Journal of Geophysical Research   Vol. 70, No. 19   October 1, 1965

Determinations of the Auroral-Zone X-Ray Spectrum

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A portion of the bremsstrahlung spectrum of electrons precipitating into the auroral-zone atmosphere is accessible to precise spectrum measurements from balloon-borne scintillation detectors. Such measurements were made near Flin Flon, Manitoba, Canada (geomagnetic latitude 64°N), during local daytime on a magnetically disturbed day (September 8, 1964; $A_p = 23$). The design of the detector embodied several features that made possible a reliable extrapolation from the spectrum observed at balloon altitude to the true spectrum at the stopping level of the electrons:

1. Measurements were made at 3.3 g cm^{-2} atmospheric depth, whereas the Compton interaction length is greater than 5.8 g cm^{-2}. This served to minimize the contribution of photons that had been Compton-scattered and hence degraded in energy. That scattered photons did not contribute appreciably to the counting rates was directly confirmed by directional measurements made from the same balloon payload [*Parks et al.,* 1965]. Absorption of the bremsstrahlung through the photoelectric process increases steeply toward lower energies; this effectively set the lower limit of the measurements at about 15 kev.
2. A thin NaI(Tl) scintillator was used. The

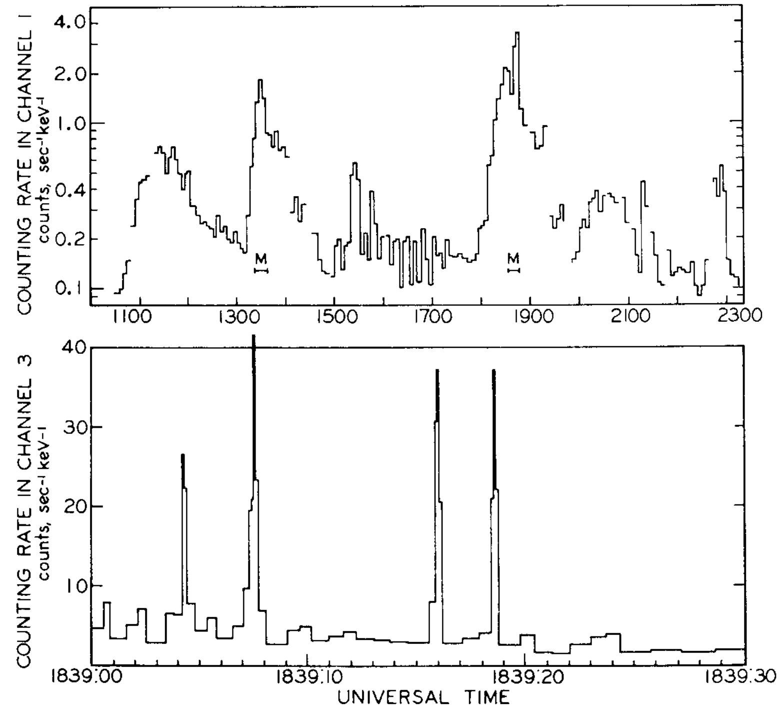

Fig. 1. *Upper:* Four-minute averages for channel 1 ($15.3 < h\nu < 19.5$ kev). Counting rates appreciably in excess of the cosmic-ray background were detected in approximately 85% of the duration of the flight. *M* denotes the presence of the microburst structure. *Lower:* Examples of microburst events. The counting rate in the peak counting channel is given at its maximum time resolution. Counting statistics are fixed at 25%.

counting efficiency for photons of energies less than about 85 kev approaches 100%; on the other hand, the thickness of 0.56 g cm^{-2} is only 0.061 Compton interaction length. Thus high-energy photons cannot contaminate the spectrum by this process and scintillations unambiguously represent total energy losses in the crystal.

3. The detector was collimated in the zenith direction so that it viewed a 30-km disk at the stopping level of the electrons. Thus a reasonably small spatial sample of the precipitation was observed. Moreover, photons from distant precipitation events that may have had a different or degraded spectrum were not detected.

