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SAS-II OBSERVATIONS OF GAMMA RAYS FROM THE GALACTIC PLANE

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ABSTRACT

The SAS-II gamma ray experiment has made measurements on the high energy (> 30 MeV) gamma rays coming from the galactic center region. The gamma radiation in this region is very much more intense than in the anticenter region, in agreement with the observations made with the OSO-III experiment of Kraushaar et al. (1973), and exhibits a narrow distribution (The 2σ width is no more than 6°.) along the plane which is nearly uniform in intensity from 330° to 30°. The average value, including present uncertainties other than statistical is ($1.15^{+.40}_{-.35}$) x 10^{-4} photons/(cm^2 sterad. sec.). The energy spectrum in the range from 35 MeV to 210 MeV is quite flat, consistent with a cosmic ray-interstellar matter interaction π°-decay spectrum, or a mixture of this spectrum and a spectrum formed by Compton radiation from cosmic ray electrons. The intensity of the radiation in the anticenter direction is consistent with that expected from the cosmic ray-interstellar matter interaction origin, namely $0.2 \cdot 10^{-4}$ photons/(cm^2 radian sec.).

I. INTRODUCTION

It has been realized for some time that high energy ($E_\gamma \geqslant 30$ MeV) gamma rays were to be expected from the galactic plane if cosmic rays were present at the intensity level observed near the earth. Kraushaar et al. (1973) with a gamma ray experiment flown on OSO-III saw an enhanced radiation coming from the galactic plane whose angular width was less than their detector angular resolution (~ 35° full width half maximum intensity). The radiation away from the galactic center region was observed to have a line intensity consistent with that expected from cosmic rays interacting with matter in the galactic plane (e.g. Pollack and Fazio, 1963; Stecker, 1969; Cavallo and Gould, 1971). However, along the galactic plane in the galactic center region, the intensity was $(1.2 \pm 0.3) \times 10^{-4}/(\text{cm}^2 \text{ radian sec.})$ for gamma ray energies above 100 MeV, about three times the expected value.

When the SAS-II satellite was launched on November 15, 1972, one of the subjects of most immediate interest was the study of the gamma radiation from the galactic plane with the larger sensitivity and increased angular and energy resolution possible with the SAS-II gamma ray experiment. The general characteristics of the experiment are discussed in the preceding letter (Fichtel, Hartman, and Kniffen, 1973) and in more detail by Derdeyn et al. (1972). Whereas the attitude information for the orientation of the spacecraft is still preliminary in the sense that somewhat better accuracy will ultimately be available, the results on the high energy gamma radiation already available for two regions of the galactic plane will be presented. One is the galactic center region from about $\ell_{II} = 315°$ to $\ell_{II} = 50°$, and the other, a region from about $\ell_{II} = 160°$ to $\ell_{II} = 230°$, provides an example of the galactic plane away from the galactic center.

II. OBSERVATIONS

An enhanced flux of high energy (> 30 MeV) gamma rays has been observed in the two regions just mentioned relative to the general celestial background. The galactic plane in the region ($315° < \ell_{II} \leq 45°$) is a particularly intense region of high energy gamma radiation which is concentrated in a narrow band along the galactic plane. Fig. 1 shows the intensity of gamma rays above 100 MeV summed from $b_{II} = -10°$ to $b_{II} = +10°$ and plotted as a function of galactic longitude. Notice that the enhanced radiation extends from about 320° to about 40° along the galactic plane, and that there are not one or two particularly intense regions, but rather that the strength of the radiation remains uniformly high throughout. Specifically, the radiation from the galactic center is not more intense than the rest of the interval.

