tions to the particles of the order of $v$. On this basis we expect the protons to receive most of the energy because of their greater mass.

**Dungey, J. W.:** The formulation in terms of $p_{\parallel}$ and $p_{\perp}$, used by fusion theorists, is convenient for the ring-current problem with axial symmetry, the equation in the equatorial plane is integrable.

If Prof. Parker's system is correct (100/cc at 1 kev) this is encouraging for mirror machines.

**Slutz, R. J.:** Prof. Singer has emphasized his viewpoint of the difficulty of explaining a negative kick before the sudden commencement from simple geomagnetic field compression. Could Prof. Parker give his views on this point?

**Parker:** I agree with Prof. Singer that the negative kick is a phenomenon which has not yet found suitable explanation. I think that Prof. Singer mentioned the negative kick to illustrate the complexity of the many different facts at the magnetic storm problem and to emphasize that the basic and idealized mechanisms currently under discussion need considerable extension before the theory will be complete.

**Kellogg, P. J.:** I would like to ask Dr. Parker how he reconciles his statement that the energy of the outer Van Allen zone is too small to produce appreciable magnetic effects with Dessler's published remark that fluxes measured by the Minnesota and Iowa groups are impossibly large because they would produce a larger magnetic effect than is observed.

**Parker:** We don't believe the Minnesota results.

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# I-3-P3. Particle Precipitations and Geomagnetic Storms*

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It has been known for many years that solar corpuscles streaming out from the sun produce various electromagnetic disturbances in the earth's upper atmosphere. In particular, an intense solar flare produces not only a plasma cloud, which is responsible for a geomagnetic storm, but also very high energy particles known as solar cosmic rays. These energetic particles are mostly protons with energies from 10 to 1000 Mev. They penetrate into the polar ionosphere causing polar cap absorption. It is also known that energetic electrons are precipitated into the auroral zone during the storm.

It is evident that the earth's upper atmosphere is exposed to particles with a very wide energy spectrum. The behavior of particles in the geomagnetic field differs considerably depending on their energies. This information may be used to explore the geomagnetic field during magnetic storms.

One of the important basic problems in the theory of geomagnetic storms is to find whether those particles entering into the geomagnetic field behave like single particles or like a conductive plasma. As shown in Fig. 1, for a typical energy versus density spectrum of solar flare particles, there is a certain critical density below which the electromagnetic interaction becomes negligible and the motion of the particles will then be nearly independent of each other. This limit of the so-called Störmer particles, occurs in the energy range of 10 to 100 Mev. Particles with energies less than this must be regarded as a conductive plasma rather

* No manuscript has been received and the preprint is reprinted.

