Resubmission of -0000

NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: September 30, 2003 **Category:** Active Galaxies

The Hardest X-ray Sources Unveiled

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
The hard Cosmic X-ray Background (CXRB) has been resolved into point sources by the Chandra deep field exposures as predominantly low luminosity objects at $z < 1$, and the nature of these AGNs is not well understood. The best X-ray population synthesis models of the CXRB require these but also a substantial component from high-L_X absorbed AGN (Type 2 QSOs). We propose Gemini spectroscopy of a sample that addresses the 2 primary questions that these populations pose. We have observed with 126 Chandra pointings a 9 deg^2 region overlapping the NOAO Deep Wide Field Survey (NDWFS). Our survey selects the heavily absorbed low-L_X objects at redshifts of a few tenths where we can likely detect their AGN spectroscopically even amidst a bright host galaxy. It also uniformly samples the largest volume to date in the hunt for the elusive Type 2 QSOs.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	GEM-N	GMOSN	3	dark	Mar - May	Feb - Jun
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

We propose Gemini spectroscopy to measure the redshifts and emission-line fluxes for a sample of X-ray sources with particular relevance to understanding the cosmic X-ray background (CXRB) and black hole growth. The goal is to understand how these objects relate to standard AGN classes, and hence how to better connect the CXRB sources with our understanding of AGN physics.

The sample consists of a subset of hard X-ray sources in a recent Chandra survey of the NOAO Deep Wide-Field Survey (NDWFS) Bootes field. The targets were chosen because they display particularly large ratios of hard to soft photons in the X-ray spectrum, probably caused by strong photoelectric absorption of the soft X-rays by gas in front of the X-ray source (Figure 1). Absorbed sources of this type are believed to contribute a significant fraction of the CXRB, based on constraints from source number counts and the background spectrum (e.g., Gilli 2003; Figure 2a).

The Bootes sample we propose here exploits the unusually large contiguous areal coverage of the Chandra-NDWFS survey, which spans 9 square degrees. The Chandra exposures for this field are rather shallow (5 ksec each), and the combination of shallow depth and large area means that many of the sources that we have identified are relatively bright and nearby. The appearance and bright optical magnitudes for these counterparts suggest that they have typical redshifts of a few tenths, which would imply low-to-intermediate X-ray luminosities (typically $\gtrsim 10^{42}$ erg s^{-1}). In contrast, most recent studies of the CXRB source population have relied heavily on small-area studies employing only a few, very deep Chandra pointings. The small areal coverage means that relatively few bright examples of low-z hard x-ray sources have been found in these surveys; a recent compilation by Cowie et al. (2003), which adds in ASCA results, has only about a dozen objects at $z \lesssim 0.5$ with hard x-ray fluxes above the flux limit of our Bootes survey (3×10^{-14} erg cm^{-2} s^{-1}).

By working with bright, nearby sources, we want to obtain high signal-to-noise spectra to get at the question of what kind of AGNs these things are. The alternatives include 1) quasar-like objects with broad lines, in which case they are prime candidates for harboring broad-absorption-line outflows that provide the absorption (e.g., Green et al. 2001); 2) Seyfert 2-like objects showing narrow, high-ionization lines, implicating a probable circumnuclear torus or similar blocking structure; 3) highly extinguished or intrinsically faint sources in which emission lines from any kind of AGN are not readily seen. All three categories are found in the existing deep surveys (e.g., Barger et al. 2003), but the quality of those very faint optical spectra is variable and the properties of the emission lines, when detected, have not been studied in detail (the spectra are often not flux-calibrated). Objects in the second category, while expected at high luminosities (Type 2 quasars) are surprisingly rare (e.g., Norman et al. 2002, Schmidt et al. 2002). Moran et al. (2002) have also noted that some of the objects in the third category may have their optical AGN signatures swamped by the circumnuclear galaxy light. The shallow nature of our survey reduces our sensitivity to this effect: distant objects with large metric apertures will have quasar-like luminosities, while in nearby sources we can resolve out much of the surrounding galaxy light (see Figure 3).

