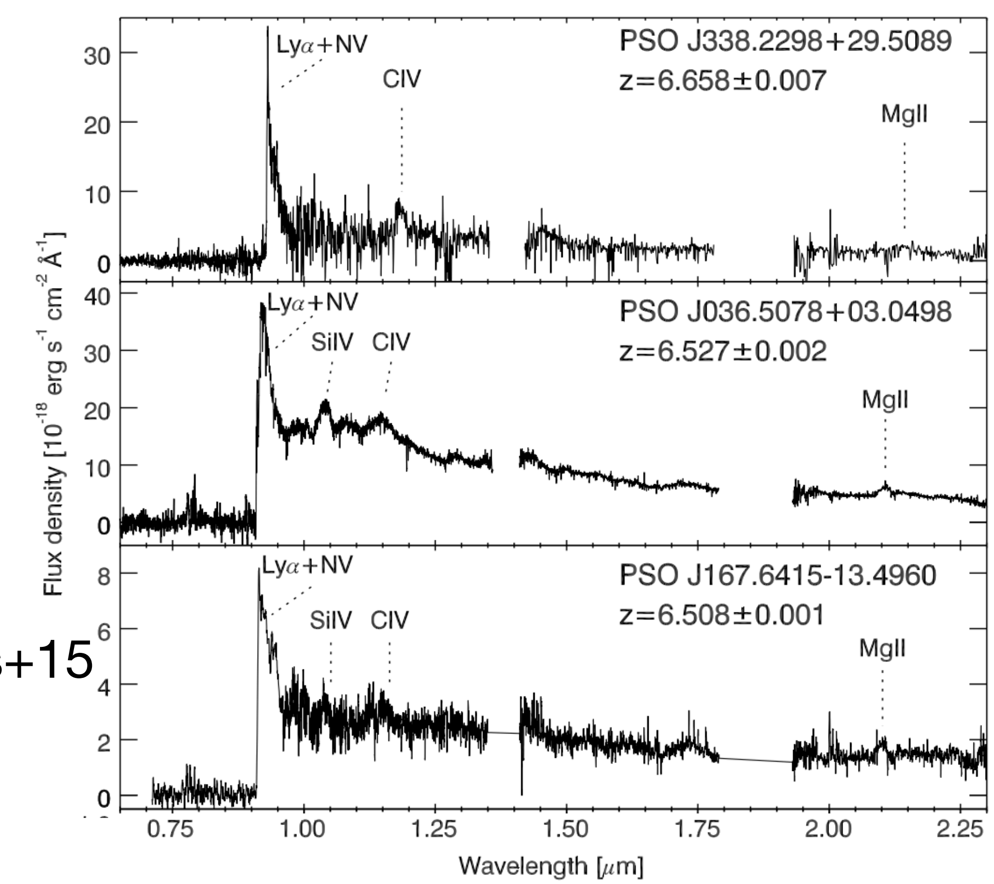
Now we have 25 *z*>6 QSOs with sensitive X-ray data and can start doing robust statistical analysis



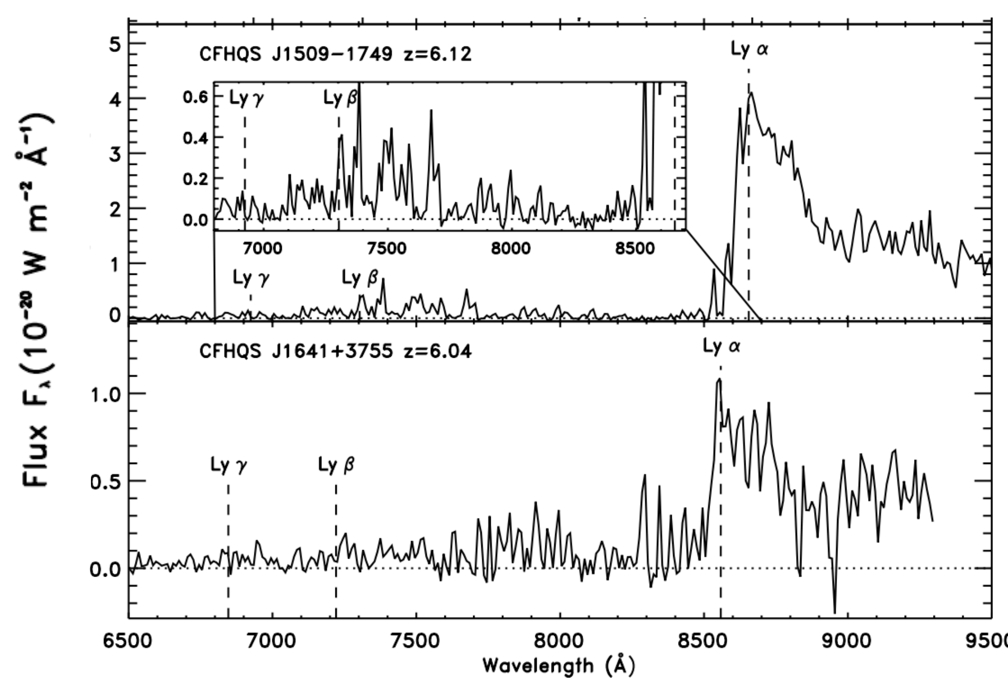


Wang+13 WLQ?

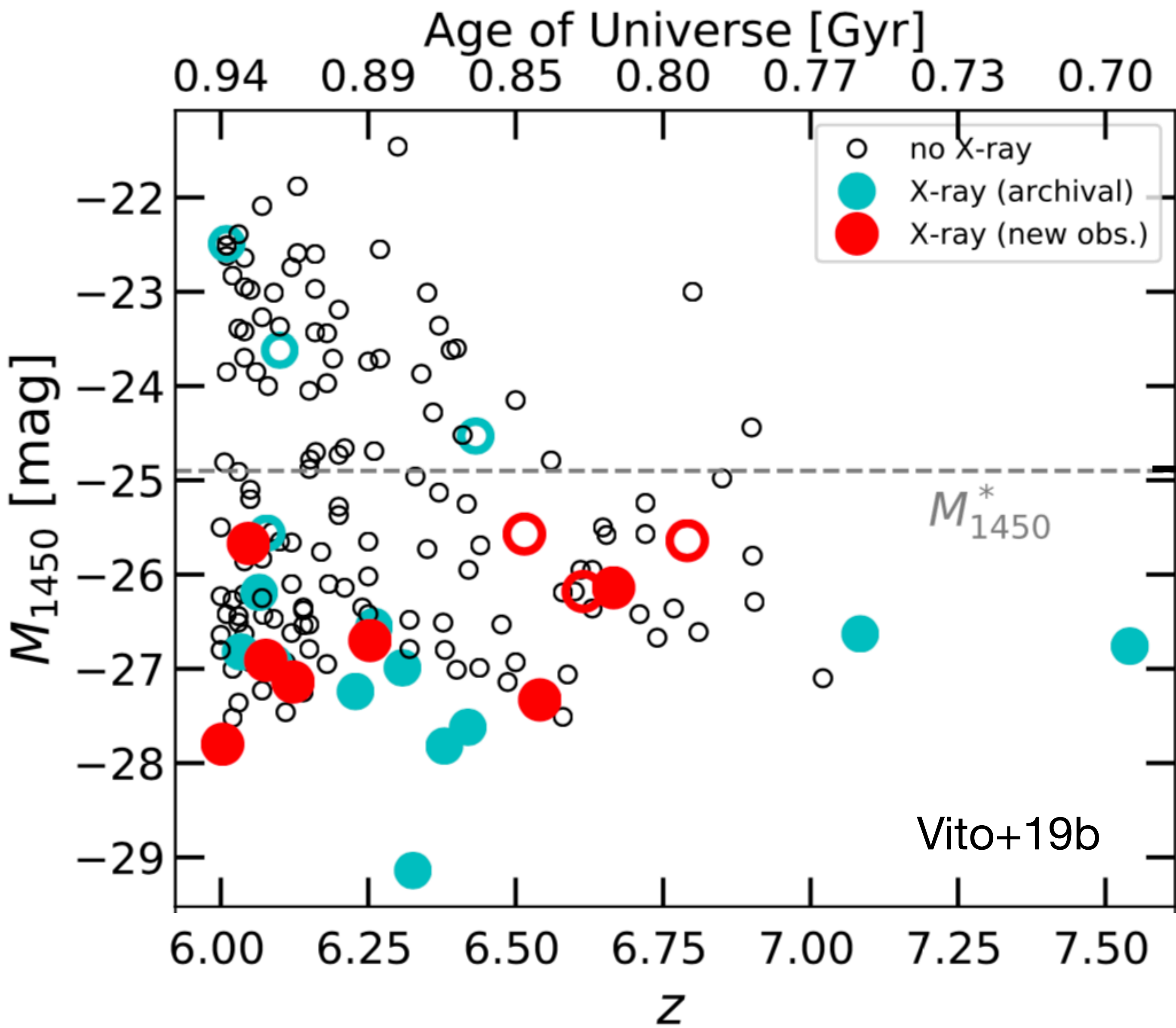


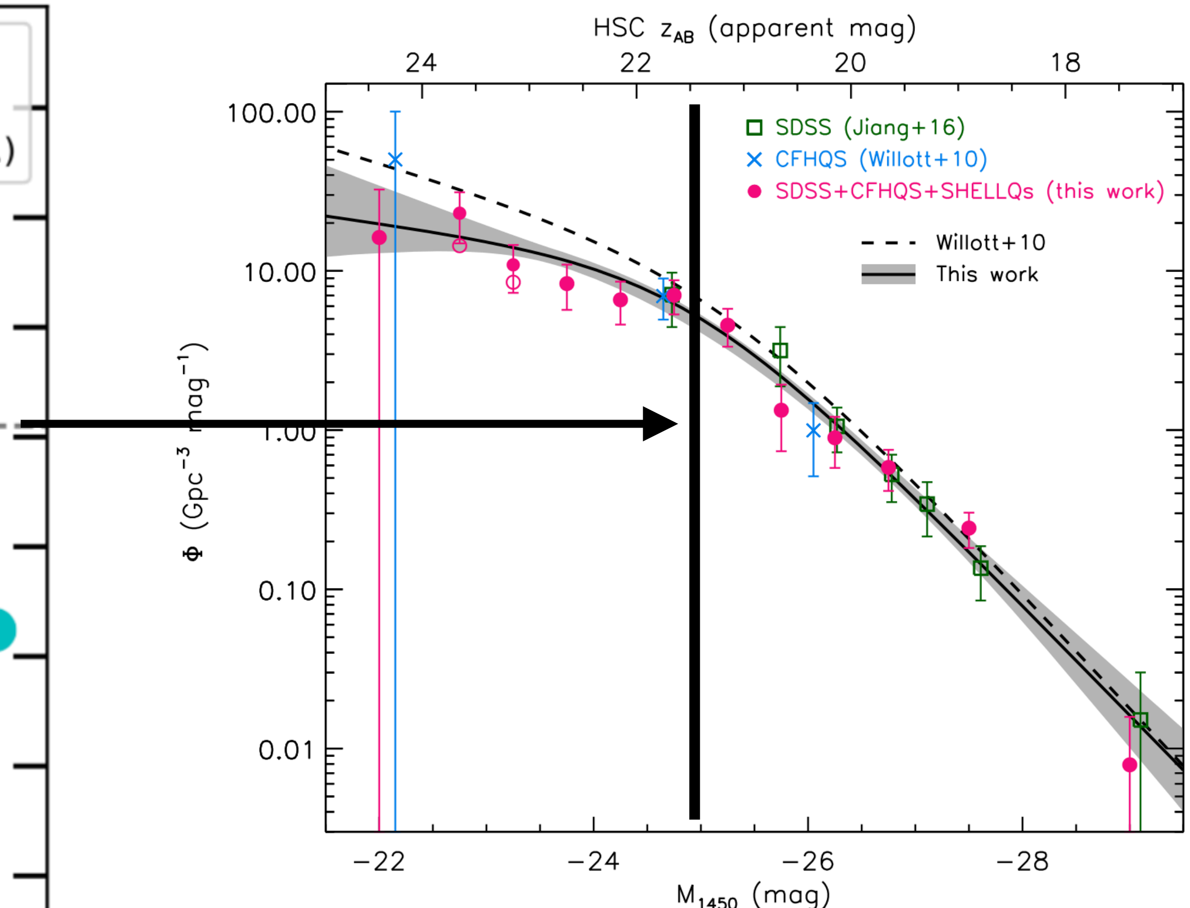


Venemans+15



Willott+07

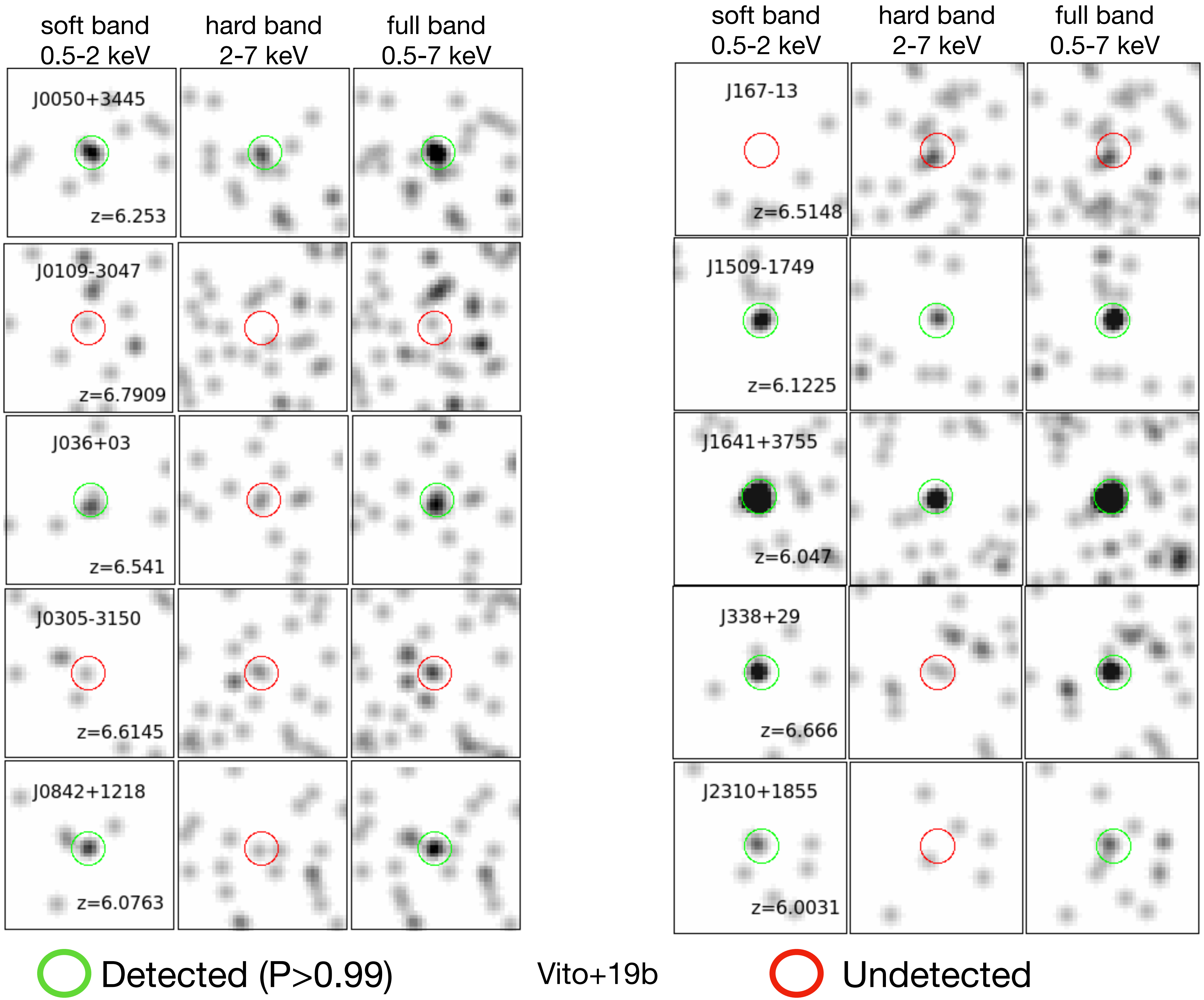




z>6 QSO LF (Matsuoka+18)

Trying to populate "moderate" luminosity (i.e., not only extreme objects) and highest redshift regimes

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

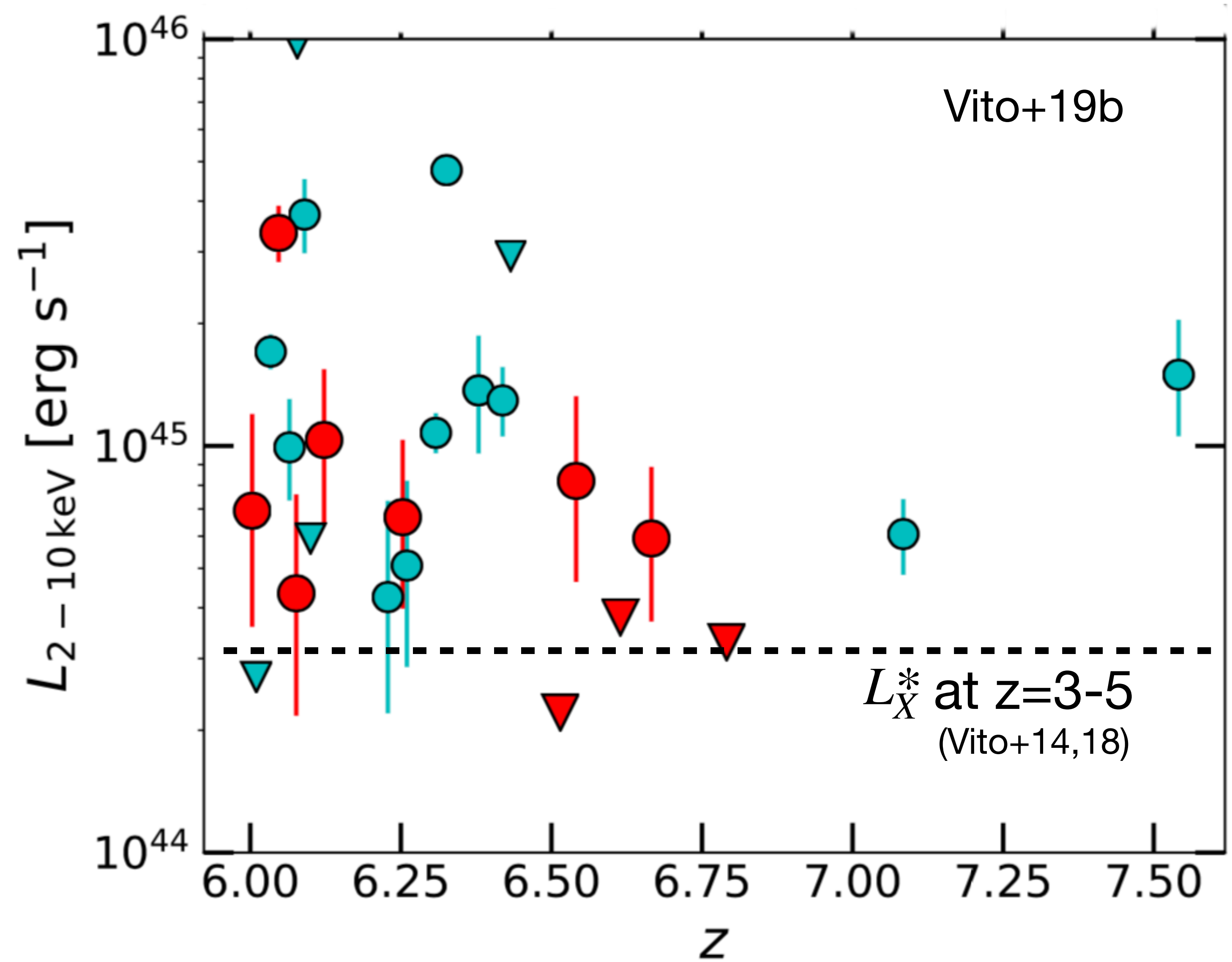


Vito+19b

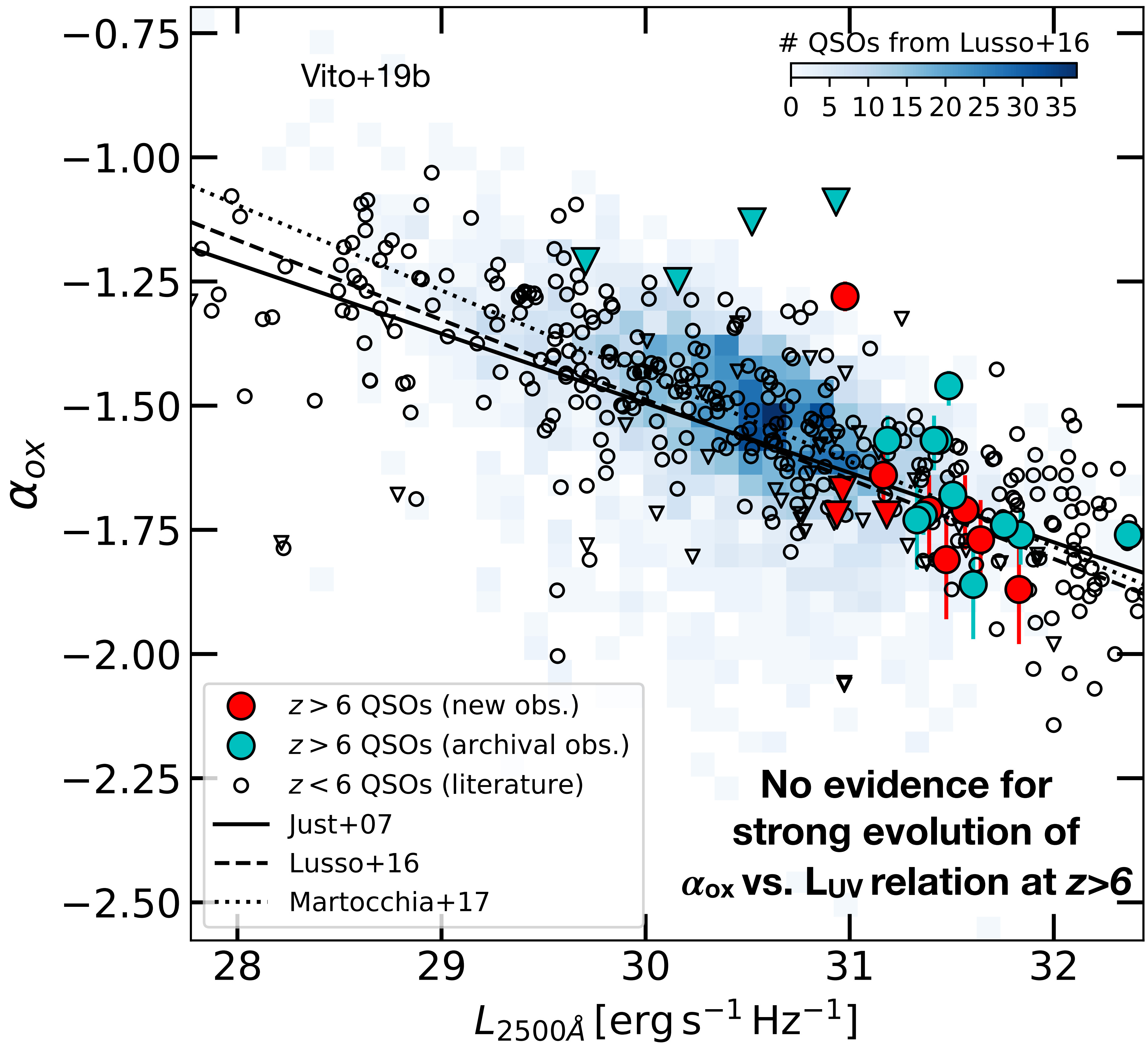
X-ray luminosity derived assuming "standard" Γ=2 (e.g., Shemmer+06, Nanni+17)

