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THE SOLAR PARTICLE EVENTS OF MAY 23 AND MAY 28, 1967

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ABSTRACT

McMath plage region 8818 passed over the visible solar disk on May 17-31, 1967. Although it was very active from its first appearance on the eastern limb, several times producing bright optical and X-ray emission accompanied by intense type II, type IV and centimeter radio bursts, no solar particles could be detected near the earth until the evening of May 23, when three bright flares were observed in close succession at 25°-28°E. During the following build-up of the solar particle flux over ~ 36 hours, the galactic cosmic ray flux >1 BeV decreased gradually by about 5%. The flux of solar particles decreased in two steps on May 25, both accompanied by decreases in the equatorial geomagnetic field. These field depressions are attributed to storm plasma ejected from the parent flare of the May 23 particle event.

A later particle event early on May 28 was also associated with a bright flare in McMath region 8818, at 33°W. This event displayed a rapid build-up, with electrons arriving first, and an exponential decay. A smooth proton peak, 20 minutes wide, was detected on May 30 closely associated with an SSC attributed to plasma ejection from the parent flare of the May 28 event.

Between the geomagnetic storms beginning on May 25 and May 30 an anomalous daily variation was observed in the cosmic ray flux >1 BeV, the time of maximum falling 7-10 hours earlier than normal. Storm time increases in the flux of galactic cosmic rays were seen on May 26 when the equatorial geomagnetic field was depressed by more than 400 gammas. Low latitude auroras were also observed during that time.

INTRODUCTION

Many phenomena observed at the earth or on space probes in the near interplanetary space can be traced back to an impulsive release of energy in some part of the solar atmosphere. Several of these phenomena display in one way or the other a strong dependence on the heliographic position of the center of the triggering solar activity.

In a statistical study of a great many geomagnetic storms, Akasofu and Yoshida (1967) were able to show that the fast plasma, which is ejected from the sun at times of enhanced activity and subsequently causes geomagnetic storms, is confined largely to a rather narrow jet, the main phase decrease of geomagnetic storms being roughly proportional to $\mathrm{sech}^2\,\Omega$, where Ω is the angular distance between the point of plasma ejection and the subterrestrial point on the sun. On the other hand, the same authors have also pointed out that certain effects of the enhanced plasma flow extend over a very large solid angle since storm sudden commencements can be observed even when the associated flares are located near the eastern or western limb of the solar disk. In such cases the sudden commencements are observed to be comparatively weak.

If the probability of observing a strong sudden commencement followed by a severe magnetic storm is high for flares near the center of the solar disk many other phenomena occur preferentially after eastern, or sometimes central, flares. In contrast to flares far over to the west, such flares produce prominent Forbush decreases (Sinno, 1962; Haurwitz et al., 1965) and cosmic ray decreases of long duration (Sinno, 1962). Strong polar cap absorption of the type associated with storm sudden commencements also belongs to this category of events. The latter observation is due to Haurwitz et al. (1965) who proposed an asymmetric plasma cloud model to explain their observations. Lindgren (1968) has suggested that the reversal of the streaming direction of cosmic rays >1 BeV which has been observed in a few cases, almost exclusively in connection with Forbush decreases, is related to the ejection of storm plasma from flares well over to the east.

In contrast to severe geomagnetic storms and large Forbush decreases, most energetic solar particle events have their parent flares in the western solar hemisphere. Studies of the propagation of such particles from the sun to detectors at or near the earth have shown that these particles are guided away from the source or storage region along the interplanetary magnetic field lines, particles from $\sim 60^{\circ}$W being easiest to observe at the earth (McCracken, 1962; Lin and Anderson, 1967; McCracken et al. 1967). During simultaneous measurements at the earth and on Mariner IV (O'Gallagher and Simpson, 1966) a particle event was detected on IMP-3 close to the earth which could not be observed on Mariner IV, at that time 40° further to the east. The parent flare was seen at $\sim 75^{\circ}$W.

The purpose of the present paper is to describe two solar particle events which began on May 23 and May 28, 1967, and related solar and terrestrial phenomena. The two May events and some of the associated phenomena offer several possibilities to study some of the east-west effects summarized above and also effects arising from interactions between diffusing energetic solar particles and advancing plasma fronts. In the discussion of these effects, we use information from several other solar particle events in order to give a broader background for conclusions.

OPTICAL FLARES, RADIO BURSTS AND GEOMAGNETIC DISTURBANCES

The particle events starting on May 23 and May 28, 1967 exhibit rather different characteristics. In particular the build-up and decay characteristics (Figure 1) are quite different. Both events were associated with optical flares in McMath plage region 8818, the former event apparently being caused by a flare, or possibly several flares, at 25^{o}-28^{o}E, the latter by a flare at 33^{o}W.

To better understand the differences between these two particle events we describe in detail the solar activity and also the magnetic storms and cosmic ray effects at energies >1 BeV observed at the earth. Since the solar activity was concentrated in McMath region 8818 during the second half of May, 1967 we first describe the development of that region. The main sources of information for this purpose are the monthly reports compiled by Aeronomy and Space Data Services, Boulder, Colorado.

McMath plage region 8818 was first observed on May 17. It was identified as the first return of region 8785. That region produced 49 subflares but only six other flares, all of importance 1. Region 8818 was very active from the time of its appearance on the eastern limb. The first flare was observed near the eastern limb on May 17. When region 8818 disappeared on May 31 it had produced 176 subflares and 76 flares of importance ≥1. Table 1 shows how these flares were distributed in time, magnitude, and brightness. It also gives the corresponding distributions for region 8785, from April 22 through May 3, and for the whole visible disk except regions 8785 and 8818 over the periods of time that these two regions were observed. During the two weeks that no less than 21 bright flares of importance 1-3 were born in region 8818, the rest of the visible disk had no such flares at all. Most of the faint flares on the other hand, in particular most of the faint subflares, were observed outside region 8818. The high flare activity in region 8818 after the first appearance on the eastern limb makes it reasonable to assume that this region was active also while behind the visible disk.

Region 8818 returned as region 8854 on June 14 but was not particularly active as it then passed over the visible solar disk. It formed parts of three different regions during the following passage, in the second half of July.

Flares observed in region 8818 and classified as 2B or 3B by at least one observatory are listed in Table 2 together with a few other flares associated with type II or type IV radio bursts. The May 21 flare and the second flare listed on May 23 were visible in white light (Carrigan and Oliver, 1967) which is a very remarkable characteristic. The double grouping of the following flare on May 23 as well as the brightest flare on May 28 is due to reports of double intensity maxima from Houston and Siberie respectively.

The X-ray intensities listed in the last column of Table 2 were observed with Geiger tubes on AIMP-1 (Van Allen and Ness, 1967).

The type II-type IV combination of radio emission is considered to be of great significance for the production of geomagnetic storms (Kundu, 1962). In Table 3a we have listed available data on type II and type IV bursts. The intensities given for these bursts range from 1 to 3. Each number covers a range of flux densities, the upper limit representing a flux density about four times that of the lower limit.

Thus, intensity 2 refers to flux densities between 20 and 80 flux units, 1 flux unit being 10^{-22} Wm^{-2} Hz^{-1}. The burst data are summarized in Figure 1. We find the combination of radio bursts which is highly correlated with production of storm plasma, on May 19, 20, 21 and 23.

In Table 4 we have listed all storm sudden commencements given in the Boulder reports for the actual period of time. They have also been marked in Figure 1. The flare associations which we find to be the most likely ones have been indicated by full lines. Broken lines indicate more doubtful associations. The third and fifth associations are rather obvious. They attribute the largest two magnetic storms to the flares which, as we shall see later, definitely produced energetic solar particles (MeV protons). The magnetic storm starting at 1235 on May 25 was severe, the H component varying over a range of 633 gammas at Trivandrum and over 737 gammas at Huancayo. Both these stations are very close to the geomagnetic equator. Auroras were observed as far south as 32°N on May 25 (Castelli, et al. 1967)

Magnetic storms of this magnitude tend to be associated with storm time increases (Lindgren and Pak, 1967) in the flux of cosmic rays observed at the surface of the earth at geomagnetic threshold rigidities of 2-10 BV. As a preliminary study we have examined the neutron monitor data from Prague, which station has a threshold rigidity of 4.0 BV and therefore is very sensitive to threshold variations. Between 2000 and 2200 UT on May 25 the count rate of the Prague monitor reaches a minimum close to 96% of the May 23 average rate. However, the count rate falls to a much deeper minimum, below 92%, early on May 27. Between these two minima the count rate is near the 99% level from 0200 to 1000 UT on May 26, during which time the H component of the geomagnetic field reaches its minimum (Figure 6). This intensity-time profile of the Prague monitor is very different from that observed at threshold rigidities ≤ 1 BV. It definitely proves that prominent storm time increases did occur on May 26. These increases and the low latitude auroral observations mentioned earlier can both be explained in terms of a distorted geomagnetic field with lower geomagnetic threshold rigidities than normal. No magnetic disturbance has been found which can be traced back to the intense type II-type IV emission on May 19. This is probably a consequence of the fact that the energy flux of solar plasma bursts is concentrated to a relatively narrow jet (Akasofu and Yoshida, 1967).

A very intense type IV burst took place on May 25. Fluxes $> 10^{-17}$ W m^{-2} Hz^{-1} were observed on the meter band 1226-1315 UT (Krüger, 1968). The burst began ~ 1045 UT. Two optical flares displayed maximum brightness within 45 minutes after the onset of the radio burst well before a rapid build-up of the radio flux ~ 1220 UT. Since both flares were close to central meridian one would expect to find a magnetic storm to associate with the intense radio emission. The storm preceded by an SSC at 1303 UT on May 28 is the only candidate, implying a delay of almost exactly three days relative to the start of the intense radio emission. This is a long delay compared to those of the magnetic storms beginning on May 25 and May 30. There was also a long delay between the optical maxima, tentatively associated with the type IV burst on May 25, and the radiowave maximum. With the latter maximum observed at ~1225 UT we find a delay of 55 minutes relative to the closest of the preceding flares. No break in the continuous observation of the sun is reported during this time. The type II burst early on May 26 was weak (Table 3a) and not accompanied by any type IV emission.

Table 4 shows that two sudden commencements were observed on May 25, separated in time by about two hours. We have attributed them to the second and third flares in a group of three flares seen on May 23 (Table 2). Both these flares were associated with great microwave bursts (Table 3b). The observation of two successive sudden commencements on May 25 has its counterpart in the observation of two separate decreases in the flux of solar particles on the same day. This observation will be described in more detail later in this paper.

A phenomenon which usually accompanies the generation of high energy particles at the sun is the occurrence of intense centimeter wave outbursts over the whole wavelength range from 3 to 30 cm (Kundu and Haddock, 1960). We have summarized this kind of burst activity in Table 3b. The times of maximum all coincide with observations of bright flares in McMath region 8818. Disregarding the 606 MHz column we can see how the peak fluxes rise monotonically from May 19 to May 23. From May 21 the peak fluxes are large enough for the bursts to be classified as great bursts. The second burst on May 23, was one of the largest ever recorded (Castelli, et al. 1967). It was observed and extremely intense even on millimeter waves (35 GHz).

The three flares on May 28 listed in Table 2 occurred at a time of the day when all American stations were within the earth's shadow. Radio data received from Europe show that the microwave bursts associated with the first of these flares were far above the requirements for great bursts.

VARIATIONS IN THE FLUX OF COSMIC RAYS >1 BeV

The passage past the earth of fast solar plasma often causes some kind of modulation even of the cosmic ray flux observable at the surface of the earth, i.e., representing kinetic energies >1 BeV. Intense geomagnetic storms are usually associated with abrupt Forbush decreases and more moderate changes in the geomagnetic activity are often accompanied by slowly developing depressions in the cosmic ray density. Severe geomagnetic storms tend to produce storm time increases at middle and low latitudes, as already discussed in the preceding section.

During the period containing the May particle events, the following observations can be made. The cosmic ray flux begins to decrease slowly early on May 24 (Figure 2). This gradual decrease is accompanied by a slowly increasing solar particle flux (Figure 1). The first of the sudden commencements marked in Figure 1 is not included in the final Boulder report (Table 4). Nevertheless the flux of galactic cosmic rays is subject to a slight modulation from that time on. This can be seen more clearly in the intensity-time profile of Alert (see Solar-Geophysical Data, IER-FB-275, July 1967) which station is looking far off the ecliptic plane and therefore does not observe much of a daily variation. The rate of decrease becomes steeper in the evening of May 24, after the second of the sudden commencements marked in Figure 1. The flux of solar particles begins to build up more rapidly at the same time. Around 2000 UT on May 25, i.e., well after the two sudden commencements reported on that day, the slow decrease in the flux of galactic cosmic rays is followed by a sudden drop amounting to ~5% over about two hours. The total decrease over two days approaches 10%. The magnetic storm on May 30 is accompanied by a cosmic ray decrease of about 3%. The flare at 33°W on May 28 thus did not affect the cosmic ray flux in the neighborhood of the earth nearly as much as the eastern flares on May 23. It is, however, an open question whether this difference is an east-west effect. There are at least two additional facts which should be considered: a difference between the energy densities of the two populations of storm plasma and the fact that the cosmic ray intensity level was already ~4% below the level on May 23, when the second decrease began.

By the time the first decrease is fully developed the earth has entered a huge region populated by storm plasma repeatedly ejected from McMath region 8818 over several days, possibly more than a week. During the next few days measurements of the galactic cosmic ray flux performed at the surface of the earth tell us something very interesting about the gross streaming properties of the cosmic ray gas. Under normal conditions there is an anisotropic flow of cosmic rays past the earth from the 1800 hour direction, i.e., the cosmic ray gas appears to corotate with the sun and with the interplanetary magnetic field. Due to the rotation of the earth this streaming generates a daily variation when the cosmic ray flux is observed at the surface of the earth. The direction can vary greatly from one day to the next but is usually contained within the sector 1500-2100 hours. In rare cases, usually in connection with Forbush decreases, the streaming direction is reversed (Lindgren and Fak, 1967; Lindgren, 1968). The most extensive period of that kind that we have so far observed occurred on May 25-31, between the largest two magnetic storms during that period of time.

