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THE GENERATION-X MISSION: BENEFITS OF A HEAVYLIFT CAPABILITY

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ABSTRACT

Generation-X (Gen-X) is a very-large-area, high-angular-resolution X-ray telescope under study for launch in the 2030s. It will be an ambitious successor to the current Chandra and XMM-Newton X-ray observatories and to the planned International X-ray Observatory (IXO). We discuss the scientific goals of the Gen-X mission, its mission architecture, and its technology challenges. We show how a heavy-lift capability—such as that planned for NASA’s Ares V—streamlines the Gen-X architecture and reduces mission cost. In particular, we emphasize mission-design trades driven by shroud dimensions and lift capability.

INTRODUCTION

Currently, the US, European, and Japanese space agencies are each operating highly successful X-ray missions—NASA’s Chandra, ESA’s XMM-Newton, and JAXA’s Suzaku observatories. Recently, these agencies joined together to develop the next major X-ray astrophysics facility—the International X-ray Observatory (IXO)—for launch around 2020.

X-ray astronomical observations are typically photon-starved and can only be done above the earth’s atmosphere. To pursue breakthrough science requires very large collecting areas and high-resolution optics. In turn, to accomplish this for a space telescope requires extremely lightweight mirrors with excellent figure control. IXO will provide an order of magnitude increase in aperture area over previous missions, while maintaining good angular resolution (see Table 1). With these
capabilities, *IXO* will enable exciting discoveries about the physics of black holes and matter under extreme conditions; galaxy formation, galaxy clusters, and cosmic feedback; and the life cycles of matter and energy in the universe.

Table 1. Comparison of X-ray telescopes.

<table>
<thead>
<tr>
<th>Mission</th>
<th>Status</th>
<th>Area m²</th>
<th>Resol. arcsec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chandra</td>
<td>Operating</td>
<td>0.08</td>
<td>0.5</td>
</tr>
<tr>
<td>XMM-Newton</td>
<td>Operating</td>
<td>0.43</td>
<td>15</td>
</tr>
<tr>
<td>IXO</td>
<td>Planning</td>
<td>3.5</td>
<td>5</td>
</tr>
<tr>
<td><em>Gen-X</em></td>
<td>Concept</td>
<td>50</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Looking a decade or so beyond *IXO*, further scientific breakthroughs in X-ray astronomy will require even larger aperture areas and much higher resolution optics. The goal of the *Generation-X* (*Gen-X*) mission is to provide these capabilities, in order to study the early universe, the evolution of galaxies and their composition, and the extreme physics of high densities and strong magnetic and gravitational fields.

Currently, we are conducting a concept study of *Gen-X*¹, with a focus on identifying technology requirements and on developing a detailed technology roadmap for the mission. The present study builds upon the successful Vision Mission (VM) study² funded by NASA in 2004-2005. During the VM study we considered two candidate mission architectures—(1) a formation-flying option, requiring 5 separate Expendable Launch Vehicle (ELV) launches, and (2) a multiple-telescope option, requiring 6 ELV launches.

The current NASA plan for the Ares V heavy-lift capability enables a simplified and more cost-effective mission concept for *Gen-X* involving a single launch of a single observatory. Such a heavy-lift capability allows mission design trades driven by the shroud dimensions and lift capability.

In the following sections we first discuss the science objectives for *Gen-X* and how they flow into mission requirements. Next we describe the two VM mission concepts and a new concept enabled by the Ares V heavy-lift capability. We conclude with a discussion of the technology challenges for the mission.

**SCIENCE OBJECTIVES AND MISSION REQUIREMENTS**

**Observe First Black Holes and Stars**

The depths of the young Universe remain an almost purely theoretical frontier. Since \(~10^8\) solar mass (M\(_{\text{sol}}\)) black holes (BHs) are detected in quasars at \(z>6\) (age<1 Gyr)³, the first stars, galaxies, and BHs must have been created earlier, and BH growth by accretion of matter must have been rapid, releasing X-rays in the process.

