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Focal Plane Instrumentation for the Wide-Field X-ray Telescope

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ABSTRACT

The three X-ray imaging focal planes of the Wide-Field X-ray Telescope (WFXT) Mission will each have a field of view up to 1 degree square, pixel pitch smaller than 1 arcsec, excellent X-ray detection efficiency and spectral resolving power near the theoretical limit for silicon over the 0.2 - 6 keV spectral band. We describe the baseline concept for the WFXT focal planes. The detectors are derived from MIT Lincoln Laboratory CCDs currently operating in orbit on Chandra and Suzaku. Here we describe the baseline WFXT focal plane instrumentation and briefly consider options for alternative detector technologies.

Keywords: X-ray telescopes, X-ray surveys, X-ray CCDs

1. THE WFXT MISSION

The Wide Field X-ray Telescope (WFXT) will explore the high-redshift Universe to the era of galaxy and cluster formation, providing sensitive, extensive X-ray surveys that complement current and planned deep, high-resolution, wide-field surveys in the optical, radio, and infrared bands. This cost-effective, medium-class PI mission will obtain a unique astrophysical data set that will support contemporaneous and planned ground-based giant telescopes and ALMA, and on-orbit facilities, including planned and proposed flagship missions such as JWST and IXO.¹

WFXT will address a wide variety of cosmological and astrophysical topics, including the formation and evolution of clusters of galaxies² and associated implications for cosmology and fundamental physics³ (e.g., the nature of dark matter, Dark Energy and gravity); black-hole formation and evolution⁴; AGN interaction with ICM and ISM in clusters and galaxies; and the high-energy stellar component and hot-phase interstellar medium of galaxies, including the Milky Way⁵.

WFXT will execute a set of complementary surveys of varying sensitivity and area. The expected survey depth, as a function of solid angle observed, is compared with other X-ray surveys in Figure 1.

WFXT's design is straightforward, and is described in detail elsewhere^{1,6}. The optical prescription for the grazing incidence mirrors⁷ is optimized for high resolution over a broad field of view rather than for the best possible performance on-axis. This produces the maximum grasp (product of effective area and field of view) at a given angular resolution, and thus maximizes survey efficiency. Prototype mirrors have demonstrated a half energy width of 10" over field nearly 1 degree in diameter which is fully adequate to meet WFXT science requirements¹. Continuing technology development is underway with a goal of achieving a half-energy width as low as 5" over a similar field.

To minimize fabrication costs, WFXT will feature three identical telescope modules, each with its own focal plane. Requirements for the WFXT focal plane can be met using existing, high-performance X-ray CCD designs derived directly from those used for the Chandra and Suzaku missions. In this paper we discuss the detector and focal plane configuration for WFXT in greater detail.