The two upper curves in Figure 2 show normalised bihourly counting rates of the neutron supermonitors at Deep River, Canada and Oulu, Finland. Arrows indicate where the diurnal maxima would normally fall, and do fall near both ends of the period considered. Since Deep River and Oulu are expected to show the same response to variations in the cosmic ray density a simple subtraction procedure should reasonably leave only variations due to the rotation of the earth in a streaming cosmic ray gas. The two stations should exhibit the same diurnal amplitudes but a phase difference of 7 hours. Arrows above the difference curve at the bottom of Figure 2 indicate the normally expected times of maximum. Again we find normal conditions near both ends of the period. On May 25 the observed time of maximum falls 7-8 hours earlier, on May 27 and May 30, 9-10 hours earlier. The streaming direction is thus not completely reversed but shifted to a sector between the solar and morning directions. During this period of anomalous daily variation the peak to peak amplitude varies between 1.2 and 2.5% which has to be compared with a normal value of $\sim 0.8\%$.

On May 28 and 29 both Deep River and Oulu show secondary maxima 2-3 hours after the expected times of maximum of the diurnal wave. This indicates the existence of a bidirectional anisotropy. At Deep River the secondary maxima fall ~ 12 hours after the primary maxima, at Oulu the time difference is only 9-10 hours.

OBSERVATIONS OF SOLAR PARTICLE FLUXES

The particle observations reported here were made by the University of California group with ion chambers and Geiger counters aboard two different satellites, AIMP-1 (also called IMP-D or Explorer 33) and IMP-4 (or IMP-F).

AIMP-1 was launched on July 1, 1966 into a highly eccentric orbit. The data presented in this section were obtained as the satellite moved outward towards and back from an apogee which was reached late on May 25 at an ecliptic longitude (counted anti-clockwise as seen from the north ecliptic pole) of $\sim 220^{\circ}$ and a geocentric distance of ~ 65 R_e (Figure 3). Only a Neher type integrating ion chamber with an energy threshold of 12 MeV for protons and 700 KeV for electrons was working during the May events. The ion chamber is mounted on top of the spacecraft which is oriented with its spin axis just a few degrees off the ecliptic plane. On May 30, 1967 the spin axis was pointing $\sim 160^{\circ}$ east of the sun.

IMP-4 was launched late on May 24, 1967. It reached apogee the first time ~1800 UT on May 26 at 34.1 R_e and an ecliptic longitude of 104°. The spin axis is perpendicular to the ecliptic plane. The satellite package carries an ion chamber which is practically identical to that on AIMP-1 and two Geiger tubes. These counters observe particle fluxes parallel to the spin axis. One of them, the scatter counter, observes essentially only electrons > 45 KeV, scattered from a gold foil. The other Geiger tube, the open counter, has a very thin mica window which admits protons > 300 KeV and electrons > 22 KeV. Besides, both counters have an omnidirectional sensitivity to penetrating particles, more specifically protons > 50 MeV and electrons > 2.5 MeV. A more detailed description of these detectors can be found in a recent dissertation (Lin, 1967). Energy thresholds and geometry factors are summarized in Table 5.

From the launch data given above it can be seen that only ion chamber data from AIMP-1 are available up to ~1500 UT on May 24. Those data, due to protons >12 MeV and electrons > 700 KeV, do not show any solar particle fluxes until the evening of May 23. This statement covers all the time back to the first appearance of McMath region 8818 on May 17. A recent check of proton data from scintillation detectors on OGO-3 allows us to push the energy thresholds above which no solar particles were observed on May 17-22, down to 4 MeV.

The ionization rate begins to go up late on May 23 (Figure 4). At first the increase is very slow, so slow that it is difficult to tell when the rise starts. We would say around 2000 UT. The build-up goes on over a very long time. If we think in terms of factors or logarithmic fluxes rather than linear fluxes the most rapid rise takes place in the first three hours of May 24, the increase during that period of time being ten-fold. Maximum ionization rate is reached 0800-1300 UT on May 25 during which time the ionization level stays rather constant. Thus, it takes about 36 hours for the particle flux to build up to its maximum value. The decay is anything but exponential. It occurs in steps, the first step down being taken 1300-1500 UT on May 25, a second step a few hours later, 2000-2200 UT. After that the decay becomes more like an exponential decay but still with a considerable structure in it, i.e., with the flux going up and down in an irregular way relative to a fitted exponential curve.

The May 28 event (Figure 5) is very different from the May 23 event. Again looking at the AIMP-1 ion chamber, we find a well-defined onset, at 0608 UT on May 28, and already 80 minutes later the flux is very close to its maximum value. The decay is smooth and well described by an exponential curve over no less than three days, with a decay constant of 15 hours. Time profiles in good agreement with the picture sketched above were observed by Masley and Goedeke (1967) with high latitude riometers operating at 30 MHz.

Let us now consider in more detail where the particles constituting the May 23 event are found in time relative to the series of storm sudden commencements observed at the earth. For the sake of convenience we normalize the AIMP-1 ion chamber pulse rate by putting the maximum rate equal to 100 units. As we have pointed out earlier, the onset is gradual. Still 23 hours after the onset the ionization rate is only 18 units (Figure 1). About 90 minutes after the SSC at 1726 UT on May 24 the rise becomes considerably steeper. Whereas it takes 23 hours for the ionization rate to build up to 18 units above background it takes only 13 hours to go from 18 to 100 units. Already 20 minutes after the SSC at 1235 UT on May 25 the ionization rate begins to drop. The rate drops from 100 units to 35-40 units in two hours, the steepest slope being confined to the first 20 minutes. The second drop, by ~ 25 units between 2000 and 2200 UT on May 25, coincides well in time with a 5% decrease in the cosmic ray flux > 1 BeV. It should be noted here that the first of the flux decreases on May 25 appears more important if we think in terms of number of pulses or counts (Figure 1) but that the reverse is true if we express the decreases in per cent of the pre-decrease levels (Figure 4). It might be more appropriate to focus the attention on fractional or percentage changes when the efficiencies of two modulating mechanisms are to be compared.

The flux versus time data given above add up to the following picture. The energetic solar particles produced at the sun late on May 23 are not to any considerable degree trapped by the solar magnetic fields dragged out by the storm plasma from the same flare, or flares. On the other hand, our data seem to indicate that a plasma cloud from an earlier flare in the same plage region acts as an obstacle to the solar particles. This obstacle might well consist of a strong radial magnetic field close to the sun. The more or less abrupt changes observed in the particle flux do not coincide with observed storm sudden commencements but come later in time. The time lag between a sudden commencement and the observation of a change in the particle density gradient varies from one plasma event to the other and is evidently also, at least in certain events, dependent on particle energy and type. Thus, Lin and Anderson (1967) have described a delayed event, starting on August 29, 1966 (Figure 12) in which the confinement of electrons is remarkably different from the confinement of protons.

The two stepwise decreases in the ionization rate on May 25 are in fact both closely associated with decreases in the horizontal component of the equatorial geomagnetic field (Figure 6). The flux of 6-8 MeV protons observed by Anderson and Kahler (private communication) on OGO-3 shows an even better agreement. It is somewhat obscure how the complicated structure of the magnetic storm should be interpreted. The Guam magnetogram in particular gives an impression of two superimposed magnetic storms.

During the time for which data are available the ion chamber on IMP-4 tracks the AIMP-1 chamber very closely which is to be expected since they are identical in design. We have made use of this fact in Figures 1 and 4 to fill some gaps in the AIMP-1 data.

The two Geiger counters respond in very much the same way as the ion chambers to the solar particle flux. When as in the May 23 event, penetrating particles are present, i.e., particles which are energetic enough to penetrate the walls of the Geiger counters, it is not possible to make any definite statements about the relative contributions of protons and electrons. The scatter counter can only be used to supply an upper limit to the flux of penetrating particles. At 1200 UT on May 25 the upper limit is 730 cm^{-2} sec^{-1} for protons > 50 MeV. This upper limit is identical to the actual flux of penetrating protons if no electrons > 45 KeV are present. Furthermore, if no electrons > 22 KeV are present the open counter can be used to get the flux due to protons > 300 KeV. In this particular case we would get 9.1×10^5 cm^{-2} sec^{-1}.

In the May 28 event the four detectors on AIMP-1 and IMP-4 do not track each other very well, not even the two ion chambers (Figure 7). Thus, the ion chamber on IMP-4 displays a burst before the onset of the event in the Geiger counters. This burst lasts for ~30 minutes and reaches its maximum at 0542 UT, the ionization rate then being five times the pre-burst rate. It is interpreted as an X-ray burst since the optical flare associated with the May 28 particle event shows maximum brightness and sudden ionospheric disturbances are also observed at this time. The reason why this X-ray burst does not show up in the ion chamber on AIMP-1 is probably a matter of orientation, the ion chamber on top of AIMP-1 at this time being shielded from solar X-rays by the spacecraft. As described earlier in this section, the spin axis of AIMP-1 points a few degrees off the ecliptic plane, and on May 30 its direction was ~160° east of the sun.

The Geiger counters reach maximum counting rate ~30 minutes after the onset of the particle event, whereas it takes the ion chambers ~85 minutes. Our interpretation of this difference is that a considerable flux of electrons > 22 KeV is present at the spacecraft early in the event. The ion chambers can only see the tail of the energy distribution since they have an energy threshold of 700 KeV for electrons. The maximum counting rate of the open counter, 2300 counts sec^{-1}, equivalent to 10^5 particles cm^{-2} sec^{-1}, exceeds that of the scatter counter by a factor of 14. With only electrons > 45 KeV around the spacecraft during this phase of the particle event, this factor would have been 7. This fact combined with the observation that the two counters track each other very closely supports the view that electrons were present early in the event, down to energies below 45 KeV.

Looking at the onset in the open counter with a higher time resolution (Figure 8), we find that it has a complicated structure. After having reached a third of the maximum count rate, the flux stays at that level for 15 minutes before it climbs to the maximum level. Furthermore, there are two peaks superimposed on the intermediate plateau. It is not clear whether this structure reflects time variations in the electron source or if it is caused by the spacecraft being poorly connected magnetically with the interplanetary magnetic field carrying the electron flux away from the sun (Figure 3).

The ion chambers do not track each other very well during the first three hours after the main rise (Figure 7). As mentioned earlier, the two chambers are practically identical in design. It is obvious that IMP-4 for some reason sees only part of the flux that AIMP-1 observes during these three hours.

Figure 7 shows that the open counter observes very high fluxes just before 1300 UT on May 28. This part of the diagram is shown in detail in Figure 8. The first and largest peak lasts for a few minutes. The particle flux seen by the open counter rises from 5.5×10^4 cm^{-2} sec^{-1} to 6.8×10^5 cm^{-2} sec^{-1}. The scatter counter also records three peaks which coincide in time with those in the open counter and thus indicate that the high fluxes are due to electrons. The ratios between the two sets of peaks imply that the exponent of the integral energy spectrum is ~5 in the 20-50 KeV region. This is a softer spectrum than usually observed for terrestrial electrons. The position of the shock and magnetopause in Figure 3 is a time average which in no way is related to measurements during the actual period of time. IMP-4 happens to be near the indicated magnetopause at a magnetic latitude of $\sim 10^{\circ}$ when the electron peaks are observed. No further electron fluxes are observed until after 1700 UT when the geocentric distance is $< 11\ R_e$. The fluxes then observed have spectral exponents between 2 and 3 in the 20-50 KeV region.

A storm sudden commencement was observed at the earth at 1426 UT on May 30. We believe it was due to a shock wave propagating through the solar wind from the same flare as the solar particles observed from May 28 onward. The flux seen by the open counter on IMP-4 (Figure 5) decays exponentially with a decay constant of 19 hours until the middle of May 29 when the flux levels off to a fairly constant value at which it stays for 24 hours. Figure 9 shows that the flux increases to very high values at the time of the sudden commencement. This increase cannot be seen in Figure 5 since only smoothed counting rates at 1 hour intervals are indicated there and increases and decreases short compared to an hour have been neglected in the smoothing process.

Figure 10 gives 10 second averages of the particle peak. What appears to be the base level in Figure 10 is actually a plateau at ~ 800 counts/sec which is about an hour wide and twice as high as the basic intensity level of 400 counts/sec 1200-1700 UT. It is obvious from Figure 10 that the build-up from 1413 to 1428 UT is very smooth. The maximum count rate corresponds to a flux of 3.3×10^5 particles cm^{-2} sec^{-1} which is ~ 20 times the flux of 1.7×10^4 particles cm^{-2} sec^{-1} measured on either side of the plateau mentioned above. The time of maximum might well coincide with the arrival of the shock to the spacecraft which at that time is ~7 R_e beyond the earth's orbit. The particle intensity falls back to the base level in discrete steps. The scatter counter shows no flux increase at the time of this peak nor at the time of any of the other peaks in the open counter 1300-1800 UT. We may thus observe either protons or electrons with energies < 45 KeV simultaneously with the sudden commencement. We favor the former alternative because of the smooth shape and the response of the IMP-4 ion chamber. The different response of the AIMP-1 ion chamber may indicate that the proton flux is highly directional, moving in the antisolar direction. We thus seem to observe a region of increased proton density pushed outward in front of the shock and radially extending over about 10^6 km.

