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SAS-II OBSERVATIONS OF THE GALACTIC GAMMA RADIATION FROM THE VELA REGION

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ABSTRACT

Data from a scan of the galactic plane by the SAS-II high energy ($E > 30$ MeV) gamma ray experiment in the region $250° < \ell^{II} < 290°$ show a statistically-significant (7σ) excess over the general radiation from the galactic plane for gamma radiation of energy > 100 MeV in the region $260° < \ell^{II} < 270°$ and $-7.5° < b^{II} < 0°$. If the enhanced gamma radiation results from interactions of cosmic rays with galactic matter, as the energy spectrum suggests, it seems reasonable to associate the enhancement with large-scale galactic features, such as spiral arm segments in that direction, or with the region surrounding the Vela supernova remnant, with which PSR 0833-45 is associated. If the excess is attributed to cosmic rays released from this supernova interacting with the interstellar matter in that region, then on the order of $3 \cdot 10^{50}$ ergs would have been released by that supernova in the form of cosmic rays.

I. INTRODUCTION

One of the objectives of the gamma-ray astronomy satellite, SAS-2, has been the investigation of the emission from the galactic plane discovered by OSO-III (Kraushaar et al., 1973). The first results from SAS-II (Kniffen et al., 1973) covered the longitude intervals $320° < \ell^{II} < 50°$ and $160° < \ell^{II} < 230°$. These observations revealed a broad,

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flat maximum in the longitude distribution around the galactic center region which is a factor of about six higher than the plane emission from the anticenter region. The latitude distribution was compatible with emission from the very thin galactic disc. The energy information available revealed a spectrum which is much flatter than the one measured for the extragalactic gamma rays, and is consistent with a π° decay hypothesis for the galactic disc photons.

These data, especially when combined with the 21-cm and continuum radio evidence, have been used recently in constructing models for the production of the high energy gamma radiation in our galaxy. Influenced primarily by the OSO-III data, Strong et al. (1973) suggested a general increase in cosmic ray density toward the galactic center, correlating the increase with an estimate of the average magnetic field strength. More recently, with the SAS-II data also available, Stecker et al (1974) and Puget and Stecker (1974) attempted to explain the observed emission especially in the central region by assuming that the galactic cosmic-ray flux varies with the radial distance from the galactic center and is about an order of magnitude higher than the local value in a toroidal region between 4 and 5 kpc from the galactic center. Bignami and Fichtel (1974) start with the hypothesis that the cosmic rays in our galaxy are preferentially tied to the magnetic fields, which are in turn largely bound to regions of high matter density (Parker, 1966). The high energy gamma radiation is then predicted to be strongly correlated with the distribution of the interstellar matter and hence with galactic arm segments and clouds. The probable importance of clouds for gamma ray emission has also been emphasized by Black and Fazio (1973).

In this letter, data from a scan of the galactic plane for the longitude region 250°< ℓ^{II}< 290° are presented and the observed distribution is discussed in terms of possible origins.

II. EXPERIMENTAL RESULTS

A brief summary of the SAS-II high-energy gamma-ray experiment is given by Fichtel et al. (1973), a more complete description of the detector system by Derdeyn et al. (1972), and a discussion of calibration and data analysis procedures by Fichtel et al. (1972) and Thompson (1973). During the period February 15 to 20, 1973, the region of the sky including the galactic plane from ℓ^{II} = 250° to ℓ^{II} = 290° was examined. The flux of gamma rays above 100 MeV has been calculated in ten-degree intervals along the galactic plane and with a 7.5° interval on each side of the plane for the portion of the data examined thus far.* The results are summarized in Table I(a).

