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Search for Soft Gamma-Ray Events in the BATSE Data Base

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1 Location Errors

We use a sample of 9 triggered events from Cygnus X-1 dated between July 1991 and January 1992. They are associated with the source Cygnus X-1 based on their spectra, light curves, and source position within $\sim 12°$ of the location of Cygnus X-1. Since these are triggered events, they have significant ($> 5.5\ \sigma$) count rates in two or more detectors in any of the 64 ms, 256 ms, or 1024 ms time intervals. For the purposes of this analysis, we use DISCLA data (1024 ms time resolution) and restrict the burst location algorithm to use counts from the lowest energy channel (channel 1) only. This step approximates the conditions of the untriggered events, which are often seen only in channel 1 DISCLA data. As a result of these restrictions, the signal-to-noise ratio in the detectors is diminished. Based on the (now reduced) relative count rates in the detectors and their uncertainties, the burst location algorithm returns a source location and the associated statistical error radius. This location is then compared with the known location of Cygnus X-1. Using the computed statistical error radius we also calculate the 92% confidence radius as discussed in Appendix A of the burst catalog [2].

Figure 1a shows the computed locations for the Cygnus X-1 events as 92% confidence-radius circles centered on the computed location. The actual location of Cygnus X-1 is shown as a solid dot. We find that the average location error for these events is $\sim 12°$ and the average statistical error radius is $\sim 13°$. The location errors seen in these events are much larger than would be seen if high time resolution data had been used in all channels. Some of these events were very significant in the high time resolution (64 ms) data, but have been diluted by the background when averaged into 1024 ms time bins. In addition, some counts are artificially truncated by using only low-energy channel 1 data. These effects reduce the significance (for the purposes of the location algorithm) of these events. Most of the circles contain Cygnus X-1, and they demonstrate that large location errors and large error radii occur when low signal-to-noise ratios are involved. Figure 1b shows a histogram of the signal-to-noise ratios for the events located in figure 1a.

Figure 1c shows the effect of signal-to-noise ratio on the magnitude of the location errors. There is an analogous plot in Figure 2 of the first burst catalog [2]. The dashed line represents the estimate (discussed in the burst catalog) of statistical location error as a function of signal-to-noise ratio. Our data follow closely this estimate. Figure 1c confirms that the channel 1 actual location errors follow the same trend as the errors studied in the burst catalog for the full range of energies and for other sources. Evidently the location errors of the Cygnus X-1 events are predominantly statistical in nature. In fact, if we vary the spectral index (for example) as a parameter in the burst location, we find that the location moves by only a few degrees. The statistical errors ($\sim 10-20°$) dominate the systematic errors due to the spectral dependence. Note however, that in the case of solar flares, which last for several seconds and do not suffer dilution by background when seen in long (1024 ms) time bins, that the statistical errors are small and become comparable to the systematic errors related to the spectral slope. In any case, for short events seen in longer time bins, statistical errors dominate.

2 Untriggered event locations

The 1992 paper [1] discusses a set of untriggered events recorded between TJD 8787-8821 and TJD 8722-8715 that are not easily attributable to obvious causes, such as solar flares, magnetospheric disturbances, etc. [1] Figure 2a shows 41 of these untriggered events as 92% confidence-radius circles centered on the locations found by the burst location software. The location of Cygnus X-1 is marked with a square, and the triangle shows the location of SGR 1900+14. There is an excess of events in the general direction of these two sources. It is important to note that these are seen within a few months of the triggered events from SGR 1900+14 [1, 3]. Many of the error circles enclose Cygnus X-1, the SGR, or both; therefore, it is impossible to rule out either one as a possible source of a given event in this data. Perhaps more interesting are the events clearly located elsewhere in the sky. Their origin is unknown.

