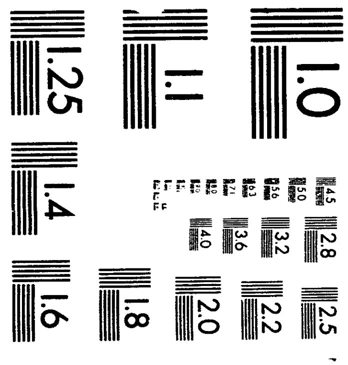
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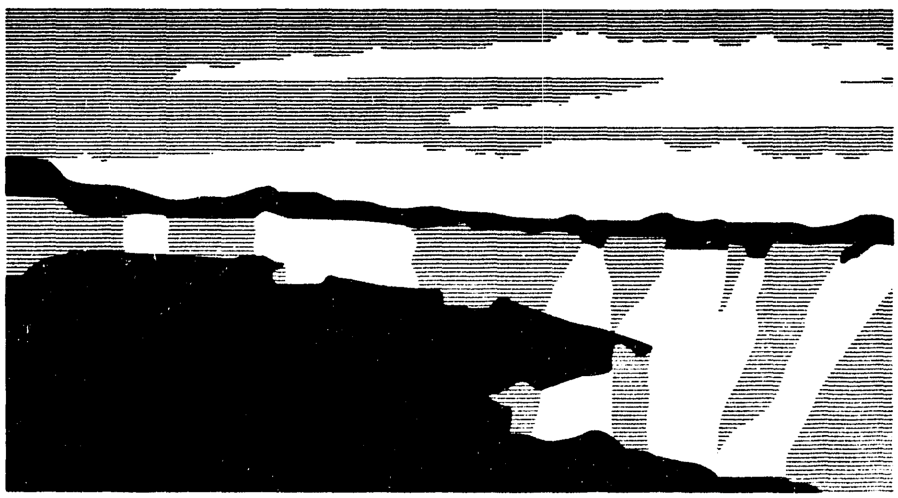

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BATSE BURST LOCATION ACCURACY AND CONSTRAINTS ON THE FRACTION OF REPEATING GRB SOURCES

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ABSTRACT

We use a one parameter model for GRB source repetition to investigate the ability of BATSE to detect source repetition and to place constraints on the fraction of repeating sources. From Monte Carlo simulations we find that the current uncertainty in BATSE burst locations severely limits our ability to confidently detect source repetition from distributions containing fewer than 10 -15% repeaters. A fit of our repetition model to 260 BATSE catalog bursts yields a best-fit repeating fraction of f_r = 21% with a 90% confidence region ranging from 5.5 to 32.5 %. By modifying the size of the measurement errors in our simulations we show that the location and width of the confidence region depends sensitively on the burst location errors. With BATSEs present location accuracy analysis of larger samples of bursts will not appreciably improve the constraint on the repeating fraction.

INTRODUCTION

If correct, the recent suggestion[1] that as many as 15% of the classical gamma ray bursts (GRBs) detected by BATSE arise from repeating sources has important implications for current burst source models. A significant fraction ($\geq$ 10 %) of repeating sources can be more easily accomodated in galactic neutron star models than extragalactic scenarios[1,2]. Thus the ability to constrain the fraction of repeating sources could provide crucial information distinguishing between the most currently favored source models. The excess nearest neighbor clustering would seem to have three possible causes. 1) Burst sources are repeating. 2) Systematic errors or biases in the measured BATSE positions mimic intrinsic clustering. 3) The clustering arises from a random, source distribution purely by chance. Assuming there are no systematic biases in the BATSE positions, the probability of 3) occurring is $\approx$ 2% for the BATSE B1 catalog[3]. Recent work by several authors[4,5] warns that systematic errors may be the cause of the excess clustering. In addition, it has been shown that certain measurement biases can produce the observed excess[6]. However, at present the existence of such a bias remains unproven. Here we investigate the ability of BATSE to both detect and measure burst source repetition.

