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PROTON EVENTS IN THE MAGNETOSPHERE ASSOCIATED WITH MAGNETIC BAYS

BY

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NASA/Goddard Space Flight Center
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ABSTRACT

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A series of 13 sudden increases in the proton flux was observed at $L > 8$ on the subsolar side of the magnetosphere during August, September and October 1961. These increases are strongly correlated with the appearance of negative magnetic bays in the auroral zone. The increases exhibit proton intensities of $J(> 100 \text{ kev}) \lesssim 10^6 \text{ p/cm}^2 \text{ sec ster.}$ The particle intensity rise time is of the order of 10 minutes. The protons have strongly peaked energy distributions and the peak energy decreases with time during a period of about 1 hour from about 300 kev to 100 kev. The events are interpreted as protons drifting in the earth's magnetosphere after being injected into it on the night side.

Author

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INTRODUCTION

Increases in the proton population of the Van Allen belts during magnetic storms have been observed and described in literature. (McIlwain, 1965; Davis, 1965; Davis and Williamson, 1965; and Vernov et al., 1965.)

In this paper we shall present observations of sudden increases in the flux of low energy protons in the distant radiation zone during magnetically relatively quiet periods. These increases are found to be strongly correlated with magnetic bays in the auroral zone. In all cases of observation the onset of the proton events occurred during periods with Kp less than 3+.

Recently Pudovkin and Smirnov, [1966], have proposed that 150-200 kev protons impulsively injected into the night side of the magnetosphere may be the cause of the production and be responsible for the delay between the onset of some negative bays on the night side and positive bays on the day side of the auroral zone.

The data used in the present study was obtained from the ion-electron detector flown by Davis and Williamson on Explorer 12.

APPARATUS

The instrument used in this analysis has been previously described, [Davis and Williamson, 1963; Davis, 1965]. Here we shall give only a brief summary of its operational characteristics. The detector is a scintillation counter consisting of a photomultiplier tube on the face of which is deposited a 5 mg/cm² thick layer of crystalline ZnS covered by a 1000-Å thick layer of Al. A wheel driven by a stepping motor introduces varying thicknesses of Ni absorber between the collimator and the phosphor, thus permitting acquisition of energy information on the incident particles. The wheel also carries three Au discs, which in some wheel positions scatter the incident flux entering through an alternate collimator into the phosphor.

The detector has a geometric factor of $5.8 \times 10^{-4} \text{ cm}^2 \text{ sec ster}$ for protons with $E > 105 \text{ kev}$ and $5.4 \times 10^{-3} \text{ cm}^2 \text{ sec ster}$ for all others.

A collimator allows particles to enter from a viewing cone with a half angle of about 11 degrees.

There are three modes of operation:

1. Pulse output from the anode measures the number of incident protons above 105, 140, 200, 255, 460, 970, and 1700 kev.
2. Normally the eighth dynode current measures the total incident flux from both protons and electrons.
3. Electrons can, however, be selected preferentially by scattering the incident beam of both protons and electrons from the Au discs. In this mode of operation the eighth dynode current measures the total incident flux only due to electrons in the energy range between 20 kev and 100 kev.

In all three modes of operation the energy cutoff can be raised by introducing varying thicknesses of Ni absorbers mounted on the wheel.

The lowest detectable proton flux is about $10^3 \text{ p/cm}^2 \text{ sec ster}$. The minimum detectable electron flux, however, depends on the energy of incident electrons and varies from $3.6 \times 10^5 \text{ /cm}^2 \text{ sec ster}$ at 20 kev to $1.4 \times 10^5 \text{ /cm}^2 \text{ sec ster}$ at 100 kev.

The proton cutoff energies of the detector are defined to be those energies at which the efficiency of the detector with a particular absorber in front of the aperture is 50%.

Owing to the directionality of the detector and the spin of the satellite it is possible to measure the pitch angle distribution of particles if the direction of the magnetic field is either known experimentally or can be calculated.

A complete set of information can be obtained every 83 seconds.

ANALYSIS

The observations reported here were made during the period between August 16, 1961 and the end of October 1961. The region covered is the morning side of the sunward magnetosphere approximately between $+10^\circ$ and -45° geomagnetic latitude.

In the rest of this section we shall give a general picture of the proton events and show the correlation between them and the appearance of magnetic bays in the auroral zone. At the end we shall discuss two large events in detail.

Figure 1 shows six Explorer XII passes through the radiation belt. These passes include a cross-section of events selected to show both clean-cut events and those whose observation is somewhat marginal.

