24. HIGH-ENERGY DISCRETE SOURCES*

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Abstract. The origin of the gamma-radiation from the galactic plane and the region near the galactic center is still uncertain. However, during this meeting, several groups reported evidence for discrete sources of cosmic gamma-rays. Most of the sources are located near the galactic plane, and some are associated with X-ray sources. The galactic gamma-radiation may be due to these previously unresolved sources. Other sources detected may be associated with variable radio galaxies.

The Crab Nebula still remains the most investigated source at gamma-ray energies. Pulsed emission from NP 0532 was detected in the 10 to 30 MeV region, but no continuous emission was observed. At the highest energies, pulsed emission was reported at $\sim 10^{12}$ eV. Continuous emission from the Crab Nebula was observed at $\sim 10^{11}$ eV; the radiation may be time variable.

The recent gamma-ray experiments on Apollo 15 and 16 and the ESRO satellite TD-1 are described, as well as future experiments on the satellites SAS-B, COS-B, and HEAO-B.

1. Introduction

Although gamma-ray astronomy has advanced rapidly, it has not enjoyed the spectacular success that X-ray astronomy has. Gamma-ray astronomy is a difficult field of research for several reasons. The incident flux is very low – e.g., at 100 MeV, it is $\approx 10^{-5}$ photon cm^{-2} s^{-1} – and what is even more important, this flux must be detected in a background radiation of charged cosmic-ray particles that is $\sim 10^4$ times greater. There are also basic technical difficulties associated with gamma-ray detectors. Because of the relatively low absorption cross section, gamma-ray detection requires rather massive experiments. Also, owing to the low incident flux, the area-time factor for a detector must be large, again leading to large detectors and long exposure times. In addition to these problems, the detectors must be placed above the atmosphere in high-altitude balloons or satellites. However, at energies above 10^{11} eV, ground-based detection of cosmic gamma-rays, through their interaction in the atmosphere, becomes feasible.

In the late 1950s, theoretical predictions of the flux of cosmic gamma-rays were very optimistic, and these predictions encouraged considerable experimental activity. However, gamma-ray astronomy has become the only field of space science where the detected fluxes were considerably lower than the theoretical predictions. Unfortunately, there have been no surprises.

Development of more sensitive detectors has advanced rapidly, and over the last 10 yr, the minimum detectable flux has been lowered by more than a factor of 10^3. Evidence for discrete sources of cosmic gamma-rays has appeared, and major advances will soon be made by means of several satellite experiments.

* Dr Fazio arranged and led the panel discussion on this topic. The other panel members were: B. Agrinier, G. Frye, H. Helmken, R. Hillier, G. Hutchinson, D. Kniffen, J. Kurfess, K. Pinkau, G. Share and T. C. Weekes.

Bradt and Giacconi (eds.), X- and Gamma-Ray Astronomy, 303–323.

This discussion on the present status of the identification of discrete sources has been divided into the following sections: (a) Crab Nebula and the pulsar NP 0532; (b) Galactic center region; (c) Galactic plane in the Cygnus-Cassiopeia region; (d) Galactic plane in the anticenter region; and (e) Future satellite experiments.

2. Crab Nebula and the Pulsar NP 0532

Before this meeting, the continuous flux of X-rays from the Crab Nebula had been measured up to energies of the order of 400 keV (Figure 1), while the pulsar NP 0532 has been detected up to energies of the order of a few MeV. Hillier *et al.* (1970) first reported evidence for pulsed emission in the 0.6 to 9 MeV region that was comparable to or exceeded in intensity the extrapolated total spectrum. In the X-ray region of the spectrum, the percentage of the total emission that was pulsed varied from ~2% at

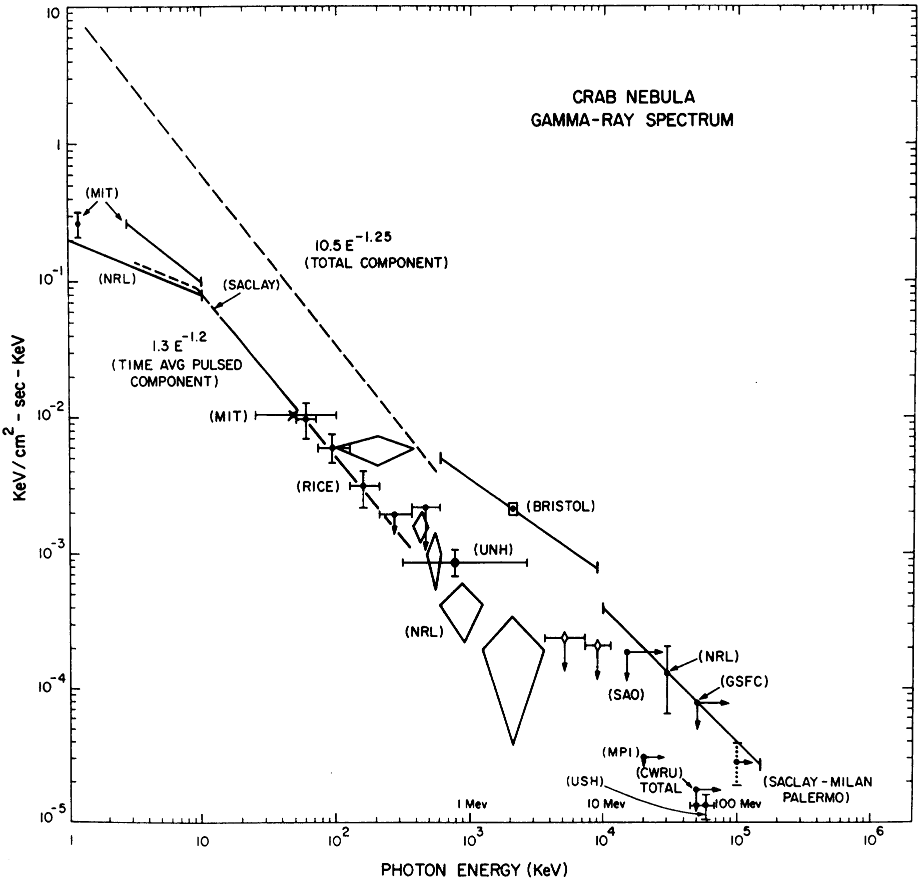

Fig. 1. Gamma-ray spectrum of the Crab Nebula. The graph summarizes information available before this symposium. The spectrum for the 'Total Component' is taken from Peterson (Figure 7, this volume).

1 keV to ~15% in the 100 keV region. Kurfess (1971) reported evidence for pulsed emission up to 1 MeV, but in the 100 to 400 keV region the pulsed emission was $42 \pm 12\%$ of the total emission, and the ratio of the secondary peak to the primary peak was 2.3 ± 0.2. The pulsed-emission spectrum assumed was $10\ E^{-2.2}$ photon $cm^{-2}\ s^{-1}\ keV^{-1}$. Orwig *et al.* (1971) simultaneously reported results consistent with Kurfess' in the 0.25 to 2.3 MeV region and indicated their results are an order of magnitude lower than those of Hillier *et al.* (1970).

During the discussion, J. D. Kurfess reviewed his results, emphasizing both the changes in the pulse shape that occurred in going from the X-ray to the gamma-ray region and the implications for the higher energy spectrum. He also noted that, owing to background corrections, his quoted flux in the 100 to 400 keV region may be overestimated by 20%. A discrepancy still exists with the data of Hillier *et al.* (1970). Hillier's results may be too high because of two factors: (i) A hard spectrum was assumed that tends to overestimate the flux, and (ii) the quoted energy range of the detector was too high. In defense of his results, Hillier noted that there was an onboard energy calibration and the atmospheric background rate was consistent with other experiments. A time-dependent flux is one solution to this problem; however, Hillier suggested more data are needed before this problem can be solved. It is also interesting to note that Kurfess has not determined the relative phase of his X-ray data with respect to the optical pulse of NP 0532.

In the region above 10 MeV, some confusion has existed as to whether a pulsed emission had been detected from NP 0532. Most of the recent results were reported at the 12th International Conference on Cosmic Rays held in August 1971 in Hobart, Tasmania, Australia. They have been summarized in the rapporteur paper by Frye (1971) and are given here in Table I. Only one positive result was reported, by the University of Southampton group (Browning *et al.*, 1971), but this was at marginal significance.

