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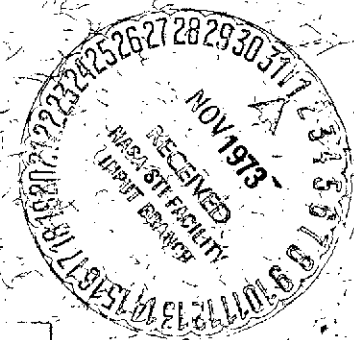
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CELESTIAL DIFFUSE GAMMA RADIATION ABOVE
30 MeV OBSERVED BY SAS-II

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ABSTRACT

The Small Astronomy Satellite (SAS)-II, launched on November 15, 1972, carried into orbit a 32-deck magnetic-core digitized spark chamber gamma ray telescope to study celestial gamma radiation in the energy range above 30 MeV. In the study of several regions with $|b_{II}| > 15^\circ$, a finite, diffuse flux of gamma rays with a steep energy spectrum in the energy region from 35 to 200 MeV is observed. Representing the energy spectrum by a power law of the form $dJ/dE = AE^{-\alpha}$ over this energy range, α is found to be $2.7^{+0.4}_{-0.3}$, and the integral flux above 100 MeV is $(2.8^{+0.9}_{-0.7}) \times 10^{-5}$ photons/cm² sterad. sec. Combining this result with existing low energy gamma ray data yields an energy spectrum which is not a simple power law in energy, as in the X-ray region, but which demonstrates first an increase and then a decrease in slope, consistent within uncertainties with that predicted by cosmological theories, including the continuous production of high energy gamma rays primarily from π^0 mesons throughout the history of the universe.

I. INTRODUCTION

The significance of gamma ray astronomy lies in its direct relationship to the highest energy celestial phenomena occurring in our galaxy and beyond. Although the rewards of gamma ray astronomy have long been known to be high, the first unambiguous positive observations of extraterrestrial gamma rays above a few tens of MeV were made by

Kraushaar, Clark, and Garmire (1973) with a detector on OSO-3 launched in 1968. This excellent pioneering experiment measured a general diffuse flux and an enhanced emission from the galactic disk above 50 MeV; however the relatively small size of the OSO-3 detector together with the limited angular and energy resolution left unanswered many questions concerning the origin of this radiation.

In order to obtain a clear identification of these high energy photons, to measure the direction of arrival of the gamma rays to within a few degrees, and to obtain information on their energy spectra, several groups developed spark chamber telescope systems (See, for example, Kniffen, 1971.). In particular, Ehrmann, Fichtel, Kniffen, and Ross (1967) developed an automated magnetic core spark chamber gamma ray telescope through a series of balloon flights. Following this development, a satellite gamma ray telescope was built (Derdeyn, Ehrmann, Fichtel, Kniffen, and Ross, 1972) and launched as the second satellite of the Small Astronomy Satellite (SAS) series on November 15, 1972. Some of the first results from this experiment will be discussed here, specifically those involving the diffuse radiation for $|b_{II}| > 15^\circ$.

II. DESCRIPTION OF THE EXPERIMENT

A schematic diagram of the gamma ray telescope flown on SAS-II is shown in Fig. 1. The spark chamber assembly consists of 16 spark chamber modules above a set of four central plastic scintillators and another 16 modules below these scintillators. Thin tungsten plates, averaging 0.03 radiation lengths thick, are interleaved between the spark chamber modules, which have an active area of approximately 640 cm^2 . The large number of thin tungsten plates and spark chambers serve a dual purpose,

first to provide material for the gamma ray to be converted into an electron pair which can then be clearly identified and from which the arrival direction of the gamma ray can be determined, and, secondly, to provide a means of determining the energy of the electrons in the pair by measuring the Coulomb scattering. The energy threshold is about 30 MeV. The energy of the gamma-ray can be measured up to about 200 MeV, and the integral flux above 200 MeV can be determined. A more complete discussion of the SAS-II gamma ray telescope is given by Derdeyn et al. (1972). The calibration and data analysis are similar to that used for previous balloon gamma ray digitized spark chambers (Fichtel et al., 1969; Kniffen, 1969; Fichtel et al., 1972; and Thompson, 1973).

The SAS-II satellite is capable of being pointed in any direction, and has normally viewed the same region of the sky for periods of about a week. The orbit is nearly equatorial at an altitude ranging from about 440 km to 610 km.

