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The 23 February 1956 solar cosmic ray event was the first ground-level event recorded by multiple neutron monitors. At the time of the occurrence of this event, the existence of the interplanetary magnetic field was not known and isotropy was assumed in the initial analyses of this event. From present knowledge it is now known that the anisotropy observed in ground-level events is a consequence of the interplanetary magnetic field. The extreme anisotropy present in the 23 February 1956 solar cosmic ray event is not generally appreciated. Using the method of analysis that employs asymptotic directions of approach and the neutron monitor yield function we show that it is possible to reproduce the observed neutron monitor time-intensity profiles of this event employing contemporary pitch angle distribution functions and an initial differential rigidity spectral exponent of -3.5 at the event onset that evolves to -4 after the event maximum.

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PROBABLE PITCH ANGLE DISTRIBUTION AND SPECTRA OF THE 23 FEBRUARY 1956 SOLAR COSMIC RAY EVENT

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Abstract

The 23 February 1956 solar cosmic ray event was the first ground-level event recorded by multiple neutron monitors. At the time of the occurrence of this event, the existence of the interplanetary magnetic field was not known and isotropy was assumed in the initial analyses of this event. From present knowledge it is now known that the anisotropy observed in ground-level events is a consequence of the interplanetary magnetic field. The extreme anisotropy present in the 23 February 1956 solar cosmic ray event is not generally appreciated. Using the method of analysis that employs asymptotic directions of approach and the neutron monitor yield function we show that it is possible to reproduce the observed neutron monitor time-intensity profiles of this event employing contemporary pitch angle distribution functions and an initial differential rigidity spectral exponent of -3.5 at the event onset that evolves to -4 after the event maximum.

Background. The 23 February 1956 solar cosmic ray event (Elliot and Gold, 1957) was the largest ground-level event recorded by neutron monitors. The source of this event was a 3+ solar flare with onset at 0334 UT at heliographic coordinates N24, W74. The initial onset for European stations was 0342 to 0344 (±1) UT, and for North American stations the initial onset was 0350±1 UT (Lust and Simpson, 1957). The earth's geomagnetic field was very quiet prior to this ground-level event, and continued to be quiet until the solar-flare initiated shock reached the earth and caused a sudden commencement geomagnetic storm at 0307 UT on 25 February. Based on this information, it is reasonable to presume the interplanetary magnetic field was in a "nominal" configuration and the standard "garden hose angle" was the probable direction of maximum particle flux. For 23 February 1956 at 0345 UT, the garden hose angle in the plane of the ecliptic would have been at an asymptotic direction of S22°, E78°.

Early analysis assumed the incoming radiation was isotropic (Meyer et al., 1956) and that the intensity variations observed by neutron monitors at various locations on the American continents could be ascribed to particle velocity dispersion in the incident solar particle flux and to the geomagnetic cutoff (then poorly known) of the various detection locations. The spectral analysis based on these assumptions (Meyer et al., 1956) and the use of the impact zones derived by Frior (1954) resulted in very steep spectra having a spectral exponent of -6 to -7. An analysis by Pfotzer (1958) based on an interpretation of data recorded in Europe derived a much harder spectra with a slope of -4.

Data. The relativistic solar particle increase on 23 February 1956 had a very impulsive onset as evidenced by the Leeds, England time-intensity profile which increases from background to a maximum of about 4500 percent within the first 15-minute interval. The time-intensity profiles for four "sea-level" neutron monitors are shown in Figure 1. There was a persistent anisotropy present in the relativistic proton flux during the entire event. In retrospect, this anisotropy seems similar to that observed in the more recent 7 May 1978 ground-level event (Smart et al., 1979; Debrunner and Lockwood, 1979, 1980, Shea and Smart, 1982).

Method of Analysis. There is a unique set of values for parameters defining the solar proton differential rigidity spectrum, anisotropy, and apparent source direction near the earth that, when transmitted through the asymptotic cone of acceptance for each neutron monitor and through the neutron monitor specific yield function, will generate the observed increase for any location on the earth. We have used an exponential form to describe the pitch angle distribution based on a simplification of the work of Beeck and Wibberanz (1986). We have found that this form is clearly superior to the Gaussian pitch angle distribution used in earlier work (Smart et al., 1971, 1979; Shea and Smart, 1982).

