Searching for PeV bursts

Roger Clay, University of Adelaide and Flinders University of South Australia
and members of the CREDO collaboration

There have been a number of searches for non-random effects in the detection rate of cosmic ray showers.

Some searches found interesting ‘bursts’. Others did not, and possibly found deficiencies in previous work. (see the next few slides)

In general, search strategies were not decided *a priori* and then there was no real hope of tracking trials to determine the statistical likelihood of a result.

We have tried to search with a strategy of looking for bursts, first with five events within 10 s, and then (in another data set) with five events in 20 s. The difference being the deadtime associated with data collection.

The number of events in ’burst’ selection, and its duration, were arbitrary but were selected *a priori*.

We found one exceptional event associated with a ‘burst’ and this is discussed.

VOLUME 50, NUMBER 26 PHYSICAL REVIEW LETTERS 27 JUNE 1983

Possible Observation of a Burst of Cosmic-Ray Events in the Form of Extensive Air Showers

Gary R. Smith, M. Ogmen, E. Buller, and S. Standil
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(Received 7 April 1983)

A series or burst of 32 extensive air showers of estimated mean energy 3×10^{15} eV was observed within a 5-min time interval beginning at 9:55 A.M. (CST) on 20 January 1981 in Winnipeg, Canada. This observation was the only one of its kind during an experiment which recorded 150 000 such showers in a period of 18 months between October 1980 and April 1982.

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Observation of a Burst of Cosmic Rays at Energies above 7×10^{13} eV

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and

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Physics Department, University College Cork, Cork, Ireland
(Received 14 September 1983)

The authors report on an unusual simultaneous increase in the cosmic-ray shower rate at two recording stations separated by 250 km. The event lasted for 20 s. This event was the only one of its kind detected in three years of observation. The duration and structure of this event is different from a recently reported single-station cosmic-ray burst. The simultaneity of the coincident event suggests that it was caused by a burst of cosmic gamma rays. There is a possibility that this event may be related to the largest observed glitch of the pulsar in the Crab Nebula.

Observation of Time Correlations in Cosmic Rays

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Abstract

A set of four detectors enclosing an area of 5000 square kilometres has been used to search for cosmic rays travelling in a wave front as if originating in a shower or in a single short burst. No such events were found; however time correlations between cosmic rays were observed with a typical spread estimated to about 0.3 ms.

Data collection

An initial data collection was done from Nov. 1988 to May 1989 with a preliminary version of the detectors. These were modified to the version just described, and a second run was done from Dec. 11th 1991 to July 27th 1992 or 234 days. The four detectors were simultaneously in operation for 149 days or about 60 % of the time, and a total of about $7.5 \cdot 10^9$ events were recorded.

Fractal behavior of cosmic ray time series: Chaos or stochasticity?

M. Aglietta
B. Alessandro,
F. Arneodo,
L. Bergamasco,
A. Campos Fauth
Sep 1, 1993

This paper presents results on the fractal and statistical behavior of cosmic ray time series detected in an air shower experiment located at 2000-m altitude above the underground Gran Sasso Laboratory, Italy. We consider single particles (muons), corresponding to primary energies of ≥10 GeV, and air showers, corresponding to primary energies of ≥80 TeV. For all time series the analysis indicates a clear stochastic monofractal, non-Gaussian character; comparing these results with those obtained for underground muons and for neutron monitors, we conclude that these properties likely belong in general to cosmic ray time series, irrespective of the nature of the particles and the energies of their progenitors. In particular, the air shower time series from high-energy primaries have a fractal dimension larger than the single-muon time series originating from low-energy primaries.

Chaos in cosmic ray air showers

T. Kitamura, S. Ohara, +6 authors Y. Kato • Published 1 February 1996 • Physics • Astroparticle Physics

Unexpected chaotic features are found in time series of arrival time intervals of successive air showers with (E > 3 × 1014 eV). Over 99 % of air shower arrival time intervals obey the Poisson distribution law representing stochastic behaviors, but occasionally there are air showers showing real chaotic behaviors as distinguished from both random and colored noises. With two systems of the Kinki university installations, we found 13 cases showing chaotic time series in 3.36 yr with the system-1… Expand

Search for chaotic features in the arrival times of air showers

M. AGLIETTA[2], B. ALESSANDRO[3], P. ANTONIOLI[3], F. ARNEODO[3], L. BERGAMASCO[1], M. BERTAINA[1], C. CASTAGNOLI[1], A. CASTELLINA[2], A. CHIAVASSA[1], G. CINI[1], B. D'ETTORRE PIAZZOLI[3], W. FULGIONE[2], P. GALEOTTI[1], P. L. GHIA[2], G. MANNOCCHI[2], C. MELAGRANA[1], N. MENGOTTI-SILVA[3], C. MORELLO[2], G. NAVARRA[1], L. RICCATI[3], O. SAAVEDRA[1], M. SERIO[1], G. C. TRINCHERO[2], P. VALLANIA[2] and S. VERNETTO[2]

[1] *Istituto di Fisica dell'Università di Torino - Torino, Italy*
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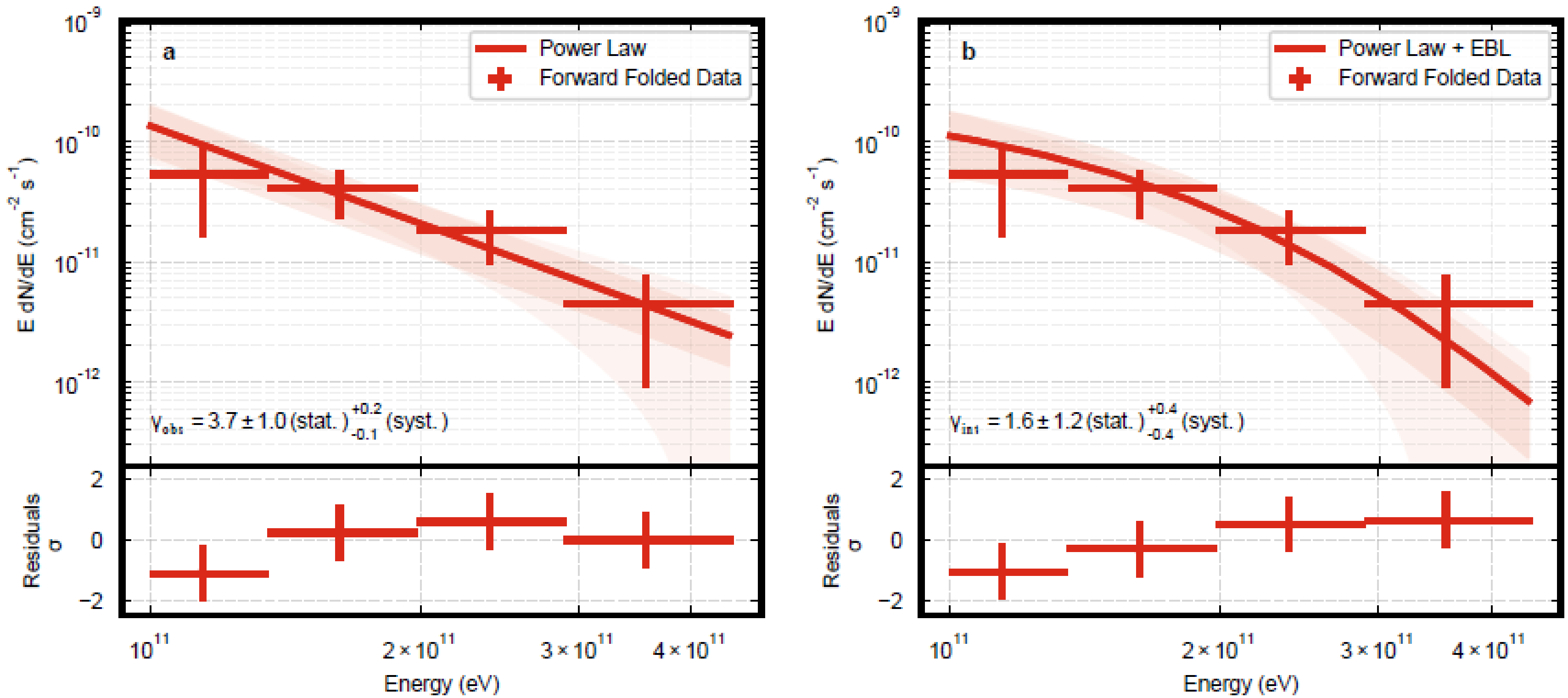
(received 18 October 1995; accepted in final form 11 March 1996)

