SEARCH FOR COSMIC GAMMA RADIATION WITH A
VIDICON SPARK CHAMBER

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The following paper, "Search for Cosmic Gamma Radiation with a Vidicon Spark Chamber," by G. G. Fazio, H. F. Helmken, S. J. Cavrak, Jr., and D. R. Hearn, will serve as the final report for Contract NSR 09-015-022 from the National Aeronautics and Space Administration. It was previously presented at the Tenth International Conference on Cosmic Rays, held in Calgary, Alberta, Canada, on June 19, 1967.
SEARCH FOR COSMIC GAMMA RADIATION WITH A VIDICON SPARK CHAMBER

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ABSTRACT

A vidicon spark chamber flown in a high-altitude balloon has been used to search for primary gamma radiation (E > 100 MeV). No celestial gamma-ray source was detected. The new upper limit to the flux from the Crab Nebula was found to be \(3.1 \times 10^{-5}\) cm\(^{-2}\) s\(^{-1}\). The flux from the quiet sun was found to be \(\leq 7.4 \times 10^{-5}\) cm\(^{-2}\) s\(^{-1}\). A solar flare (type 2) also occurred during the flight. The flux was \(\leq 6 \times 10^{-3}\) cm\(^{-2}\) s\(^{-1}\), which is also a new upper limit. The gamma-ray background flux and energy spectrum at 4 g cm\(^{-2}\) altitude were measured.

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A spark chamber with a vidicon readout has been flown from a high-altitude balloon in order (a) to search for cosmic gamma radiation \((E > 100\ MeV)\) from discrete celestial sources and (b) to test the television transmission of the spark-chamber tracks.

No source of primary gamma radiation was detected. A new upper limit to the flux from the Crab Nebula was found to be \(3.1 \times 10^{-5}\ \text{cm}^{-2}\ \text{s}^{-1}\). The flux from the quiet sun was found to be \(\leq 7.4 \times 10^{-5}\ \text{cm}^{-2}\ \text{s}^{-1}\). A solar flare (type 2) also occurred during the flight. The flux was \(\leq 6 \times 10^{-3}\ \text{cm}^{-2}\ \text{s}^{-1}\), also a new upper limit. The gamma-ray background flux at an altitude of 4 g cm\(^{-2}\) was determined, and the energy spectrum was measured in the region from 0.1 to 2.5 GeV.

Video transmission of the spark-chamber tracks was excellent during the flight. Although the system was intended primarily for satellite applications, several advantages for balloon-flight experiments were recognized: light weight, simplicity, a continuous data recording rate of 15 events s\(^{-1}\) from time of launch, and live-time monitoring of the experiment with remote control of the spark-chamber trigger mode.

Figure 1 illustrates the geometry of the detector. Chamber (1) consists of 7-in. by 7-in. aluminum plates; the first three plates are 0.02 in. thick, followed by eight \(\frac{1}{8}\)-in. plates and two 0.02-in. plates. This chamber serves mainly to convert the gamma ray into an electron-positron pair. Chambers (2) and (3) consist of five 7-in. by 7-in. by 0.02-in. aluminum plates and serve better to define the opening angle of the pair, the initial gamma-ray arrival direction, and the location of the cascade shower in the lead-glass Čerenkov detector. The spark chamber was triggered by a triple coincidence between scintillation counters \(B_1\) and \(B_2\) and the Čerenkov counter \(C\), when no pulse occurred in the scintillator \(A\). The resulting amplitude of the pulse in the Čerenkov counter was measured with a 512-channel pulse-height analyzer and used to determine the gamma-ray energy. A more detailed description of the system is given by Helmken and Fazio (1966) and Fazio and Helmken (1967).
The detector had the following characteristics: (a) 160-cm\(^2\) area at normal incidence, (b) acceptance cone of 35° half-angle about the vertical, (c) 0.16 conversion efficiency at a gamma-ray energy of 100 MeV, and (d) an angular resolution of ±5° at 100 MeV.

The experiment was launched on May 28, 1966, from Palestine, Texas (geomagnetic latitude 42° N), and reached an altitude of 4 g cm\(^{-2}\). Data were recorded during ascent and for 6 hours at the float altitude (1420 to 2020 UT). The celestial sphere from 23\(^{h}\) to 8\(^{h}\) right ascension and from 0°N to +70°N declination was scanned. The detector was suspended in a vertical position, free to rotate in azimuth. The azimuth angle was measured to less than 2° by a magnetic compass and a sun sensor. A stereoscopic view of the spark-chamber events was transmitted in real time to a portable ground station where the events were viewed and recorded on video tape and kinescope film.

During the time the experiment was at float altitude the chamber was triggered at an average rate of 2.4 events s\(^{-1}\). Of the events scanned, 505 (2%) were classified as true electron-positron pairs and 20% were single tracks originating in the chamber. The remaining events consisted of tracks not originating in the chamber, multiple tracks from nuclear interactions, and unidentifiable events. The small percentage of pair events was probably due to the lack of anticoincidence shield around the sides of the spark chambers and the Čerenkov counter.

The right ascension \(\alpha\) and the declination \(\delta\) were calculated for each particle in the electron-positron pair. The tracks were distinguished in the stereoscopic view by variations in the spark intensity along the track length. The value \((\alpha, \delta)\) was plotted for each track, and the two points were joined by a line to identify the pair. Figure 2 shows these events plotted on an equal-area projection, rotated so that the midpoint of the flight \((\alpha = 3^h 20^m, \delta = 35^\circ 0\, N)\) is centered on the graph. From the combination of multiple scattering and azimuth error, the angular resolution of the system was taken to be a cone of 5° half-angle. The number of electron (positron) tracks falling within a circle of 5° radius centered on a possible source was then
determined. Of the total number of electron (positron) tracks in the acceptance cone, approximately 50% were assumed to be due to gamma rays originating from a source centered on the cone.