The intensity of low energy protons is plotted as a function of time as it was observed during several inbound and outbound passes. Due to the orbit of the satellite the outbound passes had a higher geomagnetic latitude than the inbound passes. Underneath each pass there are reproduced traces of the horizontal component of different auroral and mid-latitude observatories lying close to the midnight geomagnetic meridian.

The numbers above the proton intensity curves give the hourly values of the radial distance, the geomagnetic latitude, the geomagnetic local time, and McIlwain's L of the satellite position. The protons shown have local pitch angles of 90°

First we shall give a general description of an event by means of an example. The pass of August 28, 1961 shows the occurrence of a rather strong event. Commencing at about 0253 U.T. the intensity of protons with energies > 200 kev begins to rise. Almost simultaneously the intensity of protons with energies > 255 kev also begins to rise at a comparable rate. The ambient flux preceding the event consisted of protons with energies between 200 and 145 kev with an intensity sufficient to mask any initial rise in this energy range. However, by 0300 it is clear that the intensity of > 140 kev protons also is increasing. If we assume that the flux of > 140 kev protons initially starts increasing at 0253 we are compelled to conclude that at that instant we observe the arrival of protons almost exclusively with energies > 255 kev. At about 0305 the flux of protons with energies > 255 kev begins to fall while the flux of protons with energies > 200 kev continues to rise. This behavior indicates that the energy of incident protons (aside from the ambient flux) has shifted to between 200 and 255 kev. At about 0310 the intensity of > 200 kev protons begins to fall while that of > 140 kev protons continues to rise, again indicating an energy shift to between 200 and 140 kev. At about 0315 the intensity of protons with energies > 140 kev begins to fall while that of > 105 kev protons (available, but not shown in the diagram) continues to rise, indicating an energy shift to between 105 and 140 kev. Eventually, by 0325 the intensity of > 105 kev protons also begins to fall. Since we have no lower energy channels it is impossible to say whether the energy of incident protons is shifting to even lower values.

The emerging picture is that an event consists of an almost mono-energetic proton flux whose energy decreases as a function of time and whose intensity increases at the same time up to some point before starting to decrease. The total increase in the proton flux may be as much as two orders of magnitude.

Another characteristic of the proton events is that in all cases observed each is preceded by or concurrent with a negative or positive (depending on the local time) midnight magnetic bay in the auroral region and frequently a positive bay in the mid-latitude and equatorial

regions. Thus, on this particular pass there is a 300γ negative bay at Marie Byrd and positive bays at Fredricksburg and at G Gonzalez Videla.

Other parts of Figure 1 show similar proton events. Since these events exhibit similar structure on both inbound and outbound passes they are clearly temporal rather than spatial in nature. Also these events can be seen to occur both at high ($\sim 35^\circ$) and low latitudes.

Interesting examples of correlation between events and magnetic bays can be seen during the passes of August 21, 1961 and September 5, 1961. In the first case one can see two events separated by about 16 minutes and in each case preceded 10 minutes earlier by a magnetic bay. In the second case three rather small events can be seen in each case preceded by a magnetic bay.

The event of October 3, 1961 took place just as the satellite was entering the magnetosphere at 1400. A negative bay can be seen to occur at about that time at College. There is another bay at about 1230 but at that time the satellite was in the magnetosheath and as can be seen there are no visible effects produced by magnetic bays in that region.

From the shape of the intensity curves it becomes clear that not all events exhibit strictly mono-energetic fluxes whose energy decreases with time (October 3, 1961; September 5, 1961); however, in each case there is an unmistakable initial hardening of the spectrum.

The on-board magnetometer flown by Cahill shows no unusual changes in the magnetic field during the onset of the proton events (Kaufmann, private communication).

Figure 2 shows three plots depicting the position coordinates of the satellite at the instant of the onset of the proton events. (Zero geomagnetic local time corresponds to the noon geomagnetic meridian).

The apparent correlation between the geomagnetic latitude and longitude of the observation point is due to the change in the satellite orbit with respect to the average position of the earth dipole axis over the period of observation (August through October 1961). Also, from the physical point of view, there is no reason to believe that there should be any latitudinal asymmetry in the observations since the protons are clearly trapped on field lines.

The increases are observed between 5 and 11 R_E radial distance but seem to be concentrated on L values between 8 and 12. We make no claim here as to the generality of this statement because due to the intensity of the ambient flux many of the weaker events would have completely escaped detection had they occurred, say at $L \lesssim 7$.

McIlwain's L is used here only in an approximate sense to indicate the skirt of the trapping region since, as Mead (1965) has shown, it

loses its meaning at distances close to the boundary of the magnetosphere.