The Wilkinson Microwave Anisotropy Probe (WMAP) results⁴⁵ place this first epoch of energy injection into the Universe at \(z=10-20\) (age=0.5-0.2 Gyr). Stars of the first generation were likely to have been massive (>100 M\(_{\text{sol}}\)), quickly burning their nuclear fuel. Stars smaller than 260 M\(_{\text{sol}}\) are expected to completely disrupt in powerful “pair instability” supernovae (SNe)⁶, while more massive stars exploded and collapsed to form the first BHs.

Early BHs of \(~1,000\ M_{\text{sol}}\) at \(z\approx15\) can be detected at their Eddington luminosity with \(~50\ \text{m}^2\) effective area (at 1 keV) and 0.1″ angular resolution (half power diameter or half-energy width) at a flux of \(3\times10^{-20}\ \text{erg cm}^{-2} \text{ s}^{-1} \ (0.1-10 \text{ keV})\), 1000 times fainter

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¹ Selected under NASA’s Astrophysics Strategic Mission Concept Study (ASMSC) program.
than Chandra can reach. Most of the high-energy radiation from quasars is emitted at less than 100 keV which, at z~15, will be observed below 7 keV, within the 0.1-10 keV Gen-X band. The 1.5 keV radiation, which can escape through the enshrouding dust and gas expected in these primordial objects, will be redshifted to ~0.1 keV. Gen-X can thus detect all active massive BHs and measure the accretion luminosity of the high-z Universe. Redshifts can be estimated photometrically from broad-band infrared detection of the Lyman-a break. The early SNe may be visible as Gamma-ray bursts (GRBs) detectable by other satellites flying contemporaneously with Gen-X. Gen-X can then obtain spectra of their X-ray afterglows, determining GRB distances and total energy output, and probing the high-z intergalactic medium (IGM).

Chemical Evolution

Gen-X will explore galaxies from high-z to the present, studying the X-ray evolution of their components with z. The cosmic star-formation rate (SFR) was 10-100 times higher at z~1-3 than at present[9]. Since X-ray luminosities in “normal” galaxies are well correlated with the SFR[10], X-ray evolution with z is expected, and has been observed with Chandra to z~1[11]. At z=1 this has been detected by the Chandra “stacking” analysis of the integrated emission of large samples of “Lyman break” galaxies[12] (z=2-4), which reveals higher X-ray luminosities at higher z. Gen-X will detect and study hundreds of these galaxies, obtaining ~400 counts in 10^6 s for a z=3 galaxy (Figure 1). Gen-X will separate spatially the integrated XRB emission from a nuclear BH emission, and separate spectrally the hard XRB emission from hot gas, revealing the true SFR, even in dust-enshrouded proto-galaxies.

Figure 1: A portion of a simulated 10^6s Gen-X image of the Hubble Deep Field. Chandra saw 17 sources in the same exposure time. With realistic fluxes and sizes most of the 3000 Hubble discovered galaxies are detected and over 800 have >400 counts.

Quasar winds and jets can have dramatic effects on accretion onto a central SMBH, with the ability to stop and even reverse the in-flow. Chandra’s discovery of cavities at the centers of clusters of galaxies just where radio structures are found (linked to the central active galaxy) supports this. Gen-X