Results. We can model the entire event and obtain a reasonable fit to the observed neutron monitor data by utilizing an anisotropic solar particle flux propagating through interplanetary space along the classic Archimedean spiral path to the earth and then propagating through the asymptotic cones of acceptance to the various locations on the earth's surface where cosmic ray stations were located. A solar particle flux source direction along the classic Archimedean spiral path is the only satisfactory position; no other source position gives a proper fit to the data.

We have ascertained that the spectra cannot be a simple power law in rigidity. A spectral form of a simple power law in rigidity calculated too large an increase at Huancayo and Mexico City. Our model spectra gradually increased in slope with increasing rigidity. Our model spectra for the maximum phase of this event in units of $(\text{cm}^2 \text{ sec ster GV})^{-1}$ is $500\ R^{-\gamma}$. For the initial burst of particles arriving at the earth, the slope of our model differential rigidity spectrum exponent is -3.5 between 1 and 2 GV with the magnitude of the slope increasing by about 0.3 per GV. Later this evolves to a differential rigidity spectra exponent of -4 between 1 and 2 GV with the magnitude of the spectral slope increasing by about 0.4 per GV.

The anisotropic pitch angle distribution of the particles in interplanetary space before they interact with the earth's magnetic field is represented by the exponential form originally derived by Beeck and Wibberanz (1986). We found it necessary to model a very anisotropic pitch angle distribution about the interplanetary magnetic field direction. These pitch angle distributions are illustrated in Figure 2. In this figure <u> is a constant describing the "average" anisotropy. During the initial event onset the particle distribution was very anisotropic, <u> = 0.25, the anisotropy widened to <u> = 0.5 by 0430 UT, and then gradually widened to <u> = 1.0 later in the event.

Discussion. In this analysis, we have found that the anisotropy of the flux distribution in space results in a mean response rigidity at many stations that is very different from the geomagnetic cutoff rigidity. We attempt to illustrate this in Table 1 by the information in the right columns. Here we have summarized the response at each station during the intensity maximum by listing the rigidity (and associated pitch angle) value by which 50% and 75% of the total response has occurred. The Leeds neutron monitor's asymptotic cone of acceptance is directly viewing the anisotropic interplanetary flux at small pitch angles and has the largest observed increase. Note that this station is also responding to particles far above its geomagnetic cutoff. During the maximum of this event, the response of the Leeds neutron monitor near geomagnetic cutoff is quite small because at the rigidities near cutoff, the pitch angles are large and the corresponding flux at those large pitch angles is small (see Figure 2).

Table 1. Stations, Maximum Observed Increase and Response to Maximum Flux.

Station	Alt.	Epoch 1955 Cutoff	maximum percent increase	50 % response Rig	50 % response α	75% response Rig	75% response α
	(m)	GV		GV	deg	GV	deg
Albuquerque	1575	4.47	1236	5.3	50	4.9	49
Chicago	200	1.72	1976	2.5	50	2.2	41
Climax	3400	3.03	2467	3.8	56	3.5	49
Huancayo	3400	13.59	26	15.	33	14.5	36
Leeds	100	2.20	4581	4.5	12	3.7	25
Mexico City	2274	9.53	115	11.5	45	10.6	60
Ottawa	101	1.08	2716	1.9	51	1.6	35
Sacramento Peak	2987	4.98	492	5.8	50	5.5	47
Wellington (USS Arneb)	0	3.42	575	3.9	63	3.8	70

We interpret the relative behavior of the various time-intensity profiles shown in Figure 1 in the following manner. As the initial very anisotropic coherent pulse of particles arrived along the Archimedean spiral path, the neutron monitor (Leeds) whose asymptotic cone of acceptance viewed in this direction observed the particle flux at small pitch angles and also observed the largest increase. (See the time-intensity profile in Figure 1 between 0345 and 0400 UT.) As the pitch angle distribution widened, those stations whose asymptotic cones passed through the Archimedean spiral path at larger (approximately 50^{o}) pitch angles then observed their maximum flux (in this case Ottawa and Chicago), and then finally as the pitch angle distribution continued to evolve and widen, those stations whose asymptotic cones passed through the Archimedean spiral path at large angles observed the flux at large pitch angle (USS Arneb). Of the stations listed in Table 1, only the neutron monitor on the USS Arneb (anchored in Wellington harbor at the time of this event) has a primary response near its geomagnetic cutoff. As the pitch angle distribution of the particles widened, the stations whose asymptotic cone of acceptance passed through the Archimedean spiral path and detected particles at similar pitch angles have relative increases that are organized by the cutoff rigidity of the station as indicated by the relative increases of Ottawa, Chicago and Leeds (heavy line) after 0430 UT.)

