ANOMALIES AND OTHER PROBLEMS ENCOUNTERED IN ANALYSIS OF VOYAGER LET AND HET DATA

H. Breneman

Space Radiation Laboratory
California Institute of Technology
Pasadena, California

SRL Internal Report #89
May 30, 1984

ANOMALIES AND OTHER PROBLEMS ENCOUNTERED IN ANALYSIS OF VOYAGER LET AND HET DATA

H. Breneman

Space Radiation Laboratory
California Institute of Technology
Pasadena, California

SRL Internal Report #89
May 30, 1984

Introduction

The analysis of data from the Voyager CRS LET and HET telescopes is complicated by several instrumental problems detailed below. The problems are described in the context of the analysis of heavy element data ($3 \leq Z \leq 30$) from solar flare events, although most of the problems are relevant to other Voyager data subsets as well. Each problem is described and illustrated, and its impact on the analysis of the solar flare data is summarized. For later reference, Table I lists all major flare events observed by the Voyager spacecraft from launch up until January 1983.

(1) Pulse Height "Multiplication" Effect.

This effect has been observed many times in numerous surface-barrier detectors, both in flight and in the laboratory (Cook (1980), Breneman (1982)). Particles passing through a detector sometimes yield pulse heights that are anomalously high (by about 10 - 30 %). It is seen only among particles that have passed completely through the detector, never among stopping particles, and it occurs most often for particles with high dE/dx in the detector in question. The latter observation implies that at a given initial energy, the effect occurs more often for elements higher on the charge scale; in the data it is most prominent for Fe. On a ΔE vs. E' plot, the effect appears as a more or less diffuse "track" above and roughly parallel to the nominal track for the element, since ΔE is anomalously high for the affected particles (Fig. 1). A charge determination of such an event will of course be high, generally by ~2-3 charge units at Fe. Since the effect is strongly dependent on dE/dx, it is usually evident only in the ΔE-detector immediately before the E'-detector. When Z is calculated for 3-parameter events involving such anomalous pulse heights, Z2 is more strongly affected than Z1, since the anomalous pulse height has the role of ΔE for Z2, while for Z1 the same detector PHA usually makes only a modest contribution to E' with ΔE normal. On a Z1 vs. Z2 plot (Fig. 2), the effect takes the form of a cluster of events to the right of, and slightly above, the main cluster along the diagonal. All of the Voyager LETs show the effect for Fe; although its rate of occurrence varies somewhat between the different telescopes, it is generally in the range of ~5 - 10% of all the 3-parameter Fe events in a given telescope. The fraction of 2-parameter events affected is larger, since the E'-detector is thinner and therefore a larger fraction of the data has high dE/dx in the ΔE-detector. At least one LET (Voyager 1 LET A; Fig. 3) shows evidence for the effect at charges as low as 20. It is almost certainly present to some degree in all elements above Ca, but the poor statistics make it unnoticeable except for Fe and perhaps Ni. Although quantitatively the different LETs show the effect to a comparable degree, they differ in the qualitative appearance of the effect. In most telescopes (e.g. Voyager 1 LET D; Fig. 2), the anomalous cluster is cleanly separated from the normal cluster; in Voyager 1 LET A (Fig. 3) there seems to be a continuum between the two, and there are intermediate cases. The anomalous clusters differ in their tightness and in their distance in charge units from the main cluster, depending on the value of the "multiplication factor" being applied to the ΔE-detector pulse height.

In the HETs the problem is worse in several respects. Its rate of occurrence at Fe, as a percentage of the total Fe event sample, is generally much larger than in the LETs (~40 % for Voyager 1 HET 2); it is clearly seen for elements as low on the charge scale as Mg in some telescopes (Voyager 1 HET 2 and Voyager 2 HET 2, Figs. 4 and 5); and for 3-parameter events it can sometimes be seen occurring in either (or both) ΔE-detectors, rather than just the last one, resulting in several displaced clusters of events in those telescopes (Voyager 1 HET 1 and Voyager 2 HET 2; Fig. 5).

Several actions are necessary to deal with this problem. For abundant elements affected by the problem, such as Fe, the 3-parameter charge consistency requirement must be made lenient enough to include the events that may be affected by pulse height multiplication, or else a correction must be made for the amount that is discarded. In Fig. 6, the rate of occurrence of the effect, in Voyager 1 HET 2, is shown as a function of Z based on the abundant elements where it is apparent; this can be used to predict its magnitude for rarer elements where limited statistics make it less apparent and less quantifiable. In addition, the energy loss in the ΔE-detector must be corrected in an approximate way for affected events, so that the total incident energy, which is required for constructing energy spectra, will be accurate. For rare elements, whose abundances are determined by maximum-likelihood calculations, care must be taken that the multiplication effect is included in the model distribution of both the element in question and its neighbors wherever appropriate.

For 2-parameter events, there is no second independent determination of Z to permit unambiguous separation of normal and abnormal events. This is not a serious problem for abundant elements, since the only abundant element significantly affected is Fe, which has no other elements of comparable abundance near it on the charge scale with which it could be confused. For rare elements the situation would be more serious, but rare element abundances from 2-parameter data are already impractical due to background from other sources.

Since dE/dx in the ΔE-detector varies inversely with total incident energy, the PHA multiplication effect is a more serious problem for observations of particle populations that have steeply falling energy spectra (i.e. solar flare events) than it is for particle populations with rising spectra (galactic cosmic rays).

(2) **LET Telescope ID Tag Bit Errors at High Counting Rates.**

When Z1 vs. Z2 plots of 3-parameter data from flare period #7 are generated for Voyager 1 LET B and Voyager 2 LETs B and D, one observes, for the more abundant elements, small clusters of events displaced slightly from the main clusters along the diagonal. In Voyager 1 LET B they are displaced above and slightly to the left of the main cluster for a given element, apparently corresponding to a high Z1 measurement and a slightly low Z2 (Fig. 7). In Voyager 2 LET B they are located below and to the right of the main cluster, corresponding to a high Z2 and a low Z1 measurement (Fig. 8). In Voyager 2 LET D, they are almost directly below the main cluster, implying a low Z1 and a nearly correct Z2 (Fig. 9). On ΔE vs. E' plots, these effects have the appearance of "ghost" tracks falling between or partially overlapping the real tracks of nearby elements (Fig. 10, 11). Corresponding effects are also seen in the 2-parameter data (Fig. 12). For the flare period #7 data set, the average rate of occurrence of this effect is about 1% in each case, and is not dependent on Z. It appears to be strongly rate-dependent, and is seen at a significant level only in flare period #7, which included the highest solar flare event rates seen by Voyager. There is no evidence of such effects in the other LETs or in the HETs. Although there are mechanisms for producing anomalously low or high pulse heights in particular detectors (e.g. pileup, edge effects, the "multiplication" effect described above), the appearance and variety of effects produced here are difficult to explain through such models.

All three anomalies were ultimately explained by a single effect, namely the occurrence of an error in one of the tag bits associated with each event. For each Block I or Block II LET event, there is a single bit which specifies from which LET telescope in that Block the event originated. Thus it distinguishes LET A from LET B events, and LET C from LET D. A near coincidence in the triggering of LETs A and B could result in the bit being set for a LET A event, causing that event to be read out as a LET B event (similarly for C and D). Since the bit is ordinarily set only for LET B events and is otherwise not set, it is possible for LET A events to be misidentified as LET B events but never the reverse. This accounts for the observation that all A and C telescopes on both spacecraft show no such effects. The requirement of a near-coincidence in the triggering of two telescopes implies a rate-dependence to the effect, as is observed.

The telescope identification bit is used in all subsequent data analysis to determine the appropriate detector thicknesses and gains to use in calculating energy losses in the detectors and, ultimately, the charge of the particle. If the telescope identification is erroneous, incorrect thicknesses and gains will be used in the calculations, resulting in incorrect determinations of Z. The magnitude and sign of the discrepancy in Z will depend only on the (coincidental) relationship between the thicknesses of the detectors in the paired telescopes, and, to a lesser degree, differences in the energy calibrations of the respective detectors.

The correctness of this model was confirmed by the observation that when ΔE vs. E' plots are prepared using the raw pulse height values, the "ghost" tracks on a LET B or D plot invariably match up exactly to the real tracks of abundant elements in the analogous plot for the corresponding A or C telescope (compare Figs. 13 and 14). No effect is seen in Voyager 1 LET D because by chance, the detector thicknesses in Voyager 1 LETs C and D are such that the two sets of tracks almost perfectly coincide.

The impact of this problem on the data analysis is relatively minor. For 3-parameter data, the previously chosen charge-consistency requirement is restrictive enough to easily exclude the misidentified events in the three cases described above; the amount of data lost is an insignificant 0.2% of the total, and the remaining data is as "clean" as that from the other telescopes. The problem is more serious for the 2-parameter data, since there is no second determination of Z to permit separation of the normal and abnormal events; it is an unremovable source of background in the data. For abundant elements this is unimportant, since the error introduced by this background is on the order of 1% or less. But the problem is serious for rare elements in cases where the "ghost" track of an abundant element overlaps the true location of a rare element, since even 1% of an abundant element could seriously contaminate a much rarer element (see, for example, Fig. 15). However, the background arising from other sources is severe enough that the 2-parameter data is already of limited usefulness in obtaining rare element abundances. It should be emphasized that this problem affects only half of the LET telescopes, and only at the very highest event rates measured to date.

Note that one effect of the mis-tagging problem, in Voyager 1 LET B, is a "ghost track" (actually LET A oxygen) in the region of fluorine on a ΔE vs. E' plot (Figs. 10, 12, 13). This effect was first noted by Cook (1980) but was not understood at the time. It can now be understood as one of the most obvious manifestations of a much more general problem with the instrument.

To further characterize the rate-dependence of the effect, flare period #7 was subdivided into shorter periods of time based on the event rate. It was found that for Voyager 1 LET B, a maximum mis-tagging rate of ~3% occurred at the peak observed LET B singles rate of $\sim 5\times10^3$ sec^{-1}. This implies a time constant for the mis-tagging effect of ~6 μs (Fig. 16). However, these values are uncertain by about 20% due to the very limited amount of flight data obtained at these high rates.

Laboratory work performed in August 1983 using the backup CRS and pulse generators (Martin (1983)) was able to reproduce the effect with greatly improved statistics; the results of this study are briefly summarized below. It was found that the mis-tagging rate is highly linear as a function of the LET B singles rate up to rates on the order of 6×10^4 sec^{-1}. The time constant implied by the slope of this line is 5.6 μs, in good agreement with the more uncertain value obtained from the flight data. Above about 6×10^4 sec^{-1}, the effect "saturates" and its rate of occurrence levels off at about 35% of all LET A events. This high a mis-tagging rate would be an intolerable situation in flight data, but fortunately the particle flux required to maintain it is an order of magnitude higher than anything seen by Voyager in flares to date or likely to be seen in the future. The 5.6-μs time constant was found to be explainable in terms of the behavior of the instrument in different regimes of delay time between the pulses. In certain ranges of delay time mistagging always occurs, and in others it never occurs, or no event is recorded at all. It was verified that the mis-tagging never occurs in reverse, with LET B events being misidentified as LET A.

In addition, another effect, possibly unrelated, was discovered in the short-delay-time regime. When in near coincidence with an LET B L1 event, the pulse height in LET A L1 can be anomalously high, by as much as the value of the LET B L1 pulse height. It is worst at the shortest delay times and, unlike the mis-tagging effect, it is symmetrical with respect to LET A and LET B. This effect is readily understood in terms of the operation of the linear summing amplifiers in the CRS analog signal processor, which routinely sum the signals from various combinations of detectors that under ordinary circumstances would be mutually exclusive. The effect is of no consequence to the heavy-ion data since it is also dependent on very high data rates, and in any case the coincident particle is most likely a proton which does not contribute significantly to the pulse height of the heavy ion being observed. No effect is noticeable in the flight data, and even same-telescope "pileup" appears minimal at the highest event rates seen in solar flares.

(3) LET L1 Detector Jupiter Encounter Radiation Damage and Post-Encounter Annealing.

As a result of their exposure to intense charged particle fluxes in the inner Jovian magnetosphere during the 1979 Jupiter encounters, the depletion characteristics of the L1 detectors of the LETs were altered. This radiation damage, which can be modeled as a reduction in the "effective thickness" of the detectors, is thought to be due to the implantation of energetic oxygen and sulfur ions known to be present in the inner Jovian magnetosphere (Gehrels (1981)). Although all LETs on both spacecraft were affected to some degree, the

Voyager 1 LETs were affected much worse than those on Voyager 2, since the former spacecraft passed closer to Jupiter and experienced a more intense radiation environment. On each spacecraft, LET C was by far the most seriously affected, showing an effective L1 thickness reduction several times larger than those of the other LETs on the same spacecraft; LET C was spatially oriented so as to receive the most intense radiation exposure during the Jupiter encounters. (LET B on Voyager 2 experienced unrelated types of radiation damage during the Jovian encounter and has returned no data since the encounter.) The front detectors of the HETs, which are much thicker than those of the LETs and are protected by a thicker window, showed no detectable effective thickness reduction.