Black holes and galaxies both experienced an era of rapid growth over 2<z<4 consistent with the strong correlation between the masses of the BH and the bulges that contain them[5]. At this age, galaxies will have several young supernova remnants (SNR) and “ultraluminous X-ray sources” (ULXs)[6], and also intermediate-mass BHs (several 1,000 M⊙)[7]. Gen-X can detect these at the expected fluxes of >10^-19 erg cm^-2 s^-1 (0.1-10 keV). Hubble shows that at such redshifts galaxies are ~0.5’’ across[8], requiring the low background rate specified in Table 1 for detection. Separating SNRs, ULXs, and low-luminosity active galactic nuclei (AGN, powered by supermassive black holes, SMBHs) against the unresolved X-ray binary (XRB) sources and the hot interstellar medium (ISM), requires an angular resolution ~0.1”, ≤1 kpc anywhere in the universe). Efficient deep surveys and mapping of sources requires a field of view of order 5 arcmin.
will extend this discovery to hundreds of systems over a wide range of $z$, so determining the outburst frequency, flow speeds and energetics over cosmological time, and probing the feedback process behind the mass–velocity-dispersion (M–$\sigma_V$) relation\[^5\]. \textit{Gen-X} will allow the in-depth study of SMBH–galaxy interaction in virtually all galaxies within a sphere of 30 Mpc, imaging the emission \textit{within} the sphere of influence of the SMBH to directly measure the gas kinematics, something that can now be accomplished only for very few nearby galaxies, and the Milky Way.

Fast winds and quasar outbursts have also been suggested as a mechanism for triggering galaxy-wide winds in elliptical galaxies\[^13\]. These winds should cause shocks in the surrounding ISM, triggering localized star formation, and may also be important for the chemical evolution of the early Universe. \textit{Gen-X} spectroscopy can determine the physics of these winds, measuring mass loss rates, abundances and velocities for material entering the ISM of the host galaxy and, eventually, intergalactic space. Spectral resolution, $E/\Delta E=10^4$, requiring a dispersive spectrometer, is needed for these observations. \textit{Gen-X}’s angular resolution will allow detailed kinematic analyses of wind/ISM shocks.

High-resolution spectra with \textit{Gen-X} of the hot X-ray emitting gas in clusters of galaxies will provide unique constraints on the star formation history of the Universe. Clusters of galaxies are closed systems that preserve a “fossil record” of past star formation in their hot gas.

**Extreme Physics**

By its nature, X-ray emission provides a direct view of processes connected with matter in extreme environments: extreme density, gravity, energy, and magnetic field. The following are examples of each:

- **Extremes of Density**: Neutron Star (NS), Quark and Hyperon Condensates. \textit{Gen-X} will give accurate gravitational redshifts and temperatures of isolated or quiescent NS surfaces, determine the mass/radius relation, strongly constraining the equation of state, and probe forms of ultra-dense matter\[^{14}\].
- **Extremes of Gravity**: At the BH Event Horizon. \textit{Gen-X} will study rapid change of the Doppler and gravitational distortions in X-ray line profiles\[^{15}\] on a dynamical crossing time, 10 times faster than \textit{IXO}, determining masses and spins for SMBHs as a function of $z$.
- **Extremes of Magnetic Field**: \textit{Gen-X} will explore: (a) X-ray radiation from the surface of magnetars that carry spectral signatures of Quantum Electrodynamics\[^{16}\]. (b) Regions between light cylinder and termination shock where pulsar winds change from Poynting flux to particle dominated.
- **Extremes of Kinetic Energy**: By observing relativistic jets in AGN and micro-quasars, \textit{Gen-X} images of jets will measure knot speeds and probe energy conversion through resolving the energy loss scale. Spectroscopy and wider field imaging will help to unravel how relativistic jets are launched.

**Derived Mission Parameters**

Table 2 summarizes the baseline mission parameters for \textit{Gen-X}, derived from the science objectives and required observations described above.
MISSION ARCHITECTURE

Design Considerations

The large collecting area of the Gen-X mirror and the grazing incidence required for efficient X-ray reflection present significant challenges in the implementation of Gen-X.

The graze angles for reflection in the 0.1 – 10 keV band, ~0.5 – 1.0 degree, lead to a mirror area roughly 100 times greater than the collecting area. We have baselined a Wolter Type I nested grazing incidence optics with ~200 radial shells to achieve the required 50 m$^2$ effective area, which will have a total glass area of ~5000 m$^2$. In order for the mass of the telescope mirror to be within practical launch limits we are driven to consider mirror shells of 0.2 to 0.4 mm thickness. Since it will not be possible to maintain the precise figure of such thin shells from ground to on-orbit, some form of active control of the mirror figure will be required.

