It might yet prove possible to account for the observed high-redshift (z~4) quasar populations with ... conventional cosmic structure formation theory

--- Ed Turner 1991

The Highest Redshift Quasars: Growth of Supermassive BHs and Their Environment at z=6-7

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KITP

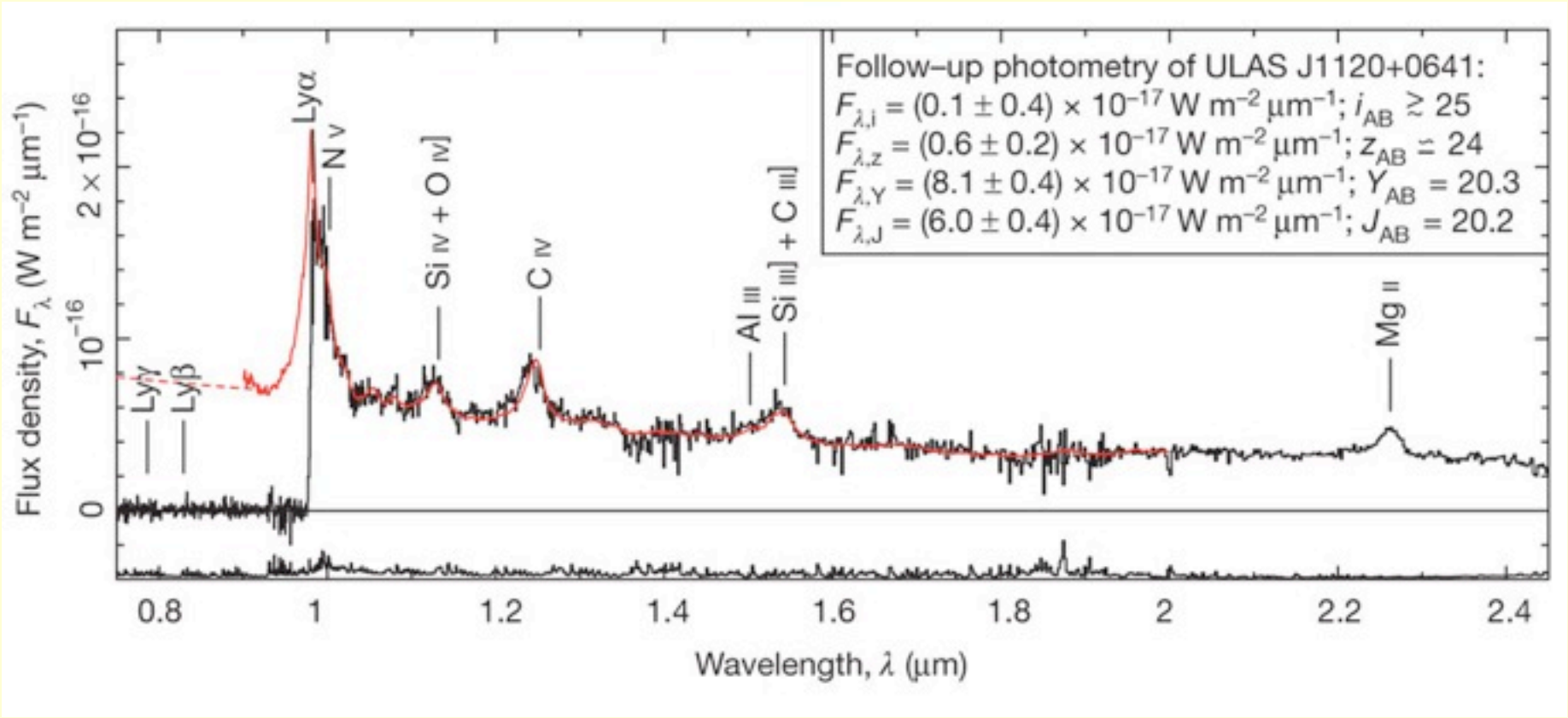
Feb 2012

Collaborators: DeCarli, de Rosa, Jiang, McGreer, Morganson, Wang,

Carilli, Kurk, Walter, Vestergaard +

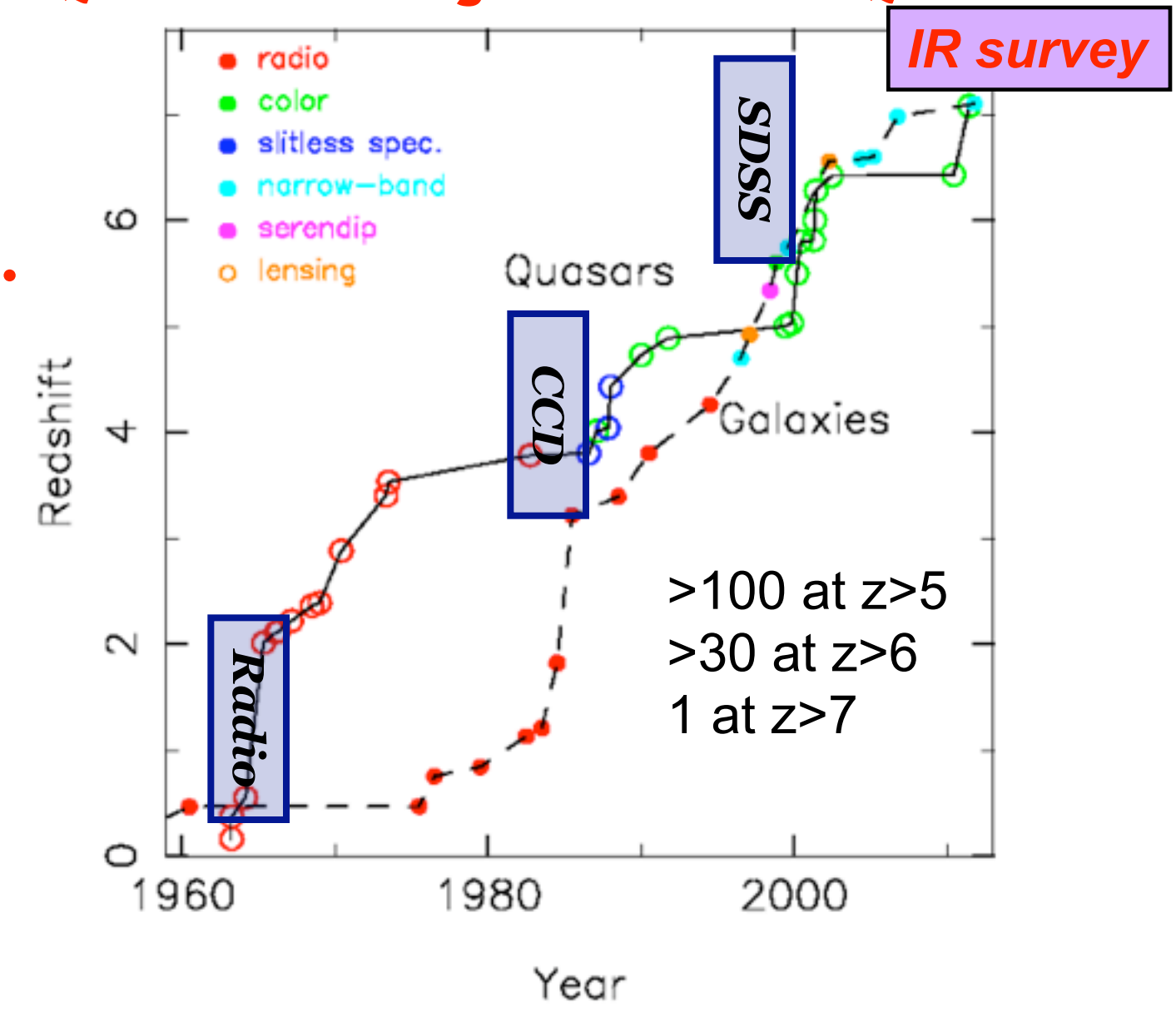
Background: 46,420 Quasars from the SDSS Data Release Three