III. RESULTS

For the portion of the celestial sphere which we have examined thus far, there is a diffuse component of high energy gamma rays which seems to be uniform for regions away from the galactic plane. The gamma-ray experiment on OSO-3 of Kraushaar et al. (1973) had previously indicated a finite, apparently constant diffuse flux for regions of the sky which were far enough from the galactic plane that no portion of the relative wide angle of the OSO-3 detector ($\sim 35^\circ$) overlapped the galactic plane. An integral value of $(3.0 \pm 0.9) \cdot 10^{-5} / (\text{cm}^2 \text{ sterad. sec.})$ was quoted for the intensity above 100 MeV, but essentially no energy spectral information was obtained. Data to be reported here comes from three separate viewing periods of

SAS-II, and includes the regions of the sky centered at ($\ell_{II} = 0$, $b_{II} = +25^\circ$), ($\ell_{II} = 0$, $b_{II} = +58^\circ$) and ($\ell_{II} = 190^\circ$, $b_{II} = -30^\circ$) and including solid angles of about 0.25 sterad. From SAS-II observations, it now appears that, at least in the regions examined thus far, for $|b_{II}| \geq 15^\circ$ the gamma ray intensity consists of a general diffuse intensity, quite different in energy spectrum from the emission from the galactic disc. Further, in the three regions mentioned the intensity is the same within uncertainties for data summed over each of the regions. Those portions of the regions for which $|b_{II}| < 15^\circ$ have been excluded. Since there is no detectable difference, the data of the three regions are combined and the diffuse energy spectrum calculated from the data is shown in Fig. 2. The uncertainty indicated in the figure is due primarily to the fact that the calibration data is not fully analyzed; so preliminary energy resolution and detection area-efficiency factors are being used. The energy spectrum curve is based on about 360 gamma rays. Notice that the spectrum is quite steep, steeper than any other gamma ray spectra observed on SAS-II or the earlier balloon work of this group (e.g. Fichtel et al., 1969 and 1972), including the galactic center region and the atmospheric secondary spectrum, upward or downward. If the differential energy spectrum is represented by the equation $dJ/dE = AE^{-\alpha}$, α is measured to be $2.7^{+0.4}_{-0.3}$. The integral intensity above 100 MeV is $(2.8^{+0.9}_{-0.7}) \cdot 10^{-5}$ photons/(cm^2 sterad. sec.) consistent with the OSO-3 result averaged over all regions of the sky (Kraushaar et al., 1973).

Figure 2 shows that when other experimental data of lower energies are added, the diffuse gamma radiation for $|b_{II}| > 15$ exhibits an enhancement in the interval from 1 to 10 MeV relative to the simple

extension of the power law spectrum valid in the X-ray region and then a rapid decrease in intensity in the region from 35 to 170 MeV.

IV. DISCUSSION

It seems a plausible hypothesis to assume that the regions examined thus far by SAS-II are representative of the whole sky and consider the possible origin of the radiation. Until more SAS-II data from many regions of the sky have been analyzed, of course, it is not possible to state definitely that the radiation is uniform over the sky, and uniform also on a fine scale. There is the possibility that the radiation is the sum of many weak discrete or extended sources of unknown origin. However, there are at least two other possibilities, one that the radiation comes from diffuse electrons interacting with matter, photons, or magnetic fields and the other is that the gamma rays are of cosmological origin.

With regard to the diffuse electron possibility, bremsstrahlung seems unlikely. In an energy region, 1 to 10 MeV, where an increased slope would be expected due to an increasing rate of energy loss, the opposite is observed. For both synchrotron and Compton radiation, the observed photon spectrum would imply a similarly shaped parent electron spectrum which would have even very much sharper spectral features. Further, for all three cases, the intensity seems high to be consistent with reasonable estimates of the interstellar parameters.

Of the pure gamma ray cosmological hypotheses, there are two of which the authors are aware that seem to be possible candidates. They are the cosmic ray-interstellar matter interaction model and the particle-anti-particle annihilation in the baryon symmetry steady state model. In both theories, the resulting gamma ray spectrum, which is primarily due to π^0 decay, is red-shifted substantially by the expansion of the universe.

In an expanding model of the universe, the density of matter is much greater in the cosmological past than it is observed to be in the present. However, since the gamma radiation produced in interactions of cosmic rays with matter in the distant past reaches us from large distances, the energy of these photons is degraded by the cosmological redshift caused by the expansion of the universe. One curve developed by Stecker (1969) involving red-shifts up to about 100 is shown in Fig. 2. The theoretical curve is seen to agree with experimental data reasonably well.

