X-ray Spectral Properties of SDSS DR5 Quasars in the ChaMP

P.J. Green[1], T.L. Aldcroft[1], G.T. Richards[2], Michael Weinstein[3],
W.A.Barkhouse[1], D.-W.Kim[1], M.Kim[4], D.-W.Kim[1], A.E. Mossman[1],
B.J. Wilkes[1], H. Tananbaum[1] and the *ChaMP Collaboration*

http://hea-www.harvard.edu/CHAMP

[1] Smithsonian Astrophysical Observatory, Cambridge, MA, [2] Drexel, [3] Penn State, [4] Seoul

Paul

Unlisted co−Author

Chandra Multiwavelength Project (ChaMP)

ChaMP *Classic*

- 148 ACIS $I+S$ fields (Cycles 1+2)
- exposures $2 < T < 120$ ksec
- Survey area $\sim 10\,\mathrm{deg}^2$
- $\sim$ 6000 detected sources published with log$N$-log$S$ ((See Kim et al. poster nearby)
- 65 fields with deep (mag$\sim$25) NOAO/MOSAIC *gri* imaging
- 68 fields with SDSS DR5 overlap

Extension: ChaMPX

- 218 *new* X-ray fields through Cycle 6 w/SDSS DR4 overlap
- 285 total SDSS overlap fields

ABSTRACT

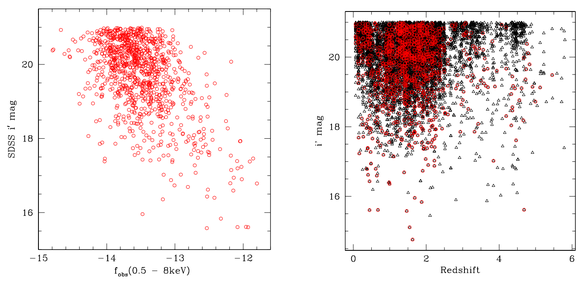
AGN unification models spawned in the optical are now confronted with multiwavelength data that break the simplest Type I/II dichotomy. For instance, some broad emission line (optical Type I) AGN (BLAGN) are found to show significant X-ray absorption, and some narow line AGN (NLAGN) show none. Some of the absorbed BLAGN are explained as BALQSOs, but some are not. We cross-correlate the largest intermediate depth *Chandra* X-ray survey, the ChaMP, with a new SDSS photometric quasar catalog (extending to fainter mags and larger populations than the SDSS spectroscopic sample), and study the X-ray properties of luminous broad line quasars. This constrains the absorbed fraction, identifies new BALQSO candidates, and tests claims of absorption trends with redshift or luminosity.

Efficient Photometric Selection of Type I Quasars

- SDSS's original quasar color selection algorithms (Richards et al. 2002) used *ugri* to identify UVX quasars, and *griz* for z>3 quasars.
- A newer algorithm (Richards et al. 2004) uses a nonparametric Bayesian classification (NBC) based on kernel density estimation (KDE), to efficiently select unresolved quasars in 4-D color using large (N>10^4) training sets of SDSS quasars spanning 0.08<z<5.4 and 14.99<i'<21.55. (See Richerds et al. poster, this workshop).
- High-z candidates with $(u-g)$>1 can now be included thanks to a larger high-z quasar sample in the training set.
- Efficiency (fraction that are truly QSOs cf. 2QZ) is >95%. Completeness is 95% to $z\sim 2$. Further tests underway.

Matching to ChaMP X-ray Catalog

- We cross-matched the list of SDSS DR5 quasars to the current ChaMP X-ray catalog with a 4″ search radius, finding 1027 unique matches
- By shifting the Declination arbitrarily 30″ North and rematching, we demonstrate a spurious match rate of 0.7%

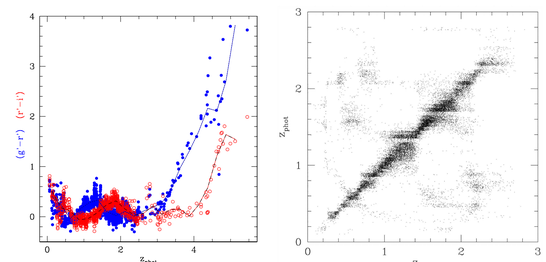


LEFT: Optical i' mag *vs* observed broadband X-ray flux for 1027 X-ray/optical matched sources from the SDSS DR5/ChaMP. The median (turnover) f_X(0.5-8 keV) is 2.4 (1.5) $\times 10^{-14}$ cgs.