The New Highest Redshift Quasar at z=7.085 from UKIDSS

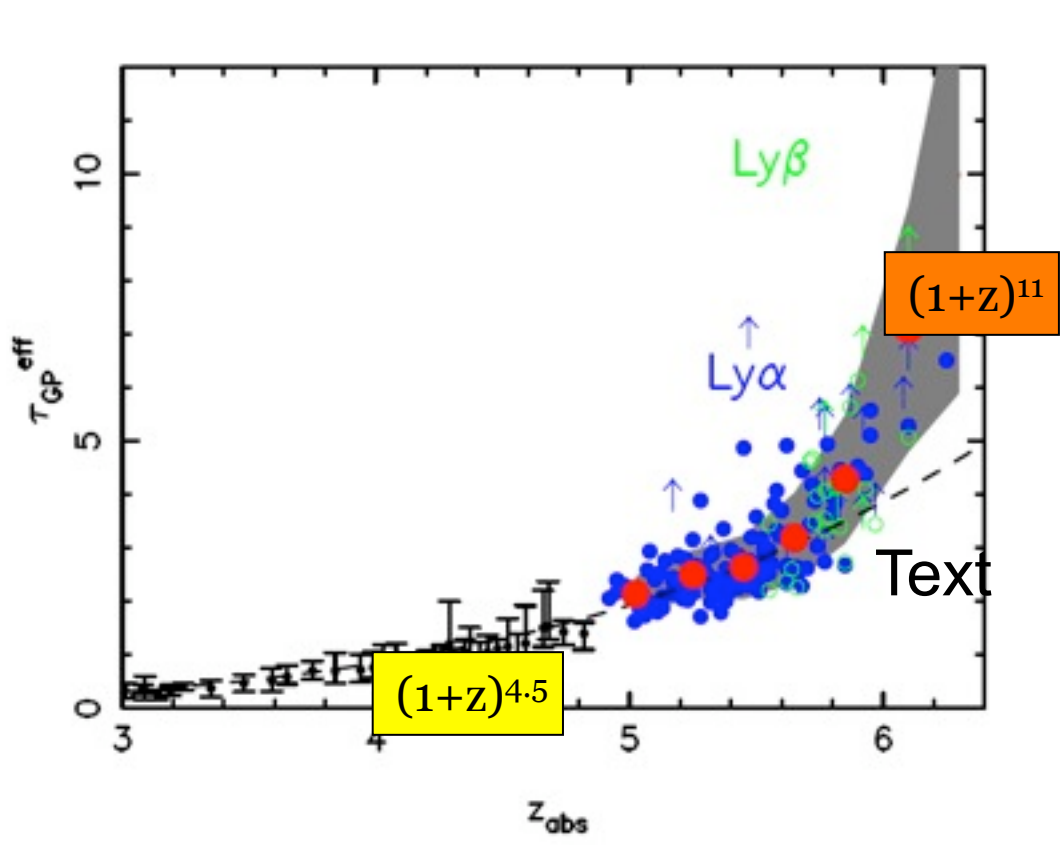


Mortlock et al. 2011

Quest to the Highest Redshift Quasars

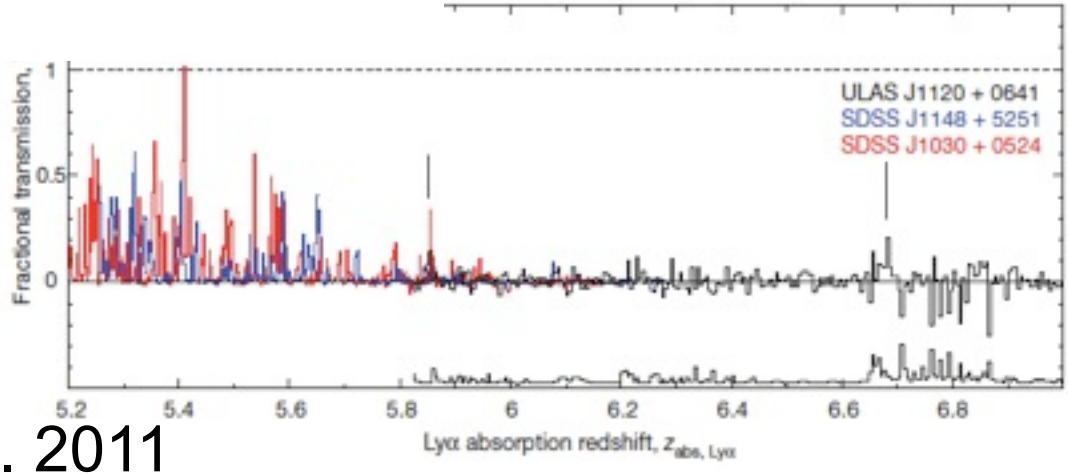


Accelerated Evolution at z>5.7



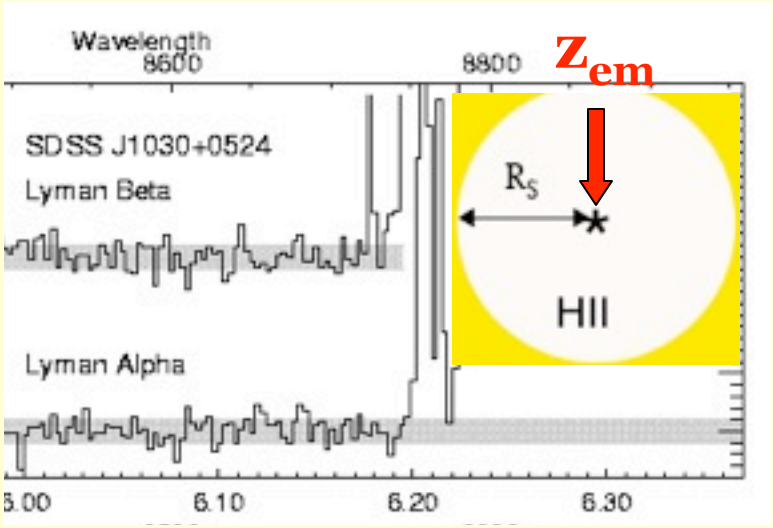
- *Optical depth evolution accelerated*
  - $z<5.7$: $\tau \sim (1+z)^{4.5}$
  - $z>5.7$: $\tau \sim (1+z)^{>11}$
  - ***End of reionization?***

XF et al. 2006



Mortlock et al. 2011

Quasar near-zone Sizes

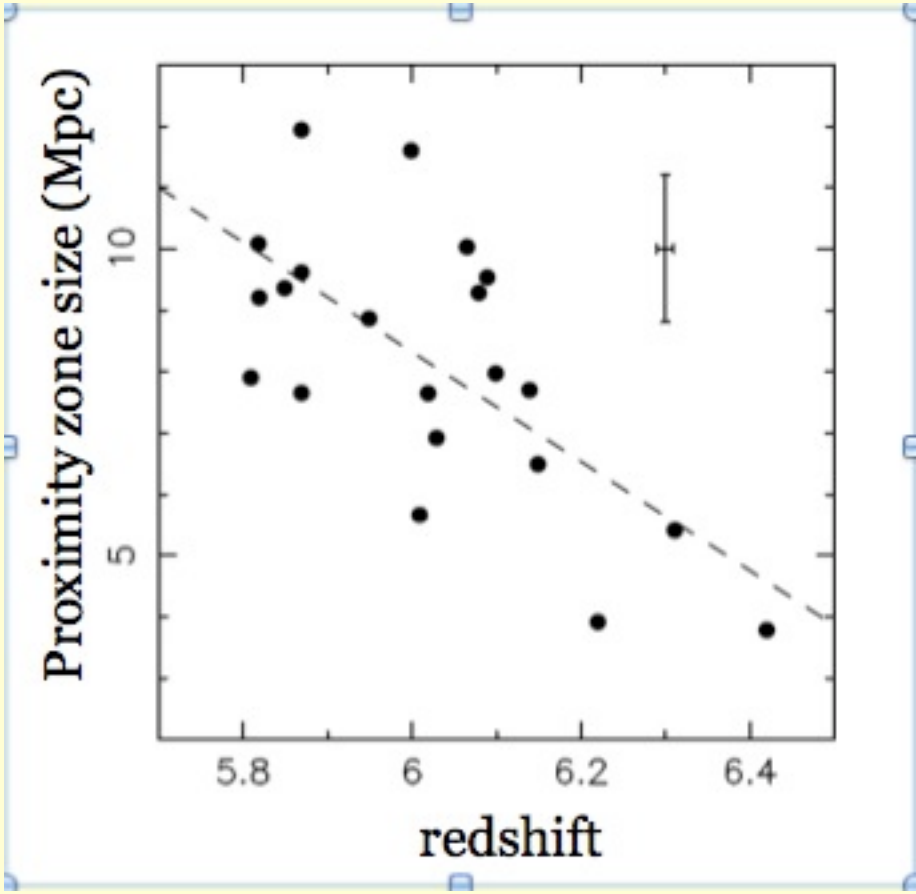


Shapiro, Haiman, Mesinger, Wyithe, Loeb, Bolton, Haehnelt, Maselli et al.

