Physical Properties of the Highest-redshift SMBHs

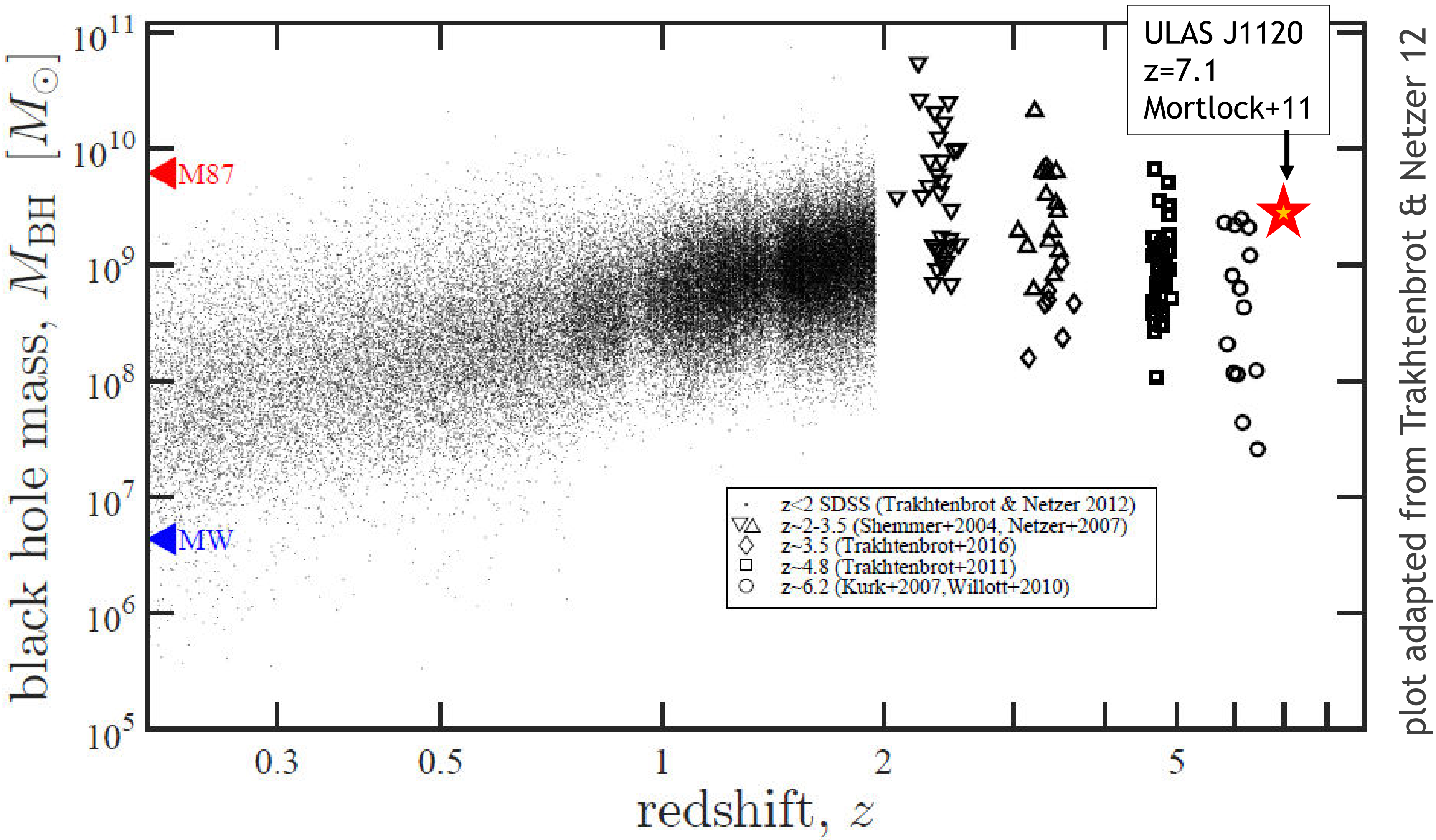
and how *Lynx* will detect their missing lower-mass counterparts and seeds

Benny Trakhtenbrot (ETH Zurich)

with: Hagai Netzer (Tel-Aviv U.), Paulina Lira (U. Chile), Claudia Cicone (INAF Brera), Roberto Maiolino (Cambridge), Ohad Shemmer (U. North Texas), Marta Volonteri (AIP), Priyamvada Natarajan (Yale)
and the "First Accretion Light" SWG

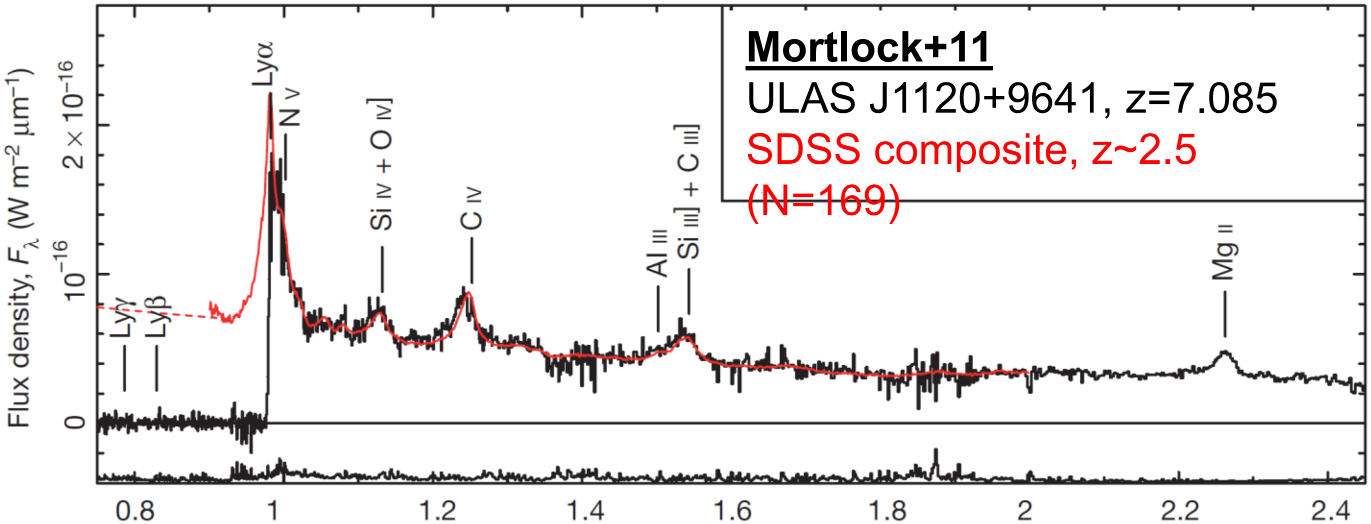
from Chandra to Lynx meeting, Cambridge, 10-Aug-2017

SMBHs at all cosmic epochs



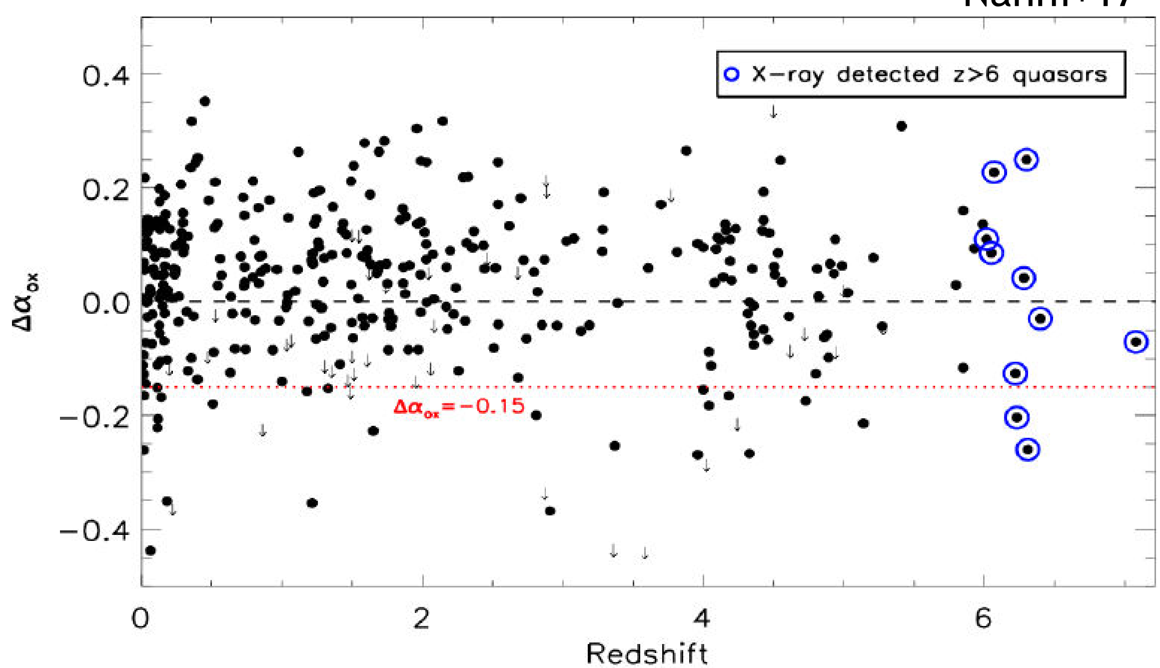
Wide-field optical/IR surveys (SDSS, DES, UKIDSS, Pan-STARRS…) found 100s of quasars at $z \geq 5$, when the universe was less than 1 Gyr old

The highest-z quasars: normal unobscured AGNs?

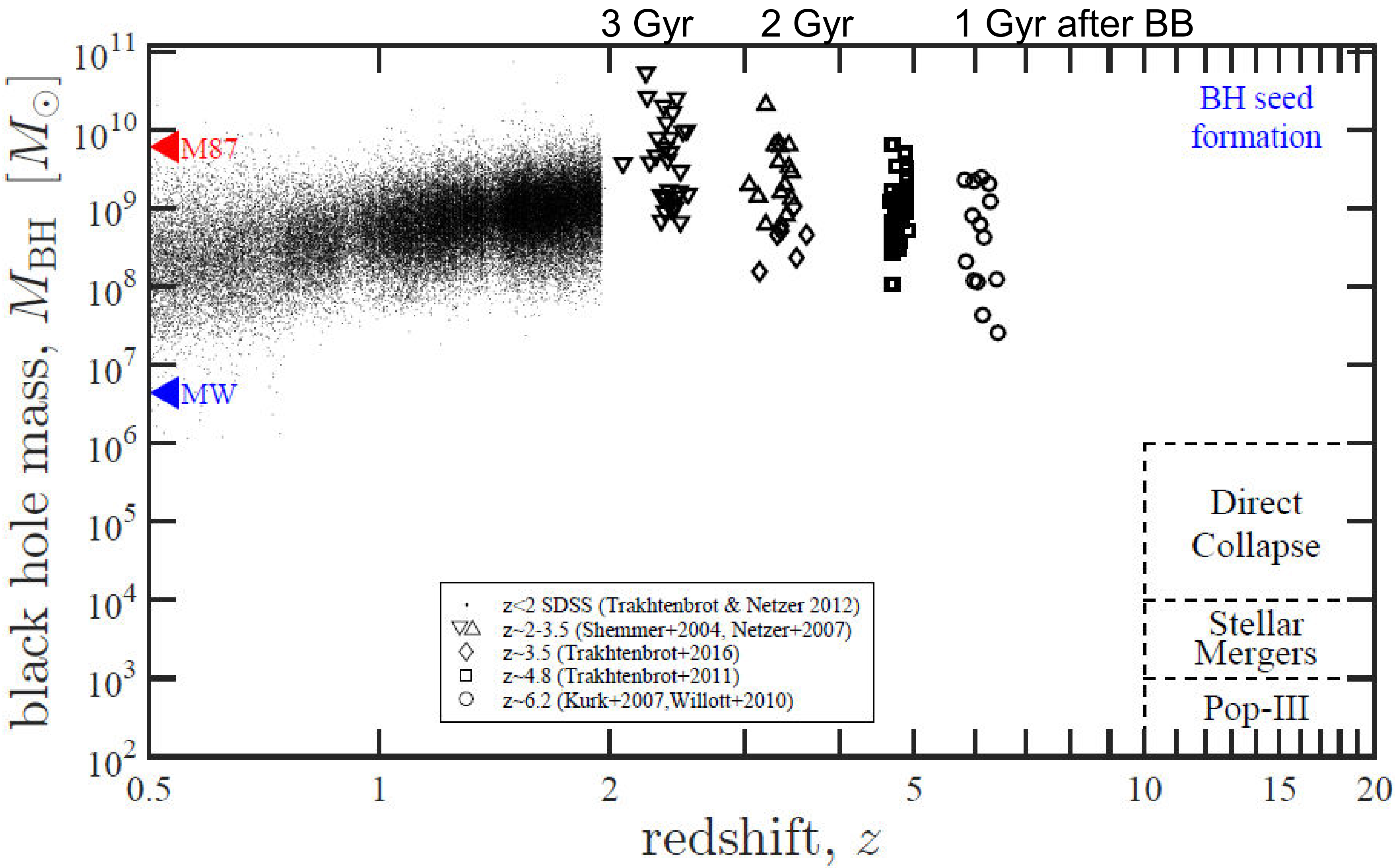


Nanni+17

deviation from "expected" X-ray emission



How to grow a SMBH in ~1 Gyr?