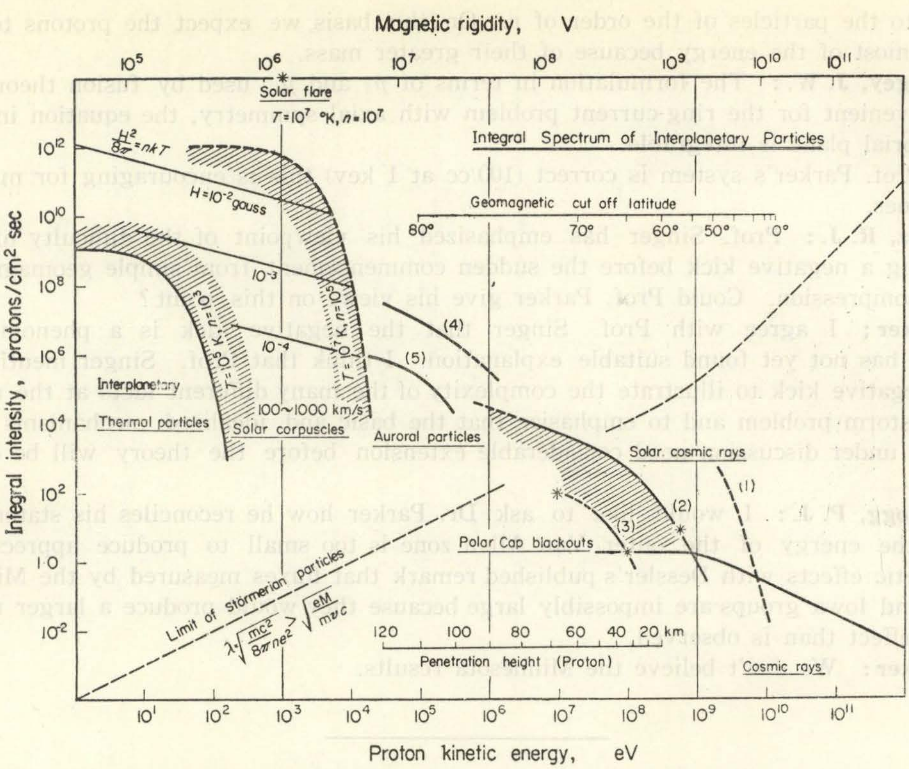


Fig. 1. The integral energy spectrum of solar particles associated with intense solar flares.

than single particles.

It follows that low energy particles will distort the geomagnetic field, penetrating down to a distance where the impact pressure of the gas is balanced by the magnetic pressure. The geomagnetic field is confined within this boundary, and particles are streaming around such a cavity. On the other hand, high energy particles enter through the cavity into the polar ionosphere. Since during geomagnetic storms, these particles are affected by the distorted field, the precipitation pattern may be quite different to that which occurs during a geomagnetically quiet period. Average patterns of polar cap absorption before and during geomagnetic storms are shown in Fig. 2. It is demonstrated that polar cap absorption before the onset of geomagnetic storms is confined above geomagnetic latitudes 60°–65°; while the absorption spread stoward low latitudes, occasionally as low as latitude 50°, during the main phase of a storm. The observed southward shifting of the high absorption region is closely related to the development of the *Dst*-field of geomagnetic storms. This effect may be explained by a lowering of geomagnetic cut-off energy for incoming particles due to distortion of the field.

During a geomagnetic storm, various particles impinge mainly along the auroral zone, where they produce aurorae, ionospheric absorption and polar magnetic storms. Many investigators found that the precipitation pattern of particles shows a spiral shape; polar blackouts form a right-hand spiral, while sporadic *E* forms a left-hand spiral. The zones of geomagnetic agitations and aurorae also show evidence of spiral precipitation patterns. There is some argument as to whether this spiral precipitation is that predicted by the Stormer theory. It must be noted that in nature Störmer's spiral can hardly be expected in its pure form, because the geomagnetic field may be considerably distorted during störms and the angular size of an apparent source of incoming particles must be enormously large. Nevertheless, the observational evidence, indicating the existence of a certain impact zone, suggests that the incoming particles are not isotropic.

