# Chapter VI

# Results of Fitting Gradual and Impulsive Flare

## Solar Flares

A solar flare is an explosion on the surface of the Sun, which often releases energetic particles. Flares occur in the corona, which is the outer portion of the Sun. The release of energetic particles from the corona is called "coronal injection." The approximate temperature of the corona is $10^6$ K. The energetic particles from the outer portion of the Sun can move out into interplanetary space, such as the particles in magnetic storms, which can disrupt radio transmissions and power systems on the Earth.

From a morphological point of view, flares have been subdivided into three groups (Pallavicini, Serio, and Vaiana 1977):

1. Flares characterized by a compact loop structure. The length of the loops ranges from $\sim 15''$ up to $\sim 1'$. The maximum observed vertical extent is less than $\sim 10,000$ km. The decay phases of such flares have a short duration ($< 10$ minutes).

2. Flares characterized by point like events. The lengths of the flares are mostly of the order of $10''$ or less, and they are approximately circular in shape. The maximum observed vertical extent is less than $\sim 6500$ km. The decays of such flares have a short duration.

3. Flares characterized by the presence of high, large, diffuse systems of loops. Generally these flares appear brighter at the top. The height of the loops range from 35,000 up to 75,000 km. The decays of such flares have a long duration ($> 3$ hours).

From a comparison of the spatial structure with physical parameters, these have been reclassified into two groups:

1. Impulsive flares, which include both point like flares and compact- loop flares. The energy release from the corona of the Sun is downward. Sometimes impulsive flares are called "short duration flares."

2. Gradual flares, which are flares characterized by the presence of high, large, diffuse systems of loops. The energy release from the corona of the Sun is upward. Gradual flares maybe also be called "long duration flares."

We want to study the results of fitting a gradual flare and an impulsive flare from the data from the U. of Chicago instrument on the *ISEE-3/ICE* spacecraft. The data from the *ISEE-3/ICE* spacecraft includes many flares, so we should select the interesting flares to test this fitting. The impulsive flare selected has a short X-ray duration ($<$ 1 hour) and the gradual flare has a long X-ray duration. Both flares selected do not display influence from a shock near the Earth and should be on the western hemisphere of the Sun, as viewed from the Earth. When we selected two interesting flares, we used the wind program for simulating them to study the injection profile of cosmic ray particles from the Sun. We selected the impulsive flare of 1982 January 2 and the gradual flare of 1981 July 20.

The data from the U. of Chicago experiment on board the *ISEE-3/ICE* spacecraft have two types:

1. Pulse height (PH) data are the data obtained for a limited number of particles. There are limited statistics because the data are so few, so the pulse height data yield inaccurate estimates of the anisotropy, but we can use them to fit the intensity data following the range of energy for consistency checks.

2. Proton rate (PR) data are the counted data from 8 directional sectors in the equatorial plane as the spacecraft rotates in the ecliptic plane. These data

have a lot of particles, so they are better data for our analysis than PH data.

## Fitting Method

The author used the wind program for fitting these flares. For this simulation we used

f_arc.c version for field.c,

ini_lowz.c version for initial.c,

p_3d_av.c version for printout.c and

s_abs.c version for stream.c.

We wanted to develop a fitting technique for finding the duration of the injection of cosmic ray particles from the data from the spacecraft. The data are the cosmic ray intensity and anisotropy near Earth versus time, and what is desired is the injection of particles from the Sun into the interplanetary medium as a function of time.

The results from the wind program are the particle distributions for various $\lambda$ that result from a delta-function injection. We thus know the response function for injection near the Sun at a single instant in time. The injection function versus time near the Sun is modeled as a piecewise linear function, i.e., as a sum of triangular functions. Ruffolo developed a program, makeff, to convolute the simulation results with a triangular function to calculate the response function due to a triangular injection function. The user must input the set of time values for the triangular injection, which starts from no injection at the start time, rising linearly to a peak injection of 1 at the peak time, and declining linearly to 0 at the end time. This peak time is the start time of the next function, and the end time becomes the peak time of the next function. A linear combination of these triangular functions is then a piecewise linear function. We used the output of the wind program, representing the response to the delta-function in-