Summing the radiation for $E_\gamma > 100$ MeV into bins with a width in b_{II} of 2.5°, the distribution in Fig. 2 is obtained. The one σ half-width is 4.5°. With the current uncertainties in the knowledge of the pointing direction, and the known accuracy for determining the arrival directions of the individual gamma rays, a pure line source would be broadened to have a σ of $4.0 \pm 0.5°$. Hence, the uncertainty of angular resolution in the preliminary data is still a significant factor in the angular distributions. However, from the above results, it can be concluded that the 2 σ line width is probably no more than 6° on the average for the 60° interval ($330° < \ell_{II} < 30°$), and could be narrower.

The energy spectrum for the gamma radiation in the region ($30° < \ell_{II} < 30°$, $-10° < b_{II} < 10°$) is shown in Fig. 3. Notice that the energy spectrum is quite flat, especially as compared to the very steep energy spectrum of the diffuse radiation reported in the preceding letter (Fichtel et al., 1973). If it is assumed that the diffuse radiation pervades the galactic plane region also, then the contribution from the galactic plane alone is obtained by subtracting the diffuse spectrum from the total. This result is shown as the dashed line in Fig. 3. It is seen that, whereas there is almost no effect on the spectrum above 100 MeV, the contribution of the diffuse background at about 40 MeV is quite significant. The integral flux above 100 MeV is $(1.15 {}^{+.40}_{-.15}) \times 10^{-4}$ photons/(cm^2 sterad. sec.), where the errors include uncertainties due to the fact that the analysis of the calibration data is not complete.

Also shown in Fig. 1 is the gamma ray intensity in the region $(160° < \ell_{II} < 230°)$. The contribution of the diffuse background is shown under the assumption that the diffuse level is at the same intensity in this region as elsewhere. The contribution of the Crab nebula which happens to fall close to one of the dividing lines for the selected bins is also indicated. The net intensity in the region $(160° < \ell_{II} < 230°)$ is about 0.2×10^{-4} photons/(cm^2 radian sec.), and it is reasonably uniform in this region.

III. DISCUSSION

Under the assumption that the cosmic rays pervade the entire galaxy at the intensity level that they are observed to be locally, there will be high energy gamma rays with a distinctive energy spectrum produced by the interaction of these cosmic rays with the interstellar matter. The gamma rays arise primarily from the decay of $\pi°$-mesons with minor contributions from other sources; as a result, the differential energy spectrum has a maximum at 70 MeV and extends to very high energies. There have been several calculations made of the expected galactic intensity including those mentioned in the introduction, with the conclusion that the intensity should average between $2 \cdot 10^{-5}$ and $4 \cdot 10^{-5}$ photons/(cm^2 radian sec.) above 100 MeV along the galactic plane. From Fig. 1, it can be seen that the SAS-II data indicate an average experimental value of just under $2 \cdot 10^{-5}$ photons/(cm^2 radian sec.) for the region $(160° < \ell_{II} < 230°)$, which is not surprising since this region is in the anticenter direction where the intensity might be expected to be the least.

Since the intensity in the galactic center region is three to four times the expected value, there must be another component - one with a reasonably hard spectrum. This energy spectrum is clearly inconsistent with the concept of the radiation being primarily due to the sum of discrete sources with steep energy spectra, such as those of the X-ray sources. If discrete sources are a significant contributor, their energy spectra must be rather flat. Further, there would have to be several sources distributed reasonably smoothly along the plane in the interval from 320° to 40° with a very narrow distribution in galactic latitude. If there were ten point sources, for example, the average intensity above 100 MeV would have to be approximately 10^{-5} photons/(cm^2 sec.) or above.

Although there can be, and very likely are, some weaker point sources yet to be resolved from the general radiation, the energy spectrum and the broad distribution of the gamma rays seem to imply that the radiation is more likely to be predominantly diffuse in origin. One possibility suggested by Cowsik and Hutcheon (1971) is that the enhancement results from Compton photons formed by the interaction of cosmic ray electrons with a much enhanced starlight photon density in the galactic center region. The energy spectrum shown in Fig. 3 is consistent with a combination of a spectrum of this type and a π° type spectrum. However, the intensity seems now to be too level over a 60° ℓ_{II} interval for the Compton-starlight process in the galactic center region to be the major component.