RIGHT: Optical i' mag *vs* redshift for all SDSS QSOs within 20′ of each *Chandra* pointing (black dots) and for those with X-ray detections (red circles). X-ray detection is slightly biased towards brighter mags mainly for $z\gtrsim 3$.

Photometric Redshifts of Quasars

- The photo-z method (Weinstein et al. 2004) minimizes the difference between the measured colors of each object and the median colors of quasars as a function of redshift.
- 86.0% of photo-zs are correct ±0.3, 64.8% within ±0.1.
- The photo-z code yields the probability of an object being in a given redshift range: these probabilities are accurate in the ensemble average. z_{phot} vs. z_{spec} is shown here (Fig 7a from Richards et al. 2004) for 22,191 confirmed QSOs in their non-parametric Bayes classifier (NBC) catalog.



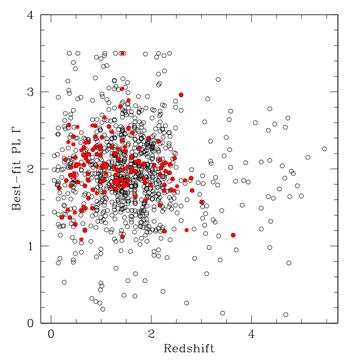
X-ray Spectral Extraction & Fitting w/ YAXX

YAXX (Yet Another X-ray Xtractor) is a Perl script (Aldcroft et al. poster, *right next door*). that batch processes *Chandra* spectral data using CIAO tools, *Sherpa*, S-lang, and Perl open source software. It includes automated spectral extraction, fitting, and report generation.

For this application, we performed 3 types of fits, each with fixed N_H^{Gal} and redshift:

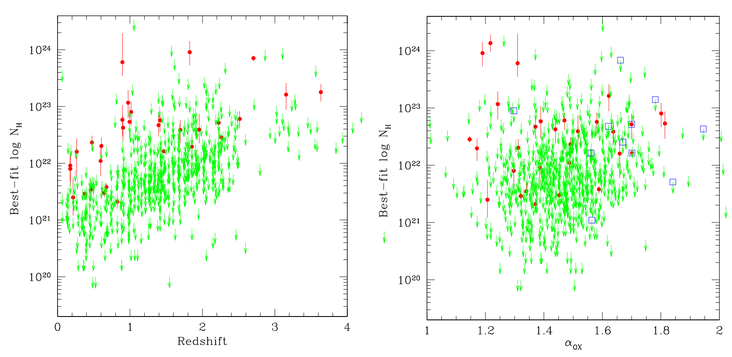
1) `pl`: Γ free with N_H frozen at N_H^{Gal} (all sources)
2) `pl_abs`: Both power-law Γ and intrinsic absorption N_H^{intr} free, for sources with (0.5-8 keV) counts>200
3) `plfix_abs`: N_H^{intr} free with Γ fixed at 1.9 (all sources)

No Trend in Spectral Slope with Redshift



Best-fit power-law Γ vs. redshift for 1027 SDSS/ChaMP Type I QSOs. No trend with redshift is evident. Open black circles are spectral fits with absorption fixed at N_H^{Gal}. Filled red circles are for both Γ and N_H^{intr} free, when counts>200.

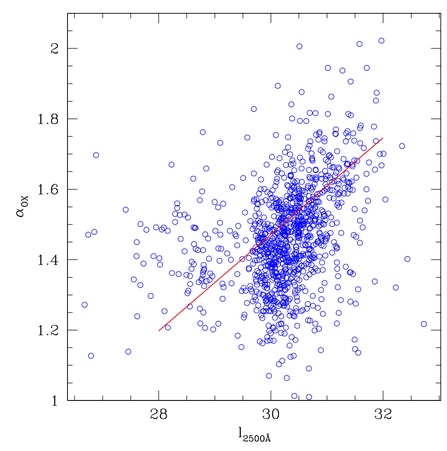
Apparent Trends in Absorption



LEFT: Best-fit log N_H^{intr} vs. log (1+z) for fixed Γ. Green arrows show upper limits to N_H^{intr} at 90% confidence. Red dots show N_H "detections" wherever the 90% lower-bound exceeds 10^{20} atoms cm^{-2}. The apparent trend is strongly affected by 2 observational effects at high-z: the weaker spectral absorption at higher rest-frame energies *and* the general decrease in counts available for fitting.

