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TITLE: **The Showerfront Time-Structure of "Anomalous Muon" Events Associated with Hercules X-1**

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THE SHOWERFRONT TIME-STRUCTURE OF "ANOMALOUS MUON" EVENTS ASSOCIATED WITH HERCULES X-1

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ABSTRACT

The 11 "in-phase" source events from the 1986 muon-rich bursts associated with Hercules X-1 (previously reported by this group) have been studied for indications of further anomalous behavior. The most significant effect observed resulted from an analysis of the showerfront time-structures of these events. This analysis was then applied *a priori* to the rest of the source day, where an additional ~9 signal events are expected to remain. The same effect was observed at a chance probability level of ~0.1% .

ANALYSIS OF THE 11 "IN-PHASE" BURST EVENTS

Figure 1 shows the published phaseogram for the 17 events that occured during 2 episodes of particularly large rate increases (bursts "A" and "B") for the day UT 24 July, 1986 [1]. The 11 events designated "in-phase" are believed to constitue a "purified" sample containing, at most, 1 background event. These were found to have a muon number anomalously large compared to that expected from gamma rays. Several other parameters have now been examined for anomalous behavior. The most significant effect yet observed involves a parameter related to the showerfront time-structure.

This parameter is computed by first determining the particle arrival times relative to a plane fit to the shower direction. Next, for the half of the triggered counters furthest from the shower core, the width of the distribution of particle arrival times is calculated. This is also done for the counters closest to the core. The ratio of inner-counter to outer-counter timing widths is then taken to be the test parameter. This parameter is sensitive to a combination of showerfront curvature and radial-dependent arrival-time fluctuations. The 11 events were found to display systematically smaller values of this parameter than similar background events at a chance probability level of $\sim3\%$. The Kologorov-Smirnov "D+" statistic was used to extract this value, as shown in Figure 2.

However, due to the nature of such an *a posteriori* analysis, the trials involved in choosing this parameter are not well defined. Therefore, the previous analysis will only be used to establish a new *a priori* hypothesis to be tested on an independent data set.

The remainder of the source day (i.e. excluding the 11 events previously studied) still contains 33 events in the angular bin size chosen for period analysis where 24 are expected. These remaining events (containing an excess of ~9) will then serve as an independent test of the parameter.

ANALYSIS OF THE REMAINING 33 EVENTS

Ensembles of similar background showers for each of the remaining 33 events were chosen from the same day according to zenith angle, shower size (from an NKG fit to the lateral distribution), and radius of the core relative to the geometric center of the array. The fraction of events in each ensemble that had a time-structure parameter smaller than the corresponding "source" event was then calculated. Figure 3 shows the resulting Kolmogorov-Smirnov distribution. The maximum deviation corresponds to a chance probability of 0.2% that this sample of time-structure parameters was drawn from a parent distribution of pure background.

If this effect is real, then one would expect that it should manifest itself entirely in a group of events possessing phase-coherence at phases consistent with those of the previously published burst events. A period scan using the Protheroe statistic yielded a period of 1.23573 seconds as the best for the day, well within 1 independent spacing of the previously published period (1.23568) that was found to be optimum for the bursts alone. Figures 4 and 5 show phaseograms at this period for the 11 previously studied events and for the remaining 33 respectively. Once again note that, due to the experimental uncertainty in determining the period, Figures 1 and 4 are *not* inconsistent. Neither should be taken to reflect the "true" light curve.

An arbitrary choice of "in-phase" events was made according to the designation given in Figure 5. The Kolmogorov-Smirnov plot for these 19 events is shown in Figure 6. Once again, recall that these events *do not* include the 11 events originally tested. The maximum deviation corresponds to a chance probability of $\sim$0.1% . Figure 7 shows this same plot for the remaining 14 "out-of-phase" events, which yields a chance probability of $\sim$20% .

As a further check of the statistical reliability of these conclusions, a similar analysis was carried out on 100 "off-source" regions. The results verify that the approach taken here is statistically well behaved.

