Final Report: A SURVEY OF VARIABLE EXTRAGALACTIC SOURCES WITH XTE'S ALL SKY MONITOR (ASM)

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1 Overview

This document is the final report for the project entitled A SURVEY OF VARIABLE EXTRAGALACTIC SOURCES WITH XTE'S ALL SKY MONITOR (ASM). The principal investigator for this A01 XTE observation project (10365) is Garrett Jernigan. The original goal of the project was the near real-time detection of AGN utilizating the SSC 3 of the ASM on XTE which does a deep integration on one 100 square degree region of the sky. Unfortunately SSC 3 has never performed sufficiently well to allow the success of this original goal. Howvever, the work on the project has led to the development of a new analysis method for coded aperture systems which has now been applied to ASM data for mapping regions near clusters of galaxies such as the Perseus Cluster (centered on AGN NGC1275) and the Coma Cluster. Publications are in preparation that describe both the new method and the results from mapping clusters of galaxies.

The entire project can be divided into several phases. The operation of the three SSCs (scanning shadow cameras) which comprise the ASM (all sky montitor) is routine since the launch of XTE in December 1995 (Levine 1996). This projects derives all its data from the ASM which has been operating nearly continuous for 25 months.

The initial phase of this project involved the development of new software that combines large quantities of data from the ASM and thereby improving the sensitivity of the instrument for the detection of sources down to a limiting flux of 1 mCrab.

The second phase involved testing of the newly developed code on real example sources (NGC1275 and CASA). The goal is to evaluate the sensitivity of the computed sky maps by checking the significance of detection of known calibration sources. Also a new set of instrument calibration parameters were incorporated into the code. This required data and code changes since the formats of the calibration information was modified. After extensive testing the performance of the method down to 10 mCrab was verified. It was then decided to modify the theory of the algorithm before attempting to demonstrate peformance down to 1 mCrab, the goal of the project. Also an effort was started to draft a methods paper.

Previously the principal investigator has developed and tested a new analysis approach, the Photon-Clean Method (PCM) for the analysis of X-ray data from imaging telescopes such as ROSAT and ASCA. PCM will be extended and adapted for the analysis of coded-aperture telescopes such as the ASM on RXTE. PCM is an inverse Monte Carlo approach that is ideally suited for the analysis of X-ray "events" that have complex ancillary information such as astigmatic off-axis response of a grazing incidence mirror. A similarly complex point spread function (PSF) can be derived for a coded-aperture telescope which then leads to a natural adaptation of PCM for such systems. Besides the two specific RXTE testbed activities the developed code will also extend the basic capabilities for the analysis of coded-aperture systems in general and may well impact future missions such as HETE, EXIST and BASIS which depend on coded-apertures for the wide field detection of sources of X-rays above 10 keV.

The final phase of the project involves the extension of the software for imaging. In particular the ASM has a large exposure on both the Coma and Perseus clusters of galaxies. These regions have been extensively mapped by previous X-ray astronomy missions. The highest quality images of this type have focussed on the inner regions of these clusters and have not sensitively mapped the large scale (5 degree) structure especially at energies above 5 keV. By combining data from the ASM accumulated over several years one should be able to

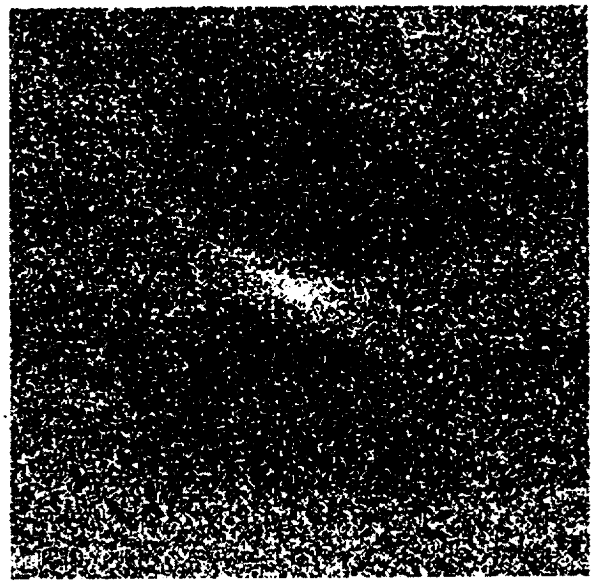

Figure 1: ASM Correlation Map (8 x 8 degrees) showing the extended emission from the Perseus Cluster of galaxies centered on NGC1275

make a definitive map of this large scale low surface brightness emission. The results could have cosmological implications related to the determination of the total mass within these clusters.