DETECTING GRB SOURCE REPETITION WITH BATSE

A test for repetition of sources is performed by computing the cumulative distribution of observed nearest neighbor separations and comparing this with the distribution expected theoretically for uniform sources[7,1]. The relevant statistic is D, the maximum vertical difference between the observed and expected cumulative distributions. The significance of a given measurement is the probability of obtaining from the uniform distribution a value for D greater than or equal to the measured value. Since nearest neighbor separations can be significantly correlated it is necessary to obtain this probability from Monte Carlo calculations[4,5].

We have developed a numerical model for source repetition which depends on a single parameter, f_r, the fraction of sources which repeat. Burst positions are assigned sequentially and with random sky positions unless the value of a random number between 0.0 and 1.0 sampled for each burst is less than or equal to f_r. When this occurs the next burst location is randomly selected from one of the existing burst locations, and represents a recurrent event. This procedure is repeated until N bursts have been generated. It is possible in this model to have multiple events from any given source. In table 1 we summarize some of the characteristics of this model for a sample of 260 bursts.

To investigate BATSEs ability to detect burst repetition we simulate the measurement of source distributions which contain repeating events and then compare these with the non-repeating hypothesis using the nearest neighbor method. To compute the measured source distributions we filter the model source positions with instrumental location errors[3,8,9]. Each model source position is randomly assigned one of the BATSE error circles and a measured position is then sampled from each sources error circle. We assume that each error circle corresponds to the 1σ value of a Gaussian distribution in angular separation, ensuring that 68% of the time the measured position will be within the error circle. Having simulated the measurement of a model distribution we compare it with the theoretical nearest neighbor distribution for random (non-repeating) sources. For a given model we generate many different realizations in order to compute the distribution of D which would be seen by BATSE. In figure 1 (left panel) we show the distributions of D so computed from 2000 realizations of 260 burst sources with repeating fractions of $f_r = 0$, (solid histogram), 0.1 (dotted histogram), and 0.2 (dashed histogram). Notice that the distribution with 10% repeaters looks quite random, since the clustered bursts tend to be smeared out upon measurement. Even with a 20% repeating fraction many of the measured distributions are still consistent with the $f_r = 0$ (random) histogram and upon measurement by BATSE would not be strongly identified with source repetition. For comparison the right panel shows the same distributions but now computed under the assumption that BATSE measures positions twice as accurately as specified in the BATSE catalog. Notice now that the 20% histogram has only a small tail which extends into the random ($f_r = 0$) histogram. This graphically demonstrates the increase in sensitivity for detecting burst source repetition produced by an improvement in burst location accuracy.

CONSTRAINTS ON THE REPEATING FRACTION

We now fit our model of burst repetition to the BATSE data. We choose to investigate two samples of bursts. The full 260 burst sample from the BATSE catalog, and the sample of $\approx$ 200 bursts investigated in ref. 1., and for which has been claimed the most significant clustering. We use the same Monte Carlo technique described above to compute the expected cumulative nearest neighbor distribution for a given value of f_r and a fixed number of bursts. The expected cumulative nearest neighbor distributions so computed are then compared to the observed BATSE distribution and the K-S statistic $D(f_r)$ is computed. We

Table I							
Bursts (N_b)	f_r	Sources (N_s)	N_0	N_1	N_2	N_3	N_4
260	0.0	260.0	260.0	0.0	0.0	0.0	0.0
260	0.1	234.1	212.8	17.9	2.7	0.6	0.1
260	0.2	208.2	173.2	25.1	6.3	2.1	0.8
260	0.3	182.3	139.8	26.6	8.4	3.5	1.6

Table I–Summary of the repeating source model for 260 total bursts. The column labelled N_s represents the average number of burst sources generated. The columns labelled N_i give the average number of sources which repeated i times in each model.

repeat this procedure for different f_r in order to minimize the statistic $D(f_r)$. For the 260 burst sample the minimum in D occurs at $f_r \approx 0.21$. Upon examination of the cumulative nearest neighbor distributions we find that the model with 21% repetition provides an improved fit to the observed distribution at small angular separations than the non-repeating model. We emphasize that this does not prove that sources are repeating. Rather, it establishes that burst repetition can reasonably account for the observed distribution.

