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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-4-12. Auroral X-Ray Observations at Minneapolis, Minnesota

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Bursts of X-rays, time associated with aurora near the zenith and negative magnetic bay storms, have been observed by balloon borne detectors. A few X-ray bursts observed during the positive magnetic disturbances indicate that the precipitation of electrons during such periods have to take place at a location farther north of the point of observation. The relation between the sign of the magnetic bay disturbance and the location of the electron precipitation responsible for the auroral X-rays is discussed.

§ 1. Introduction

In the year 1957 Winckler and co-workers[1] first observed an X-ray burst over Minneapolis which was time associated with a strong aurora at the zenith. After this on several occasions X-rays have been observed by us, and quantitative measurements have been made of the energy spectrum and of the total energy incident at the top of the atmosphere in the form of electrons of energy >20 Kev[2),3)]. These observations are made with detectors like ion chambers, Geiger conuters and NaI scintillation counters flown on high altitude balloons during magnetic disturbances and auroral storms.* Some special features of the X-ray bursts and the storms accompanying them will be discussed.

§ 2. Beginning of the Storm at Minneapolis

A typical auroral storm at Minneapolis starts in the following way. During a period when there is some activity on the sun or a CMP of an active region, the total magnetic field at Minneapolis starts increasing around 3:00–4:00 p.m. and develops into a positive bay of about an hour's duration with a field change of about 50–200 gamma. Majority of these positive bays are of the quiet type, and do not show much fluctuation of the field. The magnetic field then drops and remains 10–20 gamma above its normal value. Around 10:00 p.m. to midnight the field suddenly drops and develops into a large negative bay. Usually the negative bay is larger than the initial positive bay and shows fluctuations. During very disturbed periods the field remains disturbed throughout the night, but during moderate or mild storms the field returns to its normal value after an hour or two from the start of the negative bay. During some storms a second small negative bay develops around 3:00 a. m. and sometimes as late as 8:00 a.m. There are a few occasions when three negative bays have also been observed.

We start preparations for a balloon launch as soon as the magnetic field shows the start of the disturbances; and most of the time when the balloon reaches ceiling altitude the positive bay storm is over at Minneapolis. If the sky is clear, we see a low quiet auroral arc in the north, at the time when the negative bay starts developing, which then rapidly moves up and sometimes breaks up into rays, flaming aurora, and corona. When this happens at or near the zenith we observe a large X-ray burst on our balloon instruments.

§ 3. The X-Ray Burst

A typical X-ray burst accompanying a negative bay storm observed on July 16, 1960 is shown in Fig. 1. Its correlation with the negative bay is remarkable. As shown here and on several other occasions, these X-rays are found to be mostly of low energy of about 20–70 Kev, with very little intensity above 100 Kev. The estimated energy spectrum of the electrons responsible for these X-rays has been found to be very steep, obeying a power law of the type $N(>E)=CE^{-\gamma}$ with the value of the exponent γ around 4–5, and going up to about 7 during some intense storms, at the time of the peak X-ray intensity. The total number of electrons above 20 Kev responsible for these X-ray bursts have also been estimated and found to

* Lower energy limit for our detectors is about 20 Kev X-ray photons.

