

MIT Open Access Articles

Wide field x-ray telescope a moderate class mission

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: Murray, Stephen S. et al. "Wide Field X-ray Telescope: A Moderate Class Mission." San Diego, California, USA, 2010. Proc of SPIE. 77321W-77321W-7. © 2010 COPYRIGHT SPIE--The International Society for Optical Engineering.

As Published: <http://dx.doi.org/10.1117/12.856921>

Publisher: SPIE (Society of Photo-optical Instrumentation Engineers)

Persistent URL: <http://hdl.handle.net/1721.1/64945>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Terms of Use: Article is made available in accordance with the publisher's policy and may be subject to US copyright law. Please refer to the publisher's site for terms of use.



Wide Field X-ray Telescope A Moderate Class Mission

Stephen S. Murray^{1,2}, R. Giacconi², A. Ptak², P. Rosati³, M. Weisskopf⁴, S. Borgani⁵, C. Jones¹, G. Parseschi⁶, P. Tozzi⁷, R. Gilli⁷, S. Campana⁶, M. Paolillo⁹, G. Tagliaferri⁶, M. Bautz¹⁰, A. Vikhlinin¹, R. Hickox^{1,11}, and W. Forman¹

ABSTRACT

Sensitive surveys of the X-ray universe have been limited to small areas of the sky due to the intrinsically small field of view of Wolter-I X-ray optics, whose angular resolution degrades with the square of the off axis angle. High angular resolution is needed to achieve a low background per source, minimize source confusion, and distinguish point from extended objects. WFXT consists of three co-aligned wide field X-ray telescopes with a 1° field of view and $\lesssim 10''$ (goal of $5''$) angular resolution (HEW) over the full field. Total effective area at 1 keV will be $> 5000 \text{ cm}^2$. WFXT will perform three surveys that will cover most of the extragalactic sky to 100–1000 times the sensitivity of the ROSAT All Sky Survey, $\gtrsim 2000 \text{ deg}^2$ to deep Chandra or XMM-Newton sensitivity, and $\gtrsim 100 \text{ deg}^2$ to the deepest Chandra sensitivity. WFXT will generate a legacy X-ray data set of $\gtrsim 5 \times 10^5$ clusters and groups of galaxies to $z \sim 2$, also characterizing the physics of the intracluster gas for a significant fraction of them, thus providing an unprecedented data set for cosmological applications; it will detect $> 10^7$ AGN to $z > 6$, again obtaining spectra for a substantial fraction; it will detect $> 10^5$ normal/starburst galaxies; and it will detect and characterize star formation regions across the Galaxy. WFXT is the only X-ray survey mission that will match, in area and sensitivity, the next generation of wide-area optical, IR and radio surveys. <http://wfxt.pha.jhu.edu>

1. INTRODUCTION

Many outstanding astronomical issues e.g., the first super-massive black holes (SMBH), galaxy/active galactic nuclei (AGN) co-evolution, feedback mechanisms, the cosmic cycle of baryons, the physics of compact sources, structure formation and precision cosmology, require the combination of high sensitivity, large survey area and good angular resolution. The WFXT Mission,¹ achieves these requirements using proven technologies and a design specifically optimized for surveys.

The idea of carrying out an X-ray survey with good angular resolution has been discussed for many years. There have been several proposals by members of our team based in using a wide field of view X-ray telescope design that was developed in the early 1990's by Burrows, Burg and Giacconi.² Minor perturbations to the standard Wolter X-ray telescope can in principle yield a 1 degree field of view where the HEW of the point response function is below 5 arc seconds. The combination of a wide-field design with large effective area provides a telescope with very large grasp, and therefore one that can survey large areas of the sky to high sensitivity in relatively short times. The WFXT mission concept achieves this performance by using three co-aligned telescopes with photon-counting CCD imaging detectors, placed in a low inclination, low Earth orbit that maximizes surface brightness sensitivity.

