CHANDRA MULTIWAVELENGTH PLANE (CHAMPLANE) SURVEY: AN INTRODUCTION

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ABSTRACT

We introduce the Chandra Multiwavelength Plane (ChaMPlane) survey, designed to measure or constrain the populations of low-luminosity ($L_X \gtrsim 10^{31}$ ergs s$^{-1}$) accreting white dwarfs, neutron stars, and stellar mass black holes in the Galactic plane and bulge. ChaMPlane incorporates two surveys, X-ray (Chandra) and optical (NOAO 4 m Mosaic imaging), and a follow-up spectroscopy and IR identification program. The survey has now extended through the first 6 yr of Chandra data using serendipitous sources detected in 105 distinct ACIS-I and ACIS-S fields observed in 154 pointings and covered by 65 deep Mosaic images in $V$, $R$, $I$, and $H_\alpha$. ChaMPlane incorporates fields with Galactic latitude $|b| \lesssim 12^\circ$ and selected to be devoid of bright point or diffuse sources, with exposure time $\gtrsim 20$ ks and (where possible) minimum $N_H$. We describe the scientific goals and introduce the X-ray and optical/IR processing and databases. We derive preliminary constraints on the space density or luminosity function of cataclysmic variables (CVs) from the X-ray/optical data for 14 fields in the Galactic anticenter. The lack of ChaMPlane CVs in these anticenter fields suggests that their space density is $\sim 3$ times below the value ($3 \times 10^{-5}$ pc$^{-3}$) found for the solar neighborhood by previous X-ray surveys. Companion papers describe the X-ray and optical processing in detail, optical spectroscopy of ChaMPlane sources in selected anticenter fields, and IR imaging results for the Galactic center field. An appendix introduces the ChaMPlane Virtual Observatory (VO) for online access to the X-ray and optical images and source catalogs for ready display and further analysis.

Subject headings: surveys — X-rays: general

Online material: color figures

1. INTRODUCTION

The Chandra Multiwavelength Plane (ChaMPlane) Survey is a comprehensive effort to analyze systematically and archive the results from deep ($\gtrsim 20$–100 ks) Chandra pointings near the Galactic plane ($|b| \lesssim 12^\circ$). The primary science goals of ChaMPlane (described below) are to measure or constrain the low-luminosity ($\lesssim 10^{31}$ ergs s$^{-1}$) accretion-powered X-ray sources in the Galaxy: accreting white dwarfs in cataclysmic variables (CVs), neutron stars (NSs) and black holes (BHs) in quiescent low-mass X-ray binaries (qLMXBs), and low-luminosity high-mass X-ray binaries (HMXBs), primarily Be HMXBs. ChaMPlane is also enabling the first high-resolution search for isolated stellar mass BHs accreting from giant molecular clouds (GMCs). A key secondary goal is the study of stellar coronal emission across the H-R diagram and in a range of Galactic environments: from the anticenter disk to the Galactic bulge. The survey will produce the most comprehensive database of coronal X-ray sources (stars) yet achieved, ultimately expanding the ROSAT samples (e.g., Schmitt et al. 2004 and references therein) by $\sim 1$–2 orders of magnitude for stars in the plane and (far) beyond the solar neighborhood. While the primary goals of ChaMPlane are to survey and study point sources, the ChaMPlane X-ray and optical image archive also contains considerable rich diffuse emission that can be accessed for further study.

ChaMPlane is also a major optical imaging ($V$, $R$, $I$, and $H_\alpha$) follow-up survey conducted to identify optical counterparts of the X-ray survey sources. We have used the Mosaic camera on the Cerro Tololo Inter-American Observatory (CTIO) and the Kitt Peak National Observatory (KPNO) 4 m telescopes in a 5 yr Long Term Survey Program granted to ChaMPlane (2000) by NOAO. The images and photometry from this survey, separately processed and archived at both CfA and NOAO, constitute some of the deepest $H_\alpha$ images of the plane in the 65 Mosaic fields ($36^\prime \times 36^\prime$) obtained in our NOAO survey. The ChaMPlane database at CfA links the X-ray and optical images and, when complete, will produce a legacy database for the distribution and nature of faint X-ray sources in the Galactic plane. With initial analysis on 14 anticenter fields now nearly complete, the fraction of sources with optical counterparts is $\sim 50\%$.

ChaMPlane is deeper (given diffuse emission in many fields) and of course has much higher angular resolution, permitting optical/IR identifications, than the XMM Galactic Plane Survey (Motch et al. 2003), ROSAT All Sky Survey (Voges et al. 1999), or the Einstein Galactic Plane Survey (Hertz & Grindlay 1984; Hertz et al. 1990). Given that Chandra is the premier high-resolution X-ray imager for at least the next decade, it is important to conduct the systematic analysis of the (many) Chandra Galactic fields to create the database needed for developing a statistical understanding of the accreting binary (white dwarf, NS, and BH), as well as stellar coronal X-ray content of the Galaxy. An initial description of ChaMPlane and preliminary results for the derived source number versus flux ($\log N$–$\log S$) distributions and source types were given for several Galactic bulge fields by Grindlay et al. (2003) along with an initial description of the optical survey (Zhao et al. 2003).

The X-ray processing is described in detail in the accompanying paper by Hong et al. (2005), which presents X-ray results for the initial 14 Galactic anticenter fields ($90^\circ \lesssim l \lesssim 270^\circ$). The optical survey and photometry pipeline processing for ChaMPlane
are described in the accompanying paper by Zhao et al. (2005). A broad overview of both the X-ray and optical survey status, as well as portals to the archived data and source catalogs, is available from the ChaMPlane Web site. ChaMPlane also incorporates an extensive optical spectroscopy follow-up program (at WIYN, MMT, CTIO, and Magellan) and infrared (IR) imaging and photometry and ultimately spectroscopy. Details are given in §§ 5.2 and 5.3.

The ChaMPlane X-ray and optical surveys are now building, and releasing, significant X-ray and optical database archives of processed images and derived X-ray fluxes and colors and optical photometry. The optical database also includes photometry (\(V, R, I\), and \(H\alpha\)) and astrometry results for the full stellar content of all Mosaic fields acquired. The images and derived catalogs are released as initial science papers are submitted. We have developed tools for easy Web access to the X-ray and optical images and derived products in the database. Examples of these tools for X-ray and optical overlays are given in the Appendix.

We first summarize the key science objectives of ChaMPlane and the criteria for selection of Chandra pointings for the survey. We then describe the X-ray processing and survey coverage obtained and then the optical—IR surveys and data products. Finally, we derive initial constraints on the CV density and/or luminosity function from X-ray/optical results for the 14 fields processed for the anticenter. In the Appendix we provide an overview of the X-ray and optical database content and online display and analysis tools now available from the ChaMPlane Web site.