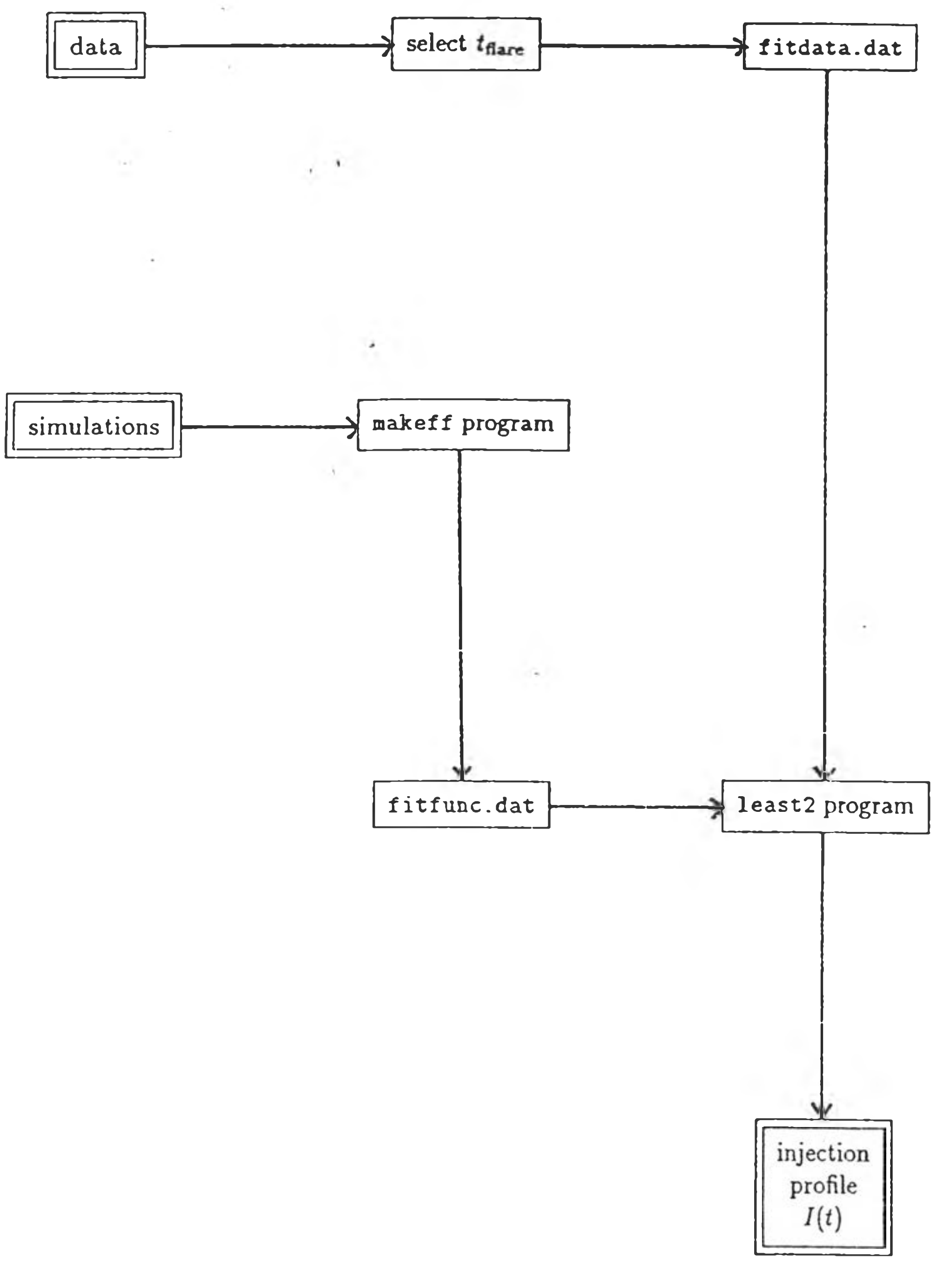


Figure 6.1: Flow chart of the fitting method for determining the injection profile for flares.

jection, convoluted with each triangular injection function, to produce the fitting functions for the least squares program. This program fits the data with a linear combination of the fitting functions to find the coefficient of each function and their uncertainies, $\sigma_i$. These coefficients represent the injection of cosmic rays at each peak time, so finally we get the best piecewise linear injection for this set of start-peak-end times.