plot adapted from
Trakhtenbrot & Netzer 12

reviews on BH seeds:
Volonter 10, Natarajan 11

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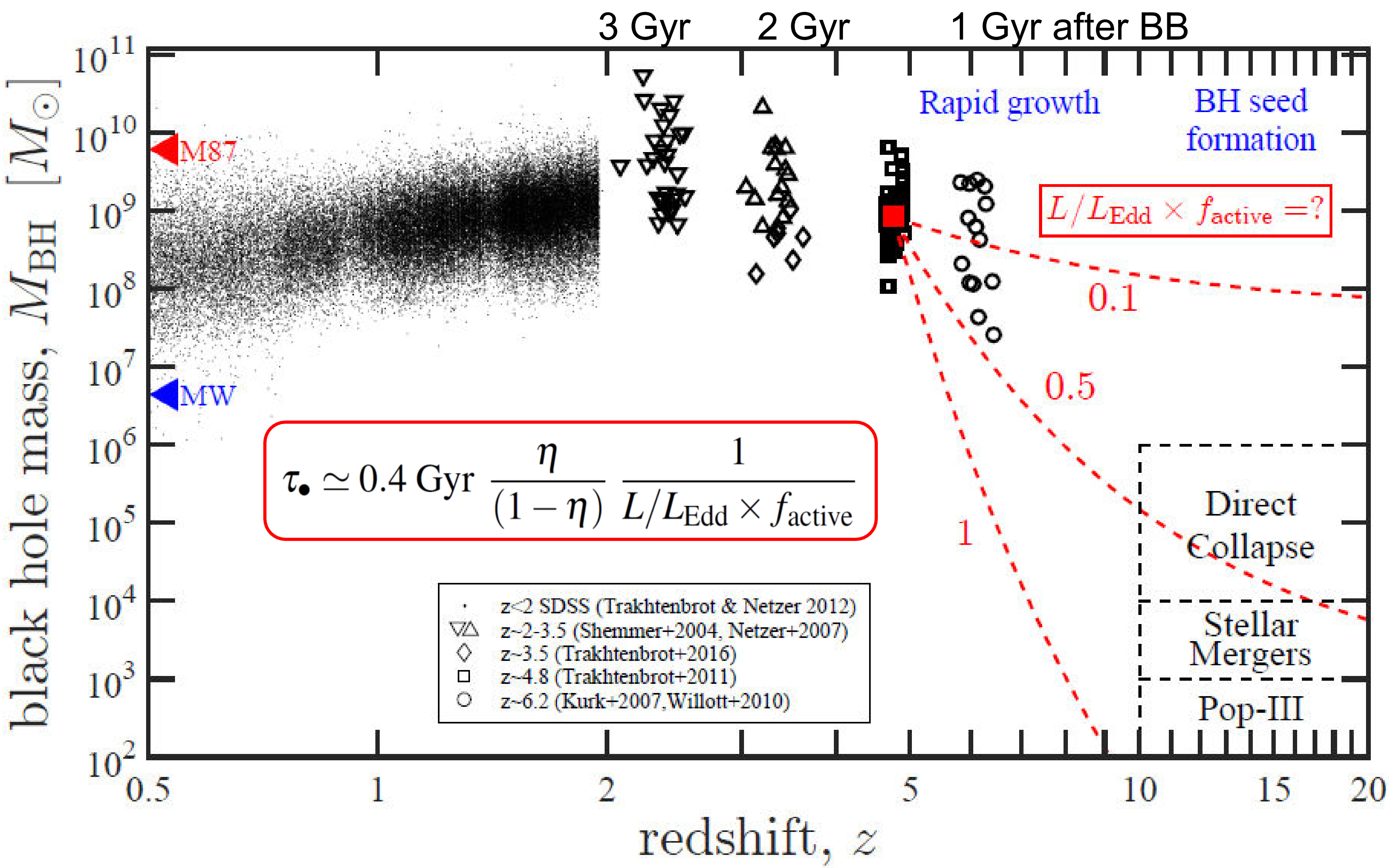

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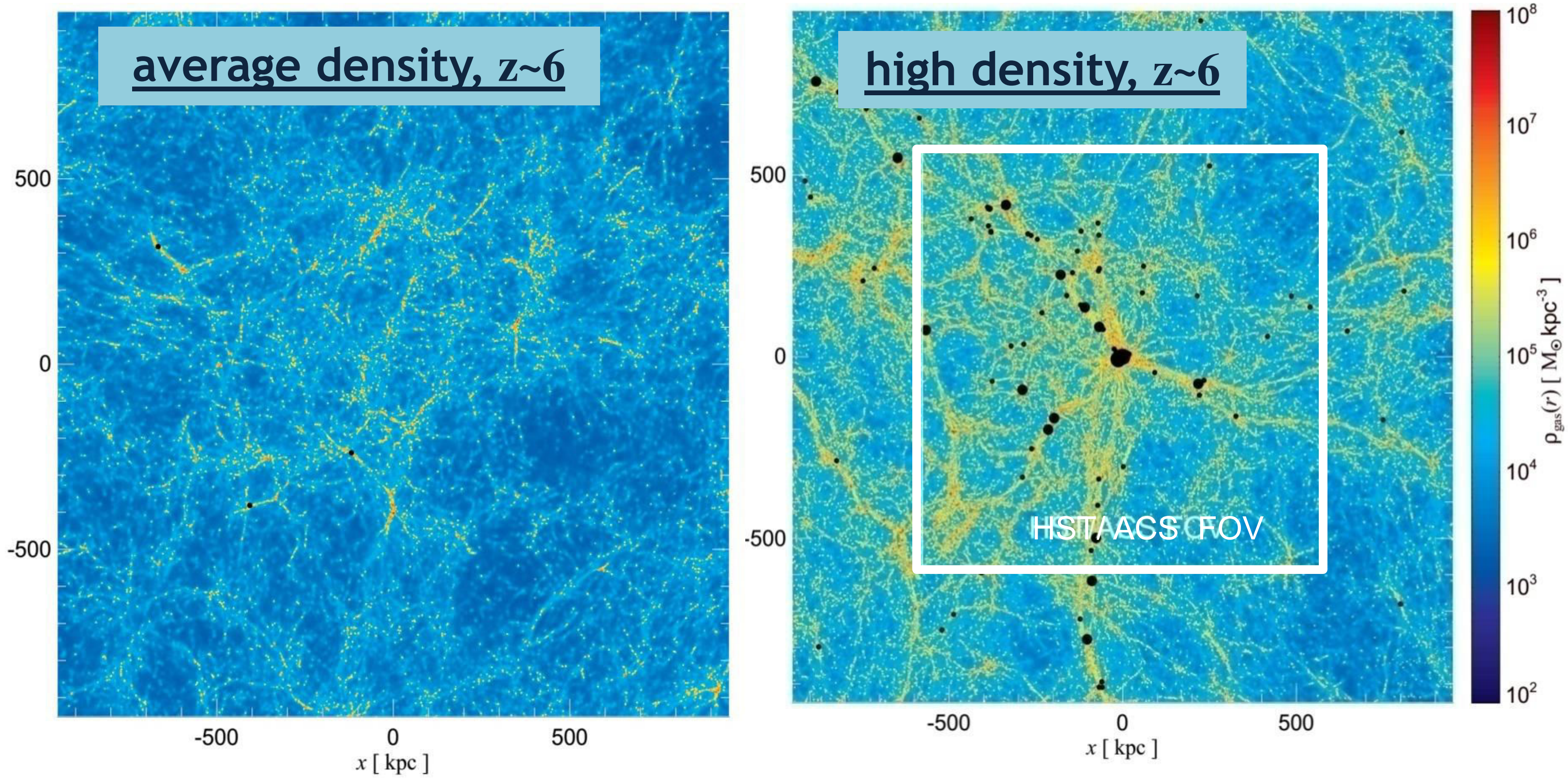
Large-scale environments of early SMBHs

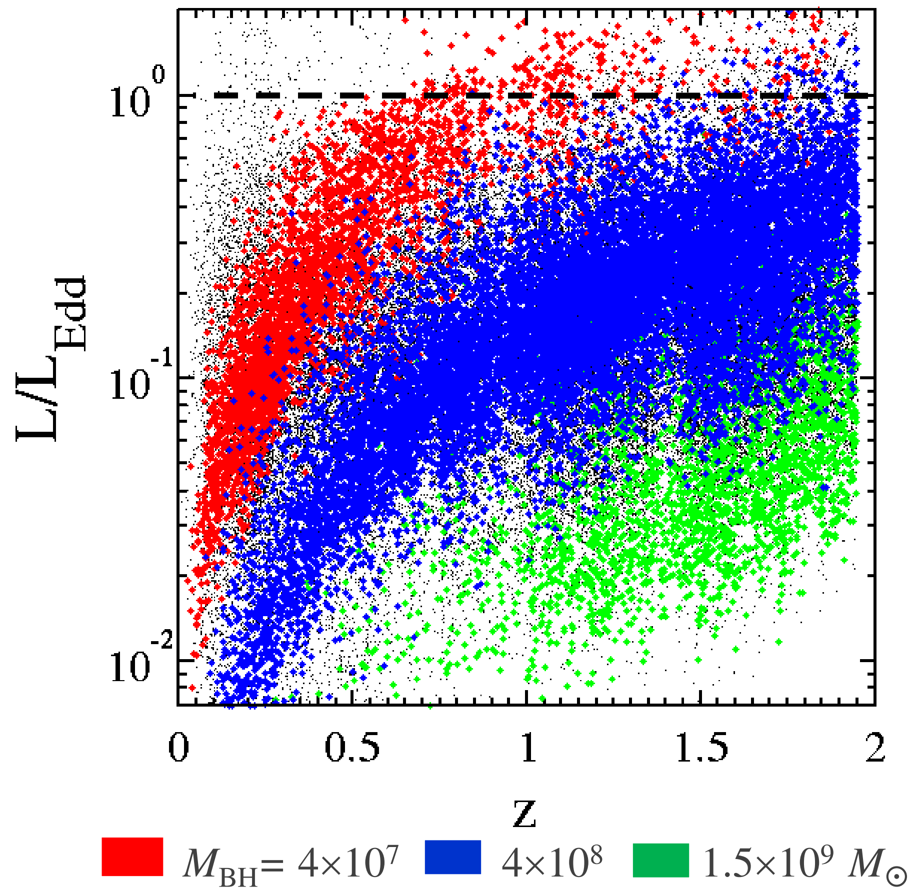
simulations from Costa+14

see also:
Dekel+09
Di-Matteo+12
Dubois+12

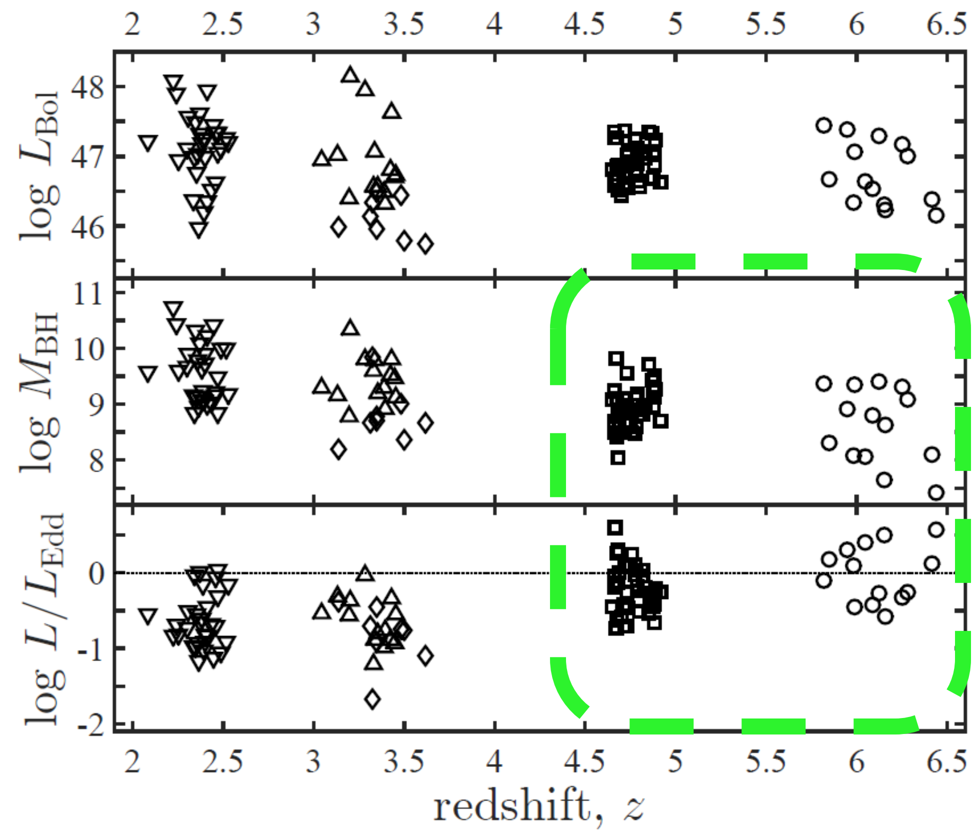


- Simulations suggest early BH mass growth favors over-dense environments
- Can be tested by counting the number of galaxies around SMBH hosts
- So far, few systems studied, with ambiguous results
  (Willott+05, Overzier+06, Kim+09, Utsumi+10, Husband+13, Banados+13, Simpson+14, Kikuta+17…)

The epoch of fastest growth of the most massive BHs



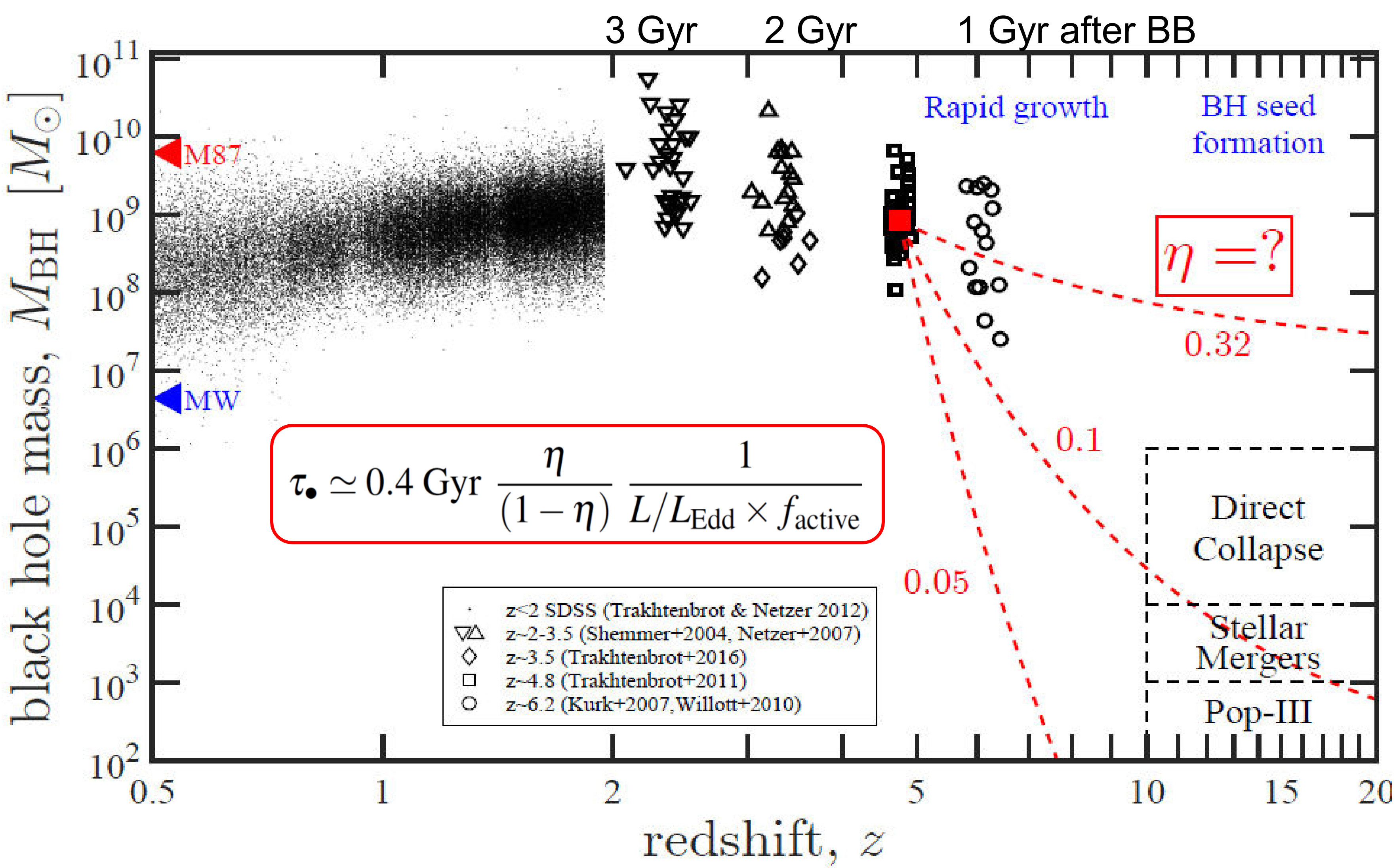
SDSS - Trakhtenbrot & Netzer 12



samples from: Shemmer+04, Netzer+07, Kurk+07, Dietrich+09, Marziani+09, Willott+10, Trakhtenbrot+11, 16, DeRosa+14

The highest-redshift quasars are powered by fast-growing SMBHs, with $M_{BH} \sim 10^{9}\ M_{\odot}$ and $L/L_{Edd} \sim 1$

How to grow a SMBH in ~1 Gyr?



