Science and predictions for the first (z>6) quasars

First Light And Reionization Explorer

FLARE

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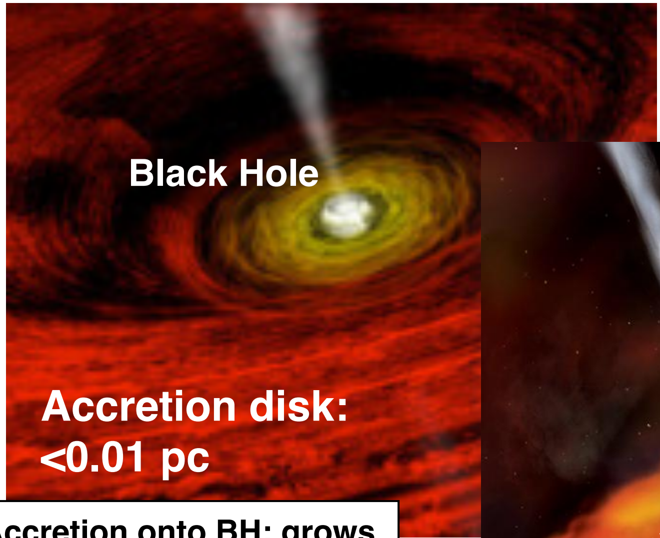
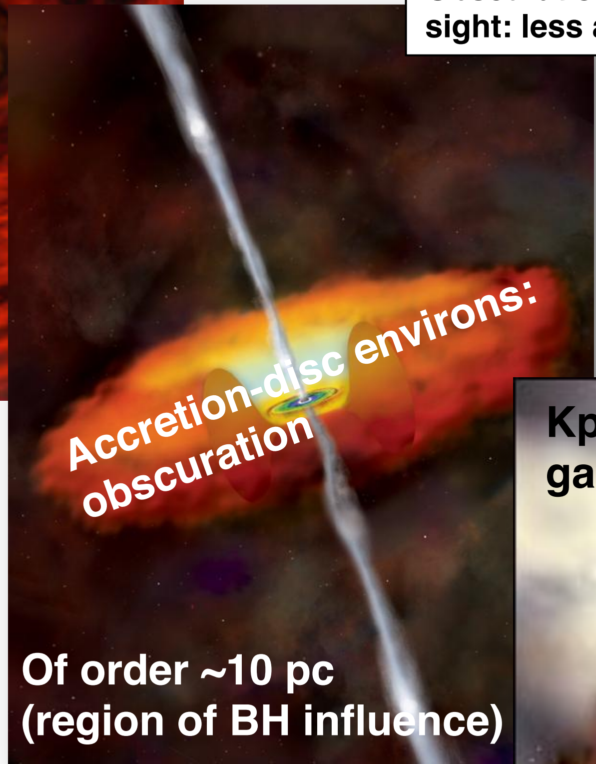
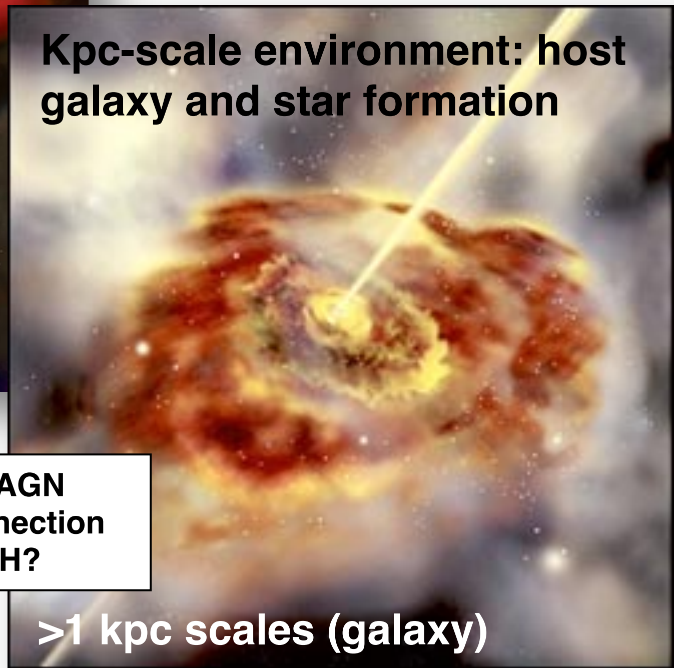
Quasars/AGNs in context







Quasars: in this talk we mean any AGN that can be detected by FLARE (including obscured)

Why study the first quasars?

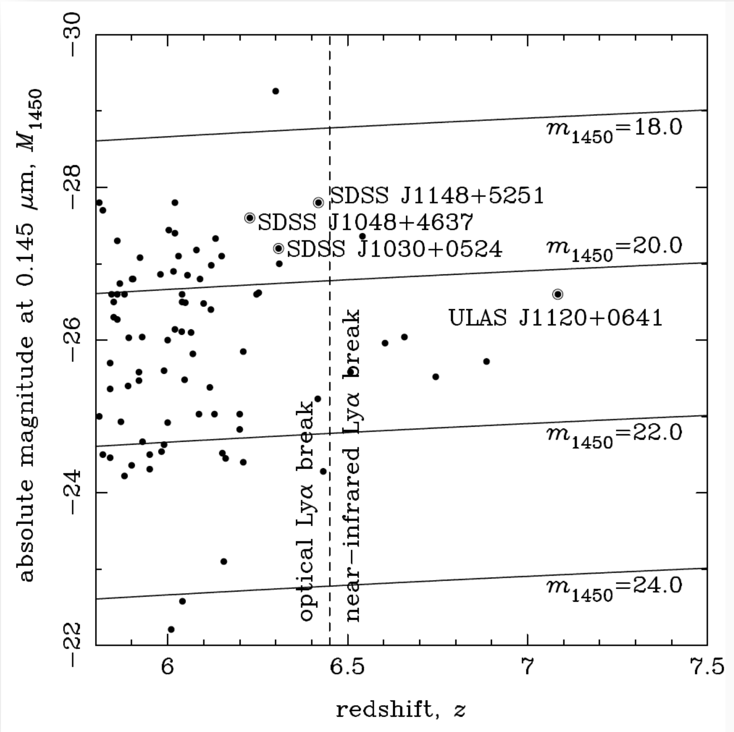
(1) **Formation of the first massive black-holes:** black hole seeds and their early growth

