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ARE ABELL CLUSTERS CORRELATED WITH GAMMA-RAY BURSTS?

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ABSTRACT

A recent study has presented marginal statistical evidence that gamma-ray burst (GRB) sources are correlated with Abell clusters, based on analyses of bursts in the BATSE 3B catalog. Using precise localization information from the Third Interplanetary Network, we have reanalyzed this possible correlation. We find that most of the Abell clusters that are in the relatively large 3B error circles are not in the much smaller IPN/BATSE error regions. We believe that this argues strongly against an Abell cluster-GRB correlation.
Subject heading: galaxies: clusters: general — gamma rays: bursts

1. INTRODUCTION

A correlation between the positions of gamma-ray bursts (GRBs) determined by the Burst and Transient Source Experiment (BATSE) aboard the *Compton Gamma Ray Observatory* (*CGRO*) and those of rich, nearby Abell clusters was recently claimed by Kolatt & Piran (1996) (hereafter KP). They analyzed the BATSE 3B catalog (Meegan et al. 1996) in conjunction with data on Abell clusters (Abell, Corwin, & Olowin 1989) and concluded that these GRBs were correlated with them at the 95% confidence level. In their study, they selected the 3B bursts with error circle radii $\lesssim 2\overset{\circ}{.}77$, and bursts and clusters with $|b| > 30°$. They then calculated the number of burst-cluster pairs, $N(\theta)$, with a separation smaller than a given angle θ, for $\theta = 1°$–$6°$. Comparing this number to the numbers found for randomly generated catalogs, they found a number for $\theta = 4°$ that was significant at the 95% confidence level.

If such findings could be confirmed, they would constitute statistical evidence for counterparts to GRB sources, and would indicate that at least some GRBs are at cosmological distances. We have attempted to confirm these results by subjecting them to more stringent tests. The positions of those Abell clusters that appear to be related to GRBs, based on their locations within BATSE error circles, must be consistent with *all* known localization information for the bursts in question. In particular, they must also lie within the annuli or the error boxes of the Third Interplanetary Network (IPN3) for those bursts. Below we present the IPN3 data, the results of our test, and our conclusions.

2. IPN3 DATA

For the period covered by the 3B catalog, IPN3 consisted of the *Ulysses* spacecraft, at distances up to 6 AU (Hurley et al. 1992), BATSE, and, until mid-1992, the *Pioneer Venus Orbiter* (*PVO*). When only *Ulysses* and BATSE observed a burst, the resulting localization was an annulus generally crossing the BATSE error circle. When *PVO* observed the burst also, an error box resulted with dimensions in the several arcminute range in the best cases. Examples may be found in Hurley et al. (1993) and Cline et al. (1992). The annuli widths varied from about 10″ to 1000″, with average width $5\overset{'}{.}7$. Descriptions of the data set have appeared in Hurley et al. (1994, 1996). Of the 136 "accurately" localized BATSE bursts selected by KP on the basis of their error circle size and Galactic latitude, 93 have IPN3 annuli associated with them, and 10 have IPN3 error boxes. The total area covered by the 10 error boxes, plus the 93 intersections of the IPN3 and BATSE locations, is less than the area covered by the corresponding BATSE error circles alone by at least an order of magnitude. This substantially reduces the probability of chance correlations between Abell clusters and GRB positions, and results in a stronger test.

3. RESULTS OF THE TEST

The all-sky catalog of Abell clusters (Abell, Corwin, & Olowin 1989) contains 4073 rich clusters, each having at least 30 bright members, and covers redshifts less than $z = 0.2$. Following KP, a latitude cut of $|b| \geq 30°$ was applied to both cluster and burst catalogs. We began by verifying the numbers of bursts and Abell clusters in the KP study, 136 (after latitude and error circle size cuts are applied) and 3616 (after the

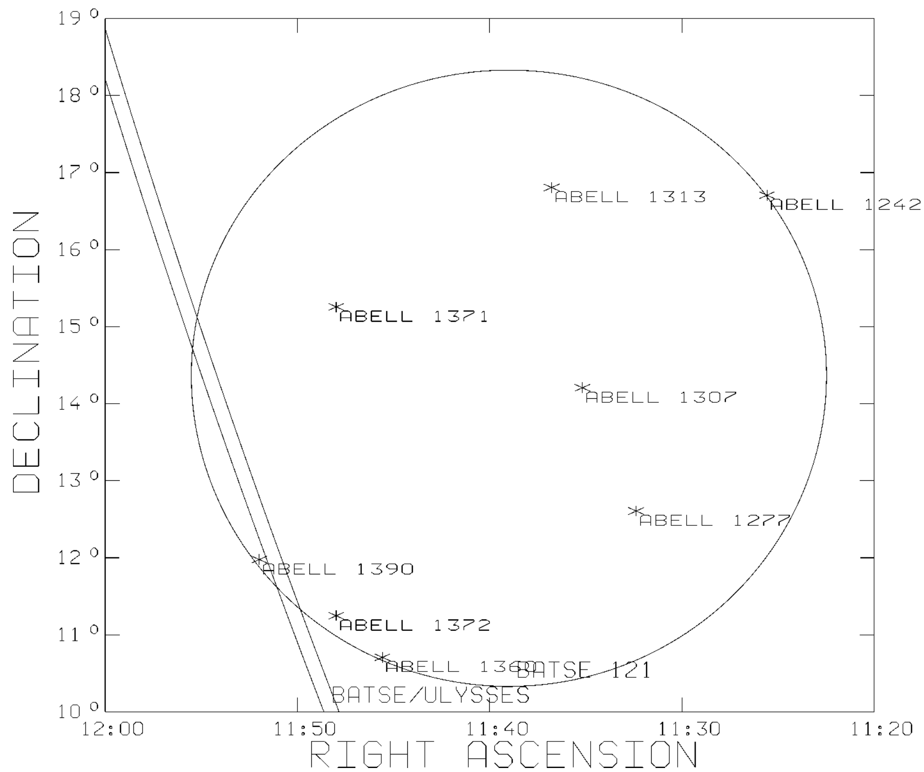

FIG. 1.—Field around BATSE burst 121. The BATSE 4° radius error circle and the *Ulysses*/BATSE triangulation annulus are shown. Some of the positions of the Abell clusters have been omitted for clarity, but none lies within the triangulation annulus.