An alternate attempt to explain the gamma radiation through red-shifted gamma rays from π^0 decay arises from the big bang theory of cosmology with the principle of baryon-symmetry. Harrison (1967) was one of the first to propose a model of this type. Omnes (1969), following Gamow (1948), considered a big-bang model in which the universe is initially at a very high temperature and density, and then shows that, if the universe is baryon-symmetric, a separation of matter from anti-matter occurred at $T > 30$ MeV. The initial phase separation of matter and anti-matter leads ultimately to regions of pure matter and pure anti-matter of the size of galaxy clusters. Stecker, Morgan, and Bredekamp (1971) have predicted the gamma ray spectrum which would be expected from annihilation at the boundaries of such clusters from the beginning of their existence to the present. This spectrum is very similar (essentially indistinguishable) to the one in Fig. 2 in the energy range for which data exists, and is not included in the figure for that reason.

Further data on the uniformity of the intensity and energy spectrum of this radiation both in local regions and over the sky will be crucial in establishing whether the cosmological gamma ray hypotheses are possible

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FIGURE CAPTIONS

- Fig. 1. Distribution of high energy ($E_\gamma > 100$ MeV) rays along the galactic plane in the interval ($-10^\circ < b_{11} < 10^\circ$). The dashed line indicates the level of the diffuse background. The relative number on the left-hand scale is approximately equal to 10^{+4} x photons/(cm^2 radian sec).
- Fig. 2. Distribution of high energy ($E_\gamma > 100$ MeV) gamma rays summed from $l_{11} = 330^\circ$ to $l_{11} = 30^\circ$ as a function of b_{11} . The OSO-III data is that of Kraushaar et al. (1973). The dashed curve through the SAS-II data is a gaussian distribution with $\sigma = 4.5^\circ$. As indicated in the text, this distribution still includes a substantial experimental angular uncertainty, so the real distribution of gamma rays is narrower.
- Fig. 3. Energy spectrum for gamma rays from the region ($-10^\circ < b_{11} < 10^\circ$, $330^\circ < l_{11} < 30^\circ$). The solid curve is the best estimate of the total spectrum and the dashed curve represents the contribution after the diffuse background has been subtracted.