(2) **Environments of the first massive black holes:** metallicity, obscuration, host properties (mass; star formation rate; larger-scale environment), quasar-driven outflows

(3) **Reionisation of the Universe:** contribution to reionisation from quasars and bright sight lines through the reionisation era

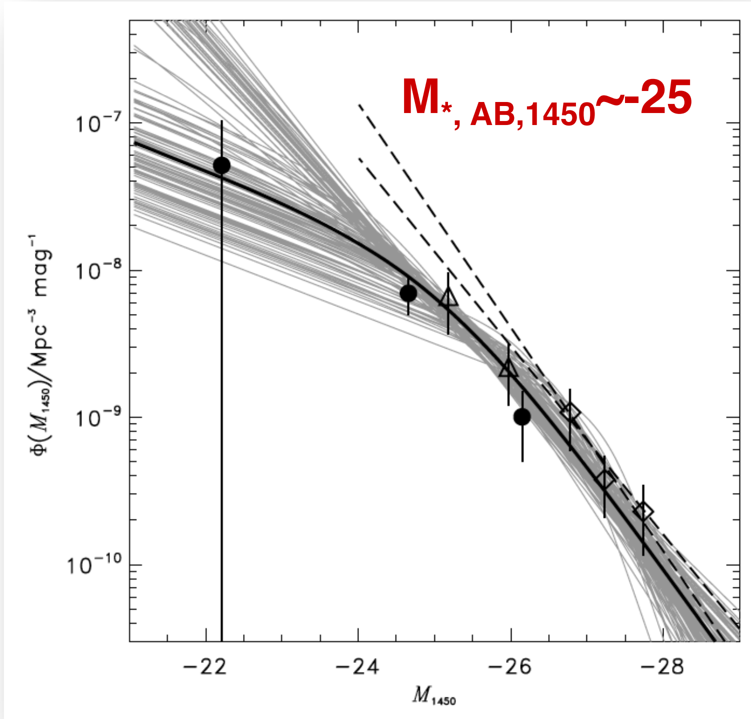
First quasars: status in ~2016

~100 quasars identified at z>6



Mortlock (2015)

z~6 Quasar luminosity function



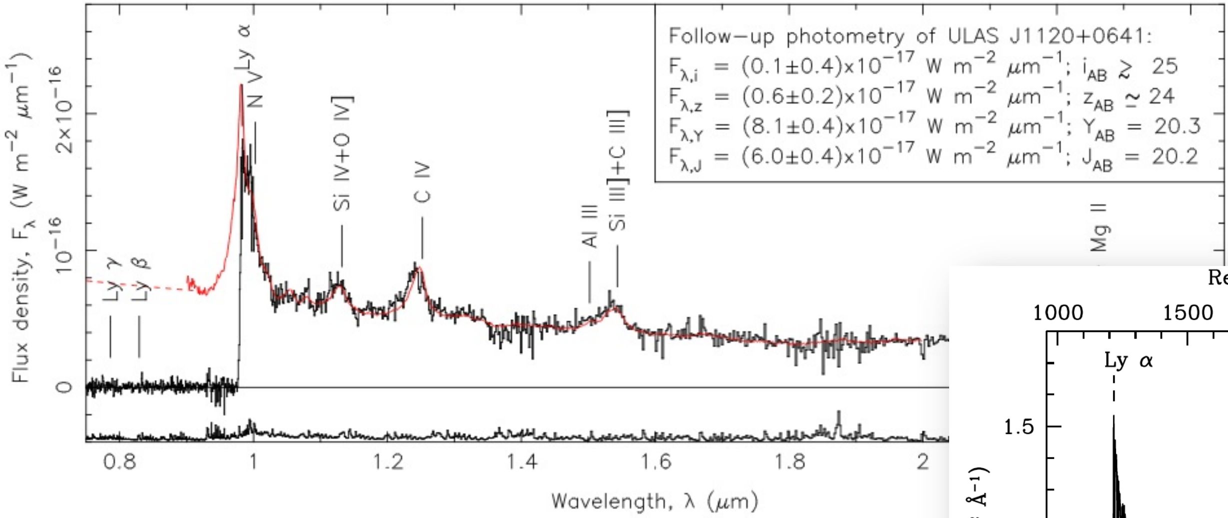
Willott et al. (2010)

Well determined bright end of z~6 quasar luminosity function – poor constraints at lower luminosity. Almost nothing known about obscured quasars at z>6. Only one quasar at z>7.

FLARE can push photometrically at z~10 to $M_{AB,1450}$~-20 (>5 mags below M_*)

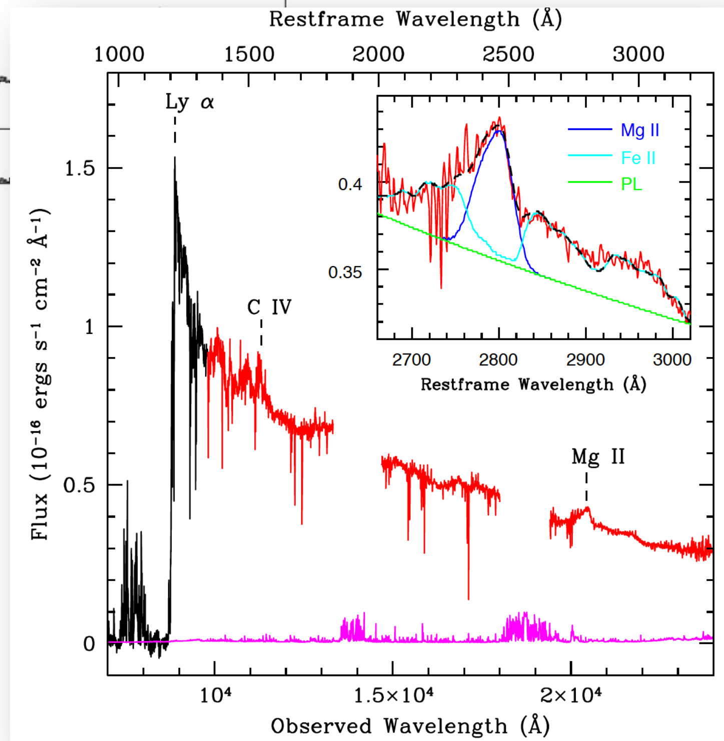
(I) Formation of the first massive black holes

z=7.1: M_{BH}~2x10^9 solar



Mortlock et al. (2011)