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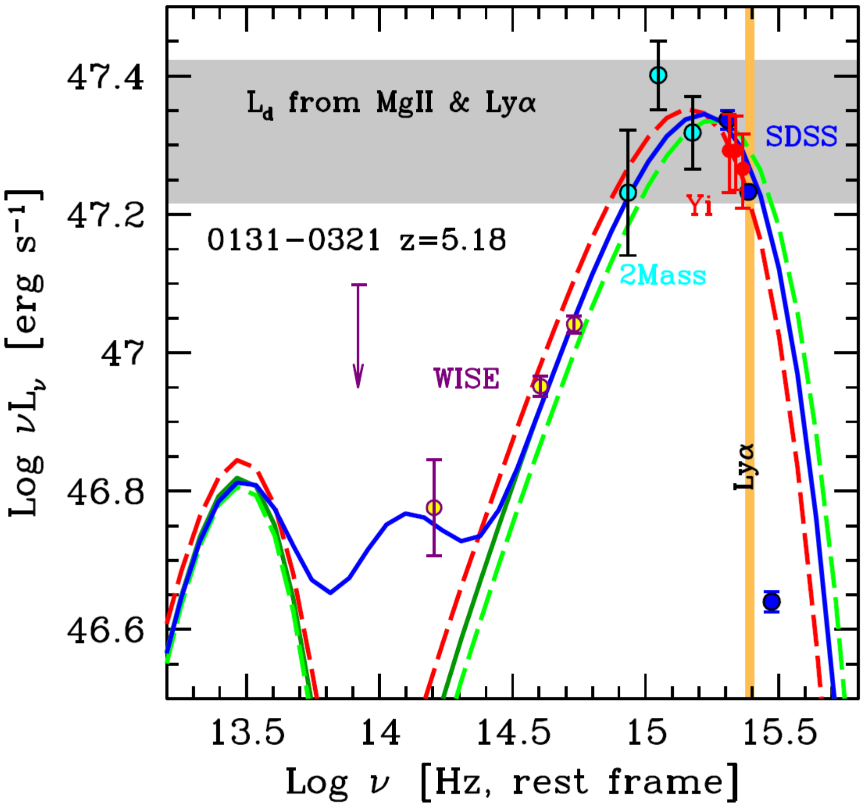
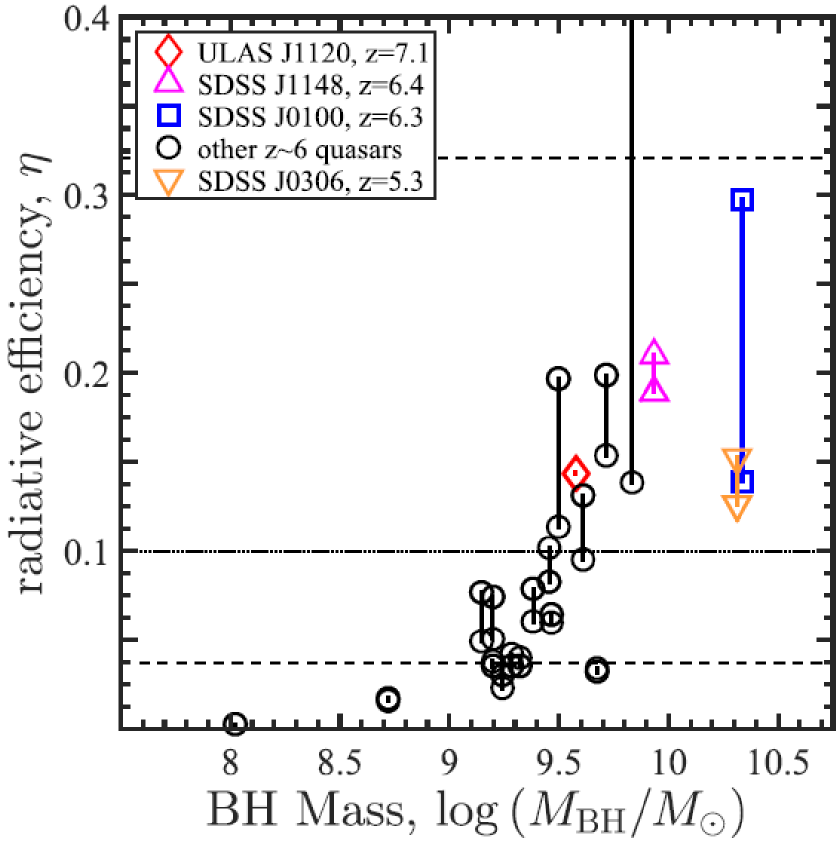
Accretion flows powering z~5-7 quasars

Applying (over?) simplified thin accretion disk models to derive $\dot{M}_{\rm disk}$ *and* η



Ghisellini+15

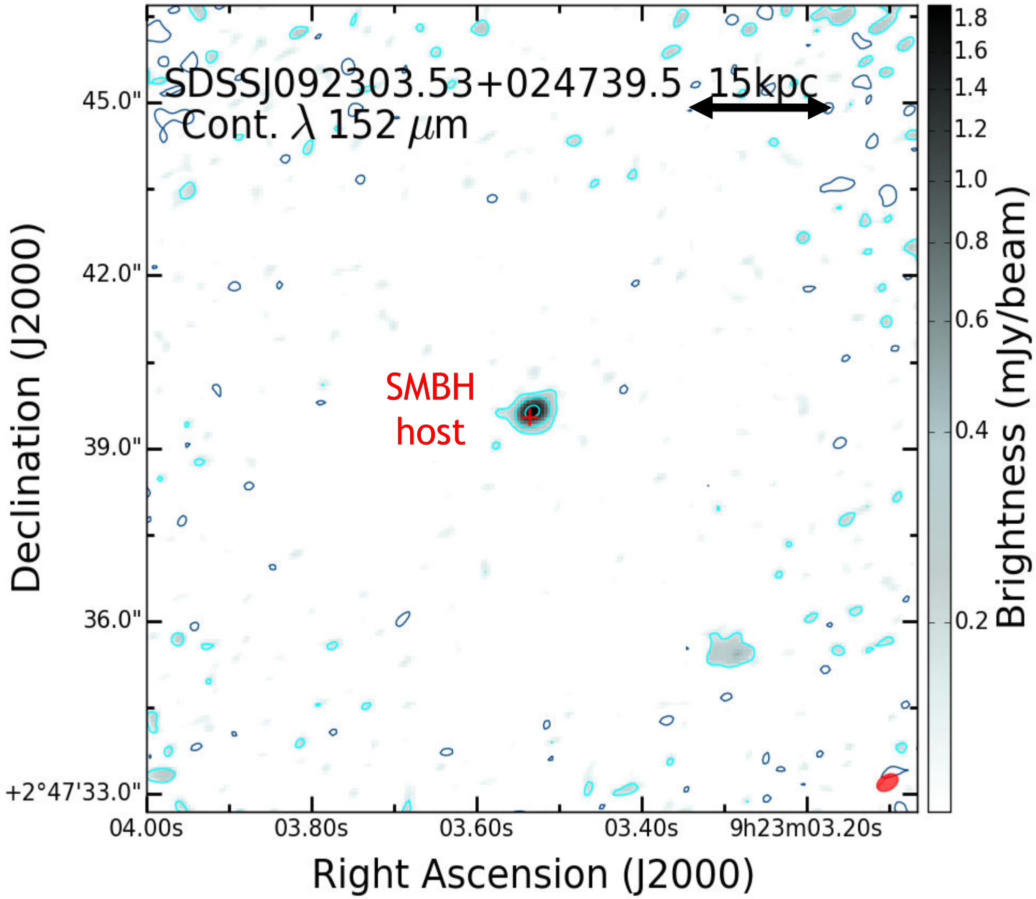


Trakhtenbrot, Volonteri & Natarajan 17

The highest-redshift quasars are consistent with
Eddington-limited, radiatively efficient, thin-disk accretion

Hosts of fast-growing SMBHs at $z\sim5$, with ALMA

Six fast-growing z~4.8 SMBHs observed w/ALMA (cycle-2, band-7, ~0.3")



- ALMA resolves the dusty, star-forming host galaxies of early SMBHs

Trakhtenbrot+17 (*ApJ*, 836, 8)

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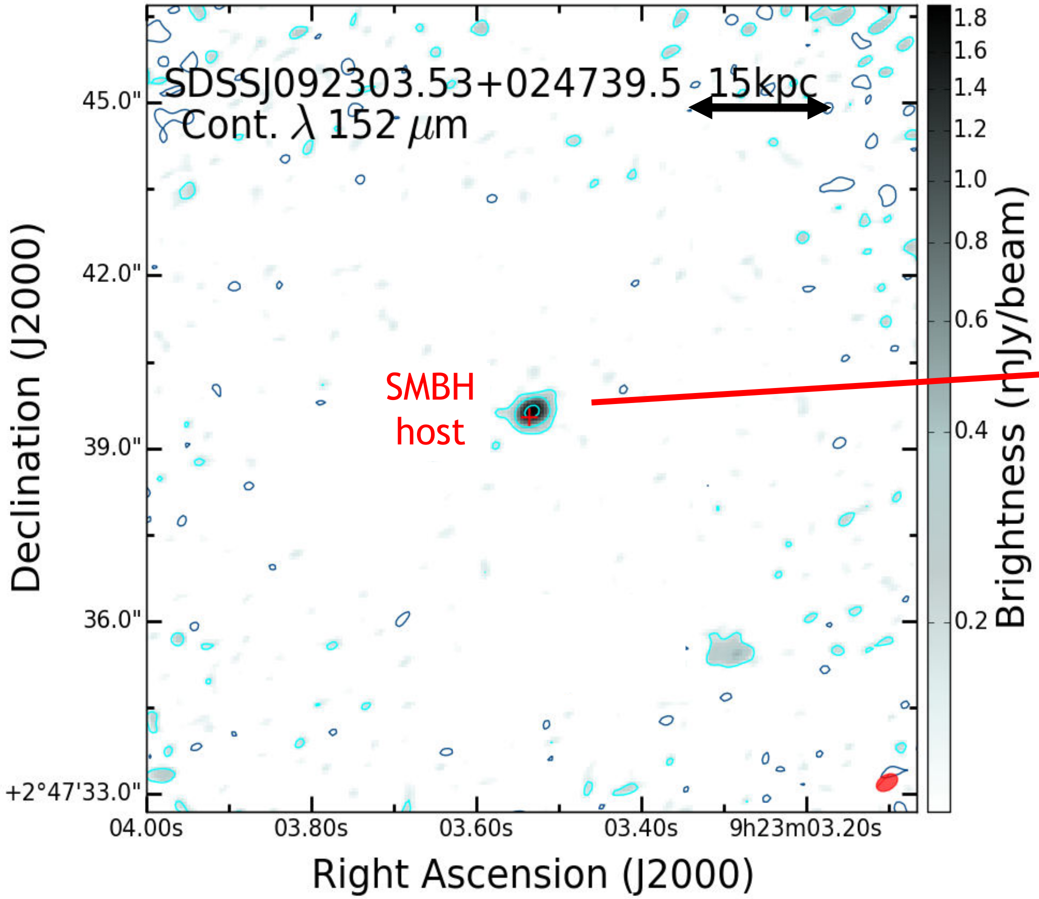
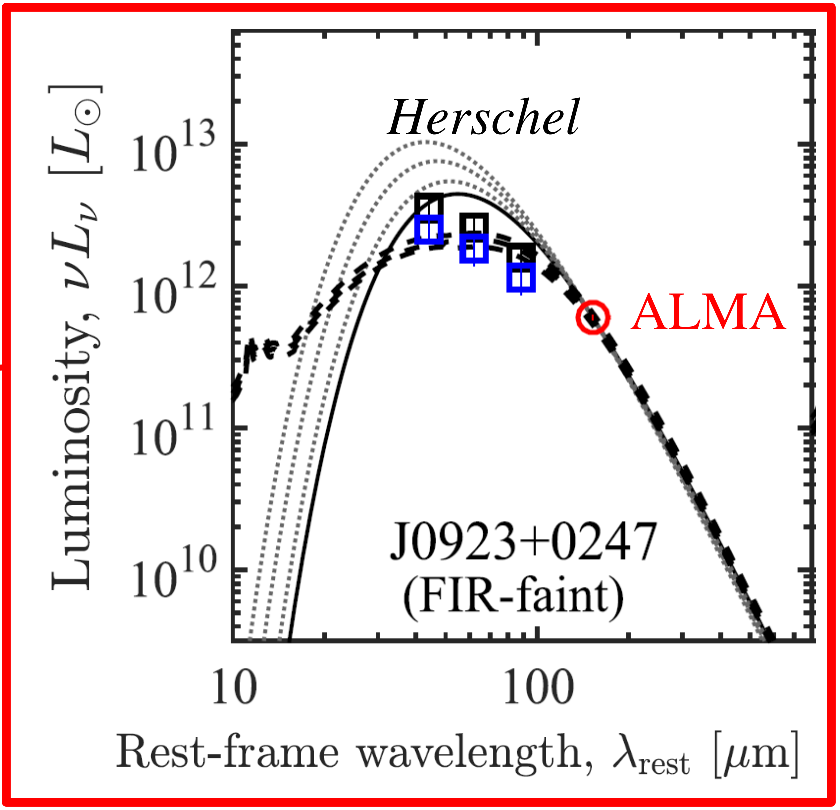