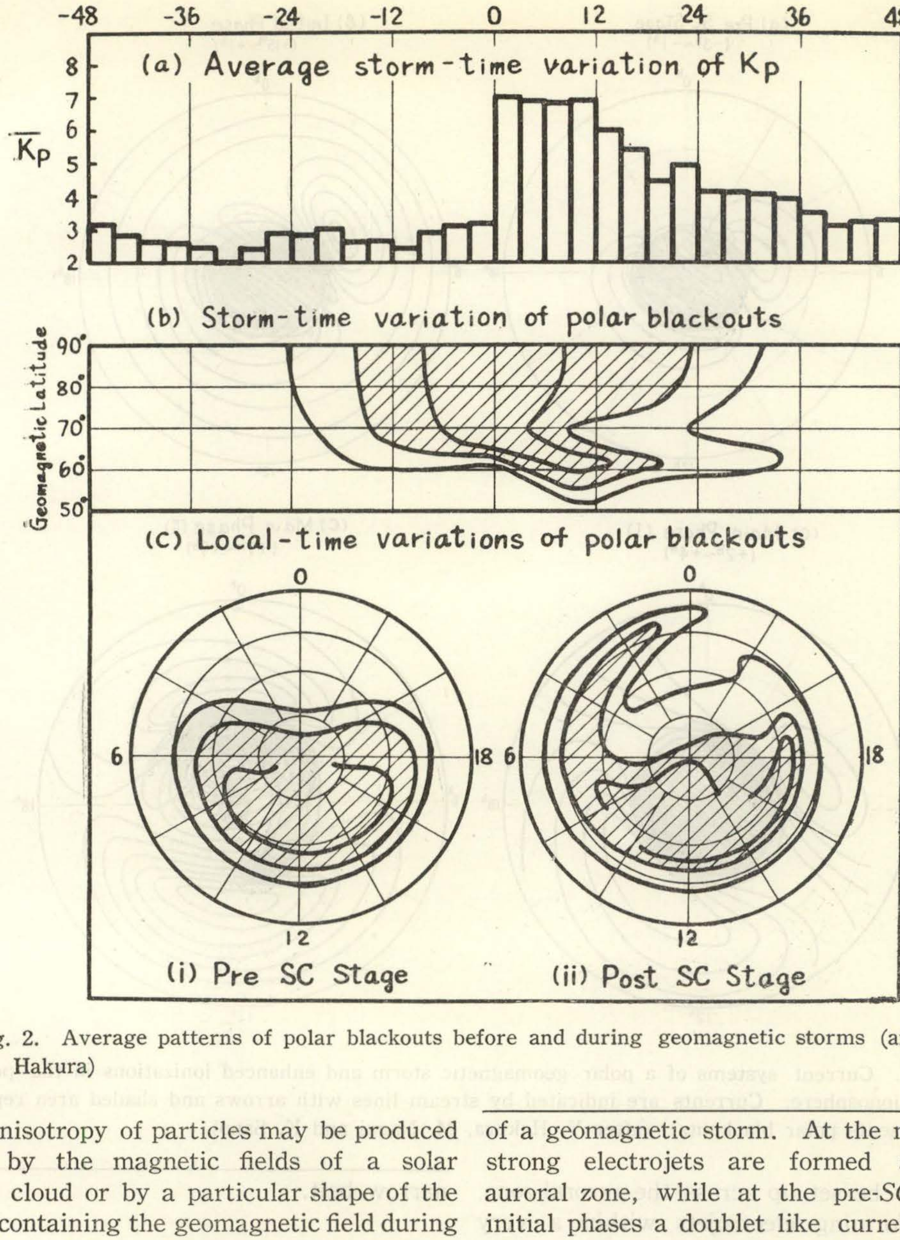


Fig. 2. Average patterns of polar blackouts before and during geomagnetic storms (after Y. Hakura)

Such anisotropy of particles may be produced either by the magnetic fields of a solar plasma cloud or by a particular shape of the cavity containing the geomagnetic field during the storm. The latter view has been developed recently by Axford and Hines, who showed that motions in the magnetosphere caused by the plasma stream from the sun can account for various disturbance phenomena in the polar regions.

In connection with particle precipitations, the current systems of geomagnetic disturbances in the polar regions are of special interest. Three types of disturbance current systems are shown in Fig. 3, *viz.*, current systems at the pre-*SC* polar cap absorption, at the initial phase and at the main phase of a geomagnetic storm. At the main phase strong electrojets are formed along the auroral zone, while at the pre-*SC* and the initial phases a doublet like current system is found in the polar cap. It is significant that currents are concentrated in the region where the particles are precipitating. It is suggested that the current system may be derived by a polarization field due to precipitating particles in the presence of the geomagnetic field. Hall current loops produced by such electric fields show some resemblance to the current systems at the pre-*SC* and the initial phases. For the main phase of a storm, the effect of the distortion of the geomagnetic field becomes important. As has been proposed by Fejer, the polarization

