The high-redshift Universe and the role of galaxies and AGN to cosmic reionization

Lecture 1

- A panchromatic view of high-redshift AGN
- Physical properties of the nucleus and of the host

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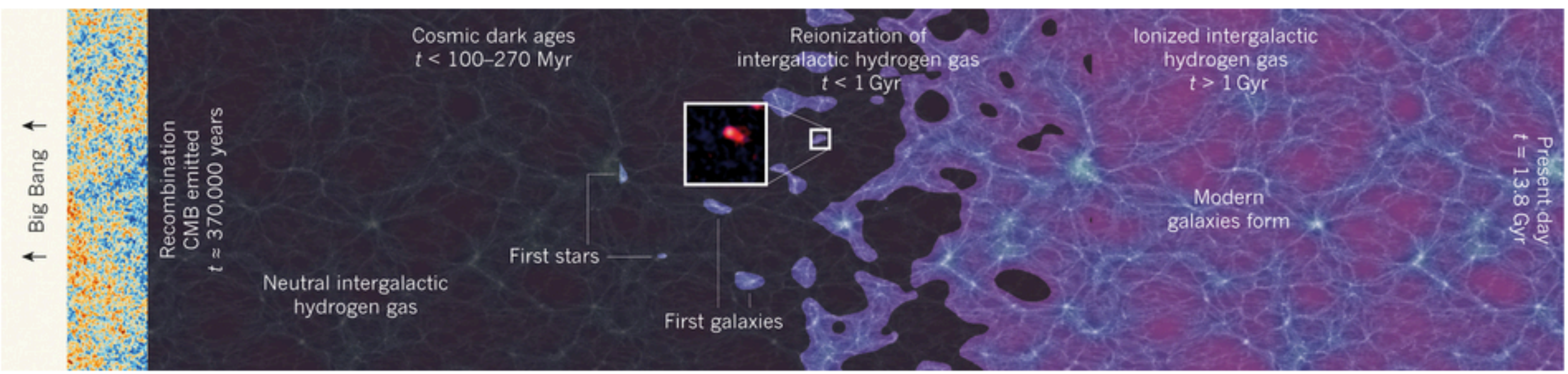
The high-redshift Universe and the role of galaxies and AGN to cosmic reionization

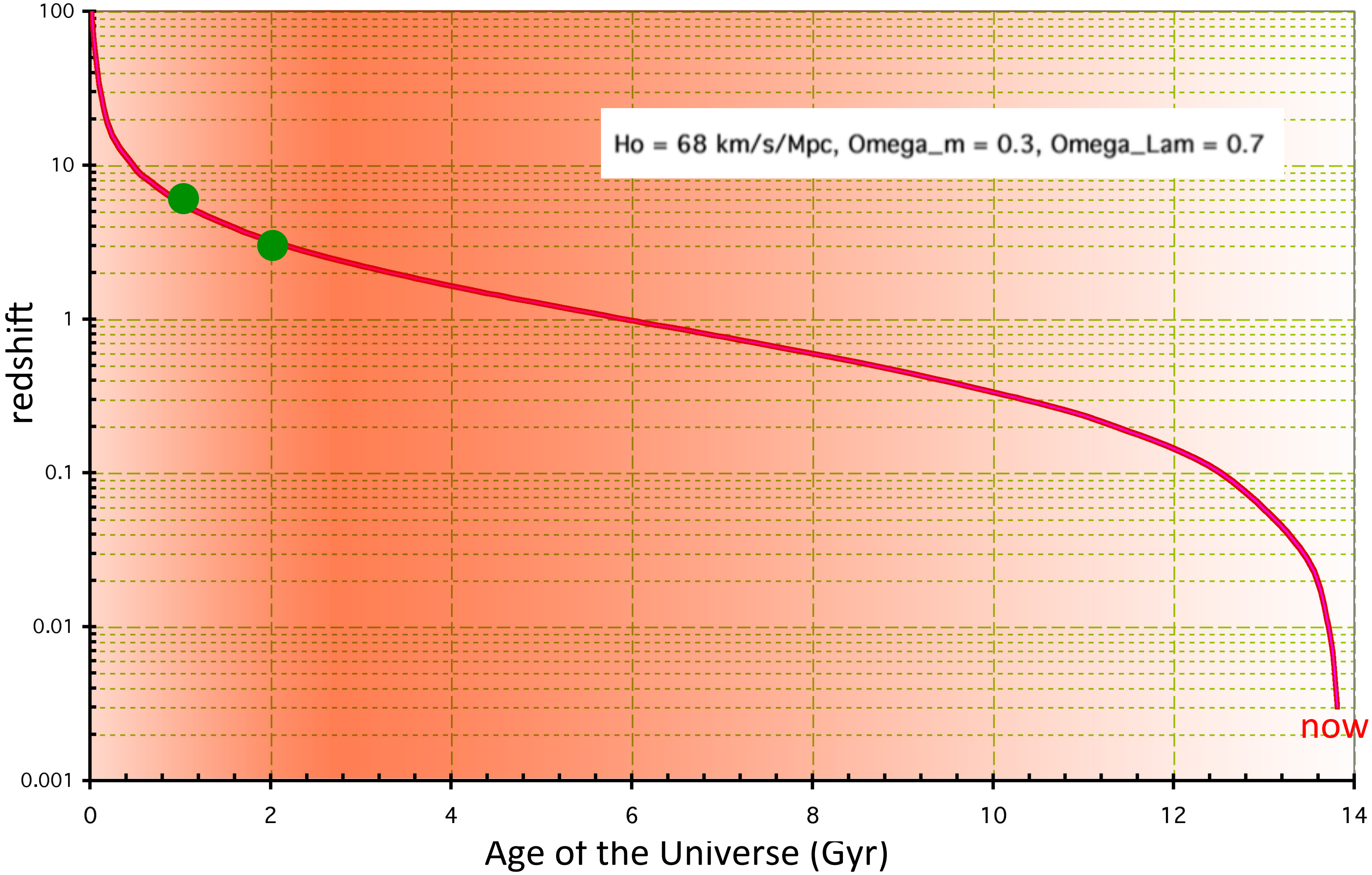
Some fundamental questions:

- At what epoch did the first generation of SMBHs form?
- What is their origin (e.g. light vs heavy seeds)?
- Where and how early "seeds" could grow to SMBHs?
- How was the Universe reionized?

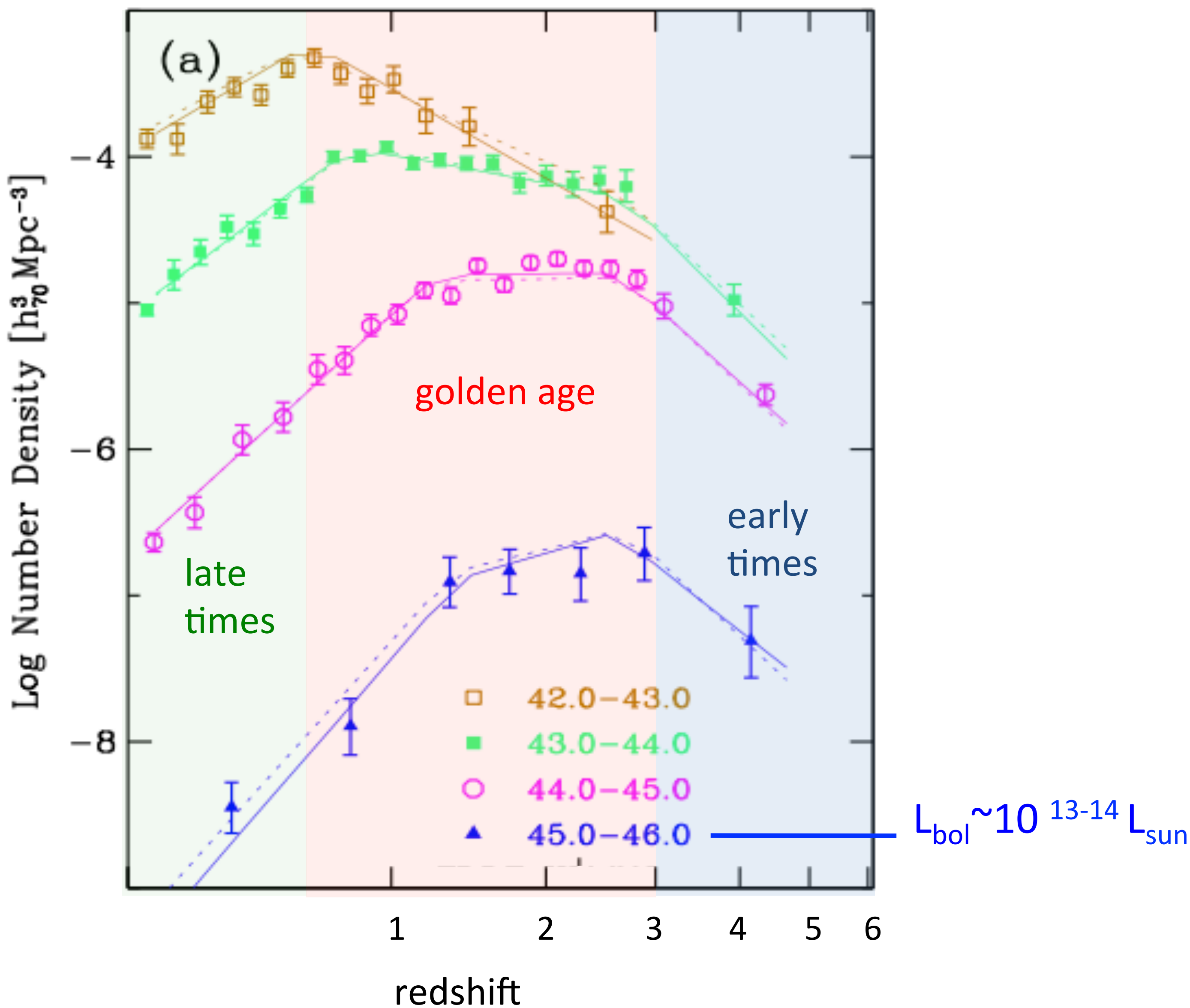


High-redshift AGN: how high??

