MODELING A HIGH ENERGY GAMMA-RAY TELESCOPE

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1. Introduction. We have developed a Monte Carlo program to simulate a high energy gamma-ray telescope using a coded aperture mask (CAMTRAC). The ultimate purpose of the calculation will be to determine the optimum design parameters for such an instrument. The model can also used to ascertain under what conditions CAMTRAC performance is superior to that of conventional telescopes which employ electron-positron pair direction as the sole means of determining gamma ray direction.

2. Procedure. The CAMTRAC telescope is assumed to consist of a coded aperture mask below which is located a position sensitive gamma-ray detector. It is assumed that an energy measurement is made for each converted photon. The model telescope is characterized by the following parameters:

an energy dependent gamma-ray conversion efficiency,

an energy dependent point spread function (PSF) for the determination of the gamma-ray direction from the pair direction,

an energy dependent PSF for the measurement of the gamma-ray conversion point in the detector plane,

a mask pattern, cell size and distance of the mask from the detector plane,

an energy dependent transmission for the opaque cells in the mask,

a resolution function for the energy measurement made on individual converted photons.

The source of photons is characterized by:

the integrated number of photons incident on the detector from a point source,

the integrated number of photons per unit solid angle incident on the detector from a uniform background,

an energy spectrum for both point source and background photons which varies as E^{-2}.

A computational run consists of generating a set of data and then analyzing it to determine whether or not a point source is apparent in the data set and, if so, to determine its position. The analysis method used is an adaptation of the maximum likelihood method used by A.M.T. Pollock, et al.(1) to search for extragalactic point sources in the COS-B data. In our application of this method, the likelihood function,

$$W(\underline{r},X) = \sum_i \ln[S(\underline{r} - \underline{R}_i;E_i)T(E_i)X + (1-X)/\Omega]$$

is formed for each of several hundred points in a selected region of the sky about seven degrees in diameter. The summation is made over all events in the data set. $\underline{r}$ is the angular position of the point on the celestial sphere where the function is being evaluated, $\underline{R}_i$ is the point on the sphere to which the gamma ray pair direction is pointing for event i, E_i is the measured energy of the photon, and $S(\underline{r}-\underline{R}_i;E_i)$ is the normalized angular PSF. $T(E_i)$ is the mask transmission if the event in question lies in the shadow of an opaque portion of the mask for a photon coming from position $\underline{r}$ in the sky, otherwise it is 1. X is the fraction of the set of events in the data that originate from a point source as opposed to background. Ω is the solid angle subtended by that portion of the sky from which the data set is drawn. The argument of the logarithm in the summation is the probability of observing the event i if there is a point source at position $\underline{r}$, from which a fraction X of the events originate. At each point, $\underline{r}$, the maximum in $W(\underline{r},X)$ is determined in the range $0 < x < 1$. The difference between this maximum and $W(\underline{r},0)$, called λ in reference 1, is the quantity whose maximum is sought in the region of the sky searched. The position of this maximum could be considered to be the point that has a maximum probability of containing a source.

To compare the CAMTRAC system to a conventional telescope, the same calculation can be performed without a mask. In this case, the procedure used for calculating the point source position is exactly the same as that used for the CAMTRAC case except that the factor $T(E_i)$ is replaced by 1 in the expression for $W(\underline{r},X)$. The CAMTRAC telescope will detect fewer photons for a given incident flux because of absorption by the mask. In addition, the decoding process implicit in any algorithm that searches for the mask shadow in the distribution of conversion points introduces noise in the likelihood function, $W(\underline{r},X)$. This noise is worse when the number of point source photons is small.

2. Results. The table below shows the source location accuracy, expressed as r.m.s. error in source location, for two different levels of background and four point source intensities. The intensities are expressed as the total number of photons incident on the telescope above 10 MeV. As can be seen, the CAMTRAC detector has a source location accuracy superior to the conventional telescope by a factor of three in those cases where the point source intensity is most intense. The maximum point source intensity given in the table corresponds to a source of approximately the intensity of the Crab exposed to a detector one square meter in area for four hours. The greater of the two background levels corresponds approximately to the background that one would experience from the diffuse galactic radiation in the anti-center region under the same conditions of exposure. The statistical error in the computed values shown in the table is 15 to 25%.

R.M.S. SOURCE LOCATION ACCURACY, MINUTES OF ARC

	CAMTRAC		CONVENTIONAL	
Background (ph/sr) =	$1.2x10^5$	$0.6x10^5$	$1.2x10^5$	$0.6x10^5$
Source (ph)				
5000	1.4	1.7	4.3	5.2
2500	5.6	4.4	7.0	8.9
1250	32.6	48.0	19.2	14.8
625	85.0	90.8	64.9	63.1

4. Conclusions. A simple model is used in this simulation and the variables of the CAMTRAC system have not been optimized. However, the results show that the coded aperture mask system holds the promise of greatly improving the accuracy of locating point sources of gamma rays. In addition, it can be expected to improve the resolution of structure in extended sources of gamma rays.

5. Acknowledgements. This work was supported by grant NAGW-451 from the U.S. National Aeronautics and Space Administration.

(1) A.M.T. Pollock, G.F. Bignami, W. Hermsen, G. Kanbach, G.G. Lichti, J.L. Masnou, B.N. Swanenburg, and R.D. Wills, (1981) Astron. Astrophys. 94, 116