ID	$L_{2-10\mathrm{keV}}$ $[10^{44}\,\mathrm{erg\,s^{-1}}]$	α_{ox}	$\Delta\alpha_{ox}$
CFHQSJ0050+3445	$6.68^{+3.67}_{-2.70}$	$-1.71^{+0.07}_{-0.09}$	$-0.02^{+0.07}_{-0.09}$
VIKJ0109−3047	< 3.29	< -1.67	< -0.04
PSOJ036+03	$8.20^{+5.05}_{-3.57}$	$-1.77^{+0.08}_{-0.10}$	$-0.05^{+0.08}_{-0.10}$
VIKJ0305−3150	< 3.79	< -1.72	< -0.06
SDSSJ0842+1218	$4.34^{+3.26}_{-2.17}$	$-1.81^{+0.09}_{-0.12}$	$-0.11^{+0.09}_{-0.12}$
PSOJ167−13	< 2.21	< -1.72	< -0.09
CFHQSJ1509−1749	$10.34^{+5.10}_{-3.86}$	$-1.71^{+0.07}_{-0.08}$	$0.01^{+0.07}_{-0.08}$
CFHQSJ1641+3755	$33.39^{+5.56}_{-5.07}$	$-1.28^{+0.03}_{-0.03}$	$0.35^{+0.03}_{-0.03}$
PSOJ338+29	$5.92^{+2.96}_{-2.22}$	$-1.64^{+0.07}_{-0.08}$	$0.01^{+0.07}_{-0.08}$
SDSSJ2310+1855	$6.93^{+5.02}_{-3.34}$	$-1.87^{+0.09}_{-0.11}$	$-0.12^{+0.09}_{-0.11}$
SDSSJ0100+2802	$47.64^{+3.27}_{-3.08}$	$-1.76^{+0.01}_{-0.01}$	$0.07^{+0.01}_{-0.01}$
ATLASJ0142−3327	$13.69^{+4.98}_{-4.11}$	$-1.76^{+0.05}_{-0.06}$	$-0.01^{+0.05}_{-0.06}$
CFHQSJ0210−0456	< 29.31	< -1.13	< 0.44
CFHQSJ0216−0455	< 2.70	< -1.21	< 0.24
SDSSJ0303−0019	< 97.70	< -1.09	< 0.54
SDSSJ1030+0524	$10.77^{+1.27}_{-1.18}$	$-1.68^{+0.02}_{-0.02}$	$0.03^{+0.02}_{-0.02}$
SDSSJ1048+4637	$4.25^{+3.08}_{-2.05}$	$-1.86^{+0.09}_{-0.11}$	$-0.15^{+0.09}_{-0.11}$
ULASJ1120+0641	$6.07^{+1.33}_{-1.25}$	$-1.72^{+0.03}_{-0.04}$	$-0.03^{+0.03}_{-0.04}$
SDSSJ1148+5251	$12.94^{+2.69}_{-2.39}$	$-1.74^{+0.03}_{-0.03}$	$-0.00^{+0.03}_{-0.03}$
SDSSJ1306+0356	$17.06^{+1.73}_{-1.63}$	$-1.57^{+0.02}_{-0.02}$	$0.12^{+0.02}_{-0.02}$
ULASJ1342+0928	$14.96^{+5.46}_{-4.40}$	$-1.57^{+0.05}_{-0.06}$	$0.12^{+0.05}_{-0.06}$
SDSSJ1602+4228	$37.04^{+8.25}_{-7.28}$	$-1.46^{+0.03}_{-0.04}$	$0.24^{+0.03}_{-0.04}$
SDSSJ1623+3112	$5.08^{+3.13}_{-2.22}$	$-1.73^{+0.08}_{-0.10}$	$-0.05^{+0.08}_{-0.10}$
SDSSJ1630+4012	$9.92^{+3.12}_{-2.58}$	$-1.57^{+0.05}_{-0.05}$	$0.09^{+0.05}_{-0.05}$
HSCJ2216−0016	< 5.92	< -1.25	< 0.27

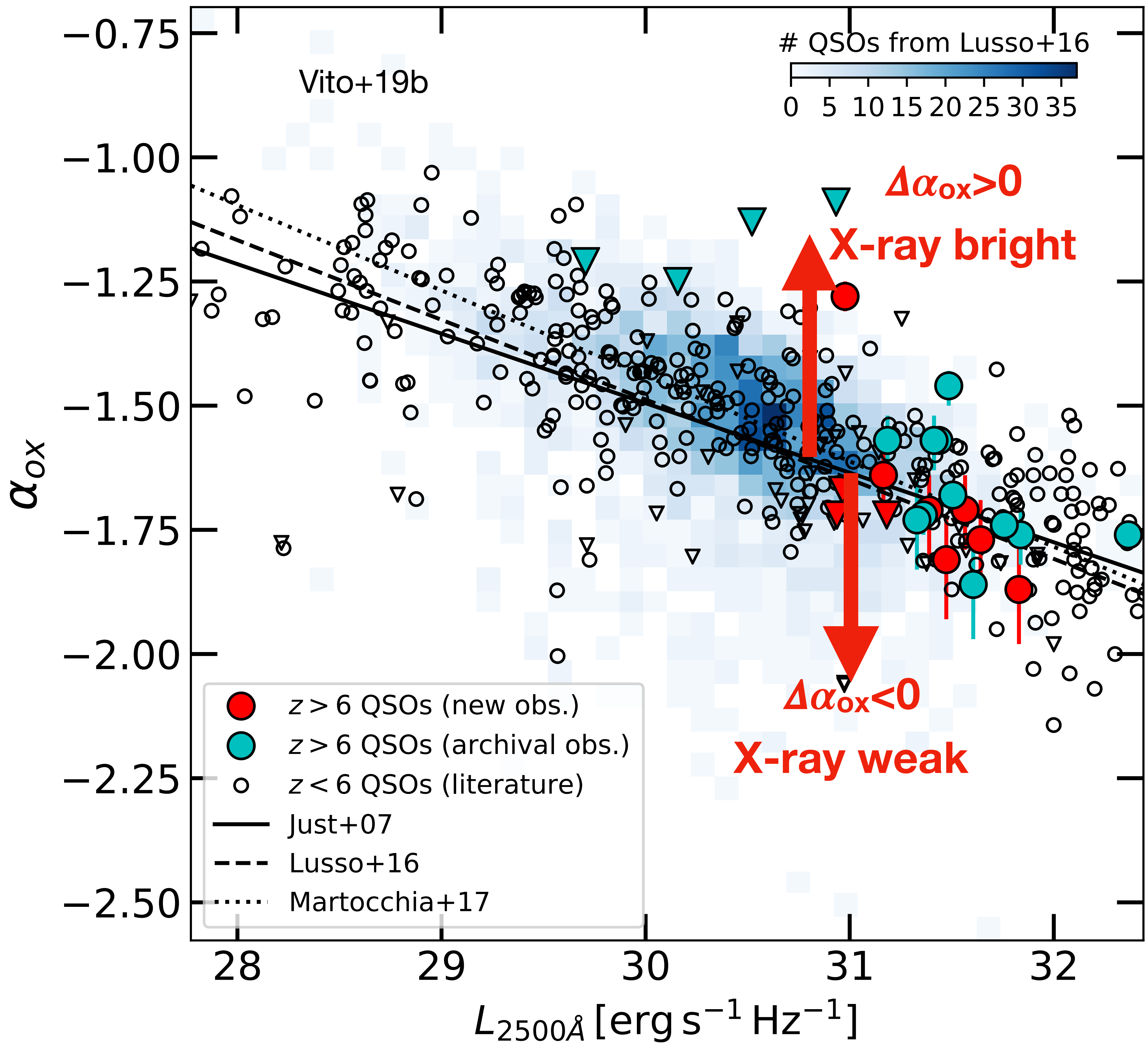
Vito+19b

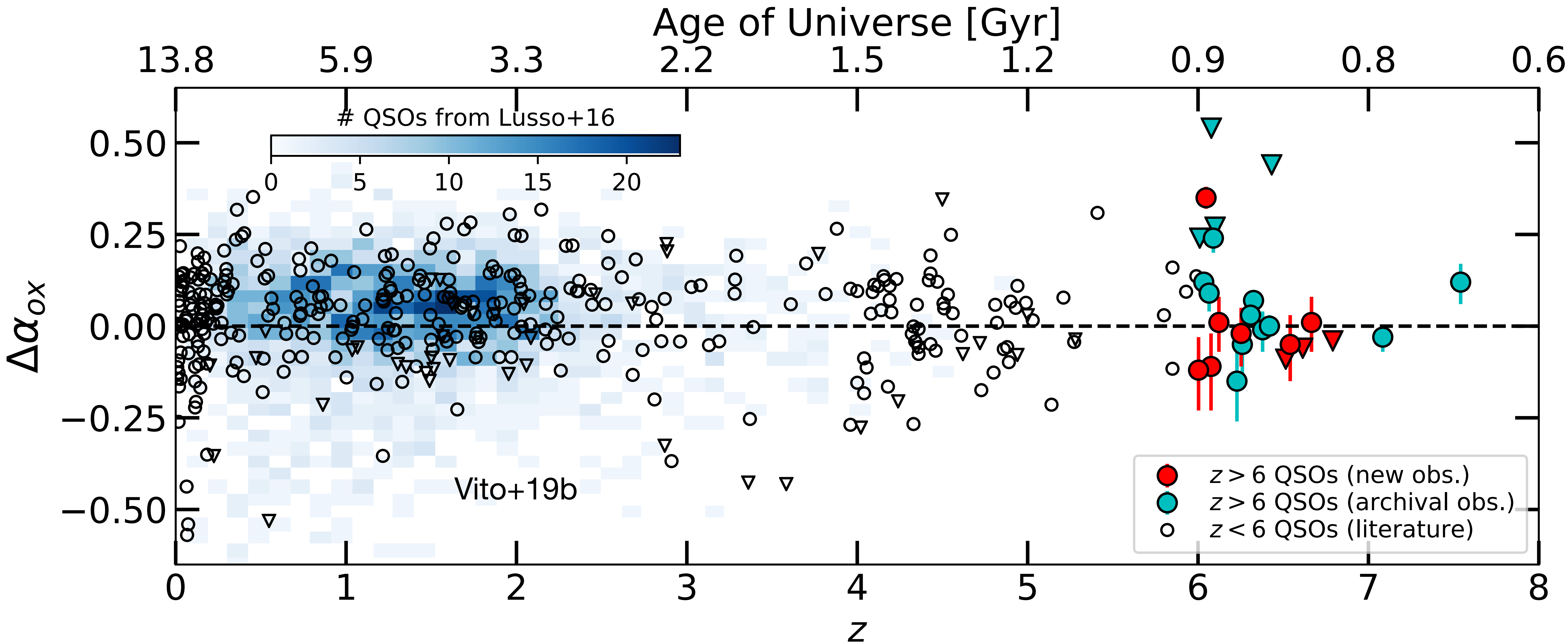


α_{ox} vs. L_{UV} relation extended at $z>6$

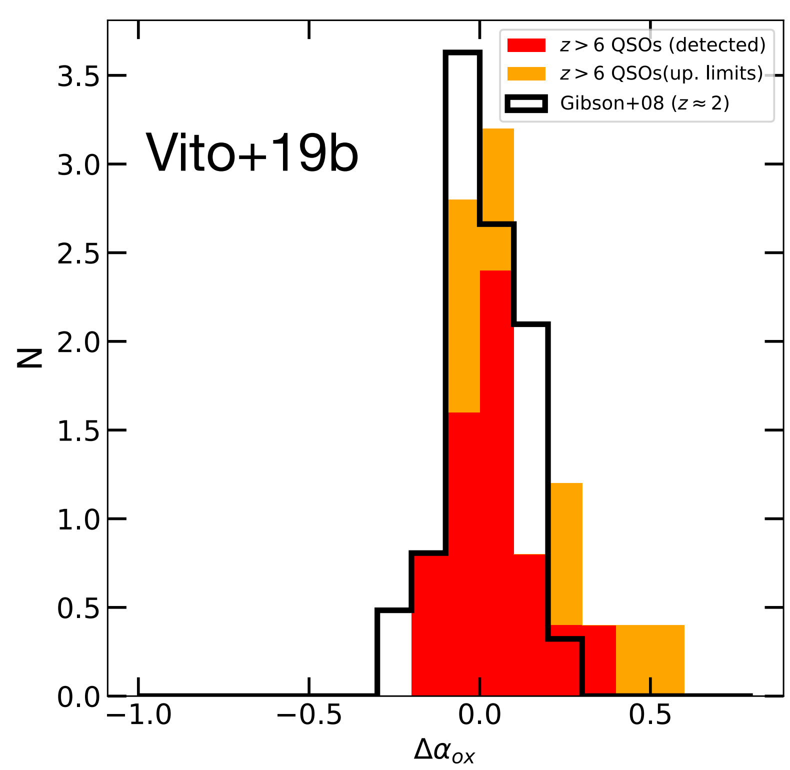


$\Delta\alpha_{ox}=\alpha_{ox}(\text{obs})-\alpha_{ox}(\text{expect.})$





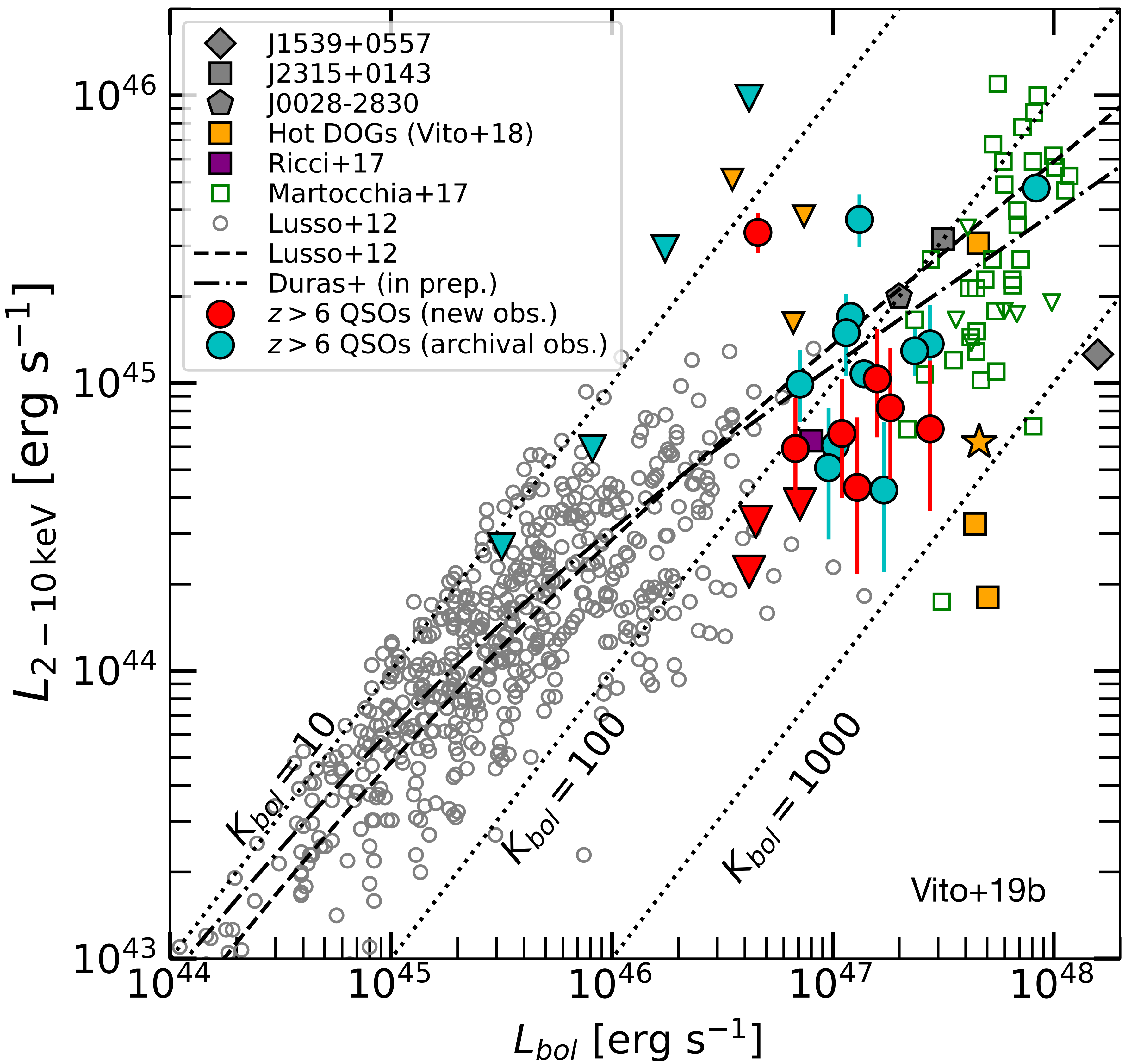
Compared also with "ultra-clean" z=2 QSO sample by Gibson+08



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

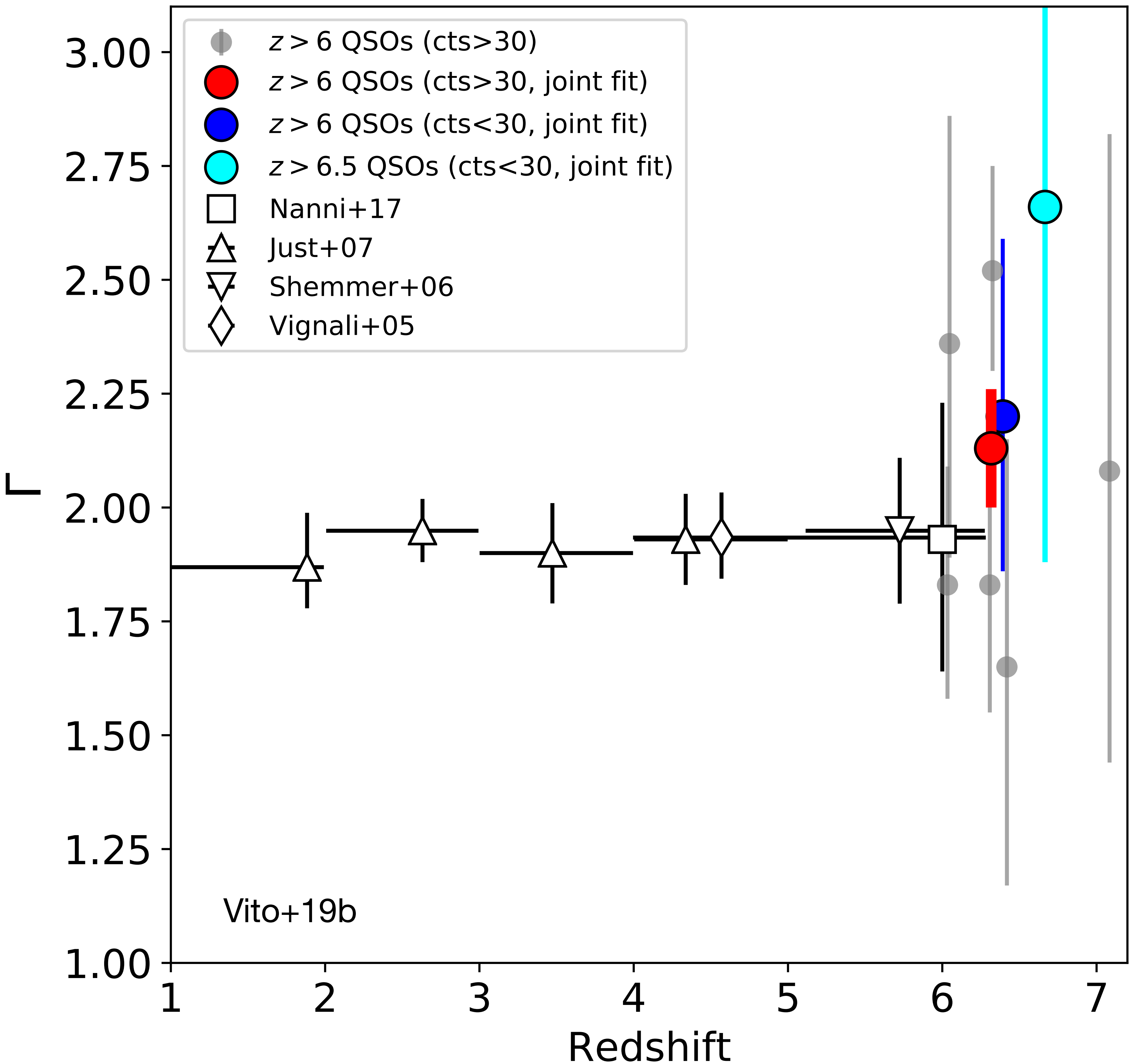


Populate the luminosity regime b/w "normal" AGN and hyper-luminous QSOs, and extend at z>6