In the concordance ΛCDM cosmological model
the Universe is 2 billions years old at z=3 and 1 billion years old at z=6

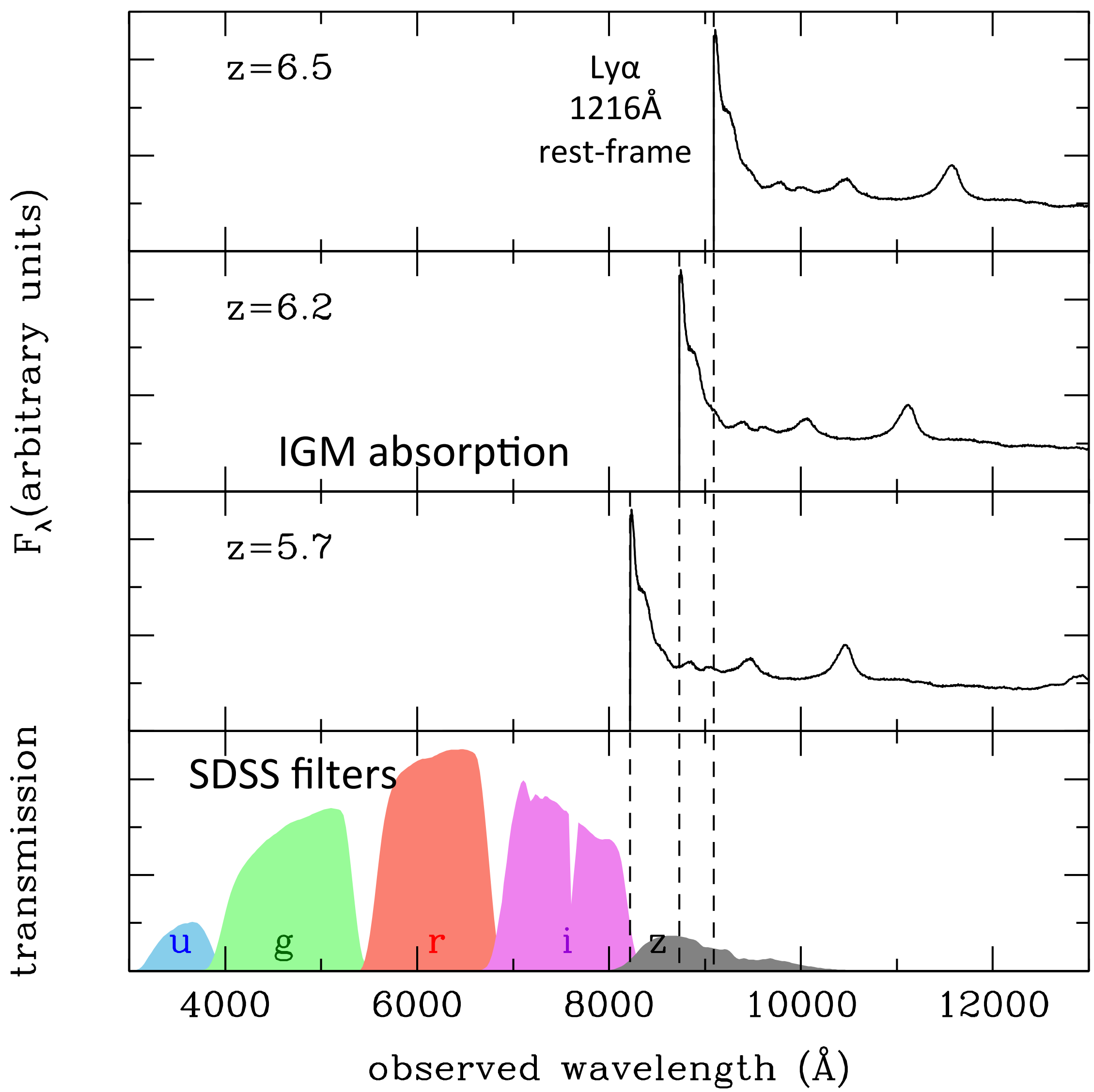


AGN space density declines at z>3: early times in BH evolution

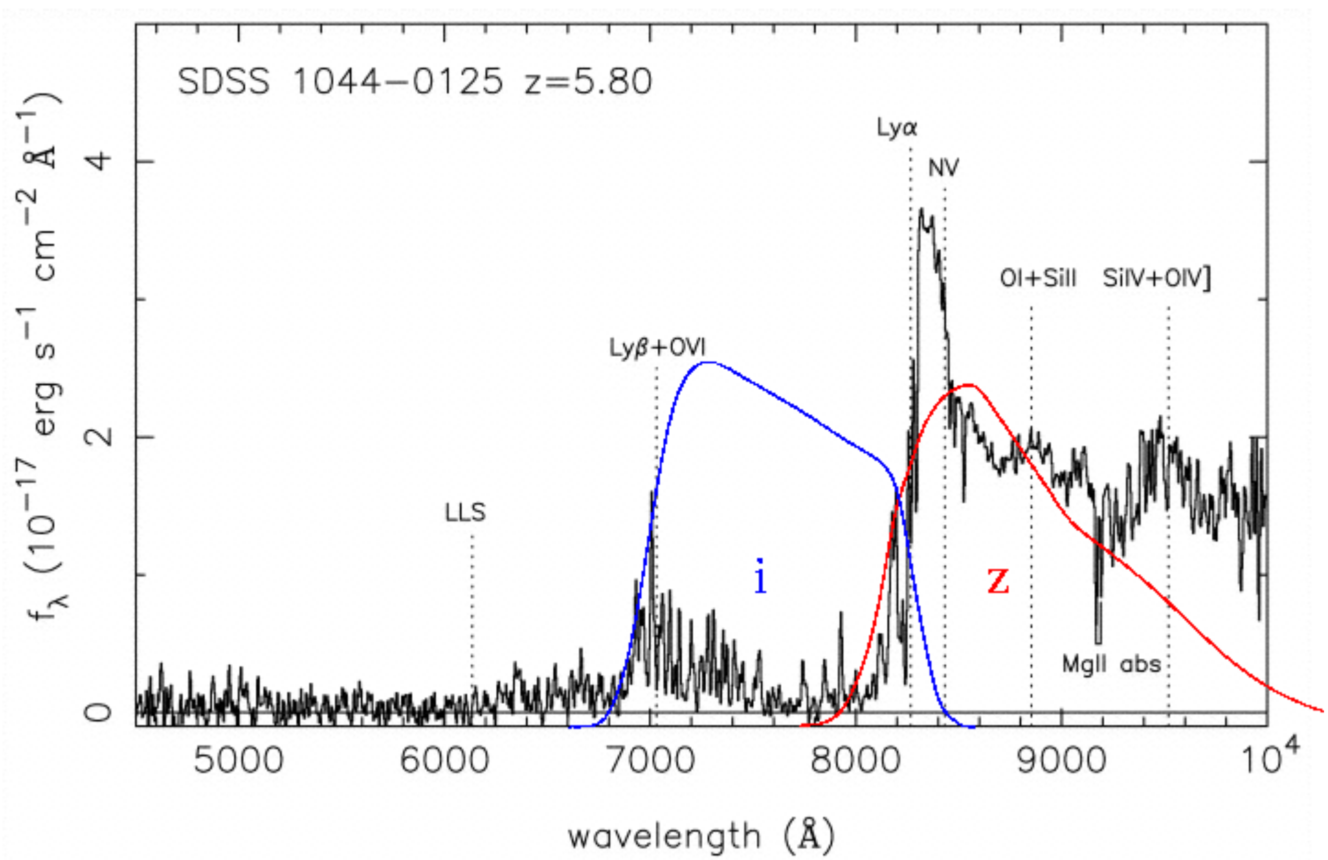


Miyaji et al. 2015

QSOs selection with optical filters (e.g. SDSS) works up to z ~ 5.7 - 6.5