We shall now proceed to discuss in detail the events of September 22, 1961 and of August 28, 1961.

Figure 3 shows an expanded plot of the September 22, 1961 event. The curves represent protons with energies > 105 kev, 140 kev, 200 kev, and 255 kev having pitch angles between 80° and 100° . In this case the pitch angle distribution is practically flat between 25° and 90° local pitch angle.

To indicate the energy change of the incident protons more clearly we constructed "difference" spectrums (Figure 4) from the expanded plot shown in Figure 3. The bars indicate the instantaneous proton intensity within energy ranges established by the cutoff energies of the integral proton channels. The intensities are normalized to unit flux which is obtained from the > 105 kev channel.

The plot shows the spectrum at 2 minute intervals starting with the onset of the event at 2035. It should be noted that initially most of the particles are concentrated in the energy range between 255 and 460 kev. As time progresses the spectrum softens and the peak of the proton intensity shifts to lower ranges. Thus at 2041 and 2051 all of the flux can be considered to be concentrated in the range between 200 and 255 kev, and 140 and 200 kev respectively. The residual flux in the two adjacent energy ranges can be explained as not being real but rather due to the non-zero and non-100% efficiency for higher and lower energy channels.

It should be pointed out that after 2103 the difference spectrum becomes less trustworthy since the fraction of the flux in a particular energy range is based on the total flux measured above 105 kev and we have no knowledge of the flux of lower energy protons.

If we now make the justifiable assumption that the incident proton flux is indeed monoenergetic we can pin down the times at which we see 255 , 200 and 140 kev protons. This is done by observing the total flux of incident protons and noting the time when the flux measured in a particular channel falls by 50% below the total flux. We can say, therefore, that we see 255 , 200 and 140 kev protons at 2039, 2047 and 2105.5 U.T. respectively.

Similarly, Figure 5 presents a more detailed view of the large proton event of August 28, 1961. Since the pitch angle distribution was quite steep, the event is presented as depicted by 90° and 15° p.a. protons. For the low pitch angle there is present a considerable amount of scatter which may be partially due to low count rates (at 2×10^3 protons/cm²sec ster the actual count rate is about 10/sec) and partially

due to the steepness of the pitch angle distribution. Also, for 15° pitch angle the intensity of > 255 kev protons was too low to be observable.

As mentioned previously, not all events give indications of strictly monoenergetic fluxes. Indeed, a careful analysis of both the events of September 22 and August 28, 1961 shows that during the initial rise of the proton intensity the > 255 kev protons trail the > 200 kev protons by as much as a factor of 1.5 - 2. Considering the later splitting between the channels of almost two orders of magnitude this is a small effect which, however, lies outside of experimental errors. Later we shall present arguments to account for it.

Note on Electrons:

As remarked above, the detector also responds to the electron flux through the Au scattering discs and the 8th dynode current. Since, however, the detector sensitivity for electrons cannot be approximated by a step function it is impossible to determine the electron energy spectrum directly. One is forced to assume a spectral form and see how the calculated response compares with the observed one. Under these conditions the determination of the spectrum is not unique. For the purposes of this report we shall confine ourselves only to a few general statements about electrons.

In general, the proton flux increases are accompanied by simultaneous (within one or two minutes) increases in the electron flux. There are, however, some cases where the increases are very gradual and it is impossible to define the starting point to within 10 minutes. In some other cases there is no observable increase in the electron flux. This is notably true for the large event of August 28, 1961. Due to the complexity of the problem we shall defer the discussion of electrons until a later time.

DISCUSSION

The appearance of monoenergetic fluxes whose energy changes with time is hard to explain on the basis of local acceleration of protons. A much more plausible hypothesis is that the energy dispersion observed is due to the drift of particles in the magnetosphere. As an example one could picture protons being produced impulsively somewhere in the magnetosphere with a certain spectrum and then drifting in longitude to the position of the satellite.

This hypothesis can be checked by calculating the drift velocities of particles with different energies and pitch angles and seeing whether by extrapolating backwards one can find a common origin of these protons in space and time. In this way one could also check whether the

appearance of a magnetic bay could be associated with the course of the production of the proton event.

The calculations were made for a dipole field [Lew, 1961] and a distorted magnetosphere [Mead, 1964; Williams and Mead, 1965; Roederer, 1966]. The results for the events of August 28, 1961 and September 22, 1961 are presented in Figure 6.

