Exploring Protogalaxies through Extended Ly-α Emission around High-Redshift QSOs

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QSO FUZZ

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QSOs and "Protogalaxies"

QSOs difficult to interpret as probes of galaxy evolution

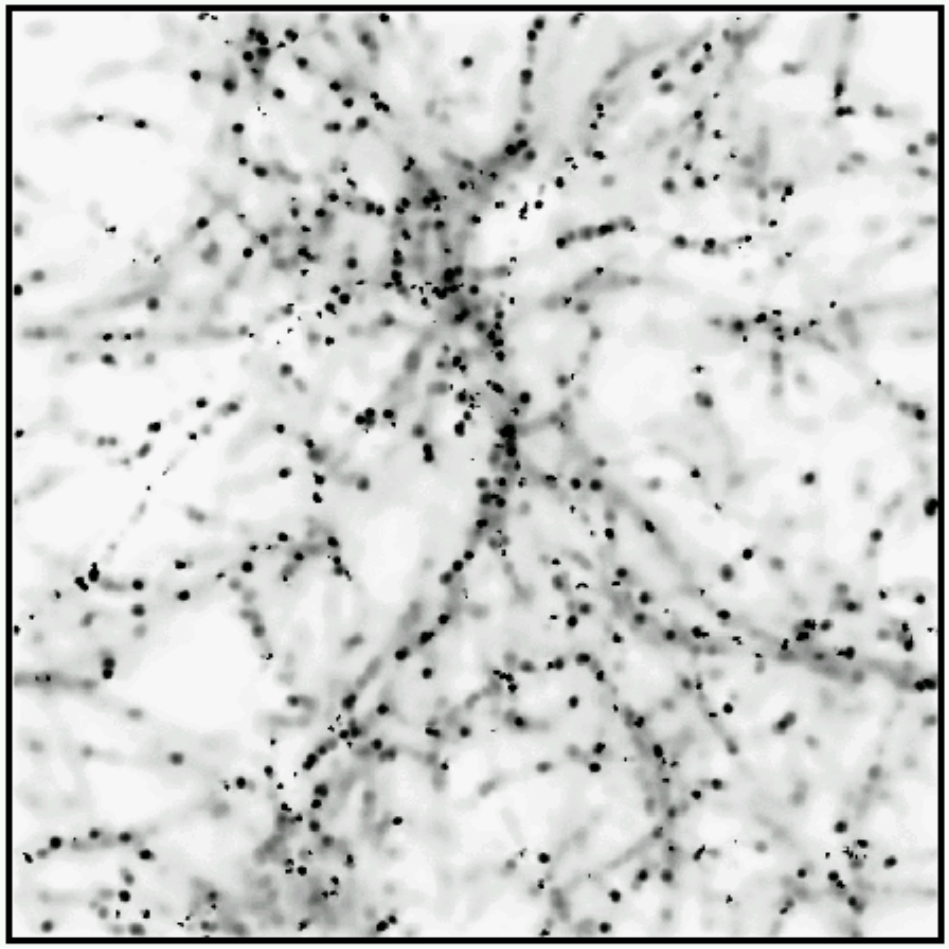
Well-established now that QSOs hosted by galaxies

