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Optical Spectroscopic Followup of Serendipitous Chandra Sources: The Chandra Multiwavelength Project (ChaMP)

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Abstract. A primary goal of the Chandra Multiwavelength Project (ChaMP) is to investigate the evolution of Active Galactic Nuclei (AGN) and quasars by measuring the luminosity function out to $z \geq 4$ including obscured AGN that have been missed by previous surveys. To do so, we are acquiring spectra of optical counterparts to serendipitious X-ray sources detected by Chandra for classification and redshift determination. We have amassed about 200 spectra using the FLWO 1.5m, WIYN 3.5m, CTIO/4m, Magellan and the MMT 6.5m. We have classified the majority of optical counterparts as 65% broad line AGN, 14% narrow emission line galaxies and 12% absorption line galaxies. The remaining counterparts are either stars (8%) or galaxy clusters (1%). We have acquired a sample of 120 AGN in 12 Chandra fields. With a limiting magnitude of $r' = 22$ for spectroscopic followup, we are able to detect quasars out to $z \sim 5$ and galaxies out to $z \sim 0.7$. This preliminary sample forms the foundation for our measurement of the X-ray luminosity function of AGNs out to $z \sim 4$.

1. Introduction

The Chandra and XMM-Newton Observatories are for the first time resolving the hard (2-10 keV) Cosmic X-ray Background (CXRB). Based on the spectral shape of the CXRB, the majority of emission from accretion powered sources has been obscured from our view. ROSAT has shown that, while unabsorbed AGN dominate the soft (0.1-2 keV) CXRB (Hasinger et al. 1998), the high energy CXRB spectrum (2-30 keV) is harder than that of known AGN (Gilli et al 2001). With recent Chandra observations of the Chandra Deep Field North (CDF-N; Brandt et al. 2001), South (CDF-S; Rosati et al. 2002) and XMM observations of the Lockman Hole(Hasinger et al. 2001) , $\sim$ 75% of the hard (2-8 keV) XRB has been resolved into point sources. Many of the hardest serendipitous sources found so far arise in otherwise unremarkable bright galaxies (Hornschemeier et al. 2001; Tozzi et al. 2001), which may contain very heavily obscured AGN. In addition, Chandra has begun to detect the extremely rare, heavily obscured, dust enshrouded quasars (Norman et al., 2001; Stern et al., 2002).

While the Chandra Deep field observations provide X-ray images to the faintest fluxes to date, they cover a small area of the sky (0.1 sq. deg) and consequently have only a small number of sources. Wider area surveys are needed in order to study these X-ray emitting populations with significant statistics.

The Chandra Multiwavelength Project (ChaMP; see P. Green in this volume) is generating a medium-depth, wide-area sample of serendipitous X-ray sources from archival Chandra fields ($|b| > 20°$; target size $< 10\%$ FOV). The ChaMP effectively bridges the gap between flux limits attained by past ROSAT surveys and recent Chandra Deep fields. The complete project expects a total of 8000 serendipitous (non-target) extragalactic sources over 14deg^2.

Throughout this paper, we assume $H_\circ$=50 km s^{-1} Mpc^{-1} and a flat cosmology with $q_\circ$=0.5.

2. Optical Spectroscopic Followup: Design

The ChaMP has an ongoing program to acquire optical imaging in three SDSS filters (g',r',i') to identify counterparts for $\sim$ 70% of X-ray sources in each field. The limiting mag-

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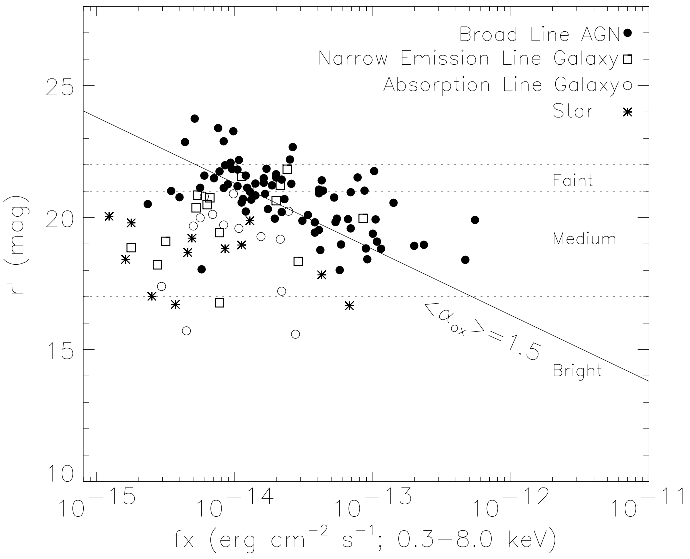

Fig. 1. Broad band X-ray flux vs. r′ optical magnitude.

nitude for the deepest (50-100 ksec) Chandra pointings can reach as faint as 25th.