PACS. 96.40Pq – Extensive air showers.

Abstract. – We study sequences of times between successive arrivals of air showers detected in the EAS-TOP experiment (primary energy between 70 and 1000 TeV) in order to establish their nature, whether stochastic or chaotic.

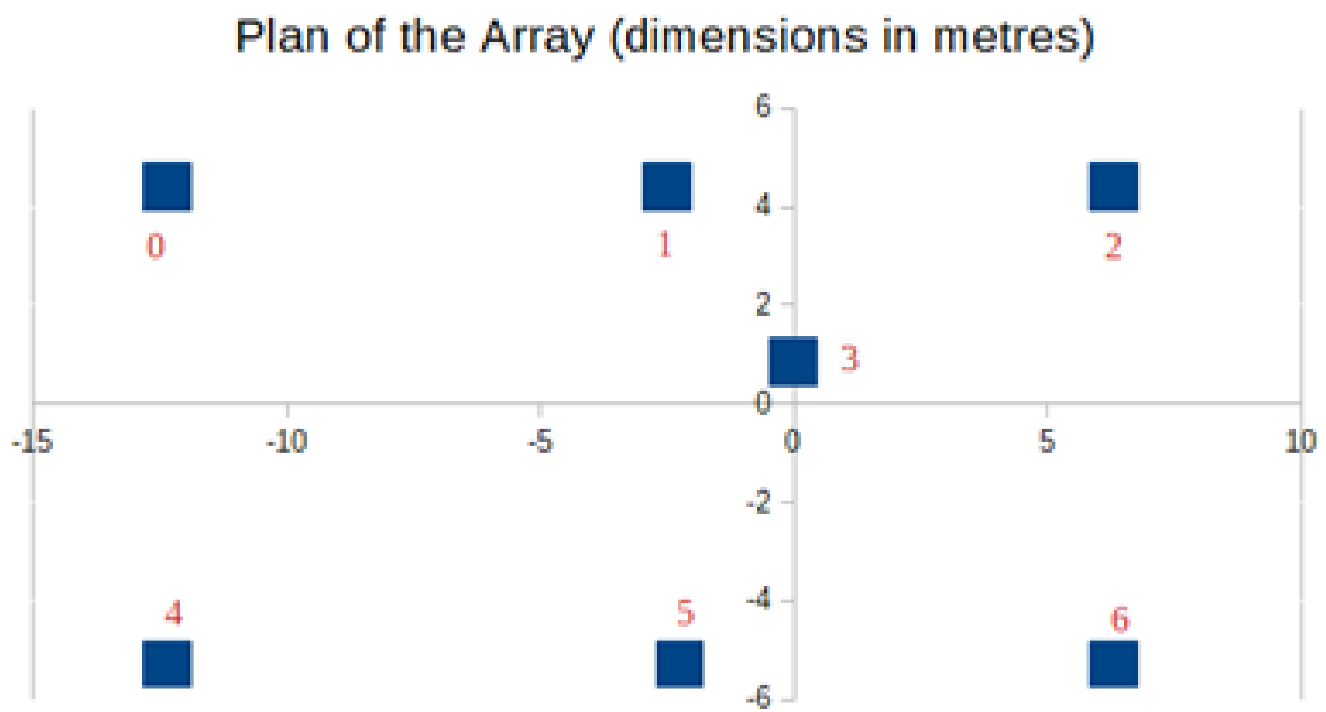
The search for chaotic features in the TBSA sequences from the EAS-TOP experiment has been carried out using various independent approaches; the results of this multiple evaluation all agree in indicating that all the sequences are stochastic, and, in particular, have features similar to white noise. Out of $\simeq 75\,000$ air showers considered we find no candidate for chaotic behaviour. Our conclusion thus goes in the opposite direction relative to that reached by the researchers of the Japanese groups; this contradiction could be related to a possible difference in the structure of the sequences detected in the various experiments, and to the difficulty of reaching an unambiguous assessment of deterministic chaos in sequences characterized by a large number of consecutive small values of Δt_i.

Gamma-ray burst spectra can reach high gamma-ray energies
Abdalla *et al.* arXiv:1911.08961