The high intensity and broad flat distribution of the gamma radiation in galactic longitude over 60° to 80° suggest that the source of the enhancement is possibly predominately diffuse radiation from the spiral arm segment closest to the sun in the direction of the galactic center. The approximate uniformity results from viewing more nearly along the arm at 30° to 40° in longitude from the galactic center and, thereby, compensating for the reduced intensity due to the greater average distance. Postulating that the predominant origin of the enhanced radiation is in this closest arm segment with possibly lesser contributions from segments closer to the galactic center, permits proposing that the radiation is due to an enhanced cosmic ray flux interacting with matter and magnetic fields with above average density without having to assume a greatly enhanced cosmic ray flux over the entire galactic center region out to 5 or 6 kiloparsecs, which has the difficulty of requiring enhanced magnetic fields and matter to contain the cosmic rays over a broad region (Parker, 1966). Further pursuit of this adjacent spiral arm theory for the origin of the enhanced gamma radiation in the region $(320^{\circ} \leq \ell_{II} \leq 40^{\circ})$ is beyond the scope of this letter; however, it is clearly an interesting avenue for experimental and theoretical study.

explanations for this radiation. If the radiation should be shown to be isotopic and the exact form of the energy spectrum confirms the shape predicted by cosmological models, the energy spectrum above 100 MeV can be used to separate these models, since the cosmic ray interaction model would predict a continuation of the gamma radiation to much higher energies than the matter-anti-matter model.

ACKNOWLEDGMENTS

Since this is the first letter reporting results from SAS-II, we wish to express our thanks to the many people who made it possible. In particular with regard to the experiment itself, we wish to acknowledge the dedication and expertise of Mr. R. Ross, the detector engineer, Mr. C. Ehrmann, the electronics engineer, Mr. W. Cruickshank, the spark chamber systems mechanical engineer, Mr. M. Calabrese, the structural engineer, Miss A. Fitzkee, the thermal engineer, Mr. S. Derdeyn, the experiment manager, and the many others whose efforts are sincerely appreciated. We also wish to express our gratitude to Mrs. M. Townsend, the SAS Project Manager, and her staff and to Mr. H. Riblet and his entire team at the Johns Hopkins Applied Physics Laboratory who were responsible for the SAS-II spacecraft control section. We congratulate the San Marco launch team of Centro Ricerche Aerospaziali for providing SAS-II with a successful launch. Finally, we acknowledge the computer support of Mr. P. Bracken and Mr. P. Yu, and the contribution of Mrs. R. Marsh whose unique data analysis ability made early presentation of these results possible.