### Case of a Gradual Flare

A flow chart of the fitting procedure is shown in Figure 6.1. Figure 6.2 shows the distribution of particles detected by the *ISEE-3/ICE* spacecraft following the time (UT) of the gradual flare of 1981 July 20 at $25°S$ $75°W$ on the Sun. We choose the time 1322 UT as the nominal start time of this flare, and the detection time for each particle from this flare is as follows:

$$\text{time (sec of July 20)} = 43.511 + (\text{frame} - 1246863) \times 0.499774. \tag{6.1}$$

where the "frame" is an interger stored along with each particle event on the data tape. Because the particles in this study are protons with energies from 27 to 147 MeV, we consider data in 5 ranges of energy in the select.c file. The data in the select.c file must be compared with PH data, and then we get the file fitdata.dat. The results from the simulation program "wind" for the various $\lambda$ and $q$ are used in the program "makeff." Makeff convolutes the Green's function with triangular injection profiles. Three input values from the user are the start, peak, and end times. The output of the makeff program is fitfunc.dat, including the amount of particles and the error in that amount. We use fitfunc.dat and fitdata.dat as input files for running the least2 program, which performs least squares fits to the data, finding the best linear combination of the fitting functions in fitfunc.dat

From fitting for the gradual flare, we find that among $\lambda$ values of 0.4, 0.6, 0.8 the most appropriate $\lambda$ is 0.6 AU for fitting the data from the flare of

1981 July 20. From Figure 6.3, we find that around 1400 UT the injection of particles started rapidly and then slowly decayed. The width is approximately the duration of emission of particles from the Sun (Figure 6.4) over a range of time from 1400 UT to 1930 UT. We found that the time of injection of particles onto the local magnetic field line takes about 5.5 hours. This long duration may be related to the long-duration X-ray emission from this flare.

### Case of an Impulsive Flare

We chose the flare on 2 January 1982 at 18°N 88°W for studying an impulsive flare. Protons were detected from this flare as shown in Figure 6.5. We found that there were many data gaps during this time. The analysis of this flare cannot employ the original version of the wind program because it analyzes the data in terms of distance traveled ($s$). The wind program was modified (to use time as the independent variable) for this flare, and it analyzes the data in terms of each time because the data gaps occur at specific times.

The various files of the wind program also had to be corrected, such as wind.c, etc. The steps of fitting this flare followed Figure 6.1. The detection time of each particle from this flare is as follows:

$$\text{time (sec of January 2)} = 41.225 + (\text{frame} - 3868544) \times 0.499774. \qquad (6.2)$$

The results of fitting the impulsive flare show that among $\lambda = 0.6$, 0.7, 0.8 the most appropriate $\lambda$ is 0.8 AU (Figure 6.5). This figure shows a fit to the data for the flare of 1982 January 2. This flare has a start time at around 0630 UT.

The profile of the injection of this flare is nearly same as for the gradual flare of 1981 July 20, but with the difference that the impulsive flare has a narrow pulse of injection of particles. The pulse of this injection started at 0630 UT and

