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INVESTIGATION OF GAMMA RAYS FROM THE GALACTIC CENTER

Final Report

Grant NGR 09-015-173

Principal Investigator
Dr. Henry F. Helmken

November 1973

Prepared for
National Aeronautics and Space Administration
NASA Headquarters
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1. INTRODUCTION

This final report summarizes the results of the two balloon flights in Argentina directed toward the galactic center (Section 2) and one balloon flight from Palestine, Texas, directed toward NP 0532 (Section 3). Section 4 briefly outlines future studies.

2. THE GALACTIC CENTER*

A pointable gas-Čerenkov gamma-ray telescope was flown twice from Paraná, Entre Rios, Argentina (Lat. 31°8 S), to search for gamma radiation from the galactic center. Paraná is an excellent location for such measurements since the galactic center passes within 3° of the zenith.

The detector is sensitive to gamma rays with $E_\gamma > 10$ MeV; it has been modified from previous descriptions (Helmken and Hoffman, 1970; Hoffman, 1971) by the installation of a new gamma-ray conversion scintillator with an area of 4×10^3 cm^2, more than twice as large as the previous one.

A 10.6×10^6-ft^3 balloon launched November 26, 1971, at 0925 UT (0625 local time) carried the detector to an overlying pressure of 3.2 g cm^{-2}. Float altitude during the first flight was constant to ± 0.2 g cm^{-2}, and the package was cut down at 2200 UT after 10.3 hr at float. A second balloon, 11.1×10^6 ft^3, was launched December 5, 1971, at 1000 UT; it reached 2.8 g cm^{-2}, but ballast control failed at launch, and during the last half of the flight the balloon descended steadily to 4.5 g cm^{-2}, where it was cut down at 2100 UT after 8.8 hr at float.

Hard X radiation and gamma radiation have been reported (Johnson et al., 1972; Clark et al., 1968, 1970; Kniffen and Fichtel, 1970; Frye et al., 1971; Kraushaar et al., 1972; Browning et al., 1972) from the region of the sky near the galactic center. There is considerable controversy whether the radiation is coming from point sources (Frye et al., 1971; Browning et al., 1972) or from a diffuse line source along the galactic plane (Kniffen and Fichtel, 1970). The present angular resolution of our detector is not good enough to resolve the source structure. The combined results of our two flights show a 3.8σ excess of gamma radiation from the direction of the galactic center

*This material is excerpted from Helmken, H. F., Gamma-Ray Observations of the Galactic-Center Region, Nature, Phys. Sci., vol. 243, pp. 6-8, 1973.

over background, corresponding to a detector count rate of 0.73 ± 0.29 counts $\min^{-1}$. Both point-source and line-source models of radiation were used in analyzing the data from this experiment.

2.1 Point-Source Model

Johnson et al. (1972) have reported positive observations of gamma rays with $E_\gamma > 1$ MeV from the Sagittarius region. They interpret their counts as coming from a single point source, perhaps GX 5-1 (Schnopper et al., 1970). Observations have been reported (Frye et al., 1971) of gamma rays with $E_\gamma > 100$ MeV from a point source $G\gamma$ 2+3 that corresponds closely in position with the hard X-ray source GX 1+4 (Lewin et al., 1971). In this experiment, the corresponding point-source photon flux is F_γ (> 15 MeV) = $(1.9 \pm 0.7) \times 10^{-4}$ photon cm^{-2} sec^{-1}. These results have been plotted in Figure 1. Spectral uncertainties preclude extrapolation of Lewin et al.'s lower energy observations of galactic-center X-ray sources up to the energies shown in Figure 1.

2.2 Line-Source Model

If the gamma rays are coming from a line source, the angular response of the detector must be unfolded from the observed flux in order to compute the galactic-plane flux. Since the angular response is energy dependent, the result depends in part on the observed spectrum, which is what is being measured. For example, variation of the spectral index of an observed power-law spectrum from 1.5 to 2.0 would decrease our reported flux by 37%, which is close to the reported uncertainties in the present observation. Different models must be fitted and tested for consistency with initial assumptions.

