SOME CHARACTERISTICS OF THE SOLAR FLARE EVENT OF FEBRUARY 16, 1984

H. Debrunner and E. Flückiger
Physikalisches Institut, University of Bern,
3012, Bern, Switzerland

J. A. Lockwood
Space Science Center, University of New Hampshire
Durham, New Hampshire 03824 USA

R. E. McGuire
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771 USA

1. Introduction In the morning of February 16, 1984 a solar cosmic ray event (GLE) was recorded by the world-wide network of neutron monitors (NM). In Fig. 1 we show the counting rate vs. time profile of the Goose Bay NM (geog. lat. = 53.3°N, geog. long. = 299.6°E) where the increase is expressed as percent of the counting rate of an equatorial sea level NM. The Goose Bay NM was observed to have the maximum response to the solar particles. Its counting rate vs. time profile exhibits a rapid increase to maximum , has a large amplitude (∿ 170%) and decays rapidly to background in ∿ 90 min. In Fig. 1 we also show the counting rate vs. time profile for the Tixie Bay NM (71.6°, 128.9°) which recorded an increase of only a few percent. Since the NMs at Goose Bay and Tixie Bay have asymptotic viewing directions ∿ 180° apart in longitude, we can deduce the anisotropy of the solar particle flux at earth from these stations using the expression:

$$A = \frac{\Delta N_{GB} - \Delta N_{TB}}{\Delta N_{GB} + \Delta N_{TB}} .$$

The anisotropy shown in the lower part of Fig. 1 is ∿ 1 for the first 45 min. of the event.

The signature of the GLE on February 16, 1984 is similar to that of the GLE on May 7, 1978 for which it has been shown that:

a) the propagation of the solar particles was nearly scatter-free between the sun and the earth [1];
b) the flare particles at the sun had relatively easy access to the footpoint of the magnetic field line connecting the sun and the earth [2].

2. Source of the Solar Flare Particles We have inspected the Hα and solar magnetic field synoptic charts and the radio observations in order to locate the active region responsible for the solar flare in which the particles producing the GLS on February 16, 1984, were accelerated. The solar synoptic charts show three major active regions at heliocentric longitudes between 40°W and 150°W: Regions 4413 at ∿ 50°W, 4410 at ∿ 95°W and 4408 at ∿ 130°W [3]. No Hα flare was reported from the observations before or during the time of the GLE. We, therefore, conclude that the source of the particles was not on the visible disk of the sun.

On February 16, 1984 at 0858 UT a type III G, a type II metric and a microwave burst started. Since the microwave spectrum showed the spectral maximum below 3.2 GHZ, the corresponding active region must have been behind the limb of the sun. An analysis of the Nançay radio heliograph data [4] and the highest frequencies at which the burst was observed, excludes a flare position at 40° beyond the west limb of the sun corresponding to active region 4408.

The possibility that the active region 4408 was the source of the solar particles can also be excluded on the basis of the intensity-time (IT) profile of the GLE observed at earth. From an analysis of the fine-time resolution data from the cosmic-ray telescopes on IMP7 and Helios A for the May 7, 1978 GLE we have shown that the acceleration of the energetic flare protons can be described by a δ-like process at the flare site and that the coronal propagation of the flare particles can be approximated by 2-dimensional diffusion with losses. We can write for the (IT) profile of the injection of the solar particles into the interplanetary medium [2]:

$$I^E(b,t) = \frac{A(E)}{t} \exp \left\{ - \frac{b^2}{4D_S^E t} - \beta^E t \right\} \qquad (1),$$

where:

b = longitudinal component of the position vector on the surface of the sun with respect to the flare site;
D_S^E = the solar diffusion coefficient for protons of energy E;
β^E = loss rate for protons of energy E;
A(E) = constant factor.

In the interval $20 < E \leq 500$ MeV the diffusion coefficient was found to be $D_S^E[\mathrm{cm}^2/\mathrm{s}] \sim 4.4 \times 10^{15} \{E[\mathrm{MeV}]\}^{1/2}$. The loss rate for $90 < E < 500$ MeV was $\beta^E \sim (2.9 \pm 0.5)\mathrm{hr}^{-1}$. Using the results of this model for the flare particle propagation at the sun we calculated the expected (IT) profiles of the solar particles at earth for the GLE on February 16, 1984 assuming the flare position at 95°W in one case and 130°W in the other case. The diffusion of the solar particles in the interplanetary magnetic field (IMF) between the sun and the earth has been neglected because the high anisotropy of the GLE indicates scatter-free propagation. D_S^E was evaluated by extrapolating the energy dependence to 2 GeV. β^E was taken as $\sim 2.9\ \mathrm{hr}^{-1}$, which is probably too small because there is evidence that β is increasing with energy [2]. The position parameter b depends on the position of the footpoint at the sun of the IMF line connecting the earth to the sun. Unfortunately, no solar wind speed (V_{SW}) data were available to us to determine this footpoint. We, therefore, evaluated V_{SW} from the time delay of the sudden commencement observed on February 10, 1984, most probably produced by the shock front of the solar flare on February 16, 1984. For the deduced value of $V_{SW} \sim 400$ km/s, the footpoint of the IMF to earth was ~ 33° from an assumed flare site at 95°W and ~ 68° from a site at 130°W.