The diagram shows the instant of observation of protons with energies of 140, 200, and 255 kev plotted on the time axis. The error bars indicate the estimated maximum uncertainty in the time of observation. Plotted below are times at which these protons would have been injected into the midnight meridian of the magnetosphere had they drifted in a dipole field or the distorted field. For the latter model calculations show that in several instances the protons must have originated on open field lines. [Roederer, private communication.]

On the bottom of the diagram are shown times at which onsets of magnetic bays were observed at different stations located close to the midnight meridian. As onset we take the time of the greatest rate of change of the H-component. The horizontal bars indicate the uncertainty in determining the onset of the bay from magnetograms.

From both events one can see that if the interpretation of the proton events as particle drift around the magnetosphere is correct then the distorted field model agrees better with the hypothesis that protons are injected into the magnetosphere at the midnight meridian during the onset of a magnetic bay than the dipole model. In particular, the distorted field model clearly supports the experimental observation that particles with low equatorial pitch angles are seen earlier than those mirroring close to the equatorial plane. This is due to the decreasing importance of the curvature drift for particles mirroring on the equator [Roederer, 1966]. By contrast the dipole model of the magnetic field predicts just the opposite effect.

A perusal of magnetograms shows that characteristic times for the onset of sharply defined negative bays is at least 3-5 minutes. If we now accept the hypothesis that protons are injected into the magnetosphere during the "fall time" of the bays, we can account for the slight mixing of different energy protons reported earlier and possibly for the initial hardening but not strictly monoenergetic behavior of the protons in some of the events.

In spite of the apparent accuracy of the prediction made by Pudovkin and Smirnov [1966], we feel that it is still premature to say that the observed drifting protons cause magnetic bays. At this point we do not have enough statistics on the occurrence of these events, nor is the mechanism clear how proton precipitation can produce ionospheric currents of the kind necessary for the production of negative bays.

SUMMARY OF OBSERVATIONS

Following is a summary of our observations and their interpretation:

1. Protons are injected impulsively at the night side into the magnetosphere during magnetically quiet periods. The intensities observed reach 10^6 p/cm² sec ster.
2. The energy of the protons observed ranges from about 300 to 100 kev with the majority having about 100 kev energy.
3. The injection is closely associated with the appearance of magnetic bays in the auroral zone.
4. Before being observed by the detector the protons drift in longitude thus appearing as monoenergetic fluxes whose energy decreases with time.
5. The distorted field model of the magnetosphere produces better agreement with the observations than does the dipole model.

ACKNOWLEDGMENTS

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I am also grateful to Mr. L. R. Davis, Dr. D. H. Fairfield, Dr. R. L. Kaufmann, Dr. M. Sugiura and Dr. J. G. Roederer for useful discussions and in addition, to Dr. D. H. Fairfield for furnishing some magnetograms and to Dr. J. G. Roederer for performing calculations of the drift times in the distorted field model.