Cosmic-ray interactions with galactic hydrogen can produce (Stecker, 1971; Cavallo and Gould, 1971; Levy and Goldsmith, 1972) the observed galactic-plane gamma radiation (Kniffen and Fichtel, 1970; Kraushaar et al., 1972) by pion decay. The excess (factor of 4) gamma radiation from the galactic-center region could be from increased cosmic-ray or hydrogen densities, or from another source such as

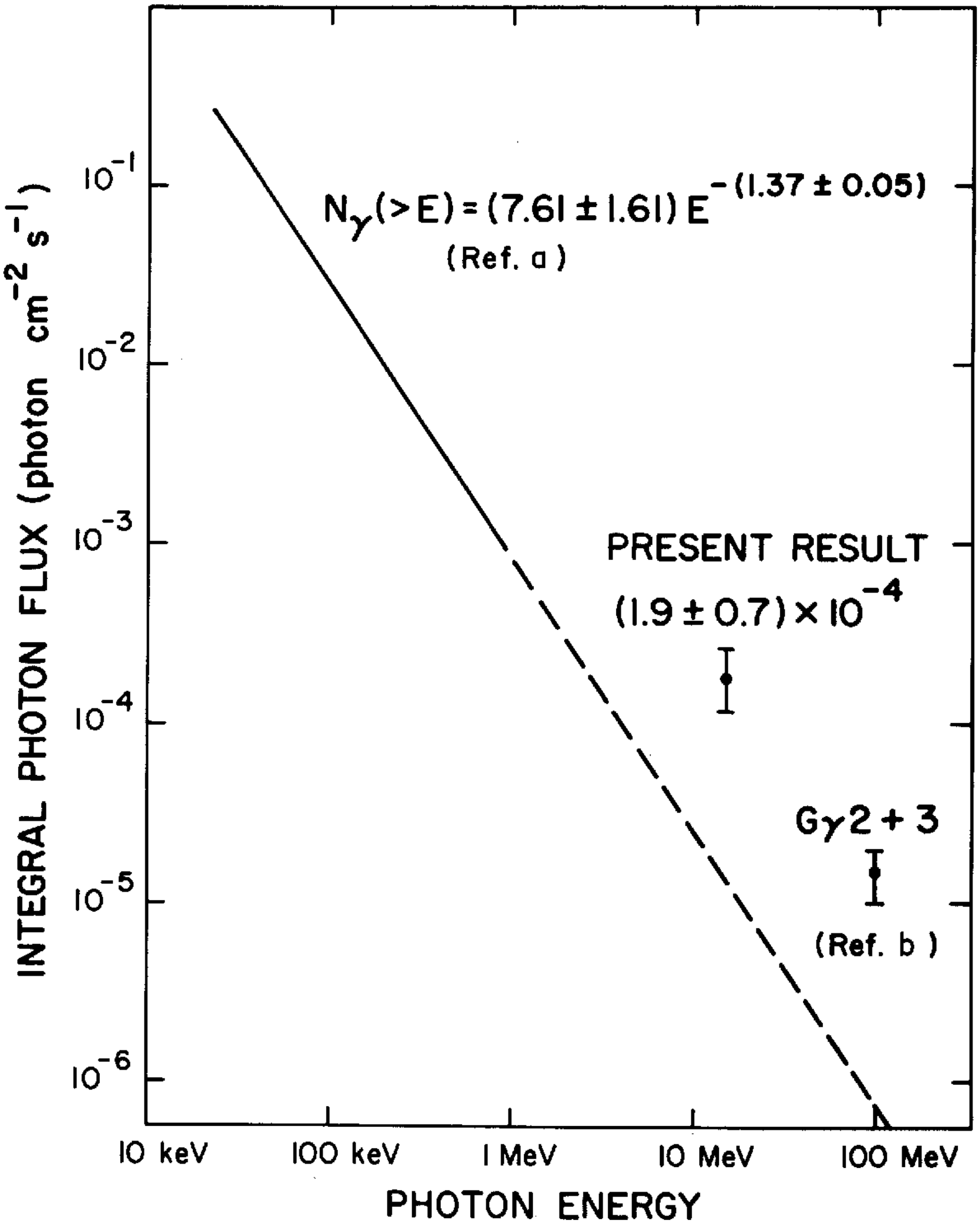

Figure 1. Gamma radiation from suspected point sources in the Sagittarius region. The spectrum from 30 to 930 keV was observed by Johnson et al. (1972, Ref. a) while their detector was pointed at GX 5−1. Gγ 2+3 was observed by Frye et al. (1971, Ref. b) with a positional accuracy of 1°. The present observations were made with the detector pointed at the galactic center.

