THE OBSERVATIONS OF THE 16 FEBRUARY 1984
SOLAR FLARE (STIP INTERVAL XV, 12-21
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A PRELIMINARY SUMMARY OF THE OBSERVATIONS OF THE 16 FEBRUARY 1984 SOLAR FLARE (STIP INTERVAL XV, 12–21 FEBRUARY 1984)

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ABSTRACT

The solar flare on 16 February 1984 (0900 UT) and the associated photon and particle emissions were perhaps the most interesting solar and interplanetary phenomena during STIP Interval XV, 12–21 February 1984. The X-ray and microwave radio emissions, as observed from the earth, were relatively weak and no optical flare was reported. However, the hard X-ray and low energy gamma-ray observations made with the Pioneer Venus Orbiter spacecraft behind the west limb of the sun indicate that the flare was, in reality, very intense. There is evidence that the flare was located ~40° behind the west limb of the sun and hence, for instruments located near the earth, the most intense parts of the X-ray and microwave radio sources were occulted by the photosphere. However, the effect of occultation on the metric type II, type III, and type IV and decimetric (type DCIM) radio sources appeared to be relatively small. Following the flare, a large increase in the counting rates was recorded by several ground level neutron monitors and energetic particle detectors located in interplanetary space. A detailed analysis of the 16 February 1984 flare observations is therefore expected to lead to a better understanding of at least the following three aspects of the solar flare phenomenon: (1) the structure of the X-ray and radio sources in the high corona, (2) the prompt acceleration of energetic particles during the impulsive phase, and (3) the anomalous propagation of energetic solar particles in the solar corona. Such propagation would permit the prompt arrival of the particles in the vicinity of the earth, even when the relevant flare is located far behind the solar limb.

1. INTRODUCTION

Observations of behind-the-limb solar flares provide information about the spatial structure of the hard X-ray and radio sources and the propagation of energetic solar particles in the corona. This is particularly true of flares behind the west limb, which often produce relatively prompt energetic particle events in the vicinity of the earth. During STIP Interval XV, which covered the time interval 12–21 February 1984, such a flare occurred at ~0900 UT on 16 February 1984. We summarize below some of the observational results related to the X-ray, radio and energetic particle emissions from that flare.

2. OBSERVATIONS

At the time of the 16 February 1984 (~0900 UT) flare, solar X-ray emission was being observed by instruments aboard three spacecraft: two near-earth spacecraft, ICE (International Cometary Explorer) and GOES (Geostationary Operational Environmental Satellite); and one near Venus, the PVO (Pioneer Venus Orbiter) [*Klebesadel*, private communication, 1985], which was located ~16° behind the west limb of the sun. The radio emission was observed by several ground-based instruments in Europe. The microwave emission was observed at Bern, Switzerland [*Magun*, private communication, 1984]. The decimetric and metric bursts were recorded by spectrographs at Weissenau, FRG and Meudon, France [*Pick*, private communication, 1984]. High time resolution digital data for 200–600 MHz emission have been obtained with a radio-polarimeter at Trieste, Italy [*Messerotti and Zlobec*, private communication, 1985]. Energetic particles have been detected by instruments aboard the PVO, ICE, GOES and other spacecraft. Neutron monitors at Deep River, Inuvik, Goose Bay, Alert and Ottawa, Canada recorded associated increases (GLE) in the relativistic particles. The X-ray, radio and energetic particle observations are summarized in Table 1. Since no optical flare was detected, it is assumed that the flare occurred behind the solar limb.

Table 1. Characteristics of 16 February 1984 Flare (Near-Earth Observations)

(A) X-Rays, Microwaves and Energetic Particles

Emission	Start (UT)	Max (UT)	Peak Flux
Soft X-rays GOES (0.5-8 Å)	0858.5	0859.9	3×10^{-4} ergs cm^{-2} sec^{-1} (Class C1)
Hard X-rays ICE ($>$25 keV)	0858.3	0859.3	1.7 photons cm^{-2} sec^{-1} keV^{-1}
Microwave Bern (5.2 GHz)	0858.5	0859.3	19 sfu
Neutron mon. Goose Bay	0905	0914.5	98% above background
Protons GOES ($>$100 MeV)	0915	0935	280 protons cm^{-2} sec^{-1} ster
Energetic Particles ICE ($\Delta E \gtrsim 1$ MeV)	0904.5	~0930	

(B) Metric-Decimetric Bursts (Weissenau)

Wavelength	Type	Start (UT)	End (UT)
Decimetric	DCIM	0858.3	0900.7
Metric	III	0858.4	0900.7
Metric	II (harm)	0900.4	0916.0
Metric	IV	0858.4	0929.0