Two and a half hours later the particle flux seen by the open counter drops suddenly by 65%. The details of this drop can be seen in Figure 10. It occurs over ~7 minutes, 1709-1716 UT, and is preceded by a series of narrow flux peaks which we ascribe to electrons with energies ≤ 45 KeV. Three of them can be seen in Figure 10 (averaged into one single peak in Figure 9).

Figure 11 shows what might be a recurrent event, i.e., an increase in the particle flux originating in the same part of the solar atmosphere as the May 23 and May 28 events. The flux seems to consist of soft protons since neither the scatter counter nor the ion chamber on IMP-4 responds to it. The [illegible]up contains three rather sudden drops by at least 50%. The times have been indicated in Figure 11. It can be seen that one of the drops occurs close to a sudden commencement, observed at 1459 UT on June 26.

Looking at Figure 1 we find that six flares produced centimeter bursts. We call the first three of these group A. They produced no detectable energetic particles near the earth. The remaining three flares are called group B, the particle-producing flares. We calculate the position of these groups at the beginning of June 25 assuming a solar rotation period T of (a) 27 days, (b) 28 days, and no latitudinal changes. Table 6 shows the result. The particle-producing flares are found $\sim 15^{\circ}$ to the east and $\sim 4^{\circ}$ to the north of the group A flares. Although the two groups are thus well separated, the maximum spread within each group is $< 4^{\circ}$ in longitude and only 1° in latitude. It is obvious from Table 6 that whatever value we choose for the rotational period it is reasonable to associate the particle fluxes seen on June 25-27 to McMath region 8854, the return of region 8818. The data gap early on June 28 is due to a perigee pass. After that pass the particle flux is down at a normal level again.

COMPARISONS WITH OTHER PARTICLE OBSERVATIONS

A well-known solar particle event began on September 28, 1961 (Bryant, et al., 1962 and 1965). The associated flare was observed at 13° N, 29° E and was of importance 3. It was thus at approximately the same longitude as the parent flare or flares of the event starting on May 23, 1967. The September 28 flare was accompanied by an ordinary, prompt particle increase at the earth, even down at energies of a few MeV. The prompt event was followed two days later by a delayed event during which the maximum flux of 9-20 MeV protons exceeded the maximum flux during the prompt event. It is very likely that a prompt event could have been detected also on May 23, 1967 by a detector suitably located relative to the parent flare. We think that the magnetic field configuration close to a region where particles have just been accelerated is of decisive importance for the following propagation out into interplanetary space, the main reason of course being that the field is strongest close to the source. We find it reasonable to assume that a strong radial field dragged out by plasma ejected over several days before the burst of the white flare on May 23 prevented the energetic solar particles produced at that time to spread out in longitude to any appreciable degree. Only a small fraction succeeded to leak through that field and reach the neighborhood of the earth directly after the flare.

It has been observed before that solar particles can propagate azimuthally only with difficulty. Thus, for example, the Chicago group observed a particle event on August 16, 1965 from the earth orbiting satellite, IMP-3. The space probe Mariner 4 which was 40° further away in longitude from the associated flare saw no particle increase at that time (O'Gallagher and Simpson, 1966). Both spacecraft were observing >1 MeV protons.

A pair of particle events showing many simularities with the May 23-May 28 pair was observed on August 28 and September 2, 1966 (Figures 12 and 13). As in May, 1967 two major particle events separated by 4.5 days in time were due to activity in one particular plage region, an important difference being that in the August-September 1966 case this region was close to central meridian when the first of the two energy bursts took place.

The event of August 28, 1966 has been discussed by Lin and Anderson (1967). It was associated with a 2+ flare at 24° N, 4° E in McMath plage region 8459. A prompt particle event on August 28 was followed by a delayed event, most of the solar particles in the latter event being observed in between two geomagnetic storm sudden commencements. As on May 25, 1967 the delayed maximum was observed ~40 hours after the onset of the primary event.

McCracken, et al., (1967) attribute what we have here called a delayed event to a 2N flare at 22° N, 7° W starting at 0542 UT on August 29. Since the low energy detectors on IMP-3 (Figure 12) show that a gradual particle increase started already three hours before that flare we still believe in the delayed type of particles.

The particle event on September 2, 1966 has been described by McCracken, et al. (1967). It was associated with a flare of importance 3 at 22°N, 58°W in McMath region 8461 which region was adjacent to region 8459, flares sometimes being observed to spread over from one region into the other (CRPL-FB-265, September 1966). There are no indications of any delayed particles superimposed on the prompt event starting on September 2. Nor do we have any reason to suspect delayed particles in this case since the location of the associated flare allowed the accelerated particles to propagate easily from the source region to the detectors at the earth from the very beginning of the event.

The hump observed by the AIMP-1 ion chamber on September 8 is consistent with the data on protons > 7.5 MeV published by McCracken, et al. (1967). Their suggestion is that a recurrent modulation event is observed. However, their statement that the decaying proton flux fits the same exponential before and after the recurrent event does not agree with the detailed AIMP-1 data. If the exponential which fits best from 1800 UT on September 6 to 0600 UT on September 8 is extrapolated to later hours we find that the observed proton fluxes are only half as high for at least 12 hours after the recurrent event. It appears as if solar particles gather in front of a boundary which is difficult to penetrate.

Part of the increase seen by the open counter on IMP-3 on September 8 is due to electrons > 40 KeV. The electron event begins ~ 0935 UT, which means that the first point after the data gap should reflect the response of the open counter to the recurrent event. What was said about different exponentials before and after the September 8 event is qualitatively true also for the open counter. Quantitatively the effect appears to be more pronounced at lower energies, as might reasonably be expected.

We want to compare the particle fluxes measured on May 25, 1967 with those of earlier events during the present sunspot cycle. The most intense of the earlier events was that of September 2, 1966. Nine hours after the onset of that event the ion chamber on AIMP-1 reached 3.7 pulses/sec, which is 42% higher than the May 25 maximum of 2.6 pulses/sec. Considering that the September 2 maximum was observed 32 hours closer to the onset of the event we arrive at the conclusion that whatever reasonable decay constant we might assume the May 23 event was definitely more intense as far as protons > 12 MeV are concerned. It should be stressed that this statement is critically dependent on the assumption that considerably higher fluxes could have been detected during the May 23 event if the particle source had been magnetically connected to the earth already at the onset.

Considering protons > 1 BeV the event of January 28, 1967 was more powerful than the two events just compared. The flux of protons > 12 MeV did, however, not reach as high as on September 2, 1966. Since no optical flare was observed on January 28 it is impossible to say if higher fluxes could have been observed during the following event if the earth had been somewhere else along its orbit. The particle intensity built up to a broad maximum in 10 hours.

Van Allen and Ness (1967) have discussed a sudden drop by 37% in the flux of protons ~0.5 MeV coinciding with the arrival of an interplanetary shock late on July 8, 1966. They suggest that the abrupt change in the flux level builds up as the shock propagates out from the sun, particles continuously being accelerated in front of the shock while losing energy behind it. Kahler et al. (1967) have described an effect during the March 24, 1966 event which they attribute to protons scattered back from a shock front already beyond the earth's orbit. They thus get a particle increase behind the shock. Their picture is nevertheless compatible with the mechanism suggested by Van Allen and Ness (1967). They may, of course, get particles scattered back even if energy is lost in the reflecting layer.

We have not found any further example of the type of particle peak which was observed on May 30 in close connection with an SSC at the earth (Figure 10). The most remarkable characteristic of that peak is the smooth and slow build-up over no less than 15 minutes. Much more short-lived particle increases, identified as electron peaks, have on the other hand been observed several times under similar conditions. A particle event is followed within 2-3 days by an SSC associated with a more or less sudden drop in the flux of protons > 300-500 KeV, this drop typcially occurring 2-4 hours after the SSC and being of the order of 50%. A highly fluctuating electron flux giving rise to a jagged intensity-versus-time structure is usually observed between the SSC and the flux decrease. The transient fluxes are typically 2-10 times the fluxes in which they are embedded and last for 2-5 minutes. Such short-lived peaks were observed 1600-1710 UT on May 30 (Figures 9 and 10).

Two further examples were seen on January 13 and June 5, 1967. The character of the latter event is shown in Figure 14. The similarities with the May 28 event (Figure 5) are obvious. A great number of electron peaks, not appearing in Figure 14, were observed on IMP-4 from 1800 to 2300 UT on June 5. The fluxes were very soft since the scatter counter responded only occasionally and not necessarily to the highest fluxes seen by the open counter. The electron peaks observed on January 13, 1967 fit the pattern just described very well and confirm the softness of this type of electron fluxes. The observations were made by the IMP-3 Geiger counters (Table 5) which had nearly the same electron thresholds. Nevertheless several peaks observed by the open counter did not affect the scatter counter at all.

CONCLUDING REMARKS

A summary of east-west effects was given in the introductory section. The data subsequently presented allow us to make some further comments on such effects.

The anomalous streaming of cosmic rays >1 BeV from a sector between the solar and morning directions observed on May 25-31, 1967 was preceded by repeated ejection of storm plasma from active regions in the eastern solar hemisphere. Similar conditions were prevailing before two other remarkable cases of reversed cosmic ray streaming (Lindgren, 1968), namely those following the abrupt Forbush decreases of July 13 and September 30, 1961.

McMath plage region 8818 produced two large solar particle events as it passed over the solar disk. The first of these, beginning on May 23, 1967, was associated with one or two flares at 25°-28° E. Not until 36 hours after the onset did the particle flux reach its maximum at energies >12 MeV. In other cases with the same longitude of the parent flare the flux can build up to a maximum in an hour or a few hours, even at lower energies, e.g., on September 28, 1961. It is suggested that the magnetic field configuration close to the source is decisive for the resulting propagation pattern.

Particle maxima observed 1-2 days after the onset of an event are not associated exclusively with eastern flares. The event of August 28, 1966 was due to a central flare, at 4°E. Other such delayed increases are associated with western flares. Thus, the event of July 7, 1966 (Lin, et al., 1968) was produced by a flare at 45° W, a later event on January 11, 1967 by a flare at 47° W.

The parent flare of the June 3, 1967 event is unknown. Many similarities between that event and those of January 11 and May 28, 1967 make it tempting to ascribe it to a flare at 30°-60° W. Thus all three of these particle events exhibit an SSC associated drop in the flux of protons > 300-500 KeV, preceded by peaks of electrons having energies ≤ 45 KeV.

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TABLE 1. Distribution in Time, Magnitude and Brightness of Optical Flares Observed April 22-May 3 and May 17-May 31, 1967

Region 8785
April-May 1967

	22	23	24	25	26	27	28	29	30	1	2	3	---
-F	1	1	4	1	1					1	1		
1F		1										1	
2F													
3F													
-N	3	2	7	7	2		6	4	1	1	3		
1N	1			1						1			
2N													
3N													
-B						1					2		
1B									1				
2B													
3B													

Region 8818
May 1967

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
-F	2	4	1	3	4	5	4		4	1	6	2	4			-F
1F				1	1								1			1F
2F																2F
3F																3F
-N		3	8	9	17	14	15	9	6	9	6	6	4	10	1	-N
1N	1	3	1	2	2	2	2	4	4	9	3	6	3	3		1N
2N			1		1				1		1	1				2N
3N			1													3N
-B				4	1	1	1	2	3		3		1	2	1	-B
1B		1	3	2	4	1	1	1	2							1B
2B		1					4									2B
3B												2				3B

All regions except 8785
April-May 1967

	22	23	24	25	26	27	28	29	30	1	2	3	---
-F	4	3	6	11	6	7	11	11	14	8	3	11	
1F			1	2	1	1	3	7	3	2			
2F					1				1				
3F													
-N	9	5	5	4	6	12	19	17	13	5	9	10	
1N		3	2	4		1	3	7	10	8	2	4	
2N							1						
3N													
-B	2	1					4	3	3		1		
1B				1	1	2	1	2	4			1	
2B											1	3	
3B												1	

All regions except 8818
May 1967

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
-F		6	3	3	4	5	5	9	11	5	6	13	5	5	6	-F
1F		1		2		1	1	1	2	2	1		2	2		1F
2F																2F
3F																3F
-N	2	3	7	1	9	3	5	13	10	4	15	8	13	9	14	-N
1N	2		1		1		3	8	2	1	6	1	2		1	1N
2N							1			1						2N
3N																.
-B			1						1	2	1	1	1	3		-B
1B																1B
2B																2B
3B																3B

Flares observed in McMath regions 8785 and 8818 (the return of 8785) form one group, all other flares a separate group. This table is based on the final flare report in Solar-Geophysical Data, IER-FB-279 (November, 1967).

TABLE 2. Selected Solar Flares Observed in McMath Region 8818 in May 1967

Day	Beginning Time	Time of Maximum Brightness	Ending Time	Magnitude and Brightness: Average	Magnitude and Brightness: Maximum	Heliographic Latitude	Heliographic Longitude	Associated Radio Bursts	Peak X-ray Intensity Relative to Quiet Sun
18	0857	0928	0939	2B	2B	N25	E84		
19	1523	1537	1612	1B	2B	N24	E65	II + IV + cm	15
20	1510	1525	1617	1B	2B	N23	E51	II + IV + cm	5
21	1919	1926	2024	2N[1]	2B	N24	E39	II + IV + cm	45
22	0001	0013	0030	1B	3B	N24	E54		7
23	1804	1814	2013	2B	2B	N30	E25		4
	1836	1845	2146	2B[1]	3B	N27	E25	II + IV + cm	27
	1904	1949	2122	2B	2B	N27	E28	II + IV + cm	4
	1935	1946	2127	2B	2B	N27	E28		
24	1805	1816	1900	-N	1N	N23	W02	IV?	
25	0632	0645	0720	1B	2B	N28	E12		
	1041	1051	1140	1N	2N, 1B	N23	W04	IV?	8
	1129	1130	1236	2N	2B	N23	W02	IV?	
26	0156	0207	0311	2N	3N	N15[3]	E19[3]	II	
	1230	1240	1308	1N	2B	N30	W05		4
	1340	1353	1449	1N	2B	N31	W04		
28	0527	0546	0712	3B	4B	N28	W33	II + cm	94[2]
	0529	0559	0642	3B	3B	N28	W34		
	0707	0735	0805	2N	2B	N25	W42		
	0718	0730	0819	1N	2B	N23	W47		
29	1856	1905	1940	1N	1N	N31	W68	IV?	

