A CODED MASK TELESCOPE FOR OBSERVATIONS OF X AND GAMMA RAY SOURCES IN THE SOUTHERN SKY

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ABSTRACT

We are developing an X and gamma-ray telescope employing coded aperture imaging technique to observe southern sky sources in the energy range of 40 KeV to 8 MeV with an angular resolution of ∿ 20 arc min. The payload to be flown at 40 km altitude on board a stratospheric balloon will utilize a stabilized platform. We discuss the technical and scientific aspects of the experiment.

I - INTRODUCTION

The Einstein Observatory has identified all varieties of radio and optical objects with X-ray emission at energies below 2 KeV. This telescope used grazing reflection techniques for imaging of objects on to detectors at focus and achieved spatial resolution ∿5 arc sec. In the medium and hard X-ray regimes (2 < E < 100 KeV), modulation collimator techniques have provided the exciting results through UHURU, SAS-3 and Ariel 5 satellites. Among the techniques, coded mask techniques offer promise for future over modulation collimator techniques.

In this paper, we outline our plan to develop a coded mask telescope for X-ray and gamma ray observations with two criteria:

1. To make stratospheric balloon borne X-ray and gamma ray observations of celestial objects in the southern sky in particular galactic center sources in the 40 KeV to 8 MeV energy interval.

2. To develop the coded mask techniques for latter construction of large area telescopes with high angular resolution and sensitivity.

II - SCIENTIFIC OBJECTIVES

Models for X-ray emission from galactic X-ray sources have refined and measurements above 20 KeV play an important role in the verification of mechanisms proposed for this emission. The scientific objectives of measurements are:

1. To determine spectral shape of X-ray emission to distinguish between power law and thermal exponential emission mechanisms.

2. To determine the intensity and energy of line emission, if exists, especially in case of binary pulsars due to cyclotron emission.

3. To determine the time variations in intensity characteristic of irregulars like transients and X-ray bursters.

4. To determine spectral character in different phases of intensity variations.

III - CODED MASK TECHNIQUE

A single pinhole in the path of radiation from an object casts a shadow of the aperture on the detector plane. If the linear dimension of the opening is a, the detector will view a segment of sky with dimension $\sim \Delta\alpha = a/b$, where b is the distance between the detector plane and the aperture plane. To obtain a good signal to noise ratio, SNR, for weak sources a larger opening of the aperture consistent with large detector area is necessary but this is, however, attended by poorer spatial resolution. A number of pinholes if located in the aperture plane provide multiple shadows from different segments of sky and preserves the high spatial resolution. The many overlapping images due to several pinholes must be subjected to a reconstruction method which will compensate for the effects of the imaging system by deconvolution techniques.

If the recorded picture is represented by the function P, the mask aperture by A and the object by O:

$$P = (O * A) + N \qquad (1)$$

where * is the correlation operator and N is the noise function (Fennimore and Cannon, 1978). The object reconstruction, through correlation method, is defined by:

$$O = P * G = RO * (A * G) + N * G \qquad (2)$$

where G is the post processing array and R is the reflection operator. The system point spread function (SPSF), A*G, defines the quality of the object reconstructed and is desirable to have properties approximating delta function. A truly non redundant array (NRA), with hole separation distance distribution truly non redundant will have no inherent noise and in matched process of reconstruction A * A approximates delta function with removable dc level. However, the transmission of this mask is poor due to lack of many holes in the aperture plane. In a random array with random location of holes with density approximating 0.5, the reconstructed object posses inherent noise even with balanced correlation process, which is superior to matched process, with noise free detectors.

IV - THE TELESCOPE

a. Detector System

The principle of Anger Camera is used to obtain spatial resolution and is similar to the Caltech experiment.

We will use a 16" x 1.5" NaI(Tl) crystal as a detector with 19 coupled photomultipliers. The anticoincidence system will consist of a 16 cm thick Polipop plastic cylinder on the sides, a 16" x 1.5" NaI(Tl) crystal at the bottom and a 0.4 cm thick Polipop plastic at the top.

The coded aperture will be located 2.5 meters above the detector and is composed of 2000 cells of which half are open and half contain hexagonal lead blocks to attenuate X and gamma-rays. The pattern of open and filled cells

cells forms a hexagonal uniformely redundant array that is optimal for coded aperture imaging.

b. Coded Mask

The coded mask we prefer to employ is an hexagonal cell array and is similar to rectangular array in function but possess some advantages. The individual hexagonal mask elements will have dimension 2.5 cm and 2 cm thick lead blocks. These individual blocks are covered with Pb, Sn, Cu graded shield to attenuate X-rays. This array of cells is supported by aluminium channels and is fixed rigidly about 250 cm in front of the detector. For this mask-detector distance we expect to have angular resolution of 0.6° in a total field of view (FOV) of 20°. In general in addition,to different statistical variations,the individual detectors will have different systematic variations due to various factors like resolution, light collection efficiency. etc. These different systematic variations from detector to detector will degrade the reconstructed sky image especially for weak sources if we have mask alone in front of the detector. For this reason, it is generally suggested to make observations of any source with mask and antimask for equal amount of time. The combined reconstructed sky images due to mask and antimask will give the best reconstructed object cancelling the effects due to systematic variations in crystal. An antimask has transmission in place of obstruction that a mask presents to the detector array for X-rays and vice versa. In experiments with rectangular array a payload should carry the mask and antimask for observations. However, in the hexagonal cell array a simple rotation of the mask around the axis by 60° acts as an antimask for the detector. This helps in reduction of payload weight and the induced X-rays due to excess lead material near the detector. Additionally this hexagonal cell array provides transmission 0.53 either in mask or antimask configuration to the FOV unlike the rectangular mask and antimask arrays.

c. Stabilized Platform

To realize good statistics and sensitivity we need continuous observation of any particular source. This necessitates tracking of any source in its diurnal motion. This can be achieved with the telescope mounted on alt-azimuth platform. The azimuth stabilization can be achieved with crossed flux gate magnetometers and zenith stabilization with gravity. The pointing can be achieved by stepper motors in three axis configuration. The important requirements of this stabilized platform are $\leq 0.5^{o}$ pointing and stabilization accuracies. Rigorous ground calibration of the sensors and pointing system are envisaged.

d. Electronics

The individual signals from the PMTs are processed through pre-amplifier, amplifier and pulse height analyser located near theh detector and we hope to achieve $\sim$ 2 msec temporal resolution of any particular event and 256 channel energy resolution covering the KeV energy band. The pulse height information, and event information will feed a PCM/FM telemetry system for ground transmission and on board storage. A PCM telecomand system will be utilized for tracking the sources through commands to the orientation platform and also for orientation of mask. We are planning to incorporate in-flight calibration of the detector system at regular intervals. The housekeeping information like pressure and temperature will be transmitted to ground at regular short intervals. The power for the entire payload consisting of detector system and orientation platform will be supplied by lithium alkali battery pack to minimize the weight of payload.

V - BALLOON FLIGHTS

We hope to fabricate the payload in 1988-89 for flight either in March 1990 or early 1991. In any particular balloon flight we hope to track any particular source for 2-3 hours to achieve the scientific objectives. This will permit observations of few sources in a ceiling float of 10-12 hours. We intend to launch the paylaod with 10 or 15 million cubic feet balloons to achieve ceiling altitudes of 3 mbar. The present estimate of the payload weight is approximately 1000 kg.

REFERENCES

Fennimore, E.E. and Cannon, T.M., Applied Optics, 17, 337-347, 1978.