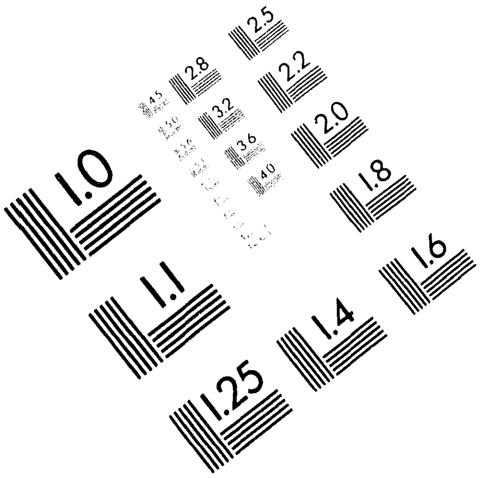

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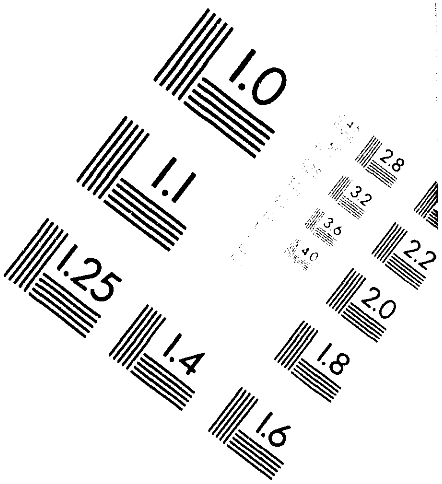

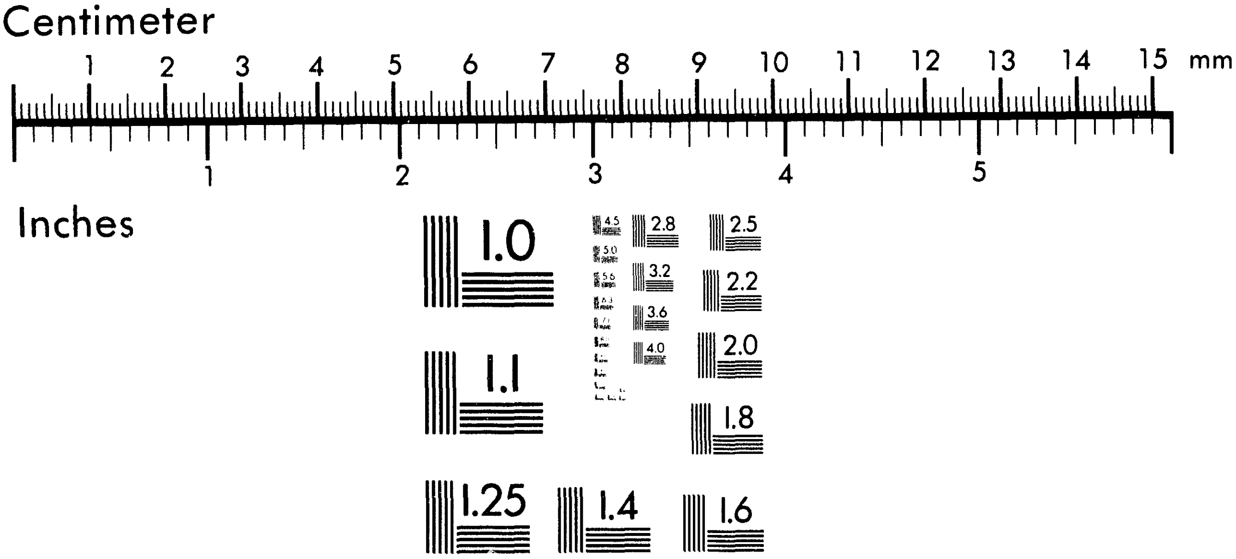

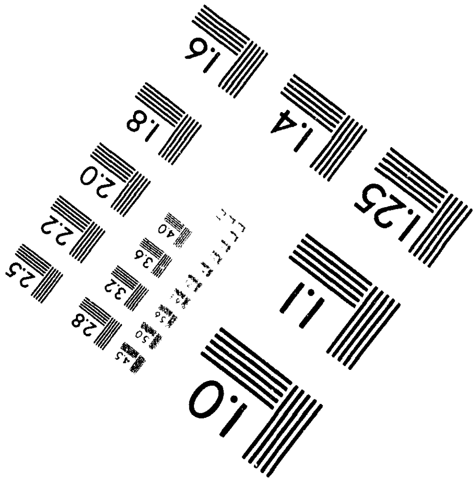

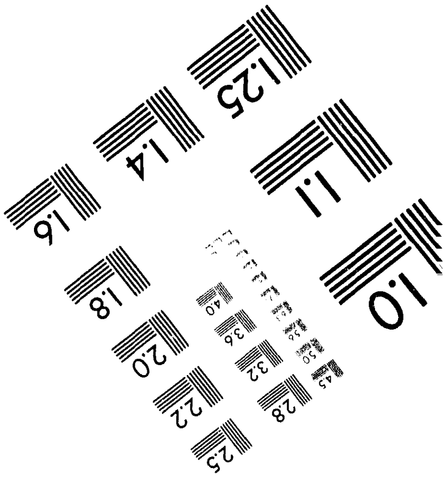

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The MOXE X-ray all-sky monitor for Spectrum-X-Gamma

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ABSTRACT

MOXE is an X-ray all-sky monitor to be flown on the Russian Spectrum-X-Gamma satellite, to be launched in a few years . It will monitor several hundred X-ray sources on a daily basis, and will be the first instrument to monitor most of the X-ray sky most of the time. MOXE will alert users of more sensitive instruments on Russia's giant high energy astrophysics observatory and of other instruments to transient activity.