The fraction of gamma-ray pairs missed because the separation of the tracks was not detectable was estimated from the distribution of the number of pairs produced as a function of the amount of aluminum traversed. Pairs originating in the lower gaps had a smaller probability of scattering into a detectable opening angle. Approximately 36% of the pairs were missed owing to this effect.

Table I gives the number \( N_p \) of gamma-ray pairs observed in the acceptance cone, the number \( N_b \) of background pairs expected, the effective area exposure time \( \epsilon AT \) for each source, and the upper limits to the gamma-ray flux \( F \) determined at a 95% confidence level. The quantity \( \epsilon AT \) was numerically integrated over the time period at float for each plate of the converter at each point \((a, \delta)\) in a grid covering the region. The upper limit to the gamma-ray flux was computed by determining the average number \( M \) of events expected in a Poisson distribution such that the probability of observing \( N_p \) events or fewer was 5%. The upper limit flux value is then given by

\[
F = \frac{(M - N_b)}{\epsilon AT}.
\]

Table II gives the upper limit to gamma-ray fluxes in a similar energy region from the Crab Nebula as determined from previous experiments.

A search was also undertaken for possible point sources of gamma rays in an arbitrary direction on the section of the celestial sphere scanned. If we assume most of the observed pair events were due to atmospheric background, the number of events in all equal solid-angle intervals was compared to the expected background number. No fluctuations of more than two standard deviations were observed, and no clustering of the intervals with fluctuations greater than one standard deviation was observed (Figure 3).
The gamma-ray energy spectrum at the float altitude was also determined by pulse-height measurements in the lead-glass Čerenkov detector (10.2 radiation lengths). For this measurement about 20% of the gamma-ray pair events were selected, in which both particles entered the lead glass near its center axis. The gamma-ray spectrum of all pair events did not differ significantly from the selected events except at the lowest energies. The integral gamma-ray spectrum is given in Figure 4, and Table III gives the average power-law index over a given photon energy interval. The data in the 100- to 500-MeV energy region are consistent with the results of Frye and Smith (1966) in the energy region 30 to 500 MeV. The solid and dashed lines in Figure 4 are theoretical gamma-ray spectra resulting from cosmic-ray proton collisions with protons.

The gamma-ray background flux \( (E > 100 \text{ MeV}) \) at an altitude of \( 4 \text{ g cm}^{-2} \) at \( 42^\circ \text{N} \) geomagnetic latitude was determined to be \( (1.9 \pm 0.2) \times 10^{-3} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \) averaged over a vertical cone of ±30°.

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REFERENCES

FAZIO, G. G. and HELMKEN, H. F. 1967. Application of the vidicon spark chamber to gamma-ray astronomy from high-altitude balloons and satellites, to be published in the proceedings of the Tenth International Conference on Cosmic Rays, Calgary, Alberta, Canada, June 19.
Fig. 1. Geometry of the vidicon spark chamber.
Fig. 2. Angular distribution over the celestial sphere of electron-positron tracks resulting from gamma-ray pair production; the corresponding electron-positron tracks are joined by a straight line.
Fig. 3. Fluctuations of gamma-ray intensity over the celestial sphere.
Fig. 4. Integral gamma-ray spectrum at 4 g cm$^{-2}$ altitude and at 42° N geomagnetic latitude. The experimental data above 1 GeV are of limited accuracy owing to resolution of the pair opening angle. The solid curves (Helmken 1964) and the dashed curves (Stecker 1967) refer to theoretical predictions of the gamma-ray spectrum due to cosmic-ray proton collisions with protons.
<table>
<thead>
<tr>
<th>Source</th>
<th>$N_p$ (observed)</th>
<th>$N_b$</th>
<th>$\epsilon AT$ (cm$^2$ s)</th>
<th>$F$ (cm$^{-2}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crab Nebula (Tau A)</td>
<td>5</td>
<td>6.3</td>
<td>$1.37 \times 10^5$</td>
<td>$\leq 3.1 \times 10^{-5}$</td>
</tr>
<tr>
<td>Quiet sun</td>
<td>12</td>
<td>7.2</td>
<td>$1.77 \times 10^5$</td>
<td>$\leq 7.4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Solar flare (type 2)</td>
<td>1.5</td>
<td>0.31</td>
<td>$9.15 \times 10^3$</td>
<td>$\leq 6 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
### TABLE II
Summary of the upper limits to the cosmic gamma-ray flux from the Crab Nebula

<table>
<thead>
<tr>
<th>Energy region (MeV)</th>
<th>Flux ( (\text{cm}^{-2} \text{s}^{-1}) )</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-500</td>
<td>( \leq 1.9 \times 10^{-4} )</td>
<td>Frye and Smith (1966)</td>
</tr>
<tr>
<td>&gt;100</td>
<td>( \leq 6.6 \times 10^{-4} )</td>
<td>Kraushaar et al. (1965)</td>
</tr>
<tr>
<td>&gt;100</td>
<td>( \leq 7 \times 10^{-5} )</td>
<td>Cobb, Duthie, and Stewart (1965)</td>
</tr>
<tr>
<td>&gt;100</td>
<td>( \leq 3.1 \times 10^{-5} )</td>
<td>This experiment</td>
</tr>
</tbody>
</table>
### TABLE III
Average power-law indices for the integral gamma-ray energy spectrum

<table>
<thead>
<tr>
<th>Energy interval (GeV)</th>
<th>Power-law index (integral energy spectrum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2-0.5</td>
<td>0.65</td>
</tr>
<tr>
<td>0.5-1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>1.5-2.5</td>
<td>2.4</td>
</tr>
</tbody>
</table>