International Conference
on
Cosmic Rays and the Earth Storm

III-1. Composition

Chairman: B. PETERS
Secretary: E. TAMAI

Date	Time	Paper Numbers
Sept. 7	15 : 30 – 17 : 30	from III–1–1 to III–1–5
Sept. 8	15 : 30 – 17 : 30	from III–1–6 to III–1–17
Sept. 12	09 : 00 – 11 : 00	from III–1–18 to III–1–22

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-1-1. Some Experimental Attempts to Detect Cosmic Gamma Rays

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Introduction

In mid-1957 a group at M.I.T. initiated a series of experiments with the purpose of detecting possible extra-terrestial sources of gamma rays. We shall report here on a satellite experiment which was designed to detect gamma rays of energy 50 Mev and over—gamma rays such as would arise from the decay of π^0 mesons.

Gamma rays in general like other forms of electromagnetic radiation are potentially valuable sources of astrophysical information

* This work was supported primarily by funds provided by the National Aeronautics and Space Administration, and partly by funds from the U.S. Atomic Energy Commission, Office of Naval Research, and Air Force Office of Scientific Research.

because they are undeflected by magnetic fields—terrestial, solar, galactic or beyond. Gamma rays from the decays of π^0 mesons are unique in that π^0 mesons can be produced only in interactions that involve energies well above those characteristic of nuclear binding energies, which are in fact more nearly typical of cosmic ray phenomena. If, for example, a gamma ray detector were to indicate intensity from a certain portion of the sky to be unusually large, the likely implication would be that someplace within the volume subtended by the solid angle of the detector there is a region characterized by a large value of the product nj where n is the matter density and j is the intensity of high energy particles. Since π^0 mesons are among the products of matter-antimatter annihilation an alternative implication would be the existance of a region characterized by a large value of $n\bar{n}$ where n and $\bar{n}$ are the matter and antimatter densities, respectively. There have been a few previous attempts to detect cosmic gamma rays. All experiments were balloon-borne and were limited in their ability to detect weak sources by the relatively large background radiation produced in the residual atmosphere. The recent balloon-borne experiment of T. Cline, at M.I.T., has shown that the source strength of gamma rays in our galaxy is smaller than 2×10^{-22} $cm^{-3}\,sec^{-1}$ and that the gamma ray flux from Cygnus A is less than $1.2\times10^{-3}\,cm^{-2}\,sec^{-1}$.[1)]

The Instrument

The gamma ray detector launched April 27, 1961, as Explorer XI or 1961 nu is shown in Fig. 1. The sandwich scintillation detector which consists of alternate slabs of sodium iodide and cesium iodide serves as a radiater in which gamma rays may produce electron-positron pairs. If one or both members of the pair traverse the Cerenkov counter a coincidence circuit is activated. Most of these coincidences from the passage of charged primary cosmic ray particles through the instrument. Only when a coincidence is not accompanied by a pulse from the large plastic anticoincidence counter is the pulse height from the sandwich detector telemetered to earth.

Source	Exposure Time	Events	Upper Limit To Flux
Cassiopia A	26.8 sec	0	$4.4\times10^{-2}cm^{-2}\,sec^{-1}$
Andromeda	95.	0	1.2×10^{-2}
Cygnus A	990.	0	$1.2\times10_{-3}$
Crab	9.	0	1.4×10^{-1}
Galactic Center	380.	1.1	4.2×10^{-3}
Large M. Cloud	330.	0.4	4.2×10^{-3}
Small M. Cloud	250.	0	4.8×10^{-3}
Sun	35.	0	3.4×10^{-2}