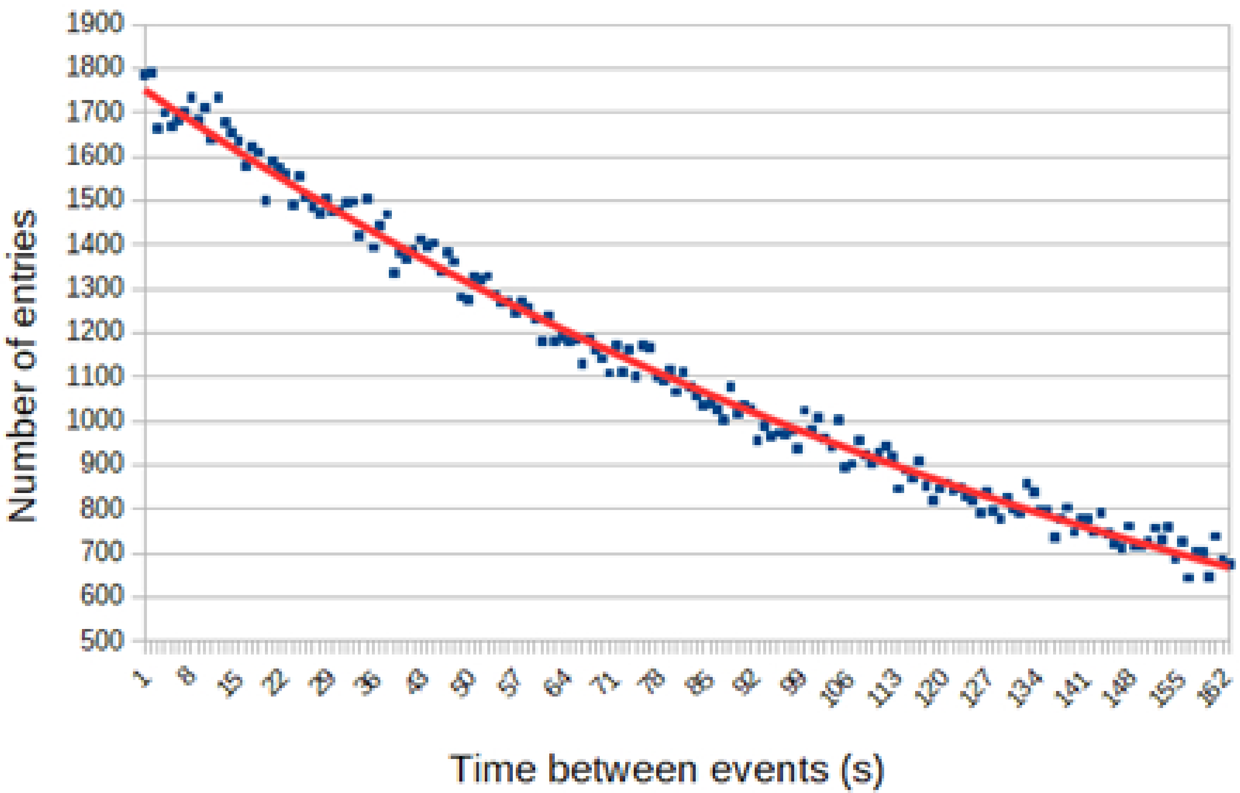


Extended Data Figure 1: **VHE spectral fit of GRB 180720B.** H.E.S.S. spectral fit to the measured emission in the energy range of 100–440 GeV. Panel **a**: Fit assuming a simple power-law model (with photon index $\gamma_{\rm obs}$). Panel **b**: Fit assuming a power-law model (with photon index $\gamma_{\rm int}$) with EBL attenuation for a source at $z = 0.653$[13]. In both cases the residual data points with 1 σ uncertainties are obtained from the forward-folded method. The shaded areas show the statistical and systematic uncertainties in each fit (1 σ confidence level). The bottom panels show the significance of the residuals between the fitted model and the data points.

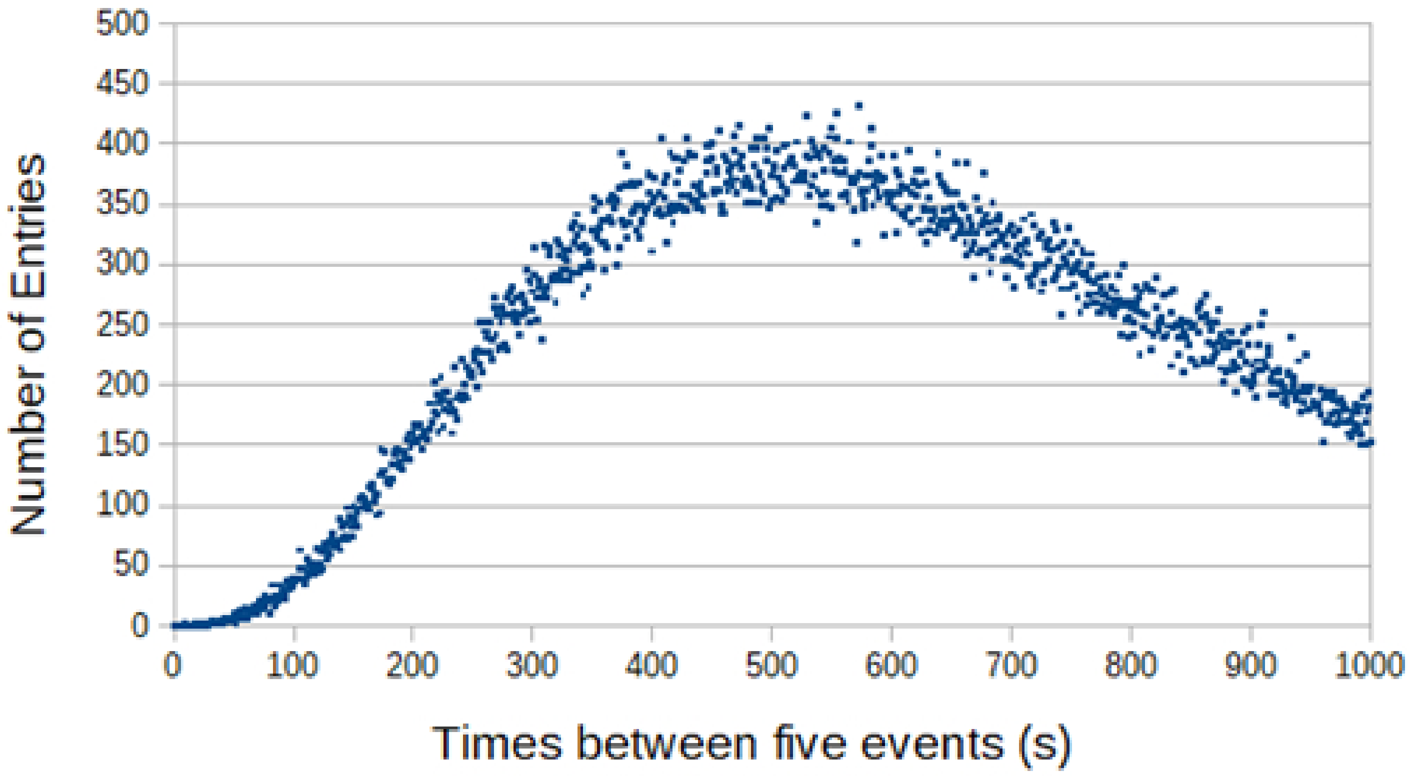
Plan view of the 'roof array', the scintillators are one metre square as indicated to scale on the diagram.



