Chandra Observations of SDSS Quasars at z=6

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ABSTRACT

Chandra snapshot observations of the three most distant quasars then known, at redshifts 5.82, 5.99, and 6.28, gave very significant detections in the short, 6 – 8 Ks, observations. Their X-ray to optical luminosity ratios indicate that quasars will easily be detectable in X-rays if they exist at even larger redshifts. At redshift ≈ 6, those quasars which have X-ray to optical luminosity ratios characteristic of low redshift quasars may be more easily found by X-rays rather than optical surveys. The present observations hint at two exciting discoveries:

1. An extended X-ray source 23 arcsec from SDSS1306+0356 may be a jet, emitting inverse Compton radiation from the Cosmic Microwave Background.
2. SDSS 1030+0524 does not appear to be a point source, and may be a gravitationally lensed system.

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Objectives

- Assess detectability at large redshifts
- Study evolution of X-ray properties
- Search for jets – "X-ray beacons"
- Search for gravitational lenses

Conclusions

- For these 3 quasars, L_x/L_o is lower than median value at z≤ 2, consistent with Quasars at z≈ 4 – 5.
  - Similar quasars can be detected at z=10, in 10 Ks!
  - Expect ≈ 0.1 Quasar deg^{-2} with $L_x \geq 10^{44}$ at z≈6
- SDSS 1030 is NOT a point source! May be gravitational lens
- SDSS 1306 has nearby extended source. May be a related jet.
- Systematic studies are needed with high angular resolution, to assess corrections to be made to fluxes and spectra measured with lower resolution.

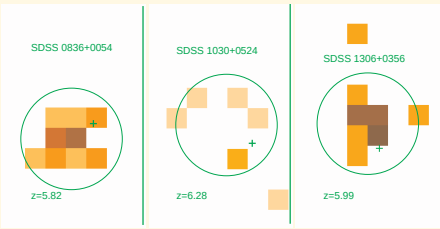

Figure 1. Detection of X-ray emission from the three SDSS quasars at z≈6. The plus signs show the positions given by Fan et al. (2001). The X-ray centroids are all consistent within the absolute astrometric accuracy of *Chandra*. In the 1.′23 radius extraction circles (95% encircled energy at 1.5 keV), we find 21, 6, and 14 counts respectively, for SDSS 0836, SDSS 1030, and SDSS 1306. The pixels displayed have from 1 to 6 counts. The fields shown are 3.′5 × 5.′4. The X-rays are binned into 0.″4913 ACIS pixels.

The photons from SDSS 1030 cannot be from a single point-like source. Even allowing one count to be from background, we must have two or more point sources, or an extended source of about 2 arcsec (12 kpc) diameter.

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SDSS Name[a]	z[a]	Time (ks)	Cnts	Flux[b]	L_X[c]	α_{ox}	Comment
0836+0054	5.82	5.7	21	2.2	2.3	1.66	
1030+0524	6.28	7.9	6	0.45	0.55	1.79	Not A Point Source
1306+0356	5.99	8.2	16	1.2	1.3	1.65	Nearby Jet?
Kaspi et al.	≈4.3					1.56	ROSAT
Vignali et al.	4.1–5.3					1.78	*CHANDRA*

[a] Fan et al. (2001)

[b] Received 0.5–7 keV flux, unabsorbed, in units of 10^{-14}ergs cm^{-2} s^{-1}

[c] Rest frame 2 –10 keV luminosity in units of 10^{45}ergs s^{-1}

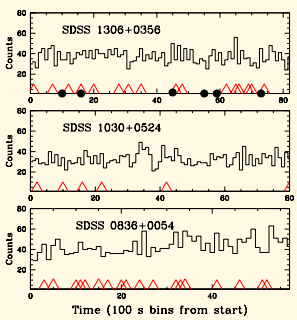

Figure 2. The solid histogram gives the arrival times of all 0.5 to 7 keV counts in the field, binned in 100s intervals from the start of each observation. (The final partial bin is not shown.) The upward triangles show the arrival time of each photon from the quasar extraction circle. The solid dots for SDSS 1306 show the arrival times of photons in the box which is a candidate as an X-ray jet. The uniformity of these assures we are not being contaminated by anomalous background.