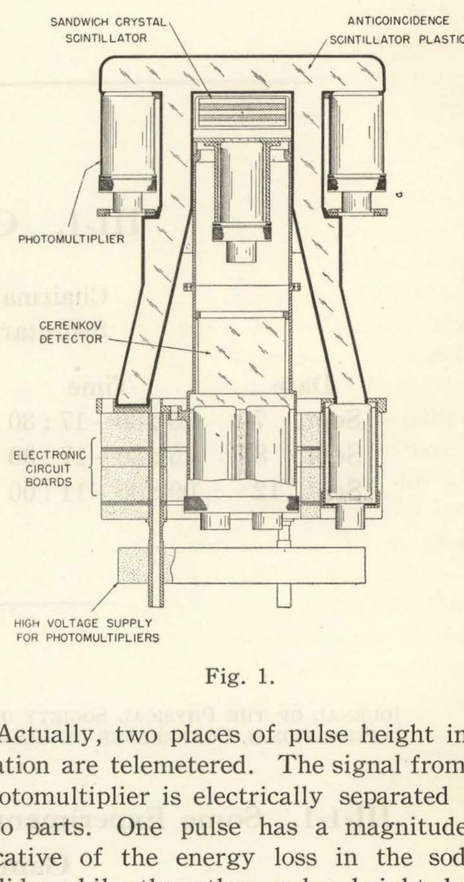

Fig. 1.

Actually, two places of pulse height information are telemetered. The signal from the photomultiplier is electrically separated into two parts. One pulse has a magnitude indicative of the energy loss in the sodium iodide while the other pulse height has a magnitude indicative of the energy loss in both crystals. This separation depends upon the difference in the scintillation decay time of the two materials. Several times a week the anticoincidence circuit is turned off of one orbit to provide an in-flight calibration of the detector and its telemetry. Unfortunately one channel of the telemetry malfunctioned early in the life of the satellite.

The purpose of the pulse separation was to provide a basis for distinguishing interaction taking place in the sandwich detector that were accompanied and unaccompanied by short range nuclear evaporation prongs. A possible source of background was thought to be neutrons produced by charge exchange interaction in the thin (7 mg cm^{-2}) foil which covers the plastic anticoincidence shield.

Initially the satellite spun about its longitudinal axis about 6 revolutions per second. Over a period of several weeks this spin rate increased, slowly at first. Then it increased quite suddenly as the angle of the cone of the motion of the satellite opened from its initial value of 0° to 90°.

The current tumble rate is 14.6 sec. and is increasing in a somewhat irregular way. The aperture of the gamma ray detector scans a great circle once energy tumble period. Of course a fraction of this scan is generally obscured by the earth.

The orientation of the satellite is determined by three types of information. One light sensor detects the sun. Another light sensor detects the earth and its horizons. Finally, the tracking stations record the intensity of the received radio signal, and since we know the radiation pattern of the satellite antenna, the times of the nulls of the received signal can be related to the instantaneous orientation of the satellite. Since launch the angular momentum vector has traced out a path in the sky as shown in Fig. 2. Part of this orientation data has been obtained by personnel under the direction of Dr. C. Lundquist at the Marshall Space Flight Center and part by us at M.I.T.

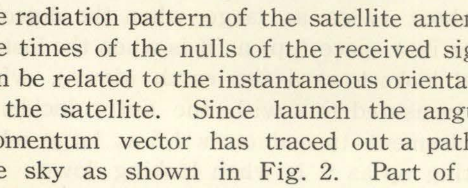

Fig. 2.

Results

Only 23 days of data has been analyzed in sufficient detail to present here, and only about 23 hours is useful observing time. The report is therefore of a tentative and very preliminary nature.

During the above period 127 events occurred which could be gamma rays. Analysis showed that 105 of these came from the general direction of the earth and are presumably therefore gamma rays produced in the earth's atmosphere by primary cosmic rays. The remaining 22 came from a variety of directions in space. The telemetered pulse heights distributions are shown in Fig. 3. The upper curve shows a sample distribution obtained when the anticoincidence requirement was turned off. About 14% of the pulses are very large and so indicate large energy losses in the sandwich detector.