[1] These flares emitted white light

[2] The most intense X-ray flare observed with Explorer 33 since July 1, 1966 (1-12Å)

[3] This flare was observed in McMath region 8821

TABLE 3. Solar Radio Bursts Observed on May 17-31, 1967

(A) Type II and Type IV Bursts

Day	Start	End	Type II	Type IV	Wavelength Band: Decimeter	Meter	Decameter
18	1848	2040		X			2B
19	1535	1555	X			3H	
	1537	1546	X				3B
	1533	1537		X	2H		
	1531	1550		X		2H	
	1537	1910		X			3B
20	1520	1536	X			3H	
	1527	1553	X				3B
	1514	1600		X			3B
	1600	1645		X			2B
21	1923	1945	X			3H	3H
	1923	2100		X	3H	2H	
	1922	2131		X			3B
23	1838	1842	X		3H		
	1838	1905	X			3H	
	1843	1900	X				3B
	1846	1905	X				2H
	1839	2252		X	3H		
	1839	2320		X		3H	
	1537	1900		X			2B
	1900	2400		X			3B
	1846	2300		X			2H
24	1813	1913		X			3B
25	<1230*	1520		X	3H	3H	
	1520	1600		X	2H	3H	
	1600	1640		X	1H	2H	
26	0205	0212	X			2C	1C
	0212	0228	X			1C	1C
28	0539	0556	X			2C	
	0545	0552	X				1C
29	1904	2035		X			2B

*From 1042 UT on 606 MHz at Sagamore Hill

For each burst there is in the appropriate wavelength column an intensity figure followed by a letter indicating the observatory according to the following codes:

Intensity in 10^{-22} Wm^{-2} Hz^{-1}

1: 5-20

2: 20-80

3: 80-300

Observatory

B: University of Colorado
Boulder, Colorado

H: Harvard Radio Astronomy Station
Fort Davis, Texas

C: Culgoora Solar Observatory
Australia

TABLE 3. (cont.)

(B) Selected Bursts on Single Frequencies

Day	Observatory	Time of Maximum at 8800 MHz	Peak Flux in Units of 10^{-22} Wm^{-2} Hz^{-1} at 8800 MHz	4995 MHz	2965 MHz	1415 MHz	606 MHz
19	S	1533.6	430	600	352	111	171
20	S	1520.2	677	1328	819	364	120
21	S	1925.7	1966	1787	1048	737	1842
23	S	1839.7	8100	3400	2500	2000	534
23	S	1947.0	23000	9600	5400	87000	370000
		3000 MHz	9100 MHz	3840 MHz	3000 MHz	610 MHz	200 MHz
28	G	0542	1830	4000			
28	N	0542			1370	>2500	>5000

Code of Observatories:

S: AFCRL Solar Radio Observatory
Sagamore Hill, Massachusetts

N: NERA, Holland

G: Gorki, USSR

TABLE 4. Geomagnetic Storm Sudden Commencements
May 17-31, 1967

Day	Time of SC	Number of Stations Reporting SC		Time of Maximum Brightness of Associated Flare	Delay (hours)
		Preliminary List	Final List		
23	1838	1	-		
24	1726	6	40	1926 May 21?	70
25	1021	4	13	1845 May 23?	40
	1235	13	45	1946 May 23	41
28	0311	1	-		
	0548	1	-		
	1303	1	18	1130 May 25	74
30	0610	1	-		
	1426	13	43	0546 May 28	57

TABLE 5. Energy Thresholds and Geometry Factors of Particle Detectors on IMP Satellites

Satellite	Detector	Energy Thresholds: Directional Protons	Energy Thresholds: Directional Electrons	Energy Thresholds: Omnidirectional Protons	Energy Thresholds: Omnidirectional Electrons	Geometry Factors: Directional cm^2 ster	Geometry Factors: Omnidirectional cm^2
IMP-3	Open counter	500 KeV	40 KeV	55 MeV	5 MeV	4.3×10^{-2}	~0.15
	Scatter counter	--	45 KeV	55 MeV	5 MeV	2.2×10^{-3}	~0.15
	Ion chamber	--	--	15 MeV	1 MeV	--	~45
AIMP-1	Open counter	300 KeV	22 KeV	50 MeV	2.5 MeV	0.29	~0.75
	Scatter counter	--	45 KeV	50 MeV	2.5 MeV	2.4×10^{-2}	~0.75
	Ion chamber	--	--	12 MeV	700 KeV	--	~80
IMP-4 & AIMP-2	Open counter	300 KeV	22 KeV	50 MeV	2.5 MeV	0.29	~0.75
	Scatter counter	--	45 KeV	50 MeV	2.5 MeV	3.6×10^{-2}	~0.75
	Ion chamber	--	--	12 MeV	700 KeV	--	~80

TABLE 6. Calculated Positions of Flare Groups A and B at 0000 UT on June 25, 1967

Flare Group	Latitude	Longitude	
		T = 27 days	T = 28 days
A	N23.7°	W58.9°	W42.2°
B	N27.3°	W42.9°	W28.6°

Groups A and B defined in the last paragraph of the section, "Observations of Solar Particle Fluxes."

FIGURE CAPTIONS

Figure 1: Summary of optical flares, radio bursts, geomagnetic activity, energetic solar particle fluxes >12 MeV and cosmic ray intensity >1 BeV over the last two weeks of May, 1967. Plage region 8818, containing all but one of the indicated flares (Table 2), passed central meridian on May 25. The intensity scales for type II and type IV bursts are defined in Table 3a. The arrows in the row labeled CM BURSTS give the peak flux at the frequency closest to 3000 MHz in Table 3b. Some of the sudden commencements (Table 4, preliminary reports) marked by wedges under the Kp diagram are tentatively associated to specific flares by full or dashed lines indicating probable or uncertain associations respectively. The Deep River neutron monitor data have been normalized to the hourly average on May 23 (= 100 units).

Figure 2: Bihourly counting rates of the supermonitors at Deep River (P_c = 1.0 BV), Canada and Oulu (P_c = 0.8 BV), Finland normalized relative to the average rate on May 23. The diagram at the bottom gives the difference between the upper two curves and shows essentially no other effects but those due to the spin of the earth in a streaming cosmic ray gas. Arrows indicate normally expected times of maximum. Notice the considerable disagreement between expected and observed times of maximum from May 25 to May 31.

Figure 3: Projection of IMP-4 and AIMP-1 orbits on the ecliptic plane at the end of May, 1967. Points indicate the positions at every 6 hours. 28.0 marks the positions at 0000 UT on May 28, etc.

Figure 4: Protons > 300 KeV (top) and > 12 MeV (bottom). Crosses in the lower diagram indicate values interpolated by use of ion chamber data from IMP-4. To convert from counts sec^{-1} in the open counter to flux cm^{-2} sec^{-1} multiply by 45.

Figure 5: Open counter sensitive to protons > 300 KeV and electrons > 22 KeV, ion chamber to protons > 12 MeV and electrons > 700 KeV. The decay constant of the ion chamber pulse rate is ~15 hours, that of the open counter ~19 hours. For details see Figures 7-10.

Figure 6: On May 25, 1977 the flux of solar particles decreased twice, both times closely associated with decreases in the horizontal component of the equatorial geomagnetic field. Filled rectangles refer to decreases in the AIMP-1 ion chamber, sensitive to protons > 12 MeV, filled and open rectangles to decreases in the flux of 6-8 MeV protons measured on OGO-3.

Figure 7: Average rates over 2.7 minute intervals. Notice the low pulse rate on IMP-4 compared to that on AIMP-1 0630-1015 UT. Maximum count rate in open counter at ~0700 UT corresponds to 10^5 particles cm^{-2} sec^{-1}. For finer details seen by the open counter, see Figure 8.

Figure 8: Average rates over 10 second intervals. Notice the anything but smooth build-up, before 0635 UT. The fluctuations are due to electrons > 40 KeV. The three peaks 1240-1300 UT consist of electrons > 22 KeV, having a very steep energy spectrum. Figure 3 shows the position of IMP-4 at that time.

Figure 9: Average rates over 2.7 minutes (IMP-4) and 5.5 minutes (AIMP-1). The SSC was observed at 1426 UT. Figure 10 shows the fine structure of the peak seen by the open counter at that time, standing on the 800 counts sec^{-1} plateau. A radially propagating interplanetary shock should have passed first the earth, then IMP-4 and finally AIMP-1 (Figure 3), all within a few minutes.

Figure 10: Average rates over 10 seconds. Notice the smooth build-up and the stepwise decay of the large peak in the upper diagram. The lower diagram shows three one-minute electron peaks, immediately preceding a 65% drop in the particle flux seen by the open counter.

Figure 11: A low energy proton event, probably caused by activity in the same part of the sun as the events on May 23 and May 28, 1967. The flux builds up very slowly and displays three sudden drops by ~50%. The times of these drops are indicated. The second step down occurs close to a SSC, observed at 1459 UT on June 26. The gap on June 28 is due to a perigee pass.

Figure 12: Open counter sensitive to protons > 500 KeV and electrons > 40 KeV, ion chamber to protons > 12 MeV and electrons > 700 KeV. Compare this event, due to a flare at 4^{o}E,

with that on May 23, 1967 (Figure 4). The only striking difference is the rapid build-up on August 28, which could not take place on May 23.

Figure 13: This event which began ~4.5 days after that on August 28, 1966 should be compared with the event on May 28, 1967 (Figure 5). Notice the smooth exponential decay over several days. The average decay constant of the ion chamber pulse rate is ~22 hours, that of the open counter ~19 hours. Different exponentials are required to fit the decays before and after the hump on September 8, suggested to be a recurrent event by McCracken et al. (1967). The open counter on IMP-3 observes an electron event superimposed on the hump. The gaps on September 2 and 8 are due to perigee passes.

Figure 14: This event to which no parent flare has been found has many characteristics in common with the May 28 event (Figure 5). After an initial exponential decay over about a day a flux of low energy protons makes the count rate level off or increase. A maximum is observed close to an SSC, followed by a sudden decrease within a few hours. Preceding this decrease is a number of electron spikes, with energies > 22 KeV.

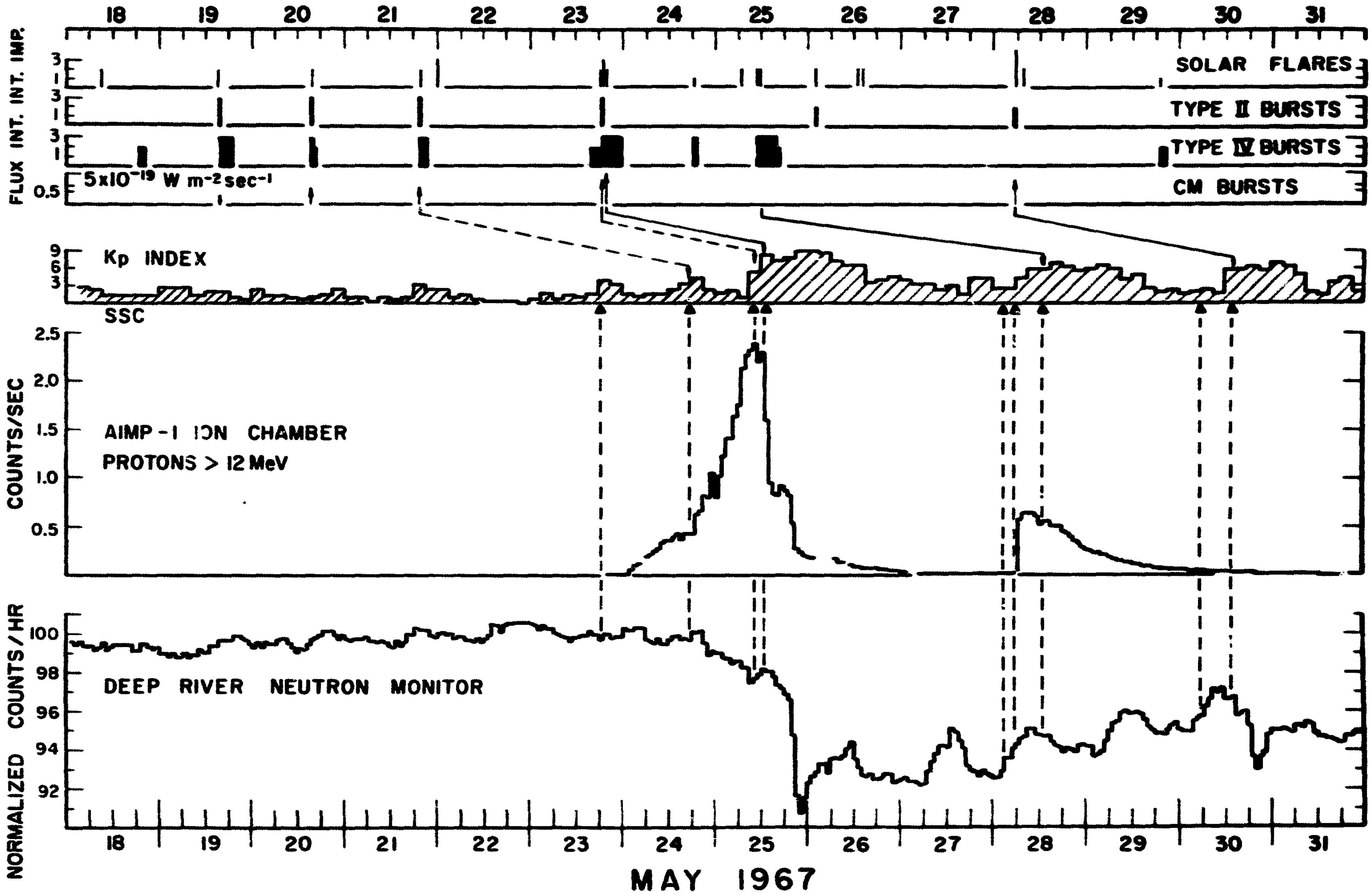
SOLAR FLARES
TYPE II BURSTS
TYPE IV BURSTS
CM BURSTS
FLUX INT. INT. IMP.
5x10^-19 W m^-2 sec^-1
Kp INDEX
SSC
COUNTS/SEC
AIMP-I ION CHAMBER
PROTONS > 12 MeV
NORMALIZED COUNTS/HR
DEEP RIVER NEUTRON MONITOR
MAY 1967

