LAPEX: A PHOSWICH BALLOON EXPERIMENT FOR HARD X-RAY ASTRONOMY

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1. Introduction. Satellite and balloon observations have shown that several classes of celestial objects are hard ($\geq$ 15 keV) X-ray emitters. A complete sky survey in the 15-180 keV energy band with a sensitivity of ~ 10 mCrab has been performed with the UCSD/MIT instrument (A4) on board the HEAO 1 satellite (1). About 70 X-ray sources were detected, including galactic and extragalactic objects. Hard X-ray emission has been detected in the Galaxy from X-ray pulsars, black hole candidates, transient X-ray sources, burst sources. Extragalactic sources of hard X-ray emission include clusters of galaxies, QSOs, BL Lac objects, Seyfert galaxies.

While the few brightest hard X-ray sources are well studied, much additional observational work is required to obtain spectral and temporal information in the 20-200 keV band from sources with flux levels in the range 1-10 mCrab (10^{-6} - 10^{-5} photons/cm^2 s keV).

Another open issue is the identification of the hard X-ray sources with objects known at lower X-ray energies or at optical wavelengths. As the HEAO 1-A4 sky survey results have shown, the central galactic plane region ($|b^{II}| \lesssim 10°$, $260 \lesssim l^{II} \lesssim 50°$) is crowded with many hard X-ray sources, which were not resolved with the 1.5° x 20° crossed collimators of the HEAO 1-A4 detectors. These crowded sky fields require observations with better angular resolution.

Future satellite missions like SAX (Italy) and XTE (U.S.A.), which have as primary objectives the observation of hard (15-200 keV) X-ray sources at sensitivity levels of about one order of magnitude better than the A4 experiment, are yet at their early study phases. Their field of view of 1° FWHM will not make it possible to resolve all of the crowded fields. Therefore selected sky fields can be profitably studied with balloon observations that have limiting sensitivities of about 1 mCrab in the 20-200 keV energy band and angular resolutions better than 1°.

In this framework, we are developing a Large Area Phoswich Experiment (LAPEX), which meets the above-mentioned requirements. It has:
i. a broad energy band of operation (20-300 keV);
ii. a 3 σ sensitivity of about 1 mCrab in 10^4 s of live observing time;
iii. imaging capabilities with an angular resolution of about 20'.

The first balloon flight of the LAPEX is scheduled for 1986.

2. Experiment Description. We report here the essential characteristics of the experiment. A detailed technical description of the entire payload has already been given (2) and an experiment summary is found in Table 1. The detection plane is an array of 16 scintillator detectors. Each detector is made of a 145 x 145 mm^2 NaI(Tl) crystal 6 mm thick, which is sandwiched with a CsI(Na) crystal having the same frontal surface and a thickness of 50 mm. The scintillations of both crystals are viewed by a photomultiplier tube (PMT) of diameter 5" through a light guide of lead glass 15 mm thick. Each group of 4 detection units is surrounded by a NE110 plastic scintillator, exclusive of the aperture. A passive graded shield (Pb, Sn, Cu) is inserted between the crystals and the lateral plastic scintillator. A bank of four passive collimators is mounted above each group of four detection units. The collimators are made of electroformed hexagonal tubes of lead (0.1 mm) surrounded by Tin (0.25 mm) and Copper (.08 mm) on both sides. The collimators cause a 9% reduction of the total geometric area. Each collimator bank is mounted so as to obtain a triangular response with a flat top of 20'. Each collimator bank can rock by 8°, indipendently of the other three, at a desired frequency.

Table 1
Experiment summary

Energy range of operation	20-300 keV
Total geometric area	3400 cm^2
Energy resolution ($\Delta E/E$) at 60 keV	17% (FWHM)
Field of view	3° (FWHM)
Angular resolution	20' (FWHM)
Time resolution	100 μs
Spectral bin width	~ 1 keV
Telescope mounting	alt-azimuthal
Post-facto attitude reconstruction	3'
Guiding system	automatic, from ground station

Above the rocking collimators one can mount a set of 16 rotating modulation collimators (RMC), one for each detection unit, in a configuration that makes the instrument a true imaging device. Through a proper choice of the distance between the grid planes of each RMC it is possible to image a sky field with an angular resolution that depends on the minimun pitch-angle (angular distance between planes of maximum transmission). A description of this multi-pitch rotation modulation collimator (MPMC) can be found in refs. 2 and 3. For our experiment we have chosen 8 different distances between grid planes, a minimum pitch-angle of 40', grid planes made of tungsten strips with 1.5 x 1.5 mm^2 square section, and a rotation period of 100 s. The MPMC will operate in the 20-200 keV band.