2. PRIMARY SCIENTIFIC OBJECTIVES: ACCRETING COMPACT OBJECTS IN THE GALAXY

ChaMPlane uses Chandra data from ACIS, primarily ACIS-I, as this provides a larger contiguous field of view (16' \(\times\) 16'), with exposure times of \(\geq 20\) ks. A typical ChaMPlane field (see Galactic distribution of ChaMPlane fields and histograms of key parameters in Figs. 1 and 2) has an absorption column with log \(N_{\text{H}}\) \(\approx 21.7\). Thus, using PIMMS\(^3\) and an assumed power-law spectrum with index 1.7, the limiting flux sensitivity for a 10 count source in a "typical" 30 ks observation is \(F_X(0.5-8\text{ keV}) = 5.7 \times 10^{-15}\) ergs cm\(^{-2}\) s\(^{-1}\) (unabsorbed), yielding a distance limit for a source with \(L_X(0.5-8\text{ keV}) = 10^{31}\) ergs s\(^{-1}\) of \(d_{31, \text{typ}} \approx 3.9\) kpc. For the deepest ChaMPlane exposures of typically 100 ks and the same \(N_{\text{H}}\), this increases to \(d_{31, \text{max}} \approx 7.1\) kpc, and for those extreme fields (e.g., Baade’s Window) with both deep exposure and minimal log \(N_{\text{H}} = 21.3\), the limiting flux is \(F_X = 1.3 \times 10^{-15}\) ergs cm\(^{-2}\) s\(^{-1}\) (unabsorbed) for "limiting" distance \(d_{31, \text{lim}} \approx 8.2\) kpc. The corresponding minimum luminosity for a more heavily reddened field with log \(N_{\text{H}} = 22.3\) at \(d = 8\) kpc (e.g., much of the Galactic center region) and a 100 ks exposure with 10 count detection limit is \(L_X(0.5-8\text{ keV}) = 2.5 \times 10^{31}\) ergs s\(^{-1}\). These values for limiting distance and \(L_X\) guide the principal scientific objectives for ChaMPlane.

**CV number density:** Our first objective is to measure, or significantly limit, the number, space density, and luminosities of CVs in the Galactic plane. Current estimates of CV space density as \(\sim 10^{-5}\) pc\(^{-3}\) (Patterson 1998) are largely based on the small number \((\sim 300)\) of CVs detected from optical (variability or color) surveys and may be uncertain by at least a factor of 10 (Warner 1995). \(ROSAT\) surveys have shown that indeed the optical surveys are (very) incomplete; a significant number (\(\geq 80\)) of CVs have now been identified in \(ROSAT\) fields, mostly with magnetic CVs (Schwope et al. 2002 and references therein). Determining the true CV space density and Galactic population is important since this must connect to problems as fundamental as the rate of novae in the Galaxy and the origin of Type Ia supernova systems (e.g., Townsley & Bildsten 2005), as well as the population of LMXBs and CVs in the bulge that originated in globular clusters, either by ejection or cluster disruption (Grindlay 1985). Estimates of the CV space density from the Einstein Galactic Plane Survey (Hertz et al. 1990) and \(ROSAT\) Bright Star Survey (Schwope et al. 2002) have both given \(n_{\text{CV}} \sim 3 \times 10^{-5}\) pc\(^{-3}\).

Although the Einstein/\(ROSAT\) CVs have reached farther than the optical surveys, none are more distant than \(\sim 1200\) pc, and very little is known about the CV space density in the bulge or radial distribution in the disk. Extrapolating the local \(n_{\text{CV}}\) estimates, a typical ACIS-I ChaMPlane field might then contain \(0.2-2\) CVs. We derive predictions below (Table 2) and compare them with preliminary results for 14 anticenter fields. The effects of \(N_{\text{H}}\) assumed spatial distribution, CV X-ray luminosity function, and X-ray/optical flux distributions make such predictions uncertain. No CVs have been confirmed spectroscopically as counterparts to Chandra sources in these fields, whereas \(\sim 1\) might be expected given our discovery of five optically selected CVs in the \(\sim 5\) times larger area of the corresponding optical Mosaic images. As also pointed out below, the fraction of optical counterparts from the Mosaic imaging that have been spectroscopically identified in these anticenter fields is only \(\sim 30\%\), so definitive CV measures are still to be derived.

**Black hole versus neutron star LMXBs.**—The space density of LMXBs, with either BH or NS primaries, is even more uncertain. The total number of BH systems in the Galaxy is probably \(\geq 10^4\), as estimated from the numbers and recurrence times of BH

\(^1\) See http://hea-www.harvard.edu/ChaMPlane.
\(^2\) See http://cxc.harvard.edu/proposer/POG/html/ACIS.html.
\(^3\) See http://asc.harvard.edu/toolkit/pimms.jsp.
X-ray novae (Tanaka & Lewin 1995). The number of LMXBs in quiescence, or qLMXBs, containing NSs is even more uncertain, yet a large population is indicated by the much larger population of millisecond pulsars (MSPs) in the Galaxy (see Yi & Grindlay 1998) and population of faint transients in the bulge (see Heise 1998). Since both qLMXBs and CVs have X-ray luminosities typically \(10^{30.5} - 10^{32.5}\) ergs s\(^{-1}\), they are best discovered by a deep X-ray survey with flux sensitivity sufficient to detect these across the Galaxy and positional resolution sufficient to allow unambiguous optical or IR identification.

**Galactic center and bulge cusp sources.**—The population of faint sources in the central cusp about Sgr A* (Muno et al. 2003) may be dominated by wind-fed HMXBs, most likely quiescent Be HMXBs. Alternatively as also proposed by Muno et al. (2003), they may be relatively luminous CVs, most likely intermediate Polars. Our deep IR imaging (\(JHK_s\)) of the Sgr A* field (Laycock et al. 2005) shows that the bulk of these sources do not have high-mass companions with spectral types B0 or B1, as expected for Be HMXBs, and thus may be magnetic CVs. The nature and number of the bulge cusp sources, versus the Galactic bulge and disk sources generally, are major objectives of the ChaMPlane Survey. This has motivated our targeted program of deep pointings on three low-extinction windows progressively closer to the Galactic center (see Fig. 1); these are reported separately.