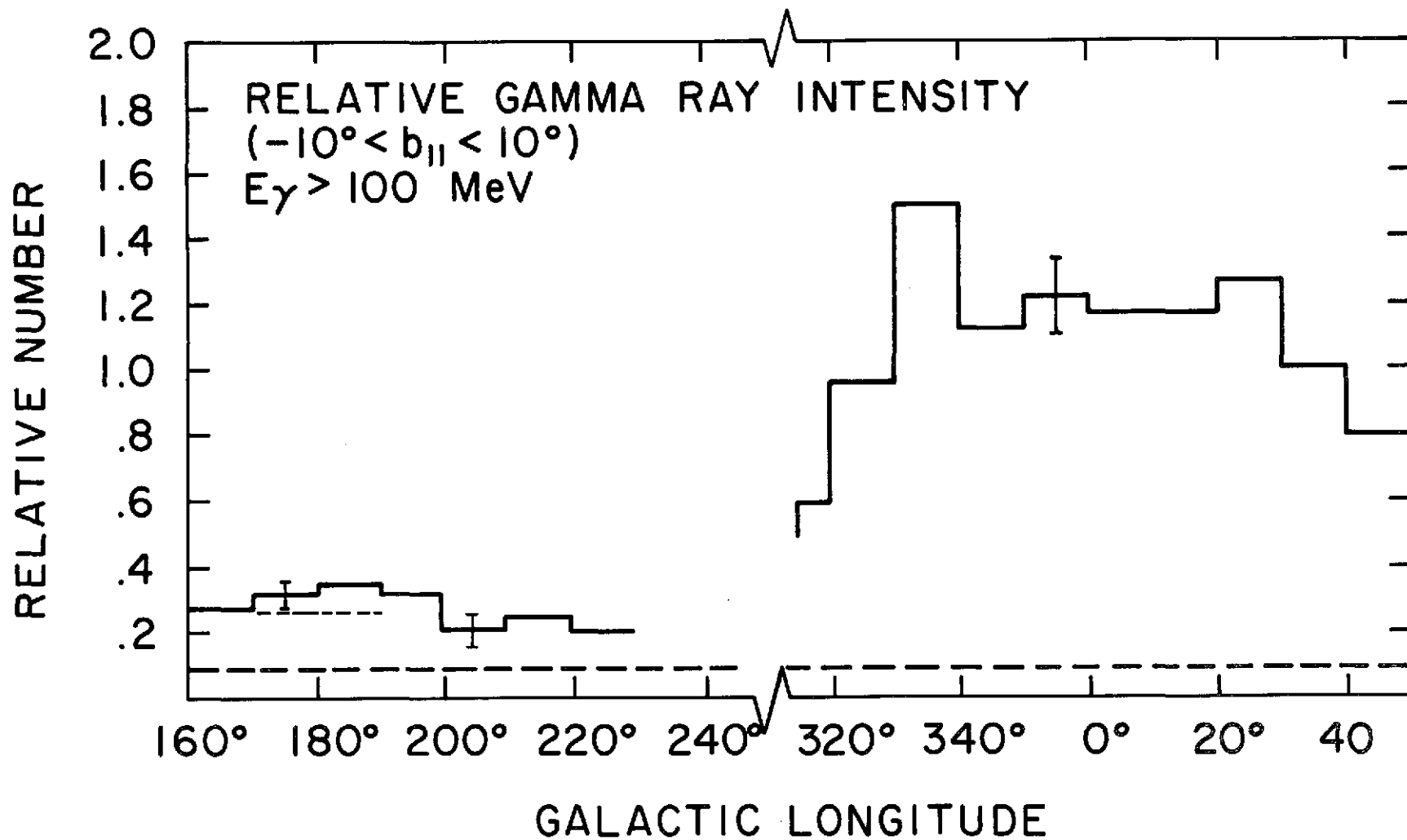


Fig. 1

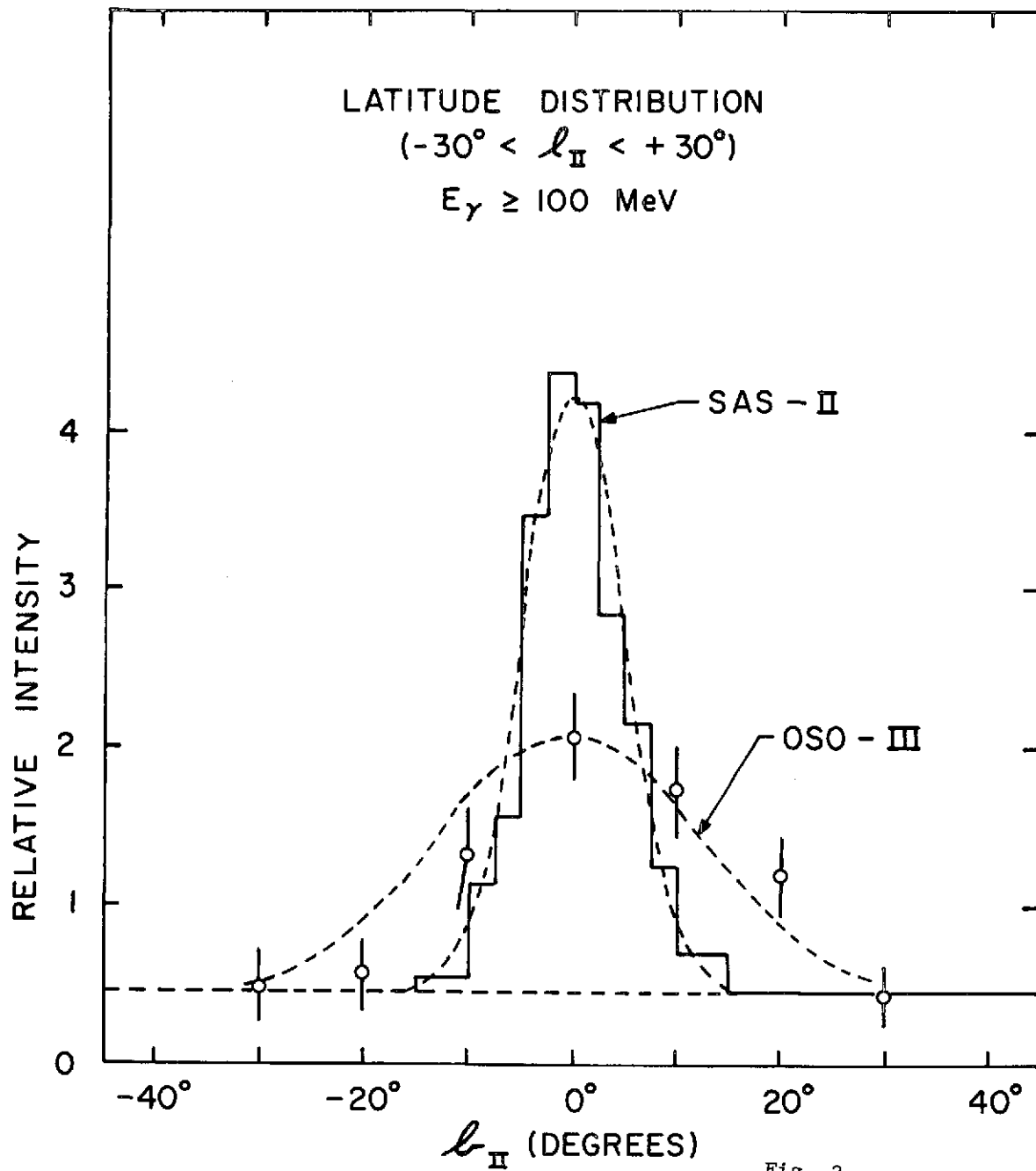