2.1. X-RAYS AND LOW ENERGY GAMMA-RAYS

The time-counting rate profiles recorded by the X-ray instruments aboard PVO, ICE and GOES are shown in Figure 1. The time for PVO and ICE data has been normalized to the arrival time of solar radiation at the earth. Similarly, the absolute photon fluxes measured by PVO and ICE have also been normalized to the earth's distance from the sun. PVO detected a very intense hard X-ray and low energy gamma-ray burst in the 100 keV to 2 MeV range. The burst profile has considerable structure and appears to be related primarily to the impulsive phase of the flare. A solar gamma-ray burst of this magnitude in the PVO data is usually associated with a very large burst in the 26–398 keV hard X-ray channels of the ICE instrument and also a very intense (class $\gtrsim$X) soft X-ray burst in the 0.5–4 and 1–8 Å bands of the GOES instrument [*Kane et al.*, 1982; *Kane*, 1983]. However, both ICE and GOES recorded very weak X-ray bursts. This indicates that a large part of the

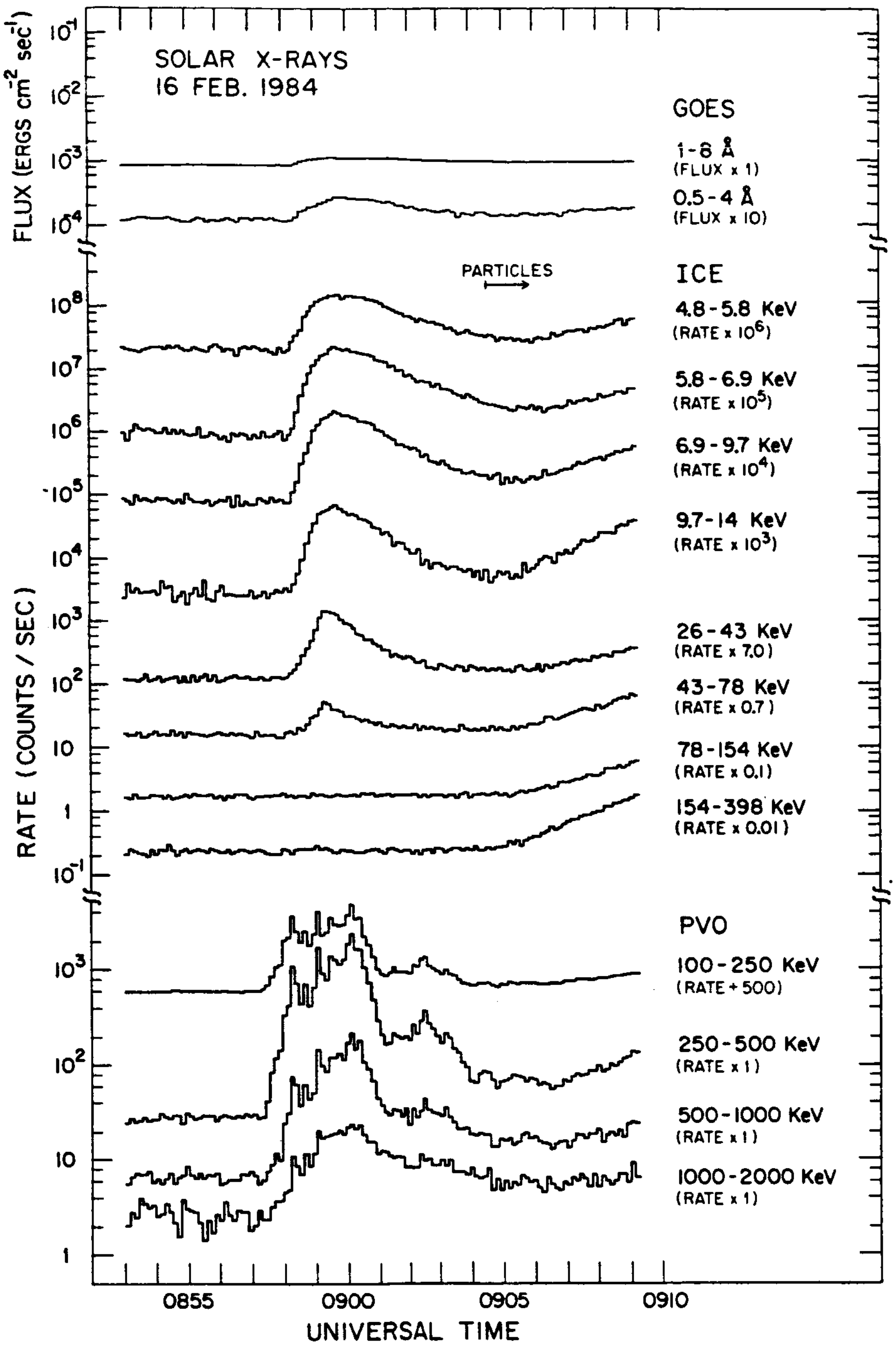

Figure 1. The hard X-ray and low energy gamma-ray observations of the 16 February 1984 solar flare made with the ICE and PVO spacecraft. The flare was in full view of the PVO instrument, which was behind the west limb of the sun. The X-ray source was occulted from the ICE line of sight, resulting in a relatively small X-ray flux observed by the ICE instrument.

X-ray source was occulted by the photosphere from the line of sight of the ICE and GOES instruments, although the source was in full view of the PVO instrument. This is confirmed by a comparison of the photon spectra measured by PVO and ICE, which shows that the ratio of the 150 keV photon flux at ICE to that at PVO is ~10^{-3}. Moreover, the relatively smooth intensity profile at ICE compared to the structure in the intensity profile at PVO suggests that the ICE observations correspond to an X-ray source in the corona resulting from a temporarily trapped population of energetic electrons.

2.2. RADIO EMISSION

A 5.2-GHz impulsive microwave burst with peak flux of 19 sfu was associated with the flare [*Solar-Geophysical Data*, 1984*a*]. Unlike the relatively large ($\gtrsim$100 sfu) microwave bursts associated with most of the medium-large on-the-disc flares, for which the frequency of maximum emission $f_{\max}$ is $\gtrsim$10 GHz, the present burst was very weak and $f_{\max}$ was <3.2 GHz. These characteristics are consistent with the microwave source being far behind the solar limb and substantially occulted by the photosphere.