The first QSO discovered at z > 5.7



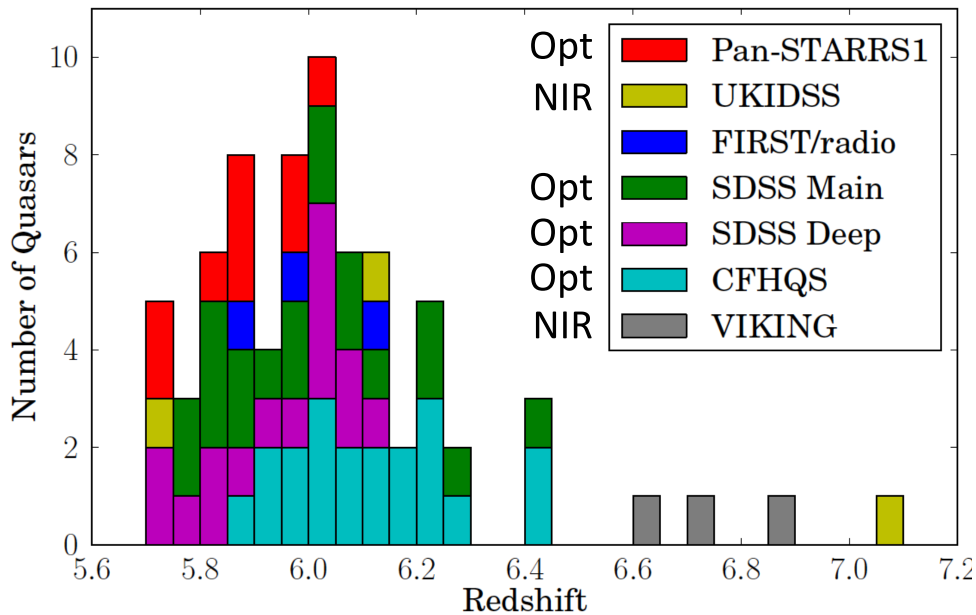
Fan et al. 2000

z_{AB} = 19.2 $M_{1450Å}$ = -27.4 ➔ $L_{bol} \sim 8\times10^{13}\ L_{sun}$

$\log L_\nu = 20.64 - 0.4\ M_\nu$

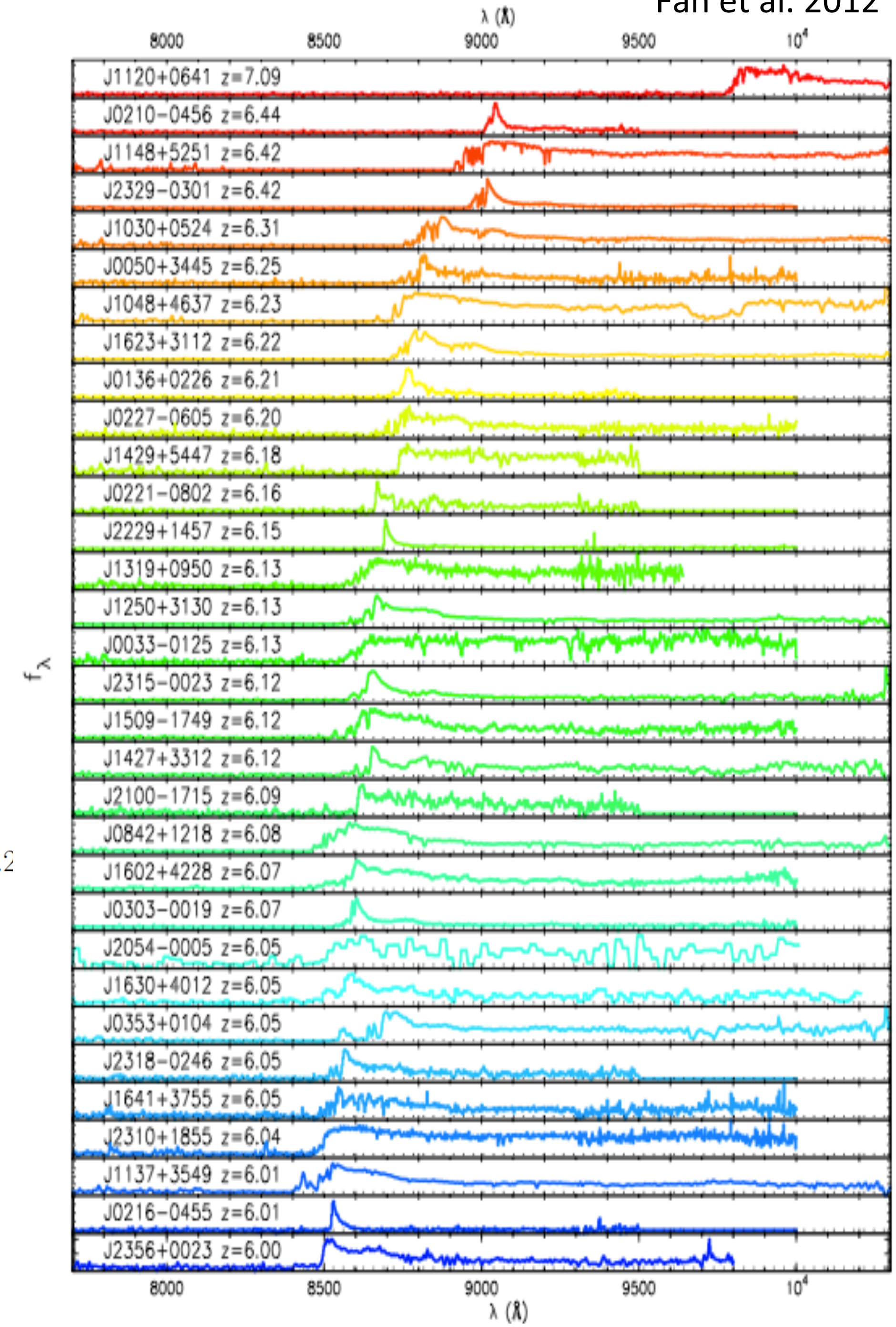
$L_{bol} = 4.4\ (\nu L_\nu)_{1450Å}$ (e.g. Willott et al. 2010)

