The early growth of supermassive black holes
Resimulating the build-up of galaxies and black holes (including spin history and kicks due to gravitational wave re-coil) in the most massive halo at $z=6$ with higher resolution.
By $z=6$ the $10^5 M_\odot$ seed black hole has grown into a supermassive black hole with mass several billion times that of the sun.

Sijacki, Springel & Haehnelt 2009
Early on the accretion rate is at the Eddington limit for more than 50% of the time.

Ringberg, 30 June 2011
The mass at $z=6$ depends strongly on the radiative efficiency of the accretion and therefore on the spin of the black hole.
Does the hierarchical growth start with a minimum seed mass? or Does the hierarchical assembly extend all the way to stellar mass black holes?

Ringberg, 30 June 2011
We most probably need massive seed black holes. How do massive seed black holes form?
A luminous quasar with a redshift of $z = 7.085$

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How neutral is the intergalactic medium surrounding the redshift $z = 7.085$ quasar ULAS J1120+0641?


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The red curve is not a fit but a template from 169 SDSS QSO spectra at 2.3<z<2.6 with large CIV blue shifts.
ULAS J1120          SDSS J1148

redshift: 7.085          6.42

MgII line width: 3800 ± 200 km/s

inferred bh mass: 2 x 10^9 M☉          3 x 10^9 M☉

L/L_{edd}: 1.2 ± 0.6

age of Universe: 0.77 Gyr          0.87 Gyr

2.33 ε_{0.1}^{-1} e-foldings earlier!
The observed transmission

ULAS J1120+0641
SDSS J1148+5251
SDSS J1030+0524

Lyα absorption redshift, $z_{\text{obs, Lyα}}$

Mortlock et al. 2011

Ringberg, 30 June 2011
The transmission in the near-zone

- very short near-zone
- first detection of a “red” damped absorption wing

Mortlock et al. 2011
Flux decrement in average Lyα forest vs proximity effect

Flux decrement:
need to know gas and temperature distribution (numerical simulations)

Proximity effect:
need to know luminosity and systematic redshift of the quasar, potential bias due to overdensity
Overall there is good agreement between recent measurements from flux decrements adapted to the same temperature density relation and measurements from the proximity effect.
Smooth evolution.
No sign of percolation.

IGM appears to be still highly ionized at z~6.
The ionizing emissivity corresponds to about 1-2 ionizing photons per hydrogen atom “photon-starved reionization”
Pushing to higher redshift

Calverley et al. (2011)

Wytche & Bolton (2011)

UVB1
UVB2
UVB3
UVB4

With quasar, $t_{\circ}=10^7$ yr

No quasar
HII region or classical proximity effect?

Very hard to tell the difference!

Ringberg, 30 June 2011
The effect of the age of the quasar on the transmission profile

For low ages of the quasar ($10^7$ yr or less) the degeneracy between HII region and proximity zone is broken.

Ringberg, 30 June 2011
Near-zone sizes

\[ R_{NZ} [\text{proper Mpc}] \]

- \( \diamond \) Carilli et al. (2010)
- \( \triangle \) J0210-0456

Scaled to \( M_{1450} = -27 \)

\[ M_{1450} \]

\[ z \]

Bolton et al. 2011
Near-zone sizes

The small $R_{NZ}$ stands out.

Bolton et al. 2011

Ringberg, 30 June 2011
The observed transmission profile appears consistent with a 10% neutral as well as a fully neutral surrounding IGM depending on quasar age.

Bolton et al. 2011
If a DLA sits in front of the quasar, the transmission profile is also consistent with a highly ionized surrounding IGM.
The observed transmission profile depends strongly on quasar age.

Bolton et al. 2011

Ringberg, 30 June 2011
The observed $R_{N_{\text{Z}}}$ and $T_{1216}$ suggest $f_{\text{HI}} \geq 0.1$ and $t_q \leq 10^7$ yr. A highly ionized surrounding IGM plus DLA are not very likely (~5%).

Ringberg, 30 June 2011
Summary

• probably the first detection of a damping wing due to a significantly neutral IGM (proximate DLA unlikely)

• surprisingly low age inferred for the quasar
  – ~10^7 yr if surrounding IGM fully neutral
  – ~10^6 yr if f_{HI} ~ 0.1

• the age is shorter than the e-folding time for a moderately spinning black hole growing at the Eddington rate with 10% efficiency (4.5 \varepsilon_{0.1} 10^7 yr); adds further to the puzzle how to form a 2x10^9 M_\odot black hole by the time the Universe is 0.77Gyr old