The most significant new result reported during the discussion was by the Case-Melbourne team, represented by G. M. Frye, Jr. They obtained an energy flux (time-averaged pulsed emission) of $(6 \pm 3) \times 10^{-5}$ keV $cm^{-2}\ s^{-1}\ keV^{-1}$ at 20 MeV. Evidence was based on a 5σ peak within 1 ms of the main pulse among events analyzed with the

TABLE I

Hobart Conference results on the Crab Nebula

Group	Energy (MeV)	Pulsed flux (photon $cm^{-2}\ s^{-1}$)	Average flux (photon $cm^{-2}\ s^{-1}$)	Reference[a]
SAO	>15	$<1.4 \times 10^{-4}$	$<4.7 \times 10^{-4}$	OG 15
NRL	>20	$<1 \times 10^{-4}$	$<2 \times 10^{-4}$	OG 13, 14
MPI	>20	$<3 \times 10^{-5}$		OG 16
Southampton	>50	$=1.3 \times 10^{-5}$		OG 17
Saclay-Milan-Palermo	>100	$=3 \times 10^{-5}$		OG 16

[a] References refer to papers presented at the 12th International Conference on Cosmic Rays, Hobart, Tasmania, Australia, August 1971.

pulsar period (Figure 2). For the continuous integral flux, only an upper limit could be placed: $\leqslant 6 \times 10^{-4}$ photon cm^{-2} s^{-1} above 10 MeV and $\leqslant 2.4 \times 10^{-4}$ above 20 MeV. This would indicate that the pulsed emission in the 10 to 30 MeV region is $\geqslant 25\%$ of the continuous emission of the Nebula. The ratio of the interpulse to the main pulse was estimated to be less than 1.7, which is a significant change from the value of 2.3 reported in the region of several hundred keV. The width of the main pulse was 2 ms. Above 50 MeV, Frye reported an upper limit to the pulsed emission of 4×10^{-5} photon cm^{-2} s^{-1}.

L. Scarsi, representing the Saclay-Milan-Palermo group, also reported detection of pulsed gamma-ray emission above 20 MeV from NP 0532. The integral flux above

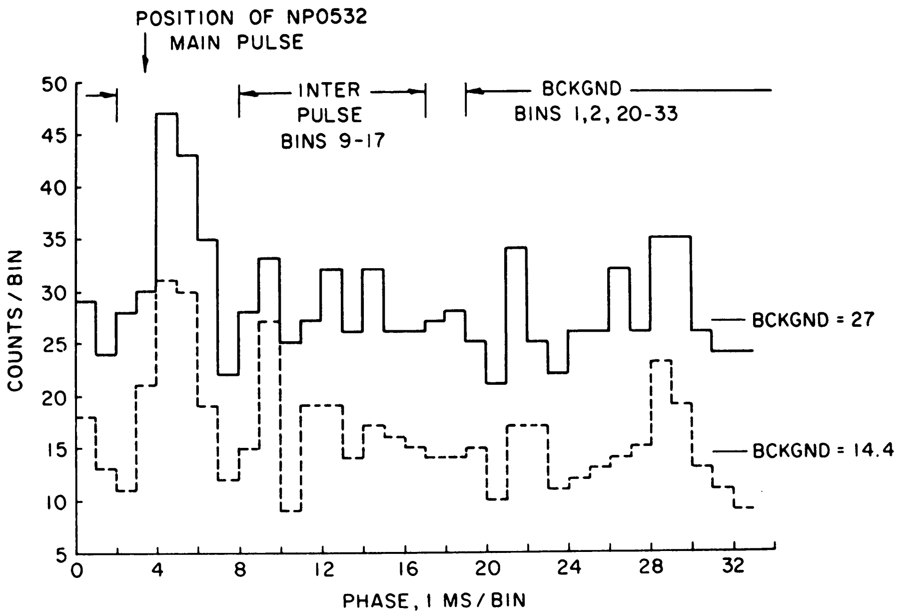

Fig. 2. Gamma-ray photon count from NP 0532 as a function of the pulsar phase in the energy interval 10 to 30 MeV (solid line) and > 10 MeV (dotted line), as presented by G. M. Frye, Jr.

20 MeV was (6 to 9) $\times 10^{-5}$ photon cm^{-2} s^{-1}, in agreement with the Case-Melbourne results. The data were based on the results of six balloon flights of a spark-chamber detector during 1969 to 1971. A 2.6σ effect was observed in the primary pulse, which was in phase with the optical, radio, and X-ray pulses. The events were summed over a gamma-ray arrival direction of 12° half-angle centered on the Crab Nebula, and the shape of the pulse as a function of phase was consistent with the results of Kurfess (Figure 3).

The above results on NP 0532 do not agree with the upper limit to the pulsed flux previously published by the Max Planck Institute in Munich (Kettenring *et al.*, 1971). K. Pinkau reviewed how these results were obtained and stated that he hoped that the additional data now being reduced will resolve this discrepancy.

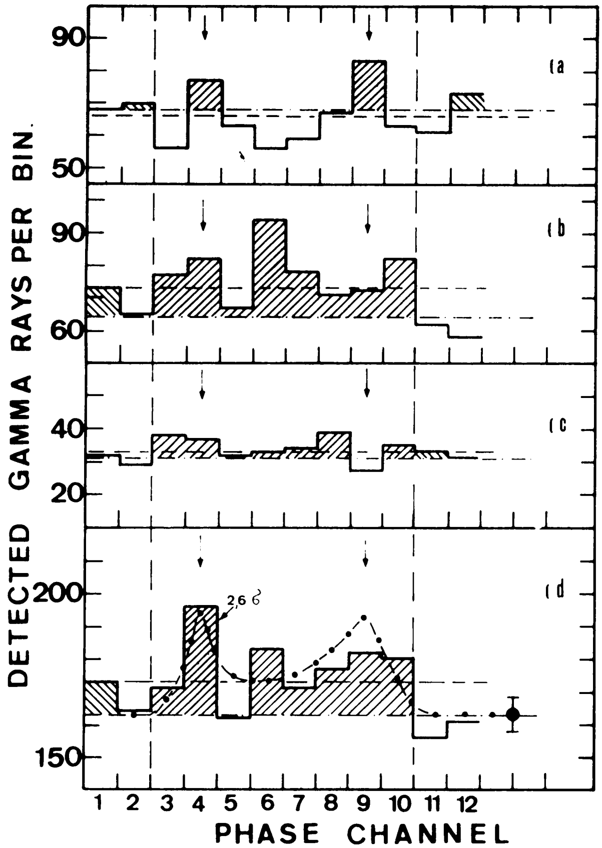

Fig. 3. Gamma-ray photon count from NP 0532 as a function of the pulsar phase in the energy region > 20 MeV from a series of six flights, summed in pairs (a), (b), and (c) and the total data (d). The data in (d) are compared with the 100 to 400 keV X-ray data. Presented by L. Scarsi.

The Laboratory for Cosmic Ray Physics, U.S. Naval Research Laboratory (NRL), had previously reported possible evidence for pulsed gamma-ray emission from NP 0532 above 10 MeV. G. Share, commenting on these results obtained with a nuclear emulsion spark-chamber detector, noted that of the 52 gamma-ray events previously detected in the spark chamber only and occurring near both optical peaks, only one photon came $\leqslant 2°$ from the Crab Nebula. This null result places an upper limit of 6×10^{-5} photon cm^{-2} s^{-1} for energies above 15 MeV. One interpretation of this is that the previously reported pulsation was due to low-energy events, $\leqslant 15$ MeV. The NRL group also set an upper limit to the total flux from the Crab Nebula of 10^{-4} photon cm^{-2} s^{-1} at energies above 15 MeV.

Above 10^{11} eV, cosmic gamma-rays interact within the atmosphere, producing Čerenkov radiation that can be detected with ground-based instruments. Cosmic-ray nuclei produce similar radiation; however, gamma-rays can be distinguished by their anisotropy in the direction of the suspected source. Using this technique, T. C. Weekes