4. Absolute calibration of the scintillation counter and associated electronics was performed at regular intervals throughout the flight. For the data discussed below, the energy discrimination levels were constant to about 1% precision.

The counting-rate profile of the X rays observed with this detector is shown in Figure 1. In the upper part of the figure the counting rate in channel 1 (photon energies between 15.3 and 19.5 kev) has been averaged for each 4-minute period during the flight; gaps in the data represent the detector calibration sequence. The highest total counting rate observed was 1080 counts/sec, about 100 times the cosmic-ray background counting rate. The microburst structure, discussed in detail in the preceding letter [*Parks et al.*, 1965], is located in the large peaks centered at 1330 and 1830 UT. Some events of this type are shown in the lower part of Figure 1.

To deduce the true X-ray spectrum in the production region it is necessary to make corrections for atmospheric absorption. The correction is severe for low photon energies; photon transmission varies from 0.6% at 15 kev to 60% at 85 kev. The extrapolation is most easily

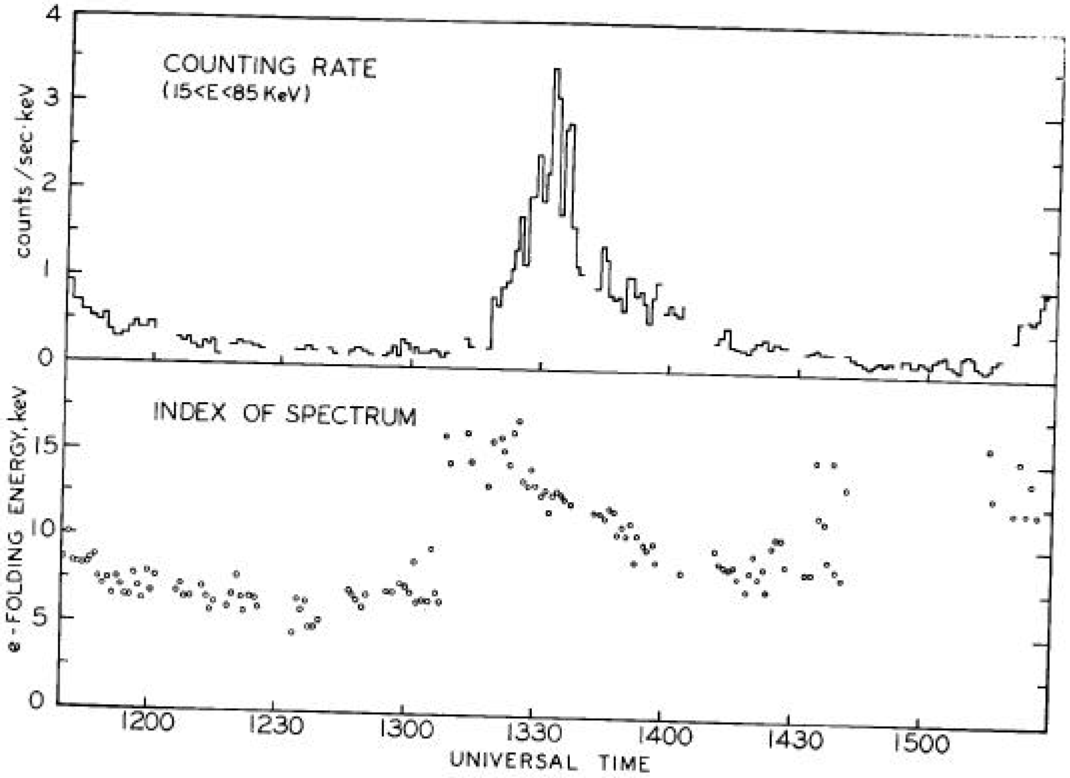

Fig. 2. *Upper:* Whole spectrum counting rates ($15 < h\nu < 85$ kev) in 1-minute samples. *Lower:* e-Folding energy for the best exponential fit to the X-ray spectrum for 1-minute samples. Gaps are due either to the calibration sequence or to counting rates too low to provide sufficiently good statistical precision for the determination.