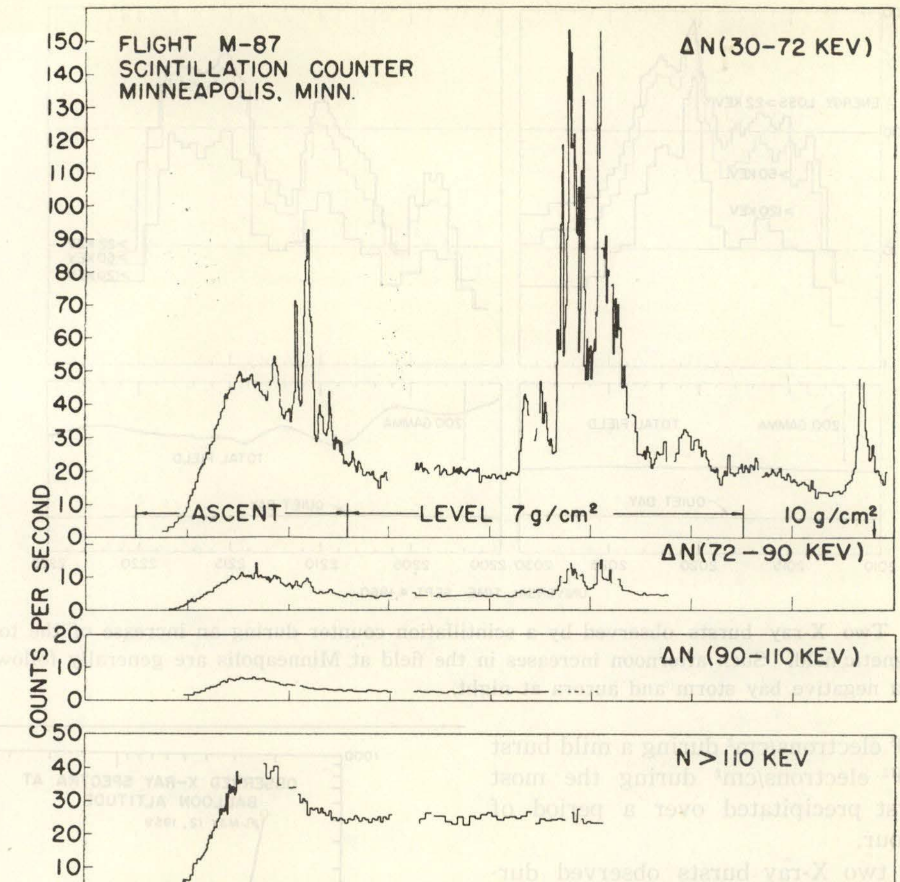

Fig. 1. A typical X-ray burst observed by a four channel NaI scintillation counter during a negative bay magnetic disturbance and visible auroral activity near the zenith.

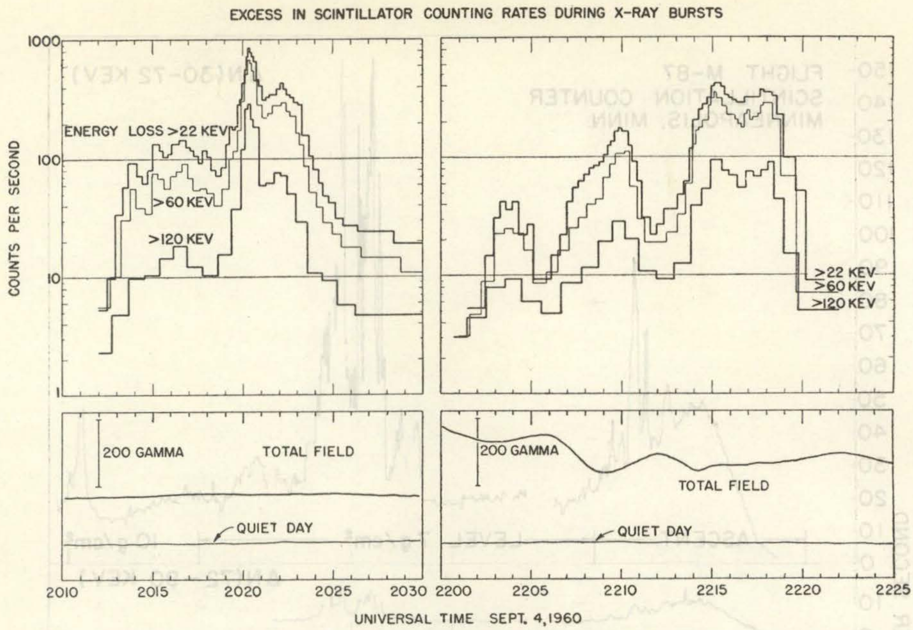

Fig. 2. Two X-ray bursts observed by a scintillation counter during an increase of the total magnetic field. Such afternoon increases in the field at Minneapolis are generally followed by a negative bay storm and aurora at night.

be about 10^8 electrons/cm^2 during a mild burst to about 10^{12} electrons/cm^2 during the most intense burst precipitated over a period of about an hour.