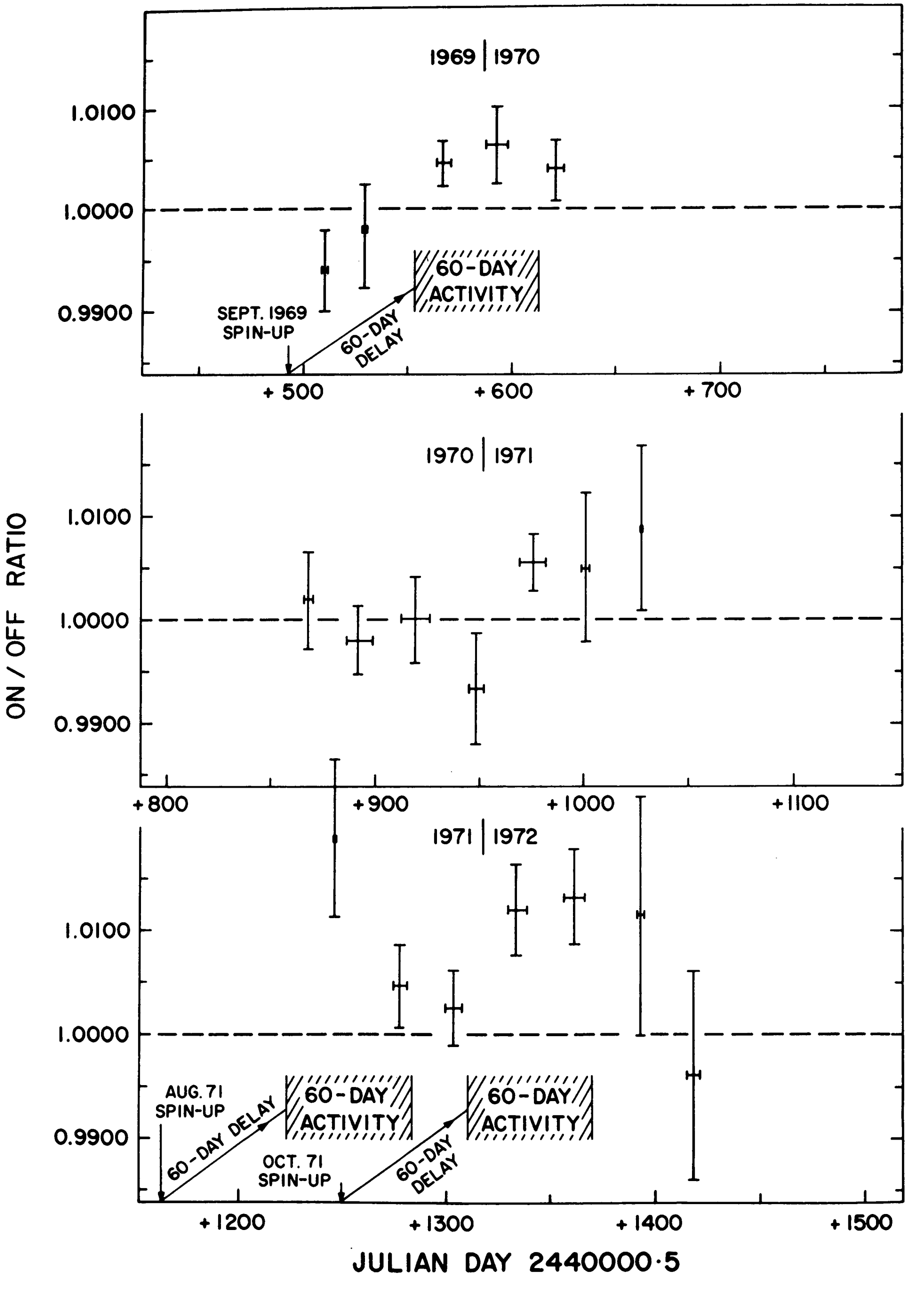

Fig. 4. Ratio of the air-shower counts recorded from the direction of the Crab Nebula to those from an arbitrary reference direction. A ratio significantly > 1 indicates a flux of 2.5×10^{11} eV gamma rays from the Nebula. Presented by T. C. Weekes.

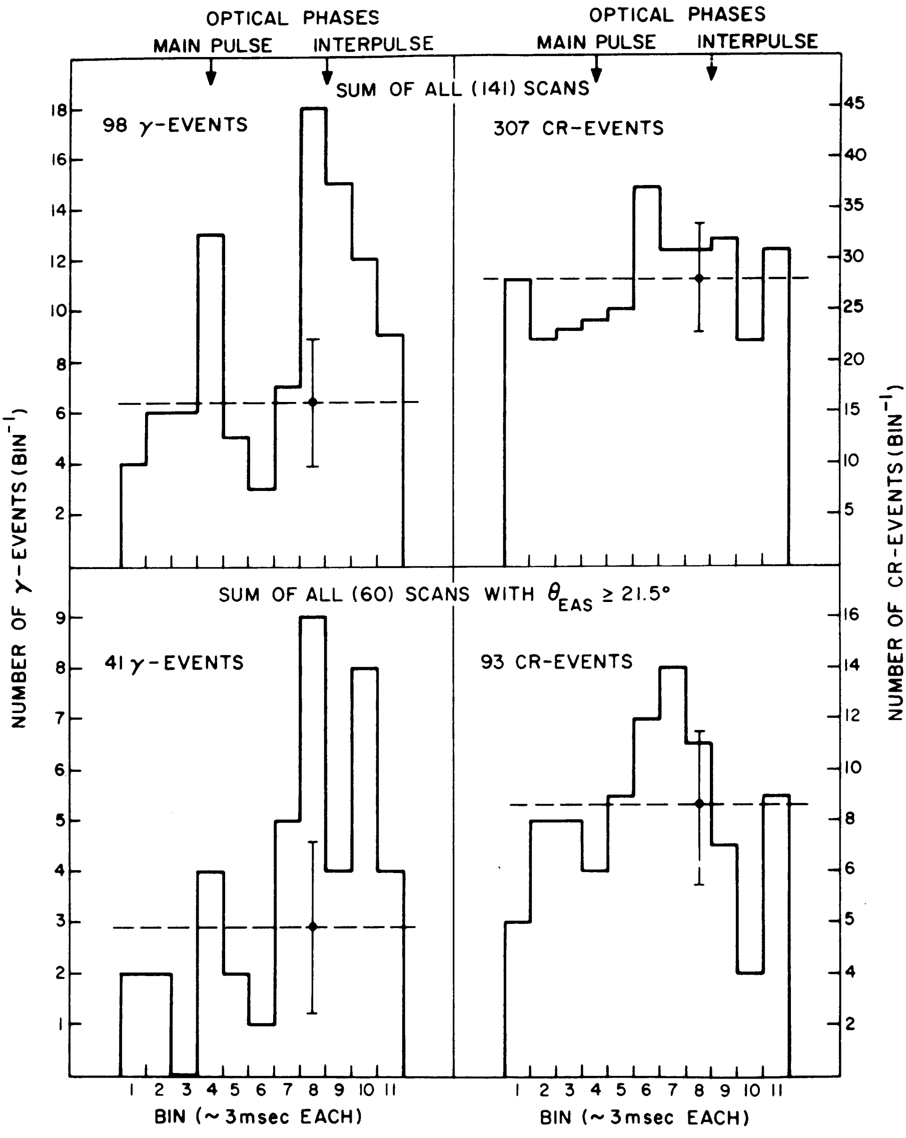

Fig. 5. Phase analysis of total gamma-ray data ($> 6 \times 10^{11}$ eV) from NP 0532. Data are divided according to the median zenith angle of NP 0532 for energy-spectrum determination. Data from Grindlay (1972).

reported the detection, by the group at the Smithsonian Astrophysical Observatory (SAO), of gamma-rays with energy greater than 2.5×10^{11} eV from the Crab Nebula. Observations of the Nebula over a 3-yr period indicate an average flux of $(4.4 \pm 1.4) \times 10^{-11}$ photon cm^{-2} s^{-1} at the 3.1σ level. This flux corresponds to an emission of 6×10^{33} ergs s^{-1}. However, the gamma-ray flux may vary with time, with the most significant flux ($(1.21 \pm 0.24) \times 10^{-10}$ photon cm^{-2} s^{-1}) occurring 60 to 120 days after a major spin-up of the pulsar NP 0532. This increase was observed on three different occasions, and if only this flux is used, the effect is at the 5σ level (Figure 4). The total gamma-ray energy observed on each occasion was $\sim 10^{41}$ ergs, an energy approximately equal to that of the pulsar spin-up.

Grindlay (1971) had previously reported evidence for the detection of pulsed gamma-rays of $\sim 10^{12}$ eV from NP 0532 and has recently confirmed these results (Grindlay, 1972). The sum of his data now yields a 5.5σ peak at the interpulse and a 3.5σ peak at the primary pulse, consistent with the pulsed flux ($\geqslant 6.8 \times 10^{11}$ eV) of 1.25×10^{-11} photon cm^{-2} s^{-1} (Figure 5). The ratio of the interpulse to the primary pulse is $\sim 3.5:1$, which follows the trend observed in the low-energy gamma-ray region but is opposite to the effect reported at this meeting in the 10 to 100 MeV region. The gamma-ray spectrum appears consistent with an extrapolation from the X-ray region.

Weekes also described the results from the teams at University College, Dublin, and U.K.A.E.R.E., Harwell, who reported evidence for the detection of a pulsed flux above 2×10^{12} eV. A significant (3.8σ) peak was observed, but it dit not occur in phase with the optical primary peak. This observation gives an upper limit to the flux of 2×10^{-12} photon cm^{-2} s^{-1}.