The impact of the radiation damage on the post-Jupiter data is apparent as a shift in the location of the element tracks on a ΔE vs. E' plot of data from flares #16 and #17, the first large post-Jupiter flares, relative to their location in plots of pre-Jupiter flares. Similarly, Z1 vs. Z2 plots of flares #16 and #17 show Z-values shifted from their proper values when Z is calculated using the detector thicknesses measured before launch, which served adequately for all pre-Jupiter flares. The change in effective thickness appears to be somewhat dependent on Z, with the magnitude of the reduction increasing with Z for any given detector. Furthermore, with the passage of time the radiation damage seems to gradually undergo a partial reversal. This "annealing" effect is evident in plots of the later large flares, #20 and #24, which show less shift in Z than do the flares immediately following Jupiter encounter.

In the analysis of post-Jupiter data, this problem was dealt with by adjusting the L1 detector thicknesses used in the calculation of Z so as to make the calculated charges fall in the proper places on the charge scale. Flares #16 and #17 were used to define the required shift for several abundant elements; a linear or weakly quadratic function of Z was fit to these to define the Z-dependence for all Z. The adjustment of the L1 thickness was then incorporated into the iterative cycle involved in calculating Z. The other large flares referred to above were used to mathematically characterize the time-dependence of the annealing effect, which was then incorporated into the determination of what L1 thickness to use in analyzing any given post-Jupiter event. The radiation damage does not seem to have had a noticeable effect on the inherent charge resolution of the telescopes, so with the above modifications the post-Jupiter flare data can be treated the same way as the pre-Jupiter data.

Table II lists the adjustment made to the thickness for each L1 detector for carbon and iron at two different times during the post-Jupiter phase. The actual expression for the thickness $L(Z,t)$ of each L1 detector was given by

$$L(Z,t) = L_0 - \Delta L_0(Z) + K \exp(\Delta t / 562.56)$$

where K is a constant, L_0 is the pre-Jupiter thickness, Δt is the time since the

Jupiter encounter in days, and $\Delta L_0(Z)$ is the linear or quadratic function of Z that closely fits the required thickness changes for the first post-Jupiter flares.

(4) **Voyager 2 LET C Temporary Gain Shift.**

During the time period 1978 Apr 3 - June 9, the L1 detector of LET C on Voyager 2 experienced, for unknown reasons, a temporary gain shift (30 - 40 %) and an associated excessively high L1 count rate ($\sim 9\times10^3$ sec^{-1}). The gain shift and excessive count rate set in abruptly, remained nearly constant until about May 29, and then gradually reverted to their former levels; a very slight decline during the central phase was consistent with the decrease in the intensity of sunlight during the same time period and suggests the possibility of a light leak in the telescope's aluminum window.

The effect on the data was to shift the locations of the element tracks on a ΔE vs. E' plot, and yield shifted charge estimates when nominal gain factors were used in the analysis. The only flares occurring during this time period were the three large events of flare period #7. Since the gain was constant at the shifted value during these flares, the data could be analyzed by adjusting the gain factors in the energy calibration in order to move the calculated charges to the proper places on the charge scale.

This effect was previously noted by Cook (1980), who rejected this telescope from analysis because of the problem. However, since the energy calibration used in the analysis is easily adjusted to compensate for the problem, since the charge resolution and background of the telescope do not seem to be affected by the problem and since the three #7 flares include a major fraction of all the SEP data, it was decided to include Voyager 2 LET C in the analysis with the special treatment described above.

There was a recurrence of the effect in the same detector during the time period 1979 March 8 - June 1, except that in this case the onset as well as the decline of the effect was gradual, and the peak L1 rate was about a factor of ten lower. This occurrence of the effect had no impact on the flare studies since no significant flares took place during this time period, but it would have to be taken into account when processing quiet-time data.

(5) **CRS Instrument Configuration Changes.**

At certain times during the Voyager mission, the configuration of the CRS instruments was changed in ways that influence data analysis. At the beginning of each flight the LETs were configured to require triggering of the L3 detector for pulse height analysis; that is, only 3-parameter events were analyzed. About 12 days after launch the L3 coincidence requirement was removed, permitting both 2- and 3-parameter events to be analyzed. For Voyager 2 this occurred before the first flares were seen, but on Voyager 1 flares #1a and #1b occurred before the configuration was changed, so no 2-parameter events were obtained from these flares. This requires that special care be taken in calculating abundances of elements over particular energy intervals, and in comparing these results to other flares.

A similar situation occurred on 17 June 1978 when Voyager 1 LET C was switched back to requiring L3 coincidence. Thus for all flares from #8 onward there are no 2-parameter events from this telescope.

Another type of configuration change is the gain state. High gain mode is sensitive mainly to protons and alpha particles and low gain responds primarily to heavy ions; usually the instrument cycles between the two modes. After Jupiter encounter, HET 1 on Voyager 2 was switched to high gain only, so no post-Jupiter SEP heavy ion data was obtained from this telescope.

(6) **Voyager 1 Block I PHA Problem.**

On 1982 Feb 8, the Voyager 1 CRS experienced a failure affecting the readout of PHA information from the Block I telescopes (LETs A and B and HET 1). The result of the failure is that in place of PHA2, the instrument reads out whichever of the three PHAs has the largest numerical value. If PHA2 happens to be numerically the largest pulse height, as is true over some energy ranges, the event is read out normally; otherwise some information is lost. The effect of this problem is that some of the 2-parameter events are lost completely, and that some of the 3-parameter events are degraded to 2-parameter events. The appearance of this problem in the ΔE vs. E' plots is as shown in Figs. 17, 18, and 19 for flare #24 data from LET B.

The effect of this problem on data analysis was minimal because it occurred very late in the time period included in the SEP data set, and thus affects only two relatively small flares. The problem was dealt with by simply discarding the data on these flares from the three telescopes affected, although in principle parts of the nominal energy range could still be used if they contributed enough to the event statistics of the affected flares to make it worthwhile to develop special procedures for handling them.

REFERENCES

(1) Breneman, H., SRL Internal Report #87, California Institute of Technology, Pasadena, California (1982).

(2) Cook, W.R., Ph.D. thesis, California Institute of Technology, Pasadena, California (1980).

(3) Gehrels, N., Ph.D. thesis, California Institute of Technology, Pasadena, California (1981).

(4) Martin, S., SRL Internal Report #91, California Institute of Technology, Pasadena, California (1983).

Table I. Complete listing of all flare periods observed by at least one Voyager spacecraft from launch until January 1983. Time periods shown are approximate, since the flares were seen over slightly different time periods at the two spacecraft. Some flare periods (e.g. #1, #7) actually consist of several closely spaced flares.

flare period	time period	S/C	% of total LET flare data
1	1977: 252-276	1,2	5.08
2	1977: 284-295	1,2	0.05
3	1977: 326-335	1,2	2.38
4	1978: 005-022	1,2	0.32
5	1978: 045-056	1,2	8.63
6	1978: 067-082	1,2	0.12
7	1978: 099-135	1,2	56.40
8	1978: 176-182	1,2	0.48
9	1978: 195-201	1,2	0.11
10	1978: 268-287	1,2	0.57
11	1979: 038-047	2	0.04
12	1979: 100-111	1	0.02
13	1979: 160-171	1,2	0.61
14	1979: 193-204	1	0.11
15	1979: 218-235	1	0.03
16	1979: 235-256	1,2	1.16
17	1979: 256-291	1,2	18.08
18	1980: 223-241	1,2	0.15
19	1980: 321-349	1,2	0.24
20	1981: 117-159	1,2	2.75
21	1981: 264-285	1,2	0.23
22	1981: 286-314	1,2	0.42
23	1982: 040-063	2	0.05
24	1982: 160-229	1,2	1.69
25	1982: 340-1983: 017	1,2	0.28

Table II. Voyager LET L1 detector effective thickness reduction resulting from Jupiter encounter radiation damage. Flare #17 occurred shortly after the encounter, flare #24 about 2.5 years later. The reduction is smaller for the later flare because of a gradual "annealing" effect following Jupiter encounter. No figures are given for Voyager 2 LET B since this telescope did not function after encounter. Note that the two LET Cs were by far the most severely affected.

S/C #	LET ID	L1 thickness (μm)	ΔL (Z = 6) flare #17	ΔL (Z = 6) flare #24	ΔL (Z = 26) flare #17	ΔL (Z = 26) flare #24
1	A	37.91	-0.89	-0.41	-3.26	-2.78
1	B	30.91	-1.00	-0.58	-2.86	-2.44
1	C	37.07	-5.53	-4.09	-9.75	-8.31
1	D	35.45	-0.62	-0.38	-2.19	-1.95
2	A	34.35	-0.03	+0.08	-0.61	-0.50
2	B	38.55	-----	-----	-----	-----
2	C	35.33	-3.21	-2.10	-6.08	-4.97
2	D	34.76	-0.07	+0.14	-1.12	-0.91

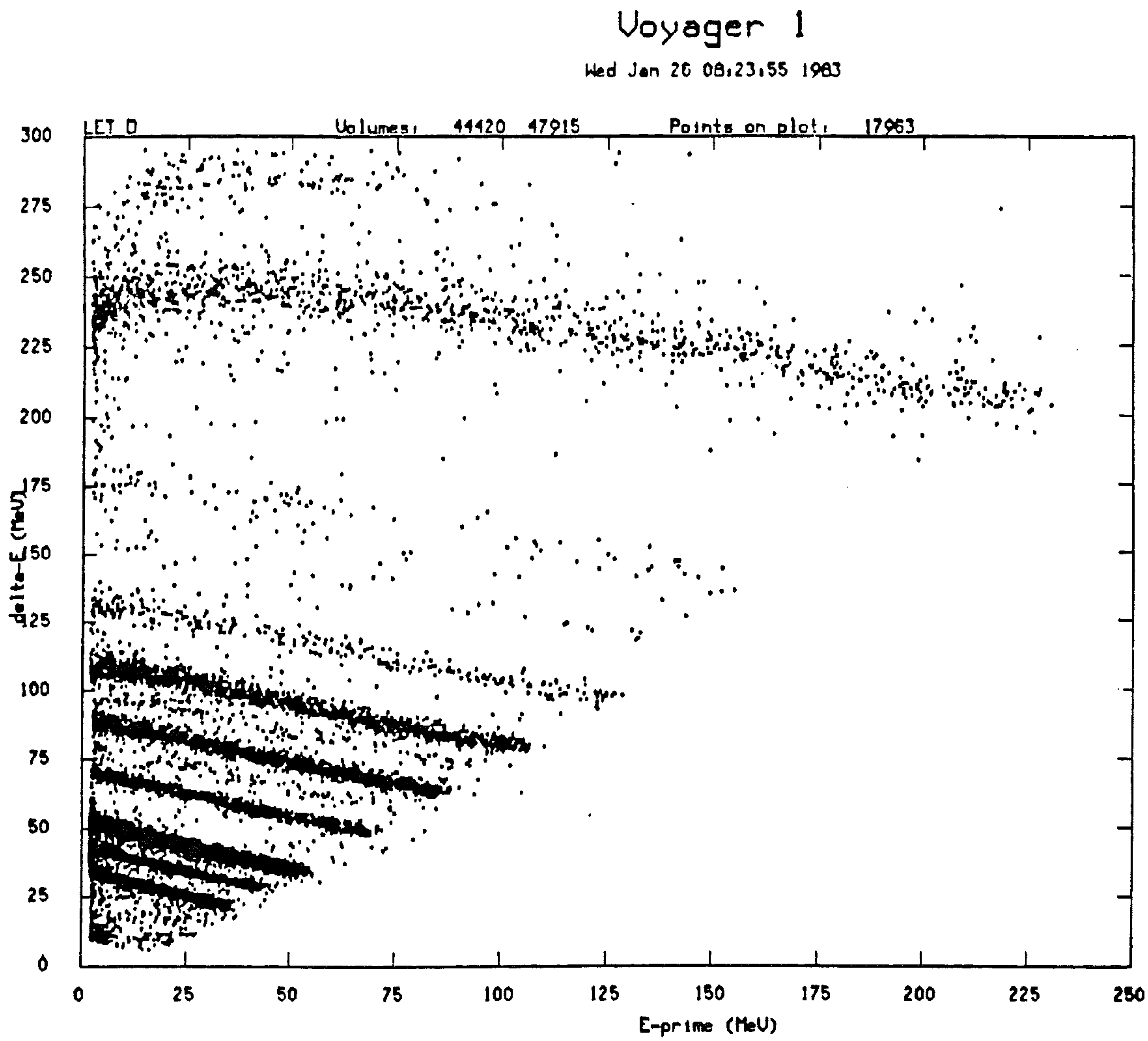

Fig. 1. ΔE vs. E' (L1 vs. L2) plot of 2-parameter solar flare data from Voyager 1 LET D. The "tracks" of the various abundant elements, C, N, O, Ne, Mg, Si, S, and Fe are apparent, as well as the less-populated tracks of Na, Al, Ar, and Ca. The diffuse track above Fe consists of Fe events exhibiting pulse height multiplication in the ΔE-detector (L1). The track fades out toward the right side of the figure because the rate of incidence of the effect is a strongly increasing function of dE/dx in the ΔE-detector.