- **The distribution of times between successive events. The solid red line is the fitted exponential distribution (beginning after a spacing of 2 s to avoid dead time effects). The red line fit is f(t) = 1763 x exp(-0.00599t).**

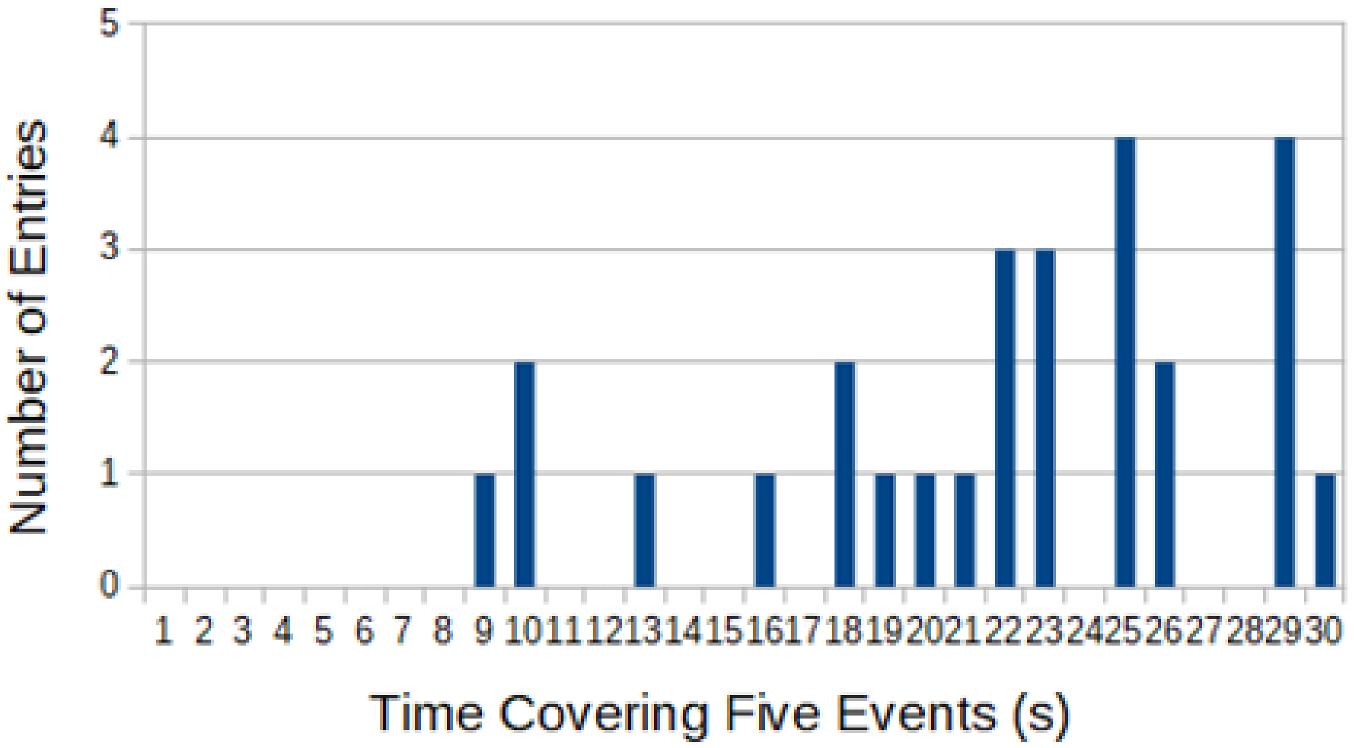


- **The distribution of times (seconds) covering five events**
- **(300k events, 0.5 s deadtime).**

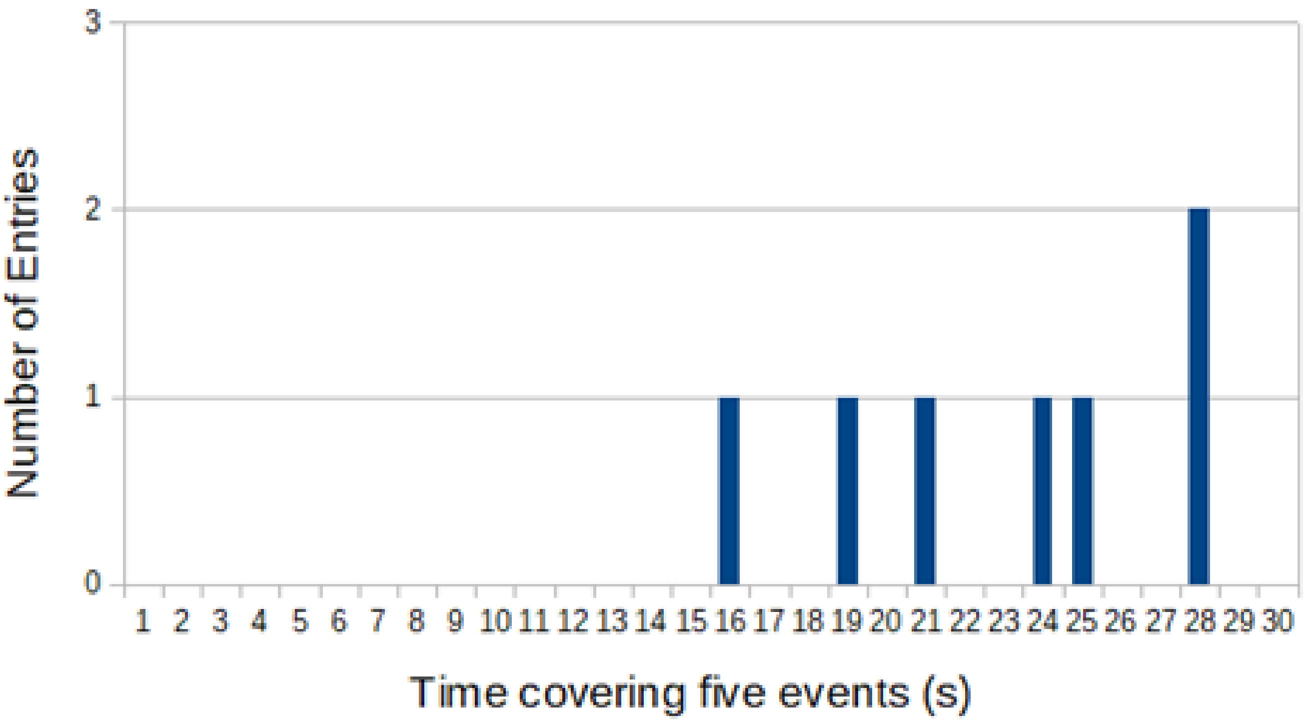


The observed distribution of 'burst' durations in a total dataset of 300,238 cosmic ray showers.

Here, a 'burst' is a succession of five events recorded by a system with 0.5 s deadtime



- **The observed distribution of 'burst' durations in a total dataset of 100k cosmic ray showers.**
- **Here, a 'burst' is a succession of five events recorded by a system with a deadtime of (1.0 +(0-1.0)) s. The bursts at 16 and 19 covered times of 15.553 s and 19.242 s (the 'burst' marked 21 covered 20.931 s and did not pass our *a priori* burst length criterion).**



Directions of three bursts.

(Conservative probability of these ‘bursts’ occurring by chance is ~2*10^-5)

Date and time (UTC)	Mean RA (deg)	Mean dec. (deg)
2019 July 19 18:48:06	25.8 +/-16	-37 +/-12
2021 Mar 25 04:05:16	16.5 +/-16	-55 +/-4
2021 Sept 01 14:30:49	173.7 +/-17	-29 +/-11

Eight events in a burst?

This (8 events) was NOT an *a priori* study.

