

GEOMETRY OF THE DIFFUSIVE PROPAGATION REGION IN THE
AUGUST 14, 1982, SOLAR ELECTRON EVENT

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ABSTRACT On August 14, 1982, relativistic electrons arrived promptly after an impulsive gamma-ray flare, indicating that very little scattering was taking place in interplanetary space. By ignoring anisotropy data the time profile of the event is well described by interplanetary diffusion except for the derived particle injection time. This discrepancy provides independent evidence that the particles are diffusing in a volume close to the sun rather than in interplanetary space. The flux at maximum method of determining the number of particles produced is still a good approximation when appropriately applied.

1. INTRODUCTION With the recent availability of high resolution gamma ray data from the solar maximum mission accurate counting of particles emitted by solar flares has assumed a new importance. Gamma ray fluences yield estimates for the number of particles interacting in the target which have been used to calculate the fraction of particles escaping the target by comparison with interplanetary observations (Von Rosenvinge et al. 1983, Evenson et al. 1984). To date these comparisons have been made using the time to maximum method (Parker, 1963) to estimate the number of escaping particles. It is well recognised that this method removes most sensitivity to the interplanetary diffusion coefficient but depends explicitly on the assumption that the particles are diffusing isotropically in interplanetary space and that the distance from the source to the observer is known.

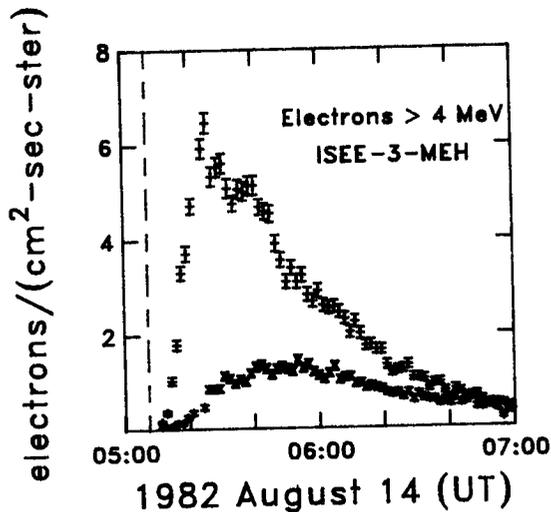


FIGURE 1

2. THE 1982 AUGUST 14 ELECTRON EVENT On the 14th of August, 1982, a solar flare located at a longitude of W66 produced an intense, highly impulsive burst of radiation (x-rays through MeV gamma rays) at 05:07:30 earth received time (Kane et al. 1985). The time profile of a relativistic electron event which followed this flare is shown in figure 1, where the dashed line gives the time of the photon impulse. A large anisotropy is evident -- the

upper trace gives the flux from the direction of the sun along the interplanetary magnetic field line and the lower trace gives the flux back toward the sun. When the observed anisotropy is considered it is obvious that isotropic diffusion in the interplanetary medium cannot be the source of the shape of the time profile. Kane et al. (1985) conclude that the time profile of this event can be explained by impulsive production of all electrons at the time of the photon impulse, followed by coronal diffusion (Reid, 1964) and interplanetary focused diffusion (Bieber et al., 1980).

3. VOLUME OF THE DIFFUSION REGION The combination of two dimensional diffusion with escape in the Reid model is in fact similar to three dimensional diffusion (Ford et al., 1977). Therefore if one ignores the anisotropy and models the average electron flux as a function of time by interplanetary isotropic diffusion a very good fit is obtained with an estimated mean free path of 0.15 AU. It is interesting to note that one can deduce that the particles have not in fact diffused in interplanetary space without reference to the anisotropy information. This conclusion is reached by considering plots of

$$\ln(I \cdot (t-t_0)^{3/2}) \text{ versus } 1/(t-t_0)$$

(e.g. Cline and McDonald, 1968). Data scaled in this manner lie on a straight line if and only if the correct choice for the origin time (t_0) of the particles is made. The slope of the line then gives the diffusion coefficient and the intercept gives the total number of particles released. determining the particle number in this manner is exactly equivalent to using the time of maximum method. By stepping the