Larger K_{bol} at higher luminosities, in agreement with steeper α_{ox} at higher luminosities

Change of the accretion-disk/hot-corona physics/geometry at high luminosities/λ_{EDD} but same change at all redshifts

Average QSO photon index as a function of *z*



Assumed simple power-law emission, i.e. no reflection (ok for luminous type-1 QSOs, e.g. Comastri+92, Piconcelli+05, Shemmer+05)

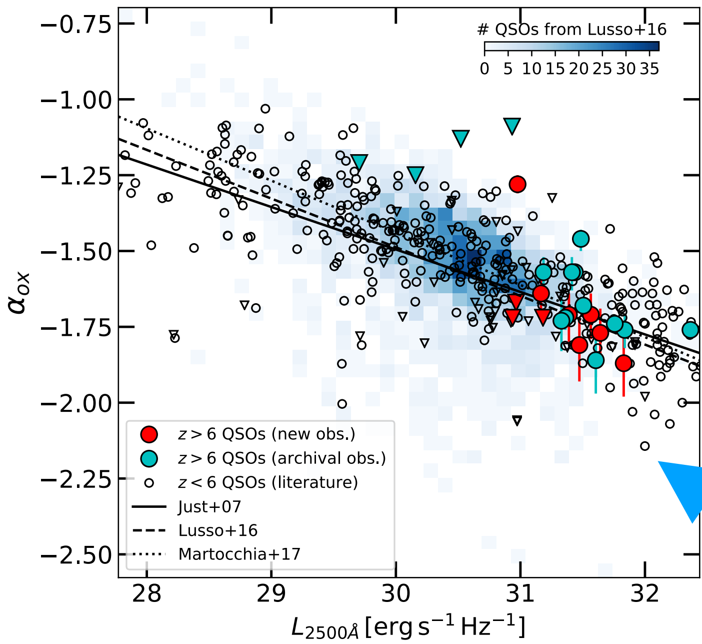
$\langle \Gamma \rangle \approx 2.1$-$2.2$ for *z*>6 QSOs

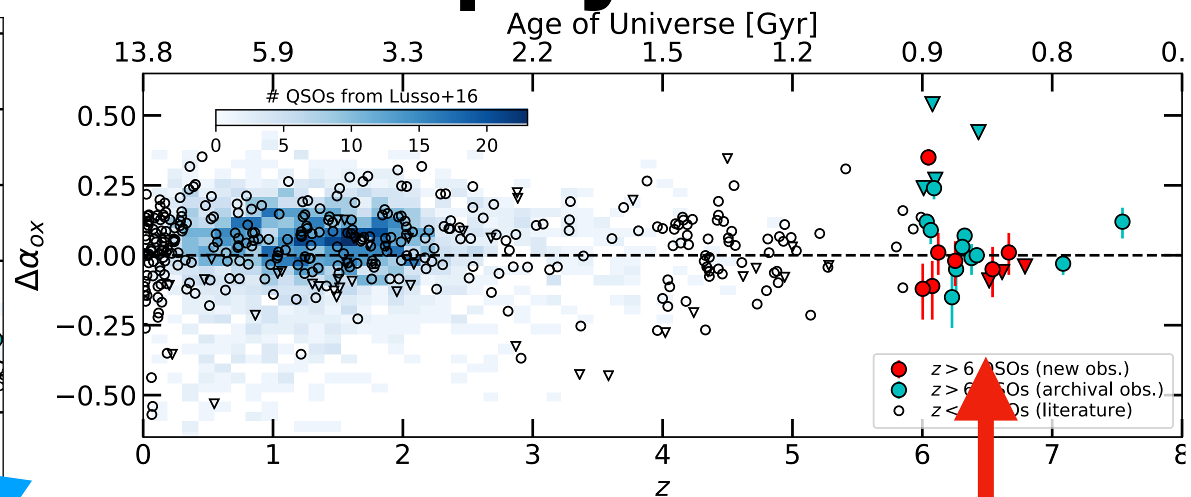
Consistent with z=1-6 results

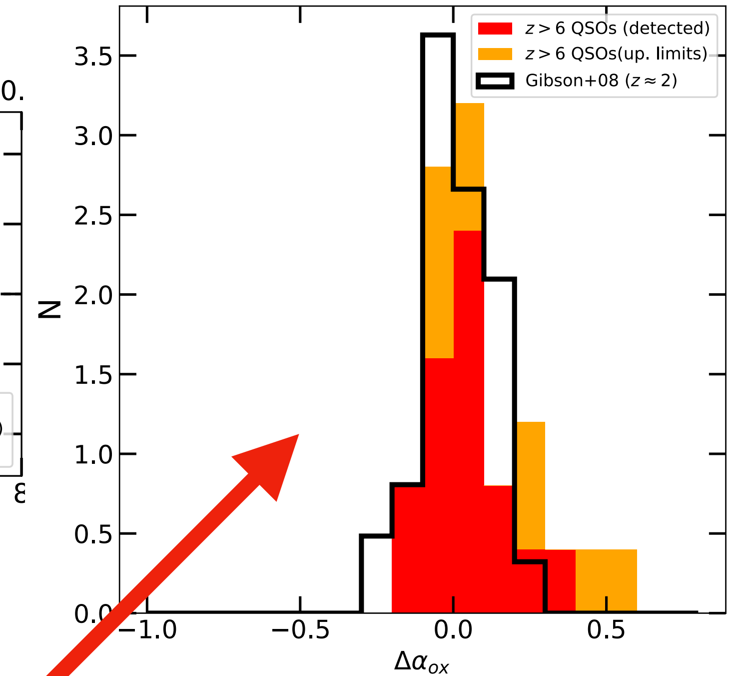
"Universal" accretion mode (λ_{EDD} dependent, redshift independent)

(but hint of a steepening?)

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

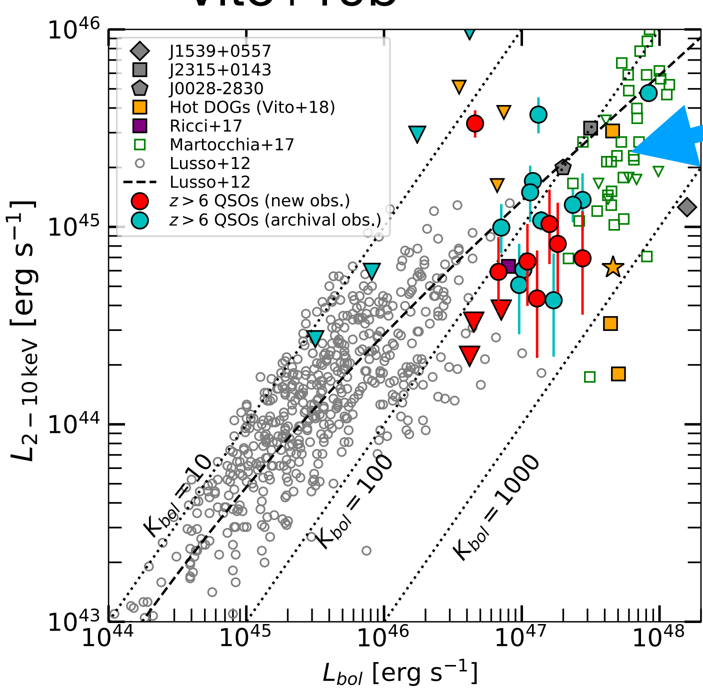


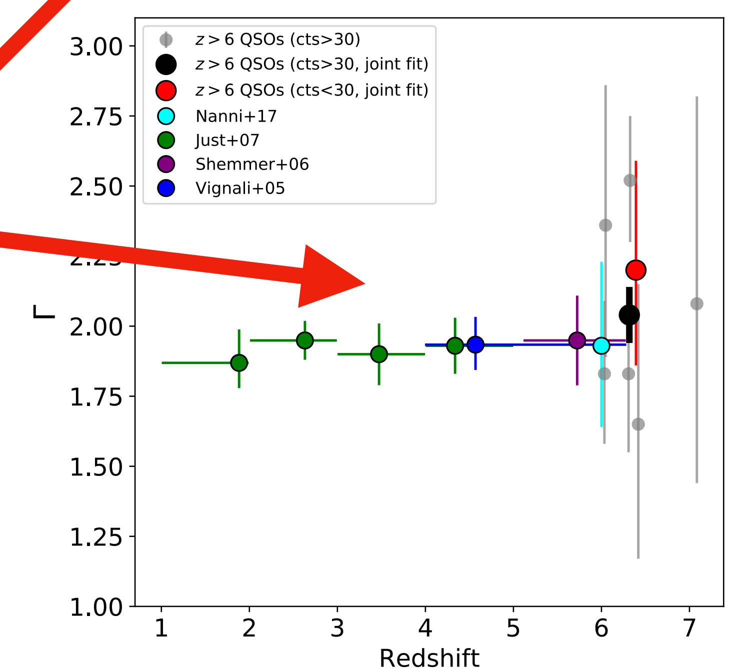




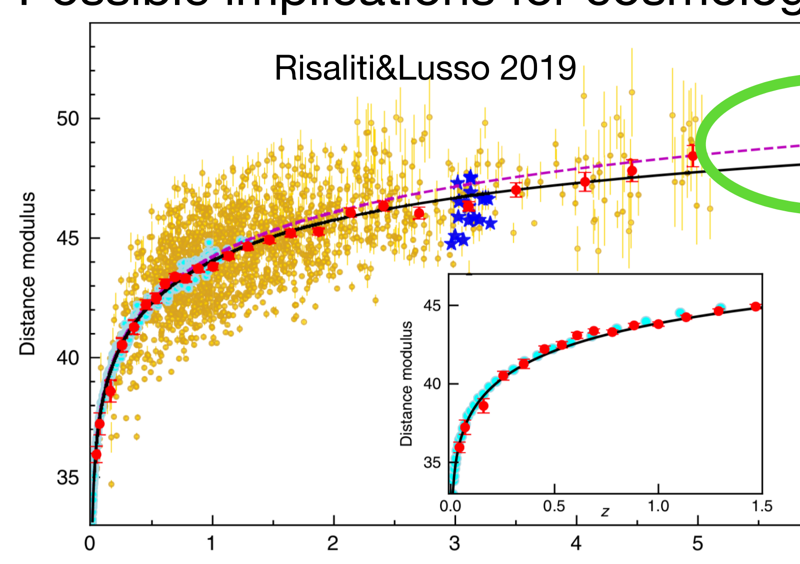
Same dependence on luminosity (i.e., λ_{EDD}?) at all redshifts