electron scattering from the infrared radiation field, reported by Hoffmann and Frederick (1969). Kraushaar et al. (1972), in a summary of models of the galactic-center region, point out that the lack of an increase in atomic hydrogen column density, combined with an enhancement of nonthermal radio emission toward the galactic center, suggests cosmic-ray electrons as the source of the extra gamma radiation. This hypothesis can be checked only by measuring the gamma-ray spectrum down to low energies.

Figure 2 (modified from Stecker, 1971) shows the integral spectrum of a two-component model of gamma-ray production – the superposition of a Compton-scattered gamma-ray spectrum (assuming the same electron spectrum as that measured at the earth) on a pion-decay gamma-ray spectrum resulting from proton-proton collisions. The only free parameter is the relative contribution of the Compton-scattered gamma rays (described in the caption as a fraction for $E_\gamma > 100$ MeV). The pion and Compton spectra are then added and normalized to Kniffen and Fichtel's (1970) observations at $E_\gamma > 100$ MeV of a galactic-center line source. The figure shows that the integral measurements most sensitive for determining the Compton-scattered contribution are those taken at lowest energies.

Kniffen and Fichtel's observation of $F_\gamma(> 50 \text{ MeV}) < 1.5\, F_\gamma(> 100 \text{ MeV})$ would limit the fractional Compton-scattered contribution to < 0.83 for $E_\gamma > 100$ MeV (curve 2). The present observations are shown in the upper left of Figure 2, with vertical error bars indicating one standard deviation, derived from counting statistics. Computing the "effective" threshold energy is more difficult for an extended than for a point source, and results are plotted for effective thresholds from 11 to 15 MeV to show the effect of the assumptions involved. The fluxes indicated by lines i and iii are computed for the spectra of curves 1 and 3, respectively, showing the sensitivity of the reported flux to the assumed incident spectral shape.

To within its statistical accuracy, the current results require the presence of a Compton-scattered gamma-ray flux from the galactic center in addition to pion-decay gamma rays. A contribution of 50% at $E_\gamma > 100$ MeV (curve 3) is consistent with the lower limits of these observations.