Figure 2 shows a part of the relevant radiospectrograph observations made at Weissenau. Intense DCIM and metric type III bursts occurred between 0858.3 and 0900.7 UT in good time coincidence with the X-ray and microwave bursts. Intense type IV emission started at 0858.3 UT. During the period 0900–0911 UT, the high frequency cutoff was at ~100 MHz, the cutoff decreasing to lower frequencies at later times. An intense type II burst started at ~0900.4 UT, with a slow drift during the initial 20 seconds. A type II harmonic at ~310 MHz started at 0900.6 UT. No significant drift in frequency was found during the period 0900.3–0904.0 UT. The very slow frequency drift for the type II emission is consistent with the geometrical effects for a type II burst associated with a behind-the-limb flare. Partial occultation of the radio source, especially at high frequencies, can also be seen from the composite radio spectrum of maximum emission shown in Figure 3.

2.3. ENERGETIC PARTICLES

The time-rate profiles of the energetic flare particles observed by the Goose Bay neutron monitor [*Wilson*, private communication, 1984] and the plastic guard scintillator in the ICE X-ray spectrometer during the early part of the particle increase are shown in Figure 4. Five-minute averages of the neutron monitor data from several stations [*Wilson*, private communication, 1984] are shown in Figure 5. The earliest detection of the energetic particles from the flare was apparently made by the ICE plastic guard scintillator. The arrival time was $\lesssim$0904:30 UT. The increase in the Goose Bay neutron monitor started at 0906 UT (±1 minute). The lower energy protons arrived at the GOES satellite considerably later, at ~0915 UT [*Solar-Geophysical Data*, 1984*b*], which also happened to be the time of maximum for the neutron monitor counting rates at Goose Bay and Alert. However, both the onset and maximum for the Inuvik and Deep River neutron monitors were delayed by ~5 and ~10 minutes, respectively. Moreover, compared to the rapid onset and decay of the Goose Bay and Alert neutron monitors, the Inuvik and Deep River neutron monitor counting rates decayed slowly over a period of about 2.5 hours, and the decay was superimposed with relatively large fluctuations. A comparison of the Goose Bay and Tixie Bay neutron monitor counting rates, presented in Figure 6, shows a very high degree of anisotropy and essentially scatter-free propagation of the relativistic solar particles [*Debrunner et al.*, 1985].