- Size of HII region

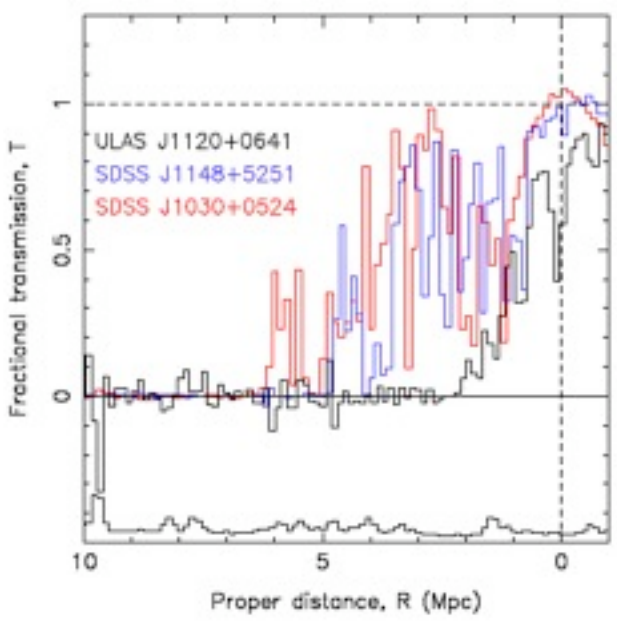
$$R_s \sim (L_Q\, t_Q / f_{HI})^{1/3}$$

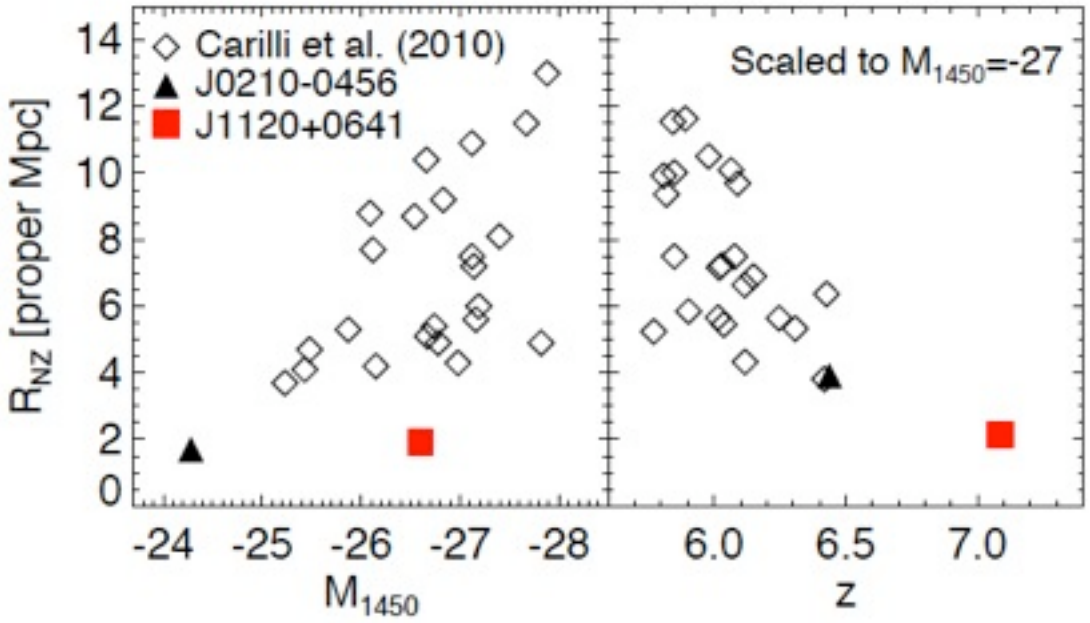
- **near-zone size evolution consistent with rapid increase of neutral fraction at z>6**
- **Can be applied to higher z and f_{HI} with lower S/N data**



Fan et al. 2006
Carilli et al. 2011

z~7 quasar near zone

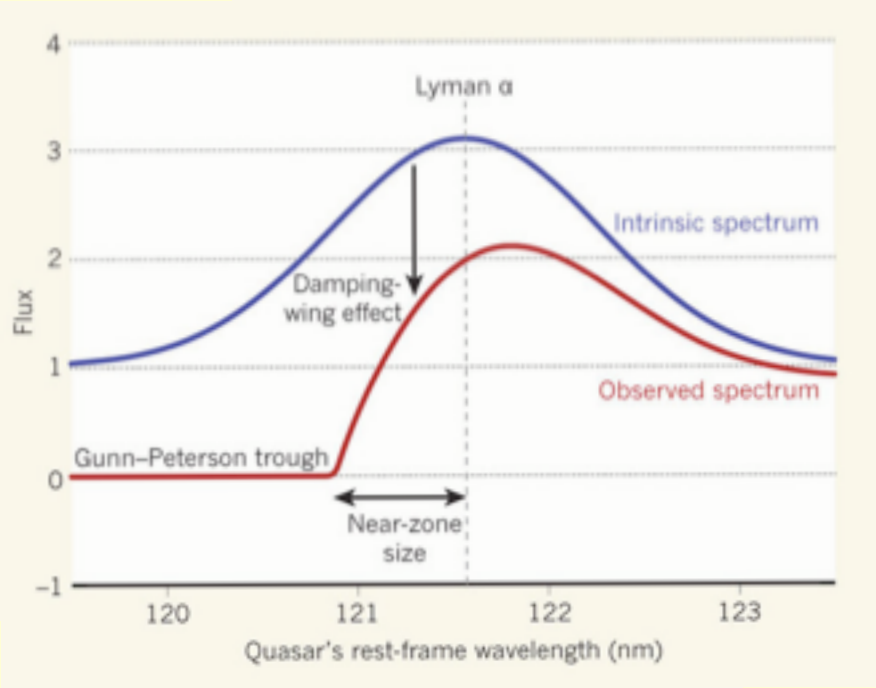


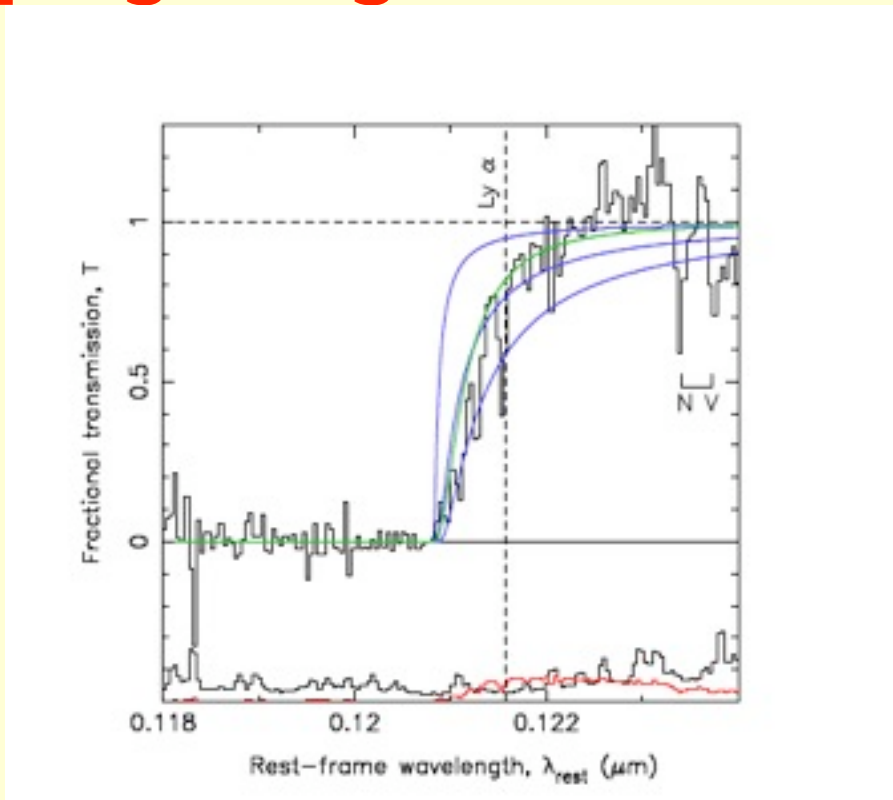


- HII region size much smaller at z~7
- f(HI) >=0.1

Mortlock et al. 2011
Bolton et al. 2011

z~7 quasar: first IGM damping wing?