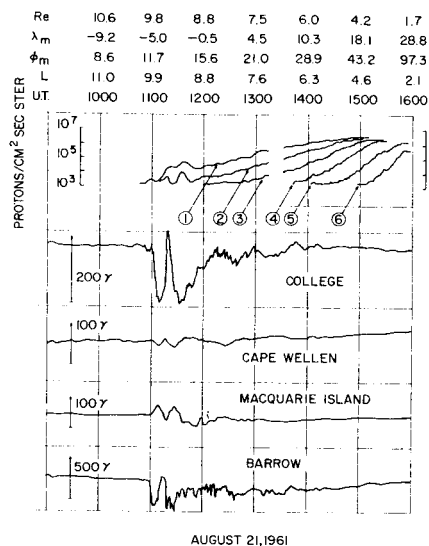
REFERENCES

- Davis, L. R., Low-energy trapped protons and electrons, Proceedings of the Plasma Space Science Symposium, edited by C. C. Chang and S. S. Huang, D. Reidel Publishing Co., 1965.
- Davis, L. R., and J. M. Williamson, Outer zone protons, Proceedings of Advanced Study Institute on Radiation Trapped in the Earth's Magnetic Field, D. Reidel Publishing Co., 1966.
- Davis, L. R., and J. M. Williamson, Low-energy trapped protons, Space Res. 3, 365-367, 1963.
- Lew, J. S., Drift rate in a dipole field, J. Geophys. Res., 66, 2681-2685, 1961.
- McIlwain, C. E., Redistribution of trapped protons during a magnetic storm, Space Research V, 374-391, 1965.
- Mead, G. D., The motion of trapped particles in a distorted field, Goddard Space Flight Center Preprint X-640-65-434, 1965.
- Mead, G. D., Deformation of the geomagnetic field by the solar wind, J. Geophys. Res., 69, 1181-1195, 1964.
- Pudovkin, M. I., and N. S. Smirnov, Two types of particle injection into the polar zone, Geomagnetism i Aeronomia, 6, 166-168, 1966.
- Roederer, J. G., On the adiabatic motion of energetic particles in a model magnetosphere, Goddard Space Flight Center Preprint X-640-66-304, 1966.
- Vernov, S. N., I. A. Savenko, M. V. Teltsov and P. I. Shavrin, Measurements of protons with the energy of 0.4 - 8 Mev on the satellite "Cosmos-41", Geomagnetism i Aeronomia, 5, 645-648, 1965.
- Williams, D. J., and G. D. Mead, Nightside magnetosphere configuration as obtained from trapped electrons at 1100 kilometers, J. Geophys. Res., 70, 3017-3029, 1965.

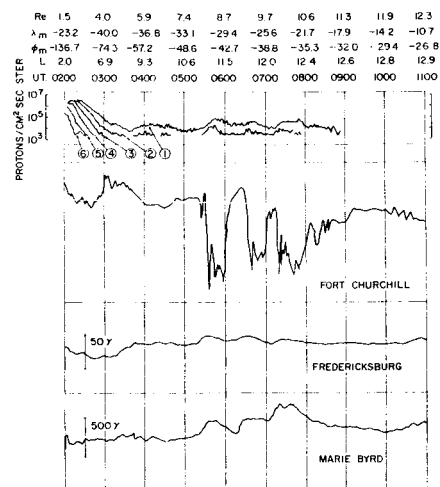
FIGURE CAPTIONS

- Figure 1: Proton intensities as a function of time on six Explorer 12 passes. In each case curves 1 through 6 show the intensities of 90° pitch angle protons with energies larger than 140, 200, 255, 460, 970 and 1700 kev. Plotted underneath each are traces of the horizontal component of the magnetic field recorded at several stations located close to the midnight meridian. Note the characteristic increases in the proton intensities associated with magnetic bays.
- Figure 2: Geomagnetic latitude, radial distance, and McIlwain's L as a function of geomagnetic local time for the times at which sudden proton flux increases were seen. All of the observed fluxes occurred in the outer zone with $L > 8$.
- Figure 3: Expanded plot of the proton intensity increase observed during the event of September 22, 1961. Note the almost simultaneous initial rise in the intensity of larger than 105, 140, 200 and 255 kev protons with a subsequent softening of the energy.
- Figure 4: Energy spectrum of the proton flux as a function of time for the event of September 22, 1961. The diagram shows the fraction of the total proton flux present in four energy intervals established by the cut-off energies of the integral flux channels. After about 2107 U.T. the data is unreliable since the > 105 kev channel probably cannot serve any longer to measure the total flux.
- Figure 5: Expanded plot of the proton intensity increase observed during the event of August 28, 1961. The depicted protons have pitch angles of 90° and 15° . Again one can see the initial increase of protons with energies larger than 255 kev with a subsequent softening of the proton energy.
- Figure 6: Times of observation of protons with energies of 140, 200 and 255 kev for the events of August 28, 1961 and September 22, 1961. Also shown are times when these protons would have been injected into the midnight meridian of the magnetosphere had they drifted around to the point of observation. For comparison the onset times of magnetic bays

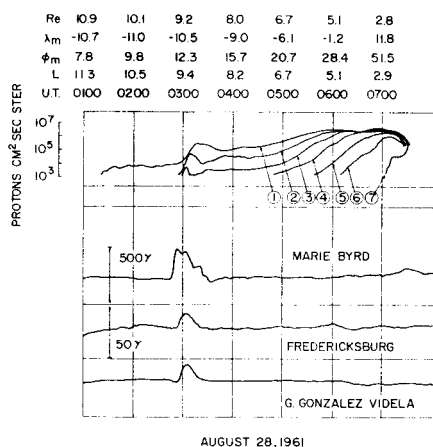
several stations are given. The error bars indicate the estimated maximum uncertainty in the time of observation of specific energy protons.