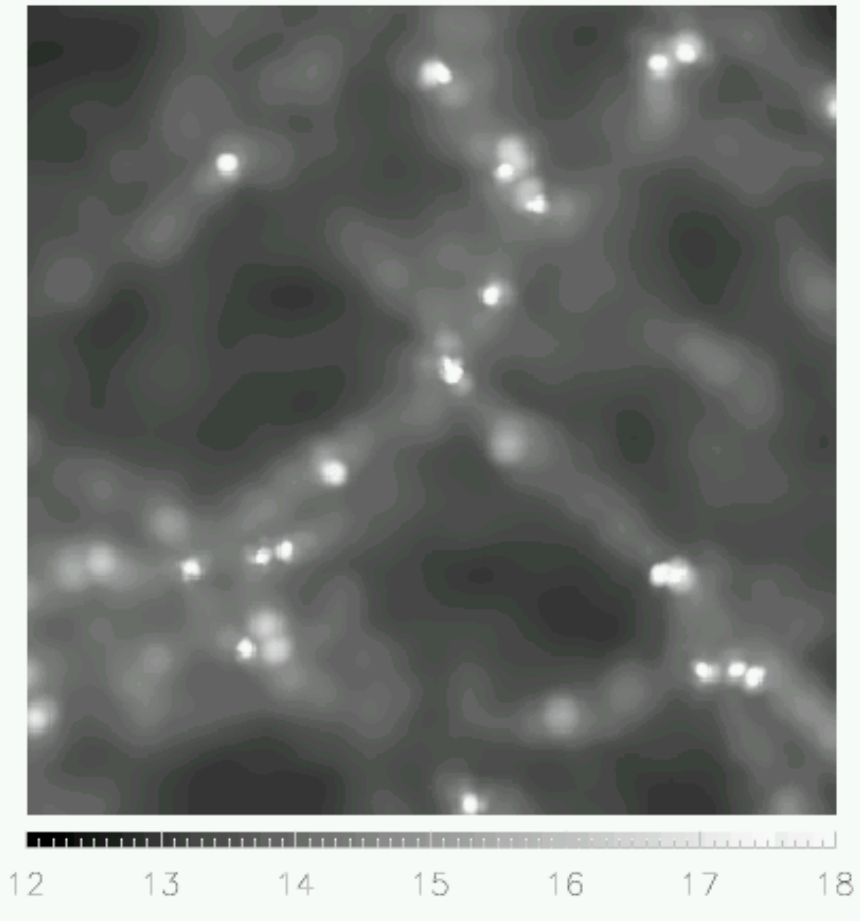
Evolution of QSO and galaxy populations expected to be linked, but exhibit different behaviour (Madau diagrams)

Quasar phase may be a natural (but brief) evolutionary phase in life of all massive galaxies

Expect spatially-extended cold gas (10,000K - radiative cooling time shorter than dynamical)

What is the physical effect of a QSO turning on within an assembling galaxy?





SPH simulations, distribution of neutral gas at z~3 (from Katz et al. and Rauch, Haehnelt & Steinmetz).