Figure 1

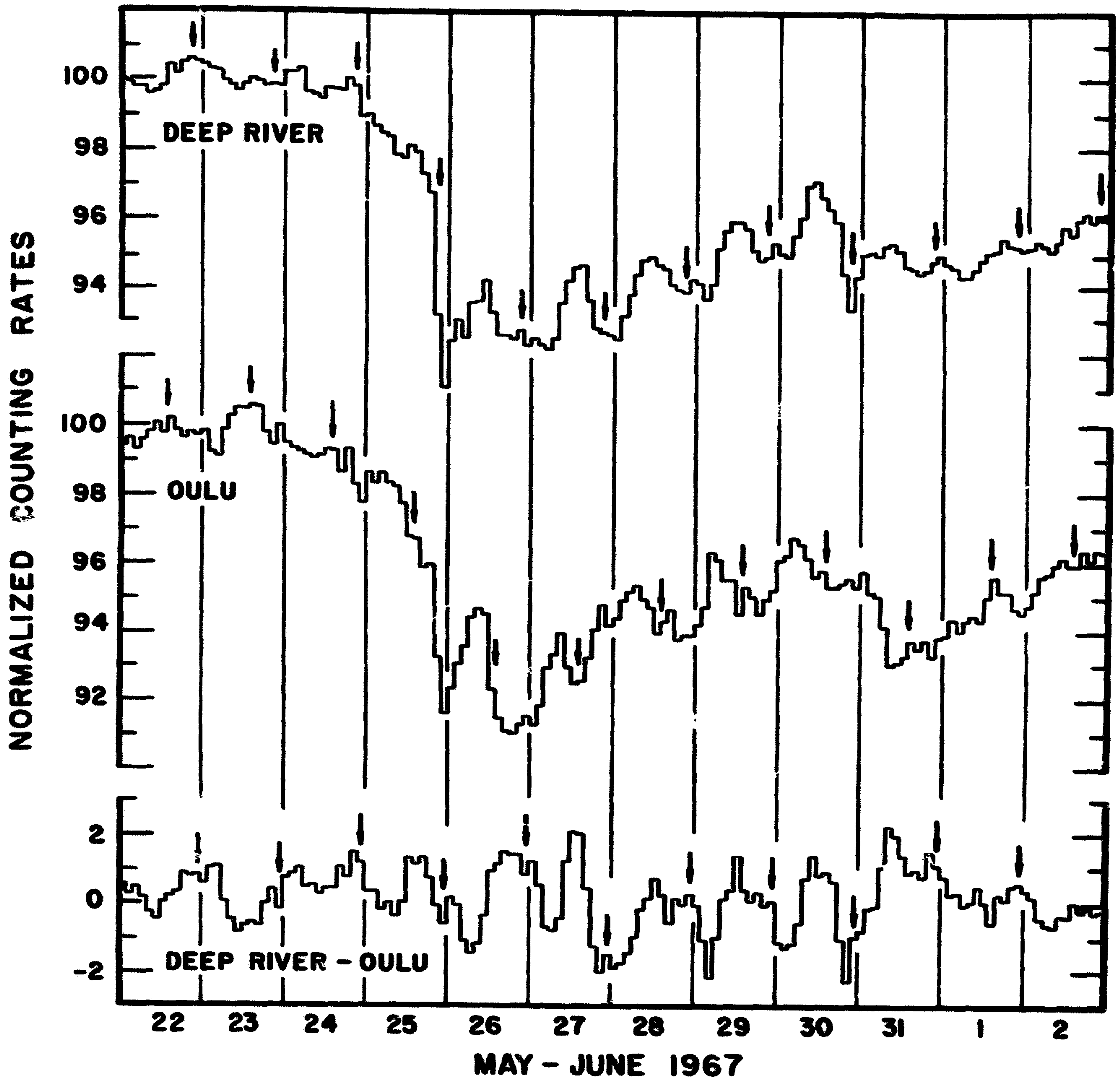
NORMALIZED COUNTING RATES
100
98
96
94
DEEP RIVER
100
98
96
94
92
OULU
2
0
-2
DEEP RIVER - OULU
22
23
24
25
26
27
28
29
30
31
1
2
MAY - JUNE 1967

Figure 2

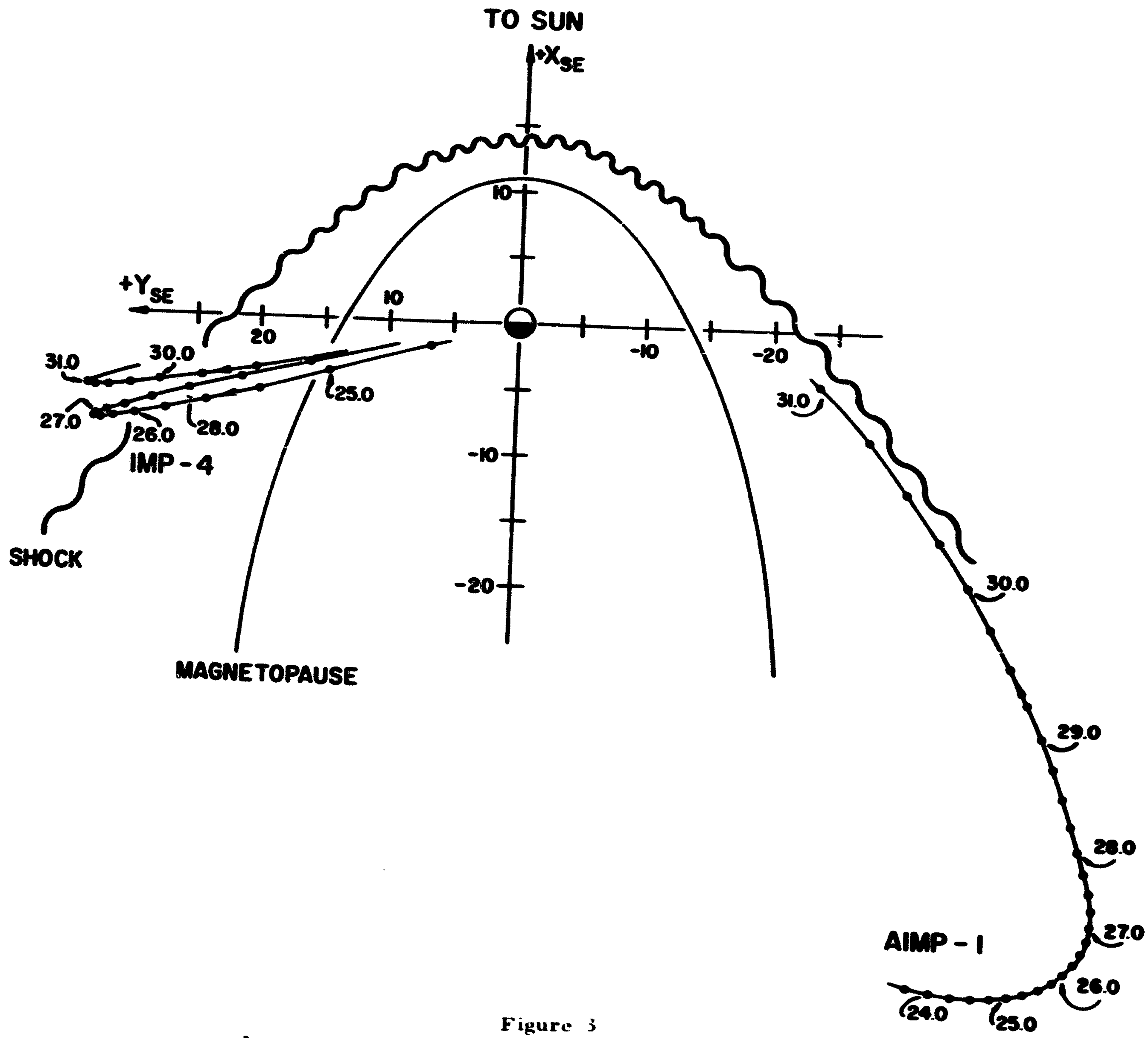
TO SUN
+X_SE
+Y_SE
10
20
-10
-20
31.0
30.0
27.0
26.0
28.0
25.0
IMP-4
SHOCK
MAGNETOPAUSE
29.0
27.0
24.0
AIMP-I

Figure 3

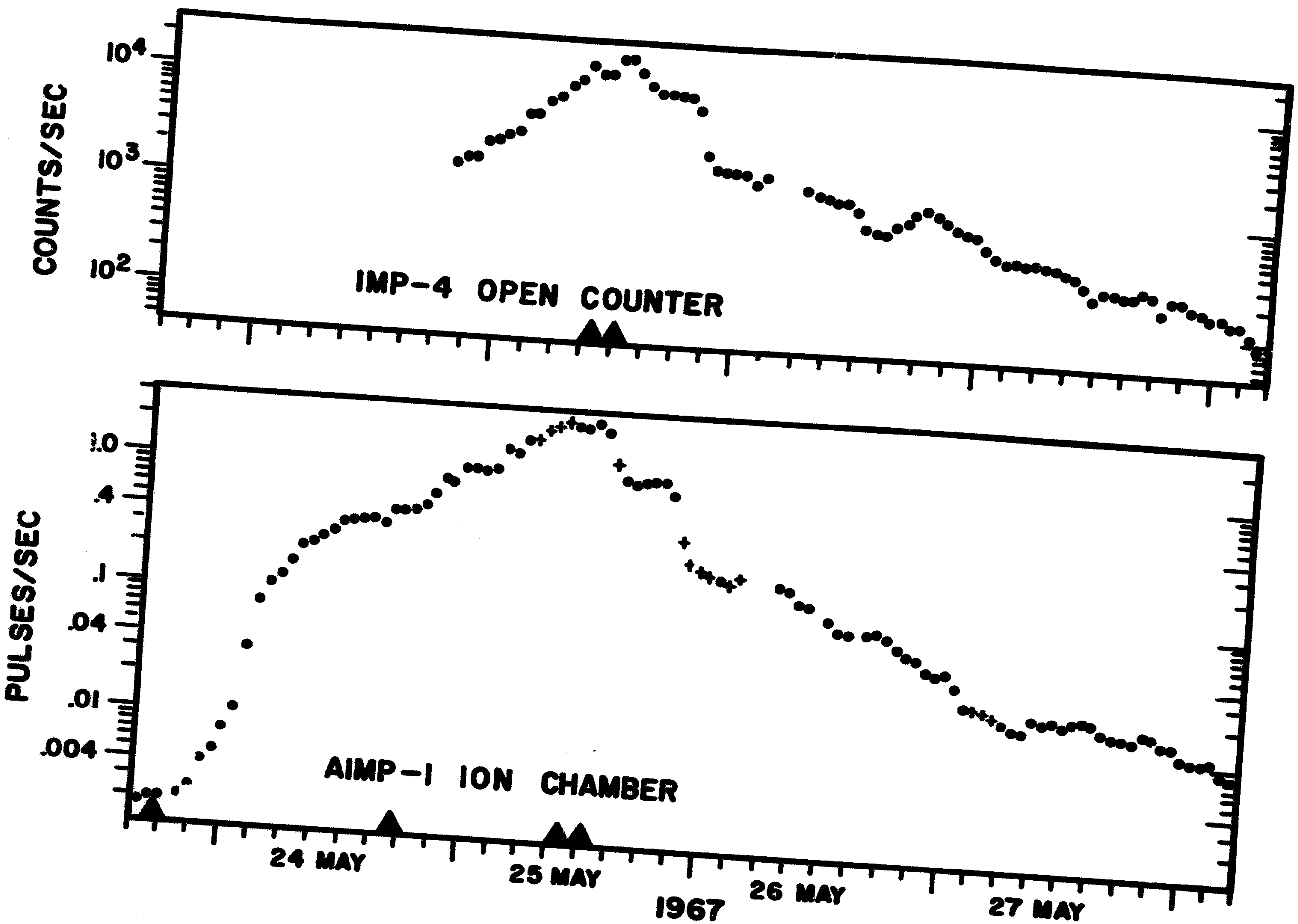
COUNTS/SEC
10^4
10^3
10^2
IMP-4 OPEN COUNTER
PULSES/SEC
1.0
.4
.1
.04
.01
.004
AIMP-I ION CHAMBER
24 MAY
25 MAY
26 MAY
27 MAY
1967

