The quest for optically selected Type 2 quasars: the SDSS sample

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Talk outline

- X-ray vs. optical: how to possibly define a Type 2 quasar
- A roundup of recent discoveries from X-ray surveys
- The Type 2 quasar population from optical surveys: SDSS candidates
- X-ray spectral properties of Type 2 quasars with Chandra and XMM-Newton
- Compton-thick AGN hiding among the X-ray faintest Type 2 quasars?
Type 2 quasar: is there a unique definition?

**Optical**: high-ionization, narrow emission-line (FWHM<1500-2000 km/s) spectrum → “big cousins” of local Seyfert 2 galaxies

**X-rays**: high-luminosity (>10^{44} erg/s), obscured (N_H>10^{22} cm^{-2}) AGN → required by XRB synthesis models

CDF-S: z=3.66

(from HELLAS2XMM (CV and Mignoli 2006))
The “ultimate” model for the XLF

Gilli et al. 2006
Prior to Chandra and XMM-Newton discoveries

Ohta et al. 1996

Akiyama et al. 2002

Some mis-identifications of Type 2 quasars due to limited-bandpass optical spectroscopy and poor S/N ratio spectra (e.g., Boyle et al. 1998, Halpern et al. 1999)

An example: AX J08493+4454

z=0.9
CXOCDFS J033229.9-275106: z=3.70 (Norman et al. 2002)

z=3.70, $L_X=10^{45}$ erg/s
$N_H>10^{24}$ cm$^{-2}$, 130 counts

2 $\sigma$ Fe K line [EW~1keV]
Lynx Field: CXO J084837.9+445352: z=3.288 (Stern et al. 2002)

z=3.288, $L_x=3.3\times10^{44}$ erg/s
$N_H=4.8\times10^{23}$ cm$^{-2}$

FWHM$<1000$ km/s
**XMM-Newton** Bright Serendipitous Survey

**XMM-BSS J0216-0435 : z=1.985** (Severgnini et al. 2006)

Type 2 quasars in the Extremely Red Object population

at high $F_X/F_{opt}$ ratios

(see Civano's and Tajer's talks, and Severgnini's poster; Brusa et al. 2005)

**z=1.985, $L_X=4.0 \times 10^{45}$ erg/s**

$N_H=4.7 \times 10^{22}$ cm$^{-2}$
... and also in the mid-infrared with Spitzer

Martinez-Sansigre et al. 2005, 2006

SELECTION MIR+radio typical of QSOs faint in the optical+NIR

AMS16

(IRS spectroscopy), Higdon et al. 2005, Lacy et al. 2005, etc.
The majority of the X-ray obscured AGN do not appear as the "big cousins" of the local Seyfert galaxies, less than 20% of the hard X-ray source population has optical counterparts with high-ionization narrow emission lines (e.g., Barger et al. 2003). To possibly extend the knowledge of the Type 2 QSO population using ground-based optical surveys such as the Sloan Digital Sky Survey (SDSS) and the Digital Palomar Sky Survey at relatively bright magnitude limits and to probe any difference in the X-ray properties of optically vs. X-ray selected Type 2 QSOs.
The SDSS Type 2 quasar sample

Composite spectra of SDSS Type 2 AGN

Zakamska et al. 2003

SELECTION: high-intensity, narrow emission-line spectra
[3800-9200 Å, 1800<R<2100]

S/N>7.5
EW[OIII] > 4 Å (rest frame)
FWHM(Hβ) < 2000 km/s
careful subtraction of the host galaxy contribution

not-homogeneous selection:
28% targets, 42% serend, 19% DSES, 11% special plates

291 Type 2 AGN
z≈0.3-0.8
Selection of Type 2 quasar candidates

[OIII] emission line as a proxy of the AGN activity - emitted from the extended (and likely less obscured) narrow-line region [see also Simpson 1998, Croom et al. 2002, Kauffmann et al. 2003].