The baseline design with a 50 m$^2$ effective area implies a ~12 m diameter filled aperture of mirror shells. The mirror diameter and grazing angle of 0.5-1 deg. to meet energy range of 0.1-10 keV yields a focal length of 50-150 m. Either multiple launches and assembly, multiple satellites, or single heavy lift are required to place such a large observatory into the desired orbit.

The science requirements of energy band and resolution, field-of-view, time resolution and non-X-ray background also drive the selection and design of the science instruments. The baseline science instrument package contains a microcalorimeter for high-resolution non-dispersive spectroscopy of on-axis and near-on-axis sources (X-ray Microcalorimeter Spectrometer – XMS) and a wide-field imager (WFI) using active-pixel detectors for moderate resolution spectroscopy of a wider field-of-view. A grating spectrometer, either transmissive or reflective, will provide the highest resolution spectroscopy below 1 KeV, where the microcalorimeter has relatively lower performance.

A number of factors drive the final orbit selection. The large optic with its adjustable shells requires a low-disturbance environment to minimize structural mass and/or station-keeping fuel or power, and provide low thermal stresses. Observation times are likely to be long as will the maneuver times between widely separated targets. The final orbit must therefore provide for the ability to perform multi-day, continuous observations. These factors argue against a Low Earth Orbit (LEO) and raise concerns about highly elliptical Chandra/XMM type-orbits. The Sun-Earth L2 however meets both the benign thermal and disturbance criteria and is selected as the baseline.

The design considerations above lead to a set of mission design parameters summarized in Table 3.

<table>
<thead>
<tr>
<th>Table 2. Gen-X Derived Requirements</th>
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<tbody>
<tr>
<td><strong>Parameter</strong></td>
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<td>Effective Area</td>
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<tr>
<td>Angular Resolution</td>
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<tr>
<td>Energy Resolution</td>
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<tr>
<td>Background (0.5 – 2.0 keV)</td>
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<td>Energy Range</td>
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<tr>
<td>Field of View, WFI</td>
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<tr>
<td>Field of View, XMS</td>
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<tr>
<td>Time Resolution</td>
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<tr>
<td>Sky Availability</td>
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<td>Calibration</td>
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**Table 3. Gen-X Mission Design Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror Effective Area</td>
<td>50 m²</td>
</tr>
<tr>
<td>Focal length</td>
<td>50-150 m</td>
</tr>
<tr>
<td>Filled aperture mirror diameter</td>
<td>12 m</td>
</tr>
<tr>
<td>Mirror shell thickness</td>
<td>0.2 – 0.4 mm</td>
</tr>
<tr>
<td>Launch Vehicle/Orbit</td>
<td>Ares V to L-2</td>
</tr>
</tbody>
</table>

**Vision Mission Study Concepts**

During VM study we considered a telescope with 100 m² effective area (subsequent refinement of the science requirements have led to a 50 m² requirement for the mission). Two mission architectures were considered, a multiple launch option of 6 identical telescopes and a formation flying option.

The multiple launch option utilizes six identical 8 meter diameter telescopes each with 16.6 m² effective area at 1 keV with focal length of 50 meter. Each telescope is launched on a separate spacecraft attached to a package of science instruments by a deployable boom. The instrument package is identical on each spacecraft and includes the XMS, WFI and grating. The mirrors are packaged as 4 separate segments, which deploy automatically to form the telescope. Figure 2 shows a concept for packaging the telescope in a Delta 4-H faring. The four telescope modules (yellow) are rotated and stacked and sit above the spacecraft bus. The retracted extendable boom (purple) connects the bus to a collapsed X-ray baffle (dark blue).

**Figure 2.** Stowed configuration in the Delta 4-H of one of the six identical telescopes in the VM multiple telescope option.

