21, p. 181.

[8]R. J. Glauber, in Quantum Optics and Electronics, edited by C. De Witt, A. Blandin, C. Cohen-Tannaudji (Gordon and Breach Publishers, Inc., New York, 1965), p. 63.

[9]We use the notation of M. C. Wang and G. E. Uhlenbeck, Rev. Mod. Phys. 17, 323 (1945), i.e., we call $W_1(y)$ the probability distribution of finding a random variable y (either photoelectric count number n or field amplitude E) in given range $(y, y+dy)$ at time t; then call the joint probability distribution of finding y "around" y_1 and y_2 at times t_1 and t_2, etc.

[10]Since the field we have been investigating is a stationary Gaussian field, a measurement of the frequency spectrum would be sufficient to determine the whole process (see, e.g., Wang and Uhlenbeck, Ref. 9). The application of our method to non-Gaussian fields, however, supplies information which is not contained in the spectrum.

[11]D. Slepian, Bell System Tech. J. 37, 163 (1958).

[12]T. P. McLean and E. R. Pike, Phys. Letters 15, 318 (1965).

[13]Since we make observations within a coherence area of the field, we specialize Eq. (14.61) of Ref. 8 for equal-space positions and different times t_1, t_2.

[14]Use of a bidimensional generating function has been suggested to us by Professor R. J. Glauber.

[15]Derivation of Eq. (5) proceeds as follows: By slight modification of Eq. (17.23) of Ref. 8 for the case of very short T, one finds

$$Q(\lambda) = \int P(\{\alpha_k\}) \exp[-\lambda |E(t, \{\alpha_k\})|^2 T] \Pi_k d^2\alpha_k.$$

This can be easily generalized at two different times t_1, t_2, under the assumption (usually realized) that $t_2 - t_1$ is long enough compared with the atomic relaxation times of the photodetector. Furthermore, one should recall, that by the same definition of the distribution function $W(E)$ for the field, an average over $P(\{\alpha_k\})$ is

[16]E. T. Whittaker and G. N. Watson, Modern Analysis, (Cambridge University Press, New York, 1940), Chap. XVI.

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EVIDENCE FOR A SOURCE OF PRIMARY GAMMA RAYS*

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Since Morrison[1] suggested the possibility of gamma-ray astronomy in 1958, there has been a growing interest in the field. Many theoretical reasons for expecting a measurable primary γ-ray flux at the top of the earth's atmosphere have been discussed. These are summarized in four excellent reviews of the field[2-5] which have been published in the past two years. To date, several experiments have been reported[6-13] in which a variety of instruments have been used to search for point sources. None of these experiments yielded any definite evidence for the existence of localized source intensities. Cobb, Duthie, and Stewart[11] have set upper limits of 5×10^{-5} cm^{-2} sec^{-1} from the Crab Nebula and a few times 10^{-4} cm^{-2} sec^{-1} from three other celestial objects. Frye and Smith[12] have also set upper limits of a few times 10^{-4} cm^{-2} sec^{-1} from a variety of celestial objects. Similar results were reported by Kraushaar et al.[6] In this Letter we wish to report the existence of an anomalously high count of gamma rays from the direction of the constellation Cygnus. This high count was associated with an energy spectrum which appears to differ significantly from the spectrum of secondary γ rays generated by cosmic rays interacting in the atmosphere above the balloon-borne detection system.

The present detection system is similar to that described elsewhere[11] except for a change in the location of the anticoincidence counter. A scintillation-and-Cherenkov telescope was used as the trigger for the detection of gamma rays converting in a $\frac{1}{16}$-in. lead radiator placed between two spark chambers. The system is estimated to become very inefficient at detecting gamma rays with energies less than 50 MeV. The conversion efficiency for vertically incident γ rays approaches 19% at high energies. The area solid angle factor was 25.8 cm^2 sr. The two spark chambers were used to identify the γ rays and to determine the direction of the incident photon. The data reported here represents observations made during the first $9\frac{1}{2}$ h of a balloon flight at 3-mm residual atmospheric pressure. The balloon was launched from Palestine, Texas on 23 October 1965 and reached altitude at 19-h 44-min U.T. The flight remained at a constant altitude except for a short period at sunset, when the balloon descended for about one hour corresponding to an average increase of 15% in residual atmospheric pressure. Assuming that all detected γ rays were of secondary origin, the effect of this small increase in pressure can be eliminated by weighting the events, where indicated, in proportion to the reciprocal of the pressure at which they occur; a residual pressure of 3 mm is considered normal. This linear normalization is well justified on the basis of experimental results, both with counter telescopes and the instrument used here over similar ranges of atmospheric pressures.

