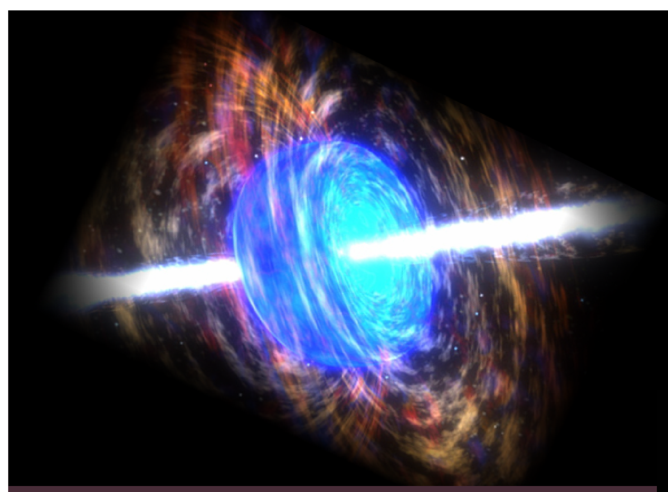
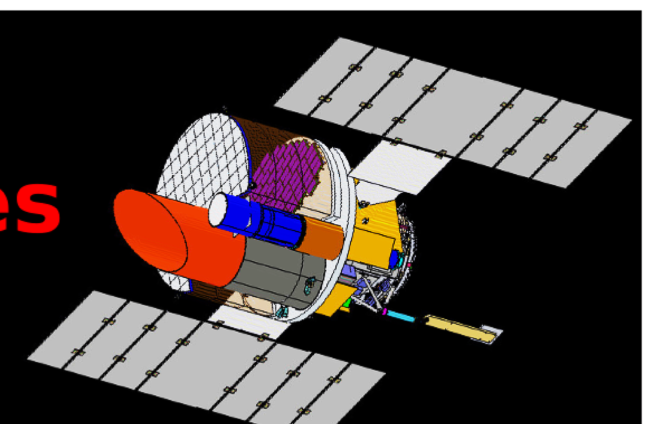


# *EXIST*: Surveying the birth and evolution of Black Holes



# Optimizing the imaging performance of the EXIST high energy telescope


Gerry SKINNER (Univ. Md, CP / CRESST / NASA-GSFC)
Branden ALLEN (Center for Astrophysics)
Mark FINGER (NSSTC)
Josh GRINDLAY (Center for Astrophysics)
Jae Sub HONG (Center for Astrophysics)
Garrett JERNIGAN (SSL, UCB)
Steve STURNER (Univ. Md, BC / CRESST / NASA-GSFC)

} The EXIST High Energy Telescope Imaging Technical Working Group (HITWG)


## *Introduction*

The baseline concept for the primary instrument of the EXIST mission, the high energy telescope (HET), is a coded mask instrument with a wide field of view and extremely good sensitivity (Hong et al., this meeting). Achieving the performance goals requires an imaging capability close to the statistical photon limit, minimizing systematic errors even when the total integration time is very long. At the same time there is a requirement to be able to reconstruct images on board in near real time in order to detect and localize gamma-ray bursts. This must be done while the spacecraft is scanning the sky with a motion designed to help reduce systematic errors and to provide all-sky coverage. During the 2008 Advanced Mission Concept Study, the HET Imaging Technical Working Group has investigated and compared numerous alternative designs for the HET. The selected baseline concept meets all of the scientific requirements, while being compatible with spacecraft and launch constraints and with those imposed by the infra-red and soft X-ray telescopes that form key parts of the mission. The approach adopted depends on a unique coded mask with two spatial scales, offering good resolution and low background at low energies, with a lower resolution but enhanced sensitivity in the upper part of the energy band. Monte Carlo simulations and analytic analysis techniques have been used to demonstrate the capabilities of the proposed design.