1. Harvard-Smithsonian Center for Astrophysics
2. Johns Hopkins University
3. European Southern Observatory
4. Marshall Space Flight Center
5. University of Trieste
6. INAF/Brera
7. INAF/Trieste
8. INAF/Bologna
9. University of Naples
10. Massachusetts Institute of Technology
11. University of Durham

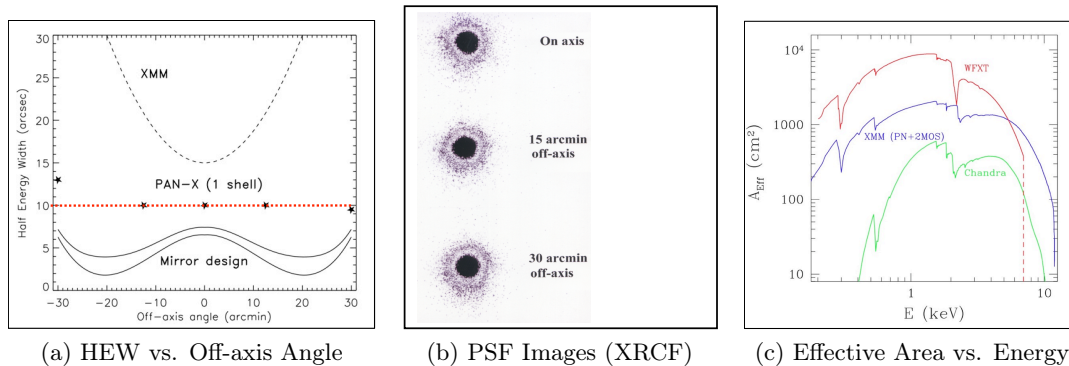


Figure 1: Key Performance elements for WFXT. Three identical telescope detector modules provide large effective area and efficient use of the launch capacity. The telescopes are designed for wide field of view with 5 arcsec HEW across the entire field.

2. SCIENCE PAYLOAD

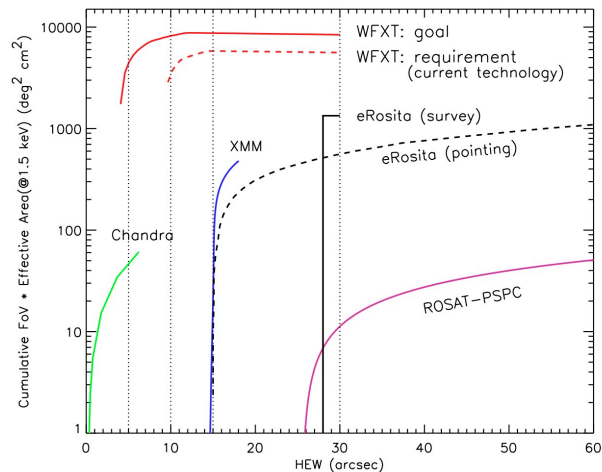
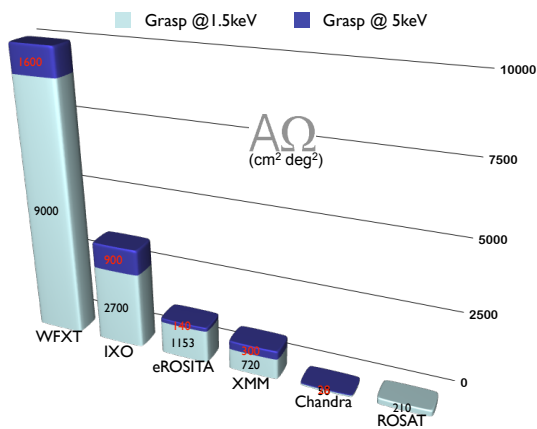
The science payload for WFXT consists of three identical telescope/detector modules. These modules are fully assembled, integrated and end-to-end tested prior to being attached to the WFXT spacecraft. The co-alignment requirement of the telescopes is very relaxed since each one has its own star tracker/fiducial light system to map X-ray photons on to the sky with arc second precision. Even their relative stability once mounted to the spacecraft is relaxed as the fiducial light system can track any small relative motions. With the exception of the X-ray telescope, all of the WFXT elements are well understood and have a high degree of flight heritage. The only significant technical challenge for WFXT is the manufacture of the telescope.

