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A new technique for eliminating ghosts from coded aperture images[⋆]

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Abstract

A new technique for eliminating ghosts from images reconstructed from coded aperture cameras is introduced. The technique involves comparing the images of the same sources obtained from multiple independently-coded cameras (MICCs) and using the fact that real sources will persist from camera to camera whereas ghosts will, in general, vary from camera to camera; in this way, we can distinguish the real sources from the ghosts in the reconstructed images. The ability of MICCs to obtain ghost-free images is illustrated using a Monte Carlo simulation with input sources based on the HEAO catalog [1] of astrophysical x-ray sources.

I. INTRODUCTION

Coded aperture cameras provide an effective means for imaging x-ray sources in either terrestrial or astrophysical applications. The pattern recorded on the detector is a complicated transformation that depends on the pattern of holes in the coding mask and on x-ray emission from the object or region of sky being viewed. An image of the x-ray sources can be recovered by inverting the transformation; however, this process of reconstructing the image,

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in general, results in an image that is polluted by ghost images, i.e., apparent sources that are not really there. These ghost images are known as coding noise.

In terrestrial applications it is usually possible to arrange a coding pattern, e.g., the uniformly redundant array (URA) of Fenimore and Canon [2], that minimizes the coding noise problem. To do this, the mask must be larger than the detector—a requirement that is awkward in astrophysical applications because they are typically constrained to the box-camera geometry in which the mask and the detector are the same size. In the box-camera geometry, coding patterns are only effective at eliminating ghosts in the central part of the field-of-view. This is not a good match to the astrophysical situations in which there are often many sources being viewed at once, some of which are likely to be near the edge of the aperture. The multiple independently-coded cameras (MICCs) technique, to be described in detail below, solves this problem and allows essentially ghost-free images to be reconstructed using box-camera geometry.

II. Eliminating coding noise with multiple independently-coded cameras

The term 'coding noise' is in some sense a misnomer for the ghost sources that appear in reconstructed images. They are not random fluctuations but instead are completely deterministic; that is, given the distribution of sources and the coding pattern of the mask, the ghosts that appear are completely determined. Ghosts, in fact, contain information about the locations and strengths of the real sources.

The dependence of ghosts on the coding pattern can be used to eliminate them; when a set of sources is viewed by multiple cameras, each with a different coding pattern, the real sources will appear in the same place in the reconstructed image obtained from each camera, but the ghosts will not—each camera will have a different set of ghosts. Thus, by retaining only the sources that appear consistently in many cameras, ghosts can be eliminated.

III. Example: sources near the 8th brightest source in the HEAO catalog

To illustrate the MICC method, we consider a 5° × 5° region centered on the eighth brightest source in the HEAO catalog (HEAO #8) being viewed by 25 coded aperture cameras, each with a 50 × 50 array of detector pixels. HEAO sources #4, #9 and #31 are also in the field of view. The mask for each camera was generated randomly to achieve $\approx$ 50% transmission. The mask holes are the same size as the detector pixels, leading to $\approx$ 1250 holes in each mask.

Monte Carlo data is generated for each of the cameras. Large statistical samples are generated ($\approx$ 1000 x-rays per mask hole from the brightest source) in order to avoid confusing the coding noise issue of interest here with the statistical noise issue that is bound to arise in a real experiment.

The unbiased balanced correlation (UBC) method of Ponman, Hammersley and Skinner [3] is used to reconstruct an image of the sky from the pattern recorded by each camera. The result for a single camera is shown in Fig. 1a. The area of the circles is proportional to the intensity of the pixel at its center. Only the thousand brightest pixels are plotted. Three of the real sources are clearly visible, but it would be difficult to recognize them among the coding noise ghosts if their locations were not known *a priori*. HEAO #31, which is only 6.4% as bright as HEAO #4, has disappeared—it is much dimmer than many of the ghosts and no pixel associated with it makes the 1000 brightest list.