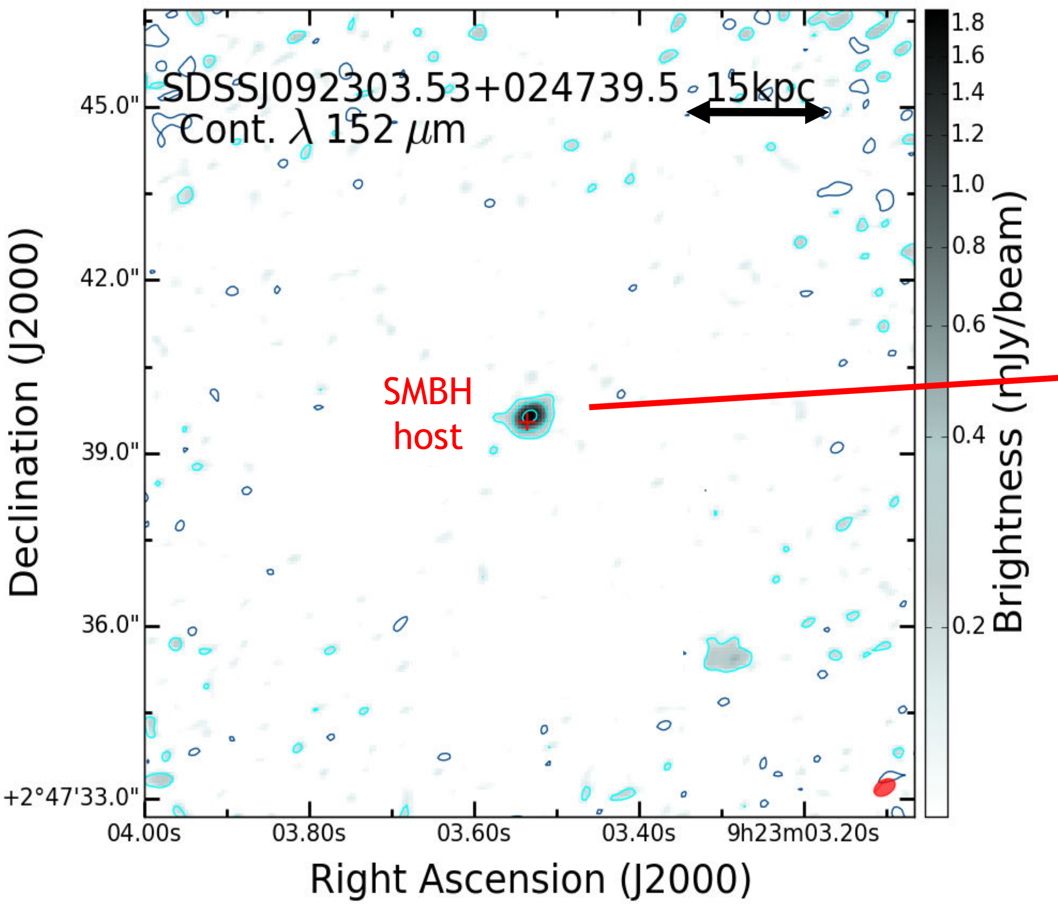
SMBH host galaxy at z=4.8

sub-mm cont. → SFR = 360 $M_\odot$ / yr

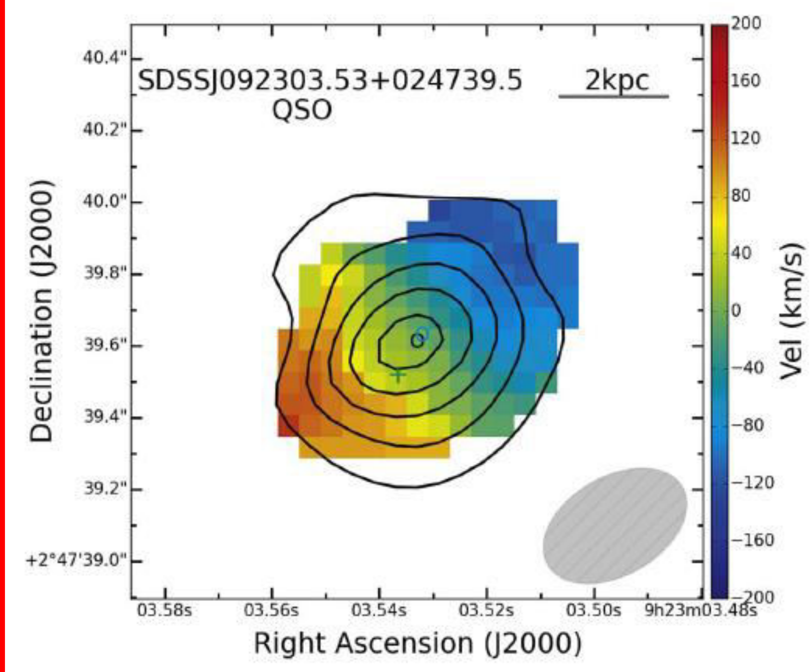
Trakhtenbrot+17 (*ApJ*, 836, 8)

Hosts of fast-growing SMBHs at z~5, with ALMA

Six fast-growing z~4.8 SMBHs (ALMA cycle-2)



Trakhtenbrot+17



The highest-z, fast-growing SMBHs are hosted in high-SFR, dust-rich galaxies

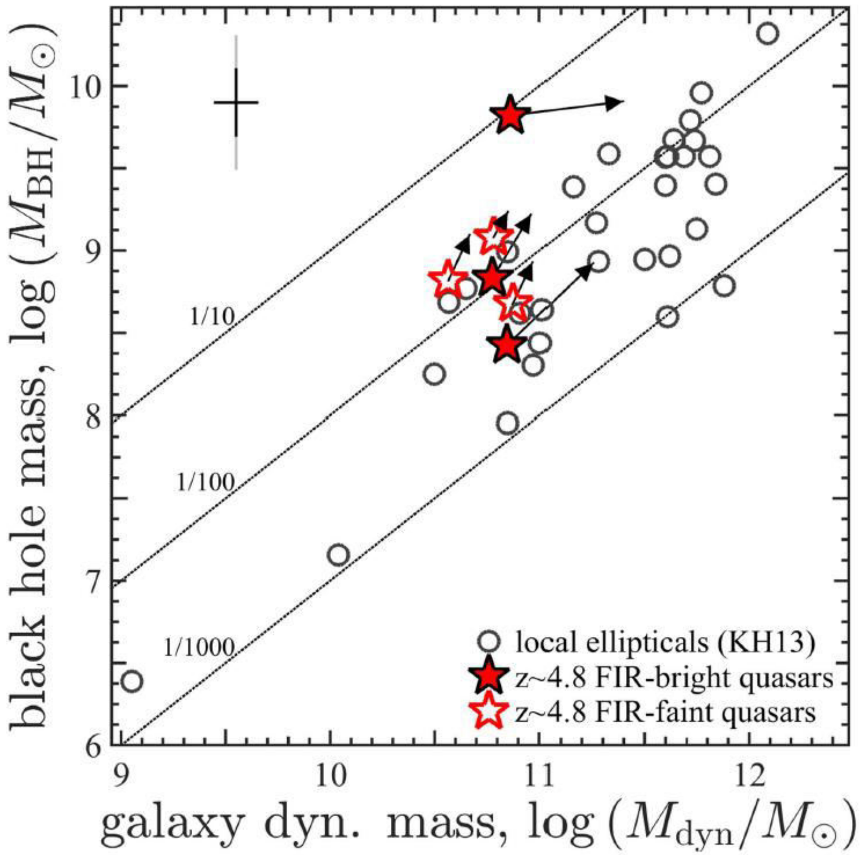
SMBH host galaxy at z=4.8

sub-mm cont. → $\mathrm{SFR} = 360\ M_\odot / \mathrm{yr}$

[CII] line → $M_{\mathrm{dyn}} \approx 7 \times 10^{10}\ M_\odot$

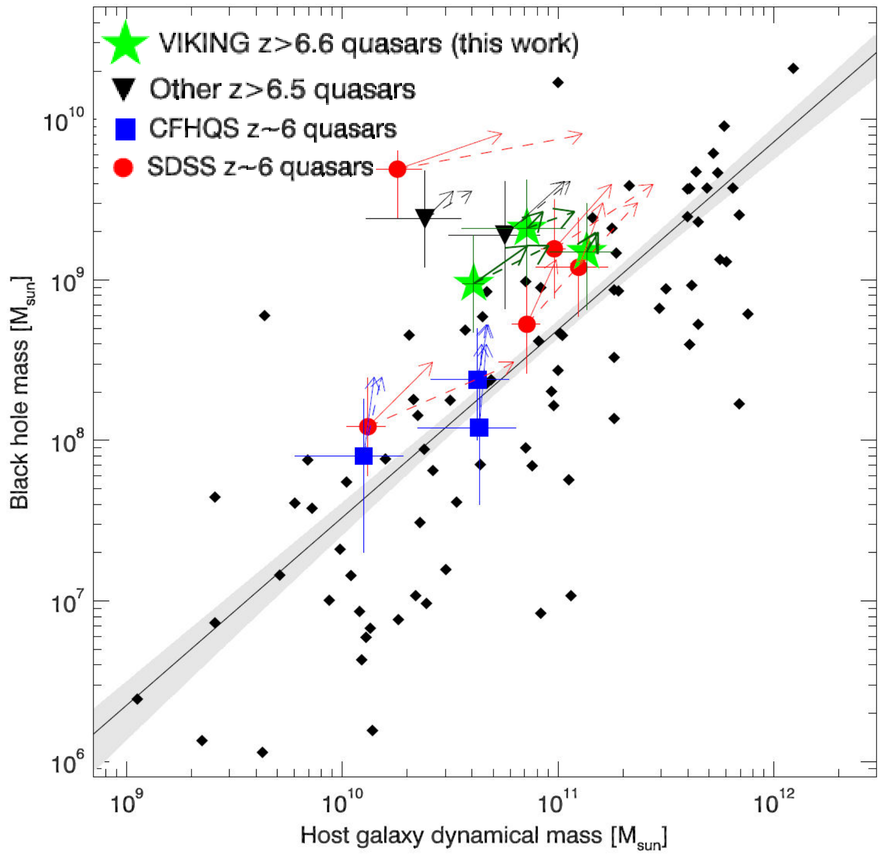
The emerging M_{BH}-M_{host} relation at z~5-7

[CII]-based dyn. host masses at z~5



Trakhtenbrot+17

… and at z~6-7

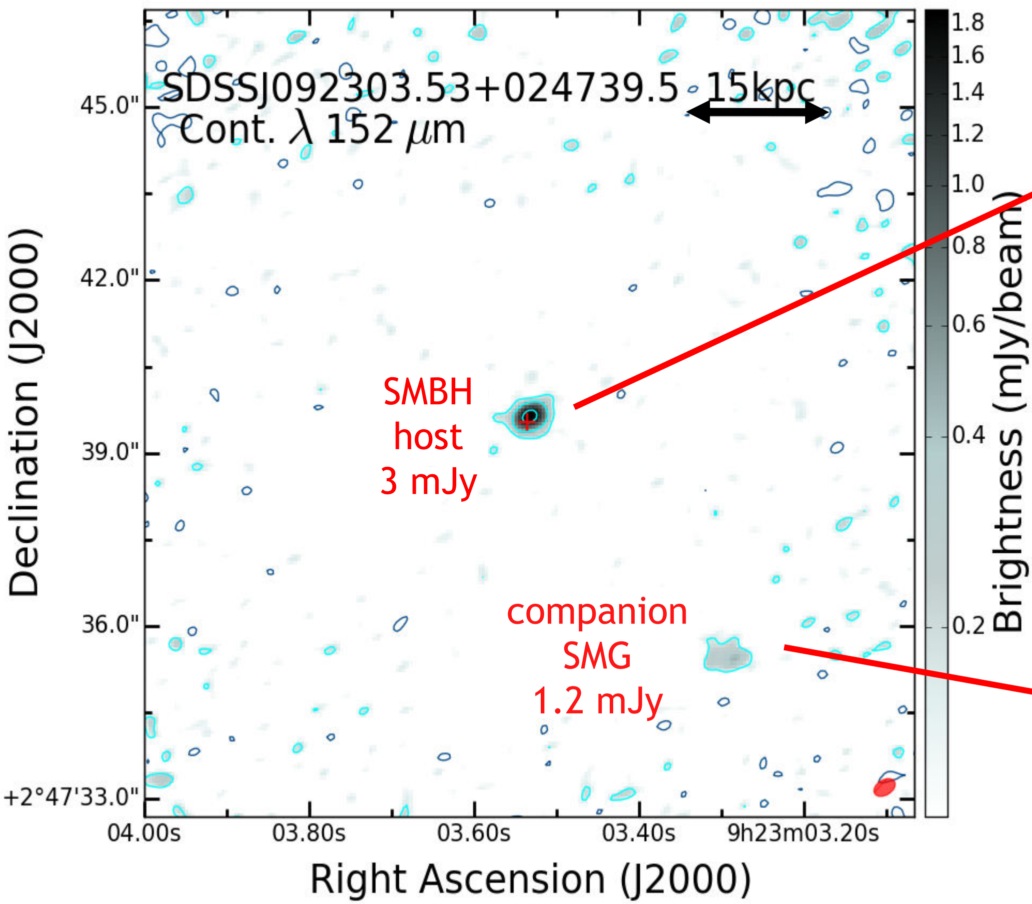


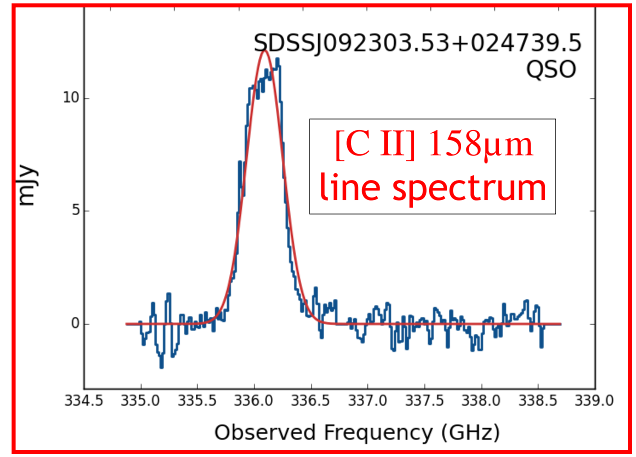
Maiolino+05, Walter+09, Venemans+12, Wang+13, Willott+13,15, Banados+15, **Venemans+16**

High-z, fast-growing SMBHs are slightly "over-massive" w.r.t. hosts

Environments of fast-growing SMBHs at $z\sim5$, with ALMA

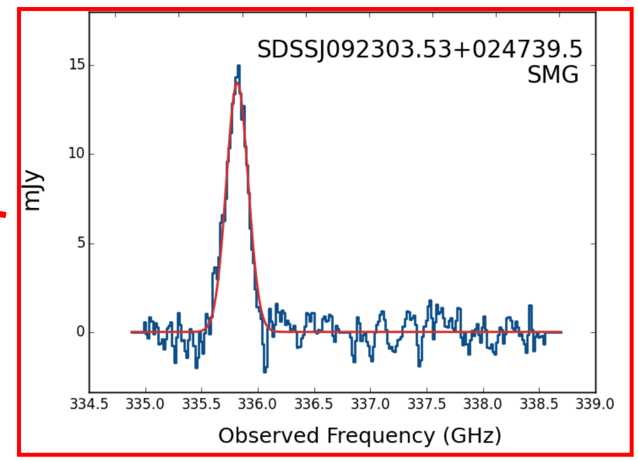
Six fast-growing z~4.8 SMBHs (ALMA cycle-2)