The wide-field telescope design has been tested and demonstrated. The plot in Figures 1-(a) and (b) show the measured performance of a prototype wide-field telescope manufactured at INAF\OAB(Brera) using silicon carbide replicated on a polished mandrel. The X-ray measurements were made at both the Panter test facility at MPE and XRCF at MSFC. This single shell already meets the 10 arc second requirement for WFXT. More recently we have begun work using quartz shells which can be ground from cylinders and then polished to meet the mission goals (see Proserpio et al.³). The advantage of quartz shells is their faster fabrication time and reduced cost, while still meeting the resolution and effective area goals within a mass budget that can be launched with an Atlas V from the Kennedy Space Center. Figure 1-(a) also shows the predicted design performance for WFXT as well as a model that includes manufacturing and assembly errors. Figure 1-(c) shows the WFXT effective area and compares that with both XMM and Chandra. Note that WFXT response extends to 6 keV with $\sim 300 \text{ cm}^2$ of effective area. The wide-field design does suffer from considerable vignetting, especially at high energies. At energies below 2 keV, the area is only 60% of the on axis area at 30 arc minutes off-axis. while the 2-7 keV area falls to about 30% at the edge of the field of view. On-axis WFXT area is roughly 10 x Chandra and 3-4 times XMM at low energy.

The focal plane detector for WFXT is based on the flight proven MIT/Lincoln Lab X-ray CCDs that are currently working on Chandra and Suzaku. The WFXT CCDs will be 2k x 2k pixel devices with $24 \mu\text{m}$ pixels (twice the size of the Suzaku devices). They focal plane has 4 CCDs arranged in an inverted pyramid to better match the telescope's curved focal plane. The WFXT focal length of 5.5 meters gives about 1 arc second per 24 micron CCD pixel which nicely over samples the HEW. Simulation studies show that the detection of source extent with this combination of telescope and detector is very efficient ($>80\%$ of simulated extended sources have been recovered in early testing).

3. SURVEYS

A wide field of view significantly increases the solid angle that can be observed to low flux levels in a fixed amount of time, which translates into much larger survey volumes at high redshift. Large volumes are needed to detect



(a) Discovery potential increases with grasp as larger volumes can be surveyed to low flux in reasonable times

(b) Discovery speed depends on robust identifications which require accurate positions over the field of view

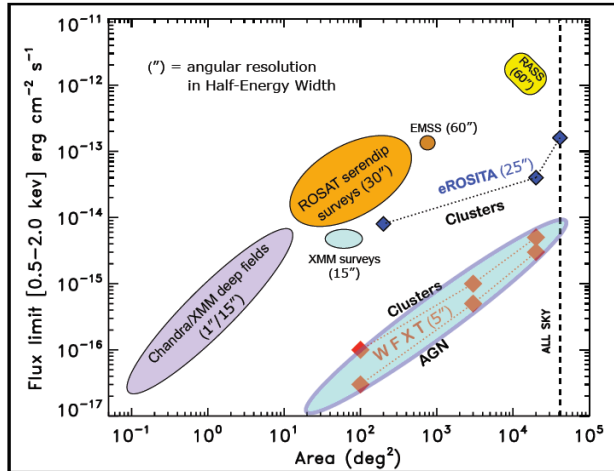
Figure 2: Discovery potential and speed for WFXT. Large grasp enables wide area surveys to be conducted quickly. Maintaining high angular resolution over the wide field of view yields accurate X-ray positions that allow sources to be identified with optical counterparts quickly and efficiently.

rare objects such as the most massive and luminous clusters of galaxies, or the most distant high luminosity quasars. WFXT has very large grasp (the product of effective area and field of view). As shown in Figure 2-(a) the grasp for WFXT (at low energy) is much greater than any other existing or planned mission. Figure 2-(b) plots the grasp at 1.5 keV as a function of the HEW of the telescope and illustrates the importance of the wide field design with good angular resolution.⁴ Only Chandra can provide any field of view with angular resolution as good as WFXT, but its grasp is much lower, and hence it is not practical to survey large areas using Chandra. Similarly, other missions simply cannot reach the sensitivity limits of WFXT in practical times, nor can they probe as deeply as WFXT before becoming confusion limited. Good X-ray positions are particularly important in identifying sources, especially at the detection limit where most of the sources are found.