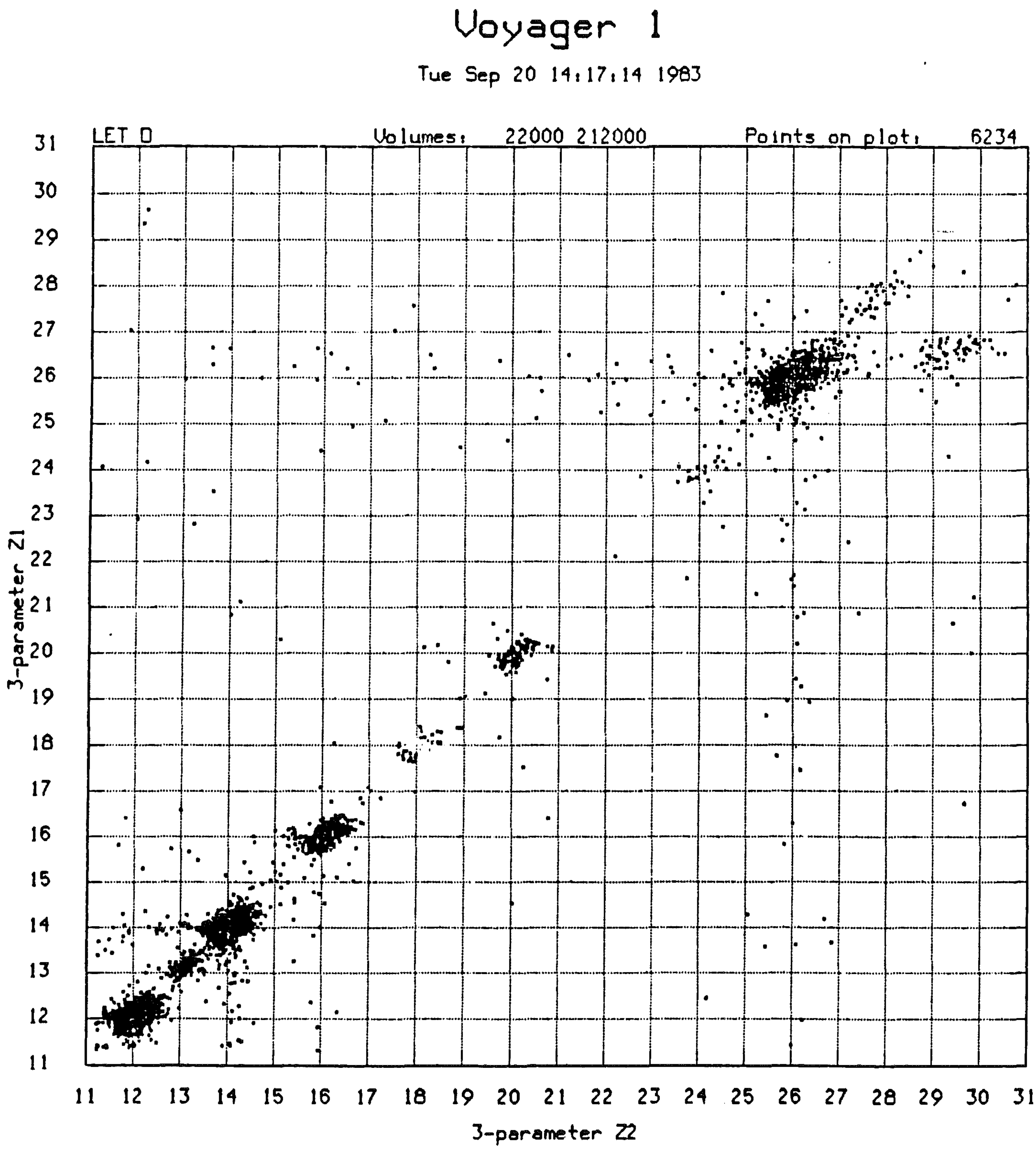

Fig. 2. Z1 vs. Z2 plot of 3-parameter solar flare data from Voyager 1 LET D. The various elements are clearly resolved along the diagonal; the cluster of events centered at (Z1 = 26.5, Z2 = 29.5) consists of Fe events affected by pulse height "multiplication" in the L2 ΔE-detector.

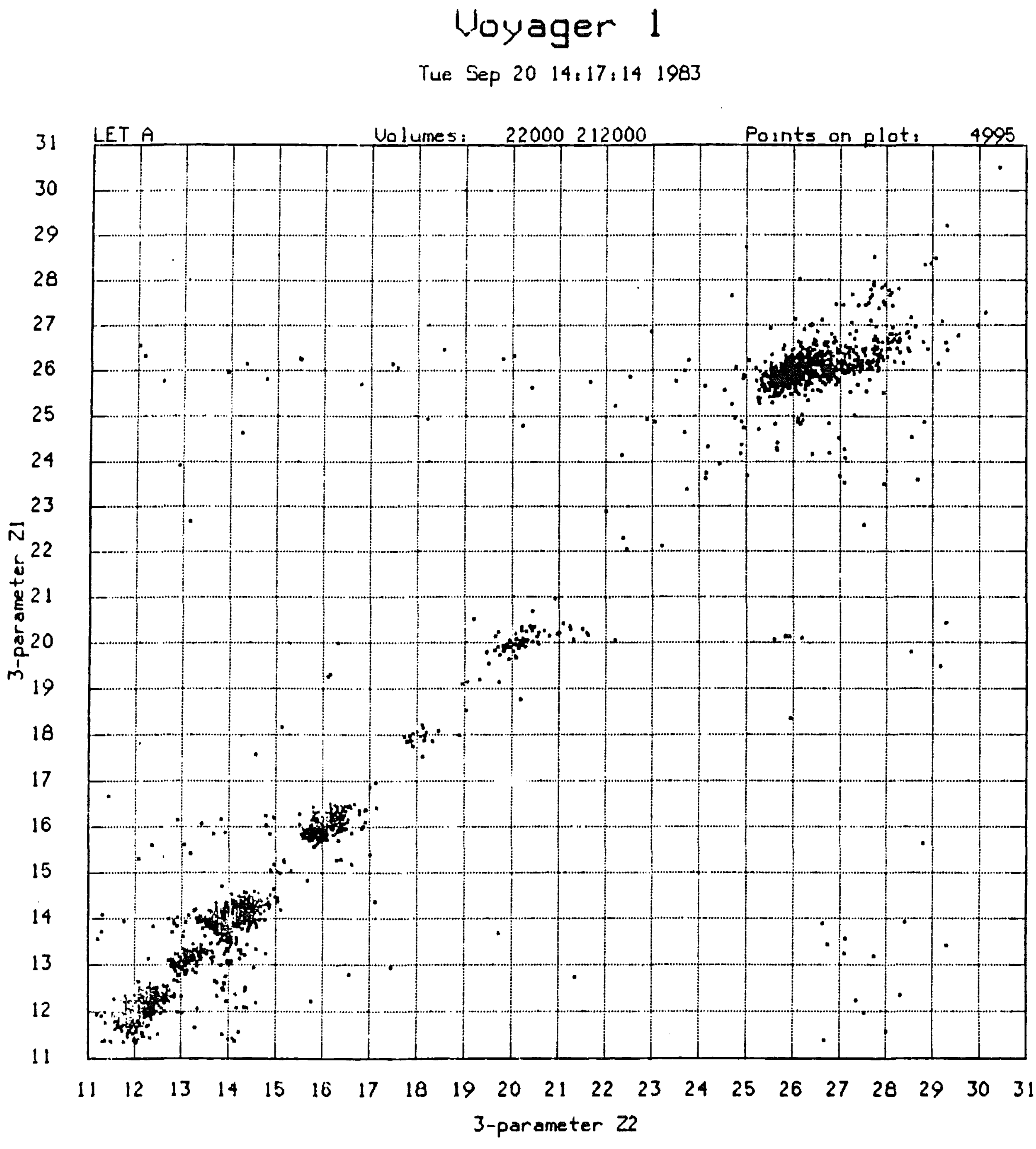

Fig. 3. Z1 vs. Z2 plot of 3-parameter solar flare data from Voyager 1 LET A. The Fe cluster has a diffuse "tail" extending toward the upper right to approximately (Z1 = 27.0, Z2 = 28.5). This appearance is much different from the case of Voyager 1 LET D (Fig. 1). Note that the Ca cluster has the same appearance, indicating pulse height multiplication for charges as low as 20 in this telescope.

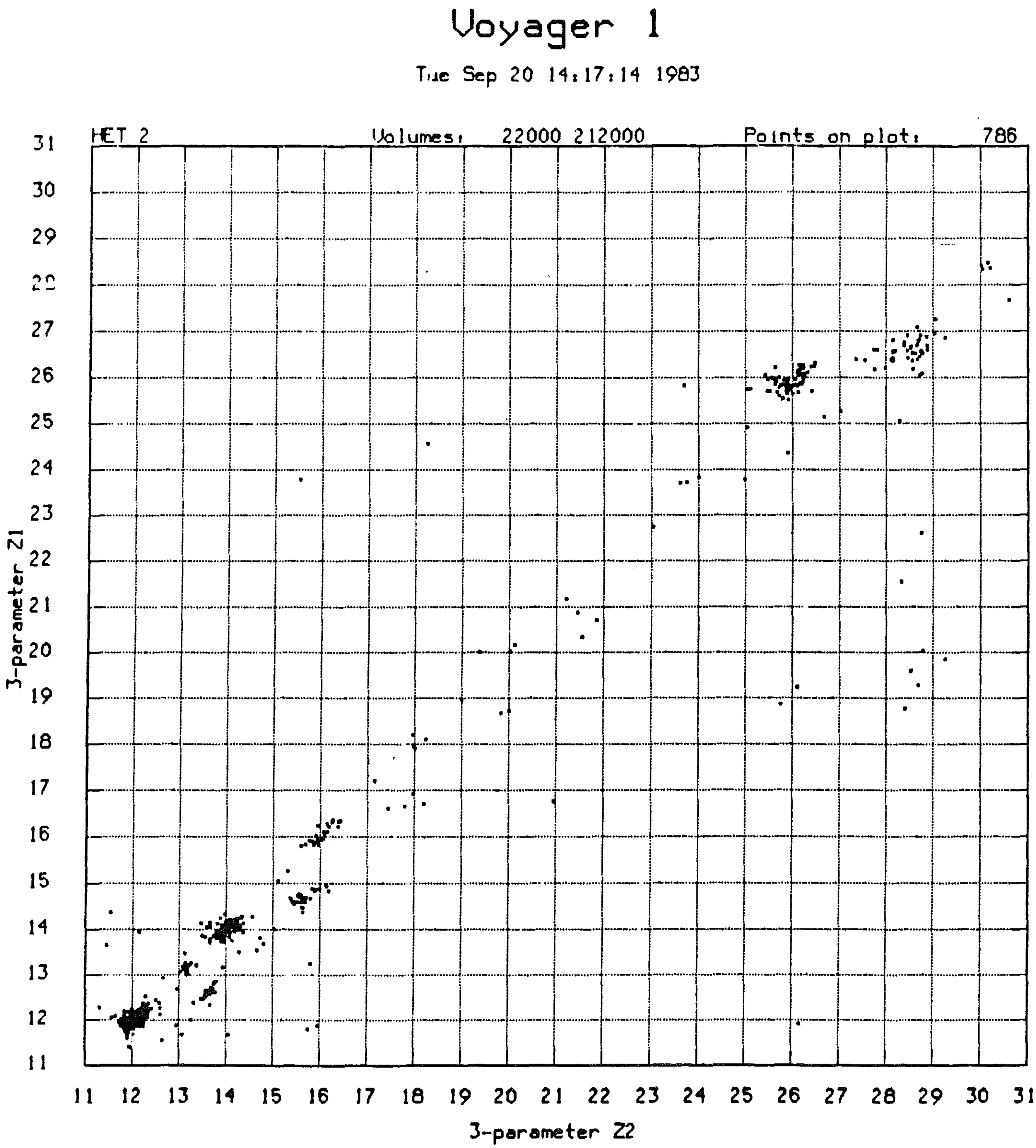

Fig. 4. Z1 vs. Z2 plot of 3-parameter solar flare data from Voyager 1 HET 2. The cluster of events centered around (Z1 = 26.5, Z2 = 28.5) consists of Fe events affected by PHA multiplication in the A2 ΔE-detector. Note similar clusters associated with the elements Mg and Si, and possibly with Na, Al, S and Ni as well.