The requirements for the EXIST High Energy Telescope (HET) include

- A large field of view
- High sensitivity, both for gamma-ray bursts (GRBs) and in survey mode
- Good angular resolution
- The capability of detecting and positioning GRBs in near real-time on-board

The EXIST High Energy Telescope Imaging working group has studied many instrument design options, some of which are shown in Fig. 1, before arriving at the configuration now adopted.

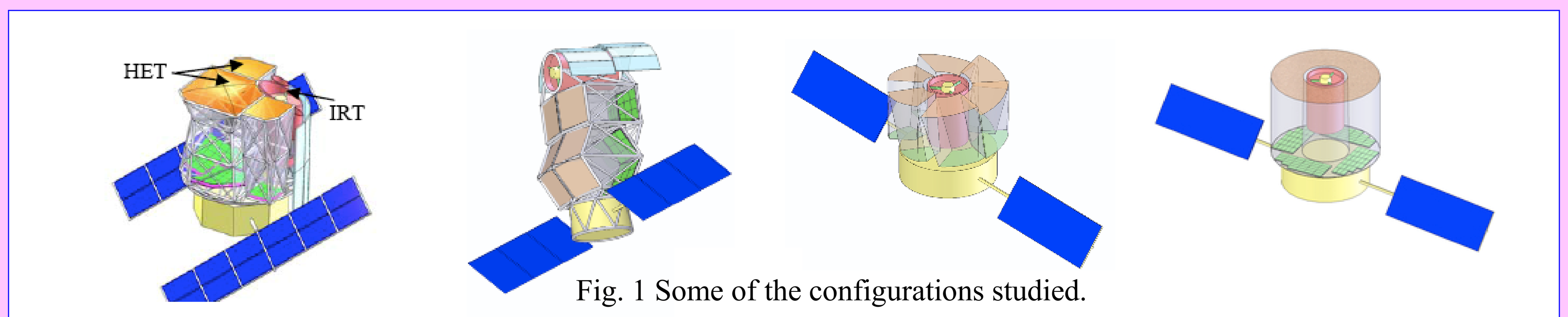
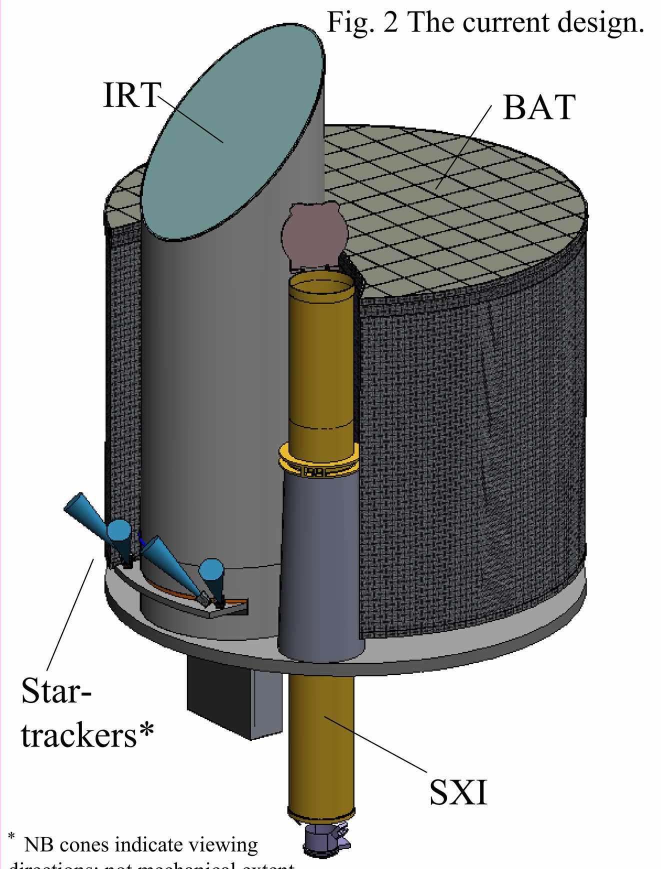



Fig. 1 Some of the configurations studied.

