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The Chandra Multi-wavelength Project (ChaMP): a serendipitous survey with Chandra archival data.

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Abstract. The launch of the Chandra X-ray Observatory in July 1999 opened a new era in X-ray astronomy. Its unprecedented, < 0.5" spatial resolution and low background are providing views of the X-ray sky 10-100 times fainter than previously possible. We have initiated a serendipitous survey (ChaMP) using Chandra archival data to flux limits covering the range between those reached by current satellites and those of the small area Chandra deep surveys. We estimate the survey will cover ~ 5 sq.deg. per year to X-ray fluxes (2−10 keV) in the range $10^{-13} - 6 \times 10^{-16}$ erg cm^{-2} s^{-1} discovering ~2000 new X-ray sources, $\sim 80\%$ of which are expected to be active galactic nuclei (AGN). The ChaMP has two parts, the extragalactic survey (ChaMP) and the galactic plane survey (ChaMPlane). Over five years of Chandra operations, the ChaMP will provide both a major resource for Chandra observers and a key research tool for the study of the cosmic X-ray background (CXRB) and the individual source populations which comprise it. ChaMP promises profoundly new science return on a number of key questions at the current frontier of many areas of astronomy including (1) locating and studying high redshift clusters and so constraining cosmological parameters, (2) defining the true population of AGN, including those that are absorbed, and so constraining the accretion history of the universe, (3) filling in the gap in the luminosity/redshift plane between Chandra deep and previous surveys in studying the CXRB, (4) studying coronal emission from late-type stars as their cores become fully convective and (5) search for cataclysmic variables (CVs) and quiescent Low-Mass X-ray Binaries (qLXMBs) to measure their luminosity functions.

In this paper we summarize the status, predictions and initial results from the X-ray analysis and optical imaging.

1. Introduction

The large fields-of-view (FoVs) typical of X-ray imaging instruments have long been exploited for serendipitous surveys, resulting in far-reaching and fundamental advances in our knowledge of the X-ray universe and indeed the universe as a whole (*e.g.*, the Einstein Medium Sensitivity Survey (EMSS, Stocke et al. 1991, Maccacaro et al. 1982); the Cambridge-Cambridge ROSAT Serendipitous Survey (CCRSS, Boyle, Wilkes & Elvis 1997); ROSAT International X-ray/Optical Survey (RIXOS, Page et al. 1996)). The next decade promises to be rich for X-ray astronomy as two major observatories, Chandra and XMM, open new vistas with their deeper flux limits and superior spatial and spectral resolution.