MOXE consists of an array of 6 X-ray pinhole cameras, sensitive from 3 to 25 keV, which views 4π steradians (except for a $20^\circ \times 80^\circ$patch which includes the Sun). The pinhole apertures of 0.625×2.556 cm^2 imply an angular resolution of $2\overset{\circ}{.}4\times9\overset{\circ}{.}7$ (on-axis). The MOXE hardware program includes an engineering model, now delivered, and a flight model. The flight instrument will mass approximately 118 kg and draw 38 Watts.

For a non-focussing all-sky instrument that is limited by sky background, the limiting sensitivity is a function only of detector area. MOXE, with 6000 cm^2 of detector area, will, for a 24 hrs exposure, have a sensitivity of approximately 2 mCrab.

MOXE distinguishes itself with respect to other all-sky monitors in its high duty cycle, thus being particularly sensitive to transient phenomena with time scales between minutes and hours.

Keywords: X-ray astronomy, pinhole camera, all-sky monitor

1 INTRODUCTION

Spectrum-X-Gamma (SXG) is a giant international high-energy astrophysics observatory which is being built under the leadership of the Space Research Institute (IKI) at Moscow. The satellite will be 3-axis stabilized with an orientation stability of better than $20''$ per pointing of several hours. SXG will contain a number of imaging instruments which are sensitive to cosmic photons with energies ranging between 0.03 and 100 keV. In late 1995 or early 1996, SXG will be launched into a high Earth orbit (orbital period $\sim$24 hrs). The observatory's main objective is the study of energetic processes in the universe as they occur within a wide variety of objects, from relatively small (e.g. on white dwarf stars, neutron stars) to large (e.g. in active nuclei of galaxies). An overview of the SXG observatory is presented by Sunyaev (1994).

SXG contains a number of instruments with unprecedented capabilities. One of these instruments is the MOnitoring X-ray Experiment MOXE. MOXE belongs to the class of X-ray all-sky monitors (ASMs). Its purpose is to track the behavior of many X-ray sources at the same time. The capability that distinguishes it from other flown or planned ASMs is that it can monitor most (98%) of the X-ray sky almost *continuously* at photon energies between 3 and 25 keV, and at a relatively high sensitivity. MOXE is being built by a collaboration of the Los Alamos National Laboratory (USA), the Goddard Space Flight Center (USA) and the Space Research Institute (Russia).

In this paper, we will review the scientific capabilities of MOXE, as well as describe some elements of the instrument design to meet these capabilities.

2 SCIENTIFIC OBJECTIVE

MOXE's primary scientific objective is twofold: 1) serve as an alarm device for unusual short term behavior of the X-ray sky and alert users of other types of instruments (i.e. in other wavelength bands or with higher sensitivity in a narrow field of view) to a target of opportunity; 2) to synoptically monitor the X-ray sky and study the long-term behavior in X-ray sources. This twofold objective of monitoring short as well as long term behavior of celestial X-ray sources is typical for an ASM (e.g. Priedhorsky & Holt 1987) and has been proven to be of continued scientific need in X-ray astronomy.

Apart from solar X-radiation, the 3-25 keV sky is dominated by emission from galactic X-ray binaries (XRBs). XRBs are two graviationally bound stars, of which at least one is a compact star such as a neutron star or black hole (for a recent review of XRBSs see e.g. White 1989). The energetic X-radiation is powered by accretion of matter into the deep gravitation well of the compact star. Besides in about 200 known galactic XRBs (Van Paradijs 1994), much celestial X-ray emission is produced in extra-galactic sources such as active galactic nuclei or intra-cluster gas. These sources are relatively dim, due to their distance to Earth.

Marked temporal variability is almost ubiquitous on the X-ray sky. Only the gaseous nebulae of supernova remnants (<1% of the galactic source population) and galaxy clusters (perhaps 10% of the thousand brightest extragalactic sources, but a rapidly decreasing fraction of the dimmer source population) fail to exhibit detectable temporal variability. Truly periodic phenomena are generally associated with rotational or orbital periods, while aperiodic or quasiperiodic variability can have diverse origins.

The most extreme type of variability is displayed by transient sources which only temporarily flare up above detection limits. Different physical processes, characterized by unique time scales, are responsible for these flares. Most of these processes have been recognized and occur in XRBs. The flares are explained as either the interplay between episodic mass loss by the 'normal' star and a compact object in an eccentric orbit, or as unstable accretion. The flare durations range from days to months (sometimes years). Some 70 out of 200 galactic XRBs are now known to be transient (Van Paradijs 1994) and there is a strong indication on both theoretical (Rappaport & Van den Heuvel 1982) and observational grounds (Koyama et al. 1990) that transients with flares of the former origin ('Be-XRB transients) are much more numerous than detected up till now. MOXE especially will be sensitive to the potentially numerous weak transients of this sort. We estimate from the above studies that MOXE will detect at least 10 Be-XRB transients per year. Considering the current database of about 30 Be XRBs, this would mean that MOXE data will increase the knowledge on these transients considerably.

Recent observations with the Watch monitor onboard the Granat satellite (Castro-Tirado 1994, Brandt 1994) seem to confirm the evidence for the existence of a separate class of transients as it was suspected by observations with the Ariel-V and HEAO-1 satellites (Pye & McHardy 1983 and Connors et al. 1986): the so-called fast transients, which have flare durations from several minutes to one day. Tentative estimates place the rate of these transients at several thousands per year with peak intensities of at least 10 mCrab[1] with an apparent isotropic sky distribution. MOXE has an exceptional sensitivity for the detection of transients with these characteristics and might provide important data to test the hypothesis that these transients have their origin in flare stars and RS CVn stars.