The larger significance of the objects we are targeting is that they trace the dominant channel for the buildup of black holes. As discussed by Cowie et al. (2003), the luminosity dependence of AGN evolution implies that black hole growth is dominated by intermediate- and low-luminosity AGNs. The X-ray background results indicate that the majority of these objects should be highly absorbed (Gilli 2003). With our selection based on X-ray hardness ratios measured in a shallow survey, we will obtain a quantitative description of the dominant mode of black hole construction and its associated phenomenology.

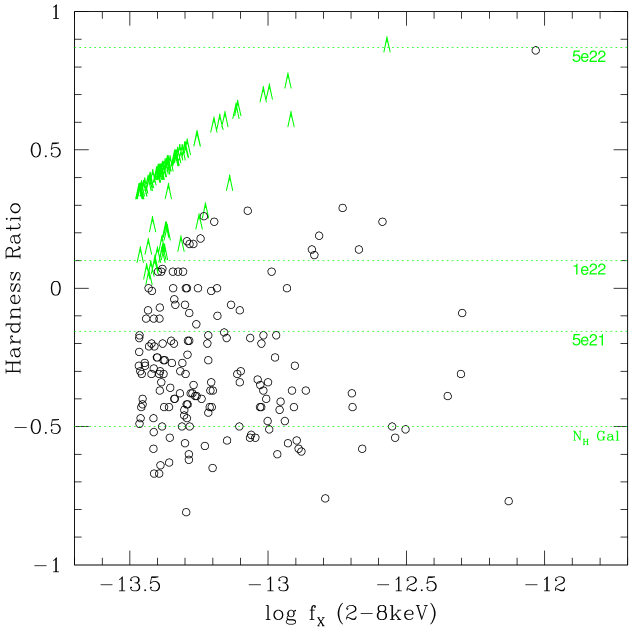

Figure 1: Hard sources detected in our 9deg^2 Chandra mosaic. The subsample we have chosen for study are all those with Hardness > 0.1, corresponding to an intrinsic absorbing column of at least $N_H = 10^{22}$ atoms cm^{-2}, similar to columns of the absorbed AGN that dominate the CXRB.