latitude cut), respectively. For each cluster, we then checked each of the BATSE error circles to see whether their positions were consistent. If they were, we finally checked for consistency with any IPN3 location information. Since, in the KP study, Abell clusters within 4° of a BATSE position were considered to be correlated with the burst, we assigned an error radius of 4° to the BATSE bursts, and also used this to define the BATSE/IPN3 error box. An example is shown in Figure 1.

We found that 1260 Abell clusters lie in the BATSE 4° radius error circles. These circles cover about 16.6% of the sky, and, given the density of Abell clusters in the sample, about 1200 would be expected to fall in the error circles by chance. This is consistent with the KP result in that it represents about a 2 σ excess of Abell clusters in these error circles, assuming a negligible cluster-cluster correlation. The BATSE/IPN error boxes cover 3.3×10^5 arcmin^2, or 1.9% of the total area of the BATSE error circles that they intersect. We found that 14 Abell clusters lie within the BATSE/IPN3 error boxes, while 16 are expected by chance. This indicates that the overwhelming majority of the Abell clusters that are in BATSE error circles are there by chance.

We reanalyzed the data using the standard 1 σ BATSE error circle radii, defined as $(\sigma_{sys}^2 + \sigma_{stat}^2)^{1/2}$, where σ_{sys} is the systematic error, 1°6, and σ_{stat} is the statistical error, given in the BATSE 3B catalog for each burst. This results in smaller error circles, covering 3.5% of the sky. The BATSE/IPN3 error boxes cover 4.5% of the total area of the BATSE error circles that they intersect, or 1.2×10^5 arcmin^2, and 5.7 Abell clusters should fall in them by chance. Four were found to actually lie in them.

4. DISCUSSION

If GRBs indeed originate at cosmological distances, their observed brightness distribution suggests that BATSE samples bursts to a redshift of order unity (e.g., Wickramasinghe et al. 1993). To yield the all-sky rate of $\sim 10^3$ yr^{-1} an average galaxy must produce one observable burst every 10^6 yr, corresponding to a mean comoving galaxy density of $n_0 = 10^{-2}$Mpc^{-3}. In the local part of the universe approximate distances are given by $D = zL_H$, where the Hubble distance is defined as $L_H = c/H_0 \sim 3000\, h^{-1}$ Mpc, where h is the Hubble constant in units of 100 km s^{-1} Mpc^{-1}. The depth of the Abell cluster sample is thus about 600 h^{-1} Mpc.

Only ~2% of all observable GRBs are thus expected to occur within the volume of space sampled by the Abell catalog. Even if we assume that all galaxies are correlated with clusters, to obtain a significant correlation of bursts with clusters would thus require that either the BATSE sampling redshift is much less than unity, and/or that all well-localized bursts are approximately confined to the sampling volume of the cluster catalog. KP obtain a sample of 549 bursts after applying their first cut (in latitude). We expect ~2% of these (11) to be correlated with clusters. As shown above, coincidences are expected in 5.7 cases, and the observed number of coincidences is four.

The KP results indicate a sampling distance (for all bursts) of $z_{max} = 0.7$ and a sampling distance of $z_a = 0.31$ for the 136 "accurately" localized bursts, which implies that 35 (± 20) bursts are within the Abell range. Thus, in addition to the number of chance coincidences between Abell clusters and the IPN3 positions (5.7), one expects 15–55 more, which is clearly in contradiction with our findings.

We believe that the Abell cluster-GRB correlation found by KP is best explained by statistics. There is a 5% chance of finding a correlation with any set of cataloged objects in their study, and certainly many catalogs have been searched for GRB counterparts. Indeed, as soon as precise GRB positions began to become available from the first IPN, they were subjected to extensive catalog searches, including Abell clusters, (e.g. Hurley 1982, Barat et al. 1984) and it seems unlikely that an Abell cluster correlation would have been missed.

If a correlation were to exist between Abell clusters and GRBs, the poor angular resolution of BATSE, the small sample size for the IPN3 positions, and the small number of low redshift events reduce our chances of detecting it. However, Abell clusters are somewhat concentrated toward the supergalactic plane to distances perhaps as large as $\sim 300\ h^{-1}$ Mpc (e.g., Tully 1987 ; but see Postman *et al.* 1989), and one might thus expect to find a significant global anisotropy of bright bursts tracing the galaxies within $z \sim 0.1$. This effect could be noticeable even if only poor localizations were available. So far, the search for a supergalactic anisotropy has not been successful (Hartmann et al. 1996).

While attempts to find GRB counterparts through correlation analysis with galaxies or clusters of galaxies may provide some evidence for a cosmological burst origin, we caution that the present data are insufficient to prove that connection. Five more years of BATSE/IPN3 data may be sufficient for this task. Another solution would be to improve burst localization accuracy to the arcsecond regime, so that one would not have to rely on statistics, but simply on the inspection of such error boxes. This may become possible with ongoing searches for optical transients, through future imaging burst detectors, or an improved triangulation network. All of these possibilities are being pursued actively at the present time.

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