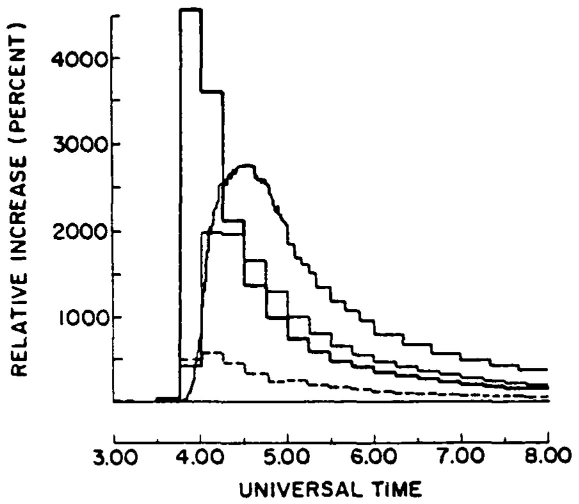

Figure 1. The relative increases observed during the 23 February 1956 ground-level event for sea-level stations. In order of maximum intensity the stations are: Leeds (heavy line), Ottawa, Chicago and USS Arneb (dashed line).

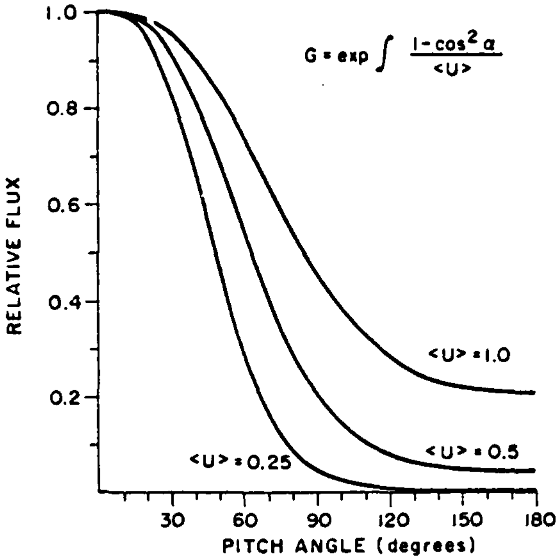

Figure 2. Model pitch angle distribution of the anisotropic particle flux during various phases of the 23 February 1956 GLE.

References.

Beeck, J. and Wibberanz, G.: 1986, Astrophy. J., 311, 437.

Debrunner, H., and Lockwood, J.A.: 1979, 16th International Cosmic ray Conference, Conference Papers, 5, 238.

Debrunner, H., and Lockwood, J.A.: 1980, J. Geophys. Res., 85, 6853.

Elliot, H., and Gold, T.: 1957. The Solar Cosmic Ray Outburst, 23 February 1956, Unpublished collection.

Frior, J.: 1954, Phys. Rev. 94, 1017.

Lust, R., and Simpson, J.A.: .1957, Phys. Rev. 108, 1563.

Meyer, P., Parker, E.N., and Simpson, J.A.: 1956, Phys. Rev. 104, 768.

Pfotzer, G.: 1958, Sup. Nuovo Cimento, 8, 180.

Smart, D.F., Shea, M.A., and Tanskanen, P.J.: 1971, 12th International Cosmic Ray Conference, Conference Papers, 2, 483.

Smart, D.F., Shea, M.A., Tanskanen, P.J. and Humble, J.E.: 1979, 16th International Cosmic Ray Conference, Conference Papers, 5, 238.

Shea, M.A., and Smart, D.F.: 1982, Space Science Reviews, 32, 251.