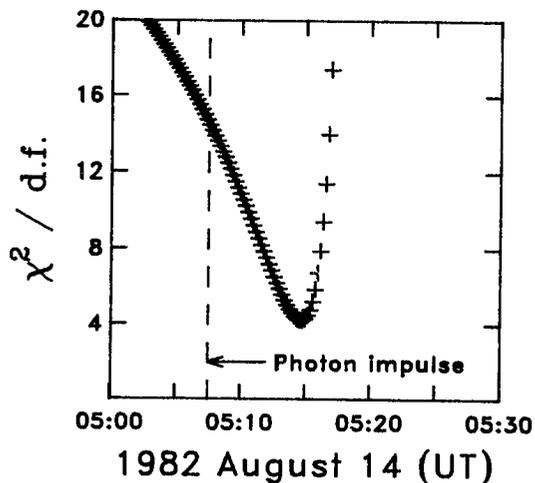


FIGURE 2

assumed origin time in small increments and fitting a straight line to the rescaled data for each time one can generate the plot in figure 2 which shows the value of chi-squared for the best fit straight line at each time step. The estimated origin time of the particles is thus 05:15, the time at which the scaled data are best represented by a straight line. In generating this figure the fit was done to the sum of the two curves in figure 1. A minimum chi-squared of greater than one is a result of scatter in the data introduced by fluctuations in the magnetic field direction at the spacecraft rather than a systematic deviation from a diffusive shape.

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The time axis of figure 2 has been adjusted to correspond to the arrival time at the spacecraft of a photon emitted from the sun at the time of the supposed acceleration of the particles. The time of the photon impulse is indicated with a vertical line. Not only is the time derived from the diffusion fit much later than the gamma ray flash, it actually is later than the arrival of the first electrons at the spacecraft. This seemingly absurd finding is actually the desired result; it indicates that the observer is not embedded in the diffusion volume but rather is seeing the diffusion process as reflected in the continuous escape of a small fraction of the diffusing particles which then propagate to the spacecraft nearly unimpeded by scattering in the interplanetary medium.

The error in the acceleration time estimate immediately provides a limit on the volume of the diffusion region. Since the transit time of an electron along the Parker field is eleven minutes it can be shown that an eight minute error implies that the radius of the diffusion region cannot be larger than 0.3 AU. Actually the situation is more complex than this because interplanetary scattering is influencing the shape of the time profile. Using the profile of the outward flux (upper trace of figure 1) yields a larger time error whereas a fit only to the backward flux interestingly gives an origin time very much closer to the gamma ray flash. This backward flux profile of course is produced predominantly by interplanetary scattering. In conjunction with other work (Bieber et al., 1985) I have done a detailed fit to this event with the conclusion that the time evolution is consistent with diffusion in the solar corona, although a diffusion region with dimensions as large as 0.1 AU probably can not be excluded.

4. NUMBER OF PARTICLES ACCELERATED The pitch angle distribution of the electrons at the spacecraft can be determined from the data, integrated over time, and projected in the radial direction to obtain the electron fluence at the spacecraft, 25200 electrons per square centimeter. Reid (1964) shows that the net outflow from any point on the surface can be determined analytically given the distance from the flare to the foot of the field line, the loss time constant and the diffusion coefficient. Using the solar wind speed (Bame, private communication) of 280 km/sec I estimate that the flare occurred 25 degrees from the best connection field line and then obtain a loss time constant of 1/hr and a mean free path of 500 km from the fit to the data. Scaling the spacecraft fluence to the solar surface by the square of the distance to the center of the sun and using the Reid expression for the fluence from the solar surface implies the production of 3.1×10^{31} electrons. This may be compared with an estimate of 6.2×10^{31} obtained using the directionally averaged flux and the time of maximum method.

The closeness of these two numbers is not completely fortuitous. As Reid (1964) points out, the fluence of particles leaving the sun is not nearly so strong a function of distance from the flare as is the maximum intensity. In the limit of slow escape the escaping fluence becomes independent of position. With the parameters derived for this event the fluence at a point 25 degrees removed from the flare site is only a factor of three more than the fluence obtained by dividing the total number of particles by the surface area of the sun. (The two fluences are approximately equal 55 degrees from the flare site.) If the subsequent diffusion in interplanetary space produces a time profile which is long compared to the duration of the injection then the time of maximum method can still yield reliable results even though the diffusion in connection longitude is taking place on the sun. In the 1982 August 14 event effects of interplanetary and coronal diffusion on the time profile are comparable. Therefore the two methods give consistent results. A good rule of thumb for counting particles from a flare would be that if the net fluence is easy to determine, i.e the event is very anisotropic, use the fluence and the Reid model. On the other hand, when an event is sufficiently isotropic that the fluence is statistically difficult to determine it is likely that the conditions for the validity of the time of maximum method are satisfied.

5. ACKNOWLEDGEMENTS I would like to thank Drs. J.A. Earl and J.W. Bieber for many helpful discussions. This work was supported in part by NASA grant NAG-374.

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