Wu et al. (2015)

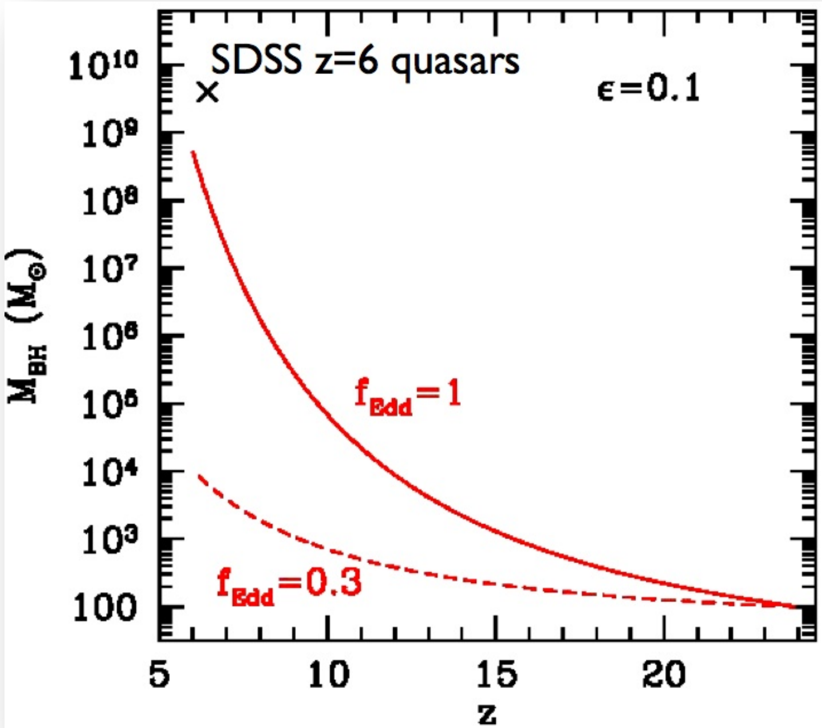


z=6.3: M_{BH}~1.2x10^{10} solar!

Challenging to understand how such massive black holes can form so rapidly within such a short time

(I) Formation of the first massive black holes

Eddington limit: the challenge in quickly growing to $M_{BH}>10^9$ solar



<u>Eddington limited growth time:</u>

$$t_{\rm growth} = 0.45\ {\rm Gyr}\ \frac{\epsilon}{1-\epsilon}\lambda^{-1}\ln\left(\frac{M_{fin}}{M_{in}}\right)$$

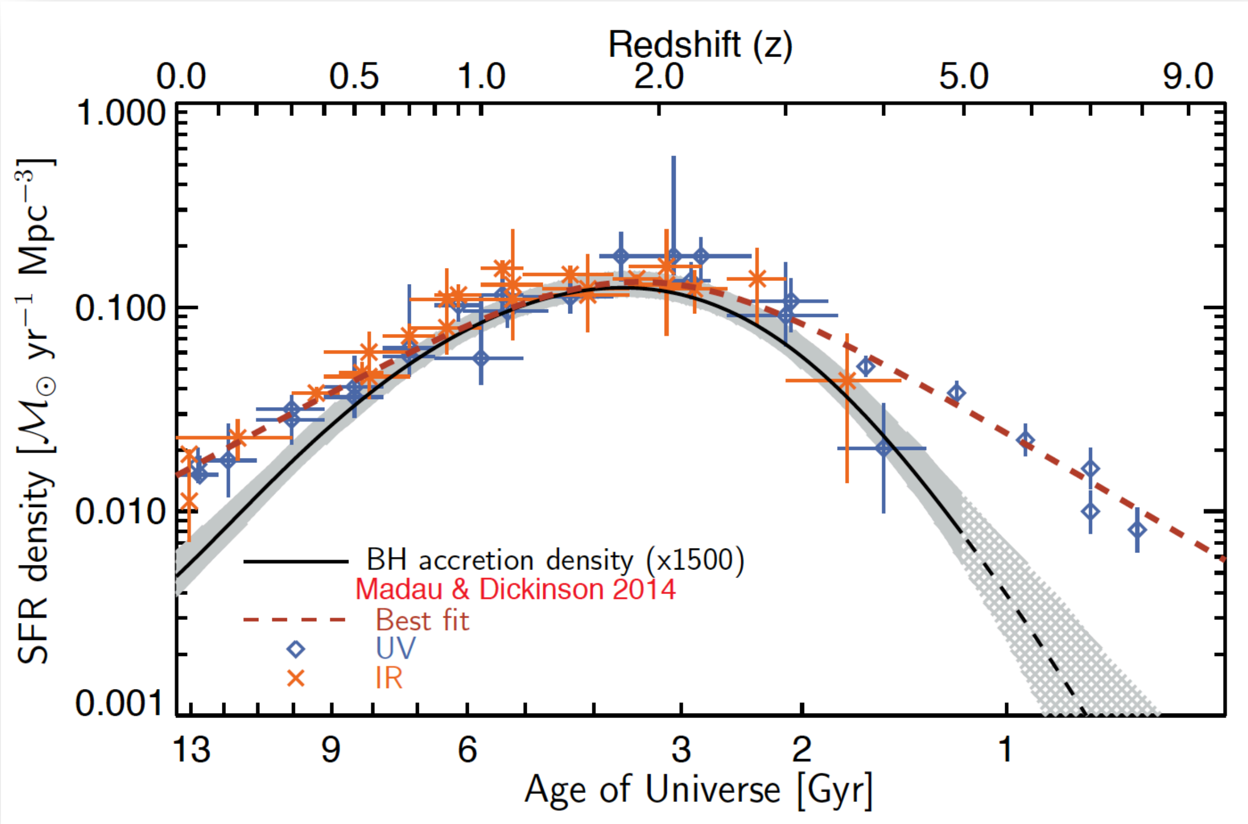
M_{BH}~10^9 solar only just possible by z~6 with formation at z~25 from M_{BH}~100 solar (pop III remnant)

Some solutions (all "exotic"): more massive BH seeds (>10^4 solar: direct gas collapse)? Multiple BH mergers? Super-Eddington accretion?