2019 July 19 18:47 UTC
(8 events in total from 18:47:42 to 18:48:30
Between-event spacings 6, 18, 14, 3, 0, 6, 1 s

19/07/2019	18:38:37
19/07/2019	18:41:47
19/07/2019	18:43:15
19/07/2019	18:47:42
19/07/2019	18:47:48
19/07/2019	18:48:06
19/07/2019	18:48:20
19/07/2019	18:48:23
19/07/2019	18:48:23
19/07/2019	18:48:29
19/07/2019	18:48:30
19/07/2019	18:50:09
19/07/2019	18:52:08
19/07/2019	18:54:22

At the time of the eight events, the underlying rate, taking atmospheric pressure and local temperature coefficients into account, gives a mean event spacing of 181 s.

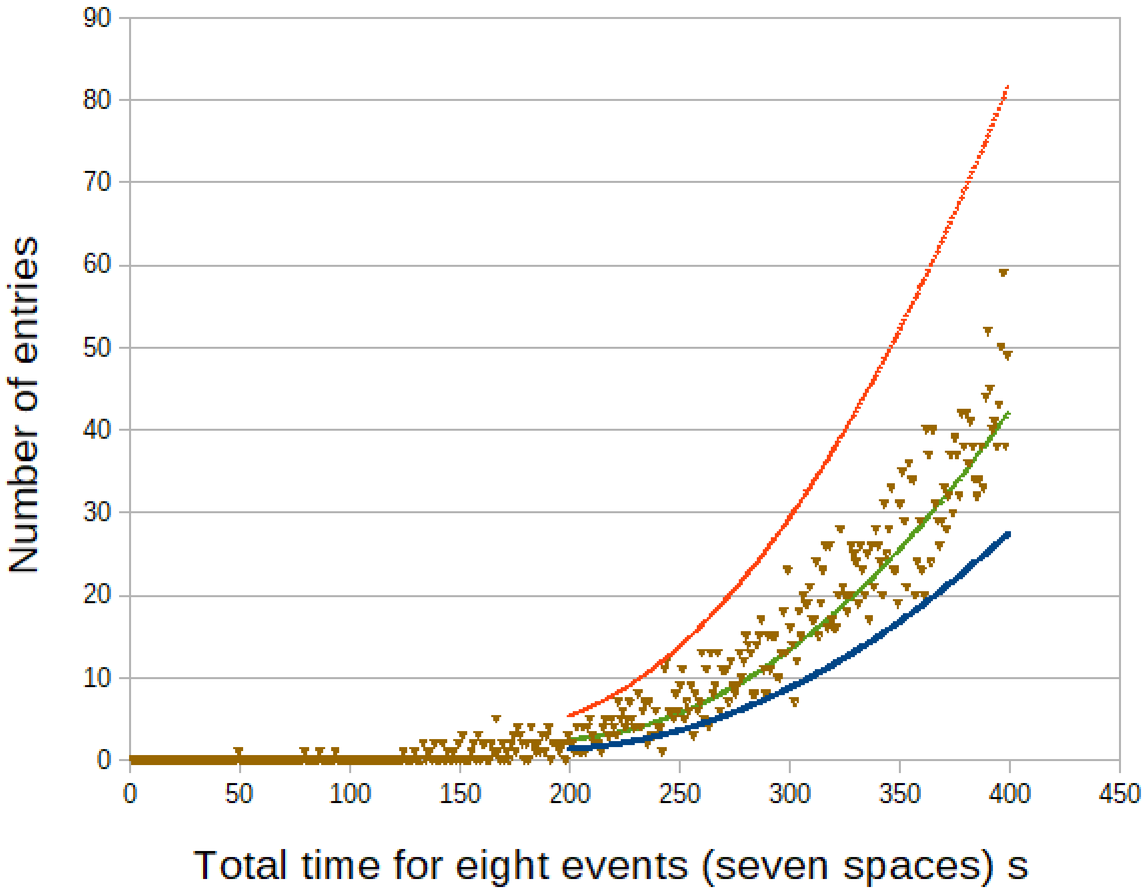
The local weather was not unusual.

No rain, slightly above normal winter temperatures (about +2 degC).

Calm winds.

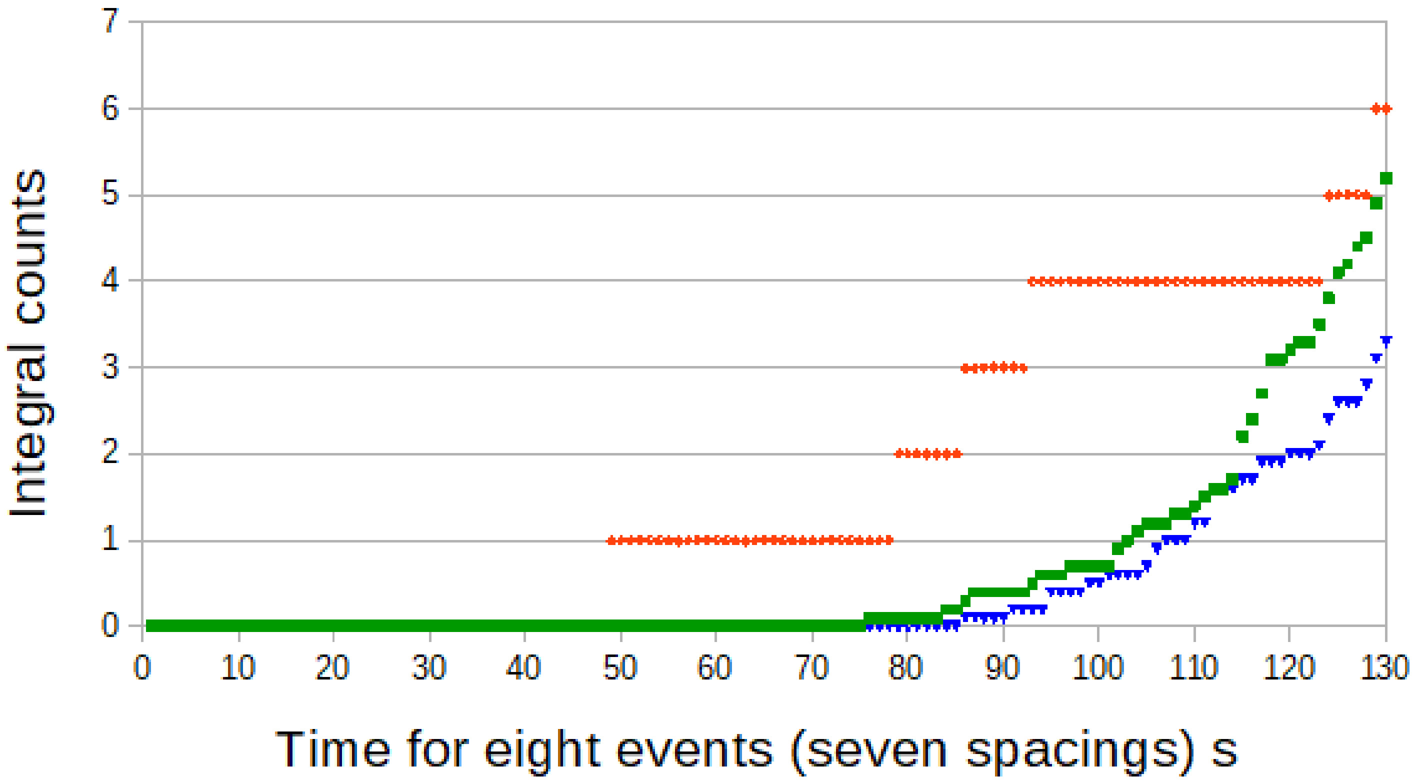
Data and models for 300 k events.