Figure 4

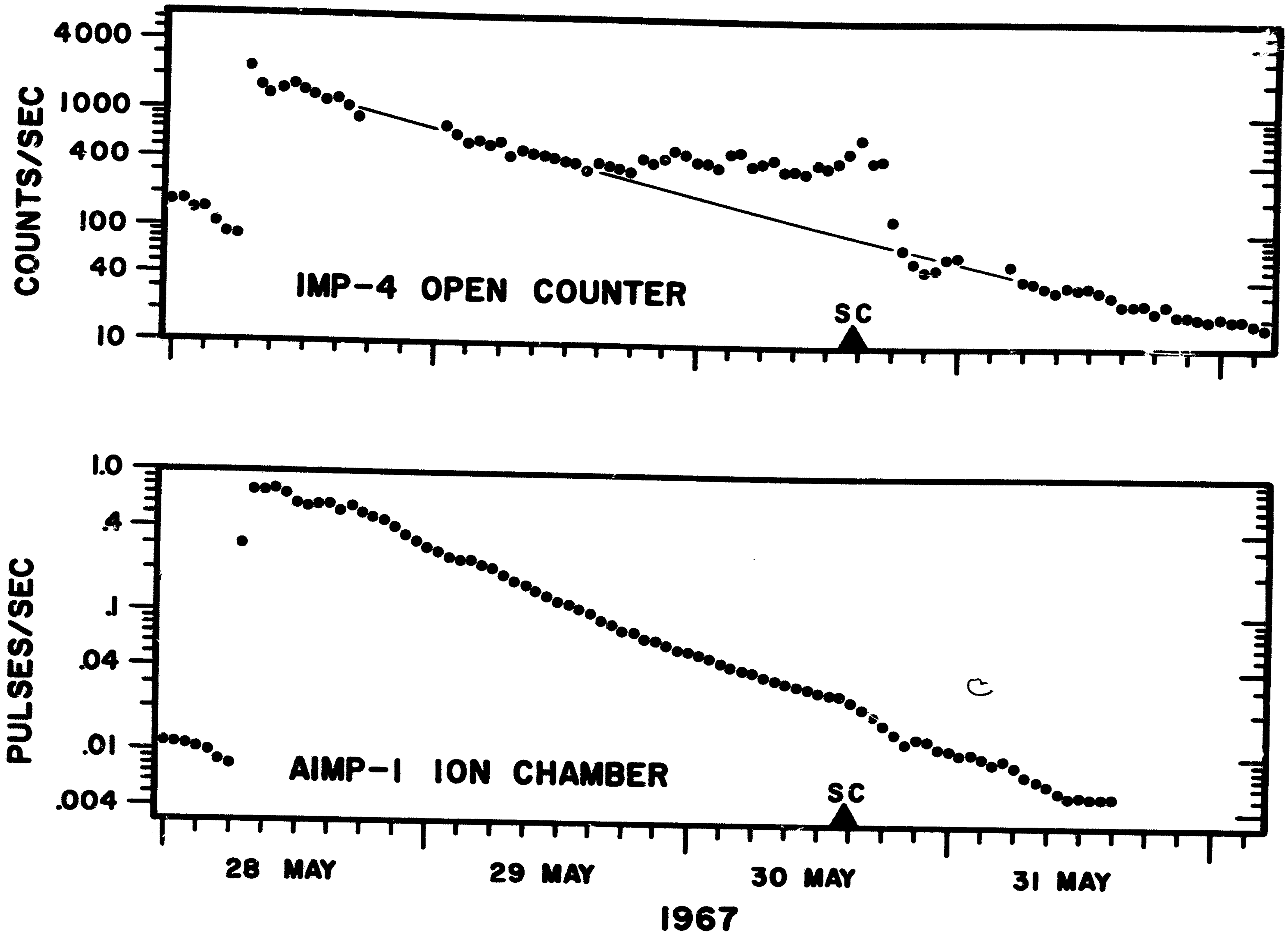
4000
1000
400
100
40
10
COUNTS/SEC
IMP-4 OPEN COUNTER
SC
1.0
.4
.1
.04
.01
.004
PULSES/SEC
AIMP-1 ION CHAMBER
SC
28 MAY
29 MAY
30 MAY
31 MAY
1967

Figure 5

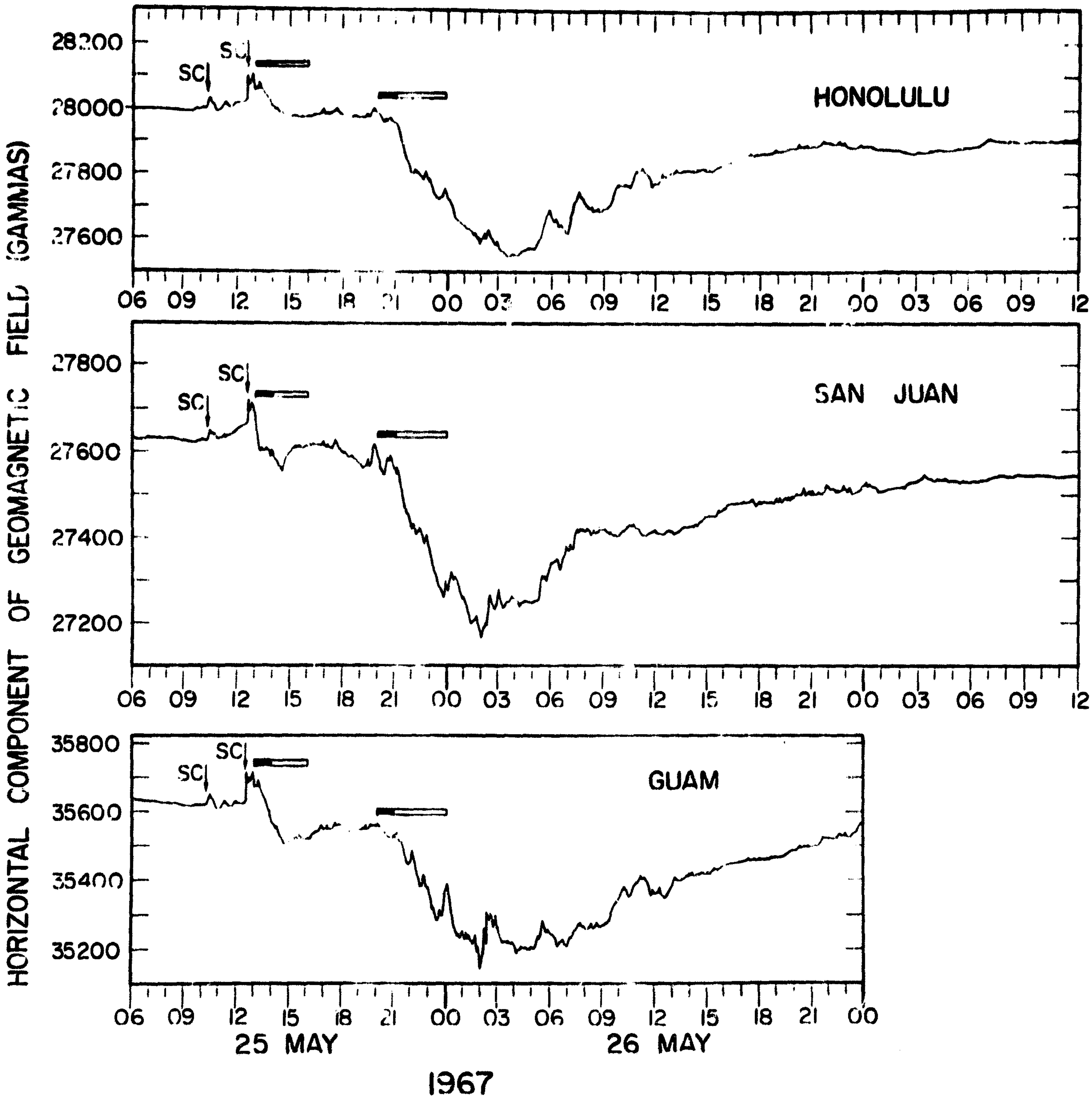
HORIZONTAL COMPONENT OF GEOMAGNETIC FIELD (GAMMAS)
HONOLULU
SAN JUAN
GUAM
SC
28200
28000
27800
27600
27400
27200
35800
35600
35400
35200
06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12
25 MAY
26 MAY
1967

Figure 6

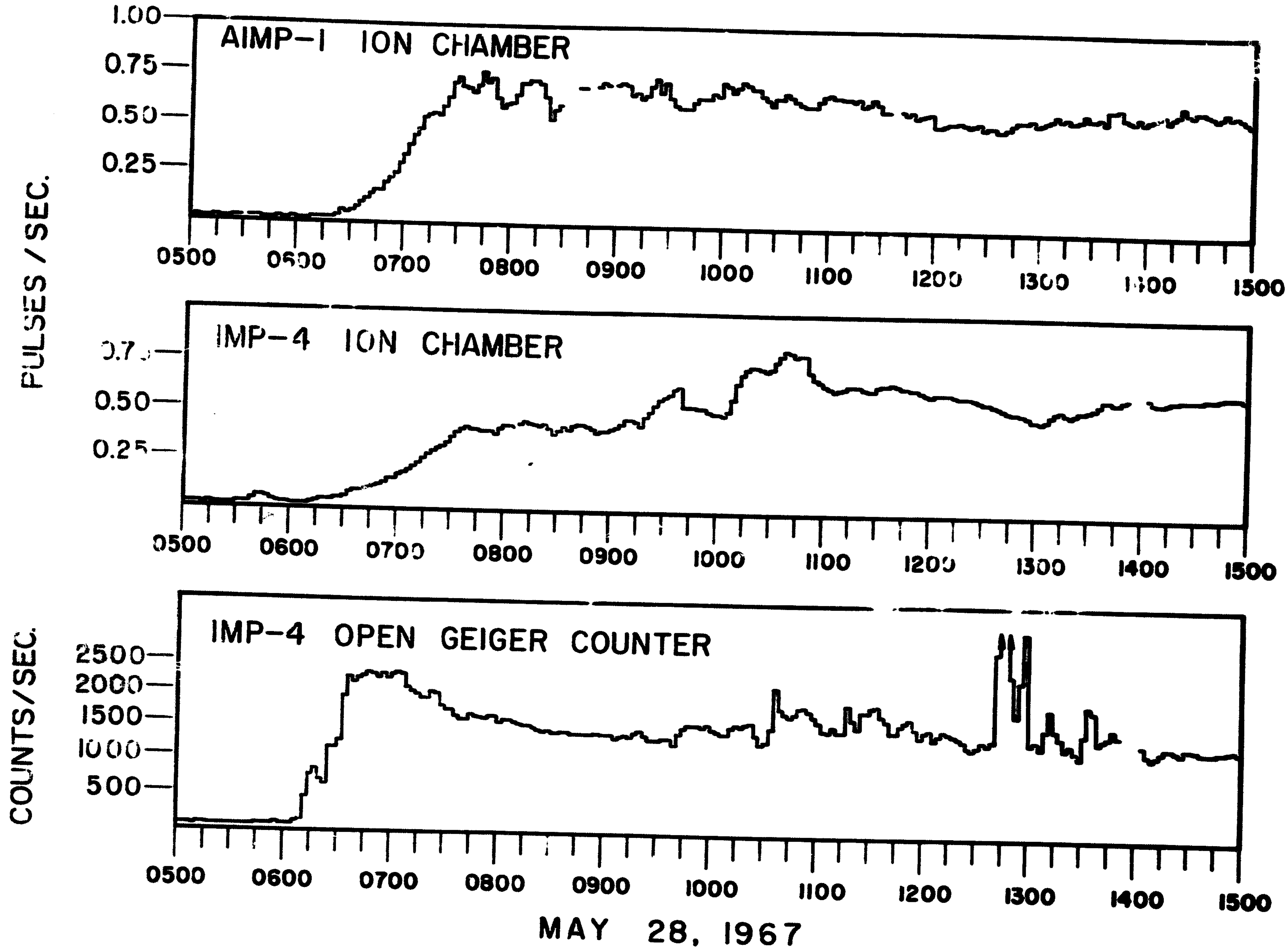
AIMP-I ION CHAMBER
IMP-4 ION CHAMBER
IMP-4 OPEN GEIGER COUNTER
PULSES / SEC.
COUNTS/SEC.
1.00
0.75
0.50
0.25
2500
2000
1500
1000
500
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
MAY 28, 1967