The most striking feature is the large excess in the interval (260°< ℓ^{II}< 270°, -7.5° < b^{II}< 0°) where the intensity is seen to be three times the level in surrounding intervals. In that interval, the intensity of $3.0 \cdot 10^{-4}$ gamma rays/(cm^{2}sr sec) is slightly over seven standard deviations above the average level of approximately $(.95 \pm .26) \cdot 10^{-4}$. The intensities in the other regions given in Table I are similar to those in the galactic plane anticenter direction (Kniffen et al., 1973). For a more direct comparison to previous results, Table 1(b) gives the

*Approximately 40% of the data during this period was lost due to interference by the SAS-I satellite transmitter.

intensities summarized over the interval $-10° < b^{II} < 10°$. Here the excess is still evident, but it is not so marked because the intensity represents a sum over positive and negative galactic latitudes.

TABLE I

(a) Intensity of gamma rays/(cm^2 ster sec) above 100 MeV in indicated solid angle interval multiplied by 10^4.

ℓ^{II} 250° 260° 270° 280° 290°

$-7.5° < b^{II} < 0°$	.8±.3	3.0 ±5	1.08±.26	1.15 ±.36
$0° < b^{II} < 7.5°$	.5±.3	.95 ±.26	.83±.23	1.04 ±.35

(b) Intensity of gamma rays/(cm^2 rad sec) above 100 MeV for $-10° < b^{II} < 10°$) in the indicated interval multiplied by 10^5.

ℓ^{II}	160°-230°	250°-260°	260°-270°	270°-280°	280°-290°
I x 10^5	2.5 ±.3	1.8 ±.6	5.4 ± 0.7	2.9 ±0.5	3.6 ±0.7

The energy spectrum of the gamma rays within 7.5° of $b^{II} = 0$ is consistent with a $\pi°$ decay type spectrum expected from cosmic ray collisions with interstellar matter. The energy spectrum of the gamma rays with $|b^{II}| > 7.5°$ measured from 35 MeV upwards is consistent with the very steep energy spectrum observed for the diffuse radiation off the galactic plane (Fichtel et al., 1973) both in spectral shape (assuming the form $dJ/dE = AE^{-\alpha}$, α is about 3.0 ±.5) and intensity ($J[E_\gamma > 100$ MeV$]$ $= [3.1 \pm .6] \cdot 10^{-5}$ gamma rays/[cm^2 sr sec]). Within the limitations of statistics, the spectral shape of the enhanced region ($260° < \ell^{II} < 270°$, $-7.5° < \ell^{II} < 0°$) does not differ from the rest of the galactic plane with $|b_{II}| < 7.5°$. Specifically, the spectrum is rather flat and definitely inconsistent with a steep spectrum, e.g., of the type of the diffuse radiation.

The limited extent in solid angle of the observed radiation, 4° to 8° in diameter, together with the gamma-ray detector resolution suggests that the source of the radiation is either more than about 2 kpcs away, if it is a galactic arm segment feature, or that it is a close compact source. The center of the excess radiation can be placed at about $\delta = -(46 \pm 1)°$ and $\alpha = 129.5° \pm 1°$, ($\ell^{II} = 264.5°$ and $b^{II} = -3°$). For a 4° radius circle centered at the above coordinates, the excess is an 8.5σ effect. If the entire excess is due to a compact source, the flux above 100 MeV would be about $0.5 \cdot 10^{-5}/cm^2 sec$.

III. DISCUSSION

The results presented in Section II show an enhancement of the gamma radiation from the galactic plane in one particular interval. Two possible explanations for this radiation seem to present themselves naturally. One is cosmic ray interactions in the large-scale galactic structure features in that region, especially in view of the "hat brim" effect of the galactic plane at those longitudes wherein the matter distribution of the plane tends to dip below $b^{II} = 0$. The other is cosmic ray interactions in the region of the Vela X supernova remnant.