If we select only pixels that are seen in at least 20 of the 25 cameras,[a] then only pixels associated with HEAO #4, HEAO #8, and HEAO #9 survive. To recover HEAO #31, we do a maximum-likelihood fit to the position and strength of the three sources reconstructed and subtract the fitted value for each detector pixel from the measured value to obtain a data set with the strong sources removed. The image constructed from a single camera after this subtraction procedure is shown in Fig. 1b. HEAO #31 is now found, but it is surrounded by substantial coding noise. However, applying the MICC procedure to this subtracted data eliminates all the pixels except those due to HEAO #31. The end result is shown in Fig. 1c. All four sources are reconstructed without any ghost sources.

IV. Conclusions

The multiple independently-coded cameras technique is a powerful means of reconstructing ghost-free images in an environment in which mask pattern schemes fail. When the MICC technique is used in conjunction with a fitting scheme for subtracting the contribution of strong sources from the data, it is possible to recover weak sources even in the presence of several substantially stronger sources.

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[a] Actually the three brightness sources appear in all 25 cameras, but in cases of lower statistics one may want to allow for misses caused by statistical fluctuations. Also, 25 cameras is overkill; 5 or so would be sufficient.

References

[1] K. S. Wood et al., “The HEAO A-1 X-ray Source Catalog,” NAVAL Research Laboratory, Washington D.C.

[2] E. Fenimore and T. Cannon, Applied Optics **17**, 337(1978)

[3] A. Hammersley, T. Ponman and G. Skinner, Nucl. Instr. and Meth. **262**, 419(1987) and Nucl. Instr. and Meth. **311**, 585(1991)

Figure Captions

Figure 1: Reconstructed images of x-ray sources in a $5^\circ \times 5^\circ$ region centered on the eight brightest sources in the HEAO catalog (HEAO #8): a) URA reconstruction of an image from one 50×50 pixel detector camera; b) Reconstruction from one camera after subtracting the three brightest sources (HEAO #4, #8 and #9); c) Image after retaining only reconstructed points that were found in at least 20 of the 25 cameras.

