# Astro 597A – X-ray Investigations of Active Galaxies: Exploring the Environments of Supermassive Black Holes

## X-rays from the First AGN in the Universe

Manodeep Sinha

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# Outline

- ***Hierarchical Structure Formation***
  - *growth of first BH*
  - *feedback to the environment*
- ***Observational Signature***
  - *xrays (of course)*
  - *ionisation of IGM*
- ***Multi-mission surveys***
  - *detect and observe in different bands*
- ***Conclusions***

# Motivation

***Structure formation***

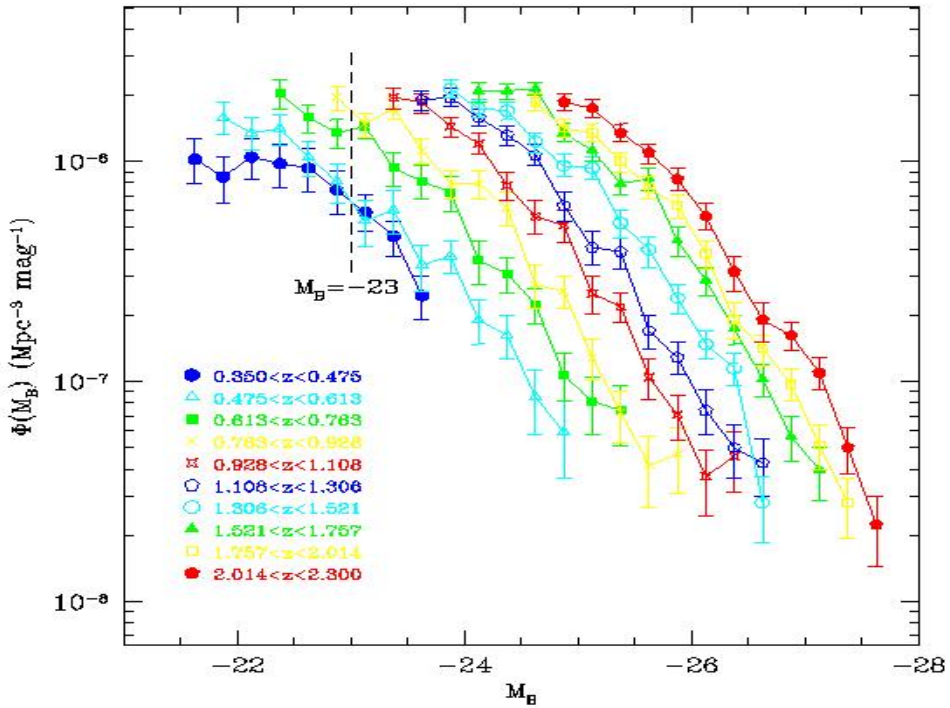
- *Reionisation epoch*
  - *WMAP & Gunn – Peterson trough*
  - *Primary source of ionising photons*

- *Growth of SMBH*
  - *Accretion mode, rate ?*
  - $t_E = \sigma_T c/4\pi G m_p \sim 50$ Myrs

- *Star formation rate*
  - *Peak at lower redshift than QSO activity?*

# High z QSOs (Cristiani et al 2004)

- *SDSS probes high end of QSO LF.*
- *6 QSOs with z >5.7*
- *Faint QSO at z > 4 are too faint*