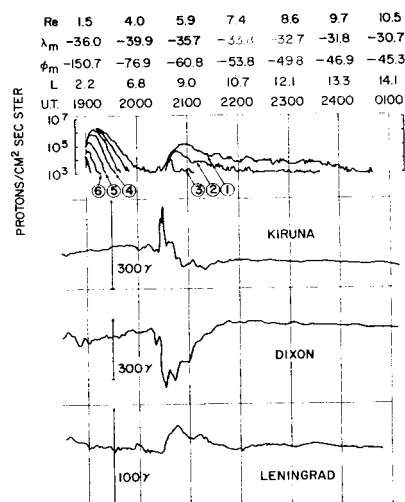
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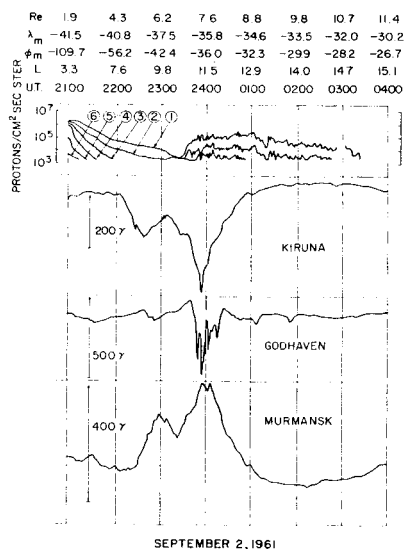
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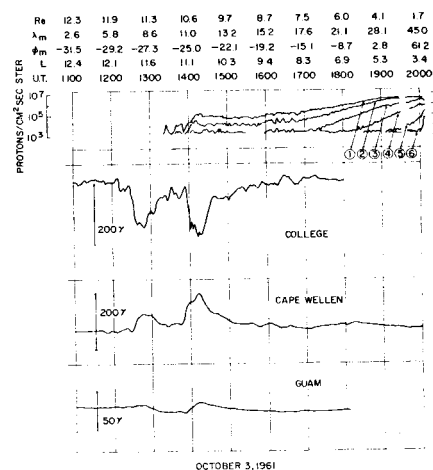
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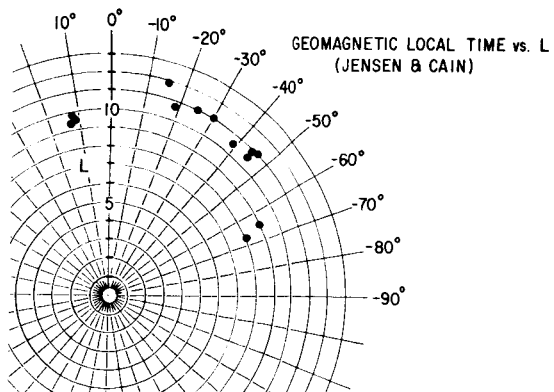
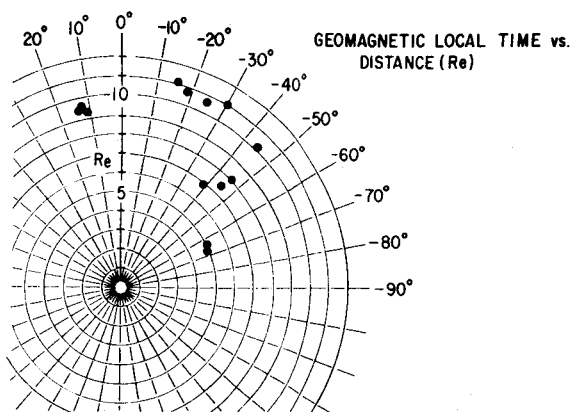
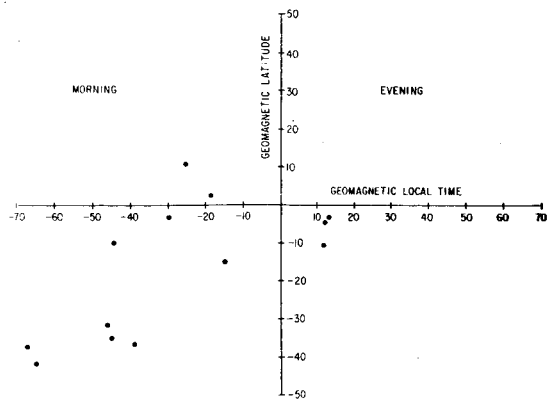
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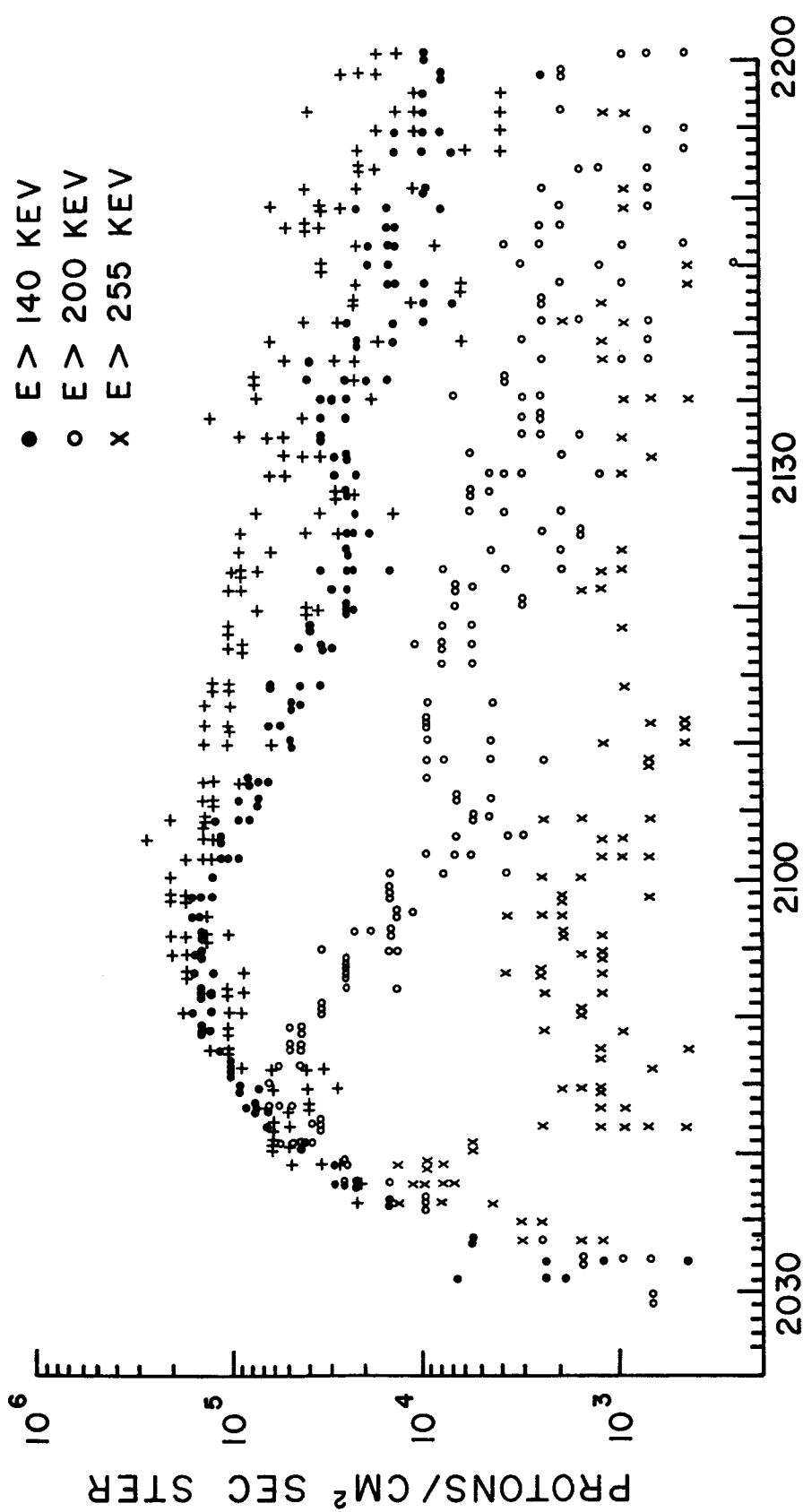