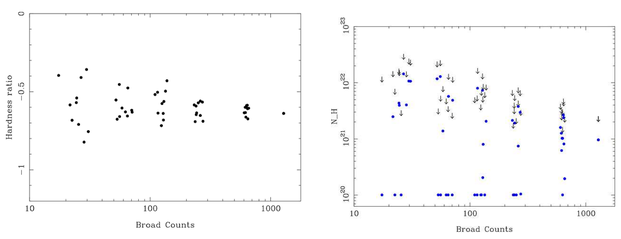
RIGHT: Best-fit log N_H^{intr} vs. α_{OX}. No strong trend is visible here. Blue boxes mark the known BALQSOs, which tend to cluster towards X-ray weak (larger α_{OX}) and large N_H^{intr} as expected (Green & Mathur 1996; Green et al. 2001, Gallagher et al. 2006). The upper right-hand region should be rich in BALQSOs. The completeness of SDSS QSO selection for BALQSOs has not yet been estimated.

Spectral Energy Distributions



X-ray to optical flux ratio (parameterized by α_{ox}, the hypothetical power-law between restframe 2keV and λ 2500Å fluxes) *vs.* optical luminosity. We derive $l_{2\,keV}$ using the best-fit powerlaw Γ with N_H^{Gal} only. Shown as a red line is the best-fit relation between the wide z-range, multi-sample compilation of Steffen et al. (2006). Their fit does not represent the current sample over its (more limited) luminosity range.

Redshift Bias in Nh Measurements



LEFT: To test for the biases in best-fit N_H^{intr} we generated 10 random subsamples of the original exposure time at each of 2%, 5%, 10%, 20%, 50% (and 100% on the far right) for a bright source, and calculated hardness ratios. As expected, no strong trend is seen. Note that this test does *not* account for decreased detection likelihood, esp. towards low counts $\leq$10.

RIGHT: Best-fit values of N_H^{intr} are shown as blue dots, with the corresponding 90% upper confidence limit shown as black arrows. This plot shows a clear trend, reflecting the skewed (one-sided positive definite and logarithmic) nature of the N_H parameter.

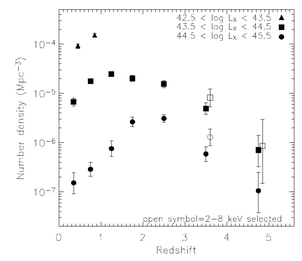
Co–Moving Space Density

Figure from *Evolution of Supermassive Black Holes at High Redshift*, Silverman, J.D. et al. 2006, in prep.

- Peak shifts to lower redshift for lower luminosity AGN.
- High L_X AGN show peak near $z=2.5$, similar to recent optical/radio surveys (Richards et al. 2006; Jiang et al. 2006; Wolf et al. 2003; Wall et al. 2005).

Our results are similar to other recent results (e.g., Hasinger, G., et al. 2005, Barger et al. 2005; Ueda et al. 2003) but with significant improvement at z>3.

Models and data still disagree beyond z=3. While the ChaMP is contributing more high-z AGN than any other deep X-ray survey, statistics and completeness are still too poor to constrain the evolution of supermassive black holes during their epoch of formation. The primary constraint is adequate time for spectroscopy on large ground-based telescopes. The SDSS/DR5 sample provides 66 X-ray-detected QSOs with z>3.



REFERENCES

Gallagher, S. et al. 2006, ApJ, 644, 709
Green, P.J. et al 2001, ApJ, 558, 109
Jiang, L., et al. 2006, AJ, 131, 2788
Richards et al. 2004 ApJ, 155, 257
... 2006 AJ, 131, 2766
Steffen, A. et al. 2006, AJ, 131, 2826
Weinstein, M.A. et al. 2004, ApJS, 155, 243
Wolf, C. et al 2003, A&A, 408, 499

SUMMARY & PLANS

- Luminous Type I quasars can now be efficiently selected from SDSS imaging, and photometric redshifts are derived that are accurate enough for luminosity functions.
- Wide-area sensitive X-ray surveys like the ChaMP are required to probe the high-redshift XLF. The ChaMP spectroscopic campaign continues with Gemini, Magellan, etc., but the high-z XLF still needs many more $z>3$ X-ray-selected quasars.
- The number of z>3 quasars with serendipitous Chandra measurements more than doubles via use of these ChaMP/SDSS DR5 quasars.
- YAXX spectral fitting provides spectral constraints and in turn more accurate luminosities to examine trends in spectral energy distributions.
- Our preliminary analysis of the SEDs and X-ray spectral properties of this sample reveals
  - No strong trends of best-fit Γ with redshift
  - Trends of best-fit N_H^{intr} can mostly be explained by measurement bias

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http://hea-www.harvard.edu/CHAMP
for papers, results, images, spectra, and data!