Figure 3 shows the deployed configuration with the detector bus (right) and telescope (left) connected by the 50 m boom. In studying this concept, innovative solutions were developed for addressing the stringent thermal requirements for the mirror. Thermal control employs body mounted radiators, constant conduction heat pipes, variable conductance heat pipes, capillary pumped loops, and radiant cooling shields.

**Figure 3.** The deployed configuration of one of the six telescopes in the VM multiple telescope option.
**The formation flying option** uses five launches to place the components of a single 20 meter diameter, 125 meter focal-length telescope into orbit and assemble at either LEO or at the Earth-Moon L1 point. The science instrument package would be located on a separate formation-flying spacecraft and launched directly to L2.

Figure 4 shows the concept for the folded 20 m diameter mirror prior to deployment. In this concept, the mirror consists of 16 telescope modules of inner radius 7m, outer radius 10 m, and depth 3 m. The depth is determined by the 1 m long plates of each of the paraboloid and hyperboloid elements, plus thermal pre- and post-collimators.

Figure 4. Folded 20 m mirror for VM formation flying option, each module containing 146 paraboloid/hyperboloid mirror shells.

Focal length and consists of the spacecraft bus and instruments (dark blue module), solar arrays (dark blue disks) and X-ray baffle (light blue). The grating is held by the X-ray baffle and is located at the end nearest the Optics craft.

One example of a design consideration for this architecture is that the mass-to-area ratios of the Optics and Detector spacecrafts be very nearly identical. Since solar radiation pressure is the dominant torque at L2, differences in those ratios will cause more frequent thruster firing to maintain the relative location requirements, implying a larger fuel requirement and perhaps less observing efficiency.

Figure 5 shows the deployed 20 m diameter mirror (black annulus) surrounded by an X-ray baffle (brown). The spacecraft bus systems sit under the flat sun shade/solar array assembly (yellow). The science instrument spacecraft is located at the 125 m focal length and consists of the spacecraft bus and instruments (dark blue module), solar arrays (dark blue disks) and X-ray baffle (light blue). The grating is held by the X-ray baffle and is located at the end nearest the Optics craft.

Figure 5. Deployed VM formation flying configuration.

Both the six telescope and the single telescope concepts would require some amount of on-orbit deployment and/or assembly followed by steps to align the component modules to the required tolerances and figure the mirror shells.
Figure 6. Deployed configuration for option 1 of the Ares V enabled architectures.

**Architecture Enabled by Ares V**

The planned availability of the Ares V launch capability now allows us to combine and greatly simplify the different architectures we considered in our VM study. Figure 6 shows the new baseline architecture consisting of a single 50 m$^2$ effective area X-ray telescope with 60 m extendible optical bench and a single science instrument focal-plane package. The mirror will be an 8.3 m diameter inner section filled with 100 shells, and four 60° fold-out sections (one split) giving a partially filled 16 m diameter mirror. As with the earlier concepts, each mirror shell will be instrumented with piezoelectric actuators so that the mirror figure can be adjusted to achieve 0.1″ angular resolution.

The science instrument package is the same as for the VM concepts with the capability to position in the central field of view either a microcalorimeter imager (XMS), giving non-dispersive resolution of 3,000 at 6 keV, or a self triggering active pixel image detector (WFI) giving high throughput capability and over-sampling the telescope response. The dispersive grating spectrometer will give spectral resolving power of $10^4$.

Figure 7. Gen-X packed in the 10 m Ares V shroud with the four mirror petals (green) folded above and below the central mirror array (purple), and folded extendible bench and spacecraft bus and instruments (blue).

The mass estimate of 22.3 metric tonnes for this design concept falls well within the expected 59.4 metric tonne capability of the Ares V and so we may plan for Gen-X to be delivered directly to L2. Figure 7 shows the concept for packing the spacecraft in the 10 m diameter Ares V shroud. The package
consists of three layers of mirror modules each of 3 m depth fitting within the 9.7 m height of the central body of the Ares V. The folded mirror diameter (8.2 m) fits within the dynamic envelope of the Ares V (8.8 m). The spacecraft bus extends within the 7.5 m cone portion of the shroud.