**Isolated BHs in GMCs.**—Whereas stellar mass BHs (sBHs) are now readily detected in binaries (usually as transients in LMXBs) as hard X-ray sources, isolated sBHs should be much more numerous. Agol & Kamionkowski (2002) estimate that there may be \(10^8 - 10^9\) sBHs in the Galaxy distributed in a disk distribution with scale height \(\sim 250\) pc. If these are born with kick velocities much less than those derived for NSs, as is plausible for SN II core-collapse models, they should be detectable by their

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**Fig. 2.**—Distributions of exposure time, \(N_H\), and Galactic coordinates \(l, b\) for 105 distinct ChaMPlane fields currently selected for ChaMPlane. Hatched bins are the 12 ks Galactic center survey fields of Wang et al. (2002). The extreme exposure bin of \(\sim 1\) Ms represents the current total of all observations on Sgr A*.
Bondi-Hoyle accretion when passing through dense molecular clouds and GMCs. Assuming only ~1% gas capture efficiency of Bondi-Hoyle accretion (Perna et al. 2003) and an additional radiative efficiency factor $\epsilon \sim 10^{-4}$ (allowing for an ADAF-like flow), the (hard) X-ray luminosity expected can still be appreciable. For a 10$^4 M_\odot$ BH with velocity $V = 10$ km s$^{-1}$ passing through a cold GMC [with sound speed $c_s < V$, so that $(V^2 + c_s^2)^{3/2} \sim V^3$] with density $n = 10^4$ cm$^{-3}$, the accretion luminosity is

$$L_X \sim 3.4 \times 10^{31} \epsilon n L_{10}/V_{10}^3 \text{ ergs s}^{-1},$$

where the $\epsilon$, $n$, $M$, and $V$ parameters are scaled to the values given above. Given the sensitivities above, this $L_X$ could be detected with ChaMP in a "typical" Galactic bulge field, with $N_{1H} \sim 2 \times 10^{22}$ cm$^{-2}$, in a 100 ks pointing. The challenge, of course, would be to identify (in the IR, given the extinction in the bulge and the GMC, which alone gives $N_{1H} \sim 3 \times 10^{23}$ cm$^{-2}$) the nature of such a source. With no binary companion, it should have an X-ray/IR flux ratio (unabused) $F_X/F_{IR} \gtrsim 1$ (since the unabsorbed $L_X/L_{IR} > 1$ for any reprocessed thermal IR) versus $F_X/F_{IR} \sim 0.1$ for the X-ray-to-$K$-band flux ratios for the BH LMXBs GRO J1022+34 and A0620–00. However, setting lower limits on $K$ magnitudes will be difficult because stellar crowding in bulge fields limits $K \lesssim 16$ (Laycock et al. 2005) and thus isolated BHs in GMCs may be best identified by high-resolution (NICMOS or AO) IR observations of highly self-absorbed ChaMP sources, or in shallower but wide surveys of relatively nearby GMCs with less stellar crowding.

Be X-ray binaries. — Be stars in binaries with NS companions (only, thus far) are perhaps the most numerous of the HMXB systems in the Galaxy. ChaMP is sensitive to the underlying population of quiescent Be HMXB (qBe-HMXB) systems; those in outburst are obvious as bright transients. From the values for $F_X/F_{IR}$ given for qBe-HMXB by van Paradijs & McClintock (1995) and converting to conventional broadband values, we derive $L_X \sim 10^{33.3 \pm 1.2}$ ergs s$^{-1}$. Isolated Be stars, on the other hand, should have $L_X \sim 10^{-7} P_{bol} \sim 10^{29.7}$ ergs s$^{-1}$ (for a B0 V star) and thus $L_X \sim 5.5$ and so be readily distinguished. Be HMXB systems with BHs as the compact object are expected from binary and stellar evolution and are another key goal of the ChaMP Survey. NS accretors, as found thus far, can be determined by X-ray pulsation analysis (all Be HMXB known thus far are accreting pulsars) although limited counting statistics makes this test possible only for the brightest sources.

Stellar coronal luminosity functions. — Most soft Galactic Chandra sources are identified (from positional matches) as coronal emission from stars, primarily K, M, and dMe stars, but extending throughout the entire H-R diagram. With typically $\gtrsim 15$ coronal sources per field, the entire survey (~100 fields) should yield $\gtrsim 1500$ stars, with photometric spectral types constrained by color-color analysis (see Zhao et al. 2005) and reddening constrained by X-ray colors (see Hong et al. 2005) or actually measured for a significant fraction from follow-up optical spectroscopy. Since ChaMP covers a wide range of the Galaxy, from fields in the anticenter to the bulge, these will allow entirely new constraints on stellar coronal emission over a range of metallicity and stellar populations not possible before with ROSAT (e.g., Schmitt et al. 2004).

3. SELECTION CRITERIA FOR SURVEY FIELDS

ChaMP uses both ACIS-I and ACIS-S Chandra pointings, which are imaging only (i.e., no grating data), without subarray or continuous clocking data mode (which restrict the field of view), and which meet the following criteria:

1. Preferably ACIS-I, for the larger field of view nearly on-axis this enables.

2. Exposure times nominally $\gtrsim 20$ ks (although some, like the Galactic center survey [Wang et al. 2002], are included with 12 ks exposures) and Galactic latitude $|b| \lesssim 12^\circ$.

3. Do not contain bright point sources or large/bright diffuse X-ray emission or extended clusters, which would systematically both limit sensitivity and contaminate survey fields with "targets."

4. Have minimal $N_{1H}$, although this choice is rarely possible to make.

These are primary criteria, in approximate priority order, used to select ChaMP fields and, in turn, to choose coordinates for the deep optical imaging (Mosaic) for our NOAO-ChaMP survey. In a few cases, we find that a short observation (5–10 ks) will be included within a Mosaic field previously acquired. These are included to help in extending the survey area coverage and thus sensitivity to bright sources in the plane with lower space density.

The fields selected for Cycles 1–6 are given on the ChaMP Web site, with their full parameters, and are shown schematically in Figure 1. The distributions of exposure time, $N_{1H}$, and Galactic longitude and latitude of the 105 distinct ChaMP fields chosen thus far are shown in Figure 2. In defining "distinct" fields, we have required pointing positions to be different by at least 4', since this is a characteristic scale for appreciable degradation of on-axis sensitivity and also the scale of half an ACIS CCD. The additional 49 ChaMP pointings (in the current total of 154) thus represent at least partial overlap fields, which allow significant new opportunities for time variability studies as part of the survey. ChaMP also includes the 30 fields observed by Wang et al. (2002) for their survey of the Galactic center region. These are counted as distinct (since their offset is 12') although in fact they overlap by 8' and thus allow variability searches for bright sources moderately far off-axis.

An overview of the current multiple-exposure coverage, in Galactic longitude versus temporal coverage, is provided in Figure 3. A "typical" ChaMP field is $\sim 30$ ks (Fig. 2) exposure and contains $\sim 70$ sources in each ACIS-I (or ACIS-S, scaled for area) field, with each source located to $\lesssim 1''$ precision in the central ~6' (diameter) field of view (FOV) and to within $\pm 2''$ even near the edge of the FOV.