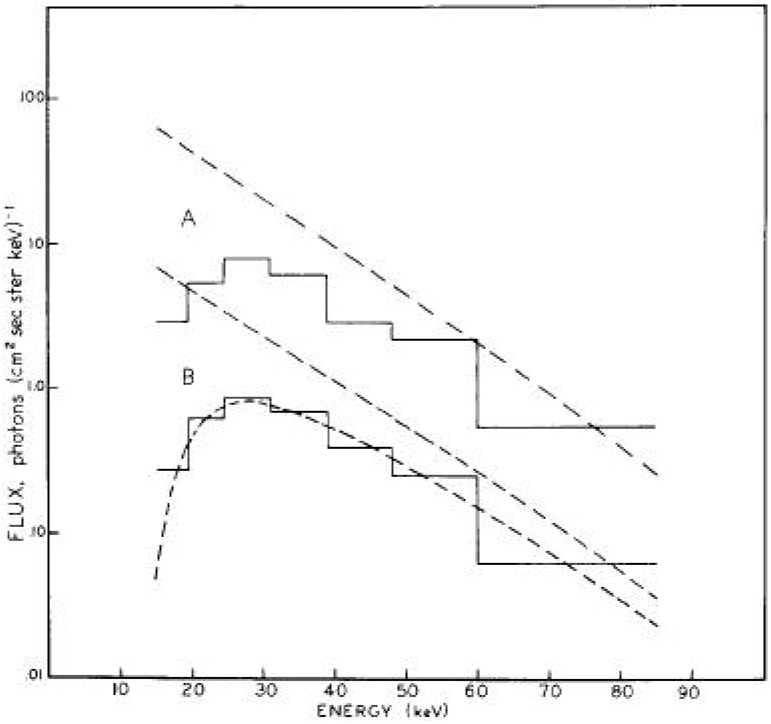

Fig. 3. Comparison of a mean microburst spectrum (A) with that of its X-ray background (B). B is based on a 40-second sample containing no apparent time structure; the microburst events are taken from a 5-minute period immediately following this quiescent activity. The histograms show the observed counting rates minus the background rates due to cosmic rays. A smooth fit is shown for the lower histogram; the upper smooth curves represent the spectrum in the production region.

performed on a smooth fit to the observed seven-point spectrum. Figure 3 illustrates the results of a typical least-squares fit in four parameters A_i:

$$n(E) = \sum_{i=1}^{4} A_i e^{-3.3\mu(E)} e^{-E/E_i}$$

where $n(E)$ is the differential flux, $\mu(E)$ is the absorption coefficient in cm² g⁻¹, and E_i takes the values 8, 12, 16, and 20 kev. Performing the absorption correction on such a smooth fit in general yields a production region spectrum that is well approximated by an exponential function. Thick-target bremsstrahlung calculations show that an exponential electron spectrum produces an X-ray spectrum that can be well approximated by an exponential function over the accessible energy range.

Determinations of the spectrum have been made for each 1-minute sample for 4 hours of data (Figure 2). The spectrum is variable and, indeed, may change radically within 2 to 3 minutes. An example is the sudden hardening at 1310 UT for which the characteristic energy of the parent electron spectrum underwent a fourfold increase, going from a value of about 8 kev to a value greater than 30 kev. This sudden spectral change is apparently related to the large precipitation event immediately following it. However, the onset of the highly ordered microburst activity that follows by about 15 minutes is not accompanied by spectral changes. Determinations of the spectrum made in 0.2-second samples centered on the microburst peaks did not disclose more than statistical deviation from the spectrum of the quiescent background activity. Figure 3 shows the mean spectrum of several microburst events and for comparison the spectrum of adjacent unstructured activity. The main conclusion drawn in this letter is that the microbursts, although strikingly different in time structure, do not deviate appreciably in energy spectrum from the associated precipitation.

Reference

Parks, G. K., H. S. Hudson, D. W. Milton, and K. A. Anderson, Spatial asymmetry and periodic time variations of X-ray microbursts in the auroral zone, *J. Geophys. Res., 70*(19), 1965.

(Received June 9, 1965.)