2.4. LOCATION OF THE FLARE

It is easy to see that the flare was located behind the west limb of the sun. However, it is not clear how far behind the west limb the flare occurred. An examination of the characteristic of the active regions visible

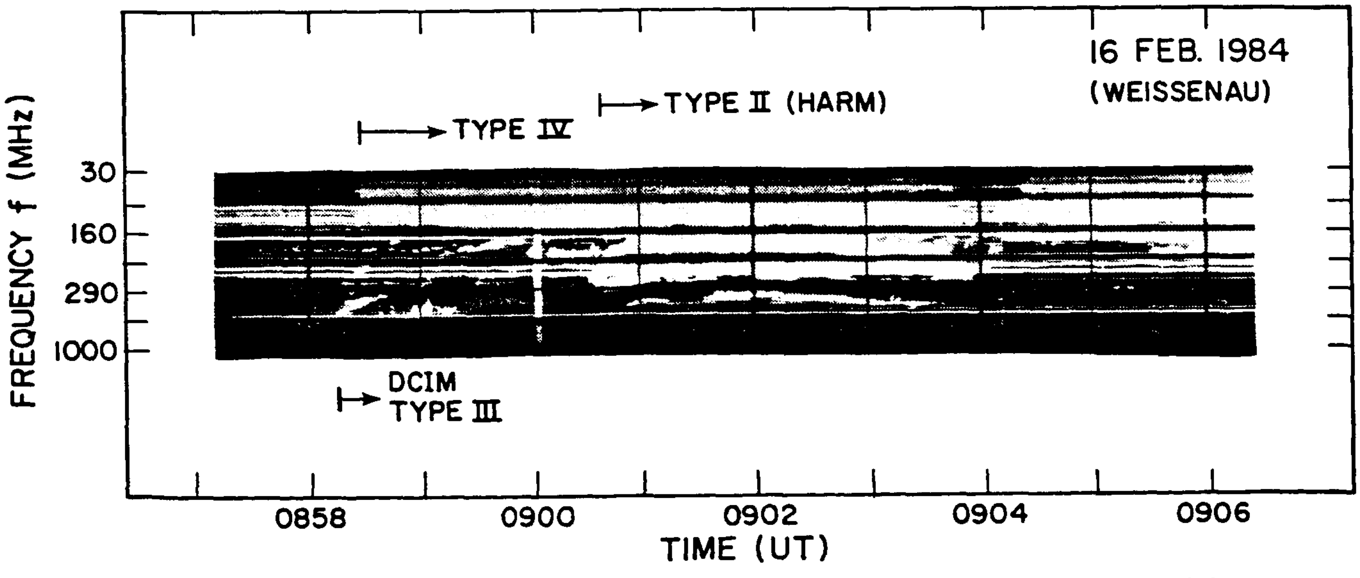

Figure 2. A part of the dynamic radio spectrum observed at Weissenau at the time of the 16 February 1984 flare.