FLARE may detect first accretion onto direct collapse BH

(I) Formation of the first massive black holes

BH accretion density versus star-formation density



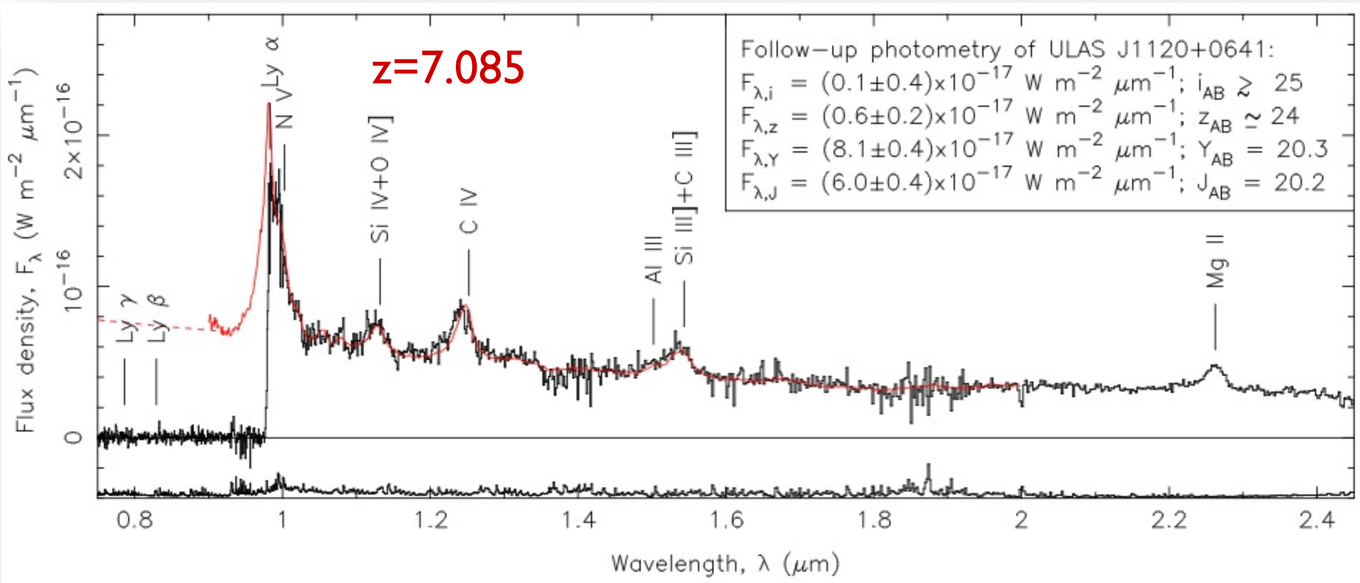
Aird et al. (2015)

Quasars/AGNs appear to become rarer wrt galaxies at z>5 but need direct measurements

FLARE+Athena (also E-ELT) can directly measure out to (potentially) z~10

(2) Environments of first massive black holes

z>6 quasars strikingly normal: metal rich by z~7 – how?



Mortlock et al. (2011)

Do metal-poor quasars exist? A drop in metallicity at yet higher redshifts?

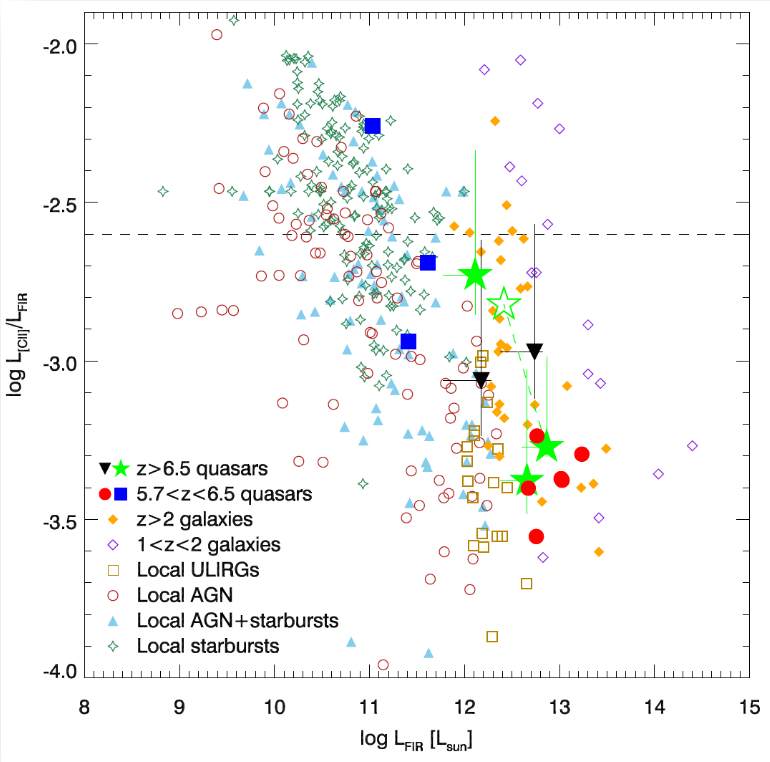
Lack of metals would mean less obscuration: few z>6 obscured quasars?

FLARE could trace metallicity in first quasars out to z~8-10

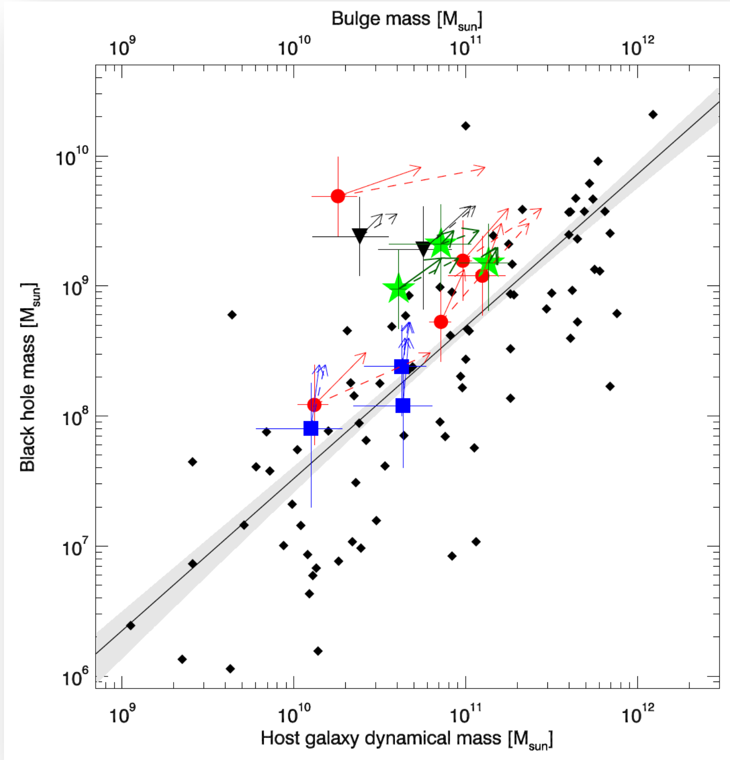
(2) Environments of first massive black holes