As in our previous report,[11] we observe both "singles" and "pairs." "Singles" are those events in which only one track is observed in the lower and none in the upper spark chamber, whereas events in which two tracks are identified in the lower chamber and none in the upper are classified as "pairs." There were 395 "single" events within the geometry of the counter telescope during the $9\frac{1}{2}$ h, but none of the results on our observation of singles will be presented here.

A total of 488 "pairs" were detected within our geometry during the first $9\frac{1}{2}$ hours of flight. Assuming a detection efficiency of 14%, this represents a flux of $(3.94 \pm 0.18) \times 10^{-3}$ cm^{-2} sec^{-1} sr^{-1} at a residual pressure of 3 mm of mercury.[14] The histogram in Fig. 1 shows the

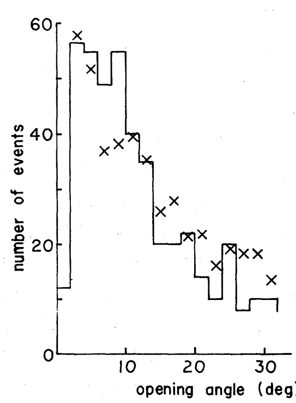

FIG. 1. Opening-angle distribution of positron-electron pairs observed during the flight. The crosses indicate the result of a Monte Carlo calculation.

distribution in the observed opening angles of the "pairs"; the opening angles are predominantly a result of multiple Coulomb scattering. The distribution has a broad maximum extending from 2 to 10°, then falls off slowly. The apparent deficiency of events with opening angles less than 2° may be experimental insofar as many such tight pairs could be classified as "singles" and would thus be absent from the present sample. The crosses represent the results of a Monte Carlo calculation[15] of the response of a similar system to the spectrum of secondary γ rays produced in the atmosphere as given by Svensson.[16] The calculated distribution involved 2588 events in the region of opening angles shown, but in the figure it has been normalized so that the number of events with opening angles between 2 and 32° is equal to the number of corresponding events in the experimental distribution. The two distributions are well matched, supporting the belief that the majority of the events are γ rays generated in the atmosphere above the detector by the nuclear interaction of cosmic rays.

The uncertainty in the direction of a gamma ray will be of the order of $\theta/2$, where θ is the observed opening angle. The fact that Fig. 1 shows many events with large θ indicates the difficulty in using the system for experiments requiring high directional resolution for the incident γ rays.

An IBM 7074 computer was used to determine the arrival direction of each γ ray and to tally the pressure-weighted number of events in cells 3° wide in right ascension (R.A.) and 3° wide in declination (dec). An examination of this tally indicated an interesting region in the vicinity of 20-h R.A. The number of events in each cell was small, however, and to improve the statistics, we have to accumulate data in larger cells. Since the detector efficiency varies with zenith angle, there will be a variation of counting rate with declination. We elected, therefore, to assembly the data into cells 9° wide R.A. and 30° wide dec, each cell centered on 31.5° N, the approximate declination of the zenith throughout the flight. Each cell then had an equal exposure. Furthermore, the collection of the data into the larger cells more realistically reflects the large uncertainty in the arrival direction of those events with large θ. Table I indicates the results of this analysis for pairs whose opening angles were less than 30°. The largest number of events

Table I. The weighted number of events for 16 cells on the sky, each cell being centered on 31.5° dec. The cells are 30° wide dec and 9° wide R.A. The first column indicates the right ascension at the center of each cell.