# High z QSOs (Cristiani et al 2004)

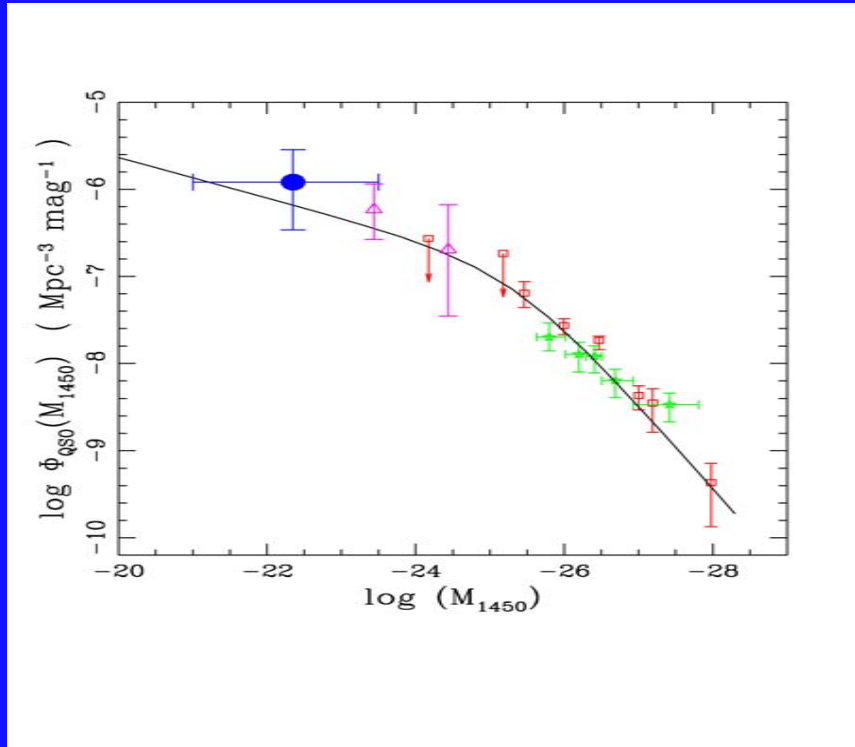
- *GOODS field*
  - *HST B,V,I,z band data*
  - *Chandra 0.5 – 8 keV (S/N = 5)*
  - *flux limits $10^{-16}$ & $10^{-15}$ erg/s/cm$^2$ (0.5-2.0 & 2-8 keV)*

- *detection in z using SExtractor*
  - *22.45 < $z_{850}$ < 25.25*
  - *optical candidates matched with Chandra (3σ)*
  - *z > 4*
- *11 in CDFS & 6 in HDFN*

*NOTE: z > 3.5 xray sources in GOODS must be AGN*

# High z QSOs (Cristiani et al 2004)

- *3 QSOs with z>4*
- *QSO $\rho_N$ reduces by 3.5/z (from 2QZ)*
- *reduction factor 2.1 – 4.3 (SDSS, Fan et al 2001)*
- *PLE fails at > 3σ level*
- *PDE predicts 2.9 QSOs*
- *MIN model*
  - *QSOs in new halos*
  - *const ε = $M_{bh}/M_{DM}$*
  - *Eddington accretion rate*




$$\Phi(L|z)dL = n_{\rm PS}(M_H|z)\int_{t(z)-t_{\rm duty}}^{t(z)} P(t_f|M_H,t(z))dt_f\epsilon^{-1}\frac{dL}{L_{\rm Edd}}$$

# High z QSOs (Cristiani et al 2004)

- ***MIN model overpredicts*** **$N_{QSO}$ z>4 (151 QSOs)**
- ***delay in QSO activity after DM formation resolves***
- ***Expected QSOs ~ 3.2 for z>4***
- ***z > 4 QSOs with $M_{1450}$ ~ -23 lower than theoretical predictions***
- ***feeding/formation of SMBH hindered at high z***

# Stacking Analysis

- *Sources from other surveys*
- *Cell of variable size surrounding source*

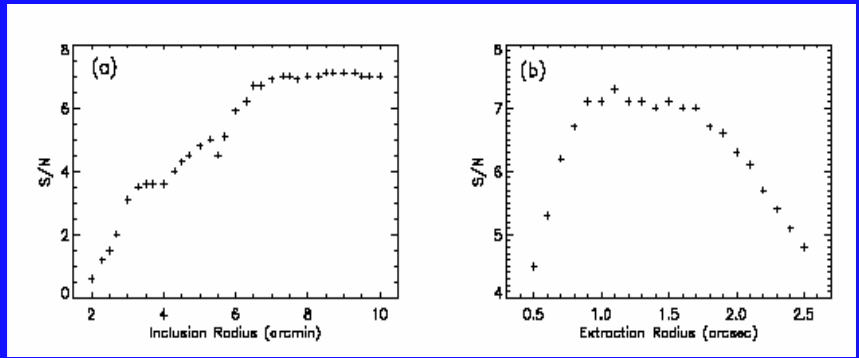
- *Variable aperture size*
  - *positioned randomly around source cell*
  - *repeated Monte-Carlo simulations*