Are the host galaxies of the first quasars unusual or special?

[CII] and far-IR from ALMA



BH and host masses



Venemans et al. (2015)

Hosts massive (~10^{10}-10^{11} solar) – gas/star formation already similar to z~0-2 systems

FLARE will find higher z and lower-lum quasars to allow host studies

(2) Environments of first massive black holes

Other "environment" measures of first quasars with FLARE:

Large-scale clustering analyses with respect to galaxies – bias and constraints on BH seed formation?

Mpc-scale environment around first quasars using FLARE IFU: co-eval galaxy and other z>6 quasar/AGN connections (multiple growing BHs)?

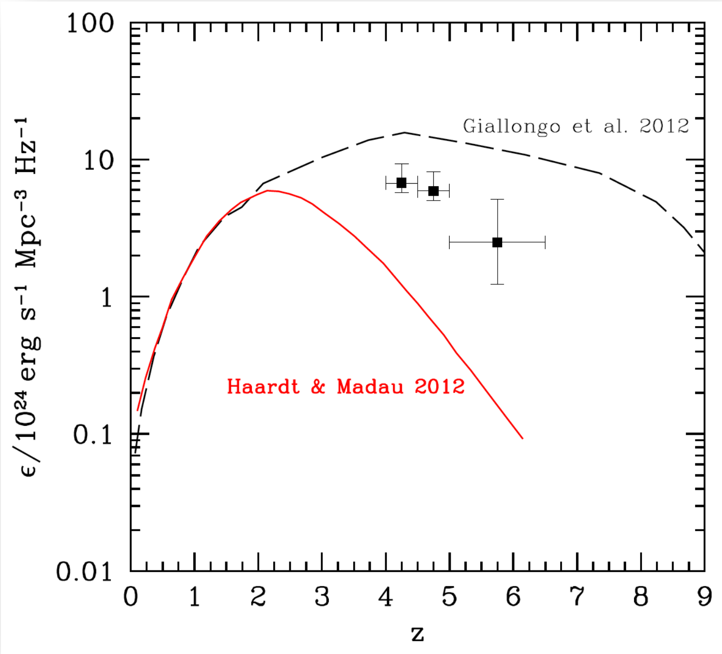
Evidence for quasar outflows (e.g., broad CIV absorption troughs; blue-shifted emission lines)?

NOTE: rest-frame optical with FLARE may allow for direct host mass constraints (if can account for quasar light)

(3) Reionisation of the Universe

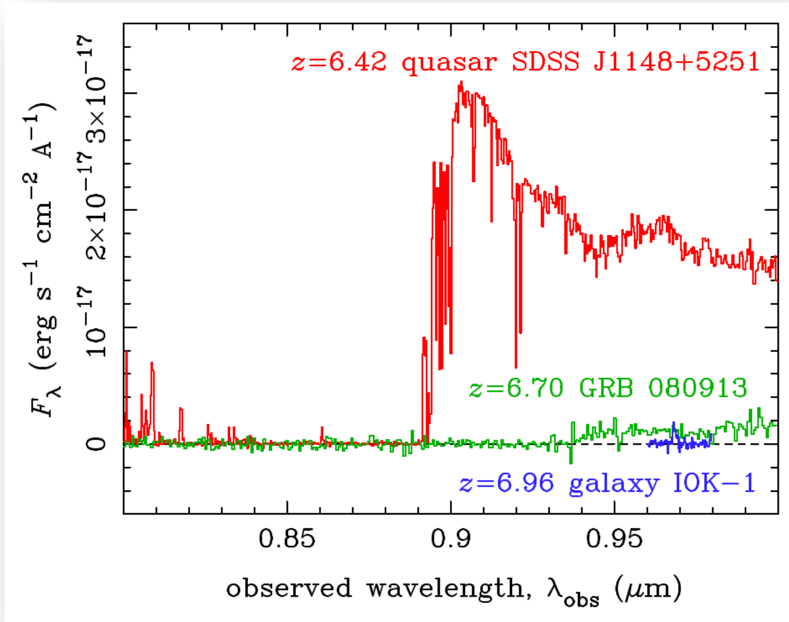
Contribution made from quasars and line of sight ionisation fraction/gas conditions

Reionisation contribution from quasars: potentially as much (more?) as galaxies



Giallongo et al. (2015)

Bright spot light to give sightline through reionisation era (for brightest quasars)