4. X-RAY SURVEY PROCESSING AND DATA PRODUCTS

ChaMP fields are processed with a uniform detection and processing pipeline, XPIPE, based on the script developed by Kim et al. (2004) for the Chandra high-latitude survey, ChaMP. ChaMP incorporates significant additional processing in a Post XPIPE Processor (PXP) as described in detail by Hong et al. (2005). The entire processing system incorporates a number of new features of (potential) general interest to the Chandra community, including a very thorough treatment of X-ray source location confidence radii (e.g., 95% confidence) versus off-axis radii and X-ray—to—optical boresighting, with total uncertainties (see also Zhao et al. 2005). Source detection and verification (for details see Hong et al. 2005) produce increasingly restrictive source catalogs: levels 1, 2, and 3. Level 2 sources are the nominal primary database for ChaMP and are derived from detections on the four ACIS-I CCDs (CCDs 0, 1, 2, 3) for ACIS-I observations or the two ACIS-S CCDs (CCDs 6 and 7) and two
continuos ACIS-I CCDs (CCDs 2 and 3) for ACIS-S observations if they were all enabled. Some ACIS-S observations have fewer CCDs enabled so that the areal coverage for level 2 ACIS-S sources is not always four CCDs per observation. Level 3 sources are closer to on-axis and thus have smaller error circles and higher sensitivity. For ACIS-I observations, they are confined to within 400 from the Chandra aim point; for ACIS-S observations they are confined to just the back-side illuminated primary S3 chip (CCD 7).

Some 90 distinct fields (of 105 total) have been currently processed for the ChaMP Survey. Source numbers and areal coverage for these fields are given in Table 1. The ACIS-I versus ACIS-S areal coverage does not scale exactly with the number of fields for level 2 sources because of the differing number of CCDs enabled for ACIS-S observations, as noted above. A total of 119 observations (of the 154 total) have been processed, so that the total source numbers are currently 10,283 (level 2) and 7518 (level 3). Comparison with Table 1 totals for distinct sources then shows that approximately 3238 (level 2) and 2519 (level 3) sources are multiple observations, although in fact some of these are new sources.

Whereas XPIPE processing and wavdetect source detection are done in the same broad band, $B_s$ (0.3–8.0 keV), as ChaMP (Kim et al. 2004), the larger $N_{\text{H}}$ expected for ChaMP sources dictates our choice of “conventional” bands $B_v$ (broad; 0.5–8.0 keV), $S_s$ (soft; 0.5–2.0 keV), and $H_s$ (hard; 2.0–8.0 keV), which are extracted in the PXP script from the counts in the wavdetect source regions and used for broadband analysis such as $\log N_s \cdots \log S$. X-ray colors and rough spectral classification are not done using conventional hardness ratios and color-color analysis, but rather more generally with quantile analysis (Hong et al. 2004). Quantile color-color diagrams (QCCDs) enable more meaningful X-ray color analysis on weak sources. The log $N_s \cdots \log S$ and quantile analysis results for 14 anticenter fields are given by Hong et al. (2005).

Output data products (source positions and uncertainties, fluxes in conventional bands for X-ray/optical flux ratios, e.g., $F_x/F_v$, $F_x/F_R$, etc.) are stored in a searchable database accessible through the ChaMPWeb site for which search and display tools have been developed (see the Appendix). Images and data products for the anticenter observations (14 fields) described by Hong et al. (2005) are now incorporated in this ChaMP database and are available from the ChaMPWeb site (see the Appendix).

5. OPTICAL–IR SURVEY AND DATA PRODUCTS

Here we provide an overview of the three principal elements of our source identification program: Mosaic imaging and photometry, spectroscopic follow-up, and IR imaging (and spectroscopic) follow-up.

5.1. Photometry from ChaMP Mosaic Images

Our NOAO optical survey program obtained 65 deep stacked Mosaic images in each of four filters that include all 105 ChaMP fields shown in Figure 1. The details of our Mosaic photometry analysis are given by Zhao et al. (2005).

Accretion sources may be identified by their ubiquitous Hα emission: most CVs (except dwarf novae in outburst) and all qLMXBs (and bright LMXBs) show Hα in emission [see below for EW(Hα) statistics] from their accretion disks or accretion columns (in the case of Polars). Be/X-ray binaries and isolated Be stellar X-ray sources are also (by definition) Hα emitters. Consequently, the ChaMP NOAO Survey program was designed as a wide-field deep Hα imaging survey, with annual allocations of five nights of deep $I$, $R$, $H_s$, $J$ (to $R \sim 24$) imaging time on the CTIO 4 m and one to two nights on the KPNO 4 m telescopes. We use the NOAO Mosaic cameras, which provide 36' × 36' fields and therefore a factor of ~5 more optical survey coverage

4 See http://cxc.harvard.edu/ciao/ahelp/wavdetect.html.

| TABLE 1 |
| Current versus Expected ChaMP Plane Coverage (ACIS-I vs. ACIS-S) |

| OBSERVATION TYPE | NUMBER OF FIELDS | NUMBER OF SOURCES | TOTAL (deg²) | AREA (deg²) |
|------------------|------------------|-------------------|--------------|-------------|
| ACIS-I........... | 63               | 5299              | 3998         | 4.92        | 2.43        |
| ACIS-S........... | 27               | 1746              | 1001         | 1.98        | 0.53        |
| Current total..... | 90               | 7045              | 4999         | 6.90        | 2.96        |
| Final total...... | 105              | 8219              | 5832         | 8.05        | 3.45        |

Notes.—Source totals of distinct ChaMP plane fields processed to date (2005 August) for level 2 vs. level 3 sources (for definitions see text and Hong et al. 2005) and respective total areas covered. Level 3 sources and survey areas are a subset of the corresponding level 2 values. The final row gives the approximate extrapolated totals expected for the current total of 105 distinct ChaMP plane fields.
than the $16\times16'$ ACIS-I field. The larger Mosaic imaging thus provides a deep optical comparison survey for CVs and emission-line objects. H$\alpha$ $-$ R versus R color-magnitude diagrams identify H$\alpha$ counterpart candidates for ChaMPlane sources (Grindlay et al. 2003; Zhao et al. 2003).

Color-color diagrams $[(V-R) \text{ vs. } (R-I)]$ are constructed for each field as an additional aid for initial source classification using X-ray constraints on source class (e.g., stellar coronal vs. accretion): objects can be dereddened using estimates of N$_H$ from QCCDs. When optical spectra are eventually obtained, we employ a technique to constrain source distances and N$_H$ (and thus X-ray luminosities) by using the photometry in combination with spectroscopy and the reddening models of Drimmel et al. (2003); details are given in X. Koenig et al. (2005, in preparation).

Our requirement to image CVs and qLMXBs, with typical absolute magnitudes $M_V \sim 7$, at 8 kpc and with (at least) $A_V = 2.5$, leads to the desired magnitude limit of $R = 24$ for the survey. Since the primary discriminant is H$\alpha$ $-$ R, we seek 5% photometry at $R = 24$ and 10% photometry in H$\alpha$, as well as $V$ and $I$, requiring a total $\sim$4 hr integration per field with the NOAO 4 m telescopes and reasonable ($\sim10^3$) seeing.