1.1 A Real RXTE Example of a raw correlation map of the Perseus Cluster

Fig. 1 is "raw" correlation map of a moderate exposure (25,000 s) centered on NGC1275 accumulated over a three month interval. It is shown to illustrate the potential of the approach. Fig. 2 is also a "raw" correlation map of a simulated point source located at the position of NGC1275. It is clear by inspection that the emission in fig. 1 is extended as compared to the point source shown in fig. 2.

2 Role of the Photon-Clean Method (PCM)

2.1 Status of the PCM

A portion of the project includes the application of a new approach for the analysis of complex multi-dimensional data in the form of a finite list of detected photons. This new approach was invented by the PI of this proposal (Jernigan and Vezie, 1995). The new approach is an inverse Monte Carlo method which starts with a list of raw events of imperfect information (observed photons) and ends with a finite list of events of perfect information (model photons). The most significant feature of the new method is that all mathematical steps are carried out without the creation of any spectral or spatial bins of photons. The new algorithm generates models or deconvolved images in the form of a list of photons via an iterative feedback scheme hence its title the Photon-Clean Method (PCM).

The basic advantage of any Monte Carlo approach is that the information for each detected photon can be maintained as an independent event with specific information. For example an off-axis event can be labeled as associated with the off-axis PSF. This means that the data space as photons in the form of a list of events with ancillary information can be combined by the simple concatenation of the lists of events. One can extend this concept to the model or image space such that the processed image is also composed of a list of events with ancillary data such as position in the sky and photon energy. Any deconvolved image can be represented in a Monte Carlo fashion as a finite list of model events whose ancillary information is detector independent.

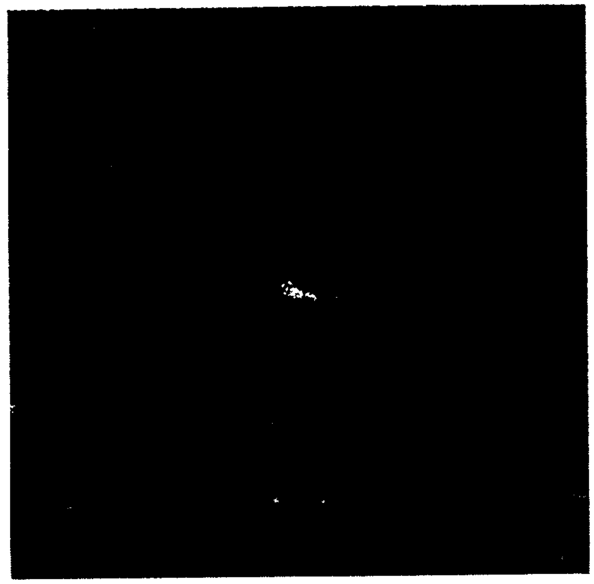

Figure 2: ASM Correlation Map (8 x 8 degrees) of a simulated point source located at the position of NGC1275. The map is the effective point spread function (PSF) of the ASM for this observation

2.2 A Deconvolution of a GIS Image of the CAS A SNR with PCM

An example of the deconvolution of a GIS Image of the CAS A SNR is shown as an illustration of PCM. A "true" model of a CAS A SNR can be represented in the form of a list of model events (photons). One can simulate all the observed data sets for the ASCA GIS observations of the object. If the model or deconvolved image is "correct" then the resulting Monte Carlo simulated detected events will statistically match the "observed" events. A single model will then simultaneously agree with all the observed data events.