SMBH host galaxy at z=4.8

$M_{\rm dyn,QSO} \approx 7\times10^{10}\,M_\odot$, SFR $=360\,M_\odot$ / yr



interacting galaxy

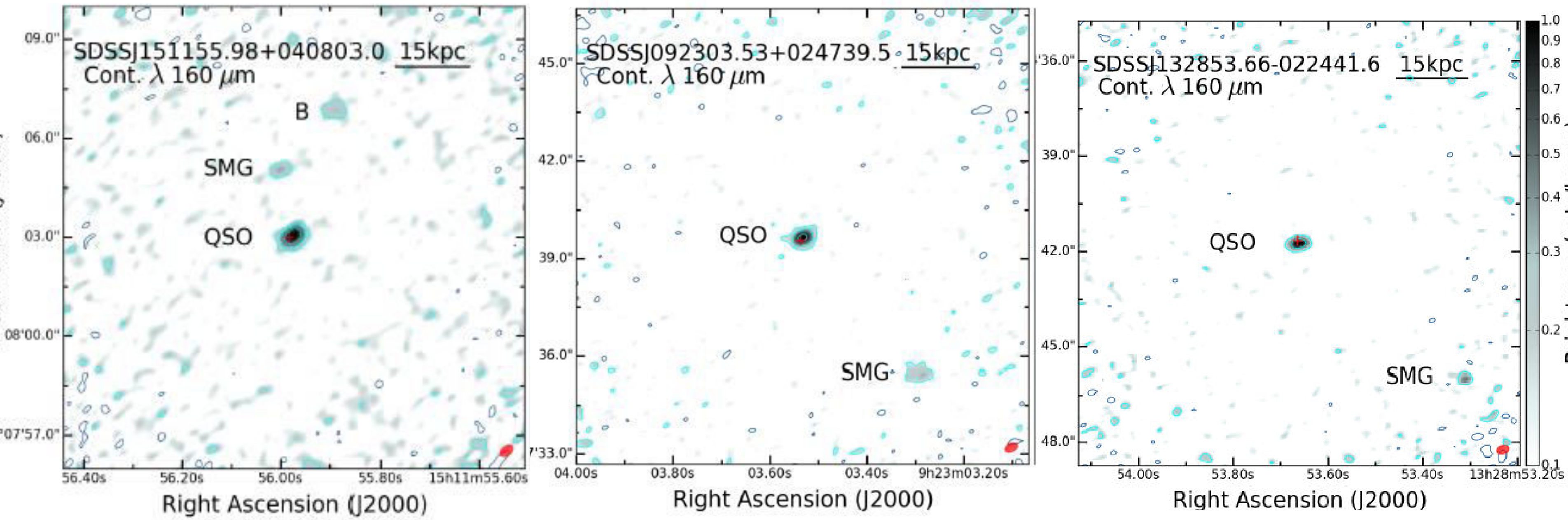
$M_{\rm dyn,SMG} \approx 2\times10^{10}\,M_\odot$, SFR $=150\,M_\odot$ / yr

Trakhtenbrot+17

Environments of fast-growing SMBHs at $z\sim5$, with ALMA

- A high fraction of companion (interacting) SMGs: ~50%

- Separations of ~15-50 kpc and < 500 km/s from quasar hosts
- All are "major mergers"; not seen in previous *Spitzer*/IRAC data

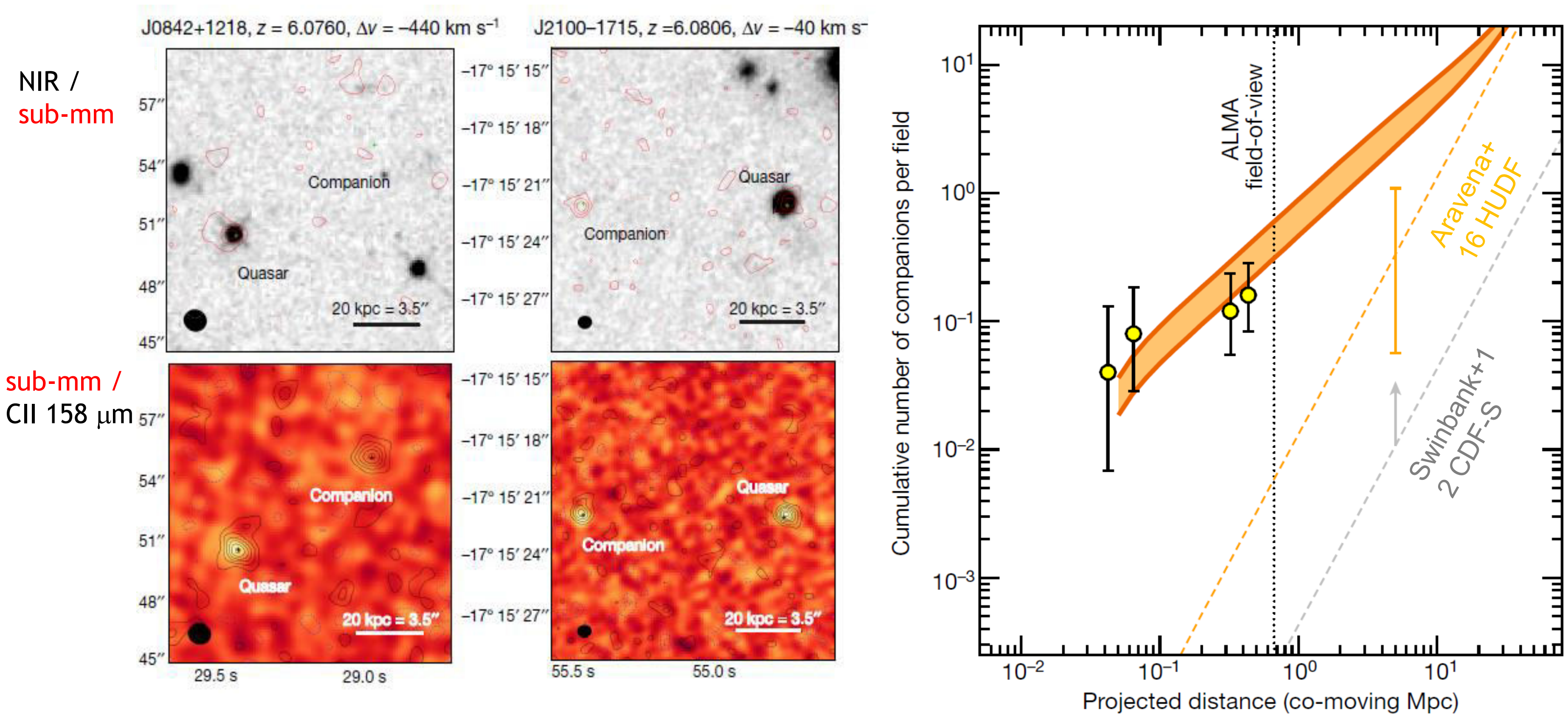


Trakhtenbrot+17

The highest-redshift quasars are found in over-dense environments

Environments of fast-growing SMBHs at *z*~6, with ALMA

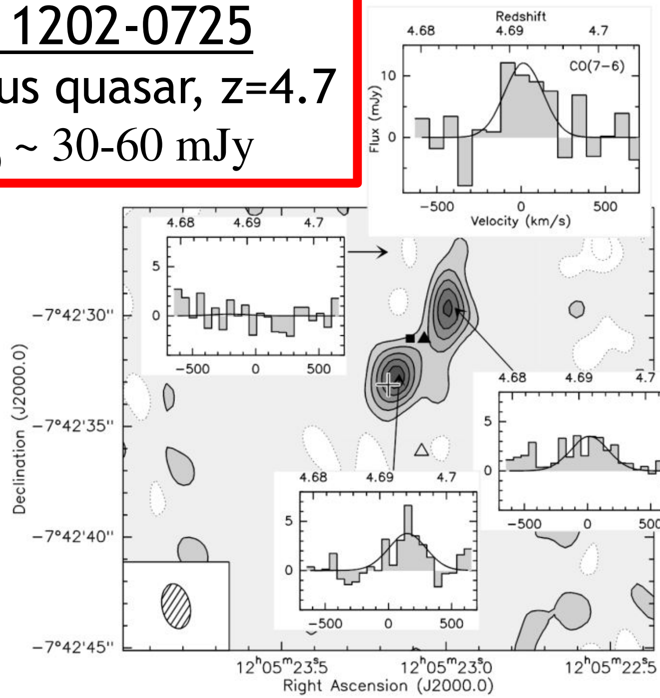
Decarli+17: ALMA observations of 25 quasars at z~6
4 of the 25 have nearby companions (~8-60 kpc)



The highest-redshift quasars are found in over-dense environments

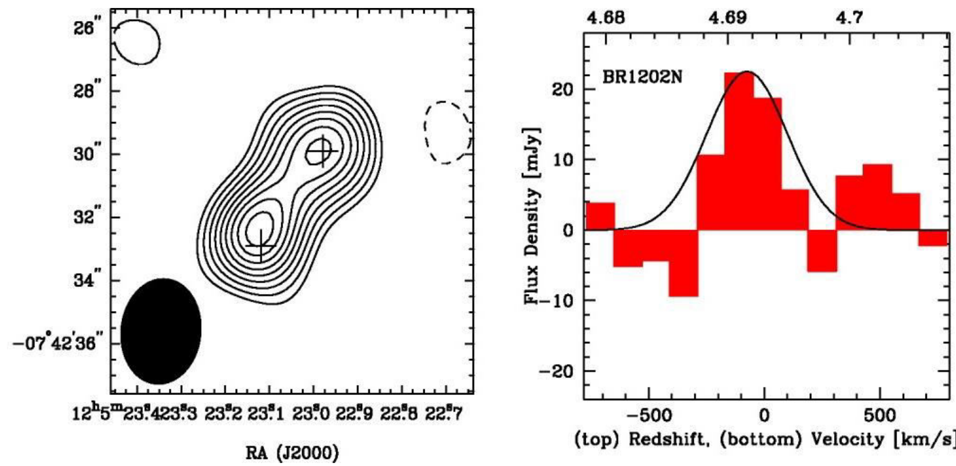
Dual fast-growing SMBHs at $z\sim5$, in sub-mm and *X-ray*?