The interesting question as to whether the continuous flux, which was detected from the Crab Nebula by the SAO group, is pulsed or not, was dicussed by H. F. Helmken of SAO. Periodic analysis of 122 hr of data, collected over 3 yr, showed no significant effects. For energies above 1.5×10^{11} eV, the upper limit to the flux was 1.2×10^{-11} photon cm^{-2} s^{-1} for an assumed primary pulse width of 1.3 ms. These results agree with previously published results by SAO. Based on the continuous flux reported, the absence of a pulsed flux places an upper limit of 30% on the fraction contributed by the pulsed flux. Grindlay's results, when extrapolated from 6×10^{11} eV to 1.5×10^{11} eV with a spectrum proportional to $E^{-1.5}$, predict a flux greater by a factor of 7 than this upper limit. Unless the pulsed spectrum is very flat, there is a disagreement with Grindlay's results that needs to be resolved.

Two tentative and probably spurious indications of delay in reception of gamma-ray pulses from NP 0532 were reported by Frye at 100 MeV (a delay of 1 ms) and the Dublin-U.K.A.E.R.E. group at 10^{12} eV (17 ms). R. C. Henry, Johns Hopkins University, stated the results are interesting in light of a paper by Rawls (1972), who used pulsar data to discuss the possibility that we live in a non-Riemannian 'Finsler' space (Rund, 1959). Rawls used data up to 1 MeV to show that the fundamental length associated with our space, if Finsler, is $\leqslant 1.9 \times 10^{-18}$ cm. The delays at higher gamma-ray energies would imply smaller lengths, and the fact that the effect is a delay would mean the length is imaginary. Henry commented that this possibility must not be taken seriously but is worth keeping in mind.

3. Galactic Center Region

The scintillation detector experiment on the OSO 3 satellite produced convincing evidence for gamma-ray emission (> 100 MeV) from the galactic plane, with maximum intensity from the region of the galactic center (Clark *et al.*, 1971; Kraushaar *et al.*, 1972). Fichtel *et al.* (1972) verified these results at the 4σ level, using a balloon-borne spark chamber. In general, these experiments have been interpreted as being consistent with a line source in the galactic plane with an intensity near the galactic center of $\sim 1.2 \times 10^{-4}$ photon cm^{-2} s^{-1} rad^{-1}. Fichtel *et al.* also reported no significant excess of gamma-rays observed in the 50 to 100 MeV interval, supporting the evidence for a π^0-decay origin for the radiation. Frye *et al.* (1969) found no evidence for a line source in the region of the galactic center, with an upper limit of 3×10^{-5} photon cm^{-2} s^{-1} rad^{-1} for a $\pm 6°$ line source, but they detected several discrete sources. Whether the gamma radiation from the galactic center results from a diffuse interstellar source or from a number of discrete sources remains an interesting problem.

From a superposition of the results of three flights in 1969, Frye *et al.* (1971) had already reported evidence for several sources: (i) Sgr $\gamma - 1$, (ii) Gγ $2+3$ and Gγ $341+1$, which are coincident with known X-ray sources, and (iii) Lib $\gamma - 1$, a time-variable

Point Sources of Cosmic γ-Rays

PER γ-1

234-P: $N_O = 26$ $N_B = 15.0$
620-P: $N_O = 65$ $N_B = 41.6$ $\}\ \sigma = 4.6$

$F = 2.3 \times 10^{-5}$ γ's cm^{-2} sec^{-1}

$\alpha = 65°$, $\delta = +36°$

CEN γ-1

429-A: $N_O = 42$ $N_B = 24.2$
467-A: $N_O = 26$ $N_B = 16.8$ $\}\ \sigma = 4.2$

$F = 2.5 \times 10^{-5}$ γ's cm^{-2} sec^{-1}

$\alpha = 212°$, $\delta = -38°$

G γ 327+2

429-A: $N_O = 49$ $N_B = 34.1$
467-A: $N_O = 22$ $N_B = 8.5$ $\}\ \sigma = 4.4$

$F = 3.0 \times 10^{-5}$ γ's cm^{-2} sec^{-1}

$\alpha = 234°$, $\delta = -52°$

Fig. 6. New point sources of cosmic gamma rays (> 50 MeV) as reported by G. M. Frye, Jr.

source seen in November 1969 but not in Febraury 1969. This last may be associated with the radio source AP Lib (PKS 1514–24), a BL Lac-type object. During the Symposium, Frye also presented evidence for two new sources at the 4σ level in this region: Cen $\gamma-1$ with an intensity of 2.5×10^{-5} photon cm^{-2} s^{-1} and Gγ 327+2 with an intensity of 3×10^{-5} photon cm^{-2} s^{-1}, both for energies above 50 MeV. This latter source may be identified with the highly variable X-ray source 2U1516−56. A summary of the positions of these sources is given in Figure 6. A number of $\geqslant 3\sigma$ peaks are seen in the fluxes measured from a region of 2 sr centered on the galactic center, but the distribution of all these sources, when analyzed as a latitude distribution, is not consistent with a $\pm 6°$ line source in the plane (Figure 7). Frye's results could still be consistent with the OSO 3 experiment since the angular resolution of that detector was $\pm 15°$.

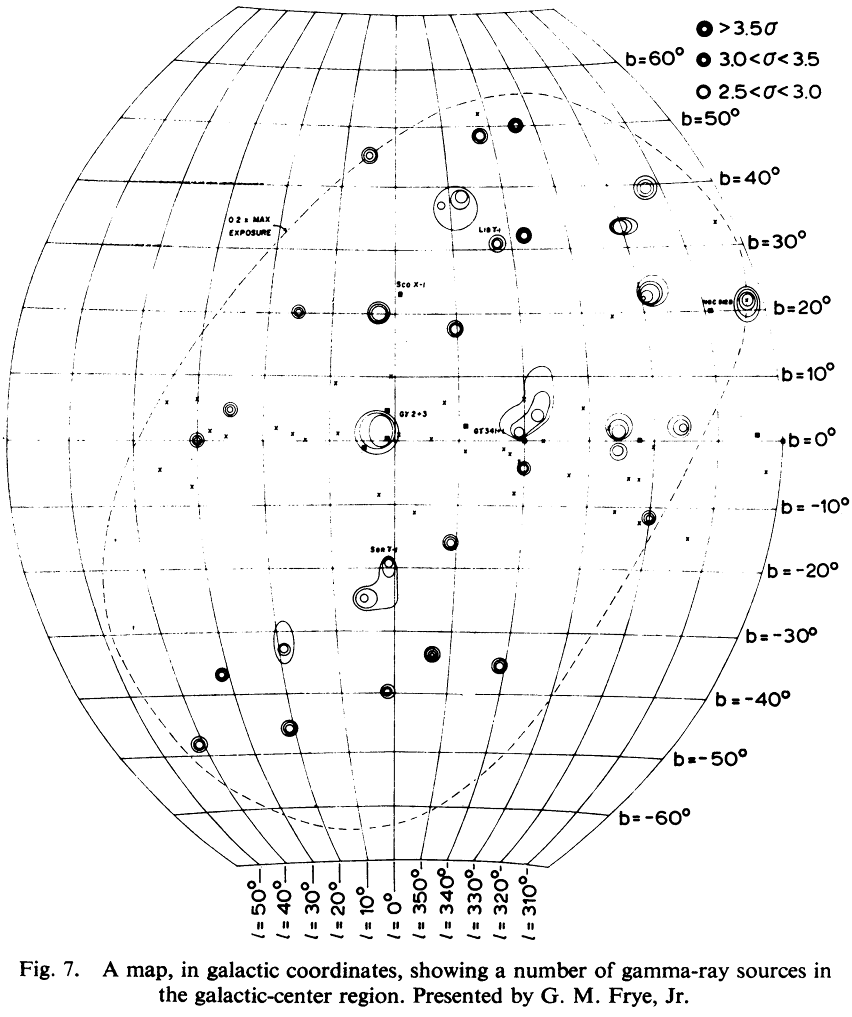

Fig. 7. A map, in galactic coordinates, showing a number of gamma-ray sources in the galactic-center region. Presented by G. M. Frye, Jr.

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D. A. Kniffen, of Goddard Space Flight Center (GSFC), summarized the results of Fichtel *et al.* (1972) and discussed the interpretation of their flux measurements on the galactic center. Although the data have been interpreted in terms of a line source, the possibility that they consist of an accumulation of several unresolved discrete sources cannot be ruled out. However, these sources must be within $\pm 6°$ of the galactic plane. This interpretation would be consistent with recent results of the University of Southampton group, but it is in clear contradiction with Frye's findings. Kniffen also pointed out that a discrete-source interpretation must be reconciled with the results of their spectral measurments (π^0-decay-type spectrum) and those of NRL.