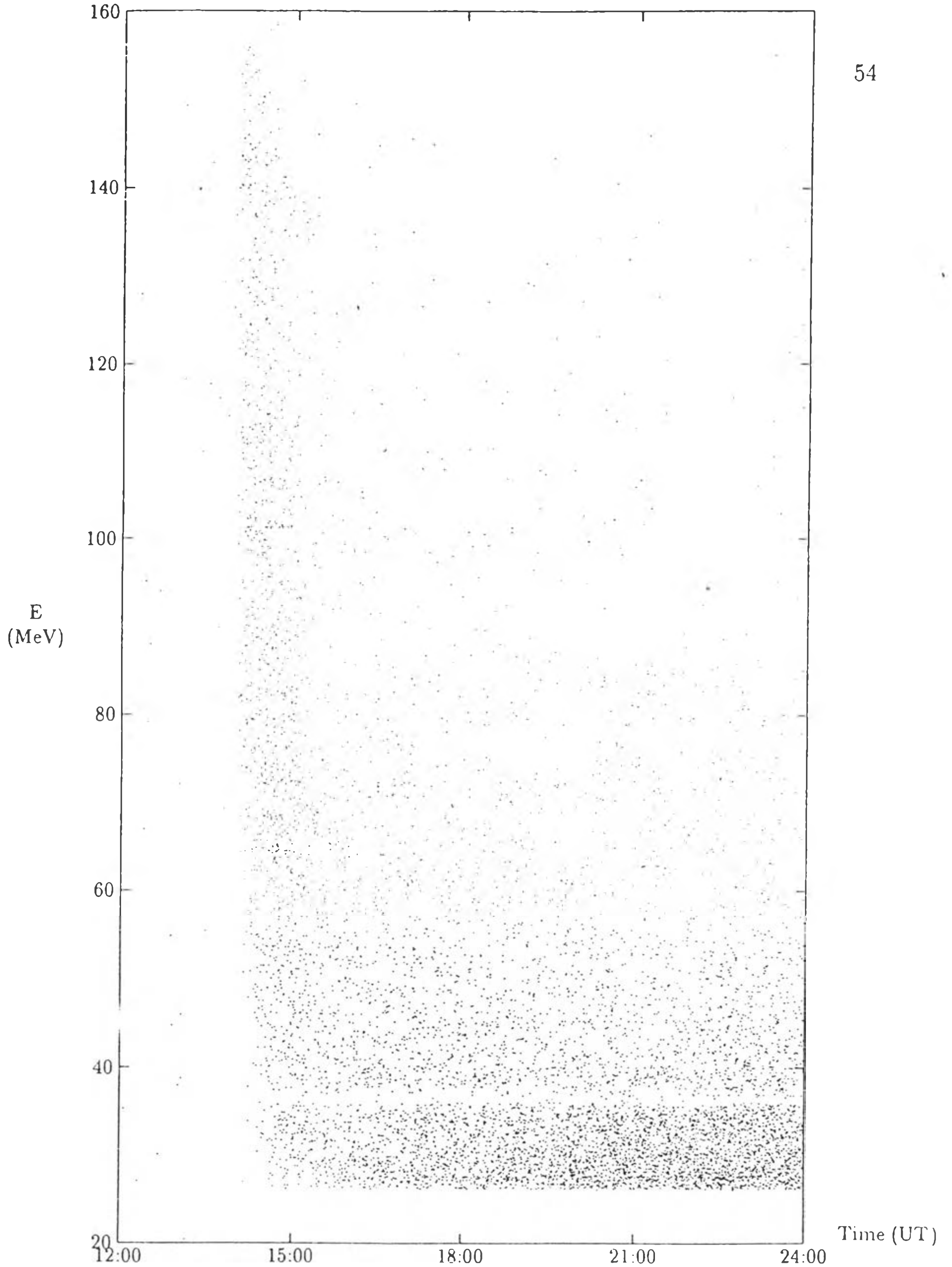


Figure 6.2: Protons detected on 1981 July 20 versus time

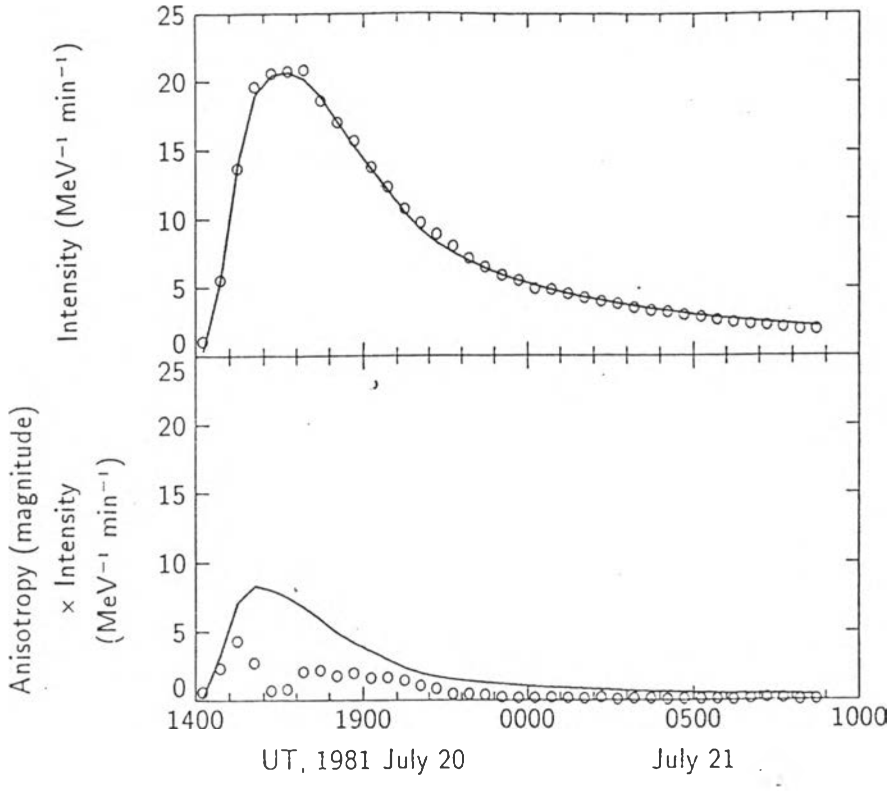


Figure 6.3: Fits to the observed intensity and