### 5.2. Spectroscopic Follow-up Program

Spectroscopic follow up is sought on all optical IDs that can be reached with WIYN Hydra or the MMT Hectospec for northern fields and either CTIO 4 m Hydra or Magellan IMACS for southern fields. Our strategy is to obtain spectra for all ChaMPlane source optical counterparts with $R \leq 22$ (as dictated by WIYN, MMT, CTIO 4 m, and Magellan), with highest priority for those with H$\alpha$ excess as given by the Mosaic photometry. We use “extra” fibers/slits for H$\alpha$ emission candidates identified with Mosaic in the surrounding larger field. We have obtained spectra of bright ($V \leq 17$) objects with FAST on the FLWO 1.5 m telescope.

Initial results for spectroscopic follow-up with WIYN Hydra for 13 ChaMPlane fields, including 11 of the 14 anticenter fields presented here, have been reported by Rogel et al. (2005). At least five CVs have been discovered in the surrounding Mosaic fields, but none inside the ChaMPlane ACIS fields (see below). Follow-up spectroscopy is most incomplete for Galactic bulge fields where we expect the largest accretion source content. We have obtained some spectra (Magellan LDSS2, Magellan IMACS, and CTIO Hydra) in 16 out of 25 distinct ChaMPlane fields in the Galactic bulge ($|l| \leq 20'$), but coverage is still very incomplete. Initial results for LDSS2 spectra are presented by X. Koenig et al. (2005, in preparation).

### 5.3. IR Photometry Program

Given the large excess of sources near the plane of the Galactic bulge, and (apart from the low-extinction “windows”) given the high extinction that precludes all but sources in the foreground $\leq 3$ kpc from optical identifications and spectra, we have implemented an extensive IR photometry program to complement the Mosaic optical imaging for these bulge fields. Initial results from a $10' \times 10'$ mosaic of IR imaging ($J, H, K$, Br$\gamma$) around Sgr A* that we have obtained with the newly commissioned PANIC instrument on Magellan are presented by Laycock et al. (2005).
$l$, $b = 165^\circ\!88, -11^\circ\!91$, are included in Zhao et al. (2005) and will be reported separately for the remaining anticenter fields. Table 2 gives the Chandra observation ID (for easy reference; see the Appendix), target, Galactic coordinates, exposure time achieved, $N_{\text{H}}$ value for absorption through the full Galaxy at each position as derived from the extinction map of Schlegel et al. (1998), approximate flux sensitivity limit in the H$_\alpha$ band (2.0–8 keV) achieved for an assumed power-law spectrum with photon index 1.7, and the number of Chandra sources detected in each field for level 2 versus level 3 (Hong et al. 2005) processing of ACIS-I (all 4 CCDs) versus ACIS-S (single S7 CCD), respectively. The final three columns of Table 2 are discussed in § 6.2. Although the nominal ChaMP Survey sources are level 2 for both ACIS-I and ACIS-S observations, in the initial analysis presented here we use the more restrictive level 3 cut for ACIS-S observations for the simplification of not having mixed CCD types (i.e., back- vs. front-side illuminated chips for ACIS-S observations).

### 6.1. Source Properties

Although 367 of the 631 level 2 (ACIS-I) and level 3 (ACIS-S) anticenter sources have optical counterparts, only 4 of these were identified, securely, with apparent H$_\alpha$ emission objects with $(H_\alpha - R) \lesssim -0.3$: the two BH qLMXBs, GRO J0422+32 and A0620–00, a QSO at $z = 4.25$ (with Ly$\alpha$ redshifted into the H$_\alpha$ filter) as a counterpart of a source in the G116.9+0.2 field, and a second source in this field that could be affected by nebular H$_\alpha$ emission. A number of marginally bright H$_\alpha$ sources with $(H_\alpha - R) \lesssim -0.2$, corresponding to equivalent widths [for the $(H_\alpha - R)$ vs. EW(H$_\alpha$) calibration see Zhao et al. (2005)] of EW(H$_\alpha$) $\sim 18$ Å$^5$ are probable counterparts. WIYN Hydra spectra of some of these objects (Rogel et al. 2005) reveal most of these to be dMe stars. Spectra have been obtained for 141 (including two BH LMXBs targets) of the 279 ChaMP sources with optical matches in 11 of these 14 fields and have shown 59 to be coronal emission from stars, 19 to be active galactic nuclei (AGNs), 5 possible AGNs, and 58 to be unidentified due to, in most cases, insufficient signal-to-noise ratio (S/N). Given variable observing conditions, not all of the fields were observed with photometric errors as small as shown (Zhao et al. 2005) for GRO J0422+32. Even in this field, with low $N_{\text{H}}$ and relatively high latitude, only 40 of the 62 ChaMP sources have optical counterparts brighter than the magnitude limit $R \sim 24.5$. For the X-ray flux limit $F_{X_{\text{lim}}}$ $\sim 1.1 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$ for this field, the corresponding unabsorbed flux limit is log $(F_X/F_R) \gtrsim 1$, implying that the still fainter unidentified sources are very likely accretion-powered sources, most likely AGNs, although this value is at the upper envelope (e.g., Brandt & Hasinger 2005) unless they are significantly self-absorbed.

Indeed, as shown by Hong et al. (2005), log $N$–log $S$ analysis in the H$_\alpha$ band shows that the sources in these 14 fields are apparently dominated by AGNs since the ChaMP anticenter sources are consistent with the high-latitude Chandra counts derived by ChaMP (Kim et al. 2004). Although optical spectroscopy (Rogel et al. 2005) shows that stars are a significant fraction (∼42%) of ChaMP counterpart candidates for which spectra have been obtained in anticenter fields, these 59 stars are only $23\%$ of the optical matches in the 11 fields for which spectroscopy was obtained and are also only $13\%$ of the total 503 sources in these 11 fields. Allowing for the incomplete spectral coverage thus far in these fields (only 141 of 279 optical IDs in the 11 fields), the fraction of stellar coronal source IDs could be doubled to ∼25% (or ∼10–20 sources per field). Since stellar coronal sources are also primarily detected in the S$_\alpha$ (0.5–2 keV) band for which the log $N$–log $S$ results of Hong et al. (2005) show that the anticenter sources may exceed the AGN background, the results are self-consistent. The stellar versus AGN contributions are also constrained by the X-ray–to–optical flux ratio $(F_X/F_R)$ distributions.