The location errors (as opposed to the computed statistical error radii) for the untriggered events can only be estimated based on the Cygnus X-1 locations. The proximity in the sky of Cygnus X-1 and SGR 1900+14 means that events from these two sources are often seen (and sometimes brightest) in the same detector, number 7, so it is reasonable to compare the Cygnus events with the untriggered events. Figure 2b shows a histogram of the signal-to-noise ratios for the untriggered events of figure 2a. They appear slightly lower than the ratios in figure 1b, which is to be expected since the untriggered events are by definition fainter and will suffer a lower signal-to-noise ratio. The corresponding statistical error radii are plotted in figure 2c, which is analogous to figure 3 in the first burst catalog [2]. Cygnus events are represented by squares and the untriggered events by triangles. Again the dotted line is the estimate that the statistical error varies inversely with the signal-to-noise ratio. The computed statistical error radii follow closely the estimate. This plot, together with figure 1c, shows that the estimated statistical error radii are consistent with known location errors. Therefore, large location errors and large 92% confidence radii (both of them $\sim 20 - 30°$) *of primarily statistical origin* are to be expected from the untriggered data. Any systematic errors appear to be drowned out by statistical errors, particularly for the brief events (restricted to channel 1 DISCLA data) characteristic of Cygnus X-1 and the selected untriggered events.

3 Conclusion

We find large location errors and error radii in the locations of channel 1 Cygnus X-1 events. These errors and their associated uncertainties are a result of low signal-to-noise ratios (a few σ) in the two brightest detectors for each event. The untriggered events suffer from similarly low signal-to-noise ratios, and their location errors are expected to be at least as large as those found for Cygnus X-1 with a given signal-to-noise ratio. The statistical error radii are consistent with those found for Cygnus X-1 and with the published estimates. We therefore expect $\sim 20 - 30°$ location errors for the untriggered events. Hence, many of the untriggered events occurring within a few months of the triggered activity from SGR 1900+14 are indeed consistent with the SGR source location, although Cygnus X-1 is also a good candidate.

References

[1] van Paradijs, J. *et al.* in *Proc. Compton Symp., St. Louis* (ed. Gehrels, H.) (in press).

[2] Fishman, G.J. *et al.* 1993, The First BATSE Gamma-Ray Burst Catalog, p. 6-7, Appendix A.

[3] Kouveliotou, C. *et al.* *Nature* **355**, 728-730 (1993).