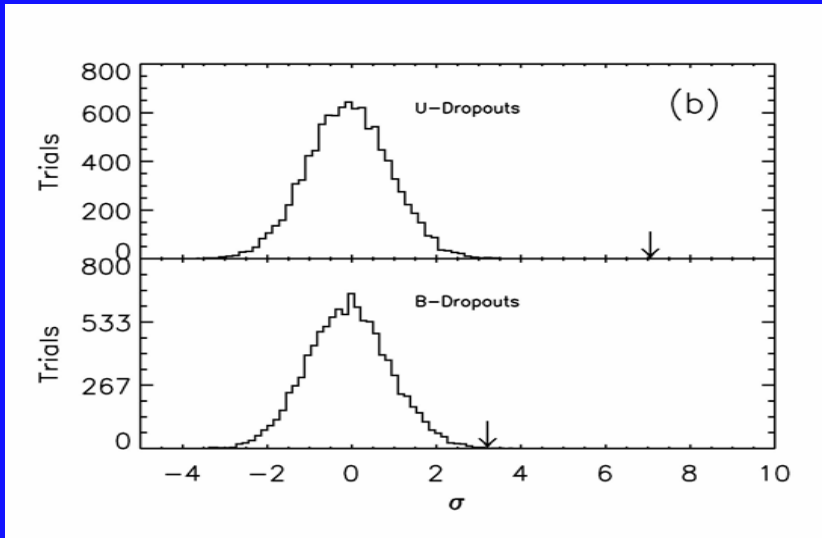
- *simulate with different aperture, cell size ( one)*

- *Iterate till S/N maximises*
- *Estimate background for each individual source*

# Stacking Analysis

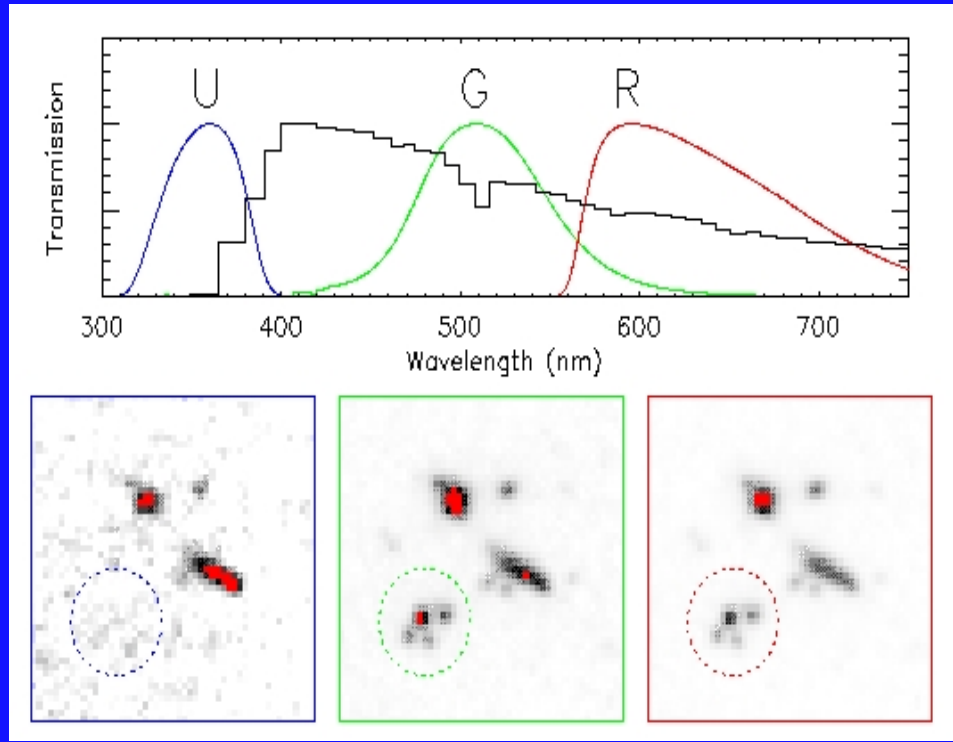
- *Stack numerous similar sources*
- *Extract mean information statistically*
- *S/N~ (S-B)/B$^{0.5}$*
- *Effective exposure times of ~ Gs !!*