About 80 QSOs known at z>5.7

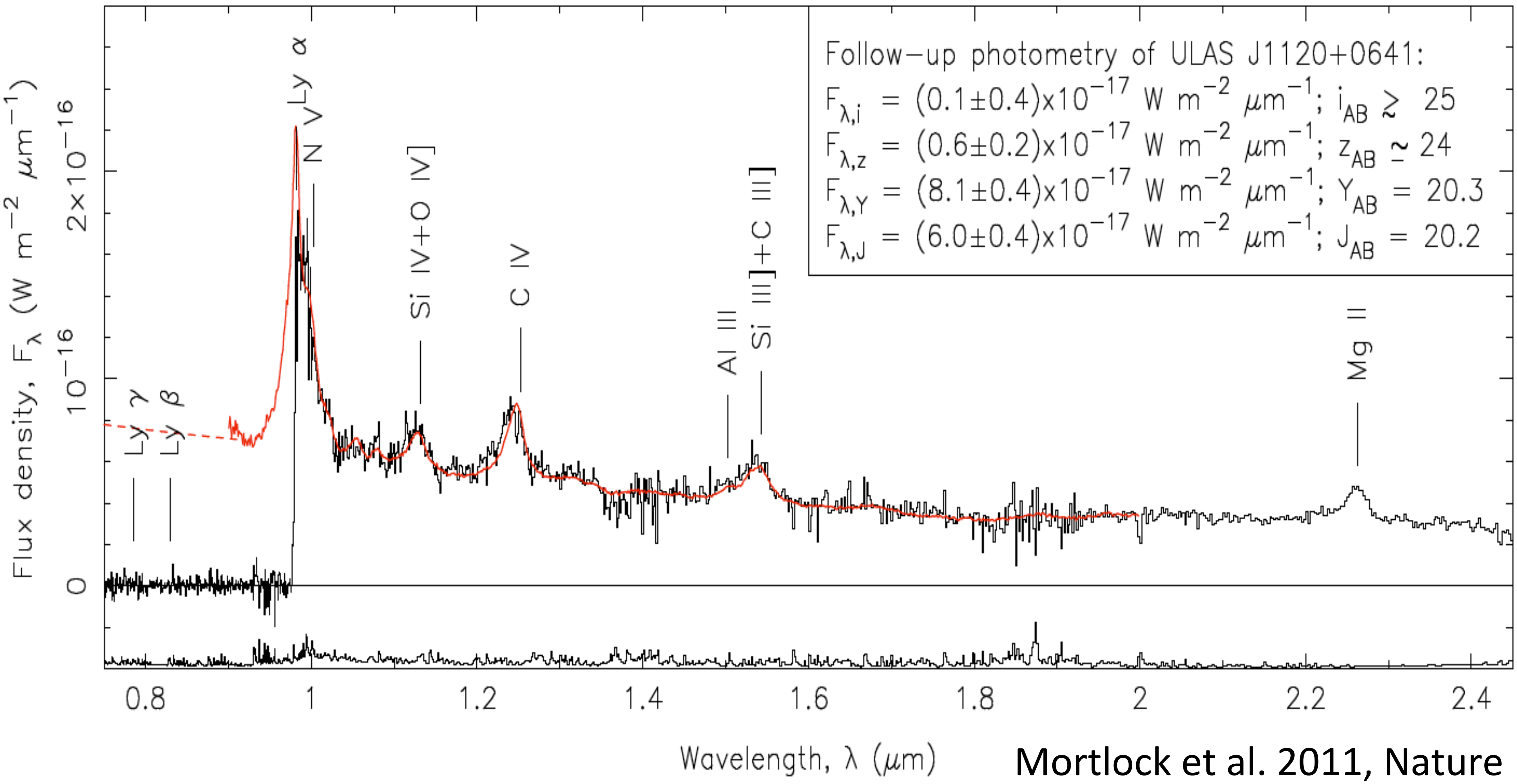


Banados et al. 2014

Fan et al. 2012



The most distant QSO known: ULAS J1120 at z=7.085

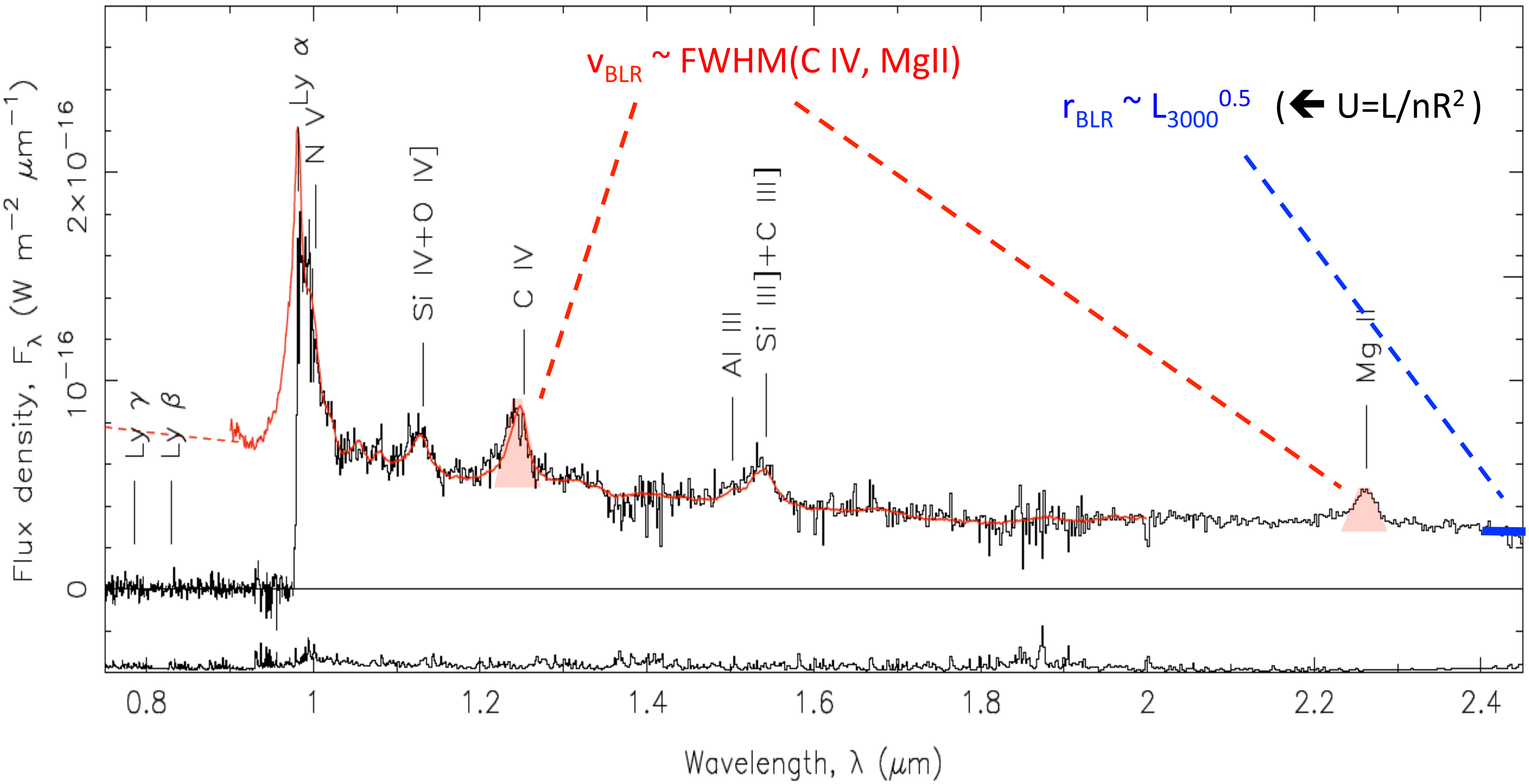


Mortlock et al. 2011, Nature

$M_{1450Å}$ =-26.6 ➔ L_{bol} =6 x 10^{13} L_{sun}

spectrum very similar to lower-z QSOs

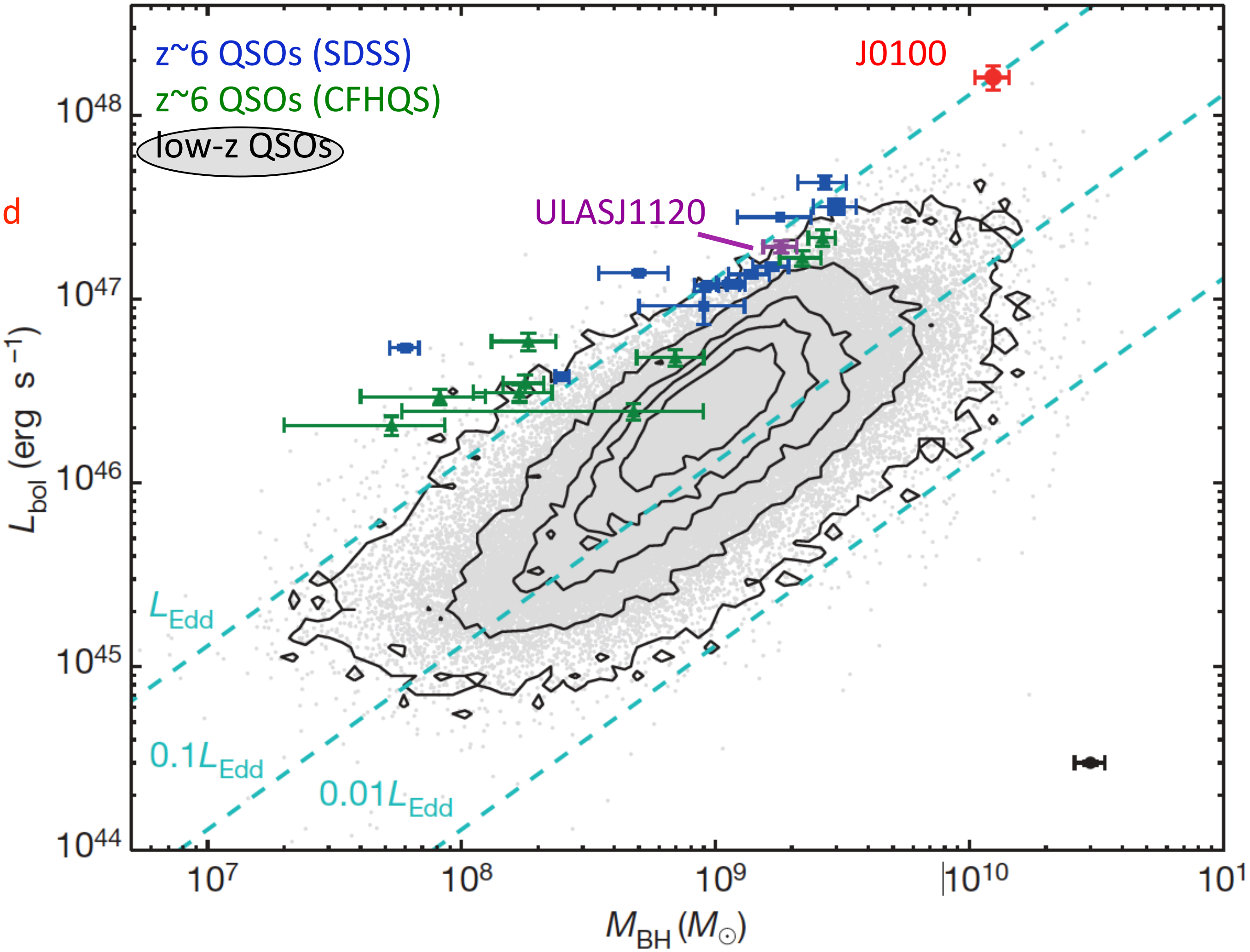
How do we weight a SMBH? Using gas dynamics: $M_{BH} \approx r_{BLR}\, v_{BLR}^2 / G$



$$M_{BH} \sim 10^9\ M_\odot \left[\frac{FWHM(MgII)}{4000\,km/s}\right]^2 \left[\frac{L_{3000}}{10^{46}\ erg/s}\right]^{0.5}$$

Eddington luminosity: $$L_E = \frac{4\pi G m_p c^2 M}{\sigma_T c} = 1.26 \times 10^{46} \frac{M}{10^8 M_\odot}\ erg/s$$