Figure 1a
Cygnus X-1 Locations with 92% Confidence Circles

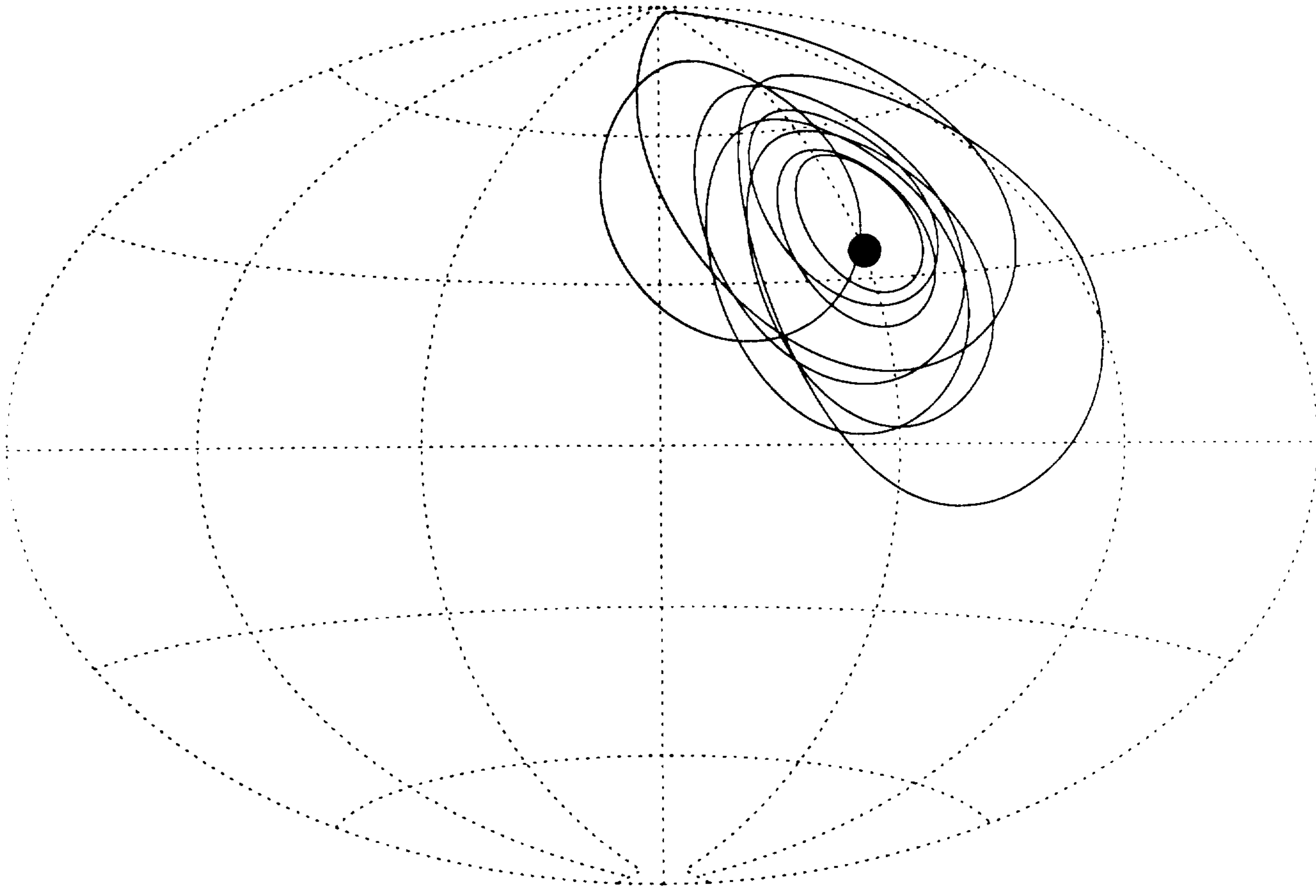
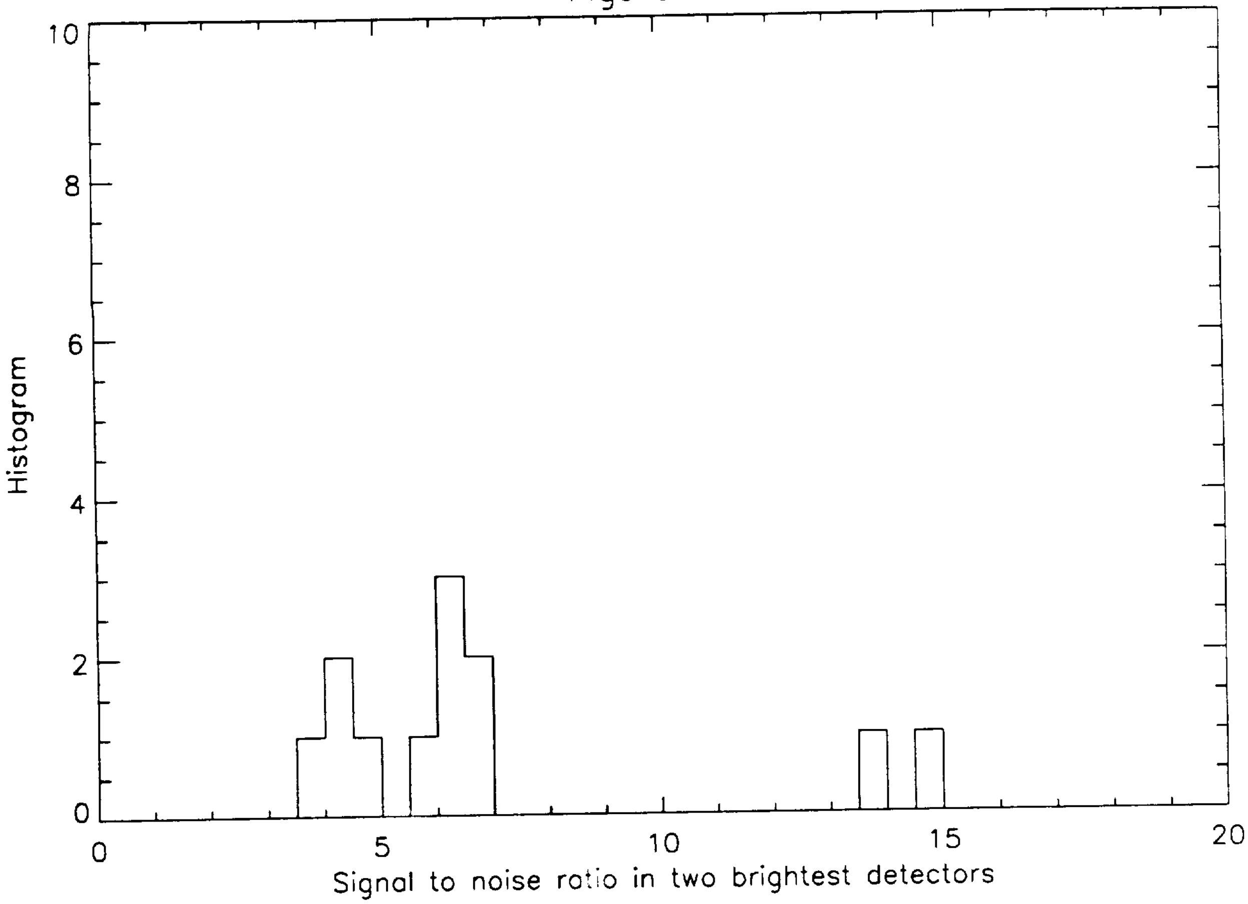