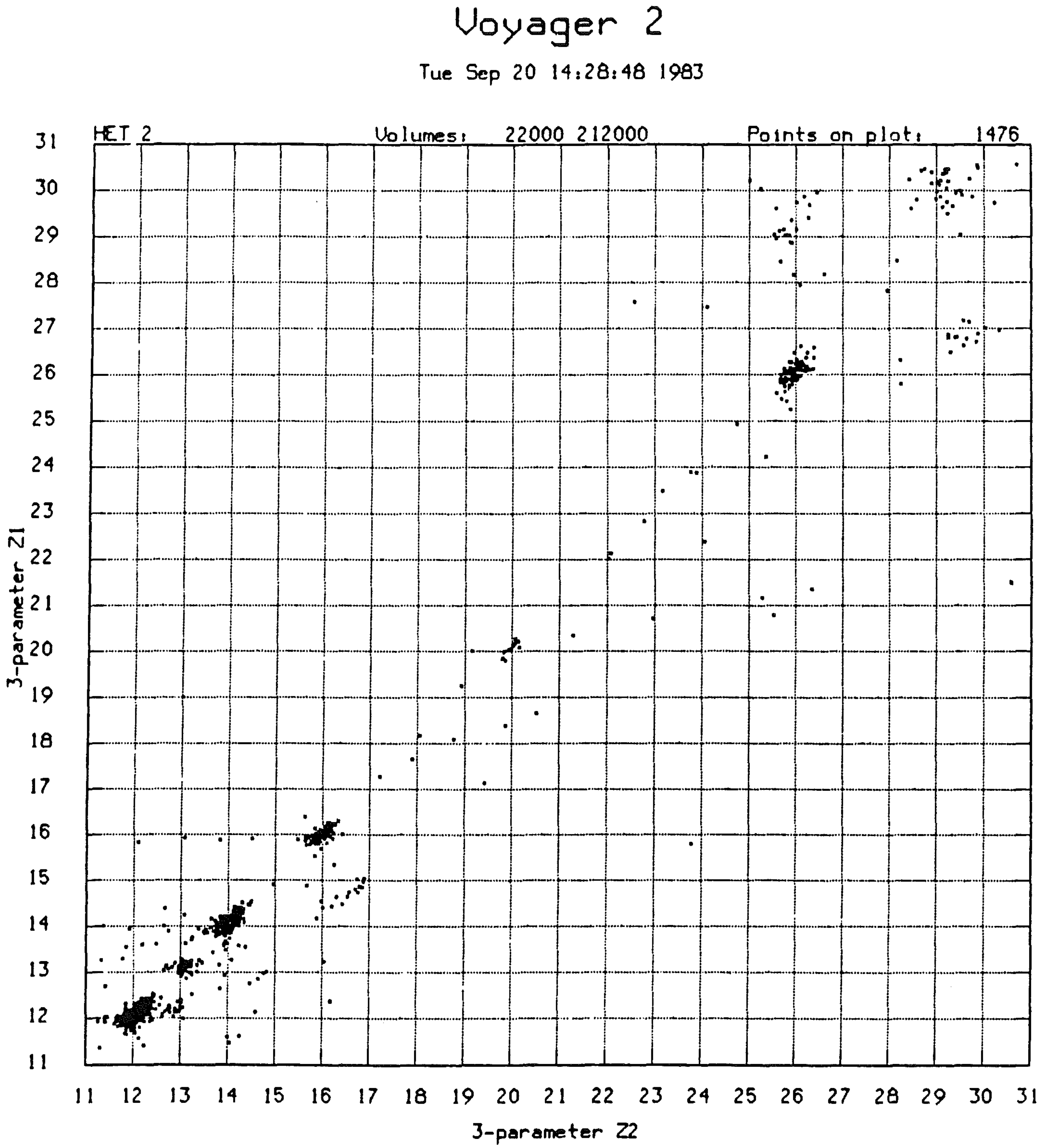

Fig. 5. Z1 vs. Z2 plot of 3-parameter solar flare data from Voyager 2 HET 2. In this telescope the multiplication effect occurs in both ΔE detectors, individually or simultaneously. The cluster located at (Z1 = 27.0, Z2 = 29.5) consists of Fe events exhibiting PHA multiplication in the A2 ΔE-detector, corresponding to the effects in Figs. 2 - 4. The cluster at (Z1 = 29.5, Z2 = 26.0) consists of Fe events showing the multiplication effect in the A1 ΔE-detector, while the A2 PHA is normal. Since A1 is not involved in the calculation of Z2, Z2 is normal for such events, while Z1 is high on account of the anomalously high A1 PHA. The cluster at (Z1 = 30, Z2 = 29) consists of Fe events showing multiplication in *both* ΔE-detectors. In this case both measurements of Z are excessively high, allowing for possible confusion with other charges. The summed event count for the three anomalous Fe clusters is about half of the total Fe. Note also the occurrence of the A2 PHA multiplication effect in lower elements such as Si.

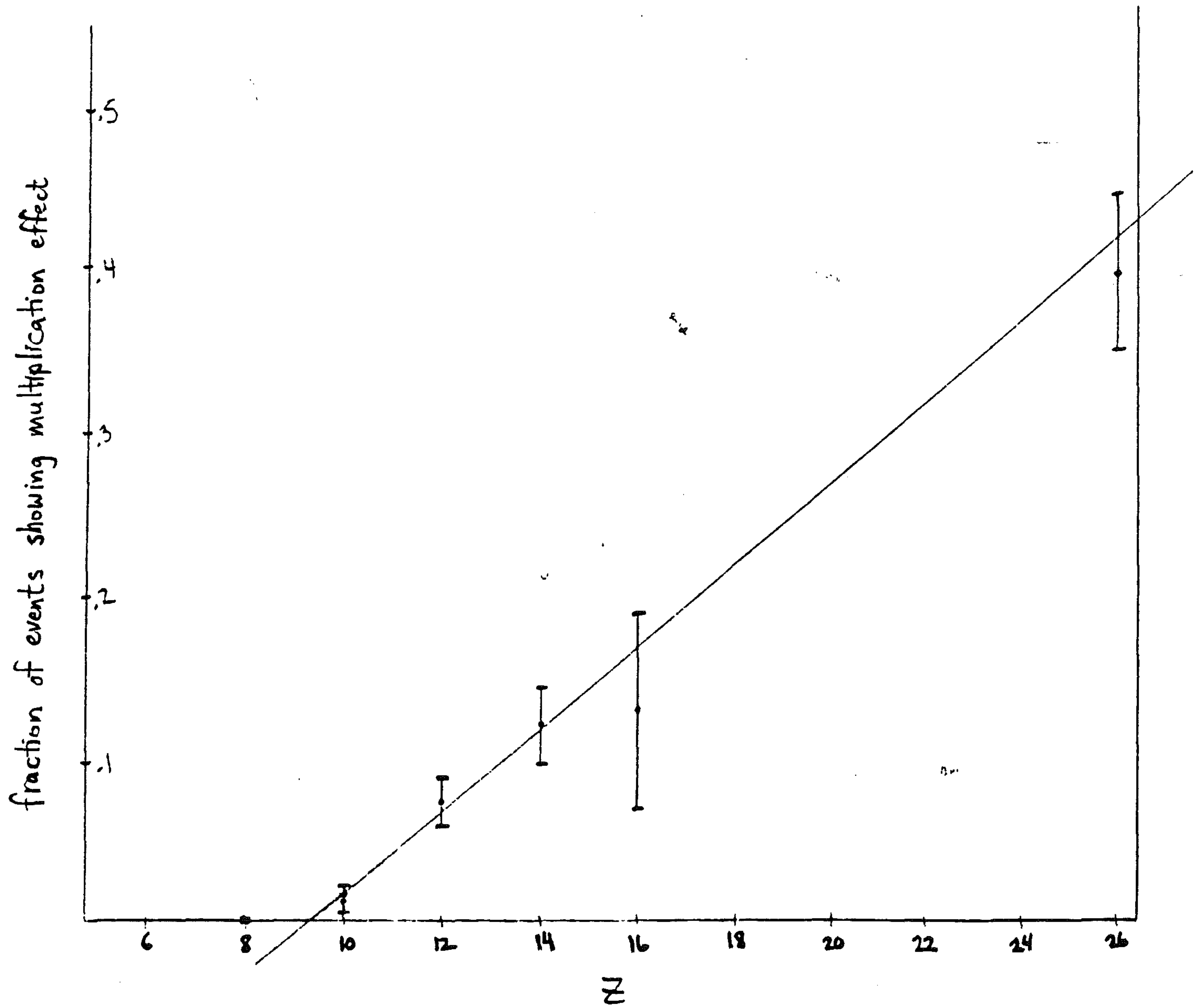

Fig. 6. Fraction of Voyager 1 HET 2 3-parameter events showing the multiplication effect, as a function of Z, obtained from the data in Fig. 4. Note that the fraction is negligible below Z = 10, and that it approaches 50% of all events for Fe. This curve can be used to estimate the fraction affected for elements where poor statistics preclude a direct count.

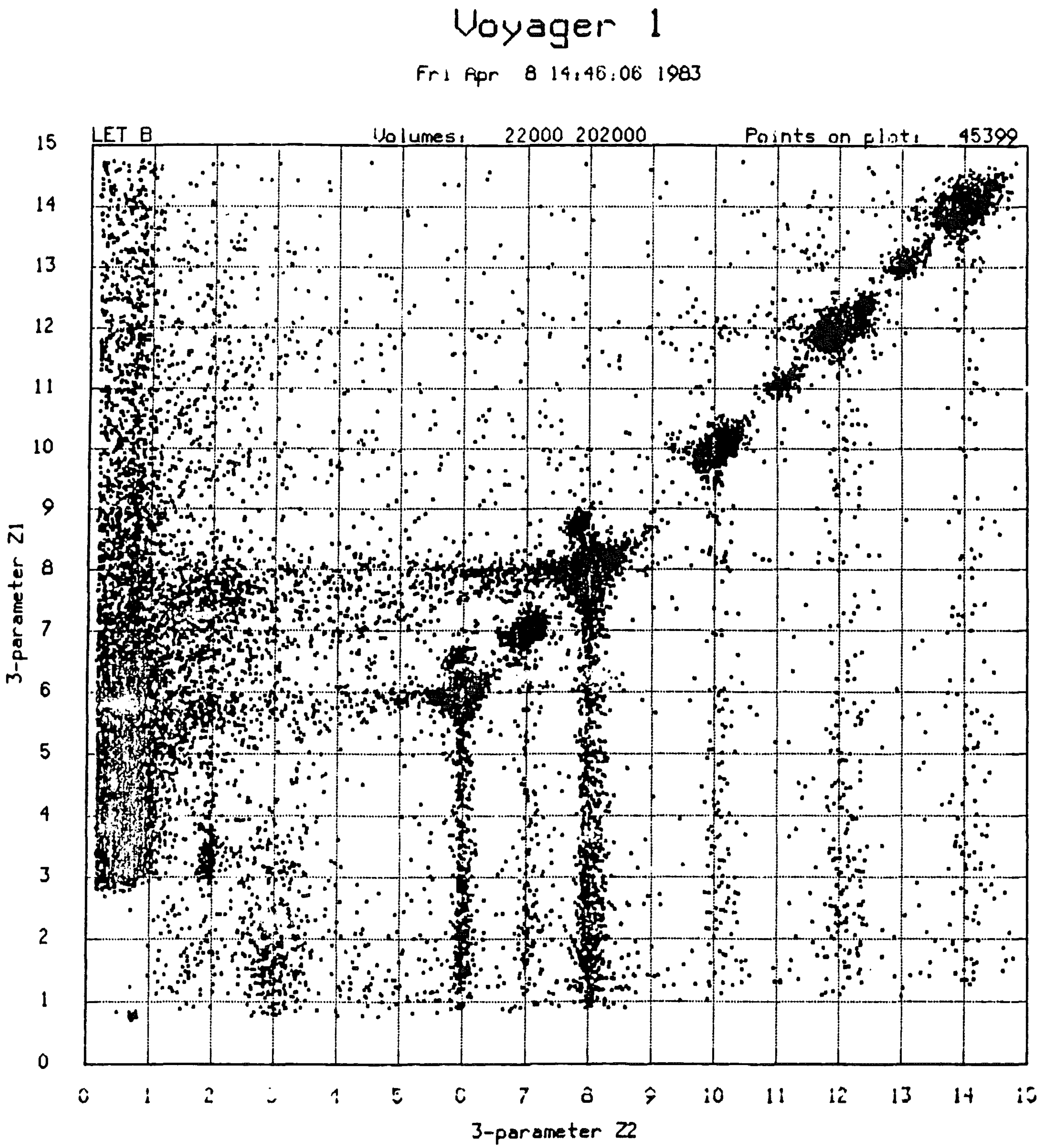

Fig. 7. Z1 vs. Z2 plot of Voyager 1 LET B 3-parameter data from flare period #7. The small event clusters above and slightly to the left of the main clusters along the diagonal (most prominent for C and O) are LET A events that were mis-tagged as LET B events, and subsequently analyzed as such. They constitute about 1% of the normal events for each element in this data set.