R.A. (h)	Number
16.1	19.55
16.7	20.08
17.3	10.73
17.9	16.35
18.5	23.45
19.1	13.79
19.7	31.80
20.3	20.35
20.9	12.27
21.5	16.67
22.1	13.89
22.7	27.12
23.3	20.79
23.9	24.37
24.5	15.62
25.1	16.68

was found to lie at about 20 h, where the total in the cell was 31.8 as opposed to an average rate of 19.5 per cell. With the exception of this cell, the data are well fitted to a Poisson distribution with a mean of 19. The probability of getting a single cell with an excess greater than 2.9 standard deviations (s.d.) is less than 1/300, and we have 16 cells in all. Shifting the boundaries of the 9° wide strips by whole 3° subcells did not significantly change the value of the maximum number of events per large cell. The investigation of events whose bisectors fell outside the declination limits of Table I showed no anomalously high number of events at any right ascension. The excess count in itself is interesting, but not really statistically significant. What is important, however, is that 2.9-s.d. excess comes at the time when the galactic plane transited and at the same time as another independent feature of the data showed an anomaly.

An approximately square region of the sky, about 18 by 18° and centered on 20-h R.A. and 35° dec, was selected for further analysis. This region was chosen on the basis that the anomalous counting rate indicated in Table I seemed to be due to events originating from a point somewhat north of the zenith direction at 20-h R.A. The opening-angle distribution of all events whose bisectors fell inside this

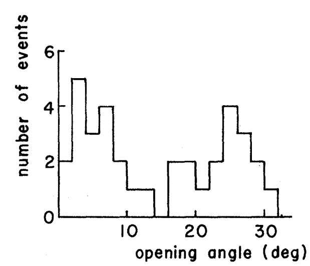

FIG. 2. Opening-angle distribution of positron-electron pairs whose bisectors fall in an 18 by 18° region of the sky centered on 20-h R.A. and 35° dec.

selected region was obtained. The results are shown in Fig. 2. The distribution is indeed quite different from the one shown on Fig. 1. A χ^2 test of the hypothesis that the data on Fig. 2 represented the same distribution as that on Fig. 1 had a confidence level of 0.3 %. The two distributions are therefore significantly different.

It remains to be established if the opening-angle distribution depends on the declination of the region. If this distribution is a function of the angle between the γ ray and the vertical axis of the detector, then the distribution for a region of the sky may depend on its declination. Thus all events in an 18° wide band of sky between 26 and 44° dec were selected. Of these events, those which fell in the 18 by 18° region of the sky centered on 20-h R.A. were eliminated and an opening-angle distribution of the remaining events was obtained. The resulting distribution was consistent with that of Fig. 1 and again different from that of Fig. 2; a χ^2 test comparing the distribution of Fig. 2 with the distribution for events from the above band gave a 1% confidence level for the hypothesis of identical distributions.

We have thus two pieces of information indicating an anomalous region of the sky at 20-h R.A. The extra counts, according to Fig. 2, are associated with opening angles greater than 14°. This indicates that the excess count is attributed to γ rays which typically are softer than those produced in the atmosphere. Fluctuations in the point of conversion in the lead radiator, disparity in the distribution of energy between the electron and positron, and effects of multiple Coulomb scattering make us unwilling to make a strong statement as to the energy of the photons. However, the suggestion that the excess lies in the events with opening angles greater than 14° allows us to attempt

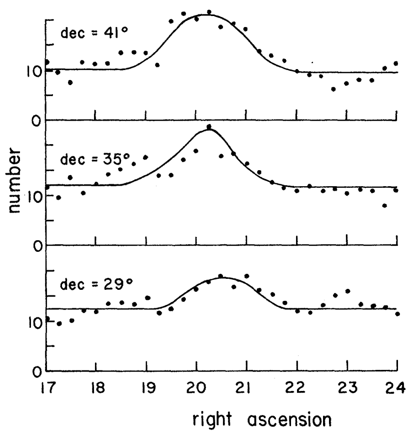

FIG. 3. "Fixed declination scans" for three declinations indicated. The scans were made using pairs having opening angles between 14 and 38°. The solid line is a visual fit to the data. The reader is cautioned not to misinterpret the meaning of "fixed declination scans" and is referred to the text for a fuller explanation.

a better method of locating the direction of the source of the anomalously high count.