Figure 1. The distributions of the K-S statistic D obtained by comparison of simulated BATSE measurements of GRB locations with the distribution expected theoretically for random sources. The solid histograms show the random (non-repeating) model. The dotted and dashed histograms show the distributions computed from source models containing 10% and 20% repeating fractions respectively. The left panel assumed the full BATSE location uncertainties, while the right panel assumed a factor of two improvement in location measurement.

To estimate the confidence region for f_r we repeat the same fitting procedure described above but now employing simulated data sets generated from model distributions with $f_r = f_r^{best}$. Since the repeating models are most readily computed at discrete values of f_r we estimate the confidence region by tabulating the fraction of fits which yield a certain value for f_r^{best}. In figure 2 (left panel) we show the fraction of realizations which resulted in best-fit values for f_r ranging from 0.01 to 0.4 in equal steps of 0.01. This estimate of the confidence region

Figure 2. Estimated confidence region for f_r derived from the analysis of the 260 burst sample (left panel). Each vertical bar represents the fraction of realizations which resulted in the corresponding best-fit value for f_r. The right hand panel shows the results of a similar calculation but assuming a factor of 4 improvement in burst location accuracy.

was computed using fits to 2000 realizations. Notice that the distribution peaks near f_r^{best} as expected, but extends from a few percent to beyond 40 %. This indicates that the BATSE measurements and accompanying uncertainties do not provide a tight constraint on the fraction of repeating sources. For comparison we show in the right panel of figure 2 the results of a similar calculation, but assuming a factor of 4 improvement in burst location accuracy. Notice that a smaller repeating fraction now gives the best fit ($\approx 7\%$) and that the confidence region is more sharply peaked around the best-fit value. These results forcefully demonstrate the need to fully understand and if possible reduce the sources of error in burst location determination.

Table II summarizes our calculations for the full 260 burst sample, the 201 burst sample, and the full sample assuming a factor of 4 improvement in source location accuracy. Column 1 gives the value of the K-S statistic D for each sample of BATSE bursts, while column 2 lists the significance α_{KS} computed via Monte Carlo for this value of D. Columns 3 and 4 contain respectively, the best-fit value for f_r and the 90 % confidence limits determined from the calculations described above. Notice that the reduction in positional error yields a smaller best-fit repeating fraction and that the accompanying confidence region is more sharply peaked around f_r^{best}. This calculation emphasizes the importance of accurate burst locations for both detecting burst source repetition and constraining the fraction of repeating burst sources.

We have also investigated how burst sample size affects the constraint on f_r. We find that with BATSEs present burst location accuracy, only marginal improvement in the ability to constrain the repeating fraction is attained by analysing larger burst samples. This results from the fact that BATSEs typical error circle becomes larger than the average separation between nearest neighbors. It appears unlikely that nearest neighbor population studies with BATSE data will ever be able to place a tight constraint on the repeating fraction.

SUMMARY AND DISCUSSION

Although our results indicate that burst source repetition at about the 20% level can account for the observed excess clustering of bursts with small

Table II				
Sample	$D_{\rm KS}$	$\alpha_{\rm KS}$	$f_{\rm r}^{\rm best}$	$\sigma_f^{90\%}$
All bursts (260)	0.117	0.018	21%	5.5% - 32.5%
QL bursts (201)	0.159	0.0013	26%	10.5% - 34.5%
All bursts ($\sigma/4$)	0.117	0.018	7.0%	1.5% - 12.0%

Table II–Summary of the fits to our repeating source model for the full 260 burst BATSE sample, the 201 burst sample[1], and the full burst sample assuming a factor of 4 improvement in burst location accuracy ($\sigma/4$).

angular separations, they also show that the substantial burst location uncertainties severely limit our ability to place useful constraints on the fraction of burst sources which repeat. This in turn reduces the confidence with which we can exclude a given source model which might only be compatible with some moderate level of burst repetition. In addition we have shown that the derived constraint on the fraction of repeating bursts depends quite sensitively on the BATSE position measurement uncertainties. It is therefore essential that these errors be calibrated.