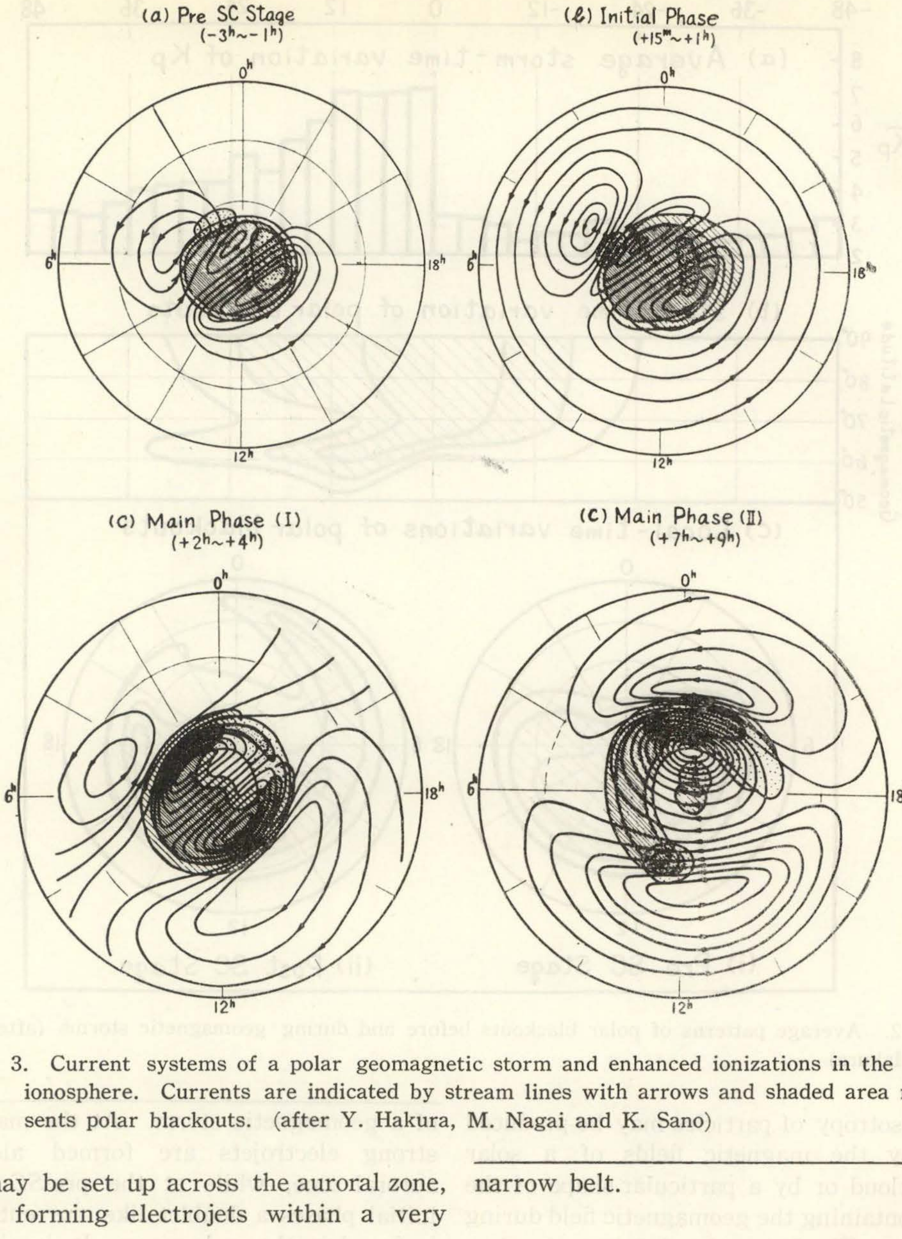


Fig. 3. Current systems of a polar geomagnetic storm and enhanced ionizations in the polar ionosphere. Currents are indicated by stream lines with arrows and shaded area represents polar blackouts. (after Y. Hakura, M. Nagai and K. Sano)

fields may be set up across the auroral zone, thereby forming electrojets within a very narrow belt.

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***Discussion*** for Paper I-3-6

**Rothwell, P.:** Is there any preferred direction in latitude to which a loaded magnetic field line would move during a magnetic storm? If a pair of field lines exchange place during a magnetic storm, would the line containing the greater density of charged particles move to a higher or lower latitude?

**Gold, T.:** It would move to a higher latitude, if the energy released in the resulting expansion exceeded that required to push another tube low down. The balance distribution of gas pressure on the equator is approximately an inverse fourth power low with distance from the center of the earth.