Other expected scientific results from MOXE are discussed in detail by Priedhorsky et al. (1989) for a wide variety of X-ray sources. To summarize, most X-ray instruments are pointed, and study one source at a time for no more than a few days. A monitor, which looks everywhere all the time, provides two capabilities: a real-time alarm for transient phenomena, and an archival record of changes in X-ray sources. The alarm capability allows more sophisticated instrumentation in all wavelength bands to be alerted to transient events such as XRB transients, fast transients, X-ray and γ-ray bursts, and novae. Once a transient is detected by MOXE, more sensitive instruments on Spectrum-X-Gamma with narrow fields-of-view can be put into play to study the transients in detail. Observers at other wavelengths, including gamma-ray and ultraviolet astronomers with space-based instruments, and optical and radio astronomers working from the ground, can also study the transient before it fades away provided, the time scale is sufficiently long. Such studies have found our best candidates for black holes. The archive produced by a monitor allows long-term studies of changes in neutron star rotation rates, binary star orbits, and accretion disk structure. We thus learn about the physics of mass transfer onto black holes and neutron stars.

3 INSTRUMENT DESCRIPTION

There are several approaches to designing an X-ray all-sky monitor. To compare approaches, one must compare scientific capabilities for a given level of resources (e.g. cost, power, telemetry), perhaps best parameterized by the total detector area. The three simplest approaches are: 1) a pinhole camera array, 2) a system of scanning, slat-collimated proportional counters similar to the Ginga all-sky monitor (Tsunemi et al. 1989), and 3) a set of coded-aperture imaging systems. For MOXE, we chose the pinhole camera (Priedhorsky et al. 1989) because of its continuous nearly 4π field of view (important for detecting fast transients), its natural cubic geometry, its lack of moving parts, the low detector count rate and therefore extended detector lifetime, the modest detector position resolution requirement, the lack of systematic cross-talk between distant sources (compared to a coded aperture), and its low telemetry rate. In making this choice, we explicitly sacrificed bright source performance for simplicity.

The MOXE instrument is a set of six X-ray pinhole cameras that stare continuously at the entire sky, with a bandpass of at least 3 to 10 keV. This passband may be enlarged towards higher energies when upcoming calibration measurements indicate this is safe. The onboard software has a provision to change the settings of the lower and upper level discriminators. The detectors are position-sensitive proportional counters that are read out by charge division. Each MOXE module covers 1/6 of the sky (i.e. one face of a cube). For a square detector with side d, the aperture-detector distance should be $f = d/2$ to cover $2\pi/3$ steradians. For MOXE, f is chosen slightly smaller so that there will be some overlap between the FOVs of the modules to guarantee full sky coverage in case of a slight misalignment. We therefore chose a detector area of 32×32 cm^2 and a 'focal length' f of 15 cm. The pinhole size was chosen such that the diffuse cosmic background and internal detector background were comparable. For modules that each view 1/6 of the sky, the pinhole area should be about 1000 times smaller than the detector area for typical values of diffuse and internal background.

In order to optimize the angular resolution, we have chosen an asymmetric pinhole of 2.556×0.625 cm^2 (Lochner & Priedhorsky 1991). This corresponds to $9^\circ\!.7\times2^\circ\!.4$ on the sky for the on-axis position. For a given source, the orientation of the long axis of the aperture as projected on the sky will vary from one pointing of SXG to the next. Two sources which are confused in one pointing may not be confused when the projected aperture

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[1] one Crab unit corresponds to 1.5×10^{-8} erg s^{-1} cm^{-2} in the 3 to 10 keV band

Figure 1: Cutaway drawing of one of the MOXE cameras. All sealing components are made out of Aluminum, except the windows (Beryllium), strongback and sunshield (Titanium, not shown here). The cone and detector sides are plated with Tin for particle protection. Each of the six detector will be placed in a holder that is attached to the satellite at various positions to ensure that no satellite component obstructs part of any detector FOV

is turned to a different angle.

Since the total expected counting rate from the six modules is about 260 cts s^{-1} (with about half from point sources), each detected photon can be individually encoded. We use 24 bits per event: 7 bits for each position axis, 4 bits of pulse height (photon energy), 3 bits of differential time information, and 3 bits to identify the detector. The total expected telemetry rate is 7.4 kbits s^{-1}, which is stored in a mass memory of 827×10^6 net bits, sufficient for 30 hours of average data, and downloaded every 24 h at ground contact.

Intense flux from the Sun, the brightest source in the X-ray sky, raises a particular problem. Since MOXE covers 4π steradians, the Sun will always be in view of at least one detector and sometimes three. The Sun can appear anywhere in a $20^\circ \times 80^\circ$ region, relative to spacecraft coordinates, as Spectrum-X-Gamma moves from one pointing to the next. To avoid overloading the detectors or saturating the telemetry stream, parts of three detectors corresponding to the $20^\circ \times 80^\circ$ (2% of the sky) region are blocked by a heavy titanium shield. This system is backed up by software throttles that exclude Sun counts and, for the highest rates, turn off detector high voltage should the Sun stray outside the shielded area. The Sun is recognized by its extremely high count rate compared to other sources.