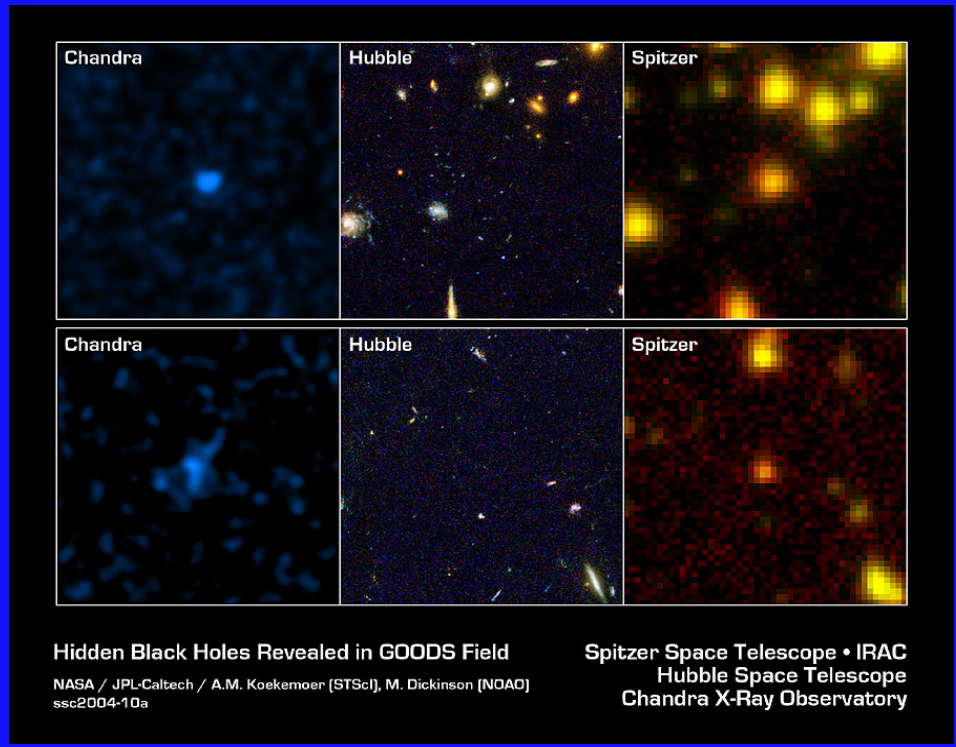
# Xray properties of LBGs in GOODS

- ***phase lag in star formation***
  - *peak between z 1.5-3 ?*
  - *evolution of $L_X/L_B$ with z*
- ***Why LBGs ?***
  - *for z > 2.5, LBGs are U-dropouts*
  - *photometric z*
  - *higher z leads to B-dropouts*



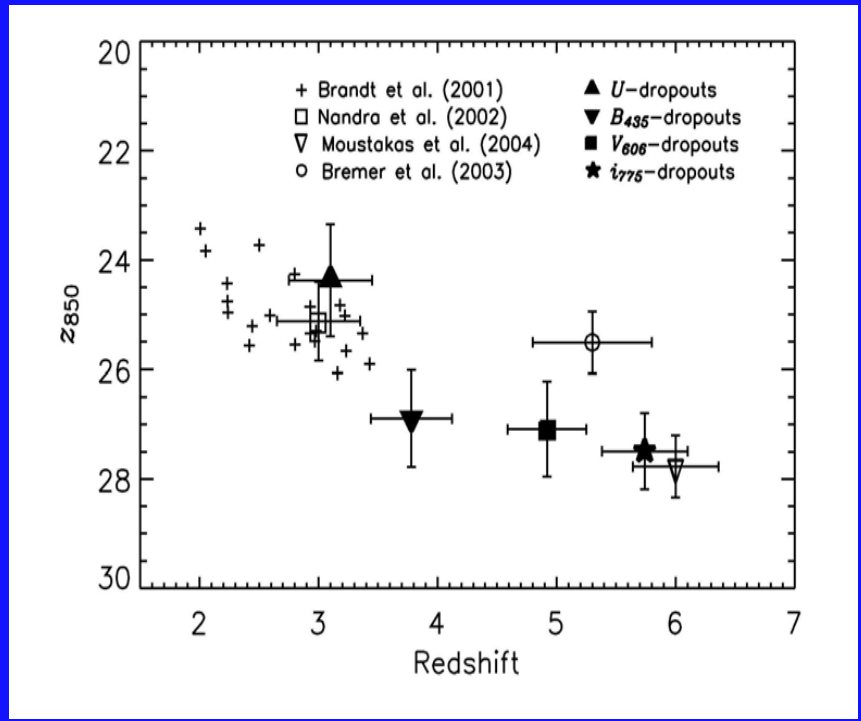
# Xray properties of LBGs in GOODS

- ***GOODS survey***
  - SPITZER, Hubble, Chandra
  - 320 sq arcmin in HDFN & CDFS
  - HST data in $B_{435}$, $V_{606}$, $i_{775}$ & $z_{850}$
  - U band data from KPNO