As an initial check on the CV population and contribution to the ChaMP anticenter sources versus AGNs and stars, we plot in Figure 4 the $F_X/F_R$ distributions for the S$_\alpha$ (0.5–2 keV) band for the optically identified sources, along with the spectroscopically confirmed stars and AGNs (Rogel et al. 2005) for a subset of these with $3\sigma$ flux measurements. The $F_X/F_R$ distributions for 324 of the 367 IDs for which $F_X/F_R$ values can be derived (43 have poorly determined $R$ magnitudes) is double peaked. From comparison with the spectroscopic samples, composed predominantly of stars (left peak) and AGNs (right peak), the 131 sources with $3\sigma$ flux measurements in the S$_\alpha$ (0.5–2 keV) band are consistent with being ∼32% stars and 68% AGNs (CVs and other accretion-powered galactic sources are also included, predominantly, in the hard peak).

The 117 ChaMP AGNs (taken from Green et al. 2004) are overplotted in Figure 4 (dotted line) and have been reddened to the ChaMP level $N_{\text{H}}$ values by dividing the ChaMP sample into 14 groups with numbers of sources proportional to the relative source numbers $N_{\text{H}}$ in Table 2 for the anticenter fields. Each group is then reddened in both $F_X$ and $F_R$ for the $N_{\text{H}}$ in that field, and a corrected $F_X/F_R$ derived. The peak of the reddened ChaMP distribution matches closely the right peak of the ChaMP distribution, further demonstrating that most are AGNs. However, so does (approximately) the peak of the ROSAT CV distribution, which is unreddened (most ROSAT CVs are nearby and have minimal $N_{\text{H}}$) and lines up approximately with the peak of stellar coronal source IDs.
the (unreddened) "raw" ChaMP AGNs. The CVs may differ from the AGNs in having a tail to lower values of $F_X/F_R$, as well as a broader peak to higher $F_X/F_R$ values. Thus, CVs, particularly magnetic CVs but also qLMXBs (with both NS and BH primaries), with their flat bremsstrahlung continua, are often harder than AGNs in their magnetic CVs but also qLMXBs (with both NS and BH primaries), with their flat bremsstrahlung continua, are often harder than AGNs in their

Moving to the harder $H_\alpha$ band also increases the contrast (separation) between the CVs (and qLMXBs) versus stars. In Figure 5 we plot the log ($F_X/F_R$) distributions for the 68 observed and unabsorbed (for the full-plane $N_H$) sources with $\geq 3$ $\sigma$ fluxes in the $H_\alpha$ band. The five source “peaks” at log ($F_X/F_R$) $\sim -2$ and $-3$ (raw vs. unabsorbed, respectively) include three stars confirmed spectroscopically so that, as expected, coronal stellar sources are almost gone in the $H_\alpha$ band. Thus, in Table 2 and the discussion that follows for initial constraints on CVs, we consider the $H_\alpha$ band only.

6.2. Constraints on CV Density or Luminosity Function

The apparent lack of bright $H_\alpha$ sources among the ChaMP anticenter source IDs allows limits to be derived for the CV space density and/or X-ray luminosity function. We make the conservative assertion that of the 367 sources with optical counterparts, at most $\sim 7$ could have $(H_\alpha - R) \leq -0.3$ or EW($H_\alpha$) $\geq 28$ $\AA$, which allows rejection of dMe stars (see Zhao et al. 2005) but not AGNs for which emission lines can be redshifted in the $H_\alpha$ filter. We include even marginal $H_\alpha$ objects (all are $\geq 1.4$–$2$ $\sigma$) for a maximum limit, and without spectroscopic identification (five were unobserved and two had insufficient counts for classification). Since the Sloan Survey CV sample (Szko'dy et al. 2002, 2003, 2004) finds that 17% of their 99 spectroscopically discovered CVs have EW($H_\alpha$) $\leq 28$ $\AA$, our photometric limits for ChaMP CVs could be increased by this factor (1.17) to $\leq 8$. Thus, a (very) conservative limit from the optically identified ChaMP anticenter sources is that $\leq 2\%$ are CVs based on these $H_\alpha$ limits. The nearly half of the anticenter source sample not yet identified optically, with absorbed log ($F_X/F_R$) $\geq 1.2$ but for which the unabsorbed limit is $\leq 0$, could allow additional CVs, although again the log $N$–log $S$ results suggest that these reddened anticenter sources are also dominated by AGNs.

We now explore whether these limits, from 14 anticenter fields, provide interesting constraints on the CV number density. Given the current estimates from ROSAT (Schwope et al. 2002) and previously Einstein (Hertz et al. 1990) that X-ray–selected CVs in the solar neighborhood ($\leq 1$ kpc) are detected with space density $n_{CV} \sim 3 \times 10^{-5}$ pc$^{-3}$, we derive the numbers expected in each of the 14 fields. Given the estimated distances of the ROSAT CVs, their luminosities in the ROSAT band are peaked at $L_X(0.5–2.5$ keV) $\sim 10^{31}$ ergs s$^{-1}$, with only 3 of 49 (Verbunt et al. 1997; Schwope et al. 2002) between $10^{29}$ and $10^{30}$ ergs s$^{-1}$. The 22 optically identified CVs detected by Chandra in the deep survey of the globular cluster 47 Tuc (Heinke et al. 2005) are distributed with a cumulative luminosity function described by either a power law, $N(\geq F(S)) \propto F(S)^{-0.31 \pm 0.04}$, or a lognormal distribution with mean log ($L_X(S_c)$) $= 31.2 \pm 0.3$. For a “typical” CV spectrum (e.g., a bremsstrahlung spectrum with $kT \sim 5–10$ keV), the $L_X(S_c)$ and $L_X(H_\alpha)$ values are comparable. Thus, for $L_X(H_\alpha) = 10^{30}$ and $10^{31}$ ergs s$^{-1}$, we derive (Table 2) the limiting detection distances $d_{30}$ and $d_{31}$ for each field using the (maximum) $N_H$ values for each as derived from Schlegel et al. (1998) and given in Table 2. Given the solid angle $\Omega \propto \theta^2$ subtended by the full field of the ACIS-I or ACIS-S exposure, with $\theta = 16$° or 8°, respectively (we use the full field and in this simplified treatment do not allow for the off-axis decline in sensitivity), we then derive the volume in the disk over which CVs could be detected. We assume that CVs are distributed in the disk with an exponential $\mu$-distribution (Warner 1995) for which we first assume a scale height $h = 400$ pc, comparable to that recently estimated for LMXBs (Grimm et al. 2002). We assume that the radial distribution scale in the disk is much larger (e.g., $\sim 3.5$ kpc, as for stars) and can to first order be ignored in this initial treatment. We then derive the effective detection volume

