Astronomical Data Analysis Software and Systems IV
ASP Conference Series, Vol. 77, 1995
R. A. Shaw, H. E. Payne, and J. J. E. Hayes, eds.

A Method for Visualizing Time Variability in X-Ray Images

P. Giommi

ESIS, Information Systems Division, ESA/ESRIN, Frascati, Italy

N. E. White, L. Angelini

HEASARC, NASA/GSFC, Greenbelt, MD 20771

Abstract. We present a new method for visualizing flux variations in X-ray images. Starting from event list files, images are created where the pixel intensity is proportional to the probability that a strong variation in flux (approximately a factor 2 or more) occurred during the observation. The method is based on the Kolmogorov-Smirnov test and is not sensitive to data interruptions due to temporary loss of telemetry, earth occultations etc. Since only strong variations can be detected this approach is also insensitive to most spurious events induced by satellite pointing instability. This method has been implemented within the XIMAGE package and was used during a systematic analysis of all publicly available *ROSAT* PSPC images. The results of this analysis were used to construct the WGA catalog of X-ray sources. In this paper we describe the method and give some specific examples. The results presented here make use of the *ROSAT* PSPC data obtained from the *ROSAT* public archive accessible via the ESIS or the HEASARC systems.

1. Introduction

Systematic studies of luminosity variability in data obtained from low orbit satellites often require binning and are complicated by the frequent data interruptions due to Earth occultation and other causes. We present here a method to detect X-ray variations that does not require binning, is simple, and numerically stable, and is not sensitive to data interruptions. Variability on time scales ranging from a few seconds to the actual observation duration can be detected. We have used this technique to systematically analyze of all PSPC images available in the *ROSAT* public archive. This project led to the construction of a catalog including more than 40,000 X-ray sources (the WGA catalog, White, Giommi, and Angelini 1994). Several hundred of these sources have been found to be rapidly variable.

2. The Method

The method consists in comparing the time arrival distribution of the photons collected in each pixel with the corresponding distribution of the entire image using a Kolmogorov-Smirnov (KS) test. The result of the KS test is a χ^2 value (with 2 degrees of freedom) that is used to assign an intensity value to each pixel. In this way, pixels where the distribution of photon arrival times is not consistent with that of the entire image are given high intensity (χ^2) values. The *time variability image* so constructed visually shows area where strong time variation occurred. To calculate the χ^2 values the event list must be *time sorted* and must be read twice. The first time the event list is read a normal intensity image is built and is stored in memory as an array of integers. This array is used during the second pass to provide the normalization values (i.e., the number of detected photons during the full exposure) in each pixel and in the entire image. The second time the event list is read, the cumulative distributions for each pixel and for the entire image are calculated. When a photon i is considered the cumulative distribution at time t_i in pixel (x_i, y_i) is obtained as the ratio of the number of photons detected up to time t_i divided by the total number of photons detected at position (x_i, y_i): $D(t_i, x_i, y_i) = N(t_i, x_i, y_i)/N_{tot}(x_i, y_i)$. The cumulative distribution of the whole image is calculated as the ratio of all the photons arrived up to time t_i, and the total number of photons in the image accumulated during the entire exposure is $D_{image}(t_i) = N(t_i)_{image}/N_{tot}$. The distance $\Delta = |D_{image}(t_i) - D(t_i, x_i, y_i)|$ between the two distributions is written into a new array at location (x_i, y_i) only if it is greater than the value previously stored in that pixel. These steps are repeated for every photon in the event list. At the end of this process the array containing the (maximum) distances between the arrival time distribution of all pixels and the entire image is converted into an array of χ^2 values using the usual formula of the KS test.

This method has been incorporated within the XIMAGE package (Giommi et al. 1991). In this particular implementation the KS test is applied only to pixels where more than 10 photons were detected during the entire observation. The resulting χ^2 values are multiplied by a factor 10, to increase the dynamic range, and are limited to a maximum value of 200 to avoid that a bright variable source with a very high χ^2 dominating the entire image. By this method, all pixels with values between $\approx$ 100 and 200 represent variable sources.

3. The Limits

The method is based on the comparison between the source light curve and that of the rest of the image. To properly detect source variations it is necessary that the image background be not strongly variable. This condition is generally satisfied in most *ROSAT* images. For the case of observations with highly variable background it is necessary to remove all the time intervals where the background was variable. This obviously reduces the sensitivity of the test. A second limitation of this method is that it is not sensitive to small amplitude variability (less than about a factor 2) and to weak periodic oscillations.

Given the limitations described, this method cannot be used to perform *uniform* variability surveys. It is, however, very useful for detecting large flares (on time scales of hours or days) or strong periodic sources. In all cases a careful check must be carried out to remove spurious events. This is an ongoing activity on the candidate variable sources included in the WGA catalog.

4. Some Examples

In this section we give some examples of rapidly variable sources found in *ROSAT* public data using the ESIS system (Giommi et al. 1994) which makes use of XIMAGE and several other Xanadu routines. Figure 1. shows the *intensity* (left) and time variability (right) image of the *ROSAT* field centered on the X-ray source MKW 3. A strongly variable source is clearly visible in the bottom-right part of the right image; its light curve is shown in Figure 2. Figure 3 shows a PSPC exposure of the Orion region where several sources have been detected (left). The corresponding time variability image is shown to the right. At least three sources varied during the observation. The light curves of two of these variable sources are shown in Figure 4. These examples clearly show the power of the method described in evidencing variable sources in crowded X-ray images.