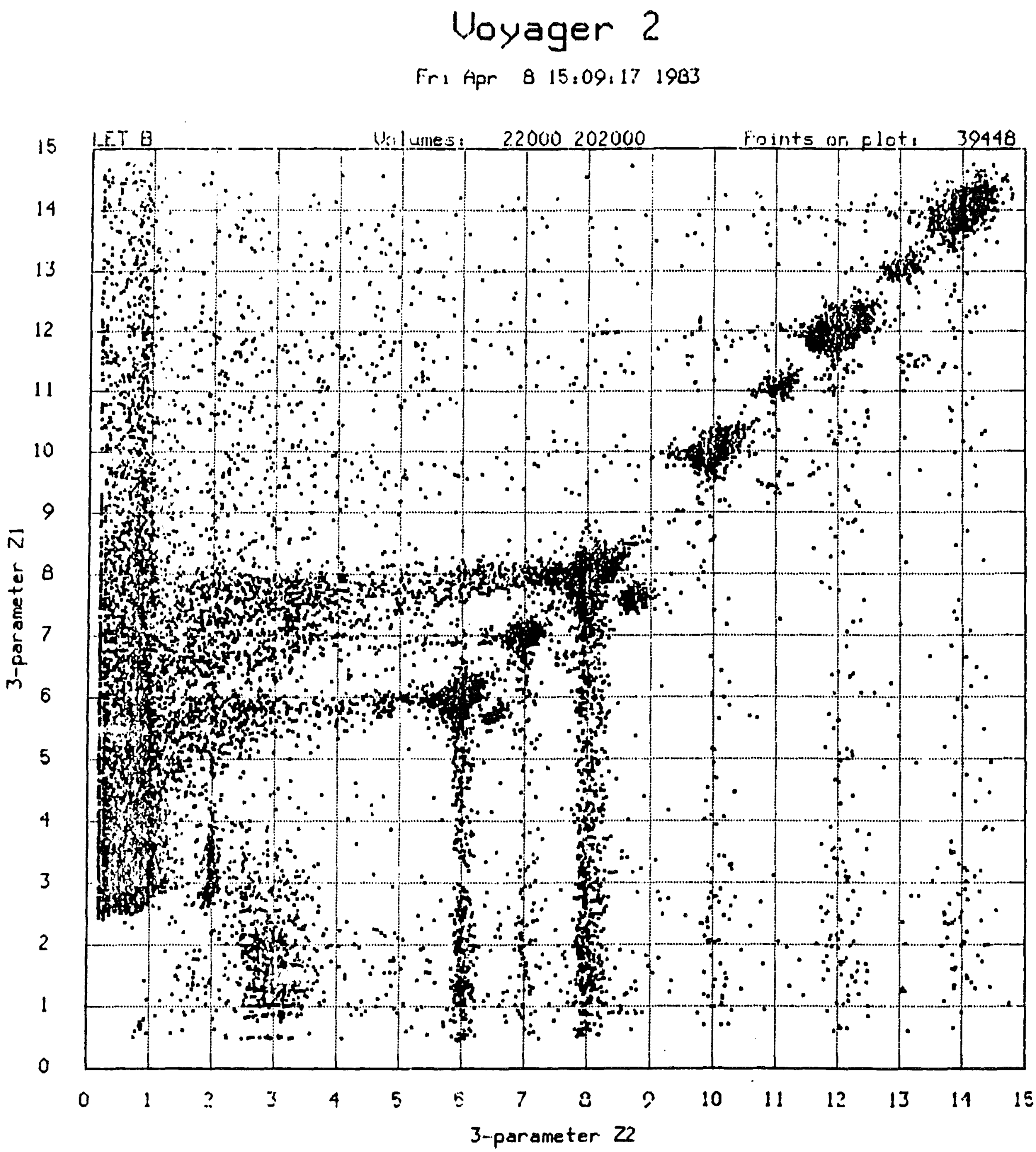

Fig. 8. Z1 vs. Z2 plot of Voyager 2 LET B 3-parameter data from flare period #7. The small event clusters below and to the right of the main clusters along the diagonal (most prominent for C and O) are LET A events that were mistagged as LET B events, and subsequently analyzed as such. They constitute about 1% of the normal events for each element in this data set.

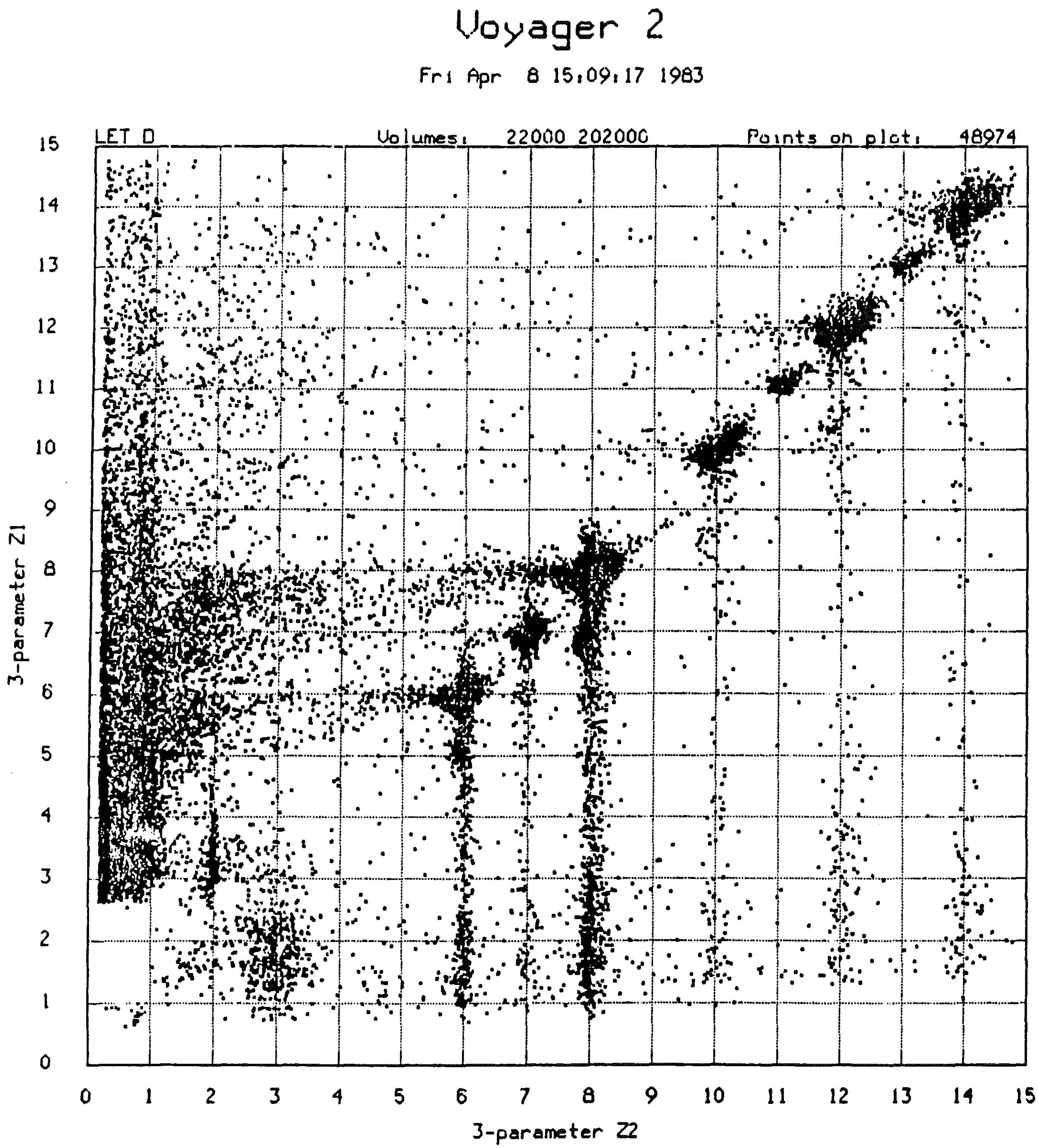

Fig. 9. Z1 vs. Z2 plot of Voyager 2 LET D 3-parameter data from flare period #7. The small event clusters almost directly below the main clusters along the diagonal are LET C events that were mis-tagged as LET D events, and subsequently analyzed as such.

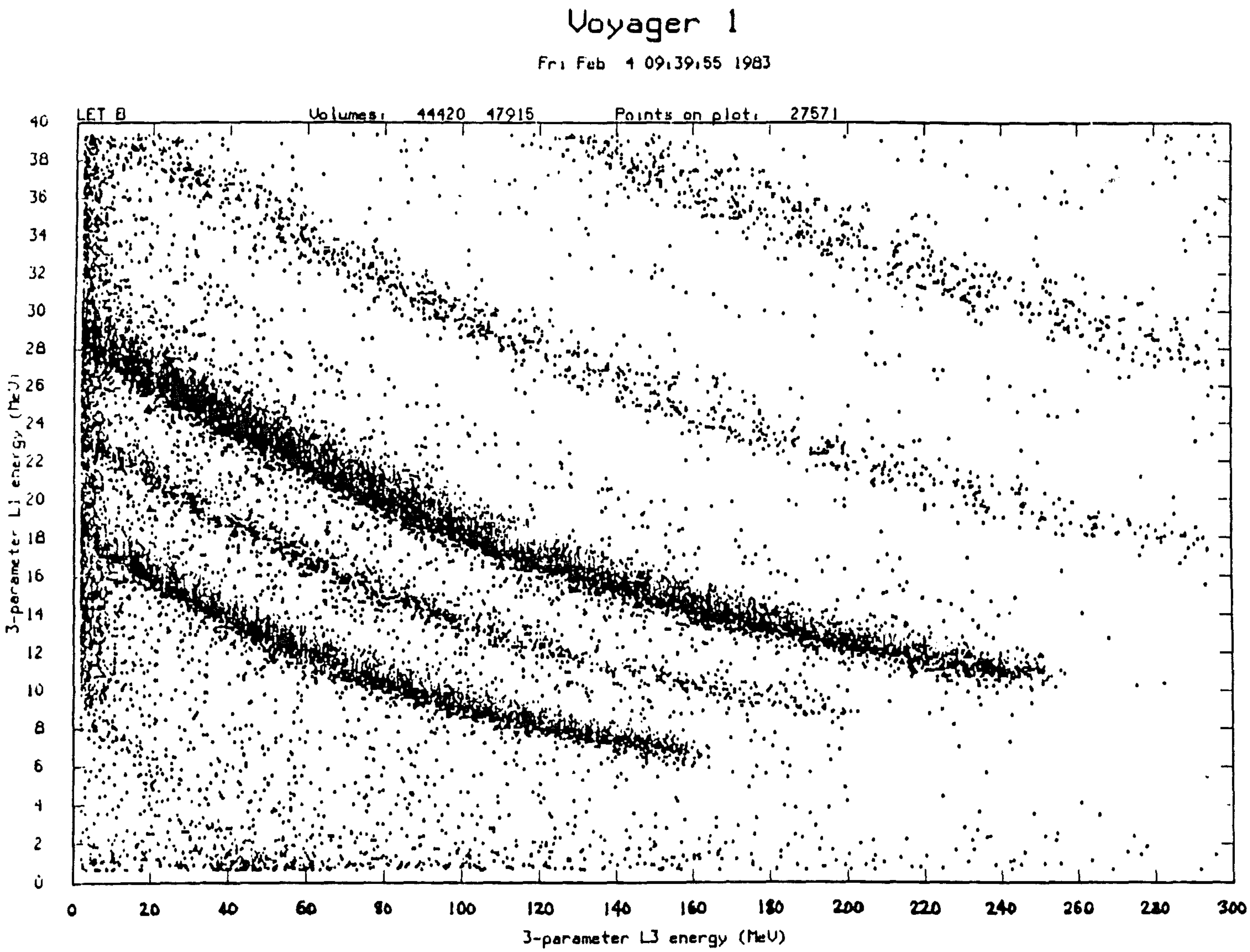

Fig. 10. ΔE vs. E' (L1 vs. L3) plot of Voyager 1 LET B 3-parameter data from flare period #7. The element "tracks" from C, N, O, Ne and part of Mg are apparent. The faint "ghost track" appearing above oxygen is due to LET A oxygen events mis-tagged as LET B events, and subsequently analyzed as such. It cannot be real fluorine because (1) it would imply a fluorine abundance orders of magnitude too high; (2) real fluorine should be found slightly above rather than slightly below the midpoint of the O and Ne tracks; (3) L2 vs. L3 plots of the same events show no perceptible track in this position; (4) all ΔE vs. E' plots of LET A and C telescope data from the same time period show no perceptible track in this position.