Compared with these, the current design (Fig. 2) has reduced mass, is comparatively simple, and provides for the accommodation of both the Infra-Red telescope (IRT) and a Soft X-ray Imager (SXI) with minimal impact on the HET field of view.

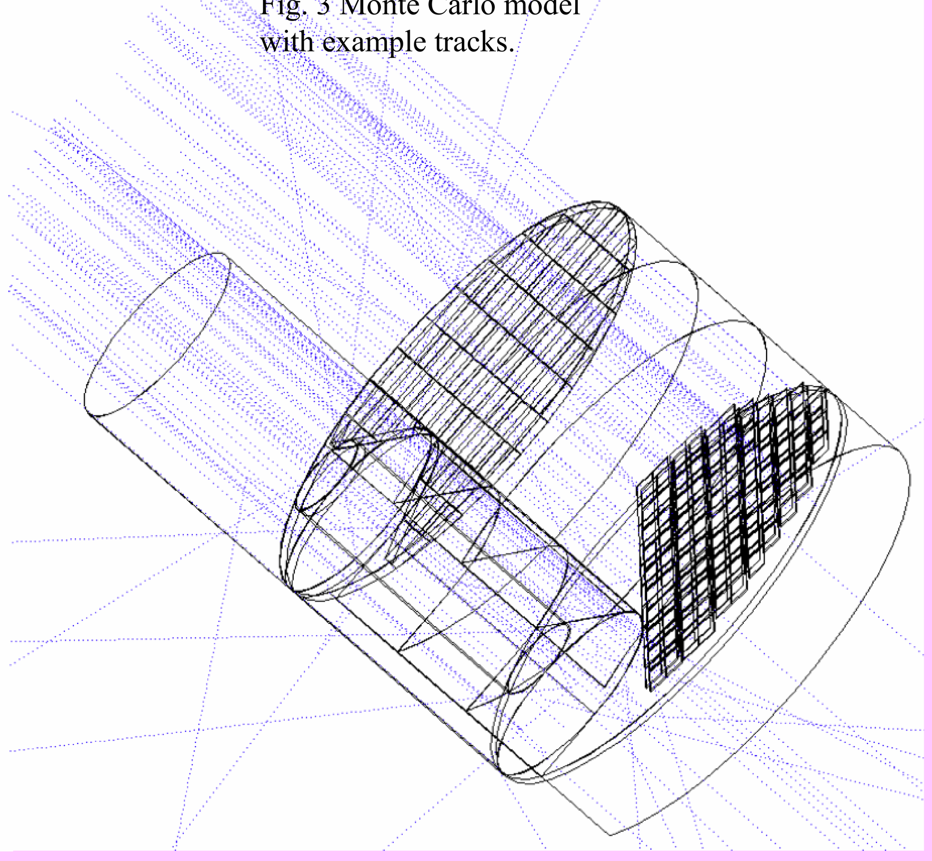
A MGEANT/ GEANT-3 model of the instrument (Fig. 3) and its surroundings is being used to evaluate the performance and allow the design to be further optimized.

Fig. 2 The current design.




* NB cones indicate viewing directions; not mechanical extent

Fig. 3 Monte Carlo model with example tracks.