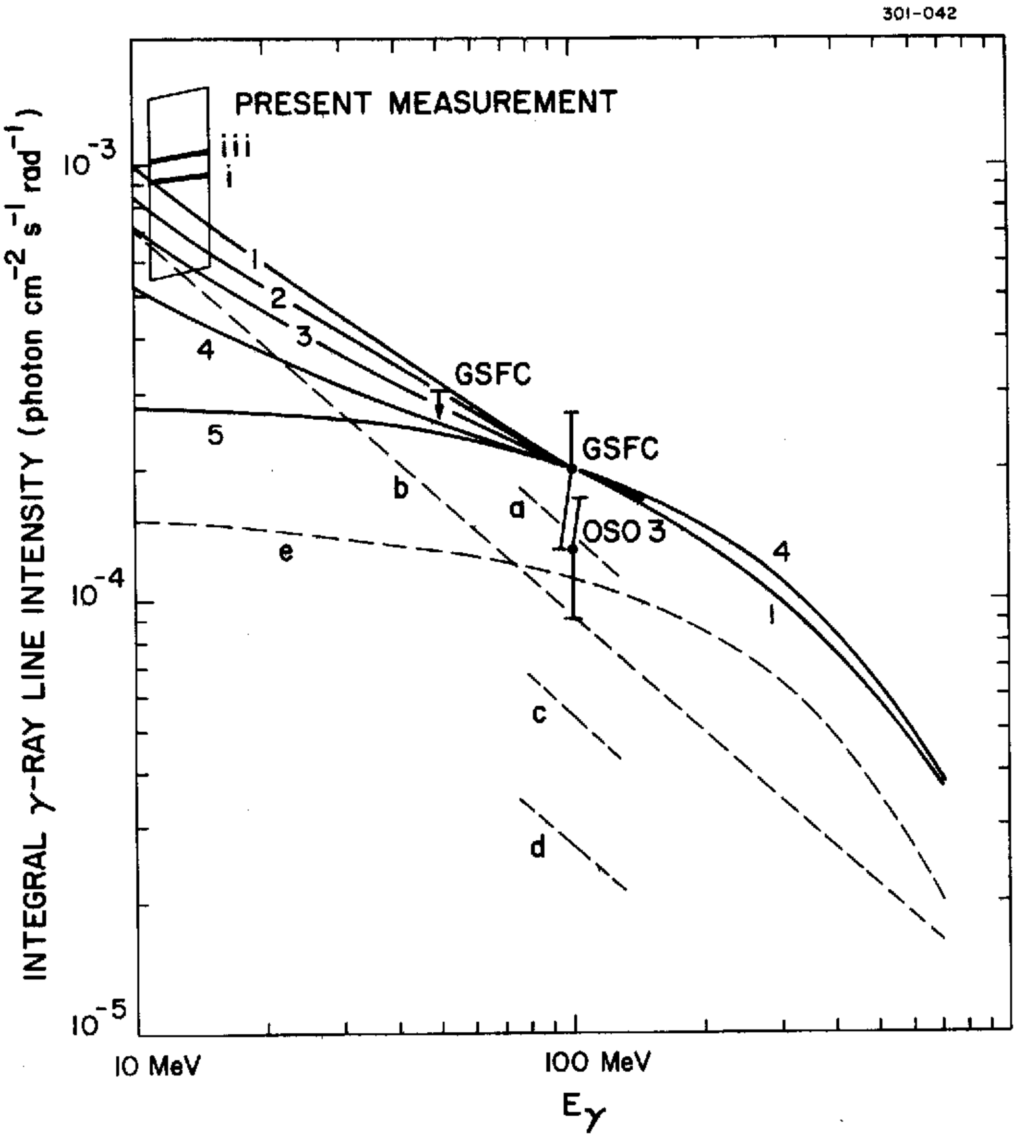

Figure 2. Two-component model of galactic-center gamma radiation. Dotted line e shows an integral pion-produced gamma-ray spectrum. Dotted lines a–d show integral gamma-ray spectra produced by cosmic-ray electrons (with the spectrum measured at earth) Compton scattering from infrared radiation near the galactic center. The curves a–d represent fractional contributions of the Compton component relative to the pion component for $E_\gamma > 100$ MeV of 1.25, 0.83, 0.50, and 0.25, respectively. The sums of the two components are shown as solid lines (1–5 corresponding to a–e, respectively) normalized to the observations (GSFC) of Kniffen and Fichtel (1970) at $E_\gamma > 100$ MeV. The present observations are shown in the upper left.

The recent OSO 3 observations of the galactic center, also shown in Figure 2, indicate a gamma-ray line intensity slightly lower than the previous Goddard results. Kraushaar et al. (1972) warn that interpretations of the reported absolute intensity should allow for an uncertainty factor of 2. With this caveat, we merely point out that as the gamma-ray flux point at $E_\gamma > 100$ MeV is lowered (effectively lowering the whole family of curves in Figure 2), a larger fraction of electron-produced gamma rays is suggested by our results.

These are the first reported results of galactic-center measurements in this energy range. The marginal statistical significance reflects the experimental difficulties of gamma-ray astronomy in this range (Greisen, 1969). It is hoped that the two-component analysis of galactic line radiation can be used by other groups in reporting and interpreting 10- to 100-MeV gamma-ray measurements in the future. More observations at energies down to 10 MeV should make it possible to determine precisely the best model for galactic-center gamma-ray production.