G. K. Rochester submitted a paper by the Imperial College, London, group verifying the flux intensities of OSO 3 and Fichtel *et al.* in the 200 MeV to 10 GeV region. Results were presented from two balloon flights in Zambia that used a scintillation detector. An excess number of counts was also observed in the region of Sgr XR-2, which accounted for almost half the excess counts from the line source.

G. Hutchinson, from the University of Southampton, presented some new data on the origin of the gamma-ray (> 100 MeV) flux in the region of the galactic center. Their balloon-borne spark chamber, launched from Palestine, Texas, in September 1971, observed the galactic center at relatively large zenith angles. They detected three sources above the 3σ level; each was associated with a galactic X-ray source listed in

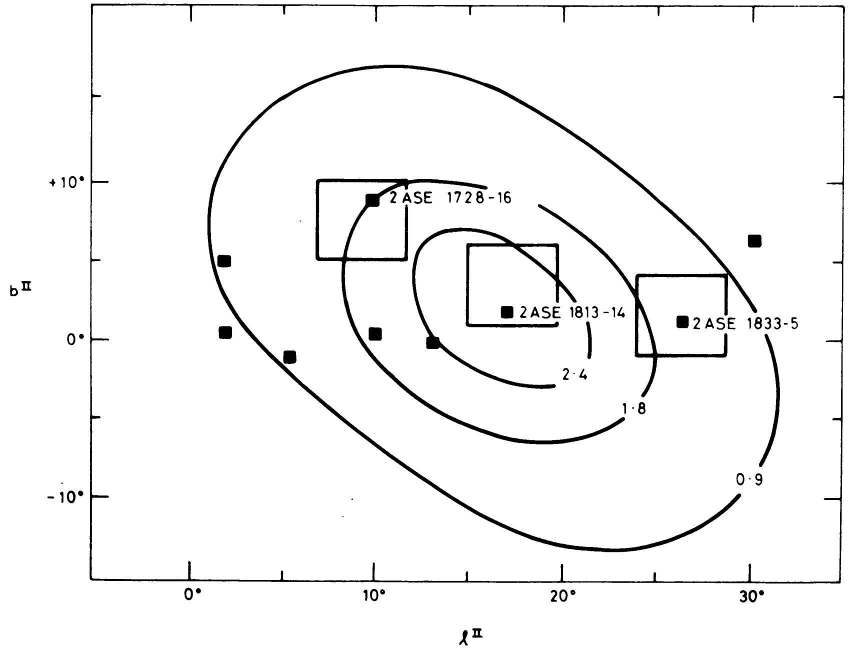

Fig. 8. Gamma-ray point sources observed by the University of Southampton group in the region of the galactic center. The black squares show the position of known X-ray sources, and the open squares indicate regions of anomalously high gamma-ray emission. Exposure-value contours are in units of 10^6 cm^2 s. Reported by G. Hutchinson.

the UHURU catalog (Figure 8). The source strengths were of the order of 2×10^{-5} photon cm^{-2} s^{-1}. Other than these sources, no other significant flux was observed within $\pm 3°$ of the galactic equator, giving an upper limit to a line source of 8×10^{-5} photon cm^{-2} s^{-1} rad^{-1}. If the three sources were viewed by a detector that could not resolve them and the result interpreted as a line source, the flux would be 1.5×10^{-4} photon cm^{-2} s^{-1} rad^{-1}, in agreement with Clark *et al.* (1971) and Fichtel *et al.* (1972). The area of the sky observed in this experiment only partially overlapped the region investigated by Frye.

Preliminary results on the galactic-center region obtained during a recent series of balloon flights from Argentina were presented by Share and Helmken.

Share quoted evidence for a possible source near Gγ 341+1 at energies >10 MeV with an intensity of $\sim 2 \times 10^{-4}$ photon cm^{-2} s^{-1}. Search for a line source of radiation (>10 MeV) gave only an upper limit to the flux of $3 \times 10^{-}4$ photon cm^{-2} s^{-1} rad^{-1}, implying that the spectrum observed above 100 MeV must flatten at lower energies, which is characteristic of a π^0-decay mechanism (Figure 9). No gamma-rays > 15 MeV were detected from Lib γ-1 at an intensity expected from Frye's results.

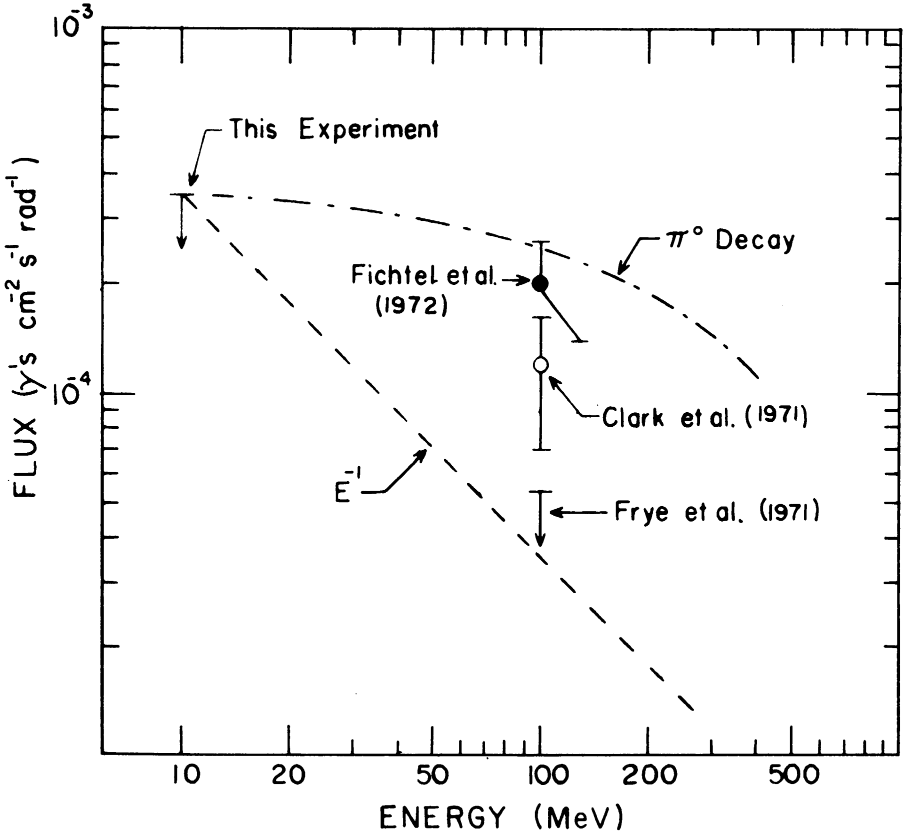

Fig. 9. Upper limit to the flux of a gamma-ray line source in the galactic plane near the center ($328.5° < l^{II} < 325°$, $-12.5° < b^{II} < 12.5°$) as determined by the NRL group and reported by G. Share.

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Using a gas-Čerenkov detector with an energy threshold of 10 MeV, Helmken observed the galactic center on each of two flights from Argentina. A positive excess flux was observed on both flights, with a total value at the 2.6σ level. Preliminary analysis of the data gives an integral flux above 12 MeV of $(1.9 \pm 0.7) \times 10^{-4}$ photon $cm^{-2}\,s^{-1}$. Comparison of this value with the results of Fichtel *et al.* shows that it is also consistent with a line source in the plane in which the source mechanism consists of equal parts of Compton scattering and π^0 decay. In Figure 10, Helmken's data point is plotted along with the low-energy gamma-ray spectrum from the galactic-center region observed previously by Johnson *et al.* (1972).

In this lower energy range, Johnson *et al.* also found evidence for a spectral feature at 0.5 MeV, the electron-positron annihilation line.