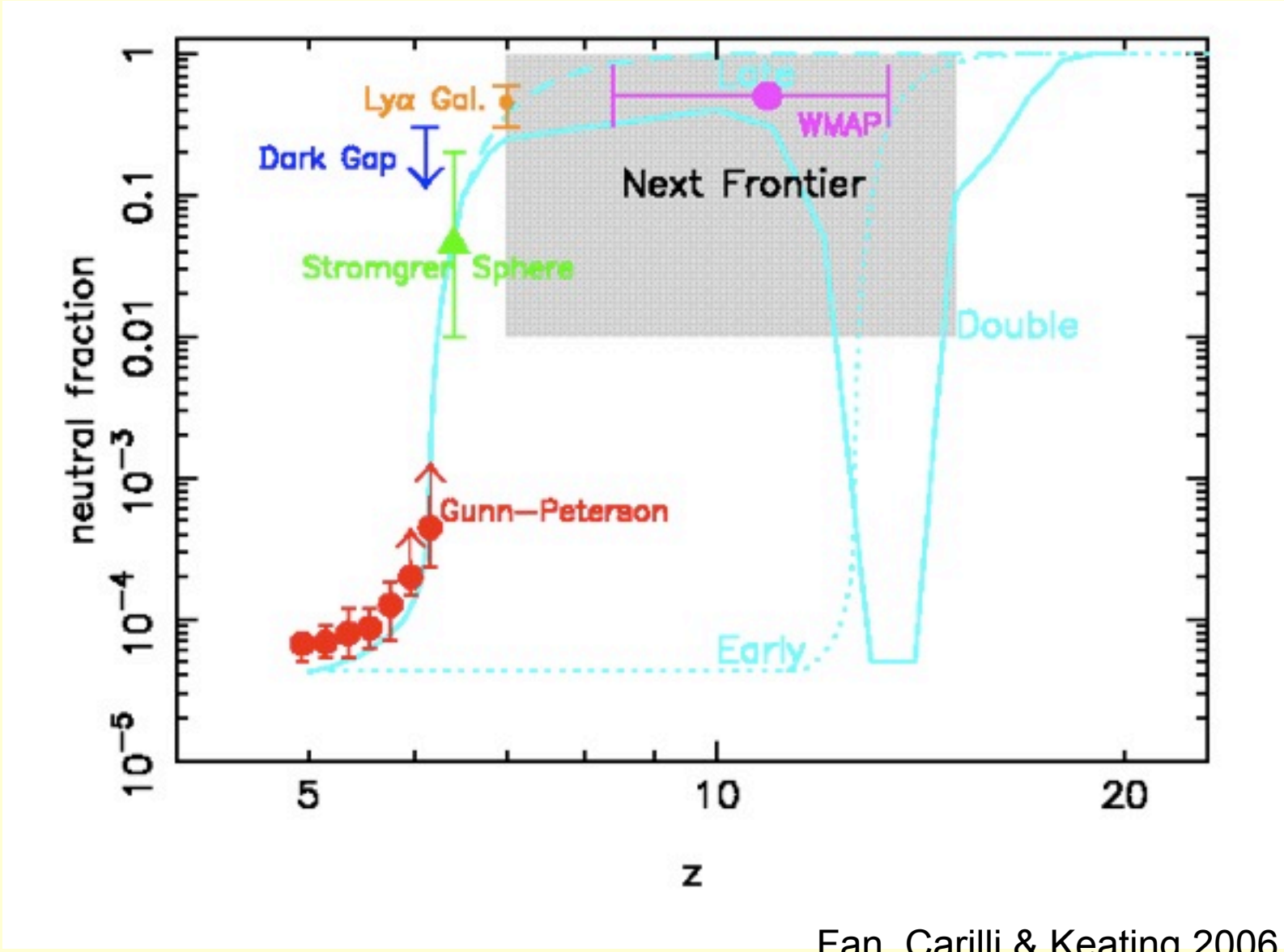




- substantial damping wing: f(HI)>=0.1

Mortlock et al. 2011

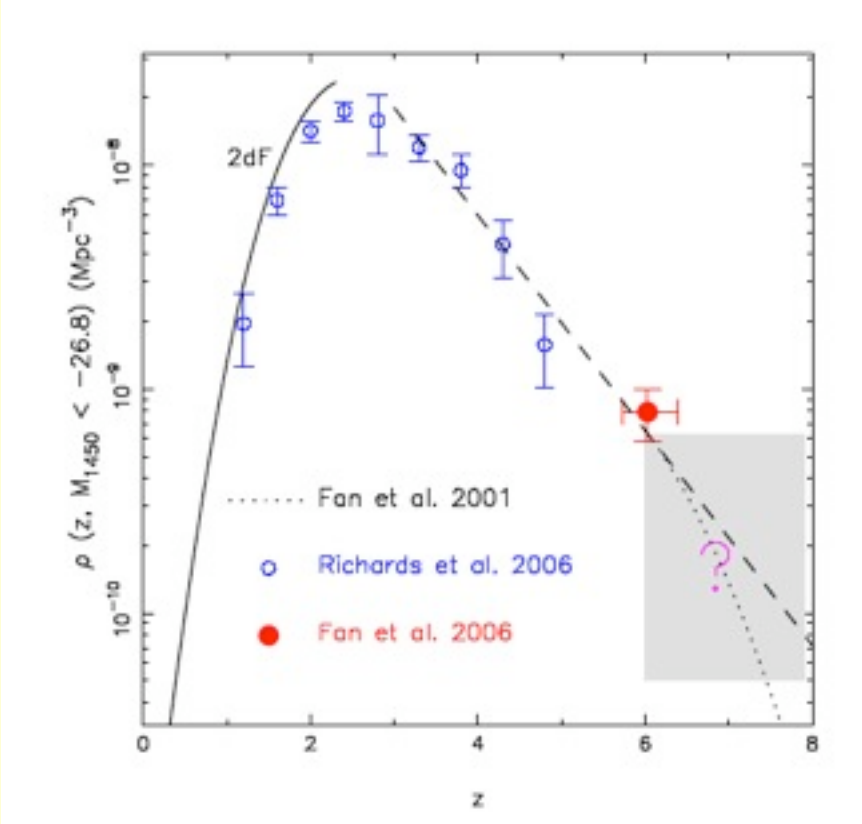
Probing Reionization History



Fan, Carilli & Keating 2006

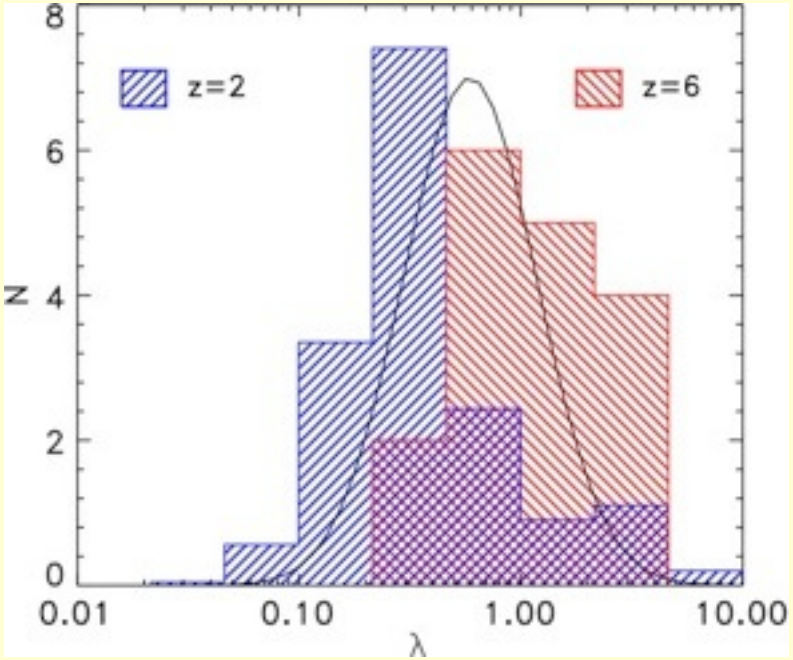
Quasar Evolution at z~6

- Strong density evolution
  - Density declines by a factor of ~40 from between z~2.5 and z~6
- Black hole mass measurements
  - $M_{BH} \sim 10^{9\text{-}10}\ M_{sun}$
  - $M_{halo} \sim 10^{12\text{-}13}\ M_{sun}$
  - rare, 5-6 sigma peaks at z~6 (density of 1 per Gpc^3)
- *How to form these BHs???*