Red line, model for spacing 137 s:
green, model for 166 s spacing (long term average):
blue, model for 181 s spacing (estimated at 8 event burst).
Data points are brown for 300 k events. – note those below 100 s

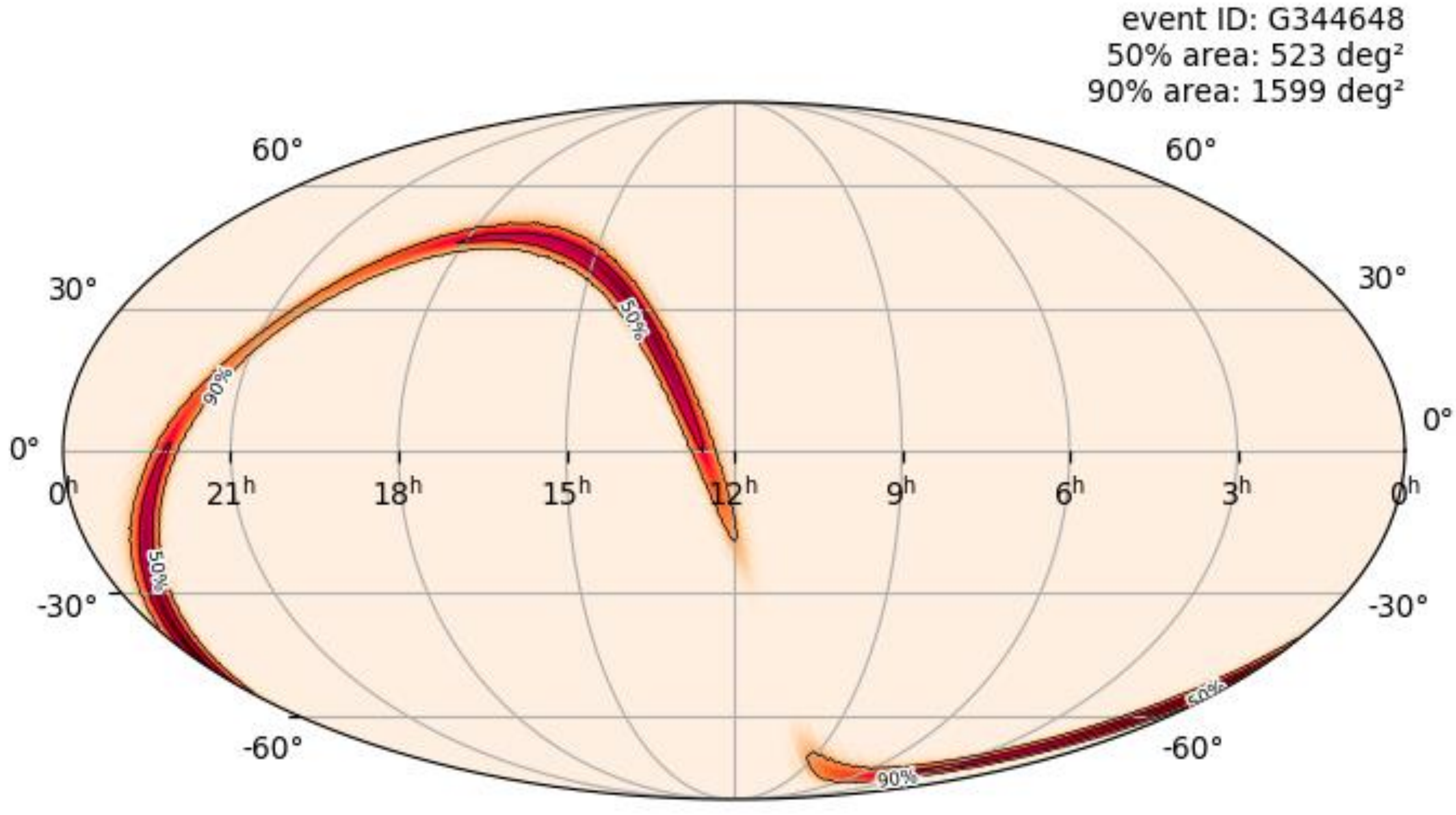


Integral counts for models and data (red) versus total time for eight events.

Models (based on 3 million events each):
blue 181 s mean spacing, green 166 s mean spacing.



For fun, the eight event burst arrived a few hours (5.5 h) before a gravitational wave event:



2019-07-20 00:09:08 UTC   accessed via GraceDB https://gracedb.ligo.org

Cosmic ray burst: RA 25.8, dec -37 (degrees) uncertainty ~ 16 deg.

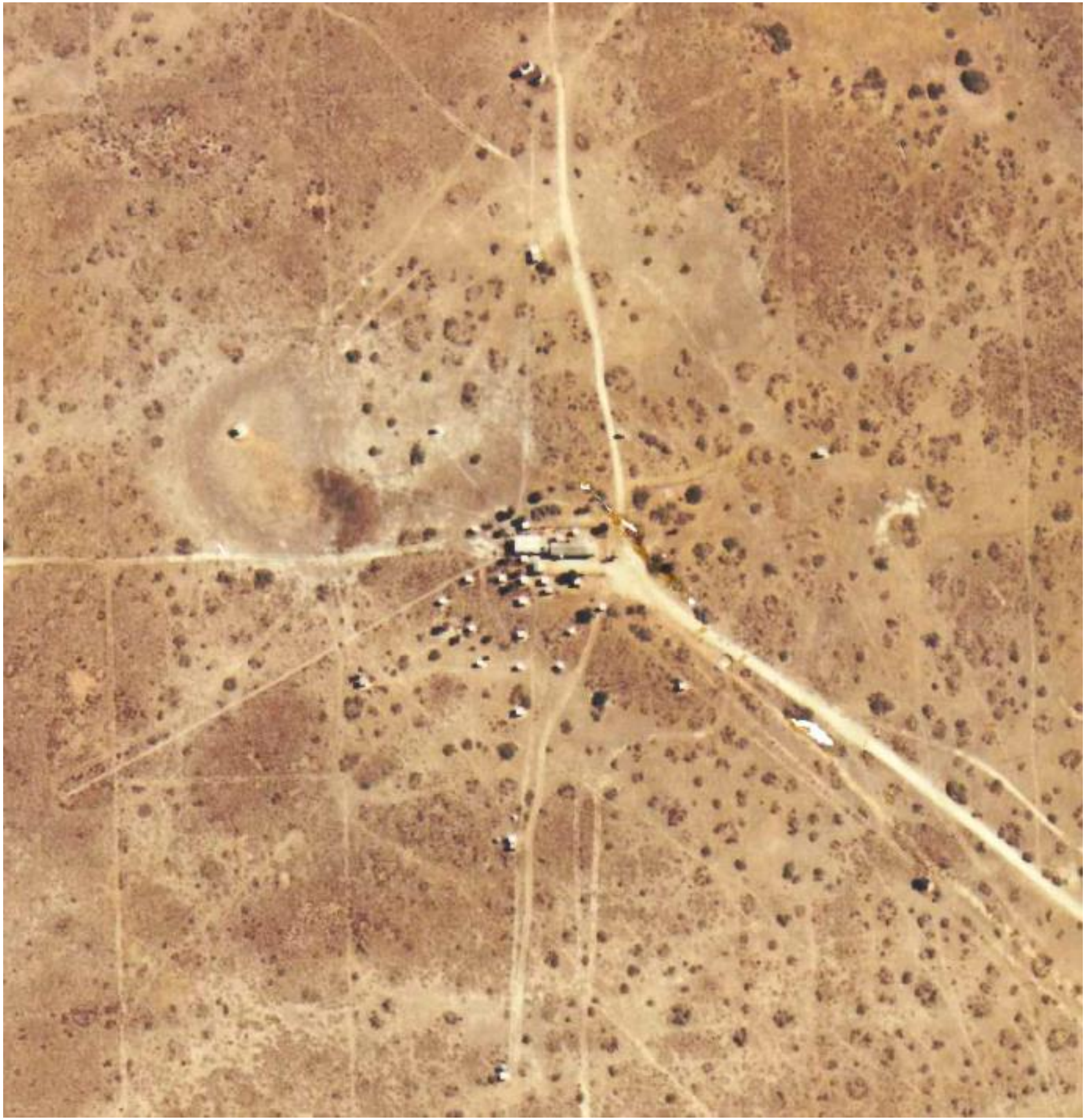
Buckland Park Air Shower array.