Vito+19b

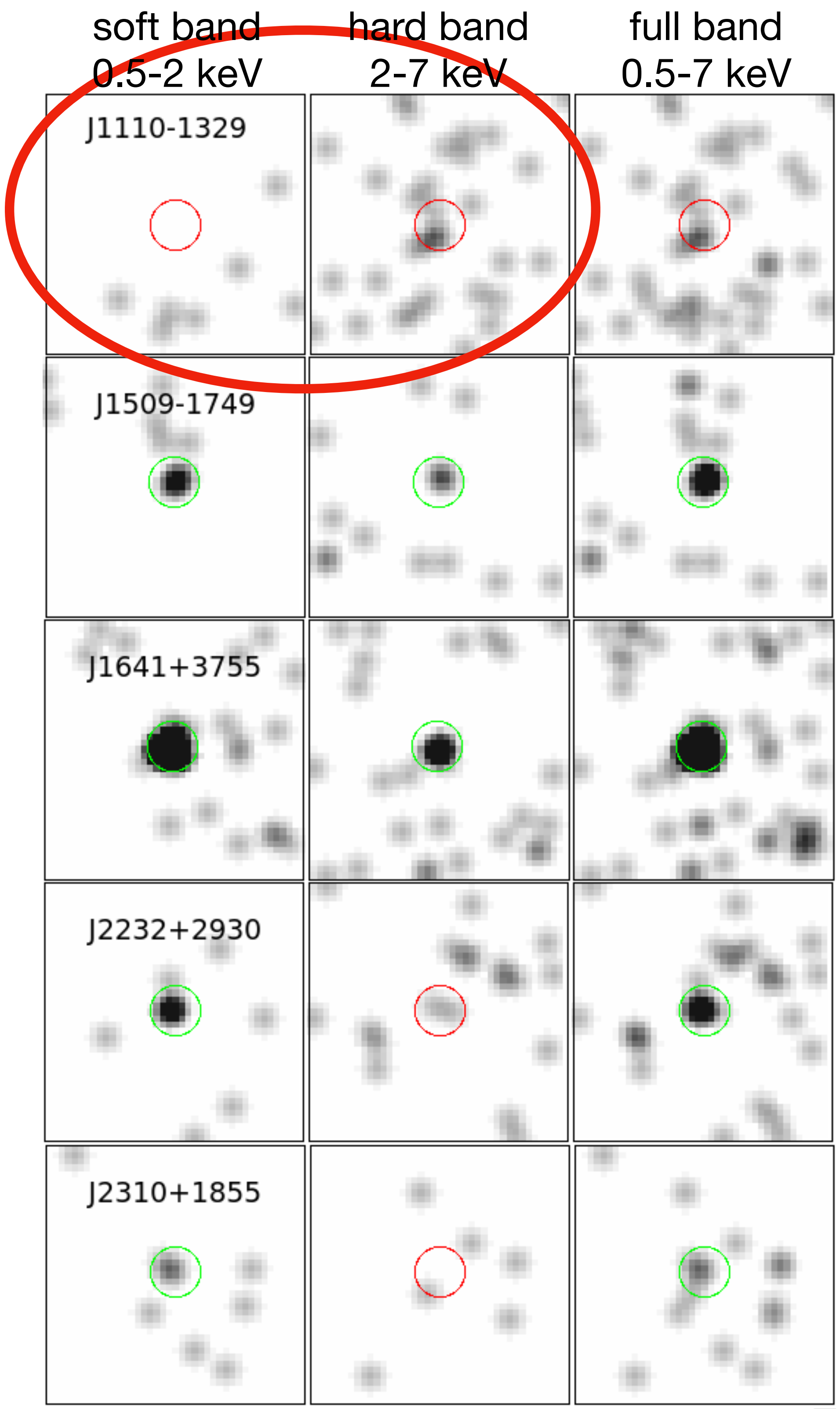




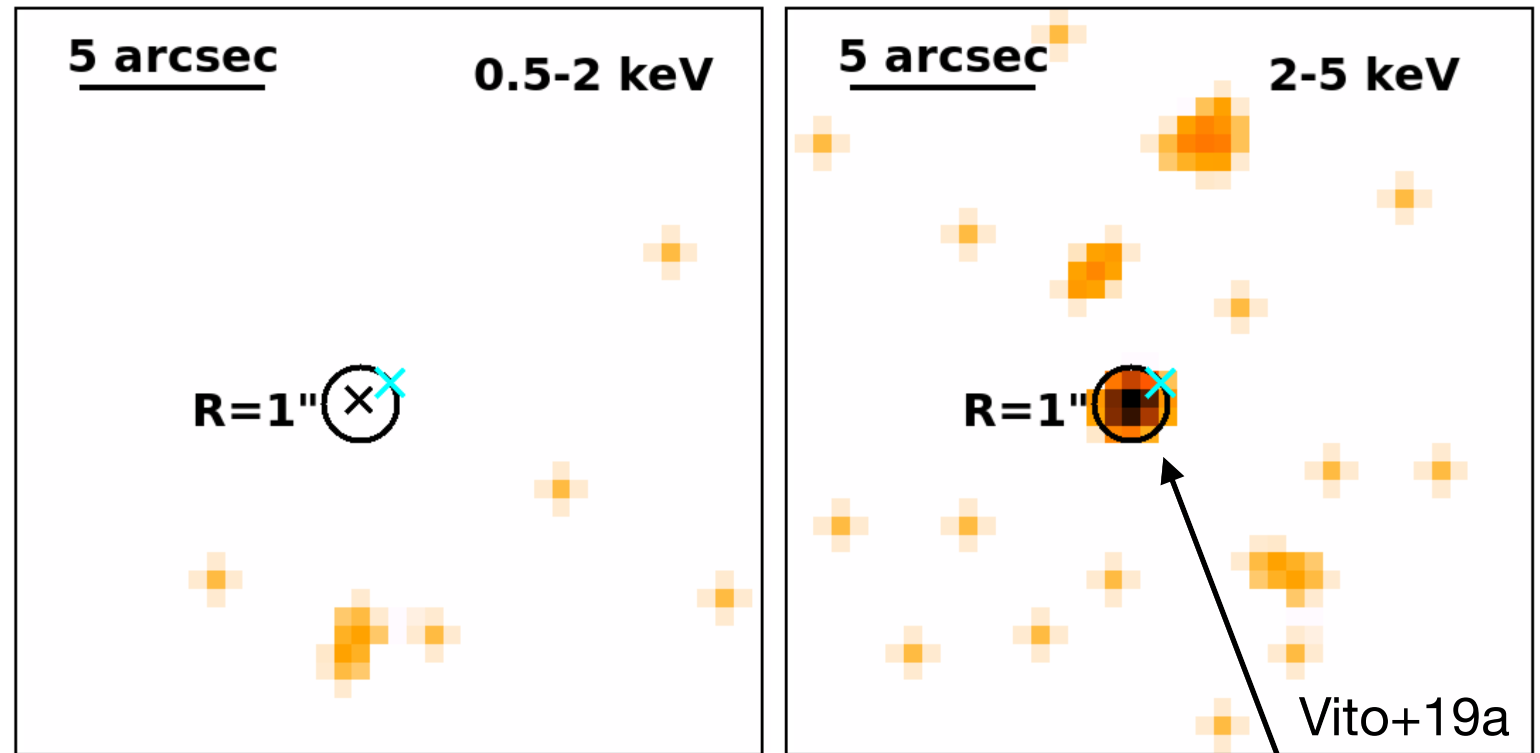
Possible implications for cosmology



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

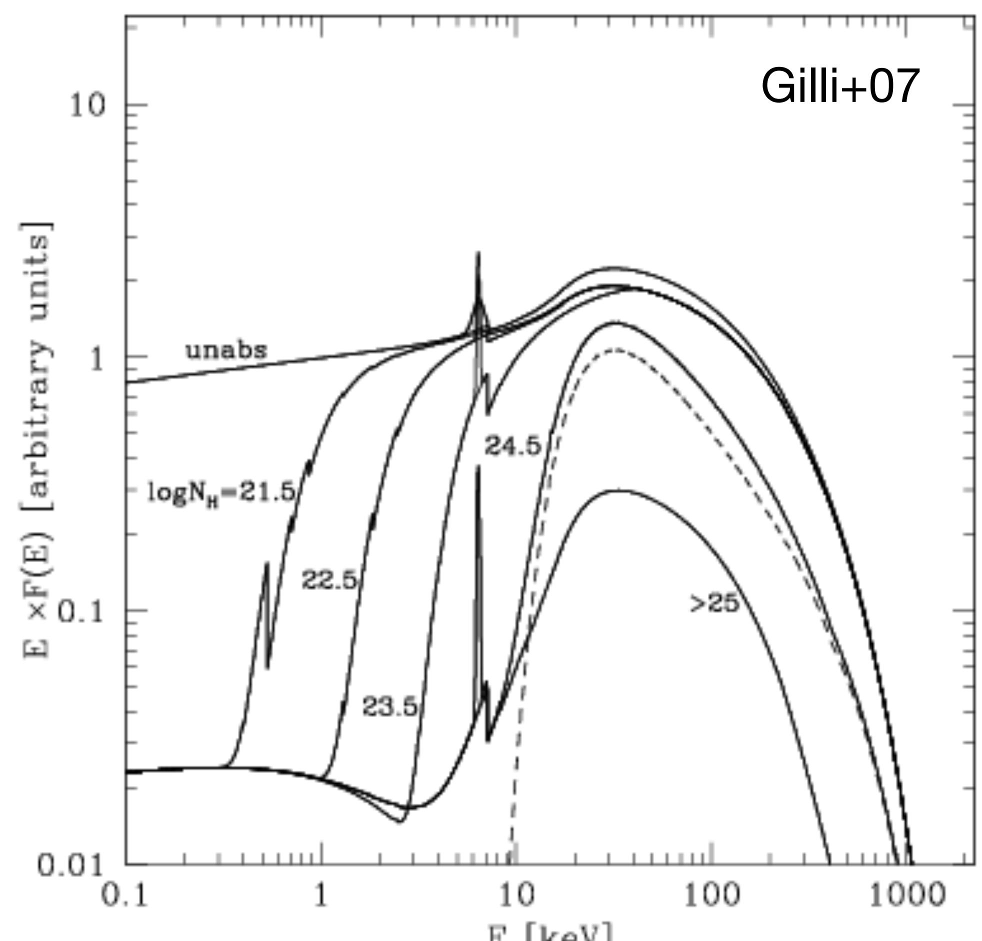


Vito+19b



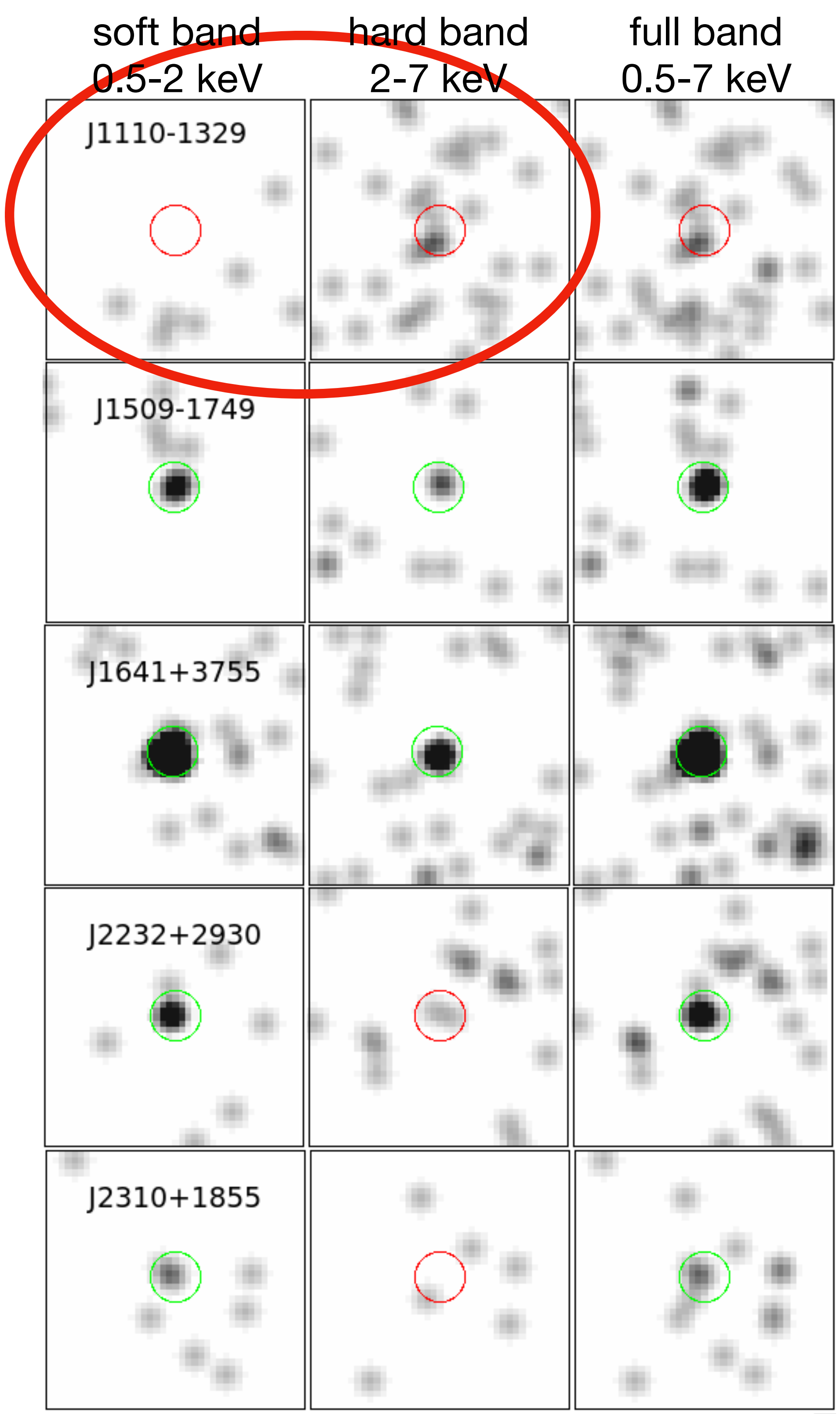
Vito+19a

3 photons
(P=0.9996,
Weisskopf+07)

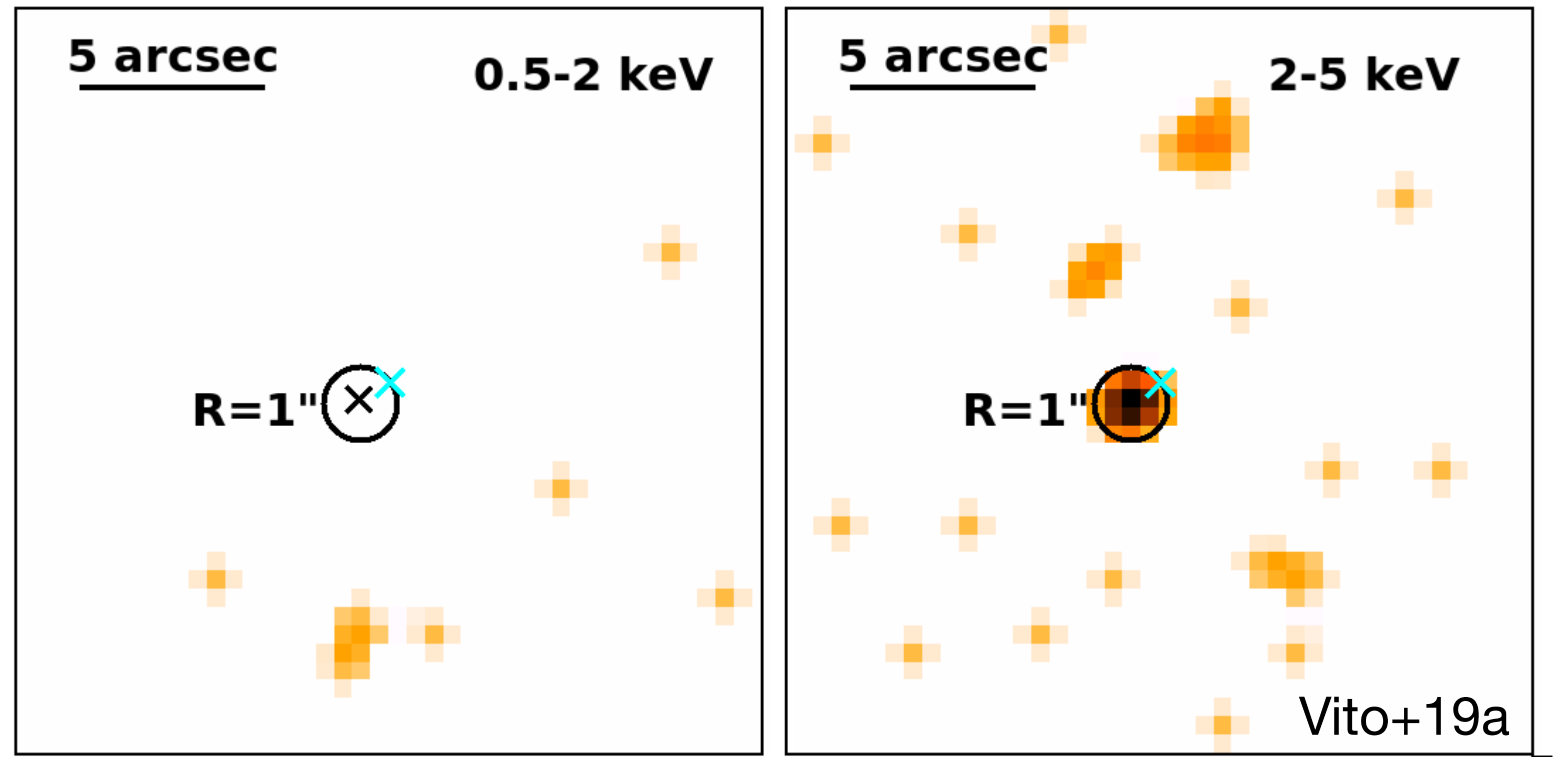


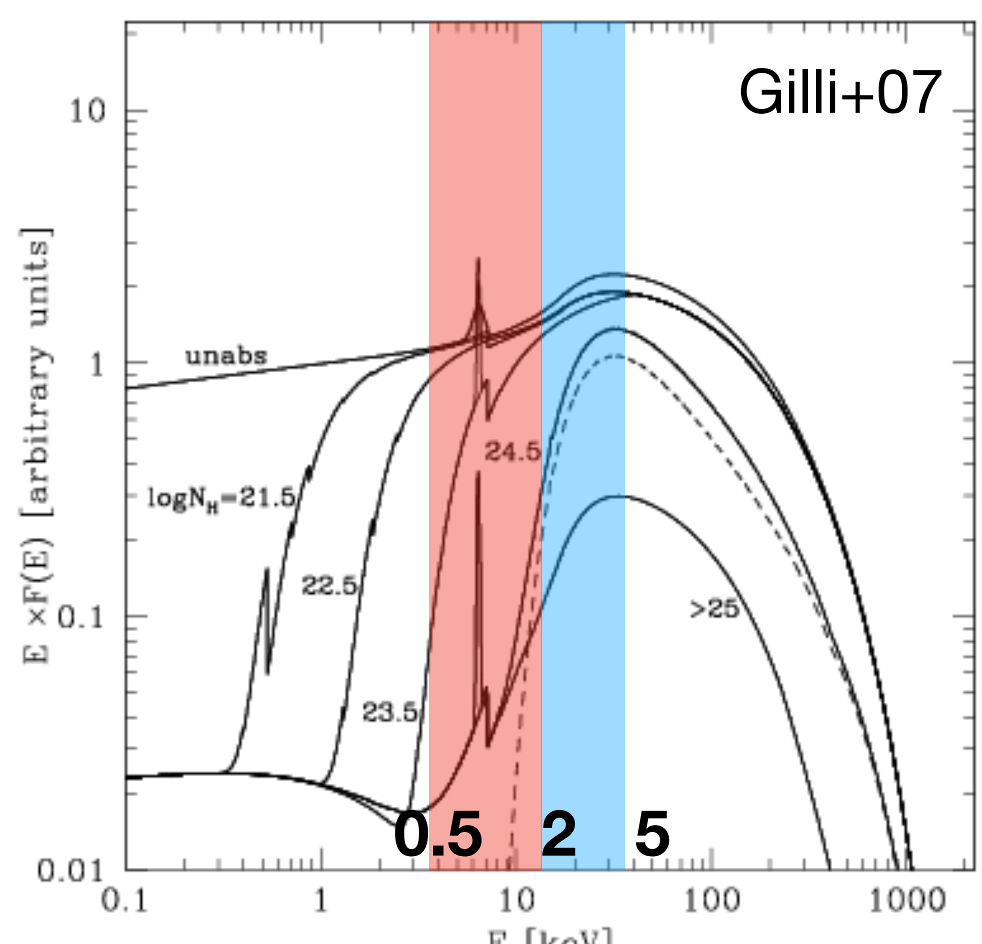
Relative emission
is soft and hard bands
gives indications
of absorption level

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



Vito+19a





N_H> 2 x 10^{24} cm^{-2}

at 68% confidence level

N_H> 6 x 10^{23} cm^{-2}

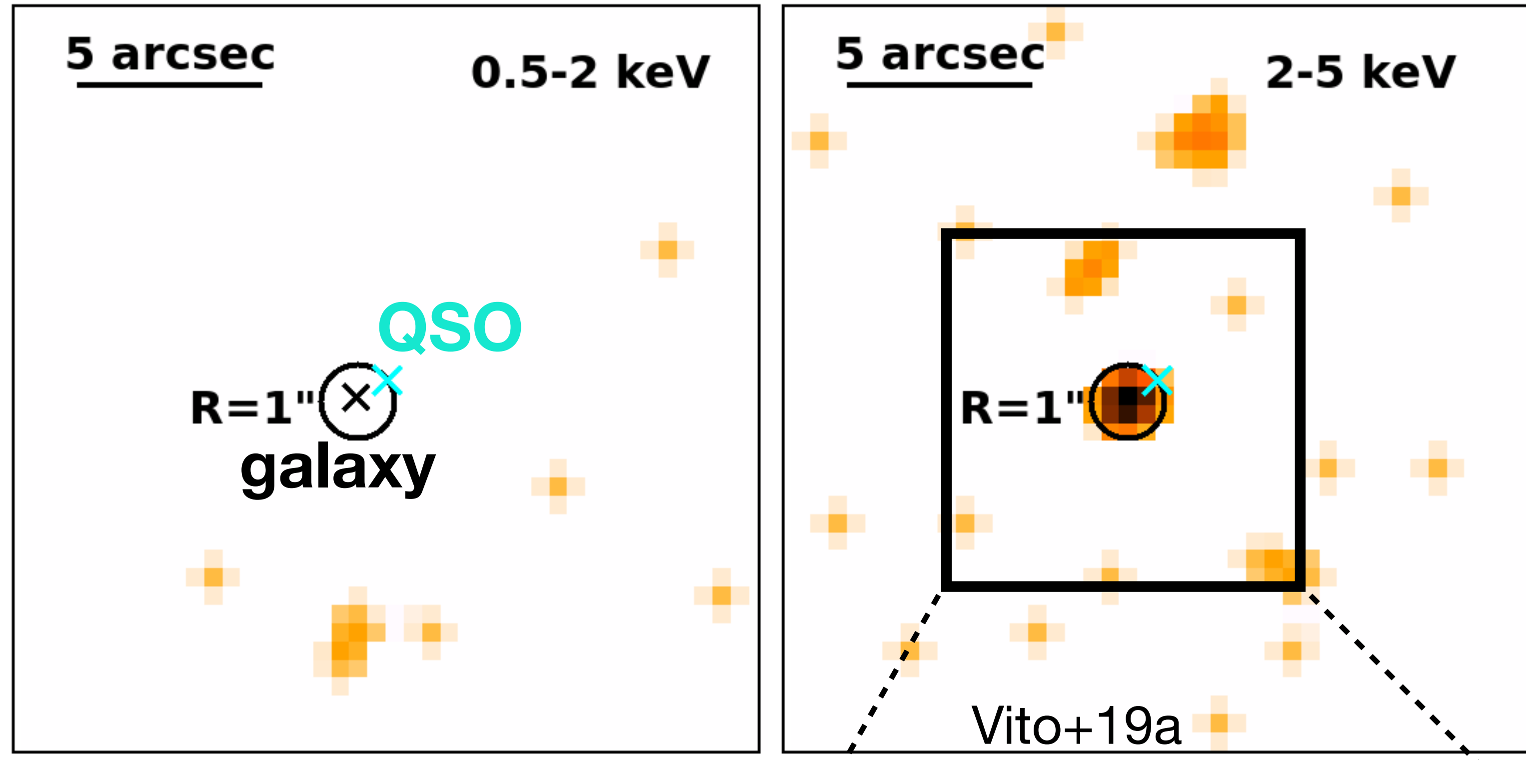
at 90% confidence level

First heavily obscured QSO candidate at z>6!

(See also Connor+19, +20)

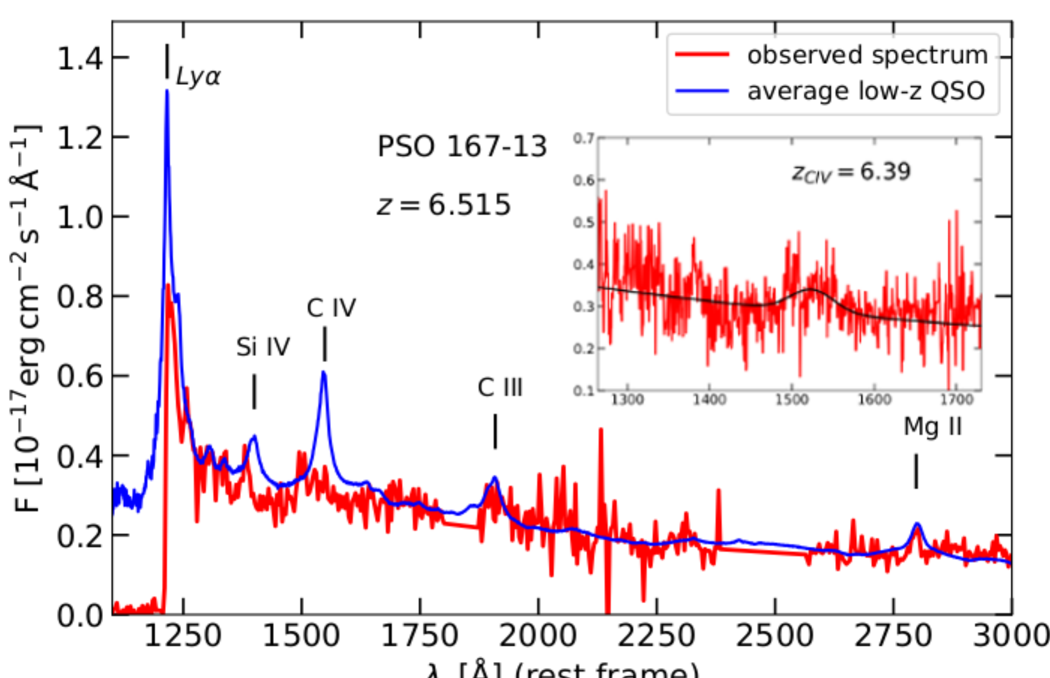
PSO167-13 (z=6.515): first heavily obscured QSO candidate at z>6!

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



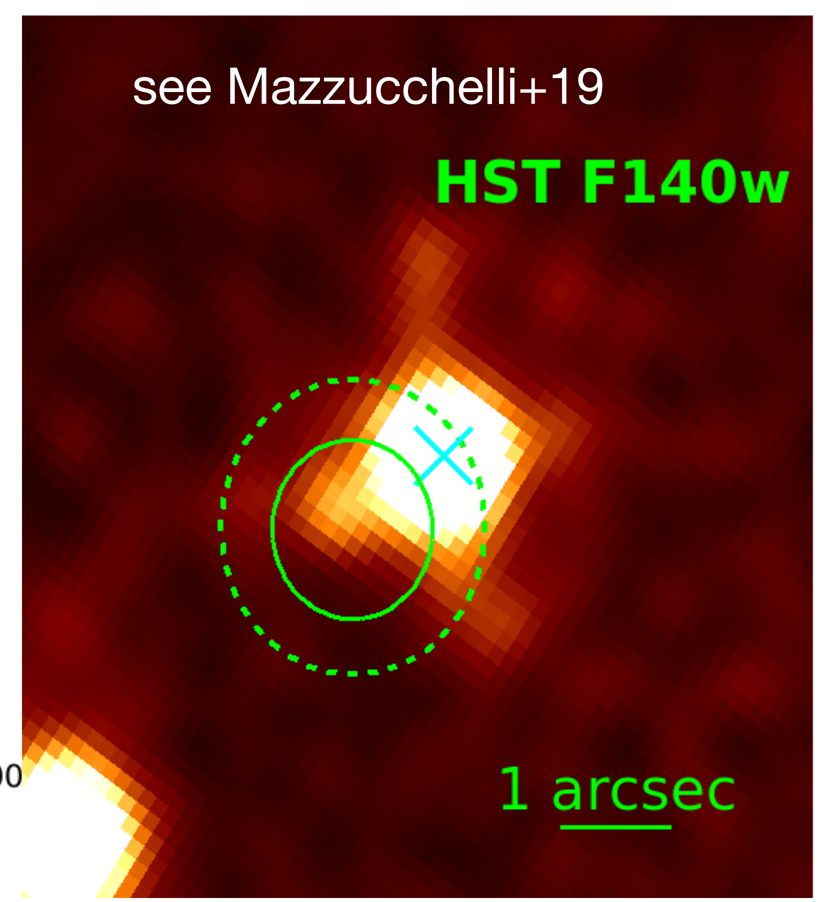
Why an optically type I QSO is heavily obscured in X-rays?