Figure 7

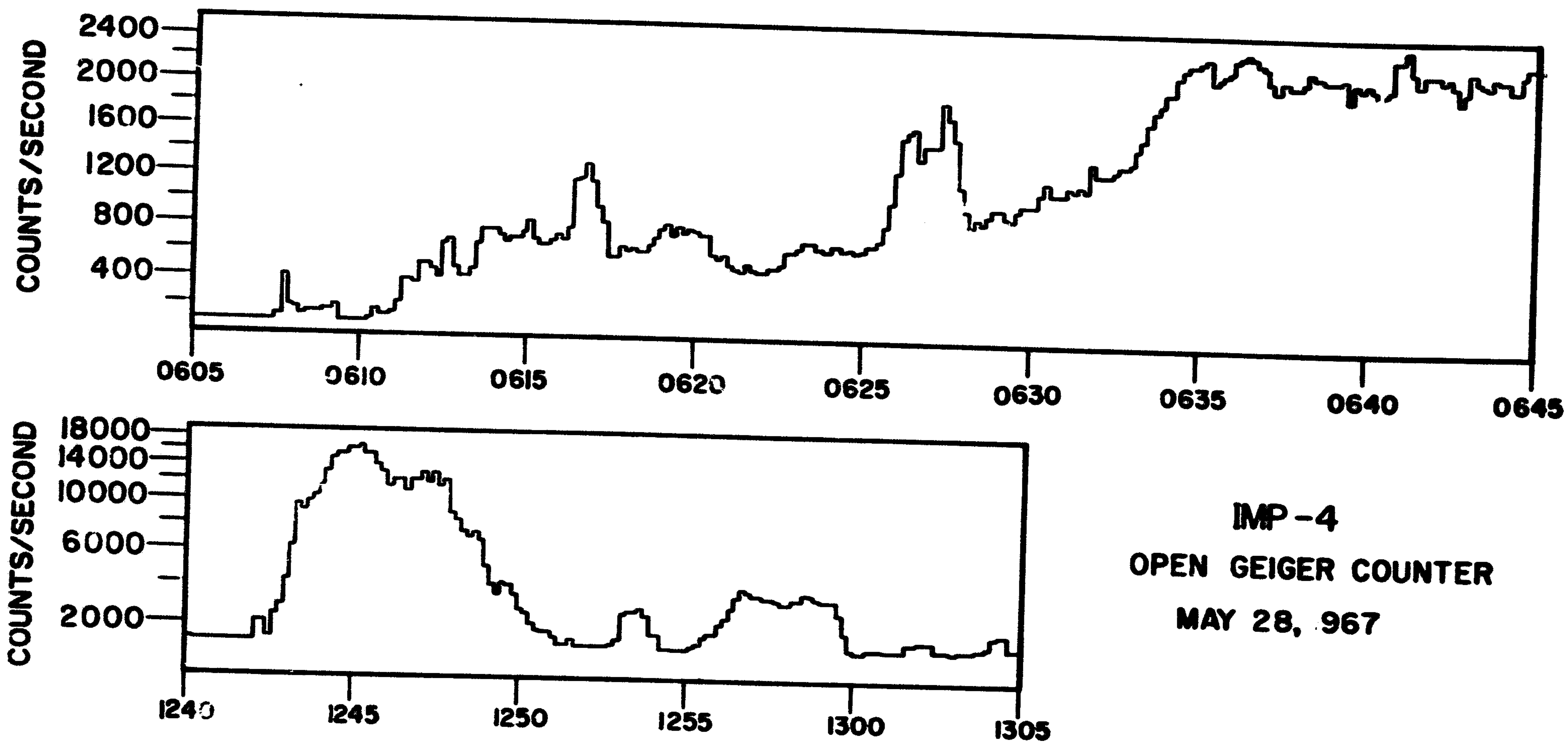
COUNTS/SECOND
2400
2000
1600
1200
800
400
0605
0610
0615
0620
0625
0630
0635
0640
0645
COUNTS/SECOND
18000
14000
10000
6000
2000
1240
1245
1250
1255
1300
1305
IMP-4
OPEN GEIGER COUNTER
MAY 28, 967

Figure 8

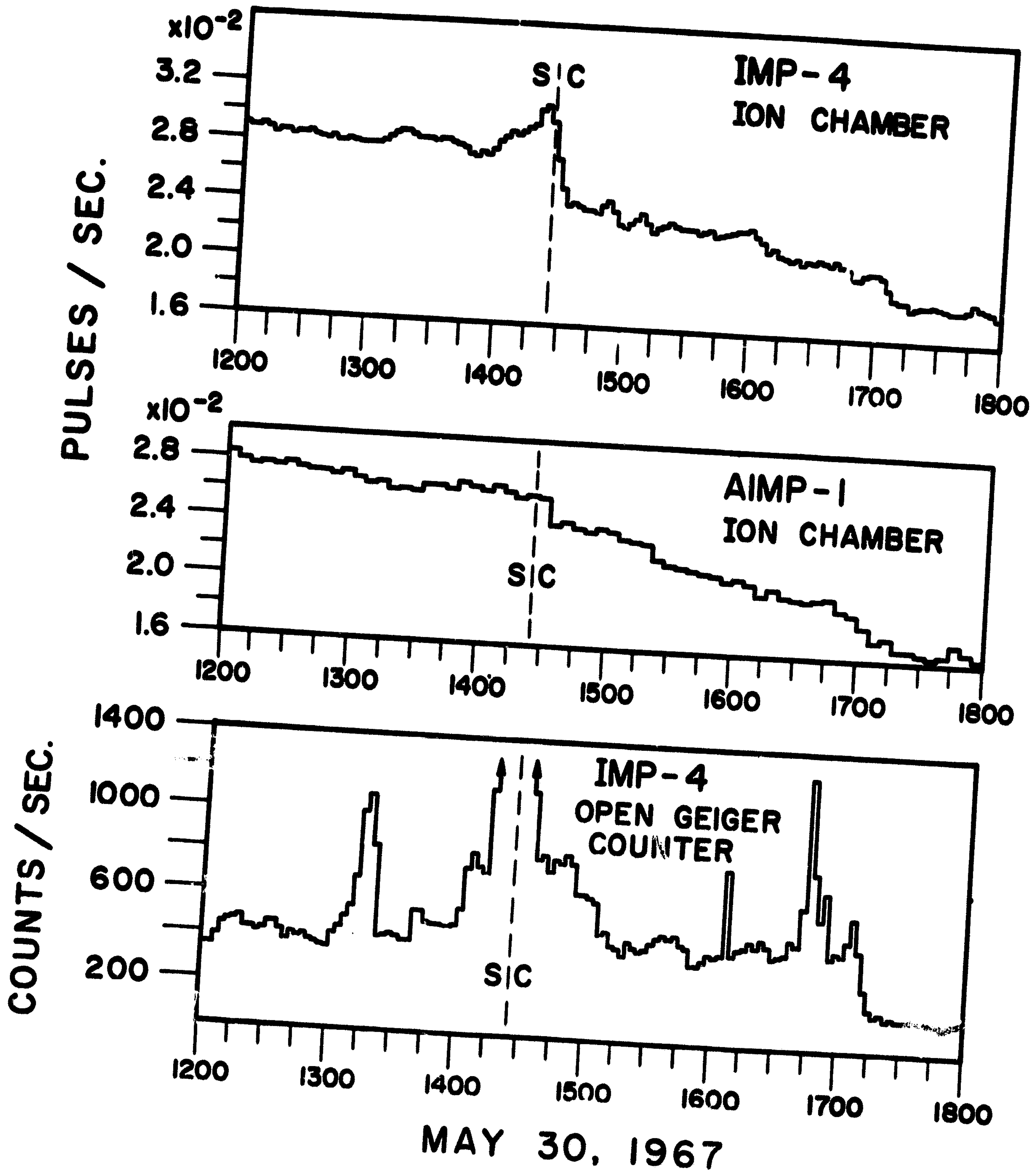
x10^-2
3.2
2.8
2.4
2.0
1.6
S|C
IMP-4
ION CHAMBER
1200
1300
1400
1500
1600
1700
1800
PULSES / SEC.
x10^-2
2.8
2.4
2.0
1.6
AIMP-1
ION CHAMBER
S|C
1200
1300
1400
1500
1600
1700
1800
1400
1000
600
200
COUNTS / SEC.
IMP-4
OPEN GEIGER
COUNTER
S|C
1200
1300
1400
1500
1600
1700
1800
MAY 30, 1967

Figure 9

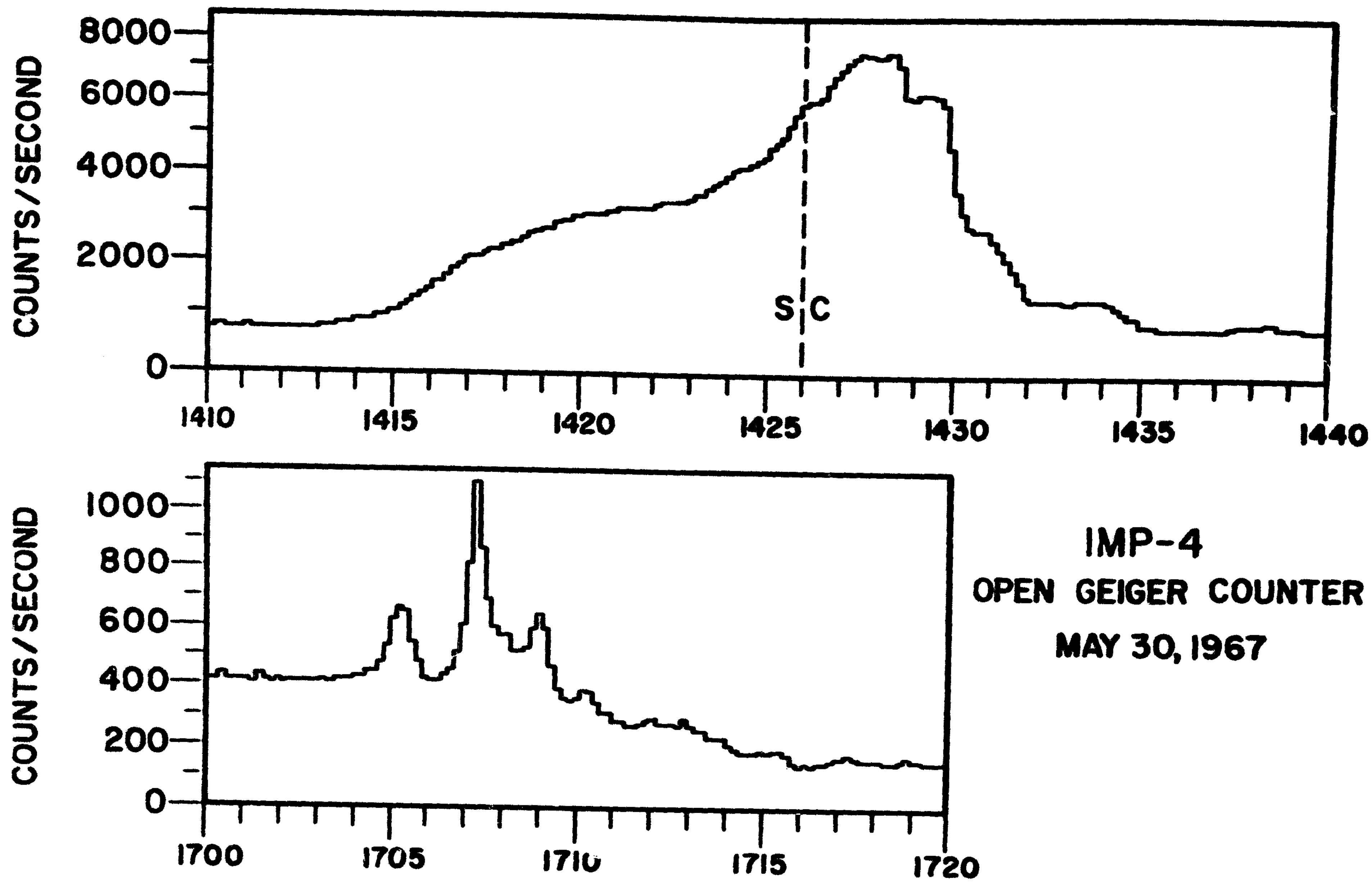
COUNTS/SECOND
8000
6000
4000
2000
0
S C
1410
1415
1420
1425
1430
1435
1440
COUNTS/SECOND
1000
800
600
400
200
0
1700
1705
1710
1715
1720
IMP-4
OPEN GEIGER COUNTER
MAY 30, 1967

Figure 10

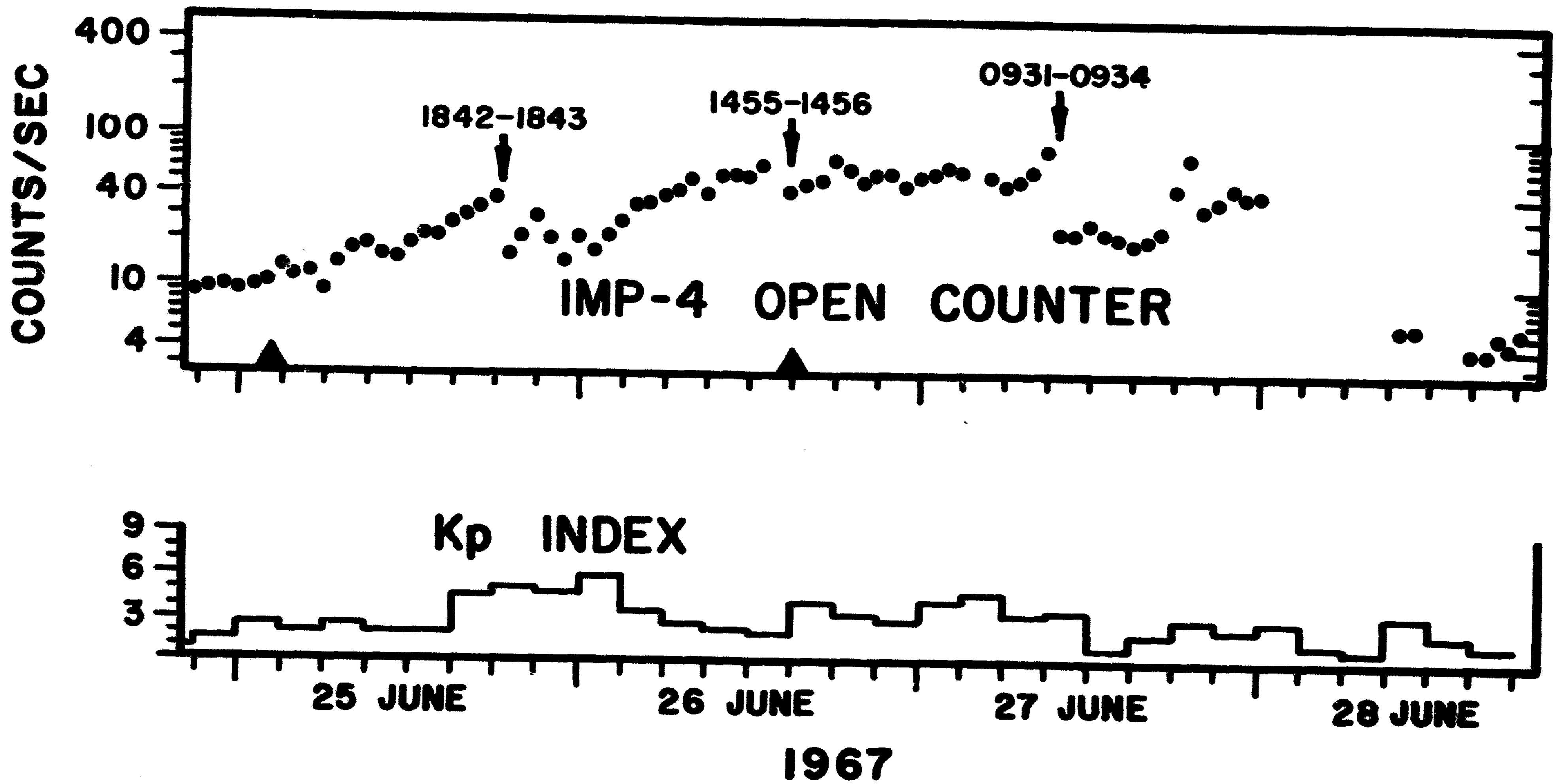
COUNTS/SEC
400
100
40
10
4
1842-1843
1455-1456
0931-0934
IMP-4 OPEN COUNTER
Kp INDEX
9
6
3
25 JUNE
26 JUNE
27 JUNE
28 JUNE
1967