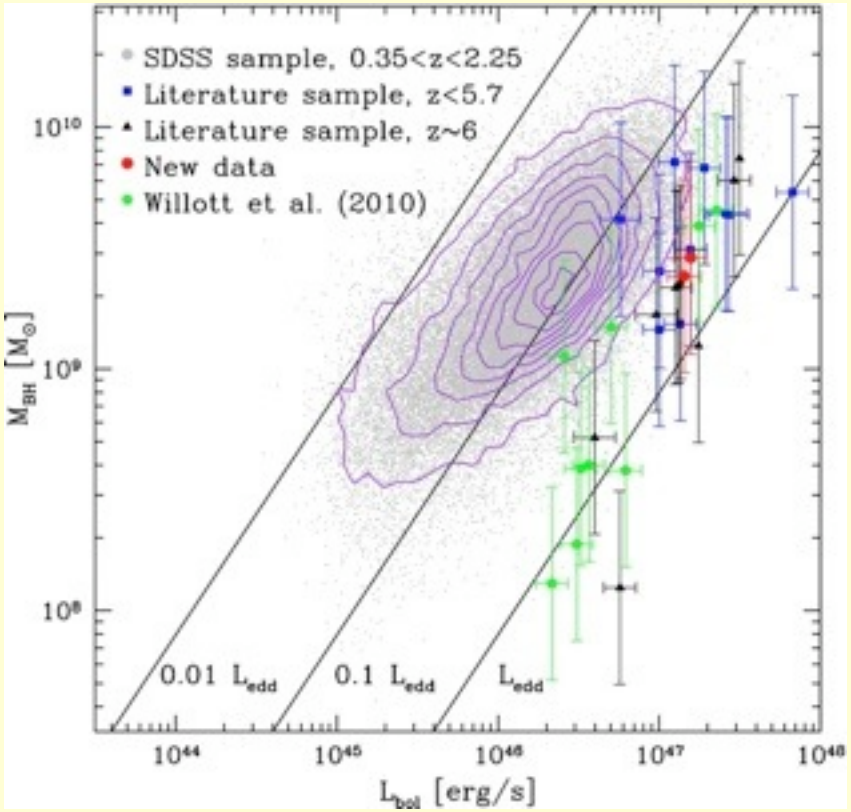


Fan et al. 2006

Quasars are accreting at close to Eddington limit at z~6



Willott et al. 2010



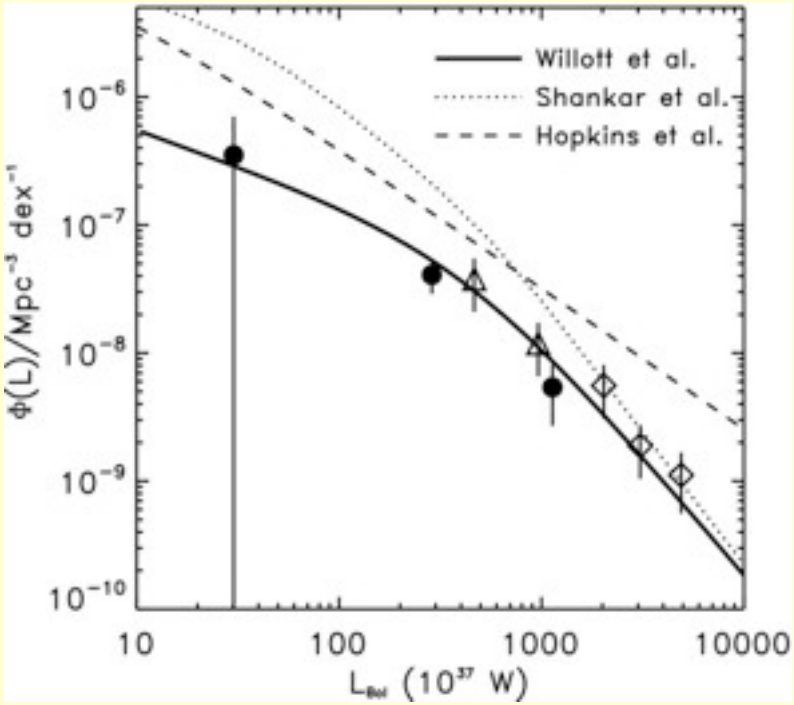
de Rosa et al. 2011

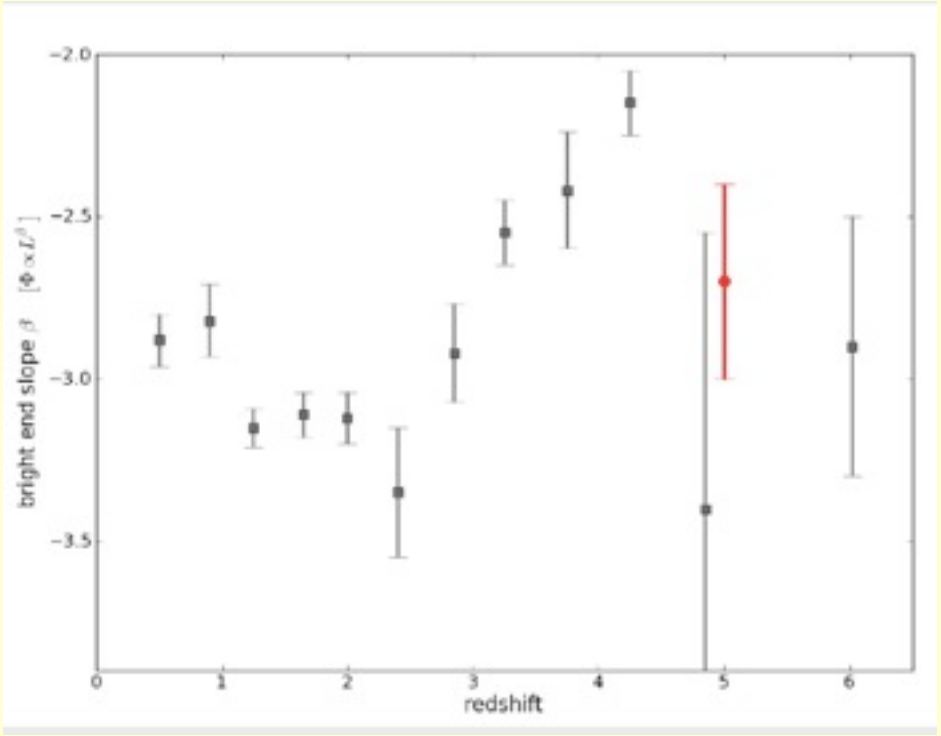
- $M_{BH} \sim (FHWM)^2 L^{0.5}$ based on MgII line
  - factor of ~3 accuracy on individual measurements

Are there luminous quasars at z>>7

- Black Holes do not grow arbitrarily fast
  - Accretion onto BHs dictated by Eddington Limit
  - E-folding time of **maximum** supermassive BH growth: 40 Myr
  - At z=7: age of the universe: 800 Myr = **maximum** 20 e-folding
- Billion solar mass BH at z>7
  - Non-stop, maximum accretion from 100 solar mass BHs at z=15 (collapse of first stars in the Universe)
  - **Theoretically difficult for formation of z>7 billion solar mass BHs**
  - What if we find them:
    - Direct collapse of "intermediate" mass BHs?
    - More efficient accretion model "super-Eddington"?

Steepening of quasar luminosity function at z~6



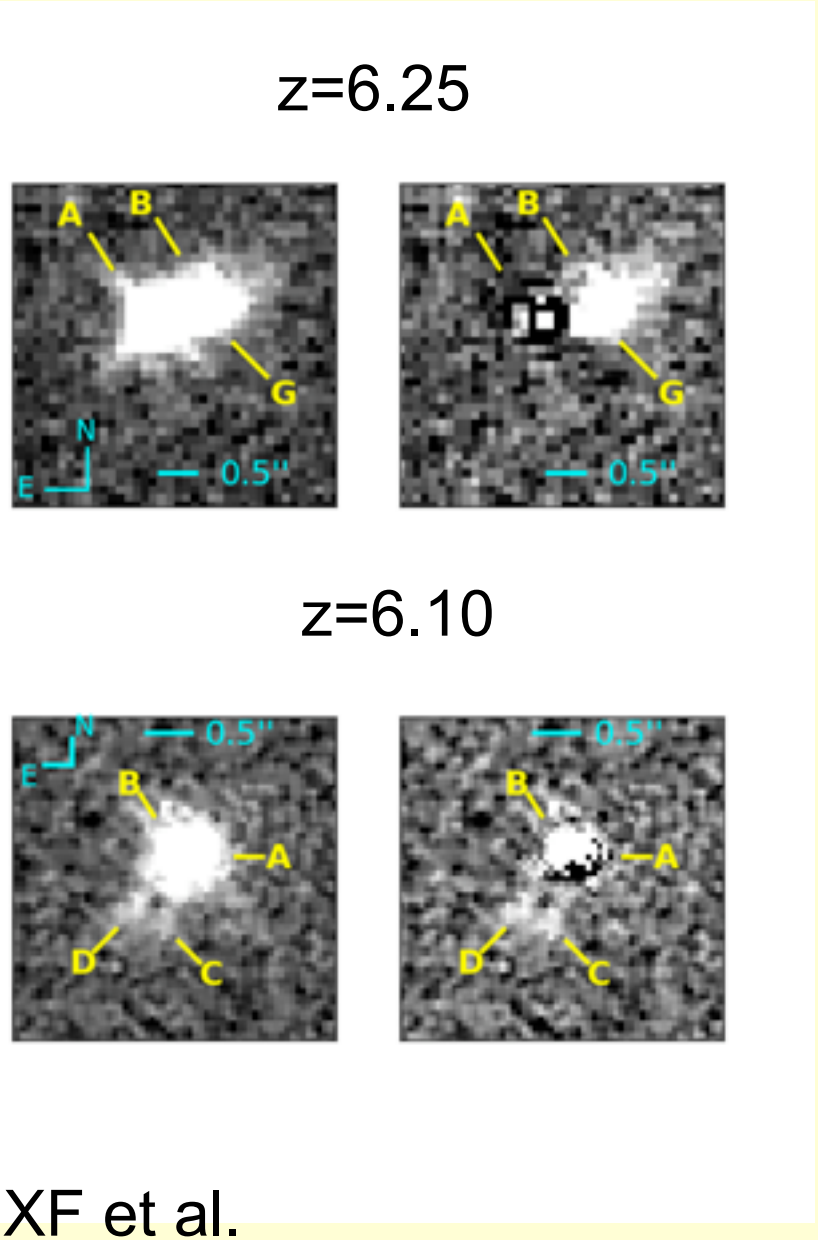


McGreer et al. in prep

- quasars not important contributor to reionization
- is BH growth starting to be limited by the number of e-holding available?
- high lensing probability?

