X-rays from Source 3C 273

Friedman and Byram (*1*) describe a high-altitude x-ray experiment and give the results obtained from a single scan through the Virgo region. In addition to M 87, the authors claim to have detected four other x-ray sources, one of them in the direction of the quasar 3C 273. Unfortunately they do not give standard deviations for their calculated flux values, and it is therefore necessary for the critical reader to make his own estimate of the statistical significance of the results. This can be done in a variety of ways, three of which will be described briefly. In each case we deal only with that part of the record between the beginning of the controlled scan at 150 seconds and the onset of atmospheric absorption at about 280 seconds. (The deflection attributable to M 87 lies outside of this region.)

1) If a horizontal straight line is fitted to the data displayed in Fig. 2 of Friedman and Byram, it is seen that it intercepts about 70 percent of the error brackets associated with the plotted points. As it is only expected that such a line will fall within 68 percent of the error brackets, under the hypothesis that the observed function is constant, it is probable that no sources were observed in the scan region under discussion.

2) An alternative form of the same criterion can be applied by computing the root mean square (r.m.s.) deviation of the data points from their mean, and comparing the value so obtained with that expected for a Poisson distribution. It is found that the mean is 875 counts per 10-second interval. If the distribution were Poisson, the r.m.s. deviation would be $(875)^{1/2}$ or 29.6. In fact, the deviation is 30.2. Application of the chi-square test shows that the difference between these two figures is not significant, even at the 25-percent confidence level, and therefore the Poisson hypothesis is acceptable.

3) This problem of identifying real sources in the presence of noise peaks also occurs in the analysis of radio-astronomy scans. Hazard (*2*) has recommended that source counting, beginning with the strongest sources seen on the record, should stop when the count has reached a density of about one source per 25 beam widths along the scan. Unless the number-flux distribution function for x-ray sources is very different from that for radio sources, this rule would be applicable to the analysis of x-ray scans. In the present case, the ratio of scan length to smoothed beam width is 130/16 or 8.1—only 0.08 of that indicated by the Hazard criterion for the reliable identification of four sources.

The method of smoothing data by computation of a running mean is unsophisticated and has no advantage other than simplicity. Its disadvantage is that it changes the spectrum of the data in an unrealistic way without effectively eliminating those high-frequency fluctuations that could not have arisen in a real source. Smoothing is better done by convolving the data with the x-ray detector instrument function (*3*), or with some other function calculated to optimize a specified feature of the data. Once a smoothing function of choice has been used it would seem difficult to justify further smoothing. This remark would apply to the unspecified further smoothing implicit in the full line in Fig. 2 of Friedman and Byram. The four-peaked waveform they interpret as four x-ray sources is very typical of smoothed counts obeying Poisson statistics. In view of these considerations the matter of x-radiation from source 3C 273 will remain an open question until further observations can be made with equipment of higher resolution or higher sensitivity. Which improvement is most needed depends on whether the present survey was "resolution limited" or "sensitivity limited" (*4*). Because the discrepancy between the observed r.m.s. deviation and that calculated in alternative 2 is very small, it would appear that the fluctuations in the record are caused by counting statistics, and not by unresolved background sources. Therefore the present experiment was probably sensitivity limited.

If this conclusion is correct it underlines the need for satellite studies of x-ray sources, as already indicated by Friedman and Byram. Without the long dwell times (very slow scans) that can be achieved by orbiting devices there is little likelihood of raising the sensitivity of the experiment to the level required and justified by this important new branch of astronomical research.

EDWARD ARGYLE
Dominion Radio Astrophysical Observatory, Penticton, B.C., Canada

References and Notes

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From his analysis of our data (*1*), Argyle concludes that the signals observed in scanning across the position of 3C 273 are within the statistical fluctuations to be expected from a random distribution. We have also received a letter (20 October, 1967) from R. Giacconi, H. Gursky, and L. Van Speybroeck offering essentially the same criticism. The latter group used the Monte Carlo method to generate a random set of data about an average of 87.6 count/sec of all the observational points from 150 to 259 seconds. When they treated the data by the running mean of 10-second averages at 2-second intervals, a pattern of scattered signal peaks was obtained with amplitudes comparable to those shown in Fig. 2 (*1*). In the following reply we present the raw data of the observations, which were not given in the original publication, and we evaluate the statistical significance of the signal associated with the scanning of 3C 273.

Table 1 lists the recorded number of counts accumulated in 1-second intervals by a pair of proportional counters as they slowly scanned some 12° of sky, which included the quasar 3C 273. Experimental details have been described (*1*). The accumulated counts are listed, corresponding to the beginning of each 1-second accumulation period.

Counts accumulated between 144 and 290 seconds were recorded as the instrument scanned a region which, prior to the experiment, was not known to contain any x-ray sources. Shortly after 290 seconds, the previously detected (*2*) source M 87 began to contribute to the counter response. Our discussion will concern (i) to what extent the frequency distribution of 1-second-count accumulations is similar to a Poisson frequency distribution of random events corresponding to the same average number of counts per second; (ii) to what extent the overall scatter of data is consistent with the assumption of constant average background count; and (iii) to what extent the count accumulations registered at the time that the slow scan crossed 3C 273 indicate the presence of a source superimposed on the background flux. In the analysis of the data, the time of most direct view of 3C 273 has been taken from star field photographs and *not* from the x-ray data itself. The time of most direct view is 178.0 seconds, with an uncertainty of the order of 0.2 second associated with possible irregularities in the rocket scan. We shall as-

Table 1. Counts per 1-second interval. This table is read as follows: the figure 94 (marked by the asterisk) indicates the number of counts between 140.0 and 141.0 seconds; the figure to the right, 88, is the number of counts between 141.0 and 142.0 seconds, and so forth.