Since all previous observations of classical bursts gave essentially no hint that classical GRBs repeat, it is perhaps troubling that the BATSE measurements yield such large best-fit repeating fractions, in fact as high as 26% for the sample of bursts investigated by QL. Could such a significant fraction of repeating events have escaped detection by previous experiments? It has been suggested that the weak BATSE events are repetitions of stronger events[1] and that previous instruments would not have detected this association. This is possible, however, the large positional uncertainties make association of specific events, especially faint and bright events, extremely tenuous. We have not attempted to investigate this possibility in further detail, but the fact that the BATSE measurements appear consistent with fairly large repeating fractions, while all other previous experiments support the opposite conclusion would seem to warrant caution in interpretation of the BATSE measurements.

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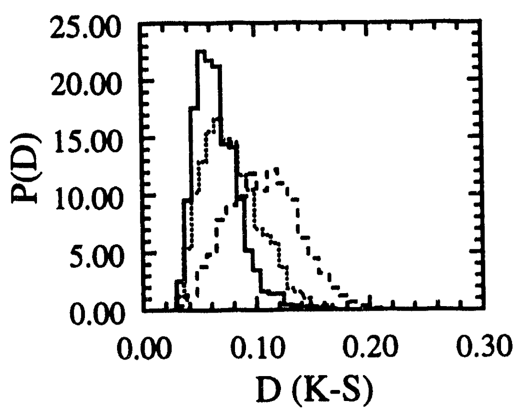

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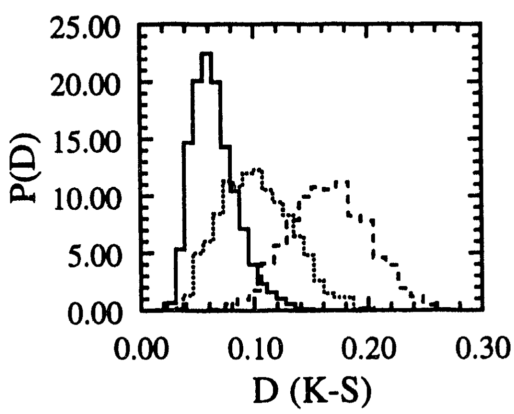
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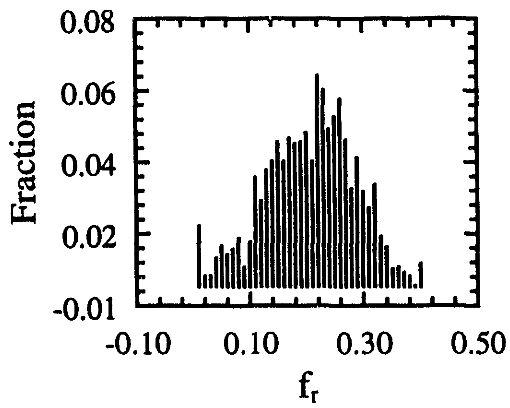
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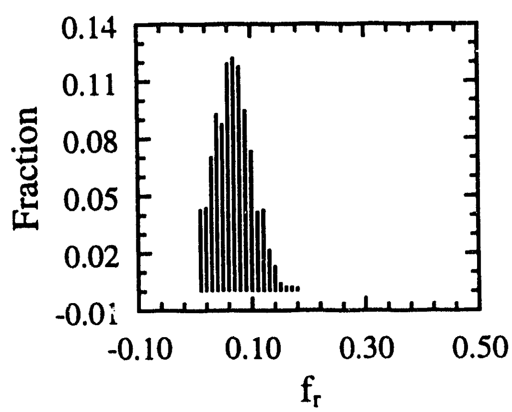
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