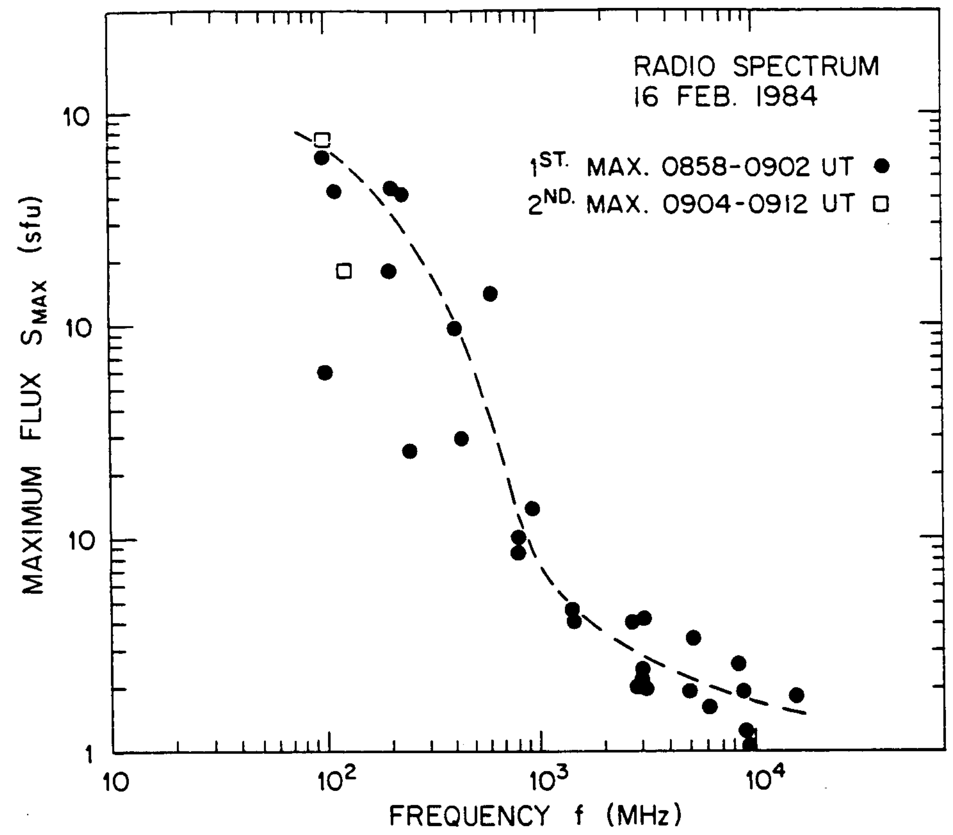

Figure 3. Composite spectrum of the maximum radio emission at the time of the 16 February 1984 flare. Note: the time of maximum emission was not the same for all frequencies.

prior to 16 February shows that the flare could have occurred in regions 4408 or 4410 [*Solar-Geophysical Data*, 1985], the corresponding locations of the 16 February flare being ~40° or ~5°, respectively, behind the west limb.

From an analysis of the energetic particle data, *Debrunner et al.* [1985] have argued that the flare occurred ~5° behind the west limb. They have based their arguments on (1) the good agreement of the observed time-rate profiles of the neutron monitors with the predictions of their theoretical model for propagation of solar particles, and (2) the Nancay observation of the type III burst at high frequencies [*Klein and Trottet*, private communication mentioned in *Debrunner et al.*].

On the other hand, the increasing area of region 4408 when it rotated behind the west limb suggests that the flare occurred at ~40° behind the west limb. Such a flare location is further supported by (1) the small frequency-drift rate for the type II radio burst, (2) the very small magnitude (class C1) of the soft X-ray burst, and (3) the small value (0.001) of the ratio R of the hard X-ray fluxes from the occulted and non-occulted parts of the X-ray source. For a flare located only ~5° behind the limb, the expected X-ray flux ratio R is ~0.01 [*Kane*, 1983]. Also, for such a flare the soft X-ray burst, consistent with the intense hard X-ray burst observed by the PVO instrument, would have a large magnitude (class $\gg$ C).

3. PRELIMINARY RESULTS

The arrival of relativistic particles near the earth within $\lesssim$4.5 minutes of the hard X-ray maximum is particularly significant, since the flare was located behind the solar limb. If the flare did occur ~40° behind the limb, as strongly suggested by the X-ray measurements, this observation becomes highly significant. If we take into account the differences in the transit time for photons, which move along the line of sight, and charged particles, which move mostly along the magnetic field lines, it appears that both electrons (radiating X-rays at the sun) and protons (escaping from the sun) were accelerated to relativistic velocities during the impulsive phase.