Table 4 summarizes a number of key launch vehicle requirements for Gen-X and shows that the present baseline for the Ares V matches the requirements well.

<table>
<thead>
<tr>
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<th>Gen-X Req.</th>
<th>Ares V Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass to Sun-Earth L2 (metric tons)</td>
<td>&gt;22.3</td>
<td>59.4</td>
</tr>
<tr>
<td>Shroud Inner Diameter (m)</td>
<td>&gt;8.2</td>
<td>8.77</td>
</tr>
<tr>
<td>Shroud Height (m)</td>
<td>&gt;16.9</td>
<td>17.2</td>
</tr>
<tr>
<td>Availability Date</td>
<td>2030+</td>
<td>2020+</td>
</tr>
</tbody>
</table>

We note that the plans for the Ares V and other heavy lift capabilities are still in formulation and this provides an opportunity for Gen-X and other future large astronomy missions to help set the requirements. In providing such input and in defining the design trades for Gen-X, considerations include:

- Large dynamic envelope (diameter and length).
- Gen-X is volume limited not mass limited:
  - ~22 tonne compared with ~60 tonne capability to L2.
  - Mass margin enables design freedom for optics and structure, supporting electronics and science instruments.

- Mechanical and acoustic launch load requirements comparable to other launch vehicles, e.g., Delta 4H.

One example of a design and cost trade that could drive the Ares V requirements is the complexity introduced by the folded mirror configuration. As discussed above under Design Considerations, a mirror with 50 m² effective area implies a fully filled aperture of ~12 m diameter. This suggests the simplest design for Gen-X would be enabled by a shroud with a dynamic envelop of ~12.4 m. This would allow telescope with a single monolithic mirror to be launched without the need for mirror deployment. Such a design would also result in simplified packaging.

Design considerations such as these, are an important input to the agencies as they develop the requirements for heavy lift capability vehicles.

**TECHNOLOGY DRIVERS**

A key output of the present NASA study of Gen-X is a detailed technology development plan that defines how the readiness of each technology can be raised to the level required to begin the formal development program, typically Technology Readiness Level six (TRL-6).

We consider Gen-X technology in terms of the telescope and optics, the science instruments and the spacecraft and mission. Of these, our VM study indicated that the principal driver for the mission is the development of the optics, with the science instrument development as the secondary driver. We provide here a brief summary of the technology under consideration for each.

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2 We note that NASA organized a workshop in April 2008 specifically to examine requirements for Ares V driven by large astronomy missions, see [http://event.arc.nasa.gov/aresv/](http://event.arc.nasa.gov/aresv/).
Optics

As discussed under Design Considerations above, the Gen-X telescope resolution and effective area requires the development of thin, on-orbit adjustable, grazing incidence optics[11]. The baseline mirror configuration has ~228 nested two-reflection Wolter I shells, assembled from paraboloid and hyperboloid segments of 1 m x 1 m glass, ~0.2–0.4 mm thick. We attain 0.1″ resolution by adjusting the figure on-orbit via piezo-electric actuators in a bi-morph configuration. Such adjustment, to ~1″, has been accomplished in synchrotron beamlines[17].

Our technology builds upon that currently under development for IXO. Our starting point is the development of IXO mirror pairs meeting their requirement of ~ 3 – 4 arc-sec Half Power Diameter. These mirrors are produced by thermal forming (slumping). Additional development of slumping for IXO will focus on thinner mirror segments (going from 0.4 mm to 0.2 mm) and increasing the size of the mirror segments. We will deposit a thin piezo material on the back of the coated pieces, and print electrode contacts to define a pattern of piezo cells. We expect the cells to be narrow rectangles. The short side of the rectangle will be in the axial direction – this will enable the greatest figure correction in the axial direction, the most critical direction for X-ray imaging. The larger effective cell size is in the azimuthal direction, which has less stringent requirements.