BR 1202-0725
luminous quasar, z=4.7
S_{900} ~ 30-60 mJy

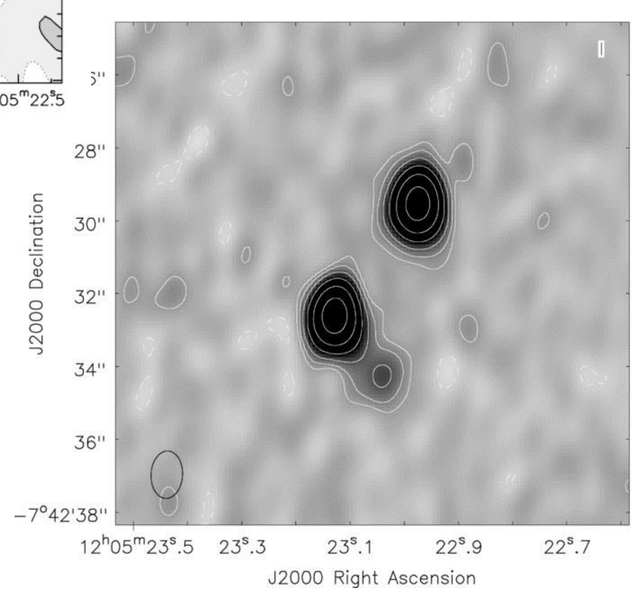


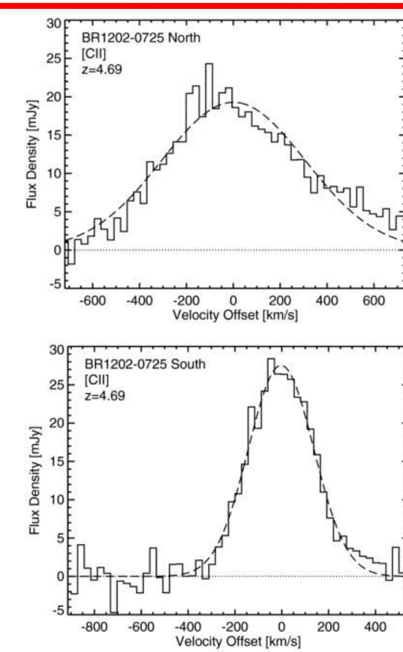
Omont+96
16 hours, PdBI

Iono+06, 20 hours, SMA



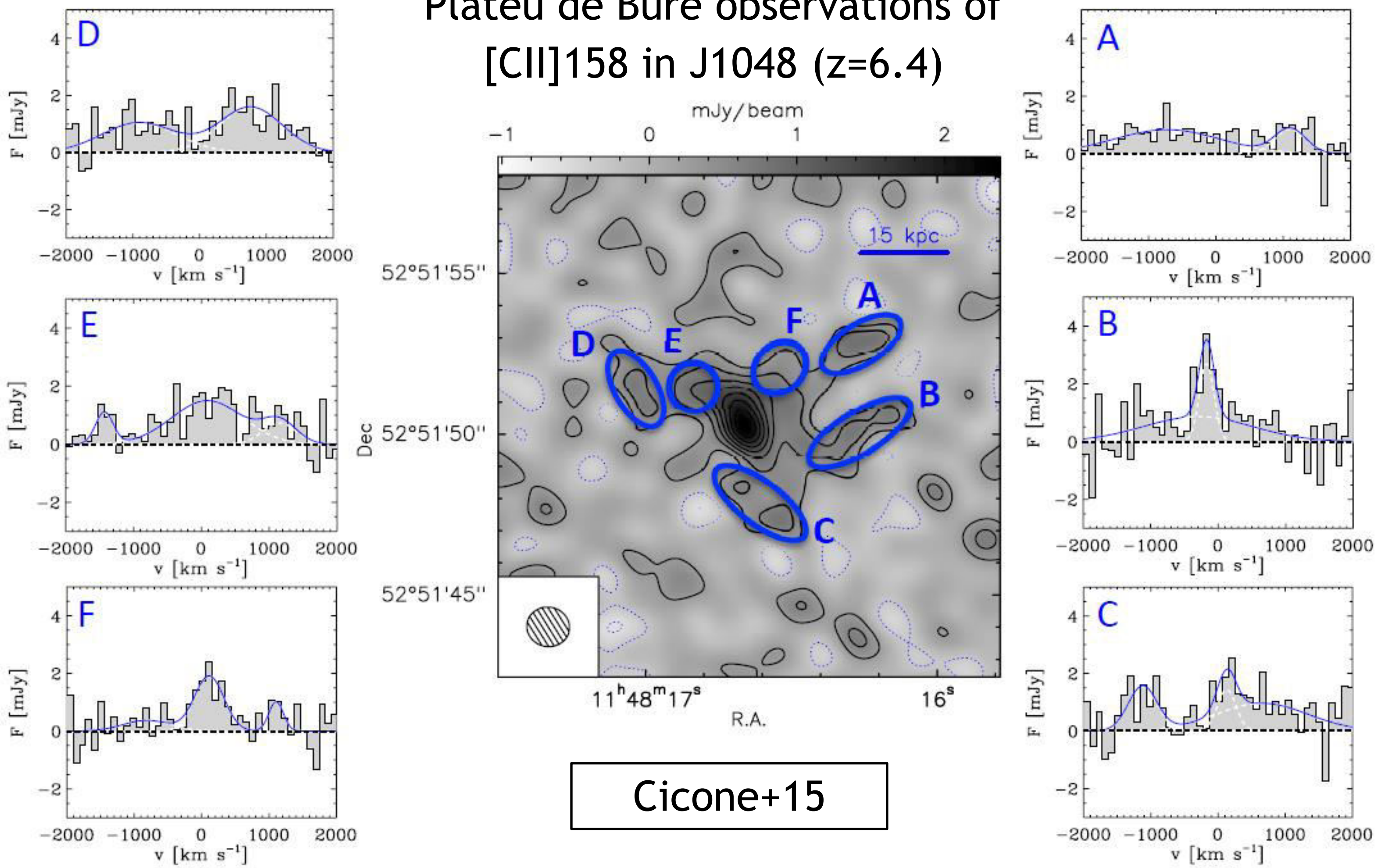
Wagg+12
25 minutes, ALMA SV





Environments of fast-growing SMBHs at $z\sim6$, in sub-mm

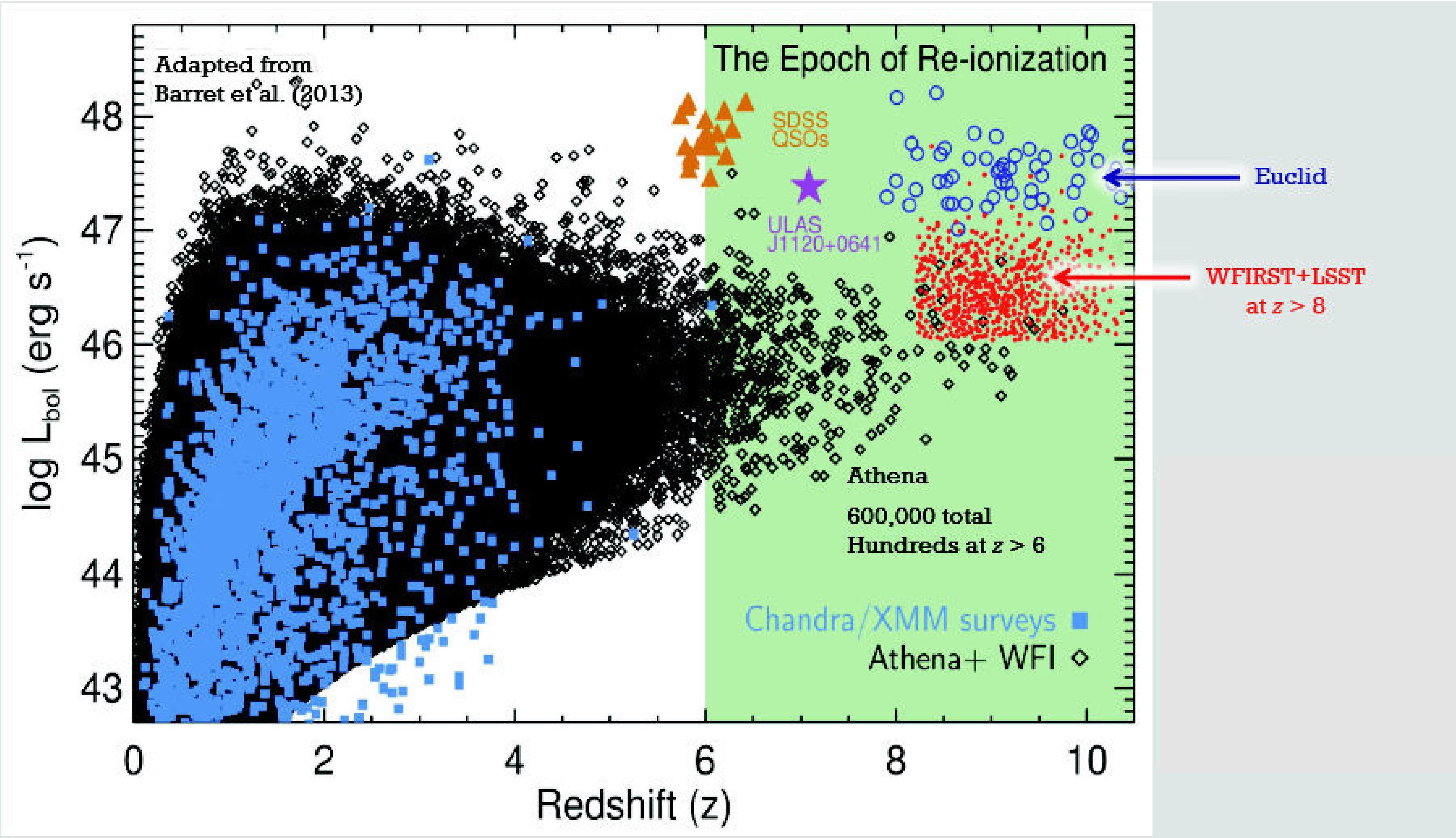
Plateu de Bure observations of [CII]158 in J1048 (z=6.4)



Cicone+15

(some of) The highest-redshift quasars drive large-scale gas outflows

More $z>5$ quasars are coming…



adapted from Niel Brand’s talk and Aird et al (2013; *Athena* science case)

Summary: z~5-7 quasars

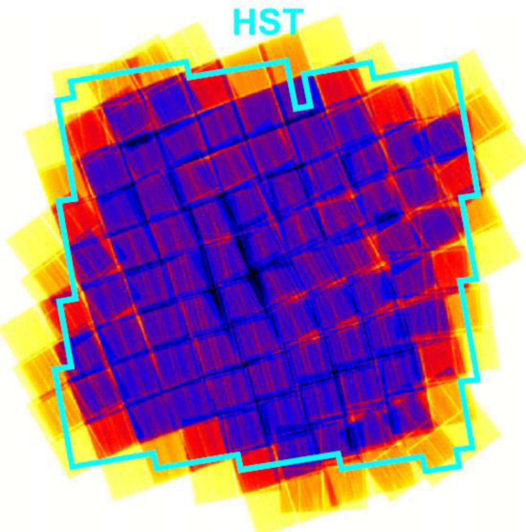
Property	Known z~5-7 quasars
Obscuration/ selection	un-obscured / UV-opt. $L_{bol} \sim 10^{47}$ erg/s
SMBH mass	$M_{BH} \sim 10^9 M_\odot$
Accretion rates	$L/L_{Edd} \sim 1$
Accretion mode	thin disk, $\eta \geq 0.1$
Duty cycle	~100% (continuous growth)
Implied BH seeds	Massive, $M_{seed} \sim 10^{4\text{-}6} M_\odot$
Host mass	$M_{host} \sim 10^{10\text{-}11} M_\odot$
Host star formation	SFR ~300-3000 $M_\odot$ / yr
Large scale env.	over-dense (+outflows?)
Demographics	Rare! $\Phi < 10^{-8}$ Mpc^{-3}
Future prospects	*wFIRST, Euclid, Athena*

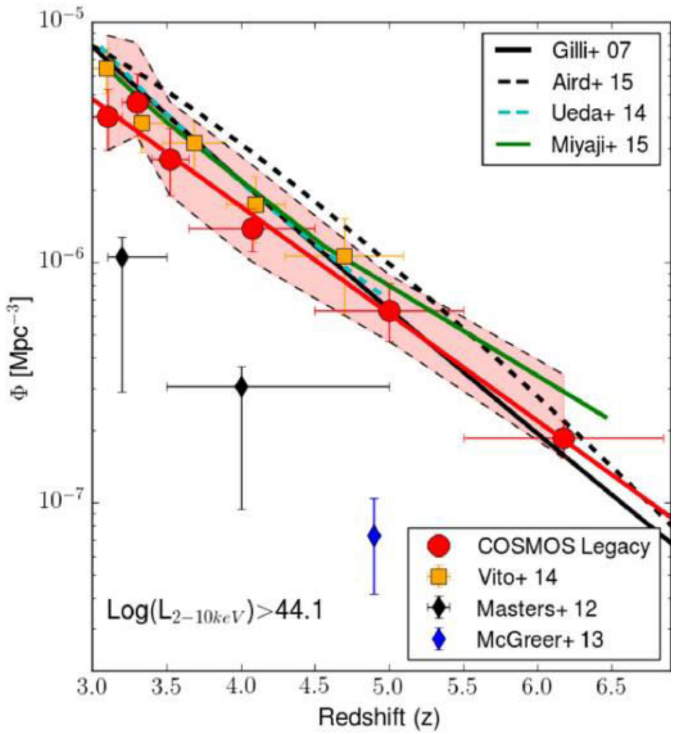
are we missing anything?

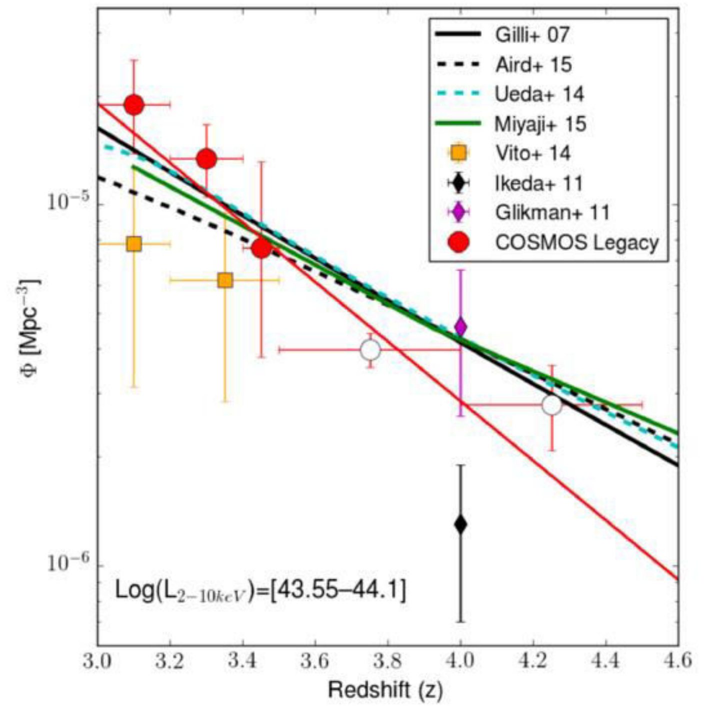
“Missing AGNs” at high-z: deep *Chandra* surveys

Chandra COSMOS Legacy Survey: >1.5 deg^2, 160 ks

(Civano+16, Marchesi+16a,b)





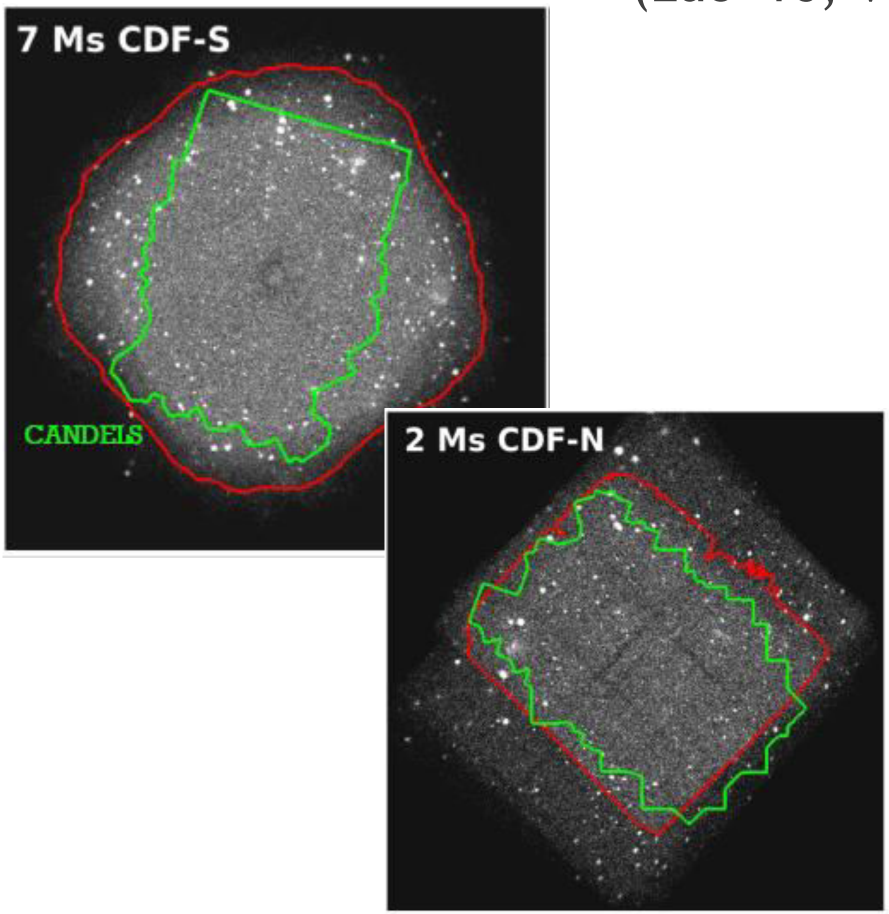


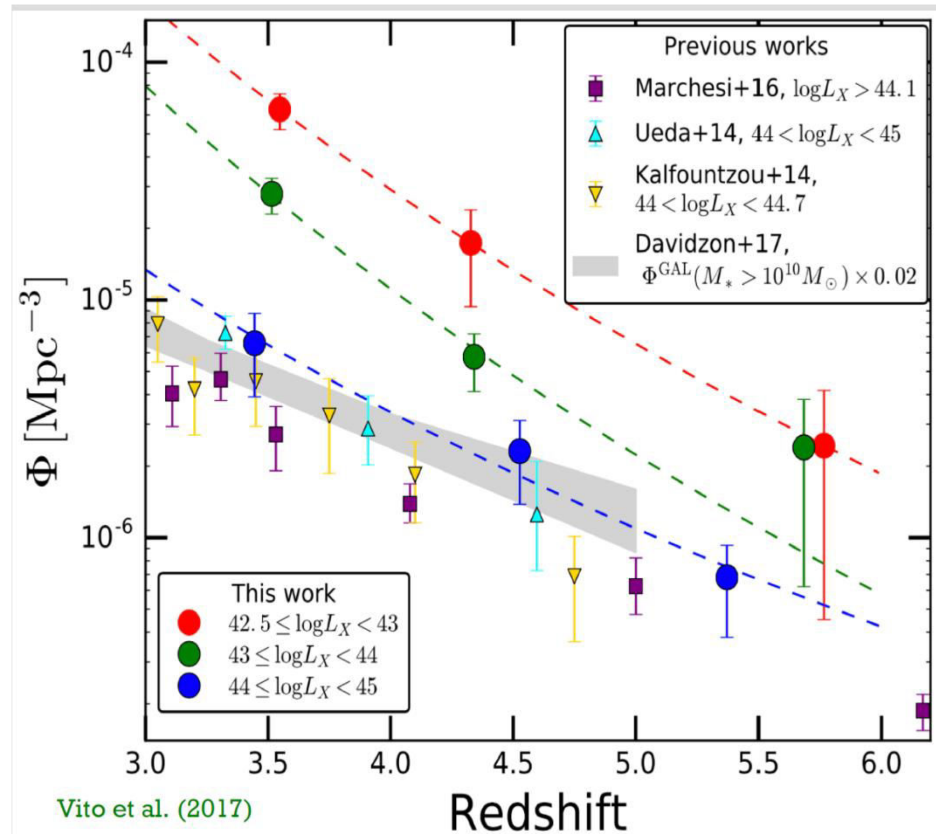
The space density of lower-L AGN drops beyond z~3

“Missing AGNs” at high-z: deep *Chandra* surveys

Chandra Deep Field South (0.13 deg^2, 7 Ms) and North (2Ms)

(Luo+16, Vito+16,17...)