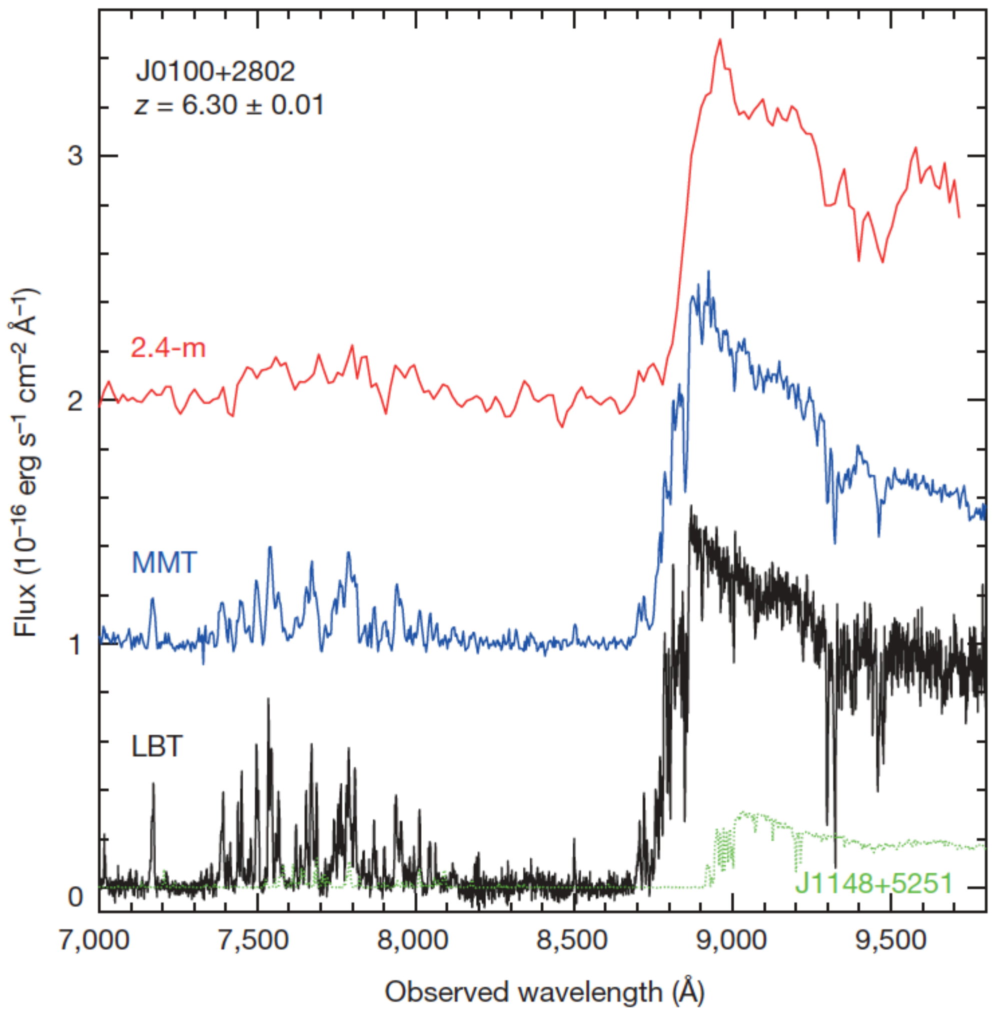
$L_{bol} \sim L_{Edd}$



$M_{BH} \sim 10^8 - 10^{10}\ M_{sun}$

Wu et al. 2015

The brigthest QSO (most massive SMBH) known at z>6: SDSS J0100+2802 at z=6.3



M_{UV} = -29.3

L_{bol} = 1.6x10^{48} erg/s
= 4.3x10^{14} L_{sun}

M_{BH} = 1.3x10^{10} M_{sun}

L_{bol}=L_{Edd}

Wu et al. 2015, Nature

Known QSOs at z~6 are powered by SMBHs with $M>10^8$ M_{sun} (even $>10^{10}$ M_{sun}) and rapidly accrete at their Eddington limit

Persistent theoretical challenge:

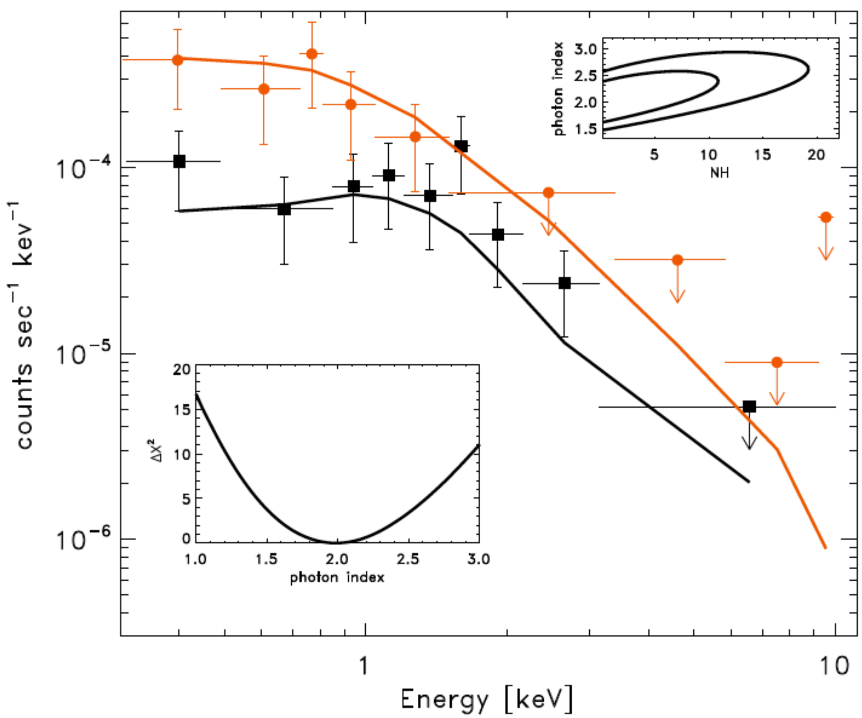
- How did they grow to such big masses so rapidly (< 1 Gyr) ?
- Were they capable to sustain uninterrupted Eddington limited accretion?

see M. Volonteri lectures

Examples of X-ray spectra

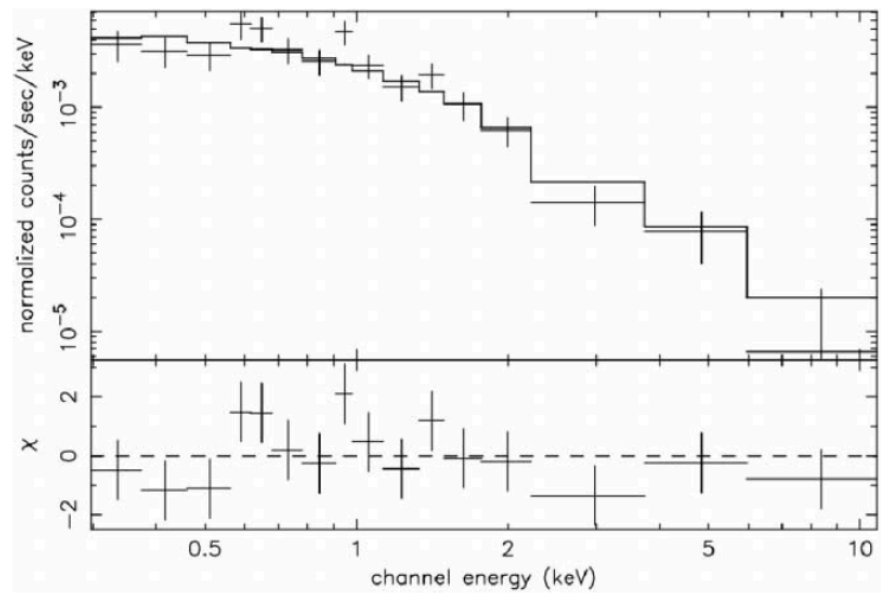
About 25% of z~6 QSOs have been observed in the X-rays

ULASJ1120 (z=7.085)



Moretti et al. 2014

SDSSJ1030+0524 (z=6.28)

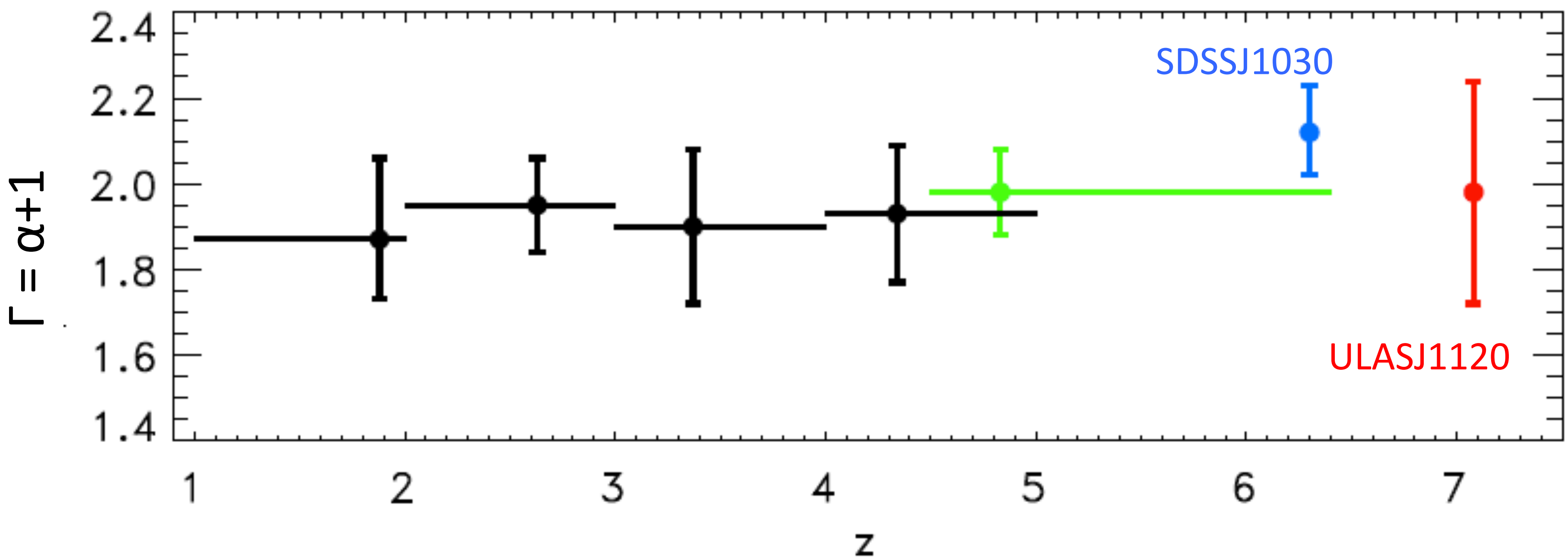


Farrah et al. 2004

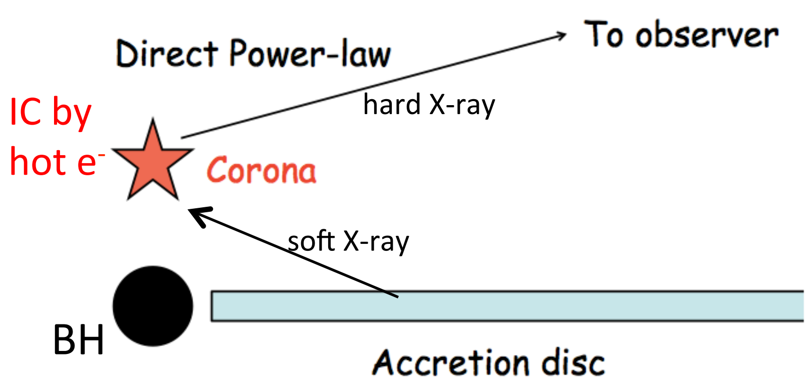
$F_E \sim E^{-\alpha}$ with $\alpha \sim 1.0 – 1.1$; or $N_E \sim E^{-\Gamma}$ with $\Gamma \sim 2.0 - 2.1$

($F_E = E \times N_E = E^{1-\Gamma}$ ➔ photon index $\Gamma = \alpha+1$)