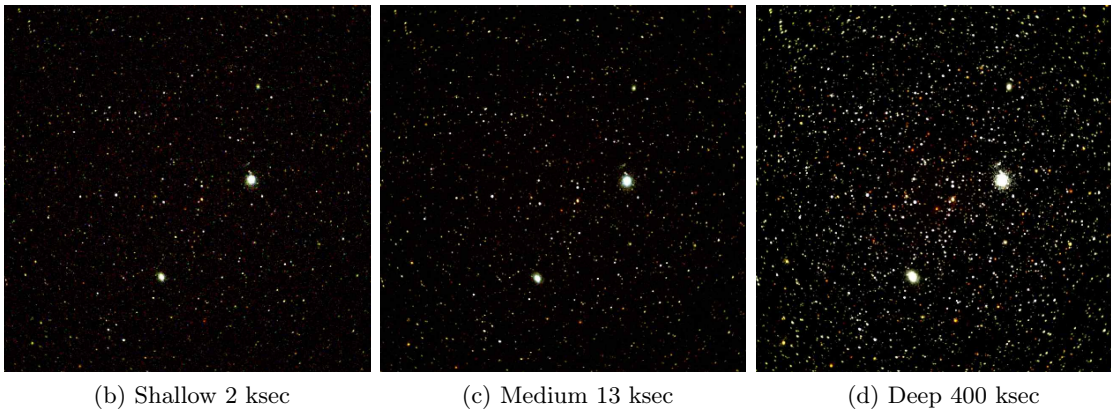
Survey	Wide	Medium	Deep
$\Omega(\text{deg}^2)$	20,000	3,000	100
Exposure time (ksec)	2	13	400
Total time (years)	1.67	1.66	1.67
S_{min} (point-like)*	3×10^{-15} (5×10^{-15})	5×10^{-16} (1×10^{-15})	3×10^{-17} (1×10^{-16})
Total AGN detected	1×10^7	4×10^6	5×10^5
$S_{\{mn\}}$ (extended)*	5×10^{-15} (7×10^{-15})	1×10^{-15} (2×10^{-15})	1×10^{-16} (3×10^{-16})
Total Clusters/Groups	3×10^5	2×10^5	3×10^4

Table 1: WFXT Surveys: (*) Flux limit in $\text{erg cm}^{-2}\text{s}^{-1}$ (0.5 -2 keV band) at 5σ detection. (2-7 keV band) flux limits $\sim 10\times$ higher. Values refer to WFXT design goals ($A_{eff} = 0.9\text{ m}^2$ and HEW=5 arcsec), those in parentheses refer to the more conservative requirements ($A_{eff} = 0.6\text{ m}^2$ and HEW=10 arcsec). Total observing time assumes 76% efficiency for the Wide survey and 90-95% efficiency for the Medium and Deep surveys since the target areas will be in the continuous viewing zone.

The WFXT mission profile consists of three surveys described in Table 1. The table gives the survey parameters, limiting flux for source detection and the number of sources expected. Figure 3-(a) compares the sensitivity



