lower energies. For simplicity, we start with Jones's[17] approximate cross section[23] for this type of process [his Eq. (8)], and write in analogy to our Eq. (A12)

$$4\pi P_2^- = 2\pi^2 \epsilon_0 r_0^2 LF(\epsilon_0)\phi^* \epsilon_0^{-2} \times \int_{\gamma_0}^{\infty} d\gamma \int_{\epsilon_1}^{\epsilon_0} d\epsilon_f \gamma^{-n-4}\left(\frac{4\gamma^2\epsilon_f}{\epsilon_0}-1\right), \quad \text{(C5)}$$

where now, however,

$$\gamma_0^2 = \epsilon_0/4\epsilon_f. \quad \text{(C6)}$$

Upon integration over γ we have

$$4\pi P_2^- = 2\pi^2 r_0^2 LF(\epsilon_0)\phi^* \epsilon_0^{-1} 2^{n+1} \times\left(\frac{4}{n+1}-\frac{4}{n+3}\right)\int_{\epsilon_i}^{\epsilon_0} d\epsilon_f \left(\frac{\epsilon_f}{\epsilon_0}\right)^{(n+3)/2}, \quad \text{(C7)}$$

or

$$4\pi P_2^- = 2\pi^2 r_0^2 LF(\epsilon_0)\phi^* 2^{n+1} 0.270[\tfrac{1}{2}(n+3)+1]^{-1} \quad \text{(C8)}$$

which is obviously even less than $4\pi P_1^-$ from Eq. (C4).

[23] The accurate formula, his Eq. (40), derived from the complete set of geometrical conditions, only changes the numerical factor 0.270 in our Eq. (7) back into 0.290; that is, we find the curly bracket of Eq. (B2) both for the energy losses and the energy gains.

PHYSICAL REVIEW VOLUME 176, NUMBER 5 25 DECEMBER 1968

Search for Cosmic Gamma Radiation in the Southern Sky*

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(Received 16 August 1968)

A balloon-borne spark chamber was flown over western Queensland on 26 November 1966 in an attempt to detect cosmic photons of energy greater than 100 MeV emanating from several celestial objects of interest. No sources were found, and upper limits in agreement with those set by other observers were obtained.

THERE have been many attempts to detect γ radiation both from balloon-borne sensors and from orbiting earth satellites. In this paper we report a search of a region of the southern celestial sphere including the galactic center for γ rays more energetic than 100 MeV.

The detector employed is shown schematically in Fig. 1. It has been used several other times by this group and has been previously described.[1]

The A plastic scintillator is an anticoincidence shield. The defining geometry is that of the B plastic scintillator and the Lucite Čerenkov counter C. The area solid-angle factor for BC coincidences is 25.8 cm² sr. A $\frac{1}{4}$-radiation-length-thick sheet of lead is located above the B counter. Energetic γ rays incident on the system penetrate the upper spark chamber and the A scintillation counter. Those that convert in the lead sheet are detected through the response of the B and C counters to the generated electron pair. The C counter is blackened on the top to insure that the system responds only to downward moving particles. The telescope has an efficiency of 18% for detecting 100-MeV γ rays. The occurrence of a $\bar{A}BC$ coincidence is used to trigger the spark chamber. A true γ ray will show no track in the upper chamber and either a pair or a single track in the lower chamber. The single tracks can probably be interpreted as pairs in which only one electron traversed the lower chamber.

Threshold levels were set on the B and C phototube amplifiers such that they responded to about 99% of pairs and about 50% of single minimum-ionizing particles.

The instrument was flown beneath a balloon launched from Longreach, Queensland, Australia on 25 November 1966. The geomagnetic cutoff at that location is 8.5 BeV/c and the geographic coordinates are approximately 23° S, 145° E. Data were recorded from 1800 U.T. on 25 November 1966 until 0430 U.T. on 26 November. Throughout this time the balloon remained near an altitude of 120 000 ft (37 000 m) at a residual pressure of 2.5 mm Hg. The balloon drifted westward at a rate of 20 knots (37 km/h) for most of the exposure time. The sky was thus examined for points of γ-ray

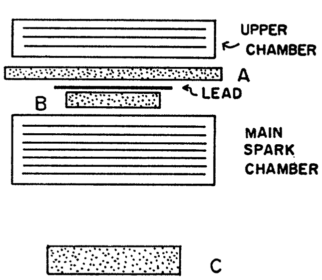

Fig. 1. Schematic diagram of the spark chamber and counter telescope used to search for energetic cosmic γ rays.

* Research supported in part by the National Science Foundation under grant Nos. GA-543 and GP 7671.

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[1] R. Cobb, J. G. Duthie, and J. V. Stewart, Phys. Rev. Letters **15**, 507 (1965).

emission in a region bounded by $+6°$ to $-54°$ in declination and from 6 to 20 h in right ascension.

Spark tracks were fitted to straight lines and the γ direction was assumed to be the bisector direction with an uncertainty of half the opening angle for pairs, and the track direction with an uncertainty of 2° for the singles in most of the calculations.

The uncertainty in gondola orientation was less than $\frac{1}{2}°$ as determined by three horizontal and one vertical magnetometers.

We detected 455 pairs and 931 singles within the geometry of the detector. The flux of γ rays ($E \gtrsim 100$ MeV) as determined from the pairs is $(3.04\pm0.15) \times 10^{-3}$ cm^{-2} sec^{-1} sr^{-1} at the location of the experiment. The error is purely statistical.

The ratio of pairs from the western half of the sky to pairs from the eastern half was 0.99 ± 0.09. For singles, the ratio was 1.14 ± 0.10.

Two types of searches for anisotropies in arrival directions of the radiation were made. A "sky map" was made, projecting γ directions into cells of dimension $3°\times3°$ in right ascension and declination. Also "point maps" were made for singles, pairs, and pairs with various opening angle ranges. These maps created points of the celestial sphere and tallied the γ rays which could be associated with each by virtue of direction uncertainty. In both sets of maps, no statistically significant anisotropies were found. In particular, the galactic center was not seen above the background.

Upper limits were placed on several possible astronomical sources of γ rays (Table I). The fluxes are quoted at 100 MeV, although both singles and pairs were included in the data and hence many events are at less than 100 MeV. The results are thus very conservative and are at the 95% statistical confidence limit; that is, a source of the flux quoted would have a 5% Poisson probability of giving a counting rate as low as observed. Previous upper limits obtained by other workers[2–4] are also shown in Table I and agree to within half an order of magnitude, which is not significant because of the low counting rates and the general state of the art.

TABLE I. Upper limits set to the flux of 100-MeV photons from a selection of celestial objects of interest in the southern sky.

Source	Flux (upper limits) (10^{-5} cm^{-2} sec^{-1})	Previously reported upper limits (10^{-5} cm^{-2} sec^{-1})
Sun	4.4	7.4 (>100 MeV)[a]
		2.4 (> 30 MeV)[b]
Scorpius X-1	7.7	3.0 (> 30 MeV)[b]
Scorpius X-2	26	
Scorpius X-3	70	
Sag. XR-2	12	3.9 (> 30 MeV)[b]
3C273	4.1	1.0 (> 30 MeV)[c]
Centaurus A	42	

[a] Reference 2.
[b] Reference 3.
[c] Reference 4.

The authors were assisted in this experiment by R. A. Majka and T. Porter of the Cosmic-Ray Laboratory at the University of Rochester and by Eric Curwood and his launch and balloon crew of the Australian Department of Supply. Thanks are due to the helpful people of western Queensland for their encouragement and hospitality.

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