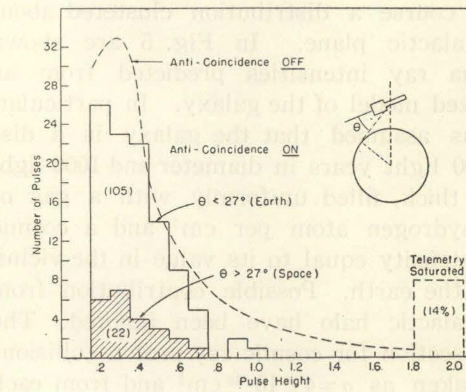

Fig. 3.

These are presumably due to a combination of nuclear interactions and incident charged cosmic rays having $Z > 1$. The lower distributions are for those events (with the anticoincidence requirement turned on) which came from the direction of the earth and from space. Notice the lack of any very large energy losses, particularly for the statistically more significant group which came from the direction of the earth. The lower two distributions are consistent with what is expected for gamma rays.

The analysis of the arrival direction data is complicated by the fact that the all portions of the sky were not scanned for the same length of time. We have therefore divided the sky into a number of cells consistent with the angular resolution of the detector. The exposure time of the detector to each of these cells has been evaluated, and the total exposure time is 9.25 hours.

The rate of events, averaged over all the directions scanned is therefore 22/9.25, or about 2.4 hr^{-1}, and if we multiply the exposure time of each cell by the rate we have an "expected" number of events assignment for each cell consistent with assumed isotropy. This assumption would be appropriate if the 22 events are to be attributed to background-anticoincidence inefficiency for example. In Fig. 4. the cells are shown on a mercator projection. The upper figure in each cell is the number of events detected while the lower figure is the number expected under the above hypothesis. Evidently, and as must be expected with so little data, convincing evidence for anisotropy is lacking.

More likely than an isotropic distribution is of course a distribution clustered about the galactic plane. In Fig. 5 are shown gamma ray intensities predicted from an idealized model of the galaxy. In particular, it was assumed that the galaxy is a disc 100,000 light years in diameter and 1000 light years thick, filled uniformly with a gas of one hydrogen atom per cm^3 and a cosmic ray intensity equal to its value in the vicinity of the earth. Possible contribution from the galactic halo have been ignored. The cross section for cosmic ray-proton collisions was taken as $\sigma=4\times10^{-26}\,cm^2$ and from each collision was assumed to come, on the average, 3 gamma rays. The predictions depend on the detector aperture, taken here to be

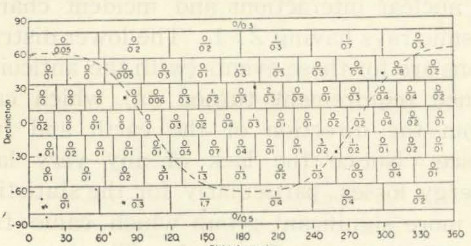

Fig. 4.

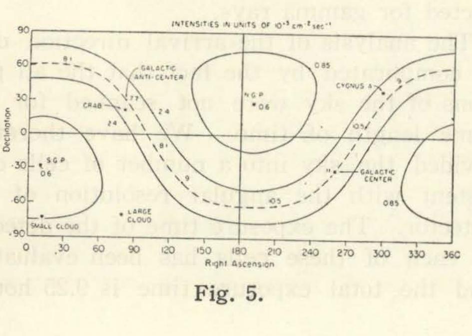

Fig. 5.

17° half angle.

These predicted intensities have been used to evaluate an "expected" number of counts in each of the cells mentioned previously. Of course account was taken of the exposure time of each cell, and the efficiency of the detector was taken as 20%. The total predicted number of counts, summed over all cells is about 6 and if we assume that the instrument responds to only gamma rays is to be compared with the 22 observed counts.