(a) Survey sensitivity vs. Sky coverage



(b) Shallow 2 ksec

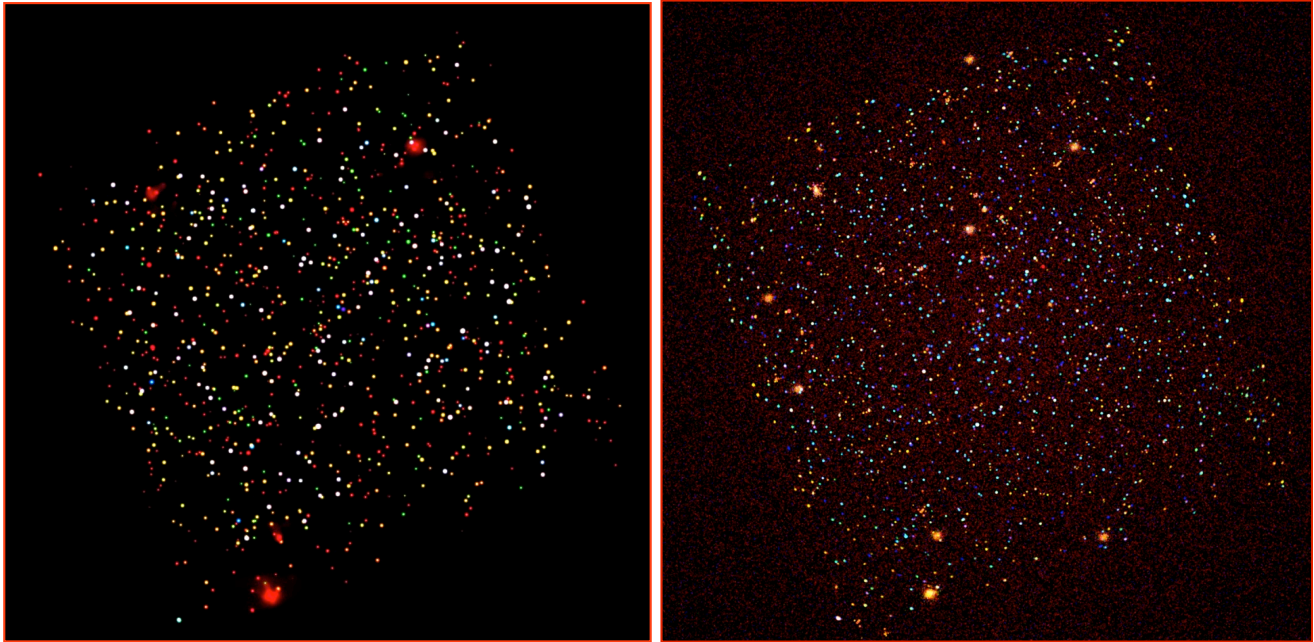
(c) Medium 13 ksec

(d) Deep 400 ksec

Figure 3: Survey Simulations

vs. sky coverage of WFXT with other X-ray missions (past, present and planned). WFXT will extend the depth of eROSITA by an order of magnitude, and with its 5 arcsec HEW it will produce the X-ray analog of the Sloan Digital Sky Survey (SDSS) by creating a legacy data archive that will be used to address a broad range of astrophysical research far beyond the operational lifetime of this mission. Figures 3-(b), (c) and (d) show simulations of a single WFXT field (1 deg^2) corresponding to the Wide (2 ksec), Medium (13 ksec) and Deep (400 ksec) surveys⁵ listed in Table 1. We have examined the sky visibility for WFXT in its low inclination, low earth, low background orbit. In addition to the continuous viewing zone towards the orbital poles, which are always observable, the sky areas in the orbital plane, where both Earth obscuration and closeness to the sun limit the possible viewing times, are still visible at least 10% of the year. There is no part of the sky that is totally inaccessible.

The mission operation plan is still being developed. The current baseline is to operate in a pointed mode. For the Wide survey we will pair targets so that we observe for about 2 ksec at a time, two fields per orbit building up the desired 20,000 square degrees over the mission lifetime. For the Medium and Deep surveys, target areas will be selected where longer continuous observing is possible, up to about 40 ksec for the Deep fields. We will select the medium and deep survey areas to correspond to regions with good multi-wavelength observations. The Deep survey exposure time of 400 ksec will be built up by re-observing the fields 10 times, spaced over the mission, to allow variability studies of the brighter sources. We are studying an alternative operating mode where WFXT will scan the sky (similar to the ROSAT All Sky Survey) to build up the Wide and Medium survey exposures, the Deep survey will still required pointed observations in order to reach the desired exposure time.