The theoretical (IT) profiles of the solar particles at earth are shown in Fig. 2 along with the NM count rate profile at Goose Bay. From an inspection of Fig. 2 we conclude that a source location of 130°W can be excluded. The only possible source is located at 95°W. Furthermore, the agreement between the observed and the theoretical (IT) profiles is very good if we consider that D_S^E was extrapolated, the value of β^E used for $E \sim 2$ GeV was determined for lower energy protons and both these parameters may vary from event to event [2].

3. Energy Spectrum and Pitch Angle Distribution of the Solar Particles

We recognize that the GLE of February 16, 1984 shows a normal signature for a flare event in which the particles at the sun have relatively easy access to the footpoint of the IMF line connecting the earth to the sun and the IMF conditions are quiet so that the flare particle propagation from the sun to the earth is essentially scatter-free. In order to determine the rigidity spectrum and pitch angle distribution of the relativistic solar protons at earth we followed the method given by [5]. The response of a neutron monitor to the anisotropic solar proton flux as a function of time, $\Delta N(t)$, can be expressed [6]:

$$\Delta N(t) = \sum_{P_c}^{\infty} S(P) \cdot I(P,t) \cdot F(\delta[P],t)$$

where P_c is the effective cutoff rigidity, $S(P)$ is the specific yield as a function of rigidity, I is the solar proton rigidity spectrum, and F is the pitch angle distribution assumed here to be independent of rigidity. The angle $\delta(P)$ represents the angular distance between the asymptotic direction of vertically incident particles at the NM and the direction of the IMF near the earth. By a trial and error procedure we can determine the apparent source position and I and F which give the best fit of the calculated to the observed data. We used NM data from Akad. Kurchatov, Alert, Alma Ata, Deep River, Durham, Goose Bay, Hermanus, Inuvik, Irkutsk, Jungfraujoch, Kerguelen, Kiel, Kiev, Leeds, Magadan, McMurdo, Moscow, Mt. Washington, Potchefstrom, Rome, Sanae, Terre Adelie, Tixie Bay, and Tsumeb and data from [7]. First results of the analysis give the apparent source direction in a region centered at the geographic coordinates ∿ 5°S, ∿ 5°E, which is 45°W of the earth-sun line.

The deduced pitch angle distribution $F(\delta)$ at the time of maximum intensity, is plotted in Fig. 3. Clearly $F(\delta)$ is very narrow, demonstrating that the propagation of the relativistic solar protons in the IMF from the sun to the earth was practically scatter-free (m.f.p. for pitch-angle scattering > 1 AU). At the time of maximum intensity the rigidity spectrum is given by $I(P)$ $[\mathrm{p/m^2\ ster\ s\ GV}] \sim 7.25 \times 10^4$ $\{P[\mathrm{GV}]\}^{-4.25}$ for $1 < P < 10$ GV, where $I(P)$ is the flux averaged over 4π. The corresponding energy spectrum is shown in Fig. 4 along with the spectrum at lower energies deduced from the cosmic-ray telescope onboard IMP8. The agreement between the two spectra is very good. Unfortunately IMP8 was in the earth's magnetotail so that no direct anisotropy measurements are available for $E < 500$ MeV.

4. Conclusion If we compare the pitch angle distribution and the energy spectrum of the GLE on February 16, 1984, with those of the GLE on May 7, 1978, we recognize that the two events had similar signatures. Therefore, the NM and spacecraft data for this event are again a key to study the acceleration of solar flare protons, their coronal propagation and their injection into the interplanetary medium.

5. Acknowledgements This research was supported by the Swiss NF (2.206-0.84) and the U.S./NSF (ATM-8324486 and INT-8118555). We thank all the principal investigators of neutron monitor stations who made data available to us. We are indebted to Drs. G. Trottet, K. L. Klein, and A. Magun for radio and microwave data and stimulating discussions. We gratefully acknowledge essential information on Hα observations by Dr. Prokakis and we thank H. Grädel for assistance in the data analysis.

6. References

1. Debrunner, H., et al., 1984, J. Geophys. Res., 89, 769.
2. Lockwood, J.A., and H. Debrunner, 1985, to be pub. J. Geophys. Res.