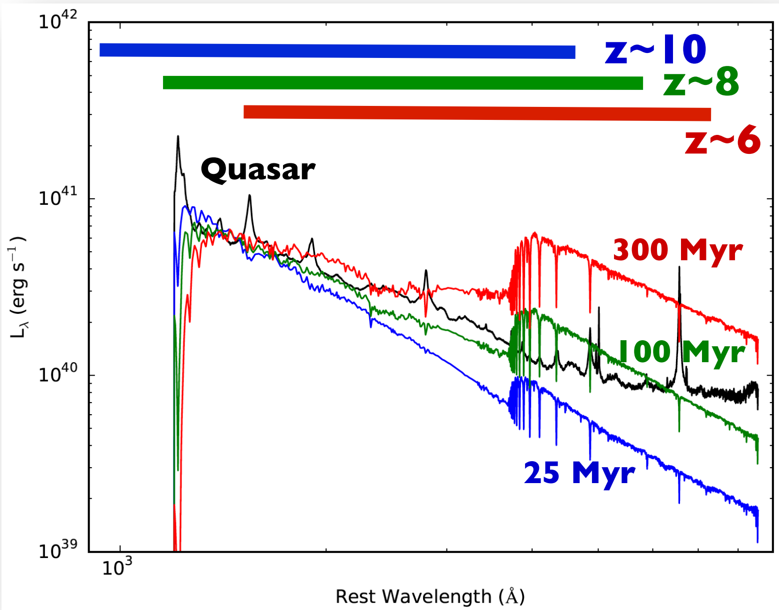


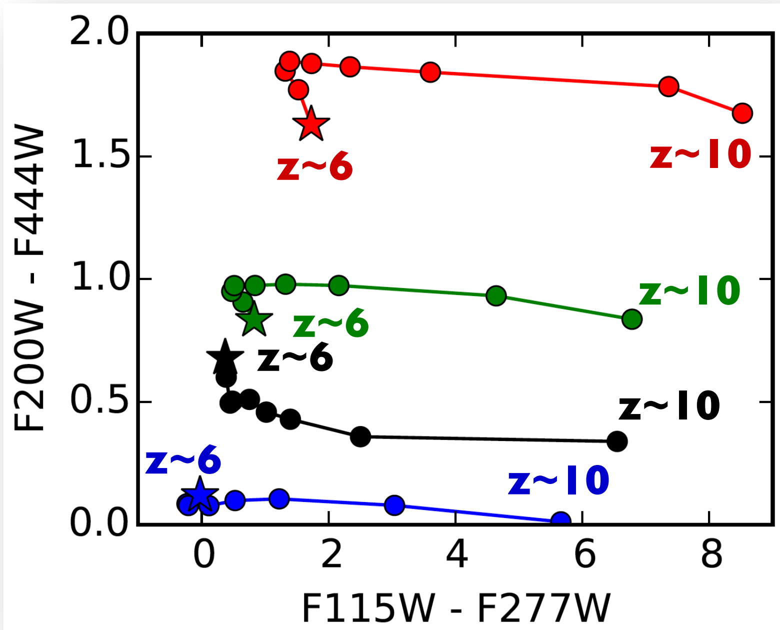
Mortlock (2015)

FLARE can push to z~10 – if brightest quasars are in the survey

FLARE and the first quasars - photometry

FLARE may photometrically select quasars from galaxies in the galaxy survey: >2um data essential!

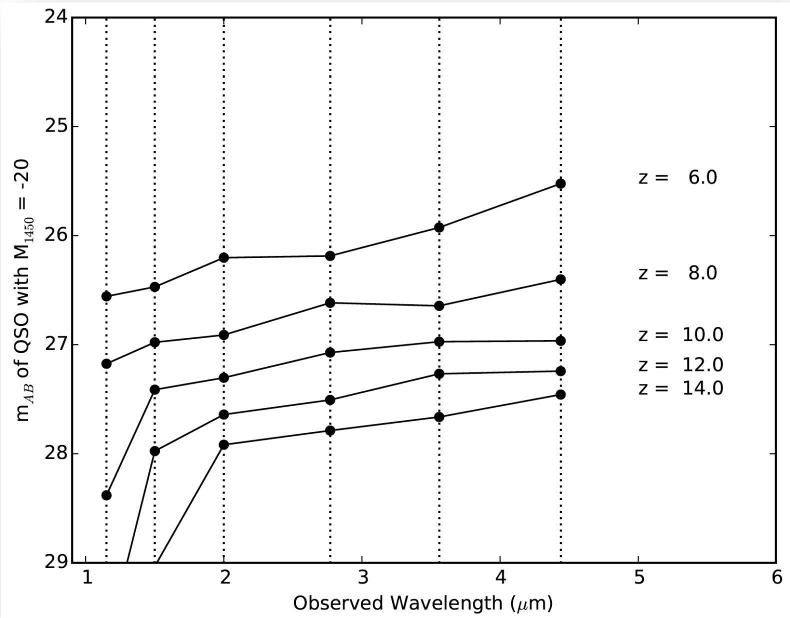


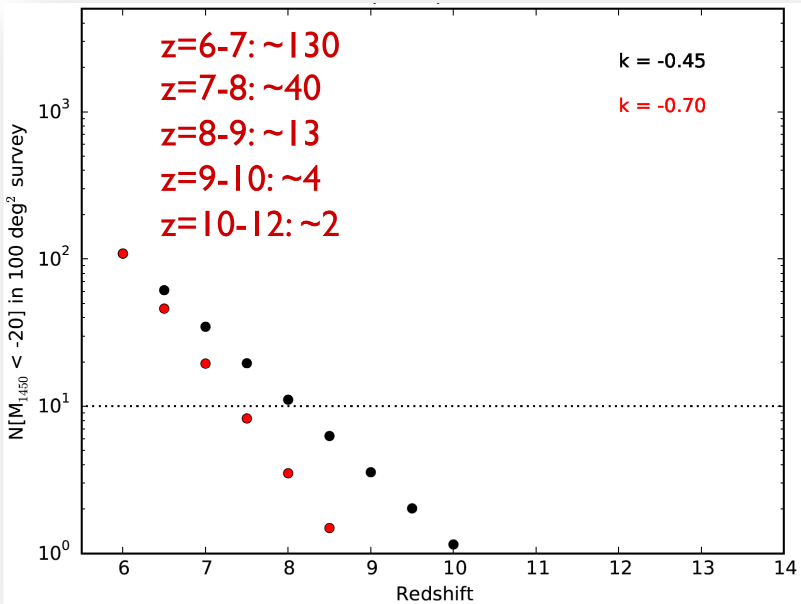


Caveats: not yet clear if unique colours from galactic sources and very young star-forming galaxies

FLARE predictions: photometry

100 sq deg survey predictions, based on Venemans et al. (2013)/Willott et al. (2010) quasar luminosity function and SDSS composite quasar spectrum





Caveats: luminosity function extrapolation; obscured quasars not included; could go up to ~1 mag fainter

FLARE: small yield (~200 z>6 from 100 sq deg) but maybe unique (area larger than JWST; deeper than Euclid/WFIRST)?