Time (sec)	Counts at 1-second intervals									
	0	1	2	3	4	5	6	7	8	9
140	94*	88	78	81	85	69	68	91	86	88
150	77	102	73	86	91	88	98	87	100	92
160	94	84	92	79	82	76	87	92	99	87
170	93	83	91	94	92	86	97	97	103	92
180	82	101	91	88	85	80	69	90	89	82
190	95	87	94	89	89	80	83	85	78	80
200	88	103	83	89	78	83	99	110	108	88
210	89	103	75	87	89	97	85	81	84	86
220	88	91	98	80	93	77	71	67	78	97
230	98	75	84	101	88	77	91	89	79	94
240	90	76	95	100	87	87	89	80	76	82
250	85	89	90	75	83	89	70	99	73	85
260	78	78	88	80	88	101	85	83	92	85
270	88	74	78	92	110	80	91	94	86	84
280	89	85	104	106	92	87	89	78	91	101
290	89	84	92	91	71	88	77	100	87	103

Table 2. Tests based on deviations from average counting rates (87.51 for 144 to 290 seconds, 89.27 for 165 to 191 seconds) within subintervals centered on 178.0 seconds.

Sample interval		Probability of chance deviation from background averaged over	
Width (sec)	Average count/sec within interval	(144–290 sec) (%)	(165–191 sec) (%)
12	92.83	2.45	9.5
8	93.75	2.97	9.0
4	97.25	1.87	4.6
2	100.00	2.96	5.4

sume that between 165 and 190 seconds the scan rate was uniform at a rate of 0.078°/sec, and that the counter angular response is an isoceles triangle of 2° base [1° full width at half maximum (FWHM)], or 26 seconds of scan time. We shall compare probabilities for the 26-second data interval and subportions thereof centered on the direct view of 3C 273 under the following assumptions.

1) Counts are caused by a constant average flux equal to that producing counts accumulated in the "146-second period" from 144 seconds to 290 seconds.

2) Counts are caused by a constant average flux equal to that producing counts accumulated in the "26-second period" centered on 3C 273.

The results of these analyses are summarized as follows.

1) The frequency distribution of counts-in-1-second periods over the 144- to 290-second interval is such that a Poisson distribution would have produced a more widely spread distribution of counts (greater χ^2) (*3*) in 32 percent of cases. This probability confirms that the counting system was working properly, and that a nearly uniform background existed.

2) If it is assumed that all counts recorded between 144 and 290 seconds are the result of a constant background x-ray flux leading to an average counting rate of 87.51 counts per second, then the value of χ^2 for the set of 146 independent counts-in-1-second is 127.4. The probability of chance occurrence of a value of $\chi^2 \geq 127.4$ in this set is 85 percent. This test shows that the set of data, when scrambled, fits a random distribution around a constant background.

3) The set of 26 1-second readings possibly affected by 3C 273, namely, the set of counts accumulated in the interval 165 to 191 seconds, shows an average value of 89.27 count/sec, which exceeds the average counting rate for the interval 144 to 290 seconds, 87.51 count/sec, by 0.96 σ_m, where σ_m is the standard deviation for the mean of 26 1-second counts. The chance that the mean value of 26 measurements is displaced by this amount, or greater, is 17 percent, which indicates that the observed 26 1-second counts, when scrambled, could have been due to a fluctuation in the average background. However, consider next subportions of the 26-second interval. Table 2 lists a set of intervals centered on 3C 273, the observed average count in each interval, and the probability that the observed value would be exceeded by chance.

We draw the following conclusions from the above tests. Tests 1 and 2 indicate that the proportional counters were operating in proper fashion, and that the contributions of any point sources scanned in the "146-second period" were small compared to the sum of the diffuse x-ray background plus unrejected cosmic ray counts; test 3 on the subportions of the 26-second interval indicates that it is relatively unlikely that the high count observed in scanning 3C 273 was the result of a random fluctuation in background. In particular, referring to the third column of Table 2, the chance that the peak is spurious is only 2 to 3 percent, when the background is taken to be the average over the entire 144- to 290-second interval. The last column of Table 2 shows that the probabilities rise to 5 to 10 percent if the background is taken to be the average of the 26-second interval. This latter assumption presumes the existence of a localized patch of higher background centered on the direction to 3C 273. In summary, we interpret these tests to mean that the observations justify the conclusion that a weak x-ray source was scanned simultaneously with 3C 273.

Argyle suggests that one should scan the raw data with the window function of the detector-collimator system rather than choose some arbitrary averaging interval for a running mean. A convolution of the count rate data with the detector angular response curve was actually used in the original data reduction and was shown by the solid-line curve drawn through the data points (*1*, Fig. 1). We regret that we failed to explain this procedure in the published figure caption.

We thank Giacconi, Gursky, and Van Speybroeck for their communication and hope that this reply answers their questions with regard to the statistical significance of the observations. We are also indebted to our colleague, D. Sadeh, for helpful discussions of these questions.

H. FRIEDMAN
E. T. BYRAM, T. A. CHUBB
E. O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D.C. 20390

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