Obayashi, T.: Is there any significant onset time difference with respect to the difference of energy precipitating into auroral zone? For example comparing with balloon observations and riometer.

Brown: Nothing of this sort has been observed—as far as we know the balloon X-ray data agree in time with the riometer data.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-2-2. The Types of Blackout, Their Time Variations, and the Mechanisms Producing Them*

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Two initially unexplained results appeared in early statistical studies of blackout: (1) Duration increases with latitude, and (2) Maximum percentage of time of blackout has a later local time of occurrence at higher latitudes. The first is the result of the fact that the polar cap absorption events are produced by solar protons entering the earth's atmosphere over periods of days (during a given event) while blackout at lower latitudes has an entirely different primary production mechanism. The explanation offered here for the second is based in part on the difference between the two primary production mechanisms. In addition, it is suggested that at auroral (and lower) latitudes blackout is produced primarily by electrons from an outer Van Allen belt rendered asymmetric by the effects of the solar wind, that photo-detachment is effective during daylight hours in maintaining the absorbing ionization, and finally that (at sub-auroral latitudes) the pre-dawn maximum in blackout occurrence is a result of moderate absorption occurring during the hours of low maximum ionization density in the F-region.

Early statistical studies of the occurrence of polar blackout [Meek, 1952; Cox and Davies, 1954; Agy, 1954] led to two unexplained conclusions:

1) The duration of blackout increases with increasing latitude (in spite of a greater prevalence of blackout near the auroral zone) —Fig. 1; and

2) The maximum frequency of occurrence of blackout is at later local times at higher latitudes—Fig. 2.

The first of these, confirmed in more recent work by Kasuya [1960] has now been explained [Bailey, 1957; Hakura *et al.* 1958; Reid and Leinbach, 1959] as due to a very real difference in type between blackouts normally observed over the polar cap and those observed near the auroral zone. The polar cap absorption events usually begin, at least, within a few hours of the time of occurrence of a solar flare. They can be attributed to the ionizing effects of high energy protons emitted by the sun (at the time and from the vicinity of the flare) and arriving at the earth more-or-less directly. There can be little doubt about their continued arrival at the earth for periods of several days over large areas of the polar cap, although it is unlikely that the emission itself is of long duration. The auroral zone blackouts, on the other hand, are of relatively short duration and are usually limited to relatively small areas—on the order of some hundreds of kilometers in extent. The polar cap absorption events may often occur during magnetically quiet periods, while the auroral

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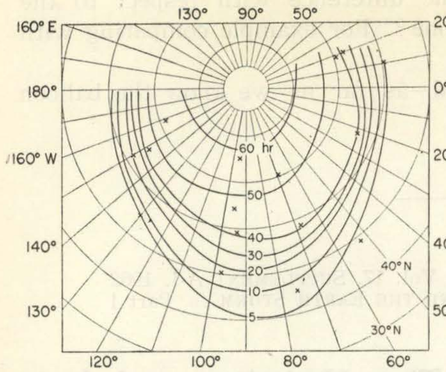

Fig. 1a. Average Duration of 8 Long-Lasting Blackouts (1949-1952).

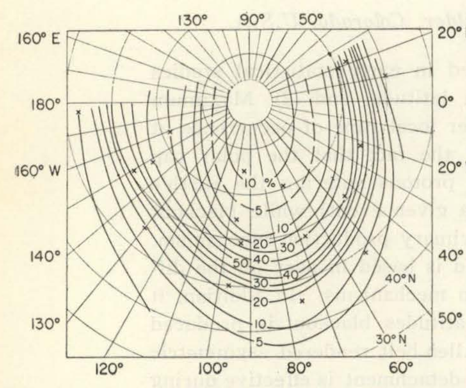

Fig. 1b. AveragePercentage of Time of Blackout —Disturbed Days (1949-1952).

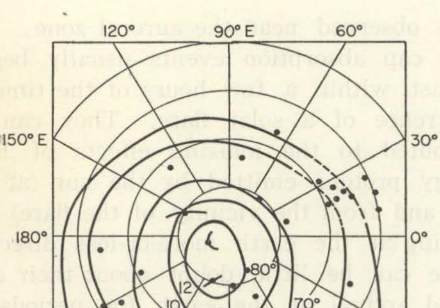

Fig. 2. Local Mean Time of Maximum Frequency of Blackout OccurrenceI—GY (Northern Hemisphere—Geographic Coordinates).

zone blackouts are usually associated with magnetic activity (although they appear to occur most frequently at a time some hours later than the time of peak magnetic disturbance).