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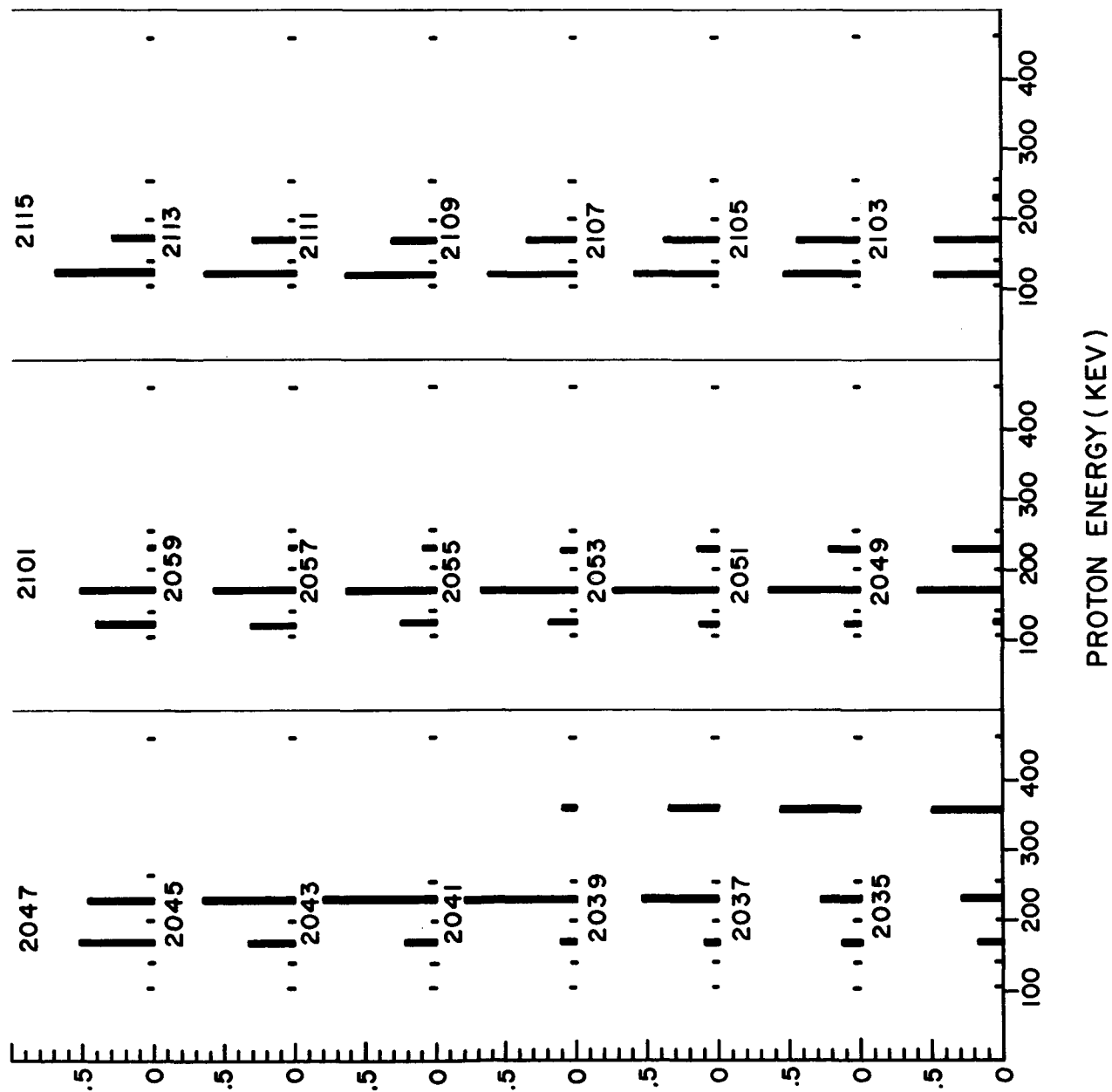
SEPTEMBER 22, 1961
80°-100° PITCH ANGLE