Left box is 22Mpc comoving, 15arcmin; right zoomed x10

Effect of QSO on host

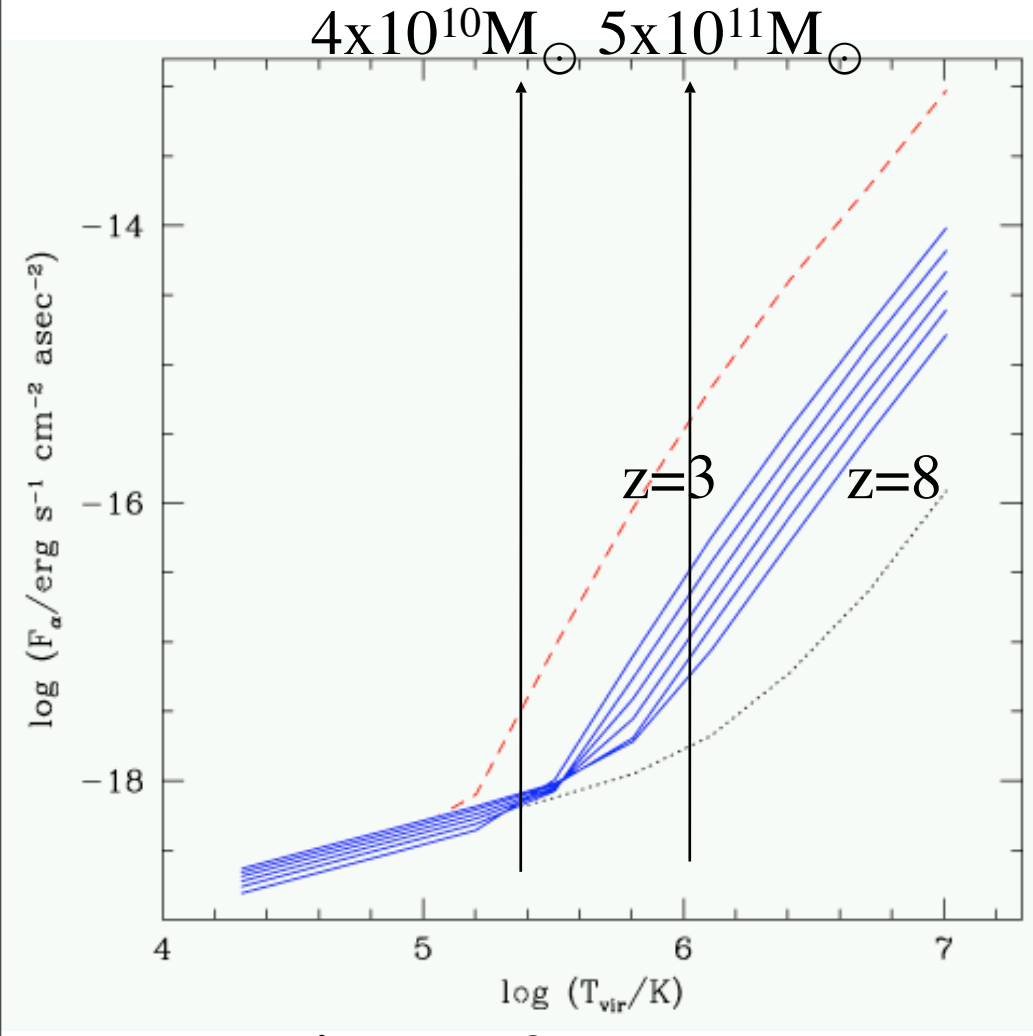
Ionizing photons from QSO → recombination line emission from optically-thick neutral hydrogen clouds

Get low surface-brightness Ly-α "fuzz" anyway from line cooling of gas in halo potential, and external photoionization by UV background - QSO enhances this

Haiman & Rees (2001 ApJ 556, 87) - Ly-α halo significant fraction of virial radius (10-100Kpc), ~3"
& surface brightness 10^{-17}erg/s/cm^2/arcsec^2
(accessible to large telescopes with spectroscopy/NB)

BUT Alam & Miralda-Escudé (astro-ph/0106424) claim 100 times fainter surface brightness and v. small (0.4")

Characteristic Surface Brightness



Haiman & Rees (2001 ApJ 556, 87)

Ly-α halo surface brightness 10^{-17}erg/s/cm^2/arcsec^2

Seen in radio galaxies, radio-loud QSOs (e.g. Bremer et al. 1992 - related to outflows)