There are seven modules to MOXE: 6 detector modules and a central electronics assembly (apart from these flight modules, there is one spare detector). The detector modules include proportional counters, cones, apertures, high voltage power supplies, preamplifiers, and a housekeeping/high voltage control box. Each detector module weighs ~13.5 kg, has a volume of about $45 \times 45 \times 26$ cm^3, and uses ~ 2.1 Watts (high voltage on). The central electronics module includes electronics for amplification, A/D conversion, event analysis, commanding, telemetry, memory, interface to the satellite, and two redundant low voltage power supplies. This central electronics module weighs 35 kg and draws 25.1 Watts of bus power (high voltage on). Because Spectrum-X-Gamma flies outside the Earth's magnetosphere, it encounters a high radiation dose. All electronics are designed to withstand at least 2×10^4 rads.

The active sensors for MOXE are 32 × 32 cm^2 sized, 1 cm deep, Xenon-filled (with 5 mass percents CO_2 quench gas), permanently sealed, position-sensitive proportional counters, which are subdivided in 4 equally deep gas layers by three co-planar grids: two cathodes and one anode. The wire grids consist of parallel 0.254 cm spaced stainless steel wires, with a diameter of 75 μm for the cathode and 13 μm for the anode. Both ends of each cathode frame are read out separately. Two preamp signals, from the lateral sections and a 1 cm deep guard layer with its own anode, are summed to form an anticoincidence signal. The wire plane that separates the photon detector layer from the guard layer acts as an over-exposure sensor, it's signal feeding a discriminator circuit. Ergo, each detector outputs seven signals. These signals are used to provide anti coincidence, safety against damage, and input to obtain the position and energy in the onboard processor. 5-sided anti-coincidence and pulse height discrimination will be used to reject cosmic ray background. The anti-coincidence plane covers the full area of the detector below the main detector volume, while the ends of the x- and y-cathode arrays provide anticoincidence volumes to guard the sides.

Event positions are sensed by charge division in the two resistive cathodes, one for each axis. The ratio of the two signals at the two ends of a given cathode will be proportional to the position of the photon interaction and the sum of all four cathode signals will be proportional to the photon energy.

Energy resolution will be standard for a proportional counter, approximately 20% (FWHM) or better at 6 keV. Position resolution and energy resolution are continuously calibrated on-orbit by a small Fe-55 source at the edge of each detector. The low-energy response will be limited by the aperture and detector windows, which are made from respectively 75 and 100 μm thick Beryllium. A conical assembly holds the 1.6 cm^2 pinhole 15 cm above the detector window. This assembly is filled with helium gas to relieve the pressure differential across the large detector window. A titanium structure on top of the detector entrance window ('strongback') supports any residual pressure differentials. The strongback has been constructed in such a way, that it causes minimum shadowing of the projected image of the aperture (see Lochner & Priedhorksy 1991). Figure 1 gives an impression of the configuration of one MOXE camera, while Table 1 provides a list of key characteristics of each MOXE camera.

The six flight detectors are at the time of this writing almost all completely built, and the process of testing has recently been started. It is foreseen that the last piece of flight hardware will be delivered for integration by December 1994.

4 STANDARD DATA ANALYSIS AND PRODUCTS

Once the data arrives on the ground, it is reformatted and provided with calibration and satellite information (e.g. dead time corrections, gas gain corrections, anticipated attitude). The data then flows immediately through a standard analysis system to extract the pointing direction of each detector and check for unusual behavior of the X-ray sky, in order to meet the most urgent part of the scientific objective: inform the SXG team of targets of opportunity.

The satellite attitude as determined by specialized SXG instruments will possibly not be available immediately after receival of the data at the ground station. Thus, in order to be able to determine celestial locations of targets of opportunity as fast as possible and also to serve as a backup system, MOXE data itself will be used to determine the attitude. It is anticipated that this data will enable the attitude solution to an accuracy of several arcminutes on a time basis of several hours. The attitude is extracted by utilizing the constellation of a set of 'standard' point sources. These sources are defined as being persistently intense, having well-known positions (i.e. known to a fraction of MOXE's location accuracy), known to be isolated (to avoid source confusion problems at this stage), and sufficiently widespread over the sky to accommodate an accurate determination of the attitude. The standard analysis will search in the data for potential candidate detections of celestial standard sources, determine the instrument coordinates of these candidates (via a PSF analysis), identify standard sources (not necessarily

Table 1: Key characteristics of each MOXE camera

Detector area	32.0×32.0 cm^2
Photon detector depth	1.0 cm
Strongback blockage	14% (normal incidence)
Sun shield blockage	0 (3 modules), 10% (2) and 14% (1)
Aperture area	1.6 cm^2
Effective area	1.4Δ cm^2 at 6 keV where $0 < \Delta < 1$
Distance aperture - detector	15.0 cm
Field of View (FWZR)	$93\overset{\circ}{.}7 \times 93\overset{\circ}{.}7$ (2.245 sr)
Angular resolution	$2\overset{\circ}{.}4 \times 9\overset{\circ}{.}7$ (FWHM on-axis)
Detector resolution	0.5 cm FWHM at 3 keV
Detector readout resolution	0.25 cm (128×128 pixels)
Active photon energy range	3 to 10 keV standard, but commandable
Photon energy resolution	20% FWHM at 6 keV
Photon energy readout resolution	16 channels
Timing resolution	commandable, 4 ms at best
Detector background	10 cts s^{-1} (3-10 keV)
Sky background	6 to 7 cts s^{-1} (3-10 keV)
Crab intensity	1.2 cts s^{-1} cm^{-2} (3-10 keV)

all) and finally find the attitude solution which is most likely in accordance with the observed constellation of standard sources via a triangulation method.