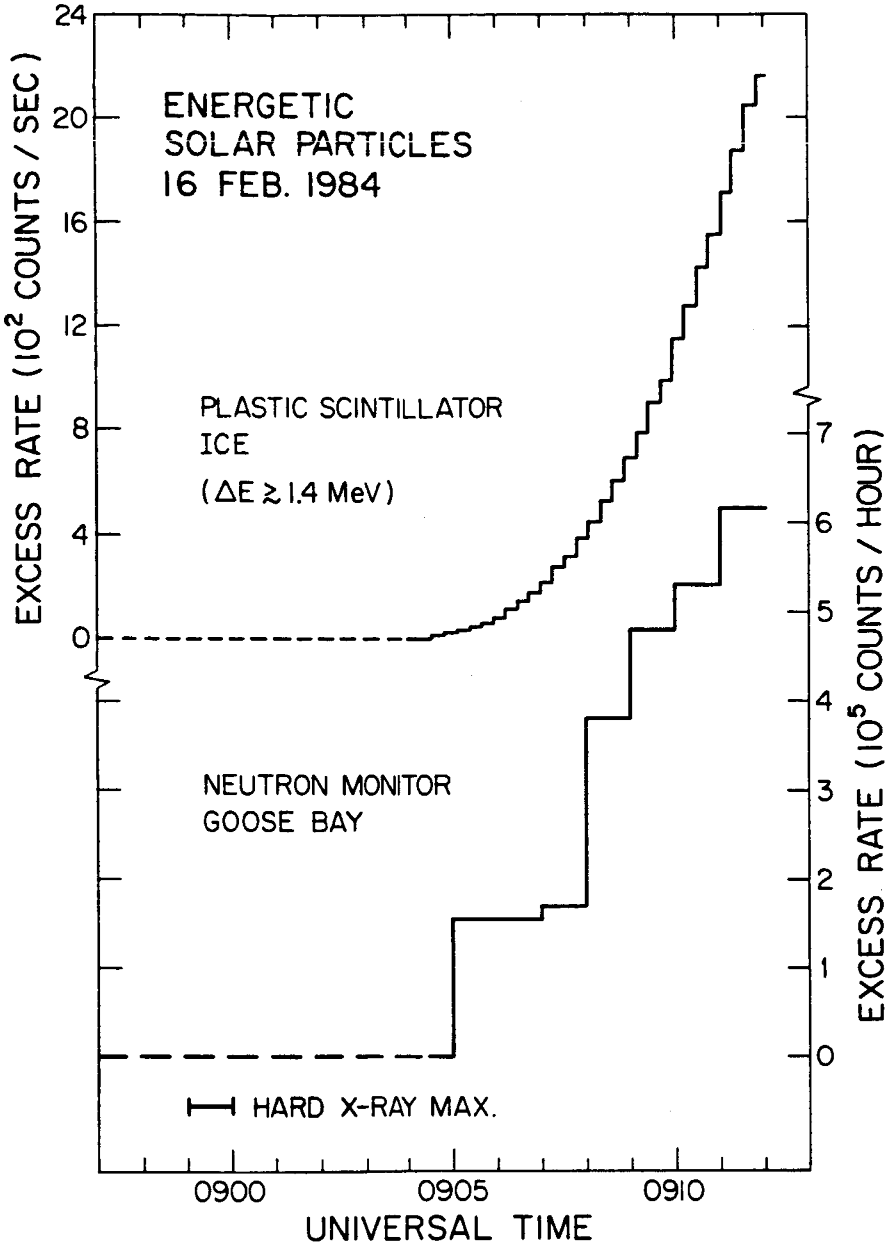

Figure 4. Early time history of energetic interplanetary solar particles observed by the Goose Bay neutron monitor [*Wilson*, private communication, 1984] and the plastic guard scintillator on ICE following the 16 February 1984 flare.

This is consistent with the findings of *Kane et al.* [1985, 1986] that (a) the relativistic electrons which escape from the sun, as well as those which remain at the sun and produce X-rays and low energy gamma-rays, are accelerated during the impulsive phase; and (b) the time for acceleration of relativistic electrons can be $\lesssim 1$ second. In the 1 September 1971 flare, which occurred ~30° behind the west limb, the relativistic protons were found to arrive near the earth within ~30 minutes of the inferred explosive phase [*Cliver*, 1982]. The acceleration of protons in that flare was attributed to the shock associated with the observed type II radio burst. A similar interpretation has been made by *Hudson et al.* [1982] for the particle acceleration in the 22 July 1972 flare which occurred ~20° behind the west limb. Compared to these two flares, the arrival time of the relativistic protons in the 16 February 1984 flare was very short, even though the flare occurred far behind the west limb. This seems to imply that energetic protons can diffuse very rapidly across magnetic field lines in the corona and be injected on the appropriate spiral interplanetary magnetic field line connecting the earth.

The large occultation of the soft and hard X-ray sources in the 16 February 1984 flare is consistent with