CONCLUSION

Further analysis of the 1986 detection of Hercules X-1 indicates the possible presence of an additional feature distinguishing source events from background. This feature manifests itself in a ratio of "inner-counter" to "outer-counter" timing widths that is smaller than that of typical background showers. Studies are currently under way to verify this apparent difference in the showerfront time-structure and to attempt to link the effect to the physical consequences of an interaction model. We are also considering the potential application of a similar procedure to various subsets of our database in an effort to enhance any "weak" signals that may be present. If such signals were to be found, this would allow us to confirm the results presented here.

REFERENCES

[1] B. L. Dingus *et al.*, Phys. Rev. Lett. **61**, 1906 (1988).

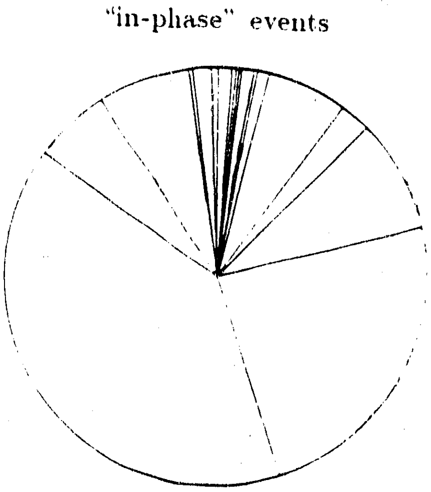


Figure 1

Phaseogram for the 17 published "burst" events at the period 1.234568 seconds.

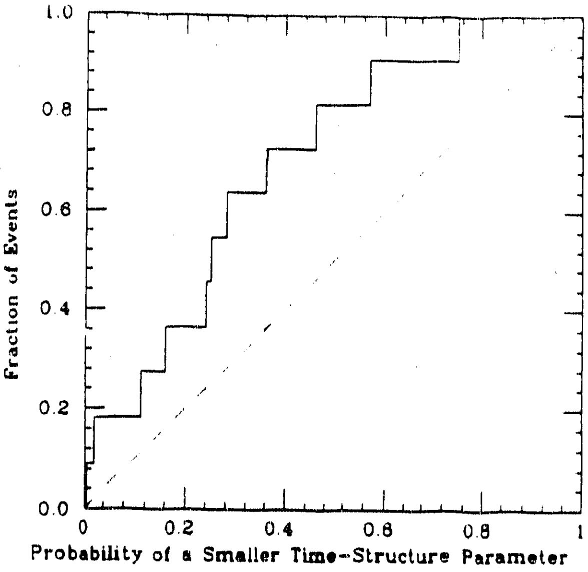


Figure 2

Integral probability plot of the time-structure parameter for the 11 published "in-phase" burst events. The maximum deviation corresponds to a chance probability of ~3% .

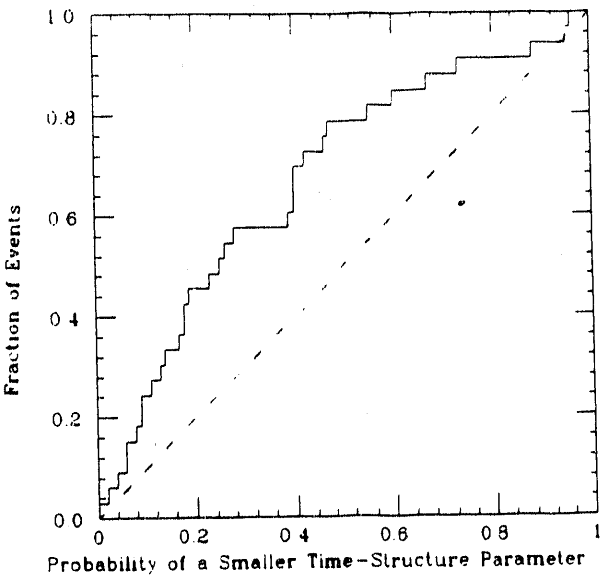


Figure 3

Integral probability plot of the time-structure parameter for the 33 remaining events in the source day (independent of the previous plot). The maximum deviation corresponds to a chance probability of ~0.2% .

