

ANISOTROPIES IN THE UNDERGROUND MUON FLUX*

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The arrival directions of 160,861 muons from primaries of energy about 10^{10} eV were determined with resolution better than 1° . The resulting distribution was examined for anisotropies. No anisotropies of compelling significance were found.

Muons seen underground in the Utah cosmic-ray detector have energies exceeding 5×10^{10} eV at production and thus represent primary particles having energies near 10^{11} eV and above. There are changes in direction from production, decay and scattering. But the small angular deviations between individual muons in muon showers in the detector indicate that the overall angular errors are less than 1° , including both machine resolution and scattering effects. The directions have been so determined for 160,861 of the underground muons. The distribution of the directions has been analyzed in a search for local cosmic-ray sources in the Galaxy and for any overall anisotropy of particles travelling in or out along the spiral arm of the Galaxy.

The search for broad anisotropies was motivated by the usual questions of cosmic-ray sources and of trapping of cosmic rays. The search for local sources was motivated in part by the narrow anisotropy which was observed by BUKATA and STANDIL [1] and supported by the observations of WANG and LEE [2]. The source seemed to have an observable lifetime of the order of two years. If the solar system and a source of charged particles are assumed both to be near different portions of a fairly uniform magnetic field line, the appearance and disappearance of the source can be understood easily. A field of about 1μ gauss and primary energies of about 10^{11} eV (appropriate for BUKATA and STANDIL) would create a pattern of cosmic rays small enough that the sun's velocity could carry us across it completely in 2 - 20 years.

If one projected the spiral paths of cosmic rays into the plane perpendicular to the magnetic field, one would see a rosette pattern as in Fig. 1. At any point in the pattern, such as point *E*, protons would be coming in from only two directions. With the range of energies and pitch angles, plus the probable motion of the source, these two points would be smeared together into one broad hump confined within a spherical zone relative to the magnetic field axis.

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At the higher energies appropriate for the Utah detector, the rosette pattern produced by the particles would be two orders of magnitude larger in diameter and hence would persist much longer. The disadvantage of the higher energies, of course, is that unless the source has a very flat spectrum, the intensities would be too low to discern. Nevertheless the search seemed worthwhile since the data were already available and since most of the celestial sphere was available for study.

The Utah detector uses an array of cylindrical spark counters (CSC's) with a sonic ranging technique to find the position of the sparks along the axis of individual CSC's. The CSC's are operated at 6,000 volts D.C. and pulses to 8,000 volts using a trigger from an array of underwater photomultiplier tubes which detect Cerenkov

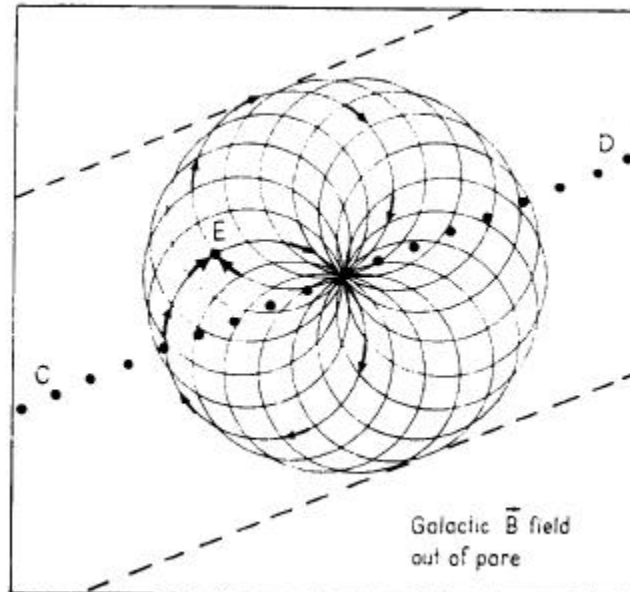


Fig. I. When projected into the plane perpendicular to the galactic magnetic field, the spiralling cosmic ray primaries form a rosette pattern with the source at the center. If the source was moving, there would be a series of patterns with centers along the line of motion CD. Point E represents the earth

light from a muon passing through tanks of water. Digital information about each spark is recorded on magnetic tape along with other digital information, such as the day and time of each event, and is later analyzed by computer to fit a straight line (or lines) to the sparks.