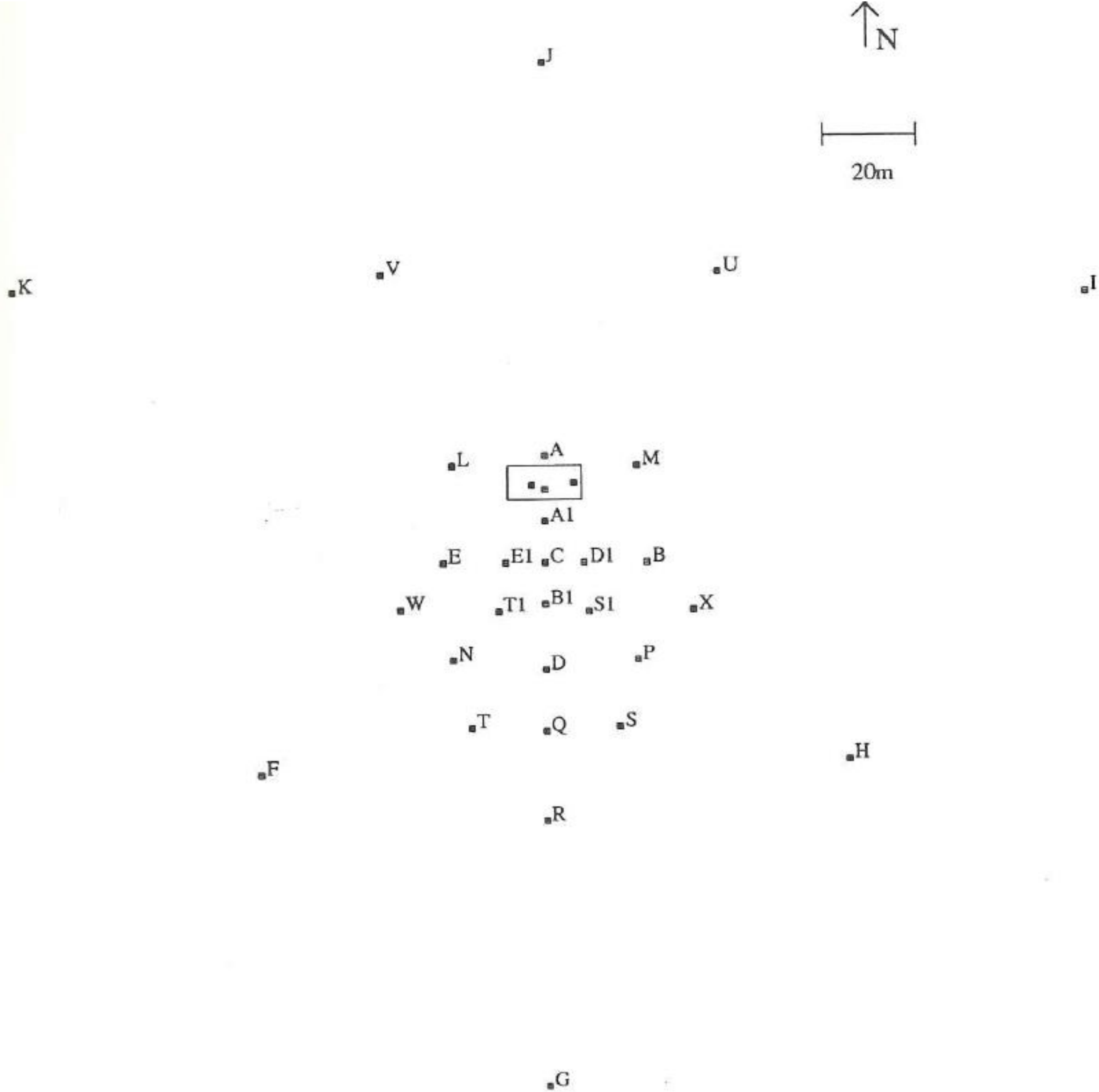
Data are to be examined for possible non-random event rates.

Data available from 1984 (second quarter) to 1989 (second quarter).

A total of ~ 7.5 million events.

Buckland Park Array (P.G. Edwards *et al*. Aust. J. Phys. 1989, **42**, 981)