The spectroscopic followup of Chandra sources operates in three modes based on optical magnitude. Spectra for the brightest sources ($r' < 17$) are obtained with the FLWO/1.5m FAST spectrograph. For sources with $17 < r' < 21$, we use the WIYN and the CTIO/4m with HYDRA, a multi-fiber spectrograph. To obtain spectra for the faint source population ($21 < r' < 22$), slit spectroscopy with a 4 to 8 m class telescope is required (i.e. KPNO/4m,MMT,Magellan). Two facilities with similar configurations are needed to access ChaMP fields in the northern and southern hemispheres.

3. X-ray emitting populations

We have acquired 200 spectra (now 75% reduced) of sources with $r' < 22$. We find the Chandra X-ray sources are classified as broad line AGN (65%; emission line FWHM > 1000 km s^{-1}), galaxies with strong, narrow emission lines (14%; FWHM < 1000 km s^{-1}), normal galaxies with absorption lines (12%), stars (8%) and galaxy clusters (1%).

As shown in figure 1, the broad line AGN lie along a locus of points similar to a typical, unabsorbed AGN ($\alpha_{ox} = 1.5$) detected by past optical and X-ray surveys. The broad line AGN span a wide range of redshift up to $z \sim 5$ (Fig 2).

At faint X-ray fluxes (Fig. 1; $f_x < 10^{-14}$ erg s^{-1} cm^{-2}), a number of optically bright galaxies with or without emission lines are associated with X-ray sources. Due to our limiting optical magnitude ($r' = 22$) for spectroscopic followup, we are finding these counterparts out to $z \sim 0.7$ (Fig. 2).

At bright optical magnitudes ($r' < 20$), we are identifying a number of stellar X-ray sources. Roughly half the detected X-ray sources are M stars, however there are spectral classes as early as A represented.

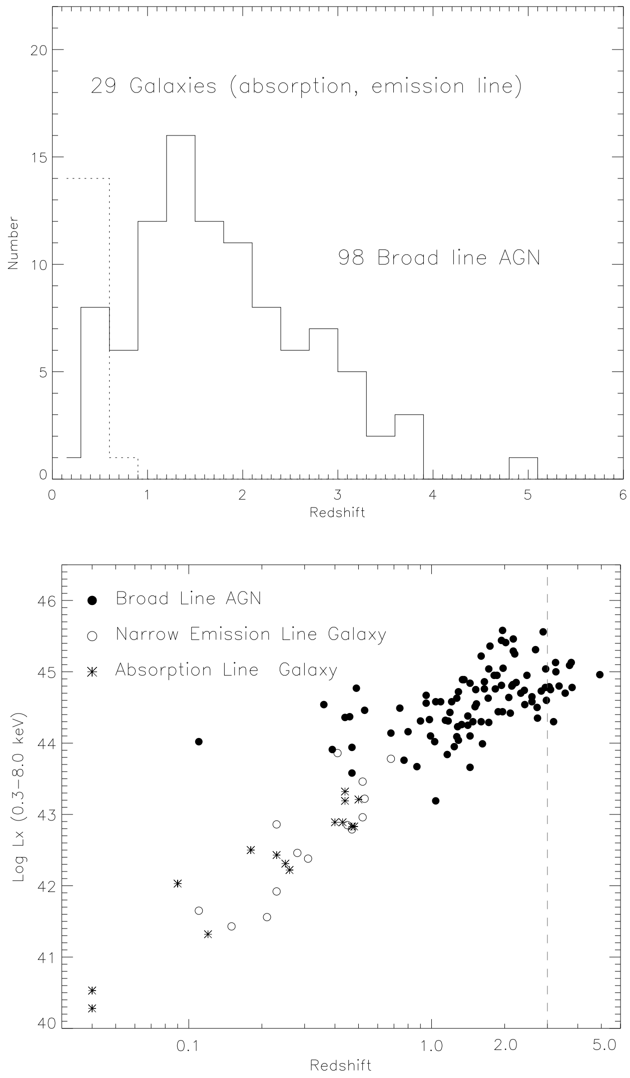

Fig. 2. The redshift distribution and luminosity,redshift plot of ChaMP X-ray sources. As shown, we are detecting broad line AGN out high redshift with our most distant quasar at a $z = 4.93$ (Silverman et al 2002). Galaxies with emission or absorption lines are detected out to $z \sim 0.8$. With $L_x > 10^{42}$ erg s^{-1} as an indicator of supermassive black hole accretion, we have unveiled a number of hidden AGN. In total, we've compiled a sample of 98 broad line AGN to date with 11 at $z > 3$. We assumed each source has an intrinsic powerlaw spectrum (Γ=2.0) with a galactic absorption component.