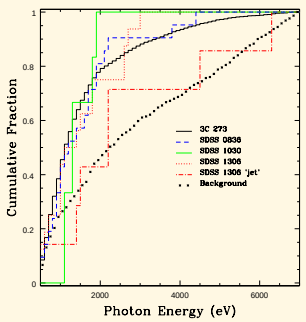

Figure 3. Integral probability distributions of the photon energies from the SDSS redshift 6 quasars. All photons are binned by 100 eV, from 500 to 7000 eV. A KS test allows all spectra to be consistent with the α=0.65 index of 3C273, shown as the heavy curve and based on 3063 photons. The jet spectrum is quite consistent with that of the background counts, shown as the small crosses, while the quasar spectra have only a small probability of consistency with the background spectrum.

Search for an X-ray Jet at Large Redshift

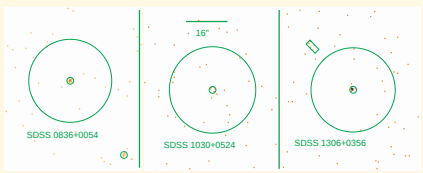

Figure 4. Fields of 52″×62″ around the SDSS quasars. The larger circles show a radius of 100 kpc, projected on the plane of the sky, at the distance of each quasar. These are 16″ to 16.″6. The box to the NE of SDSS 1306 has the 2′ full width of the telescope response, and points toward the quasar core. It contains 7 counts where 0.13 are expected due to background. We interpret this as a possible jet, but cannot exclude other combinations of sources and background. The 7 photons to the SW of SDSS 0836 clearly show the condensation expected for a point source.

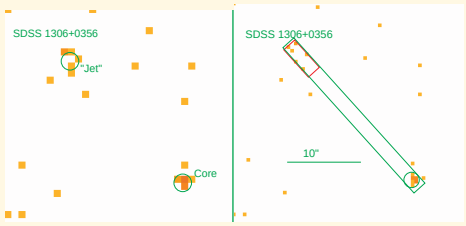

Figure 5. Enlargement of the core and "jet" of SDSS 1306+0356. Left panel bins the 0.5 to 7 keV X-rays in 1″ bins, and the right panel in 0.″492 bins.

Although not unique, the interpretation of the extended source as a jet emitting by inverse Compton scattering on the Cosmic Microwave Background (CMB), is completely reasonable. This is because the CMB energy density is enhanced by $(1+z)^4$, ~2400, and would dominate the energy density of any magnetic field of strength less than 160μG.

However, as shown below, the quasar and jet are not detected in the radio, and the extended X-ray source might be associated with a nearby galaxy.

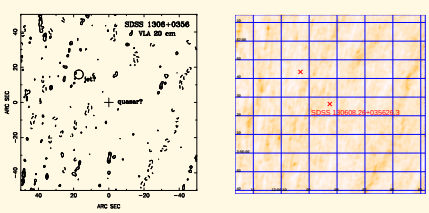

Figure 6. A 1.4 GHz VLA A-configuration image of the region of the quasar SDSS1306 and nearby extended source. Contour levels are -0.1 (broken), 0.1, 0.1*sqrt(2) mJy/beam with a beam of 2″ x 2″. The 3 sigma RMS noise is 0.1 mJy/beam, and this can be taken as the upper limit radio flux from the two exact positions of interest.

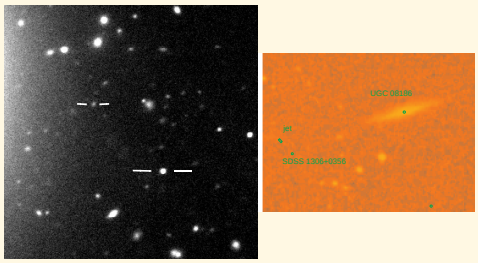

Figure 7. Optical region of the quasar SDSS1306 and nearby extended source. The left panel is from Ivanov (2002), who detects an extended optical source (upper left of the two marked) at the position of the jet. This indicates against the jet being associated with the quasar. The right panel shows the digital sky survey image, with a serendipitous X-ray source in the center of the nearby galaxy UGC 08186, which is at a redshift z=0.0233.