(a) Chandra 1.8 Msec exposure of COSMOS⁶

(b) WFXT 13 ksec exposure of COSMOS⁵

Figure 4: Comparison of Chandra and WFXT observations of the COSMOS field

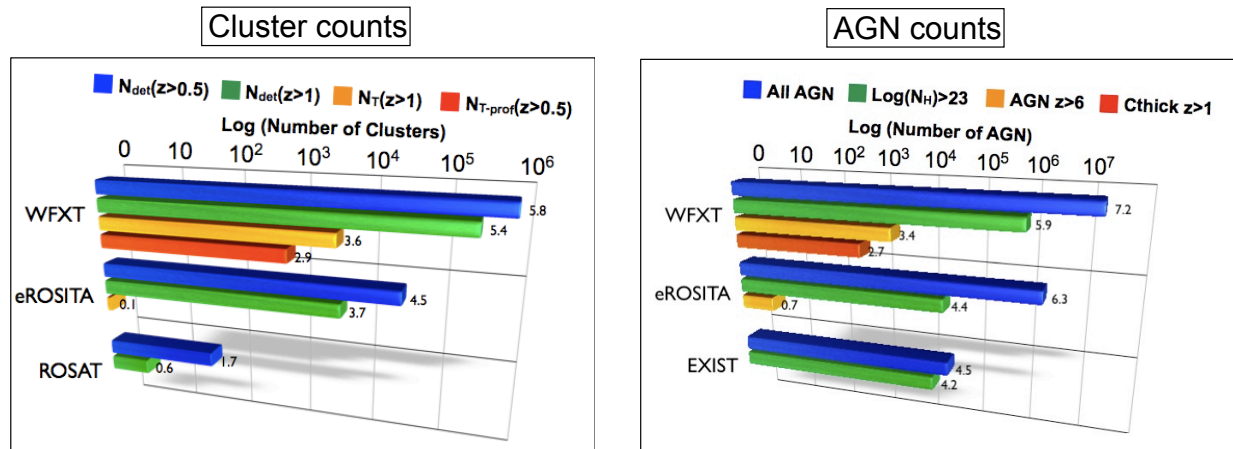
Once the initial survey period is completed (approximately 5 years), we propose continued operation of WFXT as a General Observer facility operating in pointed mode to follow-up interesting sources or target areas. We plan on releasing the WFXT survey data at regular intervals similar to the SDSS data releases. Nominally, if we operate in pointed mode, these releases would be made on approximately 6-12 month intervals. In the scanning mode, data releases would be synchronized to completion of the desired exposure depth for regions of the sky.

The planned 100 deg^2 Deep survey would take about 100 years with Chandra, but less than 2 years with WFXT. This is illustrated in Figure , where we show (a) the Chandra 1.8 Msec image of the COSMOS field⁶ (ref), which is made up of many Chandra observations, and (b) a simulation of this field (using the Chandra source catalog), which has 13 ksec exposure time. It takes only 1 WFXT pointing to cover the 1 deg^2 field, and the 5 arcsec HEW is sufficient to avoid source confusion at this exposure depth. WFXT is of order 100 times faster in surveying regions of the sky to the depth of the COSMOS field.

4. SCIENCE

As shown in Table 1 and more graphically in Figure 5, we expect to detect over 5×10^5 clusters and groups, of which about 20,000 will be bright enough to detect iron line emission and therefore determine the cluster redshift independent of any other data source. The remaining clusters and groups should have brightest galaxies that are within the limits of PanSTARRS or LSST for photometric redshift estimates. Similarly we will detect over 10^7 AGNs, of which about 300,000 will be bright enough for full spectral characterization, i.e., obscuration and redshift. Again, there will be a good match between WFXT and the limiting magnitudes of optical and NIR surveys such as PanSTARRS and LSST, to allow source identification, especially with the 5 arcsec HEW of WFXT that provides arc second source positions.