4. Unveiling the obscured AGN

From the measured X-ray luminosity (Fig. 2) of sources associated with absorption or emission line galaxies, it is apparent that we have detected a population of hidden active nuclei, powered by supermassive black hole accretion ($L_x > 10^{42}$ erg s^{-1}). Interestingly, not all of these sources show evidence for strong absorption in the X-ray.

As an example, we show (Fig. 3) an AGN found by the ChaMP that is so heavily enshrouded by dust and gas that only hard X-rays can escape the ISM of this r'=19.6 magnitude galaxy.

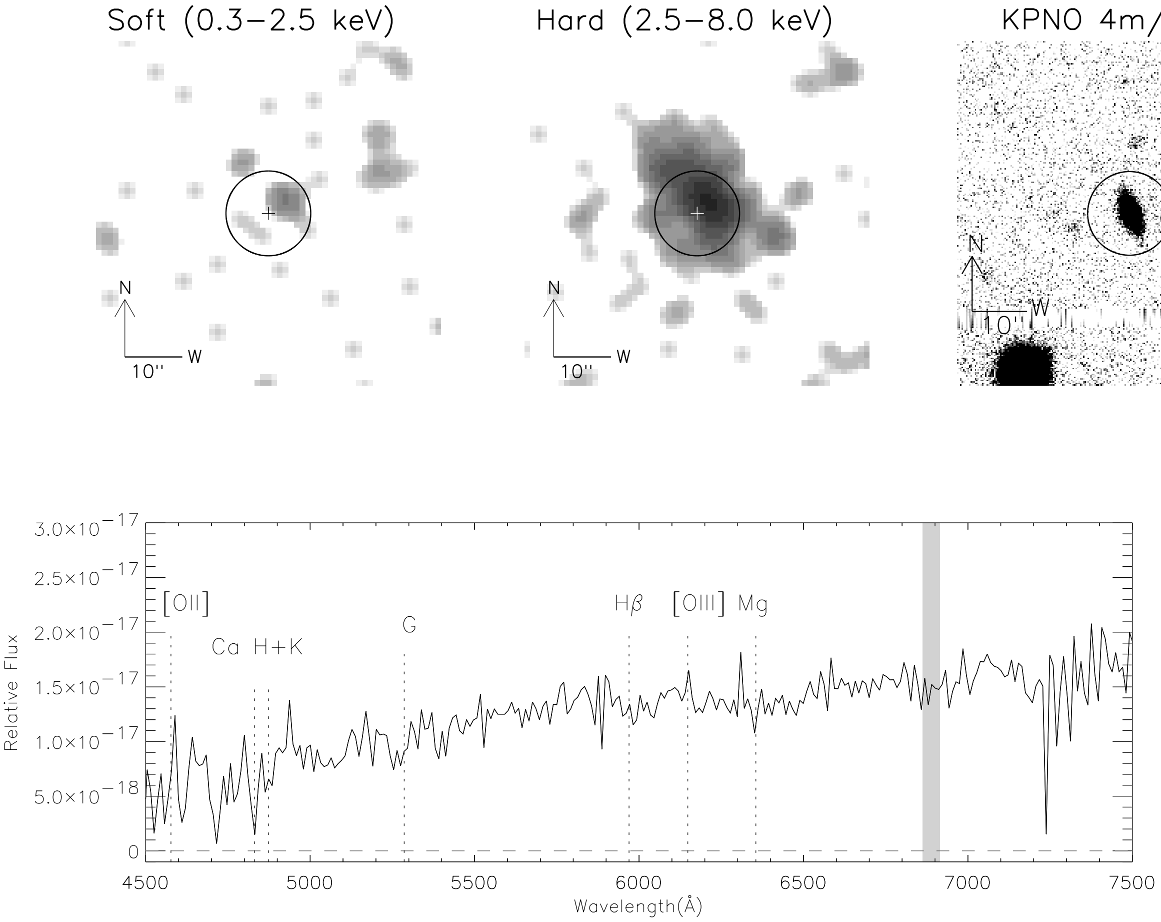

Fig. 3. An extremely obscured AGN. Here we show the Chandra image in two bands, optical r' image and spectrum of an extrememly hard X-ray source. The X-ray source was detected with 90 counts in the hard band and practically no counts in the soft band. With a redshift of 0.228, the hard X-ray luminosity is 6.6×10^{42} erg s^{-1} which secures the classification as an AGN.