![Figure 6. $A_R$ vs. distance for the 14 anticenter ChaMPPlane fields analyzed in Table 1 using the $A_r$ vs. distance model of Drimmel et al. (2003) for each $l$, $b$ value shown. $A_R = 0.75 A_{V}$ values are plotted after rescaling the asymptotic $N_0$ value in the Drimmel model for each field to that given by Schlegel et al. (1998). This rescaled $A_R$ vs. $d$ relation is used to estimate extinction at distances $d_{30}$ and $d_{31}$ (see text) for each field.](image-url)
$V_{	ext{eff}}$ for each field, using the same formalism adopted by Schwöpe et al. (2002) and Tinney et al. (1993). Assuming that the CVs are distributed with a z-distribution as $n_{\text{CV}} \propto \exp(-d\sin b)/h$, the effective detection volume out to distance $d$ is

$$V_{\text{eff}} = \Omega (h/\sin b)^3 \left[2 - (\chi^2 + 2\chi + 2)e^{-\chi}\right],$$

where $\chi = d(\sin b)/h$. We derive this volume for the limiting detection distances $d_{30}$ and $d_{31}$ and thus the total number of CVs, $N_{\text{CV}} = n_{\text{CV}} V_{\text{eff}}$, given in Table 2 as $N_{30}$ and $N_{31}$. Summing over the 14 fields gives a total of 2.3 CVs expected if their characteristic luminosity is $L_X = 10^{30}$ erg s$^{-1}$, versus 53.1 for $L_X = 10^{31}$ erg s$^{-1}$. Changing the assumed scale height to 200 pc, as assumed by Schwöpe et al. (2002), gives corresponding CV numbers 2.0–38.3. Additional limits are given below for a plausible X-ray luminosity function (XLF).

We then estimate (Table 2) the range of optical $R$ magnitudes these CVs would have for the range of log $(F_X/F_R) \sim \log(F_X/F_R) \sim -1$ to +1, typical for CVs (Hertz et al. 1990; Verbunt et al. 1997). However, since the optical counterparts for the CVs in some of these anticenter fields must be appreciably dimmed by the visual extinction, which in $R$ is $A_R = 4.2 N_{22}$, where $N_{22}$ is the $N_{1}$ value in units of $10^{22}$ cm$^{-2}$ as given in Table 2, it is necessary to allow for extinction in the expected $R$ magnitudes as a function of distance through the disk. We do this using the three-dimensional dust model of the Galaxy from Drimmel et al. (2003). The Drimmel model computes $A_R$ versus $d$, but for these anticenter fields it appears to underestimate the full-plane extinction as indicated by our log $N$–log $S$ analysis (Hong et al. 2005), for which the Schlegel et al. (1998) full-plane $N_{1}$ gives a better match to the extragalactic source number counts in the unabsorbed H$\alpha$ band. Thus, we renormalize the Drimmel $A_R$ values by the full-plane $N_{1}$ predicted by Schlegel et al. (1998) and convert to $A_R = 0.75 A_V$ for the $A_R$ versus $d$ plot in Figure 6. This gives $A_R$ for distances $d_{30}$ and $d_{31}$ and thus the expected observed range of $R$ magnitudes for CVs for the $L_X$ and $F_X/F_R$ ranges given in Table 2.

Finally, we estimate the fraction of the predicted X-ray CVs that should be identified (“easily”) with magnitudes $R \leq 23$ in our ChaMP plane sample. We use the ROSAT distribution of $F_X/F_R$ as plotted in Figure 4 [and which we assume to be approximately the same as the $F_X/F_R$ distribution, given typical CV colors $(V-R) \sim 0.3$], to derive the cumulative distribution shown in Figure 7. This gives the fraction of optical CVs versus $R$ magnitude relative to the $R$ magnitude for log $(F_X/F_R) = +1$ since these are the faint optical limits, $R_{31}$ and $R_{30} + 5$, as given in Table 2. The cumulative optical identification fractions, $C_{30}$ and $C_{31}$, of the X-ray CVs are read off the plot as the fraction value at the “offset magnitude” limits $R_{31} - 23$ and $(R_{30} + 5) - 23$ and given in Table 2. These fractions are then multiplied by the total predicted X-ray CV numbers ($C_{30}$ and $C_{31}$) to give the predicted number of CVs ($ID_{30}$ and $ID_{31}$) that should be optically identified for each field at $R \leq 23$ for these characteristic $L_X$ values.

7. CONCLUSIONS

The X-ray number counts for ChaMP plane sources in the anticenter (Hong et al. 2005) suggest that, as found in a moderately deep Chandra Galactic plane survey of $(l, b) \sim (28.5, 0^\circ)$ and ASCA Galactic plane surveys (Ebisawa et al. 2003), at fluxes $\leq 10^{-13.5}$ ergs cm$^{-2}$ s$^{-1}$ the AGNs and extragalactic source distributions dominate stars and Galactic sources. Although the photometry of an “example” ChaMP plane field, GRO J0422+32 (Zhao et al. 2005), shows that most of the 40 optical counterparts (out of 62 sources) in this field have $(V-R)$ and $(R-I)$ colors consistent with their being normal stars, spectroscopy (Rogel et al. 2005) of 33 of these counterparts showed that 14 are AGNs, 4 are stars, and 15 were unidentified (insufficient S/N).

We have conducted preliminary analysis of 14 anticenter fields to limit their CV content and contribution from compact binaries generally. Our initial analysis of the ChaMP plane anticenter CV limits suggests that the local space density of CVs may be overestimated by a factor of $\sim 3$ relative to the $3 \times 10^{-5}$ pc$^{-3}$ value derived for the solar neighborhood from the Einstein and ROSAT surveys. We derive this as follows. The ROSAT CVs are strongly peaked at $L_X \sim 10^{31}$ ergs s$^{-1}$, so we first consider the limiting case for this $L_X$. The much larger volumes in the disk (and halo) that can be reached with Chandra than with ROSAT make it unlikely that the $\sim 38–53$ CVs predicted in the 14 fields could be missed if they had local space density $n_{\text{CV}} \sim 3 \times 10^{-5}$ pc$^{-3}$ and X-ray luminosity function with characteristic $L_X \sim 10^{31}$ ergs s$^{-1}$. Our conservative upper limit of 8 CVs out of 367 optical IDs could then allow perhaps 14 CVs for the full sample of 631 sources from simple scaling, yielding a deficit factor of $\sim 2.7$.

A stronger limit is obtained from the predicted number of CVs that should have magnitudes $R \leq 23$ (“easily” detected in our Mosaic photometry), given our derived $F_X/F_R$ distribution for ROSAT CVs: for CVs with characteristic $L_X \sim 10^{31}$ ergs s$^{-1}$, some 26 CVs should have been optically identified from the ChaMP plane sources. This would suggest a factor of $\sim 3$ deficit in CV density. Since it incorporates “known” $F_X/F_R$ flux ratios for CVs and the extinction versus distance model (Drimmel et al. 2003) for each field, it should be roughly independent of the fraction of ChaMP plane sources optically identified. ChaMP plane sources with $R \leq 23$ are consistent with the $F_X/F_R$ distributions and extinction for CVs with characteristic $L_X \sim 10^{31}$ ergs s$^{-1}$ if $n_{\text{CV}} \sim 1 \times 10^{-5}$ pc$^{-3}$.