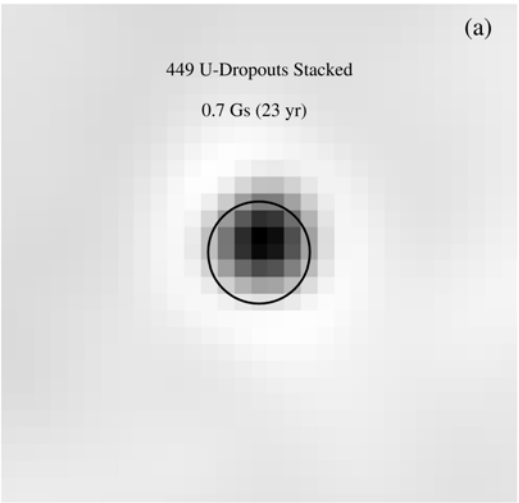


# Xray properties of LBGs in GOODS

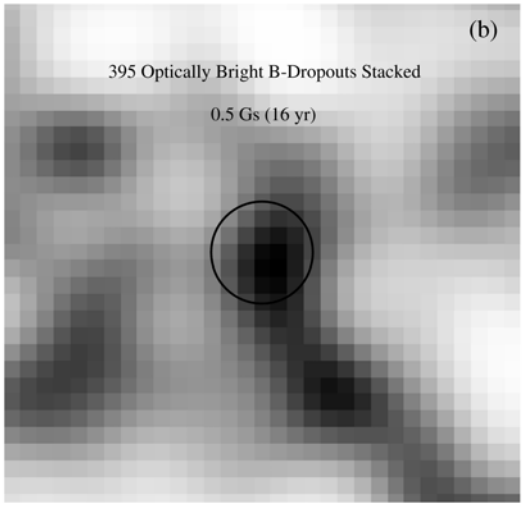
- ***color magnitude selection***
  - *galaxies with z ~ 3, 3.8, 4.9 & 5.74*
  - *error bars in z grow with z*
  - *$t_L$ = 11.5 Gyrs for U dropouts*
- ***$L_X = 4\pi d_L^2 f_X (1+z)^{\Gamma-2}$ erg/s***
  ***$\Gamma = 2$***



# Xray properties of LBGs in GOODS

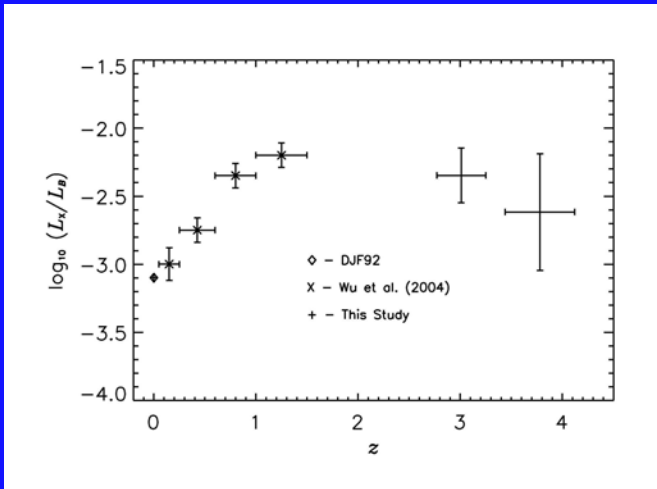


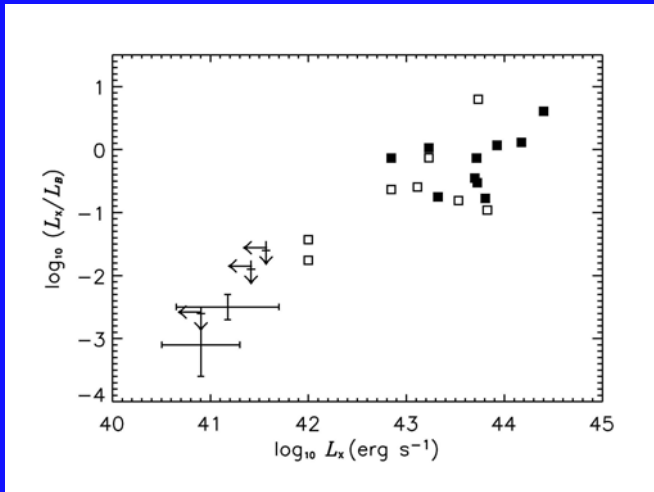

449 U-dropouts with an effective exposure 0.7 Gs. Circle represents 1.5'' aperture




393 bright B-dropouts with an effective exposure 0.5 Gs

# Xray properties of LBGs in GOODS




- $L_X/L_B$ evolves with z
  - maxima at z ~ 2
  - $L_x$ from HMXB

$L_X/L_B$ increases with $L_x$

# Xray properties of LBGs in GOODS

- ***449, 1734, 629, 247 LBGs in U, B, V, I dropouts***
- ***average $L_x \sim 10^{41}$ erg/s***