+ E > 105 KEV
● E > 140 KEV
○ E > 200 KEV
x E > 255 KEV

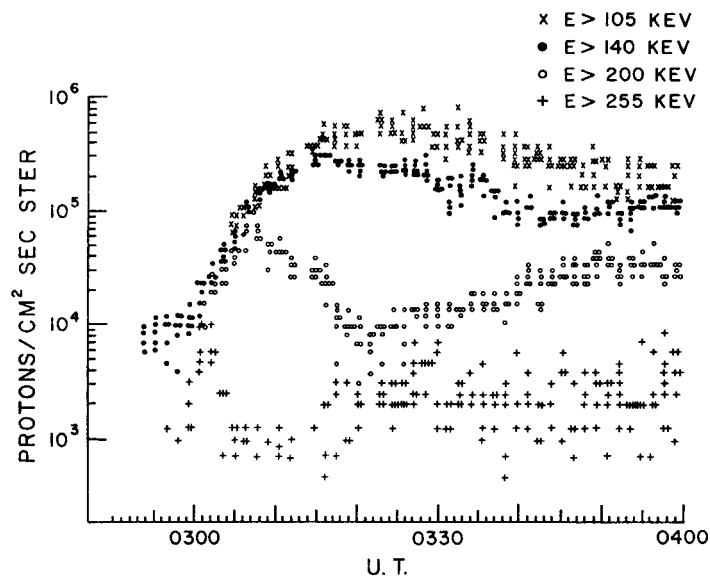


U. T.

SEPTEMBER 22, 1961



AUGUST 28, 1961
80°-100° PITCH ANGLE



AUGUST 28, 1961
0°-20° PITCH ANGLE