Allowing for a plausible XLF for disk CVs like that recently derived for CVs in the globular cluster 47 Tuc (Heinke et al. 2005), for which we approximate an integral distribution $N(\geq L_X) \propto L_X^{-0.3}$ for $L_X \leq 10^{31.5}$ ergs s$^{-1}$, steepening to an index of roughly $-1.3$ for higher luminosities, and assuming a low-luminosity cutoff at $\sim 10^{20.5}$ ergs s$^{-1}$, then $\sim 0.22$ of the sources would be detected with $L_X \geq 10^{31}$ ergs s$^{-1}$. This would appear to suggest a
reduction by this factor for the CV$_{31}$ total from that in Table 2, or comparable to our scaled limit of $\leq 14$ CVs. However, the extension of the XLF to larger $L_X$ increases the detection volume and thus CV number predicted. When combined with the addition of the larger number of lower $L_X$ CVs, a deficit is still indicated. Full consideration of the XLF and the radial scale length of CVs in the Galactic disk, e.g., $\sim 3.5$ kpc as for stars, will be explored in more detailed analysis with the full ChaMPlane anticenter sample. Our limits are relatively insensitive to the assumed vertical scale height ($h = 200$ vs. 400 pc only reduces the expected CV numbers by 28%) and are consistent with the overall CV space density $\sim 10^{-5}$ pc$^{-3}$ for the solar neighborhood (Patterson 1998).

However, the Patterson (1998) estimate is dominated (75%) by short-period CVs below the period gap with low $m$ and thus $L_X$ values $\leq 10^{30}$ ergs s$^{-1}$ expected. These can be detected in these ChaMPlane anticenter fields out to $\sim 1.5$ kpc, but the numbers expected (CV$_{30}$ in Table 2) are small. Additional fields in the anticenter can test this by probing a greater range of $l, b$ values, as well as additional regions of low $N_H$. However, the best measurements of the low-$L_X$ CV population will likely come from our low-extinction windows (e.g., Baade’s Window) in the bulge, for which analysis is in progress. Conversely, the luminous ($L_X \sim 10^{32}$–$10^{33}$ ergs s$^{-1}$) CV distribution may dominate the compact object distributions near the Galactic center. IR imaging of the sources in the cusp around Sgr A$^*$ suggests that most are not HMXBs but are consistent with being luminous CVs (Laycock et al. 2005).

With the much larger samples of ChaMPlane data from the full survey (these data represent $\leq 10\%$ of the total and cover just 0.6 deg$^2$), the CV and compact binary (qLMXBs, Be HMXBs) space density and luminosity functions will be possible to measure or constrain over Galactic scale distances for the first time. The ChaMPlane data and images will be available for easy access and analysis, as described in the Appendix.

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APPENDIX

CHAMPLANE DATA ARCHIVES AND VO ANALYSIS AND DISPLAY TOOLS$^6$

We have developed a suite of analysis tools and an online database for both the primary ChaMPlane X-ray data (source catalogs) and the optical counterpart data. Online browse access to ChaMPlane observations and data is organized by ObsID (which can also be found on the ChaMPlane Web site, where all observations can be listed and sorted) and provides a very general and intuitive platform for access to the results. We show a screenshot example$^7$ of access to ObsID 676, the field originally observed for the BH transient GRO J0422+32. The left window allows a browse selection of ObsID, the middle window enables choice of data return (e.g., formatted text or rdb tables), while the rightmost windows are the source catalog for the field selected (top: showing X-ray source ID number, right ascension, declination, etc., of the sources in that field) and the optically identified counterparts for the given source clicked on in the upper window (bottom). Following the link at the end of this paragraph of text online leads to a “walk-through” tutorial and demonstration of how to create the composite screen shown in the first online depiction.

In Chandra Cycle 5, we developed and released a Virtual Observatory (VO) node to facilitate access and online analysis of ChaMPlane data. Database access is via the VO interface in the image display and analysis package ds9,$^8$ which is a major upgrade from the original SAOimage package and allows many new features, including VO. In general, the user connects through the ds9 toolbar or via any Web browser.$^9$ Upon connection the ChaMPlane toolbar is automatically installed on the user’s own ds9 running locally on the user’s machine. Commands and results are exchanged between the user’s machine and the ChaMPlane data server at CfA running search and analysis scripts. This setup has the considerable advantage of adding custom tools and data to an already familiar platform, while maintaining the data archive and analysis and display tools at a central facility for maintenance and upgrades. A demonstration and link to a “walk-through” of this ChaMPlane VO facility is given in the following paragraph.

The ChaMPlane VO provides access to our deep Mosaic optical ($F, R, I, H_\alpha$) images, catalogs of their optical photometry, Chandra images with exposure map correction, X-ray source data, and details of X-ray sources with identified optical counterparts. Images, data tables, and plots (e.g., color-magnitude diagrams) can be generated for sources detected in any desired region on the Chandra or Mosaic images. Data can be selected by defining regions with a cursor to overlay X-ray or optical source positions selected for a given characteristic on either the ACIS or Mosaic field of view. An example is shown in the second online depiction from the source selection shown in the first online depiction. Once again, following the link on the Web appendix just after the second online depiction leads to a “walk-through” tutorial and demonstration of how to create the composite screen shown in the second online depiction. We note that as a matter of scientific interest, the two ChaMPlane sources identified as H$\alpha$ objects in the second online depiction, namely, the two sources with red (H$\alpha$ object) source circles and optical source ID numbers overlapped in this depiction on both the optical Mosaic image (image on left) and the smoothed Chandra image (image on right), are identified from WIYN spectroscopy ( Rogel et al. 2005) as a dMe star (optical ID 111135) and a QSO at $z = 1.31$ (optical ID 111329), with the (red) wing of Mg $\alpha$ at 2802 Å redshifted into the H$\alpha$ filter!

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$^6$ See http://hea-www.harvard.edu/ChaMPlane/apj...appendix.html.
$^7$ See http://hea-www.harvard.edu/ChaMPlane/walkthrough...xray.html.
$^8$ See http://hea-www.harvard.edu/RD/ds9.
$^9$ See http://hea-www.harvard.edu/ChaMPlane/data...archive.html.
Additional ChaMPlane VO tools for interactive inspection of both the X-ray and optical data are described on a separate link and via the Data Archive/Virtual Observatory link on the ChaMPlane homepage.

X-ray and optical data are now available online for the initial 14 fields in the anticenter. X-ray and optical images and source catalogs for a given field or region of the survey will be added to the database when the first corresponding analysis papers are submitted for publication. Calibrated $V$, $R$, $I$, and $Hα$ Mosaic images and photometry are submitted in parallel to the NOAO Long Term Survey archives and CDS; these have already been archived at NOAO for the initial 14 anticenter fields.

10 See http://hea-www.harvard.edu/ChaMPlane/walkthrough_ds9.html.

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