Figure 3 shows the result of what we call a "fixed declination scan" in which a direction in space is chosen, and a search for the pressure-weighted number of gamma rays which can be associated with that direction is made. The criterion for associating a gamma ray with a chosen direction involves the difference between $\frac{1}{2}\theta$ and φ, where θ is the opening angle of the pair, and φ is the angle between the direction of interest and the direction of the bisector of the observed tracks in the chamber. If $\frac{1}{2}\theta > \varphi$ for any event, then we associate that event with the direction of interest. Such searches were made at three-degree intervals right ascension on many lines of constant declination. Figure 3 illustrates the results of such scans for pairs with opening angles greater than 14° and less than 38°. The lower limit was chosen since our examination of the data indicated that the opening-angle distribution in the range $\theta < 14°$ showed no anomalous behavior. Indeed a declination scan for such events showed no region of great interest. Figure 3 shows the source to be at about 20.25-h R.A. and of 35° N dec. The mean value of the background on this representation was 12.4, and the source count from the source direction is 23.5. The statistical significance of this is not simply calculable, since the counts associated with two directions less than 38° apart are correlated; the number of directions in the sky over which an event is counted depends on θ. The result of correlation can be seen in Fig. 3. However, these scans aid in determining a most likely direction of the anomalously high count.

In addition to "fixed declination scans," one can perform "fixed right ascension scans." These are even harder to analyze as the instrumental sensitivity as a function of zenith angle and pair opening angle influences the results strongly. In Fig. 4 we show the average of several fixed right ascension scans far from 20-h R.A. as well as the data at 20 h 15 min. Again, the source is shown to stand out. We thus identify the source direction as 35° N dec, 20-h 15-min R.A. The uncertainty in the direction of the source is 6° in all directions, this being the distance such that the excess count falls to about half the peak value.

The reader is cautioned against over interpretation of Figs. 3 and 4. The method of analysis involves strong correlation between adjacent points in these scans. As a result, one might be misled into interpreting the diagrams as a reflection of the angular response of the detector to a source transiting the telescope. No such claim is made by the authors. These diagrams have been used only in an attempt to locate the anomaly rather than to establish its existence.

The flux from the source was calculated from the relation

$$F = N/\eta \int A dt.$$

Here N, the number of γ rays from the source, is taken from Table I as 12.8, the excess above background in the source cell. $\int A dt$ is the time integral of the detector area for a source at 35° dec and has the value 6×10^5 cm^2 sec. η is the detection efficiency and depends most strongly on the conversion efficiency, which

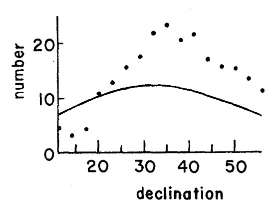

FIG. 4. "Fixed right ascension scan" for 20-h 15-min R.A. The result of the scan is indicated by dots. The solid line shows the average of several fixed R.A. scans. Each of these scans was at least $1\frac{1}{2}$-h R.A. from both 20-h 15-min R.A. and the zenith direction at the times for the beginning and end of the recording of data used in this report.

is a stronger function of energy below 200 MeV. We have taken η equal to 14%, the conversion efficiency at 75 MeV, and obtained a value of $(1.5\pm0.8)\times10^{-4}$ γ's cm^{-2} sec^{-1},[17] where the error is purely statistical. This value is subject to systematic errors, the most important reflecting our lack of knowledge of the energy spectrum.

We have considered other possible explanations for our observations. Instrumental effects, and the fact that the small altitude variation at sunset occurred at approximately the time the suspected source transited, were investigated. There was no evidence of changes of instrumental sensitivity during the flight, and it is hard to imagine such a process giving both an excess count from a single region and a variation in the detected spectrum. We believe that we have correctly weighted the data for the pressure variation. Furthermore, if we have underestimated the pressure correction, then a much larger region of the sky would have shown an increased intensity. It is also difficult to reconcile the anomalous opening-angle spectrum with the slight pressure variation.

We wish to acknowledge the steady help and encouragement given to this work by Professor M. F. Kaplon. We would like to thank Professor M. P. Savedoff and members of the Cosmic-Ray Group at the University of Rochester for many helpful discussions. Considerable engineering assistance was received from Mr. R. Majka and Mr. R. Hawrylak. The further assistance of Mr. Majka in the construction and performance of this experiment was essential to its completion. Mrs. A. M. Endler gave invaluable assistance during the examination of the film.

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