QSO X-ray spectra do not change up to z~6



Moretti et al. 2014



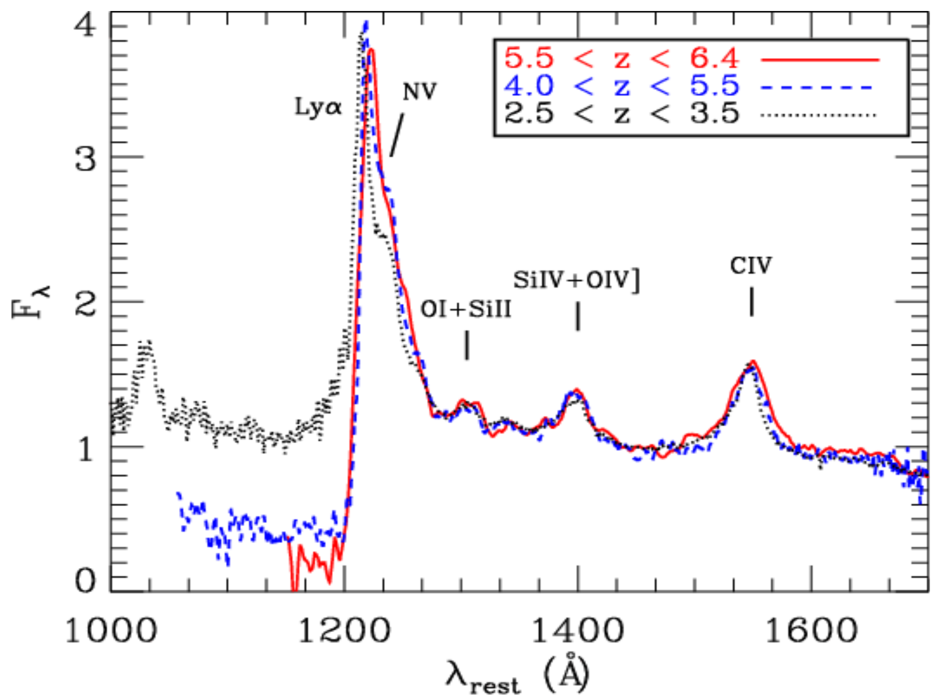
➔ inner AGN structure (disk + hot corona) already in place

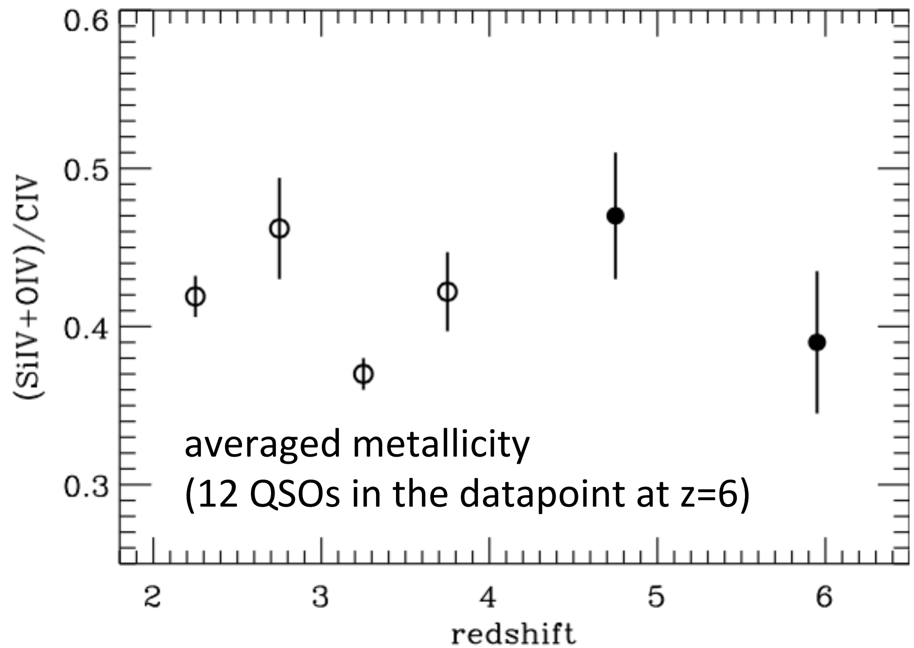
Physical properties of the hosts

Metallicity of high-z QSOs is similar to that of low-z QSOs

➔the nuclear regions are metal rich

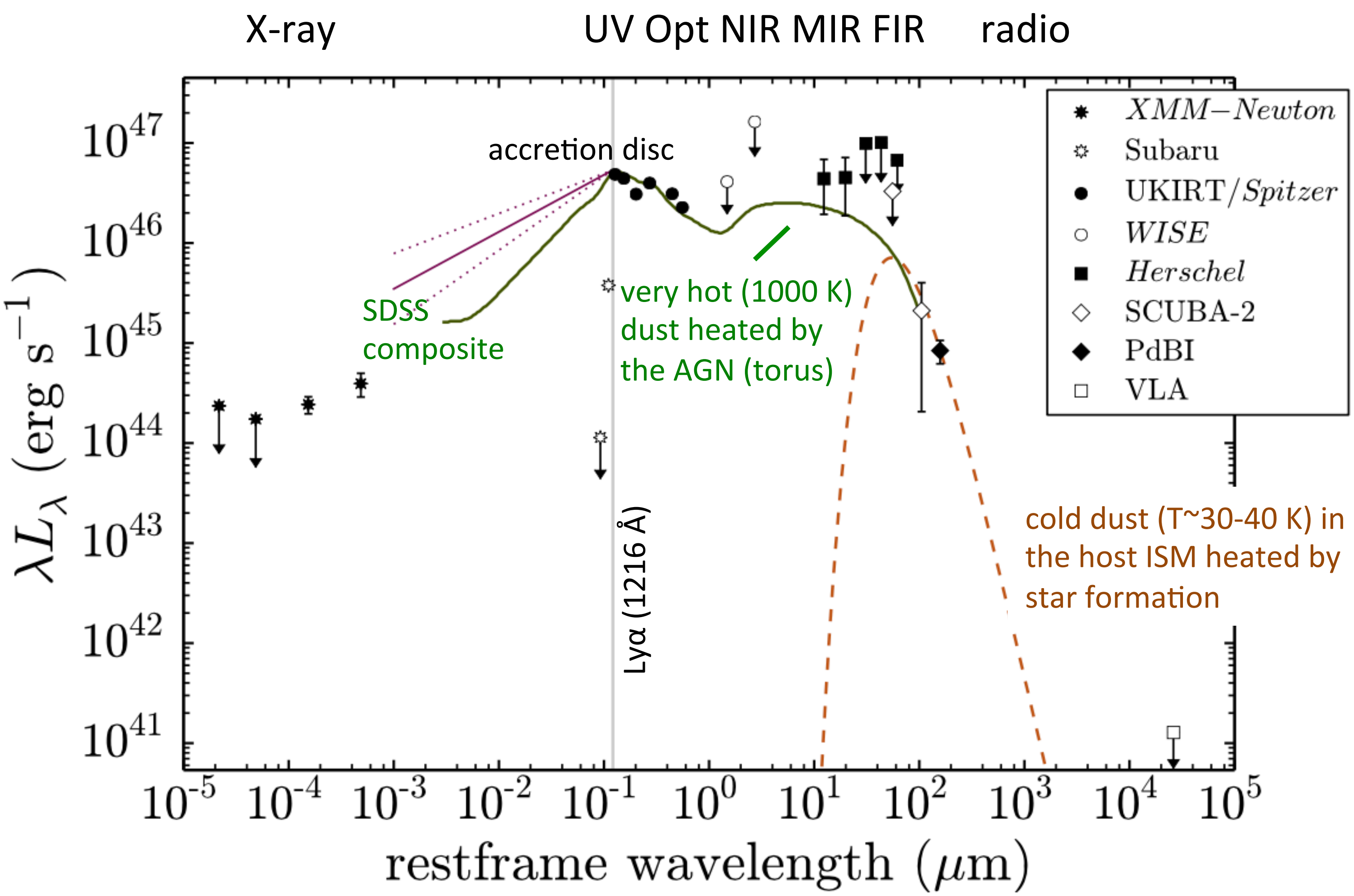
➔major episode of chemical enrichment in their hosts at t_U<1 Gyr





Juarez et al. 2009

Broad band SED of ULASJ1120



SED similar to low-z QSOs

Barnett et al. 2015

Gas and dust in the host ISM

ALMA observations of ULAS J1319+0950, z=6.13

$$\mathrm{SFR}(\mathrm{M}_\odot\,\mathrm{yr}^{-1}) = 243.6 \times L_{\mathrm{FIR}}(10^{12}\,\mathrm{L}_\odot)$$

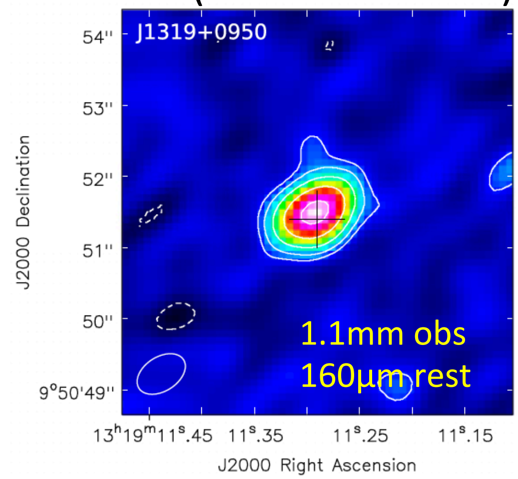
$$M_{\mathrm{d}}(10^{8}\,\mathrm{M}_\odot) = 0.56 \times L_{\mathrm{FIR}}(10^{12}\,\mathrm{L}_\odot)$$

$$M_{\mathrm{H_2}}(\mathrm{M}_\odot) = 1.6 \times 10^{4} \times L_{\mathrm{CO(1-0)}}(\mathrm{L}_\odot)$$