Figure 1i

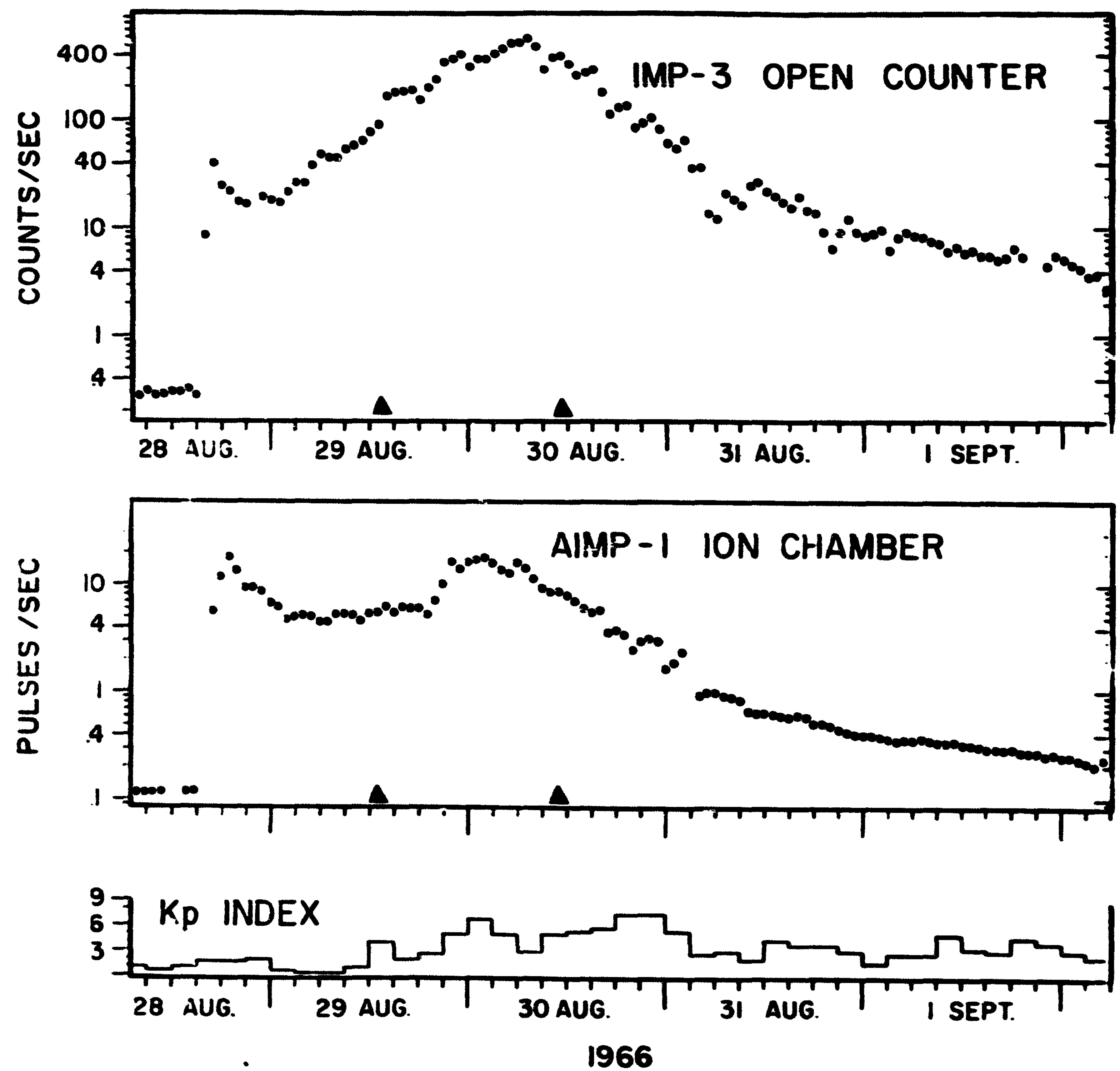
IMP-3 OPEN COUNTER
COUNTS/SEC
400
100
40
10
4
1
.4
AIMP-1 ION CHAMBER
PULSES /SEC
10
4
1
.4
.1
Kp INDEX
9
6
3
28 AUG.
29 AUG.
30 AUG.
31 AUG.
1 SEPT.
1966

Figure 12

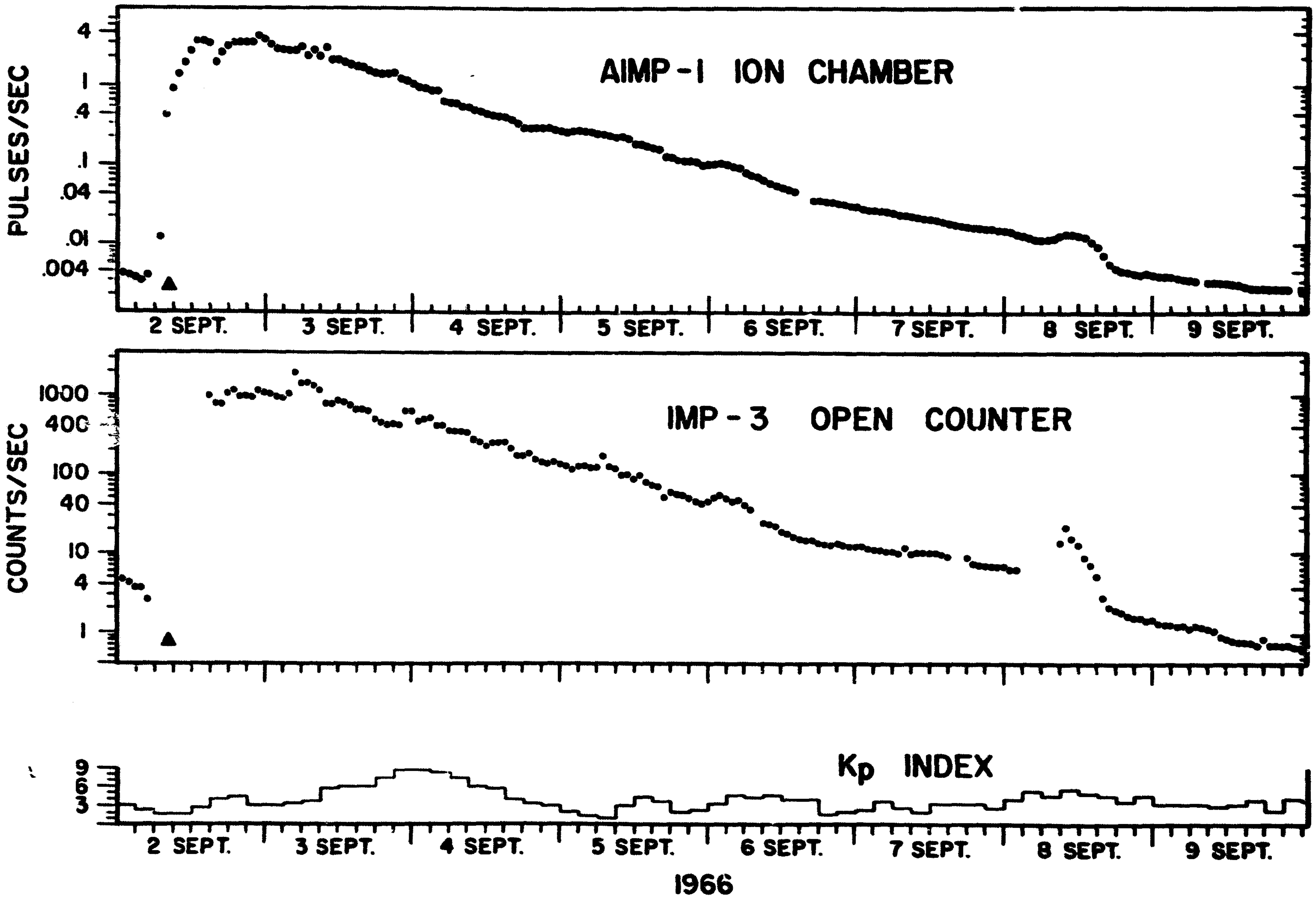
AIMP-1 ION CHAMBER
PULSES/SEC
4
1
.4
.1
.04
.01
.004
IMP-3 OPEN COUNTER
COUNTS/SEC
1000
400
100
40
10
4
1
Kp INDEX
9
6
3
2 SEPT.
3 SEPT.
4 SEPT.
5 SEPT.
6 SEPT.
7 SEPT.
8 SEPT.
9 SEPT.
1966

Figure 13

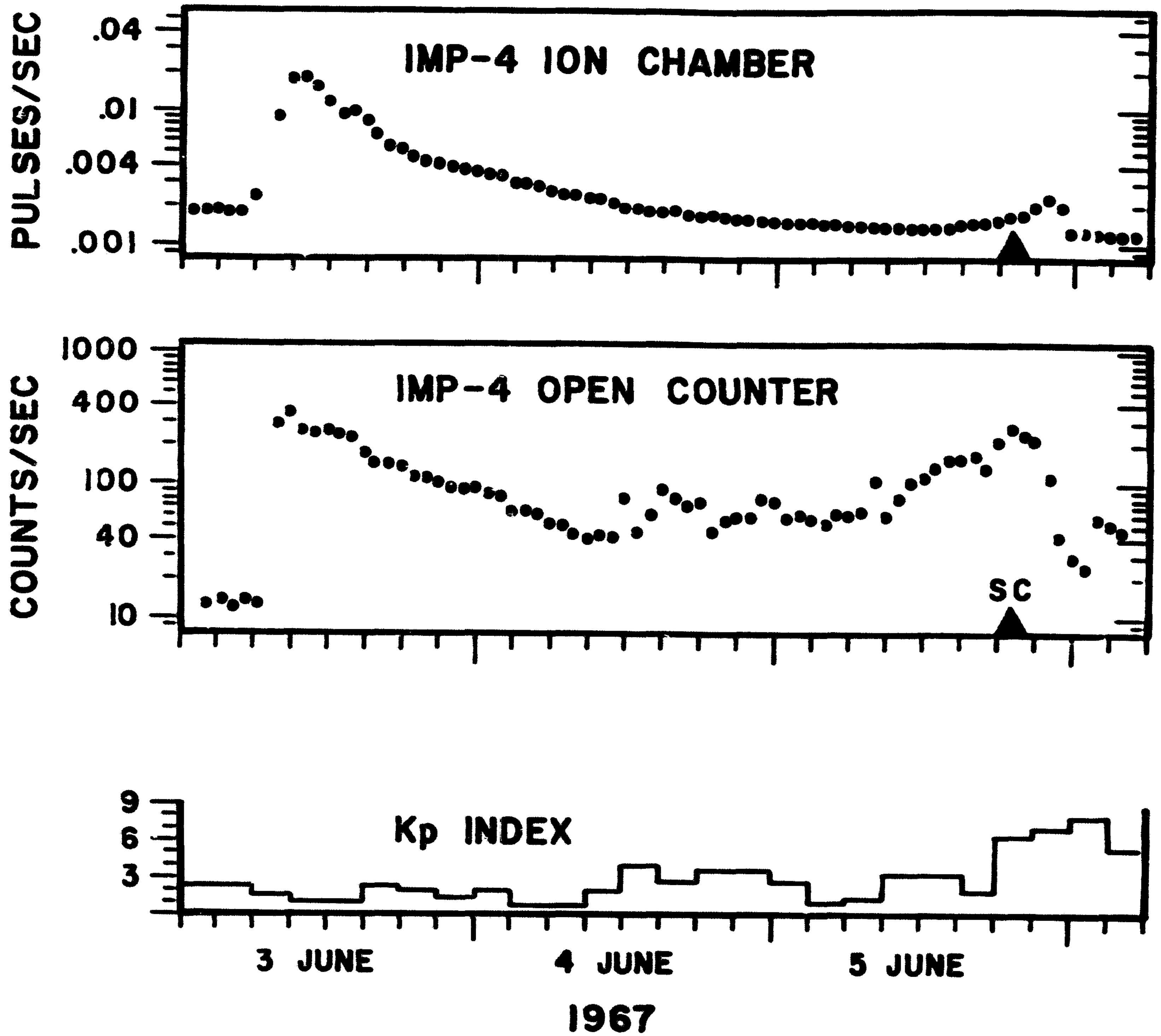
IMP-4 ION CHAMBER
PULSES/SEC
.04
.01
.004
.001
IMP-4 OPEN COUNTER
COUNTS/SEC
1000
400
100
40
10
SC
Kp INDEX
9
6
3
3 JUNE
4 JUNE
5 JUNE
1967

Figure 14