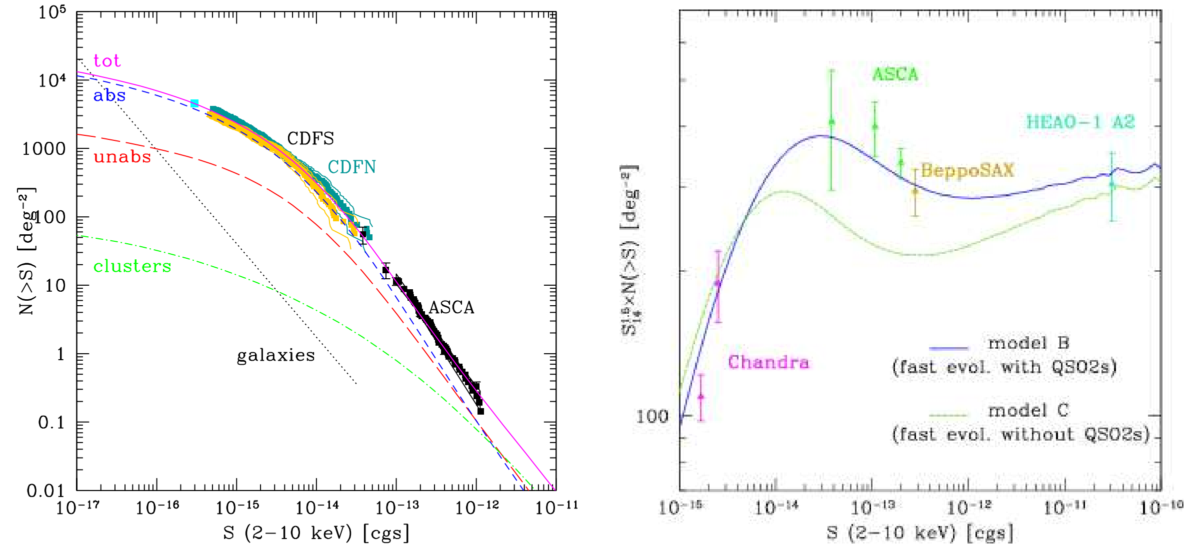

Figure 2: *LEFT:* Hard band log$N$-log$S$ with an X-ray population synthesis of absorbed AGN that reproduces the observed CXRB spectrum and normalization (Gilli et al. 2003). *RIGHT:* Most such models fail without the addition of luminous hard sources, the optically elusive Type-2 quasars.

REFERENCES

Barger, A. J., et al. 2003, AJ, 126, 632
Cowie, L. L., et al. 2003, ApJ, 584, L57
Gilli, R. 2003, astro-ph/0303115
Green, P. J., et al. 2001, ApJ, 558, 109
Moran, E. C., et al. 2002, ApJ, 579, L71
Norman, C., et al. 2002, ApJ, 571, 218
Schmidt, G., et al. 2002, ApJ, 578, L99