Figure 1b



10
8
6
4
2
0
Histogram
0
5
10
15
20
Signal to noise ratio in two brightest detectors

Figure 1c
Actual Location Error vs. Signal to Noise Ratio

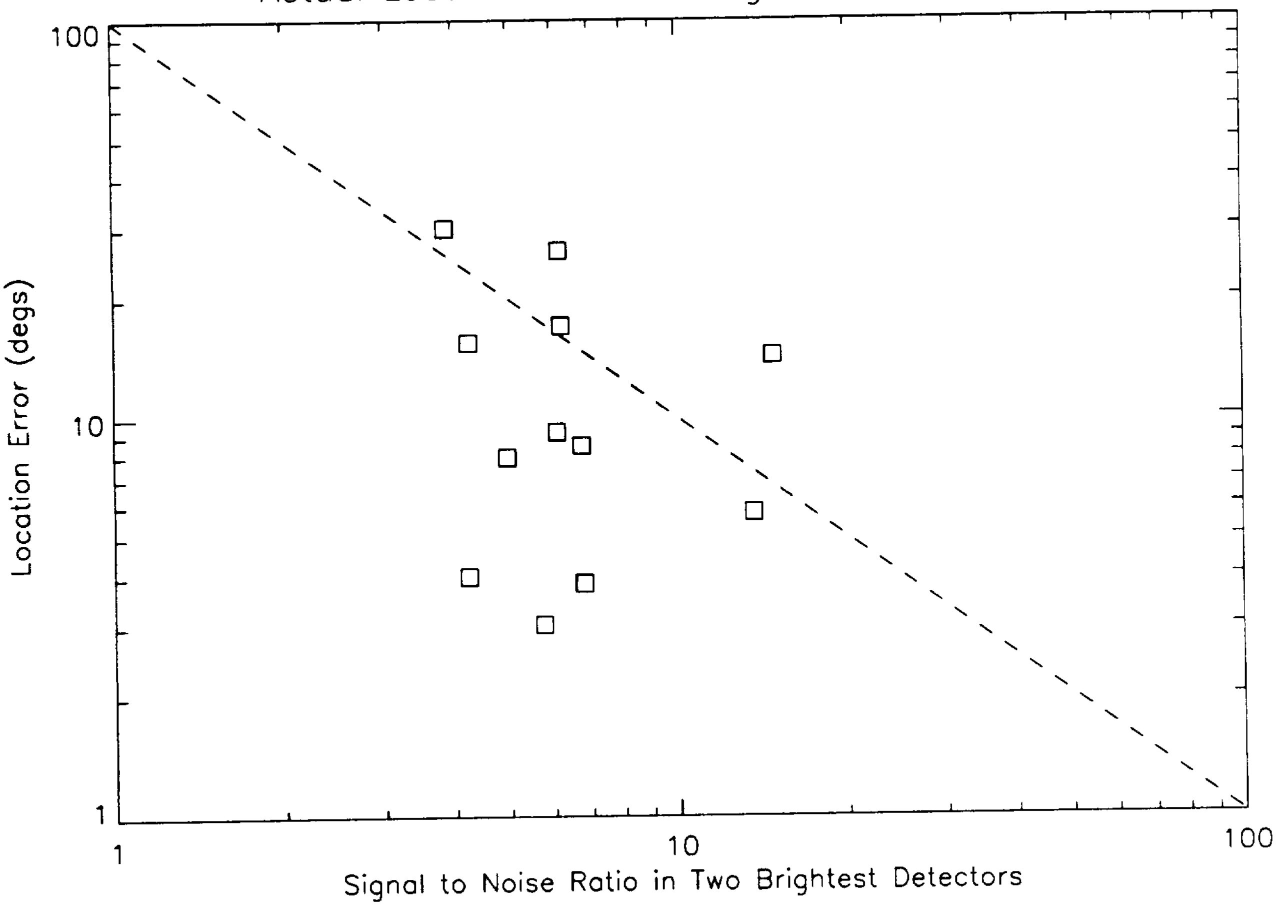