Fig. 3 illustrates an example of the analysis of a real ASCA image of the Cas A supernova remnant taken in a single long exposure with the GIS instrument. This example clearly indicates the capability of the prototype version of PCM for the deconvolution of a two dimensional image of an extended complex object. Cas A is near the center of the field of view. The PSF displayed in figure 3 (a) is obtained from an independent calibration image of an on-axis point source. Figure 3 (b) is the raw GIS image of Cas A. Figure 3 (c) and (e) is the final deconvolved image or model derived by the two dimensional version of the PCM. Note that this image shows the expected shell like structure which can be seen in higher resolution data from Einstein (Murray 1979). Figure 3 (d) is the final simulated raw image after convolution with the PSF in Figure 3 (a). The new method converges by a two dimensional KS comparison of the raw observed image, Figure 3 (b), and the simulated raw image in Fig. 3 (d). Note the dramatic difference in the raw observed image and the final deconvolved image.

2.3 Extension of PCM for the Analysis of Coded-Aperture Systems

Both testbed activities require the successful adaptation and extension of PCM for the analysis of coded-aperture systems by the introduction of an effective PSF. The example of a the correlation map generated for an X-ray "image" of the Perseus Cluster of galaxies centered on NGC1275 illustrates the first step of the approach. Fig. 1 illustrates the first step of the approach. It is a correlation map of a 8 x 8 degrees region centered on NGC1275 composed of data from 250 separate 90 second exposures of the RXTE ASM over a period of three months. Fig. 2 is a correlation map of a simulated point source located at the nucleus of NGC1275 which serves as an equilvalent PSF for the image. Notice that the PSF or beam pattern is complex and extended. The "image" derived from the raw data is clearly a convolution of an extended region of emission with the PSF. The goal of the project is to modify PCM for the deconvolution of the image. The scientific value of such a goal when applied to the deep exposure of several years of RXTE ASM data is

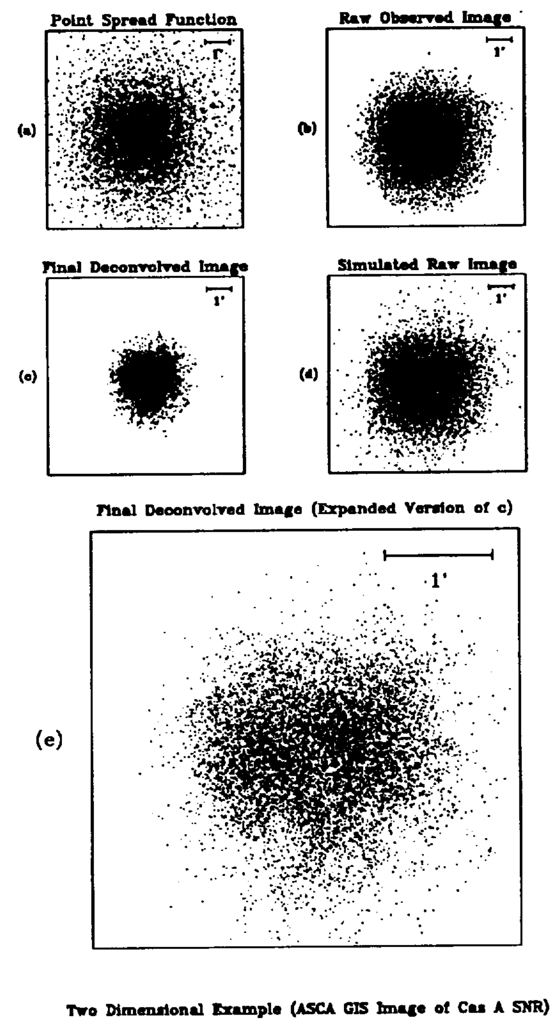

Figure 3: A two dimensional example of a PCM deconvolved image of the CAS A SNR derived from ASCA GIS data. (a) is the near on-axis PSF which is an actual GIS observation of a bright point source. All of these images are displayed with one black dot per photon and are not the usual two dimensional histograms. (b) The raw observed image of CAS A. (c) The final PCM deconvolved image. (d) The simulated image. (e) an expanded version of (c). The image in (c) and (e) has been modified by iteration until the simulated image in (d) derived from (c) matches the raw image in (b).

a map of a large region (10 degrees across) especially in 5-12 keV band which has not been measured well with previous observations. Such maps of the Perseus and Coma cluster (perhaps a few others) may have important cosmological implication for the determination of the total mass associated with clusters including dark matter. Previous work has focussed on the brighter central regions of clusters.

3 References

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