The space density of lower-L AGN drops beyond z~3

But *should* we expect faint AGNs at z~5-7 ?

Yes! progenitors of z~3 AGNs… … but we do *not* see them

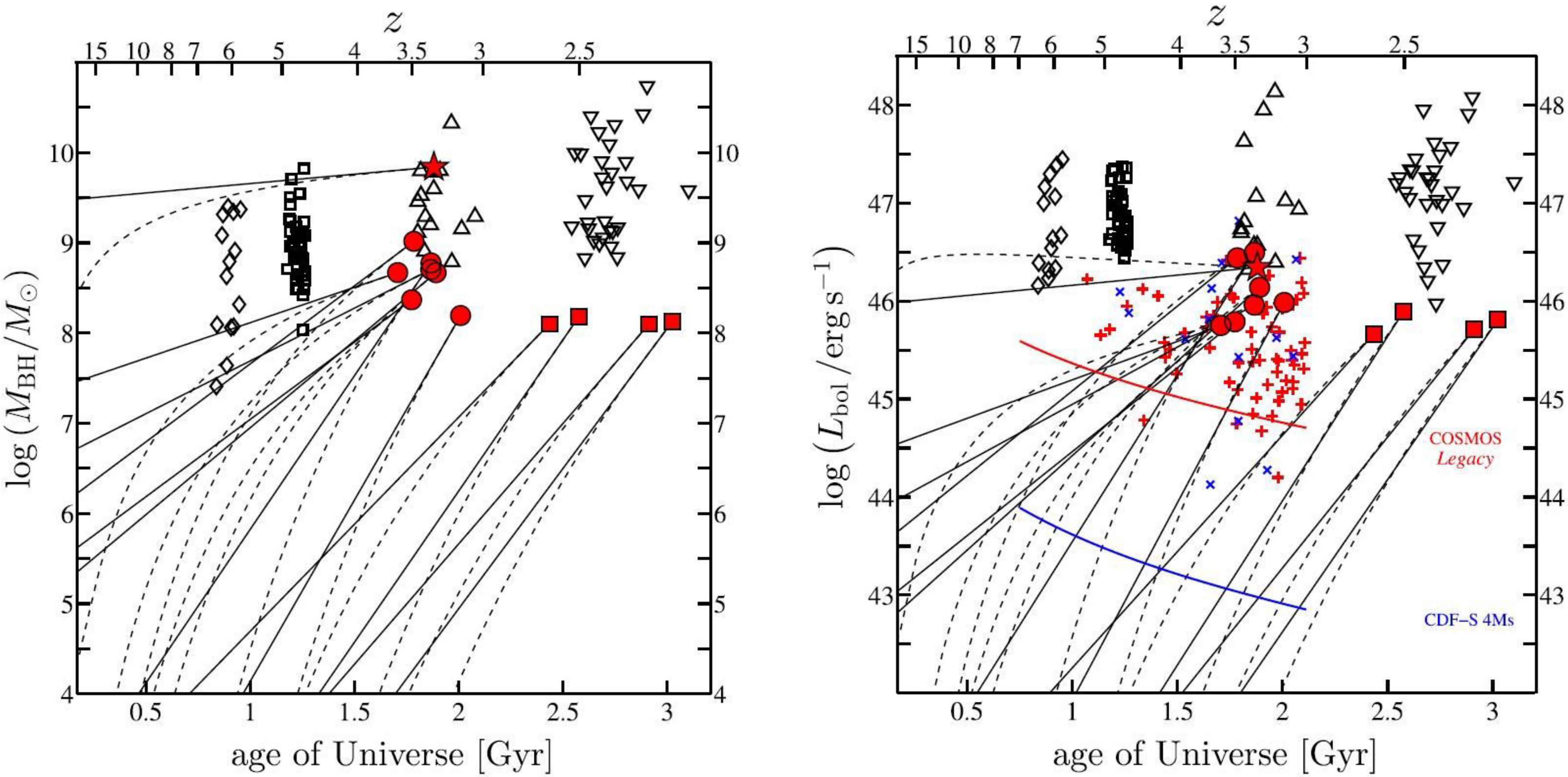


Fig. from Trakhtenbrot+16

are the missing AGNs obscured? low BH occupation fraction? low duty cycle? (“flickering”)

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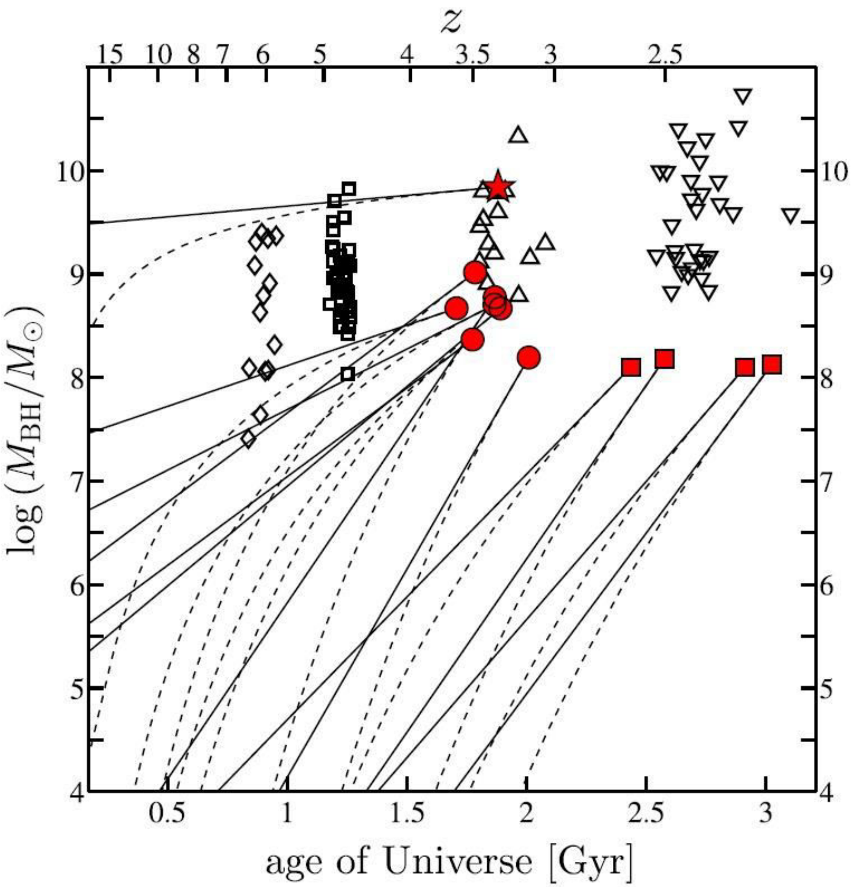

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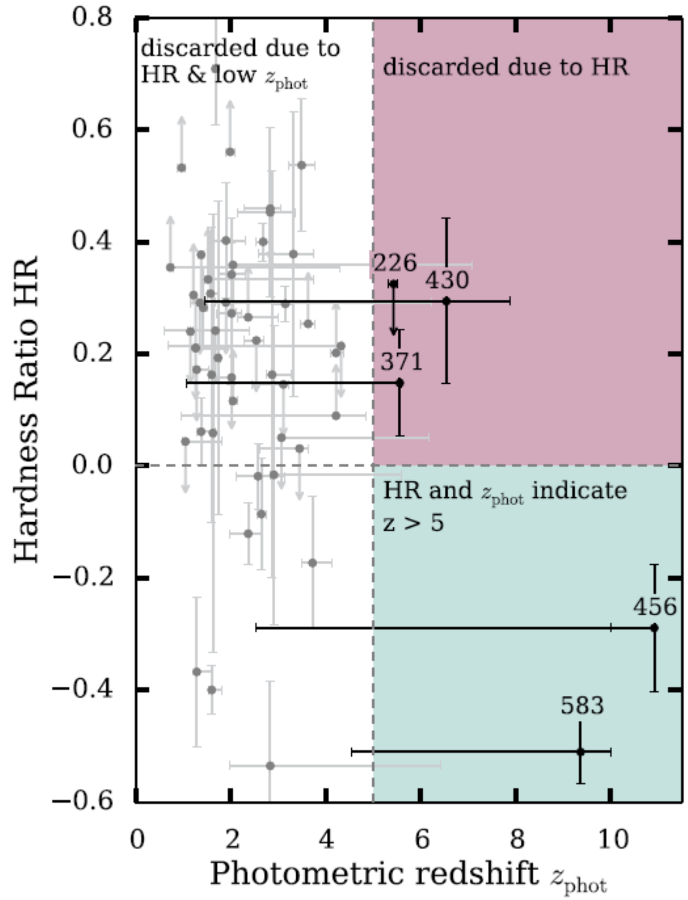

Weigel+15

are the missing AGNs obscured? low BH occupation fraction? low duty cycle? ("flickering")

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Large scale env.	over-dense (+outflows?)
Demographics	Rare! $\Phi < 10^{-8}$ Mpc^{-3}
Future prospects	*wFIRST, Euclid, Athena*

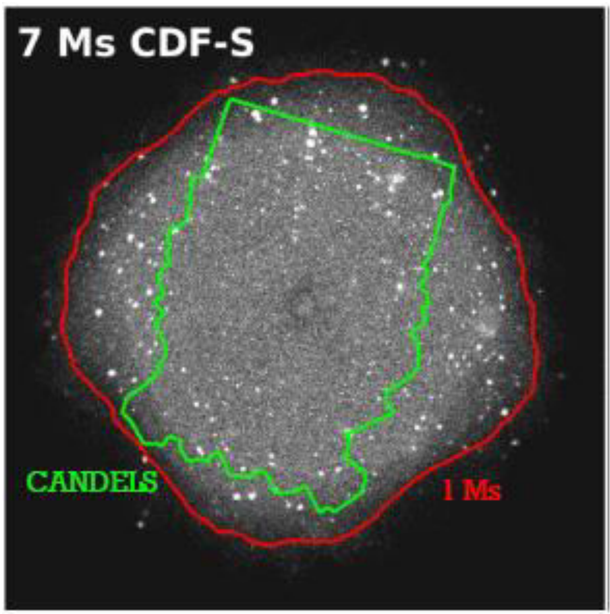
are we missing anything?

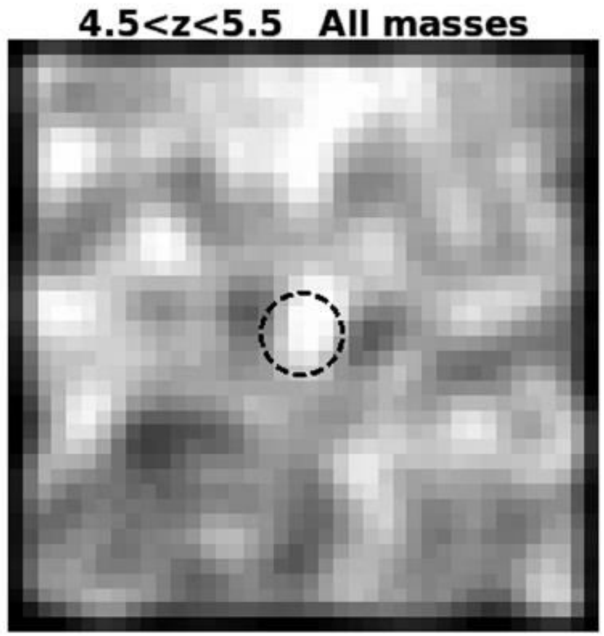
Summary: z~5-7 quasars

Property	Known z~5-7 quasars	"Typical" AGN / galaxies (?)
Obscuration/ selection	un-obscured / UV-opt. $L_{bol} \sim 10^{47}$ erg/s	~50% are obscured $L_{bol} < 10^{44}$ erg/s
SMBH mass	$M_{BH} \sim 10^9 M_\odot$	$M_{BH} \sim 10^7 M_\odot$
Accretion rates	$L/L_{Edd} \sim 1$	$L/L_{Edd} \sim 0.01 - 1$
Accretion mode	thin disk, $\eta \geq 0.1$	*(who knows, really?)*
Duty cycle	~100% (continuous growth)	<< 100%
Implied BH seeds	Massive, $M_{seed} \sim 10^{4-6} M_\odot$	Pop-III, $M_{seed} < 10^3 M_\odot$
Host mass	$M_{host} \sim 10^{10-11} M_\odot$	$M_{host} \sim 10^{9-10} M_\odot$
Host star formation	SFR ~ 300-3000 $M_\odot$ / yr	SFR < 100 $M_\odot$ / yr
Large scale env.	over-dense (+outflows?)	"normal"
Demographics	Rare! $\Phi < 10^{-8}$ Mpc^{-3}	Common? $\Phi \sim 10^{-6}$ Mpc^{-3} (~10% of galaxies? less?)
Future prospects	*wFIRST, Euclid, Athena*	***Lynx!***

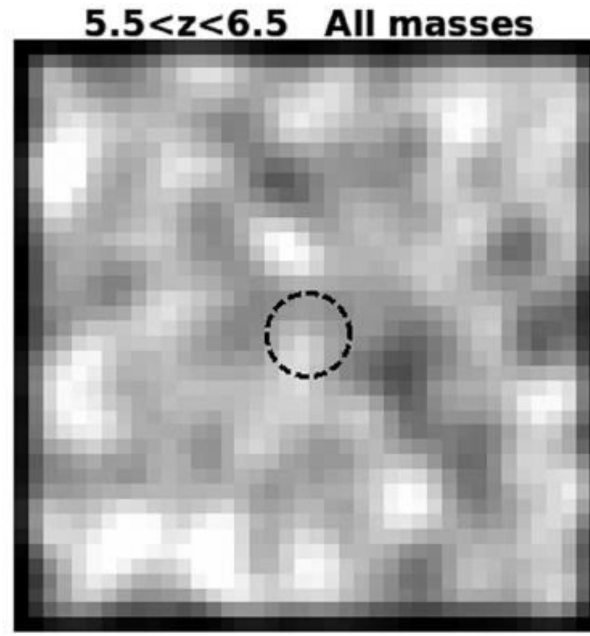
“Missing AGNs” at high-z: deep *Chandra* surveys

Chandra Deep Field South (0.13 deg^2, 7 Ms) and North (2Ms)
(Luo+16, Vito+16, 17...)