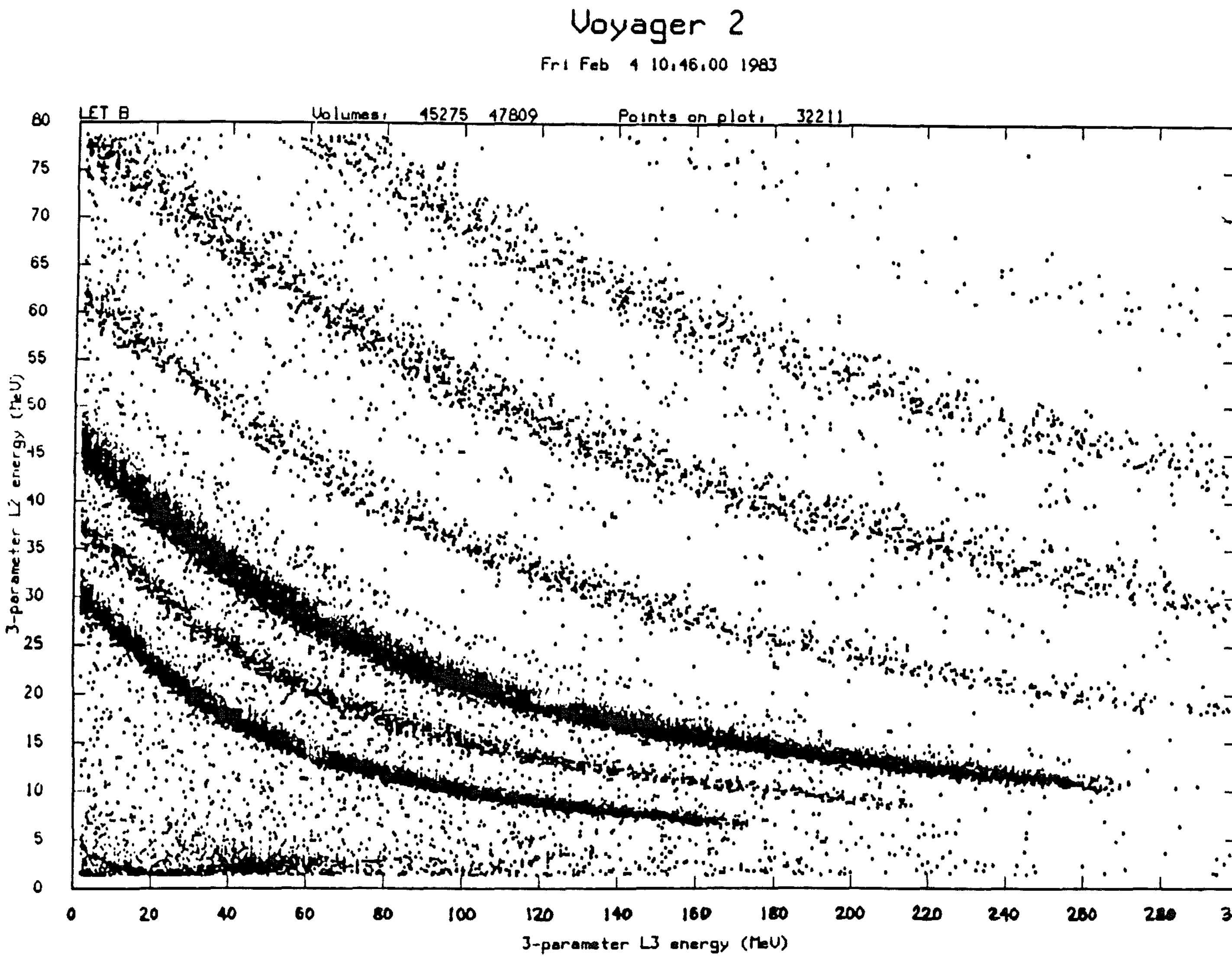

Fig. 11. ΔE vs. E' (L2 vs. L3) plot of Voyager 2 LET B 3-parameter data from flare period #7. The faint "ghost track" appearing just above oxygen is due to LET A oxygen events mis-tagged as LET B events, and subsequently analyzed as such.

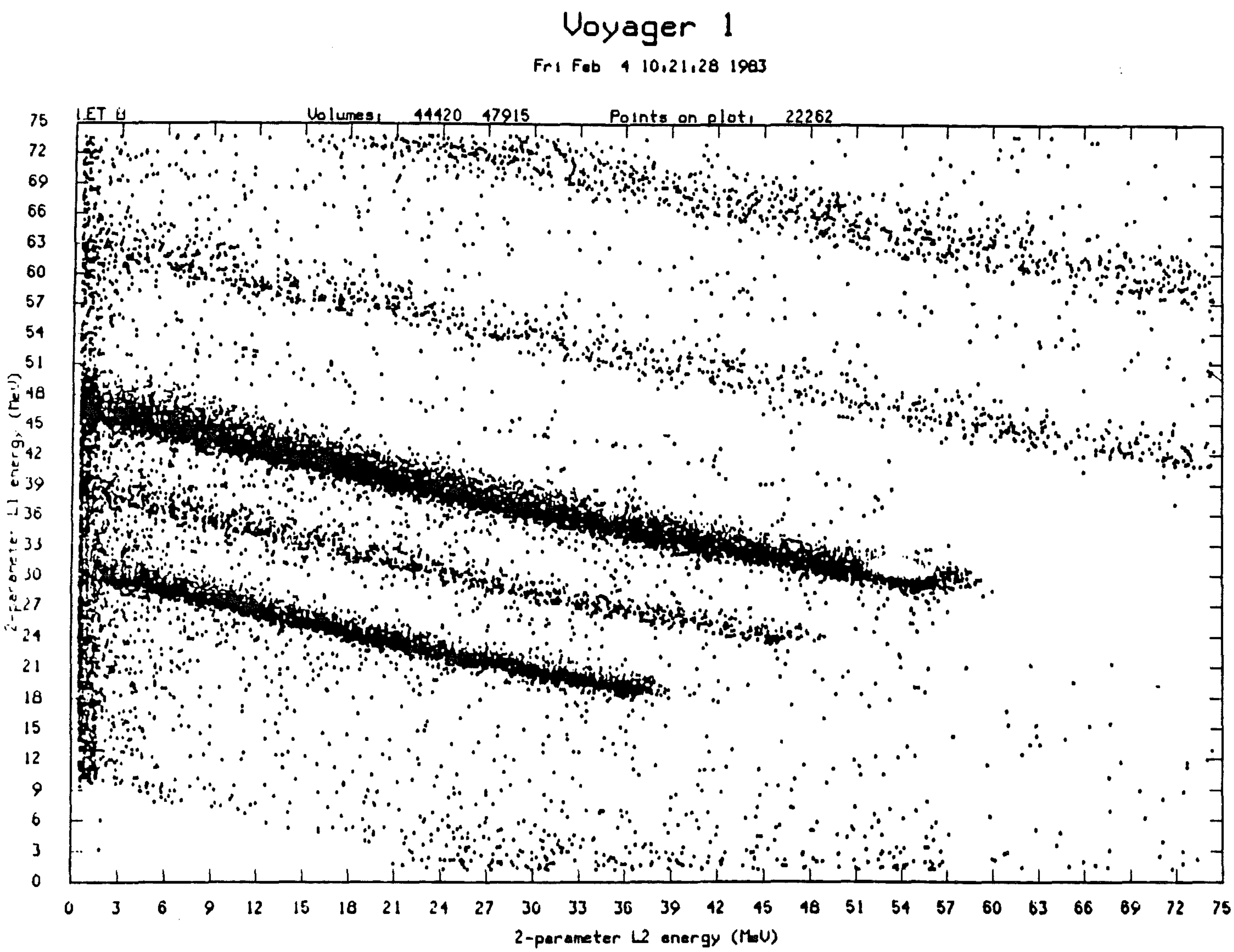

Fig. 12. ΔE vs. E′ (L1 vs. L2) plot of Voyager 1 LET B 2-parameter data from flare period #7. The faint "ghost track" appearing just above oxygen is due to LET A oxygen events mis-tagged as LET B events, and subsequently analyzed as such.

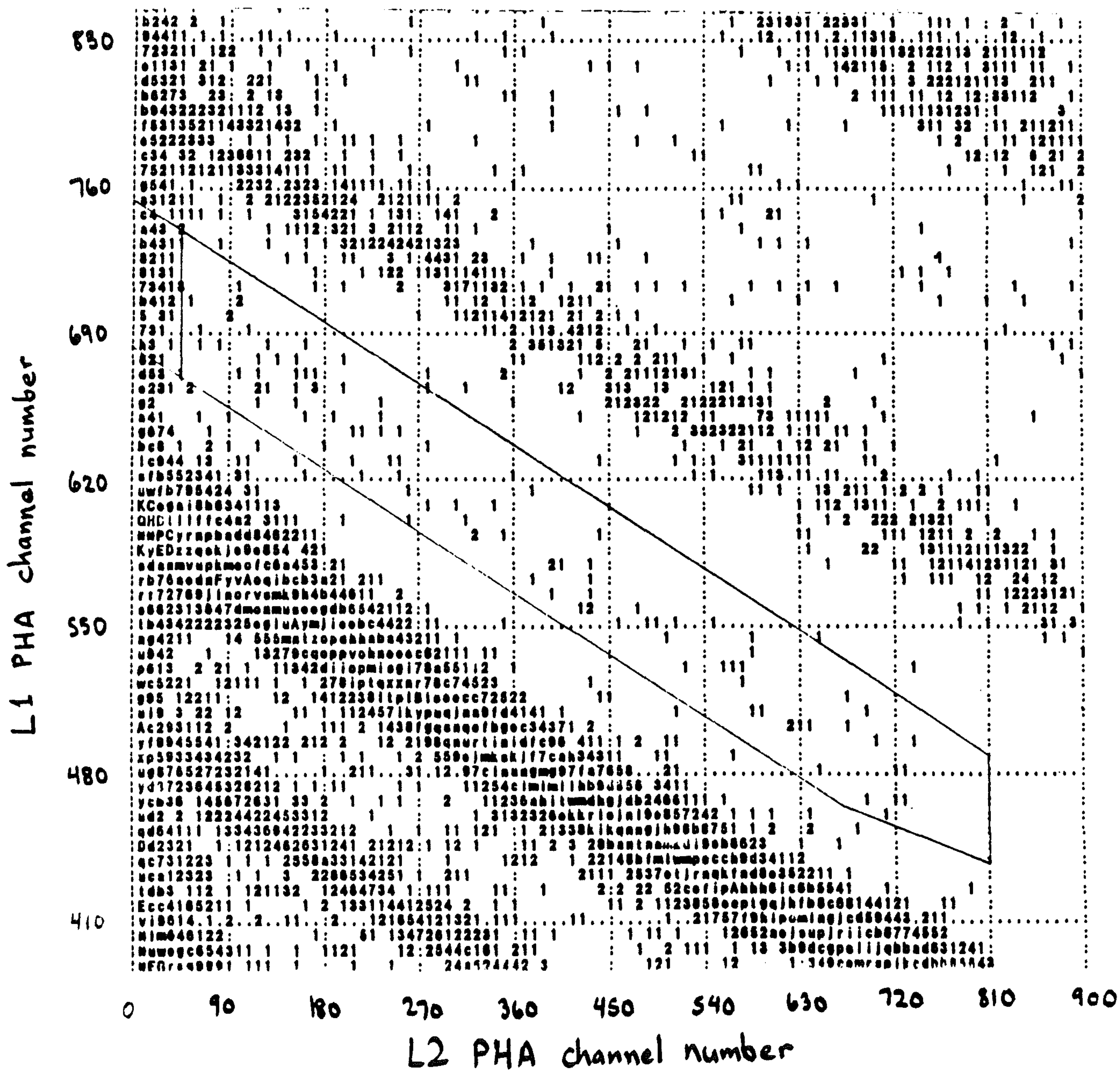

Fig. 13. L1 vs. L2 raw pulse height plot of Voyager 1 LET B 2-parameter data from flare period #7. This is the same data appearing in Fig. 12. The faint "ghost track" (boxed) is due to LET A oxygen events mis-tagged as LET B events. This can be shown by comparing it to the location of the oxygen track in Fig. 14.