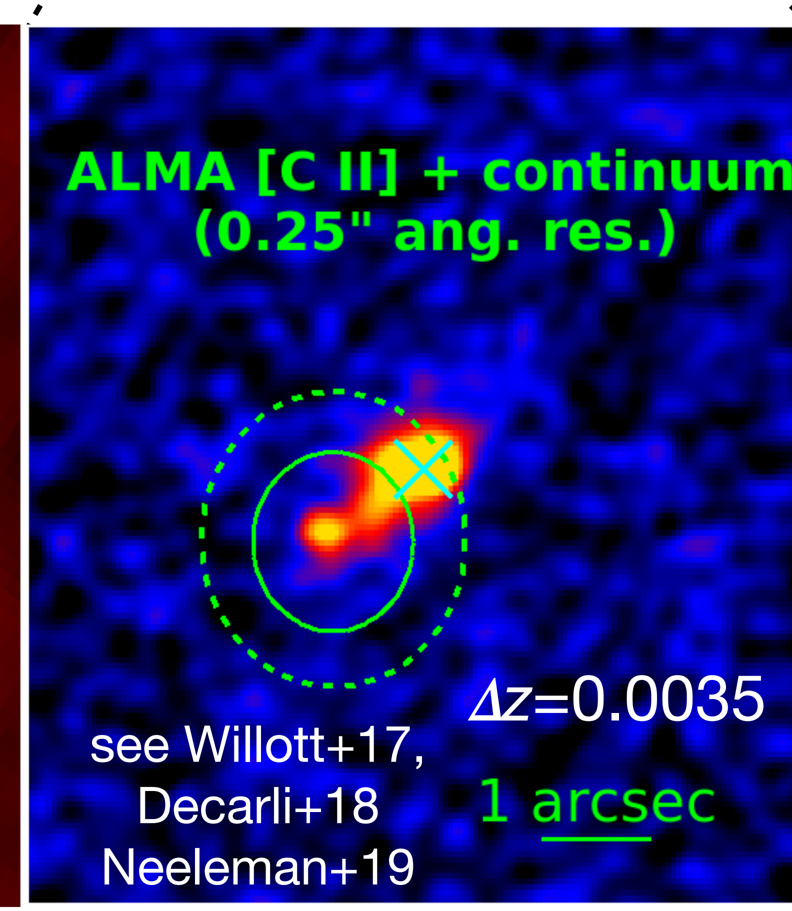
- **WLQ?**
- **BALQSO?**
- **Changing look QSO?**



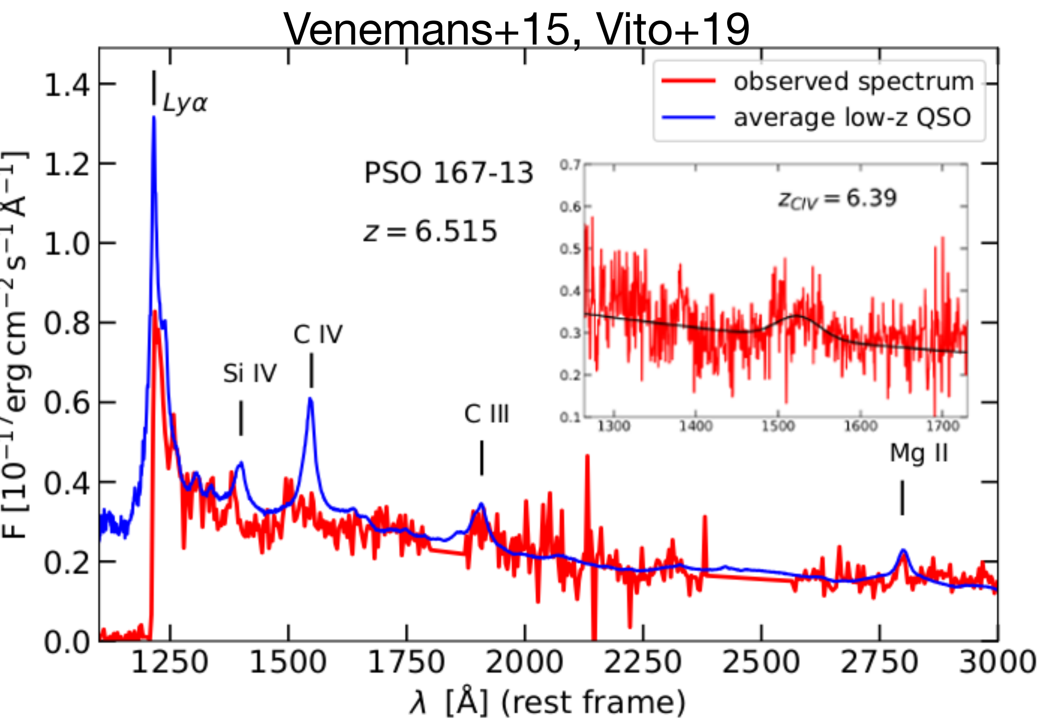
see Venemans+15

Vito+19a





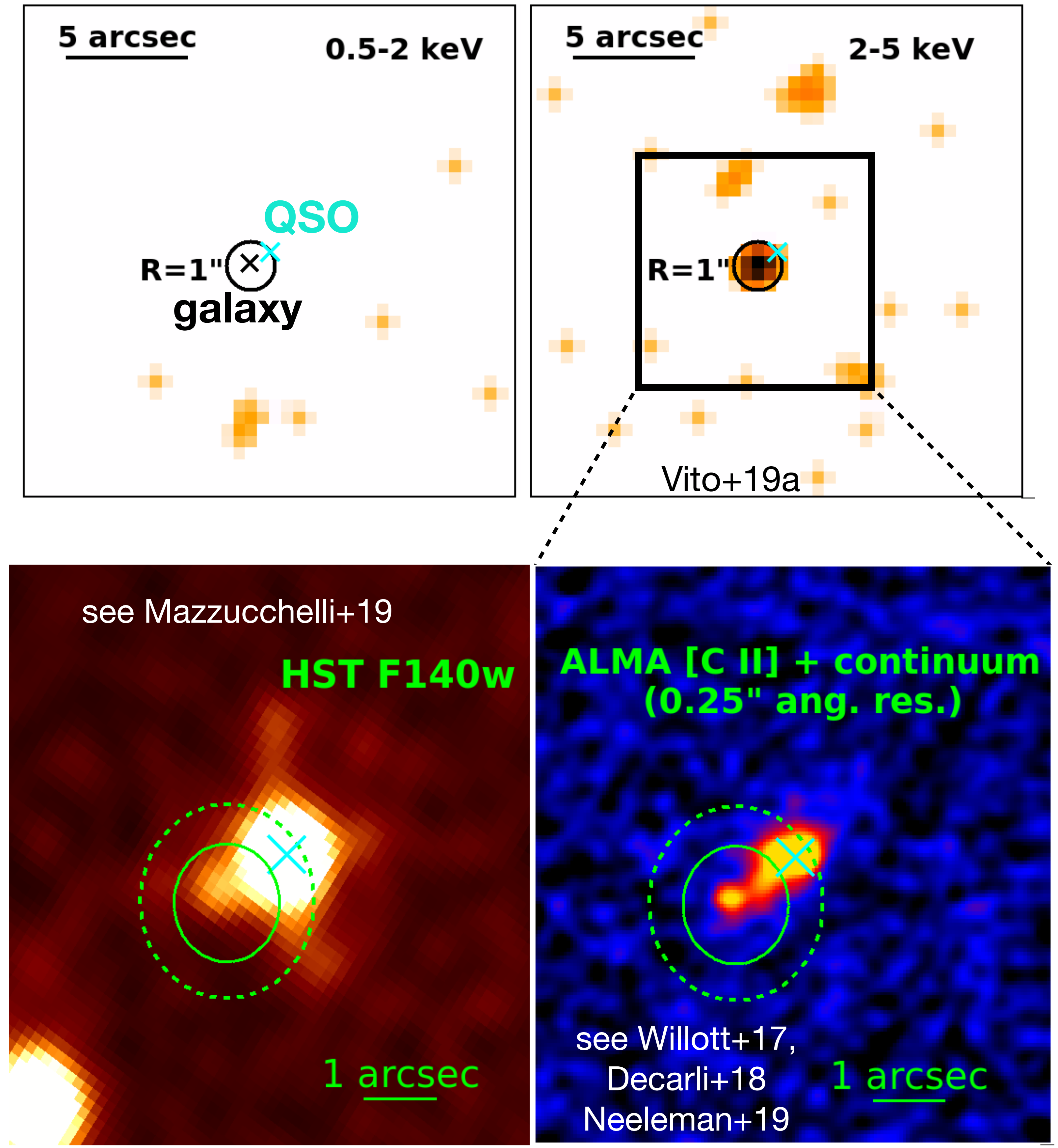
PSO167-13 (z=6.515): first heavily obscured QSO candidate at z>6!



VLT/XSHOOTER (11h)
to obtain a rest-frame UV spectrum with a higher *SNR:*
not observed (COVID)

***Chandra* (120ks)**
to confirm large N_H and improve positional accuracy:
conflicting results (Vito+ in prep.)

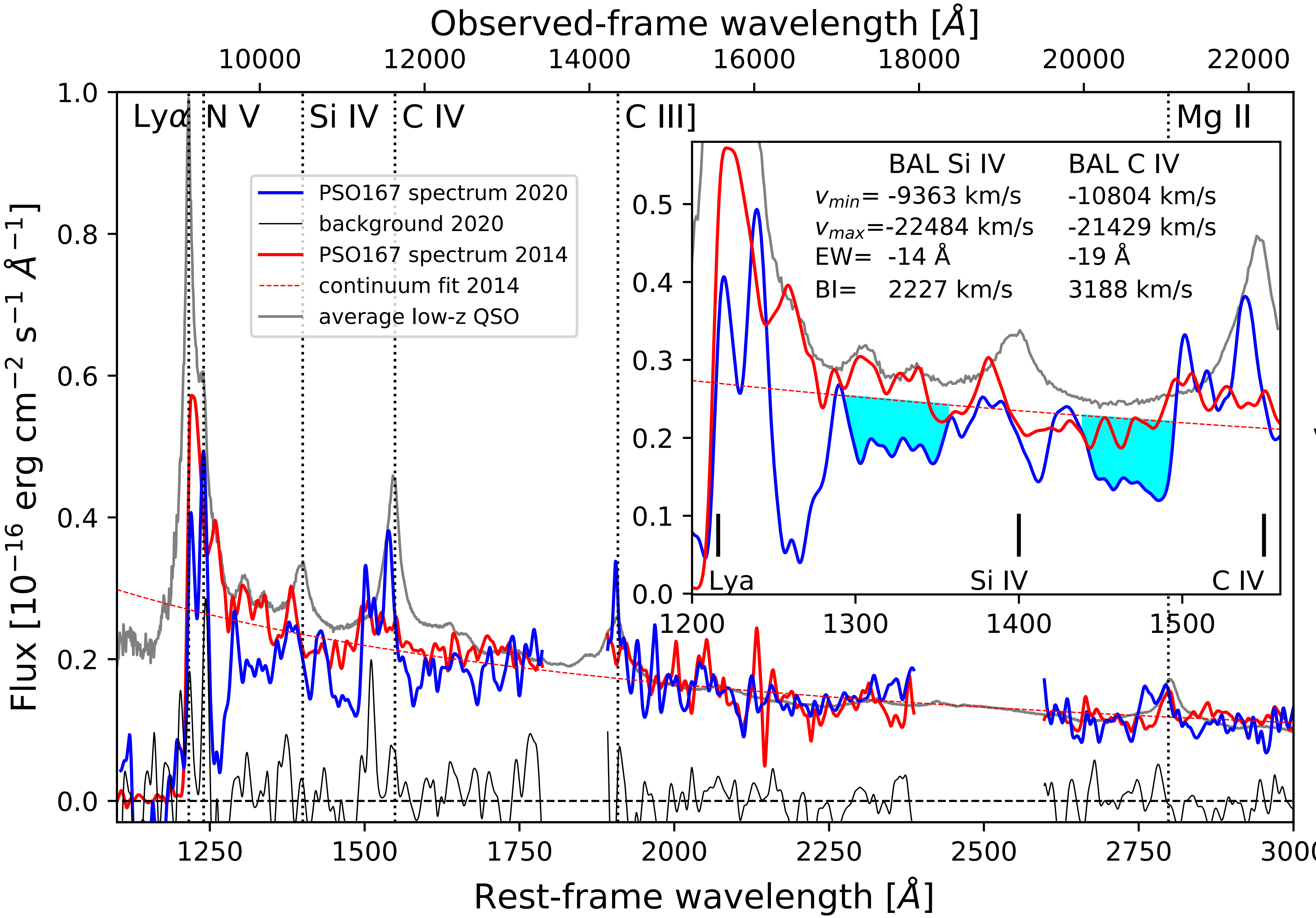
Magellan/FIRE (2 nights)
Get better UV spectrum:
observed, but bad weather
(Vito+ in prep.)



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

New Magellan/FIRE observations: emerging Broad Absorption Lines in UV spectrum?

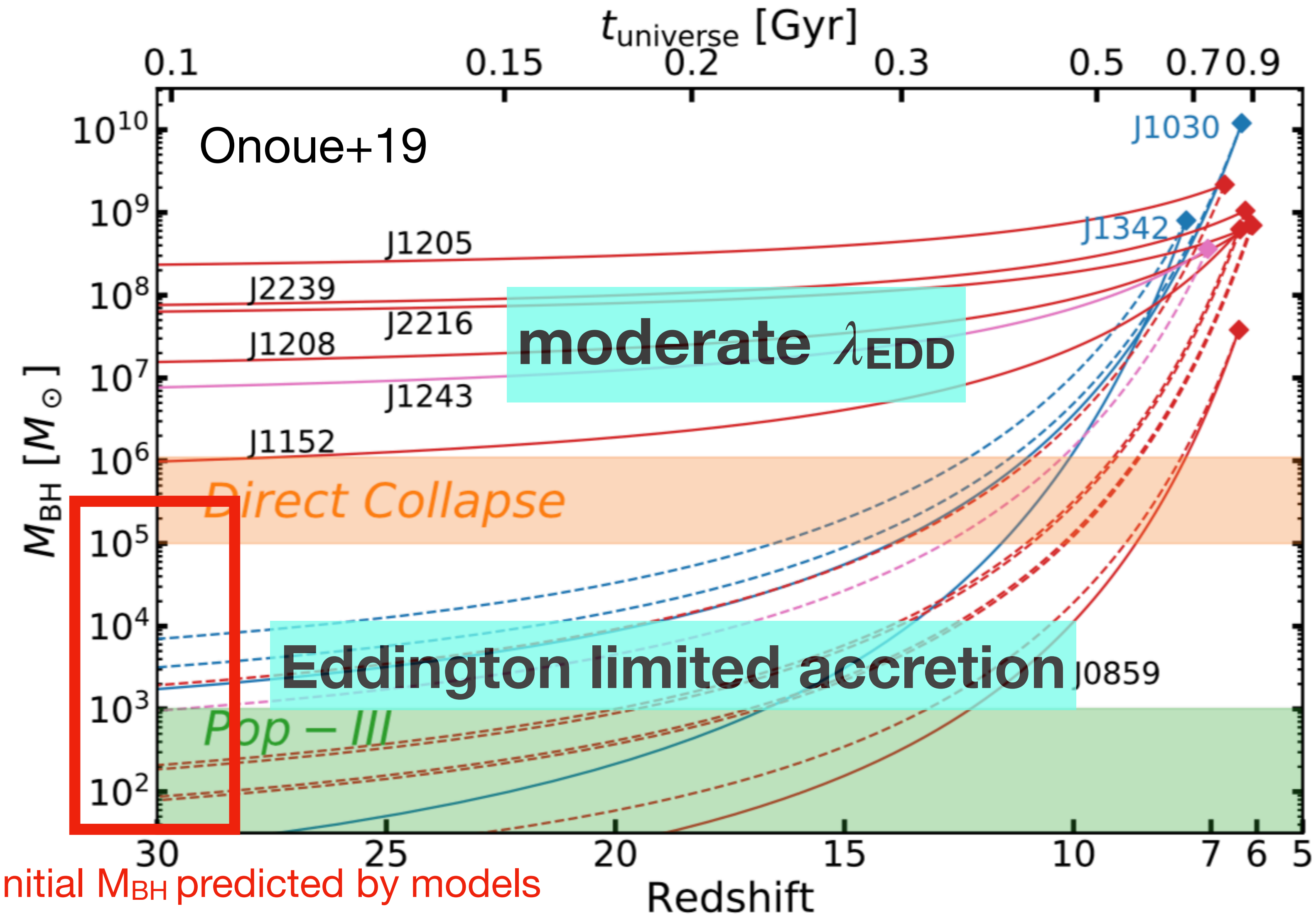
PRELIMINARY!!

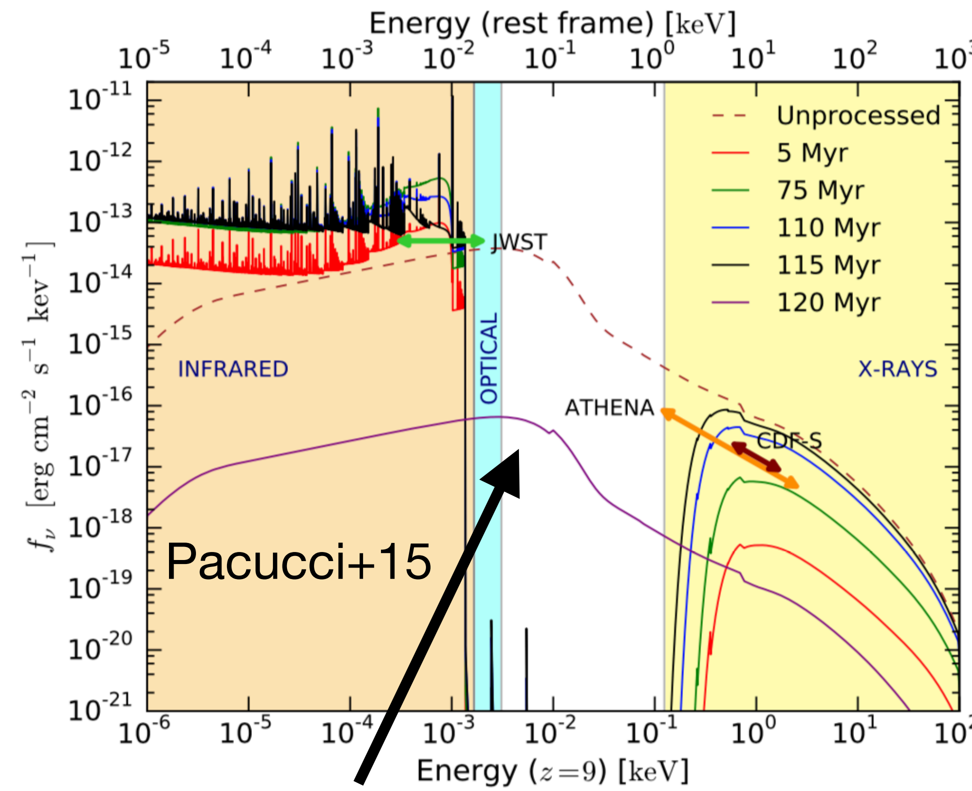


Vito+ in prep.

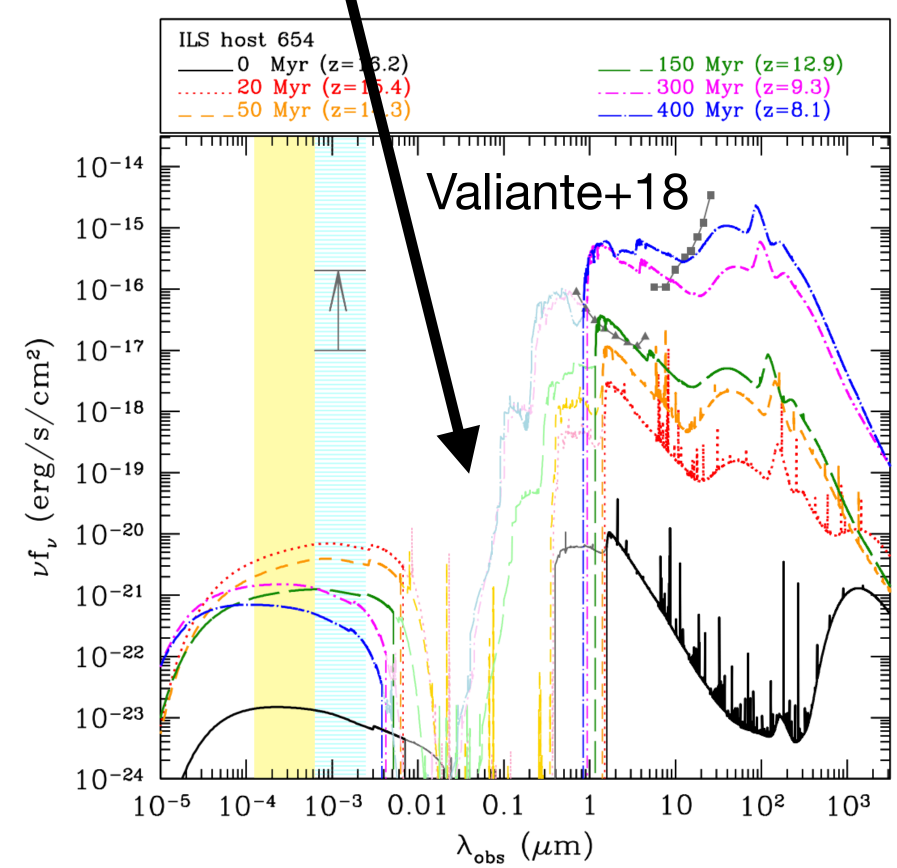
New VLT/XSHOOTER observations requested

Obscured QSOs at z>6: how many are there?





Obscuration



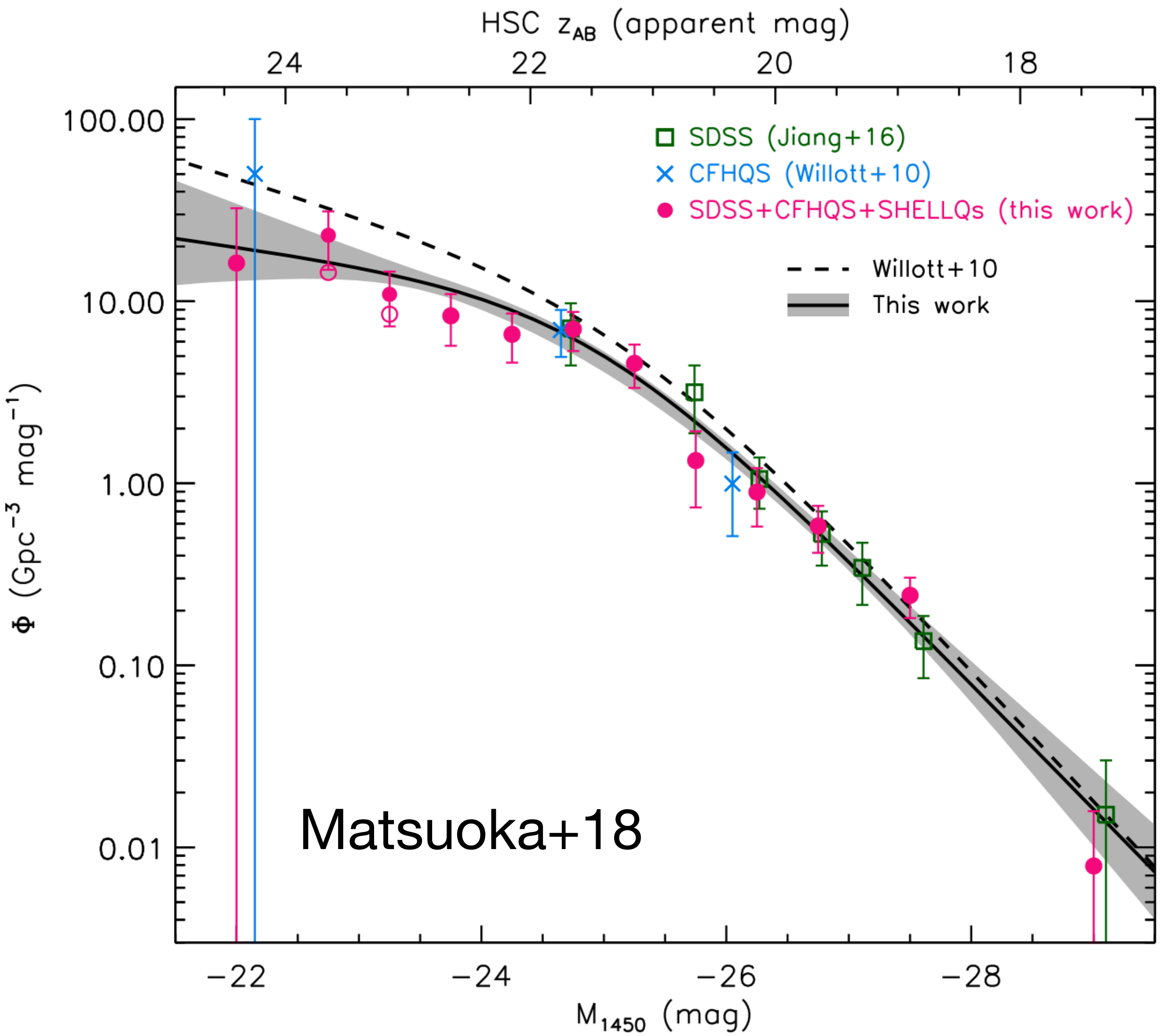
Models require fast accretion
(i.e., high Eddington ratio λ_{EDD}),
possibly in heavily obscured conditions,
to match the observed M_{BH} at z=6-7.5

Obscured QSOs at z>6: how many are there?