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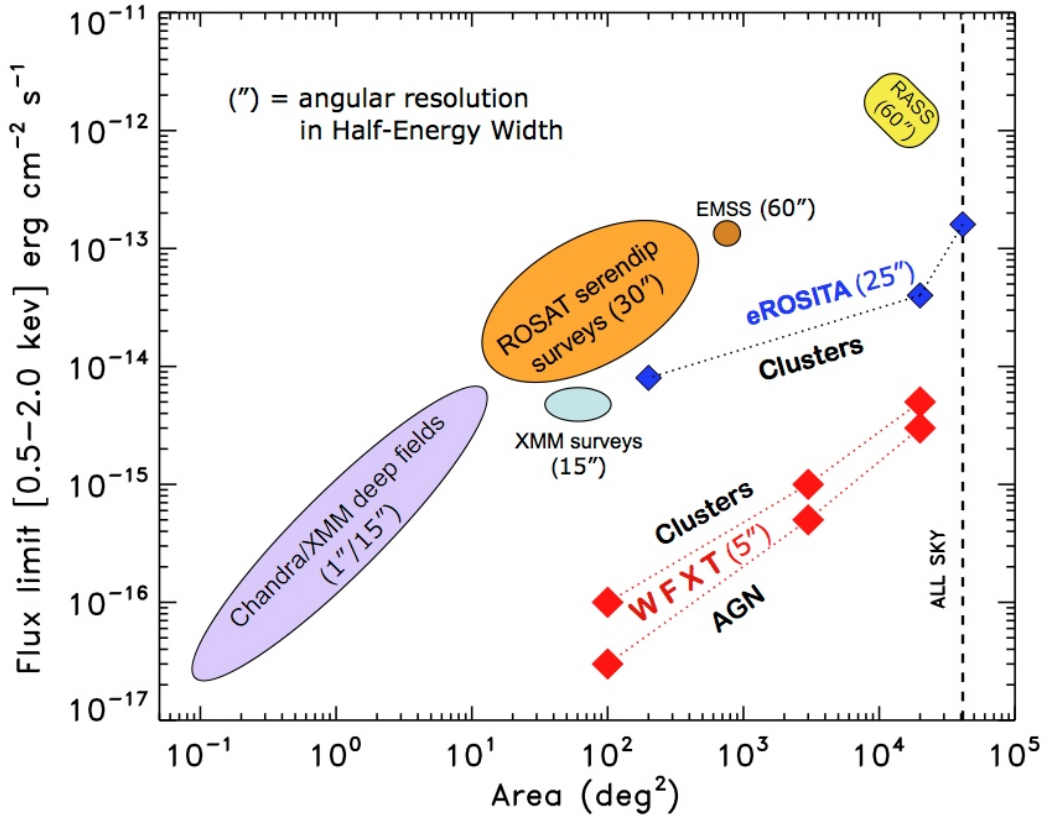


Figure 1: Effective flux limits and sky coverage for past and planned X-ray surveys. The deep, medium and wide WFXT surveys are indicated by the red diamonds. This figure taken from Murray et al. (2009)¹

2. MISSION, SYSTEM AND FOCAL PLANE REQUIREMENTS

2.1 Mission and System Requirements

Selected WFXT performance requirements are summarized in Table 1, and selected mission system requirements are listed in Table 2. As described elsewhere¹ several implementations of the X-ray mirrors are under consideration; all of these have a focal length of 5.5m.

Table 1. WFXT Performance Requirements (Murray et al., 2009)¹

Parameter	Requirement	Goal
Effective Area at: 1 keV 4 keV	6,000 cm ² 2,000 cm ²	10,000 cm ² 3,000 cm ²
Field of View (diameter)	1°	1.25°
Angular Resolution (HEW)	< 10"	≤ 5"
Passband (keV)	0.2 - 4	0.1 - 6
Spectral Resolving Power (E/ΔE at 1.0 keV)	>10	>20
Time Resolution (s)	< 3	< 1

Table 2. WFXT Mission System Requirements (Murray et al., 2009)¹

Parameter	Mission Requirement
Orbit altitude (km) inclination (°)	500, circular < 6
Mission duration (yr)	5
Payload Mass (kg)	1440
Payload Power (W)	375
Pointing Stability (°/3 s)	< 2
Slew rate (°/s)	0.3

2.2 Detector Requirements

Key requirements for the WFXT focal plane, derived from the top-level mission and system requirements and mirror characteristics, are summarized in Table 3.

Table 3. Selected WFXT focal plane requirements.

Parameter	Requirement	Goal
Size (mm x mm)	96 x 96	96 x 96
Spatial resolution ("/μm)	4"/100	2"/50
Frame readout time (s)	< 3	≤ 1
Read noise (electrons, RMS)	< 10	< 2
Quantum Efficiency		
0.5 keV	>75%	>75%
4 keV	>85%	>85%

3. WFXT FOCAL PLANE

3.1 Baseline configuration

Each of the three WFXT Telescope-Detector Modules will be equipped with a dedicated CCD Detector Assembly (DA) in its focal plane. Each DA contains a 2x2 array of X-ray photon counting CCD detectors and associated electronics. This baseline instrument configuration uses flight-proven technology to provide the high-resolution imaging and moderate resolution spectroscopy over a wide field required by the WFXT science objectives.