## *The hybrid mask concept*

Problems

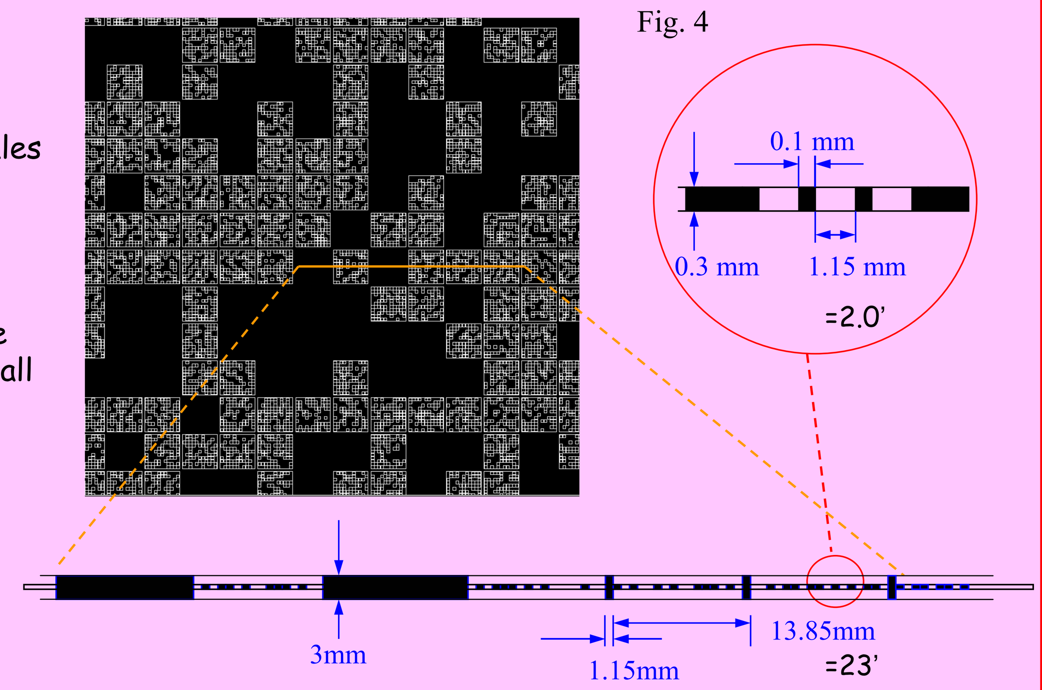
1. The optimum *'open fraction', f,* for a coded-mask is a function of the balance between the detector background that does not depend on *f* (such as that due to particles) and that which does depend on *f* (such as that due to the Cosmic X-ray Background). This balance depends on energy.
   - Particle background dominant (high energies) → $f_{opt} = 50\%$
   - Cosmic X-ray Background dominant (low energies) → $f_{opt} < 50\%$
2. The EXIST-HET field of view with the full angular resolution contains ~$2 \times 10^7$ resolution elements. Reconstruction of images involves transforms of arrays of several $\times 10^8$ pixels if sensitivity is not to be lost by undersampling. The rapid formation on-board of images of this size is not practicable.

Solution - a hybrid mask

The mask pattern (Fig. 4) is one containing structure on two spatial scales (Skinner & Grindlay 1993):

- A coarse pattern of large (14 mm) holes is etched into a Tungsten sheets totaling 3mm in thickness such that $f \sim 0.5$ (within the pattern itself there are holes at about 60% of the possible positions, but supporting structures reduce the overall open fraction).
- The holes in the coarse mask are covered with a thin (0.3 mm) fine mask with 1.15 mm holes that becomes transparent at high energies.

Fig. 4




Consequences

- The "open fraction" changes as a function of energy :-
   - Low energies $f \sim 20\%$
   - High energies $f \sim 50\%$
- The computation problem can be tackled by a 2-stage strategy
- Full angular resolution is maintained at low energies, where it is needed and where source location is best done
- Angular resolution is only degraded at high energies where it is less important.

## *A 2-stage search strategy*

1) Form a low resolution image with detector data coarsely binned and search for points exceeding a low threshold (e.g. 4σ). Although the SNR ratio is degraded, because of the low threshold, a number candidate regions (e.g. 10) are found.

2) For each candidate region perform detailed imaging (e.g. by back projection) of a small surrounding region. Search for a point exceeding a high threshold (eg 7σ) such that the probability of a false trigger is small.