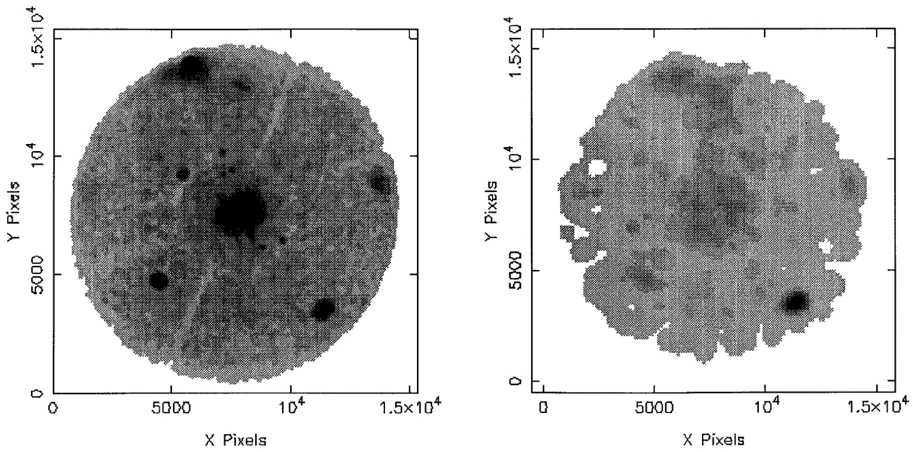

Figure 1. Intensity and time variability image of the *ROSAT* field centered on MKW 3.

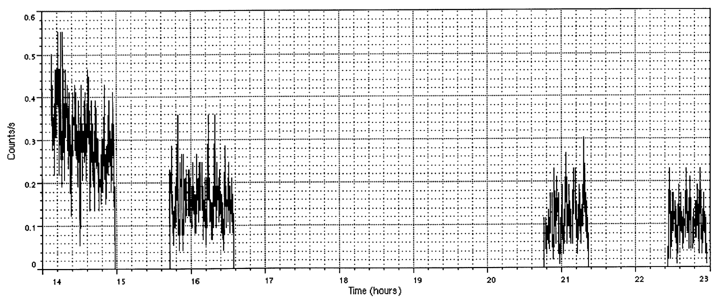

Figure 2. The light curve of the variable source shown in Figure 1.

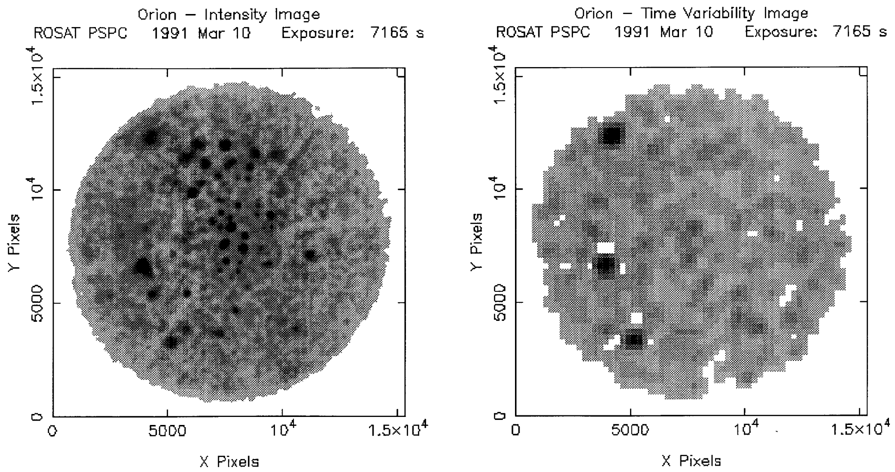

Figure 3. Intensity and time variability image of a *ROSAT* field in the Orion region.

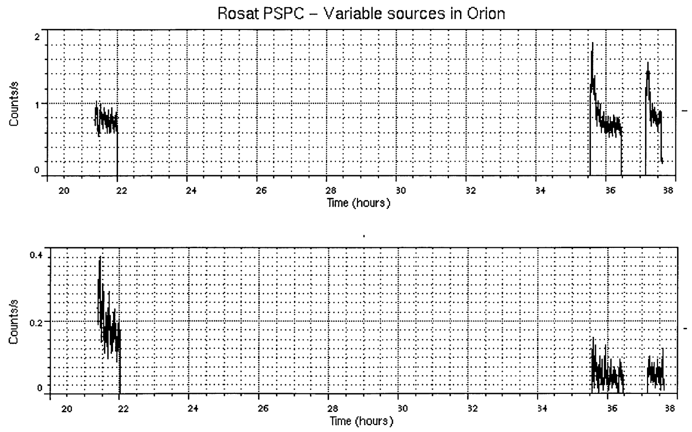

Figure 4. The light curves of the top left (upper panel) and middle left (lower panel) variable sources of Figure 3.

References

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