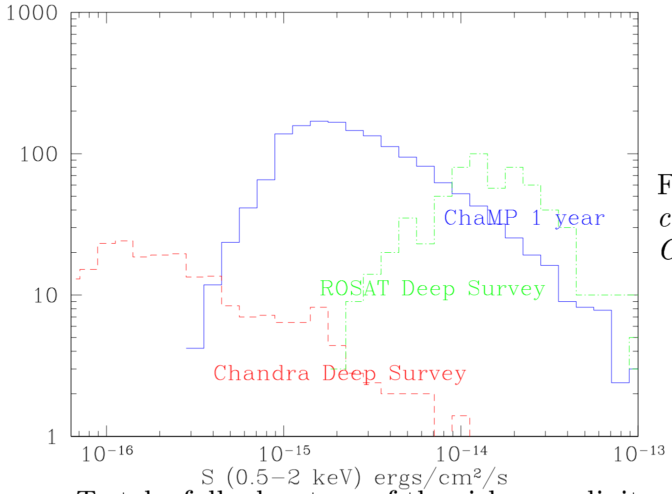

Figure 1. *Predicted source counts per flux bin for ChaMP Cycle 1.*

To take full advantage of the rich serendipitous dataset afforded by Chandra's large FoVs (ACIS-I: $16' \times 16'$) and to maximize the science per ksec of observing time, we have organized an extragalactic serendipitous X-ray survey, the ChaMP and a similar Galactic plane survey (ChaMPlane). We estimate a ChaMP X-ray sample of $\sim$ 2000 sources in the $\sim$ 5 sq. degs. of ChaMP fields in Cycle-1. $\sim$ 80% of these are likely to be AGN of various types, including those with low luminosity and/or substantial low energy X-ray absorption expected based on the spectrum of the CXRB and already being found in early results from Chandra surveys (Hornschemeier et al. 2000, Mushotzky et al. 2000, Barger et al. 2000, Giacconi et al. 2000). The remaining sources will include clusters of galaxies, stars, X-ray binaries, and supernova remnants. Unlike targeted, small area, deep Chandra surveys, which reach fainter flux levels, the ChaMP provides the wide area essential for finding rare, bright and/or unexpected sources, generating statistically meaningful samples of rare source types such as BL Lac objects, quiescent X-ray binaries and high-redshift clusters. As such the ChaMP complements existing deep Chandra surveys (Figure 1).

2. ChaMP:Data Analysis

2.1. Field List: ChaMP, extragalactic survey

Of prime importance in carrying out any survey is an accurate understanding of the selection effects present. We have defined a subset of Chandra fields to minimize bias due to the effects of known extended sources and to include a variety of target types. Each field will be analyzed as it becomes available in the archive using uniform X-ray source detection and analysis techniques (Section 2.2) resulting in a well-defined X-ray sample over the full survey area.

The 172 fields in the ChaMP extragalactic Cycle-1 and Cycle-2 lists have $|b| > 20°$. We exclude targeted survey fields, *e.g.* Hubble Deep Field, Lockman Hole (being studied optically by their Chandra PIs); special instrument modes (*e.g.*, grating observations, ACIS sub-arrays); unstable detector periods; < 4 ACIS chips and fields containing bright optical or X-ray sources covering $> 10\%$ of the Chandra FoV on the DSS optical or ROSAT/other X-ray images.

2.2. X-ray Data Analysis

We are currently refining our source detection procedures using two methods: sliding cell search and wavelet transformation; the former is optimized for point source detection while the latter provides efficient detection of diffuse/extended sources and those in crowded fields. The Chandra point-spread-function (PSF) is a strong function of off-axis angle and energy so we are carrying out simulations of source detection efficiency as a function of size, off-axis angle, background characteristics, source spectrum etc. to understand survey limits and minimize false sources while optimizing source detection. X-ray source properties will be derived for sources in the master (merged) list including: accurate positions, count rates and fluxes, spatial extent, variability and spectrum/hardness ratio when possible given the source signal. ACIS sources with 100 counts will constrain simple power law fits to within 25%, 30 counts provide hardness ratios adequate to distinguish between the high energy spectra of AGN and typically softer stellar sources and to provide an estimate of the soft X-ray absorption. Our $log\,N - log\,S$ estimates suggest ~ 400 AGN per year will yield useful hardness ratios, and ~ 130 will furnish enough counts for a spectrum.

2.3. Optical Imaging

The second essential ingredient for an X-ray survey, which opens up a much wider range of scientific questions, is optical identification of the X-ray sources. We are obtaining optical images of the ChaMP fields using the same filters with matched flux limits: $F_x/F_{opt} < 0.5$ designed to identify >90% of the normal AGN population and automatically includes larger fractions of other known source types. This is very efficient, observing all the X-ray sources in one Chandra field at one time, minimizing the large, ground-based telescope time required to reach the faint optical limiting magnitudes ($21 \lesssim \mathrm{V} \lesssim 25$, with mode of 24). The choice of filters, Sloan Digital Sky Survey (SDSS) g$'$,r$'$,i$'$, provides direct benefit from the SDSS photometric/spectroscopic database and simulations at brighter limits, allowing excellent photometric classification and redshift determination (Vikhlinin et al. 1998), invaluable at the faintest optical fluxes. To date we have observed 41 ChaMP fields in 31 observing nights (9 nights:4-m KPNO (Kitt Peak National Observatory), 6:0.9m KPNO, 3:4m CTIO (Cerro Tololo Inter-American Observatory), 17:1.2m SAO). The uniformity of the dataset and our analysis methods will provide a well-understood and highly uniform sample.