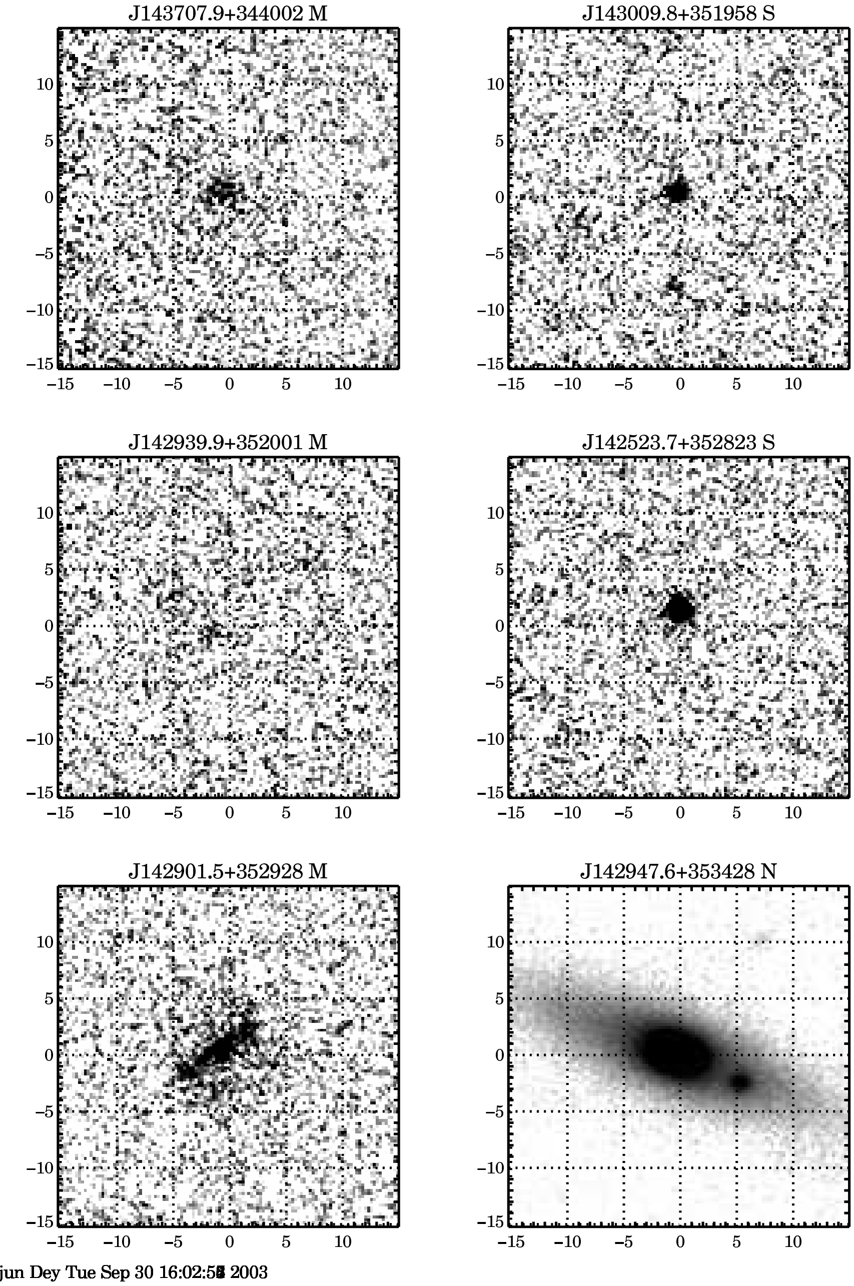

Figure 3: K-band finder charts for our hard sample. Units indicate arcsec, so finders are $30''$ on a side. Magnitudes, colors, and morphologies are consistent with most of these hard X-ray sources having nearby galaxy hosts, while some are likely to be luminous obscured QSOs at $z \lesssim 1$.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

This year with 126 contiguous pointings of 5 ksec each, we obtained the largest Chandra image to date - a 9 $\deg^2$ region towards Bootes chosen to coincide with the NOAO Deep-Wide field survey (NDWFS). The NDWFS is unique in its wide-field coverage and availability of deep multiwavelength imaging (including VLA and SIRTF). Our Chandra survey is designed to sample volumes appropriate for statistical investigations of clusters and their environments, and AGN phenomena in relation to galaxy host properties and their evolution.

By running wavelet detection in 3 bands (soft S - 0.5-2 keV, hard H - 2-7 keV, and broad - 0.5-7 keV), we detect 3400 high confidence sources ($P < 10^{-6}$) down to f_X(2-8 keV)= 10^{-14}erg cm^{-2} s^{-1}, consistent with number counts expected from previous surveys. From this list we culled all sources detected in the H band (2-7 keV), that are bright (3× the flux limit) with $\frac{S}{N} > 2$, and an X-ray spectral hardness ratio $\frac{H-S}{H+S} > 0.1$. This hardness is equivalent to a typical AGN spectrum absorbed by a column of at least $N_H = 10^{22}$ atoms cm^{-2}, similar to columns of the absorbed AGN that dominate the CXRB.

Matching to the deep ($R \sim 26$) NDWF imaging means that we sample the *full* celestial range of f_x/f_{opt} in a fair-sized census, so matching can be unbiased by f_x/f_{opt}. The deep B_W, R, I imaging also premits detailed environmental information with high quality photometric redshifts. On the other hand, high optical source densities ($\sim$ 100/arcmin^2) mean that our matching must be very careful. The Chandra PSF centroid error σ_{px} varies both as a function of Chandra off-axis angle and source strength. We match hard Chandra sources to existing NDFWS catalogs by requiring optical/X-ray source positions to agree within $3\sigma_{px}$ or $1''\!.5$, whichever is larger; the minimum radius is set by systematic uncertainties. All matches are inspected by eye. A full 90% of our bright, hard sources are matched in the NDWFS catalogue.

In the nearby Universe, our sample probes the obscured AGN proposed as the most important constituent of the CXRB. At the lowest definitively AGN luminosities ($L_X > 10^{42}$), our Chandra/NOAO survey combination is highly complete to $z = 0.1$, where an L_* E/S0 host has $R = 16$. These AGN are exactly those that appear at higher redshifts to have no AGN component (Moran et al. 2002). Gemini spectroscopy affords adequate sensitivity to the AGN optical spectroscopic signature buried in the host light, and the longslit spectra allow reconstruction of how the spectrum would appear at higher redshifts where the host fills the aperture.