The second unexplained result—that of local time variation with latitude—can be examined by drawing the isochrons in universal time. If this is done, a set of "spirals" is derived as shown in Fig. 3 [Kasuya 1960;

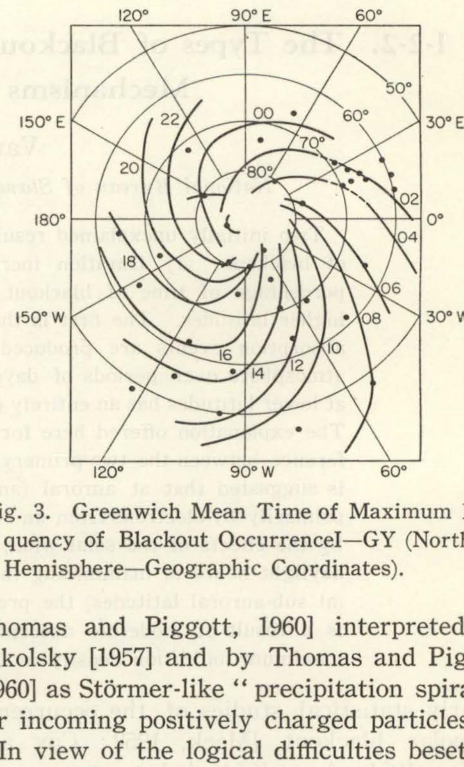

Fig. 3. Greenwich Mean Time of Maximum Frequency of Blackout OccurrenceI—GY (Northern Hemisphere—Geographic Coordinates).

Thomas and Piggott, 1960] interpreted by Nikolsky [1957] and by Thomas and Piggott [1960] as Störmer-like "precipitation spirals" for incoming positively charged particles.

In view of the logical difficulties besetting the Störmer theory, and the recently discovered complexities of interplanetary space, it seems unlikely that the Störmer precipitation patterns have any direct bearing on the problem [Agy, 1960]. It is felt that, in fact, there are numerous contributing causes for blackout occurrence and that the time patterns cannot be adequately treated without taking "all" of them into account. The explanation contained in the remarks to be given here is not entirely satisfactory nor is it logically complete, but the phenomena described are thought to be effective in producing blackout and would operate in such a way as to reproduce in large measure the time patterns actually obtained.

Over the polar cap blackout is almost if not quite entirely due to the ionizing effects (down to altitudes of 50 km or so) or energetic solar protons. They may continue to arrive over periods of several days but will be most effective in producing blackout during daylight hours when electron loss is forestalled by the photo-detachment process. In the polar cap, then, the diurnal variation will have its maximum near midday. Solar protons do at times come in along the auroral zone, but in fact do not contribute heavily to the blackout experienced at these latitudes. Therefore, since the mechanisms for polar cap and auroral zone blackout are essentially different, the high latitude (local midday) isochrons are apparently a part of the overall pattern more by coincidence than by cosmic design.

Recent observations of X-rays at balloon heights (Anderson and Enemark, 1960; Brown, 1961] (bremsstrahlung from electrons absorbed in the earth's atmosphere) appear to be correlated with riometer observations of ionospheric absorption. Ionization produced in the D-region by incoming electrons is suggested as the primary cause of auroral zone blackout. The source, to be discussed later, of these electrons is thought to be the (or perhaps *a*) Van Allen radiation belt. Here again, the diurnal variation is thought to be affected by photo-detachment and blackout occurs most frequently during the morning (sunlit) hours even though the impinging electrons are most numerous some hours earlier. The post-sunrise maximum, then, in the occurrence of blackout is not an indication that the electrons arrive in greater numbers at that time, but that their effect in producing absorption is enhanced by the effects of sunlight in maintaining the ionization through photo-detachment.

At latitudes below that of the auroral zone, blackouts occur most frequently, according to the f min analyses, in early morning before dawn. This may not, in fact, be the time of maximum absorption but absorption will be most effective at these hours in producing apparent blackout because this is the time of minimum $foF2$.

The smooth progression of local time with latitude, found by relatively long term averaging of the data, may, then, in part be due to the overlap in time and space of somewhat different mechanisms in the three latitude regions discussed—sub-auroral, auroral, and polar cap.

The suggested source of the electrons primarily responsible for blackout at auroral latitudes and below is a "trapping" region—(a Van Allen "belt")—from which the electrons escape into the earth's atmosphere. Unfortunately, postulating such a source poses more problems than it solves. The process of acceleration out of the belt is not known nor is the reason for the midnight to dawn preference for the dumping that occurs. The equatorial radius of the trapping region (in a dipole field) must be 6 or more earth radii in order to account for precipitation in the auroral zone and this is greater than that indicated by space vehicle measurements of the recognized "outer" Van Allen belt [Van Allen and Frank, 1959]. If, however, we accept the suggestion that the blackout-producing electrons arrive from such a region, it is interesting to consider it further.