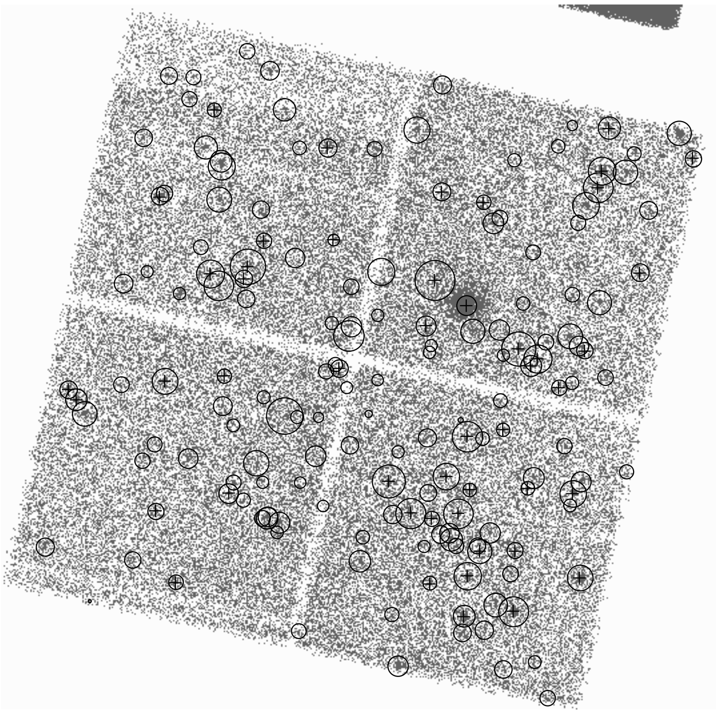

Figure 2. *ACIS data for the MS1137.5+6625 cluster showing the X-ray sources (circles, size $\propto$ log(significance)). Crosses indicate 48 possible optical counterparts <2″.*

2.4. Optical Identification

Chandra's small PSF and unprecendented, for X-ray telescopes, astrometric calibration minimize the number of possible optical counterparts per X-ray source. We are developing procedures to reduce and analyze the optical images, derive source lists and cross-correlate (solving for aspect differences), to identify the X-ray sources. In Figure 2 we show preliminary results for a 110 ksec ACIS-I observation based on a preliminary 900 sec i′-band image taken with the 4-shooter CCD imager on the SAO 1.2m telescope, 12 Feb 2000. The flux limit, $i' \sim 18$, is $\sim \times 15$ brighter than the ChaMP required limit. The 165 detected X-ray sources found using the CIAO (Chandra Interactive Analysis of Observations) *wavdetect* tool and those with optical identifications $< 2''$of the X-ray centroid.

We will determine upper limits in optical/X-ray as appropriate for sources not detected in both bands. Sources will be classified using X-ray size, optical and X-ray colors employing color-color plane methods (Newberg et al. 1999).

2.5. ChaMP Archive

We will release a list of X-ray sources and their properties along with optical images and source lists in to a web-based public archive (the X-ray data will be available via the Chandra public archive). The ChaMP database will provide an invaluable, multi-wavelength database to the community, helping to ensure that the science return from Chandra reaches its full potential.

3. ChaMPlane: galactic survey

ChaMPlane selected 15 fields in Cycle-1 such that $|b| < 10^\circ$ and exposure time > 30 ksecs. The X-ray data analysis is being carried out in close collaboration with the ChaMP (Section 2.2). However optical imaging in R and Hα filters is aimed at optimizing the identification of CVs and qLMXBs, primarily black hole X-ray novae in quiescence, in order to constrain and ultimately measure their luminosity functions. Secondary objectives are to determine the Be X-ray binary content and stellar coronal source distributions in the Galaxy. The deep Chandra galactic fields will detect 2-6 keV fluxes (allowing for low energy absorption) of F_x(2-6 keV) $= 2 \times 10^{-15}$ erg s-1 and thus CVs or qLMXBs with $L_x = 10^{31}$ erg s^{-1} out to $\sim$7 kpc. Thus most CVs and qLMXBs in the Galaxy can be reached, and the ChaMPlane survey offers the best chance for constraining their formation/evolution and the stellar BH content of the Galaxy. CVs and qLMXBs will be identified by their ubiquitous Hα excess as "blue" objects in the R vs. (Hα - R) plane down to R $\sim$ 24. We have demonstrated this technique for crowded fields with our HST discovery of the first CVs in globular cluster cores and have now conducted a successful pilot ChaMPlane survey at CTIO. ChaMPlane has been awarded 31 4-m nights of observing time at KPNO and CTIO as part of the NOAO Survey Program.