An active gain control system will allow a continuous monitoring of the instrument gain and, if required, to adjust it to a preselected value. The gain control is based on the use of ^{241}Am sources deposited into plastic scintillators placed at the bottom of the rocking collimators.

The α particles associated with the ^{241}Am X-rays give a signal in the plastic which allows to tag the X-ray events, therefore to measure the detector gain at 60 keV and, if required, to change the PMT high voltage.

An absolute calibration of the detection plane is also available and this is based on the use of ^{139}Ce sources which scan the field of view every 2000 s.

3. Observation strategy and expected performances. The instrument will operate with either the rocking collimators or the MPMC. In the first case the observation strategy of the celestial objects is to point in turn two banks of collimators in the source direction and the other two towards an empty field. The banks are swopped between ON and OFF positions at a selected frequency. We have carefully evaluated various systematic errors in the background subtraction due to this rocking technique, e.g. background variations due to variations of exposed area, atmospheric thickness and telescope zenith angle. We have found that the systematic errors can be controlled within 0.3%. As a consequence, we expect to be able to measure source fluxes as low as 1% of the background at a significance level of 3 σ. The expected background count rate is based on an in-flight test (4). Figure 1 shows the expected spectrum determination sensitivity of the instrument when it will operate with the rocking collimators. We plan to use rocking collimators to study isolated sources.

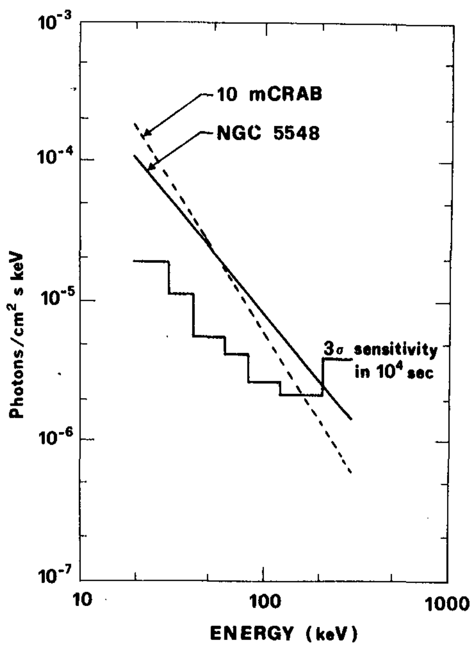

Fig. 1. – Spectrum determination sensitivity of the instrument with the rocking collimators

The MPMC will be mounted to resolve complex fields. When the instrument is used in this configuration the flux sensitivity will be lower (by a factor of ~ 3), but the angular resolution will be at least 20' FWHM. As an example, Fig. 2 shows the expected image in the 20-200 keV band of two X-ray sources 1° apart, one 0.5 Crab and the other 0.3 Crab, for an observing time of 100 s. Computer simulations have shown that the multi-pitch approach is superior to the classical RMC configuration, specially in case of crowded fields.

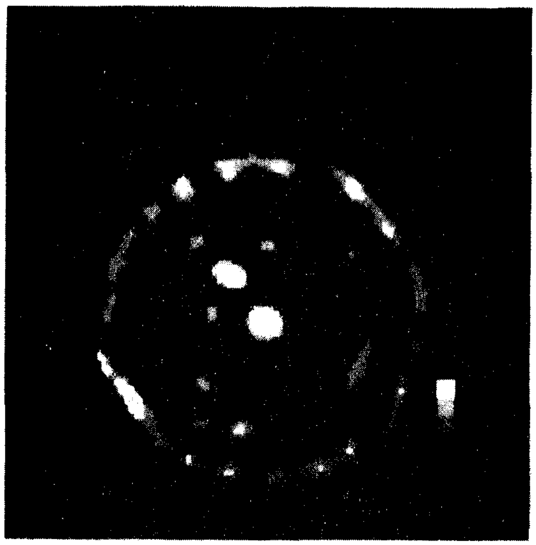

Fig. 2. – Imaging capability of the instrument with the MPMC. This image was obtained simulating a field with two X-ray sources 1° apart of comparable intensity (see text).

References
1. Levine, A.M. et al. 1984, Ap. J. Suppl. 54, 581.
2. Frontera, F. et al. 1984, Nuovo Cimento 7C, 656.
3. Makishima, K. et al. 1978, Space Astronomy XX, 277.
4. Frontera, F. et al. 1985, Nucl. Instr. and Meth. A235, 573.