There is no doubt that the galactic plane and the region near the galactic center are sources of gamma radiation. What the source of this radiation is – i.e., whether it is diffuse and interstellar in origin or a group of discrete sources – is still uncertain. At this meeting, no new and significant evidence was presented for a true diffuse source of gamma-rays in the galactic plane. The experimental results to date, however, are

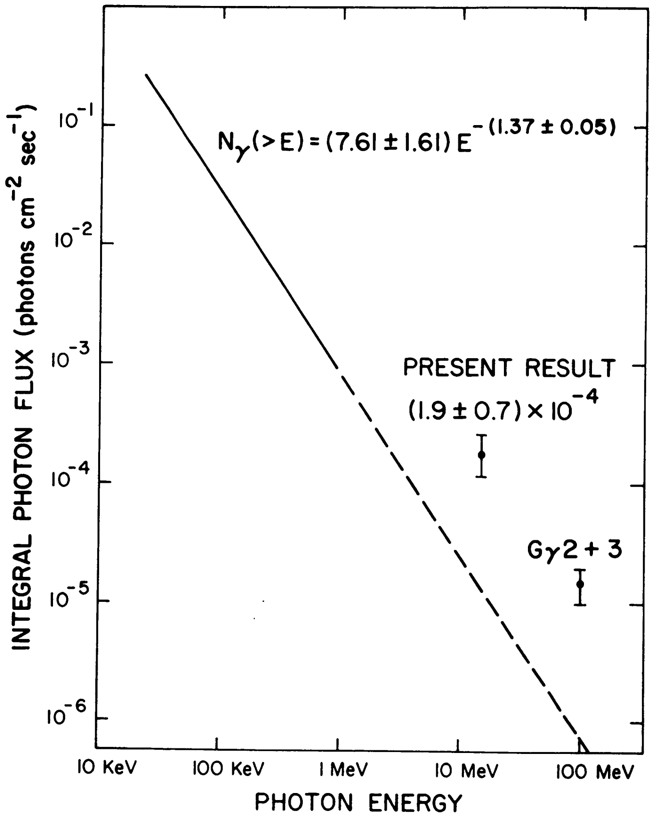

Fig. 10. Integral gamma-ray flux from the galactic center as measured by H. Helmken, compared to an extrapolation of the flux measured by W. N. Johnson *et al.* (1972) at lower energies.

not in conflict with the diffuse flux predicted from π^0 meson decay. The mesons are produced by the interaction of a uniform source of cosmic rays on atomic hydrogen. Cavallo and Gould (1971) predict a flux of $\sim 3 \times 10^{-5}$ photon cm^{-2} s^{-1} rad^{-1} in the plane and in the region of the galactic center due to this mechanism. Stecker (1970) predicts a flux a factor of 2 lower. The OSO 3 results in the galactic plane, away from the center, are consistent with the predicted flux, and the upper limits to a diffuse source in the plane as determined by Frye *et al.* (1969) are a factor of 2 (center) to 3 (anticenter) above this predicted flux.

In regard to the multitude of discrete sources reported, no source has been seen at a high statistical significance by two different groups. Owing to the rather small number of balloon flights, this may be an indication of time variability. Frye has proposed the following criteria for acceptance of a source: (i) a 5σ effect from a single observation or (ii) a 4σ effect from two observations. Further, he recommends that anything less than this should be listed as a 'possible' source and promulgated only as information for other groups. Hutchinson requested that groups exchange their sky maps to compare 'possible' source positions. Helmken has suggested that to compare data, a common method of analysis should be followed, e.g., the calculation of upper limits as proposed by Fichtel *et al.* (1969) and Hearn (1969). It would also be helpful if the value of σ was given on all suspected gamma-ray sources.

What gamma-ray astronomy needs is more sensitive experiments with good angular resolution. Perhaps the answer will come this year with the results of the TD-1A and SAS-B satellite experiments.

4. Galactic Plane in the Cygnus-Cassiopeia Region

The University of Southampton group (Browning *et al.*, 1972) recently reported evidence at the $\sim 3\sigma$ level for a number of discrete gamma-ray sources in the energy range above 100 MeV, and researchers from Toulouse (Niel *et al.*, 1972) found an enhancement in the flux (2.5 to 3.5σ) from the galactic plane in a narrow longitude zone in the Cygnus region. In the history of gamma-ray astronomy, this region of the sky has produced several sources that have never been verified.

At this Symposium, A. Dean, of the Milan-Palermo group, describing an experiment in the 0.8 to 10 MeV region flown from a balloon launched in Sicily, presented evidence for an increase in the gamma-ray count rate coincident with the transit of the X-ray sources Cyg X2 and X4. The flux above 0.8 MeV was ~ 0.12 photon cm^{-2} s^{-1}. Both these objects were possible 100 MeV sources in the results of Browning *et al.* (1972).

An OGO 5 satellite experiment by P. A. J. de Korte and B. N. Swanenburg, at the University of Leiden, searched for a gamma-ray line emission at galactic longitude of 60° but placed only an upper limit to the line flux of 5×10^{-5} photon cm^{-2} s^{-1} rad^{-1} above 400 MeV and 2.5×10^{-5} photon cm^{-2} s^{-1} rad^{-1} above 1.15 GeV.

At the Hobart Conference, Vladimirsky *et al.* (1971), of the Crimean Astrophysical Observatory, reported possible detection of a high-energy gamma-ray ($>10^{12}$ eV) source in the Cygnus region of the galactic plane. Weekes reported that SAO had searched for this source but was unable to detect it at 10^{11} eV. The Crimean group presented a paper at this meeting stating that they had searched the region a second time, and they, too, were unable to detect the source. Perhaps we are again dealing with time-variable sources.

The Crimean team (Stepanyan *et al.*, 1972) also reported a new source in Cassiopeia in the energy region above 2×10^{12} eV. Observed during three drift scans on September 29 and October 14 and 15, 1971, this source had a flux of 10^{-10} photon cm^{-2} s^{-1} at the 3.9σ level. Its position was $\alpha = 01^h 11^m \pm 6^m$ and $\delta = 62° \pm 1°$. It was not observed on three previous drift scans, on September 22, 25, and 27, 1971.

5. Galactic Plane in the Anticenter Region

Other than the Crab Nebula, one of the most spectacular sources reported in this region of the sky has been the variable Seyfert galaxy 3C120, labeled Tau γ–1. This source was reported by Volobuyev *et al.* (1971), of the Moscow Physical Engineering Institute, based on the results of scintillation-counter experiments on the satellites Cosmos 251 and 264. The flux is rather large, 5×10^{-4} photon cm^{-2} s^{-1}, a factor of 20 greater than any other source reported. These measurements were made during a period when the radio intensity of 3C120 was at a maximum. Kirillov-Ugryumov pointed out in a paper submitted to the Symposium the similarity between this object and the source reported by Frye, PKS 1514$-$24 (AP Lib), both variable radio galaxies with star-like nuclei. Other galaxies with similar characteristics that should be investigated for gamma-ray emission are VRO 42.22.01 (BL Lac) and ON 231 (W Com), which have also been suggested by Frye, as well as B2 1215+30, 3C273, and OJ 287. At this meeting, Frye reported no evidenc for OJ 287 being a gamma-ray source (Figure 11) and had previously published an upper limit to the flux from 3C273 (Frye and Wang, 1969).

Frye reported one new source in this region of the sky, observed on each of two flights with a combined effect of 4.6σ. This source, Per $\gamma - 1$, was located at $\alpha = 65°$, $\delta = 35.5°$($l = 164°$, $b = -10°$) and had an intensity of 2.3×10^{-5} photon cm^{-2} s^{-1}. No source was reported at the position of 3C120; however, a 4σ source was observed within the $\pm 10°$ error box on 3C120, located at $\alpha = 76°$, $\delta = 1°$ with a flux of 5×10^{-5} photon cm^{-2} s^{-1}. No evidence for a line source in the galactic plane has been observed (Figure 11).

Three balloon-flight experiments by the Saclay-Milan-Palermo group to search for gamma radiation in the anticenter region were described by B. Agrinier, of the Center for Nuclear Studies, Saclay. Seven discrete sources were reported at the 2 to 3σ level. The Crab Nebula was observed at the 2σ level, giving a flux ($>$20 MeV) of (6.2 to 9.0)$\times$ 10^{-5} photon cm^{-2} s^{-1}. The point sources detected are in the vicinity of the galactic disk, and hence the OSO 3 line source in this region could be accounted for by the discrete sources reported in this experiment (Figure 12).

The NRL group (Share) reported only an upper limit to the line emission ($>$15 MeV) from the plane near the anticenter ($\leqslant 3.5 \times 10^{-4}$ photon cm^{-2} s^{-1} rad^{-1}).