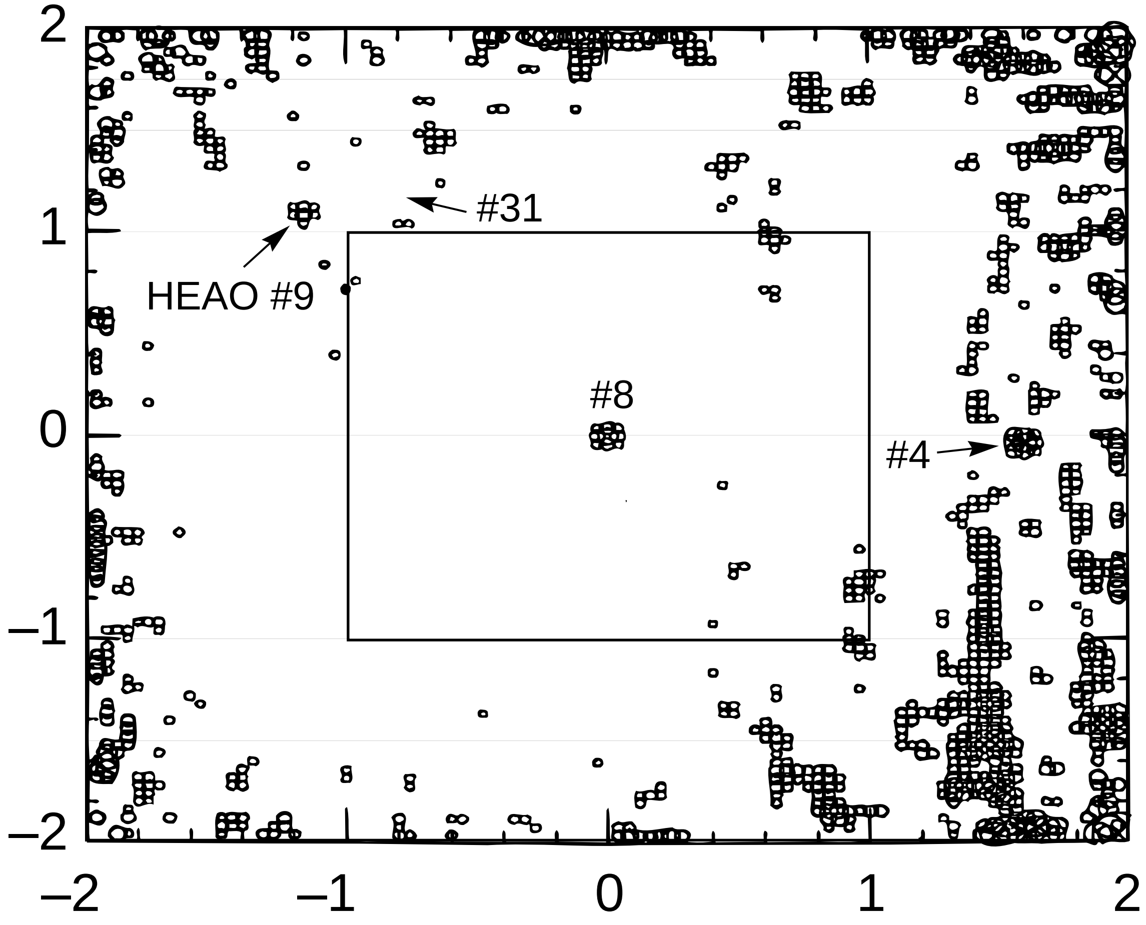

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Figure 1a