As shown in Figure 2, the three DA's function independently of one another; each DA communicates directly with the spacecraft's power, thermal and data systems. Each DA consists of a camera and an electronics box. We briefly describe each of these DA subsystems in turn.

DA Camera: The camera focal plane contains the 2x2 array of CCD detectors. The WFXT CCD detectors are direct descendents of the MIT Lincoln Laboratory CCID17 (flown on Chandra) and CCID41 (flown on Suzaku). The only changes from these earlier detectors are a doubling in the detector linear size to 2048x2048 pixels (and doubling of the number of output ports) and direct deposition of the UV/optical blocking filters. The back-illuminated detectors are

Table 4: Key WFXT focal plane parameters

Parameter	Value	Remarks
Field of View/Size	1.02 x 1.02 deg ² / 99 x 99 mm ²	0.5mm inter-chip gap
Number of CCDs per DA	4	CCDs are 3-side abutable
CCD Architecture	2048x2048 frame-transfer; back-illuminated; 8 parallel outputs	MIT Lincoln Laboratory
Detector Pixel Size	24 μm = 0.90”	
Nominal Spatial resolution	48 μm = 1.8 “	
UV/Optical Blocking Filter	100nm Al+10nm Al ₂ O ₃	Deposited on CCD
Integration time: Baseline Goal	2.6 s 1.1 s	100 kHz, 2x2 binning 500 kHz, no binning
Operating Temperature	-60 C	
Cooling	active (Peltier)	
Readout Noise Baseline Goal	< 3 electrons, RMS < 2 electrons, RMS	
Quantum Efficiency: 0.5 keV 4.0 keV	>75% >85%	

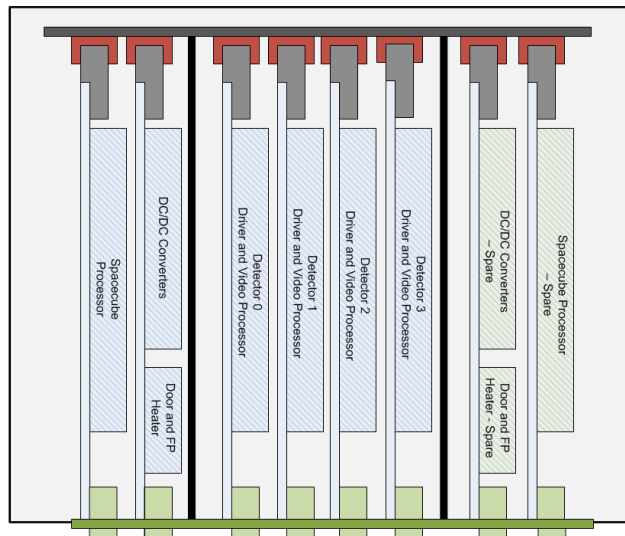


Figure 3. Detector Assembly electronics board functions.

3.2 Alternative detector technologies

The baseline WFXT focal plane incorporates proven X-ray CCD detector technology that is ready now to proceed immediately through mission development to flight. We note that X-ray active pixel sensors, though not yet flight-proven, may soon be capable of meeting WFXT focal plane requirements^{9,10,11}. These technologies offer a number of advantages over CCDs. Foremost among these for WFXT are higher detector operating temperature and faster frame readout times. The higher operating temperature would simplify cooling system design, and perhaps even allow for a passive cooling solution, with reduced power and mass requirements. The faster readout would not only allow for greater flexibility in the WFXT survey design, but might even lead to better low-energy quantum efficiency by reducing the attenuation required in the optical blocking filter.

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