FLARE predictions: photometric survey

First quasar science down to $M_{1450,AB}$<-20 from the galaxy photometric survey:

(1) Quasar luminosity function (photometric redshifts)

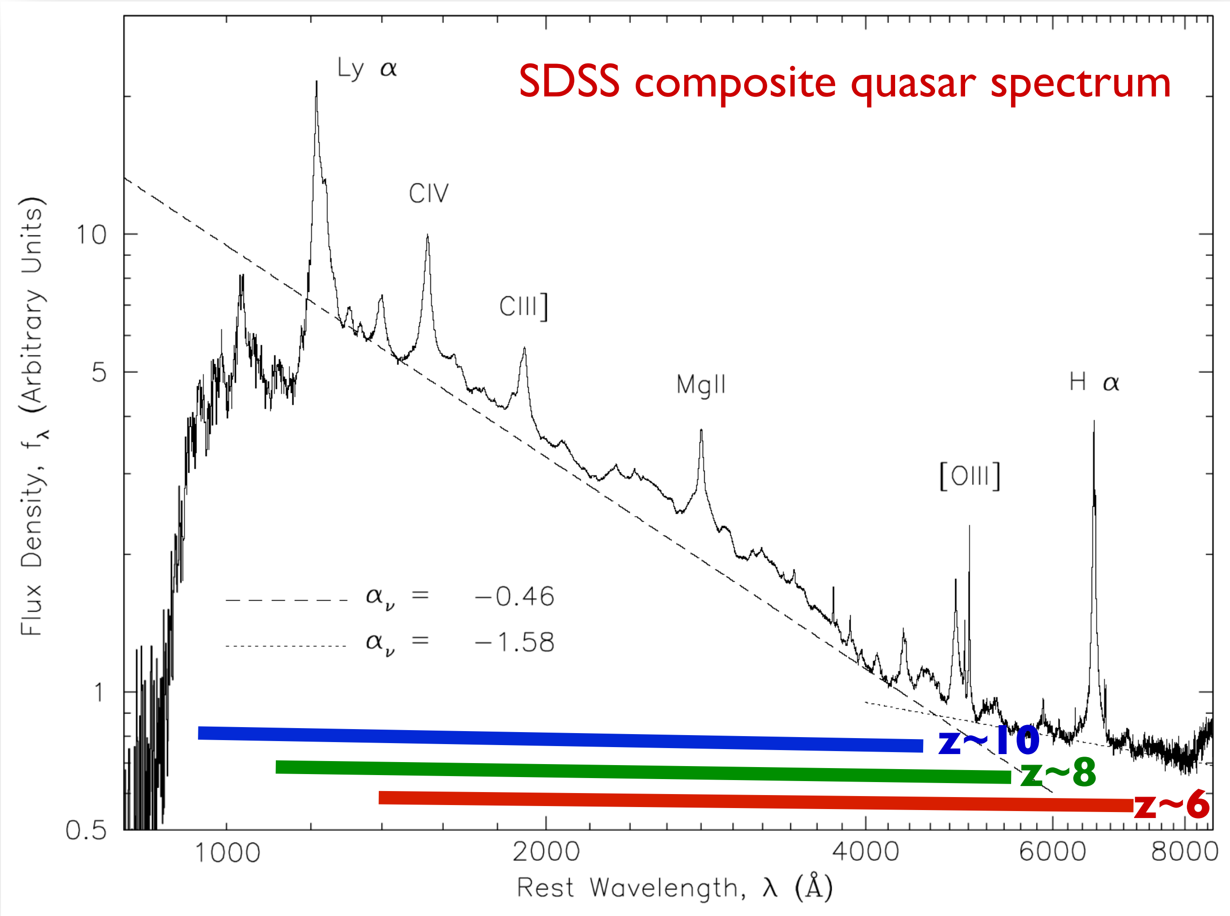
(2) Global contribution to reionisation from first quasars (photometric redshifts)

(3) Large scale clustering analyses (if photometric redshifts sufficiently accurate)

(4) Target selection from spectroscopic/multi-wavelength follow-up observations from FLARE (or E-ELT)

FLARE and first quasars - spectroscopy

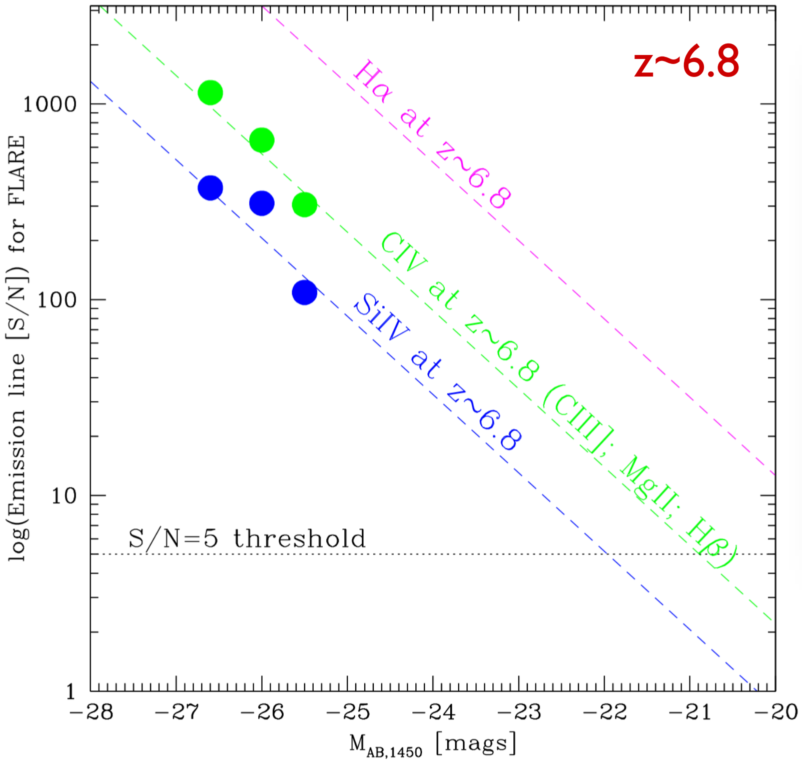
Rest wavelength spectroscopy for z~6-10 quasars with FLARE