5. Probing the high redshift universe

We are finding that 10% of ChaMP broad line AGN are at $z > 3$. With complete optical spectroscopic identification in a preliminary sample of 20 Chandra fields, we expect to acquire 20 quasars at high redshift. X-ray selected quasars from ROSAT have shown evidence for a constant space density beyond a redshift of 2 (Miyaji et al. 2000). Unfortunately, the combined ROSAT sample has only 8 quasars beyond a redshift of 3. The ChaMP will measure the comoving space density to test whether a decline beyond $z > 2$ is present in sensitive X-ray selected surveys as seen in optically selected surveys (e.g. Schmidt et al. 1995, Fan et al. 2001).

Chandra's small PSF ($\sim 1''$) and low background signal are proving an ideal combination for probing the quasar population at high redshift. Usually, we classify one $z > 3$ quasar per field with the exception of the *Einstein Cross* field where an unusual clustering of 4 quasars were detected (Fig. 3) in only a 30 ksec exposure.

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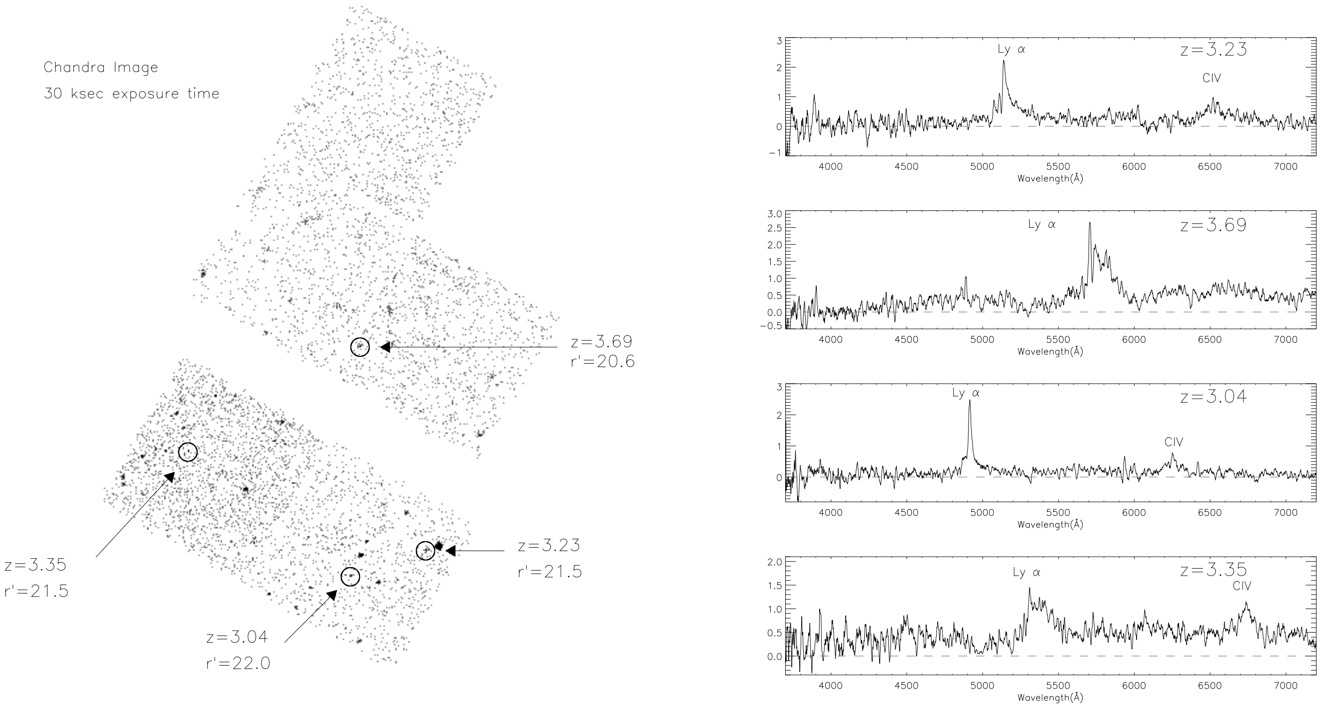

Fig. 4. The X-ray image and optical spectra of four high redshift quasars discovered in the same Chandra field. The MMT with its new 6.5m diameter mirror enabled us to acquire these optical spectra in 10 minute exposures. The FOV of each chip is $8.5' \times 8.5'$.