In Fig. 2 two X-ray bursts observed during the positive magnetic bay disturbance at Minneapolis are shown. These two bursts were observed during a flight made during the September 3, 1960 solar proton event. Both the bursts are of about 20 minutes duration. We do not see any fluctuations in the total field which is about 150 gamma above normal value during the first burst, and we see very small decreases on it during the second burst. The relation between the magnetic field changes and X-rays in this case is not at all like what we saw in Fig. 1 during a negative bay storm. A remarkable feature of these two X-ray bursts is that the X-ray energy spectra for them do not look like normally observed steep auroral X-ray spectrum during negative bay storms but are flat at lower energies. These spectra as observed at about 10 g/cm^2 atmospheric depth are shown in Fig. 3. Two regular auroral X-ray spectra observed during X-ray burst accompanying negative bay storm and the aurora overhead are also shown for comparison. The difference, as seen, is very re-

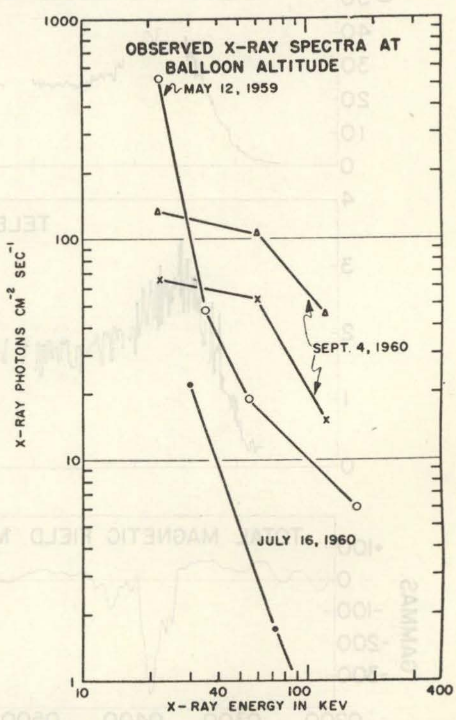

Fig. 3. Integral energy spectra of X-rays observed at balloon altitudes (about 10 g/cm^2 atmospheric depth). Note that the spectra of two bursts observed on September 4, 1960 are flat at lower energies. The two steep spectra are for X-rays during negative bay magnetic storms.

markable.

These two bursts occurred during daytime (and also during the positive bay storm); therefore, its relation with visible aurora could not be studied. However, it is definite that the precipitation of electrons responsible for these two X-ray bursts could not have taken place in the atmosphere vertically above the balloon instruments. This conclusion is drawn from the fact that another balloon which was about 40 km south of the present one did not see anything at this time. In Fig. 4 are shown the locations of the two balloons at the time of the X-ray bursts. A logical explanation is that the precipitation of electrons took place about 130 km north of the location of the balloon which observed the X-rays. This, then explains the bending over of the low energy part of the observed spectrum and no effect on the ion chamber 40 km further south on another balloon. However, a precipitation of electrons which could produce such an intense X-ray burst about 130 km away needs about 10^{13} electrons/cm^2 precipitated during each burst. This number seems abnormally high if the source of these electrons is the outer radiation belt. These two X-ray bursts could also be explained very easily if we assume that somehow a precipitation of a few hundred positrons of about a Mev energy took place in the atmosphere right above the balloon instruments. 0.511 Mev annihilation γ-rays could produce a pulse height spectrum in our detector similar to what has been observed for these two bursts. However, this is very highly improbable. This precipitation of positrons, if real, has also to be local, over an area of about a few km^2, as another balloon about 40 km away from the present balloon did not detect these X-rays.