anisotropy× intensity vs. time for the flare of 1981 July 20.

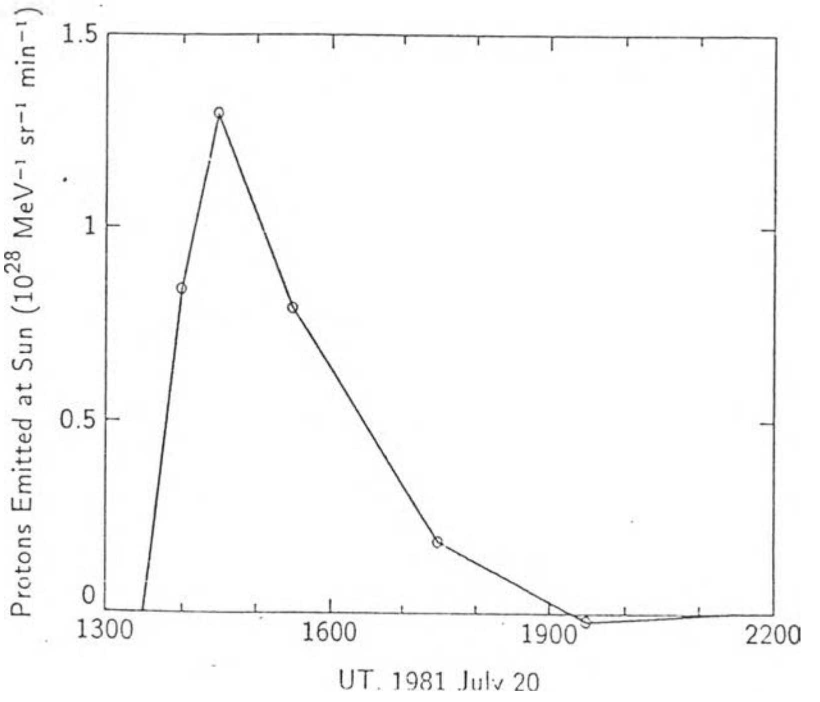


Figure 6.4: Profile of injection for the gradual flare of 1981 July 20 for $\lambda$=0.6.