Figure 2a
Untriggered Locations with 92% Confidence Circles

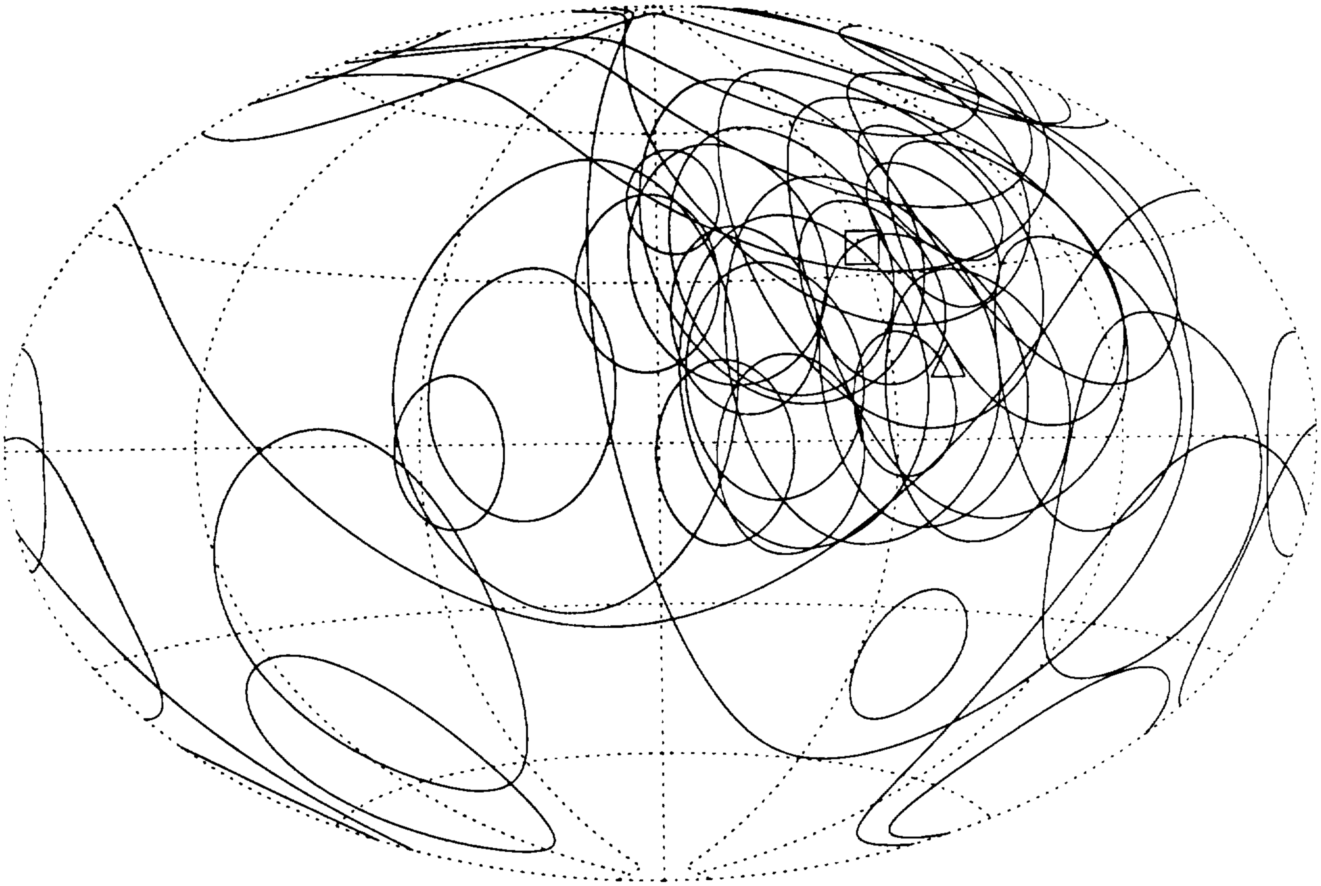


Figure 2b

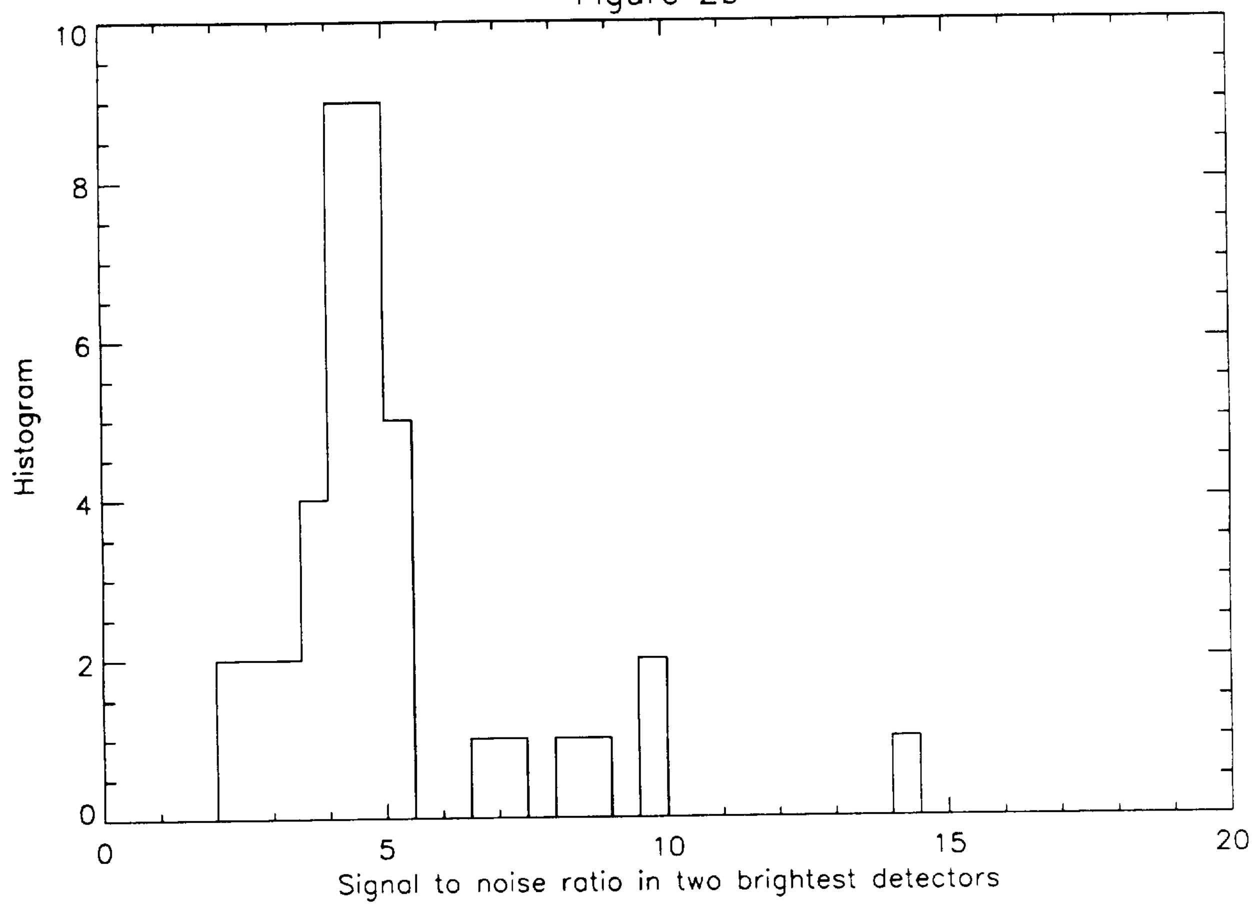
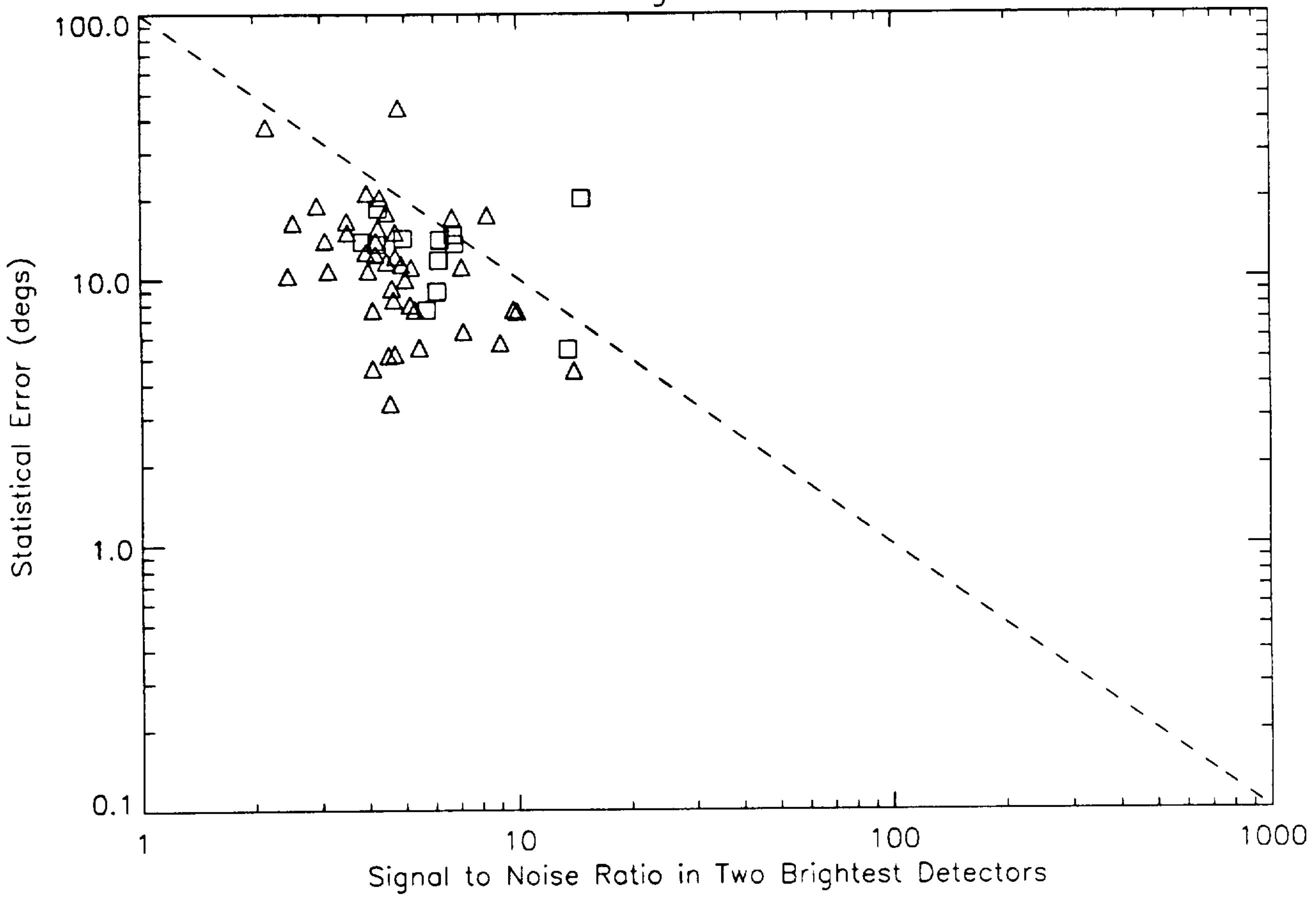

10
8
6
4
2
0
Histogram
0
5
10
15
20
Signal to noise ratio in two brightest detectors

Figure 2c



100.0
10.0
1.0
0.1
Statistical Error (degs)
1
10
100
1000
Signal to Noise Ratio in Two Brightest Detectors