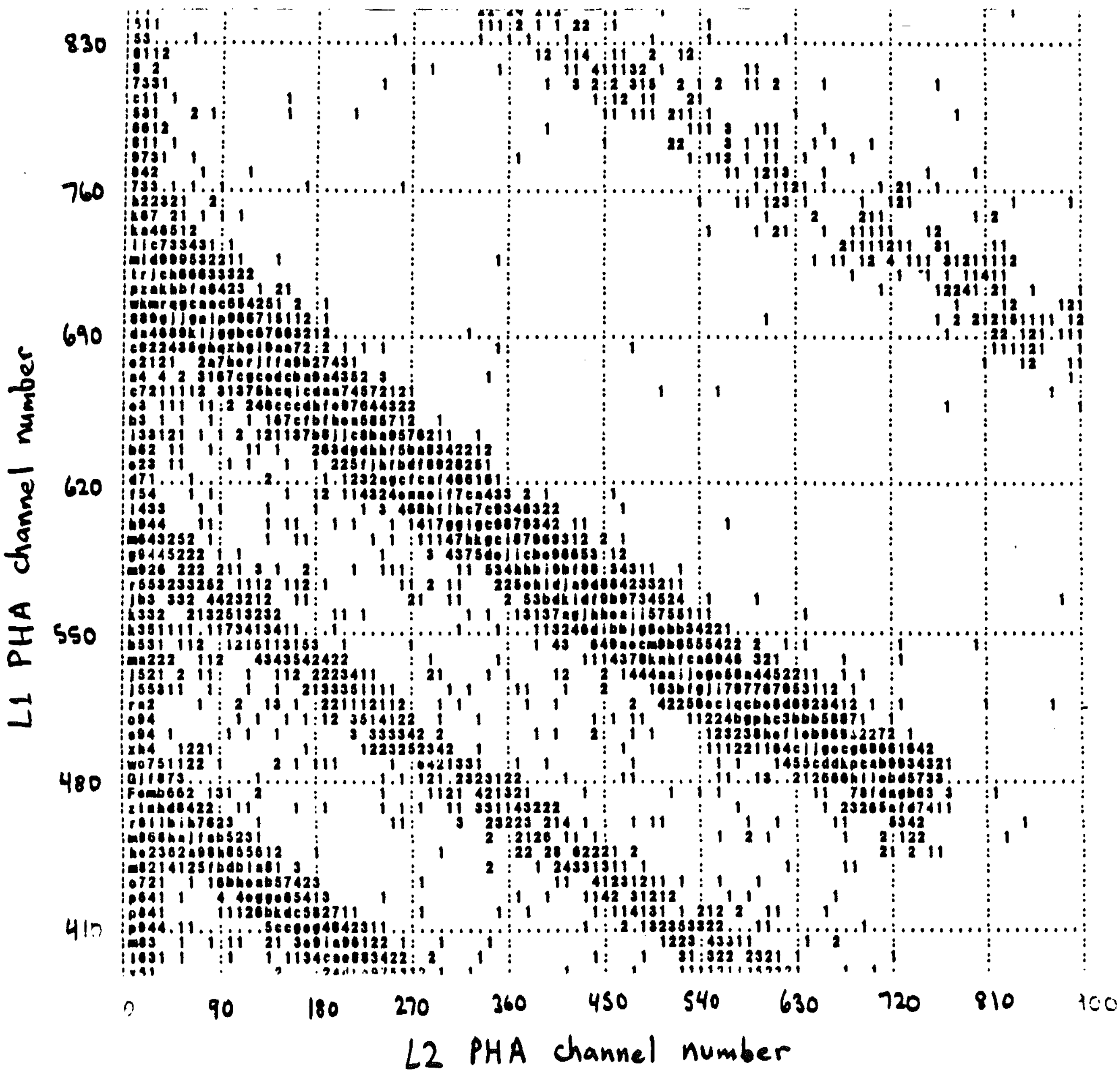

Fig. 14. L1 vs. L2 raw pulse height plot of Voyager 1 LET A 2-parameter data from flare period #7. The oxygen track coincides exactly with the "ghost" track in Fig. 13. Note also the absence of any similar "ghost track" in this plot.

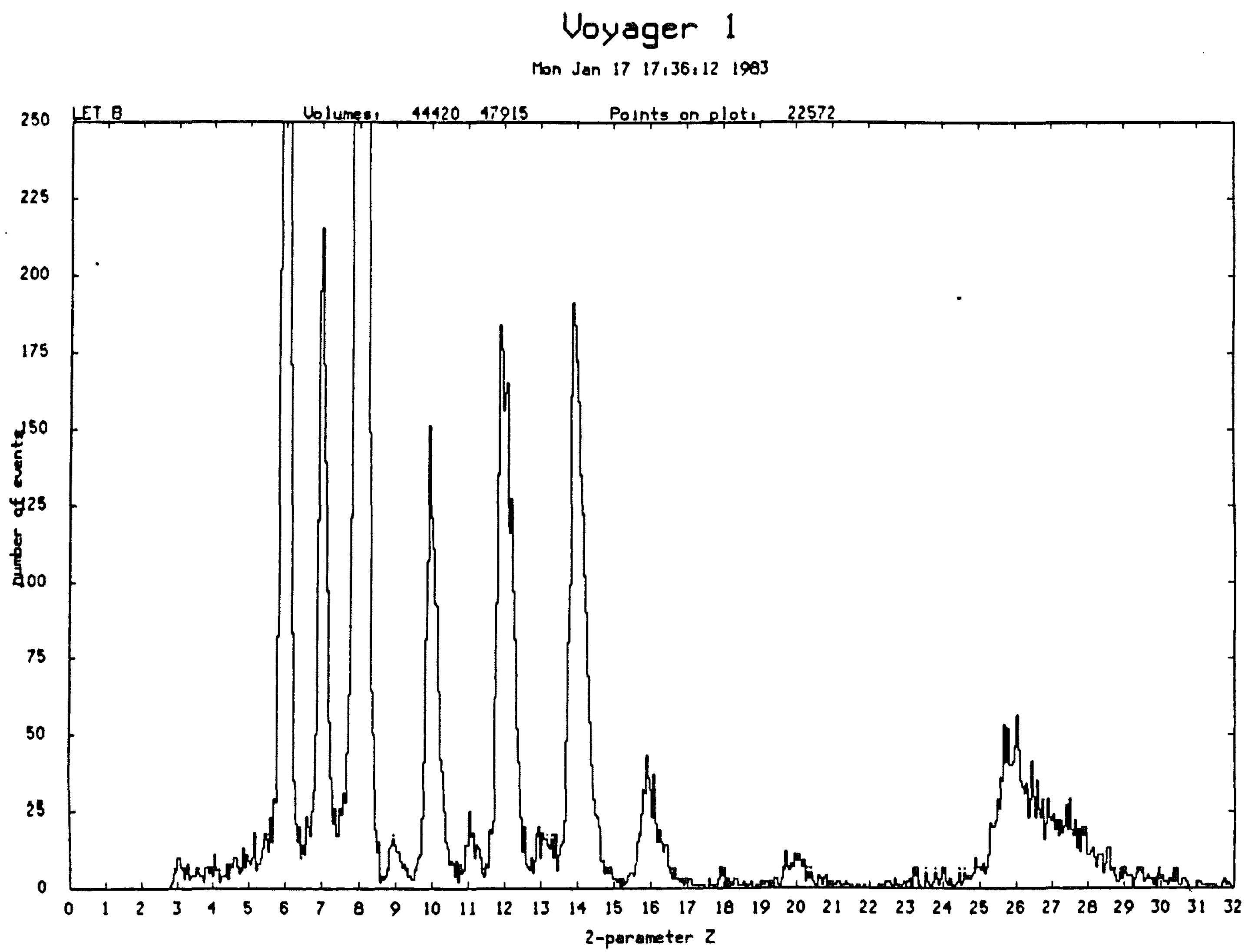

Fig. 15. Charge histogram of Voyager 1 LET B 2-parameter data from flare period #7. Note the small "fluorine peak" produced by the mis-tagged LET A oxygen events. No such peak appears in analogous plots for the other telescopes.

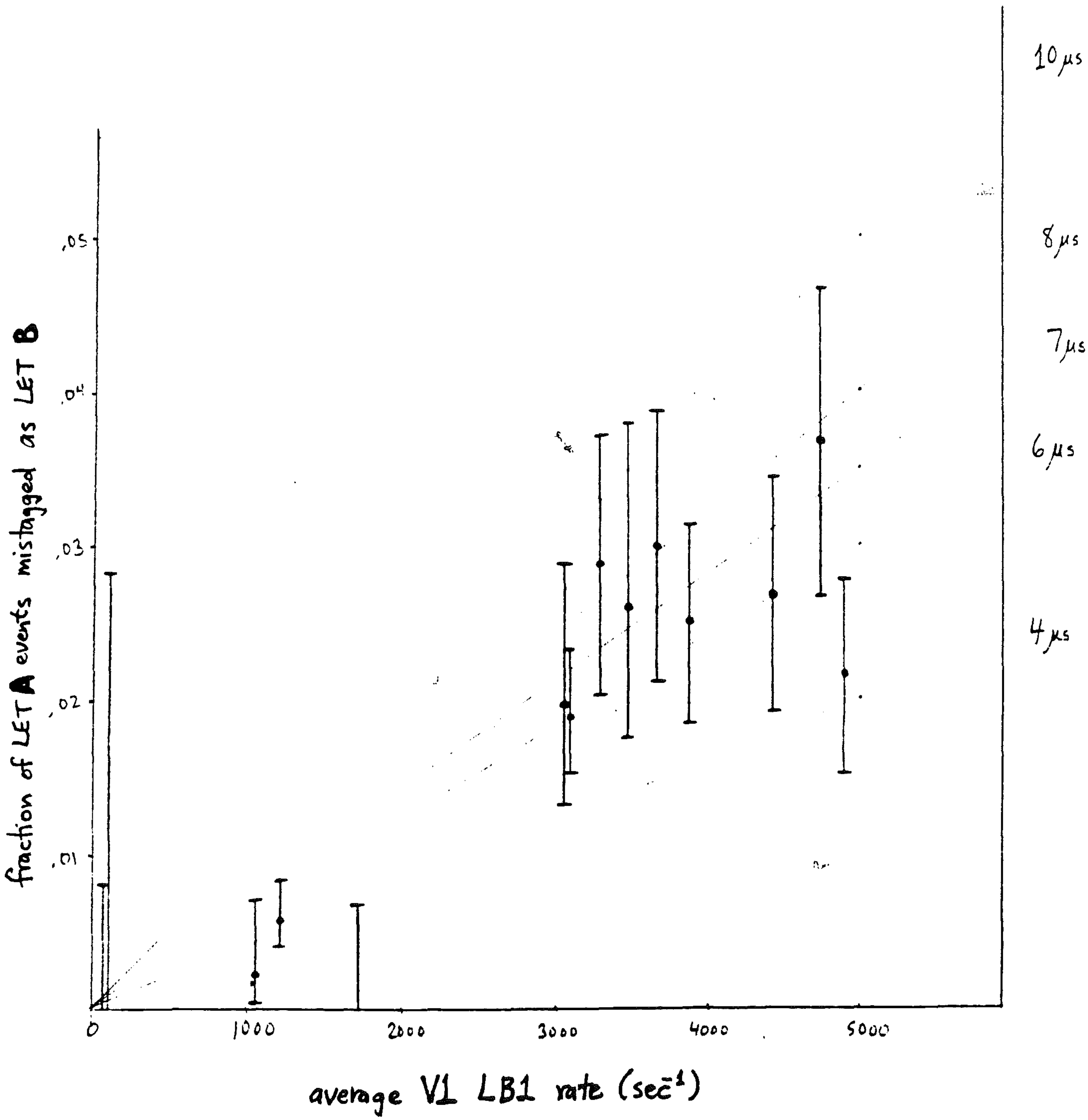

Fig. 16. Plot of fraction of Voyager 1 LET A events mis-tagged vs. Voyager 1 LET B L1 singles rate, obtained from flare period #7 data. The data are consistent with a time constant of ~6μs, in agreement with later laboratory tests.