3. PULSED GAMMA-RAY FLUX FROM NP 0532 AT $E \geq 15$ MeV*

3.1 Experiment

On June 15, 1971, the low-energy gamma-ray gas-Čerenkov detector was launched from Palestine, Texas, to an altitude of 132,400 ft to make observations of NP 0532 and the Crab Nebula. During the balloon flight, the azimuth and elevation of the detector were controlled from the ground in order to make on- and off-source measurements in the direction of the Nebula. Both charged-particle and gamma-ray events were telemetered and recorded, along with timing information derived from a crystal-controlled time-code generator. The crystal was checked daily during the week preceding the flight, and its drift was less than 500 μsec in a 24-hr period. The detector operated well throughout the entire 8-hr flight; however, a severe local thunderstorm and consequent balloon-base power failure terminated the collection of useful data approximately halfway through the flight.

On playback in the laboratory, each event in the 4 hr of useful data was digitized to a time accuracy of 250 μsec. Azimuth (magnetometer) and elevation chart recordings permitted the reconstruction of the times on and off source to a positional accuracy of ±3°.

3.2 Results

A 3.3σ excess coincident with 1 msec of the main optical pulsar was observed. If the flux is interpreted as a positive measurement, the use of the $E^{-1.1}$ spectrum observed at lower and higher energies yields a main peak flux of F_{γ} (≥ 15 MeV) $= 3.6 \times 10^{-5}$ keV cm^{-2} sec^{-1} keV^{-1}, shown in Figure 3 along with other reported results.

*A paper by this title was presented by H. F. Helmken at the 13th Cosmic-Ray Conference, University of Denver, August 1973.