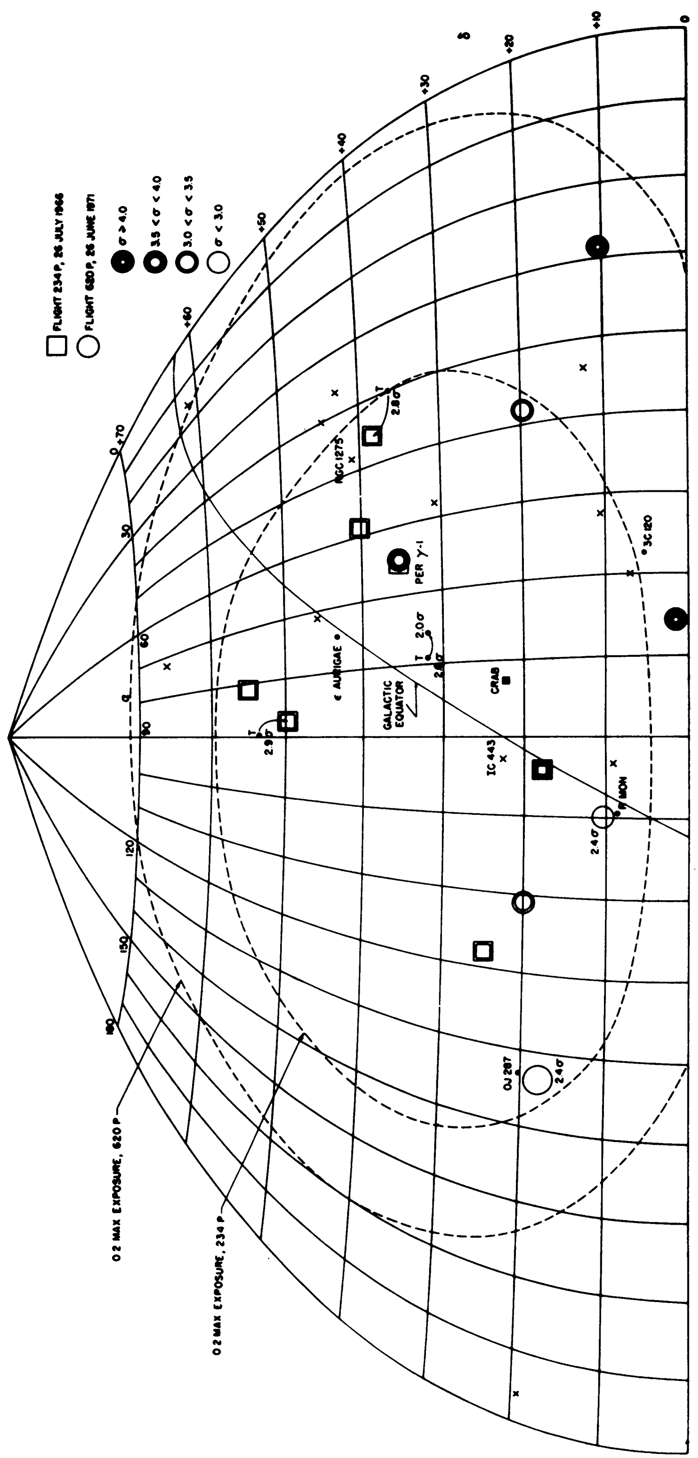

Fig. 11. A map, in celestial coordinates, showing the position of gamma-ray sources in the galactic anticenter region. Presented by G. M. Frye, Jr.

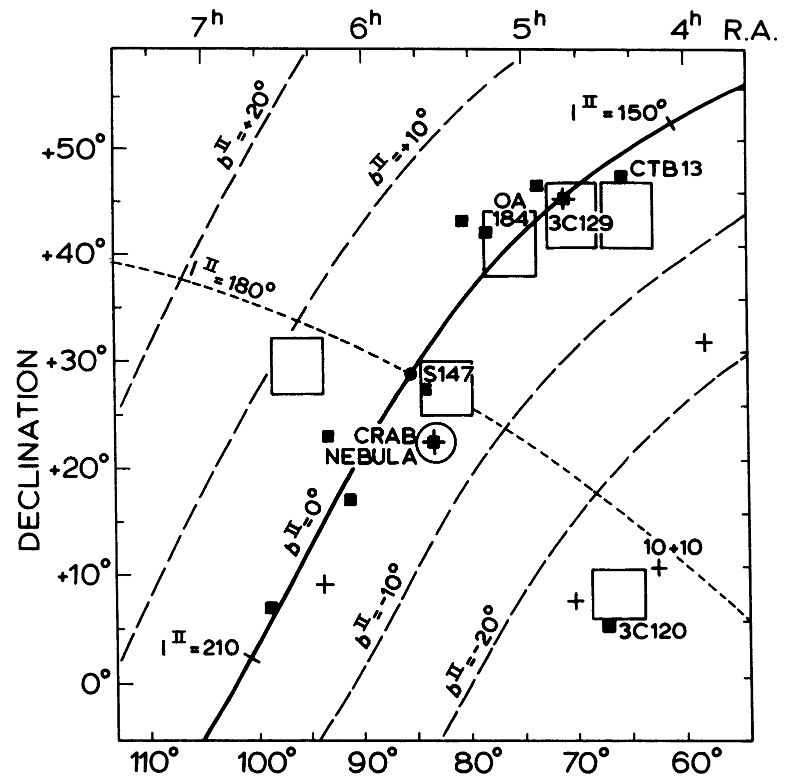

Fig. 12. A map of the sky in the region of the galactic anticenter, presented by B. Agrinier for the Saclay-Milan-Palermo group, showing gamma-ray sources as open squares or circles. The crosses indicate X-ray sources, and the black squares, supernova remnants.

6. Future Satellite Experiments

The Apollo 15 and 16 flights carried a gamma-ray spectrometer consisting of a 3″ × 3″ Na I (Tl) crystal with an anticoincidence scintillator and a 512-channel pulse-height analyzer. Measurements of the diffuse gamma-ray flux with this detector were reported earlier. During the last 30 hr of transearth coast of Apollo 16, the detector was extended to 2 m and the spacecraft arranged to rotate. The spacecraft acts as an occulting disk of about 0.25 sr solid angle. A strong source would be indicated by a reduction in count rate. Hence, a map of the sky in the 0.1 to 4.0 MeV region with about 40 resolution elements can be obtained. L. Peterson of the University of California in San Diego reported that these data are now being reduced.

In March 1972, the ESRO satellite TD-1A was launched. It contains an experiment, called MIMOSA, that uses a vidicon spark chamber to search for cosmic gamma-rays above 50 MeV (Figure 13). The sensitive area of the detector is 130 cm^2, the area-solid-angle factor is 28 cm^2 sr, and the angular resolution is ~3°. The data rate is 1 video frame per 5 s. The experiment is functioning and the gamma-ray count rate being

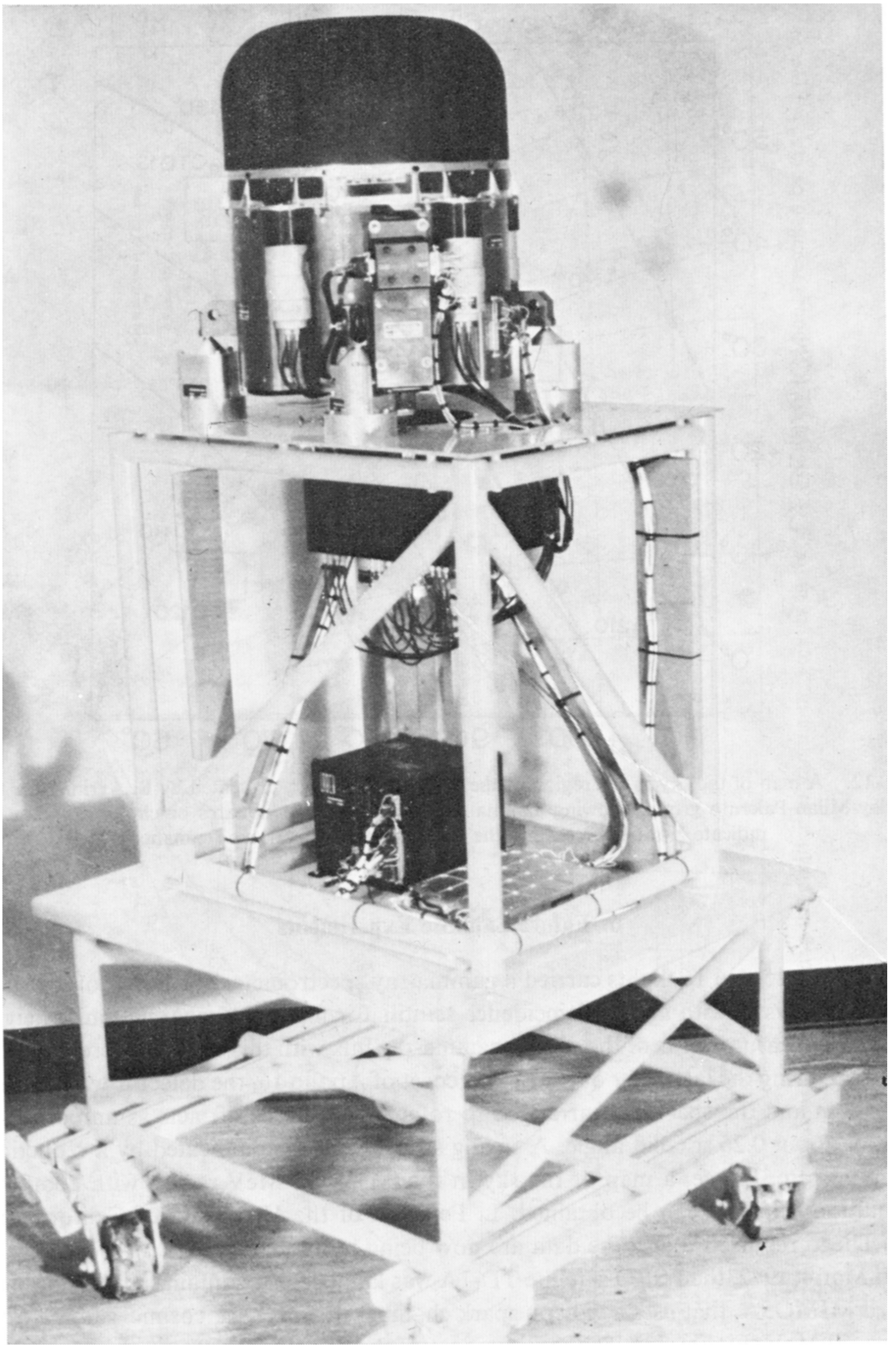

Fig. 13. The gamma-ray spark-chamber experiment (S133) on the ESRO TD-1A satellite.