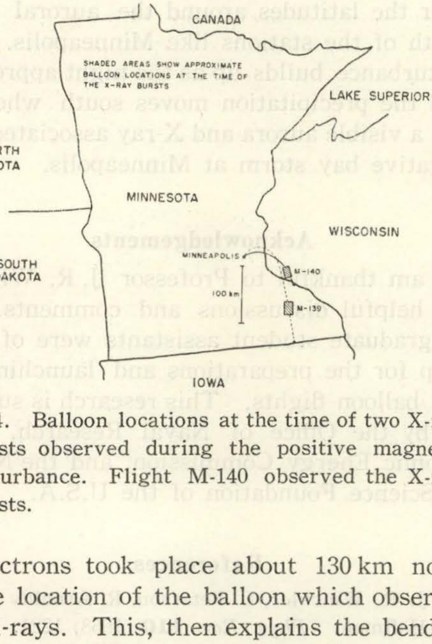

Fig. 4. Balloon locations at the time of two X-ray bursts observed during the positive magnetic disturbance. Flight M-140 observed the X-ray bursts.

Our confidence in the previous explanation, that about 10^{13} electrons/cm^2 of energy > 20 Kev, precipitated in a period of a few minutes caused these two X-ray bursts during the positive magnetic bay disturbance, is increased by a recent observation of our group at Fort Churchill. The X-ray burst was so intense that the ion chamber rate went up by a factor of 300 at the peak of the X-ray intensity. Our estimations show that about 1.8×10^5 photons/cm^2·sec of mean energy 50 Kev were crossing the balloon altitude (about 10 g/cm^2 atmospheric depth) at this time. On assuming that the X-ray energy spectrum during this burst was steep and of the same type as usually observed, 10^{12} electrons/cm^2·sec of energy > 20 Kev must have been precipitated at the top of the atmosphere during the peak of the event. The burst is shown in Fig. 5.

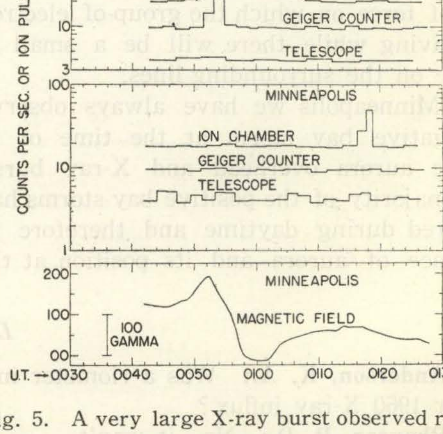

Fig. 5. A very large X-ray burst observed recently on a balloon flight from Fort Churchill. Minneapolis balloon observed X-rays about 24 minutes later.

§ 4. Discussions

Bay type magnetic disturbances have long been observed near middle and auroral zone latitudes, and their association with aurora is well established[4]. It is believed that an electric current at a height between about 150 and 100 km causes these magnetic bays. There is a difference of opinion about how this current is generated. Atmospheric winds operating on ions produced by the auroral primaries could cause this current. Alternatively, Akasofu[5] has suggested that the auroral proton and electron streams entering the ionosphere have a polarization electric field between them which might give rise to the current.

Our observations at Minneapolis show that a large number of electrons above 20 Kev are incident at the top of the atmosphere during the aurora and the X-ray bursts. The electron spectrum is found to be very steep and one does not know down to what lowest energies the electrons arrive at these times. So there could be a very large number of electrons arriving at these times below this energy. Also these electrons, if not dumped out of the outer radiation belt, at least take that path to arrive in the earth's atmosphere, and one must take into account the magnetic effects of these electrons. T. C. May[3] has made some estimations of these effects. If one takes into account only the diamagnetic effect, the position of the aurora and the electron precipitation with respect to the magnetometer location will produce different effects. There will be a field reduction on the line of force on which the group of electrons is arriving while there will be a small increase on the surrounding lines.

At Minneapolis we have always observed a negative bay storm at the time of the visible aurora overhead and X-ray bursts. The majority of the positive bay storms have occurred during daytime and therefore the presence of aurora and its position at that time could not be established. However, the results presented here, and a few more observations indicate that the electron precipitation does take place during the positive bay storms. We have also seen that to explain the observed X-ray spectrum at these times the precipitation of electrons has to be farther away from the place of observation. There are also known instances that the observations of visible aurora are associated with magnetic field increases at a station south of the auroral observation latitude.