Advantages : The initial search can be rapid because the size of the transforms involved is not too large (FFT size 'only' $4 \times 10^6$ elements instead of $4 \times 10^8$ for a full resolution reconstruction (assuming 2× over-sampling). It can use a low fidelity representation of the mask shadow. The final imaging can use a detailed model of the mask shadowing, including energy dependence, effects due to finite mask thickness and to the mask support structure.

## *An energy-dependent PSF*

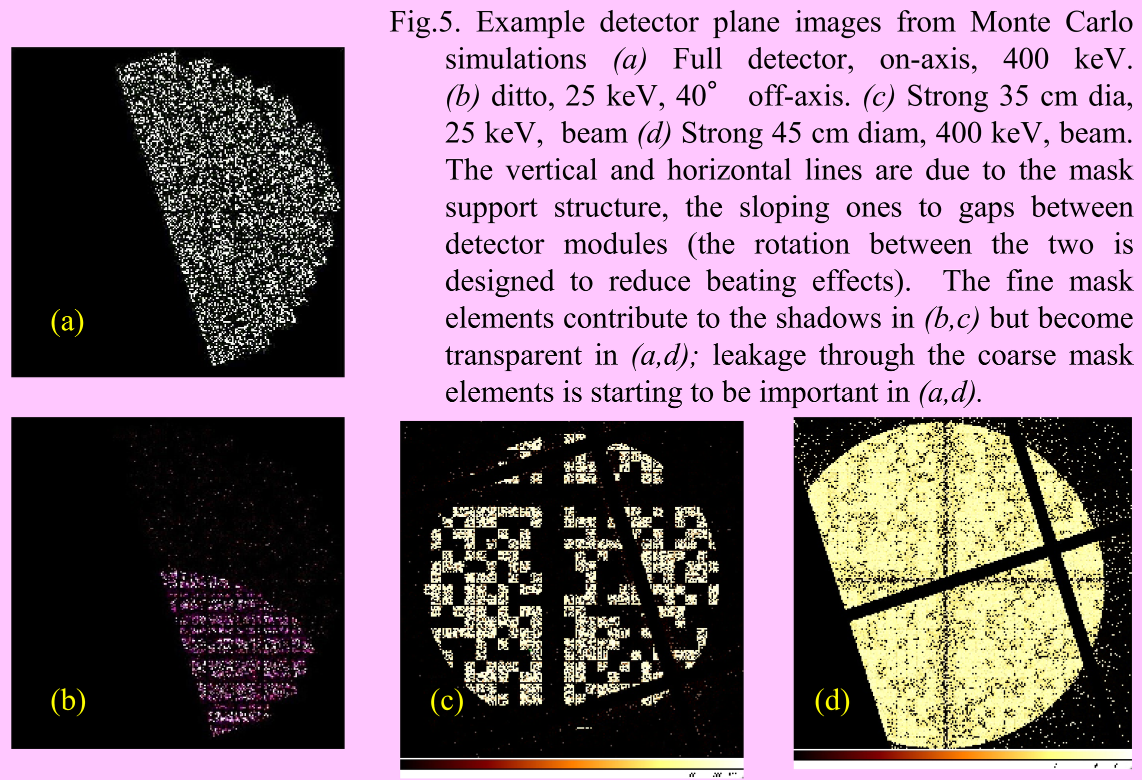



Fig.5. Example detector plane images from Monte Carlo simulations *(a)* Full detector, on-axis, 400 keV. *(b)* ditto, 25 keV, 40° off-axis. *(c)* Strong 35 cm dia, 25 keV, beam *(d)* Strong 45 cm diam, 400 keV, beam. The vertical and horizontal lines are due to the mask support structure, the sloping ones to gaps between detector modules (the rotation between the two is designed to reduce beating effects). The fine mask elements contribute to the shadows in *(b,c)* but become transparent in *(a,d);* leakage through the coarse mask elements is starting to be important in *(a,d).*