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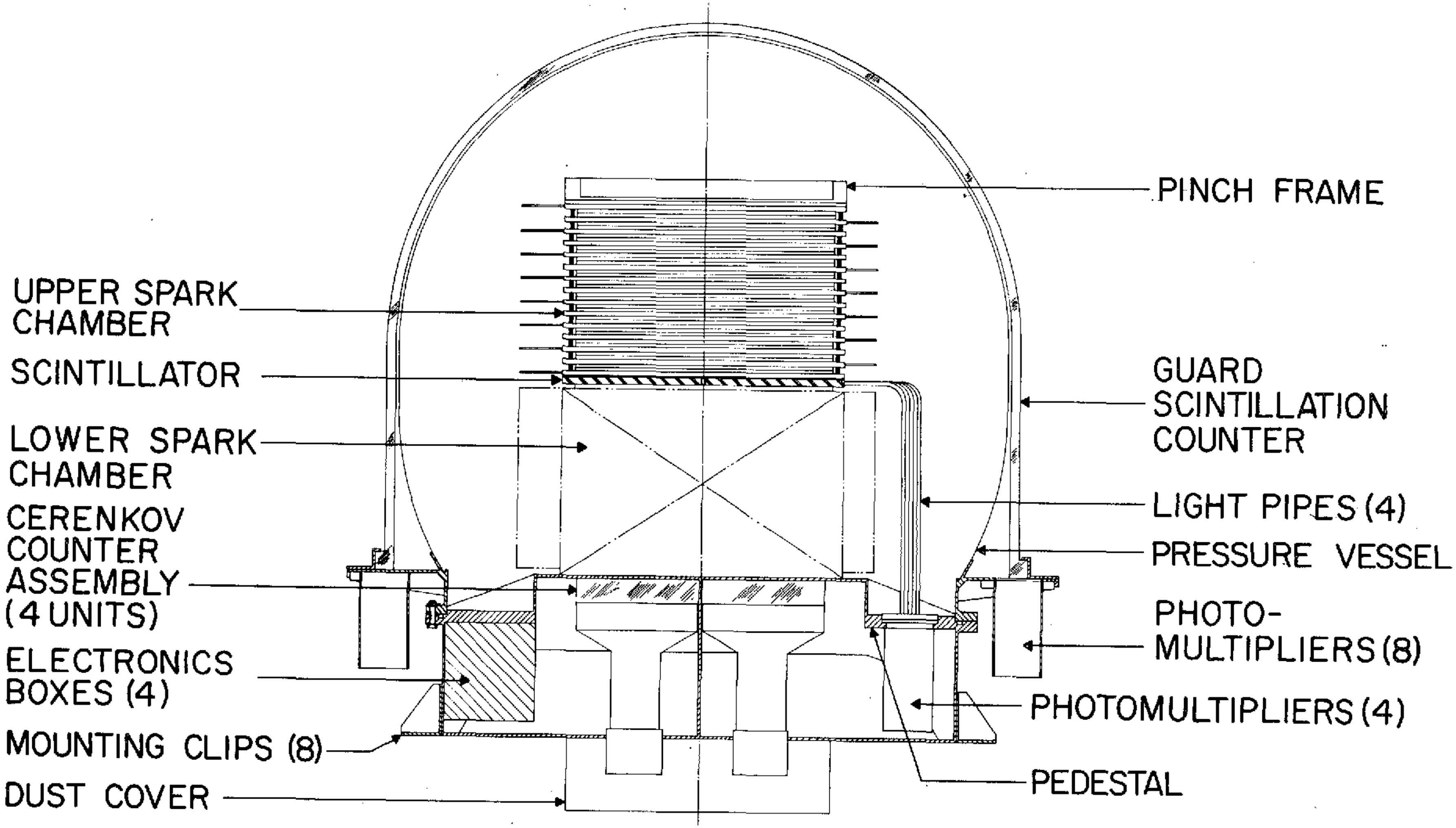
FIGURE CAPTIONS