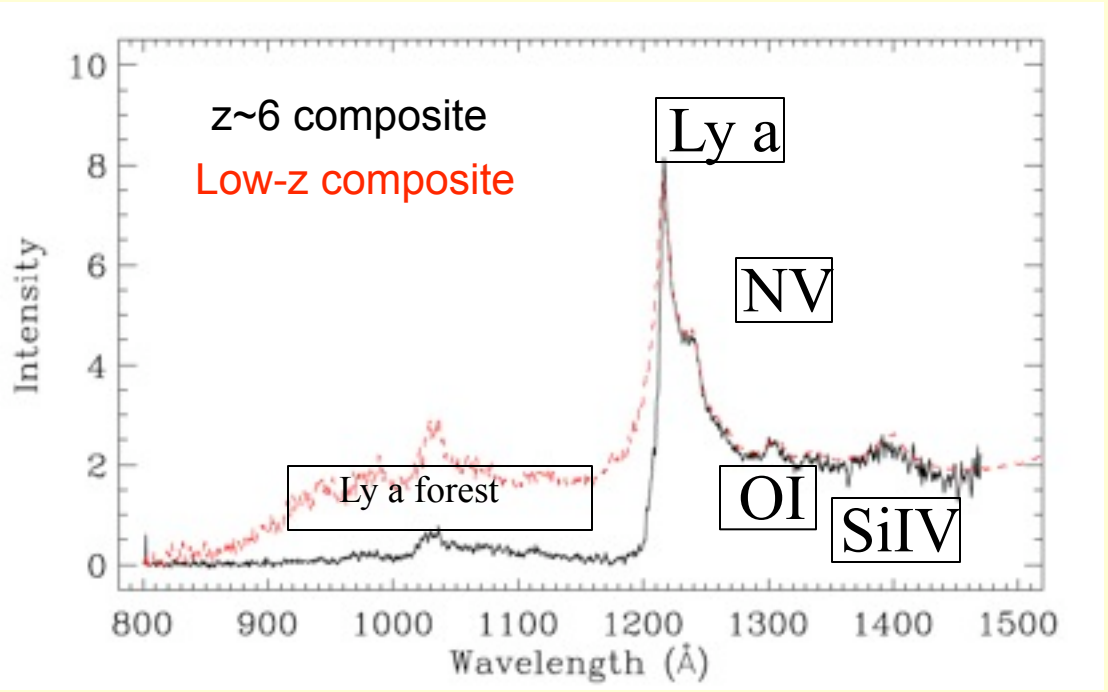
Lensing

- HST SNAP Survey
  - 30 quasars at z~6 observed
  - two lenses discovered
  - compared to HST SNAP of z~4 quasars: 150 observe, none found
  - constraints on quasar luminosity function slope
  - access to much fainter quasars

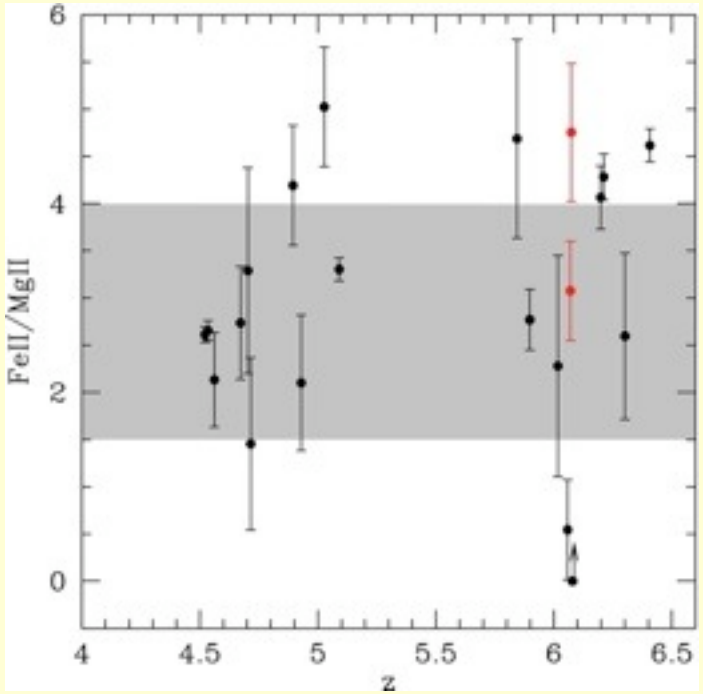


McGreer, XF et al.

non-evolution of quasar emission



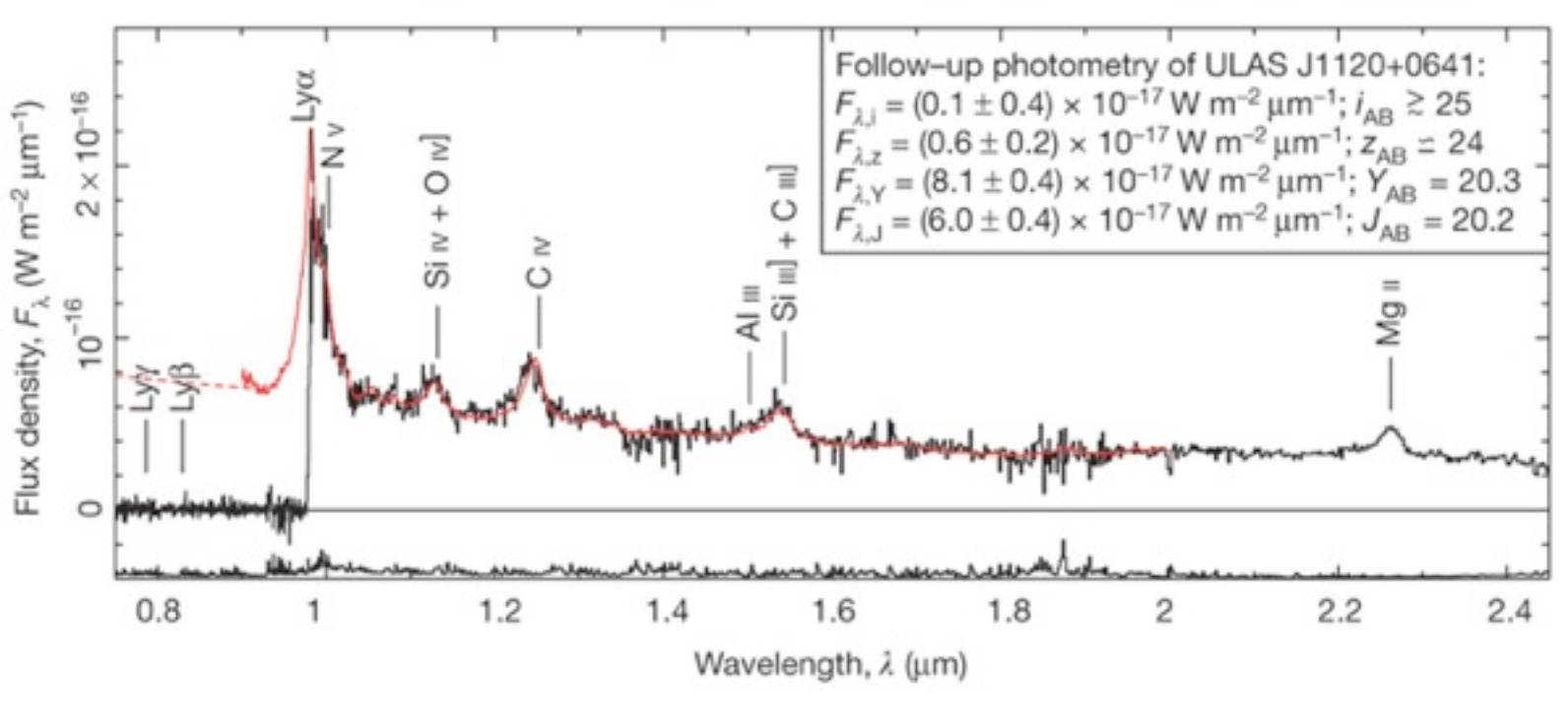
XF et al. 2010



Jiang, XF et al. 2008
de Rosa et al. 2011

- Rapid chemical enrichment in quasar vicinity
- Quasar env has supersolar metallicity : no metallicity evolution
- High-z quasars are *old,* **not yet first quasars, and live in metal enriched env similar to centers of massive galaxies**

Even at z>7

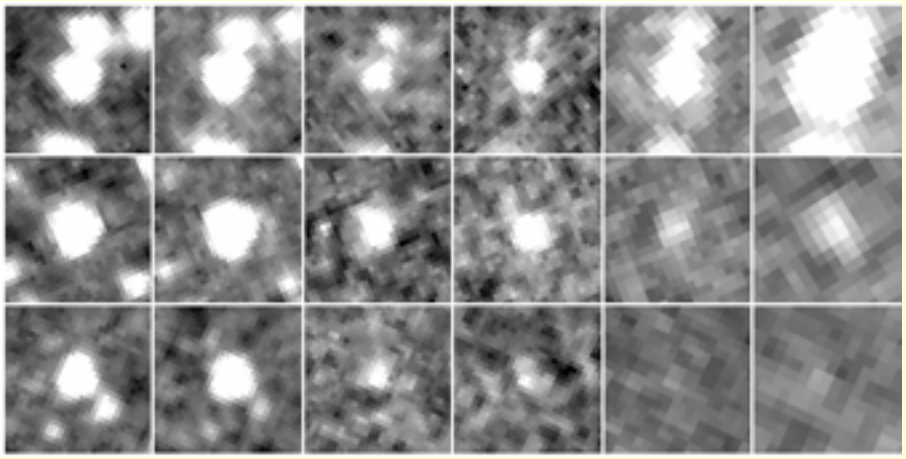


Mortlock et al. 2011

Disappearance of Dust Torus at z~6?