Once the attitude solution is calculated (and provided to the SXG community) and the resulting data is put in an archive, a full analysis of the measurements with respect to unusual behavior will take place. This involves the determination of the intensity in several energy bands of all known X-ray sources, a check of these intensities with what is expected for each source and a check of the residual measurements for the occurrence of unexpected sources. This analysis will need to be done on several time scales, to improve the sensitivity to short as well as long time scale events (e.g. bursts, slow and fast transient sources).

Throughout this analysis a detailed and dynamic catalog of X-ray sources is used. This catalog will consist of positions, fluxes, spectral information, timing information (e.g. a measure of variability in MOXE's passband) and labels attached to standard sources. New findings by MOXE (e.g. transient sources) will become part of the catalog. The initial version of the catalog will be generated in the early phase of the operations when, among other activities, the instruments will be calibrated for in-flight conditions.

The results of the standard analysis will be put in a database, as a reference for a user/object-specific analysis at a later stage.

Currently, specific MOXE data analysis software is developed by members of all partner institutes. This software will include only those tasks that are specific to MOXE, i.e. the standard analysis and the generation of data products in FITS format (NASA 1991). The FITS format will enable a detailed data analysis at a later stage by use of generally available X-ray astronomical data analysis packages such as PROS (Worrall et al. 1991) or XRONOS/XSPEC (Stella & Angelli 1992 and Shafer et al. 1991).

Since MOXE is not a narrow-field instrument, the observational plan will not be tailored for guest observers. Instead, standard data products will be made available to the community through a collaborative and archival investigator program.

5 SCIENTIFIC CAPABILITIES

Apart from the energy and timing resolution of MOXE, the scientific capabilities are largely dependent on the point spread function (PSF) and quantum efficiency. The PSF is determined by a combination of the form and size of the aperture, the detector resolution and the magnitude of photon penetration effects in the detector gas. The last two components are dependent on photon energy and, thus, on the spectrum within the passband (and slightly beyond due to escape effects) of any celestial X-ray source. The influence on the PSF differs for both: the detector resolution decreases roughly linearly with energy, while photon penetration increases with energy. Furthermore, photon penetration effects are strongly dependent on the off-axis angle, increasing in magnitude by the tangent of the off-axis angle.

5.1 Angular resolution

As mentioned in §3, the nominal angular resolution along the aperture sides is 2°.4 by 9°.7. However, this only applies for an on-axis sky position. Due to projection effects, this becomes better toward the edges of each detector's FOV where it is 1°.1 by 5°.4 (excluding minor photon penetration effects). Also, over different pointings of SXG it is expected that the asymmetry in the angular resolution vanishes so that along both dimensions it will be the lowest of these two values.

From the pairs of 497 sources brighter than 1 mCrab that are contained in the HEAO A-1 all-sky catalog (Wood et al. 1981), 1% are closer to each other than 9°.7 and 2×10^{-3}% are closer than 1°.1. Recent X-ray experiments with better angular resolution than HEAO A-1 have increased the number of close pairs slightly, particularly in the well-observed galactic center field (see e.g. Skinner et al. 1987, In 't Zand et al. 1991 and Pavlinski et al. 1994). Nevertheless, source confusion is not considered to be a serious problem, for sources brighter than 1 mCrab.

5.2 Sensitivity

The sensitivity of any instrument is determined by the duration of an observation, the effective area, and the level of the background radiation. For MOXE, several geometric effects determine the area. First, the projection of the 1.6 cm^2 aperture perpendicular to the incoming X-rays decreases with the cosine of the off-axis angle by a factor of maximum 2. Second, the detector entrance window support structure blocks part of the projected aperture, so that the effective area is a function of sky position. This is a second-order variation: the spacing of the support structure is chosen so that its transmission remains roughly constant as the projected pinholes moves across it. Finally, the edge of any camera's FOV has some overlap with the FOV of a neighboring camera (this overlap measures 1°.8), thus increasing the effective area locally.

The background radiation consists of three components: 1) the 'detector background', which is the background due to particle or energetic photon events that make it through the various anti coincidence mechanisms (anticipated value: about 10 cts s^{-1} per camera); 2) the 'sky background', which is the contribution by the diffuse isotropic cosmic background radiation. Convolving the spectrum as found by Marshall et al. (1980) with MOXE's response predicts 6 to 7 cts s^{-1} per camera, the exact value depends on the presence of a sun shield; 3) the radiation due to cross talk with other point sources, this actually represent source confusion.

In Fig. 2, a sky map of the sensitivity is presented for an observation length of 4 hrs (this duration is probably near to that of a single SXG pointing). The map is quite flat, except for some small scale variations due to the strongbacks and highlighted bands along the edges. Furthermore, the relatively large number of bright sources in the galactic bulge reduces the sensitivity locally. For most of the sky, the 5σ sensitivity is close to 5 mCrab (3 to

10 keV).

The system of 6 modules is capable of monitoring the whole sky on timescales longer than one week for sources as faint as ~1 mCrab (~1 UFU) that are separated by a few degrees with no source confusion. Every 10 mCrab source can be monitored on timescales of an hour, and bright (>100 mCrab) sources can be monitored on timescales of minutes.