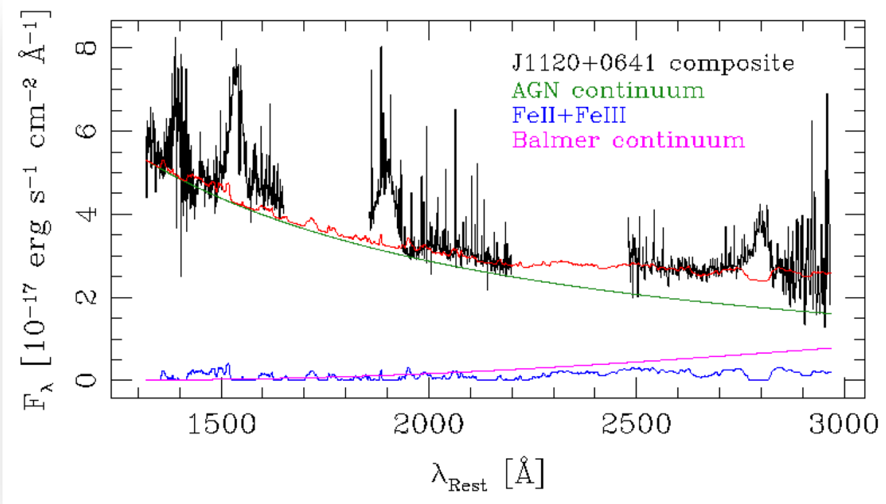


Vanden Berk et al. (2001)

FLARE predictions: spectroscopy

Predictions based on SiIV and CIV from z~6.6-7.1 quasars (De Rosa et al. 2014)
– other lines predicted from SDSS composite quasar spectrum





De Rosa et al. (2014)

Numbers in ~100 sq deg survey: ~100 z>6 overall (~10 at z>8)

Caveats: uncertain extrapolation; assumes no drop in metallicity; assumes all quasars are targetted (too rare for many in IFU with galaxy survey)

FLARE predictions: spectroscopy science

Target selection from spectroscopic follow-up observations of quasars from galaxy survey and from other facilities (e.g., Athena; SKA). First quasar science:

(1) Spectroscopic redshift confirmation – improved quasar luminosity functions and global contributions to reionisation from quasars

(2) Measurements of emission-line strengths – metallicity, black-hole masses, obscuration measurements, gas outflows, active black-hole mass function

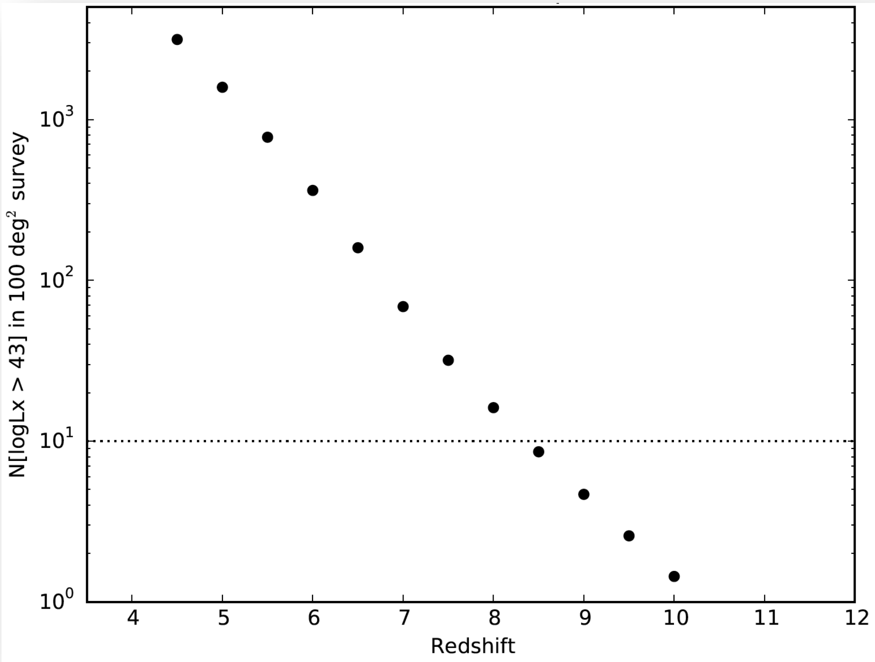
(3) Reionisation measurement sightlines (for the brightest highest redshift quasars)

(4) Mpc-scale environment traced by quasars in IFU – multiple AGNs (galaxy mergers) and galaxy companions

FLARE: co-eval complementary facilities

(1) Athena (launch ~2030):

Phot-z/Spec-z of X-ray AGN, including obscured systems (cannot be ID'd from FLARE photometry); host measurements from photometry/spectroscopy



100 sq deg Athena predictions by extrapolating Aird et al. (2015) luminosity function:

z=6-7: ~360
z=7-8: ~70
z=8-9: ~20
z=9-10: ~6
z=10-12: ~2

Well matched to FLARE

(2) SKA for radio-bright AGNs and star-formation properties

(3) ALMA for star formation and cold-gas properties

FLARE: co-eval competing facilities

(1) WFIRST:

Pro: large-area (>1000 deg^2) better for quasar science

Con: shorter wavelength (<2um) photometry and spectroscopy more limiting for quasar identification; however, most of first quasar emission lines at <2um

(2) E-ELT:

Pro: deeper spectroscopic follow-up observations
Con: shorter wavelength (<2.5um) spectroscopy more limiting for quasar identification; however, again, most of first quasar emission lines at <2um

NOTE: Athena+E-ELT may be sufficient without FLARE

(3) JWST-Euclid:

Both finished before FLARE launches: select quasars in different parameter space – JWST very few new z>6 quasars; Euclid brightest z~8 quasars

FLARE case strongest if very clear that 2.5-5um and IFU is needed (e.g., quasar/galaxy separation; hosts; Mpc scales).

FLARE: first quasars within science case

Unique science with respect to the galaxy survey – studying the first massive black holes and the host environments.

Should this be a sub section of the galaxy survey case or a separate section?

Compromises/improvements to first quasar case?

(1) Wider-area survey (~1000 deg^2) to probe brightest quasars? ~3-5x larger $z>6$ yield than 100 deg^2. WFIRST degeneracy?

(2) Longer wavelength coverage? Great for quasar selection and hosts… but less great if lose shorter wavelength (<1.5um), which are required for the rest-frame UV lines.

(3) Very few (~5-10) spec-ID'd $z>6$ quasars from FLARE unless quasars drive the spectroscopic programme (galaxies serendipitously detected) or have targetted survey.