- ***Modelling SFR as***

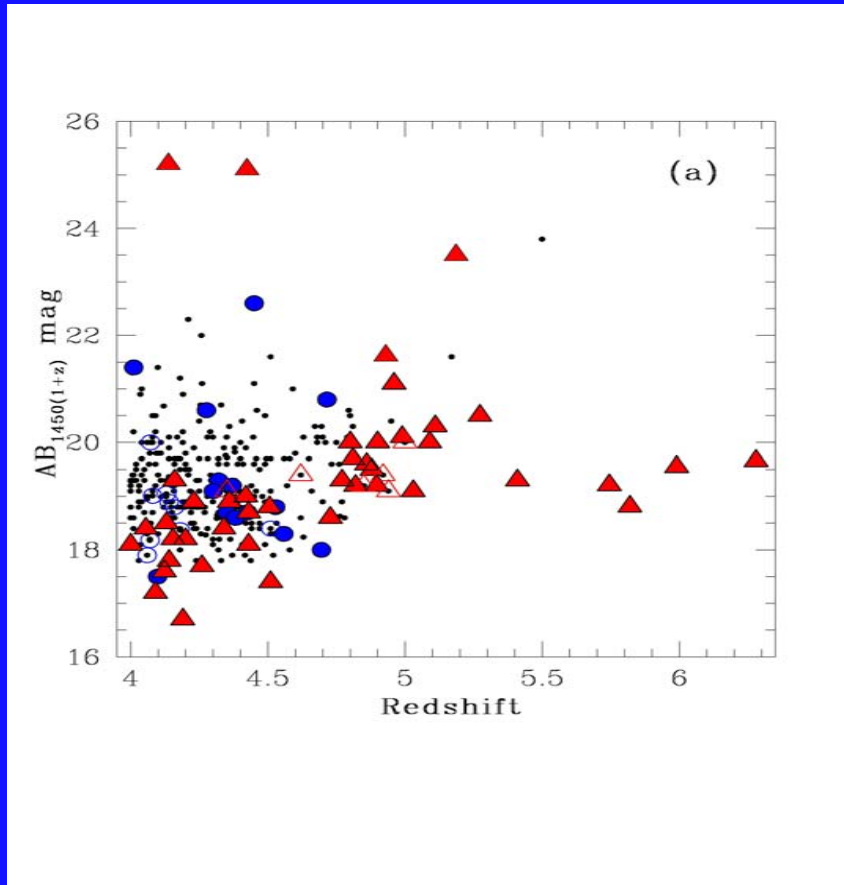
$$SFR(\geq 0.1\ M_\odot) = \frac{L_{2-10}^{\mathrm{HMXB}}}{10^{39}\ \mathrm{erg\ s^{-1}}}\ M_\odot\ \mathrm{yr}^{-1}$$

  - ***SFR: 85 – 240 $M_{sun}$/yr***

# Xrays from the First Massive Black Holes

- *"Do early BHs feed and grow the same way as local ones ?"*
  - *QSO number density changes by 100*
  - *gas fraction for accretion*