5.3 Point source location accuracy

The point source location accuracy SLA along x and y (68% confidence range for a single parameter) is given by

$$\mathrm{SLA}_{\mathrm{x,y}} = 0.4\cos\phi_{\mathrm{x,y}} A_{\mathrm{x,y}}\,/\mathrm{SNR} \quad \text{degrees}$$

where SNR is the signal-to-noise ratio of the point source, $\phi_{\mathrm{x,y}}$ the off-axis angles along x and y and $A_{\mathrm{x,y}}$ constants that depend on the PSF for the current off-axis angles, point source spectrum and passband. For a point source with a Crab-like spectrum in 3 to 10 keV and located on-axis, $A_{\mathrm{x,y}}$ is at best 25. The deviations from this value due to other source spectra are expected to be about ±10% at maximum. The change due to a different off-axis angle is estimated to be ~ 20% at maximum.

These values mean, for instance, that during a 24 h long observation a 10 mCrab source can be located at best to within roughly $0\overset{\circ}{.}3$. This is in close agreement with conclusions from similar studies by Lochner & Priedhorsky (1991).

The source location accuracy has basically two different values across the FOV: in two quadrants it is two times better than in the other two quadrants, where the quadrants are identified by the orientation of the appropriate horizontal or vertical bars of the support structure. This difference in location accuracy is due to the interference of the aperture projection and the differently oriented bars of the strongback: in a general sense one can say that the source location along one direction increases when there are more detector pixels that are part of the edge of the projection in that direction. Therefore, a horizontal support bar going right through the aperture projection will provide a better location accuracy along y, while a vertical bar will result in a better location accuracy along x.

6 COMPARISON WITH OTHER ASMs

Table 2 lists key characteristics of six all-sky monitors of the past, present and future that have at least some sensitivity between 3 and 10 keV.

MOXE distinguishes itself by a high duty cycle, a good sensitivity for timescales longer than approximately one minute and a relatively high energy readout resolution. Despite MOXE's low angular resolution (the choice for this is motivated by a limited available telemetry data rate and urge for continuous full sky coverage) and once-per-day ground contact (and therefore a 24 to 48 h SXG response time to targets of opportunity), MOXE excels in the detection probability of relatively weak or fast transient X-ray sources, and an excellent capability to monitor the behavior of a maximum number of persistent sources at time scales from minutes to years.

Figure 2: All-sky map, in galactic coordinates, of MOXE's sensitivity in 5σ mCrabs (3-10 keV) levels, for a 4 hrs observation and using the HEAO A-1 X-ray catalog (Wood et al. 1981)

Figure 3: A detector image with an exposure time of 4 hrs in the 3 to 10 keV band, aimed at the galactic center. Near the middle of the right edge, a 7 mCrab source is visible. The detection limit is 5 mCrab (5σ).

Table 2: Design capabilities of past, present and future all-sky monitors with sensitivity between 3 and 10 keV

Instrument	Operational period	Duty cycle[1]	Angular resolution (degrees)	Bandpass[2] (keV)	Sensitivity[3] (mCrab)	$T_{75\%}$[4] (hours)	S / P[5]	Ref.[6]
Vela 5B XC*	1969-1979	5×10^{-4}	6.1	3-12 (1)	400	56	S	A
Ariel V ASM	1974-1980	1×10^{-2}	10	3-6 (1)	170	1.5	S	B
Ginga ASM	1987-1991	5×10^{-4}	0.2	2-20 (16)	50	48	S	C
Watch/Granat*	1989-	1	0.2	6-180 (9)	60	0	P	D
MOXE/SXG*	1995/96-	1	1.1	3-10 (16)	7	0	P	E
XTE ASM‡	1995-	5×10^{-2}	0.2	2-10 (3)	30	1.5	S	F

* These instruments are (were) placed in satellites with high Earth orbits, with orbital periods longer than 24 hours

‡ The XTE ASM is the only instrument on the list with continuous ground contact

[1] The duty cycle is defined as the time spent on a particular sky position relative to time required to cover the whole sky

[2] The numbers between parentheses indicate the number of energy channels used to read out photon energies in bandpass

[3] The sensitivity is the 5σ intensity level in mCrabs over the bandpass for the exposure time it requires to complete 75% of the sky coverage or, if this is zero, for an exposure time of 1.5 h

[4] This is the time needed to complete monitoring 75% of the sky

[5] S = scanning instrument, P = pointed instrument

[6] A = Priedhorsky et al. (1983), B = Holt (1976), C = Tsunemi et al. (1989), D = Brandt et al. (1990), E = This publication, F = Bradt et al. (1991)

7 CONCLUSION

MOXE is an X-ray all-sky monitor that operates in the 3 to 10 keV range with an instantaneous sky coverage of almost 4π. It will fly for several years on the Spectrum X-Gamma satellite, after its launch in 1995/96. With an angular resolution of down to 1°.1, a source location accuracy of netter than a few tenths of a degree and a sensitivity of 2 mCrab in 24 hrs, it enables the simultaneous study of the variability of hundreds of celestial X-ray sources, most notably that of galactic X-ray binaries, on previous scarcely covered time scales.

MOXE presents a unique example of an all-sky monitor, due to its capability to monitor near to 100% of the sky almost continuously.