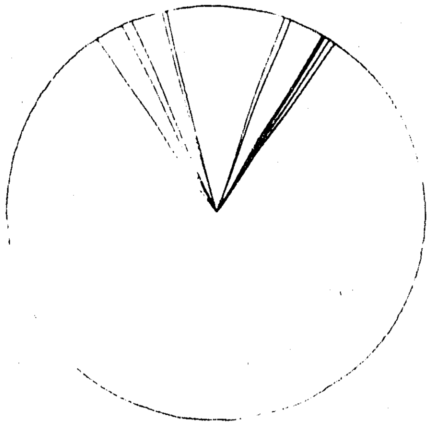


Figure 4

Phaseogram of the 11 previously published "in-phase" burst events at the period 1.23573 seconds (best for the entire day).

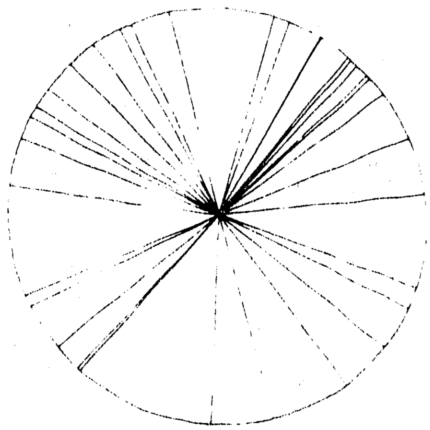
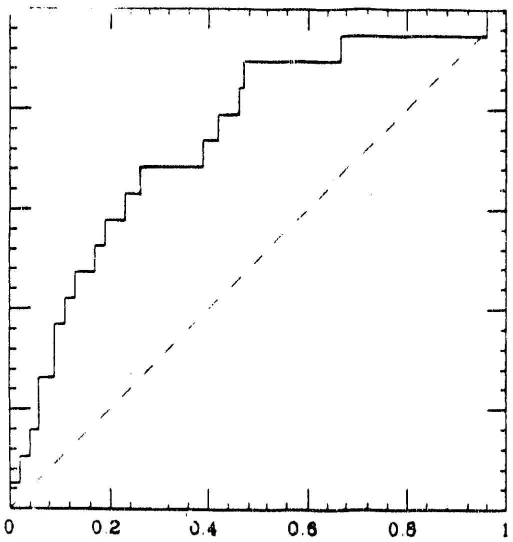


Figure 5

Phaseogram of the remaining 33 events at the period 1.23573 sec.



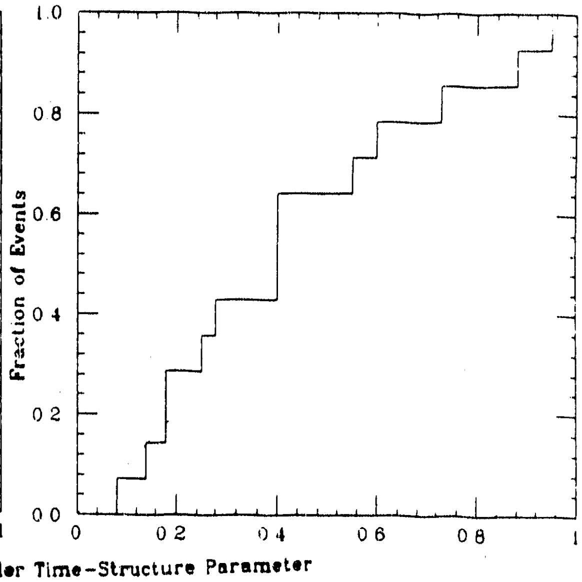


Figure 6

19 "in-phase" events

(independent of the previously published 11).

chance probability of ~0.1%

Figure 7

14 "out-of-phase" events.

chance probability of ~20%

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