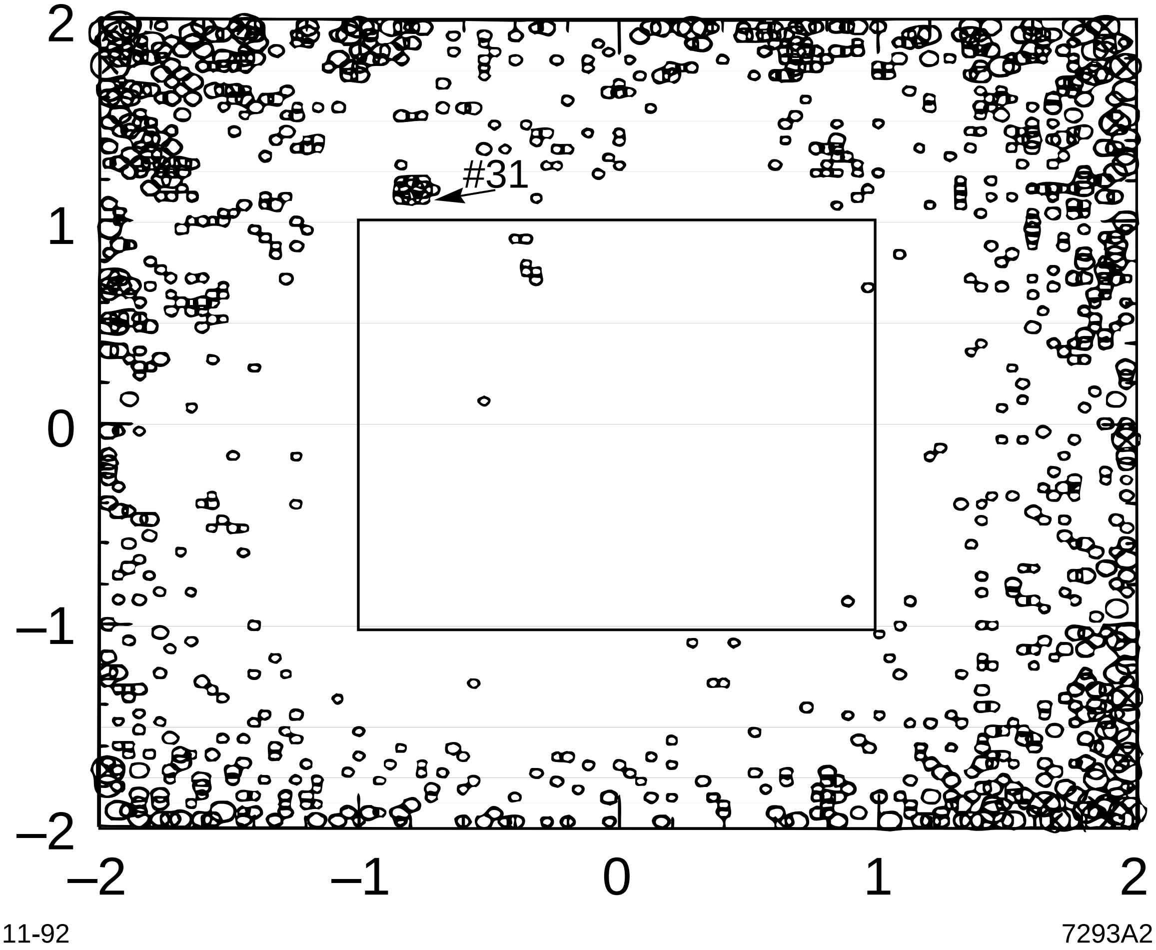

Figure 1b

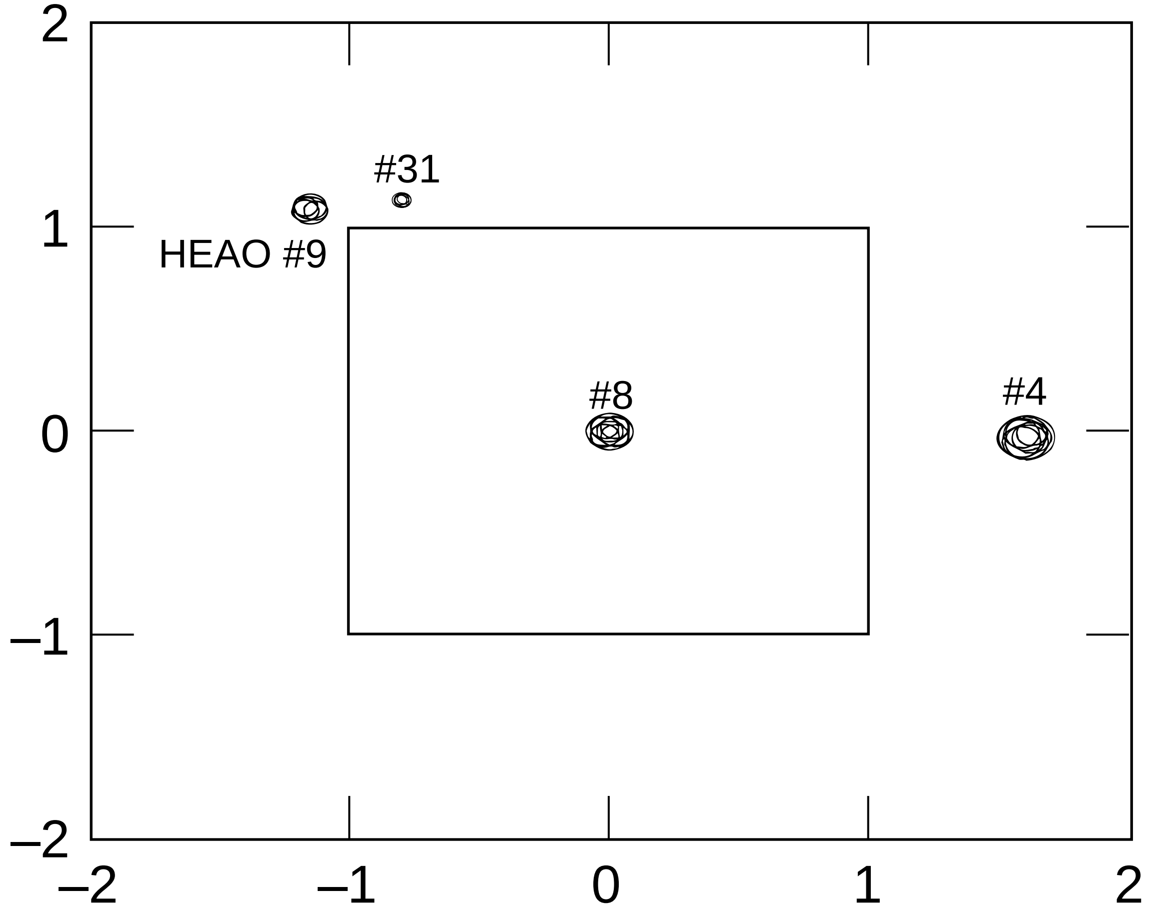

Figure 1c