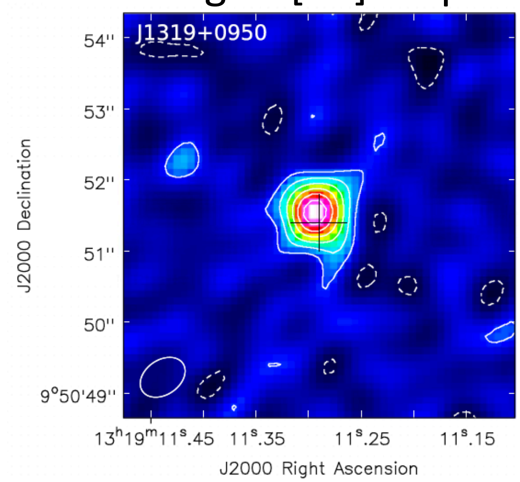
$$M_{\mathrm{HI}}(\mathrm{M}_\odot) = 0.96 \times L_{[\mathrm{C\,II}]}(\mathrm{L}_\odot)$$

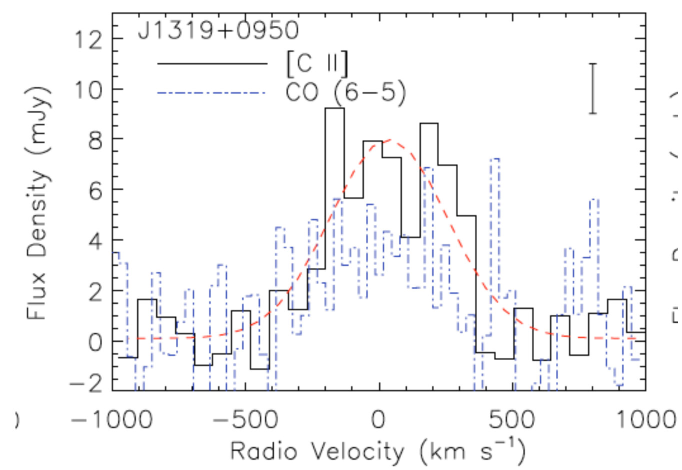
[CII] ➔ atomic gas (HI)
CO ➔ molecular gas H_2)
(see e.g. Calura et al. 2014
on the underlying assumptions)

dust (mm continuum)



atomic gas [CII]157μm





M_{dust} ~ 10^{8-9} M_{sun}
SFR ~ a few hundreds M_{sun}/yr
M_{gas} ~10^{9-10} M_{sun}

(M_{H_2} ~ 5 x M_{HI})

Large dust quantities again point towards a chemically enriched ISM

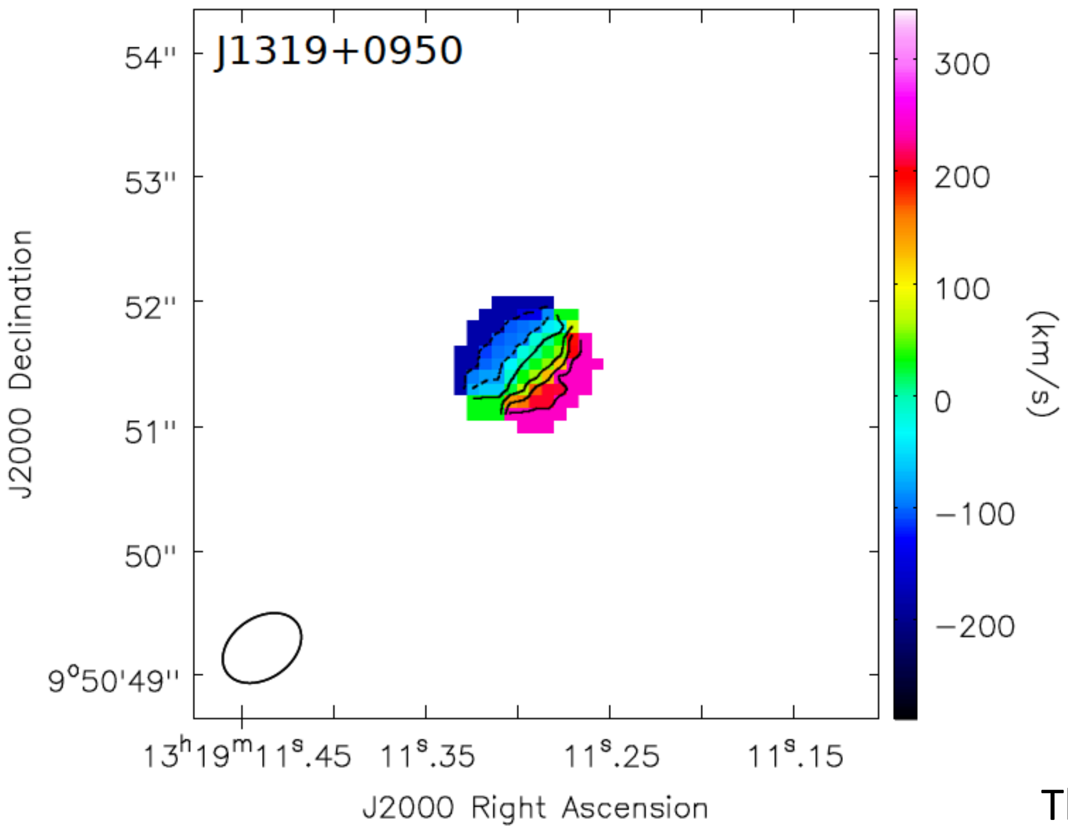
Wang et al. 2013

How do we weigth the host galaxy? Gas dynamics $M_{dyn} \approx r_{gas}\, v_{gas}^2 / G$

r_{gas} ~ Diameter[C II]/2 , v_{gas} ~ FWHM[C II]/sin i

$$M_{\rm dyn} \sin^2 i (\mathrm{M}_\odot) = 6.5 \times 10^4 [\mathrm{FWHM}(\mathrm{km\,s^{-1}})]^2\ D(\mathrm{kpc})$$

[C II] velocity map



FWHM ~ 300-400 km/s
D ~ 1-2 kpc
i ~ 30-50°
➔
M_{dyn} ~ 10^{10}-10^{11} M_{sun}

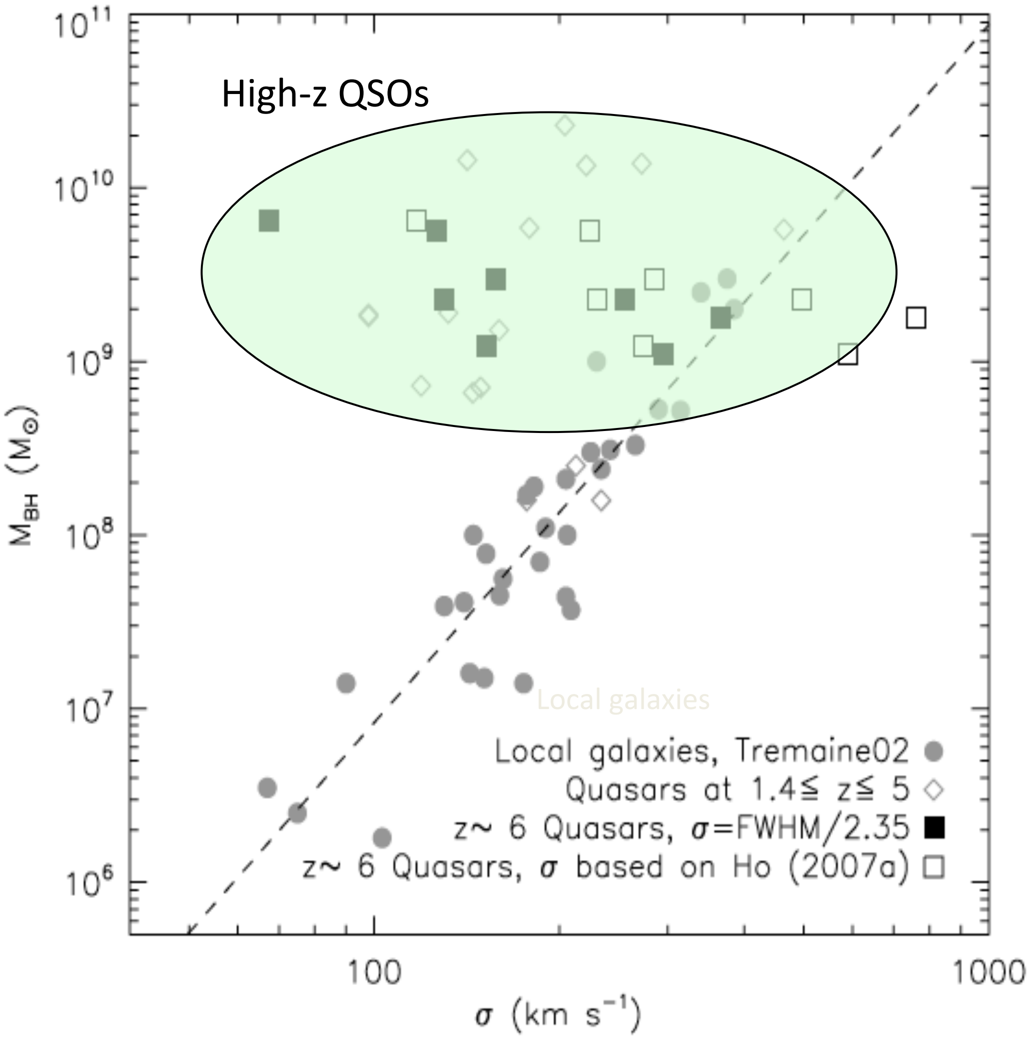
$M_* = M_{dyn} - M_{BH} - M_{dust} - M_{gas} - M_{DM}$

$M_* < M_{dyn}$ ~ 10^{10}-10^{11} M_{sun}

Wang et al. 2013

The hosts of z~6 QSOs show a high fraction (~60%) of regular, disc morphologies (but statistics still limited)

The BH to stellar mass ratio



Wang et al. 2010

Host SFR, gas and dust mass are ok for standard IMF, SFE, and grain growth if $M_* > 10^{11}$ M_{sun}
(e.g. Valiante et al. 2011, 2014, Calura et al. 2014)

Tension between M_{dust} and M_{dyn} :
1) change IMF, SFE, grain growth?
2) M_{dyn} underestimated?