Another elusive and hotly debated component of the CXRB are the Type 2 QSOs. Our X-ray flux limit samples Type 2 QSOs ($L_X > 10^{44}$) to $z = 1$, where even an L_* E/S0 galaxy host has $R < 22.2$ ($H_\circ$=70 km s^{-1} Mpc^{-1}, $\Omega_\Lambda = 0.7$, and $\Omega_M = 0.3$.). Thus we are *complete for the elusive Type 2 quasars in the largest volume available* (33 million Mpc^3) from any extant modern X-ray dataset.

Proprietary Period: 18 months

Use of Other Facilities *Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program.*

The Chandra Bootes raster imaging this past Spring 2003 required more than 180 hours of Chandra time over about 2 weeks, and represents a major legacy observation from Chandra.

Once the MMT/Hectospec combination is available, we plan to use its 1deg multifiber capability for a redshift survey of our full X-ray sample of 3300 objects. We expect the the poor sky subtraction with fibers to limit those spectra to $R \lesssim 21.5$. In any case, fibers do not allow for host/nuclear separation.

The NOAO co-Is are PIs on the NOAO Deep Wide Field Survey project, an NOAO legacy that provides the optical multicolor imaging foundation of our proposal.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

The PI observed with the WIYN/Hydra in April 2001 2001, and supervised observing and reduction of numerous NOAO 4m/MOSAIC runs for followup of optically bright, primarily soft Chandra X-ray sources. The bulk of these data are published in Green et al. 2003 (ApJS, in press) and calibrated images are posted publicly on the web at http://hea-www.harvard.edu/CHAMP/

Observing Run Details for Run 1: GEM-NQ/GMOSN

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

We have selected 85 hard X-ray targets, and we are now completing counterpart matching to existing NOAO Deep Wide Field Survey photometric catalogs. We have so far matched sources that lie within the coverage of the ONIS IR data - 35 sources in about $4.5\,\mathrm{deg}^2$, i.e., 41% of the sources. We find K-band counterparts for 90%, indicating an excellent match to the X-ray flux limit. This representative matched sample has a mag range $19 < R < 22.5$. Since the redshift, object type, and admixture of nuclear/stellar flux is unknown *a prior* for each object, we assume a survey approach geared to detect at 3σ an unresolved Hα emission line of flux 1×10^{-17}erg cm^{-2} s^{-1}, above a continuum level calculated from the observed total R mag. This assumed line flux is that expected from a low-luminosity AGN based on our limiting sample X-ray flux of 3×10^{-14} (Koratkar et al. 1995, ApJ, 400, 132). For a typical $R = 22$ object, this requires 45min on source, which we thus assume for all objects. This strategy is well-defined, and simple for the Queue Observer.

Representative mags and exposure (+overhead) times for 2 objects whose total magnitudes bracket the sample are shown in the Target Table. This Our 'snapshot survey' approach may be refined in PhaseII by incorporating photometric redshifts. While we expect 75 hard X-ray sources matched to counterparts $19 < R < 22.5$, we request 3 nights of Gemini/GMOS time for a random subsample of 30% (24 objects) for a fair probe of the nature of these targets. A detailed target table will be provided in PhaseII, depending on the amount of awarded time. Since these targets are all in the same Bootes region, classical mode is also a viable option, if the TAC prefers.

Principal Contact: Paul J. Green

Instrument Resources

Filters: GG455_G0305
Dispersers: R150_G5306
Focal Plane Units: Longslit 0.75 arcsec

R.A. range of principal targets (hours): 14 to 15

Dec. range of principal targets (degrees): 34 to 36

Target Table for Run 1: GEM-N/GMOSN

Obj ID	Object	α	δ	Epoch	Mag.	Obs. time	WFS stars	IQ %	SB %	WV %	CC %	Comment
1001	XB1	14:28:27.48	+34:51:22.2	J2000	22.23	70	PPO	70	50	any	70	typical fnt
1002	XB2	14:29:50.65	+35:08:43.0	J2000	19.06	70	PpO	70	50	any	70	typical brt

NOAO observing proposal LaTeX macros v2.9.