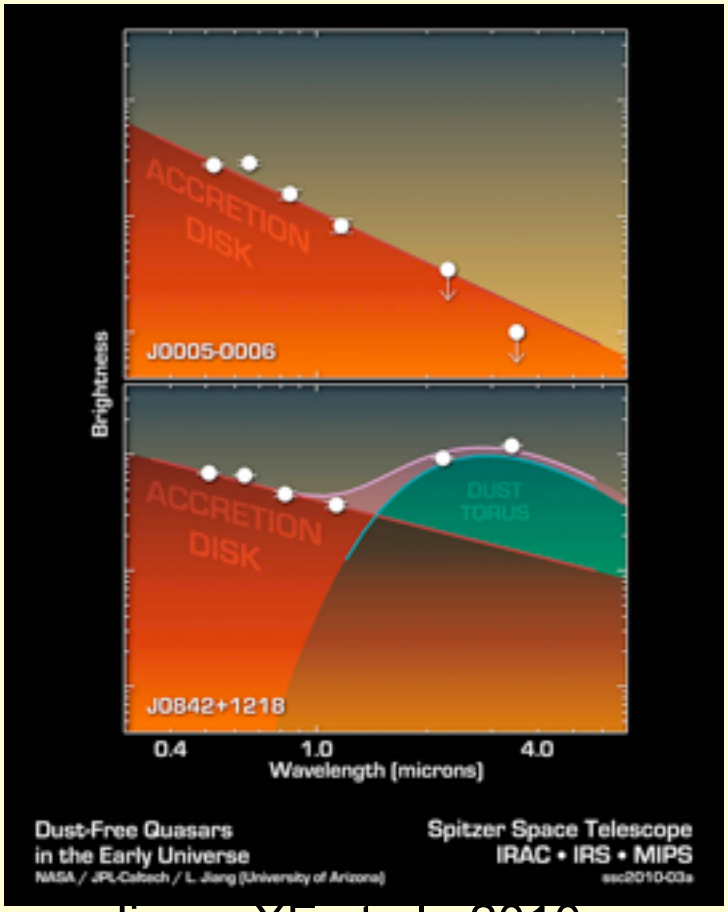
typical

J0005



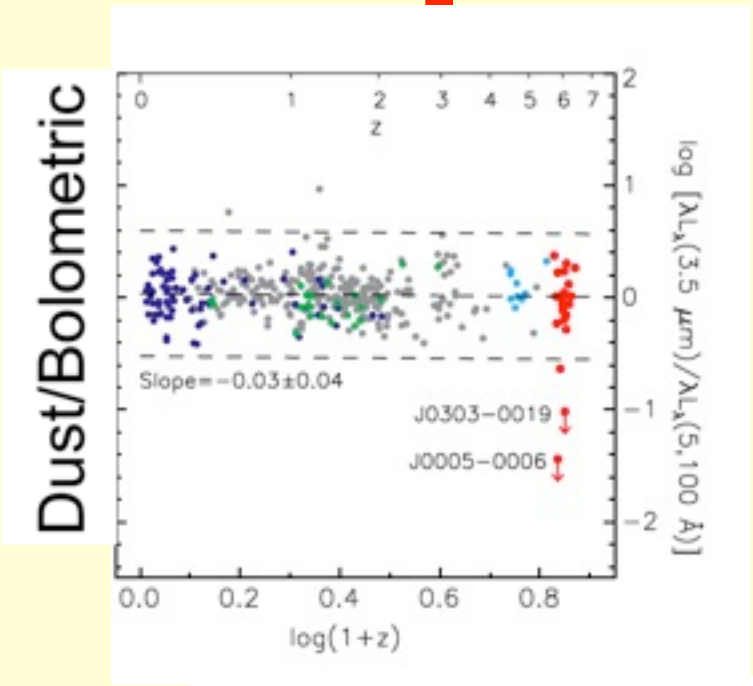
3.5μm 4.8μm 5.6μm 8.0μm 16μm 24μm

- ***quasars with no hot dust***
  - Spitzer SEDs consistent with disk continuum only
  - ***No similar objects known at low-z***
  - ***no enough time to form hot dust tori? Or formed in metal-free environment?***



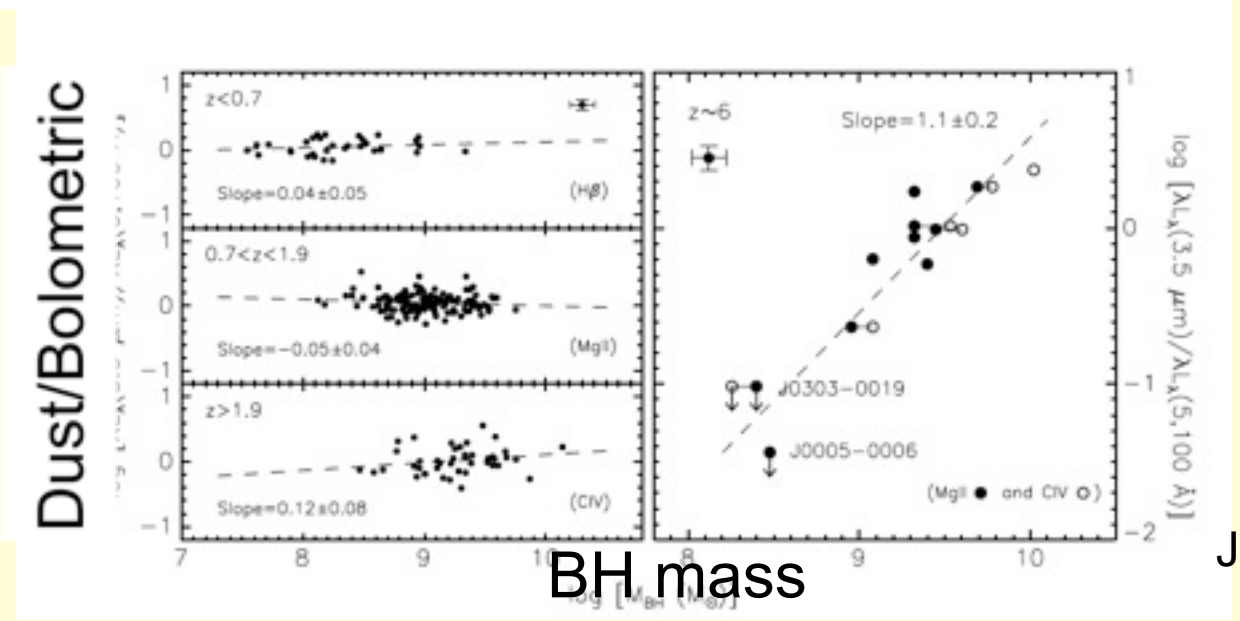
Jiang, XF et al. 2010

Epoch of first quasars?



Dust-free quasars:

- Only at the highest redshift
- With the smallest BH mass
- **First generation supermassive BHs from metal-free environment?**
- **How are they related to Pop III?**



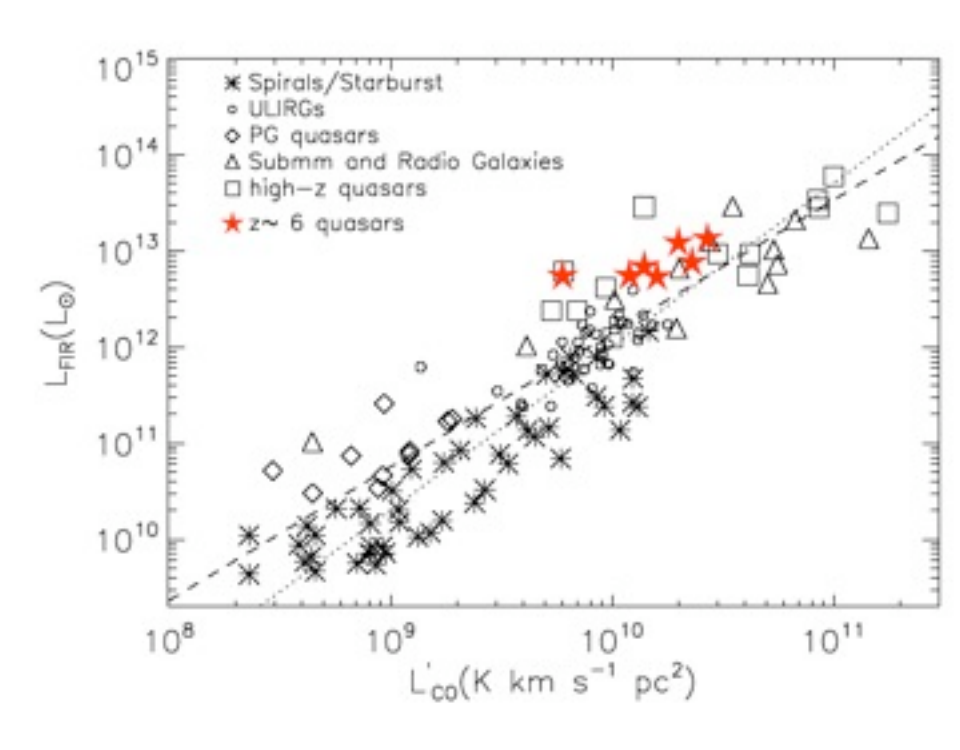
Jiang, XF et al. 2010

Sub-mm and Radio Observation of High-z Quasars

- Probing dust and star formation in the most massive high-z systems
- Advantage:
  - No AGN contamination
  - Give measurements to
    - Star formation rate
    - Gas morphology
    - Gas kinematics
- ALMA!