Extrapolate AGN X-ray LF at *z*~4 and compare with QSO UV LF at *z*~6

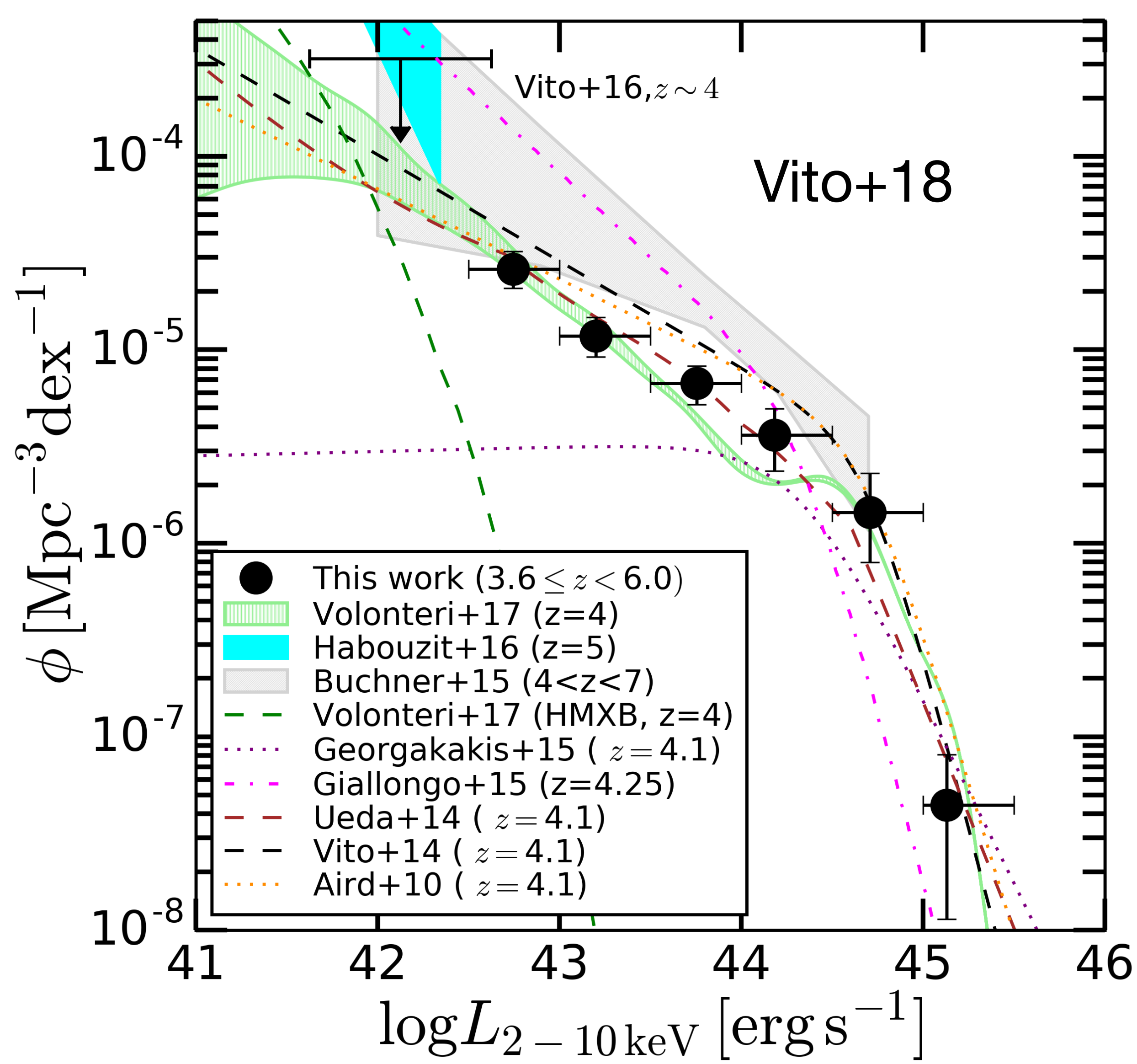
z~6 QSO UV LF (Matsuoka+18)

- Includes ~only unobscured QSOs

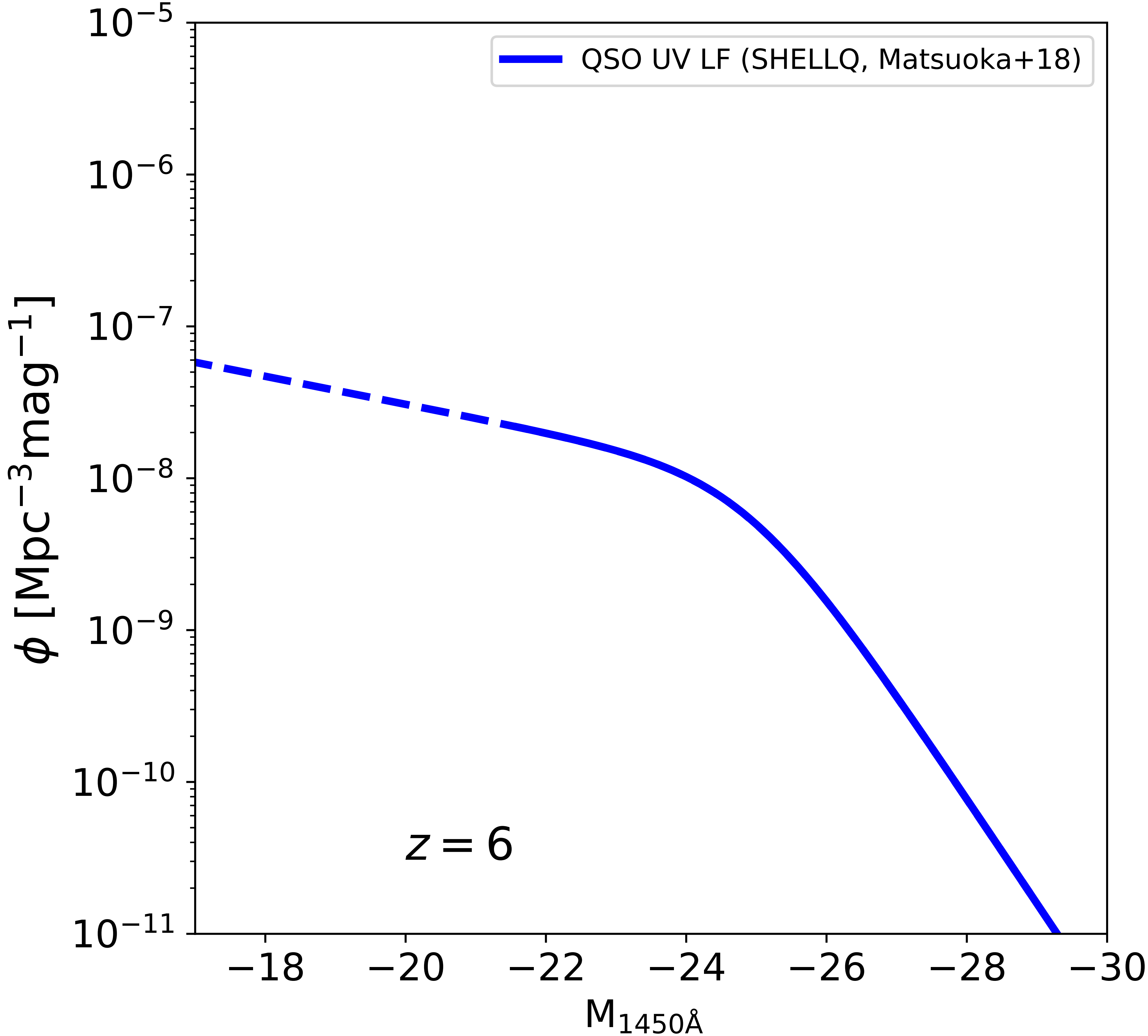


z~4 AGN XLF (Vito+14,+18)

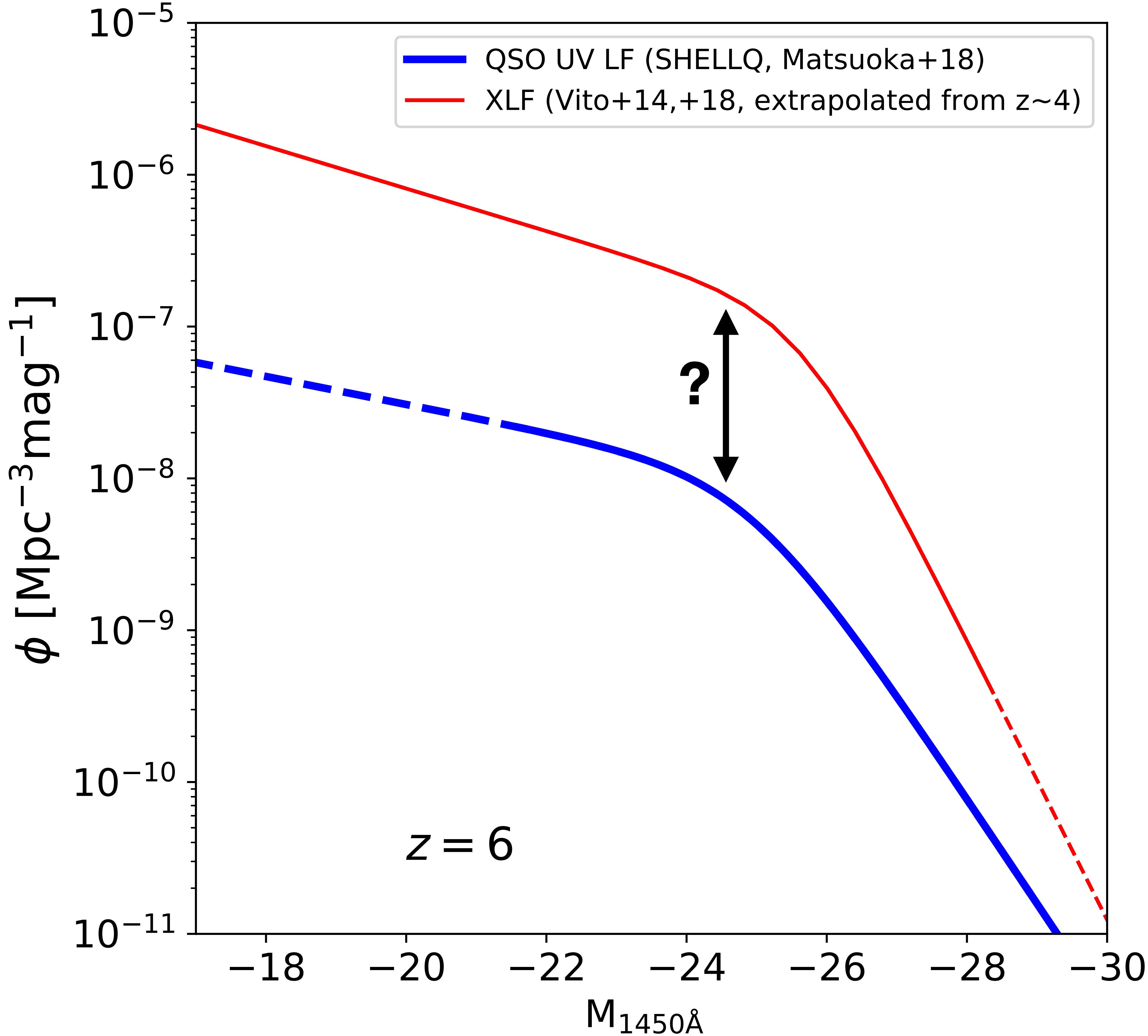
- Includes ~all obscured AGN
- normalization $\propto (1+z)^{-6}$



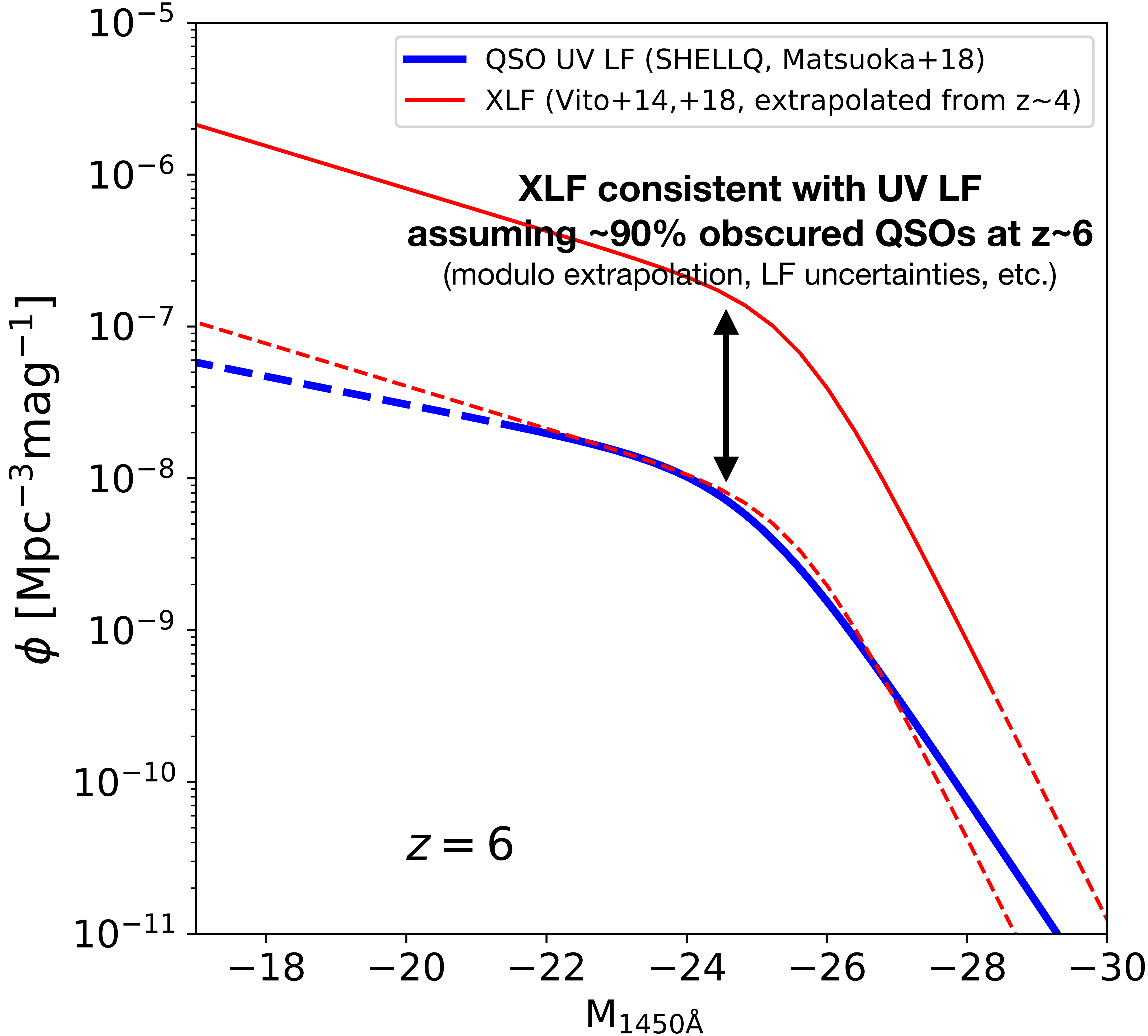
Obscured QSOs at z>6: how many are there?



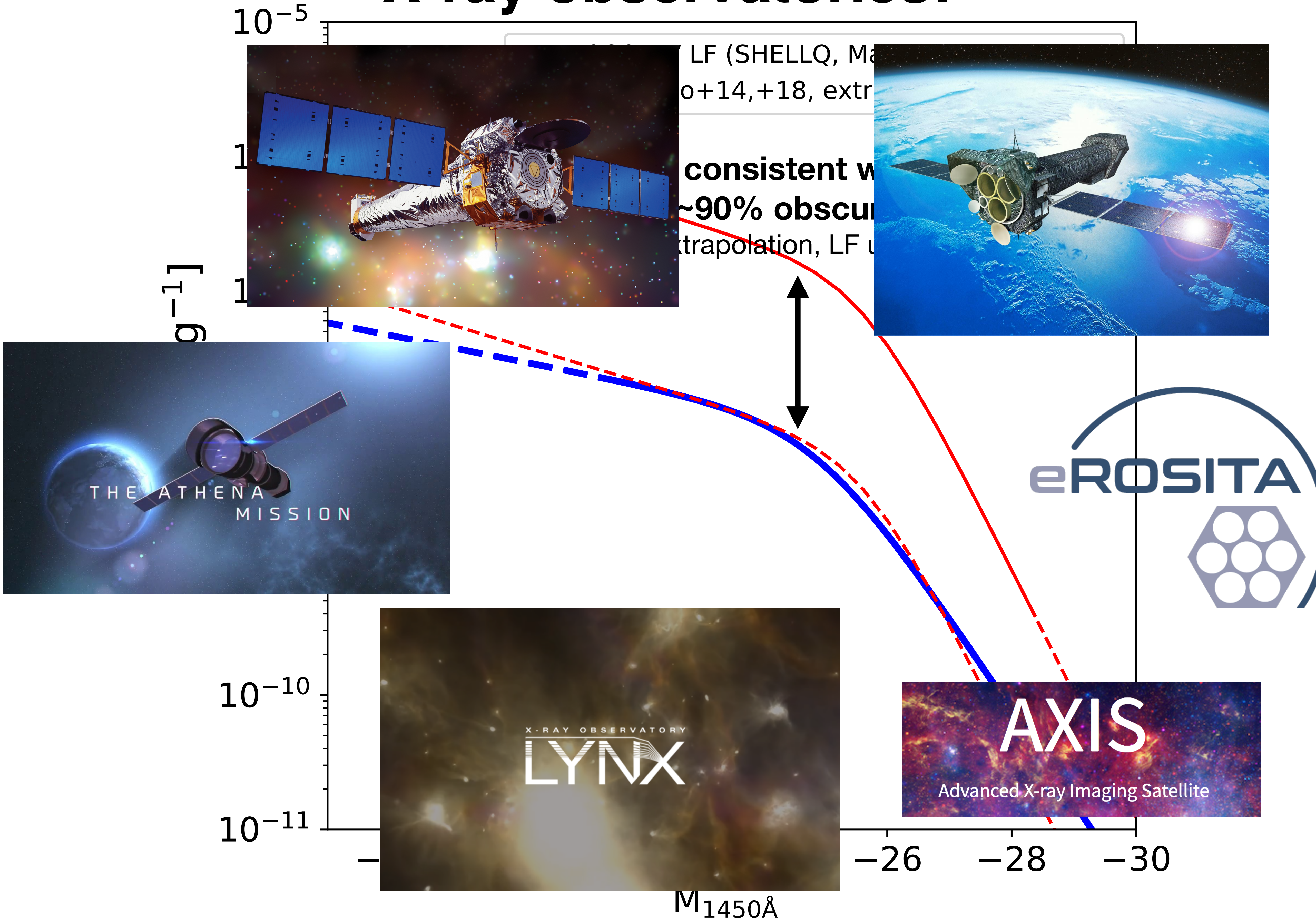
Obscured QSOs at z>6: how many are there?



Obscured QSOs at z>6: how many are there?



Huge discovery space for current and future X-ray observatories!



Hunting BH seeds in the early universe: Athena

https://www.the-athena-x-ray-observatory.eu/

Mission Formulation Review successfully passed

Category: News

On the 12th of November 2019, *Athena* has successfully passed the Mission Formulation Review (MFR).

This is a major milestone for the project and the culmination of several years of effort by ESA, the industrial contractors, the instrument teams and the *Athena* scientific community, represented by the ASST working groups and topical panels.

Looking forward to adoption in 2021 and launch in the early 2030s.

Thanks to all of you for your continuous support!