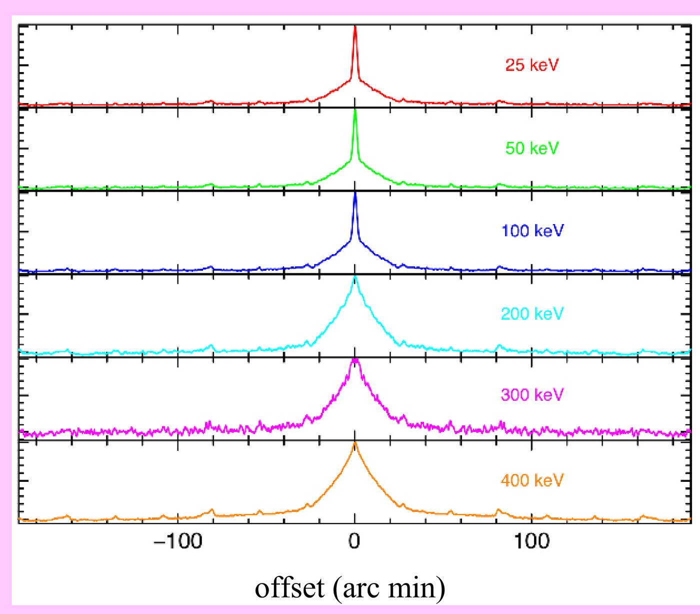



Fig. 6. On-axis Point Source Response Function shapes from Monte Carlo simulations. The peak is normalized to unity. (The noise is not the same in each case due to different sample sizes). The central spike has a FWHM of 2.4 arc minutes. That of the coarse 'shoulder' component is about 28 arc minutes. These numbers are **reduced** off-axis.

## *Monte Carlo results*

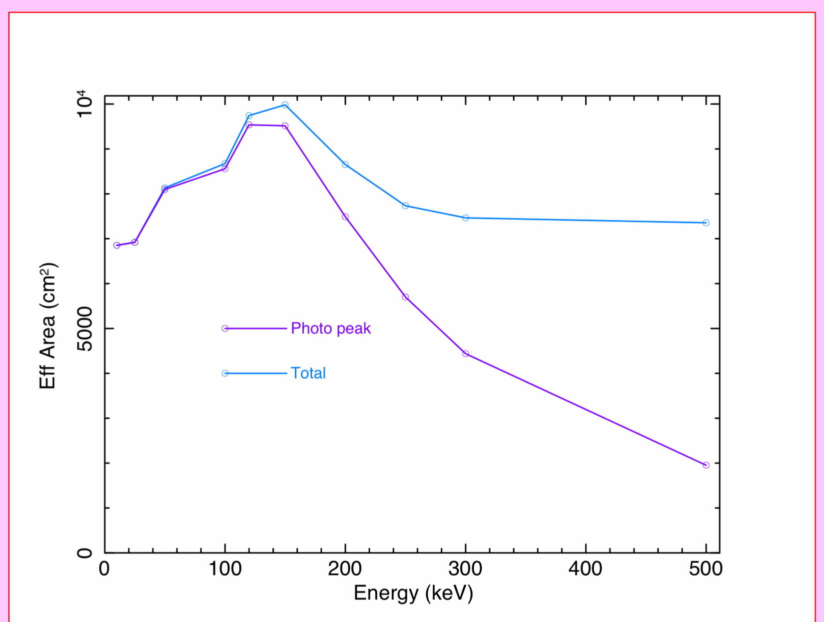



Fig. 7 The on-axis effective area from Monte Carlo simulations. The area initially increases with energy as the coarse mask takes over from the fine mask, but then declines as the detector is no longer optically thick.