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fig-1

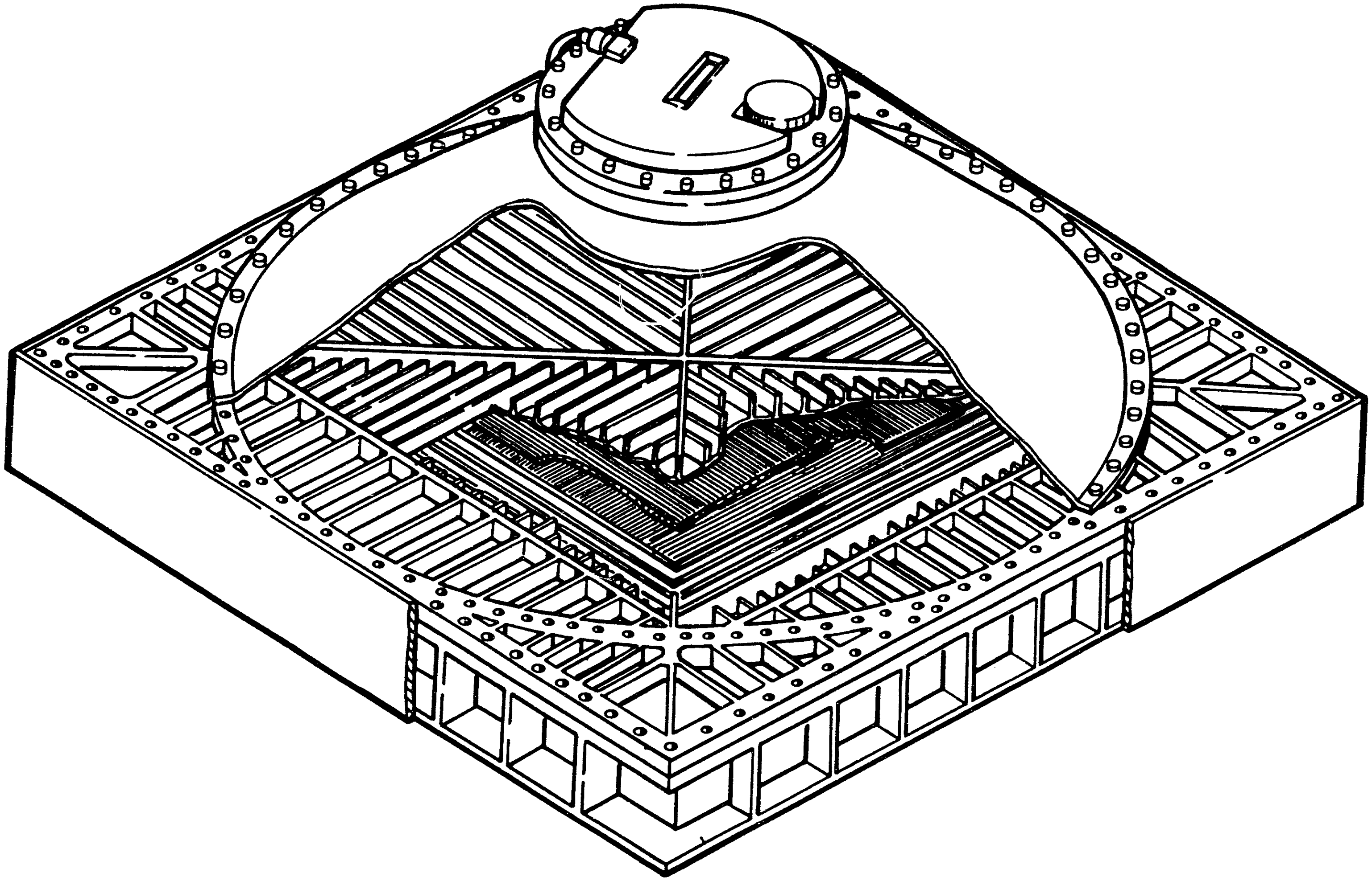
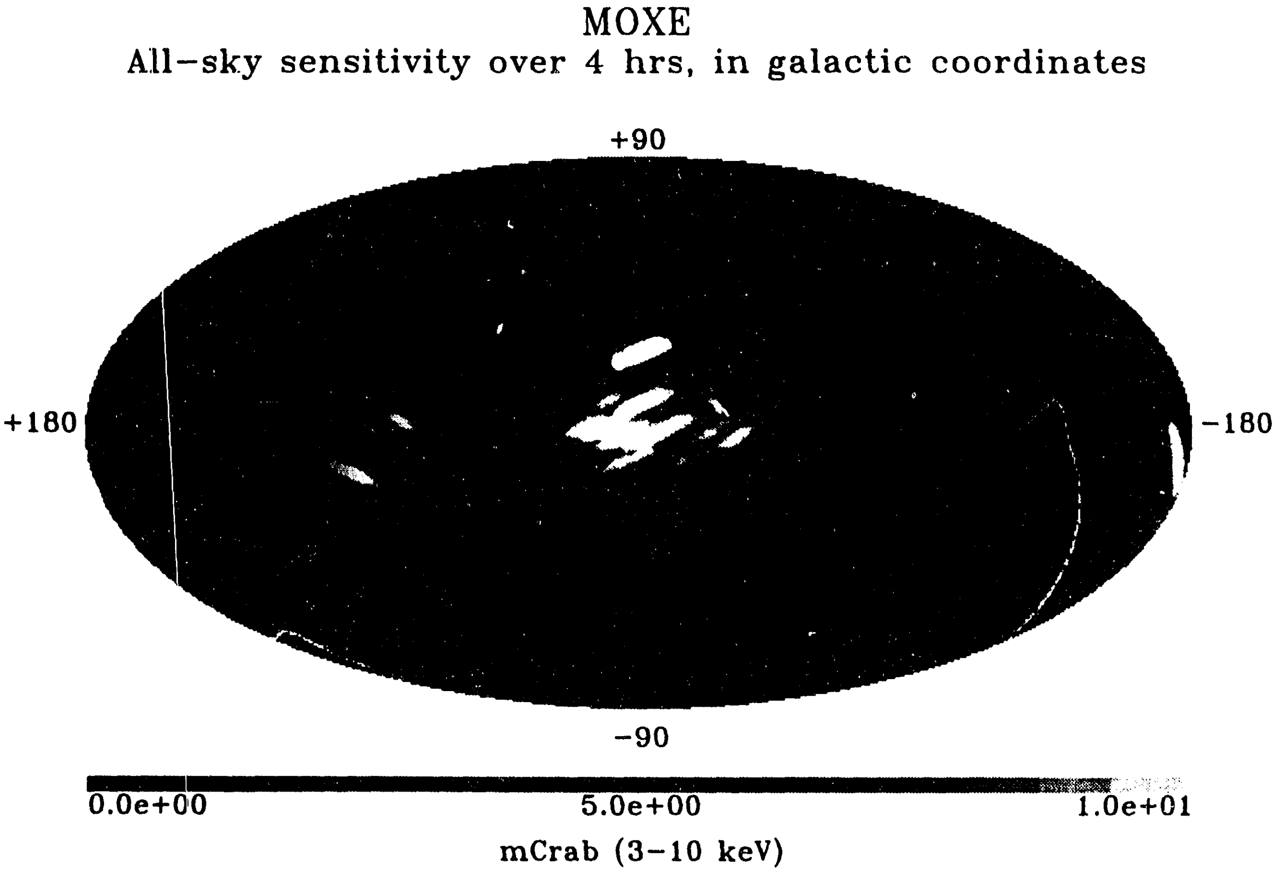