The sample of clusters and groups that have X-ray determined redshifts form a “Golden Sample” that can be used for cosmological studies that have well understood selection bias. The sample will give constraints on the values of Ω_λ and ω_0 that are statistically as significant and precise as those that can be obtained using other data sources such as SN I_a or baryonic acoustic oscillations. With a sample of 500,000 clusters and groups, WFXT will measure the cluster mass function as a function of redshift. These data can test both the geometry of the



(a) Cluster and Group Detections with WFXT

(b) AGN Detections with WFXT

Figure 5: Source Detections with WFXT

Universe and growth of structures using a proven technique, controlled selection, and promising systematics. It will complement other cosmological probes (BAO, SNIa, weak lensing) in determining the equation of state for Dark Energy.

The AGN sample from WFXT will allow numerous science studies regarding how the supermassive black holes at the centers of galaxies grow and evolve. Detections of AGN at large redshifts will give important new information on the history of the early Universe including the role of accretion power in re-ionization and the formation of the first black holes. With the very large sample of AGN, studies of the effects of environment and AGN activity will yield important results on AGN feedback and the galaxy evolution.

These are just a few examples of the wealth of science that will be enabled from the WFXT surveys. The unprecedented depth and resolution of the WFXT survey will most certainly lead to surprising and unexpected science that will have major impact in our understanding of the Universe.

5. CONCLUSION

The WFXT mission is a moderate class mission (<\$525M FY09 dollars, total life cycle exclusive of launch). In a five year lifetime, it is capable of carrying out three surveys - wide, medium and deep and creating a legacy data set analogous to the SDSS in the optical. These surveys will result in very large numbers of sources being detected. The high quality images (5-10 arc seconds HEW) allow WFXT to distinguish between extended and point-like sources sufficient to detect essentially all the massive clusters to redshift of about 2 and to avoid confusion in the deep surveys that will be able to detect AGN beyond redshift 6.

REFERENCES

- [1] Murray, S. S., Norman, C., Ptak, A., Giacconi, R., Weisskopf, M., Ramsey, B., Bautz, M., Vikhlinin, A., Brandt, N., Rosati, P., Weaver, H., Allen, S., and Flanagan, K., "Wide field x-ray telescope mission," in [Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series], Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference **7011** (Aug. 2008).
- [2] Burrows, C. J., Burg, R., and Giacconi, R., "Optimal grazing incidence optics and its application to wide-field X-ray imaging," *ApJ* **392**, 760-765 (June 1992).
- [3] Proserpio, L. et al., "Design and development by direct polishing of the polynomial mirror shells." To be published in Proceedings of SPIE Conference 7732-12, 2010.
- [4] Rosati, P., "Wide Field X-ray Telescope, The Ultimate Survey," in [Memorie della Societa' Astronomica Italiana Supplementi (on-line only)], Presented at the Workshop: Science and technology of the Wide Field X-ray Telescope: The Italian contribution (Nov. 2009).

- [5] Tozzi, P. et al., “Simulating the X-ray Sky as Seen by WFXT,” in [*Memorie della Societa’ Astronomica Italiana Supplementi (on-line only)*], Presented at the Workshop: Science and technology of the Wide Field Xray Telescope: The Italian contribution (Nov. 2009).
- [6] Elvis, M., Civano, F., Vignali, C., Puccetti, S., Fiore, F., Cappelluti, N., Aldcroft, T. L., Fruscione, A., Zamorani, G., Comastri, A., Brusa, M., Gilli, R., Miyaji, T., Damiani, F., Koekemoer, A. M., Finoguenov, A., Brunner, H., Urry, C. M., Silverman, J., Mainieri, V., Hasinger, G., Griffiths, R., Carollo, M., Hao, H., Guzzo, L., Blain, A., Calzetti, D., Carilli, C., Capak, P., Etori, S., Fabbiano, G., Impey, C., Lilly, S., Mobasher, B., Rich, M., Salvato, M., Sanders, D. B., Schinnerer, E., Scoville, N., Shopbell, P., Taylor, J. E., Taniguchi, Y., and Volonteri, M., “The Chandra COSMOS Survey. I. Overview and Point Source Catalog,” *ApJS* **184**, 158–171 (Sept. 2009).