The number of muons in each 5° by 6° bin on the celestial sphere was found. These data were then analyzed to see if any bin, or square containing 4, 9, 25, or 81 bins contained a significant excess of muons. A search was made for an excess or deficiency of muons in spherical zones relative to a wide variety of axes.

The anisotropy as used here is defined as the percentage by which the intensity in one region of the sky differs from the average intensity. This definition permits one to compare intensities in unequal as well as equal areas of the celestial sphere.

The fraction of the bins at a given declination which were within the area of interest was taken as the probability p of a particle being in the area of interest. Using the binomial distribution, the probable number at that declination inside the

area of interest was $pN \pm Np(1 - p)$, where N is the total at that declination. The usual methods of error propagation gave the error on the total number of particles in the area of interest.

The most prominent pattern in the celestial sphere when analyzed this way is a region with fewer particles than expected. This patch (zones 1 and 2 in Fig. 2) is centered around an assumed axis (B - B in Fig. 2) about right ascension 162° , declination 50° . It has 2.1 % less than average, which is a 4.2 standard deviation deficiency. Considering that about 5,000 patterns were considered, we estimate that the probability of finding this large deficiency is about one in six.

To estimate the significance of the excess in zone 3 of Fig. 2, it was necessary to remove the correlation with zones 1 and 2. The independent significance of zone 3 was about 1.5 standard deviations.

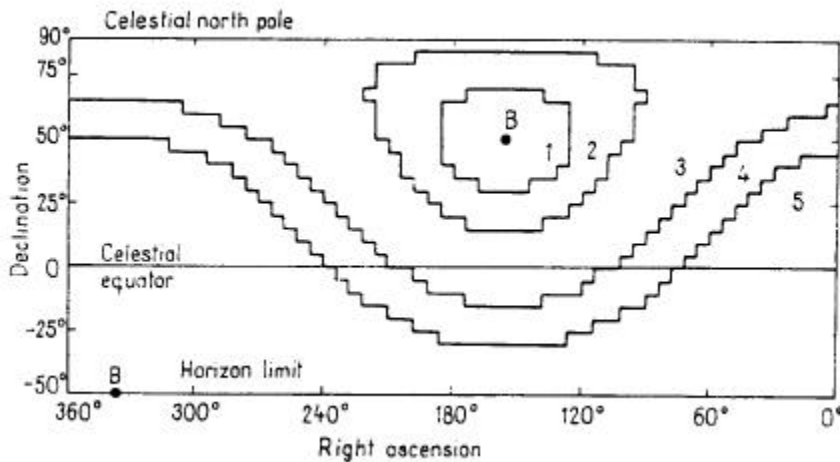


Fig. 2. The points B represent an assumed axis of the galactic magnetic field. The deviations from average numbers of particles in these five zones are: zone 1 has -1.2 % (-1.20), zone 2 has -2.5 % (3.96), zone 3 has + 1.0 % (3.06), zone 4 has 0.7 % (1.26), and zone 5 has -0.2 % (-0.66). Note, however, that these variations are not completely independent

Since the broad humps looked for would not be expected to cover more than about one-half of a zone, the method of finding significant complete zones may choose an axis which differs considerably from the real axis of the galactic magnetic field. Only when considerably more data become available can we hope to eliminate ambiguity and clarify the detailed structure of whatever pattern exists.

Looking at the hemisphere in the direction of the galactic spiral arm at about 300° right ascension and 30° declination, there was an excess of $0.29\% \pm 0.22\%$. The hemisphere toward the galactic center at right ascension 90° , declination 30° showed an excess of $0.43\% \pm 0.21\%$. However, looking at a $45^\circ \times 54^\circ$ patch of sky centered on the galactic center, we find $-0.8\% \pm 2.2\%$.

When corresponding hemispheres whose axes lie on the celestial equator were compared, the largest excess was $0.71\% \pm 0.26\%$, for all directions having right ascension within $\pm 90^\circ$ of 288° . Again, since many pairs of such hemispheres were considered, we do not consider the excess highly significant.

No point sources were found.

All these conclusions are based on sidereal variations within individual declination bands. No attempt has yet been made to compare the average at one declination with that of another. For this reason, when hemispheres or zones are compared, data have not been used from declinations lying completely in either hemisphere or zone, since it could not improve the comparison.

References

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2. C. P. WANG. A. H. LEE. Preprint. 1969.

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