453 galaxies
2.65 Giga-sec



230 galaxies
1.35 Giga-sec

Chandra sees no sign of AGN in (stacks of) typical z>5 galaxies

Faint AGN and BH seeds: prospects for *Lynx*

A proposed *Lynx* deep survey: 4 Ms over 1 deg^2

(several different fields, ~8 pointings)

	3x10
Detection threshold @ 4Msec (0.5-2 keV) (for known locations)	3.0x10^{-19} erg/s/cm^2 (1.1x10^{-19})
2–10 keV luminosity at z=10 assuming Γ=1.7	3.7x10^{41} erg/s (1.35x10^{41})
Bolometric luminosity at z=10, assuming 10% correction	3.7x10^{42} erg/s (1.35x10^{42})
Black Hole Mass assuming Eddington rate	29,000 Msun (11,000 Msun)

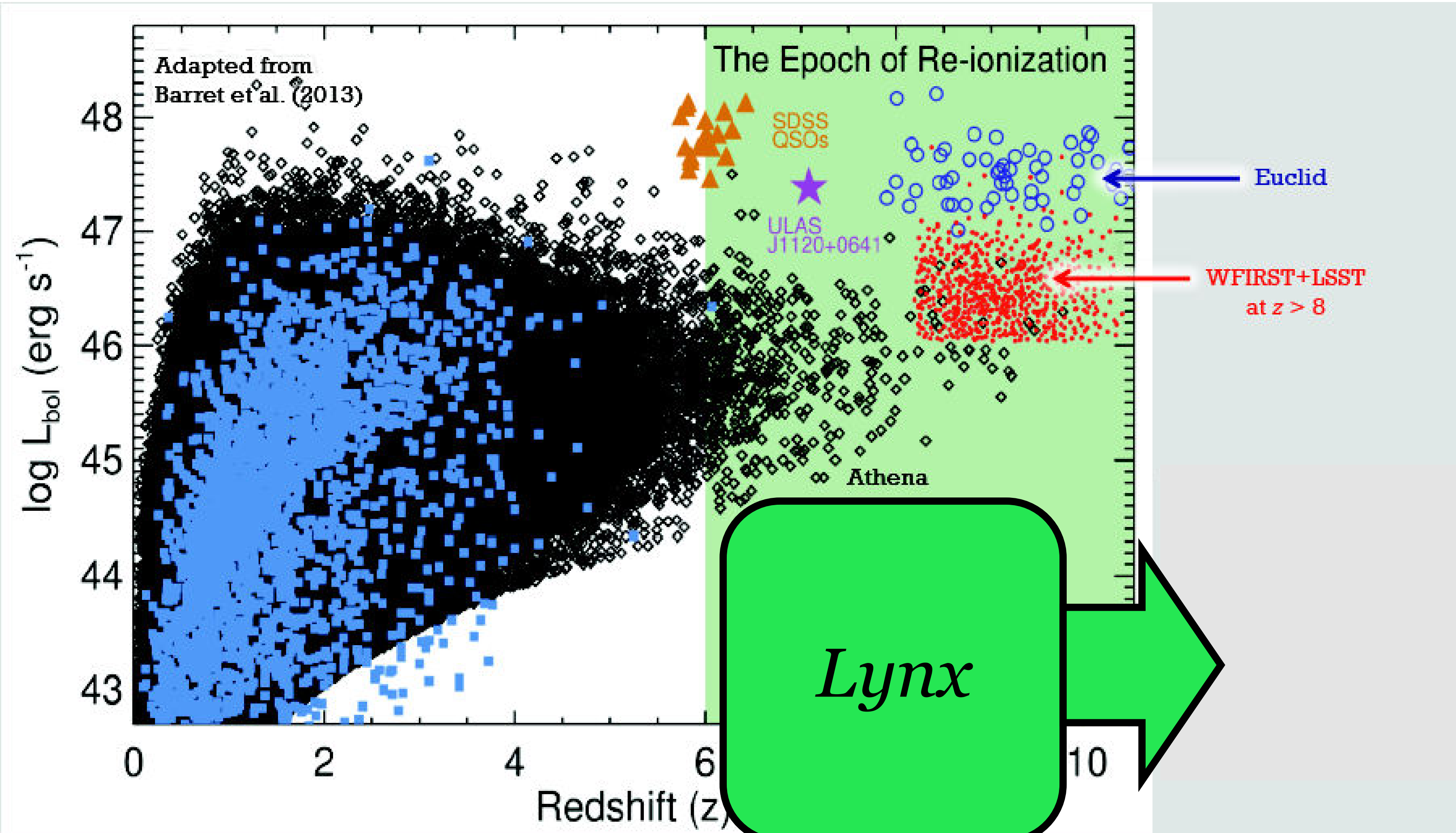
"known locations": catalogs of high-z galaxies from wFIRST, JWST… (photo-z? spec-z?)

$$L_{bol} < L_{Edd} \cong 1.3\times10^{38}\ M_{BH}$$

$$M_{BH} > L_{bol} / 1.3\times10^{38}$$

Lynx will detect the faint/low-M counterparts of the highest-redshift quasars, and will trace progenitors back to the BH seed population

Faint AGN and BH seeds: prospects for *Lynx*



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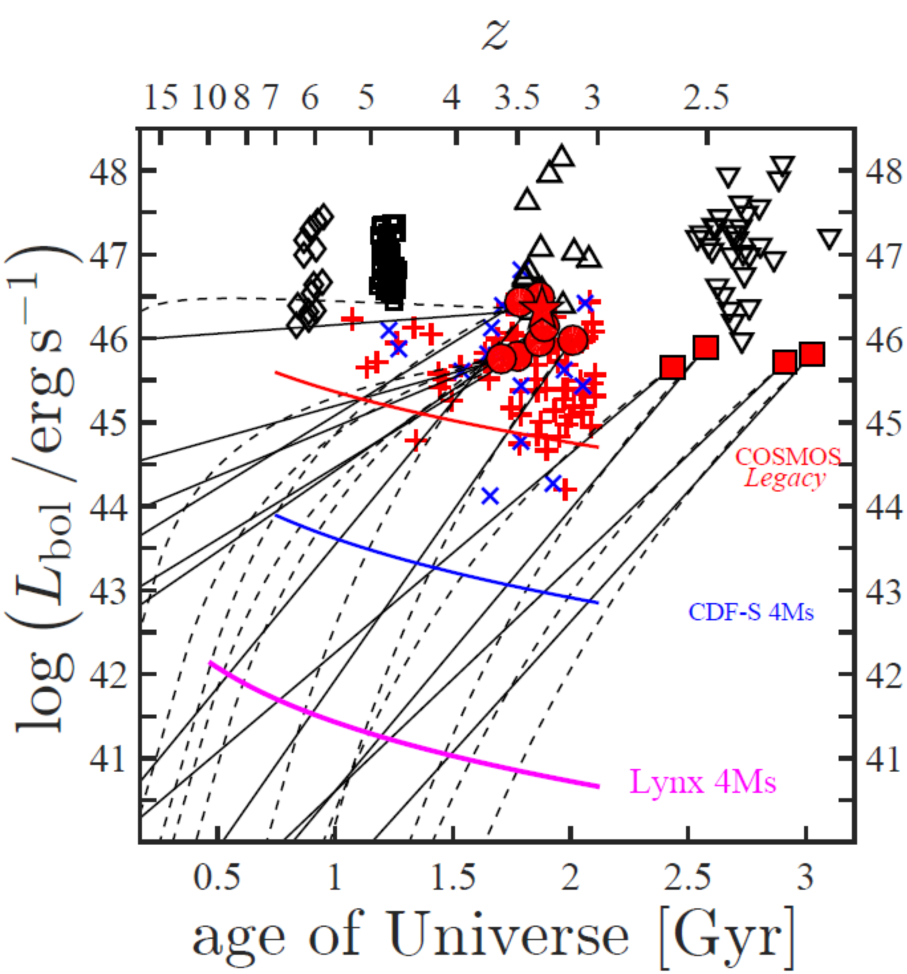

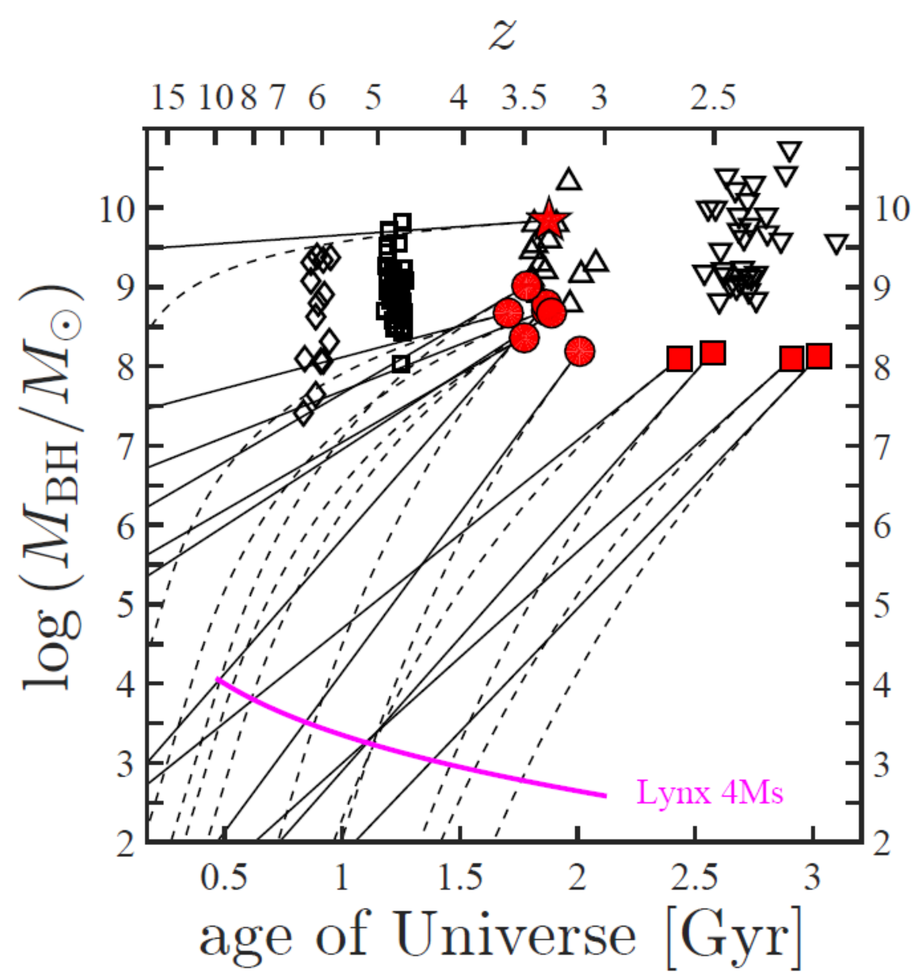

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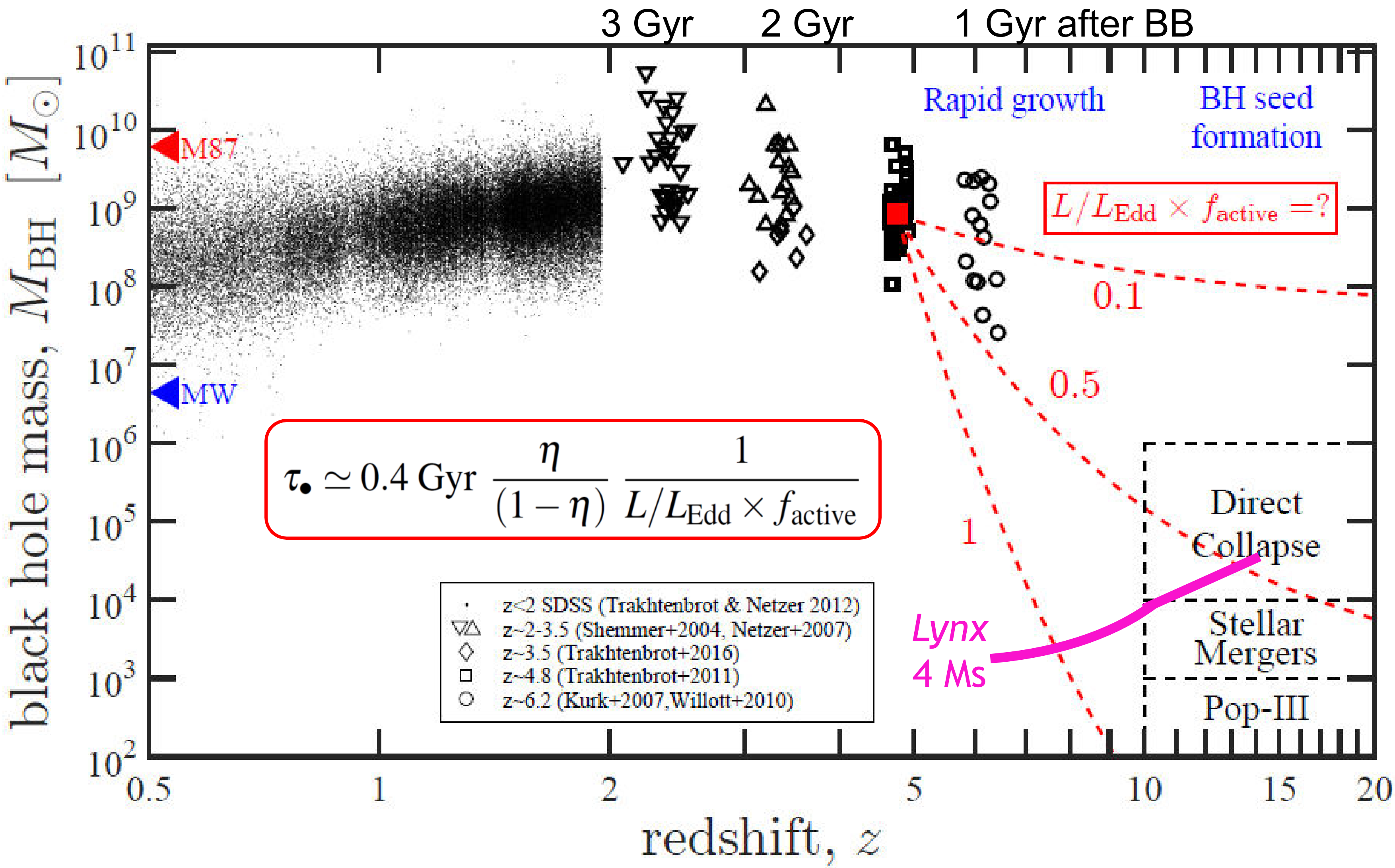

plot adapted from
Trakhtenbrot & Netzer 12

reviews on BH seeds:
Volonter 10, Natarajan 11

Summary

- Wide-field optical/IR surveys have identified 100s of quasars at $z > 5$
  These SMBHs had to grow continuously and/or from massive seeds

- We learned that the highest-redshift quasars are growing *fast* in massive, gas-rich, high-SFR hosts, located in *rare* over-dense regions.
  Are these SMBHs the rare "lucky ones" ?

- The deepest Chandra surveys suggest we're missing the fainter / lower-mass counterparts of these quasars – the progenitors of z~3-4 systems.
  Why can't we see AGN signature in "typical" high-z galaxies?

- *Lynx* will detect extremely faint/low-mass AGN out to z~10, tracing the high-z AGN population back to the epoch of massive BH seed formation.