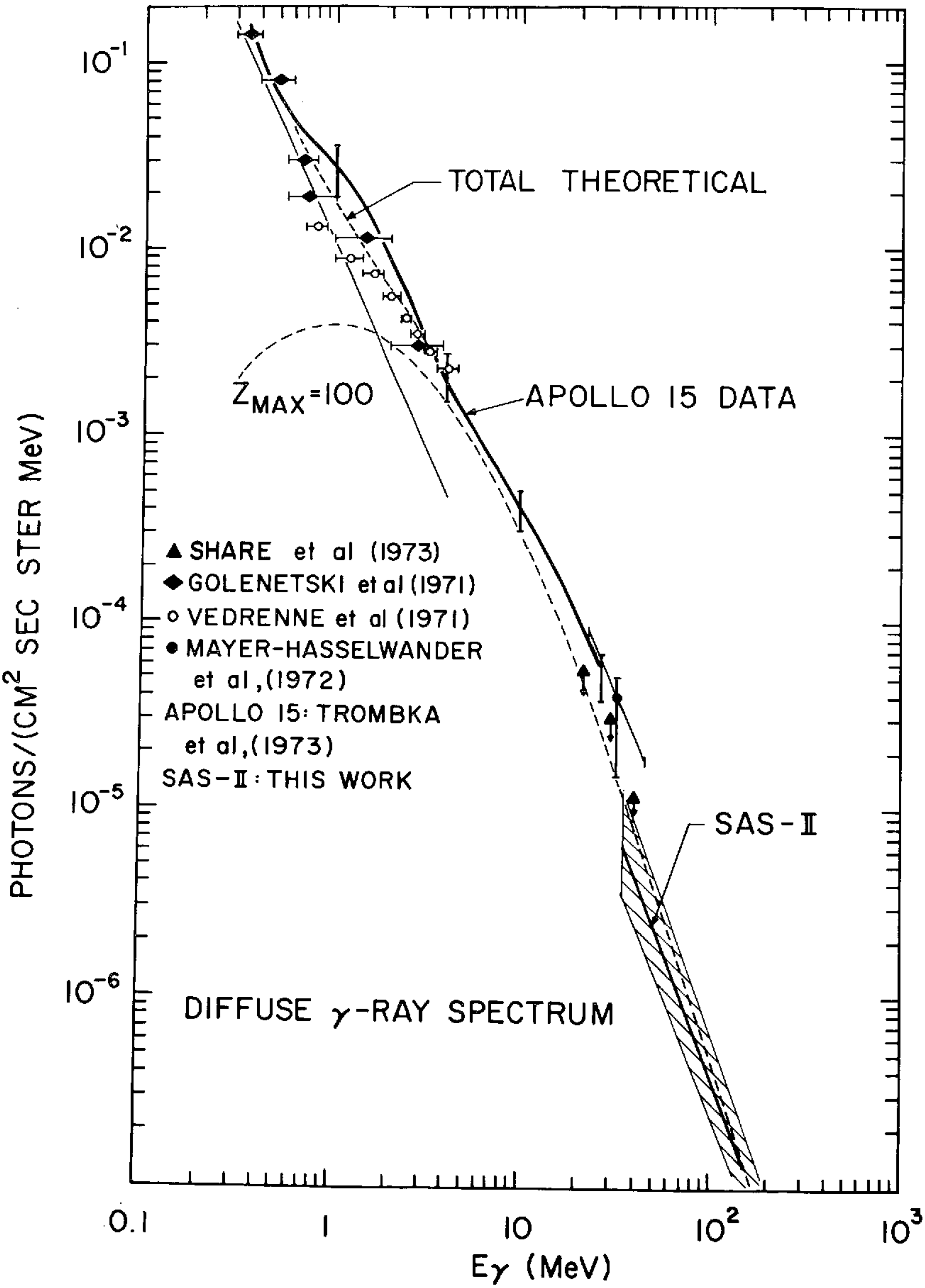
Fig. 1 Schematic Diagram of the SAS-II Gamma Ray Experiment.

Fig. 2 Diffuse Celestial Radiation Observed by Several Experiments. Also shown are the straight line extrapolation of the X-ray data (solid line) and the curve predicted by the cosmic ray-intergalactic matter interaction cosmological model with $Z_{MAX} = 100$ (Stecker, 1969) discussed in the text (dashed line).



SAS-B GAMMA RAY EXPERIMENT

Fig. 1



TOTAL THEORETICAL
APOLLO 15 DATA
ZMAX=100
SAS-II
▲ SHARE et al (1973)
◆ GOLENETSKI et al (1971)
○ VEDRENNE et al (1971)
● MAYER-HASSELWANDER et al, (1972)
APOLLO 15: TROMBKA et al, (1973)
SAS-II: THIS WORK
DIFFUSE γ-RAY SPECTRUM
PHOTONS/(CM² SEC STER MeV)
Eγ (MeV)
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
0.1
1
10
10²
10³

Fig. 2