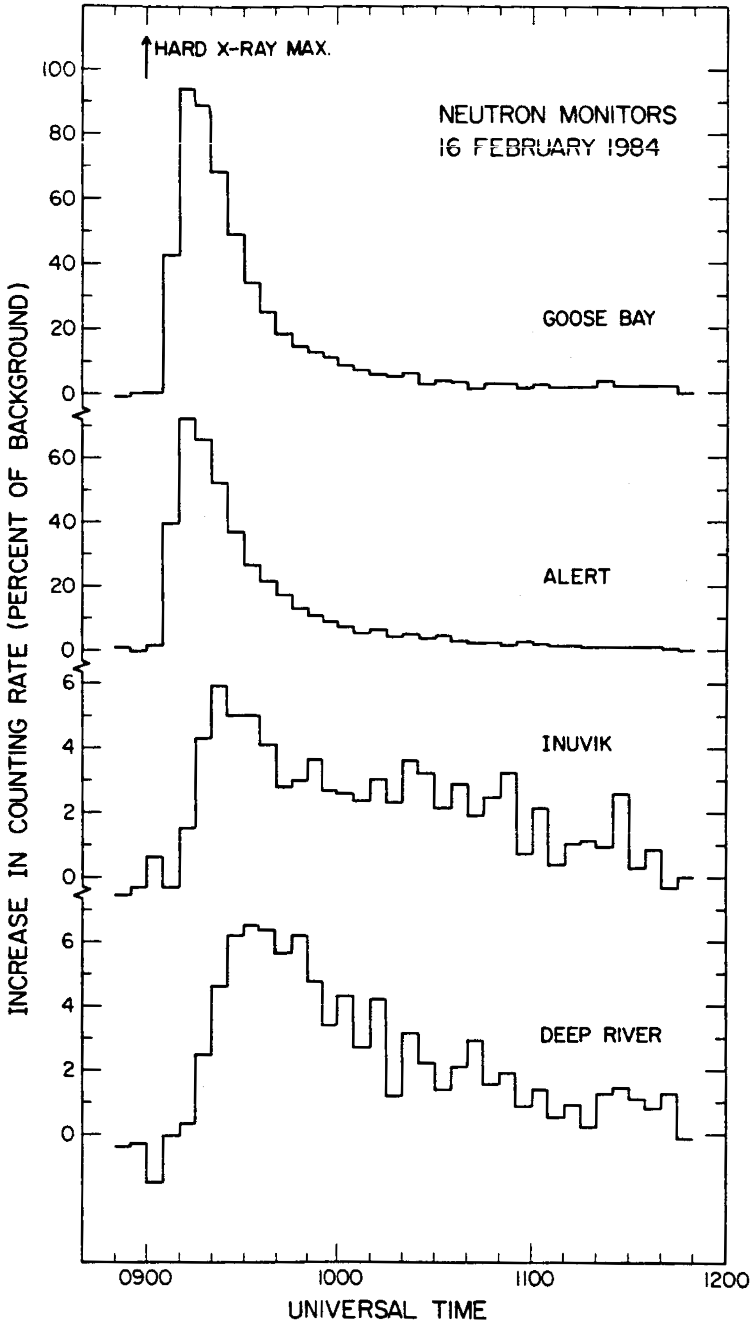

Figure 5. Increases in the counting rates of the neutron monitors at Goose Bay, Deep River, Alert and Inuvik, following the 16 February 1984 solar flare. All rates are averaged over 5 minutes. Note the differences in the response of the different neutron monitors: (1) the times of the onset and maximum at Inuvik and Deep River are delayed by ~5 and ~10 minutes, respectively, with respect to the corresponding times at Goose Bay and Alert, (2) compared to the rapid onset and decay of the Goose Bay and Alert neutron monitors, the decay of Inuvik and Deep River neutron monitor rates is slower and is superimposed with relatively large fluctuations.

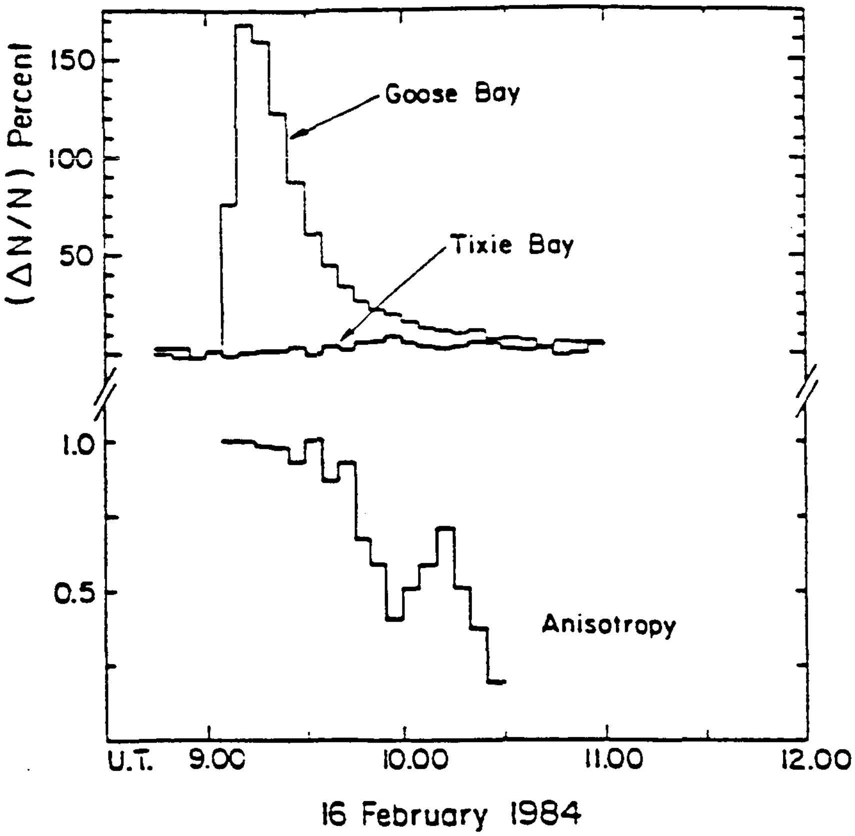

Figure 6. Increases in the counting rates of the Goose Bay and Tixie Bay neutron monitors. Note the large degree of anisotropy in the early part of the particle increase [*Debrunner et al.*, 1985].