QSO regime (classic): $M_B < -23 < L_B / L_{\text{[OIII]}} \sim 100$ for BL AGN
$M_B < -23 \rightarrow L_B > 2.9 \times 10^{10} \text{L}$
$\rightarrow L_{\text{[OIII]}} > 3 \times 10^8 \text{L}$
Spectropolarimetry of SDSS Type 2 quasars

Highest [OIII] luminosity object in the sample (log $L_{\text{[OIII]}} > 10.1$ $L_{\odot}$)

$\sim 15$ sources with polarimetry studies

$\sim 65\%$ with $<\text{polarization}> > 3\%$ [up to 17\%]

vs. NONE in the PG QSO sample
(mean =0.5\%, Berriman et al. 1990)

vs. 10\% in the 2MASS AGN sample (Smith et al. 2002)

$\rightarrow$ Continuum polarization of $\sim 16\%$

Zakamska et al. 2005
Polarization mechanisms

**1. Synchrotron emission:**

- cannot explain the lines in the polarized spectra
- same fractional polarization for Type 1 and 2 AGN in case of moderate extinction
- Type 2 AGN would not be polarized if the continuum is heavily extincted

**2. Dichroic extinction:**

- wavelength-independent polarization angle that reflects the direction of grain alignment

**3. Scattering by off-nuclear electrons or dust:**

- strong support from imaging polarimetry of local AGN
- direct observations of the SCATTERING REGIONS (cones) with HST/A

**Dust scattering** – wavelength dependent polarization fraction and scattering efficiency

- Generally produces a scattering efficiency rising to the blue and a polarization fraction of the scattered light rising to the red → OK for SDSS J1715+2807
- The dilution-corrected polarization values of 10–20% and the size of the scattering regions agree better with dust scattering

Zakamska et al., submitted
The host galaxies of SDSS Type 2 quasars

SDSS J0123+0044 (z=0.399)

- 6/9 Type 2 quasars observed with HST at 0.2<z<0.4
  - 6/9 have elliptical profiles, 1 disky, 2 mixed
  - stellar populations of the hosts are 0.3-0.7 mag brighter and 0.4 mag bluer than M* galaxies at their z

- 18.4 kpc
- Zakamska et al., submitted

- yellow band: 5700-5800 Å rest frame
- UV band: 3000-3200 Å rest frame

- negative (white) residuals: dust obscuration?
- positive (black) residuals: scattered light?

- -26<M_B<-24
Previous highest redshift H$_2$O megamaser at z=0.059 (Tarchi et al. 2003)

L=23,000 L$_\odot$

H$_2$O megamasers mostly associated with Seyfert 2 galaxies

Half of them appear to be Compton-thick

Barvainis & Antonucci 2005
The X-ray view of SDSS Type 2 quasars

Using mostly ROSAT data (CV, Alexander & Comastri 2004a,b)

3/17 SDSS Type 2 quasar candidates detected

“Toy model”: $L_{\text{[OIII]}} \rightarrow L_{[2-10 \text{ keV}]}$ using Mulchaey et al. ’94
→ extrapolated $L_{[0.5-2 \text{ keV}]}$ to be compared with that observed

XMM-Newton \(\rightarrow\) “genuine” Type 2 quasar
($L_X=4.5\times10^{44} \text{ erg/s, } N_H=1-3\times10^{22} \text{ cm}^{-2}$)
some caveats ...

- **Mulchaey et al. (1994)** correlation valid for higher luminosity (redshift) objects

- **Large uncertainties** due to the scatter in the correlation ⇒ range in the derived column densities

- **Reddening to NLR itself not accounted for** [via Balmer decrement; e.g, Maiolino et al. 98, Bassani et al. 99] ⇒ leads to a conservative determination whether or not a source is absorbed in the X-ray band

- (Predicted - Observed) 0.5-2 keV flux ascribed only to absorption

- $\Gamma=1.6$ instead of $\Gamma=2.0$ implies $NH \sim 20\%$ lower; additional soft component in the opposite direction
since 2004 ...