Hunting BH seeds in the early universe: Athena

https://www.the-athena-x-ray-observatory.eu/

Athena Science Requirements

Parameter	value	enables (driving science goals)
Effective area at 1 keV	≥1.4 m^2	Early groups, cluster entropy and metal evolution, WHIM, high redshift AGN, census AGN, first generation of stars
Effective area at 6 keV	0.25 m^2	Cluster energetics (gas bulk motions and turbulence), AGN winds & outflows, SMBH & GBH spins
PSF HEW (≤ 7 keV)	5'' on axis, 10'' off axis	High z AGN, census of AGN, early groups, AGN feedback on cluster scales
X-IFU spectral resolution	2.5 eV 0.2-12 keV	WHIM, cluster hot gas energetics and AGN feedback on cluster scales, energetics of AGN outflows at z~1-4
X-IFU FoV	5' effective diameter	Metal production & dispersal, cluster energetics, WHIM
X-IFU background	< 5 10^{-3} counts/s/cm^2/keV 2-10keV	Cluster energetics & AGN feedback on cluster scales, metal production & dispersal
WFI spectral resolution	<80eV (1keV) & <170eV (7keV)	GBH spin, reverberation mapping
WFI FoV	40' x 40'	High-z AGN, census AGN, early groups, cluster entropy evolution, jet-induced cluster ripples
WFI count rate	1 Crab > 80%	GBH spin, reverberation mapping, accretion physics
WFI background	< 5 10^{-3} counts/s/cm^2/keV 2-7keV	Cluster entropy, cluster feedback, census AGN at z~1-4
Recons. astrometric error	1'' (3s)	High z AGNs
GRB trigger efficiency	50%	WHIM
ToO reaction time	≤ 4 hours	WHIM, first generation of stars

Athena-WFI survey

Detect at least (from Aird+15 LF):

Aim1: 10 AGN z=6-7 @L_X=43-43.5 erg/s → Flim 2.4×10^{-17} over 2.4 deg^2

Aim1b: 10 AGN z=7-8 @L_X=43.5-44 erg/s → Flim 1.3×10^{-16} over 27.4 deg^2

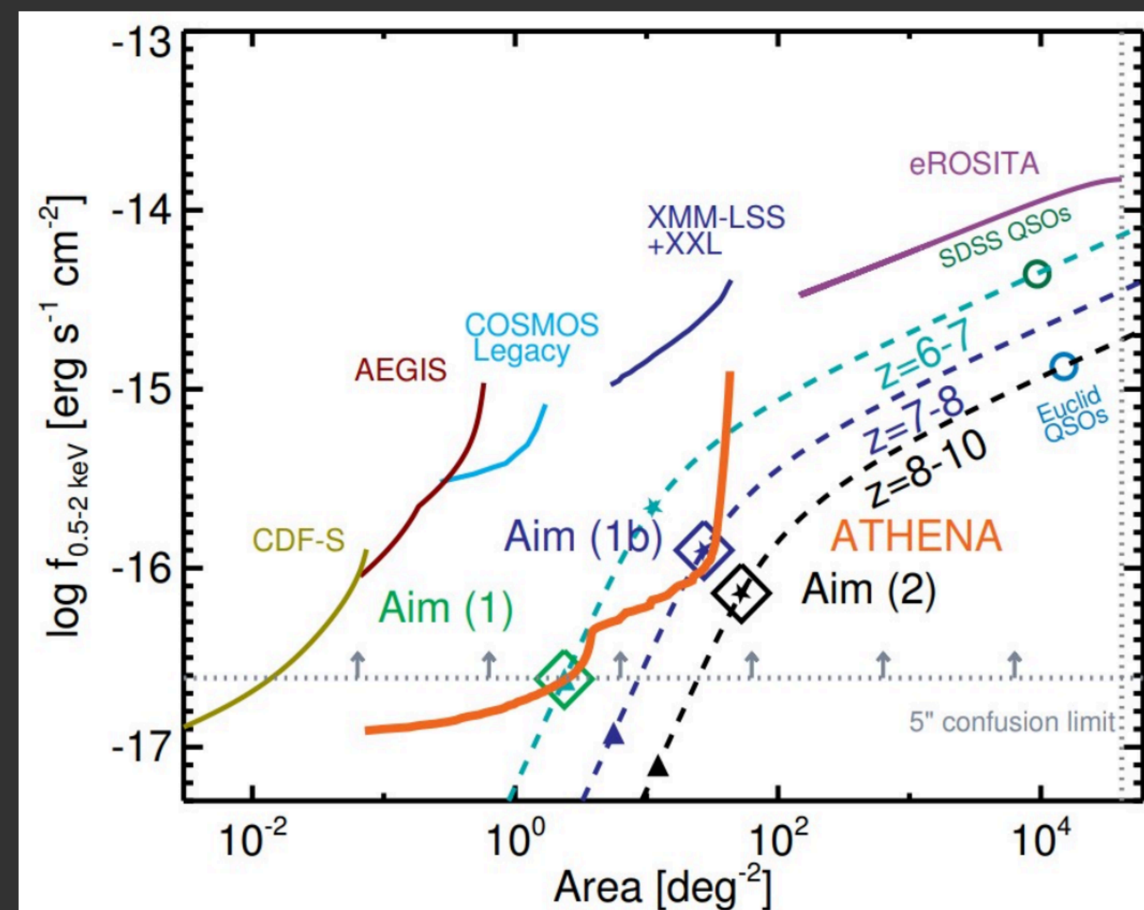
+ First Groups z>2
+ CT AGN spectroscopy z=1-4
+ AGN outflow (WA/UFO) z=1-4

→ Consolidated survey strategy:

Deep
8x1Ms+4x1.5Ms

Shallow
108x90ks

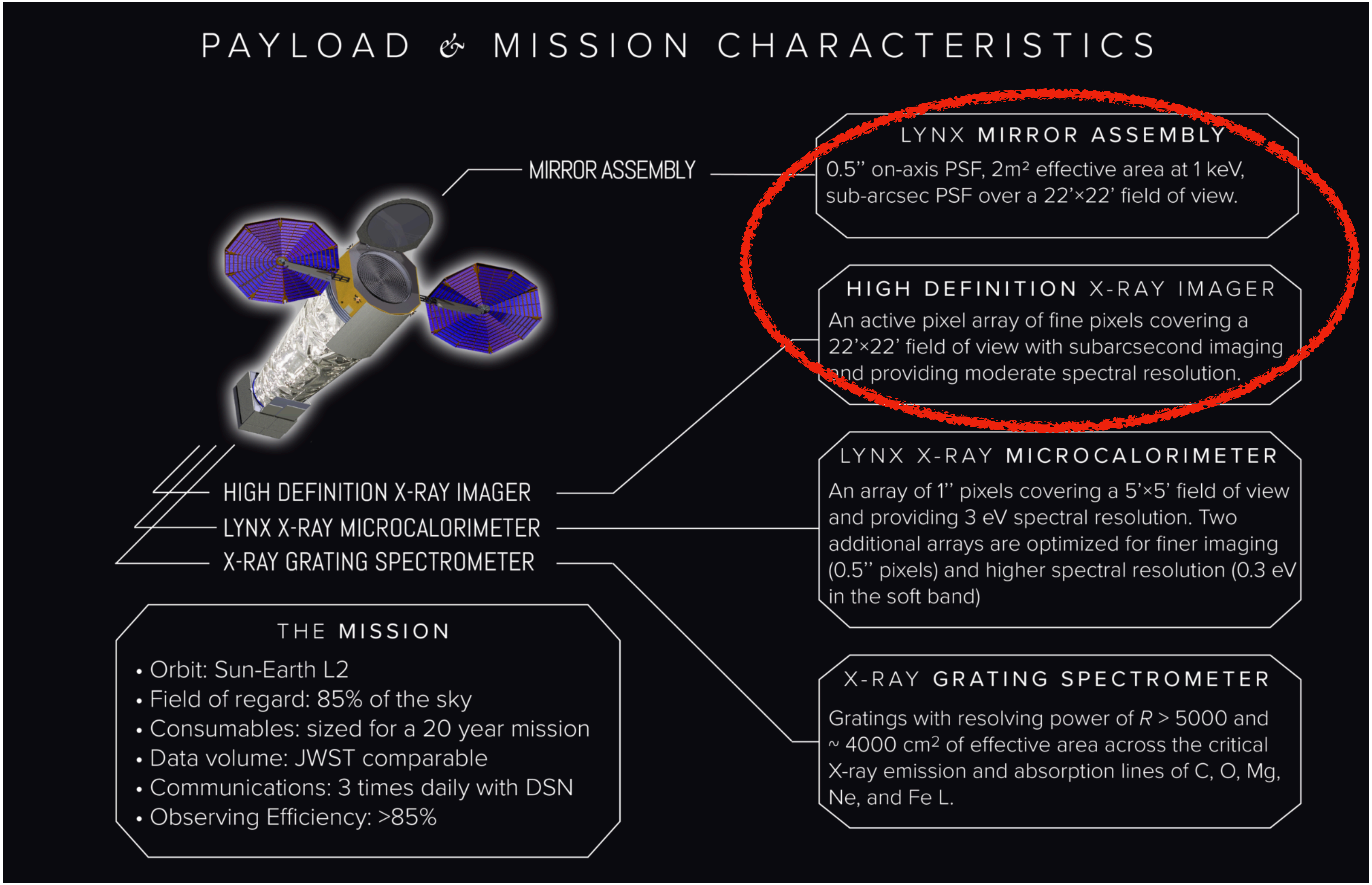
Tot=23.5 Ms (~22% of 4yr)



Credits: Giorgio Lanzuisi

Lynx **(Weisskopf et al. 2015)**

https://www.lynxobservatory.com/



Lynx (Weisskopf et al. 2015)

https://www.lynxobservatory.com/

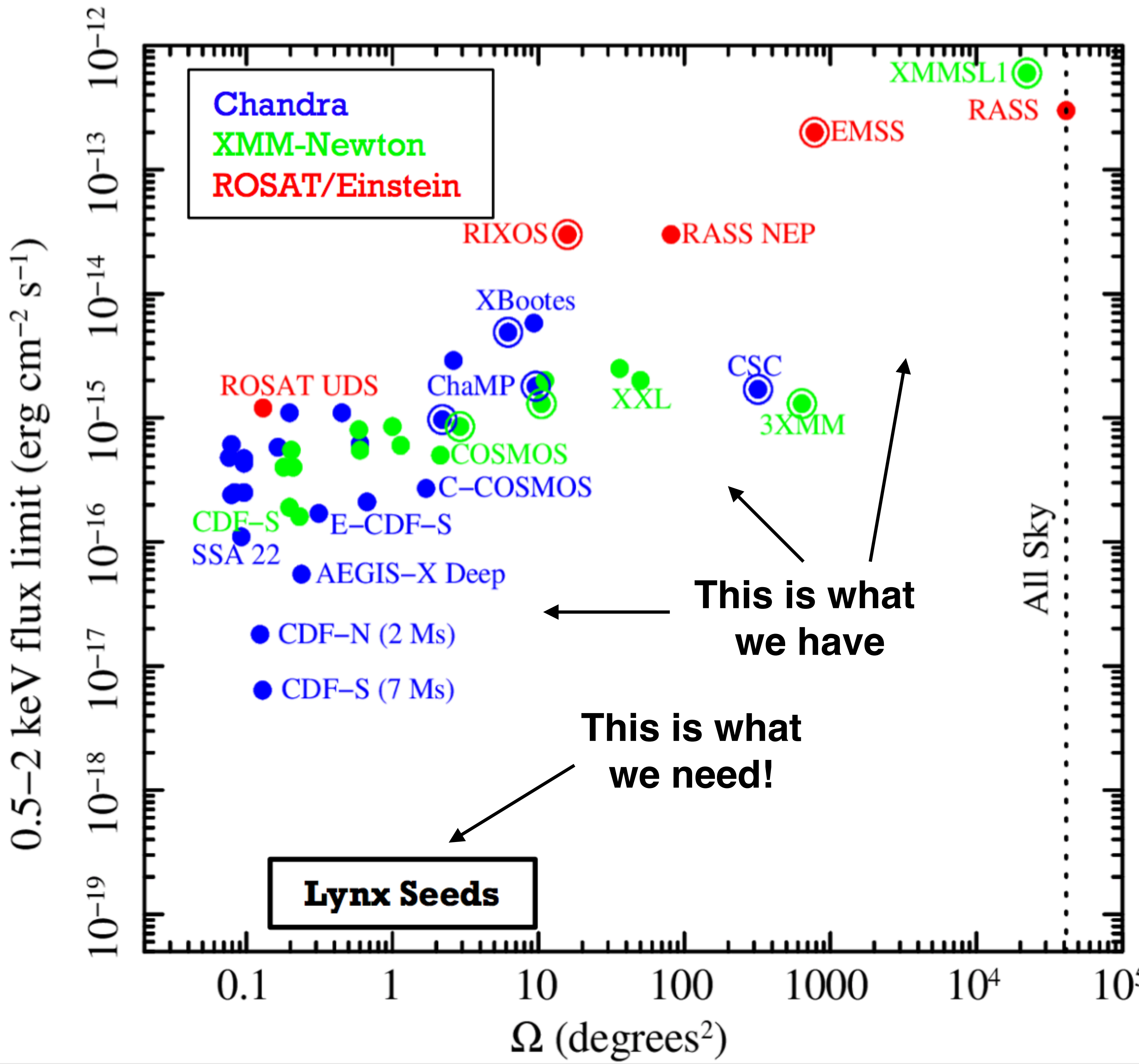
[redacted]

- *Chandra*-like angular resolution
- f.o.v.=0.12 deg^2=15x *Chandra* (for sub-arcsec resolution)
- 30-50x effective area of *Chandra*
- 20x *Chandra* sensitivity

Credits: Alexey Vikhlinin

Detection threshold @ 4Msec (0.5-2 keV) (for known locations)	3.0×10^{-19} erg/s/cm^2 (1.1×10^{-19})
2–10 keV luminosity at z=10 assuming Γ=1.7	3.7×10^{41} erg/s (1.35×10^{41})
Bolometric luminosity at z=10, assuming 10% correction	3.7×10^{42} erg/s (1.35×10^{42})
Black Hole Mass assuming Eddington rate	29,000 Msun (11,000 Msun)

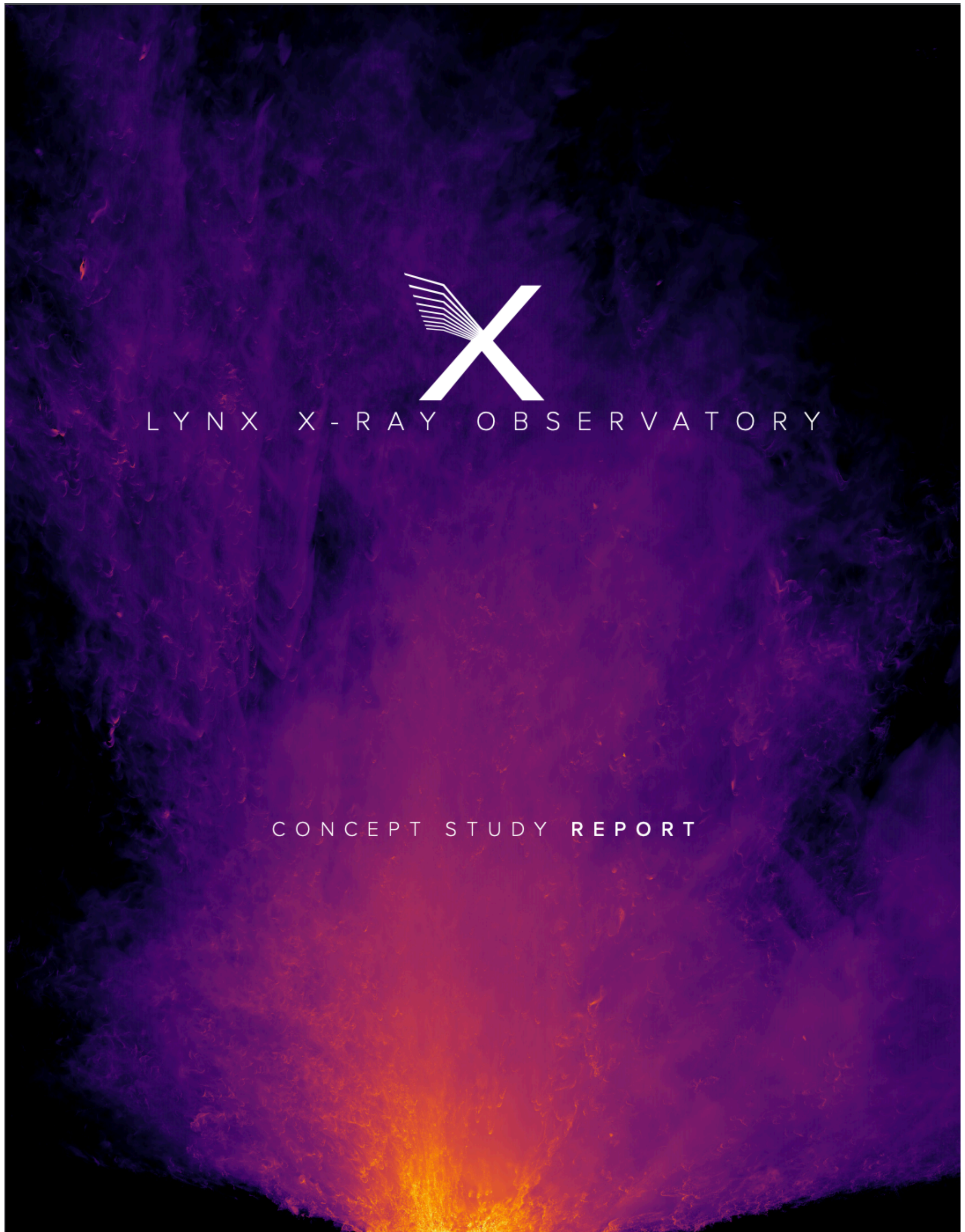
Hunting BH seeds in the early universe: Lynx



Adapted from W.N. Brandt talk at Lynx meeting

Hunting BH seeds in the early universe: Lynx

https://wwwastro.msfc.nasa.gov/lynx/docs/LynxConceptStudy.pdf



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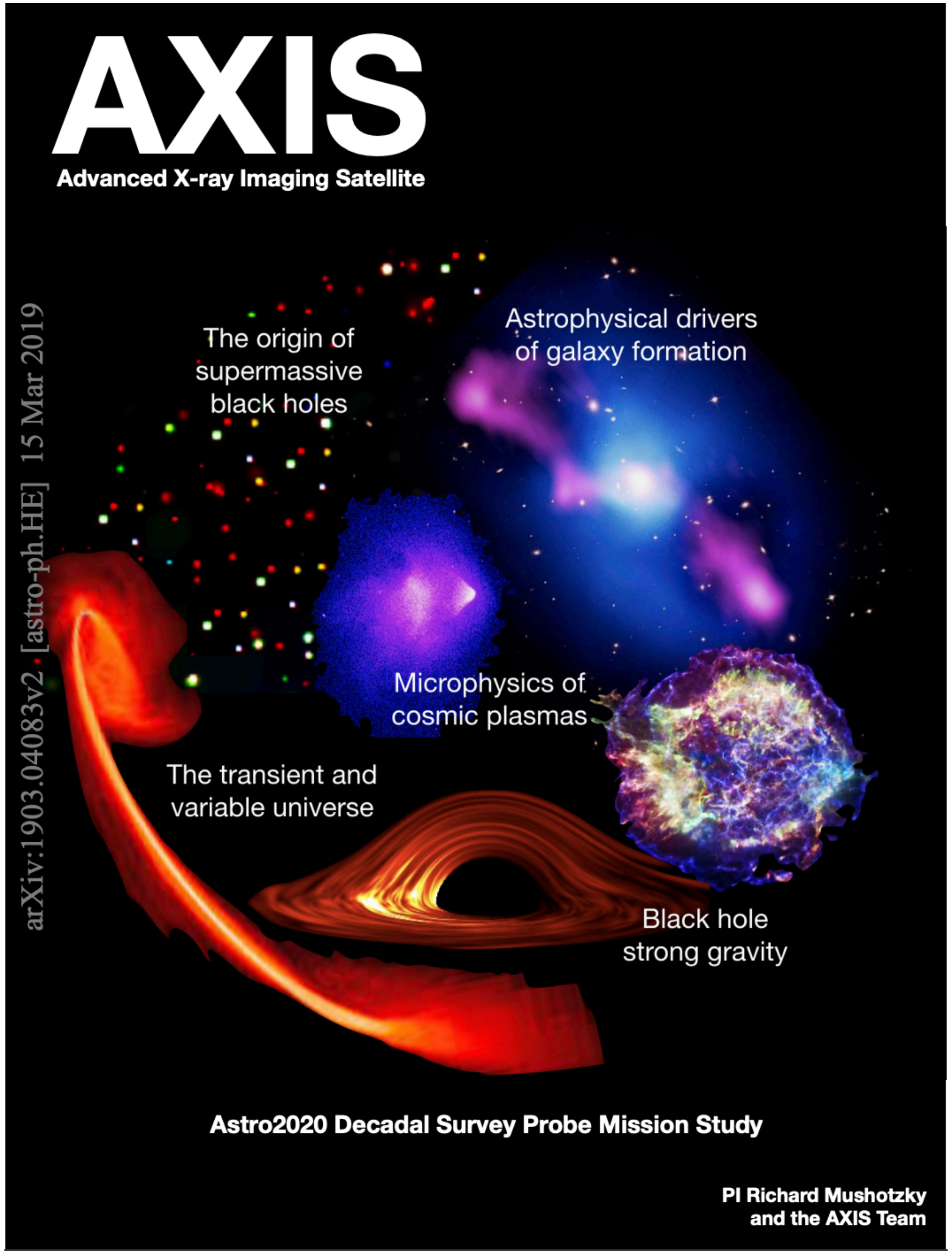
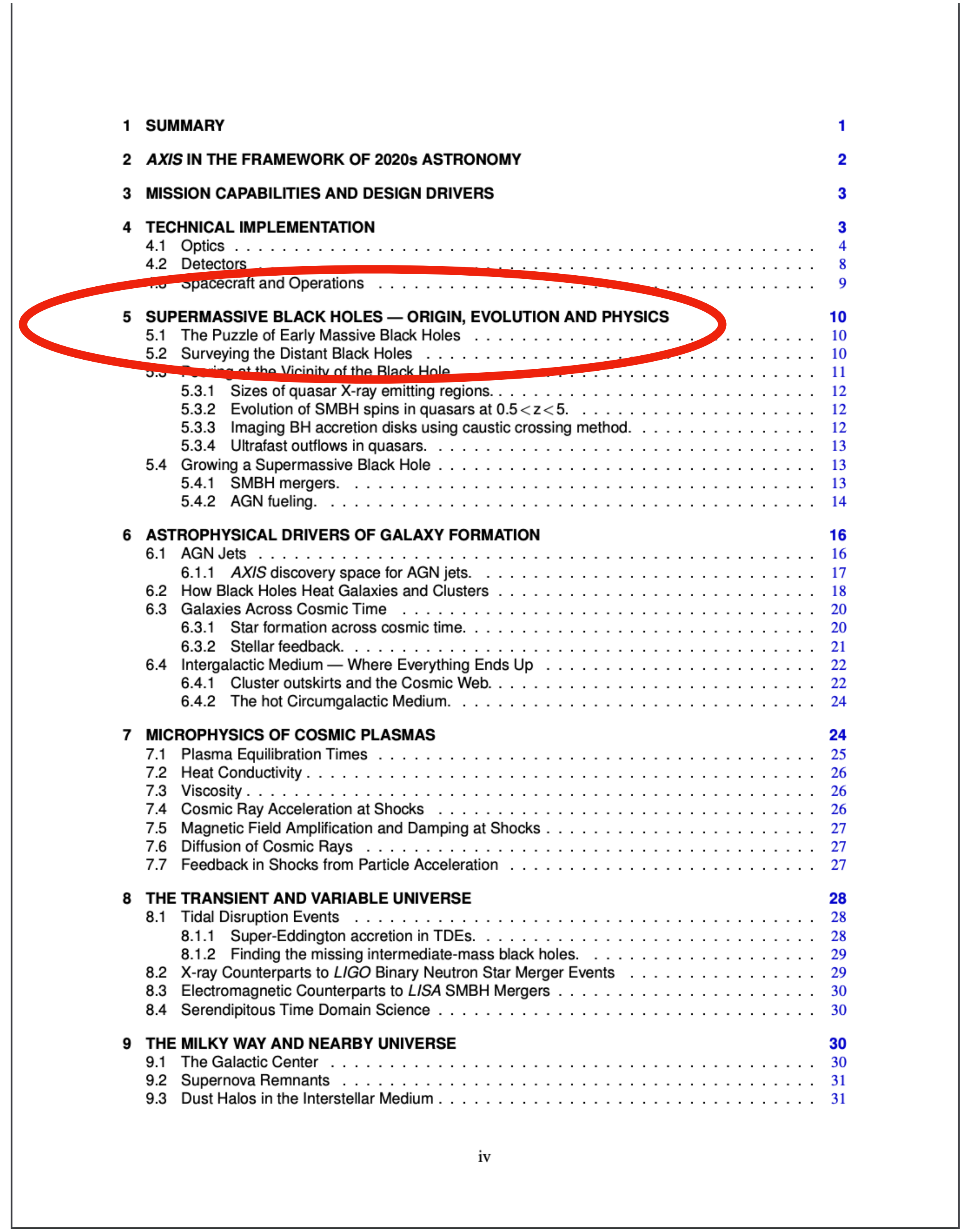
Hunting BH seeds in the early universe: AXIS