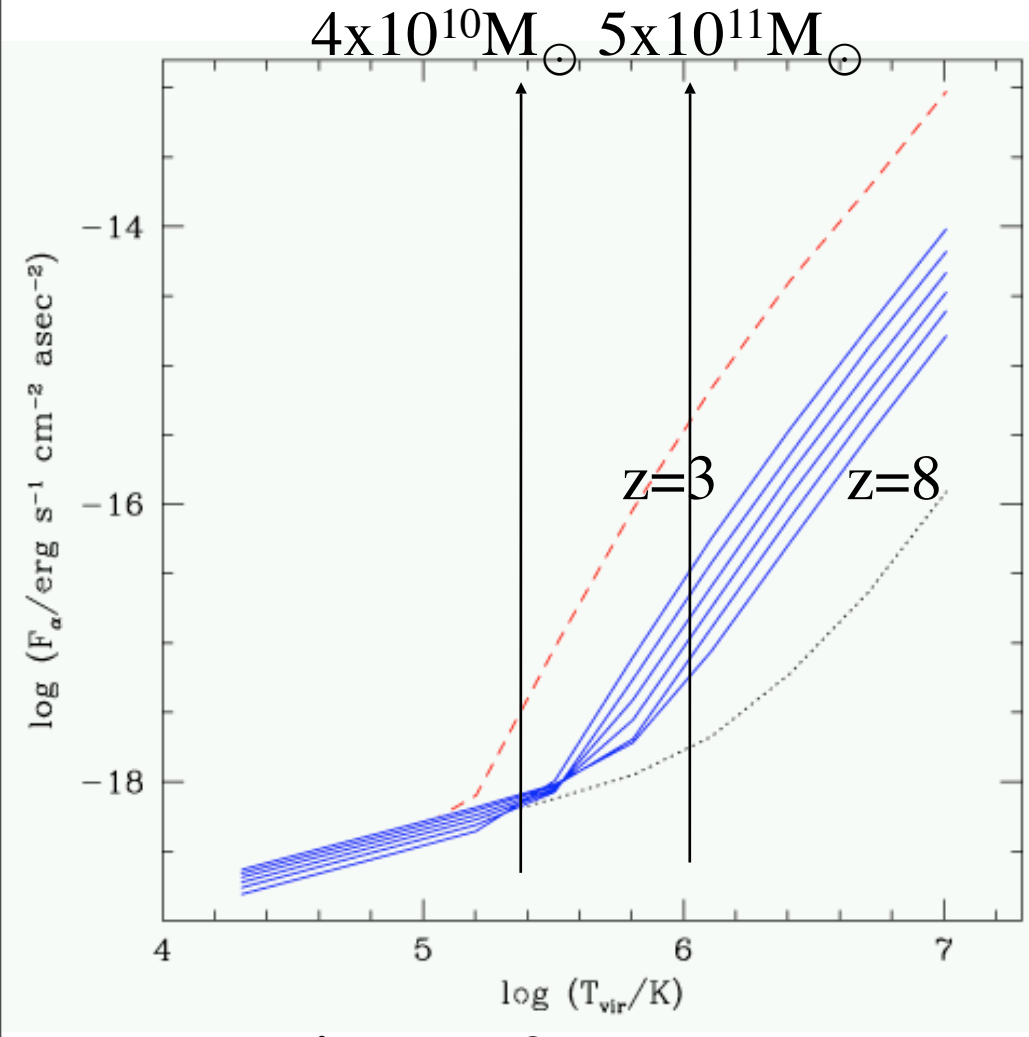
Yet to be seen for quasars which are not radio loud (Hu & Cowie 1987 - search inconclusive)

QSOs only turn on when gas has settled into thin disk or formed stars?