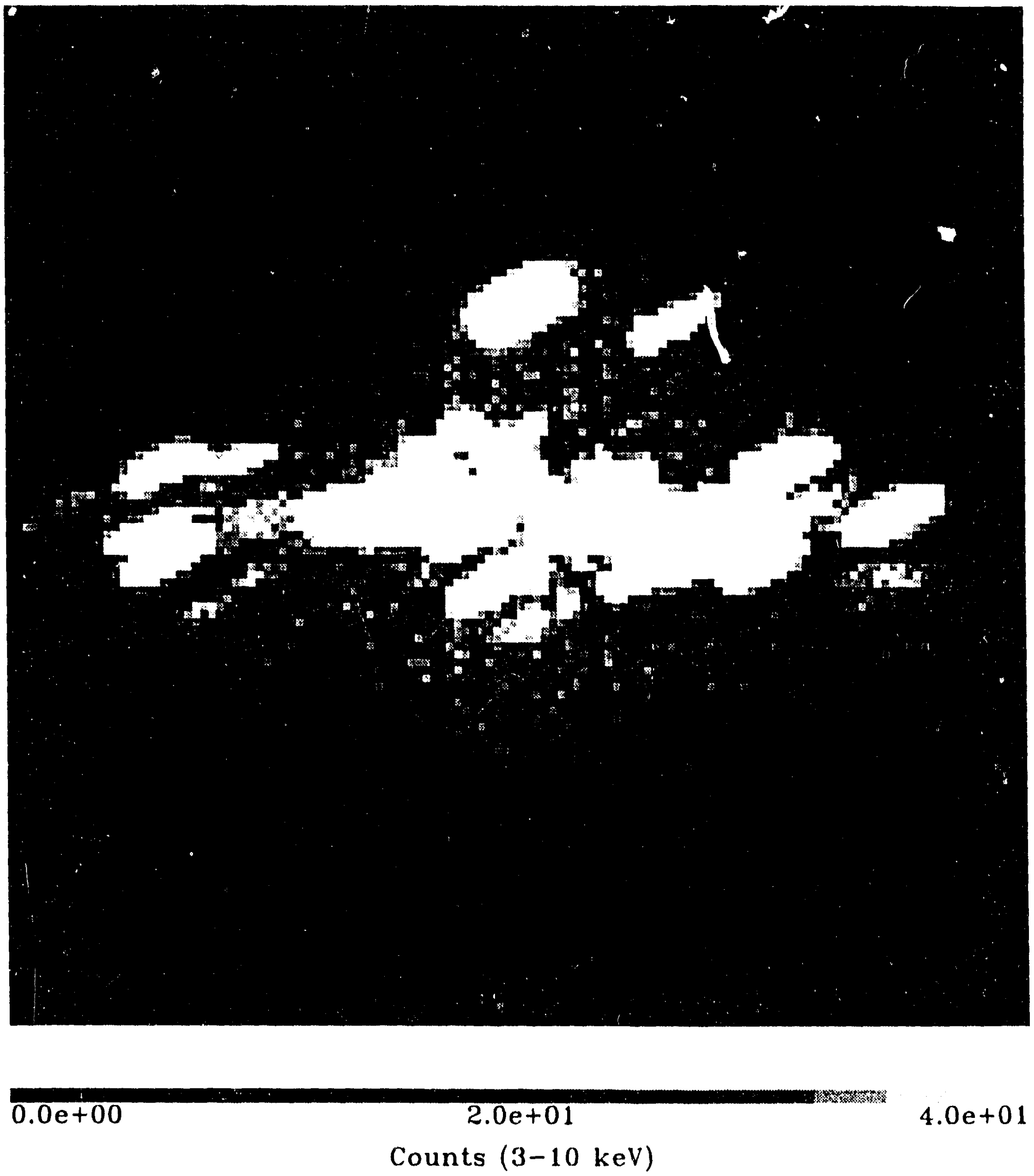
Fig. 2


MOXE
All−sky sensitivity over 4 hrs, in galactic coordinates
+90
+180
−180
−90
0.0e+00
5.0e+00
1.0e+01
mCrab (3−10 keV)

-fig. 3

MOXE

Detector image, for an exposure time of 4 hrs



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