It is certainly possible that some or even all of the events we have detected are not cosmic gamma rays. There are many potential sources of background, and only a striking anisotropy can offer definitive evidence that our "events" are cosmic gamma rays and not background. On the other hand inflight evidence that the instrument can detect gamma rays is provided by the albedo gamma ray intensity which agrees with previous measurements, and the albedo height distribution which shows no very large energy losses. Further, the measured charged particle flux (anti-coincidence requirement off) is about twice as large when the detector looks into space (up) as it is when the instrument looks toward the earth (down), while the measured flux with the anti-coincidence requirement turned on is 1/5 as large when looking up as it is when looking down.

Our results indicate that the gamma ray source strength is not large than about 4 times that predicted from cosmic ray collision processes ($S_{\text{col}} = 4\pi J\sigma nm \approx 6\times10^{-25}\,cm^{-3}\,sec^{-1}$) alone. Similarly they would be inconsistent with any postulated matter-antimatter annihilation processes which gave rise to a gamma ray source strength larger than $4\,S_{\text{col}}\approx2.4\times10^{-24}\,cm^{-3}\,sec^{-1}$, and if we take 3 as the average number of neutral meson-decay gamma rays per nucleon-antinucleon annihilation, we have an upper limit of about $8\times10^{-25}\,cm^{-3}\,sec^{-1}$ for the annihilation frequency. For purposes of comparison, the *nucleon* creation frequency required by steady state cosmology is $3\times10^{-22}\,cm^{-3}\,sec^{-1}$, more than 300 times as large.

A number of possible point sources of gamma rays have been suggested by Morrison[2] and by Savedoff[3]. Listed below are some of these sources, their exposure time, the measured number of events weighted as to include the angular response of the instrument, and an approximate upper limit to this flux of gamma rays from these directions. These upper limits are approximate to a 95% statistical confidence limit, and include as estimated 20% detection efficiency.

Acknowledgment

An experiment of this kind has of course relied upon the efforts and skills of many people. Particularly important have been the contributions of Dr. James Kupperian who coordinated the project and others of the Goddard Space Flight Center of NASA, personnel of the Marshall Space Flight Center who engineered and built much of the satellite, and G. Garmire and Charles Moore and W. B. Smith and E. Mangan of M.I.T.'s Laboratory of Nuclear Science in which the gamma ray detector was designed and built. A. Womack and A. Hershdorfer made essential contribution to the data analysis.

References

1) T. Cline, Phys. Rev. Letters **7** (1961) 109.
2) P. Morrison, Nuovo Cim. **7** (1959) 858.
3) M. P. Savedoff, Nuovo Cim. **13** (1959) 12.

Discussion

Kaplon, M.F.: What is the influence of the galactic halo? Wouldn't it effect your limits?

Kraushaar, W.L.: I believe that the gas density and probably the cosmic ray flux are comparatively small in the halo, but I agree that they should be taken into account. The purpose of the model assumed was simply to provide a basis for comparison with our experimental results, and should a contribution from the halo become evident experimentally, we would of course be very pleased.

Hayakawa, S.: Is the rate of albedo gamma rays that you have found consistent with previous measurements?

Kraushaar: Provisionally, yes. But we have more work to do on this point since previous measurement must be carefully interpretted.

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III-1-2. Some Properties of the Primary Cosmic Ray Electrons*

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The discovery of primary cosmic ray electrons in the vicinity of the earth (Meyer and Vogt, 1961; Earl, 1961) opens the question of the origin of these particles. There exist two obvious alternatives, namely (1) solar origin with subsequent storage in interplanetary space, and (2) galactic origin. In the second case the electrons would most likely be identical with the long postulated source of galactic radio noise. Their intensity and energy spectrum near the earth would be modified by the modulation mechanisms which are known to affect the flux of protons arriving from the galaxy. This modification would be strongest during periods close to

* This research was supported in part by the National Science Foundation (Grants Nos. NSF-G7829, NSF-G14889), the Office of Scientific Research, ARDC, United States Air Force (Contract No. AF 18(600)-666) and by the Office of Naval Research, Skyhook Program (Grant No. Nonr-(G)-00010-60).