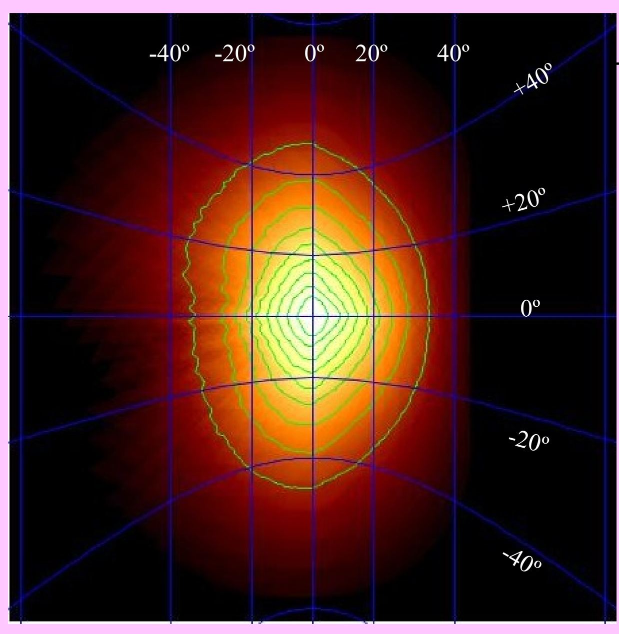



Fig. 8 Effective area as a function of position within the field of view. Contours are as 10, 20 …90% of the peak on-axis value. The extent at the 10% level is about 90×70°. Shown at 25 keV.

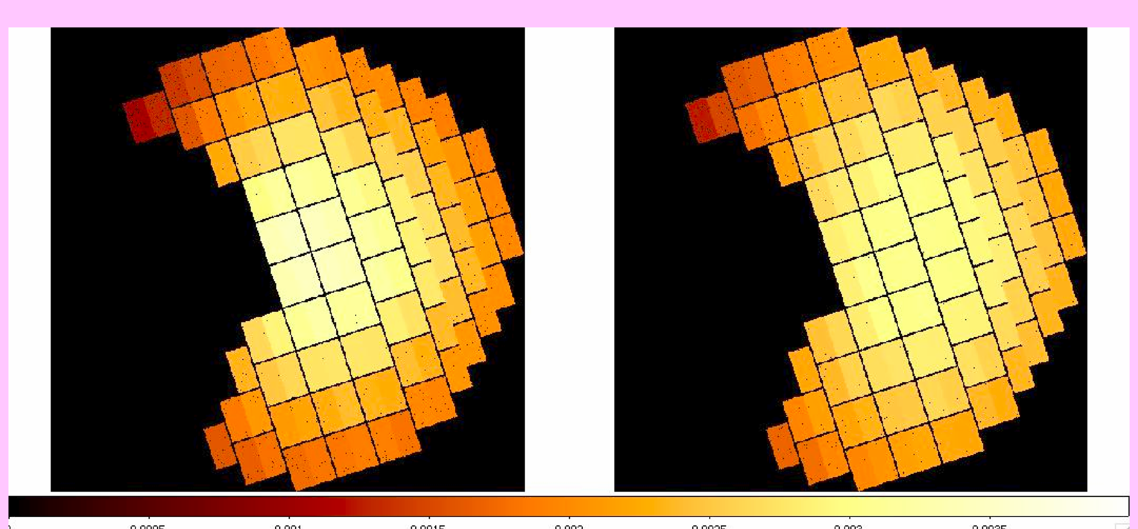


Fig. 9 The illumination of the detector plane by diffuse cosmic X-ray background radiation shining through the mask. Left with mask holes skewed towards the centre of the detector; right with parallel holes. In the current design there a no detector module at some of the trial positions in this test. Shown at 25 keV.

### Some key parameters

Energy range 5-600 keV

Detector geometric area 4.5 m²

Detector pixels $1.2 \times 10^7$

Mask holes

Coarse 15500

Fine 94000


Reference

Skinner, G. K. & Grindlay, J. E "Coded masks with two spatial scales" A&A, Vol. 276, p. 673 (1993)