Characteristic Surface Brightness

Ly-α halo surface brightness

10^{-17}erg/s/cm^2/arcsec^2



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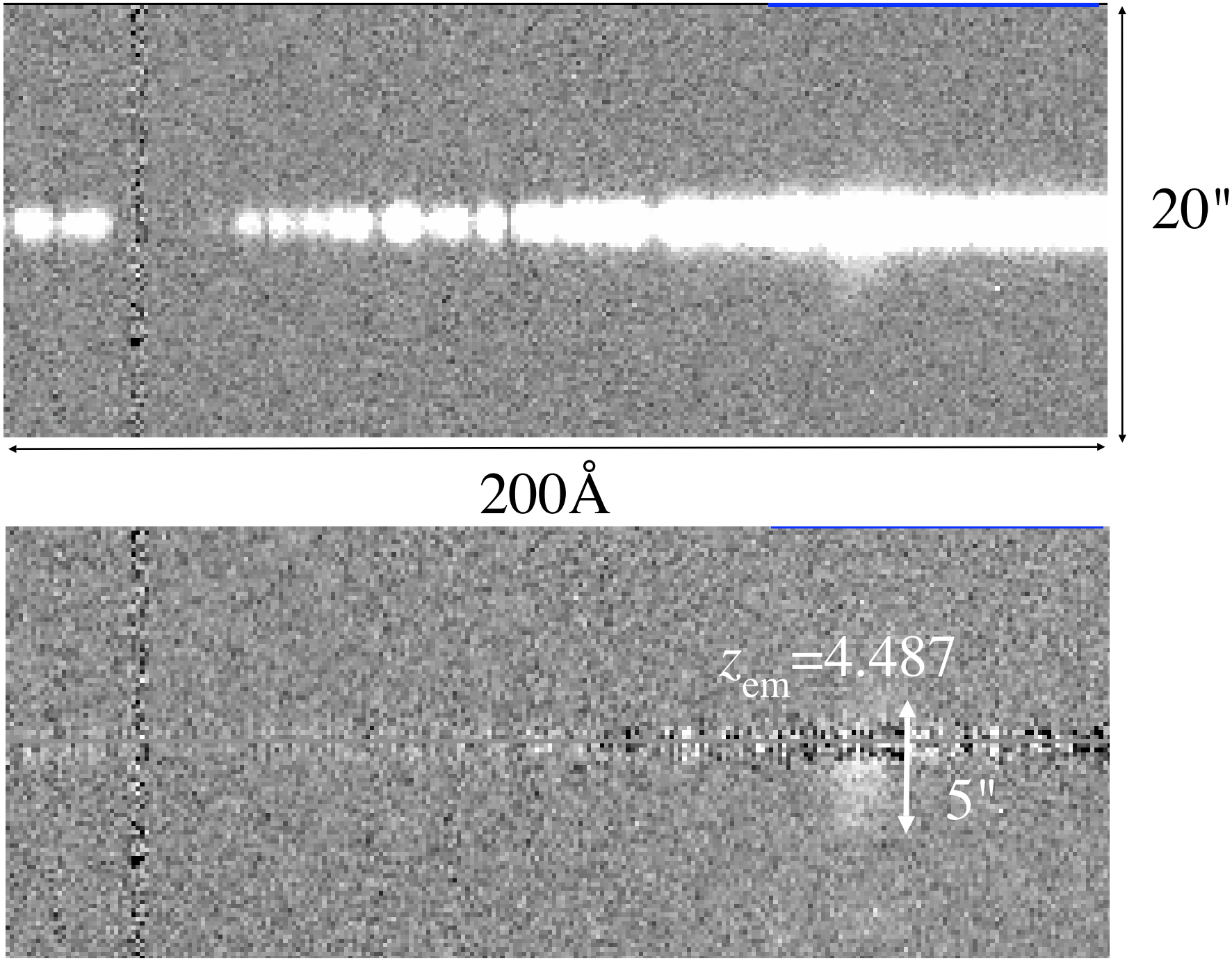
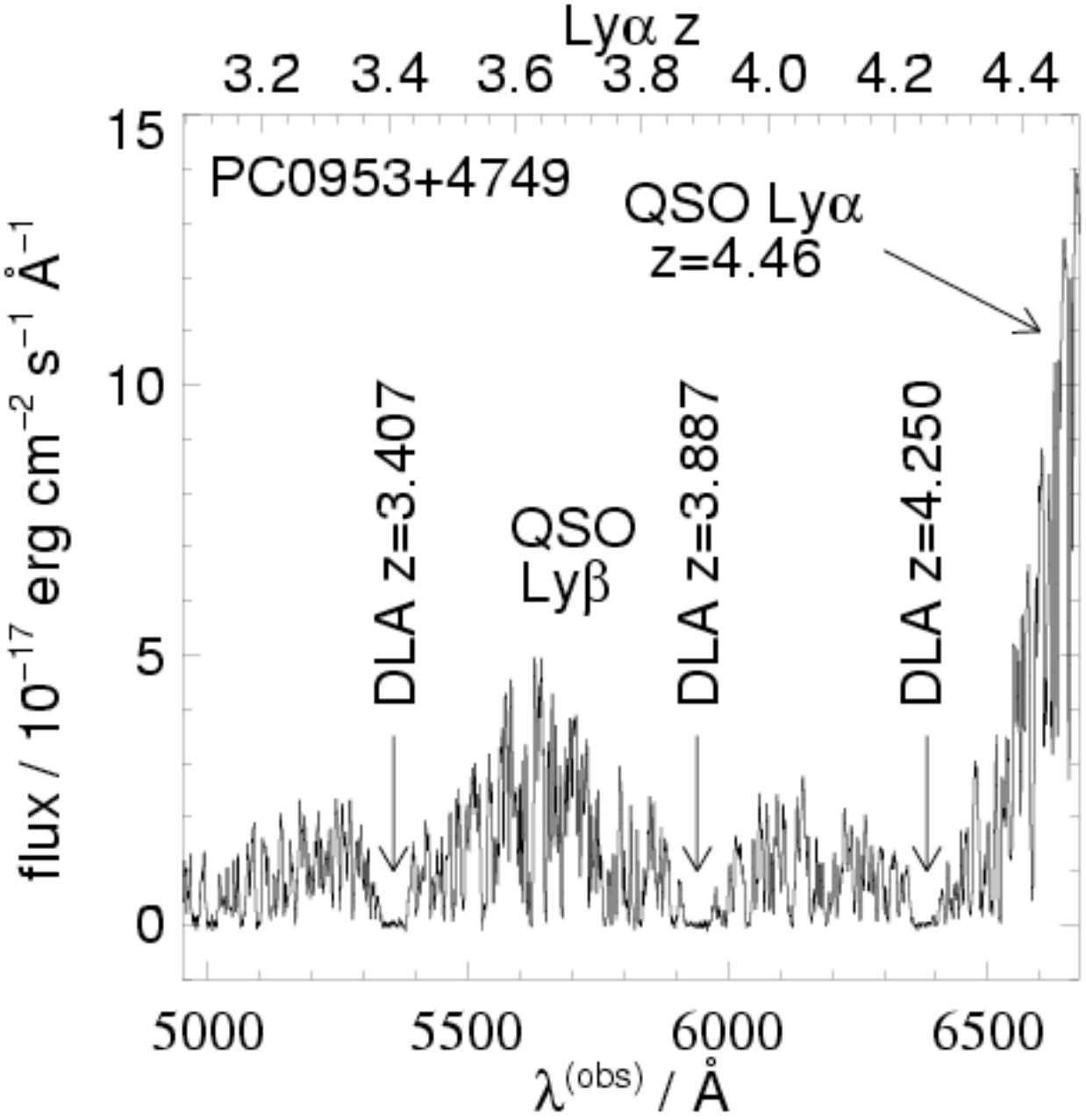
QSOs only turn on when gas has settled into thin disk or formed stars?