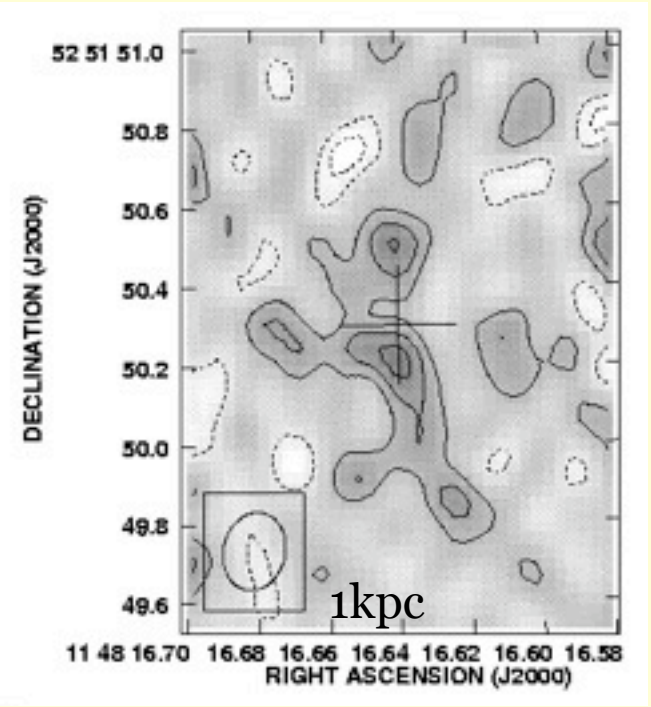
Star Formation in z~6 Quasars

- 30% of z~6 quasars detected at 1mJy level in 1-mm ->
  - $L_{FIR} \sim 10^{13} L_{sun}$
  - T~50K
  - **SFR~1000 $M_{sun} yr^{-1}$** (if dust heated by SB)
- submm-faint quasars also show detections after stacking
  - average SFR > 100 $M_{sun} yr^{-1}$



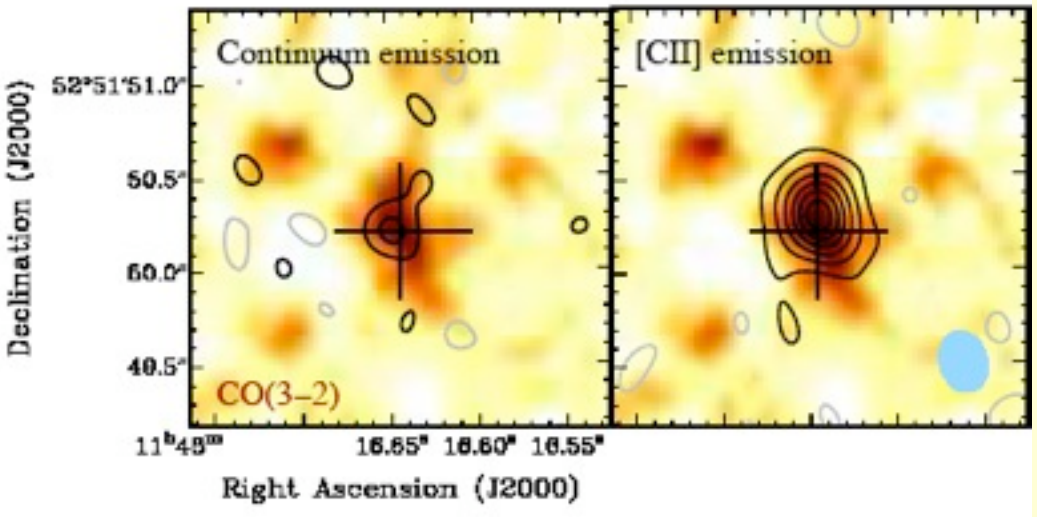
Wang et al. 2008, 2009,2011

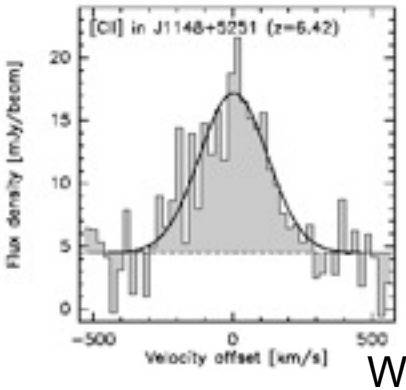
Maximum starburst in z=6.4 quasar ?



Walter et al. 2004

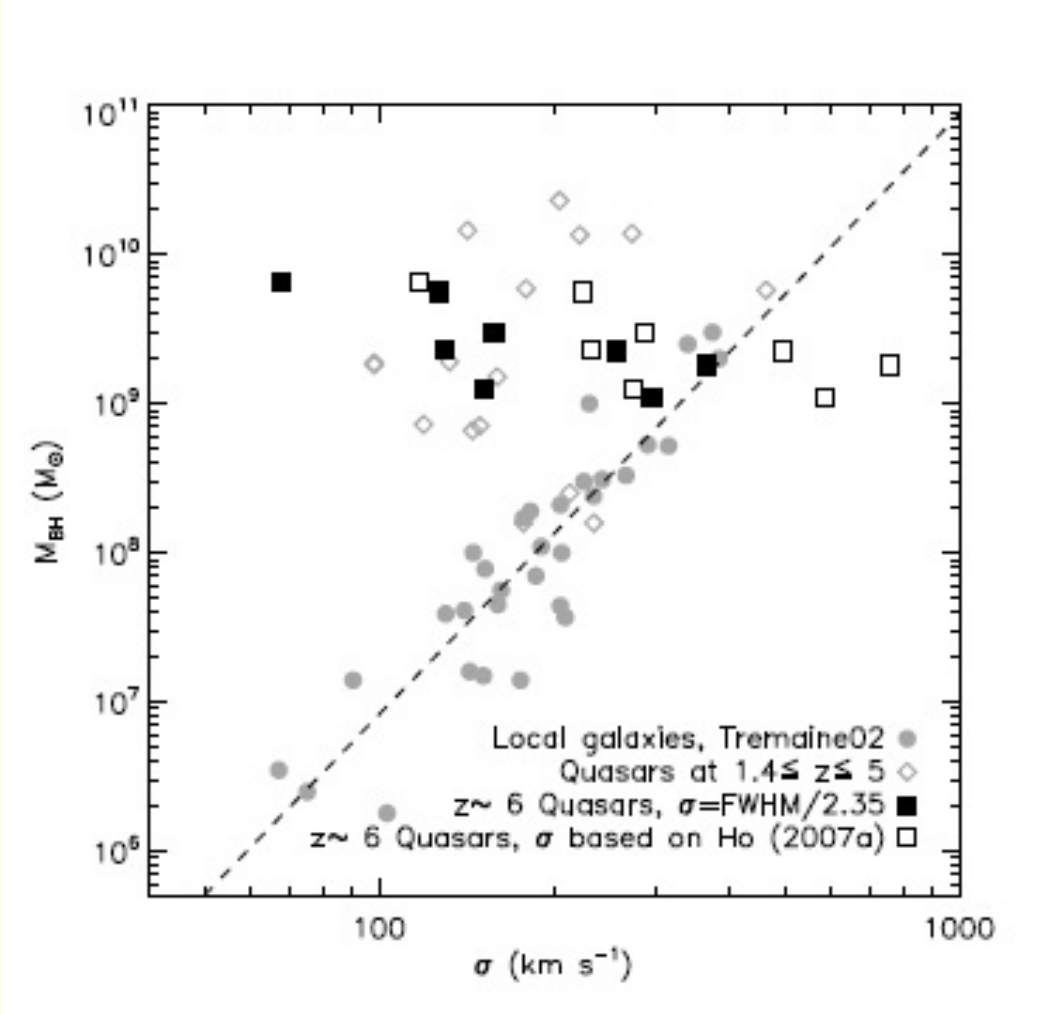
- Spatially resolved CO and [CII] emissions:
  - Size: ~1.5 kpc from [CII] (0.3")
  - Star formation intensity of: ~1000 $M_{sun}yr^{-1}kpc^{-2}$
    - Eddington limited maximum star formation rate (Thompson et al.)?
    - Gas supply exhaused over a few t_{dyn}
  - Similar SF intensity to Arp 200 but 100 times larger!
- Dynamical mass:
  - CO/CII line width ~300km/s
  - Dynamical mass ~$10^{11}M_{sun?}$
  - **BH formed earlier than completion of galaxy assembly?**





Walter et al. 2009

Evolution (lack) of M-sigma Relation?



Wang et al. 2008, 2010, 2011

Summary

- Luminous quasars existed at z>7
  - fast BH growth; challenges Eddington-limited accretion from stellar seeds
- Quasars looked normal at z~6-7
  - intense star formation and rapid enrichment in quasar environment
- Quasar hosts had modest masses at z~6
  - current day M-sigma relation not yet established
- Strong evolution of IGM absorptions at z~6-7
  - Reionization not yet completed by z~7