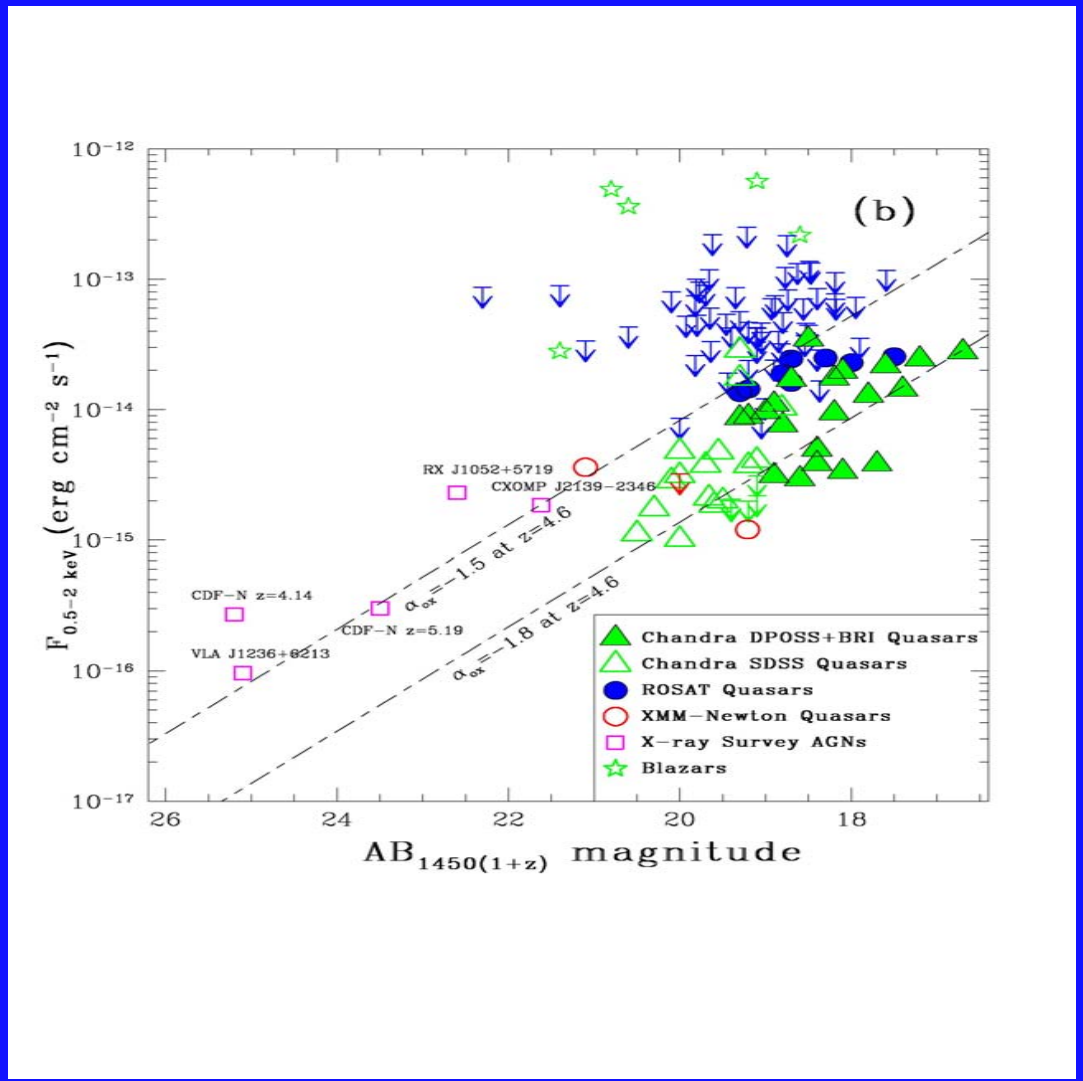
- *Observables*
  - *number density*
  - *luminosity*
  - *photon index*




**2-3 photons at a known location of a source is a significant Chandra detection**

# Xrays from the First Massive Black Holes

- *xray & optical flux correlated*
- *scatter in xray flux*
- *$L_X$ (2-10 keV) ~ $10^{43}$ - $10^{47}$ erg/s*
- *$\alpha_{ox}$ = 0.384 log($f_{2\ keV}/f_{2500\ Å}$)*
- *-1.74 for RQQ (z>4)*
- *-1.56 for low z*
- *luminosity or redshift effect ?*



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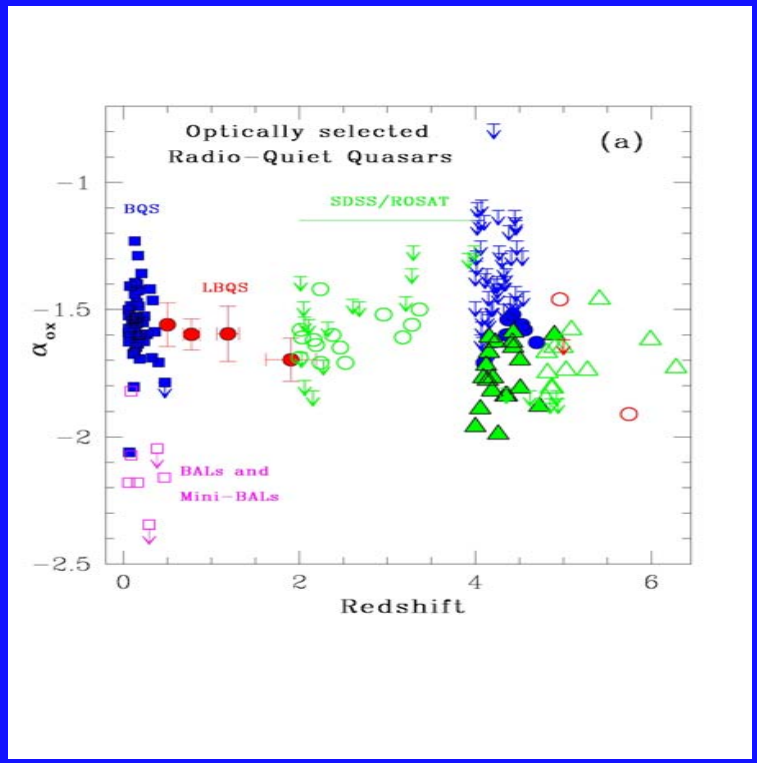