Spatially Extended Ly-α Emission



The QSO

We have been undertaking an extensive study of the quasar PC0953+4749 at z=4.46 which has 3 damped Lyman-alpha systems (DLAs) at z>3, including Keck/LRIS and HST/WFPC2



Extended Ly-α Emission

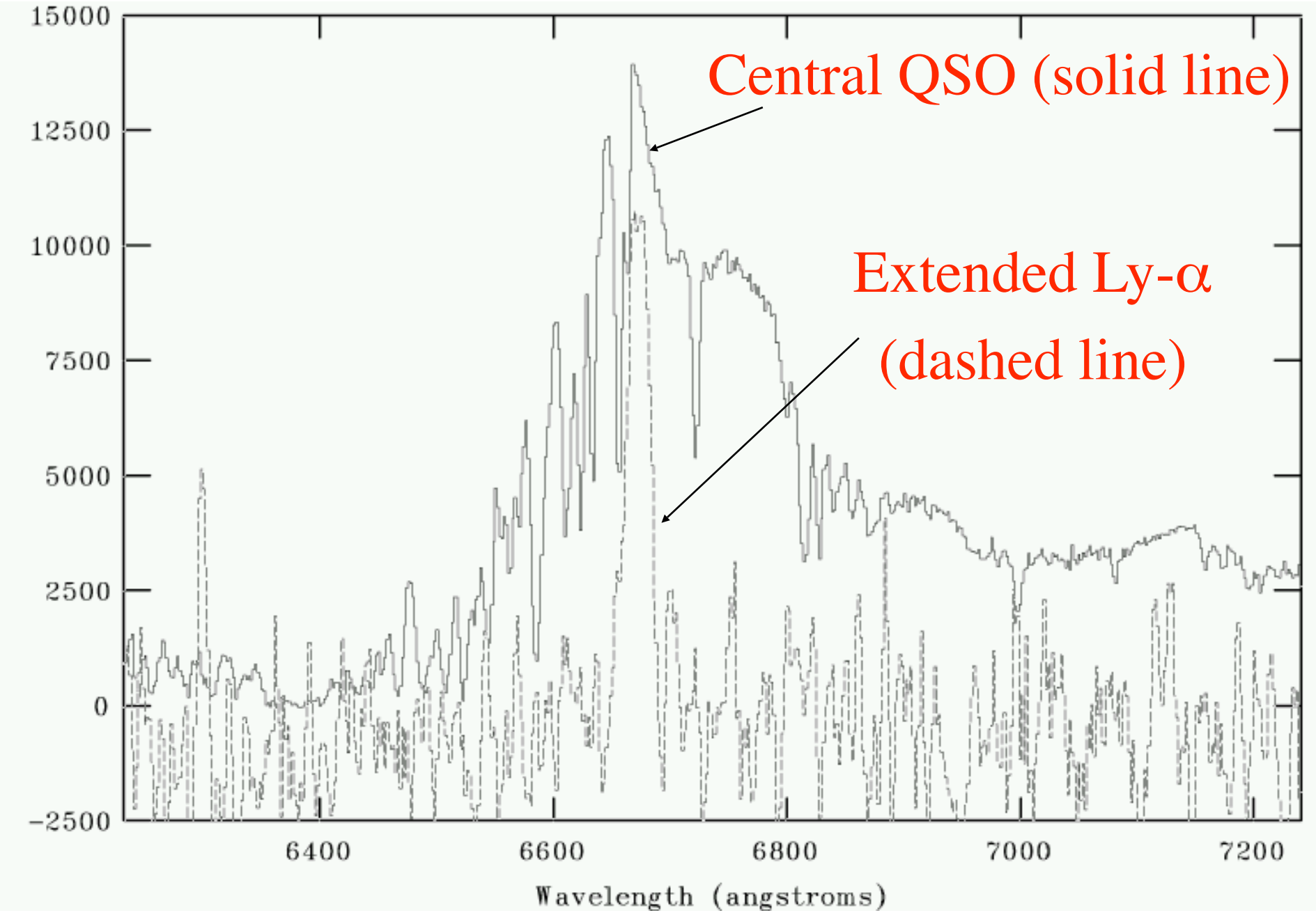
The long-slit spectroscopy was obtained using Keck/LRIS (Oke *et al*. 1995).

Inspection of the 2D spectrum reveals Ly-α at the *QSO* redshift but extended spatially beyond the continuum of the *QSO*.

This line emission extends over ~5" beyond the *QSO PSF*
Emission is asymmetric -gas is clumpy? Radiation beamed anisotropically?

First time this phenomenon has been seen at $z>4$ in a *QSO* which is not radio-loud.

Narrow Extended Ly-α



Ly-α Spectral Properties

The extended line emission (dotted line) covers a spectral extent of ≃1000km/s *FWHM* (resonantly broadened)

Much narrower than Ly-α from the *QSO* (solid line).

No evidence of continuum is seen for the extended emission line region

Recombination line probably powered by reprocessed QSO UV flux rather than by local star formation.

The HI cloud of the host galaxy is ~>35kpc/$h_{.7}$ (Ω=0.3)

Summary

Moderate resolution (R~1500) Keck/*LRIS* spectra of a high redshift *QSO* (z~4.5)

Discovered extended Lyman-α emission around *QSO*

Narrow in velocity spread and slightly offset in redshift from the broad line emission of the *QSO*

The *QSO* illuminates surrounding cold gas of host, ionizing photons producing Lyman-α fluorescence

"Fuzz" around a distant quaser places strong constraints on galaxy formation and the extended distribution of cold, infalling (?) gas (Haiman & Rees 2001)