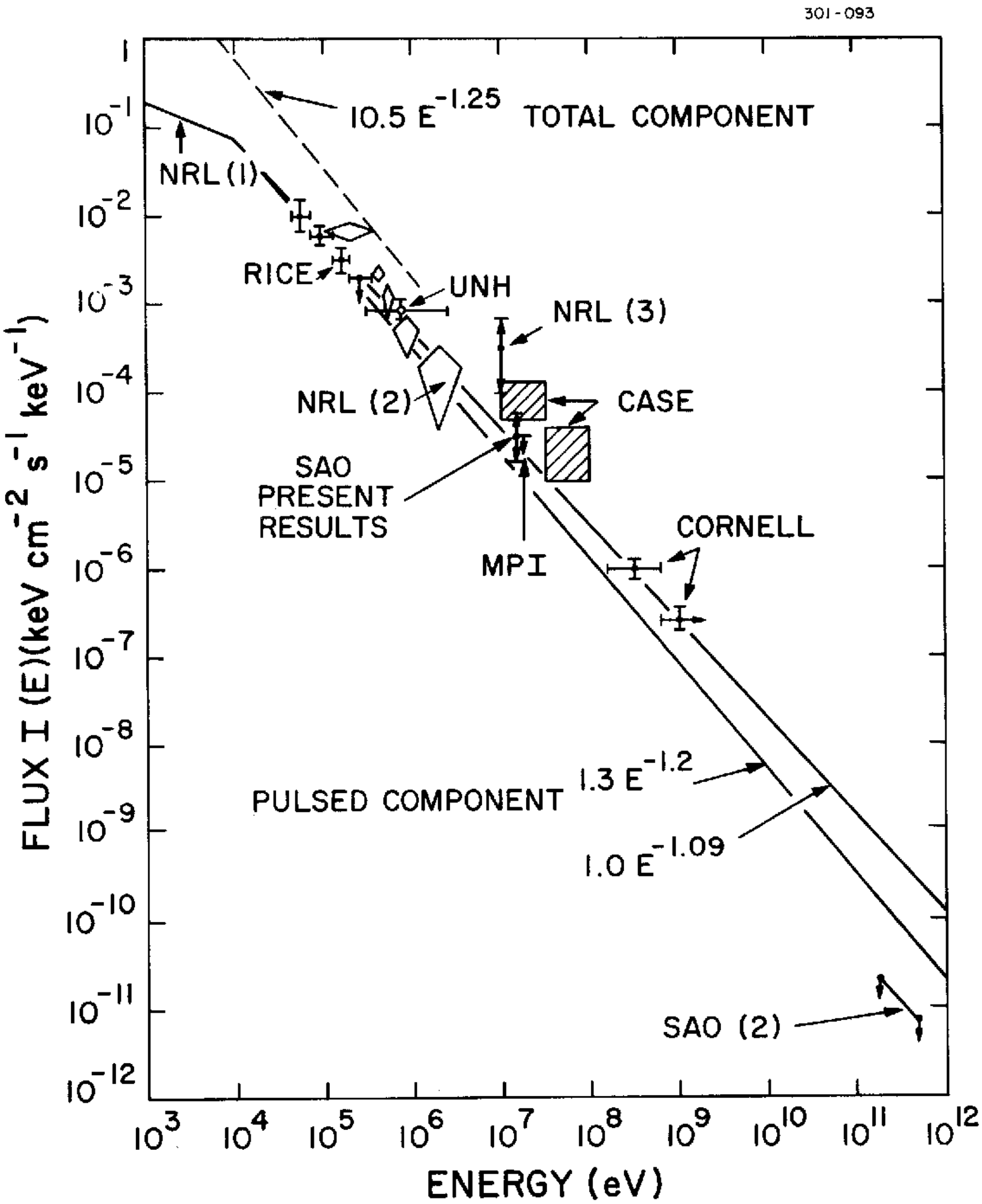

Figure 3. Gamma-ray spectrum of the Crab Nebula and NP 0532. Present results as shown. The other points were taken from the following: NRL (1): Fritz et al. (1971); NRL (2): Kurfess (1971); NRL (3): Kinzer et al. (1973); Rice: Johnson et al. (1972); UNH: Orwig et al. (1971); Case: Albats et al. (1972); SAO (2): Helmken et al. (1973); MPI: Kettenring et al. (1971); and Cornell: Campbell et al. (1973).

3.3 Discussion

If the pulsed analysis is interpreted only as an upper limit, we note that the observed feature already stands at the 3σ level and, thus, the same flux value would be derived. However, more conservatively, if the bin width is increased to 1 msec and if we assume that equal numbers of gamma rays are expected in both the main pulse and the interpulse bins, the 95% confidence upper limit on the time-averaged-pulse gamma-ray flux becomes F_{γ} ($\geq$ 15 MeV) $\geq 7.2 \times 10^{-5}$ keV cm^{-2} sec^{-1} keV^{-1}.

The pulsed results are in good agreement with most of the lower and higher energy data and support a $E^{-1.1}$ spectral shape. However, the worst-case upper limit still falls below the lower limit obtained by Kinzer et al. (1973).

The data indicate a narrow main pulse, with a width less than 1 msec, compared to the optical main-pulse width of approximately 1.5 msec and illustrate the need for high time resolution during data acquisition and for accurate phase alignment during analysis. The pulsed flux, combined with the lower limit D.C. flux, indicates a 10% lower limit on the ratio of pulsed-to-D.C. flux above 10 MeV.

In conclusion, any reasonably sensitive detector with good timing capabilities should be able to detect the pulsed flux from NP 0532 above 10 MeV. This fact alone makes NP 0532 an excellent choice for future calibrations of gamma-ray detectors *in situ* and, once the flux values are agreed on, may bring into harmony many of the different flux values reported by various groups on other suspected sources.

4. FUTURE

The experiment has survived the balloon flights in good condition and, with only a small amount of work, is ready for reflight. Part of the refurbishment involves an improvement to the detector pointing system. As part of the Harvard College Observatory (HCO) solar satellite group's work under this grant, a control system that should be capable of positioning the detector to within 1° has been designed.

When additional funds are made available, this HCO design and some sensitivity improvements will be incorporated into the system, and reflight to an altitude of less than 2.5 g cm^{-2} will be made. We hope then to measure the diffuse gamma-ray flux above 10 MeV and at the same time to make a longer exposure on NP 0532 at this higher altitude and lower background.

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