3. Solar Geophys. Data, 1984, 476, Part 1.
4. Klein, K.L., and G. Trottet, 1985, private communication.
5. Debrunner, H., and J.A. Lockwood, 1980, J. Geophys. Res., 85, 6853.
6. Smart, D., et al., 1971, Proc. ICRC 12th, 2, 483.
7. Pomerantz, M.A., et al., 1985, Proc. IS/CRMH (Japan), 437.

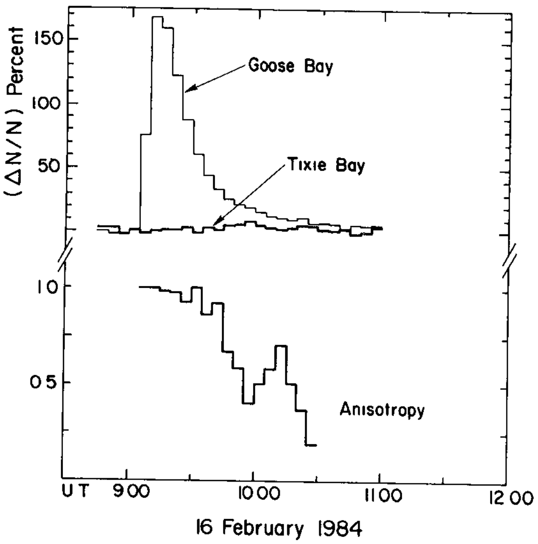

Fig. 1. Percent increase at Goose Bay and Tixie Bay NMs and anisotropy-time profile.

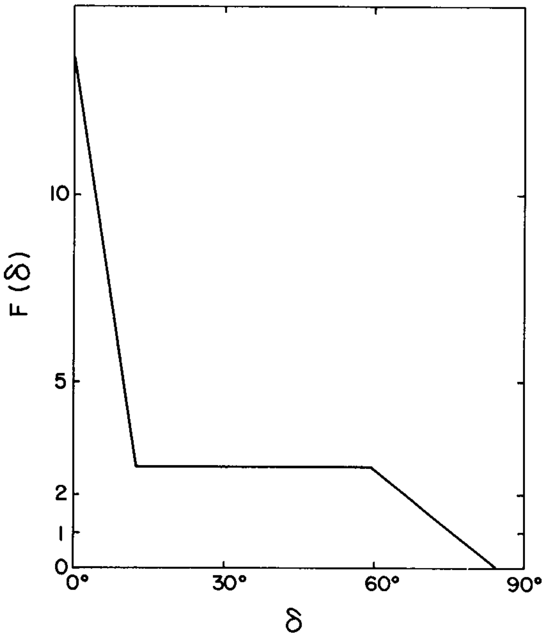

Fig. 3 Pitch angle distribution at time of maximum intensity.

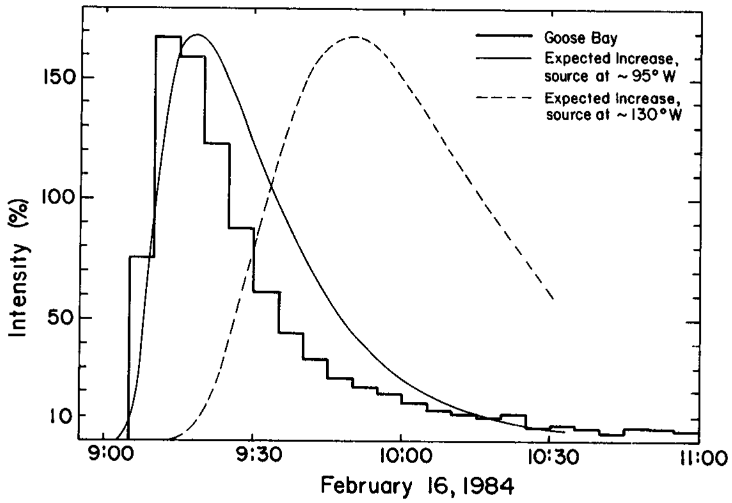

Fig. 2. Intensity-time profile at Goose Bay compared with expected increases for the solar flare locations at 95°W and 130°W.

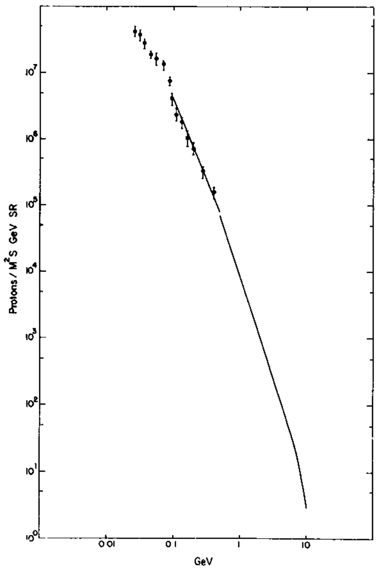

Fig. 4 Energy spectrum at the time of maximum intensity.