An example of a predicted deformation due to the energizing of a single piezo cell is shown in the left panel of Figure 8. We expect to size the piezo cells at 20 - 50 mm, to correct mirror figure errors for spatial frequencies below ~0.02 mm⁻¹. The right panel of Figure 8 shows that this enables a lower quality starting mirror figure. The mirrors are deformed to the correct figure by differential strain in the mirror and piezo material, in analogy to bi-metallic bending. We conceive 20 to 50 piezo units axially along each segment, spaced at 1 degree azimuthal increments, for a total of ~3 x10⁶ elements.

**Figure 8:** (Left) A finite-element analysis shows that piezo strain of 10⁻⁵ produces a radial displacement of 12 µm. Gen-X requires 0.4± 0.04 µm displacements. (Right) Such conditions reduce the low frequency figure errors of the IXO mirror goals to meet the Gen-X 0.1″ requirements.
Science Instruments

X-ray Microcalorimeter Spectrometer

For the XMS, a cryogenic microcalorimeter, we will leverage on-going development of transition edge sensors (TES) and metallic magnetic calorimeters (MMC) \(^\text{[18]}\). In a TES, the heat deposited by an individual X-ray photon changes the impedance of a superconducting bilayer held just below its transition temperature. Such devices provide the best spectral resolution achieved to date (1.6 eV FWHM at 1.5 keV) \(^\text{[19]}\). In an MMC the heat from an X-ray photon changes the magnetization of a paramagnetic film. MMC have potential advantages in producing less heat, having greater dynamic range, and less stringent uniformity requirements. Both of these devices are read out using SQUID amplifiers.

One area of importance in the technology development phase is to focus on concepts for very low-noise multiplexing of numbers of pixels to at least \(10^6\). One critical technology to be developed is microwave multiplexing \(^\text{[20]}\). Multiplexing complexity is reduced for position-sensitive pixels. Such concepts include a single long pixel with a thermometer at each end or multiple absorbers connected to a single sensor via varied thermal links.

Wide Field Imager

The Gen-X Wide Field Imager (WFI) will likely be based on Active Pixel Sensor (APS) technology \(^\text{[21,22]}\). In one architecture, the X-ray imagers, anticoincidence pixels and the processing electronics would be built into a monolithic CMOS structure. The high-speed readout allows anticoincidence, and operation near room temperature without optical blocking filters, since dark current or background visible light does not build up in the short readout time. A baseline point design for this imager is a 3 x 3 array of 4-side abuttalble 4K x 4K APS chips, (18 x 18 cm) with 15 \(\mu\text{m}^2\) pixels. The maximum time resolution is 50 \(\mu\text{s}\) pixels. The nominal frame rate is \(10^3\) s\(^{-1}\), with 150 bits to characterize the position and energy of each event.

Gratings

The spectral resolving power needed to utilize the full complement of diagnostics of complex, high energy phenomena, including absorption line profiles and Doppler shifts, is \(\lambda/\Delta\lambda \approx 10^4\). Such resolution requires dispersive elements be a part of the Gen-X instrument array. Diffraction gratings based on demonstrated technology exist today and will serve for Gen-X with a doubling of line density, and scaling up the manufacture and alignment of the larger number of facets. Either a portion of the WFI or a different imager of the same design will be used to read out the dispersed spectrum.

Two grating architectures are currently under study for IXO and can simply be adapted to Gen-X: an off-plane reflection array \(^\text{[23]}\) or an innovative concept for blazing transmission gratings, called Critical Angle Transmission \(^\text{[24]}\). A system based on reflection or transmission gratings can disperse through \(\sim 0.05\) radians in the blazed orders. With 0.1” resolution, Gen-X can achieve its goals with a distance from grating to focal plane <10% of the focal length, and thus the relative size and mass of the grating array can be reduced 100-fold compared with Chandra.

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