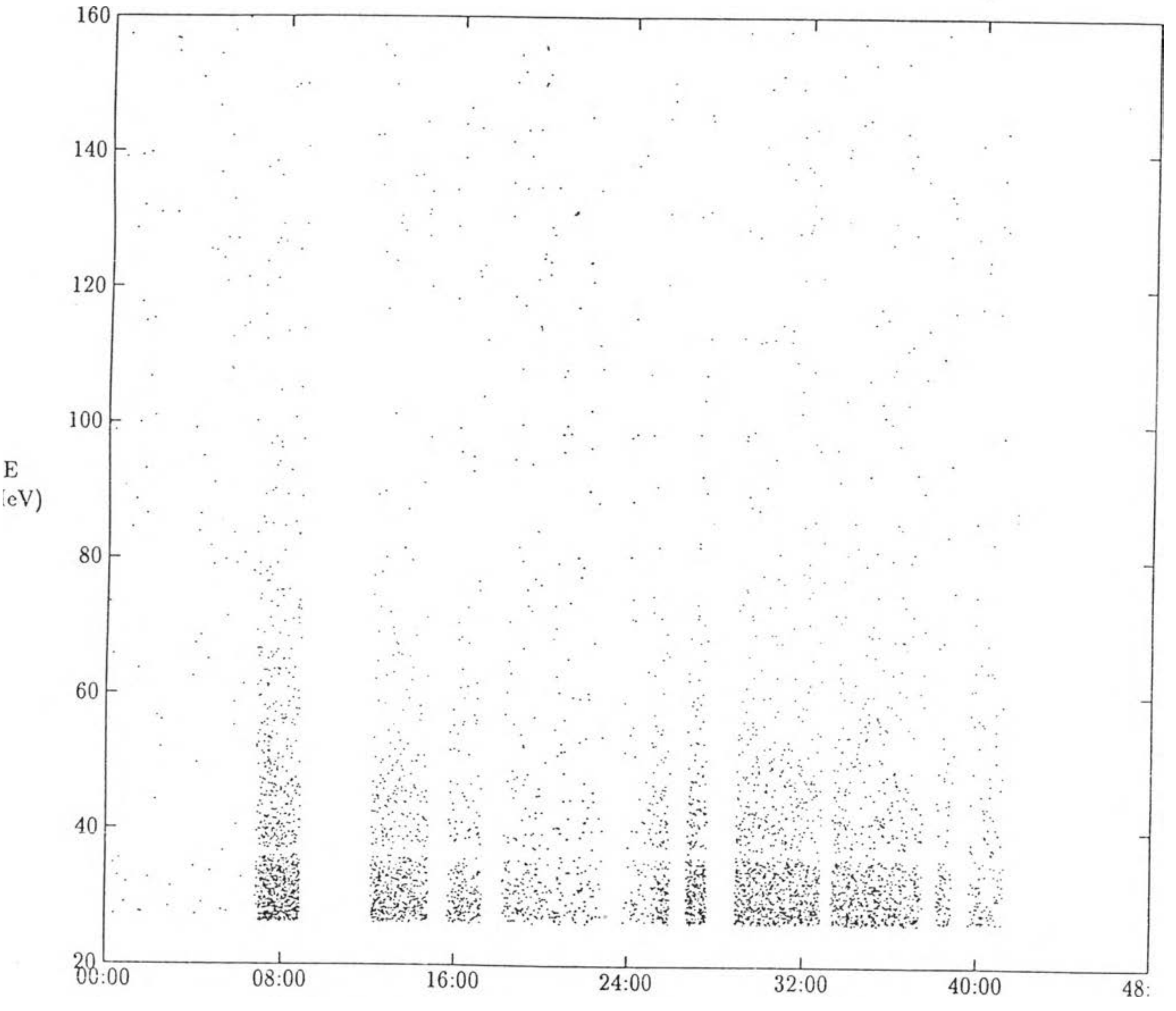


Figure 6.4: Protons detected on 1982 January 2 versus time.