Fig. 2

GALACTIC CENTER REGION

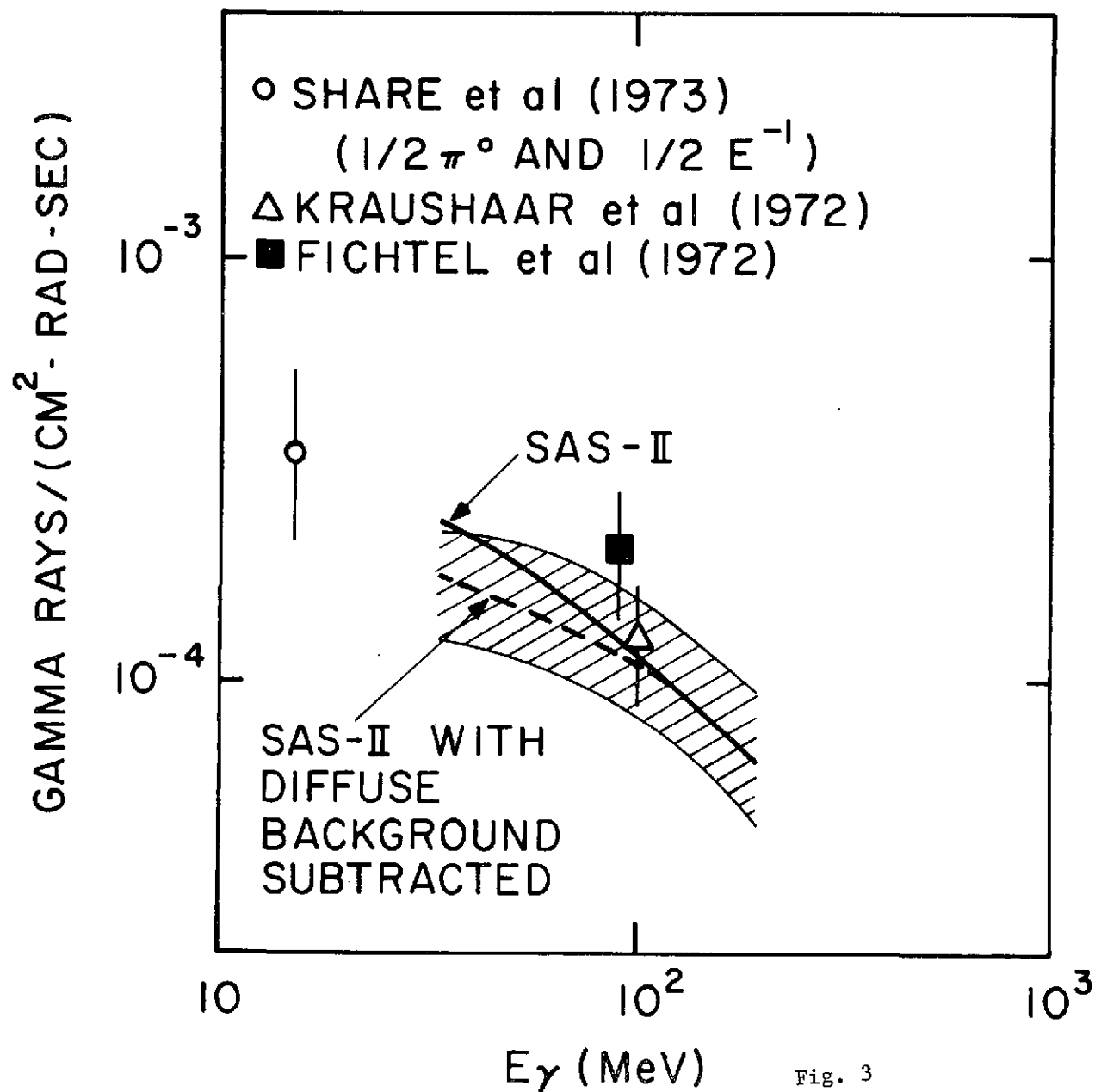


Fig. 3