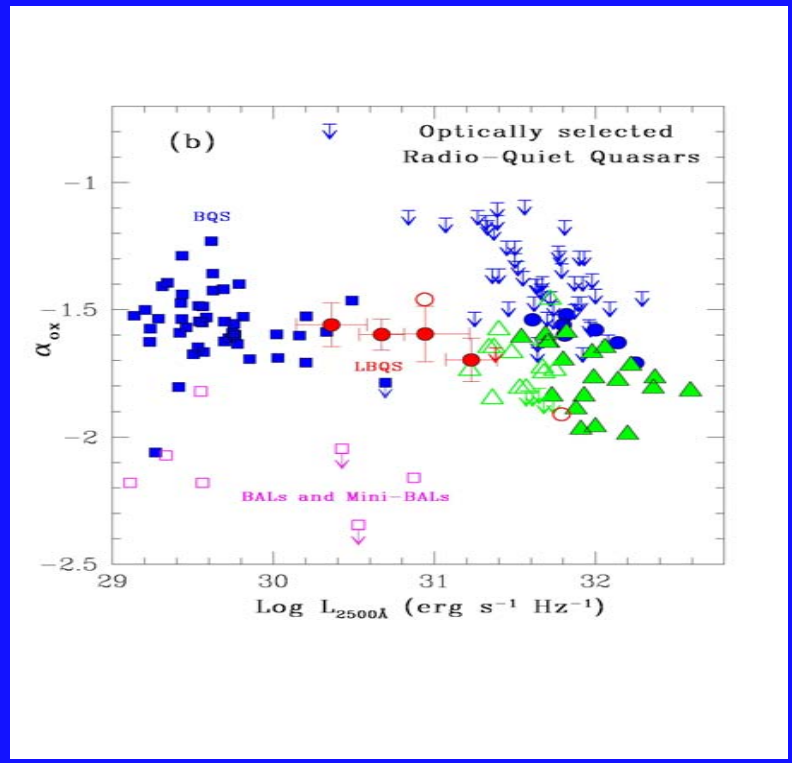


**NO significant dependence on z.**

$\alpha_{ox}$ anti-correlated with luminosity

Gravitational Lensing is an issue – changes the luminosity effect

# Xrays from the First Massive Black Holes

- *joint spectral fitting of Chandra & DPOSS*
  - *$\Gamma$ ~ 1.98 ( z = 4.09 – 4.51)*
  - *consistent with 0<z<3 samples of RQQs*
  - *$N_H$ < 8.8 x $10^{21}$ cm $^{-2}$*
- *joint spectral fitting of Chandra & SDSS*
  - *$\Gamma$ ~ 1.84 ( z = 4.81 – 6.28) with galactic absorption*
- *individual sources do not change much with z*
- *variability not studied*
  - *deepest exposures are ~ 20 mins in QSO rest-frame*

# Xrays from the First Massive Black Holes

- *AGN at z = 4-6 & 0-3 are similar*
  - *photon index ~ 2.0*
  - *$\alpha_{OX}$ ~ -1.5*
- *Similar Xray emission => similar accretion mechanism*
- *Local SED of AGN can be used for high z AGNs*
- *No intrinsic absorption in nascent AGNs*

# Discussion

- *z >4 LLQSOs not numerous enough*
  - *QSO LF flattens at low L*
  - *confirmed by low counts of lensing events in SDSS*
  - *radiative feedback in small DM halos' ? or photoionization by UV background ?*
- *High z AGNs show similar Xray properties as local AGN*
  - *use to estimate mass of SMBH in AGN*
  - *reionisation ?*
- *LBGs are modest AGNs*
  - *$L < 7 \times 10^{41}$ erg/s for z=6*
  - *SFR: 85 – 240 $M_{SUN}$/yr*
  - *$L_X/L_B$ ratio of LBG similar to local starbursts (stacked)*