M_{BH}/M_* or M_{BH}/σ higher than local

- selection effects?
- M_{dyn} underestimated?

Take home messages

Bright QSOs at z=6 appear mature systems in a young Universe

They are nearly identical to bright QSOs at lower-redshift

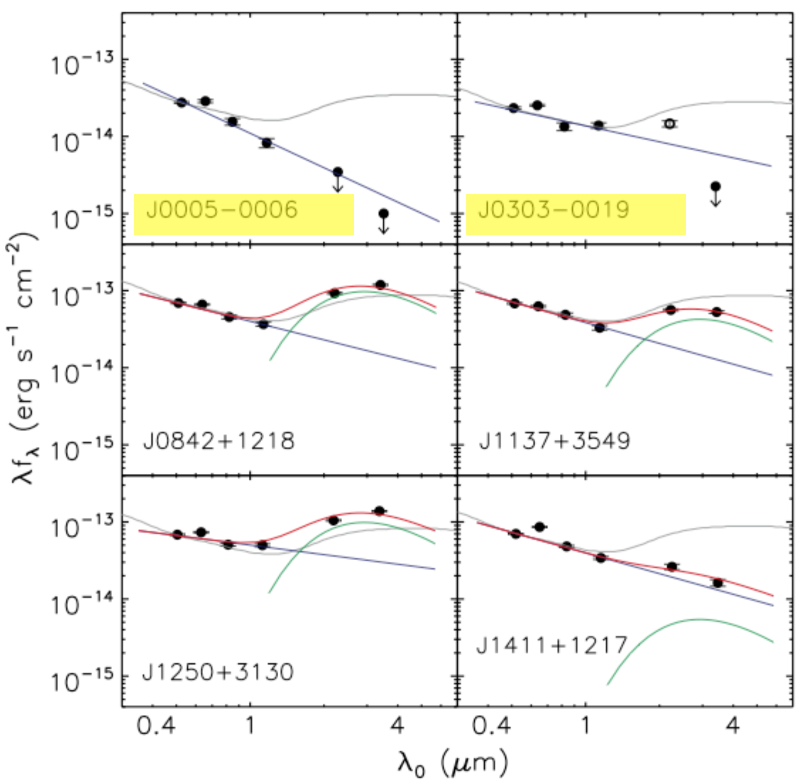
Very efficient BH growth, star assembly and chemical enrichment

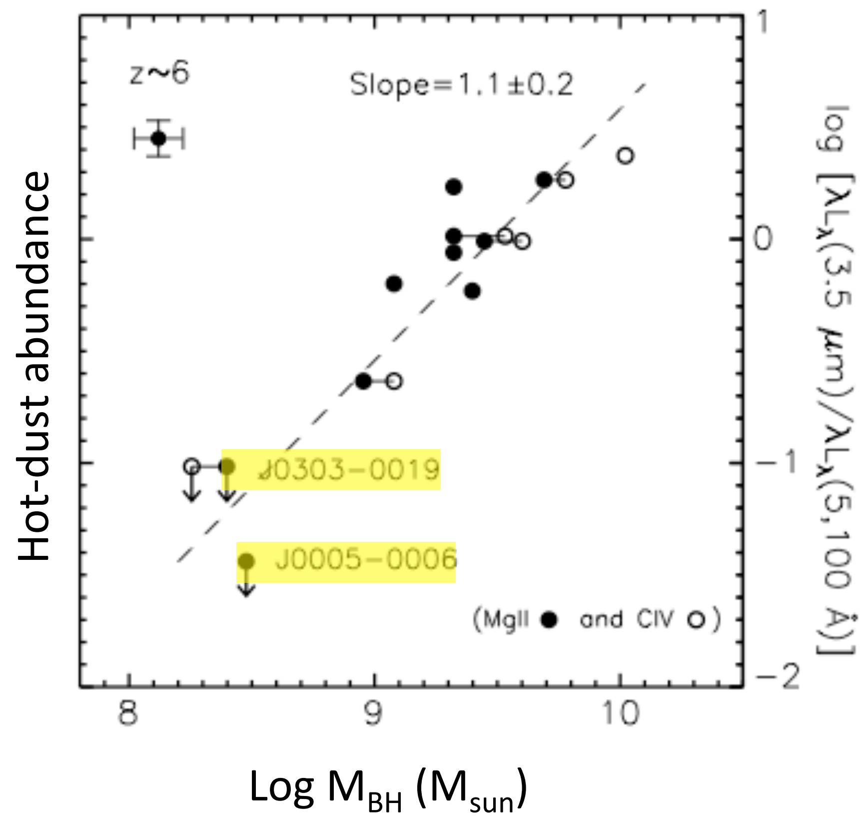
Early SMBHs may have grown earlier than their hosts

Challenges for theory? See next lectures

Two interesting counter-examples?

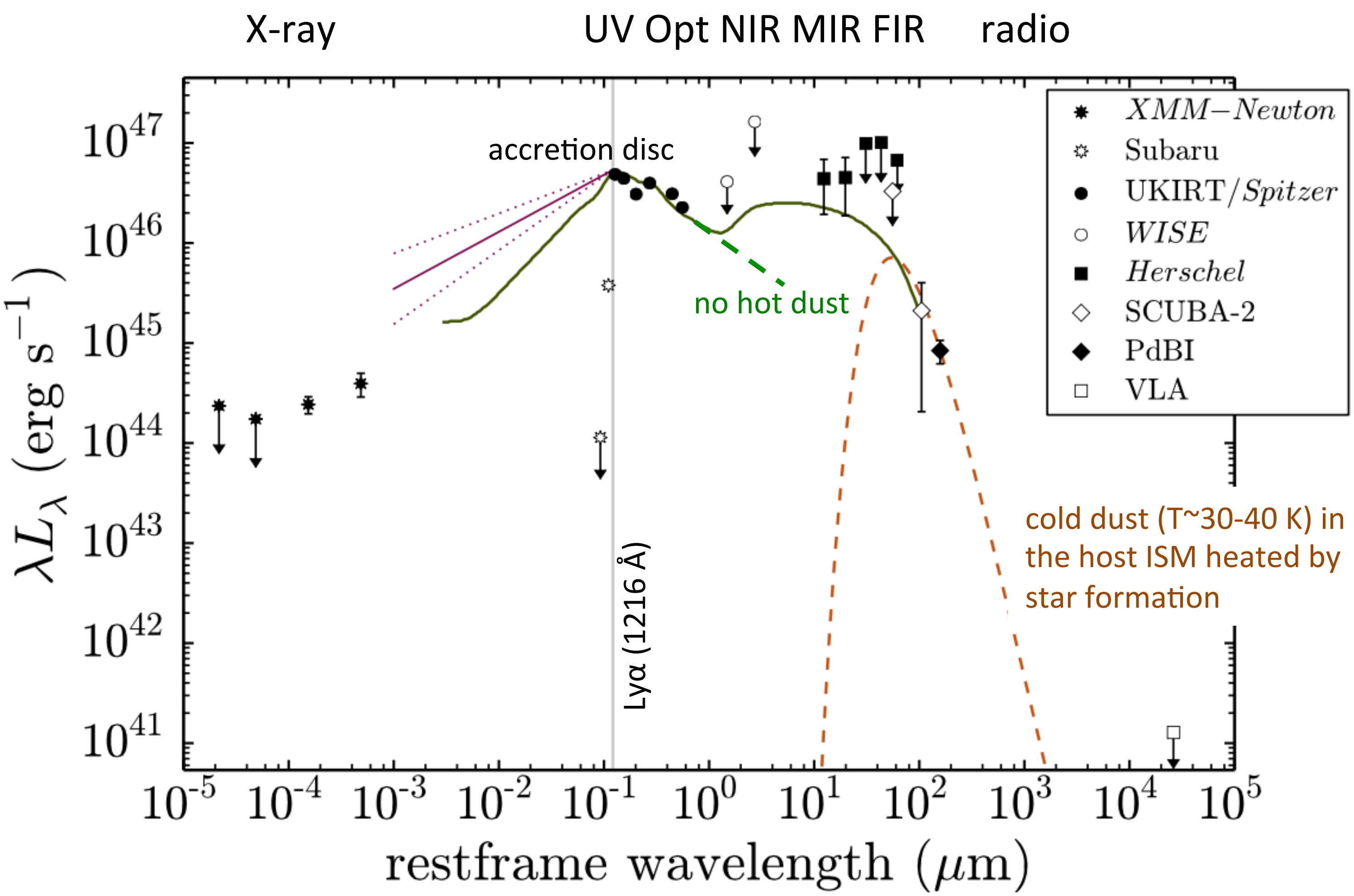
Two z~6 QSOs without NIR bump:
no hot-dust (T~1000 K): no torus? Young, just formed objects?





Jiang et al. 2010, Nature

Broad band SED of ULASJ1120



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