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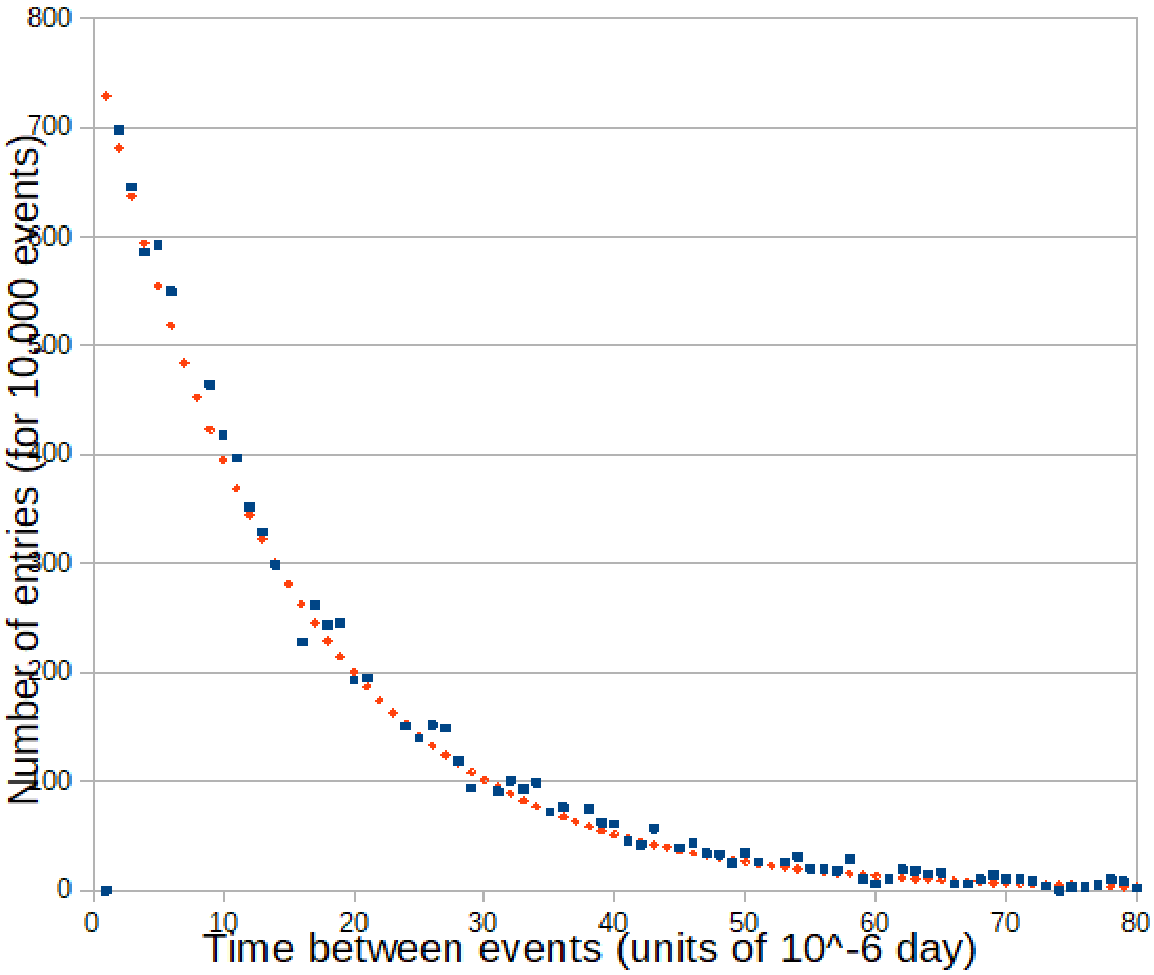
Buckland Park event spacing distribution
data (blue), exponential (red)



12.7 s mean spacing.

An *a priori* burst criterion needs to be selected before further analysis.

Interpretation comments(?)

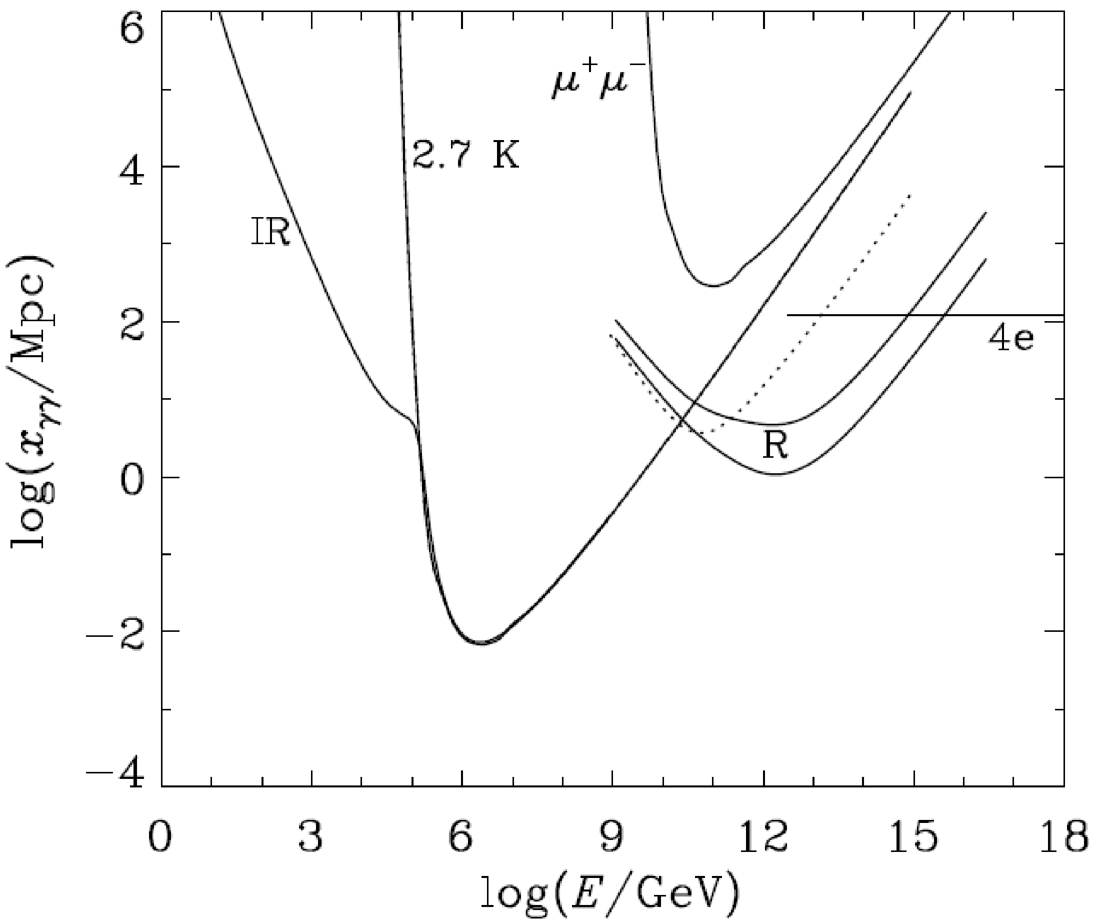
Local effects such as a primary particle break-up in the heliosphere seem unlikely to produce a burst of seconds duration.

Gamma-ray bursts can have that duration.

But (see next slide) the source must be very local to avoid strong attenuation due to photon-photon interactions.

On the other hand, this is not a well-studied parameter space and CREDO (for instance) is looking for unexpected spatial and temporal correlations.

Mean free path for photon-photon pair production



Key: IR=infrared; 2.7 K=CMBR; R=radio background (3 possibilities); $\mu^+\mu^-$=muon pair production, 4e=double electron-positron pair production (Protheroe & Biermann 1997).

Concluding thoughts:

This investigation began with the intention of setting upper limits on the possibility of bursts at >0.1 PeV.

Unexpectedly, four possible bursts were found to satisfy *a priori* criteria.

In ~400k events. One was, possibly, suspicious but the remaining three passed obvious checks.

One burst actually contained eight events and seems to be statistically highly unlikely (not *a priori* , so the confidence limit is unknown).

Work is continuing with further data collection and analysis of Buckland Park data.