recorded is ~1 event per 5 min. The detector always points at the zenith during the satellite orbit. The experiment is a cooperative effort of the Center for Nuclear Studies, Saclay, the Max Planck Institute, Munich, and the University of Milan.

Pinkau also reported on the status of the ESRO satellite COS-B, which is a single experiment devoted entirely to gamma-ray astronomy in the region above 30 MeV. The detector is a wire spark chamber with an energy calorimeter (Figure 14). The sensitive area is $\sim 576\ \text{cm}^2$ and the area-solid-angle factor, $\sim 70\ \text{cm}^2$ sr. The energy resolution will be about 50% at 100 MeV. The satellite will be spin-stabilized and, in contrast to other experiments, placed in a highly eccentric orbit. The main advantages of this orbit are reduction of Earth albedo, reduction of radiation-belt effects, minimum occultation by the Earth, and adequate ground-station coverage. The satellite, due to be launched in 1974, is a cooperative program among the groups at Leiden, ESTEC, Saclay, Milan, Palermo, and Munich.

The SAS-B satellite will also be a single gamma-ray experiment (see Figure 15) conducted by NASA/GSFC (C. E. Fichtel, R. C. Hartman, and Kniffen). The experiment will consist of a wire spark chamber sensitive to gamma-ray energies above 25 MeV. The sensitive area of the experiment is $\sim 500\ \text{cm}^2$; the area-solid-angle factor,

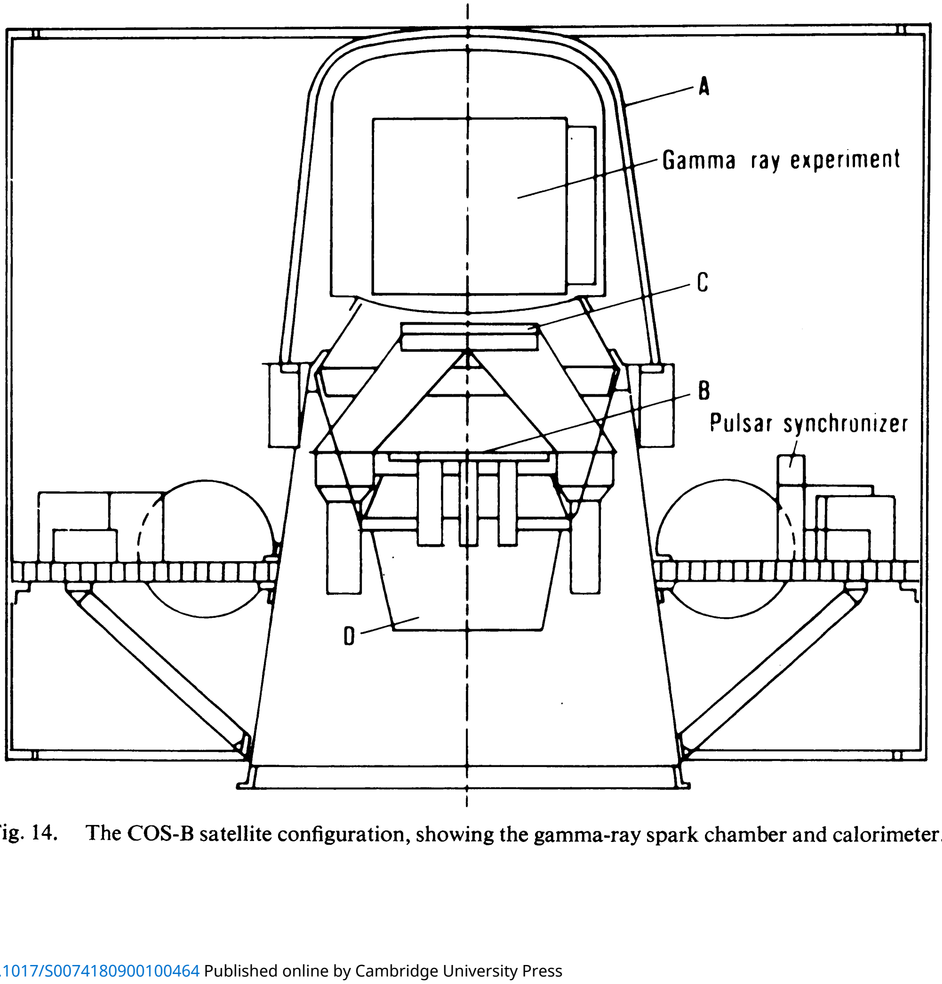

Fig. 14. The COS-B satellite configuration, showing the gamma-ray spark chamber and calorimeter.

125 cm^2 sr; and the angular resolution, $\sim 2°$ at 100 MeV. The satellite will be placed in a 550-km circular equatorial orbit in October 1972.

The HEAO-B gamma-ray experiment is a joint undertaking of the groups at NASA/GSFC, Stanford University, Grumman Aerospace Corporation, and Max Planck Institute. The design for this experiment is not yet complete, but it includes a large, digitized spark chamber and a cesium iodide crystal spectrometer to allow differential energy measurments over the interval from 20 to 10^4 MeV. The detector

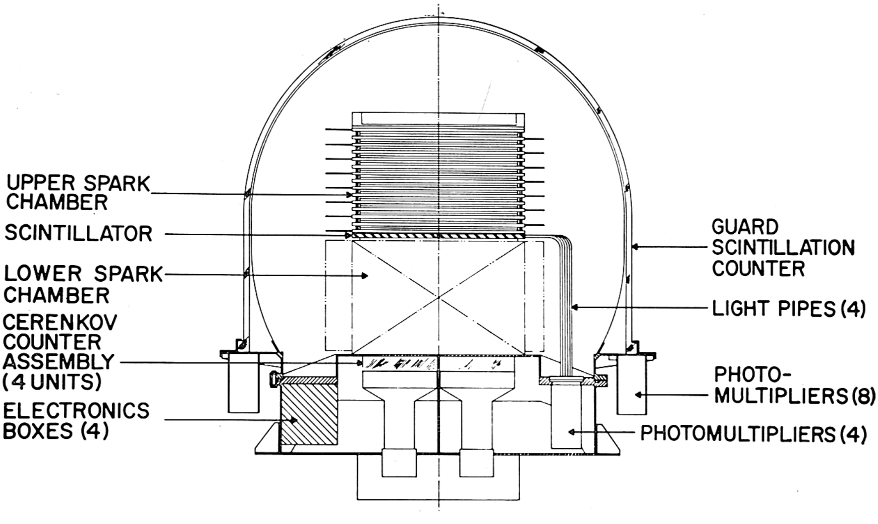

Fig. 15. Schematic of the digitized spark chamber used as a gamma-ray telescope on the satellite SAS-B.

area will be approximately a factor of 8, and the area-solid-angle product a factor of 16 larger than the SAS-B experiment. The experiment will be operated in a scanning mode.

It is interesting to note that present-day balloon-borne detectors have sensitivities of the order of 10^{-5} photon cm^{-2} s^{-1} for discrete sources, whereas future satellite experiments will increase the sensitivity to 10^{-6} to 10^{-7} photon cm^{-2} s^{-1}. However, it is possible to increase the sensitivity of future balloon-borne detectors. For example, a 1-m^2 spark chamber flown at a pressure of 0.5 mb and a cutoff rigidity of 12 GV will have a sensitivity $\sim 10^{-6}$ photon cm^{-2} s^{-1}.

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