http://axis.astro.umd.edu/





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Hunting BH seeds in the early universe: AXIS

http://axis.astro.umd.edu/

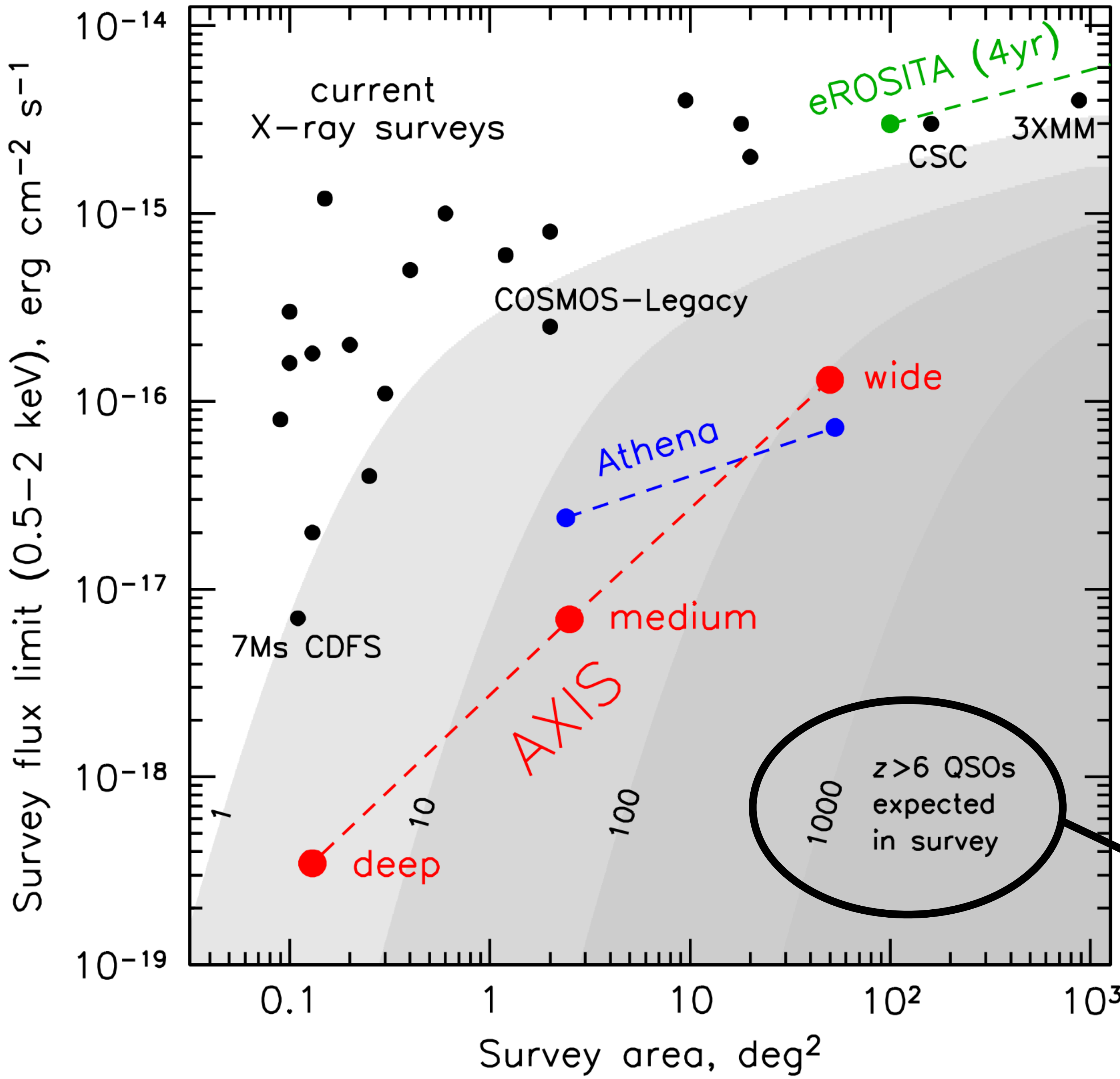
Mission Overview

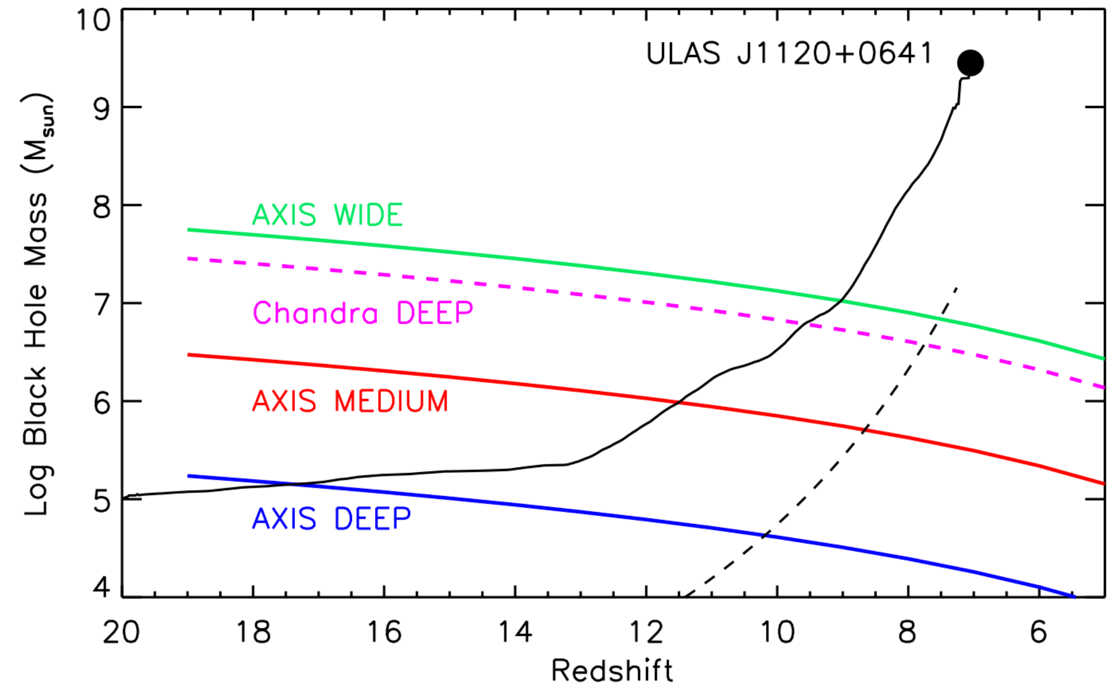
AXIS (Advanced X-ray Imaging Satellite) is a NASA Probe Mission Concept designed to be the premier high angular resolution X-ray mission of 2020s. The need for sub-arcsecond resolution in astrophysics is evident across the entire electromagnetic spectrum, and is essential for resolving the critical physical scales of virtually all classes of objects and for extending such studies to the highest redshift. AXIS will follow in the footsteps of the spectacularly successful Chandra X-ray Observatory with similar or higher angular resolution and ~10x Chandra count rates.

Read the full Probe Mission Concept Proposal **here**.

Area	Value	Requirement
Angular Resolution	~0.3 arcsec	Point source detection, separation, excision
Bandpass	~0.1-16 keV	Soft and hard X-ray sensitivity
Effective Area	7000 cm^2 @ 1 keV 1500 cm^2 @ 6 keV	Faint/low surface brightness source analysis
Energy Resolution	~150 eV @ 6 keV (CCD resolution)	Emission line separation
Timing Resolution	<50 ms	Variable source analysis
Field of View	>15 arcmin (diameter)	Extended source analysis, surveys
Detector Background	4-5x less then Chandra	Sensitivity to low surface brightness
Slew rate	120 deg / 5 min	Observing efficiency / TOOs

Hunting BH seeds in the early universe: Athena & AXIS

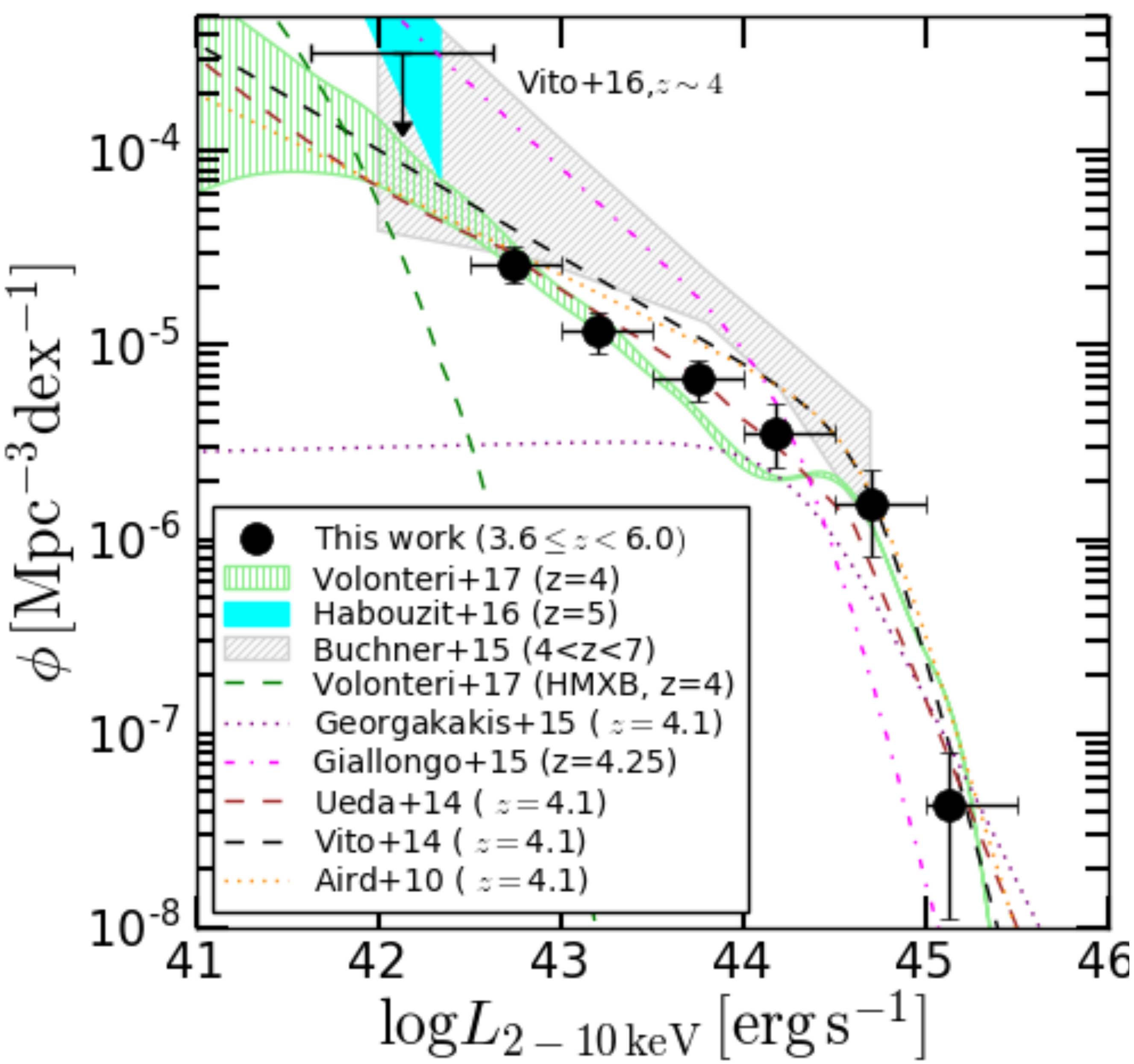


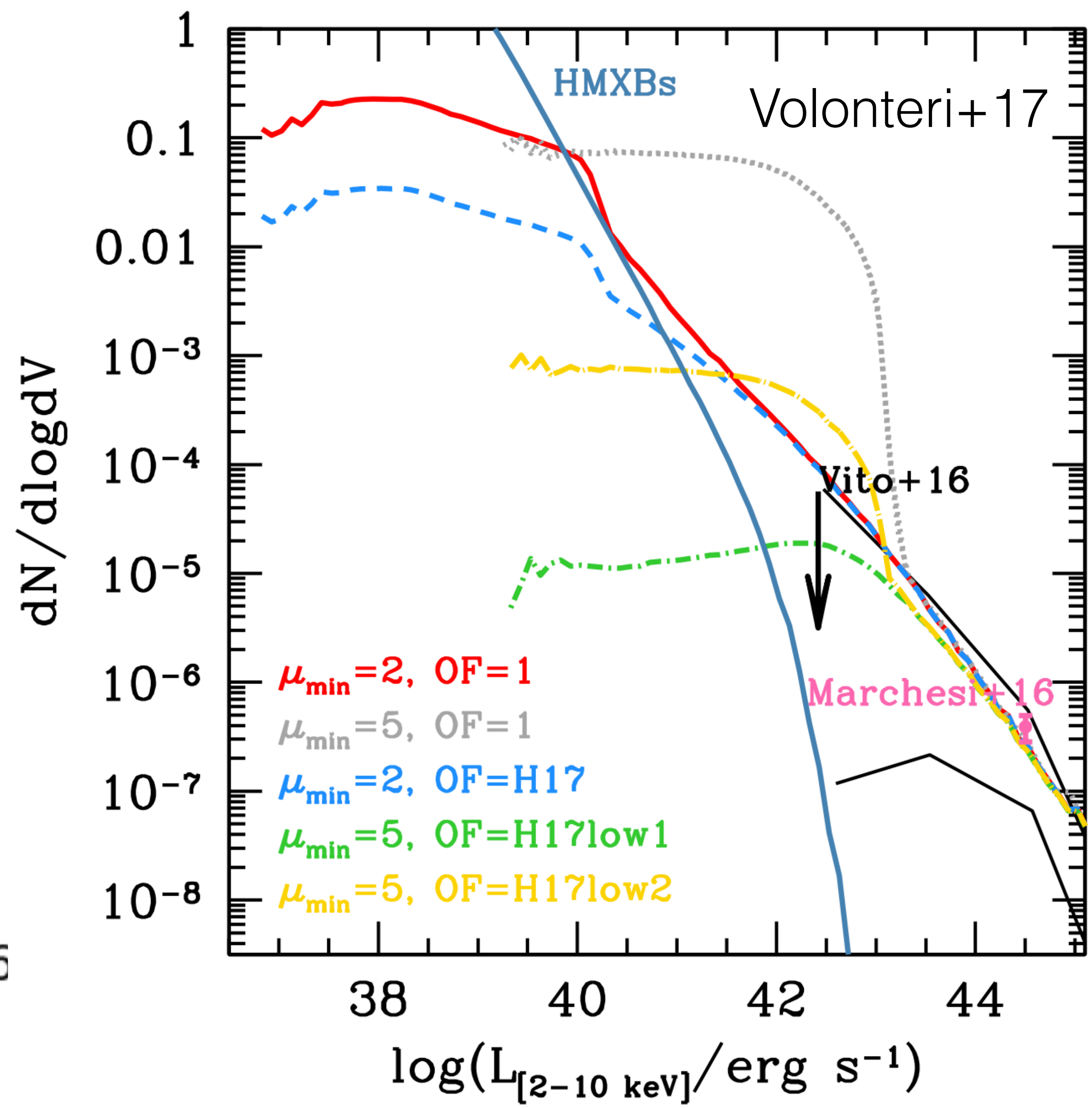


Mushotzky et al. 2019
(AXIS white paper)

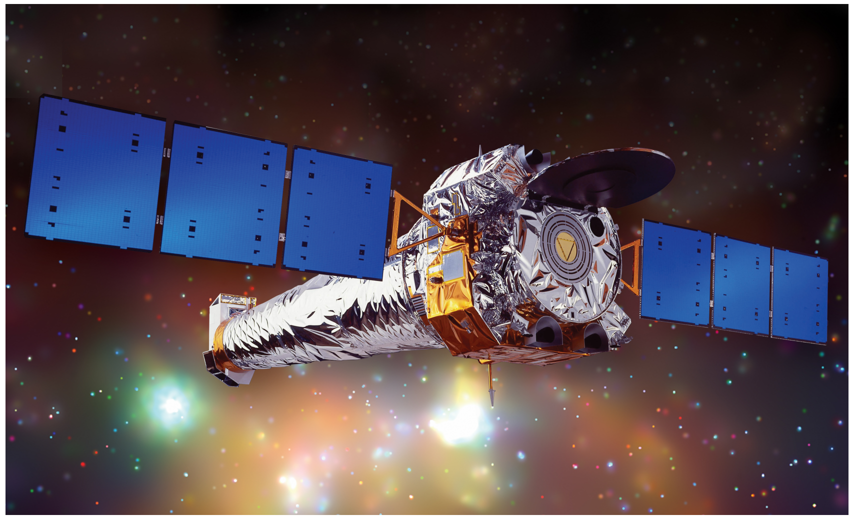
Computed from
Vito+14,+18
XLF

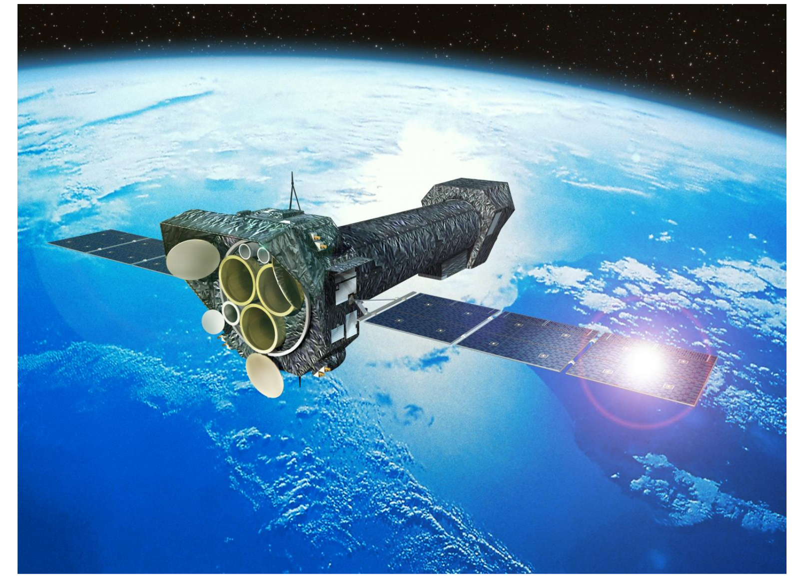
XLF faint end at high-z as a tool to study BH seed formation and growth





Need to push at lower-L and higher-z! E.g. AXIS, *Lynx*





Thanks!

eROSITA