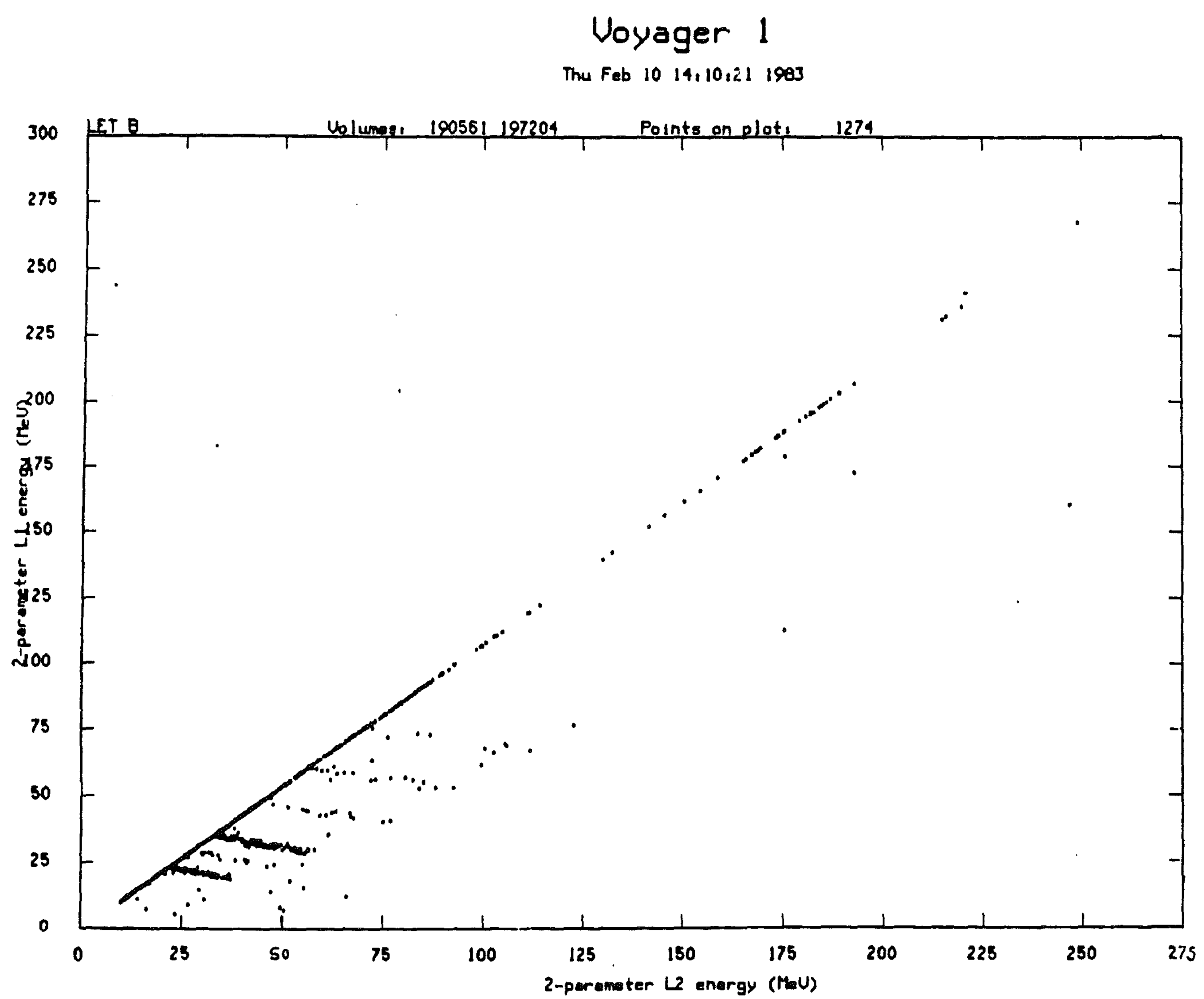

Fig. 17. ΔE vs. E′ (L1 vs. L2) plot of Voyager 1 LET B 2-parameter data from flare period #24, showing the effect of the Block I PHA problem. If PHA2 (L2) is greater than PHA1 (L1), the event is read out normally, but if PHA1 is greater it is read out in place of the correct PHA2, resulting in the diagonal line of events for which only one pulse height is known. Thus only the higher-energy part of the 2-parameter energy range is recoverable. The value of PHA3 (L3) does not affect the situation since it is always essentially zero (and therefore less than PHA2) for 2-parameter events.

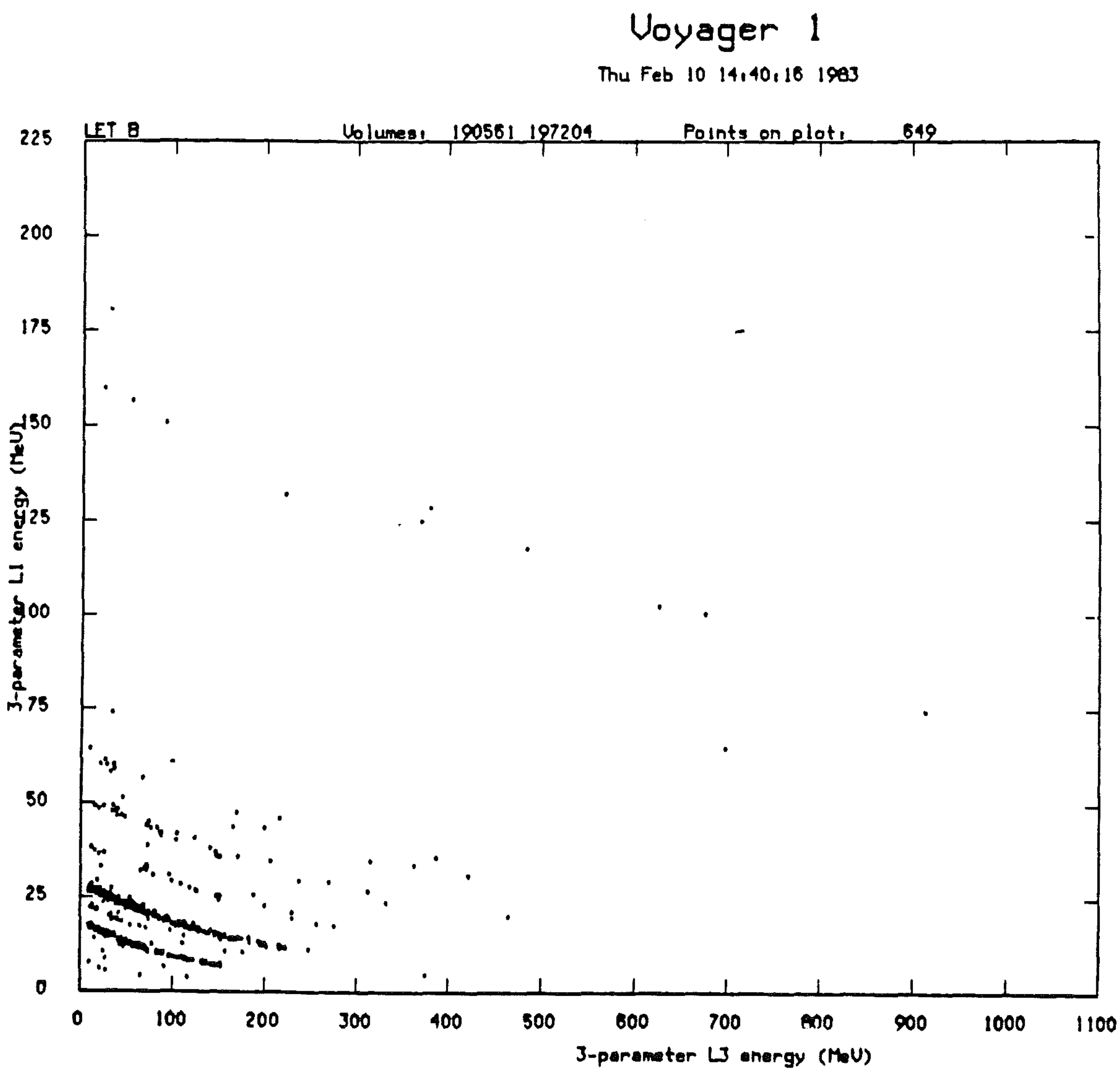

Fig. 18. ΔE vs. E' (L1 vs. L3) plot of Voyager 1 LET B 3-parameter data from flare period #24. Although this data is affected by the Block I PHA problem, this problem affects only PHA2 (L2) and is therefore not evident in this plot. Clearly these events may be analyzed as 2-parameter events if the L2 pulse height is incorrect.

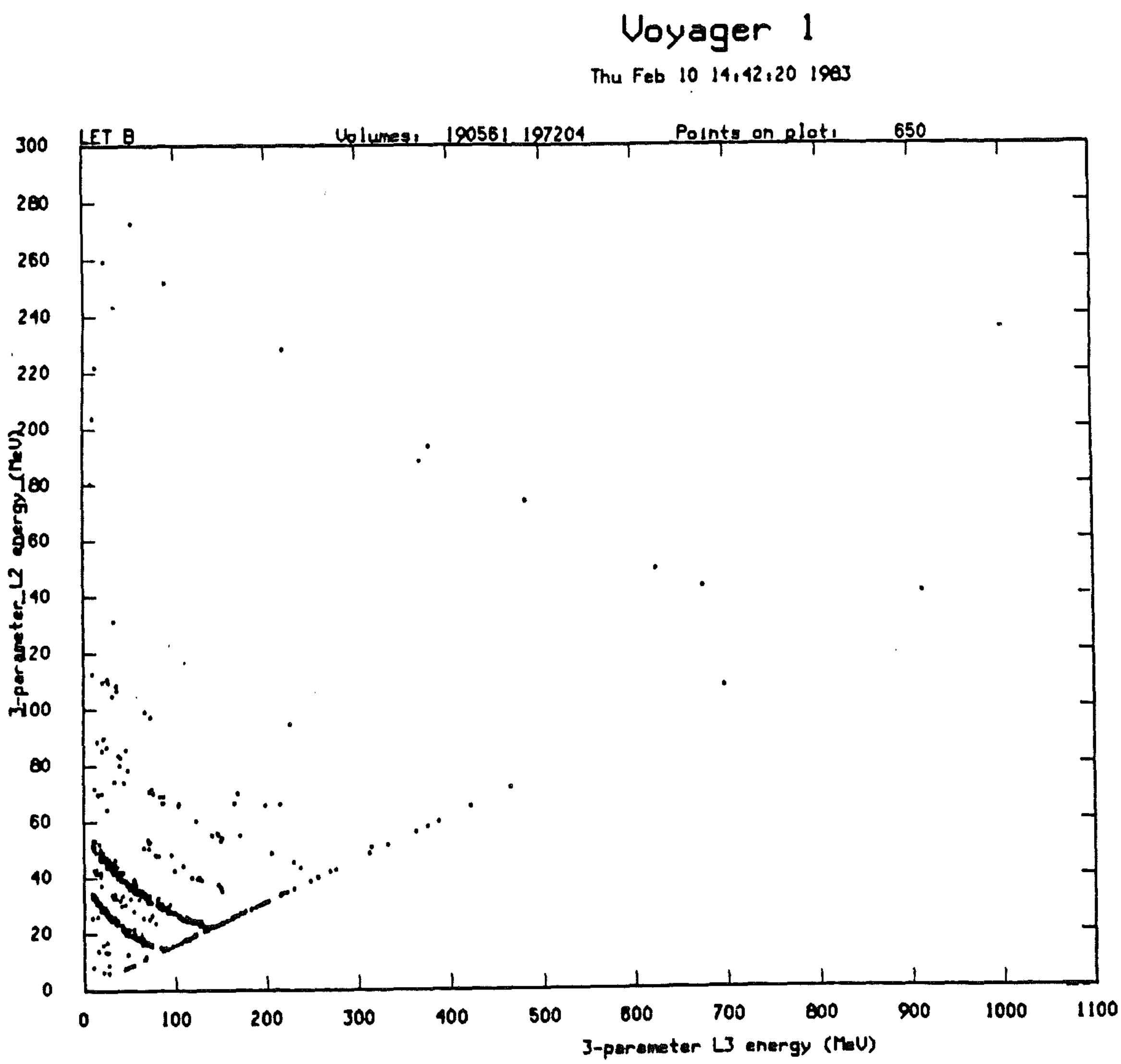

Fig. 19. ΔE vs. E' (L2 vs. L3) plot of Voyager 1 LET B 3-parameter data from flare period #24, showing the effect of the Block I PHA problem. If PHA2 (L2) is greater than PHA3 (L3), the event is read out normally, but if PHA3 is larger it is read out in place of the correct PHA2, resulting in the diagonal line of events for which only two pulse heights are known; these may be analyzed as 2-parameter events. The value of PHA1 (L1) does not affect the situation since it is always less than PHA2 for 3-parameter events on account of the inverse dependence of dE/dx on incident energy.