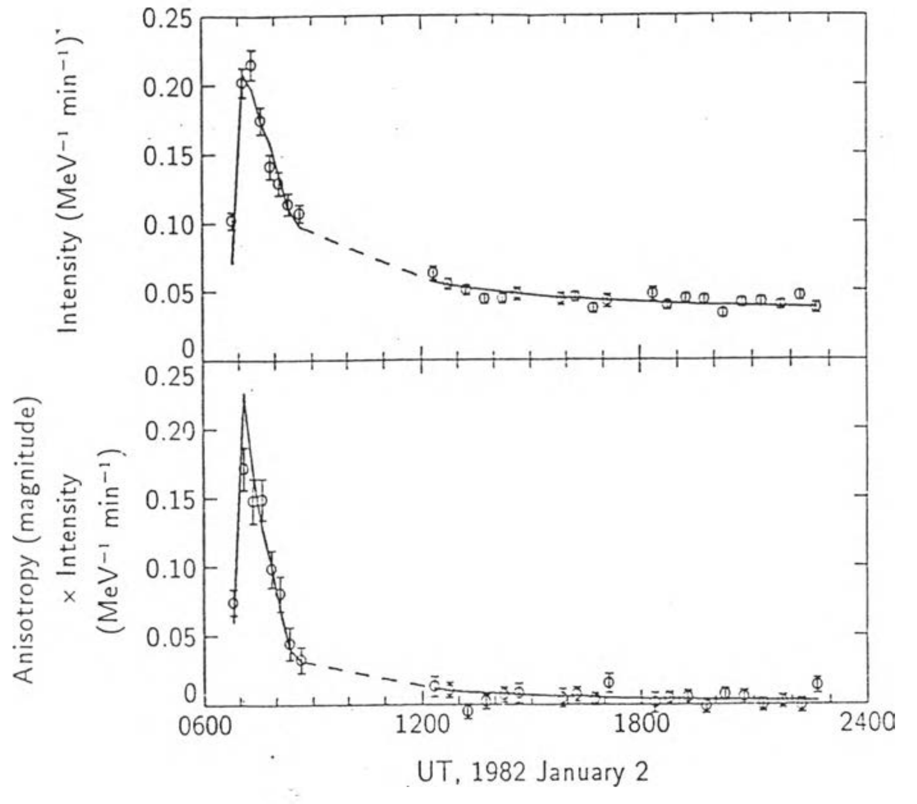


Figure 6.6: Fits to the observed intensity and anisotropy× intensity vs. time for the flare of 1982 January 2.

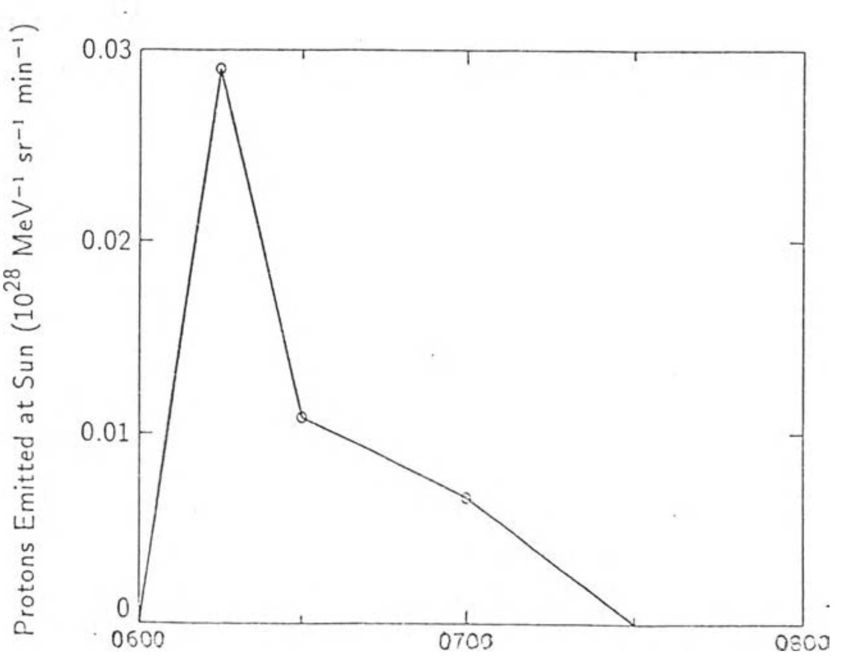


Figure 6.7: Profile of injection for the impulsive flare of 1982 January 2 for $\lambda = 0.8$.

ended at 0800 UT. The duration of emission of particles from the Sun is only about 1.5 hours, which may be related to its short-duration X-ray emission.

## Comparison between Results for the Gradual and Impulsive Flares.

The durations of injection of particles (protons) from the Sun of the gradual and impulsive flares are different. The impulsive flare has a short duration of injection ($< 2$ hours) but the gradual flare has a long duration of injection ($> 5$ hours). The duration of injection of flares may be related to the X-ray emission: if it is a gradual flare then it has a long X-ray duration, but if it is an impulsive flare then it has a short X-ray duration.

For the gradual flare we selected the anisotropy is generally lower than predicted based on a fit to the intensity. The anisotropy vector closely follows the magnetic field direction. Magnetic structures that flow past the spacecraft along with the solar wind arrive at different times, and at 1600-1700 UT the magnetude of the field dropped particularly sharply. We propose that the strong focusing in the varying magnetic field may have partially canceled out the strong diffusion anisotropy, especially during 1600-1700 UT. For the impulsive flare, the magnitude of the magnetic field is constant. This allows us to obtain good fits to both the intensity and intensity $\times$ anisotropy versus time.