*Chandra* and *XMM-Newton* follow-up observations of the optically brightest

\[ z = 0.390 \quad L_X = 8.1 \times 10^{43} \text{ erg/s} \quad N_H = 3.2 \times 10^{22} \text{ cm}^{-2} \]

\[ z = 0.596 \quad L_X = 7.4 \times 10^{44} \text{ erg/s} \quad N_H = 5.5 \times 10^{22} \text{ cm}^{-2} \]

Ptak et al. 2006
Chandra exploratory observations + archival fields
(CV, Alexander & Comastri '06)

4/6 targets detected
(3-80 counts, 7-11 ks,
$F_X \approx 10^{-15} - 10^{-13}$ erg/cm$^2$ s)
+
6/10 archival/serend
detected

direct X-ray spectral
information for 7 sources
$N_H \approx 10^{22} - 5 \times 10^{23}$ cm$^{-2}$
more deeply into the spectral results

$N_H \approx 3.8 \times 10^{23} \text{ cm}^{-2}$

$N_H \approx 1.5 \times 10^{22} \text{ cm}^{-2}$

CV, Alexander & Comastri '06

Chandra’s ability to provide X-ray constraints with $<100$ counts …
Compton-thick quasars?

possibility that the X-ray faintest Type 2 QSOs and those undetected hide Compton-thick quasars

→ needs further checks and larger samples with sensitive X-ray observations to probe the X-ray weak Type 2 quasar population
another way of looking at the results

X-ray brightest Type 2 QSOs: peak of the iceberg of the SDSS Type 2 QSO population, where most are either Compton-thick or intrinsically X-ray faint?

Highly variable population? Weak in the X-ray (X-ray quiet state) but still luminous in [OIII]?
Next steps: further observations

- To probe the X-ray properties of SDSS Type 2 QSOs further with Chandra and XMM-Newton:
  - average properties from stacking analysis for the X-ray weak sources (limited at present by the paucity of counts)
  - stacked X-ray spectra in different $N_H$ bins to search for faint spectral features (e.g., Alexander et al. 2005)

- To define the number of optically selected Type 2 QSOs → contribution to the XRB?

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<table>
<thead>
<tr>
<th>L_{2-10 keV} (erg/s)</th>
<th>L_{0.1-10 keV} (erg/s)</th>
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<tr>
<td>$10^{41}$</td>
<td>$10^{45}$</td>
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<td>$10^{42}$</td>
<td>$10^{44}$</td>
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<tr>
<td>$10^{43}$</td>
<td>$10^{45}$</td>
</tr>
</tbody>
</table>
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Requested 12 more Type 2 QSOs for observations with Chandra

...or...
The DPOSS Type 2 quasar sample

The [OIII] line in the r band $\Rightarrow z=0.31-0.38$ $ho<0.01/\text{deg}^2$ (Djorgovski et al. 2001)
15 Chandra observations (5–15 ks) in the archive... 
Laurea thesis by Agnese Del Moro

12/15 sources detected
(11 with <40 counts)
\[ F_{(0.5-8 \text{ keV})} = 1 \times 10^{-15} - 7 \times 10^{-14} \text{ erg/cm}^2\text{s} \]

11 measured HR
8 sources have HR>0
suggesting \( N_H > 10^{22} \text{ cm}^{-2} \)
Spectral results for the DPOSS Type 2 QSOs

Average spectrum

- Scattering model: $N_{H_2} \approx 8 \times 10^{22}$ cm$^{-2}$
- Scattering fraction $\approx 17\%$

Iron line? $z=0.32 \pm 0.05$ keV
- Low significance, $EW \approx 700 \pm 500$ eV

Individual X-ray spectrum for one source only (half of the total counts): $N_{H_2} \approx 4 \times 10^{22}$ cm$^{-2}$

Similar spectral results using only the 8 sources with HR>0

If the same scattering model is applied for the 3 sources with HR<0 (33 counts):
- $N_{H_2} \geq 10^{24}$ cm$^{-2}$ (Compton-thick)
a different approach to the problem

... the Calvin's attitude ...

The end