4. Preliminary Results

4.1. X-ray $log\,N - log\,S$

We have generated a preliminary $log\,N - log\,S$ from the CIAO *wavdetect* list of 165 background X-ray sources in the MS1137.5+6625 field and the 127 sources in the field of the cluster: CL 0848.6+4453. Our results, which assume a power law with α_E=1.0, (Figure 3) agree well with those from ROSAT (Hasinger et al. 1998) and extend to fainter fluxes.

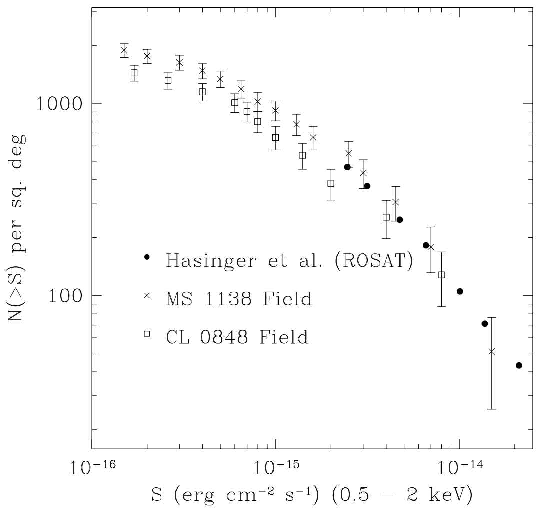

Figure 3. *Preliminary ChaMP $log\,N - log\,S$ (crosses: MS 1137.5+6625; squares: CL 0848.6+4453) with 1σ error bars, compared with the ROSAT deep survey (circles, Hasinger et al. 1989).*

4.2. Optical Spectroscopy

We plan to take advantage of the new generation of large area, multi-object spectrographs to efficiently obtain spectra and provide redshifts for a subset of

~ 1500 sources, sufficient to constrain to $\sim \pm 20\%$ the points on AGN luminosity functions (LF) for 0<z<4. Currently available instruments (*e.g.* the 6.5m MMT, on which we have 10 nights per year) limit to V$\lesssim$22 but we plan to expand our sample beyond this once the new generation of large telescopes come on-line.

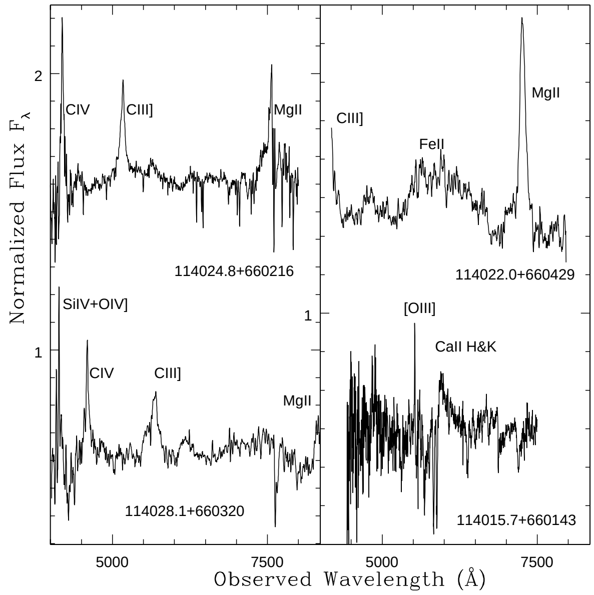

Figure 4. *Spectra of 3 ChaMP QSOs and 1 galaxy from Figure 2 taken April 29, 2000 on the Keck with LRIS, courtesy of the Keck Director.*

Initial spectra were obtained the Low-Resolution Imaging Spectrograph (LRIS) on the Keck telescope in director's discretionary time, 29 April 2000. Slitlets were placed at the positions of the closest optical couterparts to 12 X-ray soruces in a region of the MS1137.7+6625 field several of which had a low probability due to the large separation. The resulting 3600sec spectra revealed 3 stars, 5 QSOs, 2 early-type galaxies, a narrow emission line galaxy (NELG), and one mystery object with very smooth continuum (star/BL Lac?). Four of the spectra: 3 QSOs and 1 galaxy are presented in Figure 4.

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