Although the Milky Way in the region $\ell^{II} \simeq 260°$ to 270° has not been studied as thoroughly as other regions, 21-cm radio data does point to a maximum of emission around 265° and $b^{II} = -2°$ or less (Hindman and Kerr, 1970; Goniadski and Jech, 1970; Kerr et al., 1974). That a maximum of 21 cm emission should appear around 270° had also been predicted by several models of the galactic structure, from the pioneering work of Mills (1959) to the most recent applications of the density wave theory (Simonson, 1974). Also, radio continuum data at different frequencies [e.g., Wilson and Bolton (1960) at 960 MH_z, Landecker and Wielebiski (1970) at 150 MH_z; and Mathewson et al. (1962) at 1440 MH_z] show evidence for a peak at approximately 270° in agreement with the first results of Mills at 85 MH_z. All these data point to a concentration of galactic hydrogen along the line of sight in the 260° to 270° direction, either because of a tangential view of a single arm or as a result of the sum of several more distant arm segments. The excess gamma ray emission could then be explained in terms of cosmic ray interactions with the interstellar gas. The narrow extent of the excess gamma radiation would seem to be more consistent with an end-on view of a single arm than a sum of several arm segments, and the radio data do suggest such a perspective (Kerr, 1973).

The center of the gamma ray excess lies close to both the Vela X supernova remnant, at α = 130.5° and δ = -45.0°, and the second fastest pulsar known, PSR 0833-45 (period about 89.2 msec), at α = 128.8° and δ = -45.0°. A study of this portion of the sky in ultraviolet light by Miller (1973) has revealed that the supernova remnant is approximately 5.1° in diameter. Assuming a distance of 460 parsecs (Brandt et al., 1971), the diameter is 40 parsecs. The region has a complex filamentary structure with possible non-uniformities of expansion and has a complex non-thermal radio source geometry (Milne, 1968). Both soft and hard continuum X-rays have been observed from the region (Seward et al., 1971; Bunner, 1973; Kellogg et al., 1973), as well as a pulsating hard X-ray component (Harnden et al., 1972; Harnden and Gorenstein, 1973). The pulsed component, however, accounts for only about 6% of the total radiation in the 20 to 80 keV energy interval. The optical and low energy X-ray emissions appear centered on the same point in the sky.

The X-ray emission in the range 2-6 keV from the SNR is weak, according to the UHURU catalog, less than one percent that of the Crab. The spectrum for the nebula in the X-ray region below 2 keV is quite steep (Seward et al., 1971; Bunner, 1971), while the UHURU measurements from 2-10 keV indicate a flatter spectrum for the compact source. An extrapolation even of the latter spectrum to the gamma-ray region lies well below the results presented here, implying that some new production mechanism would be required.

The supernova remnant and the flat gamma ray energy spectrum both suggest cosmic rays interacting with the local interstellar matter. Supernovae have long been thought to be the most likely source of cosmic rays, and theoretical studies of the hydromagnetic shock theory of supernovae (Colgate and Johnson, 1960; Colgate and White, 1966) have shown that it should be possible to generate enough energy in the form of cosmic rays (10^{49} to 10^{51} ergs) per supernova to keep the galaxy resupplied against losses. The exact manner in which the cosmic rays expand after the supernova is not clear because of the complex interactions with the local environment. Nonetheless, it is likely that the observed approximately 5° diameter region about the Vela supernova remnant represents the maximum volume in which the cosmic rays are contained. The very high density cosmic rays will, of course, be interacting with the local matter (Pinkau, 1970) yielding strong hard gamma ray emission from the region.

Assuming the excess gamma radiation observed from the Vela region to be due to cosmic rays associated with the supernova, assuming the remnant to be 460 parsecs away, and assuming the matter density to be about 1.5 protons/cm^3, $3 \cdot 10^{50}$ ergs of energy would be in the form of cosmic rays from the supernova. (Because the parameters involved, particularly the matter density in the Vela region, are not well-known, this number should be taken as an estimate of the energy involved rather than as a definitive calculation.) This number does lie in the energy range mentioned above if supernovae are to be the main source of galactic cosmic rays.

For the moment, the question of which explanation (cosmic rays in one or more galactic arm segments or cosmic rays expanding about the Vela supernova remnant) accounts for most of the Vela excess must remain open. The question can perhaps be resolved by improved angular resolution gamma ray studies in conjunction with radio and optical measurements to determine which galactic features best correlate with the observed gamma ray excess.

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