From the evidence presented above, we are inclined to believe that on a disturbed day, at a particular longitude, the electron precipitation starts during the afternoon hours near the latitudes around the auroral zones, north of the stations like Minneapolis. The disturbance builds up as the night approaches and the precipitation moves south when we see a visible aurora and X-ray associated with negative bay storm at Minneapolis.

Acknowledgements

I am thankful to Professor J. R. Winckler for helpful discussions and comments. Undergraduate student assistants were of great help for the preparations and launchings of the balloon flights. This research is supported by the Office of Naval Research, U. S. Atomic Energy Commission, and the National Science Foundation of the U.S.A.

References

1) J. R. Winckler, L. Peterson, R. Arnoldy and R. Hoffman: *Phys. Rev.* **110** (1958) 1221.
2) P. D. Bhavsar: *J. Geophys. Res.* **66** (1961) 679.
3) T. C. May: Techni. Rep. No. CR-36, School of Phys. Univ. of Minnesota, Minneapolis, Minnesota.
4) R. C. Bless, C. W. Gartlein, D. S. Kimball and G. Sprague: *J. Geophys. Res.* **64** (1959) 949.
5) S. Akasofu: *Rep. Ionos. and Space Res. in Japan,* **12** (1958) 268.

Discussion

Anderson, K. A.: Was a riometer in operation at Minneapolis during the 4 September 1960 X-ray influx?

Bhavsar, P. D.: No., it wan't.

Young, J. M.: Low frequency sound waves we received at Washington, D. C. during the 11 February 1958 storm may in some way be related to X-ray bursts as measured at Minneapolis at that time. The direction of sound arrival at Washington points to the region north of the great lakes during that storm.

Bhavsar: It will be very interesting to study such relation between low frequency sound waves and electron precipitation in the atmosphere. We shall be very glad to part with our results to interested workers.

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I-4-P1 Theory of Auroral Bombardment*†

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An auroral theory is developed from the point of view of particle orbits in an inhomogeneous plasma confined by a magnetic field. Specifically, a mechanism is proposed for ejection into the atmosphere of geomagnetically trapped protons and electrons. It is assumed that the energetic particles are distributed in longitude irregularly. The tendency for positive and negative particles to drift in opposite directions will then lead to momentary electrostatic fields, arising from excess charges of one sign aligned along a magnetic line of force. As particles drift into this potential, they lose transverse kinetic energy and a portion of the particles immediately spiral out the ends of the flux tube into the atmosphere. As the potential grows, the drift of particles into this "discharge tube" is inhibited, but more of those entering the potential with high velocity are ejected, regaining their lost transverse kinetic energy in accelerated motion along the magnetic field. The potential may rise sufficiently to discharge particles with energies of several kev within an interval of less than a second, which is rapid enough to render neutralization by ionospheric ions and electrons unimportant.

If the density fluctuations of auroral plasma exceed a certain critical value, the electrostatic field will cause them to grow rapidly. This instability is identified with auroral ray structure. A density fluctuation may maintain its identity, even though individual particles are constantly moving through it. This characteristic may be associated with the fading and reappearance of rayed structures. The basic mechanism of electrostatic fields arising from the particle drifts will also produce local accelerations of particles, by tending to establish an equipartition of energy between protons and electrons. This is presumably the mechanism for the local acceleration of auroral electrons, although it will also modify, but less severely, the energy spectrum of trapped protons.

Various other consequences of these macroscopic but short-lived electric fields are examined, with a view toward understanding auroral morphology. It is proposed that an $E \times B$ drift accounts for the statistical preference for auroral patterns to move toward the sunlit hemisphere and for the departures of auroral forms from alignment along circles of geomagnetic latitude, even in the polar cap. The E field, when transferred to the atmosphere by bombardment and by ordinary

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