the earlier observations made with the PVO and ISEE-3 spacecraft [*Kane et al.*, 1982; *Kane*, 1983], which show a rapid decrease in the brightness of the hard X-ray source with the increase in altitude above the chromosphere. However, the fact that significant X-ray emission can be detected from altitudes $\gtrsim 1.5\times10^5$ km indicates the presence of a large population of energetic electrons in the corona during the impulsive phase.

The DCIM and type III emissions at decimetric wavelengths are believed to originate at the plasma level, where electron density is $\sim 10^9$ cm^{-3}. The sources of these radio emissions are therefore expected to be located at altitudes of $\sim 5\times10^4$ km above the photosphere, the exact altitude depending on the magnetic field structure, the presence of streamers, and the electron density distribution. In a flare far behind the limb, the decimetric radio sources are expected to be occulted by the photosphere from the direct line of sight. It is possible, however, that propagation effects play a more important role than normally assumed in the observation of these decimetric radio sources.

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DISCUSSION

Spicer: Could you draw a cartoon illustrating the possible loop configuration?

Kane: Yes

Gold: (Comment) There is an interesting relationship between the events in STIP Interval XV and observations made in the outer heliosphere. Starting at about August of 1983, 3 kHz radio emissions have been observed by Voyagers 1 and 2. They have been interpreted as emissions from the heliosphere boundary at approximately 46 AU. In our 3 to 17 MeV proton data from Voyagers 1 and 2 we see that the 3 kHz radiation appeared at the start of an unusually quiet time. However, when the events from STIP Interval XV reached Voyager in March of 1984, the 3 kHz radiation disappeared. During the period in which the radiation was seen, the interplanetary medium beyond Voyager consisted only of outwardly propagating co-rotating shocks providing a stable environment for propagation of the 3 kHz radiation. The absence of protons at Voyager suggests that there were also no protons at the heliopause. Therefore, it may be that the radiation is generated by the interaction of protons and transient shocks at the heliopause, or that the propagation of the 3 kHz radiation is inhibited by the protons and transient shocks beyond the spacecraft.

Cliver: (Comment) I'd like to point out that a similar event occurred on 1 September 1971 for which, of course, the stereoscopic hard X-ray observations were not available. In that event the flare was ~30° behind the West limb, and at about the time the GeV protons were inferred to be injected, a type II burst, reported by Clark Lake, swept across the solar western hemisphere.

Kane: An important difference between the 1 September 1971 and 16 February 1984 events is that the acceleration of particles in the latter event seems to have occurred during the impulsive phase rather than in the gradual phase.

Shea: You mentioned that the Thule neutron monitor had an increase of approximately 30%. Over what time interval was that measurement?

Kane: I think the averaging time for Thule data is one minute. The increase occurred over several minutes.

Shea: (Comment) I question your comment that this was the largest ground-level event of this solar cycle. The Kerguelen Islands neutron monitor (vertical cutoff rigidity of approximately 1.2 GV) recorded a 214% increase during the 7 May 1978 event using five-minute averages. Care must be taken that comparable time intervals be used to compare events.

Kane: I agree with you. I was mainly referring to the events since the last activity maximum in 1979.

Gergely: I don't think you can conclude that type III bursts decrease in number before a large event. To make this statement you would need to have control periods, and positional information on the type III's, in order to relate the III's to the event.

Urbarz: My remark is just a fact given by the spectral data; the interpretation is tentative. One should associate the type III events to the subflares to localize the region in question. Large statistical material is to be considered to conclude that a region decreases type III production before large events.

Dryer: This is an exciting event, in my opinion, because it might be similar to the 29 March 1969 event discussed at 80 MHz by S. F. Smerd [*Proc. Astron. Soc. Australia 1*, 305, 1970] using the Culgoora radioheliograph measurements. Do you think that we might have a similar (quasi-hemispherical) shock, followed by a piston driver (as suggested by the Type IV)?

Urbarz: Yes, this may be suggested from the associated observations mentioned. The interplanetary-magnetic field-density-shock observations should confirm this, though on the earth there were no SI or SSCs observed, because the event passed the earth westward.