The nature of the trapping is such that in addition to the spiralling motion about the lines of force and the north-south oscillation of the particles, there will be a relatively slow drift in longitude, *i.e.* in a direction determined by the cross product of the field gradient and the field itself [Gold, 1959]. The solar wind [Parker, 1958] moving toward the earth will "compress the lines of force" on the sunward side of the earth (strengthening the magnetic field), and the trapping region will assume an asymmetry with respect to the earth, being at a greater distance from the earth on the day side (Fig. 4). The trapping region and the precipitation geometry outlined (essentially similar to that proposed by Reid and Rees [1961] in explanation of the time-latitude variations of H_α in auroral spectra) accounts for the recognized magnetic field control of blackout occurrence, but in view of the mechanisms previously discussed, cannot be invoked to explain the entire time-latitude blackout spiral. Sporadic E data as analyzed by Hagg *et al*. [1959] or by Thomas [1960] suggest spiral patterns which may similarly be produced by precipitation from the trapping region on the afternoon side of the earth. This is an interesting speculation, but according to the argument presented here, the

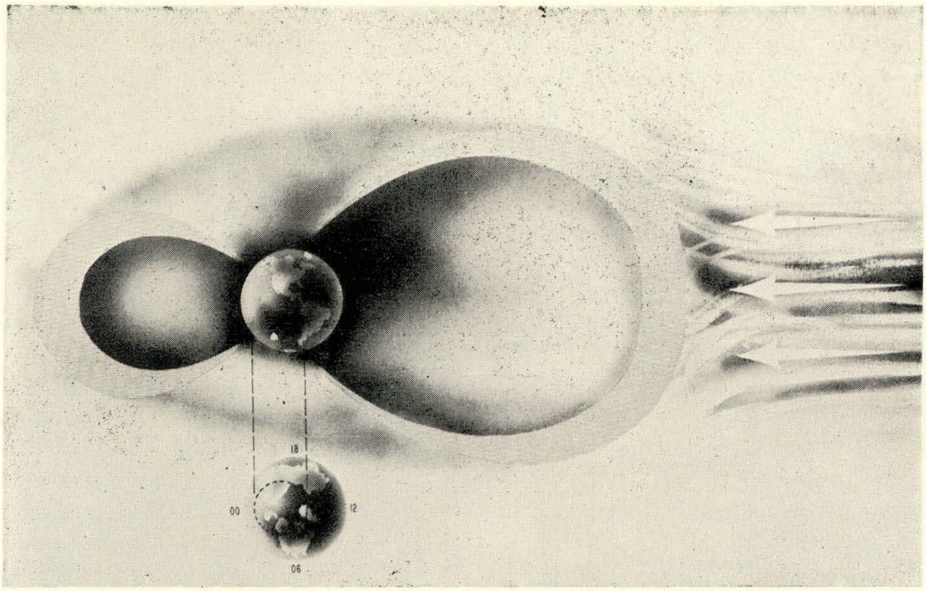

Fig. 4. Suggested Asymmetric Radiation Belt—Source of Blackout-Producing Particles.

sign of the charge carried by the impinging particles cannot be inferred from the sense of the "spirals", as would be the case if the Störmer mechanism were accepted. If, however, the sporadic E patterns are related to the blackout patterns in this way, it will then be necessary to explain the deeper atmospheric penetration of the particles on the morning side of the precipitation region (producing blackout) and the lesser penetration on the afternoon side (producing sporadic E).

Any explanation must, of course, deal first with the regular features of the phenomena. The present one is an attempt to do so. But the small scale features and the irregularities—the departures from the overall pattern stressed here—must also eventually receive proper attention. However, the *f-min* data used in the delineation of the patterns described are probably not adequate for the purpose. It is likely that at every station low $foF2$ will at times have the effect of producing apparent blackout when absorption is not necessarily excessive. The broad temporal variations described here appear to be relatively stable over the sunspot cycle, but for a precise determination of the *amount* of absorption or the percentage of time of blackout, other means must be used. For example, many stations show far more "blackout" during the sunspot minimum year of 1954 than during the active IGY period, but this is felt to be due more to the relative lack of ionization in the F region than no excessive ionization in the D region. During magnetic disturbance (highly correlated with the occurrence of blackout) the maximum ionization density in the F region is reduced and the results based on $f$min data analysis are almost certainly affected.

It is clear that much is still to be done. Further synoptic studies are required which will depend to a large extent on data which may be deemed more reliable than those used in the past. It is hoped that data from an increasing number of riometers may become more generally available by their inclusion in material now being deposited in the World Data Centers.

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Discussion

Hill, G. E.: The occurrence of more blackout in the morning hours compared to the evening may be mainly due to the diurnal variation of the $F2$ layer critical frequency.

Agy, V.: Perhaps, but it is doubtful that this effect is strong in the auroral zone where the maximum frequency of occurrence is well after sunrise.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-2-3. Polar Cap and Auroral Zone Absorption Events During the First Six Months of the I.G.Y.

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Our investigation consisted of synoptic analysis of ionosonde data for the first six months of the IGY. The purpose was to study thoroughly the development of high latitude absorption events. To do this Northern Hemisphere synoptic charts of f_{min} (the lowest frequency observed on ionograms) were analyzed for the six-month period at intervals of three hours. From these charts, a comprehensive list of polar cap and auroral zone absorption events has been compiled. To illustrate quickly the technique of analysis a typical SID is shown as it appears on a synoptic chart. Important features of this SID are seen at a glance: absorption on only the sunlit side of the earth and increased